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WHAT ARE 'CIRRUS' POINT SOURCES?[1]

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ABSTRACT. Most 'cirrus' point sources are associated with interstellar gas. We have isolated a subset of these, together with other sources showing large band 4 to band 3 flux density ratios, that are *not* associated with interstellar gas. Most of the point sources are associated with diffuse cirrus emission. The sources appear to be distributed randomly on the sky, with the exception of six clusters, one of which is not associated with any known astronomical object.

Six sources out of seventeen that were observed for redshifted H I at Arecibo were found to be associated with relatively nondescript external galaxies. Most of the sources do not appear on the Palomar Sky Survey. Deep optical observations of eight fields revealed some fairly distant galaxies, one object with a very peculiar optical spectrum, and several blank fields.

I. INTRODUCTION

IRAS 'cirrus' point sources (*i.e.*, sources detected only in band 4, $\lambda \sim 100\ \mu$m) are suspected to arise from the same stuff as the diffuse cirrus background, namely interstellar dust. Since dust and gas are intermixed, we expect the presence of clumps of 21-cm emission at the positions of 'cirrus' point sources. However, our first cursory inspection of the distribution of these sources (Figure I.C.4 in the *IRAS* Explanatory Supplement, 1984) revealed that a small fraction are located in regions containing very little interstellar gas. By 'little' we mean HI column densities smaller than 10^{20} cm^{-2}, which is very low—typical of values toward the Galactic poles, and in other regions containing the very lowest column densities as measured with HI surveys using angular resolutions of 36 arcmin or more. This made us suspect that they are, in fact, *not* associated with interstellar gas.

We developed a source list for further study using a two-stage selection process. In the first stage, we included only those sources satisfying the following criteria: (1) reliable (quality 3) band 4 flux densities ($F4$); (2) $F4/F3 > 5$; (3) $F4 > 2$ Jy; (4) Galactic latitude $|b| > 10°$. This provided more than 20000 sources. In the second stage, this was reduced to 293 sources by requiring $F4$ to be larger than the limit determined from the H I column density described by equation (1) below.

From their locations in the sky, many of these sources are obviously associated with interstellar gas. Some are positionally coincident with known astronomical objects, many of which are galaxies. Some have no obvious association with known astronomical objects. Most sources have no corresponding image on the Palomar Sky Survey (PSS).

II. STATISTICS

Most of the 20000-odd sources chosen from the first stage selection are associated with interstellar gas. This is apparent from the scatter diagram of $F4$ *vs.* N(H I) presented in Figure 1: for N(H I) $\lesssim 150$, the upper envelope of the densely-populated portion of the $F4$-N(H I) plane has a

[1]This paper is based in part on observations performed at the Lick Observatory, operated by the University of California at Santa Cruz.

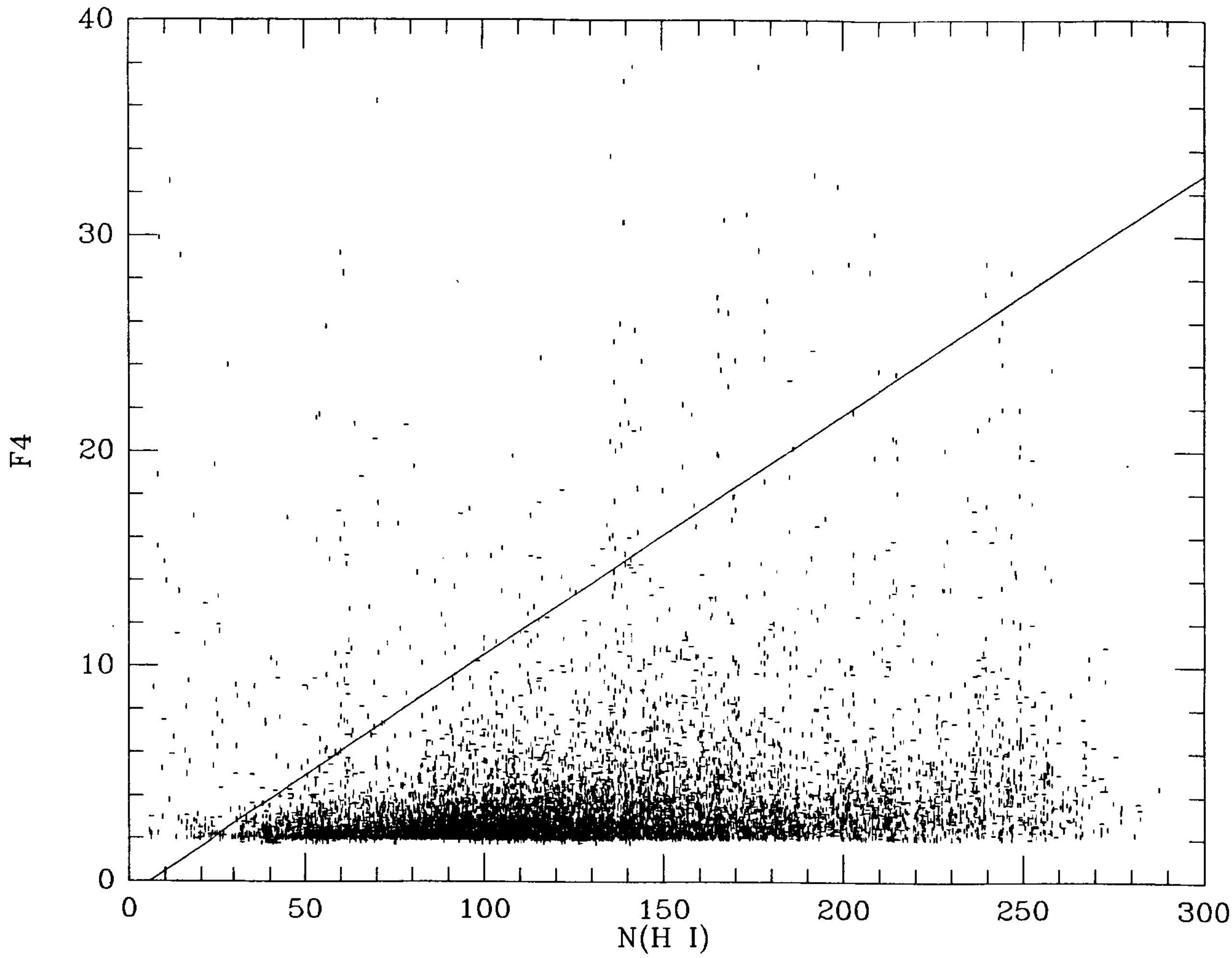

Figure 1. Scatter diagram of sources satisfying the first-stage selection process. $F4$ is the *IRAS* band 4 flux density in Jy; N(H I) is the H I column density in units of 9.96×10^{18} cm^{-2}, taken from Stark *et al.* (1986) for the Northern sky and from Cleary, Heiles, and Haslam (1974) for the Southern sky. This diagram does not include the full range of each variable, but does include the vast majority of the points. The solid line is the second-stage criterion of equation (1).

positive slope. For $F4$'s much larger than the majority, there is no obvious correlation with N(H I). We assumed that all sources with $F4$ exceeding a linear function of N(H I) should be considered as possible non-cirrus candidates, and determined the linear function by eye. The function, drawn in Figure 1, is

$$F4 = 0.1116 \text{ N(H I)} - 0.625 \text{ Jy}, \tag{1}$$

where the units of N(H I) are 9.96×10^{18} cm^{-2}, as on Figure 1.

The total number of sources satisfying the above criterion is 293. A bit fewer than half have positional coincidences with objects in astronomical catalogs other than the *IRAS* point source catalog. The distribution of the 293 sources on the sky is shown in Figure 2. The points tend to avoid low Galactic latitudes; this is a result of equation (1), because high H I column densities tend to lie at low latitudes.

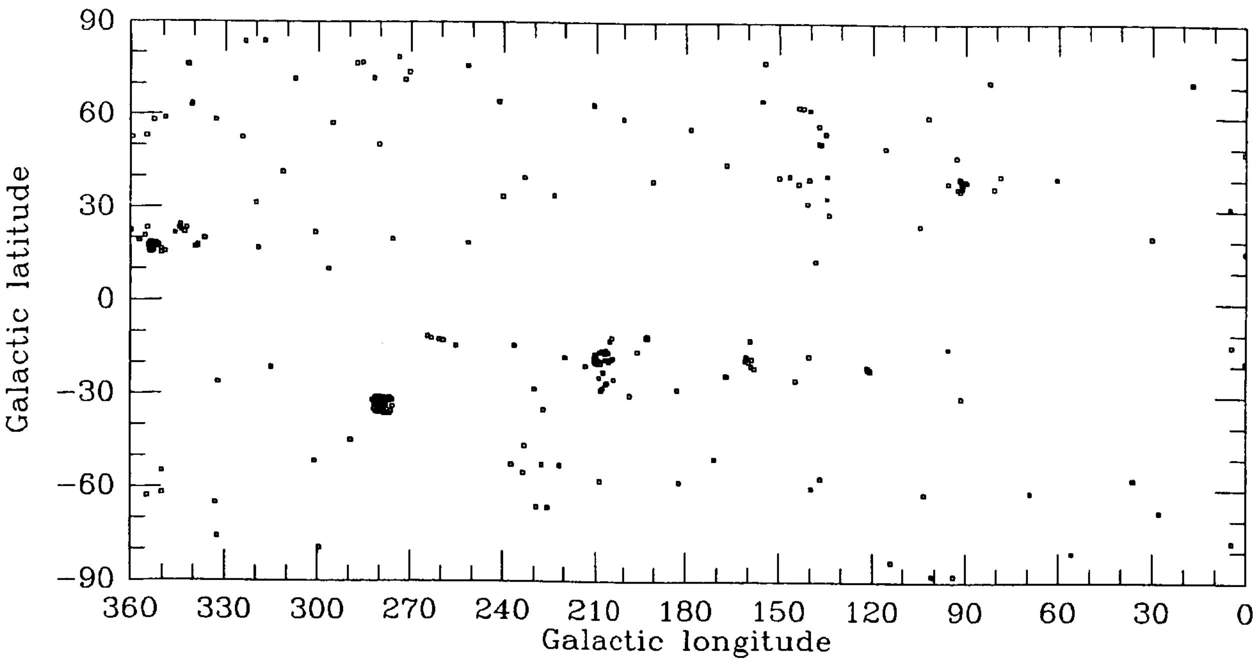

Figure 2. Distribution on the sky of sources above the solid line in Figure 1.

Some of the points are highly clustered. Five clusters can be identified with specific Galactic dust regions or extragalactic objects, as follows: $(l, b) \sim (122°, -22°)$, M31; $(161°, -19°)$, Perseus region; $(208°, -19°)$, Orion region; $(280°, -34°)$, Large Magellanic Cloud; $(353°, 17°)$, Ophiuchus region. Two clusters have no obvious identifications: $(l, b) \sim (92°, 38°)$, and the very sparse and possibly spurious cluster covering the large area centered near $(140°, 50°)$. The former is located near the nondescript external galaxies NGC 6223, 6226, 6238, and 6244, and near the nondescript Abell cluster 2232. It is also located in a region containing high-velocity H I, but because other high-velocity H I regions do not exhibit clustered sources there is probably no real association. Sources with the largest $F4$'s (> 50 Jy) are associated either with dense clouds of Galactic interstellar matter, the Large Magellanic Cloud, or the external galaxy NGC 891.

Are these 293 sources unique or do they simply occupy thê tails of the distributions of $F4$ and $F4/F3$? We are unable to tell. Our selected sources represent only a tiny fraction of all sources with interesting IR properties; the lion's share was discarded using equation (1). Answering the question would require generating a statistically unbiased list of *IRAS* point sources that are not associated with interstellar gas on arcminute scales. This might be done using high-resolution 21-cm line observations of a large unbiased sample, but this would be a tremendous undertaking.

III. GROUND-BASED OBSERVATIONS

A. 21-cm Observations

Equation (1) discriminates against regions of overall high H I column density, as measured with the large beamwidths ($\sim 1°$) used in the H I surveys. However, the possibility remains that small, arcminute-size clumps of H I exist within such regions. We used the NAIC Arecibo telescope[1] with

[1]The NAIC is a national facility operated by Cornell University under contract with the National Science Foundation.

its angular resolution of 3 arcminutes to check this possibility.

Out of 17 sources observed, 13 showed an H I column density excess relative to adjacent positions smaller than 10^{19} cm^{-2}, and the rest smaller than 3×10^{19} cm^{-2}. These are strict, absolute, and in many cases conservative upper limits. A point source with $F4 = 2$ Jy would produce an H I column density of 1.2×10^{21} cm^{-2} if the relation of Boulanger, Baud, and van Albada (1985) applies—100 times more H I than the observed upper limits. The most straightforward conclusion is the expected one, that these sources have nothing whatsoever to do with the interstellar gas.

We also used Arecibo to search for redshifted H I emission out to $\sim$ 6000 km s^{-1}. Of the sample of 17 observed, 6 were detected. All 6 were positionally associated with ordinary nearby galaxies and were so designated in the *IRAS* point source catalog. For these 6 galaxies, the ratios of H I mass to IR luminosity were typically much higher than those of the IR-bright sample studied by Young *et al.* (1986), by factors ranging from $\sim$ 10 to $\sim$ 1000. These large factors result from the combined effects of our galaxies being overly abundant in H I and underluminous in the IR, with respect to the optical brightnesses of that sample. Our 6 galaxies are very easily visible on the PSS, and are therefore intrinsically different from the PSS blank-field objects discussed below.

B. Optical Observations

We used the CCD spectrograph in the direct imaging mode on Lick Observatory's Shane 3-m telescope (Miller *et al.*, 1983) to take optical images of fields centered on 8 PSS blank-field sources. One and possibly one other showed the streaks characteristic of interstellar cirrus. Two fields clearly contained external galaxies within the *IRAS* error ellipse: one a pair of galaxies, and one a compact galaxy. One field, 1645+37, contained three very faint galaxies within the error ellipse. The other three fields were blank with R $\gtrsim$ 22.5 mag. The observations are summarized in Table 1, where the optical flux *densities* are compared to the IR flux *densities*.

TABLE 1

PROPERTIES OF OPTICALLY-OBSERVED SOURCES

SOURCE	IDENTIFICATION	R MAG	F4(Jy)	F4/(R-BAND FLUX)
0917+69	cirrus	-	3.5	
1148+58	compact galaxy	18	2.4	1.3E4
1149+61	pair of galaxies	16,19	2.0	1.8E3,2.8E4
1150-09	cirrus?	21	2.9	2.6E5
1231-05	?	>22.5	2.2	>7.8E5
1324+16	?	>22.5	2.8	>1.0E6
1325+16	?	>22.5	2.1	>7.4E5
1645+37	three galaxies	21.0-23.5	2.4	2.6E5-3.4E6

We also used the CCD spectrograph to obtain low-dispersion spectra of the three galaxies in the 1645+37 field. These data were taken very recently and are currently being analyzed. The easternmost galaxy exhibits a clear emission line. If this emission line is [OII] λ3727, then the redshift is 0.444 ± 0.002. With this redshift, the optical luminosity of the galaxy is roughly typical of L_* galaxies and the galaxy exhibits small internal reddening. The westernmost galaxy has a broadband spectrum similar to that of the easternmost galaxy, but exhibits no emission line. The central object exhibits an unusual broadband spectrum, becoming spectacularly bright towards the blue.

There is a good *a priori* probability of finding the galaxies described in the above paragraph by observing eight *randomly-selected* fields to the depth that we observed. However, the central object in the 1645+37 field is very unusual, and the *a priori* probability of finding it in eight randomly-selected fields would appear to be small. Further observations and analysis are needed to determine just how unusual this object is.

C. 1.2 mm Continuum Observations

We used the NRAO 12-m telescope at Kitt Peak[1] to observe a selection of sources at 1.2 mm wavelength. Our goal was restricted to determining whether the sources are nonthermal emitters, *i.e.* similar to ordinary continuum radio sources with flux density rising toward lower frequencies. Sensitivity was low because of power outages, hardware failures, basic errors in system software, and (least of all) weather; the average 3σ flux density limit was 5.5 Jy. No source was detected. Thus no source was significantly stronger at 1.2 mm than at 100 μm. Any typical power-law synchrotron source would have been easily detectable. The most straightforward conclusion is that the sources are thermal emitters, perhaps modified by the wavelength-dependence of the emissivity of dust particles.

IV. DISCUSSION

Our 1.2 mm observations imply that the *IRAS* point-source emission is thermal. Nevertheless, it would be remiss not to mention the unlikely alternative that the IR emission is produced by an as-yet unspecified powerful process, making the situation analagous to the early days of radio astronomy when virtually nothing was known about the basic characteristics of nonthermal radio sources. If the radiation has a blackbody spectrum, $(F4/F3) > 5$ corresponds to $T < 30.5$ K; if the emission comes from dust, which radiates less efficiently at long wavelengths, then the physical temperature of the dust is smaller. For a blackbody emitter at T=30.5 K to produce $F4 = 2$ Jy, its angular diameter > 0.6 arcsec; if the radiation is from dust, this is a lower limit.

With such angular diameters, most of the objects can hardly be anything but diffuse matter. If Galactic, their lack of concentration toward the Galactic plane would imply that they are nearby, with typical distances smaller than their z-heights above the Galactic plane. If extragalactic, they would be truly spectacular because the ratios of IR to optical flux densities are enormous. For example, for objects fainter than 22.5 mag, the ratio of $F4$ to optical R-band flux *density* is $\gtrsim 10^6$. This is about 50 times larger than the corresponding ratio for the extremely far-IR bright starburst/Seyfert galaxy Arp 220 (Rieke *et al.*, 1985; Soifer *et al.*, 1984) and about 10 times larger than the ratio for the most extreme example in the lists of Aaronson and Olszewski (1984) and Houck *et al.* (1985).

Finally, we mention ripe areas for future observational work. Most intriguing is the unidentified cluster of sources, associated with diffuse cirrus, centered near $(l,b) \sim (92°,38°)$ or $(\alpha,\delta) \sim (16^h47^m,62°)$. IR observations longward of 100 μm should be successful because of the rapid rise of flux density with decreasing frequency, unless the radiation is line emission; very low-resolution spectroscopy is the best approach for this test. If these sources obey the same statistical relationships as external galaxies they should be detectable as radio continuum sources, typically with flux densities $\gtrsim 3$ mJy at 1.4 GHz (Helou, Soifer, and Rowan-Robinson, 1985) and as CO emitters, typically at the level $T\Delta v \gtrsim 0.5$ °K-km/s with the FCRAO 14-m telescope (Young *et al.*, 1986). Finally, we will continue our optical observations.

[1]The NRAO is operated by Associated Universities, Inc., under contract with the National Science Foundation.

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