

Software Interface Specification for the Venus Climate Orbiter Akatsuki Longwave Infrared Camera Data Products

Version 1.0

June 13, 2024

Prepared by

Makoto Taguchi¹, Toru Kouyama², Shin-ya Murakami³, Armin Kleinböhl⁴

- 1 Rikkyo University
- 2 Advanced Industrial Science and Technology
- 3 Japan Aerospace Exploration Agency
- 4 Jet Propulsion Laboratory, California Institute of Technology



Table of Contents

Change Log.....	iii
Acronyms and Abbreviations	1
1 Purpose and Scope of Document.....	1
2 Applicable Documents	1
3 Data Product Characteristics and Environment	2
3.1 Instrument Overview	2
3.1.1 Instrument Layout.....	2
3.1.2 LIR operational modes	4
3.2 Onboard Data Processing	5
3.2.1 Processing Approach.....	5
3.2.2 Observation Programs	6
3.2.3 Observation Geometry.....	6
3.3 Data Product Overview.....	7
3.4 Data Processing.....	8
3.4.1 Data Processing Level.....	8
3.4.2 Data Product Generation	9
3.4.3 Data Flow	26
3.4.4 Labeling and Identification.....	26
3.5 Standards Used in Generating Data Products	29
3.5.1 PDS Standards	29
3.5.2 Time Standards	29
3.5.3 Coordinate Systems.....	29
3.5.4 Data Storage Conventions.....	31
3.6 Data Validation	31
3.7 Data Quality and Coverage	31
3.8 Relation to other datasets	33
4 Detailed Data Product Specifications	34
4.1 Data Product Structure and Organization	35
4.2 Data Format Descriptions	35
4.2.1 Level 1b - Raw Image Data	35
4.2.2 Level 2b, Level 2c, and Level 2d – Calibrated Image Data	46
4.2.3 Level 3d – Longitude-Latitude Map Data.....	47
4.2.4 geometry - Geometry Data	51
4.2.5 Calibration Data.....	51
4.3 Label and Header Descriptions.....	54
5 Applicable Software	54
5.1 Utility Programs	54
5.2 Applicable PDS Software Tools.....	54
5.3 Software Distribution and Update Procedures	54
6 Appendices.....	55
6.1 References	55
6.2 Definitions of Data Processing Levels	55
6.3 List of different primary files between PDS3 datasets and this bundle	56

Change Log

DATE	CHANGE	AFFECTED SECTIONS
2015-11-27	Initial Draft	All
2016-03-31	Ver. 0.2	5.2
2016-10-21	Ver. 0.4	All
2017-01-25	Ver. 0.5	5.1, 5.2
2017-02-08	Ver. 0.6	5.2, Figure 4
2017-02-13	Ver. 0.7	5.2
2022-11-18	Ver. 0.8	All
2024-02-09	Ver. 0.9	All
2024-02-22	Ver. 1.0 draft	Table 10
2024-06-13	Ver. 1.0	All

Acronyms and Abbreviations

Acronym/Abbreviation	Definition
A/D	Analog to Digital
ADU	Analog-digital unit
ASCII	American Standard Code for Information Interchange
CK	Orientation or Attitude kernel (“C-Matrix” kernel)
C-SODA	Science Satellite Operation and Data Archive Unit (original name of the department is Center for Science-satellite Operation and Data Archive)
CSV	Comma Separated Values
DANS	Data Analysis Network System
DARTS	Data Archives and Transmission System
DE	Digital Electronics
DN	Digital Number
DR	Data Recorder
DSV	Delimiter Separated Values
EDISON	Engineering Database for ISAS Spacecraft Operation Needs
ETI	Extended Time Indicator
FITS	Flexible Transport Image System
FK	Frames kernel
FOV	Field Of View
FWHM	Full Width Half Maximum
HDU	Header Data Unit
HK	House Keeping (packet)
IAU	International Astronomical Union
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IFOV	Instantaneous Field Of View
IK	Instrument kernel
IPDA	International Planetary Data Alliance
IR1	1-micron Camera
IR2	2-micron Camera
ISAS	Institute of Space and Astronautical Science
JAXA	Japan Aerospace Exploration Agency
JPEG	Joint Photographic Experts Group
LAC	Lightning and Airglow Camera
LIR	Longwave Infrared Camera
LSK	Leapseconds kernel
MTF	Modulation Transfer Function
NAIF	Navigation and Ancillary Information Facility
NaN	Not a Number

Acronym/Abbreviation	Definition
N/A	Not Available or Not Applicable
NetCDF	Network Common Data Form
NETD	Noise-Equivalent Temperature Difference
OFFPN	On-chip Fixed Pattern Noise
PCK	Planetary Constants kernel
PDS	Planetary Data System
PSF	Point Spread Function
ROI	Region of Interest
RS	Radio Science
S/C	Spacecraft
SCLK	Spacecraft Clock Kernel
SIRIUS	Scientific Information Retrieval and Integrated Utilization System
SIS	Software Interface Specification
S/N	Signal to noise (ratio)
SPICE	Spacecraft, Planet, Instrument, C-Matrix, Events
SPIDAr	SPICE and Data Archive (team)
SPK	Ephemeris data kernel
TI	Time Indicator
UMBA	Uncooled Micro-Bolometer Array
UTC	Coordinated Universal Time
UVI	Ultraviolet Imager
VCO	Venus Climate Orbiter
VOI	Venus Orbit Insertion
XML	Extensible Markup Language

1 Purpose and Scope of Document

The purpose of this Data Product Software Interface Specification (SIS) is to provide users of the raw, calibrated, and derived data products from the Venus Climate Orbiter (VCO) Akatsuki Longwave Infrared Camera (LIR) with a detailed description of the products, and a description of the product generation procedures, including data sources and destinations. The products defined in this document are raw image, calibrated image, and derived map data products. The products are generally of Venus but may be of other targets of opportunity.

The SIS is intended to provide enough information to enable users to read and understand the LIR data products as stored in the Data Archives and Transmission System (DARTS) and the Planetary Data System (PDS). The users for whom this SIS is intended are software developers of the programs used in generating the LIR data products and scientists who will analyze the data, including those associated with the Venus Climate Orbiter Akatsuki mission, LIR instrument, and those in the general planetary science community.

2 Applicable Documents

This SIS is consistent with the following Planetary Data System Documents as adopted by the International Planetary Data Alliance (IPDA):

1. Planetary Data System Standards Reference, Version 1.19.0, <https://doi.org/10.17189/02p7-vj89>, October 1, 2022.
2. PDS4 Data Dictionary – Abridged – Version 1.19.0.0, September 19, 2022.
3. PDS4 Information Model, Version 1.19.0.0, September 19, 2022.

This SIS makes reference to the following documents:

4. Taguchi, M., et al., Longwave Infrared Camera onboard the Venus Climate Orbiter, *Advances in Space Research*, **40**, 861-868, <https://doi.org/10.1016/j.asr.2007.05.085>, 2007.
5. Fukuhara, T., et al., LIR: Longwave Infrared Camera onboard the Venus Orbiter Akatsuki, *Earth, Planets and Space*, **63**, 1009-1018, <https://doi.org/10.5047/eps.2011.06.019>, 2011.
6. Fukuhara, T., et al., Absolute calibration of brightness temperature of the Venus disk observed by the Longwave Infrared Camera onboard Akatsuki, *Earth, Planets and Space*, **69**, 141, <https://doi.org/10.1186/s40623-017-0727-y>, 2017.
7. Ogohara, K., et al., Overview of Akatsuki data products: definition of data levels, method and accuracy of geometric correction, *Earth, Planets and Space*, **69**, 167, <https://doi.org/10.1186/s40623-017-0749-5>, 2017.
8. Taguchi, M., et al., In-orbit recalibration of Longwave Infrared Camera onboard Akatsuki, *Earth, Planets and Space*, **75**, 53, <https://doi.org/10.1186/s40623-023-01803-w>, 2023.
9. VCO Akatsuki FITS header keyword dictionary, Version 8.
10. VCO Akatsuki Observation Program List, Version 6.
11. VCO Akatsuki Level 3 Algorithm Description v01, 2019.

A complete list of the references is found at [Appendix 6.1](#).

3 Data Product Characteristics and Environment

3.1 Instrument Overview

3.1.1 Instrument Layout

Details of LIR are described in [Taguchi+2007](#) and [Fukuhara+2011](#). LIR is a single-band middle infrared imager which detects the wavelength range from 8 to 12 μm with the field-of-view covering $16.4^\circ \times 12.4^\circ$. LIR consists of a sensor unit LIR-S which manages the function of image acquisition, an external power supply unit LIR-AE which converts the primary electric power to several voltages to distribute them to a regulator and a mechanical shutter, and a baffle which keeps direct sunlight away from the optical aperture ([Figure 1](#)). A schematic of internal structure of LIR-S is shown in [Figure 2](#), and specifications of LIR are listed in [Table 1](#).

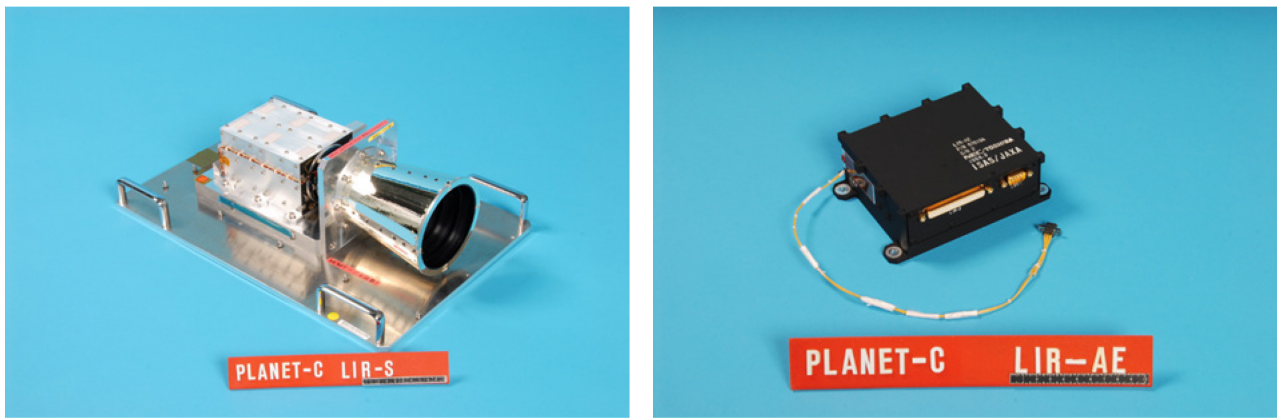


Figure 1 Photographs of the LIR sensor unit (left) and the LIR power supply unit (right).

The optics consists of germanium lenses, a mechanical shutter, and a bandpass filter. The bandpass filter is located at the pupil position of the optics. The pass band of bandpass filter targets the thermal emission from the cloud top over a rather wide wavelength range, corresponding to the spectral region that is most sensitive to temperature variation and least sensitive to variation in sulfur dioxide, which has an absorption band at 8 – 9 μm . In addition, a band of carbon dioxide exists in the wavelength region of 9.5 – 10.4 μm .

An uncooled micro-bolometer array (UMBA) (NEC 320A) with 328×248 effective pixels is used as an image detector ([Tanaka+2000](#)). [Figure 3](#) shows the shape of the spectral response function, which is a product of transmittance of the lens, the filter and the window of the bolometer package, and spectral response of the bolometer. The temperature of the detector is controlled by a thermoelectric cooler/heater (Peltier) module at 40 $^\circ\text{C}$ within 0.1 $^\circ\text{C}$ stability. The Peltier module is turned on at least 30 min before image acquisition to stabilize the temperature of the detector. The pixel field-of-view of 0.05 $^\circ$ /pixel corresponds to spatial resolution of 22 km and 69 km from distances of 4.2 R_V and 13 R_V , respectively ([Figure 2](#) in [Taguchi+2007](#)). A mechanical shutter driven by a stepping motor and two positioning sensors functions as a shield for direct solar radiation and also a calibration target.

Table 1 Specifications of LIR

Item	Value
Wavelength Range	8 – 12 μm
Instrumental Field-of-View	16.4° × 12.4°
Pixel Field-of-View	0.05°
Detector	Uncooled micro-bolometer array NEC 320A (anti-reflection coating)
Number of Pixels	344 × 260 (Number of effective pixels are 328 × 248)
Pixel Size	37 μm
Mass	3.5 kg
Power	29 W (nominal)
MTF (at Nyquist Frequency)	>0.5
F-number	1.4
Target Temperature Range	210 – 250 K
NETD	0.3 K at 230 K
Absolute Temperature Accuracy	3 K
A/D Converter	12 bit

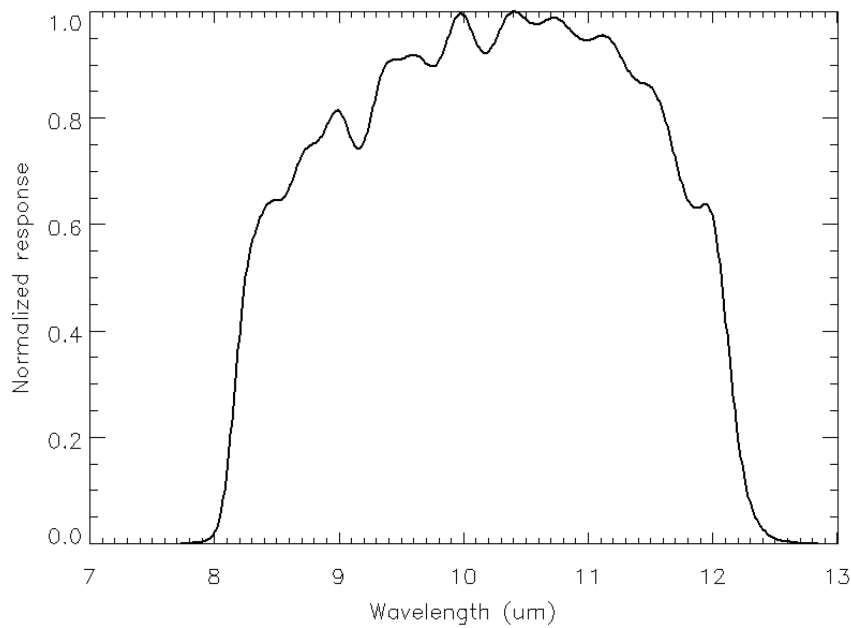


Figure 3 Normalized spectral response function of LIR. Taken from [Taguchi+2023](#).

3.1.2 LIR operational modes

LIR has six operational modes: Off, Stand-by, Protect, Idling, Parameter Setting, and Image modes, and a command to take an image can be accepted only during the Idling mode. When LIR receives the image acquisition command, LIR changes its operational mode to the Image mode. Before taking an image on-chip fixed pattern noise (OFPN) data are prepared in the LIR memory. The OFPN data are used to cancel the pixel-to-pixel non-uniformity in sensitivity and offset.

The shutter is basically closed in all modes except for Idling mode in order to avoid accidental exposure of the UMBA to direct solar radiation. The shutter surface facing to the UMBA is blackened by anodic oxidation to be a quasi-blackbody with an emissivity ~ 0.89 . Its temperature is kept at 27 to 30 °C and monitored at the resolution of 0.01 °C. Thus, a shutter image can be used as a temperature

reference for data analysis.

The primary data is thermal radiation through the applied filter that are measured as voltage with constant current by using temperature-dependent resistivity of the detector material. The measured voltages are converted using a 12-bit analog-to-digital converter, and are stored in digital counts. The resistivity is not proportional to the magnitude of thermal radiation in radiance or brightness temperature received at the detector (UMBA).

Signal readout values from the UMBA have large pixel-to-pixel differences in offset values. A pair of images is taken with the shutter close and open, and a thermal image is derived by subtracting the shutter image with shutter closed from the target image with shutter open so that the bias of each pixel is cancelled. This procedure is shown in Figure 4. LIR has been calibrated in the laboratory at target temperatures of every 10 K from 213 K (−60 °C) to 243 K (−30 °C), which covers the expected temperature of cloud-top of Venus. The calibration profiles are used for reference when brightness is converted to the brightness temperature through data processing at the ground station.



Figure 4 Examples of images obtained by LIR. (a) A raw target image, (b) a raw shutter image, and (c) the resultant image produced by subtracting the shutter image from the target image (Fukuhara+2011).

3.2 Onboard Data Processing

3.2.1 Processing Approach

Output digital signals from the detector of LIR are stored as 16-bit signed data. Raw target and shutter image data at a rate of 60 Hz are accumulated in order to improve signal-to-noise ratio (first or primary accumulation); the number of accumulations is defined as “ m .” After acquiring both target and shutter images, subtraction between them is performed to create a thermal image. Up to 32 thermal images may be accumulated again to improve signal-to-noise ratio (secondary accumulation); the number of repetitions is defined as “ n .” The best noise-equivalent temperature difference (NETD) is achieved when $m = 32$ and $n = 32$ based on experiments before launch. Digital Electronics (DE) in the spacecraft process the first and second accumulations. Then, the averaged image is stored in a data recorder and subsequently sent to the ground station.

Observation by Akatsuki is conducted by command from the ground. All observations by UVI, IR1, IR2, and LIR are done through an execution of an observation program. By executing the observation program, a sequence of image acquisitions and onboard image processing is executed. The observation program is identified by an observation program identifier (ID). The complete list of observation program IDs is described in [VCO Akatsuki Observation Program List](#). The last part of the sequence of the observation program is the compression of images and the storage of compressed images on the Data Recorder (DR). This part is described as follows: the LIR image stored to memory on DE as signed 16-bit integer after onboard image processing is converted to unsigned 16-bit integer by adding 32768 to increase compression ratio. The image is then divided into tiles where each tile has $128 \times$

128 pixels, and then each tile is compressed onboard using HIREW (also known as StarPixel Lossless algorithm; [Takada+2007](#), [Hihara+2015](#)). These compressed tiles, common ancillary data for the image, and instrument-specific ancillary data for the image are downlinked. These three kinds of files are called Level 0 (L0) data.

Data obtained before October 2016 show a rather large deviation in brightness temperature of background deep space ([Fukuhara+2017](#)). This is because LIR took an image before it was thermally stabilized after being turned on. From October 2016 onwards LIR has been always active to stabilize its internal temperature, and the deviation in brightness temperature has been improved.

3.2.2 Observation Programs

The nominal observation sequence uses repetitions of $n = 32$. It was prepared for the original orbit in order to achieve the best NETD and has been used since orbit insertion. However, an observation sequence of $n = 32$ with 120 s leads to blurring in the Venus disk image near periapsis because of the high relative velocity of the spacecraft and Venus. Thus, an observation program with $m = 32$ and $n = 1$ was additionally prepared for the periapsis observations. Venus images have been constantly acquired from the orbit near periapsis by using this observation program since October 2016. An overview over the major observation programs is given in [Table 2](#).

Table 2 Major observation programs for LIR

Observation name	Observation program ID	m	n	Instruments synchronously observing with LIR
LIR m=32, n=32	0x19_v1	32	32	–
LIR m=32, n=1	0x16_v2	32	1	–
Dayside deluxe	0x05_v1, 0x05_v2, 0x17_v2, 0x17_v3	32	32	UVI, IR1, IR2
Dayside slim	0x05_v3, 0x09_v5, 0x15_v4	32	32	UVI
	0x06_v2, 0x06_v3, 0x1f_v3			IR1, IR2
Nightside deluxe	0x01_v1, 0x01_v2, 0x0d_v4	32	32	IR2
Vicinity scan	0x1d_v2, 0x1d_v3	32	1	–
Vicinity deluxe	0x07_v1	32	32	UVI
	0x07_v3	32	1	
Vicinity slim	0x08_v3, 0x08_v4	32	1	UVI (365 nm \times 2)
Dayside vicinity scan	0x0c_v2, 0x0c_v3			UVI, IR1, IR2
Nightside vicinity scan	0x0b_v2, 0x0b_v3	32	1	IR2 (1.73, 2.26 μ m)
Limb	0x0a_v3	32	1	UVI, IR1, IR2

3.2.3 Observation Geometry

The spacecraft is in an equatorial orbit around Venus and the spacecraft +Y-axis points northward or southward in the celestial sphere. For convenient use of data analysis, the L1b, L2b, L2c, L2d, and geometry data products are all corrected for the orientation of the spacecraft as if the spacecraft +Y-axis (+Y_{sc}) were always up north. See an illustration shown in [Figure 5](#) when the spacecraft +Y-axis (+Y_{sc}) is up north in the celestial sphere. The first pixel (1, 1) is at the south-west corner with the rows to the east and the columns to the north directions, and the last pixel (328, 248) is at the north-east corner.

See [Section 3.5.3.3 Image for coordinate system used for the images and geometry products](#).

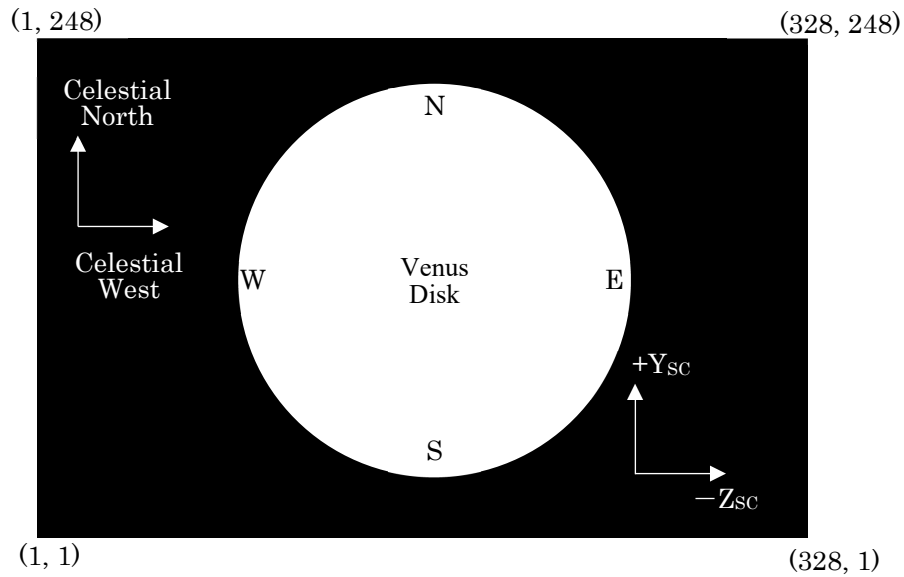


Figure 5 An illustration that shows orientation of Venus disk when the spacecraft +Y-axis points celestial north.

3.3 Data Product Overview

The LIR data products are raw, calibrated, derived mosaic images, and associated backplane data of Venus. The raw and the calibrated LIR image data are formatted natively as Flexible Transport Image System (FITS) data, with images stored as arrays, and metadata captured in the image headers. All metadata needed to use or interpret the images is duplicated in the PDS4 XML labels. The derived map data are provided in the FITS format with the BINTABLE extension which are converted from NetCDF files not included in this bundle.

The LIR data products are:

1. **LIR Raw Image Data Product:** Raw images that have been reassembled from downlinked telemetry with complete image metadata including instrument settings, states, and geometry.
2. **LIR Calibrated Image Data Product:** Images that have been calibrated into a physical brightness temperature unit (K) with complete image metadata including instrument settings, states in physical units, and corresponding observation geometry.
3. **LIR Derived Map Data Product:** Map image data that have been projected onto longitude-latitude grid.
4. **LIR Geometry Data Product:** Geometry data created for each pixel of Calibrated Image Data Product that include longitude, latitude, local solar time, and viewing geometry parameters (incident angle, emission angle, phase angle, and azimuthal angle). There are two kinds of data: one is calculated using VCO Akatsuki SPICE kernels without any modification, and the other is calculated using VCO Akatsuki SPICE kernels with a boresight correction based on a limb-fitting technique.
5. **LIR Calibration Data Product:** Calibration data that can be used for calibration, which were used for creating LIR Calibrated Image Data Product.
6. **LIR Browse Data Product:** Quick look images of other kinds of product.

3.4 Data Processing

This section of the SIS provides general information about data product content, format, size, and production rate. The specifics of the data product formats are discussed in [Section 4](#).

3.4.1 Data Processing Level

The definitions of the processing levels for the UVI, IR1, IR2, and LIR instruments are almost same for simplicity and homogeneity. The list of processing levels for LIR is shown in [Table 3](#).

Table 3 List of data processing levels and associated products

Processing level		Description of processing level	Created product	Product from which data is derived
Name	Abbr.			
Level 0	L0	Raw data files extracted from the telemetry.	L0 product	Telemetry
Level 1a	L1a	Raw data are stored to FITS file.	L1a product	L0 product
Level 1b	L1b	Raw data are flipped and rotated and geometry information is added to FITS header. Geometry information is calculated for each pixel and stored to another FITS file.	L1b product, L1b geometry product	L1a product, SPICE kernel
Level 2b	L2b	Raw data are converted to brightness temperatures with calibration.	L2b product	L1b product, calibration product
Level 2c	L2c	Raw data are converted to brightness temperatures with calibration including correction for radiation from instrument baffle.	L2c product	L1b product, calibration product
Level 2d	L2d	Raw data are converted to brightness temperatures with calibration including correction for radiation from instrument baffle and for long-term sensitivity degradation of the detector.	L2d product	L1b product, calibration product
Level 3d	L3d	Correction of pointing of the camera is performed using the limb-fitting technique and then longitude-latitude grid data is created by interpolation. Corrected geometry data product L3dx is also created as by-product.	L3d product, L3dx geometry product	L2d product, L1b geometry product, SPICE kernel

All data products in [Table 3](#) except for Level 0 and Level 1a products will be delivered to DARTS and PDS. [Table 4](#) describes the processing level of each product in both Akatsuki project terms and PDS4 terms. Definitions of the PDS4 processing levels can be found in [Appendix 6.2](#).

Table 4 LIR data products and their processing levels

LIR Product name in PDS4	LIR Product name with processing level	PDS4 Processing Level
Raw Image Data	L1b product	Raw
Calibrated Image Data	L2b, L2c, L2d products	Calibrated
Derived Map Data	L3d product	Derived
Geometry Data	L1b, L3dx geometry product	Derived
Calibration Data	–	Derived
Browse Data	–	–

3.4.2 Data Product Generation

The data processing is done on DANS (Data Analysis Network System) managed by C-SODA (Science Satellite Operation and Data Archive Unit), ISAS/JAXA at Sagamiara, Kanagawa, Japan.

Note that DANS consists of SIRIUS (Scientific Information Retrieval and Integrated Utilization System), EDISON (Engineering Database for ISAS Spacecraft Operation Needs), Reformatter, DARTS (Data Archives and Transmission System) and data analysis servers.

The summary of the data processing is as follows. The data downlinked as telemetry are transferred to the data accumulation system at ISAS. The data are added telemetry receiving time on the ground station, merged, sorted in time, and then registered to the telemetry database, SIRIUS. From SIRIUS, level 0 data are retrieved to Reformatter for the PLANET-C Project Team that is provided by C-SODA to each mission at ISAS. All processing after level 0 until level 3 are done on Reformatter. These procedures are executed automatically.

3.4.2.1 Level 0

The L0 data were retrieved from SIRIUS. The compressed tile files were decompressed at the first step. The decompressed tile files were converted from unsigned 16-bit integer into signed 16-bit integer, and then the decompressed tile files were concatenated. If one or more tile files were missing, missing value was substituted to the corresponding pixels. For pixels that have raw values of -32767 or -32768 , their values were replaced with 32767 , indicating saturation. In the case of a raw value of 32767 , this value was replaced with the L0 missing value, -32767 . Combining 6 decompressed tile files, a raw image file was created, which has 384 pixels in the horizontal and 256 pixels in the vertical direction. After that, non-effective pixels were removed, and the resultant image with 328×248 pixels was created.

If the size of a compressed tile file was not equal to the data size recorded in the header, or there were any errors in the tile structure when decoding the compressed file, such a compressed file was identified as corrupted. Even if a compressed tile file is corrupted, some of its pixels may still have uncorrupted values due to the characteristics of the data compression algorithm, HIREW (StarPixel Lossless). By a diagnostic message of the decompression command and/or by human inspection, some pixel values in an uncompressed corrupted tile data were identified as wrong values and were filled with the missing value (-32767), and other pixels were left as they were without any replacement. An example of the corrupted tile and the “salvaged area” is shown in [Figure 6](#).

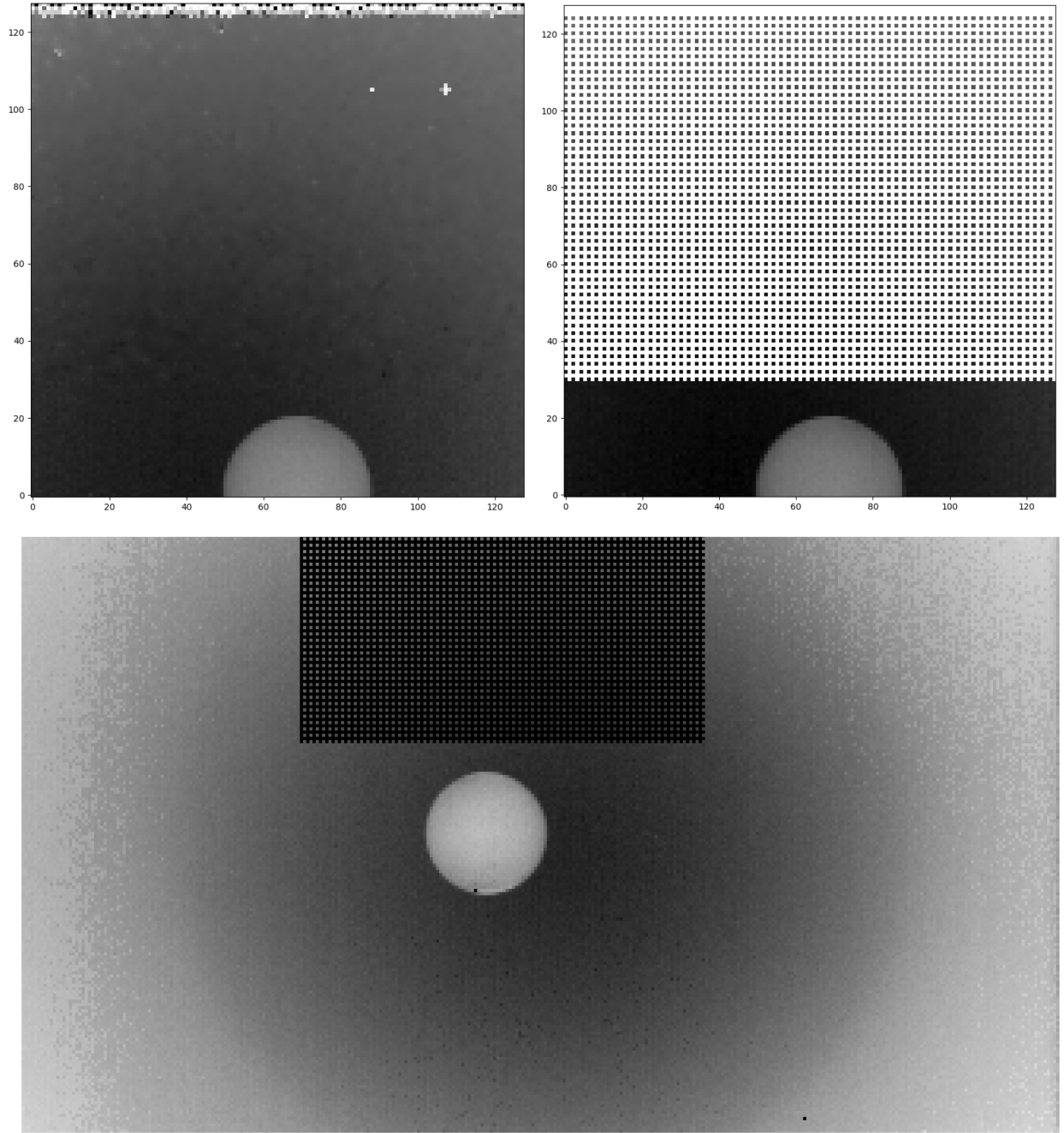


Figure 6 An example of corrupted tile (upper left) and its salvaged version (upper right). The salvaged version of the corrupted tile and its surrounding image is shown (lower) which is created from `lir_20161012_114228_pic_11b_v10.fit`.

The FITS header keywords for “salvaged area” shown in [Table 5](#) are recorded in the header of and IMAGE extension HDU (Header Data Unit) in the FITS file of L1a or later products to warn users that these areas may still contain wrong values. The FITS header keywords `P_NSALV` and `P_SALVi` and the `img:segment_corrupted_flag` attribute in the `img:Image_Compression_Segment` under the `img:StarPixel_Lossless_Parameters` class in the XML label file are used for the identification of the corrupted region. If there are no corrupted tile in the image, the value of the `P_NSALV` is 0 in the FITS header, and there are no `img:Image_Compression_Segment` class(es) in the XML label. If there are corrupted tiles, the tiles are identified by range along horizontal axis and range along vertical axis using the FITS header keyword `P_SALVi` where i indicates i -th corrupted region and ranges from 0 to

P_NSALV–1. The value of P_SALV i has the format of [x0,x1]x[y0,y1] where x0 and x1 are the smallest and the largest indices of the corrupted region in the horizontal, respectively, and y0 and y1 are the smallest and the largest indices of the corrupted region in the vertical, respectively.

Table 5 FITS header keywords on salvaged area

Keyword	Description
P_NSALV	Number of P_SALV i keywords
P_SALV i	The string indicates x- and y-ranges of salvaged area. The format of the string is “[x0,x1]x[y0,y1]” where x0, x1, y0, and y1 are positive integers. The salvaged area is within [x0,x1] in x-axis and [y0,y1] in y-axis, in the image coordinate. Please note that if the region of interest (ROI) function is used, the image coordinate differs from the full-size image coordinate. This salvaged area corresponds to one corrupted, salvaged tile data and the ranges of the area are recorded in each P_SALV i keyword. The i in the keyword used here is a non-negative integer that ranges from 0 to P_NSALV–1.

If common ancillary data for the image and/or instrument-specific ancillary data for the image had been lost, these data can be created manually. If instrument-specific ancillary data which contains instrument-specific telemetry was lost, some items in the telemetries are also stored to the HK (House Keeping) packets, but with different timing. Therefore, one can calculate the value at the imaging time by interpolating the values in the HK packets linearly. Such guess was done for some images, and the value GUESSED was set to the FITS header keyword P_STGUES at Level 1a.

3.4.2.2 Level 1a

From the raw image and ancillary data files in L0, Level 1a (L1a) a FITS file was created. FITS header keywords were filled using common ancillary data for the image and instrument-specific ancillary data.

There are three types of data in counts without any calibration. Which type of data can be determined by value of vco:LIR_Instrument_Attributes / vco:lir_image_type in the PDS4 label file or value of P_ID in the FITS header keyword as shown in [Table 6](#).

Table 6 Three types of LIR image

Type of image	vco:lir_image_type	P_ID	Description
pic	PIC	VCO_LIR_PIC	Resultant data calculated by subtraction and accumulations.
opn	OPN	VCO_LIR_OPN	Shutter-open image.
sht	SHT	VCO_LIR_SHT	Shutter-close image.

Some types of the ancillary data to be stored in the header of the HDU of L1a FITS file, e.g., the value of P_OBSPRG that represents observation program ID used to acquire image, were automatically determined by command history files or data files created from HK (House Keeping) telemetry packets. Note that the command history files store the commands sent from the ground to the spacecraft, and it can be retrieved from EDISON. The data files created from HK telemetry packets also can be retrieved from EDISON.

The FITS header keyword P_OBSPRG stores which observation program ID was executed to obtain the image, and P_OPNAME stores the short name for the observation program ID, and P_OPDATE stores

date and time when the observation program ID was executed. These FITS header keywords related to the observation program ID were added to the FITS header at this processing level using DATE-OBS and a list of executed observation program ID.

At the L1a processing level, a filename is expressed using Extended Time Indicator (ETI) which is calculated from the partition number and the Time Indicator (TI) for the packet generation time.

In the instrument-specific ancillary data, digital numbers (DN) of bolometer temperature LI_BOL_T_DN, package temperature LI_PKG_T_DN, case temperature LI_CAS_T_DN, shutter temperature LI_SHT_T_DN, lens temperature LI_LEN_T_DN, mean voltage in the circuit for a band gap reference in the micro-bolometer array LI_BGR_DN, mean voltage in the circuit for calibration of the on-chip fixed pattern noise in the micro-bolometer array LI_VB1_DN, and mean offset voltage applied to the analog input signal in the analog-to-digital converter circuit LI_ADOFS_DN, are stored in 2 byte each. These DN values are converted into physical values, LI_BOL_T, LI_PKG_T, LI_CAS_T, LI_SHT_T, LI_LEN_T, LI_BGR, LI_VB1, and LI_ADOFS, respectively, using following formulae from DN to physical values which were derived on the ground:

$$\text{LI_BOL_T [}^{\circ}\text{C]} = -14.099 + 0.019177 \times \text{LI_BOL_T_DN} \quad (1)$$

$$\text{LI_PKG_T [}^{\circ}\text{C]} = 14.057 + 0.0065098 \times \text{LI_PKG_T_DN} + 2.7271 \times 10^{-8} \times \text{LI_PKG_T_DN}^2 \quad (2)$$

$$\text{LI_CAS_T [}^{\circ}\text{C]} = 14.057 + 0.0065098 \times \text{LI_CAS_T_DN} + 2.7271 \times 10^{-8} \times \text{LI_CAS_T_DN}^2 \quad (3)$$

$$\text{LI_SHT_T [}^{\circ}\text{C]} = 14.057 + 0.0065098 \times \text{LI_SHT_T_DN} + 2.7271 \times 10^{-8} \times \text{LI_SHT_T_DN}^2 \quad (4)$$

$$\text{LI_LEN_T [}^{\circ}\text{C]} = 14.057 + 0.0065098 \times \text{LI_LEN_T_DN} + 2.7271 \times 10^{-8} \times \text{LI_LEN_T_DN}^2 \quad (5)$$

$$\text{LI_BGR [V]} = 0.00036221 \times \text{LI_BGR_DN} \quad (6)$$

$$\text{LI_VB1 [V]} = 0.0012206 \times \text{LI_VB1_DN} \quad (7)$$

$$\text{LI_ADOFS [V]} = 0.0022212 \times \text{LI_ADOFS_DN} \quad (8)$$

These values are stored to FITS header keywords, LI_BOL_T, LI_PKG_T, LI_CAS_T, LI_SHT_T, LI_LEN_T, LI_BGR, LI_VB1, and LI_ADOFS in the secondary HDU of a FITS file.

In the House Keeping packet, DN of panel temperature LI_PN_T_DN, lens mount temperature LI_LM_T_DN, analog electronics temperature LI_AE_T_DN, and hood (baffle) temperature LI_HD_T_DN are stored in 2 byte each. These DN values are converted into physical values, LI_PN_T, LI_LM_T, LI_AE_T, and LI_HD_T, respectively, using following formulae from DN to physical values which were derived on the ground:

$$\text{LI_PN_T [}^{\circ}\text{C]} = -52.79 + 0.5224 \times \text{LI_PN_T_DN} \quad (9)$$

$$\text{LI_LM_T [}^{\circ}\text{C]} = -50.7 + 0.5224 \times \text{LI_LM_T_DN} \quad (10)$$

$$\text{LI_AE_T [}^{\circ}\text{C]} = -52.27 + 0.5224 \times \text{LI_AE_T_DN} \quad (11)$$

$$\text{LI_HD_T [}^{\circ}\text{C]} = -190.45 + 1.449 \times \text{LI_HD_T_DN} \quad (12)$$

To estimate these values at image acquisition time, one needs to interpolate in time using HK packet data around the image acquisition time. Times in UTC nearest before and after an interpolation time LI_HKU are recorded in LI_HKU0 and LI_HKU1, respectively, which are calculated using VCO Akatsuki SPICE SCLK and LSK from ETIs. Currently, LI_HKU is set to the same value as DATE-OBS. Differences in seconds between LI_HKU0 and LI_HKU, and between LI_HKU1 and LI_HKU are stored to LI_HKD0 and LI_HKD1, respectively, for calculation of an interpolation quality flag. If the magnitude of LI_HKD0 is smaller or equal to 2048 seconds, HK data LI_PN_T, LI_LM_T, LI_AE_T, and LI_HD_T acquired on LI_HKU0 are stored to FITS header keywords in the secondary HDU, LI_PN_T0, LI_LM_T0, LI_AE_T0, LI_HD_T0, respectively. Otherwise, these keywords are set to N/A. The same procedure is applied to LI_HKD1 and HK data acquired on LI_HKU1 are stored to LI_PN_T1, LI_LM_T1, LI_AE_T1, LI_HD_T1, respectively. HK data calculated by linear interpolation in time at LI_HKU are stored to LI_PN_T, LI_LM_T, LI_AE_T, LI_HD_T using HK data acquired on LI_HKU0 and LI_HKU1. These interpolated data and HK packet data are summarized in [Table 7](#).

Table 7 Summary of temperature data obtained from HK data

Data item	FITS header keyword for data acquired on LI_HKU0	FITS header keyword for data acquired on LI_HKU1	FITS header keyword for interpolated data at LI_HKU
LI_PN_T	LI_PN_T0	LI_PN_T1	LI_PN_T
LI_LM_T	LI_LM_T0	LI_LM_T1	LI_LM_T
LI_AE_T	LI_AE_T0	LI_AE_T1	LI_AE_T
LI_HD_T	LI_HD_T	LI_HD_T1	LI_HD_T

HK data interpolation quality flag LI_HKIF is set depending on which data are available and how near the HK data acquisition times. Definition and how a flag value is set is described in [Table 8](#).

Table 8 Definition of HK data interpolation quality flag

LI_HKIF	Interpolation quality	Description
0	Not available	data are not found around a time LI_HKU
1	High	data are found near enough around a time LI_HKU; both data are within 120 seconds from LI_HKU.
2	Normal	data are found but not near enough around a time LI_HKU; both data are within 2048 seconds but both data are not within 120 seconds from LI_HKU.

Values of observation start time P_SCCSC and stop time P_SCCEC expressed in the SCLK string are calculated from timestamps of the instrument-specific ancillary data files (*.ihd). For each shot, one instrument-specific ancillary data is recorded with TI just before the shot. TIs of the first shot and the last shot are stored to P_SCCSC and P_SCCEC, respectively, with the partition number for TI in SCLK string ([Figure 7](#)).

There are three kinds of special pixel flag values in the data array ([Table 9](#)). These values were stored to the FITS header keywords as described in [Table 10](#).

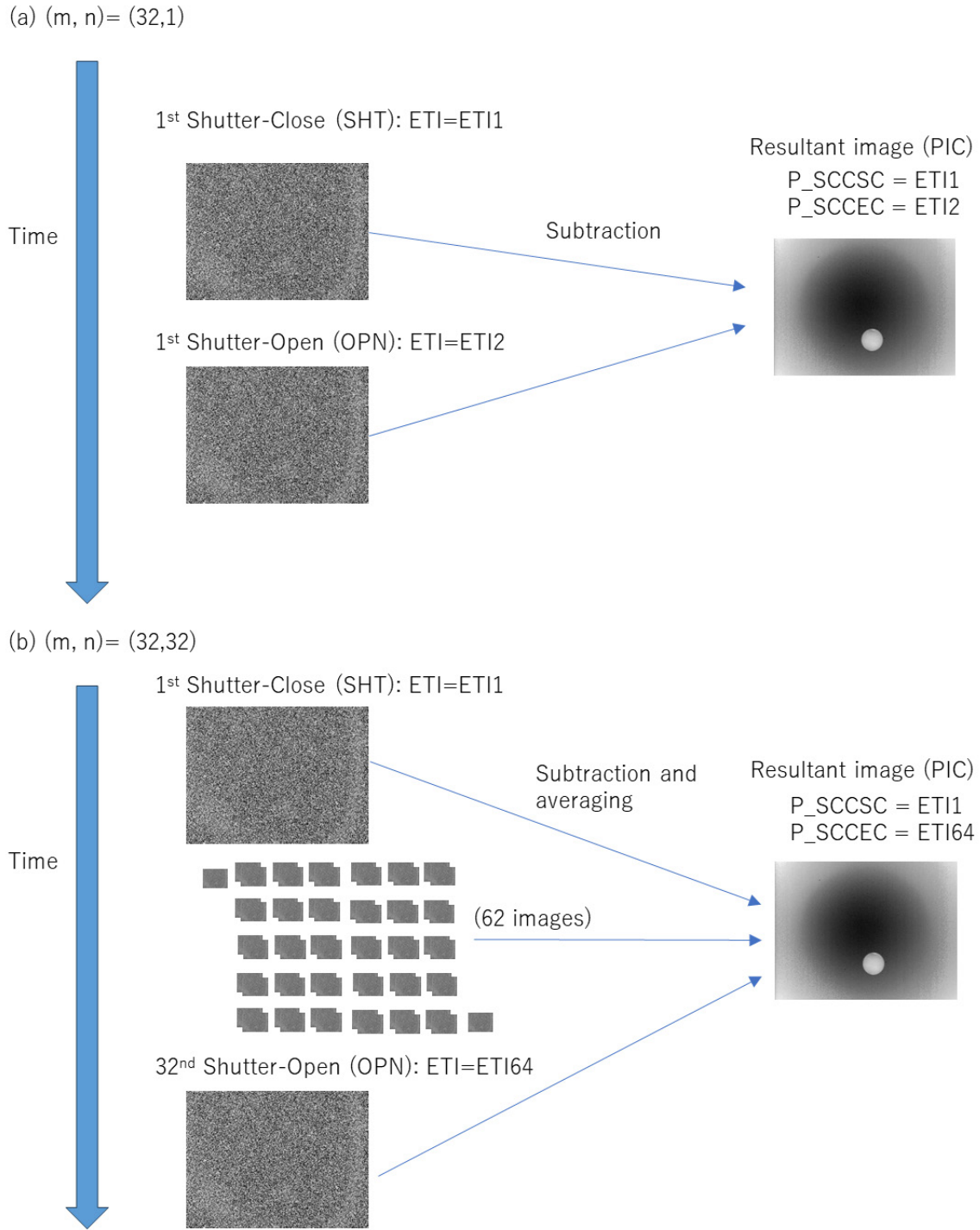


Figure 7 A schematic diagram of relationship between ETIs of sequential images and P_SCCSC and P_SCCEC for a resultant image: (a) $(m, n) = (32, 1)$ case, (b) $(m, n) = (32, 32)$ case.

The special values (missing pixel flag values, dead pixel flag values, and saturated pixel flag values) are substituted into the data. Positions of dead pixels recognized as of May 2024 are listed in [Table 11](#). They contain scientifically invalid value. Tuple of numbers (i, j) in the “position” columns is position in the image coordinate after the flip and the rotation with one-based index, same as the above. [Table 11](#) is also provided as LIR Bad Pixel Table product as part of the LIR calibration collection in the LIR bundle.

Table 9 Definition of special pixel values

terminology	Description
missing value	Pixel value is missing in the telemetry due to loss of the packets or overwritten by other data in DR (Data Recorder).
dead pixel	Detector element of the pixel is damaged permanently by some reason, e.g., hit of X-rays to the corresponding detector element.
saturated pixel	Data at the pixel that are out of range from the nominal measurement due to receiving too many photons to the detector element or due to overflow/underflow during image data processing at DE onboard.

Table 10 FITS header keywords for special pixel values

keyword	Description
P_MPIXV	Missing pixel flag value which replaces value at missing pixels.
P_DPIXV	Dead pixel flag value which replaces value at dead pixels. If dead pixel flag value is not defined, value of the keyword is set to 'N/A'.
P_SPIXV	Saturated pixel flag value which replaces saturated values. If a threshold for saturated value is not identified at this processing level or is expressed using value of the keyword P_SPIXO, the value of the keyword is set to 'N/A'.
P_SPIXO	Saturated pixel offset value which is added to the original value of each pixel if the pixel is identified as saturated. If saturated pixels are not identified at this processing level or are expressed using value of the keyword P_SPIXV, the value of the pixel will be 'N/A'. This keyword is only used for IR2 L2b data.
P_MPIXN	Number of missing pixels in the stored data.
P_DPIXN	Number of dead pixels in the stored data.
P_SPIXN	Number of saturated pixels in the stored data.

Table 11 Dead pixels in the LIR detector array

Name	Position i	Position j	Start date/time when it became dead pixel
D0	81	215	2010-05-20T18:00:00Z
D1	185	143	2010-05-20T18:00:00Z
D2	200	68	2010-05-20T18:00:00Z
D3	127	55	2010-05-20T18:00:00Z
D4	216	57	2019-12-21T21:00:00Z
D5	86	56	2021-01-29T18:00:00Z
D6	86	57	2021-01-29T18:00:00Z
D7	325	77	2021-10-28T19:00:00Z
D8	259	220	2024-01-03T08:00:00Z
D9	260	220	2024-01-03T08:00:00Z

3.4.2.3 Level 1b – Raw Image Data

From an L1a FITS file, an L1b FITS file and associated geometry information FITS file were created using SPICE kernels and the SPICE toolkit. The latter is described in [Section 3.4.2.6](#).

The primary data is thermal infrared radiation through the applied filter. Thermal infrared radiation is measured as voltage with constant current by using temperature-dependent resistivity of the detector material. The measured voltages are converted using analog-to-digital converter, and stored in digital counts. The resistivity is not proportional to the magnitude of thermal radiation in radiance or brightness temperature received at the detector (UMBA).

The data on geometry in FITS header were calculated using the VCO Akatsuki SPICE Kernel Archive Bundle, urn:jaxa:darts:vco_spice. Some FITS header keywords related to time, e.g., the DATE-OBS keyword, were also calculated using the VCO Akatsuki SPICE SCLK and LSK into time in UTC. DATE-BEG and DATE-END is calculated using the SPICE system from P_SCCSC and P_SCCEC, respectively. DATE-OBS is calculated from middle time between DATE-BEG and DATE-END. The ETI in the filename was replaced using value of DATE-OBS.

To calculate the geometry of Venus in the FOV, a sensing altitude above the surface of the planet was assumed. For example, at the IR wavelengths of LIR, the sensing altitude of imaging is assumed as 65 km, which roughly corresponds to the cloud top level at the LIR wavelength. [Table 12](#) shows the list of assumed sensing altitude for all filters of VCO. The assumed altitude was recorded in the FITS header keyword, S_CLDALT.

Table 12 Assumed sensing altitude

Camera	Channels	Assumed Sensing Altitude
UVI	283 nm	70 km
	365 nm	
IR1	0.90 μm day	60 km
	0.90 μm night	
	0.97 μm	
	1.01 μm	
IR2	1.735 μm	50 km
	2.26 μm	
	2.32 μm	
	2.02 μm	70 km
	1.65 μm	N/A
LIR	PIC	65 km

The orientation of an image is made to be aligned for all images acquired by VCO (spacecraft +Y axis is upward with the coordinate described in [Section 3.5.3.3](#)) at the L1b processing stage by performing either vertical flipping or rotation of the image. The process depends on the instruments and/or channels. [Table 13](#) describes corresponding processing for each camera and channel. Value of the P_FLPROT keyword in the header of the secondary HDU of the FITS file indicates flip and/or rotation applied to L1a data to obtain L1b data.

Table 13 List of rotation and/or flip patterns for each camera and channel.

Camera	channel	operation	P_FLPROT
UVI	all	Rotate counterclockwise (CCW) 270 degrees	3
IR1	all	Flip vertically	10
IR2	1.65 μm	No rotation/flip	0
	others	Rotate 180 degrees	2
LIR	all	Flip vertically	10

3.4.2.4 Level 2b – Calibrated Image Data

Details of the LIR in-orbit checkout and baffle temperature correction are described in [Fukuhara+2017](#).

The original LIR image sent from the spacecraft expresses brightness detected with 12 bits per each pixel. The data number for each pixel is converted to brightness temperature based on the reference data, which were derived from the blackbody images acquired during calibration tests at ISAS/JAXA, in a vacuum environment before launch ([Fukuhara+2011](#)). The blackbody used in the experiment was thermally controlled 10 K steps from 213 K ($-60\text{ }^{\circ}\text{C}$) to 243 K ($-30\text{ }^{\circ}\text{C}$).

From the L1b FITS file, an L2b FITS file is created using FITS files for calibration. The header keywords relevant to the flux calibration of LIR data are shown in [Table 14](#).

The keyword LI_SHT_T provides the mean shutter temperature during an observation sequence in which obtained images (indicated by LI_NINT2 keyword) are integrated into an LIR image during onboard processing. Discrepancy between this temperature and LI_C2TRF is used for describing a shutter count offset.

Since LIR captures thermal emission in the broad wavelength range of 8 – 12 μm , the approximation of a square band pass with these boundaries is used for calibration in Level 2b data products. Calibration tables in LI_C2TSC, LI_C2TOF, and LI_C2TSH are used for converting a count value to thermal brightness at each pixel. LI_C2TK[0-7] are coefficients of a 7-degree polynomial function for converting measured thermal brightness to brightness temperature.

Table 14 FITS header keywords used for calibration

Keyword	Description
LI_NINT1	Number of first accumulation
LI_NINT2	Number of second accumulation
LI_SHT_T	Mean shutter temperature during one observation sequence [°C]
LI_C2TSC	Filename of a scaling factor table for each pixel
LI_C2TOF	Filename of an offset parameter table for each pixel
LI_C2TSH	Filename of a correction factor table relating to shutter temperature for each pixel
LI_C2TSR	Filename of a system response function for LIR
LI_C2TRF	Reference shutter temperature for calibration [°C]
LI_C2TRB	Reference baffle temperature for calibration [°C]
LI_C2TK7 LI_C2TK6 LI_C2TK5 LI_C2TK4 LI_C2TK3 LI_C2TK2 LI_C2TK1 LI_C2TK0	<p>Conversion coefficient of a 7-degree polynomial function from measured thermal brightness to brightness temperature. Index i of LI_C2TKi is a coefficient for i-th degree, i.e., brightness temperature is calculated by</p> $\sum_{i=0}^{i=7} \text{LI_C2TK}_i \times x^i$ <p>where x is thermal brightness.</p>
LI_B_ERR	Bit error flag at LIR second accumulation performed onboard
LI_HD_T	Hood temperature at the time of image acquisition [°C]
LI_AEONT	LIR-AE operating time at observation time DATE-OBS [day]
LI_DRATE	LIR sensitivity degradation rate [1/day]
LI_RFSHT	Reference shutter temperature used for L2d [K]
LI_OTHST	Filename of a LIR-AE operating time history

An image in counts is calibrated with an "L1 to L2" program in the following steps:

- A) The header keywords LI_C2TRF, LI_SHT_T and a coefficient table, LI_C2TSH, are used to measure an offset count at each pixel in the L1b image, D_{offset} , which is resulted from difference between shutter temperature and reference temperature, as follows:

$$D_{\text{offset}}(i, j) = C(i, j) \times (T_{\text{ref}} - T_{\text{sht}}), \quad (13)$$

where $C(i, j)$ represents a calibration coefficient at (i, j) pixel described in LI_C2TSH, T_{ref} and T_{sht} are reference and shutter temperatures (LI_C2TRF and LI_SHT_T), respectively. Then a calibrated count is obtained from

$$D_{\text{cal}}(i, j) = D(i, j) + D_{\text{offset}}(i, j), \quad (14)$$

where $D(i, j)$ represents the raw count value in L1b data. Some L1b images, which were obtained from 2016-06-26 to 2016-09-28 in the accumulation mode with $n = 1$, were collected with a

wrong bit shift rule. Therefore, we used a modified equation for these images instead of Eq. (14) as follows:

$$D_{\text{cal}}(i, j) = \{4 \times D(i, j) + 2500\} \times 32 + D_{\text{offset}}(i, j). \quad (15)$$

B) The calibrated count at each pixel is converted to thermal brightness, I , using calibration coefficient tables as follows:

$$I(i, j) = A(i, j) \times D_{\text{cal}}(i, j) + E(i, j), \quad (16)$$

where $A(i, j)$ represents scaling factor stored in LI_C2TSC and $E(i, j)$ is offset in LI_C2TOF, which are prepared from ground-based experiments. When emissivity of the thermal infrared radiation from Venus is assumed to be unity, brightness temperature $T(i, j)$ for each pixel in an image can be derived from Planck's law. On the other hand, $T(i, j)$ can also be approximated by a power series of $I(i, j)$ in case the target temperature is between 210 K to 250 K. Hence the measured thermal brightness is converted to the corresponding brightness temperature, T , with a 7-degree approximated function of Planck's law of radiation:

$$T(i, j) = c_0 + c_1 \times I(i, j) + c_2 \times I(i, j)^2 + c_3 \times I(i, j)^3 + c_4 \times I(i, j)^4 + c_5 \times I(i, j)^5 + c_6 \times I(i, j)^6 + c_7 \times I(i, j)^7, \quad (17)$$

where c_0, \dots, c_7 are from LI_C2TK0, ..., LI_C2TK7, respectively. These coefficients are derived considering spectral response function of LIR as a boxcar function, and also provided in [Table 15](#).

Table 15 Coefficients for L2b and L2c data product applied in the 7th order polynomial function used for calculating brightness temperatures from measured intensities

Coefficient	Value
c_0	1.524985×10^2
c_1	2.585953×10^1
c_2	-5.194568×10^0
c_3	8.131539×10^{-1}
c_4	-8.251211×10^{-2}
c_5	5.107873×10^{-3}
c_6	-1.747440×10^{-4}
c_7	2.526066×10^{-6}

3.4.2.5 Level 2c – Calibrated Image Data corrected for baffle temperature

Details of the LIR in-orbit checkout and baffle temperature correction are described in [Fukuhara+2017](#). A precise instrumental response function has been calculated from the transmittance of the lens, the bandpass filter and the window for the detector and a spectral response function of the detector that is stored as part of the calibration collection ([Figure 3](#)). This spectral response function is used for calibration in data products Level 2c (L2c) and higher.

Since brightness temperature of the deep space measured in the wavelength region of the LIR passband shows only a few kelvins, infrared radiation power from the deep space is far below the detection limit of LIR. The procedure described in 3.4.2.4 outputs an apparent deep space temperature

around 180 K, which is out of the valid range of output brightness temperature from 210 K to 250 K. The deep space temperature derived by LIR can be used as a measure of the LIR status for null input. [Fukuhara+2017](#) points out that radiation from the heated baffle of LIR causes apparent increase in deep space temperature. A correction factor for this issue has been determined, and it has been confirmed that corrected images show rather uniform temperature of deep space. The false background temperature bias due to variation in the baffle temperature is corrected by the following formula:

$$D_{\text{cal}}'(i, j) = D_{\text{cal}}(i, j) - C_B(i, j) \times (I_{\text{baffle}} - I_{\text{baffleref}}), \quad (18)$$

where $C_B(i, j)$ is pixel-to-pixel correction coefficients of the background temperature bias due to increase in the baffle temperature, and I_{baffle} and $I_{\text{baffleref}}$ are the brightness corresponding to baffle temperature at the time of image acquisition T_{baffle} (LI_HD_T) and a reference temperature $T_{\text{baffleref}}$ (LI_C2TRB, 230 K), respectively. There are two sets of coefficients for sunlight-illumination condition of the spacecraft; sunlight incidents to +Z-panel or -Z-panel of the spacecraft. Which set is used is determined by S_SDIRZ. If it is greater or equal to zero, sunlight incidents to +Z-panel, and if it is less than zero, sunlight incidents to -Z-panel. I_{baffle} and $I_{\text{baffleref}}$ are calculated numerically from

$$I(T) = \int 2hc^2\lambda^{-5} \left[\exp\left(\frac{hc}{\lambda kT}\right) - 1 \right]^{-1} \times W(\lambda) d\lambda, \quad (19)$$

where h is Planck's constant $6.62607004081 \times 10^{-34}$ m²kg/s, c is the speed of light 299792458 m/s, λ is wavelength, k is Boltzmann's constant $1.3806485279 \times 10^{-23}$ JK⁻¹, and $W(\lambda)$ is the system response function stored in LI_C2TSR.

Then, $D_{\text{cal}}'(i, j)$ is used instead of $D_{\text{cal}}(i, j)$ in equation (16) to calculate thermal brightness I' with a bias correction due to radiation from the baffle. Using I' instead of I in Eq. (17) then gives us T' , the brightness temperature corrected for the background bias, which is provided as the L2c data product. Note that in order to create this product, the baffle temperature T_{baffle} has to be known. If T_{baffle} is not available for a particular measurement, a L2c data product is not created for this measurement.

3.4.2.6 Level 2d – Calibrated Image Data corrected for baffle temperature and long-term sensitivity degradation

Although LIR has no precise internal calibration black body, the shutter plate is used as a simple hot calibration source for the higher temperature reference. The background deep space temperature is necessarily constant and can be used as a precise lower temperature reference. However, the background temperature shows a gradual increase during the whole period of LIR observation of more than 20 K over five earth years, or approximately 1 K / 100 days since LIR was kept being turned on in October 2016, which is likely due to a calibration issue. An increasing trend is also confirmed in Venus' disk temperature, though the magnitude of this trend is smaller than that for the background temperature. On August 22, 2020, some pixels in the deep space region in an image were assigned an invalid value, which indicates that the outputs at those pixels in the raw target image were smaller than the lower limit of the dynamic range of LIR. This was not observed in the early phase of LIR observation and was observed more frequently in 2022, indicating the progression of sensitivity degradation of LIR.

LIR measures the difference in the output between the temperature-controlled reference (shutter) and a target. When sensitivity degradation occurs, the difference between the outputs for the reference and target images reduces accordingly, as illustrated in [Figure 8](#). Since the reference temperature of the LIR shutter, ~297 K, is higher than the temperature at the cloud top level of Venus, ~230 K, a reduction in the difference between the measured reference and target outputs makes the measured target temperature hotter than the actual temperature. Details of the long-term sensitivity degradation of LIR are described in [Taguchi+2023](#).

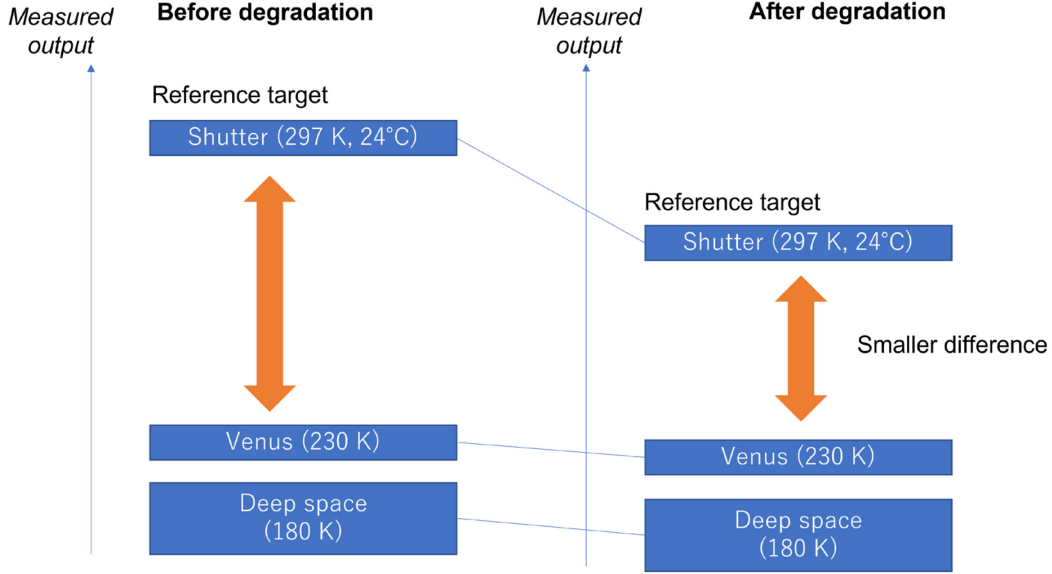


Figure 8 Schematic view of a change of output brightness temperature of Venus relative to temperatures of the shutter and deep space due to sensitivity degradation of LIR. Note that the deep space temperature is not a real temperature but an apparent temperature. Taken from Fig. 2 in [Taguchi+2023](#).

To improve the accuracy of absolute brightness temperature measurements, a method for correcting the brightness temperature using the background temperature has been developed and applied to the data. It is assumed that the sensitivity degradation linearly affects the outputs, but, because the shutter temperature is used as a reference temperature, it does not affect the output when LIR observes a target with the same temperature as the shutter temperature. The observed radiance, $I_o(T, t)$, for a target temperature, T , at a time, t , can be represented as

$$I_o(T, t) = (1 + \alpha(t'))(I(T) - I(T_s)) + I(T_s), \quad (20)$$

where $I(T)$ represents blackbody radiation as a function of the target temperature, T_s is the shutter temperature, and $\alpha(t')$ represents the magnitude of the sensitivity variation as a function of the integrated duration of LIR being turned-on, t' . For the degradation case, $\alpha(t')$ should be negative, and the degradation can be ignored at $t' = 0$, thus

$$\alpha(0) = 0. \quad (21)$$

By letting $\Delta I_b(t, t_0)$ be the difference of observed radiance of deep space at t and at the time when the degradation can be ignored (t_0), $\Delta I_b(t, t_0)$ can be evaluated using Eq. (20) as

$$\begin{aligned} \Delta I_b(t, t_0) &:= I_o(T_b, t) - I_o(T_b, t_0) = I_o(T_b, t) - I(T_b) \\ &= \alpha(t')(I(T_b) - I(T_s)), \end{aligned} \quad (22)$$

where T_b is the apparent temperature of the deep space. Then, from Eq. (22), the magnitude of sensitivity degradation can be measured as

$$\alpha(t') = \frac{\Delta I_b(t, t_0)}{I(T_b) - I(T_s)}. \quad (23)$$

As described in [Fukuhara+2011](#), in this study 297 K is used for T_s for evaluating $I(T_s)$. We used 181.4 K for T_b for evaluating the background intensity based on observation results in the cruise phase

of Akatsuki and providing zero degradation at $t' = 0$ in a fitting procedure of a linear function. Then, $\Delta I_b(t, t_0)$ can be evaluated from the observation results $I_o(T_b, t)$.

Based on the study of the degradation (Taguchi+2023), a $-2.61 \pm 0.02\%$ sensitivity degradation occurred within 1,000 days of duration of the LIR-on, and more than 5% degradation occurred as of February 2022. The error range was evaluated by considering an error of fitting a linear function to the sensitivity degradation and uncertainty in determining the background temperature (± 2 K). After the publication of Taguchi+2023, it was found that correction for radiation from baffle makes overcorrection for estimate of sensitivity degradation. Degradation rate of data using the procedure described in Taguchi+2023 was calculated again and it becomes 0.2% / 1000 days, so we use degradation rate $\beta = -2.8 \times 10^{-5} \text{ day}^{-1}$.

To cancel the overcorrection of radiation from baffle, the following equation is used instead of Eq. (18):

$$D_{\text{cal}}''(i, j) = D_{\text{cal}}(i, j) - C_B(i, j) \times (I_{\text{baffle}} - I_{\text{baffle ref}}) \times (1 + \alpha t'). \quad (24)$$

Then, $D_{\text{cal}}''(i, j)$ is used instead of $D_{\text{cal}}(i, j)$ in equation (16) to calculate thermal brightness I'' with a bias correction due to radiation from the baffle considering the sensitivity degradation.

The correction of the observed intensity of a target can be represented from Eq. (20) as

$$I'''(i, j) = \frac{I''(i, j) - I(T_s)}{1 + \beta t'} + I(T_s), \quad (25)$$

where $I(T_s)$ is evaluated using Eq. (19).

For the Level 2d (L2d) data product, I'' is based on calibrated count rates $D_{\text{cal}}''(i, j)$ that include the correction for baffle temperature (Eq. (24)). As for the L2c data product, if the baffle temperature is not available for a particular measurement, a L2d data product is not created for this measurement. In order to obtain a brightness temperature from the corrected intensity $I'''(i, j)$, Eq. (17) is employed using the coefficients based on the precise instrumental response function (Figure 3) then gives us the brightness temperature corrected for background bias and sensitivity degradation, which is provided as the L2d data product. The coefficients used in Eq. (17) are provided in Table 16.

Table 16 Coefficients for L2d data product applied in the 7th order polynomial function used for calculating brightness temperatures from measured intensities

Coefficient	Value
c_0	1.524928×10^2
c_1	2.577792×10^1
c_2	-5.161996×10^0
c_3	8.055189×10^{-1}
c_4	-8.148206×10^{-2}
c_5	5.02841×10^{-3}
c_6	-1.714920×10^{-4}
c_7	2.47000×10^{-6}

3.4.2.7 Geometry – Geometry Data

Geometry data provides ancillary information that includes longitude, latitude, local time, incidence angle, emission angle, solar phase angle, and azimuthal angle for each pixel in the L1b, L2b, L2c and L2d data products. Each kind of data is stored to the HDU as the IMAGE extension of the FITS file.

The primary source data are the SPICE kernels, provided as the VCO Akatsuki SPICE Kernel Archive Bundle, especially for the information on the position of the spacecraft and the attitude of the spacecraft, and observation time for each image provided as a raw data product and a calibrated data product.

There are two kinds of geometry data products; one is created by the SPICE kernels without any pointing corrections (L1b geometry data), and the other one (L3dx geometry data) is created with an updated geometry based on a successful limb fitting correction, as a by-product of L3d data. There are known discrepancies between the SPICE-calculated pointing (L1b geometry data) and the image data. Namely, the center of the planet as determined from best-information SPICE kernels does not match the center of the planet as determined from inspection (e.g., limb-fitting). This difference is sometimes tens of pixels. L3dx geometry data is expected to be more accurate than L1b geometry data, therefore we recommend that users always use L3dx geometry data if it is available.

To create L3dx geometry data, L1b geometry information and L2d image data are used. An L2d image in brightness temperature is converted to radiance, and then a candidate region of the Venus' limb in the L2d image is calculated. In the candidate region, limb points are estimated from a horizontal profile or a vertical profile around the limb compared with a model profile. By fitting an ellipse to the limb points, a position of the Venus disk in the image and a center of Venus are estimated. This limb fitting procedure included outlier removal from the source data of limb-fitting. There is a difference between the estimated Venus' center from limb and calculated Venus' center only by the SPICE system. By assuming that the difference comes from inaccurate attitude of the spacecraft, it is used for correcting the pointing of the camera boresight. Using corrected camera boresight, L3dx geometry information is calculated. If no Venus' limb is found in the L2d image or the fitting of the ellipse to the limb points fails, the L3dx geometry product is created without the limb fitting and not included in this bundle; it would have same content with L1b geometry product.

Geometry data is calculated using the pinhole camera model at the time of the FITS header keyword DATE-OBS or geom:Geometry / geom:Geometry_Orbiter / geom:geometry_reference_time_utc or in the PDS4 XML label.

Definitions of data included in the geometry data are described in [Table 17](#) and shown in [Figure 9](#). Note that all data except for local solar time are stored in degrees.

If the line of sight from the center of the detector element for each pixel doesn't intercept the target planet, i.e., is looking at deep space, IEEE NaN (Not a Number) is stored for pixel value.

If any of the lines of sight from the center of the detector element for each detector element intercepts Venus, the value "VENUS" is substituted to the FITS header keyword OBJECT. If none of them intercept Venus but any of them intercept the Earth, "EARTH" is substituted. Otherwise, "STAR" is substituted.

Table 17 Definition of geometry data

Name	Definition	Unit	Range ¹
Latitude	Latitude of planetocentric coordinate system defined as IAU Venus	degrees	[−90, 90]
Longitude	Longitude of planetocentric coordinate system defined as IAU Venus	degrees	[0, 360)
Local (solar) time	Local solar time calculated by $(\text{sub-solar longitude} - \text{longitude})/15 + 12$. S_SOLLON is used for sub-solar longitude.	hours	[0, 24)
Phase angle	Angle between a scatterer-Sun vector and a scatterer-observer vector. This is calculated by the <i>illum_c</i> function in the SPICE toolkit.	degrees	[0, 180]
Incidence angle	Angle between a surface normal vector and a scatterer-Sun vector. This is calculated by the <i>illum_c</i> function in the SPICE toolkit.	degrees	[0, 180]
Emission angle	Angle between a surface normal vector and a scatterer-observer vector. This is calculated by the <i>illum_c</i> function in the SPICE toolkit.	degrees	[0, 180]
Azimuthal angle	Angle between a vector from the Sun to scatterer at the scatterer projected onto the surface and a vector from scatterer to observer projected onto surface. The formula to calculate azimuthal angle θ in radians is: $\theta = \cos^{-1}\{(-\cos \alpha + \cos i \cos e) / (\sin i \sin e)\}$ where α , i , e are phase angle, incidence angle, and emission angle in radians, respectively.	degrees	[0, 180]

¹ Note that the brackets, [and] mean including the endpoints at the left and at the right of the interval, and the parentheses () mean excluding the endpoints at the left and at the right of the interval.

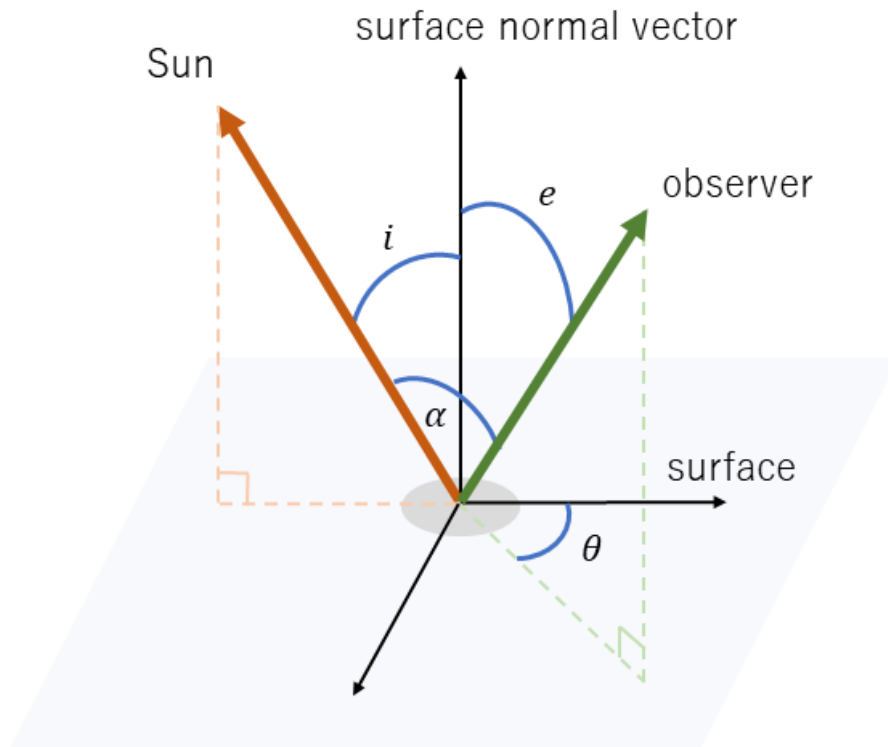


Figure 9 Definition of a phase angle α , an incidence angle i , an emission angle e , and an azimuthal angle θ . This figure is drawn in isometric view. The gray elliptical region shows a small disk on the spherical surface of the target body where scatterer or emitter exists. The surface including the disk is approximated by a plane shaded by light blue. A scatterer-Sun vector, a scatterer-observer vector, and the surface normal vector are shown as a thick dark red arrow, a thick dark green arrow, and a thin black arrow, respectively. The vector emanating from the scatterer from left to right on the surface shown as a thin black arrow is opposite vector of the projection of the scatterer-Sun vector onto the surface. This vector can be interpreted as a vector that is a projected vector of the Sun-scatterer vector onto the surface with origin at the scatterer.

3.4.2.8 Level 3d – Longitude-Latitude projected Data

From the L2d FITS files, L3d NetCDF files, L3dx NetCDF files, and L3dx FITS files are created using SPICE kernels and SPICE toolkits. A fully automated algorithm of limb-detection, limb-fitting, and projection onto equally spaced longitude-latitude grids at the sensing altitude has been implemented for the processing. Grid spacing is chosen as 0.25 degrees in latitude and longitude for the LIR L3d data products.

L3d and L3dx NetCDF files are not included in the VCO Akatsuki LIR bundle as they don't conform with PDS4 standards. Instead, the content of L3d NetCDF files is stored to the map data collection of the VCO Akatsuki LIR bundle. L3dx FITS files are archived in this bundle as a part of the geometry collection.

If no Venus' limb is found in the L2d image or the fitting of an ellipse to the limb points fails, the L3d product is created without the limb fitting. Only the L3d product with the successful limb fitting, i.e., which has FIT_STAT = 1 or 2 in the corresponding L3d NetCDF file, is stored in the bundle.

For each grid point at the 65-km altitude on Venus, interception of the detector plane and a line emanating from the grid point passing through the focal point of the camera is calculated. Using pixel values around the intersection on the detector plane, radiance at the grid point is calculated using

bilinear interpolation. If there is a pixel with a missing value, the mean value of the adjacent four pixels of the missing value pixel is used instead. If any of the adjacent four pixels has a missing value, a missing value is assigned to the grid point. If the grid point is behind Venus viewed from the spacecraft, a missing value is assigned to the grid point.

Please refer [VCO Akatsuki Level 3 Algorithm Description Document](#) for the derivation of L3d data.

3.4.2.9 Browse – Browse Data

For the purpose of quick look, a JPEG image is created for each FITS file of the raw data, calibrated data, map data, and geometry collections.

3.4.3 Data Flow

LIR raw, calibrated, and derived data products are built up in sequential data processing steps addressing specific corrections or calibrations. All data products are built from raw telemetry ingested into the SIRIUS database. The LIR data processing pipelines query the database directly for new raw science data. The LIR data files generated by the pipelines are returned for storage. [Figure 10](#) shows the LIR data flow from raw telemetry to derived data products.

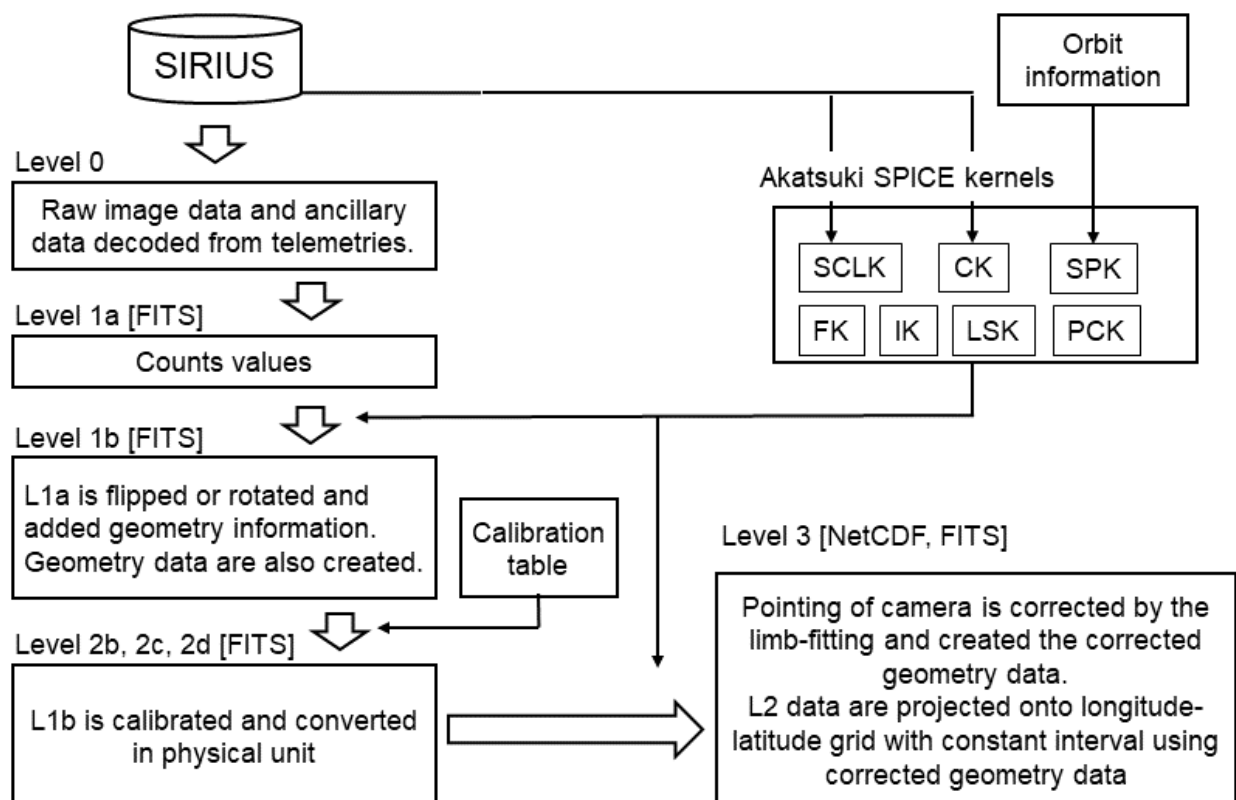


Figure 10 Schematic diagram of the pipelines taken from [Ogohara+2018](#).

3.4.4 Labeling and Identification

All LIR data products are labeled with PDS4 compliant detached XML labels. These labels describe the content and format of the associated data product. Labels and products are associated by a file name with the label having the same name as the data product except that the label file has a .lblx extension.

Labels are constructed with the PDS4 Product Class, `Product_Observational` sub-class. The `Product_Observational` sub-class describes a set of information objects produced by an observing system. A hierarchical description of the contents of `Product_Observational` products appears below for raw and calibrated data products as an example:

Product_Observational

Identification_Area – attributes that identify and name an object

logical_identifier – a unique identifier `urn:jaxa:darts:vco_lir:<collection>:<file_name_root>`, e.g., `urn:jaxa:darts:vco_lir:data_raw:lir_20151207_052704_pic_l1b`

version_id – version of product

title – Short description of product used as the PDS4 search return

information_model_version – version of PDS4 information model used to create product

product_class – attribute provides the name of the product class (`Product_Observational`)

Observation_Area – attributes that provide information about the circumstances under which the data were collected.

Time_Coordinates – time attributes of data product

Primary_Results_Summary – high-level description of the types of products included in the collection or bundle

Investigation_Area – mission, observing campaign or other coordinated, large-scale data collection attributes

Observing_System – observing system (instrument) attributes

Target_Identification – observation target attributes

Mission_Area – mission specific attributes needed to describe data product

Discipline_Area – discipline specific attributes needed to describe data product

File_Area_Observational – describes a file and one or more tagged_data_objects contained within.

File – identifies the file that contains one or more data objects

Header – defines a header of HDU of FITS file

Array_2D_Image – defines a 2D image array

Information in the preceding paragraphs was distilled from the PDS4 Information Model provided by PDS. Additional information on product labels can be found at <https://pds.nasa.gov/datastandards/about/>.

The file naming conventions for the raw image, calibrated image, derived map, and geometry products are same over the four cameras, UVI, IR1, IR2, and LIR. In addition to the four cameras, the data of LAC and RS have very similar file naming conventions. In this section, the file naming conventions for the four cameras are described.

The filename has the format

`{cam}_{YYYY}{MM}{DD}_{hh}{mm}{ss}_{filter}_{level}_v{ver}.{ext}`

where variables are denoted by strings enclosed by the braces `{ }`. The description of the variables is available in the following:

`{cam}`: an abbreviated name of cameras, i.e., uvi, ir1, ir2, and lir

Note that for LAC and RS data, lac and rs are used, respectively.

`{YYYY}`: year in four-digits

`{MM}`: zero-padded month in two digits from 01 to 12

`{DD}`: zero-padded day in two digits from 01 to 31

`{hh}`: zero-padded hour in two digits from 00 to 23

{mm}: zero-padded minute in two digits from 00 to 59

{ss}: zero-padded second in two digits from 00 to 60

Note that {YYYY}-{MM}-{DD}T{hh}:{mm}:{ss} means the representative time of observation for the image in UTC which is extracted from the FITS header keyword DATE-OBS in the IMAGE or BINTABLE extension HDU of the FITS file.

Also note that 60 is for a leap second.

{filter}: an abbreviated filter name or a type of the image

- pic: resultant image, P_ID = VCO_LIR_PIC
- opn: shutter-open image, P_ID = VCO_LIR_OPN
- sht: shutter-close image, P_ID = VCO_LIR_SHT

{level}: an abbreviated name of a product

- l1b: the L1b product
- l2b: the L2b product
- l2c: the L2c product
- l2d: the L2d product
- l3d: the L3d product
- geo: the geometry product derived only by the VCO Akatsuki SPICE kernels
- l3dx: the corrected geometry product obtained as by-product of the l3d product.

{ver}: version strings of the product in two digits. The value is larger than or equal to 10

{ext}: an extension of the file

- fit: FITS file compliant to the FITS Standard 4.0
- lblx: PDS4 XML label file
- jpg: JPEG file
- csv: CSV file

The LIR calibration product filename for the scaling, offset, and shutter data has the format

lir_{type}_m{M}n{N}_v{VV}.{ext}

where variables are denoted by string enclosed by the braces {}. The description of the variables is as follows:

{type}: scaling, offset, or shutter data for each pixel

- scaling: scaling data for each pixel
- offset: offset data for each pixel
- shutter: shutter brightness correction data for each pixel

{M}: a number of first accumulation, 1, 32

{N}: a number of second accumulation, 1, 32

{VV}: a version number of the file in two digits

{ext}: an extension of the file

- fit: FITS file compliant to the FITS Standard 4.0
- lblx: PDS4 XML label file

The LIR calibration product filename for the background bias correction coefficients estimated from deep space images acquired when the sun illuminates the spacecraft from all directions has the format:

`lir_baffle_{YYYY}_{MM}_{dir}_m{M}n{N}_v{VV}.{ext}`

where variables are denoted by strings enclosed by the braces {}. The description of the variables is as follows:

- `{YYYY}`: year in four digits for data acquisition date
- `{MM}`: zero-padded month in two digits for data acquisition date
- `{dir}`: direction for sunlight incoming to which panel of the spacecraft
 - all: all directions for incoming sunlight
 - mz: sun illuminates -Z-panel of the spacecraft
 - pz: sun illuminates +Z-panel of the spacecraft
- `{M}`: a number of first accumulation, 1, 32
- `{N}`: a number of second accumulation, 1, 32
- `{VV}`: a version number of the file in two digits
- `{ext}`: an extension of the file
 - fit: FITS file compliant to the FITS Standard 4.0
 - lblx: PDS4 XML label file

3.5 Standards Used in Generating Data Products

3.5.1 PDS Standards

All data products described in this SIS conform to PDS4 standards as described in the PDS Standards document noted in the [“Applicable Documents” section](#) of this SIS. Prior to public release, all data products will have passed a PDS peer review to ensure compliance with applicable standards.

The Venus Climate Orbiter Akatsuki mission uses the 1.18.0.0 version or later of the PDS4 information model. All Venus Climate Orbiter Akatsuki LIR products will conform to this standard, however products may have various versions of specific Discipline Dictionaries.

3.5.2 Time Standards

All Venus Climate Orbiter Akatsuki data products contain UTC times in their file names and header text that have been derived from the Venus Climate Orbiter Akatsuki spacecraft clock time, TI. The transformation table from the spacecraft clock to UTC is provided by SIRIUS and is converted to SPICE SCLK file by the Akatsuki SPICE and Data Archive (SPIDAr) team. The transformation from the spacecraft clock time to UTC time is conducted by the SPIDAr team proprietarily using the SPICE SCLK and LSK kernels and the SPICE toolkit. However, UTC time can be converted by users to other times using standard SPICE routines with the SPICE SCLK file included in the Venus Climate Orbiter Akatsuki SPICE Kernel Archive Bundle.

3.5.3 Coordinate Systems

3.5.3.1 Space

Some geometric quantities appearing in the header of FITS files are in J2000 coordinates. In this coordinate, the +Z-axis points northward along the Earth's J2000 rotation axis and the +X-axis points toward the first point of Aries.

3.5.3.2 Venus

For the Venusian geometry, IAU Venus that is defined as the cytherocentric coordinate system for Venus is used. The defined ranges of the longitude and the latitude are from 0° to 360° and from -90° to 90° , respectively.

3.5.3.3 Image

For all the data stored in the IMAGE extension HDU in FITS files provided in this bundle, the +Y-axis of the spacecraft is upward and the -Z-axis of the spacecraft is rightward, when we use the commonly-used coordinate system with the origin at the lower-left corner of the image, the horizontal axis (or X-axis or first axis) oriented (increasing) from left to right, the vertical axis (or Y-axis or second axis) oriented (increasing) from bottom to top. This coordinate system is commonly used in visualization software of a FITS file, such as SAOImage DS9.

The following FITS header keywords are used to describe size of the image coordinate. These keywords are stored in the HDU of FITS file.

- NAXIS1: Number of pixels along the first axis or the horizontal axis that is same as +Ximg_fliprot axis described in the SPICE IKs for VCO UVI, IR1, IR2, and LIR instruments.
- NAXIS2: Number of pixels along the second axis or the vertical axis that is same as +Yimg_fliprot axis described in the SPICE IKs for VCO UVI, IR1, IR2, and LIR instruments.

For the indexes of the data for the center of each pixel, the x-index or horizontal index of the data, i , are 1, 2, ..., NAXIS1, and the y-index or vertical index of the data, j , are 1, 2, ..., NAXIS2. Note that each pixel has the size with unit square, i.e., 1×1 pixel, and the index of corners of the pixel is half integer.

The [Figure 11](#) shows the relationship between each pixel and the indexes in the image coordinate.

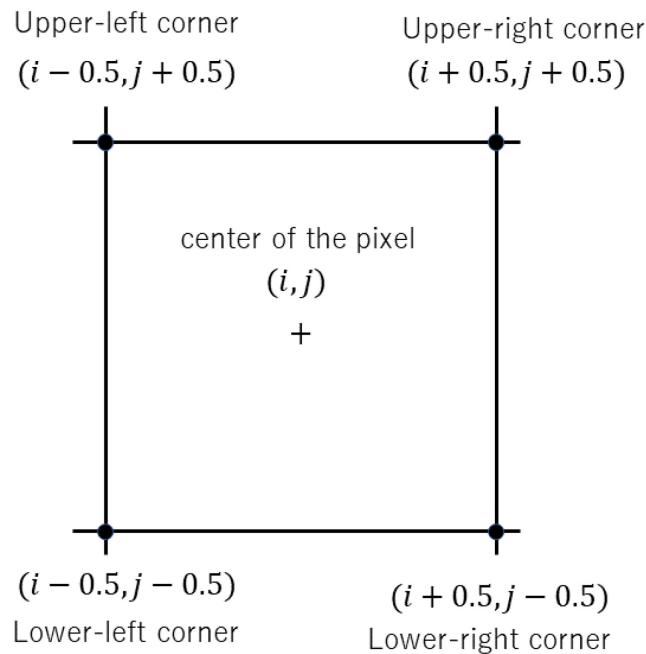


Figure 11 Layout and indexes of the center and the corners of the pixel in the image coordinate.

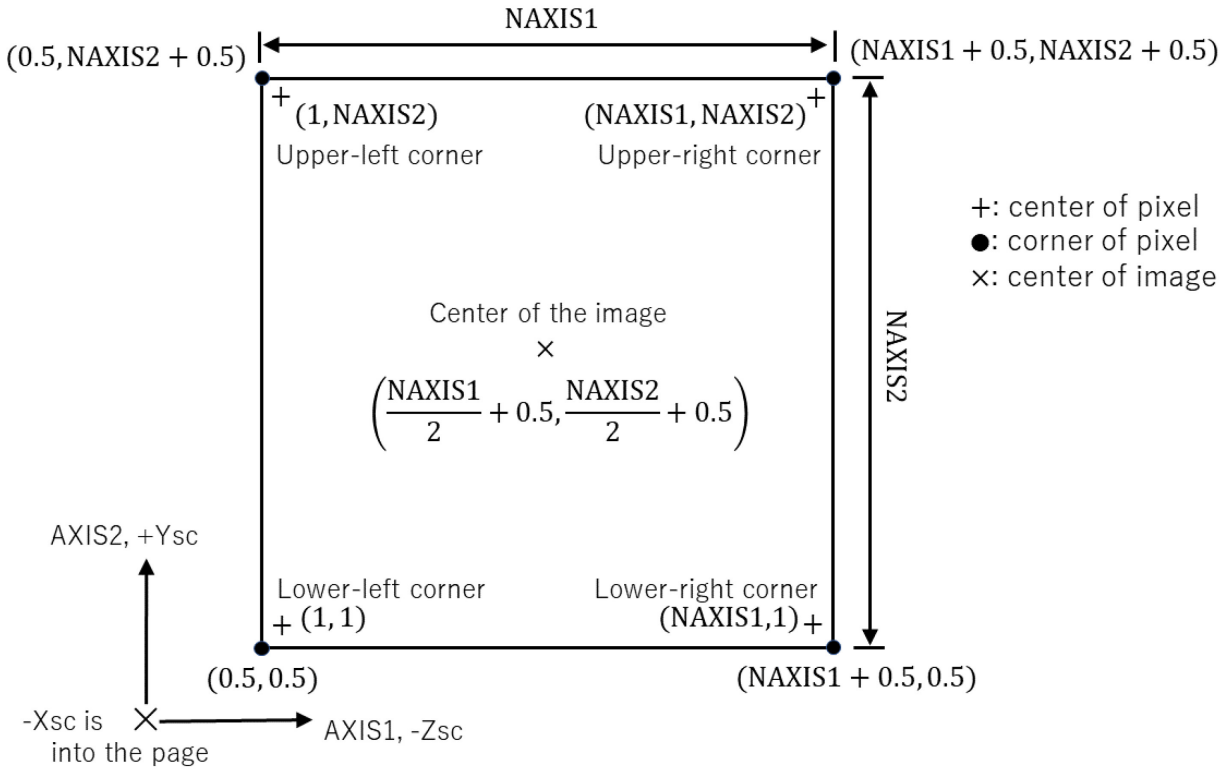


Figure 12 Layout of the image and FOV and the indexes of the center and the corners of the pixels in the image coordinate.

Figure 12 shows the layout of the FOV and indexes of the pixels in the image coordinate, where $+X_{sc}$, $+Y_{sc}$, and $+Z_{sc}$ are axes of the spacecraft frame projected onto the image. Note that the $-X_{sc}$ axis is the boresight direction of all cameras. Please refer the latest VCO Akatsuki Frames kernel (FK) and the latest VCO Akatsuki Instrument kernels (IKs) provided in the VCO Akatsuki SPICE Kernel Archive Bundle for the details.

For LIR images, no region of interest (ROI) function is used which is different from the other cameras, therefore the size of the image is 328×248 and the image coordinate is always same as full-size image coordinate.

3.5.4 Data Storage Conventions

All Venus Climate Orbiter Akatsuki data products are stored natively as FITS files or DSV files and the FITS files conform to the [FITS 4.0 standard](#).

3.6 Data Validation

The LIR team and the SPIDAr team check the validity of the data manually and visually when Level 1b images were created.

3.7 Data Quality and Coverage

The periods without observations and the reasons are summarized in [Table 18](#).

Table 18 Periods without observations and the reasons

Period	Reason
2010-05-22 – 2010-12-07	Cruise phase and 1st trial of VOI
2010-12-11 – 2015-12-06	Sun orbiting phase
2015-12-15 – 2016-01-14	Initial checkout
2016-02-10 – 2016-02-22	Not nominal attitude by misoperation
2016-05-26 – 2016-06-14	Superior conjunction
2017-12-28 – 2018-01-18	Superior conjunction
2018-07-06 – 2018-07-08	Not nominal attitude caused by single event upset
2018-07-29	Long umbra and penumbra from 12:00 to 15:48 (228 minutes)
2018-08-09	Long umbra and penumbra from 04:31 to 06:45 (133 minutes)
2019-01-19 – 2019-01-20	Long umbra and penumbra from 23:32 to 02:09 (156 minutes)
2019-01-30	Long umbra and penumbra from 11:06 to 16:08 (302 minutes)
2019-08-11 – 2019-09-04	Not nominal attitude
2019-08-07 – 2019-08-21	Superior conjunction
2019-09-16	Long penumbra from 15:09 to 22:16 (427 minutes)
2020-05-01	Long penumbra from 13:36 to 20:08 (392 minutes)
2020-12-15	Long penumbra from 15:38 to 22:30 (412 minutes)
2020-12-24 – 2020-12-25	Long penumbra from 21:35 to 01:45 (250 minutes)
2021-03-19 – 2021-04-03	Superior conjunction
2021-08-13	Long umbra and penumbra from 20:22 to 22:40 (138 minutes)
2022-01-26	Long umbra and penumbra from 00:02 to 01:58 (115 minutes)
2022-02-05	Long umbra and penumbra from 16:07 to 20:43 (276 minutes)
2022-02-15	Long penumbra from 11:55 to 15:44 (228 minutes)
2022-10-02 – 2022-10-03	Long penumbra from 20:39 to 00:12 (213 minutes)
2022-10-14 – 2022-11-01	Superior conjunction
2023-12-27	Long penumbra from 05:23 to 10:20 (297 minutes)
2024-01-05 – 2024-01-06	Long umbra and penumbra from 20:25 to 01:13 (287 minutes)

In 2018-09-17, instrument-specific ancillary data for images in the data recorder (DR) onboard were overwritten before downlink. These data include temperatures of detector, shutter, etc., and are used to process level 1 data. There are telemetries but at different acquiring timings, so the instrument status was estimated from different timing telemetry by interpolation in time. A new FITS header keyword, P_STGUES, has been introduced to indicate whether guessed instrument status is used or not. This FITS header keyword exists if P_DVER is '2019-11-12' or later. If value of P_STGUES is 'NORMAL', downlinked instrument status is used, and if value of P_STGUES is 'GUESSED', instrument status was

estimated by interpolation. Image acquisition time is also estimated from same observation program executed in September 2018. Error of estimated timing is assumed to be within about 1 second.

An abnormal image with a non-zero value of the number of saturated pixels (P_SPIXN) was found on January 10, 2020 for the first time, and such images sometimes appeared after that. Pixels with raw values out of the valid range of calibration or pixels where overflow or underflow occurred during onboard image data processing in DE are substituted by the saturated pixel flag value (P_SPIXV) of 1000 in level 2 data, and look like white dots in the dark background of the browse product. It is likely that the increase of deep space temperature and the white dots in the images are signs of sensitivity degradation due to outgassing inside the detector package (see also [Section 3.4.2.6](#)).

LIR usually acquires 32 consecutive images, sums these images onboard, and obtains a resultant image. The LIR team found that several images among the 32 images show significantly higher background temperatures than usual. The sudden changes of background temperature appear randomly. This phenomenon is under investigation.

[Table 19](#) shows a list of periods for lesser quality of images than usual.

Table 19 List of periods and reason for the quality of images is known not to be good enough.

Period	Reason
2018-07-23 – 2018-08-09	Not nominal temperature due to long penumbra and umbra
2019-01-05 – 2019-01-09	Not nominal temperature due to long penumbra and umbra
2019-01-15 – 2019-01-20	Not nominal temperature due to long penumbra and umbra
2019-01-26 – 2019-01-28	Not nominal temperature due to long penumbra and umbra
2020-12-12 – 2020-12-25	Not nominal temperature due to long penumbra
2022-02-02 – 2022-02-06	Not nominal temperature due to long penumbra and umbra
2024-01-02 – 2024-01-06	Not nominal temperature due to long penumbra and umbra

Geometry information included in the geometry data product and metadata of other data product is calculated using the SPICE toolkit and the SPICE kernels provided by the VCO Akatsuki SPICE Kernel Archive Bundle. In the VCO Akatsuki SPICE Kernel Archive Bundle, especially for the CKs, they don't have enough accuracy to derive enough accurate geometry information in pixel unit. There are two major possible sources of the resultant error in the VCO Akatsuki SPICE CKs. One is the attitude stability of the spacecraft, and the other is the measurement accuracy of the attitude of the spacecraft by the star trackers onboard the spacecraft. The latter is described in detail in the comment in the CKs.

3.8 Relation to other datasets

This bundle includes primary data migrated from the PDS3 Venus Climate Orbiter Akatsuki LIR datasets archived at DARTS released during 2017 to 2022. All data in the PDS3 VCO LIR datasets are not modified except for some incorrect files. Detail of the incorrect files is described in [Appendix 6.3](#). This bundle supersedes the VCO LIR PDS3 datasets. Mapping of PDS3 datasets and PDS4 collections is shown in [Table 20](#).

Table 20 Mapping of PDS3 datasets to PDS4 collections

Collection directory in PDS4 bundle	PDS3 DATA_SET_ID	PDS3 volume and directory
data_raw	VCO-V-LIR-2-EDR-V1.0	vcolir_0xxx/data/ ¹
data_calibrated	VCO-V-LIR-3-CDR-V1.0	vcolir_1xxx/data/ ¹
geometry	VCO-V-LIR-3-SEDR-V1.0	vcolir_2xxx/geometry/ ¹
calibration	VCO-V-LIR-3-CDR-V1.0	vcolir_1xxx/calib/ ¹

1: xxx is 001, 002, 003, 004, 005, 006, and 007.

If no Venus (or Earth for just after the launch) was in the FOV, L1b geometry file is not archived to the PDS4 bundle.

This bundle also includes data corresponding to data in non-PDS3-compliant datasets with a modification or format conversion. Mapping of non-PDS3-compliant datasets and PDS4 collections is shown in [Table 21](#).

Table 21 Mapping of non-PDS3 datasets to PDS4 collections

Collection directory in PDS4 bundle	Dataset name	Volume and directory name	Description
data_map	vco_lir_l3_v1.1	vcolir_7xxx/data/l3d/netcdf/ ¹	NetCDF is converted to BINTABLE extension of FITS
geometry	vco_lir_l3_v1.0	vcolir_7xxx/data/l3bx/fits/ ² vcolir_7xxx/data/l3cx/fits/ ²	L3bx and L3cx FITS files are archived in the vco_lir_l3_v1.0 dataset, and L3dx FITS file are not archived in vco_lir_l3_v1.0 nor vco_lir_l3_v1.1 datasets and included only in the LIR bundle.

1: xxx is 001, 002, 003, 004, 005, 006, 007, and 008 as of the date of June 2023.

2: xxx is 001, 002, 003, 004, 005, 006, and 007 as of the date of June 2023.

The original L3dx FITS file has 9th, 10th, 11th, and 12th HDUs when they were generated. In the geometry collection of PDS4 bundle, these HDUs were removed from the FITS file from data and metadata separation point-of-view. Values of FITS header keywords D_NPVAZM, D_SSCPX, D_SSCPX in the 12-th HDU were copied to FITS header keywords S_SSCPX, S_SSCPX, and S_NPVAZM in 2nd to 8th HDUs. Some of the removed extensions such as found limb points may be provided in a separate data product in future.

4 Detailed Data Product Specifications

The following sections provide detailed data product specifications for each level of LIR data product.

4.1 Data Product Structure and Organization

The Venus Climate Orbiter Akatsuki data archive is organized as bundles by instrument. The LIR bundle of the archive is organized by processing level, product type and then by orbit number. Data products are stored under each orbit number directory which is just under data collection directory or under product type directory under data collection directory. Which orbit number directory is selected to store data product is determined by the value of the `vco:orbit_number` attribute of the `Product_Observational / Observation_Area / Mission_Area / vco:Observation_Information / vco:Orbit_Information` class. The list of collections and products in each collection is summarized in [Table 22](#). These collections are under the Venus Climate Orbiter Akatsuki LIR bundle directory, `vco_lir`. Each name of collection is same as directory name in the bundle.

Table 22 List of collections and products in each collection

Directory name of collection	Collection	Products in the collection
browse	LIR Browse Collection	LIR Browse Product
calibration	LIR Calibration Collection	LIR Calibration Product
data_raw	LIR Raw Data Collection	LIR Raw Image Data Product
data_calibrated	LIR Calibrated Data Collection	LIR Calibrated Image Data Product
data_map	LIR Map Data Collection	LIR Map Data Product
document	LIR Document Collection	SIS (This file), instrument papers, and related documents
geometry	LIR Geometry Collection	LIR Geometry Data Product
miscellaneous	LIR Miscellaneous Collection	Products useful to understand data

Most of the products are stored as FITS files with a detached PDS label. The detached PDS labels are PDS4 compliant XML labels that describe the contents of the file and contain all necessary metadata to interpret the product. Files can be used and viewed using standard FITS tools, and also with standard PDS4 tools.

4.2 Data Format Descriptions

4.2.1 Level 1b - Raw Image Data

The L1b data product consists of individual FITS format files. These FITS files are compliant with the [FITS Standard Version 4.0](#). There is one possible violation of the standard on handling of keywords that store numeric value; if a value of a keyword that nominally stores numeric value is not available, the value is set to 'N/A' in string literal contrary to the data type.

For each FITS file, image data is stored in the data part of an IMAGE extension (HDU 1). The list of HDU in the file is as follows:

- HDU 0: Primary HDU (header only)
- HDU 1: Image data (IMAGE extension)

A list of metadata included in the FITS files is shown in [Table 23](#). Although the original data is 12-bit after A/D conversion, the value in each pixel is stored in 16-bit signed integer, thus the amount of an image with 328×248 pixels is about 160 KB for the L1b product.

Note that the FITS header keywords with the prefix P_ are the primary keywords for the Akatsuki mission, the keywords with the prefix S_ are the secondary or SPICE related keywords, and the keywords with the UV_, I1_, I2_, and LI_ are the instrument-specific keywords for UVI, IR1, IR2, and LIR, respectively. Detailed descriptions for the FITS header keywords are documented in [VCO Akatsuki FITS header keyword dictionary](#).

Table 23 L1b, L2b, L2c, L2d LIR image, and L1b and L3dx Geometry file metadata

PDS4 class/attribute	FITS keyword	Description for FITS keyword
Header keyword list for primary HDU		
Not assigned	SIMPLE	conformity to FITS standard
Not assigned	BITPIX	number of bits per data pixel
Not assigned	NAXIS	number of data axes
Not assigned	EXTEND	possibility of presence of extensions
Not assigned	FMTTYPE	type of format in FITS file
Not assigned	FTYPEVER	version of FMTTYPE definition
Not assigned	ORIGIN	organization responsible for the data
Not assigned	NEXTEND	number of standard extensions
Not assigned	TELESCOP	telescope used to acquire data
Not assigned	SPCECRFT	name of spacecraft
File / file_name	FILENAME	original filename
Not assigned	DATE	date of generation of this HDU in UTC
Not assigned	CNTTYPE	type of data content
Not assigned	CNTVER	version of data content
Header keyword list for secondary HDU		
Not assigned	XTENSION	type of extension
Array_2D_Image / Element_Array / data_type	BITPIX	number of bits per data pixel
Array_2D_Image / axes	NAXIS	number of data axes
Array_2D_Image / Axis_Array / elements	NAXIS1	length of data axis 1
Array_2D_Image / Axis_Array / elements	NAXIS2	length of data axis 2
Not assigned	PCOUNT	number of parameters per group
Not assigned	GCOUNT	number of groups
Not assigned	EXTNAME	name of this HDU
Not assigned	EXTVER	version of the extension
Not assigned	ORIGIN	organization responsible for the data
Not assigned	DATE	date of generation of this HDU in UTC
Time_Coordinates / start_date_time	DATE-BEG	date of the start of observation in UTC

PDS4 class/attribute	FITS keyword	Description for FITS keyword
vco:Observation_Information / vco:observation_date_time and geom:Geometry / geom:Geometry_Orbiter / geom:geometry_reference_time_utc	DATE-OBS	date of the middle of observation in UTC
Time_Coordinates / stop_date_time	DATE-END	date of the end of observation in UTC
Not assigned	TELESCOP	telescope used to acquire data
Not assigned	SPCECRFT	name of spacecraft
Not assigned	INSTRUME	name of instrument
Target_Identification / name	OBJECT	name of observed object
Array_2D_Image / Element_Array / unit	BUNIT	physical units of the array values
Array_2D_Image / Object_Statistics / maximum	DATAMAX	maximum data value
Array_2D_Image / Object_Statistics / minimum	DATAMIN	minimum data value
Not assigned	P_LONAME	filename of raw image in level 0
Array_2D_Image / Special_Constants / missing_constant	P_MPIXV	pixel flag value for missing data in data array
Not assigned	P_MPIXN	number of pixels with missing value
Array_2D_Image / Special_Constants / error_constant	P_DPIXV	dead pixel flag value in data array
Not assigned	P_DPIXN	number of dead pixels in data array
Not assigned	P_SPIXO	saturated pixel offset value in data array
Array_2D_Image / Special_Constants / saturated_constant	P_SPIXV	saturated pixel flag value in data array
Not assigned	P_SPIXN	number of saturated pixels in data array
Array_2D_Image / Object_Statistics / mean	P_MEAN	mean value of the data
Array_2D_Image / Object_Statistics / standard_deviation	P_STDDEV	standard deviation of the data
VCO Observation Information		
img:Imaging / img:Exposure / img:exposure_duration	EXPOSURE	exposure time [s]
img:Imaging / img:Optical_Filter / img:filter_name	FILTER	filter name
vco:Observation_Information / vco:naif_instrument_name	P_ID	VCO instrument/filter ID
img:Imaging/img:Optical_Filter / img:center_filter_wavelength	P_FLTCW	center wavelength for the value of FILTER [μm]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
img:Imaging / img:Optical_Filter / img:bandwidth	P_FLTBW	bandwidth for the value of FILTER [μm]
Not assigned	P_FLTAT	average transmission for the value of FILTER
Not assigned	P_BINN	number of pixels for binning: 1 (no binning), 2 (2 × 2), 4 (4 × 4), or 8 (8 × 8)
Used for geom:vertical_coordinate_pixel and geom:horizontal_coordinate_pixel in geom:Geometry/geom:Image_Display_Geometry/geom:Object_Orientation_RA_Dec/geom:Reference_Pixel	P_POSLLX P_POSLLY	X-position (P_POSLLX) and Y-position (P_POSLLY) of lower-left corner pixel of image
	P_POSURX P_POSURY	X-position (P_POSURX) and Y-position (P_POSURY) of upper-right corner pixel of image
img:detector_to_image_rotation and img:detector_to_image_flip in img:Imaging/img:Detector	P_FLPROT	flip and rotation flag: 10 (flipped vertically)
Not assigned	P_OPOSX1 P_OPOSY1 P_OPOSX2 P_OPOSY2 P_OPOSX3 P_OPOSY3 P_OPOSX4 P_OPOSY4	Positions of four corners in detector pixel coordinate for X- and Y-axes with 1-based index: <ul style="list-style-type: none"> - P_OPOSX1 and P_OPOSY1 means left-bottom position, - P_OPOSX2 and P_OPOSY2 means right-bottom position, - P_OPOSX3 and P_OPOSY3 means left-top position, and - P_OPOSX4 and P_OPOSY4 means right-top position. Using P_POS[LL,UR][X,Y] instead of P_OPOS[X,Y][1,2,3,4] is recommended for easiness to users.
VCO Onboard Image Processing Information		
img:Imaging / img:Onboard_Compression / img:onboard_compression_class	P_CMPSTY	image compression type: RAWDATA, LOSSLES, or LOSSY
img:Imaging / img:Onboard_Compression / img:onboard_compression_type	P_CMPTYP	Image compression algorithm name: RAWDATA or HIREW (StarPixel Lossless)
img:Imaging / img:Onboard_Compression / img:StarPixel_Lossless_Parameters / img:starpixel_initial_subsampling_interval	P_CMPPAR	image compression parameter: initial subsampling interval for StarPixel Lossless

PDS4 class/attribute	FITS keyword	Description for FITS keyword
vco:Observation_Information / vco:image_processing_return_status	P_IMGERR	Image processing error log: NORMAL END or brief description of error information
VCO Spacecraft Clock Information		
msn:Mission_Information / msn:spacecraft_clock_start	P_SCCSC	VCO S/C clock observation start count
msn:Mission_Information / msn:spacecraft_clock_stop	P_SCCEC	VCO S/C clock observation end count
Version of FITS Header Keyword Dictionary		
Not assigned	P_DVER	Version of common keyword dictionary for VCO
LIR Telemetry data		
Not assigned	LI_PDATE	LIR telemetry processing date in UTC
Not assigned	LI_IMID	LIR Image ID (sequence number)
img:Imaging / img:Instrument_State / img:Device_Component_State	LI_PLTON	LIR Peltier power status: ON or OFF
vco:LIR_Instrument_Attributes / vco:peltier_target_temperature	LI_PLTST	LIR Peltier target temperature: ‘10C’ for 10 deg C or ‘40C’ for 40 deg C
img:Imaging / img:Instrument_State / img:Device_Component_State	LI_BOLST	LIR bolometer status
vco:LIR_Instrument_Attributes / vco:number_of_first_accumulation	LI_NINT1	LIR number of the first accumulation
vco:LIR_Instrument_Attributes / vco:number_of_second_accumulation	LI_NINT2	LIR number of the second accumulation
vco:LIR_Instrument_Attributes / vco:bolometer_calibration_target	LI_BOLTA	LIR bolometer calibration target value
vco:LIR_Instrument_Attributes / vco:bolometer_calibration_range	LI_BOLRA	LIR bolometer calibration range
Not assigned	LI_CENT1	LIR center TI of image accumulation
In the img:Imaging / img:Instrument_State / img:Device_Temperatures / img:Device_Temperature class, img:device_name values with “Uncooled micro-bolometer array” for LI_BOL_T, “Package of LIR-S” for LI_PKG_T, “Case of LIR-S” for LI_CAS_T, “Shutter of LIR-S” for LI_SHT_T, and “Lens of LIR-S” for LI_LEN_T.	LI_BOL_T	LIR mean bolometer temperature [deg C]
	LI_PKG_T	LIR mean package temperature [deg C]
	LI_CAS_T	LIR mean case temperature [deg C]
	LI_SHT_T	LIR mean shutter temperature [deg C]
	LI_LEN_T	LIR mean lens temperature [deg C]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
In the img:Imaging / img:Instrument_State / img:Device_Voltages / img:Device_Voltage class, img:device_name values with “Output voltage of the bandgap reference circuit for readout circuit of the bolometer” for LI_BGR, “Voltage in the circuit for calibration of the on-chip fixed pattern noise in the bolometer” for LI_VB1, and “Offset voltage applied to the A/D converter” for LI_ADOFS.	LI_BGR	LIR mean band gap reference voltage [V]
	LI_VB1	LIR mean reference voltage used in the micro-bolometer array [V]
	LI_ADOFS	LIR mean A/D offset voltage [V]
LIR Heater Control Electronics temperature		
Not assigned	LI_HKU	HK date/time for calibration in UTC
In the img:Imaging / img:Instrument_State / img:Device_Temperatures / img:Device_Temperature class, img:device_name values with “Baffle” for LI_HD_T, “Panel” for LI_PN_T, “Lens mount” for LI_LM_T, and “Analog electronics” for LI_AE_T.	LI_HD_T	Baffle temperature [deg C]
	LI_PN_T	Panel temperature [deg C]
	LI_LM_T	Lens mount temperature [deg C]
	LI_AE_T	Analog electronics temperature [deg C]
vco:LIR_Instrument_Attributes / vco:lir_housekeeping_packet_interpolation_flag	LI_HKF	LIR HK interpolation flag: - 0: LI_HD_T0 or LI_HD_T1 is not available. - 1: both of LI_HD_T0 and LI_HD_T1 are within 120 seconds from DATE-OBS - 2: same as 1 but within 2048 seconds.
vco:LIR_Instrument_Attributes / vco:lir_housekeeping_packet_date_time_before_observation	LI_HKU0	LIR HK acquisition date time before observation in UTC
vco:LIR_Instrument_Attributes / vco:lir_housekeeping_packet_date_time_after_observation	LI_HKU1	LIR HK acquisition date time after observation in UTC
Not assigned	LI_HD_T0	Baffle temperature before observation [deg C]
	LI_HD_T1	Baffle temperature after observation [deg C]
	LI_PN_T0	Panel temperature before observation [deg C]
	LI_PN_T1	Panel temperature after observation [deg C]
	LI_LM_T0	Lens mount temperature before observation [deg C]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
	LI_LM_T1	Lens mount temperature after observation [deg C]
	LI_AE_T0	Analog electronics temperature before observation [deg C]
	LI_AE_T1	Analog electronics temperature after observation [deg C]
vco:LIR_Instrument_Attributes / vco:lir_housekeeping_packet_before_observation_time_delta	LI_HKD0	LIR HK delta time before observation [s]
vco:LIR_Instrument_Attributes / vco:lir_housekeeping_packet_after_observation_time_delta	LI_HKD1	LIR HK delta time after observation [s]
LIR original Telemetry data		
Not assigned	LI_TnC	TI for n -th shutter-close image
	LI_TnO	TI for n -th shutter-open image
	LI_BnC	Bolometer temperature for n -th shutter-close image [deg C]
	LI_BnO	Bolometer temperature for n -th shutter-open image [deg C]
	LI_PnC	Package temperature for n -th shutter-close image [deg C]
	LI_PnO	Package temperature for n -th shutter-open image [deg C]
	LI_CnC	Case temperature for n -th shutter-close image [deg C]
	LI_CnO	Case temperature for n -th shutter-open image [deg C]
	LI_SnC	Shutter temperature for n -th shutter-close image [deg C]
	LI_SnO	Shutter temperature for n -th shutter-open image [deg C]
	LI_LnC	Lens temperature for n -th shutter-close image [deg C]
	LI_LnO	Lens temperature for n -th shutter-open image [deg C]
	LI_GnC	Band gap reference voltage for n -th shutter-close image [V]
	LI_GnO	Band gap reference voltage for n -th shutter-open image [V]
	LI_VnC	Reference voltage used in the micro-bolometer array for n -th shutter-close image [V]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
	LI_VnO	Reference voltage used in the micro-bolometer array for n -th shutter-open image [V]
	LI_AnC	Reference voltage used in the A/D converter for n -th shutter-close image [V]
	LI_AnO	Reference voltage used in the A/D converter for n -th shutter-open image [V]
Version of FITS Header Keyword Dictionary		
Not assigned	LI_DVER	LIR keyword dictionary version
VCO Observation Program ID		
vco:Observation_Information/vco:observation_program_id	P_OBSPRG	Observation Program ID
vco:Observation_Information/vco:observation_program_name	P_OPNAME	Name of Observation Program ID for P_OBSPRG
vco:Observation_Information/vco:observation_program_start_date_time	P_OPDATE	Start time of observation program ID for P_OBSPRG
VCO Salvaged Area Information		
Used for img:Imaging / img:Onboard_Compression / img:StarPixel_Lossless_Parameters / img:Image_Compression_Segment	P_NSALV	Number of salvaged areas. P_SALVn keywords exist for $n = 0, 1, 2, \dots, P_NSALV-1$. If the value of the keyword is 0, there are no P_SALVn keyword.
	P_SALVn	x- and y-ranges of n -th salvaged areas in '[x0,x1]x[y0,y1]' form where x0, x1, y0, and y1 are positive integers. The salvaged area ranges within [x0,x1] in x-axis and [y0,y1] in y-axis in the image coordinate. This area corresponds to one corrupted, salvaged tile data.
VCO Orbital Information at Periapsis Passage Time		
msn:start_orbit_number and msn:stop_orbit_number in msn:Mission_Information / msn:Orbital_Mission class	S_ORBITN	Orbit number of the spacecraft; 0 means before the successful orbit insertion, VOI-R1
vco:Observation_Information / vco:Orbit_Information / vco:periapsis_passage_date_time	S_PERTIM	Time of periapsis passage; This time is start time of orbit number S_ORBITN

PDS4 class/attribute	FITS keyword	Description for FITS keyword
vco:Observation_Information / vco:Orbit_Information / vco:subspacecraft_latitude_at_periapsis_passage, vco:subspacecraft_longitude_at_periapsis_passage, vco:subspacecraft_altitude_at_periapsis_passage	S_PERLON S_PERLAT S_PERALT	Sub spacecraft longitude (S_PERLON, [deg]), latitude (S_PERLAT, [deg]), and altitude (S_PERALT, [km]) of Venus at periapsis passage for orbit number S_ORBITN
vco:Observation_Information / vco:Orbit_Information / vco:orbit_inclination_angle	S_INCANG	Inclination angle of the orbit of orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_eccentricity	S_ECCENT	Eccentricity of the orbit of orbit number S_ORBITN; note that value exceeds 1 for S_ORBITN=1 because the VOI-R1 was not done at the periapsis passage time.
vco:Observation_Information / vco:Orbit_Information / vco:orbit_longitude	S_LONNOD	Orbit plane longitude of ascending node for orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_argument	S_ARGPER	Orbit plane argument of periapsis for orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_semimajor_axis_length	S_SEMIAX	Semi-major axis of the orbit for orbit number S_ORBITN [km]
VCO Geometry Information at observation		
geom:spacecraft_central_body_distance and geom:spacecraft_target_center_distance in geom:Geometry / geom:Geometry_Orbiter / geom:Distances / geom:Distances_Specific	S_DISTAV	Distance between the VCO spacecraft and Venus [km]
geom:Geometry / geom:Geometry_Orbiter / geom:Distances / geom:Distances_Specific / geom:target_heliocentric_distance	S_DISTVS	Distance between the VCO spacecraft and the Sun [km]
vco:Observation_Information / vco:target_apparent_diameter	S_APPDIA	Apparent diameter of Venus seen from the spacecraft [deg]
geom:horizontal_pixel_field_of_view and geom:vertical_pixel_field_of_view in geom:Geometry / geom:Geometry_Orbiter / geom:Pixel_Dimensions	S_IFOV	Instantaneous field of view [rad]
Not assigned	S_NPVAZM	Azimuthal angle of north pole vector from the center of Venus in the image measured from horizontal line of the image [deg]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
geom:subsolar_latitude (S_SOLLAT) and geom:subsolar_longitude (S_SOLLON) in geom:Geometry / geom:Geometry_Orbiter / geom:Surface_Geometry / geom:Surface_Geometry_Specific. Note that these values are calculated at the assumed cloud altitude described in S_CLDALT.	S_SOLLAT S_SOLLON	Sub solar latitude (S_SOLLAT) and longitude (S_SOLLON) of Venus [deg]
Not assigned	S_TGRADI	Radius of target planet at the equator [km]
geom:subspacecraft_latitude (S_SSCLAT) and geom:subspacecraft_longitude (S_SSCLON) in geom:Geometry / geom:Geometry_Orbiter / geom:Surface_Geometry / geom:Surface_Geometry_Specific. Note that these values are calculated at the assumed cloud altitude described in S_CLDALT.	S_SSCLAT S_SSCLON	Sub spacecraft latitude (S_SSCLAT) and longitude (S_SSCLON) of Venus [deg]
Not assigned	S_SSCLT	Sub spacecraft local time of Venus [hour]
geom:Geometry / geom:Geometry_Orbiter / geom:Illumination_Geometry / geom:Illumination_Specific / geom:phase_angle	S_SSCPHA	Sub spacecraft phase angle [deg]
geom:vertical_coordinate_pixel (S_SSCPX) and geom:horizontal_coordinate_pixel (S_SSCPX) in geom:Geometry / geom:Geometry_Orbiter / geom:Illumination_Geometry / geom:Illumination_Specific / geom:Reference_Pixel class	S_SSCPX S_SSCPX	x-position (S_SSCPX) and y-position (S_SSCPX) of image for sub spacecraft point. These indexes are described with 1-based indexing.
Not assigned	S_CLDALT	Assumed cloud altitude [km]
geom:x_position (S_SCPJ2X), geom:y_position (S_SCPJ2Y), and geom:z_position (S_SCPJ2Z) in geom:Geometry / geom:Geometry_Orbiter / geom:Vectors / geom:Vectors_Cartesian_Specific / geom:Vector_Cartesian_Position_Sun_To_Spacecraft	S_SCPJ2X S_SCPJ2Y S_SCPJ2Z	Spacecraft X (S_SCPJ2X), Y (S_SCPJ2Y), and Z (S_SCPJ2Z) position from the Sun in J2000 [km]
Not assigned	S_SDIRX S_SDIRY S_SDIRZ	x- (S_SDIRX), y- (S_SDIRY), and z- (S_SDIRZ) components of unit vector of the Sun direction in the spacecraft frame.
RA/Dec Information at observation		

PDS4 class/attribute	FITS keyword	Description for FITS keyword
geom:right_ascension_angle (S_RA, S_RA1, S_RA2, S_RA3, S_RA4) and geom:declination_angle (S_DEC, S_DEC1, S_DEC2, S_DEC3, S_DEC4) in geom:Geometry / geom:Image_Display_Geometry / geom:Object_Orientation_RA_Dec class.	S_RA S_DEC S_RA1 S_DEC1 S_RA2 S_DEC2 S_RA3 S_DEC3 S_RA4 S_DEC4	Right Ascension (RA) and Declination (Dec) of center and corners of the image. Note that values at the corners are with reference to the corner of the FOV instead of values at the center of the pixel at the corners: <ul style="list-style-type: none"> - (S_RA, S_DEC): at the image center - (S_RA1, S_DEC1): at the bottom-left corner - (S_RA2, S_DEC2): at the bottom-right corner - (S_RA3, S_DEC3): at the top-left corner - (S_RA4, S_DEC4): at the top-right corner
Quaternion of spacecraft attitude at observation		
geom:qcos (S_Q0SPC), geom:qsin1 (S_Q1SPC), geom:qsin2 (S_Q2SPC), and geom:qsin3 (S_Q3SPC) in geom:Geometry / geom:Image_Display_Geometry / geom:Quaternion_Plus_To_From class for rotation from J2000 to VCO_SPACECRAFT.	S_Q0SPC S_Q1SPC S_Q2SPC S_Q3SPC	Quaternion of the spacecraft attitude in SPICE format: Scalar part (S_Q0SPC), 1st, 2nd, and 3rd elements of vector part (S_Q1SPC, S_Q2SPC, and S_Q3SPC)
VCO lost telemetry guess status		
vco:Observation_Information / vco:instrument_status_guess_flag	P_STGUES	Telemetry data on instrument's status are acquired normally (NORMAL) or guessed (GUESSES)
LIR Count Conversion Information: Only exist for L2b		
Not assigned	LI_C2T	Method for converting pixel counts to brightness temperature
Used for deriving Reference_List / Source_Product_Internal	LI_C2TSC	Scaling table filename used for conversion from DN to brightness temperature
	LI_C2TOF	Offset table filename used for conversion from DN to brightness temperature
	LI_C2TSH	Shutter table filename used for conversion from DN to brightness temperature
	LI_C2TBF	LIR baffle table filename
	LI_C2TSR	LIR spectral response function filename

PDS4 class/attribute	FITS keyword	Description for FITS keyword
vco:LIR_Instrument_Attributes / vco:lir_calibration_reference_shutter_temperature	LI_C2TRF	LIR reference shutter temperature [deg C]
vco:LIR_Instrument_Attributes / vco:lir_calibration_reference_baffle_temperature	LI_C2TRB	LIR reference baffle temperature [deg C]
Not assigned	LI_C2TK7 LI_C2TK6 LI_C2TK5 LI_C2TK4 LI_C2TK3 LI_C2TK2 LI_C2TK1 LI_C2TK0	Coefficients of polynomial of conversion formula from radiance in counts to brightness temperature.
vco:LIR_Instrument_Attributes / vco:lir_wrong_bit_operation_flag	LI_B_ERR	Flag for the bit-shift operation procedure error during second accumulation; 1: bad, 0: no error.
vco:LIR_Instrument_Attributes / vco:lir_degradation_rate	LI_AEONT	LIR-AE operating time until DATE-OBS [d]
vco:LIR_Instrument_Attributes / vco:lir_degradation_rate	LI_DRATE	LIR sensitivity degradation rate [d**-1]
vco:LIR_Instrument_Attributes / vco:lir_l2d_reference_shutter_temperature	LI_RFSHT	Reference shutter temp used during L2d data production [K]
Used for deriving Reference_List / Source_Product_Internal	LI_OTHST	LIR-AE operating time history filename

The special flag values for the L1b data are listed in [Table 24](#).

Table 24 special flag values for the L1b data.

Name	Value	FITS header keyword
Missing value	-32767	P_MPIXV
Dead pixel flag value	-32768	P_DPIXV
Saturated pixel flag value	32767	P_SPIXV
Saturated pixel flag offset value	Undefined	P_SPIXO

4.2.2 Level 2b, Level 2c, and Level 2d – Calibrated Image Data

The format of Calibrated Image Data, Level 2b, Level 2c, and Level 2d products, are the same as that of the Level 1b product, except that the image data is converted into IEEE 754 single-precision (32-bit) floating-point values through the ground calibration procedure (see [Section 5.3.2.2](#)). The data amount for an image with 328×248 pixels is about 0.38 MB.

Some FITS keywords such as LI_C2TSC, LI_C2TRF, or other calibration related keywords are not appeared at Level 1b data but appeared at Level 2b, Level 2c, and Level 2d data.

The special flag values for the L2b, L2c, and L2d data are listed in [Table 25](#).

Table 25 special flag values for the L2b, L2c, and L2d data.

Name	Value	FITS header keyword
Missing value	0.0	P_MPIXV
Dead pixel flag value	0.0	P_DPIXV
Saturated pixel flag value	1000.0	P_SPIXV
Saturated pixel flag offset value	Undefined	P_SPIXO

4.2.3 Level 3d – Longitude-Latitude Map Data

The L3d data product consists of individual FITS format files. For each FITS file, data is stored in the data part of a BINTABLE extension. The list of HDU in the file is as follows:

- HDU 0: Primary HDU (header only)
- HDU 1: Map data (BINTABLE extension)

A description of each column is shown in [Table 26](#).

A list of metadata included in the FITS files is shown in [Table 27](#). The source product is Level 2d data, Geometry data created by the SPICE system, and VCO Akatsuki SPICE kernels.

Note that the FITS header keywords with the prefix P_ are the primary keywords for the Akatsuki mission, the keywords with the prefix S_ are the secondary or SPICE related keywords, and the keywords with the UV_, I1_, I2_, and LI_ are the instrument-specific keywords for UVI, IR1, IR2, and LIR, respectively. Detailed descriptions for the FITS header keywords are documented in [VCO Akatsuki FITS header keyword dictionary](#).

Table 26 Summary of VCO Akatsuki LIR Derived Longitude-Latitude Map Data

	Name	Data Type	Unit	Description
1	Longitude	SingedMSB2	Degrees	Longitude of the point from 0 to 360.
2	Latitude	SingedMSB2	Degrees	Latitude of the point from -90 to 90.
3	Brightness Temperature	IEEE754MSBSingle	K	Brightness Temperature observed at the point.
4	Incidence Angle	SingedMSB2	Degrees	Incidence Angle at the point.
5	Emission Angle	SingedMSB2	Degrees	Emission Angle at the point.
6	Phase Angle	SingedMSB2	Degrees	Phase Angle at the point.
7	Azimuthal Angle	SingedMSB2	Degrees	Azimuthal Angle at the point.

Table 27 L3d file metadata

PDS4 class/attribute	FITS keyword	Description for FITS keyword
Header keyword list for primary HDU		
Not assigned	SIMPLE	conformity to FITS standard
Not assigned	BITPIX	number of bits per data pixel
Not assigned	NAXIS	number of data axes
Not assigned	EXTEND	possibility of presence of extensions
Header keyword list for secondary HDU		
Not assigned	XTENSION	type of extension
Not assigned	BITPIX	number of bits per data pixel
Not assigned	NAXIS	number of data axes
Not assigned	NAXIS1	length of data axis 1
Not assigned	NAXIS2	length of data axis 2
Not assigned	PCOUNT	number of parameters per group
Not assigned	GCOUNT	number of groups
Not assigned	TFIELDS	number of field in each row
Table_Binary / Record_Binary / Field_Binary / name	TTYPEi	name of i-th column
Not assigned	TFORMi	data format of i-th column
Table_Binary / Record_Binary / Field_Binary / unit	TUNITi	physical units of i-th column
Table_Binary / Record_Binary / Field_Binary / scaling_factor	TSCALi	scaling factor for i-th column
Table_Binary / Record_Binary / Field_Binary / value_offset	TZEROi	offset for i-th column
Table_Binary / Record_Binary / Field_Binary / /Field_Statistics / minimum, maximum	TDMINi TDMAXi	Minimum value (TDMINi) and maximum value (TDMAXi) for i-th column
Table_Binary / Record_Binary / Field_Binary / Special_Constants / valid_minimum, valid_maximum	TLMINi TLMAXi	Valid minimum value (TLMINi) and Valid maximum value (TLMAXi) for i-th column
vco:Observation_Information / vco:naif_instrument_name	P_ID	VCO instrument/filter ID
Time_Coordinates / start_date_time	DATE-BEG	date of the start of observation in UTC
geom:Geometry / geom:Geometry_Orbiter / geom:geometry_reference_time_utc	DATE-OBS	date of the middle of observation in UTC
Time_Coordinates / stop_date_time	DATE-END	date of the end of observation in UTC
Target_Identification / name	OBJECT	name of observed object
img:Imaging / img:Optical_Filter / img:filter_name	FILTER	filter name

PDS4 class/attribute	FITS keyword	Description for FITS keyword
Not assigned	P_LONAME	filename of raw image in level 0
img:Imaging / img:Exposure / img:exposure_duration	EXPOSURE	exposure time [s]
msn:start_orbit_number and msn:stop_orbit_number in msn:Mission_Information / msn:Orbital_Mission class	S_ORBITN	Orbit number of the spacecraft; 0 means before the successful orbit insertion, VOI-R1
vco:Observation_Information / vco:Orbit_Information / vco:periapsis_passage_date_time	S_PERTIM	Time of periapsis passage; This time is start time of orbit number S_ORBITN
vco:Observation_Information / vco:Orbit_Information / vco:subspacecraft_latitude_at_periapsis_passage, vco:subspacecraft_longitude_at_periapsis_passag e, vco:subspacecraft_altitude_at_periapsis_passage	S_PERLON S_PERLAT S_PERALT	Sub spacecraft longitude (S_PERLON, [deg]), latitude (S_PERLAT, [deg]), and altitude (S_PERALT, [km]) of Venus at periapsis passage for orbit number S_ORBITN
vco:Observation_Information / vco:Orbit_Information / vco:orbit_inclination_angle	S_INCANG	Inclination angle of the orbit of orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_eccentricity	S_ECCENT	Eccentricity of the orbit of orbit number S_ORBITN; note that value exceeds 1 for S_ORBITN=1 because the VOI-R1 was not done at the periapsis passage time.
vco:Observation_Information / vco:Orbit_Information / vco:orbit_longitude	S_LONNOD	Orbit plane longitude of ascending node for orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_argument	S_ARGPER	Orbit plane argument of periapsis for orbit number S_ORBITN [deg]
vco:Observation_Information / vco:Orbit_Information / vco:orbit_semimajor_axis_length	S_SEMIAX	Semi-major axis of the orbit for orbit number S_ORBITN [km]
geom:spacecraft_central_body_distance and geom:spacecraft_target_center_distance in geom:Geometry / geom:Geometry_Orbiter / geom:Distances / geom:Distances_Specific	S_DISTAV	Distance between the VCO spacecraft and Venus [km]
geom:Geometry / geom:Geometry_Orbiter / geom:Distances / geom:Distances_Specific / geom:target_heliocentric_distance	S_DISTVS	Distance between the VCO spacecraft and the Sun [km]
vco:Observation_Information / vco:target_apparent_diameter	S_APPDIA	Apparent diameter of Venus seen from the spacecraft [deg]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
geom:horizontal_pixel_field_of_view and geom:vertical_pixel_field_of_view in geom:Geometry / geom:Geometry_Orbiter / geom:Pixel_Dimensions	S_IFOV	Instantaneous field of view [rad]
Not assigned	S_NPVAZM	Azimuthal angle of north pole vector from the center of Venus in the image measured from horizontal line of the image [deg]
geom:subsolar_latitude (S_SOLLAT) and geom:subsolar_longitude (S_SOLLON) in geom:Geometry / geom:Geometry_Orbiter / geom:Surface_Geometry / geom:Surface_Geometry_Specific. Note that these values are calculated at the assumed cloud altitude described in S_CLDALT.	S_SOLLAT S_SOLLON	Sub solar latitude (S_SOLLAT) and longitude (S_SOLLON) of Venus [deg]
Not assigned	S_TGRADI	Radius of target planet at the equator [km]
geom:subspacecraft_latitude (S_SSCLAT) and geom:subspacecraft_longitude (S_SSCLON) in geom:Geometry / geom:Geometry_Orbiter / geom:Surface_Geometry / geom:Surface_Geometry_Specific. Note that these values are calculated at the assumed cloud altitude described in S_CLDALT.	S_SSCLAT S_SSCLON	Sub spacecraft latitude (S_SSCLAT) and longitude (S_SSCLON) of Venus [deg]
Not assigned	S_SSCLT	Sub spacecraft local time of Venus [hour]
geom:Geometry / geom:Geometry_Orbiter / geom:Illumination_Geometry / geom:Illumination_Specific / geom:phase_angle	S_SSCPHA	Sub spacecraft phase angle [deg]
Not assigned	S_CLDALT	Assumed cloud altitude [km]
geom:vertical_coordinate_pixel (S_SSCPX) and geom:horizontal_coordinate_pixel (S_SSCPX) in geom:Geometry / geom:Geometry_Orbiter / geom:Illumination_Geometry / geom:Illumination_Specific / geom:Reference_Pixel class	S_SSCPX S_SSCPX	x-position (S_SSCPX) and y- position (S_SSCPX) of image for sub spacecraft point. These indexes are described with 1- based index.
Not assigned	FIT_STAT	Ellipse fitting status, 0 for NG, 1 for OK
Not assigned	D_SSCPX D_SSCPX	Corrected sub S/C X (D_SSCPX) and Y (D_SSCPX) index on image [pix]
Not assigned	D_NPVAZM	Corrected azimuth of north pole vector [deg]

PDS4 class/attribute	FITS keyword	Description for FITS keyword
Not assigned	D_LVANG	Correction angle [deg] between Lvobs which is defined as a unit vector from the focal point of the optics to the center of Venus calculated using SPICE, and Lvfit which is defined as a unit vector from the focal point of the optics to the center of Venus derived from limb-fitting technique
Not assigned	D_L3NC	L3 NetCDF filename
proc:Processing_Information / proc:Input_Product	D_SRCL2	source L2 filename
Used for Source_Product_Internal	D_SRCGEO	source geometry filename

4.2.4 geometry - Geometry Data

For each geometry information file, data are stored in the data part of the several HDUs (Header Data Unit) as IMAGE extensions. The list of HDU in the geometry files is as follows:

- HDU 0: Primary HDU (header only)
- HDU 1: Latitude
- HDU 2: Longitude
- HDU 3: Local (Solar) Time
- HDU 4: Phase Angle
- HDU 5: Incidence Angle
- HDU 6: Emission Angle
- HDU 7: Azimuthal Angle

The header of the primary HDU is same as those of L1b except for COMMENT lines. All FITS header keywords were copied from the IMAGE extension of the L1b FITS file and then only EXTNAME, ORIGIN, BUNIT, DATAMAX, DATAMIN, P_MEAN, and P_STDDEV were updated. The keywords related to the special flag values, P_MPIXV, P_MPIXN, P_DPIXV, P_DPIXN, P_SPIXO, P_SPIXV, and P_SPIXN were not updated. For the L3dx geometry data, D_SSCPX, D_SSCP_Y, and D_NPVAZM recorded in the original L3dx NetCDF file are copied to S_SSCPX, S_SSCP_Y, and S_NPVAZM in each IMAGE extension.

For the HDUs from HDU 1 to 7, each pixel of the data is a 32-bit floating-point number, thus the amount of the data of one geometry file associated to 328×248 pixels image is approximately 2.4 or 2.7 MB. The FITS header keywords related to the special flag values — P_MPIXV, P_MPIXN, P_DPIXV, P_DPIXN, P_SPIXO, P_SPIXV, and P_SPIXN — are not applied to the geometry data, even though they are defined in the FITS header. For the value of the pixels looking at deep space, IEEE NaN (Not a Number) was stored to the pixel.

All geometry information is calculated at time of DATE-OBS in the FITS header keyword or vco:Observation_Information / vco:observation_date_time in the PDS4 XML label.

4.2.5 Calibration Data

This section describes format of the LIR calibration data product.

There are 8 kinds of files; offset data for each pixel, scaling data for each pixel, shutter brightness correction data for each pixel, data for calibration of radiation from the baffle, bad pixel table, spectral response function table, LIR-AE operating time table, and filter transmission table. These files and their filenames in the calibration collection are summarized in [Table 28](#).

Please note that the filter transmission table is not used for calibration but is just archived for reference.

Note that the FITS files for calibration are not rotated nor flipped, so please flip data vertically in FITS files before use.

[Table 29](#) shows entries of headers of LIR calibration files.

Table 28 Calibration data and their filenames

Calibration Data	filename
Offset data	lir_offset_m1n1_v02.fit lir_offset_m32n1_v02.fit lir_offset_m32n32_v02.fit
Scaling factor data	lir_scaling_m1n1_v02.fit lir_scaling_m32n1_v02.fit lir_scaling_m32n32_v02.fit
Shutter brightness correction data	lir_shutter_m1n1_v02.fit lir_shutter_m32n1_v02.fit lir_shutter_m32n32_v02.fit
Data for calibration on radiation from baffle	lir_baffle_201712_all_m1n1_v02.fit ¹ lir_baffle_201712_all_m32n1_v02.fit ¹ lir_baffle_201712_all_m32n32_v02.fit ¹ lir_baffle_201712_mz_m1n1_v02.fit lir_baffle_201712_mz_m32n1_v02.fit lir_baffle_201712_mz_m32n32_v02.fit lir_baffle_201712_pz_m1n1_v02.fit lir_baffle_201712_pz_m32n1_v02.fit lir_baffle_201712_pz_m32n32_v02.fit
Bad Pixel Table	lir_badpixel_vVV.csv (VV: 01, 02, ...)
Spectral Response Function table	lir_srf_v02.tab
LIR-AE Operating Time Table	lir_operating_time_v01.csv
Filter Transmission Table	ft_lir_pic.tab ²

¹ These files are used only for preliminary calibration test and not used for current calibration process and are just archived for reference.

² This file is not used for the calibration process and is just archived for reference

Table 29 LIR calibration image data FITS header format

PDS4 attribute name	Keyword	Description for FITS keyword
Header listing for the primary HDU		
Not assigned	SIMPLE	conformity to FITS standard
Not assigned	BITPIX	number of bits per data pixel

PDS4 attribute name	Keyword	Description for FITS keyword
Not assigned	NAXIS	number of data axes
Not assigned	EXTEND	possibility of presence of extensions
Not assigned	FMTTYPE	type of format in FITS file
Not assigned	FTYPEVER	version of FMTTYPE definition
Not assigned	ORIGIN	organization responsible for the data
Not assigned	NEXTEND	number of standard extensions
Not assigned	TELESCOP	telescope used to acquire data
Not assigned	SPCECRAFT	name of spacecraft
File / file_name	FILENAME	original filename
Not assigned	DATE	date of generation of this HDU in UTC
Not assigned	CNTTYPE	type of data content
Not assigned	CNTVER	version of data content
Header listing for the secondary HDU		
Not assigned	XTENSION	Image extension
Array_2D_Image / Element_Array / data_type	BITPIX	array data type
Array_2D_Image / axes	NAXIS	number of array dimensions
Array_2D_Image / Axis_Array / elements	NAXIS1	length of data axis 1
Array_2D_Image / Axis_Array / elements	NAXIS2	length of data axis 2
Not assigned	PCOUNT	number of parameters
Not assigned	GCOUNT	number of groups
Not assigned	EXTNAME	name of this HDU
Not assigned	EXTVER	version of the extension
Not assigned	ORIGIN	Organization responsible for the data
Not assigned	DATE	date of generation of this HDU in UTC
Not assigned	INSTRUME	Name of instrument
Not assigned	OBJECT	Name of Object
Not assigned	BUNITS	physical units of the array values
Not assigned	DATAMAX	maximum data value
Not assigned	DATAMIN	minimum data value
Not assigned	EXPOSURE	Exposure time [sec]
Not assigned	FILTER	Filter name
Not assigned	P_BINN	number of pixels for binning: 1 (no binning), 2 (2×2), 4 (4×4), or 8 (8×8)
Not assigned	P_ROTFLG	flip and rotation flag: 0 (no flipping and no rotation)

PDS4 attribute name	Keyword	Description for FITS keyword
Not assigned	P_OPOSX1 P_OPOSY1 P_OPOSX2 P_OPOSY2 P_OPOSX3 P_OPOSY3 P_OPOSX4 P_OPOSY4	Positions of four corners in detector pixel coordinate for X- and Y-axes with 1-based index: - P_OPOSX1 and P_OPOSY1 means left-bottom position, - P_OPOSX2 and P_OPOSY2 means right-bottom position, - P_OPOSX3 and P_OPOSY3 means left-top position, and - P_OPOSX4 and P_OPOSY4 means right-top position.
Not assigned	LI_CTYP	LIR calibration parameter type
Not assigned	LI_CINT1	LIR target number of m (first accumulation)
Not assigned	LI_CINT2	LIR target number of n (second accumulation)
Not assigned	P_DVER	Version of common keyword dictionary for VCO
Not assigned	LIR_DVER	Version of keyword dictionary for LIR

4.3 Label and Header Descriptions

All LIR data products contain date and time information that can be used to sort and correlate the LIR data with the products from other instruments. FITS file header information or metadata is duplicated in the PDS4 XML label to enable analyses in either standard FITS tools or PDS4 tools. Data product labels are in XML format and are PDS4 compliant.

5 Applicable Software

5.1 Utility Programs

At the current time, the Venus Climate Orbiter Akatsuki project team has no plans to release any mission specific utility programs.

5.2 Applicable PDS Software Tools

Data products found in the Venus Climate Orbiter Akatsuki archive can be viewed with any PDS4 compatible software utility. A listing of these tools can be found at <https://pds.nasa.gov/tools/about/>. Venus Climate Orbiter Akatsuki image data are formatted as FITS data files, which can be read by any FITS compatible viewer or library function.

5.3 Software Distribution and Update Procedures

As no Venus Climate Orbiter Akatsuki specific software will be released to the public, this section is not applicable.

6 Appendices

6.1 References

- FITS Working Group, Definition of the Flexible Image Transport System (FITS), Version 4.0, https://fits.gsfc.nasa.gov/fits_standard.html, 2018.
- Fukuhara, T., et al., LIR: Longwave Infrared Camera onboard the Venus Orbiter Akatsuki, *Earth, Planets and Space*, **63**, 1009-1018, <https://doi.org/10.5047/eps.2011.06.019>, 2011.
- Fukuhara, T., et al., Absolute calibration of brightness temperature of the Venus disk observed by the Longwave Infrared Camera onboard Akatsuki, *Earth, Planets and Space*, **69**, 141, <https://doi.org/10.1186/s40623-017-0727-y>, 2017.
- Hihara, H., et al., Onboard Image Processing System for Hyperspectral Sensor, *Sensors*, 15(10):24926-24944, <https://doi.org/10.3390/s151024926>, 2015.
- Ogohara, K., et al., Overview of Akatsuki data products: definition of data levels, method and accuracy of geometric correction, *Earth, Planets and Space*, **69**, 167, <https://doi.org/10.1186/s40623-017-0749-5>, 2017.
- Taguchi, M., et al., Longwave Infrared Camera onboard the Venus Climate Orbiter, *Advances in Space Research*, **40**, 861-868, <https://doi.org/10.1016/j.asr.2007.05.085>, 2007.
- Taguchi, M., et al., In-orbit recalibration of Longwave Infrared Camera onboard Akatsuki, *Earth, Planets and Space*, **75**, 53, <https://doi.org/10.1186/s40623-023-01803-w>, 2023.
- Takada, J., et al., A fast progressive lossless image compression method for space and satellite images, *Geoscience and Remote Sensing Symposium, IGARSS 2007, IEEE International*, 479-481, <https://doi.org/10.1109/IGARSS.2007.4422835>, 2007.
- Tanaka, A., K. Chiba, T. Endoh, K. Okuyama, A. Kawahara, K. Iida, and N. Tsukamoto, Low-noise readout circuit for uncooled infrared FPA, *Proc. SPIE 4130, Infrared Technology and Applications XXVI*, 160-167, <https://doi.org/10.1117/12.409858>, 2000.

6.2 Definitions of Data Processing Levels

PDS4 Data Processing Levels (From PDS Policy on Data Processing Levels (2013-03-11)):

Telemetry: An encoded byte stream used to transfer data from one or more instruments to temporary storage where the raw instrument data will be extracted.

Raw: Original data from an instrument. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes will be reversed so that the archived data are in a PDS approved archive format.

Partially Processed: Data that have been processed beyond the raw stage but which have not yet reached calibrated status.

Calibrated: Data converted to physical units, which makes values independent of the instrument.

Derived: Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as ‘derived’ data if not easily matched to one of the other three categories.

6.3 List of different primary files between PDS3 datasets and this bundle

The following files in the PDS3 VCO-V-LIR-2-EDR-V1.0, VCO-V-LIR-3-CDR-V1.0, VCO-V-LIR-3-SEDR-V1.0 datasets are not included in this bundle because these files were generated with wrong information and should not be used.

lir_20180515_080916_opn_11b_v10.fit,
lir_20180515_120920_opn_11b_v10.fit,
lir_20180516_000920_opn_11b_v10.fit,
lir_20180516_020831_opn_11b_v10.fit,
lir_20180517_120921_opn_11b_v10.fit,
lir_20180517_180849_opn_11b_v10.fit,
lir_20180518_000725_opn_11b_v10.fit,
lir_20180518_020718_pic_11b_v10.fit,
lir_20180519_100921_opn_11b_v10.fit,
lir_20180519_180920_opn_11b_v10.fit,
lir_20180518_020718_pic_12b_v10.fit,
lir_20180518_020718_pic_12c_v10.fit,
lir_20180518_020718_pic_geo_v10.fit,
and associated browse products.

Corresponding L3 and L3x files to the above files are also not included in this bundle. The following L3b and L3bx files in the vco_lir_l3_v1.0 dataset should not be used, therefore L3d and L3dx corresponding to the following files are not included in this bundle.

lir_20180518_020718_pic_l3b_v10.nc
lir_20180518_020718_pic_l3bx_v10.fit
and associated browse product.

Some files in the PDS3 VCO-V-LIR-2-EDR-V1.0 dataset have wrong time information in P_SCSC and P_SCCEC, therefore also DATE-BEG, DATE-END, and DATE-OBS, because of a bug of the pipeline for L1a product. The pipeline was fixed and updated files are provided with v20 version string in the filename. The following list includes 37 pairs of the original file and its updated version:

lir_20160706_212104_pic_11b_v10.fit,lir_20160706_212052_pic_11b_v20.fit
lir_20160916_204830_pic_11b_v10.fit,lir_20160916_204736_pic_11b_v20.fit
lir_20161105_113757_pic_11b_v10.fit,lir_20161105_113841_pic_11b_v20.fit
lir_20161127_220805_pic_11b_v10.fit,lir_20161127_220843_pic_11b_v20.fit
lir_20170204_100722_pic_11b_v10.fit,lir_20170204_100820_pic_11b_v20.fit
lir_20170514_084202_pic_11b_v10.fit,lir_20170514_084112_pic_11b_v20.fit
lir_20170618_103810_pic_11b_v10.fit,lir_20170618_103818_pic_11b_v20.fit
lir_20170816_070915_pic_11b_v10.fit,lir_20170816_070819_pic_11b_v20.fit
lir_20171107_120157_pic_11b_v10.fit,lir_20171107_120115_pic_11b_v20.fit
lir_20180418_190815_pic_11b_v10.fit,lir_20180418_190821_pic_11b_v20.fit
lir_20180626_050009_pic_11b_v10.fit,lir_20180626_050111_pic_11b_v20.fit
lir_20180923_200806_pic_11b_v10.fit,lir_20180923_200815_pic_11b_v20.fit
lir_20181125_090800_pic_11b_v10.fit,lir_20181125_090822_pic_11b_v20.fit
lir_20181221_150853_pic_11b_v10.fit,lir_20181221_150821_pic_11b_v20.fit
lir_20190122_020855_pic_11b_v10.fit,lir_20190122_020817_pic_11b_v20.fit
lir_20190330_050801_pic_11b_v10.fit,lir_20190330_050818_pic_11b_v20.fit

lir_20190429_090905_pic_11b_v10.fit,lir_20190429_090821_pic_11b_v20.fit
lir_20190530_190120_pic_11b_v10.fit,lir_20190530_190114_pic_11b_v20.fit
lir_20190703_140748_pic_11b_v10.fit,lir_20190703_140820_pic_11b_v20.fit
lir_20191105_230848_pic_11b_v10.fit,lir_20191105_230814_pic_11b_v20.fit
lir_20200108_140717_pic_11b_v10.fit,lir_20200108_140819_pic_11b_v20.fit
lir_20200308_150139_pic_11b_v10.fit,lir_20200308_150113_pic_11b_v20.fit
lir_20200418_200804_pic_11b_v10.fit,lir_20200418_200818_pic_11b_v20.fit
lir_20200602_180820_pic_11b_v10.fit,lir_20200602_180818_pic_11b_v20.fit
lir_20200701_083212_pic_11b_v10.fit,lir_20200701_083114_pic_11b_v20.fit
lir_20200802_163019_pic_11b_v10.fit,lir_20200802_163113_pic_11b_v20.fit
lir_20201019_170124_pic_11b_v10.fit,lir_20201019_170114_pic_11b_v20.fit
lir_20201122_100152_pic_11b_v10.fit,lir_20201122_100116_pic_11b_v20.fit
lir_20210116_000208_pic_11b_v10.fit,lir_20210116_000110_pic_11b_v20.fit
lir_20210225_170854_pic_11b_v10.fit,lir_20210225_170821_pic_11b_v20.fit
lir_20210423_230845_pic_11b_v10.fit,lir_20210423_230819_pic_11b_v20.fit
lir_20210703_100839_pic_11b_v10.fit,lir_20210703_100817_pic_11b_v20.fit
lir_20210815_170843_pic_11b_v10.fit,lir_20210815_170815_pic_11b_v20.fit
lir_20210906_120853_pic_11b_v10.fit,lir_20210906_120819_pic_11b_v20.fit
lir_20210929_210044_pic_11b_v10.fit,lir_20210929_210112_pic_11b_v20.fit
lir_20211028_090737_pic_11b_v10.fit,lir_20211028_090819_pic_11b_v20.fit
lir_20211127_220826_pic_11b_v10.fit,lir_20211127_220817_pic_11b_v20.fit