



FMG-tutorial

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Outline

- **Instrument**
- **Observation**
- **Data Process**
- **Data Products**
- **Data Usage**
- **Application Examples**

Instrument

➤ Aperture **14** cm

➤ LCVR Polarimeter

➤ Birefringent Lyot Filter

□ FWHM: **0.1** Å

□ Working Temperature: **22 ± 2**°C

□ Wavelength Stabilization: **< 0.02** Å

Observation

- Fe I λ 5324.19 Å
- Q,U,V Observed at -0.08 Å
- Field of View 34'
- CMOS 4096×4096
- Routine Temporal Resolution ~2 min
 - fast=40 s, routine=120 s, deep=1080 s
- Spatial Resolution ~1.5 arcsec [\sim 0.55 arcsec/pixel]
- Longitudinal Sensitivity 15 G (Normal Mode)

Observation

Full Stokes Modulation Mode of the Polarimeter

LCVR1		LCVR2		Signal
Azimuth (°)	Retardation (°)	Azimuth (°)	Retardation (°)	
0	0	45	0	$0.5 \times (I+Q)$
0	0	45	180	$0.5 \times (I-Q)$
0	90	45	90	$0.5 \times (I+U)$
0	90	45	270	$0.5 \times (I-U)$
0	0	45	90	$0.5 \times (I+V)$
0	0	45	270	$0.5 \times (I-V)$

Observation

➤ Dark Field

- Dark_Baffle

➤ Flat Field

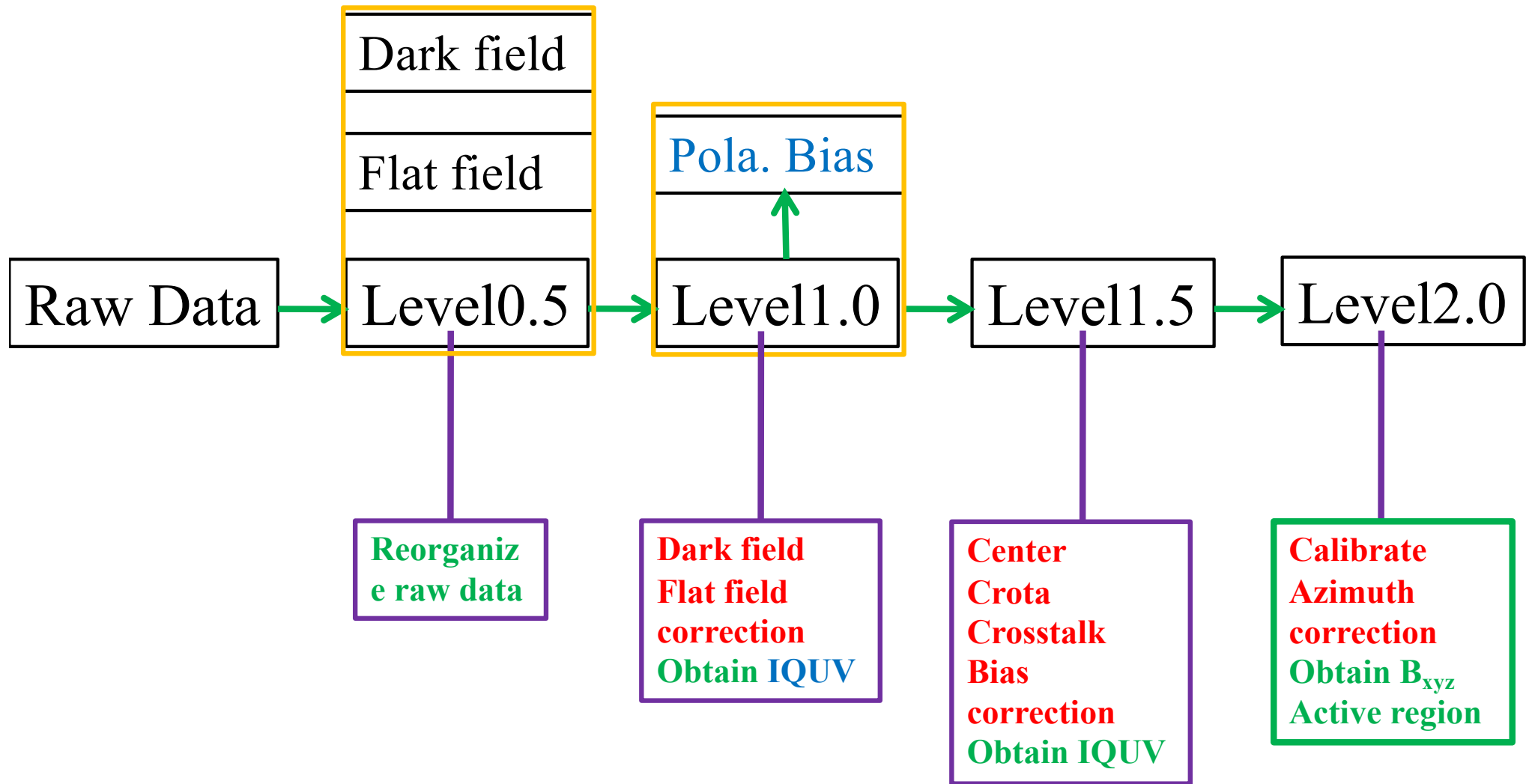
- Based on Routine_Obs.

➤ Routine Observation

- A Series of Group of Q, U, V ~2min

- Normally 700-740 Groups of Q, U, V each day

Data Process



Data Process

➤ Dark Field

- ❑ Average of **100** Dark_Baffle images regarded as **dark field**

➤ Flat Field

- ❑ Median of (I-Q), (I+Q), (I-U), (I+U), (I-V), (I+V) each day
- ❑ Median of (I-Q), (I+Q), (I-U), (I+U), (I-V), (I+V) [**7~10 days**] regarded as **flat field**

➤ Polarization Bias

- ❑ Median of Q, U, V each day
- ❑ Median of Q, U, V [**7~10 days**] regarded as **polarization bias**
 - ✓ Q, U, V for **polarization bias** calculation are updated according the flat field
 - ✓ Q, U, V for scientific data are fixed corresponding the obtained flat and bias each day.

Data Process

➤ Dark Field Correction

- $[I-Q, I+Q, I-U, I+U, I-V, I+V]-dc$

➤ Flat Field Correction

- Flat Field Calculated from Routine Observation

- $[[I-Q, I+Q, I-U, I+U, I-V, I+V]-dc]/flat$

➤ Polarization Bias Correction

- Bias Calculated based on Routine Observation

- $Q/I=0.5 \times [(I+Q) - (I-Q)] / [(I+Q) + (I-Q)] - Q_{bias}$

- $U/I=0.5 \times [(I+U) - (I-U)] / [(I+U) + (I-U)] - U_{bias}$

- $V/I=0.5 \times [(I+V) - (I-V)] / [(I+V) + (I-V)] - V_{bias}$

Data Process

➤ Calibration Magnetic Field

□ Weak-Field Approximation

$$\square B_L = C_L(v, r) V / I$$

$$\square B_T = C_T(v, r) [(Q/I)^2 + (U/I)^2]^{1/4}$$

$$\square \phi = \frac{1}{2} * \arctan((U/I)/(Q/I))$$

$$\square \theta = \arctan(B_L/B_T)$$

$$\square B = \text{sqrt}[(B_L)^2 + (B_T)^2]$$

$$\square B_x, B_y, B_z$$

$$\checkmark B_z = B \cos(\theta)$$

$$\checkmark B_x = B \sin(\theta) \cos(\phi)$$

$$\checkmark B_y = B \sin(\theta) \sin(\phi)$$

Data Process

➤ Data Format

□ Standard FITS with Multi-HDU .fits.gz

```
Filename: fmg_lev15_20230205_000024.432_scienc_rout_iqyv_v01.fits.gz
No.   Name      Ver   Type      Cards  Dimensions  Format
  0   PRIMARY    1   PrimaryHDU  5      ()
  1   Stokes I    1   ImageHDU   67     (4096, 4096)  int16 (rescales to float32)
  2   Stokes Q    1   ImageHDU   67     (4096, 4096)  int16 (rescales to float32)
  3   Stokes U    1   ImageHDU   67     (4096, 4096)  int16 (rescales to float32)
  4   Stokes V    1   ImageHDU   67     (4096, 4096)  int16 (rescales to float32)

Filename: fmg_lev20_20230305_000214.682_scienc_rout_vb_v01.fits.gz
No.   Name      Ver   Type      Cards  Dimensions  Format
  0   PRIMARY    1   PrimaryHDU  5      ()
  1   Field strength  1   ImageHDU   68     (4096, 4096)  int16 (rescales to float32)
  2   Inclination  1   ImageHDU   68     (4096, 4096)  int16 (rescales to float32)
  3   Azimuth     1   ImageHDU   68     (4096, 4096)  int16 (rescales to float32)

Filename: fmg_lev20_AR13208_20230205_110733.630_scienc_rout_bl_v01.fits.gz
No.   Name      Ver   Type      Cards  Dimensions  Format
  0   PRIMARY    1   PrimaryHDU  5      ()
  1   WL         1   ImageHDU   57     (1000, 900)   int16 (rescales to float32)
  2   BL         1   ImageHDU   57     (1000, 900)   int16 (rescales to float32)
```

Some Useful Data Information for Lev1.5/2.0 data

DATE_OBS	2023-02-05T00:00:24.432	Date and time of the observation start
INSTRUME	FMG	Instrument
R_SUN	1772.40508842	Radius of the solar image in pixels
RSUN_OBS	973.405211609	Apparent solar radius seen by ASOS in arcsecs
RSUN_REF	695990000.0	Reference radius of the sun in m
DSUN_REF	149597870691.0	Reference distance to Sun in m
IM_SCALE	0.549200190782	The predefined FMG plate scale in arcseconds
CDELTA1	0.549200190782	Pixel size along image x-axis in arcsecs
CDELTA2	0.549200190782	Pixel size along image y-axis in arcsecs
CRPIX1	2048.5	The reference pixel on image x-axis, e.g. 2048.
CRPIX2	2048.5	The reference pixel on image y-axis, e.g. 2048.
CRVAL1	0.0	Reference coordinates corresponding to CRPIX1
CRVAL2	0.0	Reference coordinates corresponding to CRPIX2
XCEN	0.0	E-W FOV center of image relative to Sun Center
YCEN	0.0	N-S FOV center of image relative to Sun Center
CROTA2	0.00000	The sum of SAT_ROT+INST_ROT in degrees

Some Useful Data Information for Active region data

DATE_OBS	2023-02-05T00:00:24.432	Date and time of the observation start
TELESCOP	ASO-S	Source telescope for data
INSTRUME	FMG	Instrument
AR_NAME	AR13208	NOAA number of active regions
CDELTA1	0.549185938109	Pixel size along image x-axis in arcsecs
CDELTA2	0.549185938109	Pixel size along image y-axis in arcsecs
CRPIX1	887.5	The reference pixel on image x-axis, e.g. 2048.
CRPIX2	-190.5	The reference pixel on image y-axis, e.g. 2048.
CRVAL1	0	Reference coordinates corresponding to CRPIX1
CRVAL2	0	Reference coordinates corresponding to CRPIX2
XCEN	-211.436586172	E-W FOV center of image relative to Sun Center
YCEN	353.126558204	N-S FOV center of image relative to Sun Center
CRLN_ARS	245.048433933	Carrington longitude of cutout ARs in degrees
CRLT_ARS	15.0000036747	Carrington latitude of cutout ARs in degrees
CRLN_OBS	258.048431203	Carrington longitude of the observer in degrees
CRLT_OBS	-6.29319109658	Carrington latitude of the observer in degrees
OBS_VR	-72.492136183806	the observer speed in radial direction in m/s

Data Products

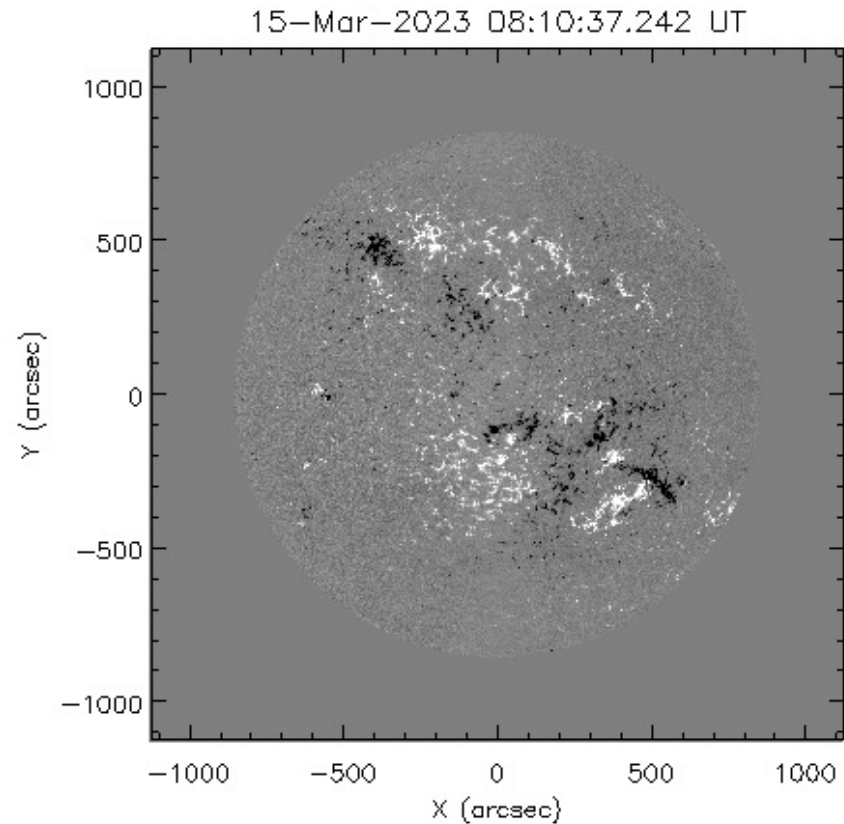
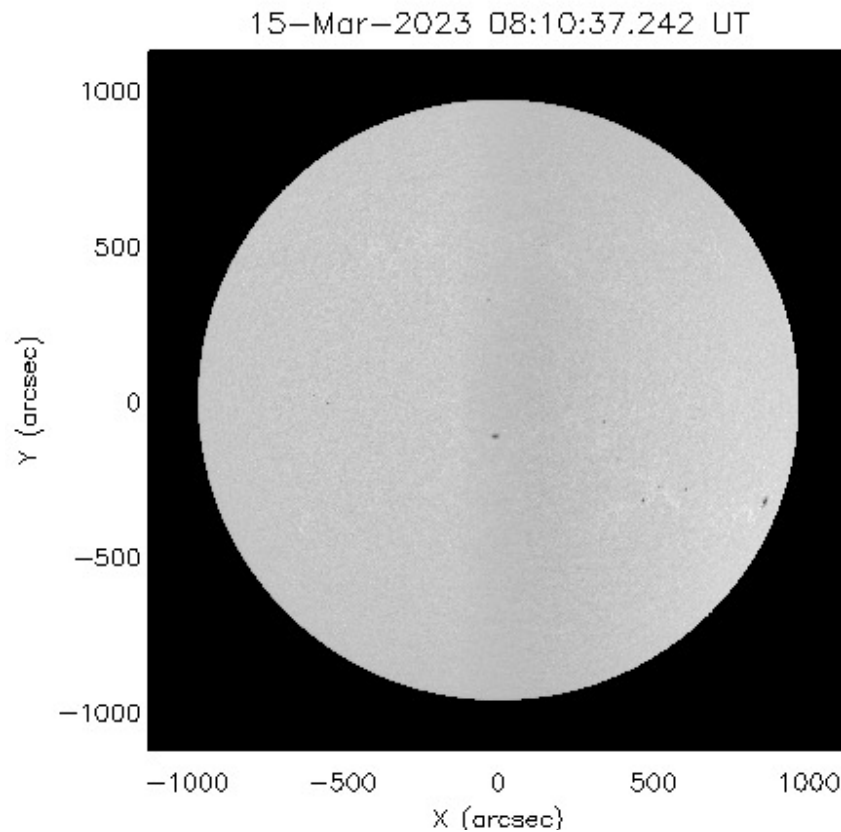
Level1.5/2.0 be observed in orbit testing process, **but not released now.**

fmg_lev15_20230315_08.10.37.242_scienc_rout_iquv_v01.fits.gz

fmg_lev20_20230315_08.10.37.242_scienc_rout_vb_v01.fits.gz

fmg_lev20_lev15_20230315_08.10.37.242_wl_0568X0518_v01.png

fmg_lev20_lev15_20230315_08.10.37.242_bl_0568X0518_v01.png



Data Products

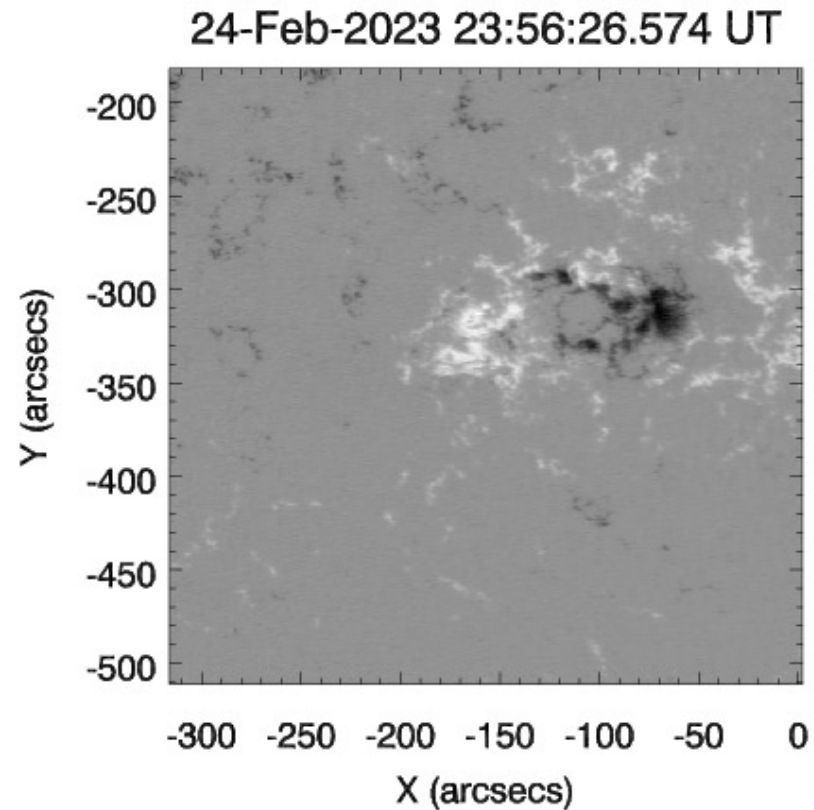
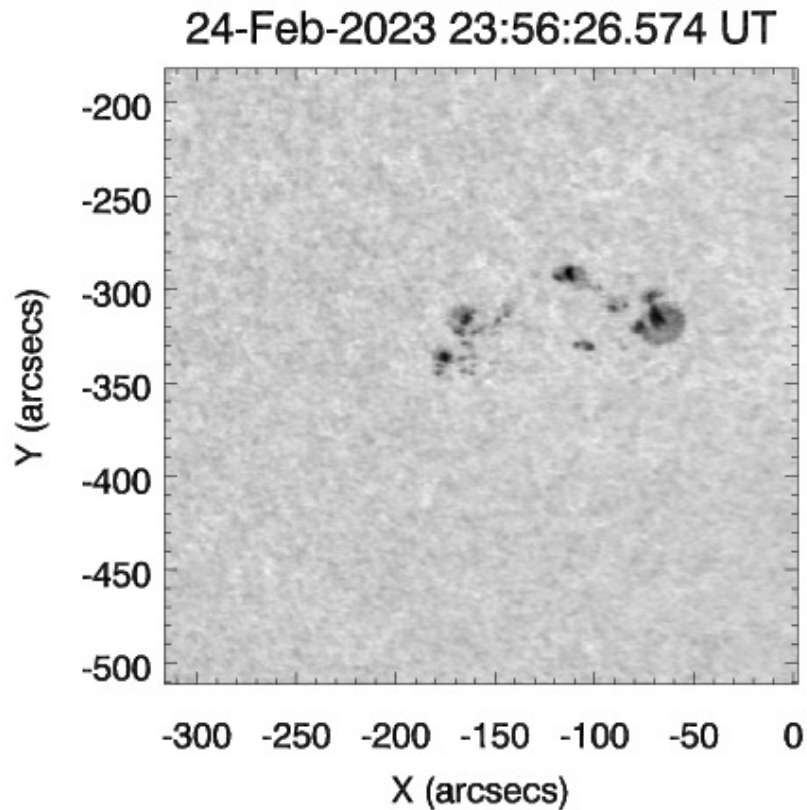
fmgevol.wmv

Level2.0 Active region longitudinal magnetic field is **released now**

fmg_lev20_AR13236_20230224_235626.574_scienc_rout_bl_v01.fits.gz

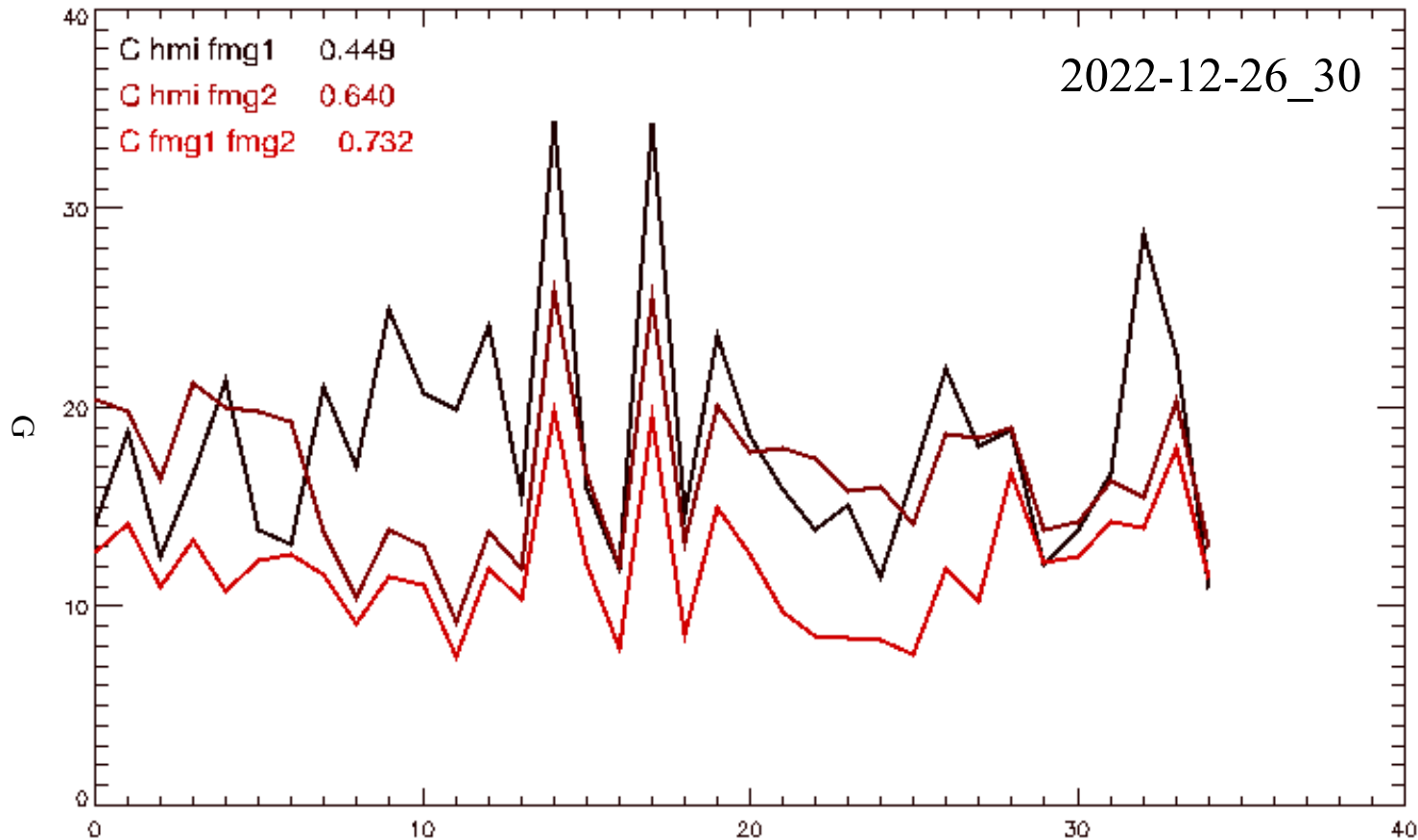
fmg_lev20_AR13236_20230224_235626.574_wl_0568X0518_v01.png

fmg_lev20_AR13236_20230224_235626.574_bl_0568X0518_v01.png



Data Products

➤ Longitudinal Sensitivity Testing



Data Products

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

The screenshot shows a web browser window with the URL aso-s.pmo.ac.cn/sodc/dataArchive.jsp. The page features a header with the text "Science Operation and Data Center" and a navigation menu with links: "Quick Look", "Data Access", "Analysis Software", "Guide", "Operation", and "Back Home".

The main content area is titled "Data Archive" and contains the following information:

- The ASO-S data policy can be found [here](#).
- The SDI data is between March 26, 2023 and March 27, 2023. The other data starts from April 1, 2023.
- Start Time: 04/08/2023 00:00
- End Time: 04/09/2023 10:37

The interface includes several data selection sections, each with a question mark icon for help:

- HXI ?**
 - Level Q1: Hourly Fits, Hourly Png, Data-production status Png
 - Level 1: Detector Data
- FMG ?** (highlighted with a red box)
 - Level: 2-AR
 - Mode: Routine, User-defined Cadence s
- LST ?**
 - SDI Level: 1, Background
 - SDI Mode: Routine, Burst-1024, Burst-4608, User-defined Cadence s
- WST ?**
 - WST Level: 1
 - WST Mode: Routine, Burst-1024, Burst-4608, User-defined Cadence s

At the bottom, there is an "Email:" input field, a "Search" button, a "Tar and Download Data" button, and a "Reset" button. Below these are fields for "Result", "File Count:", "Probable Size(KB):", and "Request ID:".

Data Usage

➤ Level2.0 Active region

- ❑ Based on Level1.5; NOAA Number; Cutout AR

- ❑ HDU1: noimage; HDU2: I; HDU3: BL

- ❑ Example:

fmg_lev20_AR13236_20230224_235430.533_scienc_rout_bl_v01.fits.gz

- ✓ The file name includes: the level of data - lev2.0; NOAA- AR13236

Observation Time - 20230224_235430.533; Observation mode – scienc_rout;

Observations - iquv; Version number - v01

Data Usage

[plot_ar2.0.mp4](#)

➤ Level2.0 Active region ---Regular Method [SSW]

- ✓ I=readfits('fmg_lev20_AR13236_20230224_235626.574_scien_rout_bl_v01.fits.gz',hdrwl,ext=1)
- ✓ BL=readfits('fmg_lev20_AR13236_20230224_235626.574_scien_rout_bl_v01.fits.gz',hdrbl,ext=2)

Data Usage

[plot_ar2.0s.mp4](#)

➤ Level2.0 Active region --- Special Code

- ✓ file=' fmg_lev20_AR13236_20230224_235626.574_scien_rout_bl_v01.fits.gz'
- ✓ read_fmg,file,index,data
- ✓ Filtergram and longitudinal magnetic field
- ✓ DATA FLOAT = Array[900, 650, 2]
- ✓ I=DATA[*,*,0]
- ✓ BL=DATA[*,*,1]
- ✓ help,index
- ✓ ** Structure <21d3d88>, 2 tags, length=1472, data length=1432, refs=1:
- ✓ HDRWL STRUCT -> <Anonymous> Array[1]
- ✓ HDRBL STRUCT -> <Anonymous> Array[1]

Data Usage

[plot_ar2.0py.mp4](#)

➤ Other Code ---Python[astropy.io.fits]

❑ HDU=fits.open(fmg_lev20_AR13236_20230224_235626.574_scien_rout_bl_v01.fits.gz)

❑ HDU.info()

Filename: fmg_lev20_AR13236_20230224_235626.574_scien_rout_bl_v011.fits

No.	Name	Ver	Type	Cards	Dimensions	Format
-----	------	-----	------	-------	------------	--------

0	PRIMARY	1	PrimaryHDU	5	()	
---	---------	---	------------	---	----	--

1	WL	1	ImageHDU	57	(580, 600)	int16 (rescales to float32)
---	----	---	----------	----	------------	-----------------------------

2	BL	1	ImageHDU	57	(580, 600)	int16 (rescales to float32)
---	----	---	----------	----	------------	-----------------------------

❑ I=HDU[1].data

❑ BL=HDU[2].data

❑ hdri=HDU[1].header

❑ hdrbl=HDU[2].header

Data Usage

[plot_ar2.0mat.mp4](#)

➤ Other Code ---MatLab

[gunzip file.gz]

- ❑ info=fitsinfo('fmg_lev20_AR13236_20230224_235626.574_scienc_rout_bl_v01.fits');
 - ✓ Contents: {'Primary' 'Image' 'Image'}
 - ✓ PrimaryData: [1×1 struct]
 - ✓ Image: [1×2 struct]

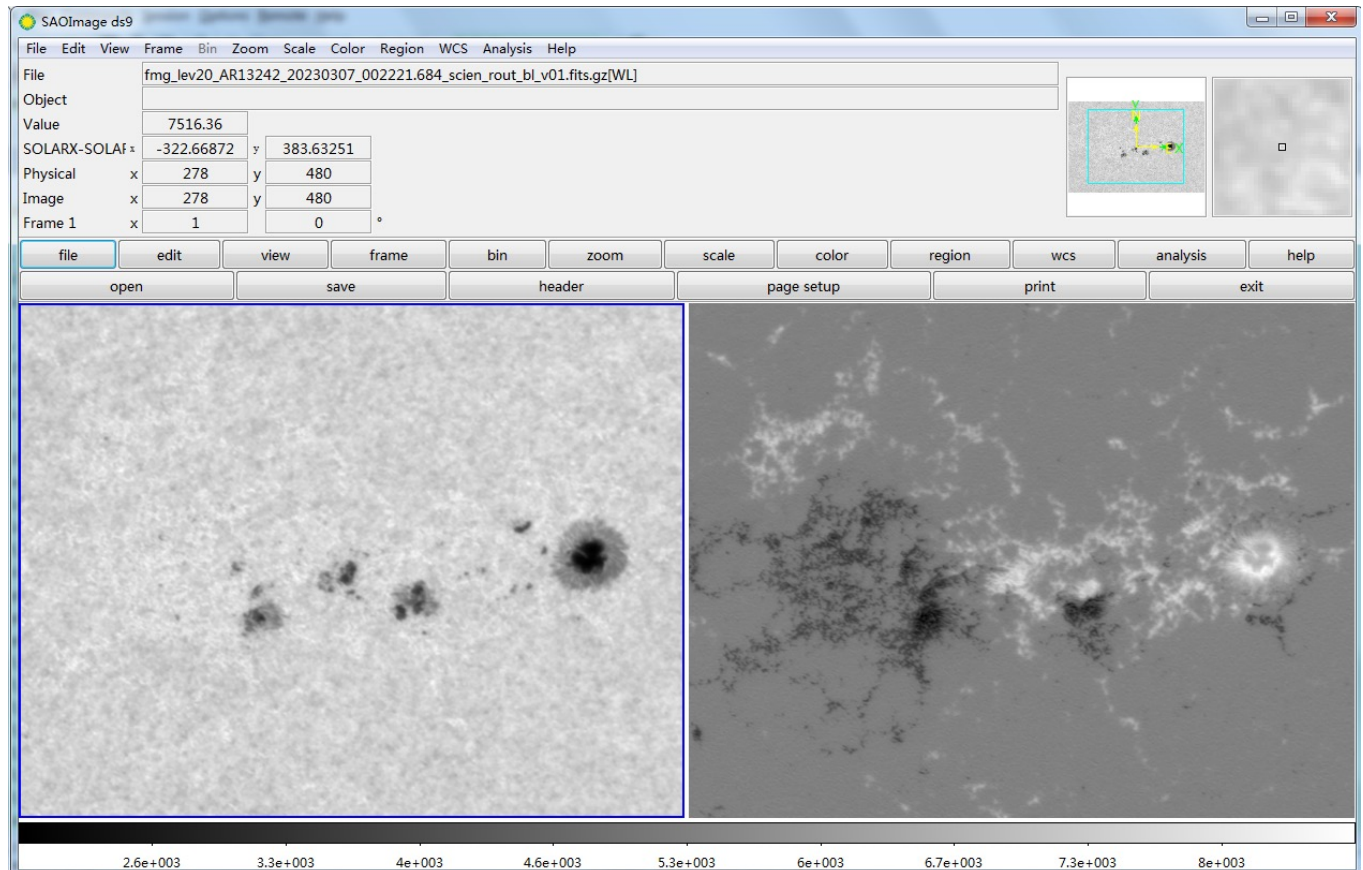
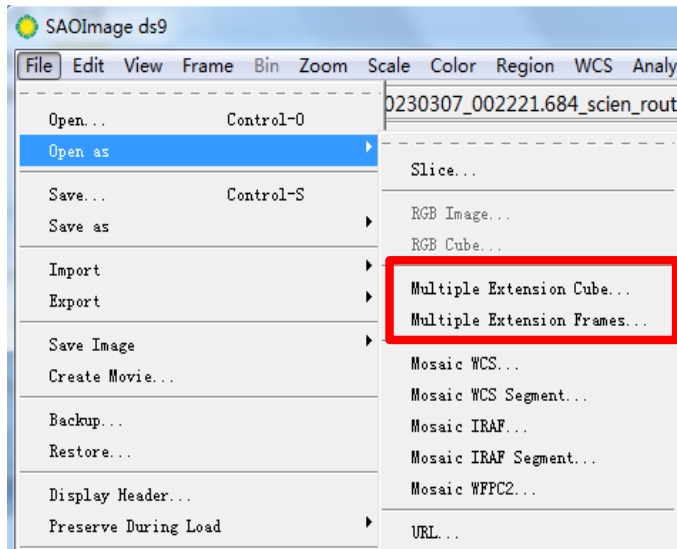
- ❑ header= info.Image(1)
 - ✓ DataType: 'int16'
 - ✓ Size: [600 580]
 - ✓ Keywords: {58×3 cell}

- ❑ I=fitsread('fmg_lev20_AR13236_20230224_235822.615_scienc_rout_bl_v01.fits','Image',1);
- ❑ BL=fitsread('fmg_lev20_AR13236_20230224_235822.615_scienc_rout_bl_v01.fits','Image',2);
- ❑ hdri= info.Image(1).Keywords ;
- ❑ hdrbl=info.Image(2).Keywords ;

Data Usage

➤ SAOImage ds9

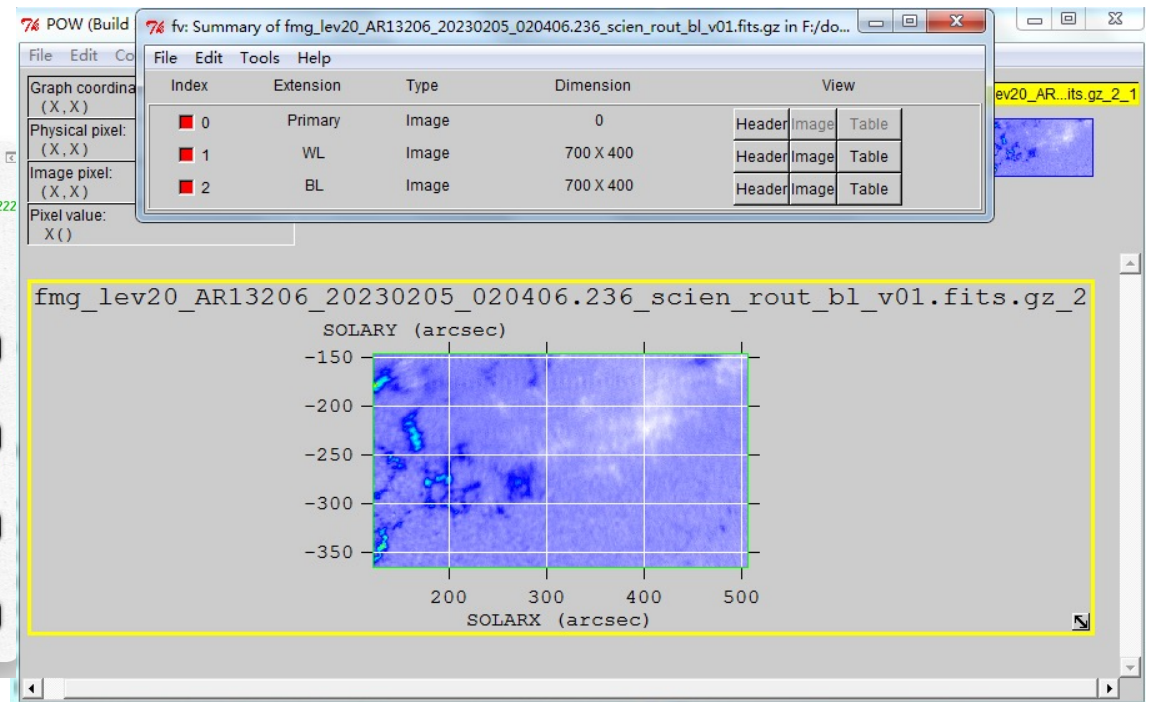
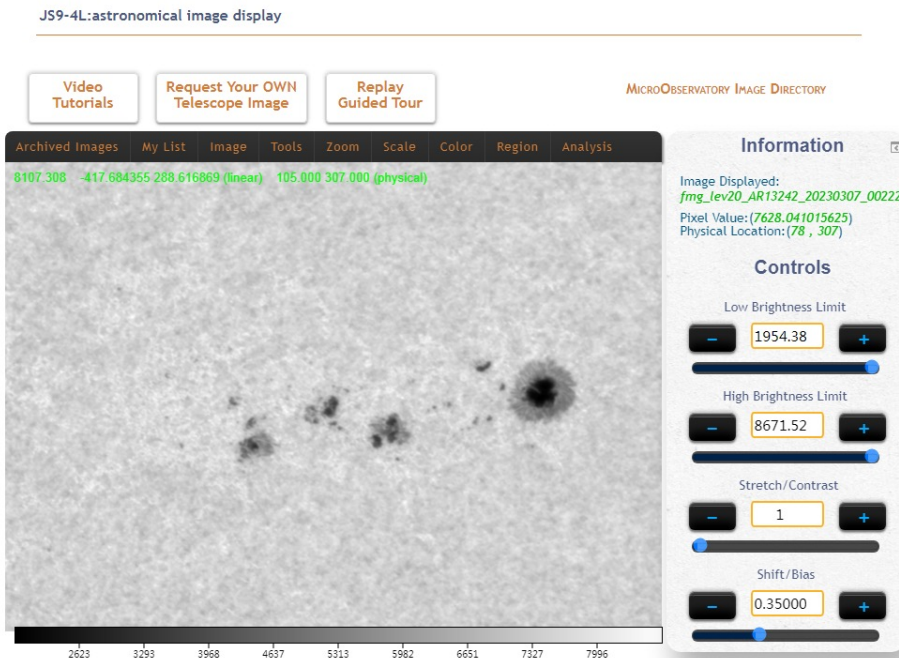
❑ <https://sites.google.com/cfa.harvard.edu/saoimages9>



Data Usage

➤ Other Visualization Software

- ❑ <https://sites.google.com/cfa.harvard.edu/saoimages9>
- ❑ <https://heasarc.gsfc.nasa.gov/docs/software/ftools/fv/>
- ❑ <https://www.gimp.org>
- ❑ <https://www.wolfram.com/mathematica/>
- ❑ <http://www.msbsoftware.it/avis/>
- ❑ <https://waps.cfa.harvard.edu/eduportal/js9/software.php>

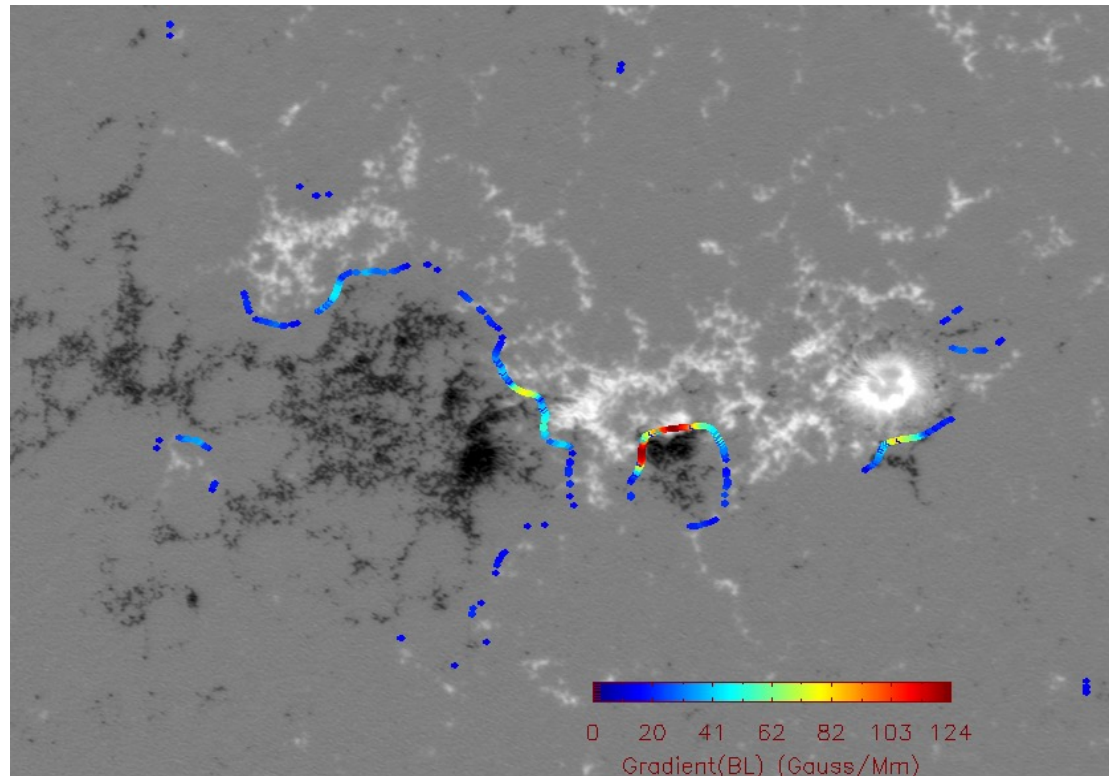


Application Examples

➤ Magnetic field Neutral Line

[plot_arpil.mp4](#)

- ✓ fmg_arpil .pro included in SSW
- ✓ filein='fmg_lev20_AR13242_20230307_002221.684_scienc_rout_bl_v01.fits.gz'
- ✓ fmg_arpil,filein,length,xmax,ymax,lon_lmax,latc_lmax



Application Examples

➤ Magnetic field Topology

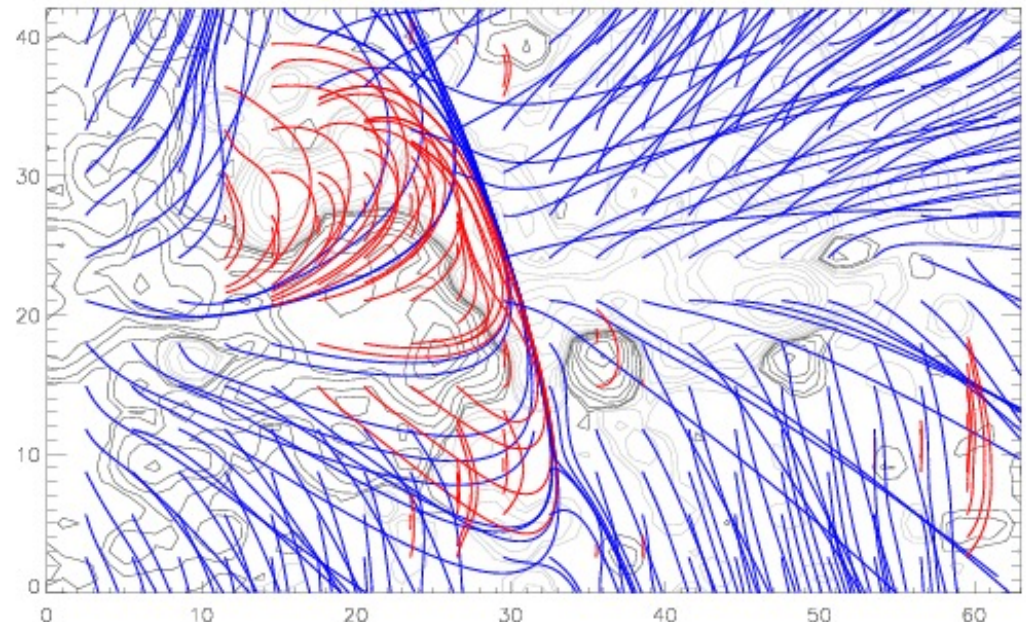
[plot_exts.mp4](#)

□ Codes: [a potential or linear FFF]

- ✓ https://github.com/liusnaoc/NLFFF_opti
- ✓ `ssw/packages/nlfff`
- ✓ `ssw/packages/gff;bff;fff`
- ✓ and so on...

□ Special Code : `read_fmng.pro`

□ `file='Bz.fits', alpha...` and so on

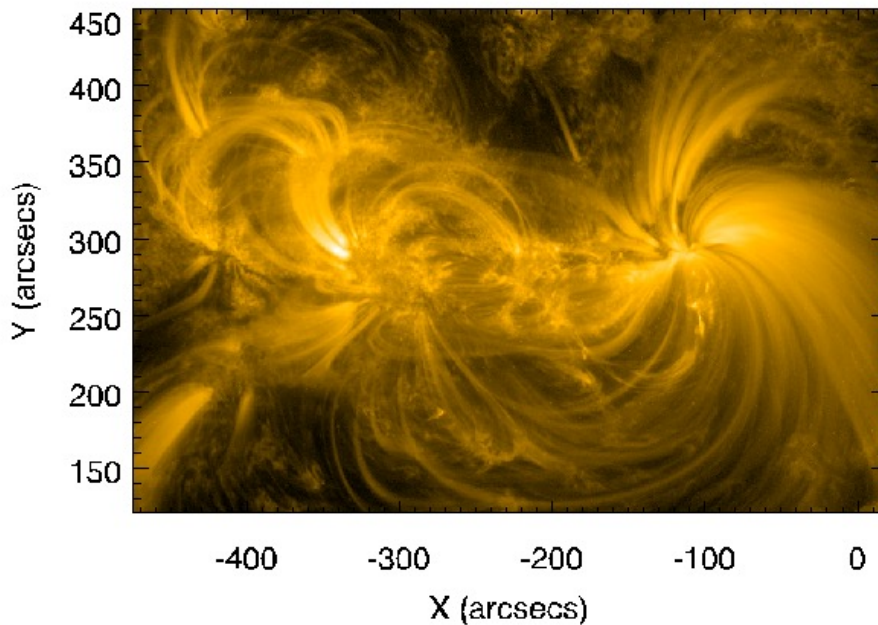


Application Examples

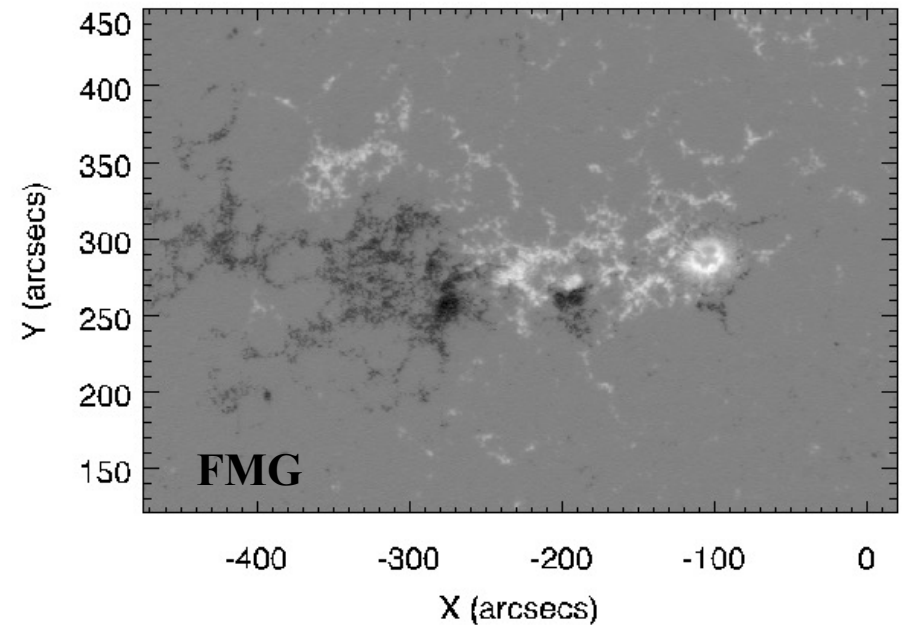
➤ Alignment

[plot_align.mp4](#)

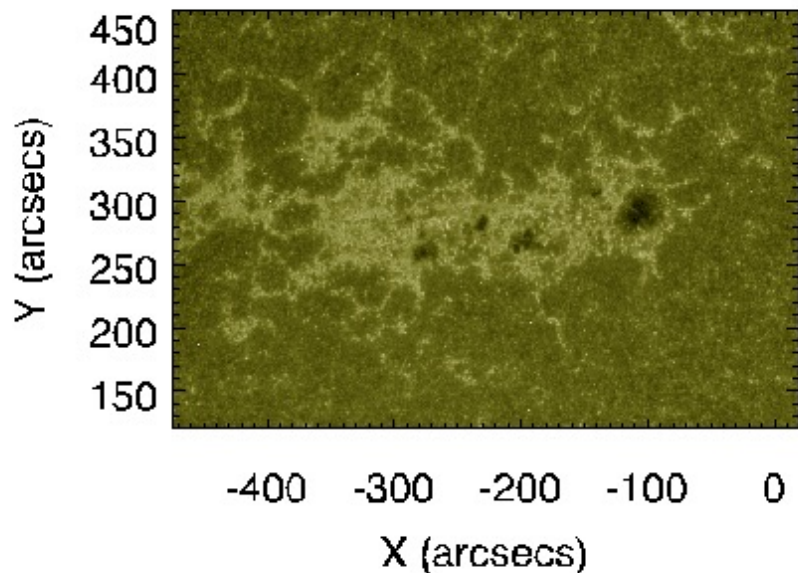
2023-03-07T00:21:45.350



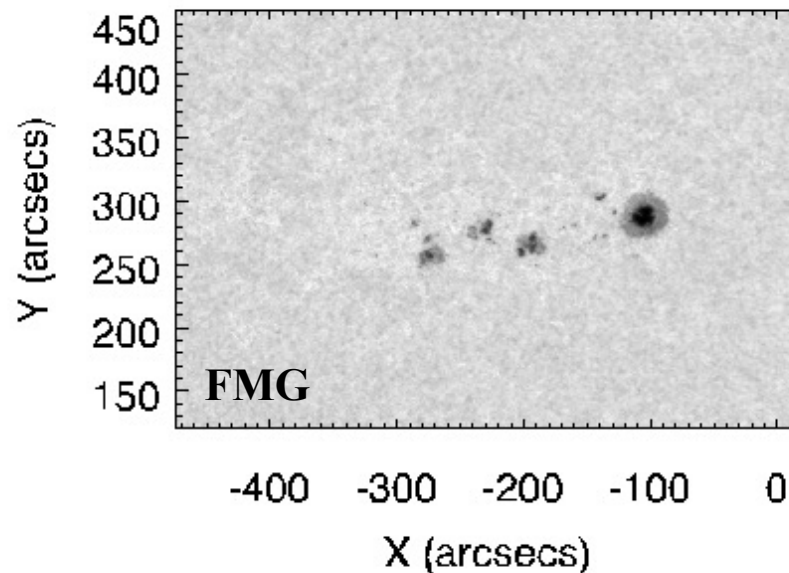
2023-03-07T00:22:21.684



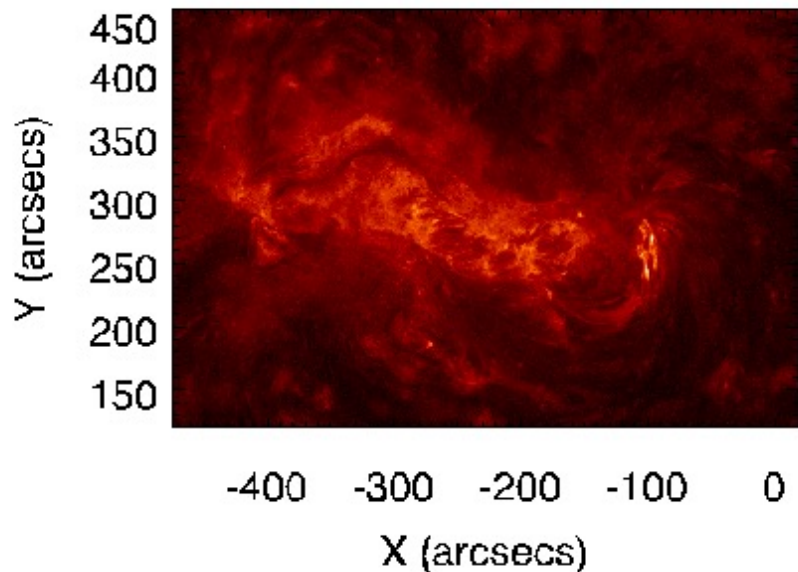
2023-03-07T00:21:26.126



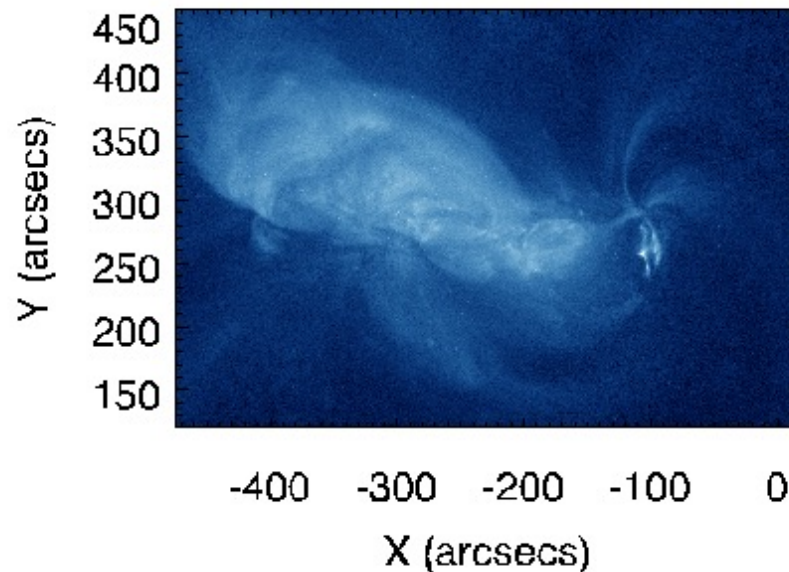
2023-03-07T00:22:21.684



2023-03-07T00:21:41.129

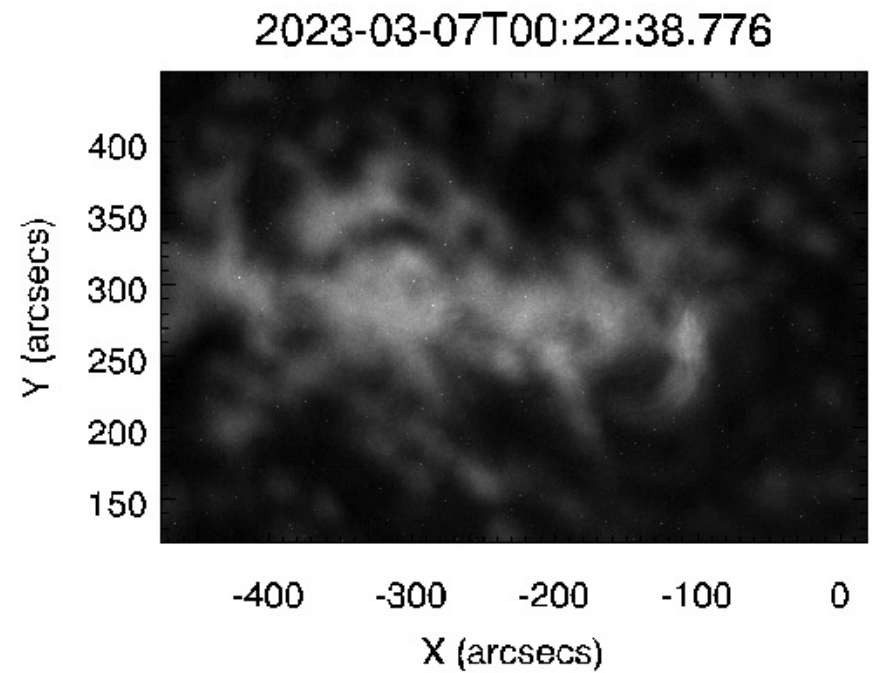
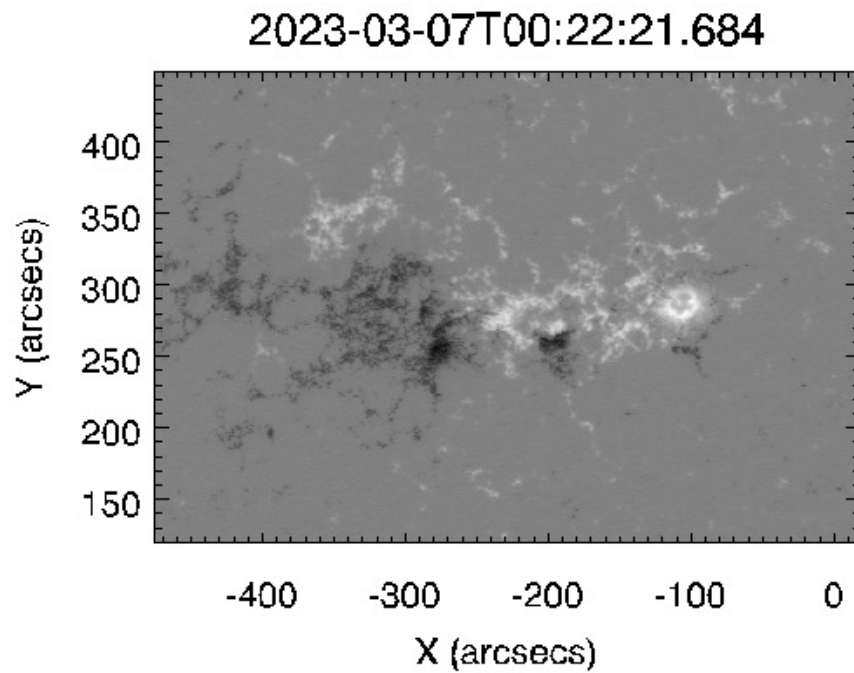


2023-03-07T00:21:36.622



Application Examples

➤ Alignment



Summary

- **The scientific data pipeline works properly**
- **Flat field, polarization bias are calculated statistically from routine observation**
- **The transverse fields have not been obtained in routine observation, but can be observed by special mode.**
- **The full-disk magnetic field can not be produced well in routine observation, due to a darker region in the full-disk image. The reason and remedy are still under investigation.**
- **Active region longitudinal magnetic field is released (delay ~3days) from April 1.**
- **There exist a possibility of updating data processing and software, based on changes and improvements in future observations**

The end

Thank you for attending