L134N/L183 REVISITED. DUST CONTENT AND GAS DEPLETION

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ABSTRACT

L134N is a cold, starless cloud, very high above the galactic plane, close to us and well delineated in continuum dust emission maps. This cloud is considered to be representative of oxygen rich dark clouds (with the presence of SO, SO_2, NO, ...). It is thus a good reference together with TMC-1 to test astrochemical models. Thanks to ISO, SCUBA, MAMBO and near IR wide field cameras, the detailed study of the dust has become possible in such cold and dark clouds. In parallel, progress in radiotelescope receiver sensitivity now permits the mapping of weak lines on large surfaces. We have thus started a project to study both dust and a few gaseous key species (CO, CS, SO and N_2H^+) to address several questions. As a first step we want to assess the quantity of dust and gas everywhere in the cloud, study possible $C^{18}O$ and/or $C^{17}O$ depletion towards dense cores, evaluate the structure of the gas, the abundance of CS and SO to possibly estimate the chemical age of the cloud (time dependent models show that the CS/SO ratio diminishes with time) and evaluate the rare isotope abundances, especially ^{17}O and ^{34}S. To constrain the molecular abundances with the highest possible confidence, we have observed several transitions for each species and each isotopomer. Preliminary results have been reported in Pagani et al. (2002) and more results are presented here. A large core is seen in the SCUBA and MAMBO maps with a mass about 1.5 $M_\odot$ and with a CO depletion factor of 35. This core is not seen in the 200 μm ISOPHOT map making ISOPHOT a doubtful tool to search for really cold cores.

Key words: ISM : molecules – ISM : dust,extinction – ISM : abundances – ISM : individual: L183 – ISM : individual: L134N – Galaxy : abundances

1. INTRODUCTION

Studying starless clouds is a fundamental first step in understanding how stars form. Because these clouds possess no internal energy input, no large kinematic motions and no grain mantle evaporation, they are cold and unperturbed. As a result the chemistry and radiative transfer in these clouds are much easier to understand and analyze. Still their structure remains complex as shown by the mapping of different species, e.g. in L134N where Swade (1989a) has shown that each species was tracing a different cloud shape.

L134N was recognized early-on as a good candidate to test chemical models. Considered as an oxygen-rich cloud it has often been compared to TMC-1 (carbon-rich cloud) to test chemical model predictions. However, to test these models, species abundances need to be accurately quantified. Until recently this has rarely been true and astrochemistry relies on measurements which are sometimes erronenous by as much as one order of magnitude. Because these models were still far from maturity, the problem was of limited importance but recent progress on our understanding of the dust, depletion, and evaporation phenomena makes better quantification of at least the most abundant species a necessity. A better understanding of the physical structure of the source is also mandatory for both the chemistry (reaction speed depends on density, e.g.) and to help evaluate the excitation parameters of each species.

L134N is ideally suited for such studies because it is close (100 pc, Mattila 1979, Franco 1989), rather large and high above the galactic plane (b^{II}= 37°). The reference position of the source in this study is : α_{2000}= $15^h54^m06.6^s$, δ_{2000}= $-2°52'19.1''$ and the LSR velocity is 2.5 km s^{-1}. Among the studies that have focused on L134N, one finds several molecular studies (Swade 1989a, Swade 1989b, Swade & Schloerb 1992, Dickens et al. 2000) which have revealed the large diversity of spatial dis-

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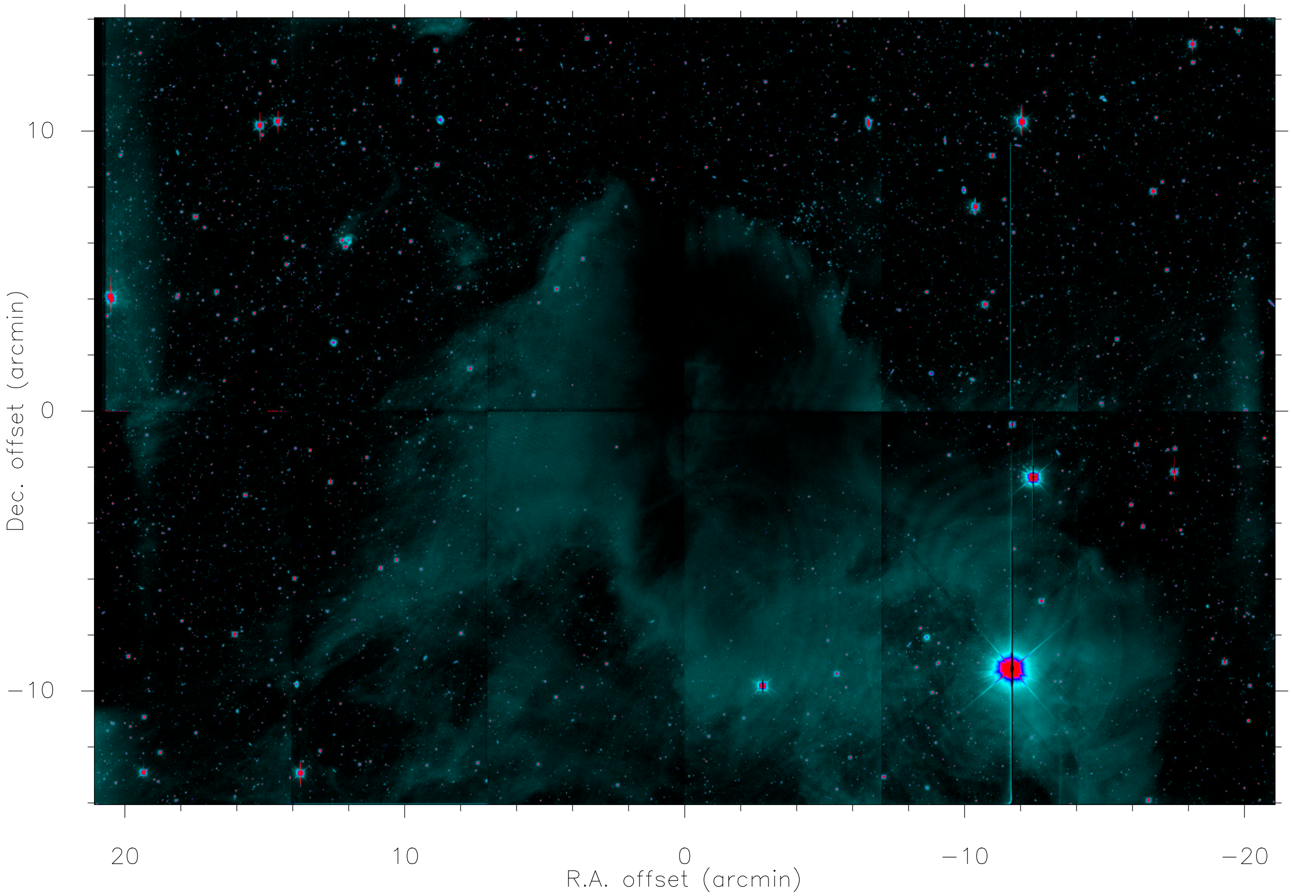

Figure 1. I Band image of L134N with the CFHT12K

tribution for different molecules in L134N, while IRAS FIR (Laureijs et al. 1991, Laureijs et al. 1995), SCUBA and MAMBO work (Ward-Thompson et al. 1994, Ward-Thompson et al. 1999) have revealed a cold condensation coincident with the molecular densest part of the cloud. ISO has also observed this cloud with both ISOCAM (Pagani et al. 2003) and ISOPHOT (Pagani et al. 2002, Juvela et al. 2002, Ward-Thompson et al. 2002). With the low spatial resolution ISOPHOT data, Pagani et al. (2002) have shown that this source suffers from a CO depletion of at least a factor of 2 on a large area. This was subsequently confirmed by a re-analysis of the same ISOPHOT data by Juvela et al. (2002).

We have undertaken a large study of this cloud, covering the main part of the cloud core ($15' \times 15'$). For the gas component, we have concentrated on 4 species at the moment, namely, CO, CS, SO and N_2H^+. For each species, at least two isotopomers have been observed in at least two transitions (except N_2H^+). CO traces total column density including diffuse gas, while CS is a widespread tracer of dense gas. However, both suffer from depletion in the densest parts of the cloud and, N_2H^+, less subject to depletion, is used to trace the very dense gas and dust (see Tafalla et al. 2002 for a similar study in other protostellar cores). To study the dust and its properties, we have analyzed the publicly available ISOPHOT data and have acquired large scale maps with SCUBA (at 850 μm) and MAMBO (at 1250 μm) to measure the dust emission, and we have also performed near infrared (NIR) observations at CFHT (IHK bands) to measure the dust absorption. A series of papers in A&A will detail all this work. Preliminary results are presented here and in Pagani et al. (2002).

2. Preliminary results

2.1. Near Infrared observations

Recent observations in the NIR have included a large scale ($48' \times 36'$) image in band I with the CFHT12K camera (Fig. 1) to measure the low extinction of the cloud envelope using star counts. The results show that the method is valid up to $A_v \approx 15$ mag (by comparison with the H-K results). The inner core (the one mapped in $C^{18}O$) has been mapped with the CFHT infrared camera

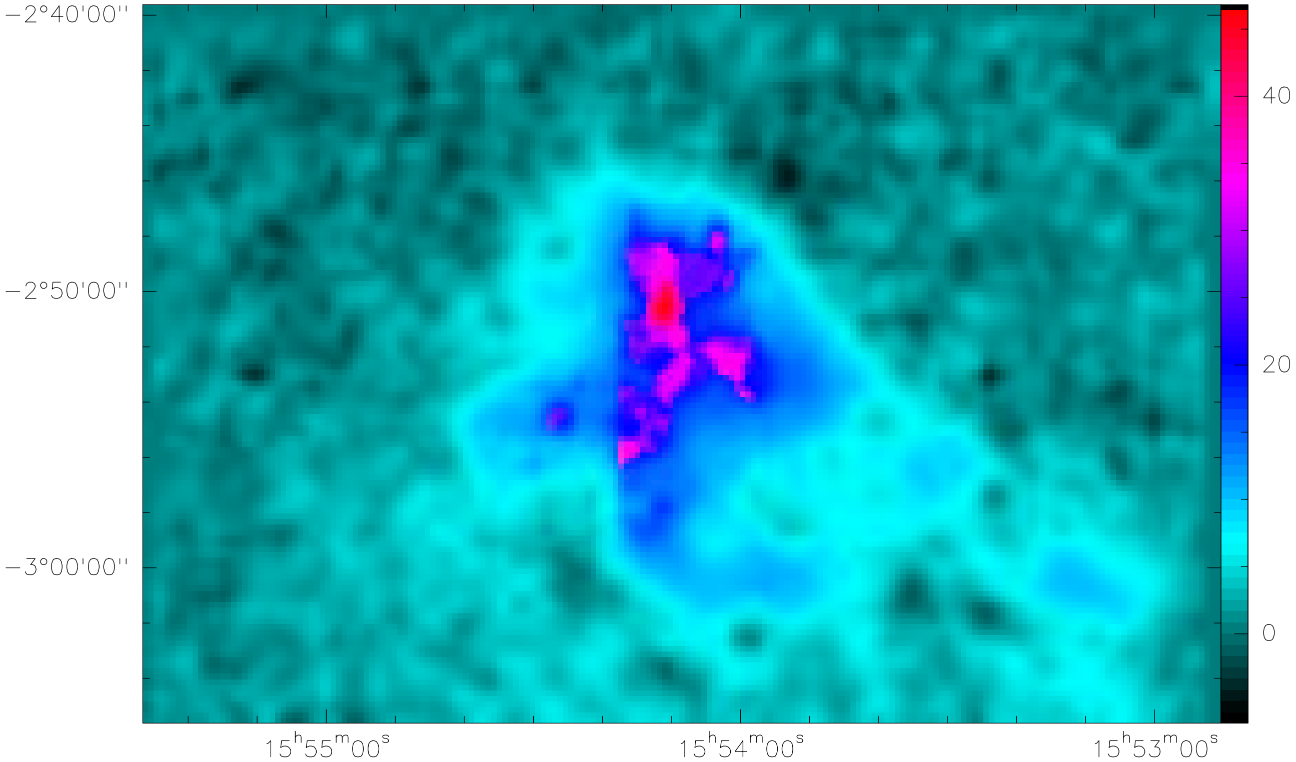

Figure 2. A_V image of L134N from the I and HK bands image combination. Scale is in magnitudes

in H and K bands. The camera covers 3.6′×3.6′on the sky and we have paved the core with 25 different exposures, with exposure time adapted to the expected opacity (a few minutes at the borders, several hours in the center). I band calibration has been done using the DENIS survey and HK calibration has been done with the 2MASS survey. The H-K reddening method described by Lada et al. (1994) has been used to measure the reddening. Because we are high above the galactic plane, the mean H-K value in the unreddened region is ≈ 0.5 mag instead of the mean 0.13 mag which applies for stars in our local Galaxy. This is due to the fact that we are dominated by unresolved galaxies at high redshift. The global extinction map combining both I and H-K results is shown in Fig. 2. Values above 40 mag. in the inner core are not reliable because this part of the core shows no sources at all with a limiting extinction A_V of ≈ 40 mag (Fig. 3). If we superimpose the MAMBO emission data on this core we find that the starless core corresponds to the 20 mJy/beam level of the Mambo emission. Thus the Mambo peak intensity of 70 mJy/beam is indicative of a dust opacity of ≈ 140 mag. This is an upper limit since large scale emission is lost in the Mambo Chopper Observing mode. If we lose as much as 20 mJy/beam, the contrast is then only a factor of 2.25 and the peak opacity would then be only 90 mag. This is much higher than the preliminary value ($A_V = 10$ mag, incorrectly underestimated by 40%) we reported in Pagani et al. (2002) and which was corrected (to $A_V = 17$ mag) by Juvela et al. (2002). As we warned at that time, the maximum A_V was probably underestimated due to both the low resolution limitation and the short wavelength of the ISOPHOT measurements. The latter at 100 and 200 μm fall beyond a 12 K blackbody peak in the Wien regime and small temperature errors induce large opacity estimate errors. Another possibility is that the core may be much colder than 12 K and even the 200 μm would then fail to trace it.

The MAMBO core is 84″ in diameter, with an average of 44 mJy/beam which converts to $A_V \approx 57$–71 mag depending on the lost large scale emission offset we reintroduce. This gives a mass of 1–1.5 $M_\odot$ for the core and if the core is spherical a volume density of 7–9 $\times 10^5$ cm^{-3}. This core has first been seen by Ward-Thompson et al. (1994) at 850 μm with the JCMT but the coordinates are wrong by almost 2′ in declination. With a size comparable to the ISOPHOT 200 μm resolution, and a contrast around 2 with the surrounding material, there is thus no reason that ISOPHOT could miss this core except if it is optically thick and/or extremely cold. Finally, within a radius of 11′, which encompasses most of

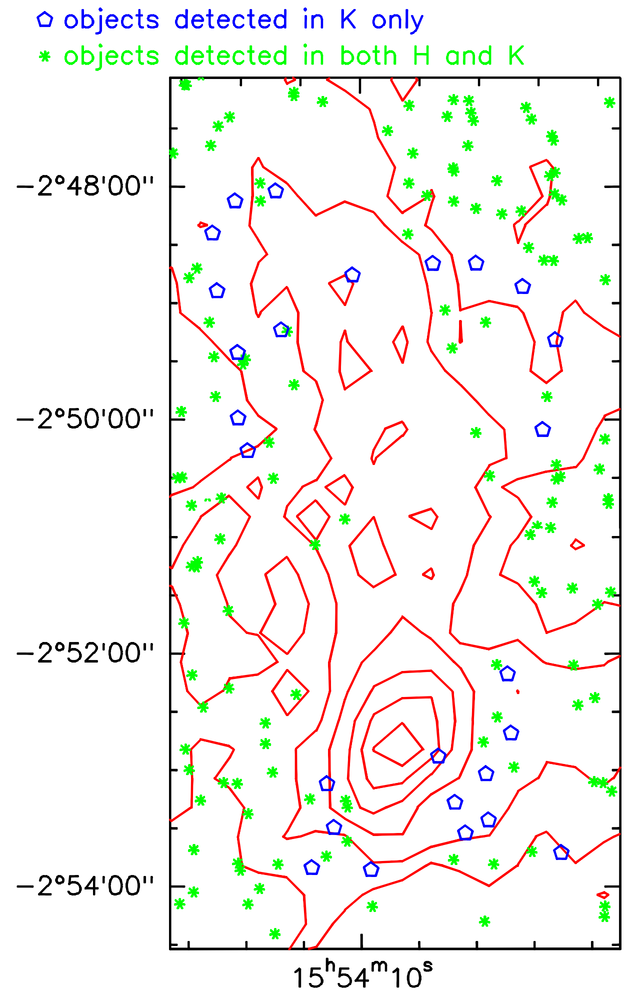

Figure 3. L134N Core. Contours represent emission at 1250 μm (MAMBO). Levels run from 10 to 60 mJy/beam by steps of 10. Almost no source is seen inside the vertical 20 mJy/beam contour, which corresponds to A$_V$ *≈ 40 mag. On the righthand side of the MAMBO peak, the increase of sources is indicative of lower extinction and thus of warmer dust*

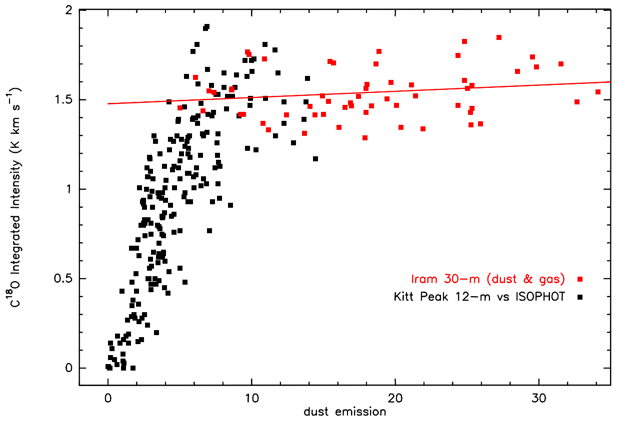

Figure 4. C^{18}*O depletion. Low (ISOPHOT vs Kitt Peak 12-m) and high (IRAM 30-m) resolution data have been assembled in this plot. The dust emission axis is in arbitrary units*

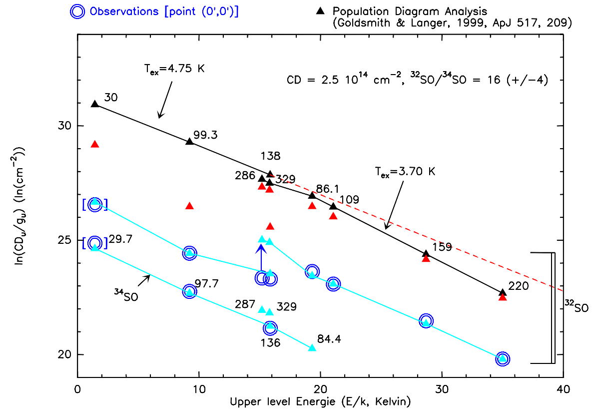

Figure 5. SO and ^{34}*SO rotational population diagram. Black triangles represent the "optically thin" evaluation, red triangles the opacity correction and the blue triangles the 3 K background correction. In fact, the diagram only helps to visualize the fit. It cannot be used to find the solution (this would introduce a two orders of magnitude error here). For* ^{34}*SO, only the solution (cyan) is shown*

the cloud, the average extinction is $A_V = 7.1$ mag which yields a total cloud mass of 36 $M_\odot$.

2.2. CO DEPLETION

CO depletion which has been predicted long ago but discovered only recently was reported for the first time in L134N by Pagani et al. (2002) and confirmed by Juvela et al. (2002). However, because dust was not correctly traced by ISOPHOT measurements, the actual depletion factor was completely underestimated in both papers. With both high resolution C^{18}O (J:1-0) and dust measurements, both from IRAM 30-m we can now extend the original plot we published in Pagani et al. (2002) and show the dramatic effect of depletion in this core (Fig. 4). The horizontal scale is only qualitative (from preliminary estimates as discussed above, it represents roughly 1/4th of the actual Av scale). Depletion appears at 7 in the horizontal scale, that is about $A_V \approx 28$ mag. The regression line fits the IRAM data. It indicates that between 10 and 70 mJy/beam, the C^{18}O (J:1-0) integrated intensity increases by 0.1 K km s^{-1}. For a 10 K core, this represents about 9% increase in column density, while for a 7.5 K core, it represents 16%, the line being optically thick (with a simple LVG model). These are order of magnitude estimates and a detailed model should be developed to investigate this problem (Pagani et al. 2003). With only a 15% increase in intensity while the dust goes from 28 to 140 mag in extinction, we can deduce that CO is depleted by a factor of ≈ 35 in the core.

Another interesting result is that the $C^{18}O$ peak at the position (4.5',-2.5') from the center (see Fig. 1 of Pagani et al. 2002) is sitting on a dust peak ($A_V \approx 20$ mag from H-K measurements) of lukewarm (15 K) dust as shown by the ISOPHOT 100 μm peak. This $C^{18}O$ peak shows no sign of depletion (but a strong absorption by foreground material in the $C^{18}O$ (J:2-1) transition, see Fig. 2 of Pagani et al. 2002). A preliminary evaluation of density towards this peak gives about 10^4 cm^{-3} while the $C^{18}O$ emitting core layer was evaluated around 3 10^4 cm^{-3} at 10 K (Pagani et al. 2002). In fact the density in the core layer is probably higher because the temperature is lower than 10 K in the core. The provisional conclusion is that in this cloud depletion occurs only above $A_V \approx 25$ mag, in a very cold core only. Whether it is a density threshold or a temperature threshold or both is not yet clear. The opacity limit for depletion to occur is a factor greater than 2 above usual determinations but it looks from this result that determinations based on ISOPHOT data alone are probably much underestimated in many cases.

2.3. SO abundance in the core

SO is interesting because the CS/SO abundance ratio is supposed to trace the cloud chemical age. However the collision coefficients published by Green (1994) are not suitable for low temperatures and lead to estimates which can be wrong by an order of magnitude (or more if one tries to fit the ground transition (1_0-0_1) at 30 GHz). In such a case and because SO has, like non-linear molecules, many lines in the mm regime sampling a full range of energy levels, it is relatively easy to study many of these lines and plot them into a rotational population diagram to retrieve the actual column density (Goldsmith & Langer 1999). We have thus mapped the 99, 109, 138 and 220 GHz lines of SO, the 98 and 136 GHz lines of ^{34}SO. A few positions have been also obtained for the 159 GHz line of SO and the 106 GHz line of ^{34}SO (no detection for the latter). To test the population diagram analysis we have included the 30 GHz SO and ^{34}SO data of Rydbeck et al. (1980) and the 86 GHz data of Swade (1989a) towards the reference position (or very close to it). The results are displayed in Fig. 5. In fact because the 30, 99 and 138 GHz lines are optically thick and because the excitation temperature is close to the 3 K background, a direct fit of the values would lead to an underestimate by two orders of magnitude of the true column density. Instead we have to guess a possible column density and excitation temperature, estimate the resulting intensities and compare them with the observations. Note that the 3K background is not subtracted in the standard rotational population diagram method. This becomes a problem at low temperature when the excitation temperature is close to the 3K background. Thus even for optically thin lines, the rotational population diagram cannot be directly applied if the excitation temperature is low, which is the case for most molecules in dark clouds. The 3K correction appears in Fig. 5 as the distance between the red and the cyan triangles. The column density we derive would be the one that is found by using the "optically thin estimates" and extrapolating them to energy zero. The value we derive in this diagram is 2.5 10^{14} cm^{-2} for SO and 16 times less for ^{34}SO. This is a factor of 5 above the result presented by Dickens et al. (2000) using extrapolated Green collision coefficients to low temperature (including a 30% over-correction they brought to their data by calibrating them in T_{MB} instead of T_r^* which is more appropriate for extended sources). This shows how cautious one must be when using column density estimates from the literature as input to chemical models.

3. Conclusions

We have brought a new insight to the L134N/L183 cloud through the work which we have described here and in Pagani et al. (2002). The new picture which emerges is the following : an opaque core ($A_V \approx 140$ mag), probably very cold (7 K ?), with a mean density just below 10^6 cm^{-3} is depleted in CO (and CS) by a factor 35. Its mass is in the range 1–1.5 $M_\odot$. It is also traced by N_2H^+ which does not coexist with CO in this cloud as predicted by chemical models. CO is apparent in both outer core layers at densities just below 3 $\times 10^4$ cm^{-3} and diffuse gas at density around 10^3 cm^{-3}. The latter absorbs preferentially the $C^{18}O$ (J:2-1) transition without signs of self-reversal and thus yields abnormally low $C^{18}O$ (J:2-1)/(J:1-0) ratios. This can be solved with the use of the optically thin $C^{18}O$ (J:3-2) line and a multilayer Monte-Carlo radiative transfer model. This shows that the $C^{18}O$ (J:2-1) transition is not a good tracer of gas in dark clouds. The mass in the envelope is an important fraction of the total mass of the cloud.

Another important result we can probably derive already is that the ISOPHOT 200 μm maps cannot reveal extremely cold, probably optically thick (!) dust cores such as the one described here. Caution must thus be used when deriving dust column density in cold clouds with only ISOPHOT data. We doubt that ISOPHOT has the possibility to reveal very cold cores.

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