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PAPER 1.2

100 MICRON SURVEYS IN THE NORTHERN AND SOUTHERN HEMISPHERES*

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ABSTRACT

Partial surveys in the far infrared in the Northern and Southern Hemispheres have covered 40% of the galactic equator and assorted regions away from the galactic plane. Approximately 120 100-micron objects are known. These are distributed extensively in galactic longitude and concentrated within ± two degrees in galactic latitude. From this information, some general conclusions can be drawn about the sensitivity and coverage required for a general sky survey in the far infrared.

INTRODUCTION

As new techniques of detection open up new parts of the spectrum to astronomical observation, a survey of the sky at the new wavelength is appropriate and valuable. Sometimes, although not always, this is a means for making unexpected new discoveries. In general, such surveys are of value for providing a general picture of the sky at the new wave length, making possible classification and statistical analysis, and providing a guide to detailed studies.

In the infrared and submillimeter part of the spectrum, there are the 2.2 micron Cal Tech sky survey (Neugebauer and Leighton 1969) and the 10 micron Air Force Cambridge Research Laboratory rocket survey (Walker and Price 1974). The shortest wavelength continuum radio survey of the galactic plane are the surveys at 6 cm of Altenhoff et al (1970) and Goss and Shaver (1970). The shortest wavelength radio survey of substantial portion of the entire sky is at 21 cm. Thus, there is a substantial gap in our systematic knowledge of the sky between the wavelengths of ten microns and 6 cm (60,000 microns).

The phenomena which dominate the emission processes over this large spectral range vary sufficiently so that knowledge gained in the infrared at 10 microns or in the radio region at 6 cm does not provide much of a clue as to the objects to be found at the intermediate wave length of 100 microns. The stellar photospheres and circumstellar dust envelopes which dominate the 10 micron sky provide little contribution at 100 microns. Similarly, the hot ionized gas which accounts for the thermal radio-continuum emission in HII regions provides very little flux in the far infrared. On the other hand, interstellar dust clouds, dust in HII regions, and dust in galactic nucleii, because of its low temperatures, emits thermally primarily in the far infrared.

For this reason, a balloon-borne far infrared astronomy program was initiated at Goddard Institute for Space Studies and is now being continued

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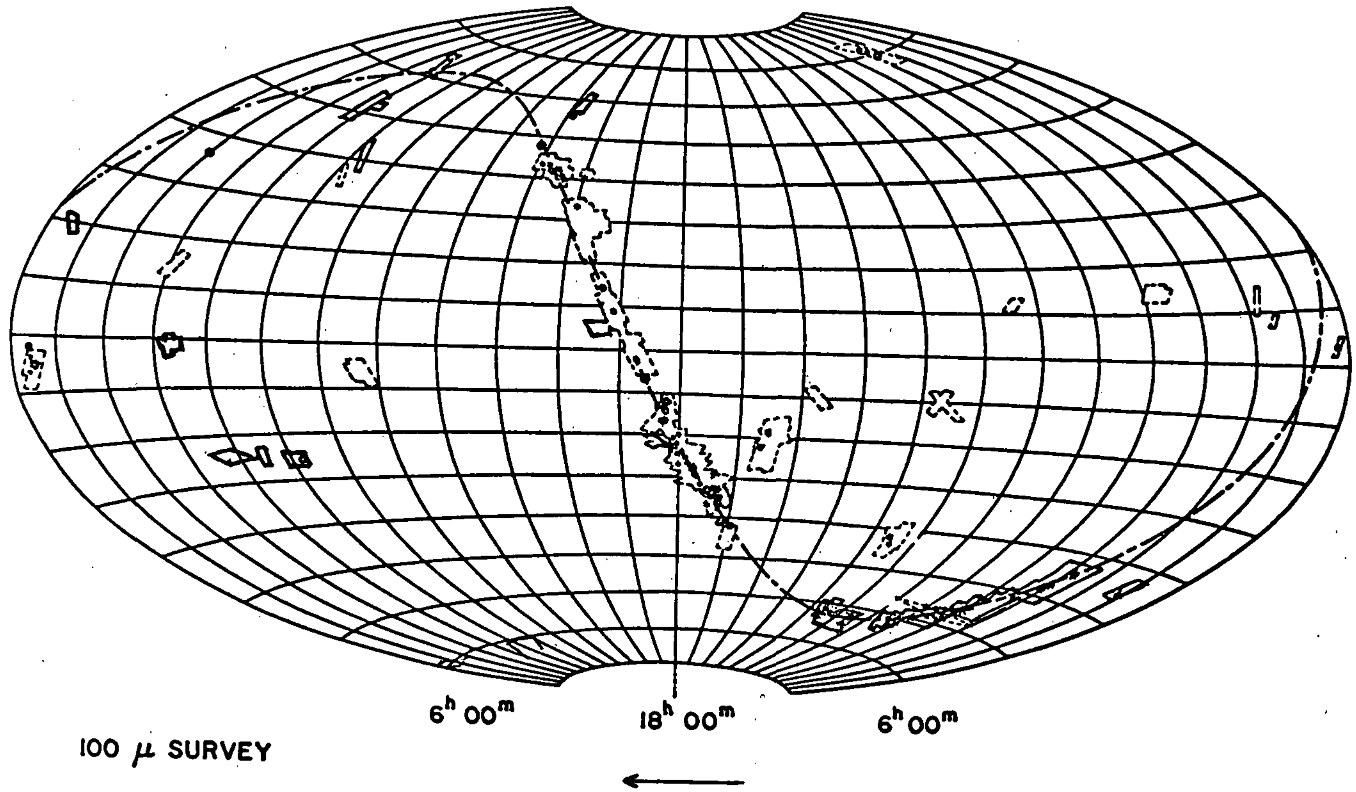

Figure 1 - The regions of the sky that have been surveyed in the balloon experiment when plotted on an equal areas projection of the entire celestial sphere. The *'s show the positions of 100 micron sources observed in the balloon survey. The open circles show the positions for additional sources observed in other experiments.

at the Steward Observatory in order to survey the sky at 100 microns. This survey is not complete. In this paper we would like to discuss what has been observed, what can be said statistically about the spatial and brightness distribution of known sources, and what level of performance is required for a more detailed and more complete survey. While the largest number of sources analyzed has come from the Goddard/Arizona balloon surveys, we have attempted to include a number of other objects not observed in that program but reported by other groups. The sources for the data analyzed are: Harper and Low (1971), Hoffmann, Frederick, and Emery (1971), Soifer, Pipher, and Houck (1972), Emerson, Jennings, and Moorewood (1973a), Emerson, Jennings, and Moorewood (1973b), Harper and Low (1973), Olthof (1974), and Hoffmann, Frederick, Emery, and Aannestad (1974).

OBSERVATIONS

Figure 1 shows the regions of the sky that have been surveyed in the balloon experiment. The *'s give the positions of 100 micron sources observed in the balloon survey. The open circles give additional sources observed in other experiments. 140^o or 40% of the galactic plane has been covered in a band varying from 4^o to 8^o wide. 700 sq. degrees of sky along the plane and 250 sq. degrees elsewhere have been surveyed. This represents about 2.4% of the entire celestial sphere. Some of the interesting areas are: to the extreme left, the Orion infrared nebula; at RA 45 min DEC-26^o, the galaxy NGC 253; at 20 hrs. 40 min., + 42^o the Cygnus region; a stretch centered on 19 hours including W51, W49, and M17; another stretch centered on the galactic center at 18 hours including M8 and the galactic center complex; in the region of 16 hrs. 30 min., - 20^o, dark clouds in the Ophiuchus region; centered on 13 hrs., - 63^o the Coal Sac Nebula; near 13 hrs. 20 min., - 43^o the Centaurus A region; at 11 hours, - 59^o the Carina Nebula; and at 10 hrs., + 70^o, the galaxy M82. As can be seen from Figure 1, this is a patchy and highly selected sample of the sky.

With some caution to avoid extracting more than is present from this limited sample, we have attempted to learn something about the distribution of the known 100 micron objects in galactic coordinates. Figure 2 shows a histogram of the sources in galactic longitude. The lower part gives the number of sources in 10^o blocks of longitude. Since this distribution can be heavily biased by the spottiness of the sample of the galactic plane, we have shown in the upper part a histogram indicating the regions of the galactic longitude which have been scanned. The full value indicates that the scans cover 4^o or more across the galactic plane. The half value indicates a narrower region less than 4^o wide. The lower part of Figure 2 shows a slight concentration of sources toward the galactic center, although this concentration is not nearly as much as might have been expected. In addition, since the region between 320 and 345 degrees galactic longitude has not been covered in the Goddard surveys, this apparent peaking may be a selection effect. The results of Ricker, Lewen, and Low (1974), when available, should partially cover this region. The relatively small number of bright sources between M17 and the Cygnus region, however, does appear to be a real effect rather than an observational selection effect. Although there remains a substantial gap in the data along the galactic equator in the northern hemisphere, it does appear that the preponderance of sources are in the southern hemisphere. From left to right, the main peaks occur in the areas of the Carina Nebula, the Coal Sac Nebula, the Galactic Center, and the Cygnus Region.

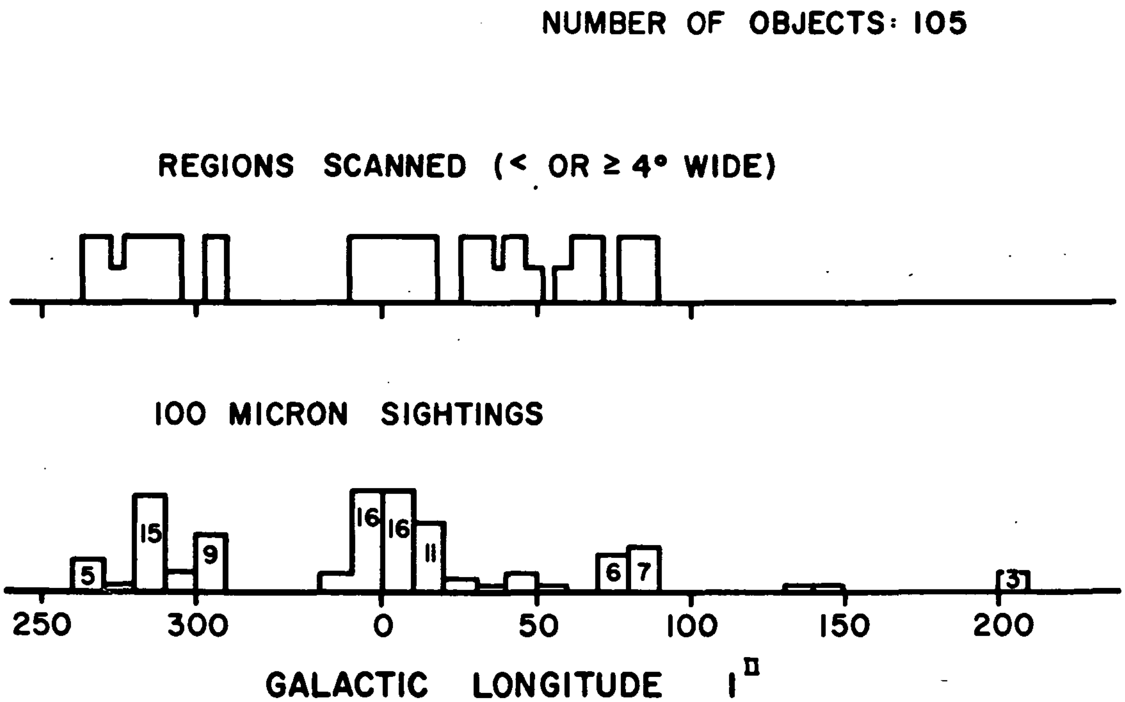

Figure 2 - Lower portion: A histogram of 100μ objects as a function of galactic longitude. Upper portion: A diagram indicating the regions in galactic longitude which have been scanned. The full value indicates that the scans covered 4° or more in the direction normal to the galactic plane, the half value corresponds to scans less than 4° wide.

Figure 3 gives a histogram in galactic latitude with intervals of 1° from the galactic equator. As in figure 2, the upper part indicates the distribution of scans in galactic latitude. The three levels represent the portion of scans at various widths. Approximately half were 6° wide or wider. Of the remaining, most were at least 4° wide and a small number were as small as 3° in width. The histogram in the lower half is substantially more concentrated toward zero galactic latitude than the distribution of scan widths. We, therefore, conclude that the distribution of 100 micron sources is very much concentrated within ± 2° or less of the galactic equator. For the sample over a 6° wide band, 62% are within ± 1° galactic latitude and 93% are within ± 2°. While the fall-off at the edge of this histogram is biased by the finite width sample, we conclude from this that the far infrared sources within 3° of the galactic equator are substantially concentrated toward the equator with over half within ± 1° of it. From the present survey information, it is not possible to tell what the wings of the distribution look like with increasing galactic latitude.

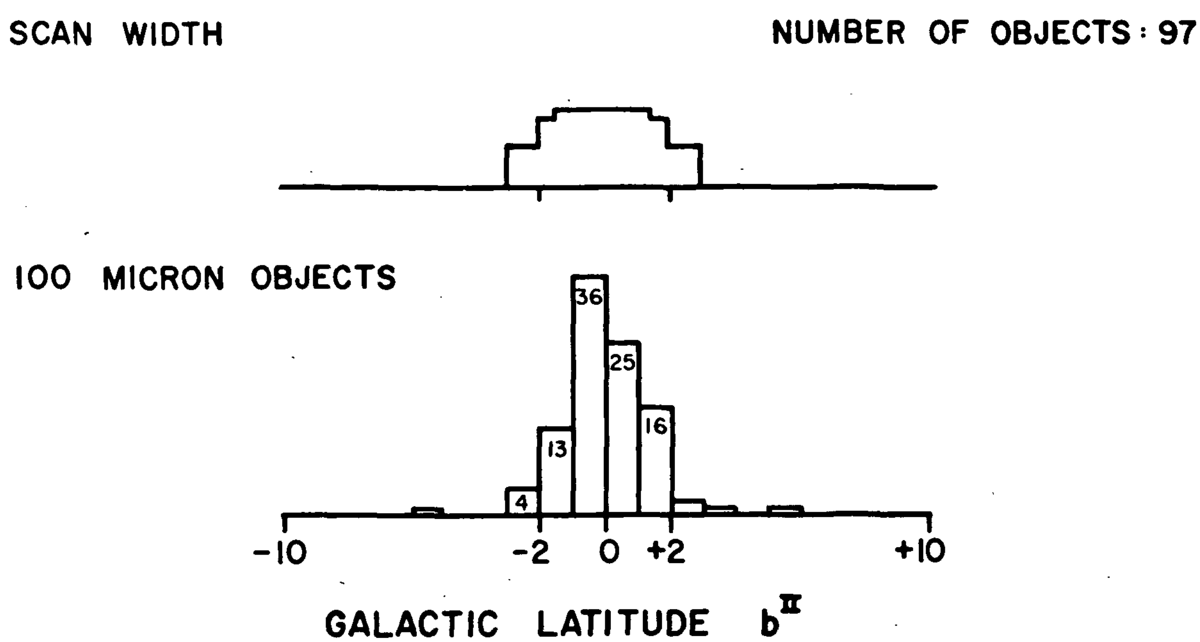

Figure 3 - Lower portion: A histogram of 100μ objects as a function of galactic latitude. Upper portion: A diagram indicating the portion of scans of various widths across the galactic plane. See text for details.

It is also interesting to analyze the known sources in terms of their brightness (flux density), as a guide to the sensitivity that should be achieved in a more extensive survey. Figure 4 shows a histogram of the sources as a function of 100 micron flux density in units of 10^{-22} W/m^2Hz. The intervals are logarithmic. The rapid falloff for the faint sources is representative of the sensitivity limit of the apparatus near 1 x 10^{-22} W/m^2Hz. The steepness of the rise in numbers from the brightest sources toward weaker ones is much slower than one would expect from a group of sources of identical intrinsic brightness uniformly distributed in volume. This is consistent with the picture that the bulk of the sources are neither solar neighborhood sources nor extragalactic sources but are primarily confined to the Milky Way and hence, constrained to a limited range of distance. It appears from Figure 4, that as the sensitivity of a survey is increased from 10,000 flux units (1 flux unit = 10^{-26} W/m^2Hz) to 1,000 flux units, the number of sources along the plane should increase substantially. As the sensitivity is further increased to 100 flux units, one would expect a continuous mapping of 100 micron emission along the galactic plane similar to the radio maps where the "sources" are peaks in a continuous distribution flux.

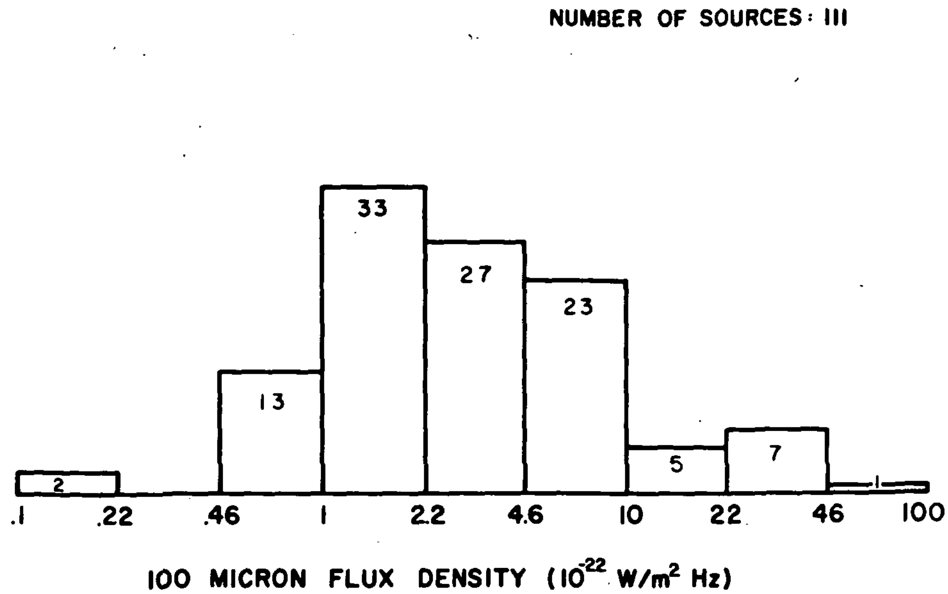

Figure 4 - A histogram of 100μ objects as a function of their 100μ flux density.

FUTURE SURVEYS

Two balloon programs now being carried out to substantially improve the sensitivity of survey type instruments are the 8-inch low emissivity off-axis Hershellian telescope of Frank Low, at the University of Arizona, and the Cornell/Arizona 16-inch cryogenically cooled telescope. Both of these instruments are aimed at high throughput (product of solid angle in sky and telescope aperture) with the thermal emission of the instrument reduced to, or below, the atmospheric emissivity in order to make possible the use of more sensitive detectors optimized for very low background flux. These two instruments are described elsewhere in these proceedings. In order to provide a set of numbers from which to start, we have considered two possible survey objectives, (a) a survey of the galactic plane, and (b) a survey of most of the celestial sphere. The first goal is compatible with a number of short duration balloon flights. The entire celestial sphere survey is ideally suited to a long duration super pressure balloon flight. Table 1 gives a set of parameters for the short duration balloon flights. Some of these are taken from our experience with the current Goddard Institute for Space Studies/Arizona balloon gondola. It would appear that with reasonable scan rates and overlapping coverage, the galactic plane can be covered redundantly in five flights. The resolution given is 3 arc minutes. The location of all but the faintest sources should be obtained to approximately 1 arc minute. While this can be achieved with a rather larger beam by careful determination of the center point of the scan signal, large beams (greater than 12 min. of arc) will probably suffer substantially from source confusion at these high sensitivity levels along the galactic plane. The integration time of 0.12 seconds is derived from the 3 min. resolution and the 48 hours of flight. While this resolution is required for adequately determining the center of sources to 1 arc minute, very faint sources can be analyzed at lower resolution to take advantage of a larger beam size. For this reason, we have shown sensitivity figures for both 3 arc minute resolution and 12 minute resolution. The latter is 1×10^{-24} W/m^2Hz. The detector NEP assumed, 10^{-14} $W/\sqrt{Hz}$ appears to be the best that is currently available.

TABLE 1

SHORT DURATION BALLOON FLIGHTS

Coverage:	Galactic Plane 3600 deg^2
Rate:	75 deg^2/hr (48 hours)
Number Flights:	5
Resolution:	3'
Integration Time:	.12 sec
Telescope Area:	$.13m^2$ (16")
Wavelength:	100μ
Detector NEP:	10^{-14} Watt/$\sqrt{Hz}$
Overall Efficiency:	10%
Sensivity (3σ) in 3':	4×10^{-24} W/m^2Hz
Sensivity in 12':	1×10^{-24} W/m^2Hz

A survey of the entire celestial sphere would be aimed at discovering extragalatic sources of far infrared radiation. As such, to be of use, it would have to be even more sensitive than a survey of the galactic plane and, at the same time, cover a substantially larger area. Assuming the same detector sensitivity, this objective can be realized by only more observing hours, hence a long duration balloon flight. In table 2, we have assumed a two-week flight with an ambient temperature low-emissivity telescope of 25 centimer diameter (and a liquid helium-cooled detector). This system offers a sensitivity of only 1×10^{-23} W/m^2Hz (1,000 flux units) at the 3 arc minute resolution. At 12 minutes, the sensitivity is 250 flux units. If the throughput is increased sufficiently to provide a 50' (1^o) beam, the sensitivity could be as good as 50 flux units. Since the density of infrared objects at high galactic altitudes is expected to be substantially less than that along the galactic plane, the problem of source confusion should be much less than along the galactic plane. For this reason, a compromise favoring greater throughput and sensitivity at the expense of resolution and position accuracy would probably be desirable.

TABLE 2

LONG DURATION BALLOON FLIGHT

Coverage	Declination $+30^{\circ}$ to -90°
Area:	31000 deg^2
Resolution:	3'
Data Points:	12×10^6
Time:	2 weeks $\equiv 1.2 \times 10^6$ seconds
Integration Time:	0.1 second
Telescope Area:	.05 m^2 (25 cm diameter)
Wavelength:	100μ (80μ - 120μ)
Detector NEP:	10^{-14} Watts/$\sqrt{Hz}$
Overall Efficiency:	10%
Sensivity in 3' (3σ):	1×10^{-23} W/m^2Hz
Sensivity in 12':	2.5×10^{-24} W/m^2Hz
Sensivity in 60':	5×10^{-25} W/m^2Hz

CONCLUSION

With a little over one hundred objects known from far infrared sky surveys to date, some characteristics of these objects in the Galaxy are beginning to become known. Two extragalactic objects have been measured in directed (non-survey) efforts (Harper and Low 1973). It is now possible to define with reasonable confidence the surveys required for detailed mapping of the galactic plane and for an all-sky survey for galactic and extragalactic objects.

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DISCUSSION SUMMARY — PAPER 1.2

It was pointed out from the floor that a collaborative investigation involving scientists from the University of Arizona and from MIT had produced a partial survey of the Milky Way. This investigation used a system with a field-of-view of 3/4 of a degree and a sensitivity threshold of 700 to 1000 flux units at 100 microns. With this system the Milky Way appears as a bright band several degrees wide. Observations were made from south of the galactic center northward to W3. It is not known if this is radiation from a continuous emitting volume such as the interstellar dust, or if it is from unresolved discrete sources.

This was observed as well by Dr. Hoffmann when surveying the galactic plane in the vicinity of the galactic center.

The discussion continued with consideration given to the relative merits of low resolution and medium resolution surveys. Higher resolution surveys of the galactic plane are in order since the initial low resolution surveys have been performed. A survey of the entire sky can be done adequately with a field-of-view of 12 to 15 arcminutes if the number of sources expected can be resolved on the average with this field-of-view.

It was asked if any evidence had been detected of water vapor associated with the balloon. None had.