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Umbral filaments: a conundrum to be solved by EST?

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Bright structures

in sunspot umbrae

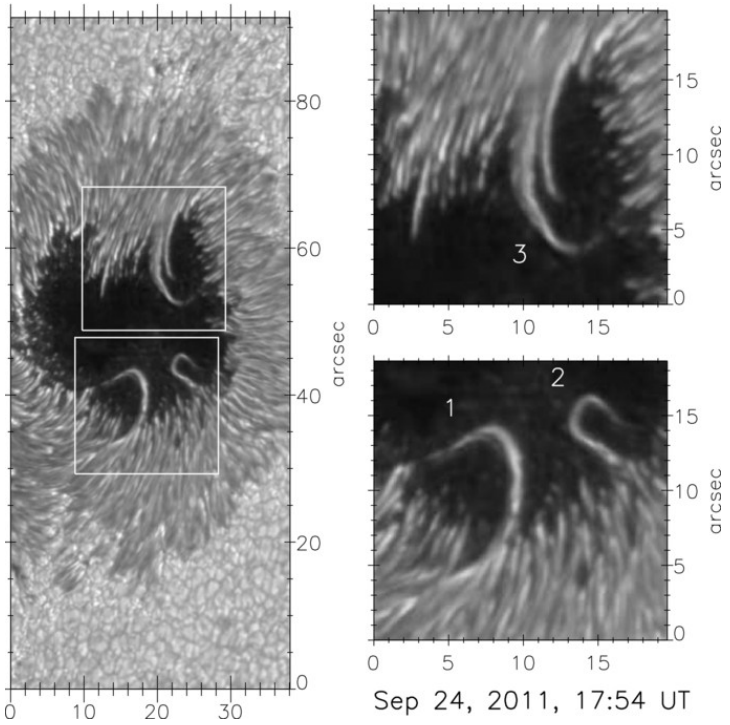
Light bridges (LBs) are bright structures that rapidly intrude sunspots from the leading edge of penumbral filaments into the umbra.

- They are observed during the assembly phase or, more frequently, during the decay phase of sunspots.
- LBs are classified into:
  - **strong** or **faint**, if they split the hosting umbra into separate umbral cores
  - **filamentary** or **granular**, depending on their internal structure
  - **segmented** or **unsegmented**, if their are formed by bright granules, somehow similar to quiet-Sun granulation, or resemble penumbral filaments

Recently, Kleint & Sainz Dalda (2013) observed filamentary structures within a sunspot umbra, formed by curled filaments, calling them **Umbral filaments (UFs)**.

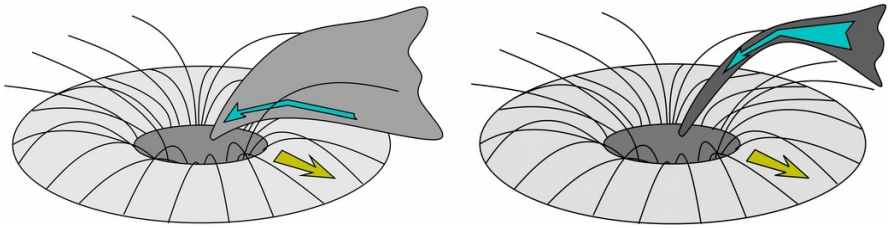
Umbral Filaments (UFs)

UFs differ both in morphology and evolution from usual LBs. They also exhibit inverse Evershed flows.



They are interpreted according to two models:

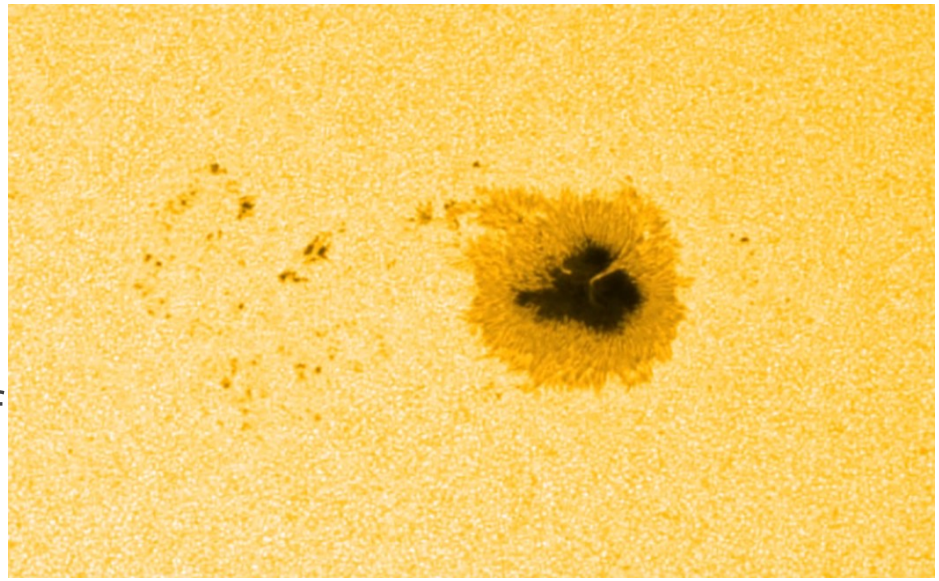
- in the 1st, the UF is formed by a **sheet**, which cuts the solar atmosphere from the photosphere to the corona
- in the 2nd, the UF is a **thick magnetic flux tube**



Active region NOAA 12529

In April 2016, the solar disk was dominated by a single active region. AR NOAA 12529 appeared on the solar disk on April 9 and was observed until April 18.

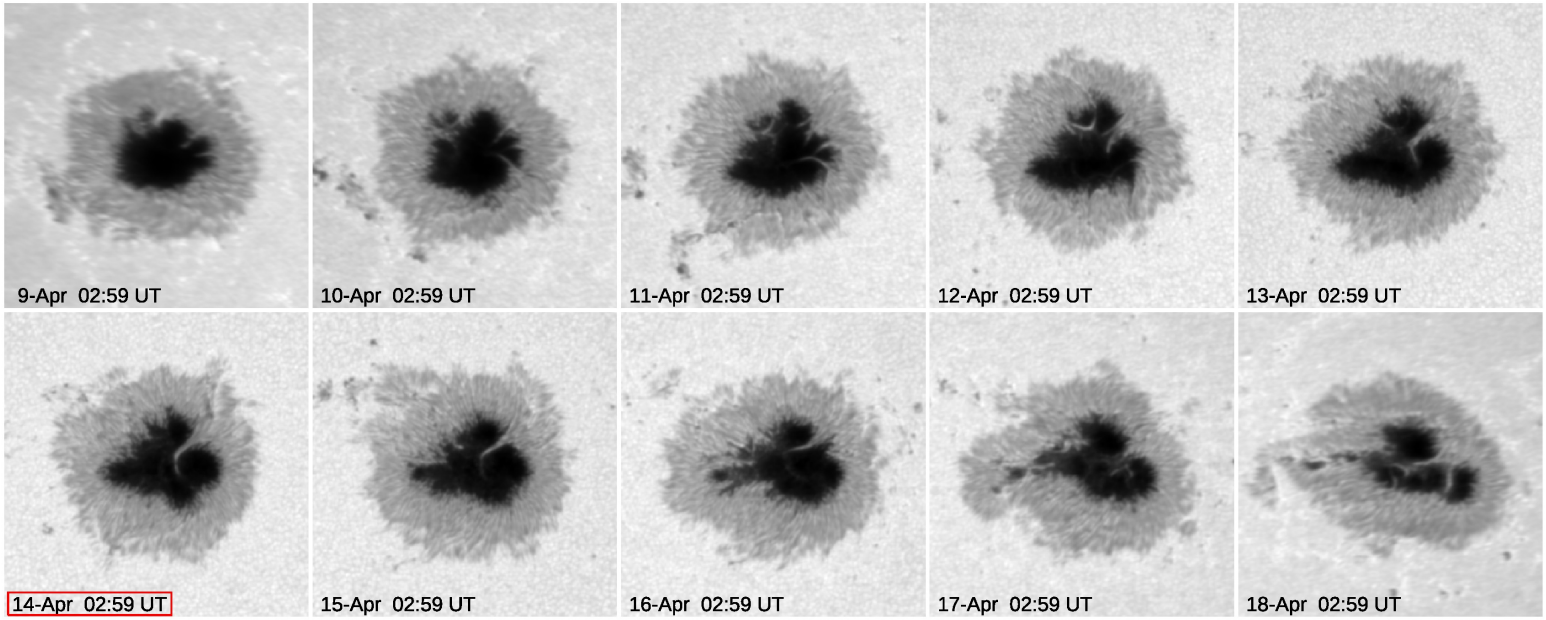
This sunspot group was rather **quiet**, with a few C-class flares, until a M6 flare occurred on April 18, when the AR was already at the West limb.

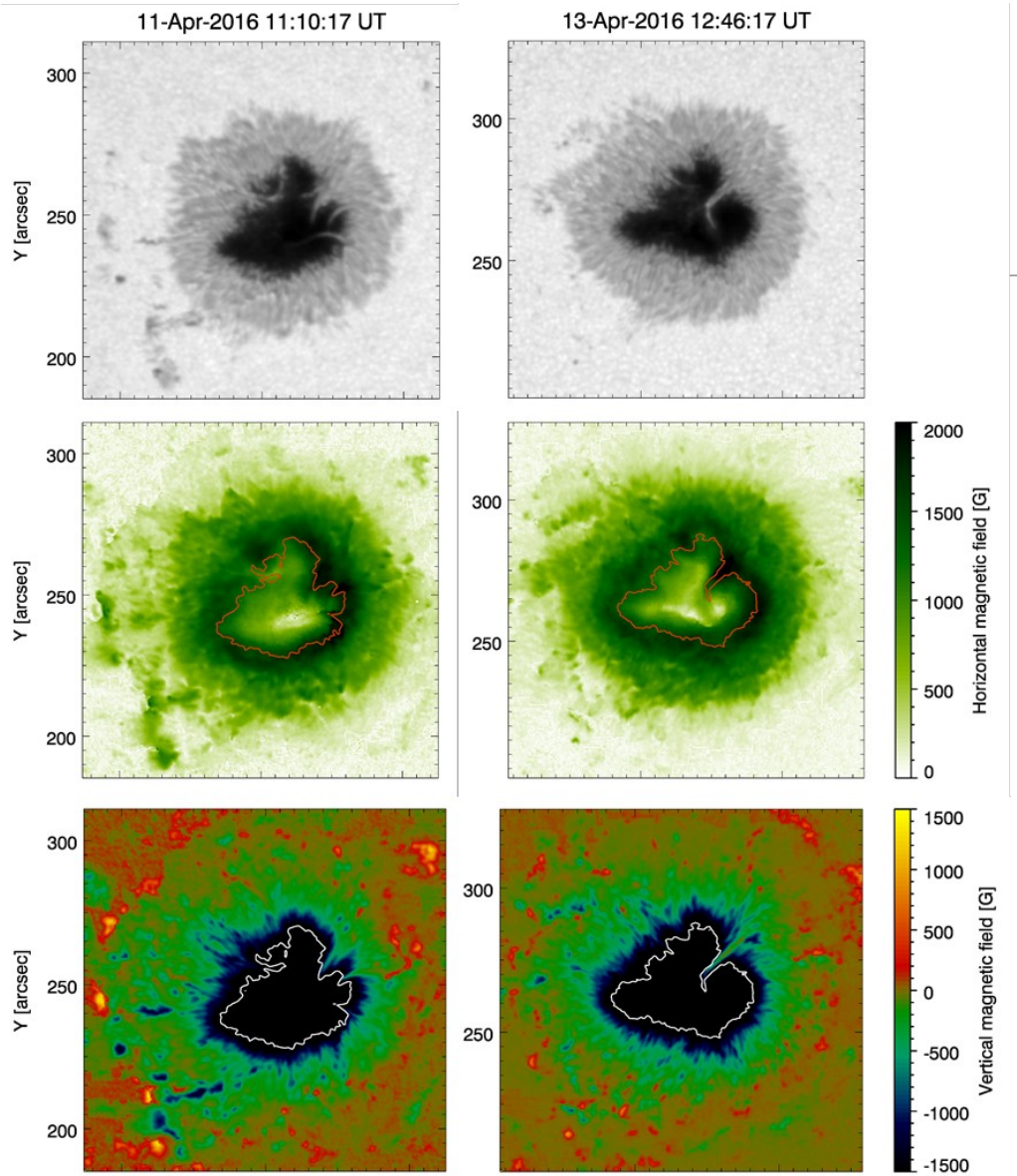


The most prominent sunspot of the AR was the preceding spot,

as large as **5 times the Earth**, looking peculiarly heart-shaped

Evolution of the giant sunspot – SDO/HMI





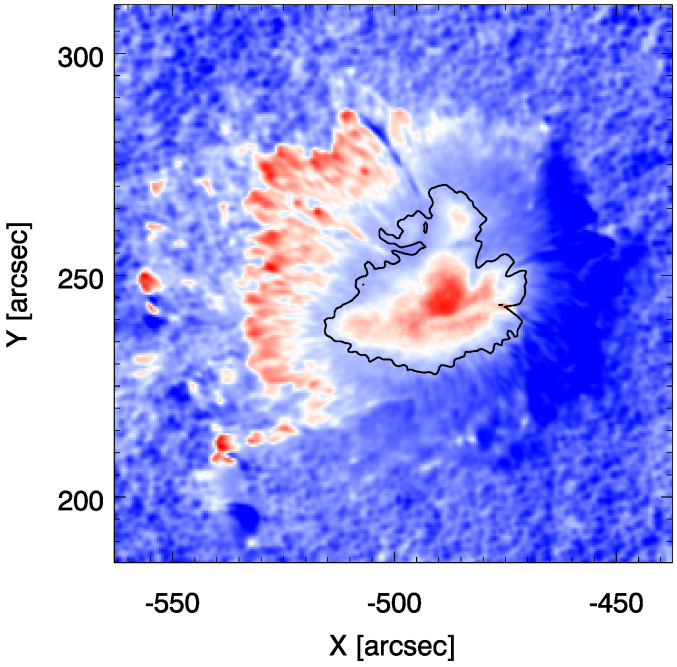
SDO/HMI SHARP data

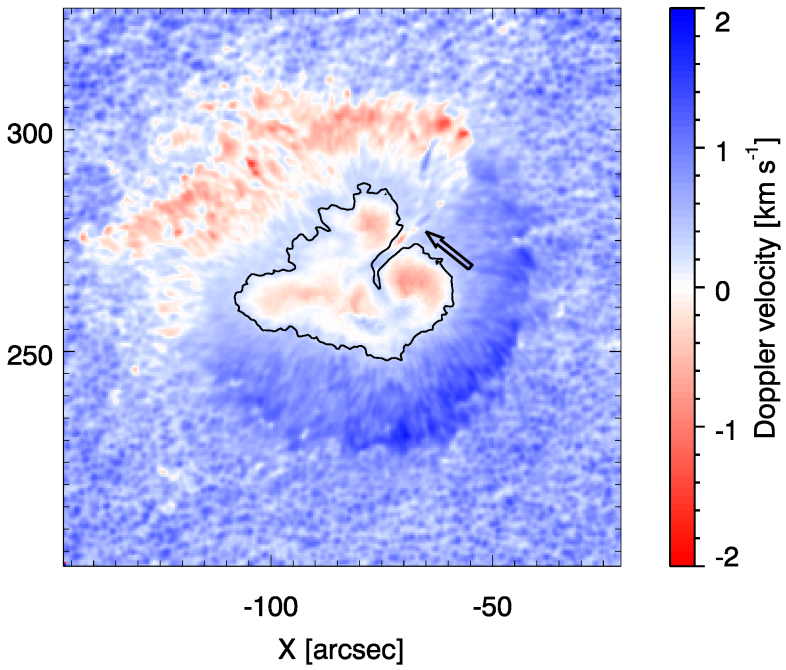
- In the **intruding structure** to the North-West of the sunspot, **no granular pattern** is seen at the HMI resolution.
- We observe the presence of a **strong horizontal field** component of the magnetic field of about **2000 G** cospatial to the feature.
- A small **portion** of the structure has magnetic

Flow pattern in the UF – SDO/HMI

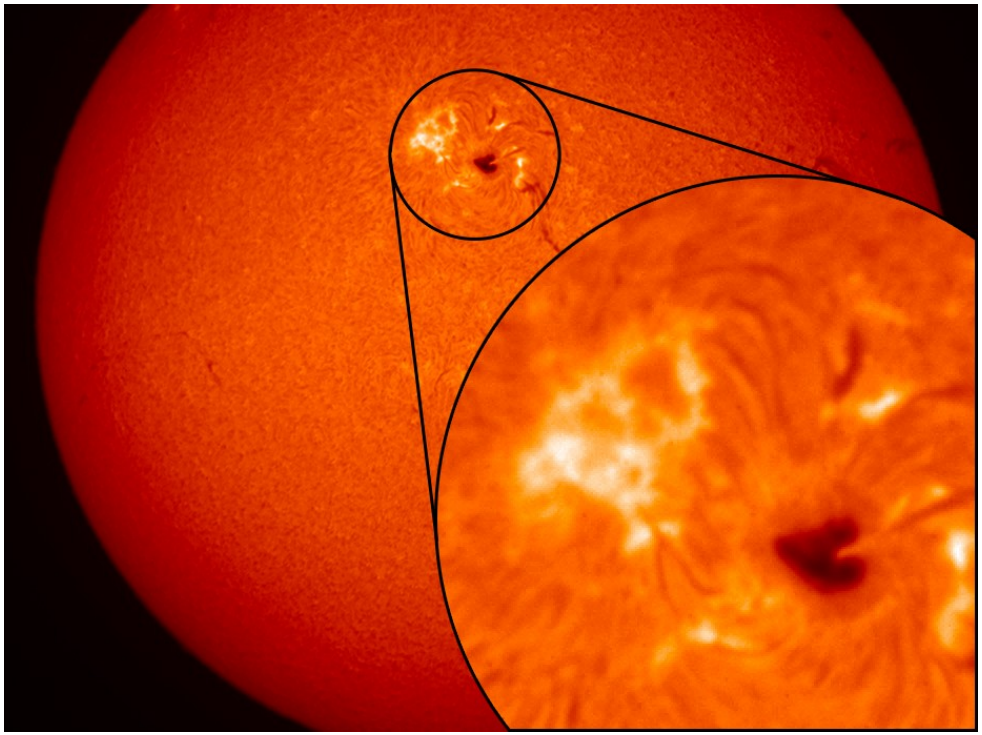
Plasma motions (normal Evershed flows) are slightly larger than in the surroundings on April 11.

Motions with both upward and downward directions seem to be present along the feature on April 13.





INAF-OACt chromospheric data



- In the image of the chromosphere acquired on April 13, we notice **bright chromospheric filaments** cospatial to the UF.
- Similar filaments with the same curvature, connecting the sunspot with network elements, also appear in SDO/AIA images at **304 Å** and **171 Å** (EUV channels).

Interpretation and high-resolution observations

Differently from LBs, we do **not** observe a **field-free** configuration in the intruding UF, **nor granular** cells.

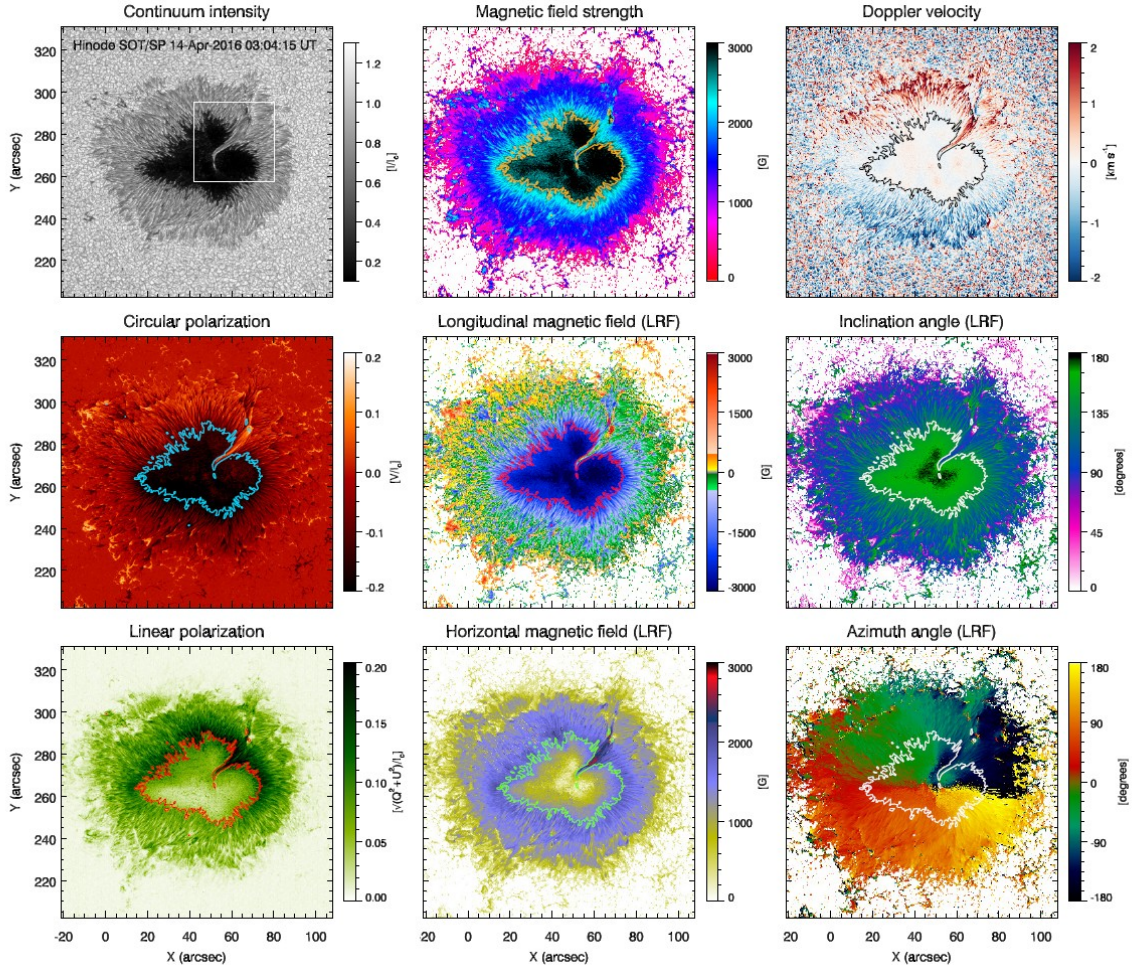
The filaments observed in the upper atmospheric layers may have a **counterpart** within the sunspot umbra.

The presence of a **flux rope**, with a helical shape, might explain:

- the **strong horizontal field**
- the portion with **opposite polarity**
- the peculiar **plasma motions**

To support such a **flux-rope scenario**, we are analyzing high-resolution observations acquired during the passage at the central meridian of AR NOAA 12529.

Data were taken by the SOT/SP on board the ***Hinode* satellite** in the photosphere and by the ***IRIS* spacecraft** in the chromosphere and transition region layers.



The giant sunspot: SIR inversion

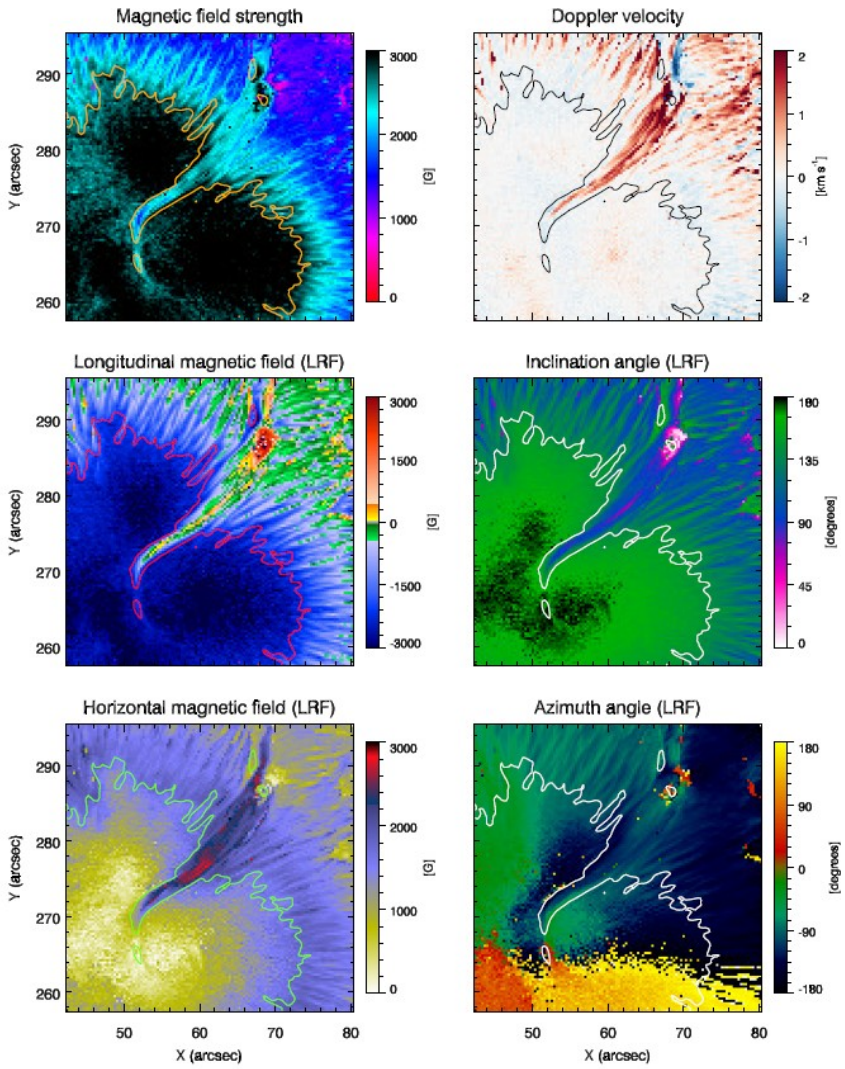
UF in detail – Hinode/SOT

We use a PCA deconvolution to remove the stray light due to the PSF of SOT/SP [following Quintero Noda et al. (2016)]

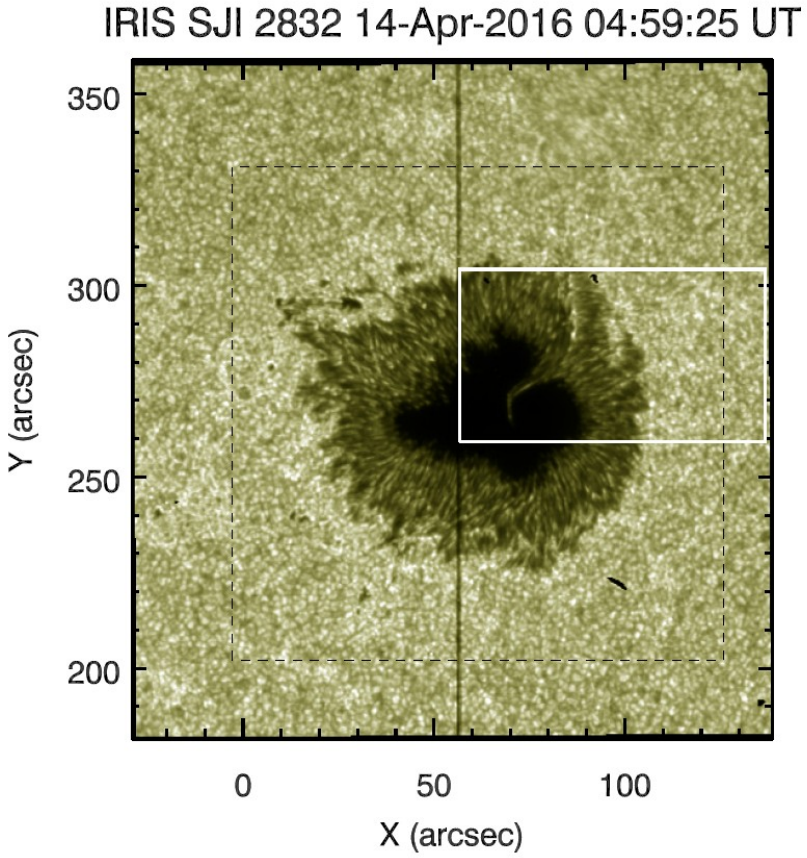
We divide the sunspot into three regions (U, P, QS) and invert each region with a different temperature stratification [following Murabito et al. (2016)]

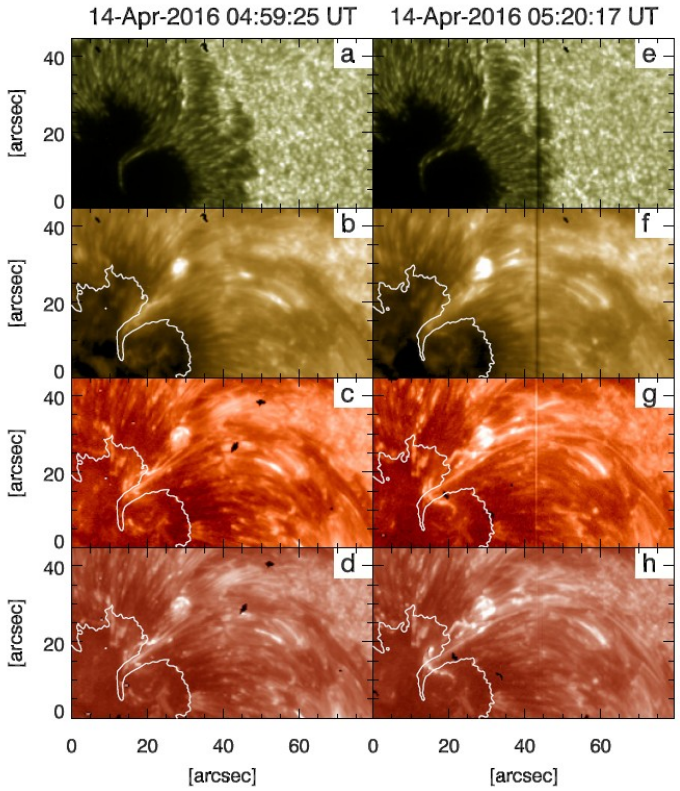
In the UF, we find:

- the presence of a **strong magnetic field**
- **horizontal** field up to **2800 G**
- larger area with **opposite polarity**
- larger-scale opposite LOS motions
- some indications of **twist**



IRIS observations





2832 Å

2796 Å

1330 Å

1400 Å

Conclusions

We studied the UF appeared in the **giant sunspot** of AR NOAA 12529.

We found observational **evidence of a flux rope** within the sunspot umbra.
[Guglielmino, Romano & Zuccarello, 2017, ApJL, 846, L16]

This scenario, according to which the UF differs from a LB, is **supported** by:

- **no field–free** region in the UF
- the presence of **strong horizontal fields**, up to 2800 G
- a large portion of the UF with **opposite polarity** with respect to the surroundings
- the presence of cospatial **filaments in the upper atmospheric layers**

High–resolution observations (*Hinode* and *IRIS*) confirm the above scenario.
[Guglielmino, Romano, Ruiz Cobo, Zuccarello, Murabito, in preparation]

What can be learnt with EST?

High spatial resolution (<0.1")

disentagle polarimetric signals of UFs from those of umbrae, by removing stray light

Multi-wavelength diagnostics

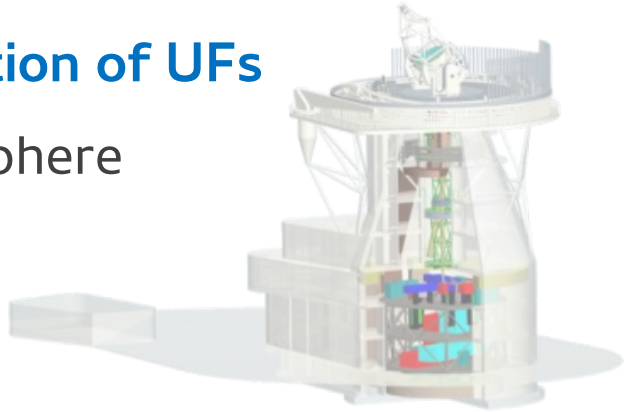
structure of UFs at different heights in the photosphere and chromosphere

High polarimetric sensitivity

fine details of the magnetic configuration of UFs

Simultaneous spectropolarimetry of photosphere and chromosphere

determine the magnetic nature and configuration of the photospheric UFs as seen in the chromospheric layer



THANKS

for your attention!