The Effect of Molecular Contamination on the Emissivity Spectral Index in Orion A

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The emissivity spectral index is a critical component in the study of the physical properties of dust grains in cold and optically thin interstellar star forming regions. Since submillimeter astronomy is an ideal tool to measure the thermal emission of those dust grains, it can be used to characterize this important parameter. We present the SCUBA-2 shared risks observations at 450 µm and 850 µm of the Orion A molecular cloud obtained at the James-Clerk-Maxwell telescope. Previous studies showed that molecular emission lines can also contribute significantly to the measured fluxes in those continuum bands. We use HARP ^{12}CO 3-2 maps to evaluate the total molecular line contamination in the SCUBA-2 maps and its effect on the determination of the spectral index in highly contaminated areas. With the corrected fluxes, we have obtained new spectral index maps for different regions of the well-known integral-shaped filament. This work is part of an ongoing effort to characterize the properties of star forming regions in the Gould belt with the new instruments available at the JCMT.

Method

We present a simple model to evaluate the emissivity spectral index in molecular clouds. Since interstellar dust dominates the continuous emission in the submillimeter wavelengths, we can simply write the flux density for a frequency ν as :

$$S_\nu(T_d, N_d, \kappa_\nu) = N_d \Omega_{\Delta\nu} \kappa_\nu g_\nu B_\nu(T_d)\,. \qquad (1)$$

The effective transmission is given by g_ν , $\Omega_{\Delta\nu}$ is the width of the telescope's beam and N_d is the dust's column density. In order to simplify the problem, we make a series of reasonable assumptions. We suppose that the source function $B_\nu(T_d)$ for the dust is Planck's law of blackbody radiation, and that the grains in the line of sight share similar properties. In order to obtain a temperature independent evaluation of the spectral index, the Rayleigh-Jeans approximation can be used as shown in figure 3. We define this index by a semi-empirical equation for emissivity at a reference frequency ν_o. It is included in a function $\chi_{\Delta\nu}(\beta, T_d)$ to generalize the equations. The flux over the entire band can be obtained if we integrate equation (1) over a frequency range $\Delta\nu$:

$$S^*_{\Delta\nu}(\beta, T_d, N_d) = \kappa_o N_d \chi_{\Delta\nu}(\beta, T_d), \qquad (2)$$

$$\chi_{\Delta\nu}(\beta, T_d) = \left(\frac{1}{\nu_o}\right)^\beta \int_{\Delta\nu} \nu^\beta g_\nu B_\nu(T_d) d\nu. \qquad (3)$$

We know from previous studies[4,5] that contamination from molecular emission lines can be important in some regions. To take this effect into account, we apply the following transformation to equation (2) : $S^*_{\Delta\nu} \rightarrow S^*_{\Delta\nu}(1 - C_{\Delta\nu})$. The extinction correction is also taken into account by the calibration factor ξ. To find the spectral index, we compare the two maps directly. In this study, we use SCUBA-2 observations at 450 µm and 850 µm combined with HARP ^{12}CO 3-2 data to define a function $f(\beta)$ that can be used to evaluate β numerically :

$$f(\beta) = \xi \frac{S^*_{850}(1 - C_{850})}{S^*_{450}} = \xi \frac{\chi_{850}(\beta, T_d)}{\chi_{450}(\beta, T_d)}. \qquad (4)$$

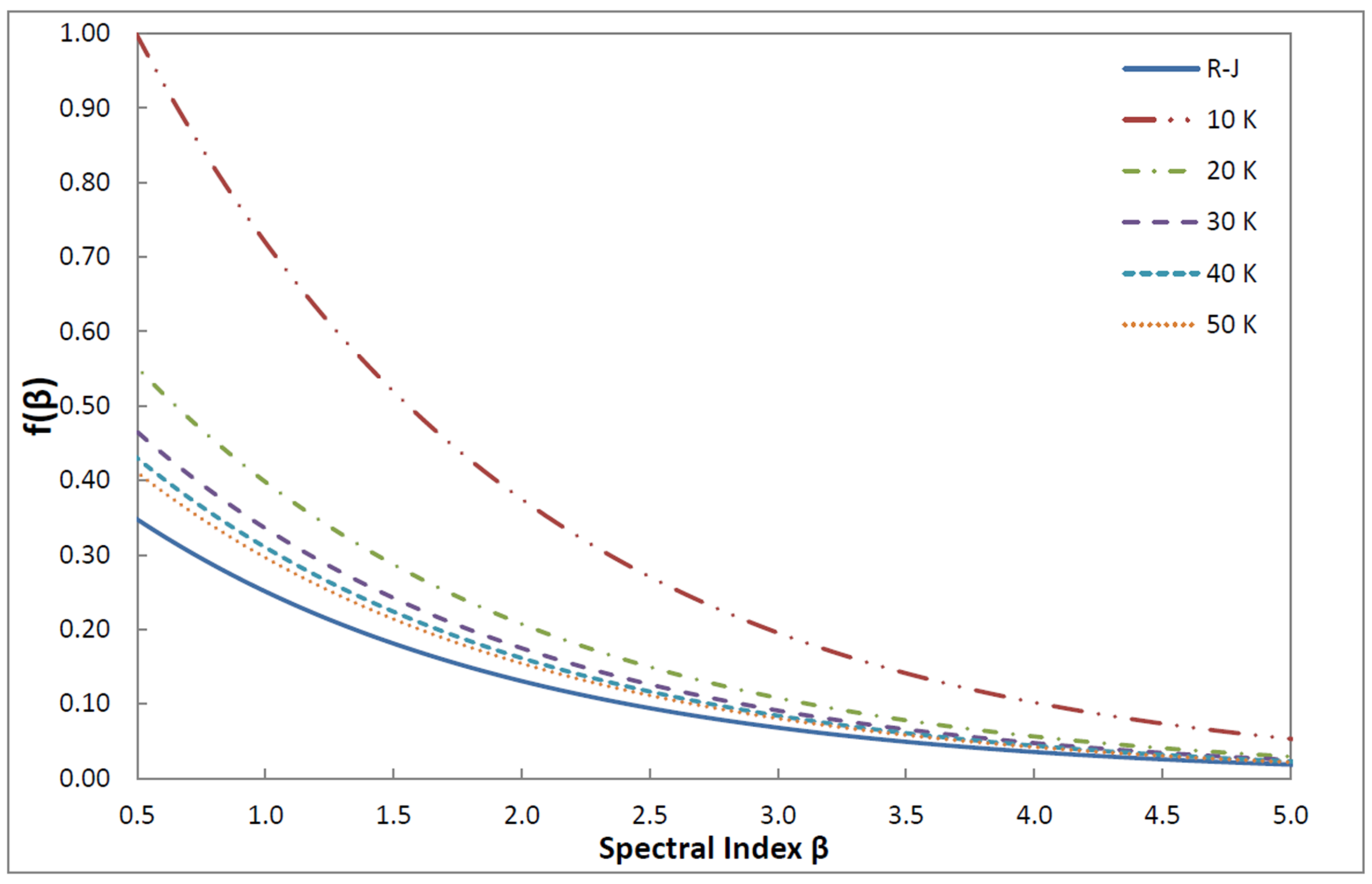

Figure 1: (*Up*) Effect of temperature on the determination of the spectral index. The plain line represents the result obtained with the Rayleigh-Jeans approximation. The spectral index can vary significantly in low temperature regions (under 20 Kelvin). This graph also shows that molecular contamination will underestimate β if not taken into account.

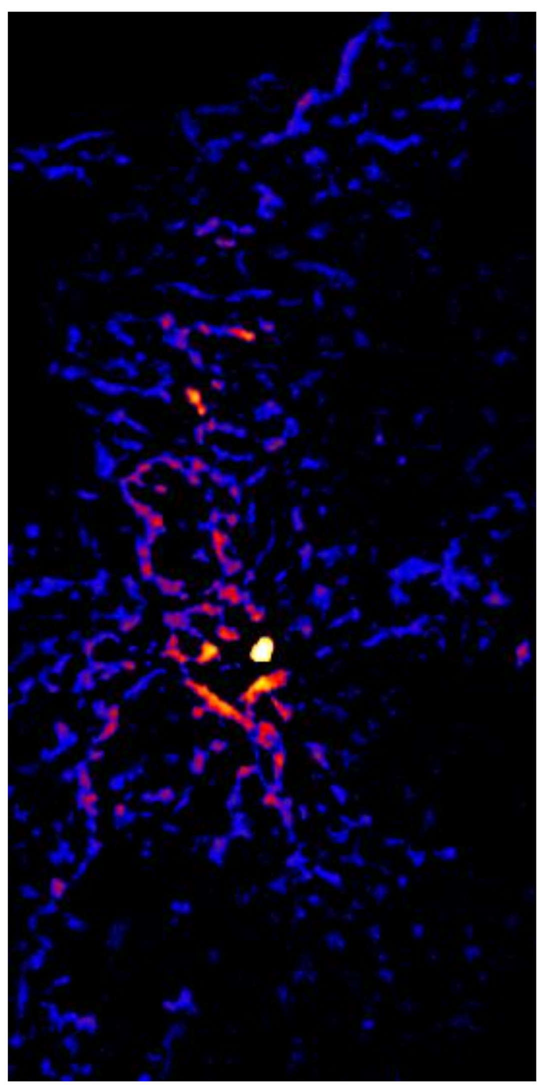

Figure 2: (*Left*) ^{12}CO 3-2 emission map at 850 µm for the Orion A molecular cloud. This map is used to estimate a lower limit for the total level of molecular contamination in the SCUBA-2 observations. It is expected to be significantly higher in hot cores or regions with forests of molecular lines. Created by Emily Drabek.

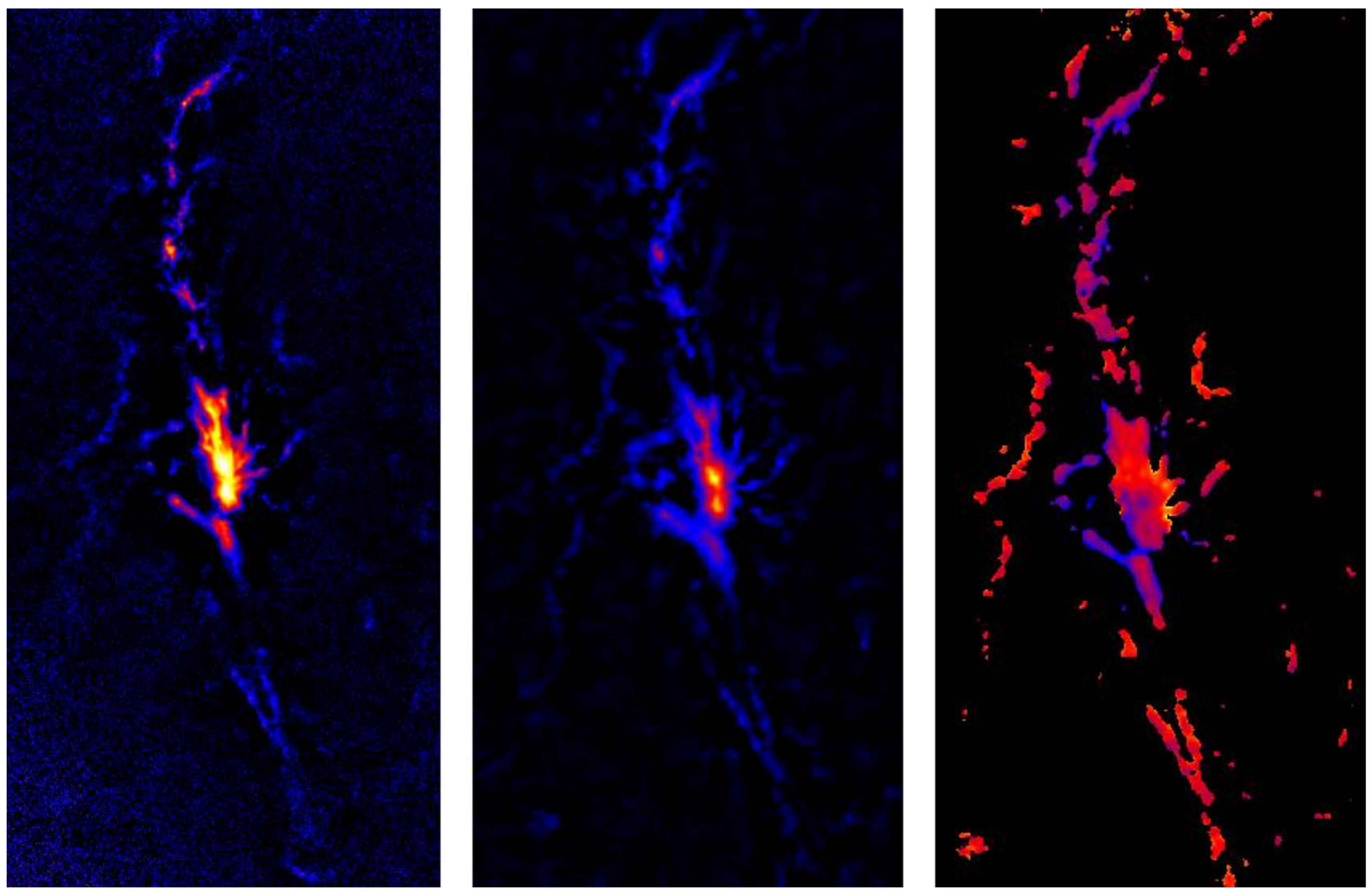

Figure 3: The integral-shaped filament of the Orion A molecular cloud (OMC). *Left panel*: Map at 450 µm (7''). Logarithmic scale up to 500 Jansky/beam. *Middle panel*: Map at 850 µm (14''). Logarithmic scale up to 170 Jansky/beam. *Right panel*: The derived spectral index β in the Rayleigh-Jeans approximation without contamination correction. Square-root scale up to 5.0. The filamentary nature of the molecular cloud is easily recognizable in both (450 & 850) maps. The R-J approximation is used to estimate the spatial variations.

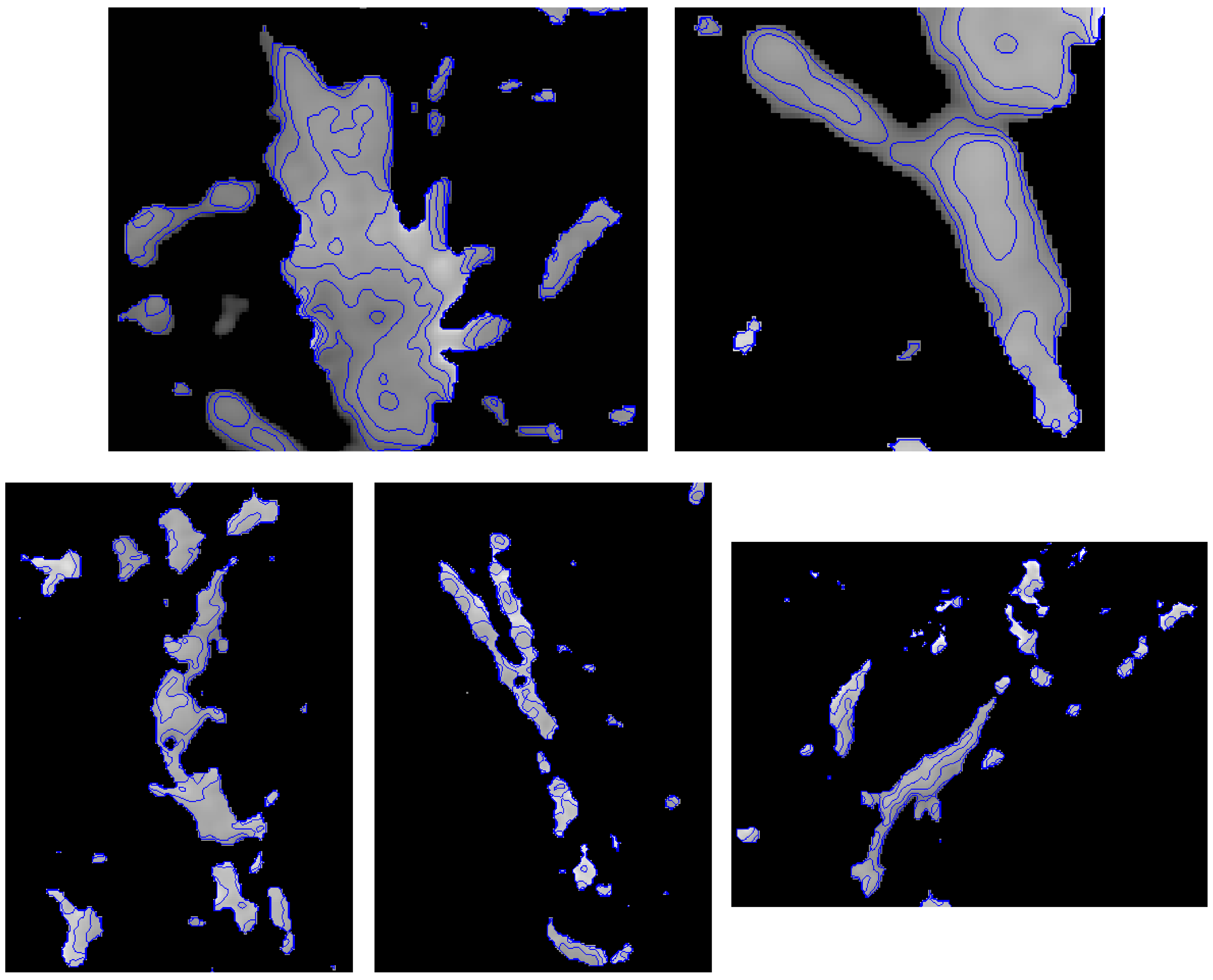

Figure 4: Emissivity spectral index with CO emission subtracted. A single-temperature blackbody fit is calculated for every region. Contours go from 1.0 to 3.0 by steps of 0.5.

***Upper left panel*: OMC-1 at a temperature[6] of 55 K. A few hot cores can be identified by anomalously low spectral indices. *Upper right panel*: The Orion bar at a temperature[7] of 45 K. Contamination up to 15%.**

***Lower left panel* : OMC-2 at a temperature[6] of 25 K. *Lower middle panel* : OMC-4 at a temperature of 45 K. *Lower right panel* : OMC-3 at a temperature[6] of 20 K.**

Conclusion

We found that contamination from molecular line emission in continuum observations can lead to an underestimation of the emissivity spectral index. We also illustrated the influence of temperature determination on the results for dust properties in cold regions. Using HARP CO observations as a tracer of molecular contamination at 850 µm, we get a first glimpse of the dust properties in Orion A through SCUBA-2 observations. In the future, by combining the SCUBA-2 science observations and the Herschel Space Telescope database, it will be possible to constrain even further the spectral energy distribution of cold interstellar dust in star-forming regions of the Gould belt.

References

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