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HIGH LATITUDE "CIRRUS" CLOUDS

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ABSTRACT

At infrared wavelengths many thin, low mass dust clouds are observed at high galactic latitudes. In this paper a number of observations, including optical observations related to these "cirrus" clouds are discussed. The clouds are excellently suitable for studies of grain properties and of the surrounding radiation field. Infrared observations clearly indicate that two populations of dust particles are involved, a population of large particles and a varying population of very small particles. The clouds themselves cannot be gravitationally bound and each cloud may be a short lived entity.

INTRODUCTION

The maps of the infrared sky at long wavelengths, obtained by IRAS, show extended emission of irregular shape (Fig 1). This was first described by Low et al /1/, who named these structures "infrared cirrus". The phenomenon appears most striking at high galactic latitudes, because at those places confusion with known galactic structures is largely absent. The large, typically degrees size spatial extent of the "cirrus" features makes it apparent that the dust clouds causing this emission, have to be located at close distances.

For most astronomers the existence of such widespread dust in the local interstellar medium appears to have come as a surprise. However, optical observations had already indicated the existence of this dust, although the observations have not always been correctly interpreted. In many directions at high galactic latitudes faint extended emission is seen at long exposure photographic plates. A correct description was presented by Sandage /2/, who interpreted this emission as reflection of the general interstellar radiation field on thin dust clouds. Based on this assumption he estimated the possible brightness of these objects to be of the order of maximally 25 magnitudes per square arcseconds, which is less than 10 % of a good night sky brightness, or about the detection limit of the Palomar sky survey. Modern deep sky survey plates (notably the southern ESO/SERC survey), which have detection limits of about 27 magnitudes per square arcsecond, make these faint reflection nebulae easily visible in many places in the sky.

A first impression of the three dimensional spatial extent of these local interstellar dust clouds came from studies of reddening of stars. A detailed report by Knude /3/ of reddening around the galactic pole showed isolated dust clouds at distances of about 100 - 200 pc with highest extinctions in the blue of about 0.15 magnitudes.

The relevance of these thin local dust clouds may be considered in two ways.

First, these objects form a unique opportunity to study the characteristics of dust grains because: a) the objects are relatively isolated, so there is no confusion with other clouds, b) optically thin clouds can be studied and thus complications arising from interpreting data from thick clouds can be avoided and, c) most of these objects are irradiated by the general galactic radiation field only, which is constant over the cloud and for which the geometry is easily modelled.

Second, the evolutionary status and importance of these "cirrus" clouds with respect to the denser molecular clouds and regions of star formation can be considered; interstellar "cirrus" is one of the components making up the interstellar medium.

INFRARED OBSERVATIONS

The IRAS infrared survey has provided us with homogeneous sets of maps, covering virtually the whole sky. This material is ideally suited to get an impression of the large scale structure of the cirrus. A first report of grand-scale galactic infrared emission has been given by Burton et al /4/. It appears quite likely that all the features called "cirrus" are

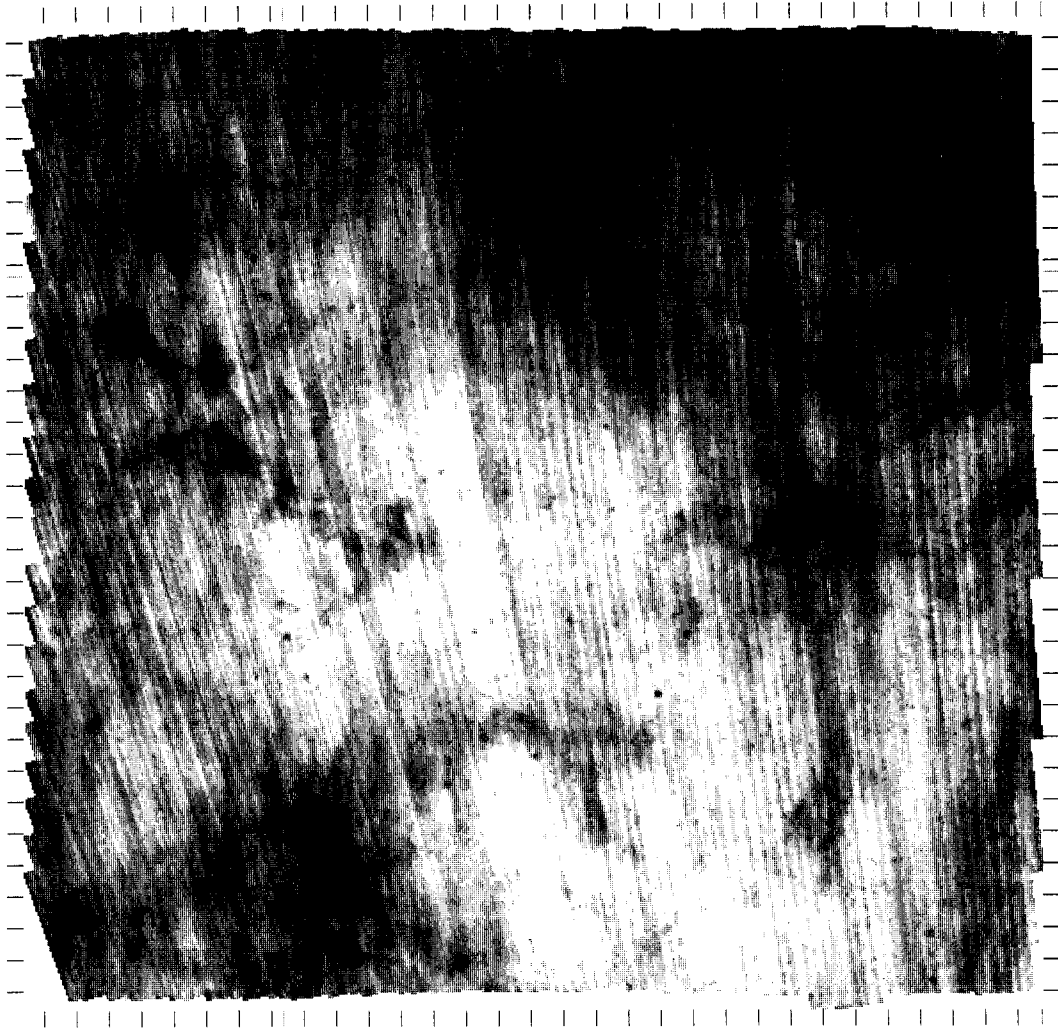


Fig 1
 100 μm IRAS skyflux map ($l = 230^\circ$, $b = -42^\circ$), showing some typical "cirrus" features. The field extends over 16 x 16 degrees. The two "blobs" at the upper left are the same (rotated 90 degrees) as the ones displayed in Fig 3.

just the local examples of the heavily blended structures seen galactic-wide at lower latitudes /4/.

So far, only a few isolated "cirrus" clouds have been studied in detail /5/,/6/. Their infrared spectral energy distributions are shown in Fig 2 (kindly made available by Walterbos /7/). On the long wavelength side these distributions are quite similar, but on the short wavelength side the actual shapes are rather different. Nevertheless, the general shape is usually the same: an increase towards long and short wavelengths and a minimum in between. This shape is also observed if we look at the integrated infrared emission over all our galaxy and M31. This may suggest that most of the infrared emission from normal spiral galaxies, like our own, is coming from "cirrus" type dust clouds.

In the general interstellar medium, dust grains are heated by absorption of the surrounding optical and UV radiation field. Because of its generally low density, the surrounding gas has no influence on the dust temperature. At long wavelengths the emission efficiency of interstellar dust is expected to be proportional to about the inverse square of the wavelength $Q_{\text{abs}} \propto 1/\lambda^2$. Using this assumption we can derive a temperature for the cirrus clouds from the 60/100 μm flux ratio of 20 - 25 K. This is in the range of temperatures expected for 0.1 - 0.01 μm sized grains (depending on their material), embedded in the general galactic radiation field, which is expected to have an energy density of about 1.2×10^{-2} erg/cm²/sec (see e.g. Mezger et al /8/). The smaller the grain, the higher the expected temperature.

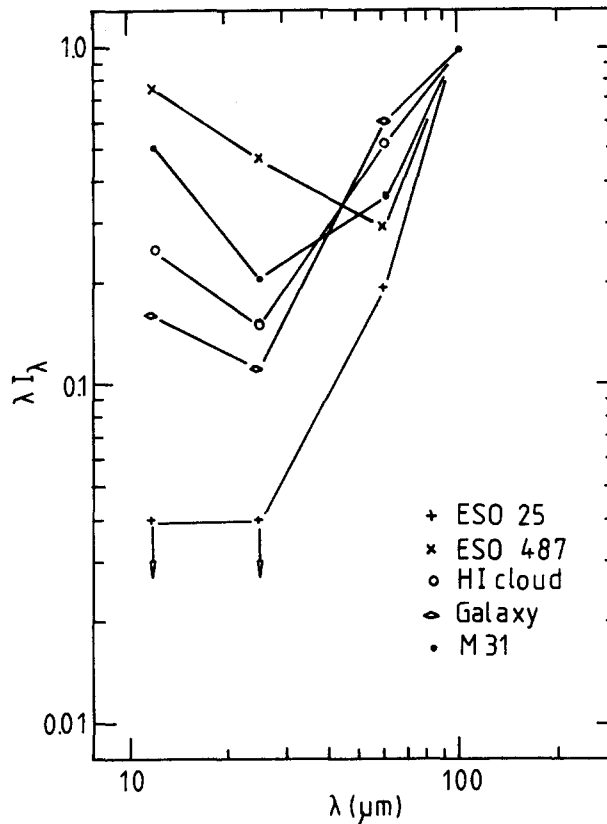


Fig 2
Comparison of infrared spectral energy distributions of "cirrus" clouds (ESO 025 and 487 /5/, and "H1" /6/) and the integrated spectra of M31 and our galaxy /7/.

It has been observed /5/ that the 60/100 μm flux ratio is remarkably constant over each cirrus cloud observed. This most certainly means that no internal energy source is heating the cloud, confirming the notion that indeed these clouds are irradiated by the general galactic radiation field only. Since dust clouds are expected to be optically thin at far infrared wavelengths, the infrared flux at 100 μm will be proportional to the number of dust grains in the line of sight.

An independent way to obtain the column density of grains, is from extinction in the line of sight, which can be determined by means of (optical) star counts. The ratio of 100 μm flux to optical extinction is a very sensitive measure of the radiation field heating the grains. Star counts are only reliable if the extinction of a cloud exceeds about 0.25 magnitudes. It is found for a number of such clouds, with extinctions in the range $A_B = 0.25 - 1.5$ magnitudes, that the ratio between 100 μm flux and optical extinction is remarkably constant at about 9 MJy/Sr per magnitude of blue extinction (A_B) /5/. This implies that the radiation field surrounding the grains responsible for the 100 μm emission is constant over large volumes of space, as can be expected for the general galactic radiation field. In addition this may indicate that the relevant radiative properties of the grains responsible for the flux at 100 μm hardly vary between clouds.

It is to be expected that for dense clouds the radiation field heating the grains will decrease towards the inner regions. Since infrared emission at long wavelengths is a strong function of temperature, this implies that at infrared wavelengths we predominantly "see" the outer, thinner parts of the denser clouds. This mechanism may cause the general galactic

infrared energy distribution to look like the "cirrus" infrared emission.

In the shorter wavelength 12 and 25 μm (IRAS) bands the behaviour of the infrared emission of the cirrus clouds is quite surprising. Where the 60/100 μm flux ratio agrees quite well with the temperatures expected, the 12/25 μm flux ratio indicates temperatures for some clouds of up to a few hundred K. Vast differences between clouds exist (see Fig 2). Since the radiative properties at long wavelengths hardly vary between clouds, the varying 12 and 25 μm fluxes must be due to an additional population of grains, which varies from cloud to cloud. The high temperatures indicate that these grains must be quite small, since they are irradiated by the (low energy density) general galactic radiation field only. Between wavelengths of about 10 and 30 μm strong resonances are expected to be present in most grain materials. Very small grains will emit almost solely at their resonance frequencies because their size will prevent emission at longer wavelengths. This fact, and the fact that the emission coefficient at infrared wavelengths is proportional to unit volume, will tend to make these particles quite warm, even in modestly energetic radiation fields. A second effect, causing these very small particles to be hot, is that the energy of the "average" photon absorbed by the grain is large compared to the heat capacity of the grain. If, as in low energetic radiation fields, the time between absorption of each photon is large compared to the cooling time of the grain, the temperature of the grain will fluctuate. Consequently a temperature higher than the expected equilibrium temperature is observed. Puget et al /9/ have first computed this effect for very small "grains" of organic material down to sizes of large molecules. The 12 and 25 μm flux expected for these polycyclic aromatic hydrocarbon molecules (PAH's) may explain the actual fluxes observed. The absence of an emission excess at the short wavelength infrared bands in some clouds is quite interesting. It may be speculated that perhaps destruction of these small and vulnerable grains has occurred during the history of those clouds.

Detailed spectra between 10 and 30 μm wavelength could resolve the real nature of the dust grains involved in this emission. Clearly, in this respect interesting results may be expected from the successor of IRAS, the ISO satellite, which will have a sensitive spectrograph onboard.

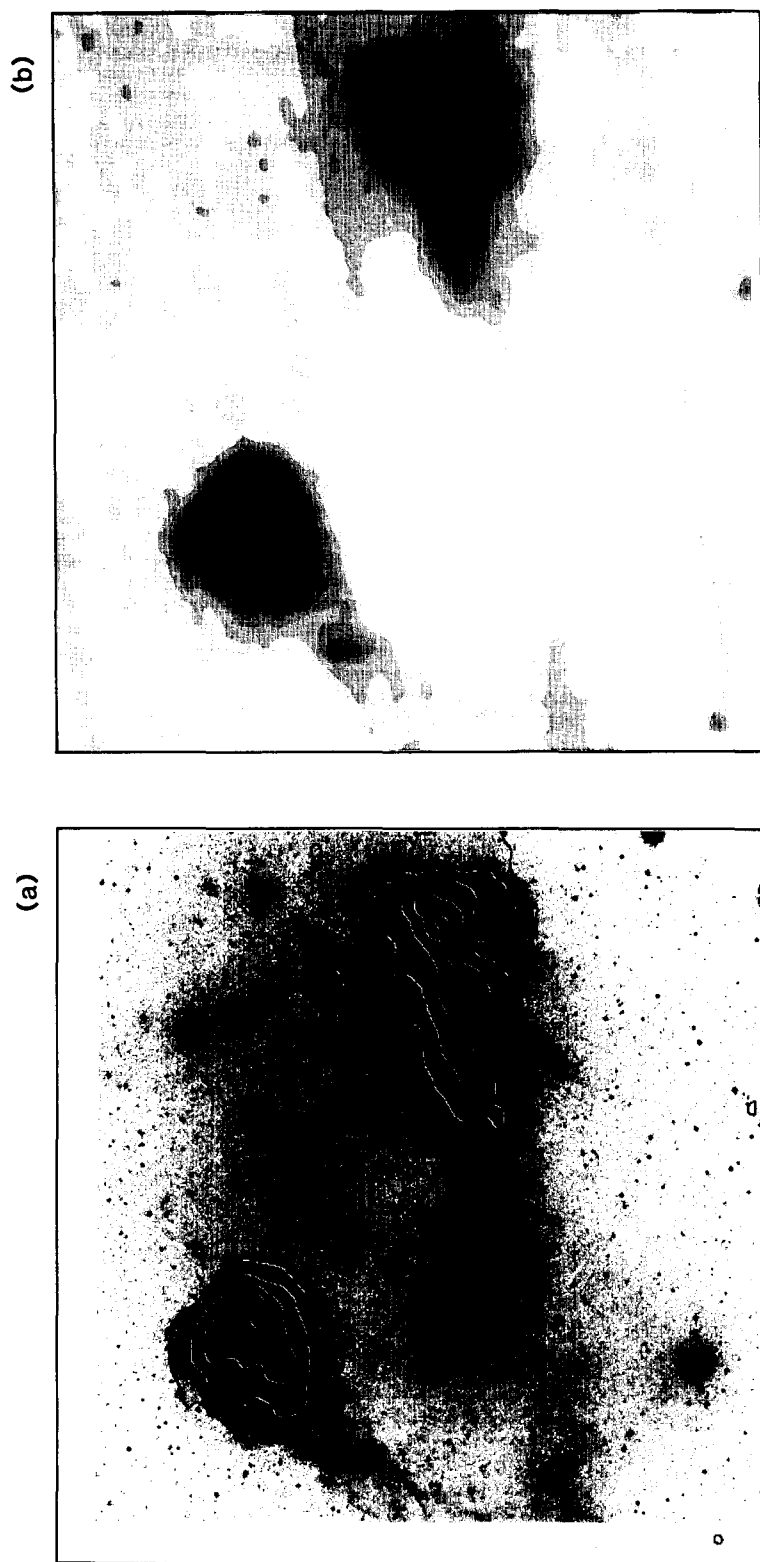
OPTICAL APPEARANCE

A very sensitive way to detect thin high latitude "cirrus" clouds is by looking for their reflected light. It is found /5/ that on IIIa-J SERC survey plates a sensitivity is obtained comparable to the 100 μm IRAS survey, but with much higher angular resolution (Fig 3). However, to properly interpret these reflected light observations, optical depth effects within the clouds should be taken into account especially since the optical depth is often not small compared to unity. Mattila /10/ was one of the first to model radiation paths through a cloud via Monte Carlo simulations. Given the geometry of the incoming radiation and the absorption and scattering properties of the grains, as expressed in albedo α and an asymmetry parameter g , the absorption and scattering by an entire cloud can be modelled. Only for clouds irradiated by the general galactic radiation field is the geometry of the incoming radiation known with confidence. (The strong forward scattering characteristic of interstellar grains makes the surface brightness of reflection nebulae irradiated by single stars notoriously hard to interpret.)

Mattila's models predict the surface brightness of spherical clouds at high latitudes. When the computed surface brightness is plotted as function of optical depth in the line of sight, it appears that, for the most probable values of α and g , a maximum surface brightness can be expected near $\tau = 1.5 - 2$. Surface brightness increases with τ at smaller values of τ . For larger values of τ multiple scattering will become important and, depending on α and g the surface brightness will decrease. Consequently, for clouds with $\tau > 1.5 - 2$, the rims of these clouds will be brighter than the center, which is commonly observed.

Only very few observations have been made of the spectral energy distribution of the reflected light. A first attempt was made by Lynds /11/. She reported on photometric measurements of L1780, and found that this cloud is brighter at redder colors. This was later confirmed by Mattila /10/, who presented a complete spectral energy distribution of the reflected light from about 3500 to 7500 \AA . Maximum intensity is observed near 7000 \AA . The general Galactic radiation field incident on the dust cloud is expected to have maximum intensity near 5000 \AA . Reflection by the cloud thus shifts the spectrum considerably to the red. Since isolated dust grains are expected to scatter light more efficiently in the blue, this phenomenon seems rather puzzling. Optical depth effects within the cloud must play a role, but whether that is sufficient to explain the magnitude of the effect needs further research. It has been speculated that the very red colors of some reflection nebula near stars are caused by fluorescence of the very small grains /12/. Perhaps a similar mechanism may be at work in the normal cirrus clouds. Clearly more data on more clouds are needed.

Cloud ESO 487

**Fig 3**

2.5 x 2.5 degree field at $l = 230^\circ$, $b = -29^\circ$ (field ESO 487)

a) Optical photograph (IIIA-J emulsion, blue light) with superimposed contours of $100 \mu\text{m}$ infrared emission at intervals of 1 MJy/Sr . Maximum extinction, as derived from star counts, is 0.5 magnitudes.

b) Gray scale plot of the $100 \mu\text{m}$ infrared surface brightness (as derived from IRAS skylux maps). Darker areas correspond to more flux. As can be seen from e.g. the faint tails of the two clouds, the sensitivity of the optical photograph (a) for these thin clouds is comparable to the IRAS survey maps.

BALANCE OF RADIATIVE ENERGY

If a dust grain is in thermal equilibrium, the sum of the amounts of the scattered and absorbed radiation will be equal to the amount of radiation incident on the grain. The ratio between the observed scattered and absorbed fluxes is related to the albedo and scattering characteristics of the grain.

For the cirrus clouds discussed, a simple analysis of this radiative energy balance is easily made. As stated before, a measure for the amount of dust grains in the line of sight, or column density of the cloud, may be obtained from star counts. All flux absorbed will be reemitted in the infrared, thus an estimate of the total infrared power output derived from the IRAS data is a direct measure of the flux absorbed. The scattered flux can be measured directly, e.g. from photoelectric measurements. Unfortunately, only data on the optically scattered flux exist. The UV scattered flux is presently unknown, although the UV flux of the incident radiation field may contribute considerably to the heating of the grains. To correct for the asymmetry in the scattered flux, models (e.g. Jura /13/) may be used.

In this way an estimate of the total cloud albedos can be obtained. In order to obtain albedo's of the single grains, models as e.g. computed by van de Hulst /14/ to correct for the optical depth effects in the clouds, have to be taken into account. In this way albedo's of 0.65 are obtained /15/ when a generally accepted value of the asymmetry parameter $g = 0.75$ /10/, /16/ is adopted. This albedo of 0.65 is surprisingly close to the values expected on the bases of theoretical models (e.g. Draine /17/). Since the UV scattered flux is not taken into account, this may imply that this UV flux is almost absent, or that an unknown component of very cold grains is emitting infrared radiation far beyond 100 μm , leading to an underestimate of the absorbed energy. Clearly, submillimeter observations in the range 100 to 1000 μm are needed to resolve this matter.

DISTANCES

The spatial extent of most cirrus complexes indicates a close distance. Magnani et al /18/ found mean distances of about 100 pc, based on the CO gas velocities of an ensemble of clouds. Star counts, although leading in most cases only to upper limits of the distances, confirm this notion, indicating distances of 100 - 200 pc /19/. Only in special cases, e.g. if clouds or parts of clouds are clearly illuminated by stars of known magnitude and spectral type, can accurate distances be obtained. Since cirrus clouds are expected to occur throughout the galaxy, the relevant parameter is not so much distance as height above (or below) the galactic plane. For all dust in the galaxy a scale height comparable to that of the cold molecular material of about 60 pc /4/ can be expected. For "cirrus" clouds, forming the low mass part of dust clouds comparable heights can thus be expected. Indeed for most cirrus clouds heights of about 30 - 50 pc /5/, /19/ can be derived.

One very special case is reported /20/ in which a very thin cloud is heated by the bright star α Cam, 300 pc above the galactic plane. If this star would have been absent, the cloud would not have been visible. This indicates that even thinner clouds occur at larger distances from the plane.

Quite a large scale height of 120 pc is reported for the 100 μm emission of the galaxy as a whole /4/. This needs not to be in conflict with a 60 pc scaleheight of the dust, since it may be expected that in the 100 μm flux we "observe" only the outer parts of clouds. Because large dust complexes tend to occur near the galactic plane and most of the dust mass in these clouds is not "seen", the effective "emissivity" per dust grain may go down near the plane, leading to a larger scaleheight inferred for this emission.

MOLECULAR GAS

Only few observations have been reported on the molecular gas contents of high latitude clouds. The clouds for which data exist all show sizeable extinction ($\tau > 0.5$) and may be regarded as the thicker part of a "continuum" of cirrus clouds extending from the observational limit of very thin clouds to the more massive clouds. Although care should be taken to interpret the data of the thick clouds as to represent all cirrus clouds, some tentative conclusions may be drawn on the basis of these observations.

Blitz et al /21/ were the first to report on CO observations of a sample of clouds. CO line temperatures and $N(\text{CO})/N(\text{HI})$ ratio's seem similar to those observed in normal quiescent dark clouds /21/, /22/, identifying these clouds as part of the "cool" interstellar medium. However, line widths and mass estimates indicate they cannot be gravitationally bound. The clouds may be bound by external pressure /22/, but this is regarded as unlikely by Blitz et

al /21/. As a consequence they estimate a lifetime for such cirrus clouds of the order of 10^6 years.

Nevertheless, it can be concluded that "cirrus" clouds must be subject to the flows and streaming motions in the medium surrounding them, and cannot maintain their own environment.

CONCLUDING REMARKS

"Cirrus" dust clouds have emerged in literature lately as still another phenomenon in the interstellar medium. Morphologically speaking they are normal, although very thin, low mass dust clouds. Although each cloud seems a temporary entity, subject to the streaming motions in the surrounding medium, their evolutionary status is still unclear.

Study of the cirrus clouds may provide significant information on the nature of the dust grains and their radiative environment. So far, it appears that the dust is heated by the general interstellar radiation field only. Two kinds of particles, small and large, are recognized in the infrared observations of the clouds. Differences between grain populations of clouds may provide clues to the history of the clouds. High resolution spectrographic observations in the near future by ISO may reveal exciting information on the exact nature of the grains.

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