The Dust and Gas Structure in the S 140 Cluster

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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 infrared 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. The dust parameters are relatively well-constrained for IRS 1, but less so for IRS2 and 3 due to the substantially overlapping emission from IRS 1.

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 – Dust

Observations

Used 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

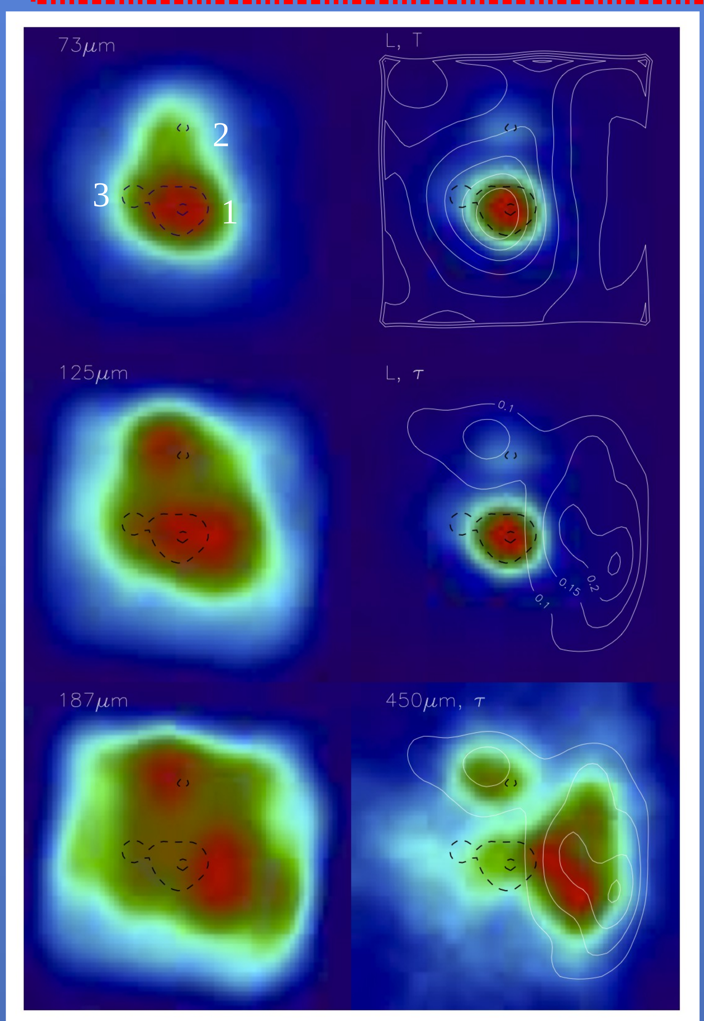


Fig.1 Left Column – Smoothed PACS images with contours of 37µm (SOFIA) emission overlaid showing the positions of IRS 1, 2, and 3.

Fig.1 Right Column – Top two panels show the total luminosity (11-400µm) 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 panel 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
Nine free parameters explored in large grid (150,000 models), OH5 dust (Ossenkopf & Henning 1994)
Fit peak fluxes at IRS1 (37, 73, 125, 187, 450µm) and SMM1 (450µm), spatial profiles along dashed lines.

IRS 1 L= 10,000$L_\odot$, R_{inner} set for T_{dust}=1400K, R_{outer}= 1500R_{in}

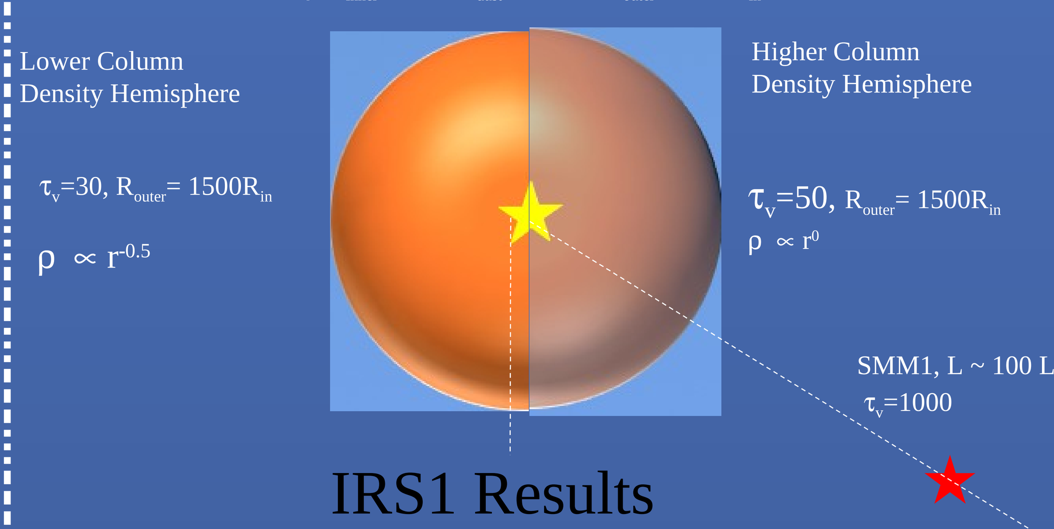


Fig. 2: Schematic diagram of model for IRS 1, with lower column density to east and higher to the west in simplified attempt to model complex column density apparent in Figure 1.

IRS1 Results

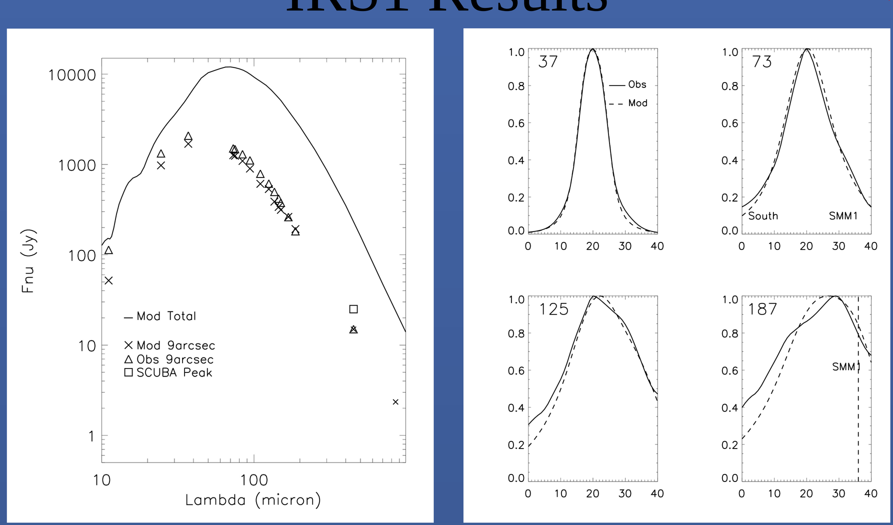


Fig. 3: Model and observed SED's (left column) and profiles along the indicated cuts for example best-fitting model for IRS 1.

Cluster Modeling Results

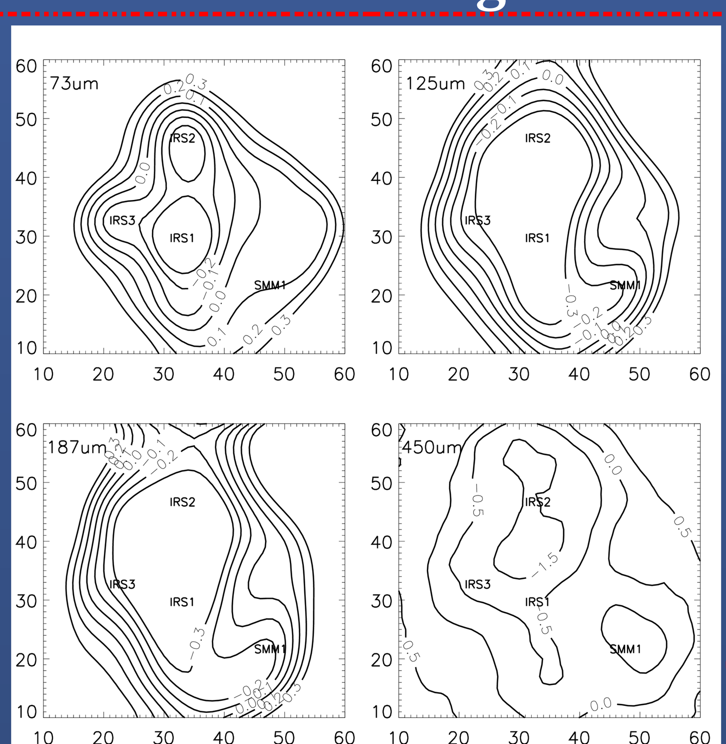


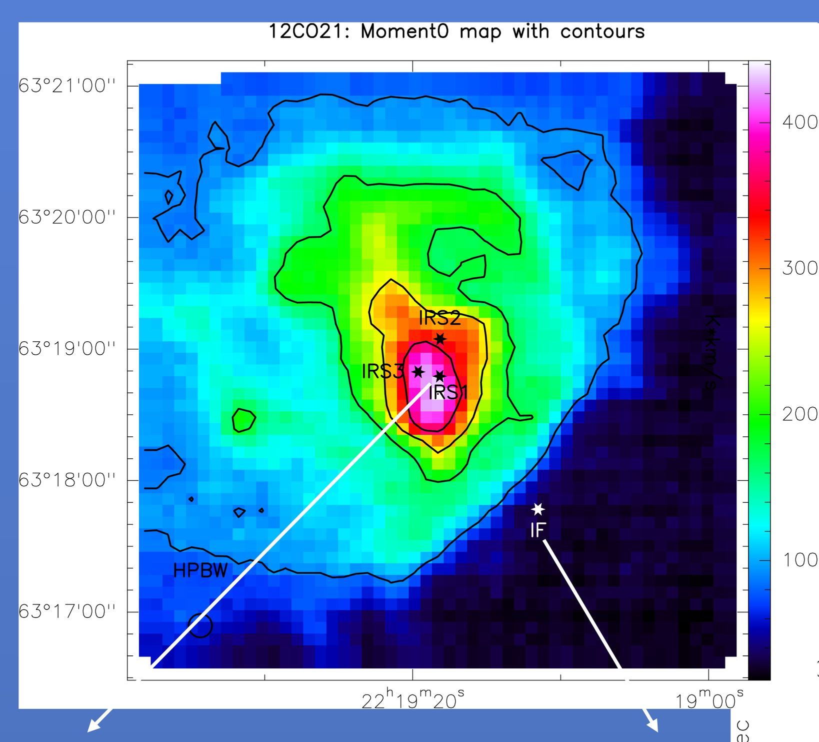
Fig. 4: (Observed-Model)/Observed fluxes for combined IRS 1,2, and 3 models. The units on the axes are arcseconds.

Spectral Line Analysis – Gas

Observations

IRAM 30m: 4´x4´ maps, covering the windows (93-97 GHz, 109-113GHz, 112-117GHz, 228-232GHz) and single pointing observations towards IRS1 and IF covering the 85-270GHz windows.
Herschel/HIFI: Single pointing observations towards IRS and interface (IF) (520-1900GHz).

Spatial distribution – Velocity Structure



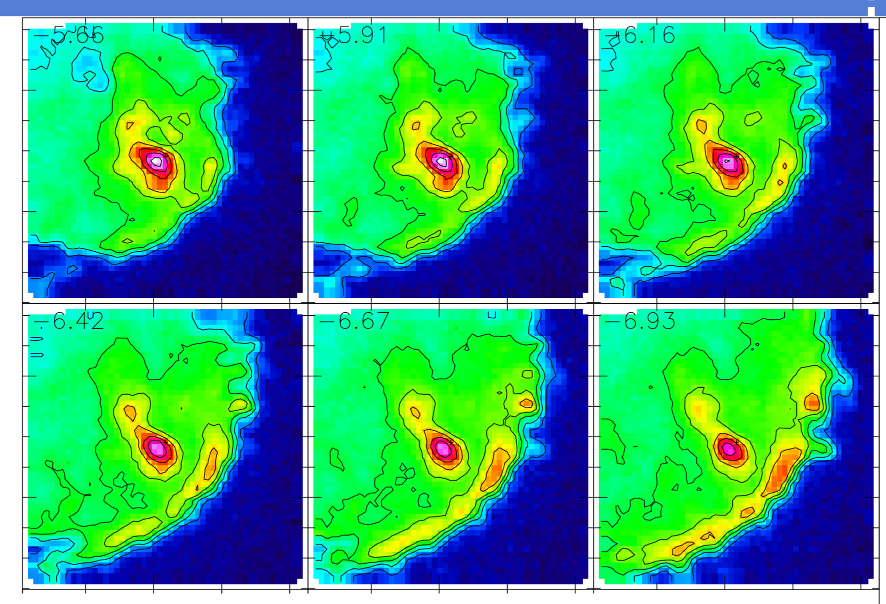
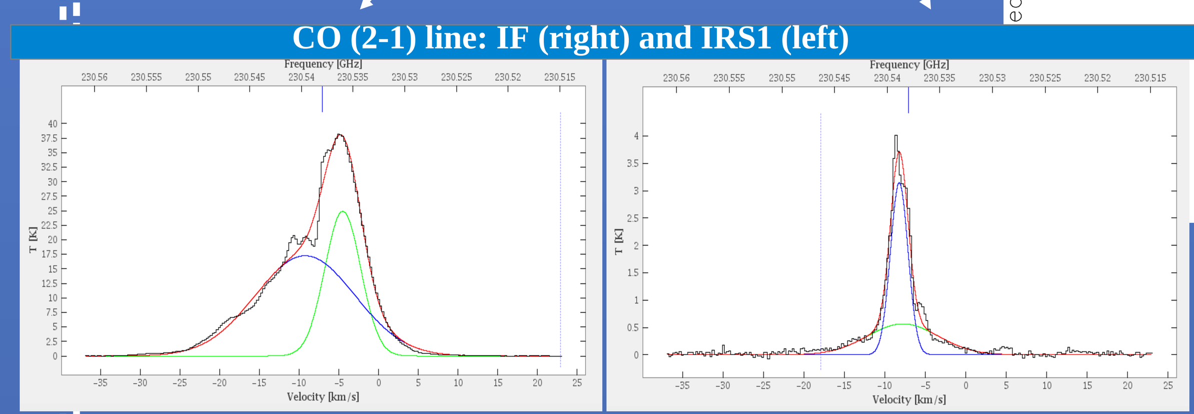


Fig. 5: Channel maps of CO (2-1)- The peak in IF appears in higher velocity than IRS.



Excitation Analysis

Fig. 6: The line profiles are results of the emission from both the envelope (narrow component) and the outflow (broad component). IF shows more narrow lines than IRS.

Rotation Diagram Analysis

A range of excitation temperatures for different species (showing ≥ 2 transitions) was determined using the Rotation Diagram Analysis. Being interested in quiescent gas we use only the narrow component.

In the case of IF only few species were found to show ≥ 2 transitions (i.e. CO).

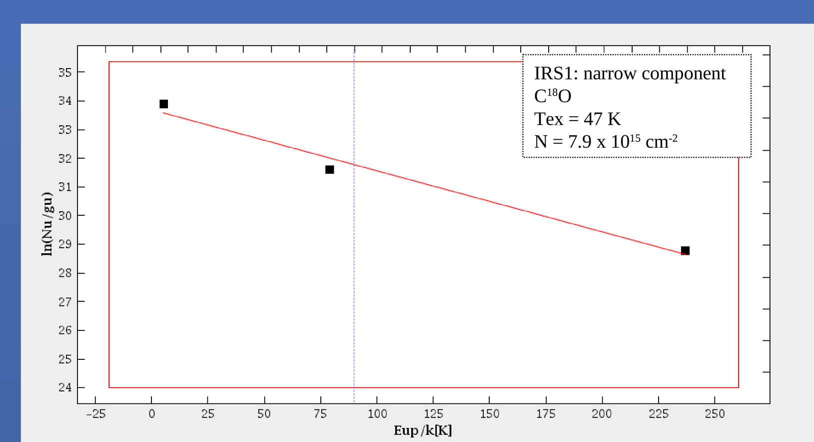
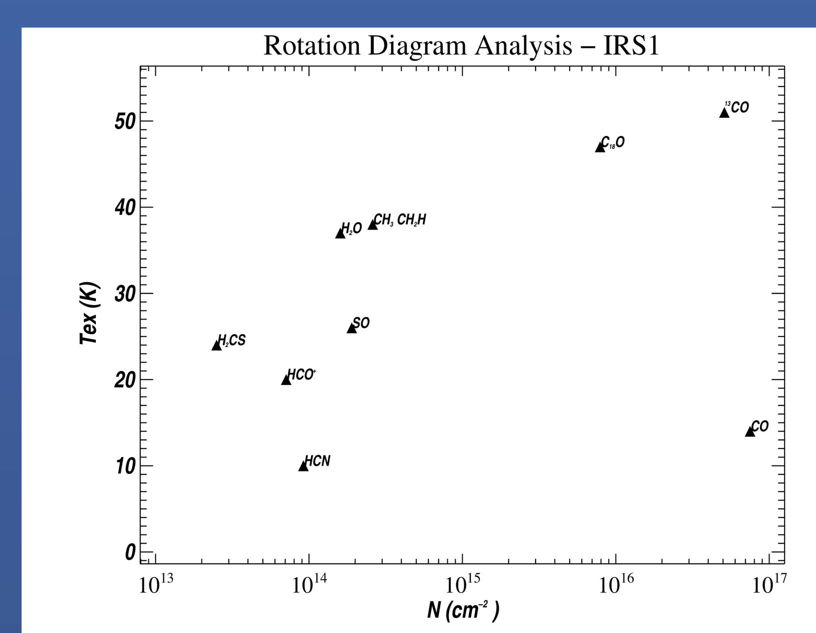
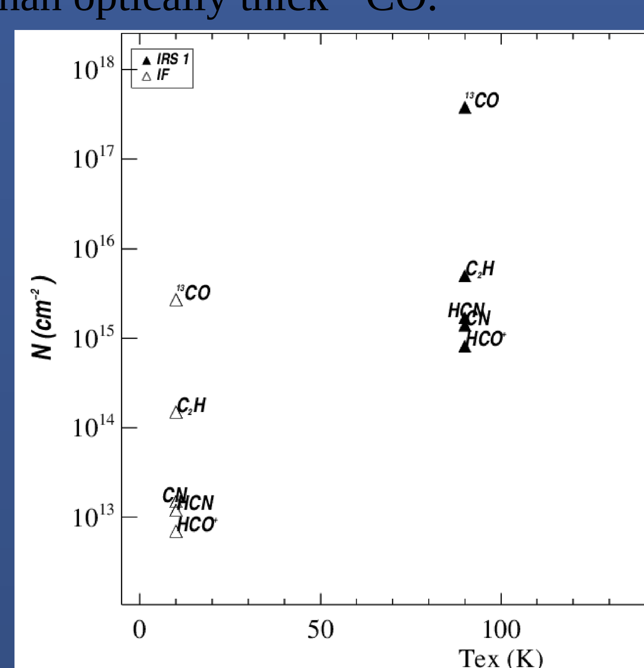


Fig. 7: $C^{18}O$ is characterized by a low critical density. Thus, the excitation temperature is almost equal with the Kinetic Temperature.

The ratios of H_2CS lines from same J-state but different K states are temperature probes. Thus, they are useful for constructing the kinetic temperature map of the region (RADEX: Future plan).

Fig8: The lower opacity CO isotopologues give more reliable constraints on H_2 column densities and physical conditions than optically thick ^{12}CO.





LTE Analysis – Column density distribution

Fig. 9: For the species that were not suitable to be used in Rotation diagram analysis (not enough lines, or lines with similar Eup) we calculated the column densities assuming a fixed excitation temperature (IRS1 – 90K and IF – 10K). At IRS1 all species, with the exception of C_2H, appear to be twice as abundant as they are at the IF.

Conclusions From Dust and Gas Analysis - Future Plans

Density gradient well-constrained to quite shallow, ~$r^{-0.5}$
Implies most of diffuse emission powered by IRS 1
Central optical depth (OH5 dust) A_v~ 40
Luminosity of SMM1 ~ 100$L_\odot$, but not well constrained

The total column density is the result of more than one velocity component.
Column density consistent with dust model and typical gas phase abundances.
RADEX analysis for more accurate modeling of the gas is in progress.