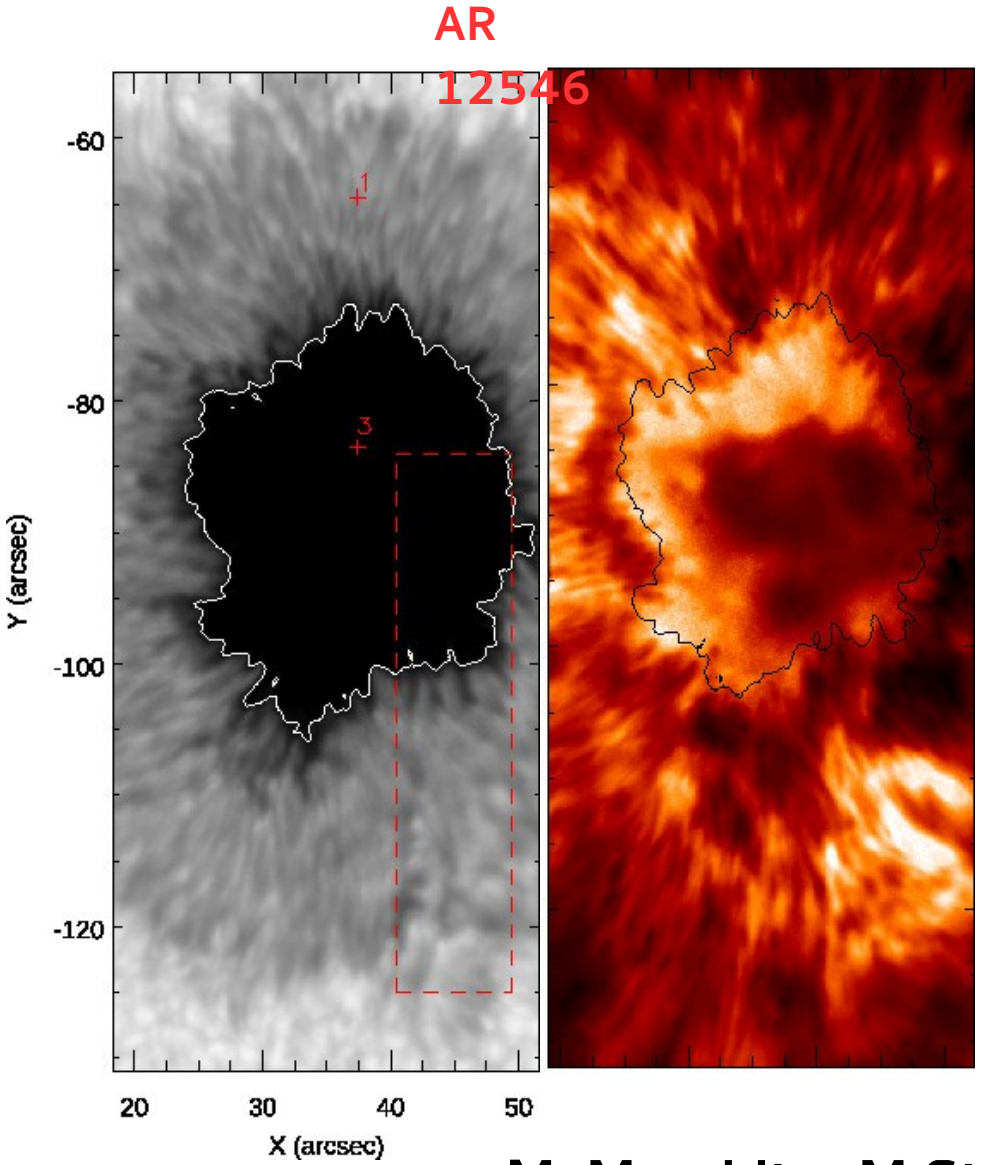
3D structure, waves, and brightening in a large and mature spot



- 3D sunspot structure
- Penumbral changes and correlated brightenings
- Penumbral waves

M. Murabito, M.Stangalini, F. Giorgi, I.Ermolli
INAF OAR–Rome Observatory

Data sets

IBIS

From 13:53 UT to 18:17 UT, 20 May 2016
Full Stokes measurements at Fe I 617.3 & Ca II 854.2 nm
318 scans, 21 λ, 48 s cadence
Pixel scale 0.09"

IRIS/SJI

From 13:17 UT to 16:25 UT
Filtergrams in the 1400 Å and 2832 Å lines 20 s and 96 s cadence
Pixel scale 0.33"

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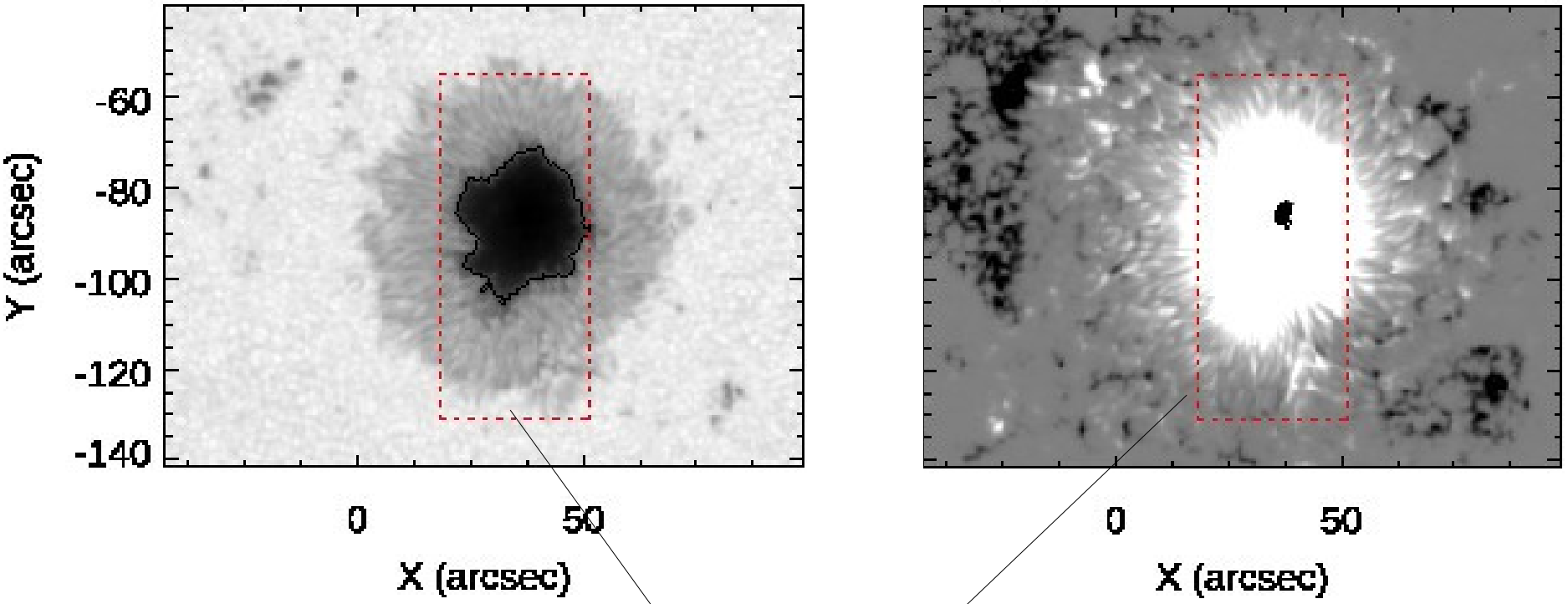
SDO/HMI SHARPs and AIA

From 10:00 UT to 22:00 UT
Continuum filtergrams, magnetograms and Dopplergrams in the Fe I 617.3 nm line
720 s cadence, pixel scale 0.50"
-The components Br, B$_{\perp}$, B$_{\parallel}$ of the vector magnetic field B in the same interval and the same cadence and resolution
-1600, 304, 171, 131, 335 Å AIA channels
24 and 12 s cadence, pixel scale 0.6"

General overview



IBIS FOV

Method of analysis

IBIS data

- NICOLE inversion multi-line (Socas Navarro et al. 2015)
  - Input model: FALC modifying the values for Bz with1.5 kG
  - Nodes: T=5
    V=3
    Bx,By,Bz=3
    Macro & Micro=1
  - Cycles: 2
  - Iterations: 20

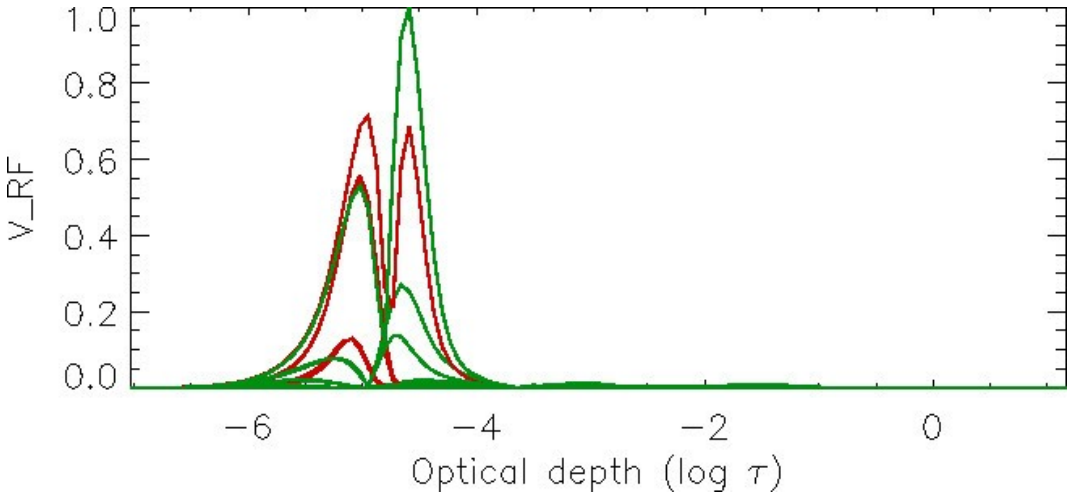
SDO & IRIS data

- Ssw procedure
- FFT filter at 5 mHz

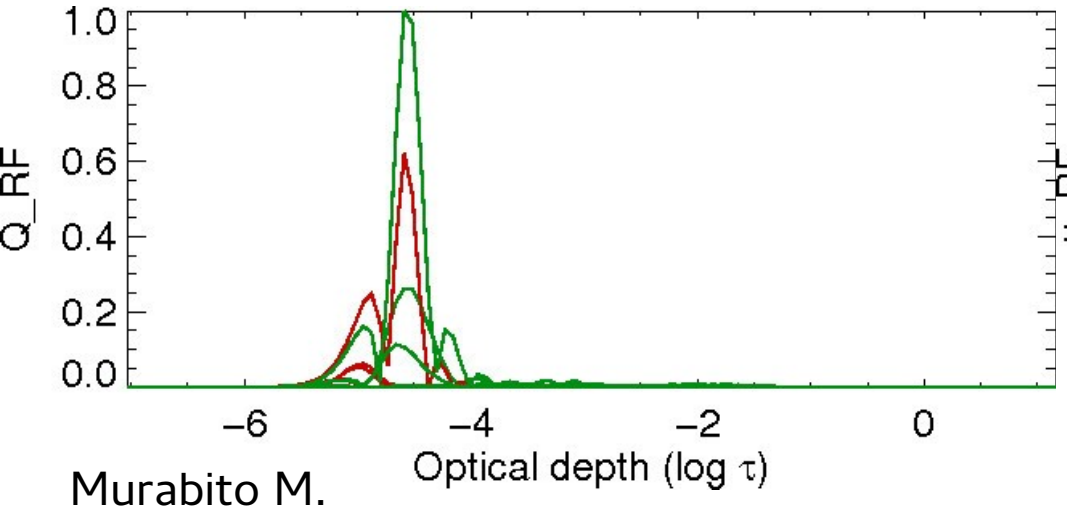
- Velocity deduced from the Doppler shift of the centroid of the line profile and calibrated using the convective blushift in a quiet sun region of about 95 km/s (for 617.3 nm at μ=0.99)
- Linear polarization : $L_s = 1/14\, I_c \sum_{1}^{14} \sqrt{Q^2+U^2}$
- Circular polarization : $V_s = 1/14\, I_c \sum_{1}^{14} \epsilon_i V_i$

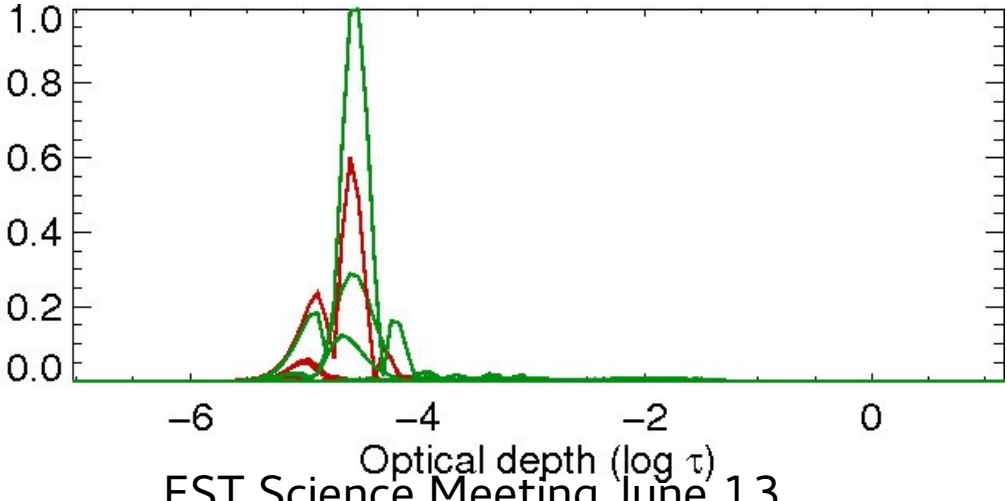
Response Functions

$RF^{S}_{B_i}$ of the Stokes profiles S to pertubations in the magnetic field components B_i



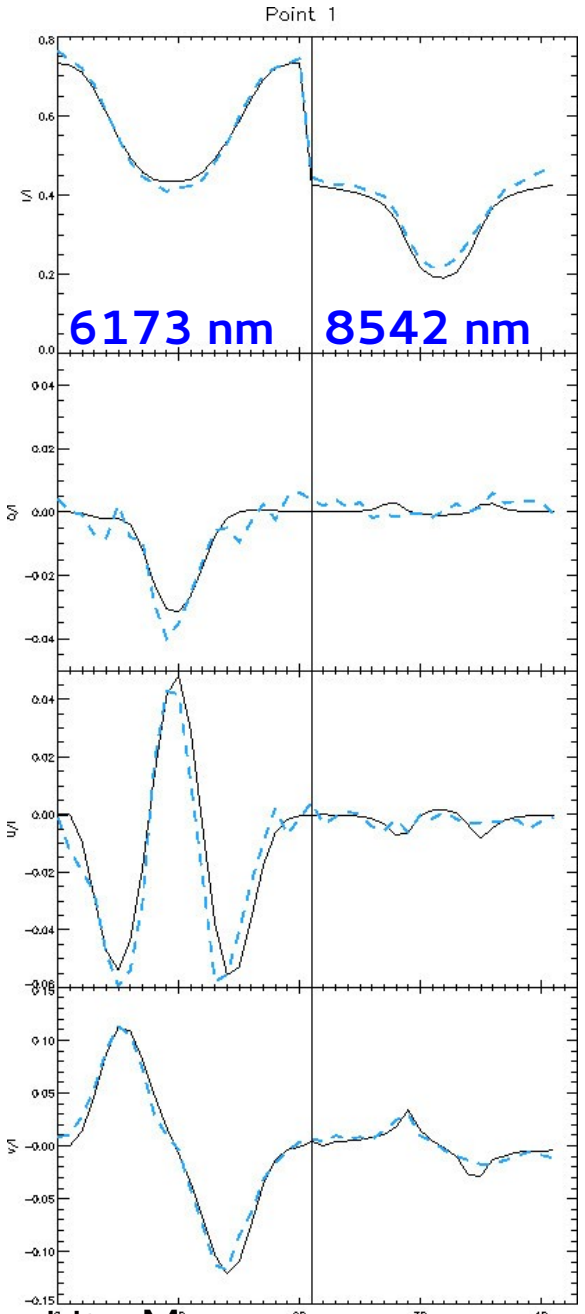
Results in agreement with Quintero Noda et al. (2016)



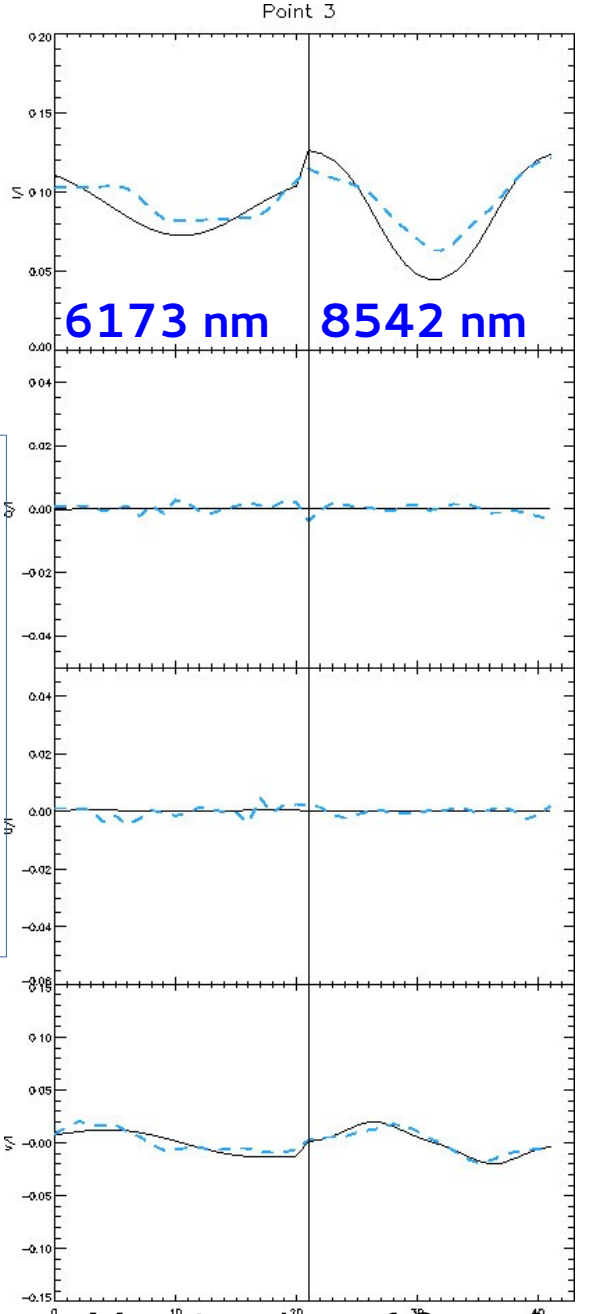


Observed and inverted IBIS profiles

Penumbra



Umbra



$h_{6173} \sim 250 - 350\ km$

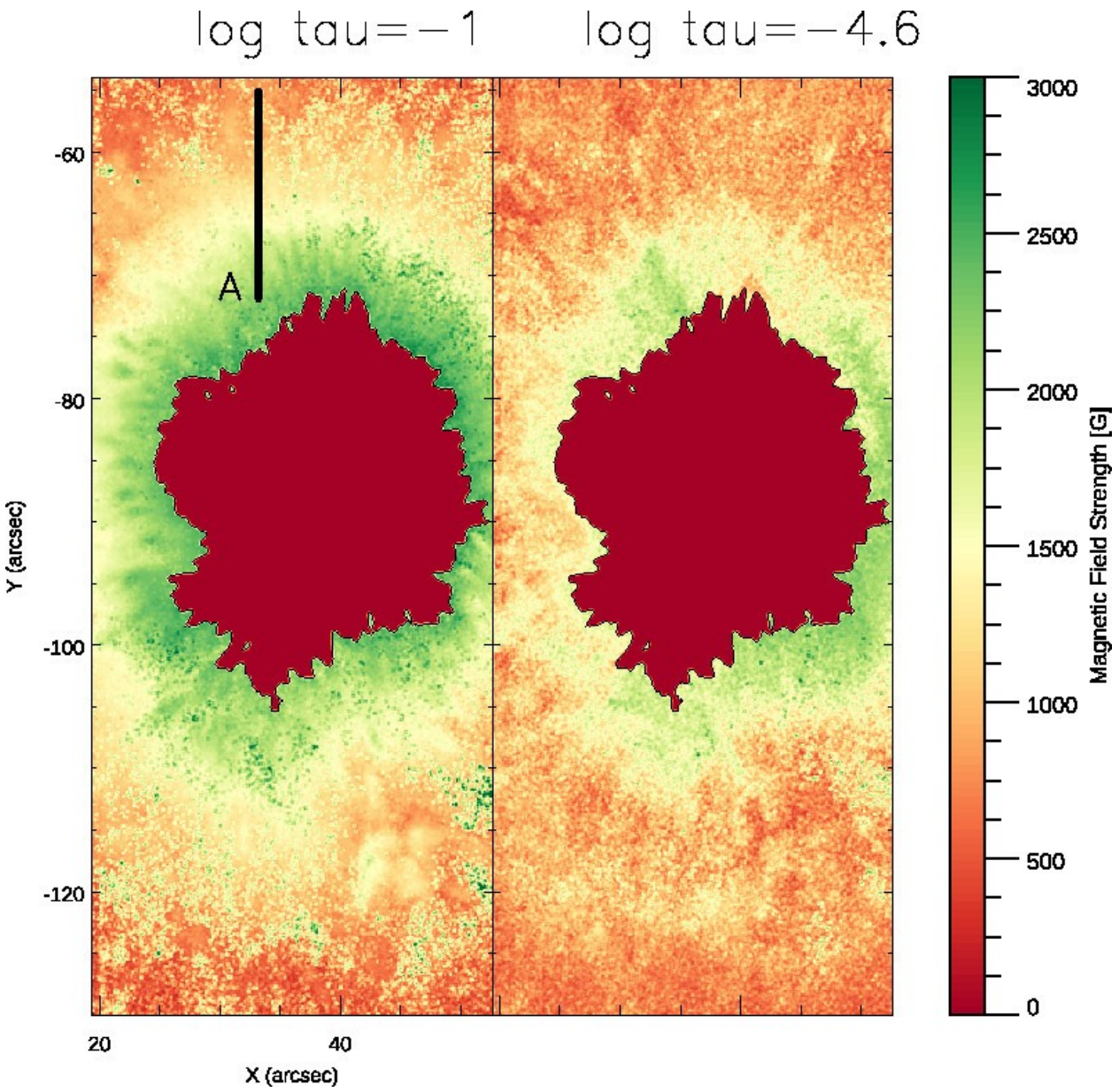
Norton et al. (2006)

$h_{8542} \sim 800 - 1000\ km$

Uitenbroek (2006)

$\Delta h \sim 550 - 650\ km$

3D structure



In the penumbra:

$\overline{B}_{photo} \sim 1.6\,kG \pm 0.4\,kG$

$\overline{B}_{chromo} \sim 1.23\,kG \pm 0.45\,kG$

$\Delta B \sim 360\,G$

$Rate \sim 0.5 - 0.7\,G/km$

It decreases of about 1.3 G

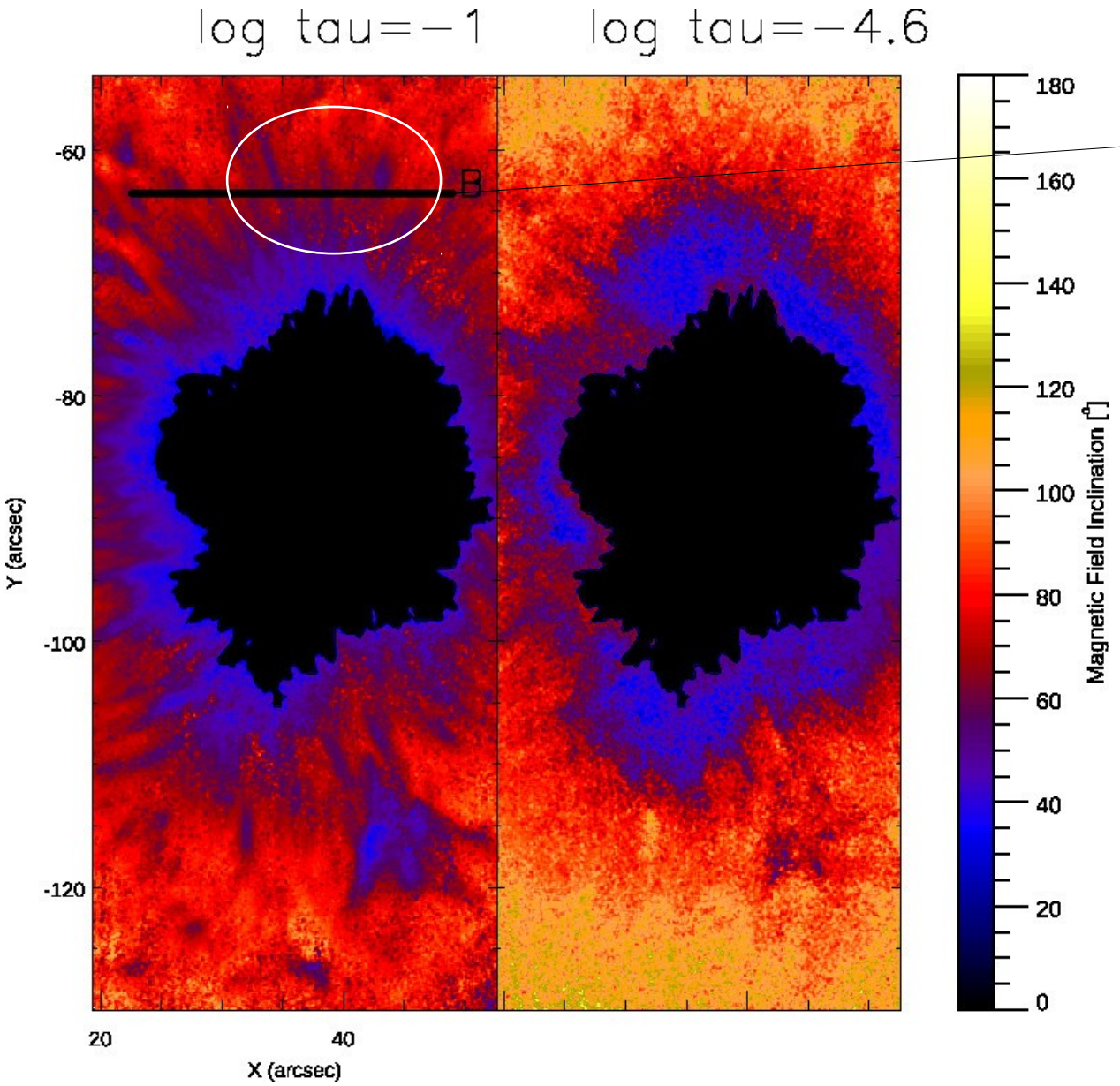
$Rate_J \sim 0 - 0.7\,G/km$

Joshi et al. (2017)

$Rate_R \sim 0.1 - 0.3\,G/km$

Rüedi et al. (1995)

3D structure



Spine and interspine structure

In the penumbra:

$\bar{\varphi}_{photo} \sim 62° \pm 9°$

$\bar{\varphi}_{chromo} \sim 69° \pm 15°$

$\Delta\varphi \sim 7°$

Outside the penumbra:

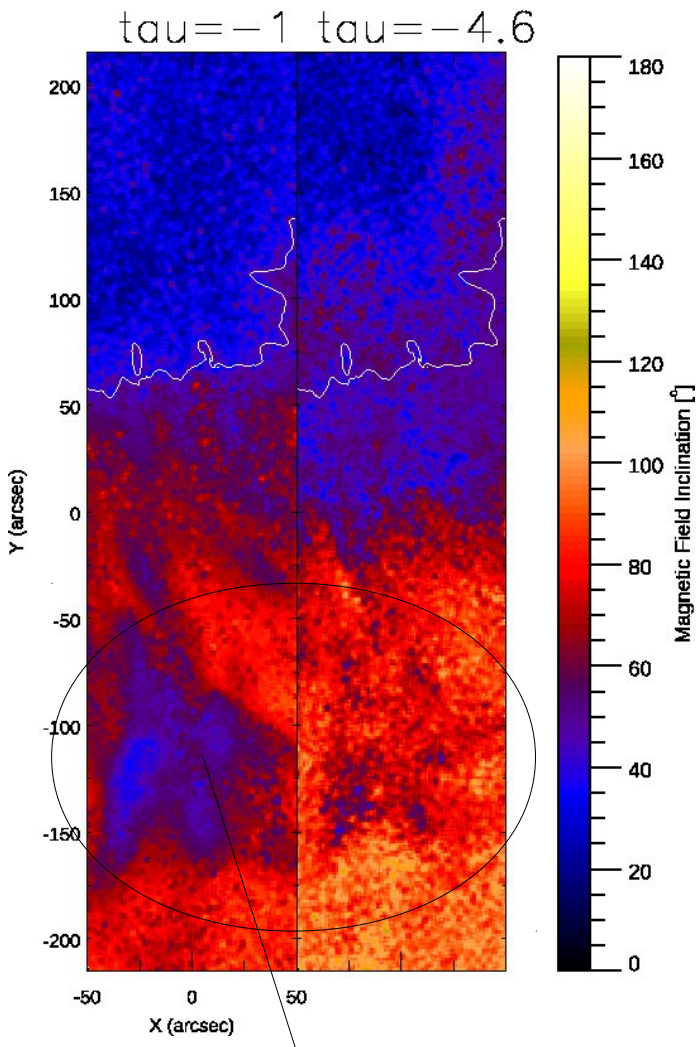
$\bar{\varphi}_{photo} \sim 78° \pm 9°$

$\bar{\varphi}_{chromo} \sim 105° \pm 15$

$\Delta\varphi \sim 27°$

Penumbral changes

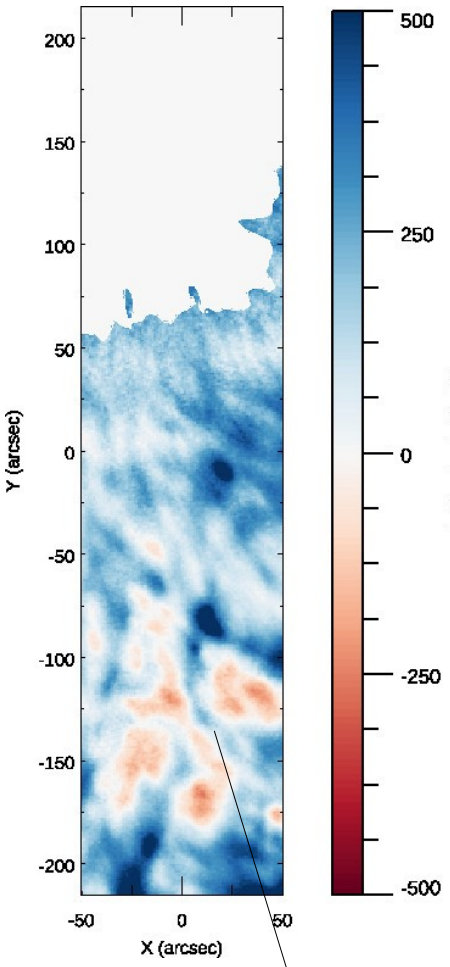
Inclination



$$\bar{\varphi}_{photo} \sim 35-50\,^{\circ}$$

$$\bar{\varphi}_{chromo} \sim 60-80\,^{\circ}$$

LOS velocity

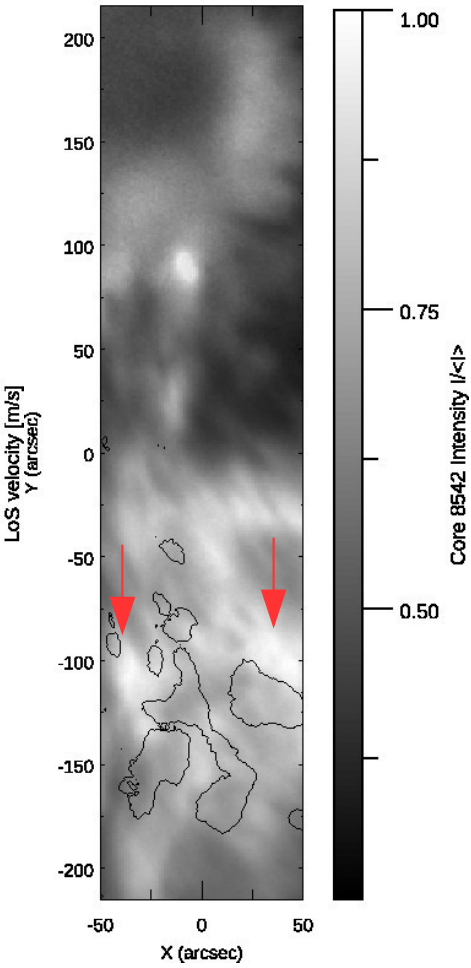


$$v_{mean} \approx -200\,m/s$$

EF:

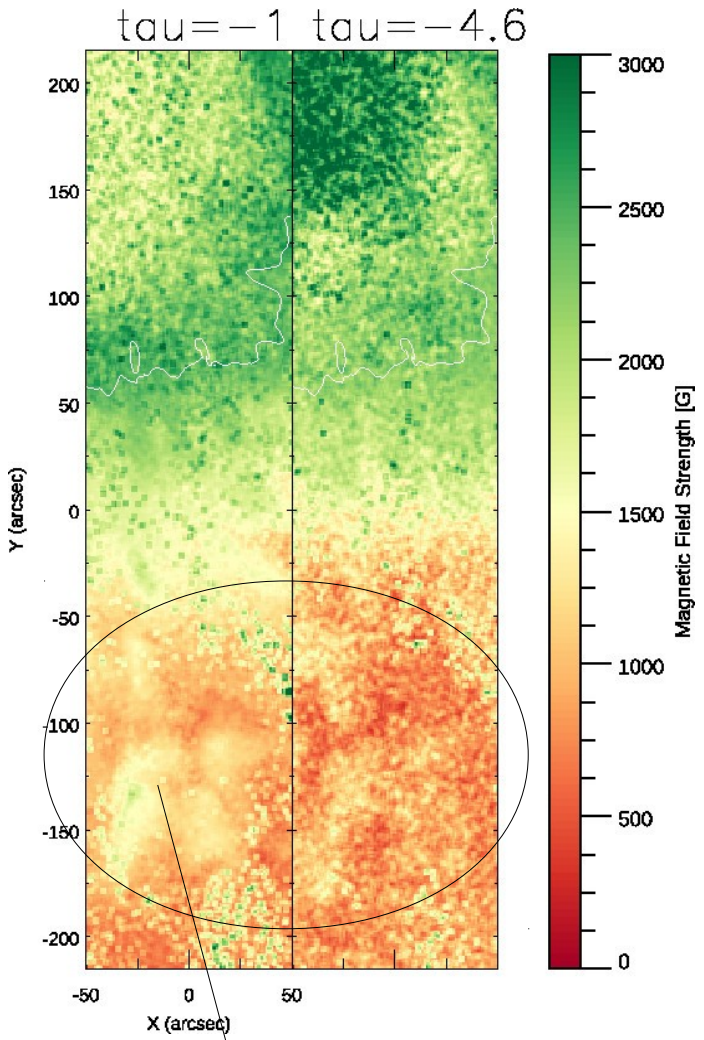
$$v_{mean} > 200\,m/s$$

Core 8542 intensity



Penumbral changes

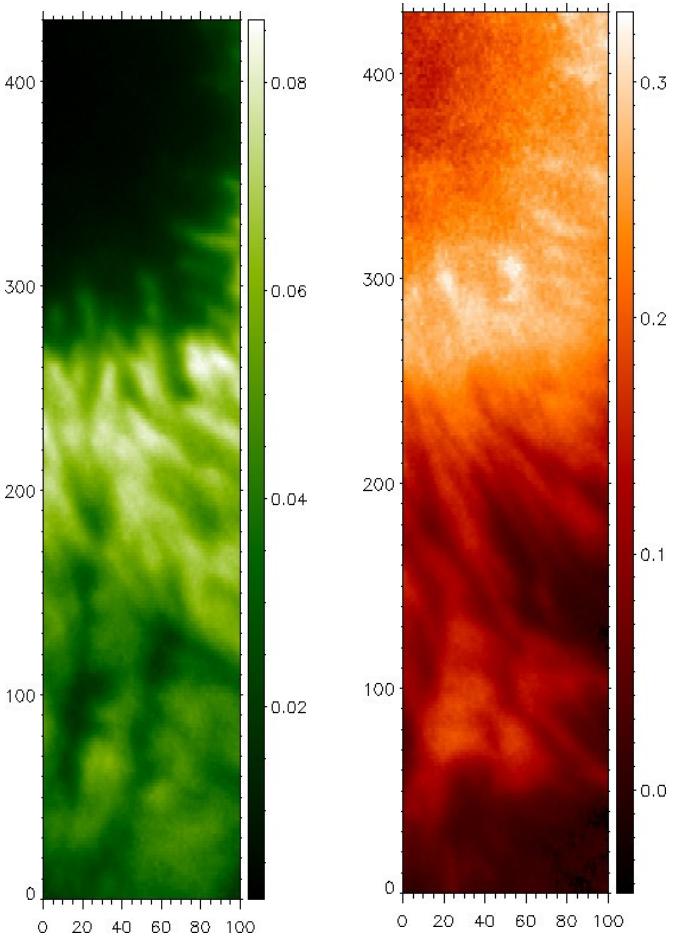
Field Strength



$$\overline{B}_{photo} \sim 1300-1500\,G$$

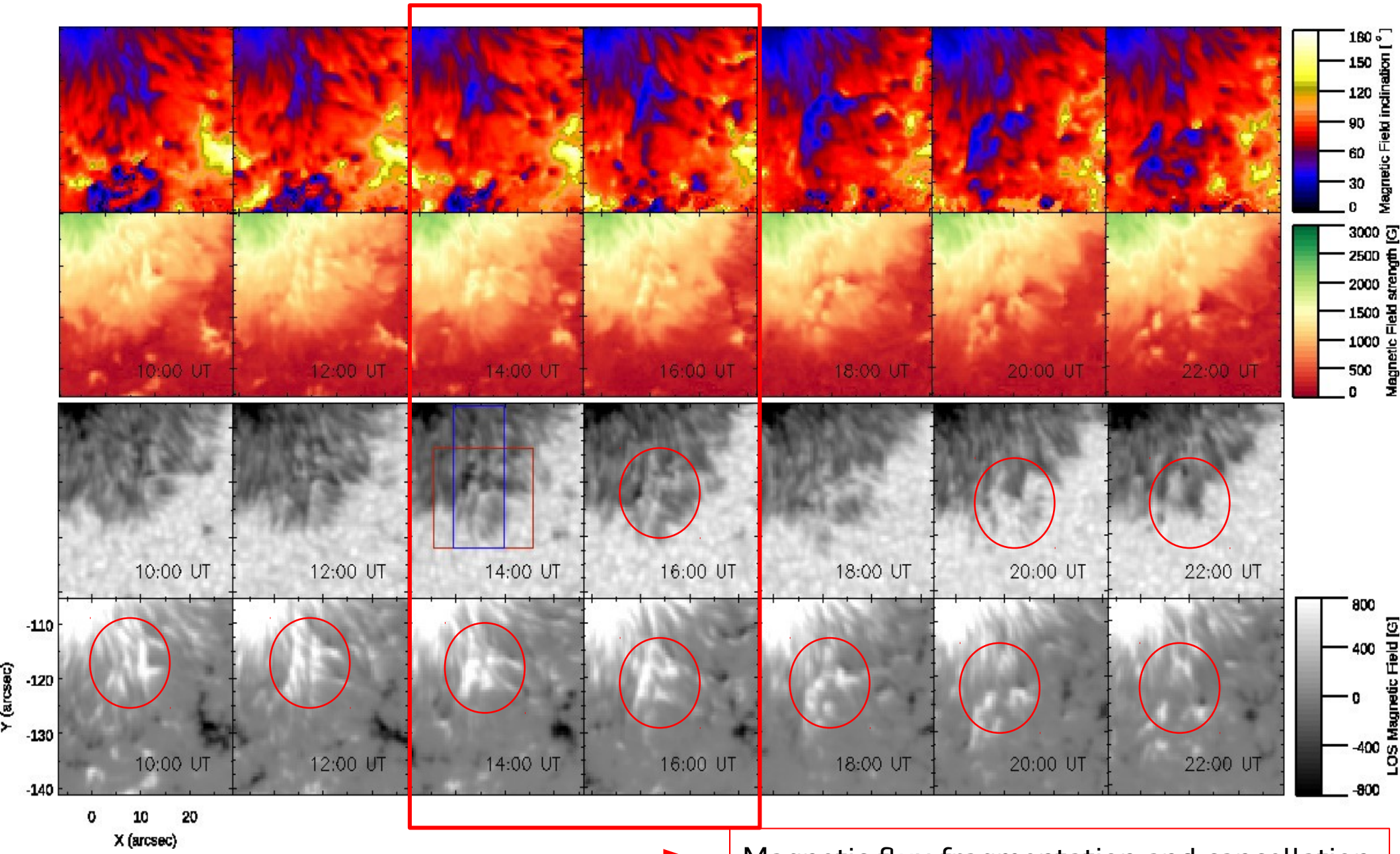
$$\overline{B}_{chromo} \sim 900-1100\,G$$

LP and CP



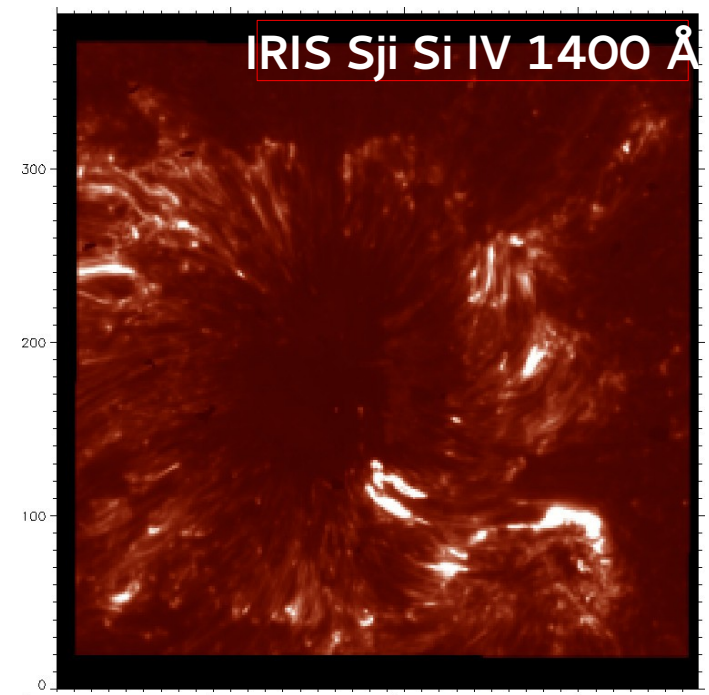
LP~2% with respect to 4-5% outside the new structure

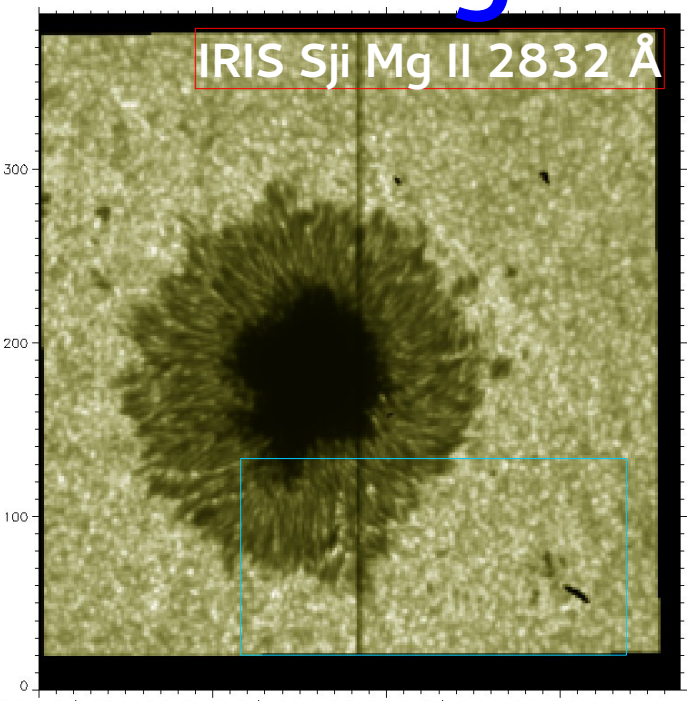
Penumbral changes: SDO/HMI



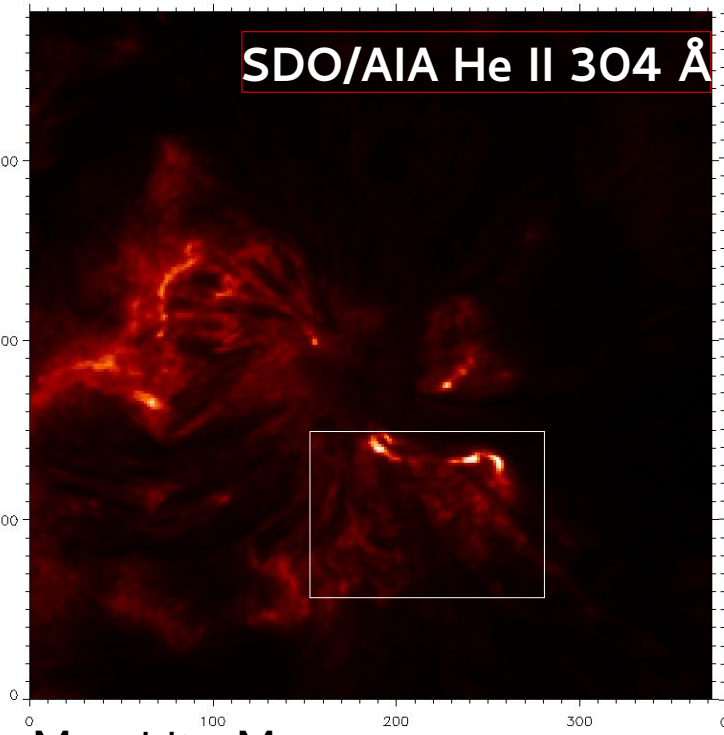
Magnetic flux fragmentation and cancellation

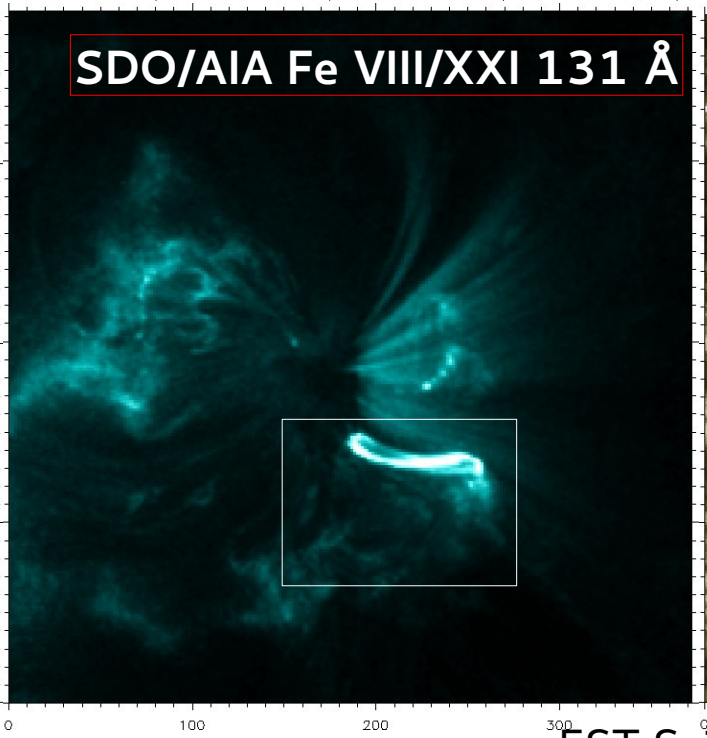
TR and coronal brightenings

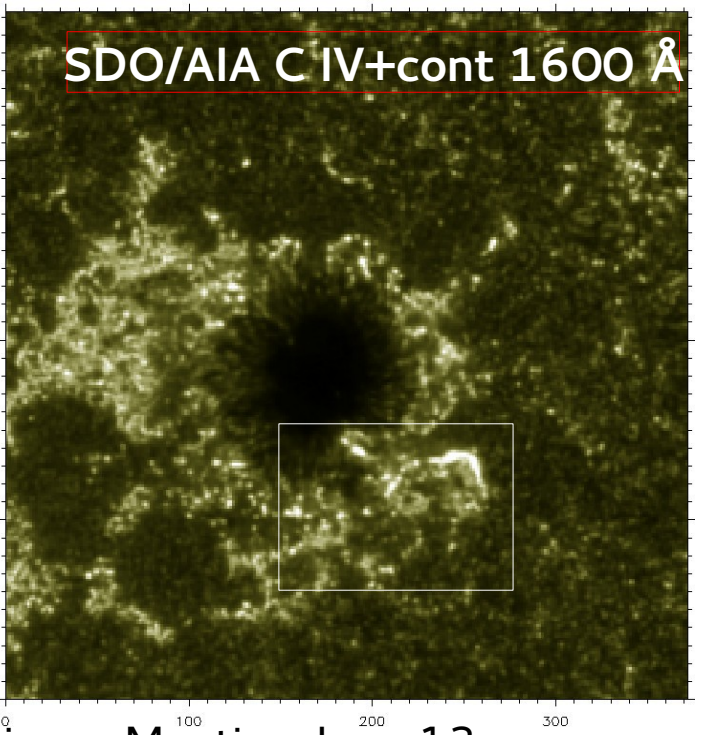




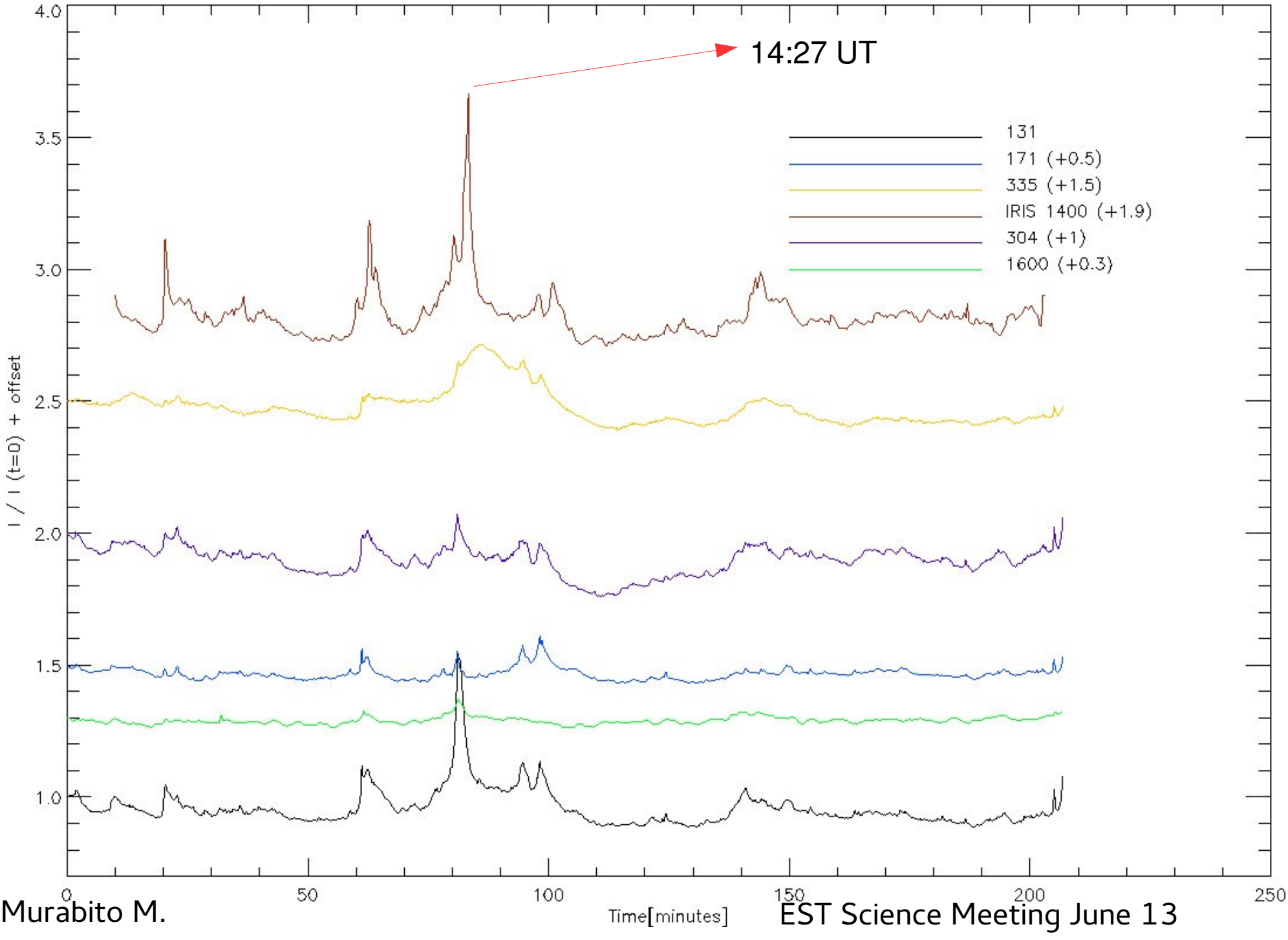
14:27 UT



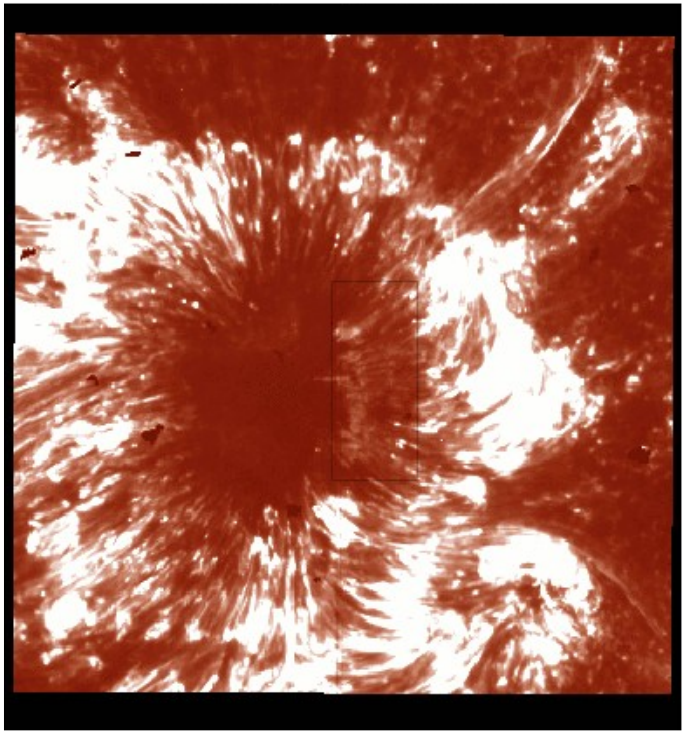




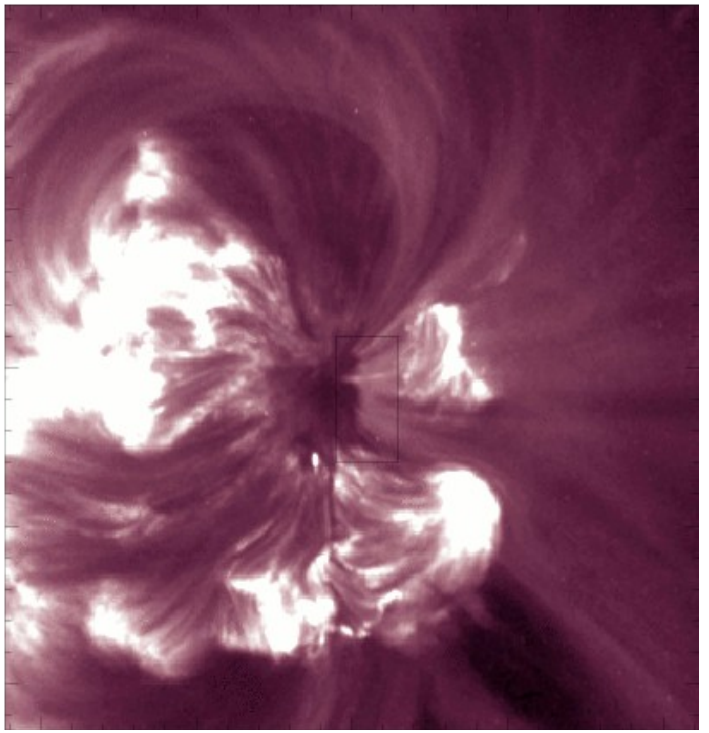
TR and coronal brightenings



Running penumbral waves



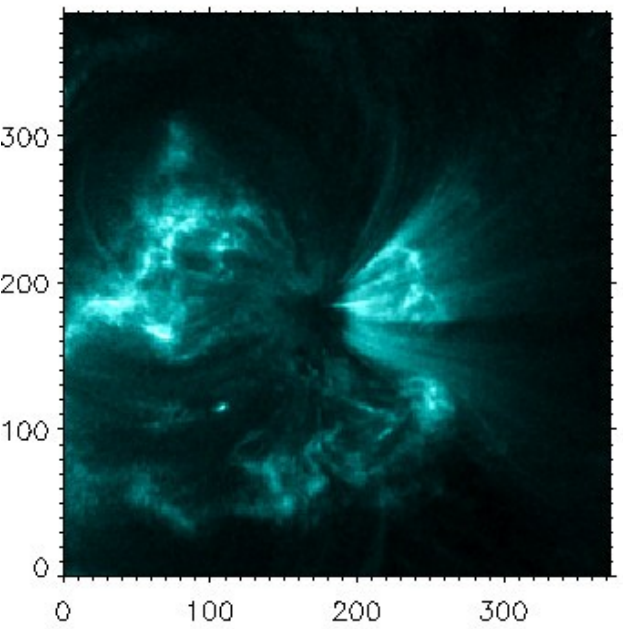
IRIS SJI images 1400 Å

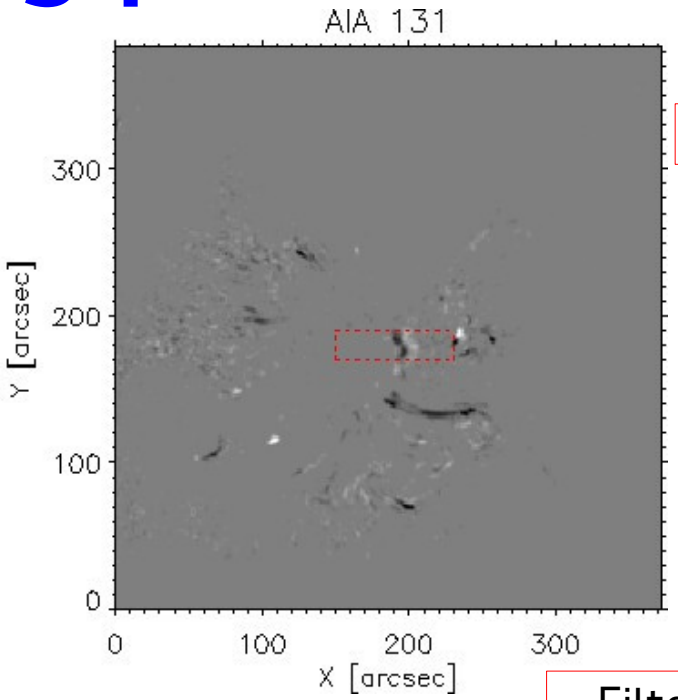


SDO/AIA 211 Å

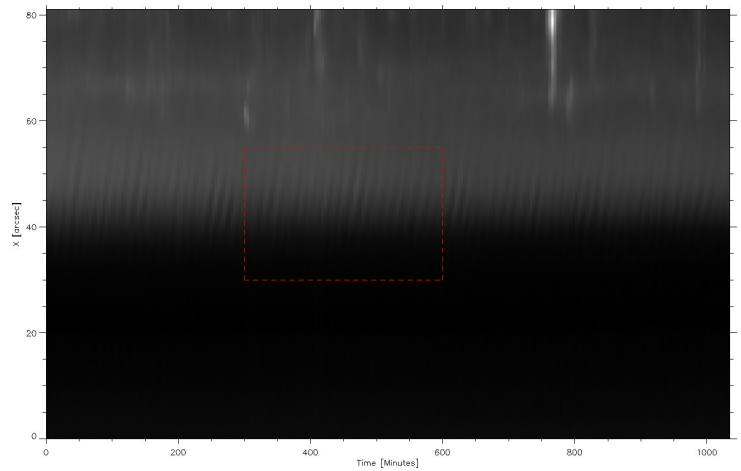
- The EUV AIA channels (131, 171, 335, 193 and 211 Å) from transition region to corona show signatures of RPWs
- IRIS Si IV 1400 Å slit-jaw images show the same signatures
- Velocity ranges from 28-42 km/s

Running penumbral waves

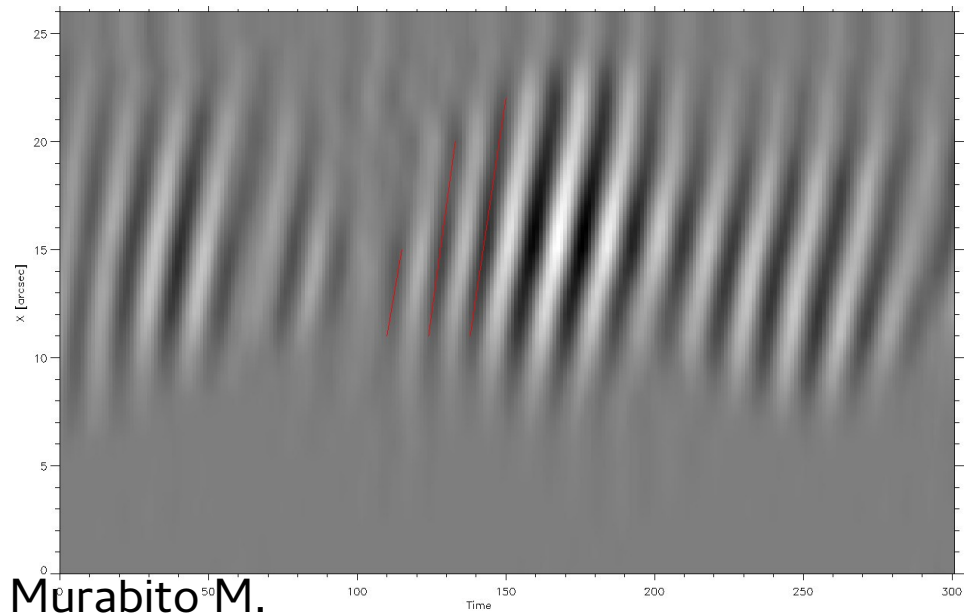


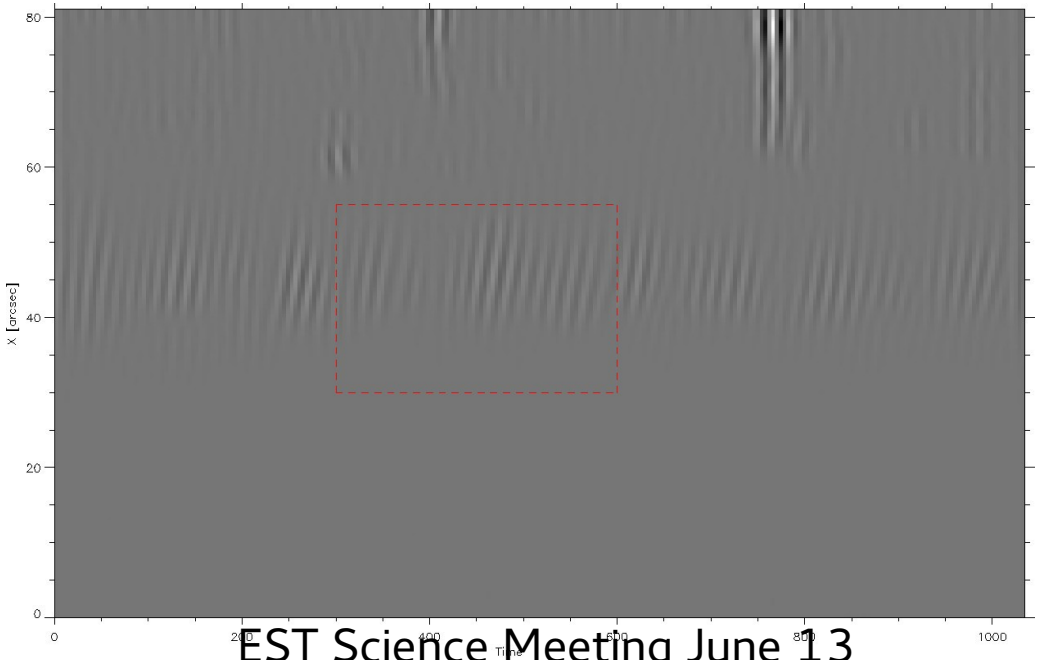


No filtered time-distance diagram



Filtered time-distance diagram





Summary and conclusion

- Nicole inversion gives us the 3D atmospheric structure of the NOAA AR 12546. We show estimates of B strength and its component at $\log\tau$=-1,-4.6.
- Results are in agreement with those reported in Joshi et al. (2017) in the penumbra
- A sector of the penumbra evolves into a new structure likely due to turbulent convection near the penumbral border (Botha et al. 2011).
- This evolution is clearly seen in the continuum intensity, magnetic field strength, inclination and the los velocity in photophere and intense brightenings appear in the 8542 core.
- A B class flare occurs from 14:00 to 15:00 UT. The structure, disappears in the following 6 hours.
- TR and coronal observations show signatures of RPWs near the UP boundary.