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INFRARED ASTRONOMY

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ABSTRACT

The infrared (IR) consist of a spectral band from 1μ to 20μ that is partially accessible to telescopes on the ground, and a band from 20μ to 1000μ that is inaccessible. In recent years there have been several exciting discoveries in the accessible IR. It is inferred that there is also a good potential for the inaccessible IR. Any facility that permits studies in the inaccessible IR will also allow studies in the partially accessible IR and thus have available a 1000:1 range of wavelengths.

IR work from above the ground naturally divides into two categories, one requiring large complex equipment that probably requires manned assistance, the other being possible with relatively small and simple equipment. Large complex equipment is required for the study of small angular diameter sources such as stars and quasars. Small simple equipment is adequate for low angular resolution, sky surveys and studies of diffuse objects. Initial equipment for such work is already being flown in rockets and unmanned balloons. Much initial progress in the observation of point sources could probably be made from aircraft. However, because strong residual absorption is expected at aircraft altitudes, and because very large telescopes will eventually be required, one expects that observations will eventually need to be made from orbiting observatories.

It is suggested that as part of the plans for developing an astronomical facility in the Apollo Extension, there should be a two phase aircraft program developing both the scientific program and the equipment in collaboration with astronauts. This would simultaneously provide valuable training experience for the astronauts, scientific results, and experience in the design of manned space observatories.

The first phase should be a use of minimal equipment to determine the IR atmospheric transparency at aircraft altitudes (45-50, 000 ft), and at the same time to make studies of the brightest sources, the Sun, the Moon and the planets. The second phase would be to fly a telescope of 24 to 40 inches aperture so that equipment can be tailored to the potential of a man in a space suit, while developing the scientific programs that will later require a larger telescope in orbit.

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INTRODUCTION

In recent years it has become apparent that infrared studies of astronomical objects are liable to lead to exciting new discoveries. Astronomical observations in the infrared have been limited because the Earth's atmosphere is only partially transparent, and so observations from space vehicles may be useful. The main limit to transparency comes from the water-vapor in the atmosphere, and since most of this is confined to the region below 40, 000 ft, some critical observations are probably possible from aircraft. This study attempts to assess the different needs for observations from aircraft, balloons, rockets, unmanned satellites and manned satellites.

ASTRONOMICAL OBSERVATIONS

Recent observations from ground based observatories have resulted in several surprising discoveries:

1. Stars have been discovered with so much of their radiation in the infrared that their existence was not suspected from studies at visible wavelengths. Some of these objects have spectral energy distributions that peak at wavelengths as long as 4μ. It is possible that stars exist with peaks at even longer wavelengths, but these would not have been discovered in existing surveys.

2. The brightest quasar, 3C273, has been found to be emitting most of its radiation in the infrared. Since neither the source of the vast amount of energy radiated, nor the emission mechanism is known, these observations

are critical in trying to understand the nature of quasars.

3. Large flickering emission patches around cool stars have been observed at a wavelength near 11μ. Mass ejection by these stars plays a critical role in stellar evolution, and presumably the radiation is coming from ejected mass. The mechanism is unknown, as is the cause of the flickering.

4. Observations near 20μ have shown that Jupiter has a source of internal energy that is being radiated away.

5. Young stars (T. Tauri stars) are emitting a substantial part of their energy in the infrared. It has been suggested that in some cases this energy is being radiated from material that will condense into planets.

Some IR observations have also been made from aloft, for example, from Stratoscope II, but there has been no regular observing program. As a result most observations have been made for very specific purposes, and have not yielded many surprises.

In the IR there are some reasons for expecting novel objects and phenomena to be found. · The lowest temperatures that objects in space are likely to reach is 3°K, the temperature of the universal radiation field. Thus the thermal radiation from any object should be concentrated at wavelengths shorter than 1 mm. Studies at visible wavelengths have only succeeded in discovering thermal radiation from objects hotter than 2000°K, and thus a large class of astronomical objects could have been missed.

The second reason for expecting exciting phenomena is that it is relatively easy to create appropriate circumstances for gasses to radiate through stimulated emission (masers and lasers) for lines at low frequencies. The first astronomical example has been at radio wavelengths for the 18 cm OH emission lines, but in the laboratory there have been many molecules found to emit at intermediate and far infrared wavelengths, for example, both CN and H_2O produce radiation at wavelengths between 100μ and 1 mm. Such phenomena are particularly likely to be associated with early phases of star formation.

Thus potentially the infrared would appear worth considerable study. However, in a spectral region that is so little studied one may well make a totally false judgement about what to expect, and the justification of large elaborate infrared programs will have to depend on initial results from simple programs.

THE TRANSMISSION OF THE ATMOSPHERE

The transmission of the atmosphere at sea level is schematically shown in Figure 1. It can be seen that the reason for the total inaccessibility of the far IR spectral region is the water vapor absorption. If water vapor were absent, the next most important absorber would be CO_2. Whereas the water is a major obstacle to IR observations, the CO_2 is a very minor problem, and the main studies complicated by its presence are the studies of CO_2 in the atmospheres of other planets.

The optical depth (absorption) over a typical spectral band is proportional to the product of the water vapor present and the atmospheric pressure. A comparison of various altitudes with sea level is given in Table 1.

TABLE 1

Abundance of Atmospheric H_2O

Altitude	Pressure	Precipitable H_2O	Pressure x H_2O
Sea level	1 atm.	~1 gm	1
8,000 ft (wet)	0.75	0.5 gm	0 · 4
8,000 ft (driest found)	0.75	0.05	4×10^{-2}
30,000 ft	0.25	~0.01	2.5×10^{-3}
40,000 ft	0.17	~ 0.002	3.4×10^{-4}
100,000 ft	0.01	~0.0001	10^{-6}

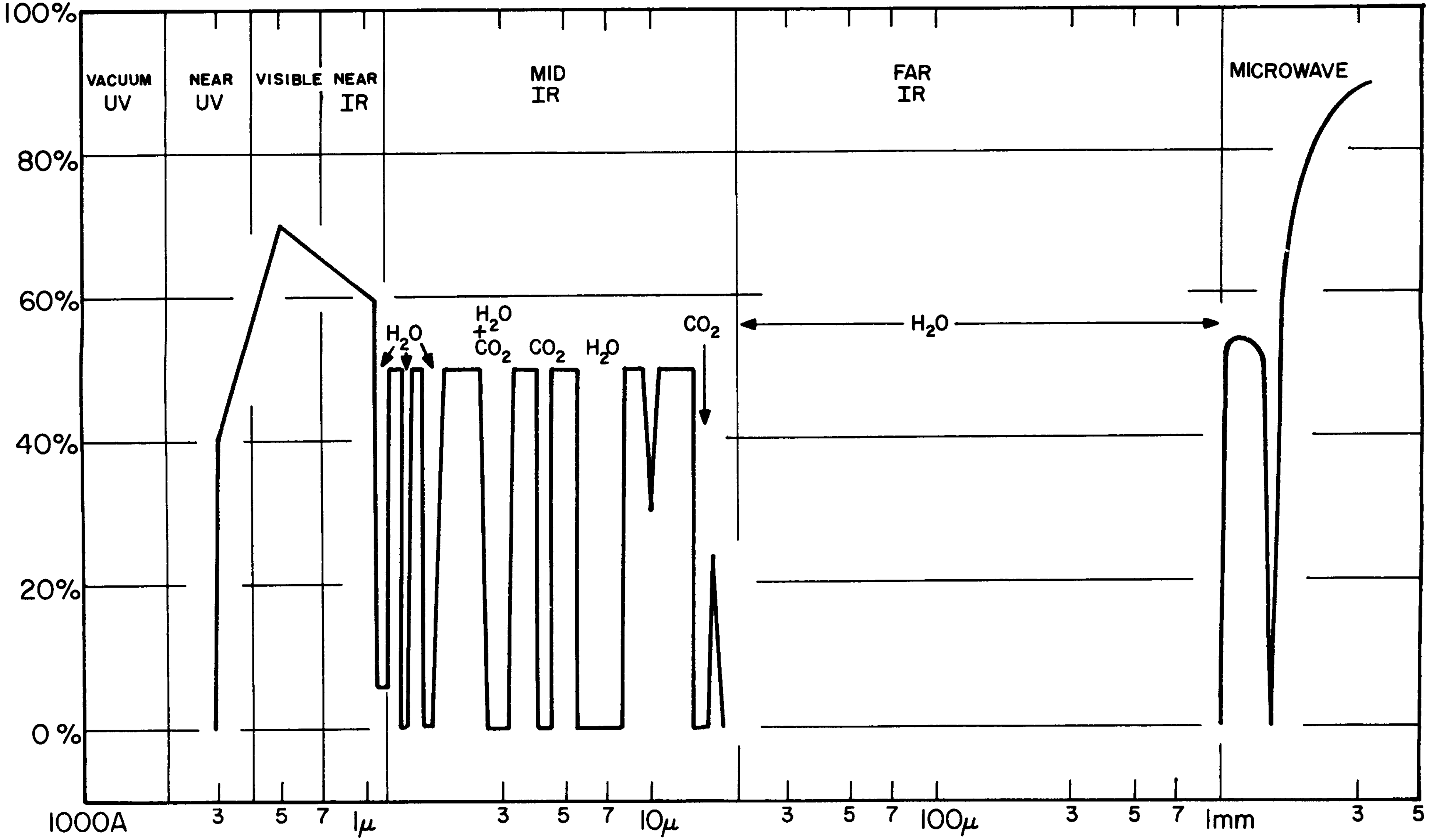

FIG. 1 TRANSMISSION OF THE ATMOSPHERE AT SEA LEVEL

The strongest H_2O bands are the rotation band from 17μ - 1 mm, and the vibration bands at 6.3 and 2.8μ. The rotation band is the strongest, and thus a study of its transparency is useful for showing the transparency of the entire infrared spectrum.

Estimates of the transmission of the atmosphere in this band are given in Figure 2 and Table 2.

It can be seen that no site at ground level will make the 20μ - 1 mm region accessible, and that at aircraft altitudes its accessibility is comparable to the accessibility of the 1-20μ region from the ground.

TYPES OF OBSERVATIONS TO BE MADE ALOFT

Because of the different instrumentation demands, IR observations naturally separate into studies of point sources, or with high angular resolution, and studies of large diffuse sources. A further division depends on the degree of detailed spectral information desired.

Studies of point sources require large collecting apertures that must be well aimed to be efficient. It can be assumed that in most IR observations the limit to the sensitivity of the detector will be set by the radiation reaching it from the telescope mirrors. Since the noise only decreases as $\sqrt{\epsilon}$, where ϵ is the emissivity of the telescope optics, it is unlikely that major improvements will result here. However, this also implies that to be sensitive the detector must be small, and illuminated by the smallest possible cone of radiation from the telescope. It can therefore be seen that the most efficient system for infrared photometry would have a detector little larger than the telescope diffraction pattern. To achieve good photometric accuracy the pointing must be good to a fraction of the detector size. Table 3 shows the sky diaphragm sizes necessary. One sees that the equipment demands are rather similar to Earth based instruments. The observing time for faint sources

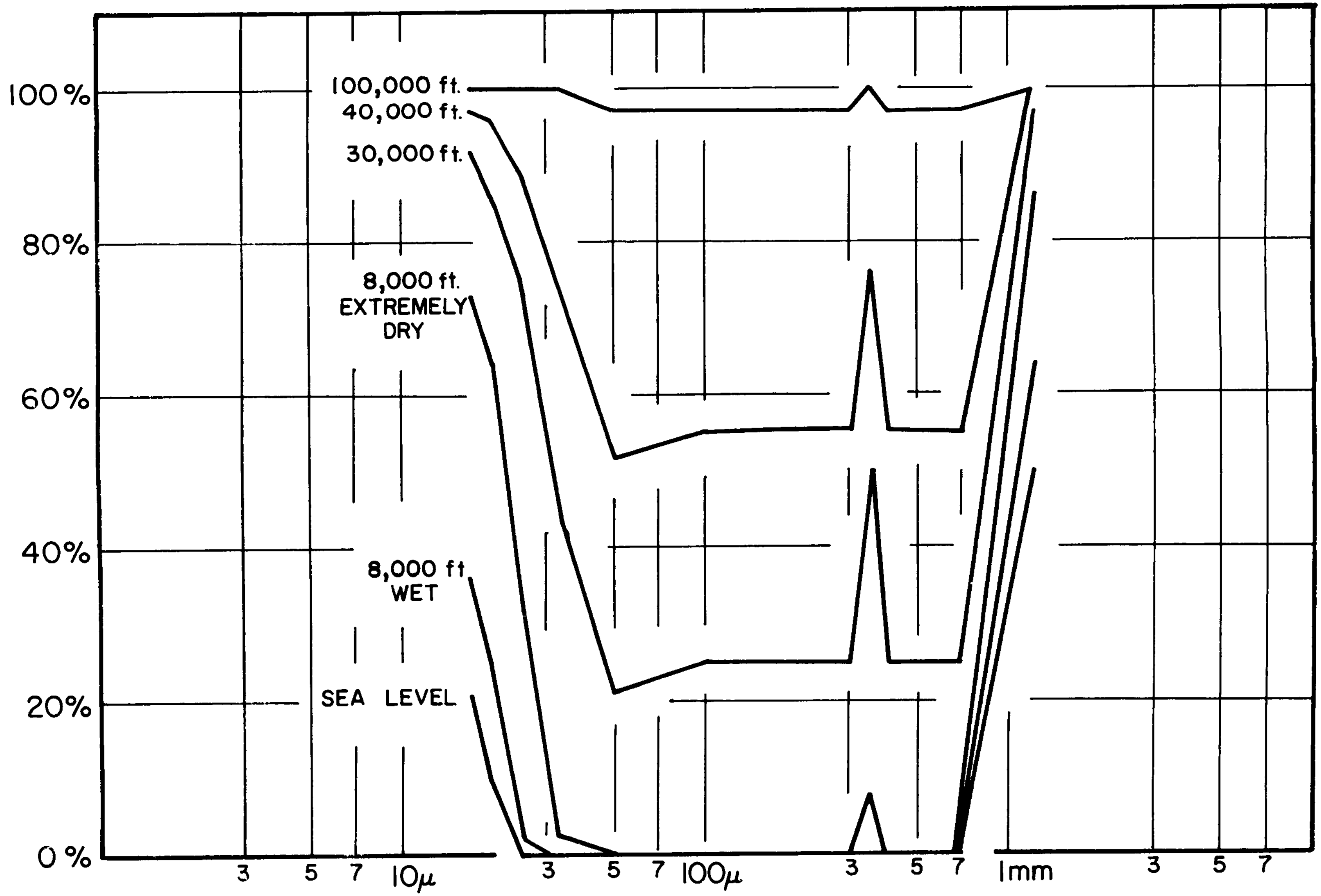

FIG. 2 TRANSMISSION OF THE H_2O ROTATION BAND

TABLE 2

Schematic* Transmission at the H_2O Rotation Band

Wavelength	Transmission					
	Sea Level	8000 ft wet	8000 ft dry	30, 000 ft	40, 000 ft	100, 000 ft
17μ	0.50	0.64	0.86	0.97	1.00	1.00
20μ	0.10	0.25	0.64	0.85	0.96	1.00
25μ	0.00	0.02	0.32	0.75	0.89	1.00
33μ	-	0.00	0.03	0.45	0.73	1.00
50μ	-	-	0.00	0.21	0.52	0.97
100μ	-	-	-	0.25	0.55	0.97
200μ	-	-	-	0.25	0.55	0.97
350μ	-	-	0.08	0.50	0.78	1.00
700μ	-	-	0.00	0.25	0.55	0.97
1.2 mm	0.50	0.64	0.86	0.97	1.00	1.00

*These are average figures for relatively broad spectral bands, and there is sufficient uncertainty in the amount of atmospheric water, and the absorption of this band that even the first significant figures are in doubt.

will decrease as 1/ (telescope diameter)^4, so that there will probably be some gain in building and operating one large telescope rather than several smaller ones.

For diffuse sources, there is no point in using a very large telescope, because in general good large detectors are hard to manufacture. For typical good detectors the angular resolution and pointing accuracy are shown in Table 4.

TABLE 3

Angular resolution and pointing accuracy required for point sources.

Aperture	Wavelength	Sky Diaphragm Required	Pointing Accuracy Needed
30 inch	300μ	200"	± 20"
-	20μ	15"	± 1.5"
120 inch	300μ	60"	± 6"
-	20μ	4"	± 0.4"

TABLE 4

Telescope diameters and pointing accuracy required for study of diffuse sources with a 1 mm detector and F:1 beam

Source Diameter	Pointing Accuracy	Telescope Diameter
2^{o}	± 12"	1 inch
12'	± 70"	10 inch

It is seen that instruments for studying diffuse sources will tend to be small, and easily pointed and guided. Thus they are probably well adapted to inexpensive unmanned operation and indeed such observations from rockets and balloons have already commenced. However, studies of point sources will require complex, large, and expensive equipment and can be most readily started with manned equipment.

THE VEHICLES

The possible infrared studies can be conducted from several facilities. These are:

1) From the ground
2) From aircraft
3) From balloons
4) From rockets
5) From small unmanned satellites
6) From large manned satellites

It is first clear that all observations that can be reasonably attempted from the ground will be tried from there. For point sources where the spectrum is expected to be a continuum, there will be little need to make observations aloft for wavelengths shorter than 20μ, since adequate observations can probably be made in the atmospheric "windows". However, from 20μ to 1 mm is a factor of 50 in wavelength, and some photometric observations will need to be made at about 4 different bands between.

For spectra the situation is less clear. Certainly the observations will need the 20μ - 1 mm window to be "opened", but there is also likely to be a substantial gain for wavelengths between 20μ and 1μ, since only about one half of that part of the spectrum is accessible from the ground. However, to some extent one spectral feature can substitute for another and unless there are unfortunate coincidences of bands or series of lines, (so that all are obliterated by water or CO_2 in the atmosphere), the short wavelength region will be able to be studied adequately from the ground.

The need for a major installation for studying point sources in the 20μ to 1 mm band is obvious. The value of equipment for the 1μ to 20μ band is sufficiently less obvious, and equipment for the 20μ to 1 mm band would be so adequate for it, that no major design effort should be spent in making equipment optimum for the shorter wavelength region.

Aircraft and Manned Satellites

The size and complexity of instruments for studying point sources will be such that manned control seems desirable. The need for manned control comes from:

A. The apparatus will be sufficiently complex that the probability of its working unaided will be low. In initially setting the instrument to work a man could prove invaluable.

B. There is a problem in pointing at faint stars and invisible objects that is not yet solved. OAO's plan to point at relatively bright stars (brighter than 9th magnitude), and for Stratoscope II the television systems and multiplicity of motors involved in pointing and setting by remote control are not practicable for an unmanned orbiting instrument. A serious study of these problems is urgently needed, but one initial suggestion would be to use an astronaut for fine setting of the instrument, possibly by semi-remote control, and to have guiding and initial setting of the instrument on an automatic operation. This would leave the man aloft with exactly those functions that most critically require an observer for a ground observatory.

The possibility of manned operation does not exist for balloon or rocket equipment, and thus complex equipment requires either a plane or a manned satellite. An aeroplane is not ideal. It will probably render the 20μ to 1 mm region only as accessible aloft as the 1μ to 20μ region is at present from the ground. Also, telescope apertures will be limited by airflow and structural problems, and the unlikelihood of special planes being designed and constructed. Furthermore the CO_2 bands are still opaque at aircraft heights. Thus there will eventually need to be a large orbiting telescope. Its justification must come after aeroplane work has been tried because the cost difference is enormous.

Balloons, Rockets and Unmanned Satellites

It has been shown that studies of extended surfaces with IR emission is possible using small remote-controlled packages. The cheapest ways of sending these aloft are by balloon or sounding rocket. The balloon has the sensitivity advantage of long integration times available. The rocket has the advantage of being above any residual atmospheric emission that might complicate the study of objects with low surface brightness. Both approaches are at present being tried. Unmanned satellites will combine both advantages, but again the cost differential precludes their use until a need has been demonstrated by the other programs.

PROPOSED MANNED PROGRAM

To develop a sensible manned astronomical program aloft it is obvious that the scientists who will use the equipment -- the astronauts -- should be a part of the program from the very beginning. Plans for observations, and equipment for such use should be developed in constant consultation with them. Initial work should be performed in the jet planes that they normally fly, so that the astronaut faces the equipment problems in as familiar surroundings as possible. Initial work should involve photometry of the brightest sources, such as the Sun and Moon so that atmospheric absorption at aircraft altitudes can be confirmed as rapidly as possible, and problems of large equipment and pointing at faint objects should be delayed until some confidence has been gained. Initial attempts to study faint objects should be started on the outer planets Uranus and Neptune, where the thermal radiation should be enough to be detected with a rather small telescope, but the finding and guiding problems here will offer most of the troubles to be encountered later.

The second phase of the work should involve a moderate aperture telescope (24 to 40 inches), installed in a larger plane. This should permit a substantial variety of interesting problems. If possible the equipment should be also capable of being orbited in Apollo extensions so that experience with it could provide a bridge to further work.