DIPARTIMENTO di
FISICA e ASTRONOMIA
"Ettore Majorana"

Investigating the X1.6 flare in the great Active Region 12192

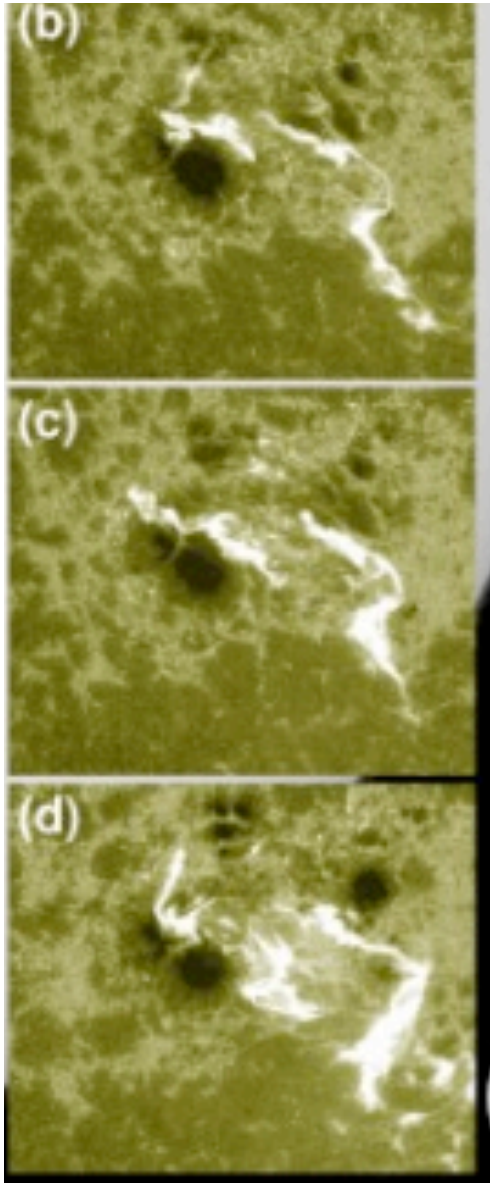
F. Zuccarello[1], S.L. Guglielmino[2], F. Ferrente[1],
S. Criscuoli[3], P. Romano[2]

[1]Dipartimento di Fisica e Astronomia – Università di Catania, Italy
[2]INAF – Osservatorio Astrofisico di Catania, Italy
[3] NSO, USA

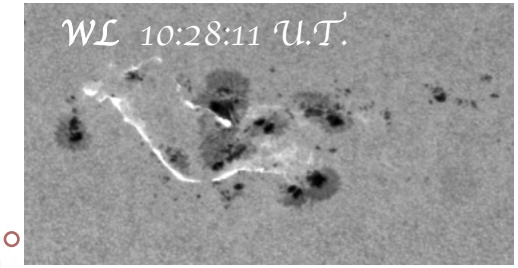
106° Congresso Società Italiana di Fisica
14 - 18 Settembre 2020

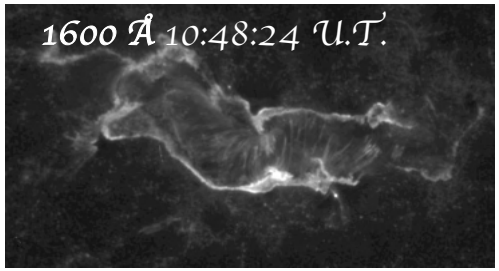
Plan of the Talk

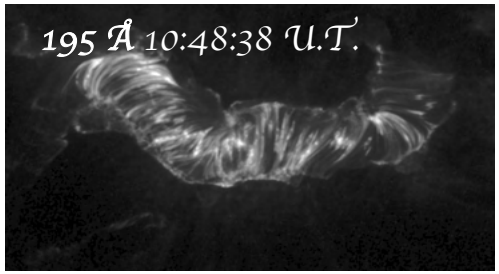
- Solar eruptive phenomena
- Main characteristics of AR 10192
- The X1.6 flare evolution (SDO and RHESSI)
- Analysis of IBIS data
- Analysis of IRIS data
- Conclusions

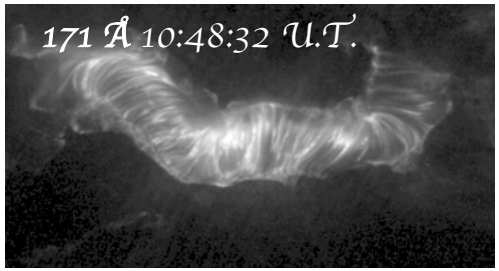


Eruptive phenomena: flares

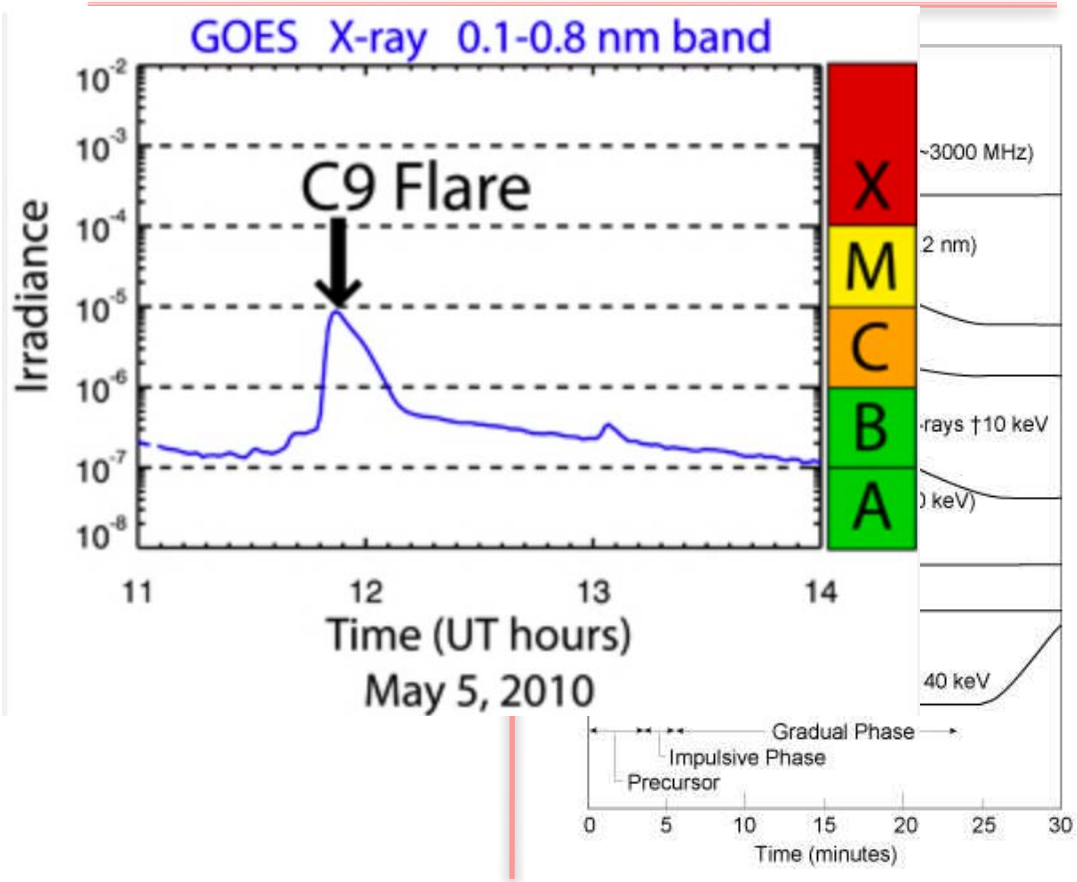




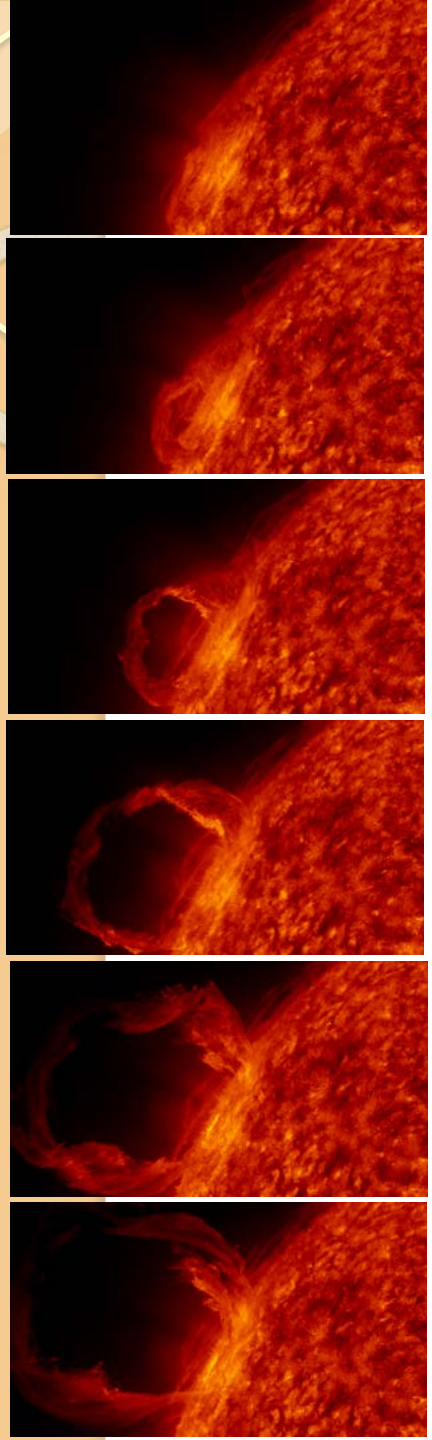




Flares are magnetically driven phenomena that can involve all the solar atmospheric layers (and beyond …)

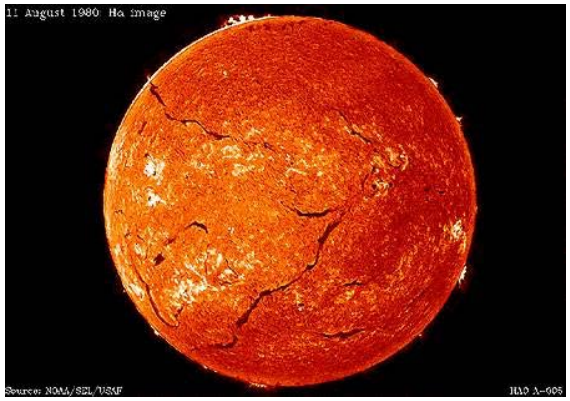


Magnetic energy is converted into particle energy, heat, waves, e.m. radiation and motion.



Eruptive phenomena: filament eruptions and CMEs

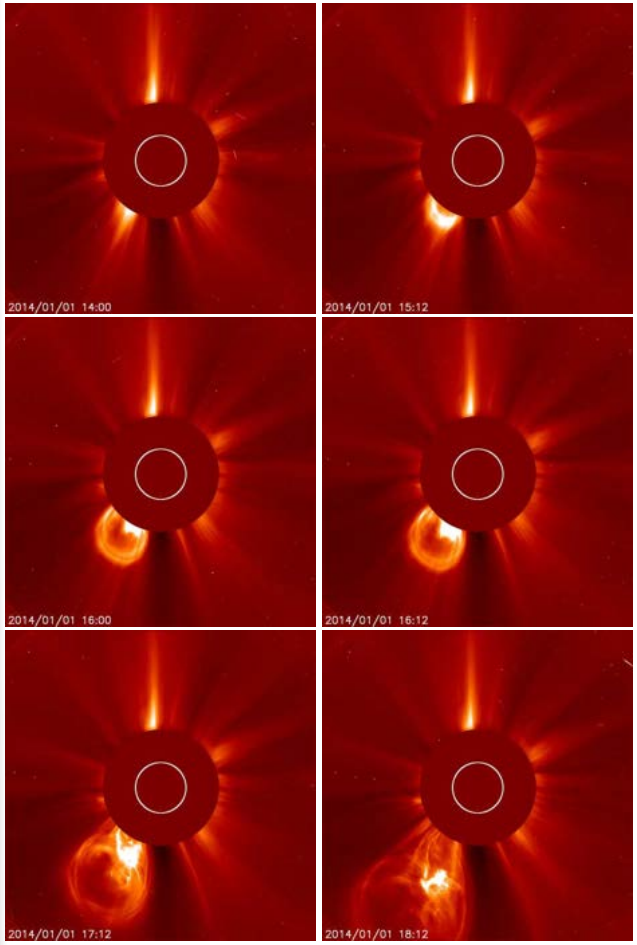
Filament activation is a precursor of approaching flare activity.



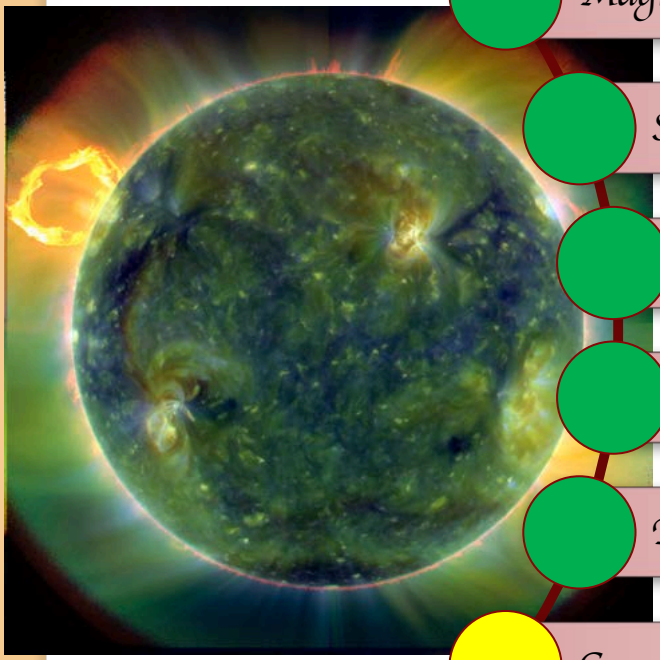
Filaments outside ARs can erupt and give rise to CMEs.

CMEs: expulsion of mass of the order of 10^{14} – 10^{16} g, with v ~ 10^{3} km/s, involving an energy release of ~ 10^{28} – 10^{32} erg.

CME observed by LASCO-C3.

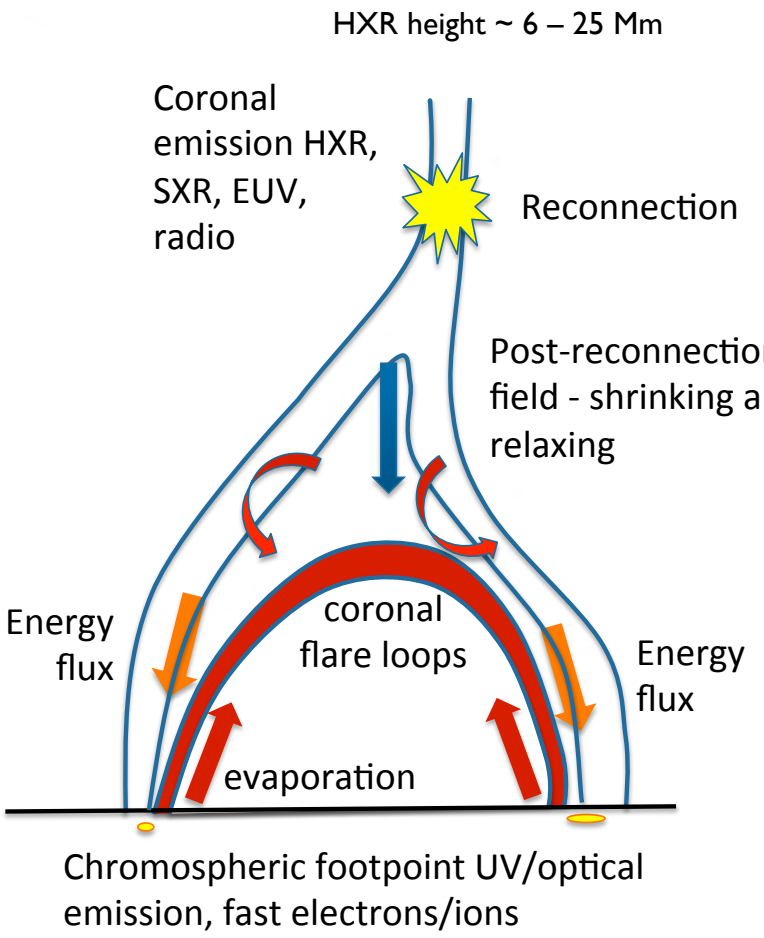


What is needed to produce an eruptive event (assuming you got the right star)



- Magnetic field
- Stressed magnetic field (currents) - Magnetic energy storage
- Trigger: Magnetic reconnection - Threshold - Instability
- Energy conversion
- Particle acceleration - e.m. emission - bulk plasma motions
- Coronal mass ejection

Flares: The Model and the Main Questions



Fletcher, 2014

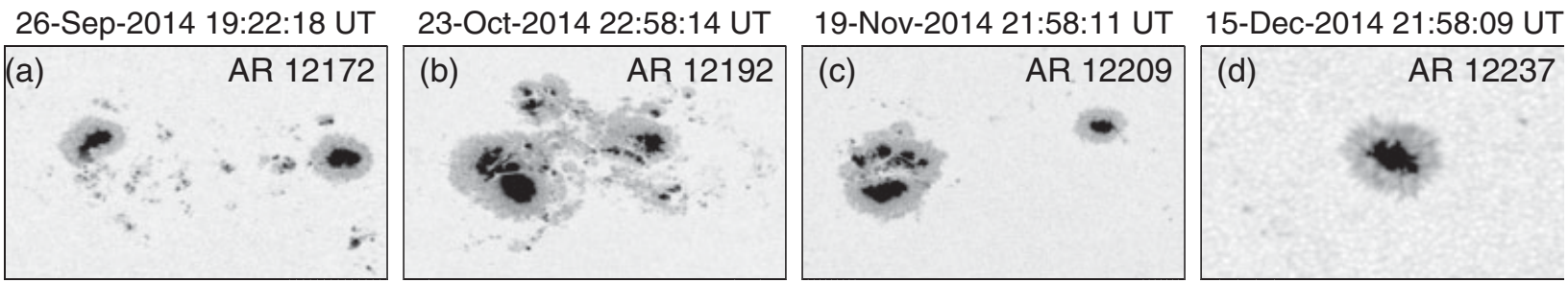
The main question of flare physics is to understand:

How the energy, previously stored in a stressed coronal magnetic field →

- *is released so rapidly,*
- *transported through the solar atmosphere,*
- *converted into the kinetic energy of the non-thermal particles and into the flare's radiation output.*

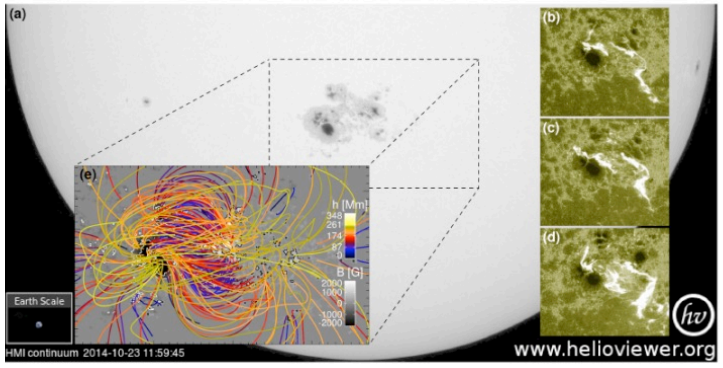
Main characteristics of AR 12192

- Active region (AR) 12192 of 2014 October hosted the ***largest sunspot group in 25 years***.
- It appeared on the visible solar disc on 17 October 2014. However, ***it was a recurrent AR***.
- The total unsigned magnetic flux of the AR at its max was 2 x 10^{23} Mx on 27 October 2014.



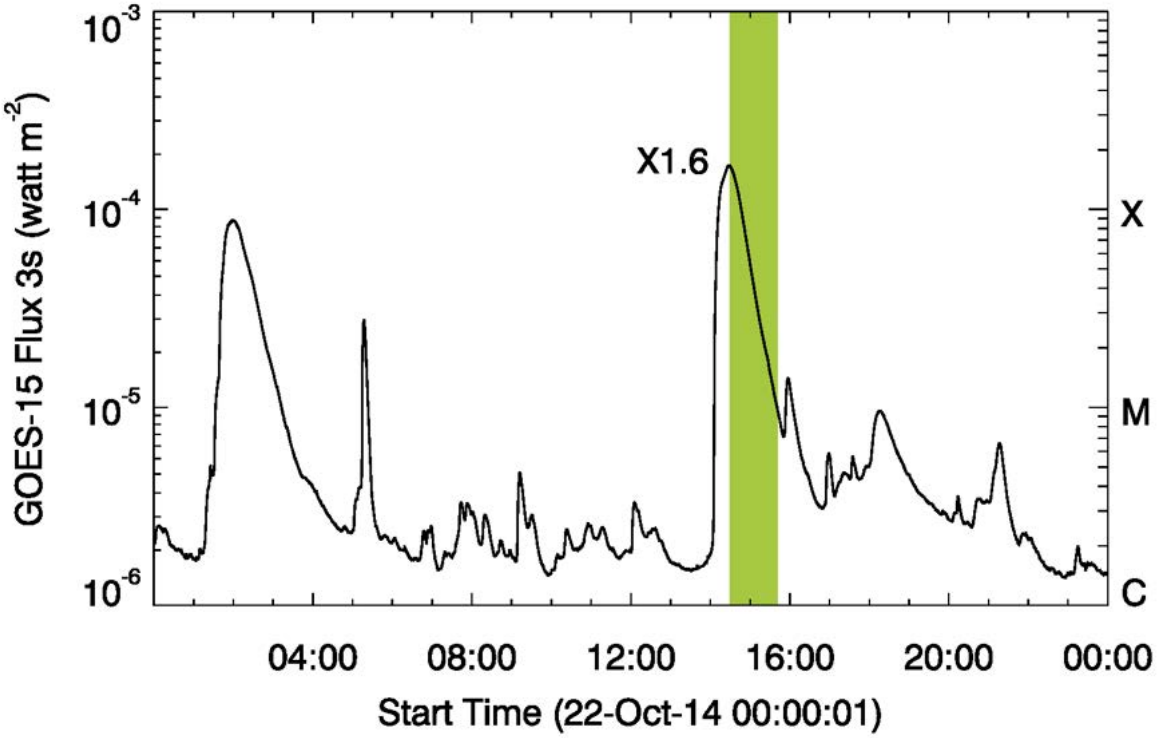
Sarkar et al. (2017)

- It has been the ***most prolific flaring site of Cycle 24***, being the source of 29 M- and 6 X-class flares and ***only 1 CME***
- The X6.1 class flare sets a record in flare energy for an event without a CME.



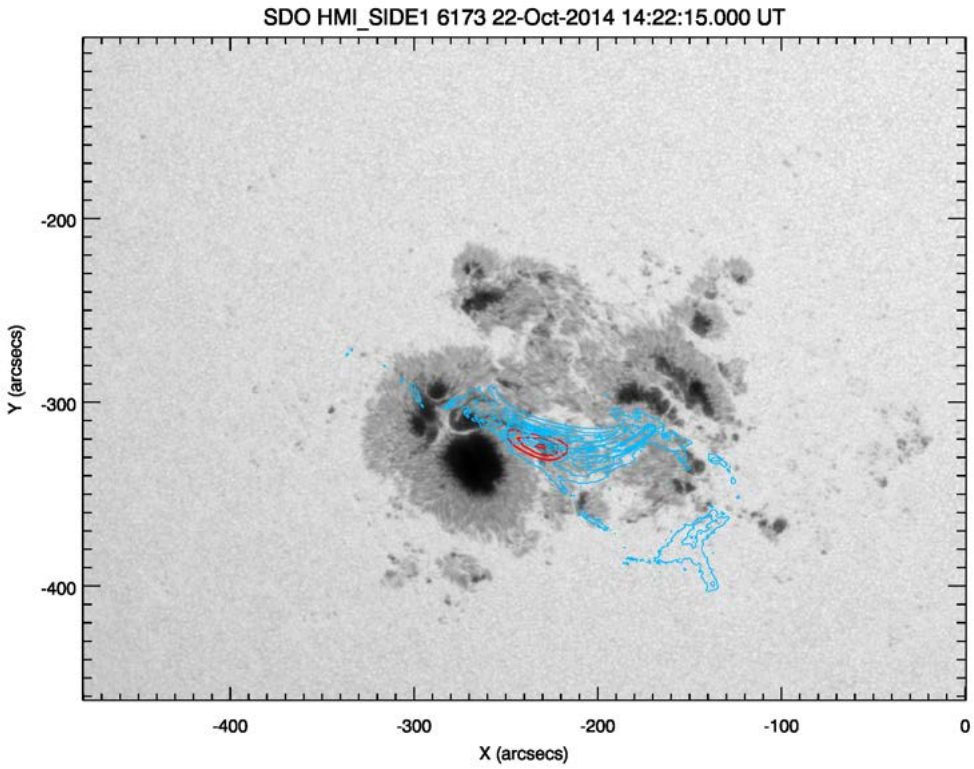
Thalmann et al. (2016)

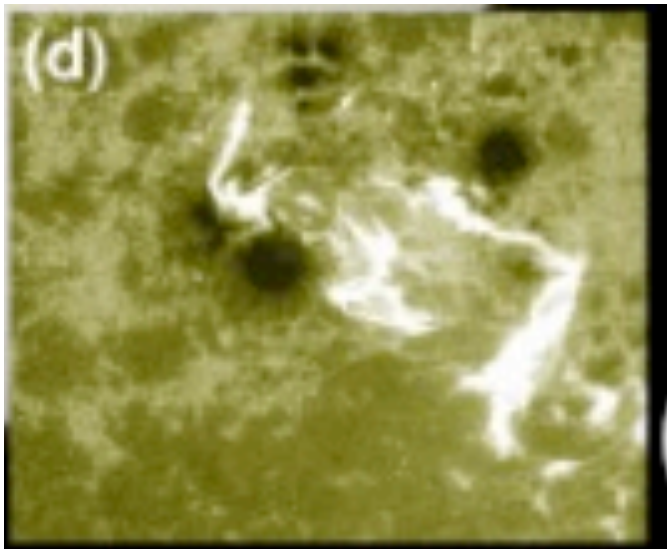
AR NOAA 12192 – 22 October 2014



GOES Flux on 22 Oct. The **IBIS** instrument at the NSO/Dunn Solar Telescope (DST) observed at high spatial and temporal resolution the inner region of AR NOAA 12192 during the X1.6 flare **SOL2014-10-22T14:02**.

AR NOAA 12192 – 22 October 2014 (the photospheric configuration)



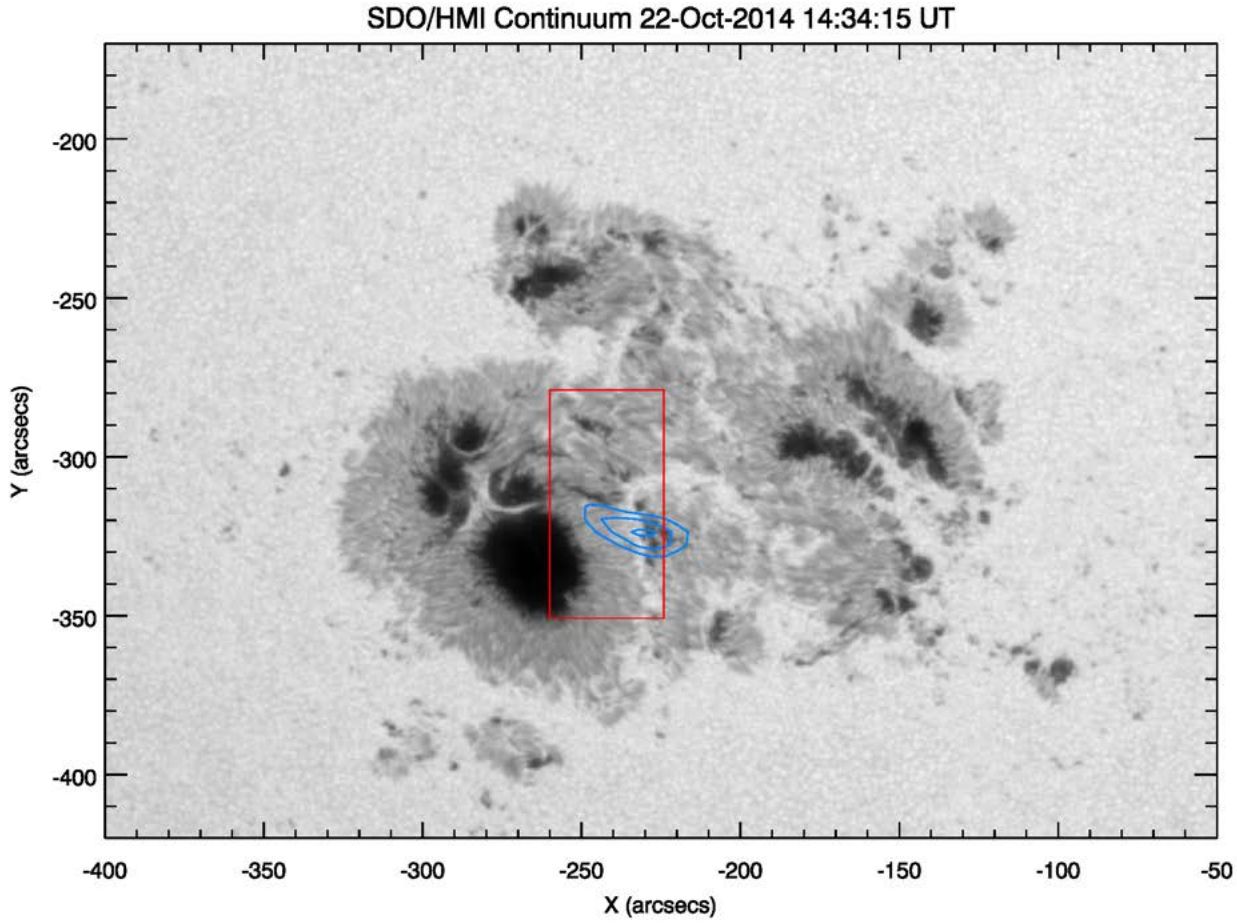


Left: SDO/HMI continuum intensity map of AR 12192, close in time with the peak of the SOL2014-10-22T14:02 flare.

The blue contours represent isophotes of the intensity in the SDO/AIA 131 filtergram. The red contours indicate the RHESSI intensity in the 25-50 keV channel.

Right: SDO/AIA 1600 Å image showing the flare ribbons.

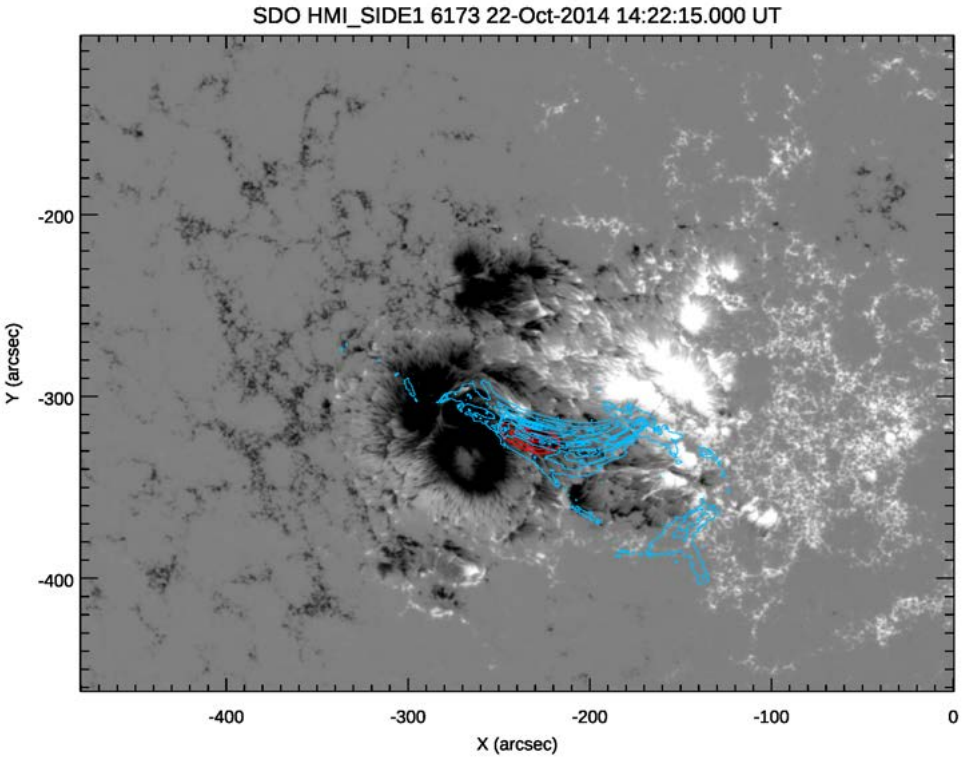
AR NOAA 12192 – 22 October 2014

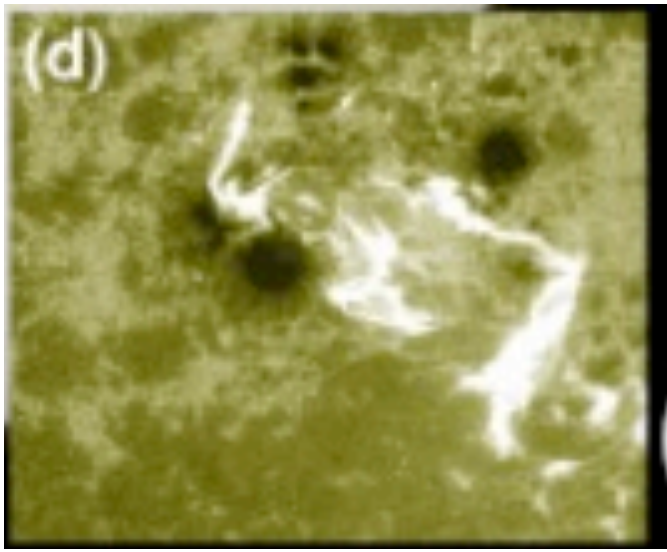


SDO/HMI continuum intensity map of AR 12192.

*Here the red box indicates the field-of-view (FOV) of the **IBIS** instrument. The blue contours represent the RHESSI intensity in the 25-50 keV channel.*

AR NOAA 12192 – 22 October 2014 (the magnetic field distribution in photosphere)

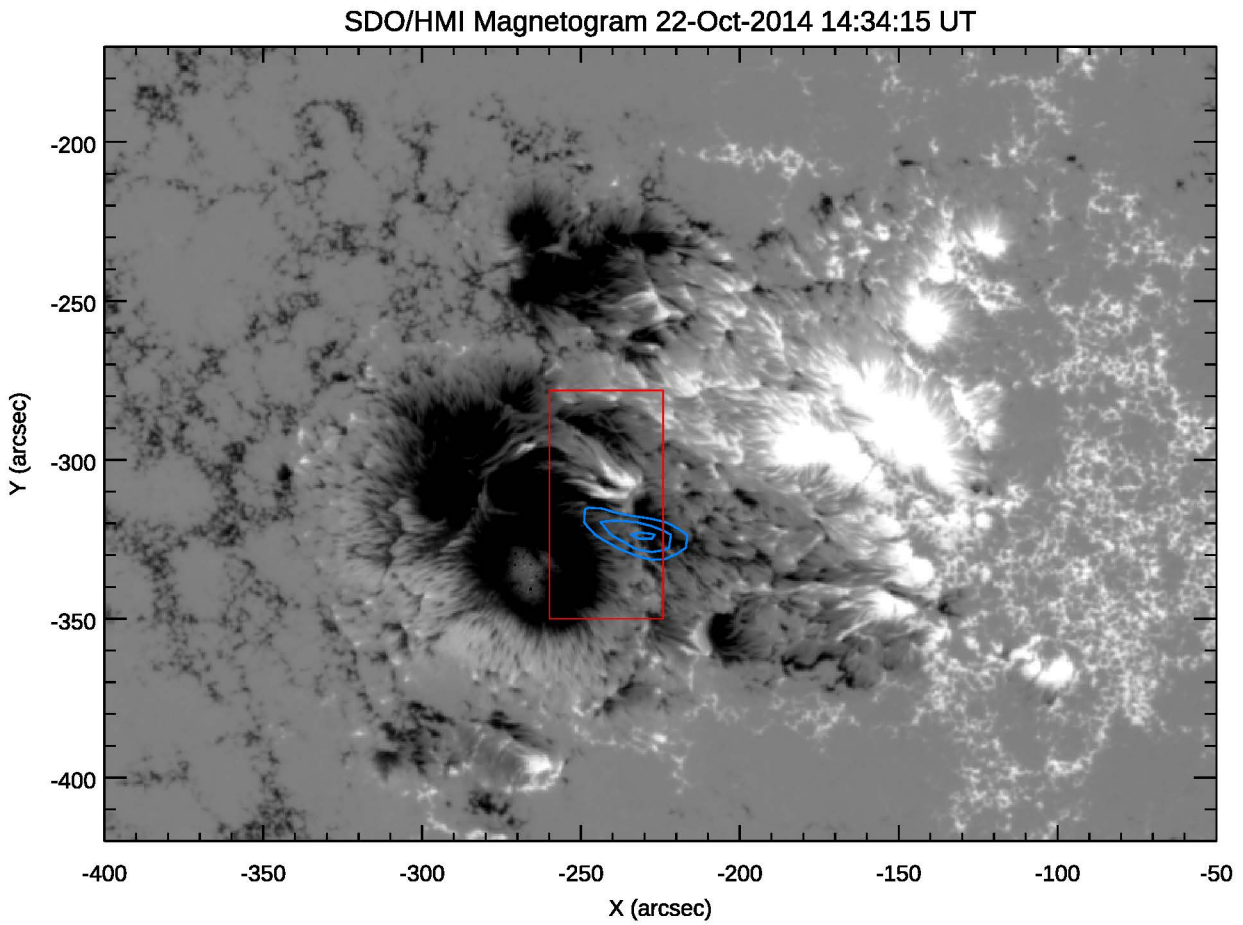




Left: SDO/HMI magnetic field map of AR 12192, close in time with the peak of the flare.

Right: SDO/AIA 1600 Å image showing the flare ribbons.

AR NOAA 12192 – 22 October 2014



SDO/HMI photospheric magnetic field map of AR 12192.

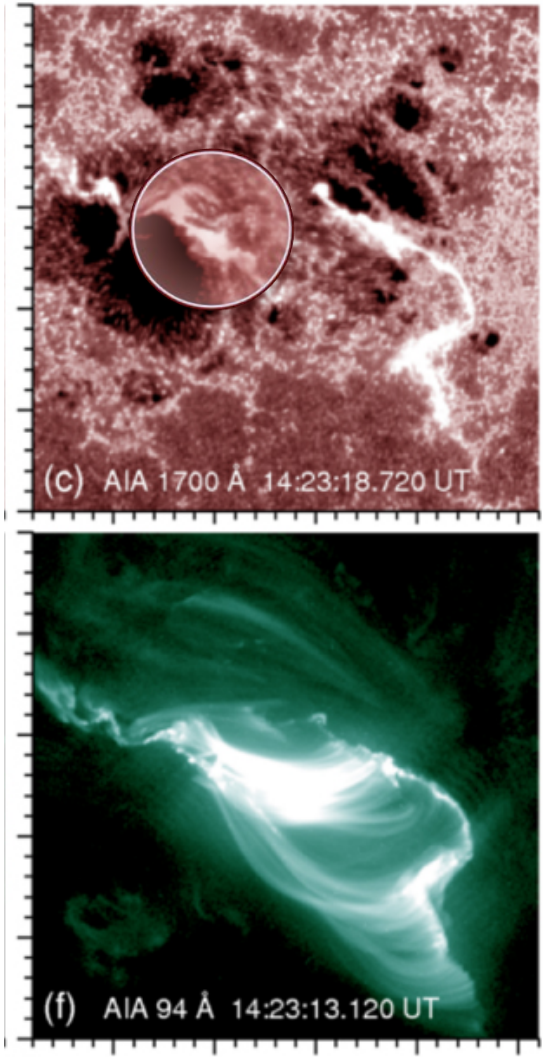
Note: the IBIS FoV (indicated by the red box) includes a region of negative magnetic polarity with some intrusions of positive polarity.

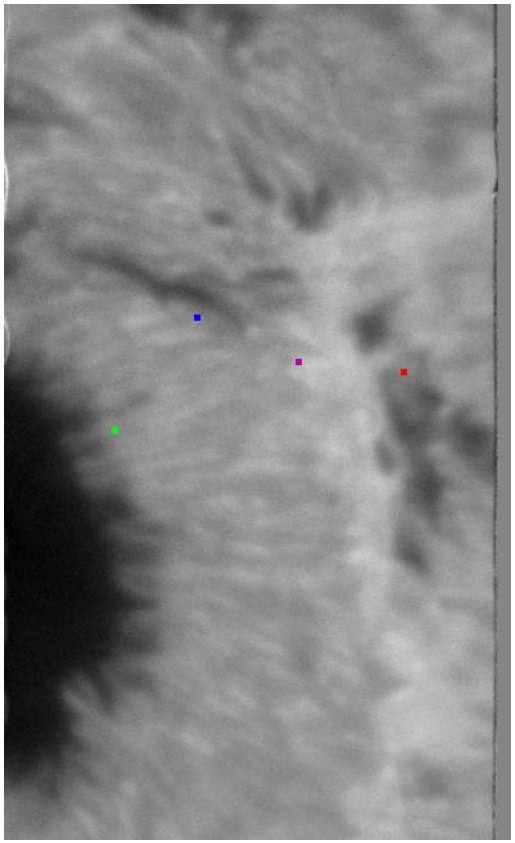
X1.6 flare – IBIS dataset

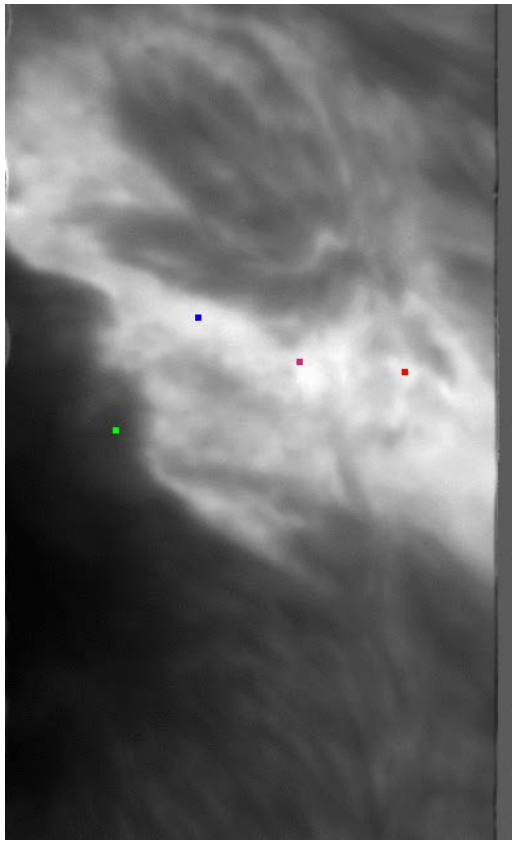
Instrument	Channel	Spectral points	Polarimetry
IBIS@DST	Fe I 6173 Å	20	I Q UV
	Hα 6563 Å	25	I only
	Ca II 8542 Å	25	I Q UV

- Pixel size **0.09 arcsec**
- Spatial resolution **max ≈0.25 arcsec**
- Time cadence **50 seconds**
- Start observing time **14:29:41 UT**
  (peak of X1.6 flare at 14:28 UT)
- Reduced data **28 sequences**
  14:29:41 – 14:54:58 UT

X1.6 flare – IBIS/Ca II 8542 Stokes I

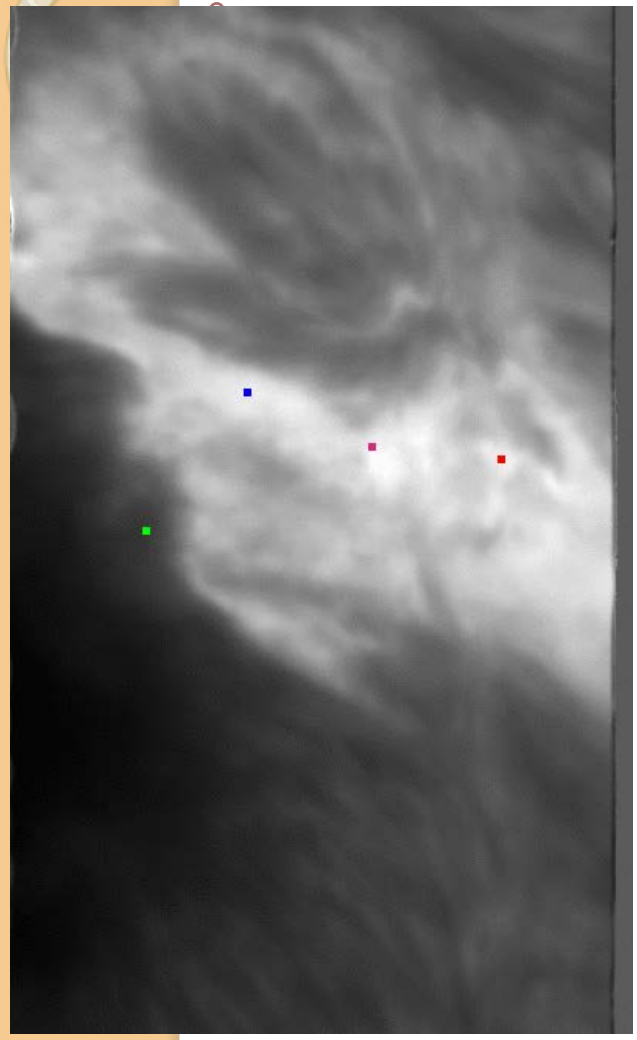






From the comparison with AIA maps from Thalmann et al. (2015), we can establish that IBIS observed the southern part of the eastern flare ribbon.

Analysis of Stokes profiles in four different locations of the flare

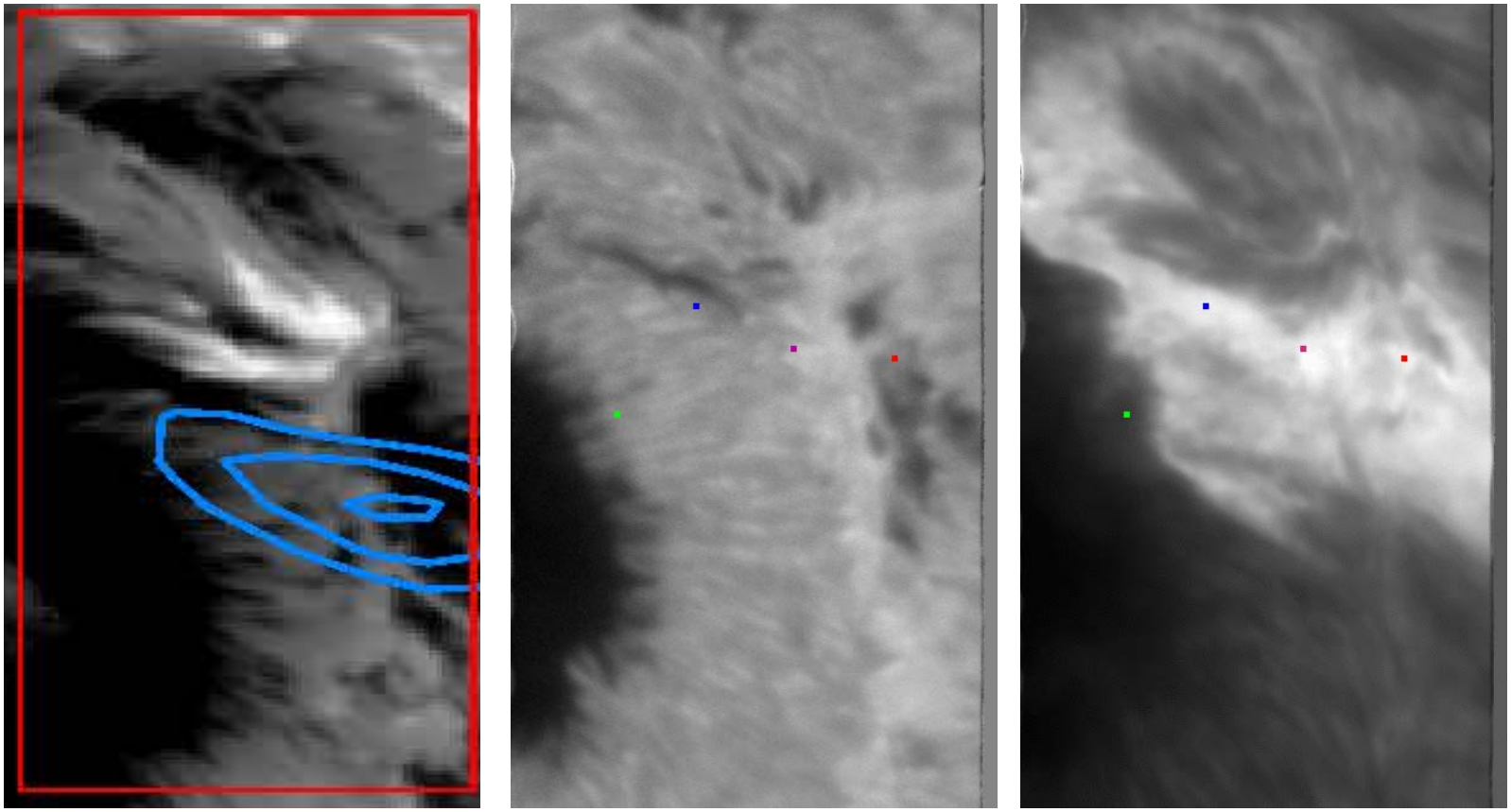


Analysis of the Ca II line spectro-polarimetric data during the flare evolution to determine the evolution of the Stokes profiles, which can provide some information on the presence of **linear polarization** (i.e., magnetic field lines in a direction perpendicular to the LoS) and **circular polarization** (magnetic field along the LoS).

We choosed four different locations:

- Flare1: region showing continuous brightening during the analyzed time interval
- Flare2: region at the border between a very bright patch and a dark patch
- Flare3: region initially very bright, but becoming dark as time goes;
- Flare4: region in the positive magnetic intrusion.

Comparison of the HMI magnetogram with locations of investigated regions



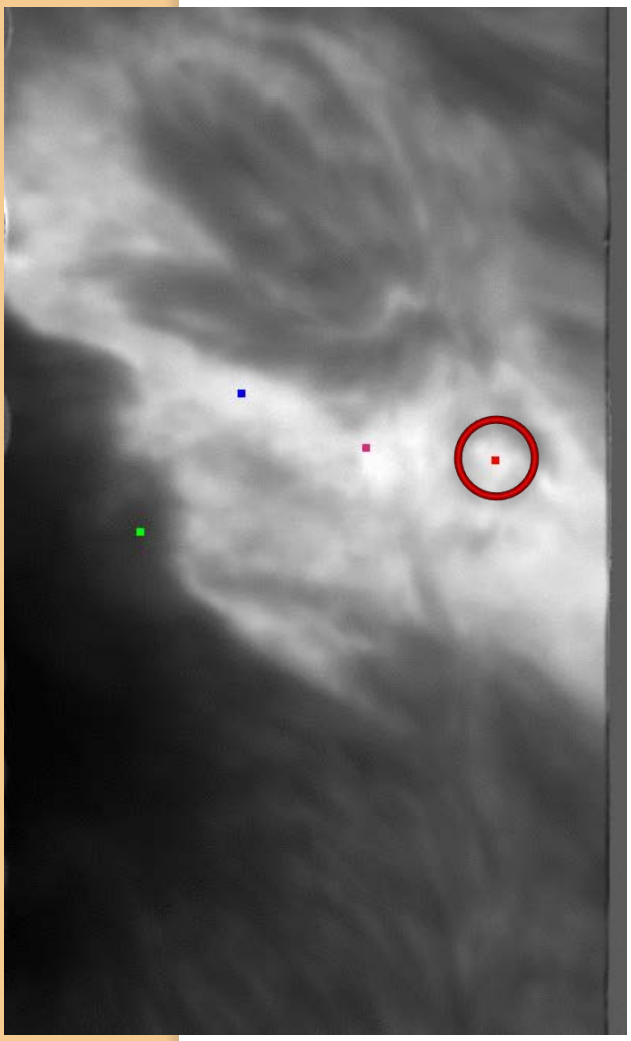
flare1: at the interface between the negative polarity and the positive intrusion

flare2: inside the negative polarity surrounded by the positive intrusion

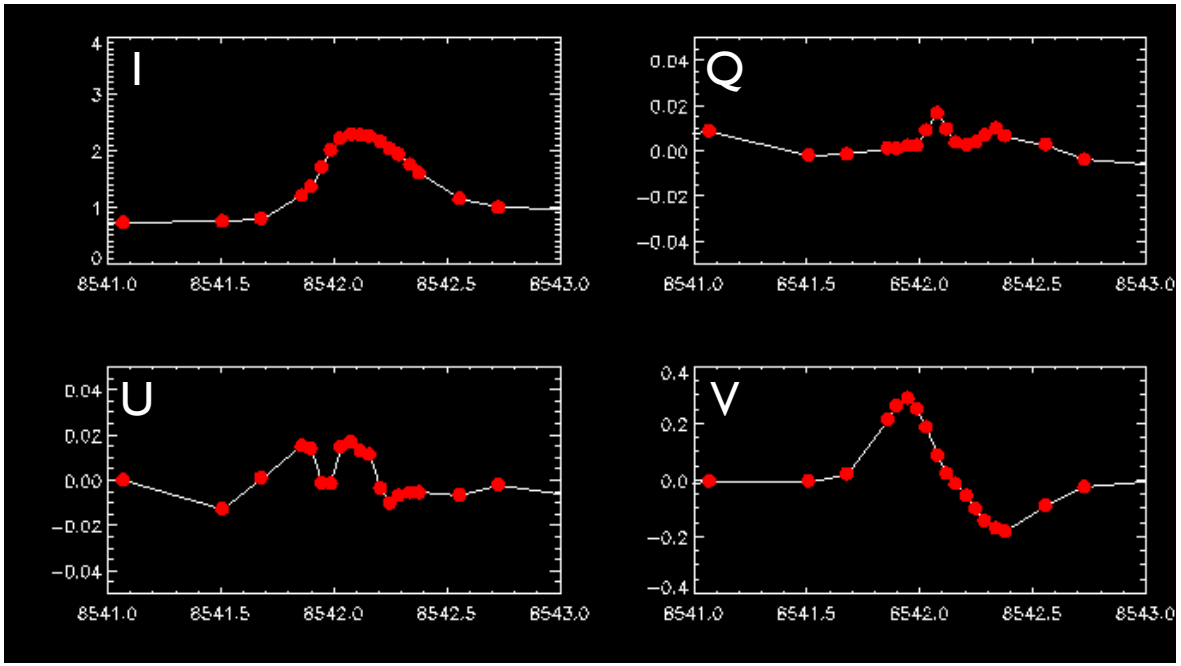
flare3: inside the negative polarity

flare4: inside a region showing positive polarity

X1.6 flare – IBIS/Ca II 8542 full Stokes

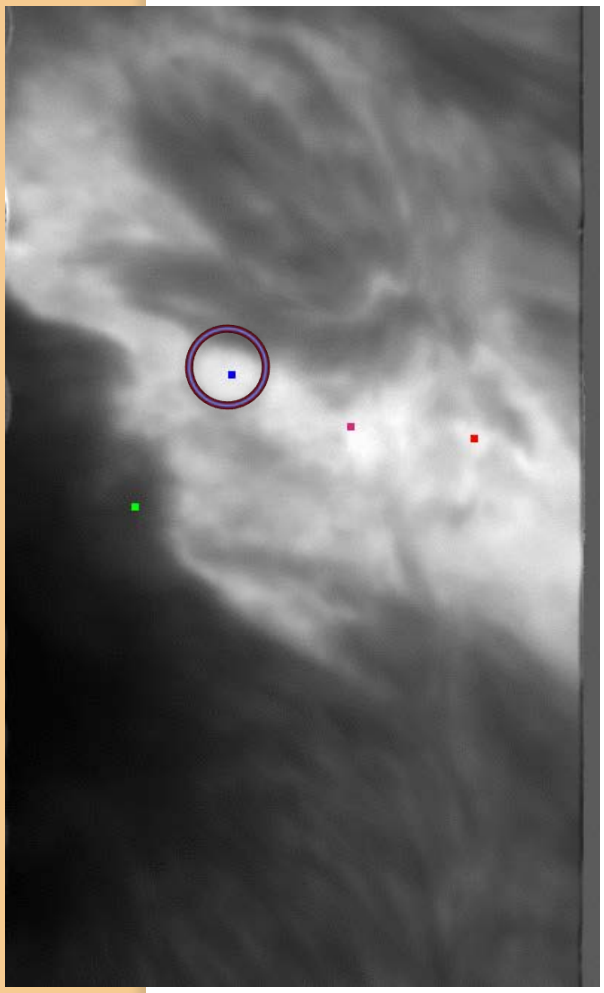


Stokes profiles for region "Flare1"

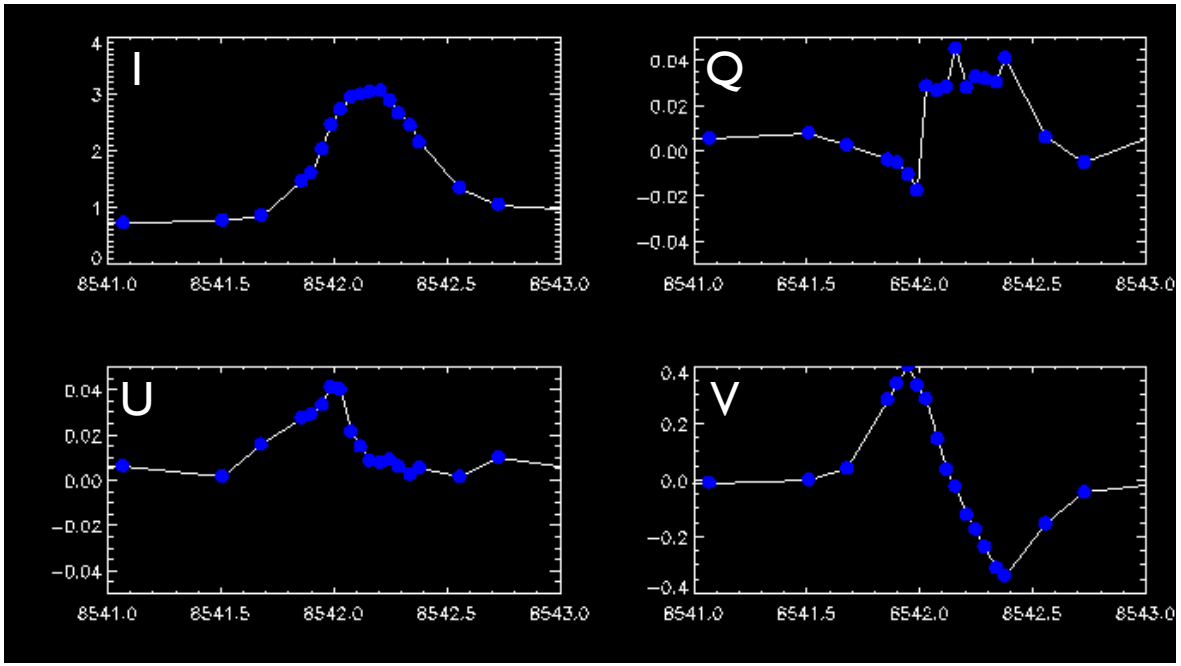


- ✓ Size of region flare1=0.27"x0.27"=0.07 arcsec^2
- ✓ Δt = 50 s
- ✓ The vertical axis reports the values with respect to I_c.

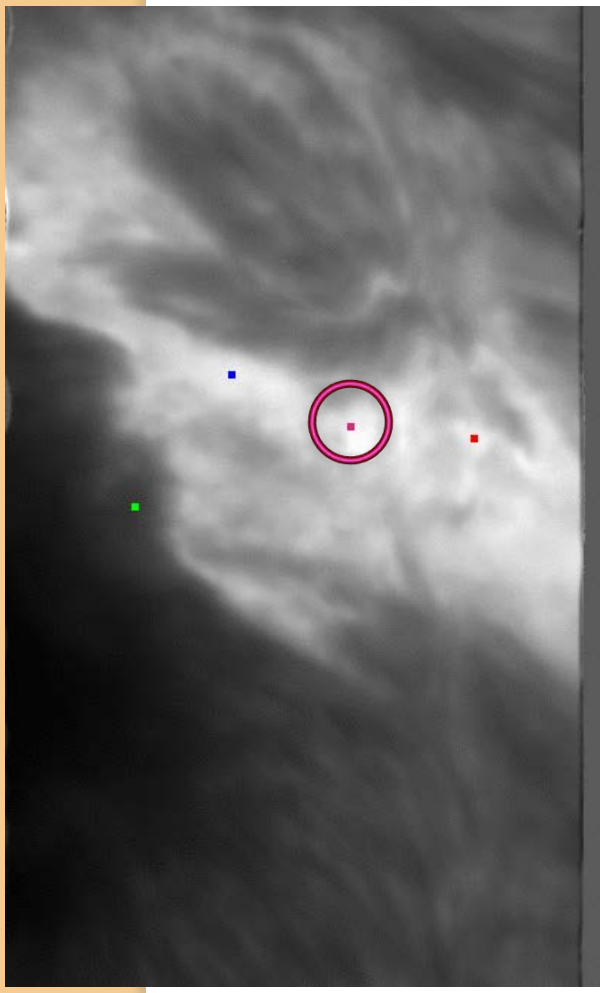
X1.6 flare – IBIS/Ca II 8542 full Stokes



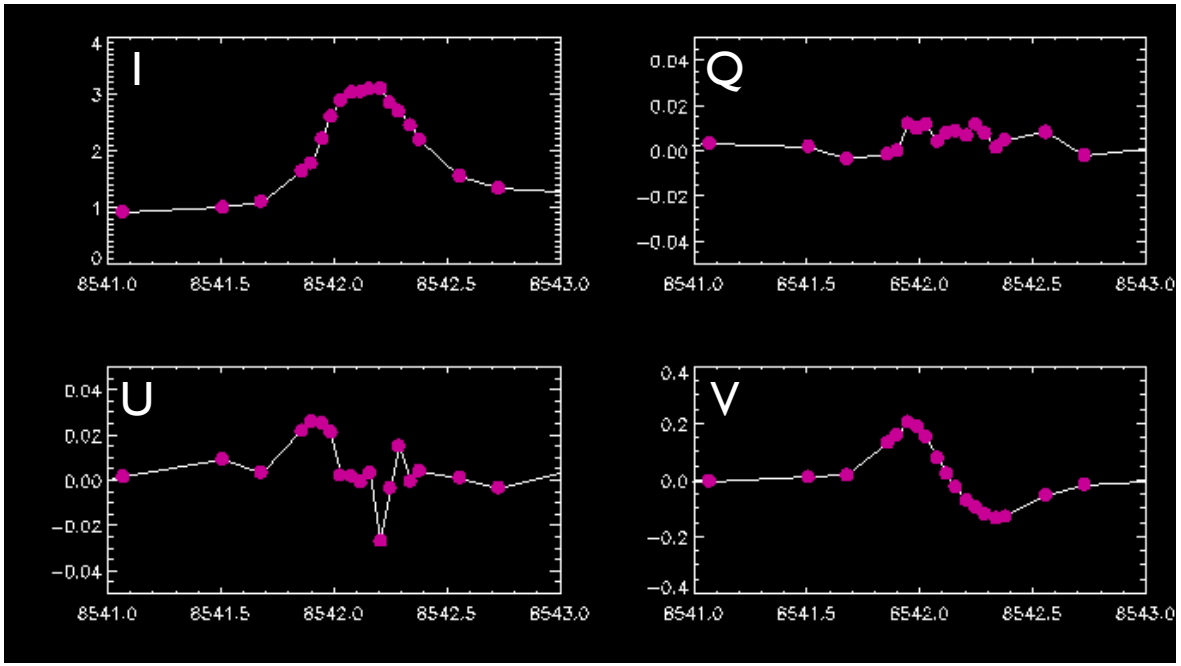
Stokes profiles for region “Flare2”



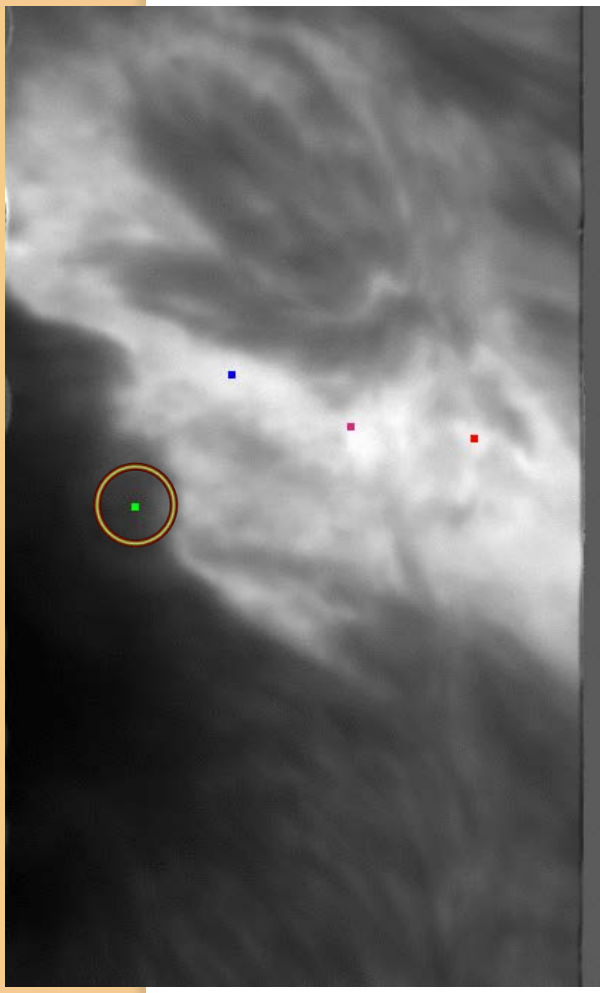
X1.6 flare – IBIS/Ca II 8542 full Stokes



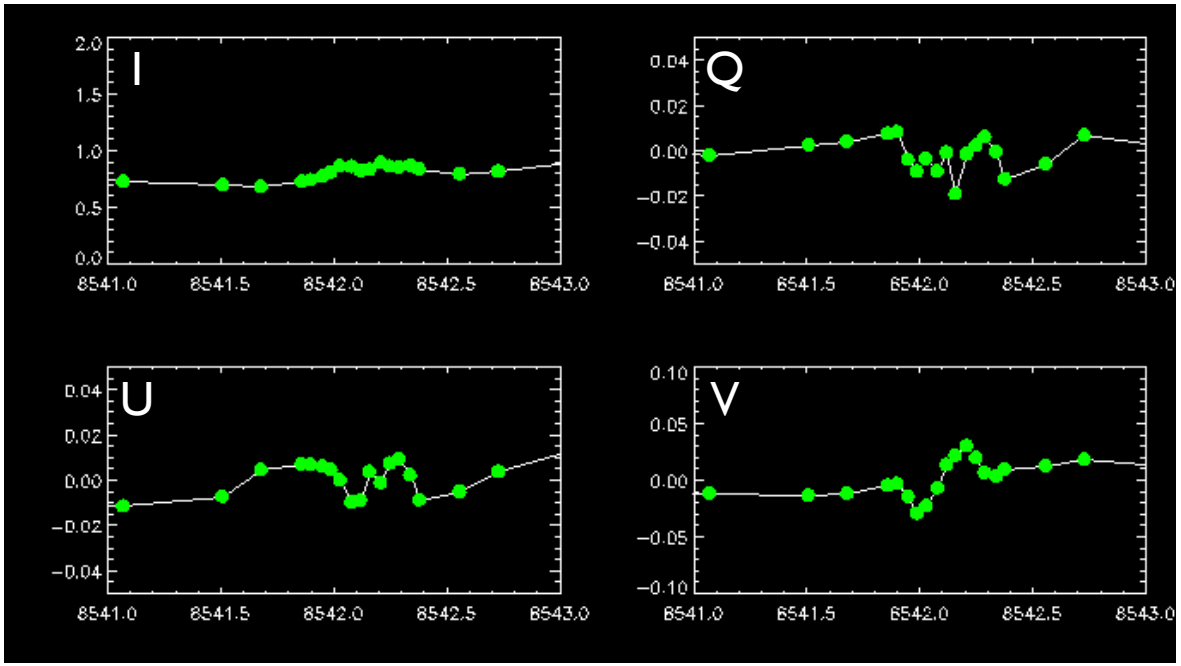
Stokes profiles for region “Flare3”



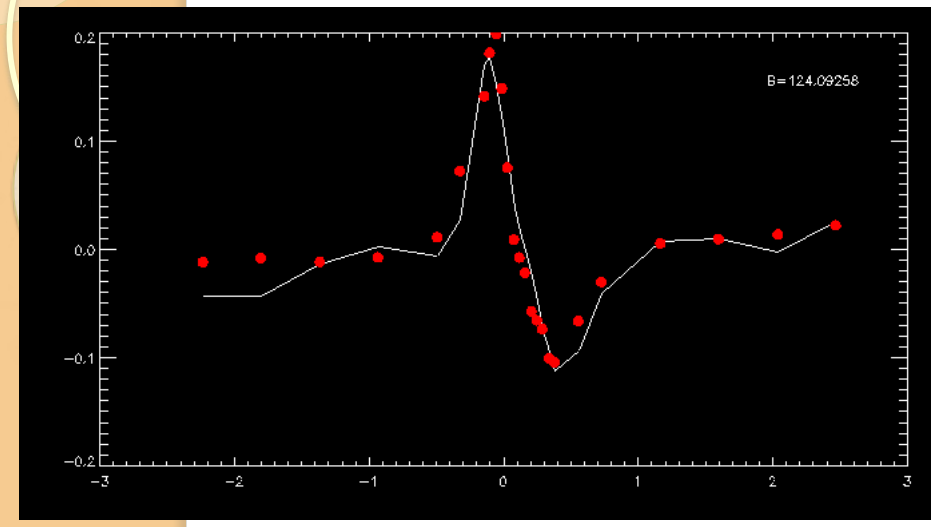
X1.6 flare – IBIS/Ca II 8542 full Stokes

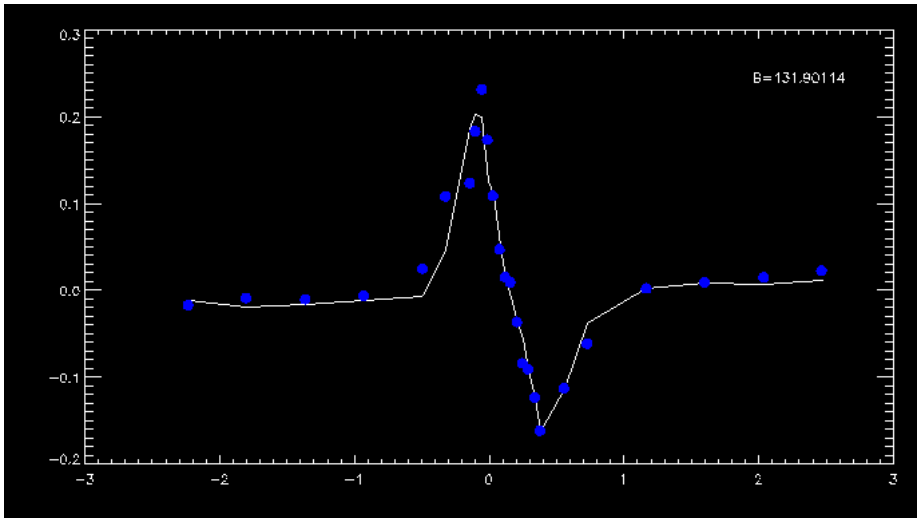


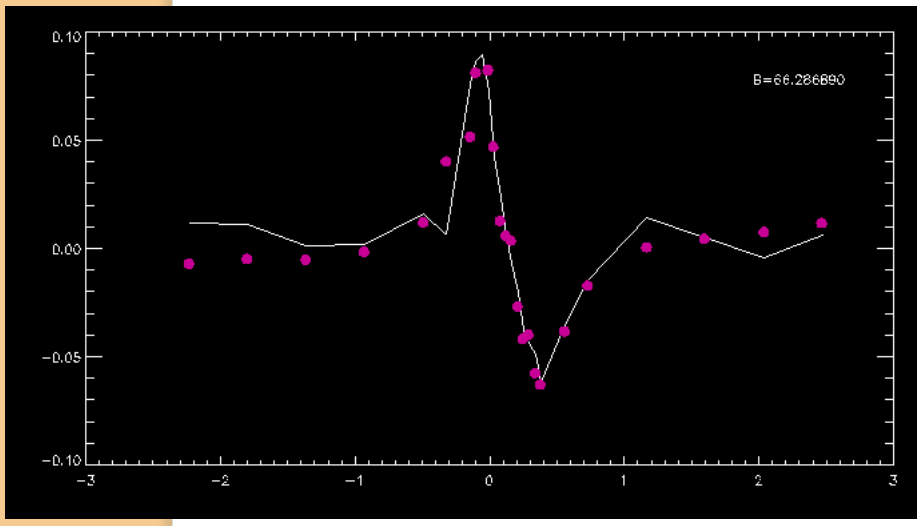
Stokes profiles for region “Flare4”

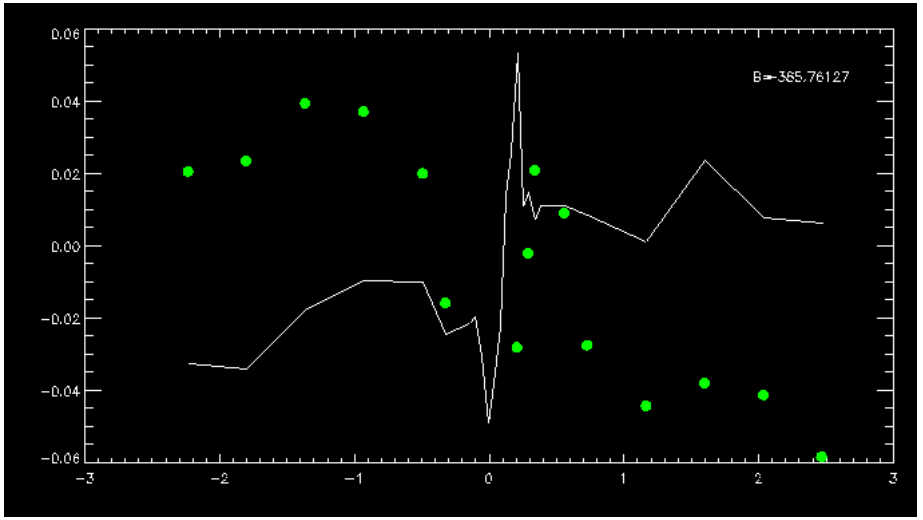


Preliminary results obtained from the Weak Field Approximation

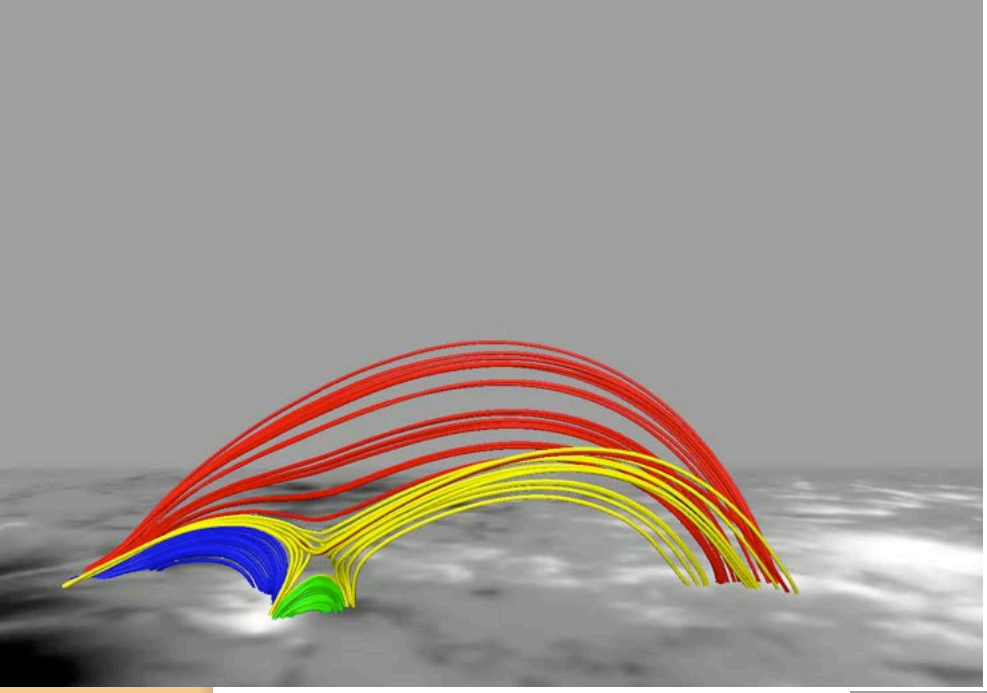








The plots show V/I (line), and the WFA fit (dots). The resulting magnetic field is provided at top right.

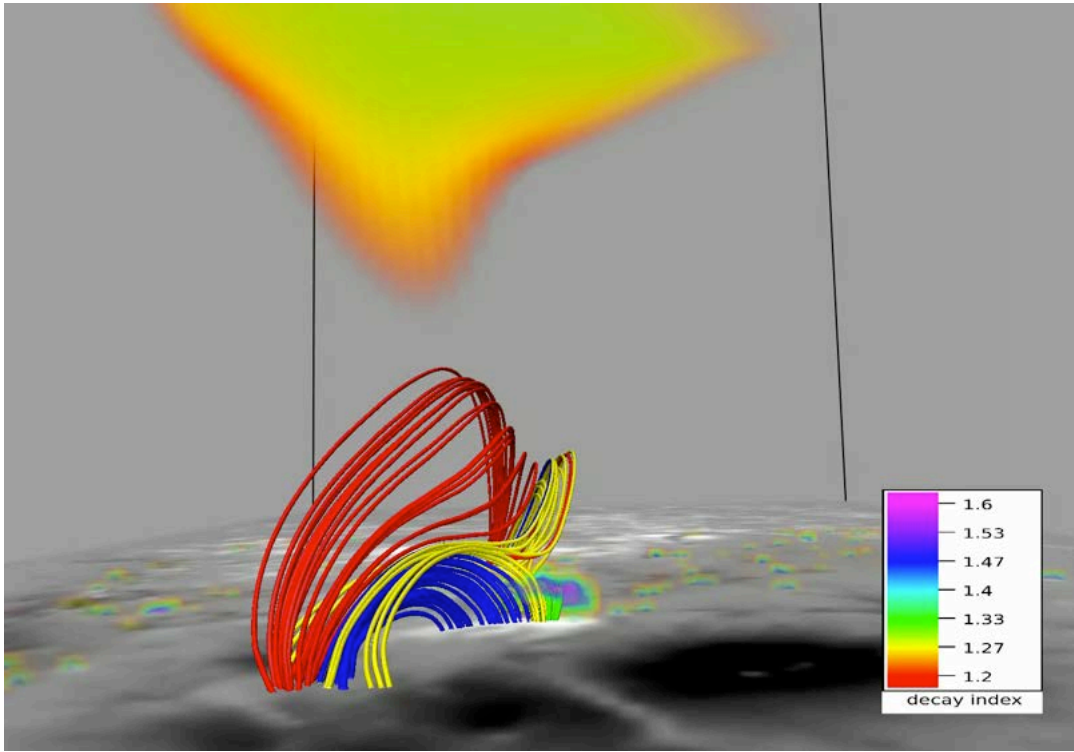


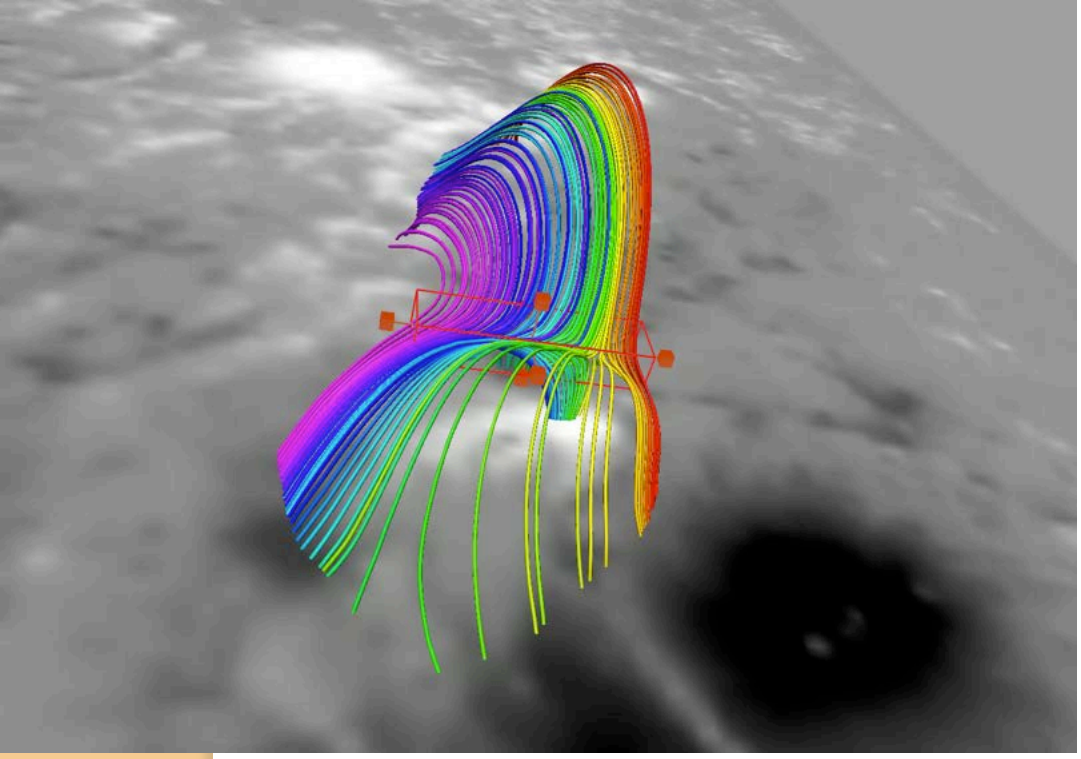
Results from a MHD simulation of Magnetic Null-point Reconnection

Simulations show the presence of a null point in the region hosting the East flare ribbon (i.e., the region observed by IBIS)

From: A Magnetohydrodynamic Simulation of Magnetic Null-point Reconnections in NOAA AR 12192, Initiated with an Extrapolated Non-force-free Field

A. Prasad et al. 2018 ApJ 860 96
doi:10.3847/1538-4357/aac265





The results of these simulations show that the region observed by IBIS is rich of on-going important phenomena:

- presence of a null point located in the chromosphere
- magnetic reconnection changing the magnetic connectivity of the field lines
- no real opening of the magnetic field lines

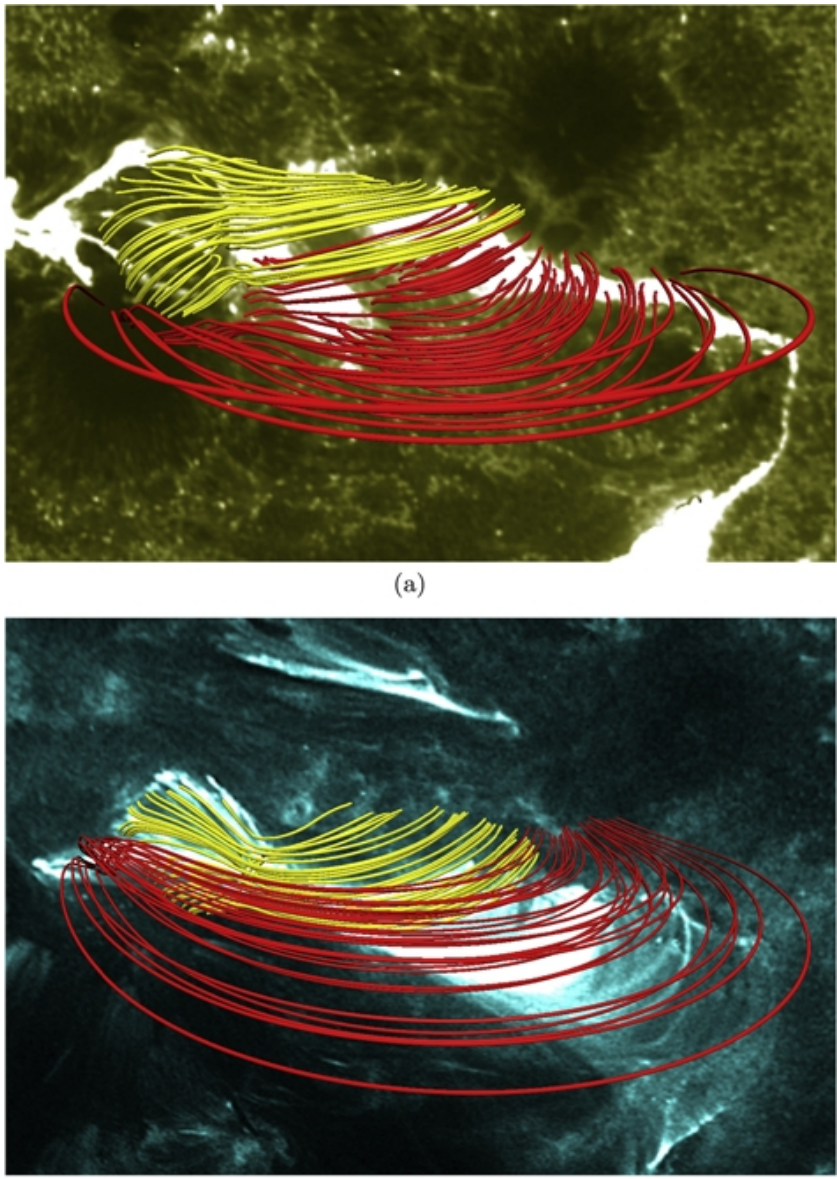
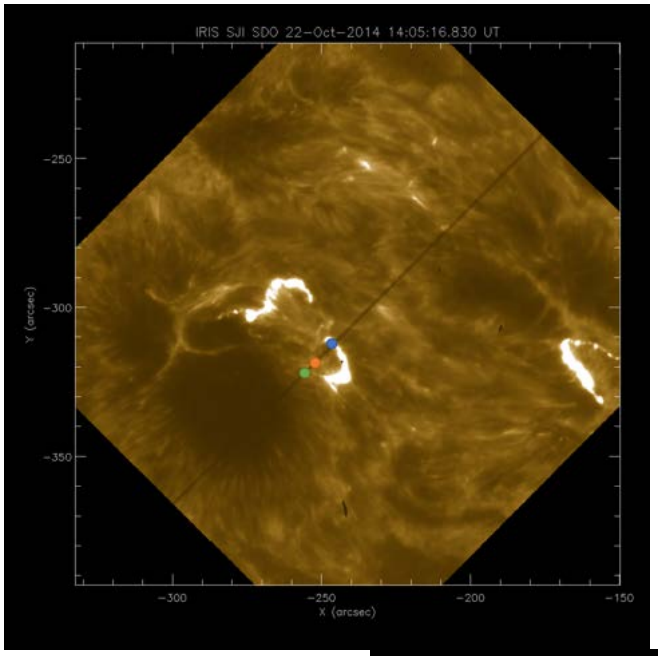
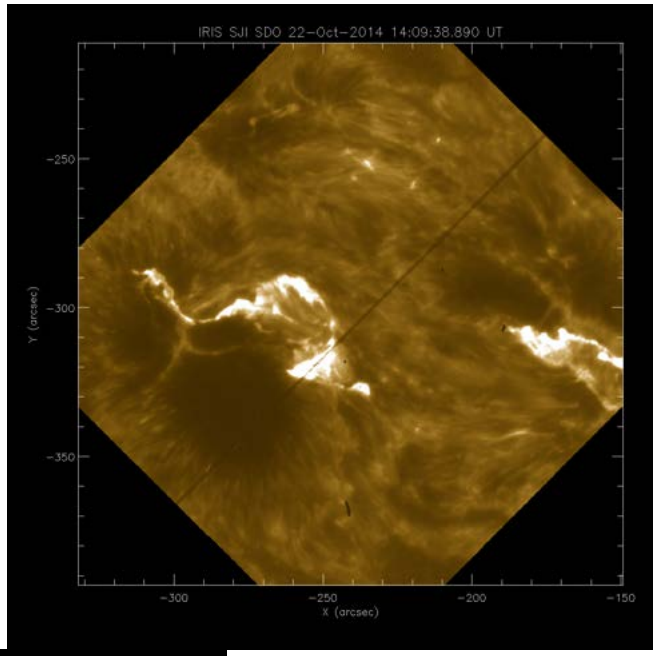
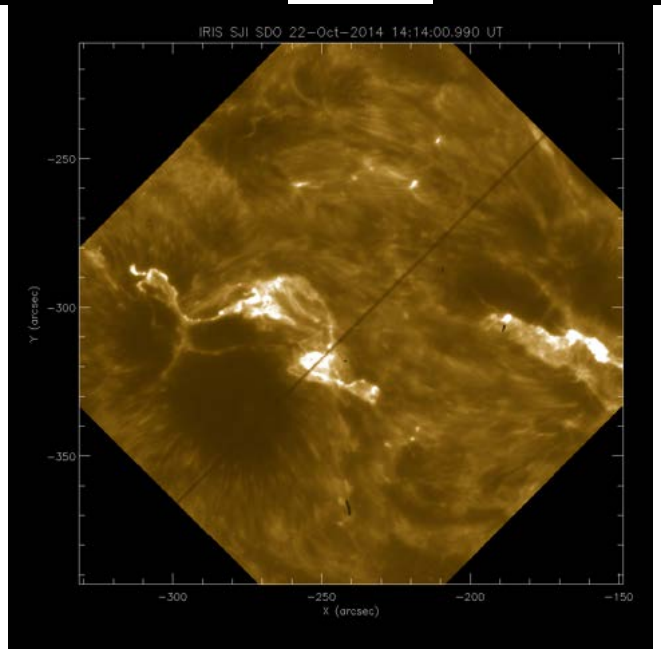


Figure 14 from **A. Prasad et al. 2018 ApJ 860 96 doi:10.3847/1538-4357/aac265**

IRIS observations

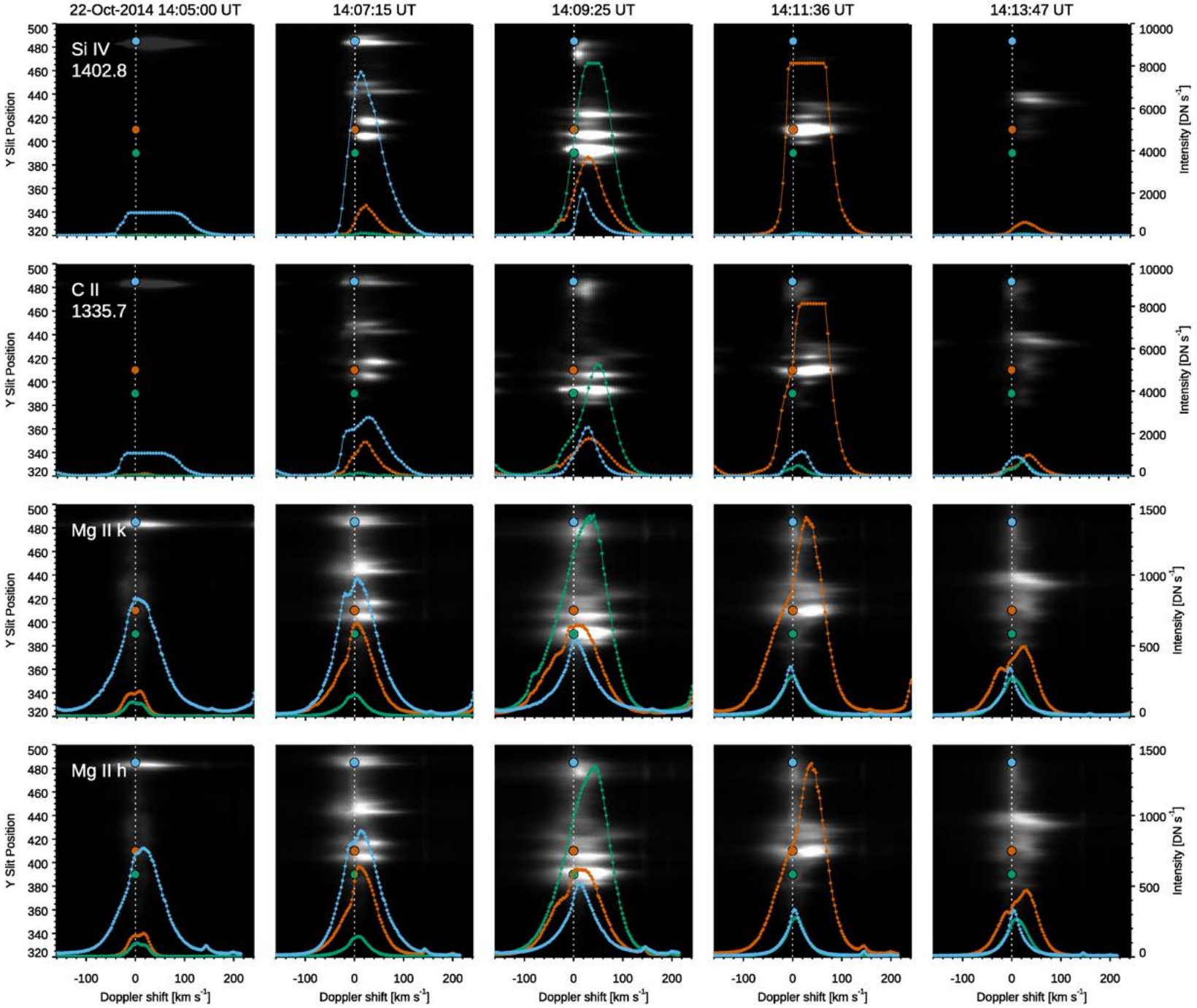


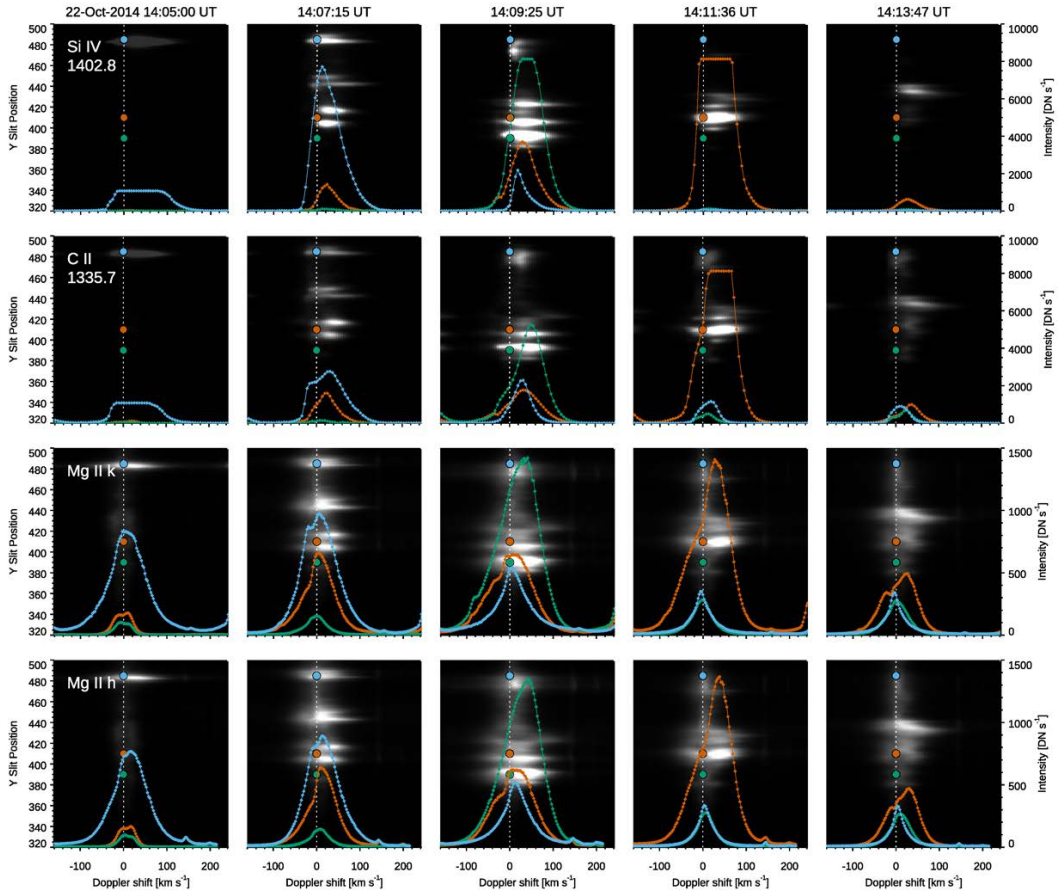




The colored circles indicate the regions where the spectral analysis has been performed

Cadence: 135 s,
Spatial resolution: 0.33”


22-Oct-2014 14:05:00 UT
14:07:15 UT
14:09:25 UT
14:11:36 UT
14:13:47 UT
Si IV
1402.8
C II
1335.7
Mg II k
Mg II h
Y Slit Position
Intensity [DN s-1]
Doppler shift [km s-1]



The spectral analysis shows that during the flare evolution there are mainly **plasma downflows** (the line profiles are red-shifted), but in few cases also **upflows** take place.

In many cases these motions are indicative of **chromospheric evaporation** and chromospheric condensations, which can be considered signatures of magnetic reconnection taking place.

Conclusions

- Clear Stokes V signals along the eastern flare ribbon have been detected using IBIS dataset in the Ca II line.
- The Stokes profiles indicate that also at chromospheric level the region is characterized by regions with positive magnetic intrusions inside the mainly negative magnetic field.
- The "mixed" polarity region seems to be cospatial with the region hosting the null point singled out by numerical simulations.
- A preliminary estimate of B_{LOS} has been determined using the WFA: these estimates are comparable with previous studies.
- The IRIS spectra show the presence of plasma motions which can be interpreted as signatures of chromospheric evaporation and condensation.
- IBIS and IRIS dataset analysis, as well as numerical simulations indicate that, in this event, conditions for CME occurrence do not hold.

Thanks for your attention

Acknowledgements

This research work has received funding from the European Commission's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreements no. 606862 (F-Chroma) no. 312495 (SOLARNET) and from the European Union's Horizon 2020 research and innovation program under the grant agreements No. 739500 (PRE-EST project) and no. 824135 (SOLARNET project). This research is also supported by the Italian MIUR-PRIN grant 2017 APKP7T, by the Università degli Studi di Catania (Piano per la Ricerca Universita` di Catania 2016-2018 —Linea di intervento 1 "Chance"'; Linea di intervento 2 "Dotazione ordinaria" and by Space Weather Italian Community (SWICO) Research Program.