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FINAL TECHNICAL REPORT

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOR

CONTRACT #NAS5-24486

MICROWAVE AND THEORETICAL STUDIES

FOR

COSMIC BACKGROUND EXPLORER SATELLITE

FROM

PRINCETON UNIVERSITY

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Overview

This contract supported activities at Princeton University directed toward studies of the COSMIC BACKGROUND EXPLORER (COBE) satellite, its instruments and scientific mission. The studies were conducted primarily by Professor David Wilkinson (member, COBE Science Working Group), Dr. M. Seldner (now at Bell Labs., Holmdel), and Dr. P. Lubin (now returned to Berkeley Space Sciences Laboratory). The tasks performed were basically those set out in the original Statement of Work. However, as the COBE concept developed some of the originally anticipated studies became less urgent, and new problems arose which required work by the Princeton group. The major studies are outlined below; more detailed results of each study were reported to the Science Working Group either by COBE Memos, or by oral presentations at meetings. Besides supporting activities at Princeton, the contract provided travel funds for members of the Princeton group to attend COBE SWG meetings, and to travel to Goddard Spaceflight Center to consult with COBE engineers.

Microwave Studies

1. Tests on Cooled Mixers and Correlation Radiometers. Early in the COBE program, D. Wilkinson performed laboratory tests on proposed radiometer configurations for the DMR instruments. These studies were mainly directed toward answering two questions: "Should COBE attempt to use cooled commercial mixers?" and "Should the COBE radiometers use the correlation configuration?"

On the first question, test on existing hardware showed that some improvement in noise figure could be realized by cooling SPACEKOM microwave mixers to - 90°C, but not as much as was expected theoretically. Apparently, the optimization of the mixers for room temperature operation did not extend to lower temperatures. Probably the IF impedance matching went bad due to changes in the impedances of the mixer diode and/or the IF input transistor. It was decided by the SWG not to pursue these studies because (a) detailed engineering studies were needed to understand the problem and (b) ground testing of the DMRs would be much easier if they were designed to operate at room temperature. This decision was reversed later in the program (see 3. below), mainly because the cold mixer studies had been done in industry, and the potential improvement in science data was judged worth the extra effort in ground testing.

The second question (correlation radiometers?) was pursued at some length at Princeton, mostly on NSF funding. Three correlation radiometers were constructed at COBE frequencies 24.8 GHz, 31.4 GHz and 46.0 GHz. The detailed properties of the correlation radiometer configuration were studied, and these radiometers were flown in balloon packages, closely simulating COBE satellite conditions. The engineering and scientific data from these flights were valuable in guiding the design of the COBE DMR instruments. After much discussion, it was decided not to use the correlation radiometer design, mainly because it is not as redundant as the two-channel Dicke-switched radiometer. Failure of a single mixer causes complete loss of data in the correlation mode, only half is lost in the Dicke mode. This consideration outweighed the several technical advantages of the correlation radiometer.

2. Studies of Galactic Radio Emission at 24.8 GHz. As part of Princeton's on-going program to study the Large-Scale Anisotropy of the Cosmic Microwave Background, a cooled maser amplifier was obtained from JPL, with NASA funding. The lowest COBE frequency (24.8 GHz) was chosen since JPL had already built highly successful masers at this frequency. A radiometer was constructed and flown from balloons - twice in Texas, once in Brazil (for good sky coverage). The result was a 5% measurement of the dipole effect and the first large-scale measurement of radio emission from our Galaxy at short (cm) wavelengths. The Galactic emission is important to COBE because it constitutes an interfering foreground source that must be subtracted out of the lower frequency DMR data.

A model for Galactic radio emission was developed based on:

(a) Extrapolation of radio sky maps made at 408 MHz. Scaling such maps by $(\text{frequency})^{-2.75}$ gives a surprisingly good fit to the 24.8 GHz data. This is the synchrotron radiation component.

(b) Extrapolation of 5 GHz and Hα maps of bremsstrahlung emission from the Galaxy. The first measures the radiation from hot HII regions, the second is more sensitive to diffuse emission. Since the distribution of bremsstrahlung is not as well known, and it falls off more slowly with frequency (-2.1 power), this component will be the most trouble for COBE.

The success of the maser-balloon observations led to a better understanding of the Galactic emission problem, and to a modification of the SWG plan to remove this component from the DMR data. The COBE radiometer at 24.8 GHz was dropped; its better sky coverage made its potential results only somewhat better than those achievable with the maser. The maser-balloon experiment is being modified (under NASA Grant NAGW-445) to 19 GHz and better angular resolution in order to better measure and understand the Galactic emission at 1 cm. It is expected that this will be the basis for a better model for cm Galactic emission than could have been achieved from the 24.8 GHz COBE DMR.

3. Studies of Tradeoffs for Cooling the DMRs. During his stay at Princeton, Phil Lubin made several studies related to the DMR instruments. Based on his experience with a cooled 90 GHz mixer, he studied the potential advantages of allowing the COBE DMRs to cool to near the ambient temperature ($\sim$ 150 K). Since the mixer engineering problems were now better understood, he was able to show that substantially better noise performance could be obtained, with little risk. The science data could be improved significantly. The problem of more complex ground testing is still a consideration, but the SWG deemed this a worthwhile price for improved scientific results. Lubin and Wilkinson participated in SWG meetings where the tradeoffs were discussed, and a testing program was outlined. The simultaneous decision to drop the 24.8 GHz radiometer resulted in a partially compensating reduction in workload for the DMR engineers.

Theoretical Studies

1. Model of Zodiacal Emission and the DIRBE Viewing Angle. An early, important, decision for the COBE SWG was, "Is there any advantage to tilting the DIRBE beam away from the spacecraft rotation axis?" This decision was a major driver on the packaging of the FIRAS and DIRBE into the COBE dewar. Since a major part of the DIRBE science is a search for isotropic, extragalactic, background radiation, it is essential to be able to scan and model the foreground radiation from zodiacal dust grains.

Mike Seldner wrote a computer program to model zodiacal emission under a variety of assumptions about the shape and size of dust grains, and their distribution and temperature around the sun. He then studied the effectiveness of DIRBE in separating and understanding the zodiacal and isotropic radiation distributions. He showed conclusively that a 30° off-axis beam made this separation much better from the DIRBE data. Subsequently, the SWG decided that the increased scientific payoff justified the complication in mechanical design and the greatly increased data rate for DIRBE.

2. Simulation of DIRBE and DMR Data Streams for Tests of CSDR Programs. The software for the COBE Science Data Room must be accurately verified before launch. Princeton, and other SWG members, are developing simulations of COBE data streams which will be used for testing the CSDR programs, and be used for studies of observing strategies. Some questions which we are asking are:

(a) "What is the effect on COBE science of interruptions of the data streams for spacecraft maneuvers, instrument tests, and particle radiation? What are the best schedules to minimize impact on the science?"

(b) "What is the effect on COBE science for various kinds of instrument imperfections - baseline drift and jumps, gain drifts, periodic interference from the moon and satellites?"

(c) "What is the effect on DIRBE science of various detector annealing procedures? Is it necessary to recalibrate after each anneal?"

These studies have only recently started, and this will be a major Princeton activity under the new contract NAS5-27590 which will support further COBE studies at Princeton.