# DENSITY STRUCTURE OF PRESTELLAR CORES SEEN IN ABSORPTION WITH ISOCAM

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ABSTRACT

An ISOCAM survey has been carried out in order to detect and map a sample of 23 starless dense cores in absorption against the diffuse mid-infrared background. The goal is to gain insight into the structure of pre-stellar dense cores. In previous submillimeter continuum studies of such starless cores, it was found that the derived column density profiles did not follow a single power-law in $N_{H_2}$ $\alpha$ $r^{-1}$ throughout their full extent but flattened out near their centre (Ward-Thompson et al. 1994, André et al. 1996). These observations however could not constrain the density profiles farther than $\sim$ 10000 AU. The present absorption study uses ISOCAM's sensitivity and angular resolution to determine the structure of the cores at angular radii that extend beyond the limits of sensitivity of the submillimeter continuum maps. Among the 23 cores observed in our survey, more than half of them show absorption features. The starless cores studied here all show a column density profile that flattens in the centre, which confirms the above-mentioned submillimeter emission results. More interestingly, beyond a radius of $\sim 4000-5000$ AU, the typical column density profile steepens with distance from core centre and gets steeper than $N_{H_2}$ $\alpha$ $r^{-1}$ until eventually the core merges with the low-density ambient molecular cloud. Thus the cores present a sharp edge at R $\sim 15000-30000$ AU and appear to be decoupled from the parent cloud, providing a finite reservoir of mass for subsequent star formation.

Key words: ISO; infrared astronomy; ISM: dust, extinction; Stars: formation.

## 1. INTRODUCTION

An ISOCAM survey has been carried out in order to detect and map starless dense cores (prestellar and precollapse) in absorption against the diffuse mid-infrared background. This study should yield interesting information about the structure of prestellar cores, the process of cloud fragmentation and the initial conditions of star formation.

Pre-stellar cores are dense, gravitationally-bound portions of molecular clouds which are undergoing a quasistatic contraction under the effect of their own gravity. They are cold (10-20K) as they are only heated by the surrounding interstellar UV radiation field and the dust that they contain emits in the millimeter and submillimiter bands. Some of them were mapped in star forming regions (such as the Rho Ophiuchi complex) and their density structure was studied (Ward-Thompson et al. 1994). It was found that the column density profile does not follow a power law in $r^{-1}$ all the way (where $r$ is the distance from the centre of the clump) which would correspond to the $r^{-2}$ density profile of a singular isothermal sphere (e.g. Shu et al. 1987, Shu 1977). Instead, the observed profiles flatten out near their centre.

A more detailed study was carried out by André, Ward-Thompson, Motte (1996 - hereafter AWM96) on the L1689B dense core situated in one of the $\rho$ Ophiuchi streamers. This core was mapped in the 1.3 mm continuum at the IRAM 30 m telescope. The $H_2$ column density profile (averaged in an East-West sector) inferred from the data was found consistent with a model in $N_{H_2}$ $\alpha$ $r^{-0.3}$ in the centre and in $r^{-1}$ for $r \geq 25$ arcsec. In a 40 deg North-South sector, the slope of the profile beyond the flat inner part was found to be steeper than $r^{-1}$.

It is however necessary to bear in mind the limitations of the millimeter continuum observations: they are mostly sensitive to the innermost parts of the cores since the mapping technique filters out any extended emission. It is therefore very difficult to trust the data at large angular radii and to find out whether or not the cores show an edge. The existing millimeter maps ($\sim$ 4 arcmin by 4 arcmin) may also be too small to show a possible edge to the cores.

Moreover, the conversion of 1.3 mm continuum flux into $H_2$ column density is strongly dependent on the assumed temperature of the core, which is not a very accurately known quantity (among others such as the dust opacity).

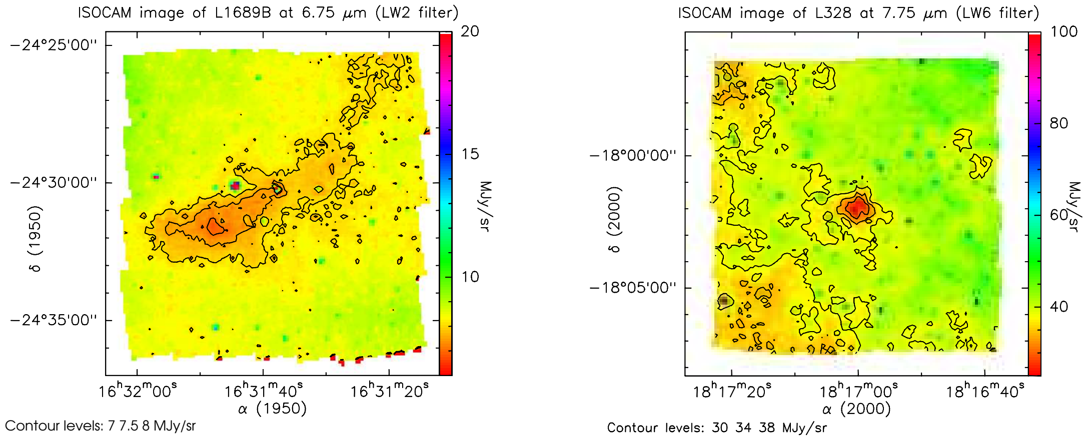


*Figure 1. (left) ISOCAM image of the dense core L1689B seen in absorption in the LW2 filter ($5\,\mu m \leq \lambda \leq 8.5\,\mu m$) centred on $6.75\,\mu m$. L1689B is situated in one of the Rho Ophiuchi molecular cloud streamers, at d = 160 pc. The elongated shape of the main component of the core in the East-West direction made it necessary to consider the East-West and the North-South directions separately. (right) ISOCAM image of the dense core L328 seen in absorption in the LW6 filter ($7\,\mu m \leq \lambda \leq 8.5\,\mu m$) centred on $7.75\,\mu m$. The core is fragmented but its main component has a circular shape. Estimated distance: d $\sim$ 200 pc.*

## 2. WORK CARRIED OUT WITH ISOCAM

To supplement the work previously done in the millimeter waveband, we observed a number of starless dense cores with the infrared camera ISOCAM, aboard the ISO satellite. The cores in this ISO survey were selected from various dark cloud catalogues (e.g. Benson & Myers 1989, Parker 1988, Schneider & Elmegreen 1979), on the ground that they contained no IRAS source and that the infrared background was strong ($\geq 1$ MJy/sr at $7\,\mu$m). The ISOCAM filters we used were LW2 ($5\,\mu m \leq \lambda \leq 8.5\,\mu m$) or LW6 ($7\,\mu m \leq \lambda \leq 8.5\,\mu m$) as these correspond to a minimum of the dust extinction curve (Draine and Lee 1984) and can thus probe the interiors of molecular clouds. The pixel field of view is 6 arcsec and the total surface area mapped per field is about 10' by 10'. For comparison, the 1.3 mm continuum maps made by AWM96 were about 4' by 4'. With a larger field of view, we tried to constrain the density profiles at larger radii.

As the cores are dense, cold and opaque, they absorb the infrared emission. They are therefore seen in absorption against the mid-infrared background arising from cloud envelopes.

Out of the 23 dense cores that we observed, 12 showed absorption features. The ISOCAM images[1] we obtained of the cores L1689B and L328 are pictured in Figure 1. A section in intensity through the main component of L328 (Figure 2) clearly shows a deep absorption and a steep profile. For a few cores, we compared the ISOCAM images with 1.3 mm continuum maps taken with the IRAM 30 m telescope. As shown in Figure 3, there is a good correspondence between the infrared absorption contours of the ISOCAM maps and the millimeter continuum images. This holds also true for the core L1689B and most of the cores not pictured here.

This result shows the consistency of both types of observations and justifies the comparison between the column density profiles obtained from the ISOCAM data and the 1.3 mm continuum data.

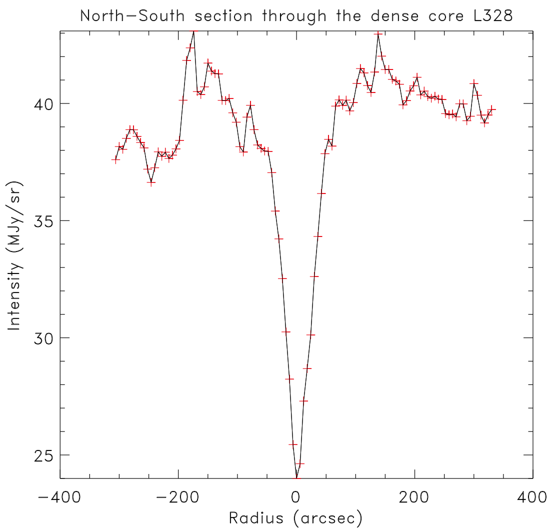


*Figure 2. Intensity cut through the ISOCAM image of the dense core L328, at $\alpha(2000)=18^h\,17^m\,00^s$. The absorption is strong and the steep profile suggests that the core has an edge.*

[1] The ISOCAM data presented in this paper was analysed using "CIA", a joint development by the ESA Astrophysics Division and the ISOCAM Consortium. The ISOCAM Consortium is led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matiere, C.E.A., France.

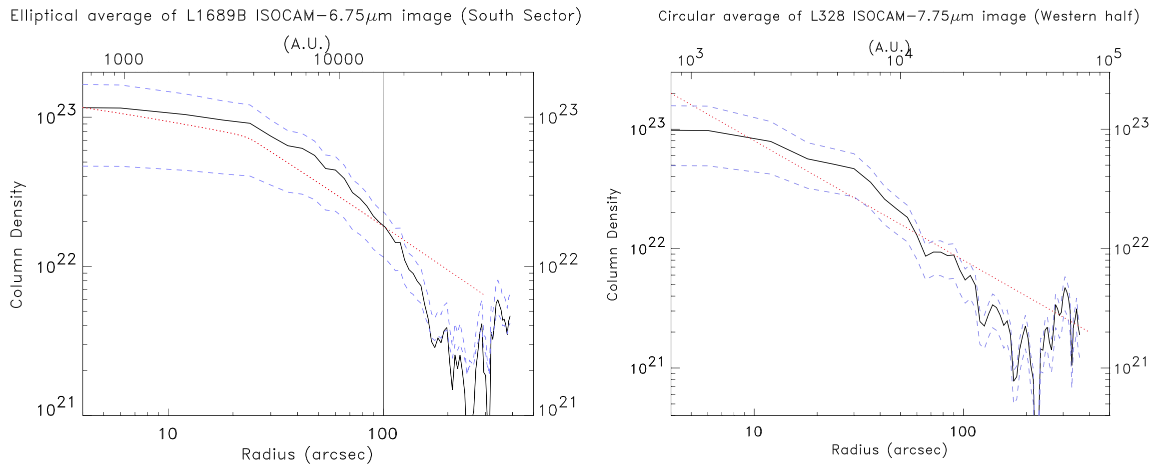


*Figure 4. (left) Column density profile of L1689B in the South direction as derived from our ISOCAM data. The vertical line represents the edge of the 1.3 mm continuum map.The column density profile over the South sector of the core is compatible with the model that fits the millimeter continuum data of AWM96 (dotted line). Indeed, it is rather flat in the centre and presents a slope very close to $r^{-1}$ beyond ∼ 5000 AU up to ∼ 15000 AU. Beyond that distance however, the profile gets steeper than $r^{-1}$ up to ∼ 30000 AU where it seems to merge with the ambient cloud. The shape of the ISOCAM profile is close to a Gaussian curve of HWHM 57 arcsec (∼ 9000 AU at d = 160 pc). (right) Column density profile of L328 calculated from the ISOCAM data. A simple power-law model in $r^{-1}$ (dotted line) was plotted for comparison.*

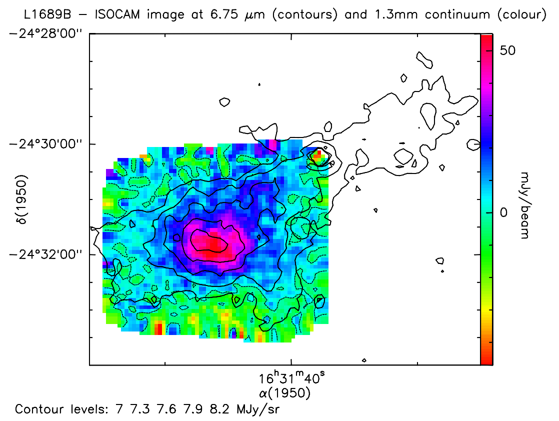


*Figure 3. L1689B - ISOCAM 6.75 μ absorption contours superposed on 1.3 mm continuum emission image (colour). There is a good correspondence between both types of data. The millimeter emission peak is located on the infrared absorption peak and the elongation of the filament is in the same direction for both types of data.*

## 3. ANALYSIS

In order to better quantify that comparison, we transformed the infrared intensity into $H_2$ column density by expressing the infrared intensity as:

$$I(r) = I_{background} \cdot e^{-\tau_r} + I_{foreground} + I_{zodiacal}$$

where $I_{background}$, $I_{foreground}$ and $I_{zodiacal}$ are respectively the background, foreground and zodiacal intensities and $\tau_r$ is the dust opacity at distance r from the centre of the core and at infrared wavelength $\lambda$.

In this simple model, we assume $I_{background}$ and $I_{foreground}$ to be uniform over the region observed. The $H_2$ column density $N_{H_2}$ is given by $N_{H_2} = \kappa_\lambda \cdot \tau_r$, where $\kappa_\lambda$ is the dust extinction at the wavelength of observation $\lambda$. For the moment, we assume $\kappa_\lambda$ to follow the Draine & Lee (1984) model in the infrared as a first approximation, but the value is rather uncertain. In the following, we noted $I_0 = I_{background}$ and $I_1 = I_{foreground} + I_{zodiacal}$. $I_0$ and $I_1$ are unknown quantities but we are able to determine a range of acceptable values. Indeed, we can use our 1.3 millimeter continuum data to estimate the column density averaged over the flat central part of the core $N_{flat}$. Considering the uncertainties on the dust temperature, which we assumed equal to 12.5 K and on the dust mass opacity, which we took equal to 0.005 $cm^2g^{-1}$ (see Preibisch et al. 1993 and AWB96, Henning et al. 1995), the value of $N_{flat}$ is known to within a factor ∼2. Besides, our $C^{18}O$(1-0) line observations of L1689B give us estimates of the ambient column density outside the core, $N_{out}$.

Taking into account these constraints on the values of $N_{flat}$ and $N_{out}$, we have derived a range of possible column density profiles. These are shown in Figure 4 for L1689B and L328. Due to the elliptical shape of the inner core of L1689B, we averaged the intensity in elliptical annuli over 40 deg sectors and considered the South sector separately from the West sector (cf. AWM96). For L328, the main component of the core has a circular shape, so we averaged the intensity in circular annuli over the Western part of the core (we rejected the Eastern half because of the presence of weaker clumps to the East of the main core - see Figure 1, right side). In Figure 4, the dashed curves correspond to the maximum and minimum possible values of $N_{flat}$. They represent the uncertainty we have on the column density profile. The solid curve corresponds to $N_{flat} \sim 10^{23}$ cm$^{-2}$, which is the value measured from the millimeter continuum data. For comparison, the model fitting the column density profile obtained by AWM96) at 1.3 mm up to 100 arcsec (16000 AU at 160 pc) in radius is plotted for L1689B and a simple model in $r^{-1}$ is plotted for L328. For both graphs we can separate three different regimes: a flat part in the centre (e.g. Ward-Thompson et al. 1994), then a steep decrease in the column density (steeper than the model in $r^{-1}$) until the edge of the dense core has been reached and the column density only shows some fluctuations. The cores L328 and L1689B seem to have a finite radius, at least in one direction. Moreover, the ISOCAM profile of L1689B is compatible with the one derived by AWM96 up to 100 arcsec (i.e. ~15000 AU).

## 4. RESULTS AND IMPLICATIONS

With our ISOCAM observations, we were able to probe the column density structure of dense prestellar cores at large radii and to detect an edge for the clumps studied here (though only in one direction for L1689B). Except for the West part of L1689B, all the profiles that we studied turned out to be steeper than $N_{H_2}\ \alpha\ r^{-1}$ expected for a singular isothermal sphere. These results are promising as they suggest that prestellar cores are not scale-free. At smaller radii, we showed there was a significant similarity between the absorption features seen with ISOCAM and the emission features seen in the millimeter continuum, assessing the fact that the dust emitting at millimeter wavelengths absorbs the infrared background arising from the surrounding interstellar medium. The comparison with the millimeter continuum observations has also proved to be useful to derive $H_2$ column density profiles from infrared intensity profiles. It is also clear from our ISOCAM images that the typical pre-stellar cores are fragmented on a small length scale (fragments of less than 10000 AU in radius) and present all sorts of morphologies (and not only spherical).

Our results are qualitatively consistent with models of magnetically supported cores (Mouschovias 1991, Ciolek & Mouschovias 1994, Basu & Mouschovias 1995) which predict a finite size for contracting cores, as well as a flat inner part in the density profile. The fact that we see a sharp edge could suggest that the cores, initially magnetically supported, may have become supercritical (eg. Ciolek & Mouschovias 1994) or that they are confined by external pressure (see Bertoldi & McKee 1992). Another hypothesis for the steep column density profile would involve thermal support (Falgarone & Puget 1985, Chièze & Pineau des Forêts) but this type of model would not account for the asymmetry that we encounter in most of our cores.
Several points need further investigations: the column density profiles that we derive are strongly dependent on the dust extinction model that we use. Other ISOCAM observations should yield more accurate values for the extinction at infrared wavelengths. We are also planning to observe the most interesting of our dense cores in molecular lines and obtain independent estimates of column densities.

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