Observational signatures of self-consistent 3D CME-flare models

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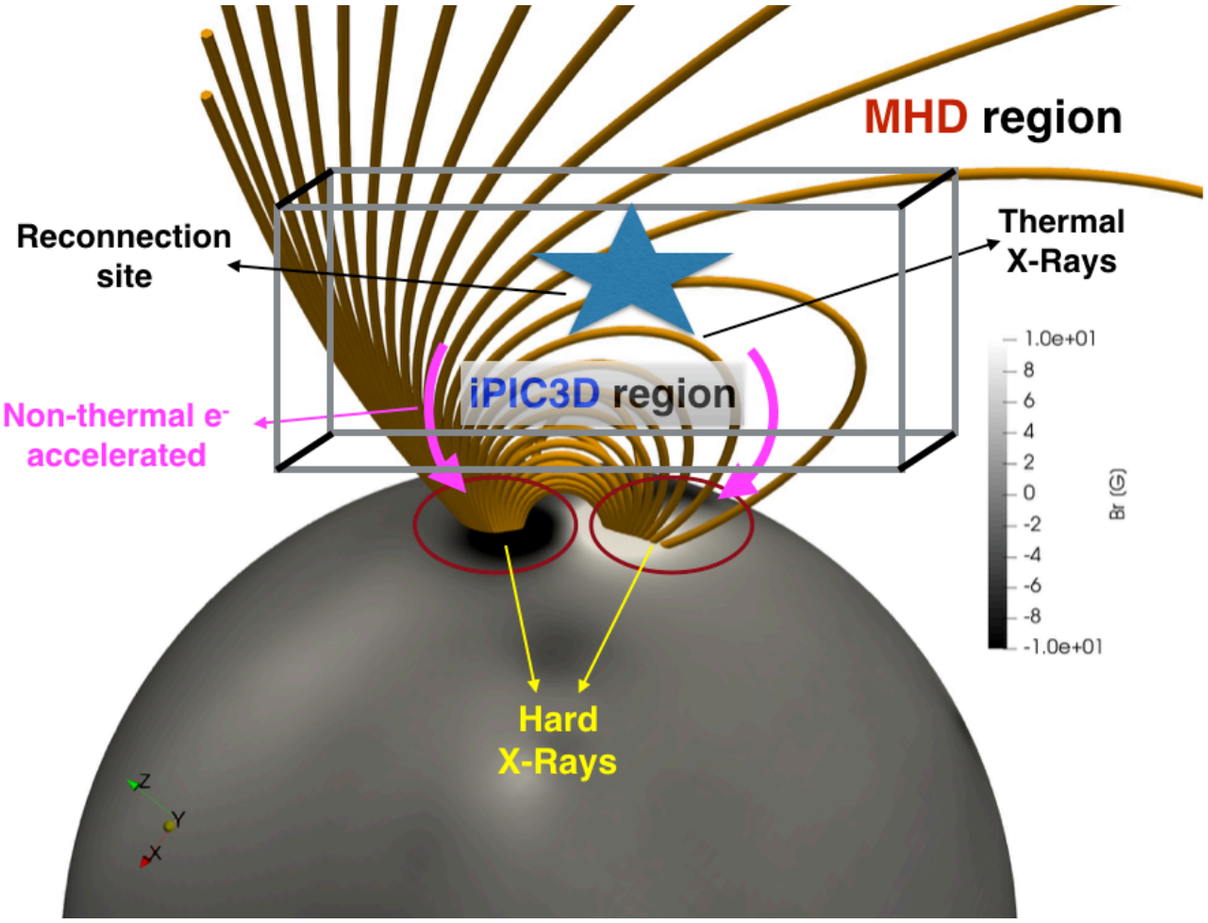

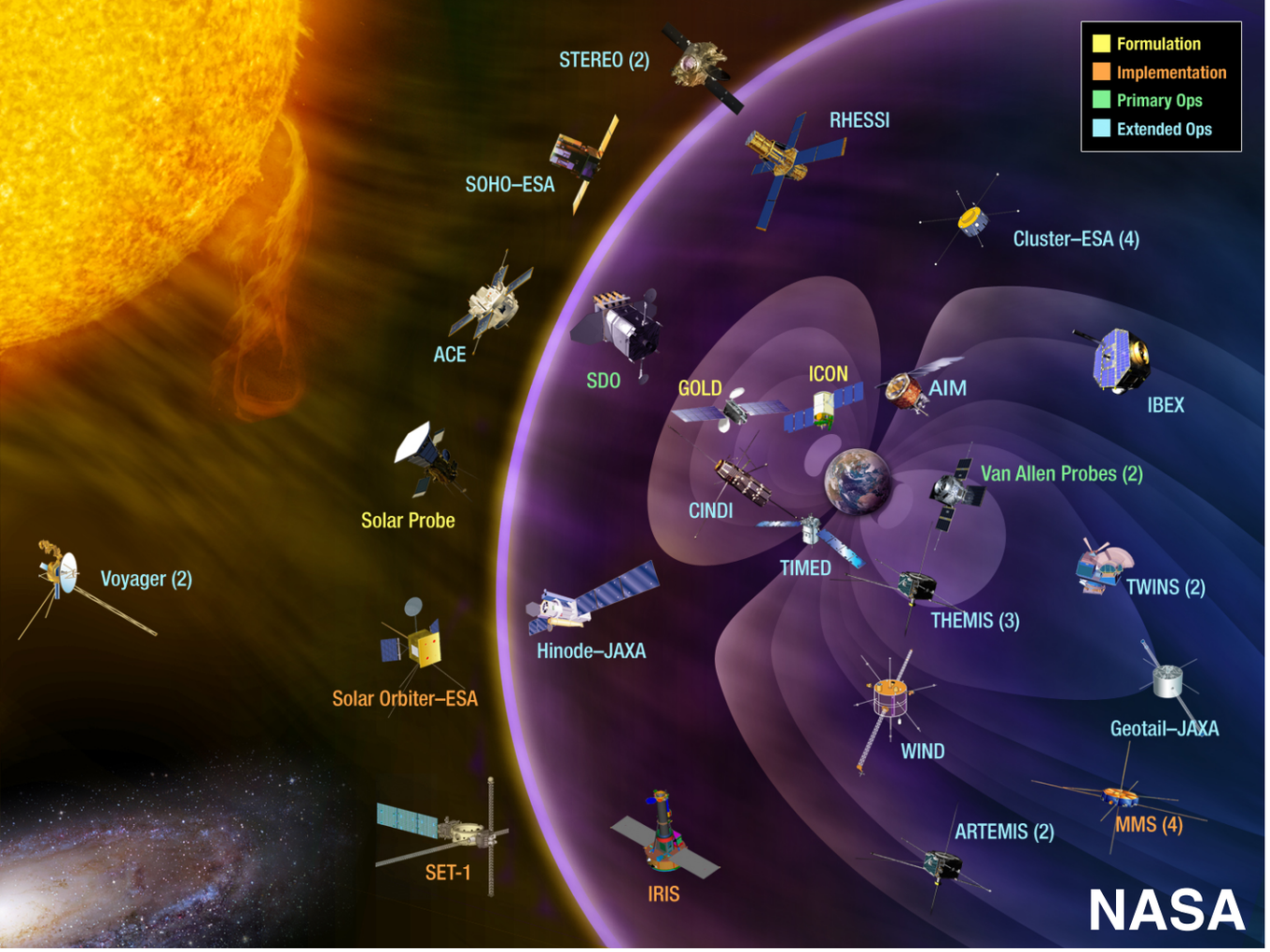
Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
RHESSI
SOHO–ESA
Cluster–ESA (4)
ACE
SDO
GOLD
ICON
AIM
IBEX
Solar Probe
CINDI
Van Allen Probes (2)
TIMED
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THEMIS (3)
Hinode–JAXA
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WIND
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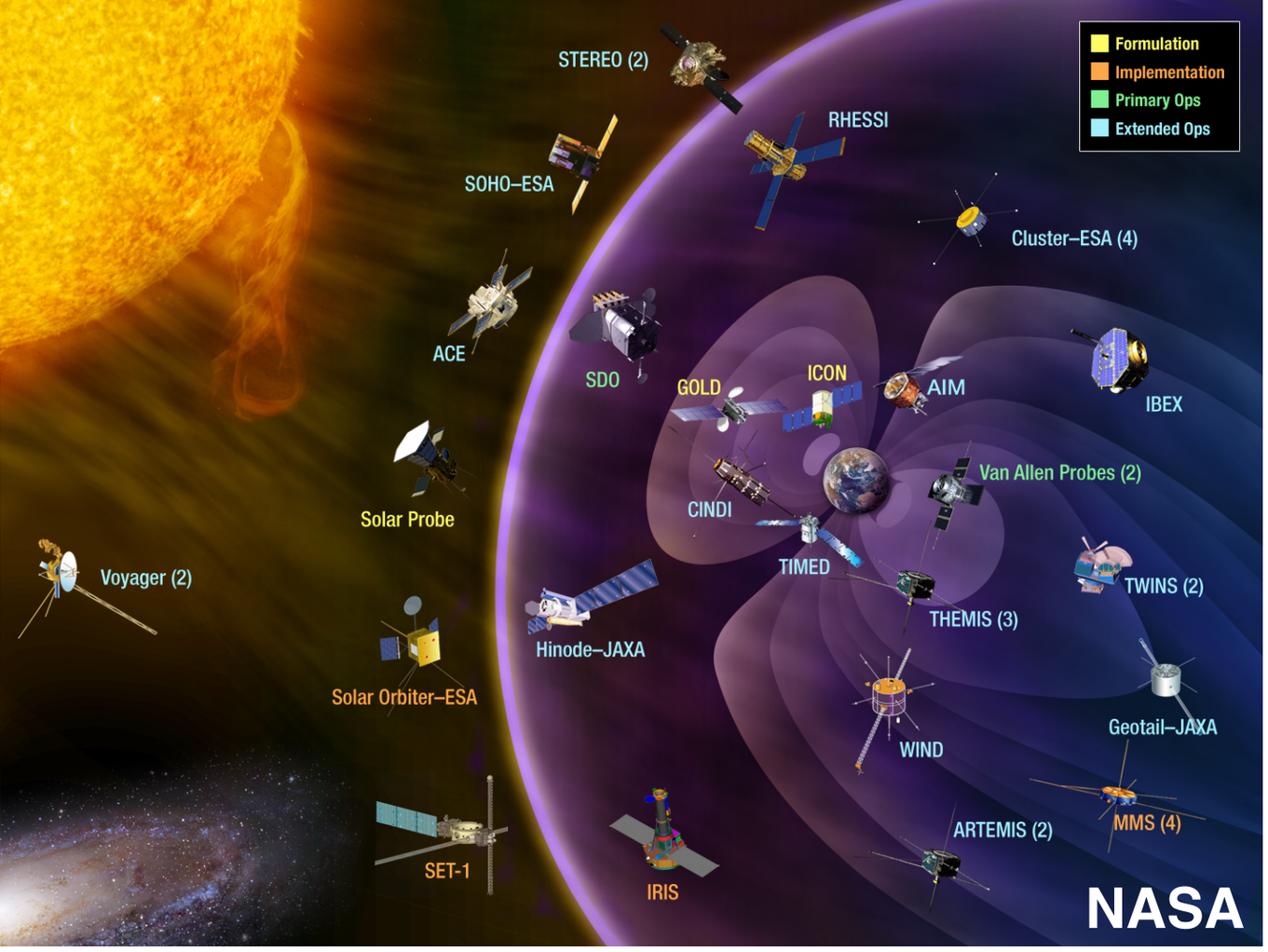
ARTEMIS (2)
SET-1
IRIS
NASA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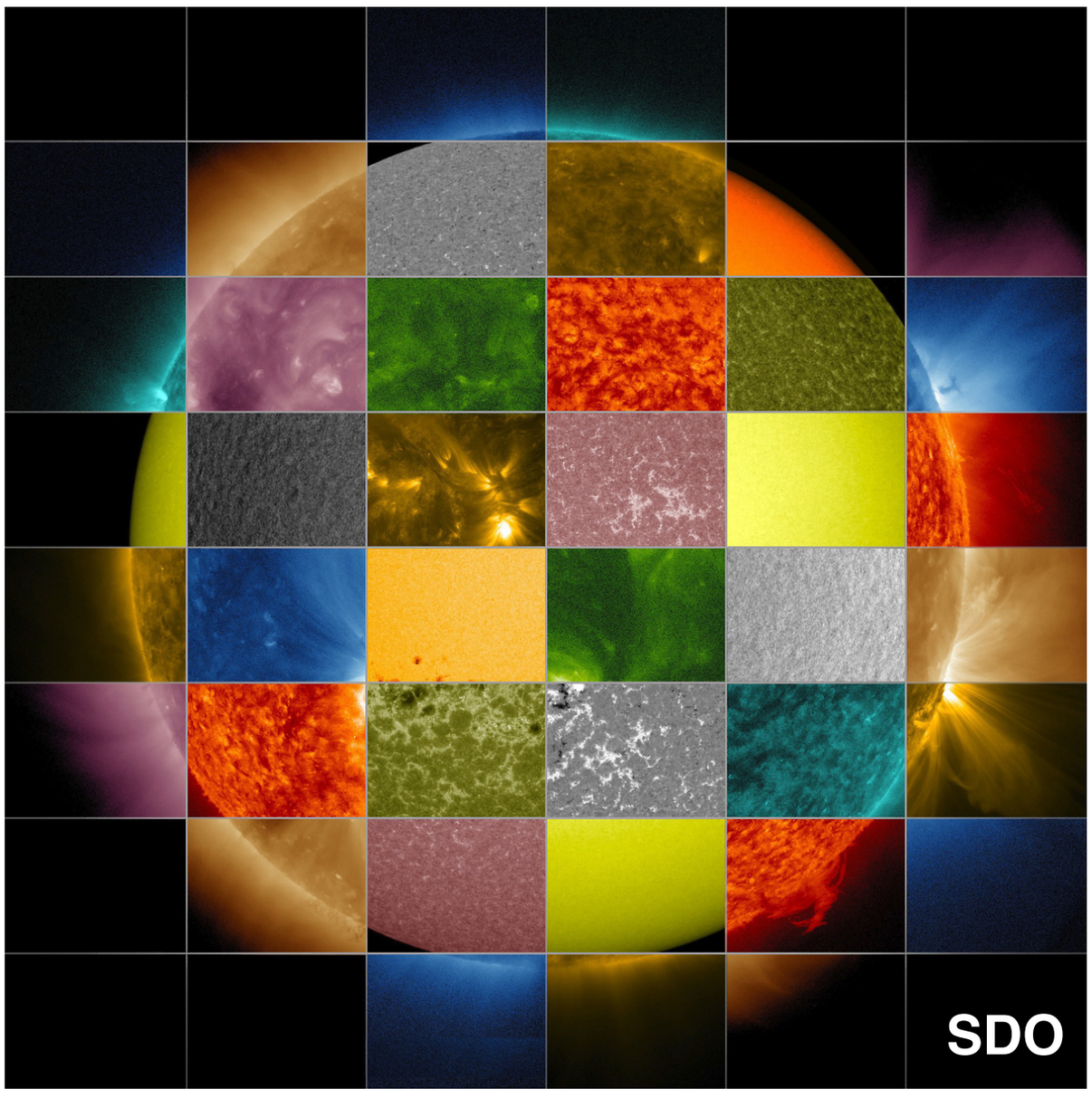
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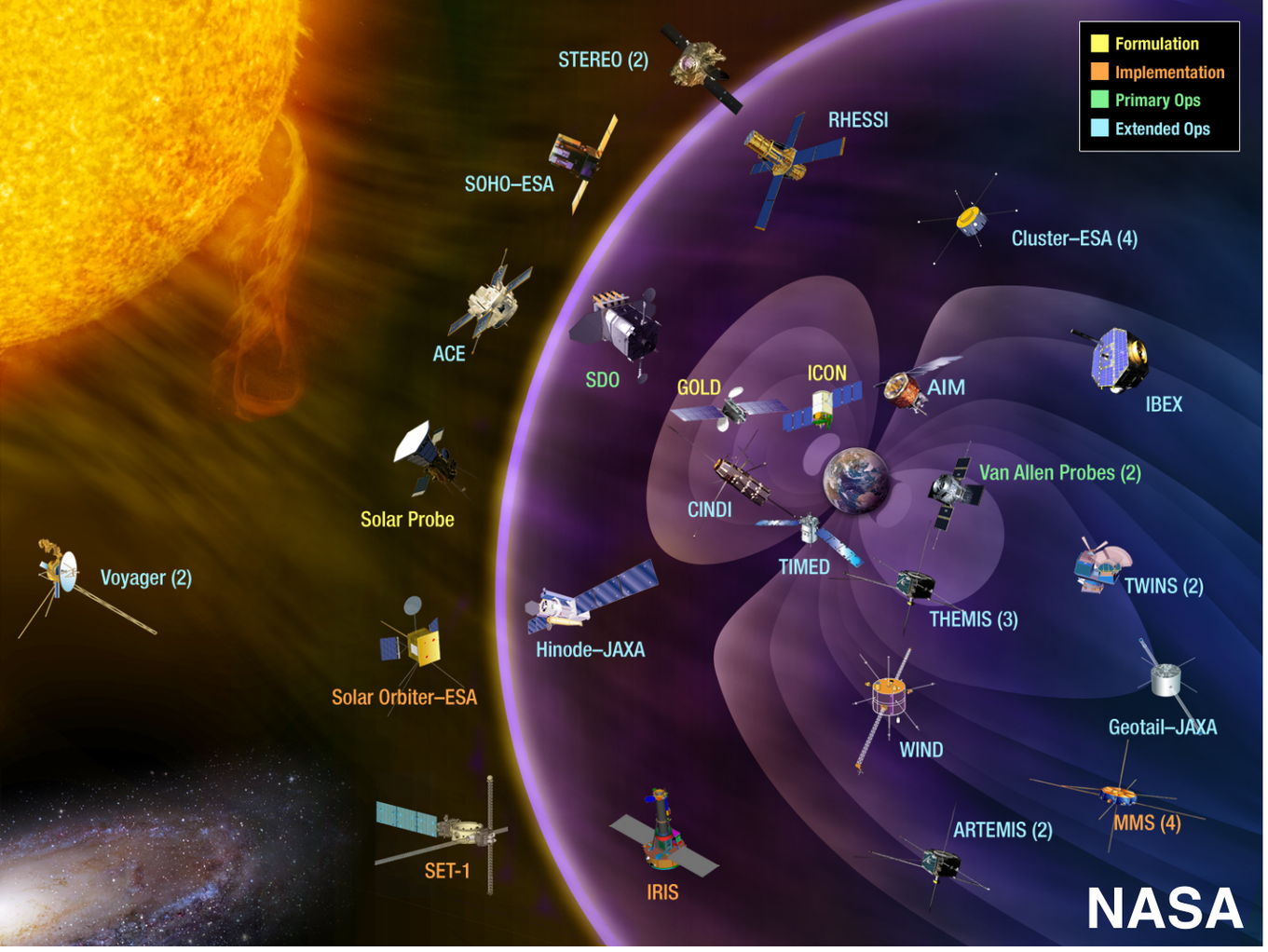
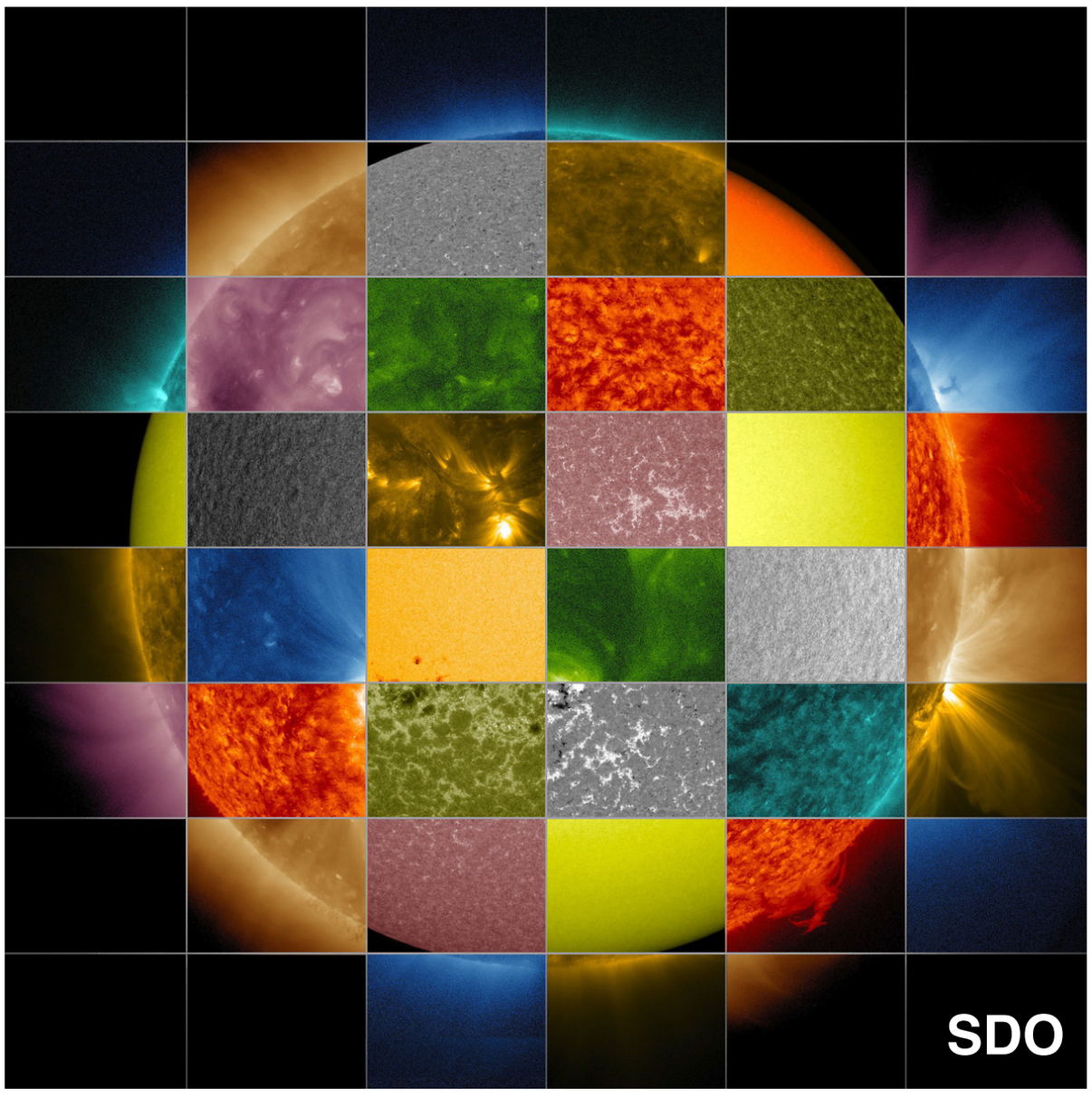
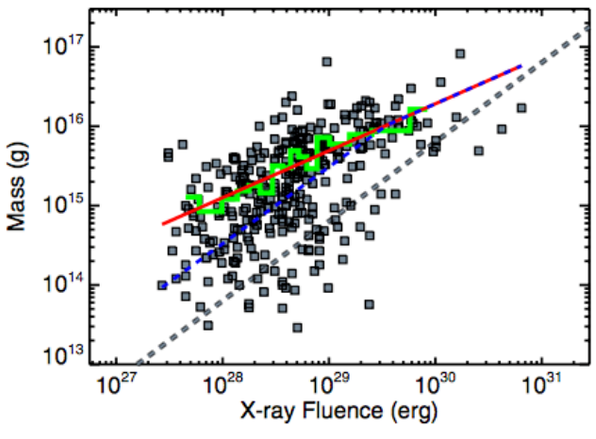
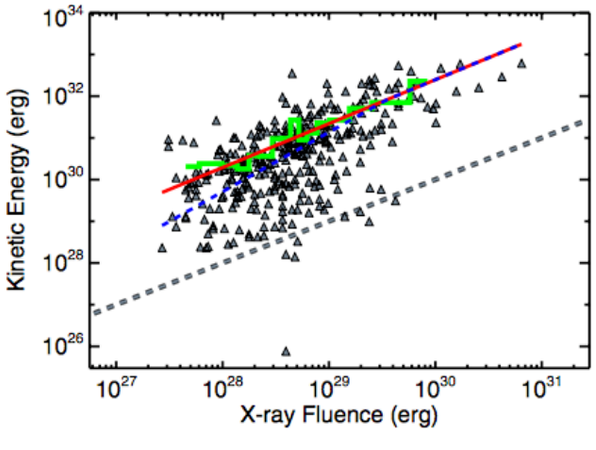
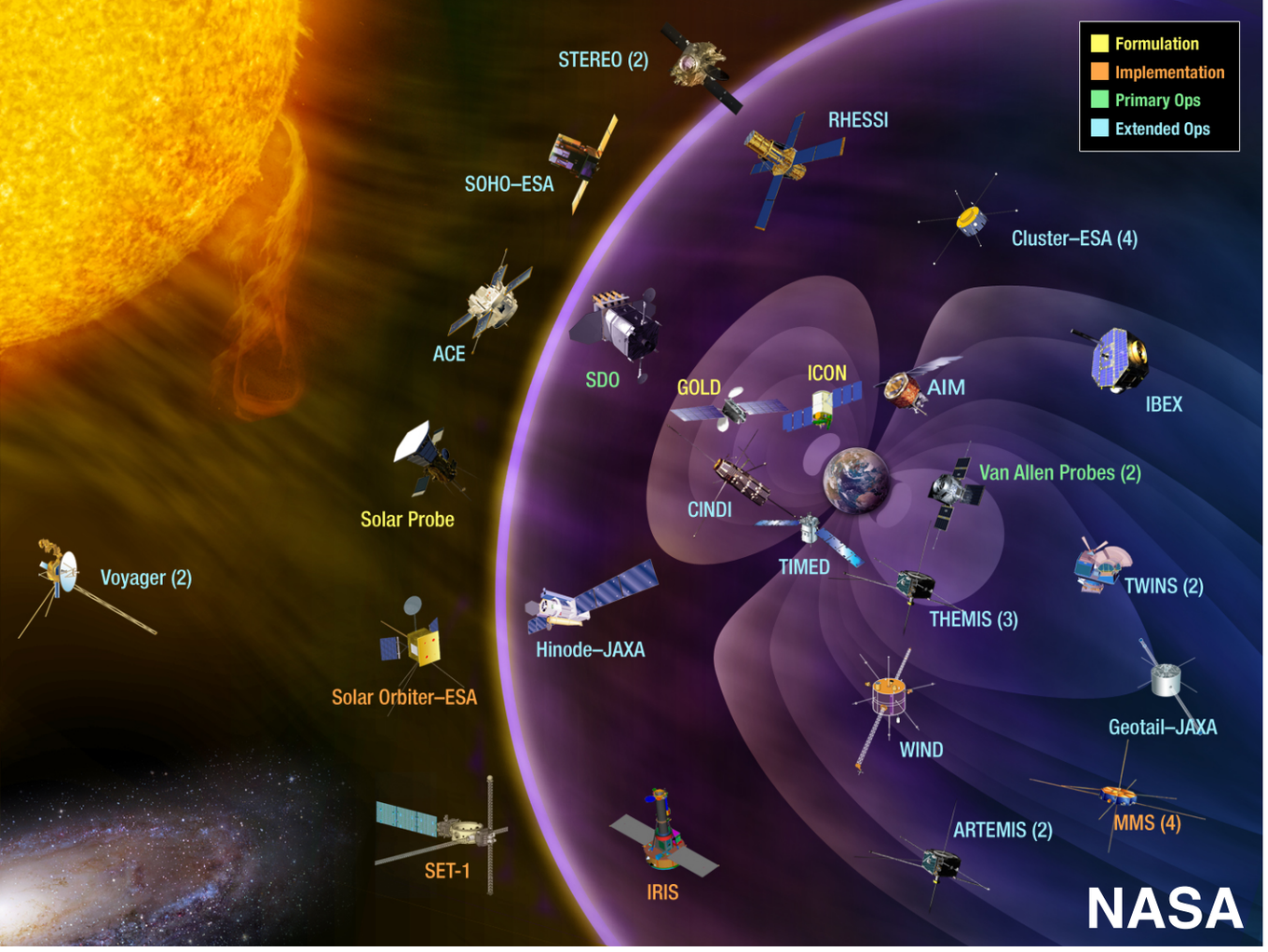


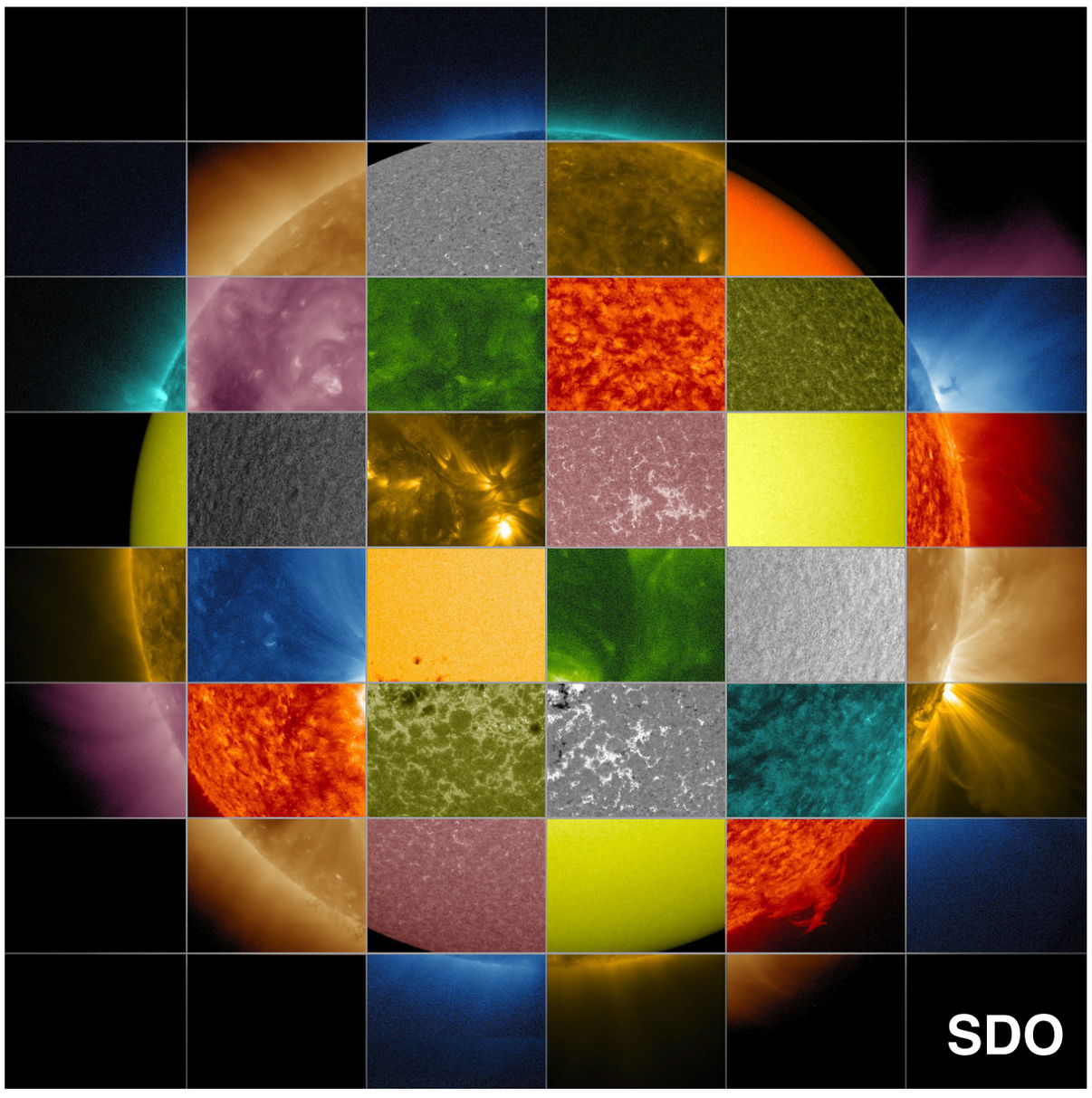


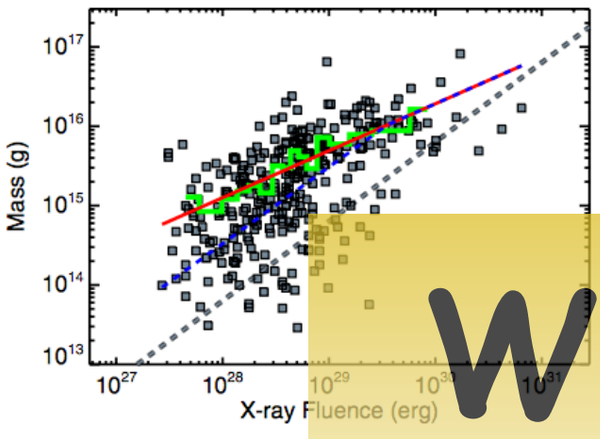




Drake et al, 2013







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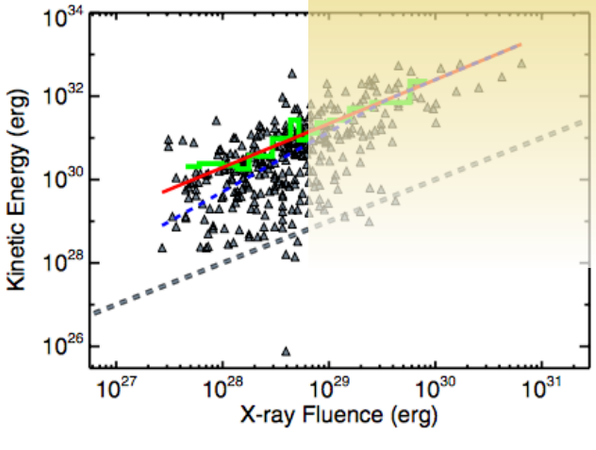
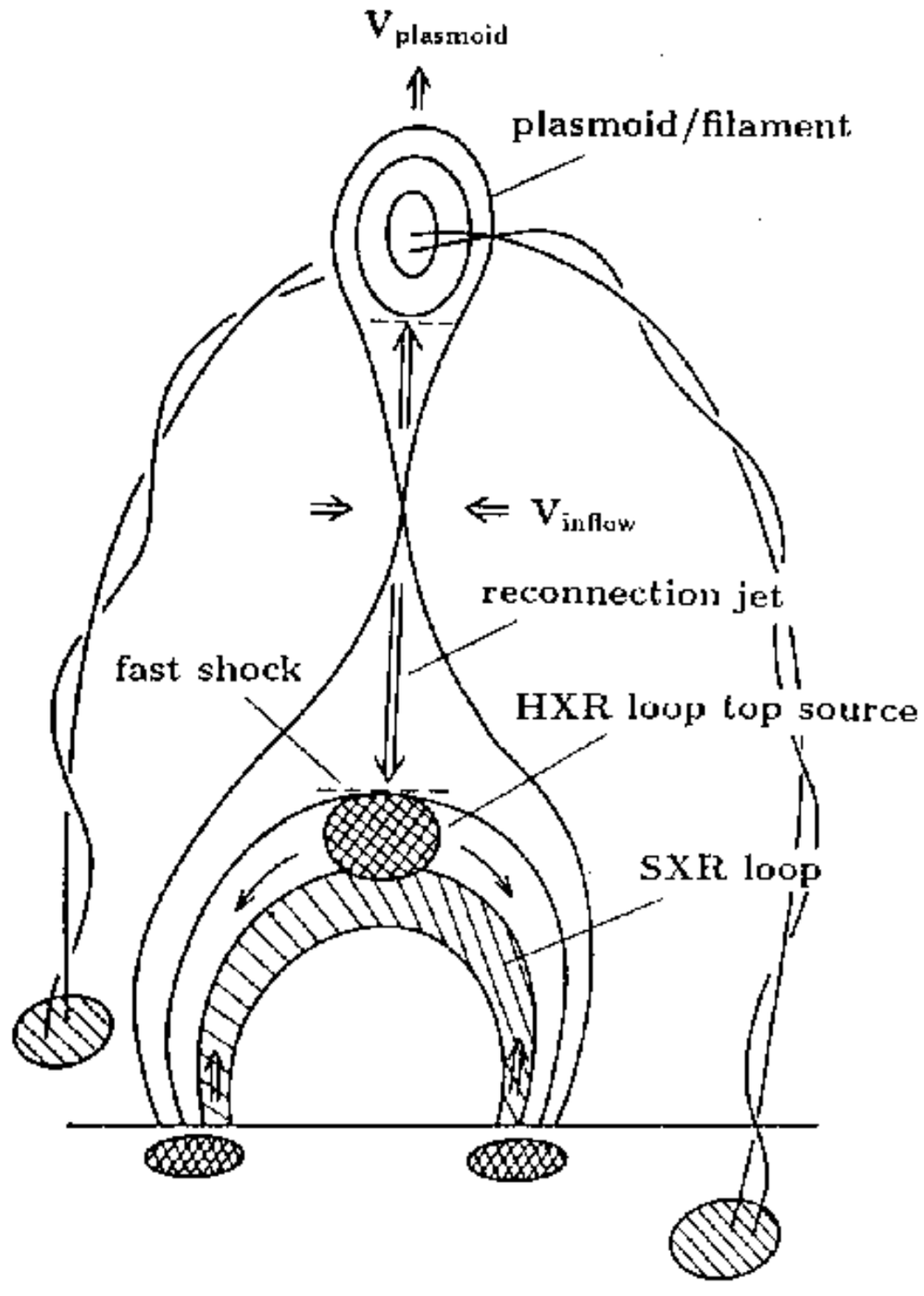


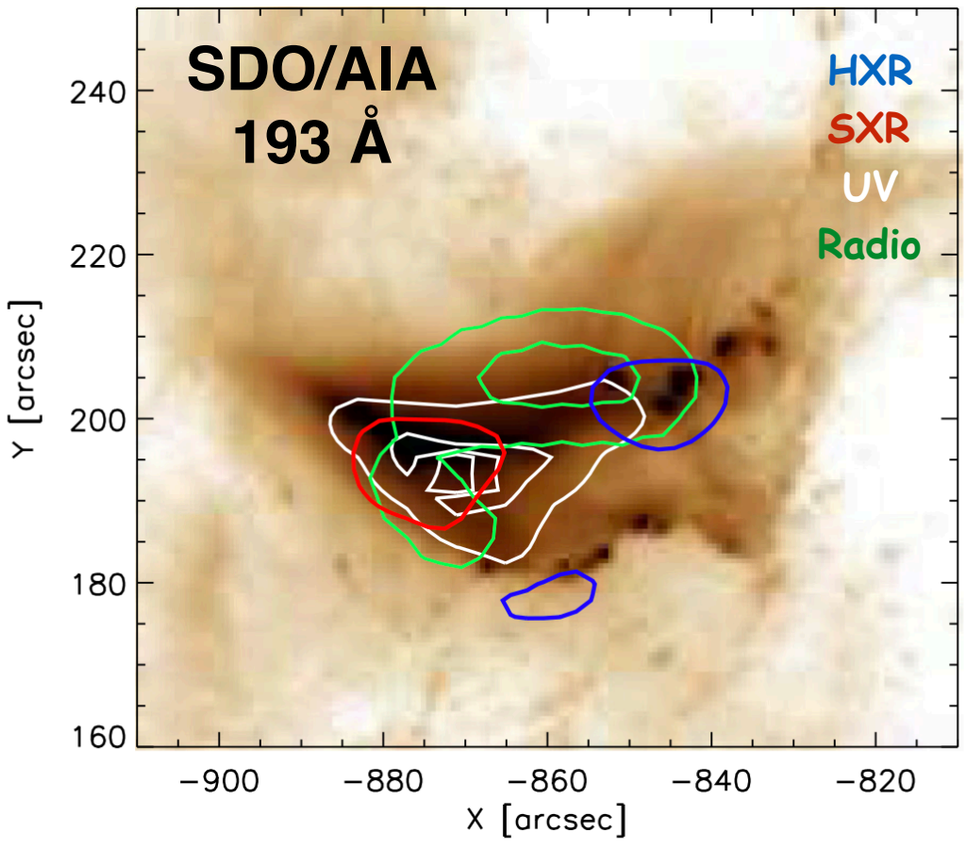
What have we learned from the Sun?

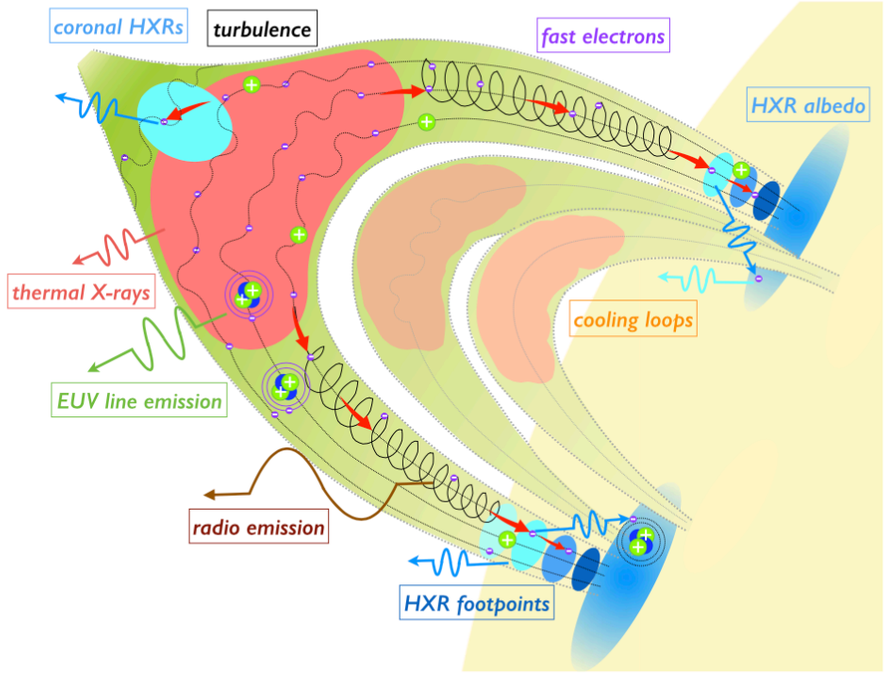
The CME-flare scenario



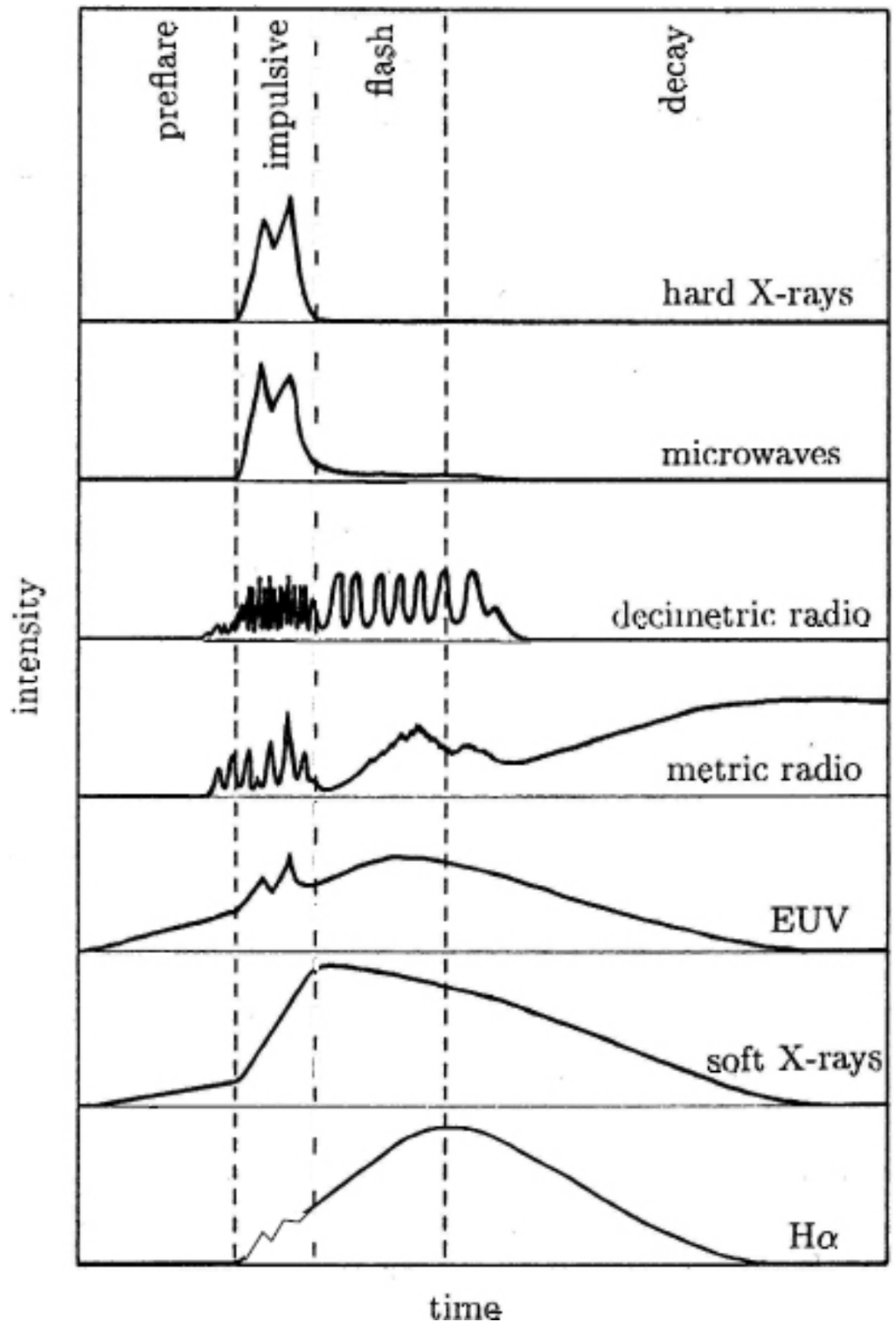
Shibata et al., ApJ, 1995

Summary of observations



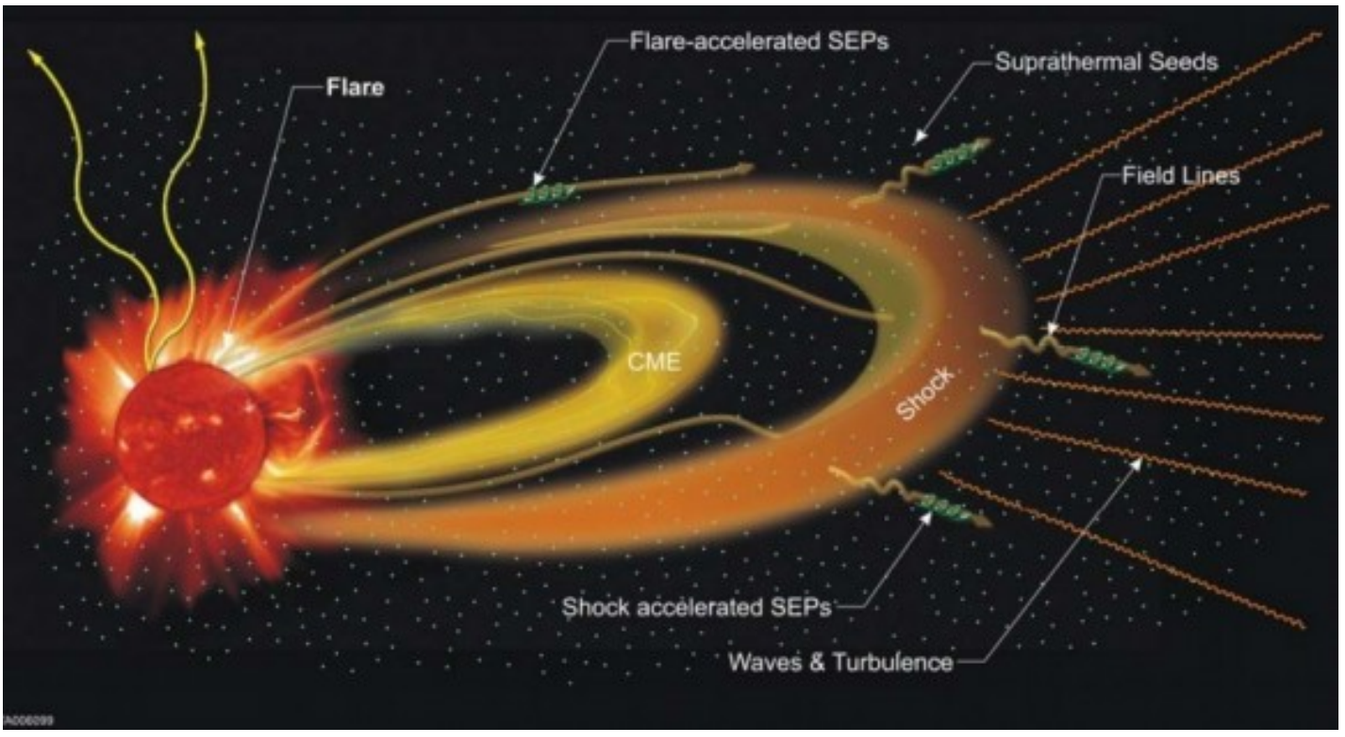


Kontar et al., PRL, 2017



Benz, 2002

Acceleration processes



Desai & Burgess, JGR, 2008

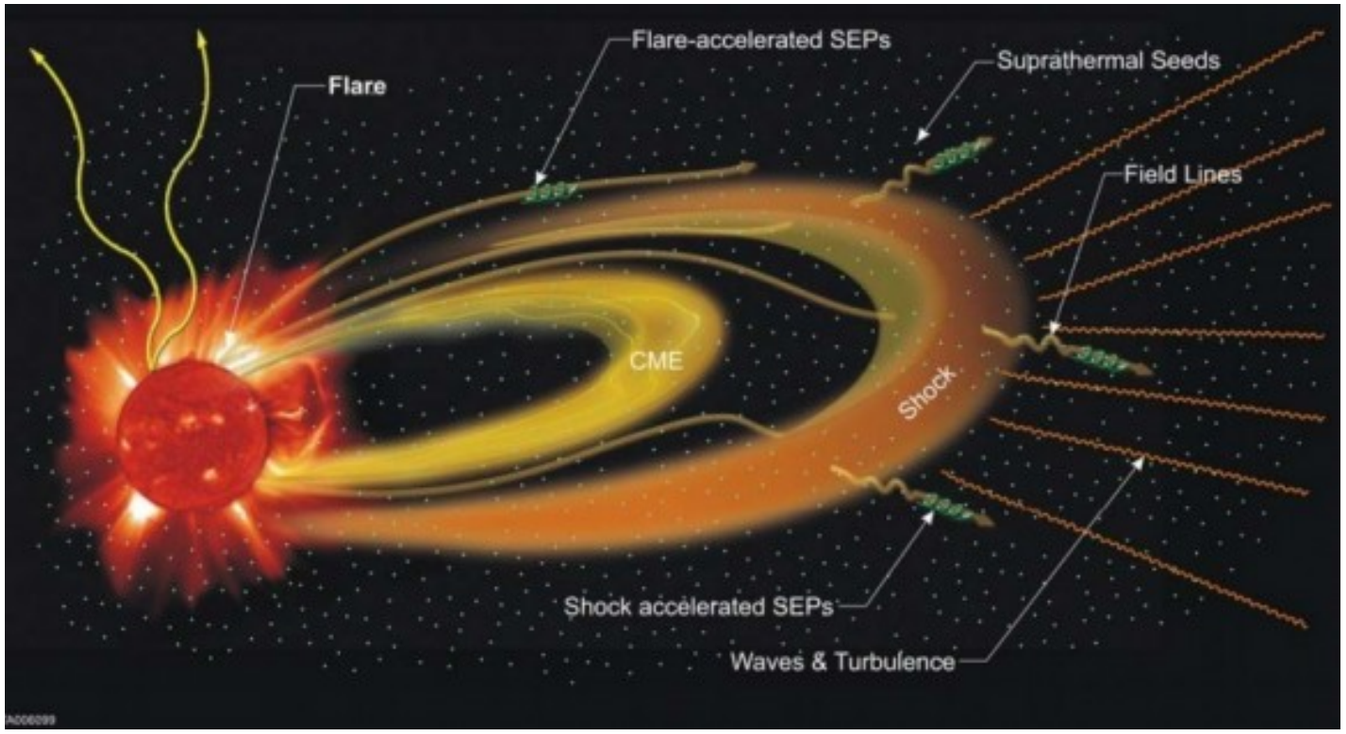
Reconnection .vs. Shocks

- Both met from solar and stellar flares to AGN jets (Sironi+,2015) and supernovae shock waves.
- SHOCKS: ~ 10% efficiency (Lin 2011)

- RECONNECTION:
  - High efficiency
  - Collisionless & fast
  - Multiple magnetic islands => merge => accelerate e- => HXR

What don't we know yet?

- CMEs and flares (& particle acceleration) different manifestations of a single grand process or not?
- Acceleration mechanisms
  - Acceleration onset e-
  - Relative importance
- Exactly how do e- escape the flaring site not understood at all



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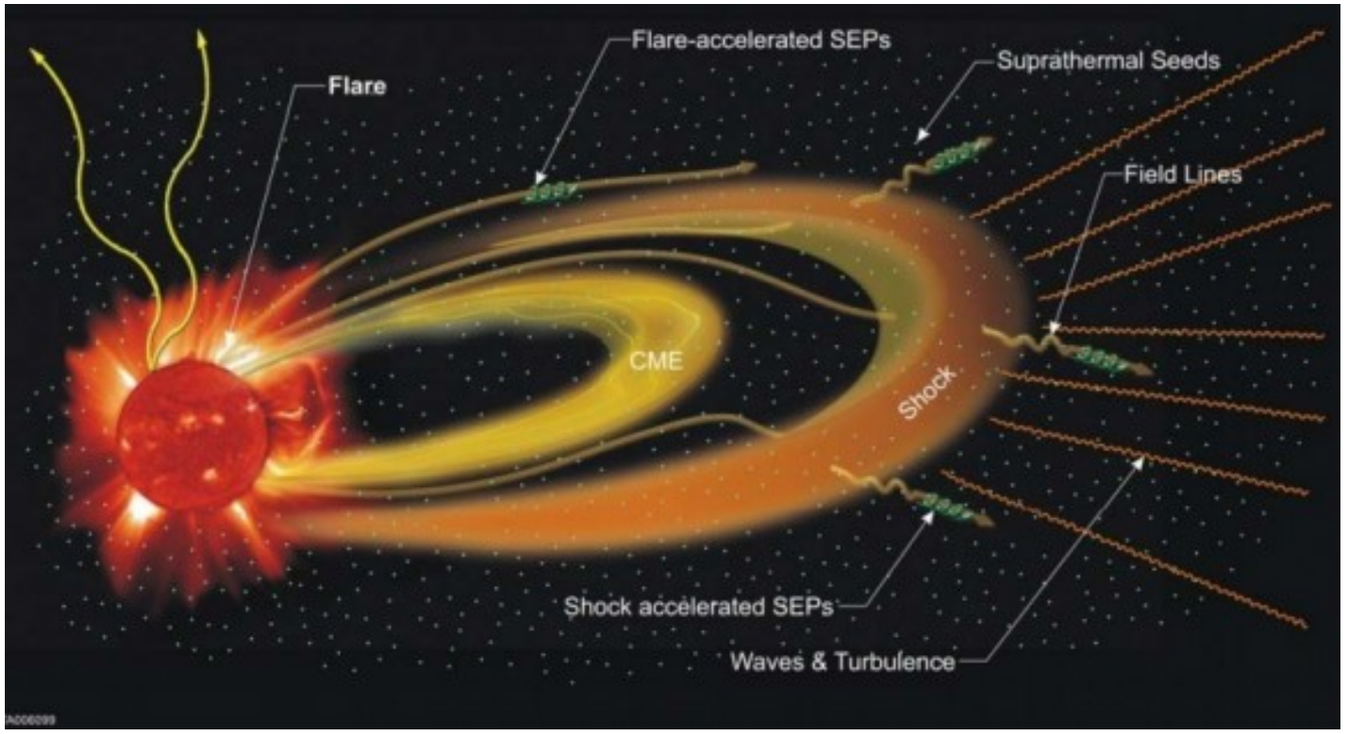


Desai & Burgess, JGR, 2008

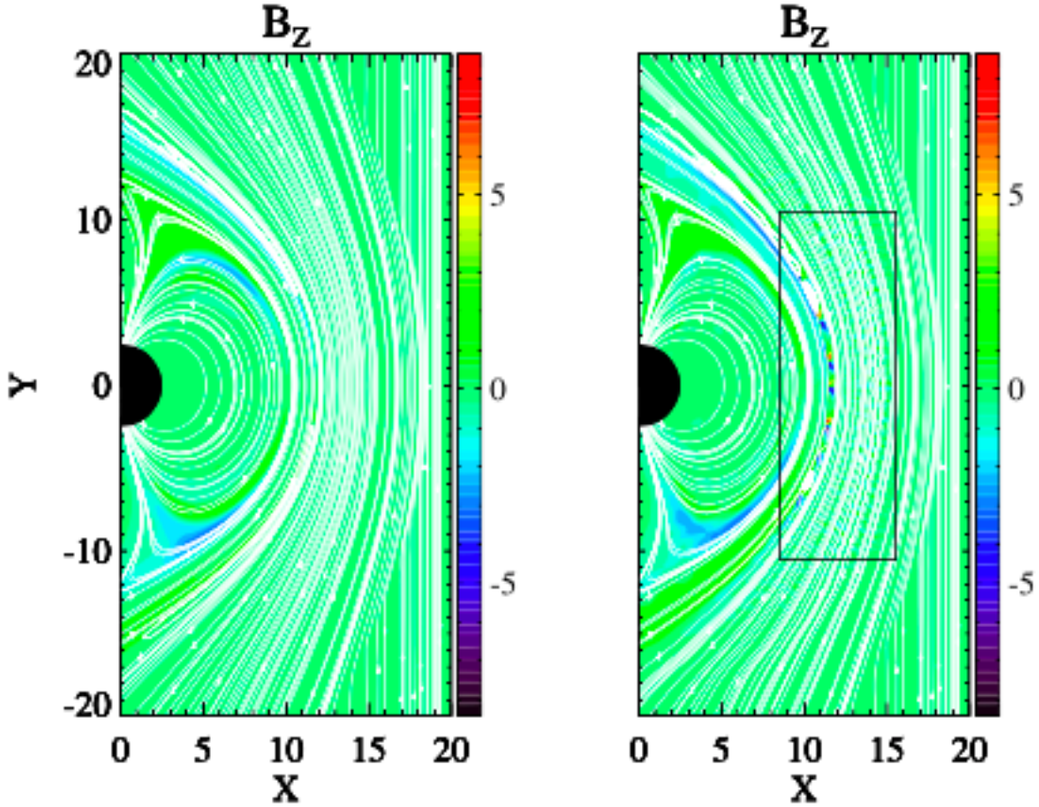
Simulations

3D MHD-EPIC simulations

Global MHD (BATS-R-US) + **local** implicit Particle-in-Cell (iPIC3D)

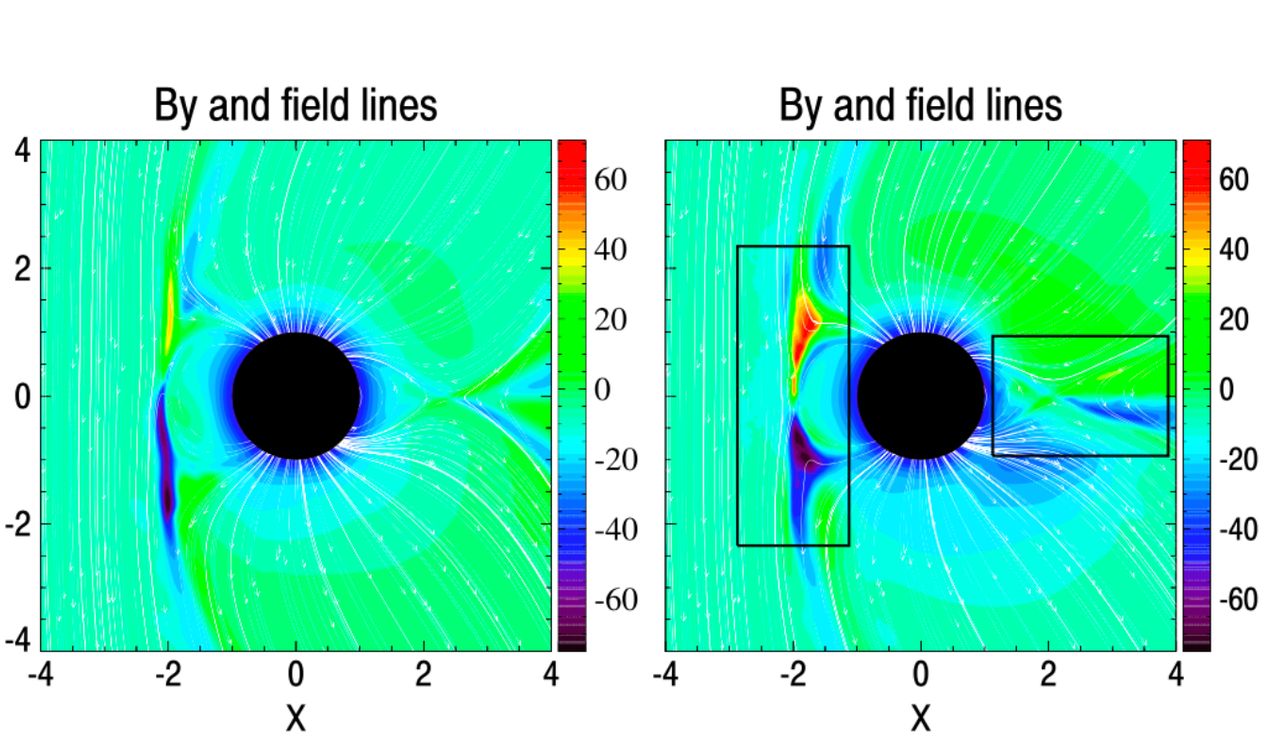
Successful Magnetospheric Studies

2D



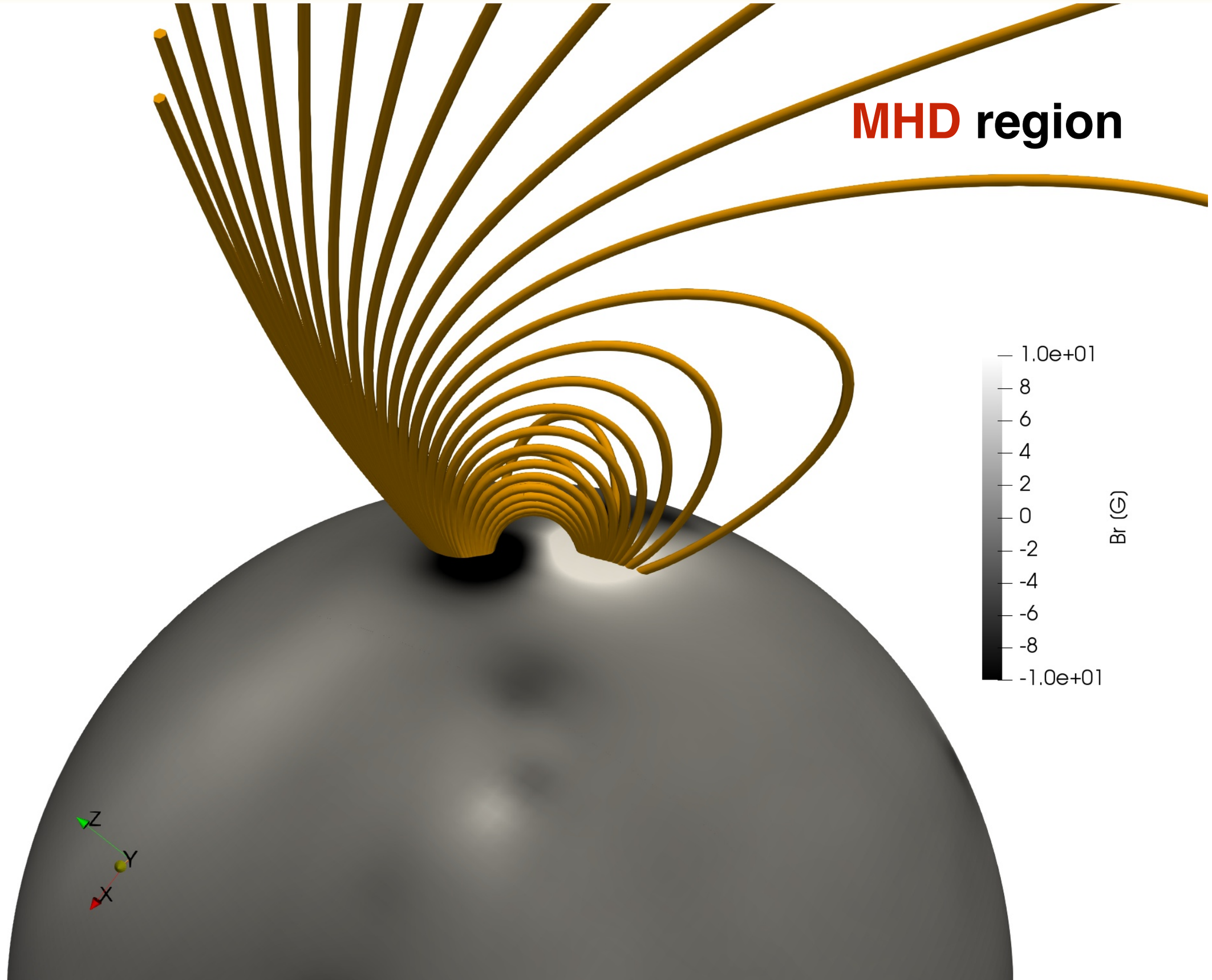
Hall MHD vs MHD-EPIC,
Daldorff et al., JCP, 2014

3D



Hall MHD vs MHD-EPIC,
Toth et al., JGR, 2016

Solar Corona



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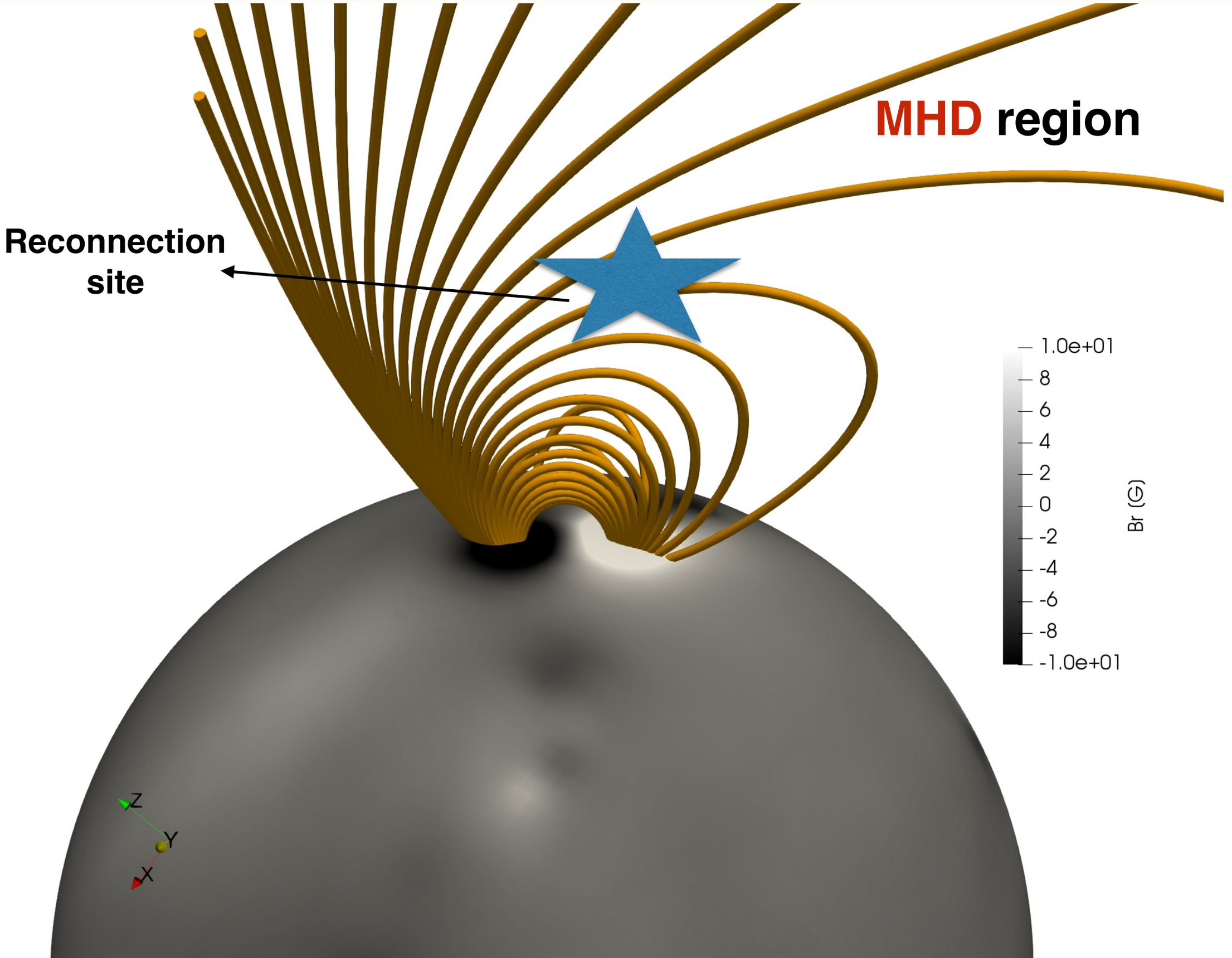

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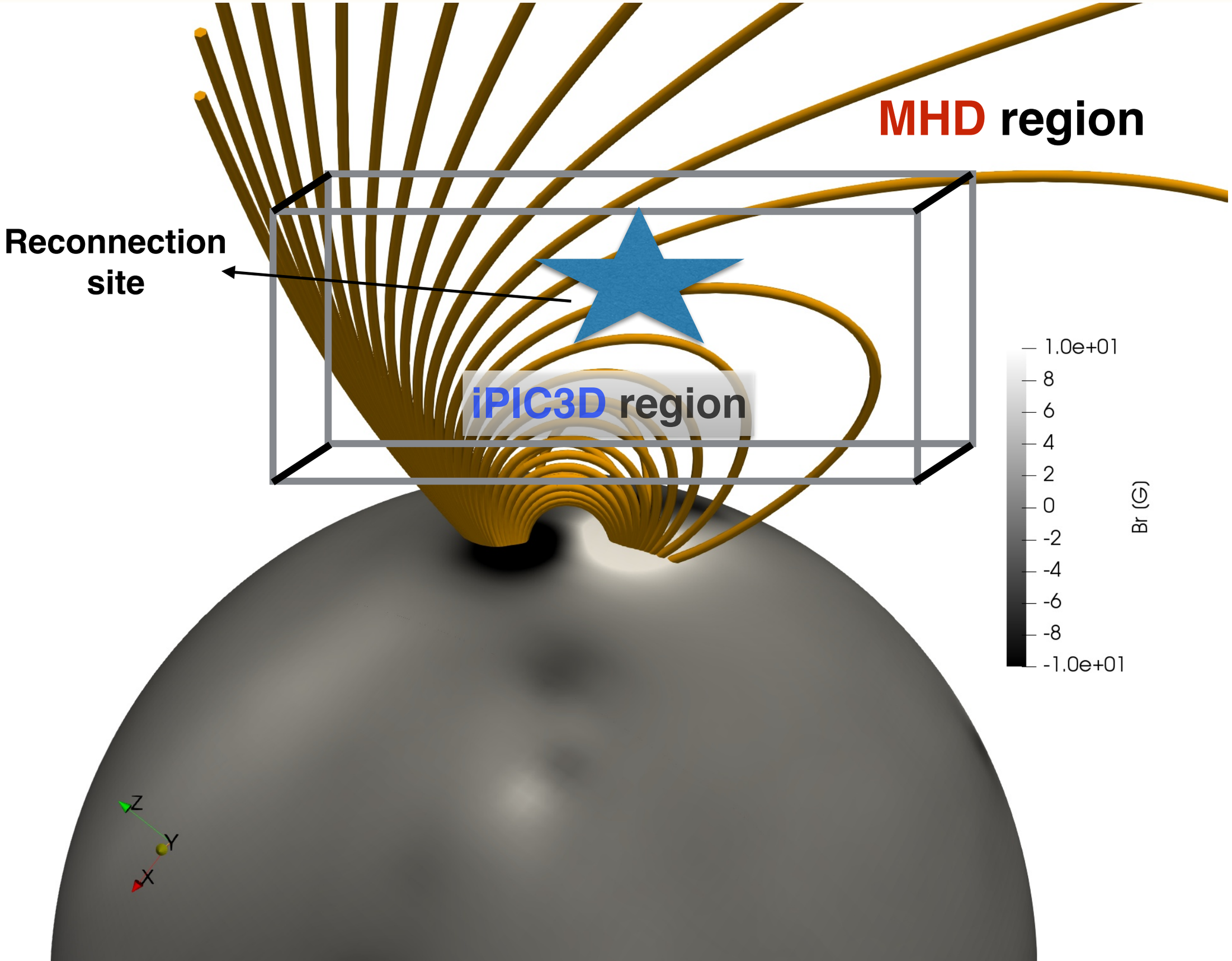

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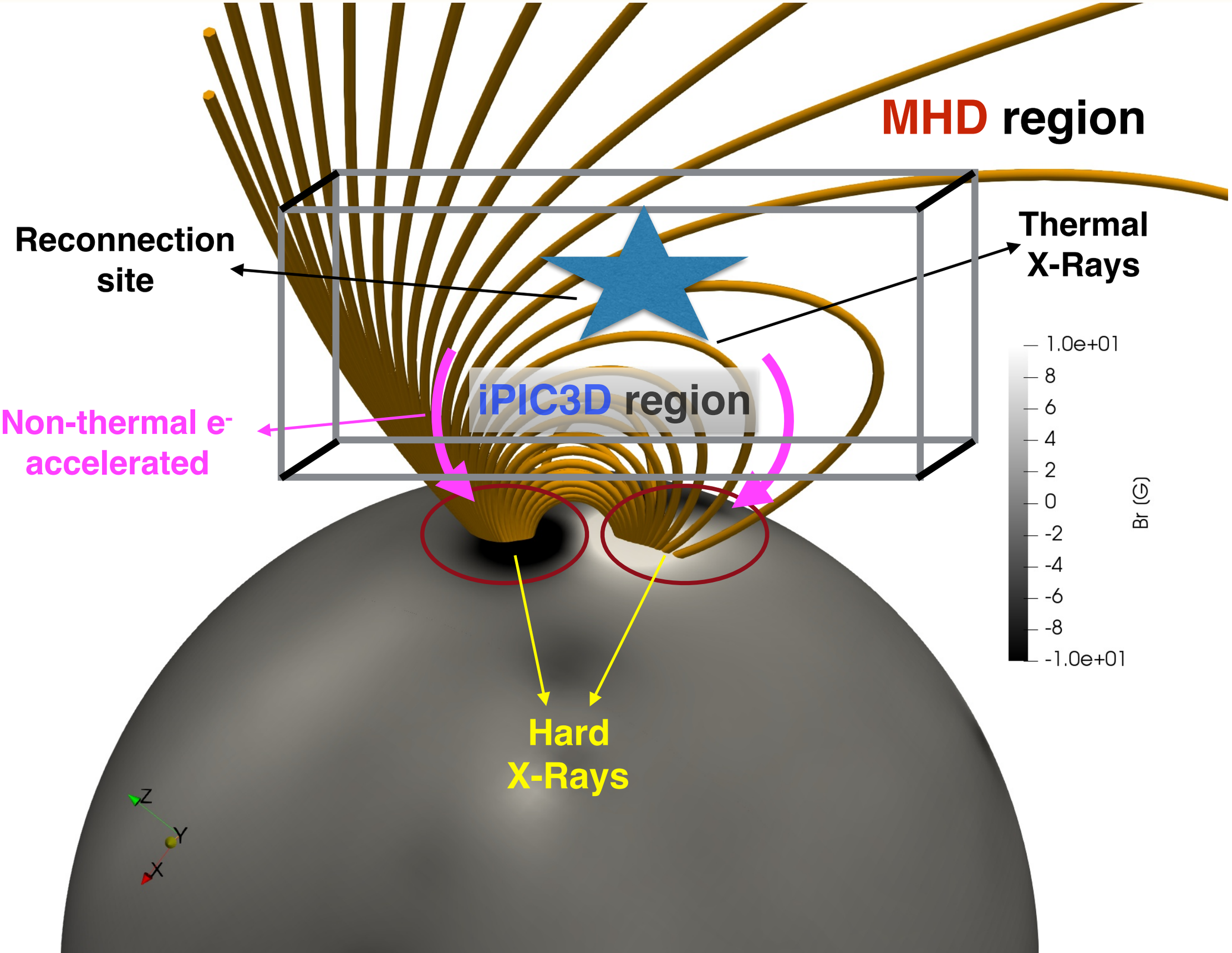
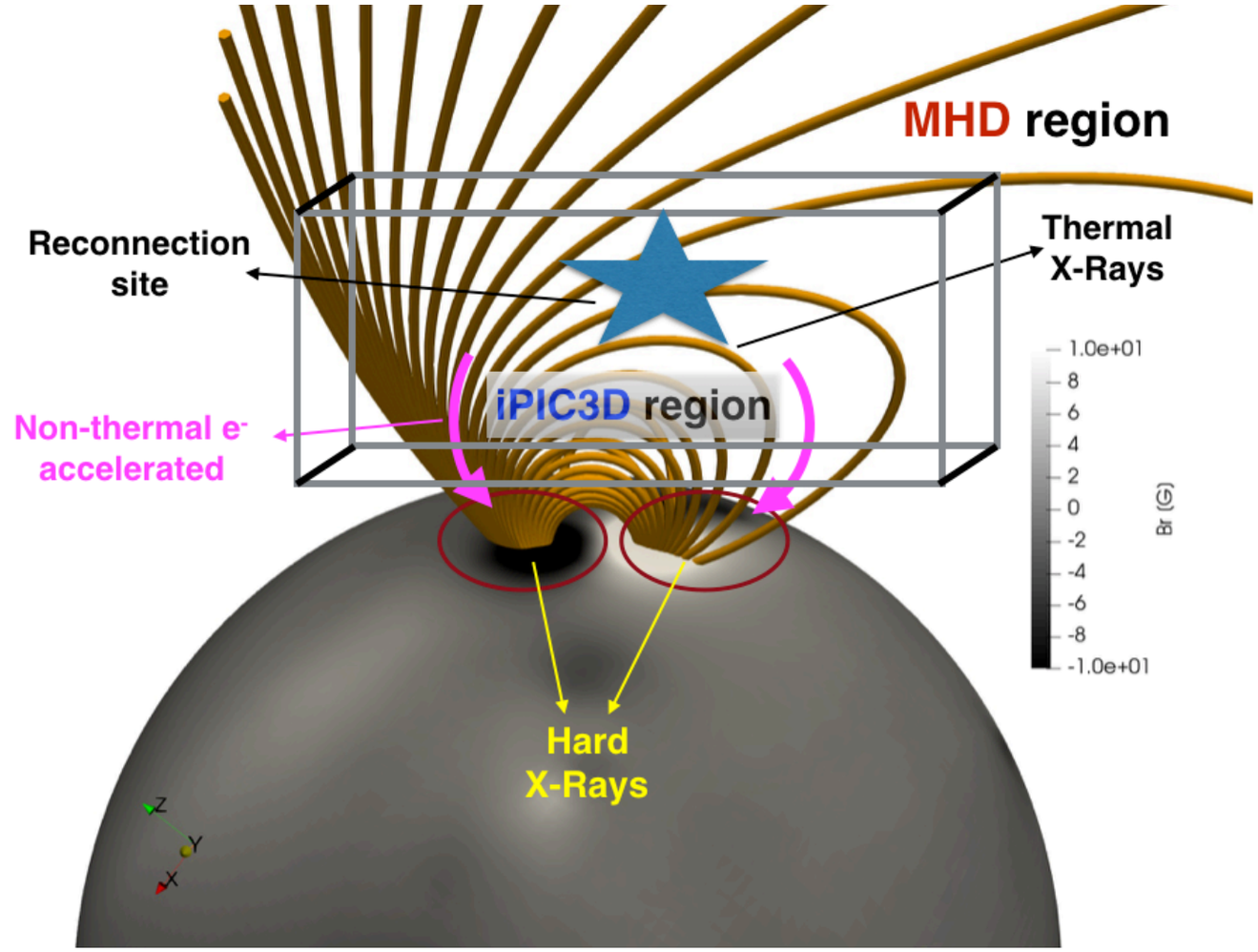
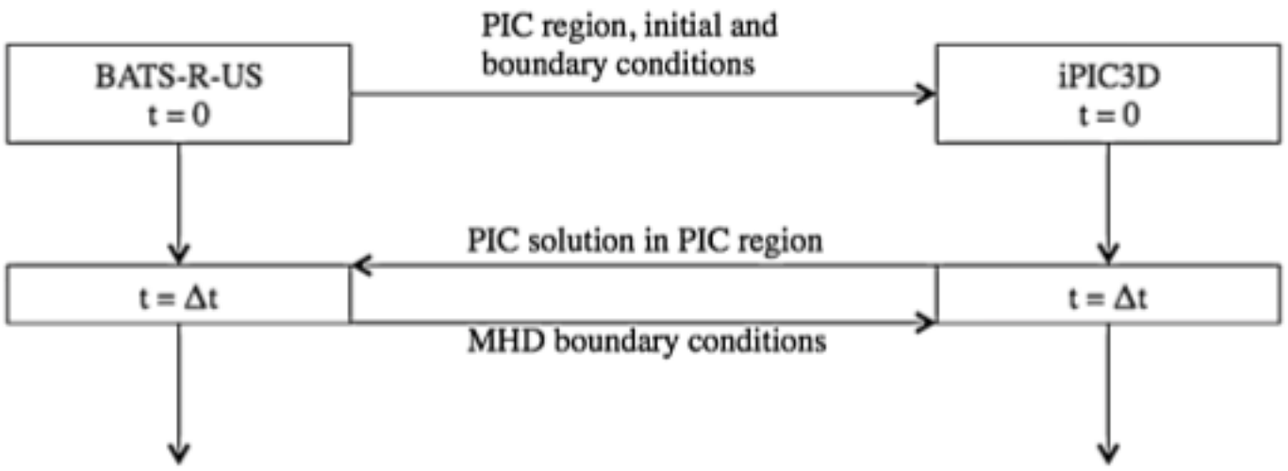


Two-way coupling





Daldorff et al., JCP, 2014

Simulations to Lynx

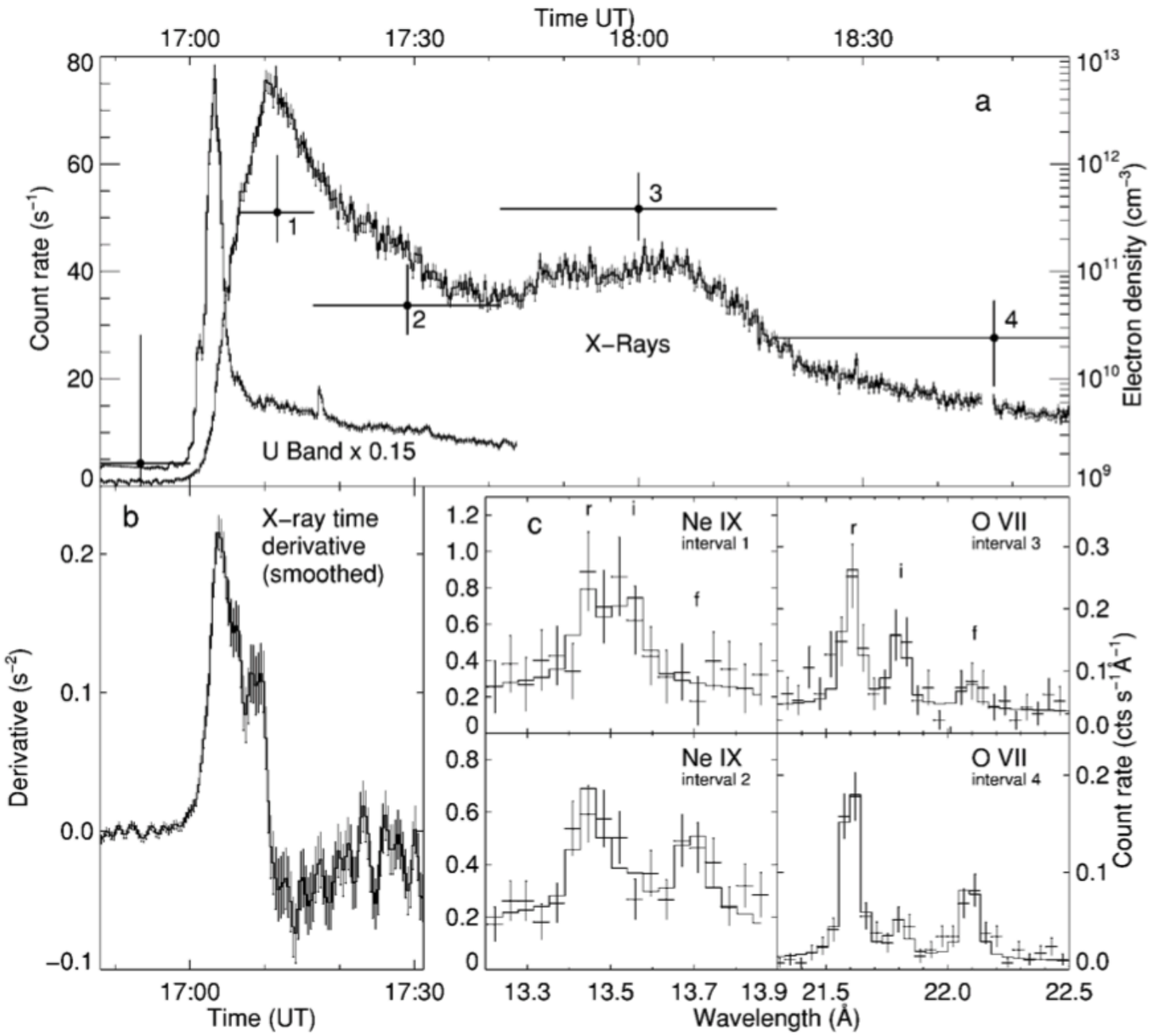
- Acceleration onset and efficiency
- Thermal—non-thermal component
- Heating-cooling in time
- Synthetic views in different wavelengths
- Emission profiles in up to strong stellar **B**
- CME-flare relation

What about stellar flares?

- Flaring activity depends on **B**, which depends on the **stellar characteristics**.
- Many X-ray stellar flares (1st Reise+,ApJ,1975)
- X-ray flares F–M stars indicating energetic transient events (~min-hours) & magnetic reconnection (e.g. Güdel & Nazé 2009).
- Large stellar flares T~100 MK (e.g. Osten+2005, 2007), while solar peak T~20–30 MK.
- Evidence of HXR persisting throughout the entire flare time evolution (Osten et al. 2007)

Stellar flares

- Large flare on Proxima Centauri (Güdel et al. 2002, 2004)
  Chromospheric evaporation evidence, $n < 10^{10} \Rightarrow 4 \times 10^{11}$ cm^{-3}
- Neupert Effect (1968): $L_U(t) \propto dL_X(t)/dt$ (e.g. Güdel+2002)



Güdel et al. 2002
XMM-Newton

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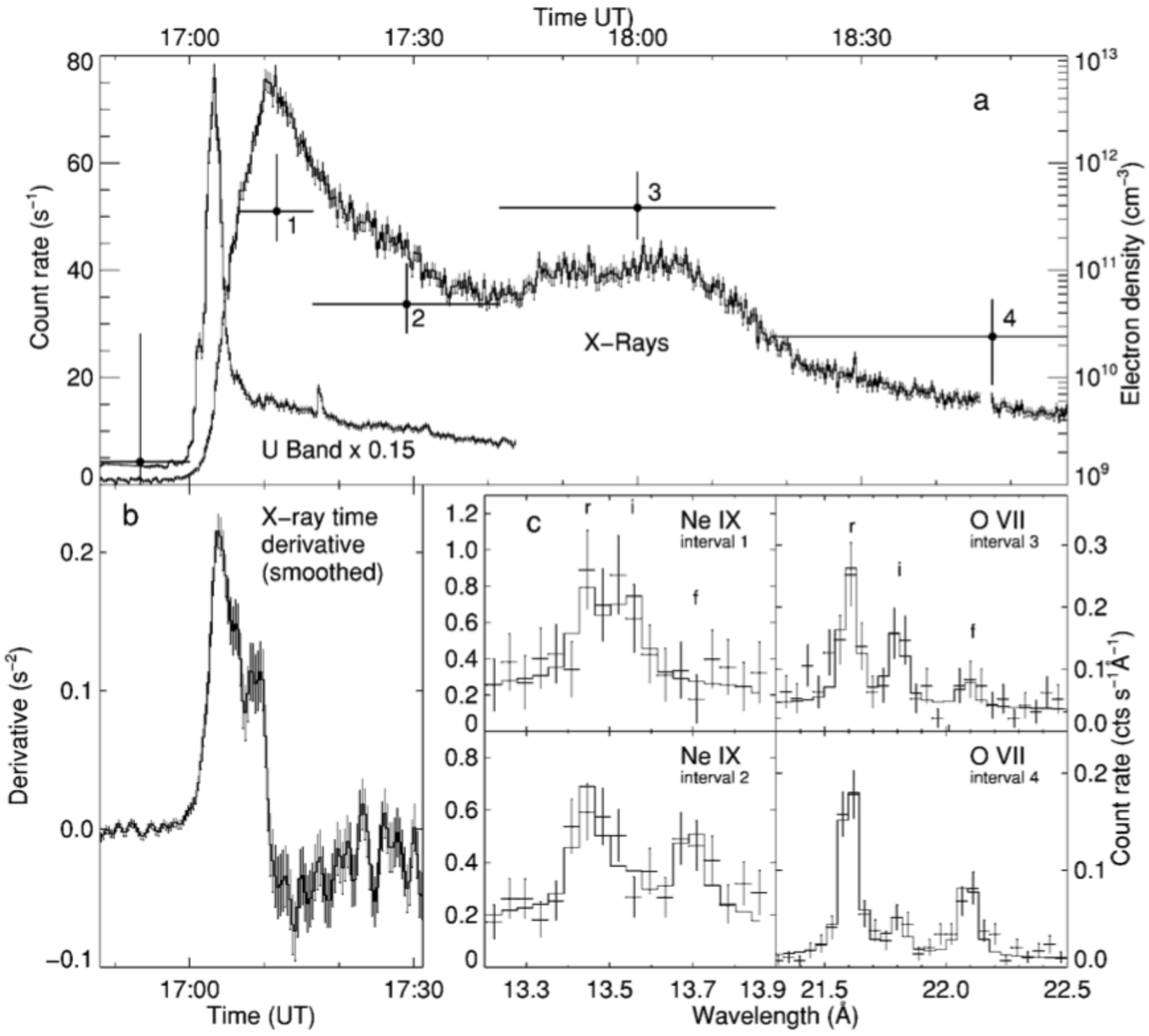
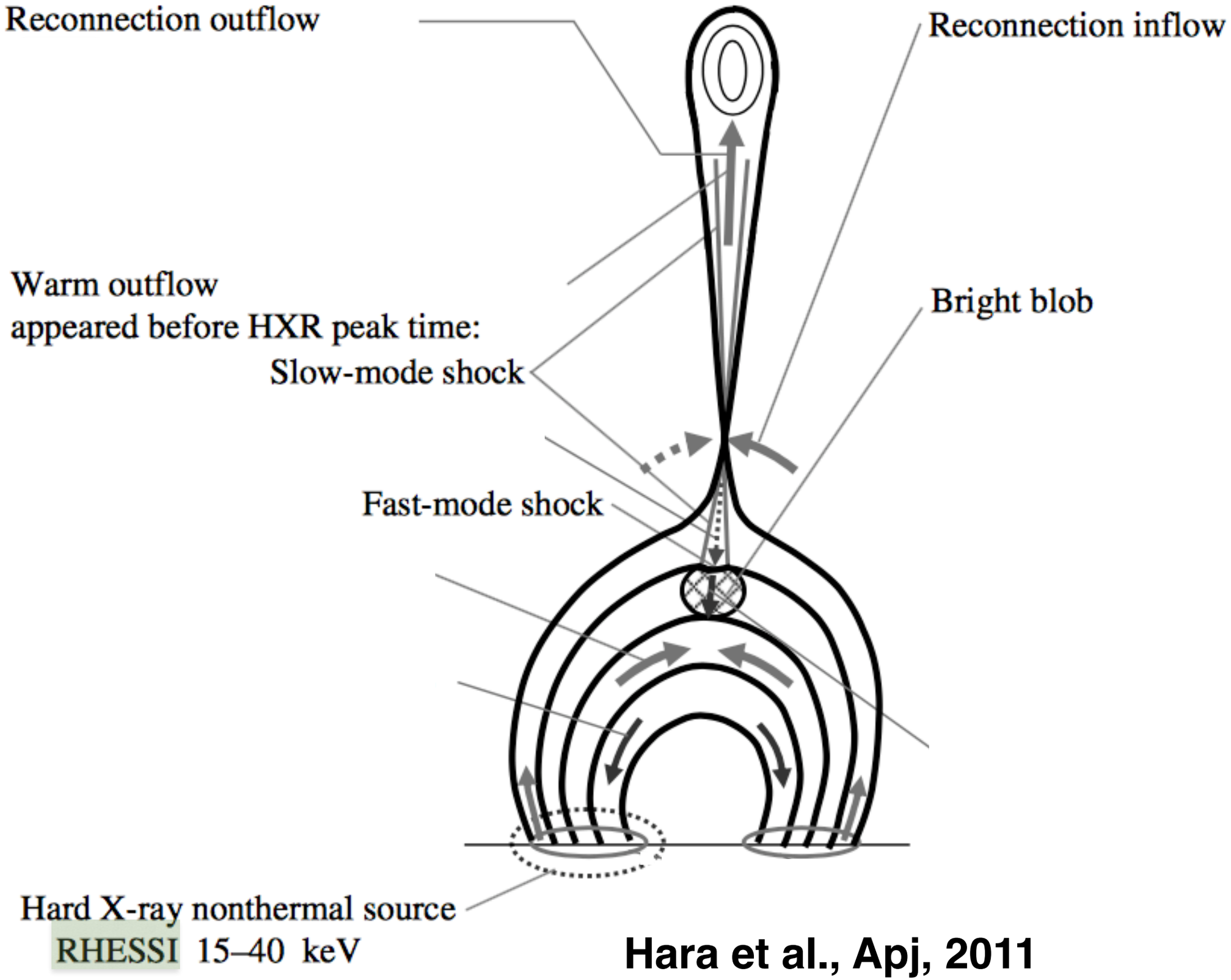


Lynx: will improve quality spectra with time slices resolving fast processes

Güdel et al. 2002
XMM-Newton

Summary of observations
What could Lynx observe?



Hara et al., Apj, 2011

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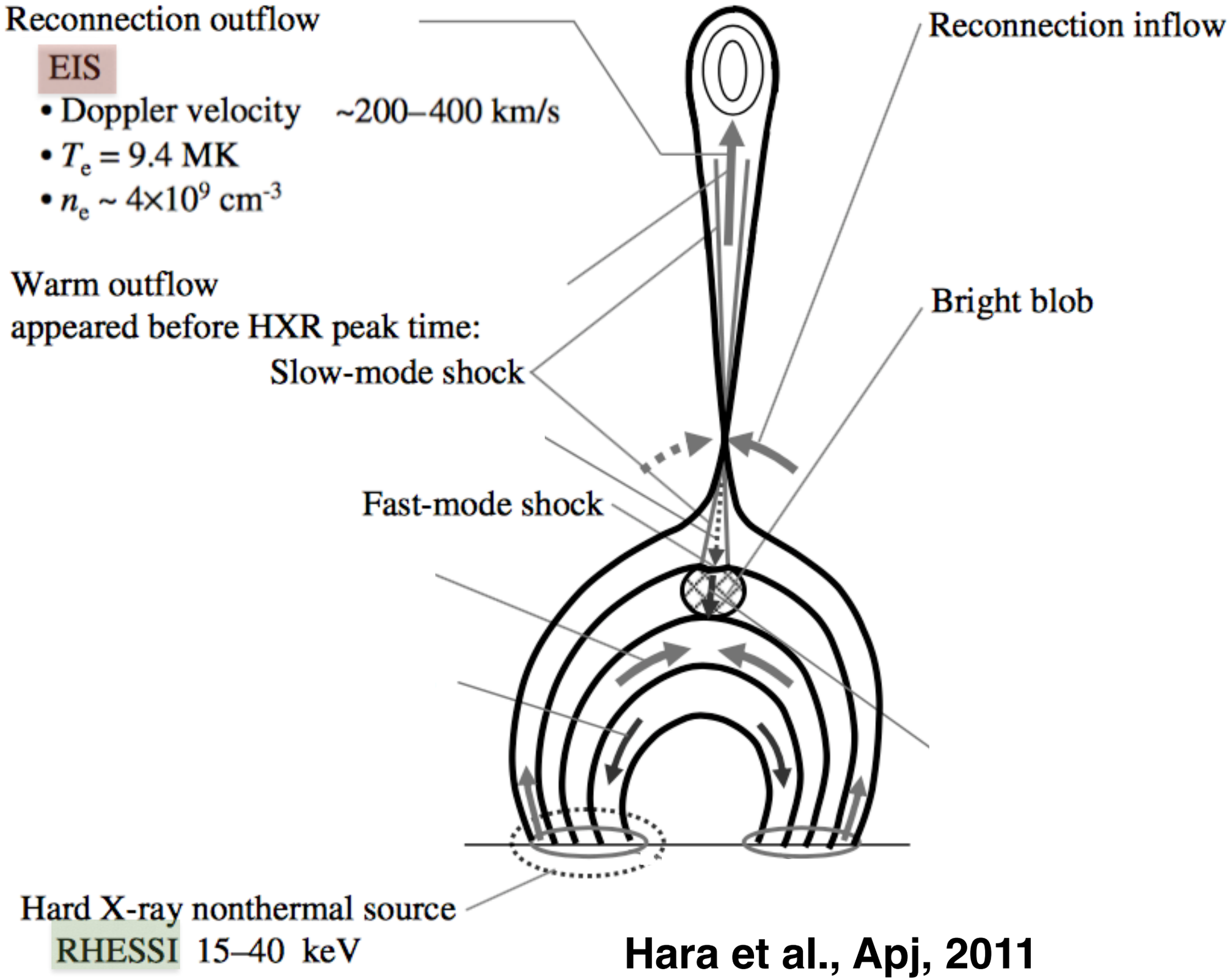


Hara et al., Apj, 2011

Summary of observations
What could Lynx observe?

Reconnection outflow

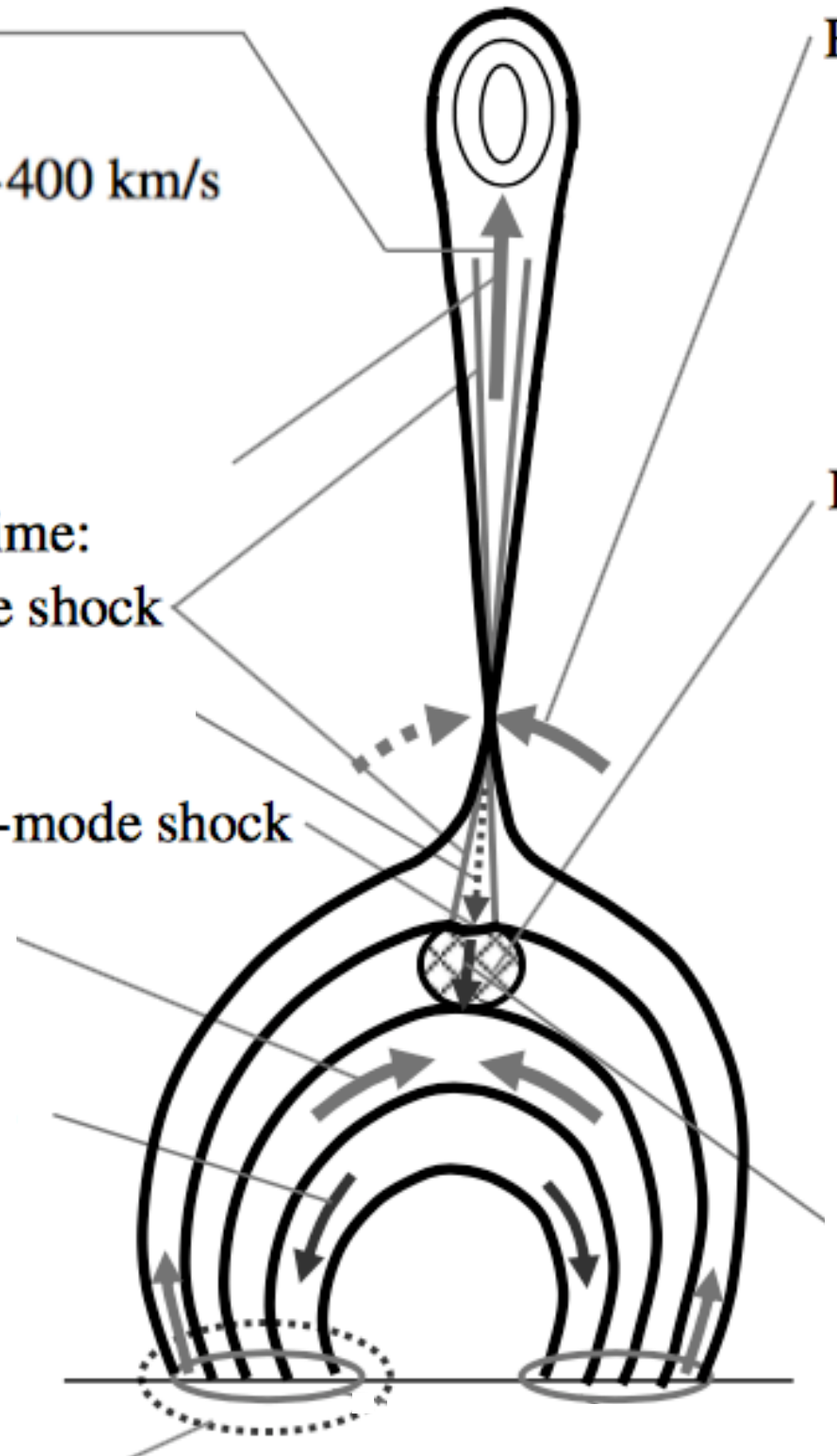
EIS

- Doppler velocity ~200–400 km/s
- $T_e = 9.4$ MK
- $n_e \sim 4\times10^9$ cm^{-3}

Warm outflow
appeared before HXR peak time:

Slow-mode shock

Fast-mode shock



Reconnection inflow

Bright blob

- EIS

  $T_e = 12$ MK

  $n_e \sim 1\times10^{10}$ cm^{-3}

  $V_{NT} \sim 100$ km/s at impulsive phase

- XRT: faint X-ray enhancement
- RHESSI 4–6 keV thermal source

  $T_e = 12$ MK from HXR spectrum

Hard X-ray nonthermal source
RHESSI 15–40 keV

Hara et al., Apj, 2011

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EIS

Downflow: $V_D \sim 10$ km/s
EIS

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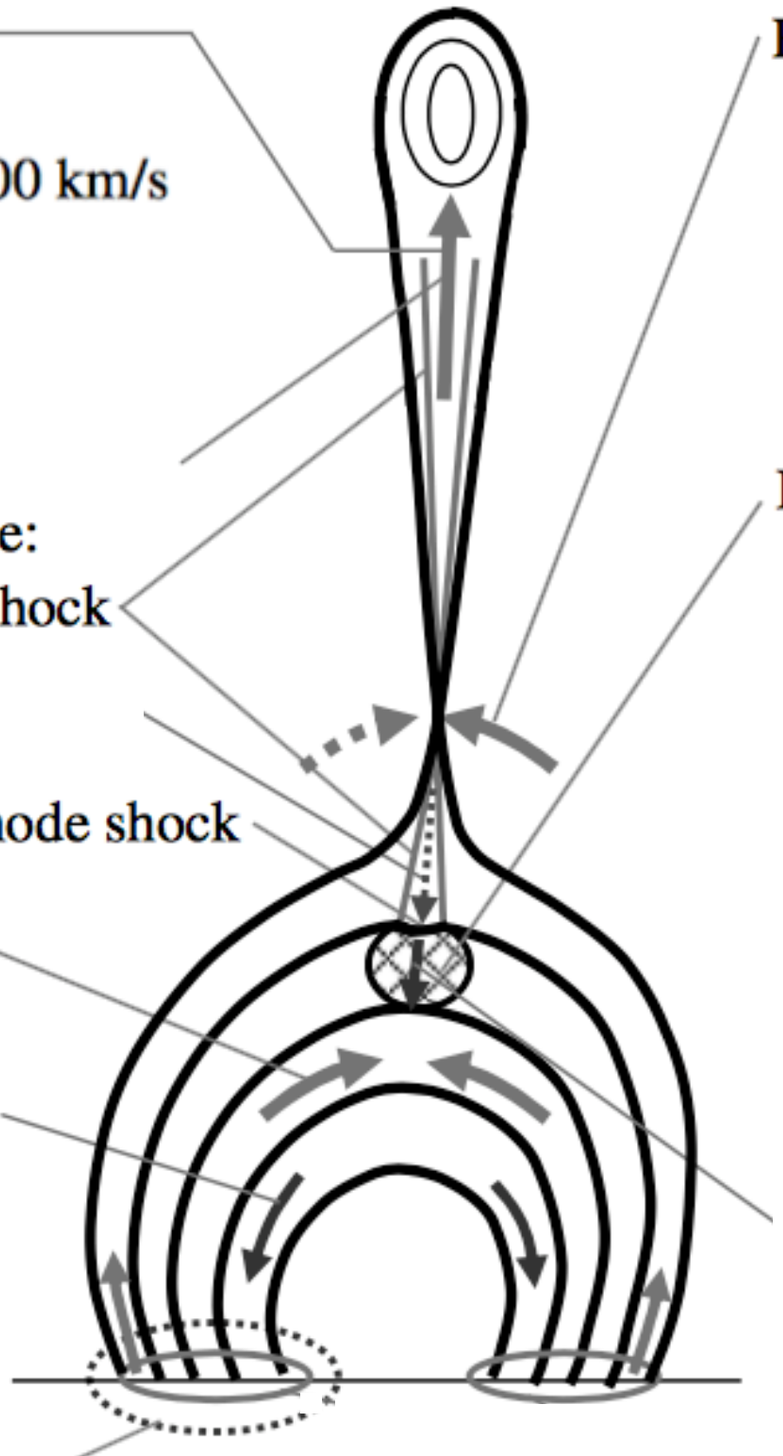

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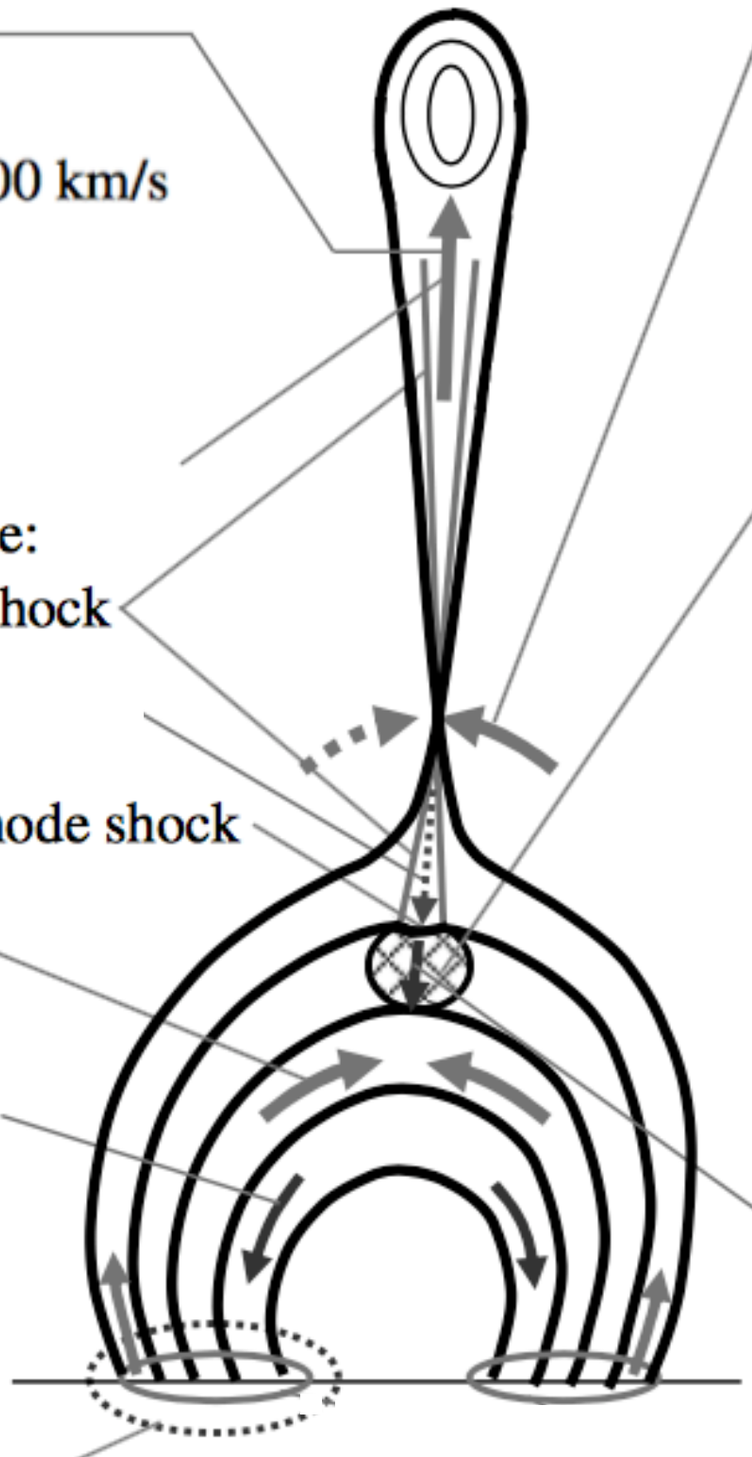

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Downward motion V_D ~ 30 km/s
EIS

Hara et al., Apj, 2011

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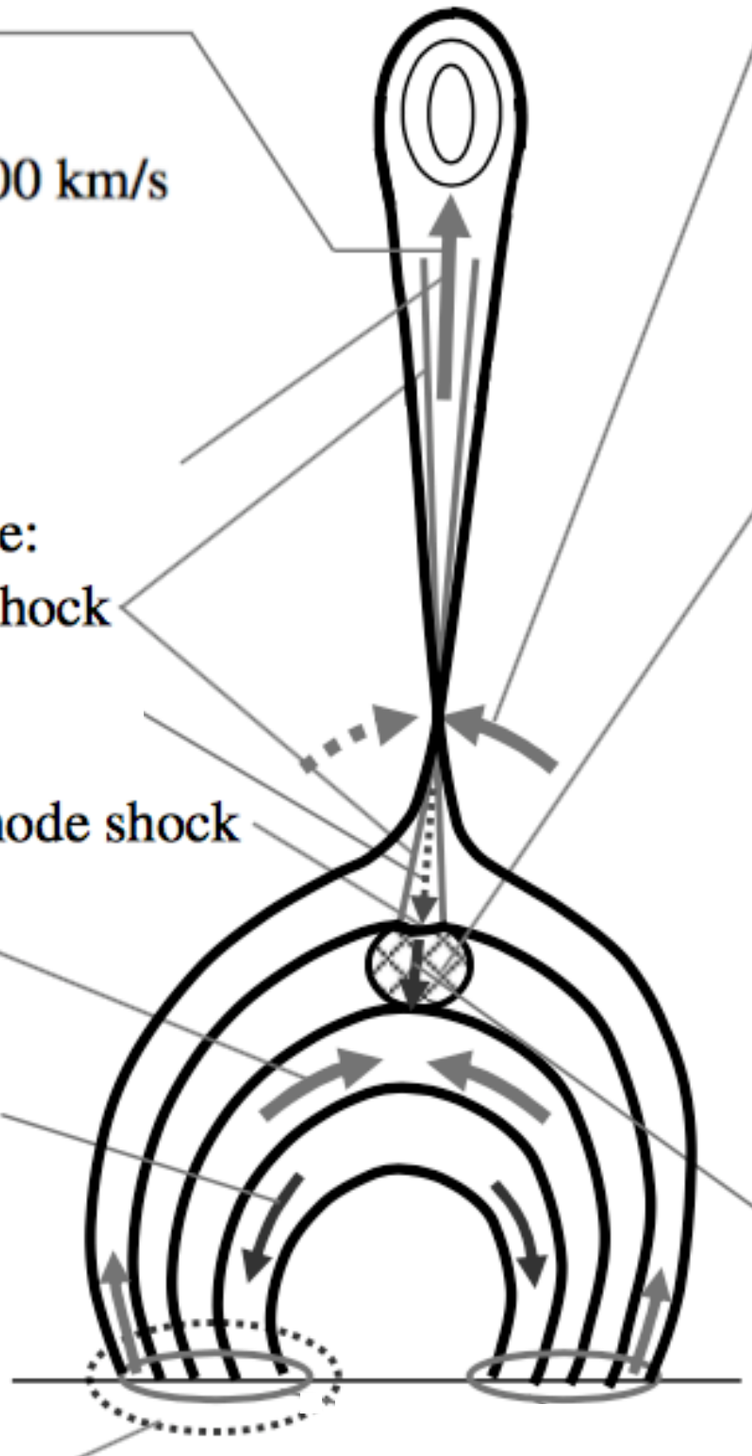

Reconnection inflow

EIS

- Doppler velocity –20 km/s
- T_e = 1.2 MK
- n_e = 2.5×10^9 cm^{-3}

Bright blob

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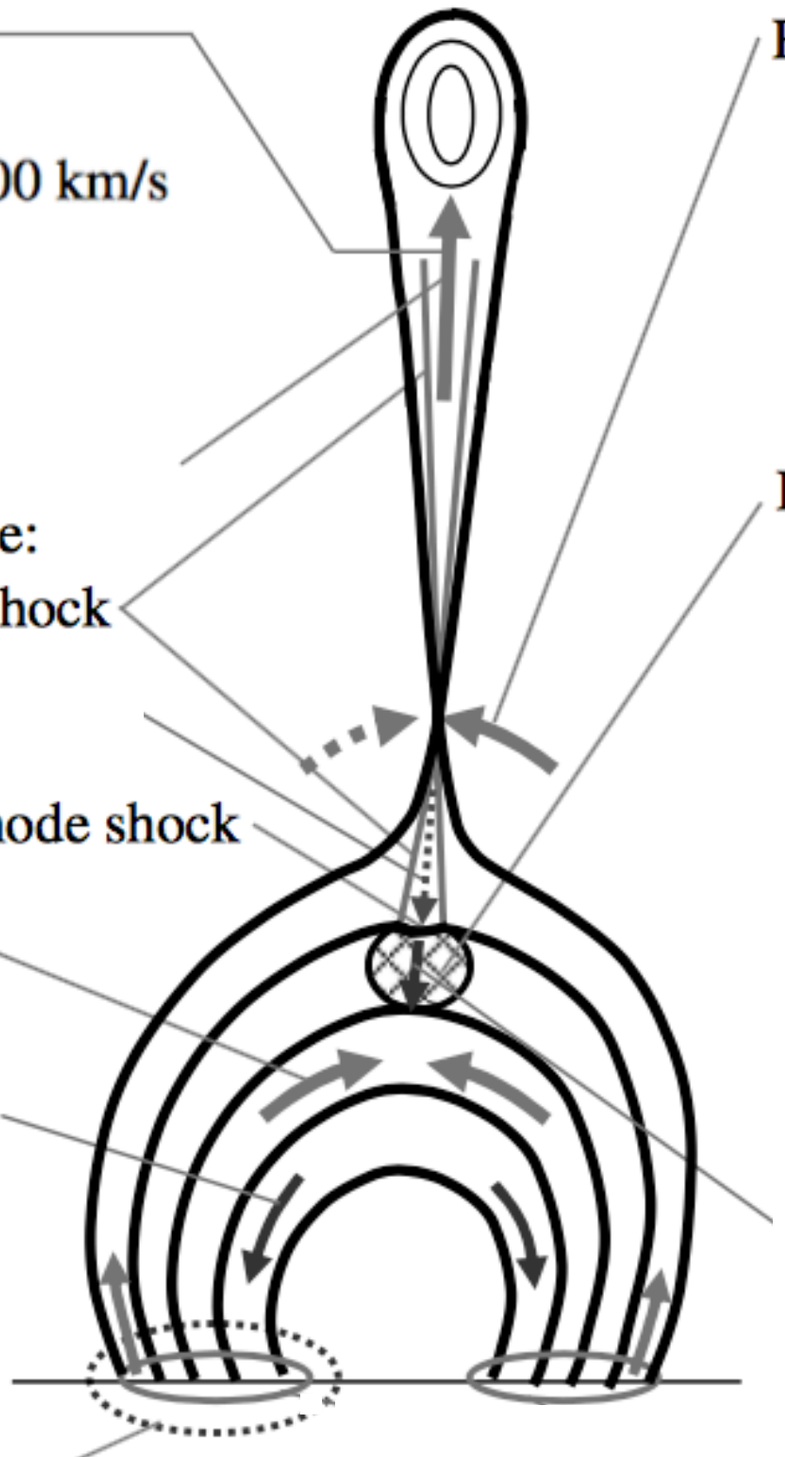

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Downward motion V_D ~ 30 km/s
EIS

R=10,000=>v~30km/s

Hara et al., Apj, 2011

Conclusions and summary

- Sun valuable laboratory, but
  - Does not provide all the answers
- Stellar flares might drastically change the picture
- Lynx observations hopefully will shed light into:
  - Densities, temperatures, emitting volumes and masses of hot plasma in stellar flares
  - May help disentangle thermal—non-thermal components
  - Resolve fast processes
  - Provide insights on acceleration processes
  - Blueshift measurements of relevant flows, maybe even chromospheric evaporation?