JEM-GLIMS Data Format Definition Document

Version 0.0

JEM-GLIMS mission team

ISAS/JAXA

Revision history

Version	Date	Details
Version 0.0	March 9, 2017	Created a rough draft based on documents pertaining to the SPRINT-A (HIASKI) project.

Contents

1. Scope

This definition document explains the version of the JEM-GLIMS L2 data and defines the formats for all L2 data products in the JEM-GLIMS scientific data archive, which has been created by the JEM-GLIMS core science team members and distributed through the Data Archives and Transmission System (DARTS) at ISAS/JAXA.

2. Mounted Sensors for Data Archiving

2.1 LSI

LSI (Lightning and Sprite Imager) is two cameras directed in the nadir direction to detect the shape of the optical emissions from lightning and TLEs and measure their spatiotemporal changes [Sato et al., 2011a]. LSI uses a CMOS sensor (STAR250) as an imaging device and is composed of two cameras, denoted as LSI-1 and LSI-2. A wideband optical filter transmitting 768-830 nm emissions is mounted on top of the LSI-1 lens, while a narrowband filter transmitting 760-775 nm emissions is mounted on top of the LSI-2 lens. In the wavelength range of the LSI-1 filter, there are lightning emissions from OI (777.4 nm), OI (794.7 nm), and NI (820.0 nm) and TLE emissions from N_2 $1P_{(2,0)}$ (775.4 nm) and N_2 $1P_{(6,5)}$ (804.7 nm). As lightning emissions are much stronger than TLE emissions in this wavelength range, LSI-1 mainly measures lightning emissions. On the other hand, in the wavelength range of the LSI-2 filter, there are the continuum component of lightning emissions and TLE emissions of N_2 $1P_{(3,1)}$ (762.7 nm). As the continuum lightning emissions are absorbed by O_2 molecules in the atmosphere when traveling from the lower altitude where lightning discharges occur to the ISS, LSI-2 mainly measures TLE emissions. By subtracting the appropriately scaled LSI-1 image data from the LSI-2 image data, it is possible to selectively extract only the TLE emissions, which is first introduced by Blanc et al. [2004]. The field of view (FOV) of LSI is 28.3° x 28.3°, which corresponds to a spatial resolution of 400 m/pixel at the ground level and 320 m/pixel at 80 km altitude. The time resolution is 32.8 ms, and the resolution of the image data is 10 bit. See more details in Sato et al. [2015].

2.2 PH

To obtain the light curve data and to estimate the absolute intensity of lightning and TLE emissions, six-channel spectrophotometers denoted as PH and directed in the nadir direction are employed [Sato et al., 2011b]. PH comprises six photometers (denoted by PH1 - PH6) and is used to detect the N_2 and N_2^+ emissions of lightning and TLEs. PH1 measures FUV emissions in the 150-280 nm wavelength range, and FUV emissions come from the N_2 Lyman-Birge-Hopfield (LBH) band system. PH1 is the same type of the photometer as the ISUAL Spectral Photometer onboard the FORMOSAT-2 satellite, and this channel is essentially effective for the identification of TLE occurrence [Kuo et al., 2005, 2007; Chang et al., 2010]. PH2 and PH5 measure optical emissions in the wavelength range of 332-342 nm and 310-321 nm, where the optical emissions of N_2 $2P_{(0,0)}$ (337.0 nm) and N_2 $2P_{(1,0)}$ (315.8 nm) exist, respectively. PH3 measures optical emissions in the 755-766 nm wavelength range and is used to detect the N_2 $1P_{(3,1)}$ (762.7 nm) emissions. PH4 also measures the N_2 1P emissions, but this channel is equipped with a wideband optical filter transmitting the 599-900 nm emissions and is mainly used to detect lightning emissions. PH6 measures the optical emissions of N_2^+ $1N_{(0,0)}$ (391.4 nm) and uses an optical filter transmitting the 386-397 nm emissions. PH1-3, PH5, and PH6 have a conical FOV of 42.7°, which is nearly equal to the circumscribed circle of the LSI FOV. In contrast, PH4 has a conical FOV of 86.8° so that it can detect parent lightning discharges that generate terrestrial gamma-ray flashes. The light curve data of all PH channels are recorded with a sampling frequency of 20 kHz (= 50 μs time resolution) and a 12-bit resolution. PH1-4 are installed in the "Unit-1" housing box (PH U1), while PH5 and PH6 are installed in the "Unit-2" housing box (PH U2). See more details in Sato et al. [2015].

2.3 VITF

Impulsive electromagnetic waves in the VHF range are usually emitted from the tips of the leader development in thunderclouds. As such impulsive VHF waves can penetrate into the ionosphere and magnetosphere, these VHF pulses can be detected at the satellite altitude. In the JEM-GLIMS mission, two components of the VHF receivers, denoted as VITF, are employed to identify the spatiotemporal development of the in-cloud currents of the CG discharges exciting TLEs [Morimoto et al., 2011]. Two patch-type antennas are installed on the base plate of the bus system, separated from each other by a 1.6-m interval, and directed in the nadir direction. These two antenna system is denoted by VITF-A and VITF-B. Directivity of the antenna is 2π rad, and the frequency range of the receiver is 70-100 MHz. Waveform data of VHF pulses are digitally sampled at a 200 MHz sampling frequency with an 8-bit resolution. When the amplitude of a VHF pulse exceeds the trigger threshold level, the waveform data at time intervals of 2.56 μs are stored in the onboard ring-buffer memory in the VITF electronics, which can store a total of 130 pulse data at maximum. See more details in [Morimoto et al., 2011, 2016; Kikuchi et al., 2016]

2.4 VLFR

Electromagnetic waves in the VLF range are excited by lightning discharges and are reflected from the ionosphere. However, some VLF waves penetrate into the ionosphere and magnetosphere as lightning whistlers and are detected by satellites. To detect lightning-excited whistlers and identify the relation between the parent lightning discharges and the occurrence of TLEs, one component of the VLF receiver denoted as VLFR is employed for the JEM-GLIMS mission. For this receiver system, a 15 cm monopole antenna directed in the nadir direction is used and attached to the base plate of the bus system. Thus, the directivity of the antenna becomes 2π rad. The VLFR frequency range is 1-30 kHz, and the sampling frequency is 100 kHz with a 14-bit resolution. The VLFR electronics was designed and provided by the VLF group at Stanford University (PI of VLFR: Profs. U. Inan and I. Linscott). See more details in Sato et al. [2015].

3. Observation Sequence and Trigger Method

The observation geometry of JEM-GLIMS is schematically shown in Figure **3.1**. In this figure, the relation between the square FOV of LSI and the conical FOV of PH are indicated. The ISS orbits at a typical altitude of ~410 km with a typical velocity of ~8 km/s. As described in Section 2, the FOVs of LSI and PH are directed toward the nadir direction, but the actual direction slightly changes within a few

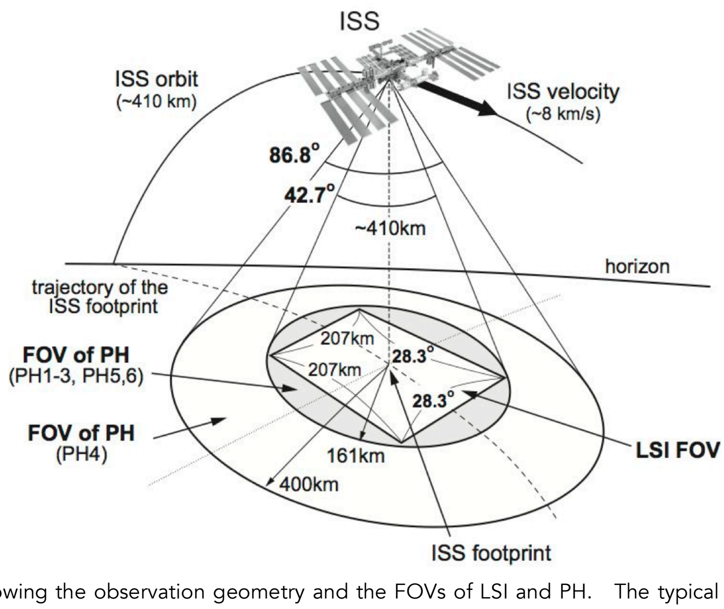

Fig. 3.1. Schematic showing the observation geometry and the FOVs of LSI and PH. The typical orbital altitude and the speed of the ISS are ~410 km and ~8 km/s, respectively. LSI has the square FOV of 28.3° x 28.3°. PH1-3, PH5, and PH6 have a conical FOV of 42.7°, which is nearly equal to the circumscribed circle of the LSI FOV. PH4 has a wider FOV (86.8°) than the other PH channels.

degrees depending on the ISS attitude.

Figure **3.2** is a schematic showing the observation sequence of JEM-GLIMS. In this figure, the ISS orbit and Earth are drawn as though looking down from the celestial pole. The JEM-GLIMS observations of lightning and TLEs are conducted when the ISS is in the Earth's shadow and above the nightside. As the orbital period of the ISS is ~90 min, the maximum observation period becomes ~30 min in one orbit. To avoid possible damage to the high-voltage (HV) units used for PH due to the precipitation of high-energy particles, JEM-GLIMS observations are interrupted when the ISS locates over the South Atlantic Anomaly (SAA).

JEM-GLIMS science data are not continuously stored; they are only stored when JEM-GLIMS detects a strong transient optical emission. Output signals from each instrument are temporarily recorded in the

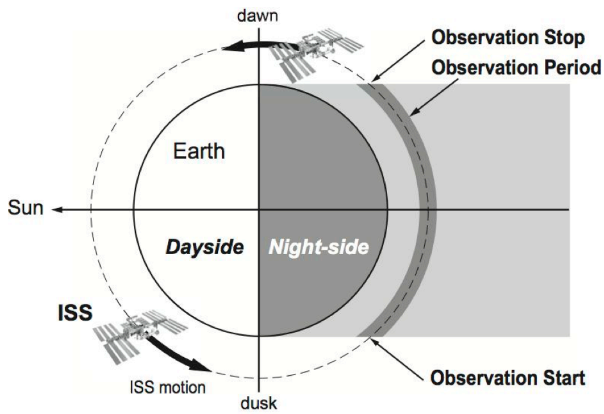

Fig. 3.2. Schematic showing the observation sequence of JEM-GLIMS.

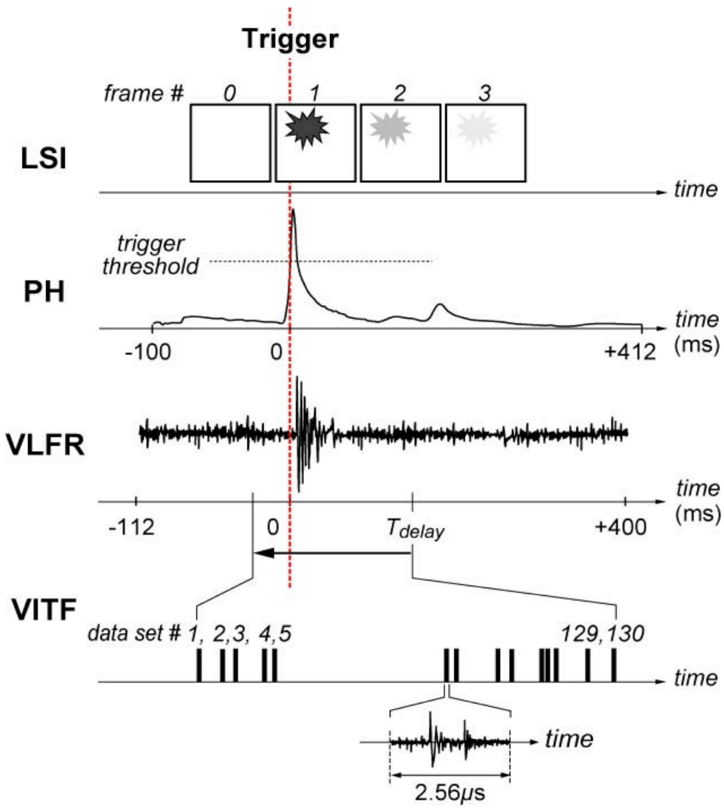

Fig. 3.3. Schematic showing the trigger sequence of JEM-GLIMS. In this trigger routine, PH is selected as the trigger instrument, and the trigger threshold level can be arbitrarily selected by a command. When the trigger signal is exploded from PH, LSI image data are obtained for four consecutive frames from one frame before the trigger time. As for PH, light curve data are recorded from 100 ms before the trigger time to 412 ms after the trigger time, while, as for VLFR, waveform data are recorded from 112 ms before the trigger time to 400 ms after the trigger time. As for VITF, waveform data for 130 VHF pulse events detected before $t = T_{delay}$ ms are stacked into one data file and stored.

ring-buffer memories in SHU, which are shown as "8 MB S-RAM" [Kikuchi et al., 2011; Sato et al., 2015]. When the trigger instrument detects a signal exceeding the trigger threshold level, which can be arbitrarily set by a command, the data buffering is stopped and the data is forwarded from the S-RAM to the 128 MB flash-ROM so that they can be downlinked to the ground system through the ISS system. When the data forwarding is completed, the data buffering will automatically start again to wait the coming trigger signal. The trigger sequence and the data length of each instrument for one trigger event are schematically shown in Figure **3.3**. In usual observations, PH is selected as the trigger instrument. When the output signal of PH exceeds the trigger threshold level, four consecutive LSI image data from one frame before the trigger time are stored. For the PH light curve and VLFR waveform, data for a 512-ms time period from 100 ms and 112 ms before the trigger time are stored, respectively. VITF detects VHF pulses on the basis of its own trigger logic, and stores the waveform data on the ring-buffer memory located in the VITF electronics at a rate of 2.56 μs time length per single pulse data. This ring-buffer memory has the capability to hold 130 VHF pulse data. When the trigger signal is exploded from the PH, the data buffering stops when it passes a specific delay time (T_{delay}) after the trigger time, which can be arbitrarily set by a command. Then, a stack of these pulse data are grabbed from the ring-buffer memory into the flash-ROM by SHU and downlinked [Kikuchi et al., 2011; Sato et al., 2015].

4. Definition of Data Level

4.1 L0

Level-0 (L0) data are the raw telemetry (TLM) data, which is directly downloaded from the ISS and depacketed for JEM-GLIMS science data. L0 data is a time series of the continuous TLM data including both housekeeping (HK) data and raw science data. These L0 data will not be opened to any researchers except the JEM-GLIMS core members.

4.2 L1

Level-1 (L1) data are the HK data and raw science data, which is depacketed from the L0 data for each triggered event and each instrument. L1 science data have relative values (*i.e.*, digit). These L1 data will not be opened to any researchers except the JEM-GLIMS core members. However, if a researcher wants to use the L1 data, the JEM-GLIMS core member can individually provide the L1 data upon request. These L1 data will not be distributed through DARTS.

4.3 L2

Level-2 (L2) data are the science data converted from the L1 data, and they have absolute values (*i.e.*, W/m^2 for LSI and PH data, and V/m for VLFR data). These L2 data will be opened to any researchers who want to use the JEM-GLIMS data and who can agree and fulfill the issues defined in the "Rules of the Road" document. These L2 data are distributed through the following DARTS and JEM-GLIMS web sites.

- DARTS web site: https://darts.isas.jaxa.jp/iss/jemglims
- JEM-GLIMS web site: http://www.ep.sci.hokudai.ac.jp/~jemglims/index-e.html
  http://www.ep.sci.hokudai.ac.jp/~jemglims/EventList/

5. Version of L2 Data Products

5.1 ver. 1.0

JEM-GLIMS L2 data (ver. 1.0) consist of following data files:

- ✓ Image data of the LSI-1 and LSI-2 (absolute optical intensity [W/m^2]),
- ✓ Time series data of the 6 PH channels (relative time from the trigger time [ms], and absolute optical intensity [W/m^2]),
- ✓ Time series data of the VLFR (relative time from the trigger time [ms], and absolute electric field intensity [V/m]),
- ✓ QL plots of LSI, PH and VLFR,
- ✓ Log file.

5.2 ver. 1.1

JEM-GLIMS L2 data (ver. 1.1) consist of following data files:

- ✓ L2 data (ver. 1.0),

plus

- ✓ Time series of VHF pulses recorded by the VITF-A and VITF-B (pulse No., trigger time, relative intensity [digit]),
- ✓ Estimation results of the source location of VHF pulses (pulse No., trigger time, source location [lon., lat.]),
- ✓ QL plot of VITF-A and VITF-B waveforms.

6. Files of L2 Data (ver. 1.0)

All JEM-GLIMS L2 data are split into each triggered event and stored at a folder whose name denotes the trigger date/time.

The folder name is like "2013-08-01_132432.69898", where "2013", "08", "01", "13", "24", and "32.69898" are the trigger year (YYYY), month (MM), day (DD), hour (hh), minutes (mm), and second (ss.sssss). These date/time show UT.

At each folder, L2 science data (ver. 1.0) listed in Table **6.1** are stored, *i.e.*, 4 consecutive LSI-1 image data, 4 consecutive LSI-2 image data, PH waveform data, VLFR waveform data, QL plots of LSI, PH, and VLFR data, and a log file.

Table **6.1** Summary of L2 data files (ver. 1.0).

File Name	**Format**	**Note**
YYYY-MM-DD_hhmmss.sssss_LSI1-1_frm0.fits	FITS	LSI-1 image data at frame #0
YYYY-MM-DD_hhmmss.sssss_LSI1-1_frm1.fits	FITS	LSI-1 image data at frame #1
YYYY-MM-DD_hhmmss.sssss_LSI1-1_frm2.fits	FITS	LSI-1 image data at frame #2
YYYY-MM-DD_hhmmss.sssss_LSI1-1_frm3.fits	FITS	LSI-1 image data at frame #3
YYYY-MM-DD_hhmmss.sssss_LSI1-2_frm0.fits	FITS	LSI-2 image data at frame #0
YYYY-MM-DD_hhmmss.sssss_LSI1-2_frm1.fits	FITS	LSI-2 image data at frame #1
YYYY-MM-DD_hhmmss.sssss_LSI1-2_frm2.fits	FITS	LSI-2 image data at frame #2
YYYY-MM-DD_hhmmss.sssss_LSI1-2_frm3.fits	FITS	LSI-2 image data at frame #3
YYYY-MM-DD_hhmmss.sssss_PH.dat	ASCII	PH light curve data (time and intensity)
YYYY-MM-DD_hhmmss.sssss_VLFR.dat	ASCII	VLFR waveform data (time and amplitude)
YYYY-MM-DD_hhmmss.sssss_LSI_QL.png	PNG	LSI QL plot (4 consecutive images of LSI-1 and LSI2)
YYYY-MM-DD_hhmmss.sssss_PH_QL.png	PNG	PH QL plot (light curve plots for 6 channels)
YYYY-MM-DD_hhmmss.sssss_VLFR_QL.png	PNG	VLFR QL plot (waveform & dynamic spectrum)
HDR_YYYY-MM-DD_hhmmss.sssss.log	ASCII	Log file (status of the instrument and geometry info. at the trigger event)

7. Formats of L2 Data (ver. 1.0)

7.1 LSI L2 Data

LSI L2 data is 2-dimensional image data provided in the FITS format. At each event, four consecutive image data (frame #0 - #3) are obtained, and the frame #2 data is the image when the trigger signal is issued. In most of the cases, PH was selected as the trigger instrument. In this case, the file name (YYYY-MM-DD_hhmmss.sssss) denotes the trigger time of PH. Consequently, the exact time when the frame #2 image data was acquired is unknown. In some cases, LSI was selected as the trigger instrument. In this case, the file name (YYYY-MM-DD_hhmmss.sssss) denotes the exact time when the acquisition of frame #2 image data was completed and when the trigger signal was issued by LSI.

Each FITS data contains a header part first and the following 2-dimensional image data. The size of 2-dimensional image is 32 bit x 512 pixels x 512 pixels. The unit of the image data is [x10^{-11} W/m^2].

The absolute optical intensities are calculated by the following procedures:

(1) subtraction of dark noise image data from L1 image data,
(2) correction of the flat-field,
(3) correction of geometrical offset of LSI-2 data,
(4) conversion from relative values to absolute values.

As for (1), (2), the dark noise subtraction and flat-field correction are performed by the following equations:

$$I_0 = \frac{I_{\mathrm{obs}} - I_{\mathrm{D}}}{\tau}$$

where I_0, I_{obs}, I_{D} are the image data corrected by the dark noise and flat-field, recorded image data, and dark noise image data. The dark noise image was calculated by averaging the LSI image data obtained at the ISS and acquired during the new-moon phase period. The flat-field image was obtained by using an integration sphere calibration system during the calibration experiment before the launch. This flat-field image was obtained.

As for (3), the offset of LSI-2 image toward LSI-1 image is corrected. This offset originated in the difference of the mechanical alignment between the LSI-1 and LSI-2 CMOS sensors. The LSI observed not only lightning emissions but also city light emissions. Using these city light images, the offset values are statistically estimated according to the following equations:

$$\begin{cases} X_{\mathrm{offset}} = (x - 0.015y + 17.6032)/1.00021 \\ Y_{\mathrm{offset}} = (0.014x + y - 0.63374)/1.00021 \end{cases}$$

where x and y are the representative X-pixel and Y-pixel coordinates of the lightning emissions in LSI-2 image, and X_{offset} and Y_{offset} are the offset values of LSI-2 image.

As for (4), the linear relation estimated by using the LSI images acquired during the calibration experiment before the launch was used. The absolute intensity of optical emissions that reach at the entrance of the 1st optical lens can be calculated using the following equations:

$$\begin{cases} I = 6.6158 \cdot I_0 - 61.024 \quad (\times 10^{-11}\ [\mathrm{W/m^2}] : \text{for LSI-1}) \\ I = 4.2046 \cdot I_0 + 10.671 \quad (\times 10^{-11}\ [\mathrm{W/m^2}] : \text{for LSI-2}) \end{cases}$$

where I_0 is the relative intensity, and I is the absolute intensity.

See more details in Sato et al. [2017].

7.2 FITS Header Keywords

The structure and meaning of the FITS header are as follows:

< Common Keywords >

```
BITPIX  =                  -32 / Bits per pixel (image resolution of FITS data)
NAXIS   =                    2 / Number of axes (2-D)
NAXIS1  =                  512 / Axis length (x-axis)
NAXIS2  =                  512 / Axis length (y-axis)
EXTEND  =                    T / FITS data may contain extensions
```

< Observation Overview Keywords >

```
INSTRUME= 'LSI'                / Name of instrument
TRG-DATE= 'YYYY-MM-DD'         / [yyyy-mm-dd] Event trigger date (UT)
TRG-TIME= 'hh:mm:ss.sssss'     / [hh:mm:ss.sssss] Event trigger time (UT)
ISS-LON =              123.456 / [deg] ISS longitude at the event trigger time (-180=180°W, +180=180°E)
ISS-LAT =               12.345 / [deg] ISS latitude at the event trigger time (-90=90°S, +90=90°N)
ISS-ALT =              123.456 / [km] ISS altitude at the event trigger times
TRG_INST= 'PH  '               / Name of trigger instrument (LSI or PH)
```

< LSI Specification Keywords >

```
WAVELEN1=                797.5 / [nm] Center wavelength of LSI-1 pass-band
FWHM1   =                 65.0 / [nm] FWHM of LSI-1 pass-band
WAVELEN2=                762.0 / [nm] Center wavelength of LSI-2 pass-band
FWHM2   =                 14.0 / [nm] FWHM of LSI-2 pass-band
APERTURE=                 18.0 / [mm] Lens Aperture of LSI-1 and LSI-2 lenses
F-VALUE =                  1.4 / F-value of LSI-1 and LSI-2 lenses
FOCAL-L =                 25.0 / [mm] Focal length of LSI-1 and LSI-2 lenses
FOV1    =                 28.7 / [deg] Angle of FOV in NAXIS1 direction
FOV2    =                 28.7 / [deg] Angle of FOV in NAXIS2 direction
SENSOR  = 'CMOS STAR-250'      / Type of sensor
PX-SIZE1=                 25.0 / [um] Pixel size in NAXIS1 direction
PX-SIZE2=                 25.0 / [um] Pixel size in NAXIS2 direction
IMG-RES =                   10 / [bit] Resolution of original raw image data
```

< LSI Obs. Parameter Setting Keywords >

```
TIME-RES=                34.48 / [ms] Time resolution of image
LSI1-G  =                  1.0 / LSI-1 amplifier gain (x1 or x2 or x4 or x8)
LSI2-G  =                  4.0 / LSI-2 amplifier gain (x1 or x2 or x4 or x8)
```

< Data Unit Keywords >

```
UNIT1   =            x10^(-11) / [W/m^2] Unit of LSI-1 L2 FITS data
UNIT2   =            x10^(-11) / [W/m^2] Unit of LSI-2 L2 data
```

< LSI FOV Geometry Keywords >

```
LB10-LON=              123.456 / [deg] Longitude of LSI FOV (Left-Bottom) @10km (-180=180°W, +180=180°E)
LB10-LAT=               12.345 / [deg] Latitude of LSI FOV (Left-Bottom) @10km (-90=90°S, +90=90°N)
LT10-LON=              123.456 / [deg] Longitude of LSI FOV (Left-Top) @10km (-180=180°W, +180=180°E)
LT10-LAT=               12.345 / [deg] Latitude of LSI FOV (Left-Top) @10km (-90=90°S, +90=90°N)
RT10-LON=              123.456 / [deg] Longitude of LSI FOV (Right-Top) @10km (-180=180°W, +180=180°E)
RT10-LAT=               12.345 / [deg] Latitude of LSI FOV (Right-Top) @10km (-90=90°S, +90=90°N)
RB10-LON=              123.456 / [deg] Longitude of LSI FOV (Right-Bottom) @10km (-180=180°W, +180=180°E)
RB10-LAT=               12.345 / [deg] Latitude of LSI FOV (Right-Bottom) @10km (-90=90°S, +90=90°N)
LB75-LON=              123.456 / [deg] Longitude of LSI FOV (Left-Bottom) @75km (-180=180°W, +180=180°E)
LB75-LAT=               12.345 / [deg] Latitude of LSI FOV (Left-Bottom) @75km (-90=90°S, +90=90°N)
LT75-LON=              123.456 / [deg] Longitude of LSI FOV (Left-Top) @75km (-180=180°W, +180=180°E)
LT75-LAT=               12.345 / [deg] Latitude of LSI FOV (Left-Top) @75km (-90=90°S, +90=90°N)
RT75-LON=              123.456 / [deg] Longitude of LSI FOV (Right-Top) @75km (-180=180°W, +180=180°E)
RT75-LAT=               12.345 / [deg] Latitude of LSI FOV (Right-Top) @75km (-90=90°S, +90=90°N)
RB75-LON=              123.456 / [deg] Longitude of LSI FOV (Right-Bottom) @75km (-180=180°W, +180=180°E)
RB75-LAT=               12.345 / [deg] Latitude of LSI FOV (Right-Bottom) @75km (-90=90°S, +90=90°N)
```

< LSI Trigger Setting Parameter Keywords >

```
FPGA-P1 = '0x03FF'             / FPGA trigger parameter #1 (LSI1_th_hotpix) used for LSI trigger
FPGA-P2 = '0x03FF'             / FPGA trigger parameter #2 (LSI1_th_pixel) used for LSI trigger
FPGA-P3 = '0x03FF'             / FPGA trigger parameter #3 (LSI1_th_frame) used for LSI trigger
FPGA-P4 = '0x03FF'             / FPGA trigger parameter #4 (LSI2_th_hotpix) used for LSI trigger
```

```
FPGA-P5 = '0x03FF'              / FPGA trigger parameter #5 (LSI2_th_pixel) used for LSI trigger
FPGA-P6 = '0x03FF'              / FPGA trigger parameter #6 (LSI2_th_frame) used for LSI trigger
CPU-P1  = '0x0000'              / CPU judgement parameter #1 (LSI_CPU_th) [<- never used]
CPU-P2  = '0x00FF'              / CPU judgement parameter #2 (LSI_CPU_fact) [<- never used]
CPU-P3  = '0x00FF'              / CPU judgement parameter #3 (LSI_CPU_offset_x) [<- never used]
CPU-P4  = '0x00FF'              / CPU judgement parameter #3 (LSI_CPU_offset_y) [<- never used]
```

< LSI Temperature Keywords >

```
LSI-TMP1=                 12.34 / [deg C] LSI-1 electronics temperature
LSI-TMP2=                 12.34 / [deg C] LSI-2 filter temperature
```

7.3 PH L2 Data

PH L2 data is the time series of optical intensity measured by 6 channel spectrophotometers. The PH L2 data are provided in the ASCII format and consist of time data (1st left column) and 6-channel light curve data (from 2nd to 7th column). The unit of time, PH1, PH2, PH3, PH4, PH5, and PH6 data are [ms], [x10^{-7} W/m^2], [x10^{-4} W/m^2], [x10^{-5} W/m^2], [x10^{-3} W/m^2], [x10^{-5} W/m^2], and [x10^{-4} W/m^2]. At each event, light curve data for 512 ms time period (from -100 ms before the trigger to +412 ms after the trigger) are recorded. The file name (YYYY-MM-DD_hhmmss.sssss) denotes the trigger time, and this trigger time corresponds to the time *t*=0 [ms] in PH light curve data.

The absolute intensity of optical emissions that reach at the entrance of the 1st optical lens can be calculated using the following equations:

$$\begin{cases} I(\lambda) = R(\lambda)\cdot \dfrac{Cts - C_{\text{offset}}}{\int R(\lambda)\cdot S(\lambda)\cdot G_{\text{Amp}}\cdot 10^{\{7.0\times\log_{10}(HV/500)\}}\,d\lambda} & \text{(for PH1-3, PH5, PH6)} \\ I(\lambda) = R(\lambda)\cdot \dfrac{Cts - C_{\text{offset}}}{\int R(\lambda)\cdot S(\lambda)\cdot G_{\text{Amp}}\,d\lambda} & \text{(for PH4)} \end{cases}$$

where $I(\lambda)$ is the absolute irradiance at the wavelength λ in the unit of W/m^2, $R(\lambda)$ is the spectral curve of the source emission in arbitrary unit, Cts is the output digital counts, C_{offset} is the offset counts, $S(\lambda)$ is the instrumental sensitivity, G_{Amp} is the gain of the amplifier, and HV is the high-voltage value supplied to the photomultiplier tube [Adachi et al., 2016]. Before the launch of JEM-GLIMS, we have carried out the calibration experiment and measured the absolute instrumental sensitivity of each PH channel. See more details in Adachi et al. [2016] and Sato et al. [2017].

7.4 VLFR

VLFR L2 data is the time series of electric field intensity of the electromagnetic waves measured by VLFR. The VLFR L2 data are provided in the ASCII format and consist of time data (1st left column) and electric field waveform data (2nd column from the left). The unit of time and waveform data are [ms] and [V/m]. At each event, electric field waveform data for 512 ms time period (from -112 ms before the trigger to +400 ms after the trigger) are recorded. The file name (YYYY-MM-DD_hhmmss.sssss) denotes the trigger time, and this trigger time corresponds to the time *t*=0 [ms] in VLFR waveform data.

The absolute amplitude of electric field can be calculated using the following equations:

$$E = \left\{\left(\frac{Cts}{32768} * 1.0\right) - 1.0\right\} \Big/ 9{,}06$$

where E and Cts are the electric field in the unit of V/m and the recorded digital counts.

7.5 Log File Keywords

The structure and meaning of the log file header information are as follows:

< Log File Keywords >

```
OBSERVATION LOG FOR THE EVENT:                  2013-08-01_132432.69898 / Trigger date and time (UT)
=====[ GENERAL ]=============================================
Trigger Time (Year) =                           YYYY                / Trigger year (UT)
Trigger Time (Month) =                          MM                  / Trigger month (UT)
Trigger Time (Day) =                            DD                  / Trigger day (UT)
Trigger Time (Hour) =                           hh                  / Trigger hour (UT)
Trigger Time (Minutes) =                        mm                  / Trigger minutes (UT)
Trigger Time (Second) =                         ss.sssss            / Trigger second (UT)
-----
ISS Longitude [deg.] =                          123.456             / Longitude of the ISS at the triggered event
ISS Latitude [deg.] =                           12.345              / Latitude of the ISS at the triggered event
ISS Altitude [km] =                             123.456             / Altitude of the ISS at the triggered event
=====[ SHU PARAMETERS ]======================================
TLM Rate (Message Mode) =                       12msg (A-a)         / TLM mode (12msg=5.8kbps, 22msg=10.6kbps)
Trigger Instrument =                            PH                  / Trigger instrument (PH or LSI)
Operation Mode =                                Night               / Operation mode (Night or Day)
Data Compression =                              DIS                 / LSI data compression (ENA or DIS)
-----
SHU +3.3V Power [V] =                           1.23                / Voltage level of +3.3V power
SHU +5  V Power [V] =                           1.23                / Voltage level of +5V power
SHU +12 V Power [V] =                           12.34               / Voltage level of +12V power
SHU -12 V Power [V] =                           -12.34              / Voltage level of -12V power
-----
H/W Readiness =                                 READY               / H/W readiness (READY or NOTREADY)
LSI-1 Power =                                   ON                  / LSI-1 power (ON or OFF)
LSI-2 Power =                                   ON                  / LSI-2 power (ON or OFF)
PH U1 (PH1-4) Power =                           ON                  / PH U1 (PH1-4) power (ON or OFF)
PH U1 (PH5,6) Power =                           ON                  / PH U2 (PH5,6) power (ON or OFF)
VLFR Power =                                    ON                  / VLFR power (ON or OFF)
VITF Power =                                    ON                  / VITF power (ON or OFF)
-----
LSI OVC =                                       NORMAL              / LSI over current status (NORMAL or OVC)
PH OVC =                                        NORMAL              / PH over current status (NORMAL or OVC)
VLFR OVC =                                      NORMAL              / VLFR over current status (NORMAL or OVC)
PH1 HV OVC =                                    NORMAL              / PH1 HV over current status (NORMAL or OVC)
PH2 HV OVC =                                    NORMAL              / PH2 HV over current status (NORMAL or OVC)
PH3 HV OVC =                                    NORMAL              / PH3 HV over current status (NORMAL or OVC)
PH5 HV OVC =                                    NORMAL              / PH5 HV over current status (NORMAL or OVC)
PH6 HV OVC =                                    NORMAL              / PH6 HV over current status (NORMAL or OVC)
=====[ LSI PARAMETERS ]======================================
Unit of LSI-1 FITS Data =                       x10^(-11) [W/m^2]   / Unit of LSI-1 FITS data
Unit of LSI-2 FITS Data =                       x10^(-11) [W/m^2]   / Unit of LSI-2 FITS data
-----
Longitude of LSI FOV (Left-Bottom) @10km [deg] =  123.456           /    Left-Top  _________________  Right-Top
Latitude  of LSI FOV (Left-Bottom) @10km [deg] =  12.345            /  (lon, lat) |                 | (lon, lat)
Longitude of LSI FOV (Left-Top) @10km [deg] =     123.456           /             |     LSI FOV     |
Latitude  of LSI FOV (Left-Top) @10km [deg] =     12.345            /             |                 |
Longitude of LSI FOV (Right-Top) @10km [deg] =    123.456           /             |   at 10km alt.  |
Latitude  of LSI FOV (Right-Top) @10km [deg] =    12.345            /             |                 |
Longitude of LSI FOV (Right-Bottom) @10km [deg] = 123.456           / Left-Bottom |_________________| Right-Bottom
Latitude  of LSI FOV (Right-Bottom) @10km [deg] = 12.345            /  (lon, lat)                       (lon, lat)
-----
Longitude of LSI FOV (Left-Bottom) @75km [deg] =  123.456           /
Latitude  of LSI FOV (Left-Bottom) @75km [deg] =  12.345            /      Left-Top  _____________  Right-Top
Longitude of LSI FOV (Left-Top) @75km [deg] =     123.456           /    (lon, lat) |             | (lon, lat)
Latitude  of LSI FOV (Left-Top) @75km [deg] =     12.345            /               |   LSI FOV   |
Longitude of LSI FOV (Right-Top) @75km [deg] =    123.456           /               |             |
Latitude  of LSI FOV (Right-Top) @75km [deg] =    12.345            /               | at 75km alt.|
Longitude of LSI FOV (Right-Bottom) @75km [deg] = 123.456           /   Left-Bottom |_____________| Right-Bottom
Latitude  of LSI FOV (Right-Bottom) @75km [deg] = 12.345            /    (lon, lat)                   (lon, lat)
-----
```

```
LSI-1 C/W of Pass-Band [nm] =                   797.5                 / Center wavelength of LSI-1 pass-band
LSI-1 FWHM of Pass-Band [nm] =                  65.0                  / FWHM of LSI-1 pass-band
LSI-2 C/W of Pass-Band [nm] =                   762.0                 / Center wavelength of LSI-2 pass-band
LSI-2 FWHM of Pass-Band [nm] =                  14.0                  / FWHM of LSI-2 pass-band
Effective Aperture of Lens [nm] =               18.0                  / Effective aperture of lens
F-value of Lens =                               1.4                   / F-value of lens
Focal Length [mm] =                             25.0                  / Focal length of lens
FOV [deg x deg] =                               28.7 x 28.7           / FOV of LSI
Total Pixel Number of Sensor =                  512 x 512             / Pixel number of sensor (CMOS/STAR-250)
Pixel Size [um x um] =                          25 x 25               / Physical size of 1 pixel
-----
Download Number of Image Data =                 04                    / Number of downloaded LSI data files
Frame Rate [fps] =                              29                    / Frame rate (29fps or 116fps or 464fps)
Resolution [bit] =                              10                    / Resolution of raw image data
Recorded Image Size [pixel x pixel] =           512 x 512             / Setting of image size for observation
-----
LSI-1 Gain =                                    x1                    / LSI-1 gain (x1 or x2 or x4 or x8)
LSI-2 Gain =                                    x4                    / LSI-2 gain (x1 or x2 or x4 or x8)
-----
LSI-1 FPGA Trig. Para.#1 (hotpixel) =           0x03FF                / FPGA trigger parameter #1 for LSI-1
LSI-1 FPGA Trig. Para.#2 (pixel)    =           0x03FF                / FPGA trigger parameter #2 for LSI-1
LSI-1 FPGA Trig. Para.#3 (frame)    =           0x03FF                / FPGA trigger parameter #3 for LSI-1
LSI-2 FPGA Trig. Para.#1 (hotpixel) =           0x03FF                / FPGA trigger parameter #1 for LSI-2
LSI-2 FPGA Trig. Para.#2 (pixel)    =           0x03FF                / FPGA trigger parameter #2 for LSI-2
LSI-2 FPGA Trig. Para.#3 (frame)    =           0x03FF                / FPGA trigger parameter #3 for LSI-2
-----
LSI CPU Trigger =                               DIS                   / CPU judgement utilization (ENA or DIS)
LSI CPU Trig. Para.#1 (threshold) =             0x0000                / CPU judgement parameter #1
LSI CPU Trig. Para.#2 (factor) =                0x00FF                / CPU judgement parameter #2
LSI CPU Trig. Para.#3 (x-offset) =              0x00FF                / CPU judgement parameter #3
LSI CPU Trig. Para.#4 (y-offset) =              0x00FF                / CPU judgement parameter #4
-----
LSI-1 Elec. Temperature [deg C] =               14.21                 / Temperature of LSI-1 electronics
LSI-2 Filter Temperature [deg C] =              10.40                 / Temperature of LSI-2 filter
=====[ PH PARAMETERS ]========================================
Unit of PH1 Data =                              x10^(-7) [W/m^2]      / Unit of PH1 light curve data
Unit of PH2 Data =                              x10^(-4) [W/m^2]      / Unit of PH2 light curve data
Unit of PH3 Data =                              x10^(-5) [W/m^2]      / Unit of PH3 light curve data
Unit of PH4 Data =                              x10^(-3) [W/m^2]      / Unit of PH4 light curve data
Unit of PH5 Data =                              x10^(-5) [W/m^2]      / Unit of PH5 light curve data
Unit of PH6 Data =                              x10^(-4) [W/m^2]      / Unit of PH6 light curve data
-----
Longitude of PH FOV Center Position @10km [deg] = 123.456             / Longitude of PH FOV center
Latitude  of PH FOV Center Position @10km [deg] = 12.345              / Latitude of PH FOV center
-----
PH1 C/W of Pass-Band [nm] =                     215.0                 / Center wavelength of PH1 pass-band
PH1 FWHM of Pass-Band [nm] =                    130.0                 / FWHM of PH1 pass-band
PH2 C/W of Pass-Band [nm] =                     337.0                 / Center wavelength of PH2 pass-band
PH2 FWHM of Pass-Band [nm] =                    10.0                  / FWHM of PH2 pass-band
PH3 C/W of Pass-Band [nm] =                     762.0                 / Center wavelength of PH3 pass-band
PH3 FWHM of Pass-Band [nm] =                    10.0                  / FWHM of PH3 pass-band
PH4 C/W of Pass-Band [nm] =                     750.0                 / Center wavelength of PH4 pass-band
PH4 FWHM of Pass-Band [nm] =                    300.0                 / FWHM of PH4 pass-band
PH5 C/W of Pass-Band [nm] =                     316.0                 / Center wavelength of PH5 pass-band
PH5 FWHM of Pass-Band [nm] =                    10.0                  / FWHM of PH5 pass-band
PH6 C/W of Pass-Band [nm] =                     392.0                 / Center wavelength of PH6 pass-band
PH6 FWHM of Pass-Band [nm] =                    10.0                  / FWHM of PH6 pass-band
Effective Aperture of Lens [nm] =               15.0                  / Effective aperture of PH1-3, PH5, PH6 lenses
Effective Aperture of Lens [nm] =               6.0                   / Effective aperture of PH4 lens
F-value of Lens =                               1.5                   / F-value of PH1-3, PH5, PH6 optics
F-value of Lens =                               1.7                   / F-value of PH4 optics
FOV (full angle) [deg] =                        42.7                  / FOV of PH1-3, PH5, PH6
FOV (full angle) [deg] =                        86.8                  / FOV of PH4
Sampling Freauency [kHz] =                      20                    / Sampling frequency
Resolution [bit] =                              12                    / Resolution of PH raw data
-----
```

```
PH Unit#1 HV Status (PH1-3) =                  ON                   / PH U1 (PH1-4) HV power status (ON or ENA or BUSY)
PH Unit#2 HV Status (PH5,6) =                  ON                   / PH U2 (PH5,6) HV power status (ON or ENA or BUSY)
-----
PH1 HV [V] =                                   -123                 / PH1 HV level
PH2 HV [V] =                                   -123                 / PH2 HV level
PH3 HV [V] =                                   -123                 / PH3 HV level
PH5 HV [V] =                                   -123                 / PH5 HV level
PH6 HV [V] =                                   -123                 / PH6 HV level
-----
PH1 Amp. Gain =                                x10                  / PH1 amplifier gain level (x1 or x2 or x5 or x10)
PH2 Amp. Gain =                                x10                  / PH2 amplifier gain level (x1 or x2 or x5 or x10)
PH3 Amp. Gain =                                x10                  / PH3 amplifier gain level (x1 or x2 or x5 or x10)
PH4 Amp. Gain =                                x1                   / PH4 amplifier gain level (x1 or x2 or x5 or x10)
PH5 Amp. Gain =                                x10                  / PH5 amplifier gain level (x1 or x2 or x5 or x10)
PH6 Amp. Gain =                                x10                  / PH6 amplifier gain level (x1 or x2 or x5 or x10)
-----
PH U1 (PH1-4) CAL-LED Level [V] =              1.23                 / PH U1 (PH1-4) calibration LED voltage level
PH U2 (PH5,6) CAL-LED Level [V] =              1.23                 / PH U2 (PH5,6) calibration LED voltage level
-----
PH Trigger Threshold [V] =                     1.23                 / Trigger threshold voltage level for PH
-----
PH U1 Elec. Temperature [deg C] =              12.34                / Temperature of PH U1 electronics
PH U1 Optics Temperature [deg C] =             12.34                / Temperature of PH U1 optics
PH U2 Elec. Temperature [deg C] =              12.23                / Temperature of PH U2 electronics
PH U2 Optics Temperature [deg C] =             12.23                / Temperature of PH U2 optics
=====[ VLFR PARAMETERS ]=======================================
Unit of VLFR Data =                            [V/m]                / Unit of VLFR waveform data
-----
Longitude of VLFR Antenna Footprint @10km [deg] = 123.456           / Longitude of the VLFR antenna footprint at 10km
Latitude  of VLFR Antenna Footprint @10km [deg] = 12.345            / Latitude of the VLFR antenna footprint at 10km
-----
Frequency Range [kHz] =                        1-30                 / Frequency range of VLFR
Antenna Directivity [rad] =                    2pi                  / Antenna directivity
Sampling Freauency [kHz] =                     100                  / Sampling frequency
Resolution [bit] =                             14                   / Resolution of VLFR raw data
-----
VLFR Temperature [deg C] =                     12.34                / Temperature of VLFR electronics
=====[ VITF PARAMETERS ]=======================================
Frequency Range [MHz] =                        70-100               / Frequency range
Antenna Directivity [rad] =                    2pi                  / Antenna directivity
Sampling Freauency [MHz] =                     200                  / Sampling frequency
Resolution [bit] =                             8                    / Resolution of VITF raw data
-----
VITF Delay Trigger Time [ms] =                 100                  / Delay trigger time
VITF Temperature [deg C] =                     12.34                / Temperature of VITF electronics
-----[ END ]---------------------------------------------------
```

8. Sample Software

In order to read the L2 data and plot them, you can use the following IDL procedures:

- plot_LSI.pro
- plot_PH.pro
- plot_VLFR.pro

In order to run the procedure "plot_LSI.pro", you need to install the "IDL Astronomy User's Library" provided by NASA (https://idlastro.gsfc.nasa.gov/) and make a path setting at the environment setting of your IDL software.

In addition to this, to read and plot the LSI L2 data (FITS data), you can use other free software, such as "SAOImage DS9".　You can download it at the web page (http://ds9.si.edu/site/Home.html).

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10. Abbreviations

Abbreviation	English name	Notes
ASCII	American Standard Code for Information Interchange	
CPU	Central Processing Unit	
C/W	Center Wavelength	
DARTS	Data Archives and Transmission System	
DIS	Disable	
ENA	Enable	
FITS	Flexible Image Transport System	
FOV	Field of View	
FPGA	Field-Programmable Gate Array	
FUV	Far-Ultraviolet	
FWHM	Full Width Half Maximum	
HK	Housekeeping	
HV	High Voltage	
H/W	Hardware	
ISS	International Space Station	
JEM-GLIMS	Global Lightning and Sprite Measurements on JEM-EF	
L0	Level-0	
L1	Level-1	
L2	Level-2	
LBH	Lyman-Birge-Hopfield	
LSI	Lightning and Sprite Imager	
OVC	Over Current	
PH	Spectrophotometer	
QL	Quick look	
ROM	Read Only Memory	
SAA	South Atlantic Anomaly	
SHU	Science Instrument Handling Unit	
S-RAM	Static Random Access Memory	
TLE(s)	Transient Luminous Event(s)	
TLM	Telemetry	
U1	Unit #1	
U2	Unit #2	
UT	Universal Time	
VHF	Very High Frequency	
VITF	VHF Interferometer	
VLF	Very Low Frequency	
VLFR	VLF Receiver	