Chain Bridge / Budapest

# Dynamics of Flux Emergence:
## Combining IRIS with Other Observations, Modeling, and New Capabilities


Shin Toriumi
(National Astronomical Observatory of Japan)


IRIS-9 (2018 Jun 27)

Invited Talk

3. Magnetic coupling and mass flux through the atmosphere

# Dynamics of Flux Emergence: Combining IRIS with Other Observations, Modeling, and New Capabilities

S. Toriumi[1]

[1] *National Astronomical Observatory of Japan*

This review talk is dedicated to the summary of what we have learned in the IRIS era about the flux emergence and related activity phenomena as well as to the perspective of what we will achieve in the near future. We first review some important findings of, especially, the UV bursts in newly emerging flux regions and the plasma dynamics in sunspot light bridges. It is shown that many of the key achievements are made through the comparison of satellite observations (IRIS, Hinode, SDO, etc.), ground-based observations (SST, GST, etc.), and a variety of numerical simulations. However, the only physical parameters we can compare between observations and simulations are the vector magnetic fields in the photosphere and the Doppler velocities of a few spectral lines. Therefore, in general, the quantitative comparison is not easy. However, this difficulty may be overcome by new instruments in the coming decade. For example, DKIST has a capability to measure magnetic fields in the atmospheres (e.g. in the chromosphere) with high spatial resolutions. The proposed Solar-C_EUVST will monitor atmospheres with wide temperature coverage from the chromosphere to the corona, providing rich plasma diagnostics of various layers. Combined with existing observations and numerical modeling, these new capabilities may open a door to the quantitative evaluation of mass and energy transport, seamlessly from the photosphere to the corona through the interface region.

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# Dynamics of Flux Emergence: Combining IRIS with Other Observations, Modeling, and New Capabilities

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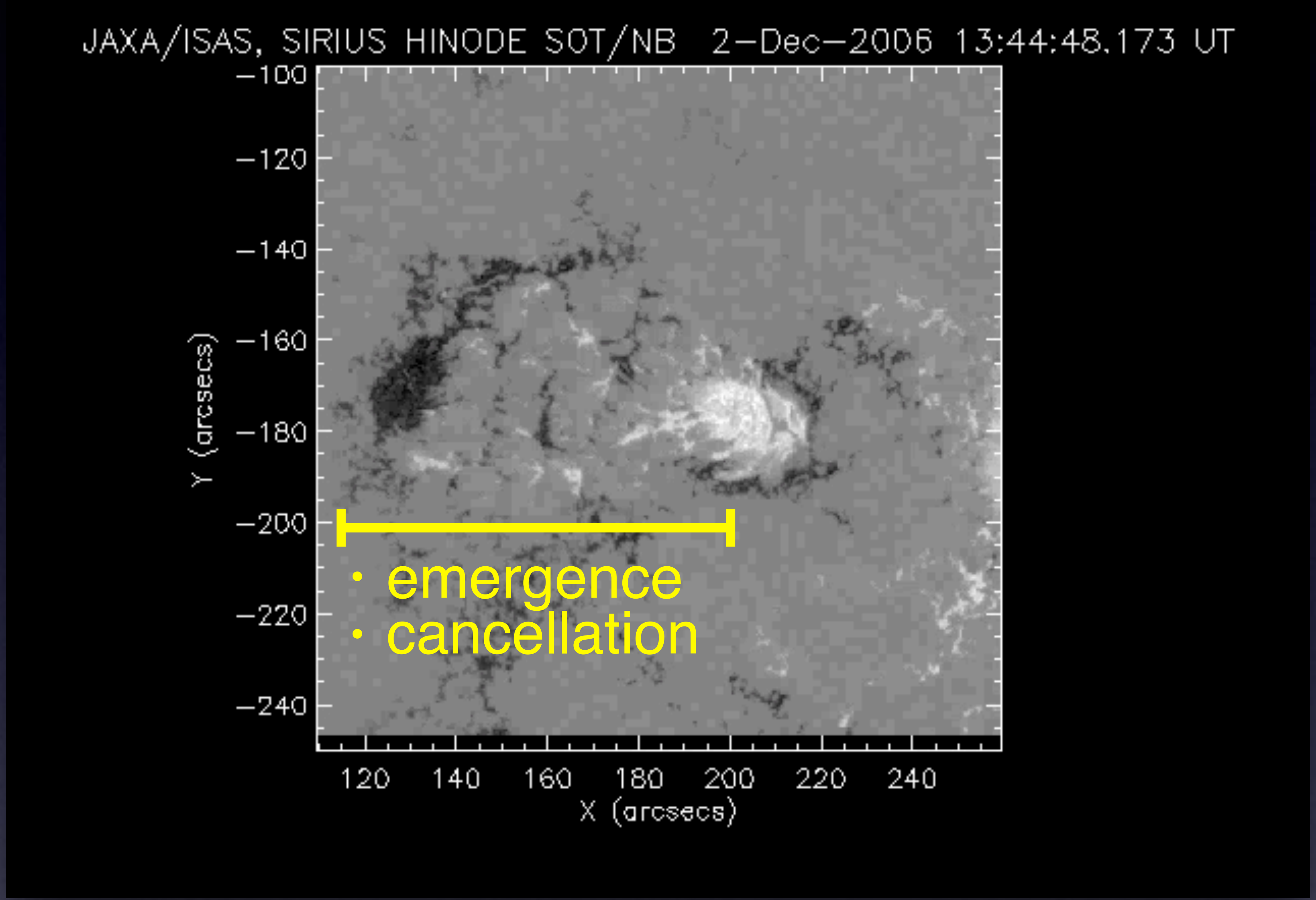
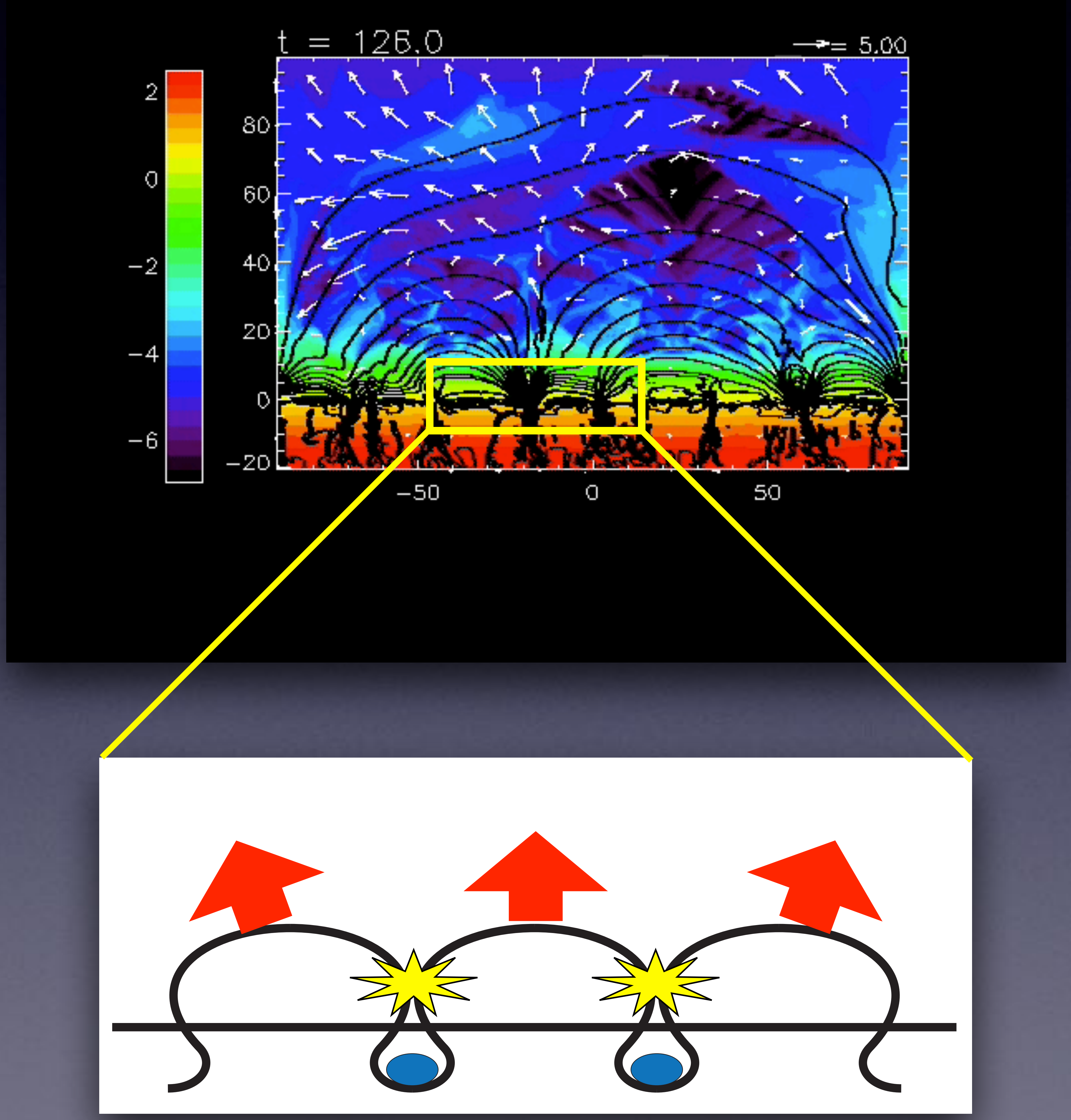
IRIS-9 (2018 Jun 27)

# 1. Introduction or “Why am I doing this?”

Hinode/SOT (Dec 1-2, 2006)




2D flux-emergence simulation




- Undergraduate study in 2009
  - Serpentine fields reconnect at dipped parts, which is observed as Ellerman bombs
  - Resistive emergence [Pariat+ 2004]

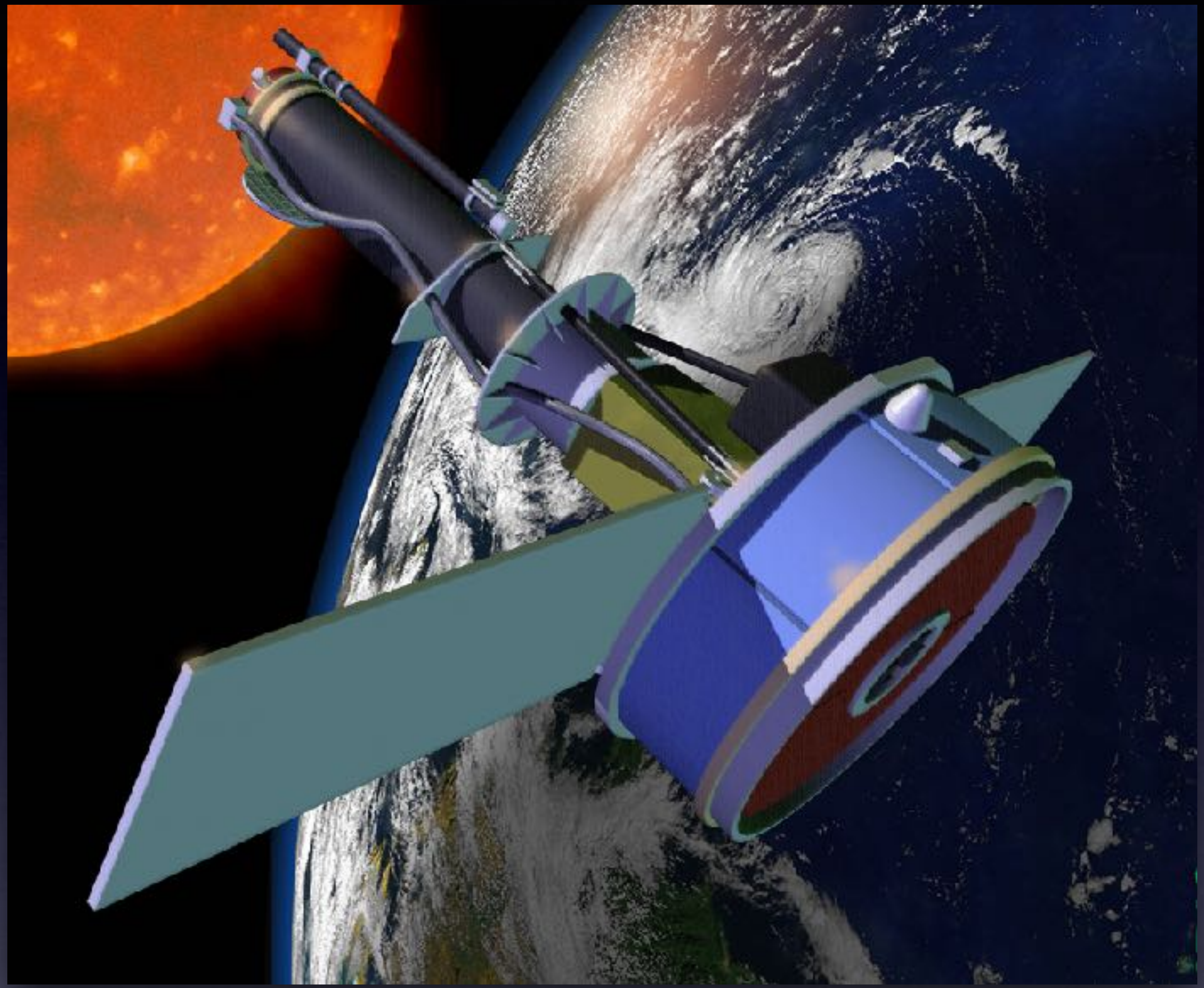
# 1. Introduction or “Why am I doing this?”

- Science objectives of IRIS
  1. Atmospheric heating: waves vs nano-flares?
  2. Mass and energy supply to the corona and heliosphere?
  3. Magnetic flux and mass transport though the lower atmosphere, and role of flux emergence in flares and CMEs?

[DePontieu et al. 2014]

→ Flux emergence is one of the most important targets of the IRIS mission

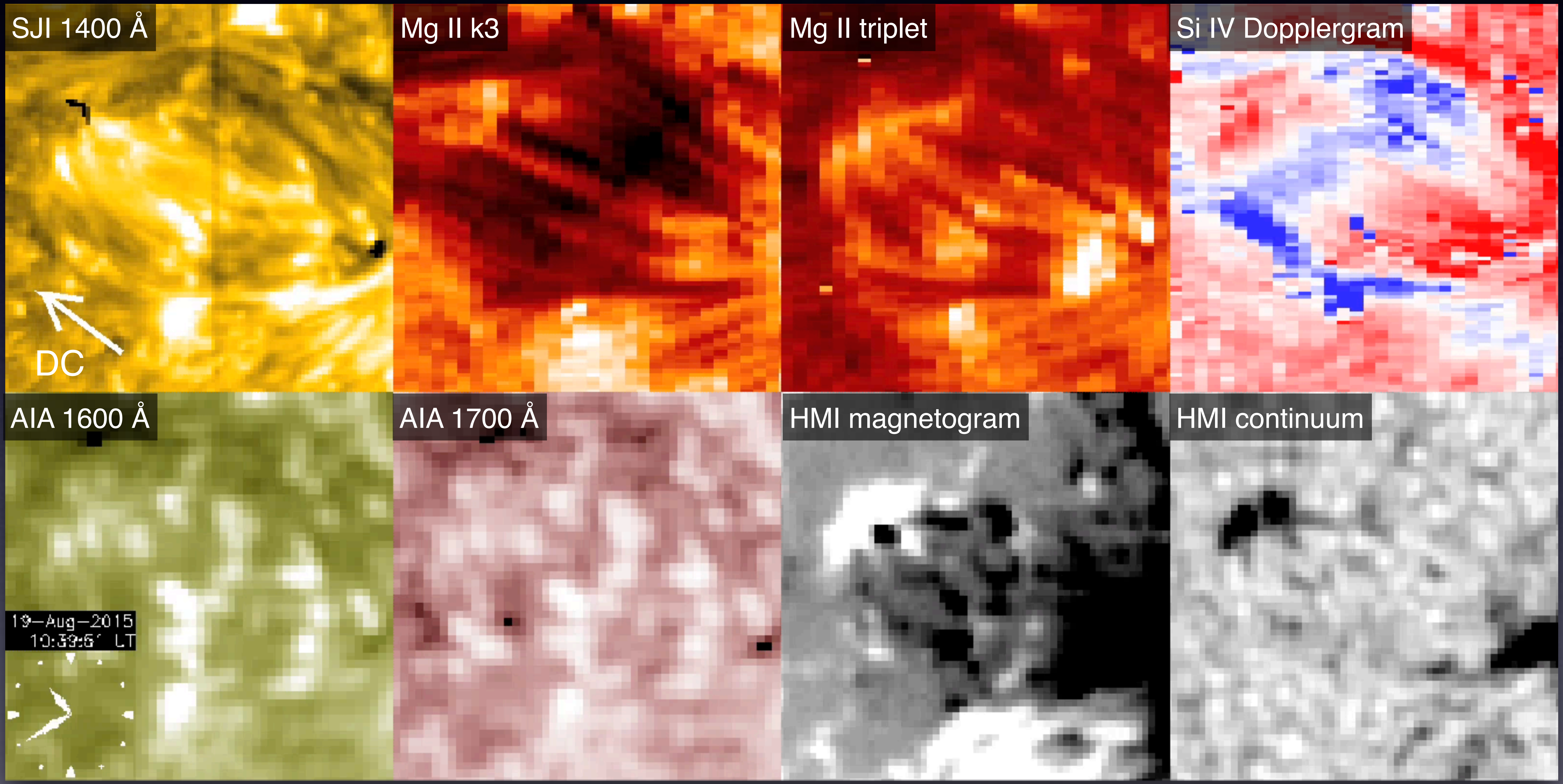
- This talk aims at
  - IRIS achievements: UV bursts and dynamics in
    - Emerging flux regions
    - Light bridges
  - Discussion on new capabilities of
    - Ground-based observatories
    - Future space missions



NASA/IRIS

# 2. UV Bursts in EFRs

- The so-called “IRIS bombs”
  - Explosive IRIS UV spectra seen at flux cancellation sites

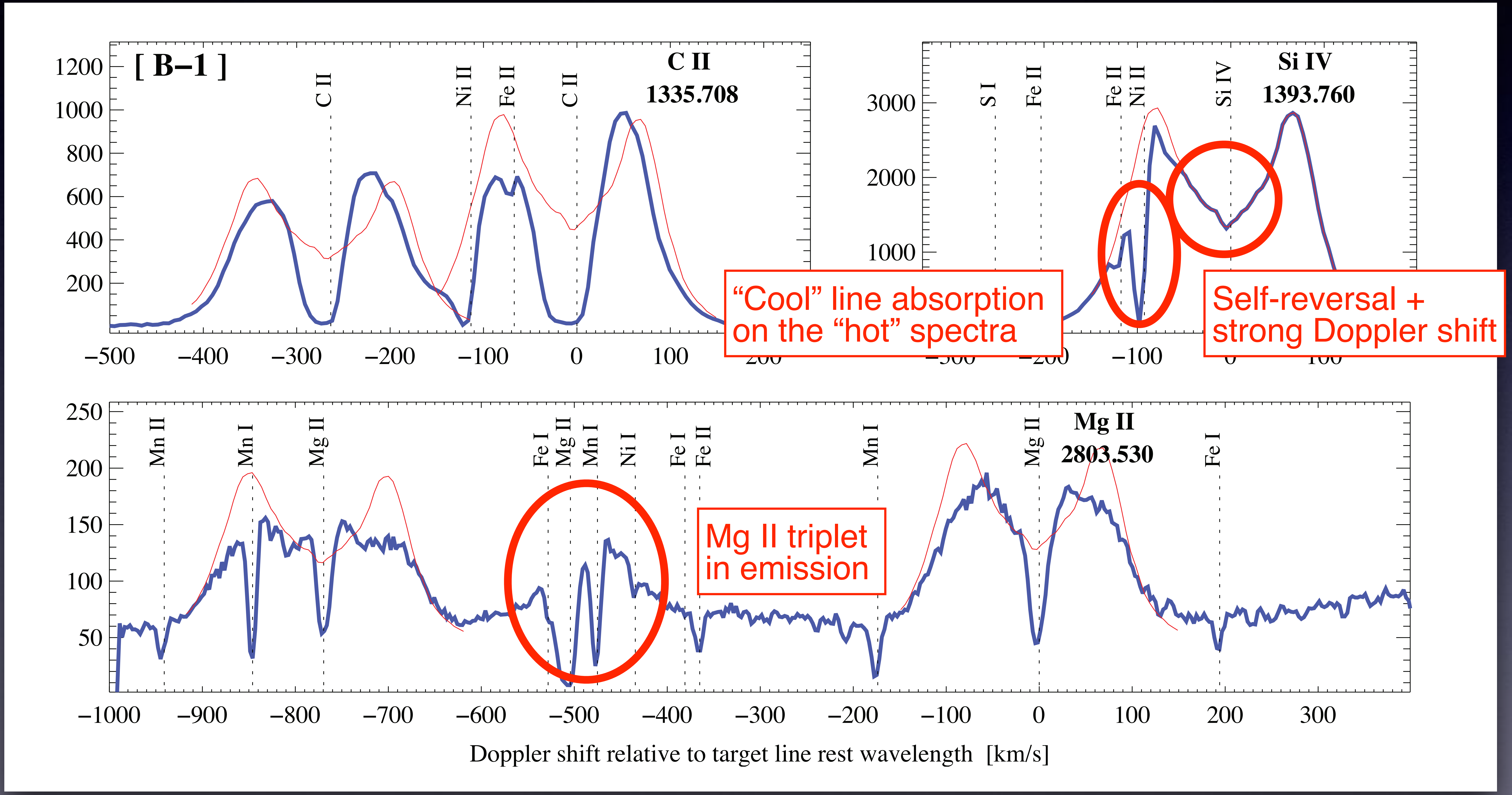



“Textbook” emergence observed by IRIS, Hinode, and SDO [Toriumi et al. 2017]

[c.f. many talks in this week; see Young et al. (2018 arXiv) for review on UV bursts]

# 2. UV Bursts in EFRs

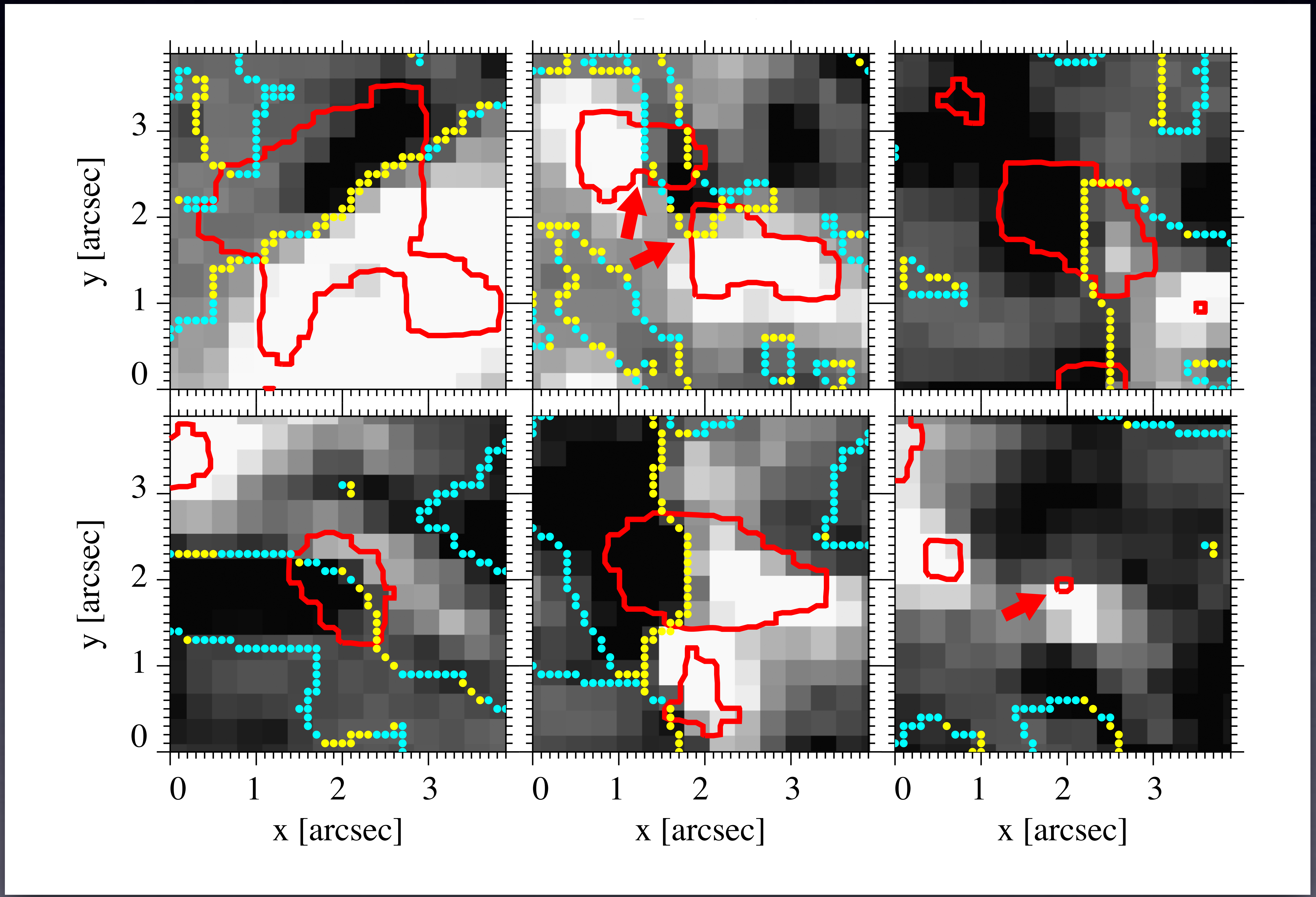
- The so-called “IRIS bombs”
  - Unusual profiles like…

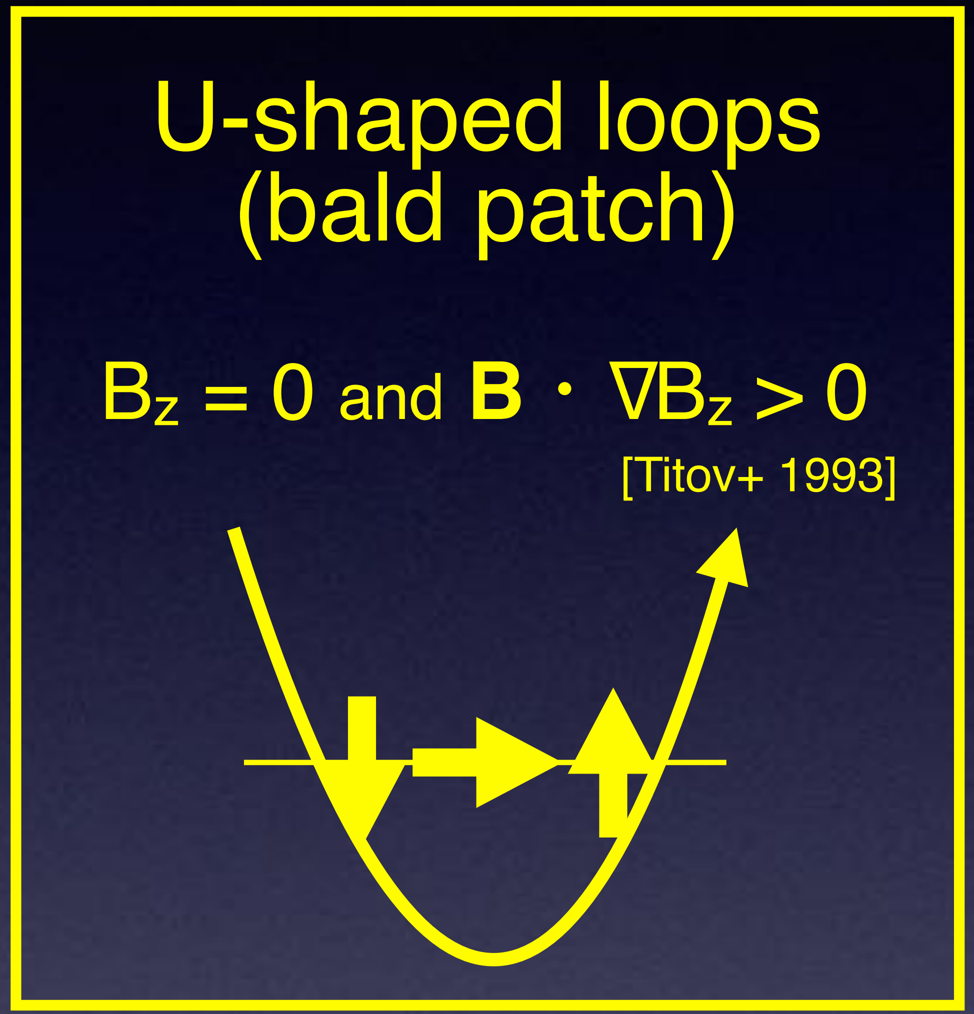


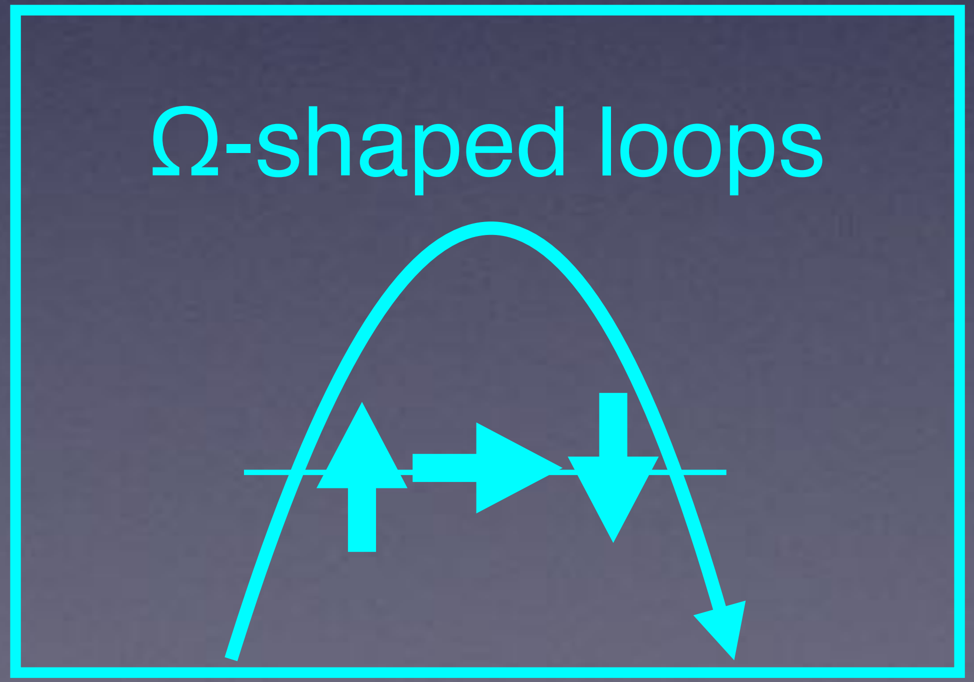

[Peter et al. 2014; see also Vissers+ 2015, Tian+ 2016, Toriumi+ 2017]

# 2. UV Bursts in EFRs

- The so-called “IRIS bombs”
  - Hinode/SOT vector fields show U-shaped loops in most cases



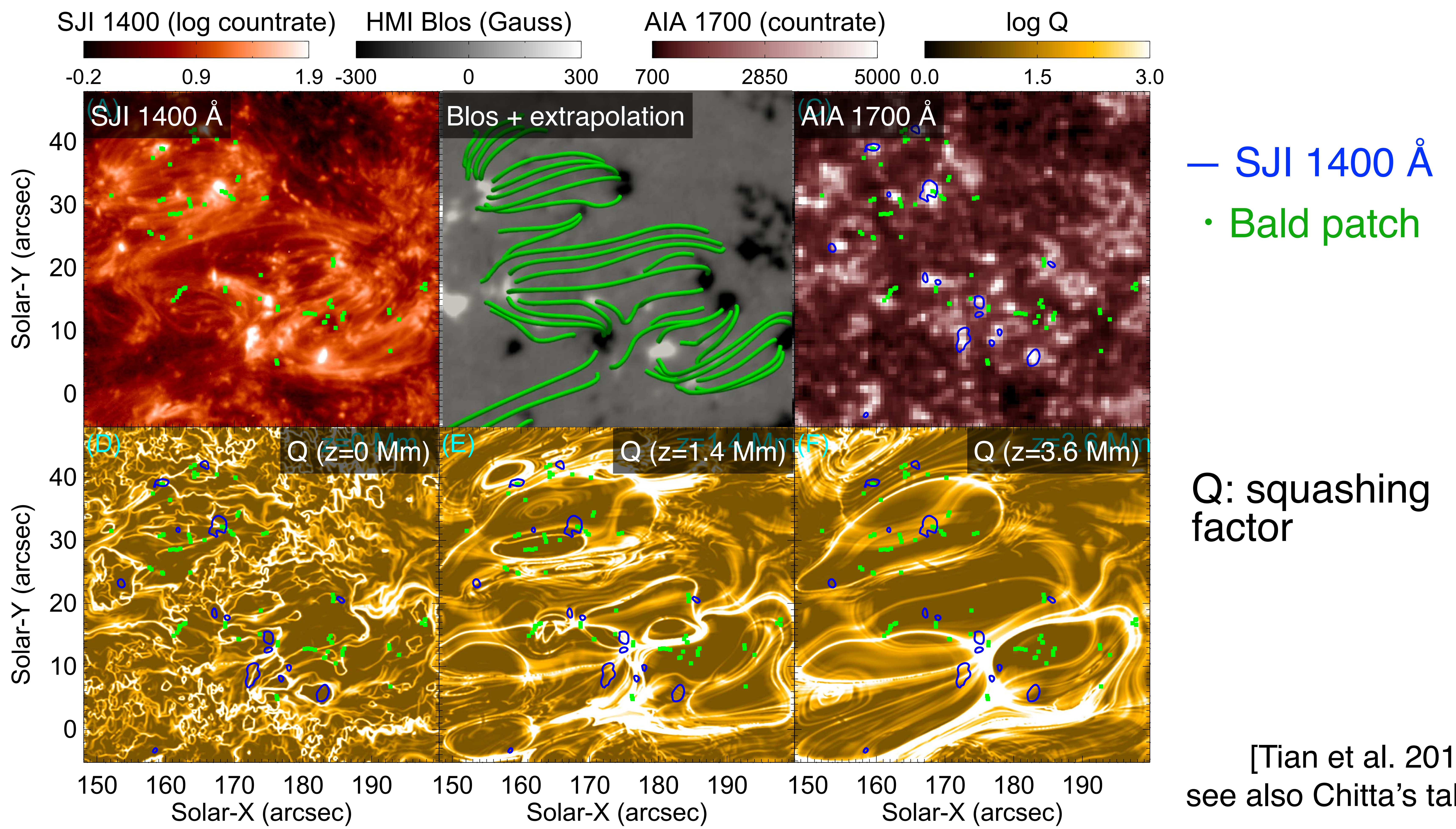




[Toriumi et al. 2017: see also Zhao+ 2017]

# 2. UV Bursts in EFRs

- The so-called "IRIS bombs"
  - Many are found at quasi-separatrix layers (QSLs) at z~1 Mm

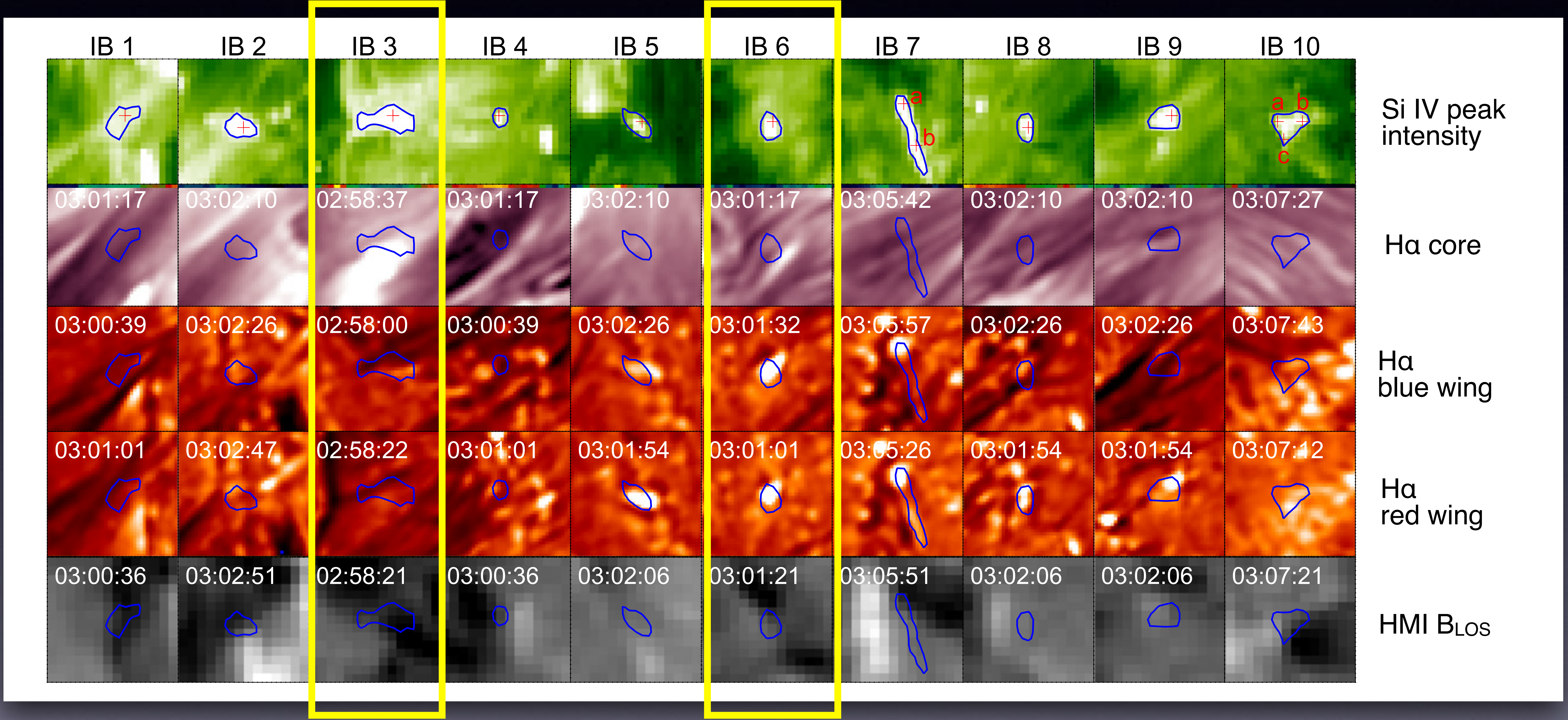



Q: squashing factor

[Tian et al. 2018; see also Chitta's talk]

# 2. UV Bursts in EFRs

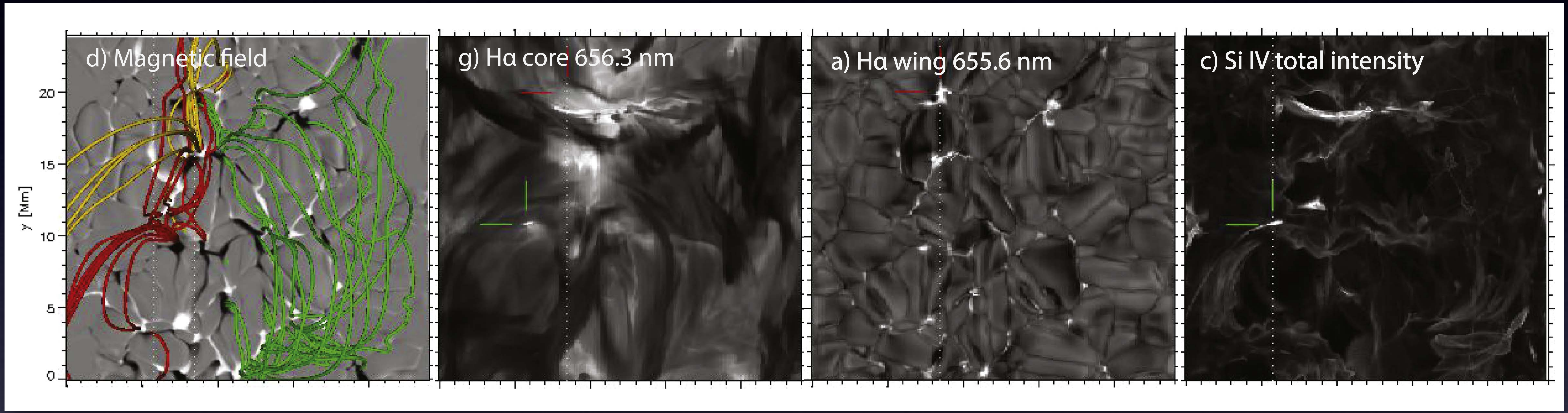
- The so-called "IRIS bombs"
  - Some are co-spatial with Ellerman bombs, but some are not

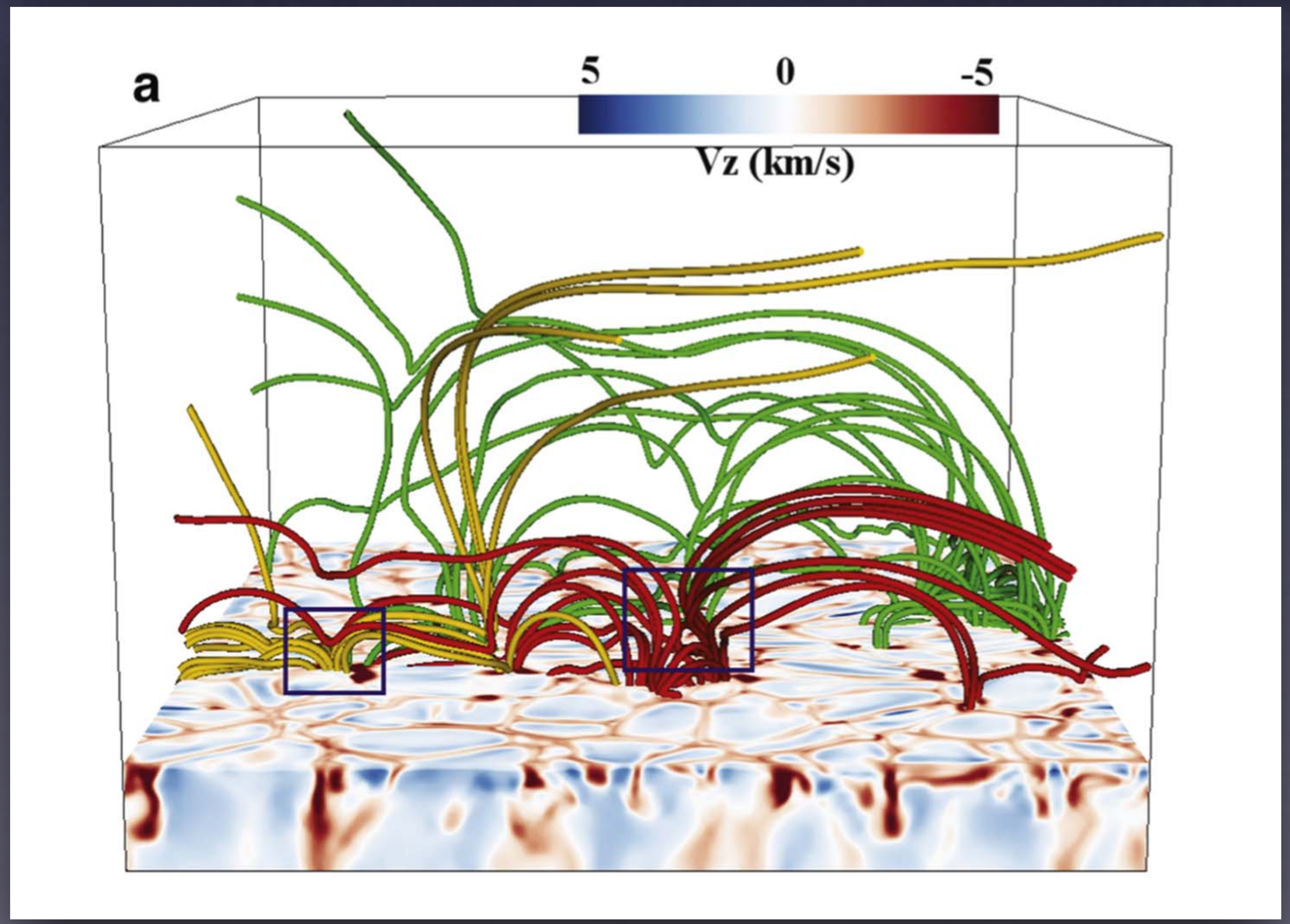



[Tian et al. 2016; see also Grubecka+ 2016]

# 2. UV Bursts in EFRs

- Numerical modeling shows the answers
  - Bifrost simulation by Hansteen et al. (2017)



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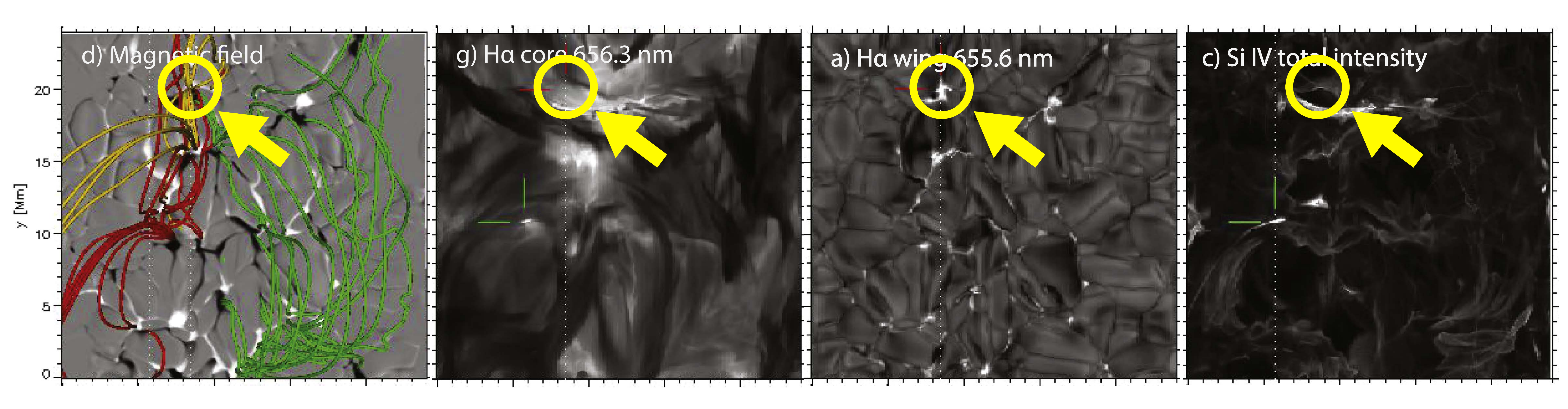


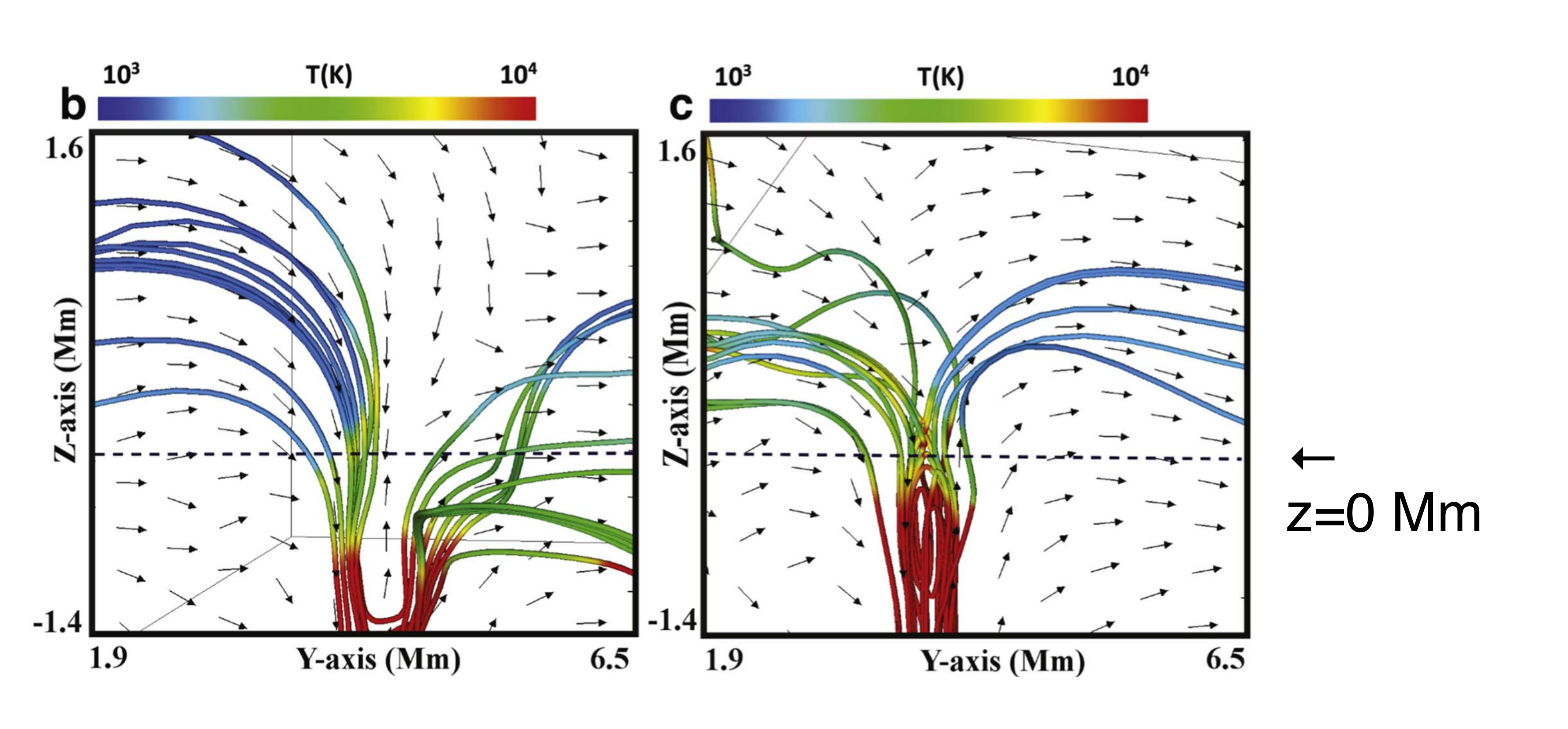


- Ellerman bombs
  - Photospheric reconnection
  - Brightening in Hα wings
  - Not seen in Hα core due to overlying canopy fields
  - Not clearly seen in Si IV
  - Photo temp = 8000–9000 K

# 2. UV Bursts in EFRs

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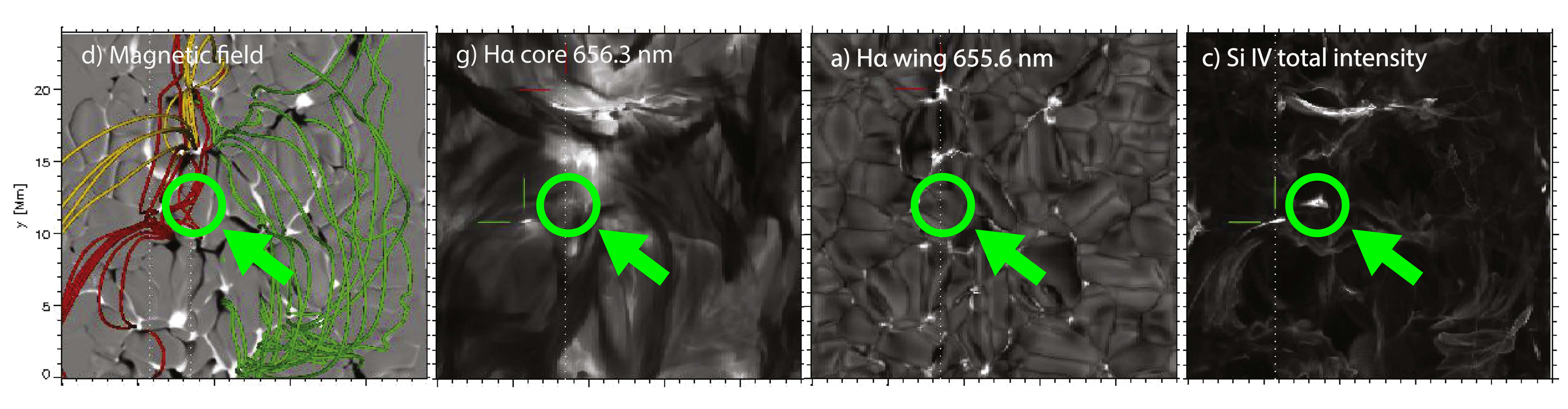


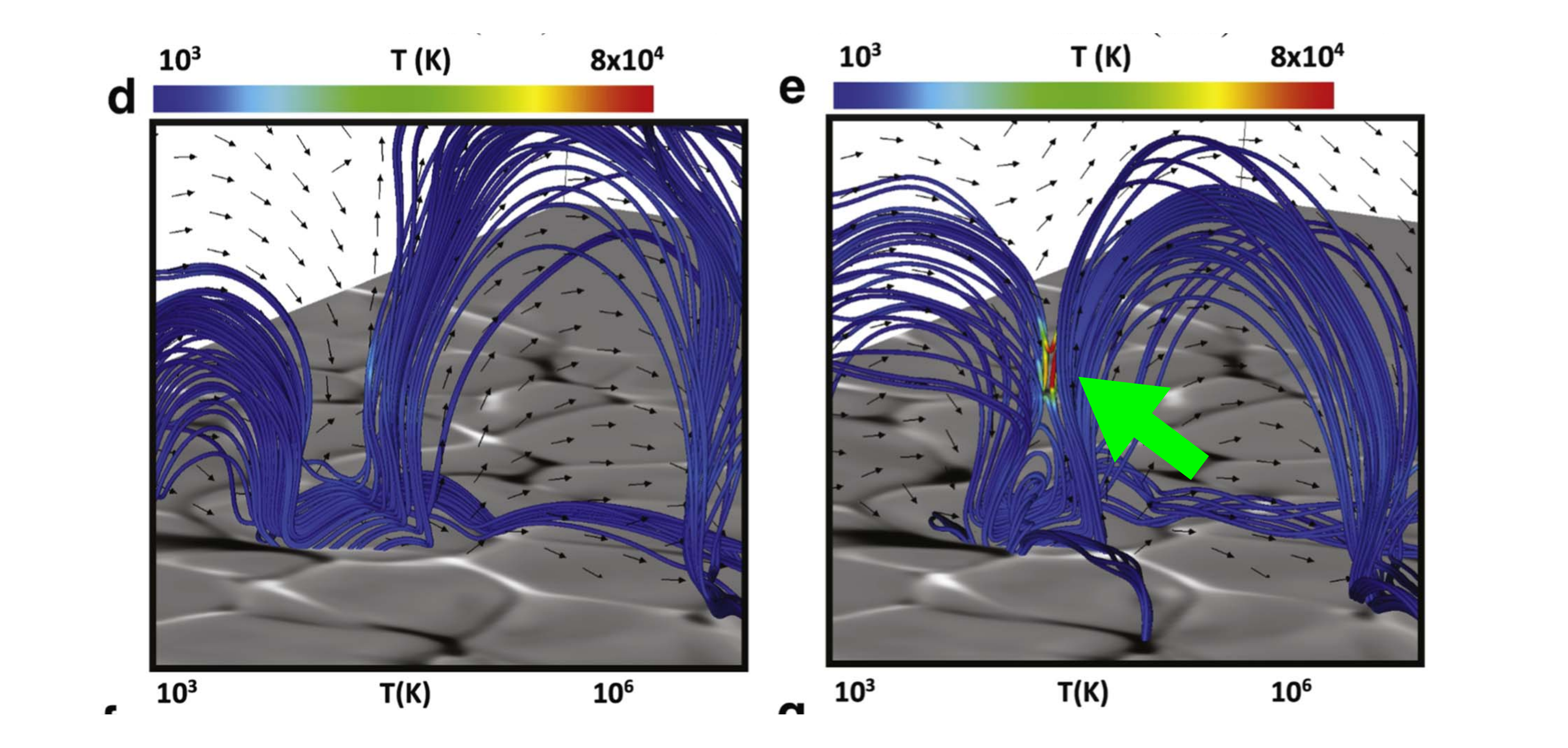


- UV bursts
  - Reconnection in higher altitude
  - Clearly seen only in Si IV (intensity 200 times stronger than average)

# 2. UV Bursts in EFRs

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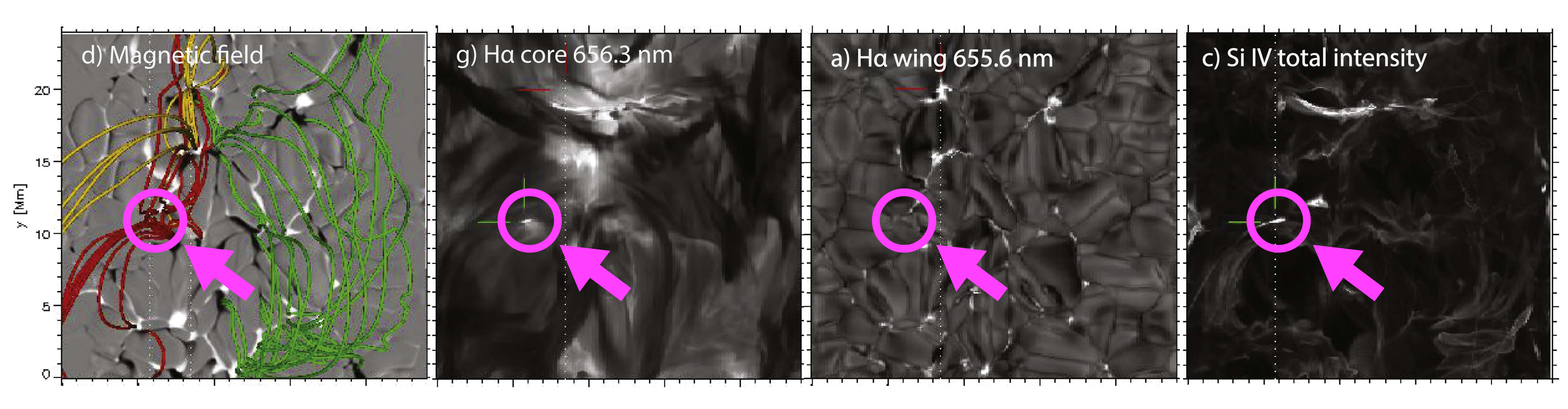


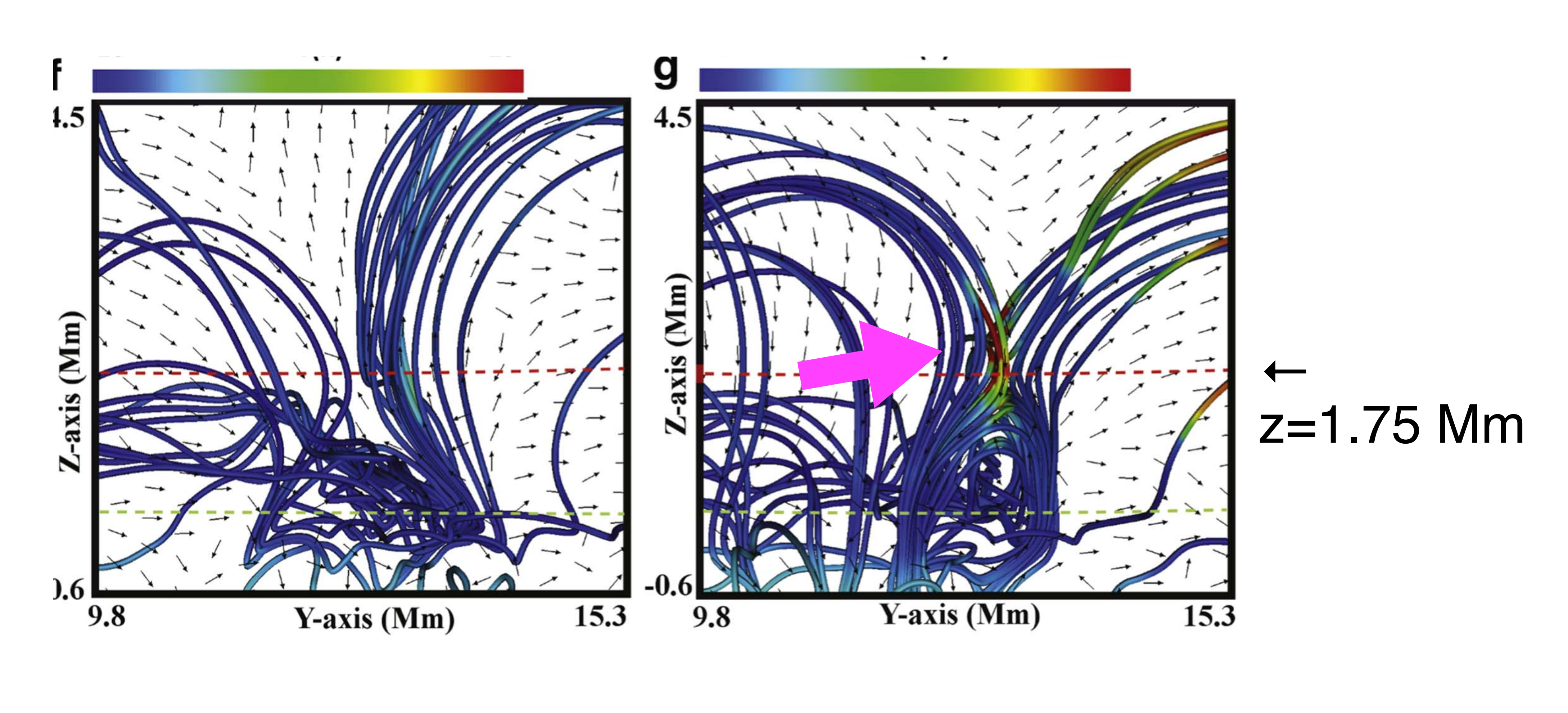


- Small flares
  - Reconnection in higher altitude (~1.8 Mm for this event)
  - Upper chrom heated to $10^6$ K
  - Brightening seen in Si IV as well as in Hα core

# 2. UV Bursts in EFRs

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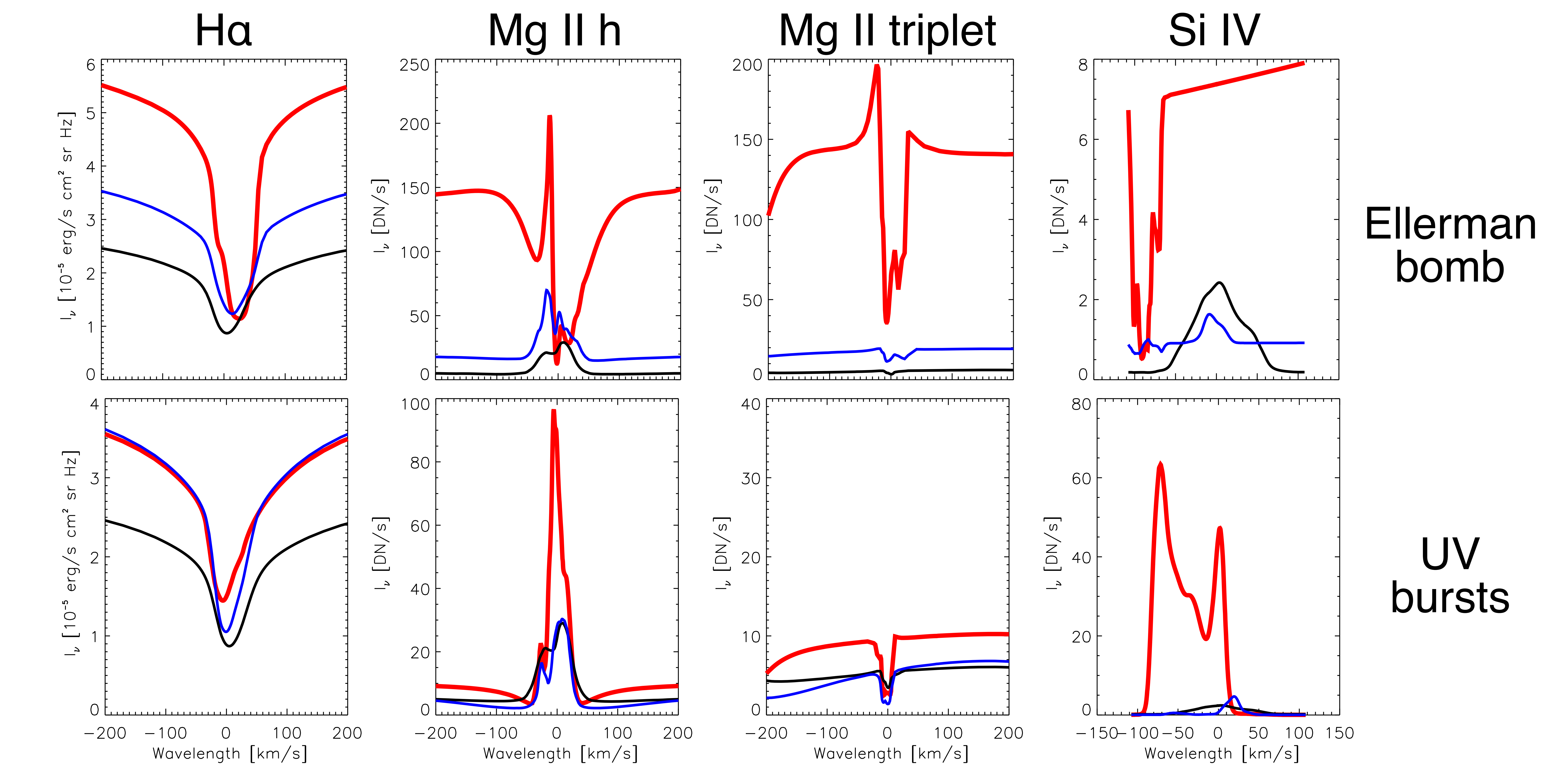

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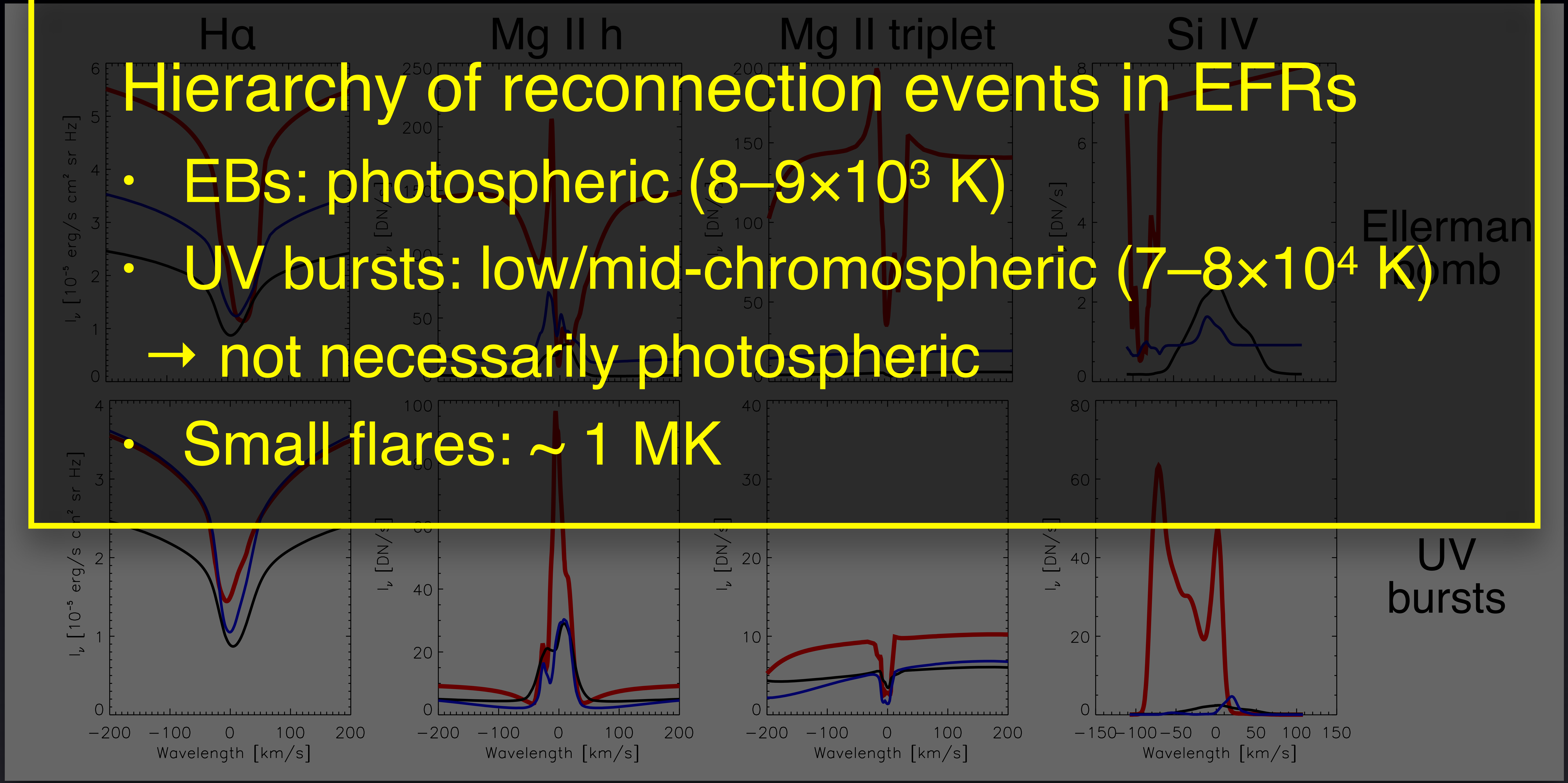


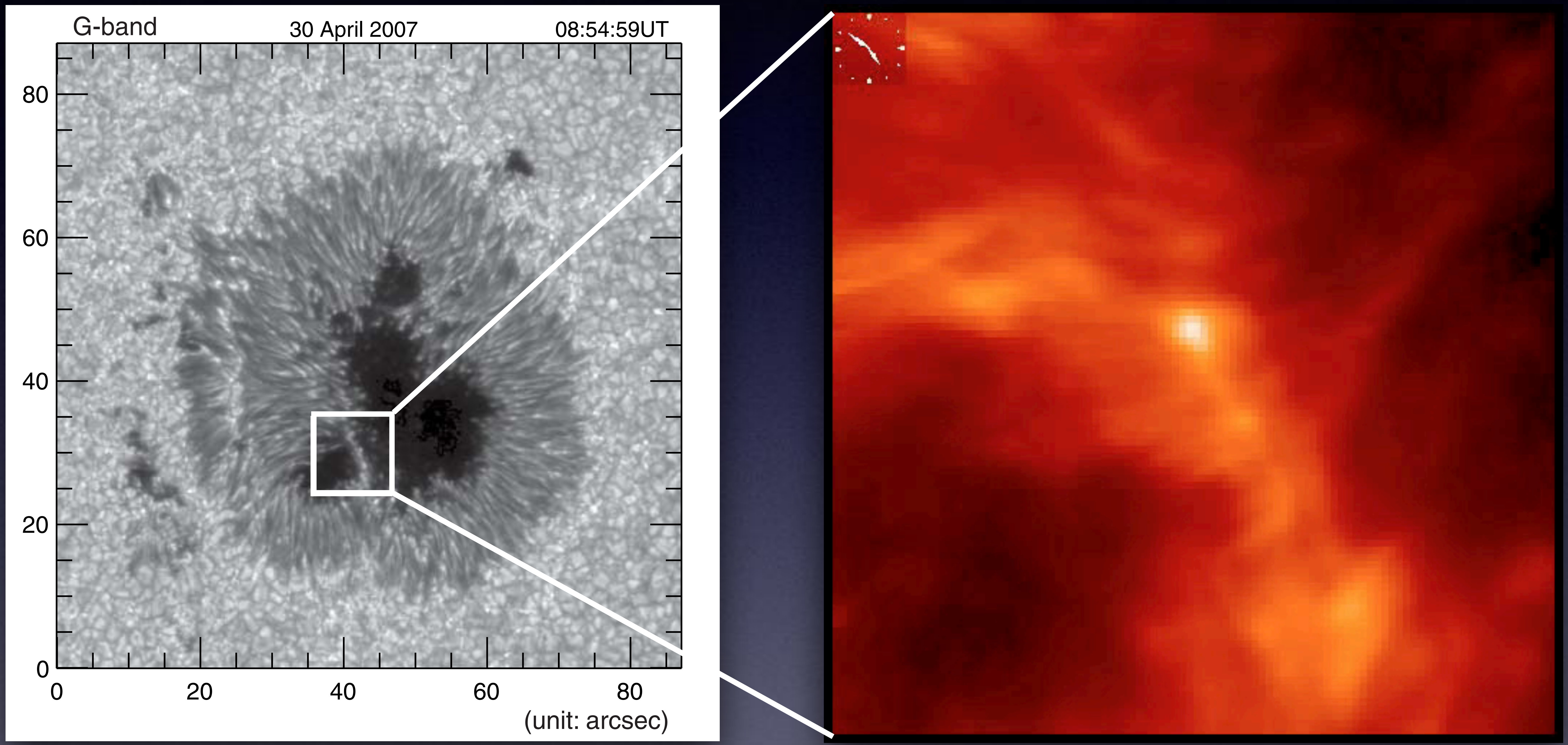

## Hierarchy of reconnection events in EFRs

- EBs: photospheric (8–9×$10^3$ K)
- UV bursts: low/mid-chromospheric (7–8×$10^4$ K)
  → not necessarily photospheric
- Small flares: ~ 1 MK

# 3. Dynamics in Light Bridges

- Variety of activity phenomena seen in LBs

Hinode/SOT G-band and Ca II H




[Shimizu et al. 2009]

- EBs and surge ejections in Hα [Roy 1973; Asai+ 2001]
- Repetitive jets in Ca II H [Shimizu+ 2009]
- UV brightening [Berger & Berdyugina 2003]
- Vigorous convection [Sobotka+ 1994, Lagg+ 2014]

# 3. Dynamics in Light Bridges

- IRIS reveals dynamics of LBs
  - Tian et al. 2014 ApJL
  - Yurchyshyn et al. 2015 ApJ
  - Yang et al. 2015 ApJL
  - Bharti 2015 MNRAS
  - Toriumi et al. 2015 ApJ
  - Straus et al. 2015 A&A
  - Chitta et al. 2016 A&A
  - Hou et al. 2016 A&A
  - Hou et al. 2016 ApJL
  - Yang et al. 2016 ApJL
  - Zhang et al. 2017 ApJ
  - Yang et al. 2017 ApJL
  - Hou et al. 2017 ApJL
  - Razaei et al. 2018 A&A
  - Tian et al. 2018 ApJ

<ADS search: “IRIS” + “light bridge” in abstract>

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  - Tian et al. 2018 ApJ

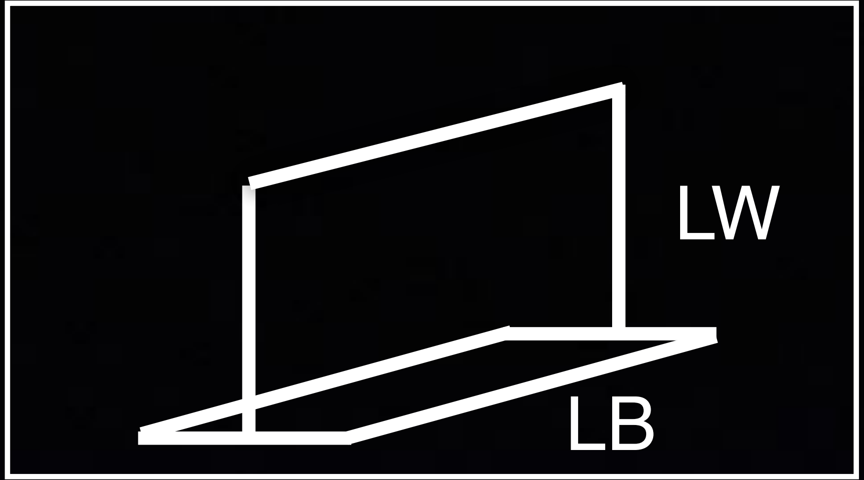
Oscillating “Light Walls” by leaked p-mode waves/shocks

Reconnection jets caused by magneto-convective evolution

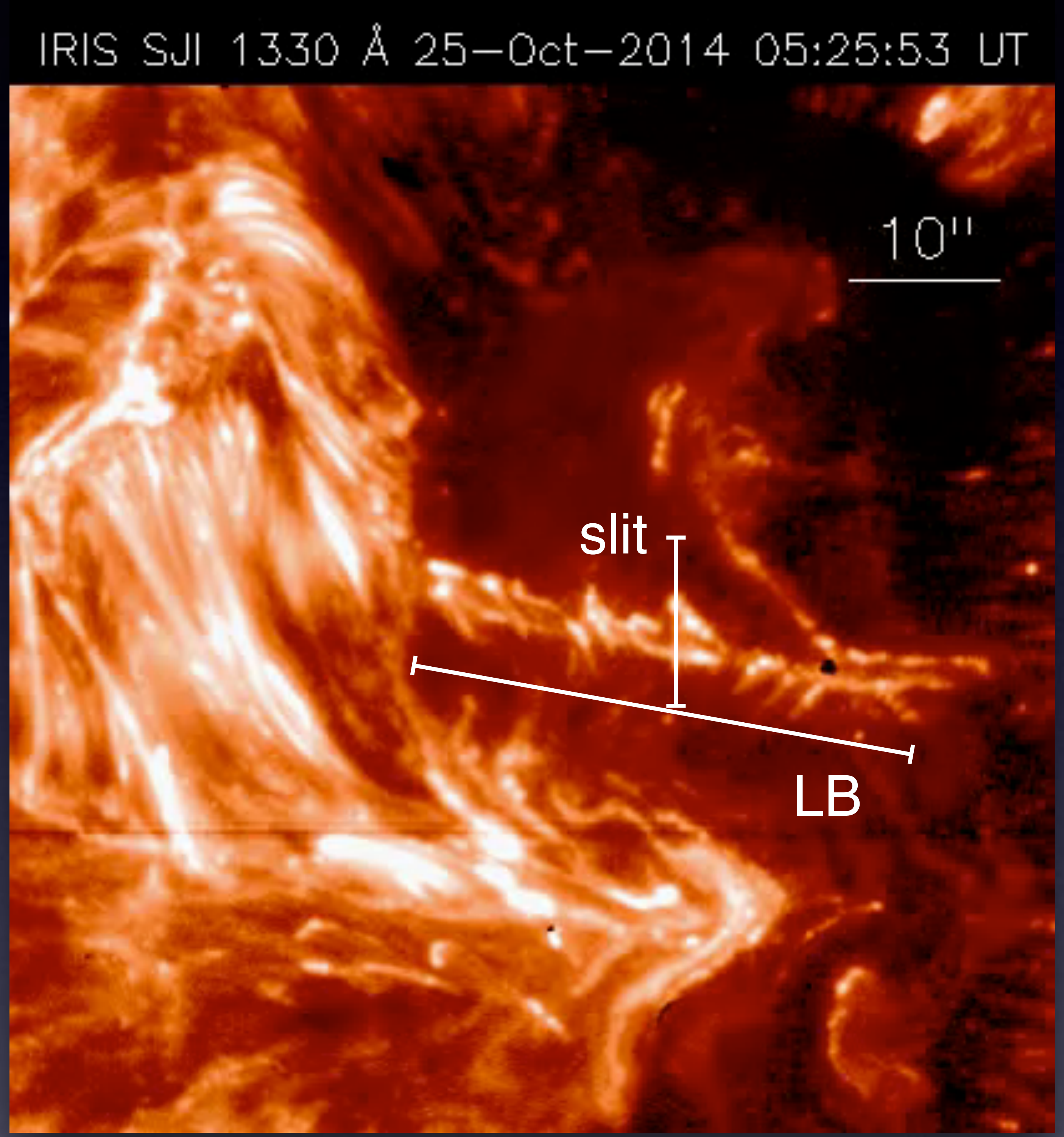
Both types may co-exist

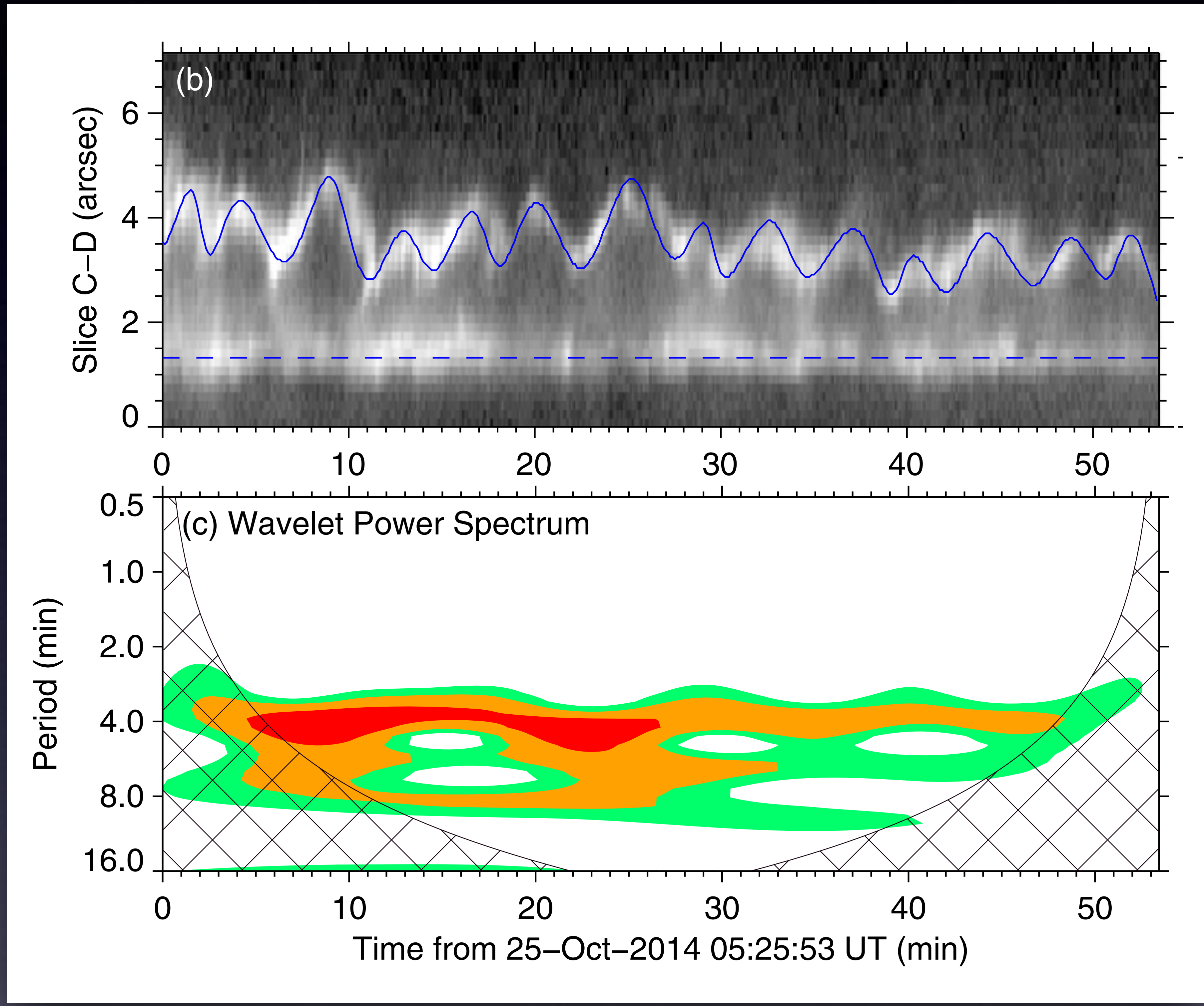
<ADS search: “IRIS” + “light bridge” in abstract>

# 3. Dynamics in Light Bridges




- Oscillating "Light Walls"



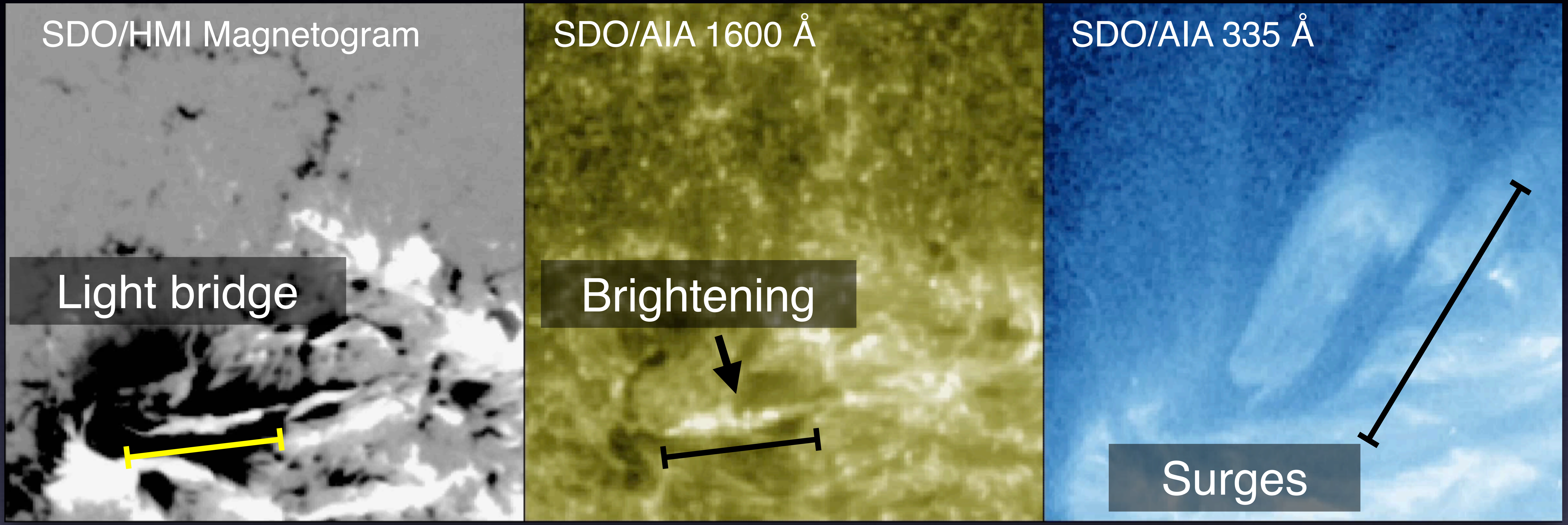

[Yang et al. 2015]

- Oscillating chrom jets rooted in LBs → "light walls"
- Height: 3.6 Mm, Amplitude: 0.9 Mm, Velocity: 15.4 km $s^{-1}$
- Period: 3.9 min → Leakage of p-mode from below photosphere

[see also Hou+ 2016a, Hou+ 2016b, Yang+ 2016, Yang+ 2017]

# 3. Dynamics in Light Bridges

- UV bursts and extended jets



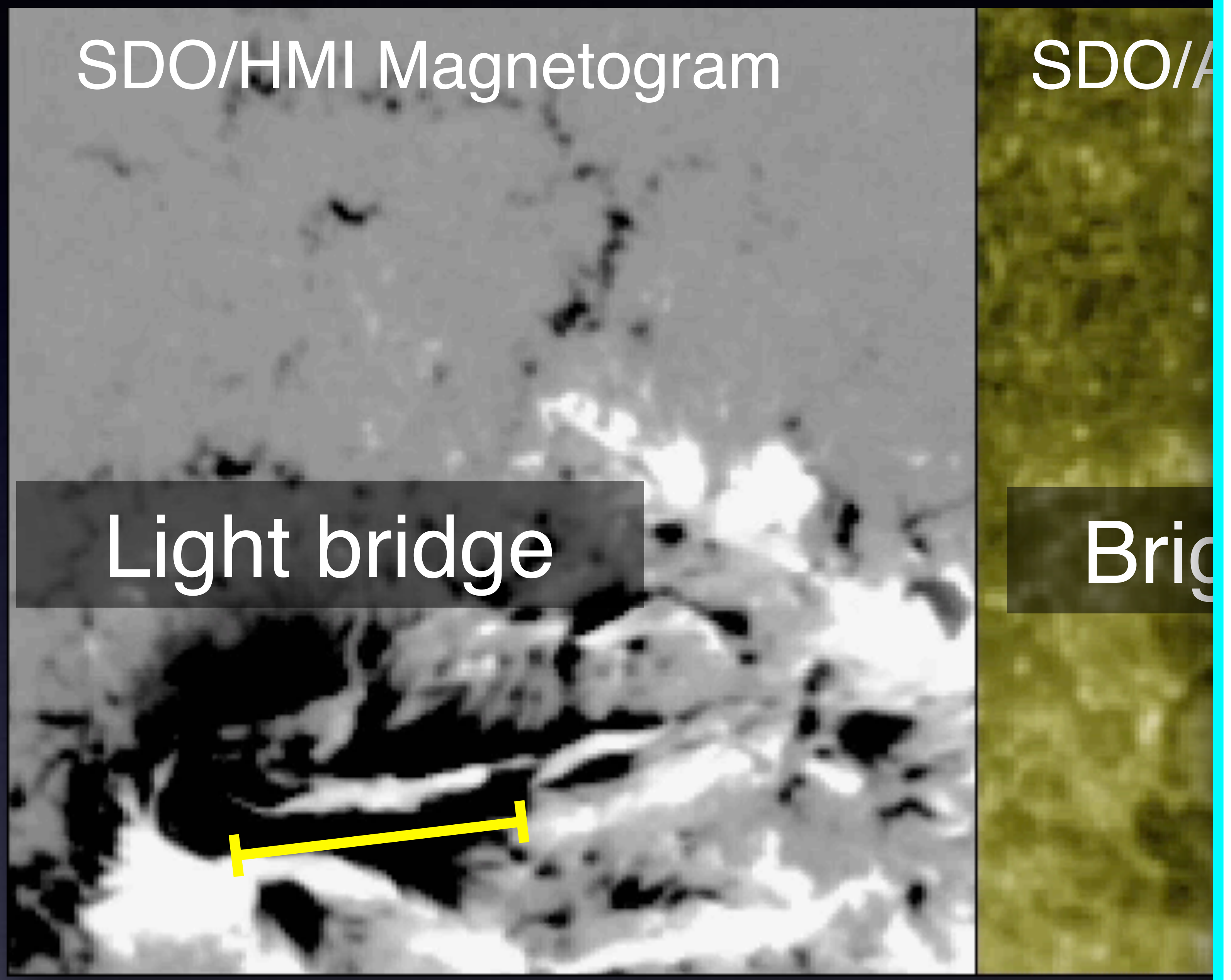

[Toriumi et al. 2015a]

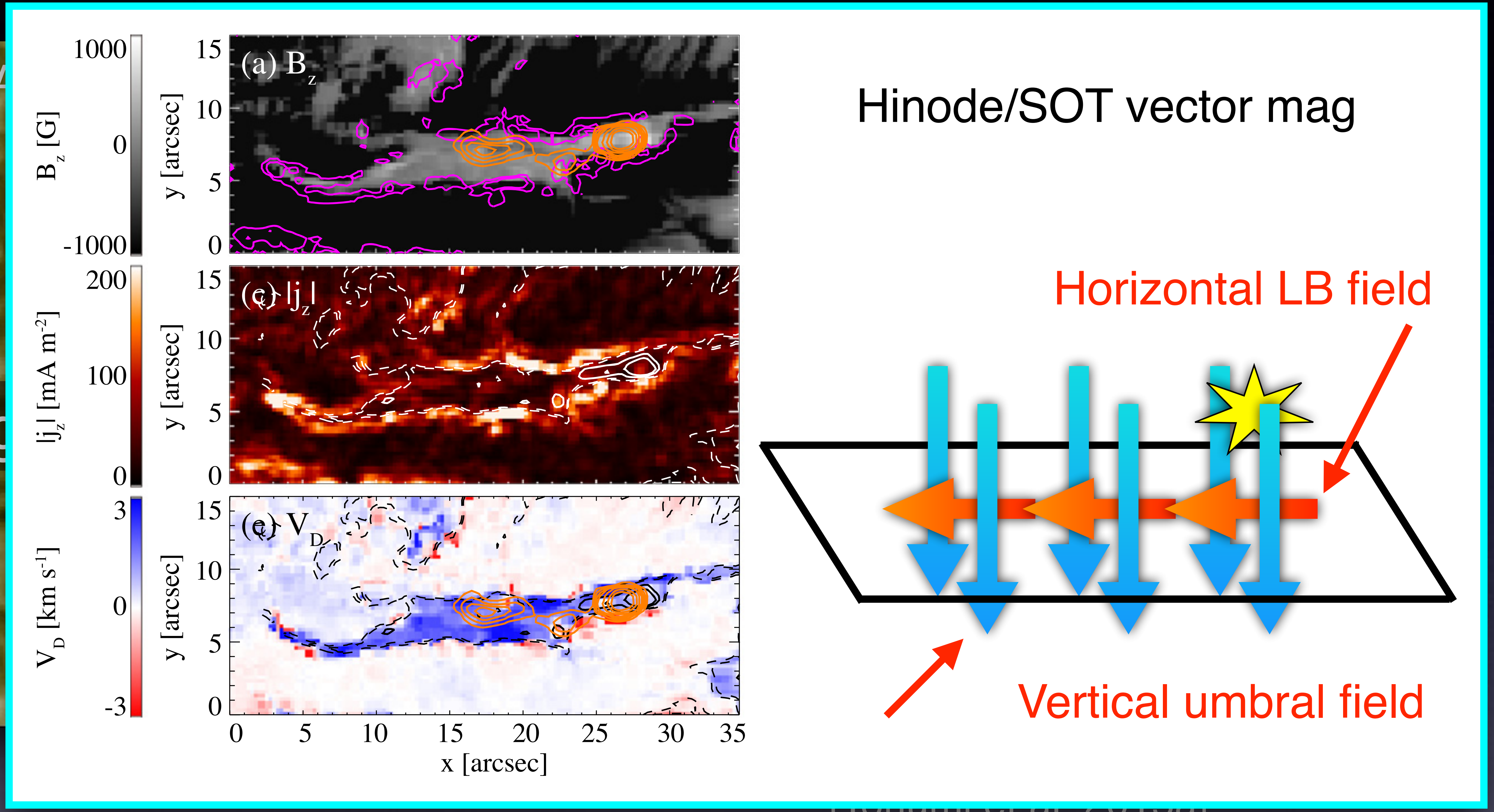
- IRIS + Hinode/SOT + SDO + simulation
- Brightening shows “IRIS bomb” spectra
- Height: ≤ 35 Mm (plane-of-sky; parabolic), Period: 10-20 min
- Simulation shows magneto-convective evolution (flux emergence) in LBs

→ Reconnection jets driven by convection

# 3. Dynamics in Light Bridges

- UV bursts and extended jets

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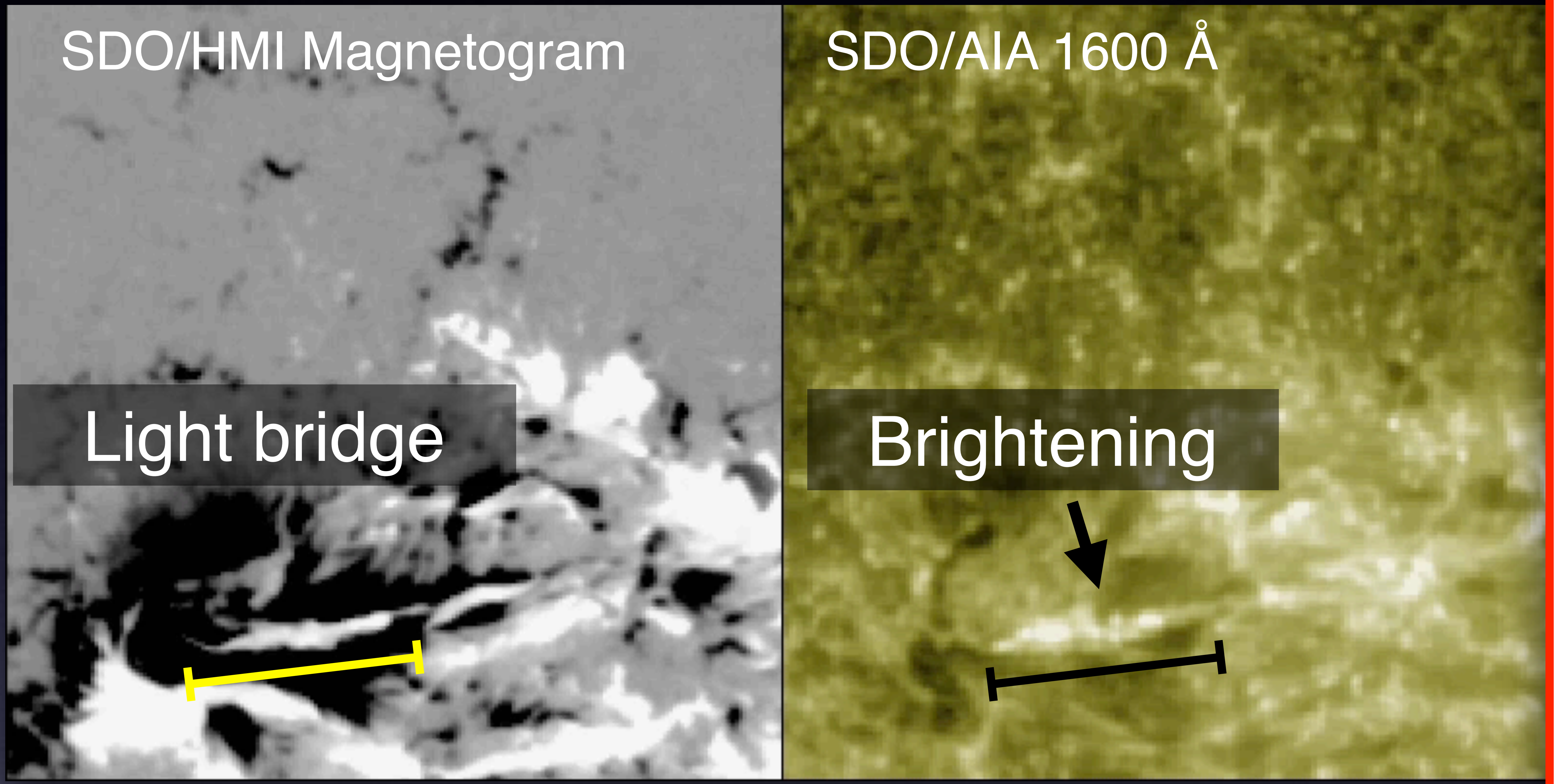


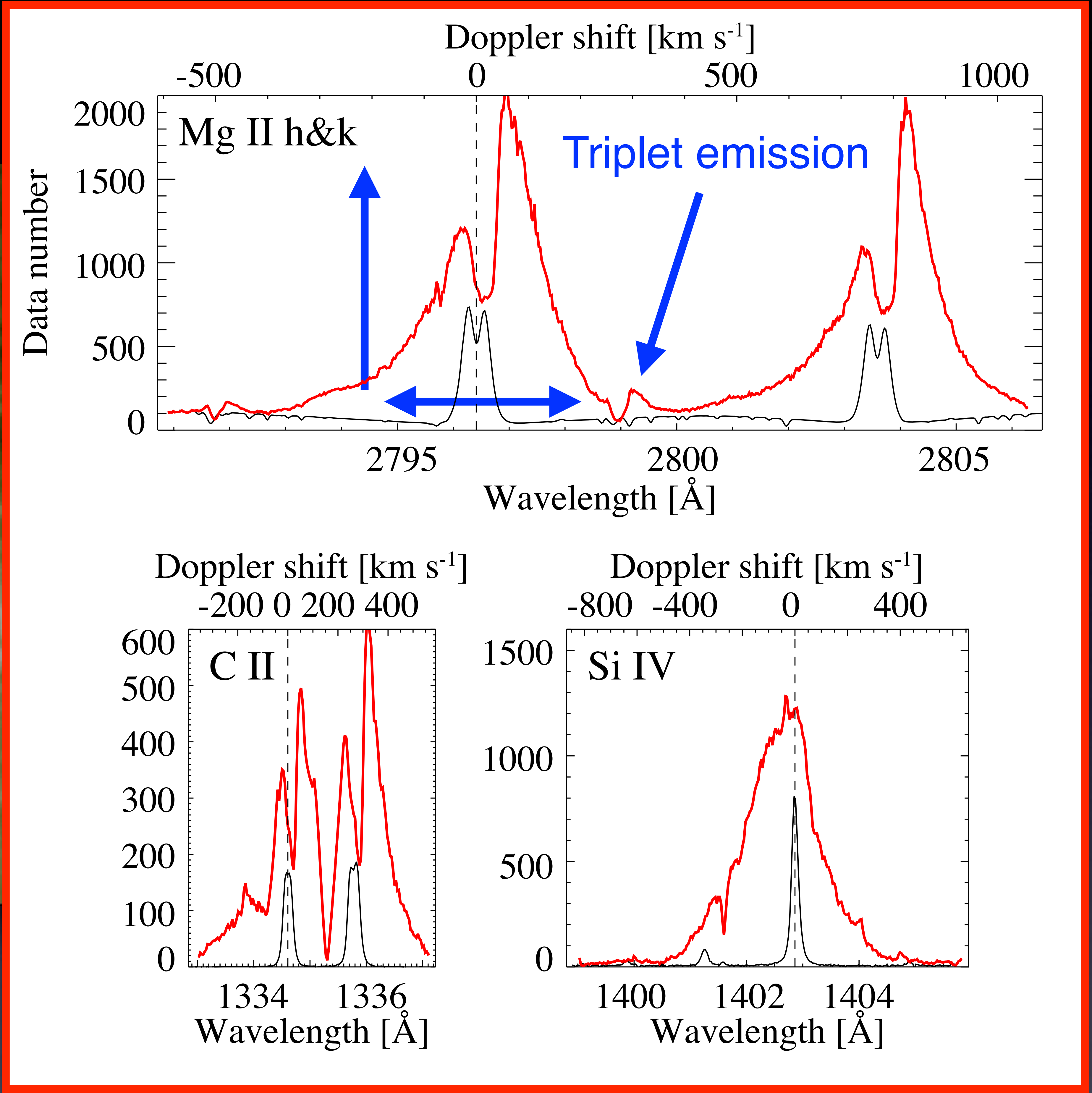


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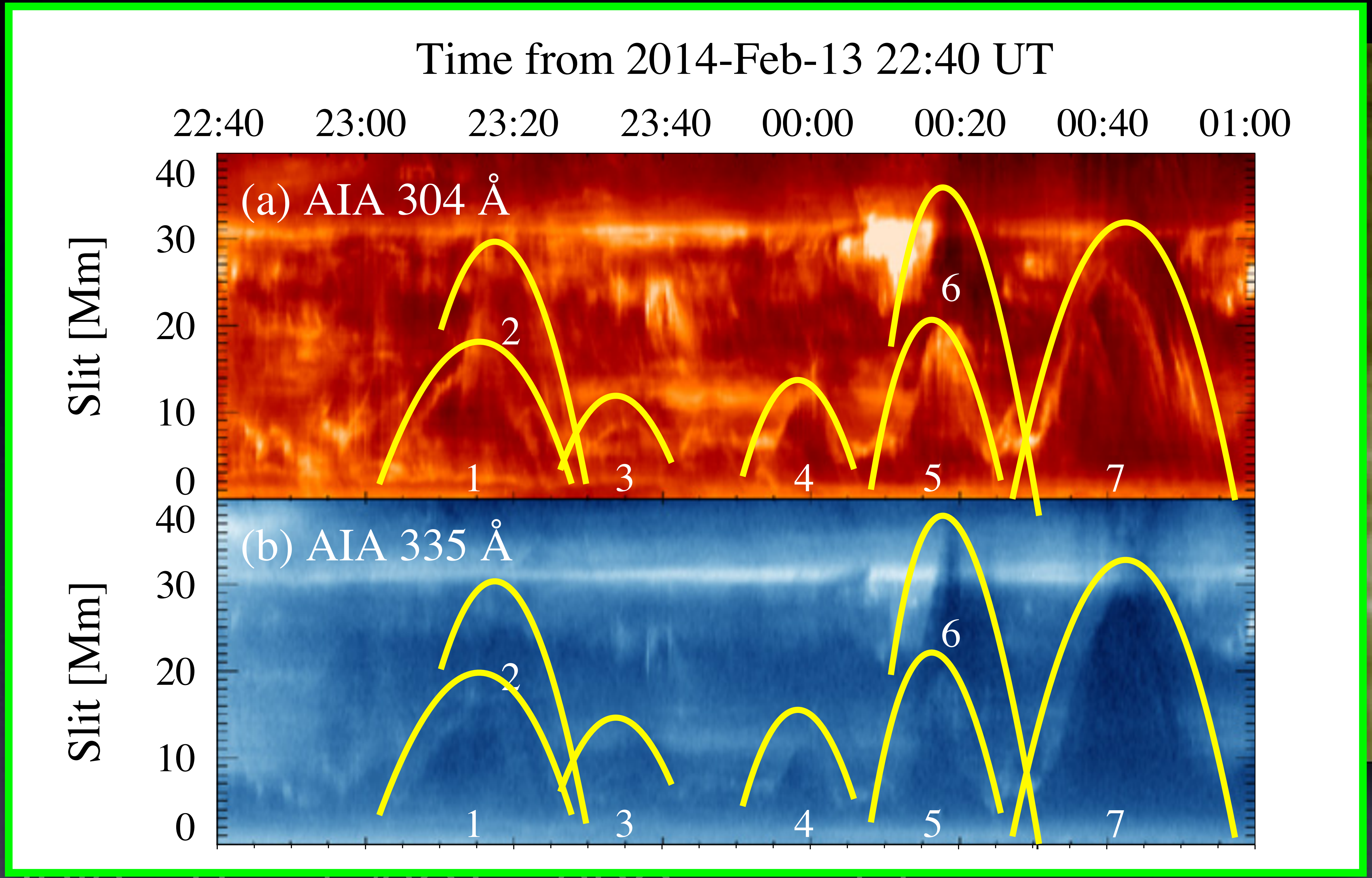


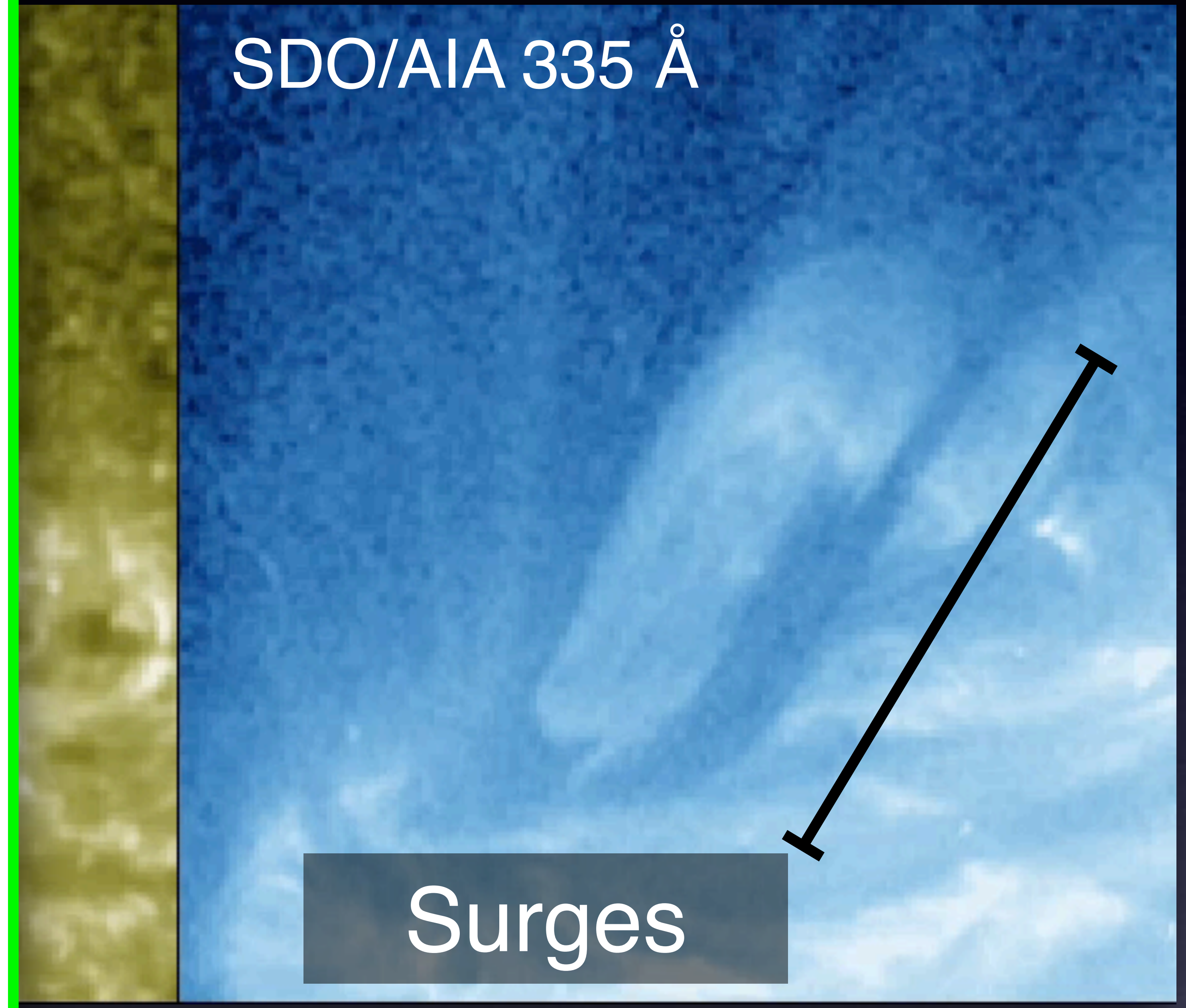


[Toriumi et al. 2015a]

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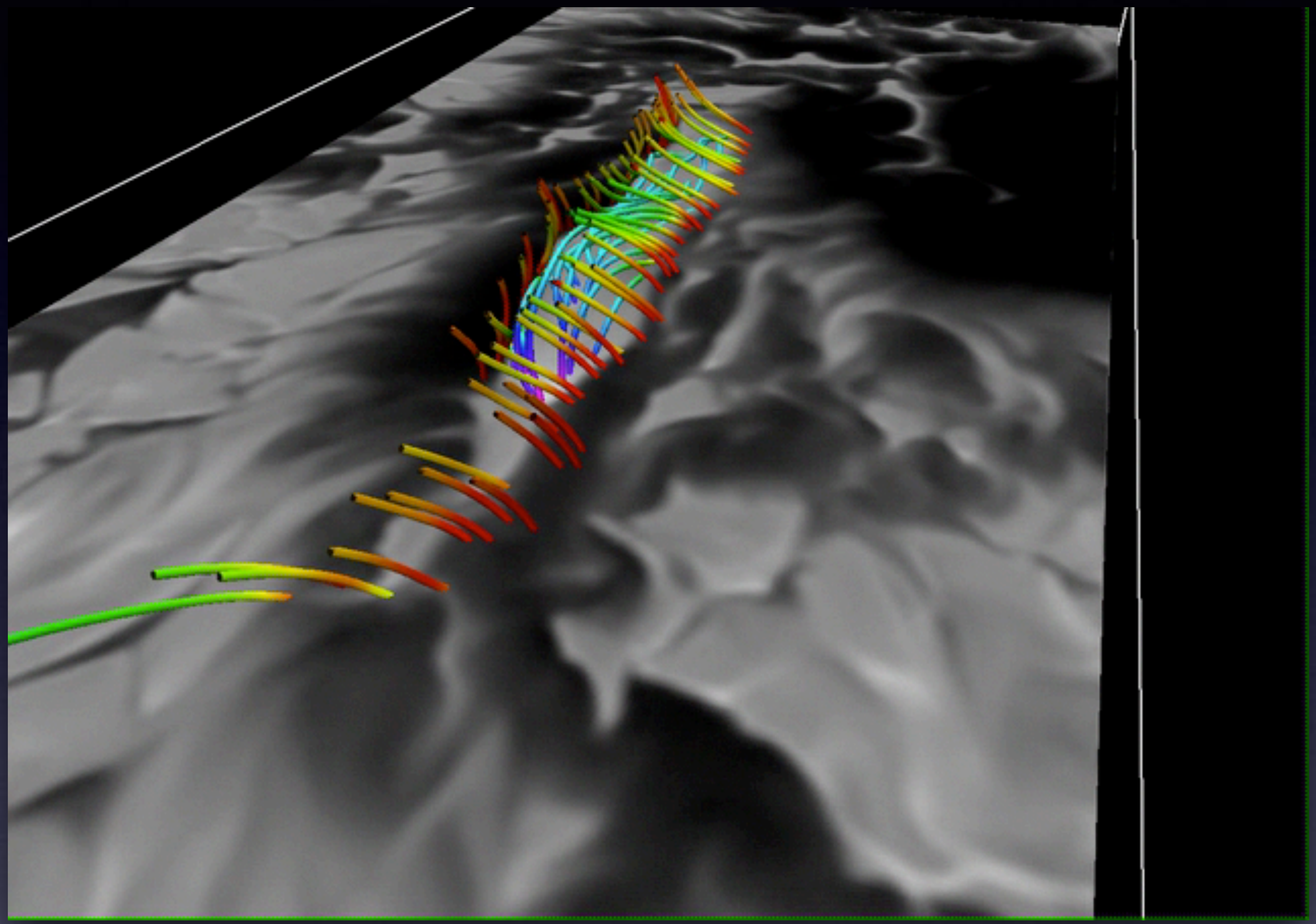
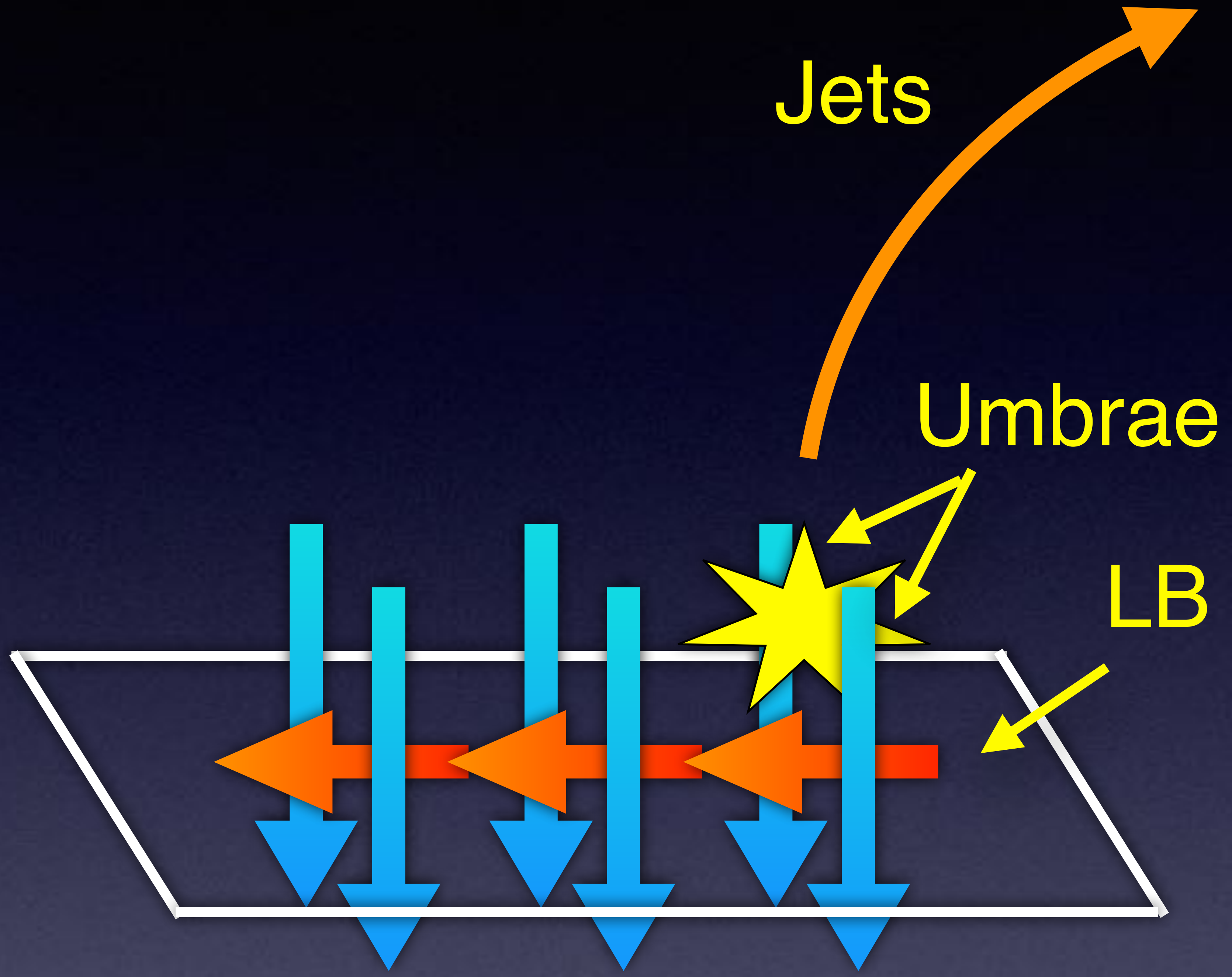
# 3. Dynamics in Light Bridges

- UV bursts and extended jets



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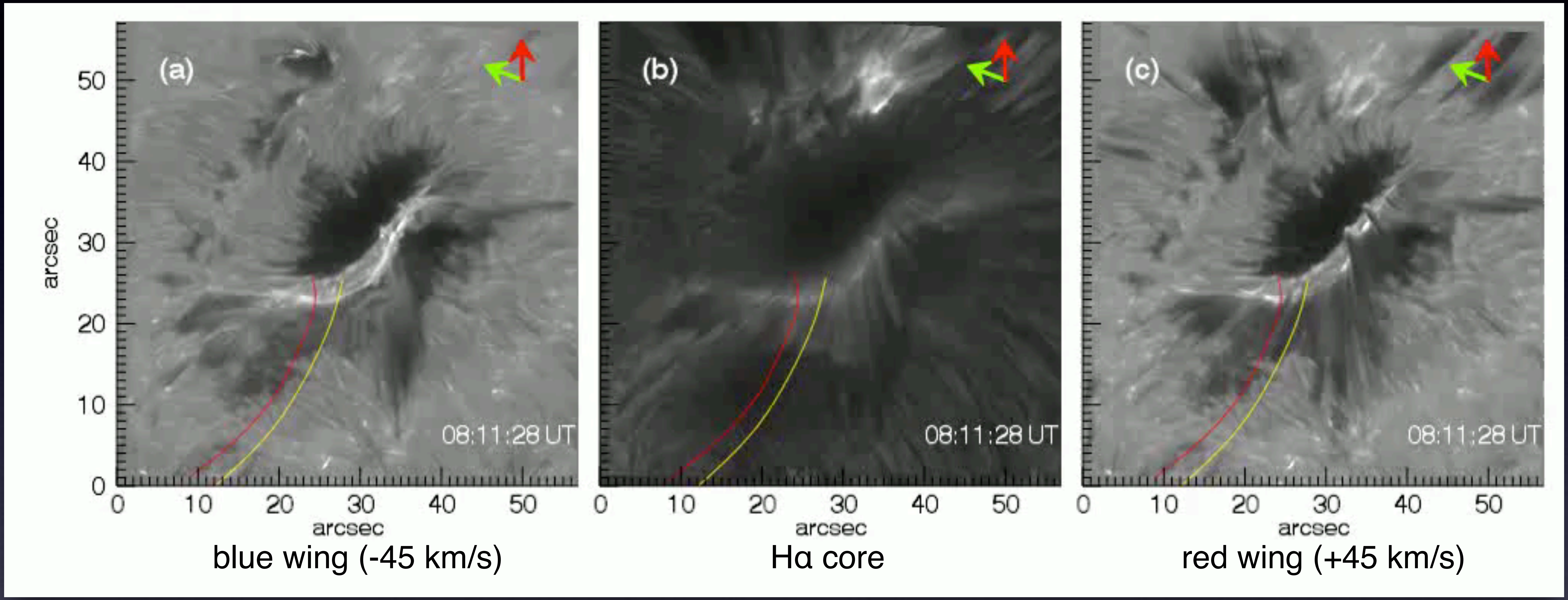
# 3. Dynamics in Light Bridges

- UV bursts and extended jets



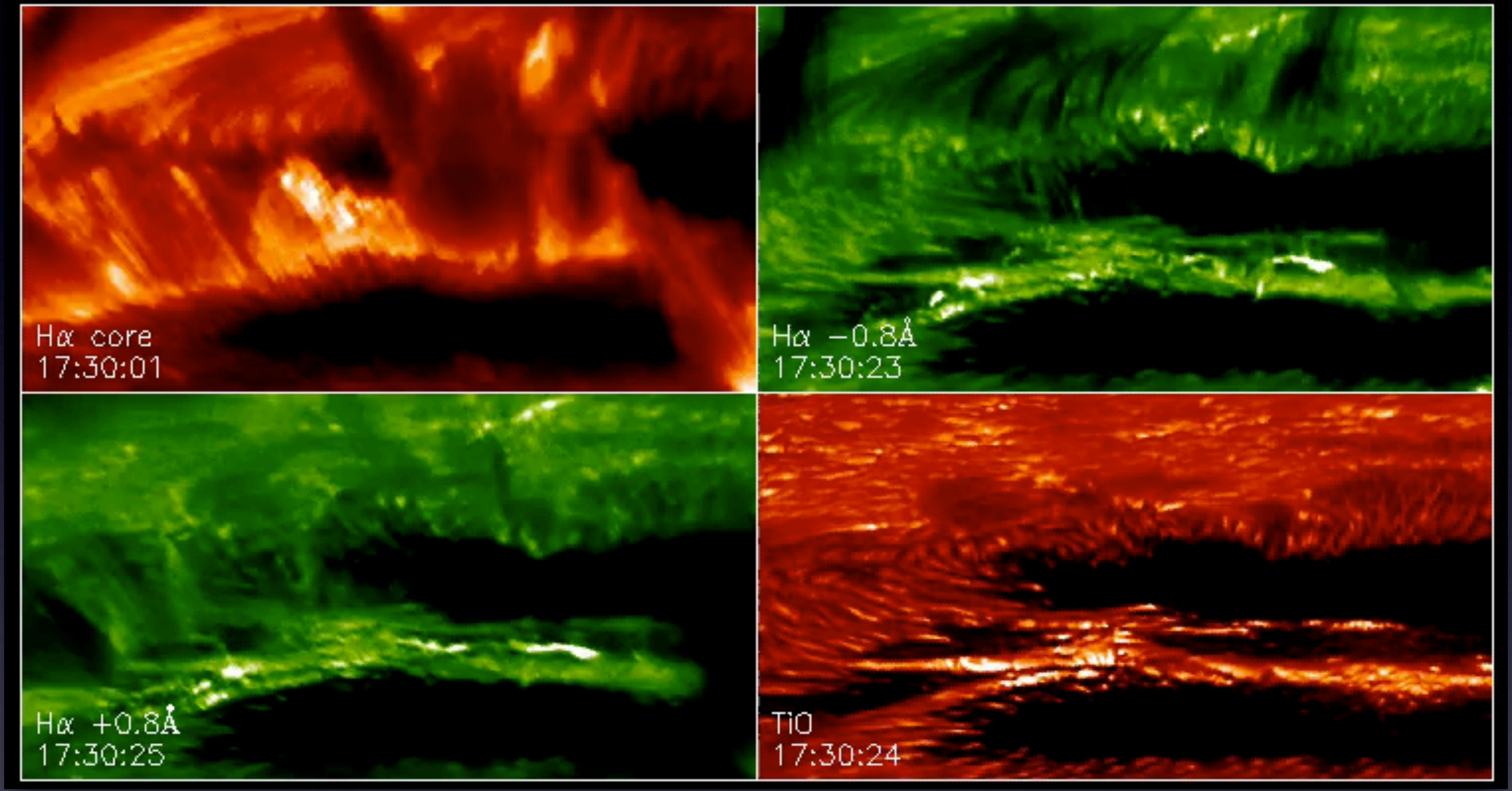

[Robustini et al. 2016]

- SST/CRISP + Hinode/SOT/SP
- Repeated fan-shaped jets of up to 40 Mm with ~100 km $s^{-1}$, following chrom brightening
- Horizontal field trapped by vertical field

→ Reconnection is the driver

# 3. Dynamics in Light Bridges

- Reconnection-driven jets? Acoustic shocks?




[Tian et al. 2018]

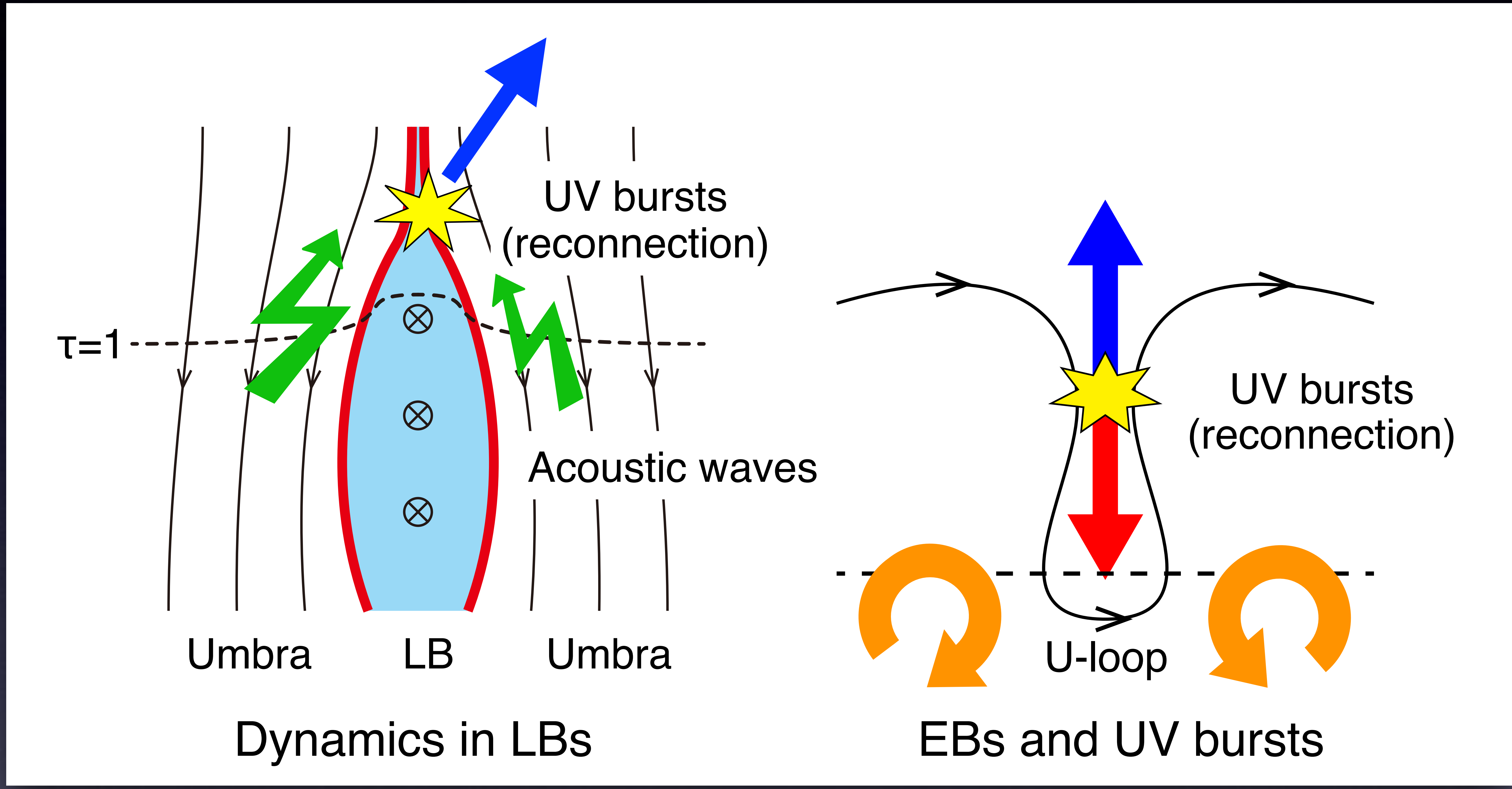
- BBSO/GST + IRIS show two types of jets
  - Persistent “light walls” : 0.5–4 Mm, 10–30 km $s^{-1}$
  - Impulsive ejections: 10 Mm or more, at selected location

→ The two types may co-exist.

[see also Zhang+ 2017 and Hou+ 2017]

# 4. Summary and Discussion

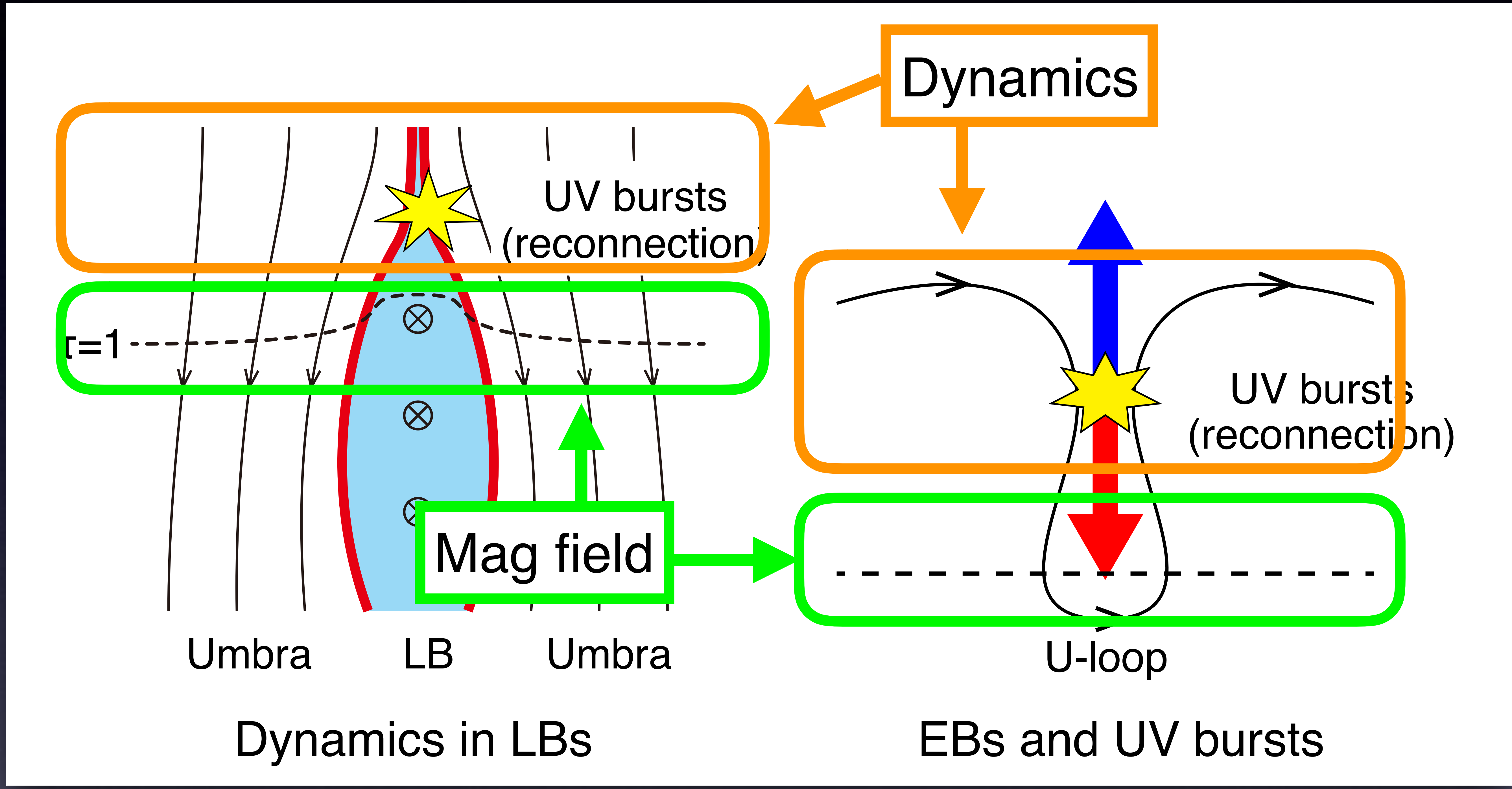
- UV dynamics and magnetic evolution




- LB jets may have two origins; impulsive reconnection-driven jets and steady acoustic wave-driven jets
- EBs and IBs are reconnection events in EFRs, coupled with convection. Difference may originate from their altitudes and mag circumstances

# 4. Summary and Discussion

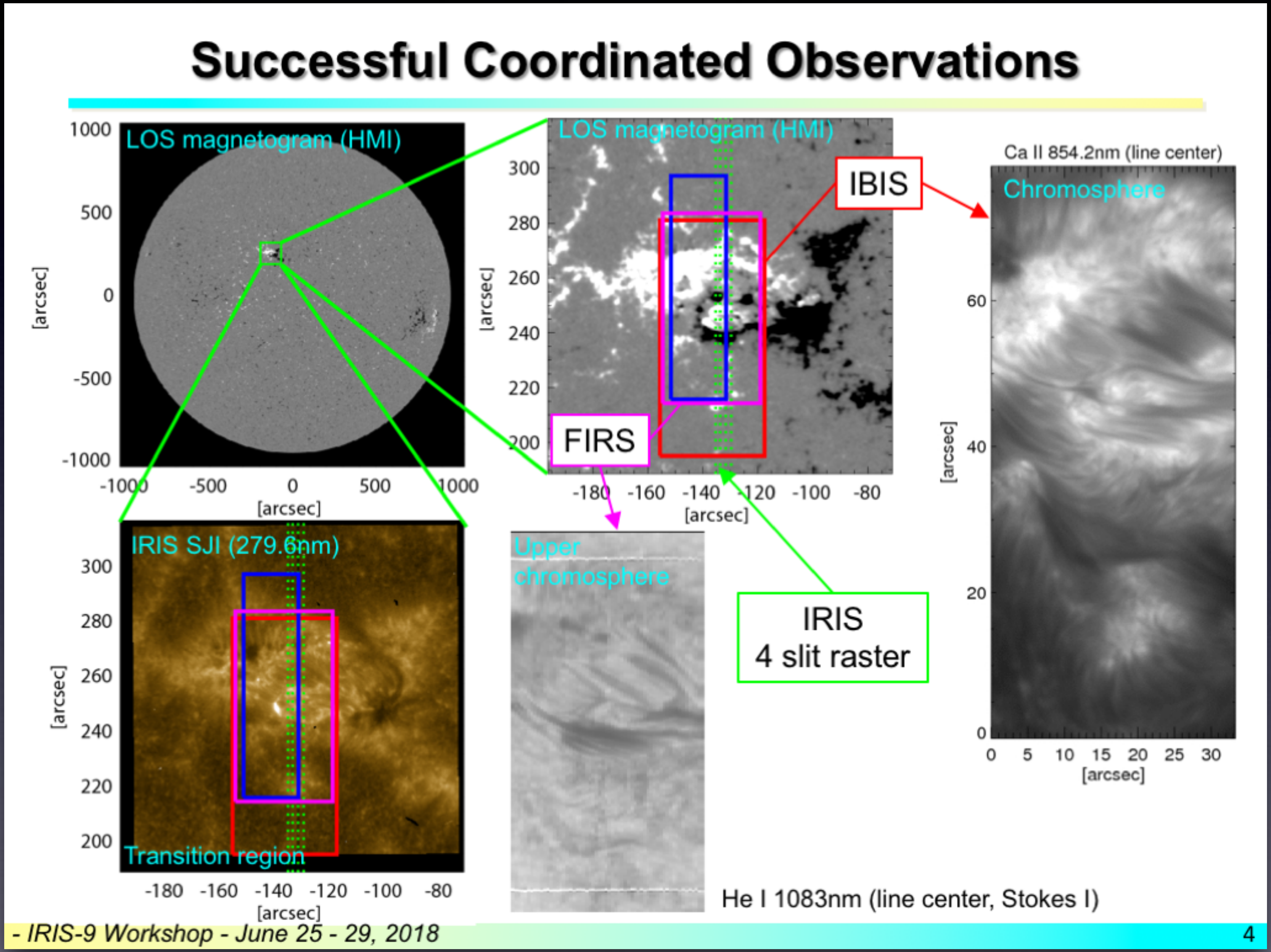
- UV dynamics and magnetic evolution



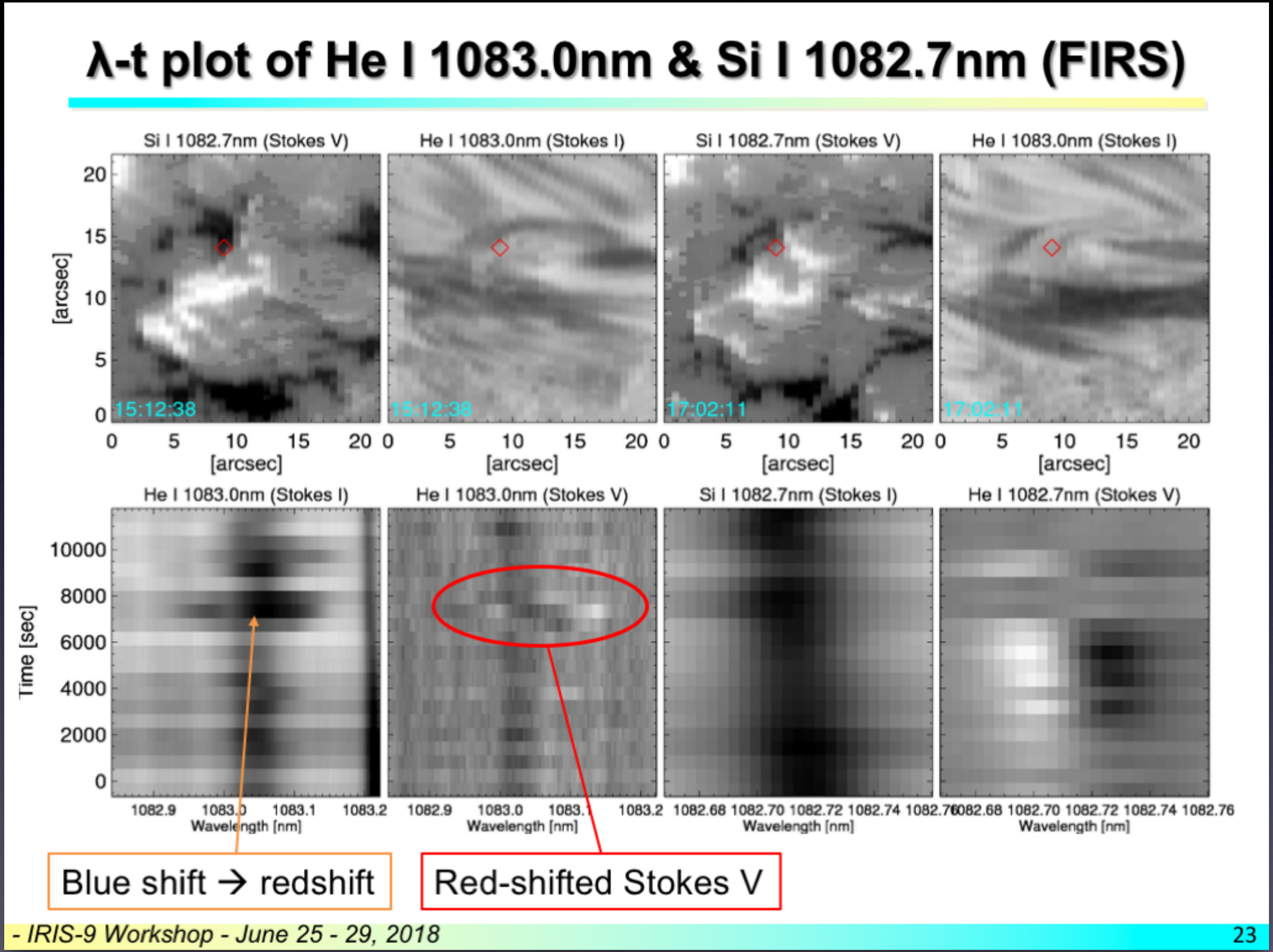


- LB jets may have two origins; impulsive reconnection-driven jets and steady acoustic wave-driven jets
- EBs and IBs are reconnection events in EFRs, coupled with convection. Difference may originate from their altitudes and mag circumstances
- But the exact location of mag reconnection is not covered yet…

# 4. Summary and Discussion

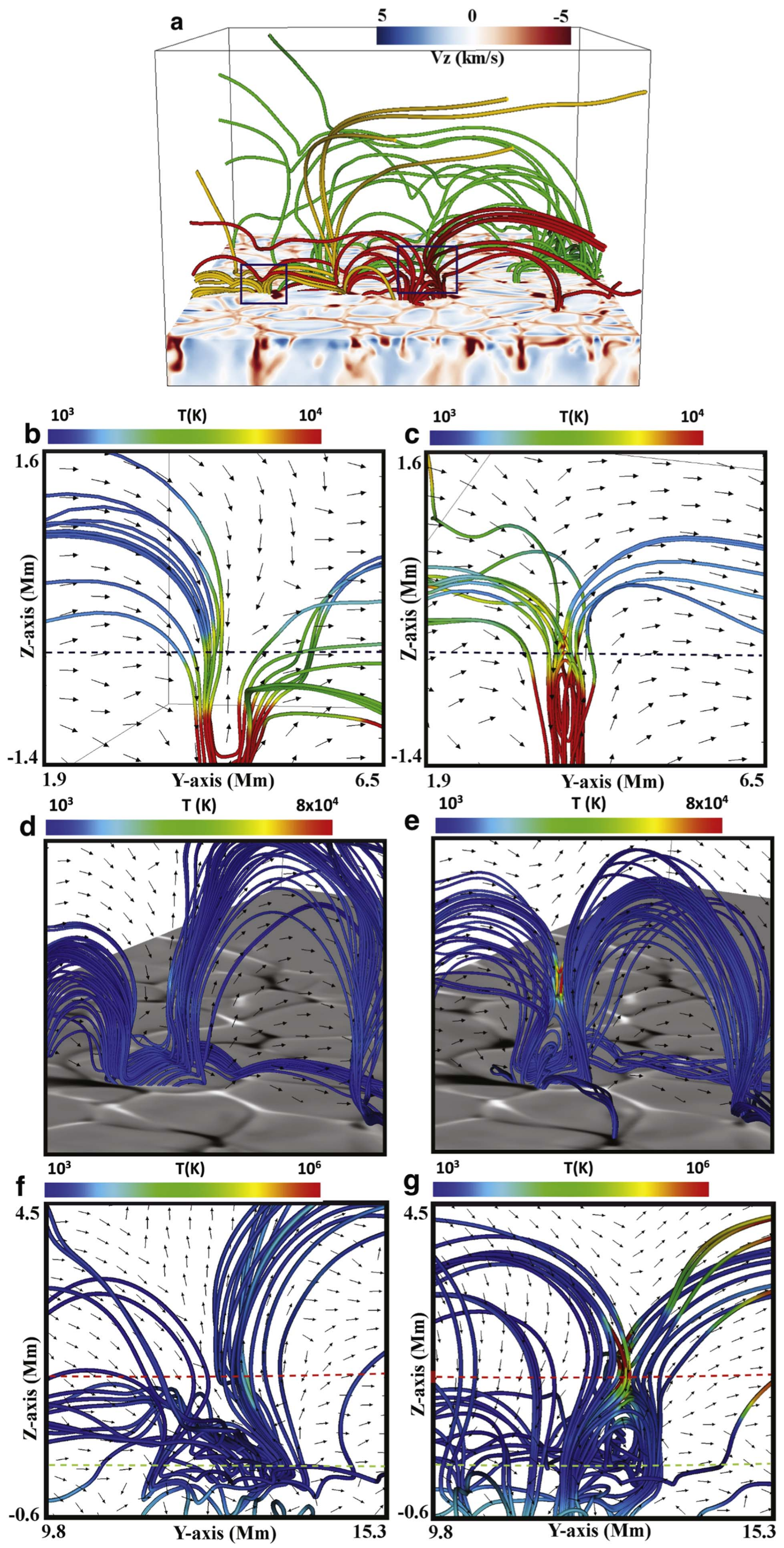


# 4. Summary and Discussion



# 4. Summary and Discussion

- Multi-temperature obs by Solar-C_EUVST

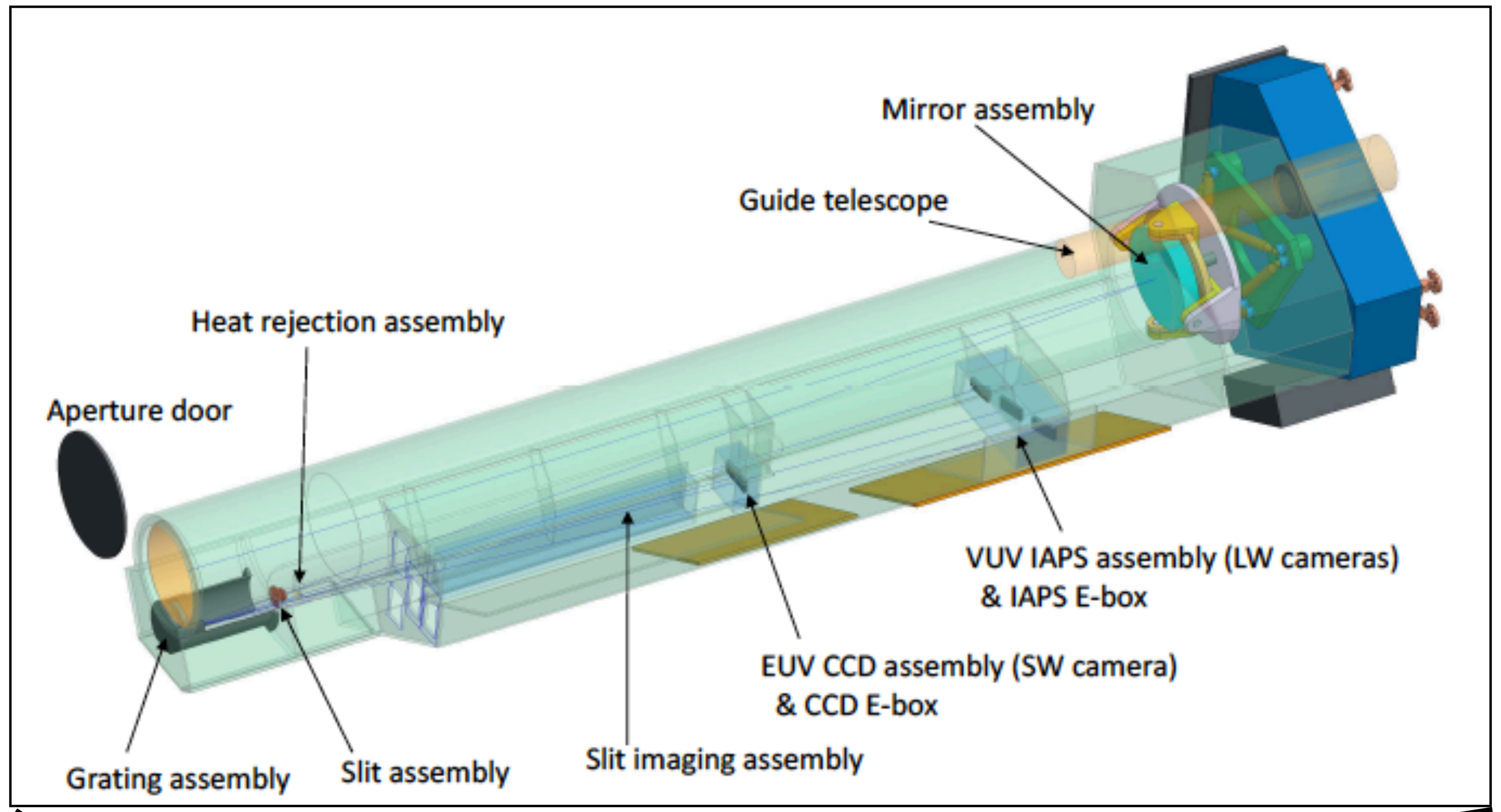


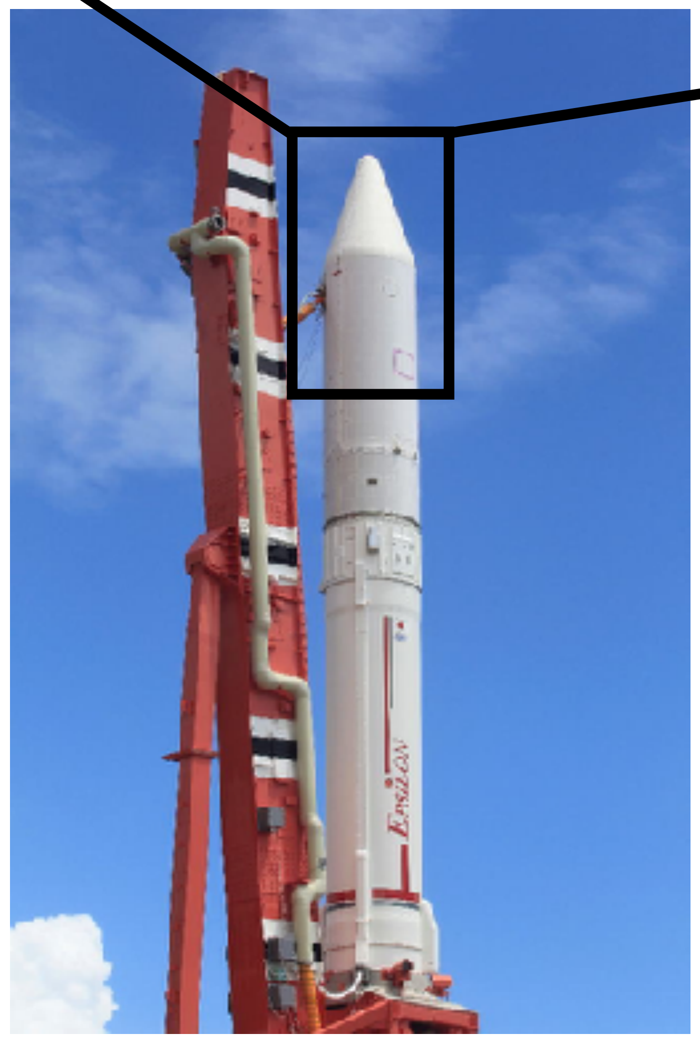

EBs
8000-9000K

UV bursts
7–8×$10^4$ K

Small flares
~$10^6$ K

[Hansteen et al. 2017]



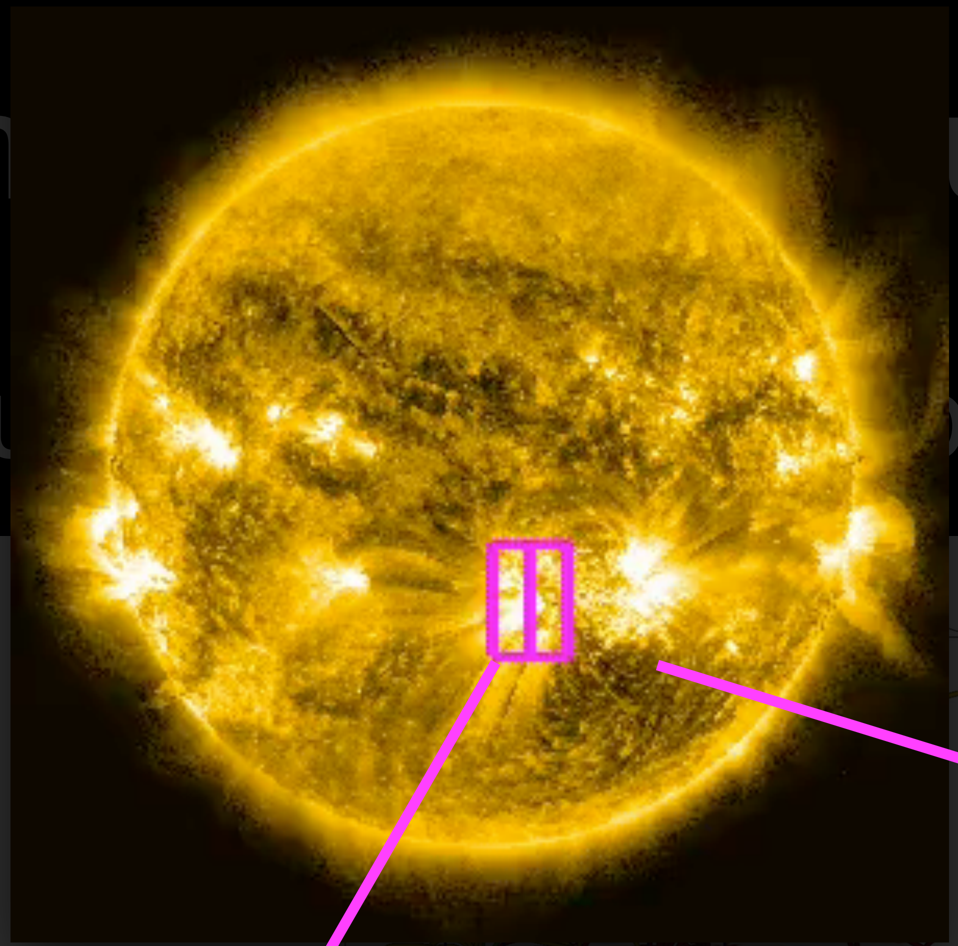



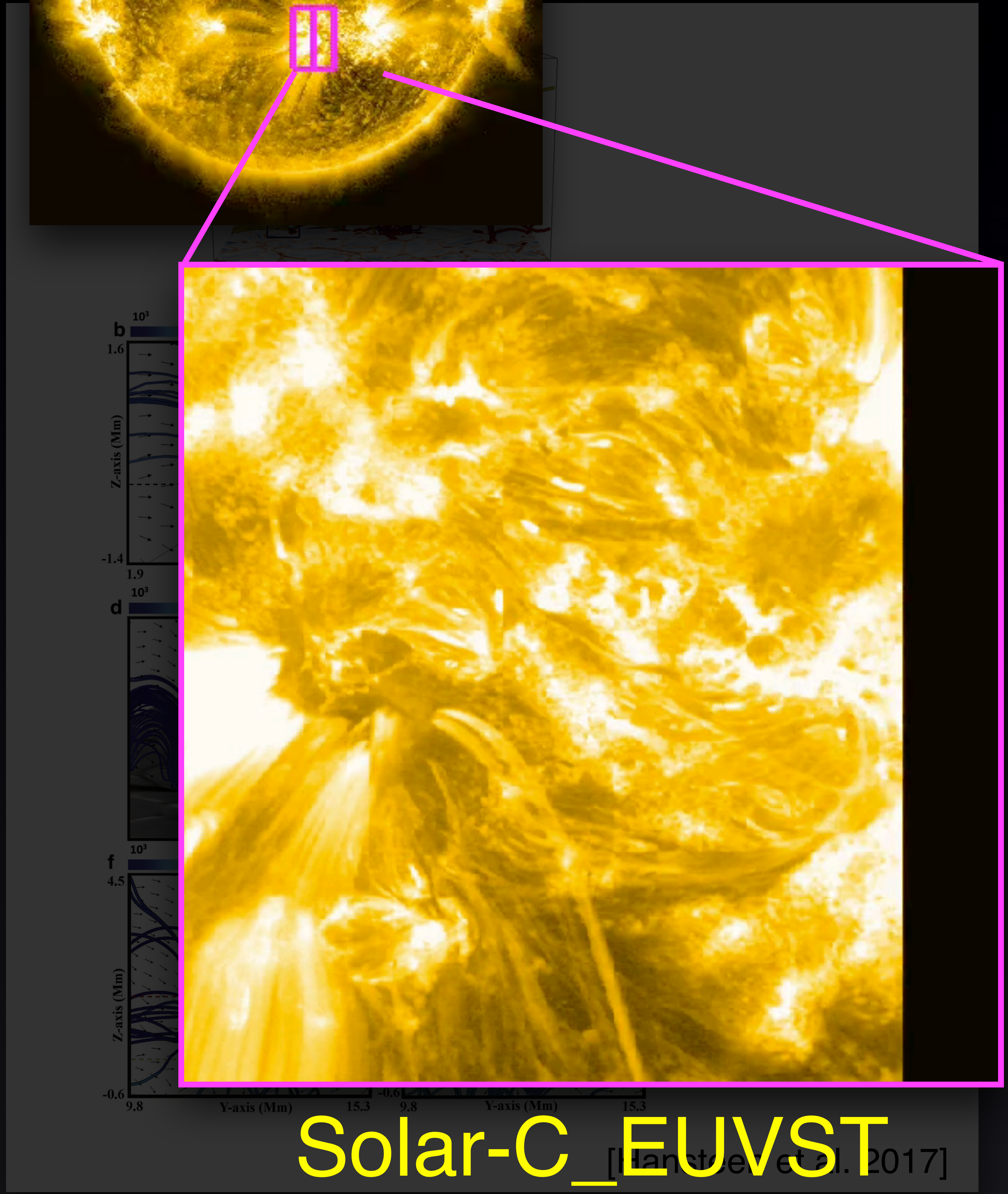
- Wide temperature coverage: **0.01—20 MK**
- High spatial resolution: **0.4”**
- High temporal resolution: exp time 0.1—20 s
- Launch: mid-2020s

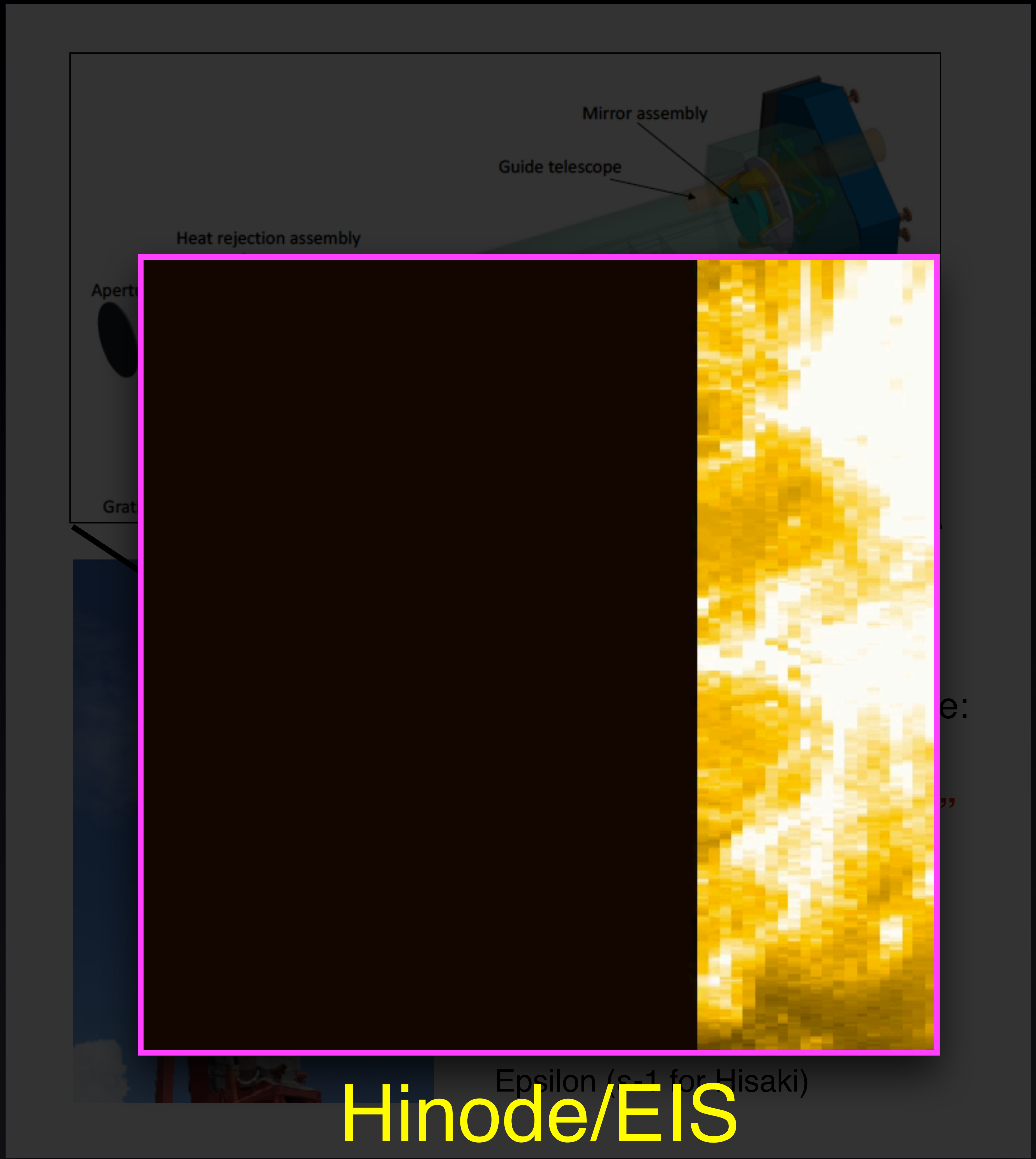
Epsilon (ε-1 for Hisaki)

# 4. Summ… …ussion

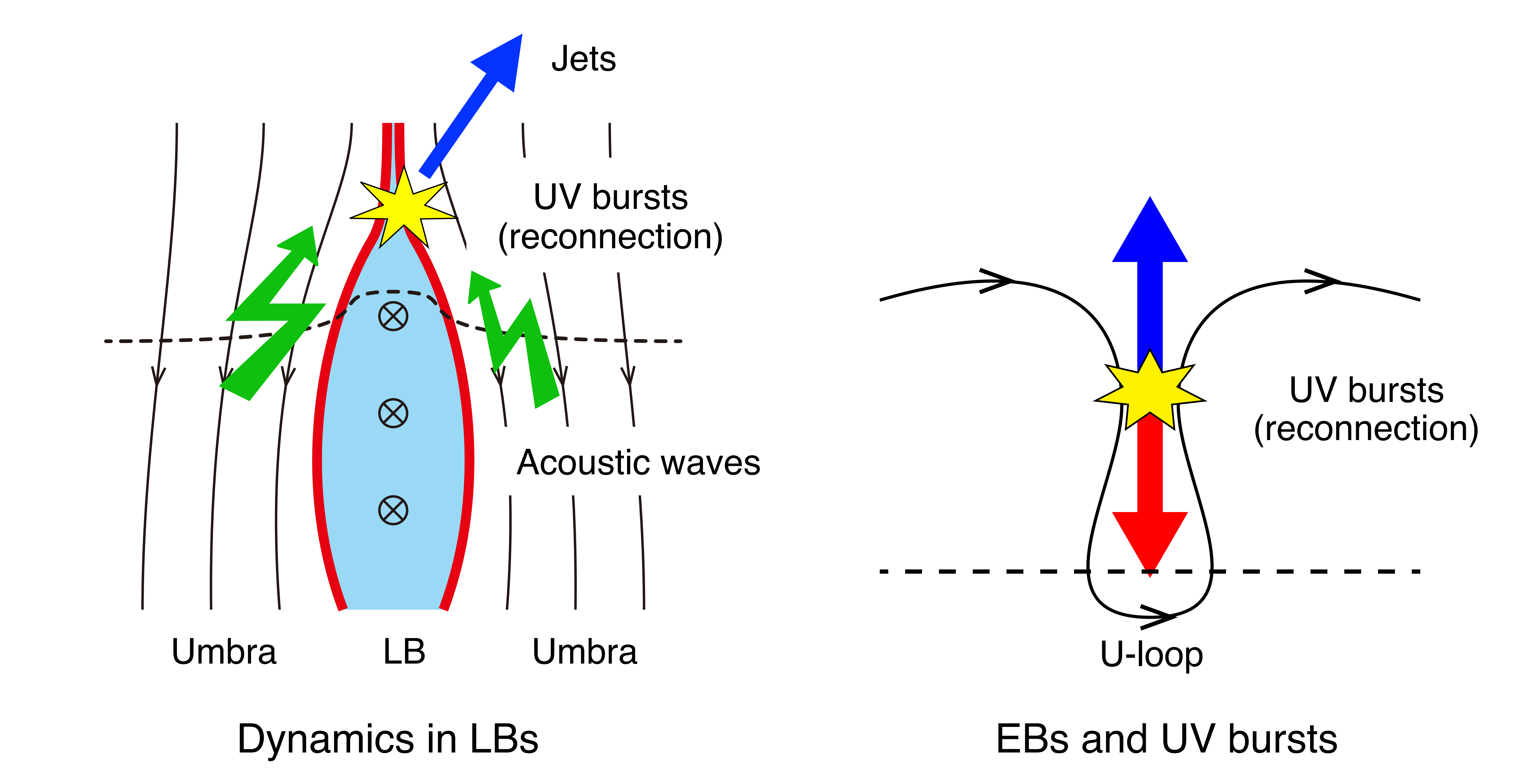
- Mu… …s by Solar-C_EUVST





# 5. Conclusion

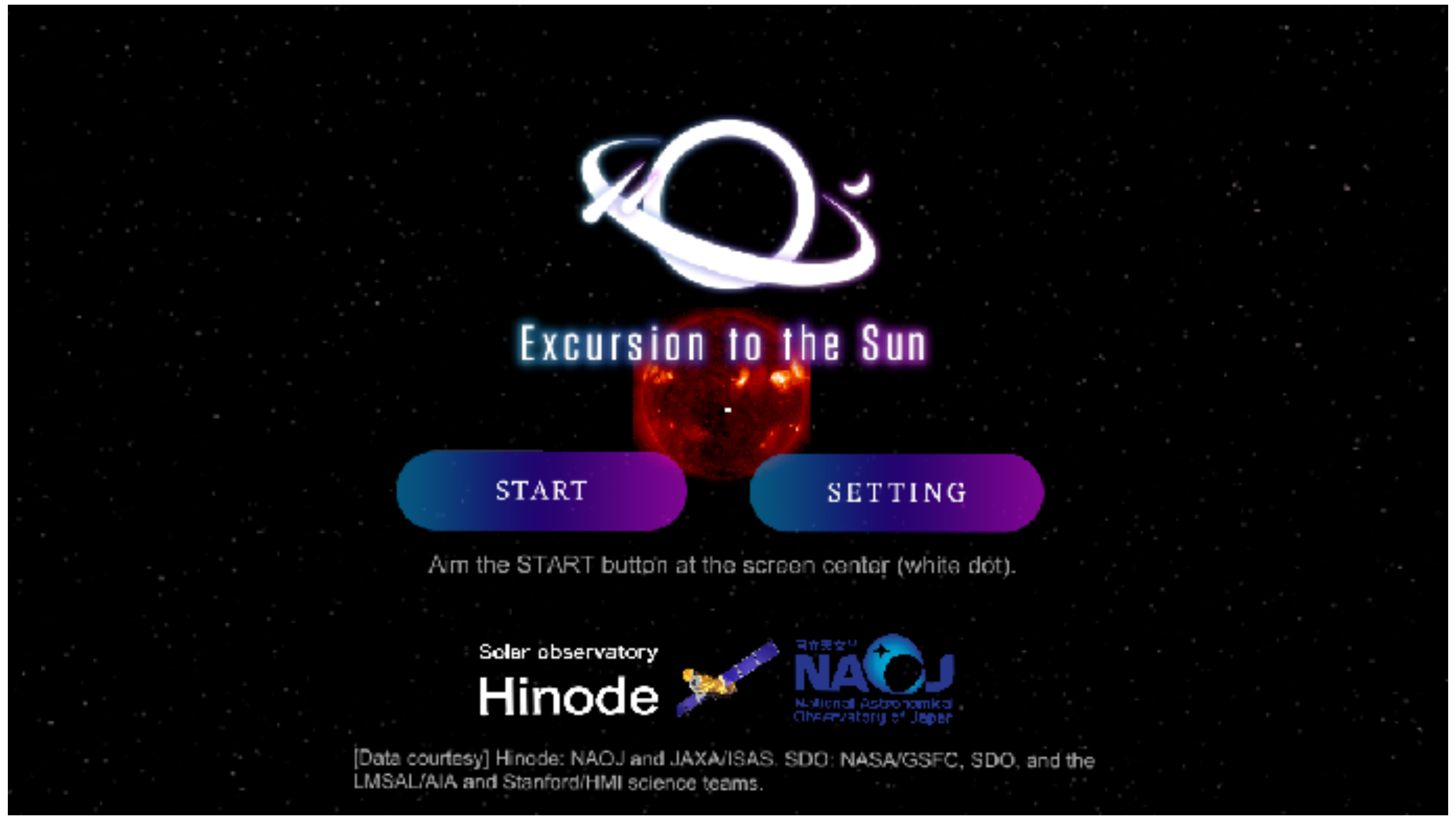


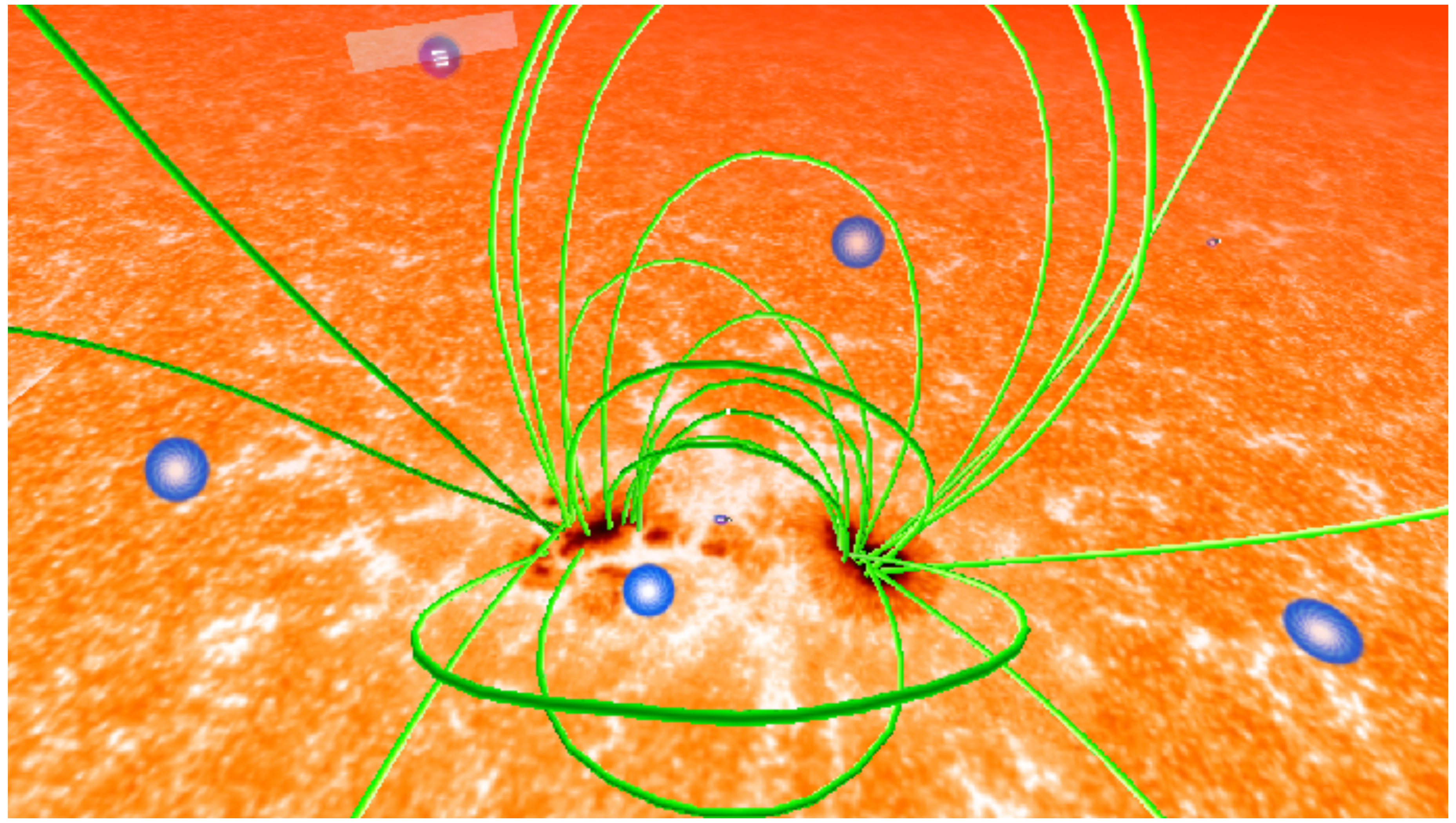


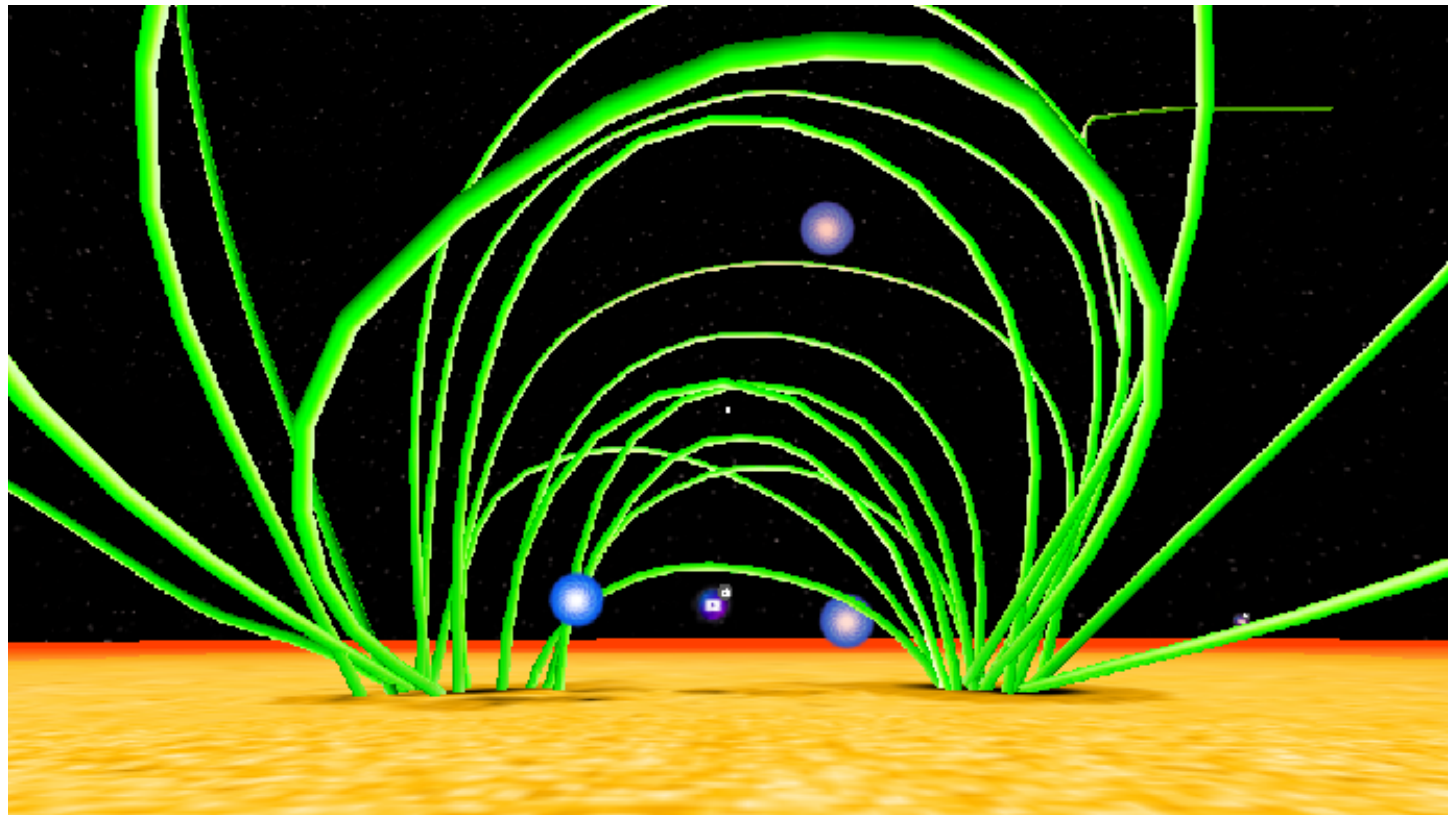

- IRIS with other instruments and simulations revealed mechanisms of
  - LB jets: reconnection-driven and p-mode-driven
  - EFR reconnection events: EBs and UV bursts
- New capabilities may widen the pictures
  - Chrom field measurement (e.g. DKIST and Sunrise-III)
  - Multi-temp dynamics (e.g. Solar-C_EUVST)

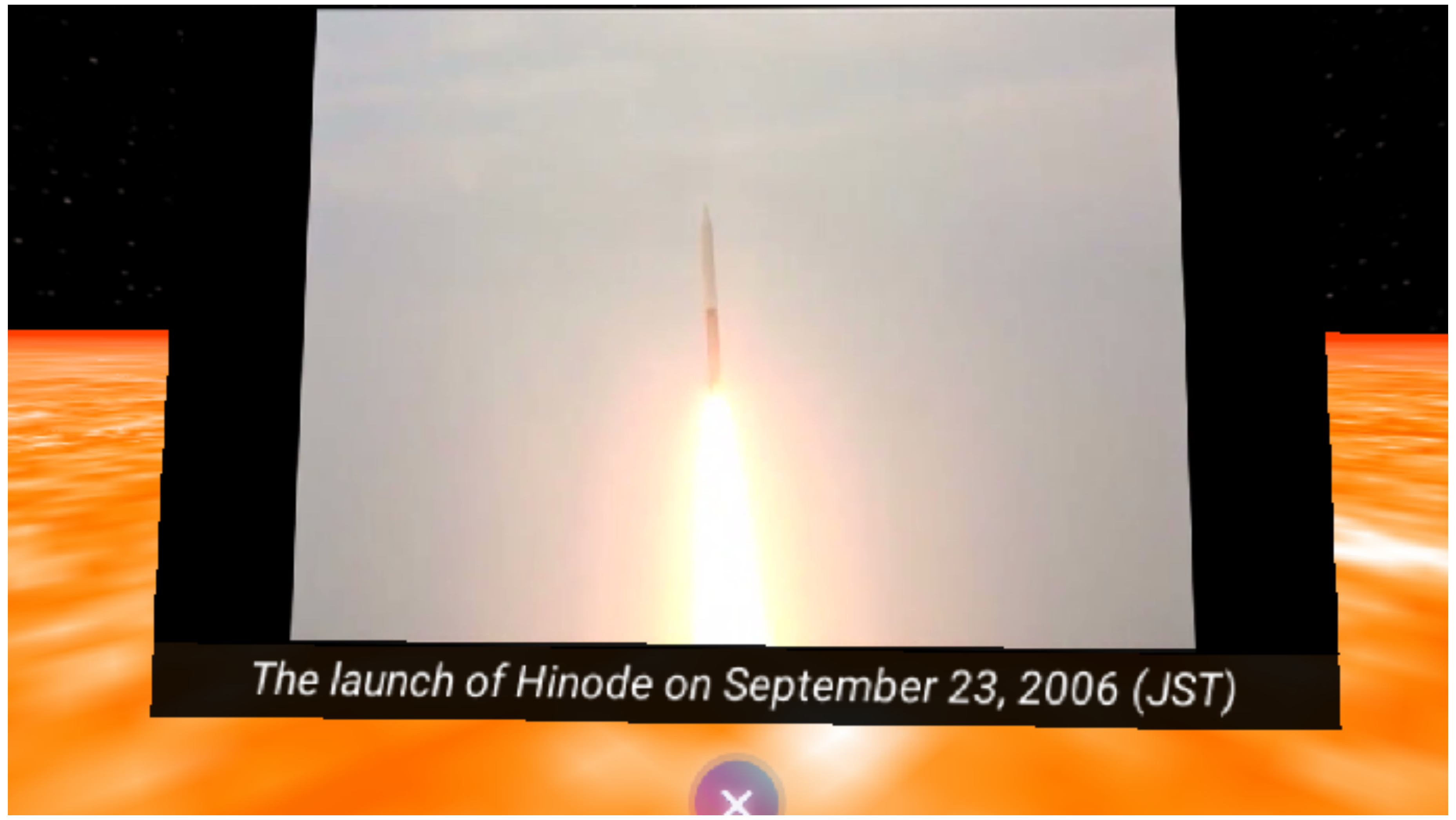
# NAOJ Hinode VR App

To be released in mid-July








Freely walk around the solar surface, look up and look down the AR, and get 4 cool movies.
Available on iOS (App Store) and Android (Google Play). It's free!

Thank you for your attention!