AFCRL-71-0387

PRELIMINARY RESULTS OF AN INFRARED SKY SURVEY

by

Frank J. Low

University of Arizona
Tucson, Arizona 85721

Contract No. F19628-70-C-0046
Project No. 5130

SEMI-ANNUAL TECHNICAL REPORT NO. 2

28 February 1971

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
University of Arizona
Tucson, Arizona 85721

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
PRELIMINARY RESULTS OF AN INFRARED SKY SURVEY

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*
Frank J. Low

6. REPORT DATE
20 February 1971

7a. TOTAL NO. OF PAGES
18

7b. NO. OF REFS
9

8a. CONTRACT OR GRANT NO.
F19628-70-C-0046 ARPA Order No. 1366

b. PROJECT ~~NO~~. Task, Work Unit Nos.
5130 n/a n/a

c. Dod Element 62301D

d. Dod Subelement n/a

9a. ORIGINATOR'S REPORT NUMBER(S)
Semi-Annual Technical Report No. 2

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
AFCRL-71-0387

10. DISTRIBUTION STATEMENT
1 - This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES
TECH., OTHER

12. SPONSORING MILITARY ACTIVITY
Air Force Cambridge Research Labs (OP)
L.G. Hanscom Field
Bedford, Mass. 01730

13. ABSTRACT

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DD FORM 1 NOV 65 **1473** REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Infrared Stars						
Infrared Sources						
Cosmic Background						

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Program Code No. 1E50

Effective date of contract .... 14 August 1969

Contract expiration date .... 31 December 1971

Principal Investigator and phone no. .... Dr. Frank J. Low/602 884-2727

Project Scientist and phone no. .... Stephan D. Price/617 861-2501

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Preliminary results of a groundbased survey of the sky at 10 microns are reported. Four different detector systems have been used; their performance is discussed. On the basis of partial reduction of the data, we can state that the space density of stars at 10 microns is no greater than 0.01 per square degree at flux levels above 3.5 x 10^{-16} w/cm^2/μ. A celestial star chart and catalog is given for 100 stars brighter than 3 x 10^{-16} w/cm^2/μ. Extragalactic sources have been observed down to a flux limit of 3 x 10^{-19} w/cm^2/μ.

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I. INTRODUCTION

In the Annual Technical Report dated 30 September 1970, many of the technical aspects of the Groundbased Infrared Sky Survey were discussed. Since that time, new apparatus has been constructed which has lead to further information on the performance of groundbased infrared systems and has yielded considerable improvement in sensitivity. These modifications will be briefly described. Basically, we have operated in four different modes utilizing different detector systems and three different telescopes. This has given us practical information showing how the performance of an infrared sky survey changes with various fundamental parameters. It has also yielded a considerable amount of survey data which will be summarized in this report. Unfortunately, the reduction of much of the digital data has been delayed by scarcity of funds and is not complete. However, the principal results and conclusions should not be greatly altered in the final data reduction.

In our first Semi-Annual Technical Report dated 15 March 1970, we published a list of 5, 10 and 22 micron photometry of celestial objects, mostly bright stars. In this report, we have recompiled these data and added to them from recently published photometry of similar nature obtained by other workers. This compilation is a useful digest of 10 micron photometry covering the known sources brighter than N magnitude minus 1.0 (flux density greater than 3.0 x 10^{-16} w/cm^2/μ). These data have been plotted on a celestial sky chart to show the distribution of these bright objects. When combined with the results of our groundbased survey, it is possible to reach fairly firm conclusions concerning the true density of sources in the brightness level covered.

As a part of this program, we have undertaken to investigate the infrared emission from extragalactic sources, principally quasars and the nuclei of galaxies. More than fifty sources have been well observed with flux limits typically less than 1 x 10^{-27} w/m^2/Hz (3 x 10^{-19} w/cm^2/μ). Apparently half of these sources have been detected and it is now possible to make a rough approximation concerning the contribution of extragalactic sources to the overall cosmic background at 10 microns. A preliminary review of these results will be given in this report.

II. The Technical Aspects of the 10 Micron Survey

Table I shows the four different systems that have been used. System I was used only for a short time and served as the prototype for System II, which was described in some detail in the 30 September 1970 Annual Technical Report. The same eight detector, four channel array was operated whenever scheduling permitted on the 60-inch metal mirror telescope at the Catalina Observatory. It can be seen that the increase in sensitivity when the apparatus was switched from the 28-inch to the 60-inch was approximately as predicted on the basis of increased area. System IV represents a new effort to extend the sensitivity to lower flux levels in order to obtain information at a flux level not covered previously. It utilized techniques developed for the single channel high sensitivity photometer used for multiband photometry on discrete sources. Utilizing the high resolution of the 61-inch telescope and the F45 modulating secondary, a four detector, four channel array was constructed with a field view of about 10 arcseconds for each detector. It was found that this system was largely background limited rather than sky noise limited and sensitivity on the order of 1 x 10^{-17} w/cm^2/μ was achieved. Unfortunately, only a limited amount of observing time was available because of the heavy commitment of the telescope to other programs. Nevertheless, the results were rewarding in that the rate at which previously unknown sources were seen by this system is substantially greater than by the lower sensitivity survey.

As part of this program, we are now in a position to analyze the effects of sky noise on the groundbased survey. It appears that System IV is much less susceptible to sky noise than the wider field Systems II and III. For this reason, it now appears that the most efficient use of groundbased telescopes in this application requires large collecting areas and small field of view.

This follows from the result that sky noise is directly proportional to the background flux, whereas photon noise is proportional to the square root of background flux. At the outset of the survey program, we did not know that the sky noise increases during the daytime to a value several times greater than the nighttime minimum. This dirunal effect means that an apparatus optimized for nighttime surveying will not be optimized for daytime work and that quiet sky conditions seldom occur during daytime.

III. Observational Results of the 10 Micron Groundbased Survey

Again referring to Table I, we have summarized the area of the sky that was covered and the number of possible sources that were seen. Of the thirteen possible sources seen by System IV, only one source has been definitely confirmed.

1971 coordinates for the new object in Camelopardalis are $\alpha = 03^h\ 26^m\ 26^s\!.4(\pm 2)$ and $\delta = 58^\circ\ 41'\!.17(\pm 0'\!.1)$. The N magnitude is minus 0.8 or 2×10^{-16} w/cm^2/μ. Photometry was carried out from 2.2 to 25 microns showing a spectral distribution quite similar to the bright infrared stars, NML Cyg and VY CMa. There is an extremely faint red star coincident with the infrared coordinates. This object is about 100 times fainter than NML Cyg; therefore, we conclude that it is about 10 times more distant.

Several of the possible sources seen by System IV appear to be brighter than magnitude plus 1. However, we have discovered a serious difficulty in confirming them. The coordinates deduced from the telescope position are found to change by several minutes of arc during the daytime as a result of solar heat within the dome. All of these data were obtained during daytime. This has generated considerable ambiguity in the positions of the sources, a problem which is not readily soluble.

We are now in the process of re-reducing all of the data from Systems II and III on a uniform basis. This will yield more precise information on the source density at the higher flux levels. This task should be complted in a few months. However, when the present preliminary results are combined with the data presented in the following section on the number of bright stars, we can reach important conclusions about the space density of sources. These conclusions will be discussed in the final section of this report.

IV. Infrared Stars Brighter than 3×10^{-16} w/cm^2/μ

In Table II, we have compiled a list of stars which are bright at 10 microns. The tabulated quantity is the N magnitude (10.1μ) based on the photometric system introduced by Low and Johnson in 1964 (ref. 1). This photometric system is such that zero magnitude corresponds to an absolute flux density of 1.2×10^{-10} w/cm^2/μ. It is thought that this absolute calibration is accurate to within ±15%. Table III lists the standard stars and the current best values for their magnitudes. The reason that these stars were adopted as standards for our photometry is that most of the brighter stars in Table III have been shown to be variable and hence unsuitable for this purpose.

Note that nearly all of the stars in Table II are bright enough to be included in the IRC 2.2 micron catalog (ref. 8) which lists approximately 5,000 stars, all brighter than K magnitude = +3.0. It is not known as yet how many more stars in the IRC Catalog are brighter than N magnitude minus 1.0. However, it is thought that Table II is fairly complete in this respect.

Figure 1 shows the brightness distribution of the stars in Table II as a function of magnitude. This distribution clearly shows that the sample is incomplete at the fainter end. Note, for example, that the only peculiar infrared stars included in Table II are at the bright end of the distribution.

Figure 2 shows how these stars are distributed on the celestial sphere. The dashed curve in Figure 2 represents the plane of the Milky Way. The most interesting feature of this map is the almost random distribution of the sources, a result which would be expected only if the spatial distribution of the objects is uniform. This is true at visual wavelengths only for the brightest stars.

V. Extragalactic Sources at 10 Microns

For the last three years, we have been studying the infrared emission from quasars and the nuclei of galaxies and discovered that these extremely luminous sources are surprisingly common. It is now thought that a universal mechanism accounts for the extraordinary infrared luminosity of these extragalactic sources. The physical mechanism by which the radiation is produced is not understood, nor do we understand the sources of the enormous energies that are involved. However, we do know that these sources, like all extragalactic sources, are uniformly distributed on the sky and it is important to ascertain what contribution they make to the cosmic background. The cosmic background can be treated in two ways. First, we know that the sky contains many discrete sources. Most of these will appear as point sources or star-like bodies because we have all ready seen that only the nuclei of galaxies are emitting appreciable infrared radiation. Second, we can expect a diffuse isotropic cosmic background generated by the integrated sum of all the infrared photons emitted by all of the sources in the universe. The present study is aimed at gaining quantitative information about both the number of discrete extragalactic sources and about their contribution to the isotropic background.

Table IV summarizes the results that have been obtained so far. Note that none of these sources are bright enough to be detected in the groundbased survey with Systems II or III. However, the survey with System IV would be capable of detecting several of the brightest extragalactic sources. Of the fifty galaxies and quasars that have been observed, about twenty-five have been detected. These are all brighter than 3×10^{-19} $w/cm^2/\mu$ (note that one flux unit equals 1×10^{-26} $w/m^2/Hz = 2.5 \times 10^{-18}$ $w/cm^2/\mu$). By far the most populous class of galaxy which is bright in the infrared are the spiral galaxies. No elliptical galaxies have so far been detected.

Work is now in progress to relate the observed infrared emission of galaxies and quasars to their radio emission. Once this relation is made quantitative, it will be possible to determine the number of extragalactic infrared sources per unit area of the sky as a function of magnitude or brightness. It will then be possible to solve the problem of the isotropic background produced by these sources (see, for example, "Contributions of Infrared Galaxies to the Cosmic Background", ref. 9).

VI. Conclusions

1. From the results of Table II shown in Figure 1, it is clear that the mean density of stars brighter than 3×10^{-16} $w/cm^2/\mu$ is at least 0.005 per square degree. These stars are almost randomly distributed across the sky.

2. The results of the survey with System II, as given in Table I, are incomplete but are compatible with a mean star density at 3.5×10^{-16} $w/cm^2/\mu$, no greater than about 0.01 per square degree. Further data processing and further observations are needed to confirm this conclusion.

3. The results of the survey at higher sensitivity with System IV, as given in Table I, suggest that the density of stars increases as brightness decreases faster than a factor of 4 per magnitude, at least in the galactic plane.

4. At flux levels below 1×10^{-18} $w/cm^2/\mu$ extragalactic sources, which are randomly distributed, may become significant. Work in progress will test this hypothesis.

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TABLE I

	I	II	III	IV
Telescope	28-inch	28-inch	60-inch	61-inch
Number of Channels	1	4	4	4
Minimum Detectable Signal (Typical)				
Flux (x 10^{-16} watts/cm^2/μ)	~10	3.5	1.2	0.5 - 0.15
Magnitude	-2.3	-1.2	0.0	+1.0 - +2.2
Scane Rate (sq. deg./hr.)	0.85	3.3	.87	.089
Observed Area (sq. deg.)	~490	~2000	~180	9.2
Number of Possible Sources	3	~20?	?	13
Number of Confirmed Sources	0	0	0	1

TABLE II

NAME	IRC	R.A. 1950	DEC.	REF. 2	REF. 3	REF. 4	REF. 5	REF. 6	REF. 7
T Cas	+60009	$00^h20^m.5$	+55°31'		-2.69		-2.50		
R And	+40009	00 21.4	+38 18	-2.60					
β And	+40019	01 06.9	+35 21	-2.06			-2.00		
γ And	+40034	02 0.8	+42 05	-1.20					
o Cet	00030	02 16.8	-03 02	-4.74		-5.28	-5.25		
S Per	+60088	02 19.3	+58 22	-2.01	-2.00	-1.87	-2.33		
α Cet	00038	02 59.7	+3 53	-1.73	-1.78	-1.78	-1.97		
ρ Per	+40054	03 02.0	+38 39	-2.06	-2.24	-2.24	-2.23		
γ Eri	-10055	03 55.7	-13 39	-1.36					
α Tau	+20087	04 33.1	+16 25	-3.11	-2.91		-2.98		
R Lep	-10080	04 57.3	-14 53		-2.29	-2.29			
W Ori	00066	05 02.8	+01 07		-1.57	-1.57			
α Aur	+50139	05 13.0	+45 56		-2.04		-2.00		
119 Tau	+20112	05 29.3	+18 34	-0.83	-1.17	-1.12	-1.26		
Kleinmann-Low Object		$05^h32.8$	-5° 28'	-2.61					
Becklin's Object		$05^h32.8$	-5° 24'	-2.90					
Y Tau	+20121	05 42.7	+20 40		-1.65				
α Ori	+10100	05 52.5	+7 24	-5.25	-5.27		-5.30	-5.3	
U Ori	+20127	05 52.9	+20 10		-2.70	-2.70	-2.48		
17 Gem	+30194	06 02.7	-16 29	-1.37					
TV Gem	+20134	06 08.8	+21 53		-.92	-.91	-1.08		
η Gem	+20139	06 11.9	+22 31		-1.68	-1.68	-1.68		
μ Gem	+20144	06 19.9	+22 32				-2.14		
HD 45677		06 25.7	-12°57	-1.47					
UU Aur	+40158	06 33.1	+38 29		-1.98				
α CMa	-20105	06 42.9	-16 39				-1.53		
VY CMa	-30087	07 20.9	-25 40	-6.08		-6.3		-6.3	
Y Lin	+50180	07 24.6	+46 06		-1.51		-1.30		
U Mon		07 28.4	-09 40				-1.3		
β Gem	+30194	07 42.2	+28 09	-1.32			-1.33		
R Cnc	+10185	08 13.8	+11 53		-2.35	-2.35	-2.30		
V Cnc		08 18.9	+17 27		-3.53	-3.53			
RS Cnc	+30209	09 07.6	+31 10		-2.85	-2.80	-2.60		
R LMi	+30215	09 42.6	+34 45		-2.58		-2.60		
R Leo	+10215	09 44.9	+11 40	-4.26	-4.34	-4.41	-4.63		
	+10216	09 45.3	+13 31	-7.18		-7.09			
CIT 6	+30219	10 13.2	+30 49	-4.50			-5.22		
γ^1 Leo	+20219	10 17.2	+20 06	-1.15					
μ UMa	+40218	10 19.4	+41 45				-1.03		
U Hya	-10242	10 35.1	-13 01		-1.76				
VY UMa	+70100	10 41.6	+67 40	-1.21	-1.21				

TABLE II (cont.)

NAME	IRC	R.A. 1950	DEC.	REF. 2	REF. 3	REF. 4	REF. 5	REF.6	REF.7
V Hya	-20218	10 49.2	-20 59		-3.90	-3.92	-3.92		
VY Leo	+10325	10 53.4	+06 27			-1.13	-1.19		
Y CVn	+50219	12 42.8	+45 43		-2.22		-1.96		
δ Vir	00226	12 53.1	+03 40			-1.55	-1.55		
RY Dra	+70116	12 54.5	+66°16'		-1.15				
SW Vir	00230	13 11.5	-02 33		-2.85				
V CVn	+50226	13 17.3	+45 47		-1.08		-1.12		
R Hya	-20254	13 27.0	-23 01	-3.37	-3.91	-4.11	-4.31		
W Hya	-30207	13 46.2	-28 07			-5.16			
R CVn	+40248	13 46.8	+39 47			-1.09			
η Boo	+20267	13 52.3	+18 39	-2.76					
α Boo	+20270	14 13.4	+19 27	-3.28	-3.27		-3.24	-3.3	
RX Boo	+30287	14^h22^m0	+25°56'		-3.37	-3.37	-3.34		
RS Vir	00243	14 24.8	+04 55		-1.01				
RV Boo	+30261	14 37.2	+32 45				-1.23		
RR UMi	+70126	14 56.8	+66 08		-1.02	-1.02			
S CrB	+30372	15 19.4	+31 33		-2.81	-2.81	-2.54		
RS Lib	-20286	15 21.4	-22 44				-1.41		
T^4 Ser	+20282	15 34.2	+15 16			-1.88	-1.88		
V CrB	+40273	15 47.7	+39 43		-1.60	-.60			
R Ser	+20285	15 48.4	+15 47		-1.03				
ST Her	+50246	15 49.3	+48 38		-1.48				
X Her	+50248	16 01.1	+47 23		-2.68	-2.68	-2.99		
CIT-8/RU Her	+30283	16 08.2	+25 12				-1.67		
U Her	+20298	16 23.6	+19 00			-2.28	-2.28		
α Sco	-30265	16 26.3	-16 04	-4.91			-4.66		
g Her	+40283	16 27.0	+41 59	-2.55	-2.72	-2.72	-2.55		
α Her	+10324	17 21.4	+14 27	-4.00		-3.97	-3.97	-4.1	
W Her	+20328	17 33.4	+15 37				-1.96		
γ Dra	+50274	17 55.4	+51°30'	-1.44					
T Dra	+60255	17 55.6	+58 14		-1.78				
ν Sgr	-30353	18 02.6	-30 26				-1.43		
UY Sct	-10422	18 24.8	-12 30			-1.74	-1.74		
T Lyr	+40321	18 30.7	+36 58				-1.45		
X Oph	+10366	18 35.9	+08 47				-2.50		
XY Lyr	+40323	18 36.5	+39 37		-.58		-1.19		
δ^2 Lyr	+40331	18 52.7	+36 50	-1.10		-1.65	-1.60		
R Lyr	+40334	18 53.8	+43°53'	-2.17	-2.31	-2.32	-2.75		
V Agl	-10486	19 01.7	-5°47'		-1.40				
R Agl	+10406	19 04.0	+08 09				-2.50		
R Cyg	+50301	19 35.5	+50 05		-1.07				
γ Agl	+10439	19 43.9	+10 29	-1.13					
χ Cyg	+30395	19 48.6	+32 47	-3.73	-3.89	-3.74	-3.52		
K3-50		19 59.8	+33 24						-1.4

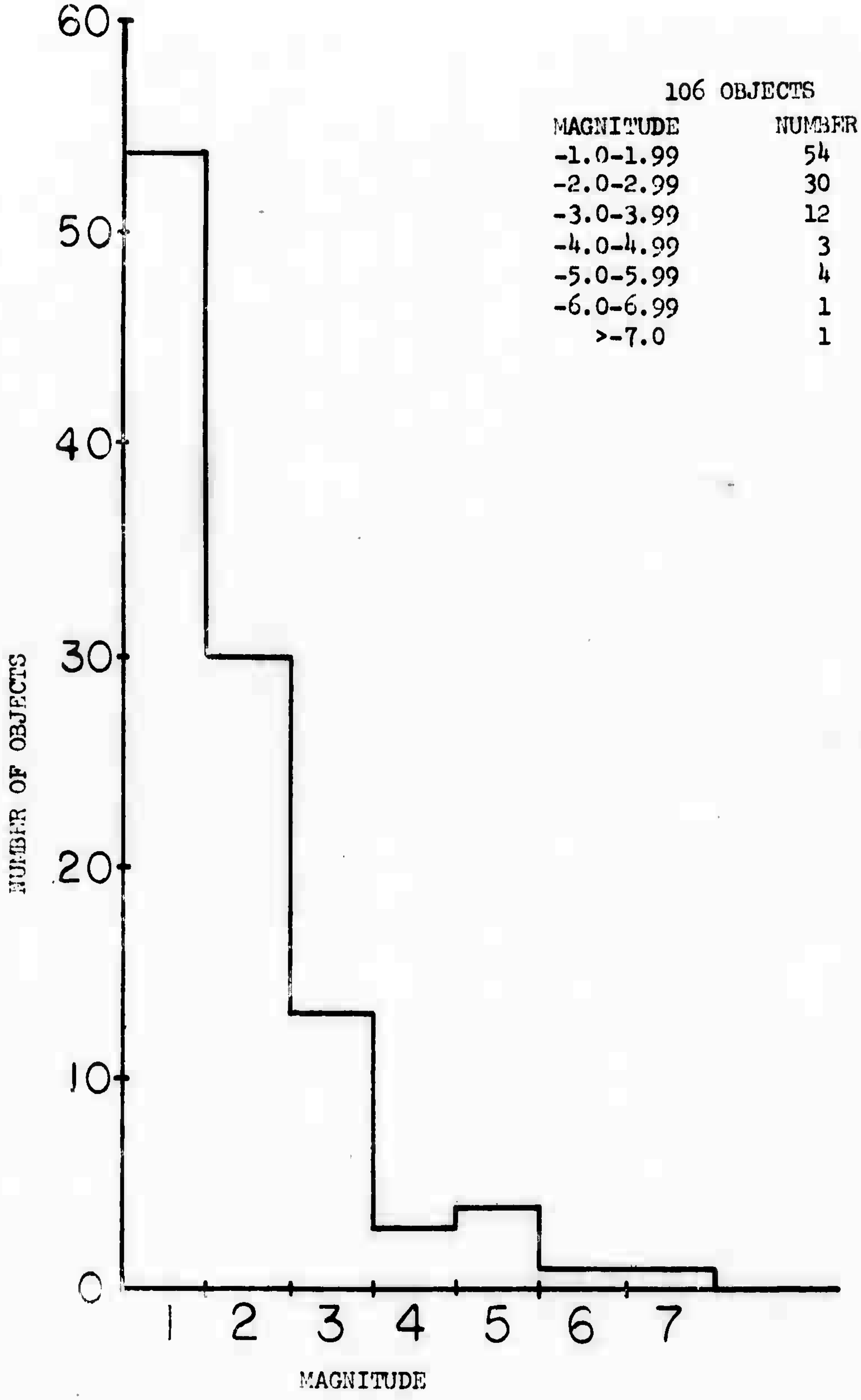
TABLE II (cont.)

NAME	IRC	R.A. 1950 DEC.		REF. 2	REF. 3	REF. 4	REF. 5	REF. 6	REF. 7
U Cyg	+50324	20 18.1	+47 44		-1.41		-1.12		
BI Cyg	+40408	20 19.5	+36 47				-2.28	-2.3	
BC Cyg	+40409	20 19.8	+37 22				-2.48	-2.6	
RW Cyg	+40424	20 27.9	+39 49		-2.14		-2.17		
MWC-349	+40431	20 31.1	+40 35	-1.73					
V Cyg	+50338	20 39.7	+47 58		-3.53				
U Del	+20481	20 43.2	+17 54		-1.39				
NML Cyg	+40448	20 44.7	+39 56	-5.16		-5.57		-5.3	
AE Cyg	+50351	20 56.3	+46 17					-1.2	
NGC 7027		21 05.1	+42 02	-0.20					-1.4
T Cep	+70168	21 08.9	+68 17		-3.01				
S Cep	+80048	21 35.9	+78 24		-2.95		-2.80		
V460 Cep	+40489	21 39.9	+35 17				-1.00		
μ Cep	+60325	21 41.9	+58 33	-3.61	-3.59		-3.64	-3.8	
TW Peg	+30481	22 01.1	+28 07				-2.12		
W Cep	+60362	22 34.5	+58 10				-1.26		
β Peg	+30504	23 01.4	+27 49	-2.40	-2.28	-2.30	-2.46		
R Peg	10527	23 04.1	+10 16		-1.58				
R Aqr	-20642	23 41.2	-15 34	-3.62			-4.22		
TX Psc	00532	23 43.8	+03 13		-1.19	-1.17	-1.32		
R Cas	+50484	23 55.9	+51 07		-3.75		-3.87		

TABLE III

CURRENT STANDARD STARS

	K	L	M	N	Q
α Ari	-.67	-.78	-.60	-.94	-.94
α Aur	-1.79	-1.89	-1.91	-2.01	-1.94
α Hya	-1.19	-1.30	-1.20	-1.45	
α Boo	-3.00	-3.15	-3.04	-3.30	-3.27
γ Dra	-1.33	-1.50	-1.30	-1.60	-1.50



106 OBJECTS

MAGNITUDE	NUMBER
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-3.0-3.99	12
-4.0-4.99	3
-5.0-5.99	4
-6.0-6.99	1
>-7.0	1

FIGURE 1

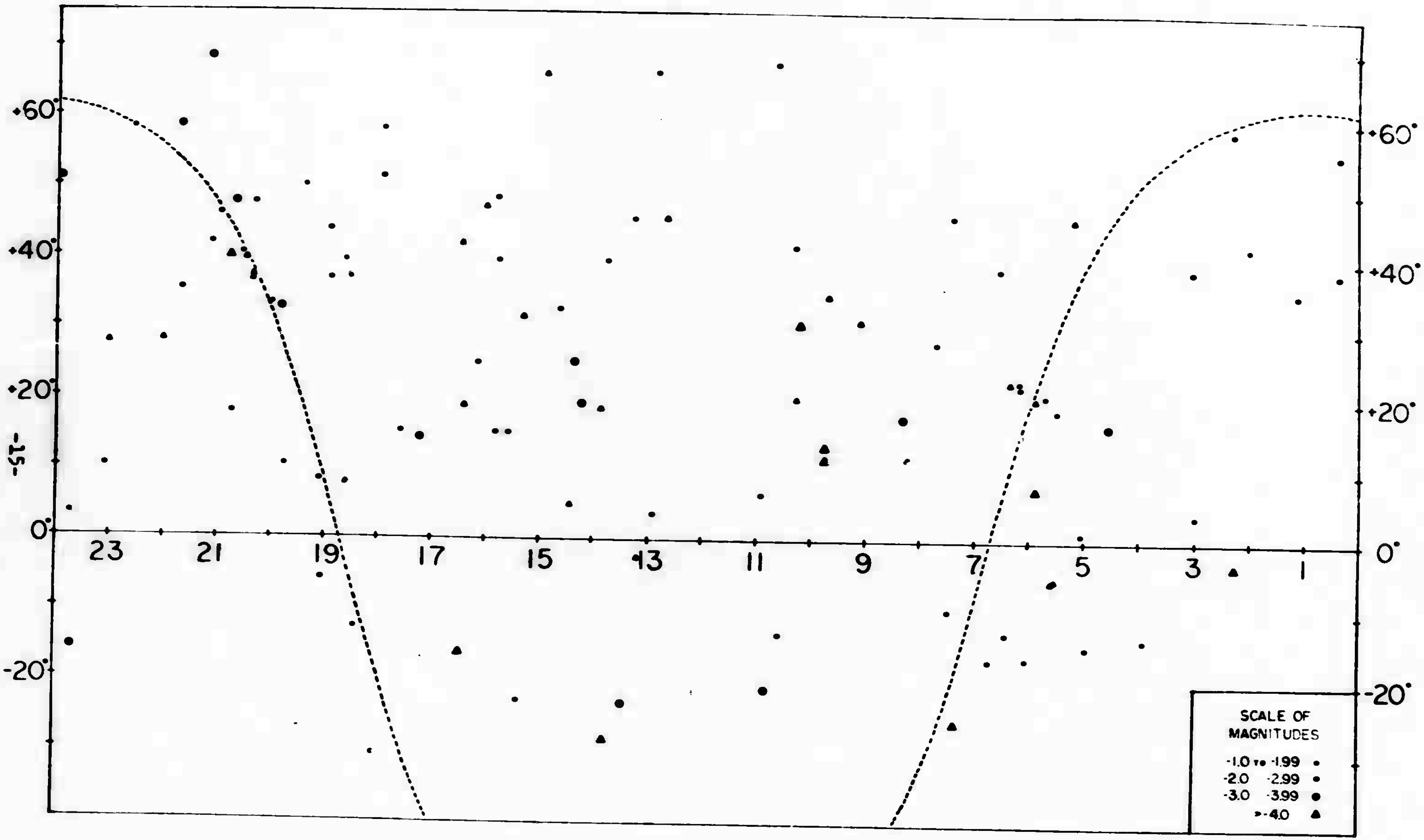
+60°
+40°
+20°
0°
-20°
23
21
19
17
15
13
11
9
7
5
3
1
+60°
+40°
+20°
0°
-20°
SCALE OF MAGNITUDES
-1.0 to -1.99 •
-2.0 -2.99 •
-3.0 -3.99 ●
>-4.0 ▲

FIGURE 2

TABLE IV

Type	Object	Flux ± St. Dev. (10^{-26} W/m^{2}Hz)	Distance (Mpc)	L/L (Gal. Center)
Seyfert Galaxies	NGC 1068 (M77)	25 (Var?)	13	7.6x10^4
	NGC 4151	1.17 ± .04	13	3.6x10^3
	NGC 1275	1.03 ± .06	70	9.2x10^4
	NGC 7469	.87 ± .09	70	7.8x10^4
	NGC 3227	.36 ± .05	15	1.5x10^3
	NGC 4051	.26 ± .06	8	300
	NGC 5548	.18 ± .06	65	1.4x10^4
	NGC 2782	.24 ± .11	25	3 x 10^3
IO - Peculiar Galaxies	NGC 3034 (M82)	27 ± 1	3.3	5.3x10^3
	NGC 5195	.29 ± .07	3.5	65
	NGC 3077	3.3 ± 1.5	3.3	650
N Galaxy	3C 120	.17 ± .04	120	5 x 10^4
Quasi-Stellar Objects	3C 273	.27 ± .02	630	2 x 10^6
	3C 232	.18 ± .05	1600	8 x 10^6
	3C 323.1	≤.1	1000	≤2 x 10^6
	3C 351	≤.02	1200	≤5 x 10^5
Spiral Galaxies	Galactic Center	550	.010	1
	NGC 4736(M94)	.31 ± .06	10	565
	NGC 4569(M90)	.16 ± .03	11	350
	NGC 5236(M83)	~.5 ± .1	4	~100
	NGC 4303(M61)	~.2 ± .05	11	~400
	NGC 5457(M101)	~.15 ± .04	3.5	~35
	NGC 4192	~.10 ± .03	11	220
	NGC 4826(M64)	.10 ± .03	8	120
	NGC 7714	.3 ± .1	40	9 x 10^3
	NGC 3675	.28 ± .10	9	400
	NGC 5713	≤2.6	25	≤3 x 10^4
	NGC 3031(M81)	≤1.5	3.3	≤300
	NGC 6814	≤1.0	21	≤8 x 10^3
	NGC 5055(M63)	≤.3	8	≤350
	NGC 224 (M31)	≤.21	.69	≤2
	NGC 4594(M104)	≤.2	13	≤600
	NGC 4654	≤.2	11	≤440
	NGC 4579(M58)	≤.14	11	≤300
	NGC 4258	≤.1	7.8	≤120
	NGC 4651	≤.1	11	≤220
	NGC 5194(M51)	≤.1	3.5	≤23
Elliptical-Lenticular Galaxies	NGC 4406	~.06 ± .03	11	~130
	NGC 4670	≤3.5	16	≤1.6x10^4
	NGC 1052	≤.9	19	≤6 x 10^3
	NGC 3516	≤.6	45	≤2 x 10^4
	NGC 4382	≤.1	11	≤220
	NGC 4486(M87)	≤.1	11	≤220
	NGC 4649	≤.1	11	≤220
	NGC 4552	≤.07	11	≤160
	NGC 3115	≤.03	5.6	≤20
	NGC 3226	≤.03	15	≤130
	NGC 4278	≤.03	8	≤35
Other	BL Lac	1.0 ± .3		
	NGC 5253	≤3.5	4	≤1 x 10^3
	Markarian 9	≤.28		
	Anon. galaxy 6' S of M87	≤.15	11	≤330
	M87 jet	≤.1	11	≤220

NOTE: 1 Flux Unit = 1 x 10^{-26} w/m^2/Hz = 2.5 x 10^{-18} w/cm^2/μ