Space Weather science and next generation 4m telescopes

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SWE SPACE WEATHER GROUP

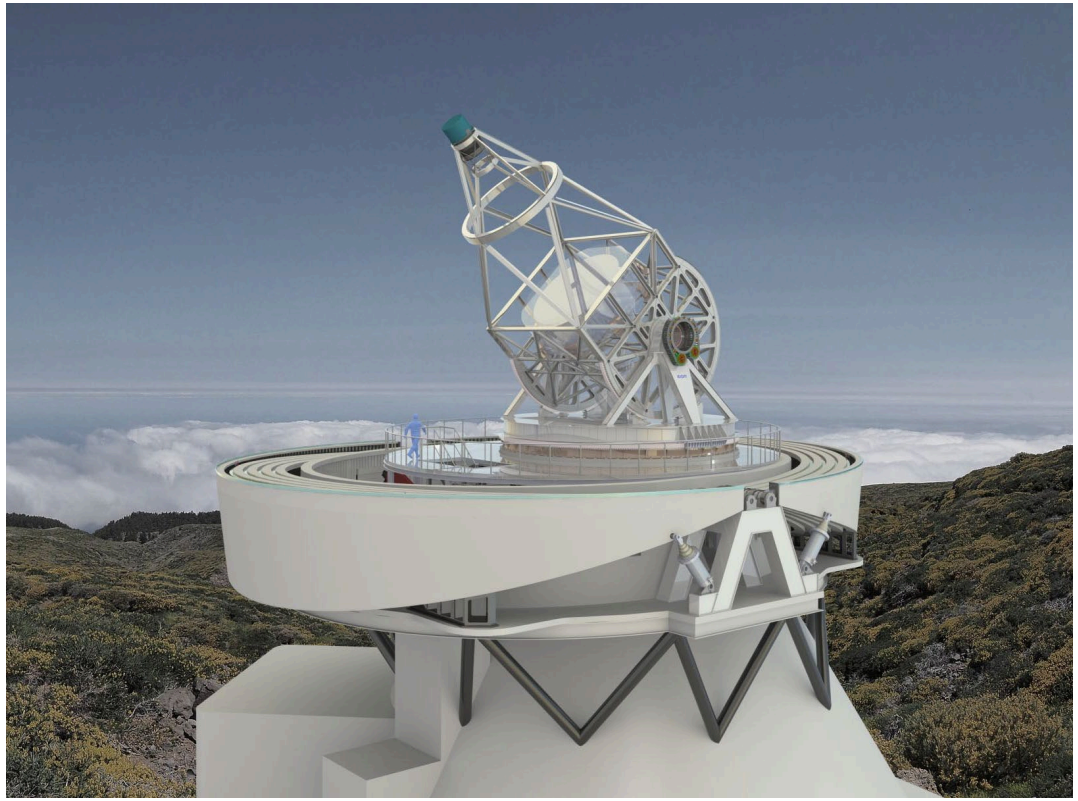
The next generation 4m telescopes. DKIST

We require an instrument with large aperture, not only to reach sufficient spatial resolution, but also to collect enough photons for accurate polarimetry. We also require the ability to observe the Sun at many wavelengths simultaneously, including in the near ultraviolet and in the infrared, to resolve the three-dimensional structure of the solar atmosphere, and at high temporal resolution to resolve the highly dynamic nature of the atmosphere. With these requirements the DKIST will be the ideal tool for magnetic remote sensing.

From DKIST web page

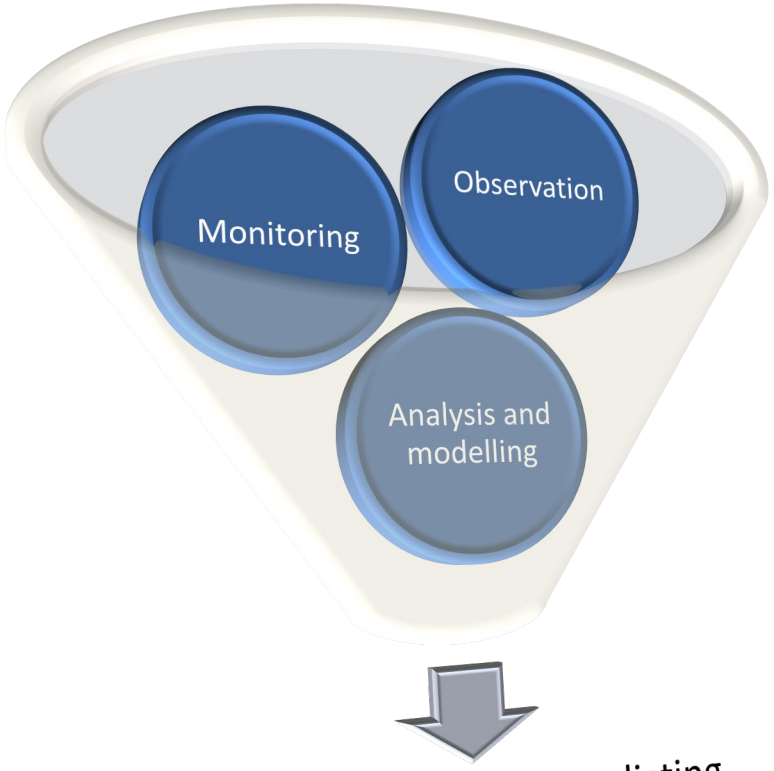
The next generation 4m telescopes. EST

With a 4.2-metre primary mirror, it will be optimised for studies of the magnetic coupling of the solar atmosphere. This will require diagnostics of the thermal, dynamic and magnetic properties of the plasma over many scale heights, by using multi-wavelength imaging, spectroscopy and spectropolarimetry. EST will specialise in high spatial and temporal resolution, using several instruments simultaneously to efficiently produce 2D spectral information



From EST web page

The goal of Space Weather Science



Space weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; and also at forecasting and nowcasting the possible impacts on biological and technological systems.'

COST Action 724 ('extract of the Final Report'), 2017

SWE typical proxies and impacts

Radio blackouts

- Physical measurement: GOES X-ray flux in the 0.1-0.8 nm range
- Effects: Problems in HF radio and Navigation from minutes to hours, …

Flares

Solar radiation Storms

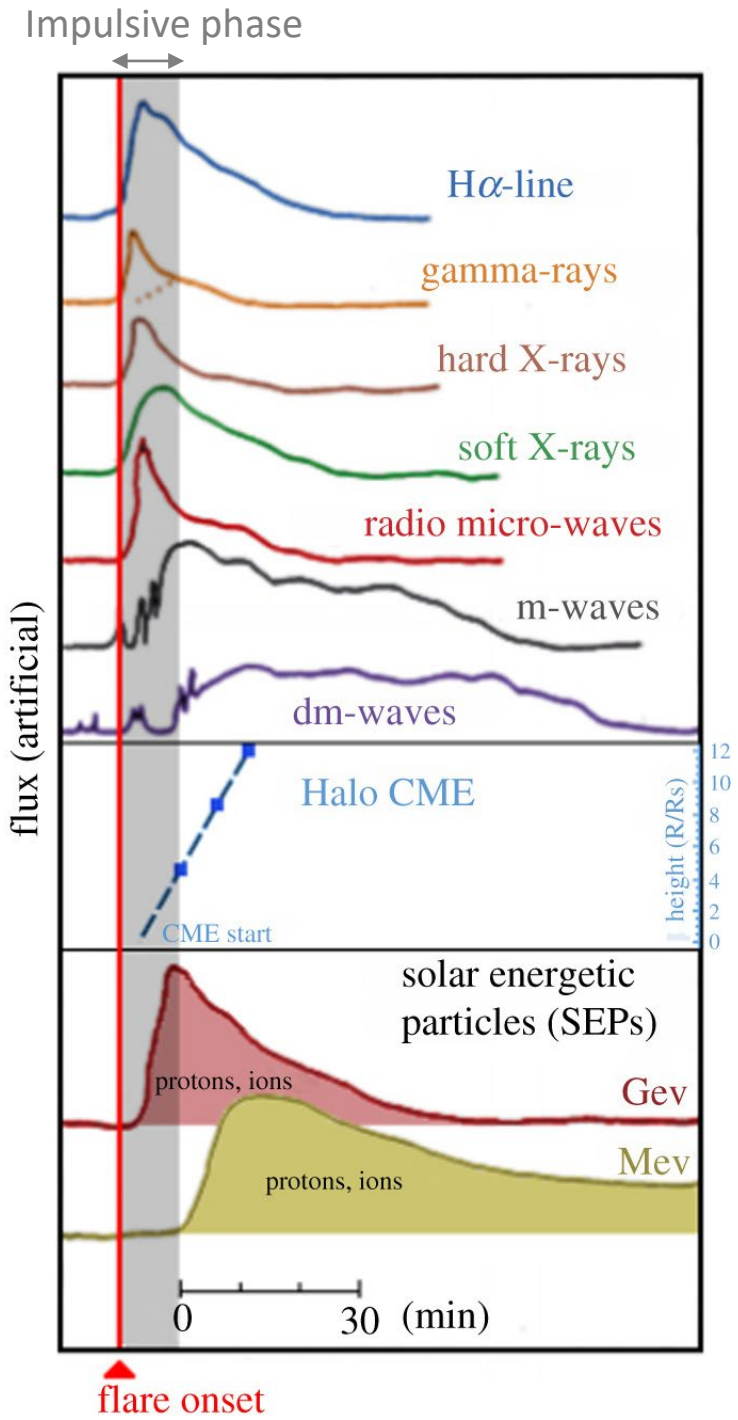
- Physical measurement: Flux level of >= 10 MeV particles
- Effects: radiation hazards, single event upsets, spacecraft charging, …

SPEs

Geomagnetic storms

- Physical measurement: Kp geomagnetic indices
- Effects: Auroras, Power blackouts, Navigation on HF communication problems from hours to days, …

Geomagnetic disturbances



Timing of an ‘academic’ SWE event

The geomagnetic disturbance is out of the time range of the Figure. It will take place between 1 to 3 days after the flare onset

(Anastasiadis+ 2019)

Space Weather Forecaster wish list

- To know the probability of a fl…
- To know at wh…
- To k…

…eruptive or confined

…ich systems will be affected

To accomplish these wishes is necesary to understand the physical mechanism of solar flares

FLARES

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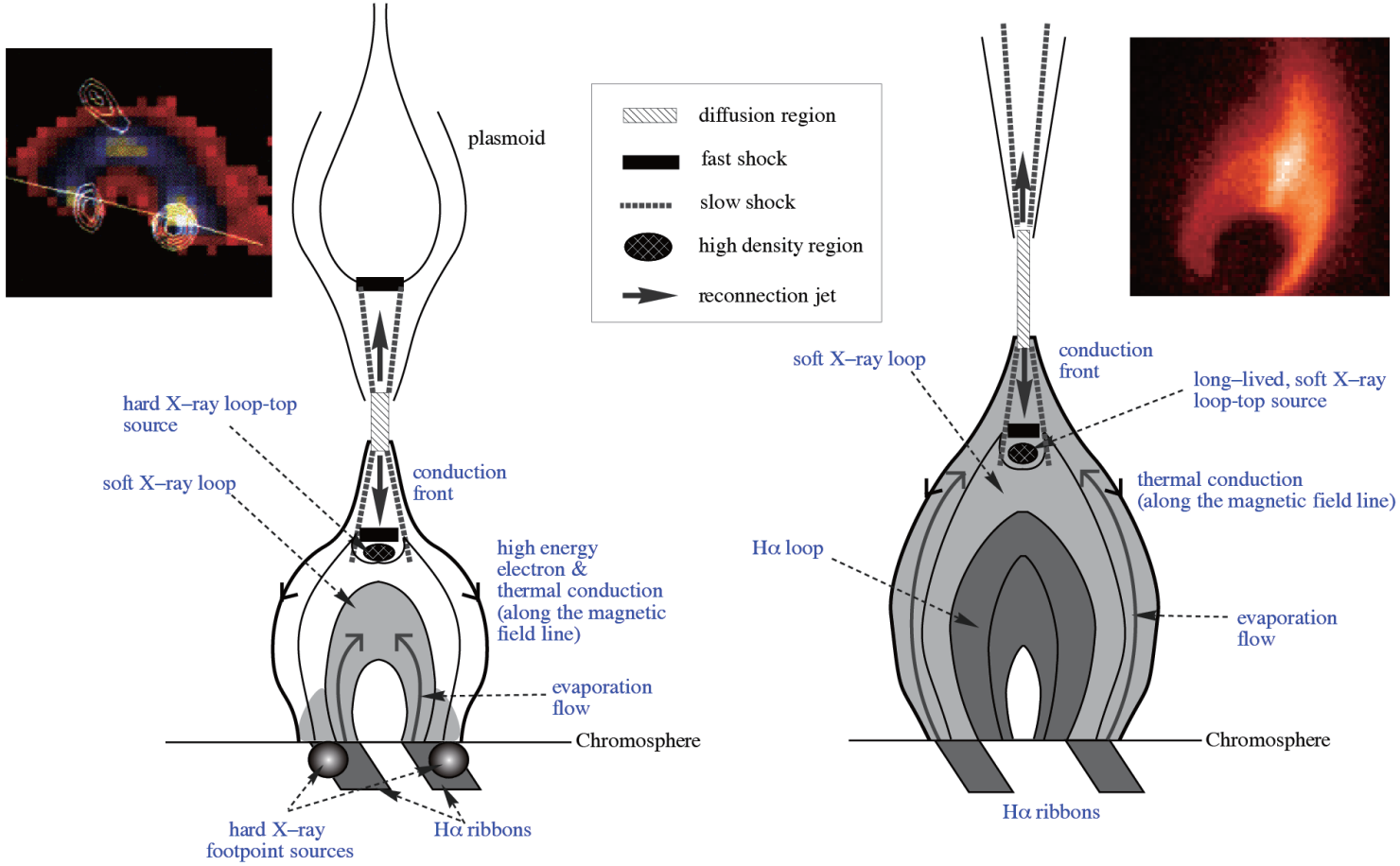
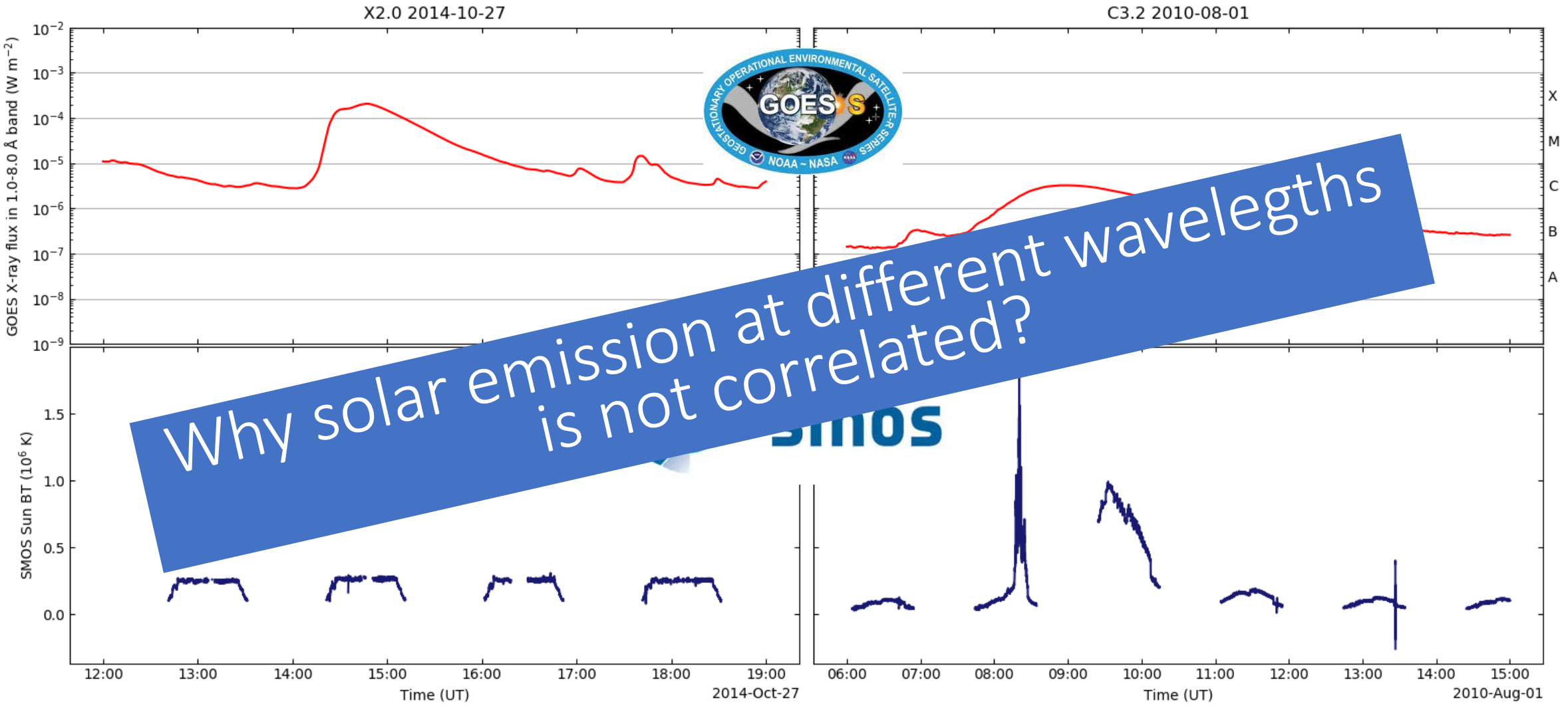
Magnetic reconnection: the central engine to produce a flare



Impulsive phase (or impulsive flare) **Gradual phase (or LDE flare)**

(Shibata+ 2011)

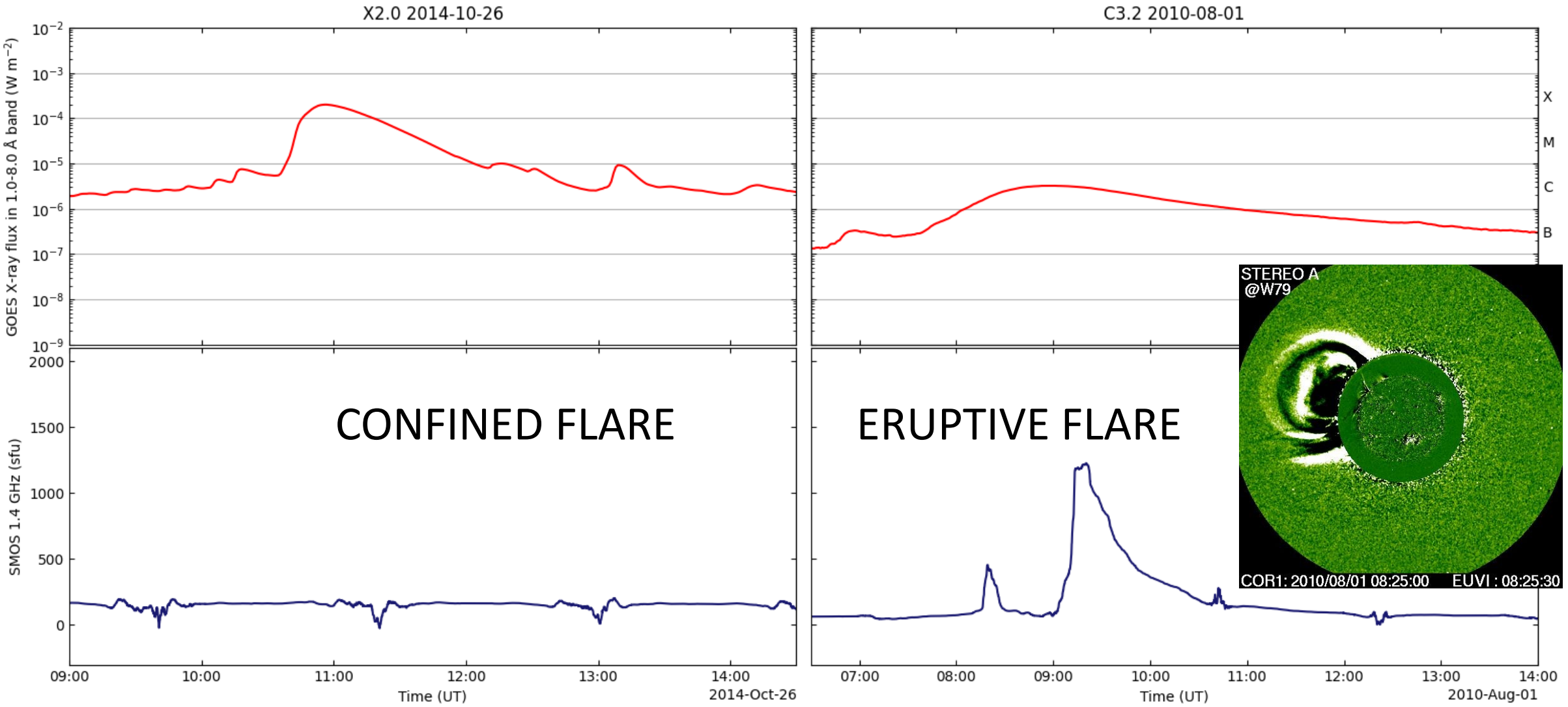
Solar X-ray flux versus radio flux



Why solar emission at different wavelegths is not correlated?

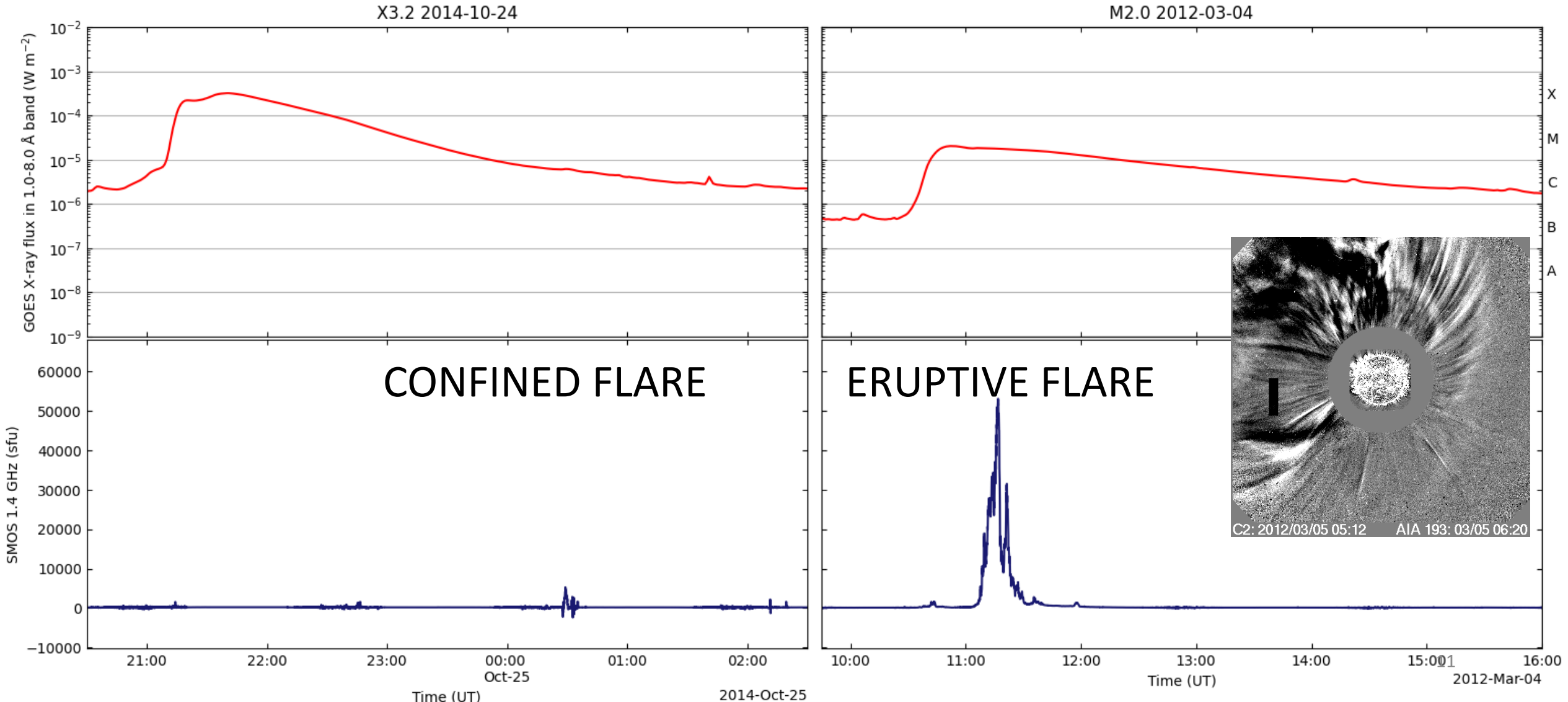
(Flores-Soriano+ 2020)

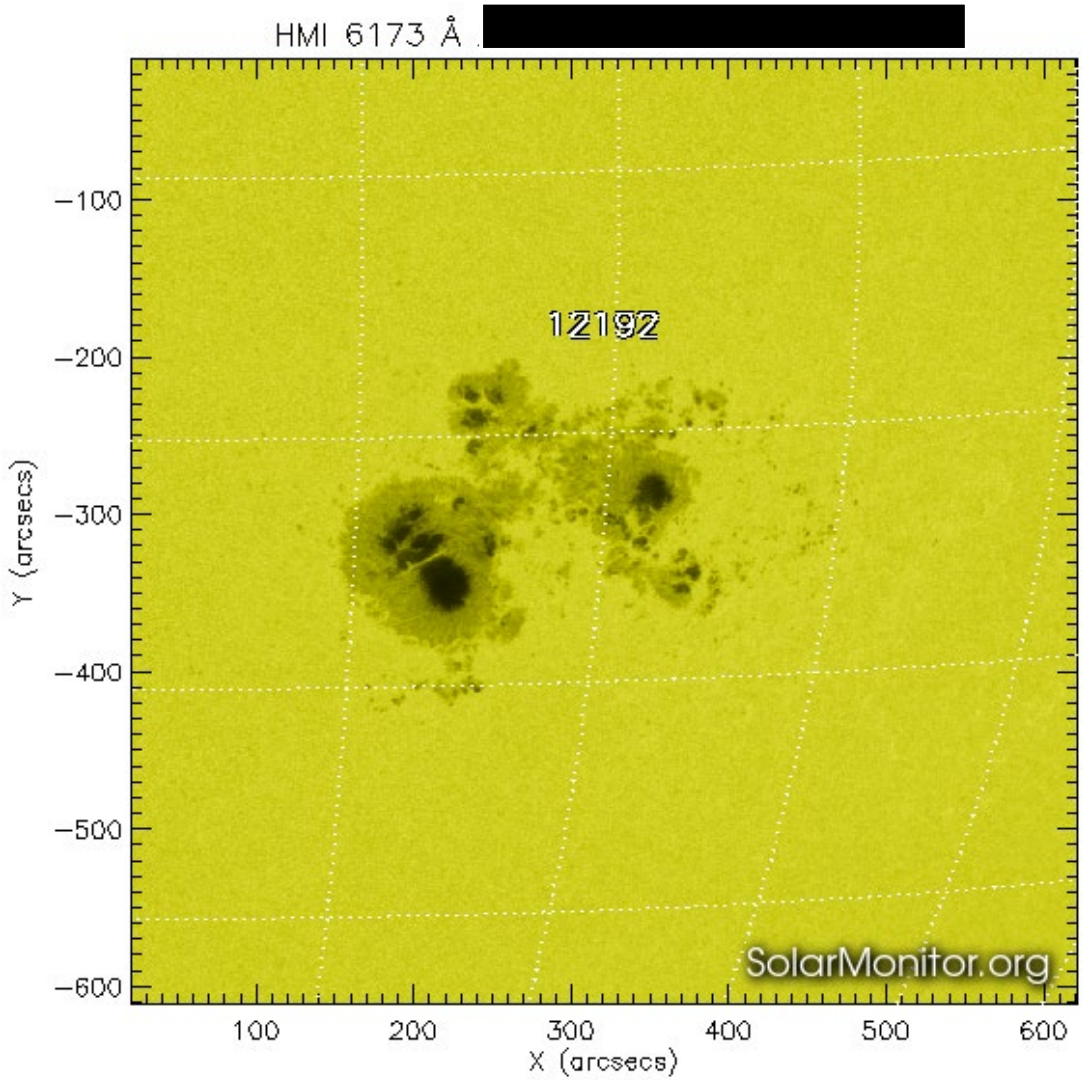
Eruptive versus confined flares



(adapted from Flores-Soriano+ 2020)

Eruptive versus confined flares

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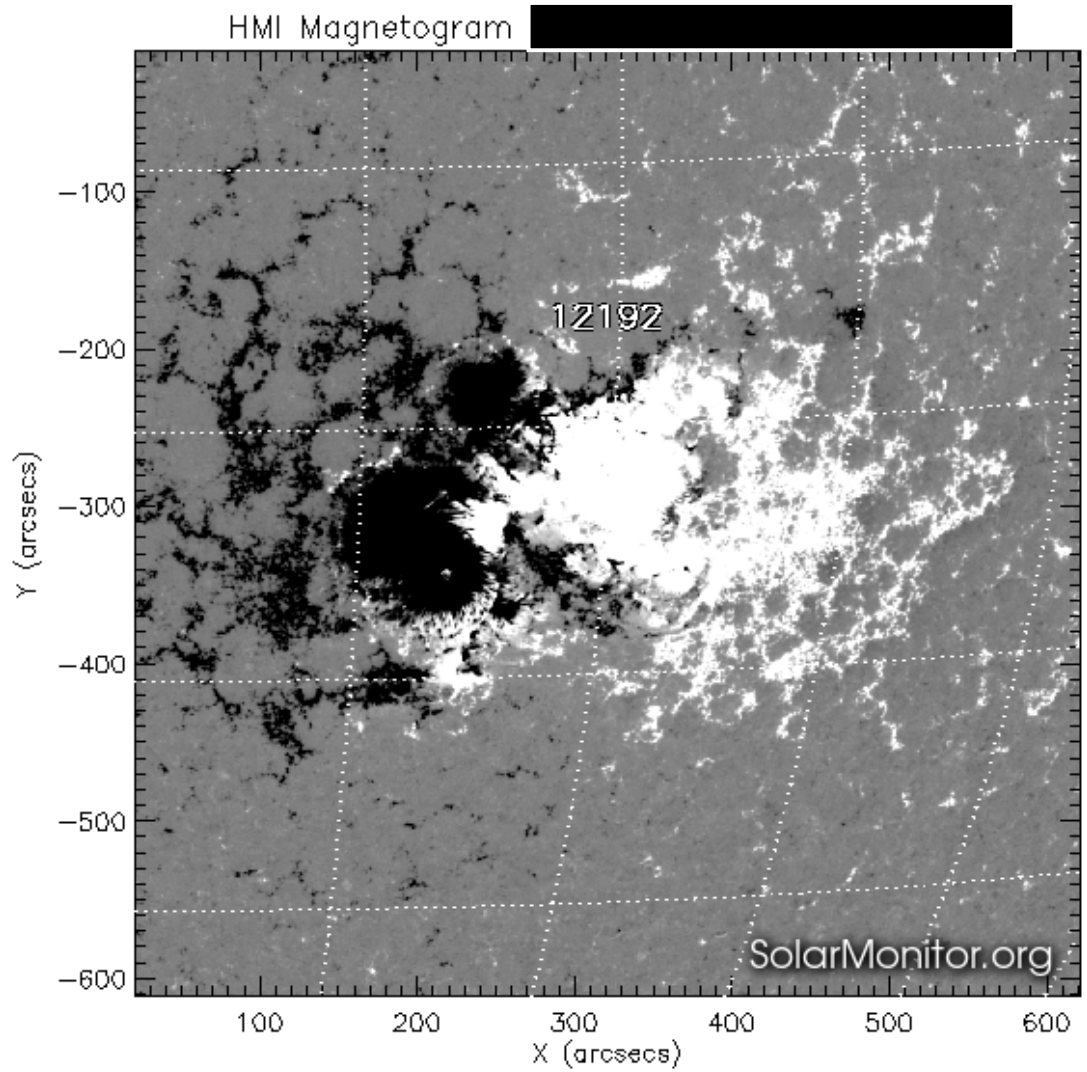
HMI Magnetogram
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SolarMonitor.org
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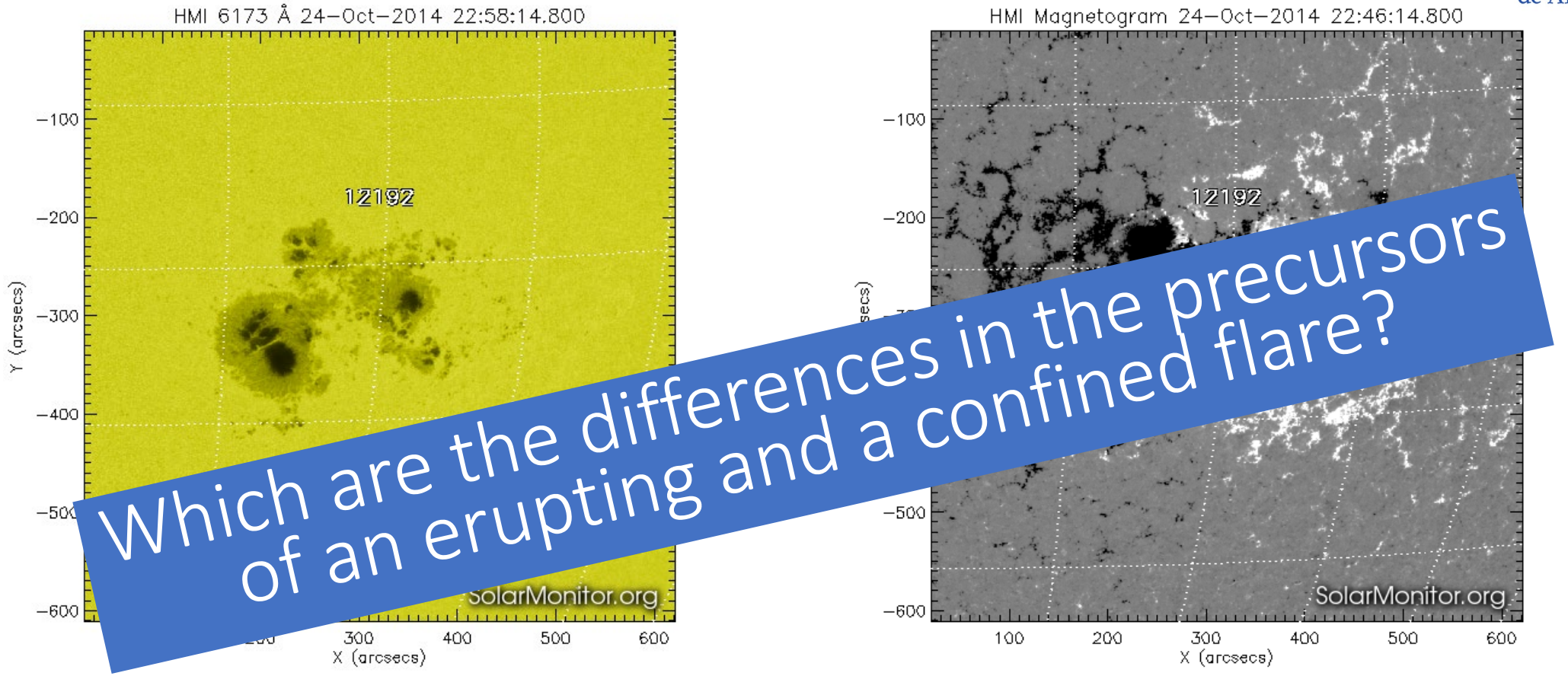

Which are the differences in the precursors of an erupting and a confined flare?

AR1219: 6 X-class and 29 M-class from October 18-29 (2014) -> all confined

(Chen+ 2015)

https://doi.org/10.3847/1538-4357/aaa199

The Astrophysical Journal, 853:41 (16pp), 2018 January 20

Reconnection Fluxes in Eruptive and Confined Flares and Implications for Superflares on the Sun

Johannes Tschernitz[1], Astrid M. Veronig[1,2], Julia K. Thalmann[1], Jürgen Hinterrei
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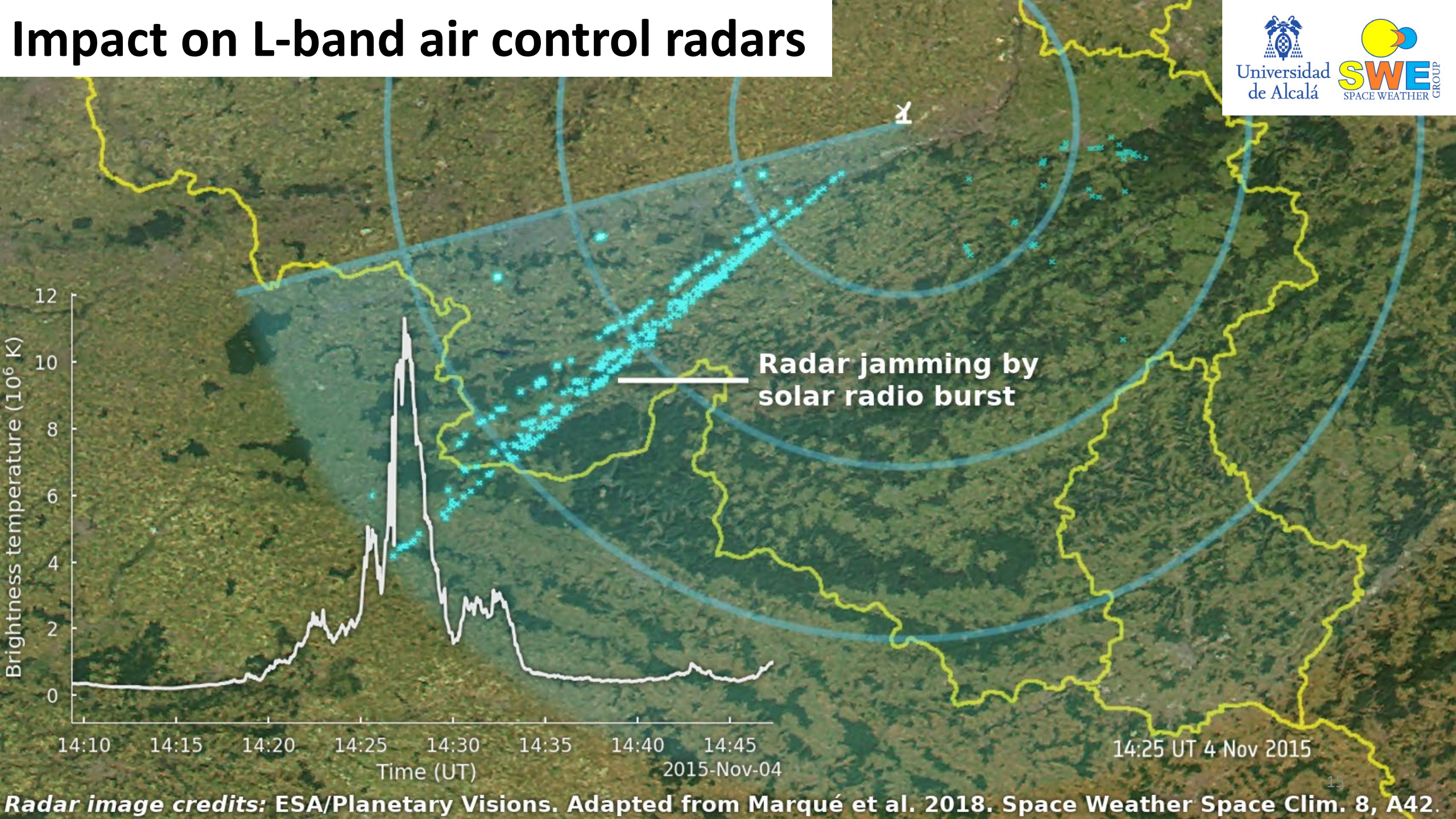
Received 2017 August 11; revised 2017 December 6; accepted 2017 December 7; publishe

Reliable measurements of coronal magnetic field are essential to go ahead

In principle, of course, it is the free magnetic energy stored in the corona of magnetically complex ARs and released during a flare via magnetic reconnection that is the most relevant and direct physical quantity describing the process. However, to calculate the energy in flares and CMEs from observations is a difficult task, and the uncertainties are an order of magnitude (e.g., Emslie et al. 2005, 2012; Veronig et al. 2005). Estimates of the magnetic energy of an AR and, even more specifically, the free magnetic energy available to power flare/CME events are not directly accessible, as we cannot reliably measure the coronal magnetic field. Therefore, such estimates are usually based on advanced three-dimensional coronal magnetic field models, using the vector magnetic field measured in the photosphere. However, the uncertainties of these estimates are again up to an order of magnitude, depending on the input data (e.g., Thalmann et al. 2008), model approach (e.g., De Rosa et al. 2009), and possibly other factors (e.g., DeRosa et al. 2015).

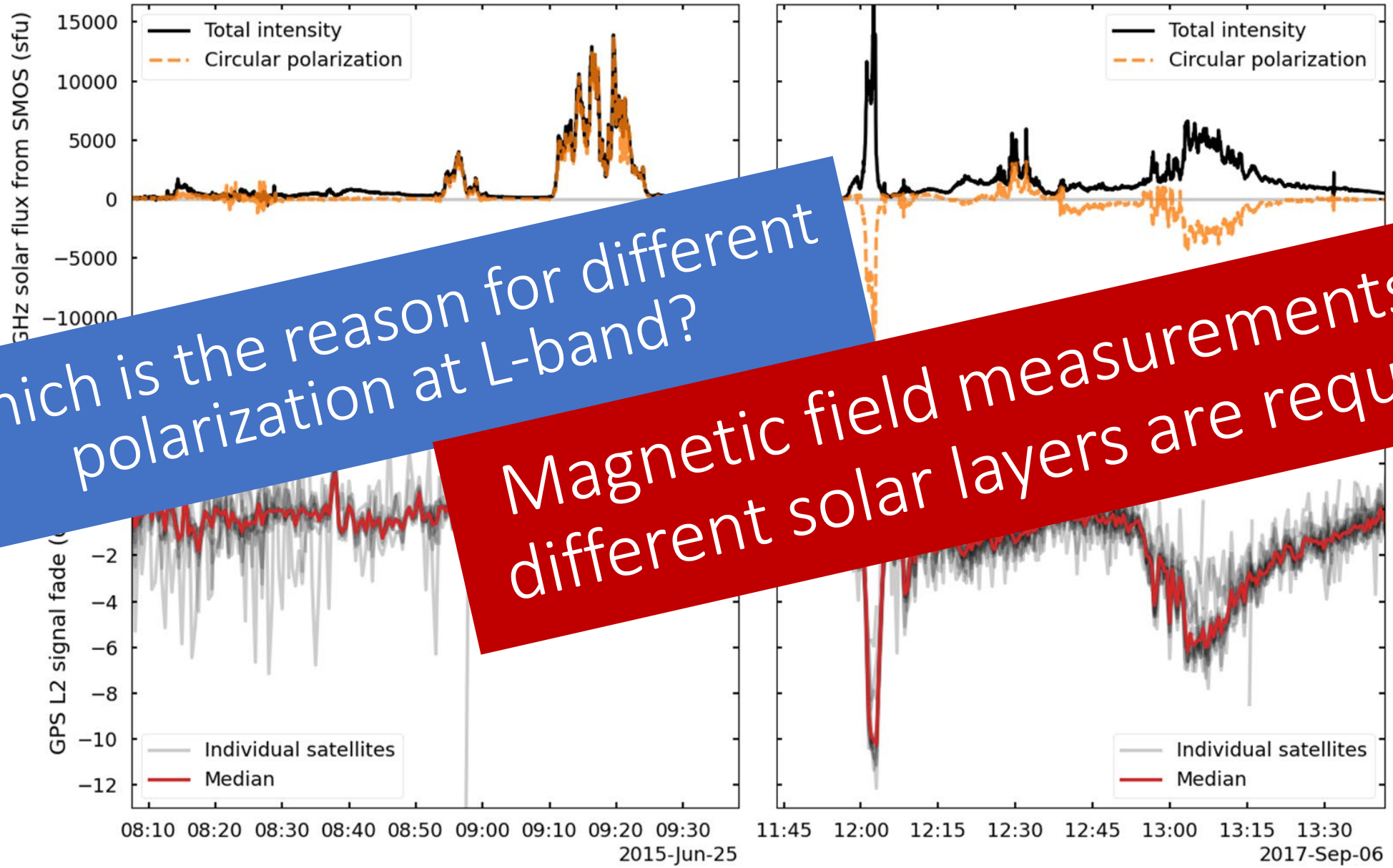
(Tschernitz+ 2018)

Impact on L-band air control radars



Radar image credits: ESA/Planetary Visions. Adapted from Marqué et al. 2018. Space Weather Space Clim. 8, A42.

Radar and GNSS are polarization sensitive



Which is the reason for different polarization at L-band?

Magnetic field measurements at different solar layers are required

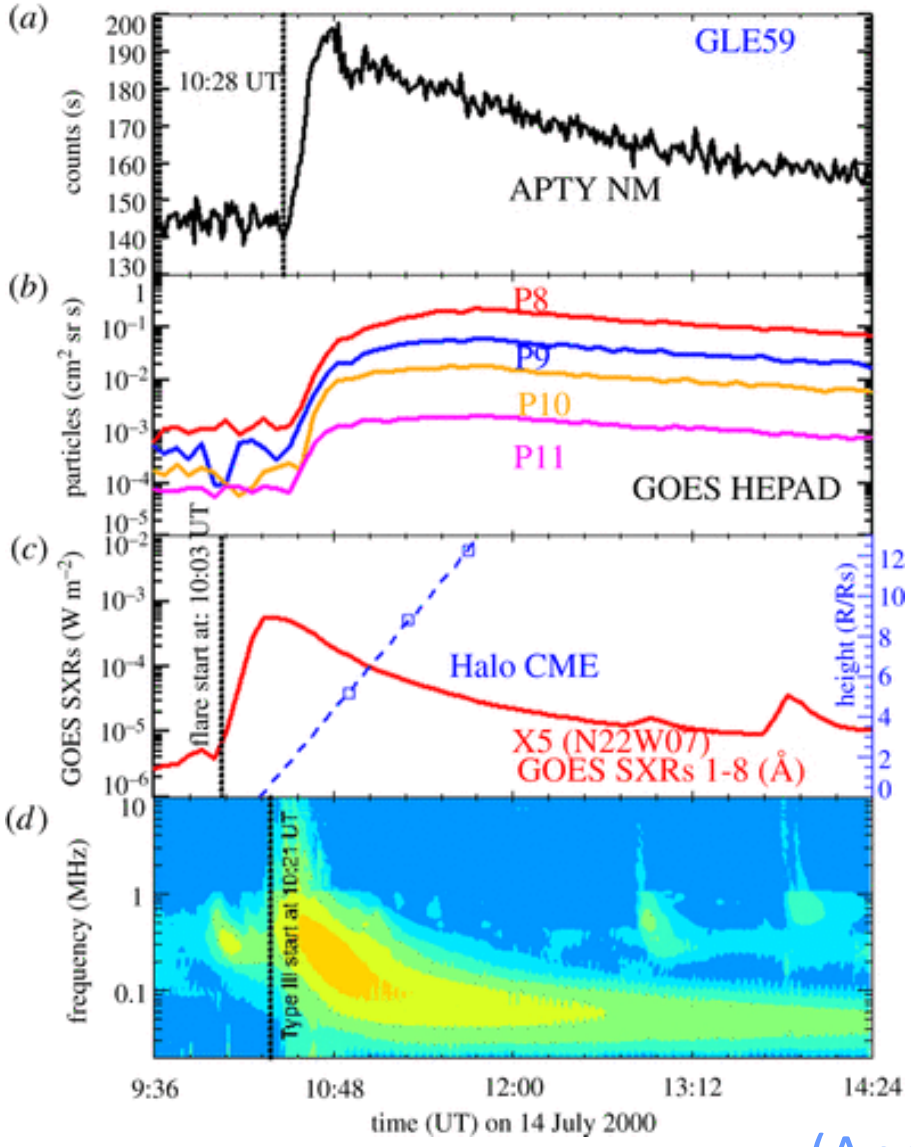
Space Weather Forecaster wish list

- To know if a flare will pro
  and in case
  SPE

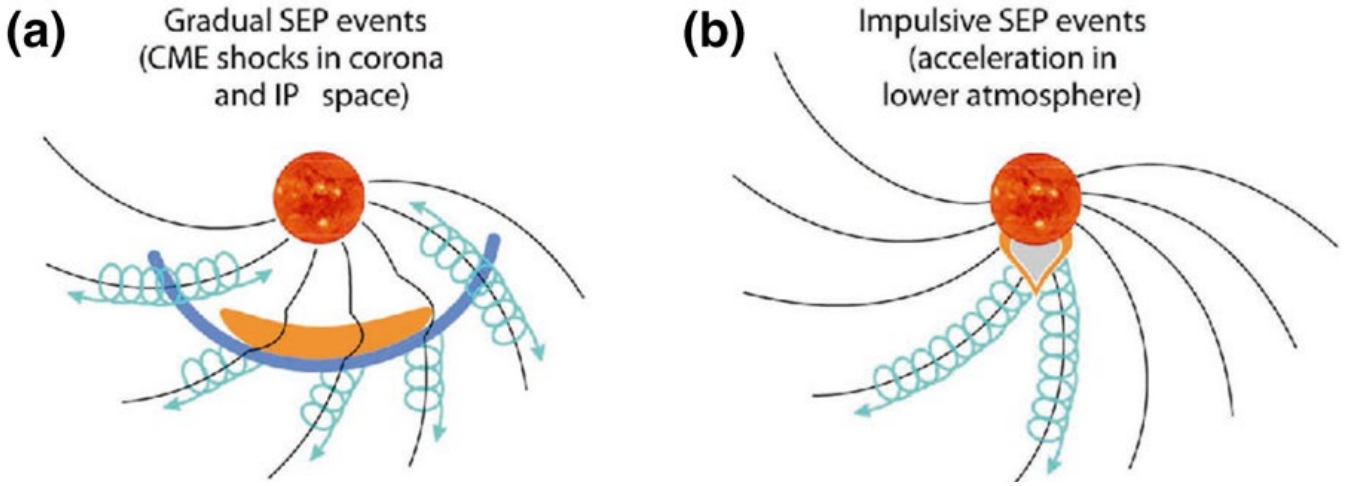
To accomplish these wishes is necesary to understand the physical mechanism of SPEs

SPEs

An ‘academic’ SPE



(Anastasiadis+ 2019)



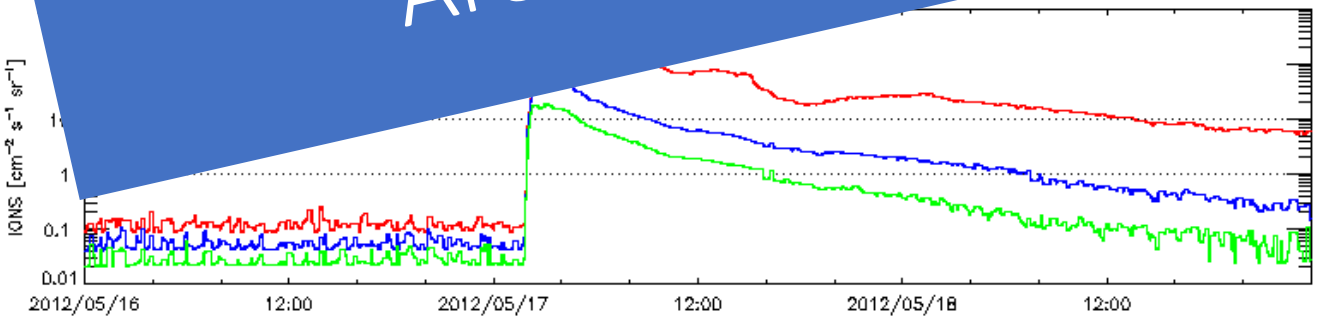
(Adapted from Temmer 2021)

But only a few times SPEs reach the ground

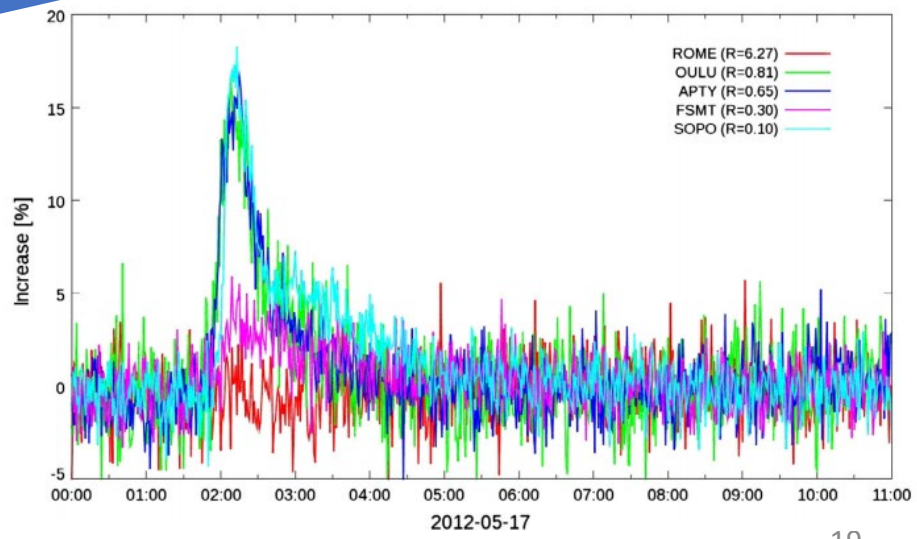
Which are the properties of a SPE to become a GLE?
Are they related to the solar precursor?

https://www.nmdb.eu/nest/gle_list.php

Number	Baseline Start	Baseline End
73	2021-10-28 14:00:00	
72		



(Berrilli+ 2014)



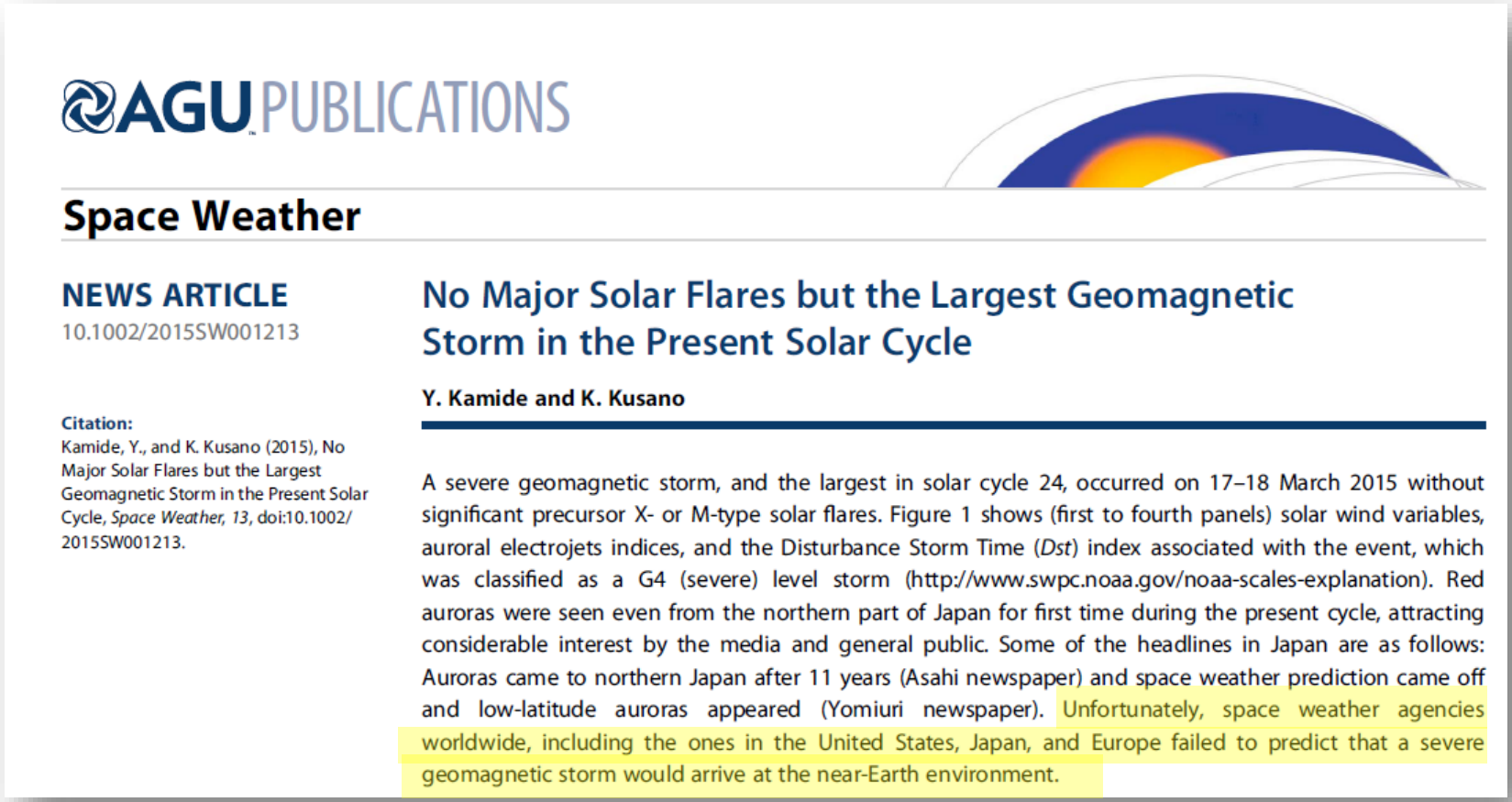
Space Weather Forecaster wish list

Geomagnetic disturbances

- To know if a flare will be eruptive or confined

  And in case of an eruptive flare,

  - To know the speed and direction of the CME
  - To know the direction of the IMF



AGU PUBLICATIONS

Space Weather

NEWS ARTICLE

10.1002/2015SW001213

Citation:
Kamide, Y., and K. Kusano (2015), No Major Solar Flares but the Largest Geomagnetic Storm in the Present Solar Cycle, *Space Weather*, *13*, doi:10.1002/2015SW001213.

No Major Solar Flares but the Largest Geomagnetic Storm in the Present Solar Cycle

Y. Kamide and K. Kusano

A severe geomagnetic storm, and the largest in solar cycle 24, occurred on 17–18 March 2015 without significant precursor X- or M-type solar flares. Figure 1 shows (first to fourth panels) solar wind variables, auroral electrojets indices, and the Disturbance Storm Time (*Dst*) index associated with the event, which was classified as a G4 (severe) level storm (http://www.swpc.noaa.gov/noaa-scales-explanation). Red auroras were seen even from the northern part of Japan for first time during the present cycle, attracting considerable interest by the media and general public. Some of the headlines in Japan are as follows: Auroras came to northern Japan after 11 years (Asahi newspaper) and space weather prediction came off and low-latitude auroras appeared (Yomiuri newspaper). Unfortunately, space weather agencies worldwide, including the ones in the United States, Japan, and Europe failed to predict that a severe geomagnetic storm would arrive at the near-Earth environment.

Solar disk precursors for eruptions (even without flares) need to be determined

Space Weather Forecaster wish list

Geomagnetic disturbances

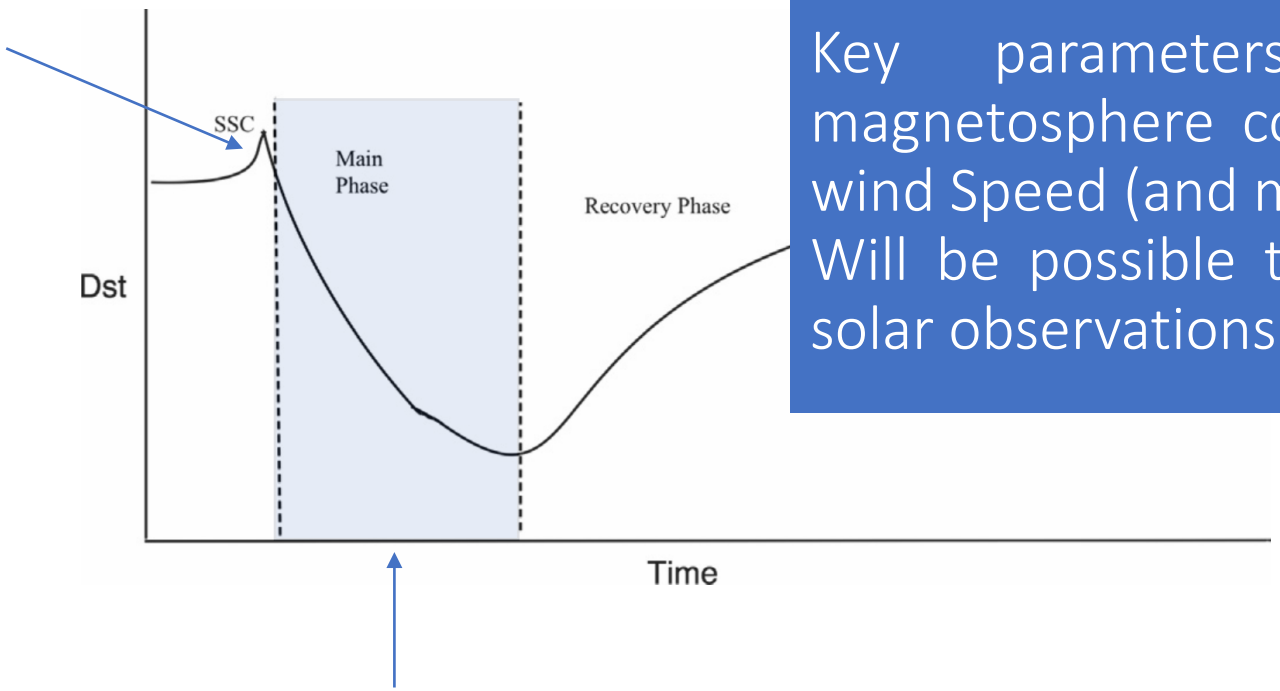
- To know if a filament will erupt and when

  And in case of filament eruption,

  - To know the speed and direction of the CME
  - To know the direction of the IMF

An ‘academic’ geomagnetic storm

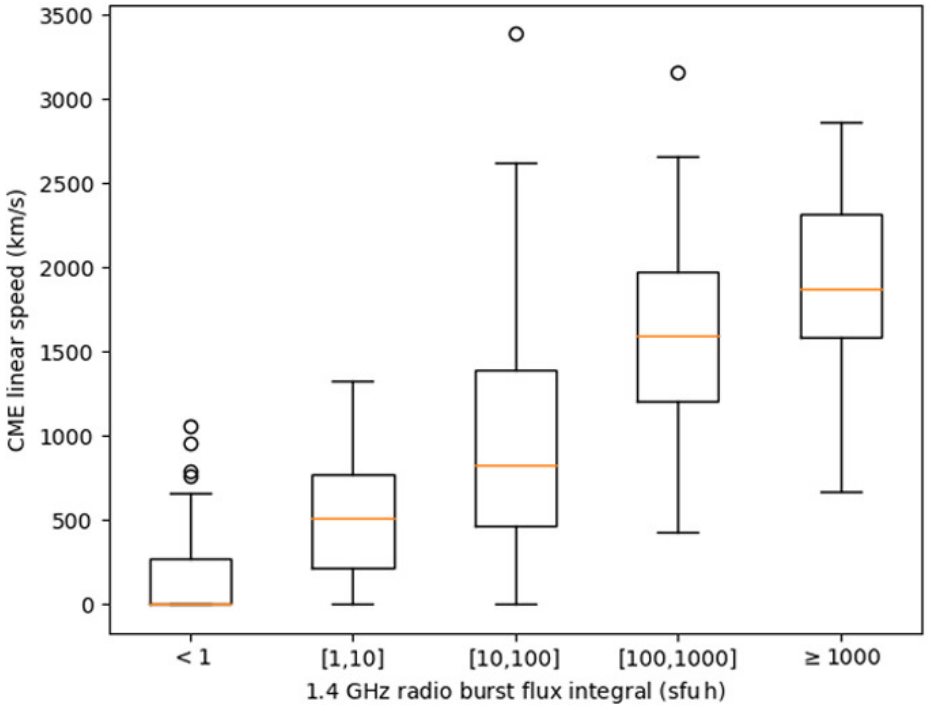
Solar wind Dynamic pressure compress the day-side magnetosphere

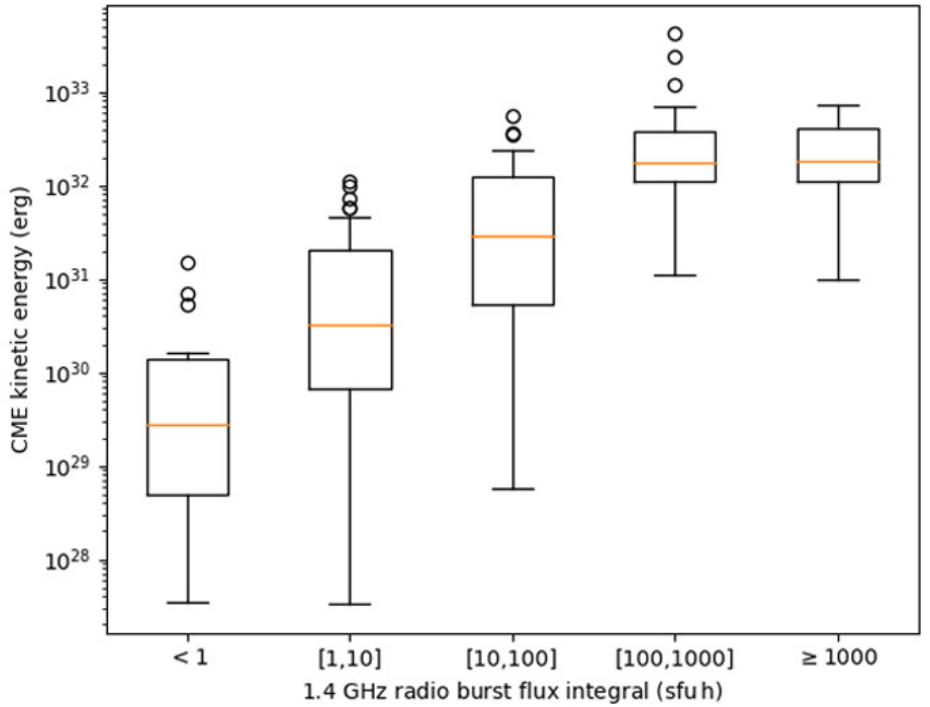


Key parameters in solar wind-magnetosphere coupling: IMF and Solar wind Speed (and may be density)
Will be possible to estimate them from solar observations?

Southward IMF and large solar wind speed contribute to the entrance of solar wind energy to terrestrial magnetosphere by reconnection

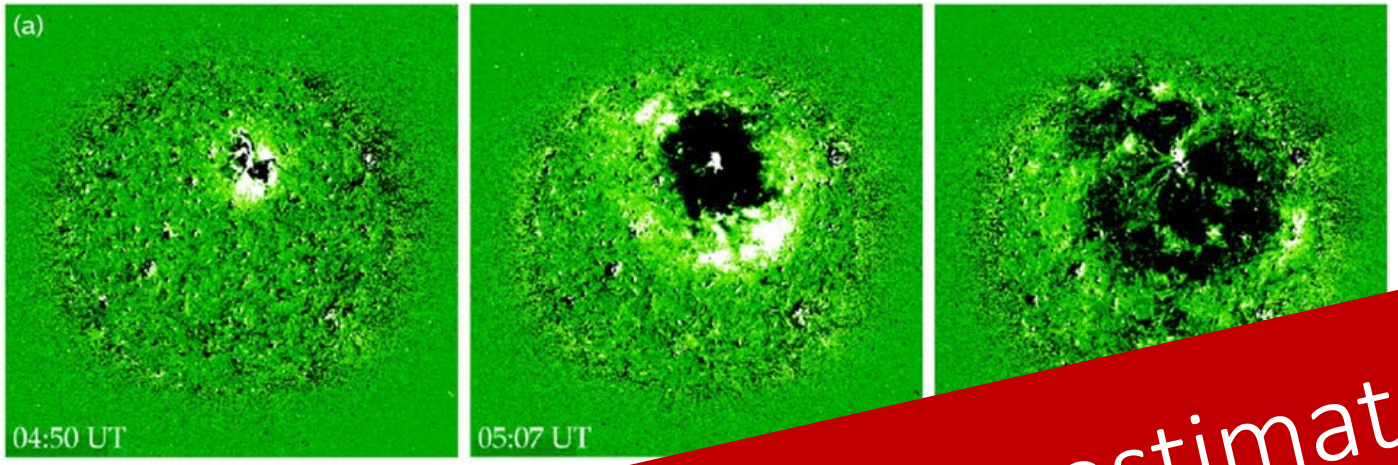
CME properties and solar radio fluence at 1.4 GHz





(adapted from Flores-Soriano+ 2020)

Large-scale coronal propagating fronts (EIT waves)

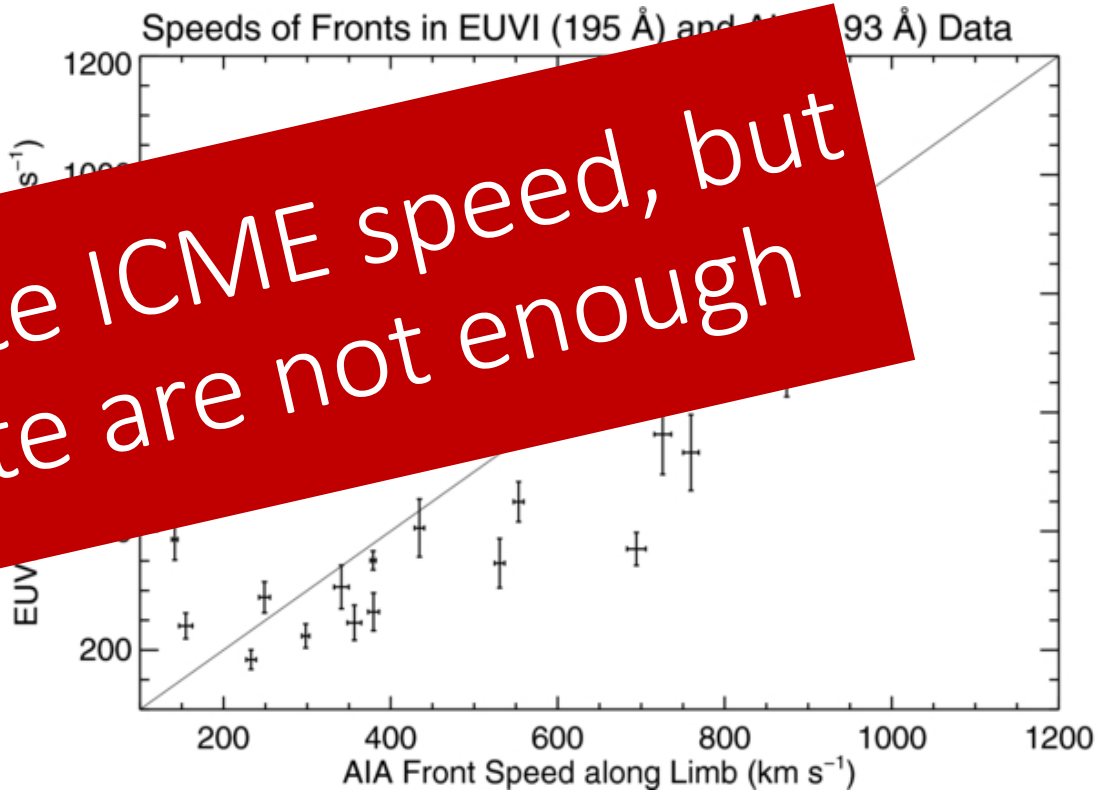


(Gallag

"The
flare
show
find a g
of LCPFs and CMEs in a subset of 86 LCPFs"

do they
ith type II bursts. We do not
correlation either between the speeds

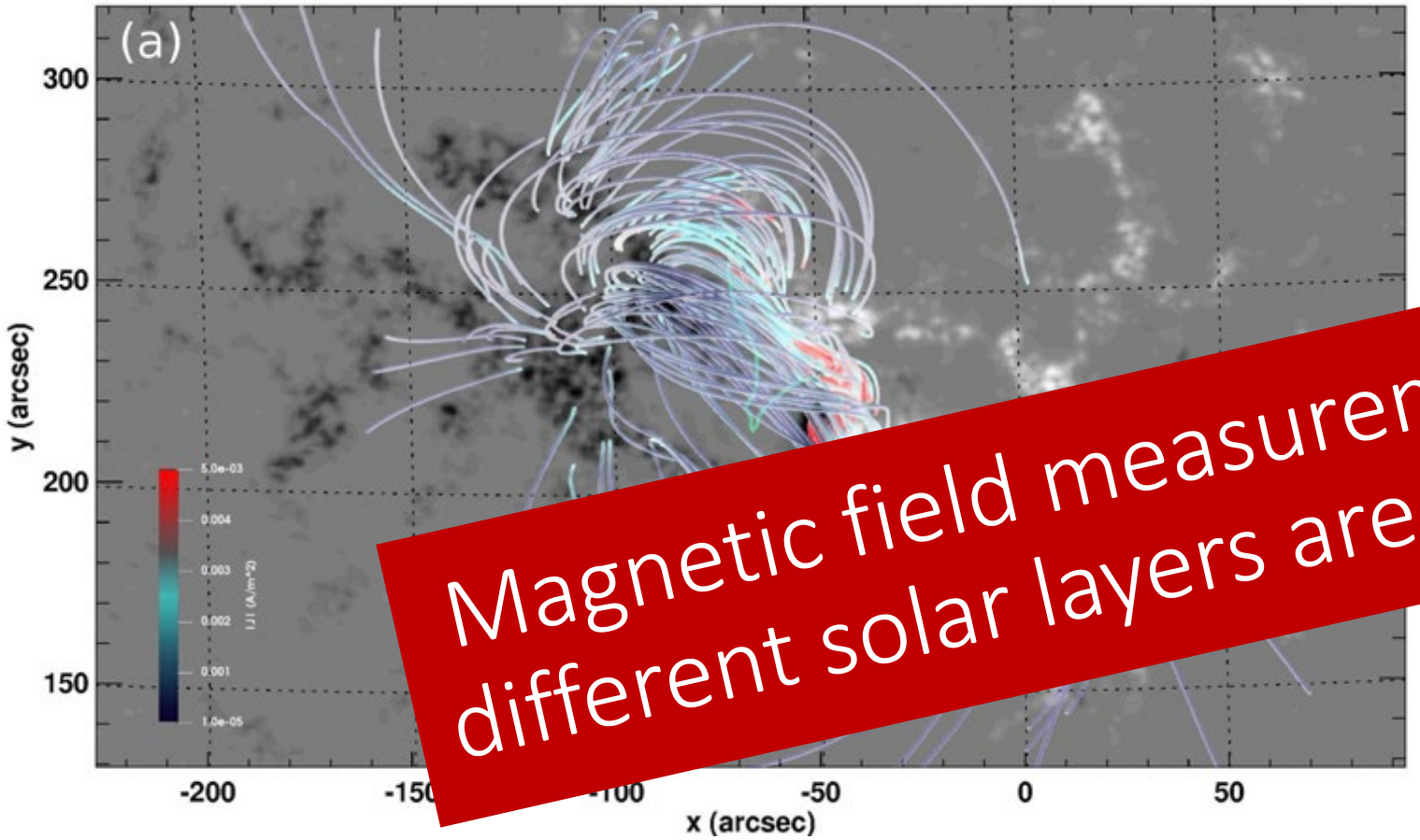
(Nitta+ 2013)

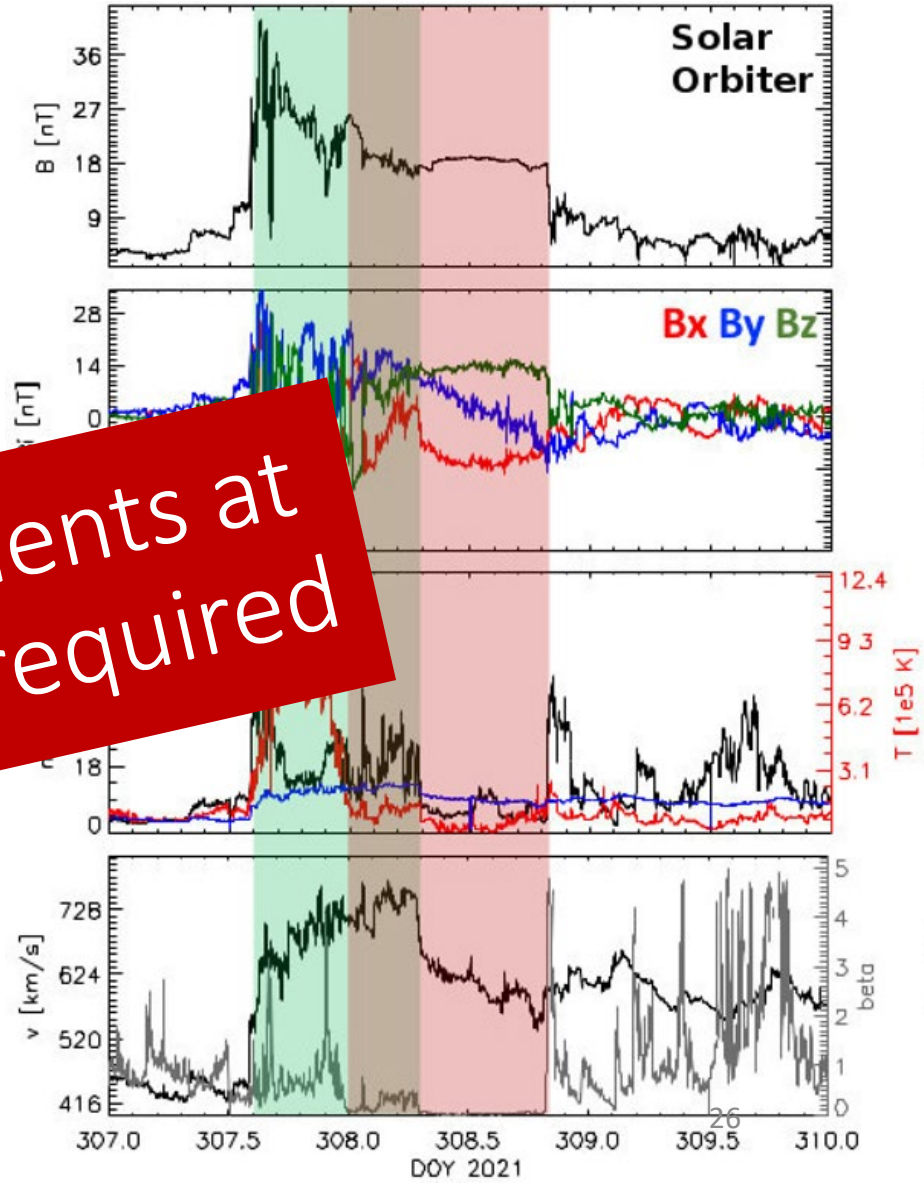


(Nitta+ 2013)

First steps done to estimate ICME speed, but measurements up to date are not enough

Tracking magnetic field from the Sun to the solar wind

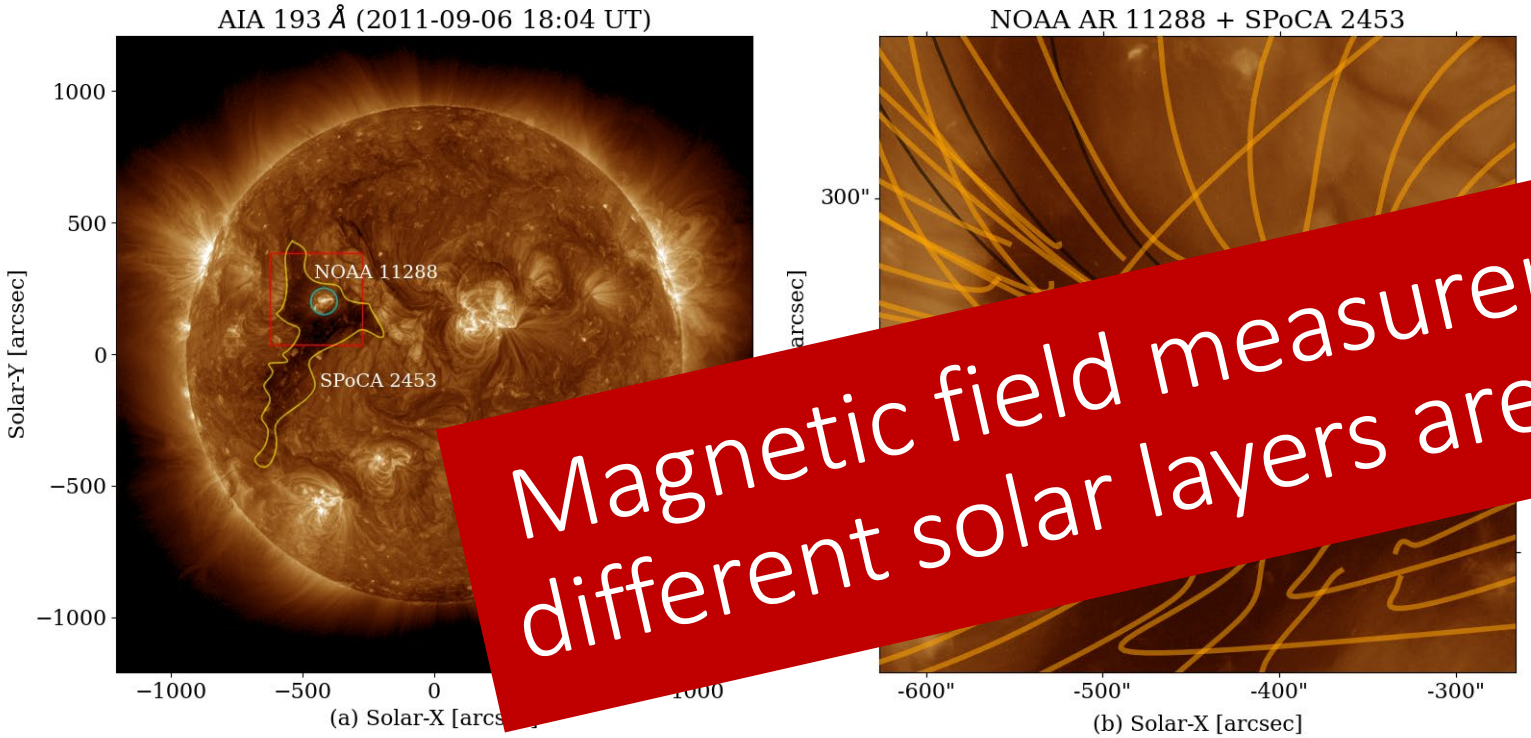


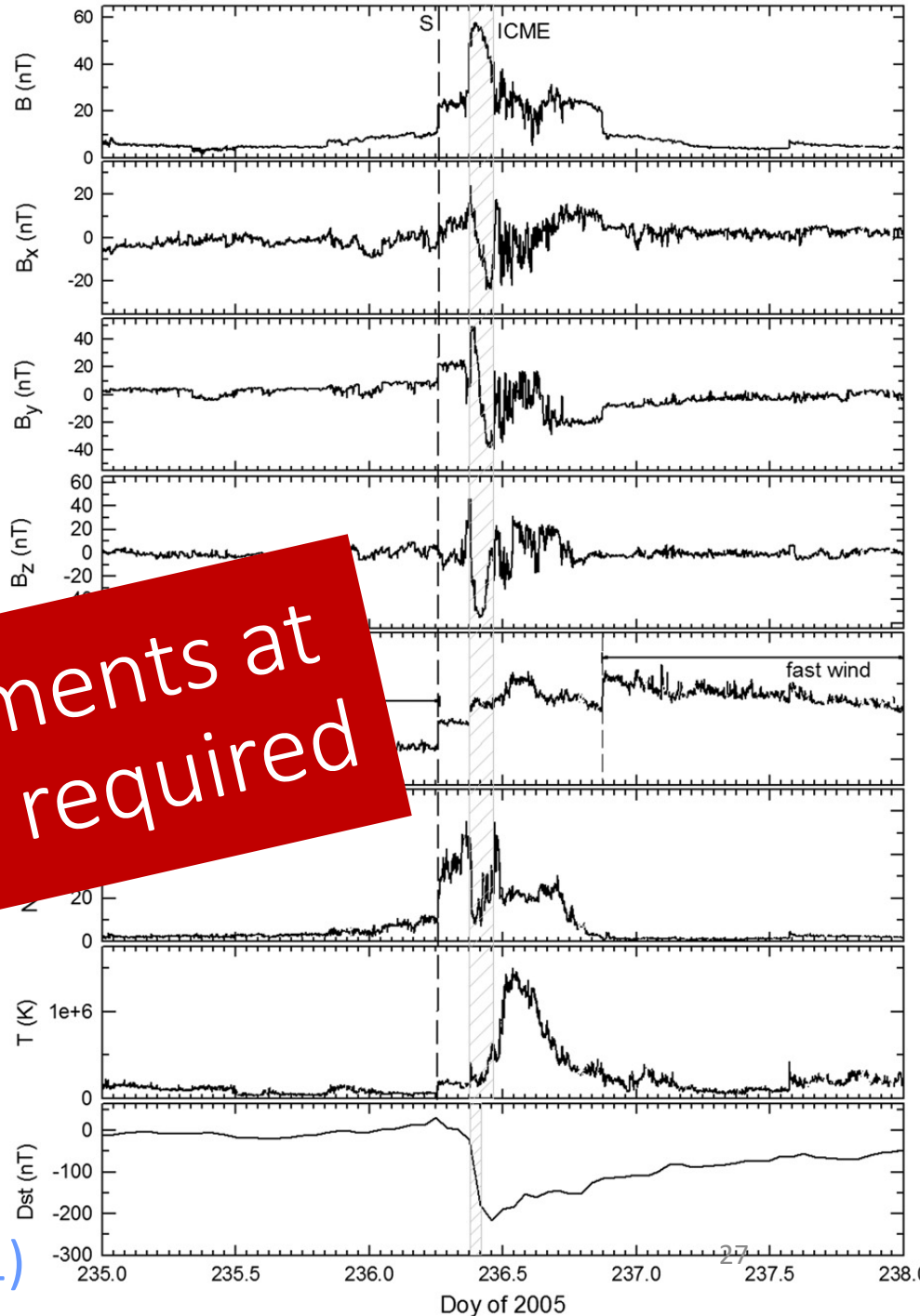


Magnetic field measurements at different solar layers are required

(Thalmann+ 2022)

Anemonae regions are a hazard for space weather and the best candidates for studying the interaction between closed and open magnetic field topologies





Magnetic field measurements at different solar layers are required

(Sharma+ 2020)

(Cerrato+ 2011)

How next generation 4m telescopes can help in these tasks?

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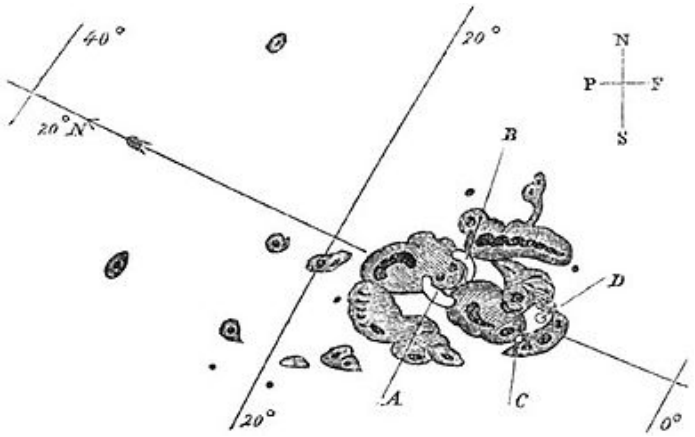

Description of a Singular Appearance seen in the Sun on September 1, 1859. By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare. The image of the sun's disk was, as usual with me, projected on to a plate of glass coated with distemper of a pale straw colour, and at a distance and under a power which presented a picture of about 11 inches diameter. I had secured diagrams of all the groups and detached spots, and was engaged at the time in counting from a chronometer and recording the contacts of the spots with the cross-wires used in the observation, when within the area of the great north group (the size of which had previously excited general remark), two patches of intensely bright and white light broke out, in the positions indicated in the appended diagram by the letters A and B, and of the forms of the spaces left white. My first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass, by which the general image is thrown into shade, for the brilliancy was fully equal to that of direct sun-light; but, by at once interrupting the current observation, and causing the image to move by turning the R.A. handle, I saw I was an unprepared witness of a very different affair. I thereupon

It has been very gratifying to me to learn that our friend Mr. Hodgson chanced to be observing the sun at his house at Highgate on the same day, and to hear that he was a witness of what he also considered a very remarkable phenomenon. I have carefully avoided exchanging any information with that gentleman, that any value which the accounts may possess may be increased by their entire independence.

Carrington (1859)

Conclussions

- Many open questions in the Space Weather Science still remains
- Next generation 4m solar telescopes, optimised for studies of the magnetic coupling of the solar atmosphere, have an opportunity to help providing magnetic field observations of solar activity simultaneously in 2D in different solar layers by using multi-wavelength imaging, spectroscopy and spectropolarimetry
- But for this purpose a "Priority Observation Programme" (POP) should be stablished modifying the observing schedules and implementing procedures for fast identification of the solar region of interest to be observed (Open Data policy in POP?)

And thank you to funding from MICINN (grant PID2020-119407GB-I00/AEI/10.13039/501100011033) and UAH (grant EPU-INV-UAH2021005)