



17-21 August, 2026
University of Cologne

<https://sfb1601.astro.uni-koeln.de/symposium2026/>

**Physics and
chemistry in
star forming
regions**



SFB 1601

COLOGNE-BONN Symposium

Habitats of massive stars across cosmic time

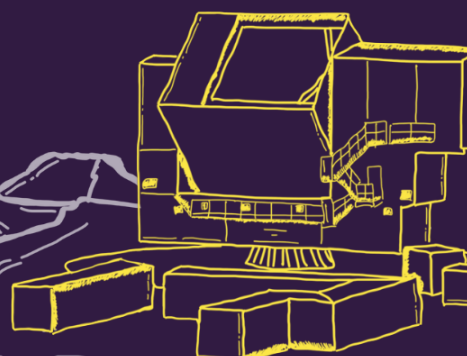
**(Extra-) Galactic
stellar
feedback and
ISM
chemistry**

**Habitats of
massive stars
on galactic
scales and at
high redshift**

**Massive star
formation
and cluster
evolution**



E. Bordier



SFB1601 Cologne-Bonn Symposium

Habitats of massive stars across cosmic time

Abstract book

Status: July 29, 2026

Monday		Tuesday		Wednesday		Thursday		Friday	
08:00 – 09:00	Registration								
09:00 – 09:10	Opening remarks								
09:10 – 10:40	S1: <i>The ISM and star formation across cosmic time</i>	09:00 – 10:30	S3: <i>Massive star formation and feedback in diverse environments</i>	09:00 – 10:30	S5: <i>Resolving the birthplaces of massive stars</i>	09:00 – 10:45	S7: <i>Large-scale surveys of the star formation landscape</i>	09:00 – 10:30	S8: <i>Stellar feedback and the evolution of the ISM</i>
	Jacqueline Hodge Sylvia Adscheid Devismita Panda Dominik Riechers Francesco Chiti Tegli		Kei Tanaka Kazutaka Kimura Daisel Abe Paul Clark Anais Pauchet		Peter Schilke Hans Zinnecker Anahat Cheema Birka Zimmermann Emma Bordier		Janice Lee Tim-Eric Rathjen Oleg Egorov Zein Bazzi Slawa Kabanovic Lina Marie Gerlach		
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	Amelie Saintonge Matus Rybak Prachi Prajapati		Yasuo Fukui Jonathan Mackey Masato Kobayashi Ekaterina Makarenko		Igor Zinchenko Shuo Kong Lucas Labadie C.-H. Rosie Chen		Thomas Salomon Maria Melamed Miguel Figueira Friedrich Wyrowski Sarwar Khan Han-Tsung Lee Jakob den Brok		Kisetsu Tsuge Xinyue Liang Jin Koda Eleonore Rodrigues da Costa Şeyma Mercimek Lennart Böhm
11:55 – 12:30	Poster Flash Presentations: P1	12:00 – 12:30	Poster Flash Presentations: P1	12:00 – 12:30	Poster Flash Presentations: P1/P	13:05 – 15:00	Lunch Break	12:30 – 14:00	Lunch Break
12:30 – 14:00	Lunch Break	12:30 – 14:00	Equity, Diversity and Inclusion (EDI) Lunch	12:30 – 14:00	Early Career Researchers (ECR) Lunch				
14:00 – 15:30	S2: <i>Modelling the ISM</i>	14:00 – 15:45	S4: <i>The chemistry of massive star formation</i>	14:00 – 15:15	S6: <i>Observing the stellar Feedback</i>	15:00 – 17:30	Excursion / Free Afternoon	14:00 – 15:30	S9: <i>Magnetic fields and non-thermal processes in SFRs</i>
	Ralf Klessen Constantina Fotopoulou Daniel Seirfield Yuto Komichi Wajdeh Chayeb		Robin Garrod Akash Gupta Melisse Bonfand Youxin Wang Caroline Gieser Tatiana Rodriguez		Anna McLeod Simon Dannhauer Kartik Rajan Neralwar Aaron Bryant				
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16:00 – 17:00	S2: <i>Modelling the ISM</i>	16:15 – 17:45	S4: <i>The chemistry of massive star formation</i>	16:30 – 17:30	S6: <i>Observing the stellar Feedback</i>			15:45 – 16:15	Coffee Break
	Theodoros Topkaras Leonard Kaiser Tejas Oak Hao He		Aurelien Pilluso Volker Ossenkopf-Okada Yanhuanie Lauryn Zhao Aditi Sinha Alexia Anguera Gonzalez Wesley G.D.P Silva		Sudeep Neupane David Rebolledo Esan Mouli Ghosh Brandt Gaches				
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The Origin of Hub-Filament Systems: Radiation-MHD Simulations toward Understanding Massive Star Formation

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Stars are born in filamentary molecular clouds, and observations show that nearly all high-mass stars form in so-called “hub–filament systems (HFS)”¹. A hub–filament system consists of multiple filaments converging to a common intersection (the hub). Motivated by these findings, a new paradigm for high-mass star formation is emerging. Observations indicate strong gas accretion along filaments, which may trigger gravitational fragmentation in circumstellar disks and lead to high-mass binaries. At the same time, the star formation efficiency—the fraction of gas converted into stars—is generally low, and its origin remains unclear.

In HFS, filamentary inflows drive mass growth at the hub, while radiation feedback from massive stars disperses diffuse gas, suppressing star formation efficiency. Understanding both the origin of high-mass binaries and the low efficiency requires a self-consistent investigation from large scales down to disk fragmentation, yet the origin of HFS itself remains poorly understood.

In this study, we investigate filament formation by shock compression using the radiation-MHD code Athena++^{2,3,4}. We find that large-scale shock-driven flows gather pre-existing filaments and assemble them into a hub, possibly aided by fluid instabilities such as the nonlinear thin-shell instability⁵. Gas accretion analysis shows that dense gas flows into the hub while diffuse gas is expelled by radiation feedback. This is consistent with observed filamentary accretion and supports a scenario in which massive star formation proceeds with low efficiency. Finally, analysis of the hub’s angular momentum provides insights into the formation of high-mass binaries.

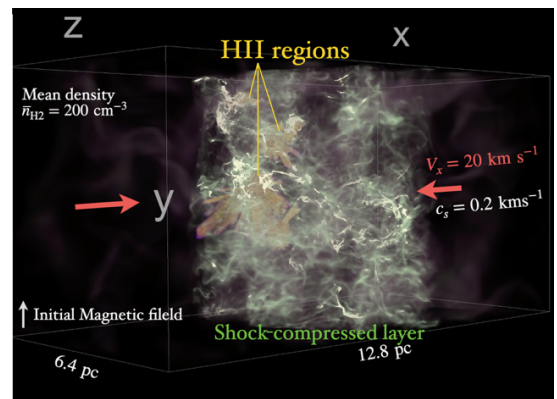


Figure 1: Three-dimensional radiation MHD simulation of a shock-compressed layer formed by supersonic flows in a molecular cloud. Dense filamentary structures and HII regions develop within the compressed layer.

¹Kumar, M.S.N., et al. 2020, AA, 642, A87

²Stone, J., et al., 2020, ApJ, Volume 249, Issue 1, id. 4

³Tomida, K., Stone, J., 2023, ApJ, Volume 266, Issue 1, id.7

⁴Kim, J.-G. et al., 2017, ApJ, Volume 851, Issue 2, article id. 93

⁵Vishniac, E., 1994, ApJ, 428, 186

The search for massive stars in the early Universe: Dissecting the FIR/(sub)mm CIB

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In order to understand massive star formation across cosmic time, it is crucial to study the environments from which they originate. The interstellar medium of highly star-forming galaxies is particularly interesting in this endeavour, as these galaxies evidently offer ideal conditions for the formation of great quantities of massive stars in comparatively short times. Representative samples of such highly star-forming galaxies are required to allow a systematic and unbiased view of this population and their modes of star formation. One way to do this is through the cosmic infrared background (CIB), which is the integrated stellar and dust emission from earlier cosmic times, and which serves as a beacon for highly star-forming galaxies. The far-infrared (FIR) part of the CIB is particularly useful in that, because it reveals the dust-obscured part of star-formation activity. In this presentation, I will present the results from our work on a sample of 260 ALMA-detected galaxies from the A3COSMOS project. These constitute a representative galaxy sample, used to infer (sub)mm number counts, constituting between between ~ 4 and $\sim 40\%$ of the CIB in four different ALMA bands. With this sample, we are able to dissect part of the FIR/(sub)mm CIB into individual sources and characterise its origin. We make use of ancillary near-infrared (NIR) imaging from the JWST COSMOS-Web and JADES programmes, and SED-fitting using CIGALE. We find that the morphologies of most galaxies in our sample appear irregular in rest-frame UV and optical wavelengths and disk-like in rest-frame NIR, indicating that these are predominantly normal star-forming galaxies, as opposed to merger-driven starburst galaxies, though highly dust-obscured. Our galaxies are at high redshift ($z_{\text{median}} \sim 2.5$) and have high stellar masses, sitting in massive haloes, requiring fast and efficient stellar build-up at early cosmic times to explain their existence. Our findings reveal that a large part of the massive stars in the early Universe are born in dust-obscured regions of massive star-forming galaxies, and show hints at a potentially increased cosmic star-formation efficiency at early cosmic times, close to theoretical expectations for the conversion of baryons into stars.

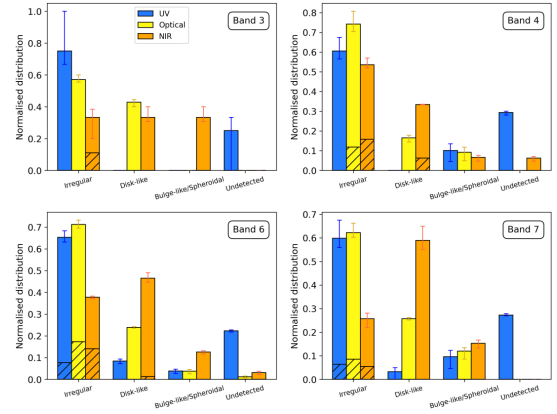


Figure 1: Distribution of the rest-frame morphology of our galaxy sample in the UV, optical, and near-infrared, by ALMA band.

Evolutionary Mapping of G14.225-0.506: Non-LTE Chemistry and Feedback

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Infrared dark clouds (IRDCs) represent a crucial stage in the evolution of the interstellar medium, where cold, dense gas collapses under the influence of gravity, magnetic fields, and feedback. The massive hub–filament system G14.225–0.506 provides an excellent laboratory to investigate how these processes regulate the earliest phases of high-mass star formation. Large-scale NH_3 observations indicate that its two main hubs, G14.2-N and G14.2-S, share similar initial physical conditions¹. However, interferometric studies reveal striking differences in their fragmentation and chemical properties², possibly linked to variations in the magnetic field configuration³.

We present new SMA 1.3 mm continuum observations and a molecular line survey aimed at characterising the chemical and physical evolution of protostellar cores within both hubs. At our angular resolution, we identified two cores in G14.2-N and four in G14.2-S. Despite the lower fragmentation level in the northern hub, it hosts a chemically rich hot core, MM1. By modelling more than 30 molecular species using XCLASS, we derive significant temperature gradients and find that key tracers, such as CH_3OH , exhibit substantial deviations from Local Thermodynamic Equilibrium (LTE). These results demonstrate that non-LTE treatments are essential for accurately constraining physical conditions in such environments. Moment maps reveal that while molecular emission follows the continuum peaks in MM1, MM4, and MM5, other regions are dominated by outflowing gas. Combined with recent VLA data showing a higher concentration of YSOs in the north⁴, our findings support an evolutionary sequence from the younger southern hub to the more evolved northern hub. This evolution is increasingly shaped by internal feedback and the influence of the nearby M17 H II region, highlighting how chemical complexity and non-LTE signatures provide powerful diagnostics of gas diversification in IRDCs.

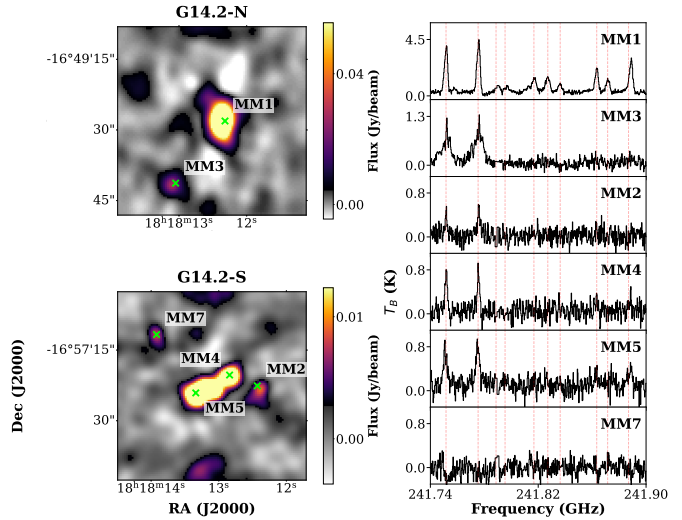


Figure 1: **Left:** SMA continuum images of G14.2-N and G14.2-S. **Right:** CH_3OH spectra, reflecting distinct physical properties across regions.

¹Busquet, B. *et al* 2013, ApJL, 764, L26

²Busquet, B. *et al* 2016, ApJ, 819, 139

³Añez-López, N. *et al* 2020, A&A, 644, A52

⁴Díaz-Márquez, E. *et al* 2024, A&A, 682, A180

The lifetime of 100,000 molecular clouds in the nearby Universe

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Multiple mechanisms are proposed for the formation of giant molecular clouds (GMCs) — from gravitational free-fall caused by self-gravity, to stellar feedback-driven gas compression. Both the galactic environment and galaxy conditions could play an additional role in enhancing the formation via their gas surface density and star formation activity. We present a catalog of 108,466 GMCs identified by F770W PHANGS-JWST imaging across 66 galaxies at a resolution of 5–30 pc (Bazzi et al. 2026a). We measure the mass spectra in various galactic regions, whose power-law slopes vary from -1.2 to -2.0 (Bazzi et al. 2026b). We then estimate the formation time of each cloud using a model in which GMCs form by multiple feedback compression, and find that clouds with masses $\leq 10^5 M_\odot$ form in 20 Myr on average, and more massive clouds ($\sim 10^{6-7} M_\odot$) take up to 100 Myr. We also find that cloud formation proceeds most rapidly in the central regions of galaxies, with formation timescales that are typically shorter by $\sim 5-10$ Myr compared to galactic disks (see Fig. 1). This highlights the role of intense massive star formation, high molecular gas surface densities, and strong supersonic compressions in accelerating cloud formation. However, star formation is generally inefficient as the cloud lifetime is $\sim 1\%$ of the molecular depletion time. The formation time of clouds is ~ 0.1 dex longer than the free-fall time. This hints that magnetic fields, stellar feedback, or other mechanisms may prolong their formation instead of immediate free-fall collapse. This also indicates a longevity of massive GMCs. The GMC ages also show only limited variation with galactocentric radius in both spiral and disk galaxies, suggesting that cloud formation proceeds similarly in these galaxy types.

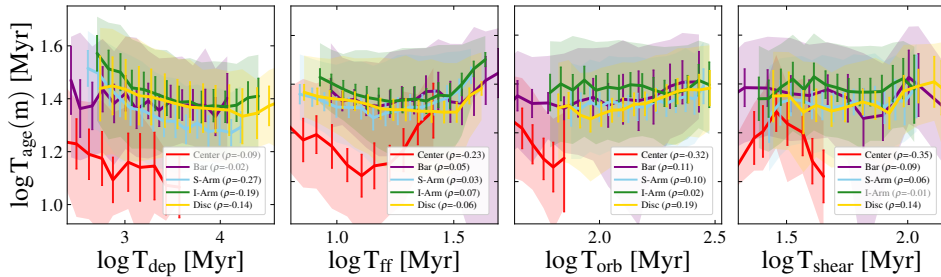


Figure 1: GMC growth time as a function of the depletion time (T_{dep}), free-fall time (T_{ff}), orbital timescale (T_{orb}), and shearing timescale (T_{shear}). The median trend is plotted across galactic environments for the galaxies in our sample. The shaded region represents the 84th – 50th, and 50th – 16th percentiles, and the error bar is the standard error on the median. The Spearman correlation coefficient ρ is written in black when the correlation is significant ($p < 0.05$). Otherwise, it is not significant.

The Godzilla Nebula: hierarchical accretion at the onset of massive-star feedback

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Massive stars form in dense, structured environments where accretion, fragmentation, and stellar feedback coexist. Hub-filament systems provide a useful framework for describing how gas is funnelled from cloud scales into the compact centres where massive stars and stellar clusters assemble. Yet a key question remains open: how relevant does this organized gas supply remain once ionizing feedback has started? Does feedback rapidly disrupt the hub, or can it escape anisotropically through a strongly inhomogeneous medium while large-scale gas feeding continues?

W33 Main in the “Godzilla Nebula” is a nearby massive cluster-forming region that appears to capture exactly this short-lived phase. It combines parsec-scale filamentary gas supply, a luminous central hub already hosting ultra-compact HII regions and embedded massive stars, and a second, younger massive star-forming centre only about 0.2 pc away. This makes W33 Main an excellent laboratory for studying the accretion-feedback interface across scales and a nearby benchmark for structured massive star-forming environments more generally.

In this talk, I will present new multi-scale results from our W33 project based on Karl G. Jansky Very Large Array ammonia (NH₃) observations, complemented by VLT/KMOS integral-field spectroscopy of the ionized gas and the **first high-resolution ALMA observations** of W33 Main at ~ 100 -200 mas resolution, corresponding to ~ 200 -400 au. The NH₃ data show that W33 Main is not well described as a single hub-filament system alone. Instead, the region forms a **hierarchical hub-filament network**: several parsec-scale filaments converge toward the main hub, additional smaller hub-filament systems are found at projected distances of more than 1 pc, and the central region itself separates into a main hub and a slightly offset sub-hub associated with a younger massive source.

At the same time, the central hub remains morphologically and kinematically linked to the larger dense-gas network despite already showing strong ionized emission and embedded feedback. The ionized gas structure is consistent with a **champagne flow-like expansion** into a highly non-uniform ambient medium, suggesting that feedback escapes preferentially along low-density channels rather than isotropically disrupting the hub. Forthcoming analysis of the new ALMA observations will extend this picture down to core scales, linking parsec-scale hierarchical gas supply to the immediate surroundings of forming massive stars and laying the groundwork for future ALMA observations toward potential disk scales and JWST studies of the embedded feedback environment. W33 Main thus emerges as a well-resolved Galactic benchmark for hierarchical massive star formation in a feedback-active phase.

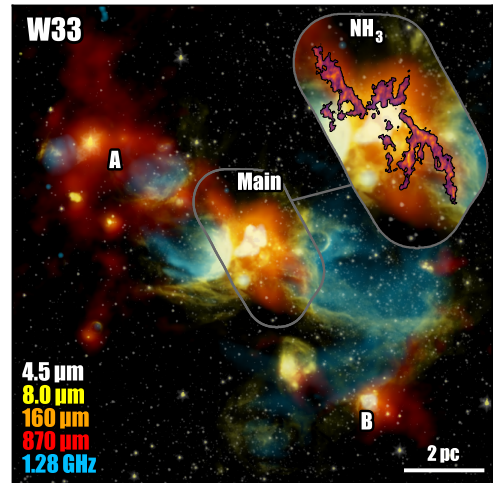


Figure 1: Multiwavelength view of the W33 complex with the footprint of our VLA observations shown in gray. The inset shows a zoom into the observed field and the peak intensity map of the NH₃ (1, 1) emission.

Radio continuum view of dwarf galaxies with galactic winds

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Starbursting low mass (or dwarf) galaxies with their shallow gravitational potential are susceptible for venting gas from their disks into their circumgalactic environment. The importance of magnetic fields and cosmic rays for properties of these galactic winds in dwarf galaxies is still much less explored than in more massive starburst galaxies. Being our best proxies for young galaxies in the early universe, starburst dwarfs and their winds are a key for the understanding the ionization and magnetization of the intergalactic medium. In this contribution we analyze radio continuum emission of different samples of low mass galaxies with currently high star-formation rates. A somewhat surprising finding is that there are significant variations of radio continuum brightness and radio morphology of the winds. We explore the correlations of radio continuum emission structure with galaxy masses, with the recent starformation histories, and with the ionized gas morphology of the outflows/winds. The goal is to start disentangling the relative importance of thermal gas structure as well as kinematics, and the evolution with time (due to changes in the SFR) relative to the effects of different transport mechanisms of cosmic rays in the magnetic fields.

Combined hydrodynamic and gas-grain chemical modeling of hot cores: Two-dimensional simulations and synthetic observations

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High-mass star-forming regions host dense, warm, and turbulent environments where complex chemistry develops under intense radiation, shocks, and dynamic infall. Observations of these regions reveal significant source-to-source variations in chemical composition, in particular in the abundances of complex organic molecules, yet the physical and evolutionary factors driving this chemical diversity remain poorly constrained. Their large distances, clustered nature, and rapid evolution complicate direct characterization, making it challenging to disentangle the effects of protostellar luminosity, mass, accretion history, and disk formation on the observed chemical inventory.

I will present results from a new modeling framework designed to simulate the physical and chemical evolution of high-mass protostellar environments. The model follows the collapse of a uniform molecular cloud onto a central massive protostar through an accretion disk, using a two-dimensional hydrodynamical approach coupled with a chemical kinetic code. The resulting chemical abundances are post-processed with a radiative transfer code to generate synthetic molecular emission maps and spectra. By directly comparing these predictions with observations, we assess how the evolutionary stage and source structure—particularly disk formation and inclination—affect the emission and spatial distribution of complex organic molecules.

A VLTI journey through the origins of massive stars: a multi-environment view

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Massive stars are the main drivers of galactic evolution, yet the "nature vs. nurture" aspect of their formation remains a fundamental question. While high-order multiplicity is a signature of most massive stars, it is still unclear how the birth environment, specifically stellar density and metallicity (Z), dictates the fragmentation of disks and the early orbital architecture of these systems.

In this contribution, we present a comprehensive overview of massive star multiplicity across

diverse environments using high-angular-resolution interferometry with the VLTI (ESO). We first discuss recent results from GRAVITY observations of the young Galactic cluster M17, comparing them to a population of 13 Massive Young Stellar Objects (MYSOs), from different clusters (all with $Z \sim Z_{\odot}$). This comparison allows us to disentangle the impact of cluster dynamics from the intrinsic processes of disk fragmentation and migration at scales of 1–100 au.

Expanding into the extreme, supersolar ($Z > Z_{\odot}$) environment of the Galactic Center, we present the first successful infrared interferometric observations of individual massive stars in IRS13 using MATISSE. Our analysis reveals visibility amplitudes that increase with spatial frequency, indicating stellar-dominated emission at short wavelengths (L -band) and fully resolved extended structures in the M-band. Using two-component geometric modeling and RADMC-3D radiative transfer simulations, we characterize an optically thin medium where both stars strongly interact with their surroundings, sublimating dust at scales of ~ 50 au.

Finally, we explore the frontier opened by GRAVITY+, which is bringing extragalactic MYSOs in the LMC and SMC within the reach of infrared interferometry for the first time. We discuss our early efforts to probe these subsolar metallicity environments ($Z < Z_{\odot}$), aiming to test the feasibility of resolving early-stage fragmentation outside our Galaxy. While pushing the current sensitivity limits, these pilot observations represent a crucial first step toward understanding whether massive star multiplicity is a universal process or one fundamentally shaped by the local environment.

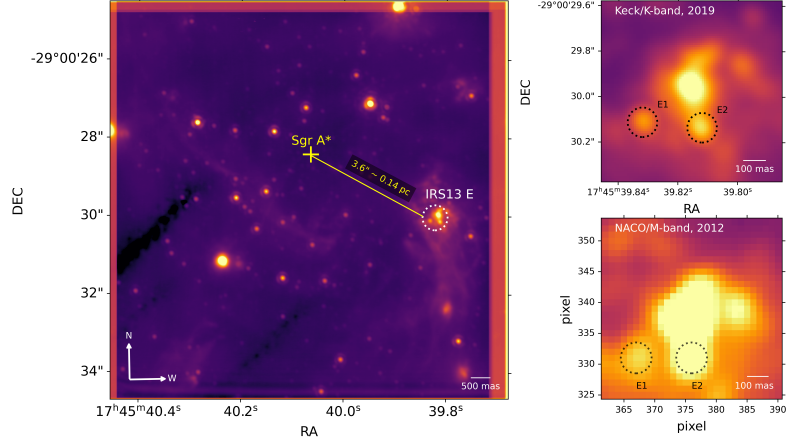


Figure 1: Keck K - and NACO M -band observations highlighting the inner parsec of the Galactic center, featuring the IRS13 E1 and E2 objects, observed with VLTI/MATISSE.

Probing Massive Star Formation in the Galactic Centre with Far-Infrared Imaging Spectroscopy

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Among the most pressing questions concerning the Galactic Centre is the "Paradox of Youth", the issue of how the dense nuclear cluster of early-type stars formed within less than a parsec of Sgr A*. If these stars formed in-situ, then the closest molecular gas reservoir would be the Circumnuclear Disk (CND), which appears as a clumpy ring, inclined along the line of sight, surrounding the nuclear cluster with an inner radius of 1.5 pc. The structure features a number of dynamic filaments and streamers, and the physical states of the various ISM phases remain inconclusively characterised. We used the Far Infrared Field-Imaging Line Spectrometer (FIFI-LS) on board the Stratospheric Observatory for Infrared Astronomy (SOFIA) to obtain spatially resolved maps of 11 far-infrared emission lines of the region with an angular resolution approximately 4 times higher than previous published data. These include the fine structure lines [CII] 158 μm , [OI] 63 μm and 145 μm , which we model as emission emanating from the thin layer of a photodissociation region (PDR) illuminated by the cluster. Together, these lines span a range of tracers of the atomic, molecular and ionised gas phases, and are used as diagnostics of the physical state of the CND. Armed with this information, we can make inferences on the role of the CND in the formation of a nuclear cluster.

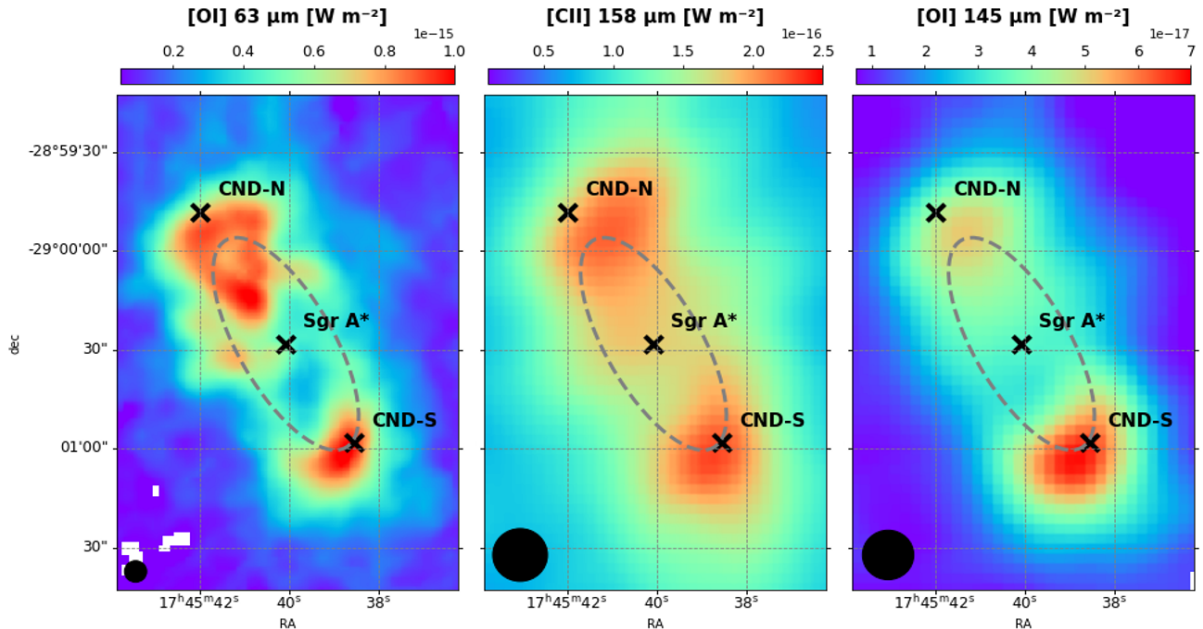


Figure 1: Fine structure line flux maps of the CND taken with FIFI-LS. The inclined torus model of the CND as defined by Lau et al. 2013 is overlaid in dashed grey.

On the Origin of Velocity Dispersion in the Warm Interstellar Medium

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Observations of atomic hydrogen velocity dispersion in disk galaxies often show a characteristic value of ~ 10 km/s. While some studies link this dispersion to star formation activities¹, its origin remains uncertain due to potential contributions from multiple physical processes, such as stellar feedback and gravity. Notably, similar dispersion values are observed in galaxy outer disks where no stellar activity occurs². Additionally, the trend of this dispersion varies: it remains constant with galactocentric radius in the Milky Way³ but declines in other galaxies.

We conducted adaptive mesh refinement simulations of an isolated Milky Way-like spiral galaxy using the FLASH code. We investigate the role of the galactic environment, i.e. the impact of spiral arms and a central bar, in generating the velocity dispersion of the warm ISM. The simulated gaseous disk is embedded in a static stellar disk and dark matter halo. Spiral arms are modeled as rigidly rotating density waves in the stellar potential.

Our findings indicate that stellar spiral arms can drive the observed velocity dispersion. The bar's contribution is limited to regions within its extension. We also find that the radial dispersion is primarily caused by the gravitational forces of the spiral arms, while the azimuthal component is mainly linked to the induced shear.

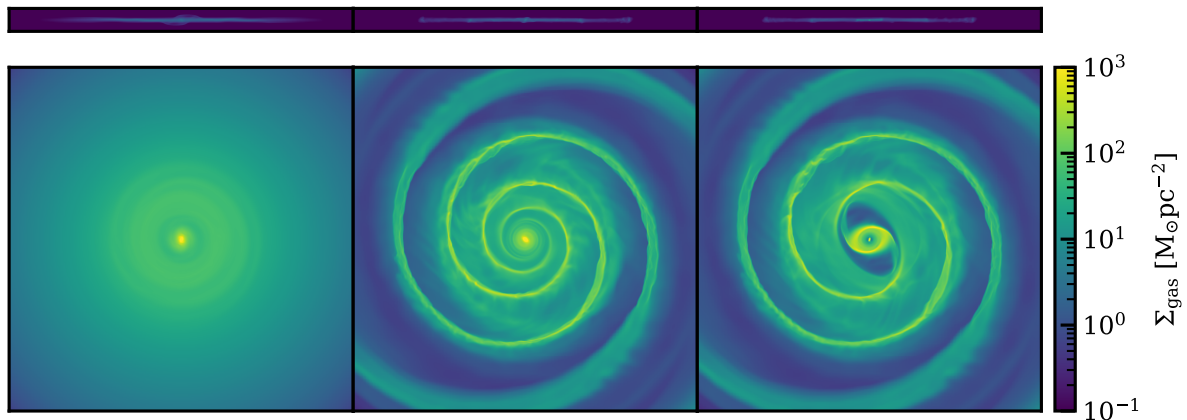


Figure 1: A snapshot of the projected density of the gas surface density for three different runs (Disk on the left, spiral in the middle, and barred-spiral on the right). The width of the shown box is ~ 10 kpc.

¹Tamburro, D., Rix, H.-W., Leroy, A. K., Mac Low, M.-M., Walter, F., Kennicutt, R. C., Brinks, E., de Blok, W. J. G., 2009, AJ, 137, 5, 4424-4435

²Petric, A. O., Rupen, M. P. 2007, AJ, 134, 5, 1952-1962

³Marasco, A., Fraternali, F., van der Hulst, J. M., and Oosterloo, T., 2017, A&A, 607, A106

Massive star formation at the Galactic crossroads: Insights from G358.69+0.03 in the Galactic center

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High-mass star formation in the nuclear regions of the Milky Way unfolds under some of the most extreme physical, chemical, and kinematic conditions found anywhere in the Galaxy, yet many fundamental questions about these environments remain open. To investigate high-mass star formation in these extreme Galactic center environments, we present a multiwavelength study of a subregion of Sagittarius E star-forming complex, located at the intersection of the Central Molecular Zone (CMZ) and the far-side dust lane (Fig. 1 Left). The subregion referred to as ‘G358.69+0.03’ has a distinct U-shaped structure, traced by both infrared and radio sources, which has not been reported in any previous study. Using radio continuum data from the Global View on Star Formation (GLOSTAR) survey (4–8 GHz) observed with the *Karl G. Jansky* Very Large Array and Effelsberg 100-m telescope, we extract 49 compact radio sources, identify counterparts to 27 confirmed HII regions, detect radio emission from 3 WISE ‘radio-quiet’ candidates, and report 5 new HII region candidates, and derive their physical properties. The identified HII regions are found to be predominantly distributed along the U-shaped arc-like structure (Fig. 1 Right). Mid-infrared flux-ratio maps reveal localized shock enhancements in the region, and many cold dust clumps exhibit SiO emission with broad components, also indicative of shocks. Together with CO data, the SiO velocity components trace a continuous velocity bridge that links the far dust-lane inflow to the CMZ stream. The largest concentration of cold dust clumps and compact HII regions lies at this interface. These combined diagnostics favor a scenario in which bar-driven cloud–cloud collision at the far dust-lane–CMZ interface compressed the gas and triggered the observed high-mass star formation.

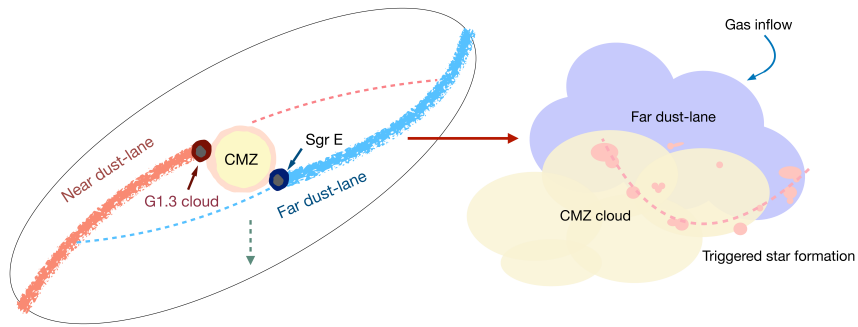


Figure 1: Schematic illustration of gas inflow into the CMZ. *Left*: gas streams along the near- and far-side dust lanes feed the CMZ, with Sagittarius E located at the intersection of the far dust-lane and the CMZ orbit. *Right*: zoom-in view of the collision, where the far dust-lane impacts the CMZ gas, compressing material and producing a U-shaped arc-like distribution of HII regions.

Driven by Shocks: SiO Outflow Properties in HMSF Regions and their Influence on Polarization

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The goal of the STREAMS (STarforming Region Energetics Across Multiple Scales) project is to assess the interplay between gravity, turbulence, and magnetic fields (B-fields) from 10 pc down to 0.01 pc to obtain a complete picture of star formation. Within this framework, characterizing outflow kinematics is crucial for evaluating their energetic contributions relative to infalling gas and local B-fields. Despite this importance, the role and impact of molecular outflows within high-mass star-forming (HMSF) regions remain a subject of considerable debate, particularly regarding their impact on the local magnetic fields and the mechanisms by which outflows inject energy into the surrounding envelope.

To address this, we are investigating nine ALMAGAL clumps (resolving scales of ~ 1000 AU) that are also part of the 23 massive clumps in the STREAMS program. Focusing on these sources, we will present preliminary results from a systematic outflow study utilizing high-resolution ALMA 1.3 mm combined continuum and spectral line images. Our unified methodology employs SiO (5–4) as the primary outflow tracer—exploiting its abundance enhancement via dust grain sputtering under extreme shock conditions in outflows—coupled with a systematic approach to infer outflow inclinations. Furthermore, we employ a Bayesian-based non-LTE model utilizing the H₂CO transitions to robustly estimate outflow temperatures.

We will discuss preliminary results indicating that SiO outflows exhibit significantly higher degrees of collimation compared to their CO counterparts. To connect these outflow properties back to the magnetic environment, we will also present our initial analysis of SMA dust polarization data. A striking feature of these data is the occasional observation of a “polarization hole” (Figure 1). This phenomenon is typically attributed to either tangled B-fields along the line-of-sight or a loss of dust-field alignment due to local physical processes; consequently, its presence underscores the critical importance of jointly investigating outflow kinematics and polarization signatures in HMSF regions.

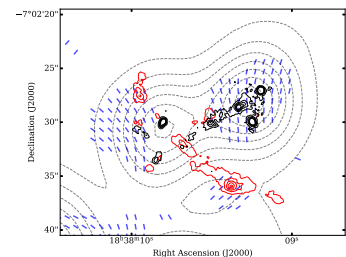


Figure 1: The “polarization hole” phenomenon in the clump C8-1.

Why are fewer high-mass stars forming at low-metallicity? A square-kpc investigation of parsec-sized clumps in the Small Magellanic Cloud

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The physical processes that dictate the fragmentation of a giant molecular cloud (GMC) determine the properties and mass function of clumps and consequently the stellar initial mass function (IMF). Numerical simulations show that variations in fragmentation may result from environmental effects such as far ultra-violet radiation, metallicity (Z), or kinetic disturbances¹. In low- Z GMCs, cooling is inefficient and may preferably form high-mass stars and flatten the IMF slope. In contrast, the Small Magellanic Cloud (SMC) with $< 0.2 Z_{\odot}$ exhibits a dearth of very high-mass stars galaxy-wide, invoking the presence of a steep IMF². Attempting to understand this IMF difference by

studying the properties of the SMC's GMCs we have conducted an unbiased APEX CO(3-2) survey at 6-pc resolution and observed a flat (exponent index > -2.0 ; Figure 1) cloud mass function similar to nearby star-forming galaxies³. While this is opposite to the reported fewer high-mass stars, we further observed a trend of decreasing surface density of star formation rate (Σ_{SFR}) from the northern to southern Bar, demonstrating the need to understand the intricate balance among the environmental effects on fragmentation processes. To examine how fragmentation of clouds affects the stellar IMF and to critically test if the simulation prediction agrees with the observed star properties and gas conditions, we have further obtained new and gathered existing ACA lower-J CO mosaics at 2–4 pc resolution of three large regions featuring distinct star formation modes. This dataset, comprising a square kpc coverage of resolved clumps, demonstrates two trends between properties of clumps and star formation rates (SFRs). First, single intensity line ratios such as $I_{\text{CO}(3-2)}/I_{\text{CO}(1-0)}$ or $I_{\text{CO}(3-2)}/I_{\text{CO}(2-1)}$ (R_{31} or R_{32}) alone do not correlate linearly with SFRs as shown in previous studies based on limited coverages of selected regions. Second, using the R_{21} - R_{32} ratio diagram, clumps appear to be optically thicker in the northern Bar that has higher Σ_{SFR} . Given that the majority of molecular mass is in the southern, not northern Bar, we discuss the environmental effects such as kinetic disturbances on star formation in the SMC. Our results will illustrate star formation and applicability of simulations for a low- Z environment and help interpret star formation studies of the low- Z early Universe.

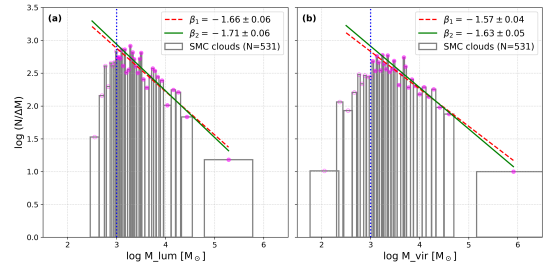


Figure 1: Differential cloud mass function with variable-size bins for masses estimated with (a) luminosity and (b) virialization.

¹Gnedin, N. Y. & Kravtsov, A. V. 2011, ApJ, 728, 88

²Schootemeijer, A., Langer, N. et al. 2021, A&A, 646, A106

³Chen, C.-H.R., Weiss, A., et al. to be submitted

Superbubbles in PHANGS: Linking ISM structure and kinematics with star formation

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The interstellar medium (ISM) of nearby galaxies is far from uniform: multi-wavelength observations from the PHANGS (Physics at High Angular resolution in Nearby Galaxies) survey have revealed a highly structured ISM, punctuated by a ubiquitous and hierarchical population of cavities and shell-like structures, spanning a range of physical scales from tens to several hundred pc. While such cavities can arise from large-scale dynamical processes, a significant fraction are driven by stellar feedback, and are commonly referred to as bubbles (or superbubbles, when they exceed ~ 150 pc in size). Seen as PAH emission deficits in JWST mid-infrared (MIR) imaging, these structures include systems not always visible in traditional star formation tracers, highlighting a multi-phase ISM porosity that classical diagnostics cannot fully capture. Pioneering studies within PHANGS have already begun to characterise this population, uncovering a seemingly self-similar hierarchy of bubbles and establishing connections to young stellar associations, both through statistical analyses and detailed case studies of flagship superbubbles. These initial results set the stage for a more systematic and physically motivated investigation: understanding what drives these structures, how they evolve, and their role in regulating, and perhaps propagating, star formation across spatial scales.

Building on this foundation, we will present a catalogue of superbubbles across 74 nearby galaxies, combining JWST MIR imaging with MUSE, ALMA, and HST data. We will focus on the largest star-formation-driven superbubbles, covering scales from a few hundred pc, just above the size of the Local Bubble, up to kpc-sized giant shells. The catalogue is based on a systematic visual identification and validated against automated methods (in contrast to previous purely visual selections), showing strong agreement for hundreds of structures and enabling a comprehensive exploration of their demographics and environments. For a well-resolved subset of superbubbles, we will further discuss their kinematics and connect their energetics to the surrounding star formation activity.

Together, these results provide new constraints on the lifecycle of superbubbles, revealing systematic trends with environment and offering new insight into their role in shaping the multi-scale structure and porosity of the ISM in nearby galaxies.

The rapid formation of massive stars in high-UV environments

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In our original paper¹, we showed that when molecular clouds are exposed to high UV (100-1000 G_0) and high cosmic ray fields (10^{-15} - 10^{-14} s^{-1}) they tend to form stellar clusters with IMFs that are flatter than the Salpeter IMF, i.e. with more high-mass stars than typical. However this initial study was unable to follow the fragmentation process right down to the opacity limit, so the question remained as to whether these high mass stellar objects might further fragment to produce lower mass stars, and thus a more standard IMF. In this talk, we present new zoom-in follow-up calculations that follow the fragmentation in the original simulations down to the opacity limit, capturing the formation and fragmentation of the protostellar discs around the class 0/1 objects. These new calculations reinforce the findings from original study. In particular, we note that the high mass stars are able to form extremely rapidly, with stars of $8 M_{\odot}$ emerging within 100 kyr. Fragmentation is prevalent at sub 1000 AU scales, and so the multiplicity is naturally high. Although these simulations neglect magnetic fields and the feedback from the young stars, they show that the conditions for high mass star formation can arise in extreme environments. We would expect feedback to only further enhance this picture.

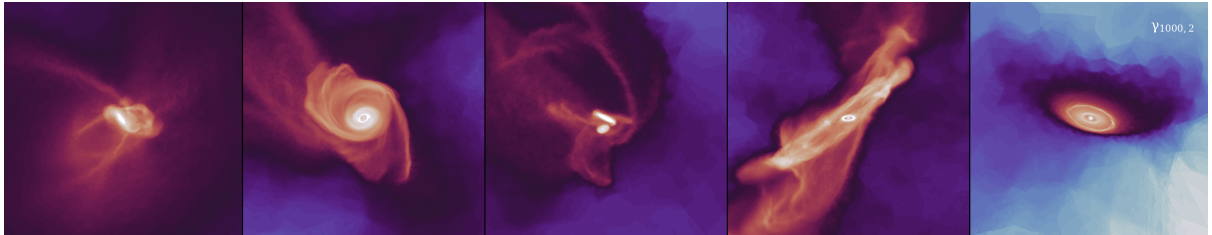


Figure 1: We show the time evolution of zoom-in of a star forming core from the main cloud simulation in 25 kyr intervals. The mass of the primary at the end of the simulation is $10 M_{\odot}$, and the region shown is 1000 AU on a side.

¹Cusack et al. 2025, MNRAS, 536, 3518

Stellar Feedback Across the Galaxy: Shaping the Interstellar Medium

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Massive stars ($M \geq 8 M_{\odot}$) continuously shape their surroundings through ionizing radiation, stellar winds, protostellar jets, and ultimately supernova explosions. Acting over different spatial and temporal scales, these feedback processes regulate the structure, dynamics, and chemistry of the interstellar medium. Together, they play a central role in regulating the lifecycle of molecular clouds and the formation of new generations of stars.

In this talk, I will review our current observational understanding of stellar feedback from massive stars in the Galactic interstellar medium. I will briefly introduce the principal feedback mechanisms and discuss the observational signatures through which their impact on the surrounding interstellar medium can be identified. I will highlight recent observational advances as well as some of the major open questions concerning the interaction between massive stars and their environments.

Finally, I will briefly review observational studies exploring how stellar feedback influences the chemical evolution of the interstellar medium, with potential implications for the molecular inventory inherited by future planetary systems.

Disentangling the accretion flow in S106

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Mass assembly in high-mass star-forming regions involves a complex interplay of accretion flows, fragmentation, and stellar feedback — yet how these processes compete and interact on small scales remains poorly understood¹. The bipolar HII region S106 in Cygnus is a particularly enigmatic case: its prominent dark lane of dense molecular gas has long been interpreted as a massive accretion flow feeding the central binary S106 IR, but the detailed kinematics and physical state of this source have remained elusive². By combining new interferometric NOEMA observations of $\text{HCO}^+(1-0)$, $\text{H}^{13}\text{CO}^+(1-0)$, $\text{HCN}(1-0)$, and $\text{SiO}(2-1)$ at $\sim 2''$ resolution (~ 2600 AU at 1.3 kpc³) with IRAM 30m single-dish data, we now reveal the small-scale kinematic and physical structure of the dark lane⁴. The velocity field shows a systematic gradient along the lane that surprisingly does not converge on the massive binary S106 IR, but rather on the embedded object S106 FIR, located a few arcseconds to the west — suggesting that feedback from the S106 IR star cluster has effectively redirected or disrupted the accretion flow, which now feeds the less evolved neighbouring condensation instead. Particularly striking is the $\text{SiO}(2-1)$ emission, a tracer of shocked gas commonly associated with outflow activity and grain destruction. We identify two spatially distinct SiO peaks within the lane: while one coincides with S106 IR, the other — S106-SiO — appears to lack any protostellar counterpart. This raises the question of what mechanism drives shocked gas emission in the apparent absence of a local protostar, and we discuss its origin in terms of outflow activity, low-velocity shocks at a filament–filament intersection, and stellar wind in the S106-IR vicinity interacting with dense clumps. Together, these results demonstrate how high-resolution dense gas tracers can disentangle competing mass assembly mechanisms in clustered environments. We place our findings in the context of fragmentation-induced starvation and competitive accretion⁵, discussing what our observations imply for the role of stellar feedback in regulating accretion flows.

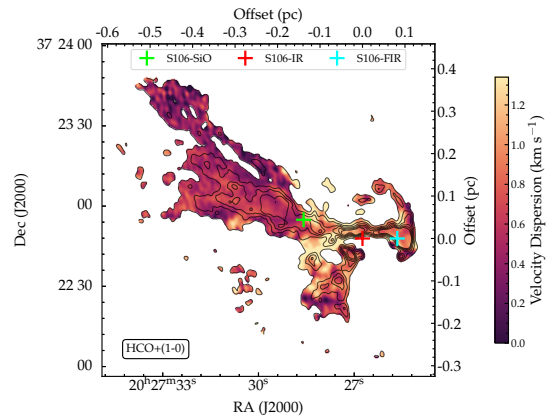


Figure 1: Moment-2 map of the HCO^+ emission tracing the dark lane. A noticeable increase of the velocity dispersion across the ionising source of the bipolar outflow nebula, S106-IR, is indicative of stellar feedback affecting the accretion stream.

¹Motte F. et al., 2018, ARA&A, 56, 41; Beuther H. et al., 2025, ARA&A 63, 1

²Richer J. et al., 1993, MNRAS 262, 839; Hodapp K. & Schneider N., 2008, SF Regions, Vol. I, p.90

³Rygl K. et al., 2012, A&A 539, 79

⁴Dannhauer S. et al., in prep.

⁵Bonnell I. A. & Bate M. R., 2006, MNRAS, 370, 488; Peters T. et al., 2010, ApJ 711, 1017

Beyond ^{12}CO : Current and Future Prospects for Probing the Physics of Extragalactic Molecular Gas

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Understanding the physical mechanisms that regulate the conversion of interstellar gas into stars remains a central challenge in astrophysics, key to developing a predictive theory of star formation and constraining galaxy evolution across cosmic time. In that regard, the PHANGS-ALMA Large Program¹ has helped transforming our view of the link between molecular gas and star formation across diverse environments in nearby galaxies using $^{12}\text{CO}(2-1)$ observations. While the bright $^{12}\text{CO}(2-1)$ line remains a cornerstone tracer of molecular gas, its optical thickness limits constraints on key physical conditions. In contrast, fainter isotopologues such as ^{13}CO and C^{18}O are typically optically thin and provide more direct access to gas temperature, density, and opacity (see Fig. 1).

Building on my previous work^{2 3 4} and combining observations from ALMA, IRAM 30m/NOEMA, and the SMA, I will present the current state of multi-line mapping of the molecular ISM across star-forming galaxies. These datasets now place us in a regime where spatially resolved, multi-line observations can be used to constrain physical conditions across extragalactic environments. At the same time, we reach the limitations of simplified modeling approaches, highlighting the need for more sophisticated frameworks that capture the astrochemical and physical state of the star-forming ISM. Fully exploiting the diagnostic power of CO isotopologues and enabling robust interpretation of extragalactic observations, will therefore rely on advances in theory and implementations of ISM simulations.

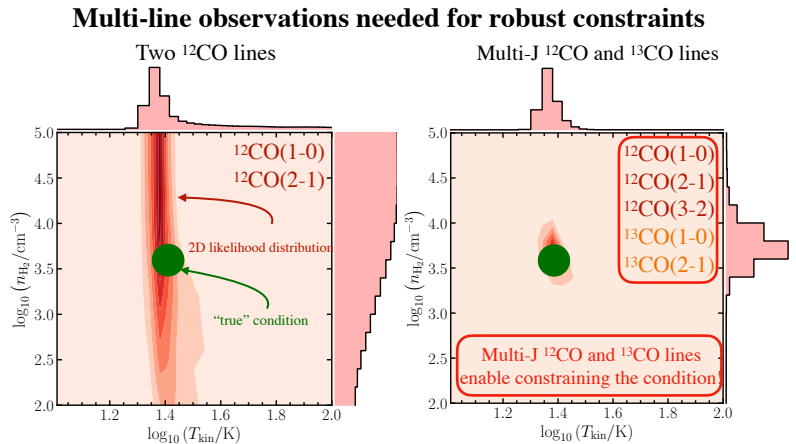


Figure 1: 2D marginalized likelihoods of GMC-scale extragalactic observations using RADEX highlight how multiple lines can constrain the actual, underlying physical conditions (here temperature and density). However, more sophisticated models are required to interpret multi-line observations beyond such single-zone RADEX models.

¹Leroy, A. K., Schinnerer, E., Hughes, A., et al. 2021b, ApJS, 257, 43

²den Brok, J. S., Leroy, A. K., Usero, A., et al. 2023, MNRAS, 526, 6347

³den Brok, J., Jiménez-Donaire, M. J., Leroy, A., et al. 2025a, AJ, 169, 18

⁴den Brok, J., Oakes, E. K., Leroy, A. K., et al. 2025b, ApJ, 988, 162

Local Volume Mapper survey: current status and future perspectives

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The Local Volume Mapper (LVM) survey, part of SDSS-V, is designed to connect massive stars to the ionized interstellar medium across an unprecedented dynamic range – from < 0.1 pc in the nearest Galactic H II regions, to ~ 10 pc in the Magellanic Clouds, and up to kiloparsec scales in more distant galaxies. Since 2023, it has been carrying out spectroscopic mosaicking of the Galactic plane and the Magellanic Clouds using a wide-field optical IFU. The survey is now approaching completion in 2027. Its successor – a dual-hemisphere LVM2 – is one of key directions for the forthcoming “After Sloan-5” (AS5; potentially SDSS-VI) survey.

LVM2 will enable 10x-deeper observations of southern H II regions at sub-parsec scales and deliver the first complete optical IFU mapping of the nearest northern galaxies – M31 (Andromeda), M33 (Triangulum), and low-metallicity star-forming dwarf galaxies – at ~ 10 pc resolution, complementing existing and forthcoming observations of stellar populations with HST and Roman observatories.

In this talk, I will provide a brief overview of the current status and future prospects of the LVM and LVM2 surveys, and their contribution to our understanding of the habitats of massive stars.

Dust as a Probe of Stellar Feedback: A Resolved Study of NGC 6946 with NIKA2

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Understanding how massive stars form and interact with their surrounding interstellar medium (ISM) requires connecting physical processes across a wide range of spatial scales and environments. Dust, as a key component of the ISM, provides a powerful probe of these processes through its thermal emission and its coupling to gas. In this work, we present a spatially resolved analysis of the nearby star-forming galaxy NGC 6946., observed with the NIKA2 instrument on the IRAM 30m telescope as part of the IMEGIN Large Program. Using NIKA2 observations at 1.15 and 2 mm, combined with multi-wavelength data from the infrared to radio regime, we decompose the millimeter emission of NGC 6946 into its components, namely thermal dust emission, free-free, and synchrotron emission, and quantify the contribution of CO(2–1) line contamination. Using a Bayesian spectral energy distribution (SED) modeling approach, we model the pure dust emission of this galaxy, adopting a single temperature modified blackbody model on both global and resolved scales. Our spatially resolved analysis is performed on 0.8 kpc (25 arcsec) scales, encompassing the galaxy center, spiral arms, and interarm regions. This enables us to investigate the spatial variations of the dust millimeter emissivity index, and its relation with dust temperature on sub-kpc scales across this galaxy. We find a strong correlation between dust temperature and star formation rate surface density, indicating that dust heating is primarily driven by recent star formation and providing direct evidence of stellar feedback acting on the ISM.

The Outer Galaxy High Resolution Survey (OGHReS) The molecular cloud catalog

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Star formation in our Galaxy occurs in the densest regions of giant molecular clouds, which are preferentially located within the spiral arms of the Milky Way. A comprehensive theory of star formation remains an active area of research, and one of the key open questions concerns the impact of the environment. Indeed, the properties of the interstellar medium vary significantly with location in the Galaxy, particularly as a function of Galactocentric radius. As we move outward from the Galactic center, the metallicity decreases, dust becomes less abundant, shielding against radiation is reduced, and the gas-to-dust ratio increases. All of these factors are expected to influence how stars form. To shed light on the role of environment in star formation, we use the Outer Galaxy High Resolution Survey (OGHReS), a new $^{12}\text{CO}(2-1)$ survey (including its isotopologues) of the outer Galaxy ($180^\circ \leq \ell \leq 280^\circ$, $|b| \leq 1^\circ$) conducted with the APEX telescope. In this talk, I will present the molecular cloud catalog constructed for the full survey using a combination of dilated masking, dendrogram analysis, and clustering algorithms. This catalog contains $\sim 25\,000$ molecular clouds, with derived properties including morphological parameters (area, radius, length, width), kinematic distances, column densities, masses, surface densities, and virial parameters. The catalog has also been cross-matched with Hi-GAL, providing new insights into star formation activity in the outer Galaxy. Finally, I will present a comparison between the cloud properties derived from OGHReS and those from SEDIGISM and COHRS, enabling a more comprehensive view on the influence of environment on star formation across the Milky Way.

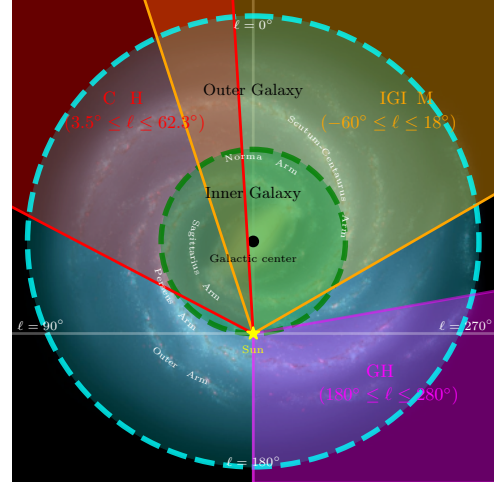


Figure 1: Artistic view of the Milky Way with the coverage of OGHReS, SEDIGISM, and COHRS shown in magenta, orange, and red, respectively.

Molecular Cloud Properties Across Galactic Environments

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Galaxy evolution is fundamentally shaped by the interplay between the interstellar medium (ISM) and star formation. The ISM regulates the cold gas reservoir for star formation, and its subsequent recycling via stellar feedback and galactic inflows and outflows. The lifecycle of molecular clouds is the key link between the multiphase ISM and star formation, yet its dependence on the galactic environment remains poorly constrained. Numerical models that resolve the multiphase ISM are therefore crucial for interpreting observations and testing theoretical models of cold cloud formation and gas depletion.

In earlier work (Fotopoulou et al. 2024), we analysed cold cloud populations in a high-resolution simulation of a dwarf galaxy merger, showing that cloud structure, scaling relations, and lifetimes are strongly shaped by stellar feedback in a highly dynamical environment. Ionising radiation and supernovae rapidly disrupt dense gas structures, producing filamentary, short-lived clouds ($t_{\text{life}} < 10$ Myr). However, the ongoing starburst does not deplete the cold gas reservoir from which stars form. These results highlight the role of environment in setting molecular cloud properties and motivate a broader question for ISM evolution: to what extent are cloud properties (i.e. structure, lifetimes, scaling relations) universal, and how do they depend on galactic conditions.

We address this question using simulations from the SILCC (Simulating the Life Cycle of molecular Clouds) project, presented in Rathjen et al. (2025), and covering a range of gas surface densities (Σ_{gas}). The simulation framework utilises the “tall-box” stratified disc model with ideal magnetohydrodynamics, self-gravity, non-equilibrium chemistry (tracking the evolution of H I, H II, H₂, and CO), cosmic ray acceleration and transport and a comprehensive stellar feedback model (winds, non-ionising and ionising radiation, supernovae).

We identify cold, dense clouds using the dendrogram algorithm from the ASTRODENDRO Python package to find density substructures in 3D. We trace the lifecycle of the identified clouds and present a comparative analysis of cloud evolution under solar-neighbourhood conditions versus high-density environments. Specifically, we quantify how deviations from standard scaling relations (e.g., Larson’s laws) correlate with the background Σ_{gas} . We further determine whether the shorter lifetimes seen in mergers are a universal feature of high-feedback environments or specific to the highly dynamical environment of the merger. Finally, we assess the impact of simulation resolution on these statistical properties to distinguish physical trends from numerical limitations.

The formation of the massive cluster R136 triggered by a high-velocity collision of a HI cloud with the disk of Large Magellanic Cloud

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The young rich cluster R136 having $4 \times 10^5 M_\odot$ in Large Magellanic Cloud (LMC) is the most massive cluster in the Local Group. We present a collision model of the cluster formation based on the MHD model¹. The collision is driven by the tidal interaction between the LMC and SMC, and the colliding gas was injected into the LMC disk at ~ 100 km/s². This high velocity allows the collision to collect massive HI gas into a small volume of ~ 10 pc rapidly in Myr, where the gas flow is guided by bent magnetic field lines created by the collision as proposed by Inoue and Fukui (2013)³. In order to make kinematical fitting by the model, we employed a half cone model which was motivated by the fan-shaped distribution of highly filamentary CO clumps discovered by the ALMA CO mapping (Figure 1)⁴. The Inoue et al. model predicts the filamentary CO gas which flows toward the cone vertex at the injected velocity, where gas is collected by the converging flows and HI is converted into H₂ gas via dust surface reaction. This flow is essential in forming a proto-cluster massive dense cloud core which grows further in mass by gravitation accretion near the cone vertex, where large HI mass is collected⁵. The collision forms a massive dense CO cloud core which continuously grows to $4.5 \times 10^5 M_\odot$ in a Myr time scale. The CO filamentary clouds are a remnant of the cone wall, which holds unbound large velocity dispersion of 20 km/s, a proof of the high velocity of the cone wall. Their velocity distribution is well fit by the half cone model. The injected HI gas had HI mass of $1 \times 10^6 M_\odot$, and collected the disk HI gas by collision, reaching total gas mass of $2 \times 10^6 M_\odot$, 20% of which formed the cluster. We argue that the high velocity gas collision is crucial in the massive cluster formation as found in the other massive clusters exhibiting cloud-cloud collisions⁶, and R136 is one of the most extreme cases showing the highest velocity.

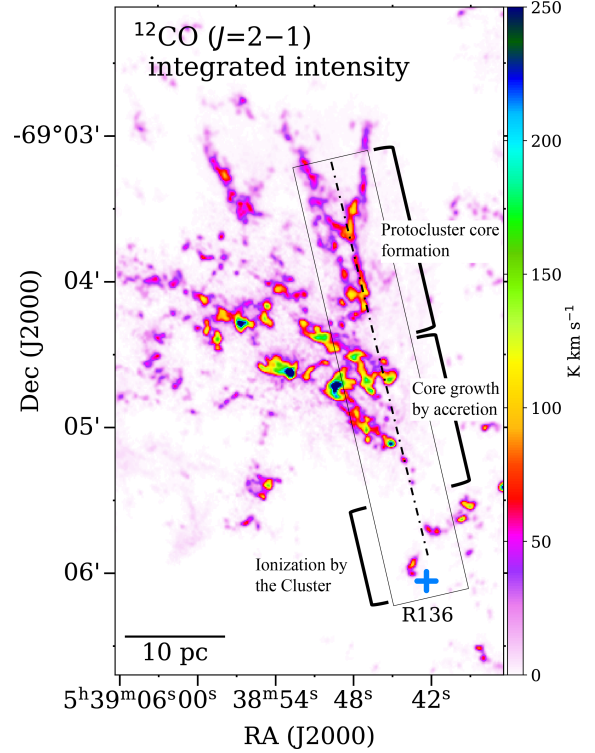


Figure 1: The ALMA $^{12}\text{CO } J=2-1$ distribution of the R136 region. The V shaped filamentary cloud formed the protocluster core from colliding HI at ~ 100 km/s, grew in mass by accretion, and formed R136.

¹Inoue, T., et al. 2018, ApJ, 70, 53

²Fukui, Y., et al. 2017, PASJ, 69L, 5

³Inoue, T. and Fukui, Y. 2013, ApJ, 774L, 31

⁴Wong, T., et al. 2022, ApJ, 932, 47

⁵Maity, A., et al. 2024, ApJ, 974, 229

⁶Fukui, Y., et al. 2021, PASJ, 73, S1

A novel three-dimensional view into dense photo-dissociation regions

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Nearly all of the neutral atomic and molecular gas in galaxies resides in photodissociation regions (PDRs), and their radiation is used as crucial observational astronomical diagnostics. For decades, the Orion Bar has been used as the prototypical PDR since it is nearly edge-on with a well characterized radiation field, providing a distinct view of the stratified chemical structure. Observations in the past decade have revealed that the locations of the H_2 dissociation and C^+ recombination fronts overlap and exhibit complex morphologies and emission structures. Current state-of-the-art astrochemical models, which are dominantly 1D slabs, have a difficult time reproducing the relative locations of these fronts and emission line features simultaneously. Furthermore, 1D models cannot reproduce the complex emission structures seen in observations. Recently, several upgrades have been made to the public PDR code, 3D-PDR, including plane-parallel irradiation in 3D and non-LTE H_2 level populations, providing unprecedented views into photochemistry.

I will present the first fully three-dimensional high-resolution PDR model of an Orion Bar analogue that resolves the important photochemical transitions. We model the PDR surface as a fractal, which enables control of the clumpiness. Figure 1 shows a volume rendering of one of these models, with the H_2 dissociation and C^+ recombination fronts annotated. I will show that the H_2 dissociation front is characterized by a complex surface structure, and the relative location changes with gas clumpiness. I will demonstrate that the 3D model reproduces overlapping H_2 photodissociation and C^+ recombination fronts, with some lines-of-sight having the latter preceding the former. I will also present predicted emission maps for key H_2 emission lines for JWST, in particular the (1-0)S(1) 2.12 μm line. Large correlated structures with pronounced cavities enable incursions of the H_2 front deep into the cloud, producing filamentary and arc-like emission features. Thus, three-dimensional models can explain the location and structure of the fronts from observations. These 3D models are novel, and will enable many interesting investigations into the photochemistry across a range of environments and comparisons to modern observations.

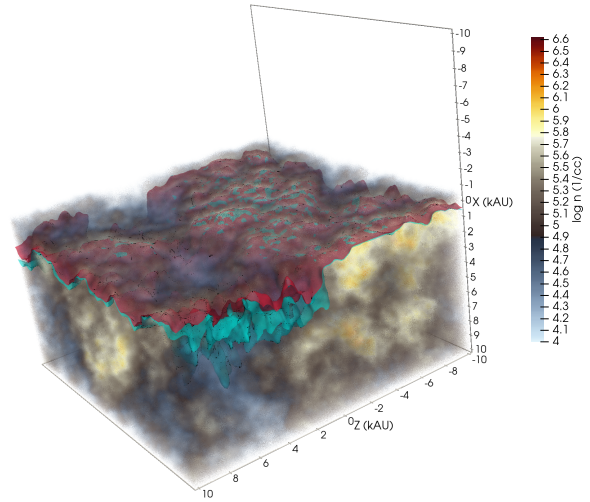


Figure 1: Left: Volume render of density of a fractal PDR with the H_2 dissociation front (red) and the C^+ recombination front (cyan) annotated. I note that the coloring scheme is deliberately chosen to highlight dense structures.

Coupled gas and grain chemistry in hot cores: a modeling view

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For several decades, astrochemical kinetics models have existed that simulate the coupled gas-phase and grain-surface chemistry occurring in star-forming regions. A critical focus of these models has been the production of larger organics, often termed “complex organic molecules” (COMs), that are one of the chemical hallmarks of the hot-core stage. While the precise mechanisms (and phases) through which individual COMs may be produced remain a topic of ongoing discussion, the role of grain-surface and ice chemistry has long been recognized as a crucial aspect of the process of chemical evolution. Indeed, evidence from observations, experiments and models indicates that a range of COMs may have their origins in grain-surface and ice chemistry that occurs long before the formation of a protostar. However, it is only recently, with the identification of solid-phase COMs with JWST, that this picture has become directly observationally verifiable. Through the combination of JWST and ALMA, a more comprehensive observational picture is now beginning to emerge of the complex organic content of star-forming regions, finally tying together the gas-phase and grain-surface ice chemistry.

I will give an overview of the current gas-grain kinetic modeling techniques and outcomes relevant to the production of complex organic molecules in star-forming cores. This includes the implementation of new “non-diffusive” reaction mechanisms on the grains that can facilitate the production of COMs at very low temperatures. I will also identify areas for improvement (or increased complexity) in the models, particularly in the treatment of ice layering and desorption characteristics that may contribute to observable behavior among different chemical species. Finally I will draw attention to the importance of comprehensive, coupled physical/dynamical modeling for testing ideas, both old and new, against the realities of observational data, and the role that these models will play in establishing new standard modeling baselines for comparison with observations.

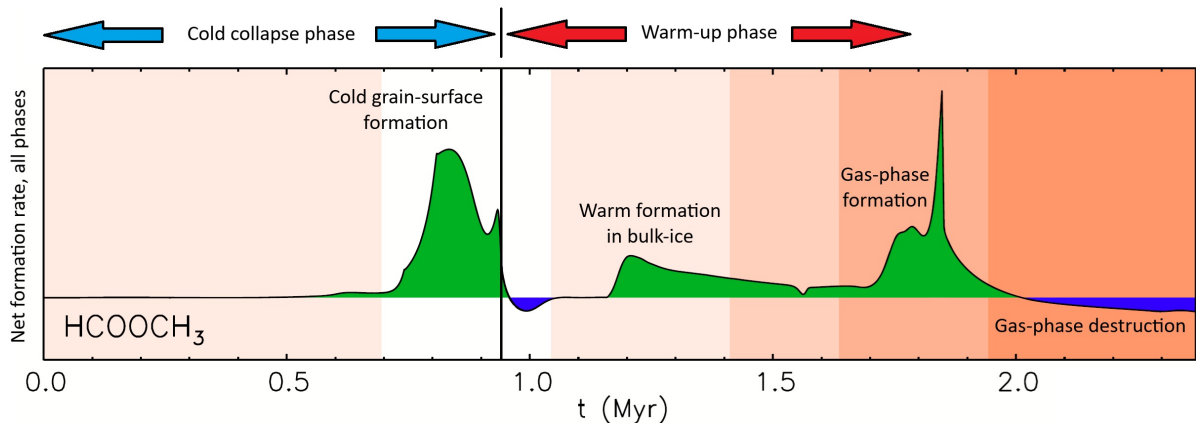


Figure 1: Net formation rate of methyl formate (HCOOCH₃) as a function of time, summed over all phases (gas + surface + bulk ice), during a representative hot-core chemical model.

Young Stellar Objects in Metal-Poor Dwarf Galaxies: JWST Studies of NGC 6822 and Sextans A

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Dwarf galaxies in the Local Group provide powerful laboratories for studying star formation in low-metallicity environments, offering nearby analogues to the conditions under which massive stars formed at high redshift. NGC 6822 (~ 490 kpc, $\sim 0.2 Z_{\odot}$) and Sextans A (~ 1.32 Mpc, $\sim 0.07 Z_{\odot}$) span a range of sub-solar metallicities and host active star-forming regions, making them ideal targets for probing how environment shapes the formation and early evolution of massive stars. Their low metallicities extend resolved studies into regimes approaching those of the early Universe.

We present new catalogues of Young Stellar Objects (YSOs) in both galaxies derived from high-resolution JWST imaging. At these distances, our observations are naturally sensitive to YSOs with masses of $15 M_{\odot}$ or higher, providing a focused and relatively unbiased view of the massive star formation channel. The data allow the identification of both deeply embedded and more evolved high-mass YSO candidates, offering a resolved view of massive star formation in these environments.

Our methodology builds on established YSO selection techniques and incorporates colour and magnitude diagnostics, as well as spectral energy distribution fitting, to robustly distinguish YSOs from contaminants. Applying a uniform selection approach to both galaxies, we construct matched catalogues that enable direct, systematic comparison. This framework allows us to investigate how metallicity and local conditions influence the demographics, spatial distribution, and clustering of massive YSOs, and to test whether star formation proceeds in a similar manner across different environments.

These catalogues form the foundation for ongoing analyses of the spatial relationship between massive YSOs and their natal gas and dust structures, as well as their inferred masses and contributions to global star formation rates. This will allow us to assess how local environmental conditions, particularly metallicity, regulate star formation. A direct comparison between NGC 6822 and Sextans A will provide new insights into how extremely low metallicity influences the earliest stages of stellar evolution and the build-up of stellar populations in dwarf galaxies. By linking resolved observations in nearby dwarf galaxies to conditions in high-redshift star-forming systems, this work directly addresses whether the processes governing massive star formation are universal over cosmic time.

In this contribution, we present the YSO catalogues and highlight their immediate value for studying massive star formation in these environments. The catalogues form the core of this contribution, and further analyses, including spatial distributions, mass estimates, and assessments of the YSOs' contributions to global star formation rates, will be conducted as the project progresses. To support future large-scale studies, we also plan to explore supervised machine learning approaches trained on validated YSO samples and theoretical models to enable efficient, homogeneous, and scalable identification of massive YSOs in JWST surveys.

Stellar Feedback in the Mini-Starburst Region W43 Traced by [C II] 158 μm Emission

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The W43 complex, located at 5.5 kpc near the junction of the Galactic bar and the Scutum–Centaurus spiral arm, is a highly active, luminous star-forming region hosting a massive WR/OB cluster and often described as a Galactic mini-starburst. We investigate the morphology, kinematics, and effects of stellar feedback in W43 using high spectral-resolution [C II] 158 μm observations obtained from SOFIA upGREAT, complemented by a unique data set such as APEX ^{12}CO (J=3-2) and ^{13}CO (J=3-2), IRAM ^{13}CO (J=2-1) and C^{18}O (J=2-1), 8 μm map from Spitzer, and Herschel Hi-GAL dust continuum maps. The [C II] emission shows integrated intensities exceeding 500 K km s^{-1} over 65–125 km/s, with position–velocity diagrams revealing multiple components dominated by emission at 75–125 km/s. We identify two bubble-like structures in both 8 μm and [C II] emission, exhibiting a bipolar morphology slightly orthogonal to the Galactic plane, with blueshifted gas to the west and redshifted gas to the east. These structures appear fragmented, with expansion velocities of 10–18 km/s. We calculate the column density of the structures by modelling the [C II] emission with RADEX and compare it with estimates from dust SED fitting to obtain the mass and kinetic energy of expanding shells. We compare these results with theoretical models and regions such as Orion to constrain whether the expansion is driven by stellar winds or ionisation feedback.

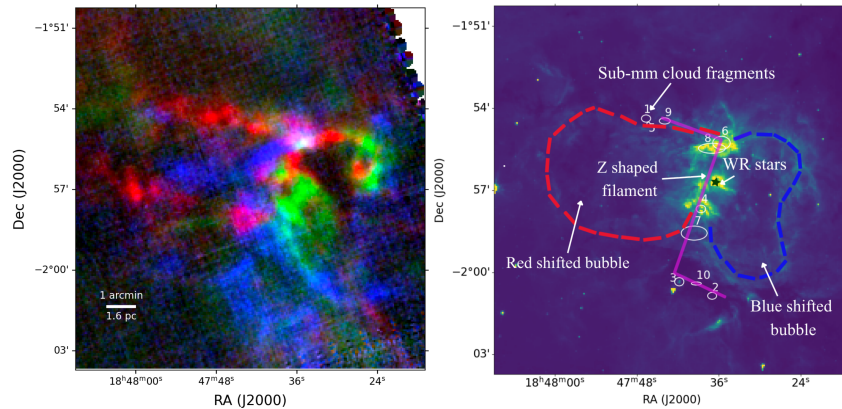


Figure 1: Left: RGB plot of 158 μm [C II] emission integrated between $V_{LSR} = 85\text{--}90 \text{ km/s}$ (blue), $95\text{--}100 \text{ km/s}$ (green) and $105\text{--}110 \text{ km/s}$ (red). Right: Spitzer 8 μm image overlaid with a schematic diagram and compact sub-mm fragments identified by Motte et al (2003)

A song of ice and fire: Linking ice and gas-phase chemistry in the high-mass hot core IRAS 18089

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The formation and destruction of molecules in the interstellar medium involve a complex interplay between gas phase reactions, as well as processes on grain surfaces and within icy mantles. In recent decades, the gas phase composition of the cold material toward star-forming regions could be well characterized using (sub)millimeter facilities. Prior to the launch of JWST, ice species other than the main constituents were challenging to detect.

Here, we present the first direct comparison¹ of the ice and gas phase molecular content towards a high-mass hot core region (within $\sim 5\,000$ au), shown in Fig. 1. We used spectroscopic data with JWST/MIRI-MRS from the JOYS program to derive the ice column densities of eleven species. We inferred the gas phase column densities for a total of 38 molecules from sensitive molecular line observations taken with ALMA at 3 mm wavelengths.

Not all species show comparable abundances in the ice and gas phases. However, we find similar trends when species show elevated ice or gas-phase abundances in the high-mass hot core IRAS 18089 compared to low-mass hot cores. There are hints of a decreasing abundance with galactocentric distance for OCN^- , CH_3OH , and CH_3CHO ices.

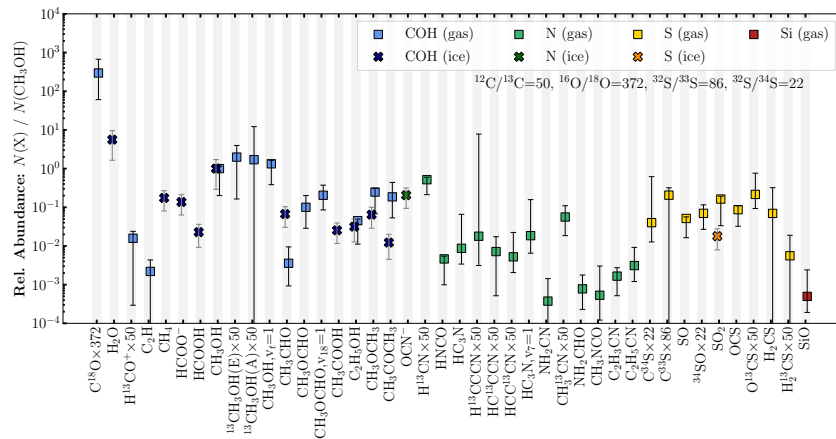


Figure 1: A comparison of the ice and gas phase molecular content in the IRAS18089 hot core.

¹Gieser et al. 2026, A&A (in press)

A Comprehensive Chemical Modeling of High-Mass Star-Forming Regions from an MHD simulation post-processing approach

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High-mass star forming regions (HMSFRs) show very rich chemistry throughout their evolution from cold cores to hot cores, but their understanding has been very limited due their rapid evolution and heavily embedded nature. We present here our comprehensive model of the chemistry in HMSFRs via post-processing of an MHD simulation using a gas-grain chemical code. While most of the hot core chemical models are dynamically static, i.e., just taking changing temperature into account, this model also takes mass transport into account, which can deliver gas with a different chemical history from outside to the inner hot regions. This is done using the tracer particles that follow the gas in detail as the cloud collapses. We also test different initial conditions in molecular clouds and how it affects the chemistry during and after cloud collapse. Our results indicate that the initial conditions of the molecular clouds significantly impact the chemical abundances during the collapse phase.

For example, a static molecular cloud at $T=15\text{K}$ will have a lot of C and O trapped in CO_2 ices, which is inert in nature, leading to lower complex molecule formation during the collapse phase. On the other hand, a static cloud at $T=10\text{K}$ will have more C and O in CO, forming more COMs via the CO hydrogenation ladder. This further affects the chemical reservoirs for various elements, because in early stages they settle into, depending on initial conditions, in various stable molecules and these reservoirs hardly change as the star formation starts and these reservoirs can mimic the initial conditions in molecular clouds.

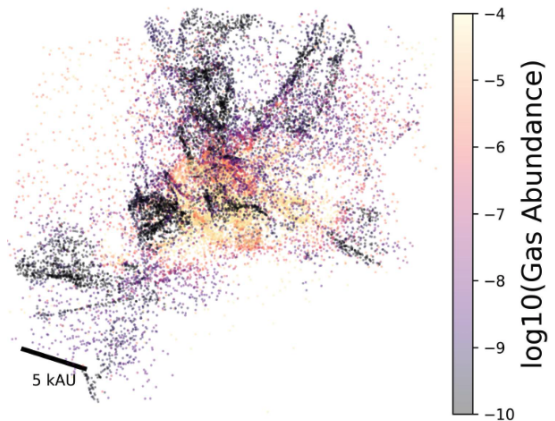


Figure 1: 3D Distribution of tracer particles encoded with CO gas-phase abundances at the end of simulation ($t=0.24$ Myr). Near the core, we can see CO totally in gas-phase, but it's still depleted in outer regions.

Probing Disk Dynamics: H I Velocity Dispersion in PHANGS-MeerKAT Galaxies

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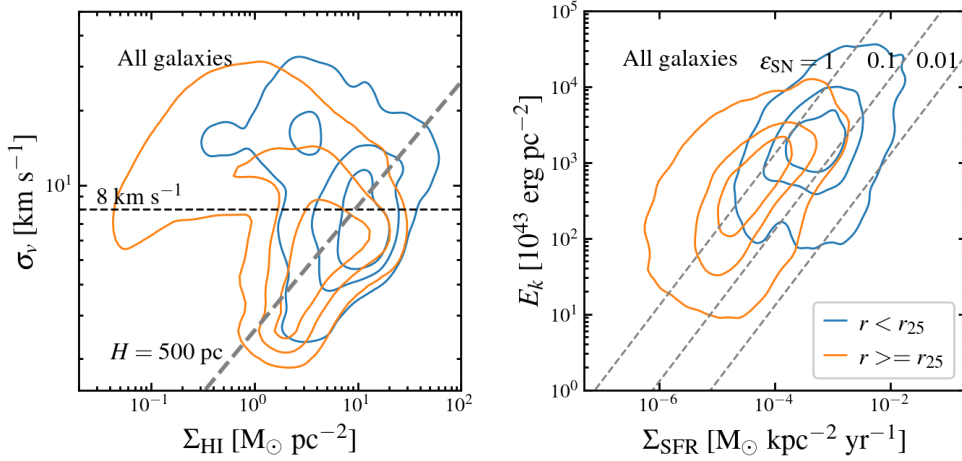


Figure 1: (*Left*) The H I velocity dispersion versus its surface density for pixels within (*blue*) and beyond (*orange*) isophotal radius (r_{25}). The gray dashed line indicates the pressure equilibrium relation assuming disk scale height of 500 pc. (*Right*) The total H I kinetic energy versus the SFR surface density. The dashed lines indicate energy balance assuming supernovae energy conversion efficiency of 100%, 10% and 1%.

H I velocity dispersion directly probes the dynamical state of a galactic disk and therefore provides a key diagnostic of the physical mechanisms governing the disk formation and evolution. Its origin likely reflects a complex interplay among H I self-gravity, the global stellar potential, and stellar feedback, and remains poorly understood. In this study, we aim to disentangle the relative roles of these factors using the latest PHANGS-MeerKAT H I observations of 15 galaxies, together with stellar surface density maps from WISE and star formation rate (SFR) surface density maps from GALEX FUV observations, at 15 arcsec resolution. For individual galaxies, the velocity dispersion σ_v shows the strongest correlation with H I surface density Σ_{HI} (median Spearman $r = 0.7$), suggesting that H I self-gravity may play a dominant role in setting the velocity dispersion. Combining measurements across the full sample, we find that the σ_v versus Σ_{HI} relation exhibits two distinct branches (Fig. 1, left panel): one following a power-law relation consistent with the pressure-equilibrium prediction for a disk scale height of 500 pc, and the other exhibiting an approximately constant σ_v , which may be dominated by the thermal motion of the gas. We also calculate the total energy budget by comparing the H I kinetic energy (E_k) with theoretically predicted energy input from supernovae (Fig. 1, right panel), and find that pixels in the outer galactic disk have E_k exceeding 100% of the total supernova energy input. This may also be due to the dominant thermal velocity component that makes us overestimate the H I kinetic energy. As a next step, we will perform spectral decomposition to separate different velocity components and correct for this effect.

The ISM and star formation at high redshift

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How the nascent stars in young galaxies formed out of the surrounding cold gas is one of the most fundamental questions in astronomy. Yet it has been known since the launch of the first infrared sky surveys that a substantial fraction of the Universe's high-redshift star formation is heavily enshrouded by dust, making it particularly challenging - historically - to obtain a complete view of star and galaxy formation in the young ($z \geq 2$) Universe. I will present ALMA+JWST imaging of the dustiest galaxies in the Universe, finally revealing their nature for the first time nearly 30 years after their discovery, and placing new constraints on high-redshift dust structure. I will also discuss our efforts to detect and resolve the cool gas reservoirs driving their growth, and the implications these observations have on (resolved) star formation laws. Finally, I will show how these multi-tracer studies can now be extended into the first billion years after the Big Bang, providing new evidence for the extremely rapid assembly of the first galaxies. I will conclude by discussing the implications of these results for our understanding of early galaxy formation, and how future facilities will transform our ability to resolve the cold Universe.

Investigating the Influence of Magnetic Fields on Bubble Morphology in Star-Forming Regions

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Magnetic fields play a fundamental role in the process of star formation, influencing the structure and evolution of molecular clouds. Massive stars within these clouds ionize their environment and produce expanding HII regions (bubbles) around them that can warp and shape the surrounding interstellar magnetic field to align tangential to the bubble. This has consequences on both the expansion and subsequent star formation, which are impacted by the higher densities of gas and dust along the edges of the structure. Thermal emission from dust grains exhibit a linear polarization due to grain alignment with magnetic fields, and can be used to infer the magnetic field morphology through their polarization. Despite their importance, the precise role of magnetic fields in bubble evolution remains an open question, and a comprehensive statistical analysis of a large sample of

bubbles is necessary in order to work towards understanding this question. I will introduce a novel technique developed to search for and study magnetic fields impacted by bubbles through detecting circular structures in dust polarization maps. This method uses circular models, kernels, in a pixel-by-pixel comparison with a polarization map. This produces circular alignment maps which signal where the field exhibit either circular and radial features. A sample of molecular clouds from the BISTRO survey are studied, and candidate bubbles for each of these clouds will be discussed, as well as established bubbles from the WISE and Simpson catalogs. This research works toward determining broader trends in how bubbles influence their environment and establish a clearer relationship between polarization efficiency and bubble properties.

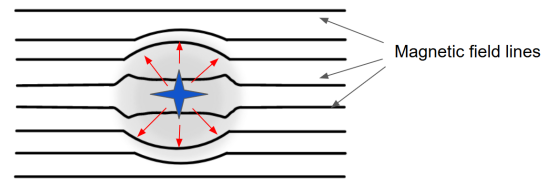


Figure 1: A cartoon showing a massive star (blue diamond) ionizing its environment to produce an HII region. Radiation and stellar winds (direction illustrated by red arrows) sweep radially outward and interacts with the surrounding interstellar magnetic field (solid black lines). This causes the field to tend to form a circular pattern which can be traced using the thermal emission of dust grains.

From Birth to Dissolution: The Lifecycle of Stellar-Feedback-Driven Bubbles in PHANGS–JWST Galaxies

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Stellar feedback injects energy and momentum via radiation and winds to create cavities in the interstellar medium, sweeping up and compressing material while simultaneously heating and dispersing dense accumulations. Stellar-feedback-driven bubbles therefore simultaneously trigger and quench star formation, making them key regulators of galactic star formation histories, but their exact role remains difficult to quantify across entire galactic environments.

Using PHANGS–JWST observations of 74 nearby galaxies, we probe this feedback cycle through structural analysis of the $7.7\,\mu\text{m}$ PAH emission at an angular resolution of $0.27''$. We identify and extract voids using a novel algorithm based on persistent homology, a technique from topological data analysis capable of detecting spatial structures on all scales accessible in the data. By tracking the topology of the emission field, this method robustly identifies voids without imposing arbitrary intensity thresholds or geometric assumptions, making it well suited for the complex, multi-scale morphology of the interstellar medium.

Although the observations provide only a snapshot in time, the large population of detected bubbles enables a statistical reconstruction of their evolutionary sequence. We characterize each bubble by constructing intensity profiles that trace the emission from the void interior outward through the surrounding medium. Using a combination of dimensionality reduction, unsupervised clustering, and self-organizing maps, we classify the bubbles into physically distinct groups and reconstruct a continuous evolutionary sequence — from young, actively expanding cavities with pronounced shells around deeply evacuated interiors, to aged, dissolving remnants in which the central void has begun to refill and the surrounding enhancement has faded. By linking with stellar clusters, we aim to quantify directly the timescales and energetics creating stellar-feedback-driven bubbles and their impact on star formation across nearby galaxies.

A modelling perspective on observations of Faraday rotation

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Faraday rotation of polarised emission is a powerful tracer of the galactic magnetic field¹. How can simulations of the ISM improve our observations of this important phenomenon?

In this contribution, we will approach this question using the SILCC IX simulations². These simulations capture the ISM physics in environments ranging from our quiescent Milky Way neighbourhood to violent starburst galaxies. We demonstrate how environmental properties and star formation influence the structure of the magnetic field and discuss how these effects impact the reconstruction of the magnetic field from Faraday rotation.

We find that the correlation length of the magnetic field is on the order of several tens of parsecs, independent of the larger-scale environment. This coincides with the typical length between sign reversals of the parallel magnetic field component, which causes Faraday rotation. Hence, Faraday tomography requires a line-of-sight resolution ~ 10 pc to accurately resolve the galactic magnetic field structure. Further, we show that the correlation length decreases with increasing star formation rate and associated turbulence, but grows with the local magnetic field strength.

We furthermore produce maps of Faraday rotation from our simulations (see Fig. 1) and show that the magnetic field strength obtained from Faraday rotation observations can be off by a factor of ten, even under ideal conditions where the electron column density is known. The estimated field strength is typically slightly overestimated due to a weak correlation between electron density and magnetic field strength in the warm ionised medium – the ISM phase contributing most to the rotation measure.

Finally, we present synthetic synchrotron emission maps, created using the simulated population of cosmic rays. The resulting synthetic observations of Faraday rotation allow us to investigate the performance of different reconstruction techniques present in the literature³, including rotation measure synthesis and QU fitting.

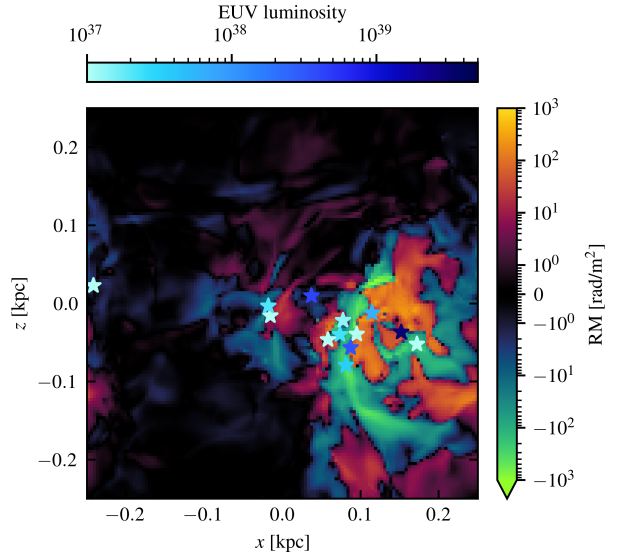


Figure 1: Rotation measure of a 500 pc cube from a SILCC IX simulation close to our local galactic environment. The markers represent star clusters, with colour indicating their brightness in the extreme ultraviolet. The rotation measure is enhanced around clusters with high luminosity.

¹Heald G., 2015, *ASSL*, 407, 41

²Brugaletta V. et al., 2025, *MNRAS*, 543, 4286

³Takahashi K., 2023, *PASJ*, 75, S50

The Complex Magnetic Field of the Massive Star-Forming Region IRAS 16562-3959

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IRAS 16562-3959 is a massive star-forming region with a total gas reservoir of $\sim 900 M_{\odot}$ that hosts 18 ALMA-identified continuum cores¹ and a massive young stellar object, G345.4938+01.4677 at a distance of 2.4 kpc². G345.49+1.47 has active disk accretion, an ultra compact H II region and drives a massive outflow³ (see Figure 1). Here we present ALMA Band 6 observations of the magnetic field (B-field) as part of the Magnetic Fields in Massive Star-forming Regions (MagMaR) project.

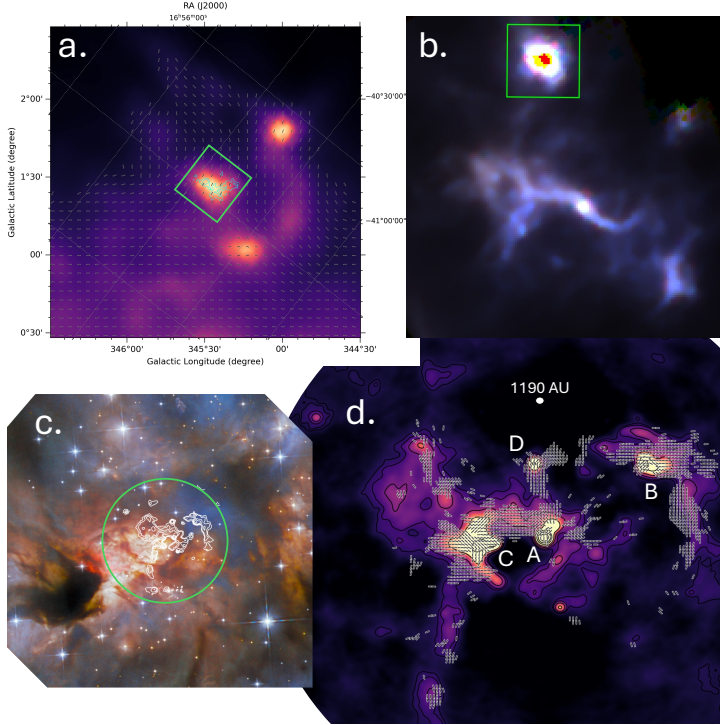


Figure 1: A series of zoom-ins on IRAS 16562-3959. The green shapes show the next panel. *a.* 353 GHz Planck dust emission map with B-field vectors and Herschel 250 μm contours in cyan. *b.* RGB image with Herschel 500 μm , 350 μm and 250 μm as the R, G and B channels respectively. *c.* Hubble color image with the MagMaR Band 6 contours in white. The outflow from G345.49+1.47 can be seen. *d.* MagMaR dust emission with B-field vectors overlaid. The four main cores are labeled A, B, C and D. The beam is 1190 AU assuming a distance of 2.4 kpc.

The magnetic field is incredibly well-ordered but complex across the whole region. We identify four cores (labeled in Figure 1) where we observe pinched, hourglass-like, magnetic field structures. These are generally indicative of magnetically-regulated star formation and are rarely seen individually, much less with four in a single region. Some of these dusty cores are chemically evolved, suggesting additional protostars may have already formed in this region. Other magnetic field structures also appear to follow outflow cavity walls. This makes IRAS 16562-3959 an extremely interesting region in which to study the influence of high-mass star formation on its surroundings and understand how small clusters form around massive stars.

¹Gúzman, A. E., et al. 2014, ApJ, 796, 117

²Lumsden, S. L., et al. 2013, ApJS, 208, 11

³Gúzman, A. E., et al. 2020, ApJ, 904, 77

The GLOSTAR Galactic Plane Survey: A GLObal view on STAR Formation

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The GLObal view on STAR formation in the Milky Way (GLOSTAR) survey uses the wide-band (4-8 GHz) C-band receivers of the VLA and the Effelsberg 100-m telescope to conduct an unbiased survey to characterize star-forming regions in the Milky Way. This survey of the Galactic mid-plane detects tell-tale tracers of early phases of high-mass star formation (Fig. 1): compact, ultra- and hyper-compact HII regions, and 6.7 GHz methanol (CH_3OH) masers, which trace some of the earliest evolutionary stages in the formation of high-mass stars and can be used to pinpoint the positions of very young stellar objects, many of them still deeply embedded in their natal material. The observations center at 5.8 GHz and also cover emission from the 4.8 GHz formaldehyde (H_2CO) and multiple Radio Recombination Lines (RRLs). The GLOSTAR observations were made with the VLA B- and D-configurations, and the Effelsberg 100-m telescope to recover emission on all angular scales. This provides a radio survey covering all angular scales down to $1''$. Here I will give an overview over the survey as well as main results and follow up works.

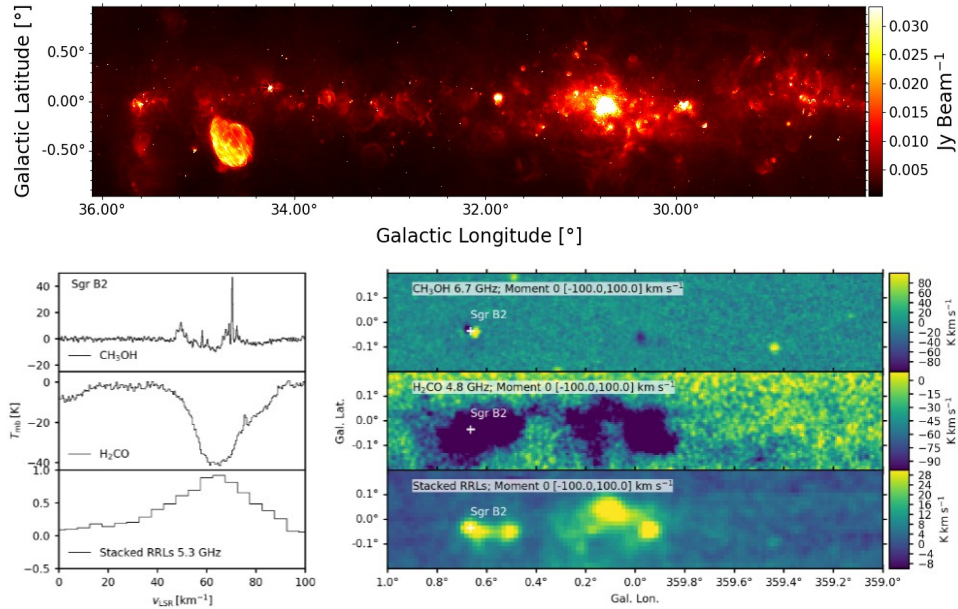


Figure 1: *Top*: Radio continuum image obtained from combination of the VLA D configuration and the Effelsberg single-dish observation of the pilot region in the range $28^\circ < \ell < 36^\circ$. *Bottom*: Example spectra (left) and moment maps (right) of the Galactic center for CH_3OH (top), H_2CO (middle), and stacked RRLs (bottom) using Effelsberg data.

3D Protostellar Evolution under Rapid Gas Accretion: Pathways to Massive Star Formation

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Protostellar evolution with mass accretion represents the fundamental stage during which a star gains most of its mass and angular momentum and grows into a massive star. The nature of this process determines the final stellar properties. However, the 3D nature of protostellar evolution remains largely unexplored. This is mainly because resolving protostellar scales is both computationally expensive and challenging from the perspective of radiative transfer. In most 3D radiation hydrodynamics (RHD) simulations, protostars have therefore been replaced by sink particles. Yet, 3D calculations at protostellar scales are essential to capture how protostars acquire entropy and angular momentum through disk accretion and interact with surrounding disks.

In this talk, we present the results of our 3D RHD simulations that directly resolve protostellar evolution up to masses exceeding $10 M_{\odot}$ under rapid accretion^{1,2}. To accurately follow radiative transfer at protostellar scales, we have developed a new RHD solver based on an explicit M1 closure scheme. Using this solver, we investigate protostellar evolution in high accretion-rate environments extracted from cosmological simulations, which are favorable sites for the formation of supermassive stars in the early Universe³.

We find that protostellar evolution in 3D simulations significantly differs from that in conventional 1D models. As seen in Fig. 1, the protostar is surrounded by a highly optically thick disk. This configuration, unique to 3D simulations, affects the accretion shock and photospheric structure, thereby modifying the internal properties of the protostar. Moreover, while the protostar continuously accretes angular momentum from the disk, its angular velocity remains nearly constant. The internal structure and spin of protostars obtained in our simulations are key ingredients in their subsequent evolution and feedback processes. They determine when and how strongly the star radiates, and also influence the nature of its supernova explosion. Our results provide new insights into these properties in realistic accretion environments.

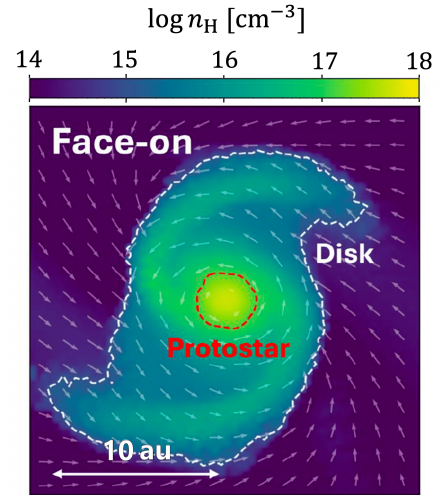


Figure 1: Density distribution in a 3D RHD simulation resolving protostars. The region enclosed by the red line corresponds to the protostar, which is supported primarily by pressure rather than centrifugal force. The white lines indicate the boundary of the circumstellar disk, which coincides with the photospheric surface.

¹Kimura K., Sugimura K., Hosokawa T., Fukushima H., & Omukai K., 2026, ApJ, 999, 257

²Kimura K., Hosokawa T., Sugimura K., & Fukushima H., 2023, ApJ, 950, 184

³Chon, S., Hosokawa, T., & Yoshida, N. 2018, MNRAS, 475, 4104

High-mass star formation: then and now

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High-mass star formation is a highly complex, multi-scale process, both at present day as well as in the early Universe. It requires a self-consistent treatment of the interplay between self-gravity of gas and dust and supersonic turbulence, magnetic fields, chemistry, radiative feedback, stellar dynamics, and the larger galactic environment. Despite the vastly different physical conditions, many of the underlying processes are common to both regimes. In this review, I draw parallels between high-mass star formation in the metal-enriched interstellar medium of the Milky Way and the formation of Population III stars from metal-free primordial gas at high redshift. I review current theoretical models and observational constraints, and argue that primordial gas is highly susceptible to fragmentation, leading to the formation of small multiple systems with a logarithmically flat mass function. I also discuss the current theoretical pathways for the formation of rapidly accreting supermassive stars, reaching masses of several hundred thousand solar masses, which may provide the seeds of the supermassive black holes powering quasars and active galactic nuclei.

The Development of Turbulence within and around Molecular Clouds driven by Multiple Supernova Explosions

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The origin of the supersonic turbulence ubiquitously observed in molecular clouds¹ is key to understanding how their density structures are shaped² and how stars form within them. Previous numerical studies suggest that a single supernova occurring near a molecular cloud cannot sustain the observed level of turbulence for more than 0.5 Myr³. However, the typical lifetime of molecular clouds (a few tens of Myr) is sufficiently long to experience multiple compressions from successive supernovae^{4 5}. Therefore, the collective impact of multiple supernovae remains an important open question.

In this study, we begin with a galactic-scale simulation of the interstellar medium (SILCC project⁶) and perform a zoom-in simulation on 100 pc scales focusing on a molecular cloud. We systematically inject six supernovae at a distance of 25 pc from the cloud’s center of mass, with a time interval of 0.3 Myr between successive explosions. We also perform post-processed synthetic observations using MAPPINGS V for H α and RADMC-3D for ¹²CO($J = 1-0$). Our results show that the majority of kinetic energy from supernovae is preferentially deposited into diffuse inter-cloud regions, which can be observed as a 20–30 km s^{−1} enhancement in H α . Meanwhile, the turbulent velocity in dense regions also increases, particularly in the form of compressive-mode turbulence. This manifests as an increased velocity dispersion in CO emission, reaching up to 10 km s^{−1}, although the effect persists for < 0.3 Myr. The density probability distribution function is broadened by the impact of supernovae, but this effect is more prominent in H₂ than in CO.

These results indicate that multiple supernovae play an important role in generating compressive-mode turbulence and shaping high-density structures in molecular clouds. However, additional energy input (e.g., from galactic-scale dynamics) is likely required to form CO-rich dense structures, sustain supersonic turbulence, and enhance star formation.

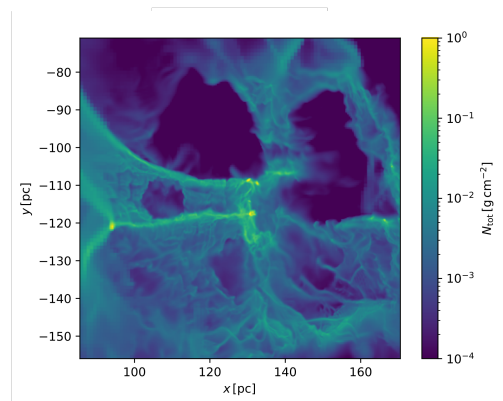


Figure 1: An example column density snapshot from our SILCC-Zoom simulations on 100 pc scales. The cloud at the center is compressed by six supernovae, each of which exploded at the distance of 25 pc from the cloud.

¹Heyer, M. H., and Brunt, C. M., 2004, ApJ, 2004, 615, 45

²Schneider, N., Ossenkopf-Okada, V., Clarke, S., et al., 2022, A&A, 666, 165

³Seifried, D., Walch, S., Haid, S., Girichidis, P., Naab, T., 2018, ApJ, 855, 81

⁴Chevance, M., Krumholz, M. R., McLeod, A. F., et al., ASPC, 534, 1

⁵Zucker, C., Goodman, A. A., Alves, J., et al., 2022, Nature, 601, 334

⁶Walch, S., Girichidis, P., Naab, T., et al., 2015, MNRAS, 454, 238

Modeling Stellar Feedback in Multiphase ISM: Towards Physically Motivated Sub-Grid Prescriptions

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Massive stars play a central role in shaping their environments through radiative and mechanical feedback, yet the efficiency and impact of these processes remain uncertain across cosmic time. Addressing this uncertainty, particularly in light of recent high-redshift observations from JWST, requires cosmological simulations that accurately capture how stellar feedback regulates the interstellar medium (ISM) and star formation in diverse environments. However, widely used simulations such as IllustrisTNG and EAGLE are limited by simplified sub-grid models that do not fully capture the complexity of stellar feedback in a turbulent, multiphase ISM.

We address this by developing a physically motivated ISM model in which feedback from core-collapse supernovae drives phase transitions within turbulent gas. Using 3D simulations of isolated supernova explosions, we derive environment-dependent prescriptions for the feedback-driven redistribution of energy and mass across ISM phases, by systematically exploring variations in gas density, metallicity, radiative cooling, UV radiation field strength, and phase structure.

In my talk, I will present results from this work and discuss how high-resolution simulations can provide key constraints for sub-grid models that link small-scale stellar feedback to galaxy-scale evolution.

Molecular Cloud Evolution, Star Formation, and Feedback in Nearby Galaxies as First Step for Galaxy Evolution and Star Formation

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I will discuss star-forming and non-star-forming molecular gas (clouds and filaments) using recent ALMA CO(1–0) observations of M83 and 12 other nearby galaxies.

Star-forming molecular gas is localized within galactic structures such as bars and spiral arms, whereas non-star-forming molecular gas is abundant outside these structures (Koda et al. 2023). This segregated distribution suggests that molecular clouds and filaments evolve in concert with large-scale galactic dynamics, and that star formation is triggered on these large scales. The evolutionary timescales of the molecular structures are therefore long, comparable to galactic rotation timescales - this is in contrast to recent suggestions of their short lifetimes.

The CO 2–1/1–0 ratio (R_{21}) maps also show that the impact of stellar feedback (i.e., regions with high line ratios) is localized, while dormant molecular gas (with low ratios) is prevalent across the galactic disks (Koda et al. 2025; Lee, Koda et al. 2026). Therefore, to understand molecular gas evolution, star formation, and stellar feedback, our framework should include this dormant gas phase and consistently explain the full life cycle of molecular gas – from dormant to star-forming and then back to a dormant phase – in sync with galactic rotation and dynamics.

I will argue that molecular structures coagulate and fragment under the influence of galactic dynamics, triggering star formation and subsequent feedback. I will also present initial results from our upcoming JWST survey of embedded star formation across the full disk of M83.

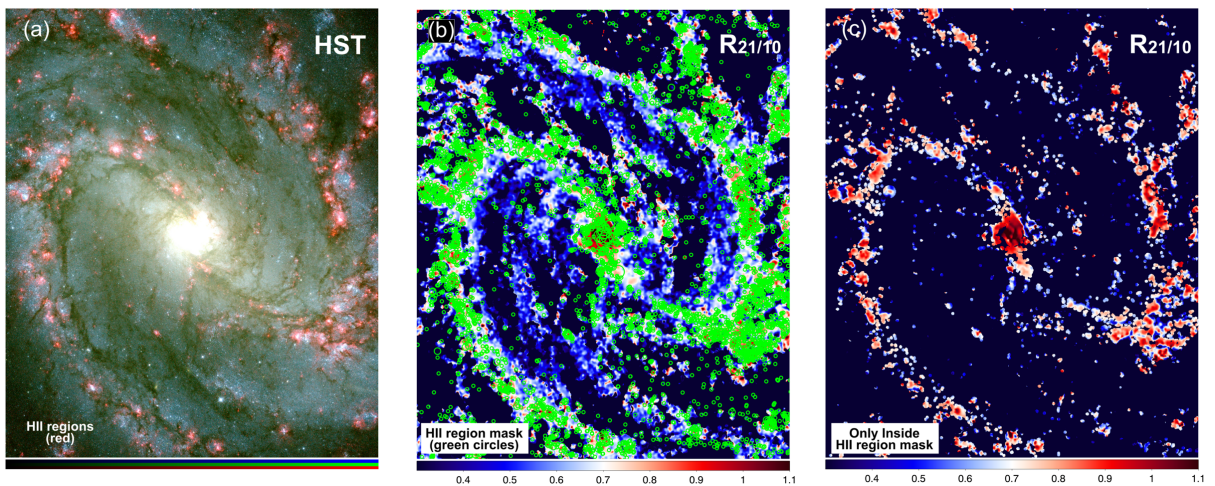


Figure 1: M83 (a) HST [red=H α]. (b) R_{21} with HII regions encircled with green. (c) R_{21} only around the HII regions. The CO(2-1) excitation correlates systematically with HII regions (c) and with galactic structures (spiral arms, bar) even outside the HII regions (b).

Time-dependent chemical evolution during cloud formation: H₂-regulated chemistry in diffuse molecular clouds

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Molecular cloud formation is a pivotal process for both star formation and astrochemistry. One of the key triggers for cloud formation is the interstellar shock wave. Previous studies performed 3 dimensional (3D) magnetohydrodynamics (MHD) simulations of converging flows of atomic gas with reduced chemical networks ($\lesssim 10$ molecules), and revealed turbulent mixing is essential for H₂ formation¹. Since molecular clouds are observed with various molecular lines of emission or absorption, we need to know if and how they correlate with H₂. However, it is computationally too expensive to solve 3D MHD and a full chemical network simultaneously.

We solve this problem with a two-step procedure. First, we conduct 3D MHD simulations of converging flow with a reduced chemical network. We put tracer particles that move along the local velocity field and obtain the temporal variation of physical parameters (e.g., gas density: n_{H}) along their trajectories. Second, we calculate a full chemical network (~ 500 chemical species, including both gas phase and ice chemistry) along them. The results of the full chemical network and reduced network show reasonable agreement, which confirms the validity of our method.

To compare with the above fiducial model, we also run "static model"; we calculate molecular abundances at each position with the physical parameters fixed to the values at the final timestep. In regions of $n_{\text{H}} \lesssim 10^3 \text{ cm}^{-3}$, the abundances of various molecules that are used in observations (e.g., CH and OH) are quite similar between the fiducial model and the static model, IF we fix the H₂ abundance in the static model to the value in the final timestep of the fiducial model. This indicates that the abundances of molecules other than H₂ in the fiducial model are determined by steady-state chemistry reflecting the local values of H₂ abundance and physical parameters. At higher densities, however, the abundances are affected by water ice formation, which changes the elemental abundance of carbon and oxygen in the gas phase.

We compare the column densities of H₂ and other molecules obtained from our fiducial model with the observations of diffuse and translucent molecular clouds. Our results show that the column densities of CH, CCH, and OH are linearly correlated with those of H₂ (Figure 1²), which supports the empirical relation obtained from observations³.

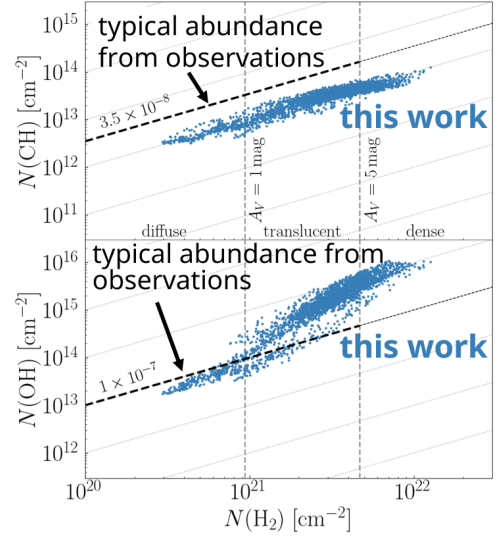


Figure 1: The calculated column densities of H₂, CH, and OH (blue dots) and the typical abundances from observations (dashed black lines).

¹Valdivia, V., Hennebelle, P., Gerin, M., Lesaffre, P. 2016, A&A, 587, A76, p.17

²Komichi, Y., Aikawa, Y., Iwasaki, K., & Furuya, K. 2026, MNRAS, 546, 2, stag027

³Sheffer, Y., Rogers, M., Federman, S. R., et al. 2008, ApJ, 687, 2, p.1075

Binary formation in a 30 $M_{\odot}$ dense core in infrared dark cloud G28

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We report high-resolution ALMA observations toward a massive protostellar core C1-Sa ($\sim 30 M_{\odot}$) in the Dragon Infrared Dark Cloud. At the resolution of 140 AU, the core fragments into two kernels (C1-Sa1 and C1-Sa2) with a projected separation of ~ 1400 AU along the elongation of C1-Sa, consistent with a Jeans length scale of ~ 1100 AU. Radiative transfer modeling using RADEX indicates that the protostellar kernel C1-Sa1 has a temperature of ~ 75 K and a mass of $0.55 M_{\odot}$. C1-Sa1 also likely drives two bipolar outflows, one being parallel to the plane-of-the-sky. C1-Sa2 is not detected in line emission and does not show any outflow activity but exhibits ortho- H_2D^+ and N_2D^+ emission in its vicinity, thus it is likely still starless. Assuming a 20 K temperature, C1-Sa2 has a mass of $1.6 M_{\odot}$. At a higher resolution of 96 AU, C1-Sa1 begins to show an irregular shape at the periphery, but no clear sign of multiple objects or disks. We suspect that C1-Sa1 hosts a tight binary with inclined disks and outflows. Currently, one member of the binary is actively accreting while the accretion in the other is significantly reduced. C1-Sa2 shows hints of fragmentation into two sub-kernels with similar masses, which requires further confirmation with higher sensitivity.

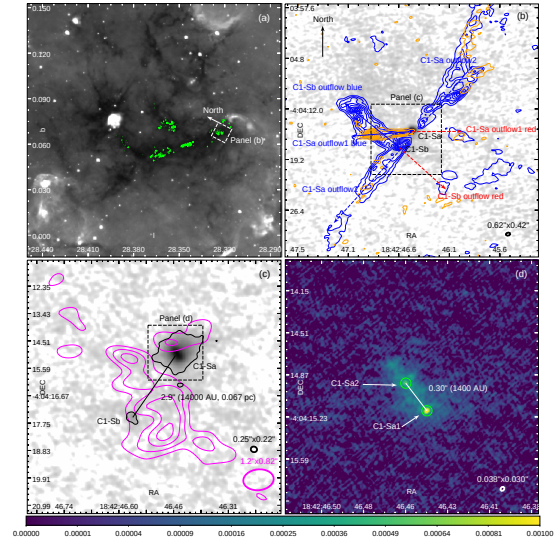


Figure 1: **(a):** Spitzer $8\mu m$ image of the Dragon IRDC (in galactic coordinates). The green contours mark the 1.3 mm continuum emission from ALMA. **(b):** A zoom-in view of the continuum cores (greyscale) within the dashed square from panel (a). The blue contours show the $^{12}CO(2-1)$ outflows. The orange contours show the $SiO(5-4)$ outflows. **(c):** A zoom-in view within the dashed square from panel (b), showing the 1.3 mm continuum with a factor of 2 higher resolution. The magenta contours show the ortho- H_2D^+ integrated intensity. **(d):** A zoom-in view within the dashed square from panel (c) of the high-resolution 1.3 mm continuum image. The massive core C1-Sa hosts two kernels.

The innermost environment of the multiple system GU CMa probed with VLTI/GRAVITY

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Multiplicity is a common property of young stellar objects (YSOs) and in particular towards the high-mass stellar range. While the origin of these multiple systems is deeply related to the mechanisms of early star formation (capture, disk fragmentation...), understanding their architecture is highly relevant to predict their fate.

Here, we studied observationally the $\sim 10 M_{\odot}$ B-type object GU CMa in the CMa R1 star-forming region, which is located in a cluster close to the active star-forming Z CMa cluster, but older by few Myr. We used high-angular resolution near-infrared interferometric observations with GRAVITY at the VLTI to probe the inner 10 au region around the known central spectroscopic binary¹. We report the discovery that the central binary is actually a triple system hosting a $4 M_{\odot}$ companion with a ~ 20 -year orbital period in an extreme eccentric orbit with $e = 0.98$. Though the system appears dynamically stable, its multiple nature is probably responsible for the rapid clearing of any circumstellar disk(s). Furthermore, we analyzed the spatial and kinematic properties of the strong Br γ emission line, which traces hot gas close to the star. The Br γ emission is found to be mostly located at the position of the spectroscopic binary, with no detectable contribution at the location of the newly detected companion. The hot gas component appears strongly time-variable at the companion periastron passage, suggesting a tidally perturbed circumbinary structure. At epochs distant from periastron, the kinematic profile is compatible with a Keplerian motion in an eccentric ring-like or one-armed spiral configuration, while the 2019 epoch near periastron shows a markedly more complex and asymmetric morphology.

GU Cam is therefore an interesting laboratory to explore the impact of multiplicity on the evolution of massive stars.

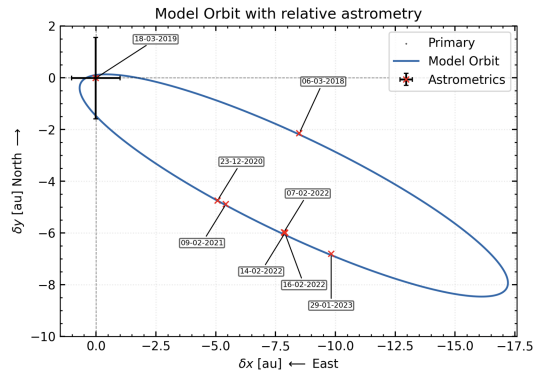


Figure 1: Best-fit orbital solution of the tertiary companion in GU CMa derived from interferometric astrometry. The close agreement between the measured astrometry and the model orbit confirms the highly eccentricity of the orbital configuration.

¹ A. Shokry, S. M. Saad, M. A. Hamdy, M. M. Beheary, M. S. Abolazm, K. A. Gadallah, M. H. El-Depsey and M. S. Al-Gazzar 2018, New Astronomy 59, 8

Characterizing temperature structures of massive star-forming clumps in ALMAGAL survey

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Star formation occurs predominately in star clusters possessing at least one massive star. The presence of high-mass stars is expected to have a significant impact on the surrounding environment. Feedback from high-mass (proto)stars plays important role on affecting the subsequent star formation by creating thermal structures in their natal clouds. ALMAGAL, an ALMA large program observing >1000 massive clumps in the Galaxy provides unprecedented opportunities to study this aspect of the star formation theory¹. We obtained short-spacing corrected line data cubes by adding single-dish data from APEX to ALMAGAL data in 7MTM2 configuration, whereby rotational temperature maps are derived for 419 clumps using the line fitting package XCLASS² with LTE assumption. We found generally higher temperature derived from H₂CO than dust temperatures calculated from FIR observations. We separate the contribution from radiative and mechanical (outflow) feedback by fitting the bulk gas and the outflow components individually and found comparable degree of heating produced by the two mechanisms. The measured total thermal energies show a correlation with clump-scale physical parameters, implying feedback from protostars is capable of influencing the immediate surroundings.

¹Molinari et al., 2025, A&A, 696, 149

²Möller et al., 2017, A&A, 598, 7

Insights into Massive Star Formation and Feedback from $\sim 100,000$ Star Clusters and Associations: PHANGS-HST & JWST today, the future with HWO

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The PHANGS-HST and JWST Treasury Programs have produced the most extensive inventories to date of optically visible and dust-obscured star clusters across nearby galaxies. A coherent picture is emerging of the earliest phases of star formation, built from complementary studies that consistently point to short ISM-clearing timescales (~ 3 Myr), in agreement with earlier optical studies. Together, these results underscore the central role of early, pre-supernova feedback in the star formation cycle. Drawing on the statistical power of tens of thousands of clusters spanning dozens of galaxies, I will synthesize what PHANGS and related programs have revealed about cluster evolution, feedback, and the use of clusters as “clocks” for timing key phases of star formation. Looking ahead, I will highlight the critical need for the Habitable Worlds Observatory (HWO), NASA’s next flagship astrophysics mission after Roman. HWO will operate as a true “Super-Hubble,” with the next generation UV–optical–NIR capabilities required to address unsolved problems in star formation and fields across astrophysics.

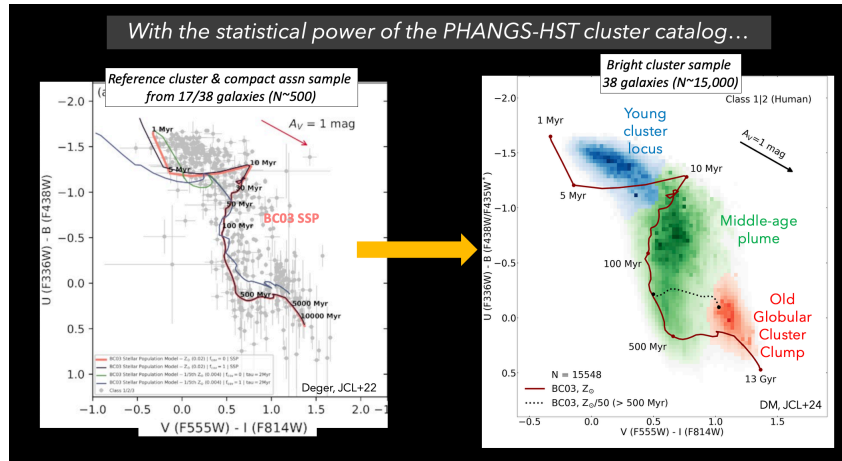


Figure 1: With the statistical power of the PHANGS-HST cluster sample, three principal are observed in the UBV color color diagram: a young cluster locus, a middle age plume, and a old globular cluster clump. Their utility for studies of stellar, cluster, and galaxy evolution will be featured in this talk.

Modeling the multi-phase ISM shaped by star formation and feedback in the LMC

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The small-scale processes of star formation and feedback are tightly linked to galaxy evolution through a multi-scale matter cycle. During this cycle, stars form from the interstellar medium (ISM), and reshape it by injecting energy, momentum and metals, completing a feedback loop. The duration and the efficiency of the successive stages of this cycle vary across and within galaxies, but the exact physical mechanisms driving it remain elusive. A detailed understanding of the small-scale mechanisms regulating star formation and feedback is the key for a full comprehension of galaxy evolution. Increasingly detailed ISM models and multi-wavelength observations now enable us to build a comprehensive view of this multi-scale cycle. As a nearby low-metallicity galaxy resolved on 10 pc scales, the LMC provides an excellent laboratory for studying the local environments of massive stars and the impact of their feedback on the surrounding gas. I will present a detailed study of the multiphase interstellar medium in the LMC, using primarily optical emission-line data from SDSS-V/LVM. By using MULTIGRIS, a new Bayesian code designed to constrain multi-component ionization models, I have determined key physical parameters of HII regions (e.g., density, ionization parameters, escape fractions of ionizing photons). Connecting the multi-phase ISM structure of individual regions with their evolutionary timeline enables us to characterize the mechanisms driving star formation and feedback, as a function of the local physical properties. Understanding how the detailed physical processes driving this cycle on 10pc scales regulate the global, galactic-scale properties will serve as a major reference for high-redshift galaxy studies, where spatial resolution is far more limited.

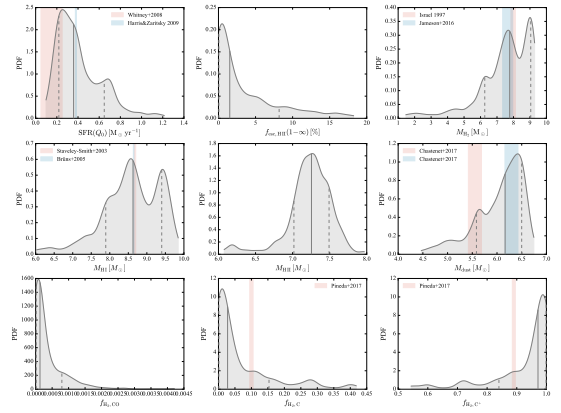


Figure 1: Posterior distributions of the physical parameters derived with MULTIGRIS for the LMC

Simulations and Observations of Bow-shock Nebulae Around Massive Stars

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Bow-shock nebulae are produced by magnetohydrodynamic (MHD) interaction of strong stellar wind from a massive star with the surrounding interstellar medium (ISM), when there is supersonic relative motion between the star and ISM. We completed the largest targeted radio survey using the VLA to search for 24 IR-selected bow shocks, with Effelsberg follow-up observations of 10 of them¹. We clearly detected 6 of the targets (e.g. Fig. 1), with lower-significance hints of emission from another 5 sources, almost doubling the number of known radio-emitting bow shocks. High-resolution 3D MHD simulations show that, while radio and IR emission from the bow shock is stable over time², X-ray emission from the hot, shocked-wind plasma can vary by ~ 1 dex and is strongly correlated with vortices generated in the sheared mixing-layer at the wind-ISM interface³. Detailed non-equilibrium-ionization studies show that spectral lines from the photoionized bow shock are stable over time and do not deviate significantly from ionization equilibrium expectations. Emission from the shocked wind is, however, both variable and far from ionization equilibrium. X-ray emitting plasma is strongly underionized, and UV-emitting plasma from the turbulent mixing layer shows strong deviations from equilibrium. Comparison of 3D simulations of winds from red supergiants embedded in the wind from a young massive star cluster⁴ show excellent agreement with JWST observations of Westerlund 1, and suggest efficient mixing of cool gas into the hot cluster wind. Our results show that bow-shock nebulae can be excellent laboratories for studying and constraining properties of shocks and the turbulent mixing layers between hot and warm gas.

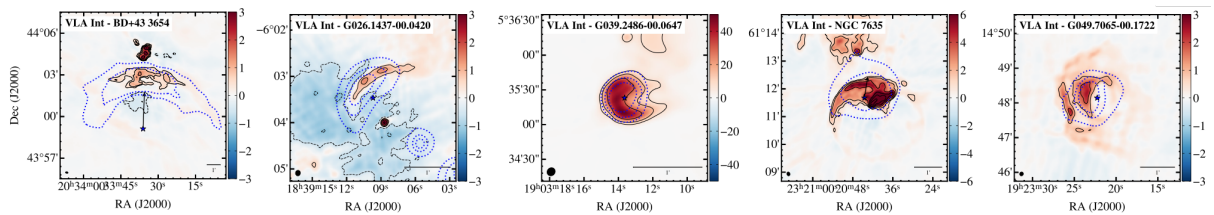


Figure 1: Radio observations of 5 bow-shock nebulae (Moutzouri+ 2025): VLA intensity map in mJy beam^{-1} with blue contours of *WISE* mid-IR emission overlaid.

¹Moutzouri *et al.*, 2025, A&A, 704, A268.

²Green *et al.*, 2022, A&A, 665, A35.

³Mackey *et al.*, 2025, A&A, 696, A91.

⁴Larkin *et al.*, 2025, A&A, 700, A60.

Shaping supernova feedback: 3D modelling of thermal X-ray emission in RCW 103

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Massive stars inject energy into the interstellar medium (ISM) through feedback, shaping its chemical and thermal evolution. However, the processes governing how this energy couples to a structured environment are not yet fully understood. The young Galactic supernova (SN) remnant RCW 103 provides an ideal laboratory to explore this. Observations point to a complex surrounding medium, including dense molecular gas traced by HCO^+ and ^{12}CO emission¹ toward its southern boundary. Radio polarisation is low (a few per cent)² and does not coincide with the brightest X-ray features, suggesting a largely disordered magnetic field. The asymmetric thermal X-ray morphology³ further indicates uneven shock interaction with this structured environment.

In this work, we present 3D (magneto-)hydrodynamic simulations with FLASH⁴ code that follow the evolution of an $18 M_{\odot}$ star up to the SN explosion, including ionising radiation and stellar wind. The resulting structured medium provides realistic initial conditions for the remnant. The simulations include radiative transfer that self-consistently models thermal X-ray emission⁵ from the cooling shock for the first time.

We explore three scenarios for the observed morphology: a large-scale magnetic field, progenitor motion, and interaction with a non-uniform medium (a dense molecular cloud). Magnetic fields can shape the SNR shell structure, but cannot explain the X-ray morphology of RCW 103 on their own, consistent with the low ordering implied by polarisation. Instead, the dominant factor is interaction with a strongly inhomogeneous environment, where density contrasts drive asymmetric expansion and rim brightening.

These results show that environmental structure regulates how SN energy is deposited in the ISM, increasing local heating and ionisation. Also, we produce synthetic multi-wavelength observations, including X-ray and optical emission, enabling direct comparison with observations and providing insight into shock physics.

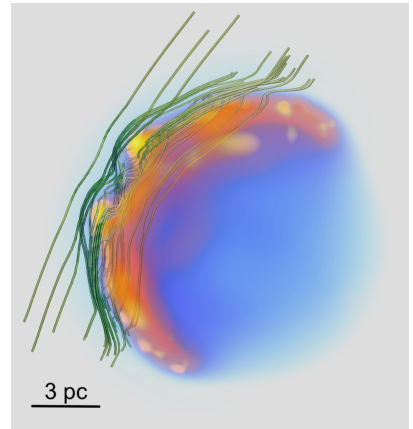


Figure 1: 3D visualisation of soft X-ray emission (0.1–1.0 keV) from SNR with magnetic field lines along a turbulent shock front at 20 000 yr.

¹Paron S. A., Reynoso E. M., Purcell C., Dubner G. M., Green A., 2006, PASA, 23, 69

²Dickel J. R., Green A., Ye T., Milne D. K., 1996, AJ, 111, 340

³Frank K. A., Burrows D. N., Park S., 2015, ApJ, 810, 113

⁴Fryxell B., Olson K., et al., 2000, ApJS, 131, 273

⁵Gaches B. A. L., Walch S., Wünsch R., Mackey J., 2023, MNRAS, 522, 4674

Nonthermal Pressures: Key to Energy Balance and Structure Formation Near SgrA* in the Milky Way

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The circumnuclear region of the Galactic Center offers a unique laboratory for investigating the energy balance and structural formation surrounding Sgr A*. This work examines the thermal and non-thermal processes within a 7 pc radius of the Galactic Center. By utilizing MeerKAT 1.3 GHz radio continuum data alongside ALMA H40 α radio recombination line emission from the ACES survey, we separate the free-free and synchrotron components at a resolution of ~ 0.2 pc. With a measured thermal fraction of $\simeq 13\%$, the 1.3 GHz emission exhibits strong correlations with *Herschel* PACS infrared data. Furthermore, the correlation between the equipartition magnetic field and molecular gas—traced by JCMT ¹²CO ($J = 3 \rightarrow 2$) observations—reveals a pressure balance between the magnetic field, cosmic rays, and molecular gas south of the circumnuclear disk on ~ 0.7 pc scales.

In contrast to the magnetic field and ionized gas, the molecular gas density declines within the central cavity ($R \leq 2$ pc), likely due to feedback from Sgr A*. We find that the non-thermal pressure from turbulent gas nearly balances the magnetic and cosmic ray pressures, exceeding the thermal pressure by two orders of magnitude. The medium surrounding Sgr A* is characterized by a low- β (thermal-to-magnetic energy) supersonic plasma, with an Alfvén Mach number of $\simeq 4$ (assuming equipartition). Finally, an analysis of the mass-to-magnetic flux ratio suggests that the circumnuclear region is predominantly subcritical; consequently, the magnetic field may play a vital role in stabilizing gas clouds against gravitational collapse.

Observations of stellar feedback across scales and environments (and maybe cosmic time)

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² Institute for Computational Cosmology, Durham University, UK

Feedback from massive stars plays a central role in shaping the evolution of galaxies. Conversely, different galactic environments play a central role in regulating the impact of massive stars. Yet, despite a solid qualitative understanding of feedback, our quantitative knowledge remains poor. Until recently, only a few star-forming regions had adequate observational information on gas and stars needed for detailed stellar feedback studies. Over the past decade, integral field units (IFUs) have revolutionized our approach to resolved stellar feedback studies in nearby galaxies. In this talk, I will highlight and discuss recent results of large IFU nearby galaxy surveys and discuss how these enable an empirical quantification of the interdependence between stellar feedback and the environments massive stars form in, and how (if?) these might be used to understand feedback processes in the earlier Universe. They also allow quantifying the importance of pre-supernova feedback in regulating the impact of subsequent SN explosions.

The Mystery of the G Objects

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The Galactic Center provides a unique opportunity to observe galactic cores, objects in close proximity to a supermassive black hole (SMBH), and star formation channels that exhibit imprints of this peculiar environment.

Within the inner parsec surrounding the SMBH Sgr A*, not only the discovery of surprisingly young cluster of the S-stars was exciting: Several bright L-band emission sources raised questions on their nature. The detection of a prominent Doppler-shifted Br- γ line accompanies most of these dust-embedded sources. The interpretation of G2 as a gas cloud moving towards Sgr A* awakened hope to observe accretion processes of a SMBH. Observations of G2 after periapse as well as other G objects challenge the pure gas cloud model and lead to several alternative theories on the nature of these mysterious objects.

In this talk, new observations conducted with various VLT instruments over several decades, and their multi-waveband analysis will be presented. Based on the results, possible interpretations on the nature of the G objects will be discussed. We conclude that a stellar component seems very likely and debate Class I YSO and binary merger models as explanation for the observed properties.

Tracing Accretion and Feedback through CO Outflows in High-Mass Star Formation: Insights from the ALMA SQUALO Project

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High-mass stars have long been the focus of heated debate regarding their formation process. Understanding multi-scale accretion in the globally collapsing, clump-fed scenario¹ is crucial. One promising approach to linking core and sub-parsec scales is to investigate accretion and ejection processes across different evolutionary stages in high-mass star-forming regions for which parsec-scale accretion properties (e.g., infall rates) are already known. In this context, we investigate 13 massive clumps spanning a wide evolutionary range ($0.1 \leq L/M \leq 107 L_{\odot}/M_{\odot}$) classified from 70 μm -quiet up to H II regions in the framework of the ALMA SQUALO project (Star formation in QUIescent And Luminous Objects;²) with the aim of constraining the clump-fed accretion scenario. These clumps exhibit parsec-scale infall motions traced by HCO⁺ line profiles^{3, 4}. We use combined ¹²CO (2–1) data (12m+7m+Total Power) to investigate outflows kinematics at an unique resolution of 0.01-0.04 pc depending on the distance. This enables us to probe the star formation process down to a typical core size (0.1 pc). In this talk, we focus on results from dense molecular gas observations, highlighting the filamentary structures revealed in the integrated intensity maps of ¹²CO, overlaid with dust continuum emission toward the target regions. We identify a total of 51 outflows, the majority of which are highly collimated, regardless of their evolutionary stage. Notably, several elongated outflows are spatially coincident with filamentary structures traced by infrared emission from the Spitzer Space Telescope at 8 μm emission, with no clear dependence on evolutionary stage. We derive outflow parameters from their geometry, including opening angle, inclination angle, and dynamical age. Subsequently, we estimate the dynamical properties of the outflows and outflow masses to investigate the relationship with the natal clumps. Our key results can be summarized as follows: clumps with higher masses tend to host a larger number of outflows, indicating a positive correlation between clump mass and outflow multiplicity. However, the outflows within these clumps do not exhibit a similarly strong correlation with accretion rate. High-velocity outflows tend to be younger and no clear correlation is found between outflow opening angle and evolutionary stage. Finally, we examine the distribution of outflow momentum flux as a function of bolometric luminosity, used as a proxy for evolutionary time, and compare our results with those reported in the literature for high- and low-mass regimes. This analysis provides new insights into feedback processes and the interplay between accretion and ejection across different environments in massive star-forming clumps.

¹Smith R. J., Longmore S., Bonnell I., 2009, MNRAS, 400, 1775

²Traficante et al., 2023, MNRAS, 520, 2306

³Fuller G. A., Williams S. J., Sridharan T. K., 2005, A&A, 442, 949

⁴Traficante A. et al., 2017, MNRAS, 470, 3882

A multi-scale evolutionary analysis of molecular gas and stellar feedback

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Stars form in the dense and cold regions of galaxies known as molecular clouds (MCs)¹. During their evolution, clouds collapse under gravity and fragment to form higher density called clumps² and cores³, which are the progenitors of star clusters and individual stars, respectively. As stars form and evolve, they inject mass, momentum, and energy back into the ISM through various processes collectively known as stellar feedback⁴.

We study⁵ the evolution of molecular clouds as they are affected by various interstellar processes, including stellar feedback. Using the STARFORGE⁶ simulations and the RADMC-3D⁷ radiative transfer algorithm, we have generated synthetic observations that match the observational setup of the SEDIGISM survey⁸. From these, we identified a population of synthetic MCs using dendrograms and analysed them to provide insights into the interpretation of observed MCs as they evolve. MCs appear as small diffuse cloudlets in early stages (Fig. 1, top left), and this is followed by their evolution to filamentary structures (Fig. 1, top right) before being shaped by stellar feedback into 3D bubbles (Fig. 1, bottom left) and getting fragmented and dispersed (Fig. 1, bottom right). The various trends in the observable properties of MCs are consistent with other suites of simulations and provide strong evidence that clouds exhibit distinct morphologies over the course of their evolution and should not be treated as a single population of quasi-static entities in near equilibrium.

To further analyse the evolution of individual clumps embedded in MCs, we have developed an algorithm to follow clumps in synthetic observations over multiple snapshots. The algorithm identifies dendrogram-based structures in consecutive simulation snapshots and recursively matches them to reconstruct their evolutionary pathways. This approach allows individual structures to be followed through mergers, fragmentation events, and structural changes, eliminating the need for evolutionary classification based solely on the simulation snapshots.

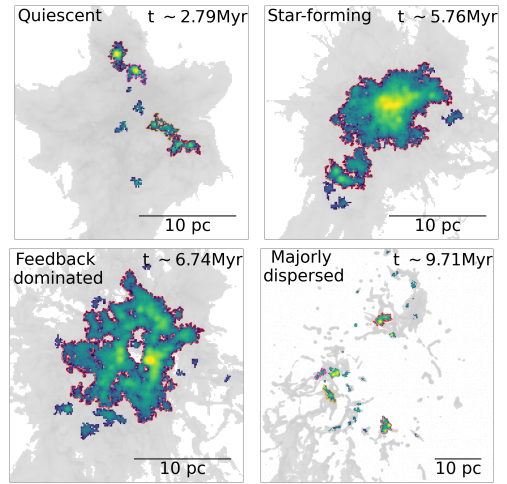


Figure 1: MCs (contours) in synthetic observations (viridis) overlaid on H₂ density (grey) at different evolutionary stages.

¹Chevance, M., Krumholz, M. 2023, ASPC, 534, 1

²Pazukhin, A. G., Zinchenko, I. I. 2025, ARep, 2, 87-102

³Offner, S., Taylor, J. 2025, APJ, 2, 138

⁴Geen, S., Agrawal, P. 2023, PASP, 1044, 021001

⁵Neralwar, K. R., Colombo, C. 2025, A&A, 704, 38

⁶Grudić, M., Guszejnov, D. 2021, MNRAS, 2, 2199-2231

⁷Dullemond, C. P., Juhasz, A. 2012, ascl, 1202.015

⁸Schuller, F., Csengeri, T. 2017, A&A, 601, 124

Kinematics and Feedback in the NGC 6334 Filamentary Complex

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Massive star-forming complexes play a key role in Galactic star formation, yet the processes driving their mass assembly and internal dynamics remain poorly understood. We present a kinematic analysis of the NGC 6334 extended filamentary complex using high-resolution observations of multiple CO isotopologues (^{12}CO and ^{13}CO $J = 3 \rightarrow 2$ (APEX/LAsMA), complemented by [C II] $158\ \mu\text{m}$ (SOFIA/FEEDBACK) and [C I] $^3P_1\text{--}^3P_0$ emission (APEX/nFLASH), tracing gas across ionized, atomic, and molecular phases at a spatial resolution of $20''$ (~ 0.16 pc at $d = 1.7$ kpc). In the molecular gas traced by ^{13}CO , we identify connected velocity coherent structures (over ~ 80 pc), gradients, discontinuities, and overlapping components, particularly near active star-forming regions, consistent with ongoing mass accretion and possible cloud–cloud interactions. Large scale V-shaped structures and signatures of gas compression further suggest converging flows and dynamical interactions within the complex (Fig. 1). The multi-phase carbon emission reveals an overall stratified structure: [C II] is the most extended and kinematically complex tracer, ^{12}CO and [C I] occupy intermediate regimes, and ^{13}CO traces the dense filamentary structure. [C II] emission is enhanced around H II region bubbles, tracing photodissociation regions, while more diffuse extended [C II] likely arises from either feedback-driven cloud dispersal or ongoing cloud formation. We find that H II regions actively shape the structure, with dense clumps preferentially located along bubble rims. Overall, NGC 6334 appears dynamically evolving and continuously fed by its surroundings, supporting a scenario in which large-scale flows, feedback, and multi-phase gas interactions jointly govern the mass assembly and structural evolution of this filamentary complex.

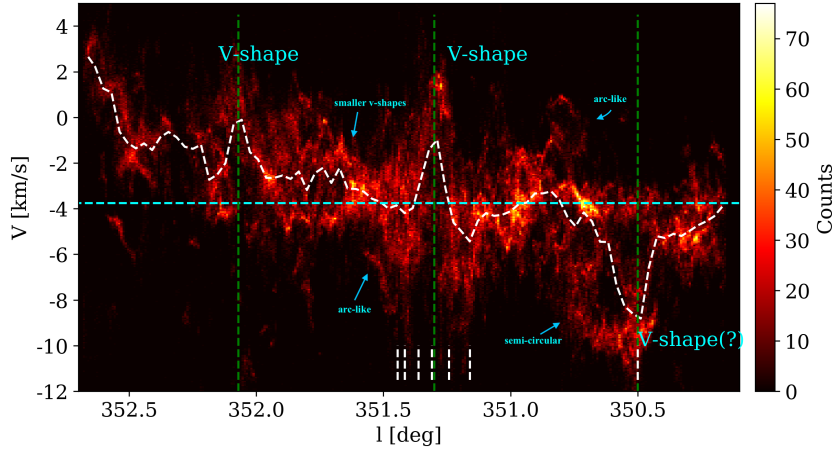


Figure 1: 2D histogram plot of ^{13}CO velocity components toward NGC 6334. The median velocity contour is drawn in white and the positions of the large scale V-shaped velocity structures are indicated by green dotted lines. [Figure adopted from Neupane et al. 2024]

The FYST Line Intensity Mapping Survey : Interloper Mitigation with Enhanced Spectral Line Deconfusion

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Probing the star formation activity of the galaxies during the epoch of reionization (EoR) is essential to understand how exactly the stellar populations drove and sustained reionization. However, this problem is challenging, as these sources are extremely distant and faint to detect individually with current telescopes. Line Intensity Mapping (LIM), overcomes this limitation by measuring the aggregate line emission from galaxies across large cosmic volumes with a broad beam. The Epoch of Reionization Spectrometer (EoR-Spec) onboard the Fred Young Submillimeter Telescope (FYST) will conduct LIM experiment targeting the [CII] (158 μm) fine-structure line, which is a direct tracer of star formation and observable from the ground in the submillimeter transmission window ¹.

A major challenge in [CII] LIM is mitigating the contaminating CO emission from the galaxies at intermediate redshifts that spectrally overlap with the target signal. At EoR redshifts, the mean intensity of the CO emission is expected to be 1-2 orders of magnitude brighter than the signal ². Additionally, similar fluctuation scales and frequency evolution of both the components makes their separation particularly difficult. To address this, we aim to develop an enhanced interloper mitigation strategy based on the spectral line deconfusion method ³.

We apply our method to the mock tomographic data derived from post-processed IllustrisTNG simulations and evaluate its performance in recovering the [CII] power spectrum by fitting and subtracting the CO emission. We further examine the effect of injecting priors (position and star formation rates) from an ancillary galaxy survey to assist the signal recovery with an enhanced variation of this technique. As the instrumental white noise tends to destroy the multi-line correlations that this technique leverages, we also make sensitivity predictions for the EoR-Spec deep sky survey to conclusively detect [CII] clustering from relatively higher redshifts of ~ 5.7 . Our results show that the enhanced spectral line deconfusion technique is effective for interloper mitigation at low frequencies, where other techniques are expected to work with diminishing efficiency. This dedicated effort with FYST will assist in constraining the luminosity functions of EoR galaxies to address the long standing questions in understanding the evolution of our universe.

¹CCAT-Prime Collaboration et al. (Dec. 2022). “CCAT-prime Collaboration: Science Goals and Forecasts with Prime- Cam on the Fred Young Submillimeter Telescope”. In: The Astrophysical Journal Supplement Series 264.1, p. 7. doi: 10.3847/1538-4365/ac9838.

²Karoumpis, C. et al. (Nov. 2024). “[CII] line intensity mapping the epoch of reionization with the Prime-Cam on FYST: II. CO foreground masking based on an external catalog”. In: AandA 691, A262, A262. doi: 10.1051/0004-6361/202450304.

³Cheng, Yun-Ting et al. (Oct. 2020). “Phase-space Spectral Line Deconfusion in Intensity Mapping”. In: APJ 901.2, 142, p. 142. doi: 10.3847/1538-4357/abb023.

Debugging chemical networks through PDR observations

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In the last years we have experienced tremendous progress in multi-line observations of star-forming and photon-dominated regions (PDRs) now typically providing observational constraints through dozens to hundreds of spectral lines for every spatial data point. On the modelling side, this has been complemented by PDR models with complex chemical networks containing hundreds of species and their isotopologues that provide predictions for the intensities of thousands of spectral lines.

Standard tools are readily available to compare models and observations but they are usually limited to χ^2 fits in a very limited parameters space, typically deriving gas density, UV field strength and column density and sometimes beam filling factor, metallicity and cosmic ray ionization rate. Hence, all models are strongly over-constrained and the reduced χ^2 values from the fits are all very bad.

Instead of just looking for the best matching parameters, the excess of information from the multitude of spectral lines should be used to systematically investigate parameters and uncertainties in the chemical networks in the models. As a first step, this asks for a search for systematic outliers in the fits of the observed lines. The corresponding species then serve as guides to search for critical reactions in the chemical network that are missing or wrongly quantified. First comparisons identify a number of species to the outlier group. A typical example are the lines of atomic carbon and oxygen and several complex molecules. While differences in oxygen line intensities can be explained by geometry effects in an optically thick configuration, carbon remains as a puzzle. Follow-up investigations with variations in the chemical network point towards dust physics and surface chemistry as a main uncertainty even for such simple gas-phase species. A more systematic analysis of JWST observations of PAHs and small dust grains in the regions may provide a key to the unknown dust physics. For the atomic carbon problem we expect some major input to come from the large statistics of [C I] observations across the Milky Way tracing many different conditions to be performed within the GEco survey taken with the Fred Young Submillimeter Telescope (FYST).

NASCENT-stars: A Study of Fragmentation and Molecular Complexity in Cygnus-X Massive Dense Cores

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The process of star formation enriches the interstellar medium with a variety of complex organic molecules (COMs). However, the link between the abundance and diversity of COMs and the physical properties, such as protostellar age, mass, and its environment, is poorly constrained. In this context, the recent NASCENT-stars large program (PI: Csengeri)¹, observing 17 massive dense cores in the Cygnus-X molecular cloud at 1mm and 3mm with NOEMA, helps in statistical analysis of the structure and evolutionary stages of the deeply embedded envelopes in these cores. The survey’s homogeneous, wide-band (~ 46.5 GHz), high spectral-resolution (250 kHz), and unprecedented sensitivity provide a nearly full molecular inventory of individual protostellar envelopes, along with their physical conditions, e.g., excitation temperature and column densities. Here, we present both the continuum and spectral analysis of two of the MDCs, CygX-N53 and CygX-N30.

Our continuum analysis of CygX-N53 resolved 38 and 24 compact fragments at 1mm and 3mm, respectively, at $\sim 0.8''$ (1200 kpc) resolution. This is more than three times the detections reported in the literature at 1.3 mm. A detailed comparison of near- and mid-IR emission from the Spitzer Cygnus-X Legacy survey reveals 12 fragments with infrared counterparts. Spectral energy distribution analysis allows us to identify a handful of Class 0 protostars, as well as 4 Class I and 1 potentially Class II object. The two most massive fragments lack infrared counterparts even at 24 microns, and the GLOSTAR survey at 6 GHz shows no corresponding radio emission toward them, confirming that they are at the earliest stage of evolution. The two youngest and most massive millimeter sources exhibit rich spectral line emission at 3mm and 1mm, which provides insights into their physical and chemical conditions. The brightest core of CygX-N30 consists of two dominant mm sources with differing chemical composition. We use XCLASS² to find the full molecular inventory, including COMs, and determine their abundances and excitation temperatures. Together, CygX-N53 and CygX-N30 offer a compelling opportunity to directly compare the chemistry of sources differing in age, mass, and physical conditions.

¹<https://nascent-stars.cnrs.fr/overview/>

²Möller, T., Endres, C., Schilke, P. 2017, A&A, 598, A7

Can we put a disk in a sink? Post-processing 1D protostellar disk model in 3D MHD simulations of core collapse

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Intro: Massive star formation is still poorly understood and the rarity of their event as well as their embedded nature make this mechanism really difficult to observe. Simulations have tried to bypass these difficulties but one major issue remains: star formation spans a large range of space scales which lead to the impossibility of resolving stars with a reasonable amount of numerical resources. They are instead described as sink particles (SP), point-like structures accreting mass. Unfortunately the physics describing the SPs is limited and does not account for the protostellar disk and the formation of binary systems, even if massive stars are well known to have a high multiplicity probability.

Method: I developed a python module, Disk model for SInk paRticlEs post-procEssing (DESIREE)¹, and analysed the SPs in simulations of massive core collapse², using the 3D MHD AMR grid code FLASH. I use the alpha-disk description³ which evolved thanks to a Euler solver. Time evolution of the Keplerian profile due to the star growth and treatment of negative angular momentum accreted are included.

Results: The "disk+star" SPs, in comparison to the "single" SPs, keep storing mass even after star formation ends (i.e. when a HII region forms). From 15 to 40% of the SP mass stays in the disk, values depending on the total mass of the SP. This implies that considering disks on the fly in simulations, would delay the start of stellar feedback which ultimately increases the Star Formation Efficiency (SFE). We also found that when the accreted angular momentum is negative, matter from the inner disk falls rapidly onto the star. Hence, only using simple prescriptions we could reproduce episodic accretion events observed in most YSOs, caused by matter accreted orthogonally with respect to the sink spin.

Conclusion: In this project we are improving the description of SPs in 3D core collapse simulations, to include disk physics, and later on, the formation of companion stars and related outflows.

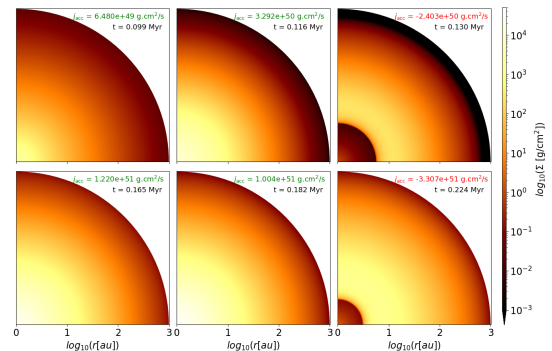


Figure 1: 2D view of the surface density evolution of the second sink particles formed in the fiducial run¹. j_{acc} is shown in green (red) when positive (negative) to highlight the correlation between the disk shape and the accreted angular momentum sign.

¹Pauchet, A., Walch, S., et al. in prep.

²Zimmermann, B., Walch, S. et al. 2025, MNRAS, 544, 2, 2136-2159

³Shakura, N. I., Sunyaev, R. A. 1973, A&A, 24, 337-355

Deciphering Photodissociation Regions: Radiative Feedback, High-Resolution Infrared Tracers, and Advanced Astrochemical Modeling.

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Photodissociation Regions (PDRs) are the critical interfaces where stellar radiation governs the physical and chemical evolution of the interstellar medium. Despite their central role, the detailed mechanisms operating in these regions remain poorly understood, particularly the impact of radiative feedback from massive stars. PDRs are therefore intrinsically complex environments in which chemistry, thermodynamics, and radiative transfer are tightly coupled and determine the physical state of the gas, making them particularly challenging to model and interpret.

Recent advances in high-resolution spectroscopy have significantly enhanced our observational capabilities in this field. Five emblematic PDRs, including the Orion Bar, the Horsehead Nebula, and S140, were observed with the ground based IGRINS spectrograph. The observations provide an unprecedented dataset, featuring over a hundred H₂ rovibrational lines detected from $v=1$ to 13. Enabled by a high spectral resolution of $R=45,000$, this work offers a uniquely detailed view of highly excited molecular states. Physical modeling of the datasets is performed via the Meudon PDR Code¹. To robustly constrain this model, we interface it with BEETROOTS², a Bayesian framework designed to systematically optimize observational fits and quantify uncertainties.

In this presentation, we show how we constrained the physical conditions in these PDRs like the thermal gas pressure and the intensity of the incident FUV radiation field. Crucially, this study also provides the first robust empirical constraints on the nascent excitation state of molecular hydrogen formed on dust grains. We present strong evidence that in moderately irradiated environments, such as the Horsehead Nebula, H₂ forms and desorbs from grain surfaces in highly vibrationally excited but rotationally cold states. Furthermore, we show that these observations probe the mechanisms that populate and depopulate H₂ rovibrational levels, and how the relative importance of these processes depends on the physical conditions. To go further, we show how additional CO vibrational transitions observed with JWST extend and complete the global picture of PDRs.

¹<https://pdr.obspm.fr>

²<https://github.com/pierrePalud/beetroots>

Vz-GAL Unlensed Dusty Star-forming Galaxies: Revisiting the CO-H₂ Conversion Factor Tension

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We present 500 μ m-selected 29 unlensed, dusty galaxies (Fig. 1) from VLA Vz-GAL, the largest CO(1–0) cold molecular gas survey to date in the early universe. Using resolved ALMA Band 7 dust sizes and $> 3\sigma$ CO(1–0) detections for 21/29 sources at $z = 1 - 4$, we derive dynamical masses and upper limits on the CO-H₂ conversion factor (α_{CO}). The systems are consistent with "puffy" rotating disks with velocity dispersion, and exhibit the persistent " α_{CO} tension" between dynamical constraints and Galactic calibrations of the conversion factor. Using LVG modeling, we investigate contributions of various parameters — such as rotational velocities described via integrated FWHM and dust-based inclinations, and velocity dispersions, and size — to the α_{CO} discrepancy. Together, these effects can majorly reconcile the α_{CO} tension without invoking metallicity evolution across redshifts. We therefore argue that combining integrated and spatially resolved low- J CO observations, especially CO(1–0), is essential to robustly derive global α_{CO} , constrain total gas content, spatial extent, and kinematics in large samples of high- z systems.

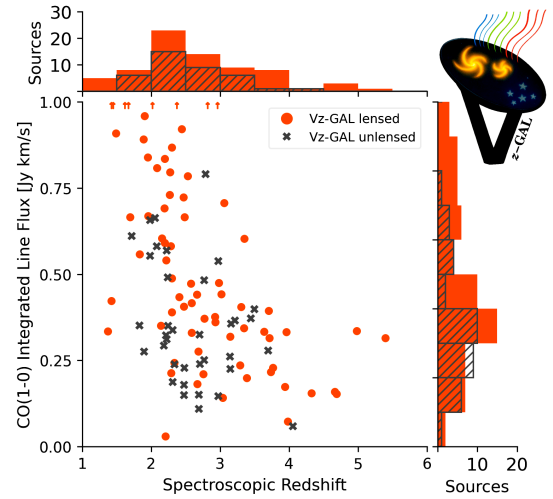


Figure 1: Classification of the Vz-GAL high- z dusty galaxies into lensed and unlensed. Their robust redshifts are adopted from Cox et al. (2023) and the CO(1–0) fluxes are from Prajapati et al. (2026). We find that fainter CO(1–0) regimes show a higher fraction of unlensed galaxies, as gravitational lensing can magnify the flux densities of background galaxies, making lensed systems more likely to appear in brighter samples.

H II regions in the simulated ISM of various environments

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Massive stars profoundly shape the interstellar medium through ionising radiation, stellar winds, and supernova explosions, yet connecting this feedback to galaxy-scale observational diagnostics remains a fundamental challenge. We present the Emission Line Diagnostics (ELD) framework, a post-processing pipeline that generates synthetic optical emission-line maps directly from high-resolution magnetohydrodynamic simulations incorporating on-the-fly radiative transfer and non-equilibrium chemistry. ELD computes line emissivities cell-by-cell from local gas and radiation properties using a precomputed model library with an efficient interpolation scheme, enabling the construction of surface-brightness maps, line-ratio maps, and Baldwin–Phillips–Terlevich (BPT) diagrams from snapshots spanning millions of resolution elements. Applied to simulated multiphase ISM environments of increasing gas surface density, ELD reveals systematic shifts in the distributions of emission-line ratios. We further demonstrate that dust attenuation, contamination from diffuse ionised gas, and finite observational resolution introduce significant biases arising from the mixing of physically distinct gas phases along the line of sight and within the telescope beam in the interpretation of classical optical diagnostics. ELD thus establishes a controlled, physically motivated bridge between simulations and observations, providing a powerful tool for quantifying how faithfully optical diagnostics recover the properties and feedback signatures of massive stars.

A resolved view of the impact of massive star formation in the atomic, molecular and ionized gas in the Carina Nebula

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The Carina Nebula Complex (CNC), located at 2.3 kpc away, is one of the nearest laboratories for studying massive star formation across scales, hosting >65 O-stars and >900 young stellar objects, and serving as a local analogue to regions such as 30 Doradus. In this talk I will present the results of a major effort to study the relationship between the different gas phases in the Carina region from 100 pc to 0.01 pc using the Australia Telescope Compact Array (ATCA), the Mopra telescope and ALMA. At large scales, CO image combined with far-infrared data from Herschel revealed the overall molecular mass and its distribution across the CNC¹. An extremely detailed map of the HI 21-cm line across the whole nebula revealed a complex filamentary structure in the atomic gas². An ATCA 1-3 GHz radio continuum image (see Figure 1) across the whole Carina region revealed a complete and spectacular view of the ionized gas in the region³. At small scales, ALMA high spatial resolution observations of molecular line tracers and dust showed that the level of stellar feedback effectively influences the fragmentation process in clumps, and provides further evidence for a higher level of turbulence in the material with a higher level of massive stellar feedback⁴. In my talk I will also report more recent high resolution ALMA observations that have complemented this view with information of the denser gas distribution (traced by N_2H^+), temperature (traced by CH_3CN), level of photo-dissociation (traced by CN) and chemistry of the molecular gas (traced by CO isotopologues and other species). Additionally, I will be reporting a recent all-CNC survey of ten dense clumps with ALMA which will shed light on the dependence of the star-formation threshold on the level of turbulence and level of feedback across the whole molecular complex.

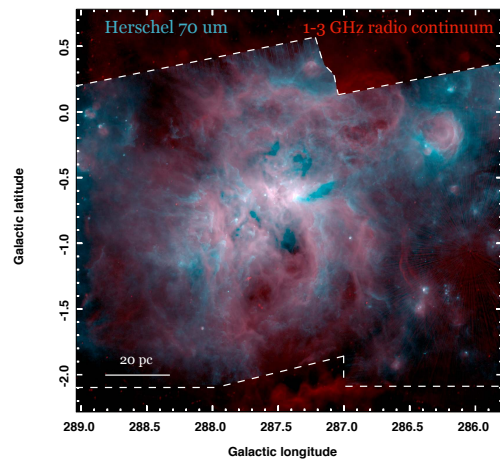


Figure 1: Color composite image of the CNC. Cyan shows the Herschel 70 μm , red color shows the ATCA 1-3 GHz continuum map released by Rebolledo et al. (2021).

¹Rebolledo, D., Burton, M. 2016, MNRAS, 456, 2406

²Rebolledo, D., Green, A. 2017, MNRAS, 472, 1685

³Rebolledo, D., Green, A. 2021, ApJ, 909, 93

⁴Rebolledo, D., Guzmán, A. 2020, ApJ, 891, 113

Kinematically Resolved Environments of Massive Star Formation through the Looking Glass in the First Billion Years of Cosmic Time

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It remains an open question to what degree the conditions for massive star formation in the local universe represent those at earlier epochs, when galaxies are generally more gas-rich and intensely star-forming than at present day. In addition, the earliest generations of star-forming galaxies necessarily show different properties of the star-forming gas, since the age of the universe increasingly limits what the mass limit for stars is that could complete their life cycles and enrich their surrounding medium.

We here present new ALMA observations of the [CII] 158 μm line (i.e., a tracer of gas bathed in the UV field from massive stars, hence gas dynamics of massive stellar environments) and far-infrared dust emission (i.e., a tracer of the re-radiated UV light, hence the massive star formation rate) of a strongly-lensed massive starburst galaxy at redshift $z=6$ at ~ 250 pc intrinsic spatial resolution (Fig. 1). Despite a “starburst-like” high star formation rate of $\sim 500 M_{\odot} \text{ yr}^{-1}$, modeling reveals a smooth, ~ 3 kpc size, centrally dispersed rotating gas disk after de-lensing, with no clear evidence for clumpiness. The star formation rate surface density remains an order of magnitude below that of the most intense, so-called “maximum starbursts”, indicating that G09-83808 is a massive, but otherwise relatively “normal” star-forming galaxy at $z\sim 6$. We however do find an order of magnitude variation of the so-called “[CII] deficit” across the source, which cannot be attributed to temperature or optical depth variations on hundreds of parsec scales. Together with a range of other findings this hints at intrinsic variations in the environments where stars form in galaxies in the first billion years after the Big Bang.¹

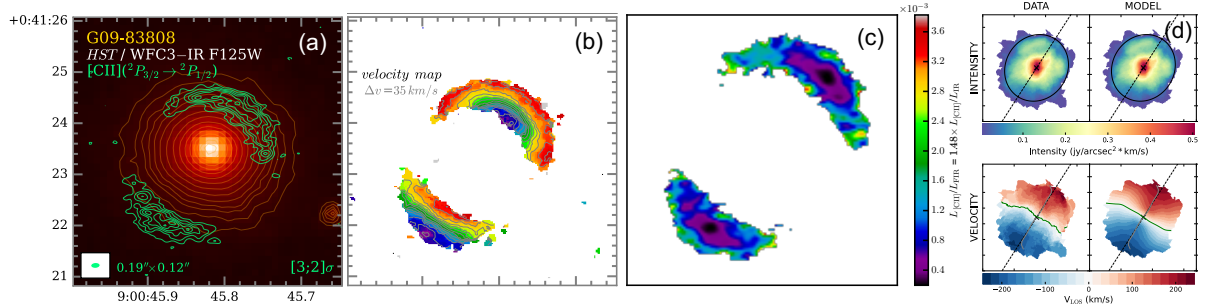


Figure 1: ALMA [CII] imaging of the redshift $z=6.027$ massive starburst G09-83808. The galaxy is strongly-lensed by a massive elliptical galaxy at $z=0.778$, seen in *HST* imaging (a). The kinematic structure of the line emission is clearly resolved across the lensed arcs of the partial Einstein ring (b). A comparison of the [CII] and dust continuum imaging shows a steepening [CII] deficit toward the central region of the galaxy (c). Lens modeling reveals a centrally dispersed, ~ 3 kpc diameter smooth rotating gas disk, where the highest dispersion region also shows the strongest [CII] deficit.

¹Riechers, D., et al. 2026, to be submitted

Probing Stellar Feedback in the Vicinity of an AmaSing Hot Core in the Outer Galaxy with ALMA(GAL) and ATCA

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Several physical and chemical properties have been found to change with Galactocentric distance. For instance, the metallicity, the dust-to-gas ratio, and the H₂ surface density decrease towards the outskirts of the Milky Way. These environmental changes are expected to impact star formation. The recent ALMA large-program ALMAGAL¹ (PIs: S. Molinari, P. Schilke, C. Battersby, P. Ho) observed ~ 1000 potential high-mass star-forming regions across the Galactic disk, covering these environmental changes as well as different evolutionary stages. More than 50 ALMAGAL targets are located in the outer Galaxy. Among these, the source AG274.0659-1.1488 stands out due to its high number of cores² $\# 20$, high core temperatures (Jones et al., in prep.) and chemical richness, containing at least one hot core. Here, we investigate stellar feedback in the high-mass star-forming region AG274.0659-1.1488 and place our results into context of its large-scale environment. We identify outflows in AG274.0659-1.1488 using ¹³CO(2–1) and shock tracers such as SiO(5–4) from ALMAGAL, and present new high-resolution radio continuum and water maser observations acquired with ATCA. We modeled the positions of the water masers to trace velocity structures and find that some positions align well with the outflow directions, while others reveal more complex structures (see Fig. 1). We find four distinct outflows in the star-forming cluster and additional candidates. AG274.0659-1.1488 is one example of a very active high-mass star-forming cluster in the outer Galaxy and a stepping stone towards understanding the impact of metallicity on star formation.

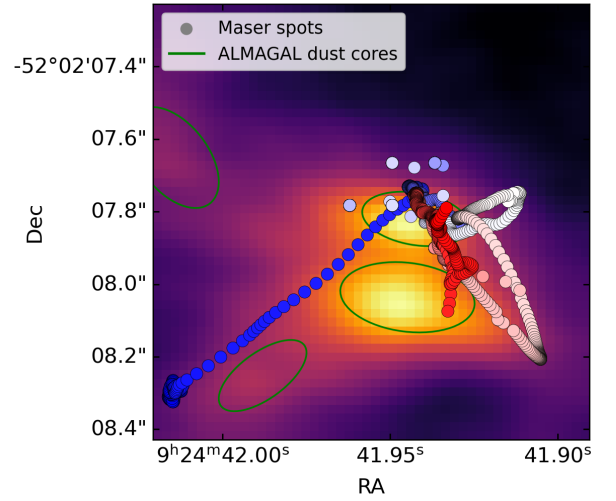


Figure 1: ALMAGAL 1.38 mm dust continuum emission and the modeled positions of the 22 GHz water masers, color-coded by velocity and spanning a range of ~ 20 km s⁻¹. The green ellipses mark the positions of the dust cores².

¹Molinari, S., Schilke, P., Battersby, C., et al. 2025, A&A, 696, A149

²Coletta, A., Molinari, S., Schisano, E., et al. 2025, A&A, 696, A151

Revisiting luminosity estimates in hot cores via molecular line fitting

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Although high-mass ($> 8 M_{\odot}$) stars significantly impact their surroundings at all scales (envelope, cluster, cloud, and even galactic scales), a complete understanding of their feedback remains elusive. This is a direct consequence of their deeply embedded nature, which makes the observational study of high-mass protostars extremely challenging. Through molecular line fitting, one can obtain a rotational temperature measurement to calculate the core luminosity using the Stefan-Boltzmann (S-B) law. Although this method is often used, it can result in core luminosities greater than clump luminosities¹, which is nonsensical. This is because the S-B law is not applicable within a core, where photons diffuse isotropically and the spectral energy distribution cannot be described by a black-body. Nevertheless, the integrated S-B luminosity at its minimum closely approximates the true luminosity, differing by only a factor of a few². We tested this approach utilizing data from the ALMAGAL³ and TEMPO⁴ surveys in a small sample of galactic hot cores. These high angular resolution observations also allowed us to probe vibrational excited states, which have well constrained excitation conditions and arise at high temperatures (100s of K). If their emission is optically thick, these help us constrain the temperature structure of hot cores. I will present our results, how they compare to other luminosity estimation methods, and discuss future prospects.

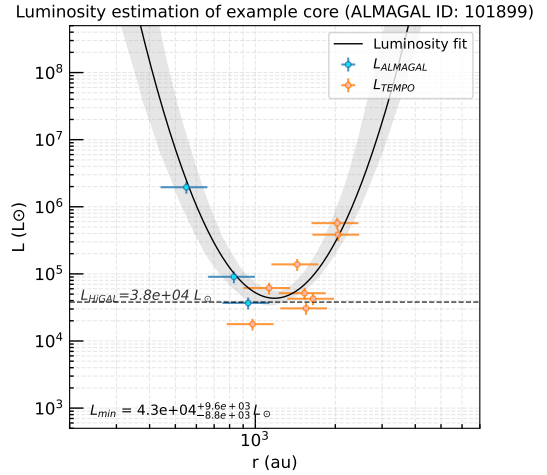


Figure 1: Luminosity as a function of radius for 101899, an example core in our sample. The dots represent the S-B luminosity derived for various optically thick molecular lines in the ALMAGAL (blue) and TEMPO (orange) data. The black solid line shows the luminosity fit and the dashed horizontal line is the clump luminosity (L_{HiGAL}). For this isolated source, the luminosity fit minimum is within a factor of a few from L_{HiGAL} , as expected. Also note that the individual data points differ greatly between them and can be orders of magnitude greater than L_{HiGAL} .

¹Motte, F., Pouteau, Y., et al. 2025, A&A, 694, A24.

²Osorio, M., Lizano, S., & D'Alessio, P. 1999, ApJ, 525, 808.

³Molinari, S., Schilke, P., et al. 2025, A&A, 696, A149.

⁴Avison, A., Fuller, G., et al. 2023, MNRAS, 526, 2278.

PRUSSIC: a comprehensive survey of dense gas in early galaxies

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The cosmic star-forming activity peaked at redshifts $z=1-4$ in the so-called "Cosmic Noon". This vigorous star production is driven by massive galaxies with star-formation rates (SFRs) $100-1000\times$ higher than the Milky Way. To properly understand these immense SFRs, we need to study dense gas from which stars are born, and its thermodynamics which regulate the star-forming efficiency and properties of the emergent stellar populations.

Until recently, studies of molecular gas in high- z galaxies have primarily targeted CO and [CII] emission lines. d reservoirs, contributing little to the observed SFR. However, these trace gas down to densities of $\approx 10^2 \text{ cm}^{-3}$, and seem to arise mainly from diffuse, extended 'halos' which do not directly contribute to the star formation. To uncover dense gas, we need observe high-density tracers such as HCN, HCO^+ , and HNC. Unfortunately, as these lines are $10-10\times$ fainter than CO or [CII], they have been detected in only a handful of high- z galaxies. That is, until now.

In this presentation, we will showcase PRUSSIC: a comprehensive census of dense gas in high redshift star-forming galaxies. Using extensive observations with ALMA, NOEMA, and VLA, and leveraging strong gravitational lensing, PRUSSIC aims to:

- Detect dense-gas tracers in 50+ galaxies at $z \geq 1$.
- Characterise dense-gas excitation and thermodynamics in early galaxies.
- Map dense and diffuse gas on sub-kpc scales in a handful of representative galaxies

Our early results reveal that high- z galaxies contain surprisingly little dense gas and have an enhanced star-forming efficiency - a direct contradiction to earlier studies. We will outline how these results can inform our understanding of early star formation and galaxy evolution, and provide insights into the physics of (high-mass) star formation in early galaxies.

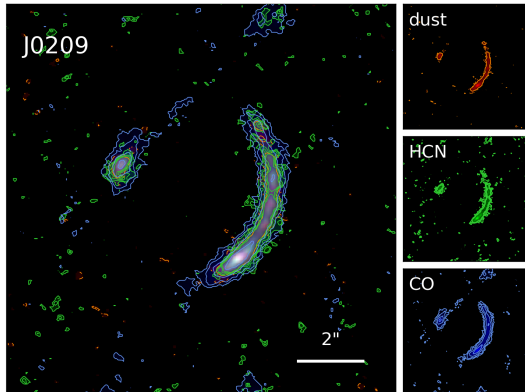


Figure 1: High-resolution ALMA imaging of dense gas (HCN(4–3), diffuse gas (CO(3–2)) and star formation (dust continuum) in the lensed galaxy J0209 at $z = 2.55$. With a source plane resolution of ≤ 1 kpc, these spatially resolved maps provide the first view of dense gas and star formation in early galaxies.

The efficiency of massive star formation on kpc scales across the local galaxy population

A. SAINTONGE¹ AND THE KILOGAS TEAM

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In order to understand why galaxies build up their mass over time to end up as diverse as they are at the present time, we need to understand what sets the initial required conditions for (massive) star formation, and what determines the efficiency of the star formation process. We have been making major strides in answering these questions by exploiting the rich environments found across the local galaxy population. Until recently, what was still lacking in those investigation, to complement the very high-resolution observations in specific galaxy types (e.g. PHANGS, WISDOM) is a large, complete survey, probing a much broader range of galactic environments/activity and revealing the full range of interactions between gas, stars and star formation.

Our answer to fill in this strategic gap is KILOGAS¹, the largest study of the resolved extra-galactic interstellar medium to date. KILOGAS is a large ALMA program, which obtained observations of the CO(2-1) line at 1kpc resolution in 451 galaxies with optical integral field spectroscopic observations from MaNGA and SAMI. The sample galaxies are fully representative of the underlying galaxy population in terms of stellar mass, size and star formation rate. KILOGAS represents nearly an order of magnitude increase in the number of imaged systems over similar surveys combining IFU and ALMA data.

KILOGAS reveals strong variations in the efficiency of massive star formation both as a function of environment within galaxies, and from galaxy to galaxy, in particular with stellar mass surface density. This talk will present highlights of studies from the KILOGAS team regarding (1) the morphology of molecular gas discs and the molecular mass-size relation (i.e. what regulates where there is fuel for massive star formation), (2) the role of kpc-scale environment in determining massive star formation efficiency, and (3) the power of the KILOGAS observations in constraining physical models implemented in large numerical simulations. All in all, KILOGAS is demonstrating clearly that the efficiency of massive star formation out of molecular gas (as traced by CO(2-1)) on kpc scales varies by orders of magnitude. The broad parameter space coverage of KILOGAS allows us to quantify these variations as a function of quantities such as dynamical equilibrium pressure, stellar mass surface density, metallicity, etc – a first necessary step towards a comprehensive physical understanding of massive star formation.

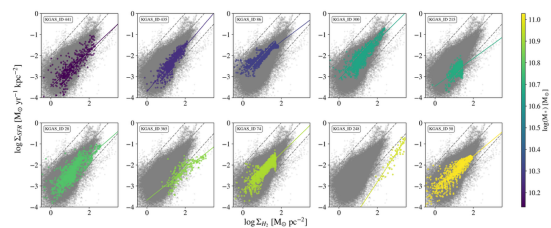


Figure 1: The Kennicutt-Schmidt relation on kpc-scale in 10 of the 451 galaxies from the KILOGAS survey. Even across such a small fraction of the sample, the systematic galaxy-to-galaxy variations in the efficiency of massive star formation are clearly visible.

¹<https://kilogas.space>

High-resolution leak-out spectroscopy of HHe_2^+

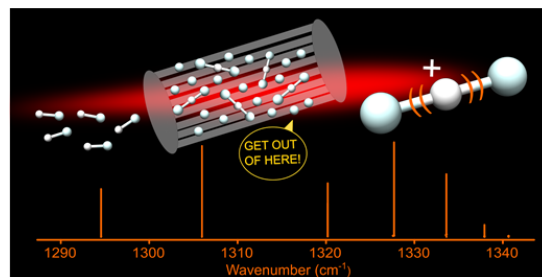
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Using the universal action spectroscopic technique known as leak-out spectroscopy, this presentation revisits the ν_3 proton shuttle motion of the symmetric linear molecule $\text{He-H}^+\text{-He}$. A 4 K cryogenic ion trap setup has been paired with a high-resolution quantum cascade laser operating near 1300 cm^{-1} . Seven rovibrational lines of this fundamental three-nucleus-four-electron system are recorded, demonstrating the leak-out method's suitability for such fundamental hydrogen-helium cations. Nuclear motion rovibrational calculations on this system will be compared with the newly acquired experimental data, showing excellent agreement and confirming the accuracy of highly precise quantum chemical calculations for these systems.



The sites of high-mass star formation

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High-mass stars dominate the energy input in galaxies, shaping not only their immediate environment, but can also have global impact on the large scale structure, powering galactic outflows and remove gas from the star-forming potential through ionisation, or even removal from the galactic potential altogether. Of equal importance is their impact on low-mass star formation in their vicinity. Most stars, including our sun, did not form as isolated stars, but in a cluster environment containing at least one high-mass star. This has ramifications on not only the star forming, but also on the protostellar disk, and planets

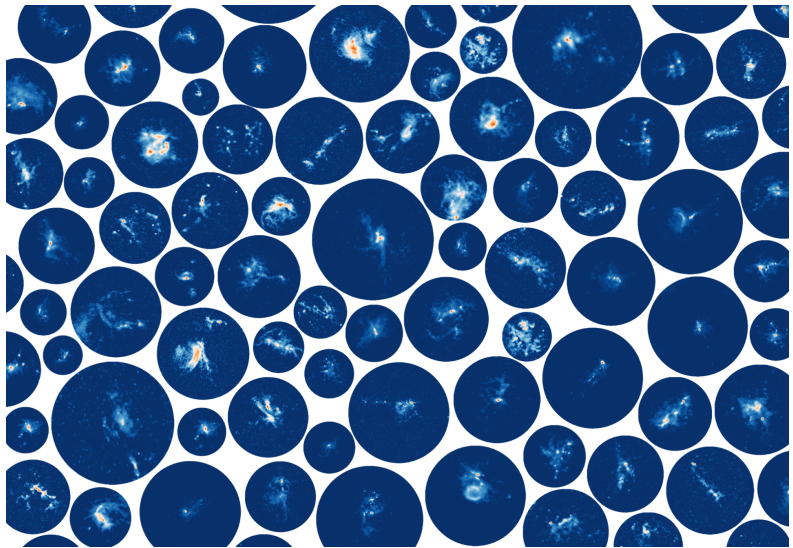


Figure 1: Gallery of 1.3 mm continuum images from ALMA-GAL. The observed fields have been scaled to the same linear size (Image credit: Chiara Mininni).

forming within: competition for mass flow in the formation process, dynamical interactions in dense clusters that can truncate disks, photoionisation of disks, and finally the impact of a nearby supernova. Thus we have to realise that the well studied isolated low mass star formation sites are not at all representative for the bulk of low mass star formation, and have to extend our studies to clustered environments.

By now, we have a good census of most high-mass star forming sites in the Galaxy, thanks to large-scale surveys such as Hi-GAL or ATKASGAL. The logical next step are high resolution studies of these sites to investigate the detailed composition, and reveal the typical processes. Since these sites span a vast range of both environmental and evolutionary conditions, statistical studies are necessary. There have been a number of studies using ALMA (ATOMS, ASHES, QUARKS) which I will briefly describe, but the main focus of my review will be the results of the large programs ALMA-IMF and ALMAGAL (Fig. 1), and give a preview of what we can expect from the ongoing *Panta Rei* large program.

MHD simulations of molecular clouds and synthetic dust polarisation maps: What can we learn from it?

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I present results of fully self-consistent synthetic dust polarisation maps created with POLARIS of simulated molecular clouds (MCs) within the SILCC-Zoom project. The MCs form in simulations of a 3-phase ISM which include its detailed chemical and dynamical evolution. First, I assess the reliability of polarisation observations from e.g. Planck and BlastPol. Next, discussing in detail the complex structure of MCs revealing both sheets and filaments, I will show how projection effects affect the observed orientation of magnetic fields. Furthermore, I will discuss the alignment efficiency of dust grains and show that polarisation observations of MCs mainly probe their dense parts up to $A_V > 1$ ($n \geq 1000 \text{ cm}^{-3}$). In addition, I combine my results with analytical considerations to shed light on the dynamical importance of magnetic fields. I will show that magnetic fields become perpendicular to (column) density structures above $N = 10^{21-22} \text{ cm}^{-2}$ and $n \sim 1000 \text{ cm}^{-3}$ and discuss how this orientation flip relates to the question where and when gravity starts to dominate over magnetic fields. This will give a holistic view of how magnetic fields affect both the dynamics and chemical evolution of molecular clouds. Finally, I will shed light on our latest results about which effects influence the wavelength dependence of the polarisation degree. Specifically, I will discuss the potential origin of V-shaped polarisation spectra in MCs.

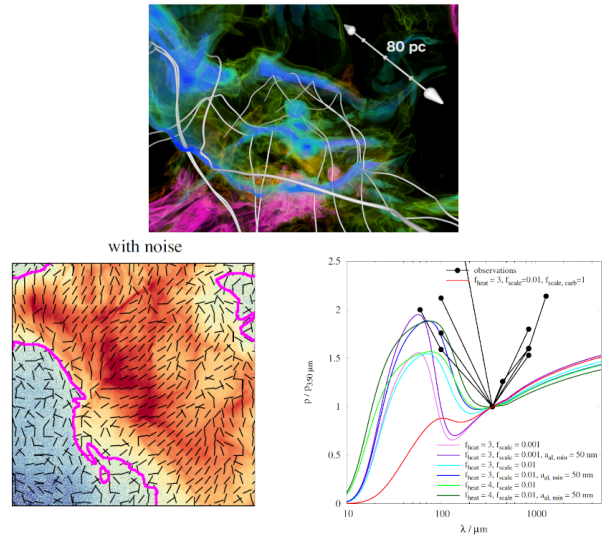


Figure 1: The top panel shows the complicated gas structure inside MCs and how the fields lines become perpendicular to the dense, filamentary structures (blue). The lower left panel shows the effect of noise on the observed polarisation pattern. The lower right panel shows novel V-shaped polarisation spectra obtained within our work in combination to observations.

Rotational spectroscopy of protonated methanol (CH_3OH_2^+): A crucial step toward its interstellar detection

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Protonated methanol (CH_3OH_2^+) has long been suggested as a key intermediate species driving chemical complexity in the interstellar medium. Yet, its high-resolution spectra, crucial for guiding astronomical searches, remain unknown. Employing the novel leak-out spectroscopy (LOS) method in a cryogenic ion trap apparatus¹, we successfully obtained the first high-resolution spectroscopic data for CH_3OH_2^+ . Rovibrational transitions within the fundamental C–H and O–H₂ stretching modes were initially measured in the infrared near 3000 cm^{−1} and 3500 cm^{−1}, respectively. Because CH_3OH_2^+ exhibits two large-amplitude motions (CH_3 rotation and OH_2 inversion), the observed spectra are extremely dense, containing thousands of transitions that arise from multiple tunneling components. Despite this complexity, several series of lines could be assigned in the infrared spectra, providing the first set of ground state parameters for CH_3OH_2^+ . These rovibrational data were subsequently used to search for pure rotational transitions of CH_3OH_2^+ in the millimeter-wave range using an infrared/millimeter-wave double resonance scheme². This combined experimental approach enabled the measurement of more than 25 rotational transitions in the 40–350 GHz frequency range. Based on the accurate transition frequencies derived in this work, first searches for this important cation in space are now in progress.

¹Schmid *et al.*, J. Phys. Chem. A, 126, 43, 8111–8117, 2022

²Asvany *et al.*, Phys. Chem. Chem. Phys., 25, 19740, 2023

Three-dimensional modelling of interstellar PDRs through clumpy ensembles

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Understanding the Interstellar Medium (ISM) across cosmic environments demands numerical simulations that bridge spatial scales and capture the interactions between dynamics, radiation, and chemistry. These hydrodynamic simulations typically prioritise either high spatial resolution or detailed physics, and rely on simplified chemical networks. While detailed astrochemical and Photodissociation Region (PDR) models can help in bridging the spatial gaps by post-processing such simulation outputs, most of the models neglect any sub-structures or inhomogeneity within the ISM, offering limited improvement beyond expanded chemical networks.

We present a framework that integrates **kosmatau3d**'s clumpy PDR prescriptions within individual cells of FLASH-based simulations to study PDRs around expanding HII regions. Systematically comparing simulation results with our post-processing outputs gives us a critical view of how FUV inhomogeneity and different thermal processes within individual clumps result in differences in molecular abundances and temperature structures. These differences arise from radiation escape through low-density regions and efficient molecule formation within dense substructure, resulting in distinct temperature and chemical stratification. Using the diverse physical conditions present in FLASH simulations to sample kosmatau3d's parameter space, we statistically identify which molecular species and emission lines are most sensitive to clumpiness. We quantify this influence via the volume filling factor and demonstrate how neglecting clumpiness can lead to significant biases in inferred physical parameters. Furthermore, applying this to M82, we model multi-wavelength observations (from SMA, NOEMA and SOFIA) to constrain clumpiness along with other parameters to study extragalactic PDRs. Our findings demonstrate the critical importance of substructure in interpreting spectral observations and constraining ISM physics.

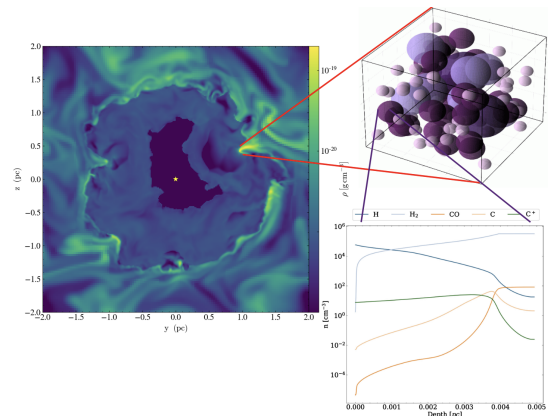


Figure 1: Schematic representation of the subgrid modelling of a PDR through kosmatau3d, dividing the ISM into voxels partially filled by ensembles of clumps precomputed through the KOSMA- τ PDR model

Massive Star Formation Across Different Metallicity Environments

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Massive stars form through the interplay of disk-mediated accretion, feedback, and fragmentation. Recent high-resolution observations in the Milky Way have revealed hot, dynamic, and chemically rich disk-envelope systems fed by larger-scale inflows and accompanied by molecular outflows and ionized gas. A central question is how much of this emerging picture remains valid across different metallicity environments, where changes in dust abundance, shielding, thermal balance, ionization, and molecular chemistry may affect both the formation process itself and the way it is observed.

In this talk, I will summarize recent theoretical and observational progress from Galactic massive protostellar disks to massive star formation in the outer Galaxy and the Magellanic Clouds. I will discuss recent studies of disk-scale structures, fragmentation, hot molecular cores, protostellar outflows, and feedback, including new ALMA results at sub-pc to thousand-au scales. These observations reveal both striking similarities and important differences across environments. Collimated jets, rotating and infalling structures, hot gas, and molecular outflows are now observed in low-metallicity massive young stellar objects, supporting a broadly common framework of massive star formation. At the same time, molecular inventories, outflow scaling relations, and the observational signatures of feedback vary substantially, especially in the Small Magellanic Cloud. These differences may reflect genuine changes in accretion and feedback, changes in molecular tracers under reduced dust shielding, or both. I will conclude by discussing which aspects of massive star formation appear universal across metallicity and which depend on environment.

TRINITY: Which Feedback Mechanism Dominates Massive Star Environments, and When?

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Massive stars regulate their natal environments through winds, radiation, and supernovae, but the relative importance of these mechanisms depends on cloud properties in ways that remain poorly quantified. Addressing this requires models that couple all major feedback processes and can be evaluated across the diverse environments in which massive stars are born.

We present TRINITY, a successor to WARPFIELD^{1,2}, that self-consistently couples stellar winds, supernovae, direct and dust-reprocessed radiation pressure, photoionized gas thermal pressure, and self-gravity to follow the evolution of feedback-driven bubbles and shells in molecular clouds. TRINITY explicitly includes photoionized gas pressure, commonly neglected in 1D feedback codes despite dominating H II region expansion at intermediate and large radii, and supports Bonnor-Ebert density profiles as physically motivated initial conditions. At every timestep, the code decomposes the force and energy budgets into individual feedback contributions, tracking which mechanism dominates the dynamics and when regime transitions occur.

We survey cloud masses of 10^4 – $10^9 M_\odot$, core densities of 10^2 – 10^4 cm^{-3} , star formation efficiencies of 0.01–0.70, and density profiles from uniform cores to steep Bonnor-Ebert configurations. The resulting scaling relations (i.e., for radius, velocity, and momentum yield) reveal how feedback efficiency depends on environment, and the breadth of the grid enables systematic study of cloud dispersal conditions, the onset of ionizing photon leakage, and feedback regime transitions. These results yield age, mass, and radius diagnostic tracks for comparison with resolved systems such as the Carina Nebula and 30 Doradus, and population-level predictions testable against bubble catalogues from JWST³ and ALMA.

¹Rahner, D., Pellegrini, E. W., Glover, S. C. O., Klessen, R. S. 2017, MNRAS, 470, 4453

²Rahner, D., Pellegrini, E. W., Glover, S. C. O., Klessen, R. S. 2019, MNRAS, 483, 2547

³Watkins, E. J., Barnes, A. T., Henny, K., et al. 2023, ApJL, 944, L24

Cosmic ray investigation with KOSMA- τ

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Cosmic rays are key components of the interstellar medium (ISM) and play a fundamental role in galaxy evolution. The ionization of hydrogen by cosmic rays (ζ_{CR}) significantly influences the chemistry of molecular clouds by altering the formation/destruction pathways of chemical species. Moreover, ζ_{CR} is considered to be attenuated beyond a column density threshold. This attenuation shows a spatial profile different from that of the UV attenuation. Thus, from their varying relative importance, some additional complexity arises.

We use the sophisticated spherical PDR code KOSMA- τ to investigate the impact of cosmic rays on the physical structure and chemistry of modeled molecular clumps, as well as to generate line-intensity grids for comparison with observations. We simulate a wide range of initial conditions that span densities of $n = 10^0$ – 10^6 , cm^{-3} , far-ultraviolet radiation fields of $\chi_0 = 10^{-0.1}$ – 10^6 Draine, and cosmic-ray ionization rates of $\zeta_{CR} = 10^{-18}$ – 10^{-13} , s^{-1} . We find that some species show monotonic changes with ζ_{CR} , while others increase and then have a sharp decrease, highlighting the complex balance of formation and destruction. Spherical integration of local abundances (i.e., X_{species}) provides a measure for identifying species sensitive to CR. Species observable in the 1–3 mm range with current ground-based telescopes (e.g., SO_2 , HCO^+) exhibit non-monotonic changes and strong sensitivity to CRs, while CO and H_2 are destroyed, pushing the cloud to be H- and [CI]-rich. Our simulations enable us to construct grids (n , FUV, ζ_{CR}) that show several lines sensitive to CR effects (e.g., C-ladder, HCO^+), which may serve as tools for measuring the cosmic ray rate in an observed molecular cloud.

High-Mass Star Formation Triggered by Colliding H I Flows and Its Relation to the Metallicity Distribution in the Large Magellanic Cloud

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Galactic tidal interactions are a key mechanism for triggering active star formation in galaxies. Using H I observations of the Large Magellanic Cloud (LMC), we show that a tidally driven H I flow (the L-component) collides with the LMC disk gas (the D-component), forming a compressed intermediate component (the I-component) associated with active star-forming regions such as R136 and N44 (Fukui et al. 2017; Tsuge et al. 2019). We found that 74% of O-type and Wolf-Rayet stars are spatially associated with the I-component, suggesting that massive star formation is preferentially triggered in collisionally compressed H I gas (Tsuge et al. 2024a). A comparison of major star-forming regions (R136, N44, N11, and N77–N79–N83 complex) reveals a positive correlation between the number of high-mass stars and the pressure of the compressed gas, indicating that large-scale dynamical compression is a key parameter regulating star formation. A similar correlation between gas pressure and cluster mass is also found in the Antennae Galaxies, suggesting a common physical scaling from nearby systems to extreme starburst environments (Tsuge et al. 2021ab). Numerical simulations further demonstrate that collisions of neutral atomic hydrogen gas can efficiently form dense molecular clouds capable of producing young massive stellar clusters (Maeda et al. 2021; 2024), providing a physical framework linking galaxy-scale gas dynamics to cluster-scale star formation. To investigate the origin of the colliding H I flows, we derived the spatial distribution of metallicity across the LMC and SMC using gas-to-dust ratios based on Planck/IRAS data. The metallicity shows a variation of nearly an order of magnitude ($Z \sim 0.1\text{--}2.0 Z_{\odot}$) in GMC scales (~ 300 pc). We found that metal-poor gas ($Z < 1 Z_{\odot}$) exhibits a spatial distribution consistent with the colliding H I component, suggesting that the H I flows include metal-poor gas accreted from the Small Magellanic Cloud via tidal interaction. These results suggest a unified picture in which galaxy-scale gas collisions regulate high-mass star formation across different environments. Our findings also provide a nearby analogue of cold-flow accretion in the early Universe, where metal-poor gas inflows are thought to play a fundamental role in driving and regulating star formation in high-redshift galaxies (e.g., Cresci et al. 2010; Sánchez Almeida et al. 2014; Elmegreen et al. 2018).

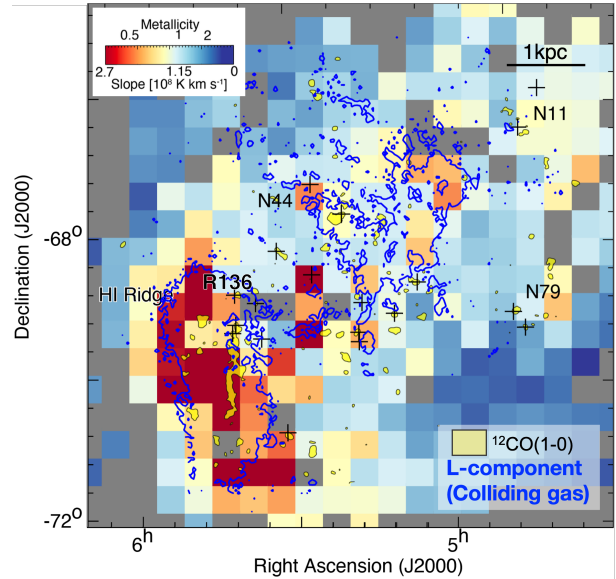


Figure 1: Dust-to-gas ratio map of the LMC. Blue contours trace colliding H I flows, yellow shows molecular clouds, and red indicates low-metallicity gas ($Z \leq 0.5Z_{\odot}$). A southeastern inflow is associated with starburst including R136.

Hot cores in the outer Galaxy: impact of metallicity on the formation of complex organic molecules

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Many complex organic molecules (COMs) in star forming regions are believed to form on the surface of dust grains or in their ice mantles¹. Therefore, we expect the reduced metallicity and dust-to-gas ratio in the outer Galaxy to have an impact on the chemical composition of these regions. To test this, we used NOEMA to perform an imaging spectral line survey of G135.27+2.79 and two other hot core candidates. The NOEMA data of G135.27 confirm it as a new hot core in the outer Galaxy. Its chemical composition correlates rather well with that of the inner and outer Galaxy hot cores G31.41+0.31 and WB89-789, but its molecular abundances relative to methanol lie in between, which may reflect the influence of metallicity on COM formation. Apart from a few notable exceptions, the predictions of our astrochemical model MAGICKAL² agree reasonably well with the chemical composition of G135.27 and with the abundance ratios between G135.27 and G31.41 (Fig. 1). Sensitivity to the reduced metallicity and dust-to-gas ratio varies between molecules, with carbon chains and nitriles most negatively affected. The lower dust-to-gas ratio leads to slower adsorption under low-metallicity conditions, so that more carbon is locked up into CO in the gas. Slow adsorption means that CO is hydrogenated more efficiently on grains, enhancing CO-related COM abundances above expectation. The analysis of the full NOEMA sample is currently underway and is expected to yield a more robust assessment.

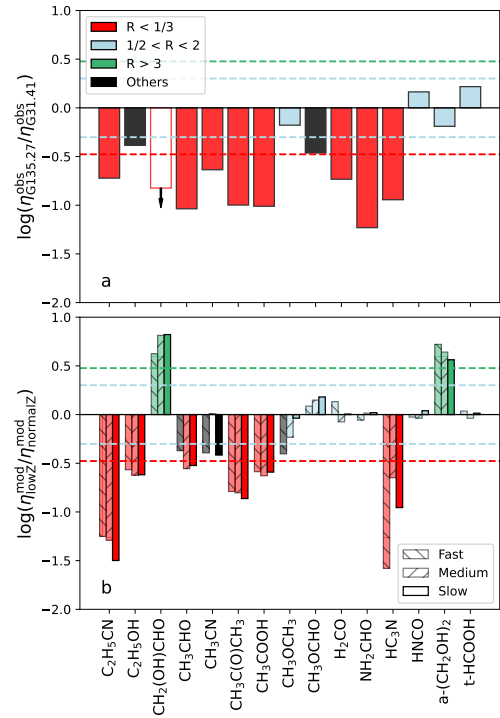


Figure 1: a: Observed abundance ratios, R , between G135.27 and G31.41. b: Abundance ratios, R , of models with low and normal metallicity. In panel b, the solid bars correspond to the best-fit model of G135.27 ($t_{wu} = 1 \times 10^6$ yr), while the hatched bars represent the ratios for the other two warm-up timescales ($t_{wu} = 5 \times 10^4$ and 2×10^5 yr).

¹Garrod, R. T. & Herbst, E. 2006, A&A, 457, 927

²Garrod, R. T., Jin, M., Matis, K. A. 2022, ApJS, 259, 1

Large-scales surveys of the Milky Way: From clouds to clumps as the reservoirs for star cluster formation.

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In recent years, significant progress has been made in sensitive, high-resolution mapping of the Milky Way at (sub)millimeter wavelengths, in both dust continuum and molecular line emission. In particular, the APEX (Atacama Pathfinder EXperiment) 12m telescope, which covers from its southern hemisphere location on the Chajnantor Plateau the full inner Galactic plane, has played a pioneering role with both the ATLASGAL (APEX Telescope Large Area Survey of the Galaxy) dust continuum survey at 870 μm and the SEDIGISM (Structure, Excitation and Dynamics of the Inner Galactic Interstellar Medium) survey of the southern Galactic plane in the ^{13}CO and C^{18}O (2–1) lines.

More recently, LASMAGAL (LASMA survey of GALactic giant molecular cloud complexes) has targeted the most prominent giant molecular cloud complexes in the Galaxy in CO (3–2) isotopologues, probing physical conditions and large-scale kinematics from cloud to clump scales. In addition, OGHReS (Outer Galaxy High Resolution Survey) complements SEDIGISM with new APEX CO (2–1) isotopologue observations in the outer Milky Way.

This contribution summarizes the main results of these surveys, which shed new light on the properties of massive clumps as the nurseries of star clusters and on their intimate connection to the large-scale molecular cloud complexes in which they are embedded.

Massive filaments and subsequent high-mass star formation in N113 in the Large Magellanic Cloud triggered by tidally driven HI flows

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High-mass star formation plays a fundamental role in shaping galaxy evolution through stellar feedback and chemical enrichment, yet its universality across diverse environments remains uncertain. The Large Magellanic Cloud (LMC) provides an excellent local analog of past star formation in the Universe, as it allows direct observation of tidal interactions between dwarf galaxies. In particular, gas infall from the Small Magellanic Cloud (SMC) is known to trigger active high-mass star formation (e.g., Tsuge et al. 2024, *PASJ*, 76, 4, 589). Multi-scale analyses combining H I data covering over 100 pc scale with ALMA observations resolving sub-parsec structures have revealed that collisions between the inflowing H I gas and the LMC disk gas lead to the formation of massive filaments, thereby inducing high-mass star formation. However, such multi-scale studies have so far been limited to the exceptionally gas-rich Molecular Ridge region located in the southeastern part of the LMC, leaving a comprehensive understanding of star formation across the LMC still incomplete.

We present a multi-scale study of the giant molecular cloud (GMC) associated with the H II region N113, which is located near the center of the galaxy. Using high-resolution (~ 0.2 pc) $^{12}\text{CO}(J=1-0)$ and $^{13}\text{CO}(J=1-0)$ observations from ALMA and APEX, we find that the GMC consists of two ~ 10 pc-long filaments forming a V-shaped structure hosting high-mass young stellar objects within gravitationally bound dense gas (Figure 1). Complementary H I data over ~ 100 pc reveal two velocity components separated by more than 40 km s^{-1} , corresponding to the low-velocity (L-) and disk (D-) components of the LMC. The L-component lies within a cavity of the D-component, with the CO filaments outlining the cavity’s boundary. These are the typical signatures of the cloud-cloud collision. We argue that GMC formation and the triggering of high-mass star formation occurred within the past ~ 1.3 Myr.

By investigating sub-parsec to hundred-parsec scales, we revealed that tidal interactions on >100 pc scales can directly trigger the formation of sub-parsec filaments. Our results offer valuable insights into star formation processes in the early Universe, when galaxy interactions were more frequent because galaxies were in closer proximity than at present. This work was accepted for publication in the *Astrophysical Journal* as Yamada et al. (2026; arXiv:2603.29899) in April.

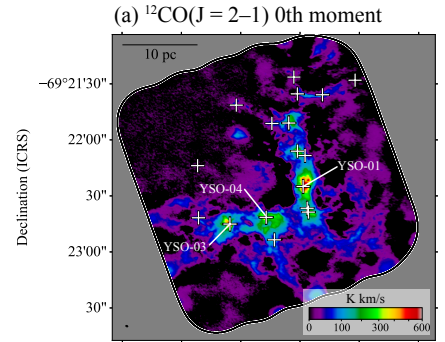


Figure 1: Filamentary CO structure revealed by ALMA+APEX. Crosses indicate the positions of massive YSOs.

Magnetic Fields in Sagittarius C: Massive Star Formation in an Extreme Environment

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The Central Molecular Zone provides a local laboratory for studying massive star formation under physical conditions that differ markedly from those in typical Galactic disc clouds. Sagittarius C (Sgr C) combines ongoing massive star formation with strong environmental influence, including irradiation and interaction with a neighbouring H II region.¹ It therefore provides a useful test case for examining how magnetic fields, gravity, and turbulence affect the evolution of dense gas in an extreme environment.

We present a multi-wavelength polarimetric study of Sgr C using JCMT POL-2 BISTRO 850 μm^2 and SOFIA HAWC+ FIREPLACE 214 μm observations to investigate the magnetic field properties and dust polarisation spectrum. We find that both the polarisation spectrum and the inferred dynamical role of the magnetic field vary strongly across the cloud. The 850 μm data suggest that Sgr C is mildly magnetically supercritical overall, including in its brightest region, while more diffuse regions appear closer to subcritical, indicating that magnetic support remains dynamically important across much of the cloud. Sightlines near the H II interface are not well reproduced by a single-temperature dust model, favouring a layered or line-of-sight mixed structure in which an externally heated envelope and a colder interior contribute differently at different wavelengths.

These results show that the role of magnetic fields in Sgr C is spatially dependent and closely tied to local cloud structure and environment. Sgr C therefore provides a useful benchmark for assessing how magnetic fields shape massive star formation under Galactic Centre conditions.

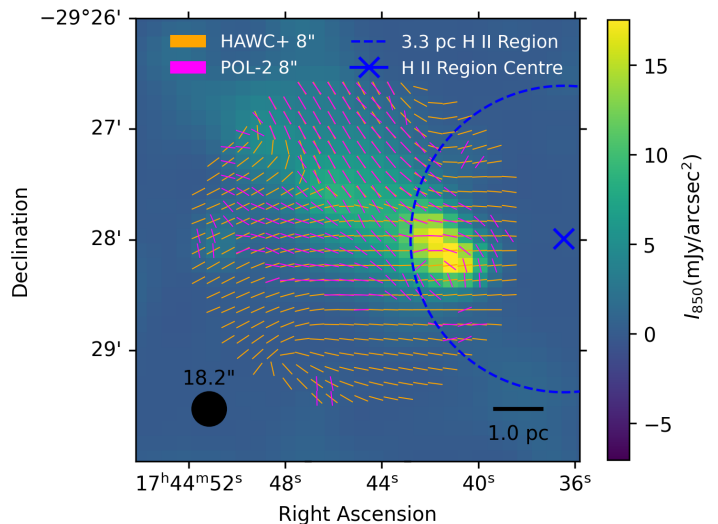


Figure 1: Magnetic field orientations in Sgr C from 850 and 214 μm polarimetry.

¹De Buizer, J. M., Lim, W., et al. 2025, ApJ, 983, 66

²Karoly, J., Ward-Thompson, D., Pattle, K., et al. 2025, ApJ, 982, L22

Polycyclic Aromatic Hydrocarbon (PAH) Emission in Photodissociation and HII Regions Associated with Molecular Clumps

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Polycyclic aromatic hydrocarbon (PAH) emission serves as an excellent tracer of photodissociation regions (PDRs) across various environments in the Milky Way and external galaxies. However, it remains unclear when PAHs become abundant during star formation, especially in later phases such as the HII region phase and OB associations. Previous observational studies (e.g., Kim et al. 2025¹, Maragkoudakis et al., 2026²) show evidence of PAHs state changes in different layers of PDRs, indicating PAHs evolve and are destroyed in different ionizing environments. However, the mechanisms by which their sizes and states change in different Galactic environments toward a large number of samples remain to be understood.

We used infrared data from the Spitzer archive, which covers the emission features of neutral PAH at $3.3\ \mu\text{m}$ and ionized PAH at $6.2\ \mu\text{m}$ and $7.7\ \mu\text{m}$. Using the unsupervised Gaussian Mixture Model (GMM) (see Figure 1), we have identified 96 regions with PAH⁰ signatures with Spitzer towards massive star-forming clumps observed in the ALMAGAL survey. The different PAH band ratios show an increase of $6.2/7.7\ \mu\text{m}$ with luminosity-to-mass ratio (l/m), while no obvious trend is found in $3.3/7.7\ \mu\text{m}$ ratio. This suggests that evolutionary stages of molecular clumps affect the ionized PAHs but not the neutral PAHs. Based on spatial distributions of neutral PAHs in ALMAGAL clumps compared with ^{13}CO 2–1 ALMAGAL data and far-UV radiation field strengths derived by Herschel $70\ \mu\text{m}$ and $160\ \mu\text{m}$ thermal dust continuum emissions, neutral PAHs are favored to be located between highly UV dominated and dense molecular gas, suggesting that neutral PAHs rise from relatively shielded layers of PDRs. We will also present additional effects, such as the inclination of the clumps, and discuss the $3.3\ \mu\text{m}$ PAH features observed by the new SPHEREx spectra.

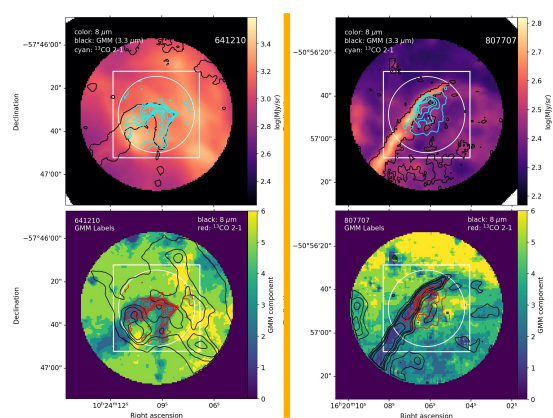


Figure 1: $3.3\ \mu\text{m}$ PAH⁰ identification using Gaussian Mixture Model (upper panel: black contours, lower panel: color map, smaller value denotes stronger $3.3\ \mu\text{m}$ PAH⁰ emission) overlaid with $8\ \mu\text{m}$ Spitzer band (covers charged PAH at $7.7\ \mu\text{m}$, upper: color map, lower: black contour) and ^{13}CO 2–1 integrated intensity from ALMAGAL survey (upper: cyan, lower: red) of selected sources (left: 641210, right: 807707).

¹Kim et al. 2025, A&A, A30, 25.

²Maragkoudakis A., et al., 2026, A&A [arXiv. 2601.23282]

Linking simulations and observations of high-mass star-forming regions

I. Masses and temperatures of ALMAGAL-like cores

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Massive stars shape the interstellar medium and beyond, yet their earliest evolution is hidden inside dense, collapsing clumps. Interpreting high-resolution (sub-)mm continuum surveys depends on how reliably we can recover the physical properties of embedded dense cores. Recent ALMA surveys resolve these cores at 1000 au scales, but continuum-based masses are systematically affected by uncertain dust temperatures, line-of-sight projection, and interferometric filtering. We quantify how reliably dense-core masses and dust temperatures can be inferred from ALMA-like synthetic continuum observations, and provide simulation-based guidance on the dominant biases affecting core catalogues. Our analysis uses AMR radiation-hydrodynamic simulations of parsec-scale, turbulent clumps, where star formation is modeled with sink particles and a self-consistent chemical network, including radiative feedback (ionizing radiation with associated radiation pressure and non-ionizing dust heating), evolved until a UC-HII region is established. We post-process snapshots to generate 1.36 mm synthetic dust-continuum maps and add telescope effects to model synthetic ALMA observations. Cores are defined around sink particles within a fixed radius of 1500 au, enabling direct comparisons between intrinsic 3D masses, projected 2D masses, idealised continuum-based masses, and ALMA-imaged masses. We evaluate dust-temperature estimators ranging from a clump-scale L/M prescription to flux-informed models and a supervised gradient-boosting approach trained on the simulations. The sink-core mass connection is complex and strongly time-dependent, so continuum cores are not straightforward proxies for stellar content. The mapping between intrinsic 3D core masses and projected 2D masses is biased by line-of-sight contamination, and interferometric imaging can further reshape the apparent core population. Accurate flux reconstruction and dust-temperature assumptions remain key bottlenecks in converting flux into reliable masses; improved dust-temperature estimates therefore yield more reliable core-mass determinations. Synthetic observations bridge simulations and observations, providing a practical framework to interpret ALMA-like core catalogues and to guide future analyses of observational data.

A comprehensive study of the S255IR high-mass star-forming region

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In recent years, strong luminosity outbursts have been detected toward several massive protostars for the first time, which were interpreted as results of episodic accretion events. One of the first of them was observed in 2015 toward the 20 $M_{\odot}$ protostar S255IR NIRS3¹. S255IR, at a distance of $1.78^{+0.12}_{-0.11}$ kpc², is a well-known site of high-mass star formation, and is a part of the large star-forming complex sandwiched between the evolved HII regions S255 and S257³. It contains three major cores SMA1 (which harbors the NIRS3 protostar), SMA2, and SMA3⁴ and several smaller condensations⁵. The SMA1 core represents an infalling sub-Keplerian pseudo-disk⁶.

As a result of this event, a jet appeared, which has been observed in the IR and radio bands⁷. Its evolution has been traced in a series of radio observations. In 2021, submillimeter observations of this area were carried out with ALMA at 0.9 mm at the highest angular resolution of ~ 15 mas, which corresponds to ~ 25 au⁸. These observations reveal two pairs of knots in the jet lobes (Fig. 1), which implies a double ejection.

The high brightness (~ 850 K) and morphology of the central source hint at a hypercompact HII region in the center although this interpretation has some problems. In the emission of the knots in the jet the free-free component apparently dominates⁸. We have detected new submillimeter methanol maser lines in this object, which are apparently related to the luminosity outburst⁹, have traced their variations and analyzed their excitation¹⁰.

In addition, evolution of the low frequency radio spectrum of this object has been investigated¹¹.

This work was supported by the Russian Science Foundation grant 24-12-00153.

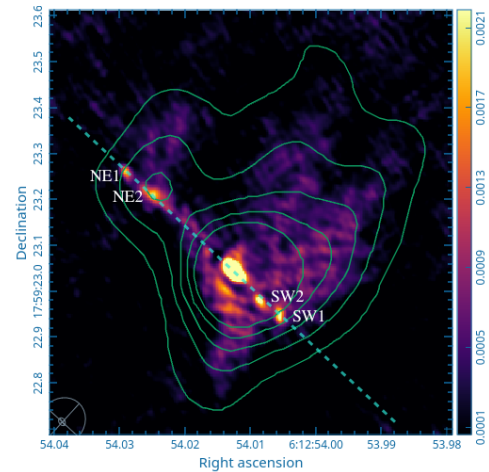


Figure 1: The continuum image of the S255IR region at 0.9 mm with the ~ 15 mas resolution. The contours show the low resolution continuum emission⁸.

¹Caratti O Garatti, A., Stecklum, B., Garcia Lopez, R., et al. 2017, Nature Physics, 13, 276

²Burns, R. A., Handa, T., Nagayama, T., Sunada, K., & Omodaka, T. 2016, MNRAS, 460, 283

³Ojha, D. K., Samal, M. R., Pandey, A. K., et al. 2011, ApJ, 738, 156

⁴Wang, Y., Beuther, H., Bik, A., et al. 2011, A&A, 527, A32

⁵Zinchenko, I. I., Liu, S.-Y., Su, Y.-N., Wang, K.-S., & Wang, Y. 2020, ApJ, 889, 43

⁶Liu, S.-Y., Su, Y.-N., Zinchenko, I., et al. 2020, ApJ, 904, 181

⁷Cesaroni, R., Moscadelli, L., Caratti o Garatti, A., et al. 2024, A&A, 683, L15

⁸Zinchenko, I. I., Liu, S.-Y., Su, Y.-N., 2024, A&A 692, A181

⁹Zinchenko I., Liu S.-Y., Su Y.-N., Sobolev A. M., 2017, A&A, 606, L6

¹⁰Zinchenko, I. I., Salii, S. V., Sobolev, A. M., Zaichikova, I. A., Liu, S.-Y., Su, Y.-N., 2025, MNRAS, 543, L9

¹¹Zemlyanukha, P. M., Zinchenko, I. I., Dombek, E. M. and Ojha D. K., 2026, Astrophys. Bull., 81, in press

7 key questions on massive star formation

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definition: massive stars $> 15\text{-}20\text{ Mo}$ (O-stars)

- 1) Do the majority of massive stars form in dense clusters or in loose associations?
- 2) Do the majority of massive stars form in tight (AU-scale) binaries or is there dynamical evolution (orbital shrinking)?
- 3) Do more massive clusters (starburst clusters) have a top-heavy IMF? Observational evidence?
- 4) Is there an upper mass limit, and if so what does it depend on (theory)?
- 5) How do (Orion-like) Trapezium systems form?
- 6) What is the fraction of runaway O-stars and/or WR stars? What is their binary nature?
- 7) What is the main formation mechanism of massive stars: monolithic collapse followed by disk accretion, competitive accretion, hierarchical accretion, cloud-cloud collisions?

There are other big questions related to massive stars, related to their main feedback mechanism.

Posters

Is the CH₃OH maser transition at 6.7 GHz a tracer of the inner outflow cavities near YSOs?

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Although the 6.7GHz maser transition from methanol gas was discovered in the early '90s, and was soon after recognized as a marker for the formation of the most massive stars¹, we have not clarified yet the physical region where this maser species is excited. For this purpose, we have conducted a high-sensitivity interferometric survey of 6.7 GHz masers towards a large sample of 40 sources belonging to the "Protostellar Outflows at the Earliest Stage" (POETS) survey^{2,3}, with the aim to correlate their positions at milli-arcsecond accuracy with those of radio thermal jets and water masers. I will present these new results showing, in particular, that we are uncovering a large population of faint masers that are far more numerous than their bright counterparts. This conclusion has important implications for next-generation radio facilities, such as the ngVLA⁴ and SKA, promising to unveil a whole new picture of the circum-stellar environment.

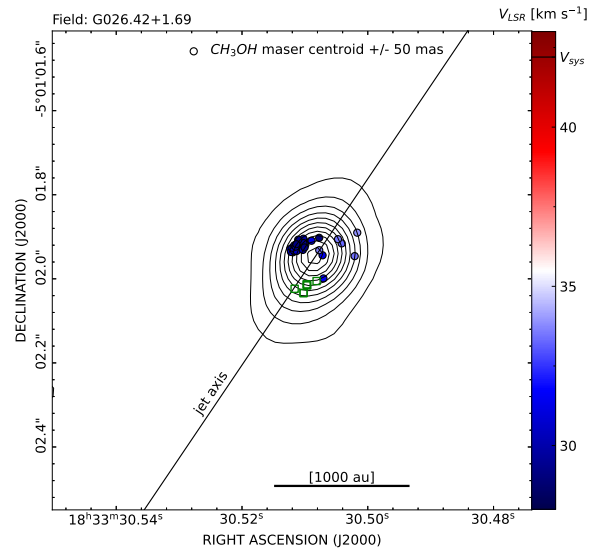


Figure 1: Example of 6.7 GHz methanol maser emission (dots) toward a source of our sample, colored by LSR velocity (right wedge), and overlaid with both the free-free continuum (contours) from a thermal jet and the 22 GHz water masers (squares) along its route.

¹Menten, K. M. 1991, ApJ, 380, L75

²Moscadelli, L. et al. 2016, A&A, 585, A71

³Sanna, A. et al. 2018, A&A, 619, A107

⁴Hunter, T. R. et al. 2018, in Astronomical Society of the Pacific Conference Series, Vol. 517, 321

Digital Sideband Separation Using Tone-Injection calibration scheme

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Sideband-separating receivers (2SB) are widely used heterodyne receivers for radio astronomical observations. They enable the simultaneous observation of the lower (LSB) and upper (USB) sidebands around a local oscillator (LO). However, phase and amplitude imbalances between the different signal paths, caused by the imperfect performance of the analog components, lead to leakage between the sidebands, limiting their separability. This effect is commonly quantified by the sideband-separation ratio (SRR).

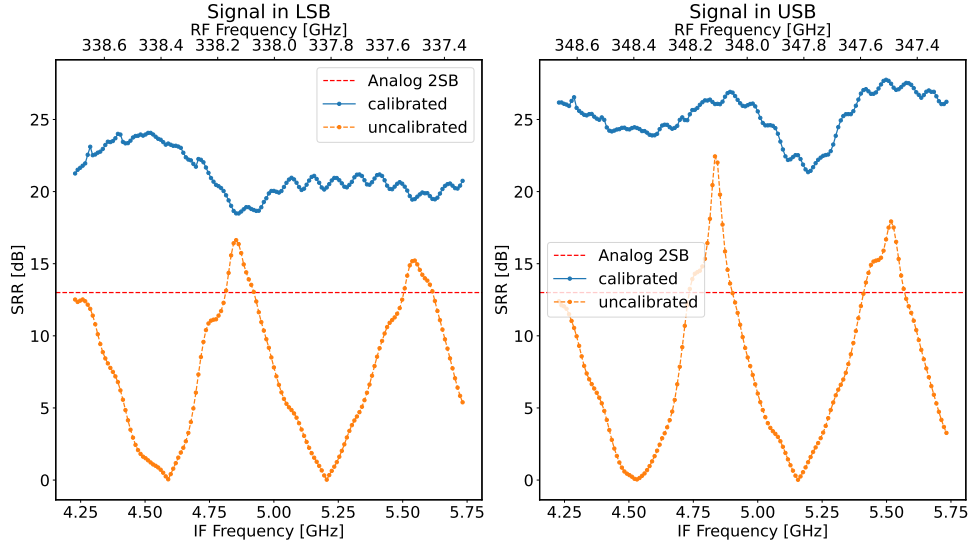


Figure 1: Exemplary SRR, comparing the measured, digitally calibrated (blue) and uncalibrated SRRs (orange) to the specified analog performance (red) of an ALMA Band 7 SIS mixer in a test setup.

One approach to mitigate these limitations is the digital compensation of such imbalances. The feasibility of this method was demonstrated in a cryogenic test setup using a modified ALMA Band 7 SIS mixer at LO frequencies around 340 GHz. Using well-defined test signals, sets of imbalance-compensating parameters were derived and applied in an offline processing stage, resulting in a significant improvement in sideband separation compared to the purely analog performance (Alt, 2026).

Building on these promising results, future work will focus on a broader implementation of this technique. This includes automating the determination of calibration coefficients, integrating the method more deeply into existing processing pipelines, and investigating the fundamental limits of achievable sideband separation. In addition, particular attention will be given to implementing this approach in existing telescope receivers without requiring major hardware modifications.

Hyperfine-resolved rovibrational and rotational spectroscopy of OH^+

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ARSHIA M. JACOB, DOMINIK RIECHERS, STEPHAN SCHLEMMER AND OSKAR ASVANY

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The OH^+ ($X^3\Sigma^-$) radical cation has been investigated by combining a 4 K 22-pole ion trap apparatus with high-resolution IR and THz radiation sources. Applying different types of action spectroscopic methods, the fundamental vibrational band in the $3\ \mu\text{m}$ range and the spin manifold of the $N = 1 \leftarrow 0$ rotational transition around 1 THz have been extended and refined. Additionally, the spin manifold of the $N = 2 \leftarrow 1$ rotational transition, scattered around 2 THz, has been measured for the first time with microwave accuracy. Although all hyperfine components of the pure rotational transitions are affected by considerable Zeeman splittings, a simulation of their contours allowed us to extract the field-free center frequencies with high accuracy. A global fit combining rovibrational and pure rotational transitions from the literature with those newly obtained in this work was performed, leading to improvements in the spectroscopic constants of OH^+ , particularly those in the ground vibrational state. These improved spectroscopic constants support astronomical detections of OH^+ .

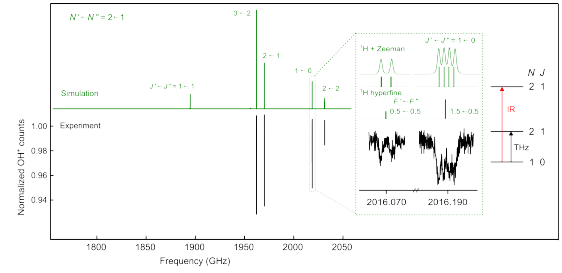


Figure 1: The rotational spectrum of OH^+ around 2 THz.

“mm-spectroscopy” across nearby galaxies - dense gas fraction and star formation efficiencies from cloud to galaxy scales

FRANK BIGIEL¹ AND THE ALMA ALMOND, IRAM SWAN, EMPIRE PHANGS
TEAMS

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I will present a series of recent results from ALMA and IRAM campaigns targeting -in particular density-sensitive - molecular line ensembles like HCN, HCO+, HNC, CS or N2H+ and low-J CO, but also a range of faint CO isotopologues like 13CO or C18O across and among nearby spiral galaxies. The data situation of resolved “mm-spectroscopy” across nearby galaxies has improved dramatically over the last 10 years and significant progress was made probing canonical, extragalactic, density-sensitive line ratios like HCN/CO or HCO+/CO and their relation to star formation in diverse samples of around 30 nearby galaxies. I will present results from the kpc-scale ALMA ACA survey (ALMOND), targeted higher-resolution ALMA follow-up and the NOEMA Large Program SWAN, mapping these molecular lines directly at cloud scales in M51. In this talk, I will synthesize the key results from these campaigns and what they tell us about dense gas fractions and star formation efficiencies across local spiral galaxies, including the impact of local conditions and galaxy dynamics on these quantities.

TOWARDS UNDERSTANDING LEAK-OUT SPECTROSCOPY (LOS) IN CRYOGENIC ION TRAPS

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Leak-Out spectroscopy (LOS) has proven to be a versatile tool in electronic, vibrational, ro-vibrational, and rotational spectroscopy of cold trapped ions¹²³⁴. The method relies on the transfer of internal to translational energy (V-T transfer) in collisions of the ions with neutral gas-phase atoms or molecules. Through the addition of kinetic energy, ΔE_{kin} , some ions overcome the static axial barrier of the trapping potential, ΔE_{pot} , and are thus guided to the detector. The principle of LOS relies on the simple relation $\Delta E_{kin} > \Delta E_{pot} > E_{kin}$, where $E_{kin} \approx kT_{ion}$ is the kinetic energy of the non-excited ions. As a result, it shall work best the larger ΔE_{kin} and the smaller E_{kin} while ΔE_{pot} shall be adjusted accordingly.

In practice, several experimental factors influence the sensitivity of LOS, e.g., the distribution of the kinetic energy of the ions, given approximately by the trap wall temperature T_{trap} , the barrier height, $\Delta E_{pot} = e(U_{exit} - U_{trap})$, which is given by the voltage difference between the trap float and the exit electrode and the number density of the collision partner, to name the most obvious experimental parameters.

We report our experimental findings when varying some of these factors and interpret the results, e.g., with the aid of a semi-quantitative kinetics model which includes the collisional energy transfer process but also subsequent cooling collisions as well as the absorption and emission of photons. The purpose of this study is to better understand the factors that influence LOS on a quantitative level with the objective of improving the technique in terms of sensitivity or line width.

¹P. Schmid et al., 2022, J. Phys. Chem. A, 126, 43

²M. Bast et al., 2023, J. Mol. Spectrosc., 398

³S. Schlemmer et al., 2023, J. Mol. Phys., 122

⁴S. Marlton et al., 2025, J. Phys. Chem. Lett., 122

Jet-Cooled Millimeter-Wave Spectroscopy of Circumstellar Refractory Species

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We report on recent developments in high-resolution rotational spectroscopy at the Laboratory Astrophysics group at the University of Kassel, focusing on refractory species relevant to circumstellar environments of evolved stars. Oxygen-rich outflows of red supergiants such as VY Canis Majoris exhibit rich chemistry, including metal oxides and other refractory species associated with dust formation processes.

To access such species under controlled laboratory conditions, we employ chirped-pulse spectroscopy in the millimeter-wave region in combination with pulsed supersonic jet expansions. Transient molecules are generated in situ via laser ablation of solid targets and subsequently cooled in the expanding gas. The experimental setup is being extended by combining laser ablation with a multipass cell to enhance effective path length and sensitivity in jet-cooled measurements, aiming to improve access to weak rotational transitions of transient species under non-equilibrium conditions.

Recent results and ongoing developments will be presented.

Systematic study of HII regions in the Magellanic Clouds with eROSITA

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HII regions are zones composed of ionized gas surrounding massive stars that are formed by the star's radiation reaching temperatures of $10^4 K$. On top of the ionizing radiation, stars produce winds, which shock the medium further ionizing it and acquiring temperatures of $10^6 K$.

Extended HII regions are a result of multiple stars in a stellar cluster or association and, due to feedback from SNe resulting from the death of massive stars, they extend further into larger HII regions, observed as superbubbles with a hot plasma interior.

Due to the nature of the eROSITA data we have the opportunity to perform a systematic population study of HII regions and superbubbles in the Magellanic Clouds and identify those which emit in the X-rays, and extend the study of their properties to a multi-wavelength picture.

We aim to perform spectral fitting of the regions that present diffuse X-ray emission and compare our findings to the standard wind-driven stellar bubble model. We present the first results of the regions studied so far within the project.

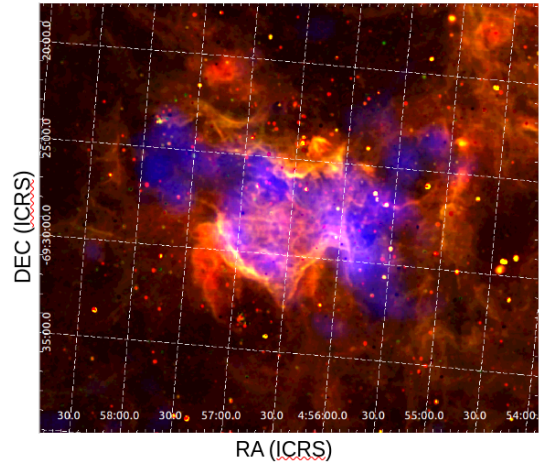


Figure 1: Image of the HII region N94B (DEML36). Red and green show the $H\alpha$ and SII emission obtained with MCELS respectively. Blue indicates the emission in the 0.2-0.7keV band obtained with eROSITA.

The first C-band rotation measure grid through the Galactic plane: Expanding the population of polarized radio sources

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The ubiquitous magnetic fields present in the Universe are the key factors influencing the interstellar medium across the full dynamic range relevant to massive star formation, from the large galactic-scale gas flows down to the small dense clumps where stars are born. Characterizing these rather elusive fields in the highly turbulent Galactic mid-plane is therefore essential for understanding the physical conditions that govern massive star formation and stellar feedback. We present the first C-band (4–8 GHz) rotation measure (RM) grid of the Galactic plane, constructed using data from the Global view on Star formation (GLOSTAR) survey. The survey observes the first quadrant of the Galactic plane using the *Karl G. Jansky* Very Large Array (VLA) and the Effelsberg 100 m telescope, providing an angular resolution down to $1.5''$ and a sensitivity of $\sim 60\text{--}150 \mu\text{Jy/beam}$. By exploiting faraday rotation of background extragalactic sources, we probe the magnetized, turbulent foreground of the inner Galaxy.

Compared to lower-frequency surveys, the reduced wavelength-dependent depolarization at C-band allows us to pierce through dense, turbulent ISM near active star-forming regions. Furthermore, the fine frequency resolution combats bandwidth depolarization and enables the detection of extreme RMs up to 10^5 rad/m . In this talk I present the polarized source catalog within the pilot region with ~ 70 new rotation measures (Fig. 1), at a RM grid density of 5 RMs deg^{-2} , five times denser than the current state-of-the-art. The rotation measures show a much broader spread than lower-frequency samples, almost twice as large, which is primarily because C-band observations can probe interstellar regions that are inaccessible to lower-frequency polarimetry. Extending this across the full GLOSTAR footprint will deliver an unprecedented magnetic field map of the Galactic massive star-forming environment.

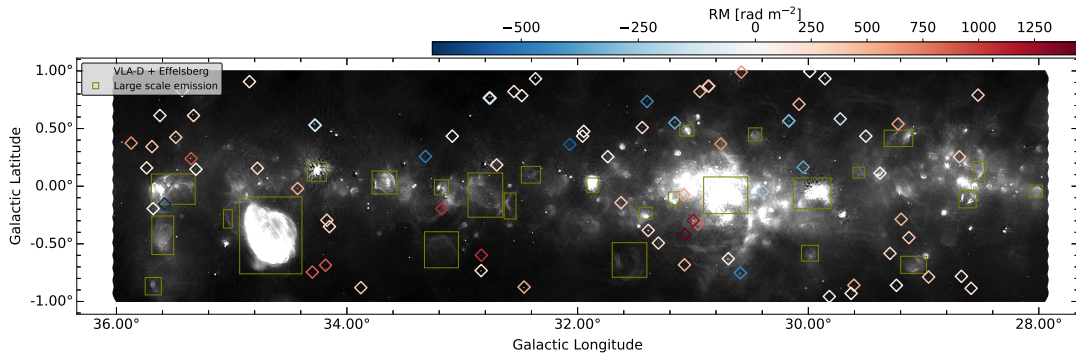


Figure 1: Rotation measure values of our sample of polarized sources. The background grey-scale image represents the GLOSTAR VLA-D + Effelsberg image. The typical RM uncertainty is about 47 rad/m .

Polarization study toward the massive protostellar jet system HH 80-81.

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Polarization measurements provide key constraints on magnetic fields and particle acceleration in star-forming systems, particularly in massive protostellar environments where such observations remain extremely scarce. We present a radio polarimetric study of the massive protostellar system IRAS 18162-2048 using Karl G. Jansky Very Large Array observations at 4-6 GHz. For the first time, we detect radio continuum circular polarization (CP) toward the central protostar, with a fractional CP of 3 – 5%. The observed CP is consistent with Gyrosynchrotron emission or Faraday conversion in a turbulent magnetized medium, both involving mildly relativistic electrons. These results enable the first direct estimate of the magnetic field strength in the immediate vicinity of a massive protostar, yielding $B \geq 20 - 35\text{G}$, and constrain the low-energy electron population to $\gamma_{\text{min}} \sim 5 - 7$ (gyrosynchrotron) and $\sim 80 - 100$ (Faraday conversion). Along the jet, the inner knots close to the protostar show linear polarization properties consistent with previous studies, supporting synchrotron emission and efficient particle acceleration. In contrast, no linear polarization is detected toward the outer Herbig-Haro objects HH 80 and HH 81, with a 3σ upper limit of $30 \mu\text{Jy}$ ($\Pi_{\text{max}} \approx 0.02$ and 0.01 , respectively). We attribute this non-detection to reduced acceleration efficiency in the outer knots when compared to inner knots and strong depolarization effects, including Faraday depolarization ($\sigma_{\text{RM}} \sim 400 \text{ rad m}^{-2}$) and beam depolarization. These results provide new constraints on magnetic fields and relativistic particle populations from the immediate vicinity of a massive protostar to its large-scale jet.

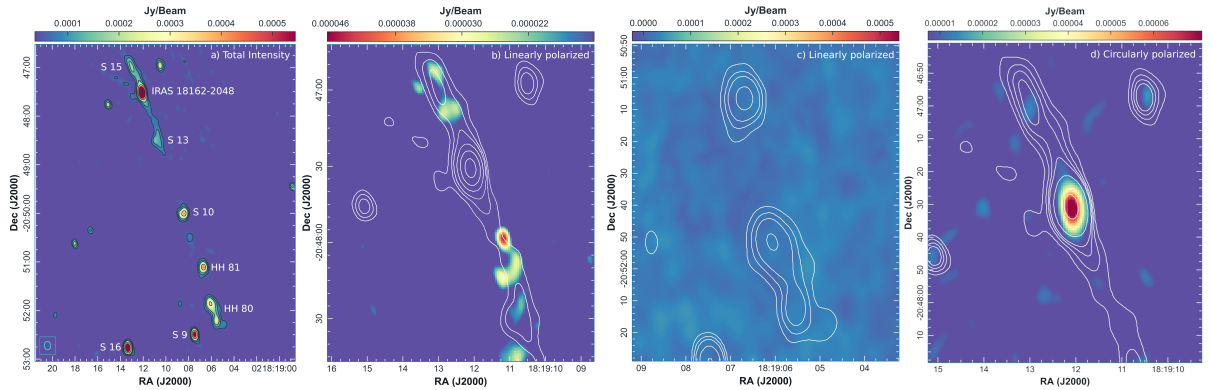


Figure 1: (a) VLA C-band radio continuum image of the HH 80-81 region, with the positions of the VLA sources and associated jet lobes marked. (b) Linearly polarized emission toward the driving source and inner knots. (c) Linearly polarized emission toward the outer knots. (d) Circularly polarized emission toward the protostar. All panels are overlaid with Stokes I contours in white.

Line intensity mapping: Modelling star-forming galaxy emission at the epoch of reionisation for FYST using catalogue data

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The Epoch of Reionisation (EoR, $6 < z < 20$) is when the earliest star-forming galaxies (SFGs) ionised the interstellar medium, a fundamental step in the history of star formation. Individual galaxy detections up to $z = 14$ made by JWST only grant a limited view into this epoch, instead of the holistic coverage required to study SFGs. Line Intensity Mapping (LIM)¹ solves this by using a wide beam to measure integrated line emission signal across a given sky area. Statistics such as the power spectra are used to measure variation in galaxy emission across spatial and redshift scales, including from faint galaxies.

Dedicated experiments are required for LIM, with the EoR-Spectrometer Deep Spectroscopic Survey (EoR-Spec DSS) being performed by the Fred Young Submm Telescope (FYST)². It will measure CO and [CII] galaxy line emission, tracers of star formation, at 210 – 420 GHz ($3.5 < z_{\text{[CII]}} < 8.2$). A corresponding suite of predictions are needed in advance of observations (beginning 2027)^{3,4}, primarily made using hydrodynamical simulations.

We complement these conventional methods by basing simulations on the COSMOS2020 galaxy catalogue^{5,6}. This existing sample covers a 1.5 deg^2 region of one of the planned EoR-Spec DSS observing fields, providing an empirical basis for our predictions. Using catalogue data on its own provides useful inherent lower limits, however we also extrapolate from it using HST and JWST sample data to include additional faint galaxies, thereby providing more complete estimates. From this starting point, we verified target [CII] and CO emission predictions from the literature, before modelling the impact of foreground CO line interlopers and their removal via targeted and blind masking. In addition, we simulated time-ordered data and analysed the effect of correlated noise on signal recovery, as well as determining a number of cross-instrument cross-correlations compatible with FYST to minimise interlopers and noise. From this we found that [CII] recovery, and so constraining star forming mechanisms, should be possible for the post-EoR period ($z < 5$) using EoR-Spec DSS, with higher redshift observations requiring cross-instrument collaboration.

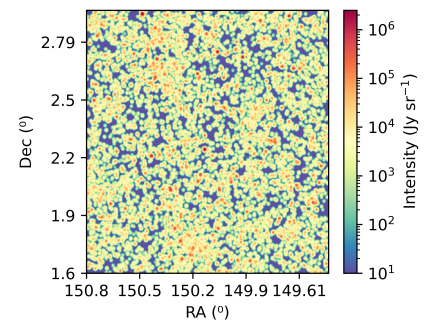


Figure 1: Cross-section of [CII] tomography based on COSMOS2020 data, from Clarke et al. ($3.52 < z_{\text{[CII]}} < 3.87$).

¹Bernal, J. L., Kovetz, E., 2022, A&A Review, 30, A5

²CCAT Collaboration, 2023, ApJS, 264, 7

³Chung, D., Viero, M. et al., 2020, ApJ, 892, 51

⁴Karoumpis, C., Magnelli, B. et al., 2022, A&A, 659, A12

⁵Clarke, J., Karoumpis, C. et al., 2024, A&A, 689, A101

⁶Clarke, J., Karoumpis, C. et al., 2026, submitted.

Tracing shock-driven shaping of molecular clouds as a trigger for star formation

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Stars form from the collapse of overdensities in molecular clouds. But what triggers the formation of these overdensities and the subsequent gravitational collapse? External feedback, such as expanding bubbles or supernova-driven shocks, can compress the ambient gas and trigger sequences of shocks that reshape the cloud and promote star formation. This is, however, a difficult phenomenon to observe and characterize, and we still know little about it.

We focus on examining NGC 1333 in the Perseus molecular cloud, a Solar-type starforming region, where gas kinematics and chemistry show signs of shock-driven compression¹. Using IRAM 30m data and astrochemistry, we infer the dynamical and chemical properties of this star-forming region. By analyzing different molecular species (such as SiO, SO, H₂CS, CH₃OH), we investigate how such energetic events can shape the morphology of the interstellar medium and the fate of future newborn stars, to make the broader connection between interstellar shocks and star formation.

¹De Simone et al., 2022a

The lifecycle of molecular clouds as seen by FEEDBACK

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We will present the SOFIA legacy project FEEDBACK that has provided the first large-scale, velocity-resolved view of stellar feedback in Galactic star-forming regions using the [CII] 158 μm and [OI] 63 μm lines that are key tracers of photodissociation regions (PDRs) at the interface between ionized and molecular gas.

A major result concerns molecular cloud formation and dispersal. Widespread high-velocity [CII] emission tracing predominantly neutral gas was detected in Cygnus X, tracing the formation of clouds via converging atomic flows¹.

Cloud dispersal, on the other hand, was seen in several FEEDBACK regions where [CII] emission reaches velocities up to 25 km/s and is organized partly in fragmented shells, but also in flows escaping through low-density channels in the cloud². This demonstrates that cloud dispersal is not a simple spherical expansion process, but is highly anisotropic and governed by the turbulent, porous cloud structure (see also Fig.1). Derived mass-loss rates of order $10^{-2} M_{\odot}/\text{yr}$ imply short cloud erosion timescales (<5 Myr), providing direct observational evidence that stellar feedback can rapidly disperse molecular clouds and regulate star formation efficiency³.

Another key outcome is the characterization of expanding [CII] bubbles. FEEDBACK shows that expanding structures are ubiquitous but complex: while classical expanding shells are observed, the [CII] data frequently reveal fragmented, incomplete, or one-sided bubbles, often accompanied by high-velocity wings and multiple kinematic components. In most of the regions, expansion velocities of >10 km/s are detected, but their dynamics often require additional energy input from stellar winds beyond pure thermal expansion.

Overall, the FEEDBACK survey has established a revised picture of feedback-driven cloud evolution: (i) molecular clouds are formed and dispersed efficiently on short timescales, (ii) [CII] traces both expanding shells and escaping gas flows, and (iii) expanding bubbles are not

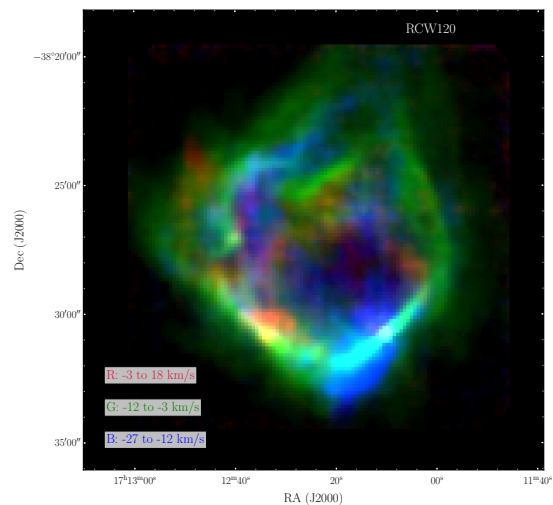


Figure 1: RGB plot of the [CII] emission in RCW120. The red- and blueshifted velocity range correspond to the parts of the line wings that exceed the escape velocity of the cloud. These gas components are thus representative of gas that will escape, and ultimately disperse, the nascent molecular cloud.

¹Schneider N. et al., 2023, Nature Astronomy, Vol. 7

²Bonne L. et al., 2023, A&A 679 L5

³Dannhauer S. et al., 2025, A&A, 703, A197; Bonne L. et al., A&A subm.

The role of massive stars in the cluster expansion phase

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Star clusters and associations are the nurseries for most stars. Especially during the first 10 Myr, these stellar groupings undergo significant changes. Many stars become unbound, and some are ejected due to close encounters. The size of the clusters increases considerably. If the clusters have a sufficient number of stars, they are likely to contain massive stars, which may have a significant impact on the other cluster members due to being gravitational foci and their strong irradiation. Individual clusters can show an overabundance or scarcity of massive stars, given their total membership.

We investigate how much the cluster expansion process itself depends on whether a cluster is rich or poor in massive stars with overabundant and underabundant bins.

We set up hundreds of realizations of clusters, drawing the individual stellar masses randomly from the initial mass function and simulate the cluster expansion process after gas expulsion for each of these clusters. Afterwards, we compare the expansion history of clusters rich in massive stars to those lacking them.

We find a clear separation in the dynamical evolution of clusters with different massive-star content. Overabundant clusters generally expand faster, reach larger half-mass radii, and produce more escapers than underabundant clusters. We quantify mean expansion velocities of order 10^{-2} – 10^{-1} pc Myr⁻¹ over 20 Myr and find that overabundant clusters can produce about 2–4 times more escapers. We further show that the internal structural evolution and mass segregation histories differ between small and large clusters, and between realizations rich and poor in massive stars. For fixed initial cluster mass and size, finite- N sampling of the upper IMF alone is sufficient to generate systematic differences in expansion, mass loss, and stellar escape.

Cluster expansion is sensitive to stochastic sampling of the upper IMF. Differences in the massive-star content lead to distinct expansion histories, velocities, and escaper fractions, even when the total initial cluster mass and size are the same. Stochastic IMF sampling may therefore contribute to the observed diversity of young cluster evolution and provides quantitative predictions that can be tested against observations.

Accretion Bursts in High-Mass Stars: Mechanisms and Observational Implications

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Episodic accretion bursts in high-mass young stellar objects (HMYSOs) arises from multiple, complementary physical processes that imprint distinct observational signatures. Using a combination of 1D, 2D, and 3D radiation-hydrodynamic models and post-processing, we show that thermal hydrogen-ionisation (TI) instabilities are ubiquitous in the hot inner discs of HMYSOs and naturally produce long (years–decades), quasi-periodic outbursts with moderate peak accretion rates—but they struggle to explain rapid, short ($\lesssim 1$ yr) bursts.

In contrast, gravitational instability and disc fragmentation generate dense, post-collapse clumps whose inward migration and tidal disruption (or merger) can produce short, high-accretion-rate events and sharp photometric/infrared signatures seen in some objects; the outcome depends sensitively on clump density and radius, inner-disc physics (viscous vs wind-driven transport), migration traps, and the numerical resolution of the inner few au. Disruption events can be non-periodic and, if sufficiently powerful, super-Eddington, driving episodic feedback.

We conclude that multiple mechanisms are likely active: TI sculpts the inner disc and produces long, periodic bursts, while fragment/planet disruption explains rapid, high-luminosity events. Discriminating these channels requires high-cadence, multiwavelength monitoring (photometry, infrared, jets/outflows) together with high-resolution, multidimensional modelling.

High-Resolution Mid-IR Observations of SiO, H₂O and NH₃ around the Massive Star VY CMa and Others Using EXES/SOFIA and TEXES/IRTF

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In the late evolutionary stages of massive stars, a dust- and molecule-rich circumstellar envelope (CSE) forms, exhibiting a complex chemical diversity. Molecules such as SiO, TiO, and other refractory species coexist with more volatile compounds, including ammonia (NH₃) and water (H₂O).

In this work, the EXES instrument on SOFIA and the TEXES spectrometer on the IRTF was used to investigate the molecular content of the CSEs surrounding the hypergiants VY CMa, NML Cyg, and other stars. For the analysis, a multi-shell model of the CSE has been developed to reproduce the observed line profiles. In addition, a newly developed multi-level excitation diagram method was applied to determine the vibrational and rotational temperatures, as well as the column densities, of the observed species. The results for SiO, H₂O, and NH₃ will be presented and discussed in the context of previous studies.

CF⁺ as a C⁺ Proxy in Low Metallicity Environments: Observations Toward the N159-W Region in the LMC

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The [CII] 158 μm (1.9 THz) line is a critical tracer of the Far-UV ($6\text{ eV} < h\nu < 13.6\text{ eV}$) radiation field from massive stars, dominating the heating and cooling in PDRs¹. With the shutdown of the SOFIA Observatory, the last access to the THz atmospheric window was closed. Recently, the Fluoromethylidinium ion (CF⁺) has emerged as a potential proxy for C⁺ due to its simple formation chemical path: $\text{C}^+ + \text{HF} \rightarrow \text{CF}^+ + \text{H}^2$. In this context, CF⁺ rotational transitions³, accessible from ground-based observatories, have been suggested as potential proxies for the [CII] 158 μm line⁴. We explore the potential of the CF⁺(1-0) rotational transition as proxy for the [CII] 158 μm line in the low metallicity environment of the N159-W region in the LMC⁵, characterize the CF⁺ gas physical conditions, and derive the gas phase [F/H] fluorine elemental abundance in the region⁶. Our results suggest that the CF⁺(1-0) emission effectively serves as a proxy for the [CII] 158 μm emission at low metallicity environments, for high S/N detections. This provides a valuable alternative to probe the FUV field of massive stars when [CII] 158 μm observations are not available.

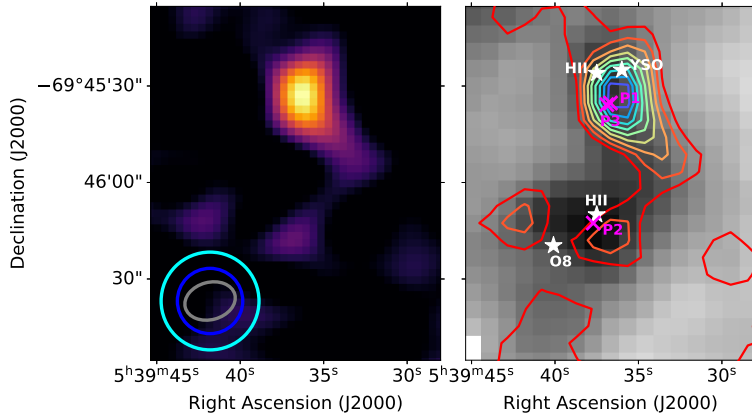


Figure 1: Left: Integrated intensity map of the CF⁺(1-0) emission toward N159-W in the LMC, obtained with the ALMA 7-m array. Right: [C II] integrated intensity map (grayscale) overlaid with CF⁺(1-0) emission in contours. White star symbols indicate the positions of an O8 star, a YSO, and the H II regions in the area.

¹Hollenbach, D. J. & Tielens, A. G. G. M. 1999, Rev. Mod. Phys., 71, 173

²Neufeld, D. A., Schilke, P., et al. 2006, A&A, 454, L37

³Guzmán, V., Pety, J., et al. 2012a, A&A, 543, L1

⁴Brinkmann, N. 2021, PhD thesis, Universitäts-und Landesbibliothek Bonn

⁵Okada, Y., Requena-Torres, et al. 2015, A&A, 580, A54

⁶Gong, Y., Menten, K. M., et al. 2024, A&A, 687, A29

Exploring Supernova Remnant Properties using Pulsars

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Supernova Remnants (SNR) are highly energetic processes that fuel star formation and induce irregularities in the interstellar plasma, and the remnant pulsars are essential to study their interaction with the medium. These rapidly rotating, highly magnetised neutron stars receive a kick at birth, making them reach supersonic velocities. This event deposits energy via shocks, resulting from the pulsar's interaction with the inhomogeneous interstellar medium. The SNR shell as well as the shocks produce intensity variations in the pulsar emission across frequency. Through scintillometry studies, we can obtain the velocities and locations of the SNR bubble and shocks. When complemented with pulsar polarimetry, we obtain the magnetic field of the neutron star, which gives us further information about the origin of the SNR through the study of the alignment between the spin and kick velocity.

The Effelsberg 100m Telescope's Ultra-Broad-Band receiver offers a unique opportunity to explore the scintillation across a broad, high-frequency regime from 2.6 to 6 GHz. In this talk, I will focus on the case of B0355+54 and B1929+10, pulsars that have been found within bow shocks and have an ideal spectrum to be studied in this large frequency range. In each observation, a large sample of pulses has been collected, which will allow us to reconstruct the magnetic field by selecting highly linearised time samples. Finally, I will present the interlink between observations and simulations in our further comprehension of the SNR input into the interstellar medium.

Tracing star cluster evolution through PAH morphology

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Star clusters (SCs) provide valuable clocks for timing the processes of star formation and feedback in nearby galaxies. Feedback from massive stars in clusters shapes the surrounding interstellar medium (ISM) over the first few Myr. Quantitative measurements of PAH morphology on characteristic (~ 10 pc) scales have the potential to provide new insight into this evolutionary process. JWST now enables PAH emission to be resolved at these scales throughout nearby galaxies, opening a new window on the earliest stages of stellar feedback. In this work, we investigate whether quantitative measurements of PAH morphology can be used to trace the evolutionary state of young star clusters. Using M33 as a test bench, we use SCs and their parameters from PHATTER, measure $H\alpha$ equivalent widths, and quantify the morphology of the surrounding $8.0\ \mu\text{m}$ PAH emission in Spitzer imaging using CAS parameters, the Gini coefficient, and measurements of the distance between SCs and dust features, as well as their brightness. We find that Gini coefficient and smoothness correlate with $\text{EW}(H\alpha)$, highlighting the connection between PAH morphology and the SC’s age. To better understand this relationship, we investigated whether physical properties of the PAH features, such as their distance from the SC and their brightness, could explain the observed trends. However, these parameters alone are insufficient to reproduce the results of the CAS analysis, suggesting that the underlying relationship depends on additional physical properties. Overall, this analysis goes beyond previous qualitative studies by providing, for the first time, quantitative morphological diagnostics to constrain the evolutionary state of young star clusters and offer a potential way of reducing the age–reddening degeneracy in broadband SED fitting.

A polychromatic analysis of the dissolving stellar association IRS 6 in the center of our Galaxy

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In the past, researchers have identified several peculiar environments in the inner parsec of the Milky Way, the most well-known of which is the black hole Sagittarius A*. Notable structures in the infrared L band are the Northern Arm, portions of the Western and Eastern Arms, the Minicavity, and IRS 13. Following these studies, ALMA observations of the 343 GHz CO transition line revealed increased radio emission surrounding the stars IRS 6E and IRS 6W. A polychromatic analysis of this “IRS 6” region using radio and four infrared wavelengths resulted in a catalogue of over 400 sources and includes their proper motions, magnitudes, fluxes, and velocity dispersion. Keplerian orbit and spectral energy distribution fits to a subset of sources suggest a common origin as well as two generations of stars. Thus, IRS 6 can be classified as a potential stellar association that may be further evolved compared to literature examples.

The next-generation U-Board - A heterogeneous, closely coupled architecture for radio astronomy

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Instrumentation for mm- and sub-mm astronomy and laboratory spectroscopy requires phase-coherent signal generation and acquisition over wide bandwidths, combined with powerful real-time signal processing. Next-generation backend systems enable direct digitization of intermediate frequency signals of coherent detectors in the range of 4- 12 GHz, or even up to 16 GHz. For kinetic inductance detectors, the next-generation backends allow signal generation and acquisition directly within the required frequency bands, eliminating the need for complex analog mixing schemes¹. In laboratory spectroscopy, techniques such as Fourier Transform Chirped Pulse Spectroscopy (FT-CPS) similarly benefit from wideband, phase-coherent signal generation and acquisition².

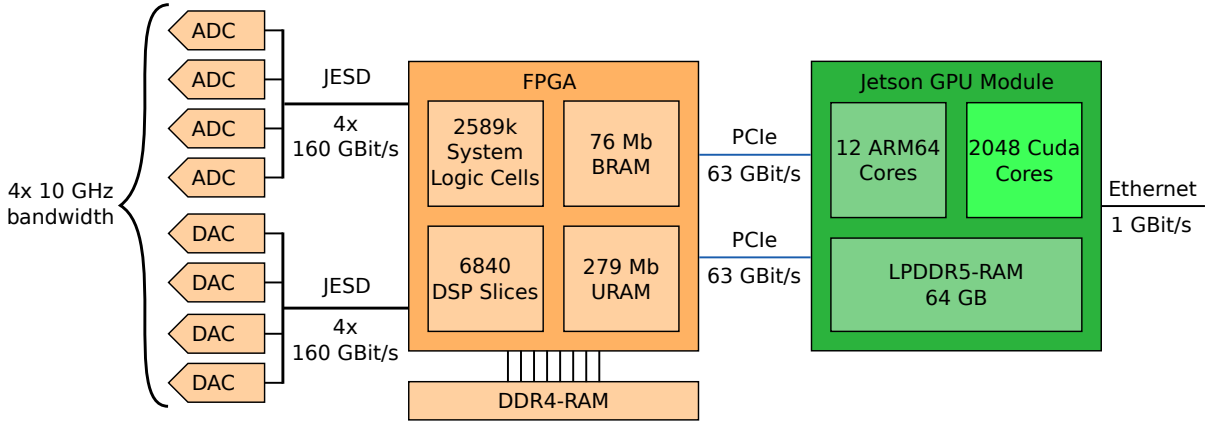


Figure 1: The next-generation analog frontend of the U-Board together with the heterogeneous processing architecture of the U-Board.

We present the next-generation U-Board, shown in figure 1, which extends the capabilities of the current system³ in the analog domain. The analog frontend supports up to four channels with 10 GHz instantaneous bandwidth each, and allows instantaneous bandwidths of up to 2 x 20 GHz when combining channels.

Signal processing is performed by a heterogeneous architecture combining a Field Programmable Gate Array (FPGA) and a Graphics Processing Unit (GPU), which are closely coupled via high-speed PCIe interfaces enabling direct data transfer. The GPU, located close to the digitization stage, enables rapid implementation of advanced algorithms and machine learning (ML) approaches, while providing substantial floating-point performance. The FPGA complements this with high-throughput fixed-point processing, as-well-as interfacing with the analog frontend.

¹Reyes, N. et al. 2026, A&A, 707

²Misra, P., Heyne, B., Grutzeck, G., Klein, B., Schlemmer, S., in prep.

³Grutzeck, G. in prep.

CIB modeling to constrain the faint-end slope of galaxy number counts

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The Cosmic Infrared Background (CIB) encodes the integrated infrared emission of star-forming galaxies in the universe across cosmic history. Disentangling this emission into individual source contributions through differential number counts dN/dS is directly linked to models of galaxy evolution. Current observations resolve the bright end of the number counts, however the faint-end slope (e.g. <2 mJy at the 350 μm band¹ still remains poorly constrained.

The FYST/CCAT telescope, currently under construction, will map the FIR/submm sky to sensitivities three times deeper than Herschel², allowing us to probe these faint source populations at large angular scales. To prepare for these observations, we develop simulated point-source CIB maps for different Schechter-function-based number counts models. For these we derive flux distributions, compare them with analytical predictions, and parametrize their shape to assess how well the faint-end slope can be constrained.

Further, we exploit gravitational lensing from galaxy clusters to probe even fainter populations, simulating lensed fields with the software LENSTOOL. Lensing magnifies faint sources into higher flux bins, resulting in skewed flux distributions³ and making faint-end slope variations more distinguishable. Finally, these simulations will be compared to archival Herschel and Planck data to understand the improvement in dN/dS constraints expected from the upcoming CCAT observations.

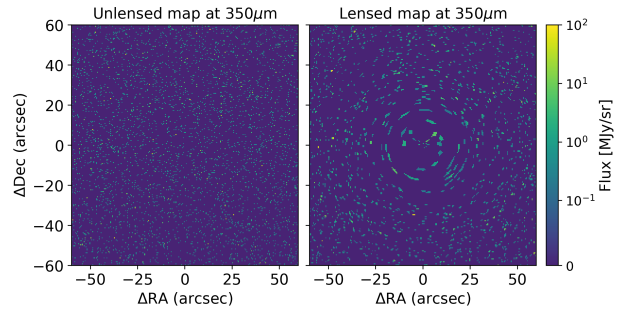


Figure 1: Simulated unlensed (left) and lensed (right) CIB maps ($60'' \times 60''$) at the 350 μm band using a Schechter function as source function (with parameters following previous observations).

¹Bethermin, M., et al., 2017, A&A, 607A, 89B

²CCAT-Prime Collaboration., et al., 2023, ApJS, 264, 7

³Hezaveh, Y., et al., 2013, ApJ, 772, 121H

First look of 18cm OH masers and Zeeman splitting of high-mass star forming regions in MMGPS

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As a chemical precursor to CO and formed through reactions with H₂, the hydroxyl radical (OH) has emerged as a powerful alternative tracer of H₂ and magnetic fields across a wide range of environments in molecular clouds. We present the first inspection of 1665/1667 MHz OH data from the spectral line survey of the Max-Planck-Institut für Radioastronomie (MPIfR)–MeerKAT Galactic Plane Survey (MMGPS¹). This survey targets 13 southern high-mass star-forming regions (HMSFRs) using the MeerKAT L-band receiver, complementing the SOFIA Legacy program HyGAL². Both narrow masing features and broader emission/absorption components are identified (see, for example, Figure 1), tracing distinct physical conditions within HMSFRs. Leveraging the full-Stokes capability of MMGPS, we also present Stokes V spectra and identify signatures of OH Zeeman splitting toward these regions. These results lay the groundwork for follow-up observations with higher sensitivity and spectral resolution, enabling more precise measurements of magnetic-field strengths and thus calibrating the magnetic field-density relationship in HMSFRs.

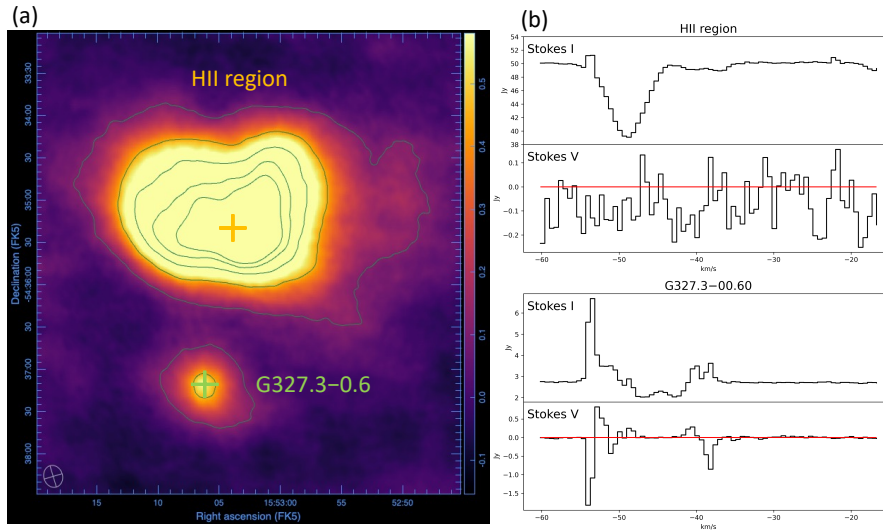


Figure 1: Continuum image and 1667MHz OH spectrum of G327.3-0.6 field. (a) The continuum image center at 1666MHz with beam size of $15''.7 \times 13''.2$ and σ of 0.037 Jy/beam. The contours start from 3σ to 39σ with steps of 9σ . (b) The OH stokes I and stokes V spectra toward HII region and G327.3-0.6, respectively.

¹Padmanabh et al. 2023, MNRAS, 524, 1291

²Jacob et al. 2022, ApJ, 930, 141

Testing the polarization-intensity polarization–intensity gradient method in molecular clouds and collapsing dense cores simulation

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Magnetic fields play a crucial role in the process of star formation and the evolution of collapsing dense cores. However, direct measurements of magnetic field strength from observations remain challenging. The polarization–intensity gradient method is a new approach to estimate the magnetic field strength using polarization angle and intensity gradient, which can provide the map of position-dependent magnetic field strength estimates.¹ In this project, we evaluate the applicability and robustness of this method when applied to realistic observational conditions. We perform synthetic Atacama Large Millimeter/submillimeter Array (ALMA) and James Clerk Maxwell Telescope (JCMT) observations based on RAMSES simulations, and apply the polarization–intensity gradient method to estimate the magnetic field strength. We then compare the derived field strengths with the intrinsic values from the simulation to quantify the associated uncertainties. Furthermore, we discuss the physical conditions and environments of dense cores under which the polarization–intensity gradient method provides reliable estimates. Our results aim to clarify the limitations and applicability of this method in interpreting observations of star-forming regions.

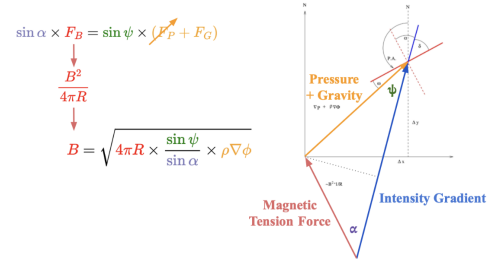


Figure 1: Equation of polarization–intensity gradient method to get the magnetic field strength.

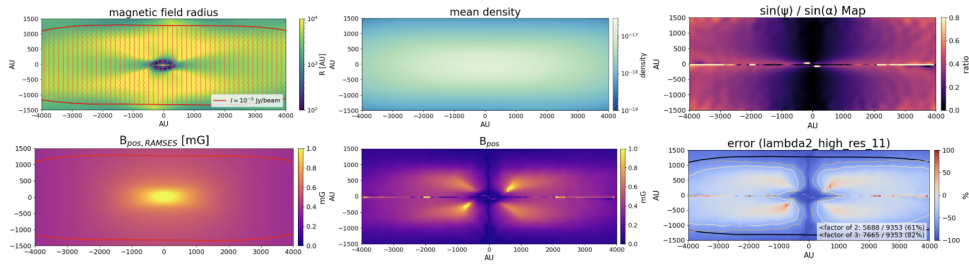


Figure 2: (top left) Magnetic field curvature radius collapsing dense core. (top center) Mass density map. (top right) Ratio map of magnetic force and gravitational force. (bottom left) Magnetic field strength in simulation. (bottom center) Magnetic field strength calculated from polarization–intensity gradient method. (bottom right) Error map by comparing estimated field strength and model field strength.

¹Koch et al. 2012

Line intensity mapping with the ALMA interferometer

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In preparation for the CCAT/FYST EoR-Spectrometer Deep Spectroscopic Survey^{1,2,3} (EoR-Spec DSS), we analyze archival Atacama Large Millimeter/ submillimeter Array (ALMA) data to place new constraints on CO($J_{\text{up}} = 3-6$) line emission from galaxies at $z = 1-5$. Utilizing a line intensity mapping⁴ (LIM) framework, which probes the aggregate emission from unresolved galaxy populations, we focus on the COSMOS field to access the small scale, shot-noise-dominated regime of CO emission. By reanalyzing archival data cubes within this framework, we derive constraints on the CO luminosity function across cosmic time. These measurements place new constraints on the molecular gas content of galaxies at intermediate redshifts and constrain the expected level of CO interloper contamination for the EoR-Spec DSS⁵, targeting high-redshift ($z \sim 3-8$) [CII] LIM emission. We present our methodology, discuss key challenges in extracting LIM signals from interferometric archival data, and highlight the potential of ALMA archive-based studies as pathfinders for CCAT/FYST science.

¹CCAT Collaboration, 2023, ApJS, 264, 7

²Karoumpis, C., Magnelli, B. et al., 2022, A&A, 659, A12

³Clarke, J., Karoumpis, C. et al., 2024, A&A, 689, A101

⁴Bernal, J. L., Kovetz, E., 2022, A&A Review, 30, A5

⁵Karoumpis, C., Magnelli, B. et al., 2024, A&A, 691, A262

Comparison of X-ray and optical AGN identification methods in local galaxies

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Local galaxies likely all host a supermassive black hole at their center. When matter is rapidly accreted onto it, the active galactic nucleus (AGN) ignites, and the extreme, highly luminous environment can be observed throughout the electromagnetic spectrum. An accurate understanding of the role that AGN play in star-formation quenching — argued to be crucial by models and simulations — is central to our comprehension of galaxy evolution. Thus, reliable AGN classification models are essential for linking current AGN activity to their predicted impact.

In this work, the galaxy sample of the extended Calar-Alto Legacy Field spectroscopy Area (CALIFA) survey¹, an optical wide-field integral field unit survey of low redshift galaxies, is combined with the Data Release 1 main source catalog of the extended ROentgen Survey with an Imaging Telescope Array (eROSITA)², a sensitive wide-field X-ray telescope. This yields a sample size of 254 local galaxies. We use BPT diagrams and the WHaD diagram, both nuclear activity diagnostics based on optical emission line information, and perform a survey cross-matching to derive an X-ray AGN classification. The AGNs for which multiple classifications agree are identified, followed by a detailed inspection of the mechanisms behind their agreement/disagreement.

Of all X-ray AGNs, 26% are also found as AGNs in the BPT diagnostic and 37% as AGNs in the WHaD diagnostic. 40% of the X-ray AGNs are classified as active in at least one of the optical classifications. The global properties of the different AGN classification subsets are further analysed using information about their stellar and gaseous content from the integrated Extragalactic Database for Galaxy Evolution (iEDGE)³. Using the established QueStNA⁴ quenching sequence, we investigate how nuclear activity identified by the different methods influences the quenching stage as well as the global star-formation activity. The analysis highlights how AGN diagnostics can disagree and can alter the number of green valley and quenched AGN-hosts identified, showing that multiwavelength AGN classifications are essential for investigating star-formation quenching in the local Universe. Multiwavelength AGN classifications like the one presented here will be essential for the next generation of galaxy surveys investigating AGN influence.

¹Sánchez, S. F., Barrera-Ballestrós, J. K., et al., 2024, *Rev. Mexicana Astron. Astrofis.*, 60, 41

²Merloni, A., Lamer, G., et al. 2014, *A&A*, 682, A34

³Colombo, D., Kalinova, V., et al., 2025, *A&A*, 644, A97

⁴Kalinova, V., Colombo, D., et al., 2021, *A&A*, 648, A64

An Apparent [C II]-Deficit in S144/RCW79 Caused by Self-Absorption

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We identify that the low observed [C II]/FIR ratio in S144 is an apparent [C II]-deficit caused by self-absorption in an optically thick outer C⁺ layer with temperature and velocity gradients. After reconstructing the absorbed [C II] flux, the [C II]–FIR relation becomes linear, and supports the idea that at least some [C II]-deficits in Galactic H II bubbles are radiative-transfer effects rather than intrinsically weak [C II] cooling.

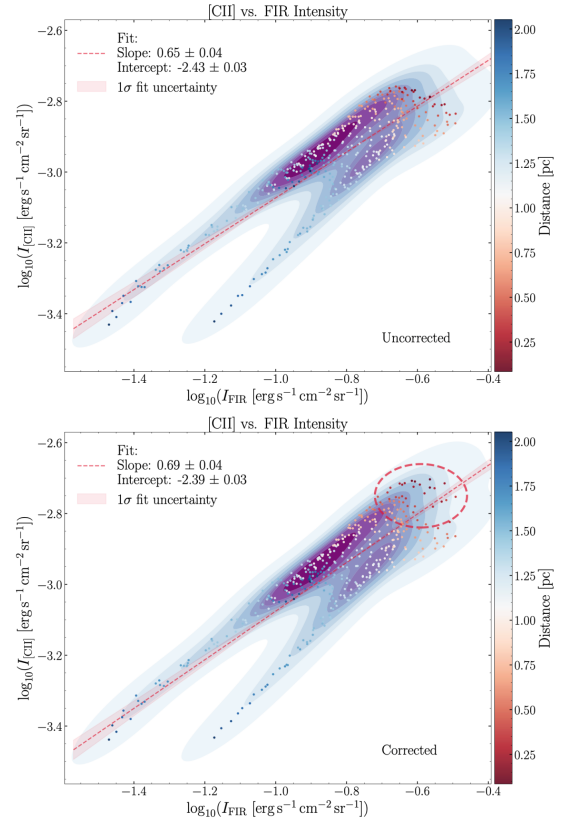


Figure 1: [C II] to FIR correlation. Top: The uncorrected [C II] emission clearly shows a [C II]-deficit for high values of [C II] and FIR emission. Bottom: The reconstructed and corrected [C II] emission is shifted upwards, encircled by a dashed red ellipse, recovering a linear correlation.

Survey of 5 Dust-Producing Wolf-Rayet Binaries Reveals Grain Size and Temperature Variation Across Stellar Environments

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Carbon-rich Wolf-Rayet (WC) stars, the descendants of massive O-stars that evolve on short ($< \text{Myr}$) timescales, can form dust via colliding winds with a binary companion. Their fast evolutionary timescales and dust production capabilities indicate they may be important contributors to the dust budget in the early Universe. Recent JWST observations have revealed that the carbonaceous material produced by massive, evolved WCd binary stars survives for hundreds of years and therefore likely enriches the ISM with dust and aromatic molecules. By calculating the dust color temperature of 5 dust producing systems (WR48a, WR112, WR125, WR137, and WR140) using JWST+MIRI Images, we find direct evidence of dust grains that are not in thermal equilibrium with the stellar radiation field. This confirms that there is a population of nano-sized dust grains that are heated by the intense stellar radiation, resulting in high, stochastic, temperature spikes. The dust surrounding these systems likely remains in this transiently heated regime out to thousands of AU from the central binaries. This implies that the carbonaceous molecules created by some WCd binaries are robust; they survive the intense circumstellar environment and, in the case of WR140, propagate toward the ISM with high velocities. By comparing several WCd binaries to each other, we can infer how the orbital properties, stellar luminosity, and stellar winds of all 5 systems affect the formation and survivability of circumstellar dust. These Galactic WCd binaries are the local laboratories that allow us to study what may be a major source of carbonaceous material in the early Universe.

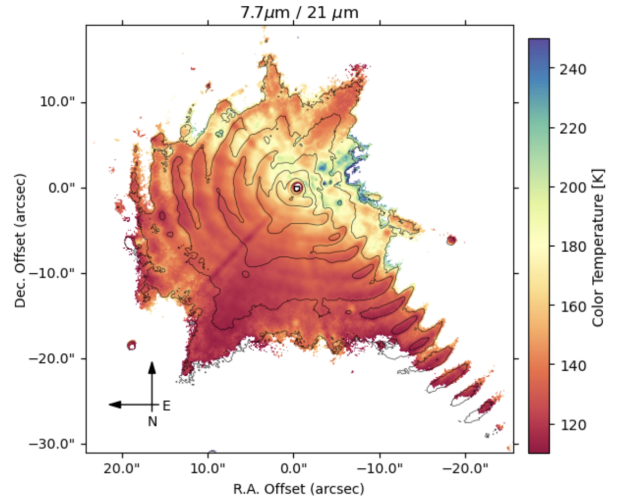


Figure 1: Dust color temperature map of WR140 calculated from the flux ratio of the $7.7\mu\text{m}$ and $21\mu\text{m}$ thermal dust emission.

Synthetic Emission Line Maps as a Benchmark for H II Region Metallicity Diagnostics

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We present the Emission Line Diagnostics (ELD) tool, a post-processing framework that generates synthetic optical emission line maps from numerical simulations, enabling direct comparison between theory and observations. By producing spatially resolved mock observations of nebular emission, ELD allows us to analyse line diagnostics under fully controlled physical conditions. We apply the tool to idealised, isolated H II region simulations to test how reliably different observational methods recover the gas metallicity. Taking the direct temperature-sensitive auroral-line method as a reference, we compare it with widely used strong-line calibrations, using the exact simulation metallicity as the ground truth. Our initial results suggest that strong-line methods can systematically misestimate metallicities, even in idealised H II regions, because they neglect internal variations and inhomogeneities within the emitting gas. ELD thus provides a powerful framework for benchmarking metallicity diagnostics with synthetic, spatially resolved emission maps.

[C II] self-absorption in M17: a large-scale view from SOFIA FEEDBACK

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M17 is one of the most luminous and massive star-forming regions in the Milky Way, hosting over 100 OB stars and two prominent photodissociation regions (PDRs) illuminated by the central cluster NGC 6618. The [C II] $158\,\mu\text{m}$ far-infrared fine-structure line is a dominant coolant of the interstellar medium and is widely used as a tracer of star formation activity in Galactic and extragalactic sources. Guevara et al. (2020)¹ showed that [C II] is optically thick in several Galactic PDRs, and that in M17-SW the bright background emission arises from multiple PDR surfaces in a clumpy cloud complex and is significantly absorbed by a large column of low-excitation, dense foreground C^+ whose origin remains unclear, but which is inconsistent with a uniform diffuse foreground layer. These findings were based on deep integrations at seven discrete positions; the spatial extent and variation of [C II] self-absorption across M17 have not been mapped on parsec scales. Here we present a new large-scale velocity-resolved [C II] map covering $\sim 11 \times 11\,\text{pc}^2$ towards M17, obtained with SOFIA/upGREAT² as part of the FEEDBACK legacy program³, significantly extending the former SOFIA/GREAT maps of M17-SW. The high spectral resolution and efficient large-scale mapping capability of the upGREAT heterodyne array receiver allowed us to detect the faint [C II] hyperfine satellite lines across the extended map, providing a direct measure of the [C II] optical depth and self-absorption along the line of sight. To maximize the signal-to-noise ratios required for reliable [C II] detection across the extended M17 map, we apply Gaussian Mixture Model for clustering⁴ spectra with similar line profiles. A two-layer multi-component model to resolve the emitting background layer and the absorbing foreground is fitted to each cluster-averaged spectrum. We find extended [C II] self-absorption across M17, tracing a cold C^+ foreground with strongly varying extent and physical conditions across the region. Complementary ^{12}CO and ^{13}CO ($J = 3 \rightarrow 2$) maps from APEX and ^{12}CO , ^{13}CO ($J = 2 \rightarrow 1$), and C^{18}O ($J = 2 \rightarrow 1$) maps from the IRAM 30m telescope are used to investigate the association of the cold absorbing C^+ foreground with the molecular gas traced by CO. Because extragalactic observations typically lack such spectral resolution, unresolved cold foreground absorption and optical depth effects can reduce the observed [C II] intensity and may contribute to the [C II] line-intensity deficits reported in some galaxies; explicitly accounting for these components is therefore important when interpreting [C II] as a star-formation tracer on galactic scales.

¹Guevara, C., Stutzki, J., Ossenkopf-Okada, V., et al. 2020, A&A, 636, A16

²Risacher, C., Güsten, R., Stutzki, J., et al. 2016, A&A, 595, A34

³Schneider, N., Simon, R., Guevara, C., et al. 2020, PASP, 132, 104301

⁴Kabanovic, S., Schneider, N., Ossenkopf-Okada, V., et al. 2022, A&A, 659, A36

Mini-CHAI, a First Light Heterodyne Instrument for the CCAT Observatory

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Mini-CHAI is a single pixel, dual frequency, heterodyne receiver installed in summer 2026 at the CCAT observatory in the Atacama desert. It is a pathfinder for the 64-pixel CCAT Heterodyne Array Instrument (CHAI)¹ to study cryogenic and optical design concepts, tuning algorithms, control electronics, telescope interfaces and operational details. Mini-CHAI will cover the atmospheric windows around 490 and 810 GHz. It will undertake test observations in support of the large-scale mapping objectives of future multi-pixel array instruments and study point-like sources. It will also be used to verify the surface accuracy and mirror alignment of the telescope. The low frequency band (455-495GHz) is implemented with a balanced SIS mixer (IBAMI²), targeting the CO J=4→3 and the [CI] 3P1→3P0 transitions. The upcoming large 64 pixel CHAI array will use balanced SIS mixers due to their efficient LO coupling through an additional waveguide port. Thus, the low frequency band of the Mini-CHAI receiver allows studying the behavior and operating conditions of IBAMI as a precursor of the final balanced mixers for CHAI. The low frequency band LO is fed into the cryostat via a waveguide thermal isolator³ to a cryogenic frequency tripler (VDI). The tripler is connected via another thermal isolator to the LO port of the balanced mixer. The high frequency band (800 - 820GHz) is populated with a single SIS mixer, a legacy flight spare mixer for the HIFI instrument on board of the Herschel space telescope⁴. It is tuned to complementary spectral lines: CO J=7→6 and [CI] 3P2→3P1. Bias electronics are directly copied from the finished design for CHAI. It is capable of controlling 8 balanced mixers (total of 16 SIS junctions) and 8 LNAs (V_{gate} , V_{drain}). The HDPE cryostat window is equipped with imprinted anti-reflection grooves to enable high transmission over both frequency bands.

To characterize the optical quality and alignment of the telescope mirrors, the instrument was first installed in the CCAT Instrument Space 1, together with a holography setup, and later moved to Instrument Space 2 for astronomical observations where a complex optics path images the telescope focal plane to the instrument.

¹I. Barrueto, U. Graf, C. Honingh, K. Jacobs, M. Justen, H. Kruger, M. Schultz, K. Vynokurova, L. Weikert, S. Wulff, and J. Stutzki, "CCAT-prime Heterodyne Instrument (CHAI) advances", 2022, IRMMW-THz, IEEE, 1-2

²M. P. Westig, K. Jacobs, J. Stutzki, M. Schultz, M. Justen, and C. E. Honingh, "Balanced superconductor-insulator-superconductor mixer on a 9 μm silicon membrane", 2011, Superconductor Science and Technology, Vol. 24, p.8

³Th. de Graauw et al., "The Herschel-Heterodyne Instrument for the Far-Infrared (HIFI)", 2010, A&A, Volume 518, id.L6, 7 pp.

⁴J. L. Hesler, A.R. Kerr and N. Horner, "A Broadband Waveguide Thermal Isolator", 2003, Proc. of the Fourteenth International Symposium on Space Terahertz Technology, p.148-154.

Superconducting Intermediate Frequency Circuitry for the CCAT Heterodyne Array Instrument

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The CCAT Heterodyne Array Instrument (CHAI) is a high-resolution spectrometer realized for the Fred Young Submillimeter Telescope (FYST), and is set to operate in the 455–498 GHz and 800–820 GHz radio frequency (RF) ranges. The detector circuitry of CHAI is developed in-house in superconducting planar technology and fabricated at our on-site nanofabrication facilities, enabling two compact arrays of 64 balanced superconductor-insulator-superconductor (SIS) mixer pixels per RF frequency band.

The intermediate frequency (IF) circuitry comprises two-step impedance transformers at the IF input ports, which provide matching between the two balanced SIS mixers and the 50 Ω environment of the 180° IF hybrid coupler, see Fig.1. On the same 9 μm silicon substrate, bias tee circuits are implemented at each DC input port (see Fig.1), which facilitate the DC biasing of the SIS junction while preventing signal leakage from the IF path. Owing to the large wavelength at the

mixer intermediate frequency (4–8 GHz) the IF circuitry would require a substantial area, if realized in transmission-line technology. A high-Q compact microwave circuit is achieved by implementing the planar lumped-element equivalent of transmission lines¹, ultimately enabled by the low surface resistance of the superconducting niobium (Nb) metallization used in fabrication². The design and performance of the CHAI IF device chain will be presented.

The near quantum-limited sensitivity and high pixel count of the instrument enable efficient large-scale surveys of the sub-mm sky by tracing [C I] and CO spectral lines in interstellar gas clouds of the Milky Way and nearby galaxies. A spectral resolution of 100 kHz becomes possible via the heterodyne detection of CHAI, needed to kinematically resolve interstellar structures, thus establishing FYST as a pathfinder for zoom-in observations of ALMA at small angular scales³. Future generations of CHAI equipped with a balanced *sideband-separating* (2SB) mixer would enhance the mapping speed even further by reducing image-band noise.

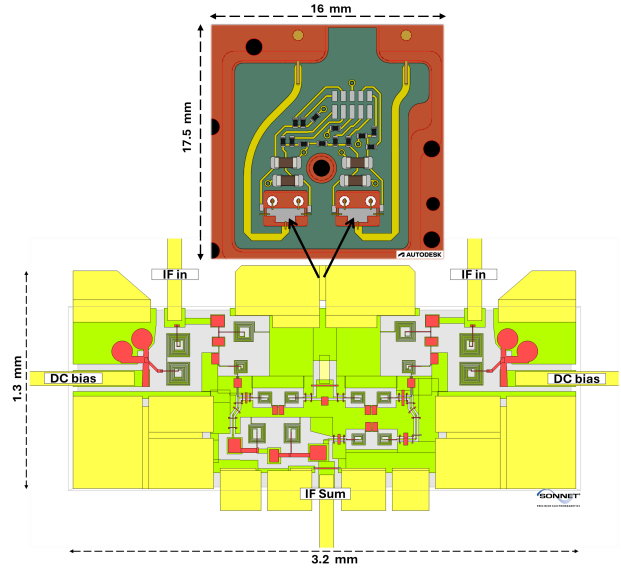


Figure 1: EM design of the impedance transformer, DC bias and 180° IF hybrid circuits (bottom), to be embedded (twofold) in the CHAI 4-pixel waveguide block-half with the DC circuitry, shown for two pixels (top).

¹Parisi, S. J. 1989, IEEE Int. Microwave Symp. Digest, 1243-1246

²Kerr, A. R., Lichtenberger, A. W. 2006, 17th Int. Symp. Space THz Tech., Paris

³Ossenkopf-Okada, V. et al. 2016, A&A, 590

Birth Radii Analysis of Milky Way Disk Stars According to APOGEE DR17 and the NIHAO-UHD Simulation Suite

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The radial position at which a star formed – its birth radius (R_{birth}) – encodes information about the state of the Milky Way disk at the time of formation. Due to radial migration and dynamical heating, stars rarely remain near their birth sites, complicating efforts to reconstruct the Milky Way’s evolution. Recent work has proposed that a star’s $[\text{Fe}/\text{H}]$ and $[\alpha/\text{Fe}]$ abundance ratios retain sufficient memory of stellar origin to infer R_{birth} independent of age or present-day location. Using the inferred birth radii of $\sim 116,000$ red giant stars from APOGEE, we show that the reconstructed R_{birth} distributions follow expectations from inside-out formation, and quantify the plausible amplitude by which the element abundance gradients in the Milky Way disk have evolved over time.

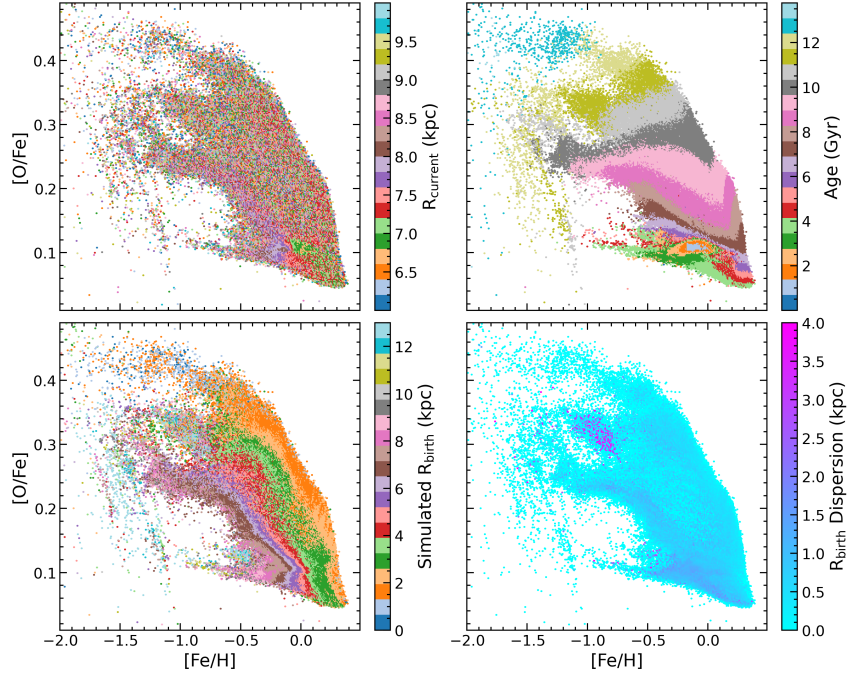


Figure 1: The $[\text{Fe}/\text{H}]$ – $[\text{O}/\text{Fe}]$ abundance plane, demonstrating correlation between elements, stellar age (top right) and birth radius (bottom left). Data is taken from galaxy g2.79e12 in the NIHAO-UHD cosmological simulation suite¹. These results are used to infer an empirical relation between iron abundance, α abundance, and R_{birth} , which is later applied to APOGEE red giants.

¹Buck, Tobias, et al. "NIHAO-UHD: The properties of MW-like stellar discs in high-resolution cosmological simulations." Monthly Notices of the Royal Astronomical Society 491.3 (2020): 3461-3478.

Rotational Spectroscopy of C₃H₄O₂ using Updated CP-FTMW Spectrometer

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Rotational spectroscopy plays a central role in laboratory astrophysics, providing the high-precision data required to identify complex organic molecules in the interstellar medium. In this work, we combine broadband, high-resolution chirped-pulse Fourier transform microwave (CP-FTMW) spectroscopy with a novel acquisition board (U-Board) originally developed as a readout for Microwave Kinetic Inductance Detectors (MKIDs) for the A-MKID camera for APEX¹. Our upgraded home-built CP-FTMW spectrometer² operates in the 75-110 GHz millimeter-wave region and integrates a modified version of the U-Board (Universal-Signal Acquisition and Generation Equipment), which unifies signal generation and digitisation within a single system. It has a heterogeneous architecture consisting of an FPGA, a GPU, and DACs/ADCs for phase-coherent signal generation and acquisition, as well as rapid integration in the time domain. The upgrade significantly enhances measurement sensitivity over the previous setup and also enables sideband separation and the study of the time evolution of molecular processes by storing data in discrete frames.

This improved instrumental capability is well-suited to the rotational study of astrochemically relevant complex organic molecules. To date, more than 340 molecular species have been detected in space³, including oxygen-bearing heterocycles such as oxirane (c-C₂H₄O)⁴ and methyloxirane (C₃H₆O)⁵. Within the C₃H₄O₂ isomeric family, 3-hydroxypropenal has been detected towards the solar-type protostar IRAS 16293–2422 B⁶, highlighting the astrochemical relevance of related cyclic isomers. In this contribution, we present the rotational spectrum of the C₃H₄O₂ isomers, specifically 2-oxetanone and 3-oxetanone. The resulting spectroscopic parameters substantially refine previous datasets^{7,8} and provide reliable frequency predictions throughout the millimeter range. These data established a robust foundation for astronomical searches for oxetanone isomers towards the high-mass star-forming region Sgr B2(N), which will also be reported in this work.

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²Hermanns, M., et al. *Review of Scientific Instruments* 94.3 (2023).

³<https://cdms.astro.uni-koeln.de/>

⁴Dickens, J. E., et al. *The astrophysical journal* 489.2 (1997): 753-757.

⁵McGuire, Brett A., et al. *Science* 352.6292 (2016): 1449-1452.

⁶Müller, H. S. P., et al. *Astronomy & Astrophysics* 687 (2024): A8.

⁷Chen, Ziqiu, and Jennifer van Wijngaarden. *Journal of Molecular Spectroscopy* 257.2 (2009): 164-169.

⁸Chen, Ziqiu, and Jennifer van Wijngaarden. *Journal of Molecular Spectroscopy* 279 (2012): 31-36.

Investigating low and high mass protostellar outflows with ALMA observations

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Understanding the formation of high-mass stars ($M > 8 M_{\odot}$) remains one of the central challenges in modern star formation studies, with their formation mechanisms still poorly constrained. In particular, it remains debated whether massive stars form as a scaled-up version of low-mass star formation or through fundamentally different processes. One promising approach to address this question is the study of protostellar outflows, which are common features in both low- and high-mass star formation.

In this work, we analyse high-resolution observations from the Atacama Large Millimeter/ sub-millimeter Array (ALMA), focusing on molecular outflow tracers, including low-J CO transition lines and SiO lines, to investigate the physical properties of massive protostellar systems. We examine the morphology and key outflow characteristics, such as radius, velocity, dynamical timescale, and opening angle, for high-mass star-forming regions from the ALMA-IMF survey and compare them with low-mass protostellar outflows in the Ophiuchus molecular cloud.

Preliminary results indicate that outflows from massive protostars generally exhibit longer dynamical timescales than those from low-mass sources. Additionally, we find that dynamical timescales increase with core mass, consistent with trends reported in previous studies. In terms of opening angle, high-mass protostellar outflows are not significantly less collimated than expected, despite forming in dense and dynamically complex clustered environments.

These findings will provide new observational constraints on massive star formation theories and contribute to a more comprehensive understanding of star formation across the mass spectrum.

ROTATIONAL SPECTROSCOPY OF VIBRATIONALLY EXCITED STATES AS A TOOL FOR ASTROPHYSICS: INVESTIGATIONS OF $^{13}\text{CH}_3\text{CN}$ AND $\text{CH}_3^{13}\text{CN}$ UP TO $v_8 = 2$ AND A SEARCH FOR $v_8 = 2$ TRANSITIONS TOWARD SAGITTARIUS B2(N)

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Methyl cyanide, CH_3CN , occurs in space in diverse environments. It is particularly abundant in the warm and dense parts of star-forming regions. Vibrational satellites up to $v_4 = 1$ (1324 K) were identified securely toward the giant molecular cloud Sagittarius B2(N) close to the Galactic center while lines of $v_4 = v_8 = 1$ (1290 cm^{-1}) were detected tentatively.¹ With transitions of $^{13}\text{CH}_3\text{CN}$ and $\text{CH}_3^{13}\text{CN}$ in $v_8 = 1$ also found in this source, transitions in $v_8 = 2$ of these isotopomers are promising targets for searches in space.

We employed samples enriched in $^{13}\text{CH}_3\text{CN}$ and $\text{CH}_3^{13}\text{CN}$, respectively, to record laboratory spectra between 35 and 1091 GHz and analyzed states up to $v_8 = 2$. Interactions within $v_8 = 2$ yielded accurate information on the energy differences of the $l = 0$ and $l = 2$ components of $v_8 = 2$, 22.93 and 21.79 cm^{-1} for $^{13}\text{CH}_3\text{CN}$ and $\text{CH}_3^{13}\text{CN}$, respectively. Fermi resonances between $v_8 = 1^{-1}$ and $v_8 = 2^{+2}$ probe their energy differences (373.84 and 365.99 cm^{-1}) without the use of high-resolution IR data. A resonance between $v = 0$ and $v_8 = 1$ in $^{13}\text{CH}_3\text{CN}$ gave information on their energy difference (364.75 cm^{-1}).

The resulting spectroscopic parameters² were used to search for transitions of $v_8 = 2$ pertaining to these ^{13}C isotopomers in Sagittarius B2(N). We will discuss the astrophysical relevance of our findings.

We acknowledge support by the Deutsche Forschungsgemeinschaft via the collaborative research center SFB 1601 (project ID 500700252), subprojects A4 and Inf, as well as the Gerätezentrum SCHL 341/15-1 ("Cologne Center for Terahertz Spectroscopy").

¹H. S. P. Müller, A. Belloche, F. Lewen, B. J. Druin, K. Sung, R. T. Garrod, and K. M. Menten, *J. Mol. Spectrosc.* **378** (2021) 111449.

²H. S. P. Müller, A. Belloche, F. Lewen, and S. Schlemmer, *ACS Earth Space Chem.* **10** (2026) 578.

A Close Look at the Multiplicity of Young Massive Stars in Galactic Embedded Clusters

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The formation of stellar multiples is a frequent outcome of massive star formation and early cluster evolution. Characterising stellar multiplicity rates, separations, and mass ratios provides essential constraints for star formation theories and for understanding how natal cluster environments shape the process. However, the multiplicity of young massive stars remains poorly constrained, as they form in small numbers within distant, heavily obscured environments, making direct observation during their first few million years particularly challenging. In this work, we investigate close multiplicity (separations < 3000 AU) of young massive stars in four embedded clusters at distances of 1.3–1.75 kpc and ages of 1–2.75 Myr.

Using VLT/NACO adaptive-optics K -band images across multiple fields of DBS 113, DBS 121, Hourglass, and RCW 108 — four Galactic massive star clusters at $Z \sim Z_{\odot}$ — we detect sources down to $K \approx 18$ around cluster members identified through $(J - H)$, $(H - K)$ colour-colour analysis of VVV/VIRAC data. The likelihood of companionship is evaluated through chance-alignment probabilities using stellar density estimates from the Besançon population synthesis model. Multiple systems are classified into hierarchical configurations using dendrogram-clustering to derive multiplicity statistics. We obtain multiplicity fractions (MF) and companion fractions (CF) across separation bins up to 3000 au. Over 1 to 3 Myr, we find a decay in multiplicity — MF declining from 0.54 to 0.31 and CF from 0.73 to 0.56 — suggesting rapid dynamical processing of native stellar multiples. The reported multiplicity properties are put in perspective with the overall stellar content of the clusters, characterised in terms of mass function, spectral type, and infrared excess of the young stars detected at near-infrared wavelengths. Together, these results provide observational constraints on the early multiplicity of massive stars and offer a basis for quantifying how cluster environments could shape the evolution of multiple stellar systems.

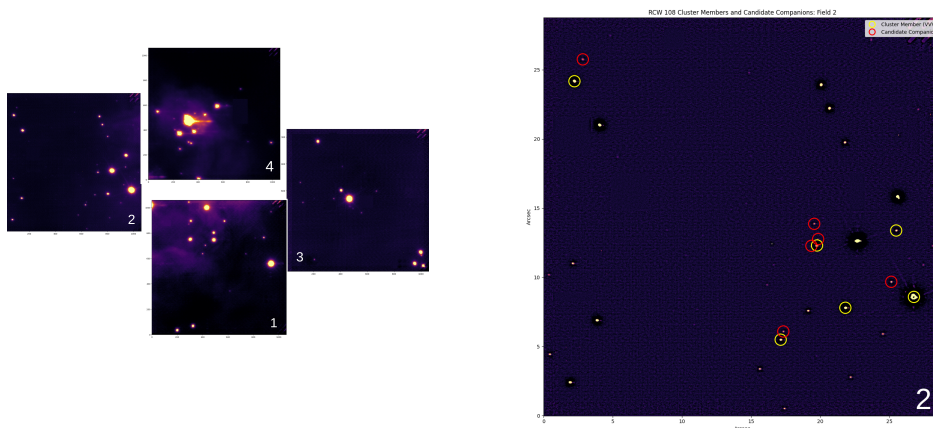


Figure 1: **Left:** VLT/NACO K -band images of the four fields of RCW 108. **Right:** High-pass filtered image of an RCW 108 field with identified cluster members (yellow) and probable companions (red).

The Carbon Budget in the Milky Way

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Carbon, in its various forms (C^+ , C^0 , and CO), is a fundamental coolant of the interstellar medium (ISM) and a key tracer of its physical conditions and energetics. Photodissociation regions (PDRs), shaped by ultraviolet (UV) radiation from massive OB stars, host the transition between ionized, atomic, and molecular carbon phases, making them ideal environments for studying the ISM as show in Figure 1 (Wolfire et al. 2022¹). Large-scale surveys such as the Herschel Open Time Key Project Galactic Observations of Terahertz C^+ (GOTC+)(Pineda et al. 2013²) have provided velocity-resolved observations of the $[CII]$ 158 μm line along ~ 452 line of sights, revealing the structure of Galactic gas and the presence of a significant CO-dark molecular gas (Grenier et al. 2005³; Wolfire et al. 2010⁴); however, the neutral atomic carbon ($[CI]$) component remains poorly constrained in Galaxy-wide studies due to observational limitations and its relatively faint emission compared to CO . Observations (Shimajiri et al. 2013⁵; Frerking et al. 1989⁶) show that $[CI]$ emission is widespread throughout molecular clouds, challenging classical PDR models in which atomic carbon is confined to cloud surfaces. To address this gap, we complement the (GOTC+) survey by combining already existing $[CII]$, CO , and HI datasets with Galaxy-wide $[CI]$ observations using the Atacama Pathfinder Experiment (APEX) telescope equipped with the nFLASH receiver., enabling simultaneous observations of the $[CI]$ $^3P_1 \rightarrow ^3P_0$ transition at 492 GHz and multiple CO isotopologues at high angular resolution. The goals of this study are to incorporate for the first time the atomic carbon component into a Galaxy-wide survey, assess the role of $[CI]$ as a tracer of CO-dark molecular gas through comparisons of velocity resolved column densities of C^+ , C^0 , CO and quantify the contribution of $[CI]$ emission in diffuse gas. These observations can provide a comprehensive view of the carbon budget in the Milky Way and improve our understanding of the distribution and phase balance of carbon across different ISM environments. We will present different ratios of line properties like peak intensity, integrated intensity, line width etc of these different carbon forms obtained from full spectral line data reduction.

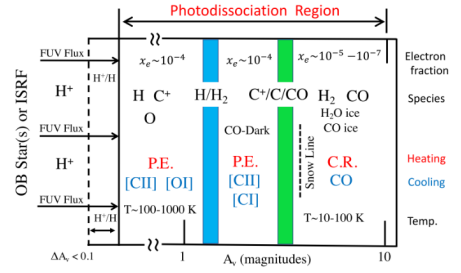


Figure 1: Schematic of a PDR as a function of visual extinction, A_V , into the cloud. CO-dark molecular gas lies between the H_2 and CO layers, where $[CII]$ and $[CI]$ dominate the cooling.

¹Wolfire, M. G., Vallini, L., et al. 2022, ARA&A, 60, 247

²Pineda, J. L., Langer, W. D., et al. 2013, A&A, 554, A103

³Grenier, I. A., Casandjian, J.-M., et al. 2005, Science, 307, 1292

⁴Wolfire, M. G., Hollenbach, D., et al. 2010, ApJ, 716, 1191

⁵Shimajiri, Y., Sakai, T., et al. 2013, ApJ, 774, L20

⁶Frerking, M. A., Keene, J., et al. 1989, ApJ, 344, 311

Operation of Cerro Chajnantor Atacama Telescope (CCAT) Observatory

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In this poster contribution, we give an overview of the system used in the operation of Fred Young Submillimeter Telescope (FYST), operated by the Cerro Chajnantor Atacama Telescope (CCAT) Observatory. FYST is the 6 m diameter, high surface accuracy telescope at 5600 m altitude in the Atacama Desert, Chile. The first light instruments (the heterodyne receiver mini-CHAI and the direct detection instrument Prime-Cam) have their own observing campaign periods, targeting submillimeter frequencies. The main scientific objectives cover Cosmic Microwave Background (CMB), galaxy evolution, magnetic fields and dust properties, accretion variability of protostars, and cycling of matter in the interstellar medium in the Milky Way. The observing plans are a mixture of large area long-term surveys and deep small field observations on a collaborative basis in the consortium.

As the core of the operation, we have developed the operations database (OpsDB). This is the metadata database tracking the full data cycle; from definitions, parameters and execution status of observing blocks, location and transfer status of raw data files, to staging and logging the data processing pipeline jobs on high-performance computers (HPC). We have built a custom system optimized for our operational model, while using best practices learned from other observatories and being based on the already available libraries.

We will present multiple essential components around the OpsDB for the observatory operation, with a particular focus on the CCAT scheduler. We use a simple sequential scheduling with the scoring algorithm based on the astroplan package, with an extensive customization for optimizing the relative weights of different constraints. To meet the diverse requirements of individual surveys, we use a hybrid of static (fixed) scheduling and dynamic scheduling. The static scheduling is applied to the Wide Field Survey (WFS) by reserving a block of 24 hours at a fixed cadence to realize a homogeneous coverage of a large area of the sky. Dynamic scheduling, used for the rest of the surveys, monitors the progress of the precipitable water vapor (PWV) and continuously updates the best proposed next observations. This naturally migrate the uncertainty of the observing overhead or unexpected down time in operation. It also has a long-term planning mode (simulation mode), which can be run independent of the operation for the planning and optimizing purpose.

From Flows to Fragments: Tracking Core Evolution in Star-Forming Environments

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The formation of massive stars remains an open problem, with competing models broadly divided into core-fed and clump-fed scenarios. In the core-fed picture, stellar masses are largely set by the initial core mass, whereas in clump-fed models, stars accrete mass from extended regions within a dynamic, clustered environment. Understanding the origin and structure of these mass reservoirs is therefore key to identifying the habitats in which massive stars form.

In this work, we investigate how gas dynamics regulate fragmentation and accretion in an existing colliding-flow simulation of the warm neutral medium (Weis et al. 2024). Using tracer particles, we reconstruct the Lagrangian evolution of the gas and track the formation history of dense cores. We combine dendrogram-based structure identification and clustering algorithms to characterize substructure within clumps and to identify filamentary structures that may act as accretion channels.

By constructing merger trees that link cores across time via shared tracer particles, we follow their growth histories and trace the origin of accreted material. Our approach is designed to investigate why some regions develop a richer substructure than others and to explore how these differences influence the formation and growth of massive cores. Preliminary results indicate that angular momentum redistribution does not solely enable accretion onto individual cores, but can instead redirect gas toward neighboring fragments, leading to a competitive growth process in which mergers between fragments play a key role in producing the most massive objects.

WCCC versus HC chemistry through the lens of deuterium fractionation

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Protostellar environments have previously been distinctly classified as either warm carbon-chain chemistry (WCCC¹) sources, dominated by unsaturated carbon chains, or hot corinos (HCs). However, recent high-resolution observations increasingly reveal ‘hybrid’ systems where both chemistries can co-exist, albeit on different spatial scales². The physical and chemical drivers behind this diversity - and whether they are determined by initial conditions, evolutionary stage, or local environment - remain unresolved. Factors such as temperature, UV radiation fields, and cosmic ray fluxes are likely key drivers of chemical differentiation, but their relative roles are unclear. Deuterium fractionation, a highly temperature-sensitive process, can serve as a powerful diagnostic of the underlying physical conditions and chemical processes. We have therefore explored the large-scale ‘hybrid’ chemical environment of IRAS 18148-0440³, a Class 0/I transitioning low-mass protostar, with APEX and IRAM 30m observations. Observations of

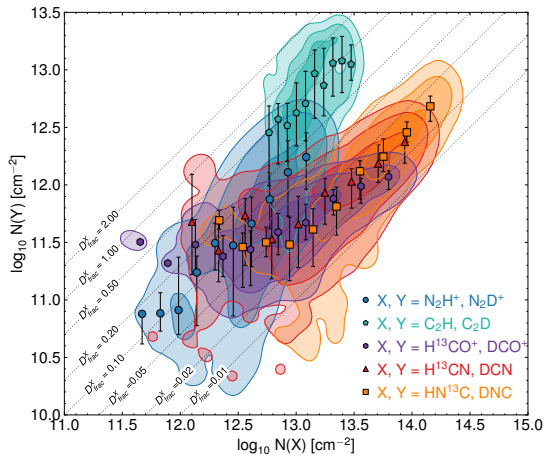


Figure 1: KDE plots of the column densities of the corresponding deuterated – hydrogenated species pairs in logarithmic scale, using the integrated intensities of the (1–0) line transitions of the species listed observed with IRAM 30m. Dotted lines of constant deuterium fraction from 2.00 to 0.01 are also shown. Markers of different shapes denote the median positions of the binned data, with error bars in the y-axis showing $\pm 1\sigma$ of the points within each bin.

multiple transitions of deuterated species allow us to distinguish regions dominated by cold (< 20 K) deuteration pathways from those where warm (30 – 80 K) deuteration reactions prevail, revealing how WCCC and HC chemistries develop within a single protostellar envelope. IRAM 30m on-the-fly observations reveal variations in the spatial distributions of deuterated, hydrogenated, and ^{13}C -substituted species over a region of $2' \times 1.5'$. These also reveal two distinct regimes of deuteration via different chemical pathways in this system, as displayed in Fig.1 which shows kernel density estimation (KDE) plots of different deuterated species column densities as a function of their hydrogenated counterparts. Further interferometric observations will be crucial for resolving these variations on sub-100 au scales. In order to disentangle the effects of evolutionary stage from variations in initial cloud conditions, we plan to explicitly test the role of environment by targeting sources that formed within the same parent molecular cloud. This work is complementary to ongoing projects concerning high-mass star formation within the SFB 1601: the emergence of chemical diversity during the process of star formation is a fundamental question whose answers are significant across mass regimes.

¹Sakai, N. & Yamamoto, S. 2013, Chem. Rev., 113, 12

²Okada, Y. et al. 2022, ApJ, 935, 136

³Oya, Y. et al. 2017, ApJ, 837, 174

Exploring the extragalactic dense gas tracers in the Milky Way with APEX

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Across the universe, massive stars play dominant roles in terms of their feedback and their synthesis and dispersal of heavy elements. Elements heavier than hydrogen and helium are the building blocks of life. These elements are forged in stars that ultimately met their end, either in explosive supernovae or by gradually releasing their enriched material into space. This stellar recycling enriches the interstellar medium (ISM) with “metals,” shaping how galaxies evolve, how stars are born, and how planets eventually form. Metallicity, the abundance of such heavy elements, is therefore a key ingredient governing the physical and chemical behaviour of the ISM. Dense molecular gas is a key ingredient of star formation, and the luminosities of HCN and HCO^+ are widely used as tracers of this component in both Galactic and extragalactic studies. However, recent observations in the Milky Way reveal that a large fraction of the HCN and HCO^+ $J = 1-0$ emission arises from relatively low-extinction, moderate-density gas^{1, 2}, calling into question their reliability as exclusive tracers of dense star-forming material.

In this talk, I will present APEX/nFLASH230 observations of HCN and HCO^+ $J = 3-2$ toward one massive inner-Galaxy cloud (G034.997+00.330) and two outer-Galaxy star-forming regions (Sh2-252 and Sh2-269). We mapped large areas ($8' \times 8'$) for these targets. These data are directly compared with existing $J = 1-0$ maps from the TRA0 14-m telescope. Because the $J = 3-2$ transitions probe significantly higher critical and effective densities, they allow us to test whether the extended $J = 1-0$ emission originates from genuinely low-density gas or from unresolved, beam-diluted dense structures. We further investigate how environmental conditions affect the behaviour of classical dense gas tracers by extending the analysis to outer Milky Way environments — where metallicity, radiation fields, and ionization rates systematically differ from the inner part of the Galaxy. This combined inner–outer Galaxy study provides an essential Galactic benchmark for interpreting extragalactic dense gas observations and for understanding how excitation and metallicity influence the connection between dense gas and star formation.

¹Evans, Neal J., I., Kim, K.-T., Wu, J., et al. 2020, ApJ, 894, 103

²Patra, S., Evans, Neal J., Kim, K.-T., et al., 2022, AJ, 164, 129

Properties of NbTiN-Nb-Al/AlOx/Nb tunnel junctions in dependence of Nb interlayer thickness

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The CCAT Observatory will equip, among other instruments, CHAI, a heterodyne array instrument covering two spectral bands: the Low-Frequency Array (LFA, 455–495 GHz) and the High-Frequency Array (HFA, 800–820 GHz), each comprising 64 pixels. The mixers for LFA rely on SIS junctions fabricated with the standard Nb/Al-AlN/Nb process. While these junctions can mix radiation across both bands, the integrated tuning structure that is formed by the Nb base layer outside the junction dissipates at HFA frequencies, thus requiring its removal via dry etching. Replacing this base layer with a higher-gap superconductor such as NbTiN will drastically improve the performance, although it introduces fabrication challenges¹. To address them, a thin Nb buffer layer was deposited on the NbTiN electrode to take advantage of the well-known excellent interface between Nb and Al². It was expected that if this layer were thin enough and there was a high Nb-NbTiN interface transparency, it would be proximity-coupled in such a way that the resulting superconducting gap of the composite NbTiN-Nb layer is high enough for HFA radiation, thus allowing to avoid the dry etching step that would otherwise compromise the yield of the 256 junctions for the array. It was found that a tunnel barrier can be successfully grown on a Nb layer of a thickness down to 2 nm (fig.1). The gap voltage decreases with thinner buffer layers, contrary to the expected behaviour of a film in proximity with NbTiN³. Nevertheless, a comparison with a standalone Nb film suggests a weak proximity-coupling(fig.2).

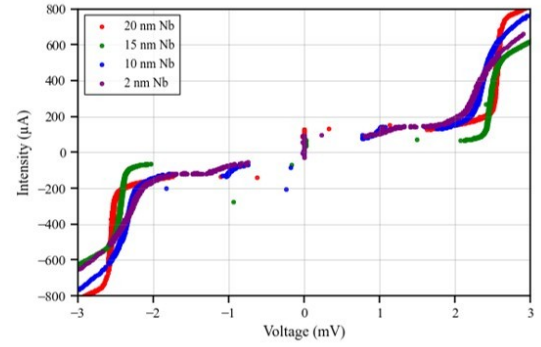


Figure 1: I-V curves from the different batches with different areas scaled to an identical area ($3.2 \mu\text{m}^2$).

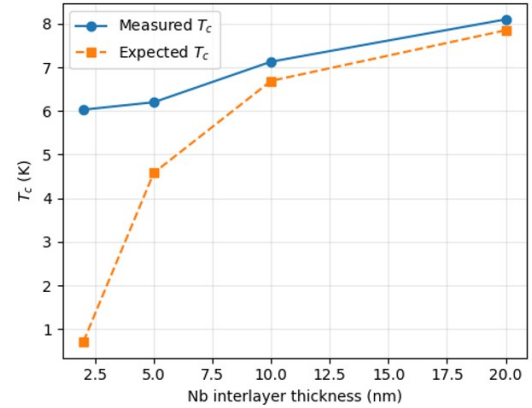


Figure 2: Measured superconducting gap in terms of the critical temperature in dependence of Nb interlayer thickness in comparison to a standalone Nb thin film.

¹[arXiv:1412.3388](#) Selig, Stefan et al. "Heat transfer coefficient saturation in superconducting Nb tunnel junctions contacted to a NbTiN circuit and an Au energy relaxation layer" IEEE Transactions on Applied Superconductivity 25.3 (2014);

²[10.1063/1.93974](#) M. Gurvitch et al.; "High quality refractory Josephson tunnel junctions utilising thin aluminium layers." Appl. Phys. Lett. 1 March 1983

³[arXiv:cond-mat/0407320](#) G. Brammertz et al "Critical temperature of superconducting bilayers: theory and experiment." Appl. Phys. Lett. 80, 2955, 2002

High resolution rovibrational and rotational spectroscopy of HC_3N^+

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Cyanopolyynes (HC_{2n+1}N where $n=1, 2, 3, \dots$) are key constituents of interstellar chemistry and have been observed across a wide range of astrophysical environments, including from cold molecular clouds to external galaxies. The simplest member of this family, cyanoacetylene (HC_3N), was among the first organic molecules discovered in space by radio astronomy being identified toward Sgr B2 as early as 1971.¹ More recently, the corresponding radical cations of several cyanopolyynes, i.e. HC_3N^+ , HC_5N^+ , and HC_7N^+ have also been detected in interstellar medium.² As no high-resolution laboratory data are available to support their astronomical identification, these detections were solely done based on quantum chemical calculations.

Here, we present the first spectroscopic data for HC_3N^+ obtained using the leak-out spectroscopy (LOS) technique in a 22-pole cryogenic ion trap apparatus.³ Rovibrational transitions within the C–N stretching mode (ν_2) at around 2170 cm^{-1} were first measured at 40 K. As HC_3N^+ is a linear open-shell species with one unpaired electron, the observed transitions show resolved characteristic splittings arising from both spin–orbit and Λ -doubling fine structure components. Based on a preliminary fit of the rovibrational data, we searched for ground state rotational transitions of HC_3N^+ using a IR/mm-wave double-resonance scheme based on LOS. Over ten transitions were observed between 80 and 250 GHz. Together, the high-resolution laboratory data reported here enable a significant improvement of the spectroscopic constants and confirm the astronomical detection of this important cation.

¹Turner, *Astrophys. J.*, 163, L35, 1971

²Cabezas *et al.*, *A&A*, 687, L22, 2024

³Schmid *et al.*, *J. Phys. Chem. A*, 126, 43, 8111–8117, 2022

Radiation and cosmic rays shaping the multiphase interstellar medium

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Far-ultraviolet (FUV) and ionising (EUV) radiation feedback, together with cosmic rays (CRs), are key agents shaping and regulating the multiphase interstellar medium (ISM), yet their coupled impact remains poorly understood. We present a new suite of magnetohydrodynamic simulations within the SILCC Project that incorporate a self-consistent, time-variable treatment of stellar far-ultraviolet and extreme-ultraviolet radiation, non-equilibrium thermal and chemical networks, stellar winds, supernova feedback, and cosmic ray injection and transport. This framework goes beyond conventional models based on static interstellar radiation fields and enables a physically motivated study of radiation–CR–ISM coupling in stratified galactic environments spanning gas surface densities, Σ_{gas} , from 10 to 100 $\text{M}_{\odot} \text{pc}^{-2}$. Despite locally extreme FUV radiation fields exceeding the solar neighbourhood value $G0 \sim 1.7$ by more than four orders of magnitude near young star clusters, we find only a negligible direct impact on global star formation rates. Instead, variable FUV irradiation primarily restructures the ISM by enhancing thermal phase separation, increasing cold neutral medium filling factors, and promoting the emergence of a cold, diffuse gas component with a molecular fraction that occupies approximately 5–10 per cent of the volume. CRs fundamentally alter ISM dynamics by providing non-thermal pressure support, which modifies both the phase structure and outflow properties. CR-supported outflows retain a persistent multiphase structure over kiloparsec scales, in contrast to purely thermally driven flows, with mass-loading factors of order unity and only weak dependence on star formation rate surface density. A key consequence of CR pressure support is the natural formation and long-term survival of cold clouds embedded within hot, supernova-heated environments. This provides a compelling explanation for perplexing structures, such as the Local Leo Cold Cloud, which resides within the Local Bubble and whose origin cannot be readily explained by colliding-flow or shock-driven scenarios alone. In our simulations, CR pressure stabilises cold gas against evaporation and compression, allowing temperatures of order 20–50 K to persist in otherwise hostile conditions. Together, these results demonstrate that while FUV radiation does not strongly regulate star formation rates, its time-variable and self-consistent treatment is essential for shaping the ISM phase structure. When combined with CR pressure, this framework offers a unified explanation for multiphase ISM structure and the presence of cold clouds embedded in hot, stellar feedback-dominated environments.

Connecting accretion and ejection rates for massive protostars using JWST/MIRI

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Protostars represent the fundamental phase (first ~ 0.5 Myr) where stars accrete most of their final mass, yet their observational characterization is limited by their thick, obscuring envelopes. Outflows emerge associated with the accretion, and they are able to shape the local environment at parsec scales. Critically, their accretion rates remain largely unconstrained; so does their connection with the ejection rates. The high-mass regime is specially striking because known models of the accretion mechanism (derived for the more-evolved, low-mass Class II sources) cannot be extrapolated to massive protostars. Therefore, observations on both accretion and ejection have the potential to constrain how stars grow beyond $8 M_{\odot}$. Our work leverages the unprecedented sensitivity and resolution of JWST/MIRI to detect and resolve emission lines at less-extincted wavelengths (5 to $27 \mu\text{m}$) than those studied so far, allowing us to peer deeper onto the young protostar itself. We report for the first time HI emission lines (e.g. HI 7-6, 6-5, 8-6) for a sample of high-mass protostars. Since these HI lines are calibrated accretion tracers, we estimate accretion luminosities (L_{acc}) and (tentative) accretion rates ($\dot{M}_{\text{acc}}$). While these detections unlock studies on accretion in such young and embedded objects, new methodological challenges arise. Firstly, I will present our published results on accretion rates as part of the JOYS collaboration, focusing on why further work on dust models, line-to-accretion luminosity calibrations, and more robust extinction methods are still necessary to confidently constrain $\dot{M}_{\text{acc}}$. Additionally, MIRI offers a rich pool of bright atomic and molecular lines (H_2 , FeI, FeII, [NeII], [SI], CO_2 , ...) that trace different gas conditions. We use the H_2 molecule in particular to estimate ejection rates. I will also present this follow-up work, connecting the accretion with the ejection flows, and I will discuss the complex environments these massive sources reside in from multi-wavelength data, where several mid-IR lines are now accessible with the JWST.

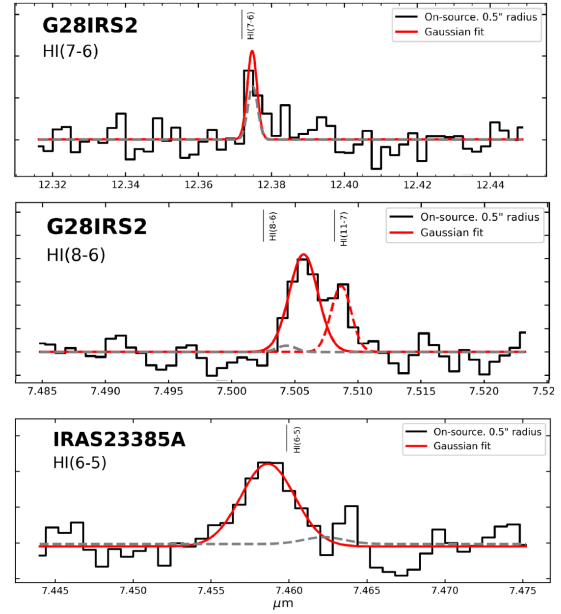


Figure 1: Detection of three Mid Infrared HI lines, which are (empirically) calibrated to trace accretion: $\text{Hu}\alpha$, $\text{Pf}\beta$, and $\text{Pf}\alpha$ (from top to bottom).

Updated H₂ ro-vibrational and UV line & continuum physics in the KOSMA- τ PDR code

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Molecular hydrogen strongly affects the chemistry and energy balance of UV-irradiated gas and provides the many diagnostic IR and UV lines for JWST-, SOFIA-, and HST/FUSE-class observations. A self-consistent PDR model must therefore treat the full H₂ level structure together with the wavelength-dependent UV field that drives its excitation and dissociation. We present a substantial update of the H₂ microphysics in the KOSMA- τ PDR code¹. The previous vibration-only approximation is replaced by the full set of bound ro-vibrational levels of the electronic ground state, with state-resolved line and continuum dissociation, line overlap and self-shielding, formation pumping, and consistent coupling to the local UV radiation field across the Lyman and Werner bands. A central new feature is the simultaneous, self-consistent generation of the emergent **UV line and continuum spectrum** together with the full **IR line spectrum** of pure-rotational, ro-vibrational and electric quadrupole transitions. Excitation, shielding, and emergent intensities are computed on the same ro-vibrational grid, removing long-standing inconsistencies between the internal radiative transfer and the spectra delivered to the user. We illustrate the impact on the H/H₂ transition, gas temperature, and key IR/UV diagnostics for representative clump conditions relevant for the massive-star environments targeted by CRC 1601.

¹Röllig, M. and Ossenkopf-Okada. V. 2022, A&A, 664, A67

Solar aesthetics – how other star forms might impact perceptual systems

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The various forms of life on Earth are heavenly influenced by the type of our sun and how the planetary atmosphere can cope with the conditions in the solar system. Here the spectral composition of light and the speed of circadian rhythms do impact not only the organization forms of life, but also how and what organisms are sensing. For instance, the co-evolution of different forms of eyes is a consequence of the specific light shining on Earth. This paper will reflect how this inherent aesthetic implications might change in solar systems with other star types resulting literally in alternative world views which allow for instance a 3d vision without a stereoscopic ocular system. Above all, the paper resumes recent studies on extraterrestrial sound perception ¹.



Figure 1: Shadows cast by a wintry forest on a planet orbiting a binary system. The anaglyphic shadows reveal an inherent encoding of spatial configurations which do not necessarily need to be decoded by a binocular optic system. Animated triple projection, ca. 16 x 3m, Haus der Elektronischen Künste Basel 2016. See: <https://www.imachination.net/stereaskia/natur/en>

¹Chide et al. 2025, Earth and Planetary Science Letters, 615

Performance modelling of Integrated Filterbank Spectrometers towards sub-millimetre Line Intensity Mapping surveys

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Line Intensity Mapping (LIM) in the sub-mm window aims to observe aggregate emission from unresolved early galaxies in lines such as [C II], tracing star formation activity across large cosmological volumes^{1,2}. Integrated Filterbank Spectrometers (IFBS) provide a promising approach for doing broadband LIM surveys. In this work, we present an instrument model for such an IFBS device and use it to estimate the instrumental effects on a simulated sub-mm sky and an atmosphere. This collaborative investigation thus provides better insights from both observational and fabrication perspectives towards developing an IFBS array instrument.

Instrument model: An IFBS is based on a filterbank circuit that uses a cascade of bandpass filters to separate the incoming sky signal into different spectral channels. We describe a network model³ that predicts the cascaded spectral transmission across channels in a practical IFBS device. A superconducting filterbank design is presented based on second-order bandpass filters. It gives a steeper roll-off in the bandpass response compared to first-order filters that have been adopted in existing IFBS devices^{4,5}. Using the network model we show that increasing the filter order improves transmission efficiency and lowers crosstalk across all channels.

Signal recovery: We further investigate the implications on increasing the filter order on the [C II] signal recovery. A simulated sky model is used², which is based on the COSMOS galaxy catalogue, with median [C II] and CO models from literature. We see that with a second-order characteristic there is less attenuation in the [C II] power spectra. This makes masking techniques^{6,7} more effective at maximising the [C II] signal power compared to CO interlopers in a given observation bandwidth. We further obtain the constraints in power spectrum recovery due to the bounds in k-modes coverage, which is dependent on the filterbank resolution R .

Detector noise level: Finally, we use the spectral response of the filterbank to estimate the atmospheric loading to the photon-noise limited detectors⁸ that are interfaced at each filter output. We show that the detector noise equivalent power (NEP) is mostly independent of the filter order, but does depend on the resolution R . This analysis enables us to adapt the individual detectors based on the expected atmosphere-dominated incident power in each channel.

¹Bernal & Kovetz, 2022, *Astron. & Astroph. Review*, 659, A12

²Clarke, J. et al., 2024, *Astron. & Astroph.*, 689, A12

³Saha, H. et al., 2025, *Proc. of the Intl. Sym. on Space THz Tech. (ISSTT)*

⁴Endo, A. et al., 2019, *Nature Astronomy*, vol. 3 no. 11, pp. 989-996

⁵Zebrowski, J. A., 2024, *Proc. of SPIE, Mm. Submm. and Far-IR det. Instr. for Astro. XII*, p. 84522G

⁶Karoumpis, C. et al., 2024, *Astron. & Astroph.*, 659, A12

⁷Clarke, J. et al. (in prep.)

⁸Yates, S.J.C. et al., 2011, *Appl. Phy. Lett.*, 99

High-resolution laboratory study of the ν_2/ν_4 bending motion of CH_3^+ and assignment of its astronomically observed lines

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The methyl cation, CH_3^+ , is a peculiar cation that has been discovered through the detection of a 7 μm (1400 cm^{-1}) band observed in the d203-506 protoplanetary disk using the MIRI-MRS spectrometer onboard the JWST ¹. This feature has since been reported in numerous astronomical sources. The original discovery relied on simulations of the molecule’s simultaneous and interacting bending modes (ν_2/ν_4), using both rough laboratory measurements and theoretical analyses. These results were then compared with astronomical data, which had an absolute wavelength calibration accurate to only a few centimeters inverse. Subsequent quantum-chemical calculations enabled a first spectroscopic assignment of the lines ². However, a comprehensive spectroscopic assignment of the astronomically observed features in the 7 μm range is awaiting high-resolution laboratory data. Here, we present a laboratory high-resolution study of the ν_2/ν_4 bending vibrations of CH_3^+ to provide accurate, calibrated data for the spectroscopic analysis of JWST detections of this species. The rovibrational structure of the ν_2/ν_4 bending vibrations of CH_3^+ is studied in a cryogenic 22-pole ion trap apparatus at 10 K. To detect vibrational excitation, the efficient leak-out spectroscopy method ³ is used in combination with a high-resolution quantum cascade laser operating at 7 μm . This is compared with MIRI-MRS data for d203-506, reduced with improved wavelength calibration. The measurement accuracy and precision of about 0.001 and 0.0007 cm^{-1} , respectively, allow spectroscopic constants and line predictions to be derived with high confidence, and thus permit accurate (Doppler velocity) diagnostics of CH_3^+ lines with JWST.

¹Berné, O., Martin-Drumel, M.-A., Schroetter, I., et al. 2023, Nature

²Changala, P. B., Chen, N. L., Le, H. L., et al. 2023, Astron. Astrophys., 680, A19

³Schmid, P. C., Asvany, O., Salomon, T., Thorwirth, S., Schlemmer, S. 2022, J. Phys. Chem. A, 126, 8111

The Role of Hierarchy in Galactic Molecular Clouds: Observational Tests of the Global Hierarchical Collapse

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Although the Global Hierarchical Collapse (GHC) scenario is a leading high-mass star formation model¹, its universality across Galactic molecular clouds remains unverified. We investigate the link between cloud hierarchies and star formation. Using the FUGIN² data and astrodendro³, we classified clouds into hierarchical (leaves, branches, trunks) and non-hierarchical (isolated) structures (see Figure 1). We compared these with star-forming activity using SPICY⁴ YSOs (low-mass precursors) and Hi-GAL⁵ clumps (high-mass precursors).

Trunks are significantly larger and more massive with lower virial parameters than isolated clouds. Despite similar sizes, leaves exhibit higher masses and stronger self-gravity than isolated clouds. Although containing comparable YSO counts, leaves host significantly more Hi-GAL clumps than isolated ones (see Figure 2).

Thus, hierarchical structures are essential for producing a large number of high-mass stars. Isolated clouds form few massive stars, lacking the continuous gas supply for further generation. Conversely, leaves grow massively via continuous gas accretion from parent envelopes (trunks) and internal interactions. This abundant gas reservoir allows hierarchical clouds to consistently generate numerous high-mass stars.

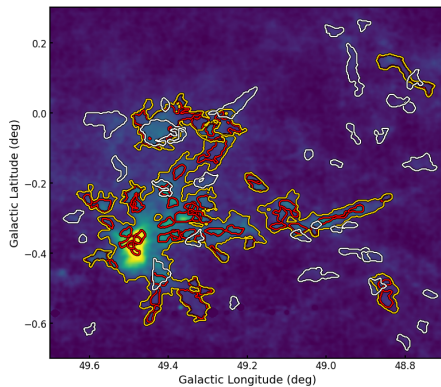


Figure 1: Dendrogram map of the identified cloud structures in W51A region.

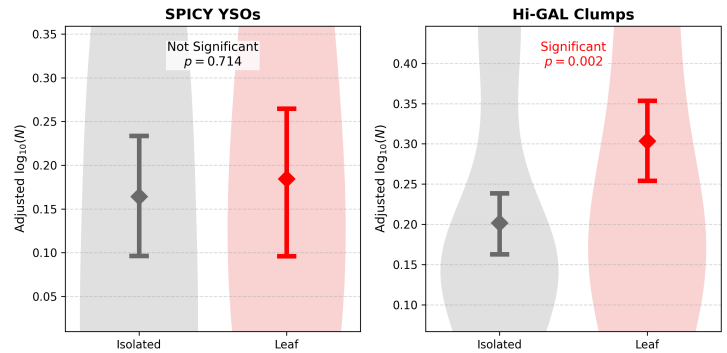


Figure 2: Comparison of the region-adjusted numbers of contained YSOs and Hi-GAL clumps between leaf and isolated structures of similar sizes.

¹Vázquez-Semadeni E., *et al.* 2019, *MNRAS*, 490, 3061

²Umemoto T., *et al.* 2017, *PASJ*, 69, 78

³Rosolowsky E. W., *et al.* 2008, *ApJ*, 679, 1338

⁴Kuhn M. A., *et al.* 2021, *ApJS*, 254, 33

⁵Elia D., *et al.* 2017, *MNRAS*, 471, 100

On the selection of nuclear spin species in an ion trap

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Hydrogen is by far the most abundant molecule in space. By the laws of quantum mechanics it comes in two nuclear spin configurations, ortho and para, where the nuclear spins of the two protons either combine to a total nuclear spin $I=1$ ($m_I=-1,0,1$) or to $I=0$ ($m_I=0$), respectively. Due to the Pauli-exclusion principle the first three ortho states combine with the odd $J=1, 3, \dots$ rotational states and the one para state with the even $J=0, 2, \dots$ rotational states. This leads to the well known 3:1 ortho to para ratio for hydrogen which means there are three times as many hydrogen molecules in the ortho state than in the para state. This holds true also for other molecules with two protons like HCCH or water, when their nuclear spin configuration is formed in a statistical process, e.g. the simple recombination process $\text{H} + \text{H} \rightarrow \text{H}_2$.

However, in space the ortho to para ratios might be affected by reactions at low temperatures or spin changing collisions. In this work we will introduce methods to determine the fractions of nuclear spin configurations of molecular ions in a trap experiment. As a simple example system we are considering the ortho and para modifications of the recently detected CH_3^+ molecule and its isotopologs, CH_2D^+ , CD_2H^+ and CD_3^+ . These are cases containing two or three protons (deuterons) which leads to quite different ortho to para ratios.

We present an easy and elegant mathematical way to determine the nuclear spin statistical weights (3 and 1 for ortho and para H_2) for all the above cases. These values will be compared to experimental results where a specific nuclear spin species is excited by a high-resolution laser and leaves the trap thanks to its extra internal energy which is transferred to kinetic energy by subsequent collisions with a buffer gas. This process is known as leak-out spectroscopy¹. In fact, all ions associated with this one nuclear spin configuration exit the trap such that a pure nuclear spin sample remains in the trap. In this way not only the nuclear spin statistical weights are determined reliably but this preparation can be the starting point to investigate the rate of nuclear spin changing collisions. We will also discuss how double resonance experiments are used to find the ortho and para species in CH_3^+ whose ratio is 1:1. Perhaps the most interesting cases concern molecules where the ortho to para ratios remain a puzzle because it has not been determined experimentally and reliable predictions do not exist. An example is the H_5^+ molecule which forms as a transition complex abundantly in collisions of $\text{H}_3^+ + \text{H}_2 \rightarrow \text{H}_5^+$.

¹"Leak-out Spectroscopy, A Universal Method of Action Spectroscopy in Cold Ion Traps", P. C. Schmid, O. Asvany, T. Salomon, S. Thorwirth, and S. Schlemmer, J. Phys. Chem. A, 126, 8111–8117 (2022)

Combining a cryogenic ion trap with a 2 THz multiplier chain source: revisiting the $J = 1 \leftarrow 0$ fundamental rotational transition of HHe^+

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The HHe^+ cation is a fundamental two-electron system, very similar to the hydrogen molecule H_2 , and is thought to be the very first diatomic molecule formed when the early universe cooled down¹. It has been first discovered 1925 in a laboratory mass spectrometer by Hogness and Lunn². The direct measurements of the fundamental rotational transition $J = 1 \leftarrow 0$ at 2010.1839(2) GHz by Matsushima et al.³ in 1997 laid the foundation for the later astrophysical detection of HHe^+ in the planetary nebula NGC 7027⁴. Now, nearly 30 years later, this transition of HHe^+ at 2.010 THz has been revisited by us, using a combination of a 4 K 22-pole ion trap apparatus (COLTRAP⁵) and a high-power frequency multiplied THz source. The THz radiation source is the local oscillator (LO), which was utilized for the Low Frequency Array (LFA) of the upGREAT receiver onboard the airborne telescope SOFIA, operating in the range 1.83-2.07 THz⁶. For the detection of the resonant absorption, three different action spectroscopic techniques have been applied: rotational state dependent association of atoms (ROSAA), double-resonance leak-out spectroscopy (DR-LOS) and one which is demonstrated here for the first time: ejection of the ion upon pure rotational excitation (rot-LOS). The different methods are evaluated and compared, and improve the precision of the former transition value by Matsushima et al. by one order of magnitude to 2010.183312(8) GHz as seen in Figure 1. The newly determined transition frequency may serve as a strict benchmark value for future ab initio calculations of this fundamental two-nucleus-two-electron system.

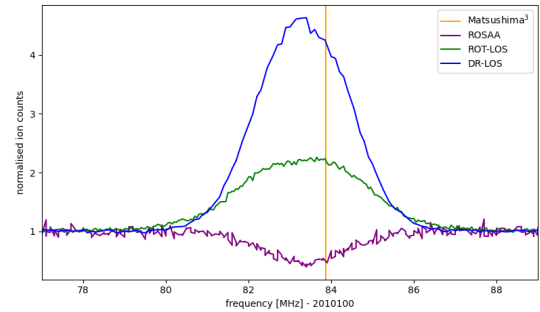


Figure 1: The $J = 1 \leftarrow 0$ fundamental rotational transition of HHe^+ , measured with three different action spectroscopic methods: a) LIICG b) rot-LOS c) DR-LOS. The FWHM of the different measurements is in the order of 3 MHz, corresponding to ion temperatures between 16 and 27 K.

¹S. Lepp, P. C. Stancil and A. Dalgarno, J. Phys. B, 2002, 35, R57–R80.

²T. R. Hogness and E. G. Lunn, Phys. Rev., 1925, 26, 44–55.

³F. Matsushima, T. Oka and K. Takagi, Phys. Rev. Lett., 1997, 78, 1664–1666.

⁴R. Güsten, H. Wiesemeyer, D. Neufeld, K. M. Menten, U. U. Graf, K. Jacobs, B. Klein, O. Ricken, C. Risacher and J. Stutzki, Nature, 2019, 568, 357–359.

⁵O. Asvany, S. Brünken, L. Kluge and S. Schlemmer, Appl. Phys. B, 2014, 114, 203–211.

⁶C. Risacher, R. Güsten, J. Stutzki, H. W. Hübers, A. Bell, C. Buchbender, D. Büchel, T. Csengeri, U. U. Graf, S. Heyminck, R. D. Higgins, C. E. Hon- ingh, K. Jacobs, B. Klein, Y. Okada, A. Parikka, P. Pütz, N. Reyes, O. Ricken, D. Riquelme, R. Simon and H. Wiesemeyer, Astron. Astrophys., 2016, 595, A34.

Synergy between GEco and FEEDBACK

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One of the primary science drivers of the GEco (Galactic Ecology) project for the FYST (Fred Young Submillimeter Telescope) is to investigate the formation, growth, evolution, and dispersal of molecular clouds in the Milky Way through submillimeter spectroscopy. The project utilizes observations in the 455–495 GHz range, covering the atomic carbon CI 1–0 line and CO 4–3, as well as a second channel spanning 800–820 GHz, including CO 7–6 and CI 2–1.

Observations will commence this year with 'Early science', using the single-pixel pilot receiver mini-CHAI, which operates both frequency channels simultaneously, and will later continue with the full 64-pixel CHAI array. The GEco Milky Way surveys have strong synergy with the SOFIA (Stratospheric Observatory for Far-Infrared Astronomy) FEEDBACK legacy program, which observed eleven high-mass star-forming regions in the CII 158 μm and OI 63 μm lines.

We present an overview of the synergy between the GEco and FEEDBACK science cases and objectives, highlighting how both surveys complement each other in constraining the efficiency of far-infrared cooling lines, the carbon budget, and the dynamics of the neutral, ionized, and molecular interstellar medium. Such a combination of data sets is unique and will have a long-lasting legacy value.

Probing the Lower Limit of Two-Level System Noise in Parallel-Plate Capacitor Kinetic Inductance Detectors using Crystalline-Silicon Dielectric

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We are developing an on-chip filterbank spectrometer¹ with microwave kinetic inductance detectors (MKID) to perform line-intensity mapping of the $158\,\mu\text{m}$ C^+ line at $z \sim 3-8$. To decrease their lateral size, MKID designs with parallel-plate capacitors (PPC) instead of planar interdigitated capacitors would be beneficial. However, MKIDs with PPC structures require additional amorphous dielectric layers to be deposited. Structural disorder in amorphous materials gives rise to Two-Level Systems (TLS), which can couple to oscillating electric fields and cause undesirable dielectric loss and a $1/f$ -like contribution to the frequency noise (TLS noise).² Under low enough optical loading, TLS noise can dominate and limit achievable detector sensitivity.

In planar structures, the TLSs reside primarily in the thin native dielectric layers at the structure's surfaces. The TLS noise contribution depends on the electric field strength intersecting these surfaces.³ PPC-based resonators locally confine the electric field to the bulk dielectric between the plates, which makes it critical to have a low TLS density in this dielectric.

Advances in the deposition of hydrogenated amorphous silicon and silicon carbide have achieved microwave loss tangents as low as 7×10^{-6} and 3×10^{-5} respectively, and show promise in enabling PPC MKIDs.^{2,4} In comparison, crystalline silicon (c-Si), which should have a negligible TLS density, has been shown to exhibit a microwave loss tangent of 5×10^{-6} or lower.^{5,6} While the mentioned works show considerable progress in the development of deposited dielectrics, and provide comparison of dielectric loss with c-Si, they do not characterize the associated frequency noise relevant to MKID operation.

We bridge this gap by developing PPC-based microwave resonators using silicon-on-insulator (SOI) wafers, in which the c-Si membrane serves as the PPC dielectric. Prior to metal deposition, buffered HF etching and argon plasma etching will be used to remove the native oxide from the surfaces, leaving the low-defect crystalline bulk as the only dielectric in the high-field region.^{2,5} Membrane thicknesses of 2, 3, 5, and $9\,\mu\text{m}$ are at our disposal, providing an additional degree of freedom to disentangle bulk from any residual surface TLS noise contributions. We will additionally fabricate planar resonators for reference, allowing a controlled noise comparison between the two architectures.

By avoiding the known TLS noise contributions with the aforementioned fabrication methods, our analysis of the noise characteristics will put a lower bound on TLS-limited noise achievable in PPC MKIDs and a reference against which to evaluate deposited dielectrics. At this stage, we present our designs and our initial fabrication progress towards this goal, and discuss our approaches to characterize the c-Si.

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⁴Buijtdorp, B. T. et al., 2022, *Physical Review Applied*, vol. 18, no. 6, 064003

⁵Weber, S. J. et al., 2011, *Applied Physics Letters*, vol. 98, 172510

⁶Beyer, A. D. et al., 2017, *Journal of Physics: Conference Series*, vol. 834, 012006

Decoding Cluster Formation and Evolution through Forward Modelling of PHANGS Star Clusters

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The recent release of the largest catalogue to-date of $\sim 100,000$ star clusters and associations by the PHANGS-HST survey has enable to approach star cluster formation and destruction history in a statistically relevant way. Using five-band HST photometry of clusters in 38 galaxies, we aim to reconstruct the formation history, destruction history, and the underlying age and mass distributions of star clusters. In this communication, we present how we developed a forward-modelling strategy that allow us to compare simulated photometry from artificial clusters distributions with observed cluster photometry to recover their underlying distribution. We also implemented a varying metallicity (as a function of the formation history) with age to take into account the different chemical properties of the observed populations and build a robust method to infer cluster formation history and original age-mass distributions of star clusters from observations. We show how changes in assumptions in the underlying population parameters shape the observed photometric distributions and demonstrate how multidimensional analysis of stacked cluster populations across multiple galaxies can provide new insight into physical processes that govern star cluster formation and evolution.

Pure-rotational spectroscopy of *cis*- and *trans*-1,3-dichloropropene

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Organochlorides are interesting to astrochemistry because several chlorine-bearing species have been detected in the interstellar- and circumstellar media by radio astronomical techniques. Among these, the detection of methyl chloride, CH₃Cl, towards a solar-type protostar is the most prominent and recent example ¹.

In the present study, we report on the first high-resolution spectroscopic study of the *cis*- and *trans*-isomers of 1,3-dichloropropene (ClCH₂CH=CHCl, Figure 1) as potential pyrolysis precursor to fundamental organochlorides such as chloroallene (chloropropadiene, ClHC=C=CH₂). Guided by high-level quantum-chemical calculations performed at the CCSD(T) level of theory, the four possible chlorine isotopic variants (³⁵Cl³⁵Cl, ³⁵Cl³⁷Cl, ³⁷Cl³⁵Cl and ³⁷Cl³⁷Cl) of each structural isomer have been studied first in a free-jet expansion ($T_{rot} \sim 5$ K), using chirped-pulse microwave spectroscopy between 12 and 26 GHz. Subsequently, spectroscopic coverage was extended to the millimeter-wave regime using a free-space absorption cell kept at room temperature. A status report of the spectroscopic analysis providing accurate rotational constants, centrifugal distortion parameters as well as chlorine quadrupole hyperfine constants will be given.

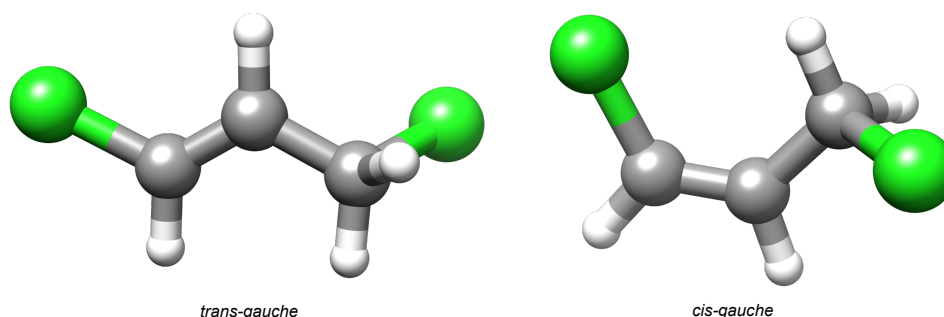


Figure 1: Molecular structures of the *trans*- (left) and *cis*--forms (right) of 1,3-dichloropropene. The chlorine-atoms of the chloromethyl-groups assume a *gauche* conformation ($\tau_{\text{HCCCl}} \approx 60^\circ$).

¹Fayolle, Öberg, Jørgensen, *et al.*, *Nat. Astron.* **1**, 703 (2017)

Laboratory spectroscopic studies of COMs in vibrationally excited states

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Complex organic molecules (COMs) are known to contribute substantially to the molecular emission observed in star-forming regions. Some species may be so abundant there that rare isotopologues, such as those containing ^{13}C and ^{15}N , can be detected with ease. Due to energetically low-lying vibrational modes, COMs in warm or hot regions of the interstellar medium may be found not only in their ground vibrational state but also in vibrationally excited states, each contributing its own pure rotational (vibrational satellite) spectrum.

In this paper, we present recent studies of vibrationally excited ethyl cyanide (aka propionitrile, $\text{C}_2\text{H}_5\text{CN}$), with a focus on its singly substituted ^{13}C isotopologues, employing high-resolution far-infrared as well as millimeter- and submillimeter-wave spectroscopy.

Mass Budgets of Episodic Protostellar Outflows in an Isolated Turbulent Core

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Protostellar jets and outflows are a key feedback channel in star-forming environments, but the relative contributions of directly launched material and swept-up ambient gas remain difficult to constrain observationally. We investigate this problem using a 3D isolated turbulent core simulation with sink particles and episodic jet/outflow feedback. As a first step, we focus on one protostellar source and analyse the local gas reservoir associated with successive outflow episodes.

We define a tracer-informed local outflow reservoir around the source and compare its gas mass with the cumulative launched mass derived from the sink history. The outflow region is identified using sink-centred radial kinematics together with connected-component and tracer-connectivity filtering, and we test several physically motivated mask definitions to evaluate how sensitively the inferred local mass budget depends on the adopted outflow selection. This yields a tracer-informed estimate of the retained local outflow reservoir rather than a strict global measurement of entrainment.

Our preliminary results show that the retained reservoir grows stepwise with successive jet episodes, while the cumulative launched mass remains substantially smaller than the retained outflow mass. Across the tested mask definitions, the retained reservoir is therefore consistently dominated by entrained ambient material, although the inferred quantitative mass fractions depend on the adopted mask. This shows that the outflow-region definition itself is a significant source of systematic uncertainty in tracer-based local mass-budget measurements and must be treated carefully when comparing different analyses or linking simulations to observables.

These results provide a practical framework for future event-based studies of episodic protostellar feedback and for connecting simulations to synthetic observational diagnostics.

Asteroseismic detection of an internal magnetic field inside an evolved massive main sequence star¹

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Internal magnetic fields are an elusive component of star formation and stellar evolution. As the interior of stars is not directly accessible, few observational constraints on these internal fields are available. Moreover, observations of magnetic fields in massive stars have long been limited to the surface with about 10% of them hosting a strong surface field. Even though little observational evidence is available, theory predicts that these magnetic fields in the radiative envelope can have a large impact on the star's structure and evolution. Firstly, the magnetic field can efficiently transport angular momentum throughout the envelope, leading to a more uniform rotation rate and changing the mixing compared to the situation without a field. Secondly, a magnetic field can inhibit core-boundary mixing, making the star shorter lived than expected and, finally, the magnetic field can alter the supernova. Hence, an internal magnetic field is a key factor throughout a massive star's life.

Recently, detections of internal magnetic fields in the radiative regions of main sequence stars have been achieved through asteroseismic means. By exploiting observed stellar pulsations and the corresponding theoretical models, observational constraints on these internal magnetic fields are now available. We present the recent discovery of an internal magnetic field inside the radiative zone of HD 192575, a $12 M_{\odot}$ B0.5V pulsator¹, and place this detection within the context of massive star evolution. We discuss the challenges and incredible probing power of massive star asteroseismology and show how the detection of the internal magnetic field was achieved. The detected field is present in the radiative envelope of the star, and it is strongly inclined with the rotation axis. Both aspects are important constraints on the formation of the star and its future path towards the supernova explosion. Moreover, asteroseismic age dating puts the star near the terminal-age main sequence ($X_c \approx 0.2 - 0.02$) at an age of around 16 million years. The current surface rotation period of around 5.3 days is much slower than if the star were to have been born at critical rotation.

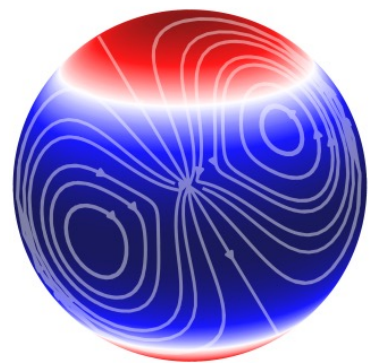


Figure 1: Illustration of a stellar pulsation and a magnetic field from the press release²

¹Vandersnickt, J., Vanlaer, V., et al., 2025, A&A, 704, L13

²<https://4d-star.org/?p=790>

grex: A Python Pipeline for SOFIA/GREAT Spectral Data Reduction

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We present ***grex***, a Python pipeline for the reduction and analysis of spectral line data obtained with the GREAT instrument aboard the Stratospheric Observatory for Infrared Astronomy (SOFIA). The pipeline operates directly on FITS files produced by the GREAT data calibration program (*kalibrate*), and is designed to handle the full complexity of large heterodyne datasets. It covers all stages from initial data filtering and quality control, to baseline subtraction, spatial gridding, and spectral cube construction. A central feature is a Principal Component Analysis (PCA) based baseline correction, which effectively removes complex spectral baselines even in the presence of telluric contamination, using a per-mission decomposition to account for the varying atmospheric conditions across observing flights. This is particularly important for datasets where a telluric feature overlaps in velocity with the target line. The pipeline was developed for and validated on the M51 [CII] SOFIA/GREAT dataset, a large, multi-flight survey comprising over one million spectra obtained across multiple observing campaigns, which represents one of the most challenging reduction problems for the GREAT instrument. The pipeline enables the reduction of the underexploited [OI] 63 μm dataset and it is built as a general-purpose tool applicable to any SOFIA/GREAT data available in the archive.

Confronting Observations with Simulations - Blister-Type H II Regions

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Massive stars regulate star formation through several feedback mechanisms. They heat and expel gas, disrupting their parental molecular clouds and thereby halting ongoing star formation. Although supernovae are often regarded as the dominant feedback mechanism, they only occur a few Myr after the first massive stars form. Long before then, pre-supernova (pre-SN) feedback can already inject substantial amounts of energy into the molecular cloud (MC), driving outflows or even disrupting the cloud. The most important pre-SN feedback mechanisms are ionizing radiation, stellar winds, and radiation pressure, each of which can dominate depending on the environment and spatial scale. Observations and numerical simulations of H II regions provide valuable insight into the relative importance of these feedback processes and their interplay. Recent observations of the $158\,\mu\text{m}$ [C II] line reveal rapidly expanding H II bubbles with velocities exceeding the isothermal sound speed of the ionized gas. Such velocities cannot be explained by the classical D-type expansion into a uniform medium, leading to the conclusion that stellar winds must be the dominant driver. Here, we propose an alternative scenario supported by hydrodynamic simulations: an H II region breaking out of a dense part of its parental MC. A simple model of this so-called blister-type H II region reproduces several key observational features: (1) the fast expansion is traced by [C II] emission rather than by emission from CO isotopologues; (2) the expansion arc in the PV diagram is smaller than the H II region itself; (3) the rapidly moving gas is approaching the observer; (4) the expansion speed is about $13\,\text{km s}^{-1}$; and (5) the strongest emission originates from the wings of the arc.

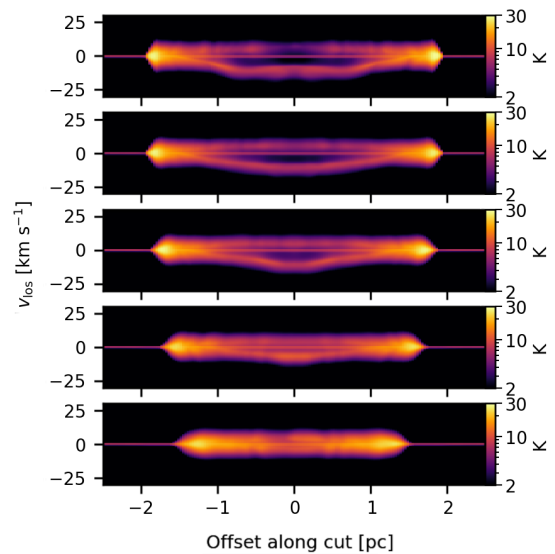


Figure 1: Position–velocity cuts of synthetic RADMC-3D [C II] emission showing the characteristic arc produced by a rapidly expanding C⁺ shell. The parallel cuts are taken along the blister-type H II region, with the outflowing gas moving towards the observer.

Probing Massive-Star Formation with Intrinsic Multiplicity Constraints from TESS Eclipsing Binaries

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Understanding how massive stars form and pair in binary systems remains a key challenge in stellar astrophysics. In this work, we present a homogenous analysis of $\sim 69\,000$ main sequence eclipsing binaries (EBs) identified through the automated TESS eclipsing binary classifier of IJspeert et al. (2024). This unprecedentedly large and uniformly selected sample allows us to probe multiplicity properties across a variety of main sequence spectral types (OBAF), hence primary mass.

To investigate the connection between mass and binary formation pathways, we examine the intrinsic binary fraction and the intrinsic distributions of orbital period P_{orb} and relative separation R_1/a . A key component of this work is a comprehensive inference framework that is based on all observables available: orbital period, sum of relative radii, observed magnitudes, and Gaia distances. This allows us to obtain homogeneous mass estimates across the full TESS EB sample. In addition, we implement a bias correction framework that explicitly accounts for geometric, observational and selection biases, enabling us to recover intrinsic multiplicity statistics starting from an EB selected sample.

Across the mass range studied, we find broadly consistent multiplicity trends in both the period and relative separation distributions, see Figure 1. While such similarities do not necessarily imply that the underlying formation channels are identical from intermediate to high-mass stars, they demonstrate that, within the orbital period range to which eclipsing binaries are most sensitive, the observable close binary population are highly comparable. The absence of sharp structural changes in this regime suggests that any transitions between formation pathways may occur outside the close-binary parameter space probed by eclipsing systems.

By characterizing how close binaries scale with mass in a homogeneous and statistically robust framework, this work lays the groundwork for extending such analyses to wider orbital separations with upcoming large scale surveys such as Gaia DR4, 4MOST and WEAVE. This approach offers a new observational foundation for connecting multiplicity statistics to proposed massive star formation scenarios, including disk and filament fragmentation, and subsequent migration.

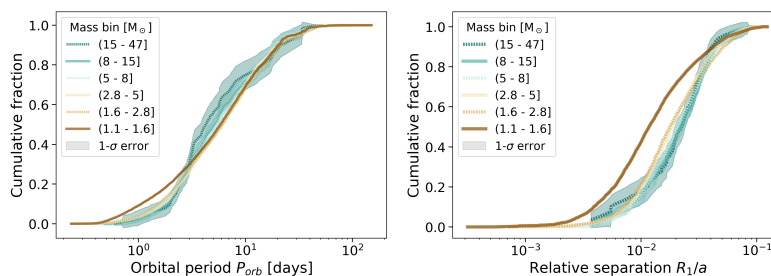


Figure 1: Bias corrected orbital period and relative separation distributions, shown across different primary mass bins. Shaded regions indicate the $1\text{-}\sigma$ uncertainty.

The Rotational Spectrum of *trans*-2,3-Epoxybutane: A Combined Chirped-Pulse Fourier Transform and Absorption Microwave Study

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Complex organic molecules (COMs) are important for understanding the chemical evolution of the interstellar medium (ISM). Among the approximately 350 molecules listed in the Cologne Database for Molecular Spectroscopy (CDMS),¹ as detected in the ISM or toward late-type stars, an increasing number belongs to cyclic species. Among them are several containing an O atom in the ring, for example the ubiquitous oxirane², which is also known as ethylene oxide, or its methyl derivative propylene oxide—the first chiral molecule detected in space.³ The molecule *trans*-2,3-epoxybutane can be viewed as the vicinal dimethyl-substituted derivative of oxirane and propylene oxide. Extending a previous microwave study,⁴ we recorded the rotational spectrum of *trans*-2,3-epoxybutane in the 12–375 GHz frequency range, utilizing a combined scheme of chirped-pulse Fourier transform and frequency-modulated absorption spectroscopy. More than 700 *b*-type transitions with quantum numbers up to $J = 60$ and $K_a = 7$ have been assigned to the vibrational ground state. Many of these transitions display splitting by the internal rotation of the two equivalent methyl rotors. The present work provides an accurate set of rotational parameters to facilitate the search for *trans*-2,3-epoxybutane across a wide range of physical conditions in the ISM, from cold molecular clouds to hot cores.

¹Endres, C. P.; Schlemmer, S.; Schilke, P.; Stutzki, J.; Müller, H. S. P.; 2016, J. Mol. Spectrosc., 327, 95-104

²Dickens, J. E.; Irvine, W. M.; Ohishi, M.; Ikeda, M.; Ishikawa, S.; Nummelin, A.; Hjalmarson, Å.; 1997, Astrophys. J., 489, 753-757. Müller, H. S. P.; Jørgensen, J. K.; Guillemin, J.-C.; Lewen, F.; Schlemmer, S.; 2023, J. Mol. Spectrosc., 394, 111777.

³McGuire, B. A.; Carroll, P. B.; Loomis, R. A.; Finneran, I. A.; Jewell, P. R.; Remijan, A. J.; Blake, G. A., 2016, Science, 352, 1449-1452.

⁴Emptage, M. R., 1967, J. Chem. Phys., 47, 1293-1299.

The Keplerian disk, envelope, and streamers surrounding an early O-type protostar in the Sagittarius C cloud of the Central Molecular Zone

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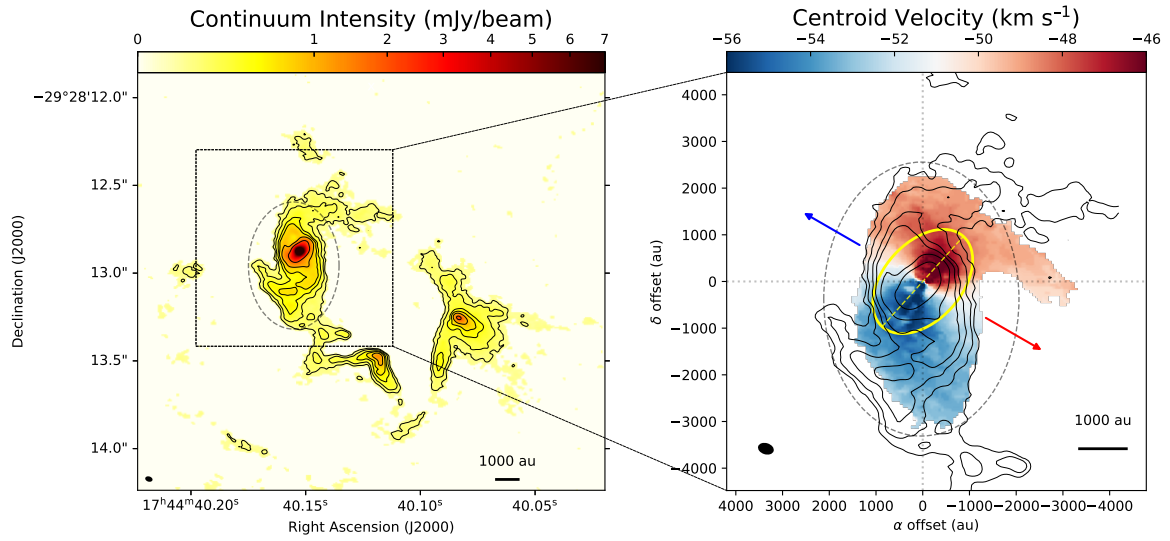


Figure 1: **Left:** ALMA 1.3 mm continuum intensity map of the Sgr C disk. **Right:** intensity-weighted velocity map of the stacked CH₃OCHO emission.

Disk-mediated accretion is central to theories of massive star formation, setting the initial conditions for their evolution. Yet observations of Keplerian disks around early O-type protostars remain scarce, as they are often blended into complex surrounding structures. We report ALMA Band 6 observations (300 au resolution) of an accretion disk surrounding a high-mass protostar in the Sagittarius C (Sgr C) cloud in the Central Molecular Zone (CMZ) around the Galactic Center. We identify spectral lines and analyze the spatial distribution of the emission of the complex organic molecules. We use a dynamical model with an inner Keplerian disk and an outer free-fall envelope to fit the three-dimensional position-position-velocity data of the stacked CH₃OCHO molecular lines and constrain the mass of the central protostar to be $\sim 40^{+2}_{-3} M_{\odot}$. The fitting results additionally show that the disk has a centrifugal radius at about 1300 au. Considering the infall velocity, radius, and mass of the envelope, we estimate the accretion rate from the envelope onto the disk to be $\sim 7 \times 10^{-3} M_{\odot} \text{ yr}^{-1}$. We also identify spiral-like structures in the disk that can be described by free-falling streamers. Our results highlight the critical role of accretion disks and streamers in the mass accumulation of early O-type stars in the CMZ.¹

¹Weng, J., The Astrophysical Journal, vol. 1003, no. 2, Art. no. 219, IOP, 2026. doi:10.3847/1538-4357/ae6813.

The APEX Microwave Kinetic Inductance Detector camera (A-MKID): from commissioning to early observations

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The APEX Microwave Kinetic Inductance Detector (A-MKID) camera is a sub-millimeter (submm) dual-color continuum camera installed at the APEX telescope in the Atacama desert, Chile. While single-color observations are possible, the camera is designed to operate simultaneously at 870 μm (LFA) and 350 μm (HFA) under fairly common weather conditions at the APEX site.

The camera achieves high mapping speeds, as it is equipped with 3520 detectors at 870 μm and 13952 at 350 μm , in part thanks to the frequency-multiplexed readout technology available with kinetic inductance detectors (KIDs). With a resolution of about 17" and 7" for the LFA and HFA, respectively, and an instantaneous field-of-view of 15.3' $\times$ 15.3', A-MKID will allow for the fast mapping of large areas of the southern sky at high angular resolution while being about 4 to 10 times faster than its predecessor LABOCA, the instru-

ment used for the 870 μm ATLASGAL¹ survey of the inner Galactic plane. Moreover, the dual-color capabilities allow studies of dust properties via spectral index measurements. Some of the intended projects for A-MKID include observing the inner Galactic plane with the HFA to obtain the 350 μm complement to the 870 μm ATLASGAL Galactic plane survey, as well as conducting surveys of the outer Galaxy with the LFA to study the gas-dust interplay toward lower metallicities and higher gas-to-dust ratios together with the OGHReS outer Galaxy CO survey at APEX.

The commissioning of the LFA is close to being complete and has already yielded science-worthy observations (see, e.g., the Galactic Center at 870 μm in Figure 1). However, improvements to the calibration and data reduction processes are still ongoing and will be ported to the calibration and reduction schemes of the HFA. Current improvements aim to reduce the calibration time, compensating for the downtime caused by the restart of the cooling system, as well as addressing KID cross-talk issues that result from frequency multiplexing.

We aim to provide an overview of the current status of the A-MKID camera, present recent advancements and early science observations to showcase the capabilities and limitations of the instrument, and outline some of the most important questions that A-MKID is already set to answer.

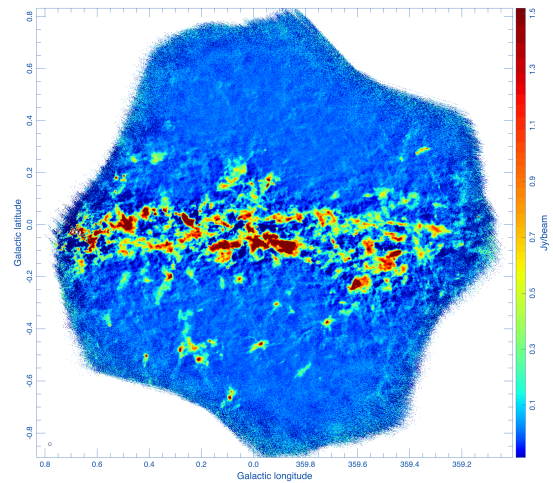


Figure 1: The Galactic Center at 870 μm as seen by A-MKID's LFA.

¹Schuller, F. et al. 2009, A&A, 504, 415

Formation of the Rich Network of Filaments Driven by an Expanding H I Bubble in the Perseus Molecular Cloud

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Filamentary molecular clouds are now recognized as the fundamental structures that set the initial conditions of star formation. However, their formation mechanism remains an open question. Among the proposed scenarios, converging gas flows induced by colliding gas layers have emerged as a compelling candidate (Inoue et al. 2018; Arzoumanian et al. 2018, 2022), yet direct observational constraints on how filament properties—such as column density and line mass—are established are still under debate.

Here, we present new observational evidence linking filament formation to colliding gas flows in the Perseus molecular cloud, one of the nearest star-cluster-forming regions at a distance of approximately 300 pc. We first analyzed H I data covering the entire Perseus molecular cloud obtained with the Arecibo Observatory. By constructing position–velocity (PV) diagrams that cut across the structure previously identified as an H I void (Bialy et al. 2021), we find arc-like features indicative of an expanding shell. In the direction of Perseus, an H I cloud with a line-of-sight velocity of approximately 10 km s^{−1}, associated with this expansion, shows evidence of interaction with another H I cloud at ∼4 km s^{−1} that is not participating in the expansion, suggesting a collision between the two components.

To investigate how such large-scale H I collisions contribute to star formation, we conducted wide-field observations of ¹²CO, ¹³CO, and C¹⁸O using the Nobeyama 45-m telescope. These observations targeted two subregions of Perseus—NGC 1333 (1° × 1°) and IC 348 (45′ × 20′)—tracing gas over a wide density range of 10²–10⁵ cm^{−3}. In both regions, we identify two molecular cloud components separated by approximately 5 km s^{−1} in ¹²CO and ¹³CO. In C¹⁸O, we detect a rich network of filaments, comprising 20 filaments in IC 348 and 54 in NGC 1333, with a characteristic width of ∼0.1 pc (Figure 1). Strikingly, all filaments with line masses exceeding 100 M_⊙ pc^{−1} are confined to regions where the two velocity components overlap.

Additionally, we identify ¹²CO filamentary structures in areas lacking C¹⁸O emission. These ¹²CO filaments are associated with the two H I gas components, each with a column density of ∼ 5 × 10²⁰ cm^{−2}. Based on these results, we propose that collisions between ¹³CO-detectable molecular clouds lead to the formation of dense filament networks with large line masses, while collisions between H I gas components give rise to lower-density ¹²CO filaments. These findings suggest that the line mass of filaments is primarily regulated by the pre-collision gas density.

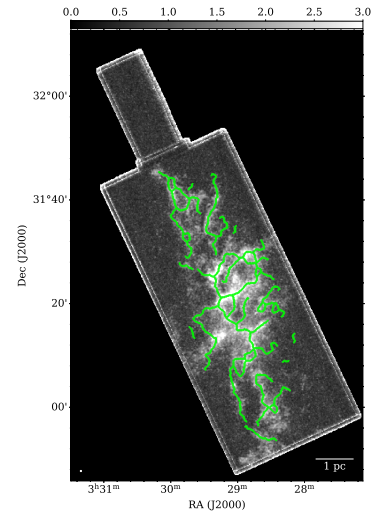


Figure 1: C¹⁸O distribution and filament identification results in NGC 1333

Multidimensional CWENO finite volume method with constrained transport for MHD simulations of shockwaves in the ISM

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Magnetohydrodynamics (MHD) simulations provide crucial insights into astrophysical processes happening in the ISM. These simulations often involve complex physics and turbulent features, such as shockwaves and magnetic fields, that make it difficult to model entire processes accurately. Thus the underlying numerical scheme in these simulations have to be efficient and accurate while maintaining its robustness. In particular, the schemes are required to be conservative, have a high order of accuracy, and be stable against numerical inaccuracies.

A finite volume code is presented, that includes a multidimensional CWENO spatial reconstruction and a higher-order explicit strong stability-preserving Runge-Kutta time integration method, to achieve a high-order spatial/temporal accuracy and to preserve positivity. In addition, the constrained transport method, with high-order inverse reconstruction methods (‘higher-order CT’), is included to maintain the divergence-free condition. Numerical tests involving shockwaves are run with this code, since shockwaves in the ISM present one of the most extreme and challenging conditions for MHD simulations.

Initial results with the code on a MHD-blast test indicate that the higher-order CWENO scheme is able to capture the sharp discontinuities between the surrounding ambient medium and the propagating shock front, while at the same time maintaining the divergence of the magnetic field to $\sim 10^{-12}$. The experimental order of convergence (EOC) with the code formally achieves 4th-order spatial and temporal accuracy in one-dimensional smooth-wave tests.

Future works include integrating the higher-order scheme into production codes, as well as investigating the use of the ‘higher-order CT’ in adaptive mesh refined (AMR) grids.

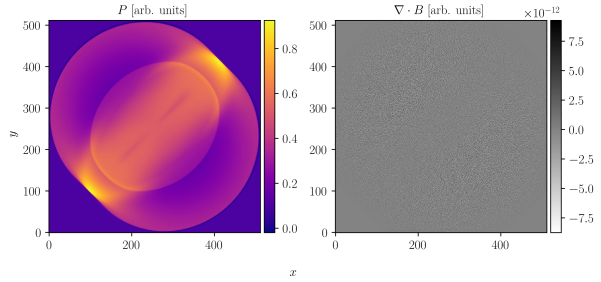


Figure 1: Pressure and magnetic field divergence plots of the MHD-blast test with the code at $t = 0.2$.