3. Mission Profile

The *COBE* was launched on 18 November 1989 into a 99° inclination, 900 km altitude sun-synchronous orbit with a 6:00 PM ascending node. The orbital period is 103 minutes, so there are almost exactly 14 orbits per day. The satellite orbit plane precesses at a rate of 1° per day so as to remain roughly perpendicular to the Earth-Sun line, and the *FIRAS* always looks away from the Earth at an angle of $91 - 94°$ from the Sun. A brief *FIRAS* mission timeline is given in Table 3.1 and Table 3.2.

As the *COBE* orbits the Earth, the *FIRAS* line of sight traces a path on the sky along a line of approximately constant ecliptic longitude. Each interferogram is a measurement of a certain swath along this line, whose width is equal to the 7° beamwidth of the instrument. The length of the swath is slightly greater than the beamwidth because of the observing time and the movement of the beam at a rate of 3.5° per minute. To organize the data, we divide the sky into 6144 equal area pixels (Figure 10.3). These are formed by constructing a cube with each face divided into $32 \times 32 = 1024$ squares, projected onto a circumscribed celestial sphere in ecliptic coordinates. The projection is adjusted to form equal area pixels having a solid angle of $4\pi/6144$ sr or 6.7 square degrees (Chan and O'Neill 1975). Because the 7° beamwidth of the sky horn is greater than the separation between pixels (2.6° average), this binning oversamples the sky.

As the *FIRAS* scans a circle almost perpendicular to the Sun direction, the coverage of the sky near the ecliptic poles is highly redundant, with some pixels being observed over a period of months. Conversely, pixels near the ecliptic plane are only observed during a two to five day period as the precessing orbit moves past them. After a six month interval *FIRAS* again scans over the same ecliptic longitudes, thereby providing redundant coverage at two widely separated epochs. Table 3.3 gives sky coverage information.

The incomplete sky coverage has two primary causes. The first cause is the 3-day calibration periods (when the XCAL filled the sky horn) that were not "made up" six months later. For the first nine months of the mission calibration periods were timed to coincide with lunar apparitions every 29 days, when contamination by lunar thermal emission where the Moon was within 22° of the horn would have meant that the sky data could not have been used. For the last six weeks of the mission the calibration periods were made shorter and more frequent, amounting to 50% of the data taken during this period.

The second cause of coverage gaps was the deliberate suspension of operation of the MTM during passage through the South Atlantic Anomaly (SAA). For the first month of the mission particle hits on the electronics caused repeated MTM malfunctions during SAA passages, when the drive motor would continue to run after the MTM had run into a stop

Table 3.1: *FIRAS* Mission Timeline

Start Time*	Stop Time	Event
893221435		*COBE* Launch
893251118		Aperture cover ejection
893261130		*FIRAS* first light
893280000		ICAL first nulled against sky
893400706		MTM toggles SS/LF scan modes
893430152		MTM held in stowed position in SAA
893531121	893552154	Calibration 1
900181432	900200255	Calibration 2
900190205		Horns commanded from 2.7 K to 2.75 K
900471432	900490255	Calibration 3
900770937	900791721	Calibration 4
900800115		MTM turned off in SAA
900810409	900840223	Galactic center crossing
901071048	901101923	Calibration 5
901290000		Start of eclipse season
901351311	901382338	Calibration 6
901391535		Horns commanded from 2.75 K to 6.0 K
901391535	901931849	6.0 K horn period
901710148		MTM SF scan mode replaced LF scan mode
901801348	901811408	Calibration 7
901931850		Horns commanded from 6.0 K to 4.0 K
901931850	902071103	4.0 K horn period
902070000		End of eclipse season
902071104		Horns commanded from 4.0 K to 2.75 K
902071104	902081119	Hot sky horn test
902141500		MTM SF scan mode discontinued
902141505	902200609	Calibration 8

*The format of the timetags is YY-DDD-HH-MM.

Table 3.2: *FIRAS* Mission Timeline, Continued

Start Time	Stop Time	Event
902200508		XCAL commanded to 2.75 K in stow
902250110		ICAL temperature toggles discontinued
902271352	902291408	Minical 1
902311344	902341455	Minical 2
902361428	902391638	Minical 3
902411552	902441356	Minical 4
902461300	902481604	Minical 5
902501540	902532300	Calibration 9
902540519	902590834	Galactic center crossing
902561414	902571040	Minical 6
902591016	902621026	Minical 7
902640949		Cryogen depletion

Table 3.3: *FIRAS* Sky Coverage

(all channels and scan modes)	
Number of pixels covered	6067 of 6144
Fractional sky coverage	99%
Total number of interferograms	1,173,514
Maximum number of IFGs in a pixel	3,433*
Minimum number of IFGs in a pixel	1
Average IFGs per pixel	191

*Maximum occurs in Pixel 5545, at ecliptic coordinates (longitude,latitude) = (135.0,-84.5) at the end of its stroke. The power dissipated as a result of these “end-of-travel” events would cause a spike in the helium bath temperature, resulting in poor quality data until the bath temperature had stabilized (typically after several minutes). One month after launch, operations were changed to force the MTM into a stowed position while in the SAA, thus minimizing the occurrence of the “end-of-travel” events. Three months later a further improvement was made when the MTM was powered off altogether during SAA passages.

Finally, the coverage gaps are due in small part to the North polar ecliptic “hole” caused by unstable horn temperatures during the eclipse period of the mission, when heating caused by the earth limb occurred.

Throughout the mission, the state of the *FIRAS* was cycled to minimize systematic errors. The scan speed of the MTM was toggled between slow and fast every other orbit to allow instrumental errors to be distinguished from sky signals. At the same time the scan length of the MTM was toggled between short and long to provide higher spectral resolution (at the expense of signal to noise). In addition, the temperature of the ICAL was toggled between a “sky null” setting to a setting 12 mK hotter every $3-4$ days to allow instrumental gain errors to be distinguished.

Table 3.4 gives the percentage of sky data taken in each scan mode over various periods of the mission. Because the LS scan mode was the most susceptible to MTM problems, it was not used after day 89343. The calibration data is 67.7% SS scan mode, 9.3% SF, and 23.0% LF. No calibration data were taken in the LS scan mode.

Table 3.4: *FIRAS* MTM Scan Modes

Time Period	SS	SF	LS	LF	All
8932611-8934301	11.1	45.4	27.4	16.1	5.2
8934301-9013915	40.7			59.3	61.9
9013915-9019318	40.6	27.6		31.7	16.6
9019318-9020711	38.3	61.7			5.9
9020711-9020811	100.0				0.1
9020811-9022004	32.5	67.5			2.6
9022005-9026409	97.8			2.2	7.8
Entire Mission	43.3	12.3	1.4	43.0	100.0

As discussed above, the *FIRAS* was calibrated photometrically on a monthly schedule in the early mission and then weekly toward the end. These calibrations are denoted as Calibration $1-9$ and Minical $1-7$ in Table 3.1. Calibration of the *FIRAS* was done by moving the XCAL into the sky horn and then adjusting the temperatures of four bodies: the XCAL, the ICAL, the sky horn, and the reference horn. The temperatures were adjusted over a range of $2 - 22$ K. The detector bias was also changed to verify the detector model parameters.

Because the *FIRAS* bolometers can operate effectively only below 2 K, the *FIRAS* was switched off when the 600 liter liquid helium supply was depleted after 10 months. During this time, the *FIRAS* scanned the sky 1.7 times.