

# ASO-S/FMG Software User Guide

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## 1. Introduction

The Advanced Space-based Solar Observatory (ASO-S, Gan 2019) was launched with the CZ-2D rocket at 07:43:55 Beijing time on October 9, 2022, opening the era of comprehensive solar space observation in China. The ASO-S mission was proposed by Chinese solar community in 2011. With the support of the “Strategic Priority Research Program of Space Science” of Chinese Academy of Sciences (CAS), ASO-S underwent Phase-0/A, Phase-A/B and comprehensive demonstration. At the end of 2017, it was formally approved by CAS. The scientific objectives can be summarized as '1M2B'. Here, '1M' stands for magnetic field while '2B' for the two major eruptive phenomena (bursts) on the Sun: solar flares and coronal mass ejections (CMEs). The mission aims at exploring connections among solar magnetic field, solar flares, and CMEs. ASO-S consists of three payloads: Full-disk Magnetograph (FMG), Lyman-alpha Solar Telescope (LST), and Hard X-ray Imager (HXI), to measure solar magnetic field, to observe CMEs and solar flares, respectively. The unique design of the payload allows simultaneous observations of vector magnetic field of the full Sun, imaging spectroscopy at high energies and propagation of CMEs near the solar disk. It will not only advance our understanding of the underlying physics of solar eruptions, but also help to improve forecast of the space weather.

This document introduces the analysis guide on the FMG data. Detailed analysis guide on the LST and HXI data can be found on the ASO-S website:

<http://aso-s.pmo.ac.cn/sodc/analysisGuide.jsp>.

## 2. FMG Instrument

The Full-disk vector MagnetoGraph (FMG) measures the photospheric magnetic field of the entire solar disk. The design of the instrument is described in detail by Deng et al. (2019).

The instrument consists of a front window filter, a telescope, an LCVR polarimeter, an image-stabilization system, a seven-stage tunable Lyot filter, a CMOS camera and a pair of calibration/focus wheels. In FMG, the pixel number of the imaging detector is 4096×4096, with a pixel size of 12.8 μm × 12.8 μm. The main parameters of the optical system can be found in **Table 1**.

**Table 1** Main Performance and Parameters of the FMG

Parameters	Value
Working Spectral Line	Fe I 532.4 nm
Field of View	34'
Aperture	14 cm
CMOS Detector	4k×4k 12.8 μm
System-wide Spatial Resolution	1.5'' (Pixel Resolution: 0.5'' pixel <sup>-1</sup> )
Effective Focus Length	5355.76 mm (F number: F/38.26)
Temporal Resolution	Normal mode: 30 s (single component); 2 min (vector magnetogram) Burst mode: 8 s (single component); 30 s (vector magnetogram)
Data rate	96 MB min <sup>-1</sup> (max.), 140 GB d <sup>-1</sup>
Longitudinal Sensitivity	15 G (normal mode)
Birefringent Lyot Filter	FWHM: 0.1 Å Working temperature: 22 ± 2°C Wavelength stabilization: < 0.02 Å
Image-stabilization Accuracy	0.25''
Dimensions	Optics package: 1335 mm × 790 mm × 380 mm Electronics box: 340 mm × 260 mm × 260 mm
Weight	101 kg
Power	265 W

In order to get higher polarization accuracy, FMG uses multi-frame add mode (deep-integration mode). In normal mode of observation, 512 frames (half for left and half for right) will be collected for one magnetogram. That means within 32s (for obtaining 512 frames) the pointing should be stabilized at least within half pixel, say 0.25". Thus, FMG has itself tip/tilt system. In normal mode, the sensitivities are 5G and 150G for longitudinal and transverse component, respectively.

Compared with the magnetograph onboard Hinode (SP), FMG has a much larger field of view and higher time cadence. Comparing to the magnetographs onboard SDO (HMI) and SOHO (MDI), FMG has a simpler observation mode and a higher measurement precision.

### 3. FMG Data Products

The data from FMG are divided into four levels, from Level 0 to Level 1 and Level 2, as well as Level Q (designed for a quick look). Level 0 data are those directly downloaded from ASO-S including Stokes Q, U and V maps, telemetry information, calibration data and header keywords. They become Level 1 data once they undergo the processing of subtracting the dark field, dividing by the flat field, calibrating the working line, correcting for Stokes -I to -Q, -U and -V, and for Stokes -V to -Q and -U crosstalks, and calibrating into magnetic fields. Finally, Level 2 data are obtained by disentangling 180 ambiguity and removing projection effects. The data reduction and calibration process of the FMG are

presented by Su et al. (2019). At this stage, only the [level 2 AR data](#) including the longitudinal magnetic field and filter images of active regions will be released.

#### 4. How to Find and Get FMG Data

The ASO-S science data could be accessed on the following website:

<http://aso-s.pmo.ac.cn/sodc/dataArchive.jsp>

We also provide the cutout service for LST data:

<http://aso-s.pmo.ac.cn/sodc/cutout.jsp>

#### 5. How to Process and Use FMG Data

##### 5.1 SSW Environment Variables Setup

Assume the SSW IDL installation is ready, to install or upgrade the ASO-S software package, please run the following in the SSWIDL environment:

```
IDL>ssw_upgrade,/spawn,/loud,/asos,/fmg,/lst,/hxi
```

In order to load the ASO-S routines into your path, you will need to modify the SSW\_INSTR environment variable to include them, on UNIX/Mac systems this can usually be found in your `.cshrc` or `.login` file:

```
setenv SSW_INSTR 'asos fmg lst hxi'
```

##### 5.2 How to read FMG data

The SSWIDL routine `read_fmg.pro` can be used to read both the header information and the data into IDL variables:

```
IDL>read_fmg,filename,index,data
```

The input argument **filename** contains one filename to be read into IDL. Note that

“read\_fmg.pro” can also read compressed fits files, such as

“fmg\_lev20\_AR13285\_20230425\_001555.051\_scienc\_rout\_bl\_v01.fits.gz” . On output, the

index (header) information and image data will appear in the variables **index** and **data**, respectively.

For example, the FMG data is located at the directory “data/” .

**Example:** For level 2 AR data, which include the [longitudinal magnetic field and filter images of active regions](#) as well as their respective header files.

```
IDL>filename='data/fmg_lev20_AR13285_20230425_001555.051_scienc_rout_bl_v01.fits.gz'
IDL>read_fmg,filename,index,data
IDL>help,data
DATA          FLOAT      = Array[800, 600, 2]
IDL>help,index
** Structure <7806218>, 2 tags, length=1440, data length=1416, refs=1:
  HDRWL        STRUCT    -> <Anonymous> Array[1]
  HDRBL        STRUCT    -> <Anonymous> Array[1]
To check out the header information of the filter image:
IDL>help,index.hdrwl
To check out the header information of the longitudinal magnetic field image:
IDL>help,index.hdrbl
```

In order to display the [filter image](#), one can

```
IDL>window,0,xsize=index.hdrbl.naxis1,ysize=index.hdrbl.naxis2
IDL>tv,bytsc1(data[*,*],0),max=7000,min=3000)
```

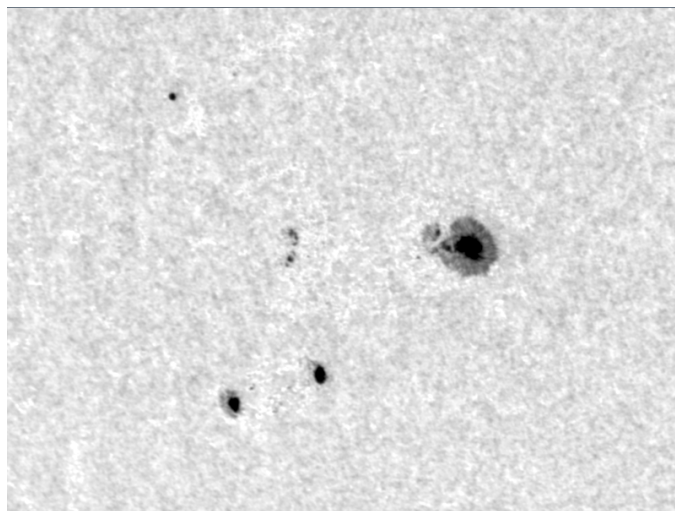


Figure 3: The FMG filter image of AR 13285 at 00:15 UT on April 25, 2023.

The [longitudinal magnetic field image](#) can be displayed via the following command:

```
IDL>window,0,xsize=index.hdrwl.naxis1,y size=index.hdrwl.naxis2
IDL>tv,bytsc1(data[*,*,1],max=500,min=-500)
```

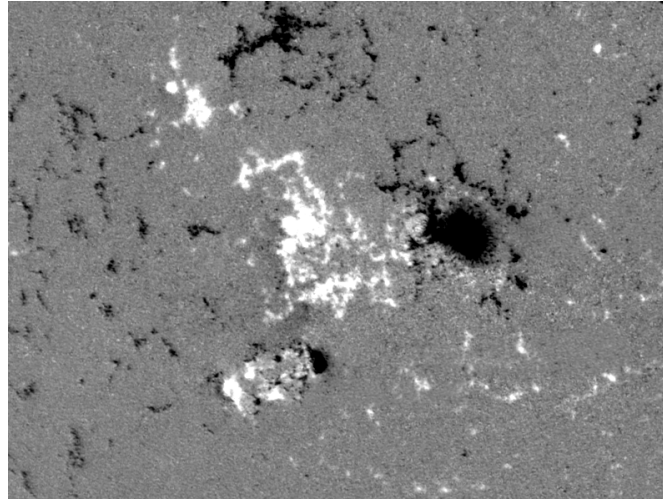


Figure 4: The FMG longitudinal magnetic field image of AR 13285  
at 00:15 UT on April 25, 2023.

### 5.3 Detection of Polarity Inversion Line

The SSWIDL routine **fmg\_arpil.pro** can be used to give the length of the magnetic polarity inversion line (unit: Mm), and return the position of the maximum value of the magnetic field gradient in the data field of view (Unit: pixels), as well as the longitude and latitude of the position of the maximum value (Unit: degrees) for an input level 1.5/2.0 fits data file.

#### Example:

```
IDL>filein='data/fmg_lev20_AR13285_20230425_001555.051_scienc_rout_bl_v01.fits.gz'
IDL>fmg_arpil, filein, length, xmax, ymax, lonc_lmax, latc_lmax
IDL>help,length, xmax, ymax, lonc_lmax, latc_lmax
LENGTH          DOUBLE    =      138.38940
XMAX             INT       =       491
YMAX             INT       =       327
LONC_LMAX        DOUBLE    =      -29.303668
LATC_LMAX        DOUBLE    =      -17.249996
```

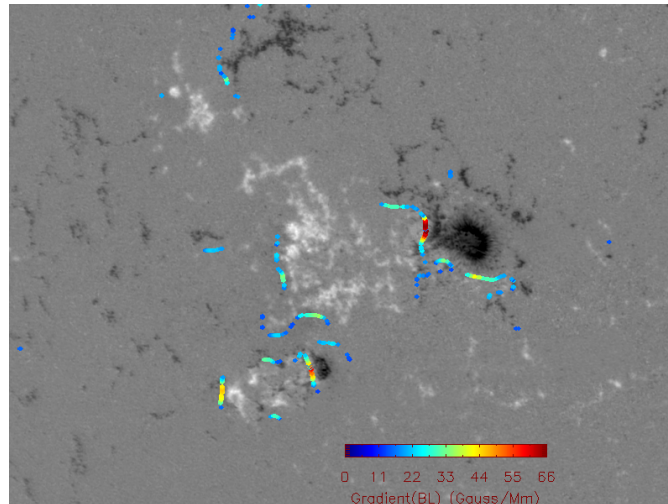


Figure 5: Longitudinal magnetic field image overlaid with magnetic polarity inversion line. The PIL is marked with different colors. The larger the magnetic field gradient is, the redder the color is.

## 6. Data Policy

(1) The scientific data of ASO-S mission are completely open to the community except the data obtained during the mission commissioning phase and some of the engineering data. All users have the same right to use the scientific data of ASO-S mission as the team member.

(2) In order to have the best knowledge of the instrumentation and meaning of the data, users when writing papers are encouraged to collaborate with team members (one is enough), who might be the payload scientist, payload data scientist, or any of team members listed on the homepage of ASO-S mission, especially for the first two years of the mission.

(3) All the scientific data, calibration and processing software, usage documentation, and update information are provided via the ASO-S homepage at [http://aso-s.pmo.ac.cn/en\\_index.jsp](http://aso-s.pmo.ac.cn/en_index.jsp). Browse and quick-look products are not intended for science analysis and publications.

(4) Users are suggested to acknowledge the sources of data used in all publications as **"ASO-S mission is supported by the Strategic Priority Research Program on Space Science, the Chinese Academy of Sciences, Grant No. XDA15320000"**. The use of ASO-S images, animations and videos for non-commercial purposes and public outreach efforts is strongly encouraged. It is requested, however, that any such use should mention explicitly the source from the ASO-S mission.

(5) Any software contributions to the data processing and analyzing by the users are welcome. The payload data scientists are the corresponding persons to contact.

## **7. References**

[1] Yuan-Yong Deng, Hai-Ying Zhang, Jian-Feng Yang, Fu Li, Jia-Ben Lin, Jun-Feng Hou, Zhen Wu, Qian Song, Wei Duan, Xian-Yong Bai et al. 2019, Res. Astron. Astrophys., 19, 157

[2] Wei-Qun Gan, Cheng Zhu, Yuan-Yong Deng, Hui Li, Yang Su, Hai-Ying Zhang, Bo Chen, Zhe Zhang, Jian Wu, Lei Deng et al. 2019, Res. Astron. Astrophys., 19, 156

[3] Jiang-Tao Su, Xian-Yong Bai, Jie Chen, Jing-Jing Guo, Suo Liu, Xiao-Fan Wang, Hai-Qing Xu, Xiao Yang, Yong-Liang Song, Yuan-Yong Deng et al. 2019, Res. Astron. Astrophys., 19, 161