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EGU GENERAL ASSEMBLY 2023

25 APRIL 2023

UCL

The Merging of a Coronal Dimming and a Coronal Hole

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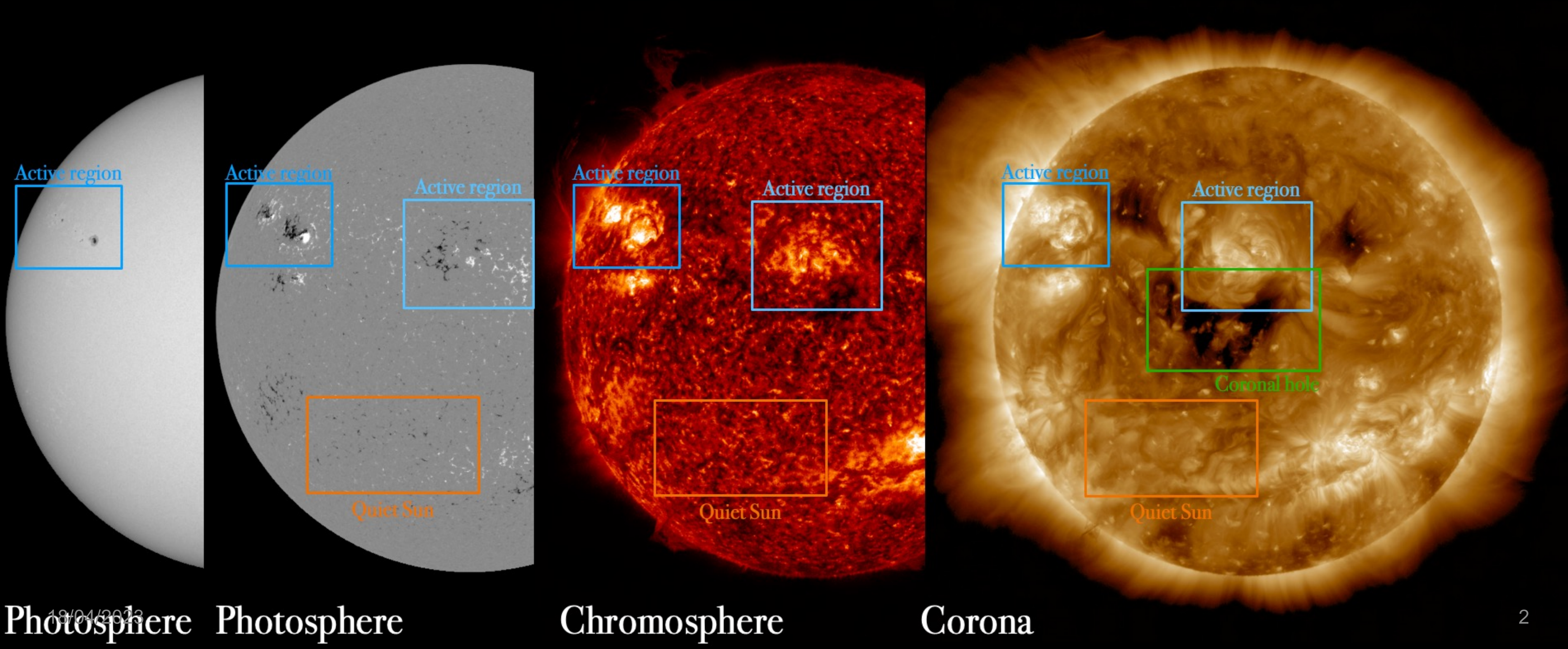
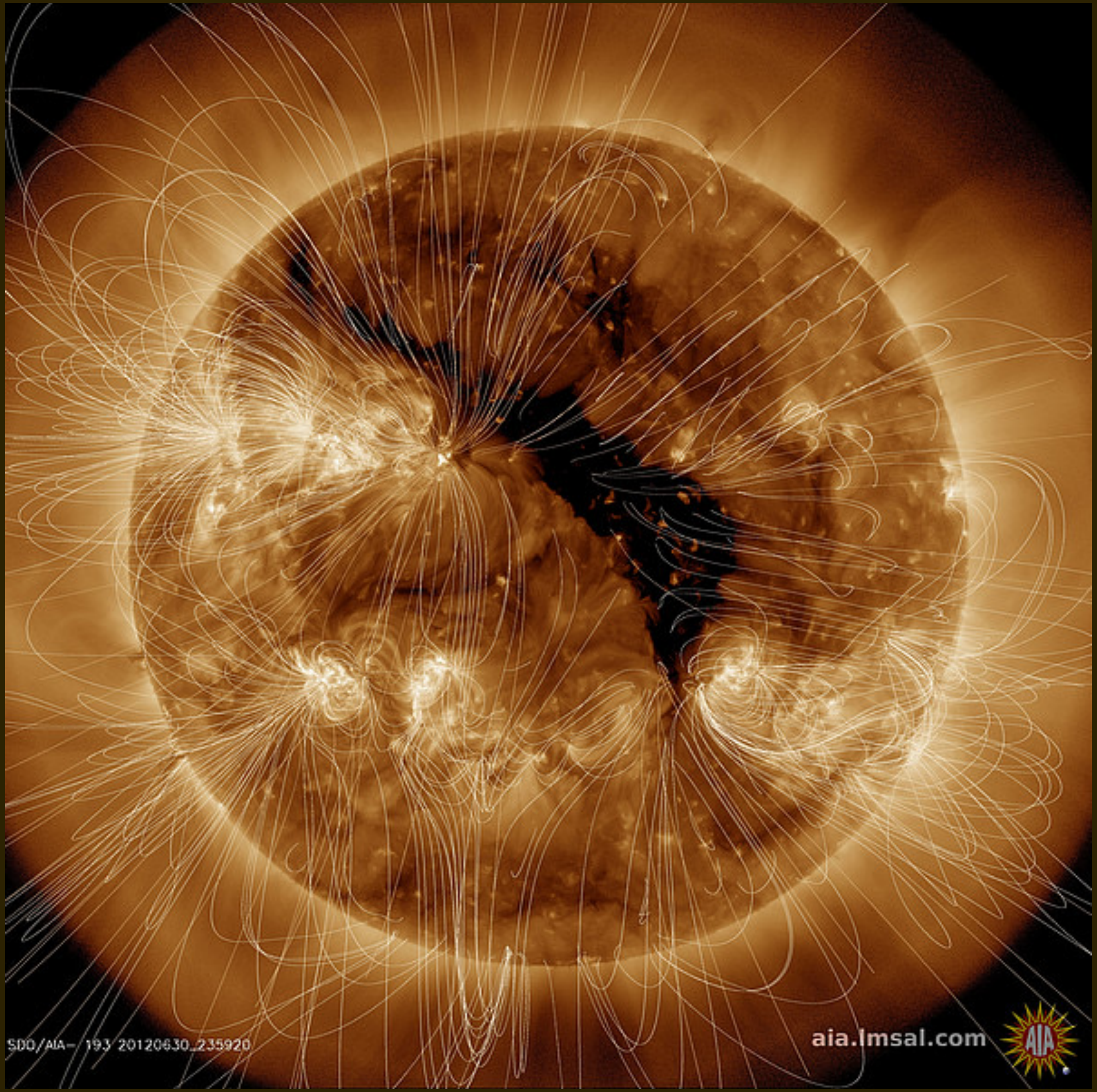
The multilayer of the Sun's Atmosphere



https://static.uni-graz.at/fileadmin/_processed_/a/e/csm_CoronalHole_b60168675a.jpg

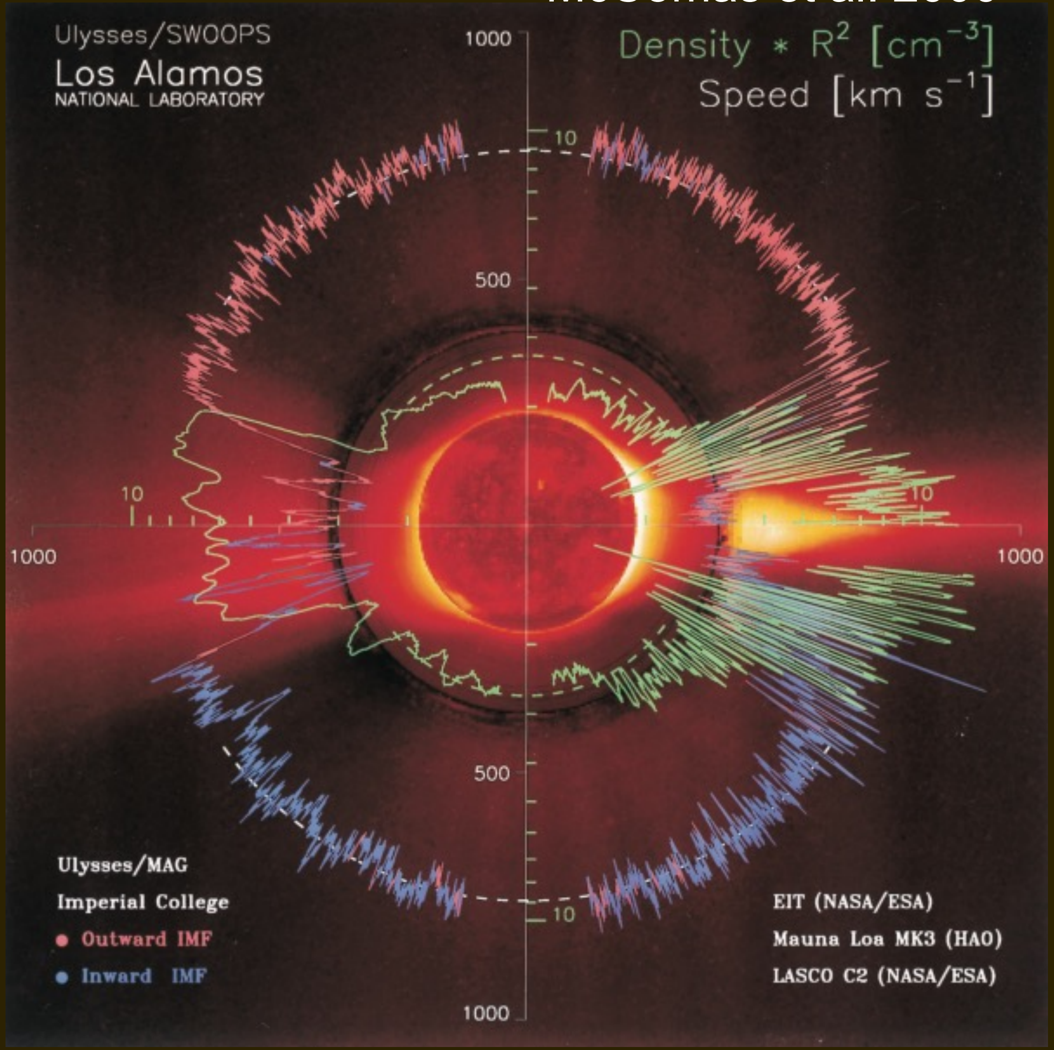
Coronal Hole (CH)

- **Region of relatively cool, less dense plasma in the solar corona that contains open magnetic field lines**
- Can be seen as dark patches on the solar disc in Extreme-UV (EUV) and X-Ray observations
- Monopolar region – dominated by one polarity
  - Open fields root in the photosphere
- Long-lived, relatively stable region
  - Last from several solar rotations up to a few years



Coronal Hole and Solar Wind

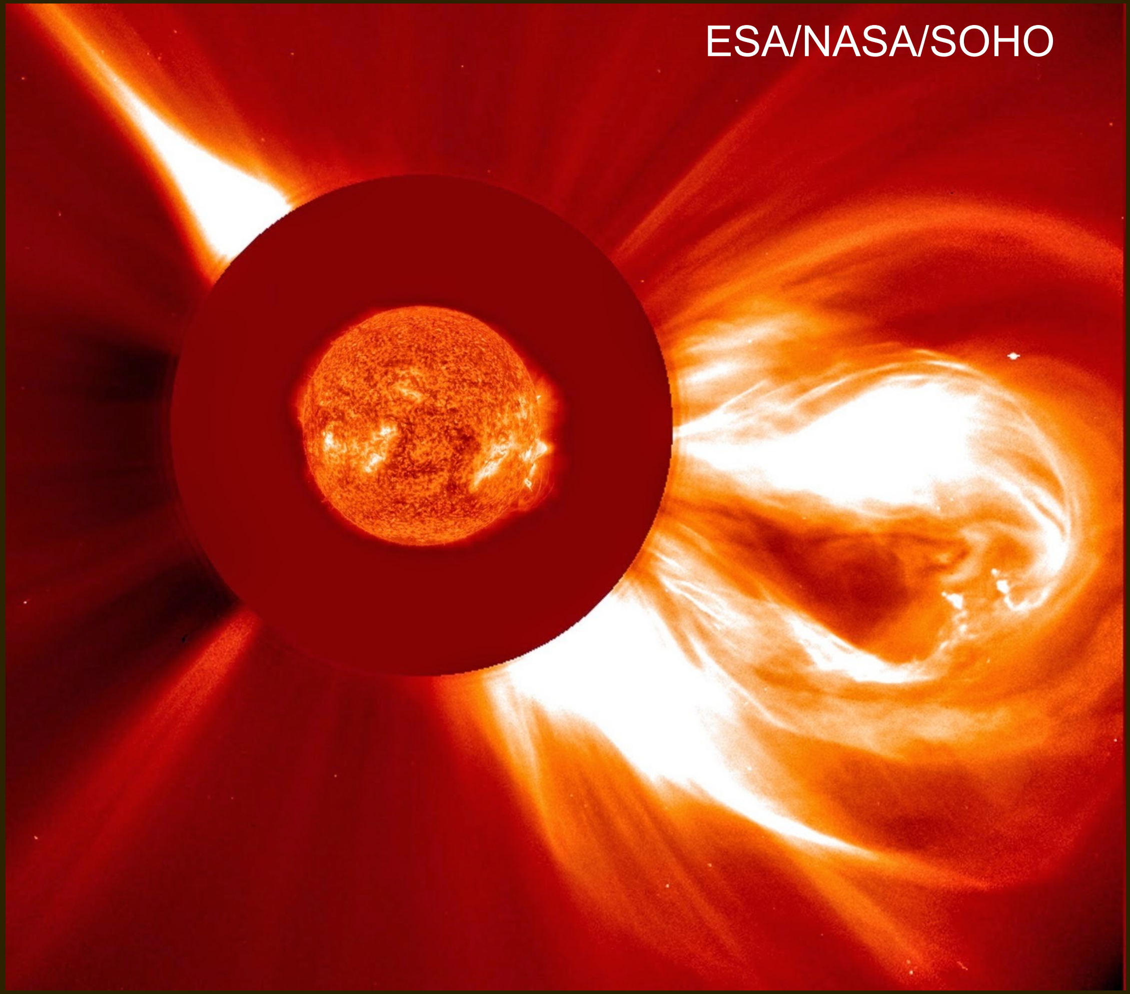
McComas et al. 2000

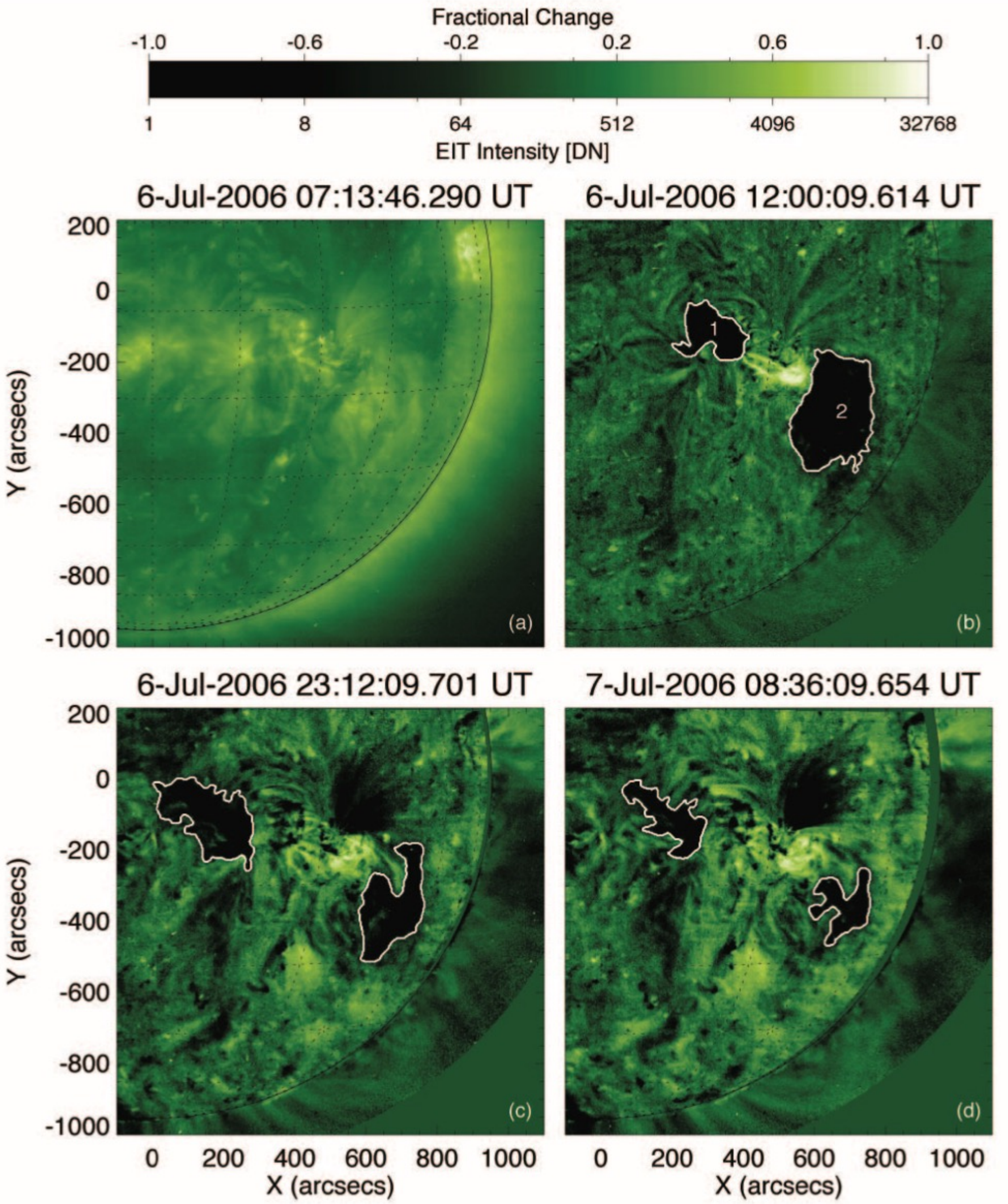


- The solar wind is the stream of charged particles from the Sun's corona
  - Carries magnetic fields onto interplanetary space, forming the heliosphere
  - Driving space weather on Earth's magnetosphere
- Fast solar wind (v > 450 km/s) originates from CH [Widely accepted]
- Slow solar wind (v < 450 km/s) origins are still in debate
  - *Interchange reconnection* at open-closed field boundaries: **CH boundaries**, Active regions edge, Helmet streamers
- Jets and Plumes may also contribute to solar wind

Coronal Mass Ejection (CME)

- A sudden release of plasma and magnetic field from the solar corona to the heliosphere
  - Release up to 10^{13} kg of plasma with speed up to thousands of km/s (Green et al., 2018)
- Converting magnetic energy -> kinetic energy through magnetic reconnection
- Often associated with Solar Flares:
  - Standard Flare-CME model (CHSKP model)
- Causing geomagnetic storms and driving space weather



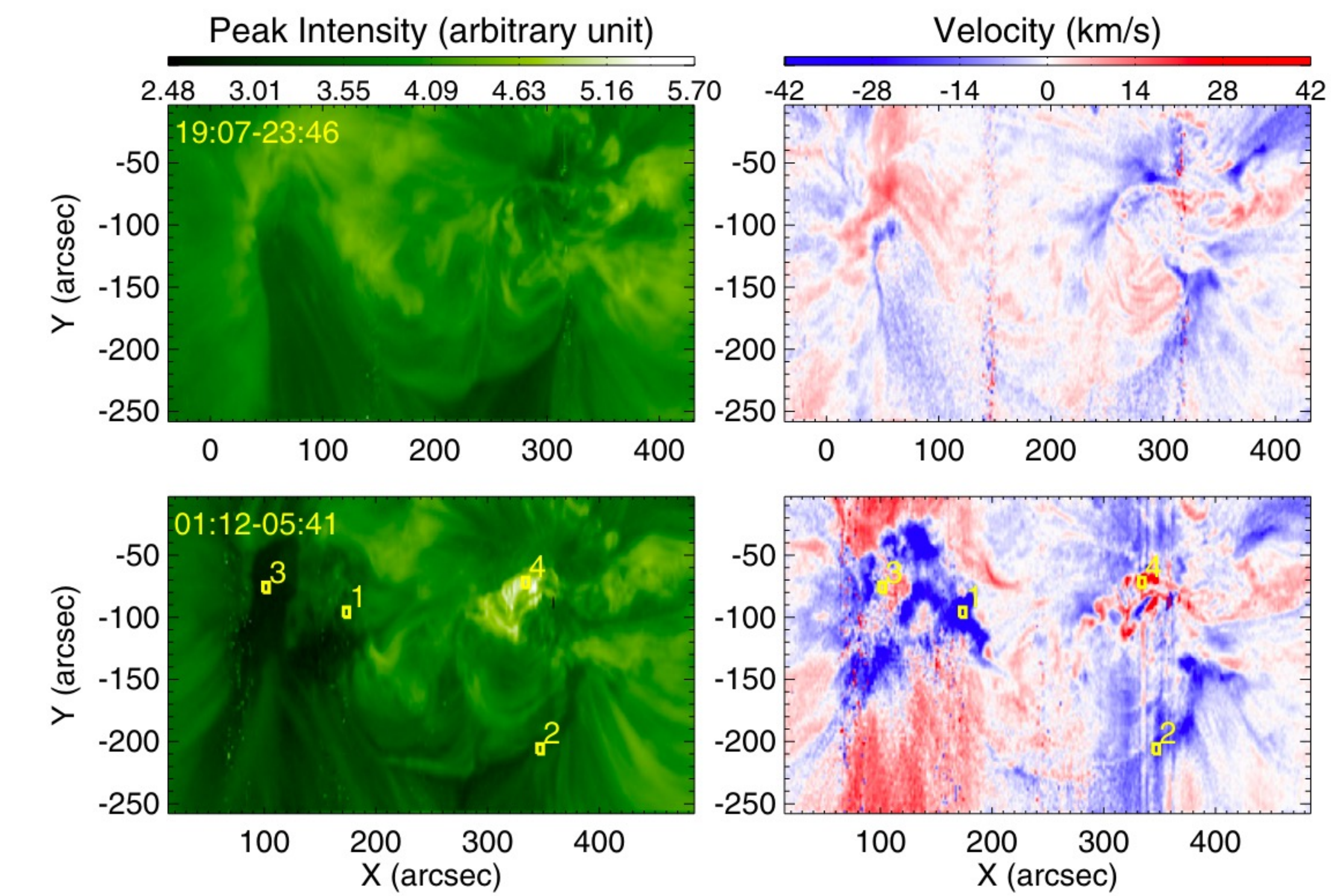


Coronal Dimming (CD)

- The plasma-devoid volumes resulted from solar eruptions
  - Reduced emission regions in EUV and X-Ray observation
- Short lifetime: 3– 12 Hours (Reinard and Biesecker 2008)
- Caused by plasma depletions along rapidly expanding magnetic fields
  - Mark the footpoints of the eruptions
  - Magnetic field lines become ‘open.’
- “Transient Coronal Hole”

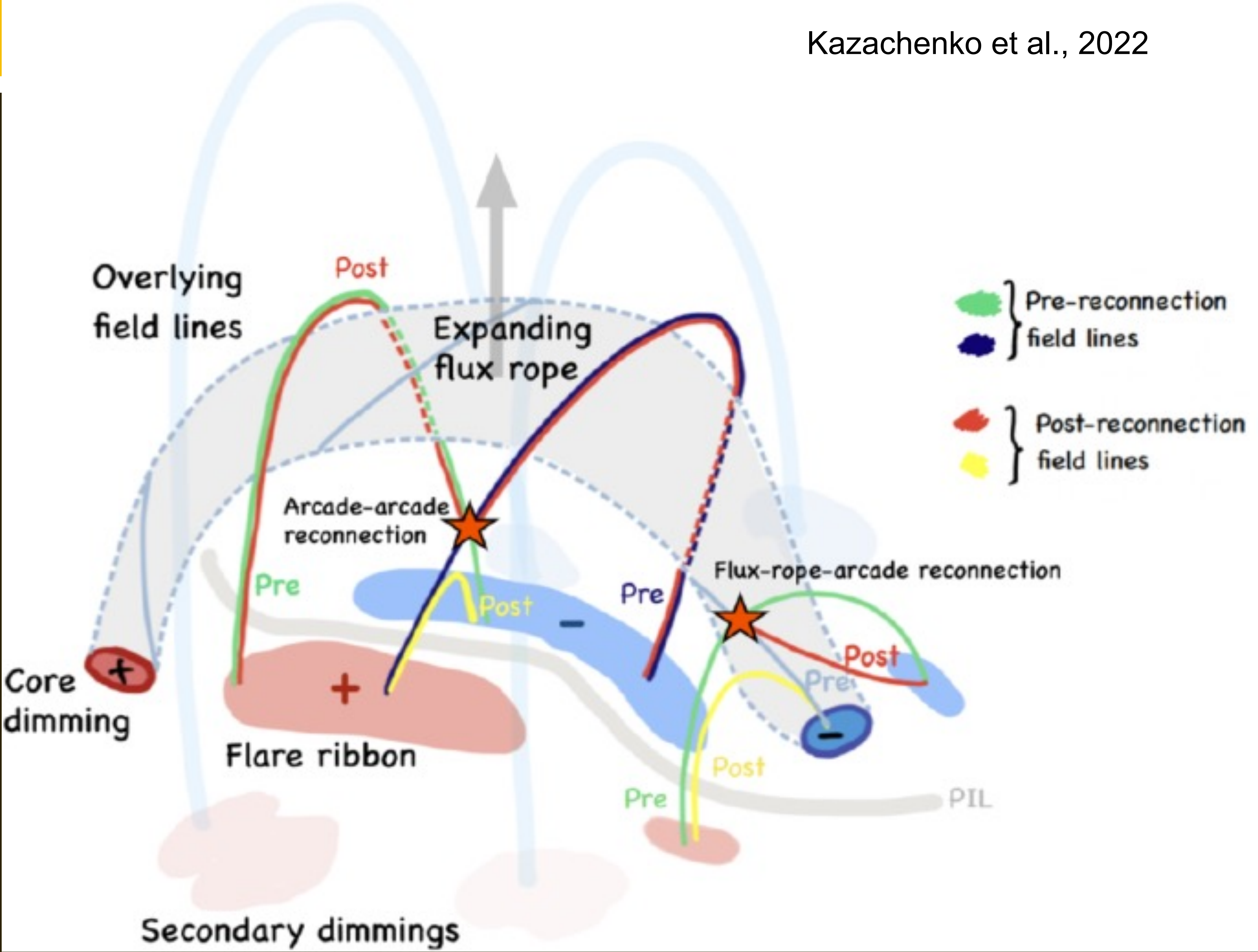
Coronal dimmings properties

(Tian et al. 2012)



- Strong plasma upflows
  - Up to 50-150 km/s (Tian et al. 2012; Veronig et al., 2019)
  - Possible sources of solar wind
- Plasma depletion
  - Density decreases up to 50 – 70 % (Vanninathan et al., 2018)
- Their recovery is associated with interchange reconnection (Attrill et al. 2008)

Kazachenko et al., 2022



Coronal Hole vs Coronal Dimming

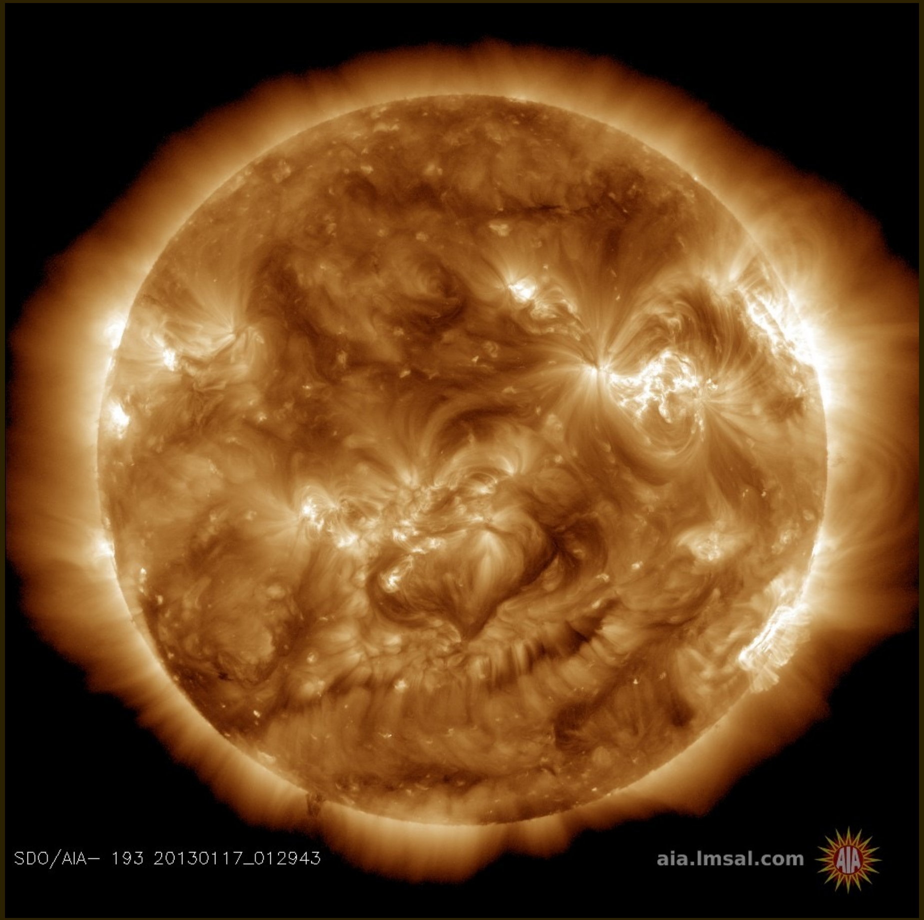
	Coronal Hole	Coronal Dimming
Lifetime	Several days up to a few years	Typically 3 - 12 Hours
Formation	Gradual Process (Active regions evolution/ Poleward migration)	Solar Eruptions (CMEs)
Plasma Upflow Speed (Tian et al. 2021)	~10 – 20 km/s ~50 – 100 km/s (Jet)	~ 50 – 150 km/s

Could it be that some CHs actually are long-lived coronal dimmings?

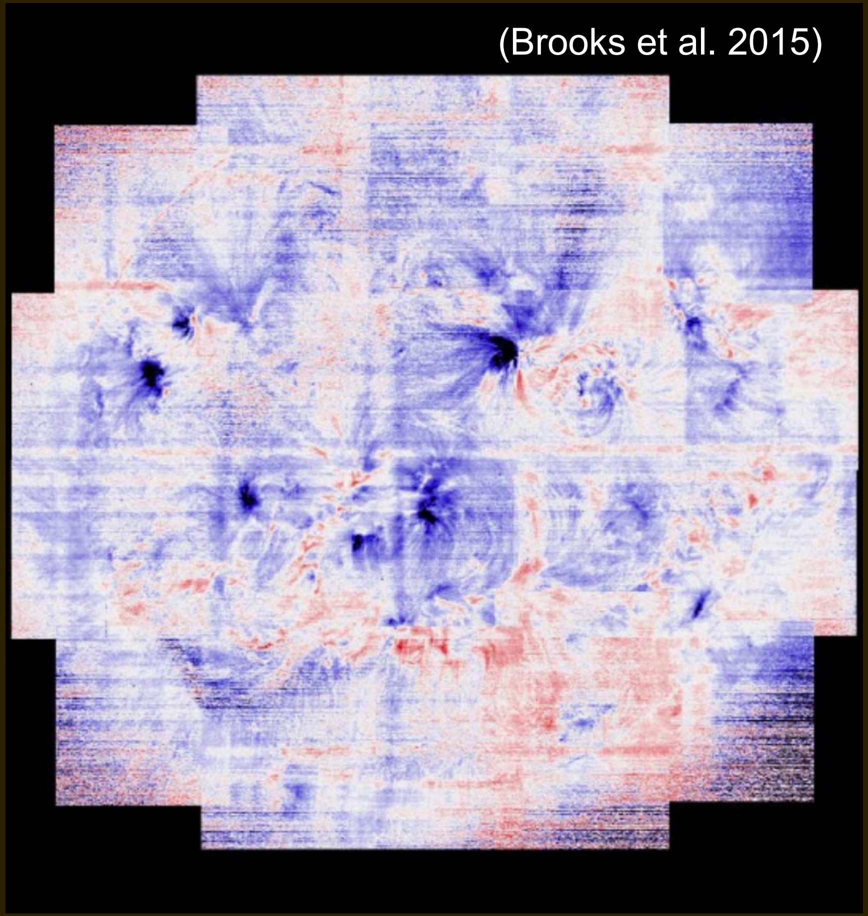
- Some coronal holes form due to solar eruptions (e.g., Heinemann et al. 2018)
- Justifying the usage of the term 'Transient coronal hole'

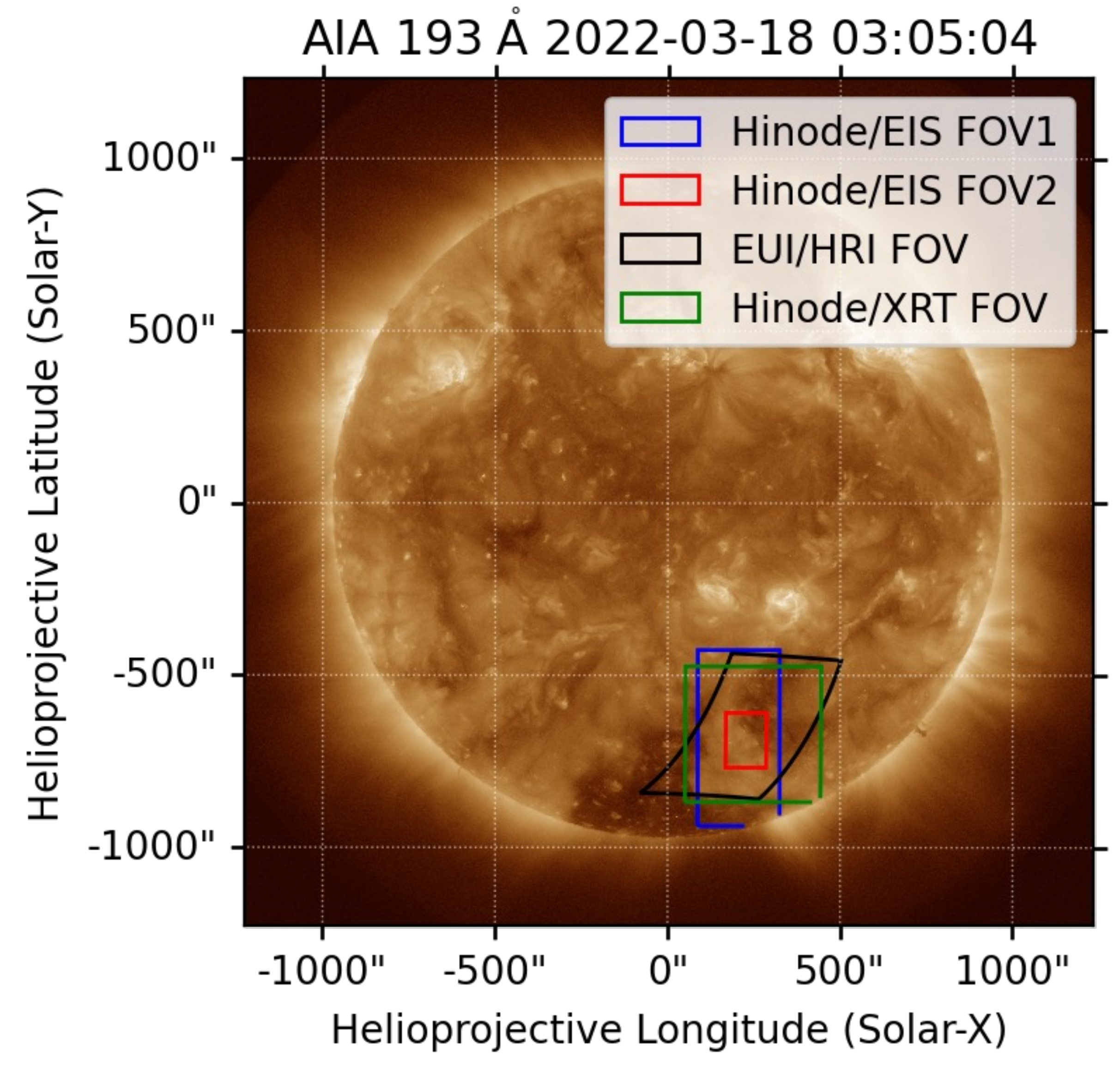
How do we observe solar corona?

- Broadband Imager:
  - High-cadence/High-resolution Image in EUV or X-ray



- Spectrometer:
  - Derive plasma dynamics and properties

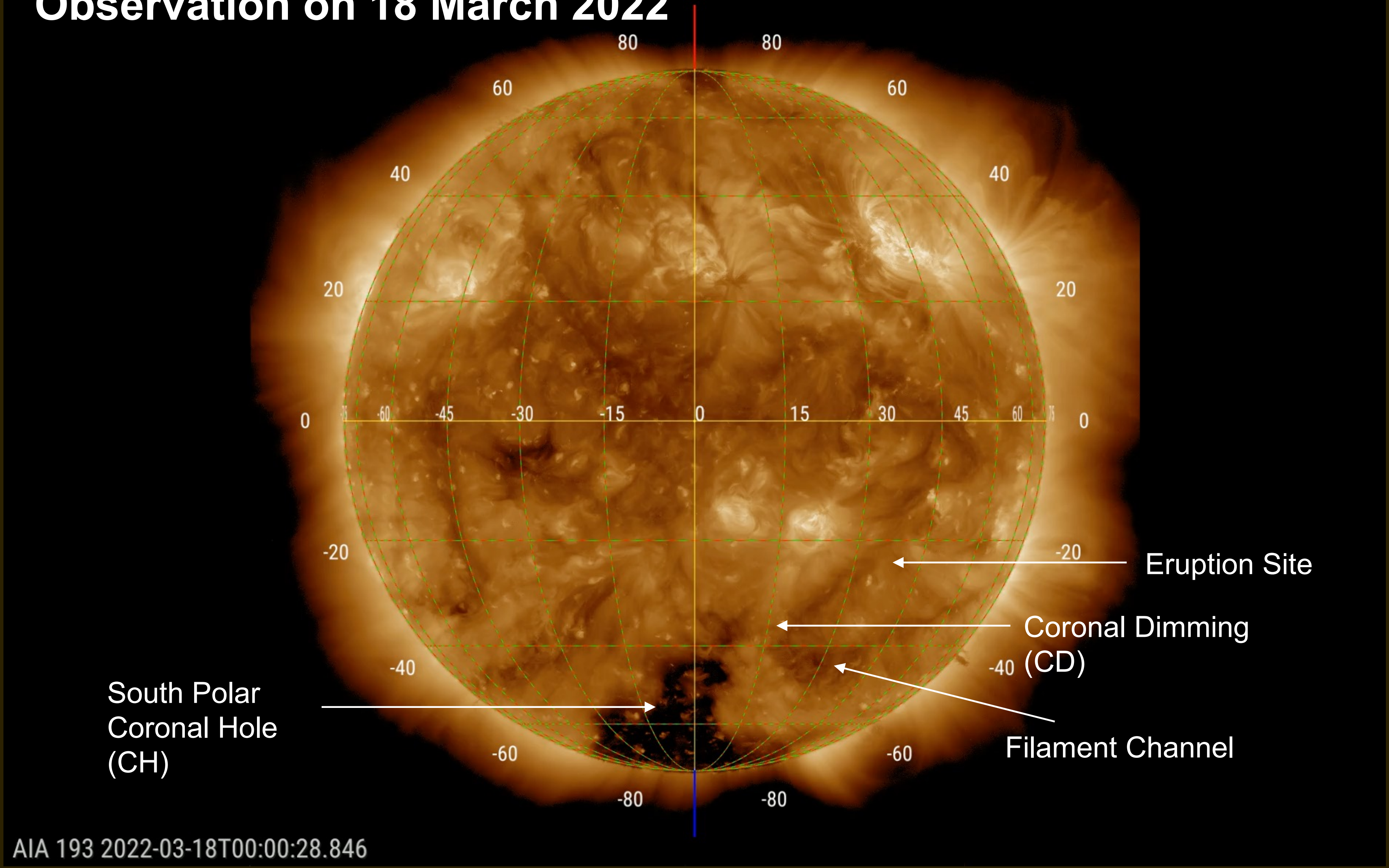




Multi-Spacecraft Coordinated Observation

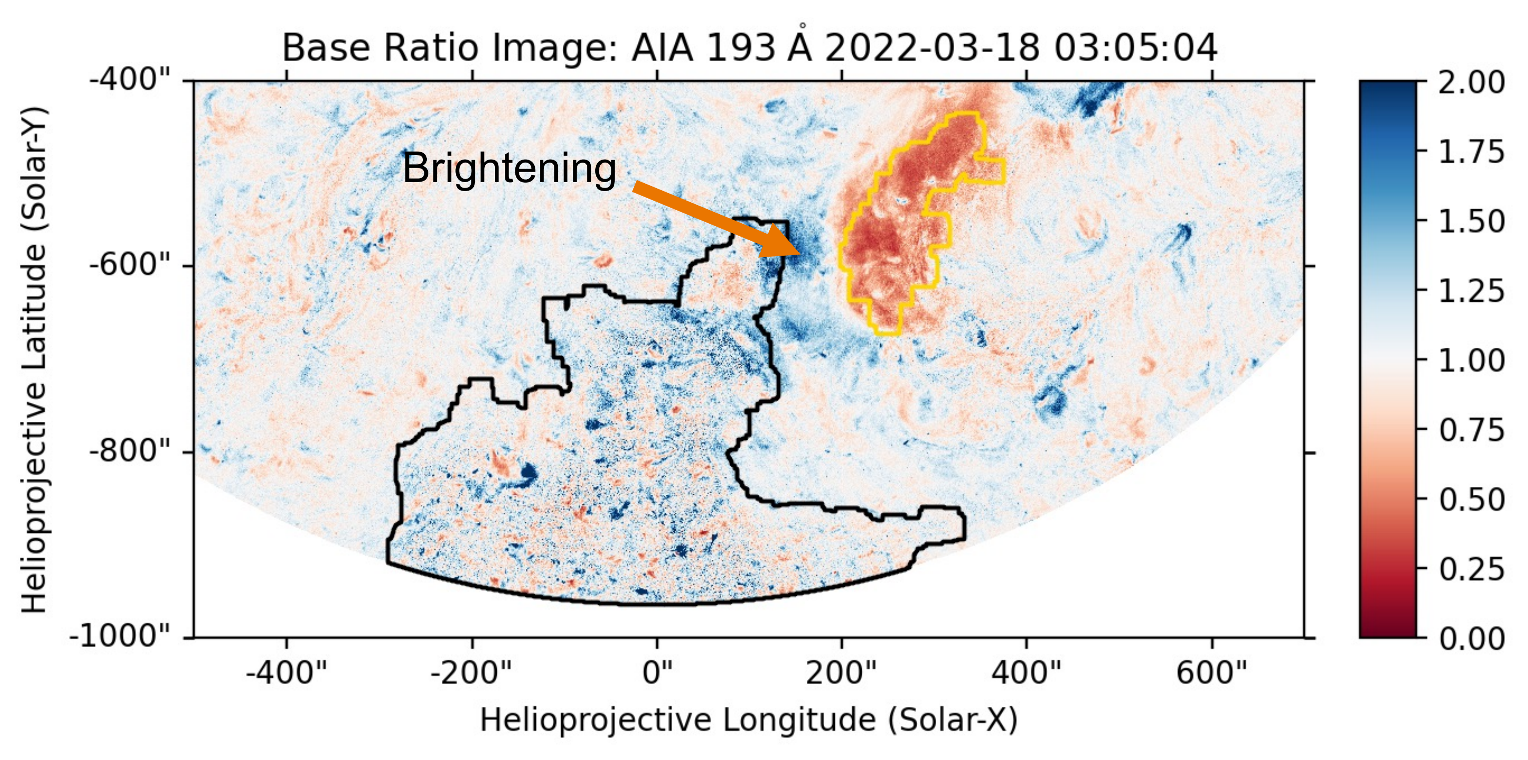
- Slow Solar Wind SOOP campaign (Yardley et al. 2023, in prep)
- SDO
  - AIA: Full solar disc EUV images across seven passbands
  - HMI: Full solar disc LOS magnetogram
- SO/EUI in 174 Å passband
  - FSI Synoptic, HRI: from 10:15 – 11:15 UT
- Hinode
  - EIS: Coronal Spectrometric observation, Running 4 Raster using two different studies
  - XRT: Thin Al poly filter - $T \sim 10^7\ K$

Observation on 18 March 2022

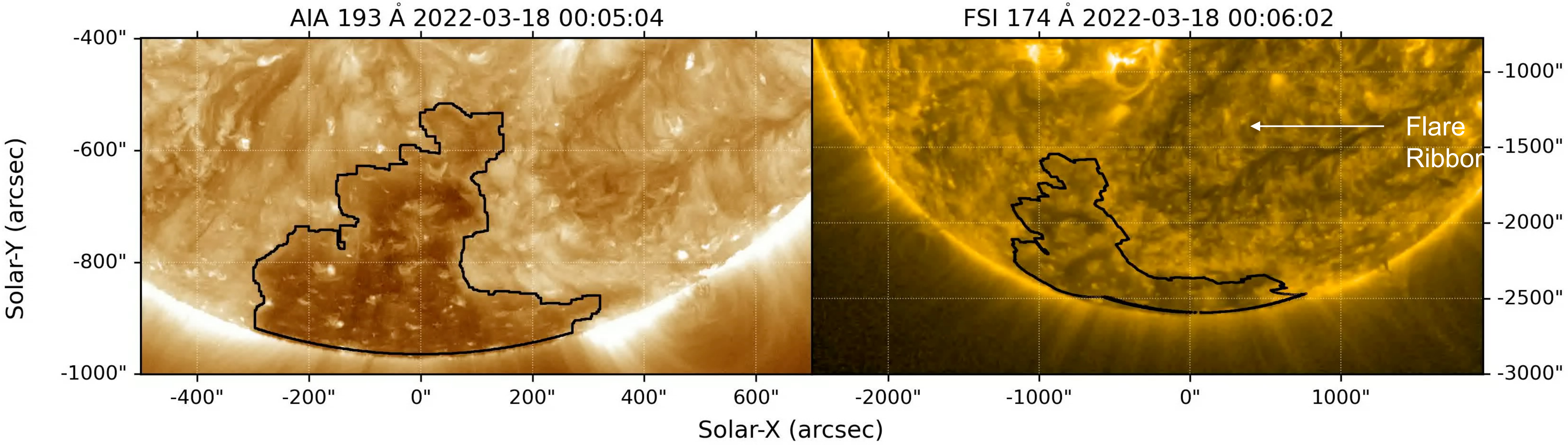


Identifying CH and CD boundaries

- The threshold for boundary identification
  - Using SDO/AIA 193 Å
  - Coronal Hole (CH: Black): 35% of solar disc median intensity (e.g., Rotter et al., 2012)
  - Coronal Dimming (CD: Yellow): Pixels with a value < 0.35 in base ratio images (Dissauer et al. 2018)
- Base Ratio image showed 'brightening' between CD and CH
  - Plasma compression inside the overlying field arcade



EUV Observation: SDO/AIA and SO/EUI



- 02:00 UT - Eruption started -> 08:15 UT – Coronal dimming (yellow) appeared to merge with CH (black)
- The merged region remained stable for at least 72 hours – CH and coronal dimming became indistinguishable from each other
- **CH and CD both had negative polarity**

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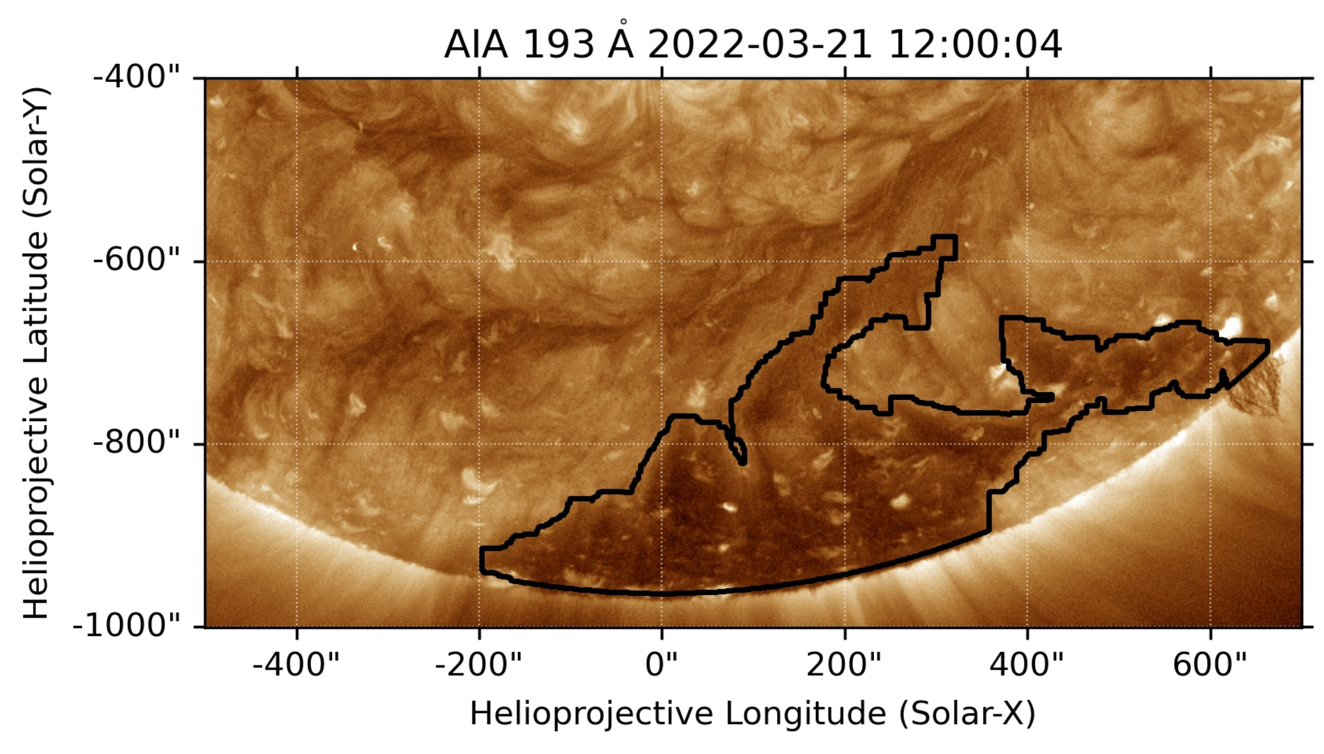

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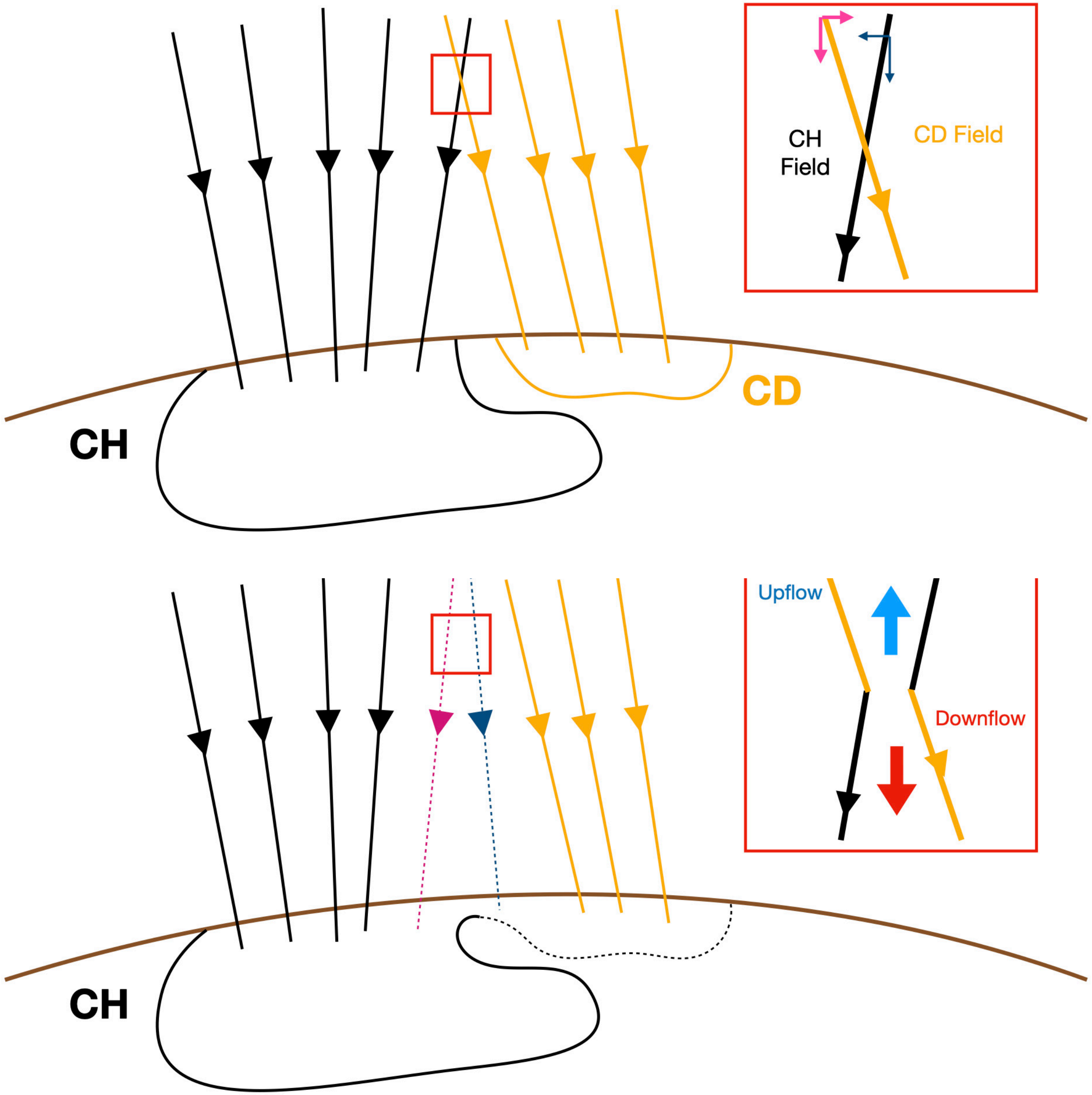
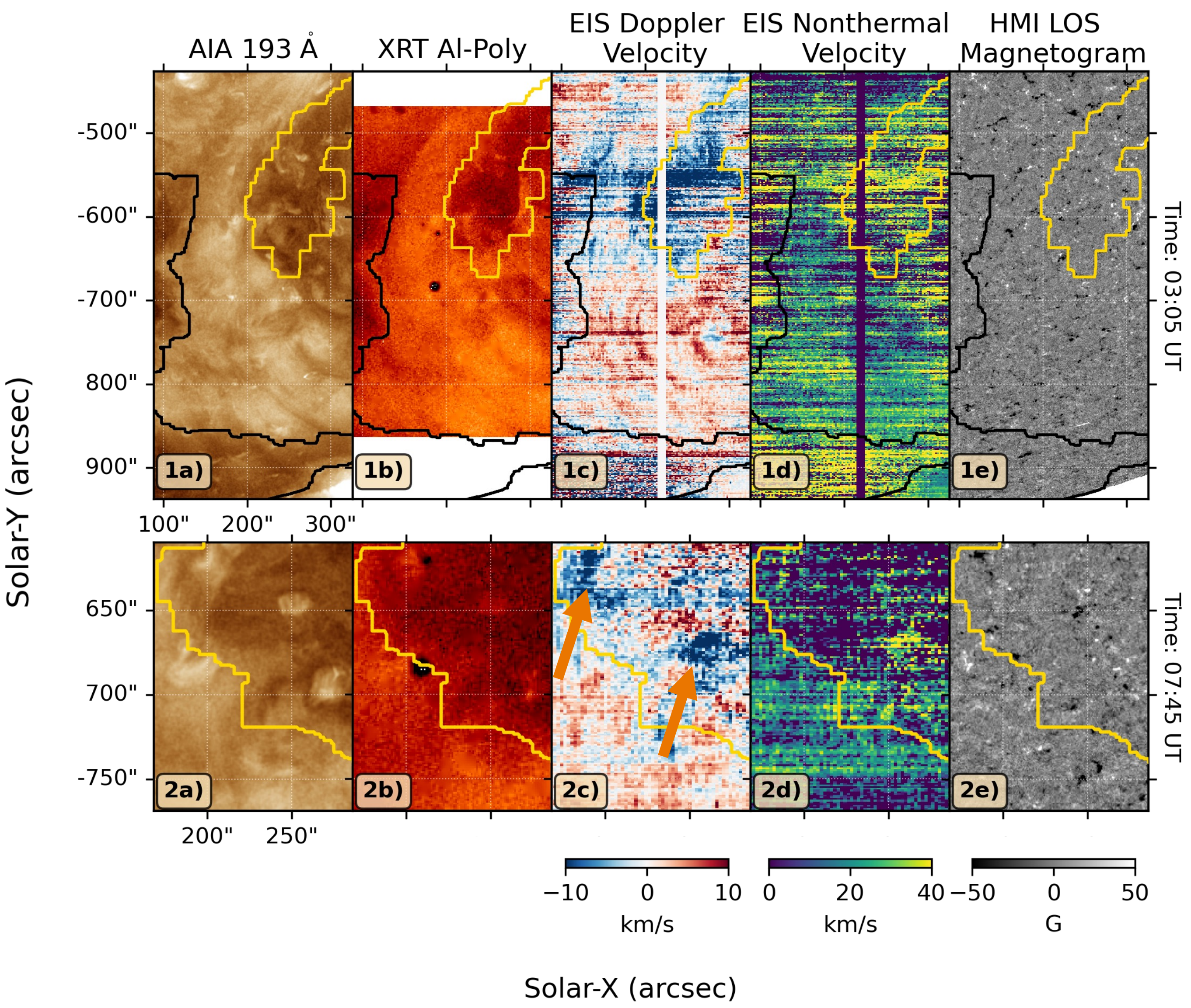


Component Reconnection

- The expanding field lines from CD (yellow) were at an angle with CH field lines (black)
- Component reconnection took place between two field lines at the boundary region
- **Footpoint Switching**: After reconnection, the CD field (pink) is rooted in CH, and the CH field (blue) is rooted in CD.
- **Upflow and downflow of plasma due to reconnection**

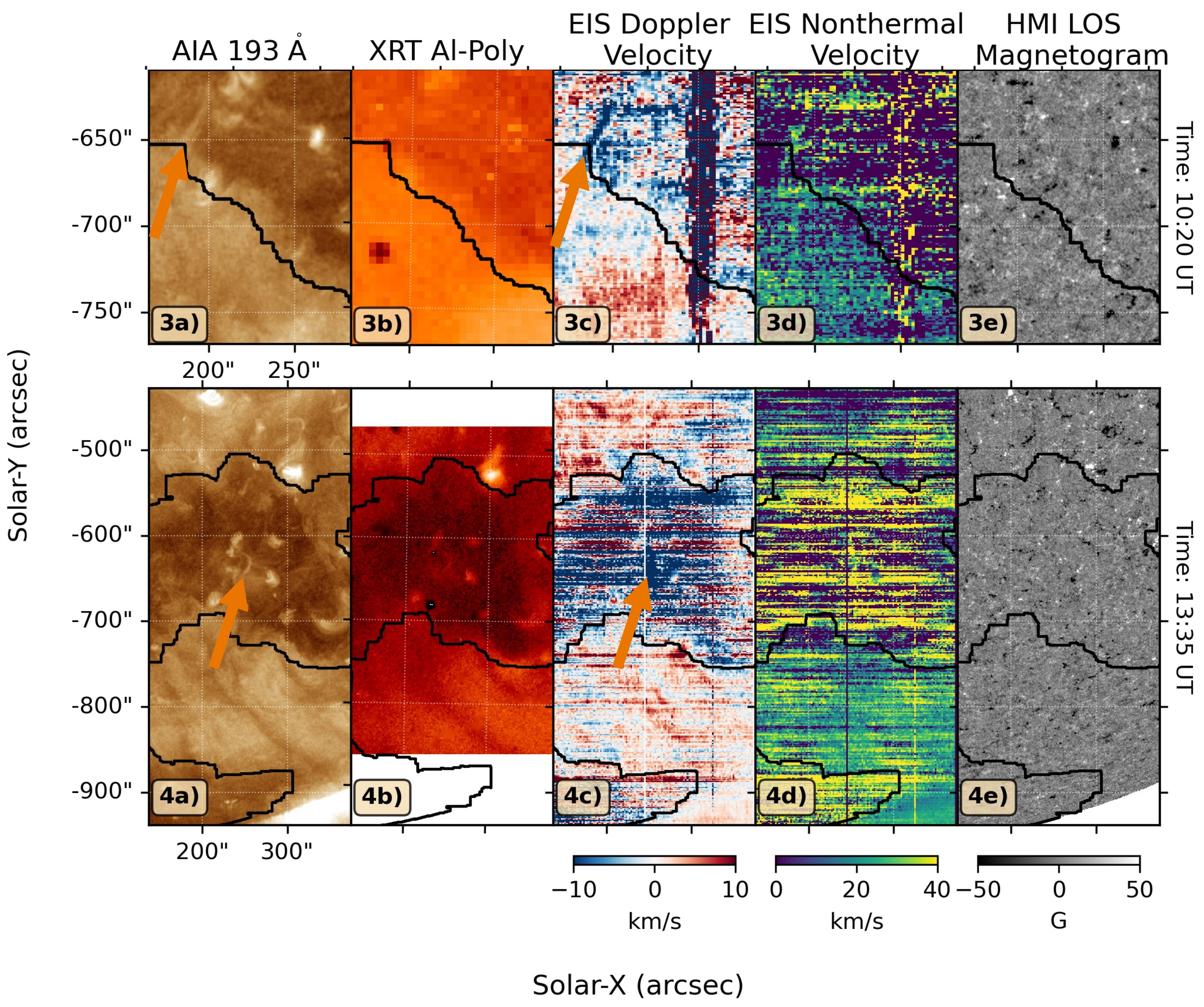
EIS Observation – Before Merging

- Observation using Fe XII 192.39 Å
- Raster 1: 03:05 UT
  - The large region of upflow
  - Plasma depletion due to expanding CME structure (Tian et al. 2012, Veronig et al. 2019)
- Raster 2: 07:45 UT
  - Two distinct upflow regions, the sources of upflow are less certain.

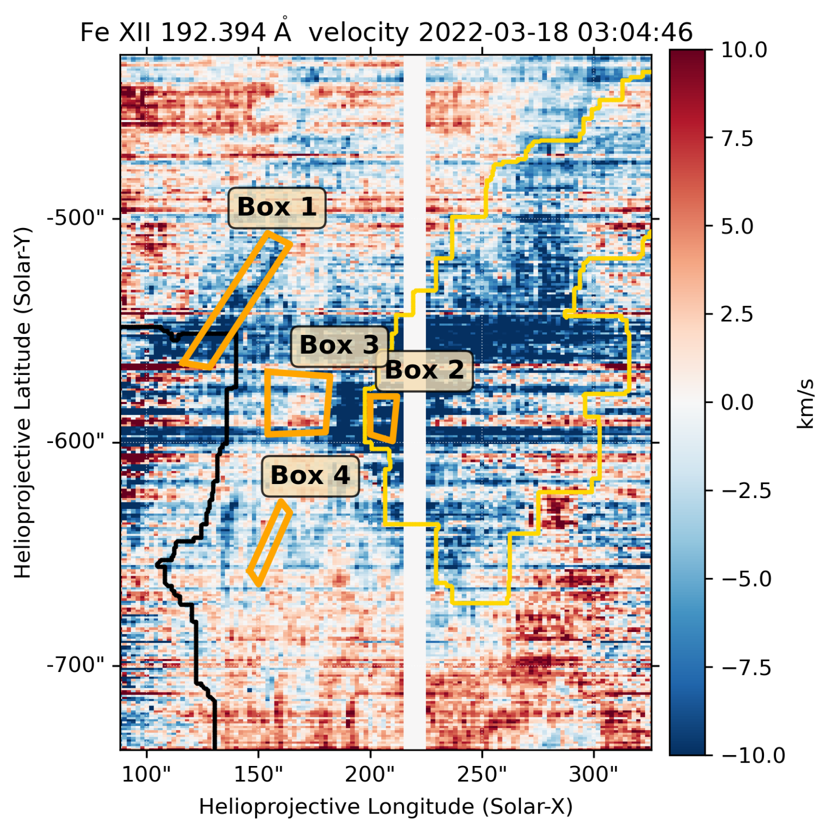


EIS Observation – After Merging

- Raster 3: 10:20 UT
  - AIA 193 Å and EIS Doppler Velocity map show a thin-collimated coronal jet inside the newly merged region. (Orange arrow)
- Raster 4: 13:35 UT
  - **A mixture of plasma upflow and downflow inside the merged region**
  - Enhanced nonthermal velocities compared to before merging
  - The flows become more 'disordered' compared to before merging



Plasma Upflows Before and After the Merging

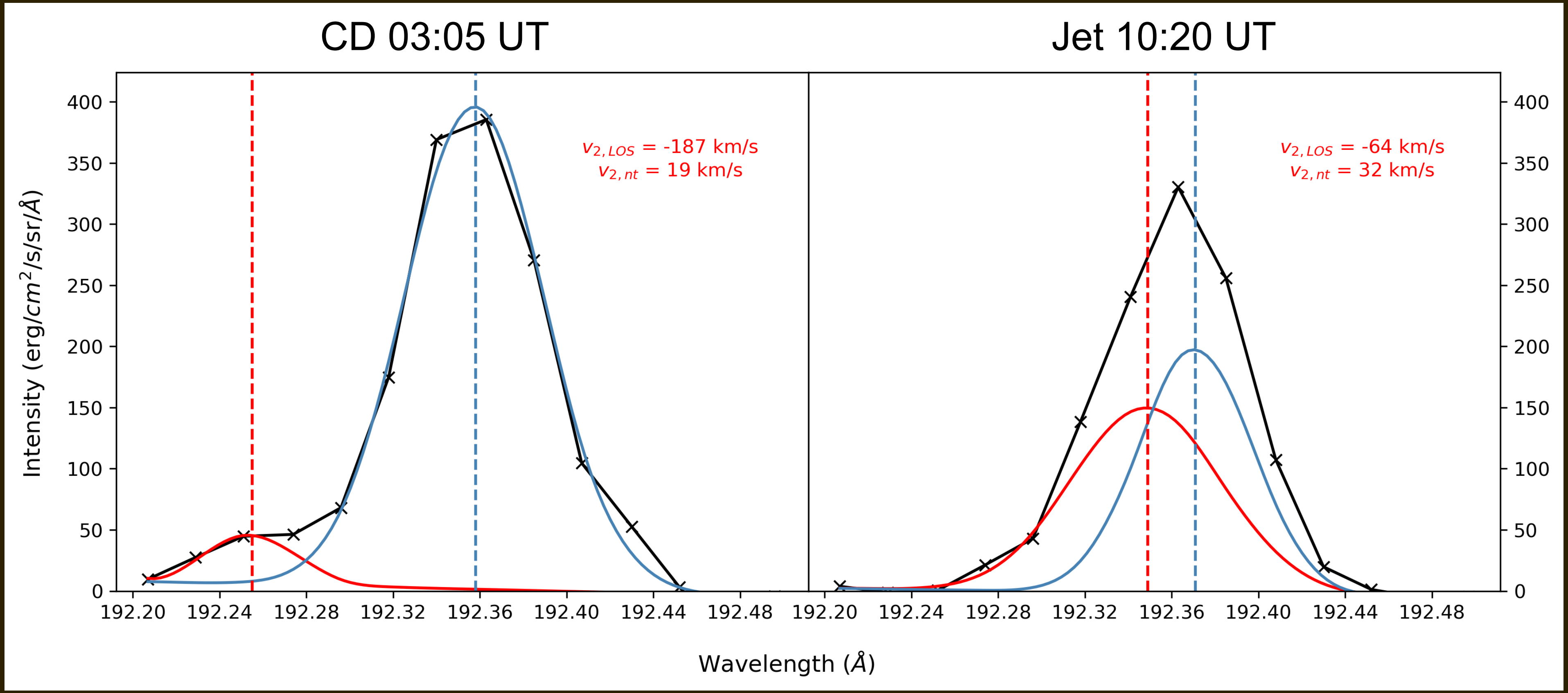


Spatially averaged the spectra from pixels inside the boxes

Location	Timing	Doppler Velocity (km/s)	Nonthermal Velocity (km/s)
CH Edge (Box 1)	Before Merging	-18	28
	After Merging	-22	31
CD (Box 2)	Before Merging	-26	20
	After Merging	-16	33
Quiet Sun (Box 3)	Before Merging	0	25
	After Merging	-3	31
Jet (Box 4)	Before Merging	-9	27
	After Merging	-23	34

- Enhanced nonthermal velocities after the merging
- The upflow speed inside CD and quiet Sun regions became more similar to CH upflow after the merging

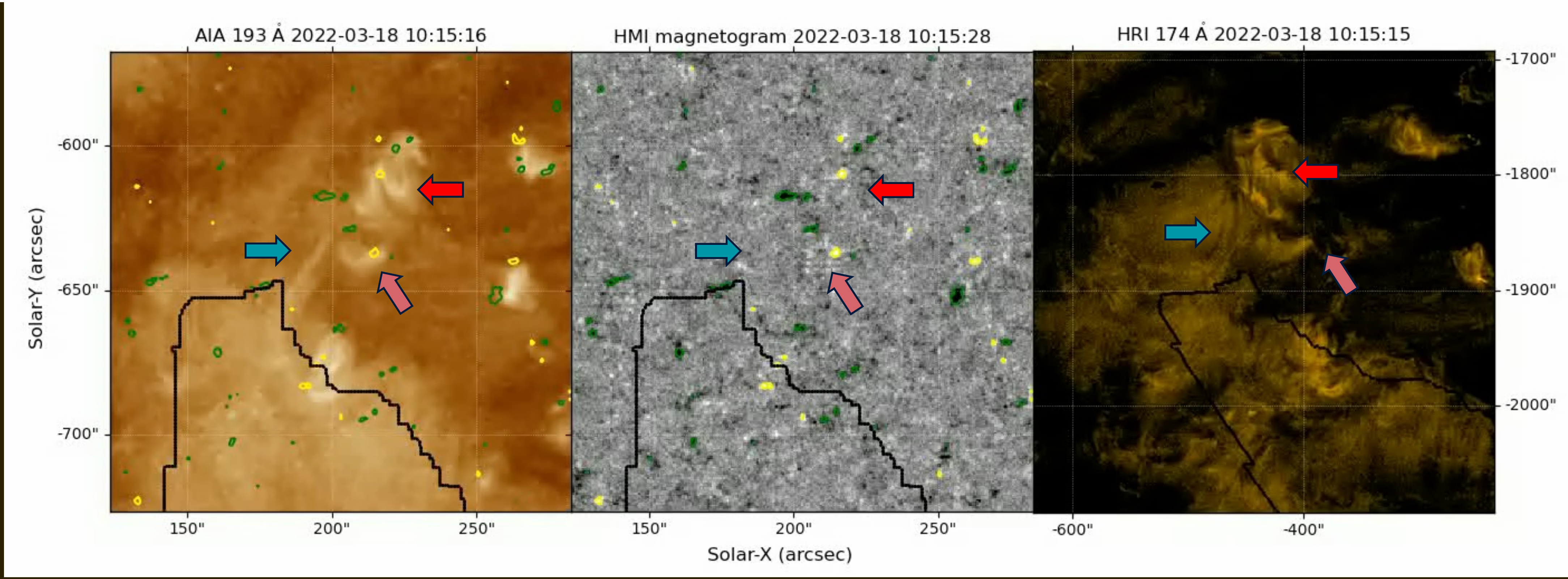
Secondary Component of Line profiles



- Left panel: CD upflows at 03:05 UT raster,
- V ~ - 187 km/s: In agreement with the previous observations

- Right Panel: Coronal jet originated from the merged region at 10:35 UT
- V ~ - 64 km/s

Jet inside the merged region



- This may be analogous to the simulation of jets from moving magnetic elements (Wyper et al. 2018)
  - The observed jet's velocity agrees with the simulation.
- Changes in magnetic field configuration allow the jets to form more frequently.

Summary

- We reported and analysed the merging of a southern polar coronal hole (CH) with a coronal dimming (CD) resulting from a filament eruption on 18 March 2022
  - The first time that the merging between two open-field structures was observed using spectroscopic observation
- CH and CD became indistinguishable from one another after the merging.
  - Lifetime longer than a typical CD lifetime of 3-12 hours
  - The upflow profile inside CD and quiet Sun region became more similar to CH upflow after the merging, with the upflow speed in the order of 10-20 km/s
  - Coronal jets and coronal plumes are found inside CD, similar to CH
- Component reconnection is considered the primary driving process in the merging of these two structures