COLD SPOTS IN THE CHAMAELEON DARK CLOUDS

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ABSTRACT

A method to detect very cold molecular cloud cores has been developed, using the ISOPHOT Serendipity Survey and the IRAS 100 μm data. As test case, three molecular cloud complexes in Chamaeleon have been investigated. Several cold spots ($T \approx 13$ K) have been detected in these fields, showing the success of the Serendipity Survey in locating cold cloud cores.

Key words: ISOPHOT Serendipity Survey ; ISM: cold dust; ISM: individual (Chamaeleon).

1. INTRODUCTION

The ISOPHOT Serendipity Survey is a far-infrared (FIR) survey at 170 μm, using the slewing time of the ISO telescope (Lemke et al. 1996). Altogether about 15 per cent of the sky is covered with an angular resolution (FWHM) of 2 arcmin (Bogun et al. 1996; for standard processing and calibration details cf. M. Stickel, these proceedings).

The long wavelength allows us to trace the cold dust of the interstellar medium. Standard dust models (Mathis et al. 1977) together with the average interstellar radiation field lead to typical grain temperatures of between $\sim$ 15 K and 19 K (Draine & Lee 1984). In Bok globules and molecular cloud cores somewhat lower temperatures are predicted and have been reported in many cases (e.g. Keene 1981, Lehtinen et al. 1998, Haikala et al. 1998). While the 60 μm IRAS data are still affected by the warmer very small grains, the FIR emission at 100 μm originates from the big grains alone (Désert et al. 1990), and so the comparison of the two bands at 100 μm (IRAS) and 170 μm (ISO) can determine the physical properties of the cold dust.

Ward-Thompson et al. (1998) reported the detection of cold cores in the Milky Way, which have been detected with ISOPHOT at 200 μm and 160 μm and in the mm and sub-mm range. Typically they remain undetected, or only weakly detected shortward of 100 μm. Temperatures of $\approx$ 13 K have been determined. These dense cores in molecular clouds are gravitationally bound but contain no embedded luminosity source. They represent the phase of star formation prior to the protostellar class 0 phase. With the 15 per cent sky coverage of the ISOPHOT Serendipity Survey it is possible for the first time to look for these objects in our Galaxy over a large fraction of the sky.

The region first investigated is Chamaeleon, containing the three molecular cloud complexes Chamaeleon I, II, and III. Several catalogues of optically opaque spots are available in this region of the sky (Vilas-Boas et al. 1994; Hartley et al. 1986), and the presence of some individual spots with cold dust is known (Haikala et al. 1998). Figure 1 gives an overview of the Chamaeleon region at 170 μm, pointing out the location of the investigated fields and showing the dense coverage of Chamaeleon with slews of the ISOPHOT Serendipity Survey.

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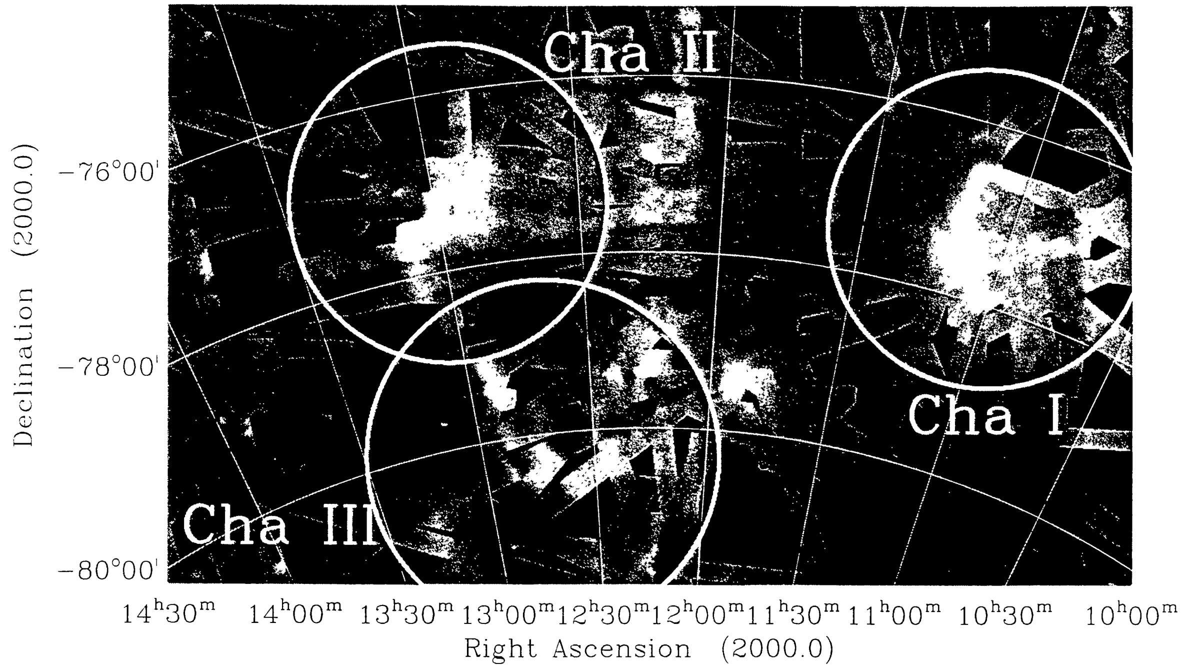

Figure 1. The Chamaeleon region at 170 μm. The map is a composite of the slews of the Serendipity Survey. It is smoothed to 4.5 arcmin resolution. The investigated (circular shaped) fields are indicated. The tiny square in Chamaeleon I marks the area covered by Figure 4.

2. THE METHOD

In order to derive dust temperatures, the 170 μm Serendipity data are compared with the 100 μm IRAS data. This is done in the following way:

After applying a deglitching algorithm (Stickel et al. 1998a, and these proceedings) all Serendipity slews are convolved one by one with a two-dimensional gaussian in order to match the IRAS resolution. As the information of the individual pixels becomes redundant at a resolution of 4.5 arcmin, the gaussian is always centred on the position of the detector centre instead of the positions of the four pixels. Thereby the data streams are reduced from 4 data points per sample (ramp) to 1 data point per sample.

The 100 μm intensity is read out of the ISSA maps along the Serendipity slews, i. e. at the detector centre position of all samples. The IRAS map pixel covering the position concerned, and all of the 8 adjacent pixels with distance dependent weight factors, are taken into account when calculating the IRAS 100 μm value of one sample.

The smoothed 170 μm slews are searched for intensity peaks. By definition, a peak is encountered where the intensity difference between two adjacent readouts increases compared to the preceding readouts. This can be quantified as a maximum in the second derivative of the intensity as a function of sky position. An increase of the intensity itself could be a background effect. To exclude that peaks are mimicked by noise, a lower limit of 1 MJy/sr for the peak intensity over the background is included. Figure 2 shows a section of a slew, where some peaks have been detected. The middle one will be followed further in Figure 3 and Figure 4.

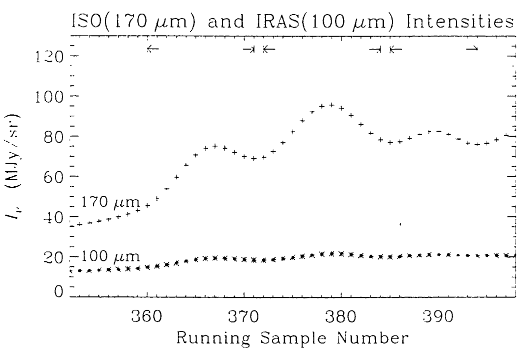

Figure 2. The course of the sky surface brightness at 170 μm (convolved Serendipity data, crosses) and at 100 μm (read out from ISSA maps, asterisks) is plotted against the sample number for a section of a slew. The solid lines represent the backgrounds. Here, 3 peaks are found as indicated below the top axis.

Wherever a peak is encountered along the 170 μm slews, a linear background is defined for both ISOPHOT Serendipity Survey and IRAS data. As the peak in the 100 μm data might be small or even not detectable in the case of very cold dust emission, the extension of the source is assumed to be the same in both wavelengths (Figure 2).

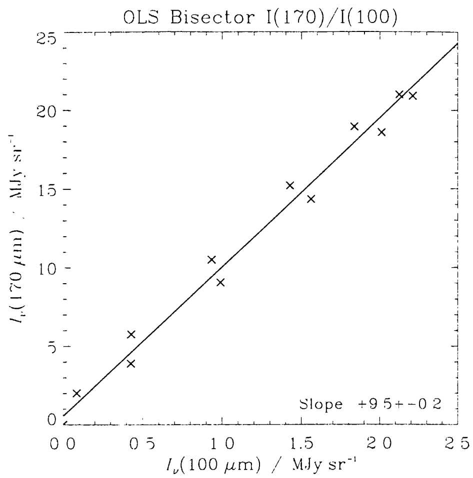

Figure 3. $I_\nu(170\ \mu m)$ versus $I_\nu(100\ \mu m)$ plot for the middle one of the peaks in Figure 2. A straight line is fitted to the data points, using the ordinary-least-squares bisector method. In this case, the slope of $I_\nu(170\ \mu m)/I_\nu(100\ \mu m)$ = 9.5 corresponds to a colour temperature of $T \approx 12.5$ K.

After subtracting the background, the $I_\nu(170\ \mu\mathrm{m})$ to $I_\nu(100\ \mu\mathrm{m})$ ratio is determined for each source. This is done by fitting a straight line to the $I_\nu(170\ \mu\mathrm{m})$ versus $I_\nu(100\ \mu\mathrm{m})$ plot (Figure 3), applying the ordinary-least-squares (OLS) bisector algorithm (Isobe et al. 1990). Although by using this procedure the absolute intensity levels at the two wavelengths are irrelevant for the intensity ratio, the background subtraction is necessary to account for a possible *slope* of the background underlying the source signal.

Finally, the dust colour temperature is calculated by modelling a modified Planck curve to the $I_\nu(170\ \mu\mathrm{m})$ to $I_\nu(100\ \mu\mathrm{m})$ ratio s. A ν^2 emissivity law is assumed, as calculated by Draine & Lee (1984) for interstellar graphite and silicate grains.

3. RESULTS

512 peaks of FIR emission have been found in the investigated region of 35 □°. About 5 per cent of these have $I_\nu(170\ \mu\mathrm{m})/I_\nu(100\ \mu\mathrm{m})$ ratios corresponding to dust colour temperatures as low as 13 K.

All sources with $T_{\mathrm{dust}} \leq 14$ K have been cross-checked against catalogues of optically opaque spots (Hartley et al. 1986, Vilas–Boas et al. 1994), molecular cloud cores (Vilas–Boas et al. 1994), and – for Chamaeleon I only – maxima of FIR dust emission as seen with ISOPHOT by Haikala et al. (1998). To do this, all slew sections concerned were projected back on the sky together with the catalogued objects. This way we can identify

- peaks in different slews that actually detect the same object

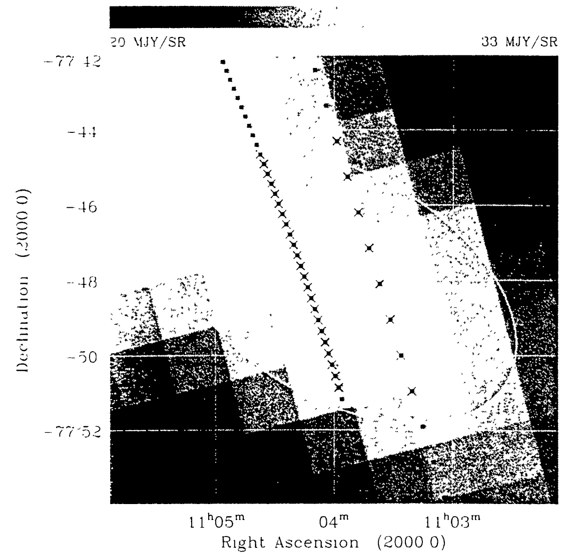

Figure 4. The area of the sky in which Figure 3 reveals the presence of a cold cloud core. The slews of the Serendipity Survey are plotted as small black dots on the IRAS 100 μm image. The samples belonging to the actual peaks are plotted as crosses. Both of the slews crossing this field have very high $I_\nu(170\ \mu m)$ to $I_\nu(100\ \mu m)$ ratio s. In this case, the slews detect a previously known molecular cloud core (indicated by the ellipse).

- detections in the ISOPHOT Serendipity Survey with objects known from other wavelengths.

This can be seen in Figure 4, which shows the location of the intensity peak presented in Figure 3. Here, actually *two* slews have almost parallel paths, and both have very high $I_\nu(170\ \mu\mathrm{m})$ to $I_\nu(100\ \mu\mathrm{m})$ ratio s. It is evident that the two findings belong to the same cloud core: it is the previously known molecular cloud core S1 (Haikala et al., 1998).

In areas where there is no object in the catalogues even though the Serendipity Survey detects cold dust, the Digitized Sky Survey has been inspected additionally by eye for putatively associated optical features.

It turned out that the vast majority of cores with $T_{\mathrm{dust}} \approx 13$ K have optical nebulosities associated, and that for a subset of these cores – where Vilas–Boas et al. (1994) measured $C^{18}O$ – the kinetic gas temperature is low. The full details of the findings will be presented elsewhere.

4. CONCLUDING REMARKS

In three test fields investigated in the Chamaeleon region, the method presented to detect cold dust in molecular clouds has proved successful. Despite the difference in data structure, the ISOPHOT Serendipity Survey and the IRAS 100 μm maps can be reliably used for finding cold dust anywhere within the

15 per cent of the sky covered by the Serendipity Survey. This was not possible before ISO, as the comparison of two IRAS bands alone cannot trace dust colour temperatures < 25 K.

In a next step we will expand the cold spot search to other regions, such as Orion, Taurus, Cygnus, Coalsack, Cepheus. Furthermore it is anticipated to make use of the full angular resolution of the ISOPHOT Serendipity Survey, while so far the Serendipity data have been smoothed to 4.5 arcmin. For selected fields this can be achieved by combining the Serendipity Survey with HIRES data instead of ISSA maps. By comparing these results with mm-wave spectroscopy data, which explore the gas content of the clouds, it will also be possible to examine the gas – dust relations in density and temperature in cold molecular cloud cores.

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