CIRRUS AND FUTURE SPACE BASED ASTRONOMY

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ABSTRACT

Astronomical observatories from space make possible observations of sensitivity and spatial resolution impossible in the past. This increase in sensitivity will both make possible the observation of new phenomena and will bring observations against limitations not encountered before. This paper discusses the effects that infrared cirrus and diffuse interstellar clouds will have on space based observations. Some special opportunities provided by space observations of cirrus are presented and a partial list of currently planned observation of cirrus by space telescopes is given.

INTRODUCTION

The IRAS sky maps show that the wispy emission structures of the infrared cirrus are found in all parts of the sky. The cirrus is densest and brightest a low galactic latitudes with fewer and fewer bright clouds appearing as one approached the galactic poles. The cirrus piles up and merges into the general galactic disk emission at very low latitudes, so that individual cirrus clouds are no longer distinguishable. Maps from the IRAS Infrared Sky Survey Atlas show that cirrus is structured on all spatial scales down to the resolution limit at 6 arc minutes. This fine structure exists at all infrared wavelengths seen by IRAS. The cirrus presents a finely structured distribution of emitting and absorbing dust, which has much to tell about the interstellar medium but through which which we must look to make observations of any celestial objects, In many respects going to space does not get telescopes out of the weather.

The same cirrus seen in the infrared is also detected in the visible, Detections of faint, highly structured visible reflection nebulae were reported by de Vaucouleurs and Freeman (1972) and Sandage (1976). These nebulae were later found to be correlated with 100 μm cirrus seen by IRAS (e.g. de Vries and le Poole, 1985). Deep ground based CCD images now routinely detect reflection nebulosity associated with infrared cirrus to surface brightnesses of 27 to 28 mag/arcsec^2, sufficient to see the large majority of 100 μm cirrus detected by IRAS. Fine structure in the visible nebulosity is seen at arc second scales.

Cirrus is also seen in absorption absorption measurements and in UV emission. Bates and Catney (1991) have seen spatial structure on the scale of a few arc minutes in interstellar Na D absorption in the direction of the globular cluster M22. Molaro, *et al.* report similar results in the direction of the large Magellanic cloud. Van Steenberg and Shun (1988) and Hackwell, *et al. (1991)* have found correlation between some kinds of IR cirrus and interstellar UV extinction using IUE spectra and the IRAS maps. Jakobsen, *et al.* (1987) found correlations at intermediate and high galactic latitudes between IRAS 100 μm and diffuse UV emission measured between 2100 angstroms and 1600 angstroms by sounding rockets.

EFFECTS OF CIRRUS

Cirrus clouds add noise to astronomical observations in three ways. Cirrus emission increases the background against which other sources must be measured, adding photon noise to measurements. Cirrus emission is not spatially smooth, thus presenting a variable background structure against which other sources must be extracted and measured. Finally, absorption by cirrus clouds is similarly mottled making correction for extinction in individual sources difficult.

The additional photon noise introduced by cirrus emission can be significant in observations from space where, particularly in the far infrared, a moderately bright cloud at mid to high galactic latitude can contribute the bulk of the background emission for lines of sight through that cloud. 'l'his increase in photon noise is inconvenient but does not present a fundamental problem since longer integration times can restore the signal to noise ratio.

The confusion noise caused by the spatial variations in surface brightness or extinction of cirrus clouds is a fundamental problem. Confusion noise from cirrus emission results from the inability to distinguish fluctuations in cirrus surface brightness from the source being measured. Longer integration times only produce an improved signal to noise ratio on the fixed fluctuation pattern which does not improve without limit the ability to sort out the cirrus from the desired source. A similar situation holds for spatial variations in extinction of background sources by cirrus clouds,

The magnitude of cirrus emission confusion noise can be calculated from distribution functions of cirrus brightness. Gautier, *et al.* (1992) discusses calculation of cirrus confusion noise from the spatial power spectrum of the cirrus surface brightness distribution. Cirrus clouds generally display a power law spectrum over the range of spatial scales observed by IRAS, as shown in figure 1 for a typical moderately bright cirrus cloud. Figure 2 shows the cirrus confusion noise calculated for an 85 cm space based telescope using a small photometer aperture and a closely spaced annular reference region with a line of sight through this cloud and through a very dim cirrus cloud . The cirrus spectrum power law was extrapolated to small spatial scales for this calculation. Point source confusion noise away from the galactic plane, calculated for the same aperture arrangement by the method of Helou and Beichman (1990), is also shown. Note that point source confusion may be expected to dominate cirrus confusion only for the dimmest cirrus clouds. The dim cirrus is from a region of low HI emission at $l = 151°$, $b = +50°$. Only several hundreds of square degrees of sky is no noisier than the dim cirrus. Some few hundred square degrees in smaller patches than 10 x 10 degrees may be dimmer yet and have less cirrus confusion noise.

Cutri (1993) has obtained the spatial power spectrum of a cirrus cloud in reflected V band light and finds that the spectrum is well approxirnated by a

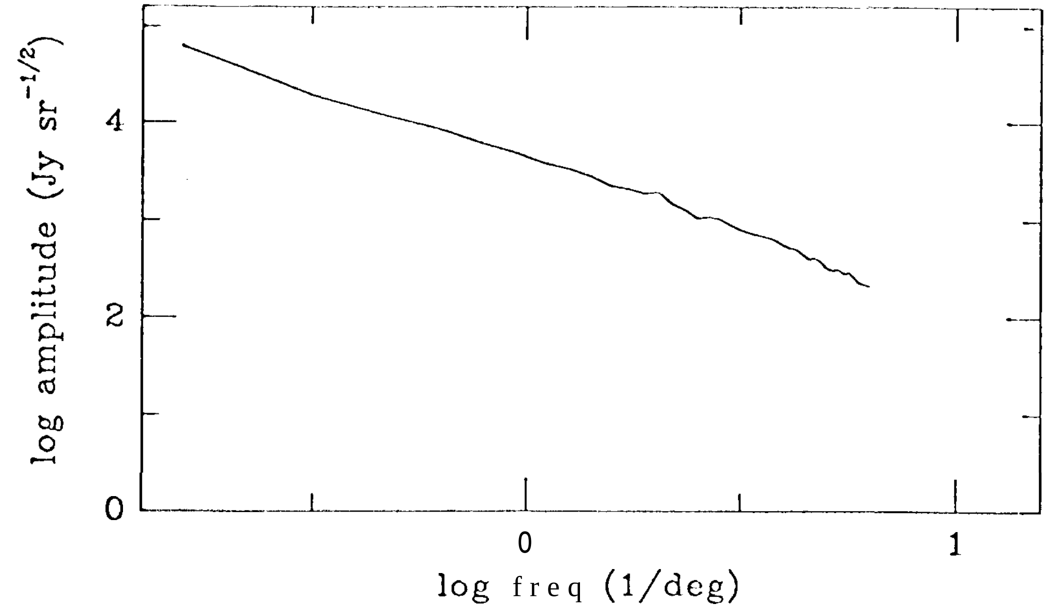

Figure 1. Spatial power spectrum of 100 μm emission from a moderately bright cirrus cloud near the north equatorial pole. This cloud is about 9 MJy/sr brighter than its surroundings. The spectrum is an azimuthal average of the amplitude of the 2 dimensional Fourier transform of the IRAS 100 μm map of the cloud.

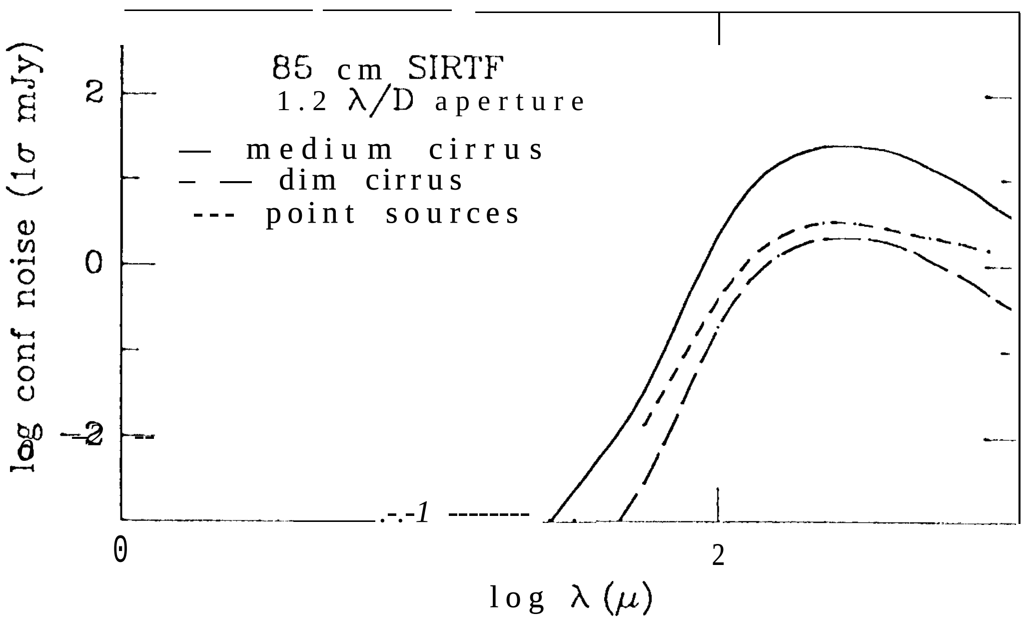

Figure 2. Predicted cirrus and point source confusion for the planned 85 cm SIRTF telescope. The 'medium cirrus" is derived from the cirrus cloud used for the spectrum in figure 1. See text for explanation of point source and dim cirrus curves.

power law with the same index as found at 100 μm over spatial scales from 5 arc minutes to 1 arc second. No quantitative confusion noise calculation have been done for the reflection cirrus but there will clearly be confusion effects from this material when very sensitive observations are made. Guhathakurta and Tyson (1989) indicate that reflection cirrus confusion noise should become a problem in the visible at surface bright nesses of 30 to 31 B_J mag/arcsec^2. That is 15 times fainter than the V band cirrus referred to earlier.

Before leaving the subject of cirrus confusion I should point out that often one man's noise is another man's signal and the presence of spatial structure in the cirrus offers many opportunities to study the properties of the interstellar medium. Some of these opportunities will be discussed below.

Since the IR emission from cirrus is very often correlated with visible and UV extinction we can expect cirrus to produce a kind of absorption confusion noise in the visible and UV. The magnitude of this effect can be estimated using some representative values for the relation of A_v to the 100 μm surface brightness, S_{100}. Using $A_V(\mathrm{mag}) = 5.3 \times 10^{-22} N_H$ and $N_H(\mathrm{cm}^{-3}) = 10^{20} S_{100}(\mathrm{MJy/sr})$ the variation in visible extinction with 100 μm brightness is $\delta A_V = 5.3 \times 10^{-2}\, \delta S_{100}$. Take, for example, the measurement of the 2 point correlation function for galaxies. The brightnesses of pairs of galaxies, measured through apertures of of diameter *d*, separated by distance Θ are compared. The double aperture form of the confusion noise formula in Gautier, *et al.* (1992), though not strictly applicable to this aperture geometry, can be used to estimate the cirrus noise from the cloud of figure 1. The power law index for 100 μm spatial spectra is generally near -2.9 which produces: $\delta S_{100}(\mathrm{MJy/sr}) = 0.32\, A_0\, \Theta(\mathrm{degrees})^{.63}\, d(\mathrm{arcsec})^{-.18}$ where A_0 is the amplitude of the power spectrum at 1 arcmin^{-1}. $\Theta = 2°$ is interesting for galaxy correlation functions. Take $d = 1$ arcsec and use $A_0 = 11\,\mathrm{Jy}/\sqrt{\mathrm{sr}}$ from the spectrum in figure 1. Then $\delta S_{100} = 5.4$ MJy/sr and $\delta A_V = 2.9$ msg. De Lapparent *et al.* (1986) indicate that $\delta A_V < 0.04$ mag is needed to usefully measure the correlation function of galaxies at the depth of the Shane-Wirtanen counts at scales as large as 2.5 degrees. Smaller errors are needed for accuracy at larger spatial scales.

C) RSERVATION OPPORTUNITIES FROM SPACE

Future spaced based astronomy promises many new opportunities to use cirrus to study structures and processes in the interstellar medium, Larger apertures and improved detectors will provide future infrared space telescopes with sensitivities in the IR hundreds to thousands of times greater than that of IRAS. Higher spatial resolution and higher spectral resolution will be available. In the visible and UV the higher spatial resolution, lower backgrounds and extended spectral coverage available from space make interesting cirrus studies possible,

An incomplete list of cirrus studies from space gives some idea of the possibilities:

1. Study of cirrus spatial structure at higher spatial resolution should eventually allow us to sce structure characteristic of the processes which form and maintain the cirrus.

2. Spectral studies at moderate resolution should settle the question of what is emitting the mid IR flux from the cirrus.

3. Measurement and mapping of the CII(158 μm) line, an important coolant of cirrus, can study energy balance and kinematics.

4. The three dimension structure of the cirrus could be mapped by combining the methods of Gaustad and van Buren (1993) for finding heated dust around stars with Hipparcos data for star positions. 'l'he high sensitivity and spatial resolution of planned telescopes should be able to detect dust in the normal interstellar medium at densities of 1 H atom/cm^3 around AO stars at distances greater than 200 pc.

5. Low surface brightness measurements in the visible and UV can be combined with IR emission measurements to yield composition information for the cirrus dust.

6. UV spectroscopic measurements of H_2 fluorescence may be possible and would allow determination of the H_2 density in cirrus clouds as ha-s been done for reflection nebulae by Witt *et al.* (1989).

PLANNED CIRRUS OBSERVATIONS FROM SPACE

A partial summary of currently planned space observations of cirrus:

ISO (Europe)

A key project will map cirrus structure at high spatial resolution. ISO instrumentation can do spectral measurements of cirrus. The launch date is currently in late 199.5.

IRTS (Japan)

Will mainly look at sky structure at low (8 arc. minute) spatial resolution. About half of its two weeks of planned observations will look at the galactic plane and half at high latitudes. IRTS carries near and mid IR spectrometers and a far IR line mapper for 63 μm 01 and 158 pm CII. a 1/2 degree resolution far IR photometer covers 4 bands from 120 to 1000 μm for cosmic background measurements. The flight is planned for 1995.

MSX (US Air Force)

Covers many photometric bands from 2 to 30 pm with spatial resolution greater than 10 to 20 times that of IRAS. Also carries a Fourier transform spectrometer. MSX will look at '*everything". There are plans to release the data to the astronomical community sometime after the planned flight in early 1994.

SIRTF (USA)

SIRTF will carry large format arrays, matched to the resolution of its 8.5 cm aperture, to perform photometry from 2 to 200 μm. Mid and high resolution spectrometers will cover wavelengths from the near IR to about 200 μm. No specific observing plans have been made. Launch is unlikely before 2001.

HST (USA)

Several on going observing programs are concerned with cirrus and several of the papers in this volume contain some of these results. Correction of the spherical aberration late this year should provide even greater opportunity for cirrus studies.

IUE (USA and Europe)

IUE will continue line absorption work relating to interstellar clouds until it dies.

Note that not all of the ideas above are well suited to planned space telescopes. In particular, planned and existing telescopes may not have large enough fields of view or small enough plate scales for optimum measurement of low surface brightness extended emission. Some consideration might usefully be given to intermediate sized telescopes, at all wavelengths, optimized for low surface brightness measurements.

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