The *COBE* FIRAS Project Pipeline Software System

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ABSTRACT

The Far Infrared Absolute Spectrophotometer (FIRAS) on *COBE* was designed to measure extremely small deviations of the cosmic microwave background radiation (CMBR) from a blackbody spectrum. The data, taken by a rapid scan polarizing Michelson interferometer, cover a frequency range of 1 to 100 cm^{-1}. Data are taken by four detectors, two at 1 to 20 cm^{-1} and two at 20 to 100 cm^{-1}, at two stroke lengths and two scan speeds of the mirror transport mechanism. The two low frequency detectors are used for CMBR and cosmological studies. The two high frequency detectors are used for study of the galactic plane. On orbit calibration is performed with a movable, high precision, external blackbody calibrator. The FIRAS Project Pipeline (Figure I) is a complex software system which takes the time ordered, raw interferograms (IFGs) and produces skymap data sets of calibrated spectra. The pipeline software is designed to handle unique problems such as the asynchronous relation of science and engineering data. The software is designed so that intermediate products can be created for analysis and validation purposes.

Subject headings: COBE, software system, FIRAS, infrared, cosmic microwave background, spectroscopy, cosmology

1. Preliminary Processing and Quality Checking

The Preprocessor is the first program in the pipeline processing of FIRAS data. Its primary function is to compute the midpoint of the collection time of the IFGs. Because science data from the detector are transmitted from the spacecraft asynchronously with engineering and instrument state data, the latter must be correlated with the science data. An IFG is valid only if status data remain constant during the entire IFG collection. The program reports telemetry gaps, finds the engineering and instrument state data associated in time with the science data, and extracts the stroke length, scan speed, and status data. Using the extracted data, the Preprocessor computes the midpoint of collect time and flags anomalous results.

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The Data Qualify Program sets quality flags which are used to make the primary decision on whether the raw IFG record will be passed on to the remainder of the pipeline for further processing. This program is designed to handle unique problems such as the asynchronous relation of each detector's data to the engineering data and the correlation of the FIRAS line-of-sight with the observation. Using the midpoint of collect time, derived attitude parameters are computed from the line-of-sight. The science records are aligned between two bracketing housekeeping records for interpolation followed by conversion to engineering units. Sets of the four detector IFGs are associated with the engineering data and engineering statistics are computed by orbital period. Finally, the program performs limit checking on engineering and attitude parameters and sets quality flags accordingly.

2. Averaging of the Data for Calibration and Sky Branches

After the data quality checking, the FIRAS Pipeline splits into two processing streams; one stream is for calibration and the other for sky data. Both branches of data feed back into the program which does the averaging.

During calibration, commands were sent to set and control several components of the instrument at temperatures over a range of 2 deg to 25 deg K. The Extract Calibration Program identifies time ranges during which the temperatures remain within a specified tolerance for time-ordered groups of calibration IFGs. In contrast, the sky data must be rearranged into groups of IFGs from the same location in the sky so that the data can be averaged. Sky IFGs have been binned into 6144 pixels in the sky using a quadrilateralized spherical cube format. Data are sorted by pixel, scan mode and internal calibrator temperature. Other optional selections are available based on galactic latitude, position within the *COBE* orbit, and whether associated engineering data meet specified criteria.

Ensembles of IFGs are averaged to improve signal-to-noise. The Average Data Program performs this function separately for both sky and calibration data. Ensembles of IFGs are checked

Fig. 1.— The *COBE* FIRAS Project Pipeline Software System

for consistent shapes and instrument states. Following this, a pattern-recognition technique is used to remove cosmic ray hits on the detectors. All IFGs in the ensemble which pass the consistency checks are averaged and a quartic baseline is fitted and subtracted. This is the first skymap data set (Figure II). Weights and covariance matrices are calculated for statistical purposes. Several intermediate products are created at this stage of the pipeline. Templates made from midaveraging the IFGs can be used to study contributions of galactic gas and dust. Analysis of residual IFGs can demonstrate that cosmic ray effects are successfully removed.

3. Calibration

The FIRAS calibration model is composed of a detector model used to convert the spectra from volts to ergs/sec and an optical model defined by a set of complex emissivities that characterize the thermal emission of various components of the instrument. The Make Instrument Models Program solves iteratively for the calibration model using a polytopic search algorithm. Input to the program consists of the averaged calibration data and laboratory measured values for the detector parameters. Detector parameters and emissivities are varied to minimize the least square differences between calibrated spectra and Planck curves for the instrument component temperature. For each of the detectors and instrument scan modes, a corresponding model solution is produced.

The Calibrate Spectra Program uses the calibration models to produce monthly calibrated spectra from either the sky-averaged or calibration-averaged IFGs. Rotation about the peak position, followed by apodization and a Fourier transform, creates the spectrum, which is then normalized by the electronics transfer function. The detector responsivity and time constant for the spectrum are computed from the bolometer parameters and the detector temperature and voltage. Finally, the program applies the calibration model to the spectra. This is the second skymap data set (Figure II).

FIRAS observes each part of the sky twice a year. In order to have a final product of a single

Fig. 2.— Averaged Sky Interferogram and Calibrated Sky Spectrum

calibrated spectrum for each scan mode and pixel in the sky, the Combine Monthly Sky Spectra Program uses a statistical weighting scheme to combine the monthly spectra.

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