An Atomic and Molecular view of the diffuse/dense interface in the local ISM

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Introduction: The past decades have witnessed a radical change in our view of the ISM and the star formation process. The filamentary structures that are observed reflect the processes by which stars form, and the stellar dynamic and radiative impact in the interstellar environment. The intimately mixed nebular atomic and molecular gas, ionized and heated by the young stars, see their energetic budget profoundly modified. As part of the Herschel Key Program "The evolution of Interstellar Dust", we have map the emission of the main cooling lines ([CII] 158μm, [OI] 63 and 145μm), high excited molecular species, and dust emission in a representative sample of 14 PDRs covering a range of physical conditions and phases of the ISM. These observations give an unprecedented view to the chemistry and energetics of these regions, which are closely related to that of starburst galaxies where they can be used as a template.

Atomic Lines - Morphology

PACS observations of the main cooling lines trace the evolution of the energetics across the PDR interface.

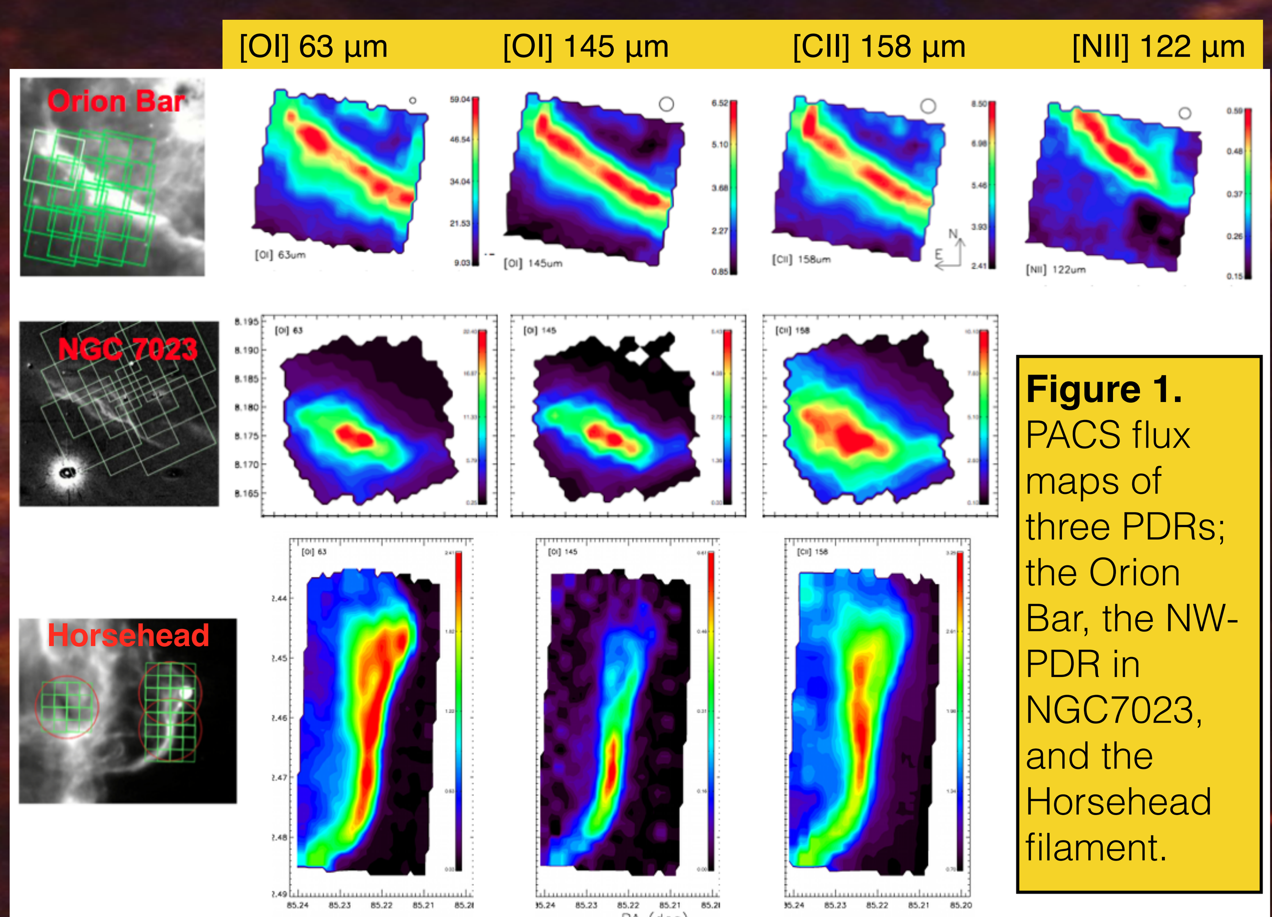
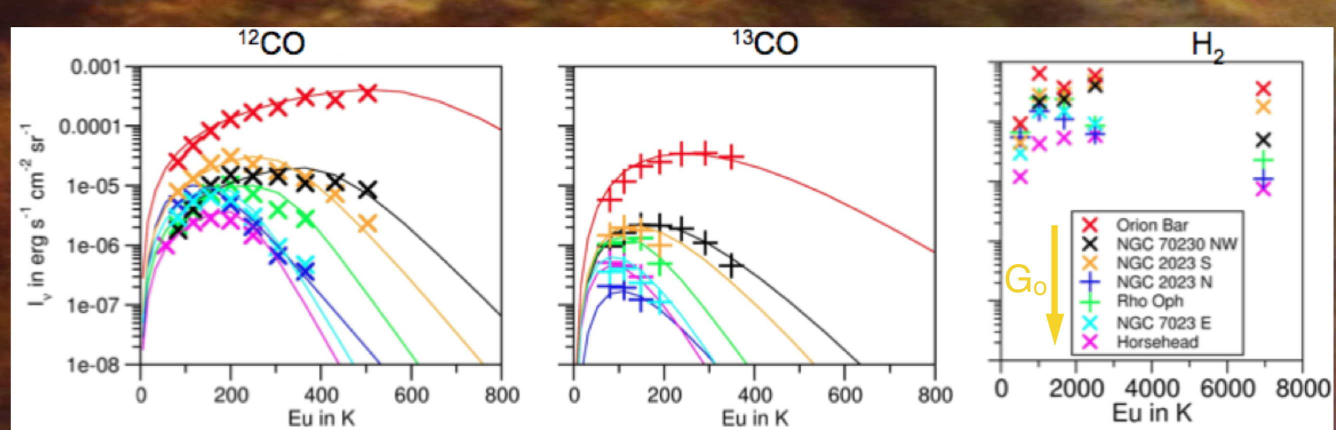


Figure 1. PACS flux maps of three PDRs; the Orion Bar, the NW-PDR in NGC7023, and the Horsehead filament.

- Strongest emission at cloud surface, where gas is warmer.
- Cooling lines peak in the densest PDR zone revealing irradiated clumps or filaments which will evaporate or form new stars.
- [NII] in the Orion Bar delineates the ionised front. Strongest [NII] emission coincides with the inter bar gap seen in [OI] and [CII] emission, indicating photo evaporation.

Molecules - Warm CO and H_2

Figure 4. Cooling curves of ^{12}CO, ^{13}CO (fitted with RADEX), and H_2 towards some PDRs in our *sample*.



- Using derived density from dust emission, and temperature from CO emission, we find a high gas thermal pressure (~1e8 K cm^{-3}) at the cooling emission peak for excited PDRs (G_0>10^3).
- CO temperatures decreases rapidly with G_0, like bulk of the dust.
- H_2 traces a more diffuse gas still warm in lower excited PDRs (G_0<10^2). Additional source of heating ?
- Warm gas in galaxies explained via XDRs, but same lines seen in Orion (with no X-rays). Other excitation mechanisms are possible!

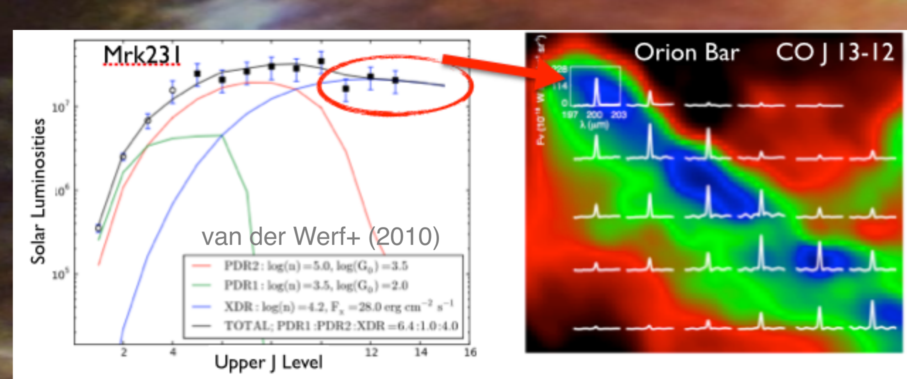


Figure 5. High-J CO in luminous IR galaxies and Orion.

Gas Cooling - Spatially Resolved Budget

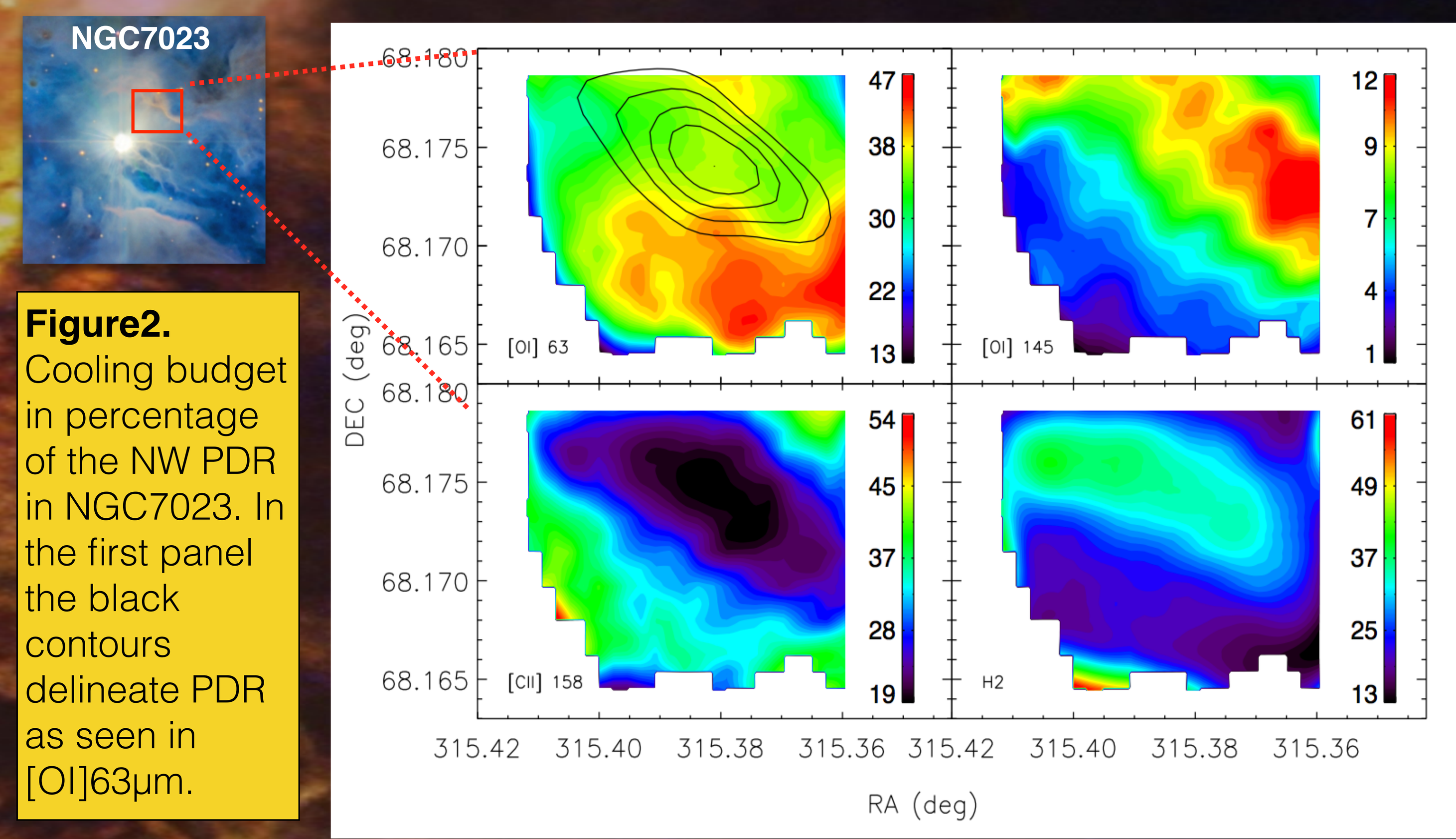


Figure2. Cooling budget in percentage of the NW PDR in NGC7023. In the first panel the black contours delineate PDR as seen in [OI]63μm.

- [OI]63μm is the main contributor (>35%) to the cooling budget over the entire NW-PDR in NGC7023.
- However, H_2 is an important contributor in the PDR (>35%) and so is [CII] outside the PDR (>30%).
- [CII] importance is greater in regions of low excitation/density where other species cannot be excited.
- [OI145um contribution is maximal at the PDR, but is not a main component. Other FIR species contribute little (CO & [CI] ~5%).

Gas Cooling - Evolution

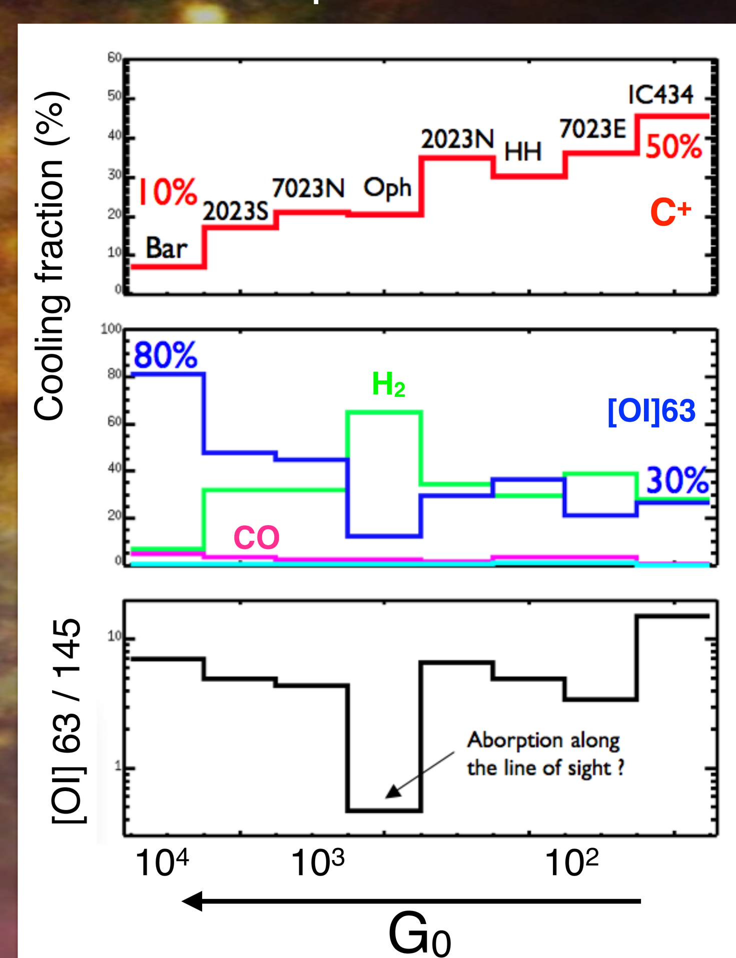
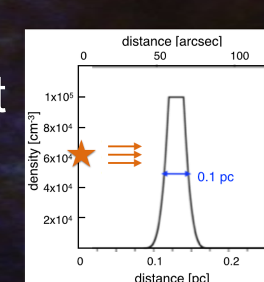


Figure 3. Cooling fraction of several PDRs as a function of the incident radiation field.

- C^+ contributes up to 50% for radiation fields (G_0)< 1000
- [OI]63 contributes up to 80% for G_0>1000
- H_2 contribution is significant 20-40%
- Other species contribute <5%
- Ratio of [OI] lines indicates self-absorption effect in most of the PDRs.
- PDR code reproduces well C^+ and [OI]145 over a large range of G_0. These models however, overpredict [OI]63 and underpredict H_2 rotational lines at low G_0: → *careful when using these to trace Star Formation in galaxies.*

Dust Properties

Using radiative transfer modelling we derive a density profile that mimics the increase/decrease in density across PDRs.



- The model satisfactorily reproduces the mid/FIR dust, as well as the atomic gas emission.
- Deviations at 70μm and >350μm are ascribed to dust evolution, and variations of the spectral emissivity index. This is general to Galactic PDRs.

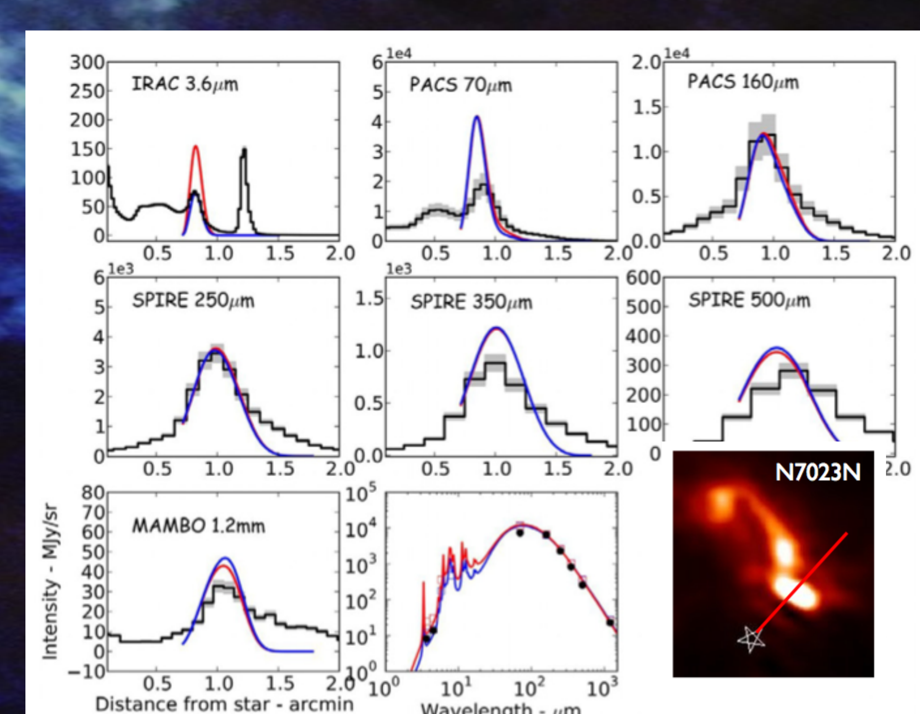


Figure 6. Comparison of modelled and observed dust emission for an adopted cut across the NW PDR in NGC7023.

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Articles: Abergel et al. 2010, 518, 96; Arab et al. 2012, A&A, 541, 19; Bernard-Salas et al. 2012, A&A, 538, 37; Bernard-Salas et al. 2014, A&A, sub.; Habart et al. 2010, A&A, 518, 116; Köhler et al. 2014, A&A, 569, 109; Parikka et al. 2014, A&A, in prep.

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