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and Supplements

"ASTRONOMY AT SUB-MILLIMETER WAVELENGTHS"



These reports will be given in terms of calendar years, since the starting date for this Grant was February 1, 1971.

1971: When the initial grant was received, a flight system had already been constructed and was on the point of being flown. The gondola contained a Newtonian telescope with 16" primary mirror; chopping of the IR signals was achieved by oscillation of a flat secondary; and the detector was a Texas Instruments germanium bolometer. Filtering was accomplished via the quartz window on the dewar, with quartz and black polyethylene at the entrance of a conical lightpipe that terminated at the detector chip.

The gondola had been designed on the basis of experience gained in the flight with an earlier system (Friedlander and Joseph, *Astrophys. J.* 162, L. 87, 1970). In the early flight, four prominent sources had been detected, but each had been seen once only; it was felt that future flights should provide for repeated observation of any source, and so the second gondola was designed to allow elevation adjustment via radio command from the ground. The intention was to sweep continuously in azimuth; when an object was sighted, the elevation would be changed so that on the next azimuthal sweep the telescope would be pointing at the new direction and thus allow a second sighting. The dewar, lightpipe and detector were the same that had been used on the early flight.

The flight was launched from the NCAR balloon facility in Palestine on 11 March 1971, and the flight itself was successful. However, no data were obtained, due to malfunctioning of our system. The system worked perfectly through the pre-flight checkout and was working when the recovery crew reached the package after flight, but from the telemetry and the post-flight examination of the on-board photographic record we were able to reconstruct the operation. It seems that the secondary mirror did not rock as required, and we attribute this to the extreme cold encountered during ascent. We were unable to decide whether this caused differential contractions which froze a driving rod in its bearings, or whether the ascent through a thunderstorm resulted in catching enough water that subsequently froze. In addition, there were problems with the NCAR telemetry, and commands to switch the chopper on and off were not always received.

It must be emphasized that the entire flight system had been designed and constructed before the NASA grant had been received; earlier funding had been minimal and many design features were based on economy. With the problems encountered on the flight and the award of the new grant, it was decided to undertake a thorough review of the entire system, and the remainder of the year was

occupied in this way, together with extensive laboratory testing of the bolometer.

During the fall semester, the Principal Investigator was on leave, in the Infrared Astronomy Group at Imperial College, England, and the day-to-day operation was under the direction of Dr. R. D. Joseph. During this leave, the P.I. was studying the role that cosmic rays seem to play in infrared astronomy.

1972: Based on the bolometer testing and the gondola design studies, it was decided to make some changes in the system. First, the mechanical operation was to be simplified to reduce the chances of malfunction, and to that end the elevation control was eliminated. The mechanical system that had operated the chopper was the subject of continued trouble. With the $f/2.5$ 40 cm primary, the secondary needed to be large (about 9" along the major axis) and the 10Hz chopping introduced considerable vibration that was picked up by the detector. The elimination of this vibration was the task that took longest and was the major factor that delayed the next flight. Extended vibration analysis and many variations of the system were required.

With the removal of the elevation control, it was decided to use two detectors, and, after several designs had been considered, it was decided to place the two detectors one beneath the other, each with its own lightpipe. A major decision then involved the dewar, and it was decided to retain the original dewar, and to make internal changes to accommodate the two lightpipes. This also required minor modifications to the dewar window. (At that time, it was felt that it would take too long to design and build a completely new dewar. In retrospect, having a larger dewar would have allowed improved optics and permitted other improvement: also).

A further major decision was the switch from the germanium to silicon bolometers. The lower specific heat of the silicon suggested greater sensitivity, and the cost was much lower than for the germanium chips.

The remainder of the year was taken up with the complete rebuilding of the electronics including the design and construction of considerably improved low-noise preamplifiers, and the design and construction of the new lightpipes.

A subject of major astrophysical interest has been the 3° cosmic background. Joseph designed an experiment to search for anisotropies in this radiation. In principle, the experiment is simply the comparison of the radiation received alternately from two sky directions at the same elevation but opposite azimuths; at the same time, the system would be rotated in azimuth and thus sweep out a large area of the sky during a flight. A single silicon bolometer was chosen, and a new dewar designed and constructed. Inside the dewar were located the beam-switching optics; filtering restricted the spectral region to wavelengths beyond about 500 microns.

The entire system was designed, constructed and tested during 1972/3, and was taken to Palestine with the sky survey experiment in August 1973. En route, the internal neck on the dewar fractured, and after repair the vacuum was not good. Because of the delays with the sky survey flights, the isotropy experiment was not flown, but Joseph still proposes to undertake this flight, and the bolometer, scanner and optics have been lent to him in his new position (at Imperial College, London).

1973: Construction of the survey system continued, with considerable study and testing of different filter combinations. The enlargement of the dewar window and the aperture in the internal radiation shield had reduced the helium hold-time, and improved insulation was needed together with a filter on the radiation shield.

The spectral sensitivity of the system was tested with the Fourier-transform spectrometer at the University of Missouri-Rolla, and the cut-on at 50 microns was gratifyingly sharp. Continued testing of the silicon bolometers was being conducted to try to set the best operating conditions for a flight. As the background radiation is quite different at flight altitude from laboratory conditions, this is a critical item. The main source of trouble was still the vibration from the oscillating secondary.

The entire system was taken to NCAR (Palestine) at the beginning of August, and testing was continued with the large environmental test chambers there. In particular, the complete gondola could be accommodated in the Bemco chamber, and this allowed testing of a sort that we cannot undertake at home. While the electronics generally operated well, some low-temperature problems emerged during the testing, with the sky cameras and the photo-diodes

used for providing a reference signal from the chopper. With the cameras, the trouble was traced to a low temperature grease that was simply not functioning properly and as a result was freezing the bearings; the temperature dependence of the diodes was compensated, and the system was flown twice, during September.

A large DC offset was encountered during the first flight, but this was considerably reduced for the second flight. The second flight yielded a very large number of apparent sources of far infrared radiation.

The gondola survived the first flight in good order, but the frame was cracked in several places on the second flight, and will require replacement before further flying.

1974: The post flight analysis of the data occupied the last few months of 1973 and the first half of 1974. The results have since been published, but some additional comments are in order here.

The flight system had redundant data recording capabilities that proved to be extremely useful. In a very simple system of on-board recording, a camera photographed panel meters that displayed the outputs of the two detectors. This was intended purely as a back-up; very large signals were seen, but the main use was for the reduction of housekeeping data. Each bolometer had its own telemetry, with high-gain and low-gain channels. In addition, the preamplifier outputs were telemetered, with the original intention being to use these latter data for diagnostic purposes. With the DC offset encountered, the on-board lockin amplifiers tended to saturate, but the preamp signals could be re-played in the lab (after the flight), using new lockins, and signals could be then extracted.

In the total flight record, about 160 large signals were noted; about half of these appeared to have the correct shape for genuine signals and the others were clearly noise spikes, i.e. they were large but the signal shape could not have been produced by the observation of a celestial object. A considerable number of the genuine signals turned up repeatedly at the same celestial co-ordinates (to within about 1° , i.e. the telescope field of view) and we consider these as representing the repeated detection of celestial objects. It is significant that only one pair of the noise spikes, out of 80 events,

should have come within 1° of each other. Exhaustive analysis has failed to reveal any mechanism by which apparently genuine signals could, by accident of systematic bias, repeat at the same celestial coordinates.

Publications:

The results of the 1973 flight have been published:

M. W. Friedlander, J. H. Goebel and R. D. Joseph, Ap. J. Lett. 194, L.5 (1974) and are also contained in a Ph.D. thesis:

J. H. Goebel: Astronomical Far Infra-Red Sky Survey (Washington University 1974).

The sky camera system used for coordinate checking, has been described:

R. D. Joseph: Orientation Measurement for Balloon-Borne Telescopes
Journal of Physics (E): Scientific Instruments 8, 92 (1975).

Another paper, describing the performance of the silicon bolometers, is in preparation.

Further work:

At this time, continued funding is not available, but applications are being submitted in the hope that the program can be continued.

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