THE STRUCTURE OF CIRRUS CLOUDS AT DIFFERENT GALACTIC ALTITUDES

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Abstract

Galactic cirrus clouds, often also called high-latitude clouds, span a wide range of physical parameters. Some of them appear to consist of pure atomic gas; other are partly molecular. Cirrus clouds can be separated into three classes depending on their radial velocities: low-, intermediate- and high-velocity clouds. The origin of the last two classes is completely unknown. The different distances to the plane of our Galaxy make cirrus clouds ideal targets, to study the formation and structure of molecular clouds in different environments and also to probe the structure of our Galaxy and its halo. They might help to answer the questions, how the structure of a molecular cloud influences the formation of stars and how it is linked to the IMF. Much of the cloud structure can be deduced from the transition region from H to H_2 and from C^+ over C to CO. We have therefore set up a program to study cirrus clouds in the fine structure lines of neutral and ionized atomic carbon and various molecular transitions. We describe the status of this project and discuss why e.g. spectrally resolved [CII] observations, as possible with *HIFI* on board of *FIRST*, are needed to learn more about the structure of the clouds and about their environment.

Key words: Interstellar Medium (ISM): clouds – ISM: abundances – Stars: formation

1. Introduction

Cirrus clouds span a wide range of physical parameters: some appear to be diffuse, consisting of pure atomic gas, others are translucent, revealing molecular line emission. At higher galactic latitude - outside the bulk of emission from the galactic plane - cirrus clouds can be separated into three classes, characterized by their radial velocity and distance:

- Low-velocity clouds (LVCs): distances approx. 100pc, velocity: $|v_{LSR}| < 20$ km/s
- Intermediate-velocity clouds (IVC): distances < 1 kpc, velocities: 20 km/s < $|v_{LSR}|$ <100 km/s
- High-velocity clouds (HVC): distances > 1000pc, velocity: $|v_{LSR}| > 100$ km/s

Towards high latitudes the velocities of the latter two types of clouds are inconsistent with simple galactic rotation models and their origin is a matter of debate. The different distances of these clouds above the galactic plane make them ideal targets to study the formation of (molecular) clouds in different galactic environment.

All these clouds are easily detectable in the 21 cm line of neutral atomic hydrogen. LVCs and IVCs are furthermore known from the *IRAS* survey as infrared cirrus clouds at 100 μm. The neutral hydrogen column densities are of the order $N(\mathrm{HI}) \approx 1 - 10 \times 10^{20}\,\mathrm{cm}^{-2}$, which correponds to visual extinctions of about 1 mag adopting, a normal gas-to-dust ratio. This places the clouds in the diffuse to translucent cloud regime, which means that photochemical effects play an important role for the chemical composition of the clouds. Much of the structure of the clouds can thus be learned from the transition region from H to H_2 and from C^+ over C to CO. Because these transitions depend much on the external radiation field and pressure (van Dishoeck & Black 1988; Wolfire et al. 1995) one can in turn also learn much about the external medium surrounding the clouds, i.e. on the structure of our own Galaxy.

We have set up a program to study galactic cirrus clouds at different positions in our Galaxy in various atomic and molecular lines and in the dust continuum emission at mm- and submm-wavelength. In this paper we describe why submm observations as possible only from airplanes an satellites are urgently needed to learn more about the structure of cirrus clouds.

2. Local cirrus clouds

Most of the galactic cirrus clouds are nearby objects. They have been studied in a number of molecular and atomic transitions and their physical structure and chemical compositions is well known (e.g. Magnani et al. 1985, de Vries et al. 1987). They form the low-mass end of the normal galactic population of molecular clouds which happen to be nearby and thus can be studied with comparable high angular resolution especially if they are located at high galactic latitudes.

Galactic cirrus clouds are commonly found to be gravitationally unbound. Their kinematics is largely dominated by turbulence and their virial masses are 1-2 orders of magnitudes larger than their observed masses (e.g. Magnani et al. 1985). Some of these cirrus clouds harbour

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dense cores with molecular abundances similar to that of dark clouds in star-forming regions (e.g. Grossmann & Heithausen 1992). Only for one high-latitude cloud, L1457, the observation suggest a possible association with low mass T Tauri stars (Hearty et al. 2000) while for the other clouds searches for associated young stars remained negative (e.g. Martin & Kun 1996). Recently, evidence for inward motion has been detected in a dense cirrus cores (Heithausen 1999), raising the question whether star-formation is possible in clouds which are as a whole not gravitationally bound objects.

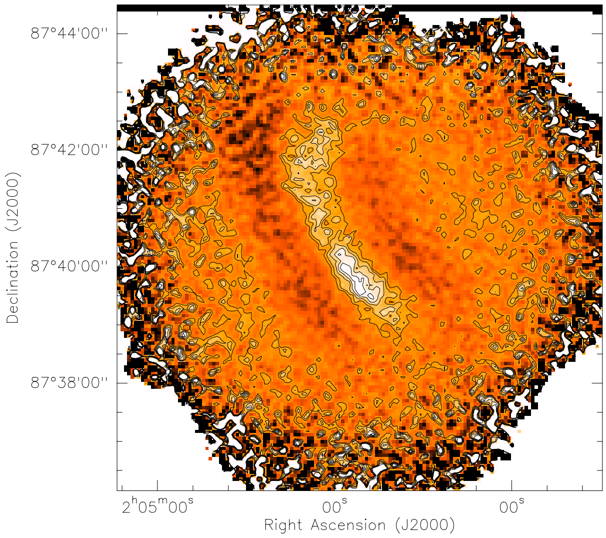

Figure 1. The dust continuum of the local cirrus core in MCLD123.5+24.9 recently obtained at 240GHz with the IRAM 30m telescope (from Heithausen & Bertoldi, 2001).

Much is known about the distribution of atoms and molecules in local cirrus clouds (e.g. Magnani et al. 1985; de Vries et al. 1987; Grossmann & Heithausen 1992). Most of the information about the distribution of dust comes from the *IRAS* mission (e.g. Boulanger et al. 1985; de Vries et al. 1987). With its longest wavelength at 100 μm *IRAS* provide only information on the Wien part of the dust spectrum, observations on the Rayleigh-Jeans part are still very sparse (e.g. Bernard et al. 1999).

To overcome the gap we have started to study the emission of cold dust at 1.3 mm and 0.8 mm using the *IRAM* and *HHT* radio telescopes. As an example, Fig. 1 shows the dust continuum emission of the local cirrus core in MCLD123.5+24.9 as recently obtained with *MAMBO* at 240GHz with the IRAM 30m telescope (Heithausen & Bertoldi 2001). These observations help to constrain dust models for diffuse and translucent clouds which is a necessary prerequisite to understand the dust emisson arising from more distant cirrus clouds, as IVCs. Furthermore these observations help to determine the star forming capabilities of cirrus clouds by providing independent values for the column density and by the possibility to detect embedded cool dust cores.

3. Intermediate-velocity clouds

Intermediate- and high-velocity clouds, IVCs and HVCs, are defined by their radial velocities which are inconsistent with normal galactic rotation. Their origin remains unknown. Papers have used a formal limit of $|v_{LSR}| = 100$ km/s which separates both types of clouds. Unlike for HVCs the distances to IVCs are known within some brackets, they are between 200 and 1000pc (Clarke et al. 1999), placing them in the transition region between galactic plane and halo.

IVCs have first been detected in the 21 cm line of neutral hydrogen (Wesselius & Fejes 1973). Most of the clouds are also visible at 60 μm and 100 μm in the IRAS maps (e.g. Herbstmeier et al. 1993; Weiss et al. 1999). A few IVCs have been detected in CO (Mebold et al. 1985; Heiles et al. 1988; Désert et al. 1990).

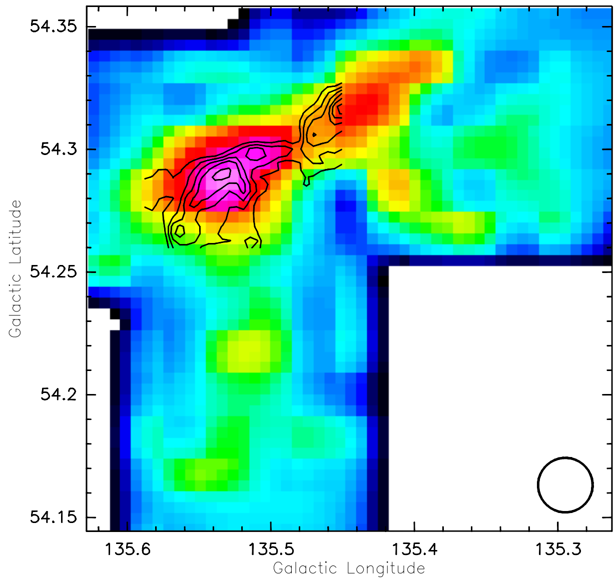

Figure 2. CO in IVC135+54−46. Colors represent the integrated CO (3→2) map as obtained with the KOSMA 3 m telescope. Contours show our (incomplete) high angular resolution map of the integrated CO (1→0) line as obtained with the IRAM 30 m telescope (Weiss et al. 1999).

We have started to search for molecular line emission in a sample of IVCs with well determined distances (see Clarke et al. 1999). Fig. 2 shows an example of our ongoing mapping project of various IVCs in CO lines. As shown by Herbstmeier et al. (1993) and Weiss et al. (1999) the molecular emission in IVCs is more concentrated in smaller clumps as compared to the LVcs. This means that the region with neutral atomic carbon will become relatively more important compared to the "pure" CO region.

To study the transition region from CII over CI to CO we thus are also searching for the 492 GHz and 809 GHz fine structure lines of CI in various IVCs. As part of this project we have recently succeeded to detect the 492 GHz line of CI in several IVCs.

4. High-velocity clouds

High-velocity clouds (HVC) have so far been only detected in emission in the 21 cm line of atomic hydrogen and in the Hα line. (cf. Wakker & van Woerden 1997; Tufte et al. 1998). Until recently, only very few detections of other elements than hydrogen have been reported, all of them are in absorption to distant stars or quasars (e.g. Savage & de Boer 1979, Savage & de Boer 1981; Savage & Sembach 1996). The UV-satellite *FUSE* changed this deficite, and HVCs are now seen in absorption lines of various elements, as e.g. O VI, C II, N I, N II, S II, and Fe II (Murphy et al. 2000; Gibson et al. 2000). Derived metallicities are between 0.1 and 0.5. Searches for dust in HVCs were so far not successful (Wakker & Boulanger 1986). As a consequence the origin of the HVCs is still unclear: Are they galactic gas, ejected from the plane now falling back (Bregman et al. 1980; Richter et al. 1999)? Are they primordial gas with low metallicity that the Milky Way is accreting (Wakker et al. 1999)?

As for the other clouds we have started to look for a cool molecular component in HVCs. So far our searches for CO lines remained negative. This is however not surprising because in a low metallicity environment as that of HVCs the transition region from C^+ to CO is shifted inwards and the region where CO might be detectable shrinks (e.g. Pak et al. 1998). Due to its efficient self-shielding the transition from atomic to molecular hydrogen is largely uneffected in a low metallicity environment. This means that the fine structure lines of either ionized or neutral atomic carbon become more important in comparison to the rotational lines of CO to trace molecular gas.

In Fig. 3 we show a very deep spectrum of C^+ obtained with *ISO* along a line of sight to a HVC. In Fig. 4 we show spectrum of the 21cm line of atomic hydrogen for along the same line, showing emission mainly at intermediate and high velocities. Due to insufficient spectral resolution in the *ISO* spectrum it is not possible to identify the source of C^+ emission, either HVC or IVC. This ambiguity will be overcome by *FIRST* observations which are spectrally resolved. Such observations provide reliable measures on the cooling rate of ionized carbon. For gas hotter than 100K the cooling rate of CII depends only on density and C^+ abundance. One could use the CII cooling rate to determine ranges of these parameters which also help to get estimates of the distance of HVCs (Heithausen & Herbstmeier 2001).

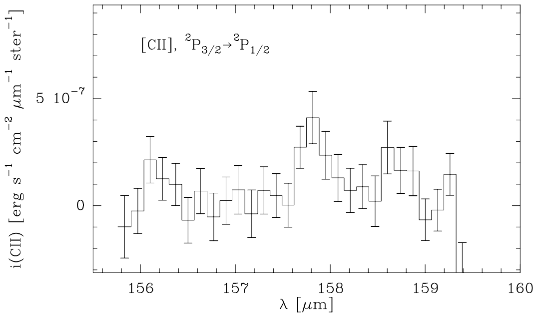

Figure 3. ISO LWS spectrum at 157.8 μm towards $l, b = 134.^\circ5, 55.^\circ3$. *Errorbars are standard deviations for the single channels (from Heithausen & Herbstmeier, 2001).*

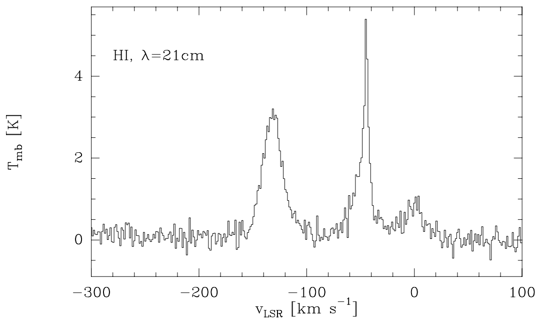

Figure 4. HI spectrum towards $l, b = 134.^\circ5, 55.^\circ3$ *as obtained with the MPIfR 100 m radio telescope (from Heithausen & Herbstmeier 2001).*

5. Prospects for *FIRST*

Cirrus clouds are low temperature objects, which means that they emit most of their radiation in the mm- to submm-wavelength regime. Only part of this is accessible with ground based observatories. Therefore, only airborne and space observatories as *FIRST* or *SOFIA* offer the opportunity to study this radiation. Especially the dust continuum emission and the radiation from the CII fines structure line at 158 μm will provide important information about the structure and composition of galactic cirrus clouds as illustrated in the previous sections.

The following studies might be especially worthwhile to be done with *First*:

– determine dust spectrum of IVCs and LVCs
– search for dust in HVCs
– spectrally and spacially resolved [CII]-observations
– analyse the transition region from C^+ to CO
– determine the structure of the cloud
– study chemical composition

These studies will not only provide information on the clouds themselves but will also allow to determine galactic structure as function of z height above the plane, information which are otherwise hard to get.

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References

Bernard J.P., Abergel A., Ristorcelli I., et al., 1999, A&A 347, 640

Boulanger F., Baud B., van Albada G.D., 1985, A&A 144, L9

Bregman J.N., 1980, ApJ 236, 577

Clarke T.E., Gladders M., Mallen-Ornelas G., 1999, ASP Conf. Ser. 168, Eds Taylor et al., p. 323

Désert F.X., Bazell D., Blitz L., 1990, ApJ 355, L51

de Vries H.W., Heithausen A., Thaddeus P., 1987, ApJ 319, 723

Gibson B.K., Giroux M.L., Penton S.V., Putman M.E., Stocke J.T., Shull J. M., 2000, AJ 120, 1830

Grossmann V., Heithausen A., 1992, A&A 264, 195

Hearty T., Neuhäuser R., Stelzer B., et al., 2000, A&A 353, 104

Heiles C., Reach W.T., Koo B.C., 1988, ApJ 332, 313

Heithausen A., 1999, A&A 349, L53

Heithausen A., Bertoldi F., 2001, (in prep.)

Heithausen A., Herbstmeier U., 2001, A&A (subm)

Herbstmeier U., Heithausen A., Mebold U., 1993, A&A 272, 514

Magnani L., Blitz L., Mundy L., 1985, ApJ 295, 402

Martin E.L., Kun M., 1996, A&AS 116, 467

Mebold U., Cernicharo J., Velden L., Reif K., Crezelius C., Goerigk W., 1985, A&A 151, 427

Murphy E.M., Sembach K.R., Gibson B.K., et al., 2000, ApJ 538, L35

Pak S., Jaffe D.T., van Dishoeck E.F., Johanson L.E.B., Booth R.S., 1998, ApJ 498, 735

Richter P., de Boer K.S., Widmann H., et al., 1999, Nat 402, 386

Savage B.D., de Boer K.S., 1979, ApJ 230, L77

Savage B.D., de Boer K.S., 1981, ApJ 243, 460

Savage B.D., Sembach K.R., 1966, ARA&A 34, 279

Tufte S.L., Reynolds R.J., Haffner L.M., 1998, ApJ 504, 773

van Dishoeck E.F., Black J., 1988, ApJ 334, 771

Wakker B., Boulanger F., 1986, A&A 170, 84

Wakker B., van Woerden H., 1997, ARA&A 35, 217

Wakker B.P., Howk J.C., Savage B., et al., 1999, Nat. 402, 388

Weiss A., Heithausen A., Herbstmeier U. Mebold U., 1999, A&A 344, 955

Wesselius P.R., Fejes I., 1973, A&A 24, 15

Wolfire M.G., McKee C.F., Hollenbach D., Tielens A.G.G.M., 1995, ApJ 453, 673