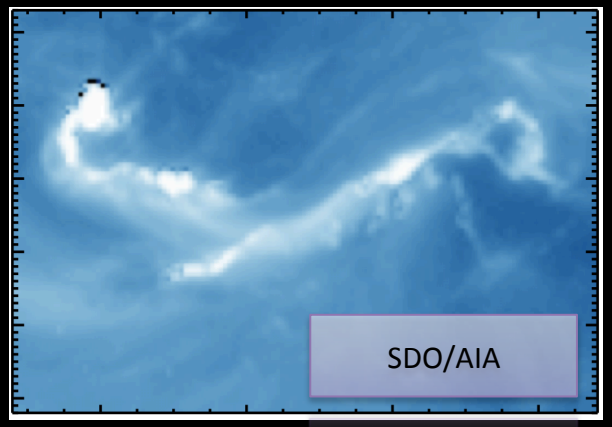
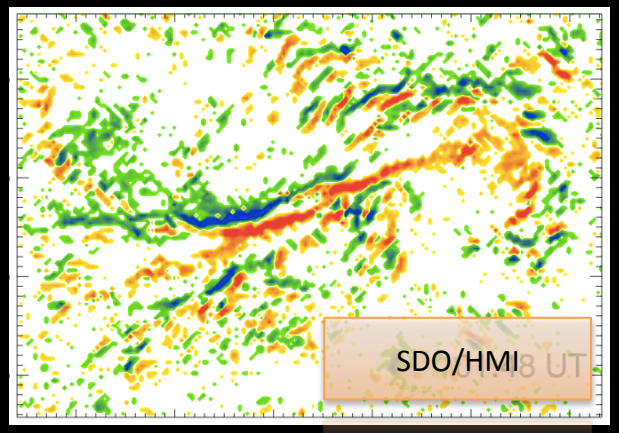
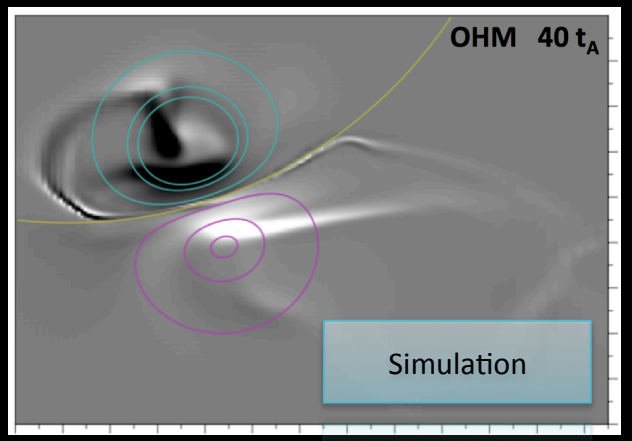






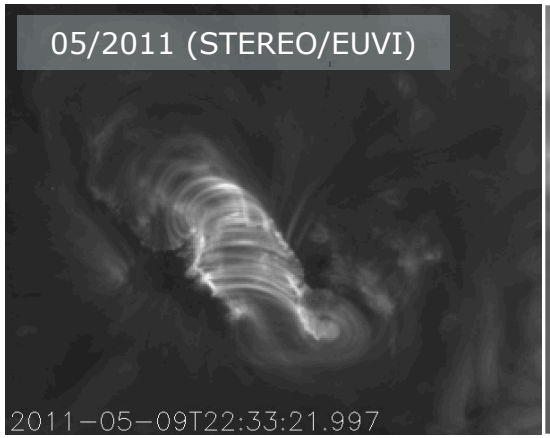
Evolution of electric currents and their connection with the 2011 February 15 X-class flare ribbons

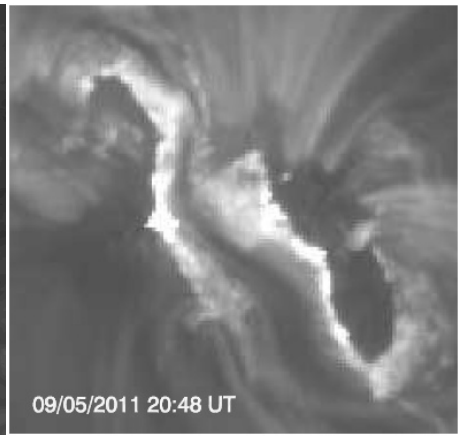
Miho Janvier

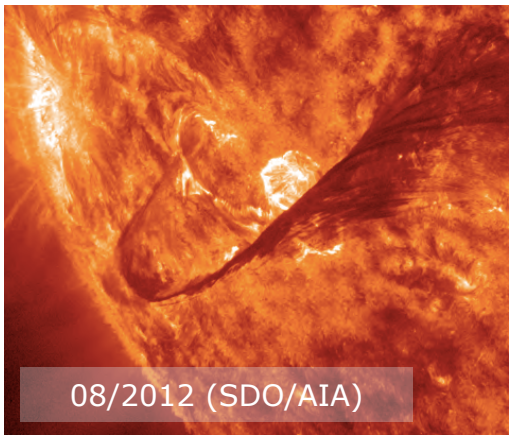
G. Aulanier, V. Bommier, B. Schmieder, P. Démoulin

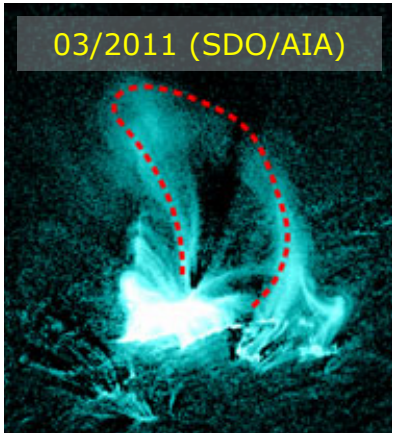
LESIA – Observatoire de Paris

Eruptive flares characteristics: flare loops, flare ribbons and flux rope









Flare loops and flare ribbons

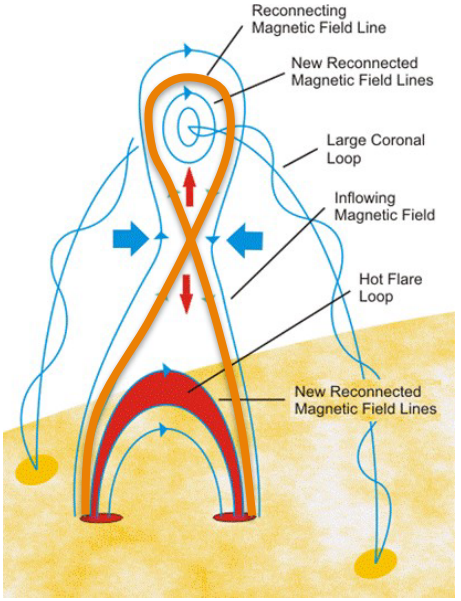
[Schmieder et al. 1995, Asai et al. 2003, Fletcher et al. 2011]

Flux rope

[Chen et al. 1997, Zhang et al. 2011, Patsourakos 2013]

- Flare loops: regions of high density and temperature (X/UV rays)
- Ribbons: collisional region between descending particles and higher density chromosphere
- Flux rope: twisted magnetic structure that can support a prominence

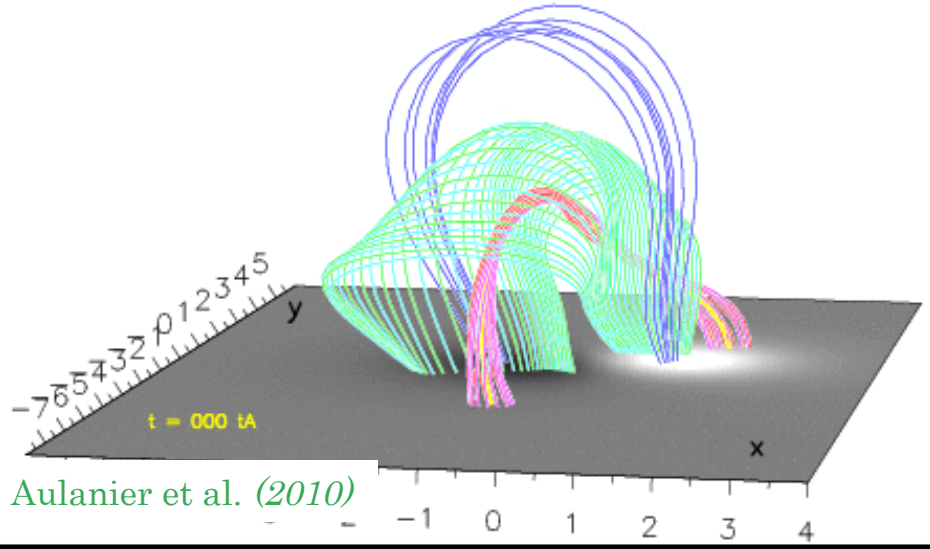
Carmichael (1964),
Sturrock (1966) ,
Hirayama (1974)
Kopp & Pneumann (1976)
Forbes & Malherbe (1986)
Shibata et al (1995)



OHM code: 3D, non uniform mesh, $\beta = g = 0$, $\eta_{coronal} = cst$

Free expansion of a torus-unstable flux rope

→ 3D (slipping) reconnection Janvier et al. *(2013)*



Aulanier et al. *(2010)*

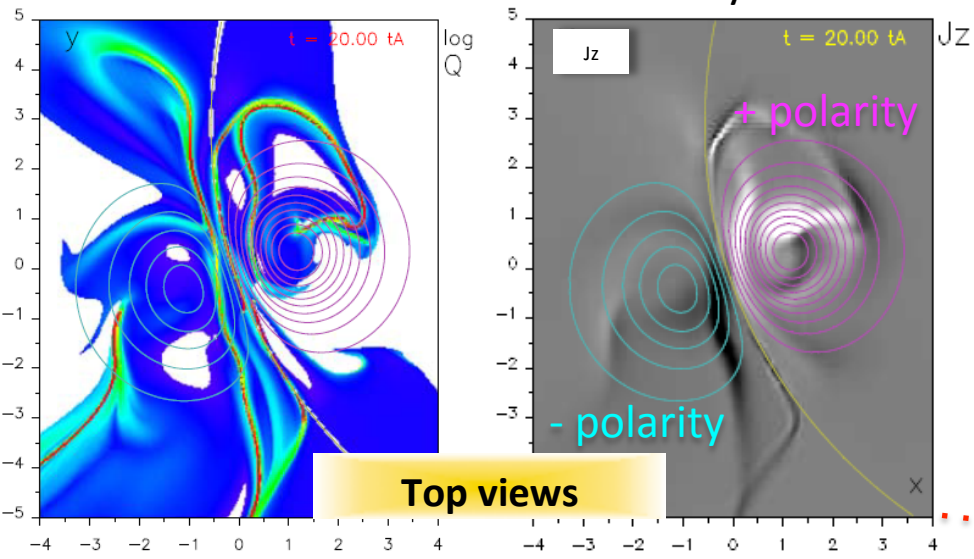
OHM code: 3D, non uniform mesh, $\beta = g = 0$, $\eta_{coronal} = cst$

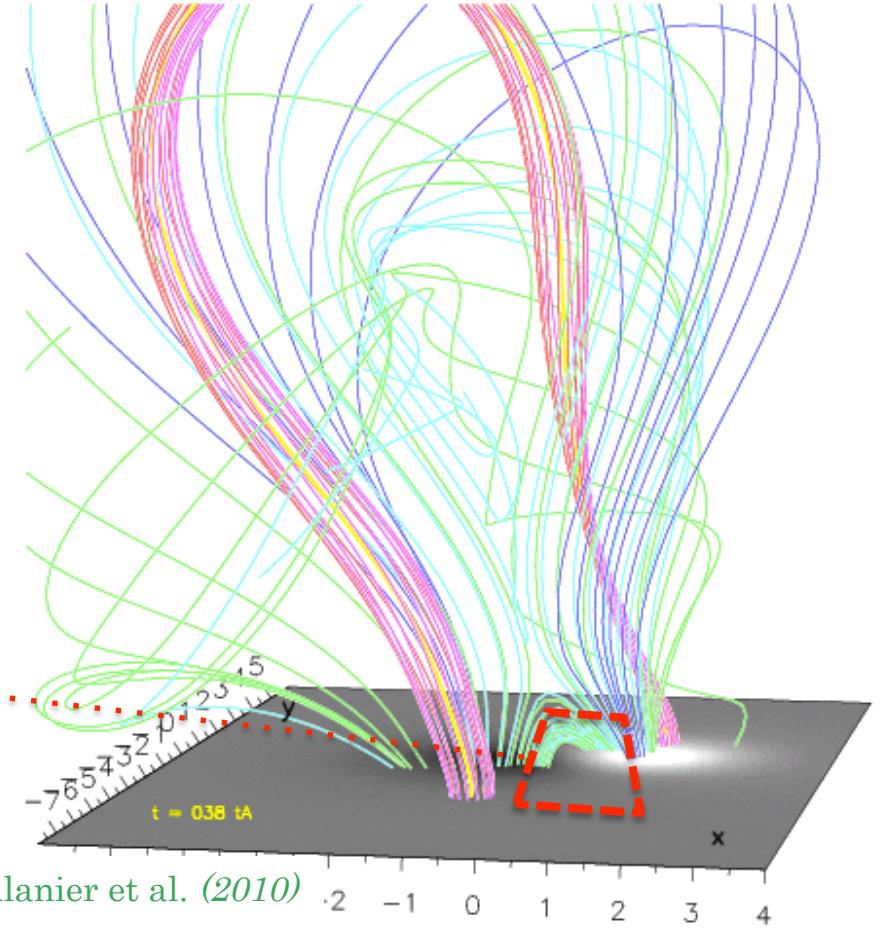
Free expansion of a torus-unstable flux rope

→ 3D (slipping) reconnection Janvier et al. *(2013)*

Quasi-Separatrix Layers

J_z photospheric layers



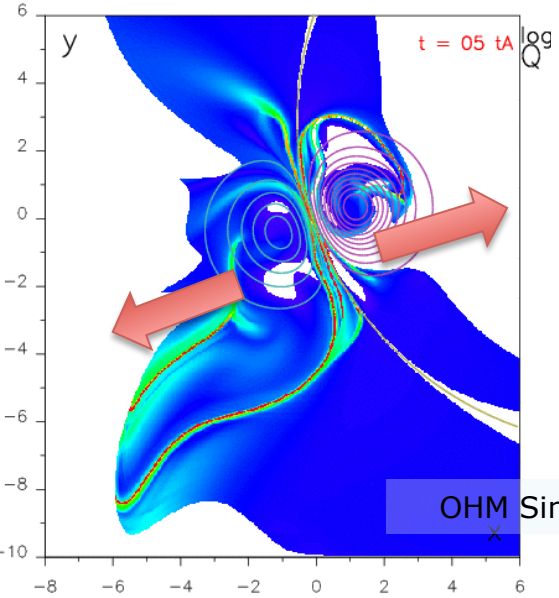


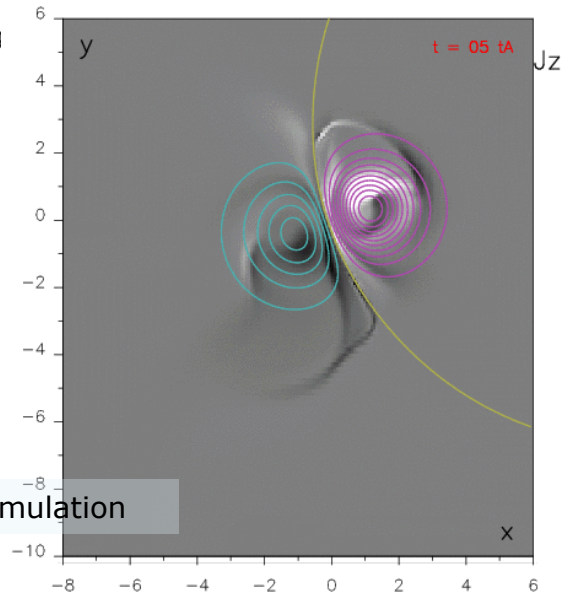
Aulanier et al. *(2010)*

Predictions for the flare ribbons from this 3D standard model

Qualitative evolution of the flare ribbons via the evolution of the QSLs/current ribbons

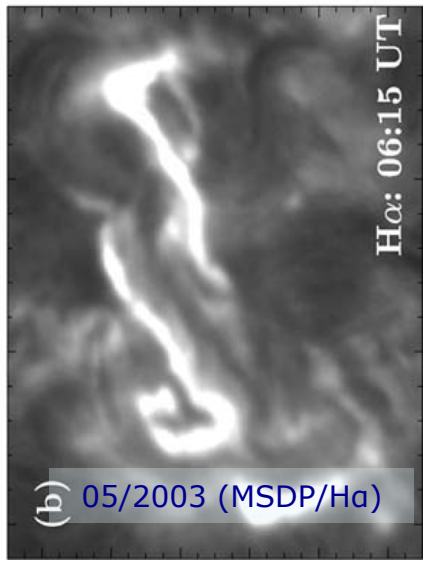
- Ribbon separation
- J-shape structure





OHM Simulation

Janvier et al (2013)
Dudìk et al. *(submitted)*

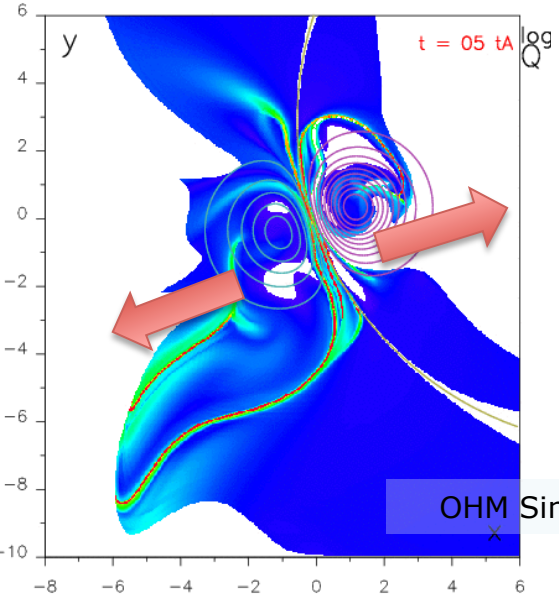


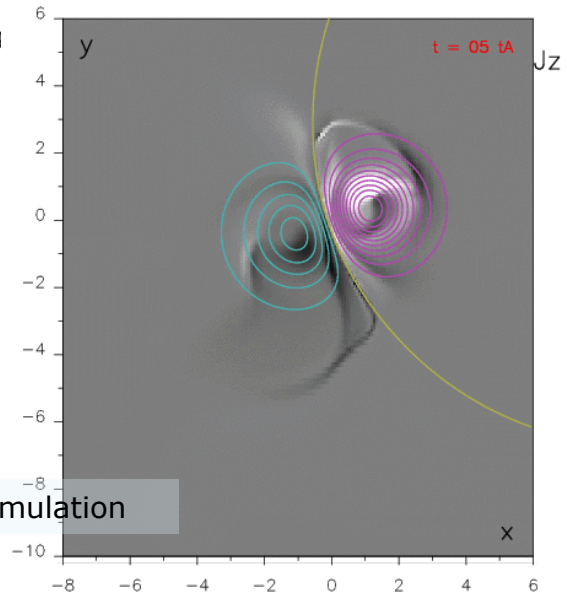
Chandra et al. *(2009)*

Does the "real" Sun confirm these predictions?

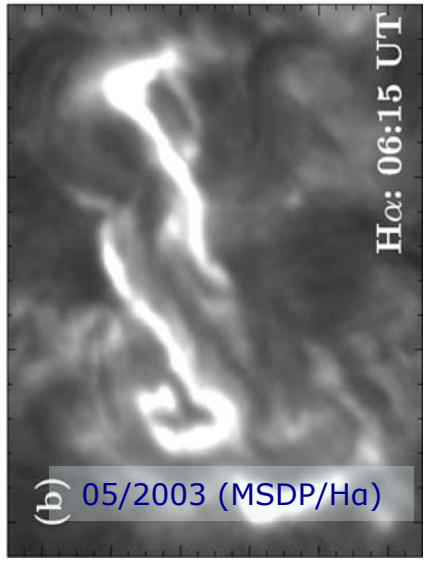
Qualitative evolution of the flare ribbons via the evolution of the QSLs/current ribbons

- Ribbon separation
- J-shape structure





Janvier et al (2013)
Dudìk et al. *(submitted)*

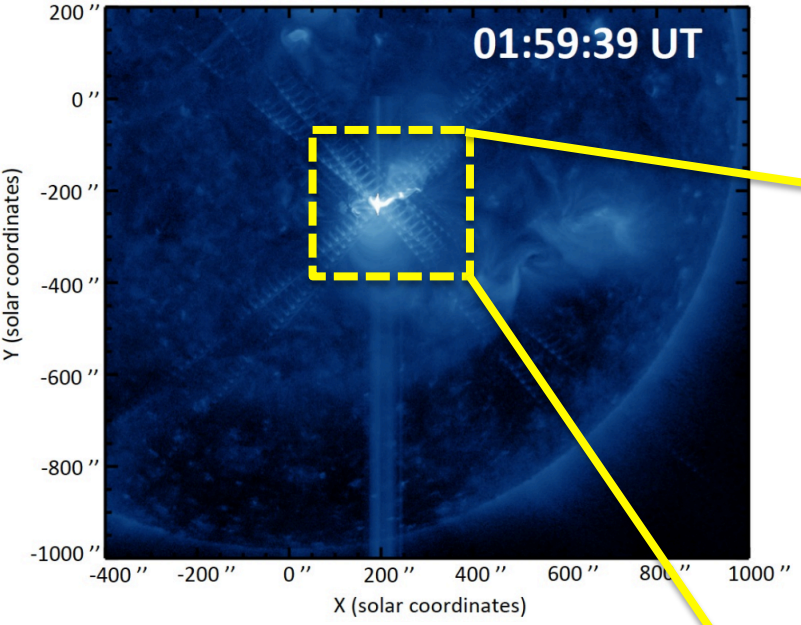


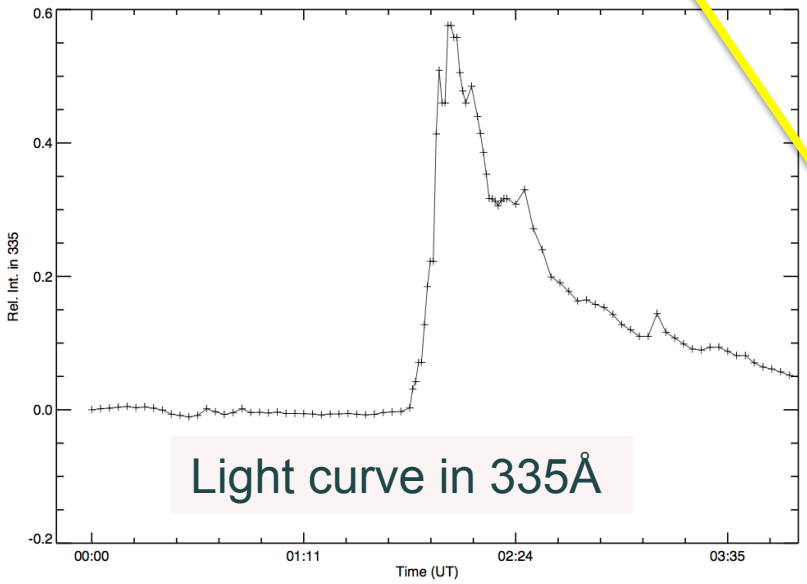
Chandra et al. *(2009)*

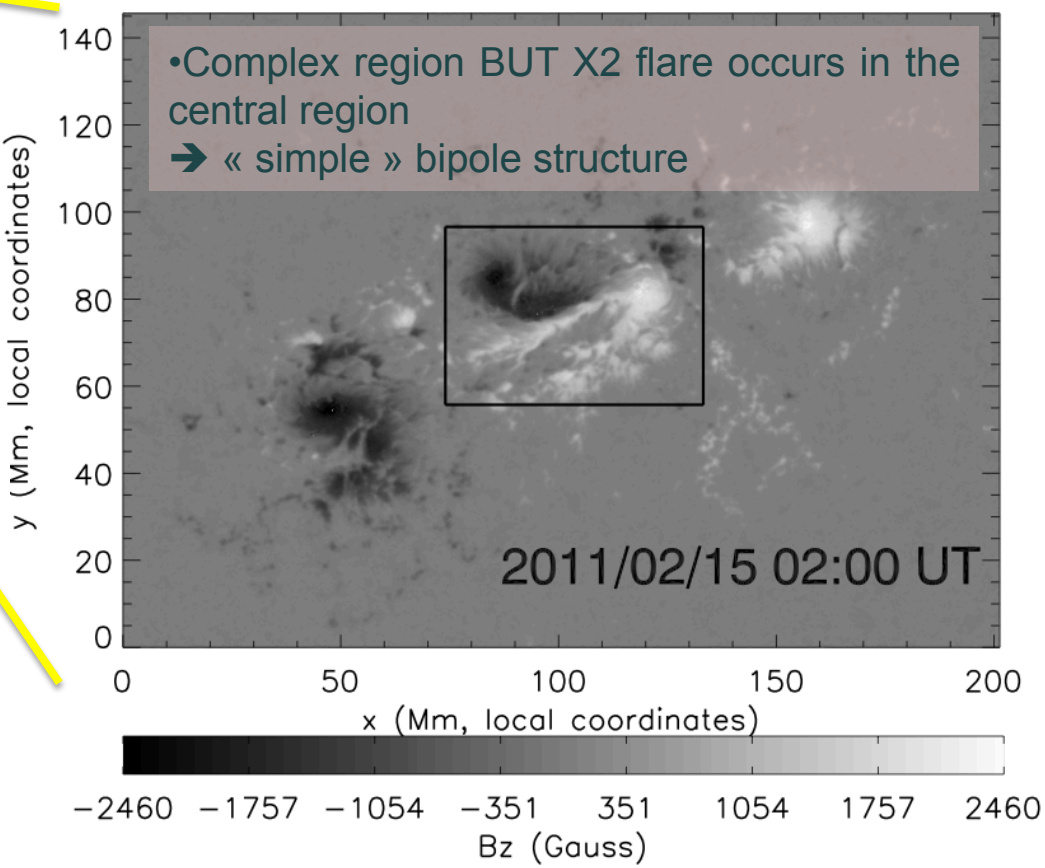
➔ Photospheric currents: **measurements** vs idealized « zero-β » boundary currents?

➔ What would **their evolution** tell us about the energy release?
Should **current decrease** as the magnetic field goes back toward a potential state?

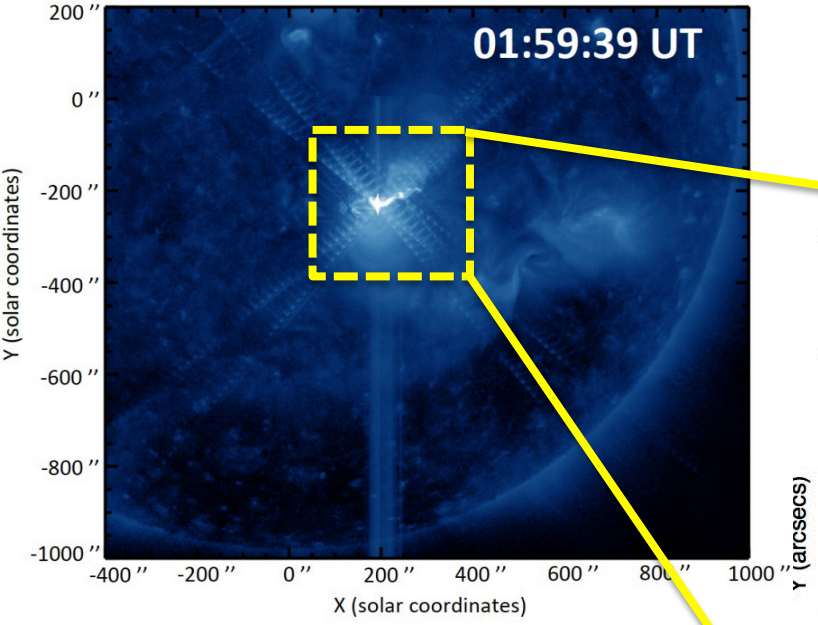
Case study: AR 11158 and the Feb. 15, 2011 X2 flare

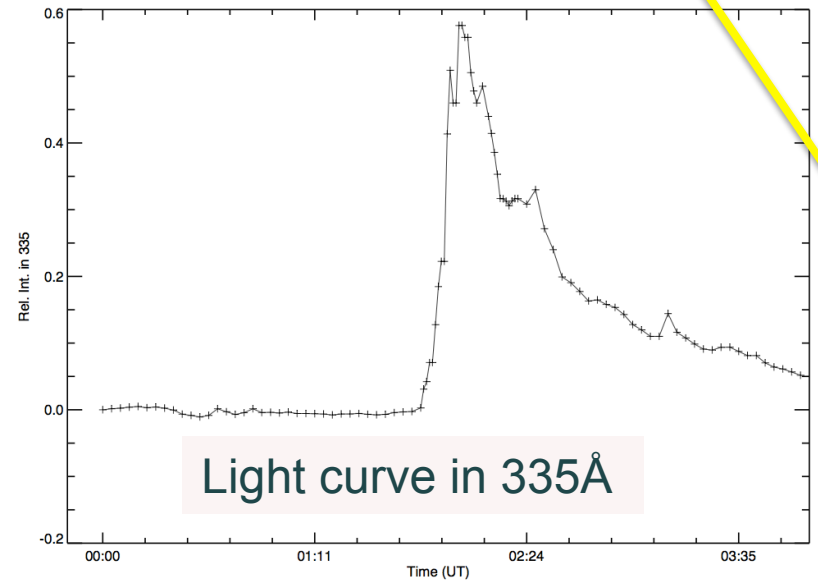




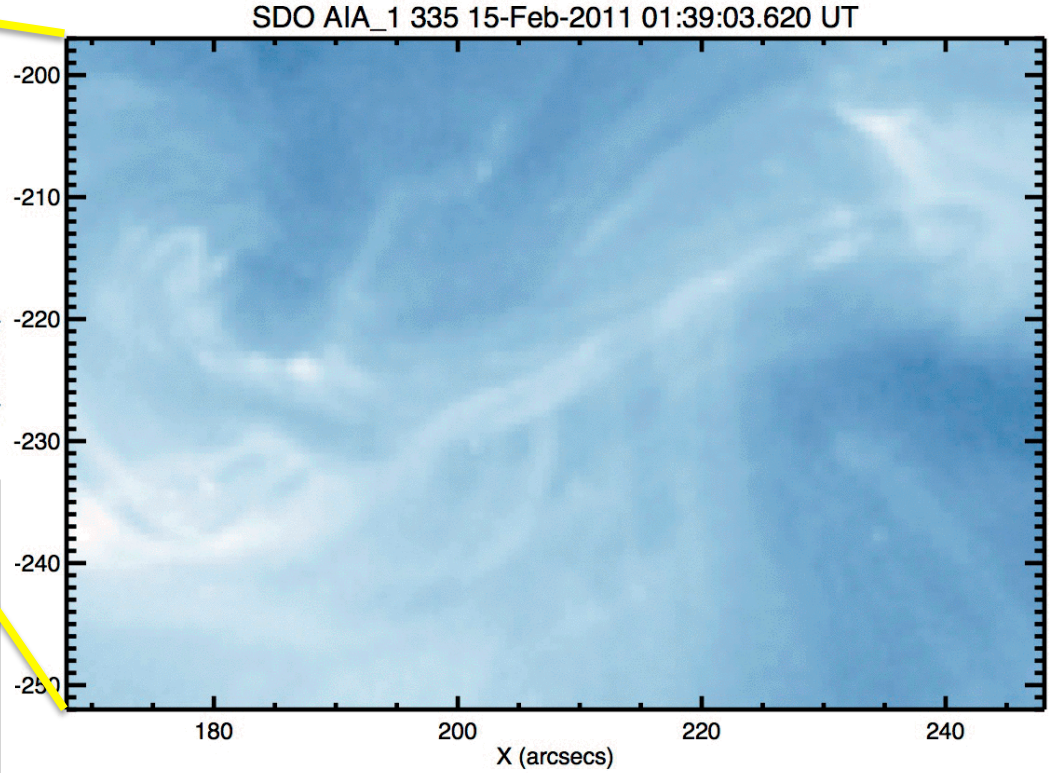


Case study: AR 11158 and the Feb. 15, 2011 X2 flare





Light curve in 335Å



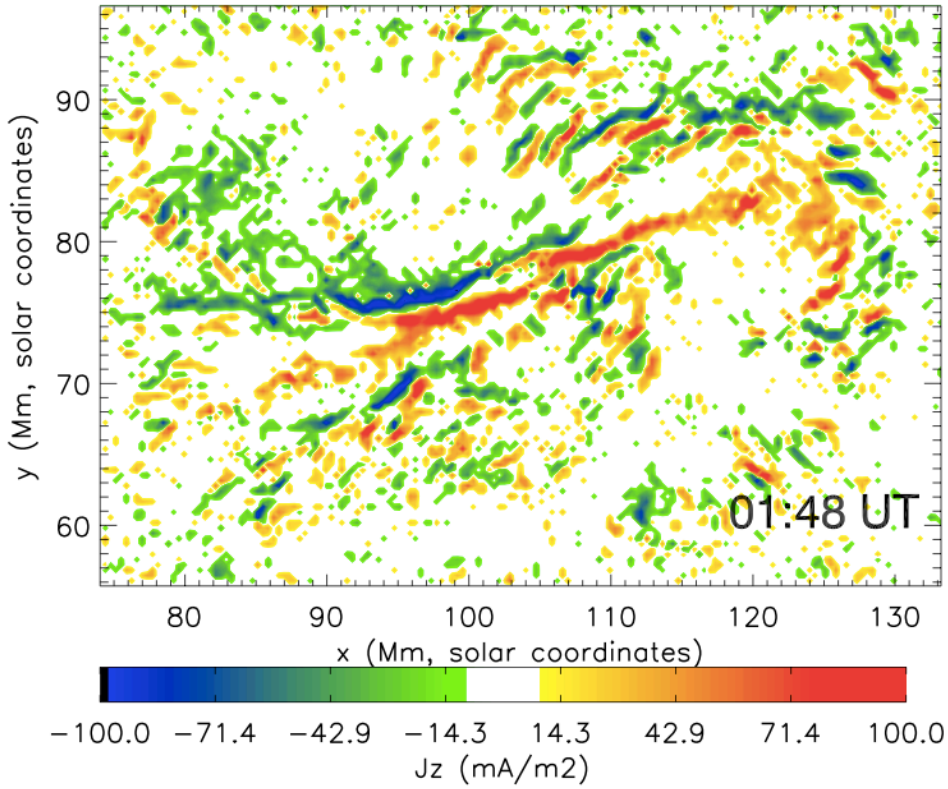
Flare ribbon evolution

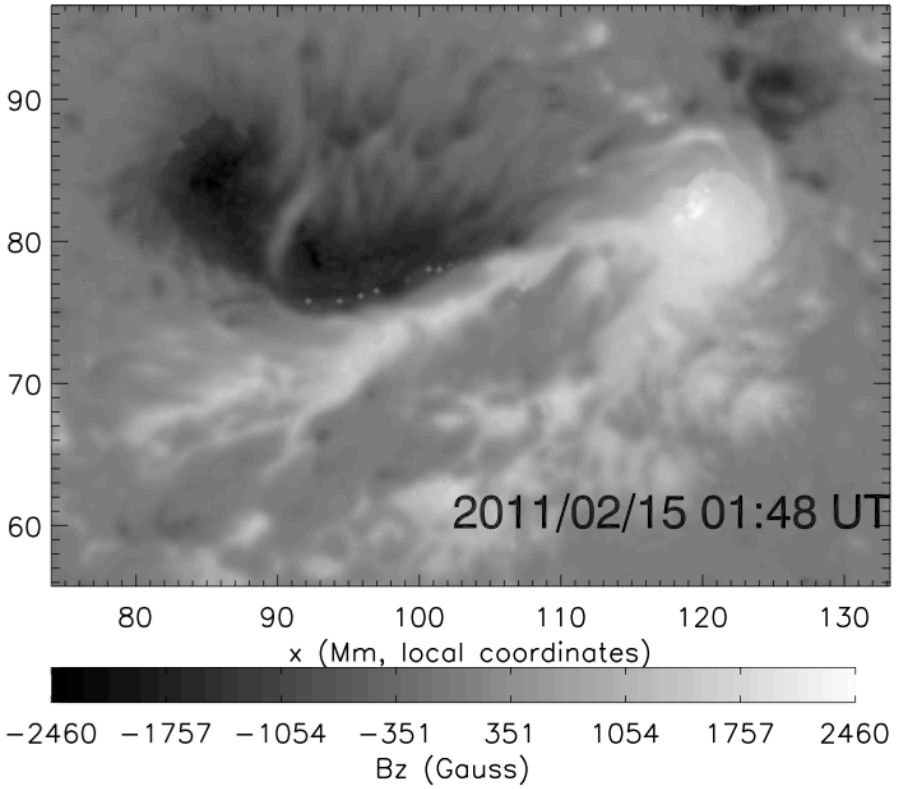
From HMI (raw) data to current density maps

Unnofit inversion method: Bommier et al. *(2007)* see also Bommier's poster (S1P12)

➔ B(x,y,z) is calculated ➔ Maps of the current density are available

signal with $|J|>0.02$ A.m^{-2}





➔ 4 regions: -« Straight parts » of the J-shape
-« Hook parts » of the J-shape for positive and negative B

Evolution of the current density in the defined regions

Unnofit inversion method: Bommier et al. *(2007)* see also Bommier's poster (S1P12)

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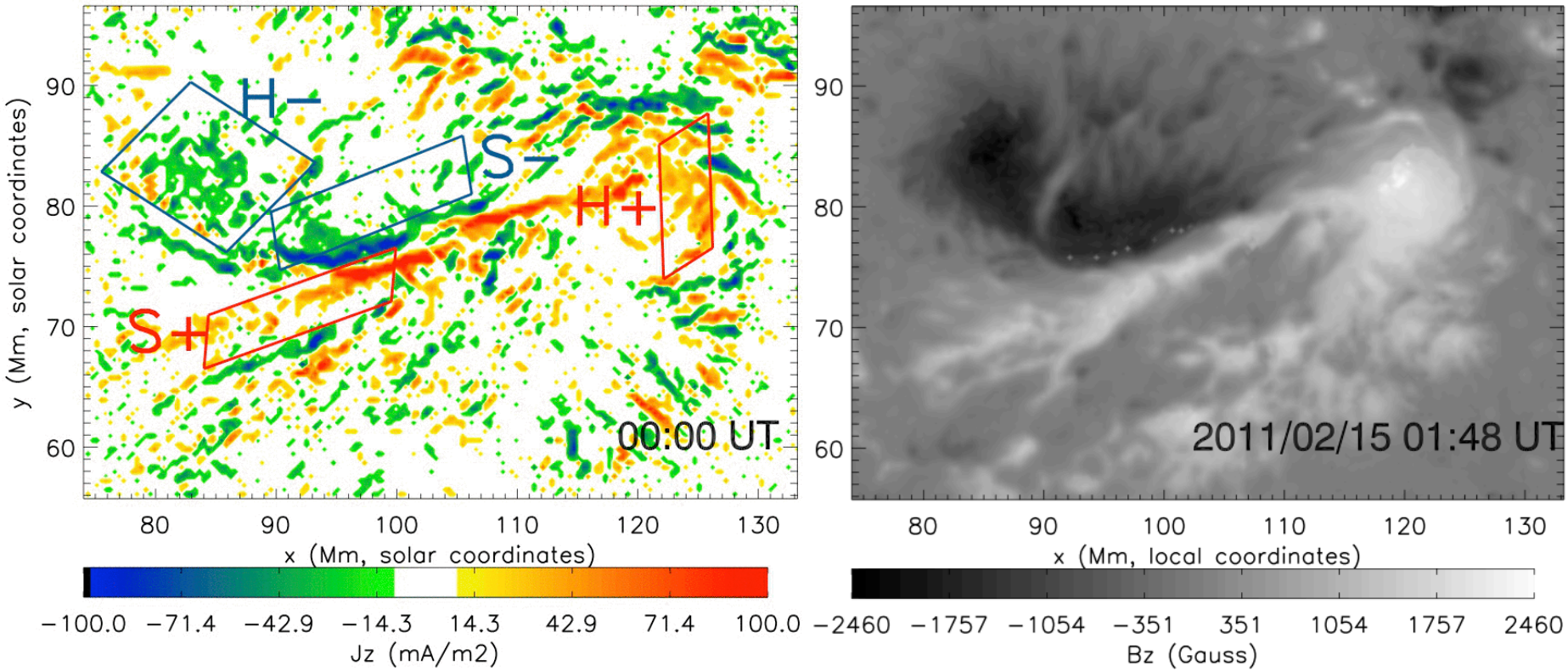
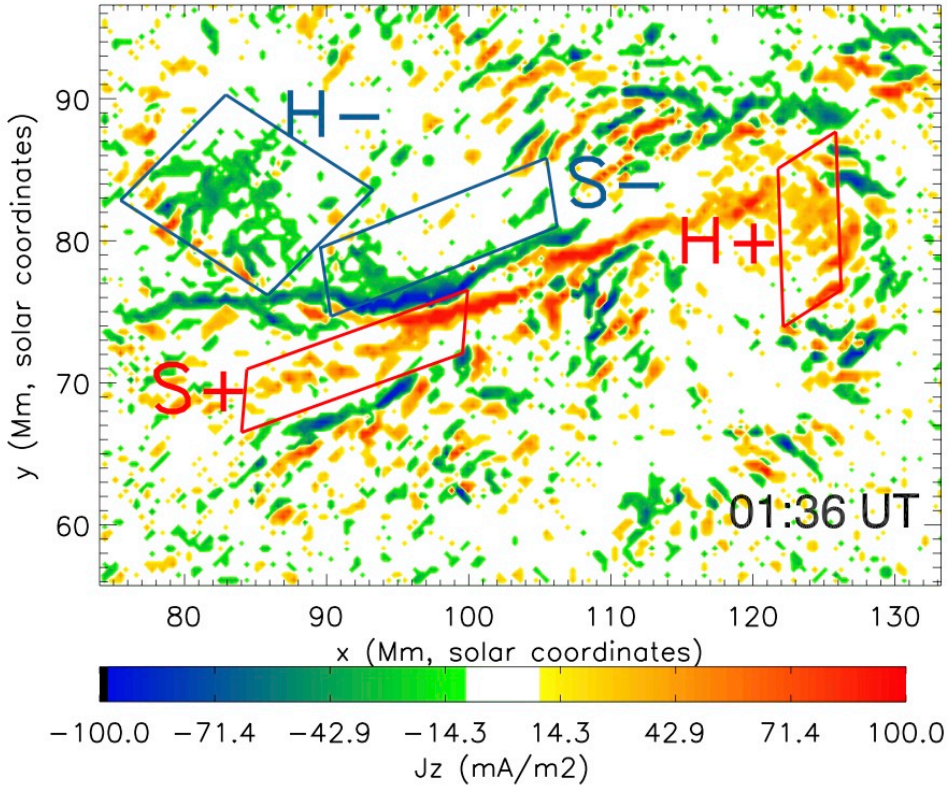
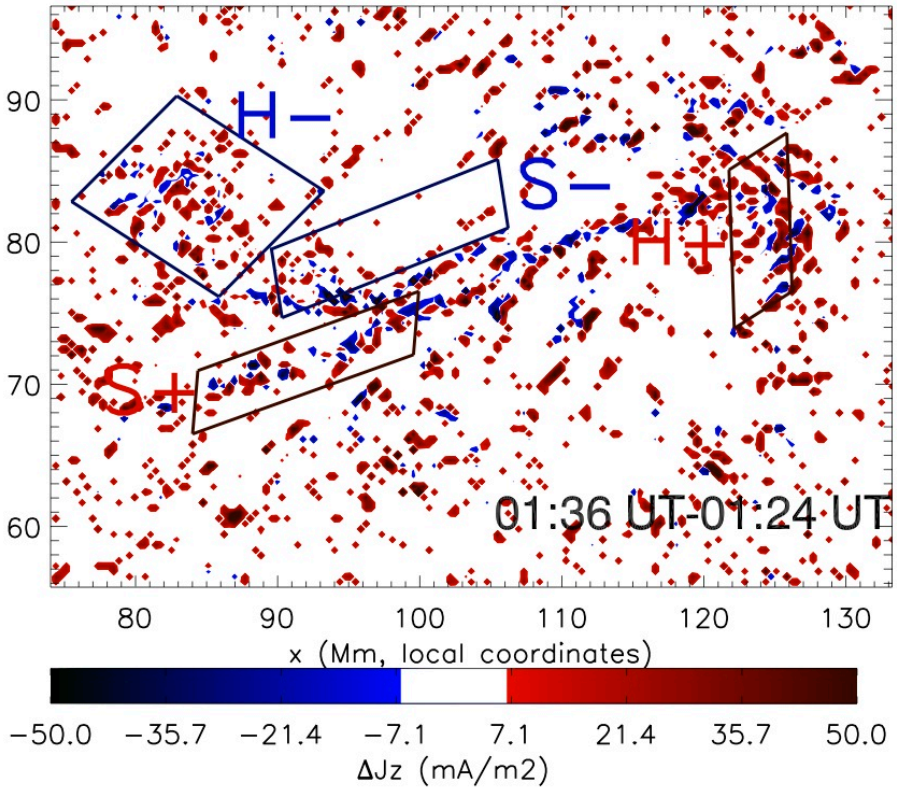


➔ 4 regions: -« Straight parts » of the J-shape
-« Hook parts » of the J-shape for positive and negative B

Evolution of the current density in the defined regions

Base difference: $J_{direct}(t) - J_{direct}(01:24\ UT)$
Red: increase, Blue: decrease





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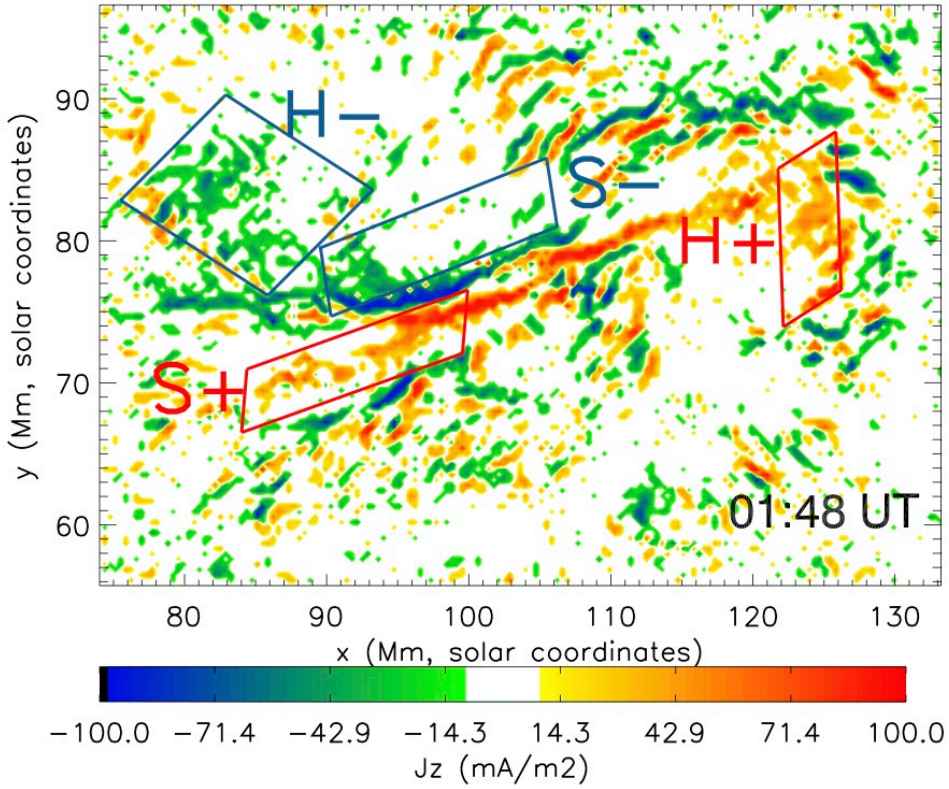

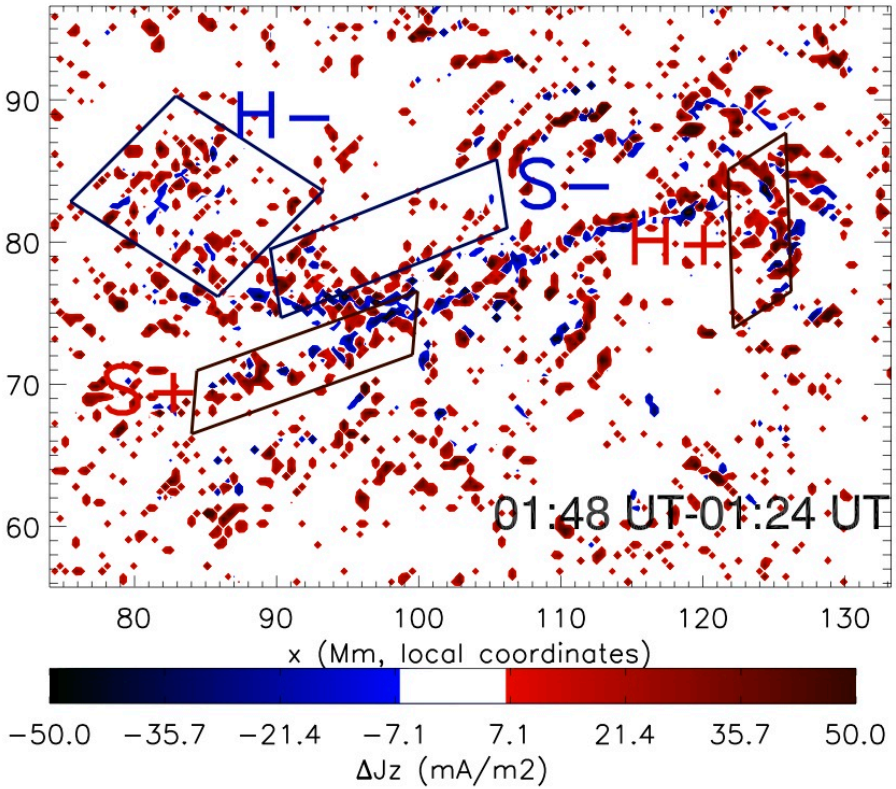

Evolution of the current density in the defined regions

Base difference: $J_{direct}(t) - J_{direct}(01:24\ UT)$
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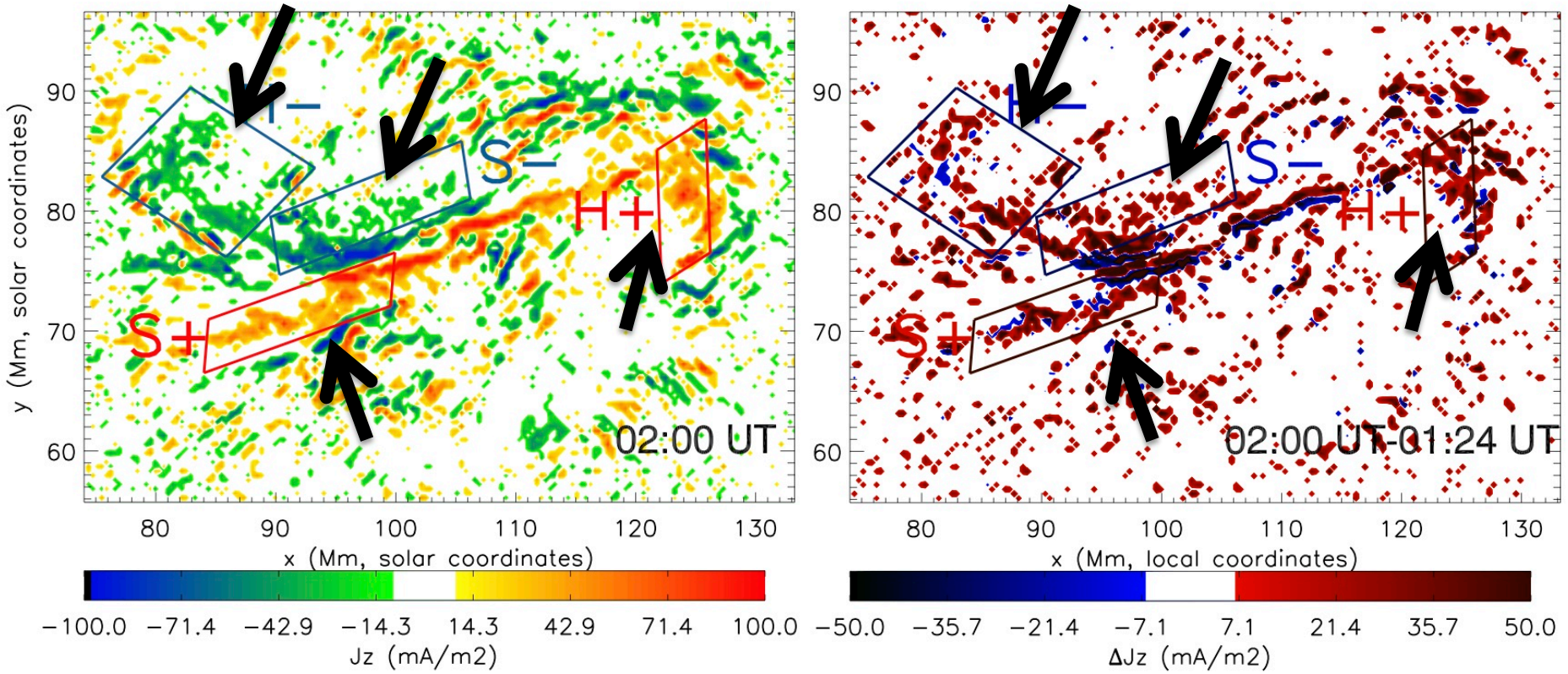
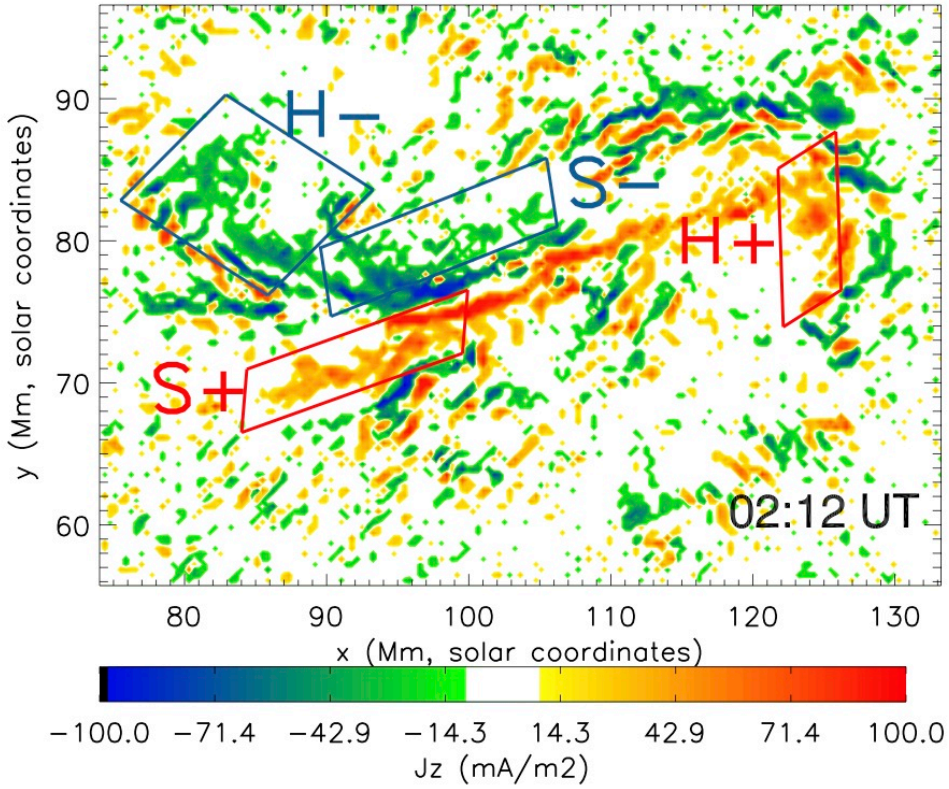
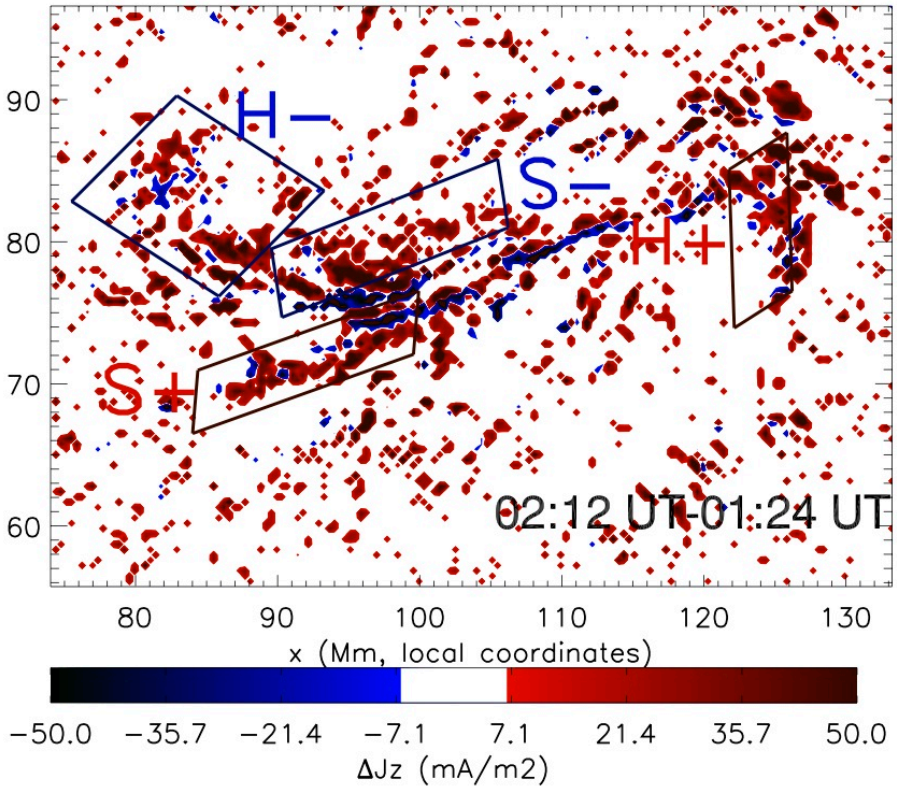


H- : Signal more consistent for the hook, S- : broadening of the current ribbon
S+: Elongation of the current ribbon, H+: Signal increase in the hook

Evolution of the current density in the defined regions

Base difference: $J_{direct}(t) - J_{direct}(01:24\ UT)$
Red: increase, Blue: decrease



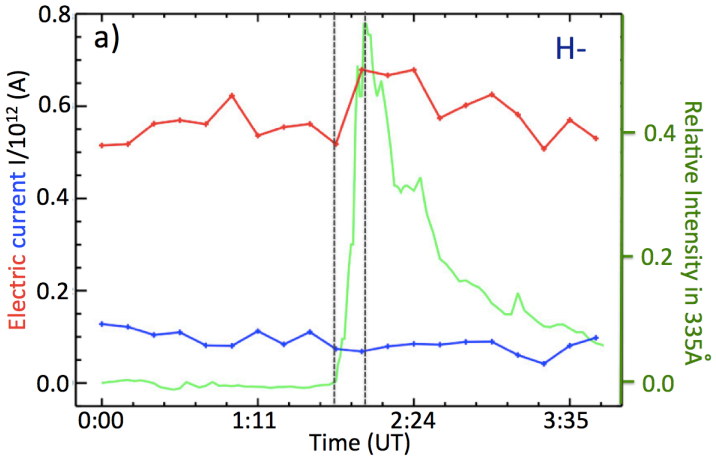


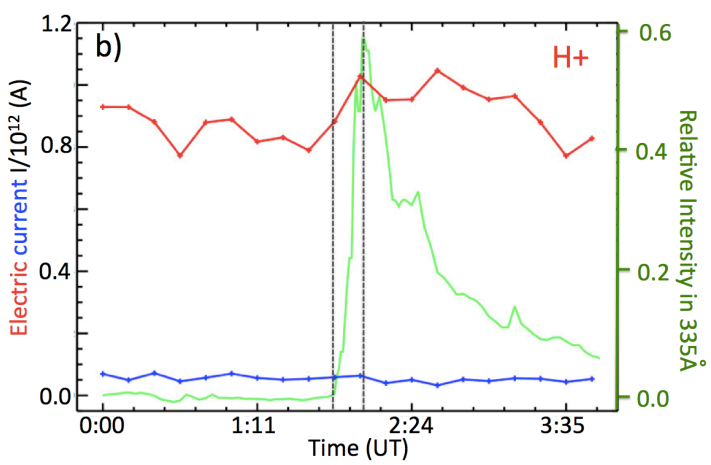
Integration of the current densities in the designed boxes:

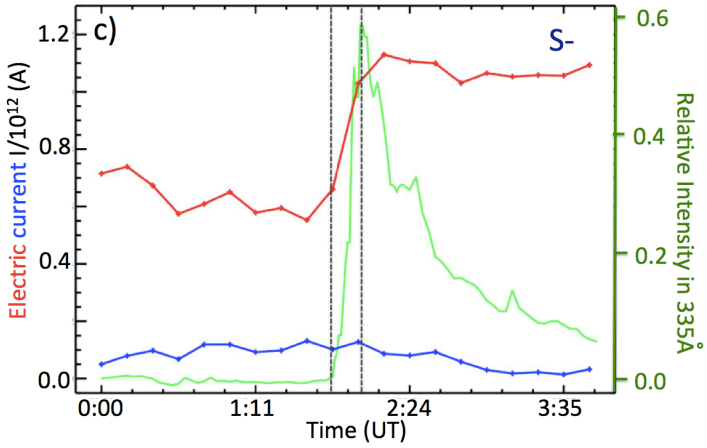
➔ Separation between direct current ($B_zJ_z>0$) and return current ($B_zJ_z<0$)

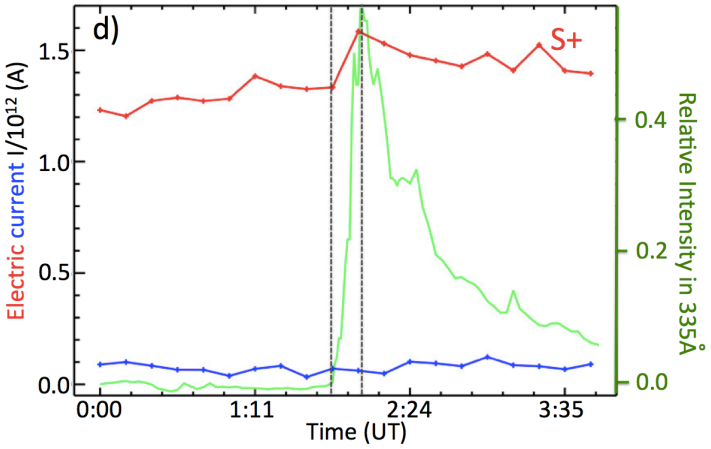
➔ Evolution in time

$$I = \iint_{(x,y)} J_z dx dy$$







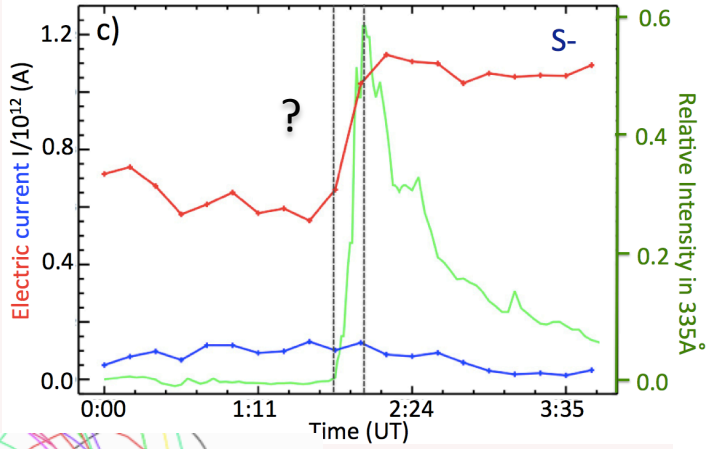


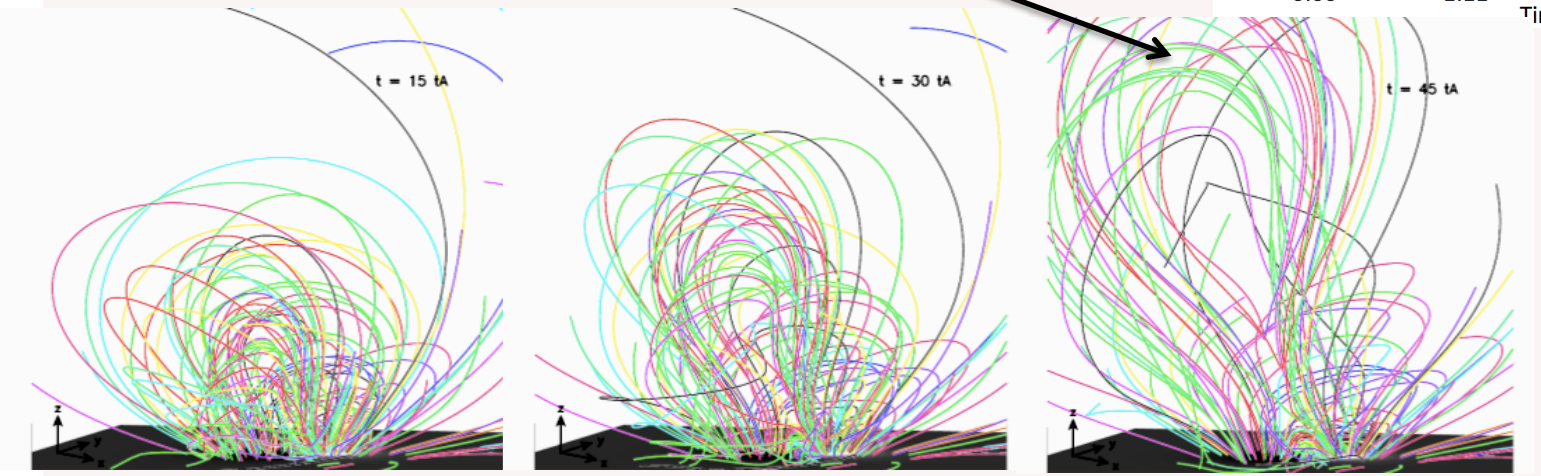
Increase in the current signal during the flare!

Why does the current increase?

Flare = energy release (**E_B decreases**)

→ Magnetic field evolution towards **potential state** as helicity is ejected via the CME

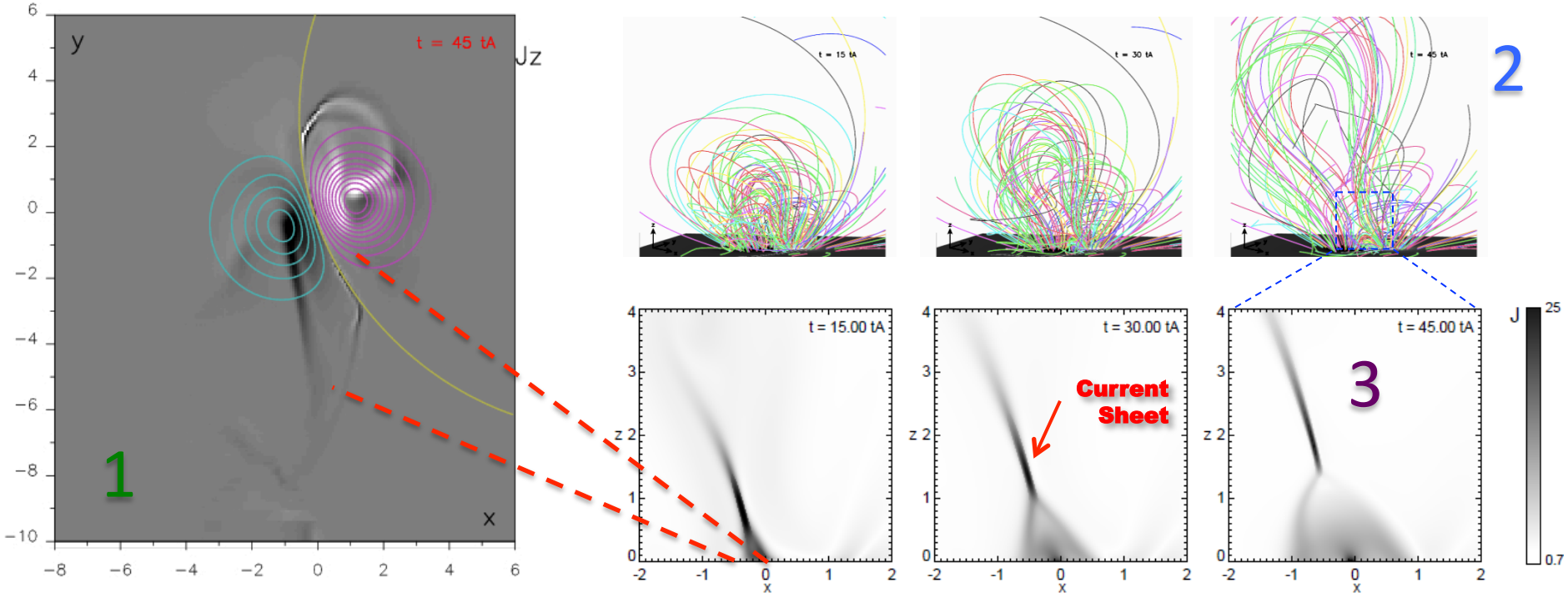




→ Current density *J* **should be decreasing**…

OTHER PHYSICAL EFFECT THAT IS DISMISSED IN THIS REASONING?
(or false signal?)

What was dismissed: the **CURRENT SHEETS!**

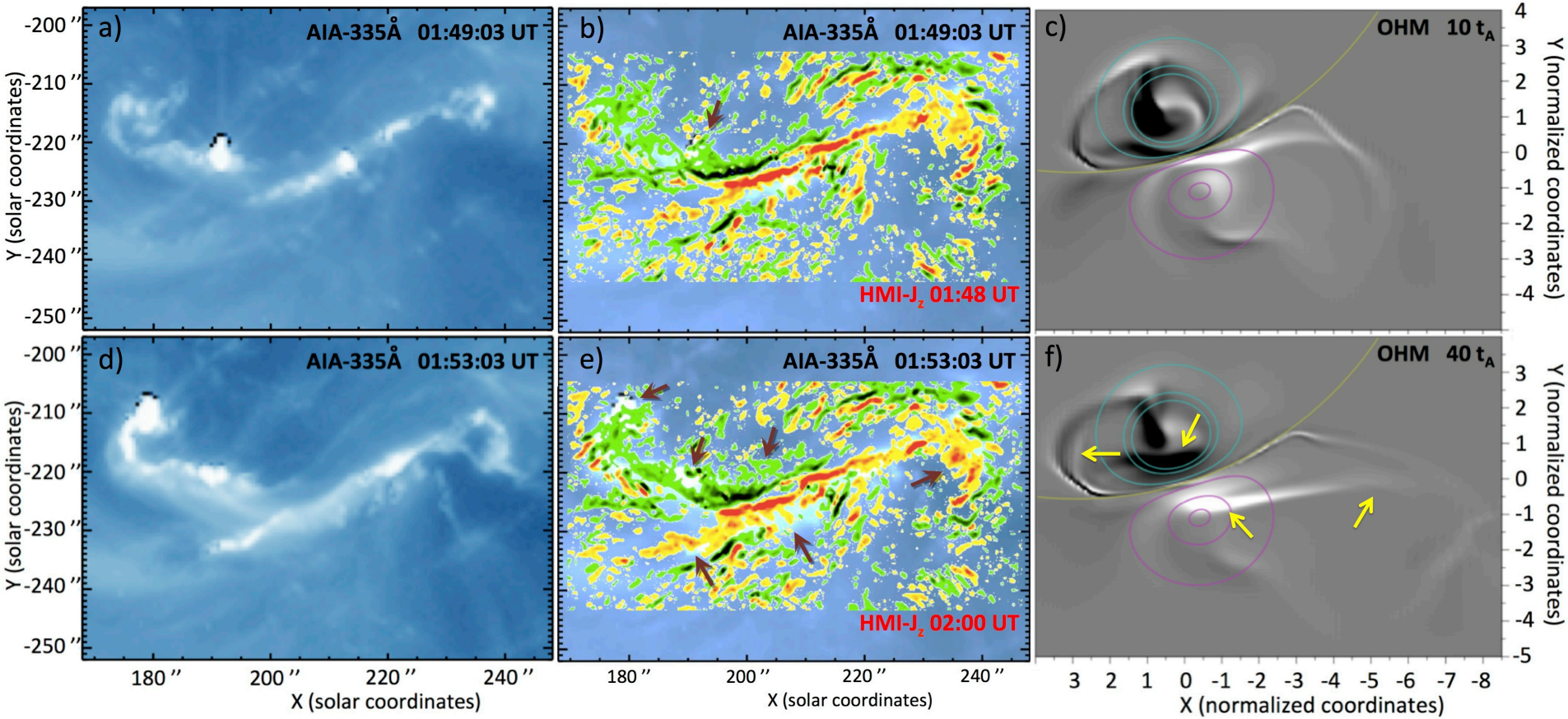


Janvier et al (2013)

1. Photospheric current = footprints of current structure in the corona
2. Flux rope eruption: magnetic field forced to evolve ➔ shear and converging flows
3. ➔Current density increase ➔ collapse of the coronal J layer ➔ reconnection ++

Flare ribbons evolution with AIA data:

➔ Superposition of J_z-maps from HMI data



- Broadening/elongation of the « straight » parts
- Consistent hook structures after the peak

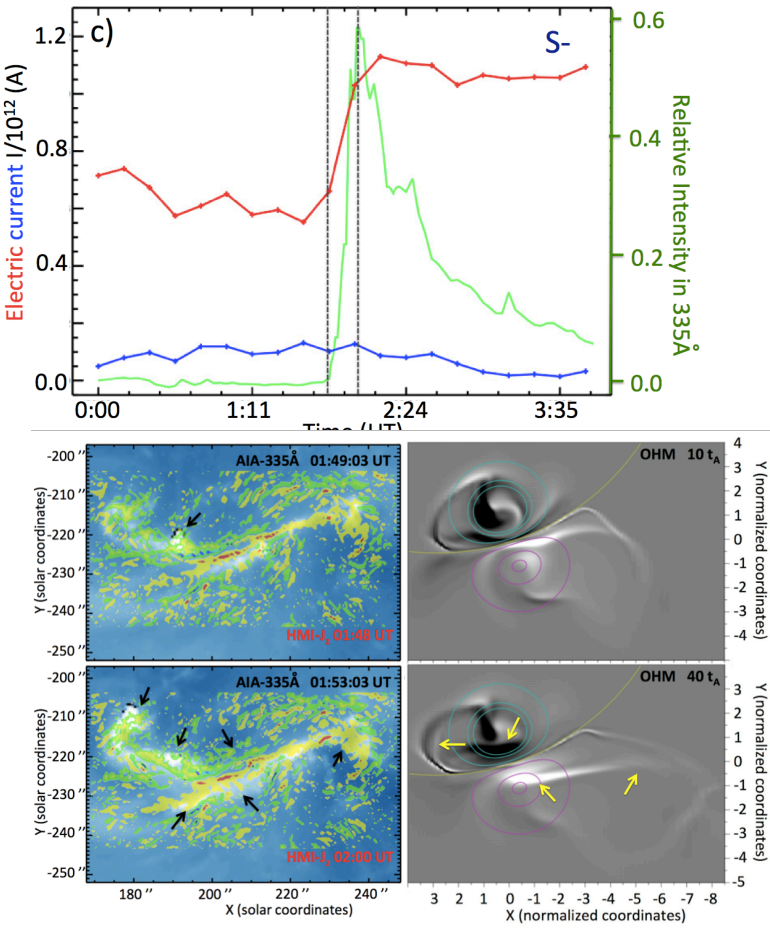
➔ All features well reproduced in J_z maps! (obs/simu)

Conclusion: observational match for the 3D standard model

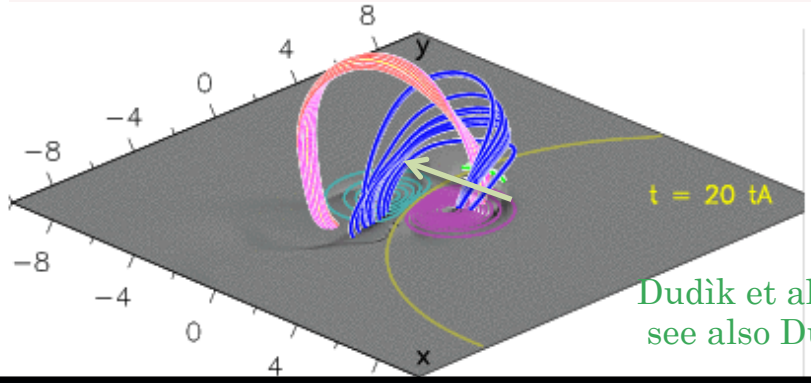
1. **First comparisons** of flare ribbons and current density ribbons evolutions with **high time cadence from AIA and HMI**. <u>They match the predictions of the 3D standard model</u>

2. Photospheric current **increases** during the impulsive phase:
Due to collapse of the coronal current layer and development of currents all along QSLs

3. Hook evolution :
➔ hook broadens as FR is further built up during the eruption



Janvier et al (in prep.)



Dudìk et al. *(submitted)*,
see also Dudìk's poster (S4P26)