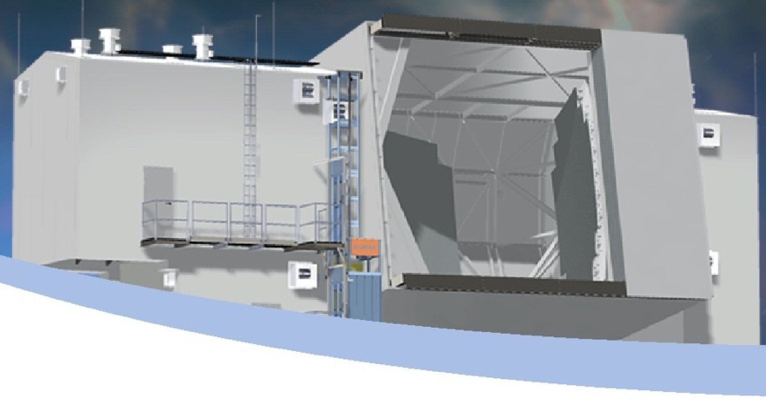
Habitats of massive stars across cosmic time



CRC 1601

A6 | Tracing star formation through observations of UV chemistry

Progress in PDR Modelling and Observations

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Overall goal

The project works on a better understanding of the physics of photon-dominated regions (PDRs) where UV radiation from young massive stars creates a characteristic chemistry and excitation that can be used to derive the properties of the embedded young O- and B-type stars responsible for the UV radiation through infrared and radio observations. This is a prerequisite to interpret observations of diagnostic lines from spatially unresolved sources, in particular at different metallicities, high cosmic ray fluxes, and higher redshifts. It provides the base to derive UV fields from radio-to-FIR observations throughout the observational projects of the CRC.

CO, [CI], and [CII] – FIR relations

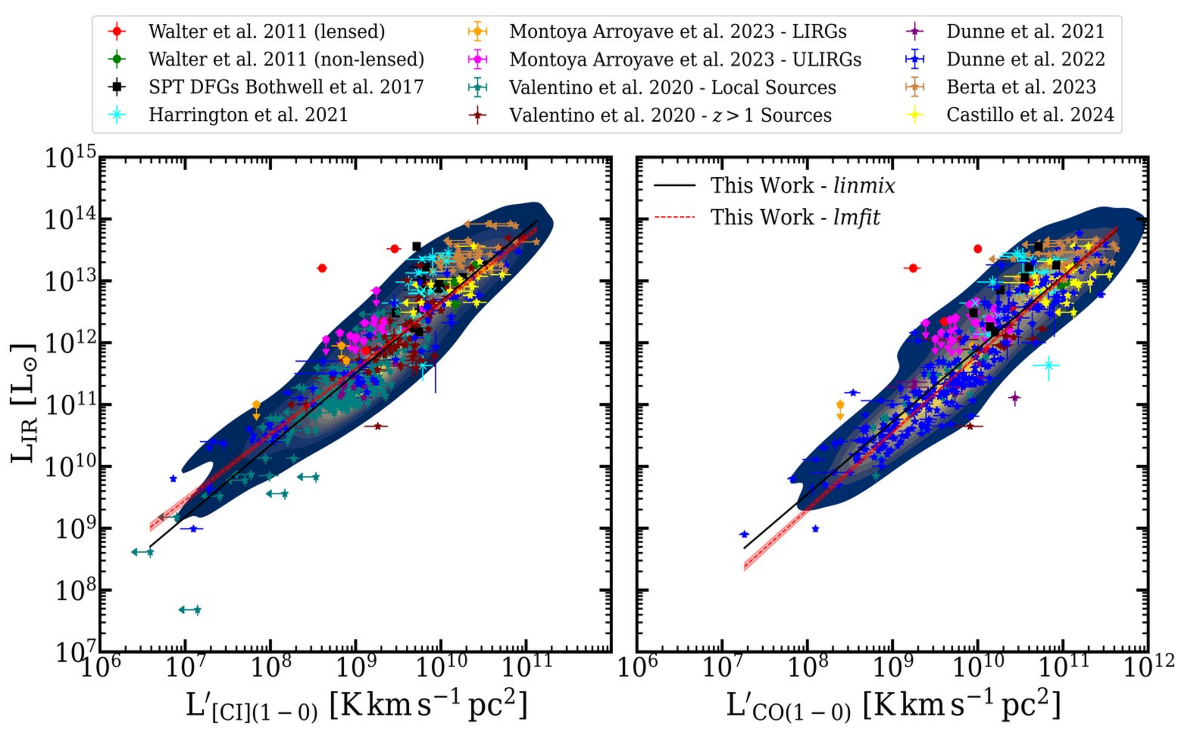


Figure 1: L_{IR} versus $L'_{[CI](1-0)}$, $L'_{CO(1-0)}$. Best fit using lmfit is shown as red dashed line, with linmix as solid black line.

We collected the largest literature sample of galaxies (885 sources) with [CI](1-0) and CO(1-0) observations to investigate the correlation between L_{IR} versus $L'_{[CI](1-0)}$ and $L'_{CO(1-0)}$. We further utilized a sample of sources with [CII] observations, to correlate the L_{IR} versus $L'_{[CII]}$. We derived a power law correlation for all gas tracers with L_{IR} across redshifts 0<z<6.5.

Although there is no direct physical relation between star-formation and atomic carbon we find a better correlation between [CI] and the FIR than for [CII], that is usually considered the direct star-formation tracer.

PDRs4All

Continued analysis of the data from the JWST early science project resulted our involvement in numerous publications just in the 2024 (Fuente et al., Van de Putte et al., Chown et al. Peeters et al., Habart et al. Zannese et al., Berné et al.).
They showed the stratification of the Orion Bar PDR, mainly in terms of PAHs and H_2 lines and revealed major challenges for the PDR modelling that will keep us busy for the next years.

[CI] observations

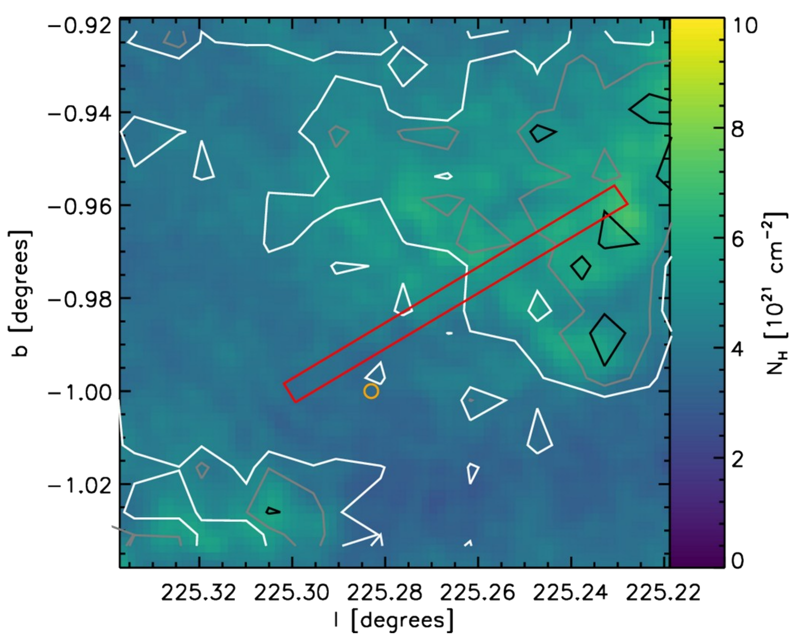


Figure 2: Mapped strip in the "Forgotten Quadrant". Colors give the gas column from dust emission. Contours show ^{13}CO 1-0. The orange circle gives the beam and position of the existing [CII] observation.

We performed APEX [CI] observations of a small strip in the "Forgotten Quadrant". The [CI] line is always brighter than ^{13}CO and in one velocity-component even brighter than CO. In contrast to many star-forming regions, the emission extends beyond the molecular gas, in line with PDR models.

However, the PDR model fit to the observations fails because the models either predict more molecular gas, traced through $C^{18}O$, or more diffuse gas, traced through [CII], than observed.

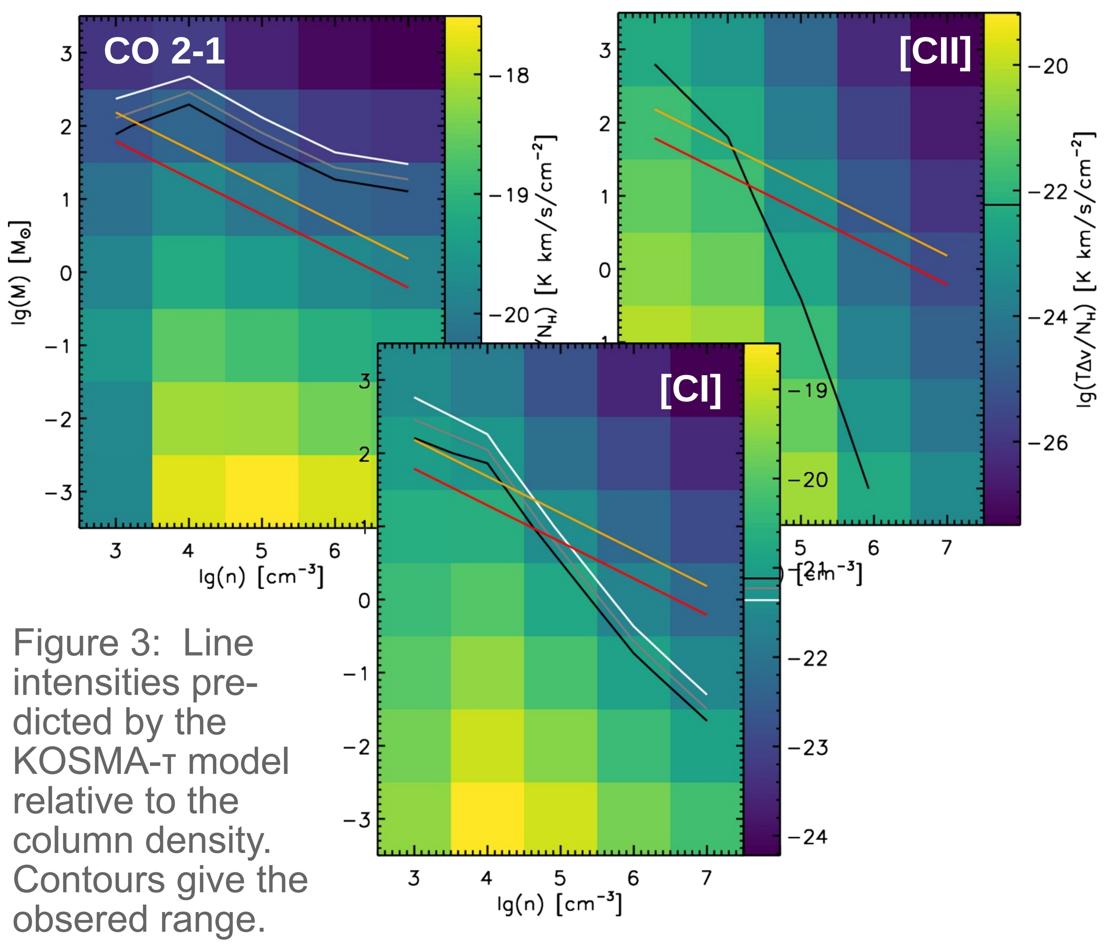
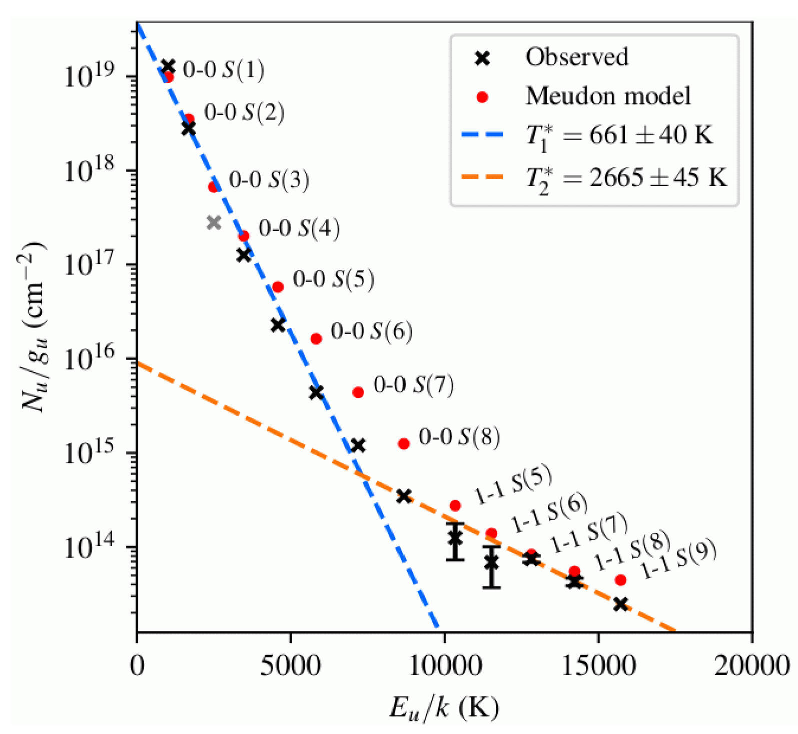


Figure 3: Line intensities predicted by the KOSMA-τ model relative to the column density. Contours give the obsered range.

To understand the [CI] emission from galaxies it is necessary to get the full statistics for the quiescent gas outside of the star-forming regions. Large-scale mapping of [CI], including the non-prominent, but statistically dominant diffuse regions, is essential to get the full carbon budget. This is the goal of the planned GEco project at CCAT/FYST.

Figure 4: Fit to the observed H_2 vibrational transitions with a two-temperature model and the Meudon PDR model for a bright filament in the Orion Bar (van de Putte et al. 2024).



Subgrid model for MHD simulations

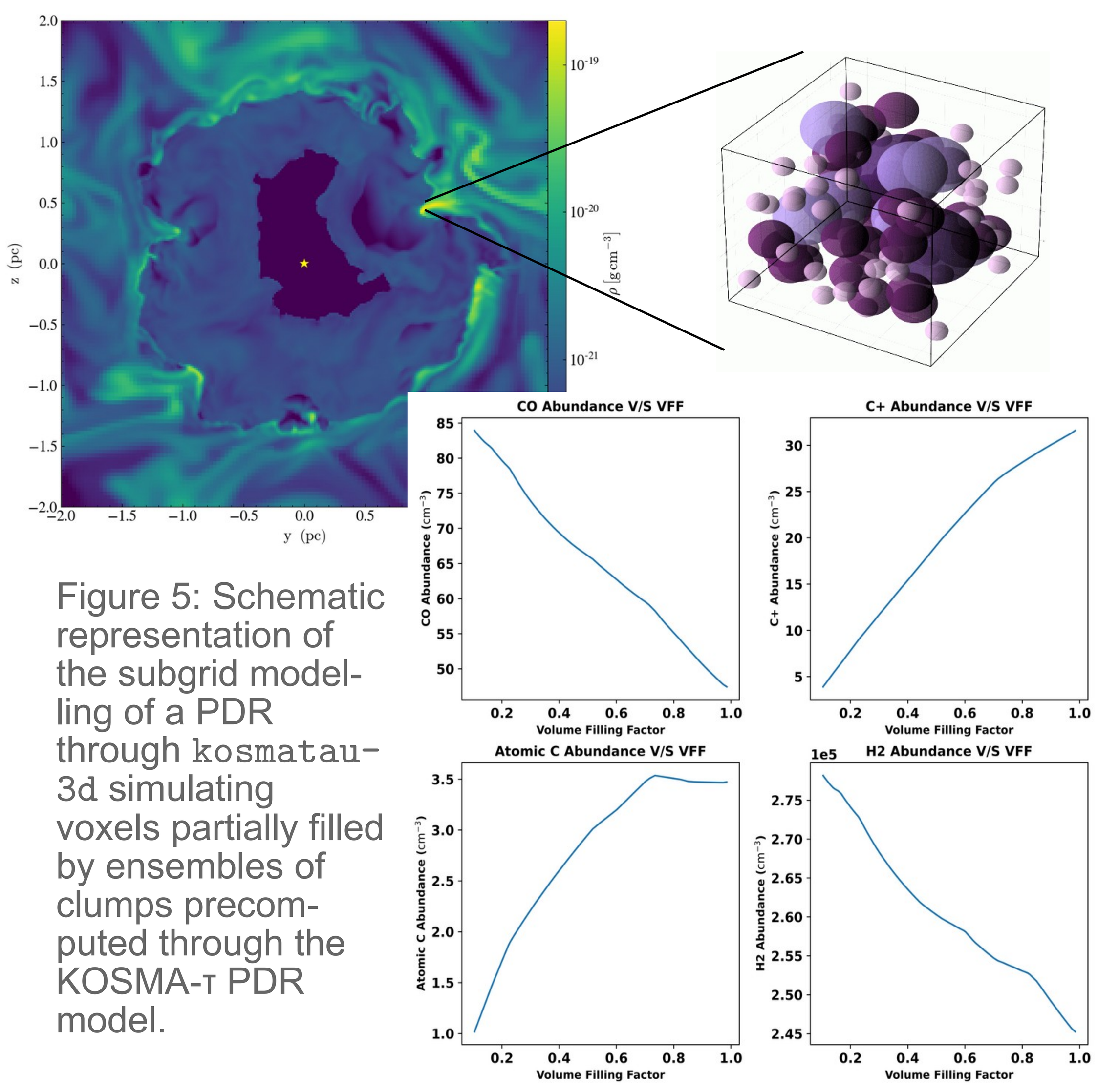


Figure 5: Schematic representation of the subgrid modelling of a PDR through `kosmatau-3d` simulating voxels partially filled by ensembles of clumps precomputed through the KOSMA-τ PDR model.

We combined kosmatau3d with MHD simulations of HII regions to postprocess the outputs to study how emission from PDR cells change when clumpiness is introduced at sub-parsec scales. A sensitivity analysis on the parameter space of a single-voxel, shows us how the abundances of ionic, atomic and molecular species change with different free parameters. Notably, we see a saturation in the abundance of atomic carbon as we increase the volume filling factor.

Measuring CR attenuation through PDR chemistry

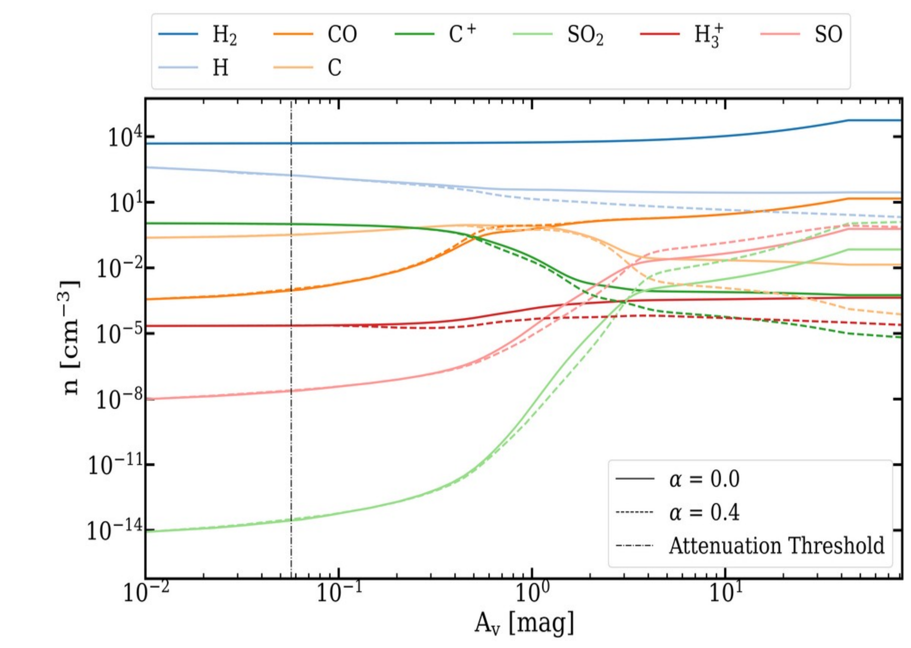


Figure 6: Density of species as a function of visual extinction, A_V. α gives the exponent of the attenuation, α=0.0 stands for the non-attenuated model. The unattenuated cosmic ray ionization rate for both models is $\zeta_{CR} = 10^{-15}$ s^{-1}

Cosmic rays influence the structure and chemistry of PDRs. They penetrate deeper than FUV radiation, regulating the chemistry closer to the PDR cores. We updated KOSMA-τ to incorporate attenuation of the cosmic rays in the PDR. We identified species whose densities are sensitive to the cosmic rays within the cloud. By measuring the line intensities from those species, we aim to provide an observational tool to determine how chemical differences in a molecular cloud can constrain ζ_{CR}.