AFCRL-71-0160

INVESTIGATION OF BRIGHT SOURCES OF FAR INFRARED RADIATION

Frank J. Low
Doyle A. Harper, Jr.
Carlton M. Gillespie, Jr.

Rice University
Space Science Department
Houston, Texas 77001

Contract No. F19628-69-C-0302

Project No. 8692

Semi-Annual Technical Report No. 2

1 June 1970

Contract Monitor: Stephan D. Price
Optical Physics Laboratory

This research was partially supported by the National Aeronautics and Space Administration and partially by the Advanced Research Projects Agency (ARPA). The ARPA portion was sponsored under ARPA order No. 1366 and monitored by:

Air Force Cambridge Research Laboratories
Air Force Systems Command
United States Air Force
Bedford, Massachusetts 01730

31

Program Code No. 9E50

Effective Date of Contract. . . . . .26 June 1969

Contract Expiration Date. . . . . .30 April 1971

Principal Investigator and Phone No. . . . . .Dr. Frank J. Low/602
884-2727

Air Force Project Scientist or
Engineer and Phone No. . . . . .Stephan D. Price/617
861-2501

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

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) Rice University Space Science Department Houston, Texas 77001	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

INVESTIGATION OF BRIGHT SOURCES OF FAR INFRARED RADIATION

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

Scientific Interim

5. AUTHOR(S) (First name, middle initial, last name)

Frank J. Low
Doyle A. Harper, Jr.
Carlton M. Gillespie, Jr.

6. REPORT DATE 1 June 1970	7a. TOTAL NO. OF PAGES 27	7b. NO. OF REFS 17

8a. CONTRACT OR GRANT NO F19628-69-C-0302, ARPA Order #1366 b. PROJECT NO. 8692 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 - 0160

10. DISTRIBUTION STATEMENT

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

11. SUPPLEMENTARY NOTES This research was supported in part by the Advanced Research Projects Agency.	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (OP) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

The Flying Infrared Telescope (described in Semi-Annual Technical Report No. 1) has been operational during the six-month period ending 31 May 1970 with twenty-eight high altitude missions being flown. We have measured the total infrared luminosities of the galactic center and the Seyfert galaxy NGC-1068, the first extra-galactic object to be observed at far-infrared wavelengths. Likewise, the galactic nebula M-17 and the IR object(s) in the Orion nebula have been observed. Observations of the planets Jupiter, Saturn, Mars and Venus have been made at several wavelength intervals between 60 microns and 300 microns.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Infrared Telescope						
Infrared Radiation						
Sky Survey						
Astronomical LWIR Sources						

AFCRL-71-0160

INVESTIGATION OF BRIGHT SOURCES OF FAR INFRARED RADIATION

Frank J. Low
Doyle A. Harper, Jr.
Carlton M. Gillespie, Jr.

Rice University
Space Science Department
Houston, Texas 77001

Contract No. F19628-69-C-0302

Project No. 8692

Semi-Annual Technical Report No. 2

1 June 1970

Contract Monitor: Stephan D. Price
Optical Physics Laboratory

This research was partially supported by the National Aeronautics and Space Administration and partially by the Advanced Research Projects Agency (ARPA). The ARPA portion was sponsored under ARPA order No. 1366 and monitored by:

Air Force Cambridge Research Laboratories
Air Force Systems Command
United States Air Force
Bedford, Massachusetts 01730

ABSTRACT

The Flying Infrared Telescope (described in Semi-Annual Technical Report No. 1) has been operational during the six-month period ending 31 May 1970 with twenty-eight high altitude missions being flown. We have measured the total infrared luminosities of the galactic center and the Seyfert galaxy NGC-1068, the first extragalactic object to be observed at far-infrared wavelengths. Likewise, the galactic nebula M-17 and the IR object(s) in the Orion nebula have been observed. Observations of the planets Jupiter, Saturn, Mars and Venus have been made at several wavelength intervals between 60 microns and 300 microns.

TABLE OF CONTENTS

Page

TABLE

FIGURE

I. INTRODUCTION

The concept of operating a far infrared astronomical telescope system in the stratosphere above most of the obscuring water vapor was proven during a series of high altitude flights(1) made during October, November and December 1968. At that time, when the Rice University _Flying Infrared Telescope_ became operational, it was evident that by combining these new techniques with information gained from ground-based observations it should be possible to provide needed information on the number and spatial distribution of astronomical far infrared sources that are above a given level of flux.

A dual approach to the problem was proposed using ground-based facilities at the University of Arizona, Catalina Station (separate Arizona Proposal) for the basic survey and the _Flying Infrared Telescope_ (Rice Proposal) with its unique ability to operate beyond the 25 micron atmospheric cut-off as a supporting facility. It is expected that a number of new LWIR sources will be discovered by the Arizona survey. Some of these expected new sources will be observed from the stratosphere and thus extend the scientific usefulness of the ground-based observations.

The work reported herein represents the first three series of research flights totaling twenty-eight altitude missions. Emphasis has been placed on structuring the _Flying Infrared Telescope_ missions to aid in understanding the nature of the far infrared sources located in the region near the center of our galaxy and in a broad sense the infrared galaxy phenomenon.

---

(1) The Internal Powers and Effective Temperatures of Jupiter and Saturn, H. H. Aumann, C. M. Gillespie, Jr. and F. J. Low, _Astrophysical Journal_, _157_, L69-72, 1969.

II. RESEARCH PROGRAM PLAN

The operational plan established at the start of this contract provided for modifications and improvements to the Flying Infrared Telescope to be followed by several series of high altitude research flights aboard a NASA operated Learjet. This plan has been followed and the results of flights conducted between the commencement date (1 September 1969) and 31 May 1970 are reported herein.

The time remaining in the contract period will be utilized as follows:

(1) There will be a down period of at least two months while NASA negotiates for the lease of a different Learjet. Rice University will use this time to perform some additional modifications to the telescope system. A new guide telescope and gyrostabilization of the yaw axis are the most important of these modifications.

(2) There will be at least one additional series of research flights. The successful measurement of the galactic nebula M-17 on 20 May 1970 suggests the advisability of looking for LWIR radiation from other galactic HII regions.

(3) Data reduction and analysis.

III. DESCRIPTION OF THE RESEARCH MISSIONS

Table 1 lists chronologically the missions flown by the Flying Infrared Telescope during the period 1 September 1969 (contract commencement date) and 31 May 1970. These 31 missions were divided into four series as follows:

Series 1, September 1969:

These three flights (although technically flown within the period of this contract) actually came at the end of a series of missions primarily concerned with the galactic center and the planet Mars in late August 1969 and are mentioned here only for the sake of completeness.

Series 2, February 1970:

The series had three objectives: (a) observation of the Seyfert galaxy NGC-1068; (b) observation of the comet Tago-Sato-Koska; and (c) planetary observations.

Series 3, March-early April 1970:

The objectives during these missions were to observe Comet Bennett, make a study of the in-flight system noise characteristics, and to flight test and debug some instrumental improvements in preparation for a systematic survey of the galactic center region.

Series 4, late April-May 1970:

Seven of the nine missions in this last series were devoted to galactic center observations. One flight was made to obtain data in four wavelength regions from Venus and Jupiter so that it will be possible to directly establish the LWIR flux ratios for the four planets Jupiter, Mars, Saturn, and Venus. The galactic nebula M-17, an H II region, was observed for the first time at far infrared wavelengths with in-flight calibration of the radiometer on the planet Jupiter.

The instrumentation used(2) and the observational techniques(3) unique to the *Flying Infrared Telescope* have already been described. The successful execution of a 2, 3, or 4 body mission requires careful and extensive pre-flight planning by the observers, the pilots and a navigator (who does not fly on the Learjet).

---

(2) Investigation of Bright Sources of Long-Wave Infrared Radiation, F. J. Low, H. H. Aumann and C. M. Gillespie, Jr., Semi-Annual Technical Report No. 1, 1 December 1969, Contract No. F19628-69-C-0302.

(3) Closing Astronomy's Last Frontier -- Far Infrared, F. J. Low, H. H. Aumann and C. M. Gillespie, Jr., *Astronautics and Aeronautics*, *Vol. 8*, No. 7, July 1970.

TABLE 1

Flying Infrared Telescope

Flight Record

1 September 1969 - 31 May 1970

Mission Number	Date	Mission Objective	Observer(s)
(32)	2 Sept 69	NGC-1068	Low
(33)	3 Sept 69	Engineering Test Flight	Low & Aumann
(34)	3 Sept 69	NGC-1068 (2nd Flight)	Low
(35)	3 Feb 70	Engineering Test Flight	Low & Gillespie
(36)	4 Feb 70	Saturn and Comet Tago-Sato-Koska	Low & O'Dell
(37)	5 Feb 70	Saturn and Comet Tago-Sato-Koska	Gillespie & O'Dell
(38)	11 Feb 70	Jupiter	Gillespie & Cauthen
(39)	11 Feb 70	IR Object in Orion and Jupiter (2nd Flight)	Gillespie & Cauthen
(40)	12 Feb 70	NGC-1068 and Saturn	Gillespie & Cauthen
(41)	17 Feb 70	IR Object in Orion and Jupiter	Gillespie & Cauthen
(42)	18 Feb 70	NGC-1068, Mars, Saturn and IR Object in Leo	Low & Gillespie
(43)	19 Feb 70	NGC-1068, Mars, Saturn and IR Object in Leo	Low & Cauthen
(44)	19 Feb 70	Jupiter and Altitude Dependence Study of the Received IR Signal	Gillespie & Low
(45)	24 Feb 70	NGC-1068, Mars, Saturn and IR Object in Leo	Gillespie & Low
(46)	25 Feb 70	Study of Noise Characteristics at High Altitude	Gillespie
(47)	24 Mar 70	Engineering Test Flight to Evaluate Noise Characteristics	Gillespie & Cauthen
(48)	26 Mar 70	Orion Nebula - Jupiter	Cauthen

TABLE 1, Continued:

Mission Number	Date	Mission Objective	Observer(s)
(49)	27 Mar 70	Comet Bennett - Jupiter	Gillespie
(50)	31 Mar 70	Comet Bennett - Jupiter	Gillespie & O'Dell
(51)	1 Apr 70	Comet Bennett - Jupiter - Moon with Investigation of LWIR Attenuation vs Altitude	Low & O'Dell
(52)	2 Apr 70	Orion Nebula - Jupiter	Gillespie
(53)	3 Apr 70	Galactic Center Region - Jupiter	Low
(54)	22 Apr 70	Galactic Center Region - Jupiter	Aumann & Gillespie
(55)	23 Apr 70	Galactic Center Region - Jupiter	Aumann & Gillespie
(56)	24 Apr 70	Galactic Center Region - Jupiter	Aumann & Gillespie
(57)	6 May 70	Galactic Center Region	Low & Aumann
(58)	7 May 70	Galactic Center Region - Jupiter	Low & Aumann
(59)	8 May 70	Galactic Center Region	Low & Harper
(60)	19 May 70	Galactic Center Region - Jupiter	Aumann & Gillespie
(61)	20 May 70 (Morning)	Galactic Nebula M-17 - Jupiter	Aumann & Cauthen
(62)	20 May 70	Venus - Jupiter	Gillespie & Cauthen

IV. SCIENTIFIC RESULTS

Far infrared observations have been made of the galactic nucleus, of two discrete sources near the galactic nucleus, of two sources associated with H II regions and of two extragalactic sources. In addition, a considerable body of planetary data (Venus, Mars, Jupiter and Saturn) have been obtained in the wavelength region beyond 25 microns. The planetary and cometary data are still being analyzed and will be covered in the final report. Following is the analysis of the galactic and extragalactic data.

The Galactic Center Region

With a beam diameter of 7 arcminutes we can distinguish three discrete sources in an area extending ±1.5 degrees along and ±1 degree to the north and south of the galactic plane, centered on Sgr A.

Table II lists the positions of these sources, referred to as Sgr IRA, Sgr IRB and Sgr IRC. Observations with beam sizes ranging from 3.5 arcminutes to 14 arcminutes (full width at 1/2 peak) are listed in Table III in terms of the total flux directly observable between 50μ and 300μ, F_{50-300} (watt/cm^2). The observed deflections relative to Jupiter increase with increasing beam diameters. We interpret these beam size effects as due to the extended nature of the sources. Figure 1, shows that the flux F_{50-300} increases for Sgr IRA as (beam diameter)$^{0.9\pm.2}$. The fluxes from Sgr IRB and Sgr IRC increase at slower rates, approximately as (beam diameter)$^{0.6\pm.2}$.

Typical scans parallel to the chopping direction through Sgr IRA, Sgr IRB and Jupiter are shown in Figure 2. The scan through Sgr IRA was made at an angle of approximately 60° to the galactic equator and extends from near 1°

TABLE II

OBSERVED AND CALCULATED PARAMETERS OF FAR INFRARED SOURCES

		Sgr IRA	Sgr IRB	Sgr IRC	M17	Ori IRA +IRB	NGC 1068	M82
Coordinates (1950)	α	$17^h\ 42.5^m$	$17^h\ 44.4^m$	$17^h\ 41.4^m$	$18^h\ 18^m$	$5^h\ 32.6^m$	2^h 40.[illegible]^m	$9^h\ 51.7^m$
	δ	$-28^\circ\ 59'$	$-28^\circ\ 22'$	$-29^\circ\ 26'$	$-16^\circ\ 18'$	$-5^\circ\ 24'$	$-00^\circ\ 1.7'$	$69^\circ\ 55.1'$
Distance (pc)		10^4	10^{4*}	10^{4*}	1800	500	1.3×10^7	3.2×10^6
Beam Diameter (')		7±1	7±1	7±1	7±1	8±1	7±1	8±1
$F_{50\mu-300\mu}$ $(10^{-14}$ watt/cm$^2)$		54±3	49±6	18±4	70±10	90±10	2.5±.7	<6
ν_{max} $(10^{12}$ Hz)		4.5±.3	3.8±.3	4.5*	4.5*	4.5*	4.5*	4.5*
$(F_\nu)_{max}$ $(10^{-22}$ watt/m^{2}Hz)		43±4	32±3	14	56	7	1.5±.5	<4
$F_{10\mu-300\mu}$ (watt/cm^2)		1.3×10^{-12}	6.4×10^{-13}	4.3×10^{-13}	1.7×10^{-12}	2.2×10^{-12}	4.2×10^{-14}	$<10^{-13}$
$L_{10\mu-300\mu}$ (L_o)		3.5×10^7	1.7×10^7	1.2×10^7	1.3×10^6	1.6×10^5	2×10^{12}	$<6\times10^{11}$

* Assumed

TABLE III

BEAM SIZE EFFECT

Beam Diameter (arcminutes)		3.5±.5	7±1	8±1	14±2
Chopper Throw (arcminutes)		9	9	9'	14
F_{50-300} (10^{-13} watt/cm^2)	Sgr IRA	2.9±.3	5.4±.2	6.0±1.2	11±2
	Sgr IRB	3.4±.2	4.8±.5	6.4±1.2	-
	Sgr IRC	-	2.5±.9	-	3.4±.5

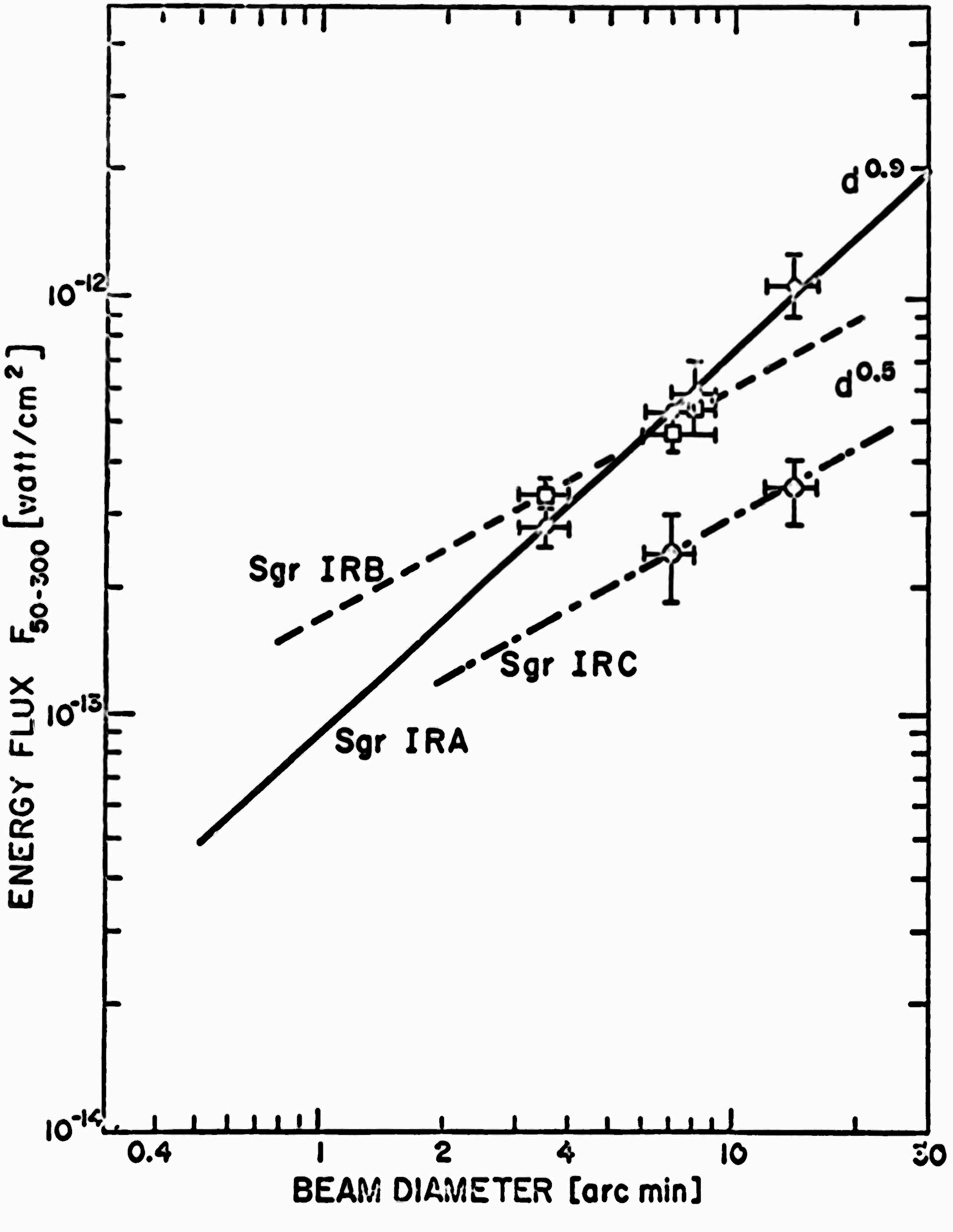
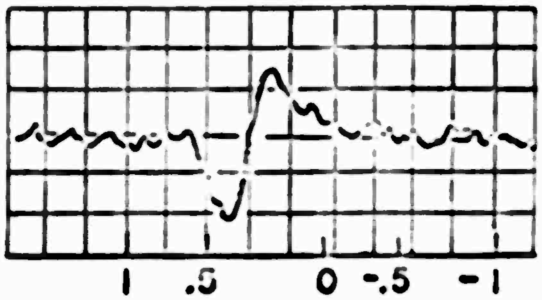
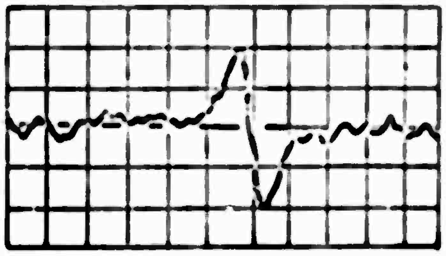


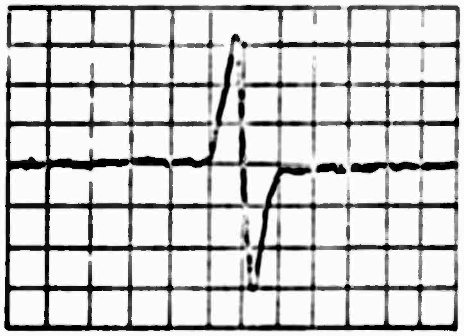
Figure 1: The 50μ - 300μ energy fluxes of Sgr IRA. Sgr IRB and Sgr IRC increase with increasing beam sizes.



a.Sgr IRA



b.Sgr IRB



c. JUPITER
(gain reduced by a factor 3)

Figure 2: Scans through Sgr IRA, Sgr IRB and Jupiter with a 7 arcminute beam and 9 arcminute chopper throw. The scan through Sgr IRA extends from -1° east to 1° west of the galactic plane (markers relative to x Sgr). The manually controlled scan rates differ on the three scans.

to the east to 1° to the west of the galactic center. The extended nature of the source, deduced from observations of beam size effects, is not immediately apparent from scans; nor is there evidence of the large 2° x 6° source reported by Hoffman and Fredrick$^{(4)}$. However, the gradient of the radiation from such a source may be sufficiently low, so that the signal produced by our differential chopping technique is lost in the noise level. The scan shown in Figure 2a could thus be compatible with a 10-15 arcminute diameter source superimposed on a much more extended source with a flux gradient of the order of 4×10^{-13} watt/cm^2 degree. Assuming a width of 2 degrees the luminosity of the extended source could be near 4×10^8 $L_\odot$, comparable to Hoffman and Fredrick's$^{(4)}$ result.

Observations of Sgr IRA and Sgr IRB with 20% spectral resolution at 65μ and 105μ are still in preliminary analysis but suggest continuum radiation rather than one or a small number of emission lines. For frequencies between 6×10^{12} Hz and 10^{12} Hz a continuum distribution given by:

$$F = (F_\nu)_{max} \, , \quad \begin{array}{ll} (\nu/\nu_{max})^{-3.5\pm.5} & \nu \geq \nu_{max} \\ (\nu/\nu_{max})^{3.5\pm.5} & \nu < \nu_{max} \end{array} \qquad (1)$$

can be fitted to the observations. $(F\nu)_{max}$, ν max, the extrapolated integrated flux between 10μ and 300μ, F_{10-300}, and the total infrared luminosity, L_{10-300}, for observations with a 3.5 arcminute beam are listed in Table II. We have assumed that all three sources are at a distance of 10 kpc.

---

(4) Far Infrared Observations of the Galactic Center Region at 100 Microns, W. F. Hoffman and C. L. Fredrick, Astrophysical Journal, 155, L9, 1969.

Figure 3 shows the spectral power distribution for Sgr IRA with the 3.5 arcminute beam. Observations at 5, 10 and 22μ reveal the existence of a source ≈ 15 arcseconds in diameter. Recent observations at 10μ show structure smaller than 15 arcseconds but less than 20 percent increase in flux with beam diameter from 25 to 120 arcseconds. Therefore, the published(5) 5 to 24.5μ flux densities are plotted. The spectral power distribution of Sgr A at cm-wavelengths is taken from the literature and is based on beam diameters ≈ 3 arcminutes. The upper limit at 1 mm was obtained with a 1 arcminute beam.

We have failed to detect Sgr IRB at 10 microns with a 2 arcminute beam, indicating an upper limit well below the flux density of Sgr IRA. This is consistent with the results based on narrowband observations which show that the peak flux density occurs at a significantly lower frequency than for Sgr IRA.

Scans were made with the 3.5 arcminute beam between Sgr IRA and Sgr IRB and no detectable flux was observed.

The Trapezium Region in Orion

Observations of the Trapezium region in Orion with an 8 arcminute beam and 9 arcminute chopper throw have resulted in $F_{50-300} = (1.5 \pm .2) \times 10^{-12}$ watt/cm^2 (Table III). Although our beam contains at least three IR objects, the Becklin-Neugebauer(6) point source at 2.2μ, the

---

(5) The Infrared Spectrum, Diameter and Polarization of the Galactic Nucleus, F. J. Low, D. E. Kleinmann, F. F. Forbes and H. H. Aumann, Astrophysical Journal, 157, L97, 1969.

(6) Observations of an Infrared Star in the Orion Nebula, E. E. Becklin and G. Neugebauer, Astrophysical Journal, 147, L99, 1967.

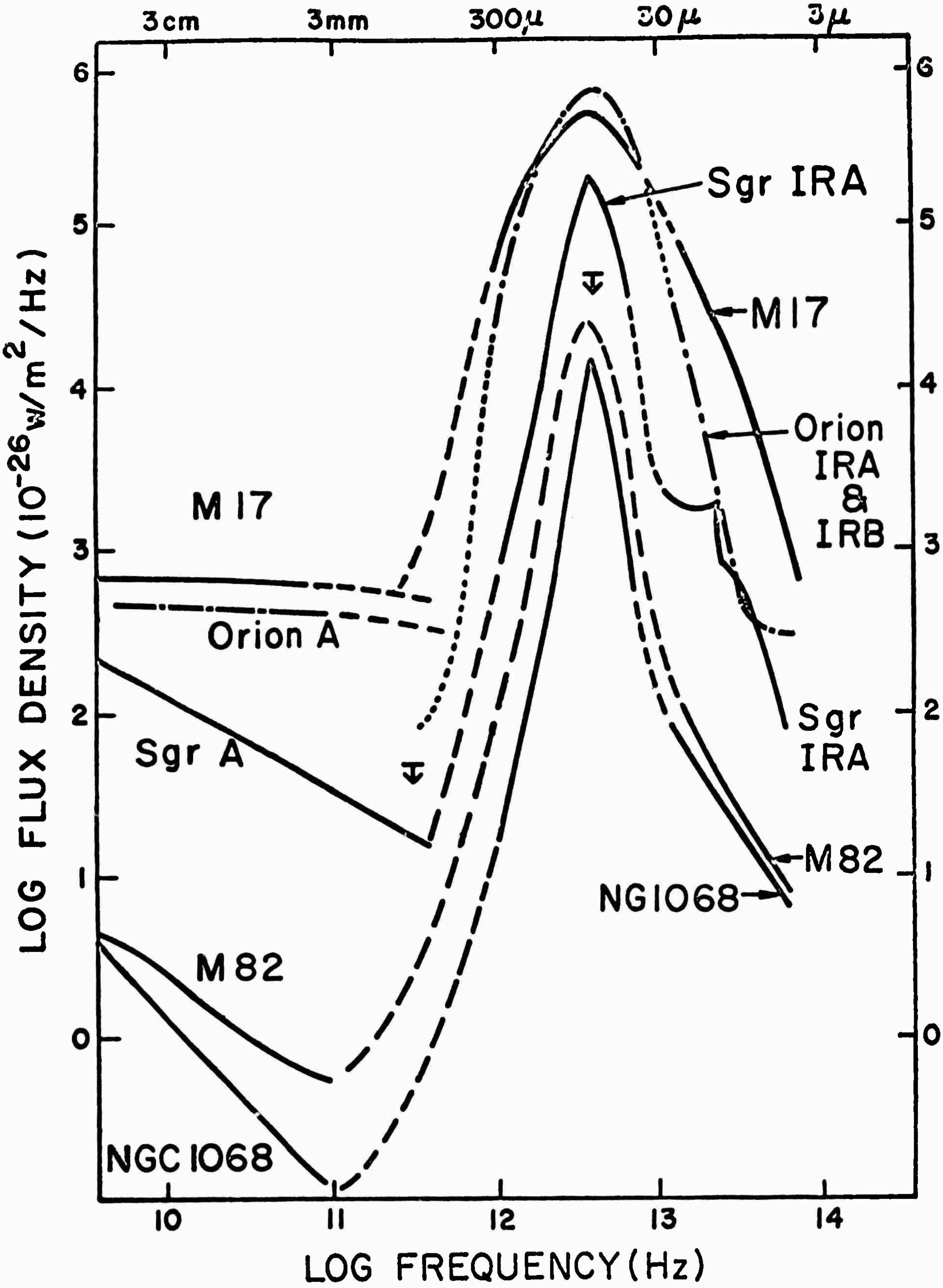


Figure 3: The spectral power distributions of the galactic and extragalactic sources. Data are lacking for wavelength intervals where dashed lines are shown. Upper limits applied to M82 at 70μ and to Sgr A a 1000μ.

Ney-Allen$^{(7)}$ source (Ori IRA) and the Kleinmann-Low$^{(8)}$ source (Ori IRB) and the radio source Orion A, we believe that the cool wings of Ori IRB dominate the far infrared emission. Observations at 60μ with 20% spectral resolution indicate that the peak of the spectral power distribution falls near 4.5×10^{12} Hz. Assuming the spectral power distribution given in Equation 1 we calculate $L_{10-300} = 1.6 \times 10^5 L_\odot$ at a distance of 500 pc. Observations with a 3 arcminute beam and passband from 1.5μ - 300μ$^{(9)}$ result in a total IR luminosity for Ori IRA plus Ori IRB of $1.5 \times 10^5 L_\odot$. Figure 3 shows the far infrared spectrum and the 10μ and 20μ flux densities for a 2 arcminute beam$^{(9)}$. From 10μ to 100μ the spectral distribution can be approximated by a 75°K blackbody. Beyond 100μ the deduced spectrum falls off much steeper than a blackbody in agreement with the 100 F.U. which was observed at 1 mm with a 1 arcminute beam centered on Ori IRB.

---

(7) The Infrared Sources in the Trapezium Region of M42, E. P. Ney and D. A. Allen, Astrophysical Journal, 155, L193, 1969.

(8) Discovery of An Infrared Nebula in Orion, D. E. Kleinmann and F. J. Low, Astrophysical Journal, 149, L1, 1967.

(9) In preparation, H. H. Aumann, D. E. Kleinmann and F. J. Low.

M 17

M 17 is a galactic H II region which has been resolved at cm-wavelength into a double source about 5 arcminutes by 12 arcminutes by Schraml and Mezger(10). Observations with a 7 arcminute beam and a 9 arcminute chopper throw result in a 50μ - 300μ flux of (7±2) x 10^{-13} watt/cm^2. In order to calculate the flux density and total luminosity given in Table II we have assumed the continuum spectrum defined by Equation 1 with $\nu_{max} = 4.5 \times 10^{12}$ Hz and a distance of 1.8 kpc(11). The spectral power distribution is plotted in Figure 3 including the 5, 10, and 22μ flux densities for the double source given by Kleinmann(12).

NGC-1068

Observations of the Seyfert galaxy NGC-1068 with a 7 arcminute beam and a 9 arcminute chopper throw produced an integrated 50μ - 300μ flux $F_{50-300} = (2.5 \pm .7) \times 10^{-14}$ watt/cm^2. The 7 arcminute beam contains essentially the whole galaxy. Assuming that the spectral power distribution can be approximated by Equation 1, and $\nu_{max} = 4.5 \times 10^{12}$ Hz, we obtain a luminosity $L_{10-300} = 2 \times 10^{12} L_{\odot}$, of which $1.2 \times 10^{12} L_{\odot}$ is radiated between 60μ - 300μ . This is based on a distance of 13 mpc, assuming a Hubble constant

---

(10) Galactic H II Regions. IV. 1.95 cm Observations with High Angular Resolution and High Positional Accuracy, J. Schraml and P. G. Mezger, Astrophysical Journal, 156, 269, 1969.

(11) Astrophysical Quantities, C. W. Allen, Athlone Press, 1962.

(12) 1970 Boulder, Colorado Meeting of AAS, D. E. Kleinmann, 1970.

H_o = 75 km/sec mpc^{-1} (13). The measured total infrared luminosity of NGC-1068 is a factor 3 below the luminosity deduced by Kleinmann and Low (14) under the assumption that the ratio of the 10μ flux density to the total infrared flux is the same for all galaxies including the galactic nucleus. This is clearly not the case when there are large beam size effects. At 5, 10 and 22μ Kleinmann and Low (14) found no beam size effects down to 5 arcseconds and $L_{5-25} = 2 \times 10^{11} L_\odot$. The spectral power distribution of NGC-1068 is plotted in Figure 3.

M 82

Observations of M 82 established only an upper limit of F_{50-300} 6×10^{-14} watts/cm^2, using a 7 arcminute beam. This upper limit is a factor 3 above the flux observed for NGC-1068. Again assuming the validity of Equation 1 with $\nu_{max} = 4.5 \times 10^{12}$ Hz and a distance of 4.3 mpc, we calculate $L_{10-300} < 6 \times 10^{11} L_\odot$. It is interesting to note that the fluxes measured at 5, 10 and 22μ for M 82 and NGC-1068 are quite similar (14). At 10μ M 82 extends 15" x 30" along its galactic plane (15).

---

(13) A New Determination of the Hubble Constant from Globular Clusters in M 87, A. R. Sandage, Astrophysical Journal, 152, L149, 1968.

(14) Observations of Infrared Galaxies, D. E. Kleinmann and F. J. Low, Astrophysical Journal, 159, L165, 1970.

(15) In preparation, D. E. Kleinmann and F. J. Low.

Summarizing, there are far infrared sources in H II regions which emit a large fraction of the total luminosity of the galactic system. Ori IRA and Ori IRB are so close together that the far infrared observations cannot be interpreted unambiguously but it appears that Ori IRB, which is not an H II region, may account for most of the flux. Sgr IRB is near but not coincident with the H II region Sgr B2. All five of the galactic sources reported here are associated with sources of molecular line emission in the microwave and millimeter wave spectrum. This implies a direct physical relation between the two classes of phenomena and suggests the existance of many additional far infrared sources.

The luminosity of Sgr IRB appears to be greater than 10^7 $L_\odot$. Comparable power may be emitted by ηCar, a much hotter infrared source observed by Westphal and Neugebauer(16). It is possible that thermo-nuclear energy released by one or more massive stars is reradiated by dust as in the sources imbedded in H II regions. For a temperature of 75°K the far infrared emissivity is only about one percent or less for all the galactic sources, indicating that they are optically thin.

In addition to the radio source Sgr A and the ensemble of stars observed by Becklin and Neugebauer(17), the galactic nucleus contains at least two infrared components: (a) the small diameter complex at an apparent temperature of 230°K embedded in (b) an extended halo at an apparent temperature

---

(16) Infrared Observations of Eta Carinae to 20 Microns, J. A. Westphal and G. Neugebauer, Astrophysical Journal, 156, L45, 1969.

(17) Infrared Observations of the Galactic Center, E. E. Becklin and G. Neugebauer, Astrophysical Journal, 151, 145, 1968.

of 75°K. Outside the immediate region of the nucleus there are the two luminous infrared sources colder than 70°K and a diffuse background extending along the galactic equator observed by Hoffman and Fredrick (4). The infrared luminosity of the nucleus increases nearly linearly with diameter over the range 10 to 40 pc.

V. SUPPORTING LABORATORY RESEARCH

A. Far Infrared Filter Program

The primary goal of our filter development program has been the construction of high throughput, moderate to wide passband filter systems to be used for photometry of faint far infrared sources with the *Flying Infrared Telescope* system. We are concerned with the spectral region from ~ 30-300μm. The 30-100μm interval is particularly important since most of the sources we have observed radiate their peak flux in this region.

Conventional thin film technology begins to fail between 20μm and 30μm because of the dearth of suitable dielectric materials and the difficulty of depositing increasingly thick films in durable multilayers. On the other hand, techniques which are applicable at submillimeter wavelengths (e.g., multilayer low pass filters constructed from capacitive meshes deposited on thin plastic films) become extremely difficult as the characteristic dimensions of the systems drop below 100μm. Extension of either the thin film or submillimeter technology would require a complex and expensive development program and would probably result in extremely fragile filters unsuitable for the demanding experimental environment of the *Flying Infrared Telescope* system. Therefore, we have concentrated on utilizing the natural absorption characteristics of plastics and crystalline materials and on those submillimeter techniques which can be readily scaled down to the 30-100μm wavelength region without sacrificing simplicity and durability (i.e., interference filters constructed from commercially available electroformed metal mesh).

Emphasis has been placed on integration of the various filter techniques into the infrared radiometer in such a manner that the overall signal-to-noise ratio of the system is maximized. The required filter characteristics are determined by the following considerations:

(1) Since it is necessary to use the planets as calibration objects, the stopband blocking below 30µm must be quite effective, particularly for systems with narrow bandwidths or low pass cutons beyond 100µm. The problem is especially acute for Jupiter which has an anomalous peak in its spectrum at ~ 4-5µm in a region which is difficult to attenuate due to a scarcity of materials which absorb in the desired interval yet transmit efficiently beyond 30µm. For instance, 0.1 mm thick black polyethylene transmits 4% of the radiation at 5µm but only 50% at 40µm. Crystalline materials which are transparent beyond 30µm are, as a rule, also transparent at 5µm (e.g., quartz, sapphire, silicon, and germanium).

(2) The major source of noise in the <u>Flying Infrared Telescope</u> system has been vibrational modulation of the instrumental thermal background radiation. Thus the lowest intrinsic system noise will be achieved with helium cooled filters with narrow bandwidth or long wavelength cutons. Ambient temperature filters will attenuate the signal while resulting in noise at a level greater than or equal to its broadband value.

(3) In the far infrared, the most useful calibration objects (Saturn, Jupiter and Mars) have approximately black body spectra with characteristic temperatures greater than 95°K. Most of the objects observed thus far have spectra

which peak at a wavelength between 30μm and 100μm. Thus, to obtain the maximum amount of information about the spectra of the sources, the filters should have sharp high frequency cutoffs.

We have found that satisfactory solutions to the problems stated above can be achieved by the following means:

(1) We have developed efficient low pass filters for blocking 4-5μm wavelengths. These filters consist of a layer of high refractive index particles (diamond dust) deposited on a polyethylene substrate and bonded with plastic spray paint. The diamond scatters wavelengths smaller than the particle size with high efficiency. The layer rapidly becomes transparent at longer wavelengths, however. For an equivalent amount of attenuation at 5μm, the diamond dust filter is more than twice as efficient as black polyethylene at 50μm. Since the properties of the filters are dependent on the refractive index and size of the particles rather than absorption, they can be tailored to meet a wide range of specifications. An additional advantage of the process is that the required blocking may be achieved by treating the surface of the polyethylene vacuum window of the radiometer dewar, eliminating an extra element from the optical path. Such a window has operated in the <u>Flying Infrared Telescope</u> system for more than ten flights without sign of deterioration.

(2) A helium cooled filter turret has been designed and installed in one of the flight radiometer systems. The device allows us to restrict noise and bandwidth simultaneously. It also permits the use of crystal filter materials which display sharp low pass cutons when cooled to cryogenic temperatures. Such materials are useful as low pass filters, as

blocking filters for Fabry-Perot interference filters, and in conjunction with multilayer metal mesh high pass filters as medium bandwidth filters. A system having interchangeable CaF_2 and BaF_2 elements has been used for observations of the planets and galactic H II regions.

(3) In single band radiometers a useful technique for maximizing overall system transmission is to mount the crystalline materials used to block thermal background radiation and provide a low pass cuton in optical contact with the silicon field lens used to focus the radiation from the telescope secondary onto the bolometer. By this means we avoid the Fresnel reflection losses associated with the separate filter elements.

In addition to the work mentioned above, we have constructed a series of metal mesh interference filters having narrow band and high pass characteristics. Several of these filters were used to make measurements of the galactic center, Venus, and Jupiter. However, they were operated at room temperature. Similar filters will be incorporated into the cold filter turret for a series of planetary measurements in January 1971. The reduction in noise realizable with the cooled filters and the use of cooled crystals as low pass elements should allow higher resolution in the narrow band filters and improved characteristics for the medium bandwidth filters.

B. Dewar Research

The *Flying Infrared Telescope* has successfully evolved, in part, because of the availability of a liquid helium instrument dewar sufficiently rugged to permit operation in the 2°K temperature region under all conditions aboard high performance military (Douglas A3-B and civilian (Learjet Model 23) jet aircraft. A small continuing program of dewar development (mostly supported by other programs) has concentrated on increasing cryogenic liquid hold time by testing various types of materials for gas cooled radiation shields and neck tubes. A system is now being fabricated for use on the *Flying Infrared Telescope* which will permit up to six helium cooled LWIR filters to be switched in flight. This mechanical system, taken together with the work reported in A above, will provide a powerful new tool for LWIR spectral studies.