TEXES
ARCHIVED DATA PRODUCTS (ADP)
SOFTWARE INTERFACE SPECIFICATION

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REVISION NOTICE

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1. PURPOSE AND SCOPE OF DOCUMENT

The purpose of this Archived Data Product SIS is to provide users of the TEXES data product with a detailed description of the product and a description of how it was generated, including data sources and destinations. The raw and reduced TEXES data retrieved from the NASA IRTF since November 2000 have been archived in the NASA/IPAC InfraRed Science Archive (IRSA) (https://irsa.ipac.caltech.edu/frontpage/) under the IRTF Link. The archived data products include the raw data, unique header information, data logs, the scripts used to run the pipeline software for each night of data, and reduced data including optimally extracted point source spectra and spectral data cubes of scan mode observations. The reduced data have been geometrically corrected, flat fielded, and radiance/flux calibrated as best as possible. This SIS is intended to provide enough information to enable users to read and understand the data product. The users for whom this SIS is intended are the scientists who will analyze the data, including those associated with the TEXES instrument, TEXES collaborators, and those in the general planetary, astrophysics, and astronomy science communities.

This Data Product SIS describes how the data in the archive were acquired by the TEXES instrument, and how they are processed, formatted, labeled, and uniquely identified. The document discusses standards used in generating the product and software that may be used to access the product. The data product structure and organization are described in sufficient detail to enable a user to read the product.

2. APPLICABLE DOCUMENTS

This Data Product SIS is intended to be consistent with the following documents:

1. Definition of the Flexible Image Transport System (FITS), version 2.1b, December 9, 2005, IAU FITS Working Group (http://fits.gsfc.nasa.gov/iaufwg/).

3. DATA PRODUCT CHARACTERISTICS AND ENVIRONMENT

This section describes the TEXES data product in greater detail, including how the data are acquired, the types of data, and how the data are processed.

3.1. Instrument Overview

The Texas Echelon cross Echelle Spectrograph, TEXES (Lacy et al., 2002), is a mid-infrared (5-25 µm) imaging spectrograph capable of operating in several modes recording point and extended source spectra at a variety of spectral resolutions. In this document we will quote performance metrics for TEXES when mounted at the NASA Infrared Telescope Facility, a 3-meter diameter infrared-optimized telescope atop Mauna Kea in Hawaii. Observations using TEXES mounted on the Gemini North 8-meter telescope have also been performed over the years, but those data have been reduced and archived within the Gemini Observatory Archive (https://archive.gemini.edu/searchform) and will not be discussed further here.

The most frequently used TEXES instrument mode is “hi-med”, a high-resolution cross-dispersed (by the medium-resolution echelle) mode achieving a resolving power $R \approx \lambda/\delta\lambda \sim 100{,}000$, 0.5% spectral coverage and a (1-2) x (4-10)″ slit. “Hi-lo” mode is a high-resolution cross-dispersed (by low-resolution grating) mode achieving $R \approx 100{,}000$, 0.25 µm spectral coverage, and a very short 1.4″ x 2″ slit. Medium resolution long-slit mode (“med”) achieves $R \approx 15{,}000$, 0.5% spectral coverage, and utilizes a 1.4″ x 45″ slit. Low resolution long slit mode (“lo”) achieves $\delta\lambda \approx 0.004$ µm, 0.25 µm coverage, and a ~1.4″ x 45″ slit. Two additional modes (source acquisition imaging and pupil imaging) are available, though these modes have not been used for science observations.

3.2. Data Product Overview

3.2.1. Data Acquisition

3.2.1.1 Observing Modes

At the telescope at the time of the observations TEXES data is written out in pairs of files consisting of an obs.####.hd header file (ascii format) and an obs.#### data file (binary format) (where obs is usually chosen by the observer as a 2 or more letter name to identify the object, i.e. jup=Jupiter, aher=Alpha Hercules, etc.). Each observation of a target or calibration object such as a flux standard or telluric divisor is preceded by a flat field measurement. To capture a flat the TEXES instrument rotates an ambient temperature blackbody in front of the instrument window. The software nominally measures two blackbody frames, rotates the chopper wheel to an open position, and then measures two sky frames. These calibration frames are saved in a flat.#### binary file and a flat.####.hd ascii header file where the number corresponds to the same number of the source or calibration observation. For nodded observations the sky for the flat field is retrieved from a position on the sky offset by 3 times the nod for that observation. So, a 3″ nodded observation would have a flat retrieved 9″ away from the source. For scan data it is assumed that the first position in the scan is on sky and thus the flat field is performed at the first position of the defined scan sequence.

TEXES science data are obtained using either the NOD observing mode or the SCAN observing mode. Both modes have to do with removing the sky+telescope background as is typical in mid-IR observing. In NOD mode, the telescope is periodically moved between two points on the sky. For point sources, both nod positions have the source on the slit provided the slit is long enough to accommodate that. When observing extended objects in nod mode or when observing with very short slits, the telescope is nodded to blank sky. TEXES nods use an alternating pattern best described as BABA. This means blank sky or offset position along the slit (the “B” beam) is observed first. This choice was made to help with hand guiding. In SCAN mode, the telescope starts on blank sky which will be used to subtract the background. The telescope steps across the object by step size of TELSTEP. In almost every case, the telescope motion is perpendicular to the slit. The telescope is not continuously moving; it steps to a position and dwells there for the desired time (see below for a comment about the detector integration during a SCAN). For best results, blank sky is again observed at the end of the SCAN on the other side of the object. The process is repeated depending on the desired file duration and the sky conditions. At the end of a SCAN observation, the telescope is moved back to the starting position and blank sky is again observed.

There are some common detector settings for both NOD and SCAN mode. FRAMETIM is the integration time for a single frame. Typical FRAMETIM values when observing in hi-med mode are 1 or 2 seconds depending on the background flux (wavelength dependent) and the observing mode. Intermediate values sometimes had residual pickup noise. To reduce data transfer, frames can be combined in hardware using the parameter NFRAME. Additionally, frames can be combined in software using the parameter NSUM. An advantage to keeping NSUM high relative to NFRAME is that time lost after telescope moves is less when the frames are combined in software. The total number of detector reads that go into a single TEXES raw image (256 x 256 pixels saved to disk) is thus NFRAME * NSUM. Because of the time required for the electronics to read and process the detector data, there are minimum times for the product of NFRAME*FRAMETIM for the different modes. Another parameter used, particularly in the SCAN observing mode, is NWRITE. This is the number of times to write a raw image to the file per telescope position.

For both NOD and SCAN data, the raw data are stored sequentially. In other words, the file is opened at the start of the observation and after every FRAMETIM seconds each pixel has integrated the desired time and the data are transferred to hardware. NFRAME images will be combined in hardware. NSUM hardware sums will be combined in software and stored to the file. Writing to the file at this telescope position will be done NWRITE times. At this point, the telescope will be commanded to move.

For NOD mode data, the parameter NNOD determines how many times to complete a nod pair. Therefore, there are 2*NNOD two images written to the file. In other words, assuming NWRITE = 1 and NNOD = 16, the raw NOD file will have 32 separate 256x256 pixel images.

For SCAN mode data, NPOINTS determines the number of points to collect data during the scan. Note that NPOINTS is one more than the number of telescope steps. There can be multiple scans saved to a single file using the NSCAN keyword. There will be extra sky frames at the end as set by NSKY. Because the first frame is always assumed to be blank sky, there are occasions where the telescope was moved during a file if the first scan was found to be poorly centered on the object.

A derivative of the SCAN mode observation is FSCAN. For FSCAN rather than stepping the instrument by the same repetitive step size TELSTEP, the software opens a user defined ascii file that has a list of offset pairs (east arcsec step and north arcsec step). The FSCAN then steps by the amount indicated in the file for each line in the file. FSCAN has often been used for Saturn observations when the observer wanted only to observe Saturn, but a normal scan would have required hundreds of steps to ensure that blank sky was obtained on the far side of Saturn's rings. Instead, the FSCAN file would have an initial large step (moving the instrument off onto sky), followed by ~5 steps of 0 E and 0 N (i.e. remaining stationary on sky), then another large move to get close to but not on Saturn, followed by steps of half slit width E and 0 N to step across the planet.

A final infrequently used derivative of SCAN mode is MAP mode. Map mode is a combination of SCAN and NOD mode. In MAP mode for each step of your scan you also nod the slit off the source. In this case, the telescope initially moves to the OFFSET position, then moves by the NOD distance. It takes a FRAME*NFRAME*NSUM*NWRITE integration in that position, then nods back to the OFFSET position and takes another integration. The telescope is then stepped by TELSTEP and the process is repeated.

An oddity regarding the SCAN and FSCAN data is that the array is continuously read out and the pixels reset with the data stored in a hardware buffer that can be saved or ignored. While each pixel integrates for the same duration (as set by FRAMETIM), the actual time of this integration depends on the individual pixel position with (1,1) the first to finish its integration and (256,256) the last. For scans, therefore, some pixels integrate during the telescope motion and the early pixels of the array have data from the previous position while the last pixels have data from the current telescope position. Because map steps are generally small (usually taken as half the size of the slit width), we accept this blurring.

3.2.1.2 Telescope Pointing

In general, the pointing accuracy and pointing reporting at the IRTF is less than optimal, which adds a level of complexity to the analysis of SCAN mode data in particular. During the course of a scan across an object, the telescope typically drifts relative to the object, in addition to the commanded discrete telescope steps. This drift is typically worse for non-sidereal objects and occurs even when non-sidereal rates are entered into the telescope pointing software. The drifting can be significantly reduced by using a guide star, but a guide star is not always available (particularly as many TEXES planetary science observations are obtained during the day) and guide star acquisition adds to the overhead time considerably.

This telescope drift causes the effective step size during scans to be slightly different to the commanded step size. This can cause the shape of the extended object in the scan to appear unusual. If the telescope is drifting in the same direction as the step direction, the object will look narrower than expected and if the telescope is drifting in the opposite direction as the step direction, the object will appear wider than expected. The telescope can also drift perpendicular to the step direction, which will give the object a skewed appearance. The telescope drift also requires the observer to manually adjust the pointing during the brief interval between successive scans in a file to keep the object centered within the scan.

When working with SCAN mode data of planetary objects, the only way to obtain accurate geometric calibration for each pixel is to fit the planetary limb and to solve for the center of the planet and the relative positions of each pixel. **This information is not included in the TEXES archived data and must be calculated by the user.** Due to the movement of the object between successive scans, geometric calibration must be carried out separately for each individual scan within a file (see Section 3.2.2.3.2 for the reduced file formats).

Telescope drift does also affect the acquisition of NOD mode data, as the observer must manually adjust the pointing to remain on target. However, the movement of the object within the slit is accounted for in the data reduction of co-added NOD mode data (see Section 3.3.4) and so the effect on the end user is minimal.

3.2.2. Pipeline Reduction and Production of Reduced Data

3.2.2.1. Raw Data FITS File Production

After collection of the data, the pipeline reduction code named "fife" is run on the data. This Fortran 95 code is archived in a public repository on GITHUB at https://github.com/TEXESArch/pipecode. For any given observation at the telescope the raw observations consist of a flat file, a science file, and header files for both. Fife takes the flat data and header file and converts it to a FITS file with the naming convention nom-name.flt.fits (flt = flat), where nom-name is formed by a set of rules. For example, TX21A0626.1058.flt.fits, the TX stands for TEXES, 21A for year and semester (A or B), month and day, followed by the sequence number of the file taken that night of observing. That information is followed by the flt.fits. It also takes the source or calibration data and header file and converts it to a FITS file with the final extension *.raw.fits. For the archive, these flt.fits and raw.fits are the uncalibrated as-measured observations from TEXES.

3.2.2.2. Raw Data Fits File Format

In general, the raw data (flat files, nod mode data files, and scan mode data files) are long-integer format. There are typically 3 axes (NAXIS = 3) with the first two being pixels on the detector with NAXIS1 being pixels within a given detector row (the fast clock, 256) and NAXIS2 representing steps to new detector rows (the slow clock, 256). In the cross-dispersed mode, high resolution orders run mostly along columns and the cross-dispersion direction is mostly along rows. For medium- and low-resolution modes the spectral dimension runs mostly along rows with the spatial information along the slit running mostly along columns.

The prime difference in the 3 file types is in the third dimension (NAXIS3).

3.2.2.2.1.Raw Flat Data File Format

For the raw data flat FITS files the nominal organization of the flat is to record 2 blackbody observations (producing two detector readouts for NAXIS3) and then two sky observations (producing two more detector readouts for NAXIS3). The number of blacks and skies can be changed by the operator and is often increased to 8 (for each) when observing bright sources like Venus or Mars. The number of blacks or skies recorded are reflected in the NNOD key word in the header, even though the actual recording of data is to record the NNOD blacks sequentially followed by the NNOD skies sequentially.

3.2.2.2.2.Raw Nod Mode Data File Format

For the raw data nod mode files, the nominal organization of the data is to record nod position B then nod position A. That is repeated for NNOD times. Thus, the number of total 256 x 256 images contained in a nod mode observation should be 2 x NNOD. It is possible that the nodded observations can be ended earlier than planned. If at the start NNOD is equal to 16, but the observations is ended after 8 the final file will contain only 2 x 8 frames. However, it is not possible to end the file in the middle of a nod pair. The file should always contain an even number of frames.

3.2.2.2.3.Raw Scan Mode Data File Format

For the raw data scan mode files, the nominal organization of the data is to record a frame for each position of the scan in order from scan offset position and then consecutive steps within the scan. This is repeated NSCAN times (full scan followed by next full scan). At the end the instrument records 3 extra sky frames (256 x 256 images) recorded at the initial offset position. Thus, the number of frames in a scan file should be NPOINTS*NSCAN+3. That said, it is possible to abort a scan after less than the full NSCAN requested at the start so a file started as NSCAN=4 could be ended after 1, 2 or 3 scans with the consequence of only recording NPOINTS*1+3, NPOINTS*2+3, or NPOINTS*3+3 frames, respectively.

3.2.2.3. Reduced/Calibrated Data Production

The source of the data contained in the TEXES calibrated data files is the original raw data described in the previous section. Not only does the pipeline reduction code "fife" write the raw data out to FITS file format, but it also proceeds to reduce and calibrate the data. The reduction consists of flat fielding, correcting for optical geometric distortions, radiometric calibrating, as well as coaddition of nod data within a file or over many observing files for NOD mode data. In general, our SCAN mode data has not been coadded. Given the variety of targets and needs for each target's science, it was deemed best to reduce the individual scans separately and allow the user to do the shifting/coaddition as they see fit.

3.2.2.3.1.Reduced Nod Mode Data File Format

The reduced Nod Mode data is written out into the primary HDU of the red.fits files in a 2- dimensional array of 32-bit real values. This 2-d array has naxis1 corresponding to the spectral dimension and Naxis2 corresponding to the spatial dimension (pixels along the slit). It is accompanied by a single extra table extension (Extension 1) which has 5 columns that are each naxis1 (spectral pixels) long. The columns of the first extension are: 1) wavenumber (cm^{-1}) not corrected for the motion of the Earth or Sun, 2) extracted flux (Jy), 3) noise (Jy) an estimate of the flux uncertainty, 4) Atmo, an estimate of the telluric transmission from (blackbody-sky)/blackbody, 5) wavelength (μm) in vacuum. The naming convention is similar to the raw data files with the "red" replacing "raw" (ie. TX21A0626.1058.red.fits). When a single sequence number (1058 in this case) is reported it is the reduced file for that single raw file. When a series is indicated, TX21A0626.1058-1062.red.fits, it indicates this reduced file is coaddition of files 1058-1062.

3.2.2.3.2.Reduced Scan Mode Data File Format

The data is written out into the primary HDU of the FITS files in a 3-dimensional spectro-spatial array of 32-bit real values. The 3-d array's Naxis1 is the spectral dimension, Naxis2 is the spatial dimension along the slit, and Naxis3 is the spatial dimension in the step direction of the scan. It is accompanied by a single extra table extension (Extension 1) which has 5 columns that are each naxis1 (spectral pixels) long. The columns of the first extension are: 1) wavenumber (cm^{-1}) not corrected for the motion of the Earth or Sun, 2) extracted flux (Jy), 3) noise (Jy) an estimate of the flux uncertainty, 4) Atmo, an estimate of the telluric transmission from (blackbody-sky)/blackbody, 5) wavelength (μm) in vacuum. Note, columns 2-4 are less useful when working with the scan data as they are averaged over the entire datacube rather than per scan step. The scan data FITS files come with a second extension which is a 2-d, spectral/spatial along the slit image, of the sky which was subtracted from the scan frames with units of erg/(s cm^2 cm^{-1} sr). A 3rd extension captures the 2-d, spectral/spatial along the slit image, of the scan noise with units of erg/(s cm^2 cm^{-1} sr). Note that this 3rd extension doesn't attempt to remove the source data before calculating the noise thus a bright source (something comparable to the telluric emission) would significantly bias this data and make it useless for a true noise measure. The naming convention is similar to the raw data files with the "red" replacing "raw" i.e. file TX21A0626.1058.red.fits would contain the reduced, coadded scans of the

1058 file. Given the issues with guiding and telescope drift it is strongly suggested that you use the single scan reduced data files. These are designated by an additional .0#. after the sequence number indicating the number of the scan from that file (i.e. TX21A0626.1058.02.red.fits is the second scan from file 1058).

Detailed specifications for the TEXES data products can be found in Appendix A and B of this document.

3.3. Data Processing

Data volume will vary because it is a function of the instrument mode used and the observing mode employed (i.e. SCAN mode observations generally require more data volume than NOD mode observations of point sources).

3.3.1. Data Processing Level

The TEXES archived data product contains the raw recorded observations as well as the calibrated infrared spectra, 2-dimensional echellograms, spectral data cubes (for SCAN, FSCAN and MAP data), and associated data.

3.3.2. Data Product Generation

The TEXES data is collected and recorded on the TEXES instrument computer operated at the NASA IRTF. Each night of observations along with a text notes file is recorded in a unique directory. Prior to and including the February 2013 observing run, a handwritten logbook was kept. These logbooks have been digitized and are included in an ancillary directory structure with each run/night. Since February 2013, the notes file has also included comments from the observer made throughout the night, replacing the handwritten logbooks.

3.3.3. Data Flow

At the end of each night, recorded observations are copied to the IRTF computers for backup. Over the following month (typically the following night), the TEXES team prepares a pipescript to be used by the fife pipeline reduction code to process the data. This reduced data set is saved to a subdirectory named pipe. After an observing run is completed all the raw and reduced data are copied over to the IRTF TEXES archive housed on a unique machine owned by the IRTF. There the pipescripts are copied to files named pipescript_archive and checked for accuracy and completeness. Then the pipeline software fife is run using the pipescript_archive files, creating the FITS files (raw, flt, red) to be archived at IRSA. The FITS files are then run through a quality control program that ensures that the data are ready to be archived. This program: (i) converts the date and time into the standardized format, (ii) adds the project title to each file, (iii) converts the object name into a standardized version, (iv) compares the nominal object name position with the actual RA and Dec to ensure that the correct object name was entered, and corrects the name if necessary, and (v) adds the true RA and Dec of the object based on either SIMBAD or NAIF SPICE kernels. No header information is deleted in this process; the original header entries are retained alongside the new values. The new corrected values adopt the nominal header name while the original values have the nominal header name appended by "_T" to denote that it is the telescope recorded value (i.e. RA and RA_T). Once the quality control is complete, the data is ready for delivery to IRSA to be made available to the public after the 18-month propriety period expires.

3.3.4. Data Processing Steps

The pipeline reduction code "fife" writes out the binary formatted raw data into raw FITS file without altering the data. It then performs calibration steps to convert the raw data into reduced calibrated data products also written out in unique FITS files. The reduction of the raw FITS format data can be repeated, possibly changing reduction parameters in pipescript_archive, by inserting a line 'rdfits = true' in the pipescript and running the reduction program fife.F90. In this case, the file names are left as the original names and are converted to the *.raw.fits names by fife. The major steps performed within the pipeline software are as follows:

1. The flat field for each *.raw.fits file is made from the *.flt.fits file with the same file name. The flat field, which is divided into the object file, is (black-sky)/$B_{wno}(T_{telescope})$, where B_{wno} is the Planck function at wavenumber (wno) and temperature, T. Black is the signal from a black spot on the chopper just above the instrument entrance window. In addition to providing intensity calibration, the flat field corrects for absorption of astronomical signals by the Earth's atmosphere to the extent that the telescope temperature equals the atmospheric temperature. If later correction for telluric absorption by division by a model is desired, a flat field of black/ $B_{wno}(T_{telescope})$ can be specified with a line 'flatmode = black' in the pipescript. There are other flat-fielding options, but they are rarely used. At times a statement 'flatmode = old' will be used in the pipescript. When invoked, fife will use the flat recorded from the previous file reduced in the pipescipt as the flat for the current observation. This is done primarily in cases where the drifting of the telescope caused the source to be in the field of view of the sky integrations during the flat. After the reduction of the object file the 'flatmode' reverts back to the way it was set prior to the 'flatmode = old' command in the pipescript. (Note that 'flatmode = old' should only be used when the file to be reduced has precisely the same spectral setup as the previous file in the pipescript.)

2. Distortions introduced by the spectrograph are corrected, based on the known distortions caused by the cross-dispersed grating optics. Parameters dependent on the spectrograph alignment can be changed in the pipescript, but in most cases are set automatically based on the observation date. The interpolation used in the distortion correction assumes that the echellogram is Nyquist sampled. This is strictly true only at wavelengths longer than 11µm but is a good approximation at all wavelengths and avoids smoothing caused by interpolation.

3. The distortion correction routine puts the spectrum on a logarithmic wavenumber (or wavelength) scale so that a Doppler shift correction is done by simply shifting the spectrum. The zero point of the wavenumber scale is determined by comparing the sky emission spectrum with a model. The dispersion is first determined by the spectrograph parameters but is adjusted based on the correlation with the atmospheric model. If a line 'checkall = true' is in the pipescript the correlation with the telluric model is done for every file. Otherwise, it is done each time the spectral setting or object is changed.

4. For nod-mode data a line 'weight = true' is usually included in the pipescript. This specifies that when the spectrum is extracted from the echellogram the signal along the slit is optimally weighted before being summed and that when nod pairs in the data file are added together, they are given weights proportional to the signal strength. Both weighting procedures significantly improve the signal-to noise ratio of the final spectrum. The extracted spectrum for each data file is stored in the *.red.fits file. If the line 'sumspec = whatever' is put in the pipescript before a set of file names and the line 'storesum' is put in after the set, the spectra are combined into a sum in a file labeled with the range of sequence numbers summed plus the .red.fits (i.e. 1058-1062.sum.fits, for a sum of files 1058-1062).

5. Spectra may be shifted along the slit both within a file and when adding files together to correct for guiding errors, if 'shift = true' is specified in the pipescript. In addition, small shifts are made before differencing A and B nod echellograms to correct for shifts in the spectrograph optics caused by the motion of the telescope, if 'bounce = x' is specified, where x, typically 0.2, gives the trial pixel shift.

6. Spectrum extraction and weighting is not done for scan-mode data. Whether scans within a file or among several files are added is set by the pipescript flags sumscan and sumspec. If sumscan is set to false the individual scans within a file are stored to *.nn.red.fits, where nn = 01, 02, 03, ... Scans within a file can be shifted with 'shift = true', but it is usually best to set 'sumscan = false' and shift after running fife.

4. DETAILED DATA PRODUCT SPECIFICATIONS

The TEXES data products shall be grouped into a hierarchal directory structure with the observing run as the top level and lower-level directories each observing day. Observing day is defined to be start of observing day in UTC until end of observing period for that day even if it may run into the next UTC Day.

4.1. Data Product Structure and Organization

The structure of the DATA directory is based primarily on observing run month and year (i.e., August 2022 = aug22) and sub directories as the date number of that month (aug22/11 is the 11th of August 2022). For observing runs that cross over month boundaries the numbering of days remains consecutive to retain clarity and not break the observing run directory structure (i.e., aug22/33 would be 2nd Sept. 2022).

4.2. Data Format Descriptions

The types of data included in the TEXES data product are listed in Section 3.2. All these data are stored in a single FITS file. Each data type within the FITS file is stored in a separate HDU (Header and Data Unit).

5. APPLICABLE SOFTWARE

The format of the TEXES data product is standard FITS. There are a few different software libraries available that enable the reading and writing of standard FITS files. These libraries are written in several different languages and are available for a variety of different computing platforms. A list of these libraries can be found at the FITS Support Office web site (http://fits.gsfc.nasa.gov/). Commonly used FITS libraries include the IDL Astronomy Library (http://idlastro.gsfc.nasa.gov/fitsio.html) and the CFITSIO/FITSIO library (http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html). For this reason, no additional special software will be included in the TEXES archive to parse and interpret the data files.

5.1. Utility Programs

No utility programs are currently planned. However, they may be included in future revisions.

6. REFERENCES

Lacy, J. H., M. J. Richter, T. K. Greathouse, D. T. Jaffe, and Q. Zhu (2002), TEXES: A sensitive high-resolution grating spectrograph for the mid-infrared, *Publications of the Astronomical Society of the Pacific*, *114*(792), 153-168.

APPENDIX A – DETAILED TEXES RAW DATA FITS FILE SPECIFICATIONS

For each of the FITS HDUs described in Section 4.2 of this document, this Appendix lists and describes the specific header keywords and provides details on the format and layout of the data. Values followed by an asterisk (*) are variable on a per-file basis and are examples only.

1. SAMPLE SCAN MODE DATA FILE

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	
SIMPLE	T	
BITPIX	32	
NAXIS	3	
NAXIS1	256	
NAXIS2	256	
NAXIS3	148*	
EXTEND	T	
COMMENT	Raw data is stored as nx x ny x nz = 256x 256x 148 integer array*	
FILENAME	'ven.1058'*	
OBJECT_T	'Venus'*	object name entered at telescope
OBJECT	'Venus'*	standardized/corrected object name
NAIF_ID	'299'*	
LONGSTRN	'OGIP 1.0'	The OGIP long string convention may be used.
COMMENT	This FITS file may contain long string keyword values that are	
COMMENT	continued over multiple keywords. This convention uses the '&'	
COMMENT	character at the end of a string which is then continued	
COMMENT	on subsequent keywords whose name = 'CONTINUE'.	
TITLE	'The thermal structure of Venus' mesosphere from high resolution o&'*	
CONTINUE	'bservations of CO2 lines'*	project title
PI	'Giles'*	
PID	'2021A015'*	IRTF program ID

FITS Header Keyword	Value	Description
OBJTYPE	'targ'*	primary science target
FEATURE	'co2'*	spectral feature
WAVENO0	7.933000E+02*	planned central wavenumber
ORDER	4*	cross-dispersion grating order number
TEMPER	2.935000E+02*	ambient temperature
TAU	''	
HUMIDITY	2.270000E+01*	dome level humidity; not related to pwv
OBSMODE	'scan'*	
TELSTEP	'0.70 E 0.00 N'*	
OFFSET	'-12.00 E 0.00 N'*	
NOD	0.000000E+00*	0.00 E 0.00 N
NPOINTS	34*	number of points in scan
NODWAIT	'4.05'*	
FRAMETIM	2.023834E+00*	integration time / frame
NFRAME	1*	number of frames coadded in hardware
NSUM	1*	number of frames coadded in software
NWRITE	1*	number of frames written per nod phase
NSCAN	4*	number of scans
OBSTIME	8.100000E+00*	calculated observation time (s)
TOTTIME	3.756600E+02*	calculated total clock time (s)
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	5.314479E+01*	echelle grating angle (deg)
LORES	-1.429236E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.400000E+02*	slit wheel angle
FILTER	2.859000E+02*	filter wheel angle
PARAB	'49.320'*	

FITS Header Keyword	Value	Description
NSKY	3*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'7.076'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	
SVOLT	'5.962'*	
FVOLT	'6.743'*	
PVOLT	'5.057'*	
EVOLT0	'14.188'*	
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	
FVOLT0	' 1.978'*	
PVOLT0	' 4.920'*	
TEMP_DET	3.470000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.343'*	
TEMP_LHE	'0.046'*	
TEMP_LN2	'0.010'*	
PRESSURE	1.422000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	2.270000E+01*	dome level humidity; not related to pwv
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-06-26'*	yyyy-mm-dd observation date
DATE-REL	'2022-12-26'*	yyyy-mm-dd public release date

FITS Header Keyword	Value	Description
TIME-OBS	'22:10:16.000'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)
RA_T	122.182700000*	RA reported by telescope (degrees)
DEC_T	21.7590600000*	Dec reported by telescope (degrees)
RA	121.895757542*	actual RA of object (degrees)
DEC	21.8211159567*	actual Dec of object (degrees)
LST	'06:09:22.19'*	
HA	-1.989350E+00*	degrees
AIRMASS	1.131000E+00*	at start of integration
FOCUS	'-3.763'*	
ENDTIME	'22:10:16.000'*	
EQUINOX	2.000000E+03*	
VEHELIO	9.773205E+00*	heliocentric motion of Earth from object(km/s)
VELSR	1.940307E+01*	LSR motion of Earth from object (km/s)
PLTSCL	3.373787E-01*	arcsec / pixel after focal reduction
CDELT2	9.371629E-05*	deg / pixel along slit
SLITWID	1.299343E+00*	slit width (arcsec)
BEAMTIME	2.023834E+00*	frtime*nframe*nsum*nwrite
ORIGIN	'University of Texas'	
END		

2.

2. SAMPLE NOD MODE DATA FILE

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	
BITPIX	32	
NAXIS	3	
NAXIS1	256	
NAXIS2	256	
NAXIS3	32*	
EXTEND	T	
COMMENT	Raw data is stored as nx x ny x nz = 256x 256x 32 integer array*	
FILENAME	'io.9033'*	
OBJECT_T	'Io'*	object name entered at telescope
OBJECT	'Io' *	standardized/corrected object name
NAIF_ID	'501'*	
LONGSTRN	'OGIP 1.0'	The OGIP long string convention may be used.
COMMENT	This FITS file may contain long string keyword values that are	
COMMENT	continued over multiple keywords. This convention uses the '&'	
COMMENT	character at the end of a string which is then continued	
COMMENT	on subsequent keywords whose name = 'CONTINUE'.	
TITLE	'Studying Io's Seasonal Atmosphere and Investigating Volcanic Emis&'*	
CONTINUE	'sions'*	project title
PI	'Tsang'*	
PID	'2021A028'*	IRTF program ID
OBJTYPE	'targ'*	primary science target
FEATURE	'so2'*	spectral feature
WAVENO0	5.306000E+02*	planned central wavenumber
ORDER	3*	cross-dispersion grating order number

FITS Header Keyword	Value	Description
TEMPER	2.835000E+02*	ambient temperature
TAU	''	
HUMIDITY	9.400000E+00*	dome level humidity; not related to pwv
OBSMODE	'nod'*	
TELSTEP	'0.00 E 0.00 N'*	
OFFSET	'0.00 E 0.00 N'*	
NOD	6.000000E+00*	0.00 E 6.00 N
NODWAIT	'1.2'*	
FRAMETIM	1.011917E+00*	integration time / frame
NFRAME	1*	number of frames coadded in hardware
NSUM	6*	number of frames coadded in software
NWRITE	1*	number of frames written per nod phase
NNOD	16*	number of nod pairs
OBSTIME	1.942900E+02*	calculated observation time (s)
TOTTIME	2.665700E+02*	calculated total clock time (s)
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	6.396559E+01*	echelle grating angle (deg)
LORES	-1.420200E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.599800E+02*	slit wheel angle
FILTER	3.010200E+02*	filter wheel angle
PARAB	' 0.360'*	
NSKY	0*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'5.622'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	

FITS Header Keyword	Value	Description
SVOLT	'6.295'*	
FVOLT	'6.995'*	
PVOLT	'4.921'*	
EVOLT0	'14.188'*	
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	
FVOLT0	' 1.978'*	
PVOLT0	' 4.920'*	
TEMP_DET	3.530000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.347'*	
TEMP_LHE	'0.047'*	
TEMP_LN2	'0.011'*	
PRESSURE	1.381000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	9.400000E+00*	dome level humidity; not related to pwv
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-07-04'*	yyyy-mm-dd observation date
DATE-REL	'2023-01-04'*	yyyy-mm-dd public release date
TIME-OBS	'14:02:56.250'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)

FITS Header Keyword	Value	Description
RA_T	334.277500000*	RA reported by telescope (degrees)
DEC_T	-11.7414700000*	Dec reported by telescope (degrees)
RA	333.998624224*	actual RA of object (degrees)
DEC	-11.8578275699*	actual Dec of object (degrees)
LST	'22:32:14.82'*	
HA	2.522806E-01*	degrees
AIRMASS	1.176000E+00*	at start of integration
FOCUS	'-5.391'*	
EQUINOX	2.000000E+03*	
VEHELIO	-2.046073E+01*	heliocentric motion of Earth from object(km/s)
VELSR	-2.559892E+01*	LSR motion of Earth from object (km/s)
PLTSCL	3.087496E-01*	arcsec / pixel after focal reduction
CDELT2	8.576378E-05*	deg / pixel along slit
SLITWID	1.949014E+00*	slit width (arcsec)
BEAMTIME	6.071501E+00*	frtime*nframe*nsum*nwrite
ORIGIN	'University of Texas'	
END		

3.

3. SAMPLE FLAT FILE

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	
BITPIX	32	
NAXIS	3	
NAXIS1	256	

FITS Header Keyword	Value	Description
NAXIS2	256	
NAXIS3	4*	
EXTEND	T	
COMMENT	Raw data is stored as nx x ny x nz = 256x 256x 4 integer array*	
FILENAME	'flat.9033'*	
OBJECT_T	'Io'*	object name entered at telescope
OBJECT	'Io'*	standardized/corrected object name
NAIF_ID	'501'*	
LONGSTRN	'OGIP 1.0'	The OGIP long string convention may be used.
COMMENT	This FITS file may contain long string keyword values that are	
COMMENT	continued over multiple keywords. This convention uses the '&'	
COMMENT	character at the end of a string which is then continued	
COMMENT	on subsequent keywords whose name = 'CONTINUE'.	
TITLE	'Studying Io's Seasonal Atmosphere and Investigating Volcanic Emis&'*	
CONTINUE	'sions'*	project title
PI	'Tsang'*	
PID	'2021A028'*	IRTF program ID
FEATURE	'so2'*	spectral feature
WAVENO0	5.306000E+02*	planned central wavenumber
ORDER	3*	cross-dispersion grating order number
TEMPER	2.835000E+02*	ambient temperature
TAU	''	
HUMIDITY	9.500000E+00*	dome level humidity; not related to pwv
OBSMODE	'flat'	
TELSTEP	'0.00 E 0.00 N'*	
OFFSET	'0.00 E 0.00 N'*	
NOD	6.000000E+00*	0.00 E 6.00 N

FITS Header Keyword	Value	Description
NODWAIT	'1.2'*	
FRAMETIM	1.011917E+00*	integration time / frame
NFRAME	1*	number of frames coadded in hardware
NSUM	6*	number of frames coadded in software
NWRITE	2*	number of frames written per nod phase
NNOD	2*	number of nod pairs
OBSTIME	2.429000E+01*	calculated observation time (s)
TOTTIME	5.817000E+01*	calculated total clock time (s)
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	6.396559E+01*	echelle grating angle (deg)
LORES	-1.420200E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.599800E+02*	slit wheel angle
FILTER	3.010200E+02*	filter wheel angle
PARAB	' 0.360'*	
NSKY	0*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'5.622'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	
SVOLT	'6.295'*	
FVOLT	'6.995'*	
PVOLT	'4.921'*	
EVOLT0	'14.188'*	
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	

FITS Header Keyword	Value	Description
FVOLT0	' 1.978'*	
PVOLT0	' 4.920'*	
TEMP_DET	3.530000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.347'*	
TEMP_LHE	'0.047'*	
TEMP_LN2	'0.011'*	
PRESSURE	1.380000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	9.500000E+00*	dome level humidity; not related to pwv
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-07-04'*	yyyy-mm-dd observation date
DATE-REL	'2023-01-04'*	yyyy-mm-dd public release date
TIME-OBS	'14:02:12.550'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)
RA_T	334.277500000*	RA reported by telescope (degrees)
DEC_T	-11.7414700000*	Dec reported by telescope (degrees)
RA	333.998617564*	actual RA of object (degrees)
DEC	-11.8578279028*	actual Dec of object (degrees)
LST	'22:31:31.00'*	
HA	2.401139E-01*	degrees
AIRMASS	1.176000E+00*	at start of integration

FITS Header Keyword	Value	Description
FOCUS	'-5.391'*	
ENDTIME	'14:02:12.550'*	
EQUINOX	2.000000E+03*	
COMMENT	End of flat header	
ORIGIN	'University of Texas'	
END		

4.

APPENDIX B – DETAILED TEXES REDUCED DATA FITS FILE SPECIFICATIONS

For each of the FITS HDUs described in Section 4.2 of this document, this Appendix lists and describes the specific header keywords and provides details on the format and layout of the data. Values followed by an asterisk (*) are variable on a per-file basis and are examples only.

1. SAMPLE REDUCED NOD FILE (SINGLE NOD FILE OBSERVATION)

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	
BITPIX	-32	
NAXIS	2	
NAXIS1	768*	
NAXIS2	64*	
EXTEND	T	
COMMENT	The primary HDU contains a 2-D spectral-spatial image	
COMMENT	The primary HDU is followed by a table extension	
COMMENT	(EXTNAME = EXTRACTED)	
COMMENT	giving the observed vacuum wavenumbers,	
COMMENT	flux through the slit, estimated flux uncertainty,	

FITS Header Keyword	Value	Description
COMMENT	estimated atmo transmission = (black-sky)/black	
COMMENT	and the observed vacuum wavelengths	
CTYPE1	'spectral pixel'*	
CTYPE2	'pixel along slit'	
FILENAME	'io.9033'*	
OBJECT_T	'Io'*	object name entered at telescope
OBJECT	'Io'*	standardized/corrected object name
NAIF_ID	'501'*	
LONGSTRN	'OGIP 1.0'	The OGIP long string convention may be used.
COMMENT	This FITS file may contain long string keyword values that are	
COMMENT	continued over multiple keywords. This convention uses the '&'	
COMMENT	character at the end of a string which is then continued	
COMMENT	on subsequent keywords whose name = 'CONTINUE'.	
TITLE	'Studying Io's Seasonal Atmosphere and Investigating Volcanic Emis&'*	
CONTINUE	'sions'*	project title
PI	'Tsang'*	
PID	'2021A028'*	IRTF program ID
OBJTYPE	'targ'*	primary science target
FEATURE	'so2'*	spectral feature
WAVENO0	5.306000E+02*	planned central wavenumber
ORDER	3*	cross-dispersion grating order number
TEMPER	2.835000E+02*	ambient temperature
TAU	''	
HUMIDITY	9.400000E+00*	dome level humidity; not related to pwv
OBSMODE	'nod'*	
TELSTEP	'0.00 E 0.00 N'*	

FITS Header Keyword	Value	Description
OFFSET	'0.00 E 0.00 N'*	
NOD	6.000000E+00*	0.00 E 6.00 N
NODWAIT	'1.2'*	
FRAMETIM	1.011917E+00*	integration time / frame
NFRAME	1*	number of frames coadded in hardware
NSUM	6*	number of frames coadded in software
NWRITE	1*	number of frames written per nod phase
NNOD	16*	number of nod pairs
OBSTIME	1.942900E+02*	calculated observation time (s)
TOTTIME	2.665700E+02*	calculated total clock time (s)
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	6.396559E+01*	echelle grating angle (deg)
LORES	-1.420200E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.599800E+02*	slit wheel angle
FILTER	3.010200E+02*	filter wheel angle
PARAB	' 0.360'*	
NSKY	0*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'5.622'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	
SVOLT	'6.295'*	
FVOLT	'6.995'*	
PVOLT	'4.921'*	
EVOLT0	'14.188'*	

FITS Header Keyword	Value	Description
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	
FVOLT0	' 1.978'*	
PVOLT0	' 4.920'*	
TEMP_DET	3.530000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.347'*	
TEMP_LHE	'0.047'*	
TEMP_LN2	'0.011'*	
PRESSURE	1.381000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	9.400000E+00*	dome level humidity; not related to pwv
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-07-04'*	yyyy-mm-dd observation date
DATE-REL	'2023-01-04'*	yyyy-mm-dd public release date
TIME-OBS	'14:02:56.250'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)
RA_T	334.277500000*	RA reported by telescope (degrees)
DEC_T	-11.7414700000*	Dec reported by telescope (degrees)
RA	333.998624224*	actual RA of object (degrees)

FITS Header Keyword	Value	Description
DEC	-11.8578275699*	actual Dec of object (degrees)
LST	'22:32:14.82'*	
HA	2.522806E-01*	degrees
AIRMASS	1.176000E+00*	at start of integration
FOCUS	'-5.391'*	
EQUINOX	2.000000E+03	
VEHELIO	-2.046073E+01*	heliocentric motion of Earth from object(km/s)
VELSR	-2.559892E+01*	LSR motion of Earth from object (km/s)
PLTSCL	3.087496E-01*	arcsec / pixel after focal reduction
CDELT2	8.576378E-05*	deg / pixel along slit
SLITWID	1.949014E+00*	slit width (arcsec)
BEAMTIME	6.071501E+00*	frtime*nframe*nsum*nwrite
PIPELINE	' fife.F90 version 23.0226'*	
COMMENT	The following 24 lines are pipe reduction parameters	
CARDMODE	5*	
THRFAC	5.000000E-01*	
SPIKEFAC	2.000000E+01*	
STDFAC	2.000000E+01*	
SATVAL	6.160384E+04*	
XNLIN	0.000000E+00*	
CLOUD	0.000000E+00*	
BOUNCE	0.000000E+00*	grating bounce was removed if != 0
SLITROT	-1.000000E-02*	
KROT	-1.028298E-03*	
DETROT	8.000000E-02*	
HRFL	5.021227E+01*	

FITS Header Keyword	Value	Description
HRR	9.758028E+00*	may have changed after header write
HRG	1.000000E-02*	
HRDGR	7.589141E-01*	
XDFL	3.765921E+01*	
XDR	2.046546E+00*	
XDG	1.330000E-02*	
XDDGR	3.151000E-03*	
BRL	1.500000E+00*	
X0BRL	0.000000E+00*	
Y0BRL	0.000000E+00*	
FRED	2.120000E+00*	
SKYNOISE	5.076805E-03*	sky rms / min
SKYNOISE	5.644476E-03*	sky rms / min
CALIBRAT	T*	data were intensity calibrated with blackbody
CLEAN	T*	bad pixels cleaned
TORT	T*	distortions have been corrected
SHIFT	T*	data have been shifted along slit
ADDWT	T*	nod pairs weighted by signal
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.252052E+02*	effective on-source time after weighting (s)
SPACING	6.414769E+01*	order separation in pixels
XORDER1	4.574034E+01*	first pixel of order 1
HRR	9.758028E+00*	R number of echelon grating
WNO0	5.298293E+02*	wavenumber at pixel 128 in int(central order)
WNO_MIN	5.289644E+02*	minimum wavenumber (cm-1)
WNO_MAX	5.306965E+02*	maximum wavenumber (cm-1)

FITS Header Keyword	Value	Description
DVPIX	-9.042425E-01*	velocity interval between pixels (km/s)
RESOLV	4.573988E+04*	approximate resolving power
BUNIT	'erg/s cm2 sr cm-1'	cgs intensity units
ORIGIN	'University of Texas'	
END		
Extension 1	**Extracted**	**ASCII Table**
XTENSION	'TABLE '	
BITPIX	8	
NAXIS	2	
NAXIS1	80*	
NAXIS2	768*	
PCOUNT	0	
GCOUNT	1	
TFIELDS	5	
EXTNAME	'EXTRACTED'	
TTYPE1	'WAVENUMBER'	observed vacuum wavenumber
TBCOL1	1	
TFORM1	'F12.4'	
TUNIT1	'cm^-1 '	
COMMENT	'not corrected for motion of Earth or Sun'	
TTYPE2	'FLUX '	estimated flux through slit
TBCOL2	13	
TFORM2	'E12.4'	
TUNIT2	'Jy '	
TTYPE3	'NOISE '	estimated flux uncertainty

FITS Header Keyword	Value	Description
TBCOL3	25	
TFORM3	'E12.4'	
TUNIT3	'Jy '	
TTYPE4	'ATMO '	estimated atmo transmission
TBCOL4	37	
TFORM4	'E12.4'	
COMMENT	'from (blackbody-sky)/blackbody'	
TUNIT4	'none '	
TTYPE5	'WAVELENGTH'	observed vacuum wavelength
TBCOL5	49	
TFORM5	'F12.6'	
TUNIT5	'micron '	
END		

2.

2. SAMPLE REDUCED SUMMED NOD FILE (SUM OVER MULTIPLE NOD OBSERVATION)

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	
BITPIX	-32	
NAXIS	2	
NAXIS1	768*	
NAXIS2	64*	

FITS Header Keyword	Value	Description
EXTEND	T	
COMMENT	The primary HDU contains a 2-D spectral-spatial image	
COMMENT	The primary HDU is followed by a table extension	
COMMENT	(EXTNAME = EXTRACTED)	
COMMENT	giving the observed vacuum wavenumbers,	
COMMENT	flux through the slit, estimated flux uncertainty,	
COMMENT	estimated atmo transmission = (black-sky)/black	
COMMENT	and the observed vacuum wavelengths	
CTYPE1	'spectral pixel'	
CTYPE2	'pixel along slit'	
FILENAME	'io.9026'*	
OBJECT	'Io'*	
PI	'Tsang'*	
PID	'2021A028'*	IRTF program ID
OBJTYPE	'targ'*	primary science target
FEATURE	'so2'*	spectral feature
WAVENO0	5.306000E+02*	planned central wavenumber
ORDER	3*	cross-dispersion grating order number
TEMPER	2.833000E+02*	ambient temperature
TAU	"	
HUMIDITY	1.030000E+01*	dome level humidity; not related to pwv
OBSMODE	'nod'	
TELSTEP	'0.00 E 0.00 N'*	
OFFSET	'0.00 E 0.00 N'*	
NOD	6.000000E+00*	0.00 E 6.00 N
NODWAIT	'1.2'*	
FRAMETIM	1.011917E+00*	integration time / frame

FITS Header Keyword	Value	Description
NFRAME	1*	number of frames coadded in hardware
NSUM	6*	number of frames coadded in software
NWRITE	1*	number of frames written per nod phase
NNOD	16*	number of nod pairs
OBSTIME	1.942900E+02*	calculated observation time (s)
TOTTIME	2.665700E+02*	calculated total clock time (s)
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	6.395858E+01*	echelle grating angle (deg)
LORES	-1.420200E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.599800E+02*	slit wheel angle
FILTER	3.010800E+02*	filter wheel angle
PARAB	' 0.360'*	
INSTRPA	0.000000E+00*	instrument position angle
NSKY	0*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'5.623'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	
SVOLT	'6.295'*	
FVOLT	'6.996'*	
PVOLT	'4.921'*	
EVOLT0	'14.188'*	
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	
FVOLT0	' 1.978'*	

FITS Header Keyword	Value	Description
PVOLT0	' 4.920'*	
TEMP_DET	3.520000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.346'*	
TEMP_LHE	'0.047'*	
TEMP_LN2	'0.011'*	
PRESSURE	1.393000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	1.030000E+01*	dome level humidity; not related to pwv
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-07-04'*	yyyy-mm-dd observation date
DATE-REL	'2023-01-04'*	yyyy-mm-dd public release date
TIME-OBS	'13:26:24.450'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)
RA	3.342792E+02*	22:17:07.02
DEC	-1.174269E+01*	-11:44:33.7
LST	'21:55:37.01'*	
HA	-3.583333E-01*	degrees
AIRMASS	1.179000E+00*	at start of integration
FOCUS	'-5.386'*	
EQUINOX	2.000000E+03*	
VEHELIO	-2.047009E+01*	heliocentric motion of Earth from object(km/

FITS Header Keyword	Value	Description
VELSR	-2.560760E+01*	LSR motion of Earth from object (km/s)
PLTSCL	3.087496E-01*	arcsec / pixel after focal reduction
CDELT2	8.576378E-05*	deg / pixel along slit
SLITWID	1.949014E+00*	slit width (arcsec)
BEAMTIME	6.071501E+00*	frtime*nframe*nsum*nwrite
PIPELINE	' fife.F90 version 23.0226'*	
COMMENT	The following 24 lines are pipe reduction parameters	
CARDMODE	5*	
THRFAC	5.000000E-01*	
SPIKEFAC	2.000000E+01*	
STDFAC	2.000000E+01*	
SATVAL	6.160384E+04*	
XNLIN	0.000000E+00*	
CLOUD	0.000000E+00*	
BOUNCE	0.000000E+00*	grating bounce was removed if != 0
SLITROT	-1.000000E-02*	
KROT	-1.028298E-03*	
DETROT	8.000000E-02*	
HRFL	5.021227E+01*	
HRR	9.758028E+00*	may have changed after header write
HRG	1.000000E-02*	
HRDGR	7.589141E-01*	
XDFL	3.765921E+01*	
XDR	2.046546E+00*	
XDG	1.330000E-02*	
XDDGR	3.151000E-03*	
BRL	1.500000E+00*	

FITS Header Keyword	Value	Description
X0BRL	0.000000E+00*	
Y0BRL	0.000000E+00*	
FRED	2.120000E+00*	
RAWFILE	'io.9026'*	
SHIFT	T*	data have been shifted along slit
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.366197E+02*	effective on-source time after weighting (s)
SPACING	6.407726E+01*	order separation in pixels
XORDER1	4.579154E+01*	first pixel of order 1
HRR	9.758028E+00*	R number of echelon grating
WNO0	5.298293E+02*	wavenumber at pixel 128 in int(central order)
WNO_MIN	5.289644E+02*	minimum wavenumber (cm-1)
WNO_MAX	5.306965E+02*	maximum wavenumber (cm-1)
DVPIX	-9.042425E-01*	velocity interval between pixels (km/s)
RESOLV	4.573988E+04*	approximate resolving power
RAWFILE	'io.9027'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.341962E+02*	effective on-source time after weighting (s)
RAWFILE	'io.9028'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	9.614410E+01*	effective on-source time after weighting (s)
RAWFILE	'io.9029'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.506882E+02*	effective on-source time after weighting (s)
RAWFILE	'io.9030'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	9.898191E+01*	effective on-source time after weighting (s)

FITS Header Keyword	Value	Description
RAWFILE	'io.9031'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	9.594447E+01*	effective on-source time after weighting (s)
RAWFILE	'io.9032'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.396140E+02*	effective on-source time after weighting (s)
RAWFILE	'io.9033'*	
ACCUMTIM	1.942880E+02*	accumulated on-source time per beam (s)
ADDTIME	1.252052E+02*	effective on-source time after weighting (s)
SUMTIME	9.773938E+02*	summed effective time (s)
BUNIT	'erg/s cm2 sr cm-1'	cgs intensity units
ORIGIN	'University of Texas'	
END		
Extension 1	**Extracted**	**ASCII Table**
XTENSION	'TABLE '	
BITPIX	8	
NAXIS	2	
NAXIS1	80*	
NAXIS2	768*	
PCOUNT	0	
GCOUNT	1	
TFIELDS	5	
EXTNAME	'EXTRACTED'	
TTYPE1	'WAVENUMBER'	observed vacuum wavenumber
TBCOL1	1	
TFORM1	'F12.4'	

FITS Header Keyword	Value	Description
TUNIT1	'cm^-1 '	
COMMENT	'not corrected for motion of Earth or Sun'	
TTYPE2	'FLUX '	estimated flux through slit
TBCOL2	13	
TFORM2	'E12.4'	
TUNIT2	'Jy '	
TTYPE3	'NOISE '	estimated flux uncertainty
TBCOL3	25	
TFORM3	'E12.4'	
TUNIT3	'Jy '	
TTYPE4	'ATMO '	estimated atmo transmission
TBCOL4	37	
TFORM4	'E12.4'	
COMMENT	'from (blackbody-sky)/blackbody'	
TUNIT4	'none '	
TTYPE5	'WAVELENGTH'	observed vacuum wavelength
TBCOL5	49	
TFORM5	'F12.6'	
TUNIT5	'micron '	
END		

3.

3. SAMPLE REDUCED SCAN FILE (SINGLE SCAN OBSERVATION)

FITS Header Keyword	Value	Description
FITS File Header	Primary HDU	
SIMPLE	T	

FITS Header Keyword	Value	Description
BITPIX	-32	
NAXIS	3	
NAXIS1	2304*	
NAXIS2	26*	
NAXIS3	37*	
EXTEND	T	
COMMENT	The primary data unit contains a spectral-spatial-spatial	
COMMENT	data cube	
COMMENT	The primary HDU is followed by a table extension	
COMMENT	(EXTNAME = EXTRACTED)	
COMMENT	giving the observed vacuum wavenumbers,	
COMMENT	flux through the slit, estimated flux uncertainty,	
COMMENT	estimated atmo transmission = (black-sky)/black	
COMMENT	and the observed vacuum wavelengths	
COMMENT	After the table extension are two 2-D extensions	
COMMENT	giving the sky frame which has been subtracted from the	
COMMENT	scan frames (EXTNAME = SKY),	
COMMENT	and the calculated noise frame (EXTNAME = SCAN-NOISE)	
CTYPE1	'spectral pixel'	
CTYPE2	'pixel along slit'	
CTYPE3	'pixel along scan'	
FILENAME	'ven.1058'*	
OBJECT_T	'Venus'*	object name entered at telescope
OBJECT	'Venus'*	standardized/corrected object name
NAIF_ID	'299'*	
LONGSTRN	'OGIP 1.0'	The OGIP long string convention may be used.
COMMENT	This FITS file may contain long string keyword values that are	

FITS Header Keyword	Value	Description
COMMENT	continued over multiple keywords. This convention uses the '&'	
COMMENT	character at the end of a string which is then continued	
COMMENT	on subsequent keywords whose name = 'CONTINUE'.	
TITLE	'The thermal structure of Venus' mesosphere from high resolution o&'*	
CONTINUE	'bservations of CO2 lines'*	project title
PI	'Giles'*	
PID	'2021A015'*	IRTF program ID
OBJTYPE	'targ'*	primary science target
FEATURE	'co2'*	spectral feature
WAVENO0	7.933000E+02*	planned central wavenumber
ORDER	4*	cross-dispersion grating order number
TEMPER	2.935000E+02*	ambient temperature
TAU	''	
HUMIDITY	2.270000E+01*	dome level humidity; not related to pwv
OBSMODE	'scan'*	
TELSTEP	'0.70 E 0.00 N'*	
OFFSET	'-12.00 E 0.00 N'*	
NOD	0.000000E+00*	0.00 E 0.00 N
NPOINTS	34*	number of points in scan
NODWAIT	'4.05'*	
FRAMETIM	2.023834E+00*	integration time / frame
NFRAME	1*	number of frames coadded in hardware
NSUM	1*	number of frames coadded in software
NWRITE	1*	number of frames written per nod phase
NSCAN	4*	number of scans
OBSTIME	8.100000E+00*	calculated observation time (s)
TOTTIME	3.756600E+02*	calculated total clock time (s)

FITS Header Keyword	Value	Description
INSTMODE	'hi-med'*	echelon x echelle
ECHELLE	5.314479E+01*	echelle grating angle (deg)
LORES	-1.429236E+01*	lo-res grating angle (deg)
KMIRROR	4.500000E-02*	K-mirror angle
SLIT	2.400000E+02*	slit wheel angle
FILTER	2.859000E+02*	filter wheel angle
PARAB	'49.320'*	
NSKY	3*	number of extra points on sky
INSTRUME	'TEXES'	
EVOLT	'7.076'*	
LVOLT	'8.863'*	
KVOLT	'2.033'*	
SVOLT	'5.962'*	
FVOLT	'6.743'*	
PVOLT	'5.057'*	
EVOLT0	'14.188'*	
LVOLT0	' 6.996'*	
KVOLT0	' 2.031'*	
SVOLT0	' 1.962'*	
FVOLT0	' 1.978'*	
PVOLT0	' 4.920'*	
TEMP_DET	3.470000E-01*	detector temperature (unknown units)
TEMP_ECH	'0.343'*	
TEMP_LHE	'0.046'*	
TEMP_LN2	'0.010'*	
PRESSURE	1.422000E+01*	LN2 pumping line pressure (Torr)
HUMIDITY	2.270000E+01*	dome level humidity; not related to pwv

FITS Header Keyword	Value	Description
GAIN	2.500000E+01*	electronic gain
BANDWID	'3000 kHz'	
DAS	'IR Observer: 28 May 09'*	
NSPEC	256	array size in spectral dimension
NSPAT	256	array size in spatial dimension
DATE-OBS	'2021-06-26'*	yyyy-mm-dd observation date
DATE-REL	'2022-12-26'*	yyyy-mm-dd public release date
TIME-OBS	'22:10:16.000'*	UTC
TIMESYS	'UTC'	
OBSERVER	'rg tg'*	
TELESCOP	'IRTF'	
SLITPA	-0.000000E+00*	slit position angle (deg)
RA_T	122.182700000*	RA reported by telescope (degrees)
DEC_T	21.7590600000*	Dec reported by telescope (degrees)
RA	121.895757542*	actual RA of object (degrees)
DEC	21.8211159567*	actual Dec of object (degrees)
LST	'06:09:22.19'*	
HA	-1.989350E+00*	degrees
AIRMASS	1.131000E+00*	at start of integration
FOCUS	'-3.763'*	
ENDTIME	'22:10:16.000'*	
EQUINOX	2.000000E+03*	
VEHELIO	9.773205E+00*	heliocentric motion of Earth from object(km/s)
VELSR	1.940307E+01*	LSR motion of Earth from object (km/s)
PLTSCL	3.373787E-01*	arcsec / pixel after focal reduction
CDELT2	9.371629E-05*	deg / pixel along slit
SLITWID	1.299343E+00*	slit width (arcsec)

FITS Header Keyword	Value	Description
BEAMTIME	2.023834E+00*	frtime*nframe*nsum*nwrite
PIPELINE	' fife.F90 version 23.0222'*	
COMMENT	The following 24 lines are pipe reduction parameters	
CARDMODE	2*	
THRFAC	5.000000E-01*	
SPIKEFAC	2.000000E+01*	
STDFAC	2.000000E+01*	
SATVAL	6.160384E+04*	
XNLIN	0.000000E+00*	
CLOUD	0.000000E+00*	
BOUNCE	0.000000E+00*	grating bounce was removed if != 0
SLITROT	-1.000000E-02*	
KROT	-4.587660E-03*	
DETROT	8.000000E-02*	
HRFL	4.797221E+01*	
HRR	9.969110E+00*	may have changed after header write
HRG	1.000000E-02*	
HRDGR	7.589141E-01*	
XDFL	3.597916E+01*	
XDR	1.334045E+00*	
XDG	1.330000E-02*	
XDDGR	3.151000E-03*	
BRL	1.500000E+00*	
X0BRL	0.000000E+00*	
Y0BRL	0.000000E+00*	
FRED	2.120000E+00*	
SKYNOISE	3.127726E-01*	sky rms / min

FITS Header Keyword	Value	Description
CALIBRAT	T*	data were intensity calibrated with blackbody
WNO0	7.932466E+02*	wavenumber at pixel 128 of middle order
WNO_MIN	7.902879E+02*	minimum wavenumber (cm-1)
WNO_MAX	7.962101E+02*	maximum wavenumber (cm-1)
DVPIX	-9.264261E-01*	delta v per pixel (km/s)
RESOLV	7.235948E+04*	approximate resolving power
SUMTIME	0.000000E+00*	summed time per point (s)
BUNIT	'erg/(s cm2 sr cm-1)'	cgs intensity units
ORIGIN	'University of Texas'	
END		
Extension 1	**Extracted**	**ASCII Table**
XTENSION	'TABLE '	
BITPIX	8	
NAXIS	2	
NAXIS1	80*	
NAXIS2	2304*	
PCOUNT	0	
GCOUNT	1	
TFIELDS	5	
EXTNAME	'EXTRACTED'	
TTYPE1	'WAVENUMBER'	observed vacuum wavenumber
TBCOL1	1	
TFORM1	'F12.4'	
TUNIT1	'cm^-1 '	
COMMENT	'not corrected for motion of Earth or Sun'	

FITS Header Keyword	Value	Description
TTYPE2	'FLUX '	estimated flux through slit
TBCOL2	13	
TFORM2	'E12.4'	
TUNIT2	'Jy '	
TTYPE3	'NOISE '	estimated flux uncertainty
TBCOL3	25	
TFORM3	'E12.4'	
TUNIT3	'Jy '	
TTYPE4	'ATMO '	estimated atmo transmission
TBCOL4	37	
TFORM4	'E12.4'	
COMMENT	'from (blackbody-sky)/blackbody'	
TUNIT4	'none '	
TTYPE5	'WAVELENGTH'	observed vacuum wavelength
TBCOL5	49	
TFORM5	'F12.6'	
TUNIT5	'micron '	
END		
Extension 2	**SKY**	**Image**
XTENSION	'IMAGE '	
BITPIX	-32	
NAXIS	2	
NAXIS1	2304*	
NAXIS2	26*	
PCOUNT	0	
GCOUNT	1	

FITS Header Keyword	Value	Description
CTYPE1	'spectral pixel'	
EXTNAME	'SKY'	sky frame which was subtracted from scan frames
BUNIT	'erg / s cm2 cm-1 sr'	
CTYPE2	'pixel along slit'	
END		
Extension 3	**SCAN-NOISE**	**Image**
XTENSION	'IMAGE '	
BITPIX	-32	
NAXIS	2	
NAXIS1	2304*	
NAXIS2	26*	
PCOUNT	0	
GCOUNT	1	
CTYPE1	'spectral pixel'	
EXTNAME	'SCAN-NOISE'	calculated noise in each scan frame
BUNIT	'erg / s cm2 cm-1 sr'	
CTYPE2	'pixel along slit'	
END		