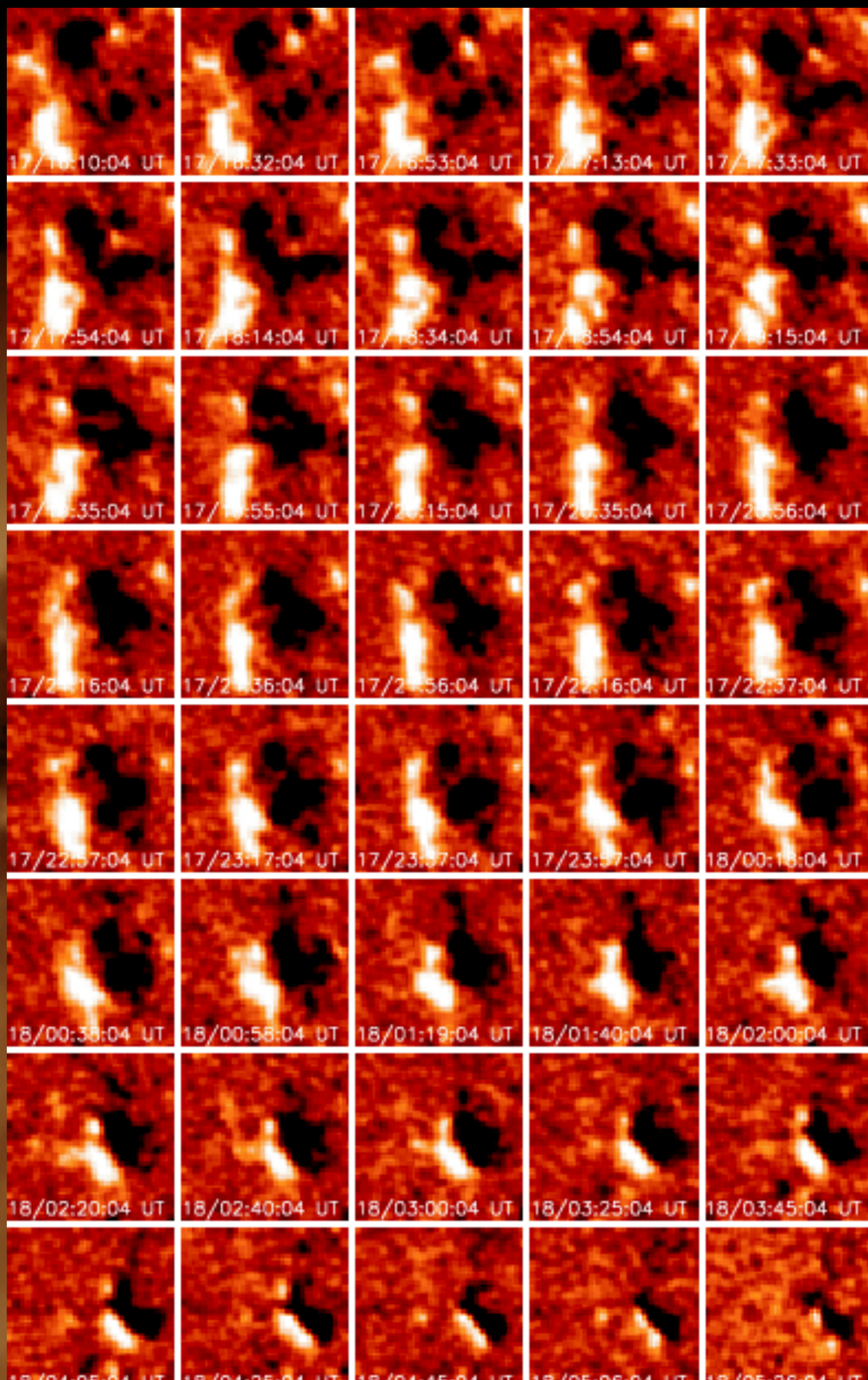
Magnetic flux and Coronal Bright Points



SOHO/MDI view on a coronal bright point magnetic flux

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What do you see here?

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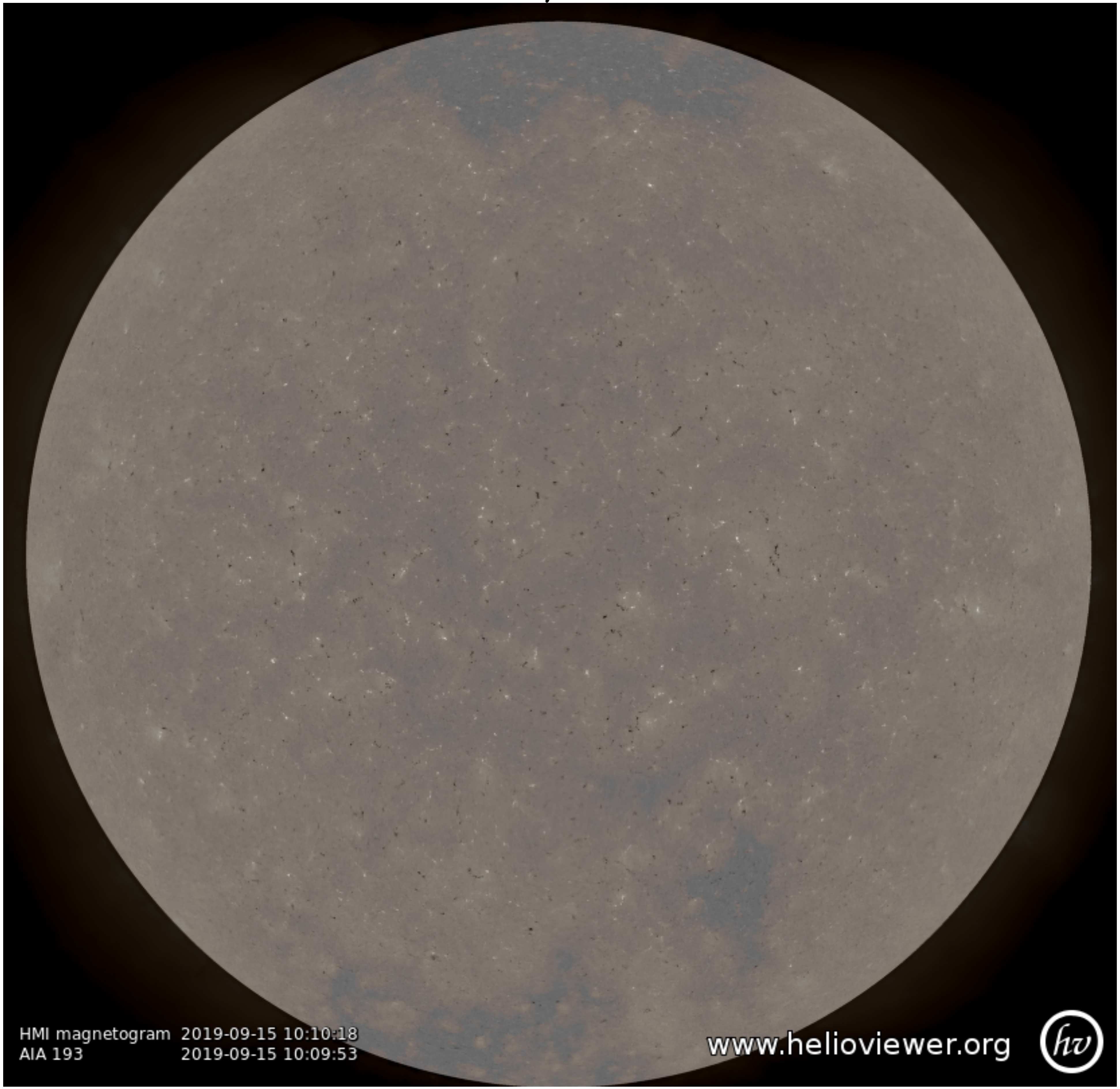

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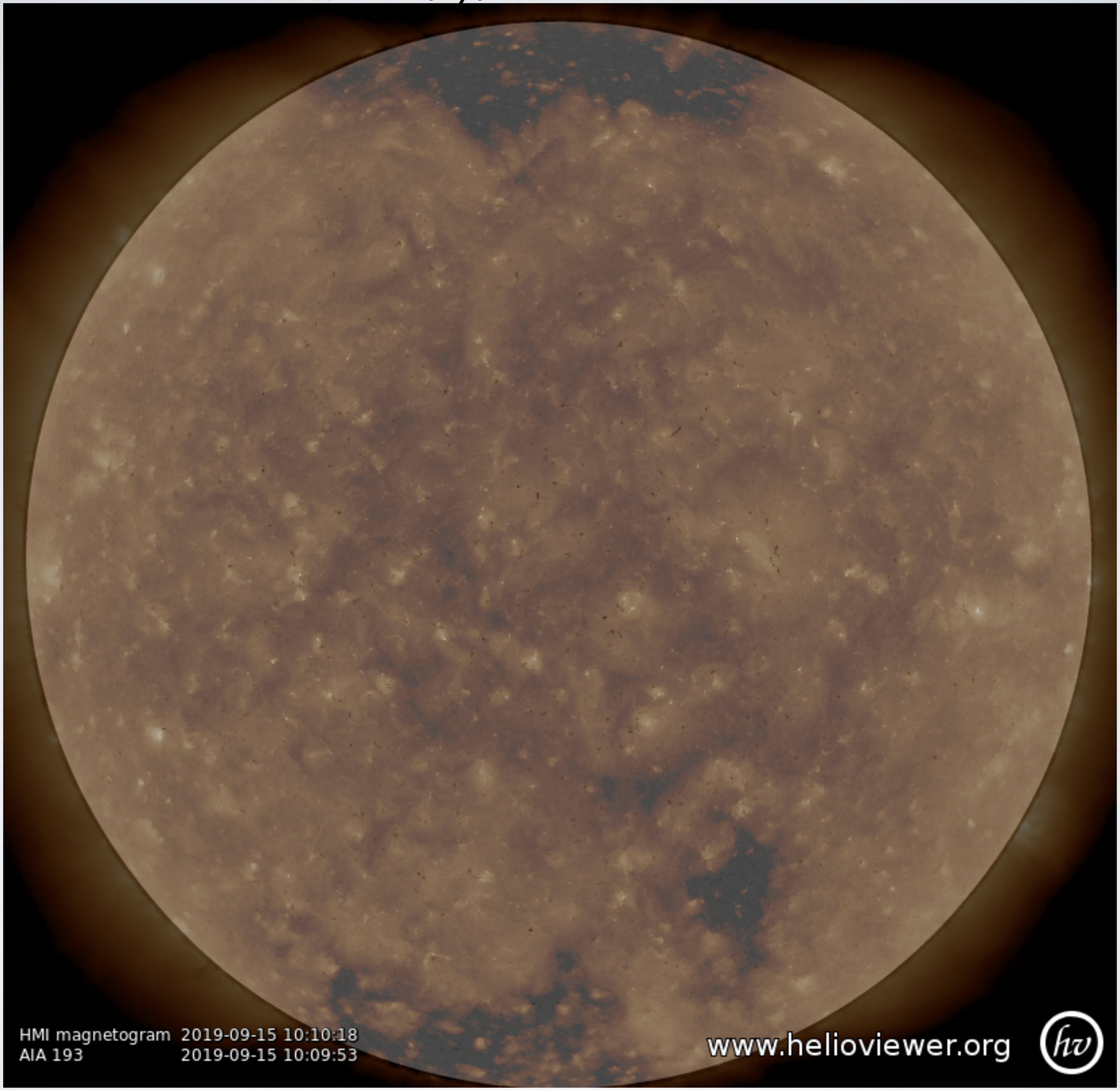

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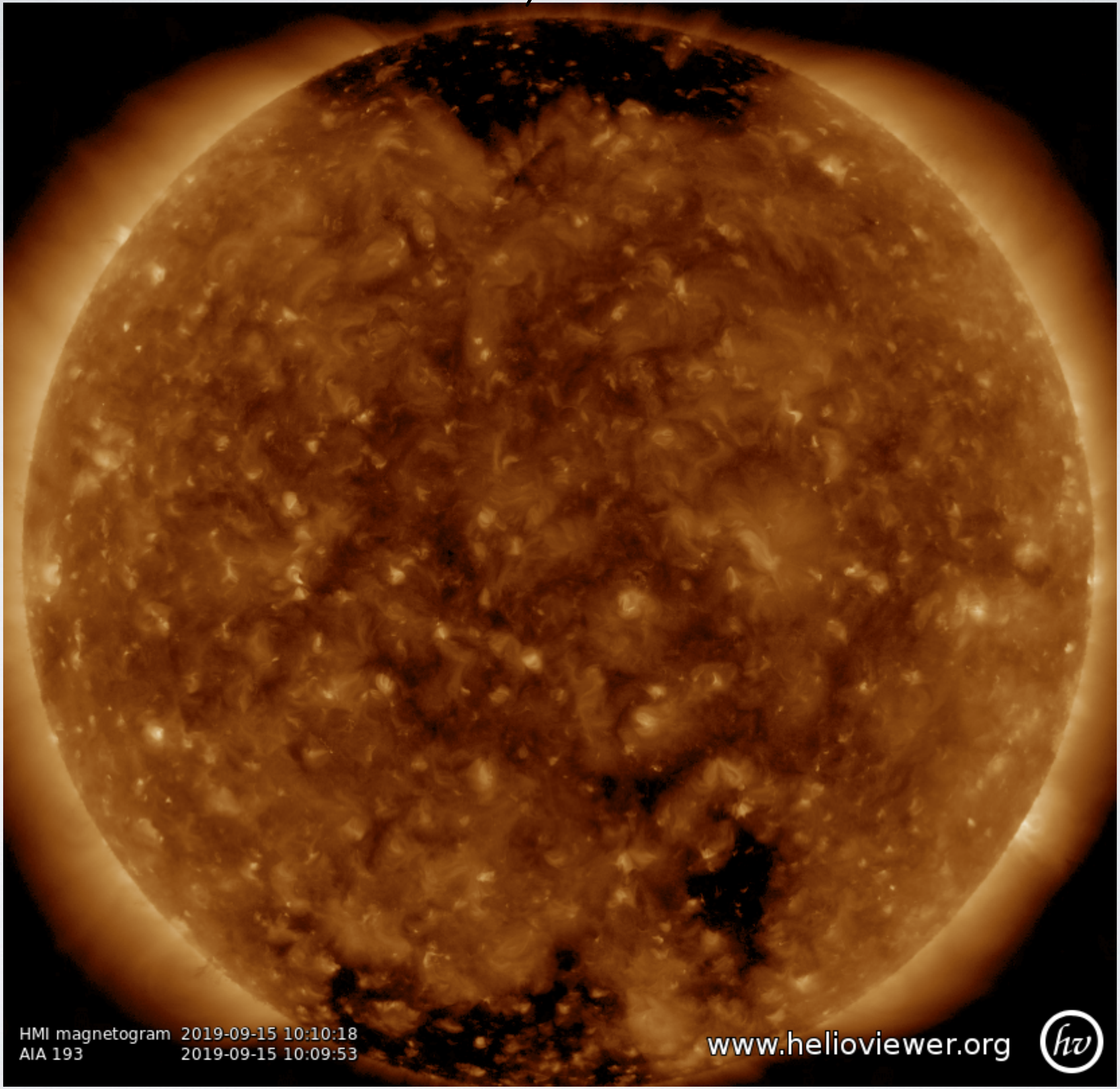


Outline

- ✓ What are Coronal Bright Points (CBPs)?
  - ➡ Historical review
  - ➡ General properties: morphology, sizes, heights & lifetimes
  - ➡ CBPs' occurence rate
  - ➡ CBPs and transient dynamic phenomena
  - ➡ General definition and conclusions
- ✓ Photospheric magnetic flux and coronal bright points: history and general properties
- ✓ CBPs' photospheric magnetic flux range, emergence and disappearance rates, examples
- ✓ CBPs' formation and evolution: examples of emergence, coalescence, rotation, cancellation, smallest loops, faint loops
- ✓ CBPs' photospheric magnetic flux correlation with coronal emission
- ✓ CBPs' photospheric magnetic flux evolution and transient dynamic phenomena
- ✓ Coronal magnetic field topology of CBPs
- ✓ What to take away?

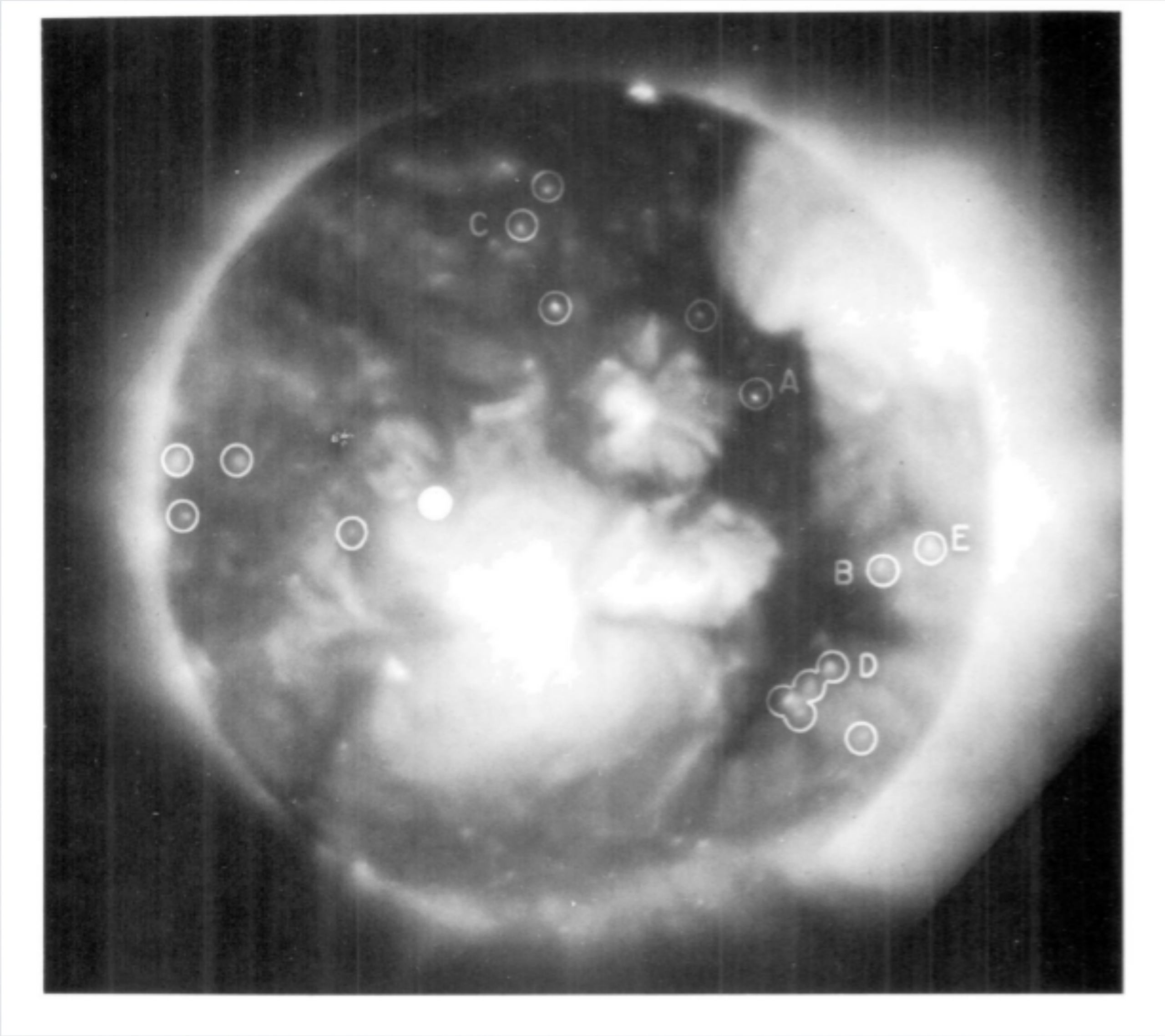
Animations in the lectures

✓ALL ANIMATIONS - 23 ANIMATIONS MARKED AS MOVIE_NO_ISSS.MOV ON EACH ANIMATION IN THE SLIDES CAN BE FOUND HERE: https://www2.mps.mpg.de/data/outgoing/madjarska/movies_isss.tar

✓ To use any movie that has not been published (i.e. from papers in prep), please ask Maria for permission

Historical review

- ✓ First X-ray observations - rocket flights (1969 - 1973) (Vaiana et al. 1973)
- ✓ 1969 April 8 observations revealed that the "quiet homogeneous" solar corona as known until then is highly structured with numerous bright point-like soft X-ray emission sources randomly distributed on the solar disk including polar regions (Vaiana et al., 1973)

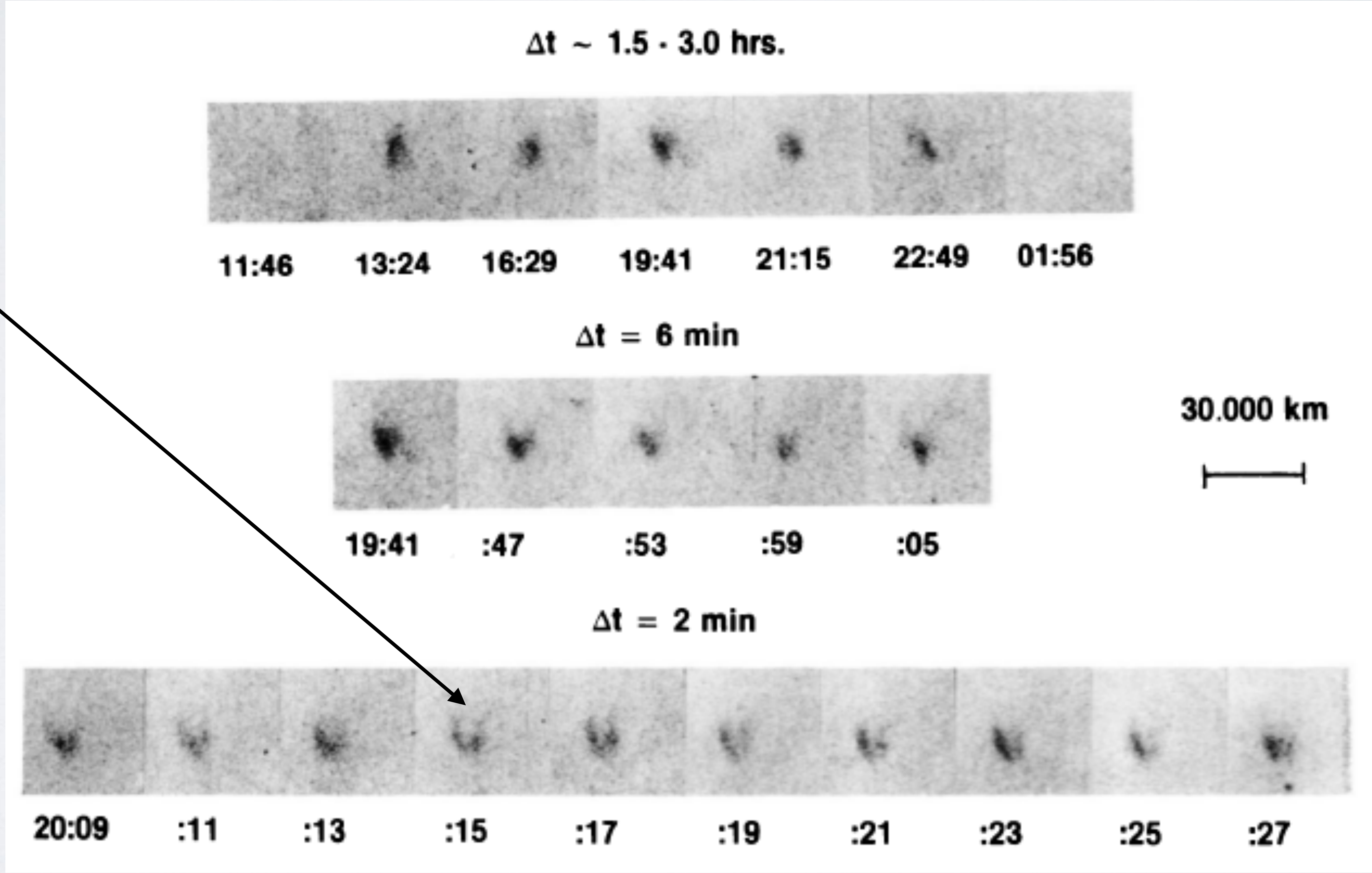


Full disk X-ray image taken with the S-054 spectroheliographic telescope with some of the XBPs encircled (from Nolte et al., 1979).

Historical review

✓ From the spectrometer on the Apollo Telescope Mount (ATM) at Skylab - the bright "points" consist of rapidly and independently evolving 2-3 small-scale loops (Sheeley and Golub, 1979)

Small-scale loops, 2″ resolution



CBPs in a sequence of Fexv 284 Å spectroheliograms (negative) taken on 1974 January 19-20 (Sheeley and Golub, 1979).

Historical review

- ✓ Habbal et al. (1990) - multi-temperature spectroheliogram study based on Skylab data => CBPs are composed of loops at different temperatures
- ✓ From 1973 - S-054 and S-056, X-ray telescopes and spectrometer on ATM/Skylab
- ✓ Followed by studies based on data from VLA, Yohkoh/SXT, SOHO/EIT/MDI/CDS/ SUMER, TRACE, Hinode/EIS/SOT/XRT, Stereo/EUVI, SDO/AIA/HMI, IRIS, EUI/SPICE/ SoLO
- ✓ Modelling - analytical analysis, 2D, 2.5D and 3D MHD models

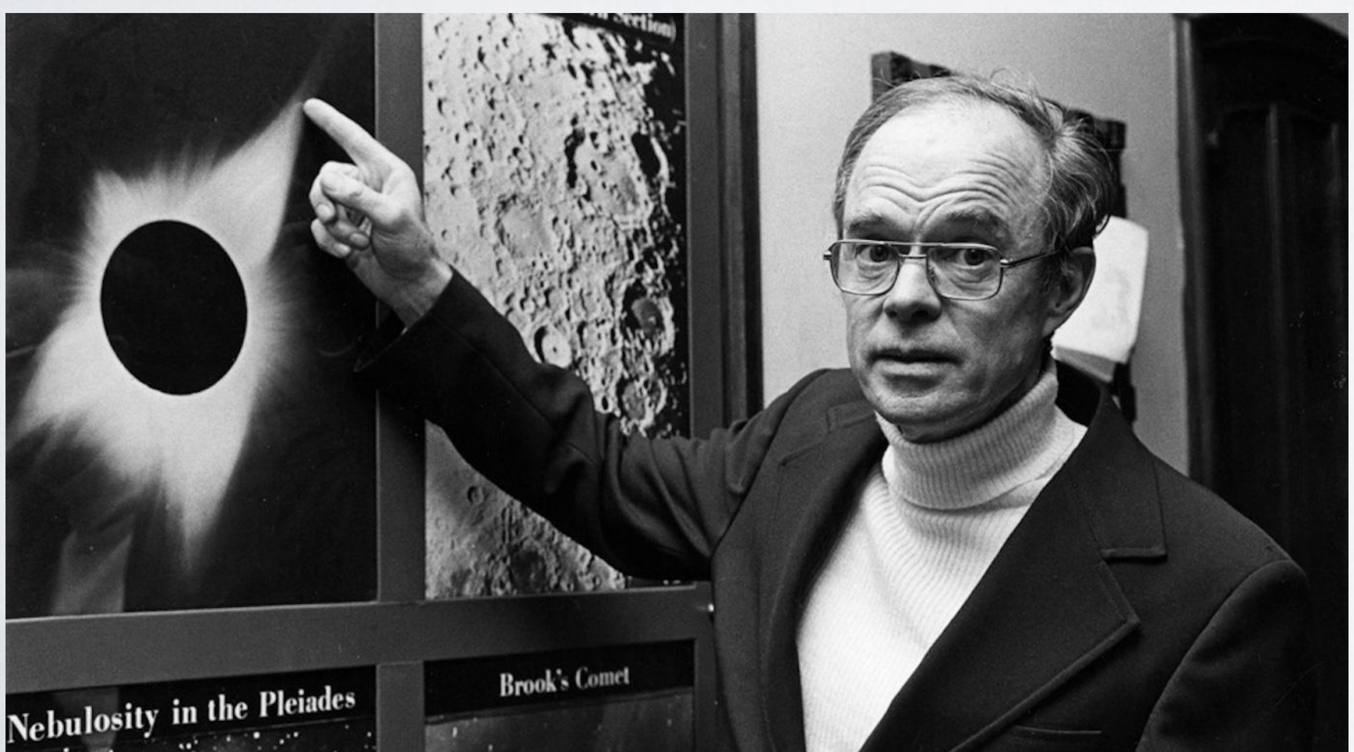


Photo credit: University of Chicago /HO/AFP/APA| ()

"X-ray bright spots on the sun and the nonequilibrium of a twisted flux rope in a stratified atmosphere." (Parker, 1975)

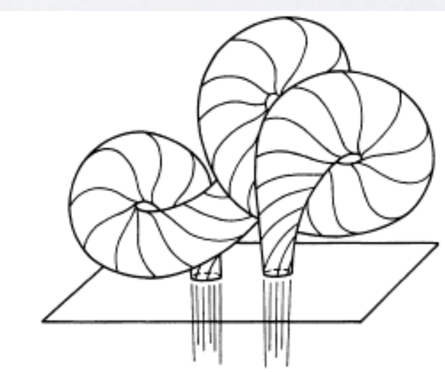


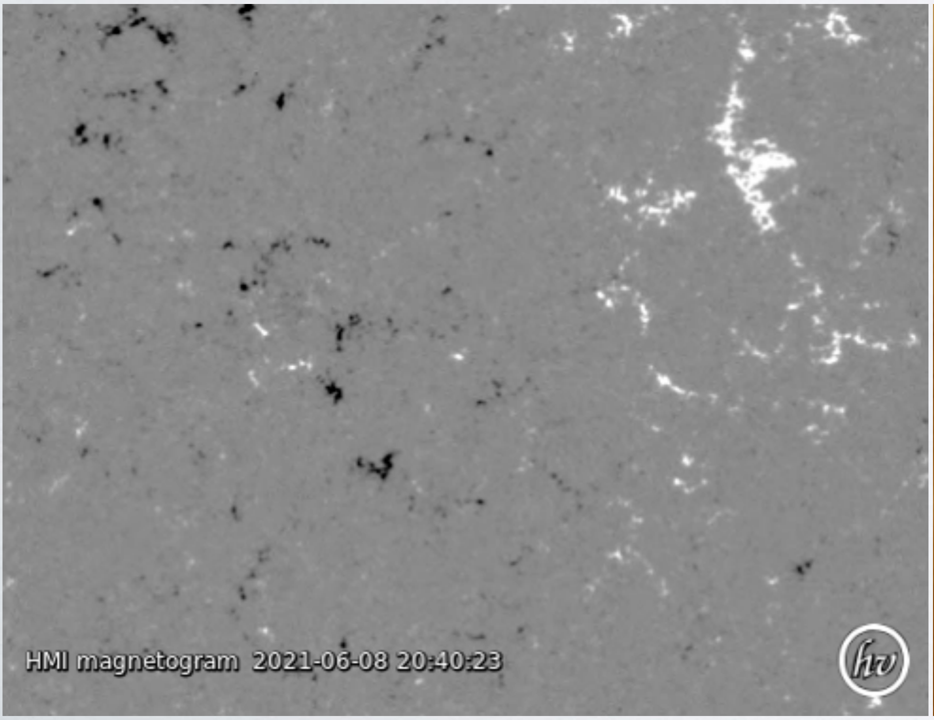
FIG. 2.—Sketch, based on imagination, of the contorted form of a twisted magnetic flux tube with more than the allowable azimuthal flux above the anchor points of the tube in the horizontal plane.

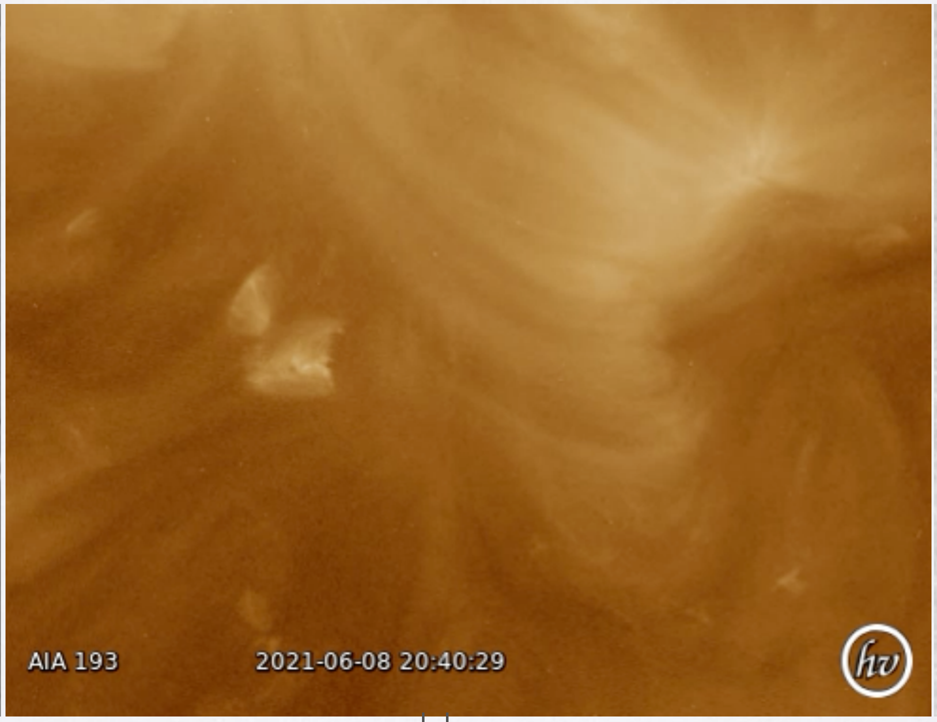
CBPs result from the rising of an elementary flux tube through the solar atmosphere by magnetic buoyancy.

General properties: morphology, sizes, heights & lifetimes

- ✓ Morphology: Skylab/X-ray, Yohkoh/SXT, EIT/SoHO - bright diffused cloud/point/oneloop, TRACE (Brown et al., 2001, Ugarte-Urra et al., 2004), IRIS and SDO/AIA (Kashyap & Dwivedi, 2017), SoLO/EUI/HRI - small-scale dynamically evolving loops, SoLO/SPICE & EUI/FSI - compact brightening or point

- ✓ Sizes:
  - ➡ SDO/AIA - CBPs from magnetic flux emergence initially appear as loops as small as 5″ (3.5Mm) that grow to reach up to 60″ (43Mm) (Mou et al., 2018), and even 100″ (72Mm). At the end of lifetime as small as 5″ (3.5Mm).
  - ➡ CBPs vs ARs - As long as no pores and sunspots are detected => a CBP





General properties: morphology, sizes, heights & lifetimes

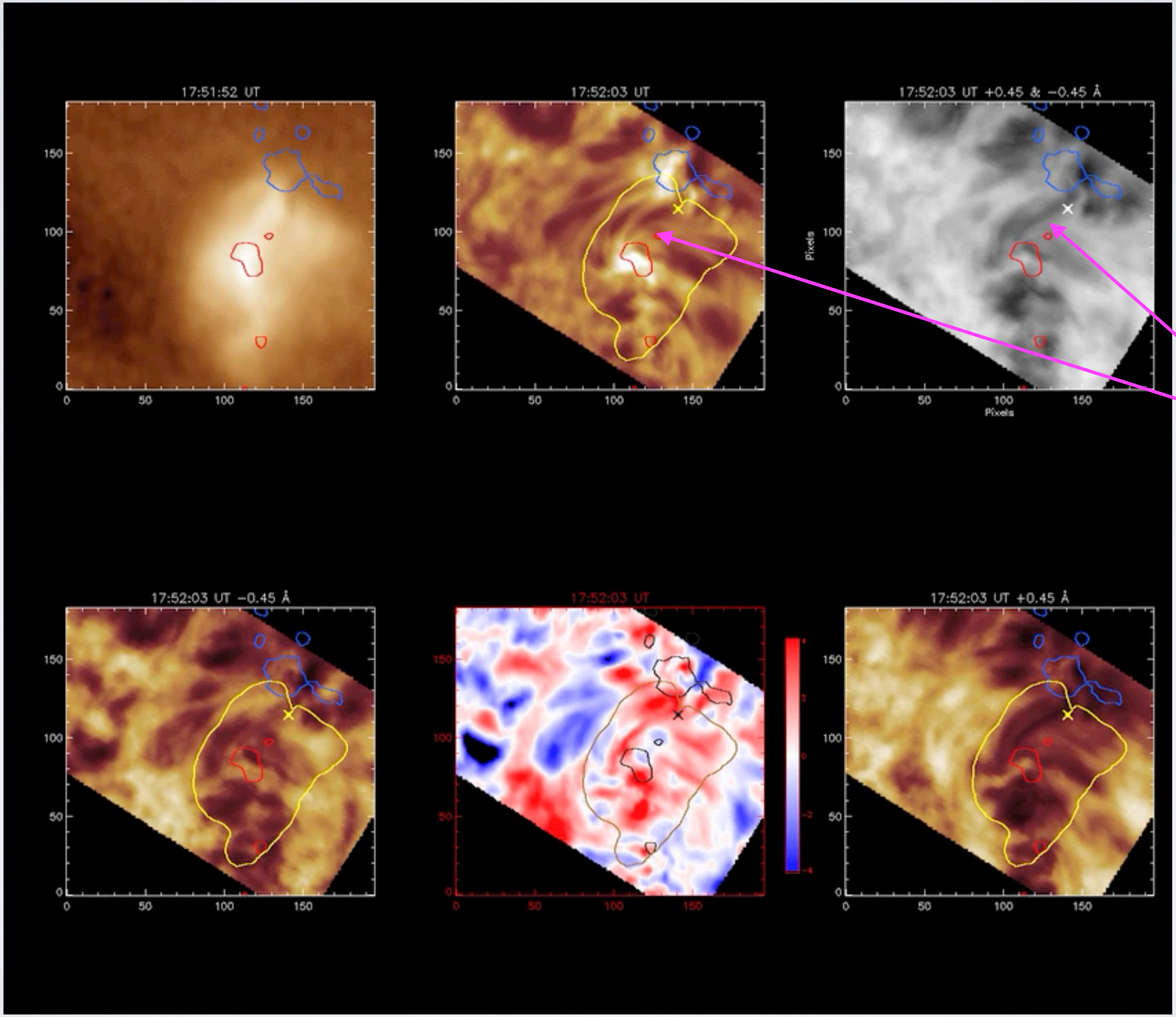
✓ Heights:

- ➡ CBPs heights are found in EUV coronal observations to be in the range from 5000 to 10000 km. An average height of 6500 km should be expected at a lifetime peak (Brajša et al., 2004, Tian et al., 2007, Sudar et al., 2016, Kwon et al., 2010). Based on emission height and stereoscopic approach.
- ➡ Kwon et al. (2010) - multi-temperature loop system composed of hot loops (logT (K) ~ 6.2) overlying cooler ones (logT (K) ~ 6.0) with cool legs (logT (K) ~ 4.9)
- ➡ Madjarska et al. (2021) - chromospheric loops (T<10000 K) seen as dark “fibrils” in Halpha represent the coolest part of the CBP system. Height less than 1.5 Mm (Halpha maximum formation height).

General properties: morphology, sizes, heights & lifetimes

AIA 193

FISS/BBSO

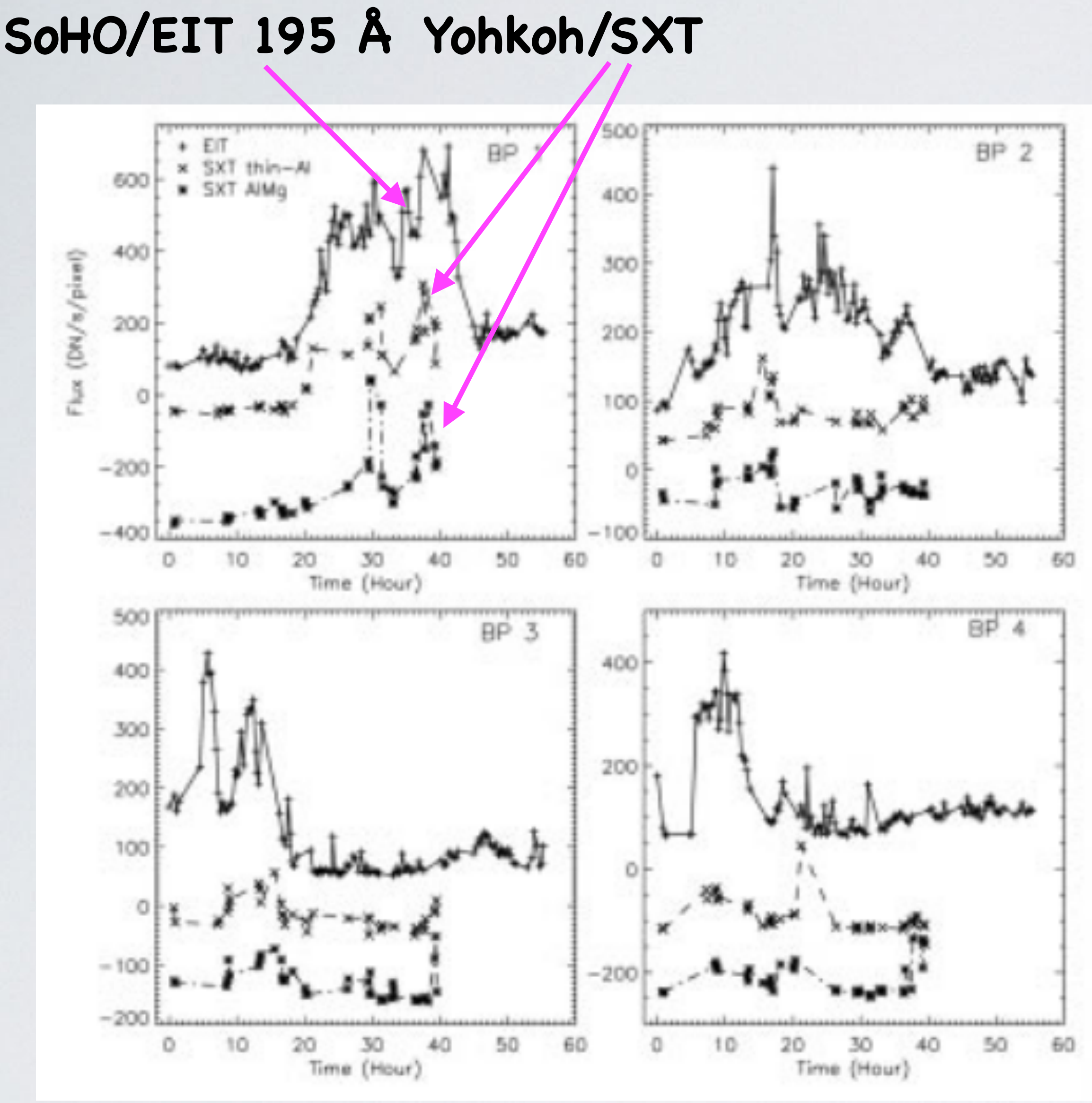


Halpha loops

movie_1_isss

Madjarska et al. (2021)

General properties: morphology, sizes, heights & lifetimes

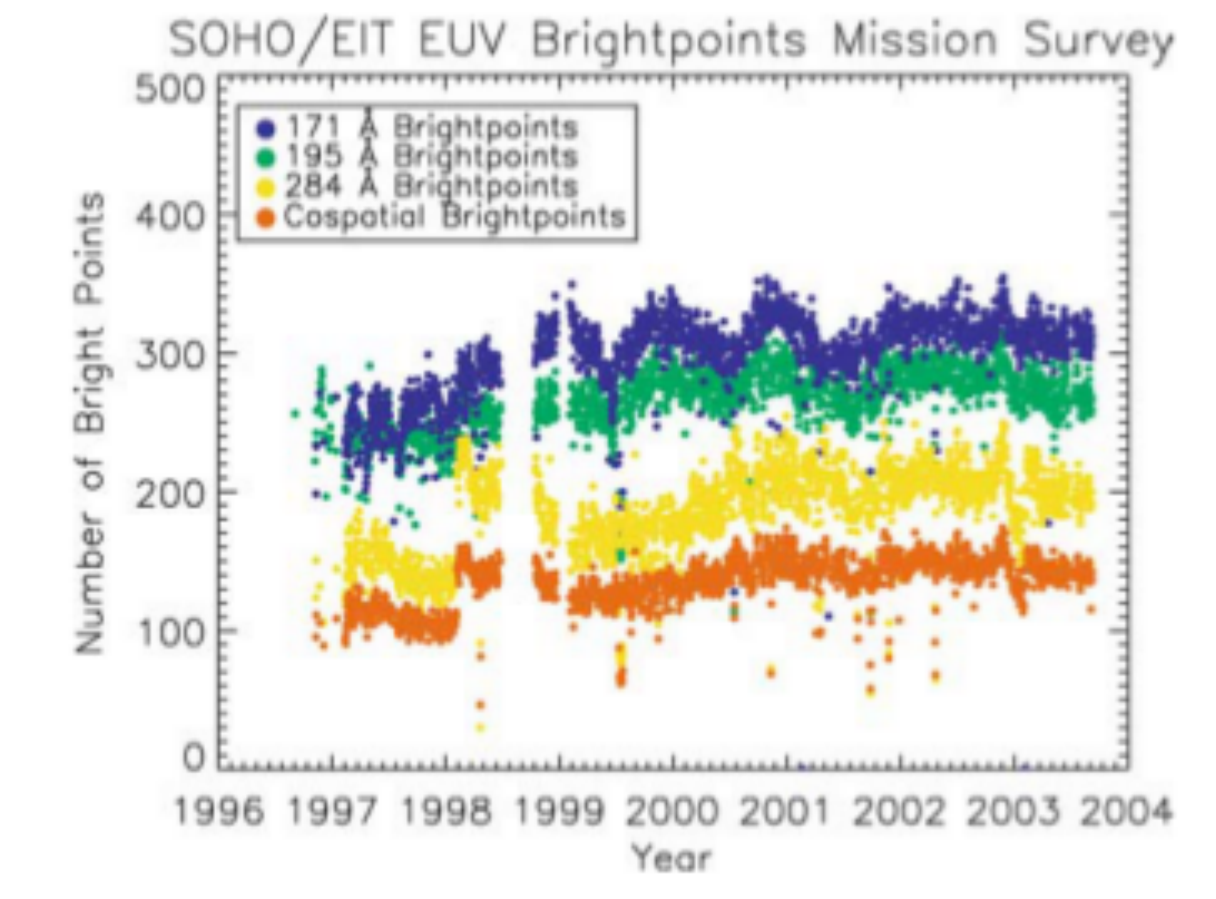


Zhang et al. (2001)

- Golub et al. (1974), Golub et al. (1976), Harvey et al. (1993) - 11 hrs in X-rays on average.
- Zhang et al. (2001) - average in EUV, EIT 195 Å, 20 hrs, shorter appearance in X-rays. Mou et al. (2016) - 2.7 to 58.8 hrs; Madjarska & Galsgaard (in prep) - shortest 6 hrs; Madjarska et al. (2020) - 9 days, a very large CBPs (diameter 100" or 720Mm diameter)

CBPs' occurence rate

✓More CBPs are seen in EUV at lower temperatures.



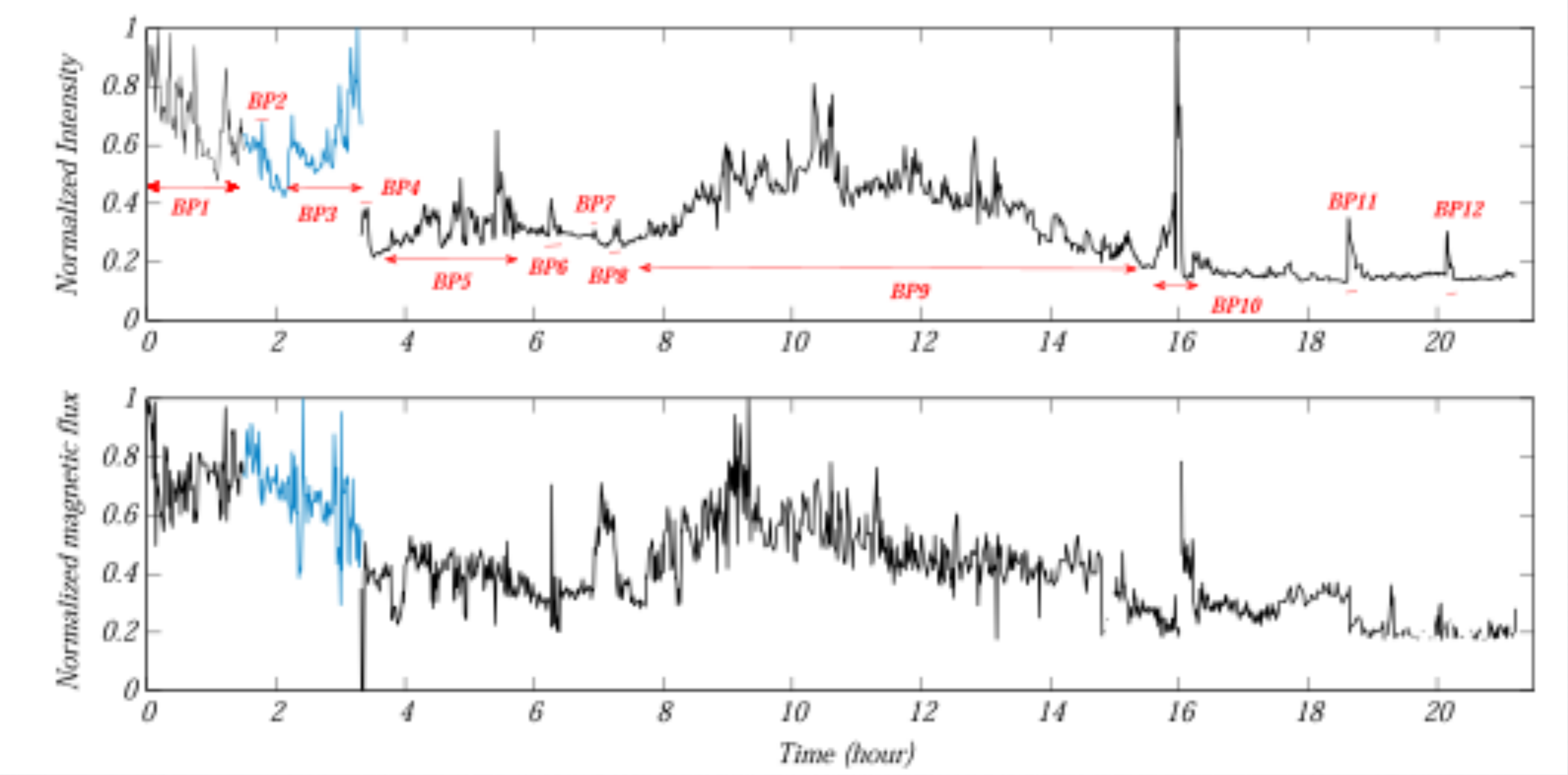
McIntosh & Gurman (2005)

✓ The daily average number of CBPs in the EUV 193 Å passband using the highest present EUV imaging observations from SDO/AIA is ~ 570 (visible disk), with a range from 427 to 790 (Alipour & Safari, 2015).

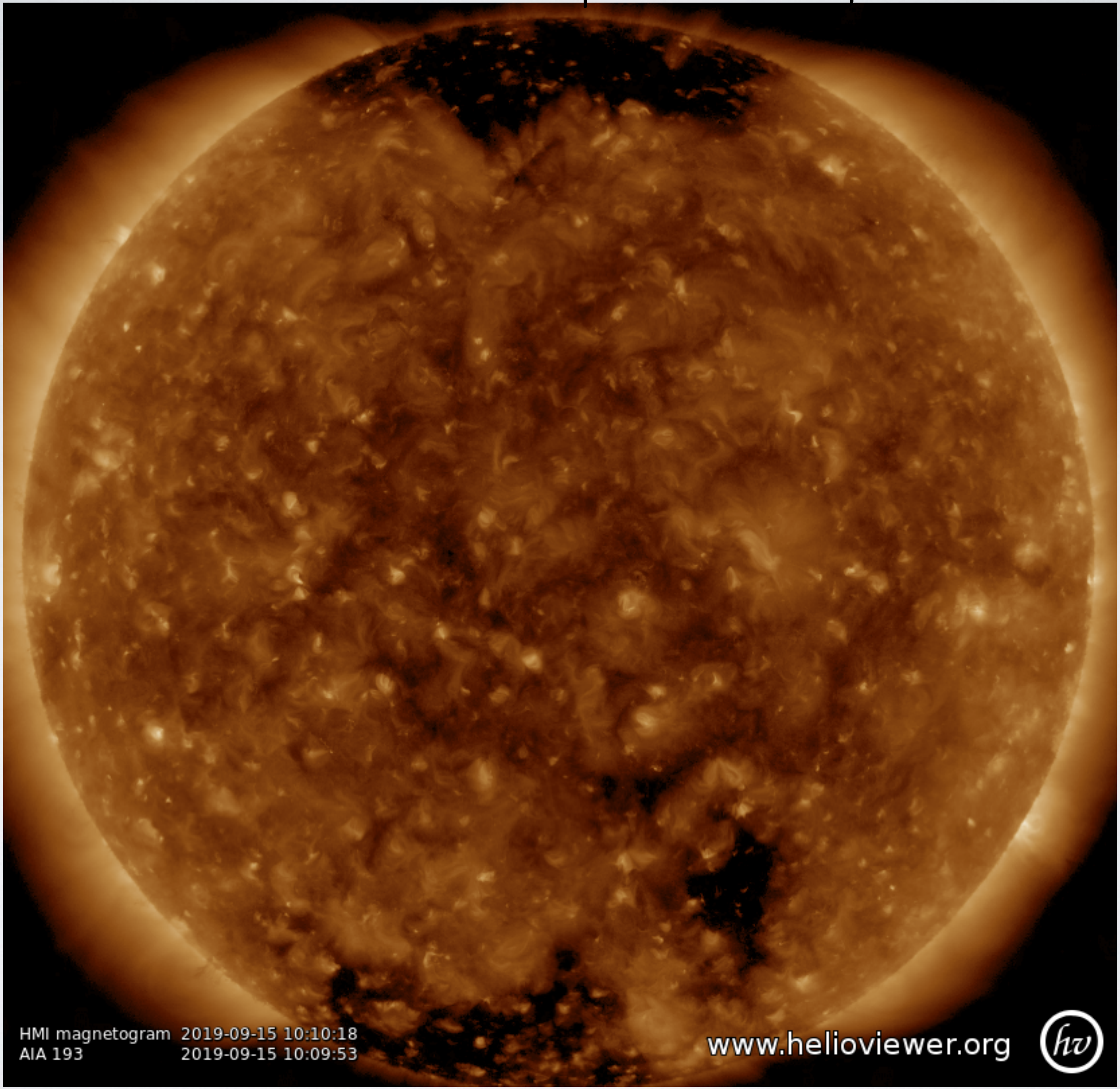
✓ Needs to be re-evaluated!

General properties: morphology, sizes, heights & lifetimes

Automatic identification (Alipour & Safari, 2015) from machine leaning => not straightforward because of the dynamic evolution of CBPs.



What are the small-scale loops - Coronal Bright Points?



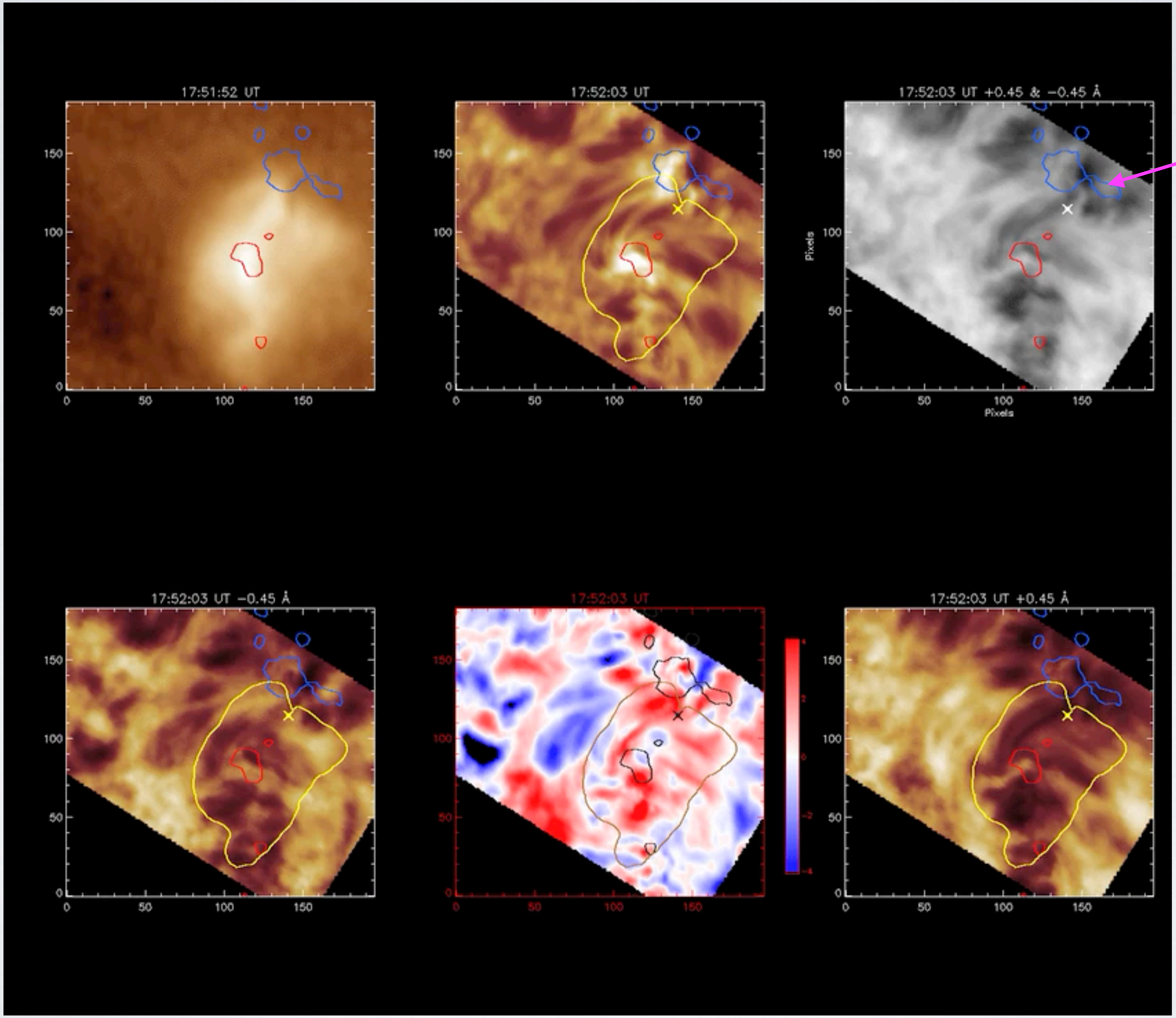
CBPs and transient dynamic phenomena

- ✓ **Spicules/mottles:** Populate the footpoints of CBP loops, some rise and fall along the footpoints of the loops.
- ✓ Microflares:
  - ➡ Sudden intensity increase of a few order of magnitude above the CBP background emission (Golub et al., 1974, Skylab, Strong et al., 1992, Yohkoh/SXT)
  - ➡ Magnetic flux convergence, magnetic reconnection close to the opolarity inversion line (PIL), duration ~10-20 min
  - ➡ While QS microflares in CBPs were linked to the formation mini-eruptions (mini-CMEs), in CHs CBPs' jets are produced in relation to the microflares (Kamio et al., 2011); different background magnetic field configuration.
- ✓ Jets: In coronal holes CBPs produce collimated flows seen in EUV and X-rays.
- ✓ Mini-CMEs: In the quiet Sun almost 80% of CBPs produce eruptions, at least 870/24h CBP over the whole Sun.
- ✓ Mini-filaments are usually observed to erupt during mini-CMEs & jets occupying part of the `dimming' regions or being part of the jet outflows in coronal holes. Average lifetime ~70hr and size 15", at least 600/24h over the whole Sun (Hermanns & Martin, 1986)

CBPs and transient dynamic phenomena: spicules/mottles

AIA 193

FISS/BBSO



spicules/mottles

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Madjarska et al. (2021)

CBPs and transient dynamic phenomena

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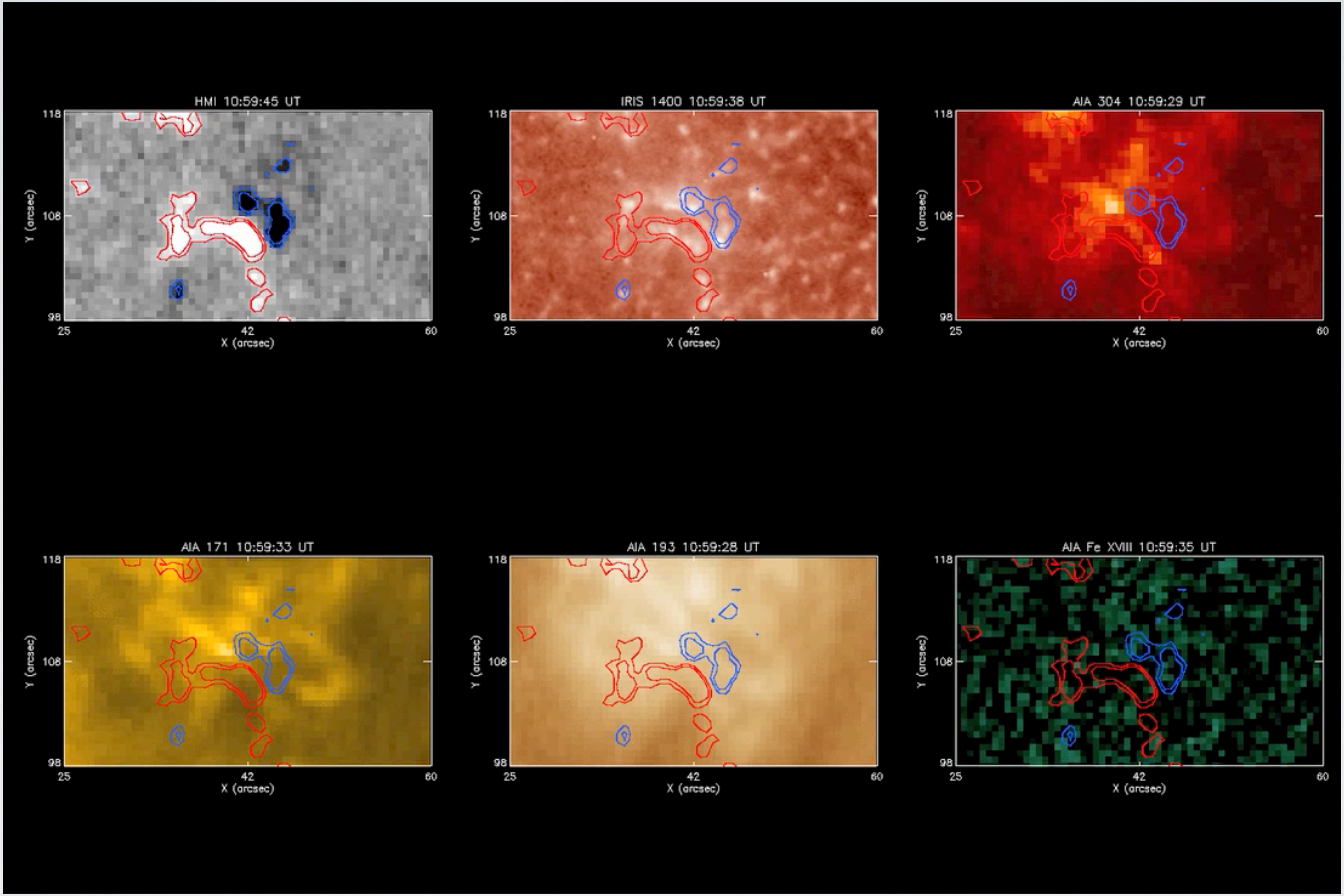
CBPs and transient dynamic phenomena: microflares



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Madjarska et al. (2022)

CBPs and transient dynamic phenomena: jets

- ✓ Spicules/mottles: Populate the footpoints of CBP loops, some rise and fall along the footpoints of the loops.
- ✓ Microflares:
  - ➡ Sudden intensity increase of a few order of magnitude above the CBP background emission (Golub et al., 1974, Skylab, Strong et al., 1992, Yohkoh/SXT)
  - ➡ Magnetic flux convergence, magnetic reconnection close to the polarity inversion line (PIL), duration ~10-20 min
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CBPs and transient dynamic phenomena: mini-CMEs

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CBPs and transient dynamic phenomena: mini-CMEs

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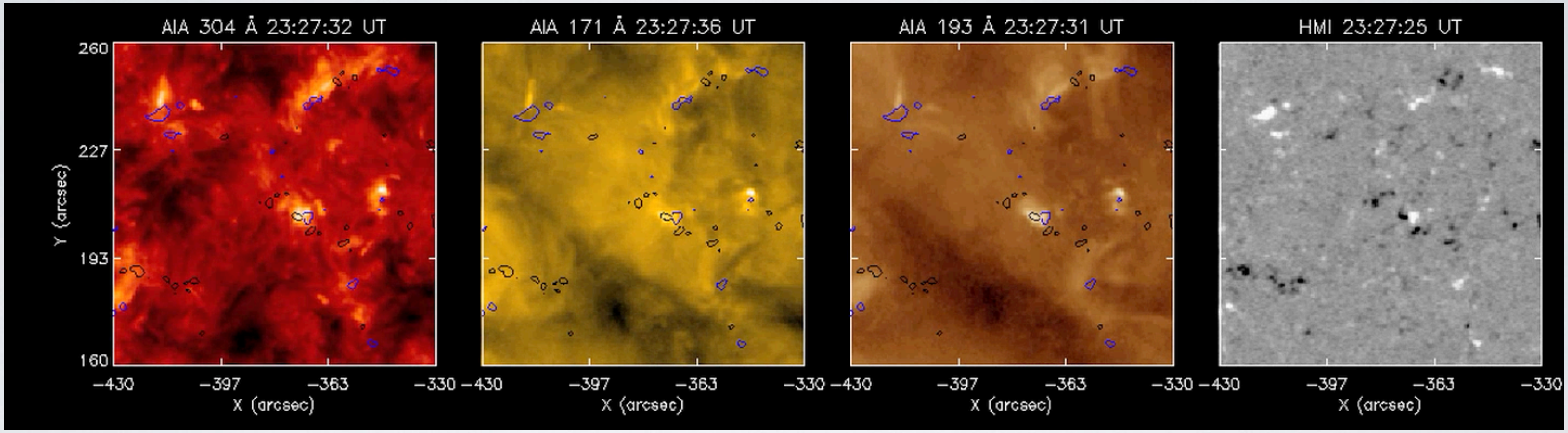

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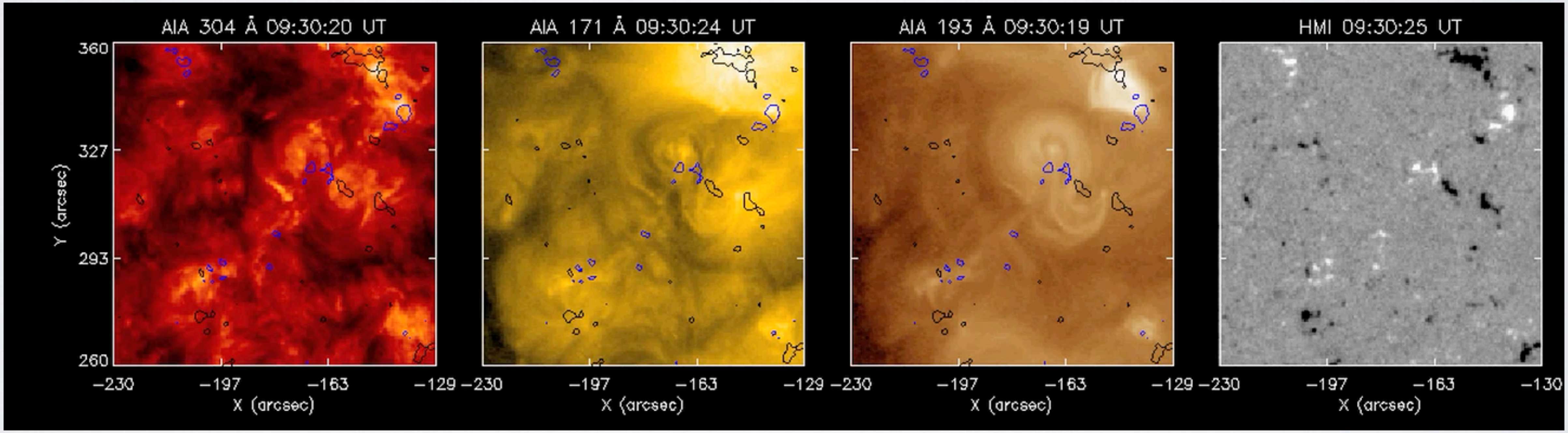

Mou et al. (2018)

CBPs and transient dynamic phenomena: mini-filaments

✓ Spicules/mottles: Populate the footpoints of CBP loops, some rise and fall along the footpoints of the loops.

✓ Microflares:

- ➡ Sudden intensity increase of a few order of magnitude above the CBP background emission (Golub et al., 1974, Skylab, Strong et al., 1992, Yohkoh/SXT)
- ➡ Magnetic flux convergence, magnetic reconnection close to the opolarity inversion line (PIL), duration ~10-20 min
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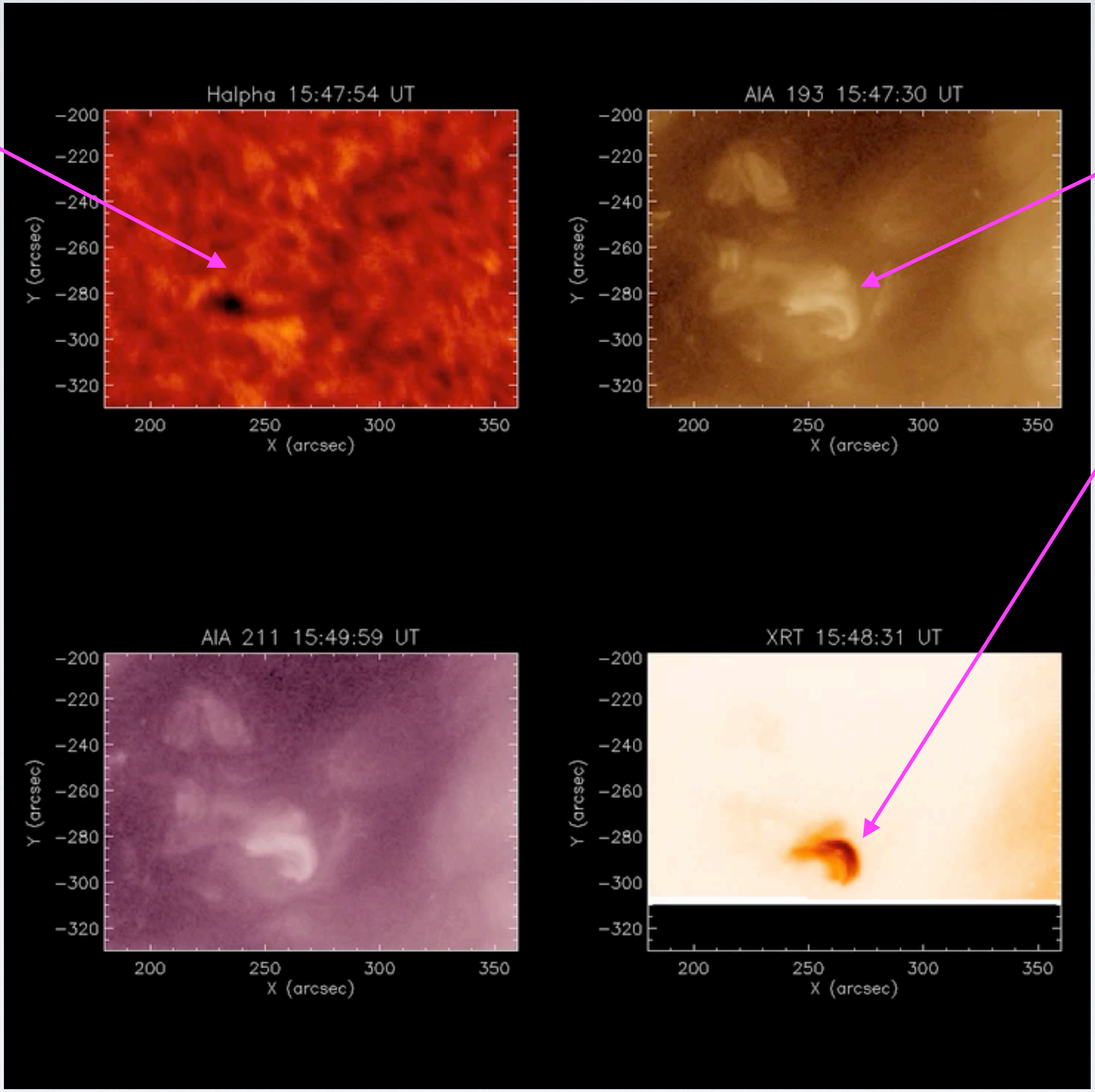
CBPs and transient dynamic phenomena: mini-filaments

Mini-filament, GONG data

CBP in a coronal hole



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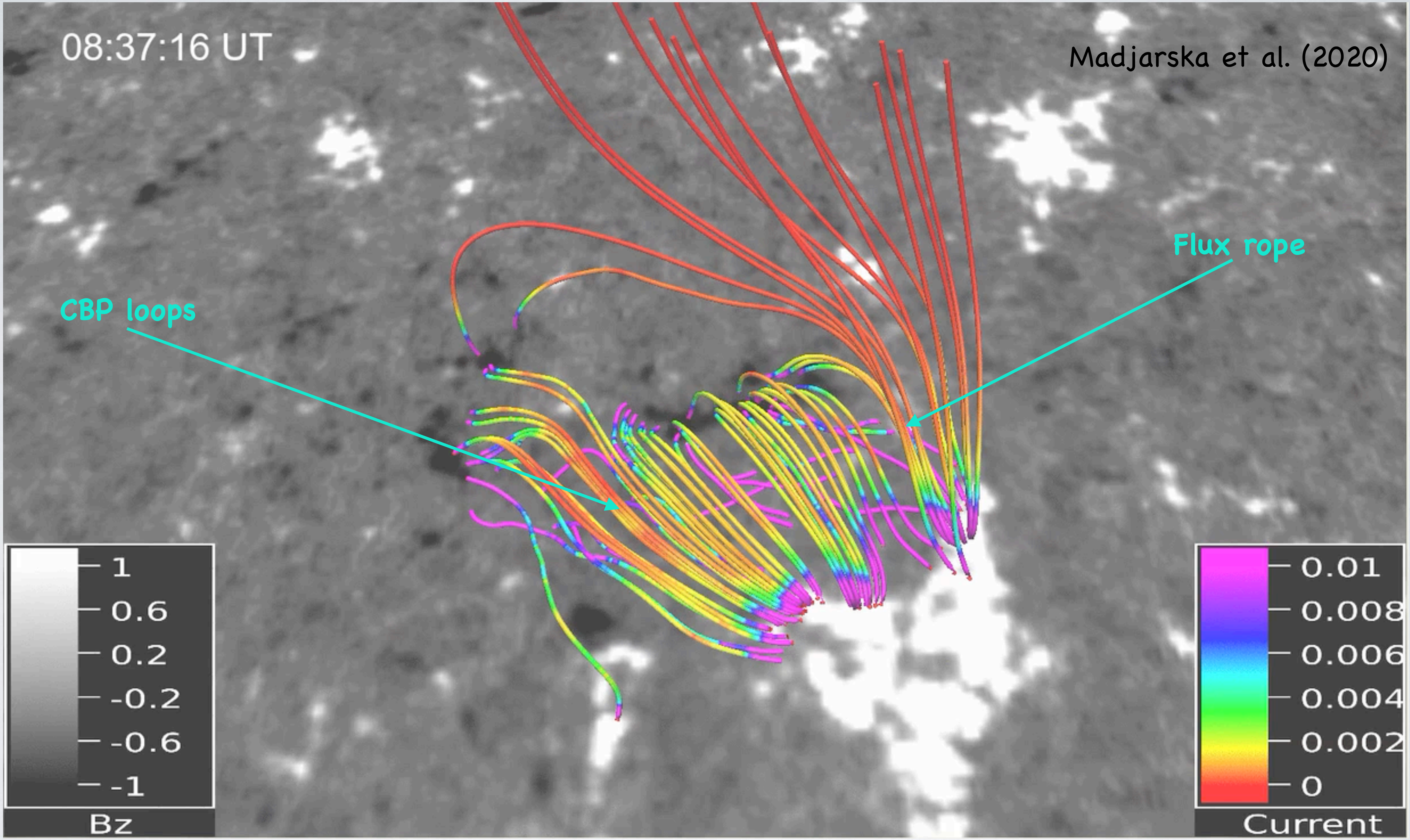
Madjarska et al. (2020)

CBPs and transient dynamic phenomena: flux-rope formation



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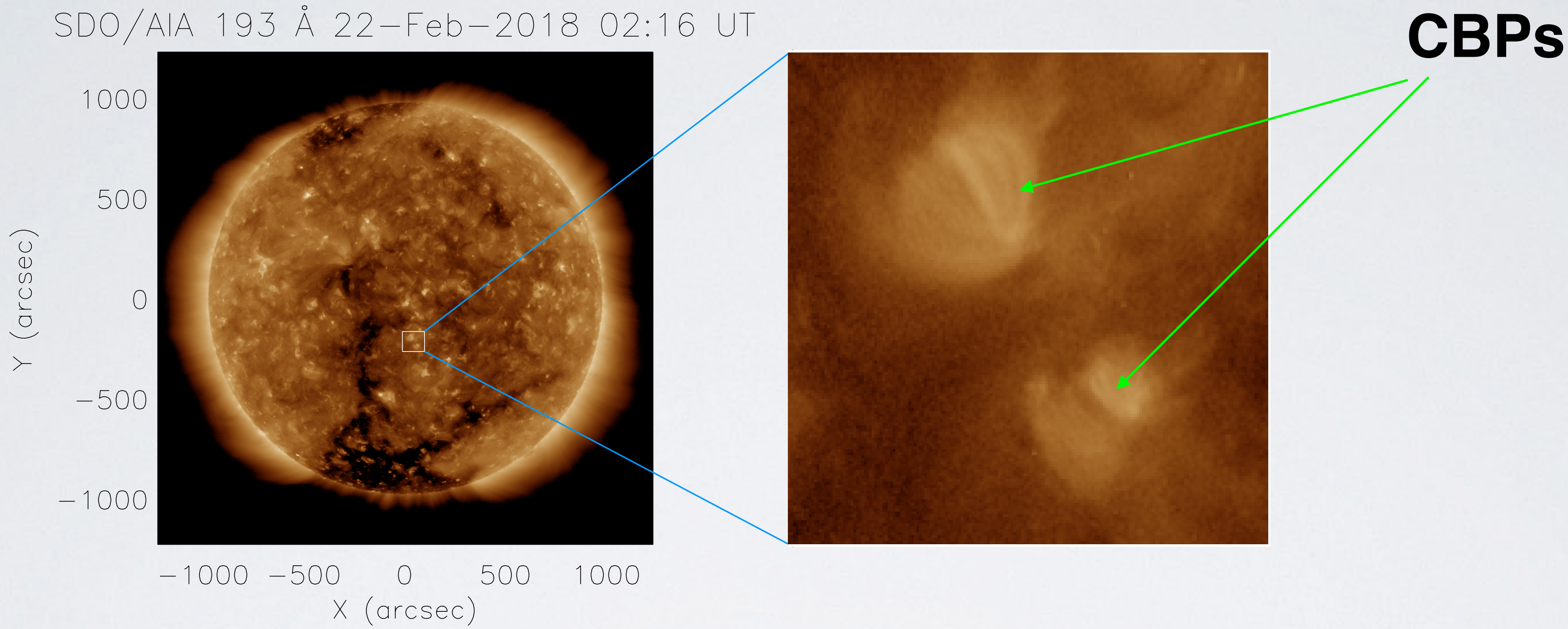
Magneto-frictional modeling of the formation of magnetic flux rope that hosts a mini-filament beneath the CBP loops

General definition and conclusions

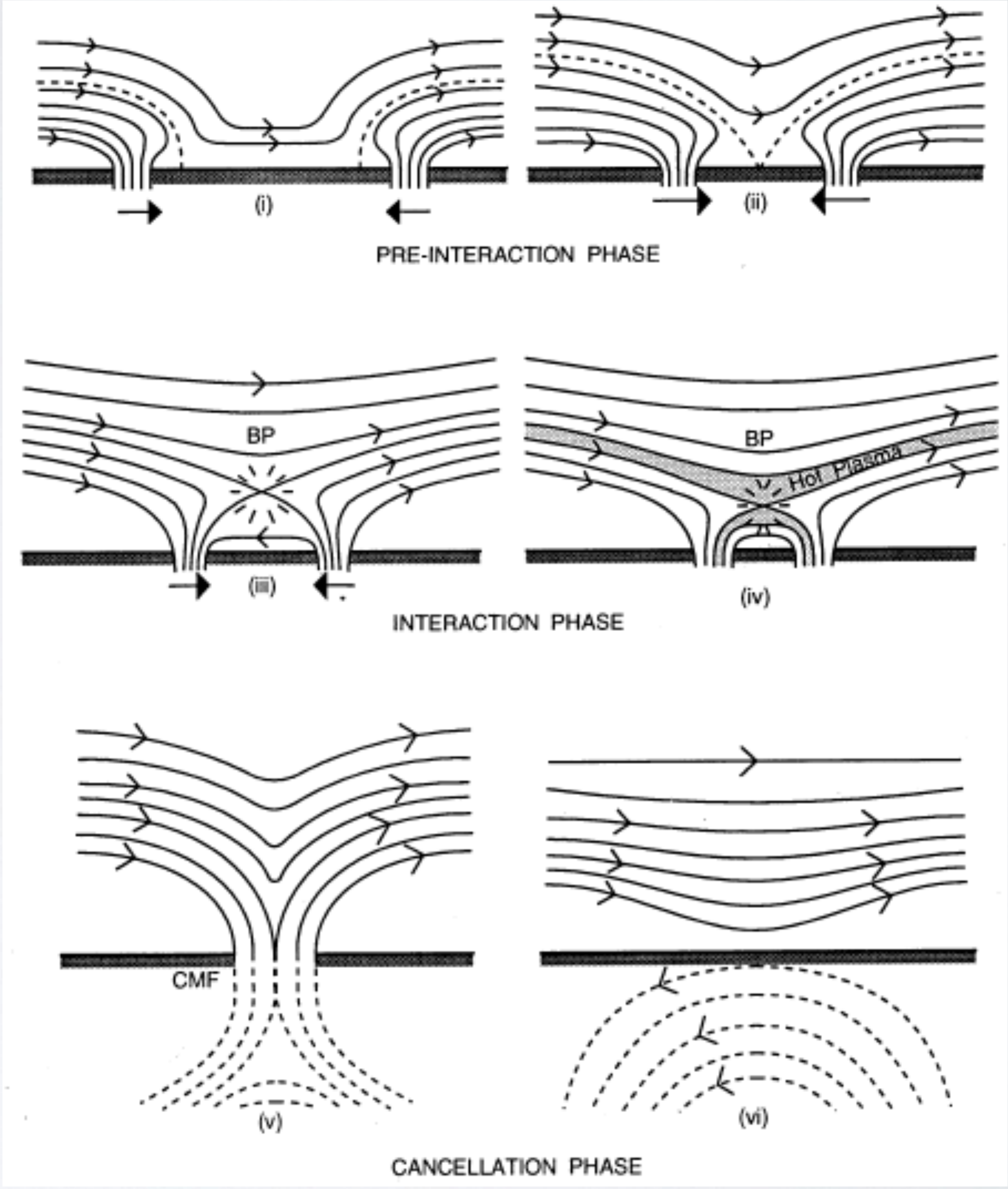
Coronal Bright Points - small-scale loops in the quiet Sun



- ✓ Definition: Coronal Bright Points (CBPs) describe small-scale multi-loop systems that appear in extreme-ultraviolet and X-ray images with enhanced emission and are associated with bipolar magnetic flux concentrations.
- ✓ A loop system does not need to be bright to be a CBP!!!! There are numerous faint loops that may have been or not been bright during their lifetime.
- ✓ Plasma parameters: temperatures and density closer to AR than the QS => CBPs are downscaled ARs

Modelling: Converging Flux Model (CFM)

(i) Two magnetic fragments converge driven by the horizontal phot. flow reaching a certain distance
(ii) Null point in the photosphere
(iii) Interaction phase - the null point lifts up to form an X-type null point in the corona reaching a maximum height that is half the interactive distance
(iv) Plasma is ejected along the newly reconnected field lines
(v) Null point moves down to the photosphere
(vi) Magn. fragments come into contact that causes magnetic reconnection in the photosphere which is the cancellation phase
(vii) Most recent: Wyper et al. 2018 - "A Model for Coronal Hole Bright Points and Jets Due to Moving Magnetic Elements"



Priest et al., 1994

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Coronal bright points

Maria S. Madjarska

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Solar Activity

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About this article

Abstract

Coronal bright points (CBPs) are a fundamental class of solar activity. They represent a set of low-corona small-scale loops with enhanced emission in the extreme-ultraviolet and X-ray spectrum that connect magnetic flux concentrations of opposite polarities. CBPs are one of the main building blocks of the solar atmosphere outside active regions uniformly populating the solar atmosphere including active region latitudes and coronal holes. Their plasma properties classify them as downscaled active regions. Most importantly, their simple structure and short lifetimes of less than 20 h that allow to follow their full lifetime evolution present a unique opportunity to investigate outstanding questions in solar physics including coronal heating. The present Living Review is the first review of this essential class of solar phenomena and aims to give an overview of the current knowledge about the CBP general, plasma and magnetic properties. Several transient dynamic phenomena associated with CBPs are also briefly introduced. The observationally derived energetics and the theoretical modelling that aims at explaining the CBP formation and eruptive behaviour are reviewed.

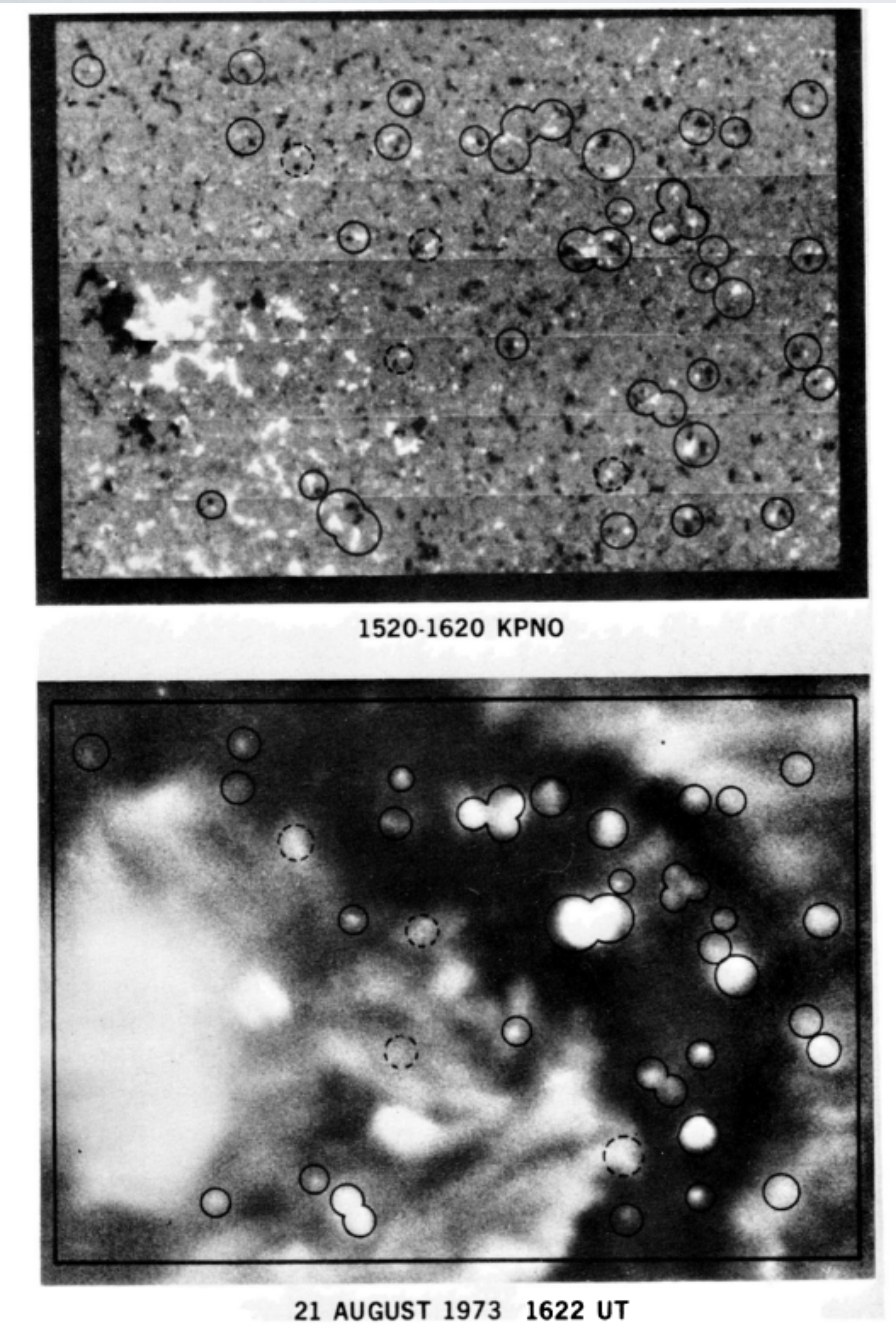
Introduction

The solar corona seen in extreme-ultraviolet (EUV) and X-rays is mainly composed of loops with a wide spectrum of sizes. Luminous active region (AR) loops together with AR

Photospheric magnetic flux and coronal bright points

- ✓ The very first time solar X-ray observations were coupled with photospheric longitudinal magnetic field images, it became apparent that X-ray bright point-like structures are associated with underlying photospheric magnetic flux concentration.
- ✓ **CBPs are associated with photospheric flux of opposite polarities** (Krieger et al, 1971, Harvey et al. 1975, Golub et al., 1976, 1977, Harvey et al. 1984, 1985, 1994, Webb et al. 1993, Pres & Phillips., 1999, Brown et al. 2001, Madjarska et al. 2003, Mandrini et al. 2005, Mou et al. 2016, 2018, Madjarska & Galsgaard, in prep)
- ✓ **Loops (CBPs) always connect magnetic flux concentrations of opposite polarities!!!**
- ✓ If only one polarity is visible:
  - ➡ Golub (1977), all XBPs are associated with bipolar regions except newly emerging or decaying loops => below the resolving power of the observing instrument
  - ➡ from extrapolations: loops connect magnetic polarities with different strength (Wiegelmann et al., 2010, Xie et al., 2017, Madjarska et al., 2021).
  - ➡ could be a footpoint of a very large loop which other footpoint is rooted at a far away distance

Photospheric magnetic flux and coronal bright points



Golub et al. (1977)

Golub et al. (1977):

- **used:** Kitt Peak National Observatory magnetograms and Skylab X-ray images to study Ephemeral Regions (ER) and their relation to CBPs
  - ER - Dodson (1953) to describe a newly emerging and short lasting bipolar region on the Sun
  - Harvey and Martin (1973) and Harvey et al. (1975) defined ERs as small bipolar regions (size of ~40") with a total magnetic flux of up to ~10^{20} Mx that is now known to be as low as 10^{16} Mx (Guglielmino et al. 2012).
- **to answer:** qualitative and quantitative questions concerning the bipolarity of XBPs, their relation to flux emergence, and the CBP contribution to the total emerging flux on the Sun.
- **found:** 49% of the ERs are linked to XBPs (36 out of 73 XBPs), the remaining ERs - with diffuse X-ray brightenings overlaid by large coronal structures

Photospheric magnetic flux and coronal bright points

- ✓ Tang et al. (1982) - no one-to-one correspondence of ERs and CBPs at transition region and coronal temperatures, with more ERs than CBPs present at any given time
- ✓ Harvey et al. (1985) - He I 10830 "dark" points, 11 year period, 1/3 assoc. with ERs, 2/3 - chance encounter => chance encounter of magnetic flux and magnetic reconnection is the mechanism to "remove" magnetic flux on the Sun.
- ✓ Harvey et al. (1994) - simultaneous time sequences of longitudinal magnetic field data taken at the Kitt Peak National Observatory and Yohkoh/SXT images => complex than previously thought. Two-thirds of all magnetic bipoles appeared not to be related to XBPs. => not all bipoles can support loops with plasma heated to high temperatures.
- ✓ The authors concluded that "emergence and cancelation of magnetic flux in the photosphere is not in itself a necessary and sufficient condition for the occurrence of an XBP. Rather, it is the interaction and reconnection of magnetic field with the existing, overlying magnetic field configuration that results in the occurrence and variability of XBPs."
- ✓ XBPs (very high temperatures) are associated with decaying and cancelling magnetic features (Harvey, 1988, Webb et al., 1993).

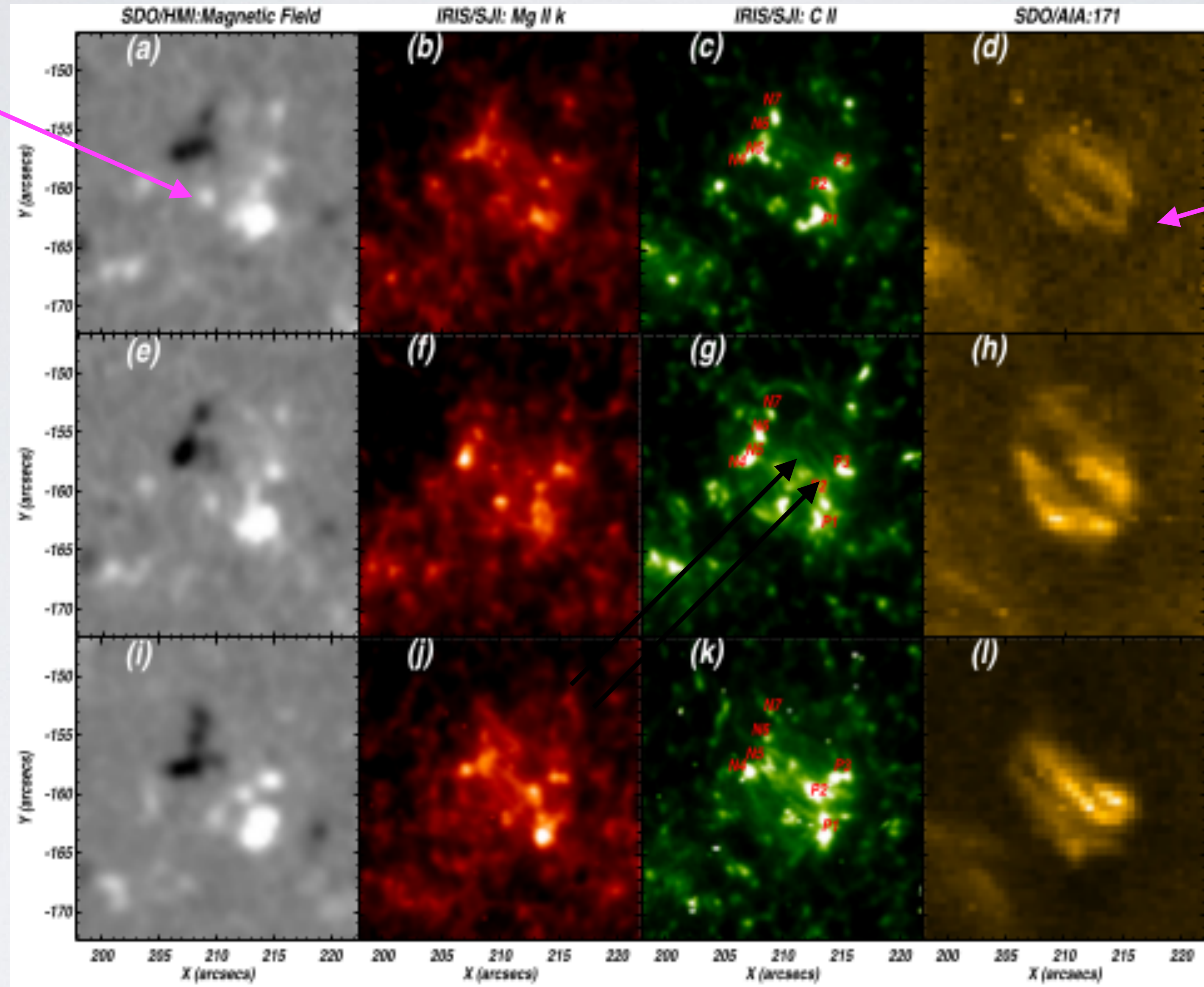
Photospheric magnetic flux and coronal bright points

Bipolar region

Chrom

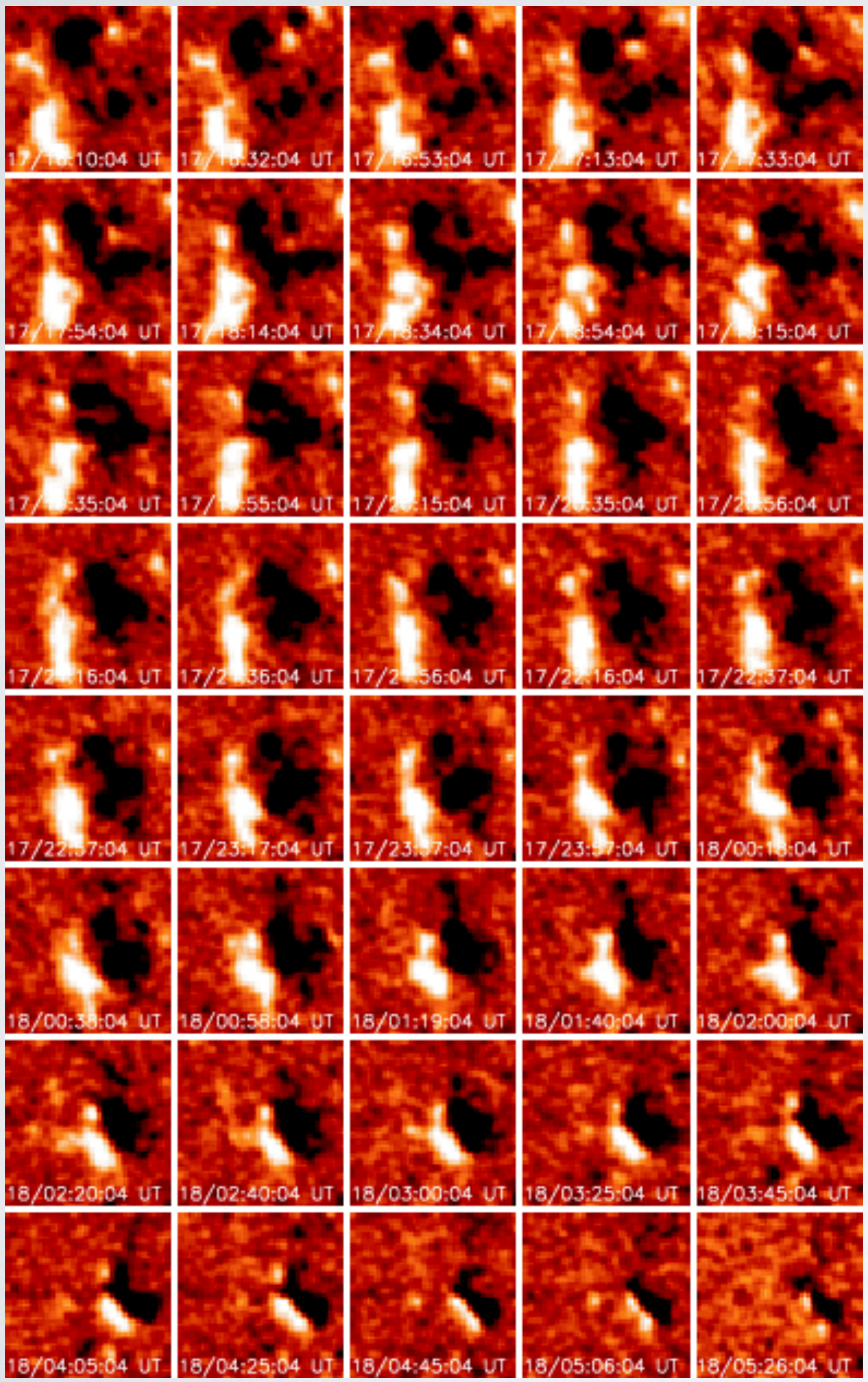
Chrom/TR

Corona: CBP <=> loop system



Temporal evolution of a CBP. From left to right: SDO/HMI longitudinal magnetograms showing the bipole associated with the CBP. IRIS SJ images in the MgII k 2796 Å passband, SJI in the CII 1330 Å passband, and SDO/AIA 171 Å images. The top row images are taken at 11:33 UT, the middle row at 11:43 UT, and the bottom row at 12:03 UT (Kayshap and Dwivedi, 2017).

Photospheric magnetic flux and coronal bright points



Madjarska et al. (2003)

- ✓ Older studies: Harvey (1984) and Harvey et al. (1994) established that 70% - 80% of XBPs are associated with the chance encounter of network flux and only 20% - 30% are related to newly emerging bipolar fluxes
- ✓ Recent studies: 50% of CBPs are formed from flux emergence (Mou et al., 2016, Madjarska & Galsgaard, in prep)

CBPs' photospheric magnetic flux range, emergence and disappearance rate

- ✓ Past studies: 10^{19} - 10^{20} Mx (Krieger et al., 1971; Harvey et al 1975, Golub et al., 1976; 1977), with most typical values of 2 – 5 × 10^{19} Mx
- ✓ Case studies: – Prés & Philips (1999) (SOHO/MDI), 5 × 10^{19} Mx, Madjarska et al. (2003) – 2.0 × 10^{20} Mx at the peak of the evolution (SOHO/MDI), Longcope et al. (2001) – average 1.3 × 10^{19} Mx (SOHO/MDI)
- ✓ The total magnetic flux emerging on the Sun per day associated with XBPs ranges between 1.2 × 10^{22} Mx and 3.6 × 10^{22} Mx (Golub et al., 1976)
- ✓ for AR latitudes only – 1.2 × 10^{21} – 1.2 × 10^{22} Mx (Golub et al., 1976)

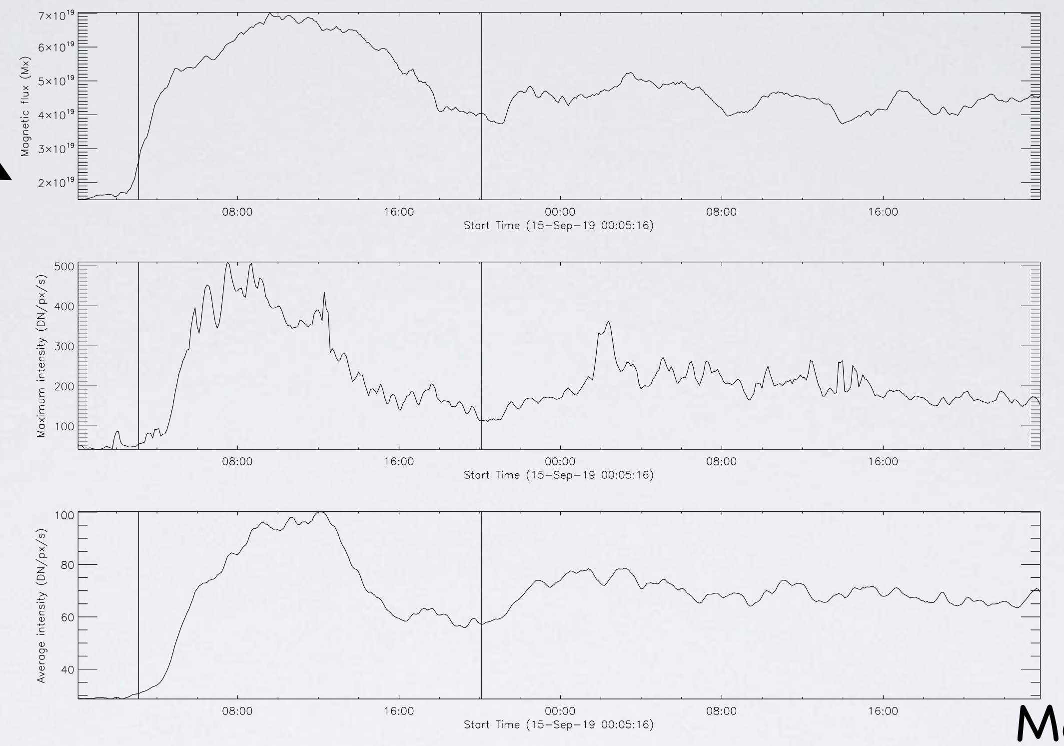
CBPs' photospheric magnetic flux range, emergence and disappearance rate

✓ Madjarska & Galsgaard (in prep) - revisited the magnetic properties of CBPs with SDO/HMI combined with co-temporal AIA data

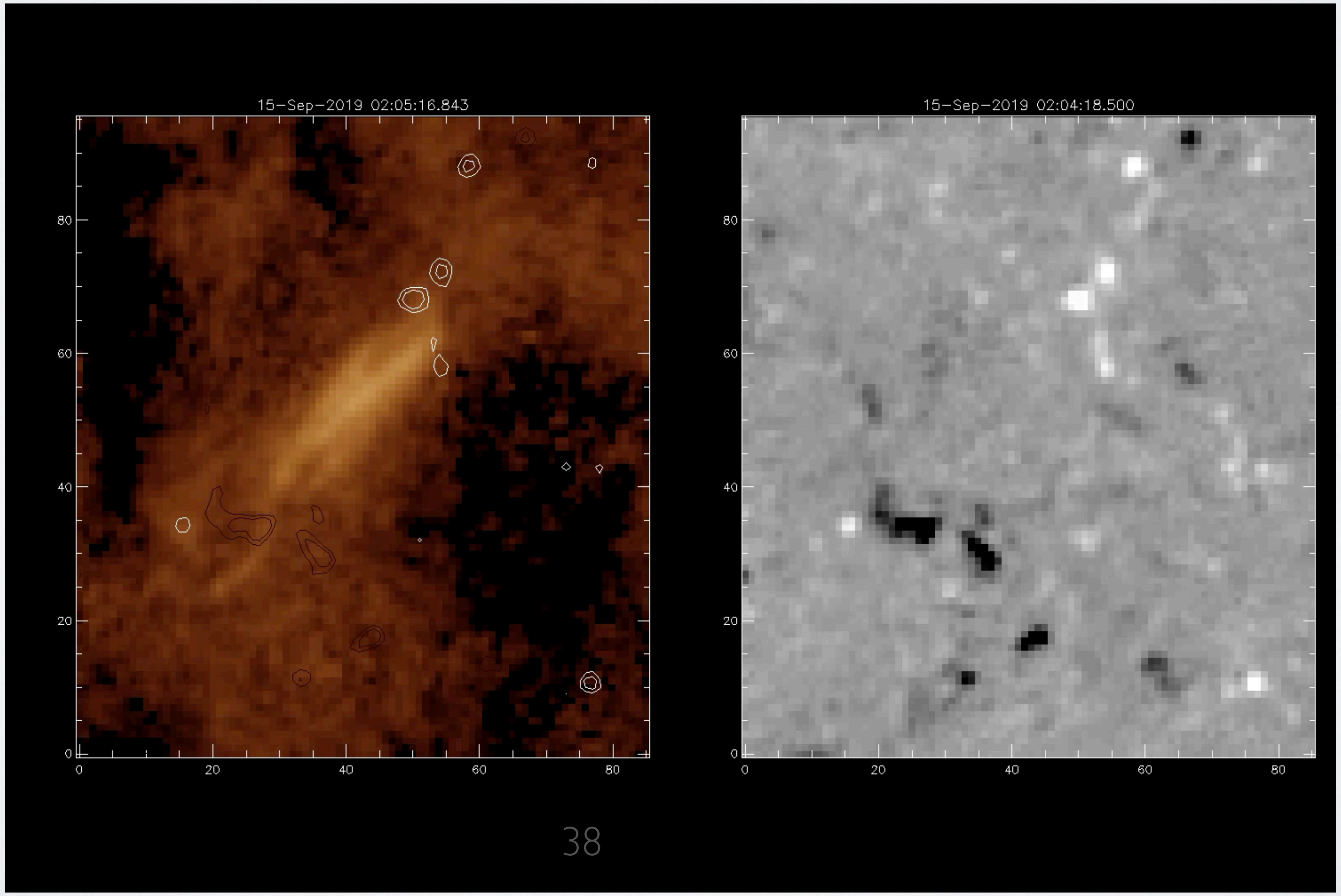
- from 3×10^{18} Mx to 1.8×10^{20} Mx (HMI, B_{los})
- magnetic flux emergence rate: average 2.3×10^{15} Mx s^{-1}, ranging from 1.2 to 4.8×10^{15} Mx s^{-1}
- disappearance rate - 0.49×10^{15} Mx s^{-1}, from 0.3 to 1.1×10^{15} Mx s^{-1}
- How this compares with studies that report on the properties of ERs?
    - mean magnetic flux - 9.3×10^{18} Mx (Yang and Zhang, 2014), 1.13×10^{19} Mx (Hagenaar, 2001), 1.3×10^{19} Mx (Schrijver et al., 1998) and studies that report larger values 2.5×10^{19} Mx (Martin, 1989), 3.3×10^{19} Mx (Chae et al., 2001), etc.
    - emergence rate - 3.4×10^{15} Mx s^{-1} (Harvey & Harvey, 1976), 2.2×10^{15} Mx s^{-1} (Wang, 1988), 1.6×10^{15} Mx s^{-1} (Hagenaar, 2001), 2.31×10^{15} Mx s^{-1} (Zhao & Li, 2012), 2.6×10^{15} Mx s^{-1} (Yang and Zhang 2014)

Examples: Flux emergence

fast, 4.3 $\times 10^{15}$ Mx s^{-1}



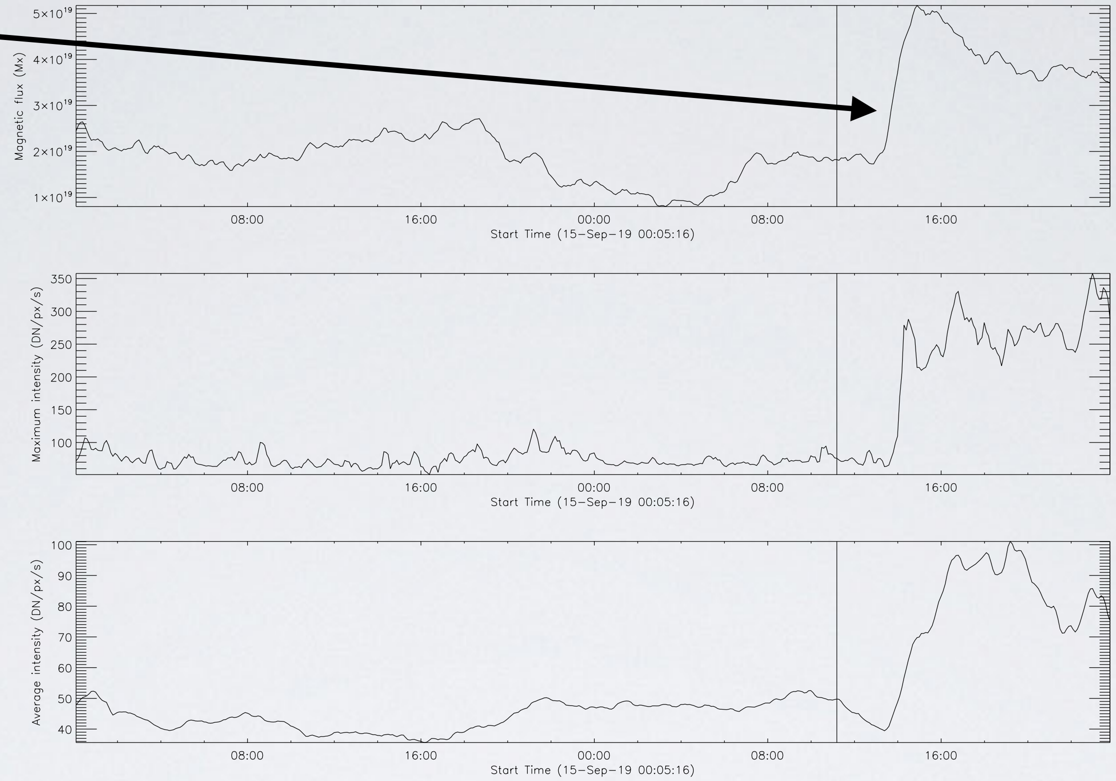
Madjarska & Galsgaard (in prep)



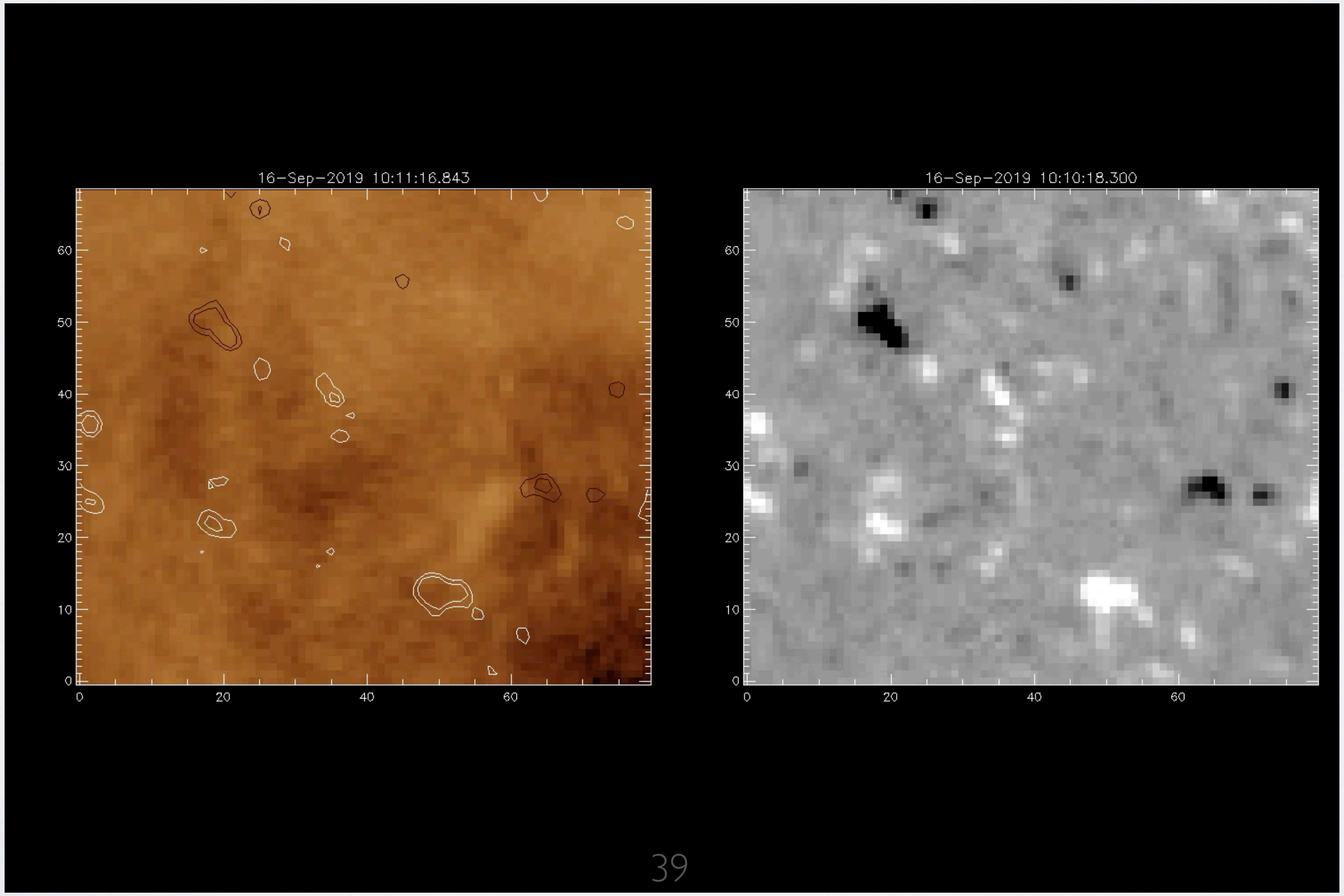
movie_7_isss

Examples: Flux emergence

fast, 4.9×10^{15} Mx s^{-1}



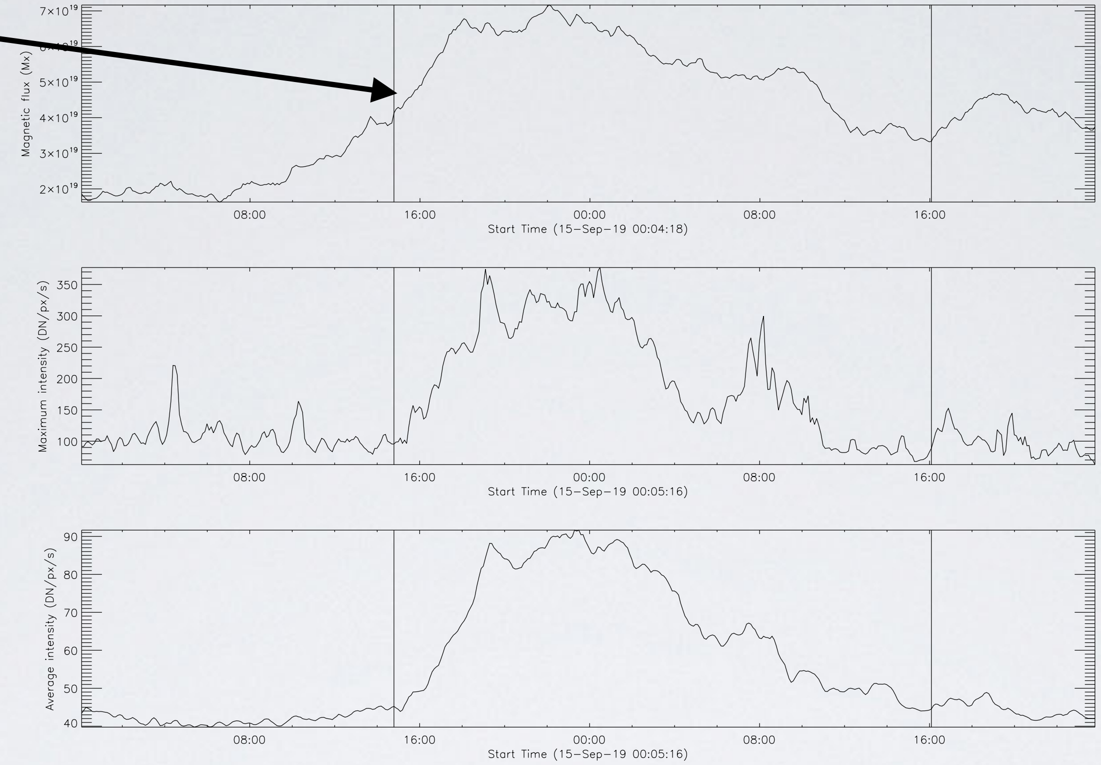
Madjarska & Galsgaard (in prep)



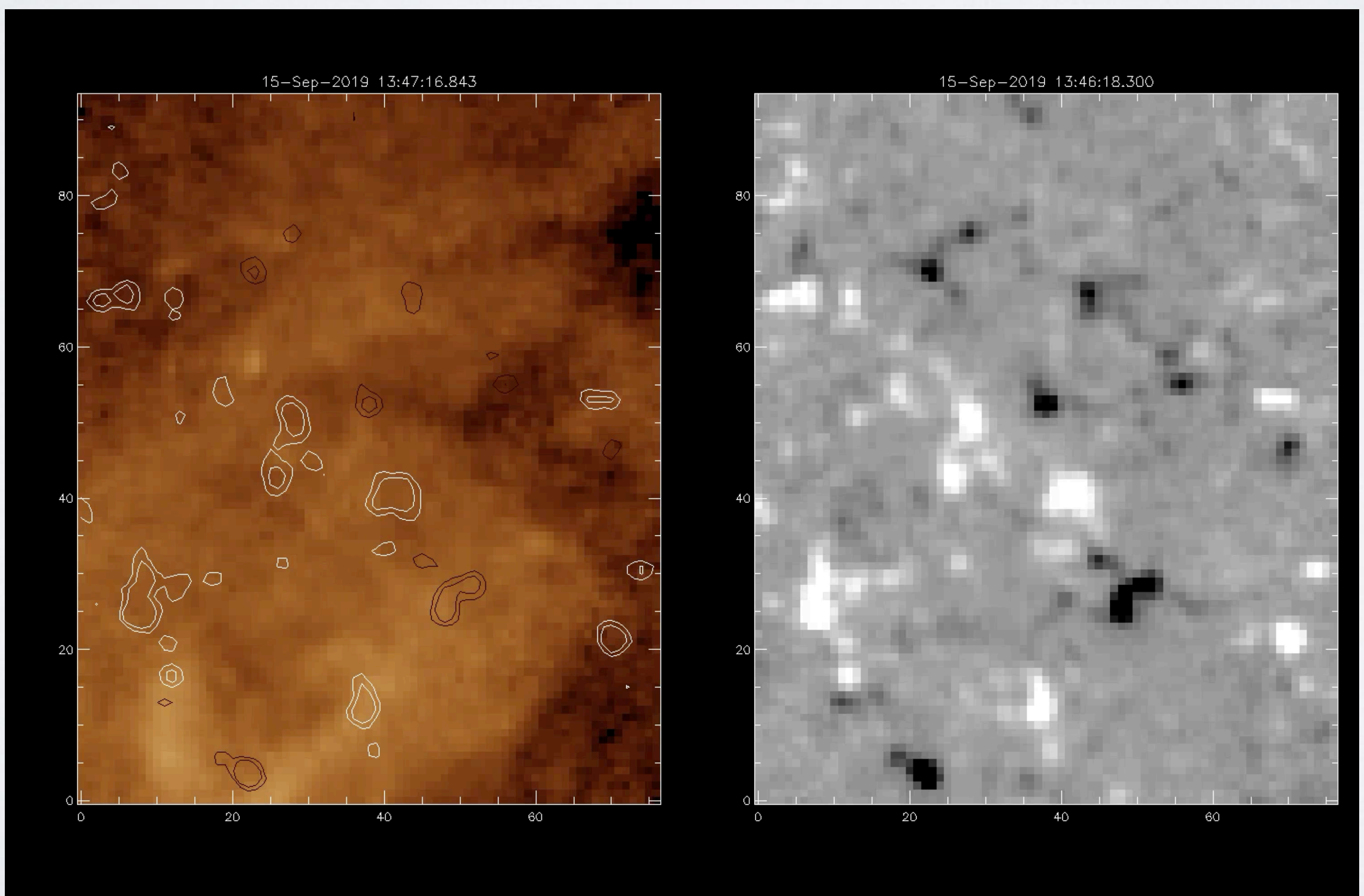
movie_8_isss

Examples: Flux emergence

2.1×10^{15} Mx s^{-1}



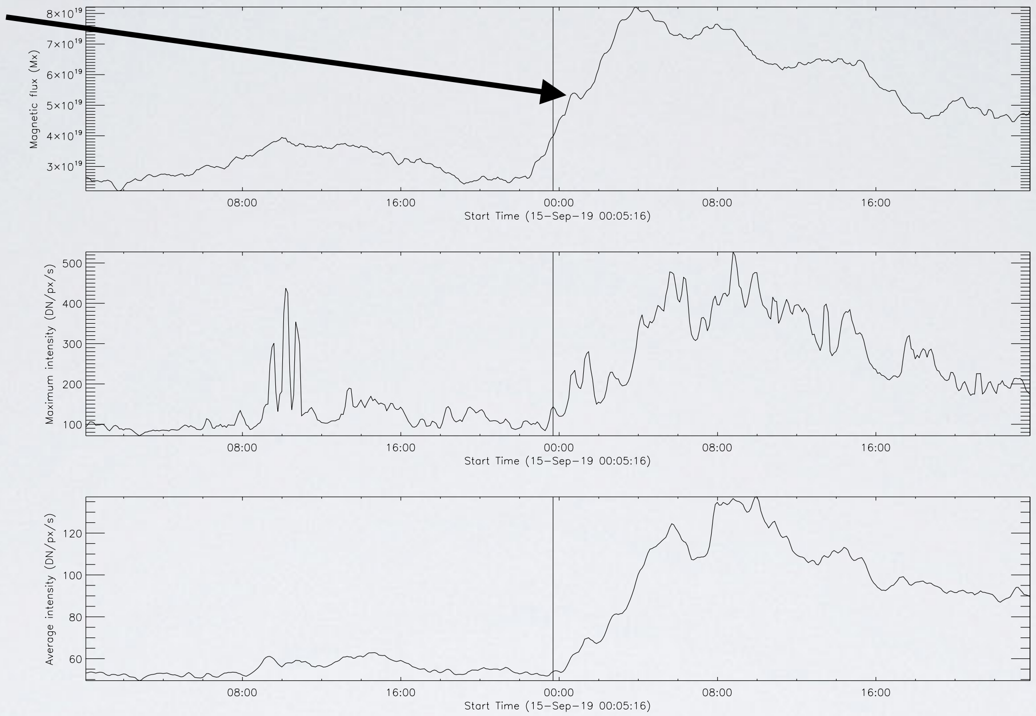
Madjarska & Galsgaard (in prep)



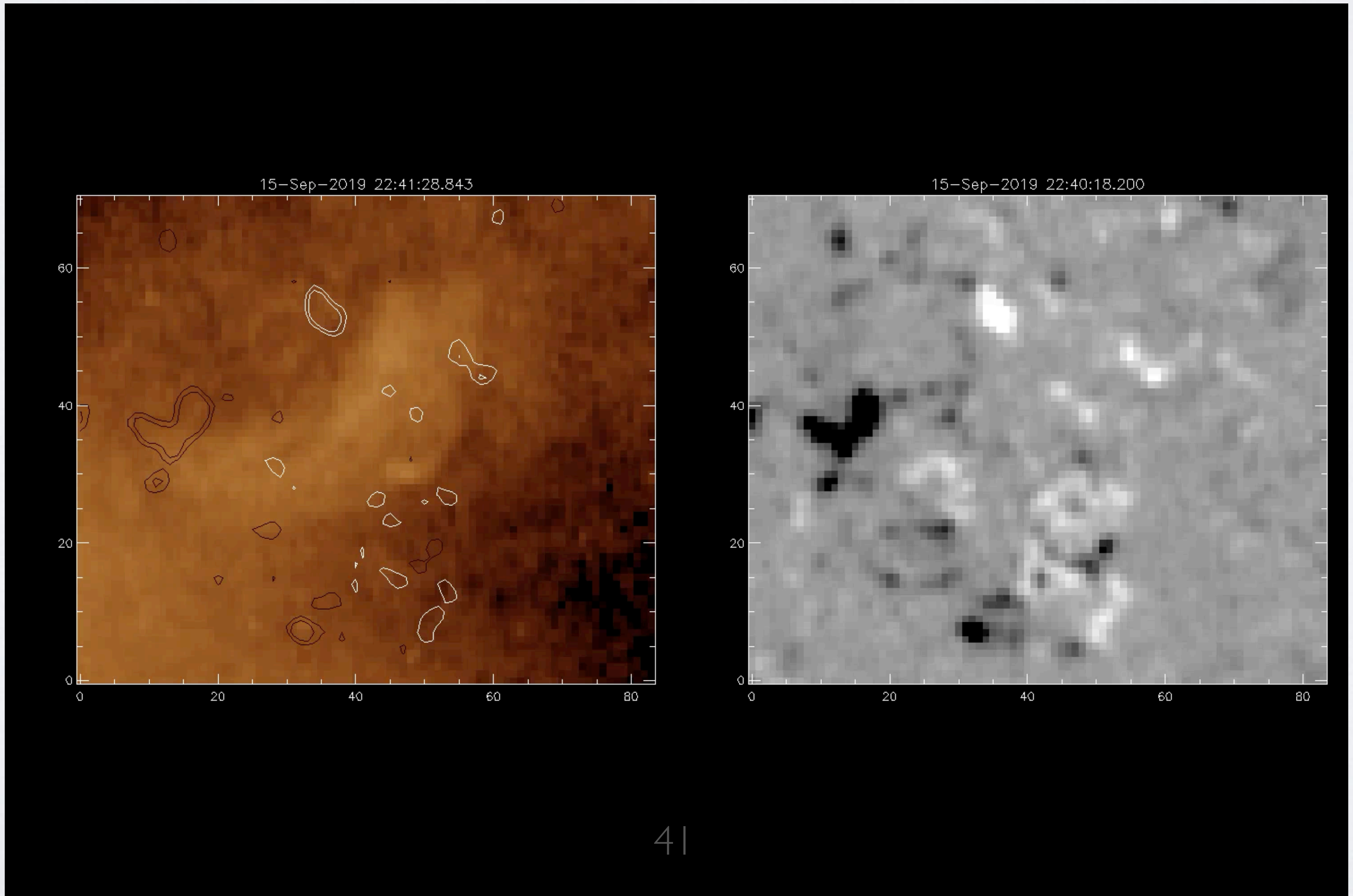
movie_9_isss

Examples: Flux emergence

1.7×10^{15} Mx s^{-1}



Madjarska & Galsgaard (in prep)



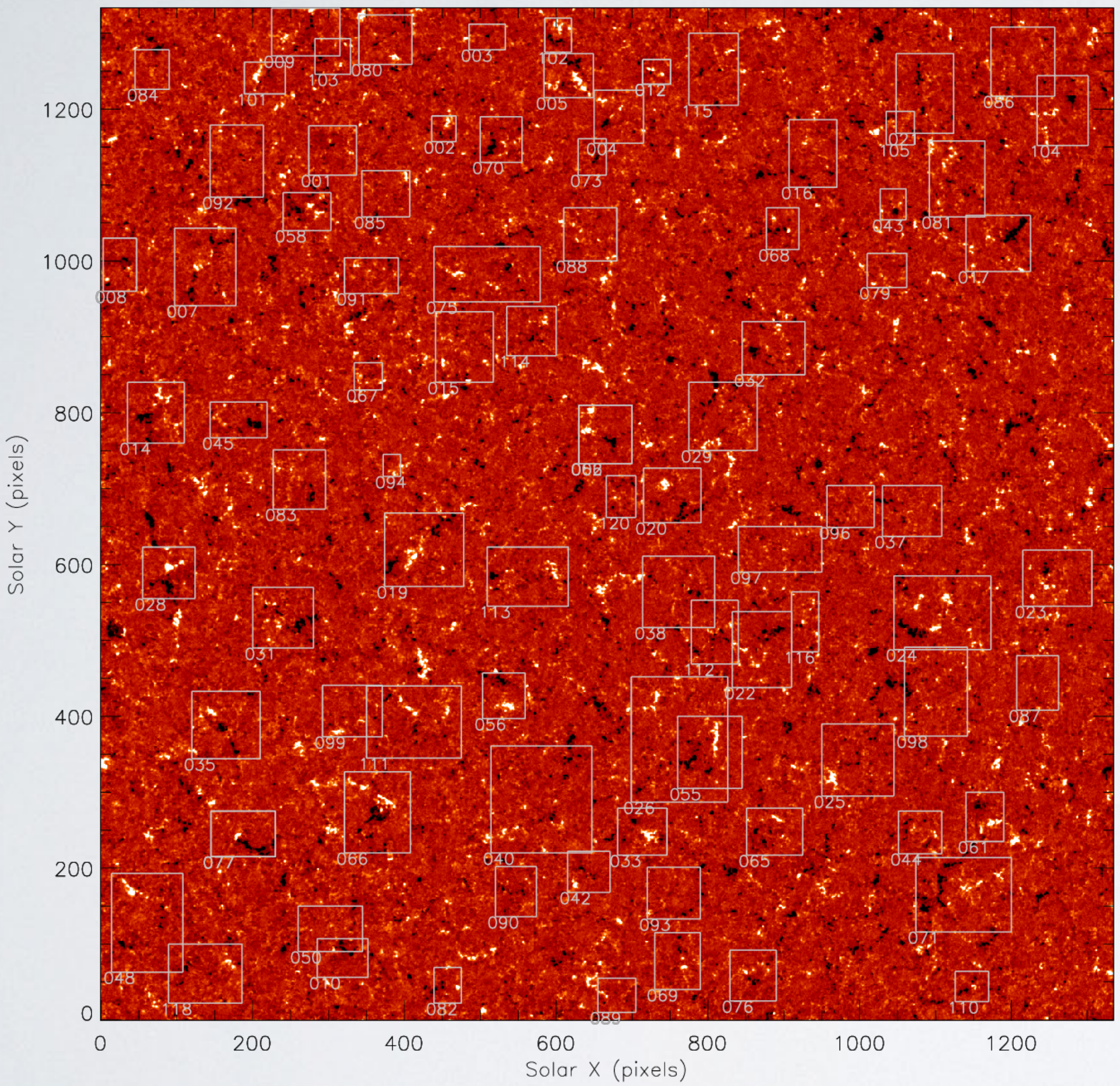
movie_10_isss

CBPs' photospheric magnetic flux: formation, evolution and disappearance

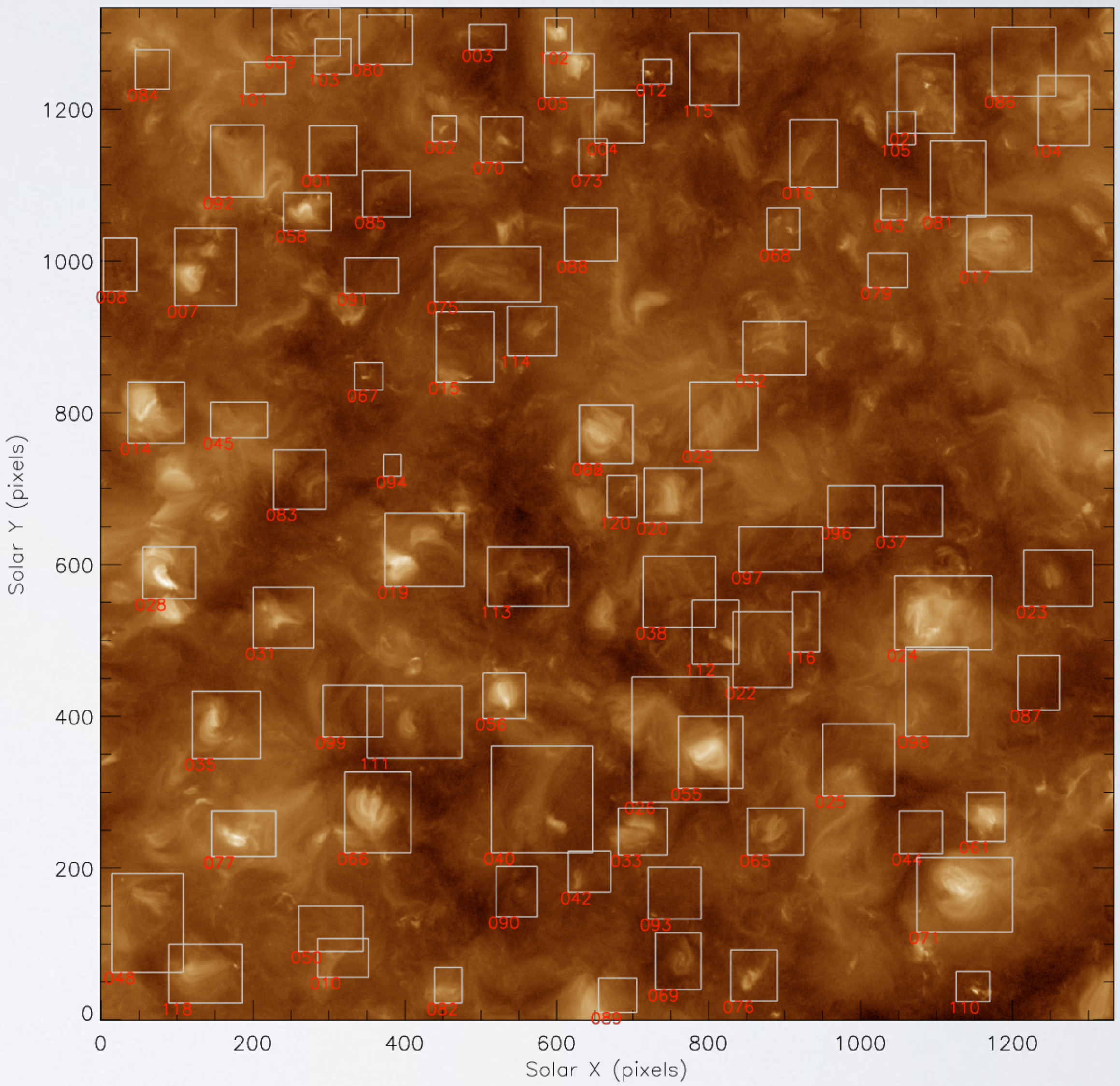
- ✓ Flux emergence => divergence => convergence => cancellation
- ✓ Flux emergence => divergence => decrease
- ✓ Flux coalescence => divergence => decrease
- ✓ Flux coalescence => convergence => cancellation
- ✓ Multiple flux emergence
  - ✓ convergence => cancellation
  - ✓ convergence of multiple bipoles
  - ✓ one bipole convergences, the other diverges

CBPs' photospheric magnetic flux: formation, evolution and disappearance

HMI/SDO



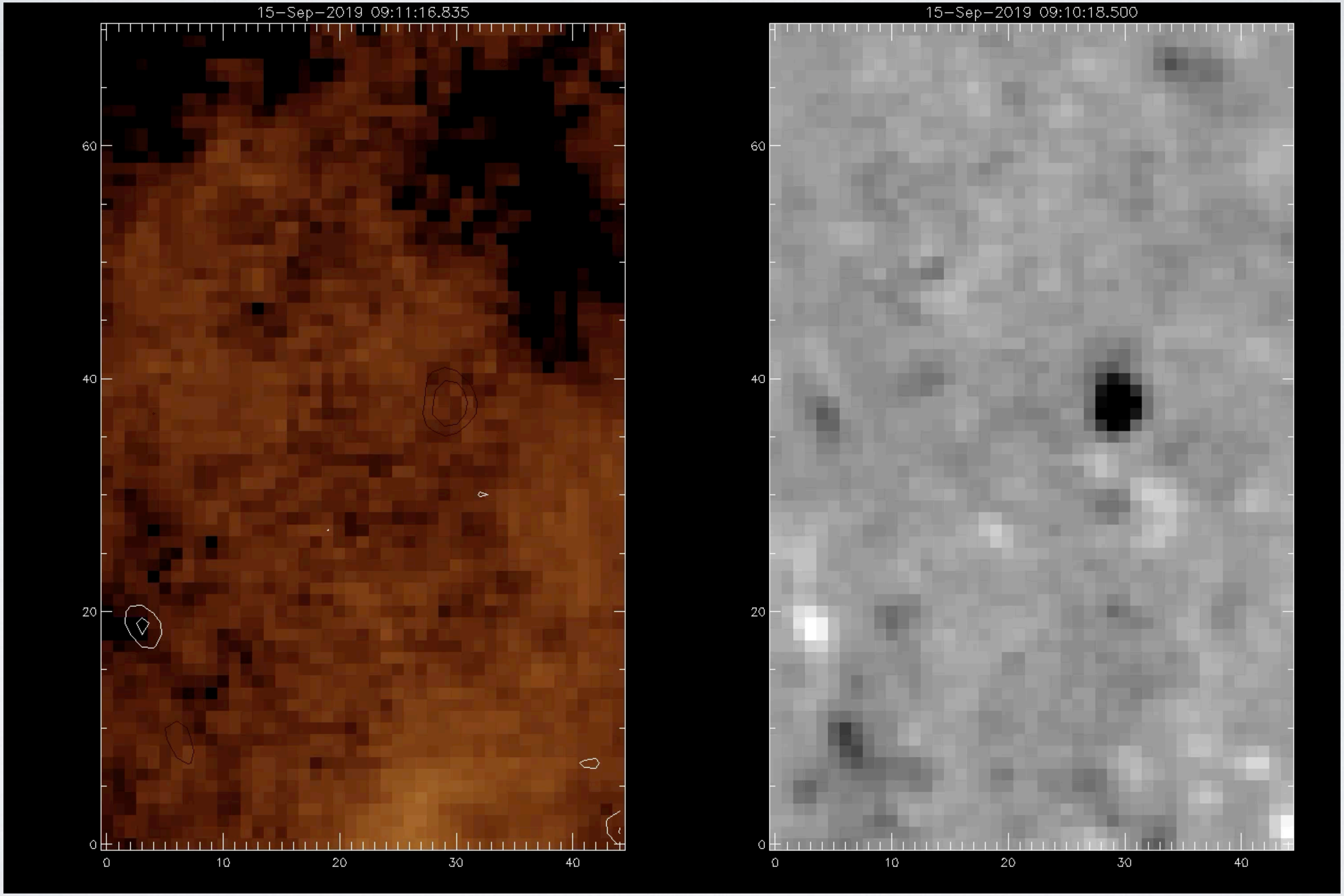
AIA 193/SDO



6 min cadence, 48 hr dataset

Madjarska & Galsgaard (in prep)

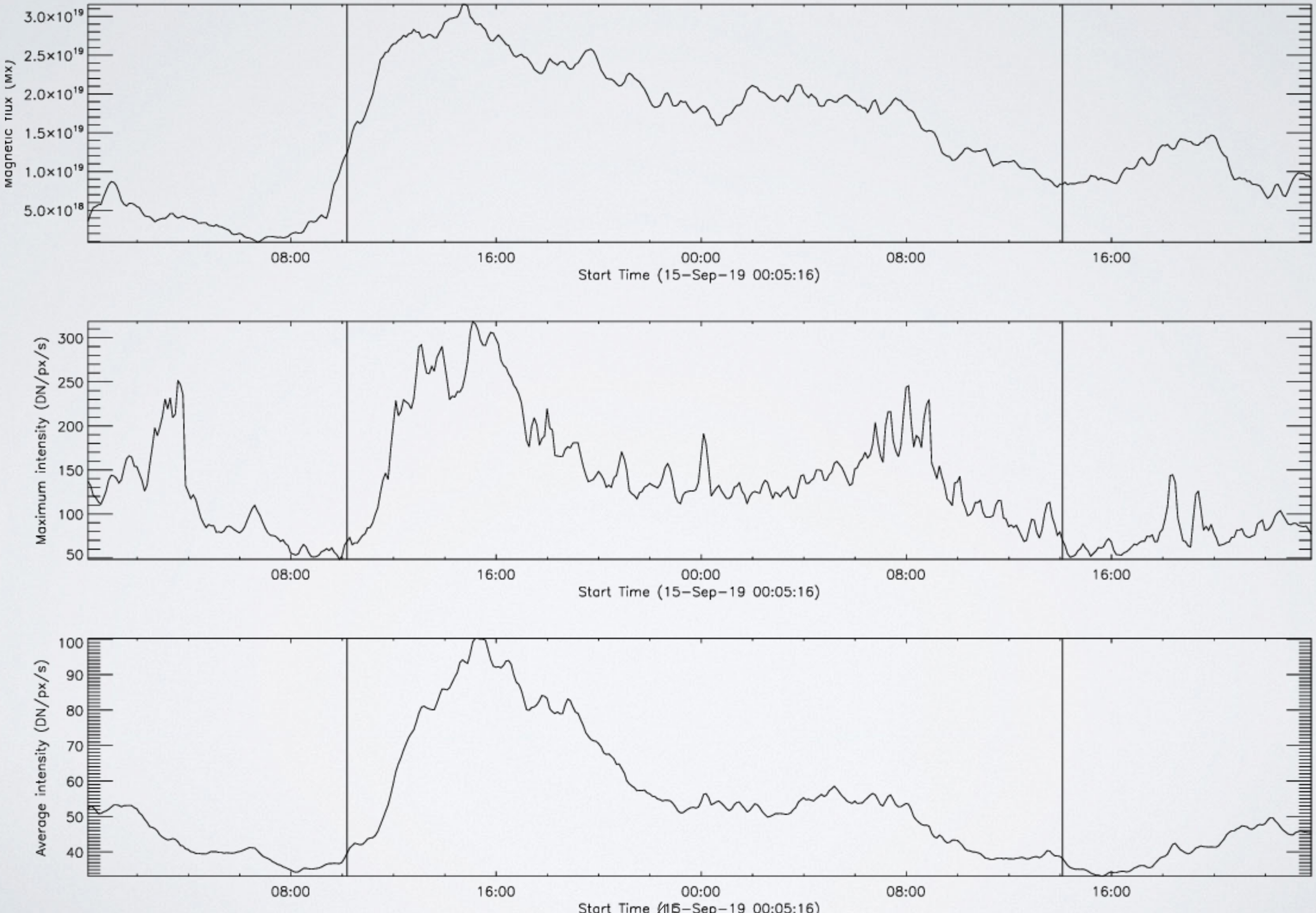
CBPs' formation and evolution: flux emergence, divergence, convergence and cancellation



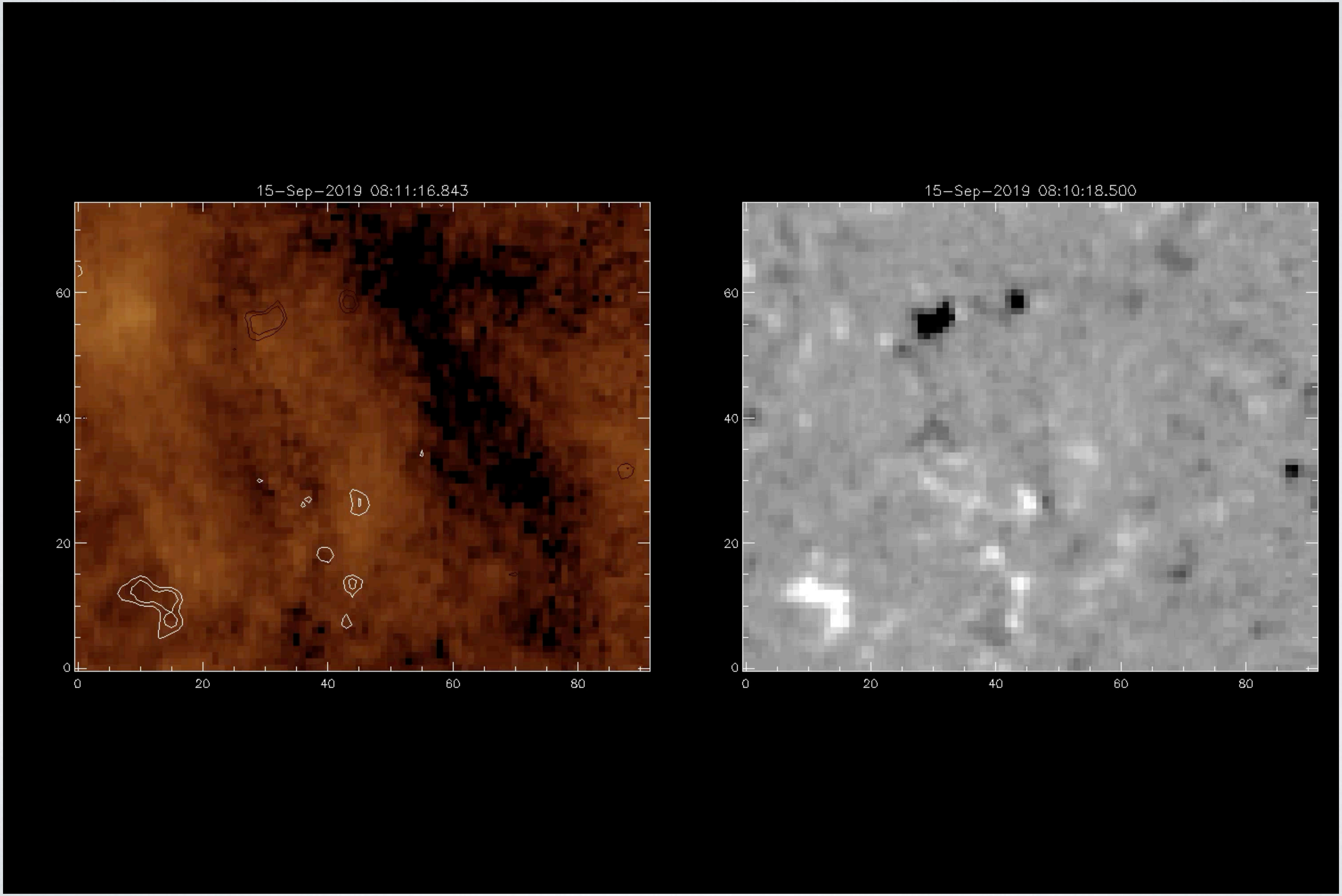
movie_11_isss

Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: flux emergence, divergence, convergence, and cancellation



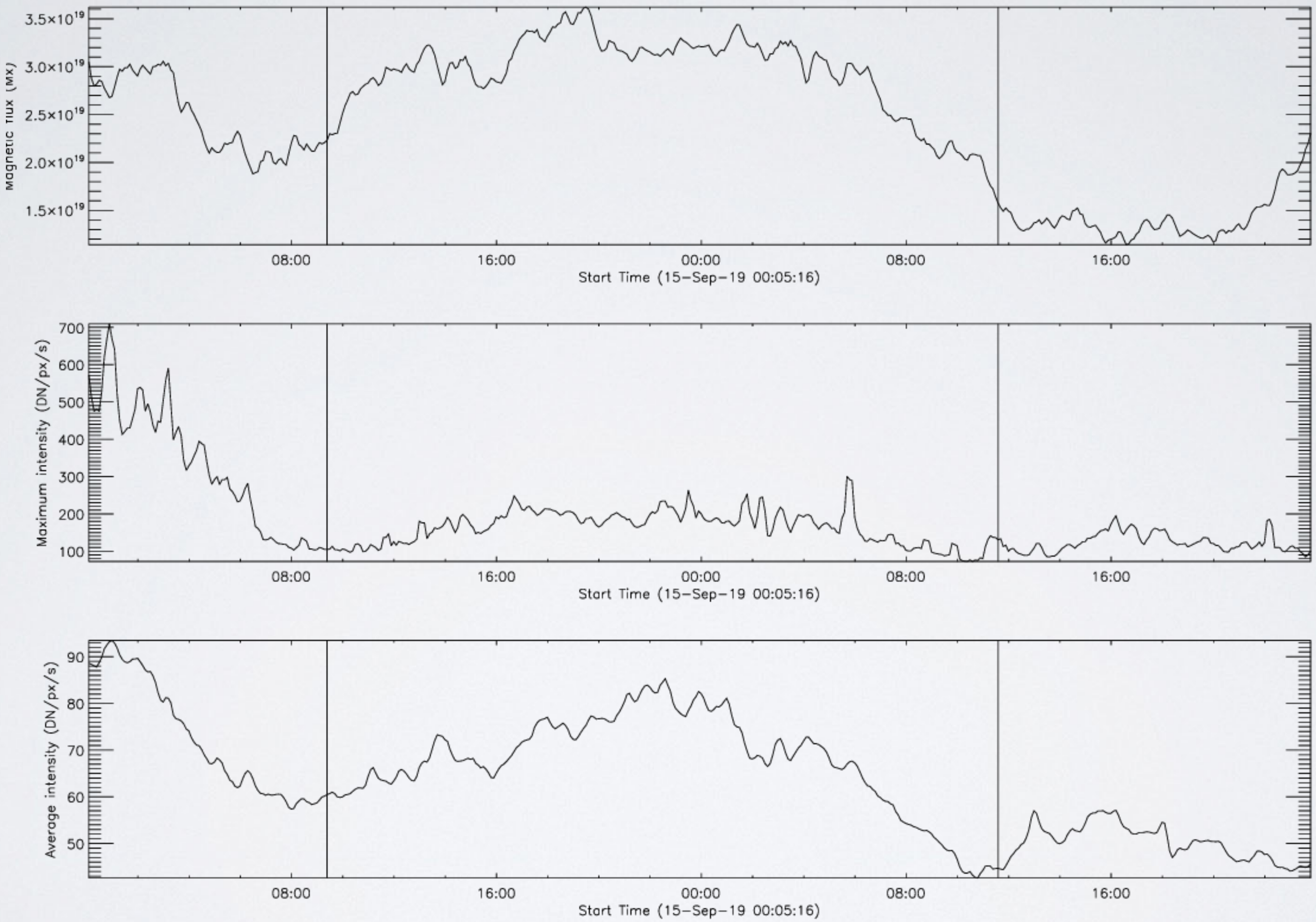
CBPs' formation and evolution: flux emergence, divergence, convergence, and cancellation



movie_12_isss

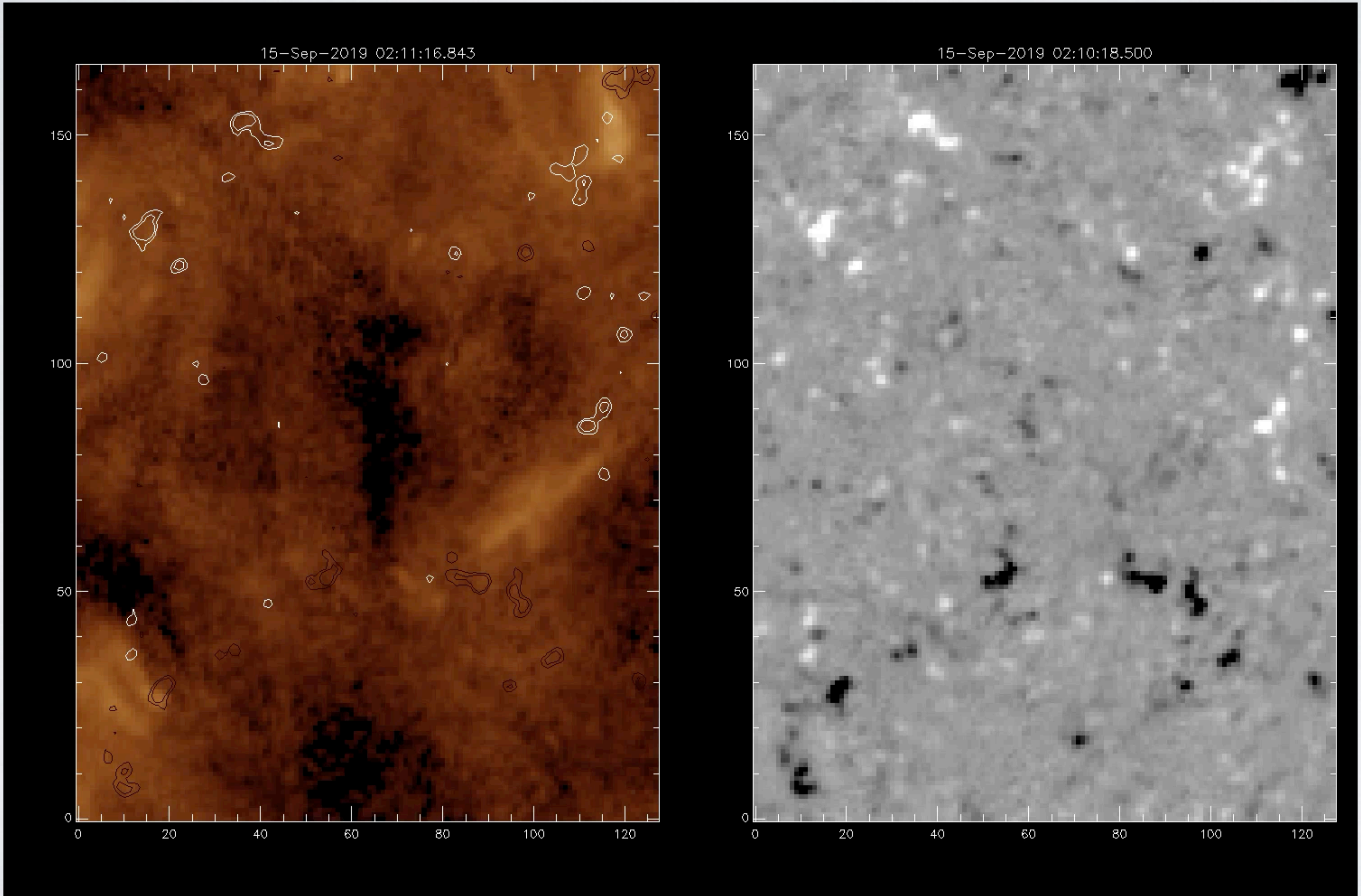
Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: flux emergence



Madjarska & Galsgaard (in prep)

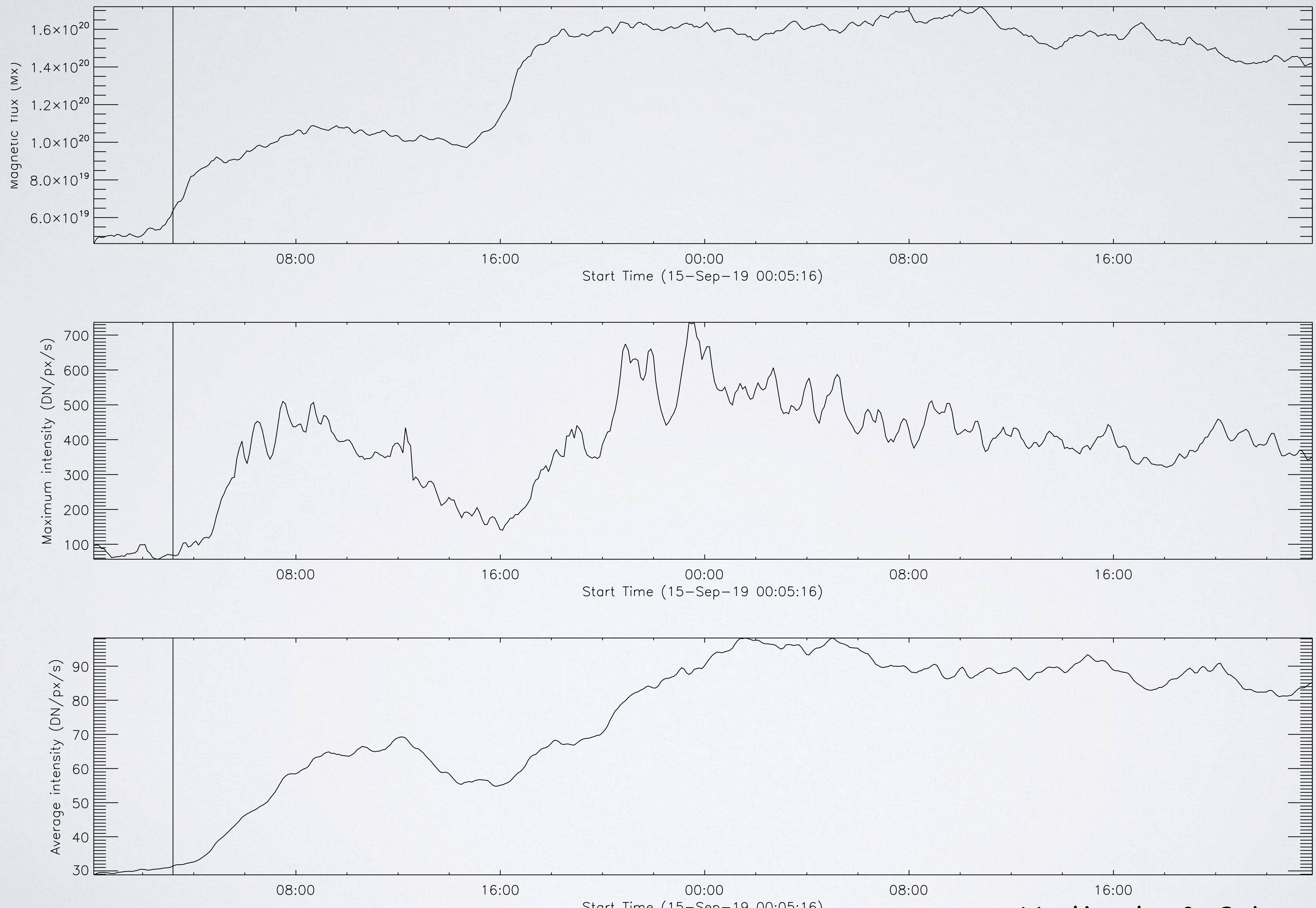
CBPs' formation and evolution: multiple magnetic flux emergence



movie_13_isss

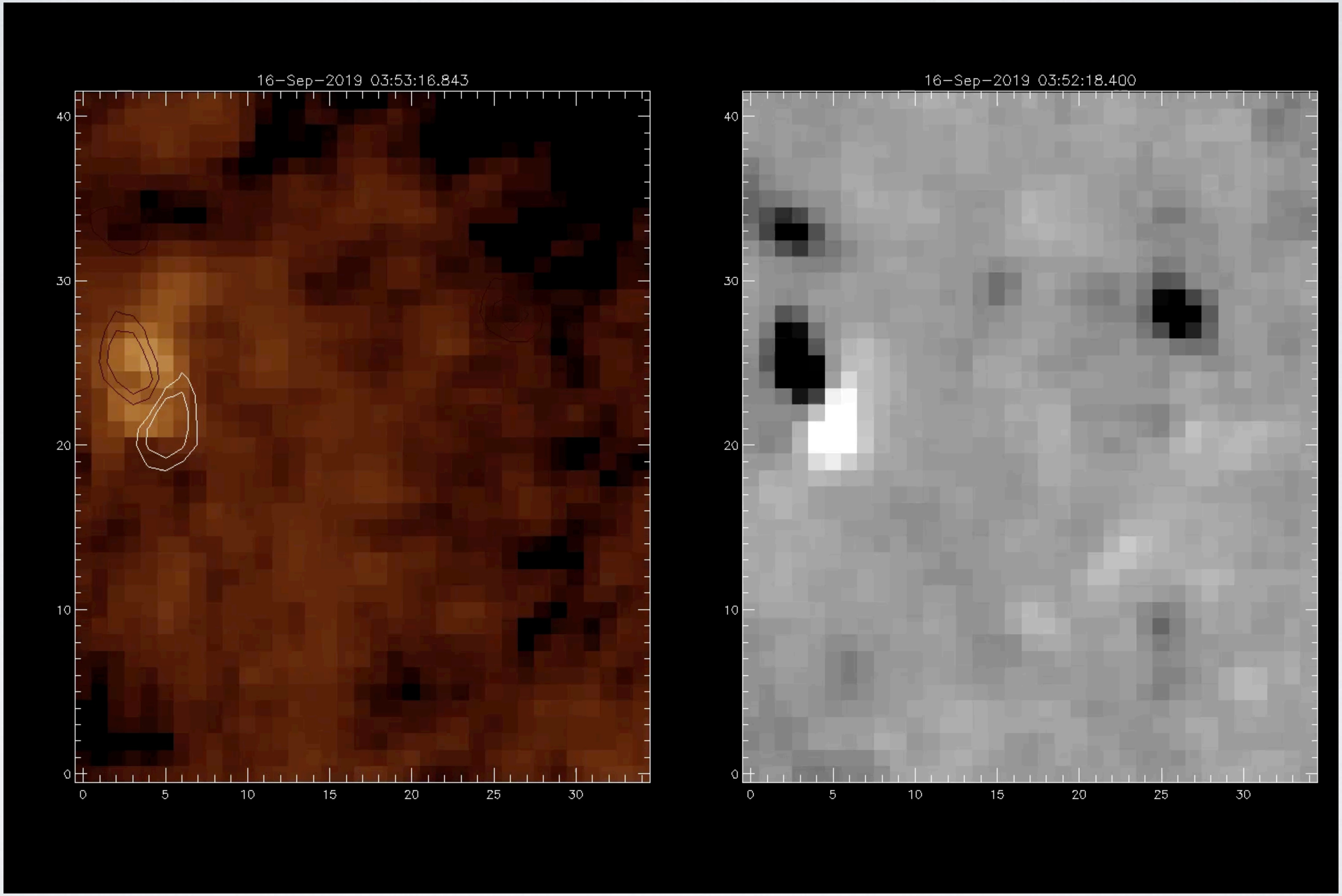
Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: multiple magnetic flux emergence



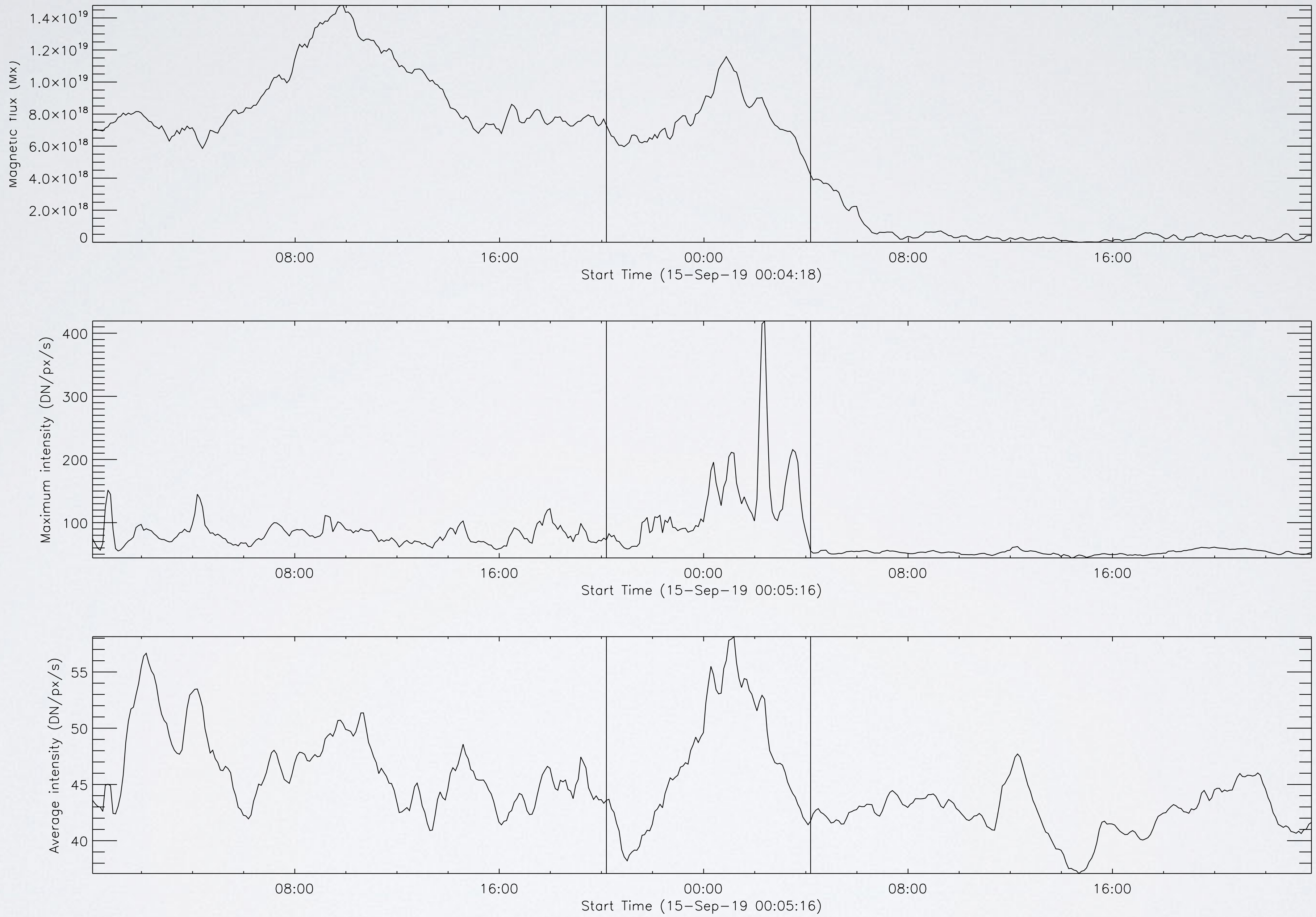
Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: very small bipole

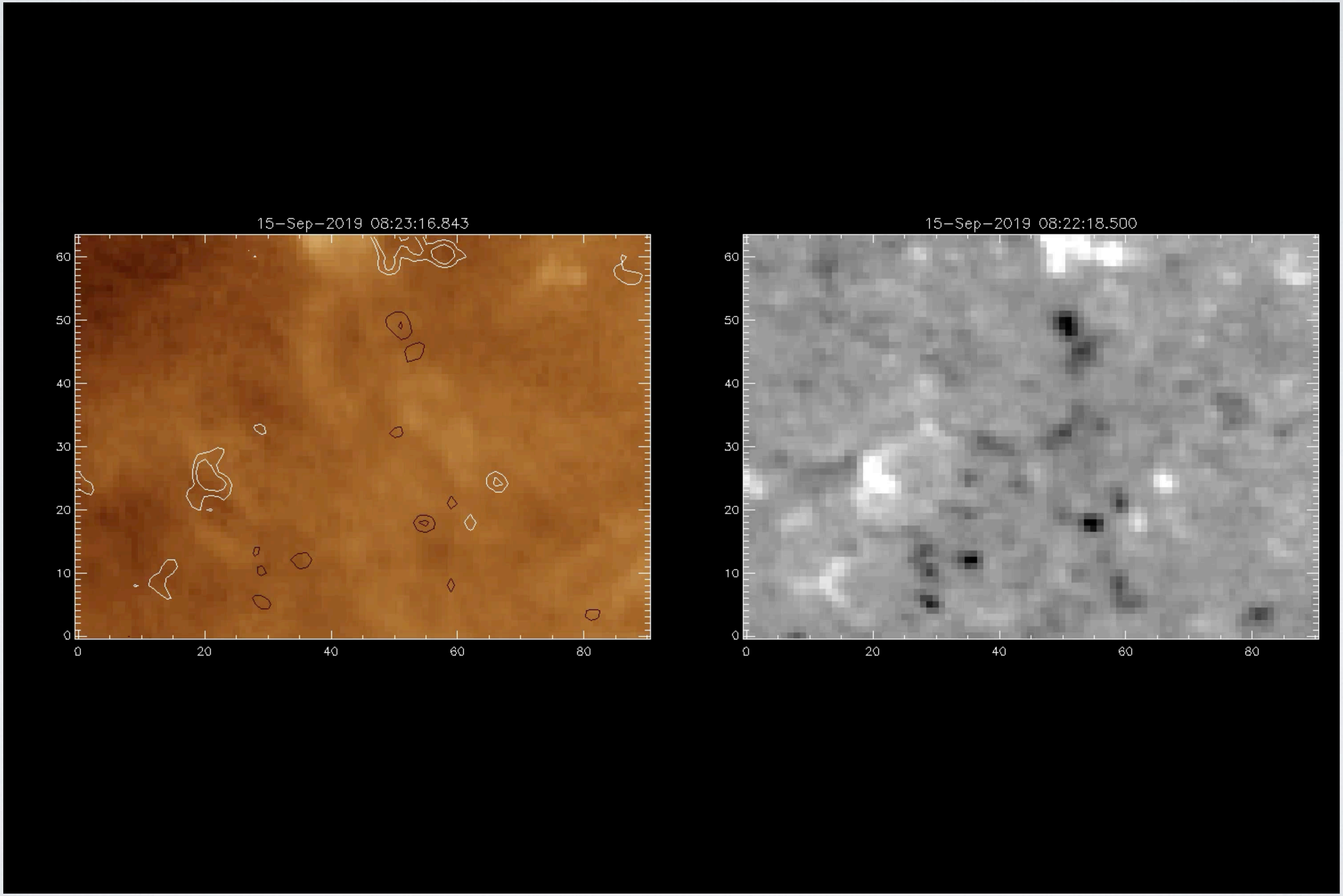


movie_14_isss

CBPs' formation and evolution: very small bipole



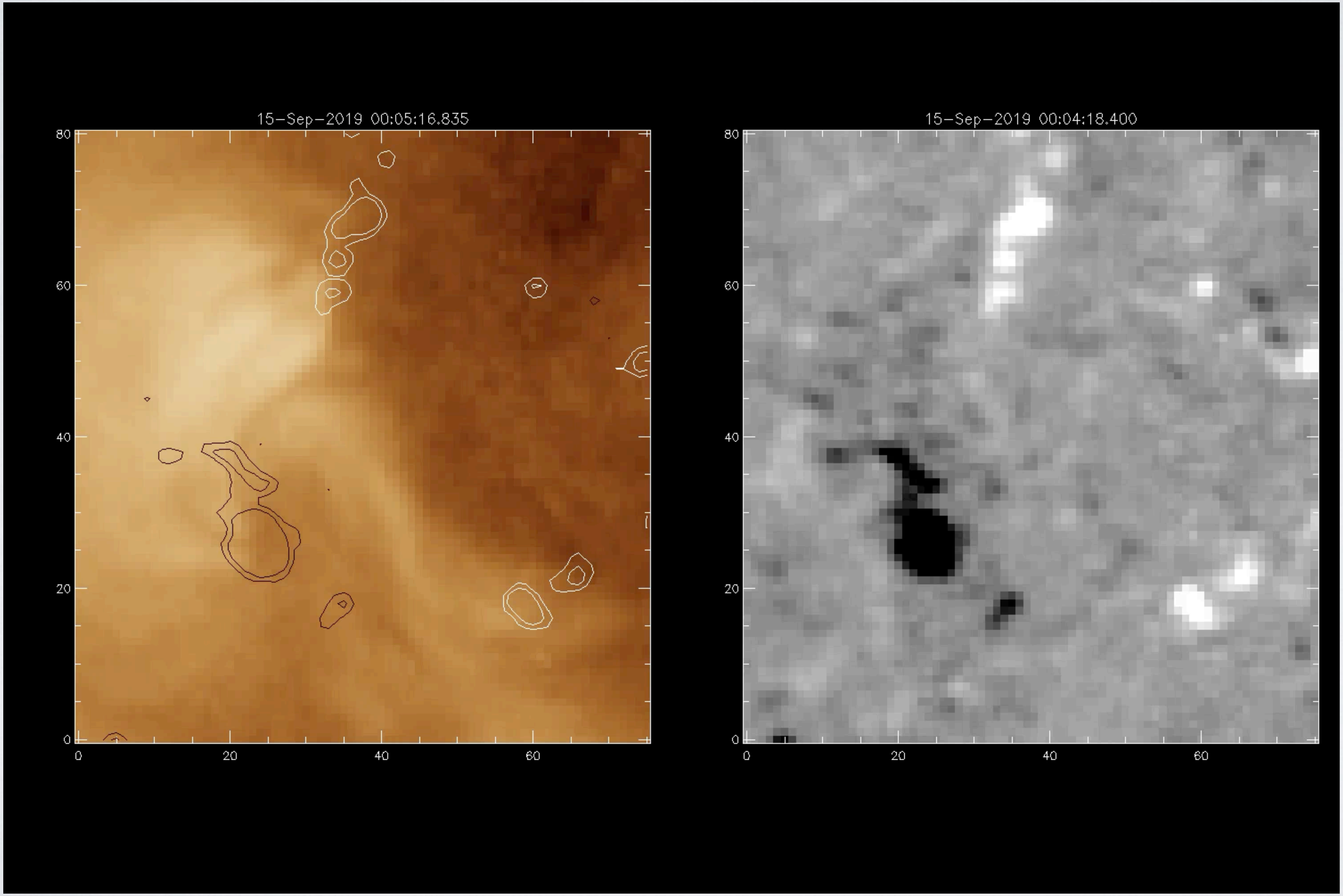
CBPs' formation and evolution: coalescence



movie_15_isss

Madjarska & Galsgaard (in prep)

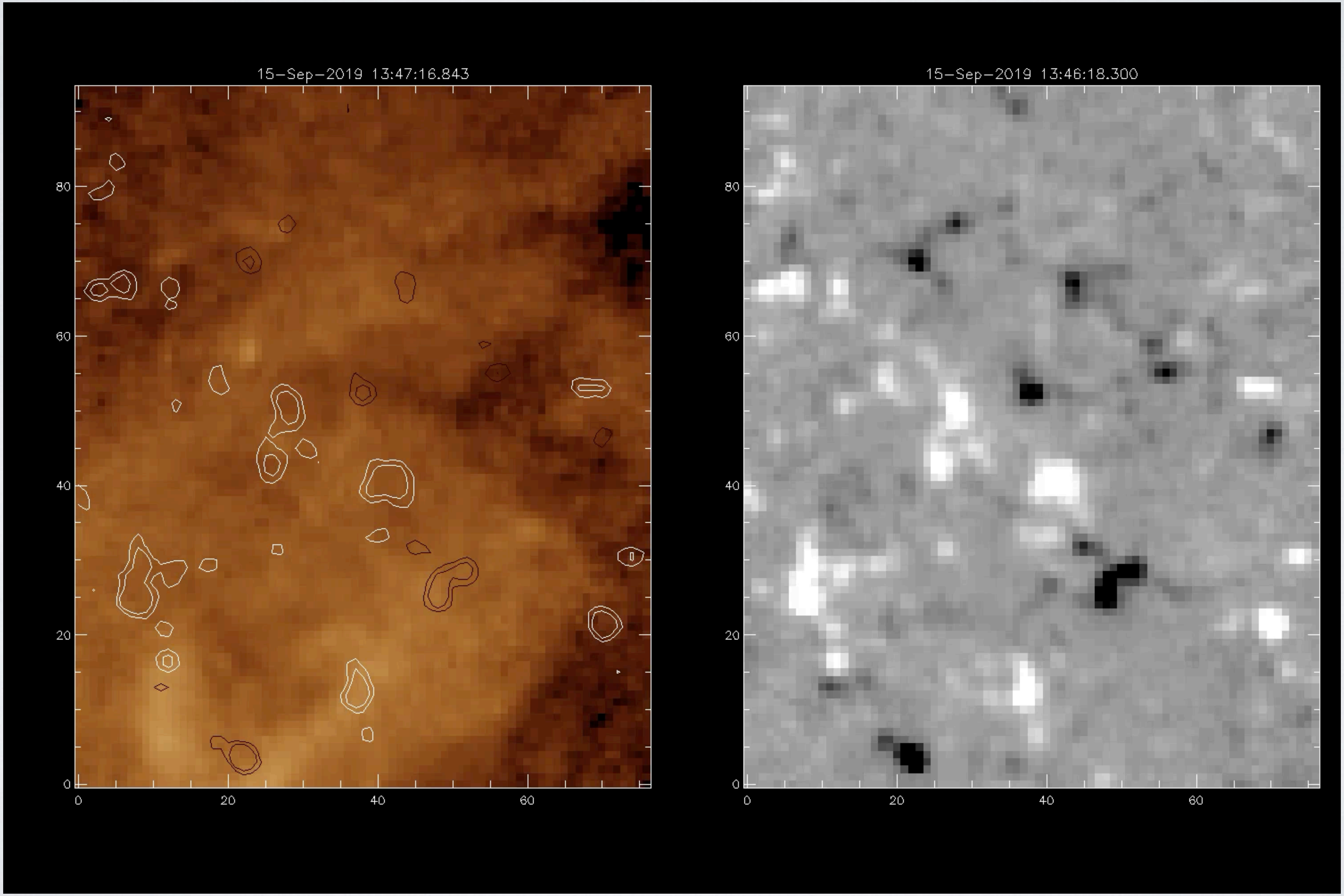
CBPs' formation and evolution: rotation



movie_16_isss

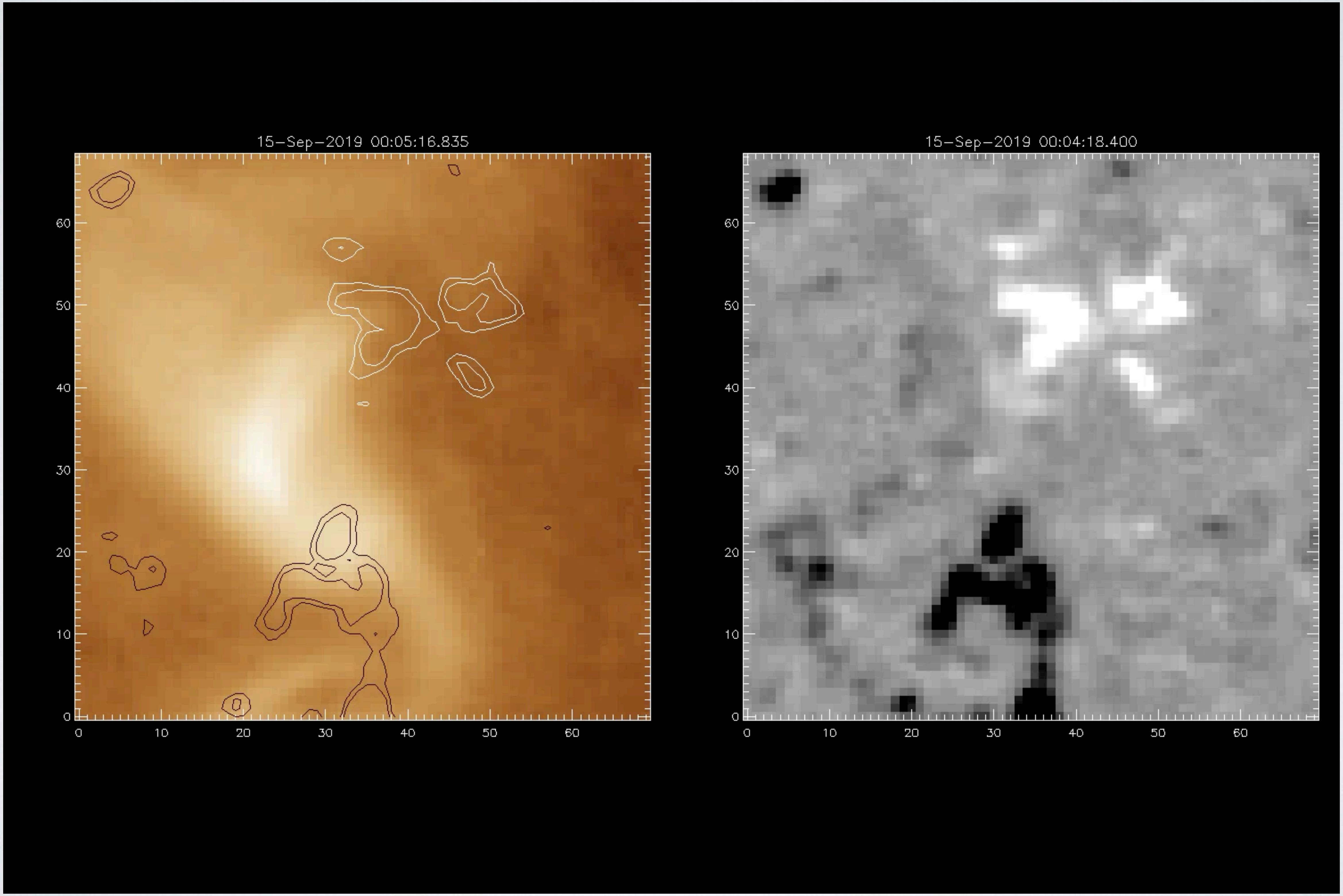
Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: pre-existing + emergence, opposite polarity + rec with opposite flux + divergence



movie_17_isss

CBPs' formation and evolution: convergence and cancellation

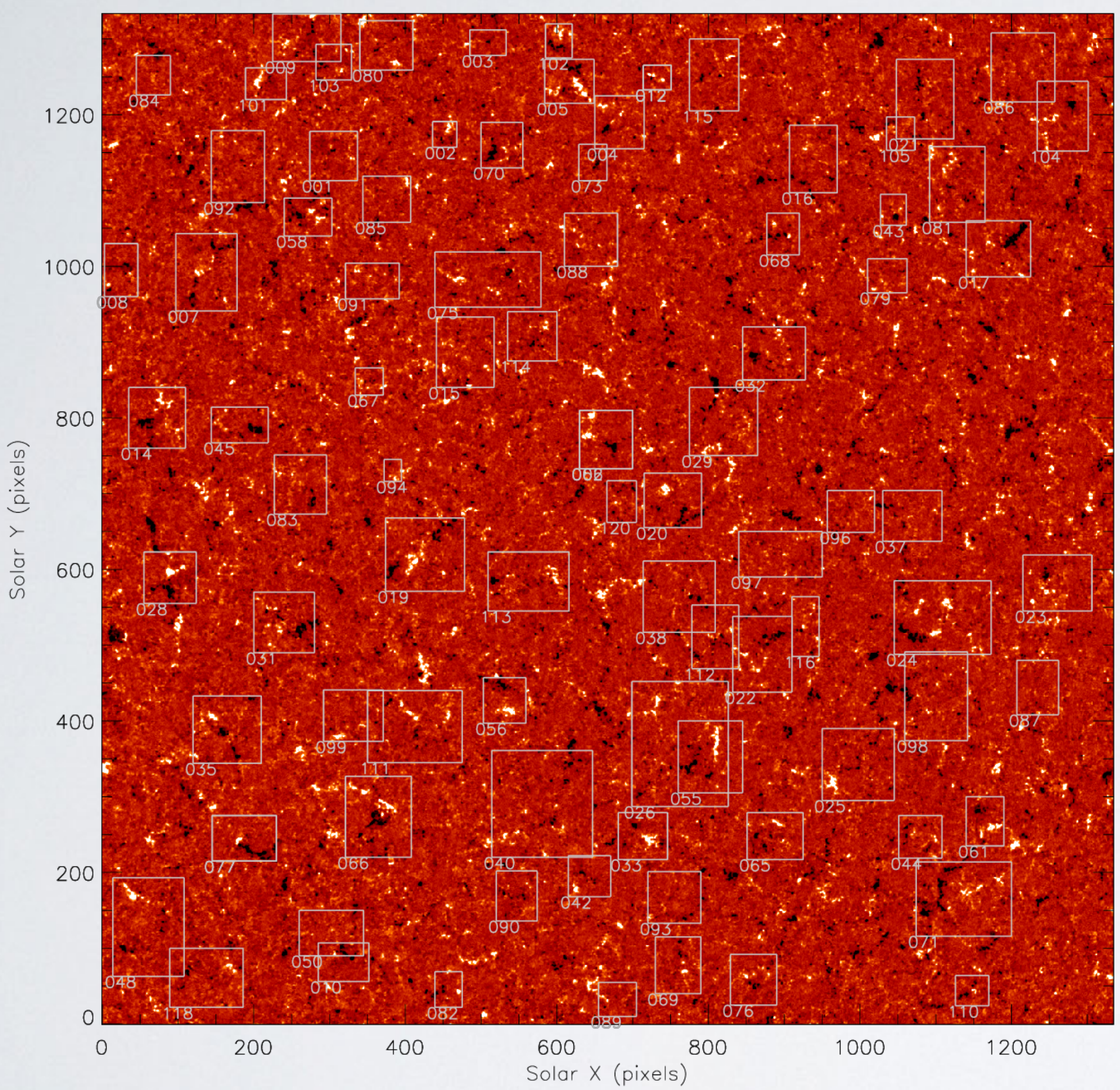


movie_18_isss

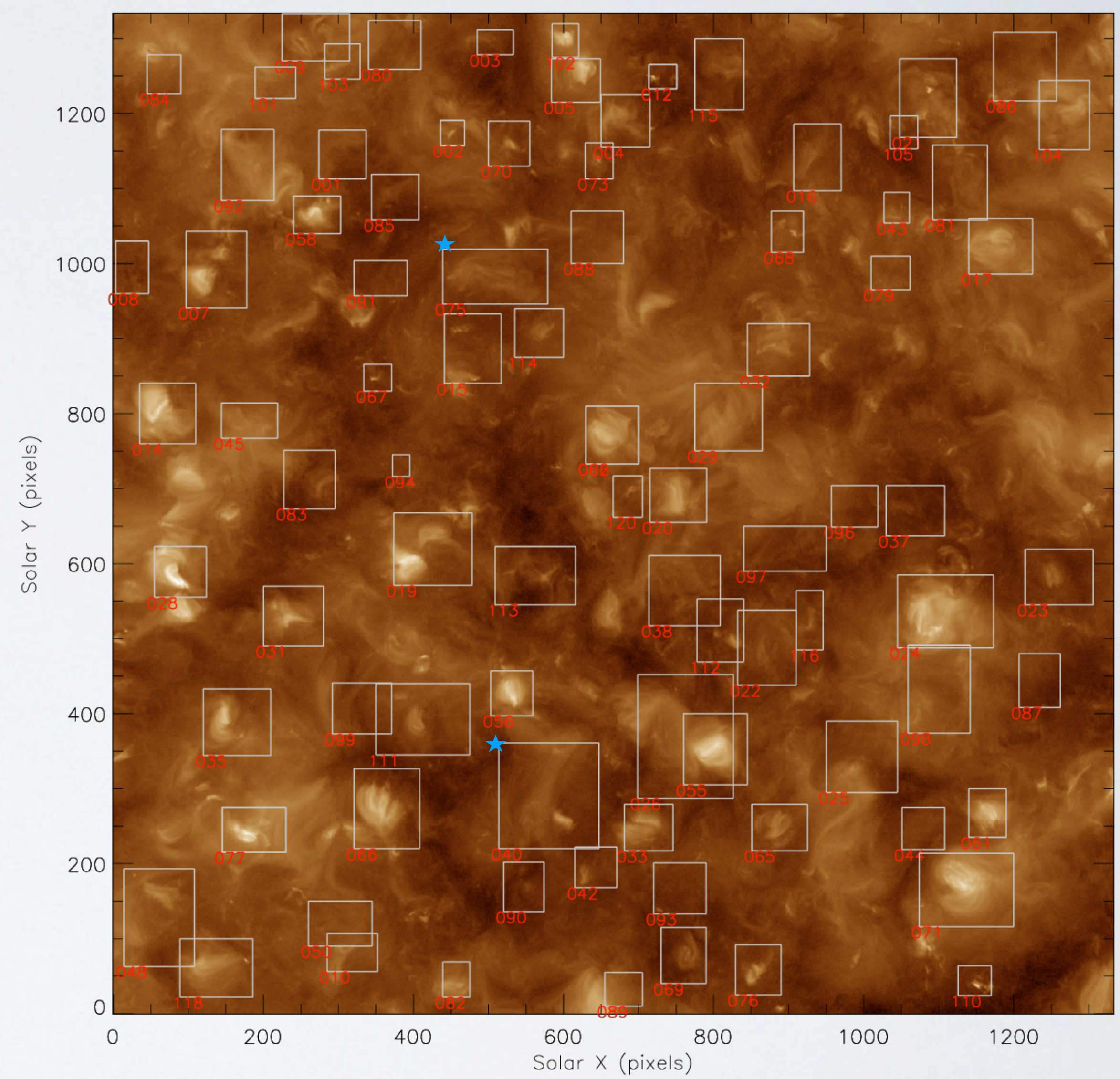
Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: faint loops

HMI/SDO



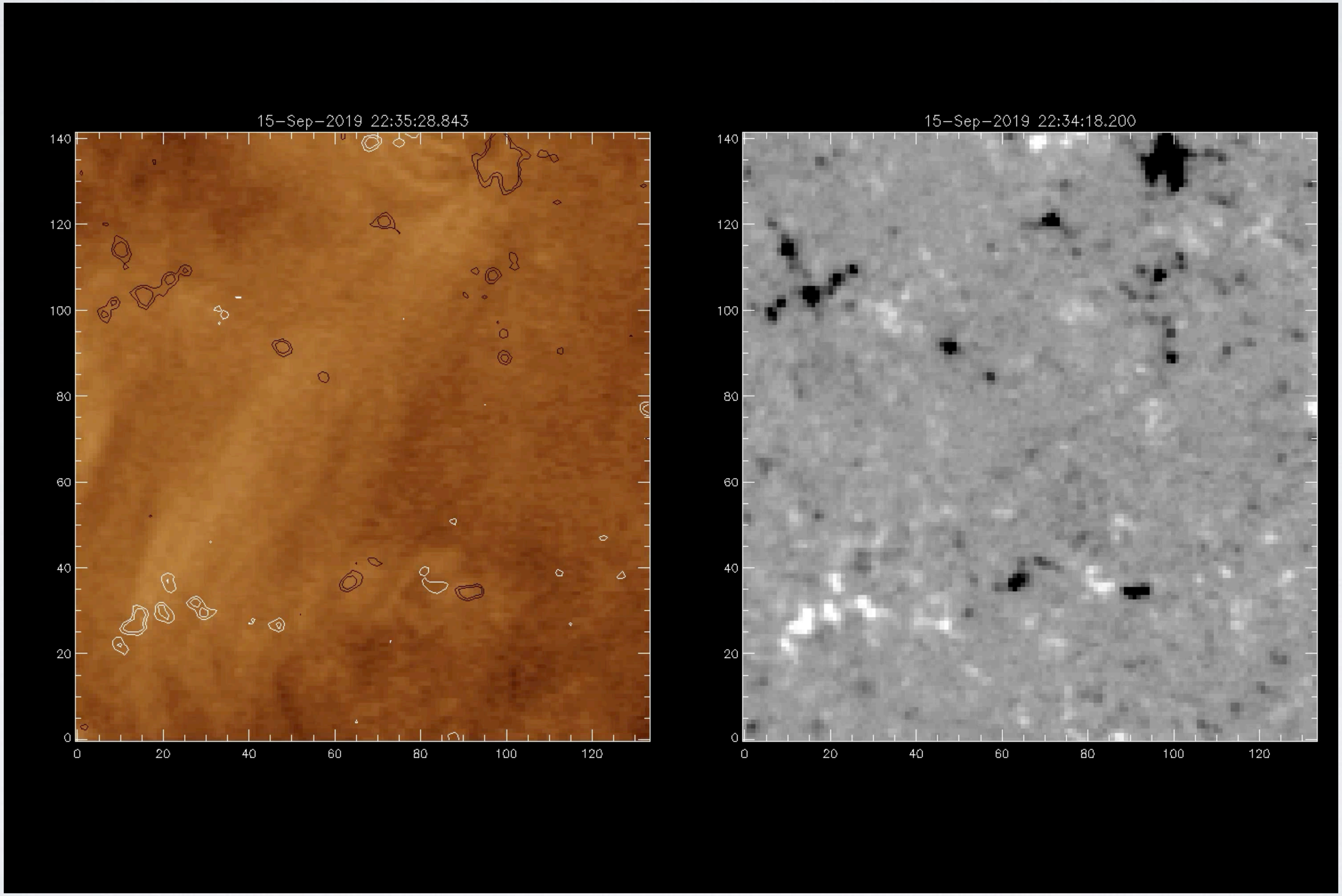
AIA 193/SDO



6 min cadence, 48 hr dataset

Madjarska & Galsgaard (in prep)

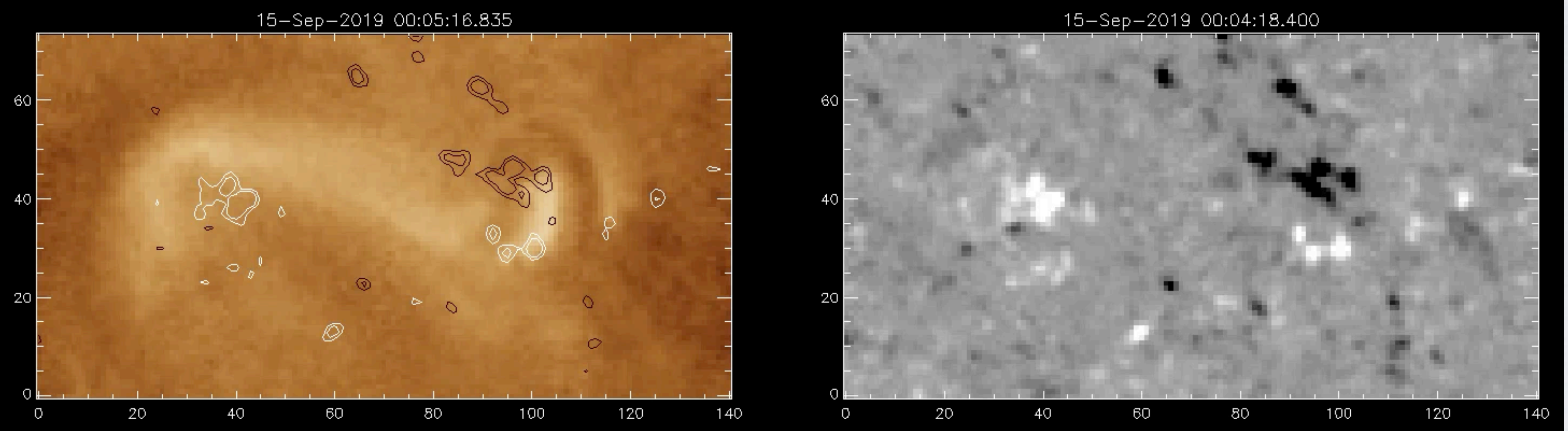
CBPs' formation and evolution: faint loops



movie_19_isss

Madjarska & Galsgaard (in prep)

CBPs' formation and evolution: faint loops



movie_20_isss

Madjarska & Galsgaard (in prep)

CBPs' photospheric magnetic flux correlation with coronal emission

- ✓ Madjarska & Galsgaard (in prep) - Linear correlation between coronal intensity and photospheric magnetic flux with a Pearson coefficient of up to 0.97. Estimated by removing the background field of up to 20 G.
- ✓ Fisher et al. (1998) - report that X-ray intensity scales almost linearly with the total unsigned magnetic flux.
- ✓ Toriumi & Airapetian (2022) report similar results for different temperature emission on the Sun and other stars => "the mechanism of atmospheric heating is universal among the Sun and Sun-like stars"
- ✓ The estimated relationship limits the possible heating mechanisms of small-scale coronal loops.

CBPs' photospheric magnetic flux correlation with coronal emission

- ✓ Prés & Philips (1999), Madjarska et al. (2003), Mou et al. (2018) - correlation between magnetic flux evolution and the intensity of the CBPs

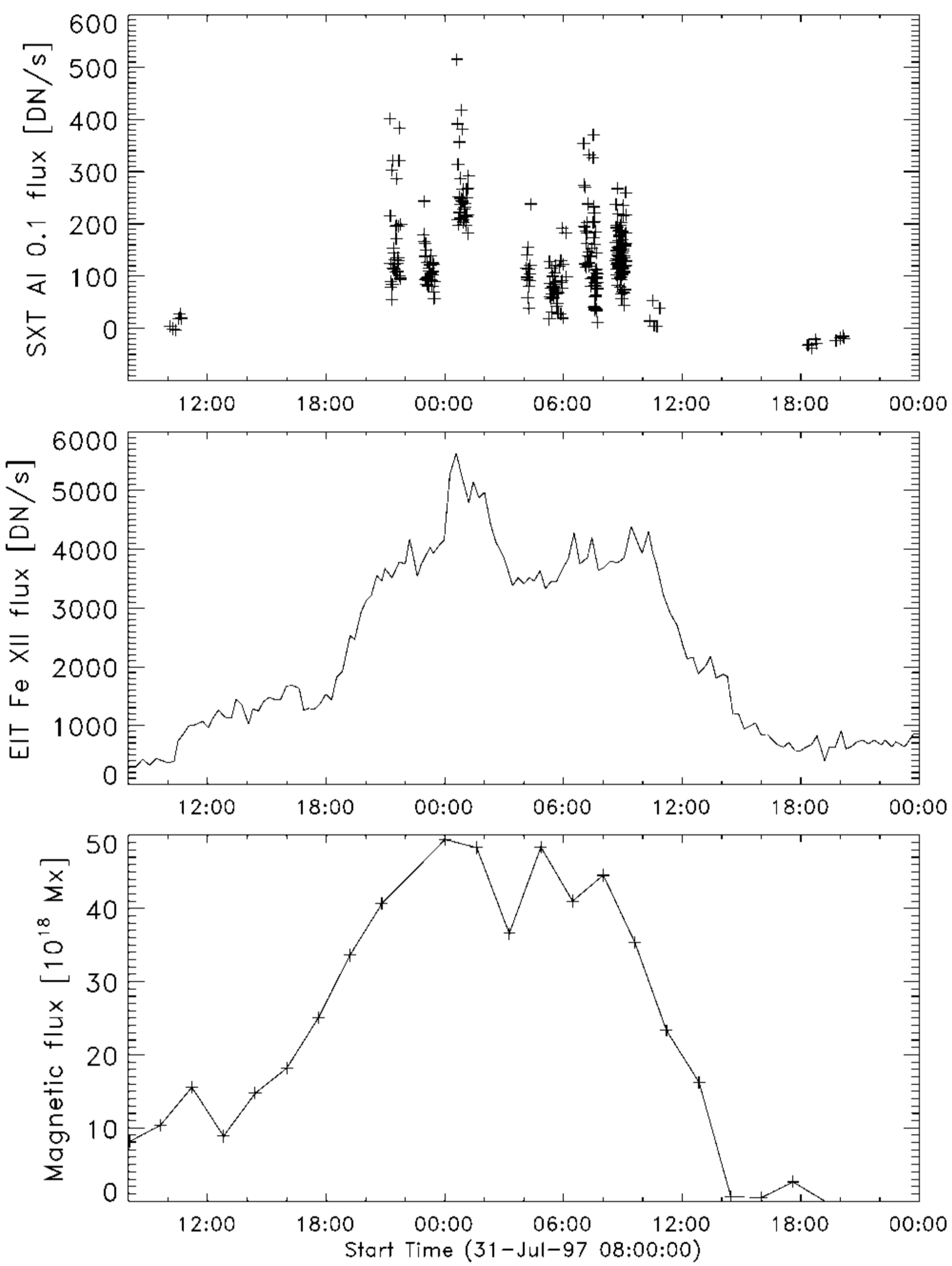
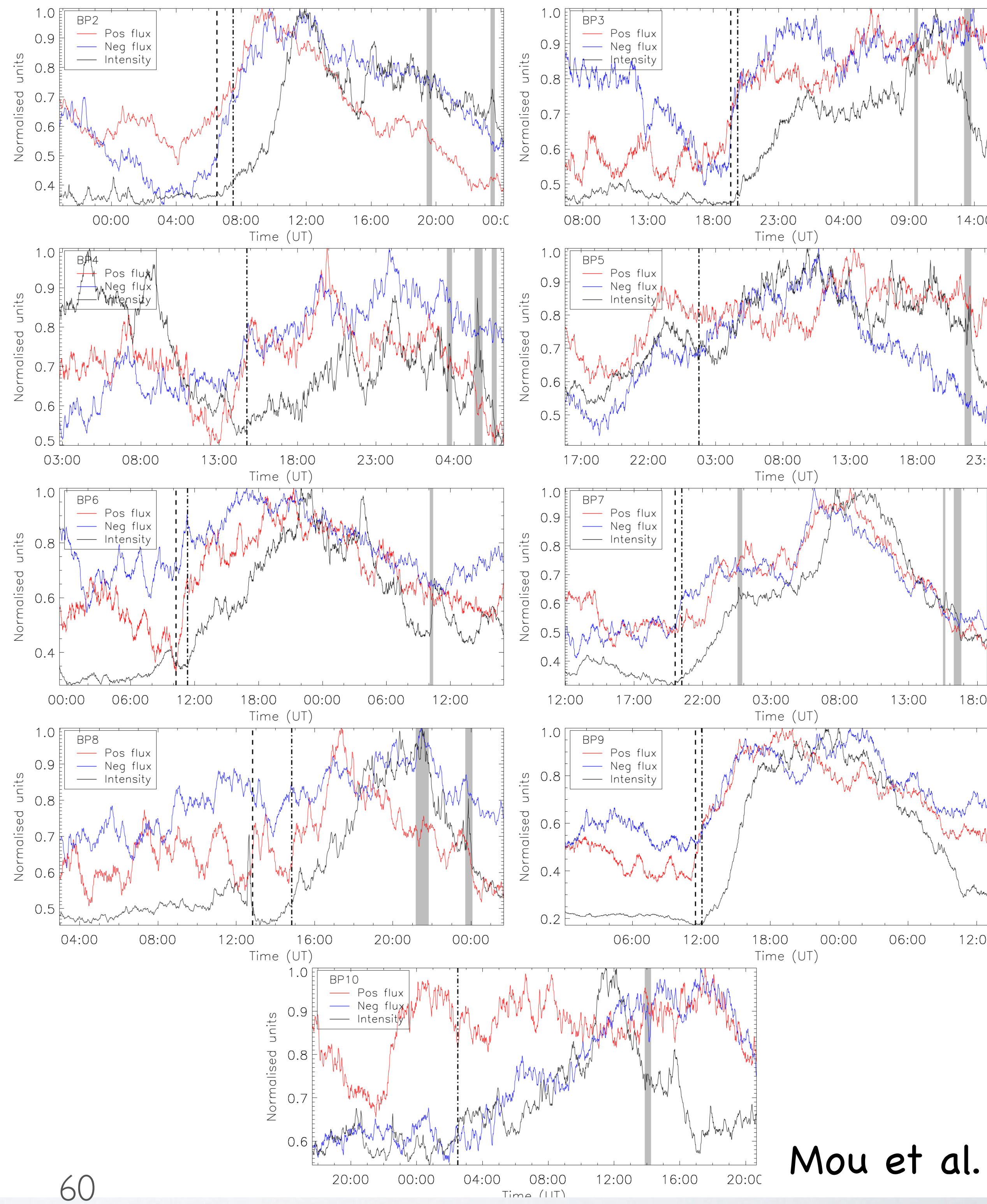


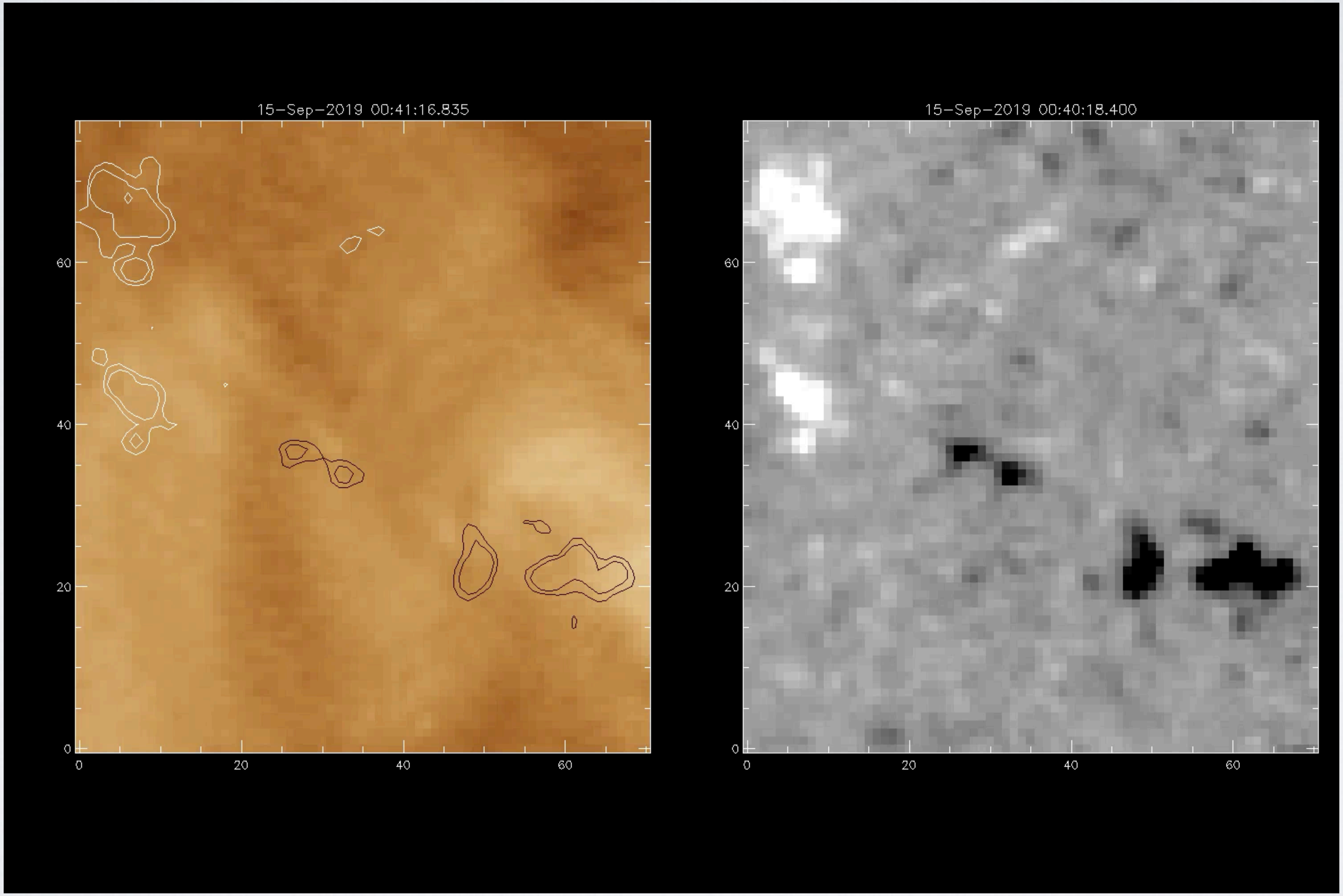
FIG. 2.—SXT Al 0.1 (top) and EIT Fe XII (middle) light curves of the coronal bright point A, together with time variations in the local magnetic flux Φ from the MDI instrument (bottom).

Prés & Philips (1999)



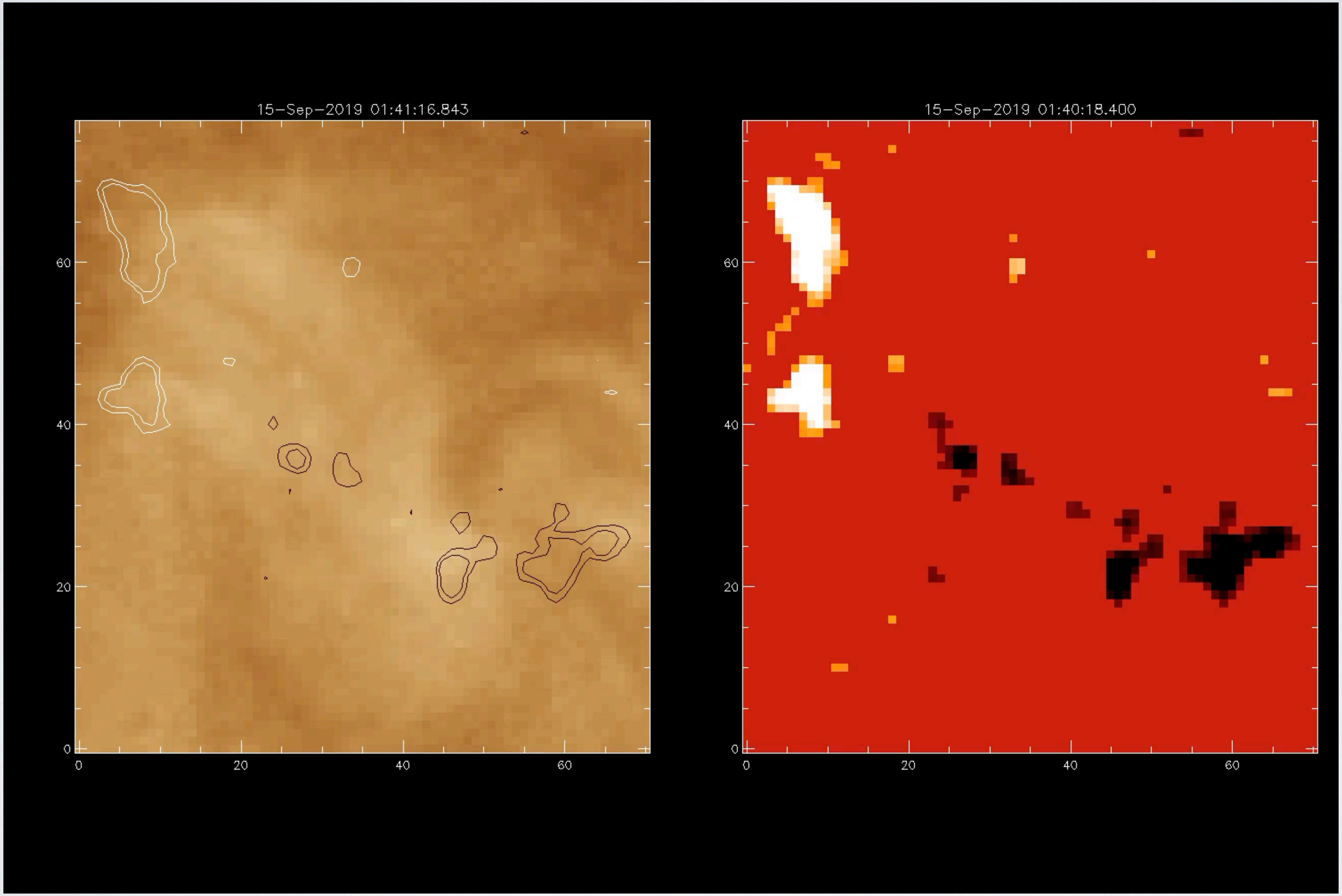
Mou et al. (2018)

CBPs' photospheric magnetic flux correlation with coronal emission



movie_21_isss

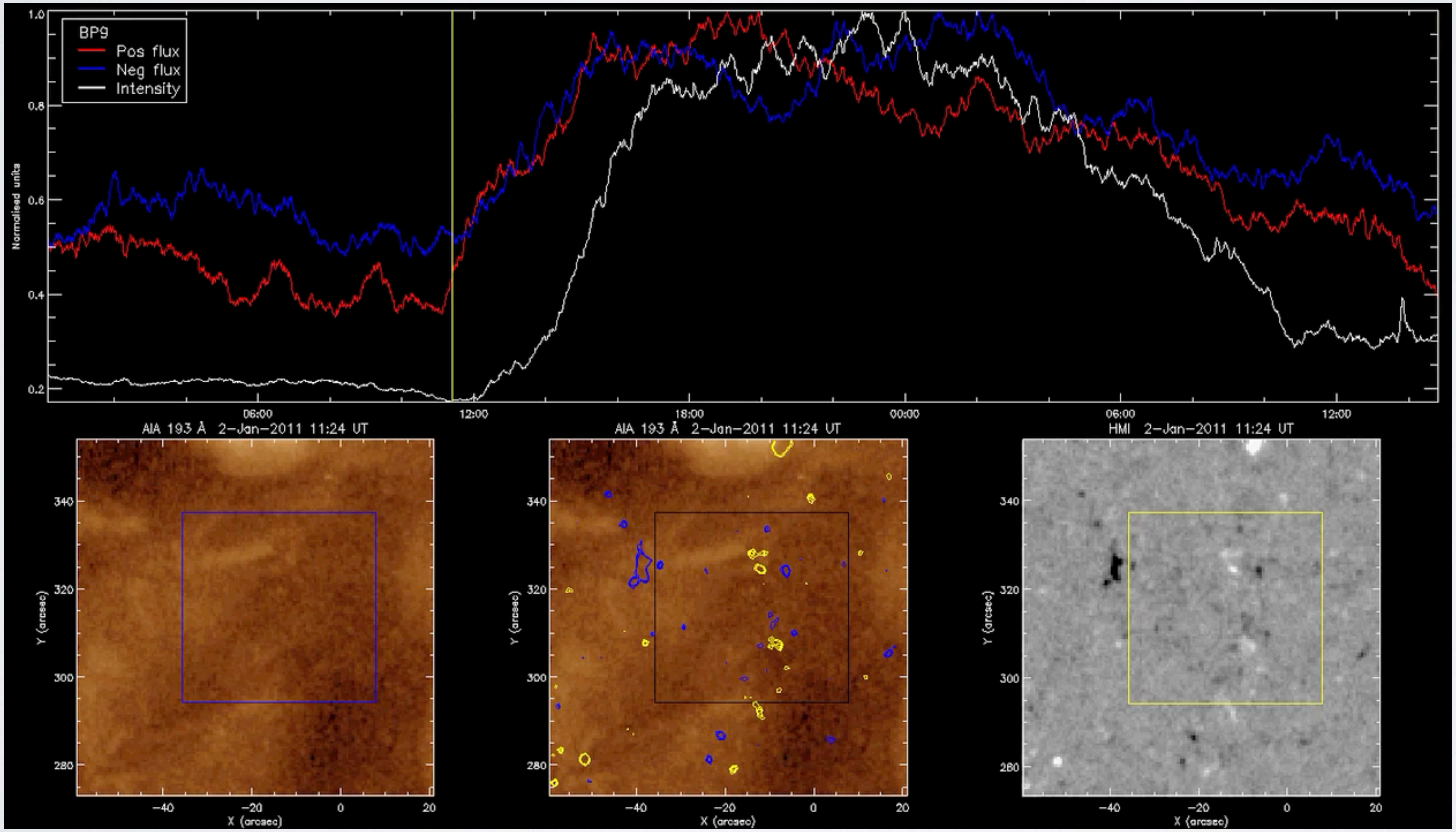
CBPs' photospheric magnetic flux correlation with coronal emission



movie_22_isss

CBPs' photospheric magnetic flux correlation with coronal emission

✓ CBPs resulting from flux emergence appear at coronal temperatures from 30 to 60 min after the start of the flux emergence (Mou et al. 2018)



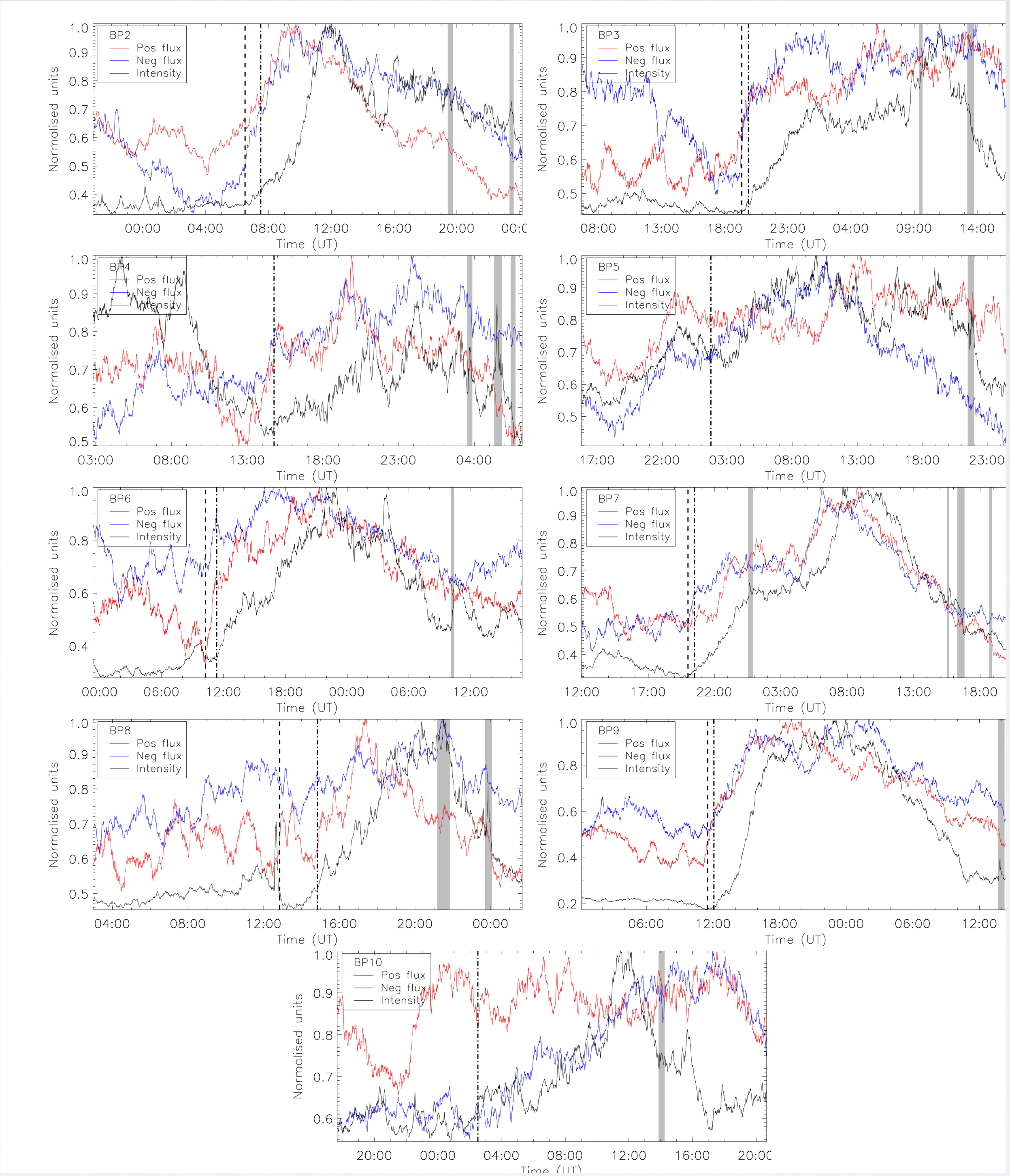
movie_23_isss

Mou et al. (2018)

CBPs' photospheric magnetic flux evolution and transient dynamic phenomena

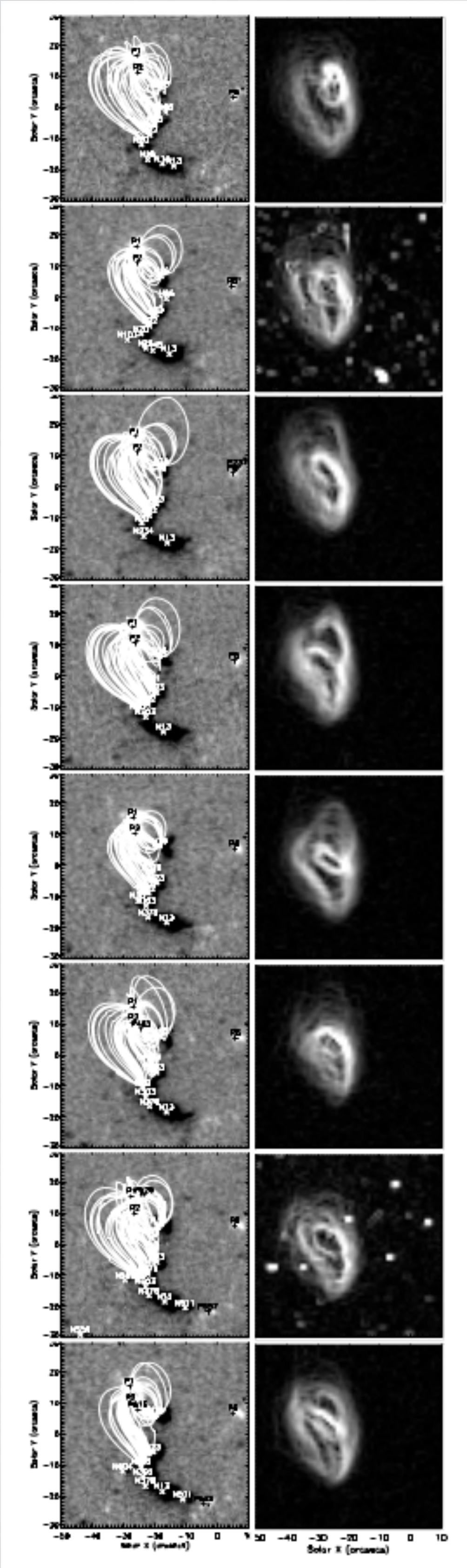
- ✓ CBPs are possibly the host of all (no dedicated study) coronal jets (in coronal holes) and mini-CMEs (in the quiet Sun).
- ✓ The eruptions occur often during the late stage of the lifetime of CBPs while magnetic polarities converge and cancel, but not only.
- ✓ They can occur when one of the CBP flux concentration approaches and cancels with pre-existing or newly emerging close by opposite polarity flux (Mou et al., 2018; Galsgaard et al., 2019; Madjarska et al., 2020, 2021, 2022) during any time of the CBPs lifetime.
- ✓ During these eruptions microflares triggered by mini-filaments' destabilization and eruption, as well hot loop eruptions, are typically observed.
- ✓ Microflares seem to occur also during magnetic flux emergence (no mini-filaments involved) from reconnection between emerging and pre-exiting fluxes (Madjarska & Galsgaard, in prep).

CBPs' photospheric magnetic flux evolution and transient dynamic phenomena



Mou et al. (2018)

CBPs coronal magnetic field topology



Peres-Suarez et al. (2008)

From potential field extrapolations: CBP coronal magnetic structures represent a simple set of field lines connecting opposite polarity flux (Parnell et al. 1994, Perez et al., 2008, Alexander et al. 2011)

Perez et al., 2008 - close to potential???

Using MPOLE topology code of Longcope (1996)

CBPs coronal magnetic field topology

✓ From linear force-field extrapolations that match closely observed loops: coronal field of CBPs is possibly non-potential

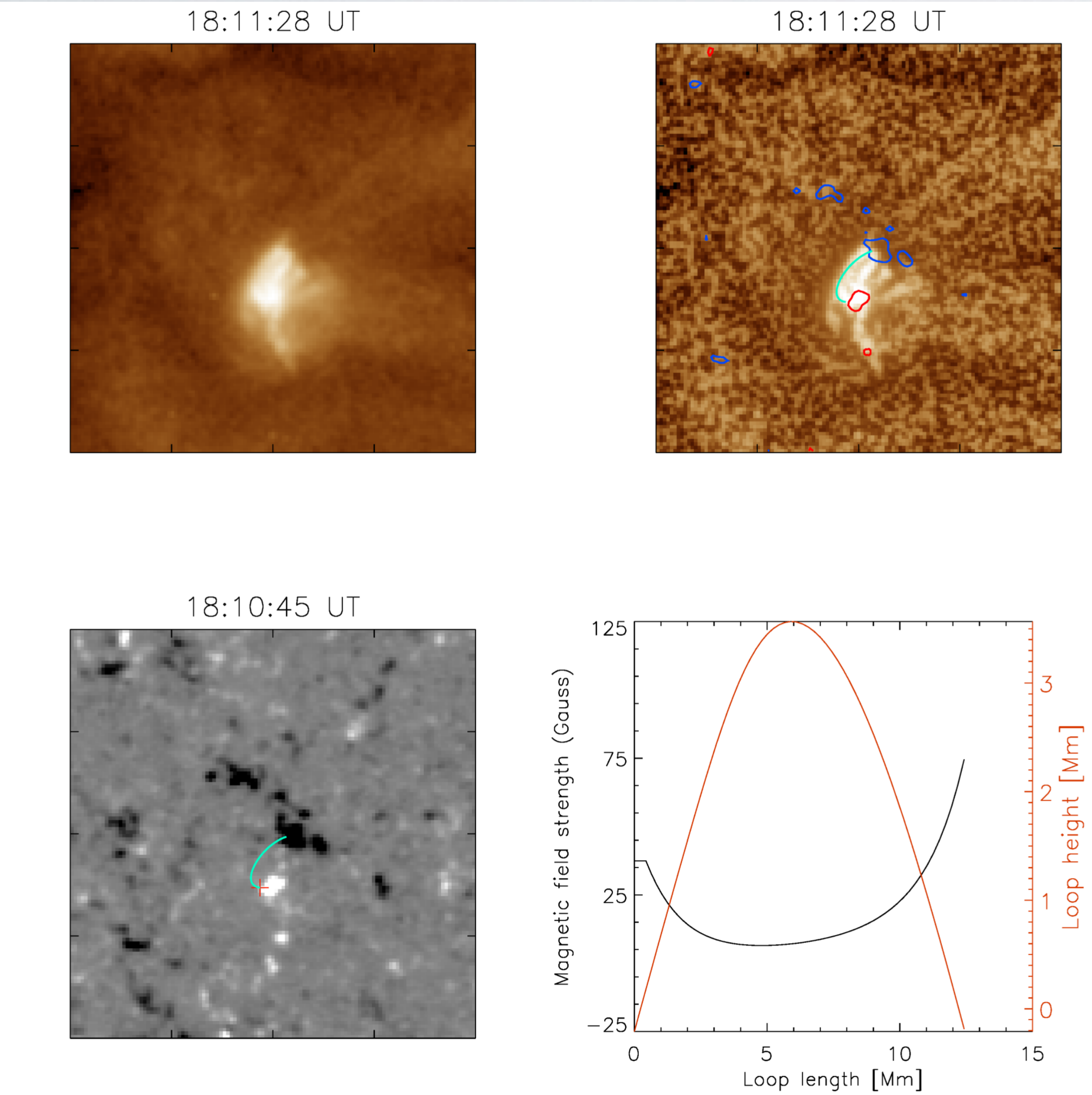


Fig. 10. Linear force-free field extrapolation of a CBP loop. Top left: AIA 193 image. Top right: A MGN processed AIA 193 image with overplotted a magnetic field line that matches one of the extrapolated CBP loops. Bottom left: An HMI magnetogram with the same magnetic field line. The cross indicates the location from which the magnetic field line was traced. Bottom right: Magnetic-field-line parameters.

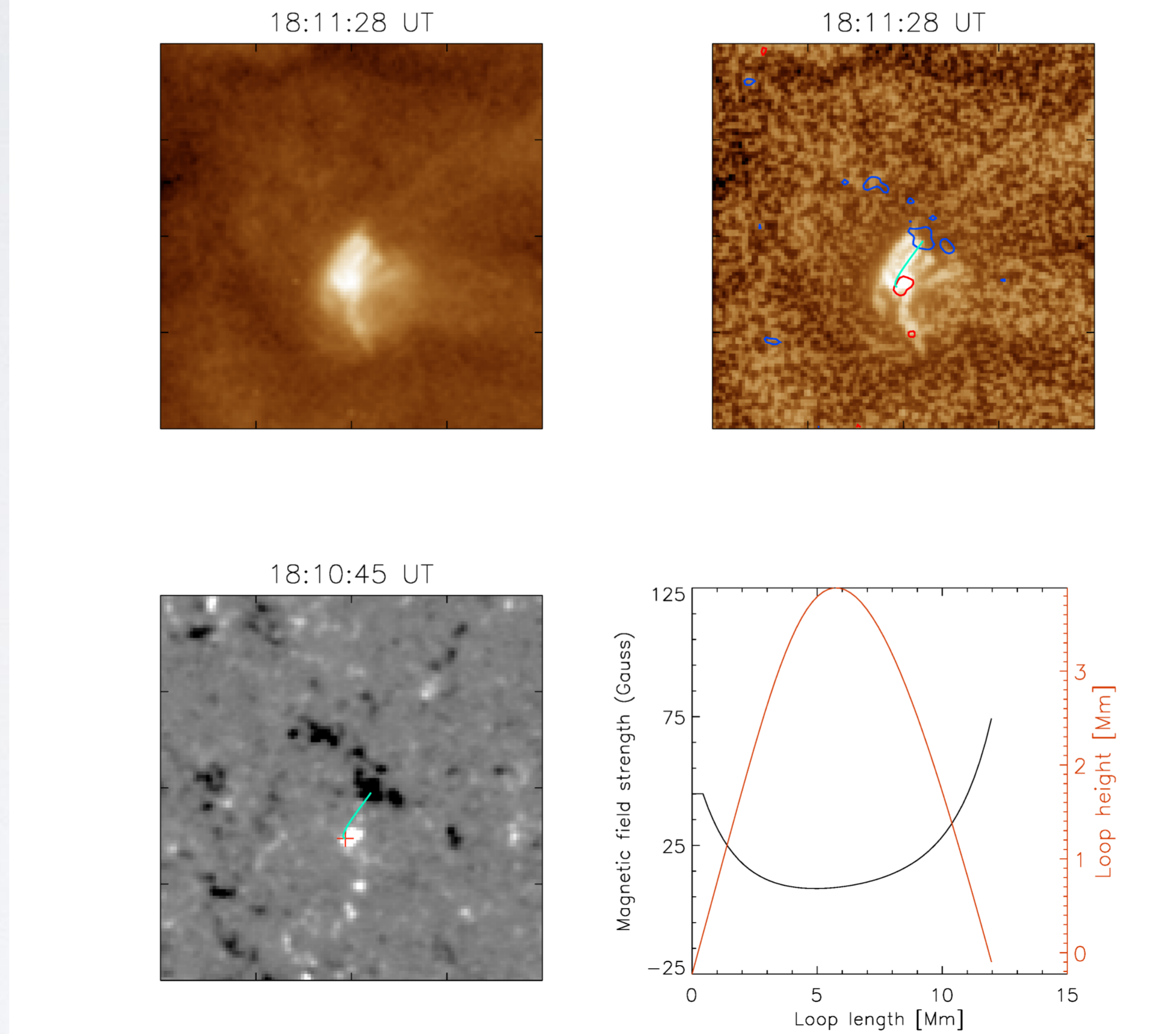
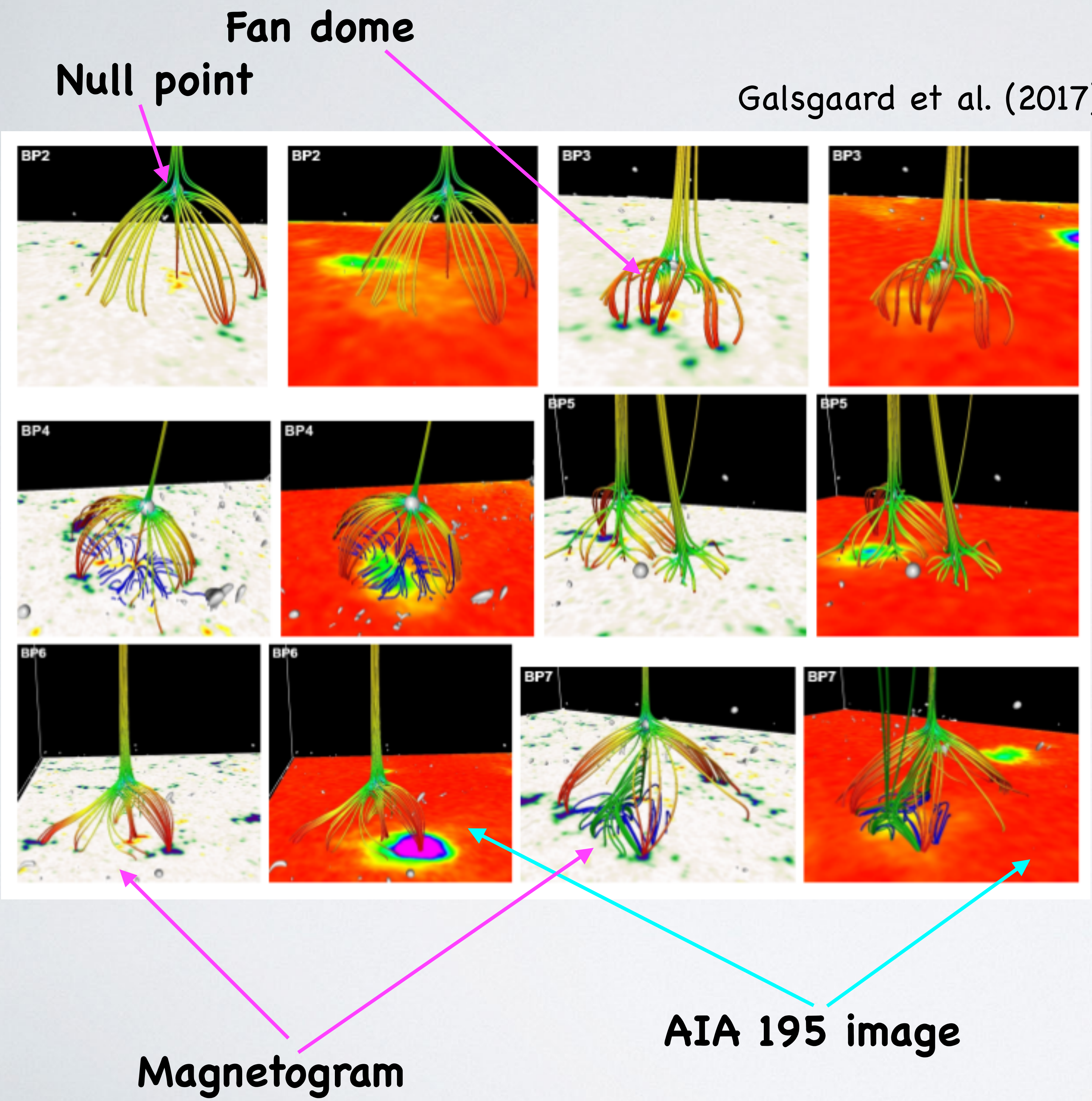


Fig. A.4. Linear force-free field extrapolation of a CBP loop. Top left: AIA 193 image. Top right: An MGN processed AIA 193 image overplotted with a magnetic field line that matches one of the extrapolated CBP loops. Bottom left: An HMI magnetogram overplotted with the same magnetic field line. The cross indicates the location from which the magnetic-field line was traced. Bottom right: Magnetic-field-line parameters.

Madjarska et al. (2021)

CBPs coronal magnetic field topology

Galsgaard et al. (2017)



✓In many cases this structure appears embedded in a limited part of a fan-dome structure that is formed by one polarity flux surrounded by opposite polarities (Zhang et al., 2001, Galsgaard et al. 2017).

✓In nine out of ten cases the bright point resides in areas where the coronal magnetic field contains an opposite polarity intrusion defining a magnetic null point above it.

What to take away?

- ✓ Small-scale loops outside ARs are the main building blocks of the solar atmosphere
- ✓ They have physical properties suggesting that they represent downscaled ARs
- ✓ 50% are related to flux emergence, while the rest form from the chance encounter of magnetic fluxes
- ✓ CBP that result from flux emergence are detected at coronal temperatures 30 to 60 min after the detected emergence in the photosphere
- ✓ Bright and fainter loops represent the same phenomena, with only difference probably related the different scale of the loops (watch for a forthcoming study by Madjarska et al.)
- ✓ Associated with polar regions with magnetic fluxes ranging from 3×10^{18} - 1.7×10^{20} Mx
- ✓ Magnetic flux emergence rate 2.3×10^{15} Mx s^{-1}, in the same range as reported about ephemeral regions.
- ✓ No recent study on how many ER are related to CBPs, older study used only X-ray data and find that only 1/3 of CBPs are related to ERs….

What to take away?

- ✓ Typical formation from emergence involves - magnetic flux divergence, convergence, cancelation or divergence followed by disappearance
- ✓ Typical formation from magnetic flux coalescence (chance encounter) involves - magnetic flux coalescence, convergence, cancelation or coalescence, convergence, divergence
- ✓ Rotation of bipoles is driven by supergranulation flows: not often observed
- ✓ Correlation (up to 0.95) of magnetic flux and coronal intensity best observed in cases of flux emergence with little contamination of background (and other not associated with the CBP) magnetic flux
- ✓ CBPs are the hosts of microflares, minifilament eruptions, jets, mini coronal mass ejections => all like in ARs but downscaled
- ✓ CBP loop system in the the corona is found to reside in a limited part of a fan-dome projected with a null point often detected in the corona which could be the location where the heating of these small-scale loops is generated during magnetic reconnection, still an open question.