The Dust and Gas Structure in S 140

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Abstract

We have analyzed the temperature and column density around the S140 cluster of young stellar objects by combining Herschel PACS and HIFI observations with ground-based mapping observations of mm-wave lines and continuum.

We used the DUSTY radiative transfer code to fit simple models to the continuum observations to derive constraints on the source luminosities and dust distributions around IRS 1, 2, and 3, as well as SMM 1. The high spatial resolution of the Herschel data allows us to analyze the relative effects of the gas and dust density distribution and the location and luminosity of heating sources on the overall intensity distribution.

We also compare the spatial distribution of gas and dust temperatures and find significant differences between them. The velocity information in the lines allows us to separate the quiescent component from outflows when deriving the gas temperature and column density.

From the mapping observations of multiple ^{13}CO transitions we perform an LTE analysis via rotation diagrams. A detailed comparison of the conditions at the position of IRS 1 and at the ionization front, close to the submm peak, shows very different chemical compositions and excitation temperatures.

Continuum Analysis

Observations

Single pointing of Herschel PACS/Spec in Range Scan Mode
Continuum sampled at 11 wavelengths from 73 – 187μm; line emission was masked
Added published ground-based and airborne images at 11, 24, 31, 37, and 450μm

Luminosity, Temperature, Optical Depth Analysis

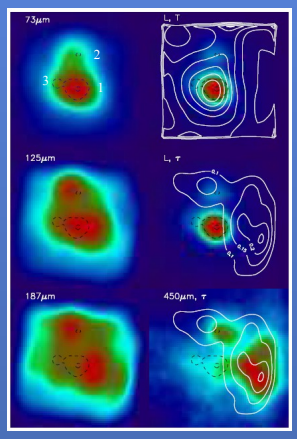
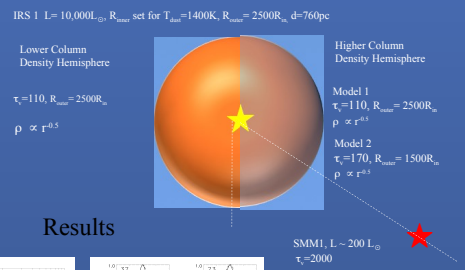


Fig.1 Left Column – Smoothed PACS/Spec Images with highest contours of 37μm emission overlaid showing the positions of IRS 1, 2, and 3.

Fig.1 Right Column – Top two panels show the total luminosity (11-400 μm) image with dust temperature contours at 75, 70, 65, 60, …K in the top right, and dust optical depth contours in center right at levels of 0.1, 0.15, 0.2, and 0.25. The lower right panels shows the same dust optical depth contours overlaid on the 450μm SCUBA archive image of S140.

DUSTY Radiative Transfer Modeling of IRS 1

Divided IRS1/SMM1 region into 3 parts with separate DUSTY component for each
- Low Column Hemisphere to East; High Column to West; Compact SMM source; Draine & Lee (1984) dust
- Nine free parameters explored in large grid (576,000 models)
- Fit peak fluxes at IRS1 (37, 73, 125, 187, 450μm) and SMM1 (450μm), spatial profiles along dashed lines



Results

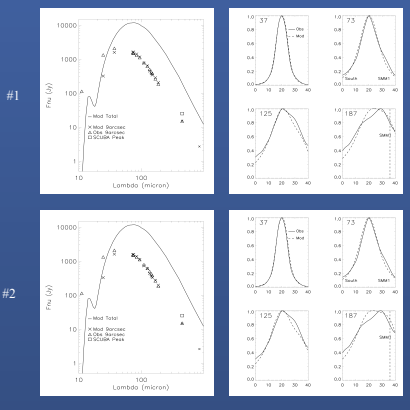


Fig. 3: Model and Observed SEDs (left column) and profiles along the indicated cuts for two best-fitting models

Conclusions From Dust Modeling

- Density gradient well-constrained to quite shallow, $\sim r^{-0.6}$
- Implies most of diffuse emission powered by IRS 1
- Central optical depth (DL dust) ~ 120
- Luminosity of SMM1 ~ 200$L_\odot$, but not well constrained

Spectral Line Analysis

Observations

4'x4' maps using the IRAM-30m telescope in the 85-270GHz windows
→ spatial distribution of the emission from common tracers such as CO isotopes, HCN isotopes, CN, C_2H, CS, HCO^+, SiO, …
Combined with single point Herschel/HIFI observations of many species between 520 and 1900GHz.

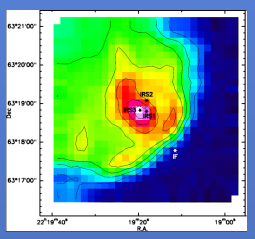


Fig. 4: Integrated CO 1-0 map showing IRS1-3, and a stratified outer cloud surface near to SMM1

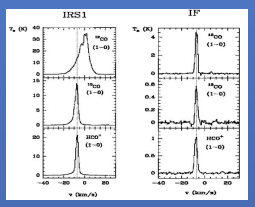


Fig. 5: Typical line profiles towards IRS1 and the outer IF

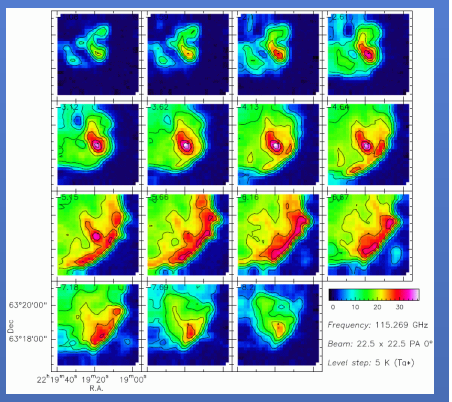
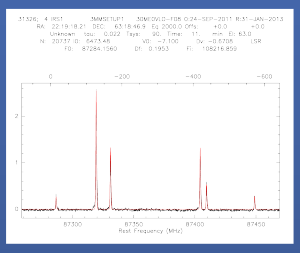


Fig. 6: Channel maps of CO 1-0 showing the complex velocity structure, with very broad lines towards IRS1

Separate temperature and column density analysis for different velocity components!

Temperature determination



The simultaneous observation of many lines from the same species allows to constrain the gas temperature.

Rotation diagrams provide a range of temperatures for different species (narrow velocity component):

Molecule	Excitation Temperature	Column density
^{13}CO	74 K	2.1e16 cm^{-2}
$C_{18}O$	57K	5.9e15 cm^{-2}
H_2O	37K	1.6e14 cm^{-2}

Fig.7: C_2H is fit by an LTE model with T_{kin}=40K

The column density distribution

Use of separately fitted temperatures for dense and thin gas to measure column densities

Position	Molecule	Excitation Temperature	Column density
IRS 1	CN	90	1.4e15
IRS 1	HCO^+	90	8.2e14
IRS 1	HCN	90	1.7e15
IRS 1	C_2H	40	2.3e15
IRS 1	$C_{18}O$	90	4.5e16
IF	CN	10	1.5e13
IF	HCO^+	10	7e12
IF	HCN	10	1.2e13
IF	C_2H	10	1.5e14

Table 1: Selected examples of derived column densities for the single position of IRS1

A full analysis of the different velocity components is ongoing.

Conclusions From Gas Analysis

- Multiple velocity components contribute to the total column density
- Column densities towards IRS1 are consistent with dust model and normal gas phase abundances
- Hot gas detected towards the South-West, favoring the model with additional heating from SMM1