Solar Dynamics Observatory (SDO)
Extreme Ultraviolet Variability Experiment (EVE):
MEGS-A and MEGS-B Level 0b science data product

README
11/13/23

Table of Contents

Table of Figures

Introduction

EVE level 0B data files were created at the Laboratory for Atmospheric and Space Physics in Boulder, Colorado for the NASA Solar Dynamics Observatory (SDO) Extreme Ultraviolet Variability Experiment (EVE). The Science Processing and Operations Center (SPOC) is responsible for creating and maintaining access to all EVE products. For a high-level introduction to the EVE instrument please visit:
https://lasp.colorado.edu/eve/science/instrument/

Level 0B products contain one Charge Coupled Device (CCD) image (MEGS-A or MEGS-B) in HDU (Header/Data Unit) #0 and one binary table in HDU #1. Level 0B products are processed from telemetry and contain the least processed data. The level 0B processing software converts telemetry into images: unpacking, decoding 2s complement, parity checking, and assigning pixel values into the corresponding locations in the images. Users should be aware that these data contain particle strikes/streaks. One count above the dark represents approximately 2 electrons, but users should refer to the references for calibration information. The CCD temperature is converted from DN to degrees C. The filter position is determined from a lookup table using the filter resolver. The MEGS-A, SAM, and MEGS-B filter mechanisms are independent and operate independently, however the integration timing control circuitry of the CCDs are linked to the same electronic hardware clock. Integrations are restricted to only integer multiples of 10 seconds.

The SDO EVE spectrograph primary science images contain the spectrally dispersed entrance slit images across the detectors. Slit images of solar emission lines appear as curved lines on the detector. The intensity is proportional to irradiance and the proportionality varies with wavelength, filter, time (from degradation) and temperature. MEGS-A is an off-Rowland circle grazing incidence grating spectrograph with two entrance slits using two different optical paths on the grating and detector. MEGS-A also has a pinhole camera, Solar Aspect Monitor (SAM), to image the sun using photon counting in soft X-rays. MEGS-B is a near normal-incidence, two-grating cross-dispersing spectrograph.

For access and data product issues please contact Don.Woodraska@lasp.colorado.edu.

For science issues please contact Frank.Eparvier@lasp.colorado.edu.

Responsible Data Usage

Please refer to the Goddard Space Flight Center SDO web page for data rights and rules for use: https://sdo.gsfc.nasa.gov/data/rules.php

> **WARNINGS**: The MEGS-A detector experienced a capacitor short on May 26, 2014 (day 146) that prevents the detector from working. No solar spectra are measured for wavelengths shorter than 33 nm after that anomaly. MEGS-B has been extended to its shortest possible wavelength of 33.34 nm. EUV spectra are only available when MEGS-B is exposed, usually for 3 hours per day.

For an in-depth discussion of EVE instrumentation please visit: https://lasp.colorado.edu/home/eve/science/instrument/

Reference Publications

More information about the EVE instrument measurements, and calibrations can be found in these references:

Woods, T. N., F. G. Eparvier, R. Hock, A. R. Jones, D. Woodraska, D.Judge, L. Didkovsky, J. Lean, J. Mariska, H. Warren, D. McMullin, P. Chamberlin, G. Berthiaume, S. Bailey, T. Fuller-Rowell, J. Sojka, W. K. Tobiska, and R. Viereck, "Extreme Ultraviolet Variability Experiment (EVE) on the Solar Dynamics Observatory (SDO): Overview of Science Objectives, Instrument Design, Data Products, and Model Developments", *Solar Physics, 275*, 115-143,
doi: 10.1007/s11207-009-9487-6, 2012.
https://lasp.colorado.edu/home/eve/files/2011/06/EVE_Overview_SolarPhys.pdf

Hock, R. A., P. C. Chamberlin, T. N. Woods, D. Crotser, F. G. Eparvier, D. L. Woodraska, and E. C. Woods, "Extreme Ultraviolet Variability Experiment (EVE) Multiple EUV Grating Spectrographs (MEGS): Radiometric Calibrations and Results", *Solar Physics, 275*, 145-178,
doi: 10.1007/s11207-010-9520-9, 2012.
https://lasp.colorado.edu/home/eve/files/2011/06/Final_Sol_Phy_Hock_1April_2010.pdf

Didkovsky, L., D. Judge, S. Wieman, T. Woods, and A. Jones, "EUV SpectroPhotometer (ESP) in Extreme Ultraviolet Variability Experiment (EVE): Algorithms and Calibrations", *Solar Physics, 275*, 179-205, doi: 10.1007/s11207-009-9485-8, 2012.

HDU#0 – Image

The MEGS image data contain 2048×1024 pixels stored as 16-bit unsigned integers, but only the least significant 14-bits contain data (from the 14-bit ADC). The valid data range is from 0-16382 inclusive. A value of 16383 is a saturated, non-measurement, and should be treated as missing.

The MEGS-A image contains 3 regions: slit 1 is on one side, slit 2 and the SAM are on the other. Slit 1 has a different amplifier (different gain and dark offset) than slit 2 and SAM.

The slit 1 wavelength range is approximately 6–17 nm. Higher order light may be significant for slit 1 for wavelengths longer than ~12 nm. The grating efficiency falls of quickly for wavelengths that are shorter than 6 nm.

The slit 2 wavelength range is approximately 17–37 nm (second order lines are detectable at 34.2 nm and longer wavelengths). Due to the grazing-incidence design, solar emission lines are partially imaged in MEGS-A in the cross-dispersion direction. Each solar line on the detector represents the sum of a large collection of point sources from the (~0.5 degree) sun that collectively add up to the curved line on the CCD. During bright flares, one spot on the sun can suddenly brighten producing a brighter strip across slit 1 and slit 2 spectra that corresponds to that spot on the sun. The corresponding bright spot on SAM also brightens.

The SAM wavelength range is ~0.1–7 nm. The range is dictated by the transmission from the C/Al/Ti/C filter and the thickness of the CCD. The SAM soft X-ray image is located on the short wavelength side of the slit 2 spectrum where most wavelengths are absorbed by the aluminum filter. Unfortunately, some slit 2 spectral features can be detected across the SAM image during large flares. The detector is rotated slightly relative to the pinhole producing an ellipsoidal sun image when multiple images are added. No WCS is available in the FITS file for interpreting SAM, but the SDO spacecraft orientation keeps the solar north pole axis aligned vertically and typically tracks very well. When flares occur, the SAM image brightens at the location of the flare. When very bright flares occur, the SAM bright point becomes surrounded by a large bright circle. When flares have large contributions from harder X-rays the thick pinhole holder material begins acting like a second larger pinhole camera for harder X-rays. This unambiguously defines the soft X-ray flare location.

The MEGS-B uses a two-grating design with near-normal incidence, cross-dispersion gratings, and an intermediate slit that results in spectral lines varying in curvature and magnification from one side to the other. This design suppresses higher orders and out-of-band light.

HDU#1 – Binary Table

A binary table is stored in HDU#1. It contains 20 values. Here a Ulong=32-bit unsigned integer, Uint=16-bit unsigned integer, byte=8 bits, float=32 bit floating point.

Name	Data Type	Description
YYYYDOY	Ulong	7-digit year and day of year
SOD	Ulong	Seconds of UTC day at end of exposure
TAI_SEC	Ulong	Second elapsed since the TAI epoch Jan 1, 1958 (no leap seconds) at the end of the exposure
TAI_SUBSEC	Ulong	Fraction of a second at the end of the exposure
VCDU_COUNT	Uint	Number of VCDUs used to create the image. 2395 is complete
INT_TIME	Uint	Integration time code. Number of 10-second units. 1=10 seconds, 2=20 seconds, 6=60 seconds, etc.
HW_TEST	Byte	0=not a test pattern, 1=a test pattern (not science)
SW_TEST	Byte	0=not a test pattern, 1=a test pattern (not science)
REVERSE_CLOCK	Byte	0=forward clocking (default science), 1=reverse (not science)
VALID	Byte	1=valid data transfer from CCD, 0=no transfer occurred (duplicated data)
RAM_BANK	Byte	0 or 1 indicating which RAM bank contained the CCD image
INT_TIME_WARN	Byte	0 is no warning, 1 means flight software interrupted this integration before it completed normally
FILTER_POSITION	Byte	0=moving 1=Dark on both slit 1 and slit 2 2=second order C/Zr/Si/C & Al/Mg/Al 3=primary C/Zr/C & Al/Ge/C 4=prime2, 70-sec/day C/Zr/C & Al/Ge/C 5=prime3, 70-sec/week C/Zr/C & Al/Ge/C
READOUT_MODE	Byte	2-bit code defining the amplifier combination 0=left,left 1=left,right 2=right,left (MEGS-A default) 3=right,right
CCD_TEMP	Float	Temperature in degrees C for the MEGS-A CCD, usually around -100 deg C
LED_ON	Byte	Power status for the LED circuit, 0=off, 1=on
LED0_LEVEL	Byte	Current level setting 0-8
LED1_LEVEL	Byte	Current level setting 0-8
RESOLVER	Uint	0–65535 encoder value for the MEGS-A filter mechanism, the resolver is used to determine FILTER_POSITION from a lookup table
SAM_RESOLVER	Uint	0–65535 encoder value for the SAM filter mechanism, SAM filters are defined as 0–2239 & 65000-65535=Dark, no science (1) 12308–17937=Acton 240 nm +/- 40 nm saturates, no science (2) **26888–29720**=C/Al/Ti/C primary science (3) 39785–42827=C/Al/Ti/C secondary science (4) 51728–57321=Acton 170-300 nm, saturated, no science (5) All intermediate values are dark between filter positions and do not contain science

File Naming Convention

Level 0B MEGS-A and MEGS-B products follow this naming convention

`MA__L0B_YYYYDDD_hhmmss_VV_vvv_rr.fit` where:

`MA` designates this as an SDO EVE MEGS-A product, MB for MEGS-B

`L0B` designates this as a level 0B product

`YYYY` is the year

`DDD` is the day of year (001-366)

`hhmmss` is the hour minute second in the UTC day

`VV` is the DDS telemetry file version number (00)

`vvv` is the version number (001)

`rr` is the revision number (01)

The version numbers are static and not expected to change.

Explanation and Examples in IDL

Level 0B MEGS-A and MEGS-B image data products are stored in FITS format and may be read by a variety of software using standard FITS readers in multiple languages and with standard browse tools, such as fv. See the documentation section at http://lasp.colorado.edu/eve/data_access/index.html for more details. Recall that there is no WCS information in the FITS headers. LASP provides an IDL function called eve_read_whole_fits.pro which allows easy reading of any EVE data product that is in FITS format. IDL users that are more comfortable with mrdfits may wish to use that (eve_read_whole_fits is a wrapper to mrdfits). The software eve_read_whole_fits.pro may be downloaded from the EVE website. https://lasp.colorado.edu/eve/data_access/software/eve_read_whole_fits.pro

Reading a file

We will use the IDL function mrdfits.pro (eve_read_whole_fits also works) that is available from Wayne Landsman at the IDL astronomy library https://idlastro.gsfc.nasa.gov/ftp/pro/fits/. Other useful routines are also in that site. The IDL astronomy library strives to be compatible with open source interpreters GDL and FL.

To read in one MEGS-A image, download a file and call the function with the filename.

Read the image, HDU #0.

```
IDL> d0=mrdfits('MA__L0B_4_2010120_235915_00_001_01.fit.gz',0,hdr0,/unsign)

IDL> help,d0,hdr0
    D0              UINT      = Array[2048, 1024]
    HDR0            STRING    = Array[23]
```

Read the binary table, HDU #1.

```
IDL> d1=mrdfits('MA__L0B_4_2010120_235915_00_001_01.fit.gz',1,hdr1,/unsign)

IDL> help,d1,hdr1,/str
    ** Structure <25db918>, 20 tags, length=40, data length=39, refs=1:
       YYYYDOY         ULONG          2010120
       SOD             ULONG            86355
       TAI_SEC         ULONG       1651363189
       TAI_SUBSEC      ULONG       2077256417
       VCDU_COUNT      UINT          2395
       INT_TIME        UINT             1
       HW_TEST         BYTE         0
       SW_TEST         BYTE         0
       REVERSE_CLOCK   BYTE         0
       VALID           BYTE         1
       RAM_BANK        BYTE         1
       INT_TIME_WARN   BYTE         0
       FILTER_POSITION BYTE         4
       READOUT_MODE    BYTE         2
       CCD_TEMP        FLOAT          -103.303
       LED_ON          BYTE         0
       LED0_LEVEL      BYTE         0
       LED1_LEVEL      BYTE         0
       RESOLVER        UINT             0
       SAM_RESOLVER    UINT         28328
       HDR1            STRING    = Array[66]
```

To see the HDU#0 header contents, and HDU #1 contents:

```
IDL> print,hdr0
    SIMPLE  =                    T / file does conform to FITS standard
    BITPIX  =                   16 / number of bits per data pixel
    NAXIS   =                    2 / number of data axes
    NAXIS1  =                 2048 / length of data axis 1
    NAXIS2  =                 1024 / length of data axis 2
    EXTEND  =                    T / FITS dataset may contain extensions
    COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
    COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
    BZERO   =                    0 /Updated by MRDFITS v2.20
    BSCALE  =                    1 / default scaling factor
    EXTNAME = 'MEGS_IMAGE'         / Extension Name
    SOD     =                86355 / Seconds in day
    DOY     =              2010120 / Year - Day of year
    TAI_TIME=           1651363189 / tai time
    INT_TIME=                    1 / Integration time
    RAM_BANK=                    1 / Ram bank
    VALID   =                    1 / Validity flag
    HW_TEST =                    0 / Test pattern
    SW_TEST =                    0 / Test pattern
    REV_CLK =                    0 / Reverse clock
    HIERARCH tlm_filename = 'VC03_2010_120_23_58_45_0006a842cf0_07068_00.tlm' / TLM
    HISTORY VC03_2010_120_23_58_45_0006a842cf0_07068_00.tlm


IDL> print,hdr1
    XTENSION= 'BINTABLE'           / binary table extension
    BITPIX  =                    8 / 8-bit bytes
    NAXIS   =                    2 / 2-dimensional binary table
    NAXIS1  =                   39 / width of table in bytes
    NAXIS2  =                    1 / number of rows in table
    PCOUNT  =                    0 / size of special data area
    GCOUNT  =                    1 / one data group (required keyword)
    TFIELDS =                   20 / number of fields in each row
    TTYPE1  = 'yyyydoy '           / label for field   1
    TFORM1  = '1J      '           / data format of field: 4-byte INTEGER
    TZERO1  =                    0 /Modified by MRDFITS V2.20
    TSCAL1  =                    1 / data are not scaled
    TTYPE2  = 'sod     '           / label for field   2
    TFORM2  = '1J      '           / data format of field: 4-byte INTEGER
    TZERO2  =                    0 /Modified by MRDFITS V2.20
```

```
TSCAL2  =                    1 / data are not scaled
TTYPE3  = 'tai_sec '           / label for field   3
TFORM3  = '1J      '           / data format of field: 4-byte INTEGER
TZERO3  =                    0 /Modified by MRDFITS V2.20
TSCAL3  =                    1 / data are not scaled
TTYPE4  = 'tai_subsec'         / label for field   4
TFORM4  = '1J      '           / data format of field: 4-byte INTEGER
TZERO4  =                    0 /Modified by MRDFITS V2.20
TSCAL4  =                    1 / data are not scaled
TTYPE5  = 'vcdu_count'         / label for field   5
TFORM5  = '1I      '           / data format of field: 2-byte INTEGER
TZERO5  =                    0 /Modified by MRDFITS V2.20
TSCAL5  =                    1 / data are not scaled
TTYPE6  = 'int_time'           / label for field   6
TFORM6  = '1I      '           / data format of field: 2-byte INTEGER
TZERO6  =                    0 /Modified by MRDFITS V2.20
TSCAL6  =                    1 / data are not scaled
TTYPE7  = 'hw_test '           / label for field   7
TFORM7  = '1B      '           / data format of field: BYTE
TTYPE8  = 'sw_test '           / label for field   8
TFORM8  = '1B      '           / data format of field: BYTE
TTYPE9  = 'reverse_clock'      / label for field   9
TFORM9  = '1B      '           / data format of field: BYTE
TTYPE10 = 'valid   '           / label for field  10
TFORM10 = '1B      '           / data format of field: BYTE
TTYPE11 = 'ram_bank'           / label for field  11
TFORM11 = '1B      '           / data format of field: BYTE
TTYPE12 = 'int_time_warn'      / label for field  12
TFORM12 = '1B      '           / data format of field: BYTE
TTYPE13 = 'filter_position'    / label for field  13
TFORM13 = '1B      '           / data format of field: BYTE
TTYPE14 = 'readout_mode'       / label for field  14
TFORM14 = '1B      '           / data format of field: BYTE
TTYPE15 = 'ccd_temp'           / label for field  15
TFORM15 = '1E      '           / data format of field: 4-byte REAL
TTYPE16 = 'led_on  '           / label for field  16
TFORM16 = '1B      '           / data format of field: BYTE
TTYPE17 = 'led0_level'         / label for field  17
TFORM17 = '1B      '           / data format of field: BYTE
TTYPE18 = 'led1_level'         / label for field  18
TFORM18 = '1B      '           / data format of field: BYTE
TTYPE19 = 'resolver'           / label for field  19
TFORM19 = '1I      '           / data format of field: 2-byte INTEGER
TZERO19 =                    0 /Modified by MRDFITS V2.20
TSCAL19 =                    1 / data are not scaled
TTYPE20 = 'sam_resolver'       / label for field  20
TFORM20 = '1I      '           / data format of field: 2-byte INTEGER
TZERO20 =                    0 /Modified by MRDFITS V2.20
TSCAL20 =                    1 / data are not scaled
EXTNAME = 'MEGSA_TABLE'        / name of this binary table extension
```

Display an image

Each file can be read to display one image at a time.

```
IDL> d0=mrdfits('MA__L0B_4_2010120_235905_00_001_01.fit.gz',0,hdr0,/unsign)
IDL> loadct,3
IDL> device,decomp=0
IDL> tvscl,hist_equal(congrid(d0,1024,512))
```

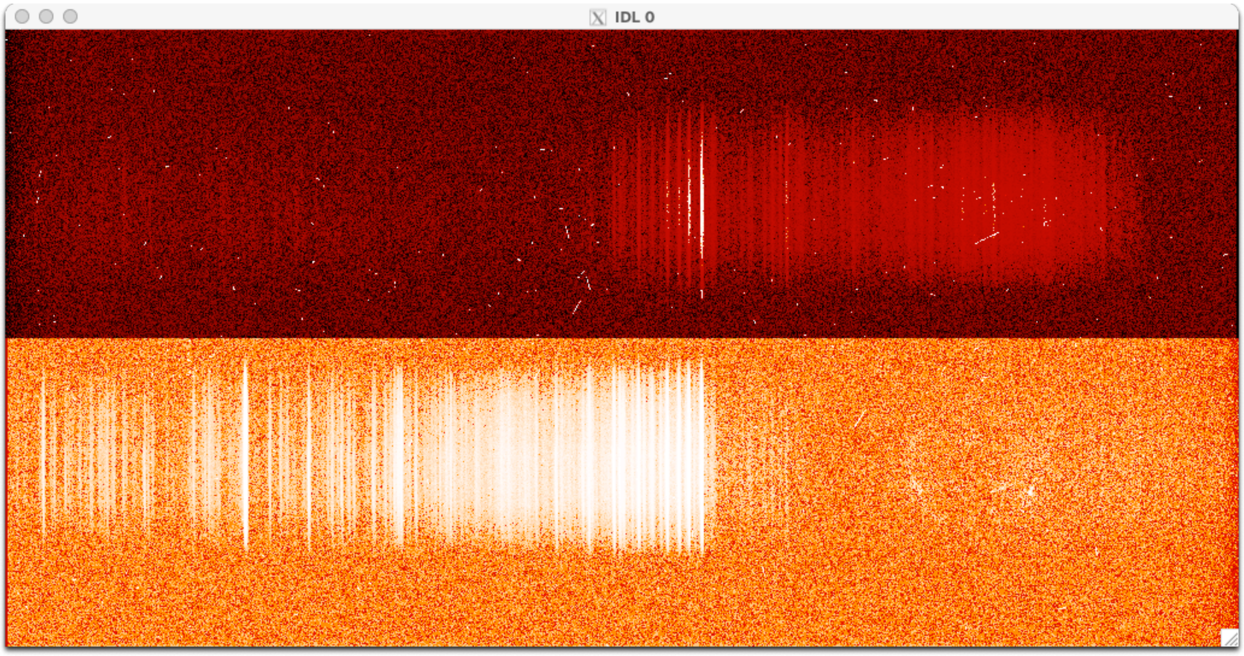

Figure 1 One histogram equalized MEGS-A image with 10-second integration time. The slit 1 spectrum is dispersed across the top with short wavelengths on the right side. The bright Fe IX line at 17.1 nm is the brightest line in slit 1. Slit 2 also shows 17.1 and all of the longer wavelengths to the left. The SAM pinhole camera is in the lower right. Particle spikes and streaks are scattered across the detector.

Read multiple files.

Search for ~5 minutes of data and display the sum of the images.

```
IDL> files = file_search('MA__L0B_4_2010120_235[0-5]*fit.gz')
IDL> img=fltarr(2048,1024)
IDL> foreach file,files do img += float(mrdfits(file,0,/unsign))
IDL> tvscl,hist_equal(congrid(img,1024,512))
```

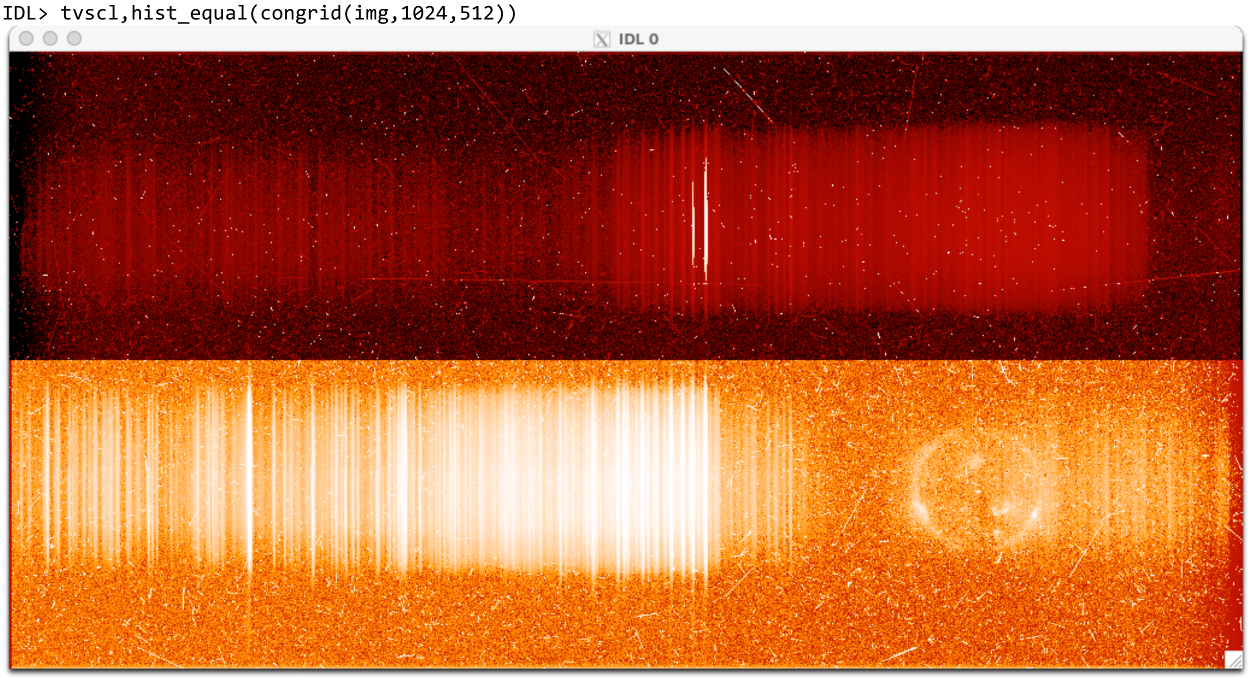

Figure 2 A 5-minute sum of 10-second integrations with histogram equalization makes it easier to see the SAM image and lines transmitted through slit 2. Larger particle spikes and streaks are easily observed when viewing multiple images.

Plot uncalibrated spectrum

A rough, uncalibrated solar spectrum can be viewed by plotting a selection from each side of the detector. Note that the wavelengths are not uniformly distributed and slightly curved.

```
IDL> !p.charsize=1.5 & !p.color=0 & !p.background='ffffff'x
IDL> plot,median(img[*,800:808],dim=2),ys=1,xr=[1000,2048],ps=10,ytitle='Arb',xtitle='Pixel',
title='Slit 1',xs=1
IDL> plot, median(img[*,300:308],dim=2),ys=1,xr=[0,1200],ps=10,ytitle='Arb',xtitle='Pixel',
title='Slit 2'
```

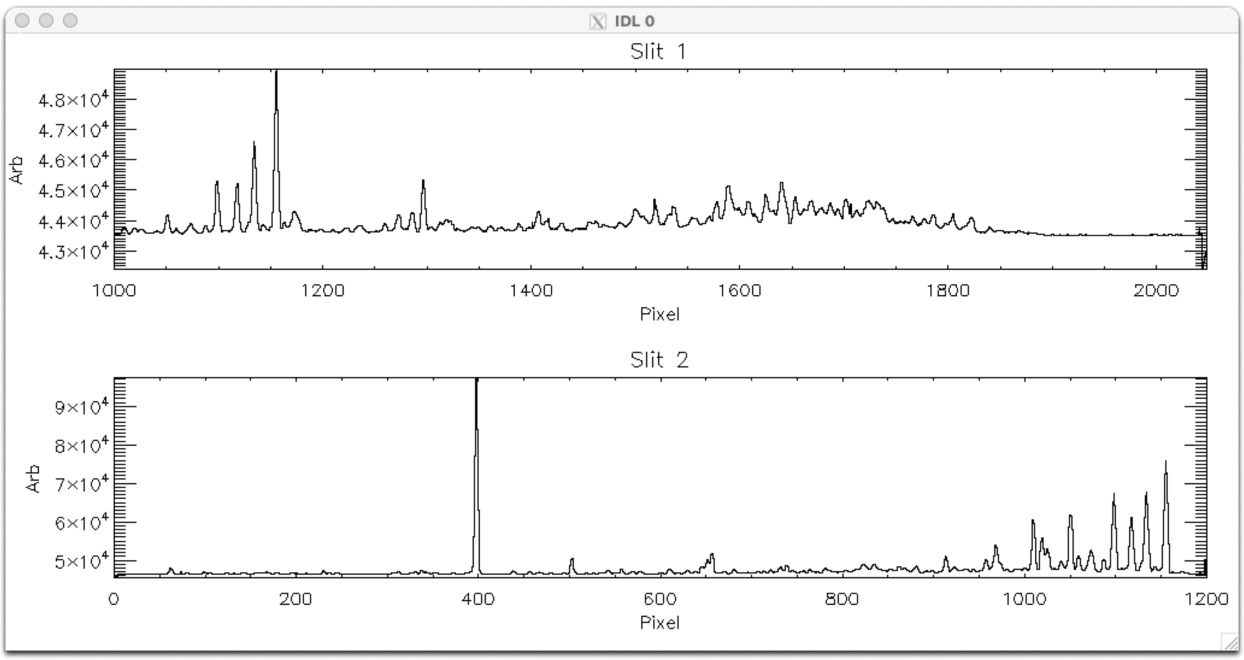

Figure 3 Uncalibrated spectra from MEGS-A slit 1 and 2 near the centers of each slit. The vertical axis has arbitrary units, and the horizontal axis is a reversed non-linear function of wavelength. Median filtering was applied in cross-dispersion to reduce the effect of particle strikes.

The bright line in slit 2 near 400 pixels is 30.4 nm He I, and near 1155 the bright line is 17.1 nm Fe IX. In the slit 1 spectrum the bright line near 1150 is 17.1 nm Fe IX with shorter wavelengths towards the right. It should be clear that the response is not the same for the two slits since the filters are different and the response varies with wavelength.

Read MEGS-B file.

```
IDL> file='MB__L0B_3_2010123_180006_00_001_01.fit.gz'
IDL> mb_img = mrdfits(file,0,/unsign,hdr0)
IDL> loadct,1 & device,decomp=0
```

```
IDL> tvscl,hist_equal(congrid(mb_img,1024,512))
```

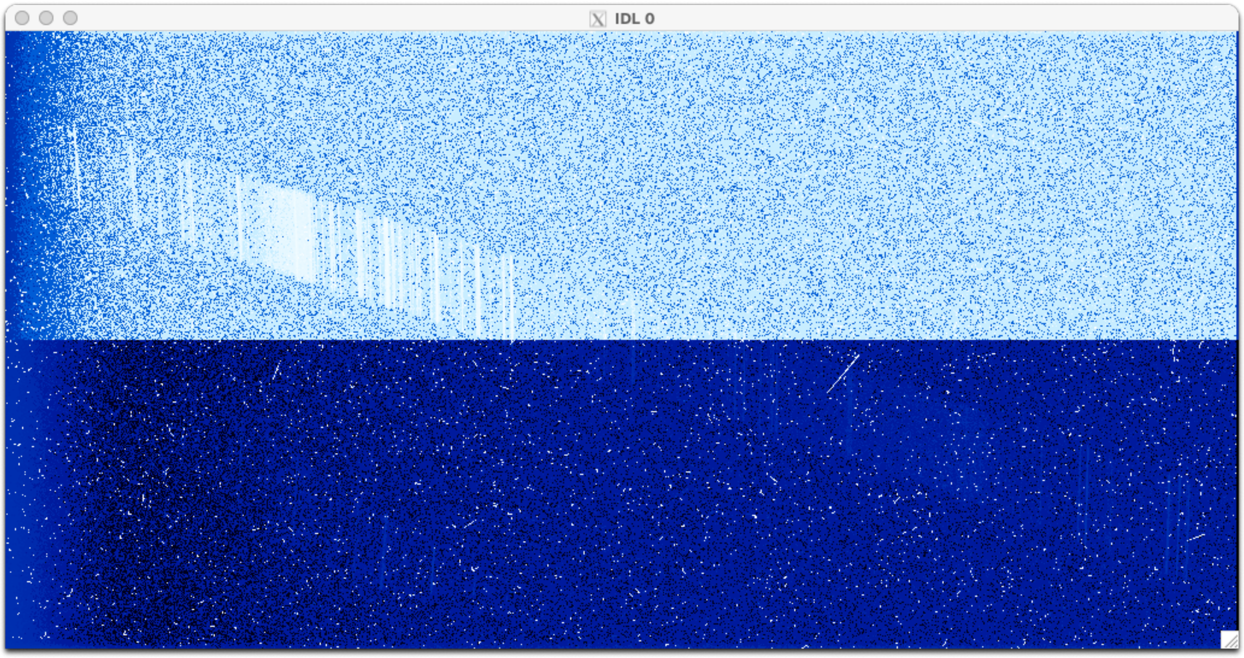

Figure 4 MEGS-B 10-second solar spectrum on the first rocket day, 2010 day 123, near 18:00 UTC.

The primary spectrum is first order off both gratings dispersing the light across the detector diagonally with the spectral lines being non-uniformly curved across the detector with non-uniform wavelength scale, and non-uniform magnification (line height). As with MEGS-A, the offsets are different on each amplifier (top/bottom).

In the next example, the median is subtracted from the top and bottom to help flatten the image. This subtraction approximates the detector dark (ignoring the initial ramps from the amplifiers). The dark correction used in level 1 processing is a function of temperature and time for each pixel. The frozen dark shape has the opposite effect on the top and bottom amplifiers where the top ramps up from left to right (short to long wavelengths) and the bottom ramps down from left to right. Both rapidly flatten. The default readout mode for MEGS-B is 0 (left-left).

```
IDL> flatmb = float(mb_img)
IDL> flatmb[*,0:511] -= median(mb_img[*,0:511])
IDL> flatmb[*,512:*] -= median(mb_img[*,512:*])
```

```
IDL> tvscl,hist_equal(congrid(flatmb,1024,512))
```

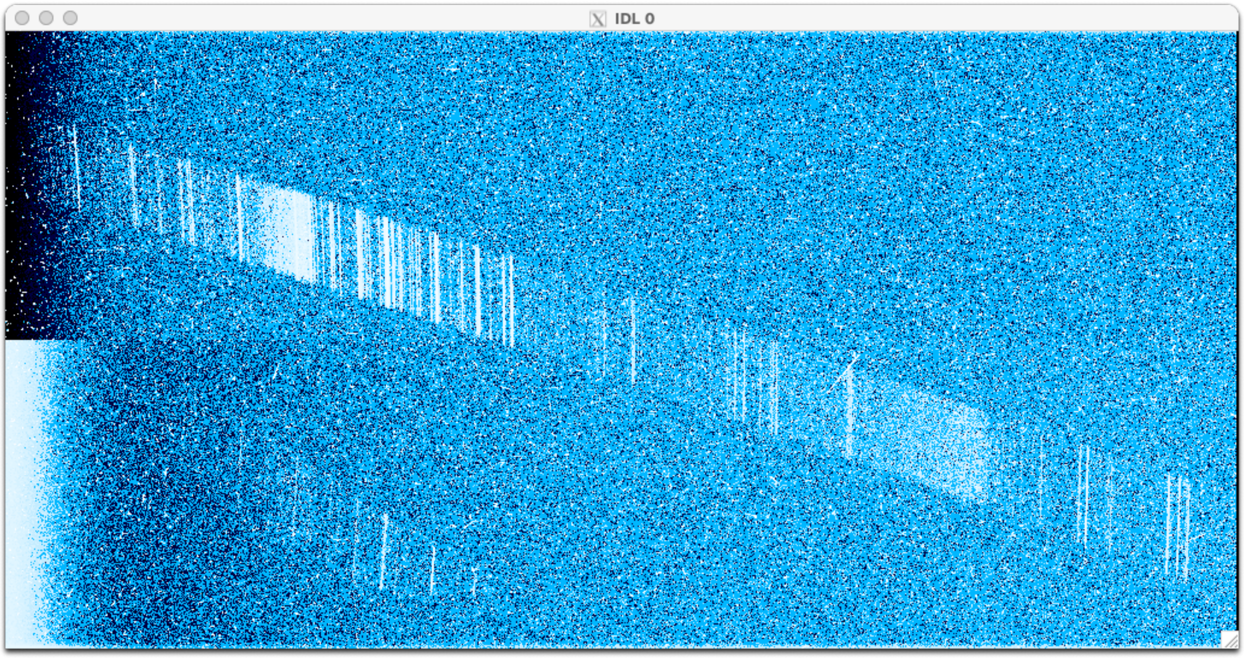

Figure 5 The same MEGS-B image data with median subtraction from each amplifier and histogram equalization reveals the solar spectrum spread diagonally across the detector with non-uniform background, magnification, line curvature, and wavelength scale, plus particle streaks/spikes and a higher order spectrum in the lower left.

The MEGS-B image shows the highest counts for the bright lines at 58.43, 60.98, and 62.97 nm. In the top left side, a ramp is observable that corresponds to the He I continuum with the Si XII 49.9 nm line near the peak. For reference, the long wavelength side shows the very weak hydrogen continuum as a dim ramp, and also the 3 bright lines for 102.5, 103.2, and 103.7 nm. The lines on the detector are not curved the same way on the top left side compared to the lower right side. Level 1 processing accounts for this complexity in creating the solar spectrum. Another feature detectable in the figure is higher order light from the grating that is located in the lower left side of the figure. This higher order spectrum is clipped by internal baffles and stops around 58.4 nm and it is believed to represent first order of the first grating and second order off the second grating.

Similar to MEGS-A, summing multiple images improves the signal. MEGS-B has very low signals.

Examples in Python

Python code for a similar set of examples as shown above in IDL is also included here. The Jupyter notebook can be downloaded from SDO/EVE's GitHub repo at https://github.com/sdo-eve/eve_python_examples/tree/dc7c3732f9736ce44b36ca079a55e6b5d1066c3a/level_0b.

Read the binary table, HDU #1

In [ ]:
```
from astropy.io import fits

# this uses the url for the file
# but can alternatively use a local file instead
base_url = 'https://lasp.colorado.edu/eve/data_access/eve_data/products/level0b/megs_a'
megsa_url = f'{base_url}/2010/120/MA__L0B_4_2010120_235905_00_001_01.fit.gz'
hdul = fits.open(megsa_url)

# read the binary table in HDU #1
for name_val_pair in zip(hdul[1].data.names, hdul[1].data[0]):
    print(f"{name_val_pair[0]} = {name_val_pair[1]}")
```

```
yyyydoy = 2010120
sod = 86345
tai_sec = 1651363179
tai_subsec = 2077186843
vcdu_count = 2395
int_time = 1
hw_test = 0
sw_test = 0
reverse_clock = 0
valid = 1
ram_bank = 0
int_time_warn = 0
filter_position = 4
readout_mode = 2
ccd_temp = -103.40232849121094
led_on = 0
led0_level = 0
led1_level = 0
resolver = 0
sam_resolver = 28328
```

And peek at the header contents for the binary table HDU #1:

In [ ]:
```
hdul[1].header
```

Out[ ]:
```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   39 / width of table in bytes
NAXIS2  =                    1 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                   20 / number of fields in each row
TTYPE1  = 'yyyydoy '           / label for field   1
TFORM1  = '1J      '           / data format of field: 4-byte INTEGER
TZERO1  =           2147483648 / offset for unsigned integers
TSCAL1  =                    1 / data are not scaled
TTYPE2  = 'sod     '           / label for field   2
TFORM2  = '1J      '           / data format of field: 4-byte INTEGER
TZERO2  =           2147483648 / offset for unsigned integers
TSCAL2  =                    1 / data are not scaled
TTYPE3  = 'tai_sec '           / label for field   3
TFORM3  = '1J      '           / data format of field: 4-byte INTEGER
TZERO3  =           2147483648 / offset for unsigned integers
TSCAL3  =                    1 / data are not scaled
TTYPE4  = 'tai_subsec'         / label for field   4
TFORM4  = '1J      '           / data format of field: 4-byte INTEGER
TZERO4  =           2147483648 / offset for unsigned integers
TSCAL4  =                    1 / data are not scaled
TTYPE5  = 'vcdu_count'         / label for field   5
TFORM5  = '1I      '           / data format of field: 2-byte INTEGER
TZERO5  =                32768 / offset for unsigned integers
TSCAL5  =                    1 / data are not scaled
TTYPE6  = 'int_time'           / label for field   6
TFORM6  = '1I      '           / data format of field: 2-byte INTEGER
TZERO6  =                32768 / offset for unsigned integers
TSCAL6  =                    1 / data are not scaled
TTYPE7  = 'hw_test '           / label for field   7
TFORM7  = '1B      '           / data format of field: BYTE
TTYPE8  = 'sw_test '           / label for field   8
TFORM8  = '1B      '           / data format of field: BYTE
TTYPE9  = 'reverse_clock'      / label for field   9
TFORM9  = '1B      '           / data format of field: BYTE
TTYPE10 = 'valid   '           / label for field  10
TFORM10 = '1B      '           / data format of field: BYTE
TTYPE11 = 'ram_bank'           / label for field  11
TFORM11 = '1B      '           / data format of field: BYTE
TTYPE12 = 'int_time_warn'      / label for field  12
TFORM12 = '1B      '           / data format of field: BYTE
TTYPE13 = 'filter_position'    / label for field  13
TFORM13 = '1B      '           / data format of field: BYTE
TTYPE14 = 'readout_mode'       / label for field  14
TFORM14 = '1B      '           / data format of field: BYTE
TTYPE15 = 'ccd_temp'           / label for field  15
TFORM15 = '1E      '           / data format of field: 4-byte REAL
TTYPE16 = 'led_on  '           / label for field  16
TFORM16 = '1B      '           / data format of field: BYTE
TTYPE17 = 'led0_level'         / label for field  17
TFORM17 = '1B      '           / data format of field: BYTE
TTYPE18 = 'led1_level'         / label for field  18
TFORM18 = '1B      '           / data format of field: BYTE
TTYPE19 = 'resolver'           / label for field  19
TFORM19 = '1I      '           / data format of field: 2-byte INTEGER
TZERO19 =                32768 / offset for unsigned integers
TSCAL19 =                    1 / data are not scaled
TTYPE20 = 'sam_resolver'       / label for field  20
TFORM20 = '1I      '           / data format of field: 2-byte INTEGER
TZERO20 =                32768 / offset for unsigned integers
TSCAL20 =                    1 / data are not scaled
EXTNAME = 'MEGSA_TABLE'        / name of this binary table extension
```

We can also examine the contents of the header for the imaage in HDU #0:

In [ ]:
```
hdul[0].header
```

Out[ ]:
```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    2 / number of data axes
NAXIS1  =                 2048 / length of data axis 1
NAXIS2  =                 1024 / length of data axis 2
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
BZERO   =                32768 / offset data range to that of unsigned short
BSCALE  =                    1 / default scaling factor
EXTNAME = 'MEGS_IMAGE'         / Extension Name
SOD     =                86345 / Seconds in day
DOY     =              2010120 / Year - Day of year
TAI_TIME=           1651363179 / tai time
INT_TIME=                    1 / Integration time
RAM_BANK=                    0 / Ram bank
VALID   =                    1 / Validity flag
HW_TEST =                    0 / Test pattern
SW_TEST =                    0 / Test pattern
REV_CLK =                    0 / Reverse clock
HIERARCH tlm_filename = 'VC03_2010_120_23_58_45_0006a842cf0_07068_00.tlm' / TLM
HISTORY VC03_2010_120_23_58_45_0006a842cf0_07068_00.tlm
```

Read and display the image (HDU #0)

In [ ]:
```python
import os
import matplotlib.pyplot as plt
from skimage import exposure
from astropy.io import fits

with fits.open(megsa_url) as hdul:
    image = hdul[0].data    # the image is the first HDU

# histogram equalization is helpful for viewing the features in the image
image_eq = exposure.equalize_hist(image)
plt.figure(figsize=(12,6))
plt.imshow(image_eq, cmap='gist_heat', origin='lower')
plt.title(os.path.basename(megsa_url), fontsize=16)
plt.show()
```

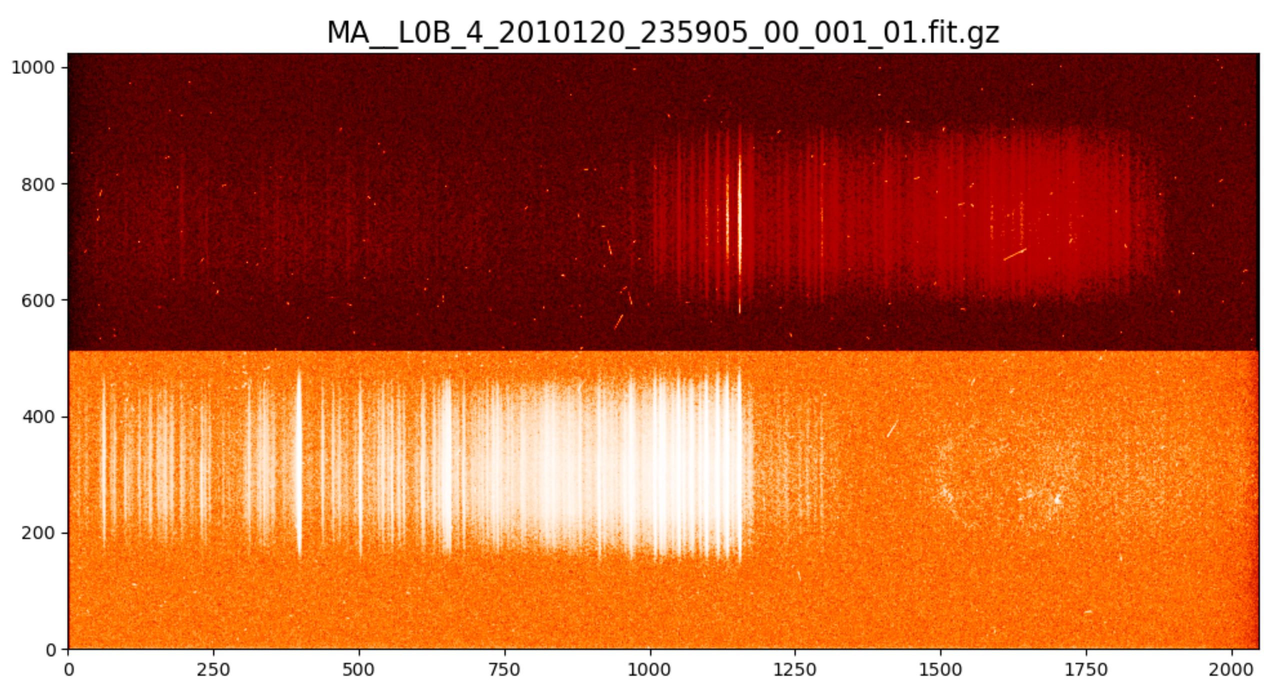

Figure 6: A single histogram equalized MEGS-A image with 10-second integration time. The slit 1 spectrum is dispersed across the top with short wavelengths on the right side. The bright Fe IX line at 17.1 nm is the brightest line in slit 1. Slit 2 also shows 17.1 and all of the longer wavelengths to the left. The SAM pinhole camera is in the lower right. Particle spikes and streaks are scattered across the detector.

Read multiple files

In [ ]:
```
import numpy as np
import os
from urllib.error import HTTPError

# this gives us five minutes of MEGS-A L0B files
base_url = 'https://lasp.colorado.edu/eve/data_access/eve_data/products/level0b/megs_a'
files = [f'{base_url}/2010/120/MA__L0B_4_2010120_235{x}{y}5_00_001_01.fit.gz' for x in range(5) for y in ra

image_sum = np.zeros((1024,2048))       # accumulate the running sum of each image

# loop over the files and add each image to the running total
# if the file isn't found on the web, skip it
for this_file in files:
    try:
        with fits.open(this_file) as hdul:
            image_sum += hdul[0].data    # the image is the first HDU
    except HTTPError:
        print(f"File not found: {os.path.basename(this_file)}")
        continue

# display the histogram equalized sum of images
image_sum_eq = exposure.equalize_hist(image_sum)
plt.figure(figsize=(12,6))
plt.imshow(image_sum_eq, cmap='gist_heat', origin='lower')
plt.title("Level 0B MEGS-A 5-minute image", fontsize=16)
plt.show()
```

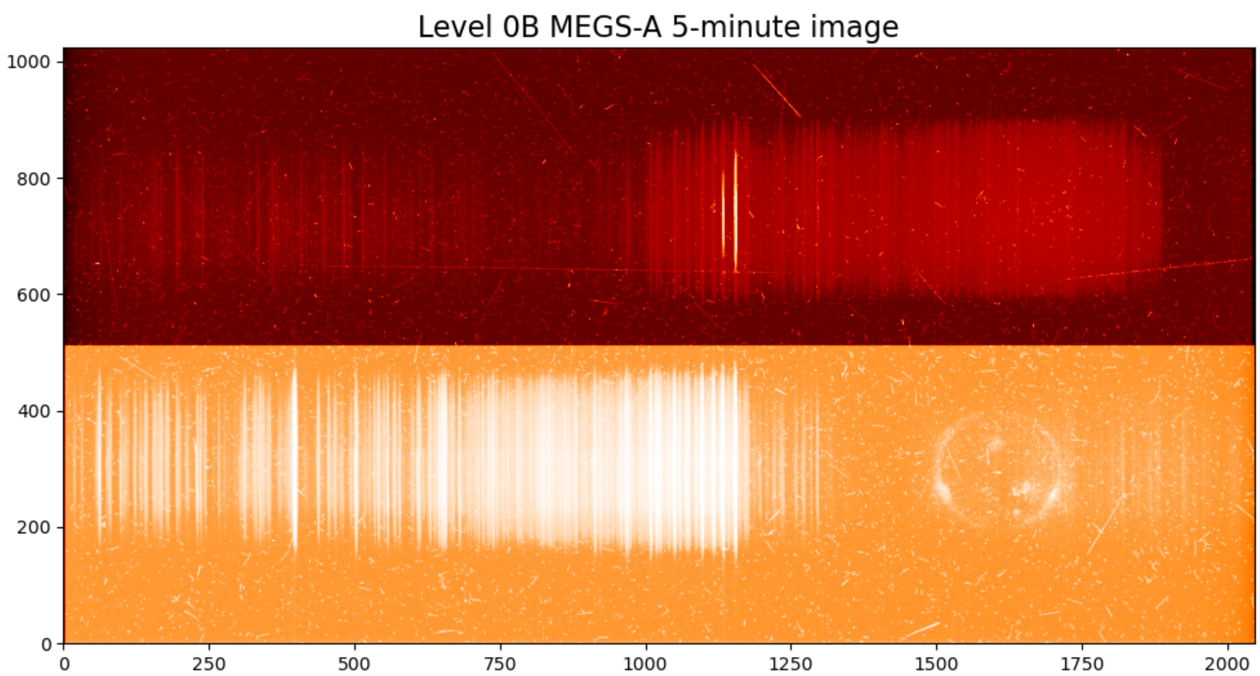

Figure 7: A 5-minute sum of 10-second integrations with histogram equalization makes it easier to see the SAM image and lines transmitted through slit 2. Larger particle spikes and streaks are easily observed when viewing multiple images.

Plot uncalibrated spectrum

Use the 5-minute image from the last step to plot an uncalibrated spectrum. As noted in the IDL section, the wavelengths are not uniformly distributed and are slighly curved.

In [ ]:
```
fig, axes = plt.subplots(2, 1, figsize=(12,8))

axes[0].plot(np.arange(1024)+1024, np.median(image_sum[800:808,1024:], axis=0))
axes[1].plot(np.arange(1200), np.median(image_sum[300:308,:1200], axis=0))

for i, ax in enumerate(axes):
    ax.grid(linestyle='dotted', zorder=0, color='grey')
```

```
    ax.set_title(f'Slit {i+1}')
    ax.set_ylabel('Arbitrary')
    ax.autoscale(enable=True, axis='x', tight=True)
axes[1].set_xlabel('Pixel')

plt.show()
```

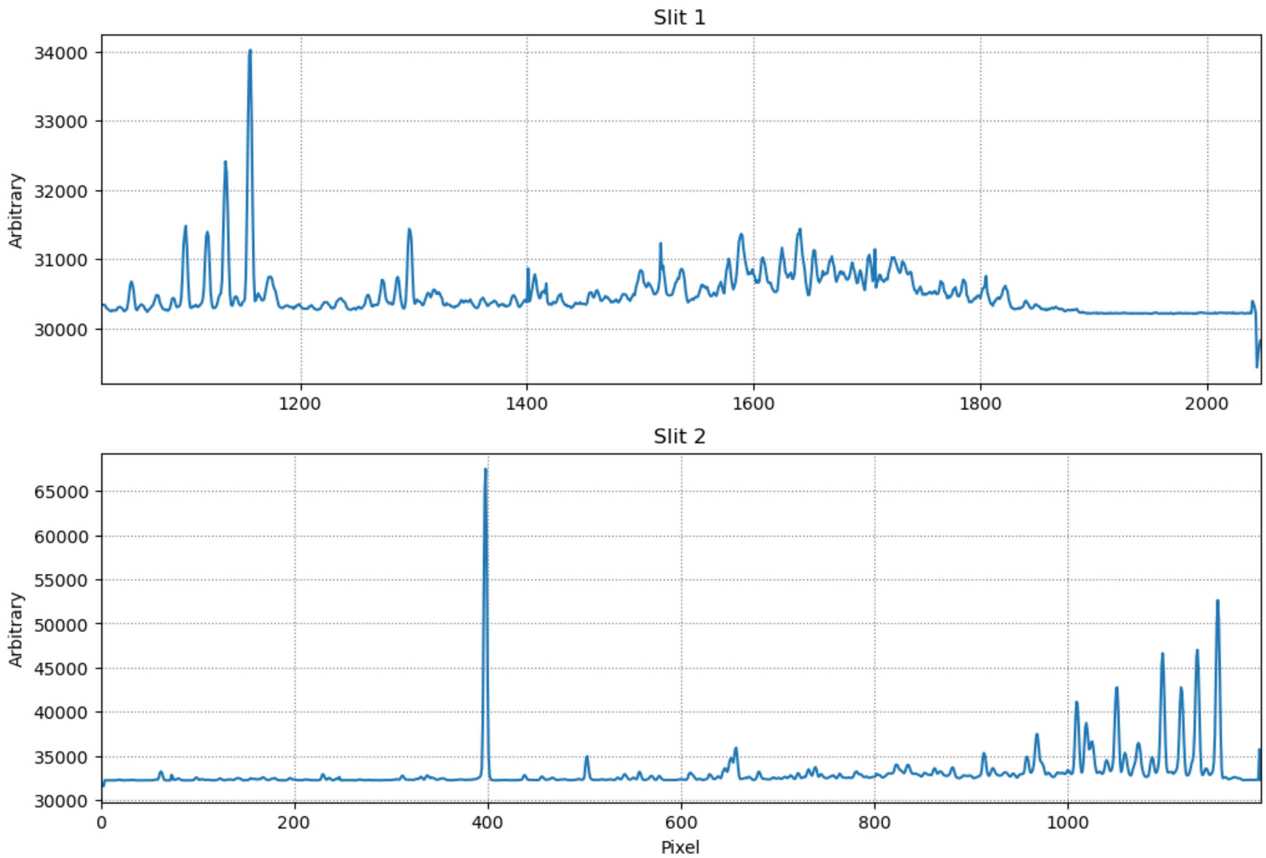

Figure 8: Uncalibrated spectra from MEGS-A slit 1 and 2 near the centers of each slit. The vertical axis has arbitrary units, and the horizontal axis is a reversed non-linear function of wavelength. Median filtering was applied in cross-dispersion to reduce the effect of particle strikes.

Read a MEGS-B file and display the image

In [ ]:

```
mb_file_url = 'https://lasp.colorado.edu/eve/data_access/eve_data/products/level0b/megs_b/2010/123/MB__L0B_

with fits.open(mb_file_url) as hdul:
    image = hdul[0].data

image_eq = exposure.equalize_hist(image)
plt.figure(figsize=(12,6))
plt.imshow(image_eq, cmap='Blues_r', origin='lower')
plt.title(os.path.basename(mb_file_url), fontsize=16)
plt.show()
```

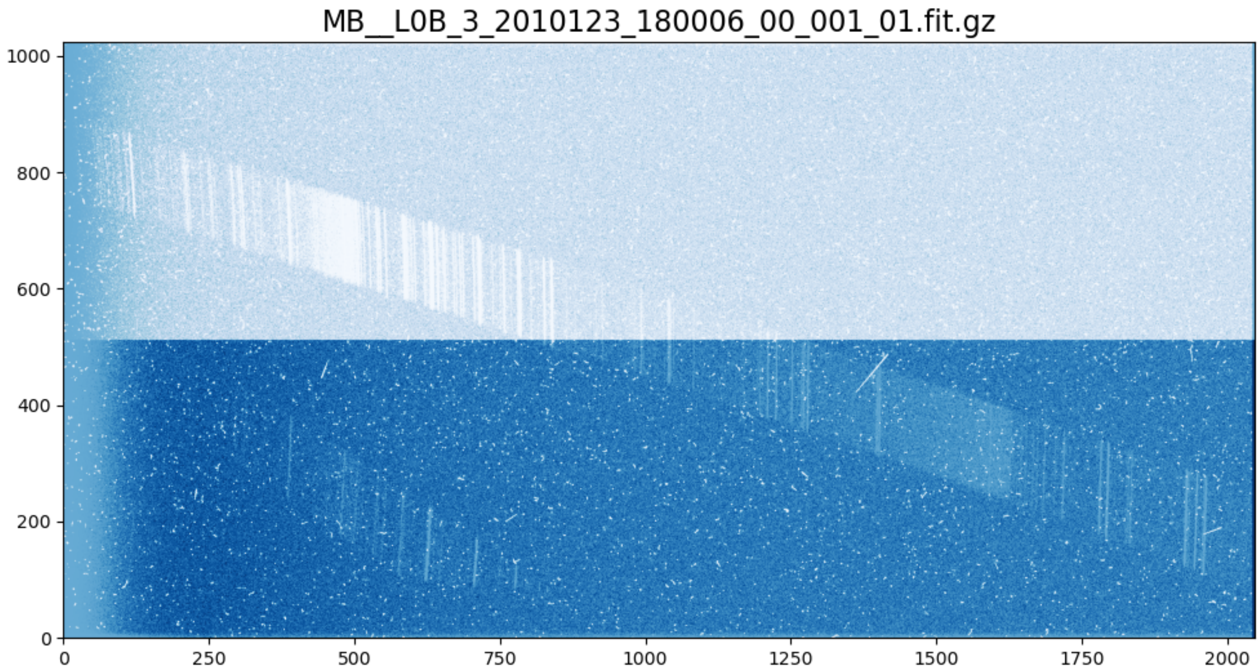

Figure 9: MEGS-B 10-second solar spectrum on the first rocket day, 2010 day 123, near 18:00 UTC.

More detailed information about the images and features is in the IDL section of the Level 0B readme.