DKIST: Synergy with EIS/Hinode

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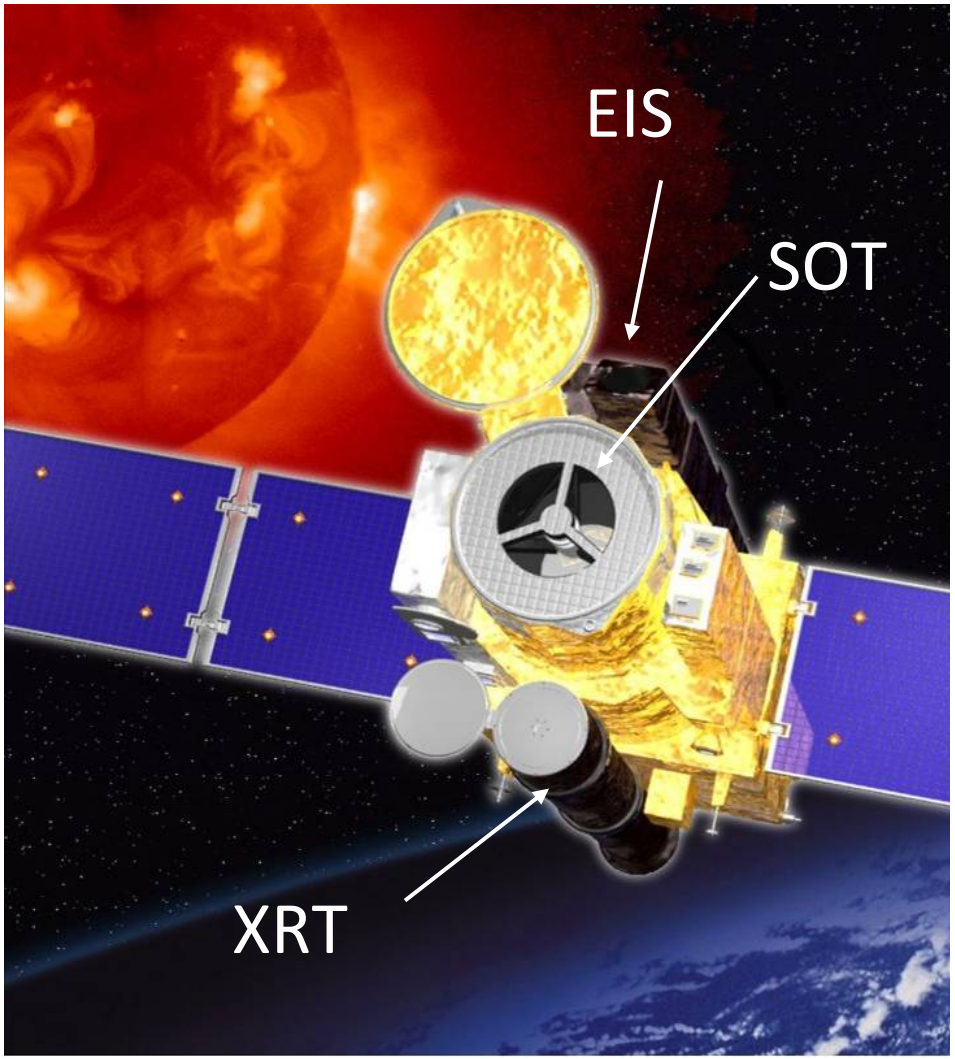
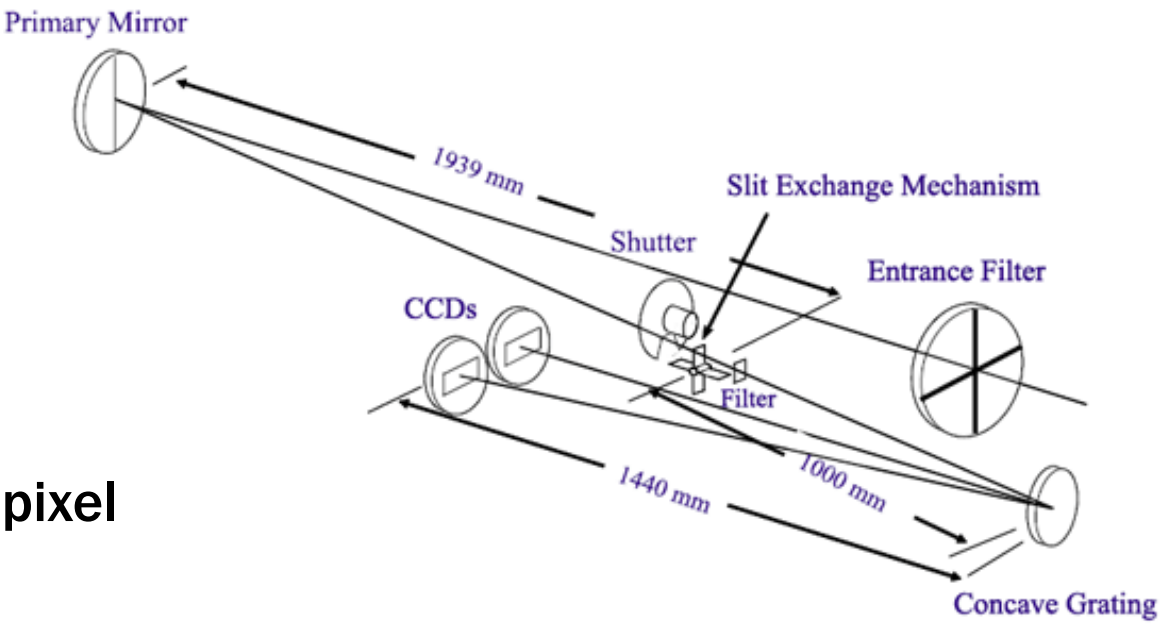
HINODE Spacecraft

- HINODE (which was called SOLAR-B before launch) was successfully launched on 23 Sep, 2006.
- Observations started from the beginning of Nov 2006.



The Instrument

- Wavelength bands
  170Å-210Å
  250Å-290Å
- Slits & slots
  1”, 2”, 40”, and 266”
- High resolutions
  0.0223Å/pixel & 1”/pixel
- High throughput
  Minimum number of reflection
  Multi-layer coating of the mirror
  ➔Suitable for transient phenomena

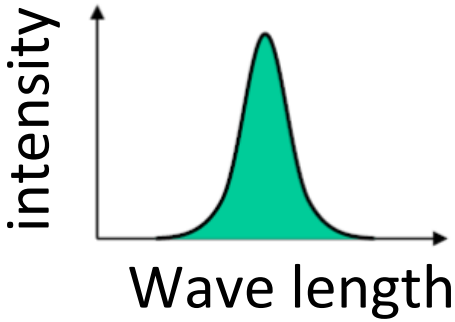


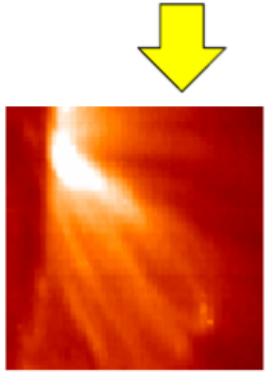
Hinode EIS

What is line spectroscopy?

If you are beginner of line spectroscopy, imagine velocity distribution function!

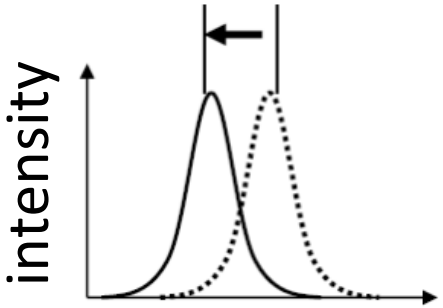
1. Line intensity





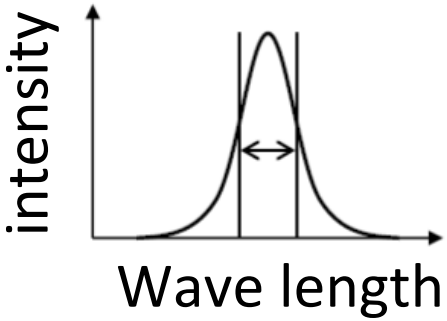
intensity map

→Density



2. Doppler shift

→ Velocity

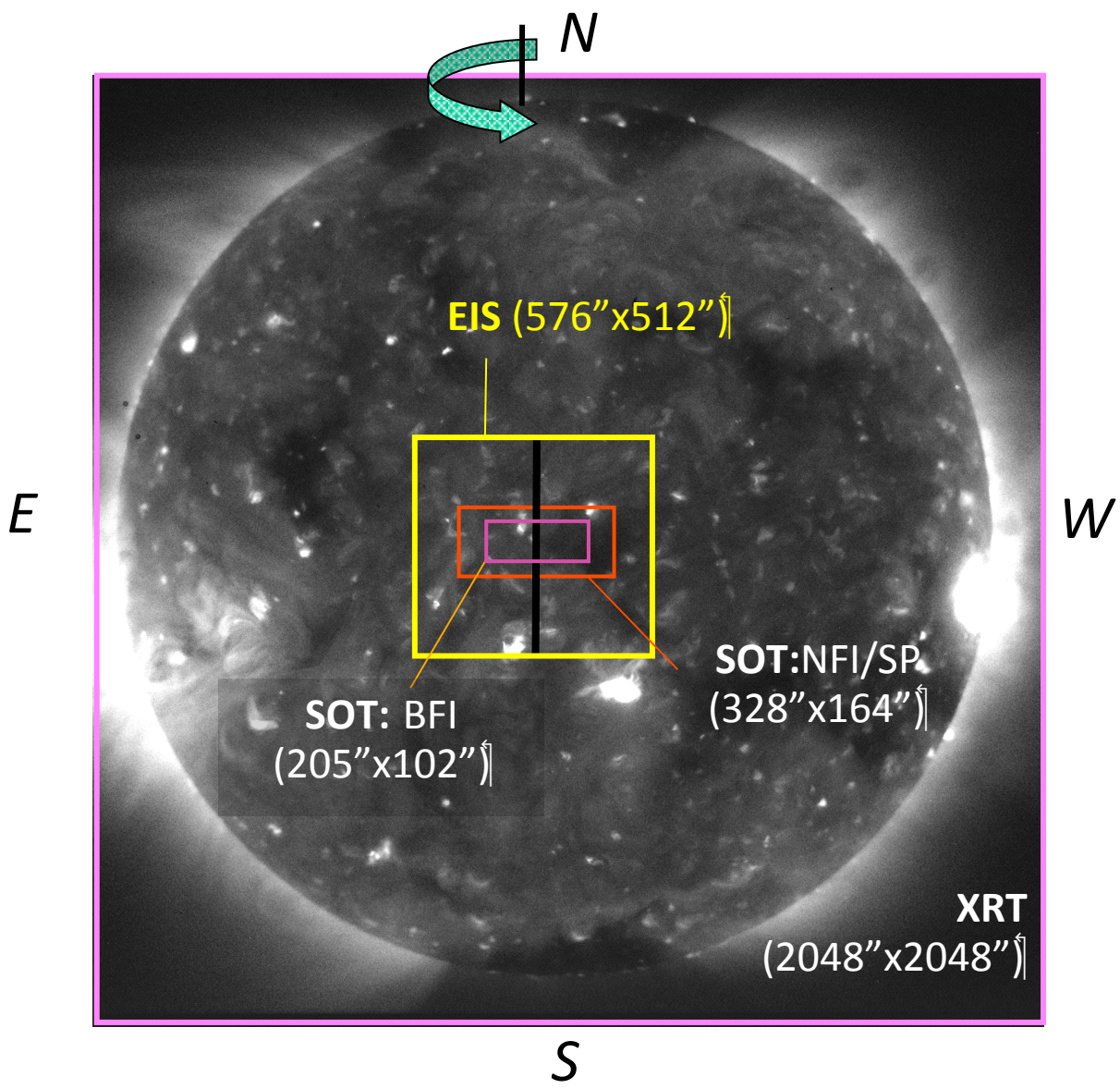


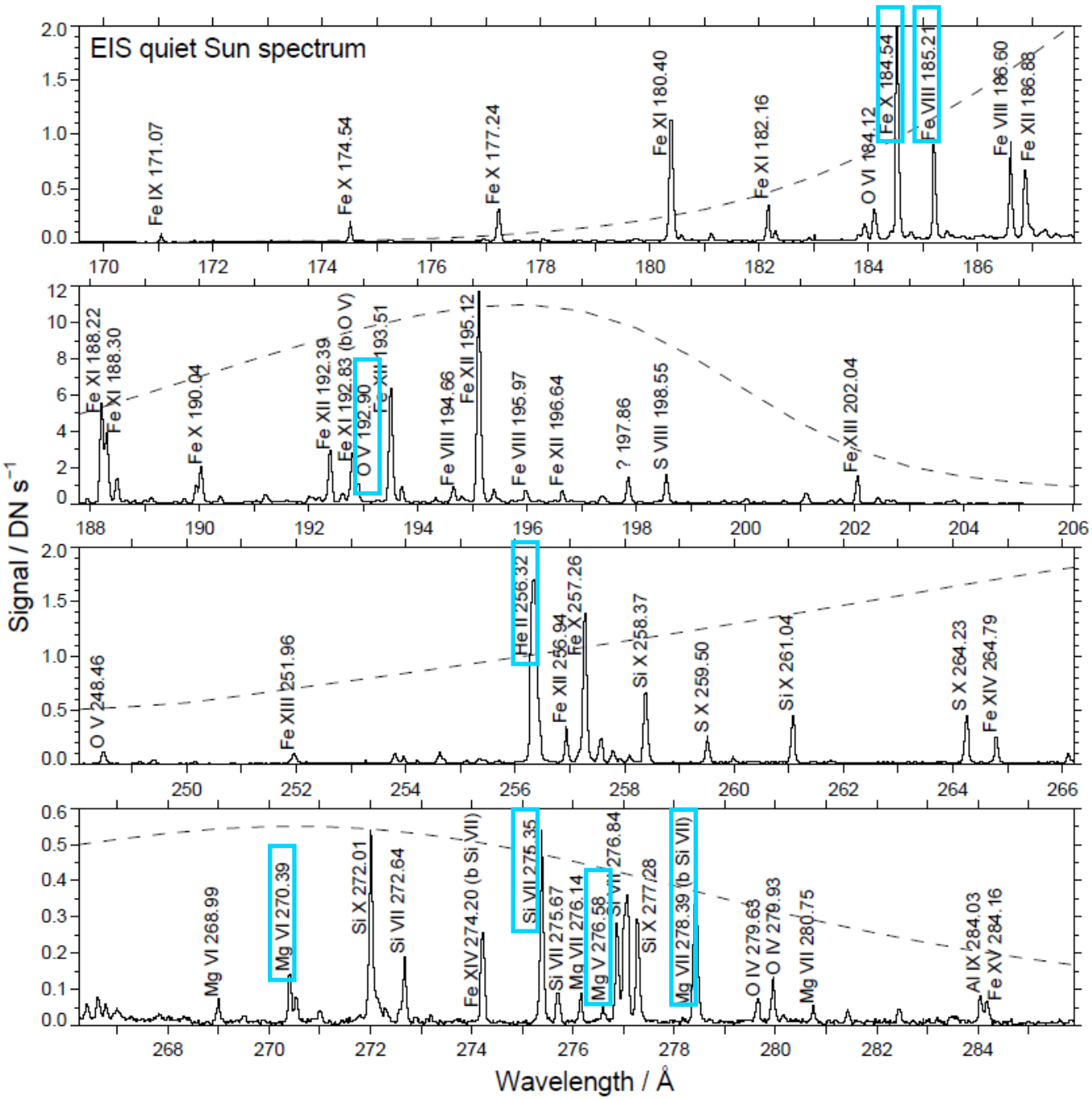
3. Line width

→Temperature

Non-thermal vel.

Field of View





Cold lines < 1MK

HeII: 256.3 A (T=4.9)

OV: 192.9 A (T=5.4)

MgV: 276.6 A (T=5.4)

FeVIII: 185.1 A (T=5.6)

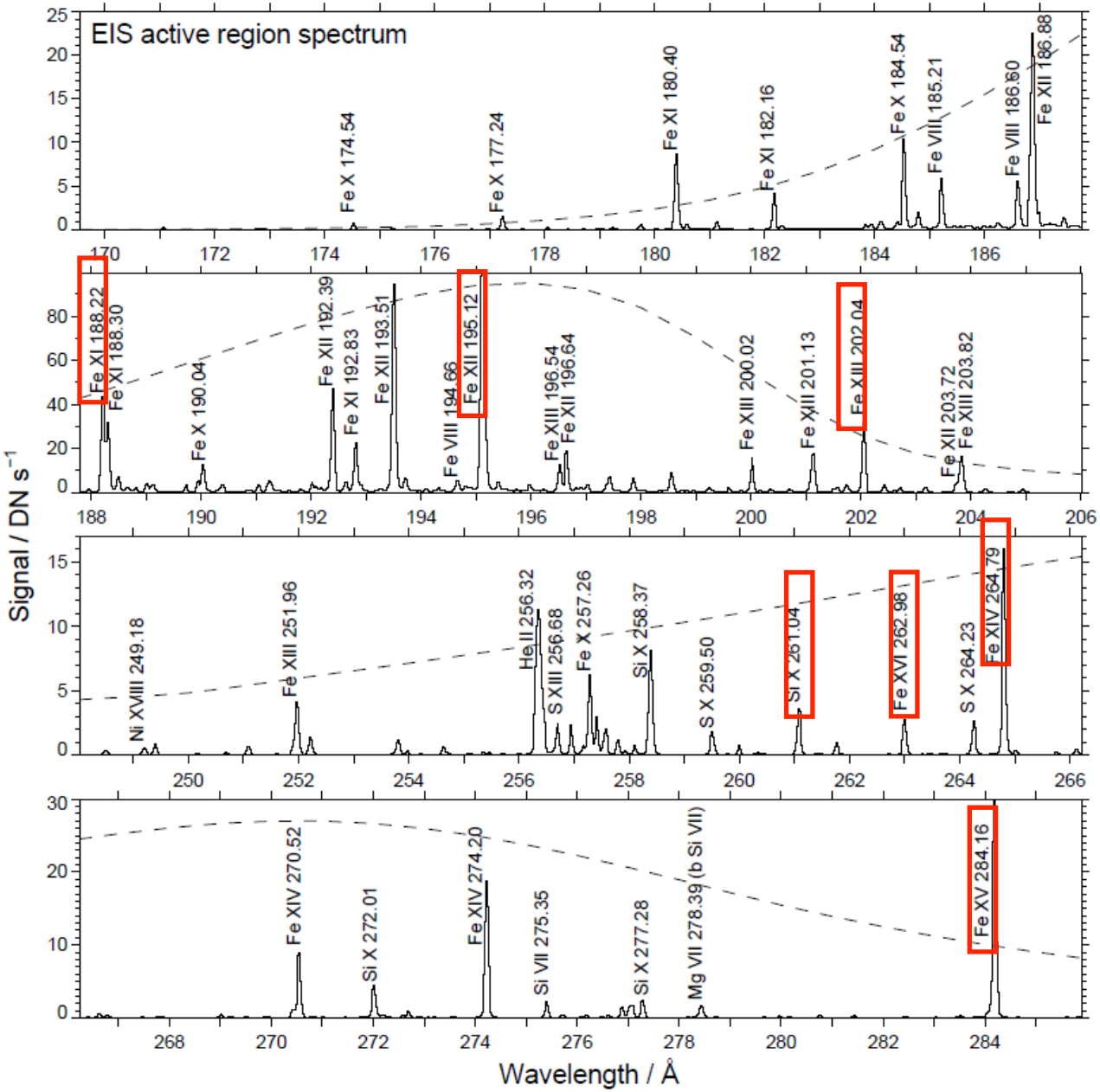
MgVI: 269.0A (T=5.6)

MgVII:278.4A(T=5.8)

SiVII:275.4A(T=5.8)

FeX:184.5A(T=6.0)

Young et al (2007)



Hot lines >1MK

FeXI: 188.2 A (T=6.1)

SiX: 261.0 A (T=6.1)

FeXII: 195.1 A (T=6.1)

FeXIII: 202.0 A (T=6.2)

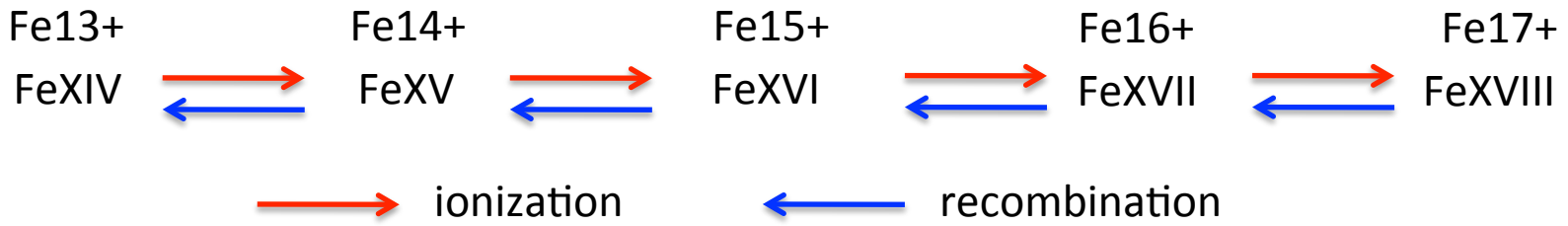
FeXIV: 264.8A (T=6.3)

FeXV:284.2A(T=6.3)

FeXVI:263.0A(T=6.4)

Why we can estimate temperature?

Because of its ionization!



$$\frac{\partial n_i^Z}{\partial t} + \nabla \cdot n_i^Z \boldsymbol{v} = R_i^Z$$

$$\left(Z = 1, \ldots, N_{\text{elem}}\right) \quad \left(i = 1, \ldots, N_{\text{ion}}^Z\right),$$

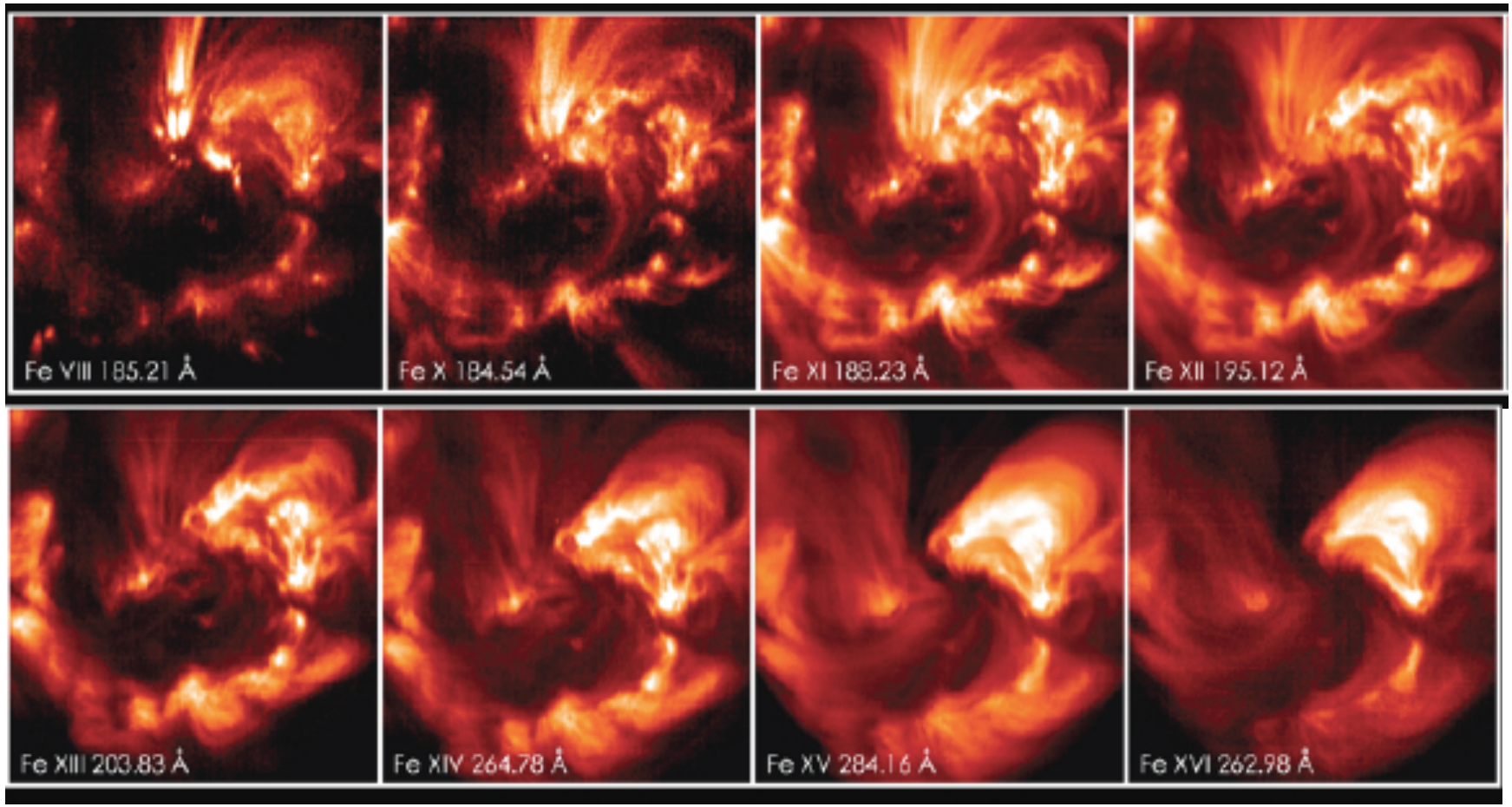
where

$$R_i^Z = n_e \left[n_{i+1}^Z \alpha_{i+1}^Z + n_{i-1}^Z S_{i-1}^Z - n_i^Z \left(\alpha_i^Z + S_i^Z \right) \right],$$

α collisional and dielectronic recombination
S collisional ionization

Active Region

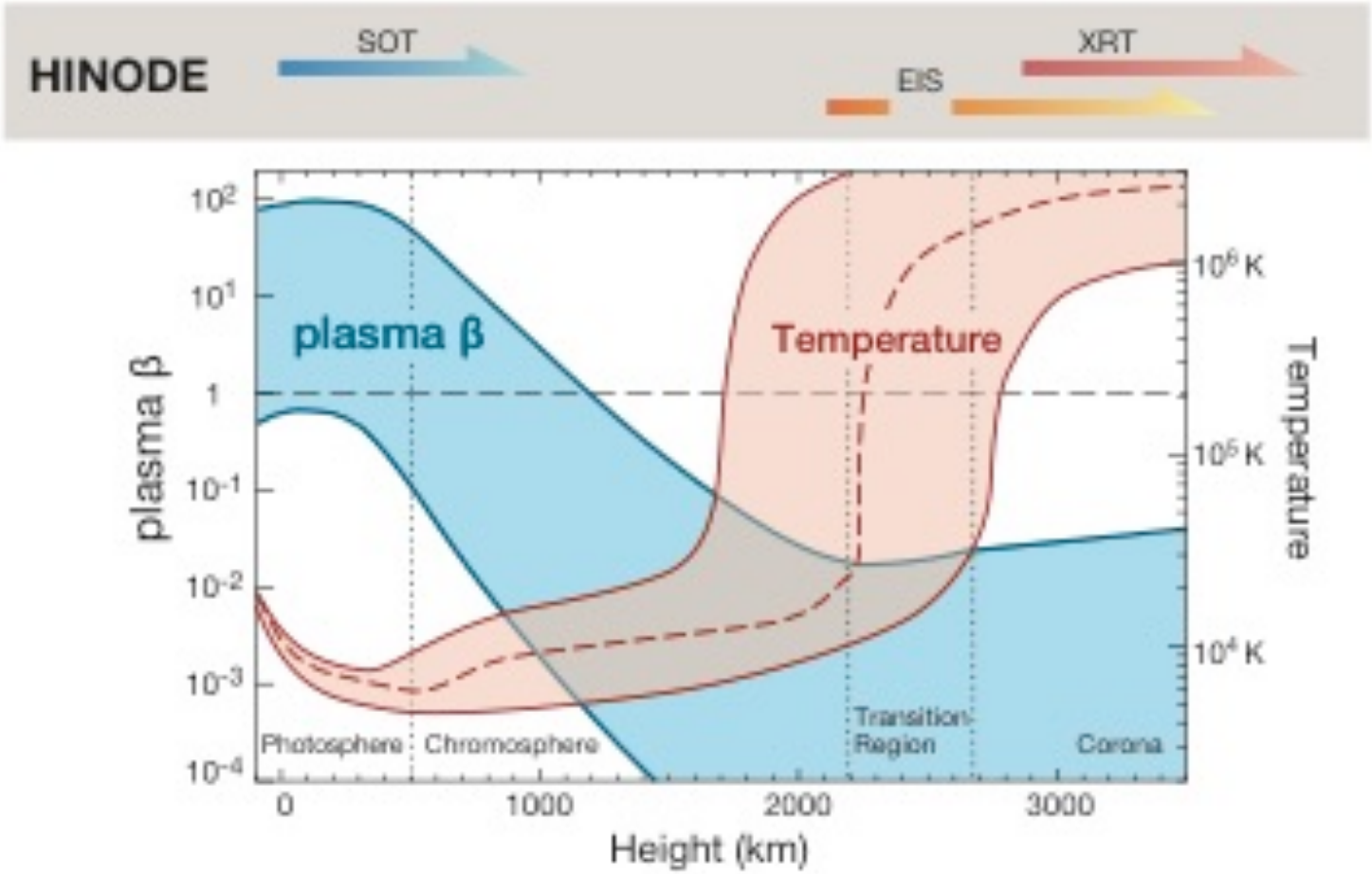
0.8 MK



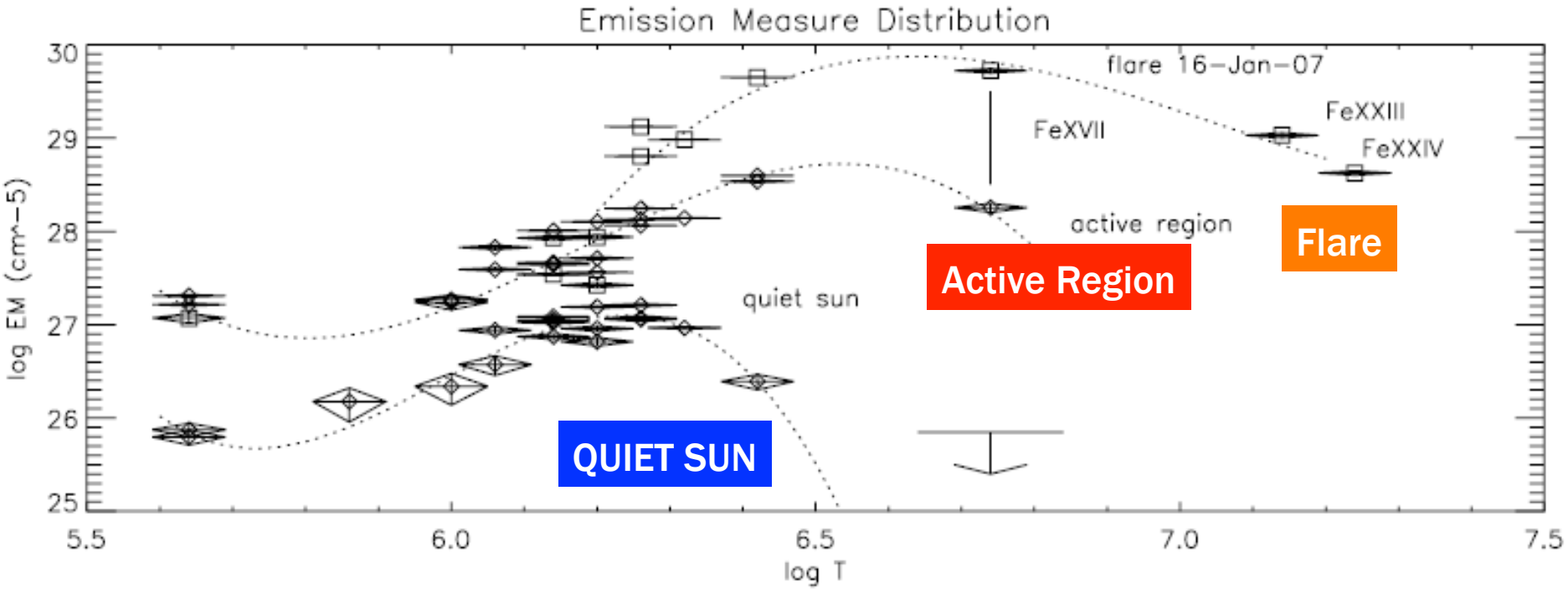
2.5 MK

Multi-Temperature Structure of active region. One may find that High-Temperature loops are wider than Low-Temperature loops!!

Hinode EIS temperature coverage

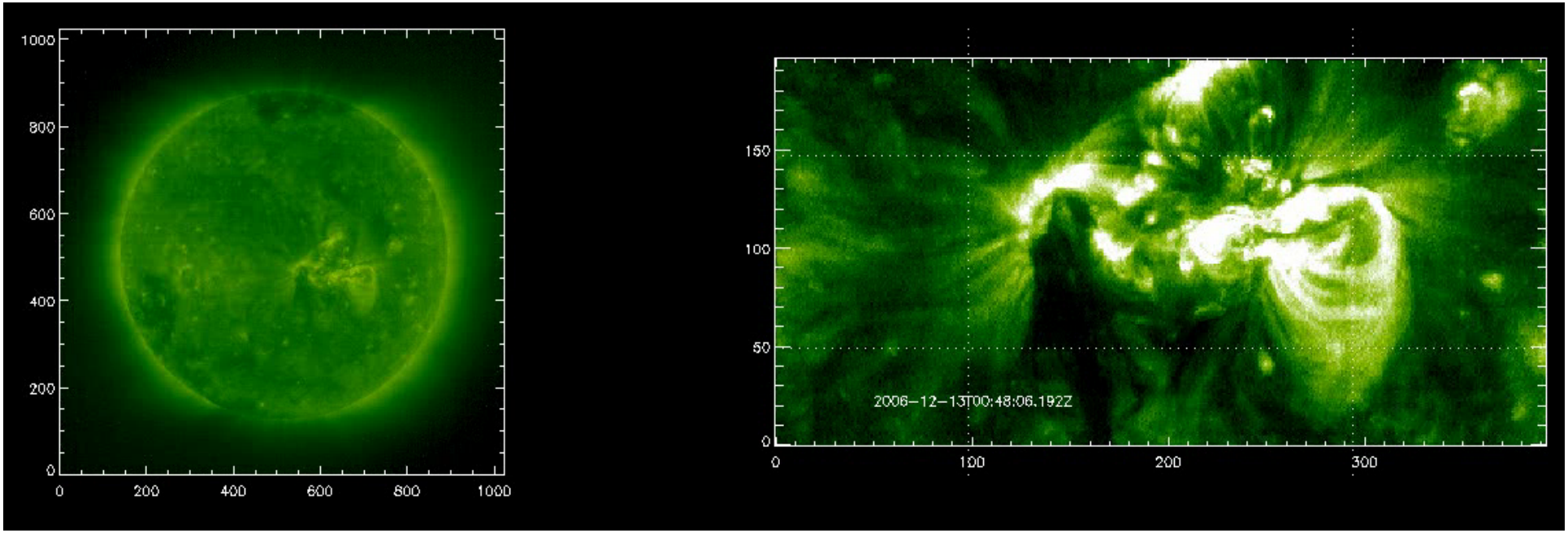


Emission Measure



Watanabe et al (2007)

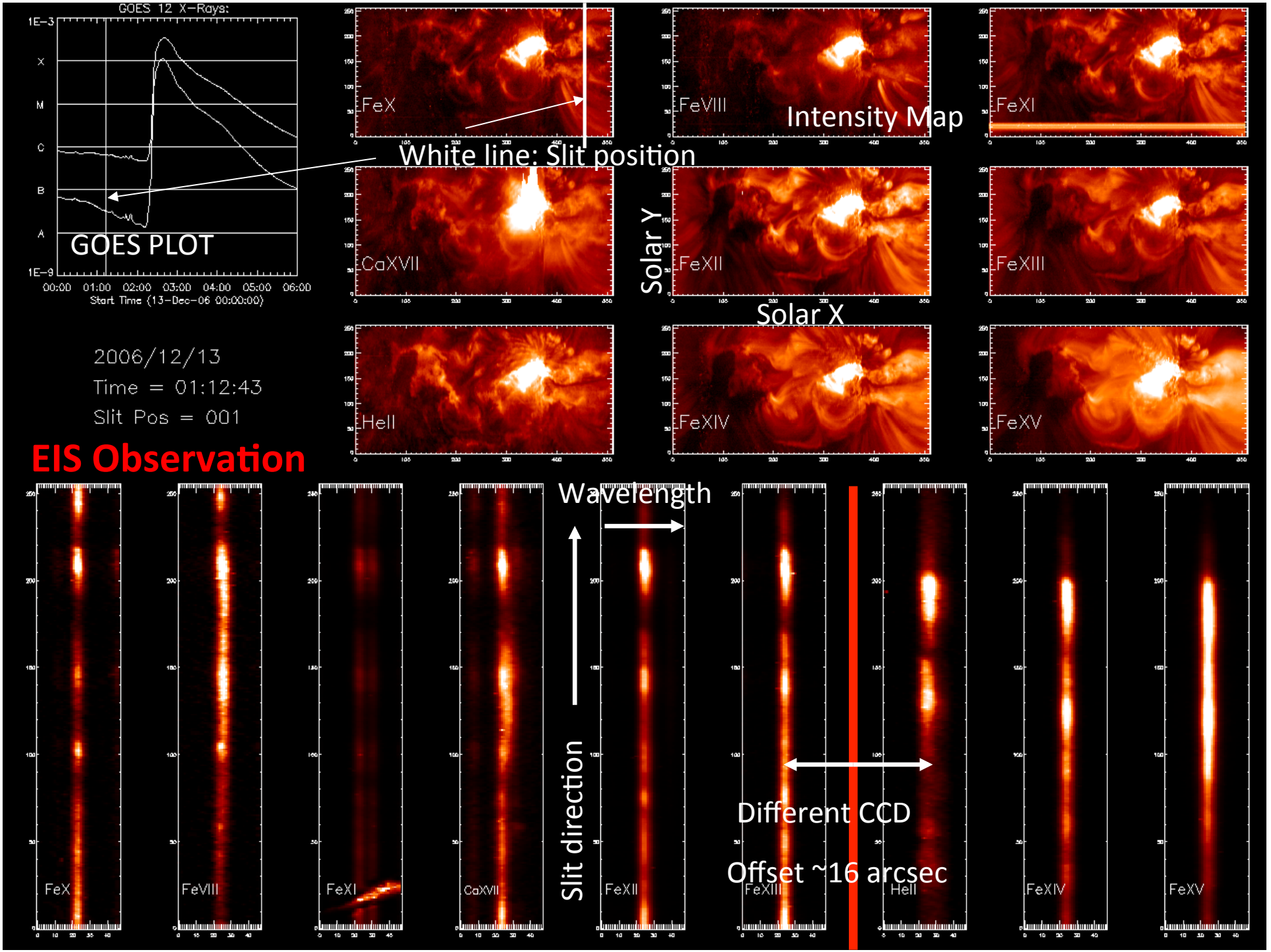
EIT （FeXII 195A）

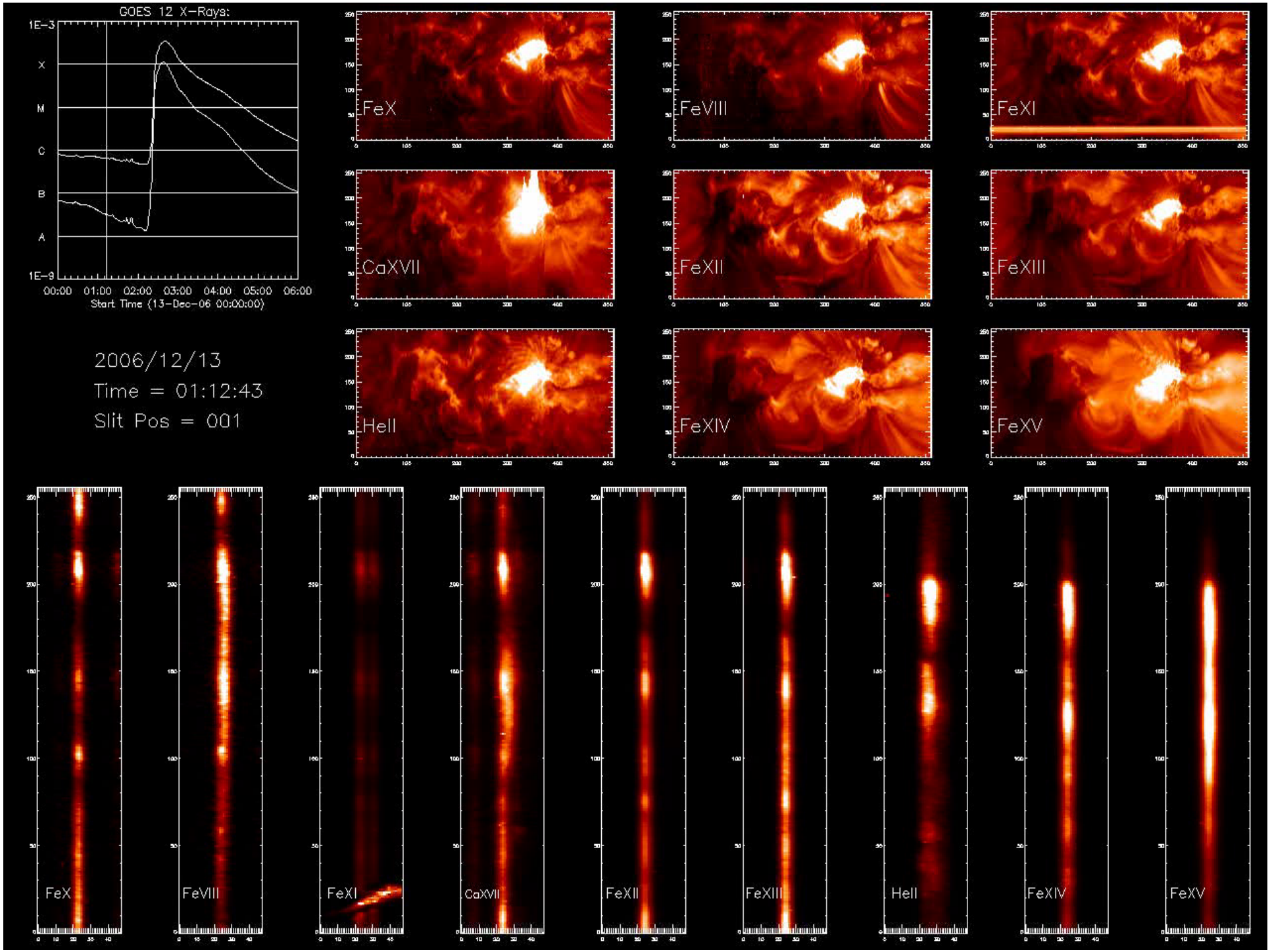


There is Semi-Coronal hole.

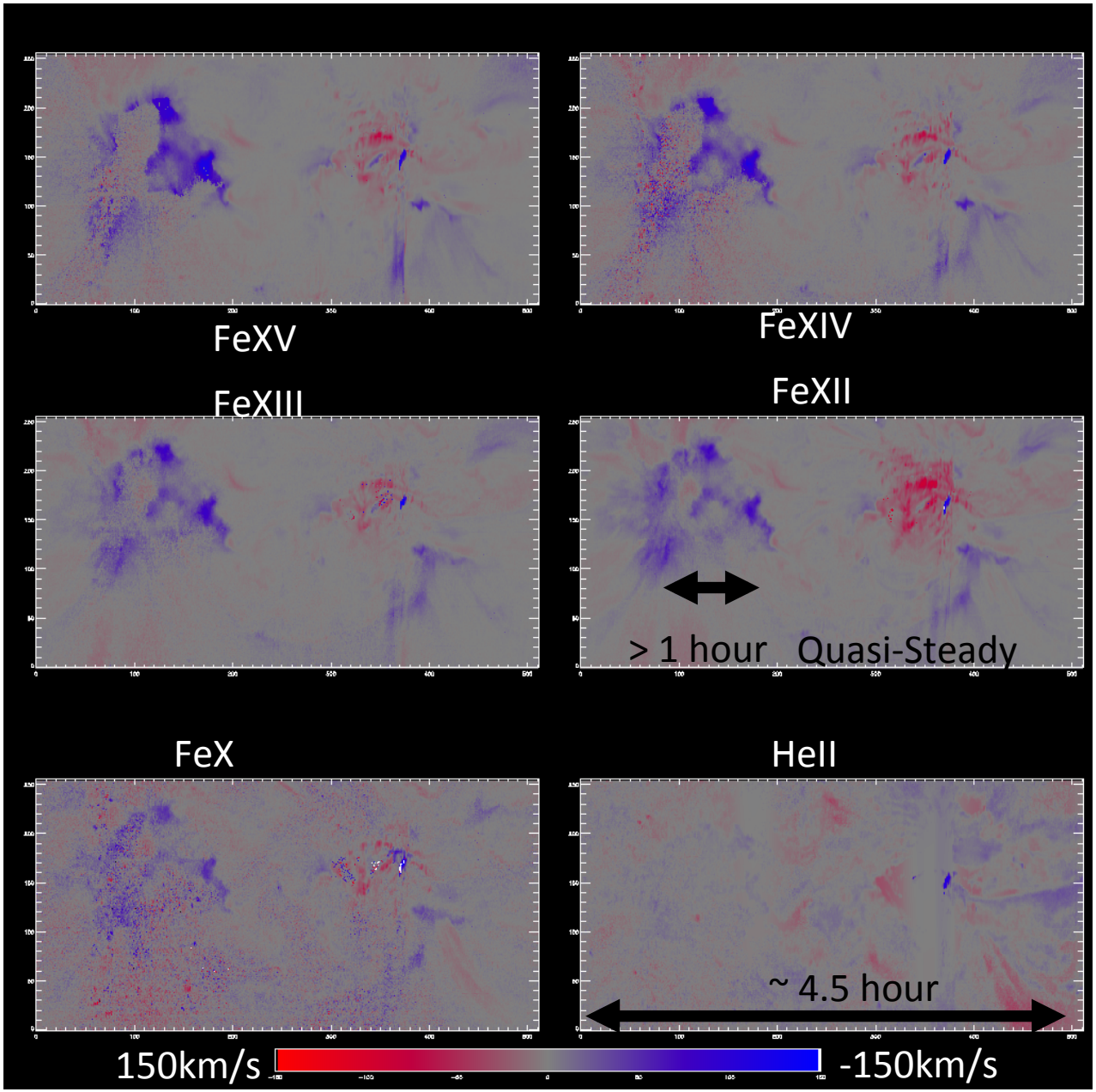
EIT wave was observed associate with Flare.

Plage region get darker associate with EIT wave and some recovery can be observed.


GOES 12 X-Rays:
1E-3
X
M
C
B
A
1E-9
00:00 01:00 02:00 03:00 04:00 05:00 06:00
Start Time (13-Dec-06 00:00:00)
GOES PLOT
White line: Slit position
Intensity Map
FeX
FeVIII
FeXI
CaXVII
FeXII
FeXIII
HeII
FeXIV
FeXV
Solar Y
Solar X
2006/12/13
Time = 01:12:43
Slit Pos = 001
EIS Observation
Wavelength
Slit direction
Different CCD
Offset ~16 arcsec


GOES 12 X-Rays:
1E-3
X
M
C
B
A
1E-9
00:00 01:00 02:00 03:00 04:00 05:00 06:00
Start Time (13-Dec-06 00:00:00)
2006/12/13
Time = 01:12:43
Slit Pos = 001
FeX
FeVIII
FeXI
CaXVII
FeXII
FeXIII
HeII
FeXIV
FeXV

Doppler Shift (Single Gauss Fit)



What is Non-Gaussian Broad Line Profiles?

$$W = \sqrt{(\Delta\lambda)^2 + 4\ln 2\left(\frac{\lambda}{c}\right)^2\left(\frac{2kT}{M} + \xi^2\right)}$$

Instrumental

Thermal

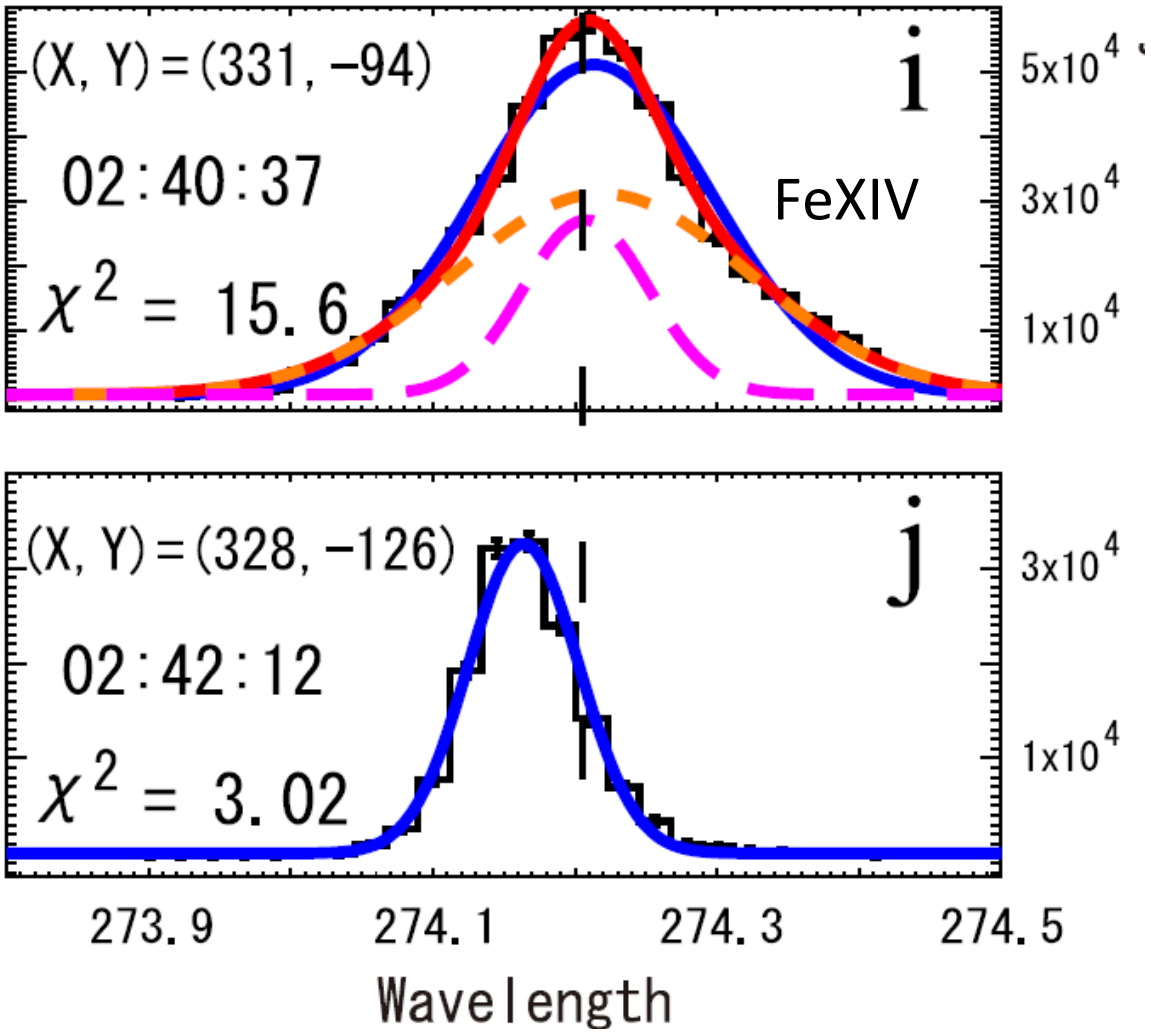
Non-Thermal

Thermal: T is decided by the line (Te ~ Ti)

for example, FeXIV: T ~ 2MK

Non-thermal: Others, not thermal one

How it looks like?



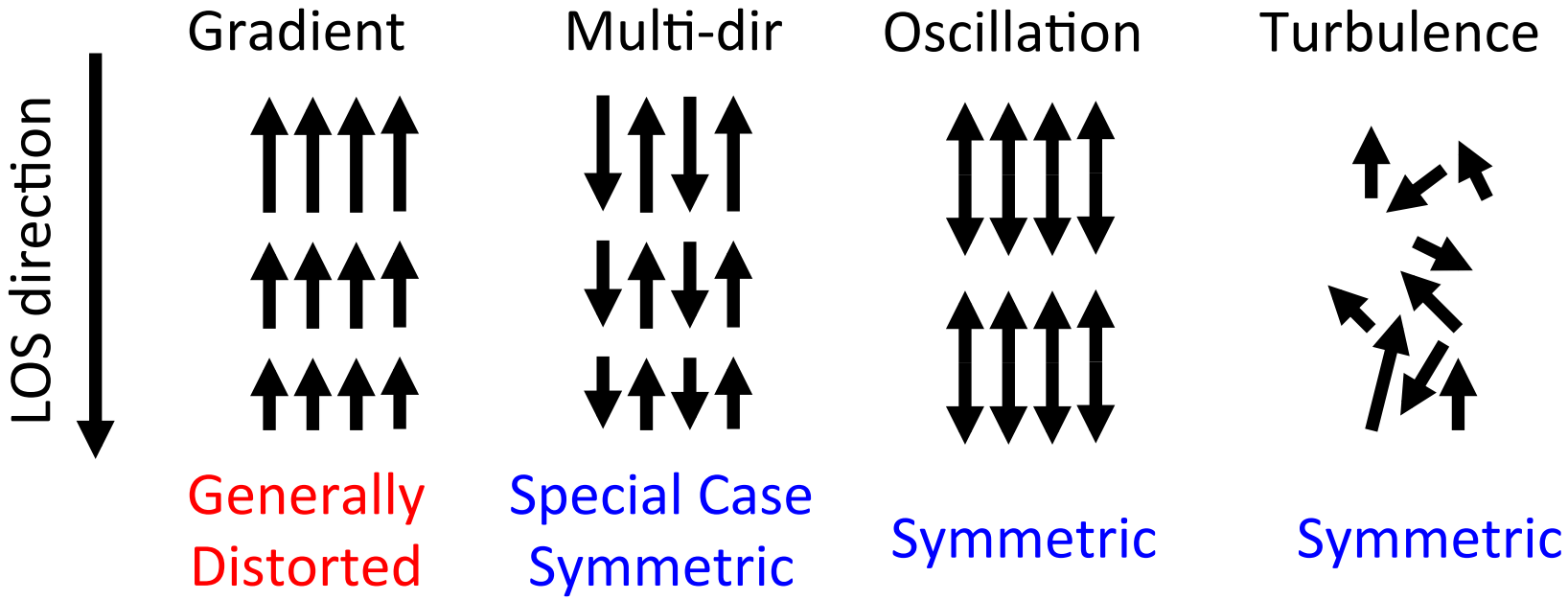
FWHM ~ 215km/sec

FWHM ~ 100km/sec

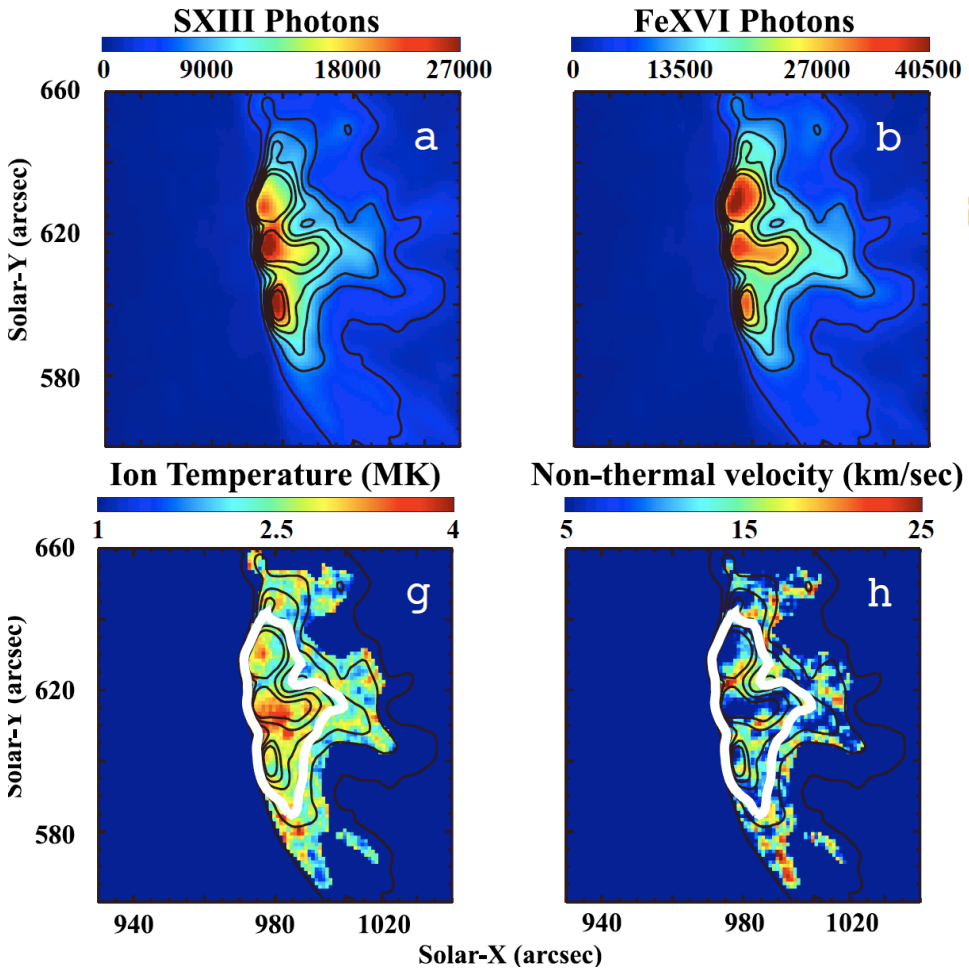
Imada et al. 2008

Physical Meaning of Broadening

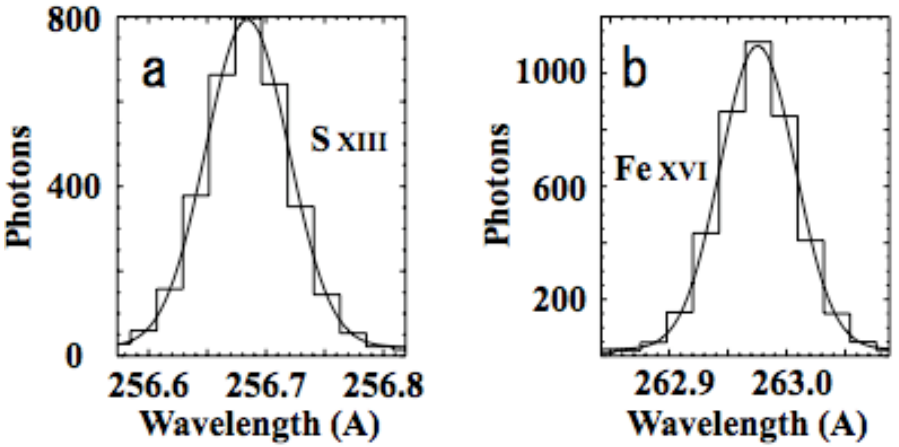
- Velocity Gradient
- Multi-dir flow (no typical direction)
- Velocity Oscillation (include waves)
- Turbulence



Ion Temperature



$$W_{obs} = \sqrt{W_I^2 + 4\log 2\left(\frac{2k_B T_{ion}}{M} + \xi^2\right)},$$

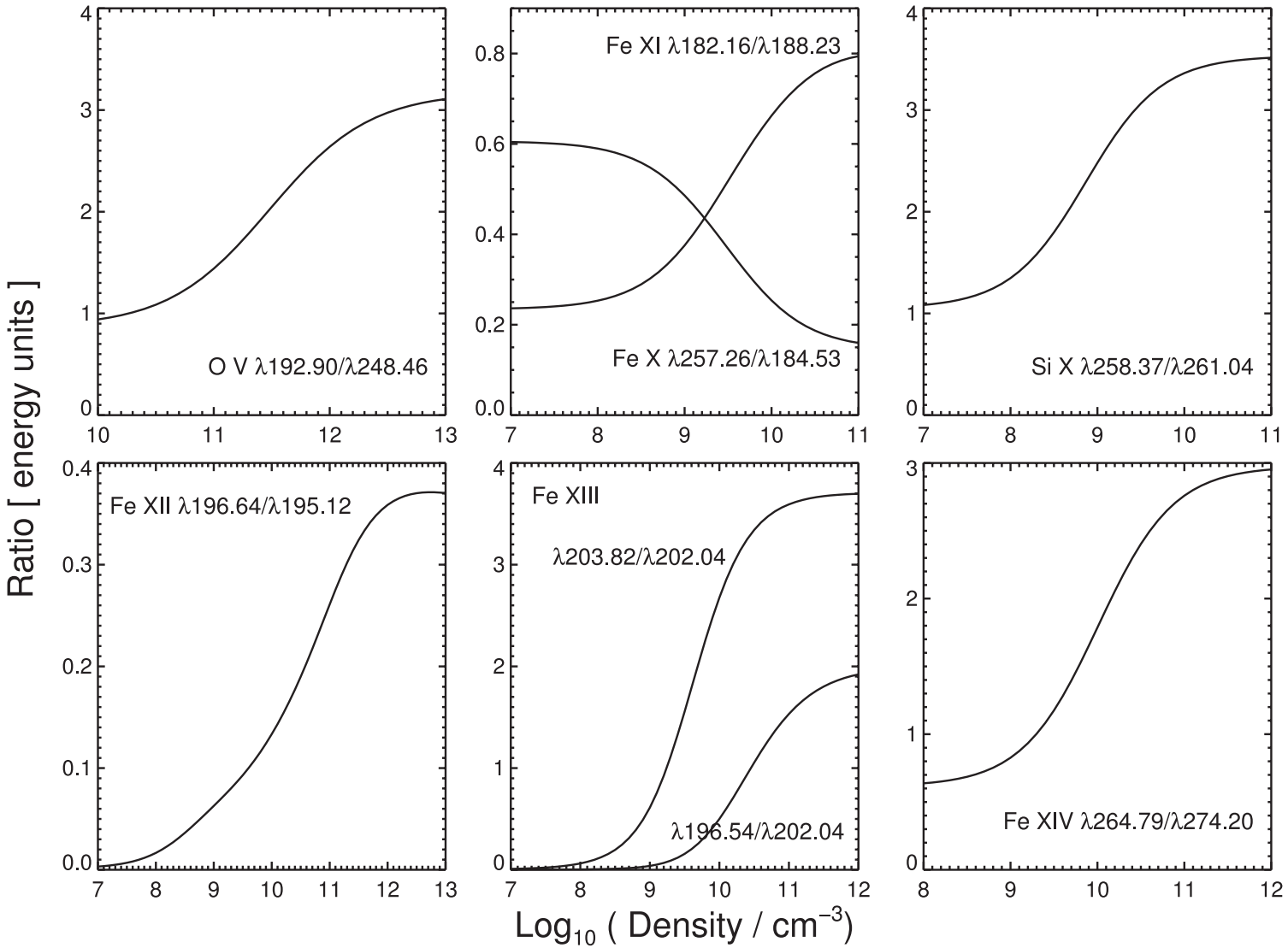


$$T_{ion} = \frac{\widehat{W}_1^2 - \widehat{W}_2^2}{8k_B \log 2} \frac{M_1 M_2}{M_2 - M_1},$$

$$\xi^2 = \frac{M_2 \widehat{W}_2^2 - M_1 \widehat{W}_1^2}{4\log 2(M_2 - M_1)},$$

Imada et al., APJL 2009

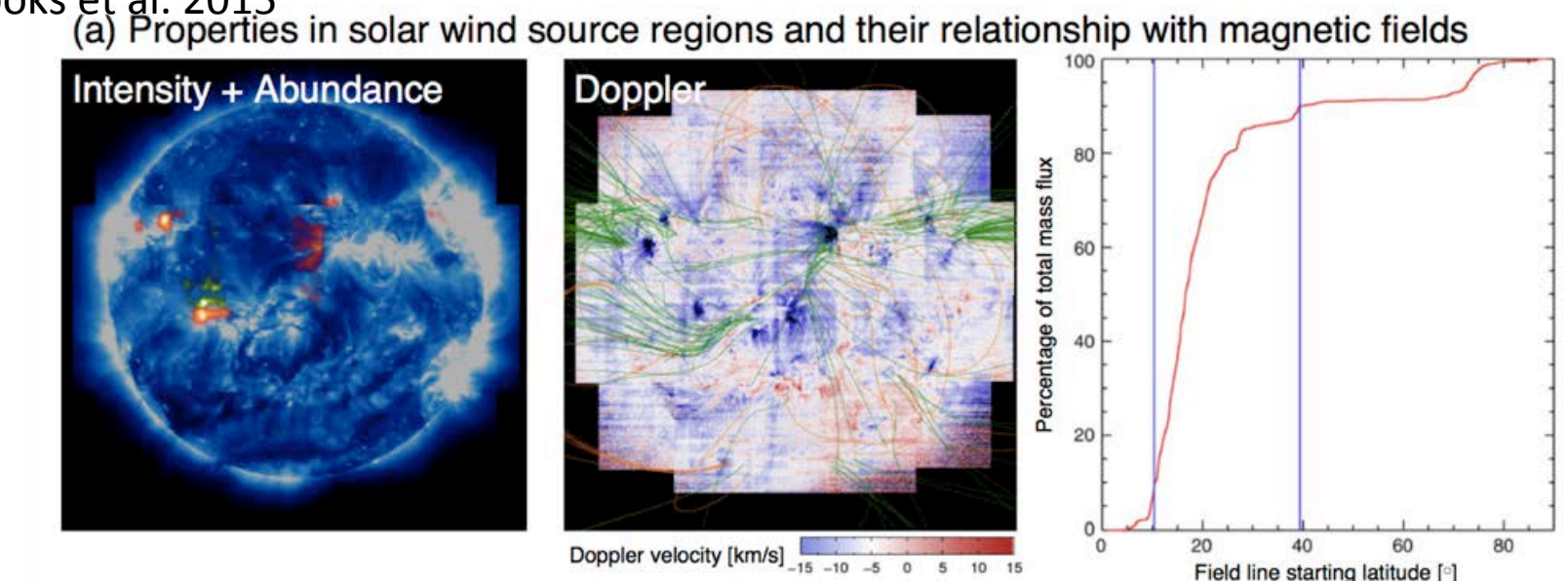
Density Diagnostics capability



Synergy observation with DKIST

Off-limb wave observation

Brooks et al. 2015

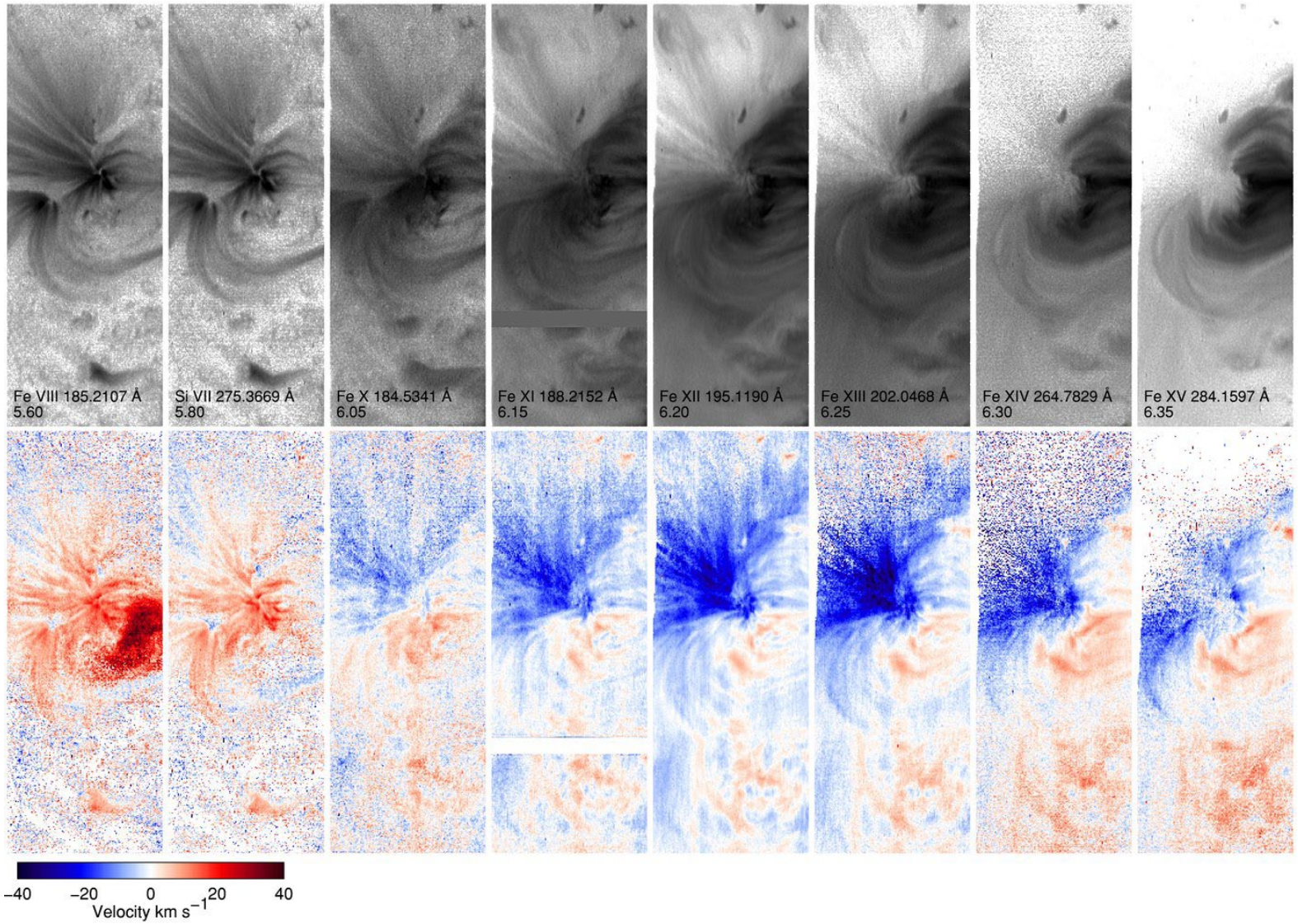


Teriaca et al. 2003

Hahn & Savin 2013

AR footpoint

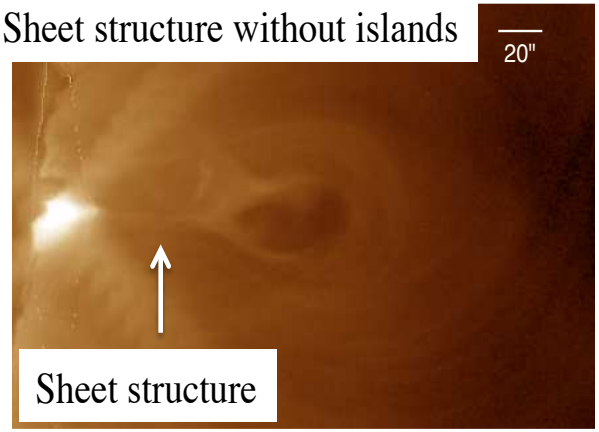
Warren et al. 2011



Reconnection observation: Turbulent flow & Magnetic field?

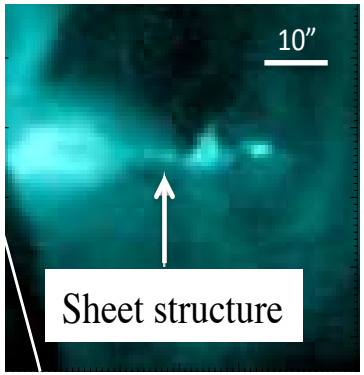
Warren et al., 2018

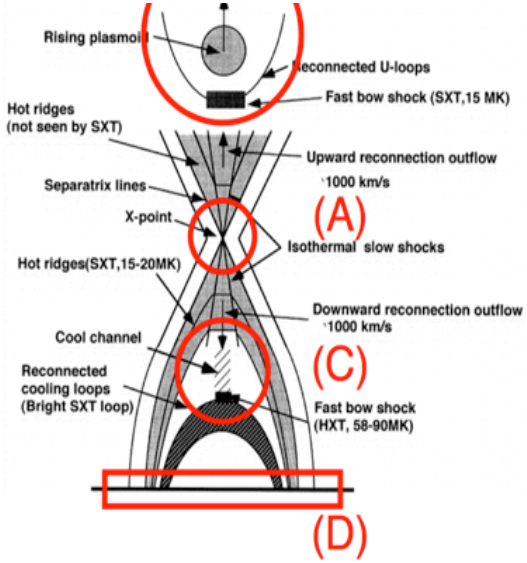
A) Sheet structure without islands



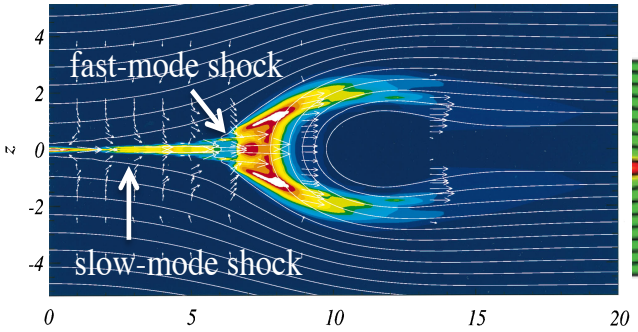
Takasao et al., 2012

(B) Sheet structure with islands



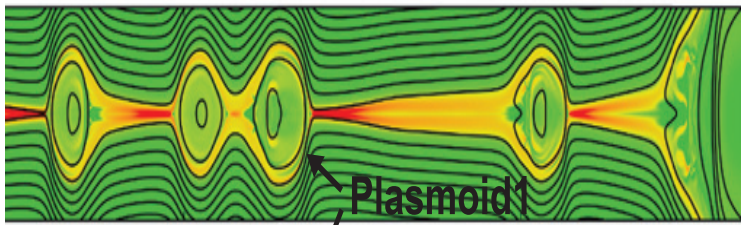


(C) Petschek Reconnection



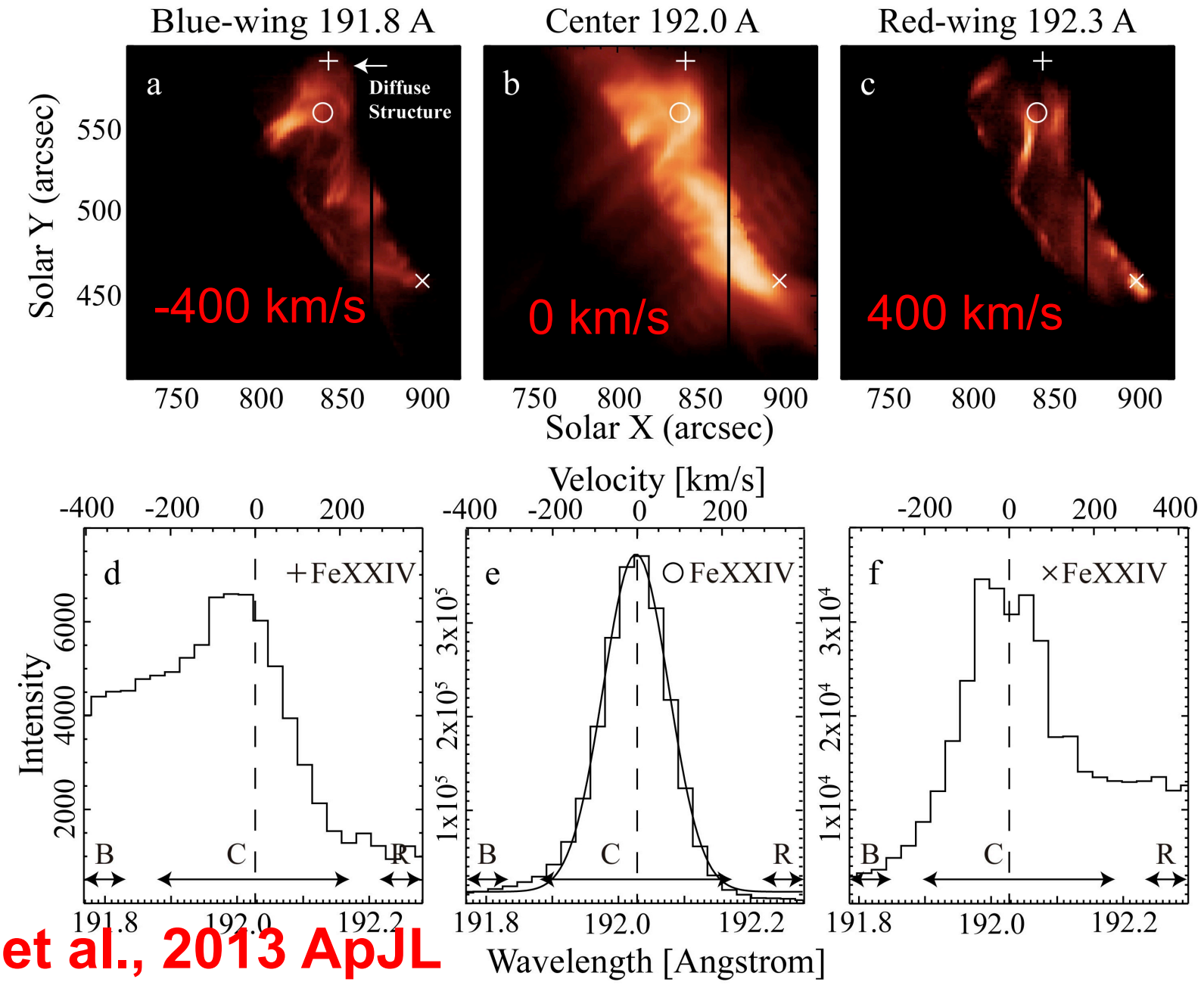
Yokoyama & Shibata, 1997

(D) Plasmoid-Unstable Reconnection



Shibayama et al., 2015

Spectroscopic obs: EIS Line Profiles



Imada et al., 2013 ApJL