# SUBMILLIMETER WAVELENGTH ASTRONOMY MISSIONS FOR THE 1990s

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## ABSTRACT

The submillimeter spectral band between wavelengths of 100 μm and 1000 μm is of key importance for the investigation of a wide range of astronomical topics. These include star-forming molecular cloud regions, planetary atmospheres, galaxies, and cosmic background radiation. Space telescopes will ultimately be required to study these objects at submillimeter wavelengths with complete freedom from the interference due to the terrestrial atmosphere. Ground based, airplane, and balloon observations have been and will continue to be important in developing the field. Several small and modest-sized astronomical space projects for the 1990s have been studied which could dramatically open the window on the submillimeter and far infrared spectral ranges. This paper presents an overview of the science and instrumentation under discussion for these 1990s projects.

## 1. INTRODUCTION

Our knowledge of the sky will take a large step forward during the decade of the nineties due to the operation of a number of submillimeter and far infrared astronomy space missions, starting first with the COSMIC BACKGROUND EXPLORER (COBE) launched in late 1989. The submillimeter spectral region, defined here to range from 100 to 1000 μm (micrometers), is important to studies of most aspects of astronomy including the solar system, the galaxy, extragalactic objects, and cosmology. This spectral region has not been explored in any detail to date because of the high opacity (and variability) of the terrestrial atmosphere in the submillimeter range due primarily to H2O, O2, and O3. Melnick (1988) gives a good discussion of the atmospheric transparency in the submillimeter range. He also discusses the unique role that balloons can make in helping to study the sky in the era before the large space based submillimeter telescopes come into being. This paper presents and overview of the science and instrumentation for a number of submillimeter and far infrared space missions currently under discussion.

## 2. SUBMILLIMETER SPACE MISSIONS

TABLE I lists six submillimeter/far infrared space missions for the decade from 1990-2000 and their estimated (nominal) observation times in orbit. Of the six mission, only one, COBE, is presently in orbit. The others are in varying states of approval and readiness.

**TABLE I**

**SUBMILLIMETER / FAR INFRARED SPACE MISSIONS**

| PROJECT NAME | ESTIMATED ORBIT TIMES (YEARS) |
|---|---|
| COSMIC BACKGROUND EXPLORER(COBE) | 1989-1990 |
| INFRARED TELESCOPE IN SPACE(IRTS) | 1993 |
| SUMILLIMETER WAVE ASTRONOMY SATELLITE(SWAS) | 1994-1995 |
| INFRARED SPACE OBSERVATORY(ISO) | 1993-1994 |
| SUBMILLIMETER MISSION(SMMM) | 1999-2001 |
| SPACE INFRARED TELESCOPE FACILITY(SIRTF) | 1999-2004 |

In addition to these space missions, a number of balloon projects and astronomy research aircraft will allow considerable access to the submillimeter sky. These vehicles will serve as platforms for instrument development and modest research projects during the decade. The newest of these projects, the Stratospheric Observatory of Infrared Astronomy(SOFIA), will provide a considerable improvement in capability if approved. SOFIA is planned to carry a warm, 2.5 meter telescope to heights of 14 km.

Two additional space submillimeter projects are also in the planning stages but launch dates will probably not take place until the next century. These are the ESA-Far infrared Space Telescope(FIRST) and the Large Deployable Reflector(LDR). A submillimeter lunar interferometer is also under discussion at the present time. These three missions are critically dependent on the development of terahertz technology.

The COBE mission is designed to study cosmic background radiation over the wavelength range from 1 μm to 1 centimeter. Primary mission objectives are to search for angular anisotropies in the cosmic microwave background, to measure the spectrum of the background radiation, and to search for diffuse infrared emission from the first stars and galaxies. The COBE spacecraft was launched into a polar orbit in November 1989 and is designed to have nominal lifetime of 1 year. The COBE spacecraft carries three instruments, a set of differential microwave radiometers at 31GHz, 53 GHz, and 90 GHz, a polarizing Michelson interferometer which operates over the wavelength range 1 cm to 100 μm, and a diffuse infrared experiment which measures in ten bands from 1 μm to 300 μm. The microwave instruments are based on Schottky Diode receivers. The receivers at 53 and 90 GHz are radiatively cooled to about 135 K. The Michelson interferometer and diffuse infrared experiments are both located inside a 600 liter cryostat which contains liquid helium.

IRTS is a Japanese mission with potential for U.S. participation. IRTS will study galactic and extragalactic radiation on angular scales of 0.1 degrees. The primary light collector is a 15 cm cryogenically cooled telescope. Mission lifetime is two to three weeks. The data collected from IRTS will be complementary to the COBE data.

The mission objectives for SWAS are to study cloud chemistry, energy balance, and structure of galactic molecular clouds by studying emission from four submillimeter spectral lines: 1)the ground state ortho transition at 556.936 GHz, 2)the 487.249 GHz transition of O2, 3)the ground state fine structure transition of carbon at 492.162 GHz, and 4)a rotational transition of 13CO at 550.926. SWAS plans to use a 55 cm, ambient temperature, off-axis Casegrain telescope. Passive radiators will be used to cool the Schottky diode receivers to temperatures near 100 K. An acousto optical spectrometer(AOS) will be used to provide the spectral line backend.

The ISO mission is an ESA mission with potential for collaboration with U.S. astronomers. The ISO spacecraft will contain four focal plane instruments ( 1 camera, 2 spectrometers, and 1 photopolarimeter) which cover the wavelength interval from 3 to 200 μm. The expected launch vehicle is an Ariane 44 which will place the spacecraft into a highly elliptic (1000 - 70500 km) orbit having an inclination of 5 degrees. The telescope is a 60 cm, Ritchey-Chretien telescope cooled to less than 3.2 K.

The submillimeter mission(SMMM) is designed to make physical and chemical studies of high red-shift galaxies, molecular clouds, star forming regions and planets. SMMM will utilize a roughly 4 meter ambient temperature telescope with a liquid helium cooled focal plane. It will achieve a complete submillimeter spectroscopic survey of a large number of sources between 100 and 700 μm. Heterodyne techniques will be used at the longer wavelengths to provide this spectroscopic capability. Direct detection in conjunction with a far-infrared spectrometer will be used for spectroscopy at the shorter wavelengths. SMMM will also carry a far-infrared camera with a bolometer array. Superconduction tunnel junction (SIS) detectors will form the basis for the heterodyne receivers. The expected lifetime is about 2 years. This mission is critically dependent on the development of terahertz technology.

The Space Infrared Telescope Facility(SIRTF) planned for the later part of the decade will perform astronomical studies including imaging, photometry, and spectroscopy over the wavelength range of 1.8 to 700 μm. The telescope is a helium cooled 0.85 meter system. SIRTF will carry three scientific instruments, a multiband imaging photometer which operates in the band 3 to 700 μm, an infrared array camera that operates from 1.8 to 30 μm, and an infrared spectrograph that operates in several bands from 2 to 200 μm. The highest spectral resolution is about 2500.

## 3. TECHNOLOGY EVOLUTION

Many new technologies( including new applications in space) are going to be needed to fully exploit the submillimeter spectral range. Future space projects will certainly require the knowledge and heritage gained from predecessor space missions. Table II shows the evolutionary technology trends in the current mission set.

**TABLE II**

**SPACE-BASED SUBMILLIMETER TECHNOLOGY EVOLUTION**

| | | | | |
|---|---|---|---|---|
| COOLED FIR SCANNING SPECTROMETER | COBE<br>ISO | | | |
| SCHOTTKY MIXERS | COBE | | | |
| SPECTROMETERS(AOS)<br>GUNN MULTIPLIERS | SWAS | | | |
| CARBON EPOXY PANELS<br>WAVEFRONT SENSING<br>SIS RECEIVERS(500GHz-1.2 THz) | | | SMMM | |
| IMAGING SIS RECEIVERS | | | | FIRST/LDR |
| YEAR | 1990 | 1995 | 2000 | 2005 |

## 4. CONCLUSIONS

The scientific arguments for submillimeter astrophysics space missions are compelling and multi-disciplinary. Science objectives include studies of planetary and satellite atmospheres, comets, the interstellar medium, star formation regions, stars, galaxies, and cosmology. Terahertz technology will play a crucial role in the planning and implementation of space missions. The instrument requirements for space astronomy are very challenging. A great deal of laboratory and field work must be done to meet the requirements of future space missions. The technology evolution built into the present mission set for the 1990s provides an orderly transition of technology from the laboratory to space.

## REFERENCES

Melnick, G. J. ,"ON THE ROAD TO THE LARGE DEPLOYABLE REFLECTOR(LDR): THE UTILITY OF BALLOON-BORNE PLATFORMS FOR FAR-INFRARED AND SUBMILLIMETER SPECTROSCOPY", International Journal of Infrared and Millimeter Waves, Vol. 9, No. 9,1988.

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