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Cold clumps in massive high extinction clouds

From an observational point of view it is extremely difficult to observe the process of massive star formation (MSF). MSF occurs deeply embedded in molecular clouds and the events are rare, at large distances and very fast. Following a novel selection criterion of high mid infrared (MIR) extinction, a new sample of massive clouds was attained. We study these clouds for traces of MSF to constrain an evolutionary scenario for them. Our tools consist of single dish bolometer maps and spectral line data and maps.

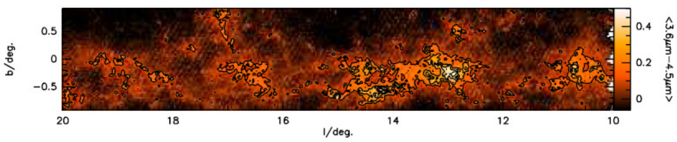


Figure 1. A MIR extinction image of the galactic plane of longitude between 10 and 20 degrees.

High extinction clouds: A population of massive clouds in the Galaxy!

Using the data from the GLIMPSE survey point source catalog, we extended the method pioneered by Lada et al. (1994) to measure the extinction to longer wavelengths (Indebetouw et al. 2005). This means that we look much deeper and hence are able to pinpoint the places with extreme visual extinctions: the densest and most massive clouds (see Fig. 1). Removing the clouds already known for MSF activity, a number of 23 massive (typically of the order of 10,000 $M_{\odot}$) high extinction clouds were selected to make up our sample.

A first image of the clouds: MAMBO 1.3 continuum maps

Dust emission using the MAMBO bolometer array at the IRAM 30m telescope was detected in all clouds, showing that they are associated with high column densities. The clouds come in various morphologies of which examples are presented in Fig. 2. There are clouds with no clear structure nor clumps, which we call the *diffuse clouds* (right). Other clouds have clear clumps, that either look single (middle) or dynamically connected (right). The first more quiescent clouds we call *peaked clouds,* and the second ones, which often have an interesting filamentary or curved shape the *multi peaked clouds*. These MAMBO maps of 23 clouds produced 56 targets for further study, namely the clumps (~20") or the highest emission peaks in the diffuse cloud cases. The masses of these clumps can be deduced from the continuum flux (see Motte et al. 2007) and they are of the order of 250 to 500 $M_{\odot}$ for these 3 prototypes.

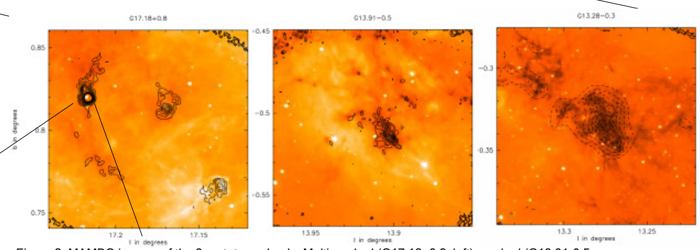
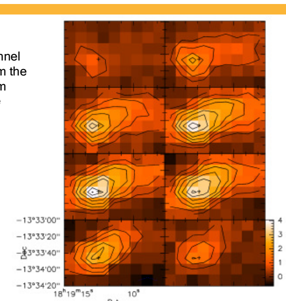


Figure 2. MAMBO images of the 3 prototype clouds: Multi-peaked (G17.18+0.8, left), peaked (G13.91-0.5, middle) and diffuse (G13.28-0.3, right). The solid contours start on 45 mJy (3σ), with steps of 20. In G13.28-0.3 the diffuse contours result from a smoothed map, and start on 15 mJy, with steps of 10.

A first spectral line follow up: Probing the temperature with ammonia

We performed ammonia spectral line observations with the 100m Effelsberg Telescope to determine the velocities and the temperatures of the clumps. In more than 52 of the 56 cores we find ammonia emission, a known infrared thermometer of dense material. We derive rotational temperatures between 11 and 18 K and column densities of 10^{15} cm^{-2} from the ammonia spectra. The average deduced kinematic distances are of the order 2 to 5 kpc.

Figure 3. N_2H^+ channel maps from the IRAM 30m telescope



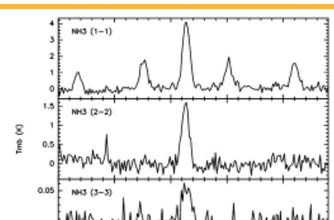


Figure 4. The ammonia (1-1), (2-2) and (3-3) spectra from the Effelsberg 100m telescope.

An impression: G17.18+0.8 clump B

From the NH_3 lines (Fig. 4) we deduce a rotational temperature of 13K and a column density of 10^{15} cm^{-2}. The spectral line data (Fig. 5) indicate that there are (proto) stars inside (heating), that there are outflows (CO line wings), shocks (SiO) and evidence for collapse (HCO^+). The N_2H^+ map (Fig. 3) shows a bright clump in the filamentary structure of the cloud.

Spectral line study: evolutionary states

For mm/submm line follow up studies, the clumps were observed with the IRAM 30m and the APEX telescope. Different spectral lines were observed: indicators of cold and dense material (N_2H^+, $H^{13}CO^+$), of outflows (HCO^+, CO), of shocks (SiO) and of heating (CH_3CN). The combination of different J transitions will allow to constrain the excitation of the dense gas. For the spatial information of the line emission, On-the-fly maps were observed.

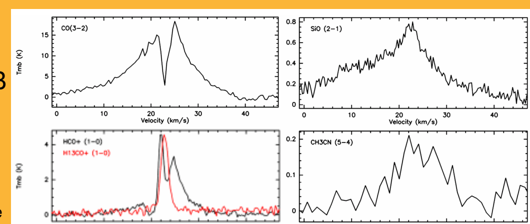


Figure 5. The from upper left to lower right: outflow indicator- CO (3-2), shock indicator - SiO (2-1), high density and kinematics probes $H^{13}CO^+$ and HCO^+ (1-0) and heating indicator- CH_3CN (5-4).

A preliminary classification of the clouds into an evolutionary sequence

From the bolometer dust images and the ammonia measurements we conclude that the high extinction clouds are indeed massive and harbour cold clumps similar to the infra-red dark clouds that are already known as MSF places (Pillai et al. 2007). Based on their temperature and the occurrence of star formation tracers like outflows and heating it is tempting to order the observed clouds into an evolutionary sequence. All 3 prototypes of the clouds are similar in mass content. But, the absence of star formation indicators in diffuse clouds could indicate them to be the predecessors of the peaked clouds.

prototype	diffuse(7)	peaked (5)	multi-peaked (12)
Trot	~13K	~13K	~15K
$N(NH_3)$	10^{15}	10^{15}	10^{15}
heating	0	2	10
shocks	1	3	9
infall	2	3	2
self.abs	2	0	2
complicated line-profiles	0	0	5

Table 1. An overview of the preliminary results of the investigation of the clumps so far with data from the Effelsberg 100m, APEX and IRAM 30m telescope.

A detailed analysis of the spectral dust emission line data is in progress to investigate the physical conditions and evolutionary stages of the clouds further. But, already at this stage of the analysis it is clear that the newly found sources will provide important clues for the various early stages of MSF.

References:
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Lada et al., 1994 ApJ, 429, 694
Motte et al., 2007, astro-ph, 0708.2774v1
Pillai et al., 2007, A&A, 467, 207