

## VI. INFRARED INSTRUMENTATION AND ASTRONOMY

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The spectral region from 10  $\mu\text{m}$  to 1 mm is an important frontier of astronomical research. The major difficulties in examining this region arise because of the scarcity of good detectors and the opacity of the atmosphere, which precludes observing from the ground except in several narrow "windows." Our research is directed toward improving far infrared detector technology, continuing a program of observing from high-altitude balloons, and initiating a program of ground-based high-resolution observations of spectral lines in astronomical sources.

### 1. MEASUREMENT OF THE ANISOTROPY OF THE COSMIC BACKGROUND RADIATION IN THE FAR INFRARED

JSEP

Joint Services Electronics Program (Contract DAAB07-75-C-1346)  
National Aeronautics and Space Administration (Grant NGR 22-009-526)

Richard L. Benford, Dirk J. Muehlner, Rainer Weiss

Our objective is to measure the anisotropy of the cosmic background radiation with a broad beam ( $\sim 17^\circ$ ) and sufficient precision (better than  $\sim 0.03\%$ ) to measure the velocity of the Earth with respect to the universal rest frame. While the goal of measuring the peculiar velocity of the Earth sets the required sensitivity of this experiment, the main scientific interest of it lies in gaining the information about the early universe which the background radiation carries.

The instrument used in this program, a dual-channel differential radiometer carried by high-altitude balloons, was described in Quarterly Progress Report No. 112 (pp. 23-27). In previous flights we have established that the background radiation is isotropic to at least  $\sim 0.1\%$  in the 3-10  $\text{cm}^{-1}$  spectral region. Figure VI-I shows the Fourier amplitudes of the radiometer output at the rotation frequency of the package for both North-South and East-West components averaged over 30 rotations ( $\sim 7\frac{1}{2}$  min) plotted against sidereal time. Also plotted is the signal expected for a 700 km/s velocity in the direction  $\alpha = 3^{\text{h}}$ ,  $\delta = 58^\circ$  which results if a measurement made by Vera Rubin (Private communication) of a red shift anomaly in a sample of ScI galaxies at  $Z \approx 0.2$  is interpreted as being due to Earth motion. This estimate clearly does not fit the data. The data, however, are not clean. There are obvious long-term correlations in the E-W component that we do not understand. At present, these correlations are the major puzzle in the experiment.

Difficulties with apparent systematic noise have prevented us from reaching a positive result for the background anisotropy from the data of past flights. The signal in the July 9, 1975 flight which we hoped would clear up some of the questions about our earlier data, was seriously contaminated by excess noise that was probably traceable

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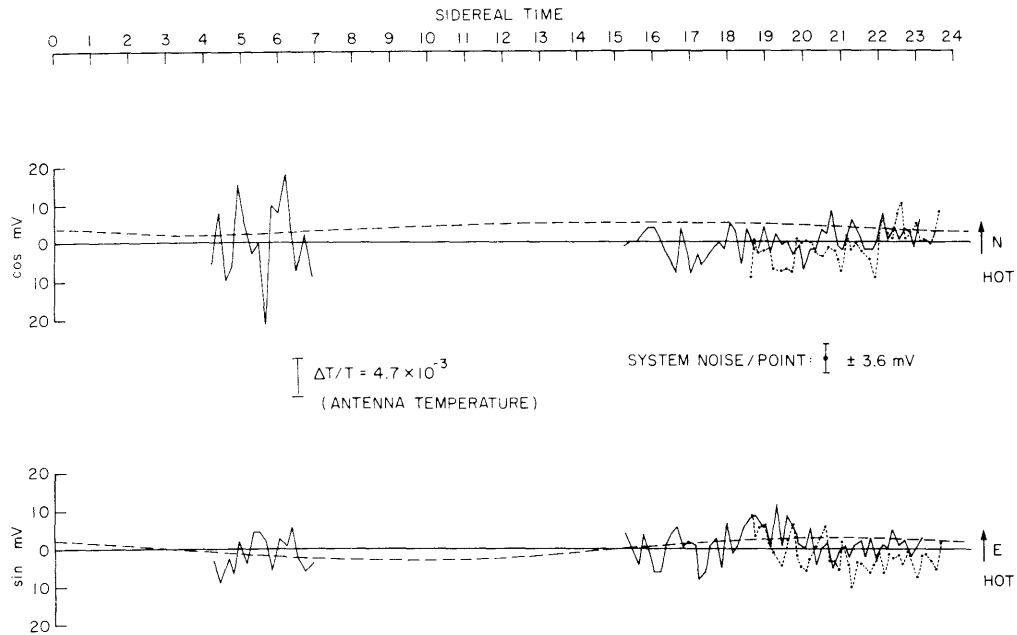


Fig. VI-1. Data from isotropy experiment.

to the fact that, because of an accident at launch, a reel that normally lowers the radiometer 2000 ft below the balloon failed to work. The explanation of systematic trends in earlier data and a positive measurement of the background anisotropy must await future flights.

We are now implementing improvements in the radiometer.

(i) The InSb detectors are being replaced by composite bolometers which are germanium thermometers on sapphire substrates coated with metallic absorbing films. The improvement in the noise equivalent power (NEP) should be close to a factor of 100. While the experiment is limited at present by systematic effects rather than by detector noise, better detectors will greatly improve the speed and precision of diagnostic studies.

(ii) Any possibility of significant large-angle diffraction or scattering of radiation from below the apparatus into the radiometer beams will be eliminated. This (possible) problem had almost certainly been obviated by addition of extra shielding for the July 1975 isotropy flight; for flights in 1976 we may add horns especially shaped to minimize large-angle sidelobes.

Because the results of the anisotropy measurement must be corrected for any significant contribution to the signal from galactic or other discrete sources, the results of the Sky Survey program (Sec. VI-3) will also be important in the isotropy measurements.

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2. HETERODYNE DETECTION IN THE INFRARED

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Joint Services Electronics Program (Contract DAAB07-75-C-1346)  
National Aeronautics and Space Administration (Grant NGR 22-009-526)

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The immediate objective of this program is the development of a compact tunable infrared heterodyne receiver for astronomical use that can be bolted as a single unit to a telescope. A tunable semiconductor diode laser is used as the local oscillator in the same package (a small liquid helium dewar) as the mixer and the associated optical apparatus. The laser will be chosen initially to be tunable to the astrophysically interesting  $H_2$  rotational line at  $12.3 \mu m$ . It is not intended that the heterodyne receiver will compete with conventional infrared detectors in terms of ultimate sensitivity, although at longer wavelengths this qualification may be unnecessary. The almost unlimited frequency selectivity of heterodyne detection will make its greatest impact in ultrahigh-resolution studies of sharp spectral lines. The first astronomical test of the new receiver will be in measuring the  $12.3 \mu m$   $H_2$  line in the atmosphere of Jupiter. Next we shall attempt to detect this molecule in dark interstellar clouds where it must occur in great abundance but cannot be seen with conventional methods. In the future the program will be extended to develop heterodyne detection at much longer wavelengths in the far infrared.

The  $12\text{-}\mu m$  receiver is essentially complete. Using a laser emitting a fraction of a milliwatt near  $12 \mu m$  in conjunction with a HgCdTe mixer (kindly supplied by David L. Spears of Lincoln Laboratory, M. I. T.), we have achieved heterodyne detection of thermal radiation with a sensitivity approximately  $1/8$  that of the theoretical prediction. We are awaiting delivery of a more powerful laser capable of hitting the  $12.3 \mu m$   $H_2$  line, and we expect to test the system this winter on Jupiter at the M. I. T. Wallace Astrophysical Observatory, Westford, Massachusetts.

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3. SUBMILLIMETER SKY SURVEY

National Aeronautics and Space Administration (Grant NGR 22-009-526)

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The aim of this project is to carry out a sky survey with an angular resolution of approximately  $1^\circ$  in roughly the same spectral bands ( $3\text{-}10$  and  $10\text{-}25 \text{ cm}^{-1}$ ) that are used in the isotropy experiment described in Section VI-1. (This resolution may be improved in the future.) In addition to the intrinsic interest of sources in this relatively unexplored region of the spectrum, the results of the survey will be important for the isotropy experiment. Indeed, this project was initiated because a bright localized source was observed in the high-frequency channel during flights for the isotropy measurements. The instrument in the survey is the balloon-borne dual-channel radiometer that was used in the isotropy experiment modified to have a beam diameter of approximately  $1.5^\circ$  rather than  $17^\circ$  as in the isotropy experiment.

The experiment was flown in July 1975, with the following results. The source that was observed in the isotropy experiment, described in Progress Report No. 115 (page 66), which was thought originally to be  $\sim 10^\circ$  away from the galactic plane, is actually distributed along the plane. The brightest source observed in the survey flight was the region of the galactic center and a bright strip was observed along the galactic plane out to  $l_{II}$  (galactic longitude)  $\approx 40^\circ$ . Between this point and  $l_{II} \approx 85^\circ$  there was

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a gap in our coverage of the galactic plane; on the far side the plane was not observed. No off-plane sources were observed, with a limiting sensitivity of  $\sim 10^5$  Jy in our  $1:5$  beam. Positions were measured with an accuracy of  $\sim 1^\circ$ . The galactic center and plane were not seen in the low-frequency channel, which gives a limit of  $n \gtrsim 3$  for the spectral index ( $I(\nu) \sim \nu^n$ ) of these sources. In the future the survey experiment will benefit from better detectors that are being made for it and for the isotropy experiment and other improvements concerned mainly with better determination of position.

### 4. INFRARED SURVEY SATELLITE STUDY

National Aeronautics and Space Administration (Contract NAS5-22828)

Dirk J. Muehlner, Rainer Weiss

In collaboration with Dr. John Mather, of the Goddard Institute for Space Studies, we are making a feasibility study of an experiment to measure the spectrum of the submillimeter cosmic background radiation from a space platform. Several options are open in this experiment. It may be an auxiliary experiment on an infrared survey satellite planned as a joint effort by the United States and The Netherlands, provided it does not compromise the survey. It may be an early space shuttle payload and finally part of a free flight mission dedicated exclusively to measurement of the spectrum and isotropy of the background radiation in several bands in the infrared and submillimeter regions.

The instrument that we are studying is a differential cryogenic Fourier transform spectrometer that continuously refers the background radiation to an internal blackbody reference source. In a few hours of integration we hope to be able to measure the  $2.7^\circ\text{K}$  background radiation with a signal-to-noise (S/N) ratio of  $10^4$  in the region around the blackbody peak at  $6\text{ cm}^{-1}$ . At  $25\text{ cm}^{-1}$  the S/N ratio will be  $\sim 10$ .

At present we are focusing on the following problems:

- a. Design of multimode beam-forming systems with extremely low sidelobes, with off-axis rejection of more than  $10^8$  at angles greater than  $45^\circ$ . This study is being carried out by computer calculations of various horn designs with the use of Keller's extension of geometrical optics to account for diffraction, as well as an experiment to determine the validity of Keller's theory for simple two-dimensional systems.
- b. Study of various schemes to phase-modulate submillimeter waves by using the Pockels effect to eliminate mechanical motions in Fourier transform spectroscopy.
- c. Application of integrated circuit technology in the construction of composite bolometer detectors for the far infrared.