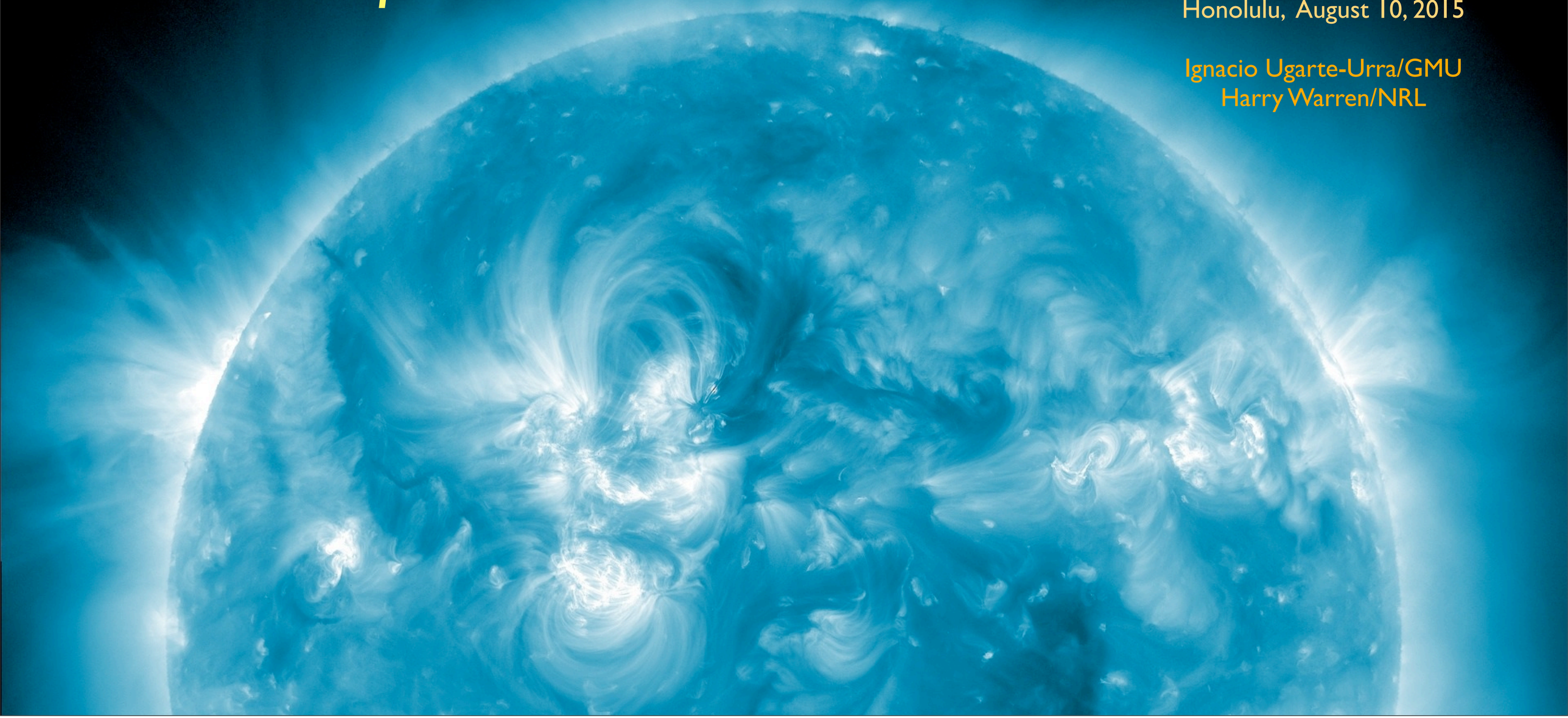
Recent Highlights on Solar Coronal Abundances from Hinode

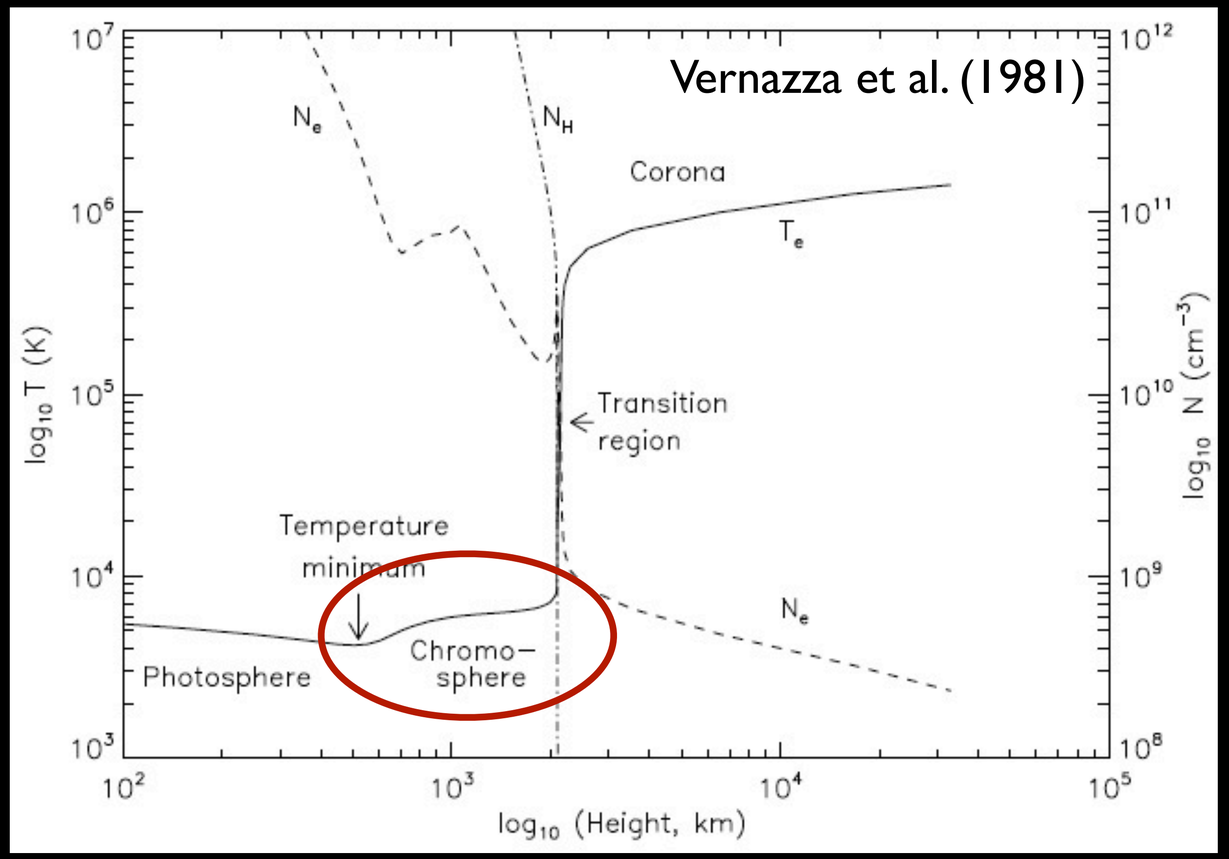
David H. Brooks
George Mason University
Honolulu, August 10, 2015

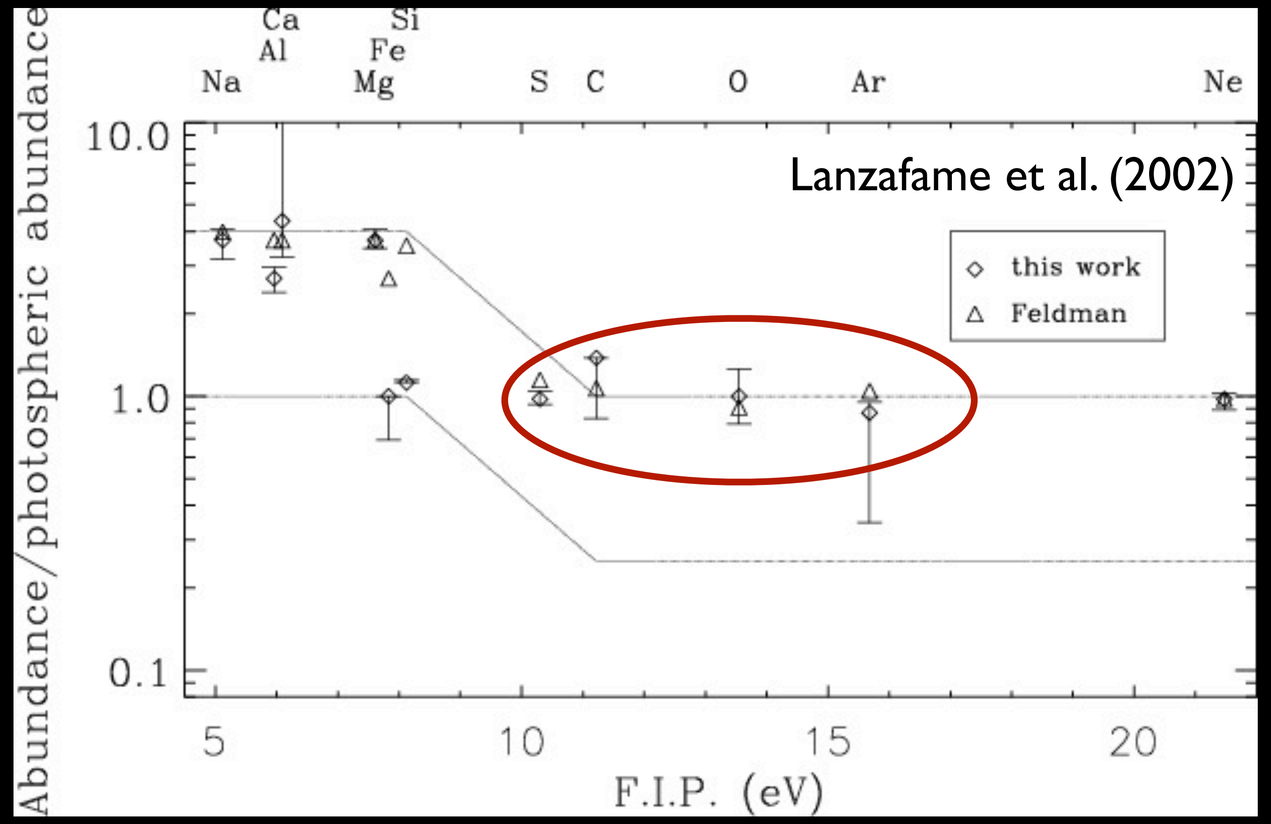
Ignacio Ugarte-Urra/GMU
Harry Warren/NRL



First Ionization Potential (FIP) Effect

Solar composition is not constant! Variations correlate with FIP, not charge/mass





High FIP elements neutral in the chromosphere ⟶ photospheric abundances in the corona

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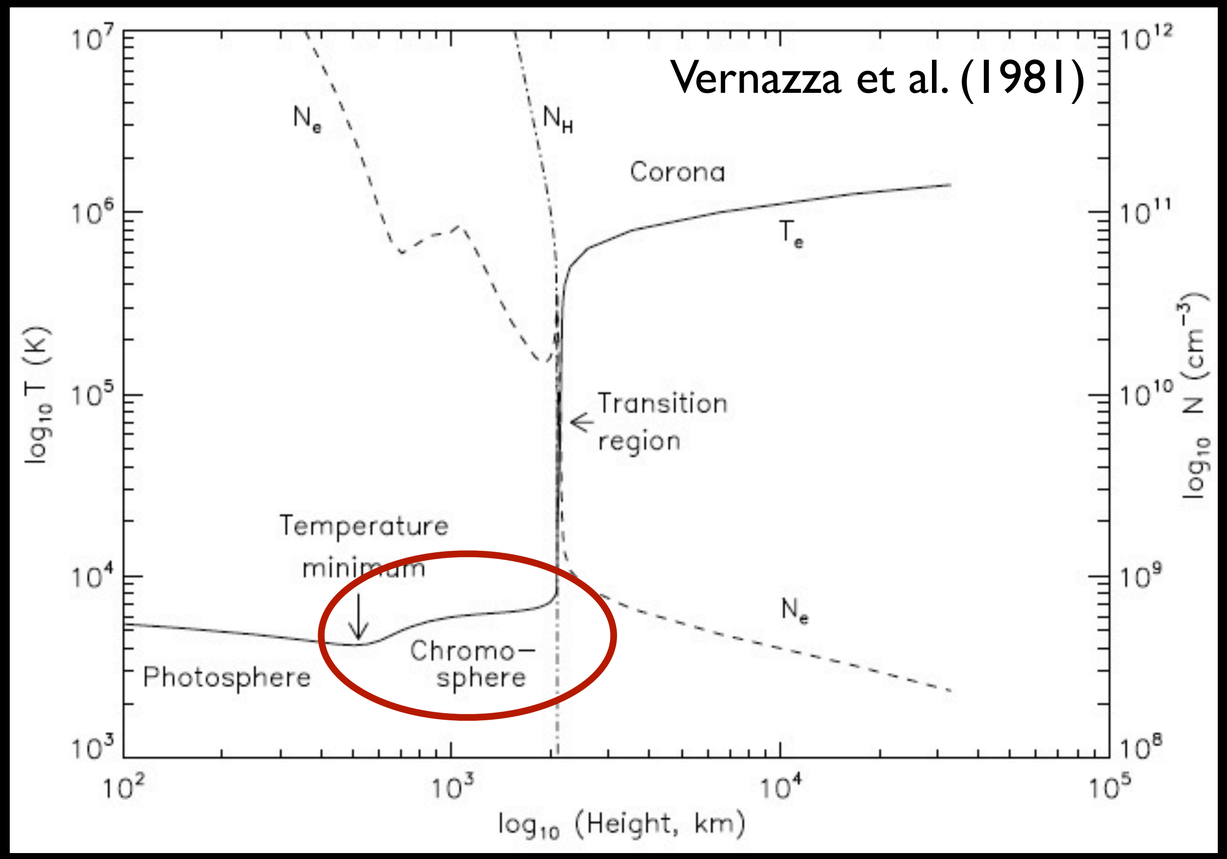

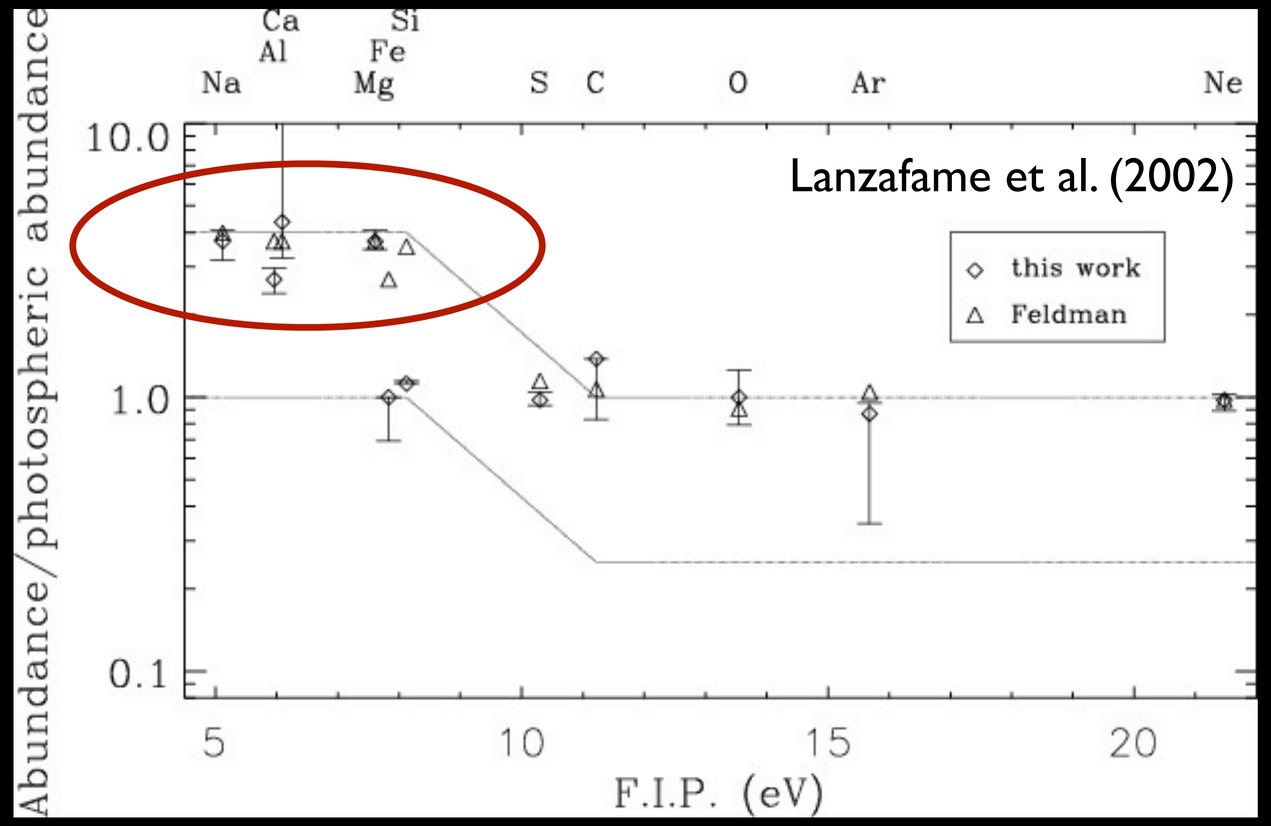

Low FIP elements ionized in the chromosphere ⟶ enhanced abundances in the corona

First Ionization Potential (FIP) Effect

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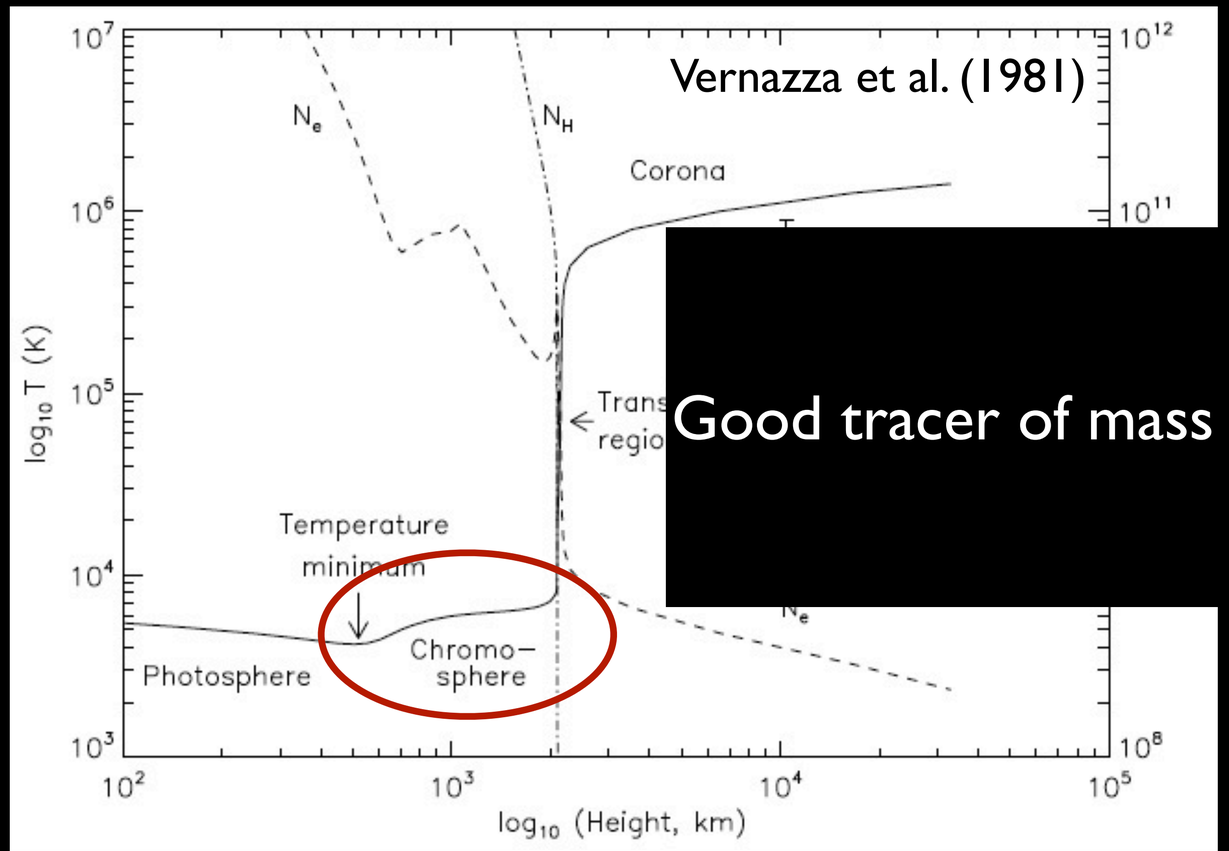

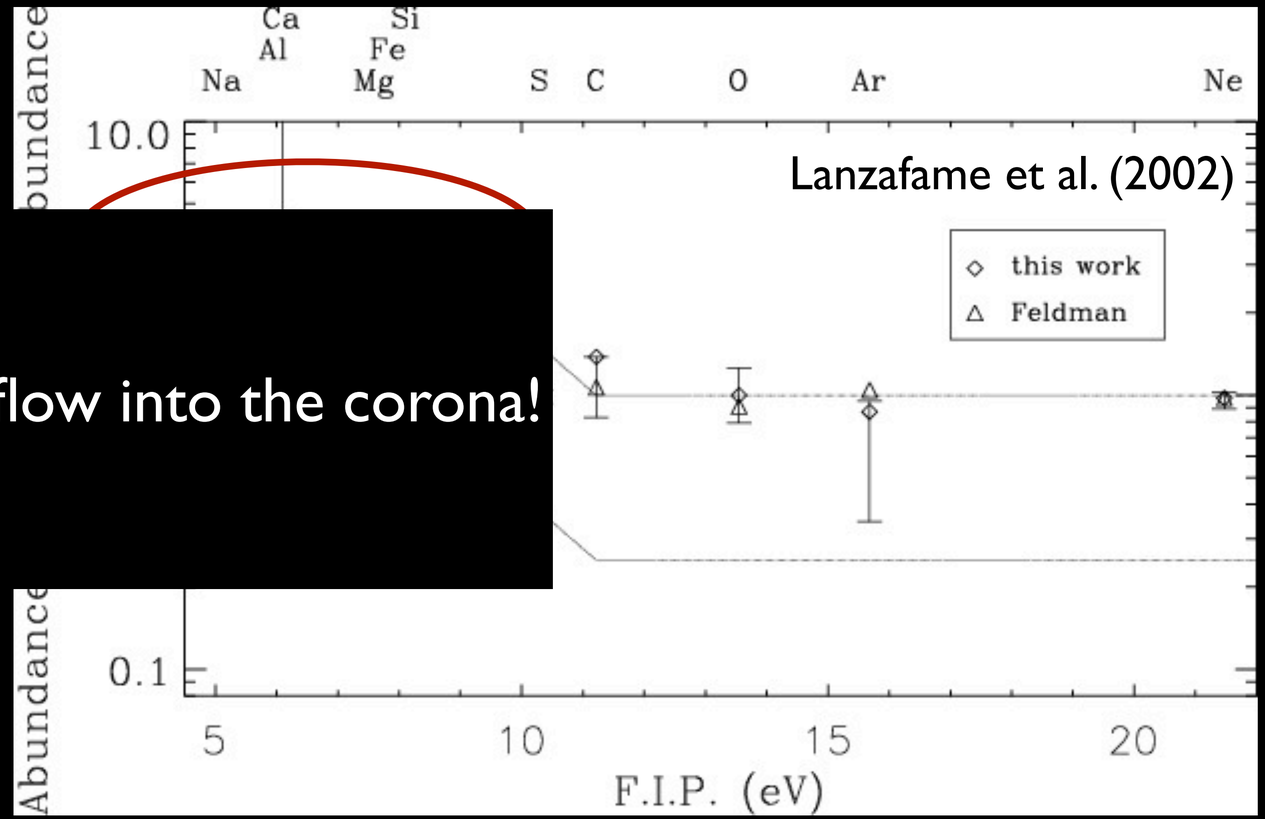

Good tracer of mass flow into the corona!

Low FIP elements ionized in the chromosphere ⟶ enhanced abundances in the corona

First Ionization Potential (FIP) Effect

Hinode/EIS has opened a new era of well constrained, high spatial resolution measurements of elemental abundances (Feldman et al. 2009, Brooks & Warren 2011)

Ar XIV 188 or 194Å/ Ca XIV 194Å: useful for active regions an flares.

Si X 258Å/S X 264Å: useful for coronal holes, quiet sun, active regions.

O, Mg, Si lines useful for impulsive events in the transition region.

-- density and temperature sensitivity can be removed by full DEM inversion using many Fe VIII-XVII lines.

FIP bias maps of whole active regions.

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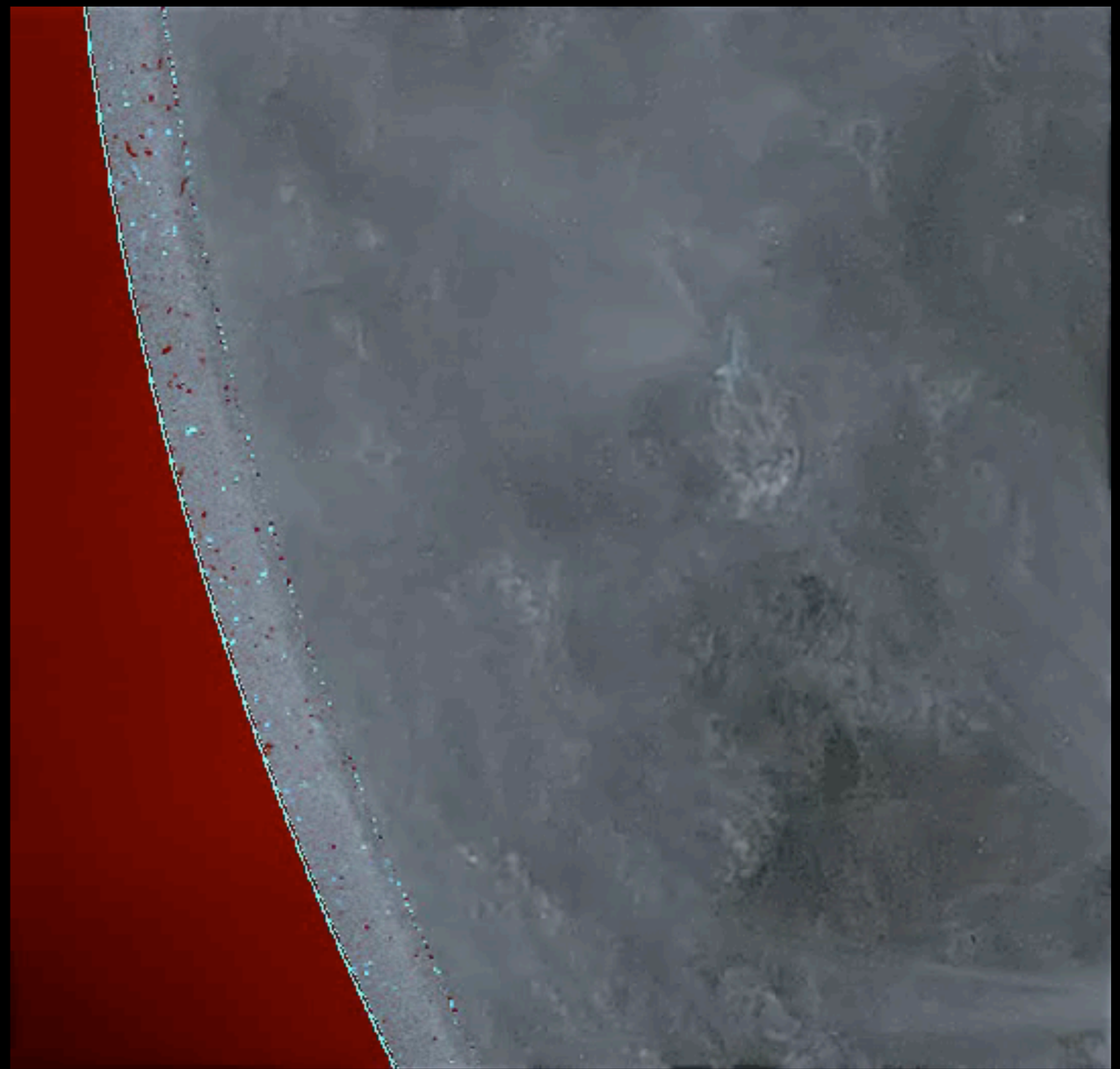
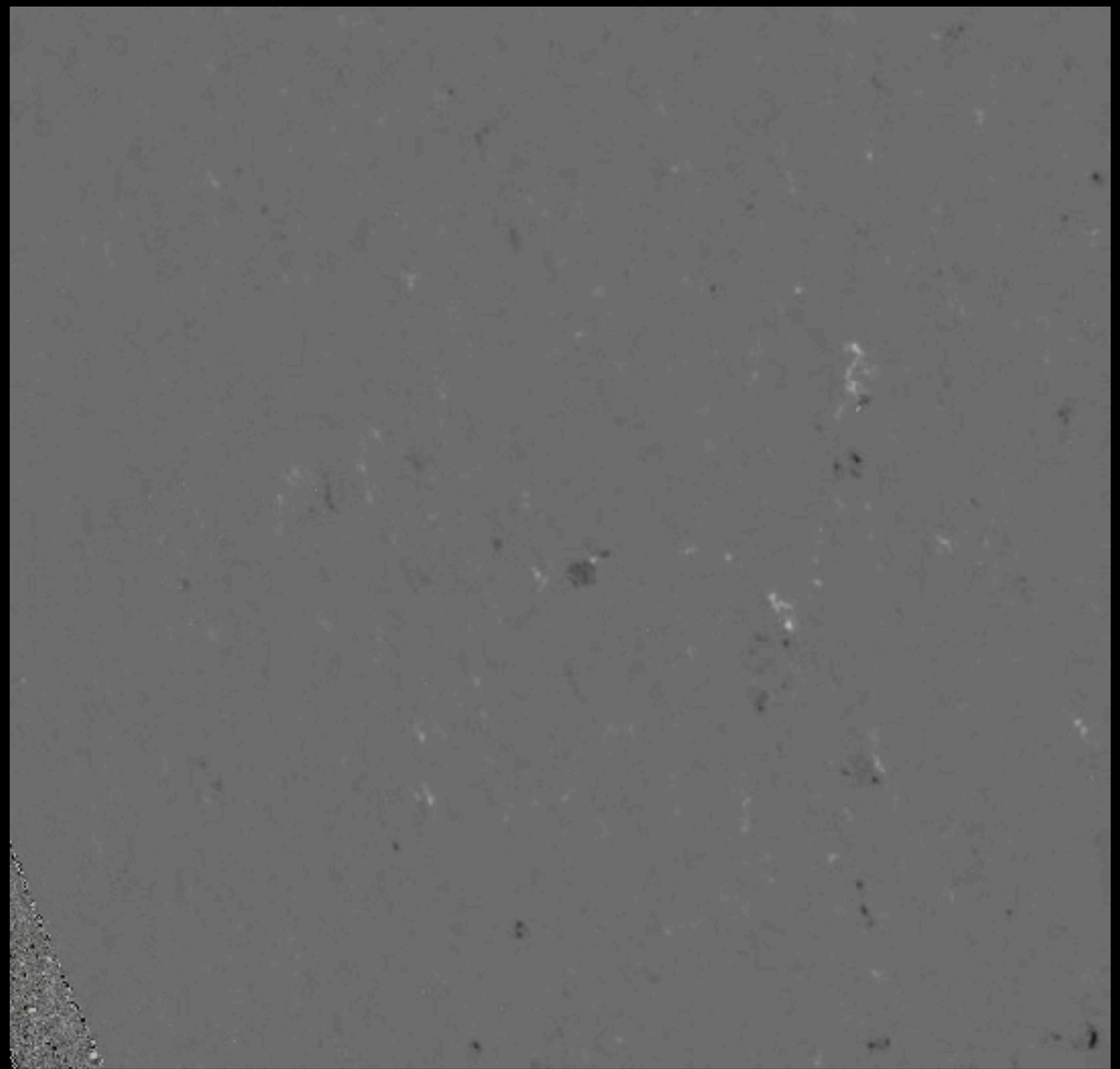
What can we learn about:

- Solar coronal heating?
- Fast and slow solar wind sources?
- Fundamental processes?

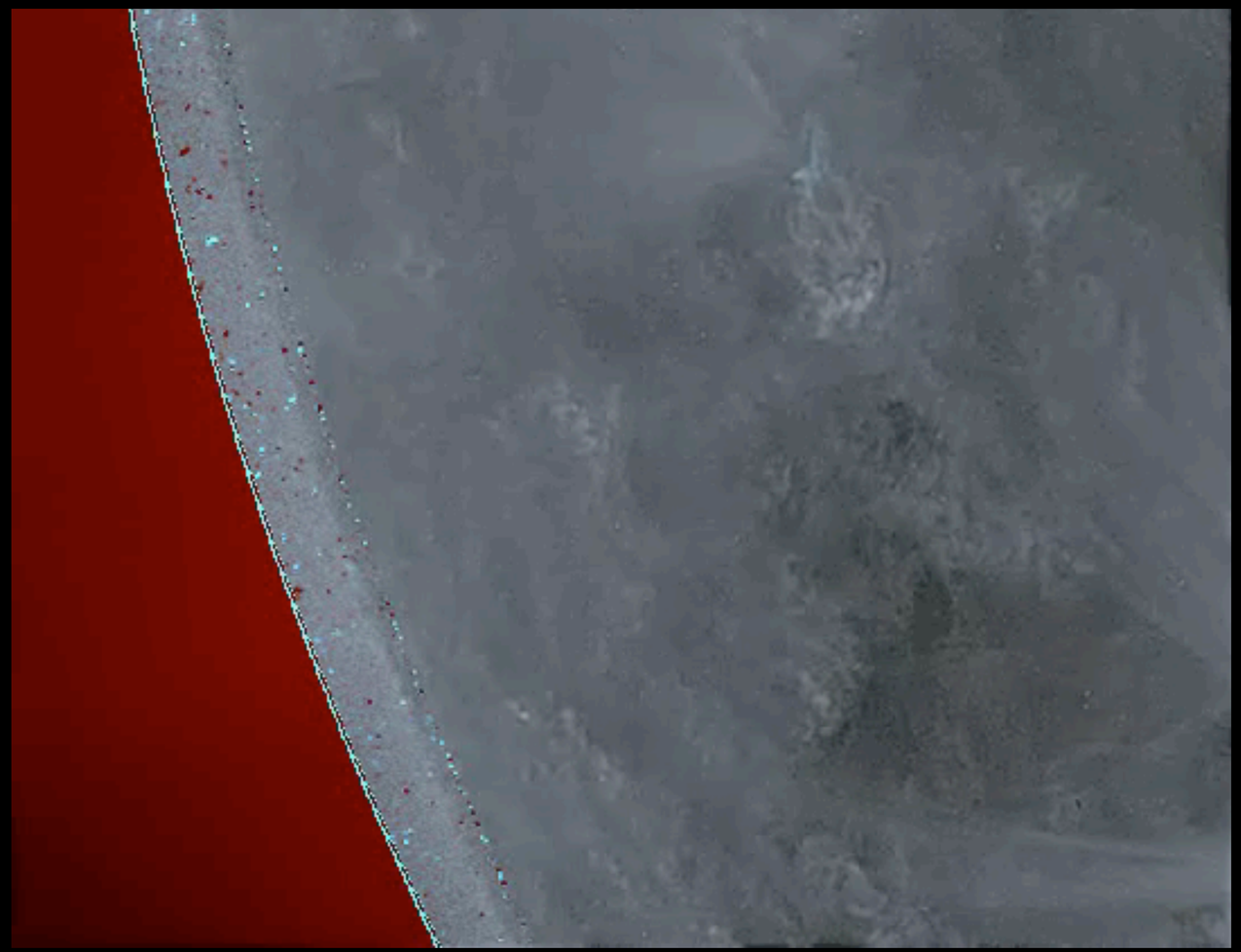
Composition Changes in Active Regions

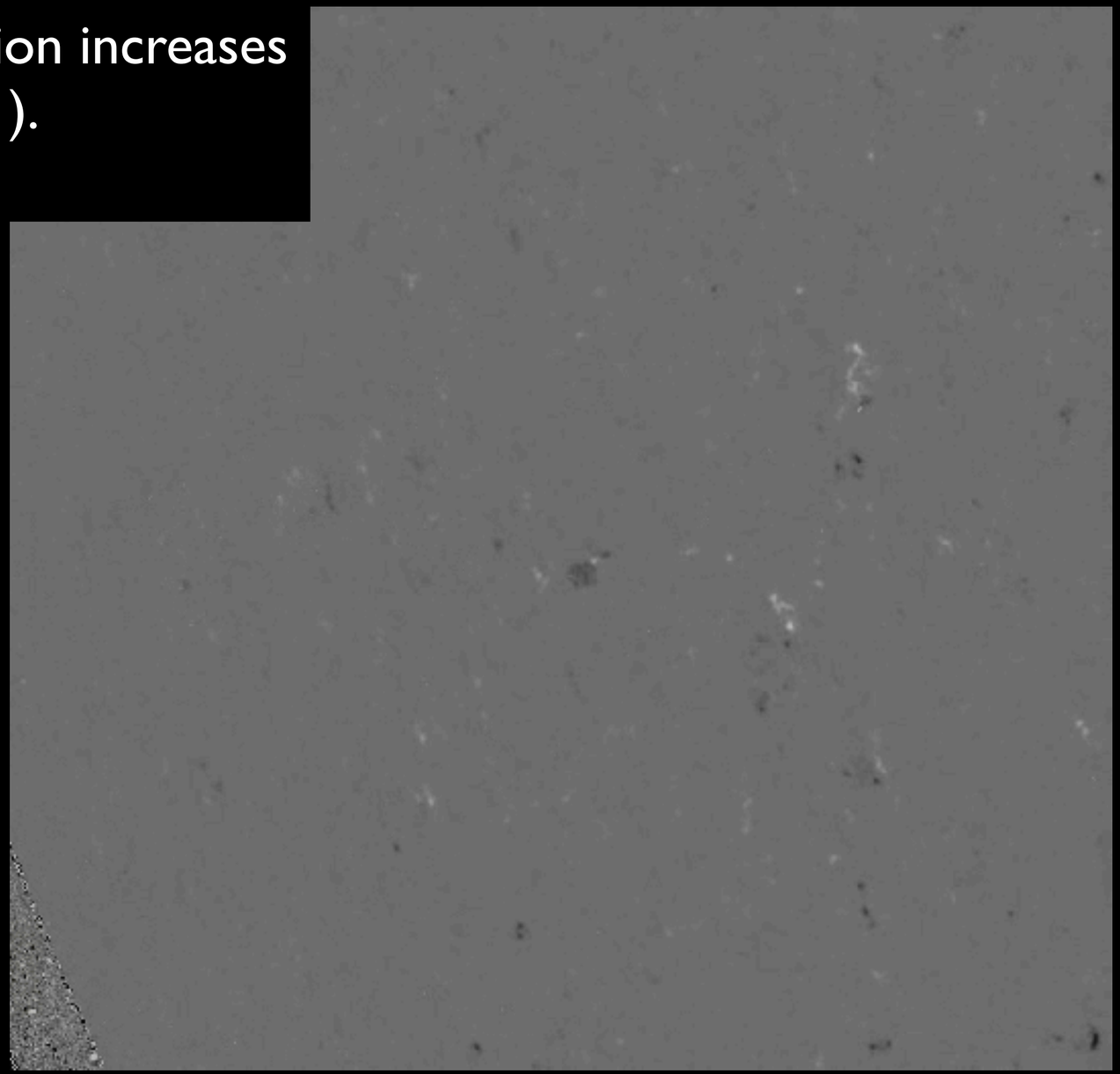




Composition Changes in Active Regions

Skylab observations suggested that AR composition increases almost linearly with age (Widing & Feldman 2001).

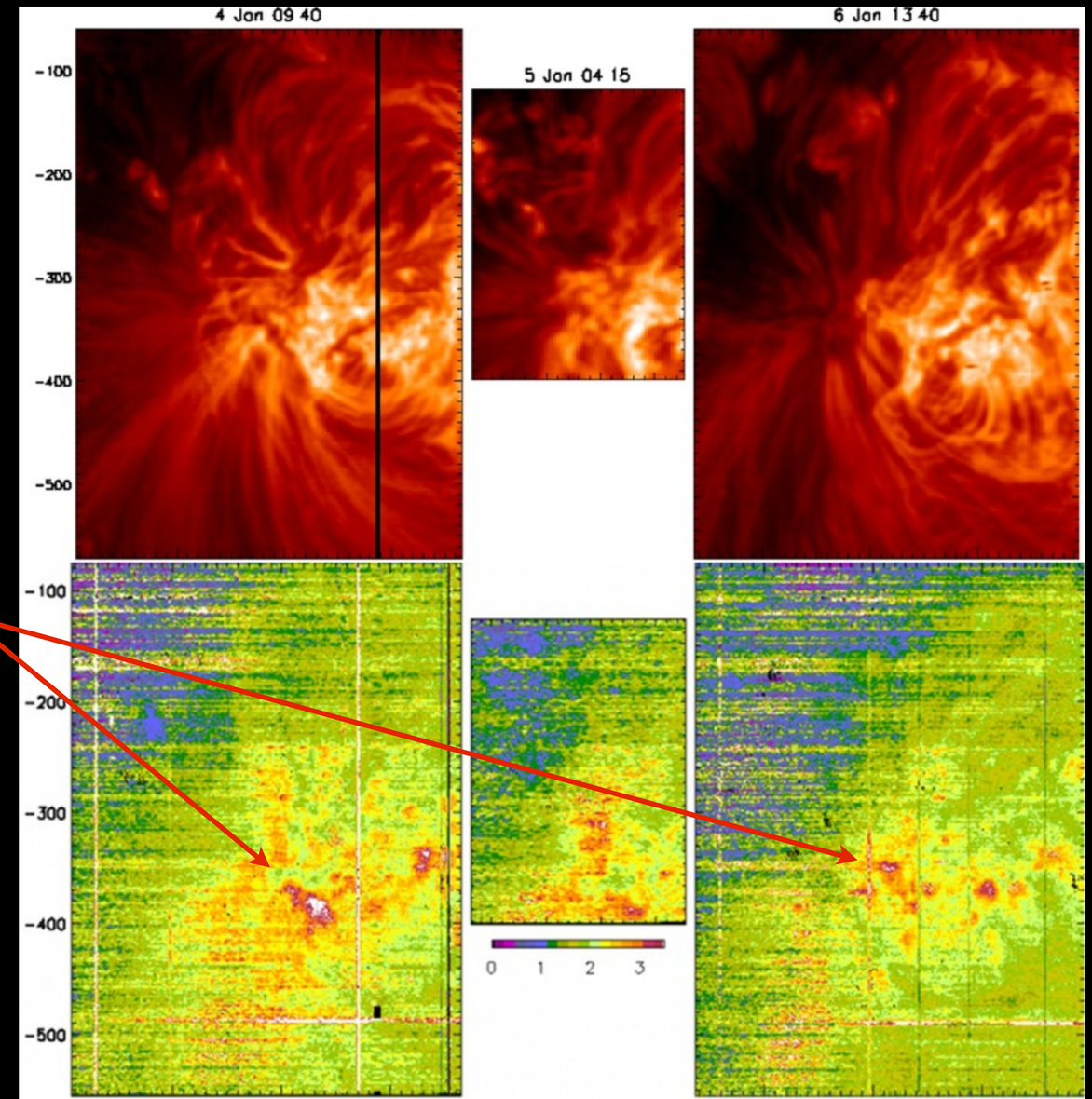




Composition Changes in Active Regions

Hinode observations show this is not always true (Baker et al. 2015):

Fractionation process is sustained in the AR core.



Composition Changes in Active Regions

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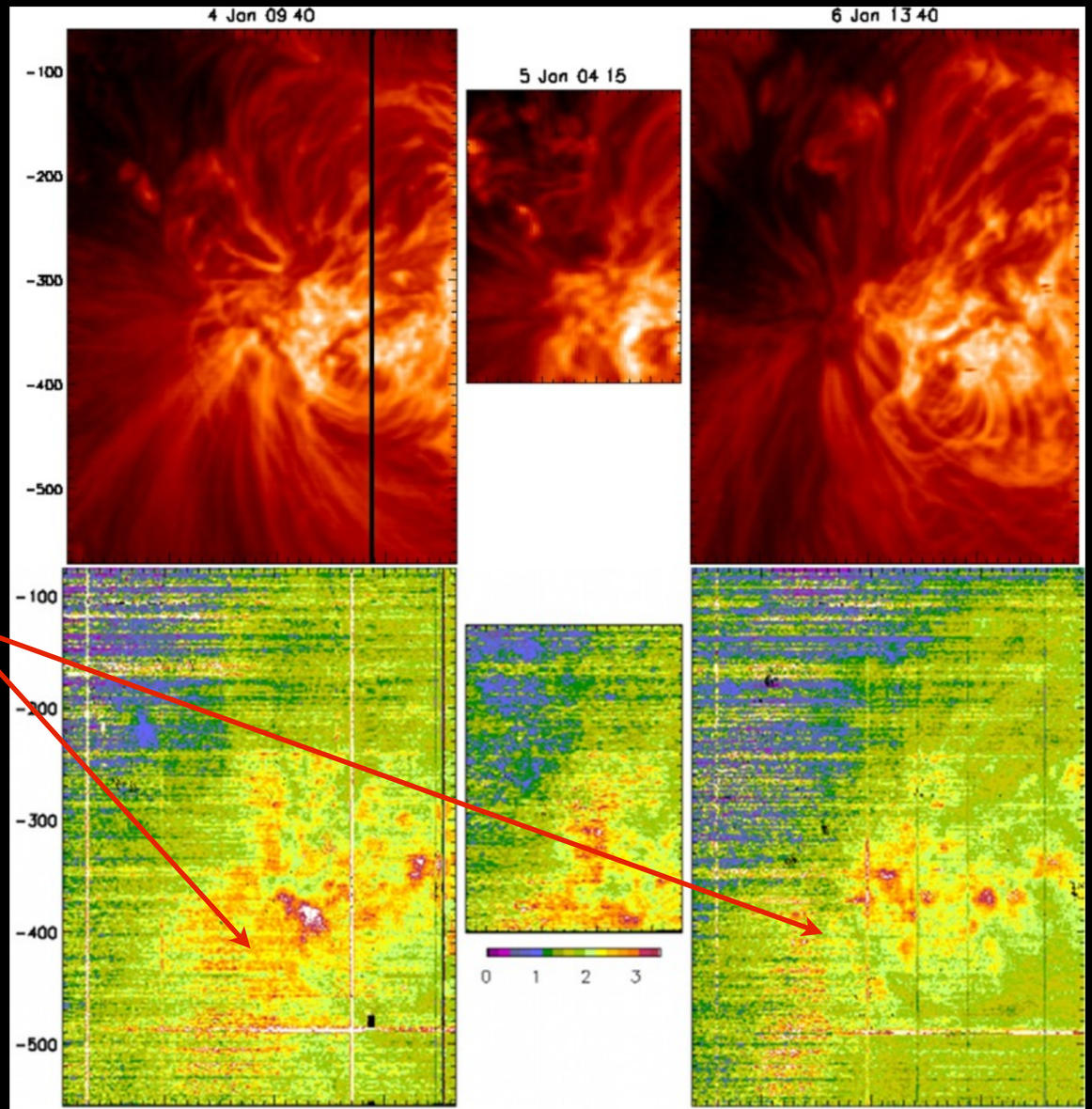
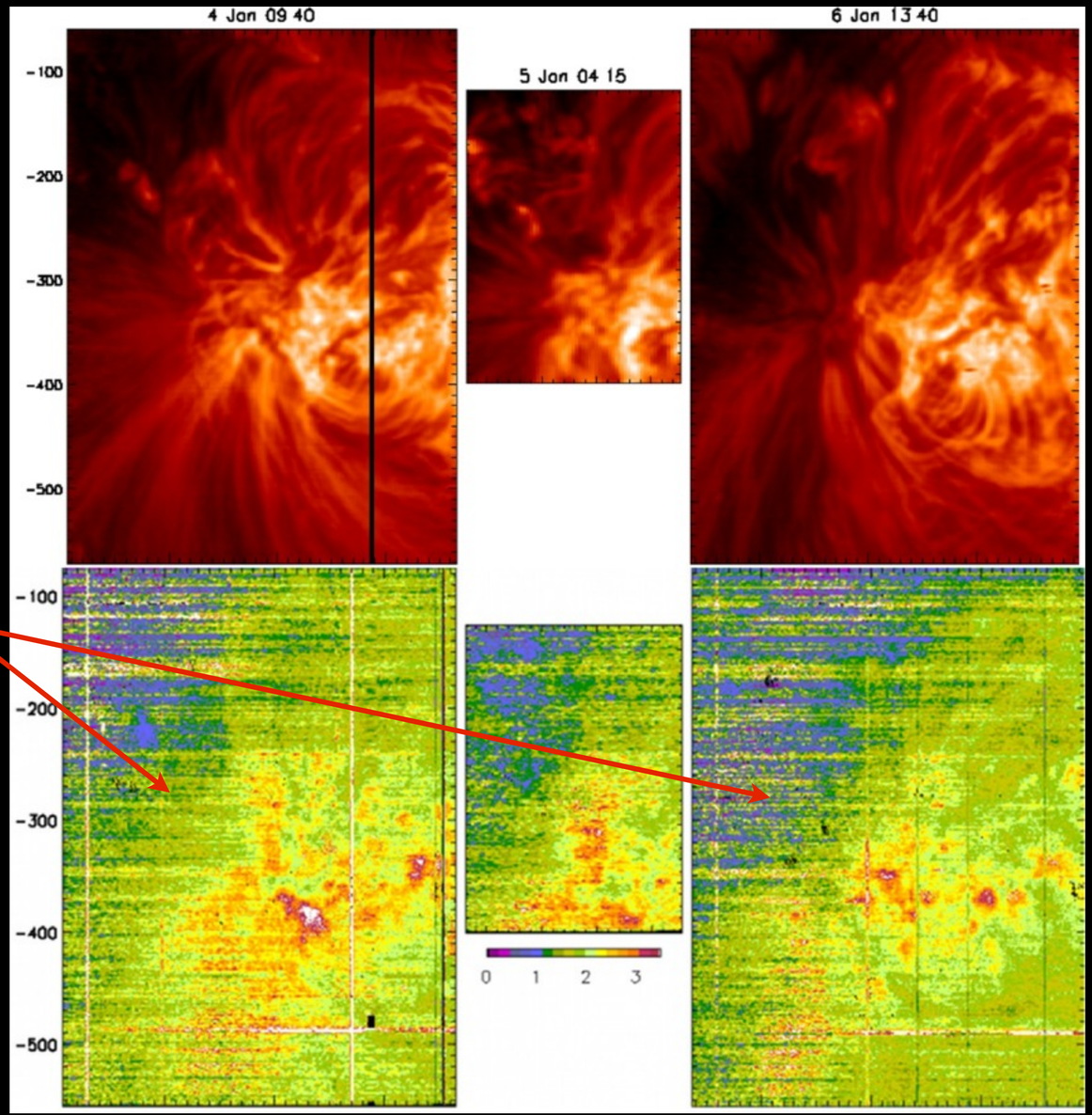
Composition of surrounding structures is reduced by photospheric flux emergence.



Composition Changes in Active Regions

Hinode observations show this is not always true (Baker et al. 2015):

Composition of coronal hole boundary reduced by mini-eruption.



Coronal Heating: What is the moss?

The moss is the bright emission at the footpoints of hot loops: Peres et al. 1994; Berger et al. 1999; Fletcher & de Pontieu 1999; Martens et al. 2000; Vourlidas et al. 2001

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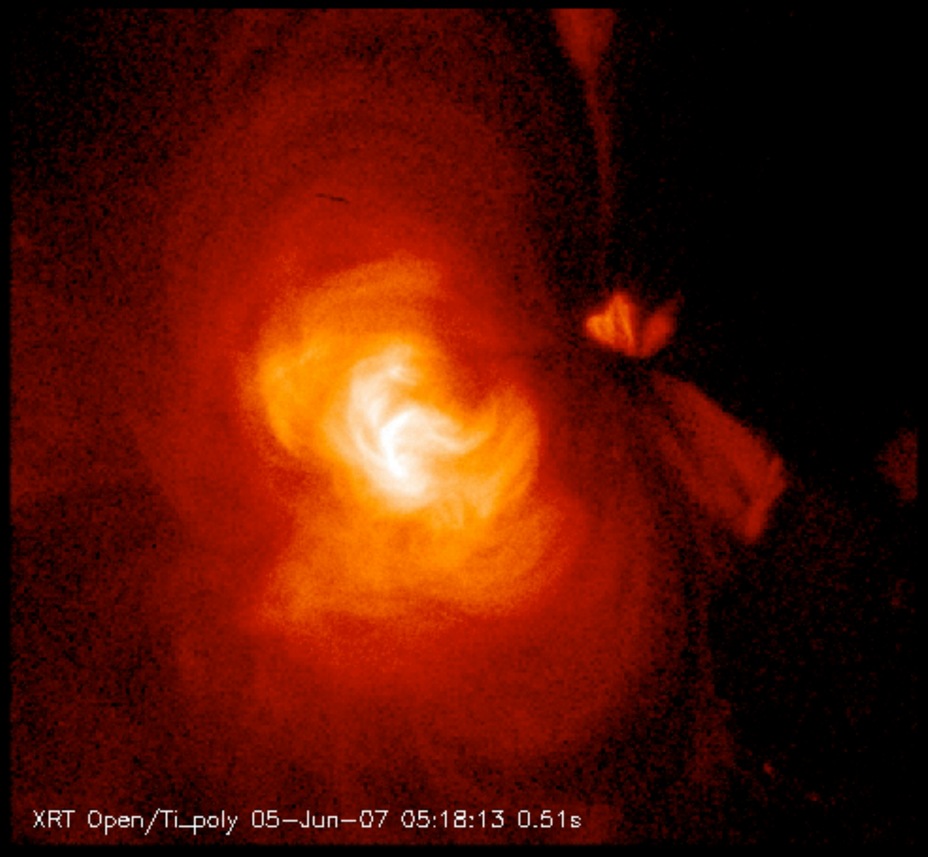
XRT Open/TiPoly (hot)



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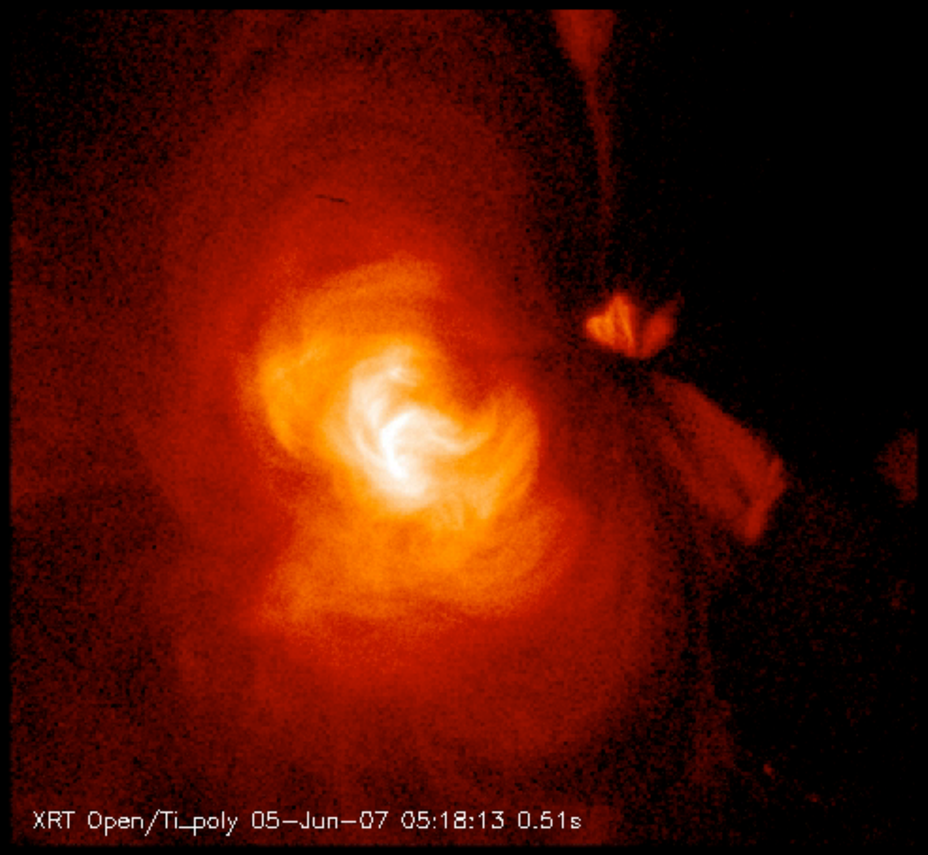
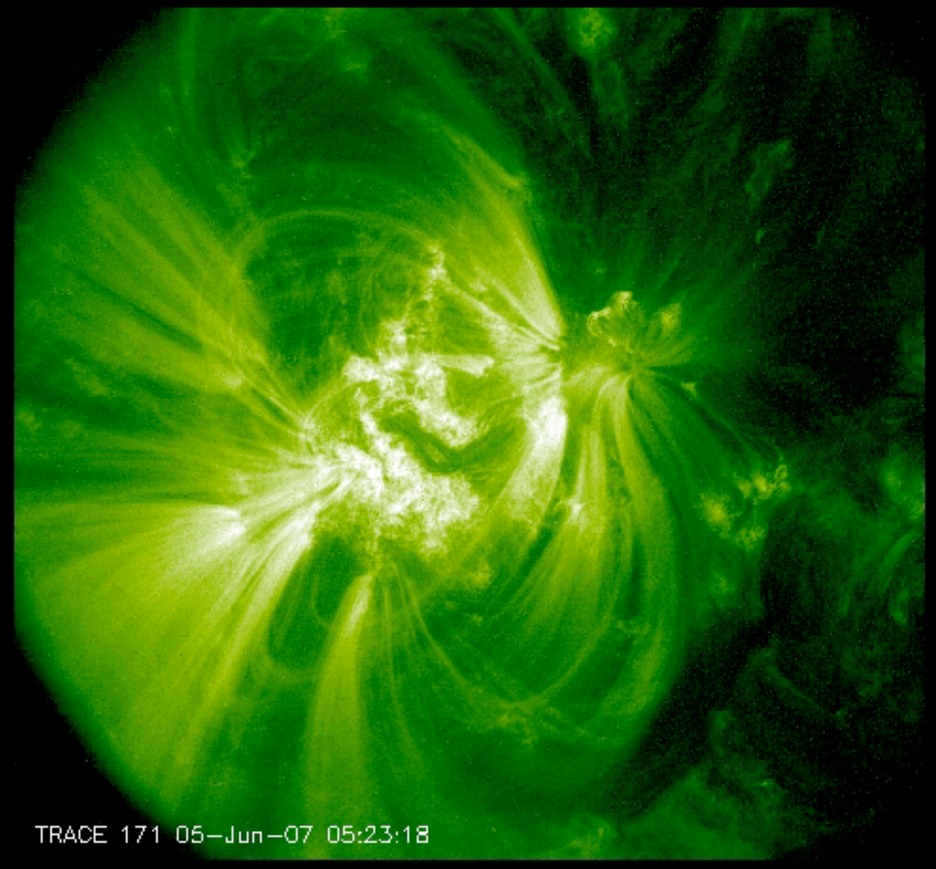


TRACE 171 Å (warm)



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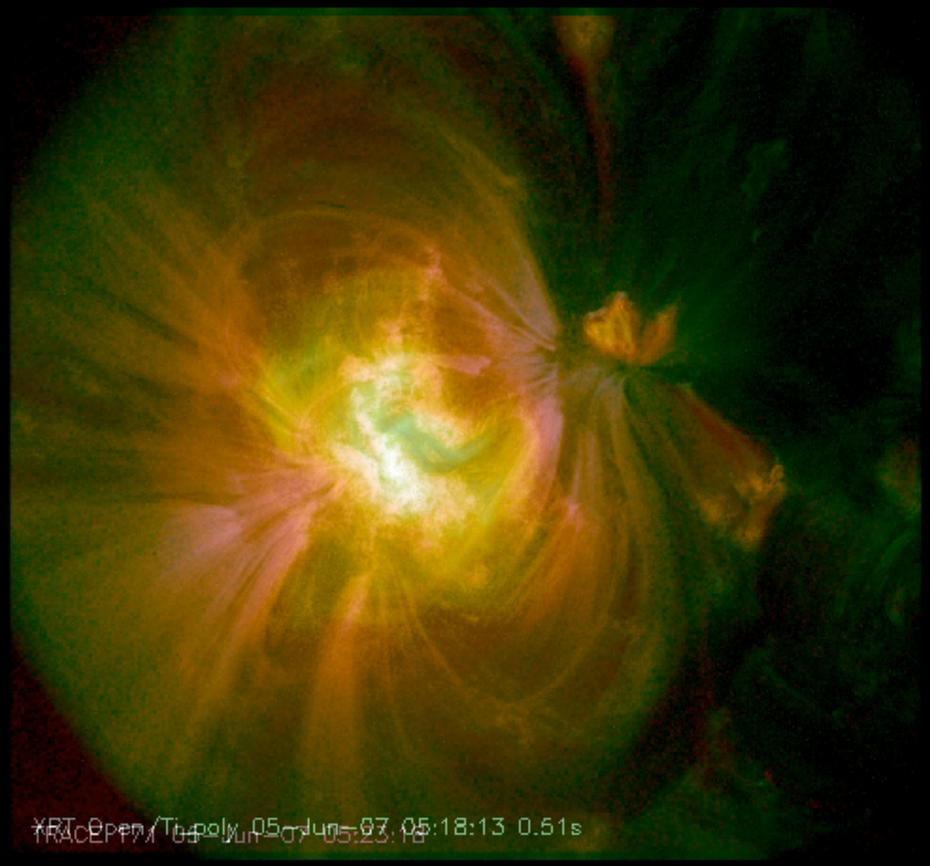

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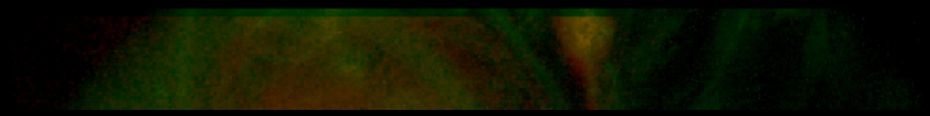
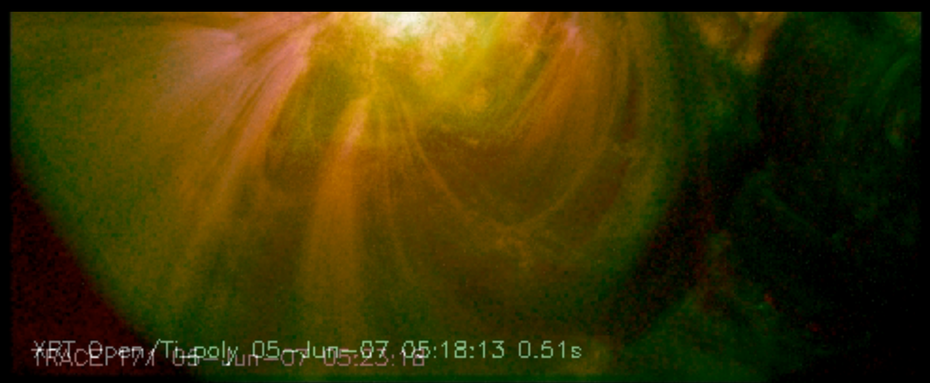
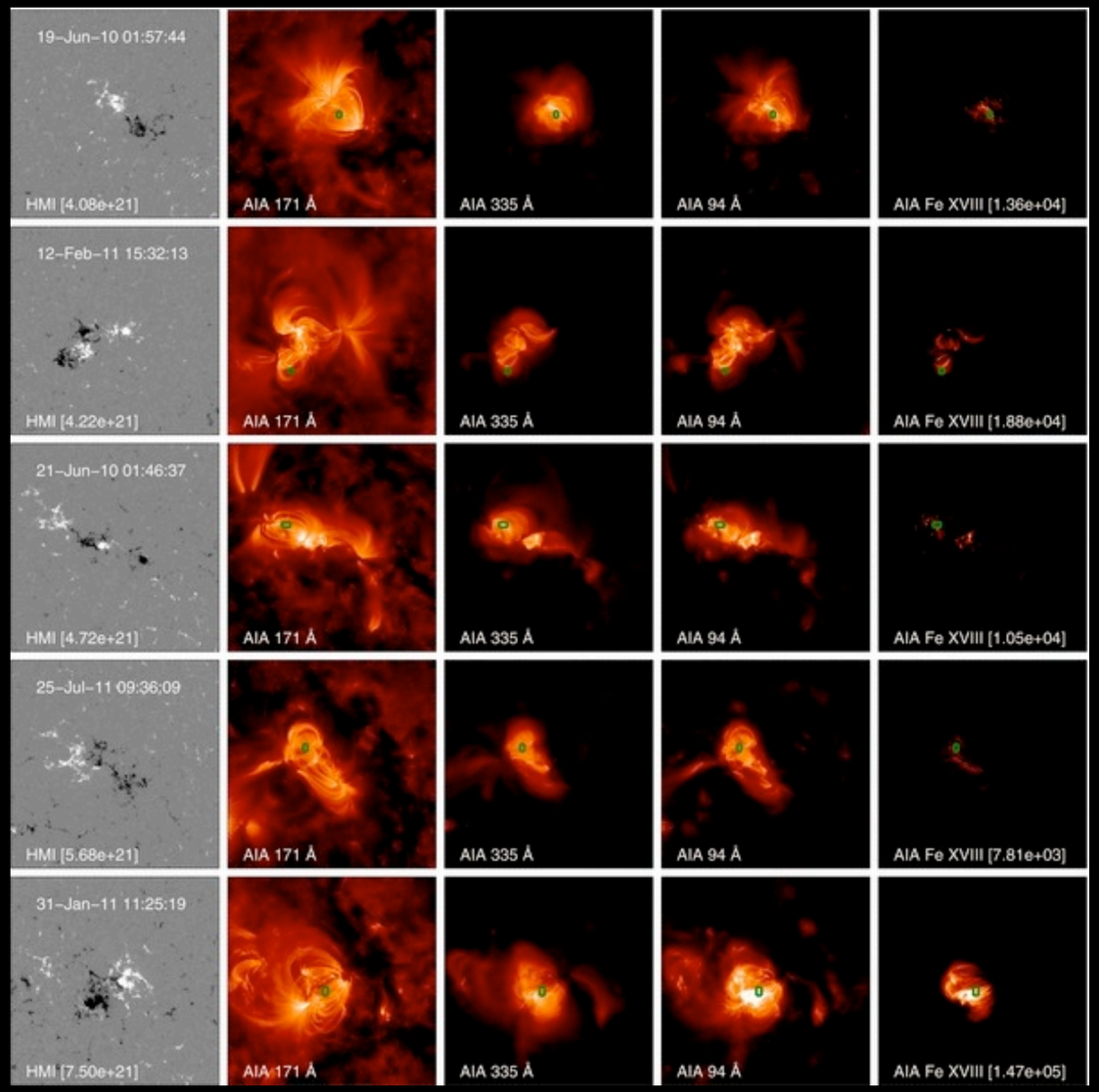


Material supplied from chromosphere? Evaporation/spicules?



Coronal Heating: Abundances in inter-moss AR core

Warren et al (2011)
Warren et al (2012)



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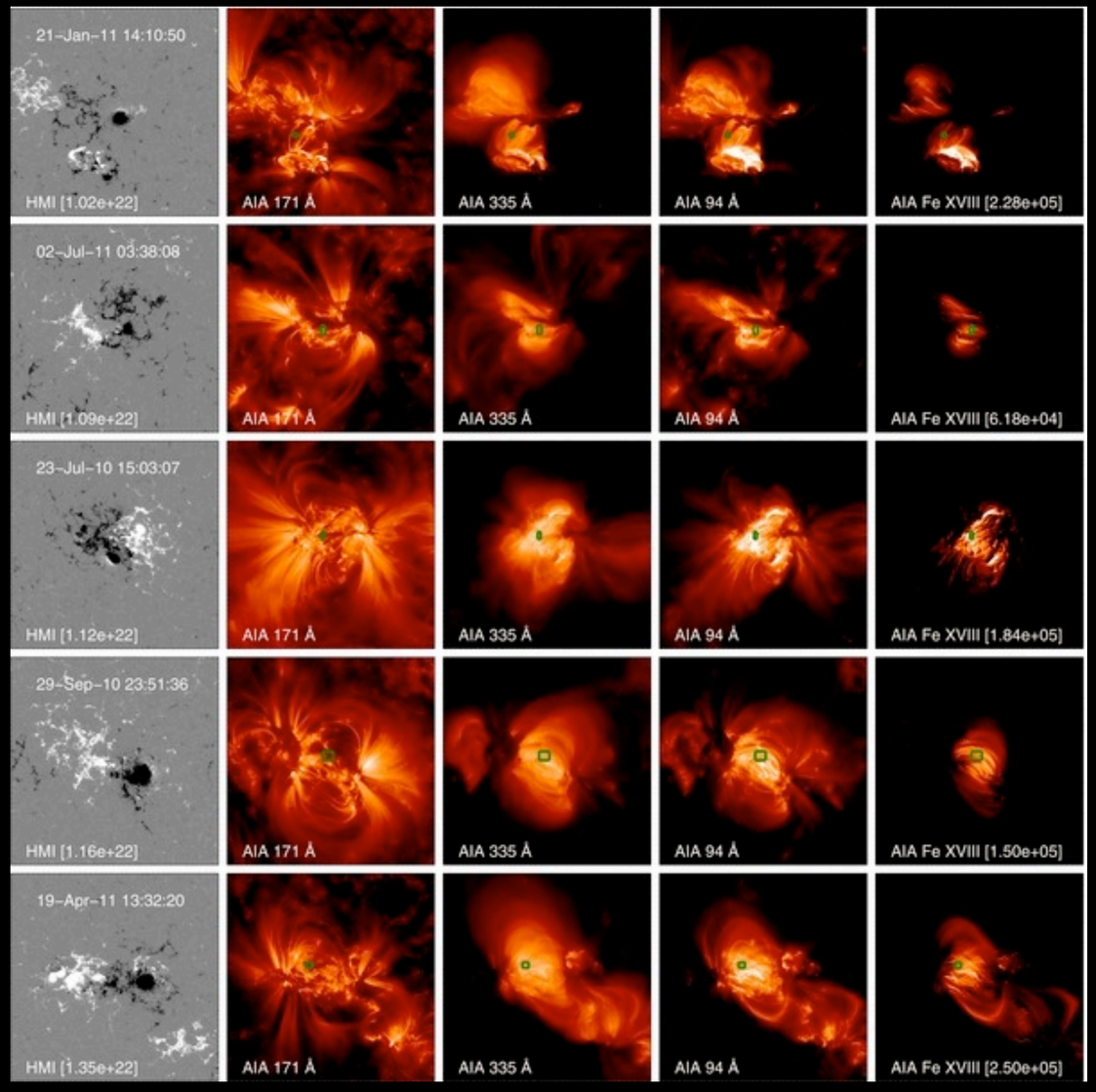

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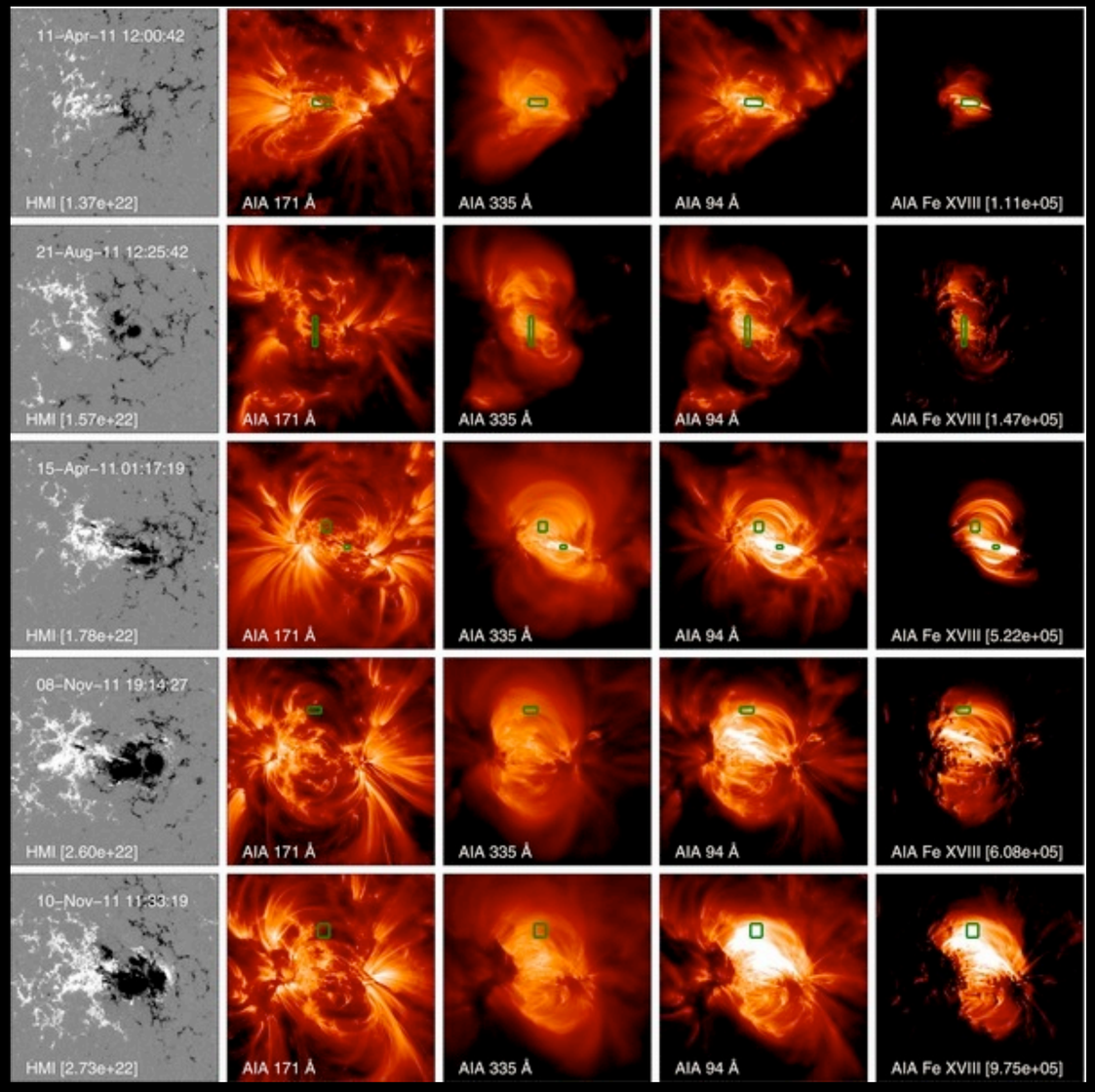

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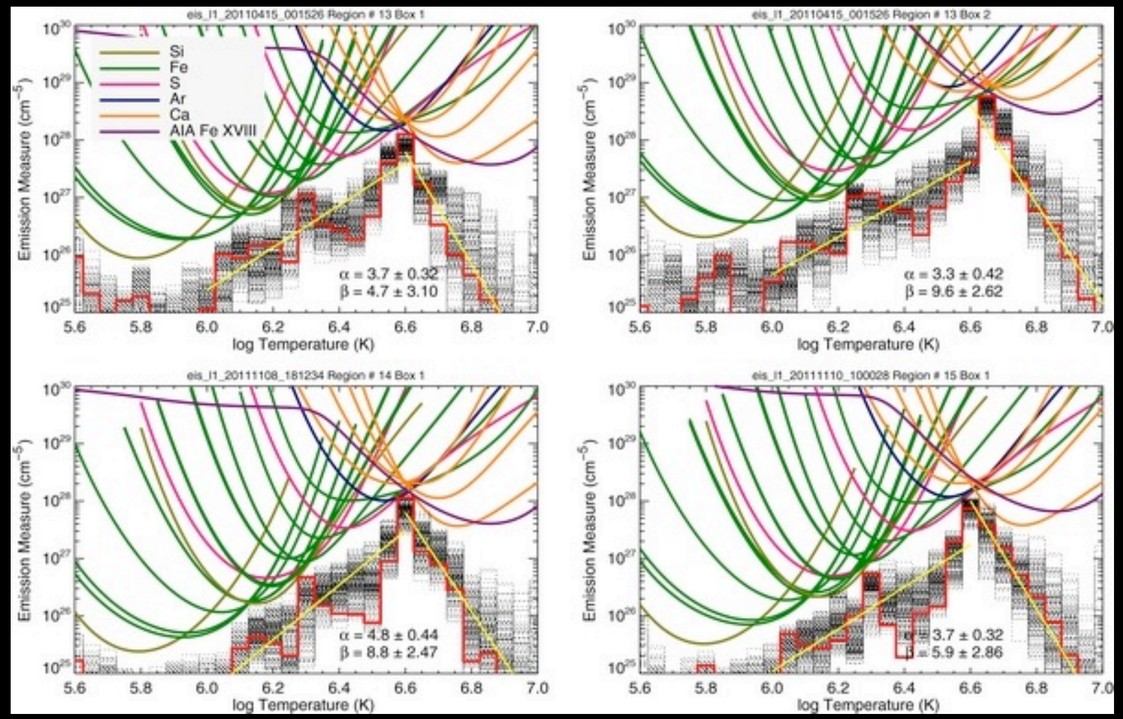
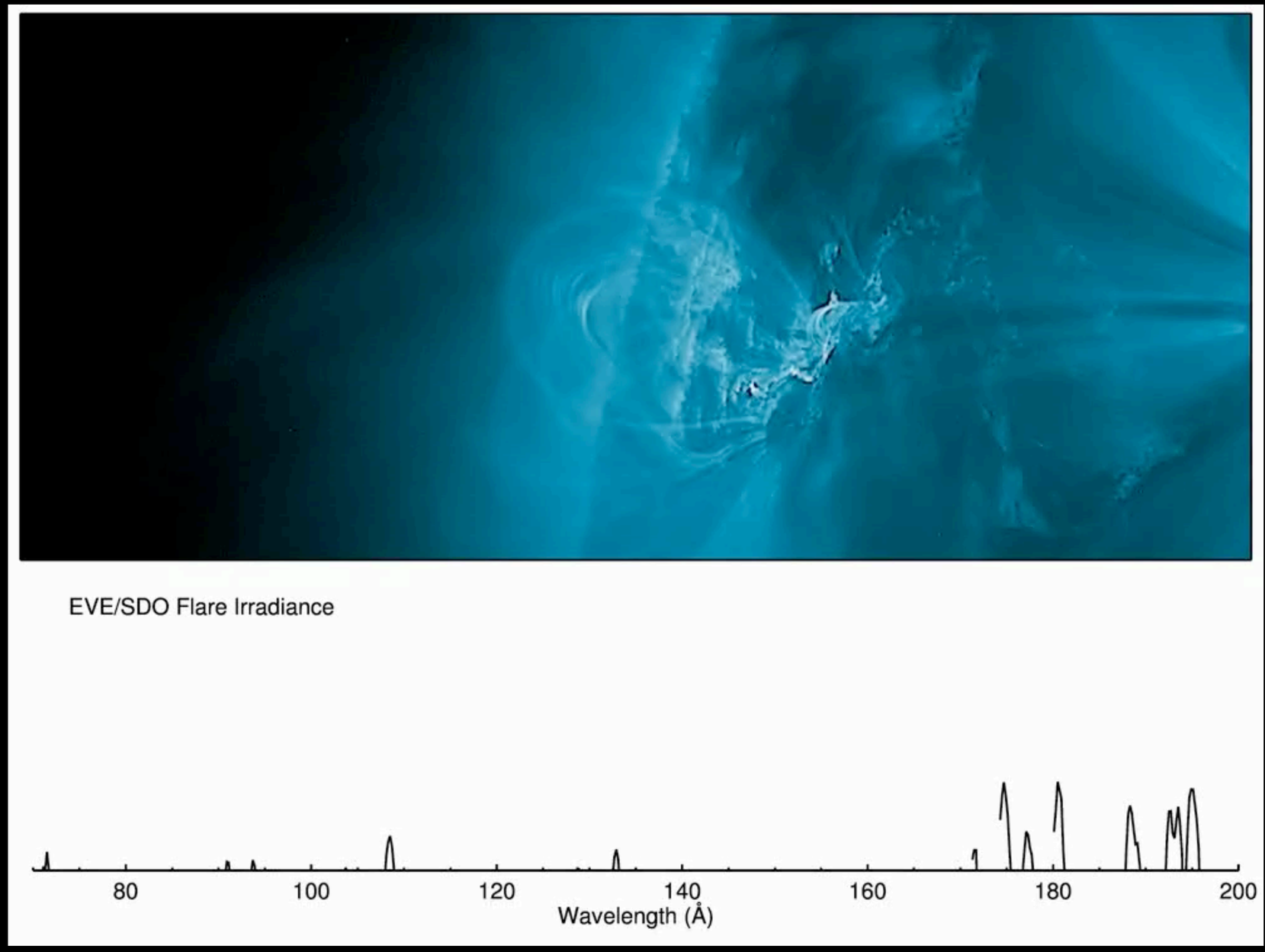


See also:

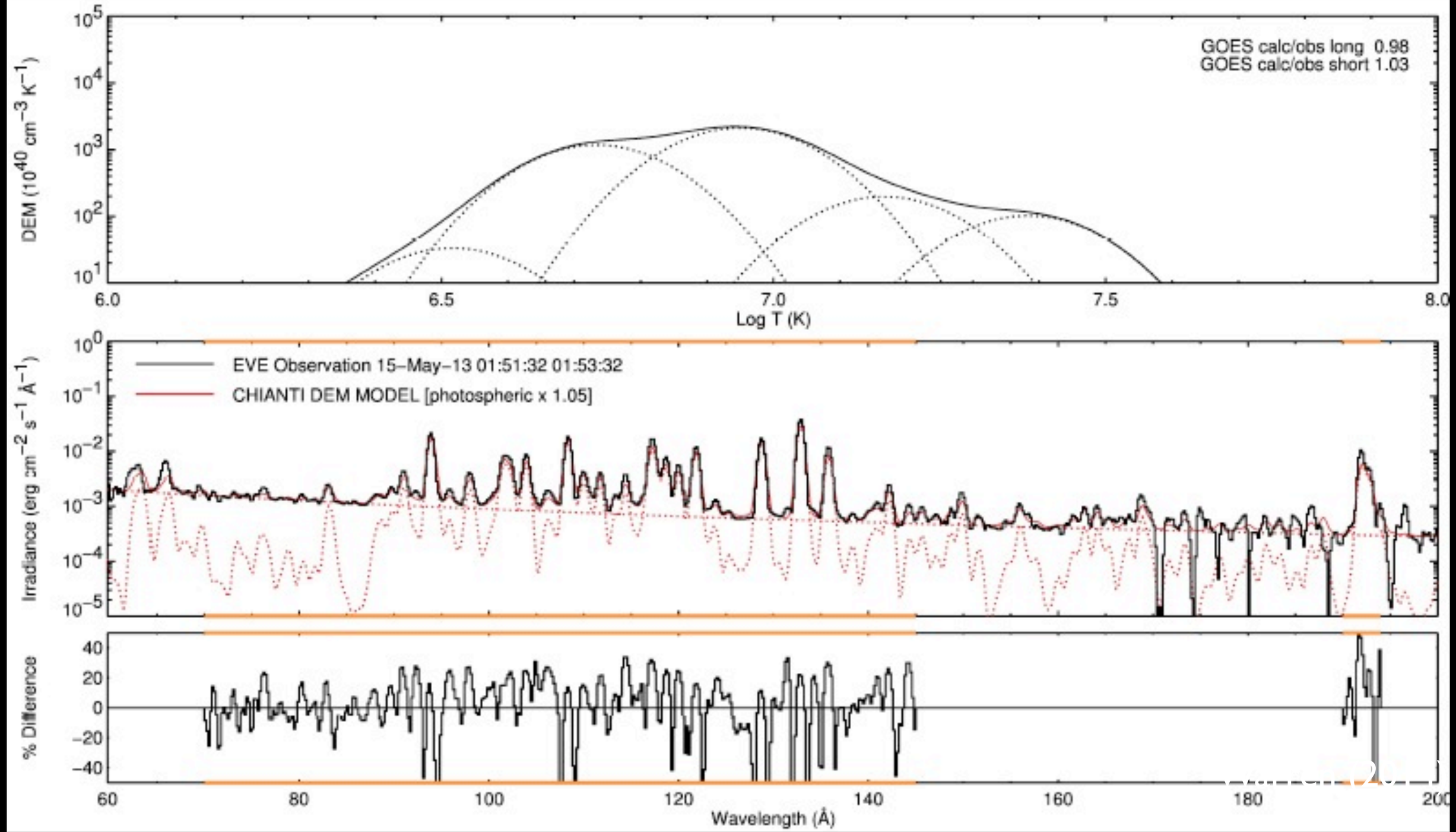
Tripathi et al (2011)
Del Zanna (2012, 2013)
Del Zanna & Mason (2014)

Impulsive Heating - Photospheric Composition in Flares



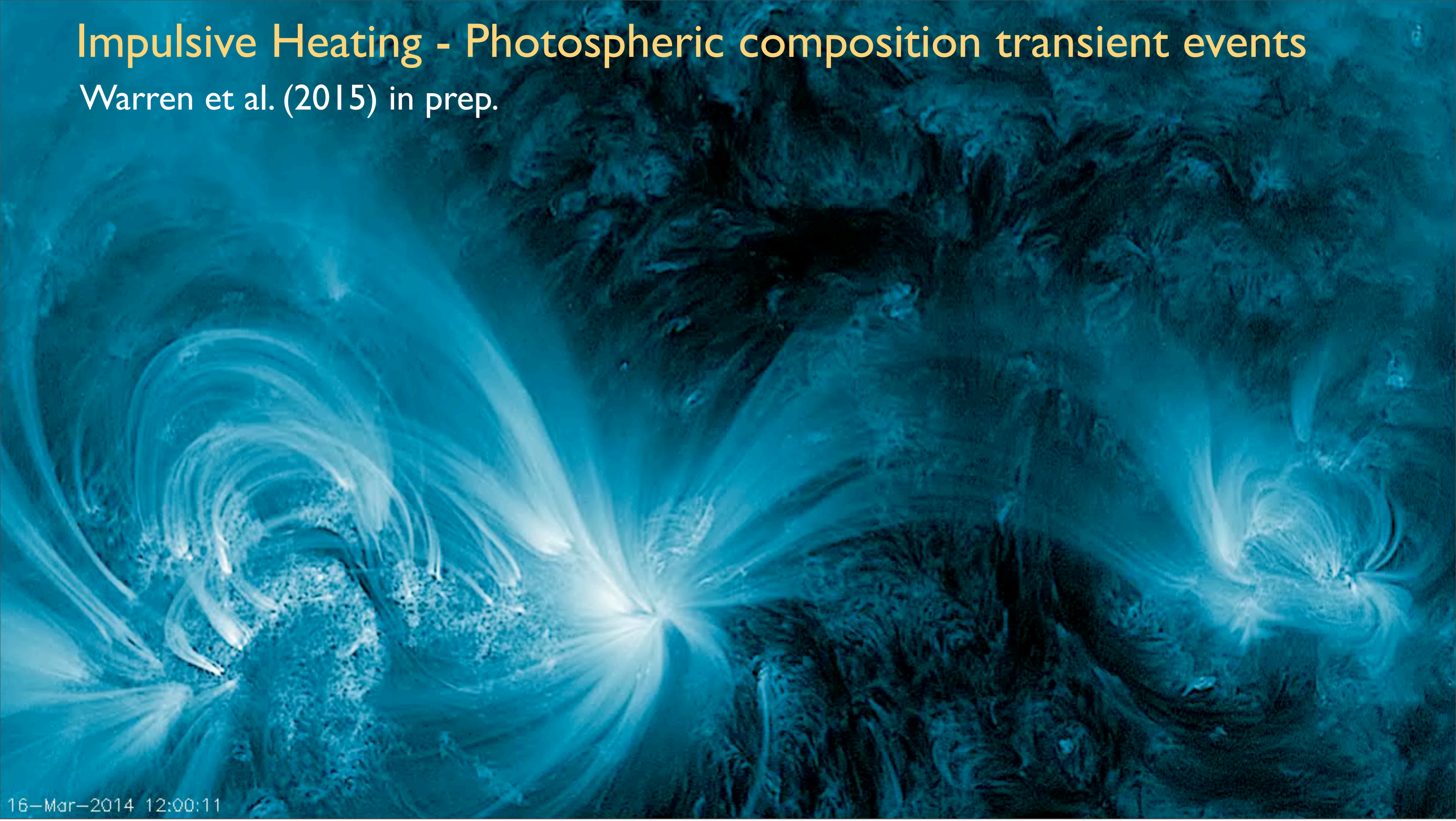
EVE/SDO Flare Irradiance

Warren (2014)


GOES calc/obs long 0.98
GOES calc/obs short 1.03
DEM (10^{40} cm^{-3} K^{-1})
Log T (K)
EVE Observation 15–May–13 01:51:32 01:53:32
CHIANTI DEM MODEL [photospheric x 1.05]
Irradiance (erg cm^{-2} s^{-1} Å^{-1})
% Difference
Wavelength (Å)

Impulsive Heating - Photospheric composition transient events

Warren et al. (2015) in prep.



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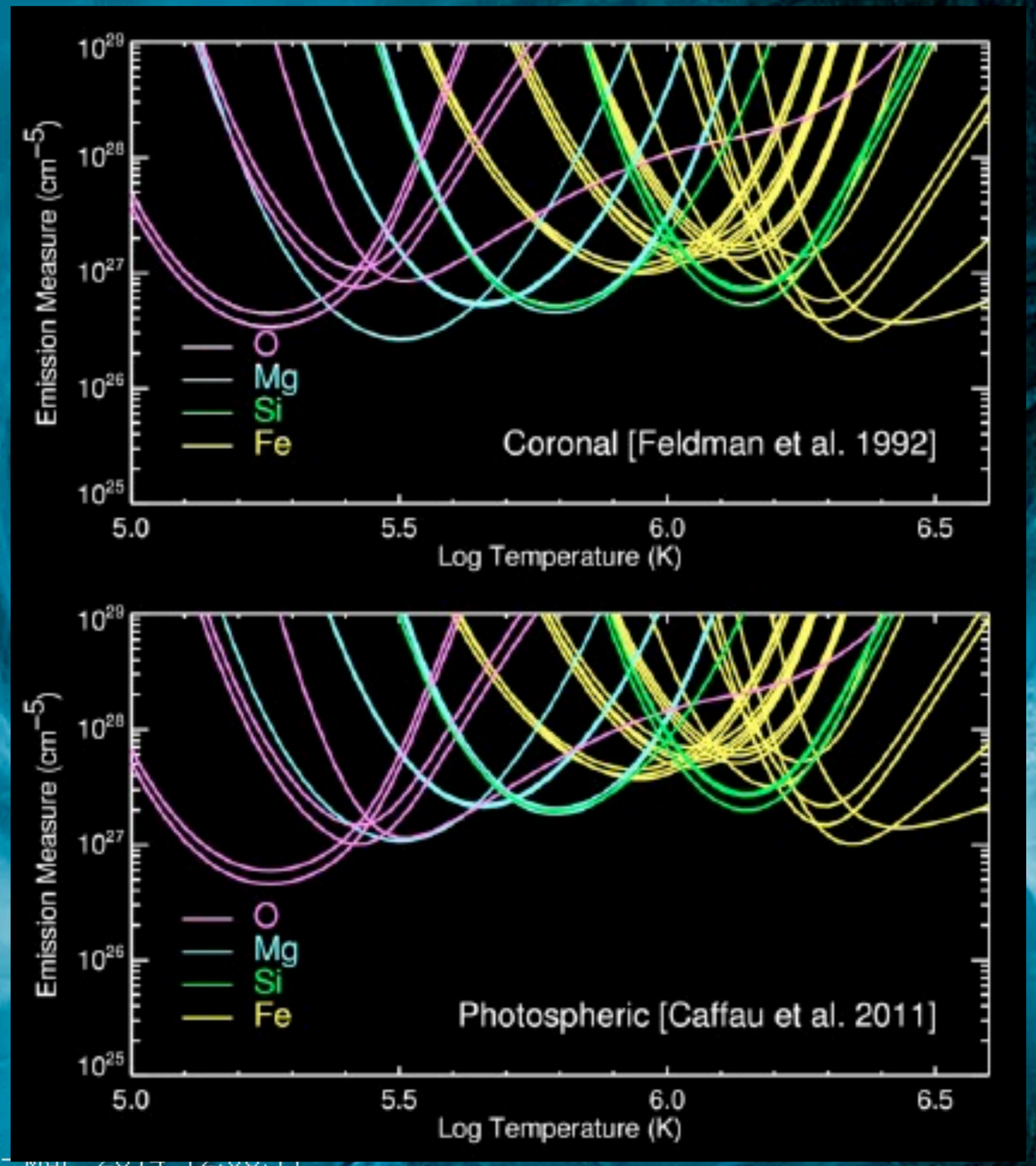
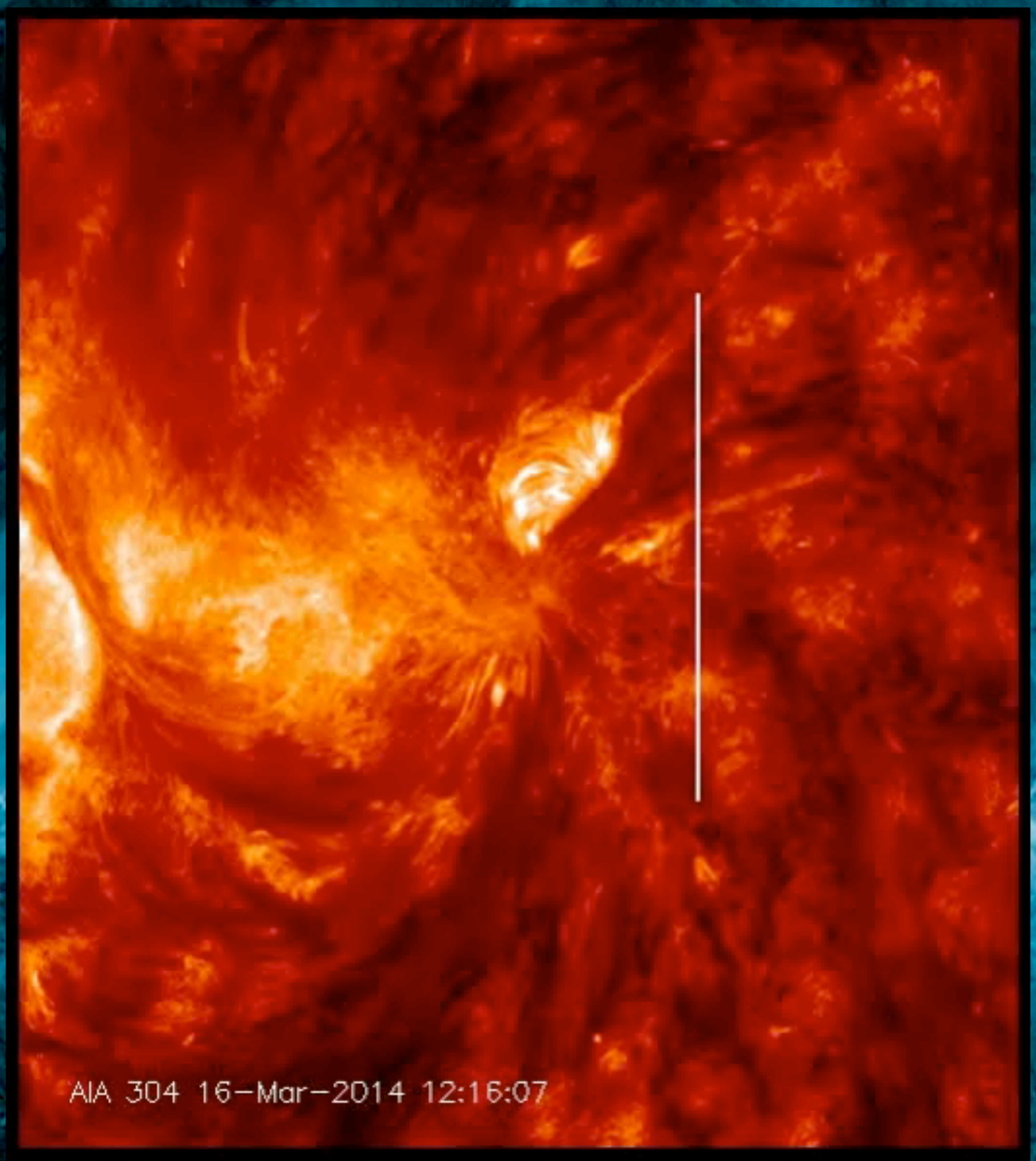


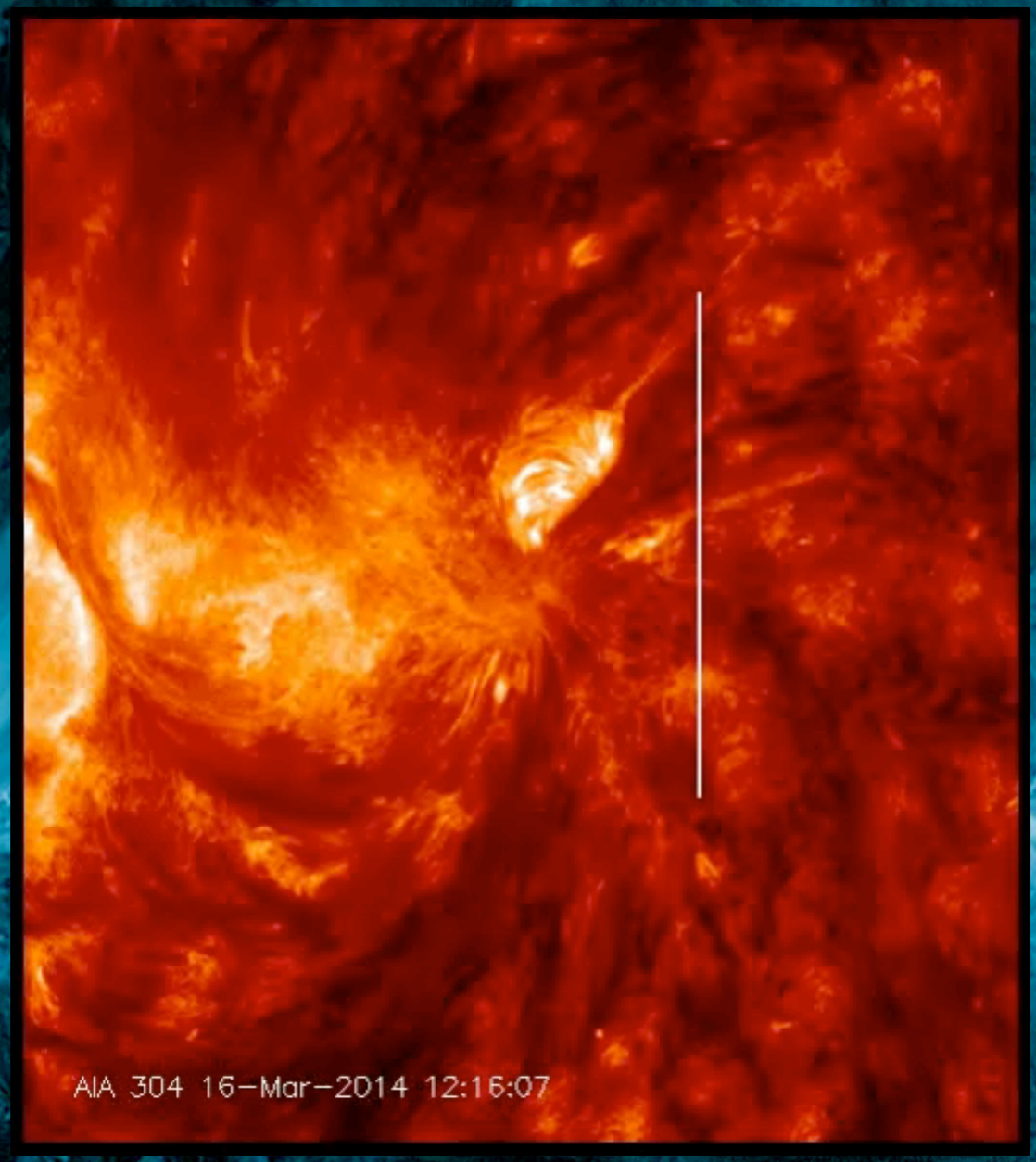


Impulsive Heating - Photospheric composition transient events

Warren et al. (2015) in prep.

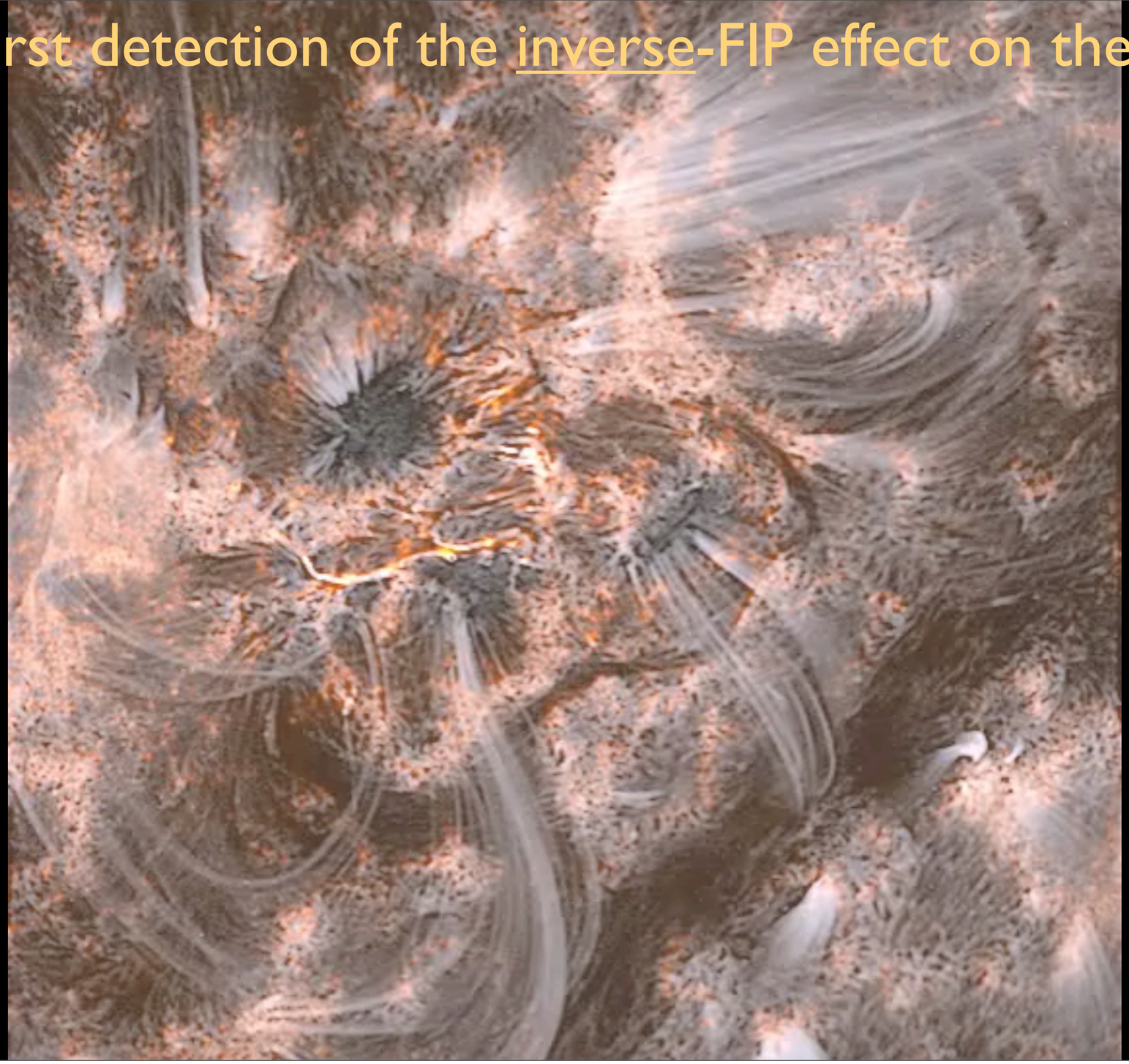
Impulsively heated loops
-> photospheric abundances, broad DEM

"Long lived" 1MK fan loops, AR core
-> coronal abundances, narrow DEM

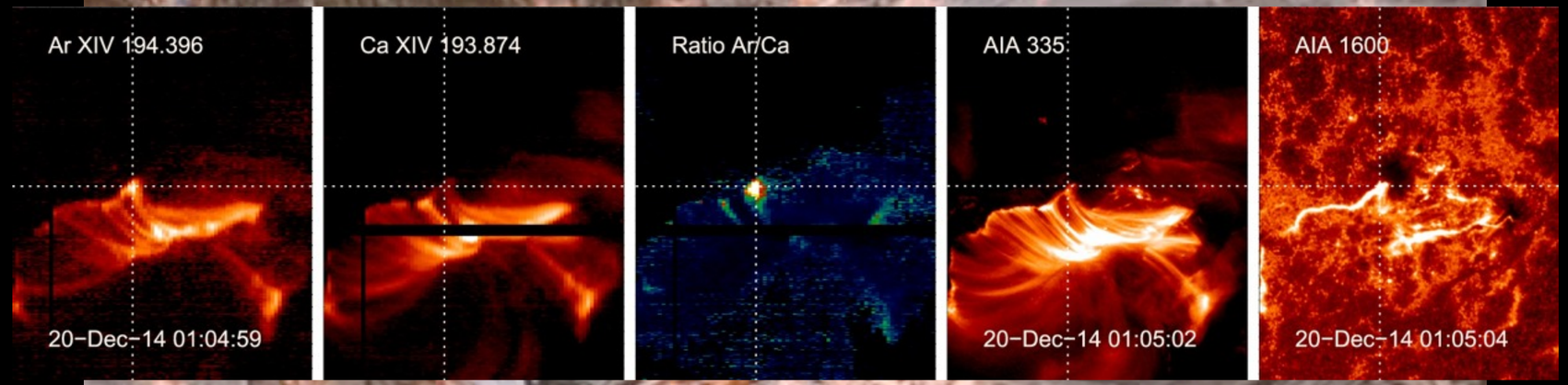


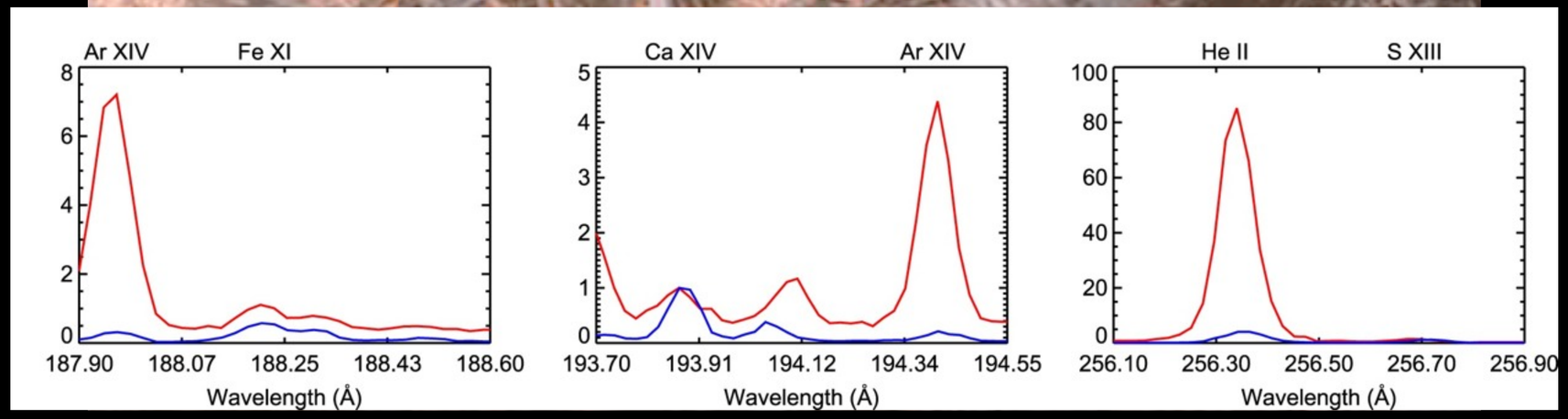
16-Mar-2014 12:00:11

First detection of the inverse-FIP effect on the Sun?



First detection of the inverse-FIP effect on the Sun?

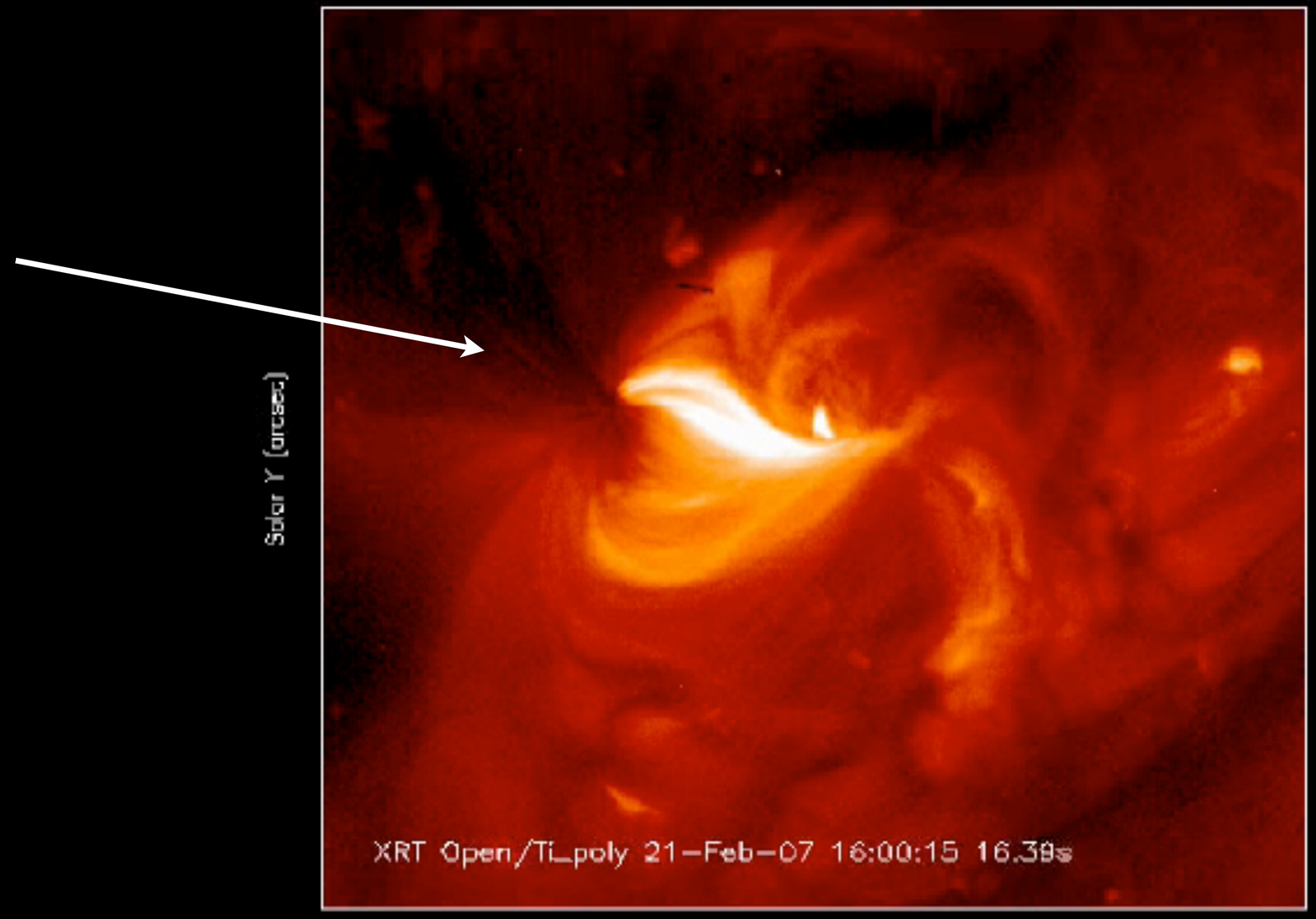




AR XIV (high FIP) brighter than Ca XIV (low FIP) in a localized flare loop (Doschek et al. 2015)

Tracer of plasma origin II: Slow solar wind

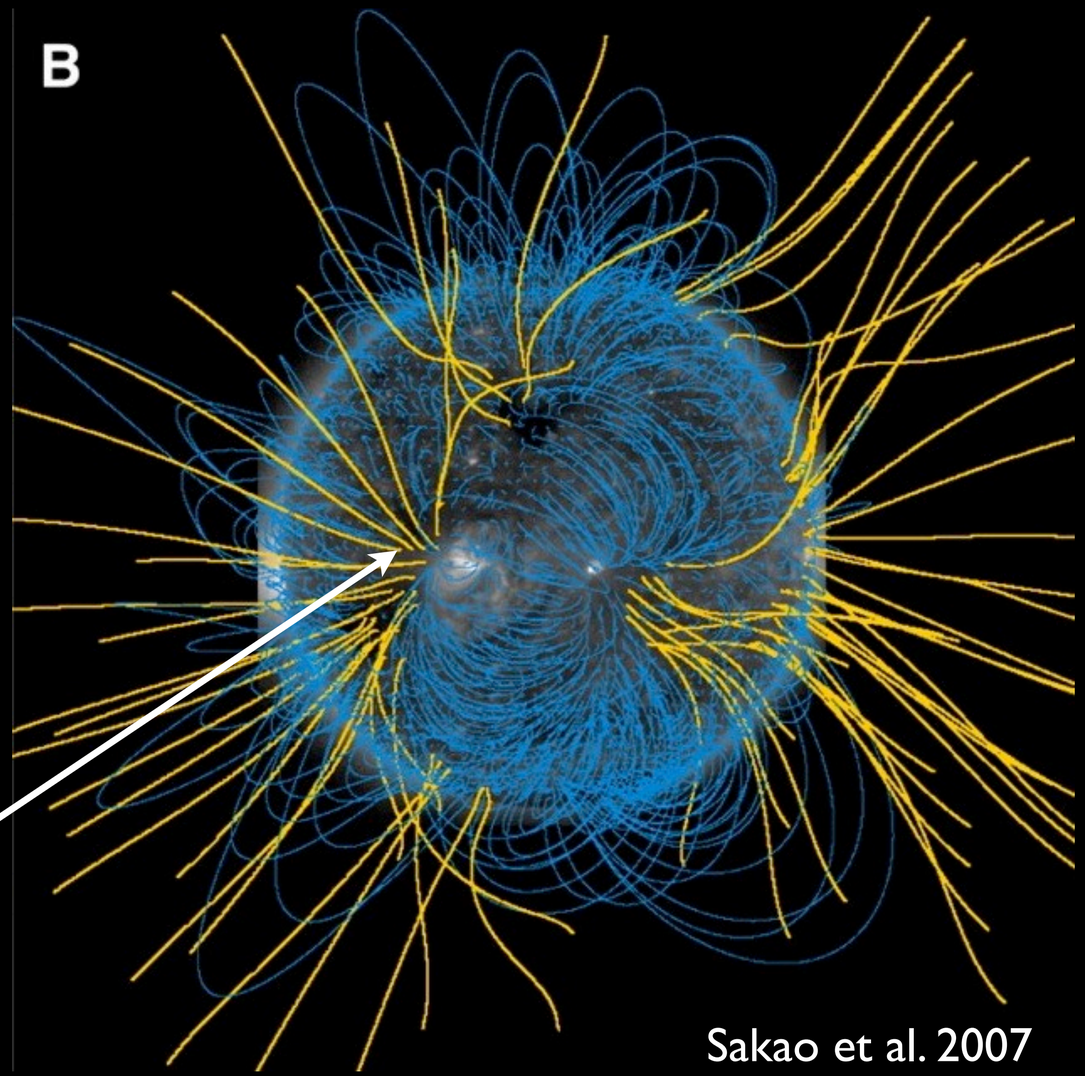
High temperature (few MK) outflow motions observed at the edges of active regions by Hinode (Sakao 2007).



Active Region Outflows

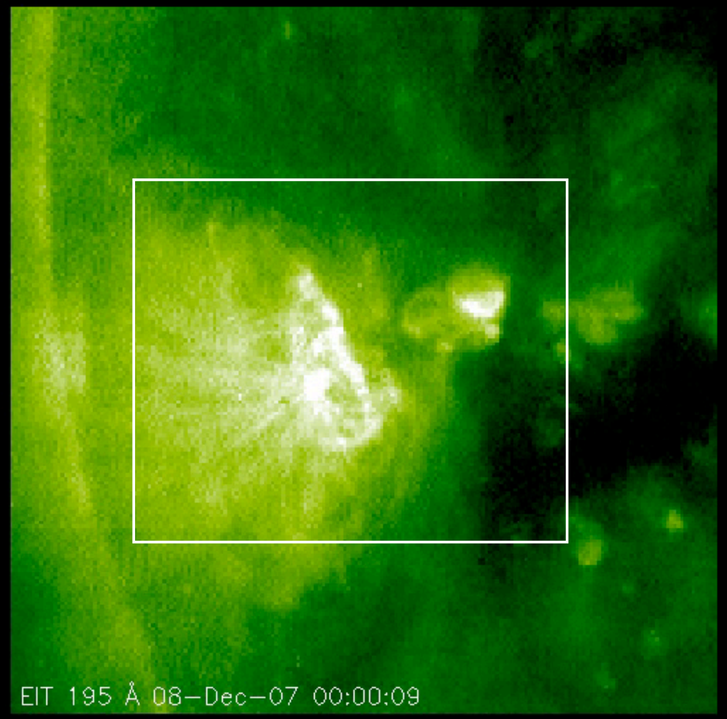
Flows sourced to open magnetic field lines.

May connect to the heliosphere and contribute to the slow wind (Sakao 2007, Harra 2008, Doschek 2008, Baker 2009).



Sakao et al. 2007

EIS spectroscopy confirms they are upflows
> 50km/s (Doschek 2008, Harra 2008)

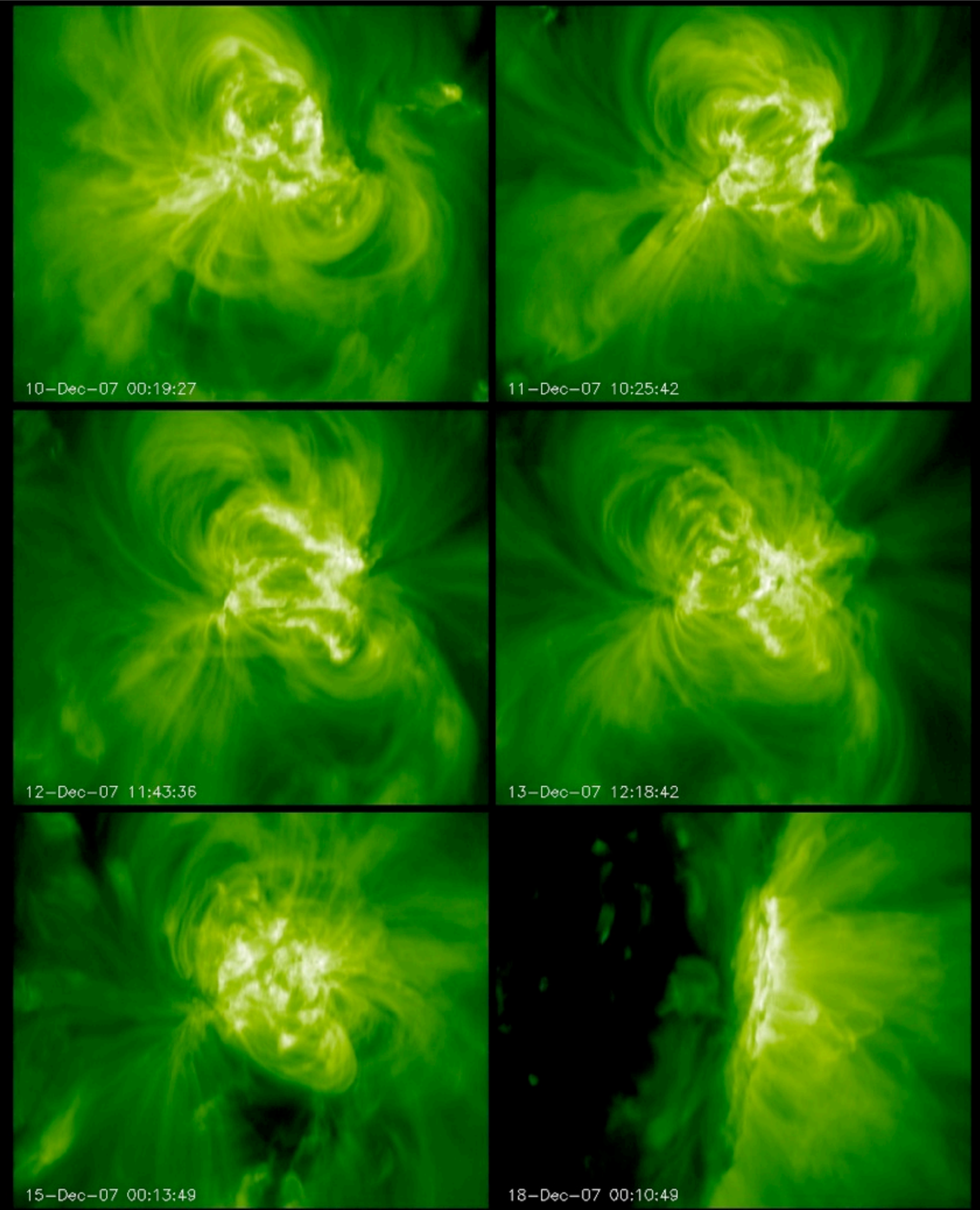


December 8 – 18, 2007

-460″x384″ slit raster

-1″ slit, 40s exposures, ~5 hours

-Fe VIII - Fe XVI



EIS Fe XII 195.119 Å

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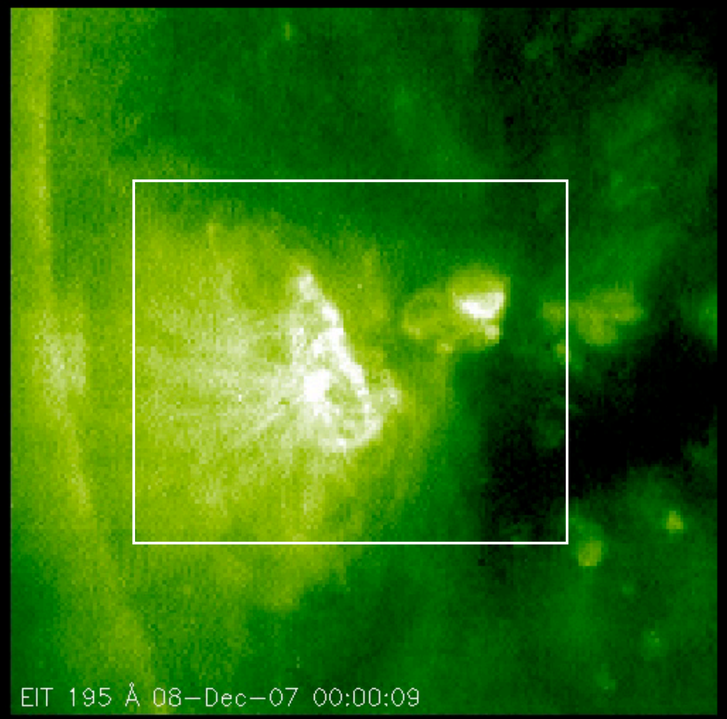

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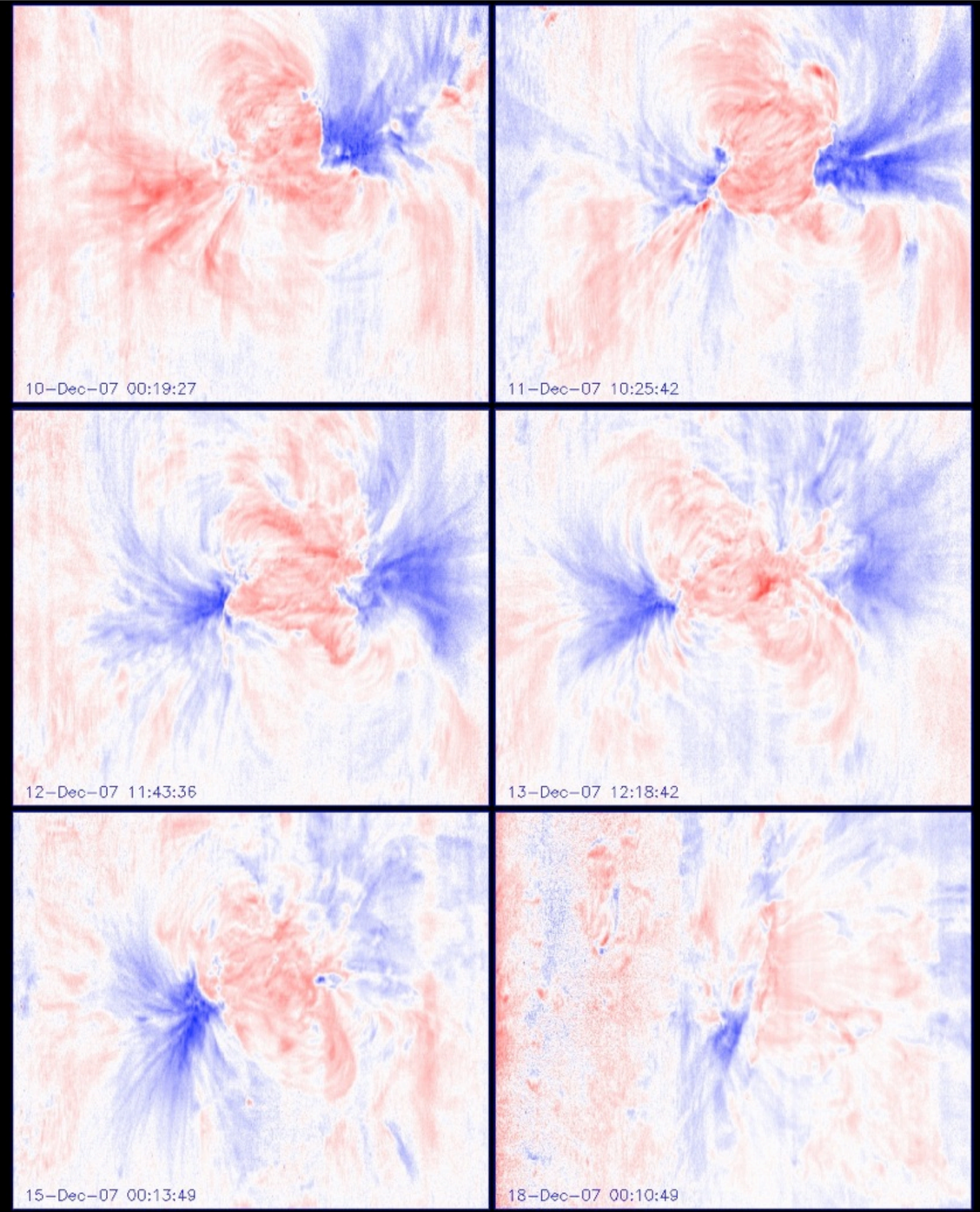


EIS Fe XII 195.119 Å

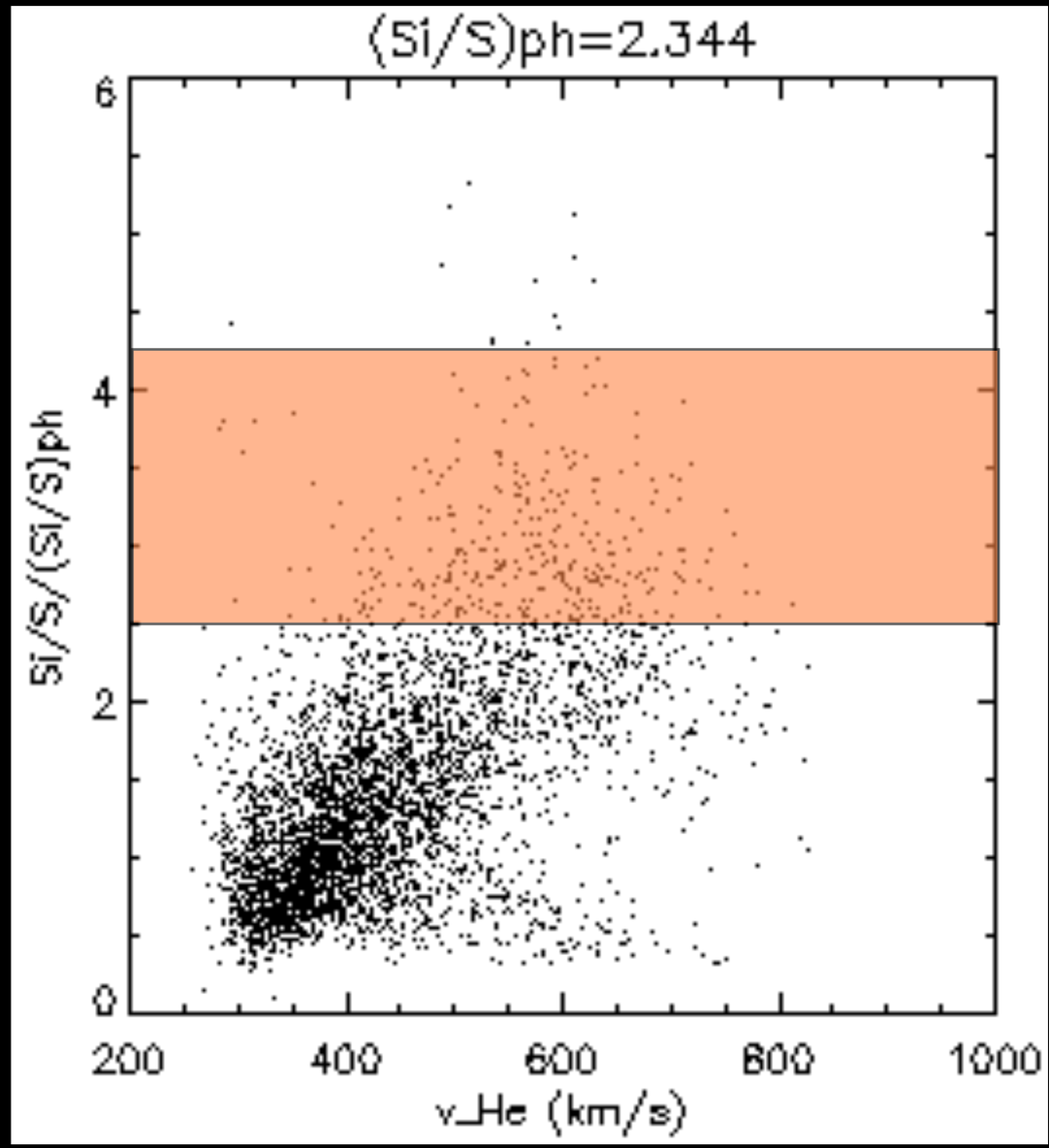
Abundance Measurements in AR Outflows

EIS spectroscopy confirms the composition of the outflows is consistent with slow wind values (Brooks & Warren 2011).

FIP enhancement factors for December 2007 region are 2.5-4.1. Average = 3.4.

Outflows

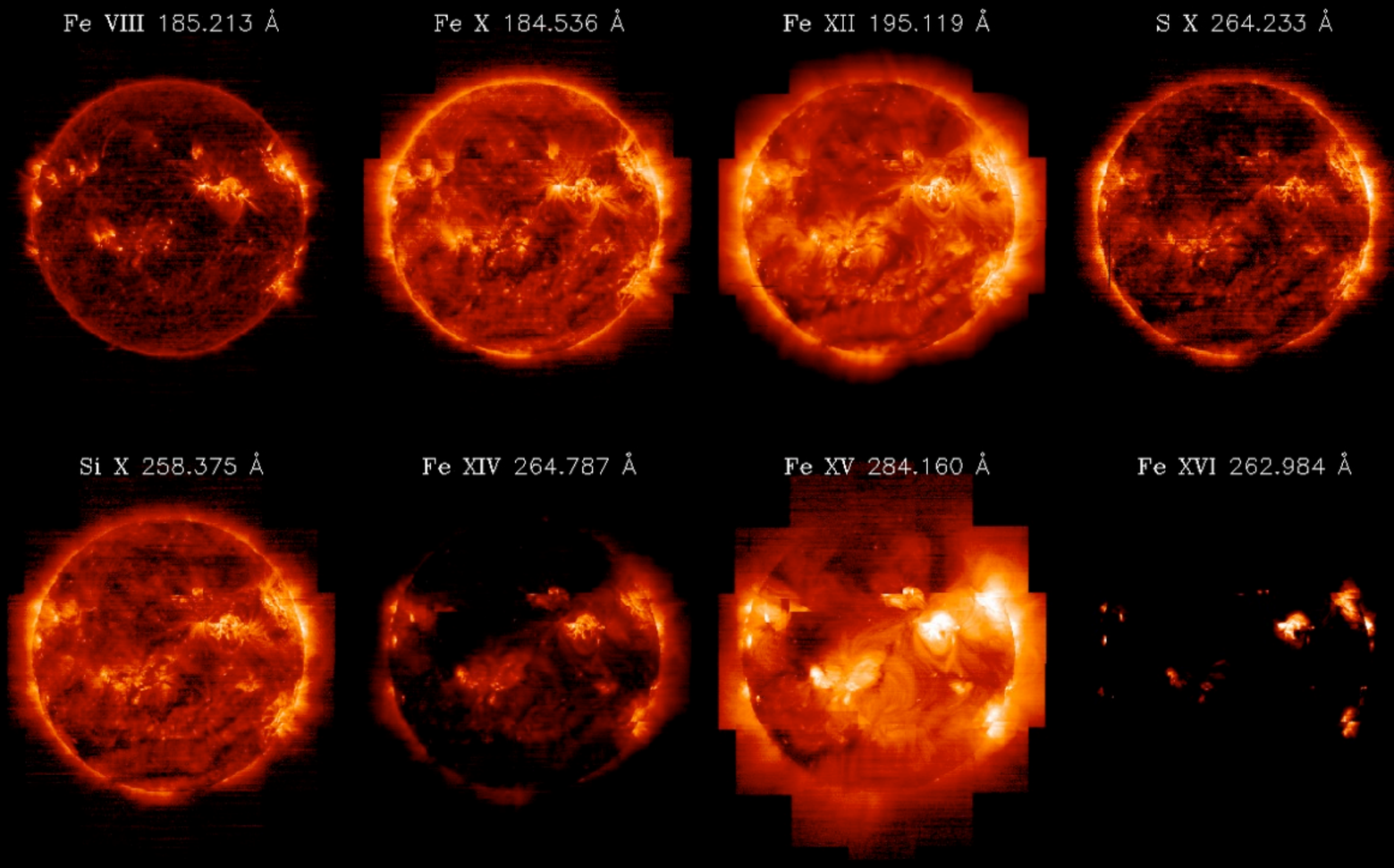
ACE/SWICS 1-day averages
Jan. 1998 - Feb. 2010



Slow Solar Wind Source Map of the Entire Sun

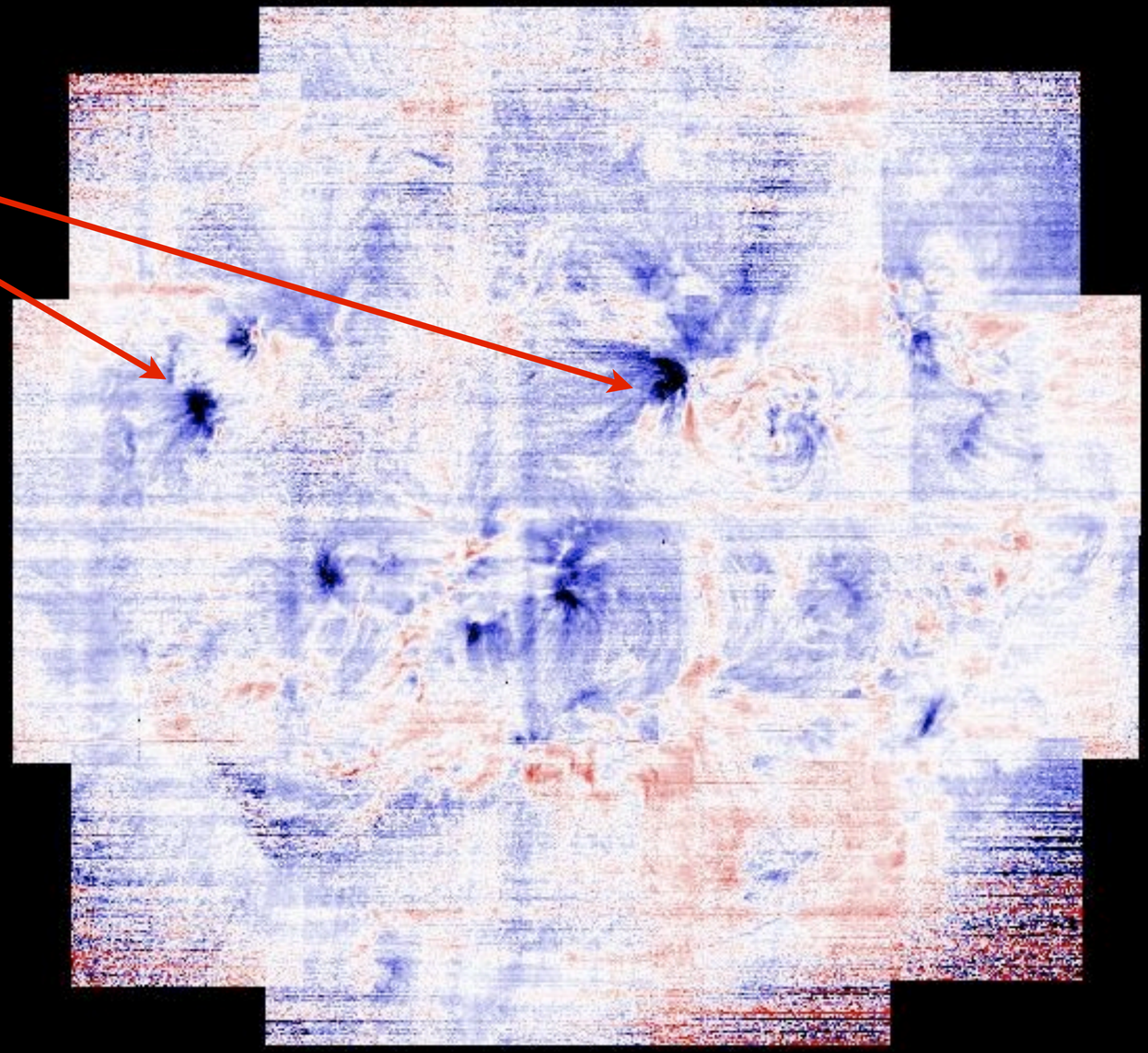
(Brooks et al. 2015)

- Full Sun scan gives Doppler velocity (upflow) map
- Potential field source surface model gives magnetic topology (open field) map
- Full Sun scan gives plasma composition map
- We combine these to make the SSWS map



Fe XIII 202Å Doppler Velocity Map

Identify locations of upflow



Blue - Upflow

Red - Downflow

Some of these upflows may be within closed magnetic field

Fe XIII 202Å Doppler Velocity Map + PFSS Model

Identify locations of upflow on open magnetic field lines.

Upflows that <u>are</u> Outflows

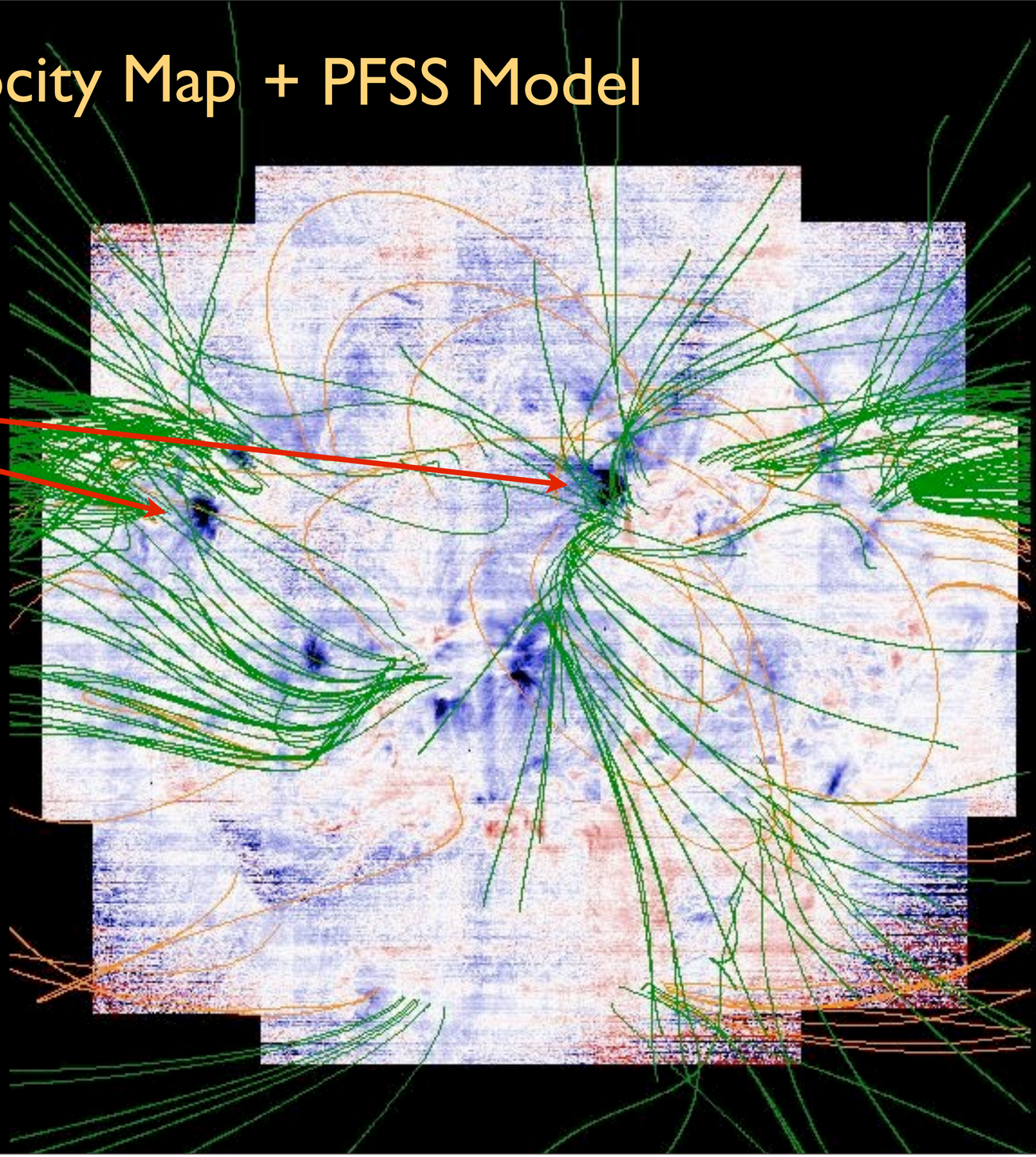
Blue - Upflow

Red - Downflow

Green - Open Field

Orange - Closed Field

PFSS model: De Rosa & Schrijver (2003).

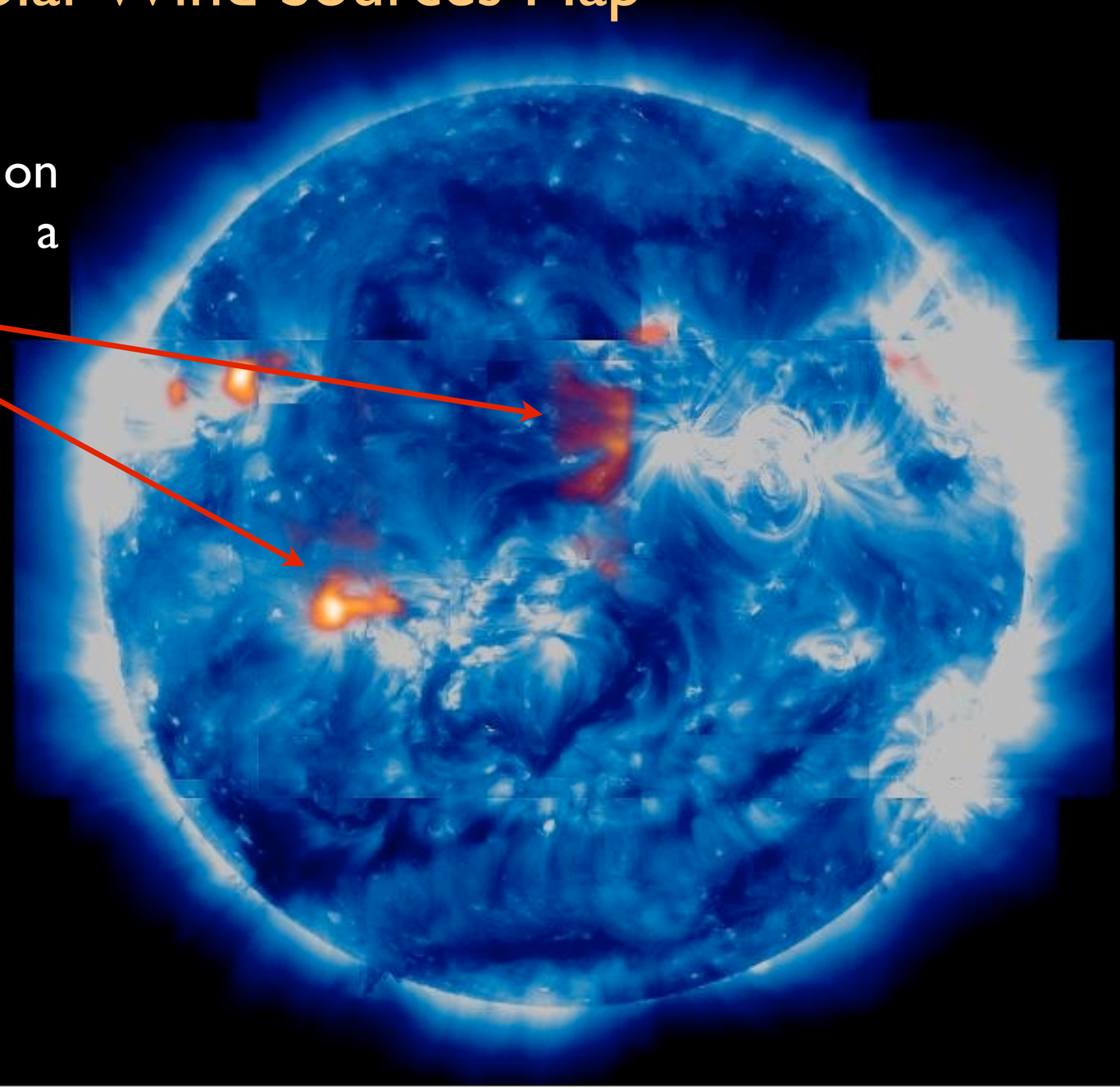


Slow Solar Wind Sources Map

Identify locations of outflow on open magnetic field lines with a slow wind composition.

Blue - AIA 193Å image

Red - Slow Wind Sources



Slow Solar Wind Sources Map

Identify locations of outflow on open magnetic field lines with a slow wind composition.

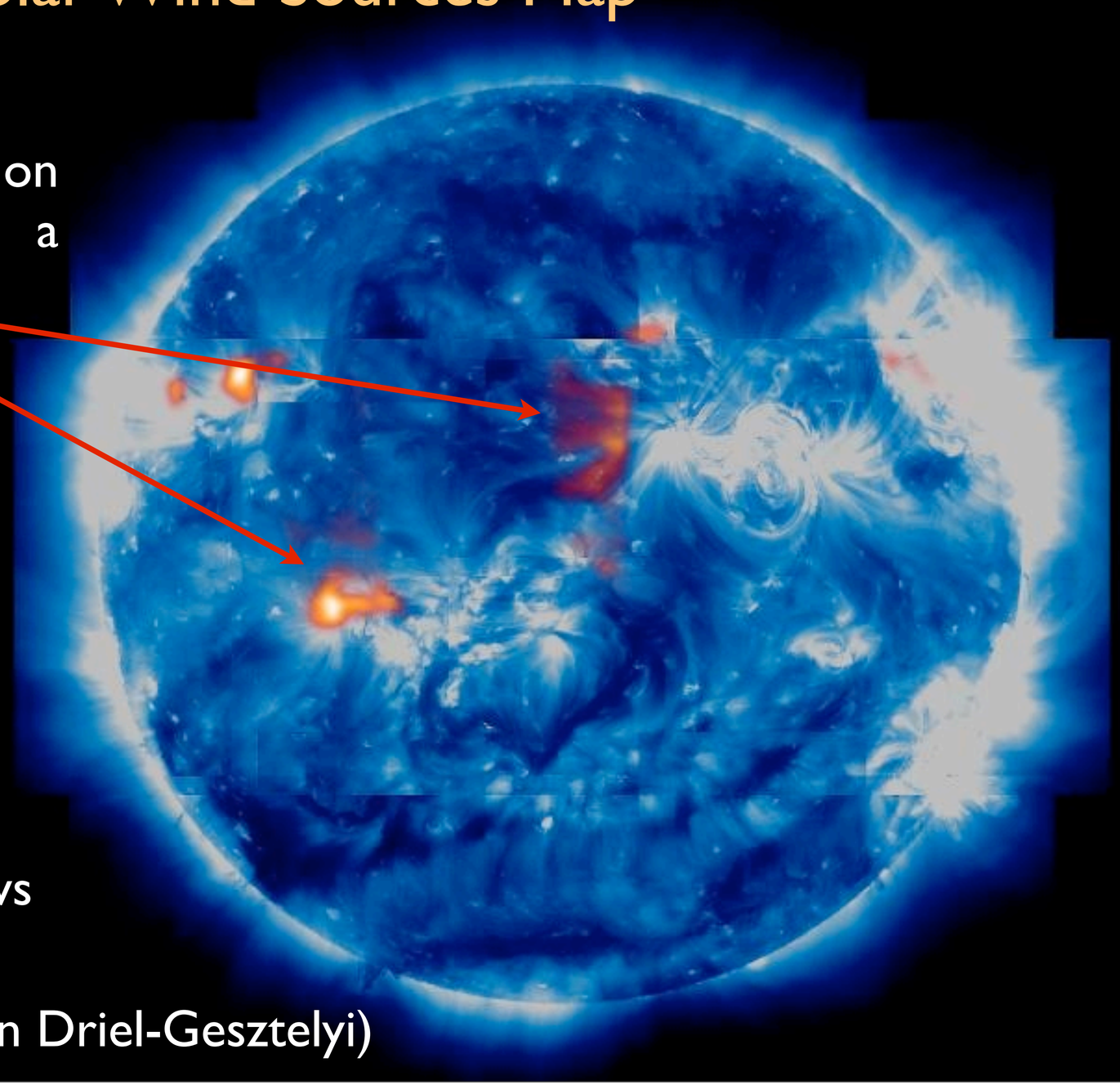
Blue - AIA 193Å image

Red - Slow Wind Sources

The sources deliver enough mass flux to the ecliptic to explain measurements made at ACE.

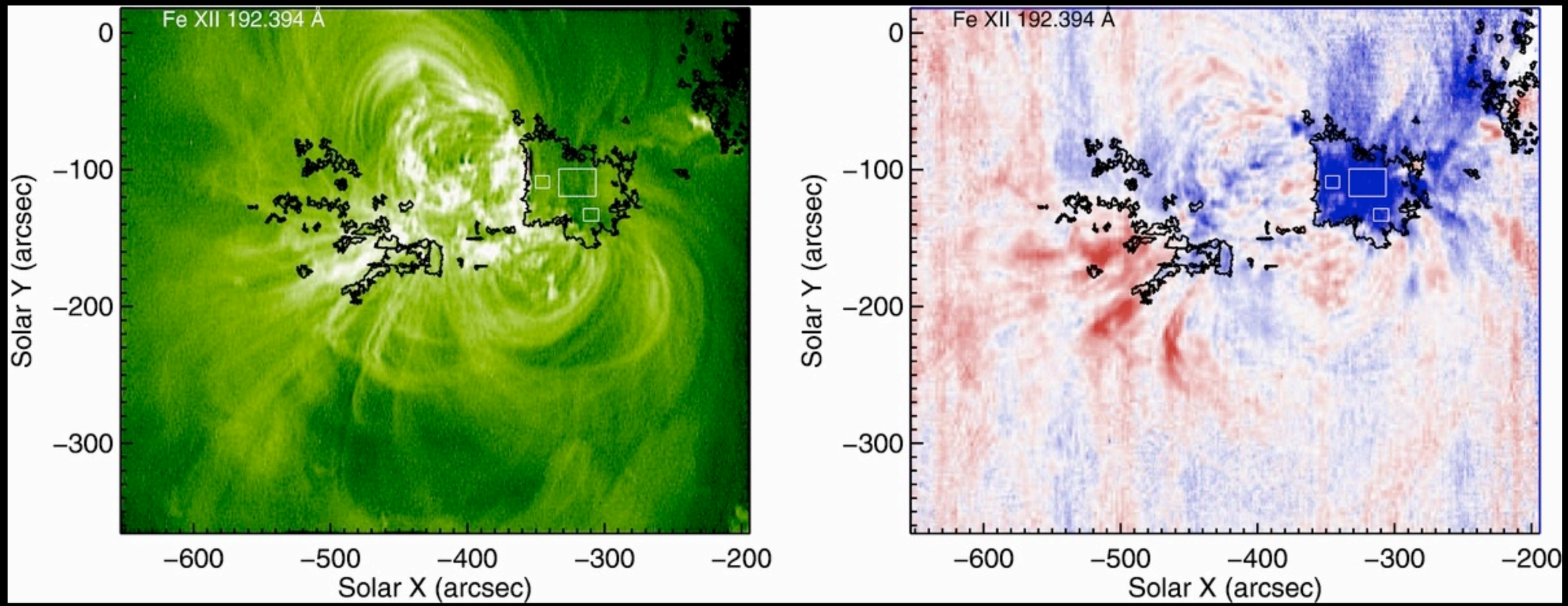
Dominant sources are AR outflows for these observations.

(General discussion DEp.2.06 - van Driel-Gesztelyi)



Tracer of Plasma Origin II. Coronal Line Asymmetries

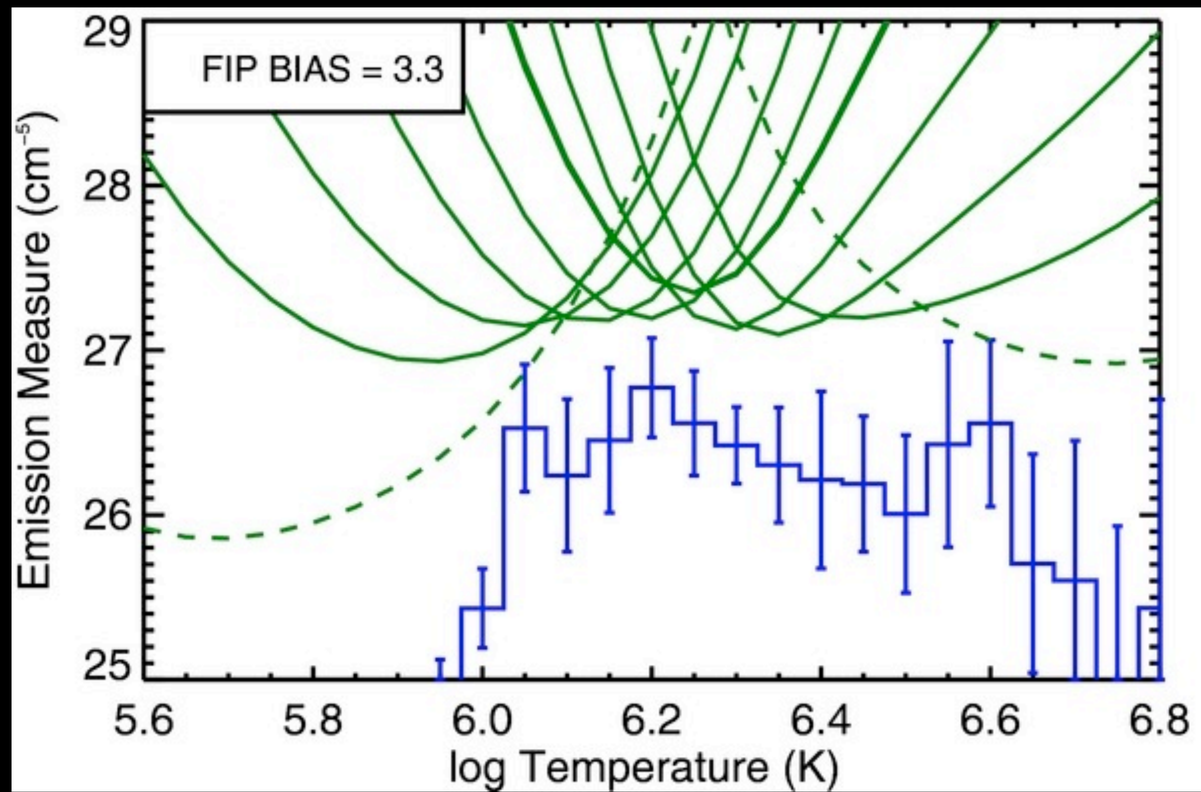
Locations of asymmetric profiles in the same region



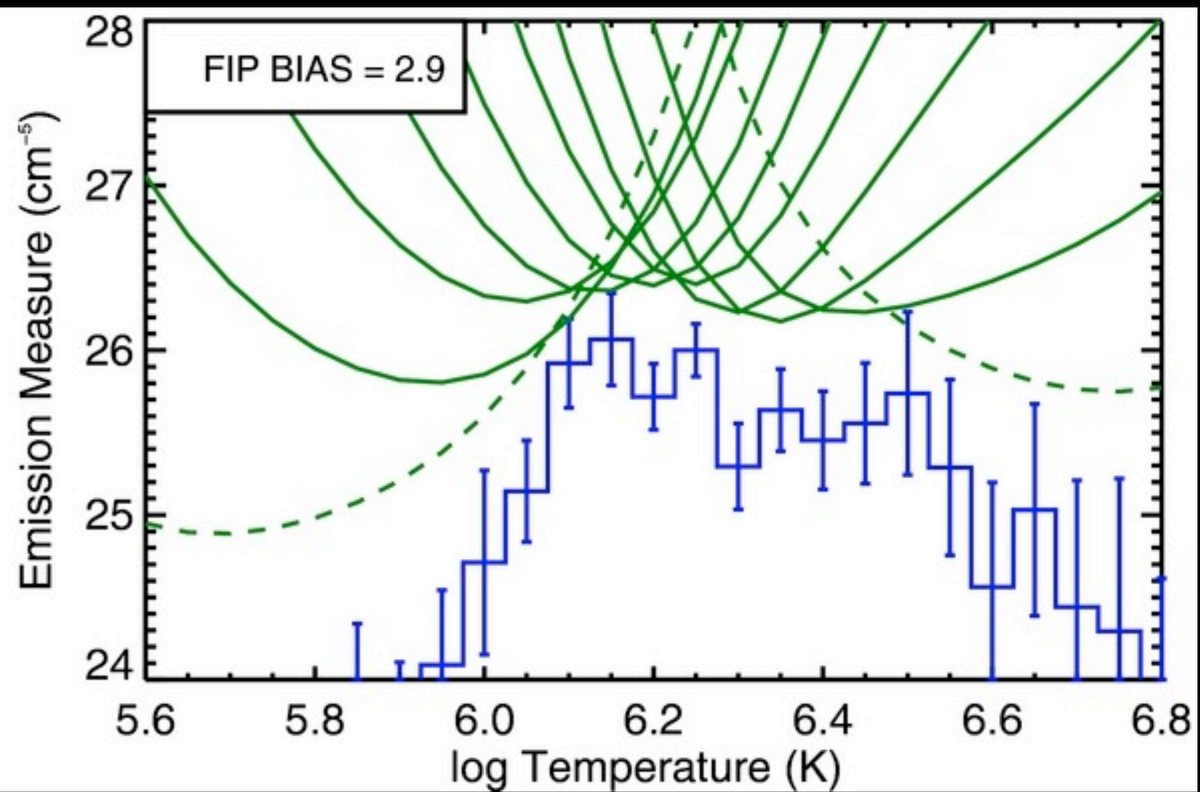
Brooks & Warren (2012)

Tracer of Plasma Origin II. Coronal Line Asymmetries

DEMs for bulk outflow and blue wing are dominated by coronal emission and the FIP bias is similar.



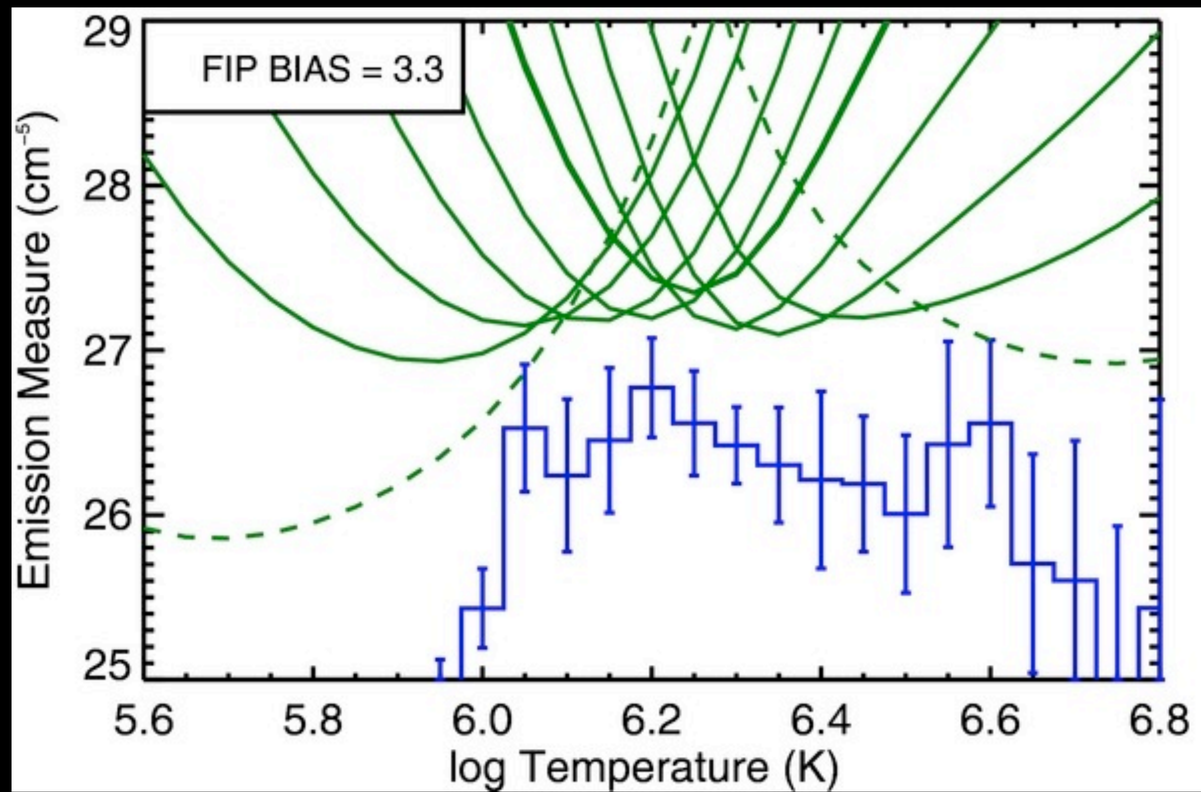
Bulk Outflow



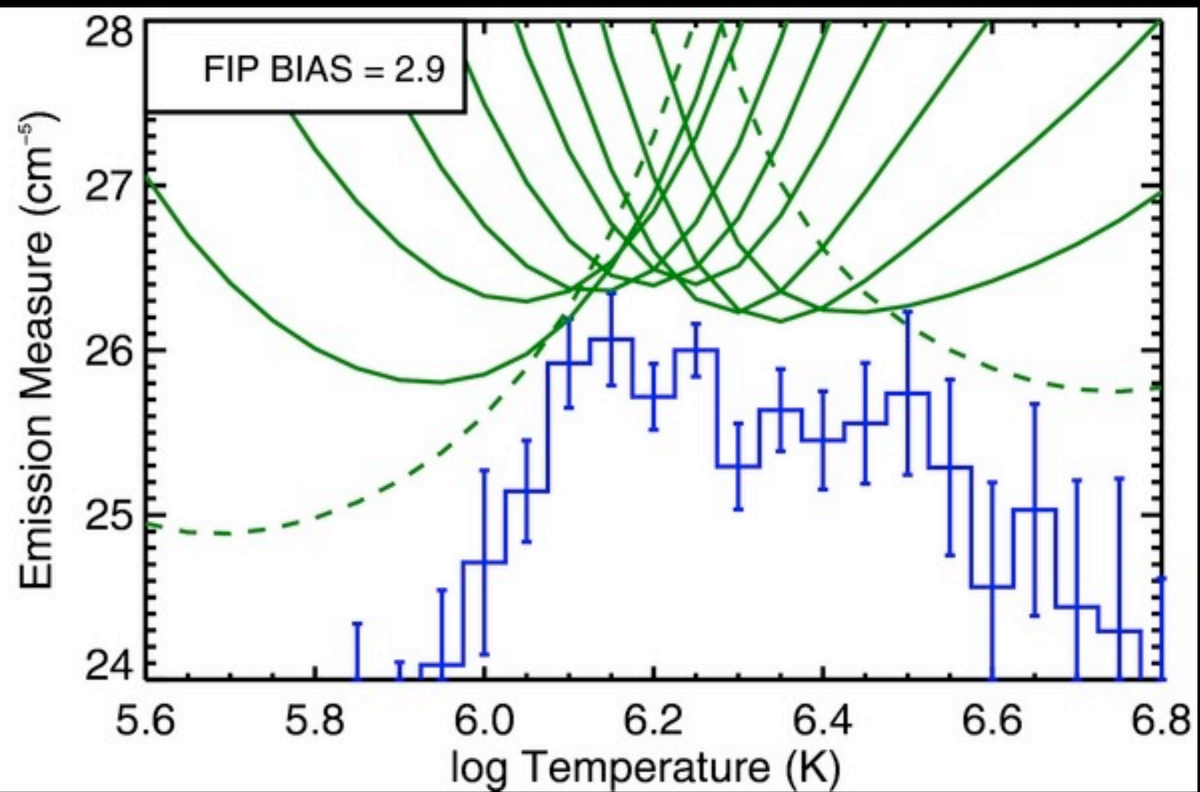
Blue wing

Tracer of Plasma Origin II. Coronal Line Asymmetries

Asymmetries produced by *coronal* plasma. Casts doubt on type II spicule explanation.



Bulk Outflow

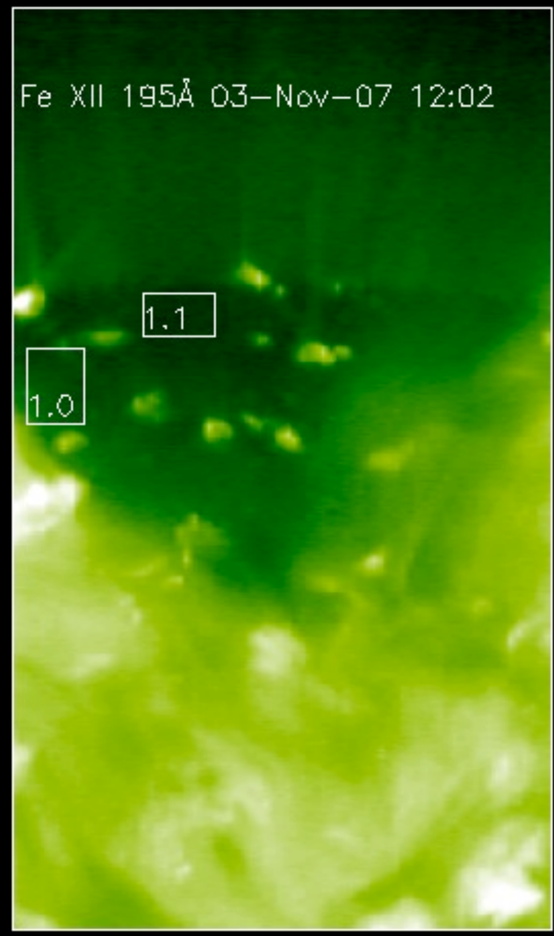


Blue wing

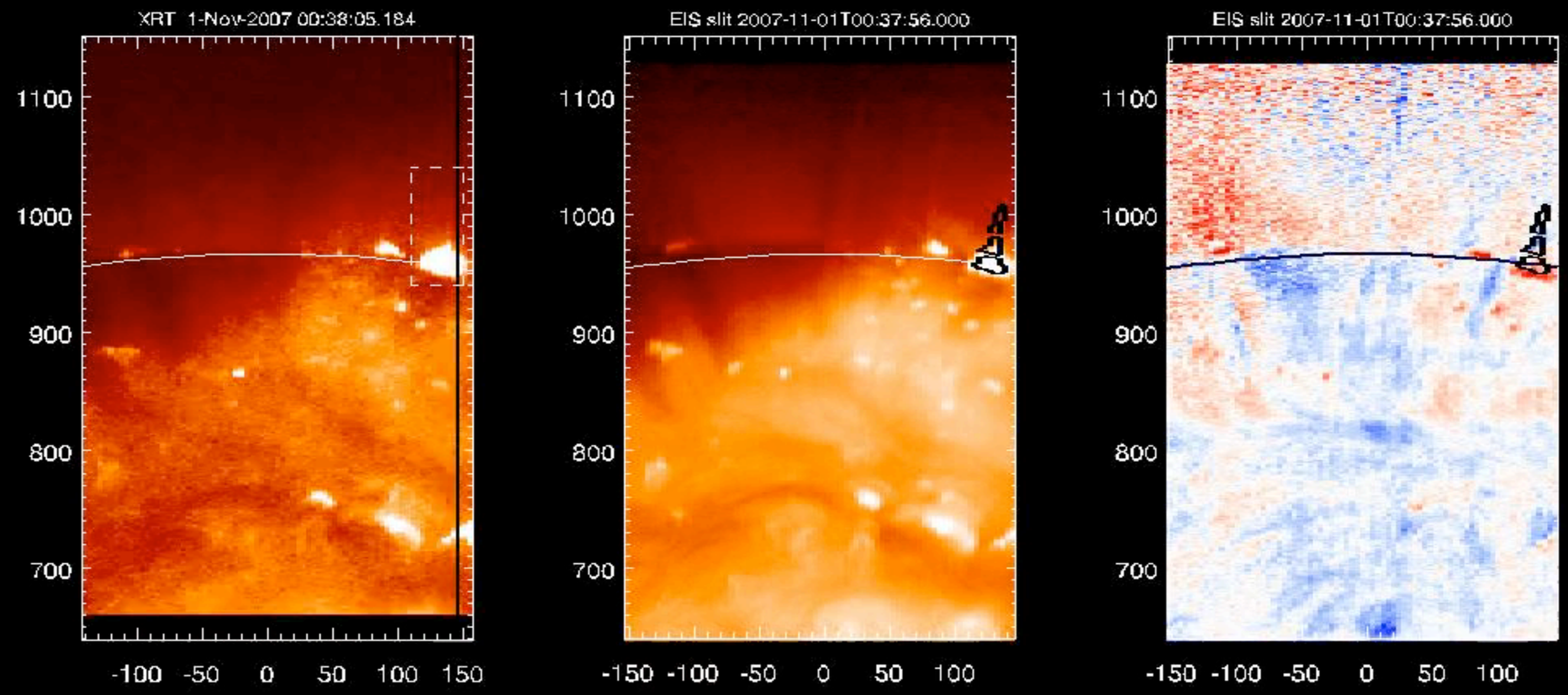
Tracer of plasma origin III. Fast solar wind

Photospheric Abundances in polar CH (Brooks & Warren 2011).

Consistent with fast wind.



Tracer of plasma origin III. Fast solar wind

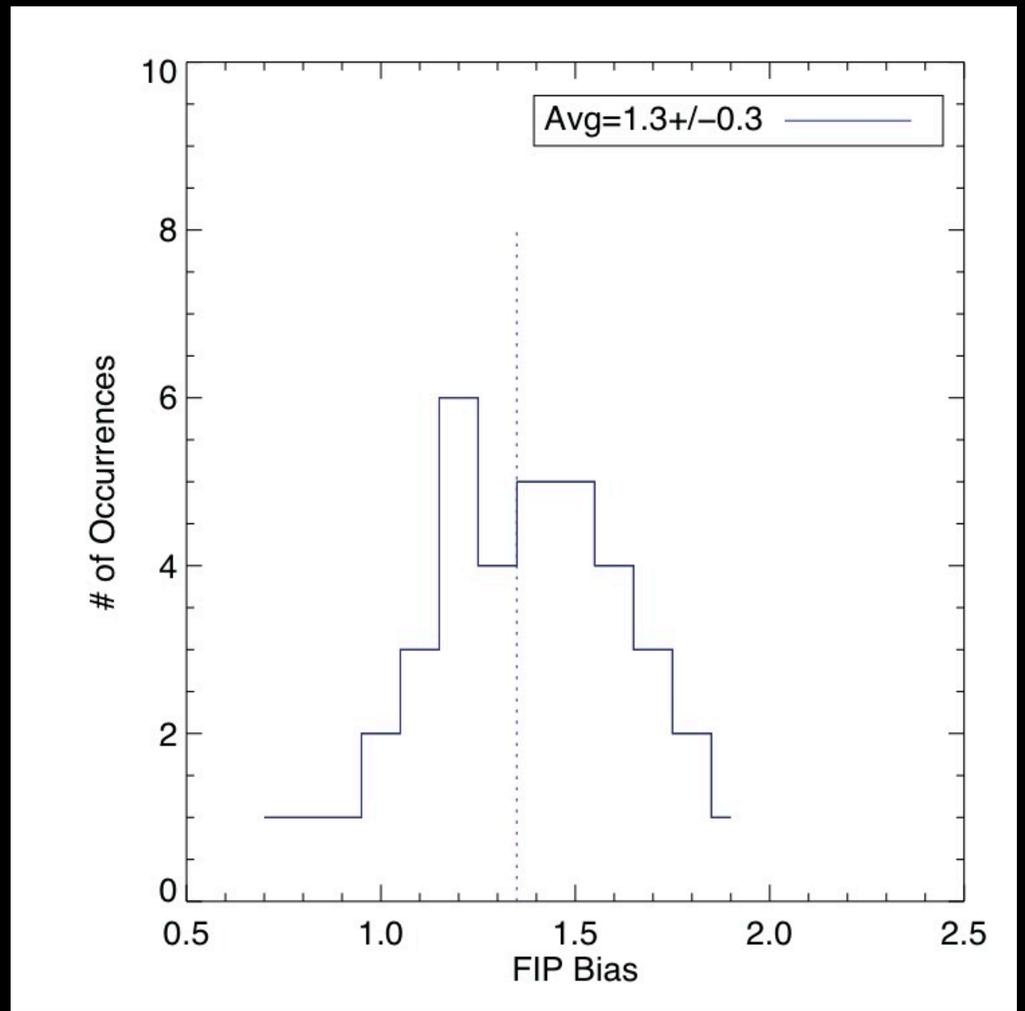


XRT/EIS Study of 22 polar X-ray jets (Lee et al. 2015)

Tracer of plasma origin III. Fast solar wind

Polar jets have photospheric abundances (Lee et al. 2015).

Consistent with fast wind.

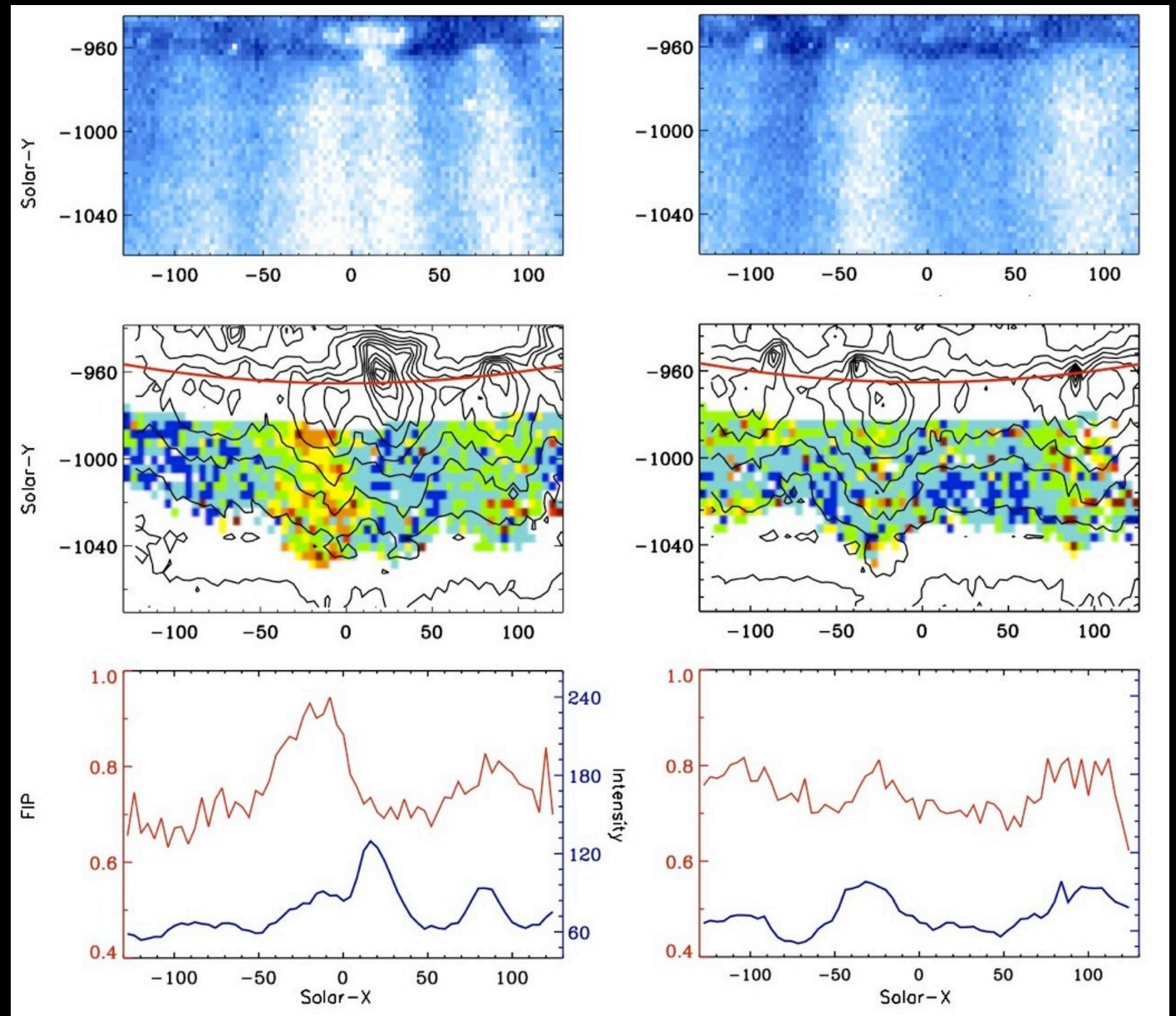


Tracer of plasma origin III. Fast solar wind

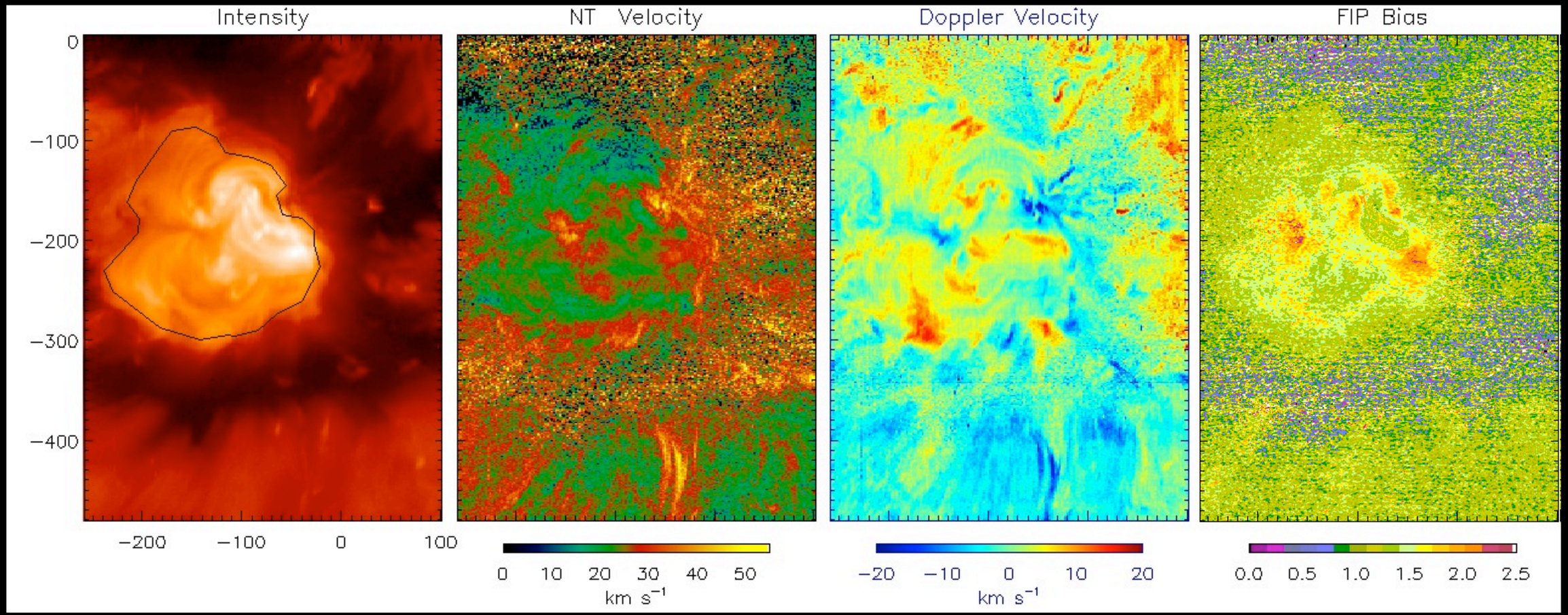
Plumes and Inter-Plumes have photospheric abundances (Guennou et al. 2015).

Consistent with fast wind.

Plume abundance is higher than inter-plume and can vary with time.



Evidence of Mixing Process in loops/Location of Fractionation

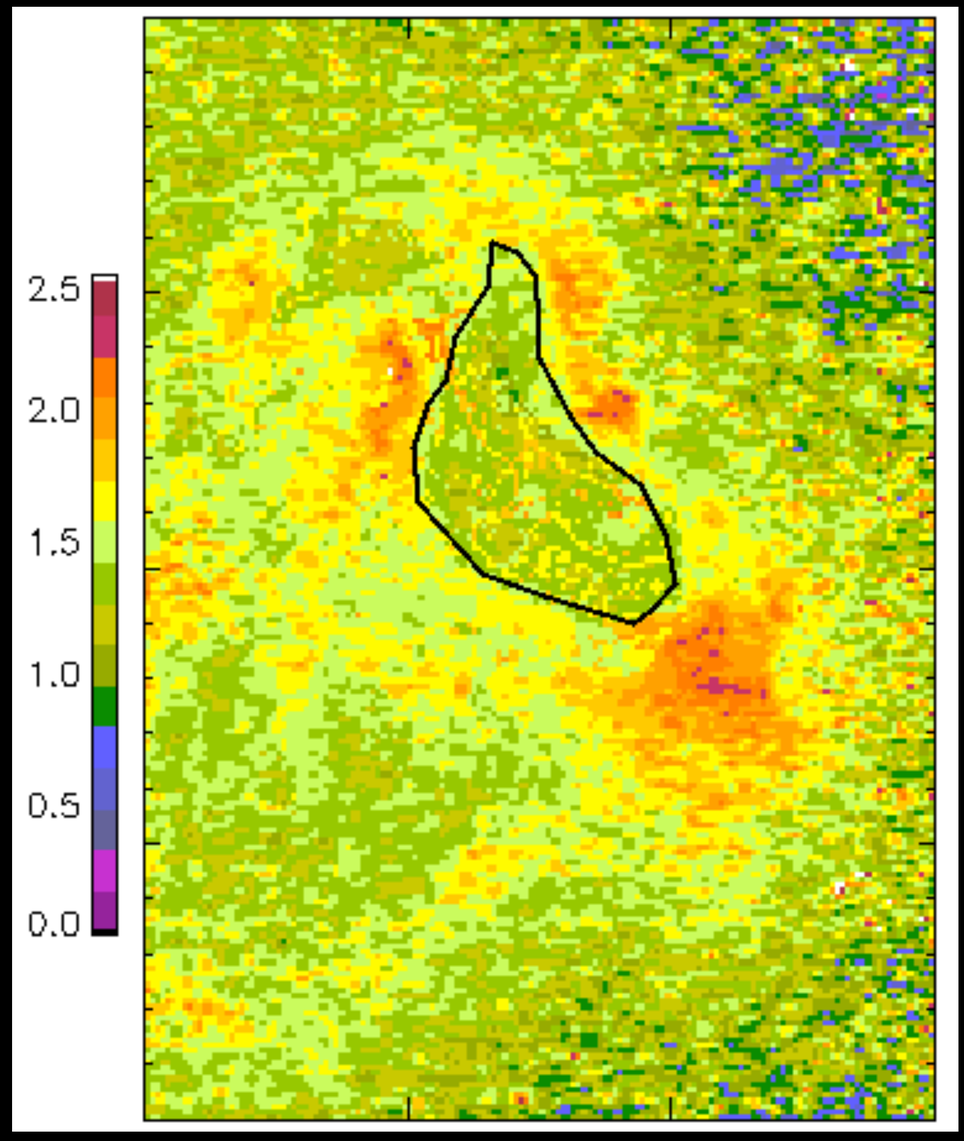


Baker et al (2013) - Anemone AR emerging in an equatorial coronal hole

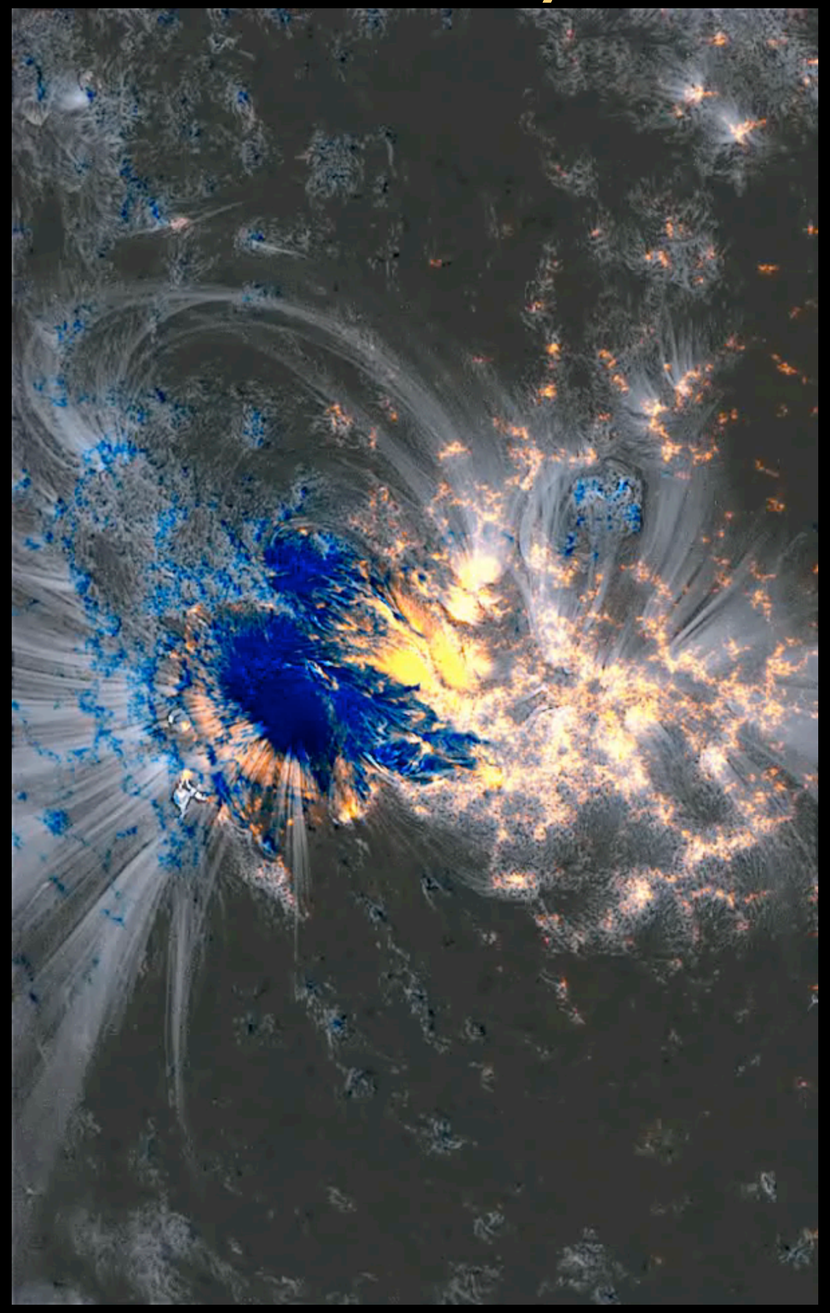
New Evidence of Bald Patch Topology?

Low FIP bias in channel where sigmoid is forming (Baker et al 2013)

If flux rope is forming low down, reconnection at bald patch heats and lifts up photospheric plasma (Green & Kliem 2009)



Summary



- Largely unexplored field - new results & information.
- *Sometimes contradictory!* Chromospheric plasma heats AR moss and supplies loops & outflows or not?
- *Sometimes unhelpful!* CHs, X-ray jets, plumes, inter-plumes all have fast wind composition. Are they all sources?
- *Often exciting!* Observations of key processes: loop filling, magnetic topology. Possible identification SW sources.
- Investigate all of these in the solar laboratory - implications for stellar astronomy (inverse FIP effect...).