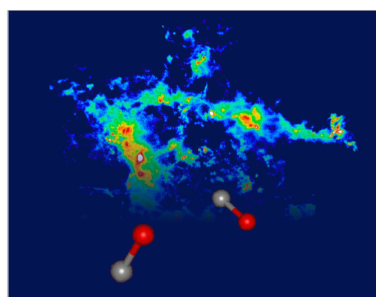

FIR lines from clumpy PDRs tracing structures from kpc to 100 AU scales

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Motivation

Most lines observable in the ALMA bands 7-10 stem from warm molecular gas heated either by UV radiation or by the dynamic impact of violent outflows. To prepare for the new data it is thus essential to understand the physics and chemistry of this gas.

Observations of molecular clouds show a ubiquitous occurrence of filamentary, turbulent structures and substructures on all scales observed so far (Ossenkopf et al. 2000). Consequently, a large part of the molecular material is located in surface structures, exposed to the interstellar radiation field. The clouds can be described as photon-dominated regions (PDRs) and the fractal cloud distribution leads to the picture of PDRs everywhere (Tielens & Hollenbach 1985).

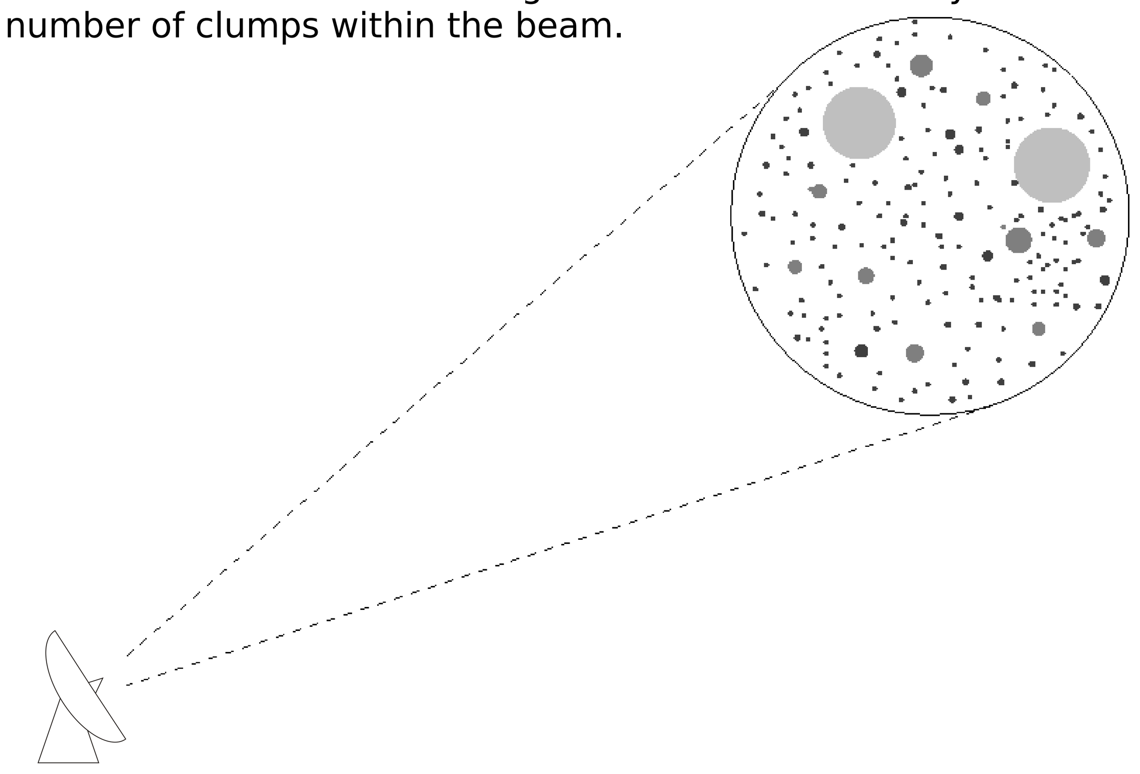
A fractal cloud distribution can be mimicked by an equivalent superposition of spherical clumps following a well-defined mass spectrum and mass-size relation (Stutzki et al. 1998). We use this picture to study the emission of FIR lines from molecular clouds within the Galaxy representing them by a distribution of spherical PDR structures. In this way we can explain all emission in molecular lines, in [CI], [OI], and [CII] measured by COBE as emission from PDRs.

This global model, where the ensemble average matches the overall Galactic emission in the different lines of sight, needs to be modified to represent the properties of individual sources. The PDR computations show an ambiguity of the line ratios with respect to the slope of the clump mass spectrum and the minimum and maximum sizes of the clumps. Thus ALMA observations are needed to resolve the actual clumpy PDR structure to better constrain the actual size parameters of the model.

The clumpy PDR model

The KOSMA-τ PDR code, provides the physical and chemical structure of clouds with spherical geometry using radiative transfer calculations and the solution of a chemical reaction network at given mass, density, ultraviolet radiation field and metallicity, balancing heating and cooling throughout the cloud (Röllig et al. 2006).

When observed with a low angular resolution we always find a large number of clumps within the beam.



- Each individual clump is represented by a spherical model cloud, calculated by the KOSMA-τ PDR-model.
- The clump distribution follows a clump mass spectrum, $dN/dM \sim M^{-\alpha}$ and a mass-size relation $M \sim r^{\gamma}$

Modelling the emission from the Milky Way

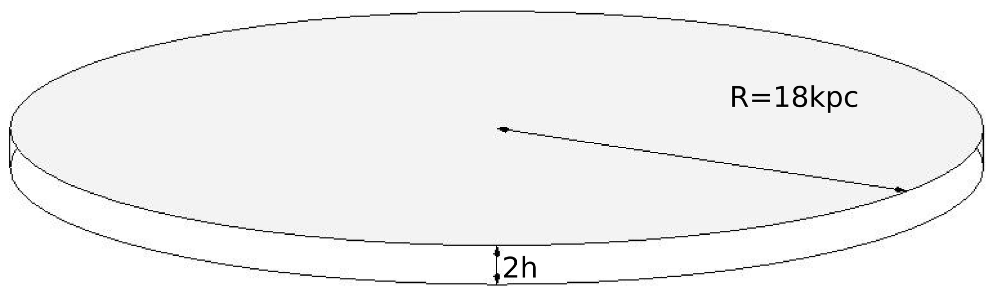
The large scale far infrared (FIR) emission of our Galaxy has been observed by the FIR Absolute Spectrophotometer (FIRAS) instrument on-board the Cosmic Background Explorer (COBE) satellite in the wavelength range from 100µm to 1cm (Fixsen et al. 1999).

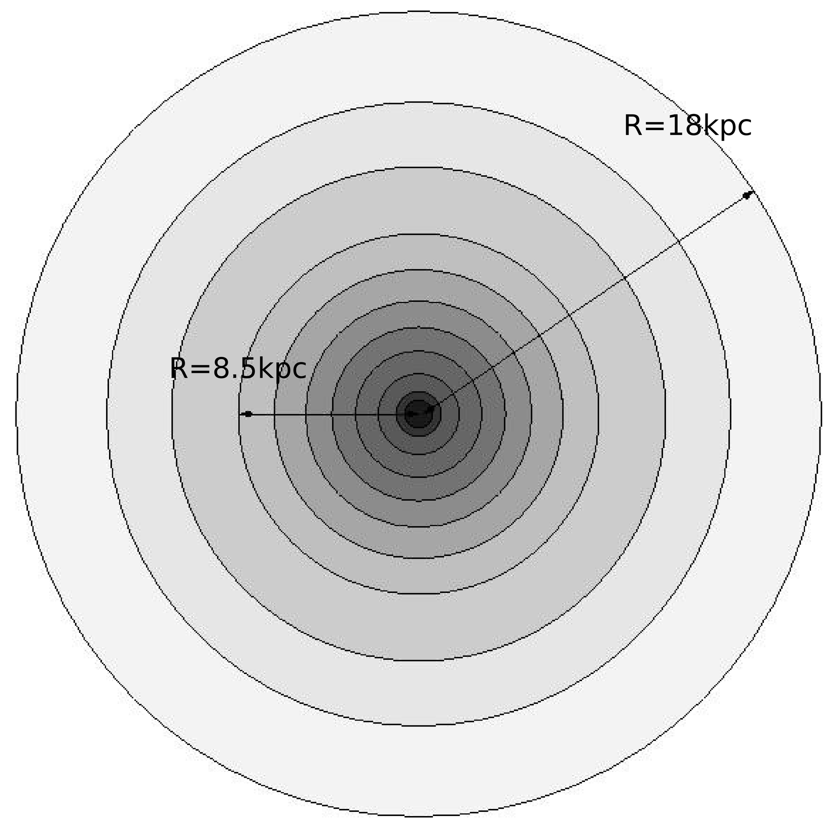
We have modelled the measured line emission using the clumpy PDR model using the following assumptions:

We apply a simple disk model of our Galaxy:
- mass distributed in a disk with half height h and total radius R=18kpc.
- the clump parameters mass, density, and metallicity are functions of galactocentric radius given by Wolfire et al. (2003)
- the spiral arms and the bulge of our Galaxy are neglected.

The FUV field is kept constant at 100 X_0, corresponding to a constant distance between OB clusters and molecular clouds across the Galaxy in contrast to Wolfire et al. (2003)

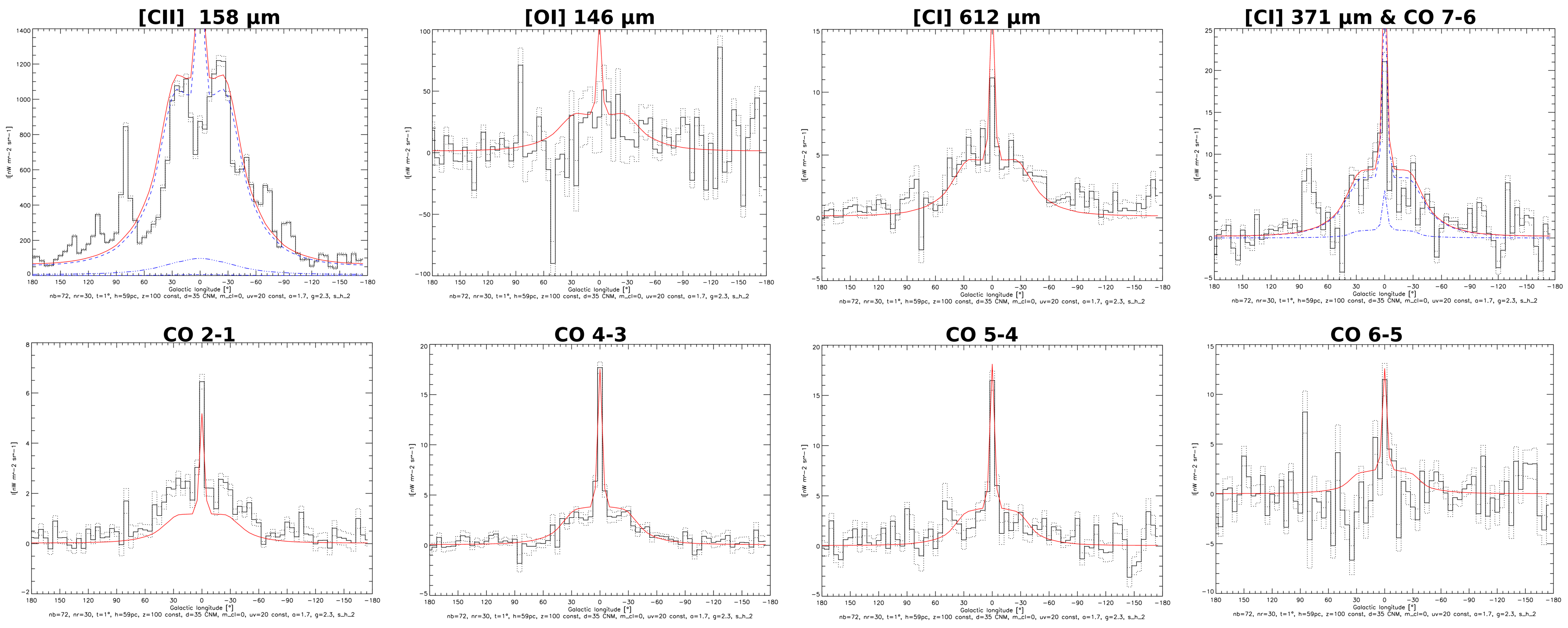
The clump distribution has a clump-mass spectrum with a=1.8 and a mass-size relation with γ=2.3 as generally found (e.g. Heithausen et al. 1998, Kramer et al. 1996)





Fit results

Comparison of the Galactic distribution of the integrated line intensities observed by FIRAS with the intensities predicted by the clumpy PDR model. The plots show latitude-averaged intensities vs. Galactic longitude. The dashed-dotted line in the [CII] data represent the contribution from the diffuse neutral gas using the distribution from Wolfire et al. (2003). The dashed-dotted line in the CO 7-6 plot represents the contribution from the [CI] line which falls into the same spectral point at the FIRAS resolution.

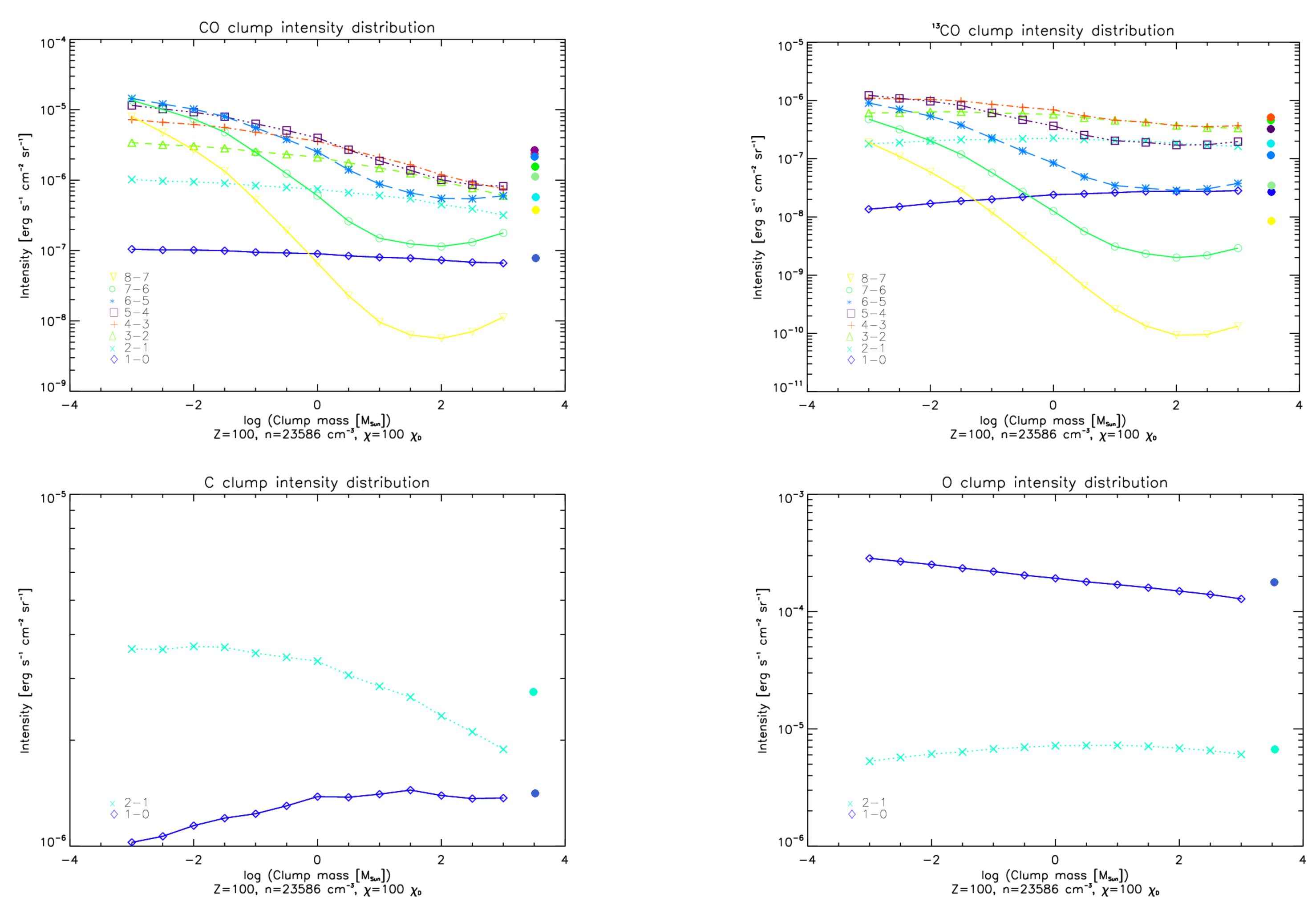


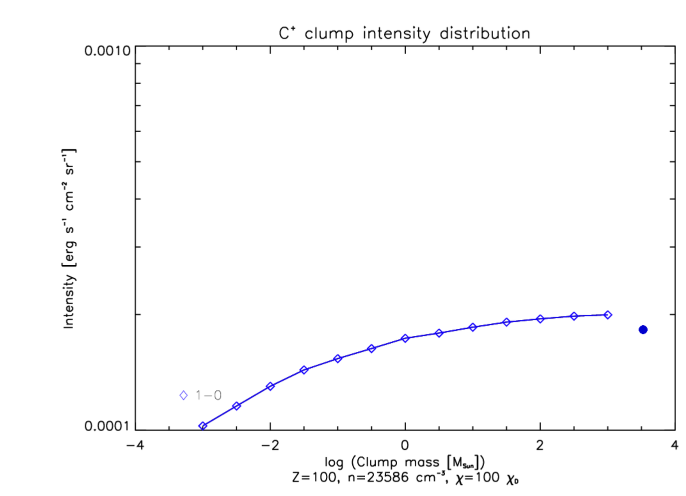
Using the clumpy KOSMA-τ PDR model we can give a self-consistent explanation of the general shape of the observed intensitiy distributions of the mid-J CO, [CI], [CII], and [OI] lines across the Milky Way. We reproduce the intensities using a clump mass spectrum $dN/dM \sim M^{-\alpha}$ with a=1.8. Individual clumps must have sizes between 500 AU and 0.5 pc.

Consequently, we can give a a self-consistent model of the dense ISM in the Galaxy where most of the FIR line emission can be attributed to clumpy PDRs. The contribution from the ionized gas to the [CII] intensity is small, the contribution to all atomic lines is negligible. The conclusion by Abel (2006), that a large part of the COBE-measured [CII] intensity stems from the ionized medium, is thus only applicable when using one particular PDR model, but does not hold in general.

The need for resolution

When a large number of different transitions is observed, the line intensities and the line ratios can be used to constrain the exact shape of the clump size spectrum or to derive the masses/radii of individual clumps. This is however difficult due to the small size dependence of many line ratios which do not allow an unambiguous identification of clump sizes. A definite determination of the clump size spectrum thus asks for the direct mapping of individual clumps, a task, that can be provided only by the high spatial resolution of ALMA.





Clump mass dependence of the integrated line emissivities from spherical PDR clumps in the lines of CO, ^{13}CO, [CI], [CII], and [OI]. The dots at the right edge of each plot represent the corresponding ensemble intensities for the clump distribution used to model the overall Galactic emission.

Conclusion & Outlook

A substantial part of the observed Galactic far-infrared lines can be explained by the emission of clumpy PDRs. With a simple PDR model using only independent information on the typical clump size spectrum and the average properties of the molecular material across the Milky Way, we reproduce almost all the FIR line intensity distributions observed by FIRAS.

Further improvements of the modelling is required to understand the detailed variations of the ISM properties across our Galaxy. An improved model should include the spiral structure, the bulge, and a better representation of the conditions inside 3 kpc galactocentric radius.

We also expect variations of the clump size spectrum in different sources. Then we have to substitute the universal clump size spectrum by individual spectra for each source. This requires, however, high spatial resolution observations which will be obtained only by ALMA.

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