UV/EUV Spectroscopic Observations

by

G. A. Doschek

Space Science Division, NRL

Solar-C Science Definition Meeting

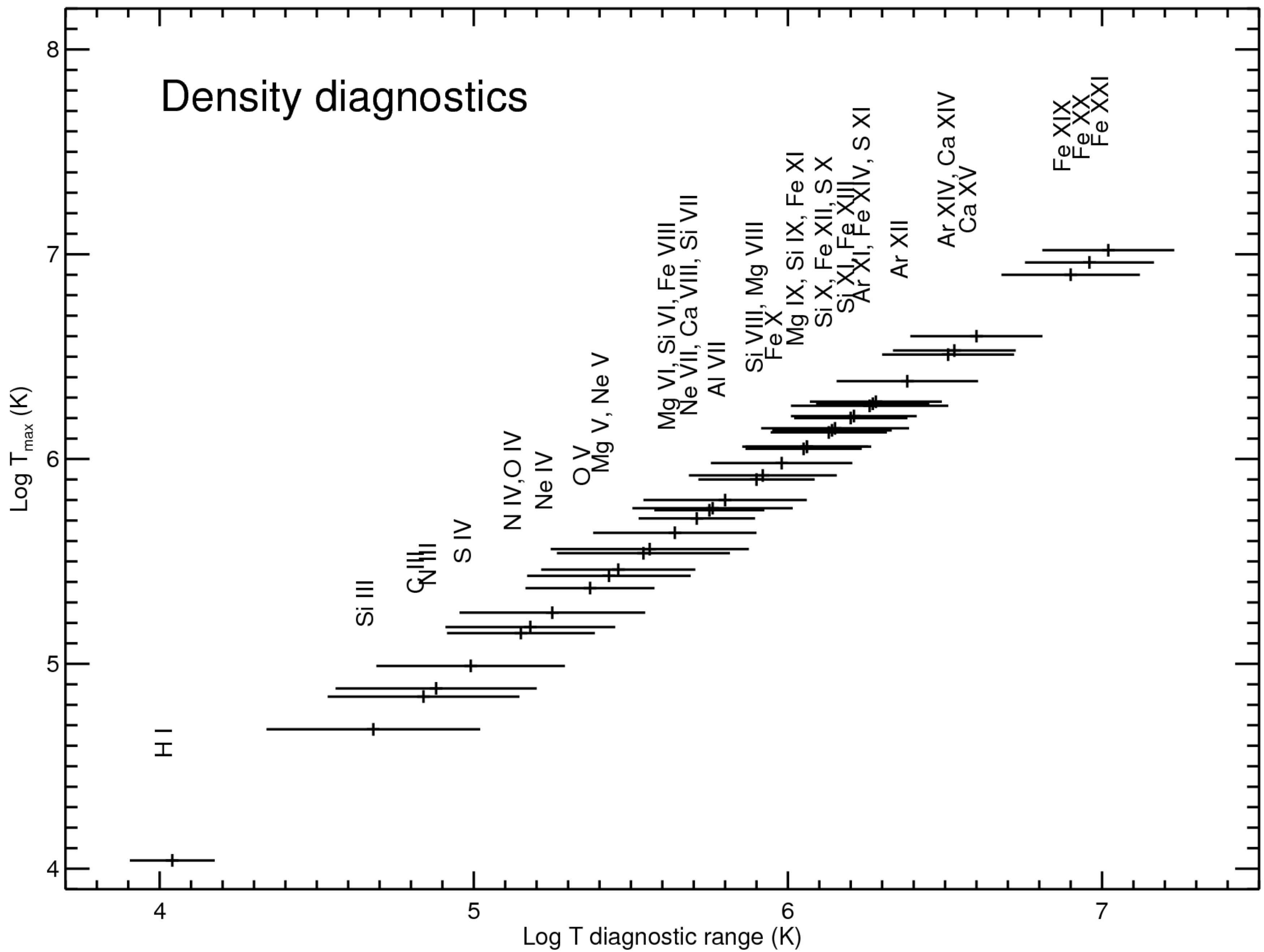
19 November 2008

The Solar Atmosphere: Outstanding Problems

- **The connectivity of the atmosphere from the photosphere into the corona is unclear**
  - **Current instrumentation cannot spatially resolve the UV/EUV chromosphere/transition region**
  - **There is a mismatch in present spatial resolution from the photosphere into the corona**
  - **Plasma diagnostics are averages over too large spatial and temporal scales**
- **Testing models of the solar atmosphere requires data that do not exist**
  - **Physical parameters as a function of spatial position in coronal flux tubes and the connectivity of the flux tubes with the photosphere and magnetic field are inadequately known**
  - **The time evolution of coronal flux tubes is currently only poorly known.**
- **CONCLUSION: If the above observational problems are not overcome, we will not be able to test adequately our models of the energetics and dynamics of the solar atmosphere. Plan B addresses these problems. *Achieving seamless (same very high spatial/spectral/temporal resolution with co-alignment) from the photosphere all the way into the corona is much more than an incremental increase in capabilities.***

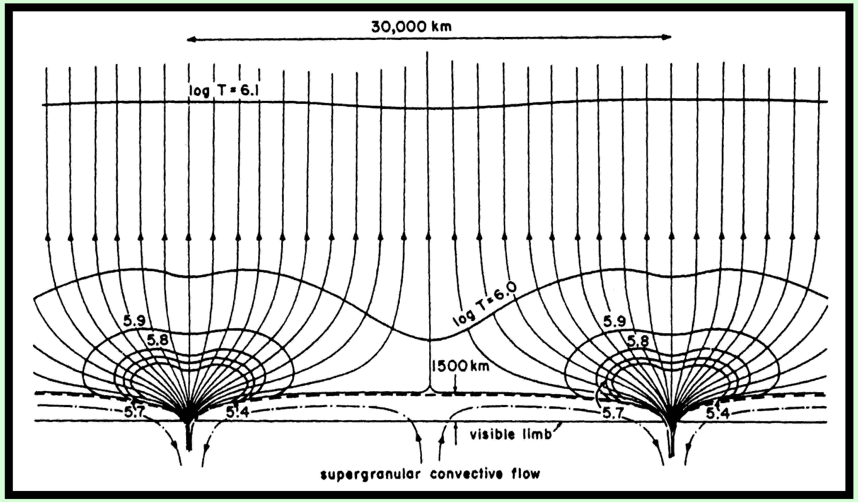
Some Specific Noteworthy Plan B Coronal Science Objectives

- **The origin of the solar wind**
- **The nature of coronal loops**
  - **What are they?**
  - **What heats them?**
  - **How do they evolve?**
- **Solar flares**
  - **Testing the "Standard Model"**
  - **Understanding the physics in the reconnection region**
- **Flux emergence and CME initiation**

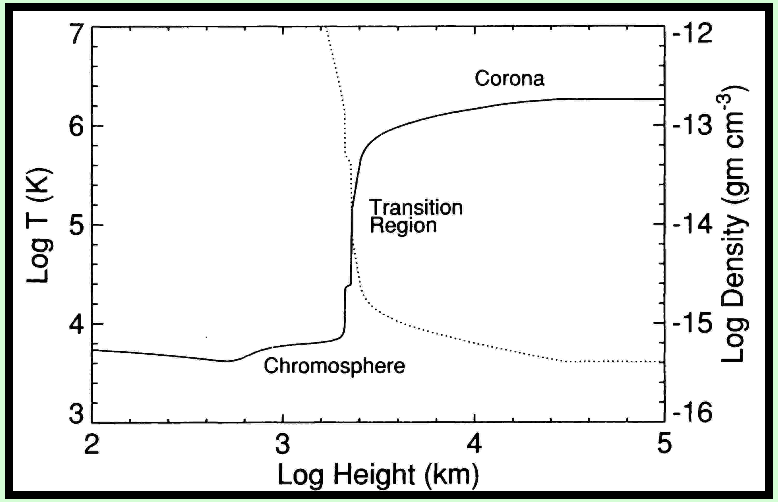


Density diagnostics
Log T_max (K)
Log T diagnostic range (K)
H I
Si III
C III
N III
S IV
N IV,O IV
Ne IV
O V
Mg V, Ne V
Mg VI, Si VI, Fe VIII
Ne VII, Ca VIII, Si VII
Al VII
Si VIII, Mg VIII
Fe X
Mg IX, Si IX, Fe XI
Si X, Fe XII, S X
Si XI, Fe XIII
Ar XI, Fe XIV, S XI
Ar XII
Ar XIV, Ca XIV
Ca XV
Fe XIX
Fe XX
Fe XXI

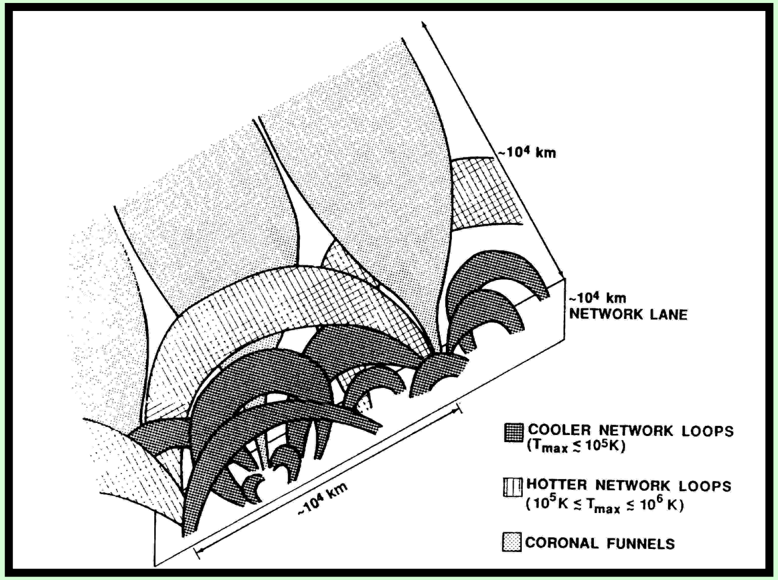
The Structure of the Solar Transition Region



The classical transition region

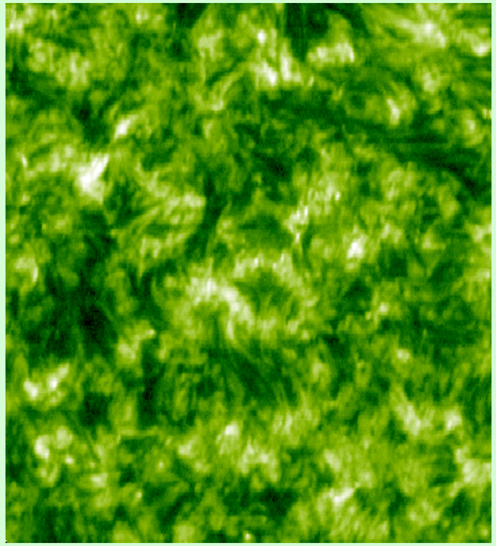


Classical temperature structure

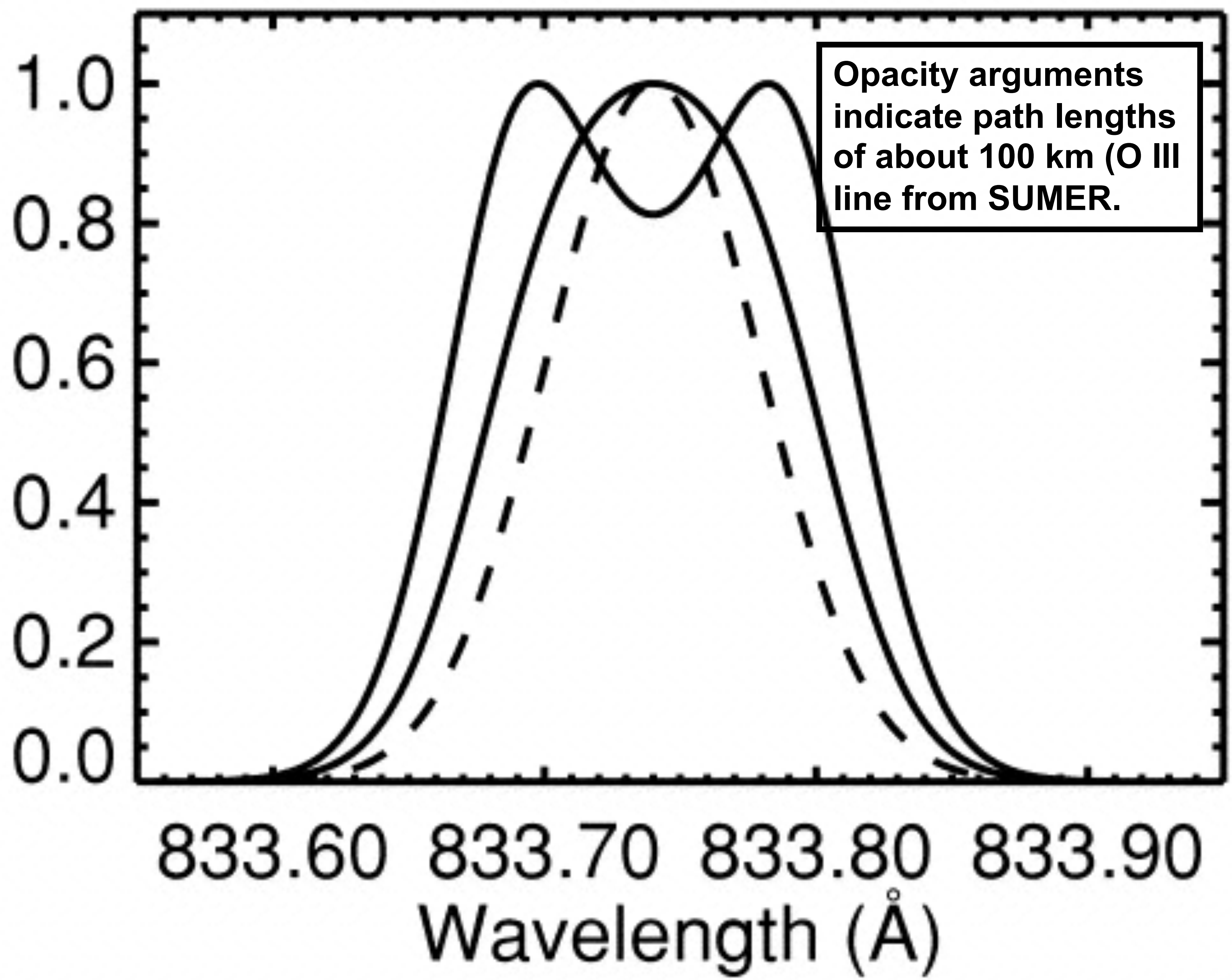


The cool loop/funnel model

What best describes the solar transition region – e.g., the classical transition region, cool loops, or separatrix surfaces? Transition region structures are around 100 km is size, below most current EUV instrument resolution.

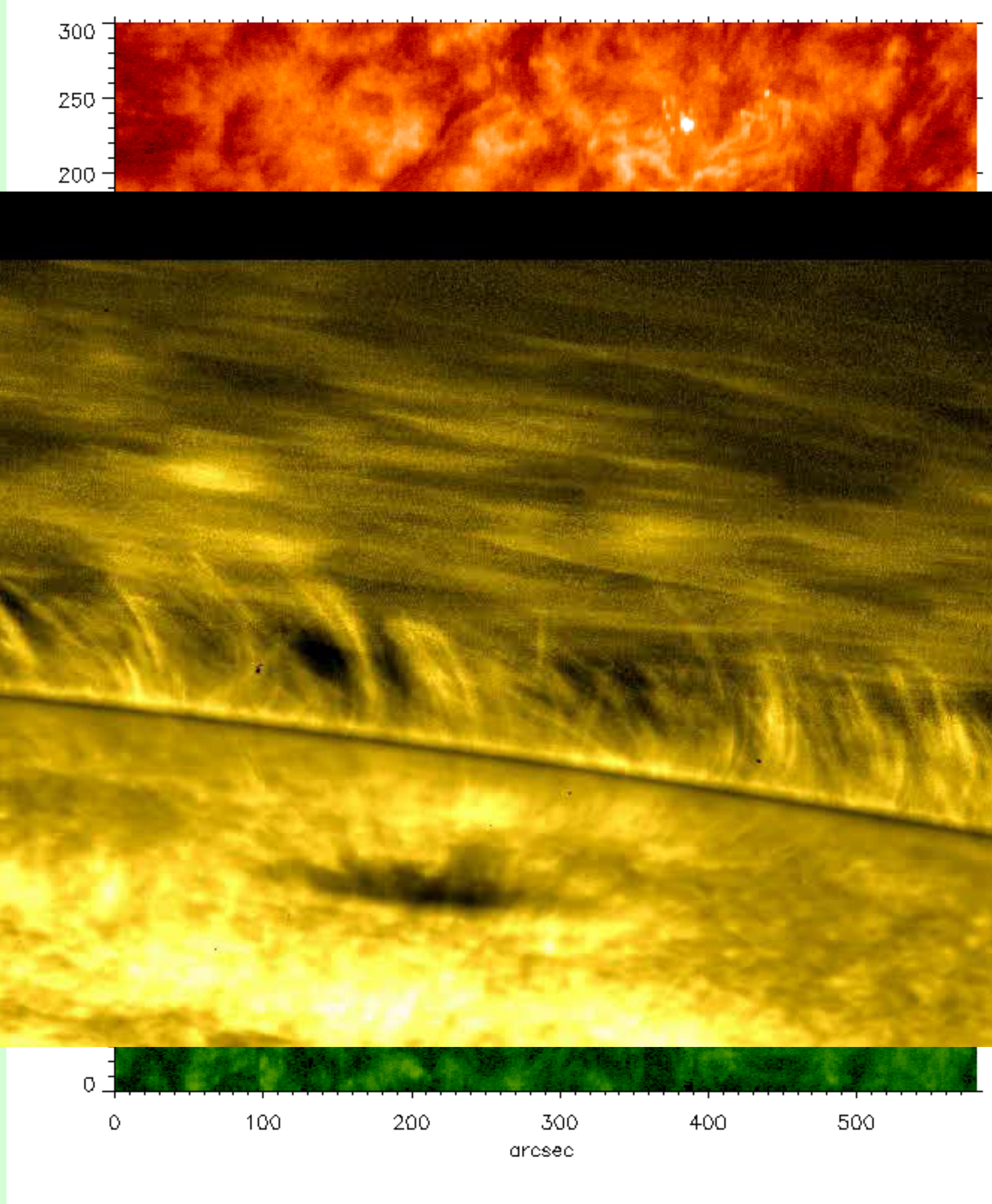


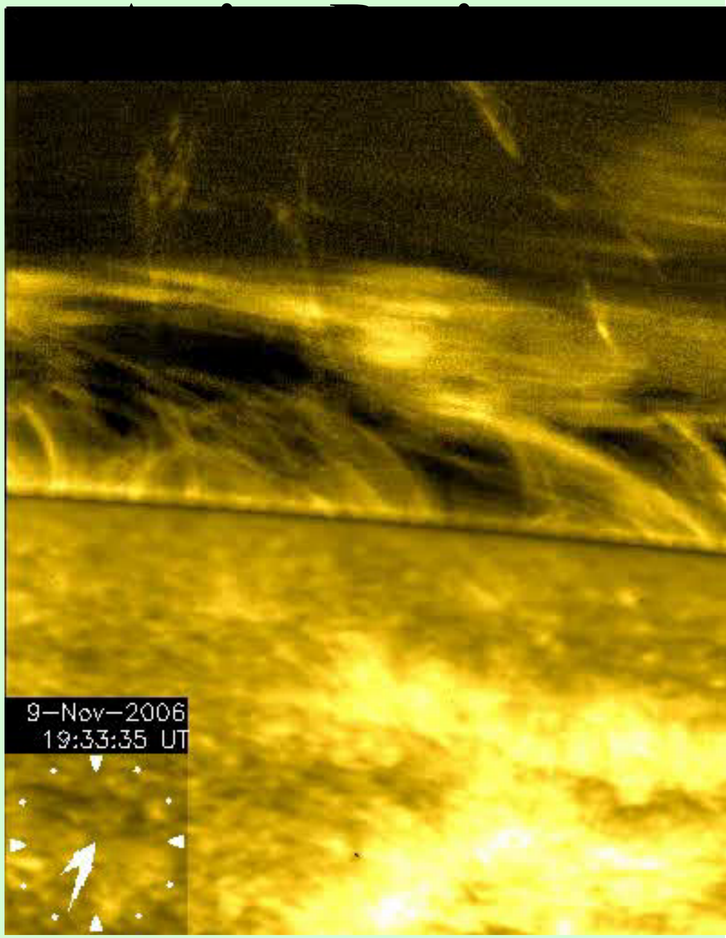
The Sun at 320,000 K
(2 x 10^5 km^2, SUMER)



1.0
0.8
0.6
0.4
0.2
0.0
833.60
833.70
833.80
833.90
Wavelength (Å)
Opacity arguments indicate path lengths of about 100 km (O III line from SUMER.

Note A. Vourlidas Ly-alpha talk





Plan B allows a new physics regime of the chromosphere to be explored.

Brooks

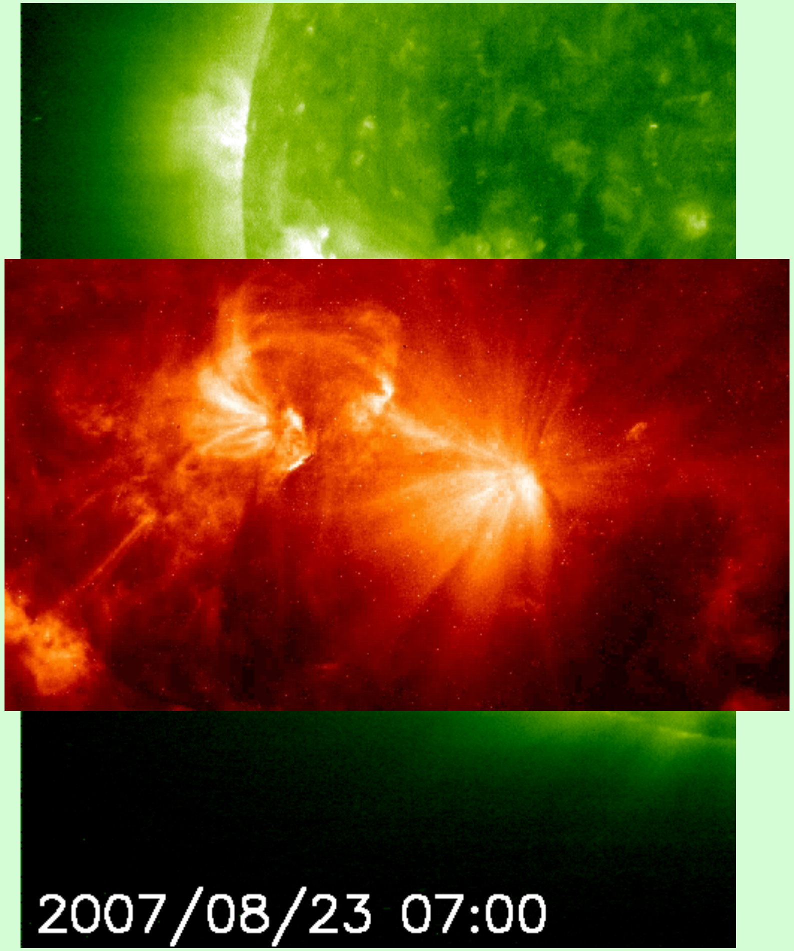
Ugarte–Urra & Warren

EIS Fe XVI 40'' slot raster

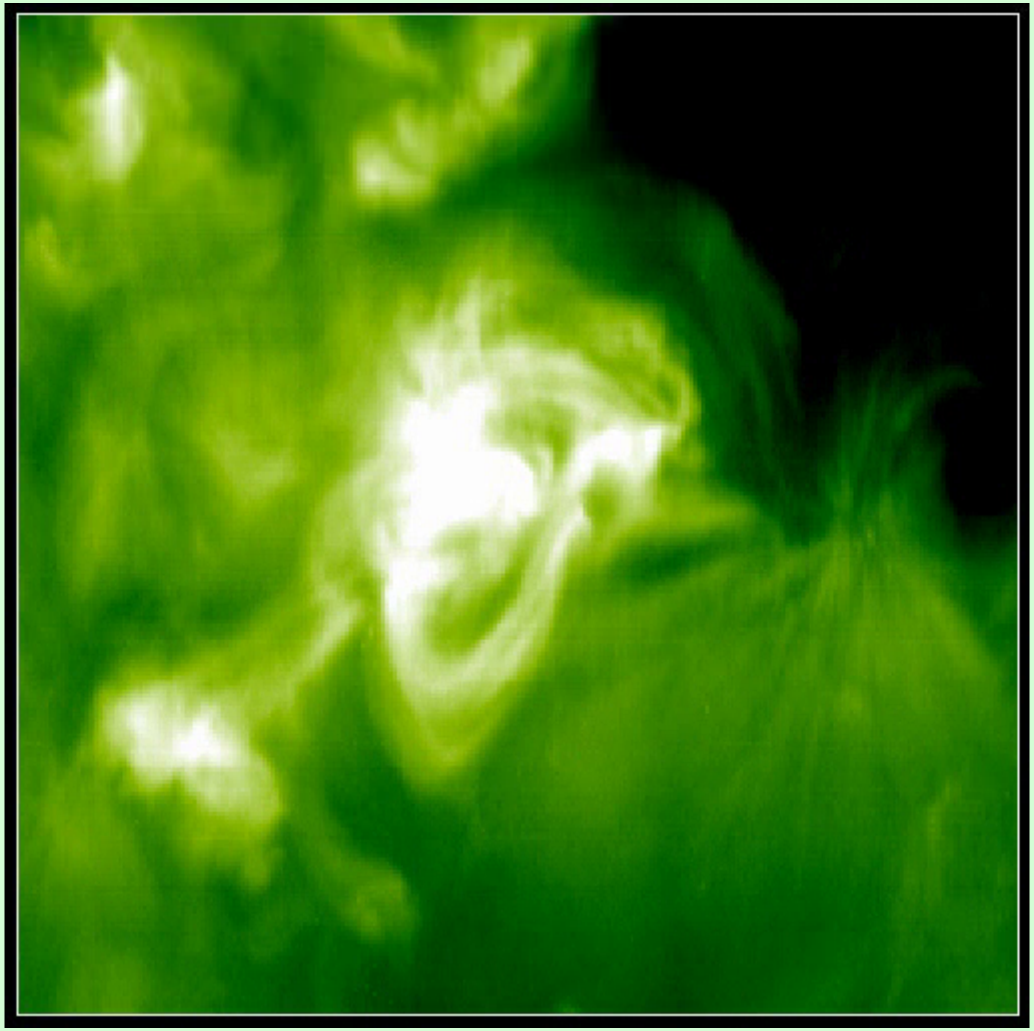
on SOT Magnetograms

START

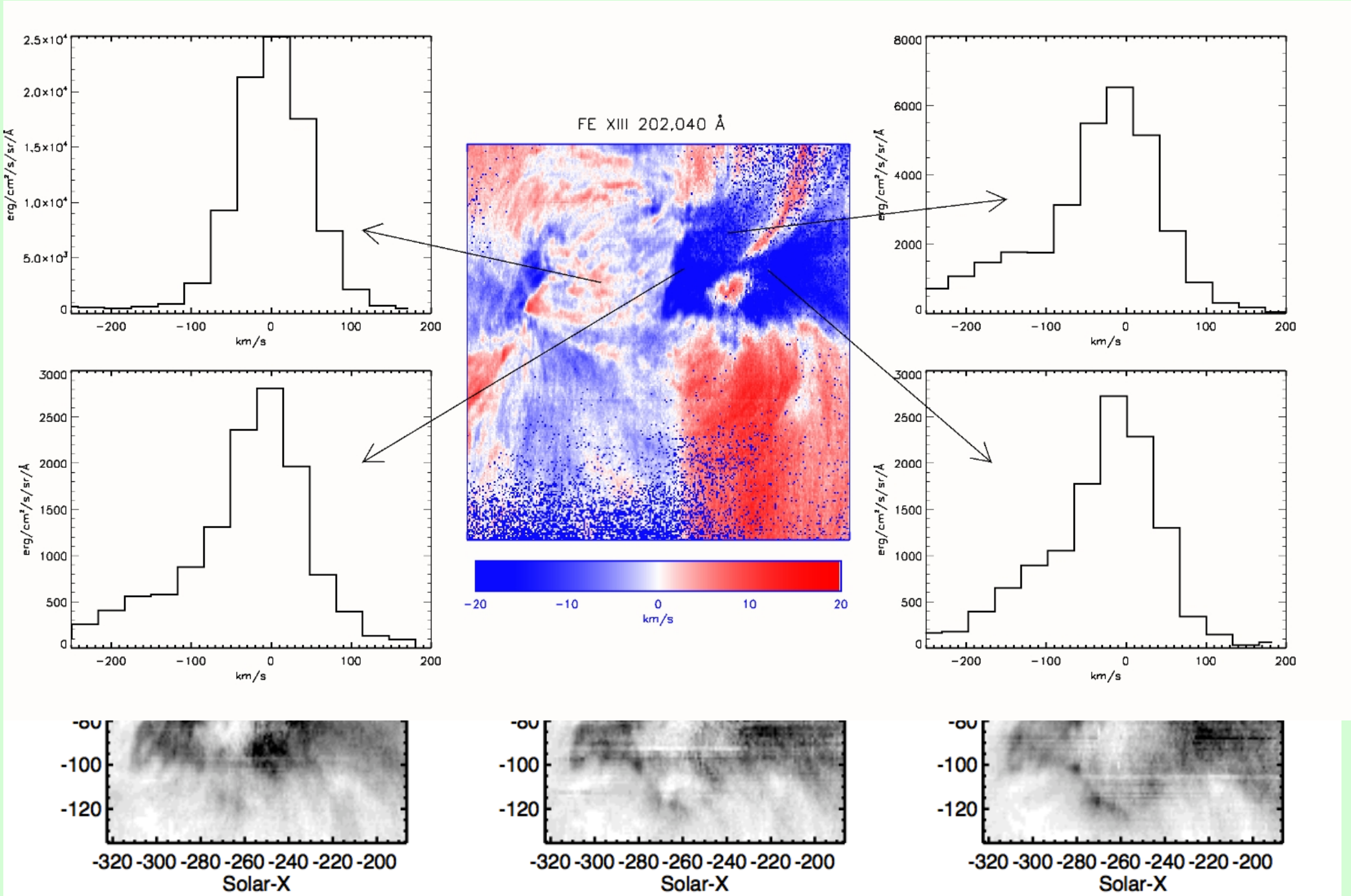
Active Region Outflows



SOHO/EIT: "Fe XII"

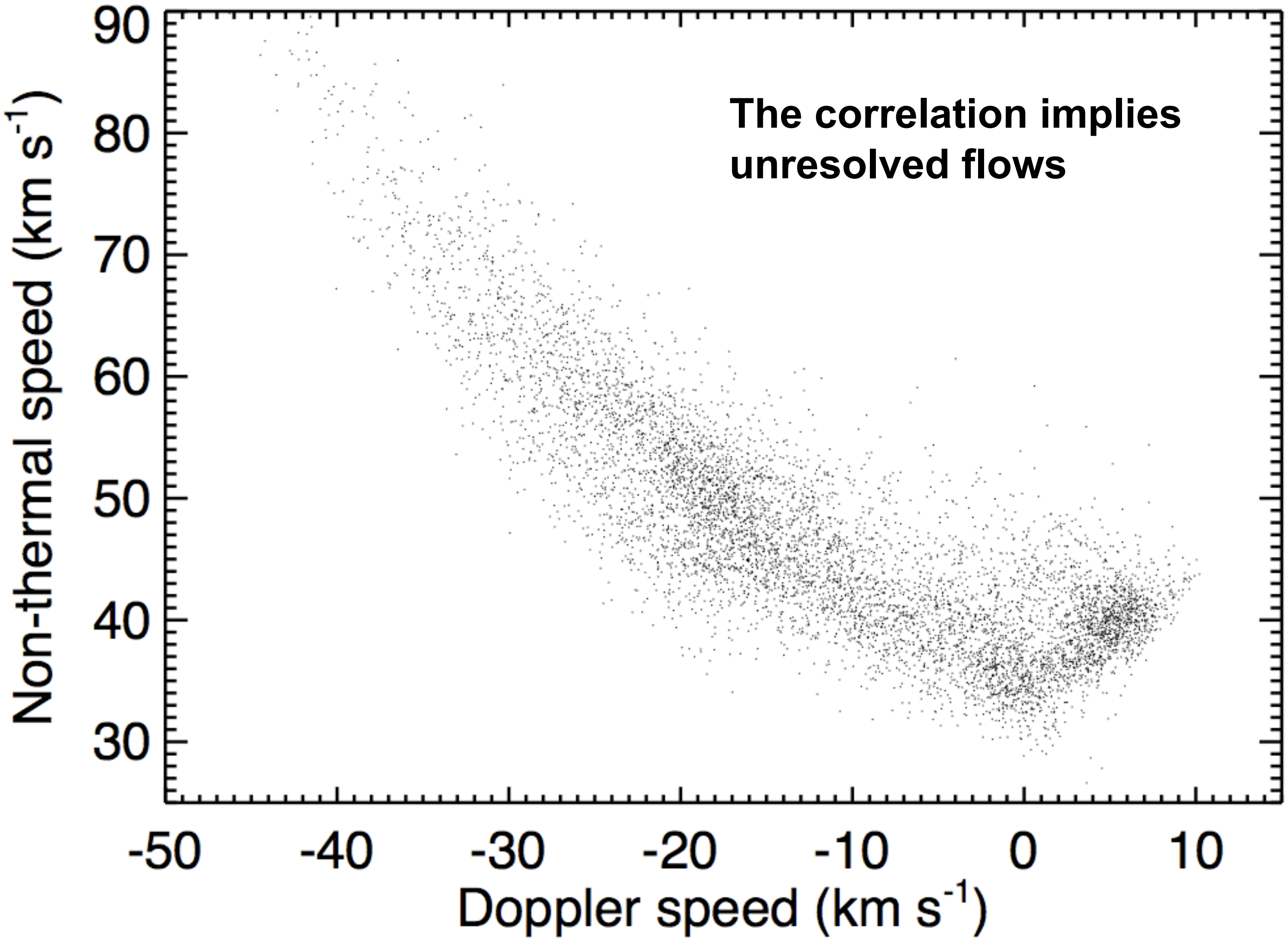


Hinode/EIS: Fe XII 195.12 Ǻ

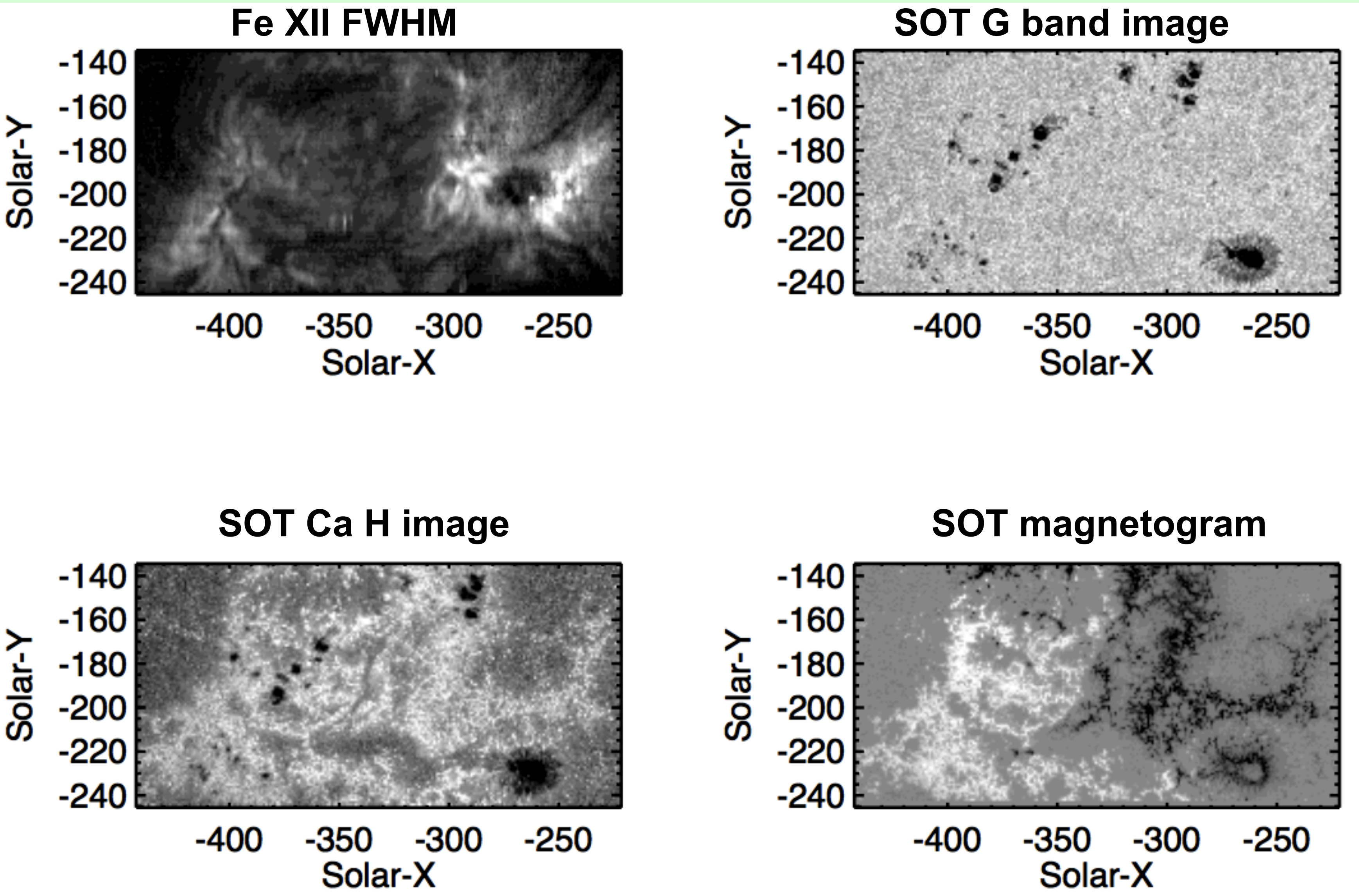


from Doschek et al. 2008, ApJ, 686, 1362

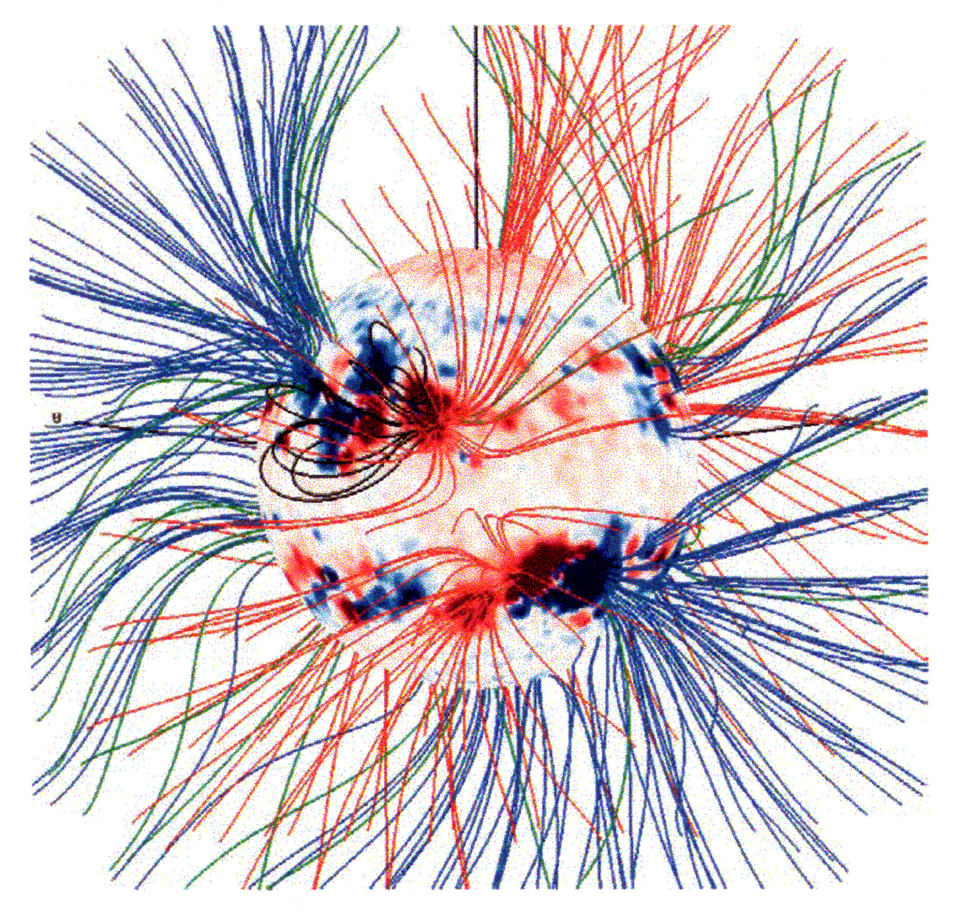
Correlation of Doppler Outflow Velocities
Non-thermal motions



Photospheric Properties of Outflow Regions



Modeling Contributions of Active Regions To the Heliospheric Magnetic Field

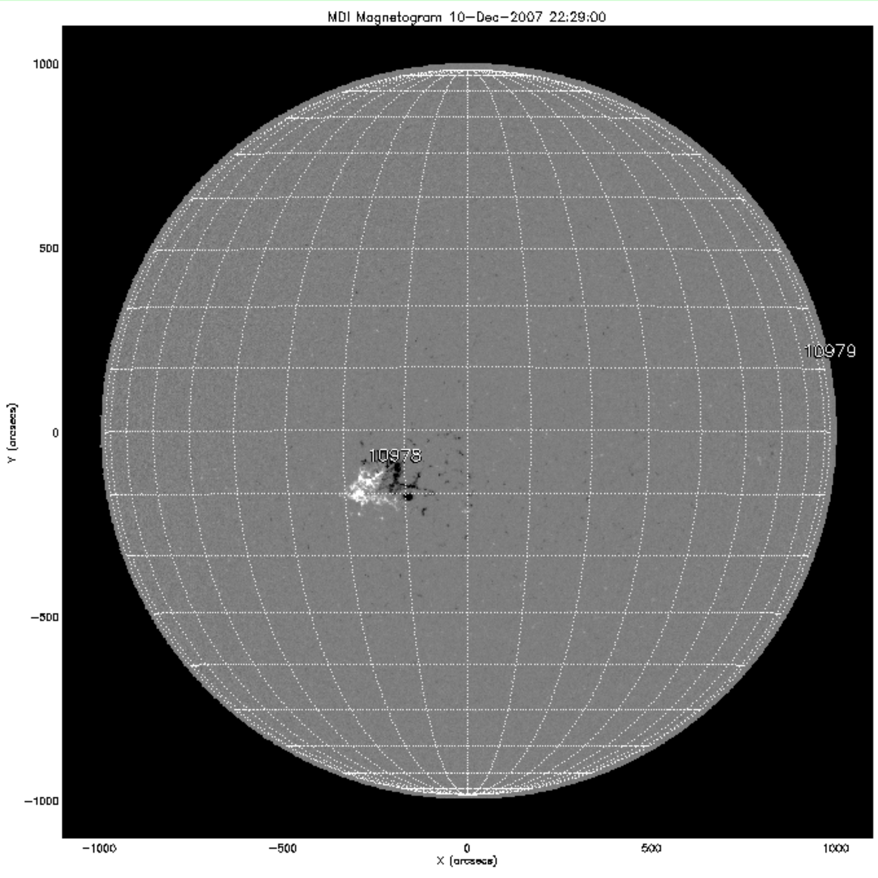


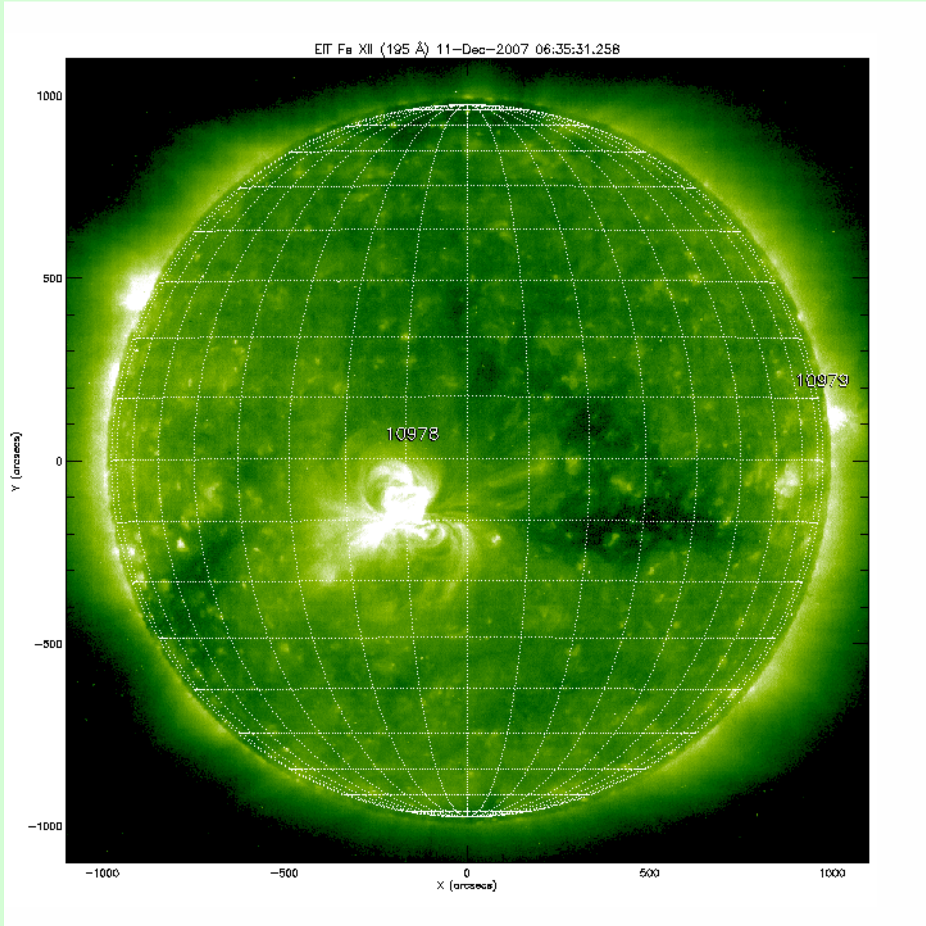
Potential field source surface coronal model

SOHO/EIT 284 Å image. Yellow lines are closed field lines; gray lines are open field lines that connect to the ACE satellite.

From Liewer, Neugebauer, & Zurbuchen 2004, Solar Physics, 223, 209

11 December 2007 Active Region





EIT 171 Å Image

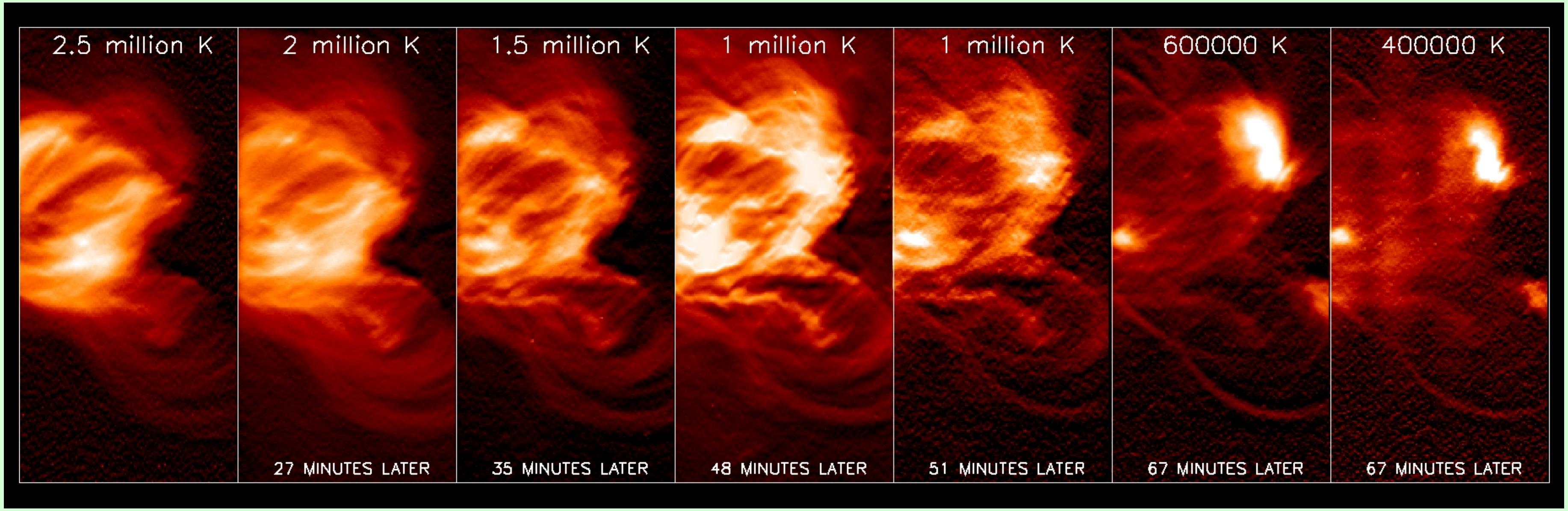
MWO Potential Field Extrapolation (Wang & Sheeley)

Do EIS upflows flow along open field lines and contribute to the solar wind?

Conclusions: EIS Flows

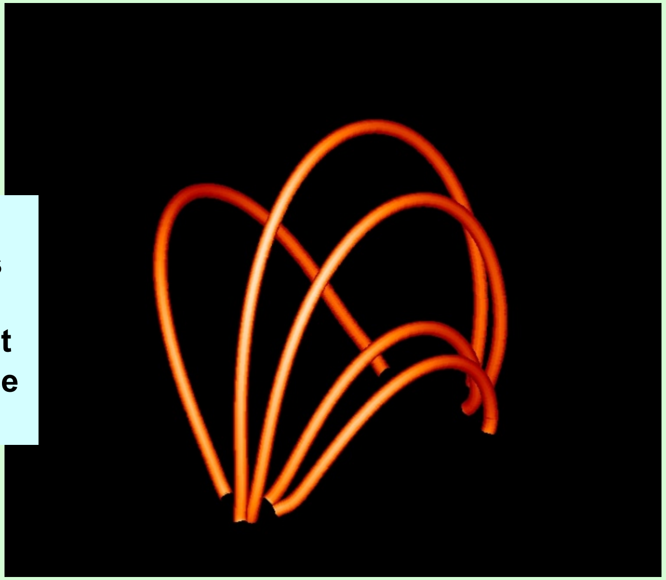
- **Large non-thermal motions and outflows in active regions occur in regions weak in intensity.**
- **Line profiles are in some areas represent the superposition of Gaussians with different outflow speeds.**
- **The outflow regions have QS temperatures of about 1.4 MK and electron densities of about $5 \times 10^8 - 10^{10}$ cm^{-3}.**
- **The outflow/turbulent regions are concentrated over magnetic regions of primarily a single polarity and can last for at least a day.**
- **There are temperature variations within flow structures and a multiplicity of unresolved loops.**
- **Some of the outflow plasma might occur in very long loops or along open field lines that extend into the heliosphere. Therefore, some of this flow might contribute to the solar wind.**
- ***At current spatial resolution, the connection of these outflows to the photosphere and chromosphere will remain unclear. A Plan B instrument can clarify the connection.***

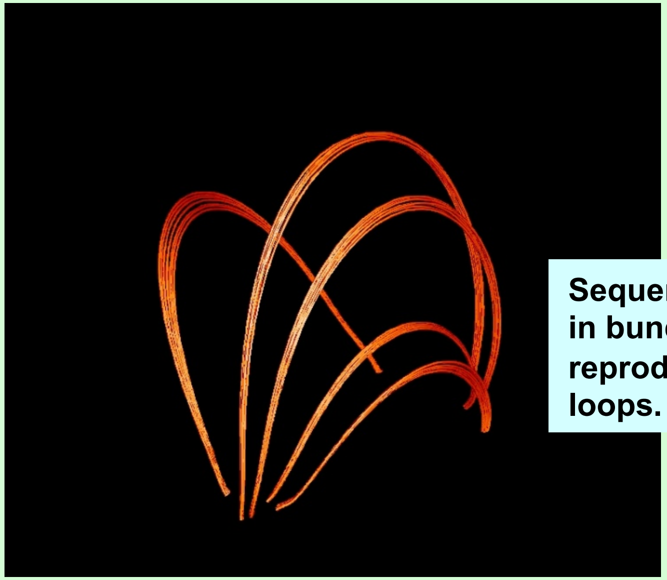
Active Region Coronal Loops



Single loop strands?

Steady-state heating models can reproduce “hot” loops, but fail to reproduce “warm” loops.

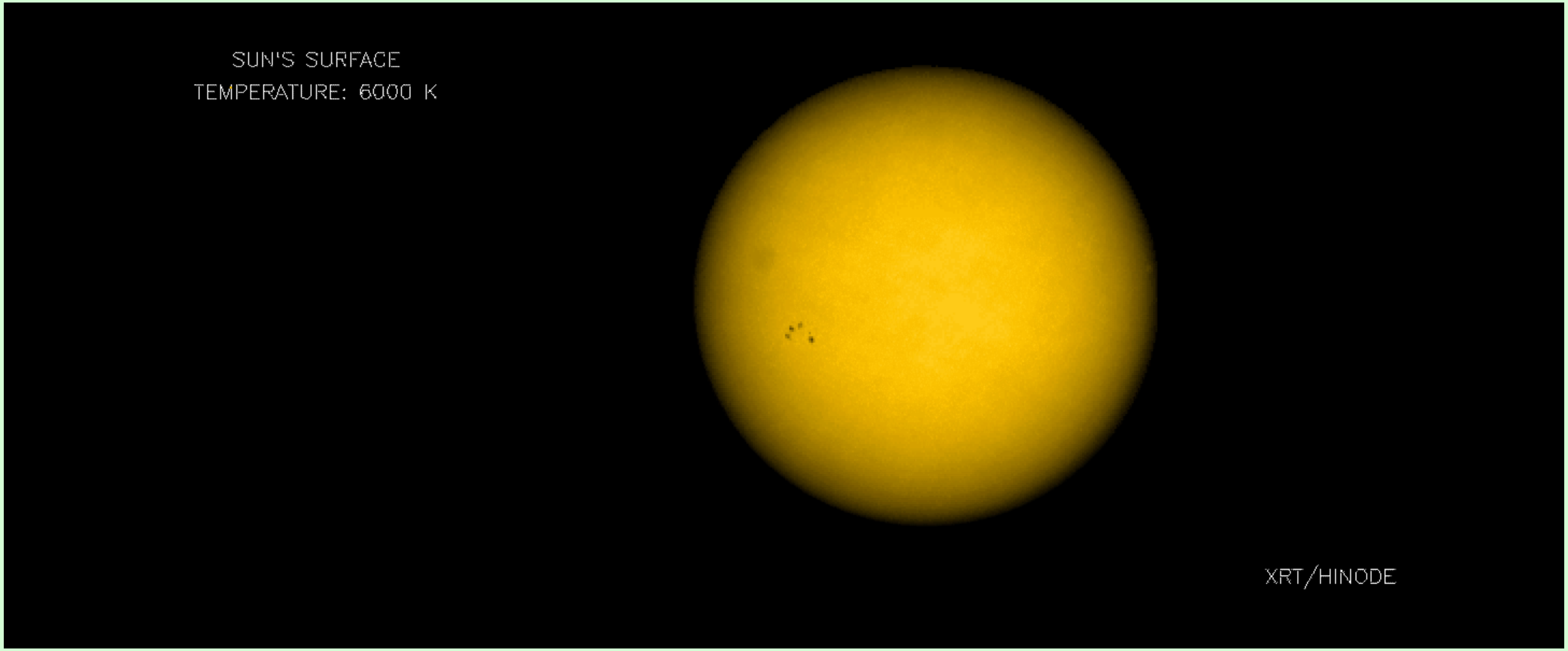




Or multi-loop threads?

Sequential heating in bundles of strands reproduces “warm” loops.

Cooling Coronal Loops from Active Region 40" Slot Rasters from EIS



from Warren et al. 2008, 686, L131

EIS: Loop Filling Factors are ~ 10%

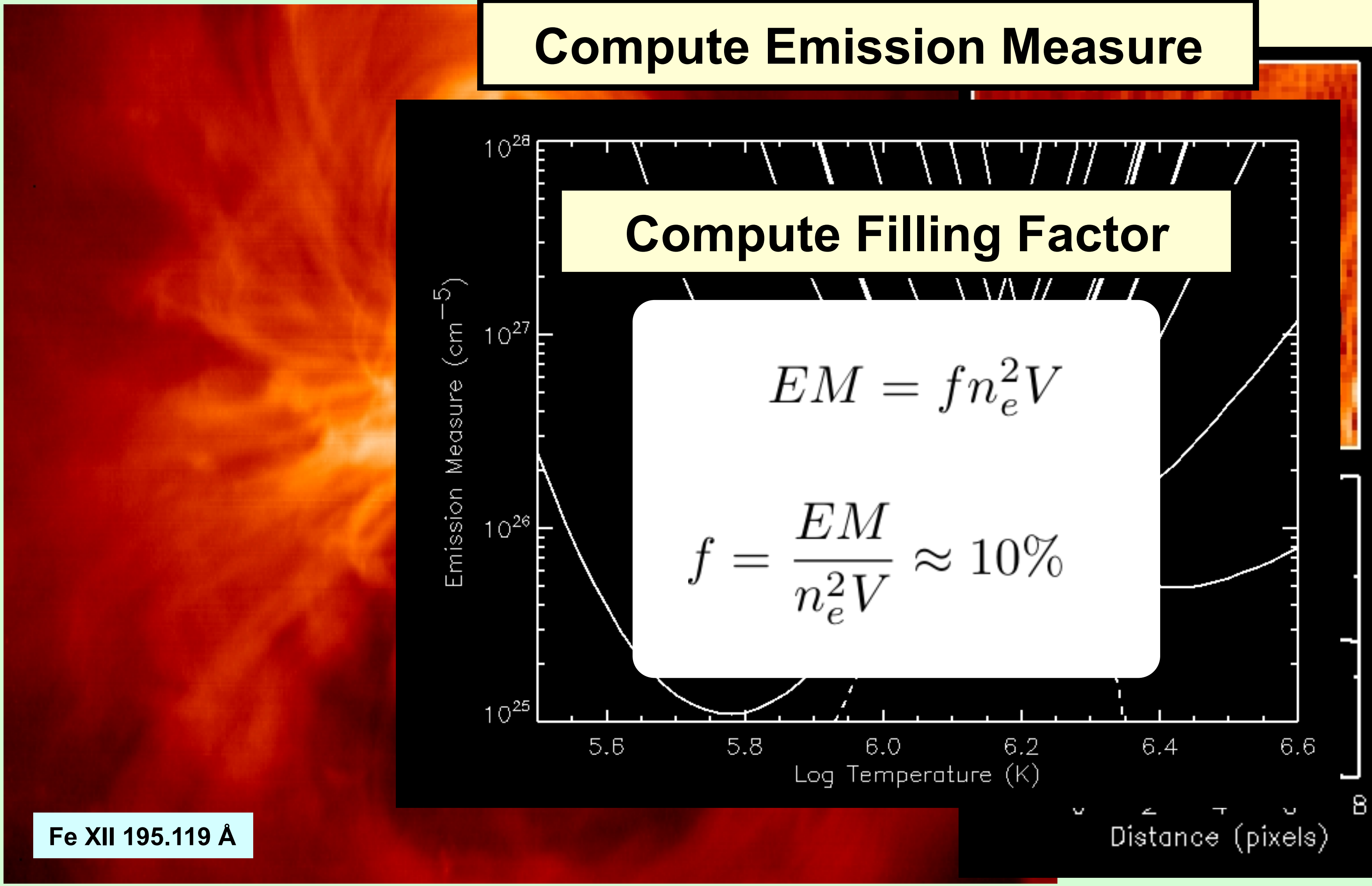
Compute Line Intensities and

Compute Emission Measure

Compute Filling Factor

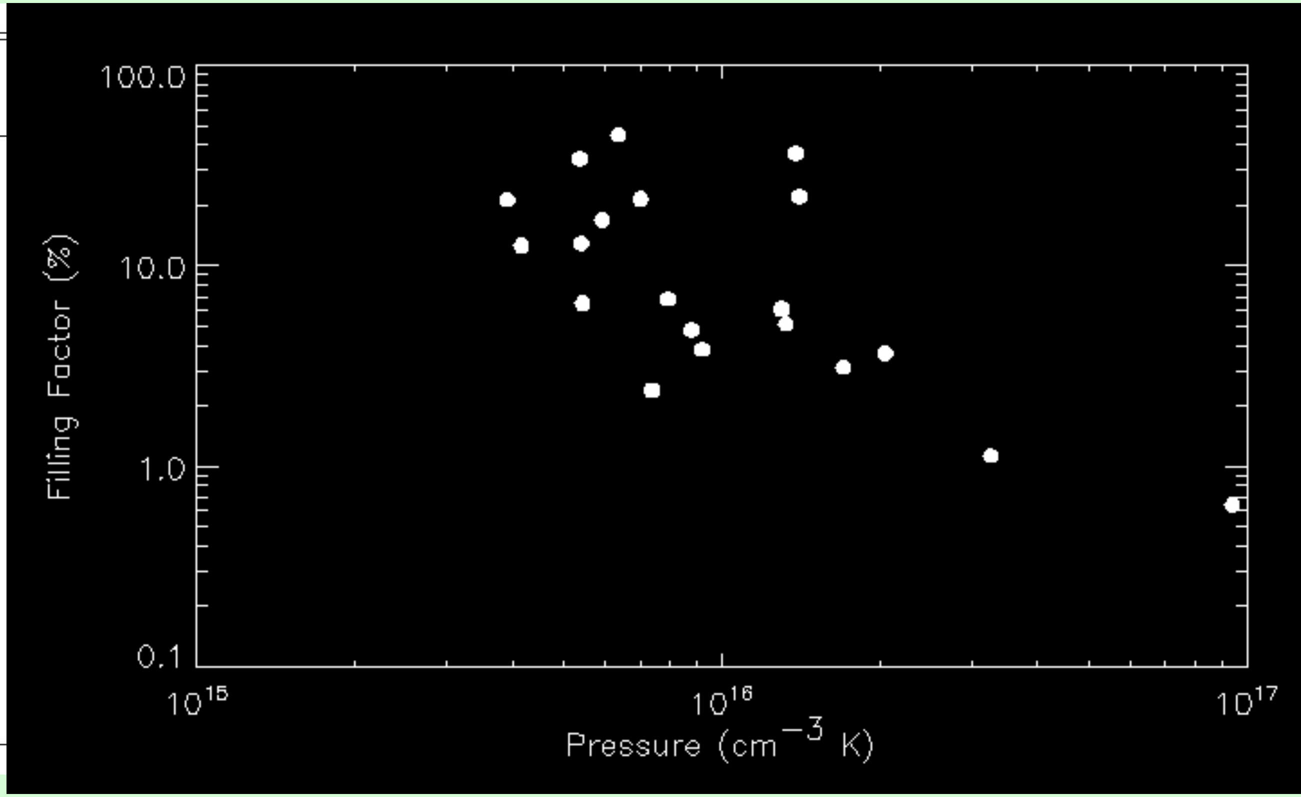
$$EM = f n_e^2 V$$

$$f = \frac{EM}{n_e^2 V} \approx 10\%$$



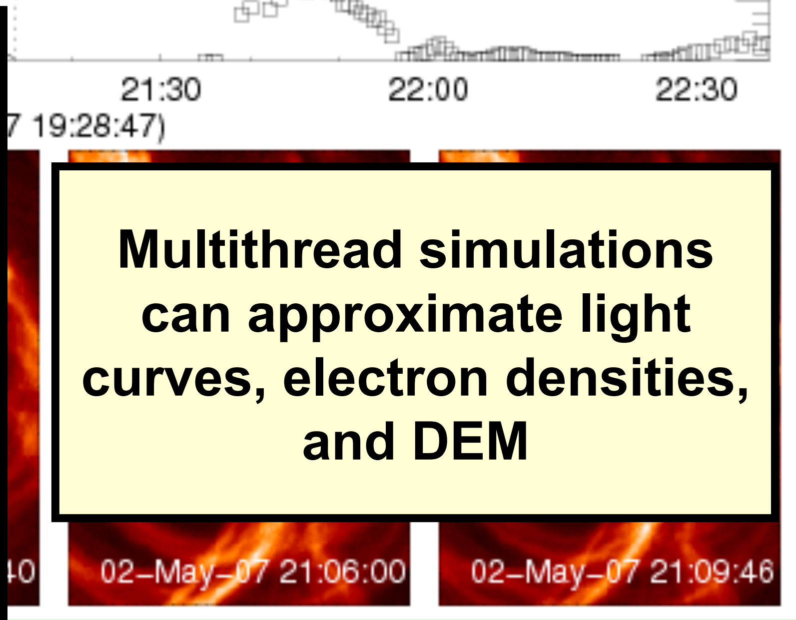
Analysis of 20 Loops

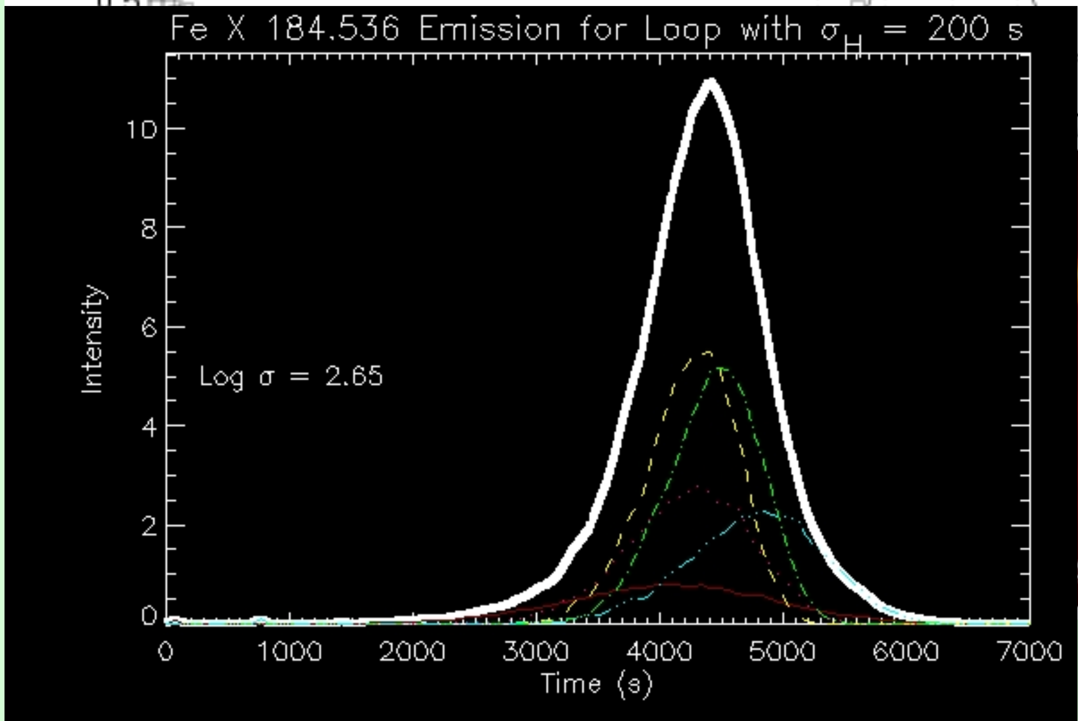
#	Date	t_{start}	$f(\%)$
1	10-Dec-07	03:36:43	16.8
2	11-Dec-07	13:11:02	3.7
3	11-Dec-07	12:57:50	6.1
4	12-Dec-07	06:31:29	4.8
5	12-Dec-07	06:29:24	36.2
6	12-Dec-07	14:52:33	44.7
7	12-Dec-07	15:01:34	12.5
8	13-Dec-07	15:35:17	22.0
9	13-Dec-07	13:45:32	34.0
10	15-Dec-07	03:40:08	12.9
11	15-Dec-07	01:44:07	5.1
12	15-Dec-07	21:17:07	6.5
13	15-Dec-07	19:50:59	2.4
14	18-Dec-07	02:15:51	0.6
15	18-Dec-07	01:11:14	21.3
16	18-Dec-07	01:39:43	3.8
17	18-Dec-07	19:51:37	3.1
18	10-Dec-07	03:27:00	21.4
19	11-Dec-07	13:13:48	1.1
20	13-Dec-07	16:08:38	6.8



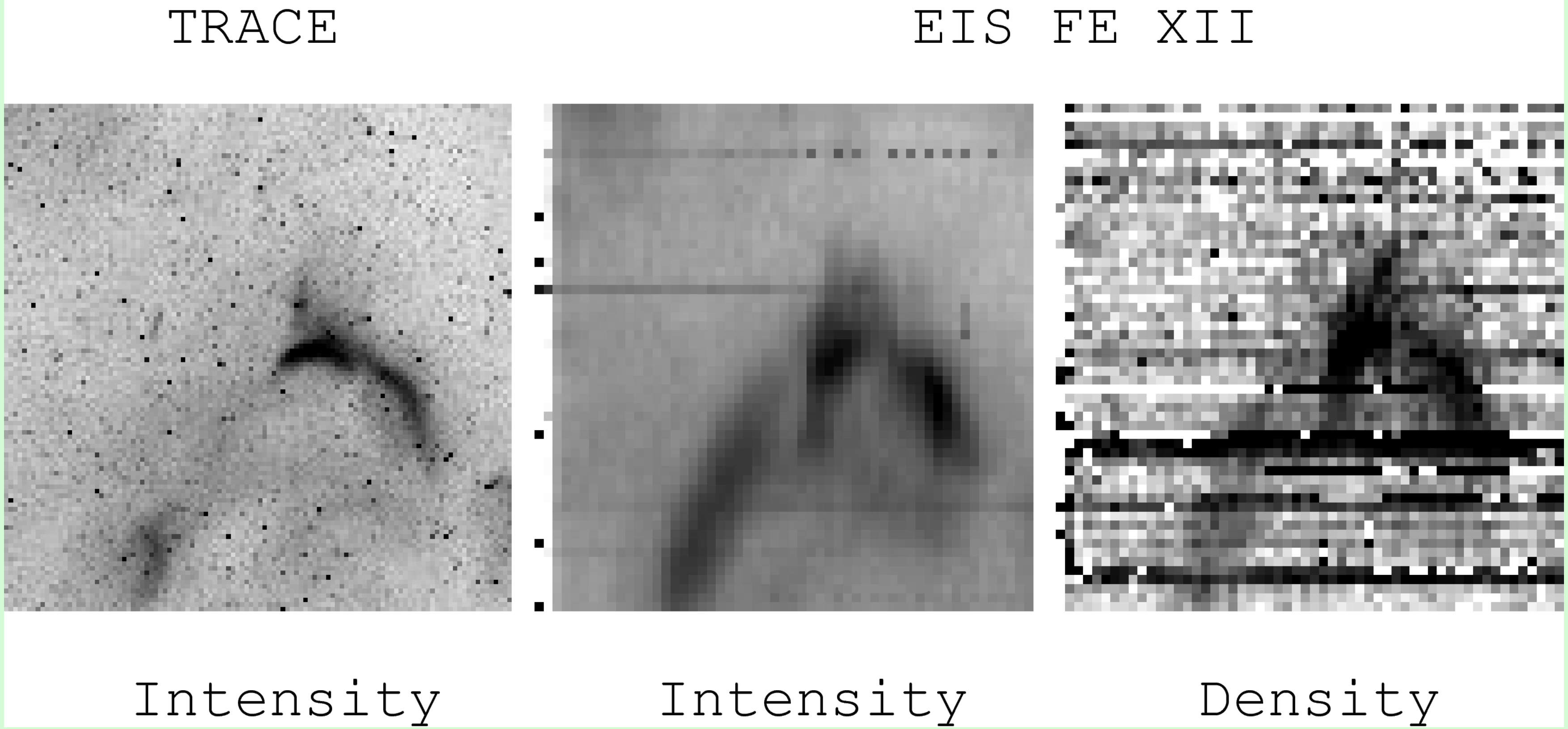
Loop Cooling: Evidence for Threads?

Predicted Cooling: 90s
Observed Cooling: 300s



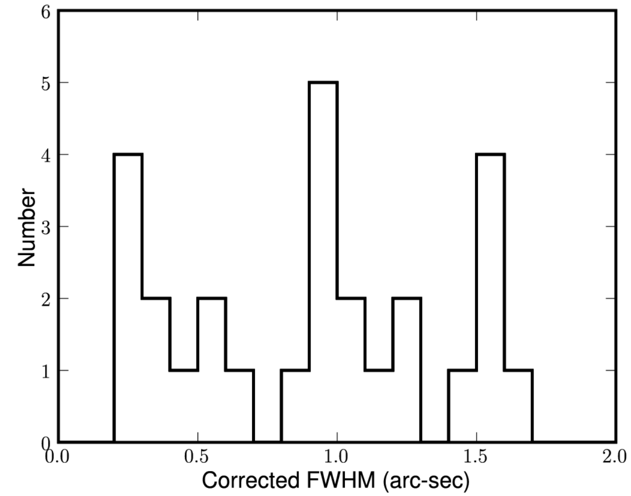


Multithread simulations can approximate light curves, electron densities, and DEM

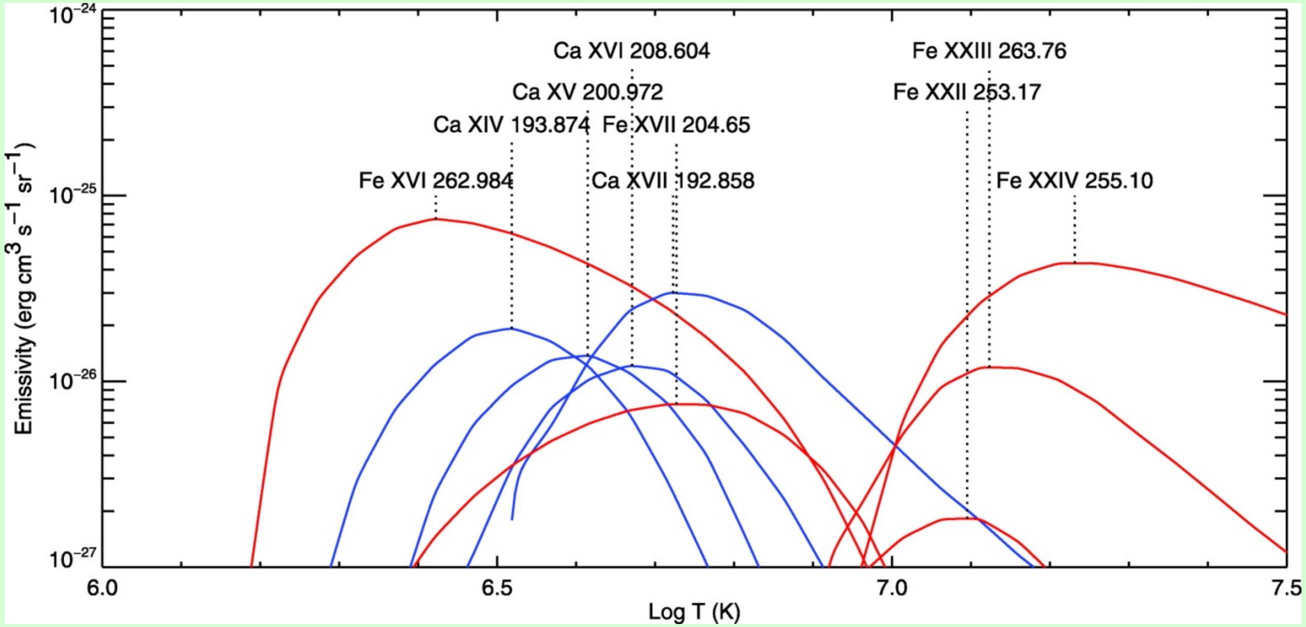


Filling Factors of Coronal Bright Points From Combined TRACE/EIS Observations

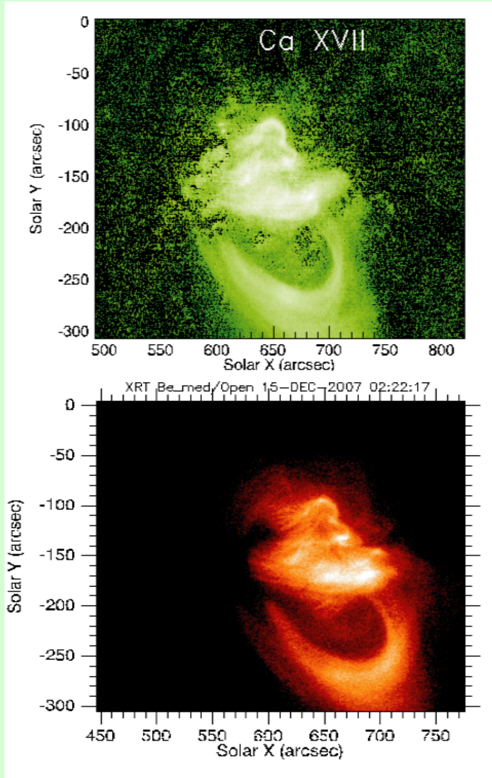
Right panel: histogram of inferred sub- resolution bright point filaments. Filling factors are << 1. Spatial resolution << 1" is needed to resolve structures and connect bright points to the chromosphere. From Dere 2008, submitted to Astronomy &Astrophysics

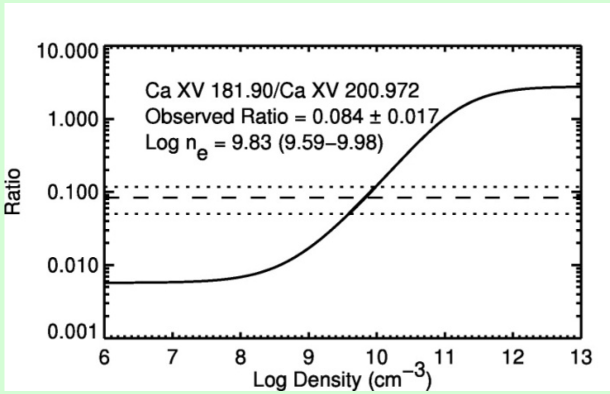


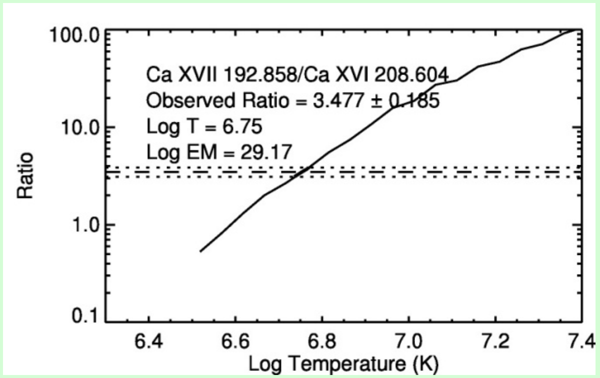
Testing loop heating models such as the nanoflare model requires spectroscopic temperature diagnostics, e.g., it is necessary to observe at high temperatures. From Warren et al. 2008, 685, 1277.



Note: Klimchuk, this meeting







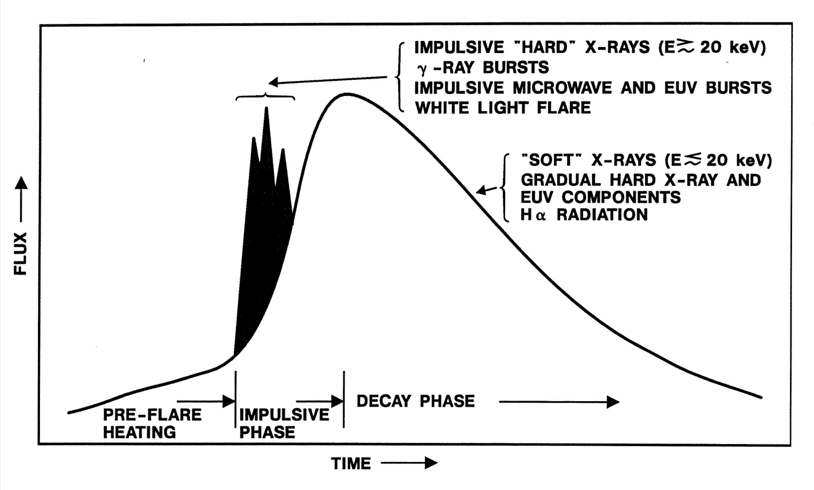
EIS and XRT

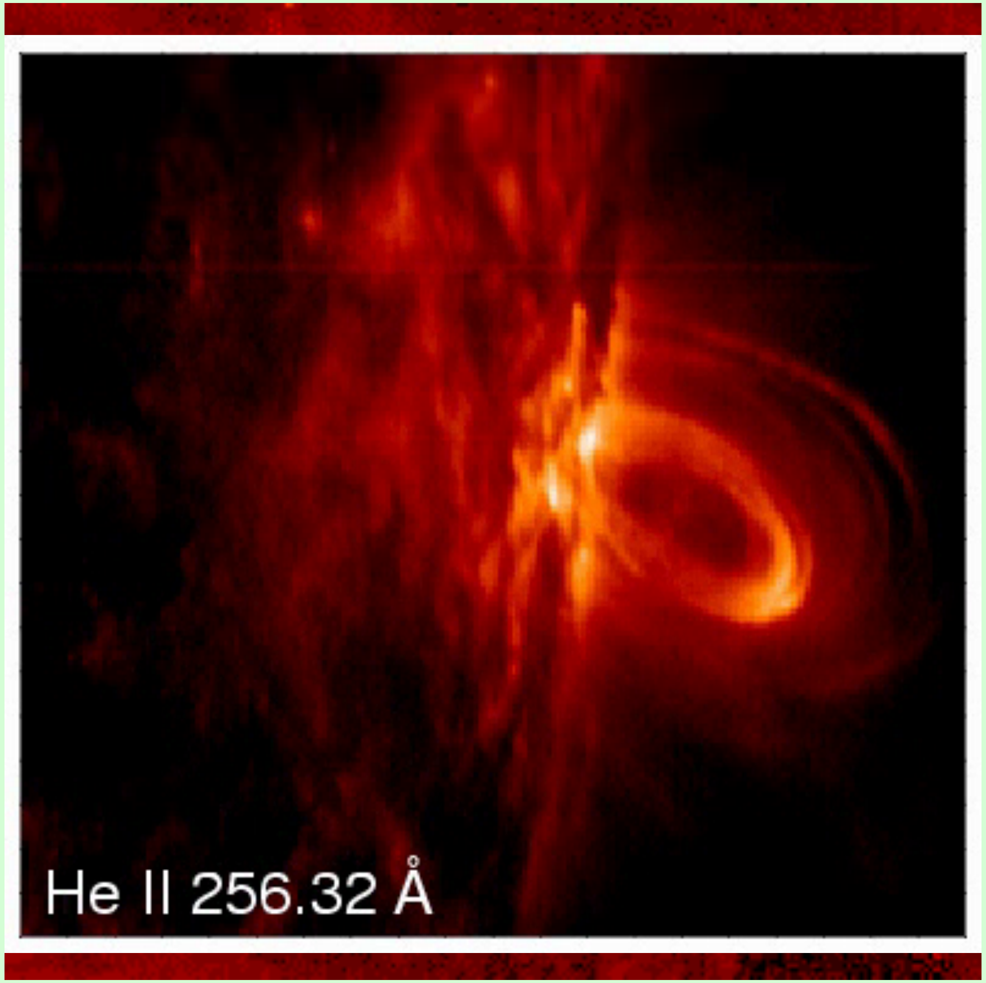
Summary/Conclusions: Loops

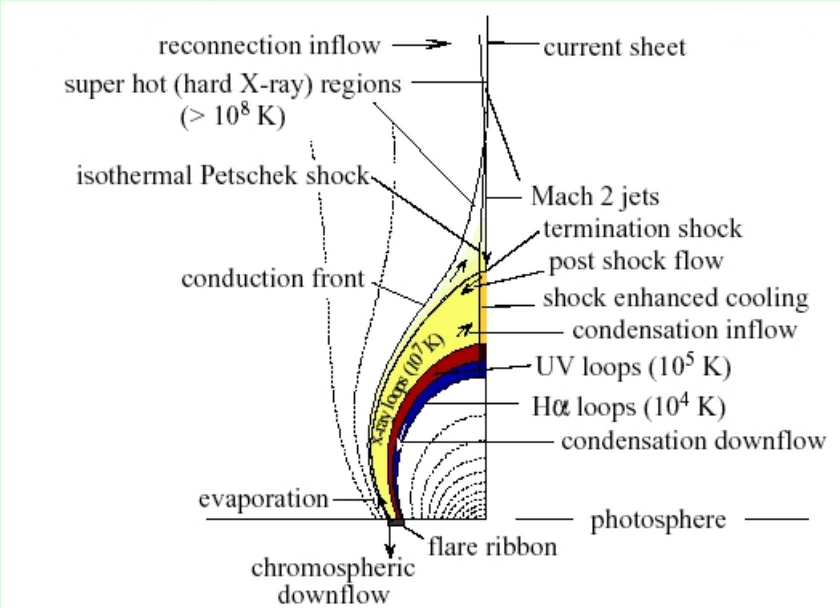
- **Physical properties of loops in active regions, such as temperature, density, and dynamics, have been measured with a quantum improvement in spectral and spatial resolution with EIS.**
- **Most "warm" loops (~1.4 MK) are not isothermal, but the temperature distribution around the average is narrow.**
- **Filling factors of dense warm loops are about 10%, supporting an unresolved strand model. Filling factors are inversely proportional to loop pressure.**
- **The combination of high densities and narrow temperatures present challenges for understanding active region heating.**
- **Warm loops appear to be loops that were heated up to higher temperatures and are cooling. The cooling indicates that unresolved strands are evolving coherently. Loop simulations are consistent with this scenario.**
- **It is highly desirable to connect the strands to their chromospheric/ photospheric counterparts for testing loop heating models (hear Vourlidas Ly-alpha talk)**
- ***To make further progress, a Plan B-type instrument is required.***

Solar Flare Reconnection Model – The "Standard Model"

from Hara et al. 2008
PASJ, 60, 275



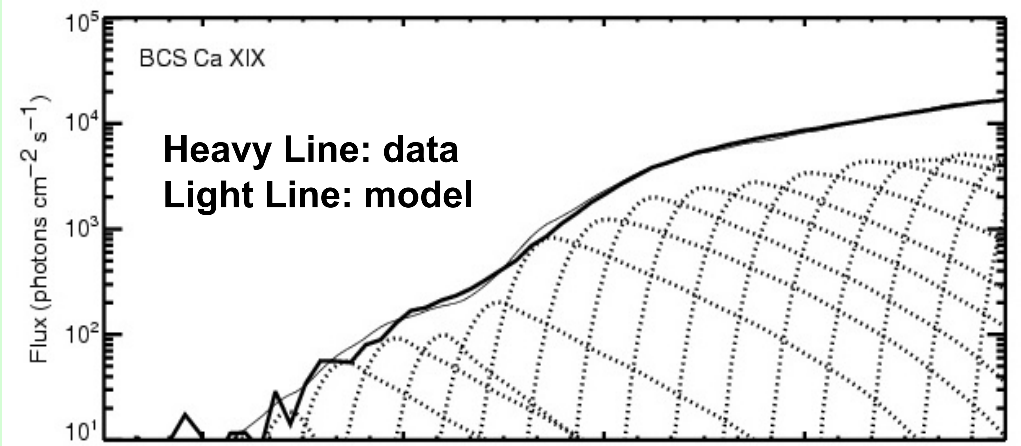


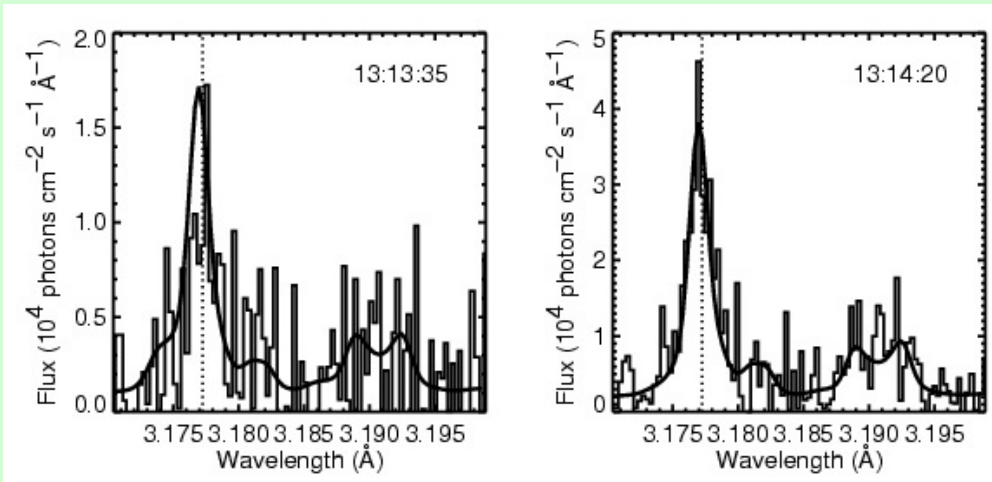


This schematic "Standard Flare Model" provides theoretical guidance for analyzing solar flare data.

Multi-Thread Simulation of the 5 January 1992 Flare

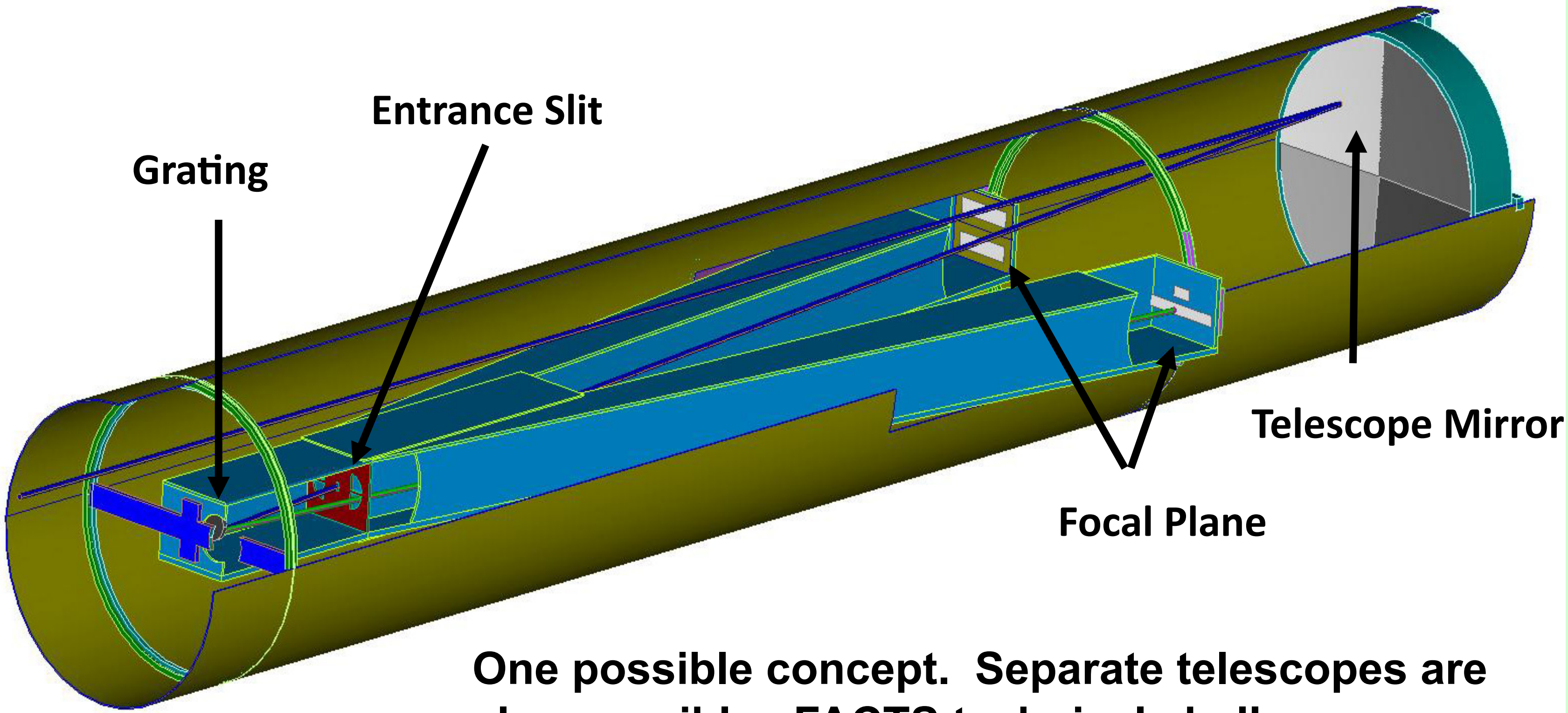
Numerical simulations reproduce the BCS *Yohkoh* light curves in the resonance lines of Fe XXV, Ca XIX, and S XV. A multi-thread model can successfully account for BCS light curves and spectra. We can account for chromospheric evaporation with a multi-thread model.





from Warren & Doschek 2005, ApJ, 618, L157

A concept for a Plan B Telescope/Spectrometer. The NRL Fine-Scale Advanced Coronal and Transition-region Spectrograph (FACTS, Korendyke et al. 2008)



One possible concept. Separate telescopes are also possible. FACTS technical challenge: the primary mirror

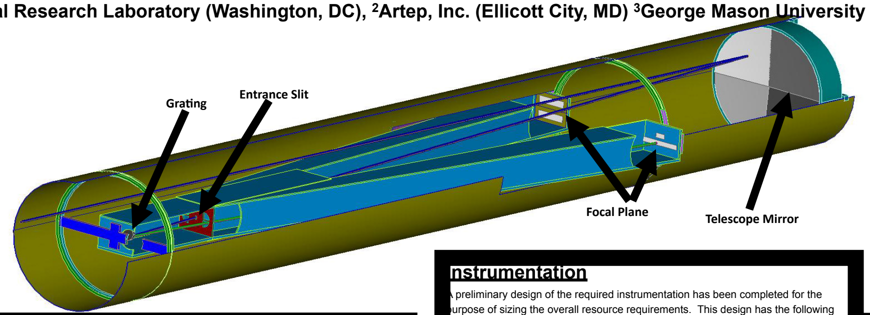
FACTS Instrument Parameters

- Telescope: 60 cm usable diameter; 360 cm focal length; segmented into 4 quadrants with different coatings; *high and matched spatial resolution from the photosphere to the corona*
- UV/Visible bandpass: 2000 – 8000 Å
  - Spatial resolution - ~0.2”/pixel
  - Spectral resolution - ~0.030 Å/pixel
- EUV1 bandpass: 170 – 210 Å; 330 – 370 Å (alternate)
  - Spatial resolution - 0.1”/pixel
  - Spectral resolution - 0.010 Å/pixel
- EUV2 bandpass: 500 – 1000 Å
  - Spatial resolution - 0.14”/pixel
  - Spectral resolution - 0.050 Å/pixel
- EUV3 bandpass: 1000 – 2000 Å
  - Spatial resolution - 0.1” and 0.14”/pixel
  - Spectral resolution - ~0.060 Å/pixel
- Time resolution
  - A nominal 1s exposure gives reasonable counts in the brightest lines, especially in active regions.
  - With a 1s exposure FACTS will produce a 60” x 200” image of the solar atmosphere in 300s, at 0.2” spatial resolution and full temperature coverage.
  - FACTS will produce 200” x 200” context images at 1” resolution in 20 s.

Fine-scale Advanced Coronal and Transition-region Spectrograph (FACTS)

C. Korendyke[1], C. Brown[1], G. Doschek[1], E. Landi[2], J. Karpen[1], Y.-K. Ko[1], J. Laming[1], J. Mariska[1], J. Morrill[1], K. Muglach[2], S. Patsourakos[3], J. Seely[1], I. Ugarte-Urra[3], A. Vourlidas[1] and H. Warren[1]

[1] Naval Research Laboratory (Washington, DC), [2]Artep, Inc. (Ellicott City, MD) [3]George Mason University (Fairfax, VA)



Introduction

The FACTS mission will determine and characterize the dominant physical processes responsible for the structure, dynamics, and evolution of the upper solar atmosphere. These physical processes drive the flow of mass and energy through the solar atmosphere and are at the root of space weather phenomena. Theoretical modeling and current observations show that these processes generally have small spatial scales, drive plasmas over a broad temperature range, and are often intermittent and sporadic in nature.

Definitive observations with the following characteristics are required:

- broad but well differentiated temperature coverage to comprehensively observe the solar atmosphere and follow different structures as they evolve.
- measure the physical properties of the emitting plasma - electron densities, temperatures, velocities, abundances, etc..
- sufficient cadence to follow the dynamic evolution of the structures and processes.
- sufficient spatial resolution (<0.25") to discern individual structures and approach characteristic physical scales suggested by theory and current visible/UV observations.

The Naval Research Laboratory is presently developing a next generation solar spectrograph to meet these requirements. The FACTS instrument combines the UV diagnostic capability of CDS/SOHO, SUMER/SOHO and EIS/Hinode with the spatial resolution and visible light imaging of SOT/Hinode. FACTS has a factor of 10 more collecting area and spatial resolution than previous EUV instrumentation and broad wavelength coverage.

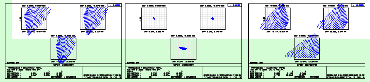
The FACTS mission will investigate a wide range of physical processes in the solar atmosphere. These include the following:

Characterize and determine the role of waves and reconnection in heating the solar transition region and corona. Spectroscopic diagnostic observations at the relevant spatial scales will discriminate between proposed coronal heating mechanisms.

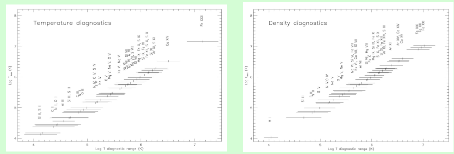
Follow the connectivity of coronal magnetic fields into the chromosphere and photosphere. Complementary visible light observations and spectroscopic diagnostics at small spatial scales are ideally suited to address this difficult issue.

Follow the slow and fast solar wind streams to their origins. Identify the source of acoustic and Alfven waves that propagate into the heliosphere.

F1: Understand magnetic reconnection … flares, CMEs, …;
F2: Understand processes … that accelerate … particles;
H1: Understand causes…solar activity … that affects earth;
J2: Develop prediction capability of … solar activity…;



Representative spot diagrams for a FACTS grating geometry in the EUV1 band. Three wavelengths are shown 185Å, 195Å and 205Å with fields of 0, +50 and +100 arcseconds along the slit. Spot RMS is <6 microns. 12



FACTS temperature and density diagnostics using line intensity ratios. Line ratios that involve only lines of the same ion eliminate uncertainties tied to relative ion abundances. The plots show the temperature range where each ionization level is formed. The lines indicate where the fractional abundance is larger than 10%. Only the

Instrumentation

A preliminary design of the required instrumentation has been completed for the purpose of sizing the overall resource requirements. This design has the following important features:

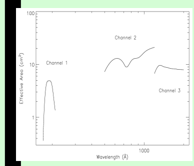
Factor of ~10 improvement in light gathering power and spatial resolution over previous instruments.

Simultaneous spectra across the EUV wavelength range.

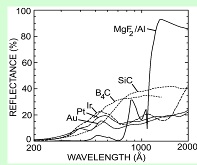
Intrinsic spatial coregistration of the EUV, UV/Vis spectra and slit jaw images.

Four separate wavelength bandpasses that yield unprecedented wavelength coverage for a single instrument.

We envision achieving line of sight stabilization by active pitch/yaw tilt control of the primary mirror. Similar systems with large optics have been built for JPL for their planetary cameras and have also been used in DoD. The error signal is provided by a correlation tracker system built into the UV/Visible broadband filter imaging system



Effective areas (cm[2]) of the three channels of FACTS, as a function of wavelength.



Candidate EUV optical coatings for wavelengths above 50nm.

Observations

The FACTS optical design, coatings and detector efficiencies have been combined to determine the instrument collecting area in each channel. The expected count rates were calculated for a 0.2" spatial element. A nominal one second exposure gives reasonable counts in the brightest lines, particularly in active regions.

Using the nominal exposure time, FACTS will produce a 60" x 200" image of the solar atmosphere in 300 seconds, at 0.2" resolution with full temperature coverage.

FACTS will produce 200" x 200" context images of the

Calculated Count Rates

Ion	Wavelength (Å)	Log (T)	QS	AR
I	1215.67	4.04	24,975	241,316
e I	584.34	4.15	71	427
II	1335.71	4.37	599	40,795
III	1206.50	4.68	357	1639
e II	1640.35	4.72	115	3,589
		4.84	433	1,716
V	629.73	5.37	147	383
VI	1031.91	5.47	146	775
XI	195.12	6.13	9	162
e XIII	202.04	6.20	2	57

Theoretical intensities calculated using CHIANTI, except for H I 1215 Å and He II 1640 Å where observed intensities were used when available. These count rates are for a pixel of 0.2"x 0.2". With a 1"x 1"

The FACTS Mission

The complete FACTS instrument is straightforward to incorporate into a large class mission. The heaviest portion of the instrument (telescope mirror/bulkhead) could be mounted directly to the S/C structure. The instrument optical axis will be coaligned to the spacecraft fine sun sensor. Preliminary resource requirements are given in the following table.

Instrument resource	Preliminary value
power	80W

A combined mission package where FACTS is accompanied by a resolution EUV context imager would be particularly powerful. This complement would combine spectroscopic measurements of FACTS with high resolution imaging of the transition region and corona. FACTS data set will be highly complementary to existing ground and space based observatories; the spatial resolution of FACTS is comparable to the next generation of ground based observatories.

Technology development

In general, the technology required to implement FACTS is relatively mature. Further enhancements to the mission implementation/science could be achieved with improvements in the following areas:

1) light weight mirror technology and line of sight stabilization mechanisms for half meter optics.
2) efficiency and durability of broadband EUV coatings.
3) EUV and visible detectors especially active pixel sensors, solar blind EUV detectors.
4) high quality EUV ellipsoidal variable line spaced gratings.
5) improvements in ACS and TM related spacecraft technology, transmitters/receivers, reaction wheels, star trackers, etc.

References

S. Tsuneta, Y. Suematsu, K. Ichimoto, T. Shimizu, S. Nagata, S. Tsuneta, T. Tarbell, C. Edwards, R. Shine, C. Hoffmann, E. Thomas, S. Hour, R. Rehse, O. Ito, Y. Kashiwagi, M. Tabata, K. Kodeki, M. Nagase, K. Matsuzaki, K. Kobayashi, K. Ichimoto, Y. Suematsu, "Image Stabilization System for Hinode (Solar-B) Solar Optical Telescope", Solar Physics (Oct. 2007), p. 154.
Hasse, Ottenbreit, Alexander Krabbe, "The visible light broad-band Imager for ATST: preliminary Design", Ground based and Airborne Instrumentation for Astronomy, edited by Ian S. McLean, Masanori

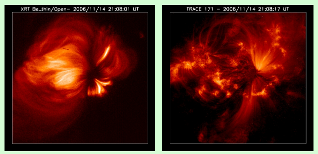
Scientific/technical characteristics of the FACTS preliminary design

Telescope design parameters	Baseline or nominal value
Type	Single paraboloid mirror, each quadrant coated for a particular EUV/UV/Vis spectral range
Optical properties	60cm usable aperture diameter, 360cm focal length, <λ/80rms wavefront error over each quadrant, <0.5nm microroughness, 17.5 microns/arcsecond.
Mirror blank	lightweighted premium grade zerodur blank (TBC), expansion class 0 (<0.02x10⁻⁶ CTE).
Mirror stabilization mechanism	heritage design with voice coil actuators and integral feedback sensor, <0.03 arcsecond control, 15Hz bandwidth.

Slit design parameters	Baseline or nominal value
General	>5 slits and >3 slots of variable width available for observation, front face reflective coating, > 200" length
Defined widths	0.1", 0.2", 0.5", 1", rest – TBD

Sample FACTS Science Topics

The High Temperature Corona



Active region images from Hinode/XRT and TRACE

Active region loops with T ~ 3-5 MK appear steady and disconnected from more variable cooler loops that are rooted in the lower level fine structure (Moss).

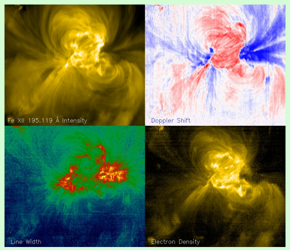
Steady heating models require filling factors of about 10% to reconcile with observations. Moss studies also suggest approximately 10% filling factors.

Are these hot active region loops bundles of nanoflare heated filaments or are they steadily heated?

Nanoflare heated loops will show temporal evolution, Doppler shifts from chromospheric evaporation, and low densities.

- *FACTS will:*
  - *Resolve coronal loops at temperatures near 3 MK*

The Million Degree Corona



Maps of intensity, Doppler shift, line width, and electron density from EIS/*Hinode*

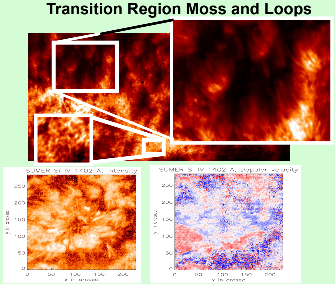
Loops observed near 1 MK are not in equilibrium. These loops have high densities, show strong flows, and are evolving.

Models suggest time-varying and impulsive heating along filamentary structures.

The detailed temperature distribution within coronal loops is not well known.

- *observe the internal structure of coronal loops over a broad range of temperature.*

Transition Region Moss and Loops



Transition region (TR) is composed of footprints of coronal loops and dynamic loop-like structures protruding above the chromospheric canopy (VAULT and SUMER).

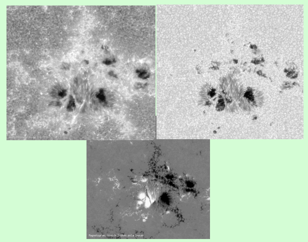
These structures undergo rapid evolution and change. The physical processes driving this ubiquitous transient behavior (explosive events, blinkers, etc.) is poorly understood.

The coupling of the TR structure to the upper and lower atmosphere is the key to the transport of mass and energy from the solar interior to the heliosphere.

FACTS will:

- *obtain detailed spectroscopic observations of transition region loops and coronal loop footpoints.*
- *obtain simultaneous co-spatial measurements in the corona and photosphere/chromosphere.*

Photospheric Drivers



SOT/*Hinode* observations of an active region: High resolution Ca II H (left), G Band image (right), Stokes V magnetogram (center).

High resolution visible observations show the magnetic field complexity in the photosphere and chromosphere. These fields anchor the magnetic structures in the TR and corona.

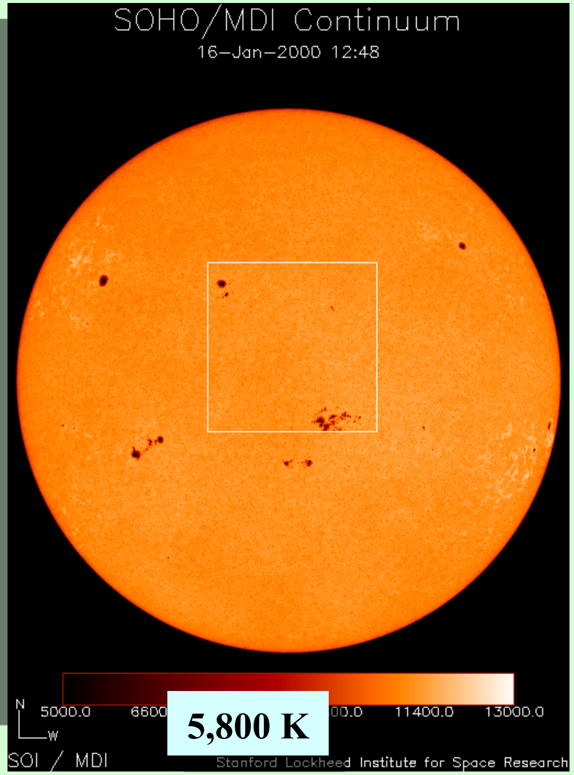
Recent results from SOT/*Hinode* demonstrate the wealth of the phenomena such as small-scale emerging flux, formation and dynamics of sunspots and pores and their substructures (e.g. light bridges, umbral dots, Evershed flows) as well as ubiquitous waves and oscillations. The impact of these structures on the upper atmosphere is not well understood.

FACTS will:

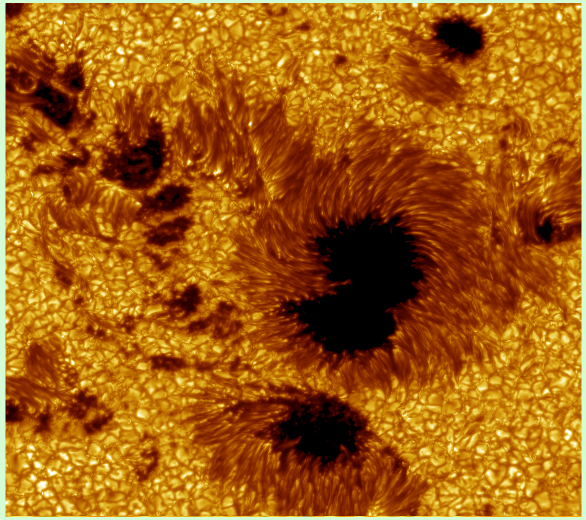
- *provide observations of comparable resolution to all levels of the atmosphere to trace the connections between the photosphere and the*
- *determine the small-scale topology of the photospheric magnetic field from Stokes polarimetry in quiet Sun and active regions.*
- *follow the evolution of the magnetic*

Solar Physics: Fundamental Questions

1- What are the fundamental structures of the solar atmosphere?
2- What are the heating and energy dissipation mechanisms in the structures?
3- What drives extreme transient events: flares and CMEs?

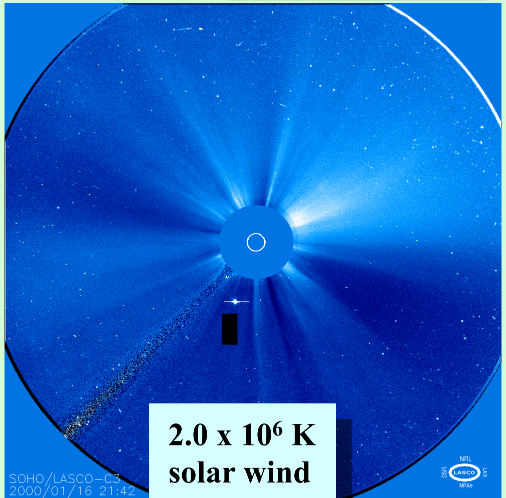


5,800 K

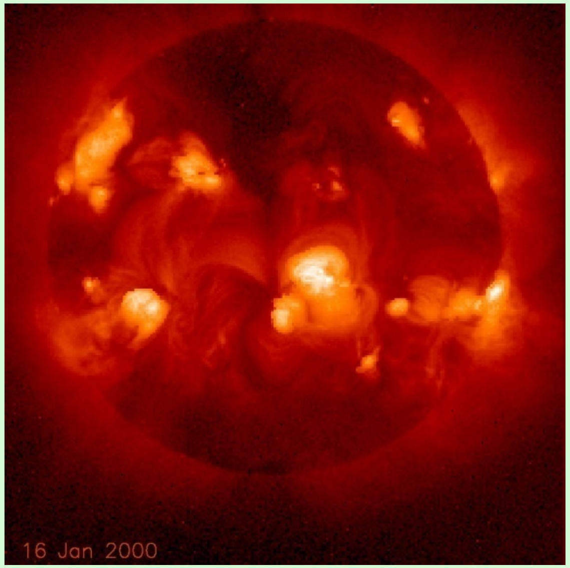


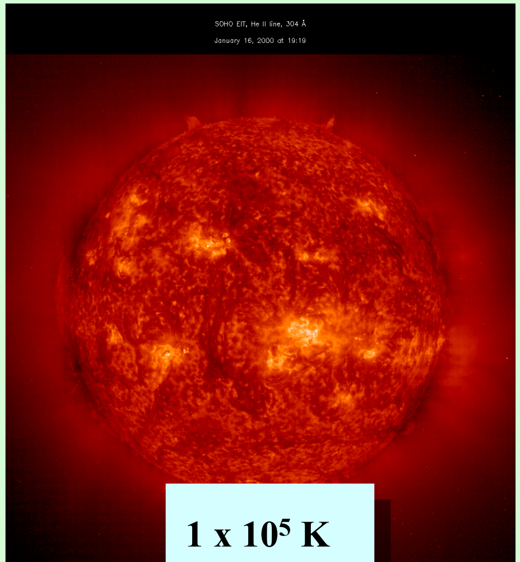
Solar "granules" or convection cells near sunspots in an active region. Granules are about 1000 km (~1.5") in size.

2.0×10^6 K
inner corona



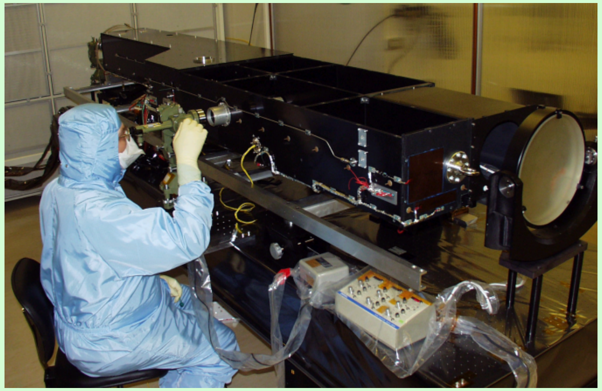
2.0×10^6 K
solar wind





1×10^5 K

The Extreme-ultraviolet Imaging Spectrometer (EIS) on *Hinode*

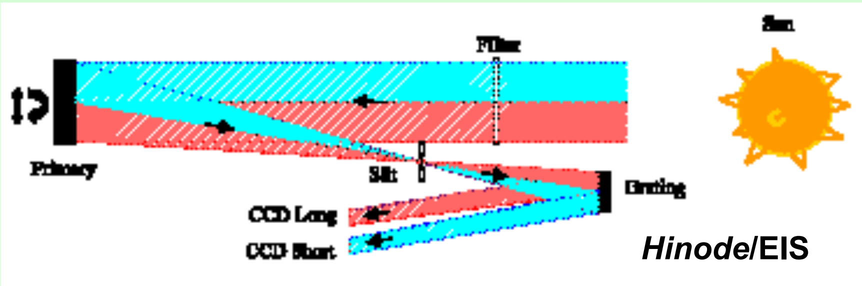


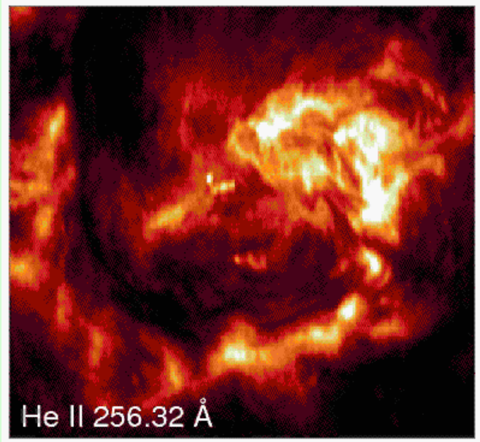
EIS obtains high resolution spectra in two EUV wavebands: 170-210 Å and 250-290 Å. High optical reflectivity for these wavebands is achieved using multilayer optics. Spectra can be obtained with narrow slits or with wider slots.

Sunlight passes through an Al filter and is imaged by an articulated primary mirror onto either a slit or slot. The light passes through the slit/slot and is diffracted by a grating and focused onto two CCD cameras. Below the green and pink refer to the two wavebands.

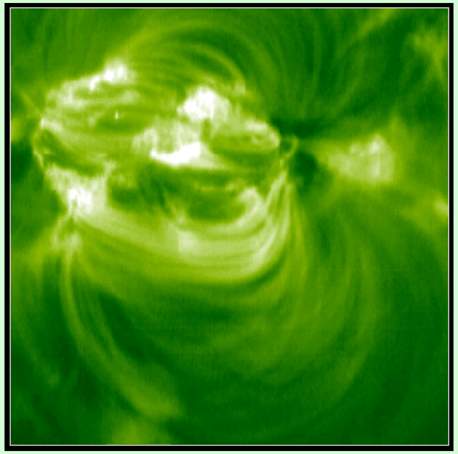
EIS can measure the electron temperature and density, turbulence, and plasma flows in solar plasmas with unprecedented precision.

The spatial resolution of EIS is 2" (1400 km) and the spectral resolution is 0.0223 Å.

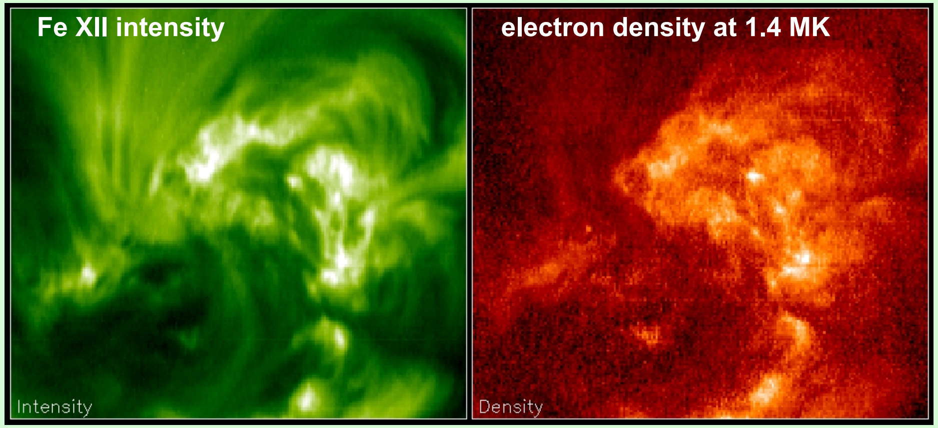




active region temperatures movie



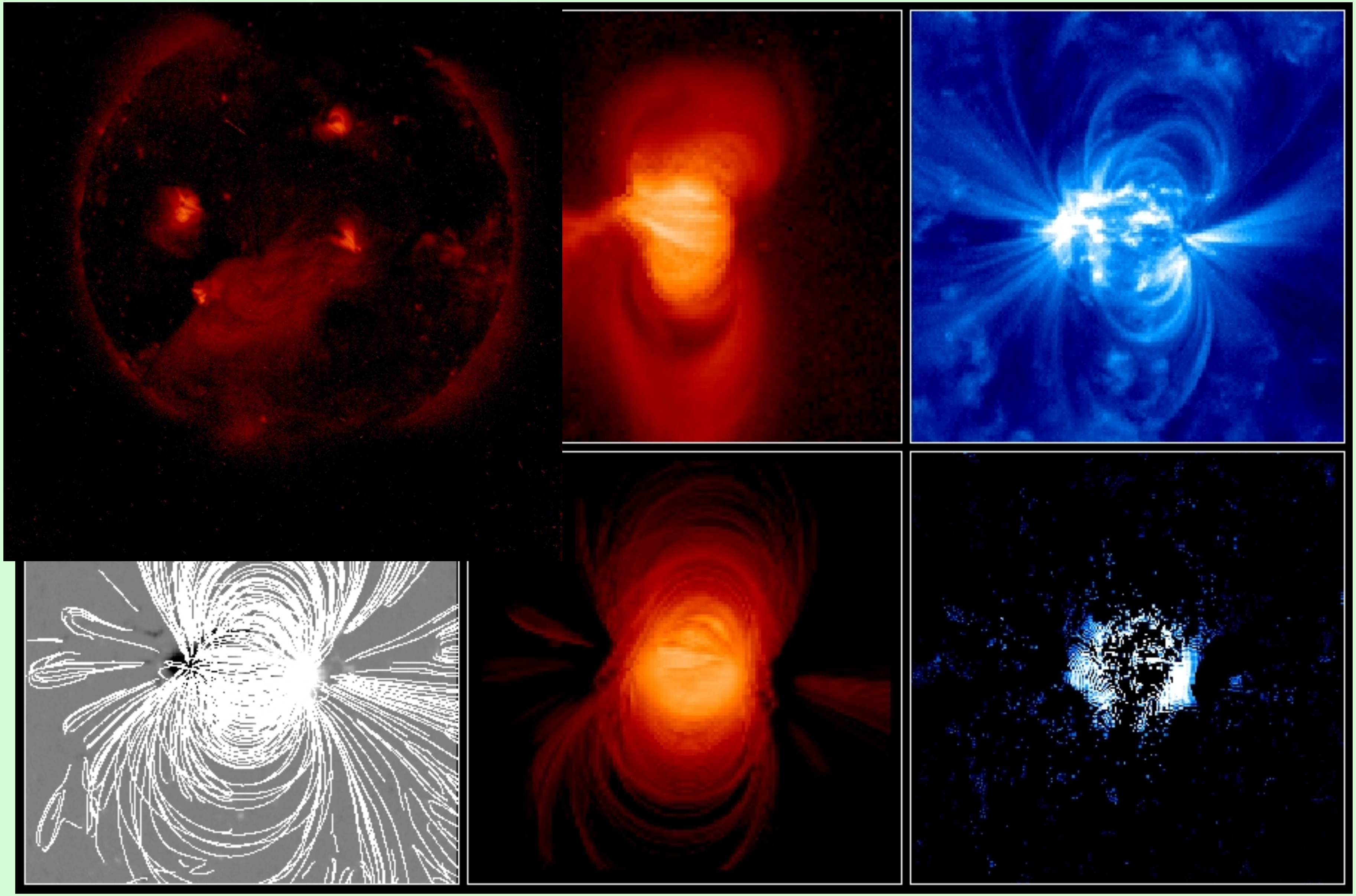
active region dynamics movie



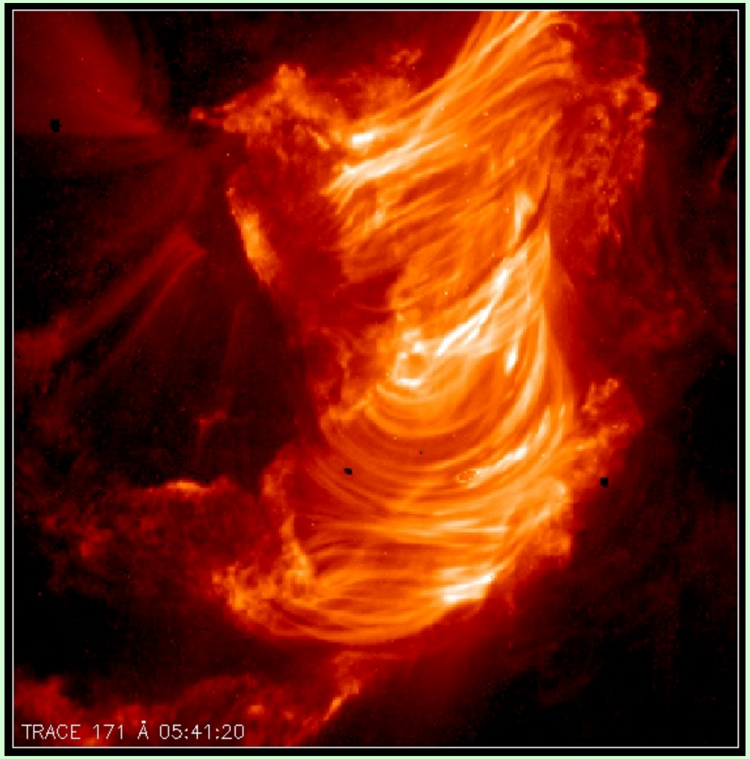
Active Region Raster Data from *Hinode*/EIS

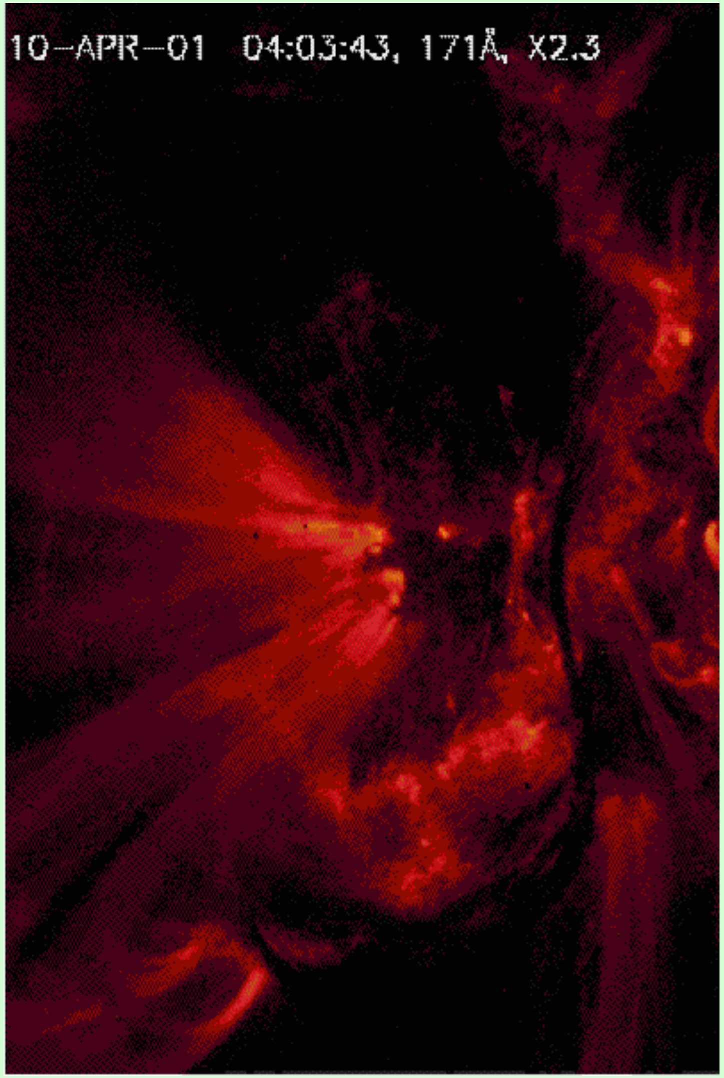
from Warren & Winebarger 2006, ApJ, 645, 711

Active Region Modeling



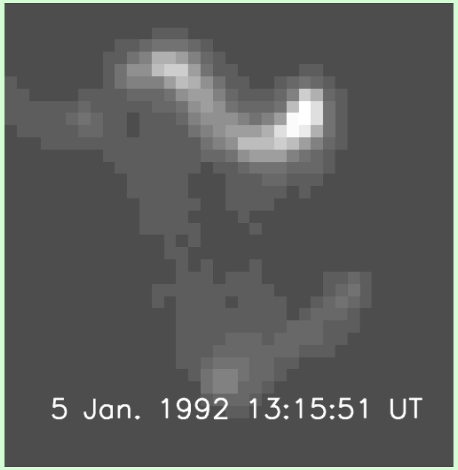
Typical Large Flare Morphology and Evolution

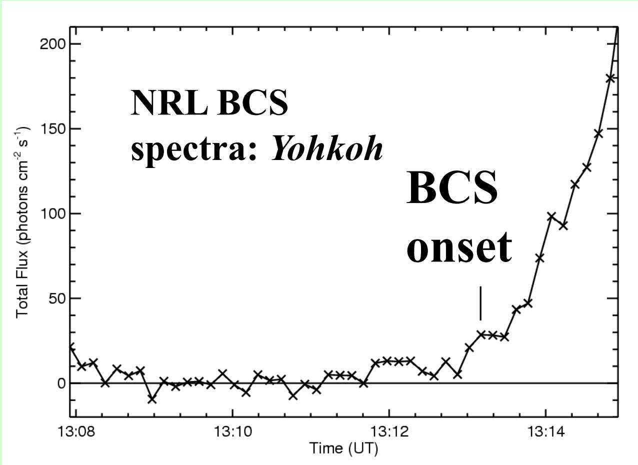




Flares show a rising arcade of soft X-ray emitting loops with a distribution of temperatures and continuous energy deposition.

The First Sign of Multi-million Degree Solar Flare Loops





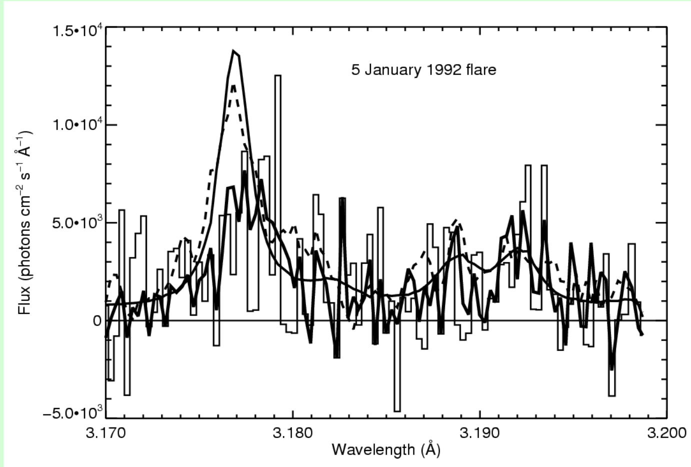
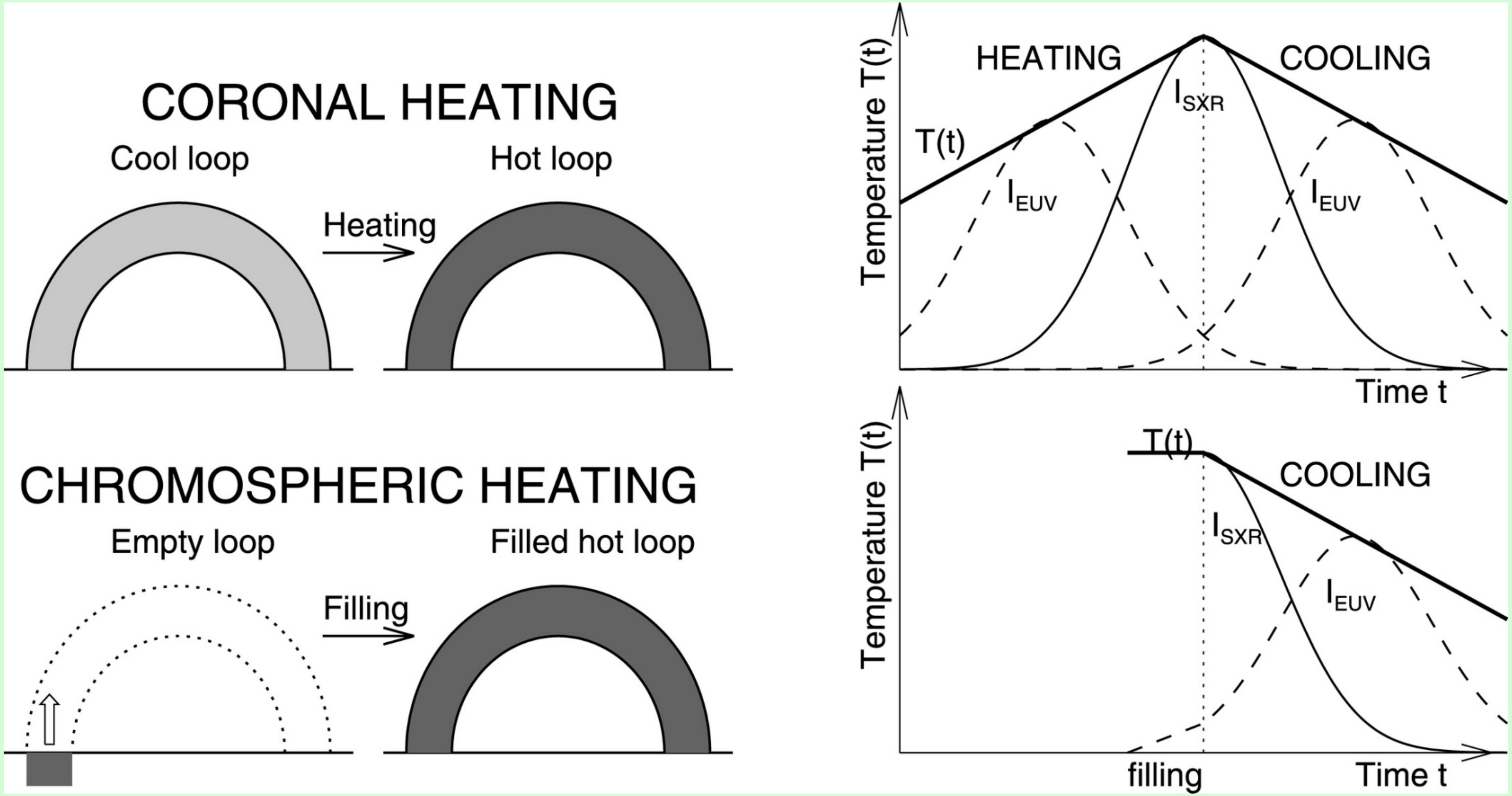


Table 2: Soft X-ray Flare Onset Time Parameters

Parameter	1992 Jan. 5	1992 Sep. 6 (05 UT)	1992 Sep. 6 (08 UT)
Electron Temperature (K)	12×10^6	12×10^6	12×10^6
Emission Measure (cm^3)	6.4×10^{46}	4.9×10^{46}	5.9×10^{46}
Electron Density (cm^{-3})	3.8×10^{10}	3.0×10^{10}	3.7×10^{10}
Loop Volume (cm^3)	4.4×10^{25}	5.4×10^{25}	4.2×10^{25}
Energy Content (ergs)	8.3×10^{27}	8.2×10^{27}	7.7×10^{27}

How are coronal loops heated?
Plasma parameters are necessary to find out.
Current instrumentation cannot resolve multi-threaded coronal loops

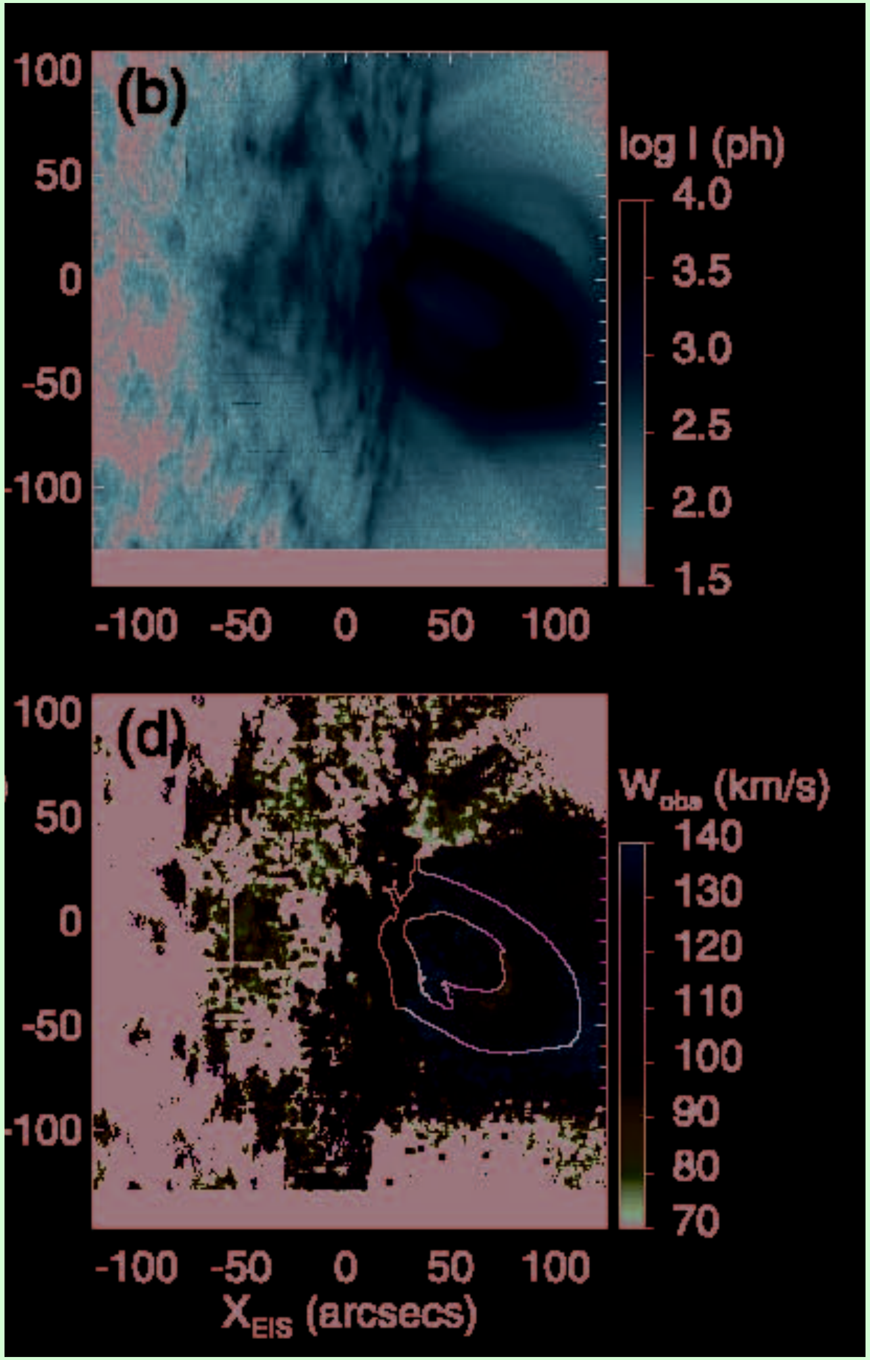


from Aschwanden et al., ApJ, 659, 1673 (2007)

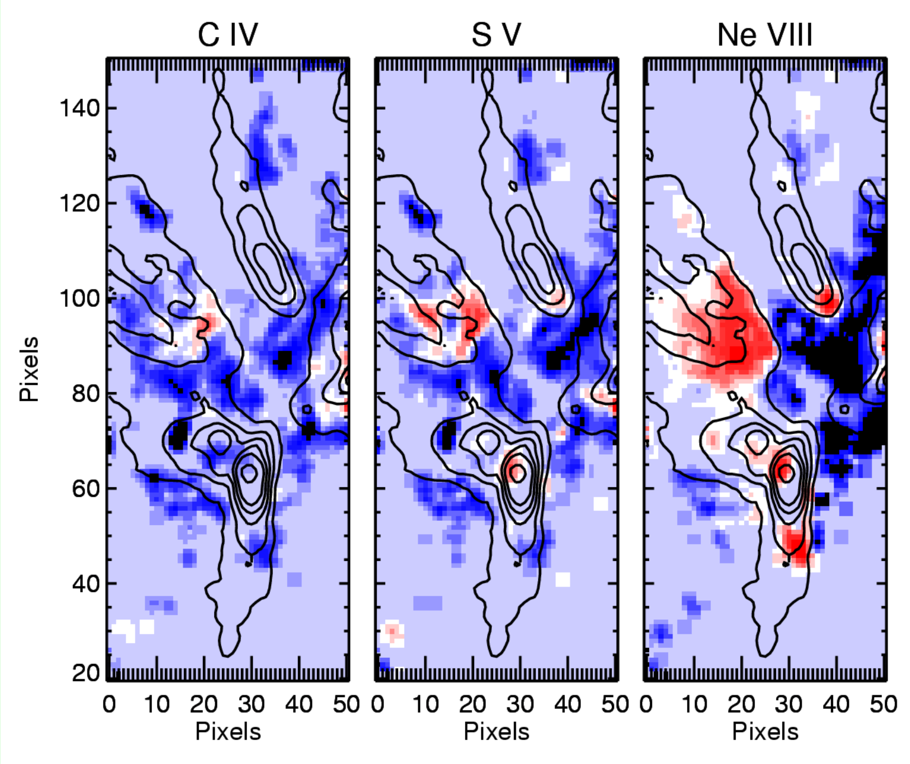
The 2006 December 17 Long Duration Flare – EIS Spectra

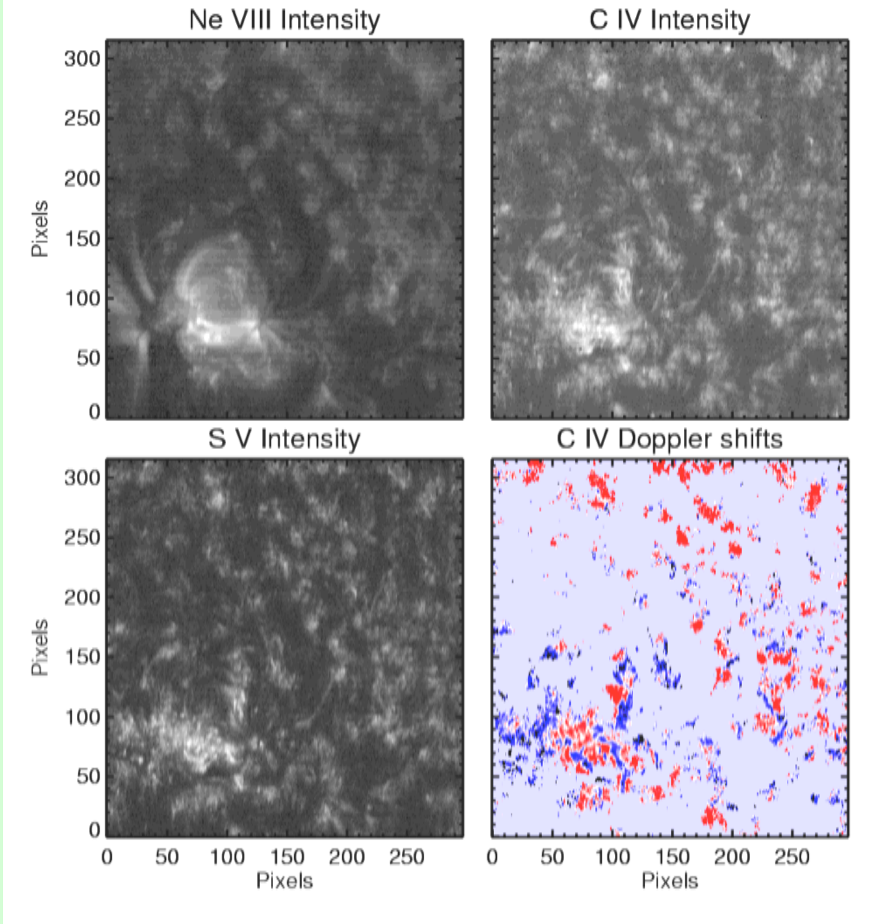
Ca XVII (6 MK) intensity and non-thermal motions. High spatial resolution is needed to understand the physics of the reconnection region. Are the non-thermal motions true turbulence, or are they due to a multiplicity of sub-resolution loop "threads" that are moving relative to each other? Reconnection might be propagated along flare arcades via turbulence. We need higher spatial resolution to properly interpret the observations.

From Hara et al. 2008, PASJ, 60, 275



The Dynamics of the Solar Transition Region

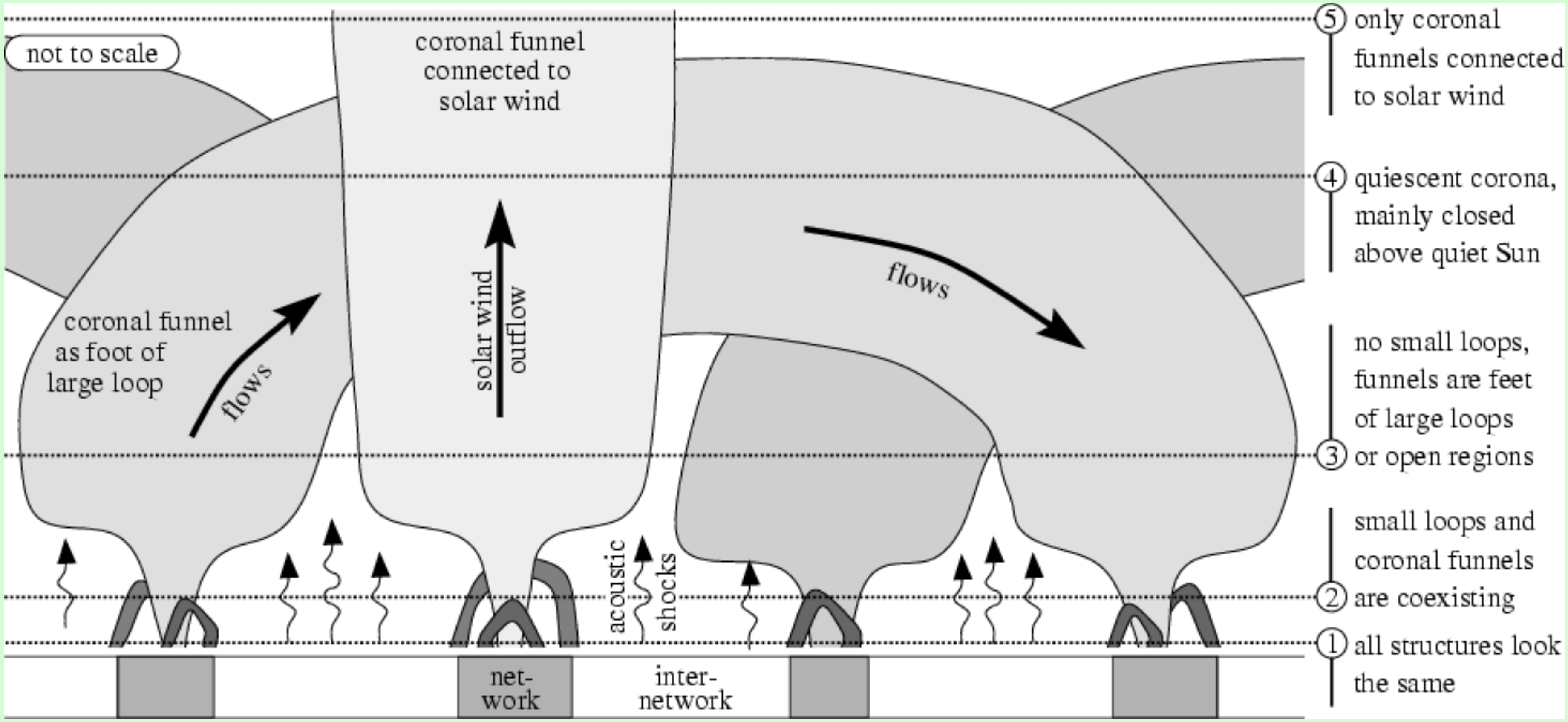




The dynamical connection between the lower transition region (C IV, S V, 1.2 x 10^5 K) and the upper transition region (Ne VIII 8 x 10^5 K) is very unclear.

SUMER spectral images: Note the active region complex in the lower left of each intensity image above. This region is highlighted in the upper left Doppler image. Ne VIII contours are shown.

One Current View of the Transition region/Corona: We Need Plan B to Test Chromosphere/Transition Region Models



from Peter, H., A&A, 374, 1108 (2001)