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# L134N Revisited

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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 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 allows to map 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. We want to assess the quantity of dust and gas all over 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 $^{34}S$ in a first step. To constrain the molecular abundances with the highest possible confidence, we have observed several transitions for each species and each isotopomer. Though we have observed far less species than Dickens et al. [1], we have done it on a larger area, including thus the strongest $C^{18}O$ peak and two other peaks, with a better signal-to-noise ratio. Most of the data are already acquired. We present here preliminary results.

## 1 INTRODUCTION

Studying starless clouds is a fundamental step in understanding how stars form. Because these clouds are cold and unperturbed by stars they also seem more simple to understand and analyze when it comes to chemistry and radiative transfer. One such cloud is L134N (= L183). Starless, high above the galactic plane (b = +37°), rather rich in oxygen (detection of SO, $SO_2$,...) and very cold (8-12K). It is one of the two reference dark clouds (with TMC-1) used as benchmarks for comparison with astrochemical models. It is also a main target for ODIN, and later on HERSCHEL.

The first step is to evaluate the column density of all rare species, starting with CO isotopes. To do this, a careful excitation analysis is needed which requires a good knowledge of the

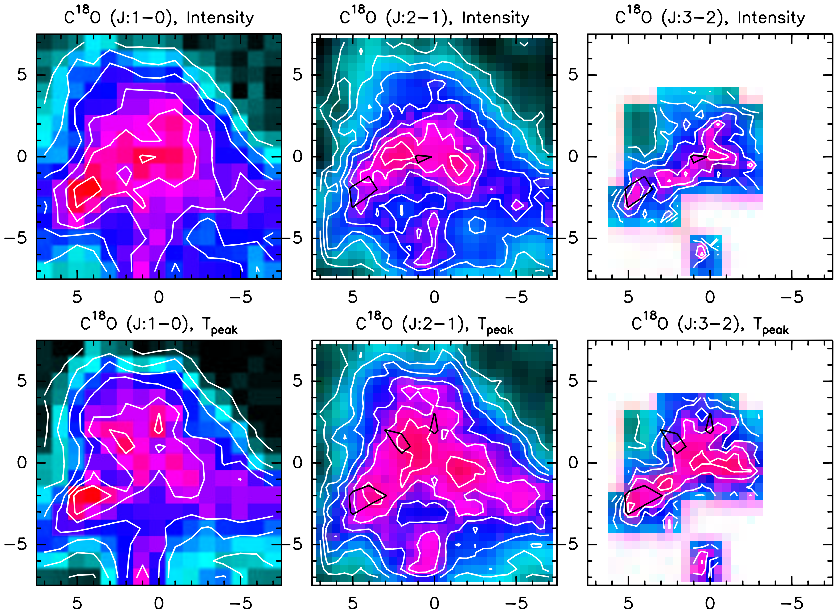

**Fig. 1.** $C^{18}O$ maps. For both rows, the highest 1-0 contour is repeated on the two other maps in black. **Top row** Levels (K.km/s) 1-0 : 0.3/1.8/0.3, 2-1 : 0.2/1.4/0.2, 3-2 : 0.1/0.6/0.1 **Bottom row** Levels (K) 1-0 : 0.5/3/0.5, 2-1 : 0.3/1.8/0.3, 3-2 : 0.2/0.8/0.15

dominant density and temperature phases present in the cloud. Because each species does not necessarily exists at the same place as the others and because its emission characteristics can differ widely from others, we think it is necessary to observe several transitions for each species to independently estimate its excitation temperature and total column density. For a long time such an approach has rarely been done because it would have required large amounts of telescope time. It seems that now, at least for a cloud as important as L134N, such an effort is both possible and fruitful, leading to a coherent view of the chemical and physical structure of its contents.

We have thus started a large scale (15'×15') mapping of L134N. The following species have been mapped : $^{12}CO$, $^{13}CO$, $C^{18}O$, $C^{17}O$, $C^{32}S$, $C^{34}S$, $^{32}SO$, $^{34}SO$ and $N_2H^+$. Except for $N_2H^+$, each species has been observed at least in two different transitions with the NRAO 12-m and/or CSO 10-m telescopes. ISOPHOT maps of the dust at 100 and 200 $\mu$m have been reduced and a first run with SCUBA has just been done. The data collection is almost complete and data reduction is ongoing.

## 2 PRELIMINARY RESULTS

If usually the $C^{18}O$ (1-0) line emission measurement alone is considered sufficient to derive the species column density and subsequently the total gas column density in most cases, it does not allow to disentangle envelope and core emission neither does it indicate a possible saturation. In cold, dark clouds, the risk of saturation is not negligible because most of the molecules are in their lowest energy levels. Here, the $C^{18}O$ (1-0), (2-1) and (3-2) lines have been mapped (Fig.1). CS (2-1) and (3-2) and $C^{34}S$ (2-1) have been mapped also and a few positions have been observed for CS (1-0) and $C^{34}S$ (1-0) (with the Haystack 34-m antenna) and (3-2). Two $C^{18}O$ positions, (0,0) and (5',-2'), and an average of the CS lines towards (-1',0), (0,0) and (1',0) positions have been analyzed with a Monte-Carlo code. Towards the reference position a single solution could be found for all $C^{18}O$, CS and $C^{34}S$ transitions (Fig. 2) which indicates the existence of an important envelope and a moderately dense core. The

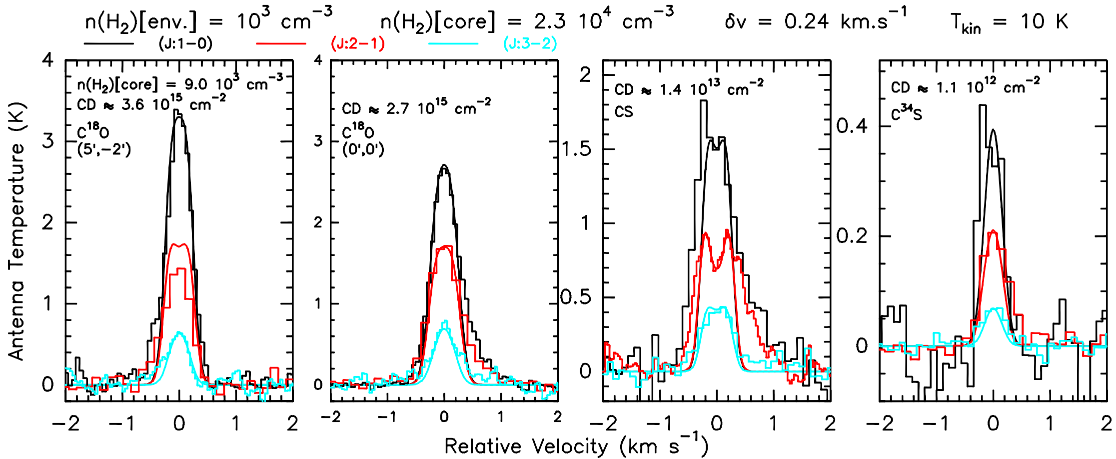

**Fig. 2.** CS, C$^{34}$S and C$^{18}$O 1-0, 2-1 and 3-2 lines fit with the same Monte-Carlo model parameters except for the (5',-2') position which requires a lower core density. The CS and C$^{34}$S data are the average of 3 adjacent positions (-1',0),(0,0) and (1',0) for better signal-to-noise ratio

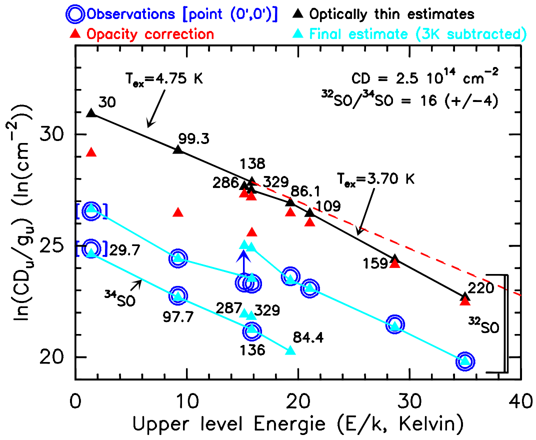

**Fig. 3.** SO and $^{34}$SO population diagram fit. For $^{34}$SO, only the solution (cyan) is shown

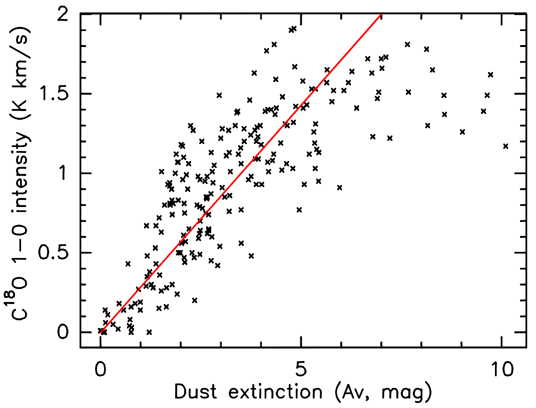

**Fig. 4.** C$^{18}$O depletion. Dust extinction is derived from ISOPHOT 100 and 200 $\mu$m maps. Coarse resolution and short wavelength may cause an underestimate of A$_v$ by at least a factor of 2

envelope contains as much C$^{18}$O as the core but 10 times less CS. The low core density is probably due to both CO and CS depletion onto grains in the densest part traced by N$_2$H$^+$. Interestingly enough, the C$^{18}$O (1-0) and (2-1) transitions alone, when fitted with a LVG model e.g., lead to higher column densities, lower densities and the model predicts (3-2) intensities twice as low as observed. This is perfectly explained by the fact that the (2-1) transition is optically thick and self-absorbed by the envelope without showing clear signs of saturation. The profiles computed by the Monte-Carlo code can mimic this behavior. Without the envelope, the (2-1) transition would be above 2.5 K instead of the 1.8 K observed and the only trace of self-absorption is the larger width of the (2-1) transition. This shows that the C$^{18}$O (2-1) line is strongly misleading to derive CO column densities in cold clouds. The most extreme case is the (5',-2') position which is the strongest position in the (1-0) map but rather weak in the (2-1) map. The (2-1)/(1-0) ratio of 0.4 is extremely low and we have not been able to fit it with the Monte-Carlo model. LVG did not succeed either to explain all 3 transitions.

SO is interesting because the CS/SO abundance ratio is supposed to trace the cloud chemical age. However the collision coefficients published by Green [2] 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 [3] to retrieve the actual column density. 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 of SO and 106 GHz 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. [4] and the 86 GHz data of Swade [5] towards the reference position (or very close to it). The results are displayed in Fig. 3. 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.

While much work is devoted to the chemical composition of L134N, little concerns the dust and its properties [6], [7], [8] and none of them address the CO depletion problem nor try to get independent estimates of the hydrogen column density therefore publishing species relative abundances which can be wrong by a factor of up to 10 or even more. The easiest way to evaluate $H_2$ independently from CO is to evaluate the dust content of the cloud and use a dust-to-gas conversion factor. ISOPHOT maps at 100 and 200 $\mu$m tracing the cold dust emission exist and we have used them to make a preliminary search for CO depletion (Fig.4). Though we are seemingly successful, we have met some limitations which are linked to the ISOPHOT data : the CO depletion appears but at a surprisingly low value of $A_v = 5$ with a maximum $A_v$ of $\approx 10$ for the peak dust emission. Both $A_v$ values are probably too low by a factor at least 2. The ISOPHOT limitations come from a coarse spatial resolution (3' @ 200 $\mu$m) and from the wavelength of the maps, both situated beyond the black body peak of cold dust (estimated to be between 8 and 14 K), that is in the Wien regime. Moreover these emissions result from the combination of dust at two different temperatures and thus can easily lead to a wrong dust column density estimate if the two temperatures are not evaluated properly and/or if the spectral index deviates from its standard value. The coarse spatial resolution is also a possible limitation on the peak opacity estimate.

## References

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