Explanatory Supplement of the Far-Infrared Line Mapper (FILM) on board the Infrared Telescope in Space (IRTS)

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1. INTRODUCTION

The Far-Infrared Line Mapper (FILM) is one of the focal-plane instruments on board the Infrared Telescope in Space (IRTS). The design and overview of the IRTS mission was described by Murakami et al. (1994, 1996). The design of the FILM is explained by Shibai et al. (1994). Here, we explain the data reduction procedure for the archived data set as well as detailed information of the FILM instrument necessary for data analysis.

2. THE FILM INSTRUMENT

The FILM is a grating spectrometer. The grating is a specially made, varied line-space, cylindrically concave reflection grating, and the detectors are stressed and unstressed Ge:Ga photoconductors (see Figure 1). The FILM has four detector channels. The channel 2 and 4 are for the [CII] 158 micron and [OI] 63 micron line measurement, respectively. The channel 1 and 3 are for 155 micron and 160 micron continuum emission measurement, respectively.

At this moment (December 3, 2002), the intensity maps of 155 micron continuum emission and the [CII] 158 micron line emission are available for public. The basic parameters of the data are listed in Table 1.

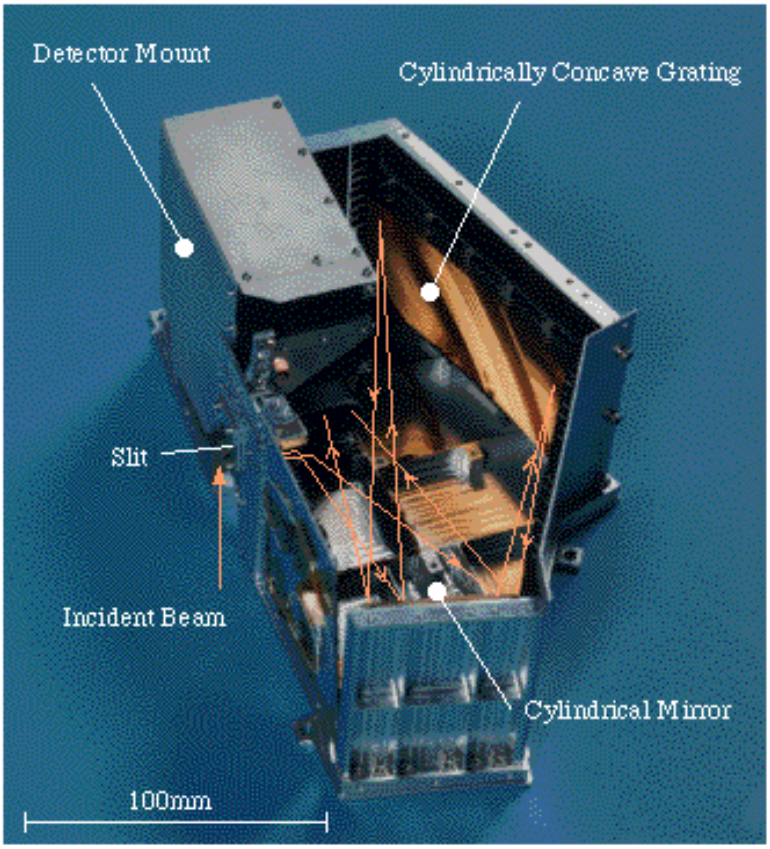

Fig. 1. FILM Optics View

Table 1. Basic parameters of the FILM archive data

Data Number			**1**	**2**
Data			**155 □m Continuum**	**[CII] Line**
Band Center		(cm^{-1})	64.4	63.4
		(μm)	155.3	157.7
Resolution		(cm^{-1})	0.495	(0.155)
		(μm)	1.19	(0.386)
Resolving Power			130	(409)
Beam Size (FWHM)			8' × 13' (scanning direction)×(cross-scanning direction)	
System NEP		$W \cdot Hz^{-1/2}$	1.8×10^{-16}	6.0×10^{-17}
Target			Continuum	[CII] Line
RMS Noise	in $\nu \cdot I_\nu$	$W \cdot m^{-2} \cdot sr^{-1}$	2×10^{-7}	3.5×10^{-9}
(without stripe noise)	in I_ν	$MJy \cdot sr^{-1}$	10	
Uncertainty in Zero Level	in $\nu \cdot I_\nu$	$W \cdot m^{-2} \cdot sr^{-1}$	6×10^{-7}	3×10^{-10}
(including stripe noise)	in I_ν	$MJy \cdot sr^{-1}$	30	
Uncertainty in Intensity Scale			-19% to +26%	
Pixel Size			4'×4'	4'×4'
Number of Pixel			192×192	192×192
Image Size			12.8°×12.8°	12.8°×12.8°
Uncertainty in Map Position			4'-8'	4'-8'

2. OPERATION

(To be filled)

3. Data Products

The FILM has two line channels ([CII], [OI]) and two continuum channels (155, 160 microns). However, the data qualities of the two channels of [OI] and 160 micron are worse than those of the other two channels due to excess noises and unpredicted behavior. Therefore, the data reduction effort was concentrated into the better two channels, [CII] and 155 micron.

3-1. Image Selection

The surveyed sky area on the Galactic coordinate is shown in figure 2. The area is splitted into two belts, the north scan and the south scan as is shown in figure 3. One can select a sky area to get images there. Preview images of the 155 micron continuum (figure 4) and the [CII] line (figure 5) are available as image files. If one needs to have quantitative data or if one needs to make image processing by himself, one can download fits files (see figures 6 and 7). This set of the fits files consist of the image data itself and the axiliary files, such as, error maps, sample number maps, etc, described bellow.

3-2. Data Format

All data files of images are given in simple FITS format files and are drawn on gnomonic projection of the galactic coordinate. The size of the images is 12.8 × 12.8 degrees with 4' pixels (192 × 192 pixels). Synopsis files are available for short explanation of both data sets (see Appendixes 2 and 3).

3-3. Continuum maps

Five kinds of files are available for each sky area.

(1) film-155-ns/ssXX-raw.fits (ns/ssXX_filmc1_flux.fits)

Average intensity images at 155 micron in W m^{-2} sr^{-1}. Color correction procedures did not carry out for the data, because the FILM 155 micron observation was the narrow-band photometry.

(2) film-155-ns/ssXX-err.fits (ns/ssXX_filmc1_error.fits)

Standard deviations of the mean of the pixel.

(3) film-155-ns/ssXX-smp.fits (ns/ssXX_filmc1_no.fits)

The number of observations in pixel.

(4) film-155-ns/ssXX-intp.fits (ns/ssXX_filmc1_flux_intp.fits)

Average intensity and interpolated intensity data. The index of the interpolation procedure is described in files (E)

(5) film-155-ns/ssXX-flag.fits (ns/ssXX_filmc1_flag_intp.fits)

The number of the interpolation index for the files (D). The indexes are as follows:

0: original average intensity.
1: linearly interpolated from the nearest non-bad pixels within 3×3 box.
2: non-linearly interpolated from the nearest non-bad pixels within 5×5 pixel circle.
3: non-linearly interpolated from the nearest non-bad pixels within 7×7 pixel circle.

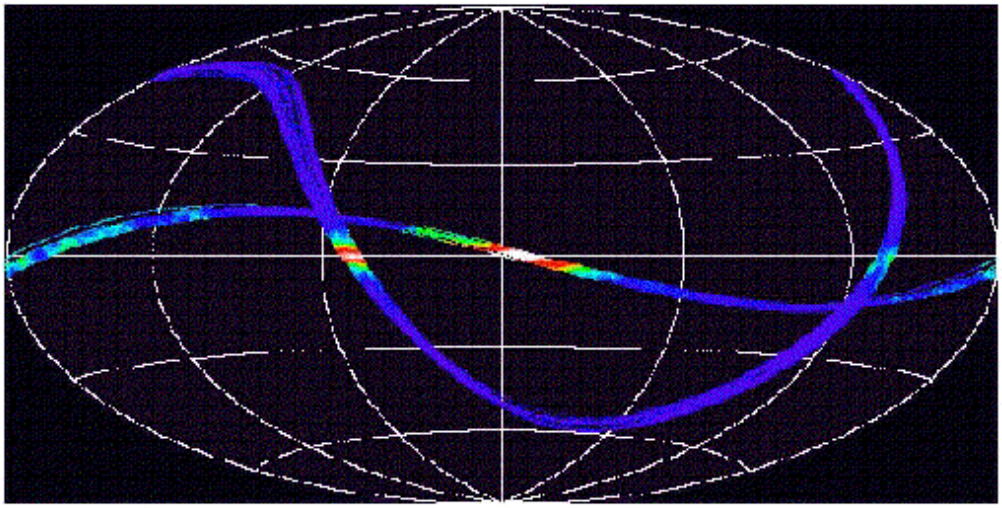

Fig. 2. IRTS surveyed sky area in the Galactic coordinate

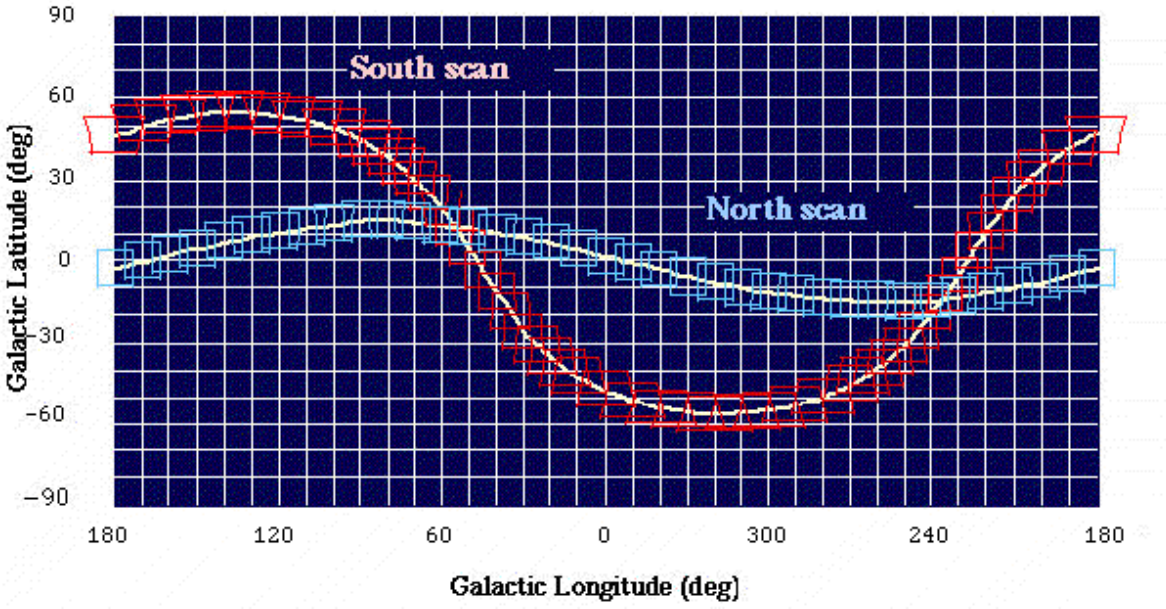

Fig. 3. Atlas for map selection

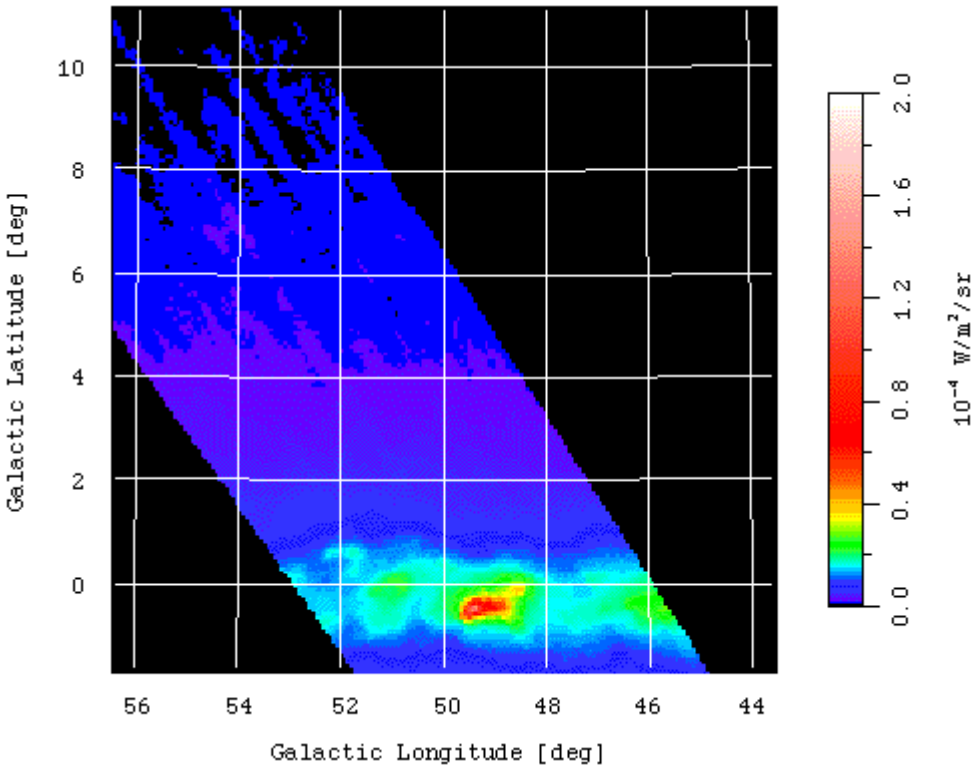

Fig. 4. 155 micron continuum intensity preview image near W51

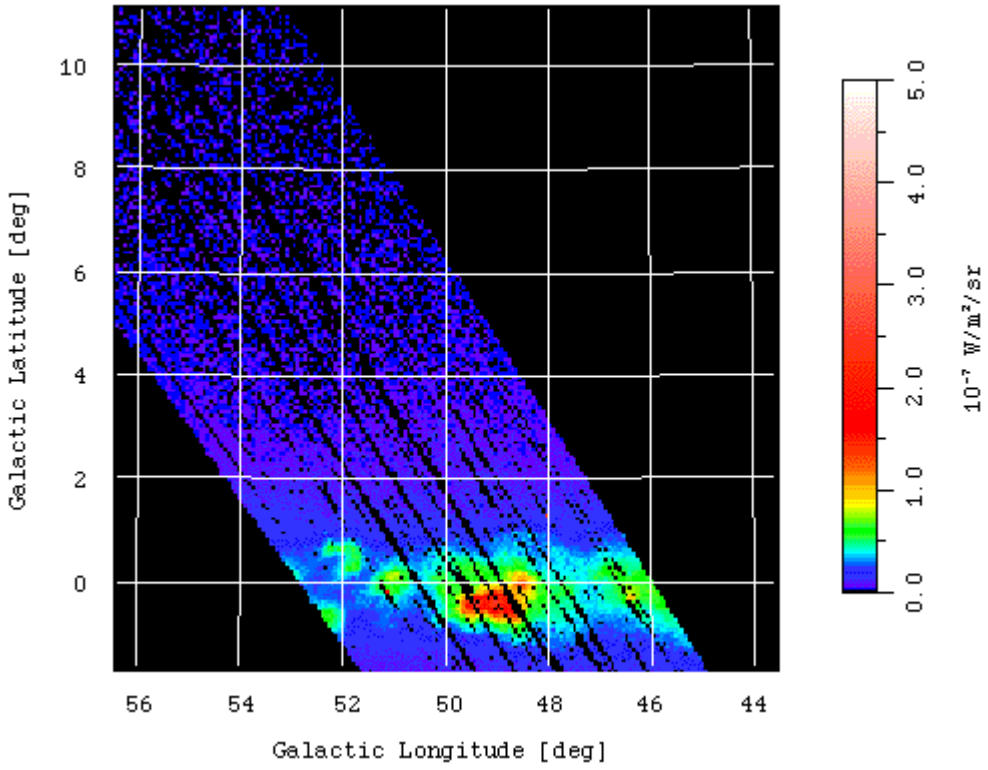

Fig. 5. [CII] 158 micron line intensity preview image near W51

Available Data Sets of FILM 155 Micron Continuum on SS18 Region

film-155-ss18-intp.fits
film-155-ss18-raw.fits
film-155-ss18-flug.fits
film-155-ss18-err.fits
film-155-ss18-smp.fits

See "Synopsis of FILM 155 micron Image Maps" to derive the information of these data.

Fig. 6. Image fits files of various processed quantities

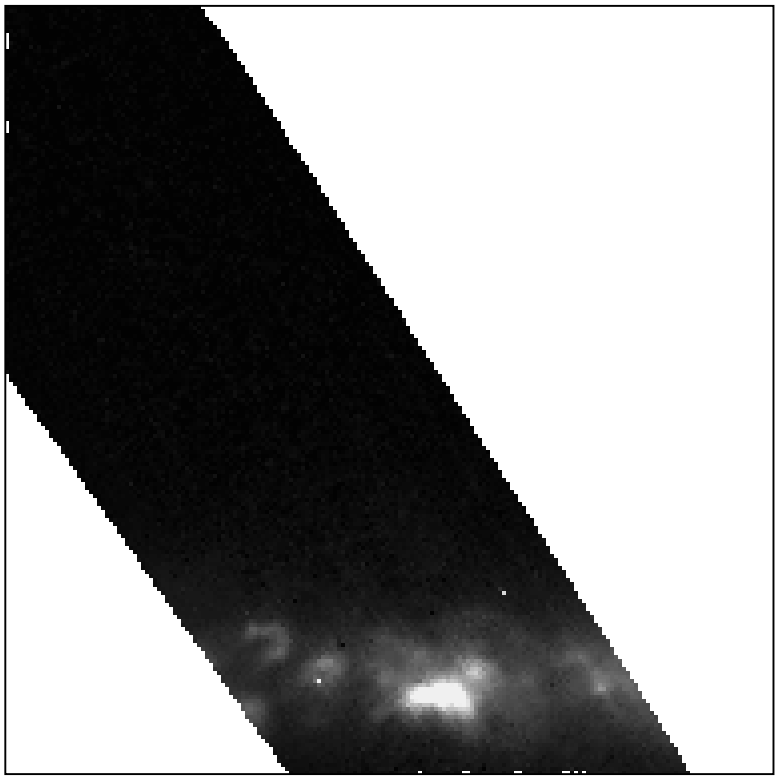

Fig. 7. 155 Micron Continuum Intensity Image Map of the same area of Fig. 4.

3-4. [CII] 158 micron maps

The following four maps are available for the [CII] 158 micron line intensity images.

(1) ??-??-??-raw.fits : [CII] line intensity map
(2) ??-??-??-err.fits : statistical error (1-sigma) map
(3) ??-??-??-smp.fits : map of sample number in a pixel
(4) ??-??-??-intp.fits : interpolated [CII] line intensity map

ex.) film-c2-ns01-raw.fits (ns=North-Scan, ss=South-Scan)-(Map Number)

4. DATA REDUCTION

Responsivity of the Ge:Ga detector has always fluctuated mainly owing to hitting of cosmic ray. Signals for the internal periodic calibrator lamp have acquired at certain intervals during the observation and slow components of responsivity fluctuations have been corrected by post flight analysis with those data. Most of fast fluctuation components by cosmic ray hits have removed.

As for the data reduction of the ch1 (155 micron continuum), the details of the processing are described in Okumura (1999).

The IRTS/FILM has a cold shutter at an entrance aperture, and it was closed during 8 seconds at certain intervals (1048 secconds period). The zero flux level for the [CII] line intensity was determined by using the mean values of the data while the shutter was closed. The zero flux level was stable during the whole observation perod.

5. ACCURACIES

5-1. Determination of the Dark (Zero) Level

The uncertainty of the zero level is less than 3×10^{-7} ergs cm^{-2} s^{-1} sr^{-1} for the [CII] line intensity. This value is remarkably small. However, it can still dominate the uncertainty in the estimation of high latitude [CII] line emission.

5-2. Intensity Scale

(1) 155 micron Continuum maps

The absolute intensity calibration of the 155 micron data was based on the pre-launch test of the internal calibration light. The uncertainty of the absolute intensity was estimated in the range from -19% to +26%.

The FILM has an internal calibrator lamp in order to calibrate and correct fluctuations of detector responsivity. Absolute calibration has been made independently from preflight experiments.

The typical rms error was 2×10^{-7} W m^{-2} sr^{-1} for the detector noise. In addition to this, there are stripe patterns in the in-scan direction in each FITS image. They are caused by the correction error for the change in the responsivity of FILM detectors, stressed Ge:Ga photoconductors.

(2) [CII] 158 micron maps

However, calibrated [CII] line intensity of the IRTS/FILM is different from results of other observations at present. We compared the independent observations of the IRTS/FILM and the balloon-borne telescope BICE (Nakagawa et al. 1998) for objects near the Galactic plane. The [CII] line intensity from the IRTS/FILM is about 65 % to 85 % (depending on intensity) compared to the BICE. It is also reported that the observation from the BICE is about 65 % compared to the COBE/FIRAS (Nakagawa et al. 1998; Bennett et al. 1994).

The levels of detector noise (statistical) were almost steady during the observation. Noise equivalent line intensity (1-sigma, 1/2sec integrated) is about 3.5×10^{-6} ergs cm^{-2} s^{-1} sr^{-1}.

5-3. Flux Scale

Pre-flight and onboard calibration were sucessfully made for the diffuse emissions descrived above. However, the calibration for point sources was not made well mainly due to the uncertainty of the beam size/pattern. The FILM has elongated ellipsoidal beam shape. Accoding to the mecahnical and optical design of the FILM hardware, the beam pattern must be rectangler with 8×20 arcminutes without diffraction. Even considering the diffraction, the beam patter n is expected to have the length of approximately 20 arcminutes. On the other hand, the measured beam pattern had only 13 arcminutes length in the cross-scanning direction both in the laboratory and on the orbit. Therefore, we adopted the measured beam pattern for the data reduction/analysis.

5-4. Position

The pointing information was determined using a star sensor (STS) instrument on board IRTS by collaborating with IPAC/NASA. The pointing accuracy obtained about within 1 arc-min. The position of the FILM was calculated as the distance between itself and the center of the IRTS was 1 degree. Since the distance has an uncertainty, a systematic pointing error may have crept into the FILM images within 4'-8'.

6. TIME-ORDERED DATA

A time-ordered data set is available, too. This dataset contains intensity, position in various cordinates, and status flags in a time-oedered manner during the observation. It is useful for one who wants to make custom size/resolution maps. If some need to use the time-ordered dataset, please contact tothe following address. The time-ordered dataset will be archived fully on the web, soon.

irts_help@ir.isas.ac.jp

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Appendix 1. Sample header of FITS files

```
SIMPLE  =                    T / Standard FITS format
BITPIX  =                   32 / 32 bit Integer
NAXIS   =                    3 / # of axes
NAXIS1  =                  192 / Number of positions along axis 1 for FILM
NAXIS2  =                  192 / Number of positions along axis 2 for FILM
NAXIS3  =                    1 / Number of positions along axis 3
BSCALE  =               01E-13 / TRUE=TAPE*BSCALE+BZERO
BZERO   =               00E+00 /
BUNIT   = 'W/m**2/sr'          / Intensity (DELTA-LAMBDA*I-LAMBDA) for line
BLANK   =          -2147483647 / Tape value for empty pixel
CTYPE1  = 'GLON-TAN'           / Galactic longitude (Gnomonic projection)
CRVAL1  =           5.0000E+01 / L at origin (degree)
CRPIX1  =                   96 / Sample axis origin (pixel) for FILM
CDELT1  =         -6.66666E-02 / Coord value incr deg/pixel for FILM
CTYPE2  = 'GLAT-TAN'           / Galactic latitude (Gnomonic projection)
CRVAL2  =           4.7500E+00 / B at origin (degree)
CRPIX2  =                   96 / Line axis origin (pixel) for FILM
CDELT2  =          6.66666E-02 / Coord value incr deg/pixel for FILM
CTYPE3  = 'WAVE    '           / Wavelength of band center
CRVAL3  =            157.7E-06 / Wavelength in meters
CRPIX3  =                    1 /
CDELT3  =            3.856E-07 / Band width
CUNIT3  = 'm       '           / Unit of wavelength
DATAMAX =           2.5651E-07 / True value
DATAMIN =          -1.0010E-08 / True value
DATE    = '2001-03-10'         / Date tape written (YYYY-MM-DD)
DATE-MAP= '2001-03-10'         / Map creation date (YYYY-MM-DD)
DATE-BGN= '1995-03-29'         / IRTS mission start
DATE-END= '1995-04-25'         / IRTS mission end
ORIGIN  = 'ISAS    '           / Institution
TELESCOP= 'IRTS    '           /
INSTRUME= 'FILM    '           /
CHANNEL =                    2 / Channel number of each instrument
OBJECT  = 'SS-18   '           / (SS=South-Scan, NS=North-Scan)-(Map Number)
PROCESS = '03i     '           / FITS file version
VERSION = '0001    '           / IRTS_LAN (original data set) version
COMMENT   The IRTS/FILM [CII]-line intensity interpolated map
HISTORY
END
```

Appendix 2. Synopsis of FITS images of the IRTS/FILM 155 micron continuum data

1.FILM 155 micron continuum

This set of FITS files is the far-infrared continuum images at 155 micron, which were measured by the Far-infrared Line Mapper (FILM), one of the four focal plane instruments onboard the IRTS. The FWHM beam size of the FILM 155 micron continuum channel was a rectangular of 8' in the in-scan direction by 13' in the cross-scan direction. The spectrum resolution was 1.2 micron.

The data processing of the 155 micron data had been carried out by FILM members. The details of the processing were described by Okumura (1999). The obtained typical rms error was 2×10^{-7} W m^{-2} sr^{-1}. There are stripe patterns in the in-scan direction in each FITS image. They are caused by the correction error for the change in the responsivity of FILM detectors, stressed Ge:Ga photoconductors. The absolute intensity calibration of the 155 micron data was based on the pre-launch test of the internal calibration light. The uncertainty of the absolute intensity was estimated in the range from -19% to +26%.

The pointing information was determined using a star sensor (STS) instrument on board IRTS by collaborating with IPAC/NASA. The pointing accuracy obtained about within 1 arc-min. The position of the FILM was calculated as the distance between itself and the center of the IRTS was 1 degree. Since the distance has an uncertainty, a systematic pointing error may have crept into the FILM images within 4'-8'.

2. FITS image files

All data files are given in single FITS formats and are drawn on gnomonic projection with the galactic coordinate. The size of the images is 12.8 × 12.8 degrees with 4' pixels (192 × 192 pixels). Five kinds of FITS file are produced as follows (A--E).

A. film-155-ns/ssXX-raw.fits (ns/ssXX_filmc1_flux.fits)

Average intensity images at 155 micron in W m^{-2} sr^{-1}. Color correction procedures did not carry out for the data, because the FILM 155 micron observation was the narrow-band photometry.

B. film-155-ns/ssXX-err.fits (ns/ssXX_filmc1_error.fits)

Standard deviations of the mean of the pixel.

C. film-155-ns/ssXX-smp.fits (ns/ssXX_filmc1_no.fits)

The number of observations in pixel.

D. film-155-ns/ssXX-intp.fits (ns/ssXX_filmc1_flux_intp.fits)

Average intensity and interpolated intensity data. The index of the interpolation procedure is described in files (E)

E. film-155-ns/ssXX-flag.fits (ns/ssXX_filmc1_flag_intp.fits)

The number of the interpolation index for the files (D). The indexes are as follows:

0: original average intensity.

1: linearly interpolated from the nearest non-bad pixels within 3×3 box.

2: non-linearly interpolated from the nearest non-bad pixels within 5×5 pixel circle.

3: non-linearly interpolated from the nearest non-bad pixels within 7×7 pixel circle.

3/Mar/2001 By K. Okumura

Appendix 3. Synopsis of FITS images of the IRTS/FILM [CII] 158 micron data

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IRTS/FILM [CII] 158-micron Line Channel (ch.2) Map

synopsis ver.2 31 January 2001

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1. Data Sets (Image map files)

Four kinds of image maps are provided as below. Each map covers 12.8 × 12.8 degrees with pixel size of 4 arcmin (consequently 192 × 192 pixels for a map). Line intensities are averaged in each pixel. Coordinate system is the Galactic on gnomonic projection. An interpolated image may be convenient to take a general view of a map.

(1) ??-??-??-raw.fits : [CII] line intensity map
(2) ??-??-??-err.fits : statistical error (1-sigma) map
(3) ??-??-??-smp.fits : map of sample number in a pixel
(4) ??-??-??-intp.fits : interpolated [CII] line intensity map

ex.) film-c2-ns01-raw.fits (ns=North-Scan, ss=South-Scan)-(Map Number)

2. The FILM Instrument

The Far-infrared Line Mapper (FILM) onboard the IRTS is the far-infrared spectrometer. The detector of the FILM is Ge:Ga photoconductor (Hiromoto et al. 1992). It observed the [CII] 158 micron line and FIR continuum (155 micron; see another document for ch.1). Detailed information of the instrument is described in other documents and references shown below.

Instrument Summary

Detector : stressed (for [CII] line) and unstressed (for continuum) Ge:Ga photoconductor
Beam Size : 8 arcmin (dispersion direction) × 13 arcmin (FWHM)
Grating : a varied line-space cylindrically concave grating
Resolving Power : 409 for the [CII] line channel and 130 for the continuum channel

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3. Calibration

The FILM has an internal calibrator lamp in order to calibrate and correct fluctuations of detector responsivity. Absolute calibration has been made independently from preflight experiments. However, calibrated [CII] line intensity of the IRTS/FILM is different from results of other observations at present. We compared the independent observations of the IRTS/FILM and the balloon-borne telescope BICE (Nakagawa et al. 1998) for objects near

the Galactic plane. The [CII] line intensity from the IRTS/FILM is about 65 % to 85 % (depending on intensity) compared to the BICE. It is also reported that the observation from the BICE is about 65 % compared to the COBE/FIRAS (Nakagawa et al. 1998; Bennett et al. 1994).

4. Responsivity

Responsivity of the Ge:Ga detector has always fluctuated mainly owing to hitting of cosmic ray. Signals for the calibrator lamp have acquired at certain intervals during the observation and slow components of responsivity fluctuations have been corrected by post flight analysis with those data. Most of fast fluctuations components by cosmic ray have removed.

5. Zero Flux Level

The IRTS/FILM has a cold shutter at an entrance aperture, and it was closed at certain intervals. The zero flux level for the [CII] line intensity was decided by those data. The zero flux level might be dominant uncertainty for estimation of high latitude [CII] line emission that is very weak. The zero flux level was stable on the whole. An accuracy estimated from the uncertainty in decision of the zero level is less than 3×10^{-7} erg cm^{-2} s^{-1} sr^{-1}.

6. Detector Noise Level

The levels of detector noise (statistical) were almost steady during the observation. Noise equivalent line intensity (1-sigma, 1/2sec integrated) is about 3.5×10^{-6} erg cm^{-2} s^{-1} sr^{-1}.

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