Photo-induced chemistry at the surface of PDRs: new insights with Herschel observations of NGC 7023

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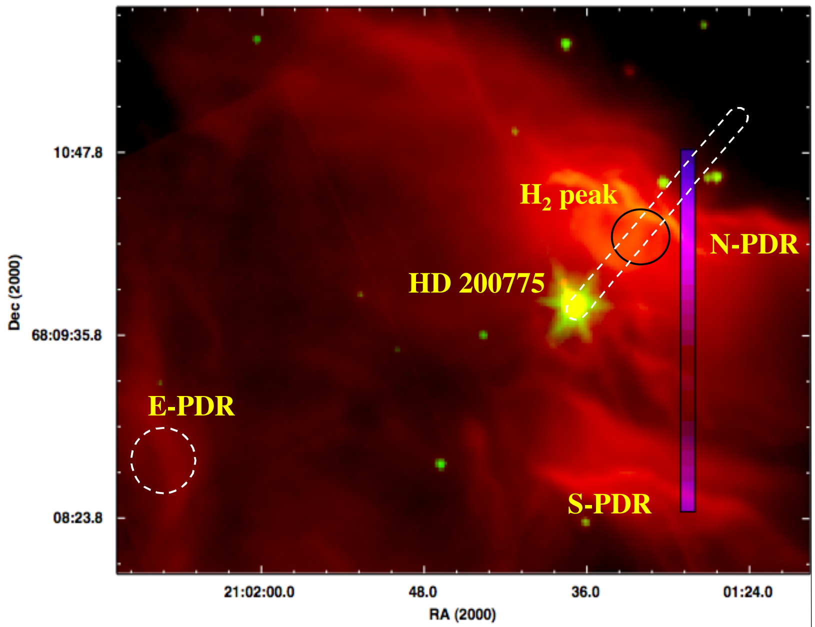
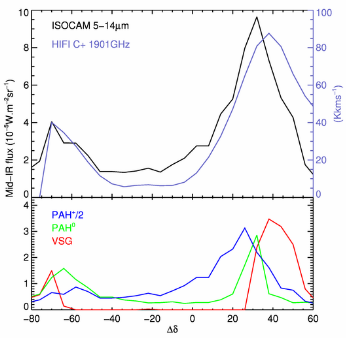
Context

NGC 7023 is the prototype of a PDR illuminated by a B star. It has been widely studied at all wavelengths and it seems now clear that the northern dust filaments host an active gas chemistry involving gas-phase species and very small dust particles. Herschel observations provide new insights into the (complex) mechanisms that drives the chemistry and hence the energetics of this prototypical PDR. In this work, the velocity structure of the [CII] emission is used to constrain the geometry of the nebula. We also present the spatial correlation of the [CII] emission at 1901 GHz with the mid-IR emission from Polycyclic Aromatic Hydrocarbons (PAHs). Finally, the detection of the HCO+ (J=6-5) transition allows to better constrain the physical conditions in the high-density filaments toward the northern rim of this complex nebula.



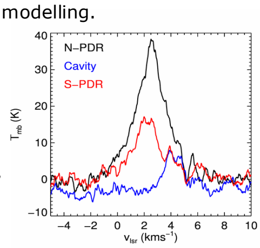
RGB image of NGC 7023 composed by IRAC 8 µm (red) and 3.6 µm (green) images, and HIFI C+ integrated intensities (blue). Black lines indicate the positions of HIFI observations. White dotted lines indicate the forthcoming observations for HIFI and PACS spectroscopy.

C+ and PAH emission



Top: Intensity of C+ (blue) and ISOCAM (5-14 µm) integrated emission along the cut covering the brightest PDR (north), the cavity and the milder PDR (south).
Bottom: Decomposition of the mid-IR flux in ionised and neutral PAHs and Very Small Grains emission. Δδ = 0 corresponds to the star declination.

We observed [CII] emission along a cut through the northern and southern PDRs. We separed the mid-IR flux emitted from neutral and ionised PAHs (PAH^0 and PAH$^+$) and Very Small Grains (VSG) populations *[Rapacioli et al 2005]*. The spatial correlation between these components and the C$^+$ emission shows that PAH^0 and VSGs are the main contributors to the heating of the gas by photo-electric effect; there seems also to be a contribution from the PAH$^+$ population (formation of PAH^{++}?). This will be analysed in details by convolving ISOCAM data to the spatial resolution of Herschel C$^+$ observations and interpreted by PDR modelling.



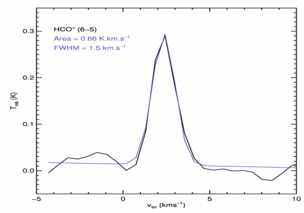
HIFI-HRS spectra of [CII] emission toward three different positions along the cut.

The [CII] spectra show several velocity components, which are associated to high density (10^5-10^6 cm^{-3}) filaments in the PDRs (1.9, 2.4, 2.9, 4.0 kms^{-1}) and to the bulk of the molecular cloud (2-4 kms^{-1}) *[Fuente et al. 1996]*. The [CII] spectra towards the 'cavity' suggests that emission is most likely associated to a sheet of material in front of the cavity and not to the ionised gas in the cavity itself, which should present broader emission *[Fuente et al. 1996]*. The presence of the same velocity components toward the N-PDR and S-PDR suggests that this is up-front material associated with the PDR, possibly the remaining of the cavity edge *[Gerin et al. 1998]*. More detailed studies on the velocity components will provide further insights on the geometrical and physical properties of the nebula.

HCO+ emission from high-density filaments

We report the detection of the HCO$^+$ (J=6-5) at 535GHz with the HIFI-WBS spectrometer toward the H_2 peak position in the northern PDR. The emission peaks between 1.5 and 4 kms^{-1}, and arises most likely from the high density filaments previously detected in infrared continuum *[Sellgren et al. 1992]* and molecular line emission *[Fuente et al. 1996]*.
The main beam temperature of this spectral line is 0.3 K with a FWHM = 1.5 kms^{-1}. Interferometric observations show that the thickness of these filaments is about 6''. Assuming that high-J emission for this molecule arises only from these dense filaments, we derive a beam dilution factor of ~5. We combined the HIFI data with ground-based observations of lower-J HCO+ transitions observed at the IRAM 30m telescope and the Plateau de Bure Interferometer *[Fuente et al.1996]* to derive the physical conditions in these high density filaments. Preliminary results obtained with the escape probability code RADEX *[van der Tak et al. 2007]* show that these filaments are sensibly warmer (90 K) than the molecular gas, and are most likely localised between the warm atomic medium (100K) and the colder molecular cloud.

HCO$^+$ (J = 6-5, 535 GHz) emission, at the H_2 peak of the N-PDR. The emission is tracing molecular gas in the dense filaments of this PDR. The integrated intensity of this line is 0.66 K.km.s^{-1} and the FWHM is 1.5 km.s^{-1}.



Conclusions

The complex geometry and physical conditions in NGC 7023 have been preliminarly studied through [CII] emission covering the S-PDR, the cavity and the brighter N-PDR. We also report observations of the HCO$^+$ (6-5) emission toward the H_2 peak in the northern rim.
The mid-IR PAH and VSG emission is well correlated with the [CII] emission. The velocity structure of the [CII] emission suggests that some emission is arising from molecular gas in front of the cavity. We used the HCO$^+$ (6-5) transition observed in the high density filaments in the northern PDR to estimate the physical conditions in these environments, deriving a warm temperature (90K) and high density (~10^5 cm^{-3}). The chemical and physical properties of the three PDRs associated with NGC 7023 will be assessed with complementary PACS and HIFI observations of several molecular tracers, and detailed analysis with PDR modelling.

Acknowledgements

HIFI has been designed and built by a consortium of institutes and university departments from across Europe, Canada and the United States under the leadership of SRON Netherlands Institute for Space Research, Groningen, The Netherlands and with major contributions from Germany, France and the US. Consortium members are: Canada: CSA, U.Waterloo; France: CESR, LAB, LERMA, IRAM; Germany: KOSMA, MPIfR, MPS; Ireland, NUI Maynooth; Italy: ASI, IFSI-INAF, Osservatorio Astrofisico di Arcetri- INAF; Netherlands: SRON, TUD; Poland: CAMK, CBK; Spain: Observatorio Astronmico Nacional (IGN), Centro de Astrobiologa (CSIC-INTA). Sweden: Chalmers University of Technology - MC2, RSS & GARD; Onsala Space Observatory; Swedish National Space Board, Stockholm University - Stockholm Observatory; Switzerland: ETH Zurich, FHNW; USA: Caltech, JPL, NHSC.