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Excitation of carbon species in the DR21 PDR

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Introduction

DR21 is a deeply embedded HII region created by the radiation from at least six OB stars (Roelfsema et al., 1989). It sits within and behind a ridge of dense molecular material that obscures the HII-region at optical wavelengths. The embedded cluster drives a violent bipolar outflow in north-east to south-west direction. It is prominent in the 2 μm emission of vibrationally excited H_2, tracing hot, shocked gas and in the Spitzer 4.5 μm channel (Garden et al., 1986; Davis et al., 2007).

The bright H_2 emission indicates shock heating in the outflow and the wings of the molecular lines prove its dynamical impact, but excitation models of the observed emission of CO, [CI], [C II], and [OI] by Lane et al. (1990) and Jakob et al. (2007) have shown that the emission of those tracers cannot be explained by shocks, but is consistent with a pure UV heating, i.e., PDR physics. To quantify the heating of the gas, we analyze spectra taken with the HIFI instrument (de Graauw et al., 2010) on board the Herschel Space Observatory (Pilbratt et al., 2010) during the performance verification campaign.

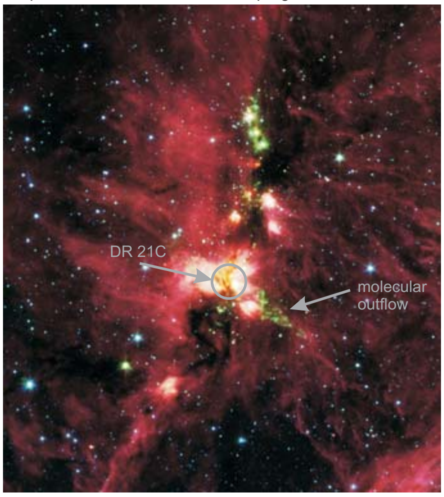


Figure 1: Large-scale IRAC view of the DR 21 region. This three-color rendition is composed of 3.6 μm band (blue), 4.5 μm band (green), and 8.0 μm band (red) data.

Data

HIFI Data: All spectra presented here were obtained in performance verification observations for the HIFI instrument. Most observations where single-pointings towards the central position of the DR21 HII region (DR21 C) at RA=20h39m01.1s, DEC=42°19'43.0'' (J2000).

Complementary Data: ISO Long Wavelength Spectrometer 43 − 197 μm grating scans were obtained for the DR21 central position from the ISO Data Archive. Integrated line intensities were extracted for [OI] at 63 and 145 μm and the CO 14–13 to 17–16 transitions. Mid-J CO lines of the DR21 region were mapped with the KOSMA 3 m submm telescope (Jakob et al., 2007). We use the lines of CO and ^{13}CO from J = 3-2 to 7-6, which have been observed at native angular resolutions from 80'' to 40''. The HCO^+ 1-0, $H^{13}CO^+$ 1-0, and HCO^+ 3-2 observations were taken with the IRAM 30 m telescope (Schneider et al., 2010). Native angular resolutions at the 1-0 and 3-2 transition frequencies are 28'' and 9'', respectively.

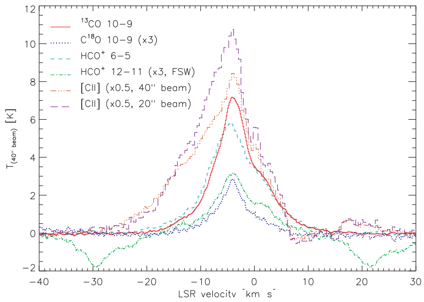


Figure 2: HIFI spectra of the lines used in the fit of the PDR properties. The [CII] data are convolved either to the resolution of the HCO^+ 6-5 line or to that of the CO 10-9 lines. The negative features in the HCO^+ 12-11 line are artifacts from the frequency-switch observing mode.

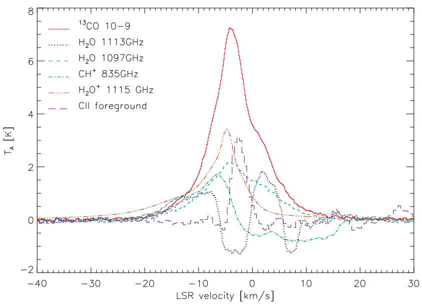


Figure 3: Auxiliary lines measured by HIFI towards the same position. They can be used to estimate the contribution of the foreground material. The ^{13}CO 10-9 profile is also displayed for comparison.

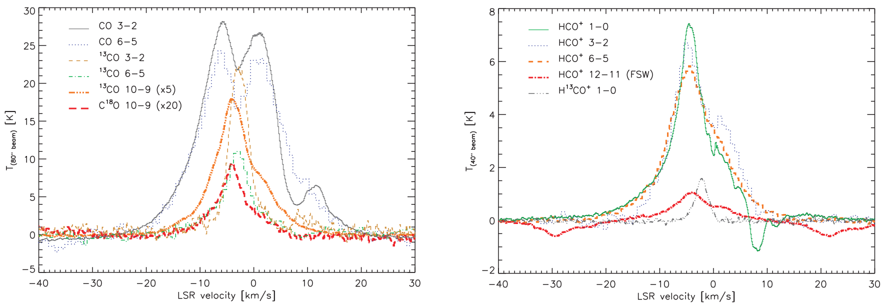


Figure 4+5: Selected profiles of CO isotope lines (left plot) and HCO^+ isotope lines (right plot) towards the DR21 central position. All lines are convolved or scaled to the coarsest common resolution

Model Results

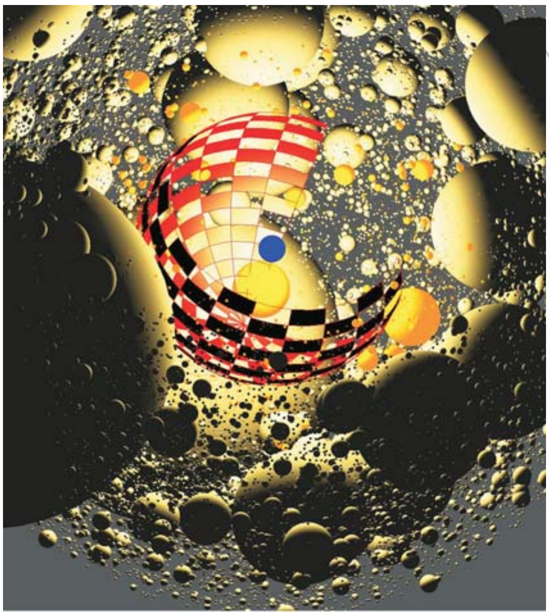


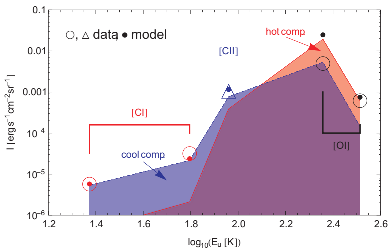
Figure 7: Examplary realisation of a two-ensemble model configuration. All dimensions are plotted true to scale. The position of the central OB cluster is indicated by a blue sphere. The edge of the surrounding HII region is shown by the red wireframe sphere. The hot component clumps are shown as orange spheres. They populate the inner shell. The cool component clumps are shown in beige populating the outer shell. All clumps are randomly positioned and assumedly embedded in a diffuse inter-clump gas.

We use the KOSMA-τ PDR code (Röllig et al., 2006) to model the emission of PDR ensembles, representing a distribution of spherical clumps with $dN/dM \propto M^{-1.8}$ (Cubick et al., 2008). For DR21 two ensembles with different properties had to be superimposed, a hot component, close to the inner HII region with strong FUV illumination, but only a small fraction of the total mass (orange clumps in Fig. 7), and a cooler component that provides the bulk of the material (beige clumps in Fig.7). We fit absolute line intensities, using the available ground-based observations, complementary ISO data, and the HIFI lines. The clump superposition ignores mutual line shading between different clumps, i.e., optical depth effects are only considered within individual clumps. The best fit result is shown in the following Table:

	ensemble 1 (hot)	emsemble 2 (cool)
mass [$M_\odot$]	150	830
mean density [cm^{-3}]	1.3×10^6	1.1×10^6
FUV intensity	1×10^5	3×10^2
mass range [$M_\odot$]	0.01-80	0.001-10

The parameters of the model are in agreement with independent estimates. As the two-ensemble PDR model is able to fit all of the observed lines, we find no evidence for a shock heating of the dense gas. This is in agreement with the analysis of Lane et al. (1990), explicitely excluding a shock origin of the fine-structure lines, but seems to be in contradiction with the line profiles that show excited outflow material.

We conclude that the material visible in the blue line wing, characterizing the blister outflow, is contained in dense clumps that are accelerated by the outflow, but that are chemically and energetically fully dominated by the UV field and not by the associated shock.



Two-ensemble PDR model fit to the observed CO, HCO^+, and fine structure line intensities, shown as function of the upper level energy. HIFI measurements are depicted as open triangles, complementary data points as open circles.

Figure 8 (top): Cooling lines of [CI], [CII], and [OI]. The shaded areas indicate the contributions from the two ensembles (blue:cool comp., red:hot comp). As expected, the model predicts a too high [OI] intensity, as it ignores that the outer clumps of the cooler ensemble block the contribution from the hot inner component.

Figure 9 (bottom): CO and HCO^+ line emission. The gray lines (dotted: cool comp. and short-dashed: hot comp.) indicate the contributions from the two ensembles to the total ^{12}CO line emission. For the CO lines showing clear self-absorption dips, we estimate the total emission including the blocked radiation from the inner clumps close to the HII-region. The model slightly overestimates the emission for the optically thick rotational lines of ^{13}CO and HCO^+.