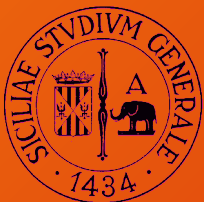


Formation of a stable penumbra in a region of flux emergence

M. Murabito¹, P. Romano², S. L. Guglielmino¹, F. Zuccarello¹

Murabito et al. 2017,ApJ,834,76

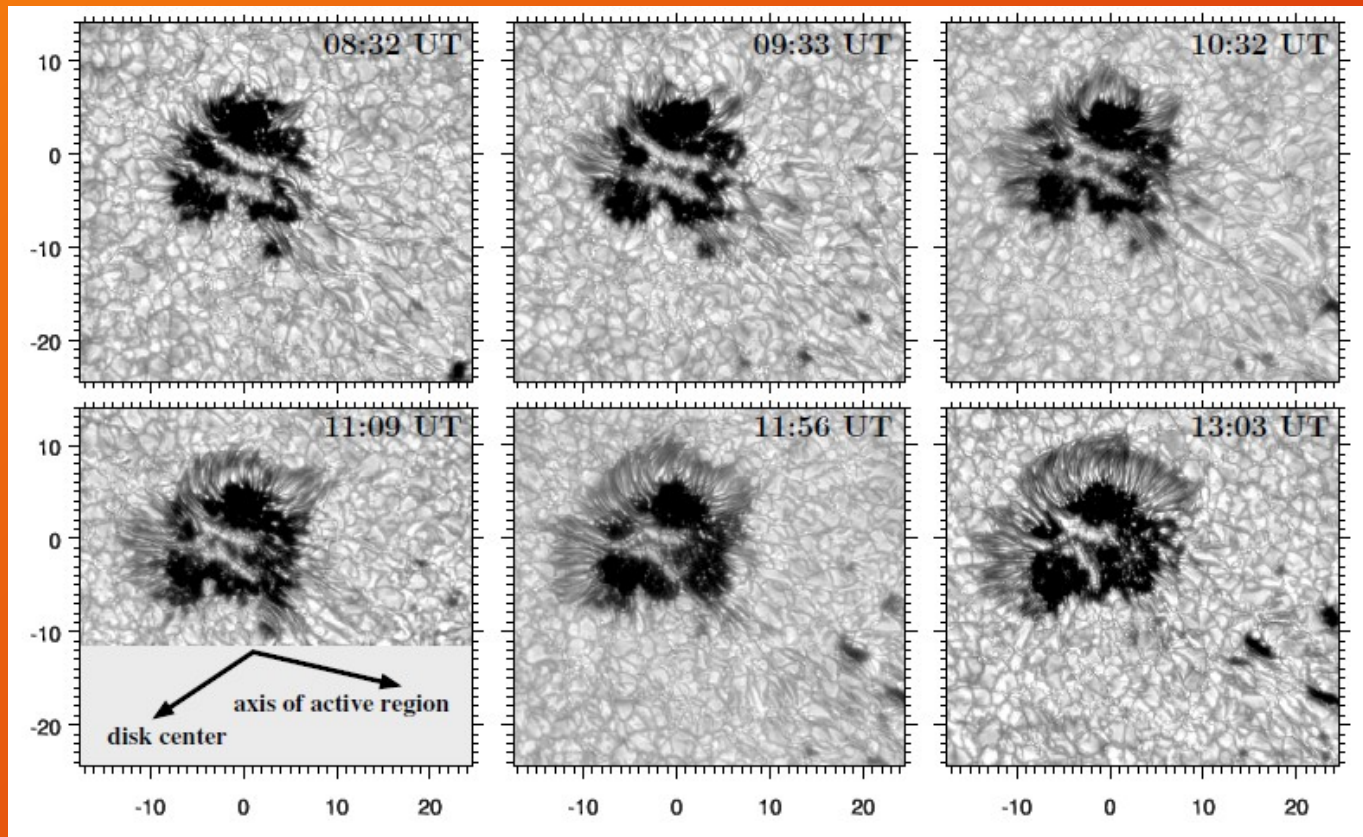
¹Università degli Studi di Catania – *Dip. di Fisica e Astronomia*
²INAF OAcT – *Osservatorio Astrofisico di Catania*



Penumbra Formation

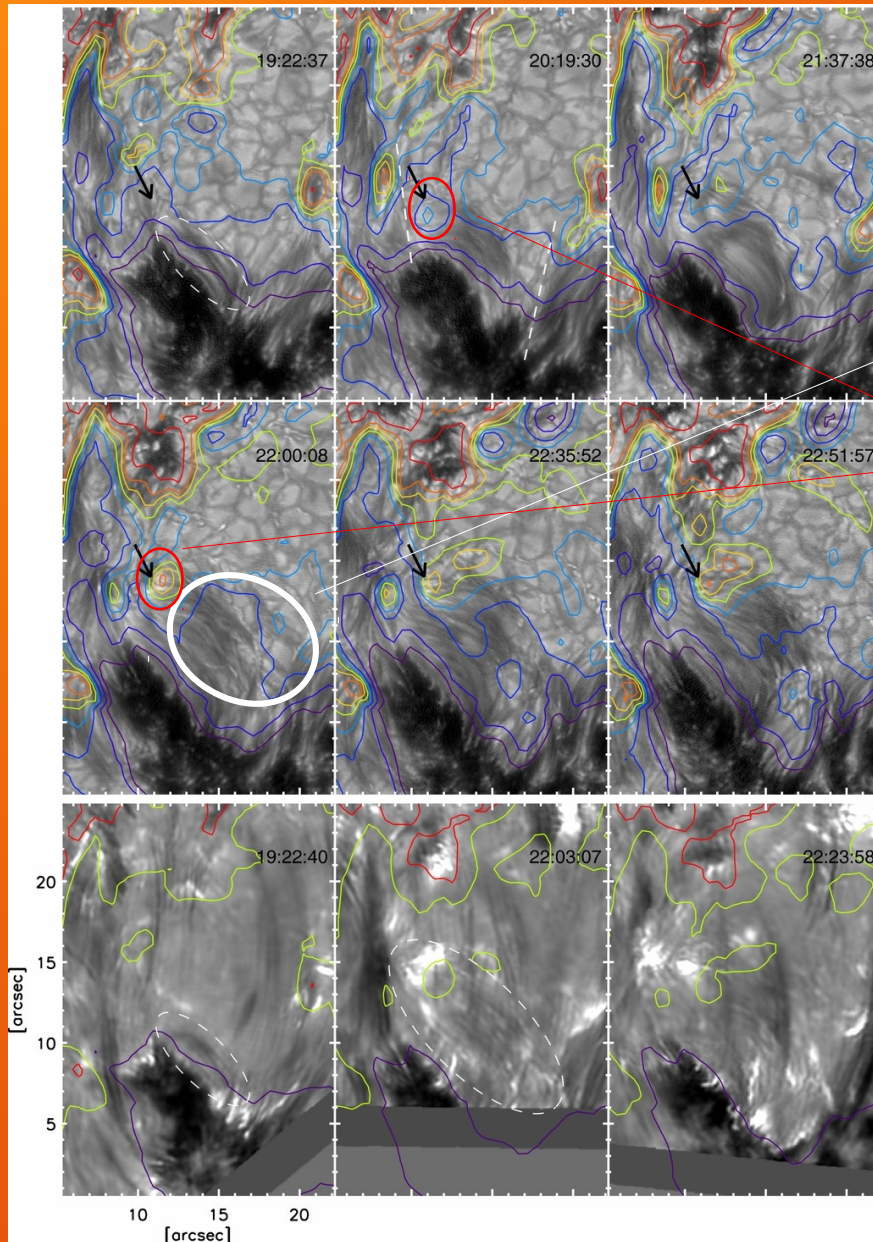
- The penumbra forms in sectors
- The penumbra firstly forms away the opposite polarity
- The region toward the opposite polarity is characterized by elongated granules

VTT observations in the G-band and Call K



Schlichenmaier et al. (2010) 2

Non radial penumbra in a flux region



- Elongated granules detected in association with an emerging flux in this region.
- Non-radial penumbra on the side toward the opposite polarity.
- Negative magnetic flux density gradually decreases and is replaced by positive flux

↓
The penumbral filaments may have formed as a result of the flux emergence

Lim et al. 2013,ApJL,769,L18

IBIS and SDO/HMI data sets

IBIS DATA SET

- on 2012 *May 28*, from 14:20 UT to 14:38 UT (18 scans)

The scans with 67 s cadence contain:

- Fe I 617.3 nm

sampled with 30 λ in spectropolarimetric mode
six modulation states

(I + S with S = [+Q,+V,-Q,-V,-U,+U])

-Ca II 854.2 nm

sampled with 25 λ in spectroscopic mode

SDO/HMI SHARP_s DATA SET

-Continuum filtergrams in the Fe I 617.3 nm line and
LOS magnetograms from May 28 at 14:58 UT to 20:58
UT with 12 minutes of cadence and a resolution of 1".

Method of Analysis (IBIS data)

1) Data reduction:

- ✓ Dark
- ✓ Flat
- ✓ Blueshift
- ✓ Gain CCD
- ✓ MOMFBD
- ✓ Polarimetric Calibration

2) Single-component

inversion of the Stokes profiles with **SIR** of the Fe I 630.25 nm line

↓
B, γ , ϕ

3) With Non Potential Field Calculation (**NPFC**) code (Georgoulis,2005) we solved the 180°-azimuth ambiguity

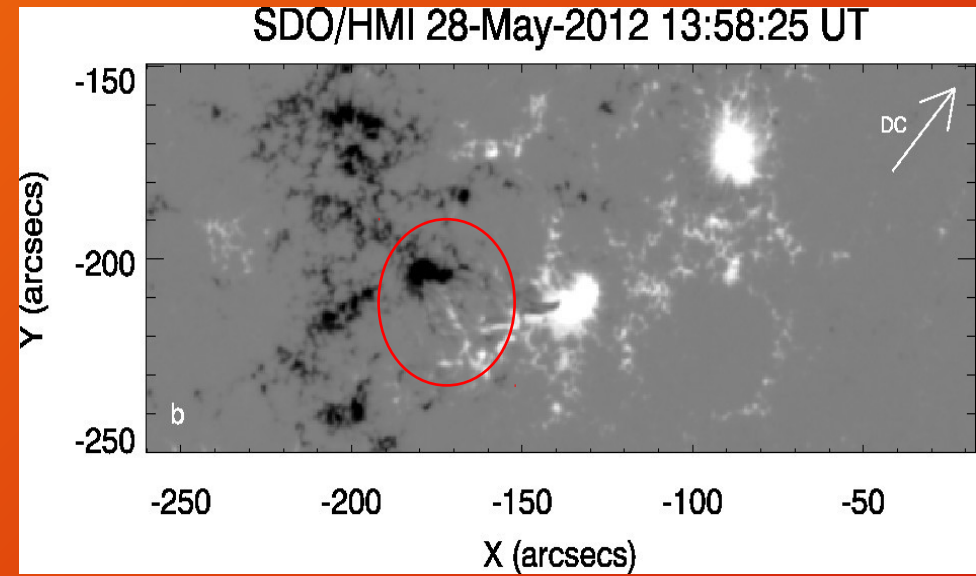
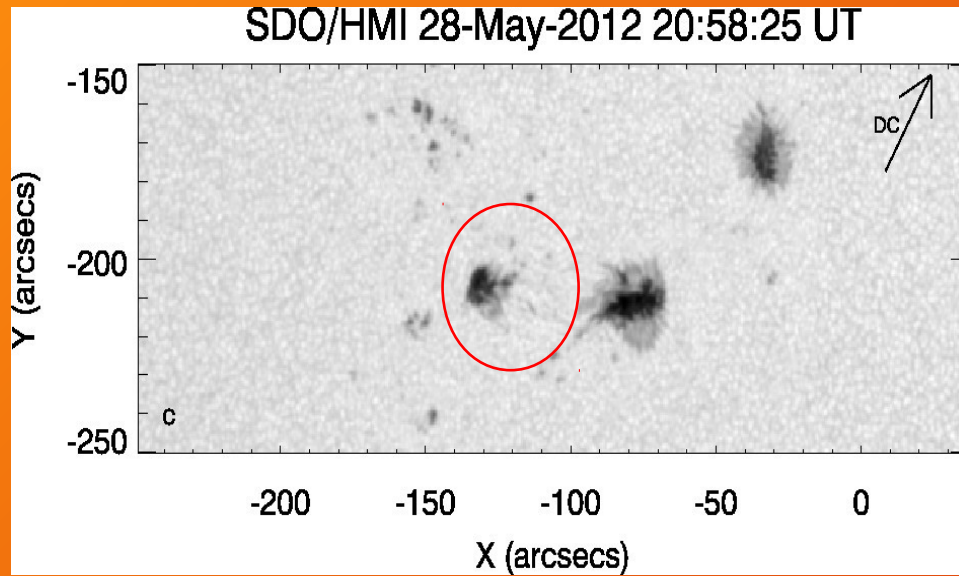
↓
 γ , ϕ in the LSF
(Local Solar Frame)

Linear and circular polarization maps calculated by :

$$V_s = \frac{1}{12 \langle I_c \rangle} \sum_{i=1}^{12} \epsilon_i V_i$$

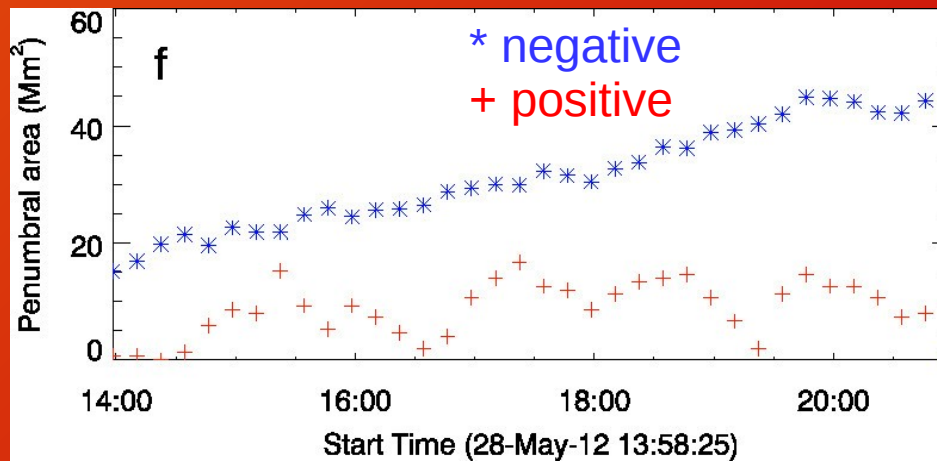
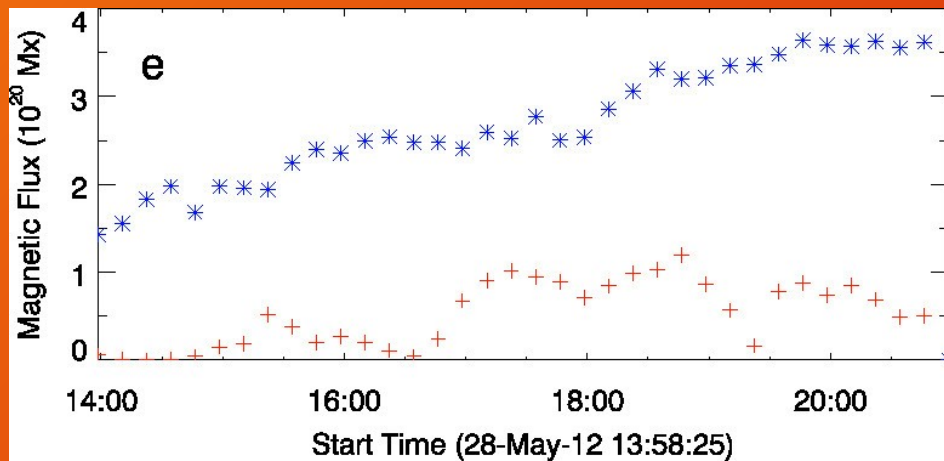
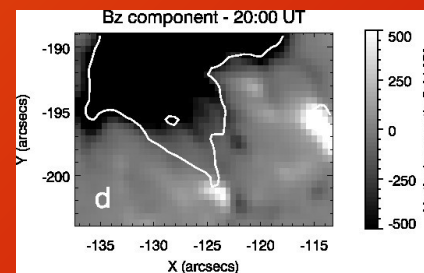
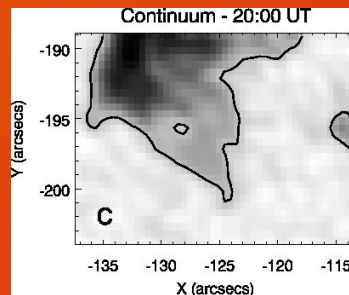
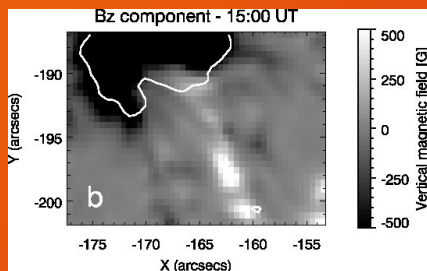
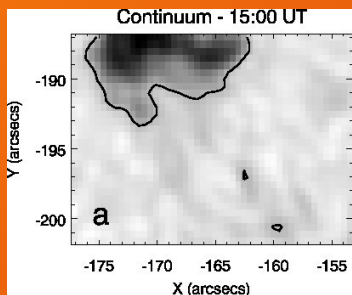
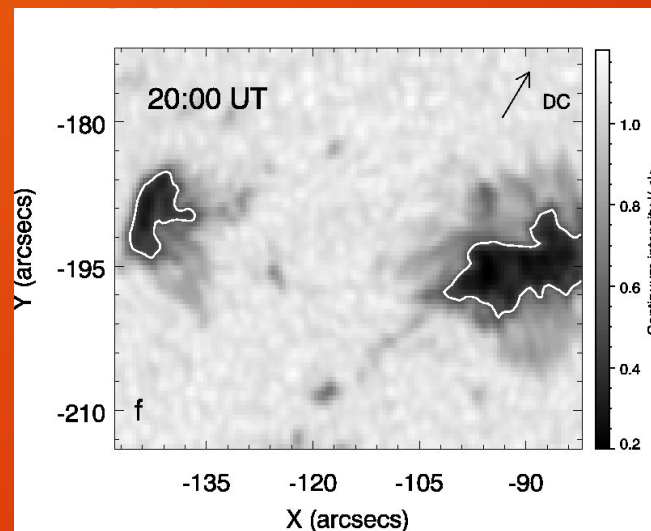
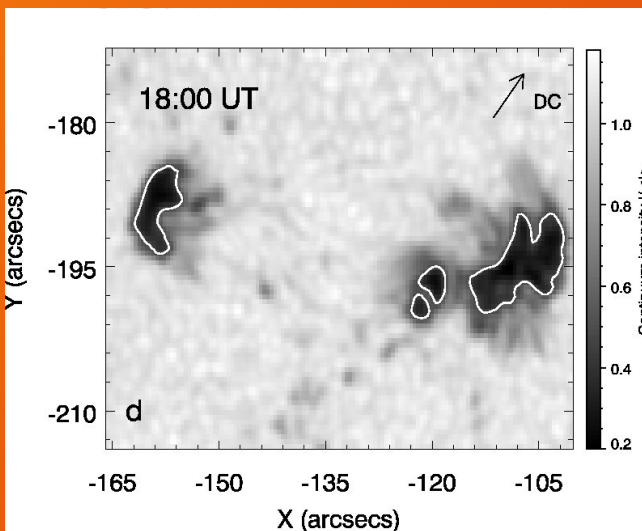
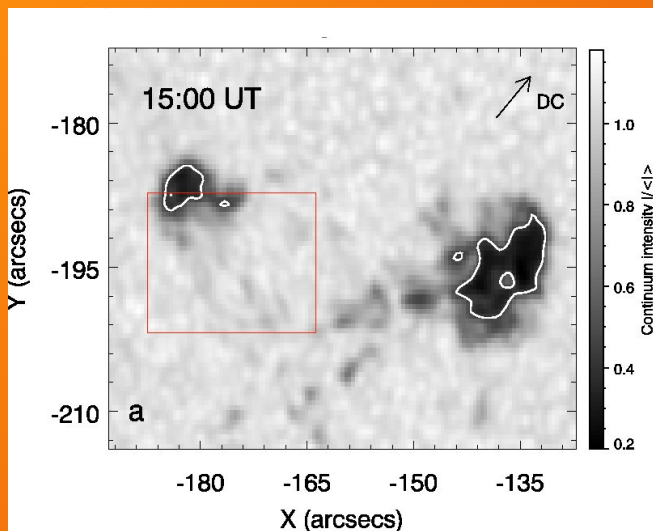
$$L_s = \frac{1}{12 \langle I_c \rangle} \sum_{i=1}^{12} \sqrt{Q_i^2 + U_i^2}$$

Target: AR NOAA 11490

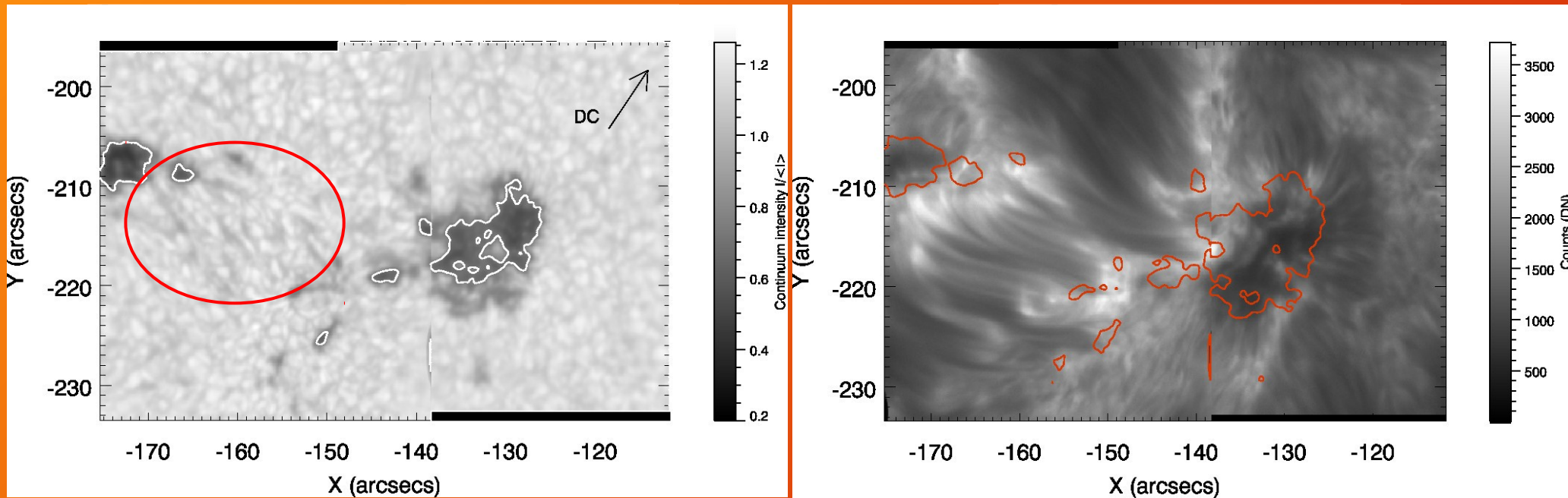


- Leading spot forms the penumbra in about 10 hrs and the first sector develops away from the opposite polarity
- The following pore evolve into a mature sunspot and forms a fully penumbra in about 15 hrs

First penumbral sector

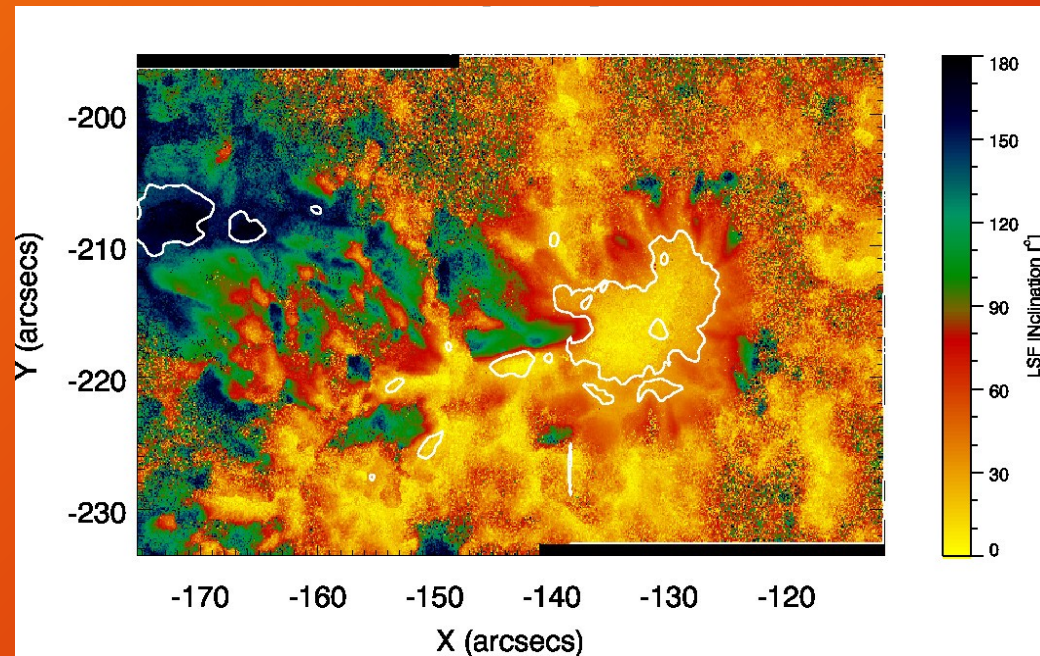
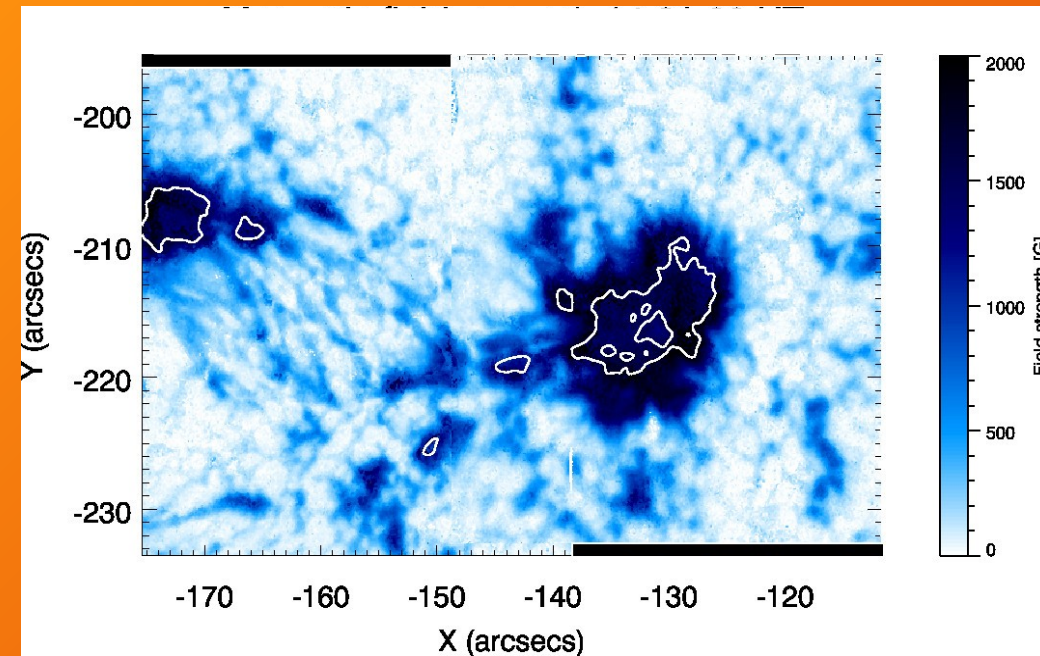


Elongated granules and AFS



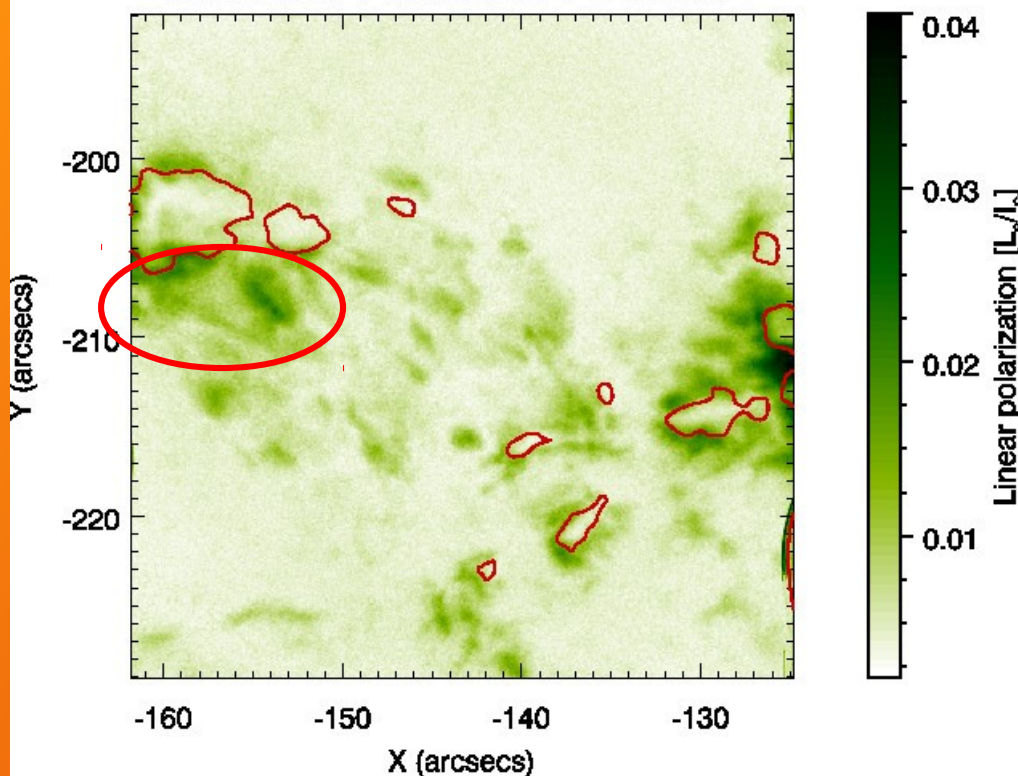
Full IBIS region observed from 13:39 to 14:12 UT and from 14:19 to 14:38 UT

- Elongated granules in photosphere and AFS in chromosphere → region of **magnetic flux emergence**

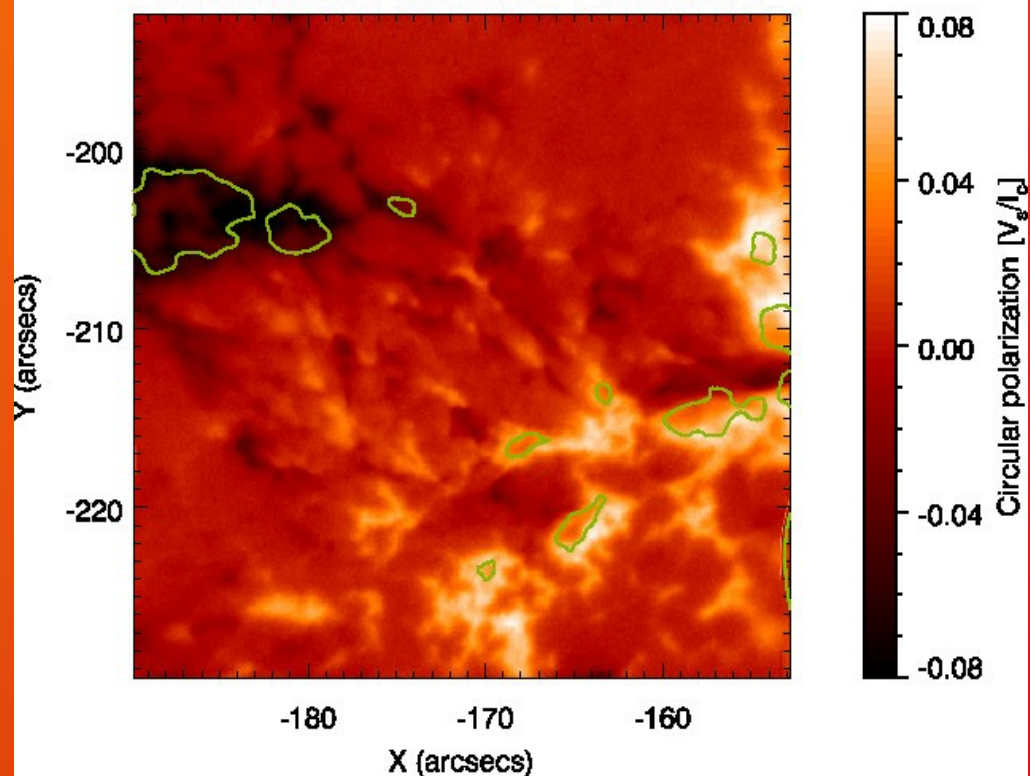


- Filamentary shape for the magnetic field configuration with a **sea-serpent configuration**
- Filamentary shape not aligned with the structure of the AFS
- Filamentary and mixed pattern in the inclination map on a larger scale

IBIS Linear Polarization 14:21:43 UT



IBIS Circular Polarization 14:21:43 UT



- Wide region with different values of linear polarization.
- Linear polarization larger than 4% in the region where later the penumbra starts to form.
- Alternate positive and negative bipoles with a sea-serpent configuration between the two polarities in the circular polarization map.

Conclusions

Our findings

- 1) Penumbral filaments form in the side facing the opposite polarity.
- 2) Elongated granules in photosphere and an AFS in chromosphere are present between the two polarities.
- 3) Filamentary pattern for magnetic field inclination and strength, polarization maps and continuum intensity map similar to the sea-serpent configuration.
- 4) Presence of horizontal fields at the photospheric level before the penumbra formation.

a) Even if Schlichenmaier et al. 2010 observed elongated granules they concluded that this region cannot form stable penumbra.



b) Lim et al. 2013 observed the penumbra formation associated with flux emergence under preexisting chromospheric canopy fields.



c) Weiss et al. 2004 suggested that turbulent pumping by granular convection drags the flux tubes downward in the moat region to form a sea-serpent configuration → This configuration may be considered as a further precursor of the penumbra formation.

d) Mac Taggart et al. 2016 demonstrated that there is a low probability of finding near-horizontal field in the region between the two polarities → formation of overlying magnetic canopies

Thanks!