Title of Grant:



# Anisotropy of the Cosmic Microwave Background Radiation on Large and Medium Angular Scales



Type of Report:

**Summary of Research**

Principal Investigator:

Anthony Houghton (during the period 01/01/97 – 06/30/97)
Peter T. Timbie (during the period 07/01/94 – 12/31/96)

Name and Address of grantee's institution:

Brown University, Providence, RI 02912

Grant Number: NAG5-2629

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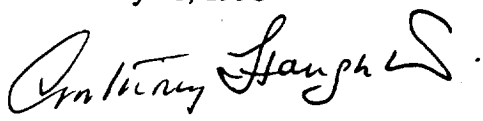

Anthony Houghton
Professor of Physics

Peter Timbie
Associate Professor of Physics

## Summary of Research

This grant has supported work at Brown University on measurements of the 2.7 K Cosmic Microwave Background Radiation (CMB). The goal has been to characterize the spatial variations in the temperature of the CMB in order to understand the formation of large-scale structure in the universe. We have concurrently pursued two measurements using millimeter-wave telescopes carried aloft by scientific balloons. Both systems operate over a range of wavelengths, chosen to allow spectral removal of foreground sources such as the atmosphere, Galaxy, etc. The angular resolution of ~ 25 arcminutes is near the angular scale at which the most structure is predicted by current models to be visible in the CMB angular power spectrum. The main goal is to determine the angular scale of this structure; in turn we can infer the density parameter, $\Omega$, for the universe as well as other cosmological parameters, such as the Hubble constant.

**MSAM2:** The Medium-Scale Anisotropy Measurement has measured thermal radiation from the early universe using several technologies developed specifically for this project.

1.) Sensitive millimeter-wave detectors. We have built bolometers coupled to single-mode waveguides. The detectors are cooled to 100 mK and are the most sensitive detectors ever made for broad-band radiometry in the 4mm to 2mm range.
2.) Single-mode optical system. The instrument views a single pixel on the sky in 5 bands from 4mm to 2mm (65 to 170 GHz) with a nearly-constant beam width of 25 arcminutes
3.) Cryogenics. The detectors are cooled to 100 mK by a portable and robust adiabatic demagnetization refrigerator (ADR). The ADR has heritage from the SIRTF program.

On June 1, 1997, MSAM2 successfully completed its first flight from the National Scientific Balloon Facility in Palestine, TX. The telescope, telemetry, detectors, and cryogenics performed nearly flawlessly. We have calibrated the instrument using in-flight observations of Jupiter and Saturn. The sensitivity is consistent with our model for the bolometers. A second flight is under consideration to increase the sky-coverage of the observations and to improve the sensitivity of the instrument; potentially a factor of ~2 improvement is feasible by reducing the optical loading on the bolometers. Analysis of the data is still in progress.

**TopHat:** During this period we have worked with collaborators at NASA/GSFC, Chicago, and Bartol to develop a next-generation instrument that will map the CMB over 5% of the sky. The instrument is mounted to the top of a scientific balloon and is scheduled to fly from Antarctica in a 2 week mission in late 1999. At Brown we have been developing the optical filters to define the spectral bands of the instrument. Further, we have developed a cryostat for testing the bolometers for this instrument at temperatures from 50 mK to 4.2 K.

**Education:** This grant has partially supported the following young scientists:
Grant Wilson received his Ph.D. in September 1997 from this work and is now an NRC Fellow at NASA/GSFC working on TopHat.
Khurram Farooqui is working on his Ph.D.
Sean Cordone is analyzing the MSAM2 data as part of his Ph.D. research.
Dr. Junwei Zhou worked on the MSAM2 bolometers and is now at Princeton Electronic Systems.
Dr. Josh Gundersen is working on the MSAM2 analysis and assisted in the flight and flight preparations.
Undergraduates:
B. J. Whalen, now at Microsoft
Zeyneb Pervane
Peter Wied, now at Harvard Law School
Nan Shen, paid lab assistant, now at Harvard University
Julia Steinberger, now at MIT
Julio Da Graca, at MIT

The following **publications** have resulted from this work:


1. Wilson, G. W., Farooqui, K., Timbie, P. T., Zhou, Jun-Wei "Low-Noise Optics for a Measurement of the Anisotropy in the Cosmic Microwave Background Radiation," Proc. of the European Workshop on Low-Noise Quasioptics, Bonn, Germany, (1994).

2. Timbie, P. T., Farooqui, K. H., Wilson, G. W., Zhou, J.-W., Piccirillo, L., Schaefer, R., Inman, C. A., Meyer, S. S., Puchalla, J. L., Ruhl, J., Cheng, E. S., Cottingham, D. A., Fixsen, D. J., Kowitt, M. S., Silverberg, R. F., and Page, L. A. "Future Observations of the CMBR with the MSAM," Proceedings of the National Radio Science Meeting (1994).

3. Timbie, P. T., Zhou, J.-W., Farooqui, K., and Wilson, G., "Issues in the Readout of FIR and MM-Wave Bolometers for Astrophysical Applications," SPIE Proc. **2226**, 2 (1994).

4. Farooqui, K., Gundersen, J. O., Timbie, P. T., Wilson. G. W., Zhou, J.-W., Allen, C. A., Chen, T. C., Moseley, S. H., and Mott, D. B. "The Monolithic Silicon Bolometer as an Ultrasensitive Detector for MM and Sub-MM Wavelengths," Proceedings of the 9th International Symposium on Space TeraHertz Technology, Boston, MA (1997).

5. Zhou, J. W., Farooqui, K., Timbie, P. T., Wilson, G. W., Allen, C., Moseley, S. H., and Mott, D. B., "Monolithic Silicon Bolometers as Sensitive MM-Wave Detectors," IEEE Trans. Microwave Theory Tech., MTT-43, 1347 (1995).

6. Kowitt, M. S., Cheng, E. S., Cottingham, D. A., Farooqui, K., Fixsen, D. J., Ganga, K., Inman, C. A., Meyer, S. S., Page, L. A., Piccirillo, L., Puchalla, J. L., Ruhl, J., Schaefer, R. K., Silverberg, R. F., Timbie, P. T., Wilson, G., Zhou, J. W., "The MSAM/*TopHat* Program of Anisotropy Measurements," Astro. Lett. and Communications **32**, 273 (1995).

7. Timbie, P., Farooqui, K., Wilson, G., Zhou, J.-W. "Bolometers in Radio Astronomy Receivers," Proceedings of the National Radio Science Meeting (1996).