Waves in the Coronal holes

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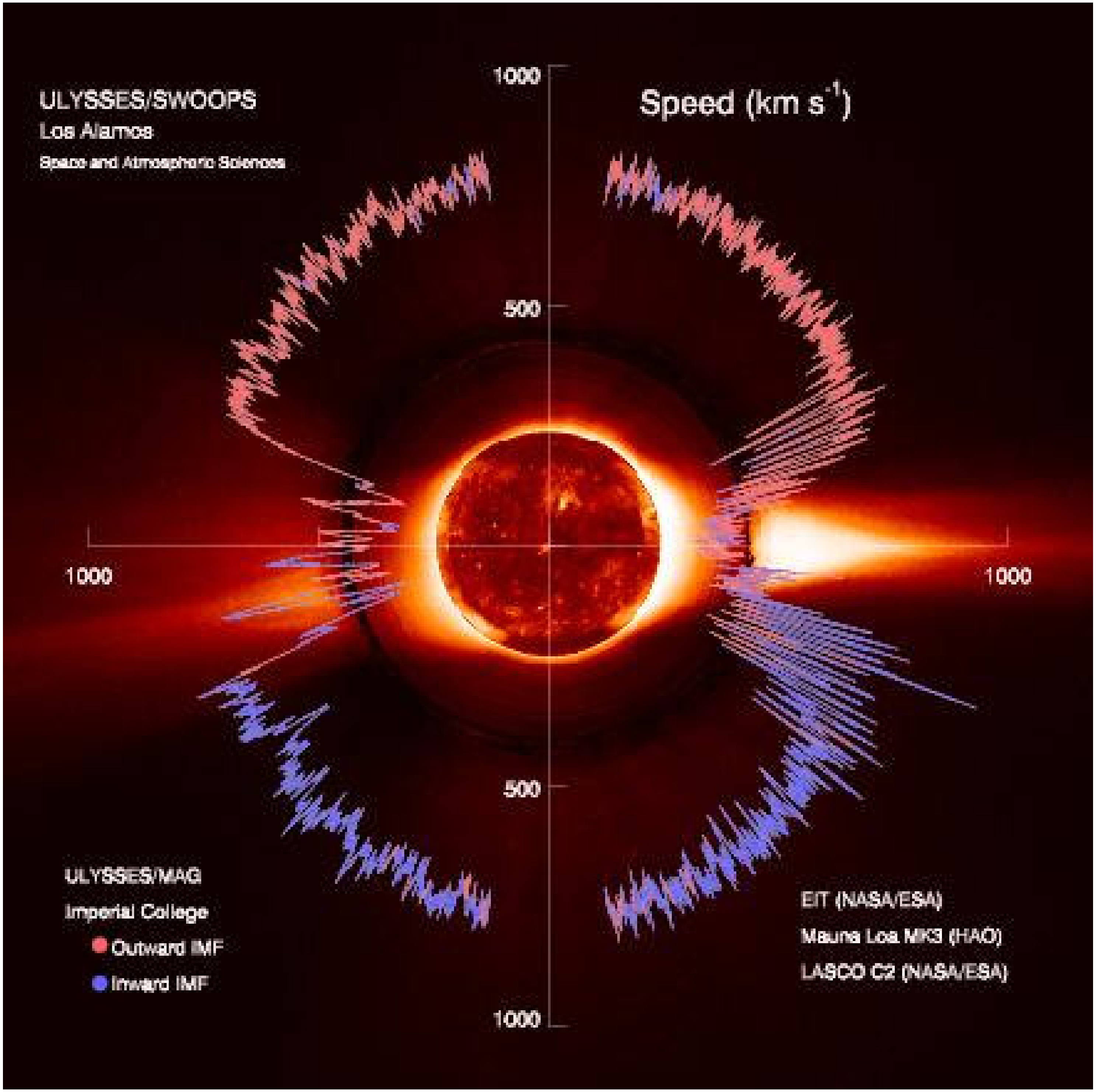
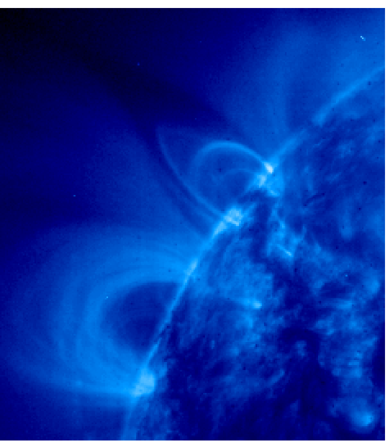
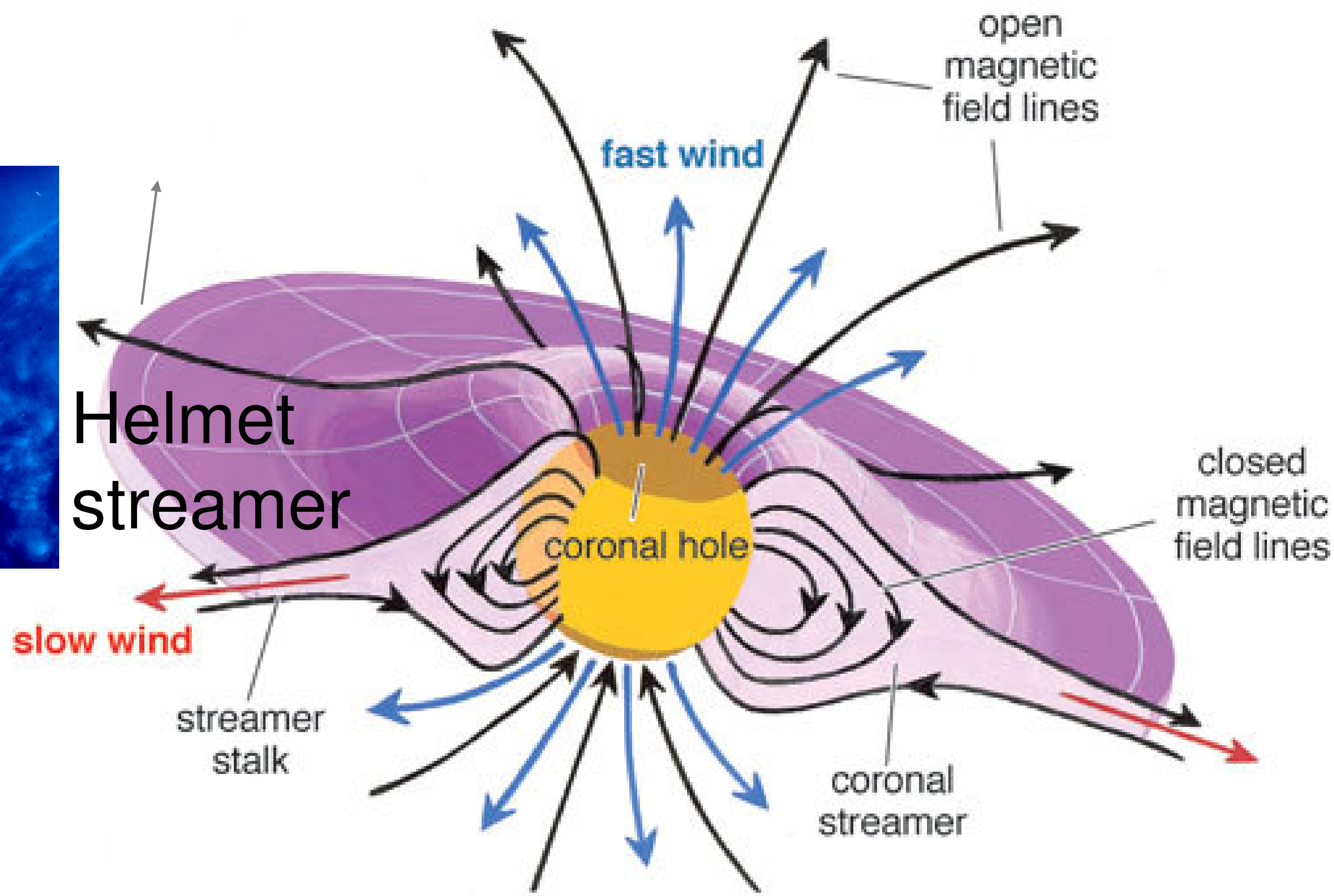

ULYSSES/SWOOPS
Los Alamos
Space and Atmospheric Sciences
Speed (km s^{-1})
1000
500
1000
1000
500
1000
ULYSSES/MAG
Imperial College
Outward IMF
Inward IMF
EIT (NASA/ESA)
Mauna Loa MK3 (HAO)
LASCO C2 (NASA/ESA)

- The Solar Wind: A constant stream of particles from the Sun into space.
- One of the effects of the open field lines at the poles and the closed field lines at equatorial regions is a difference in the solar wind speed.

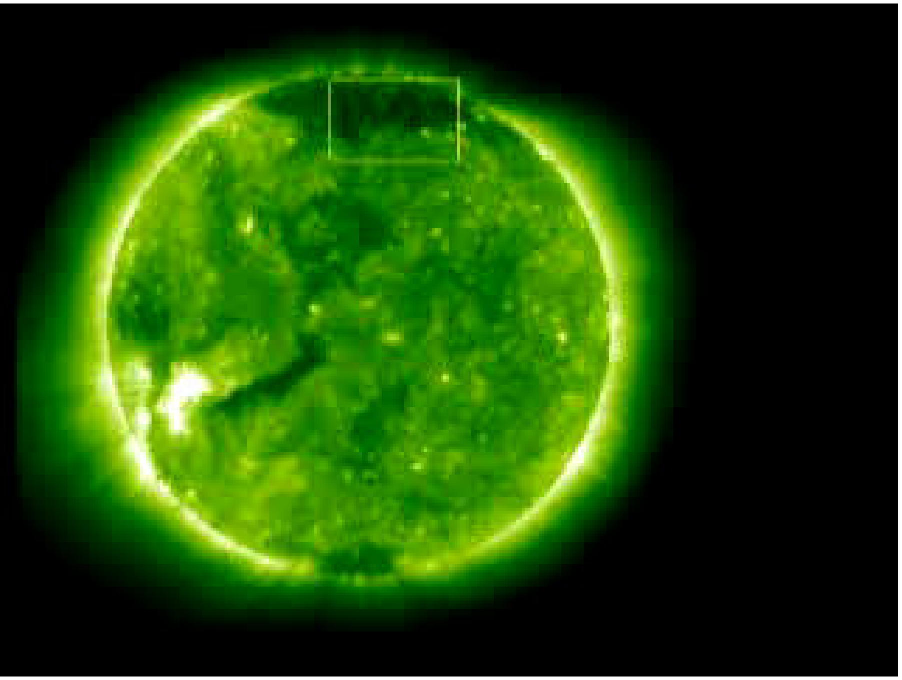
At the poles there is the ‘fast’ solar wind



Helmet streamer

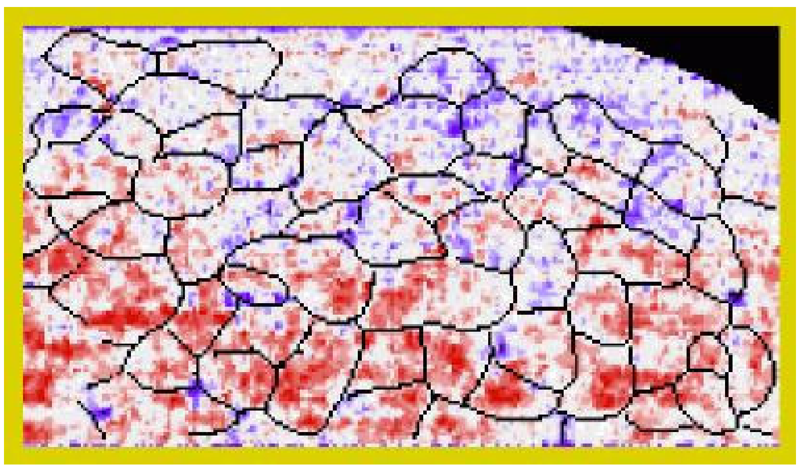


At equatorial regions there is the ‘slow’ wind



Observations with SUMER (UV Spectrometer)

Dopplergram showing the up- and downflows



SUMER spectroscopic observations in a coronal hole in Ne VIII 770Å (650 000 K)

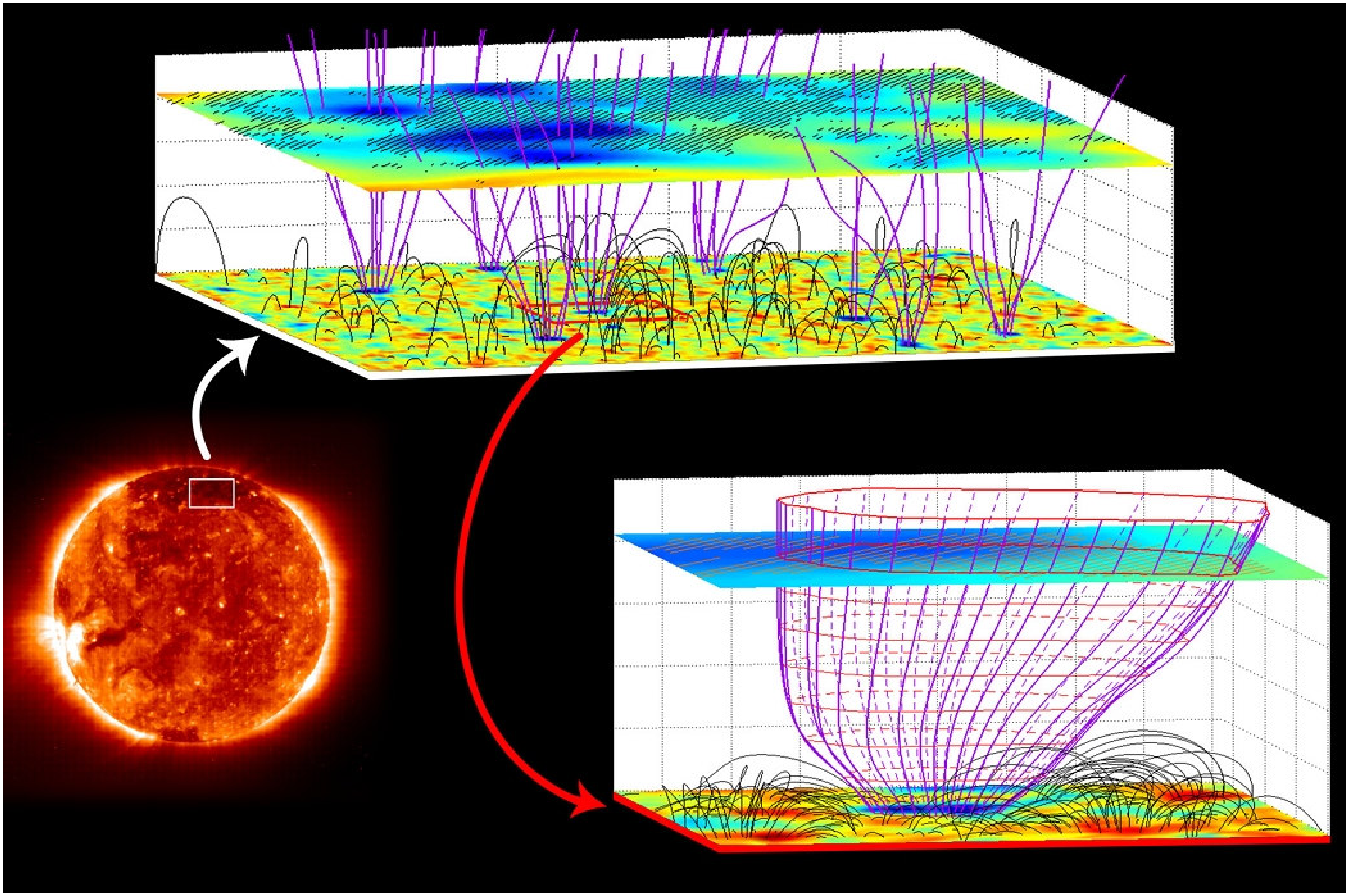
Shows outflows (blue shifts) in coronal hole as compared to red shifts in quiet Sun

Largest outflows occur along the boundaries and the intersections of the chromospheric network (superimposed dark lanes)

- Hassler et al. 1999 Science

Solar wind originates in coronal funnels

Tu et al. 2005 Science



Motivation

Coronal Holes (CH) ⇒ Source region of Fast Solar Wind

CH are often *peppered* with vertical radial structures called , `*plumes*´, structures seen upto 30 R_0 (DeForest et al. 2001)

Coronal plumes occur near regions of mixed magnetic polarity ⇒ *Origin of plumes and spicules*

Plume formation by small bipoles within a CH reconnect with unipolar flux concentrations at network bounaries (Wang 1995, Young 1999)

Alfvén Waves in the Solar Corona (Science, 2007) by Tomczyk et al

Alfvén waves and x-ray jets, spicules etc..(Recent work from Hinode)

Spectroscopic observations:

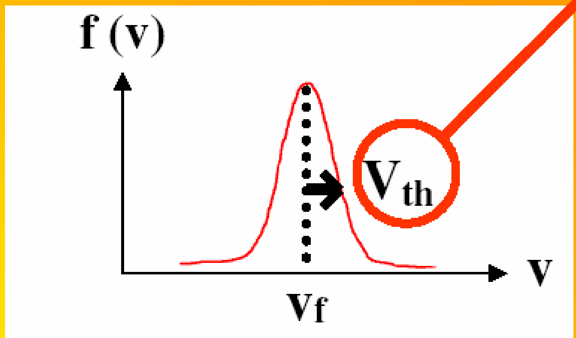
The line width : a mix of 2 informations

Gaussian width :
(optically thin)

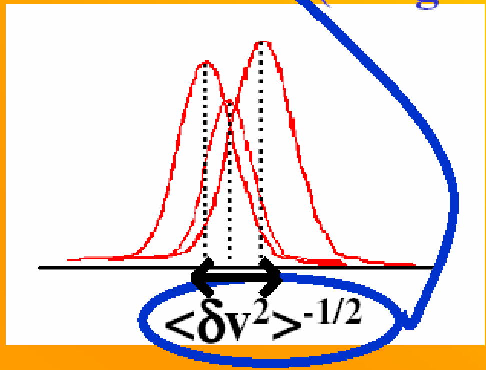
$$\sigma^2 = \frac{\lambda^2}{2c^2}\left(\frac{2kT}{M} + \xi^2\right) + \sigma_I^2.$$

Instrumental width

Thermal Doppler effect (one volume element) :



« non-thermal » velocity (integration effect)



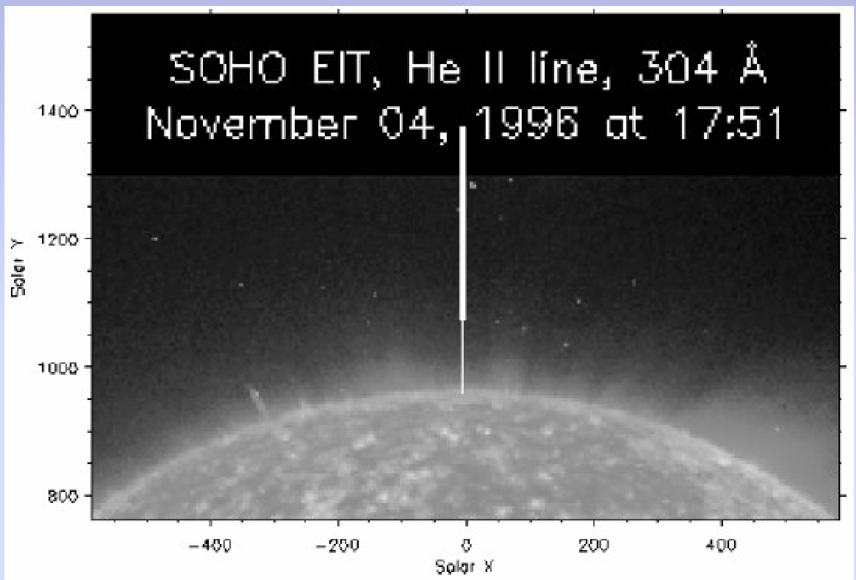
- **Temperature** : thermal Doppler effect in one volume element
- « **non-thermal velocity** », or « unresolved velocity » : results from the integration over a lot of volume elements driven by fluid velocity fluctuations :

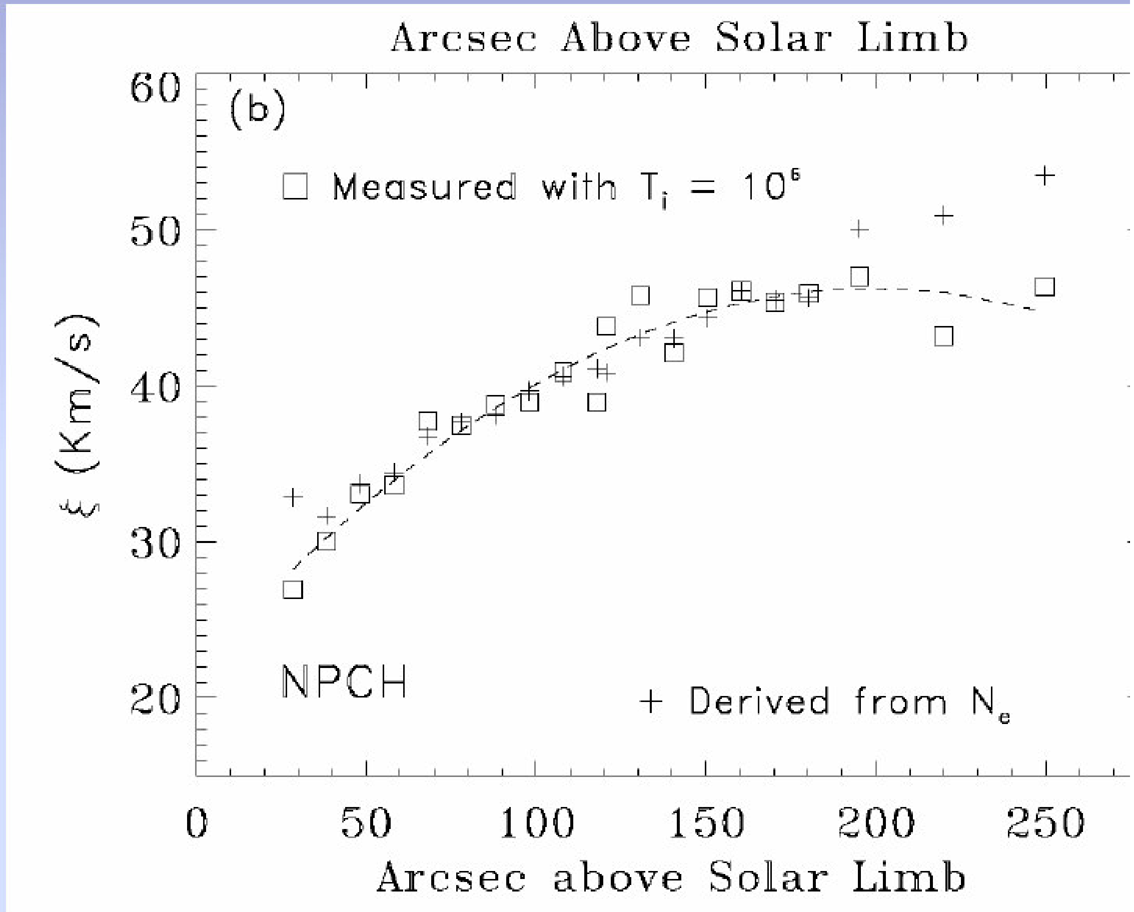
  → on the line of sight

  → on spatial and temporal scales smaller than the resolution scale

Source of velocity fluctuations : Alfvén waves, turbulence ?

Nonthermal motions in coronal holes (SUMER)



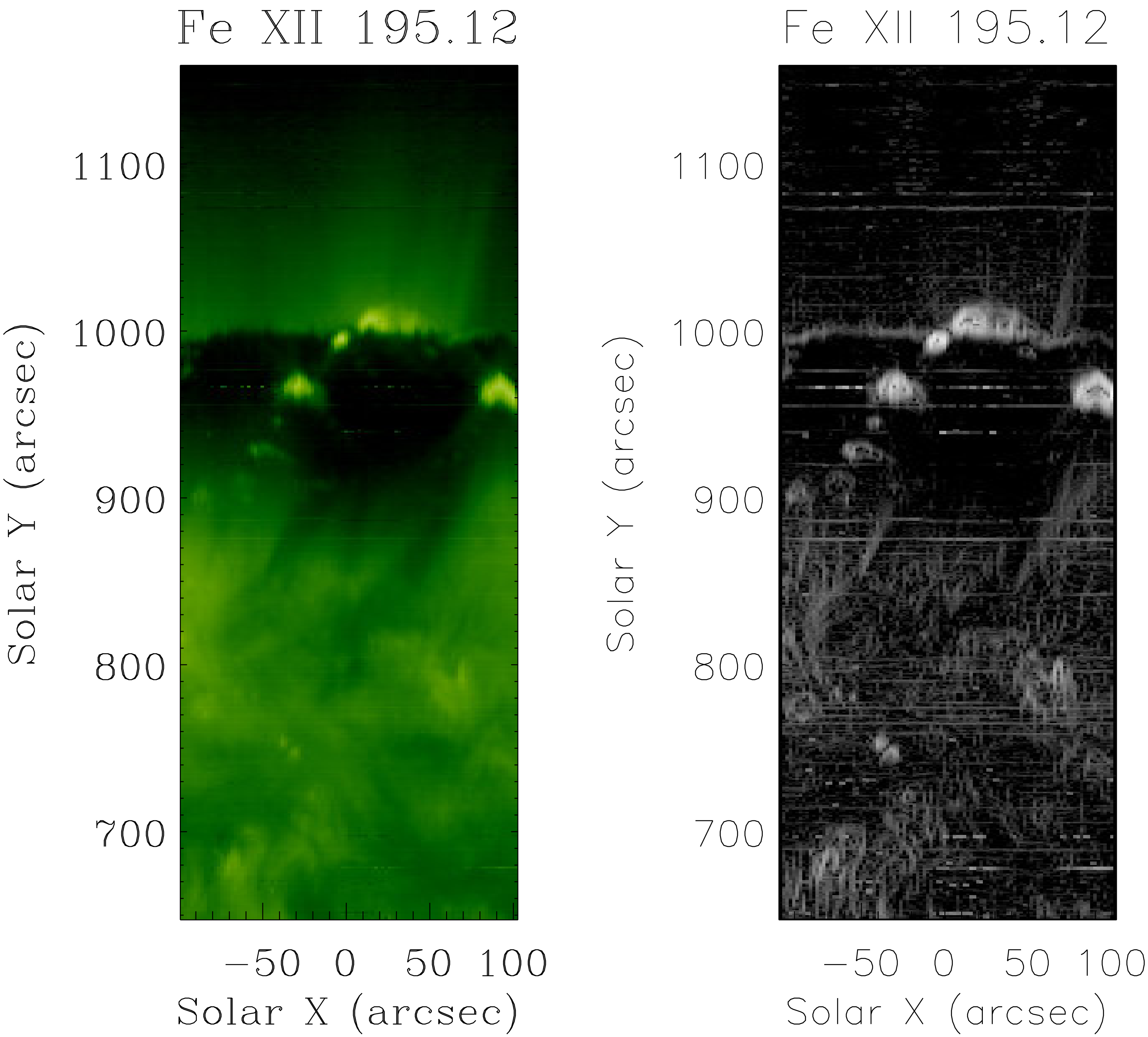


Banerjee et al 1998

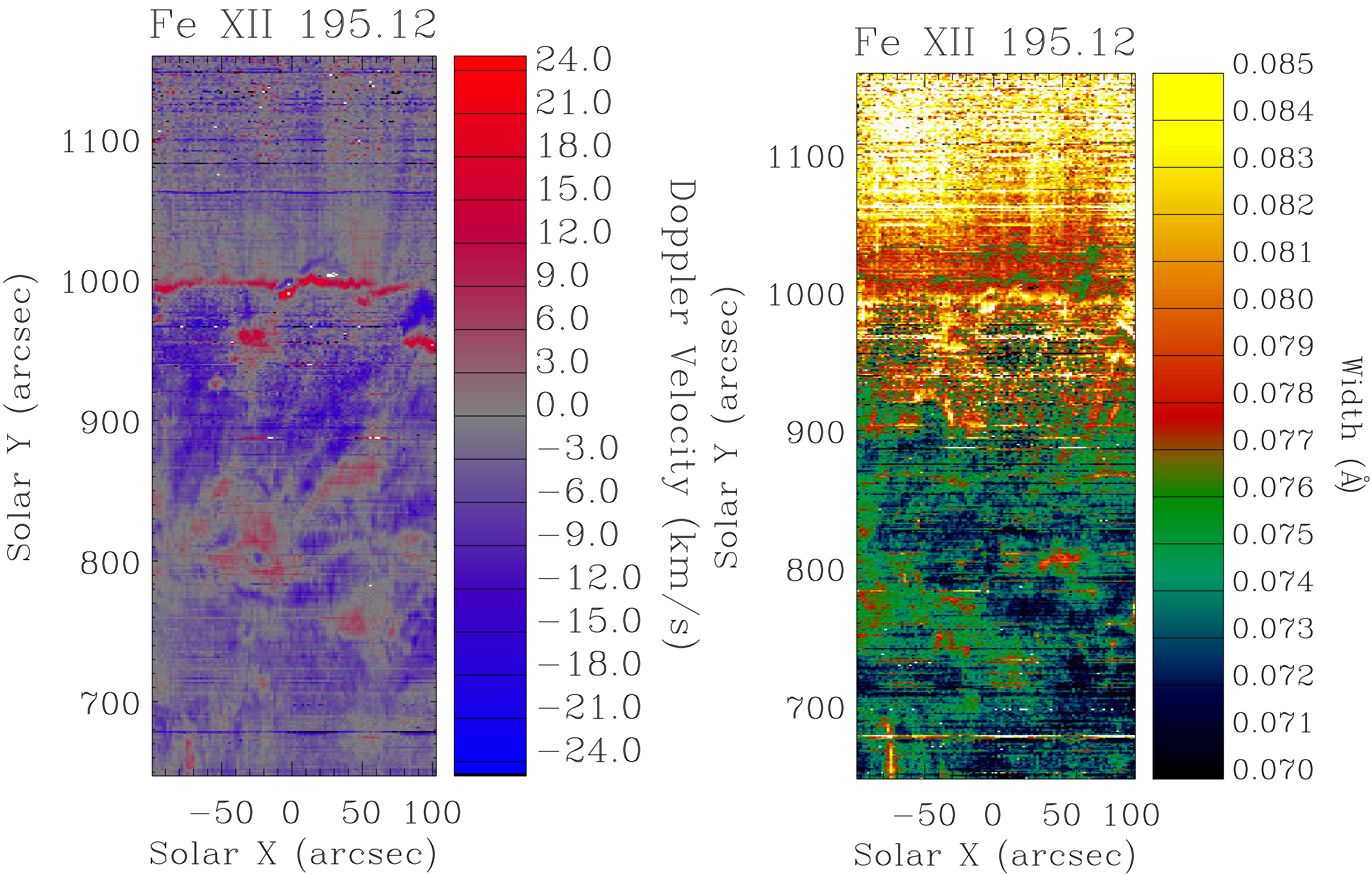
- *On the widths and ratios of Mg x lines in polar off-limb region*
- *O'Shea, Banerjee & Doyle, A&A, 2005, **436**, L35*

Observation of polar coronal holes with EIS/HINODE

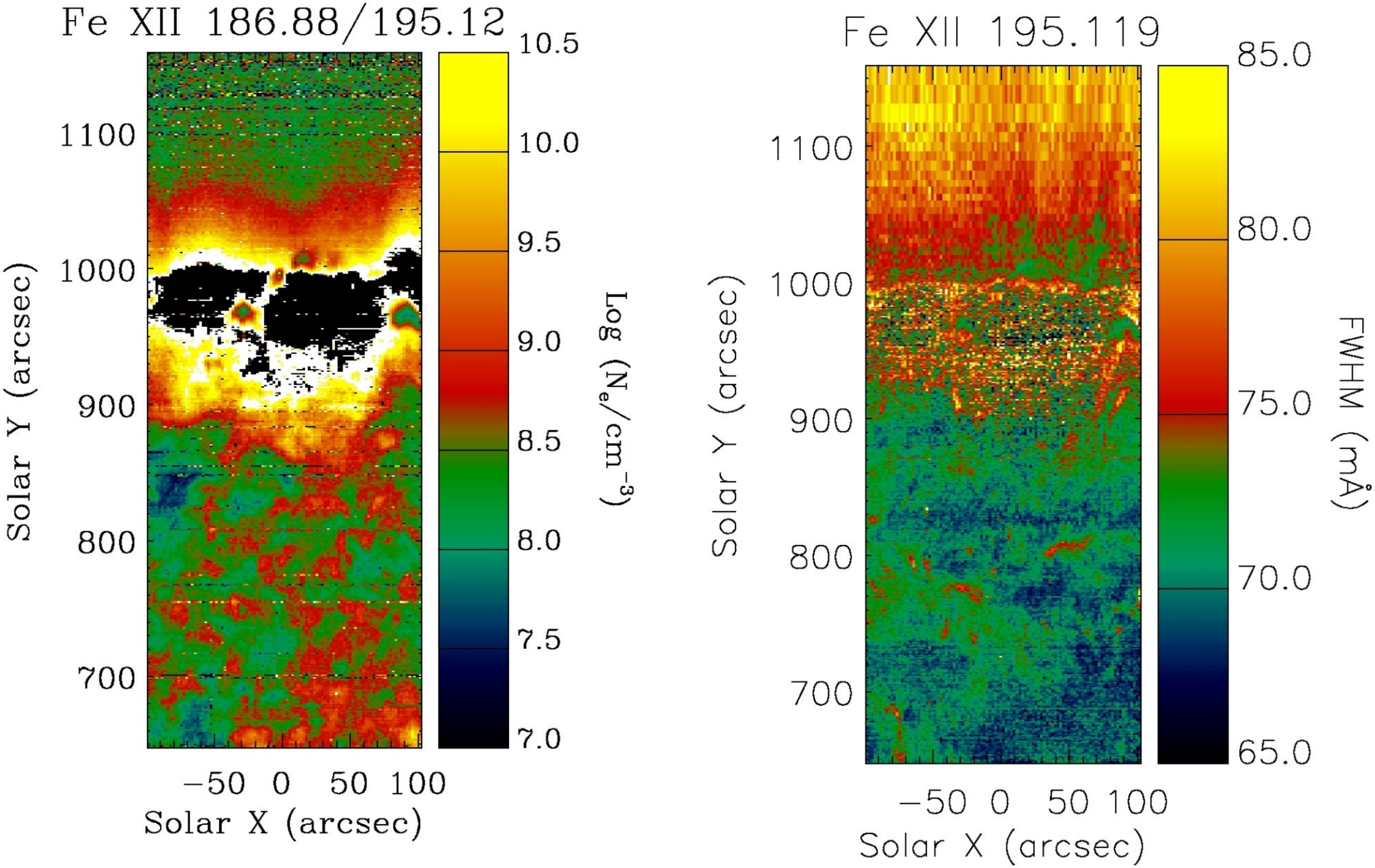
- Raster Scans with 2 x 500 arc sec slit
- For Density diagnostic
- Line width studies
- Doppler shift studies
- Plume versus inter-plume properties
- Is plume or the inter-plume preferred locations for the acceleration of the fast solar wind



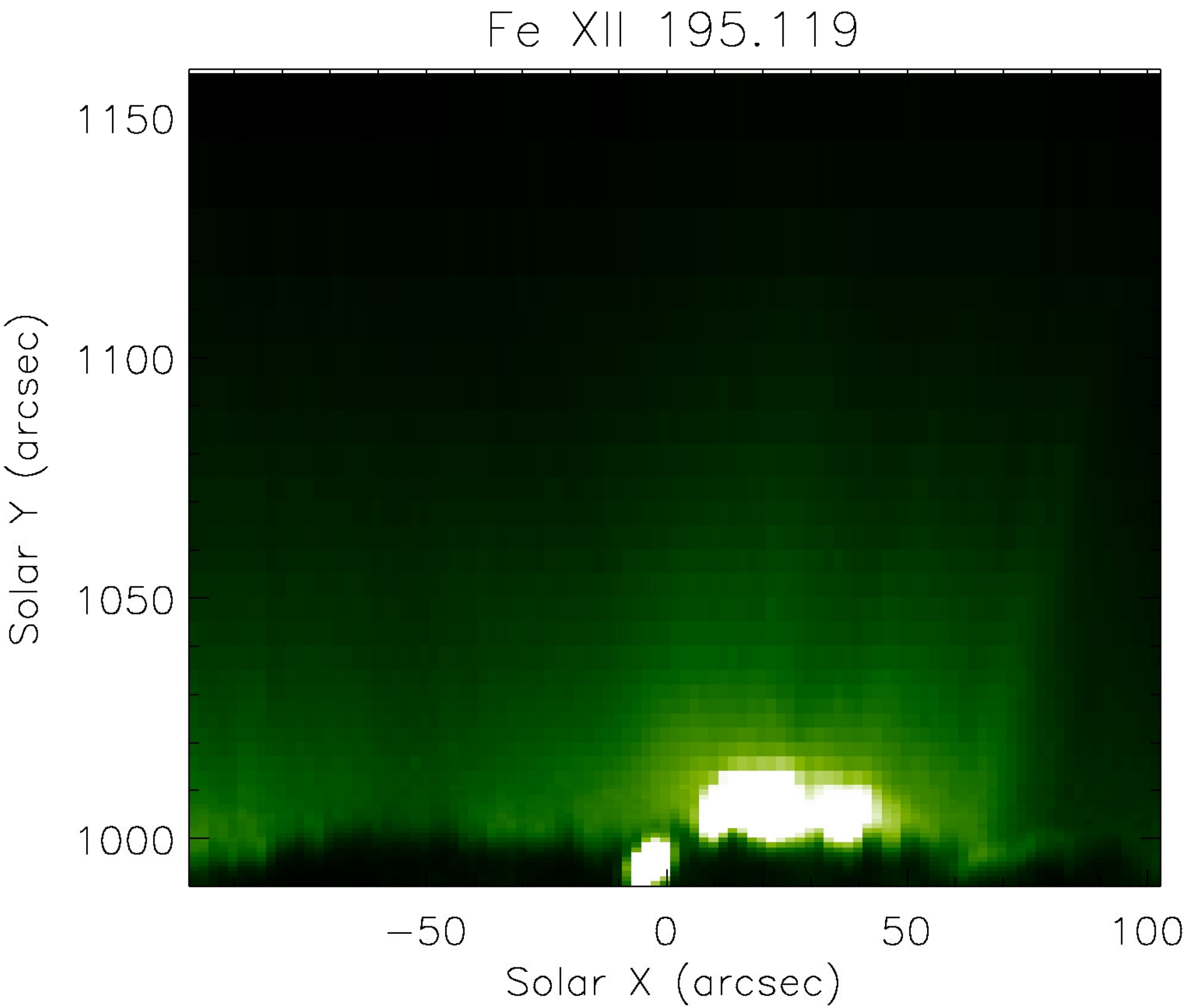
Fe XII 195.12
Fe XII 195.12
Solar Y (arcsec)
1100
1000
900
800
700
−50 0 50 100
Solar X (arcsec)

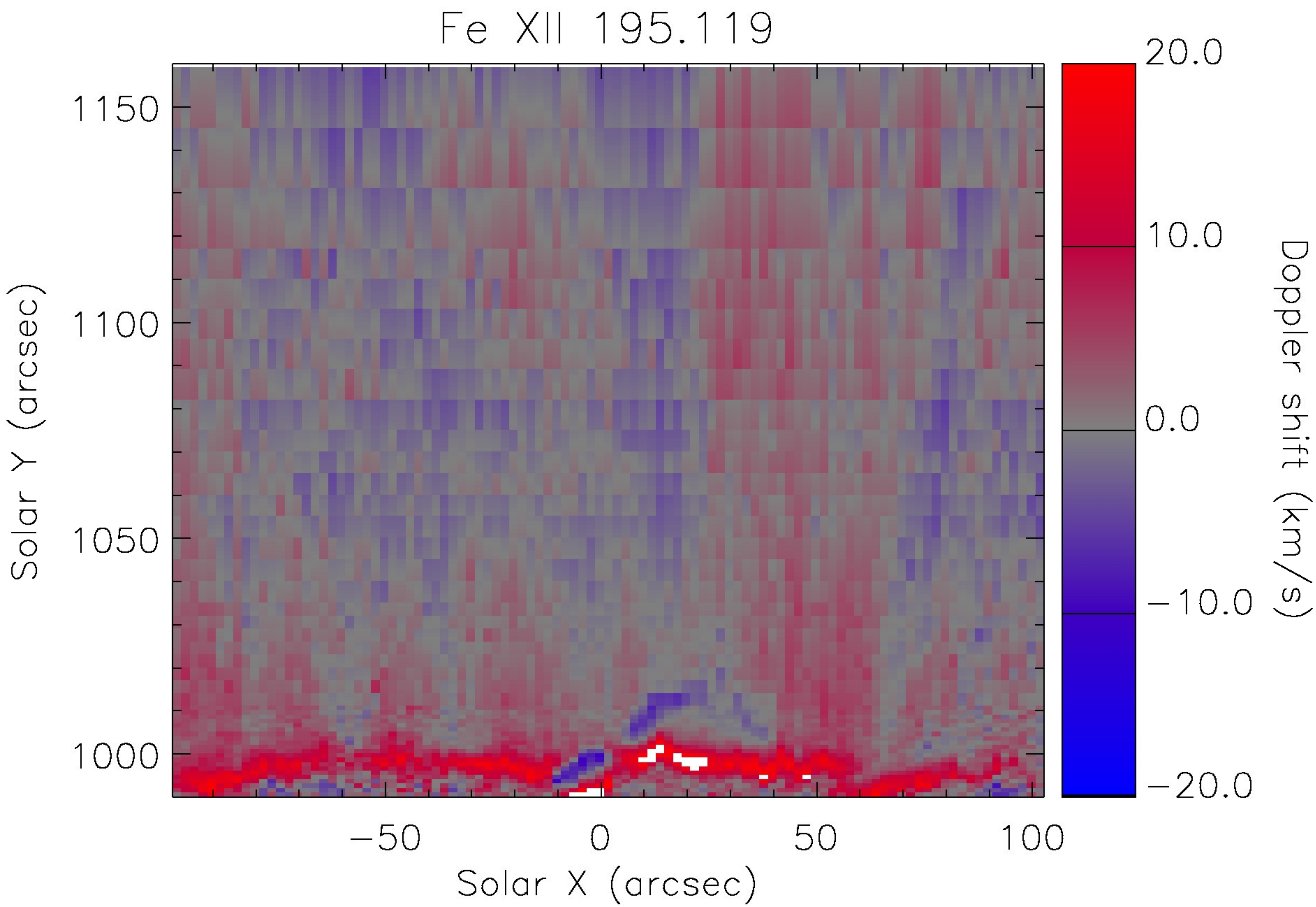


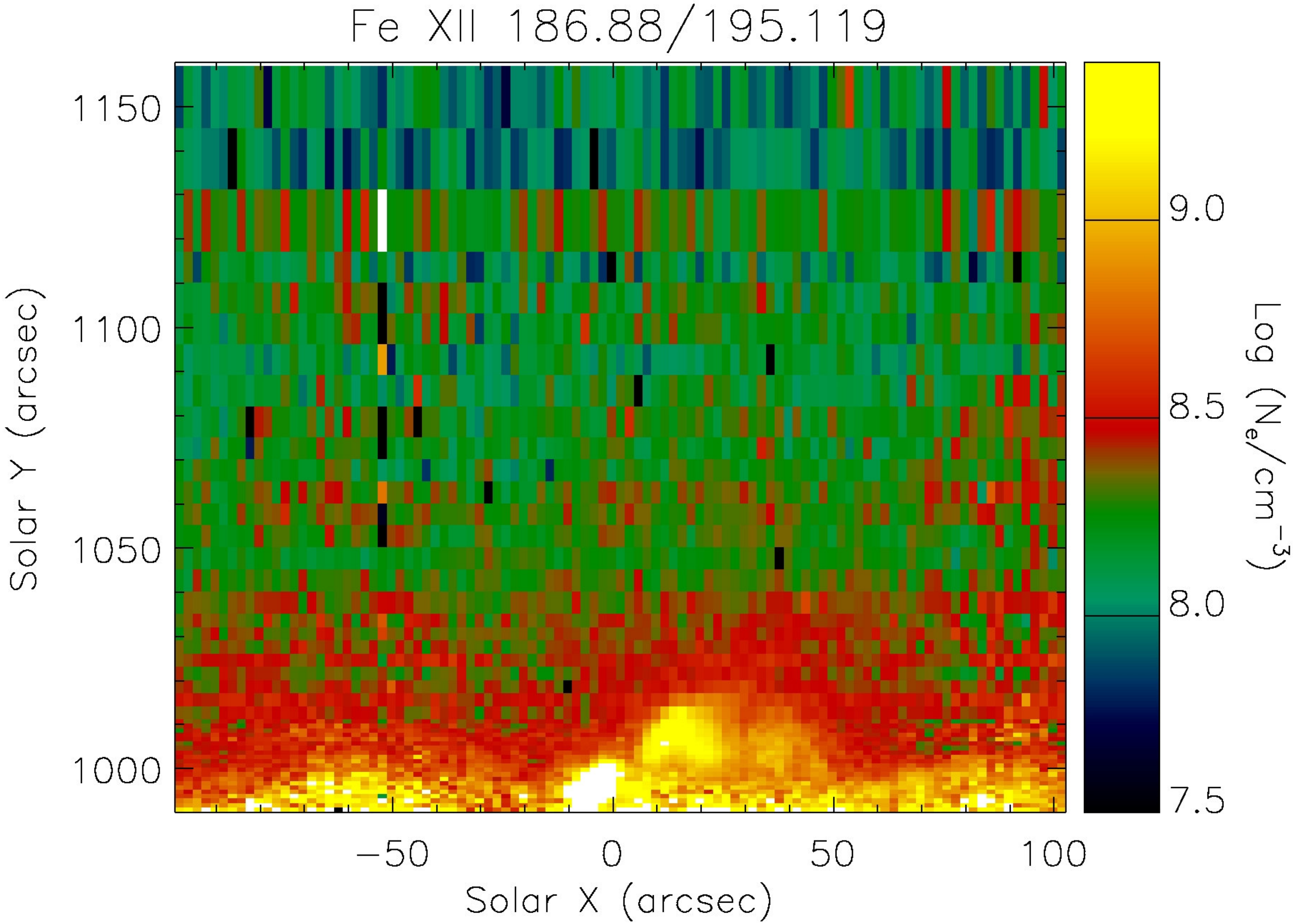
Fe XII 195.12
Solar Y (arcsec)
Solar X (arcsec)
Doppler Velocity (km/s)
24.0
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
−3.0
−6.0
−9.0
−12.0
−15.0
−18.0
−21.0
−24.0
1100
1000
900
800
700
−50
0
50
100
Fe XII 195.12
Solar Y (arcsec)
Solar X (arcsec)
Width (Å)
0.085
0.084
0.083
0.082
0.081
0.080
0.079
0.078
0.077
0.076
0.075
0.074
0.073
0.072
0.071
0.070



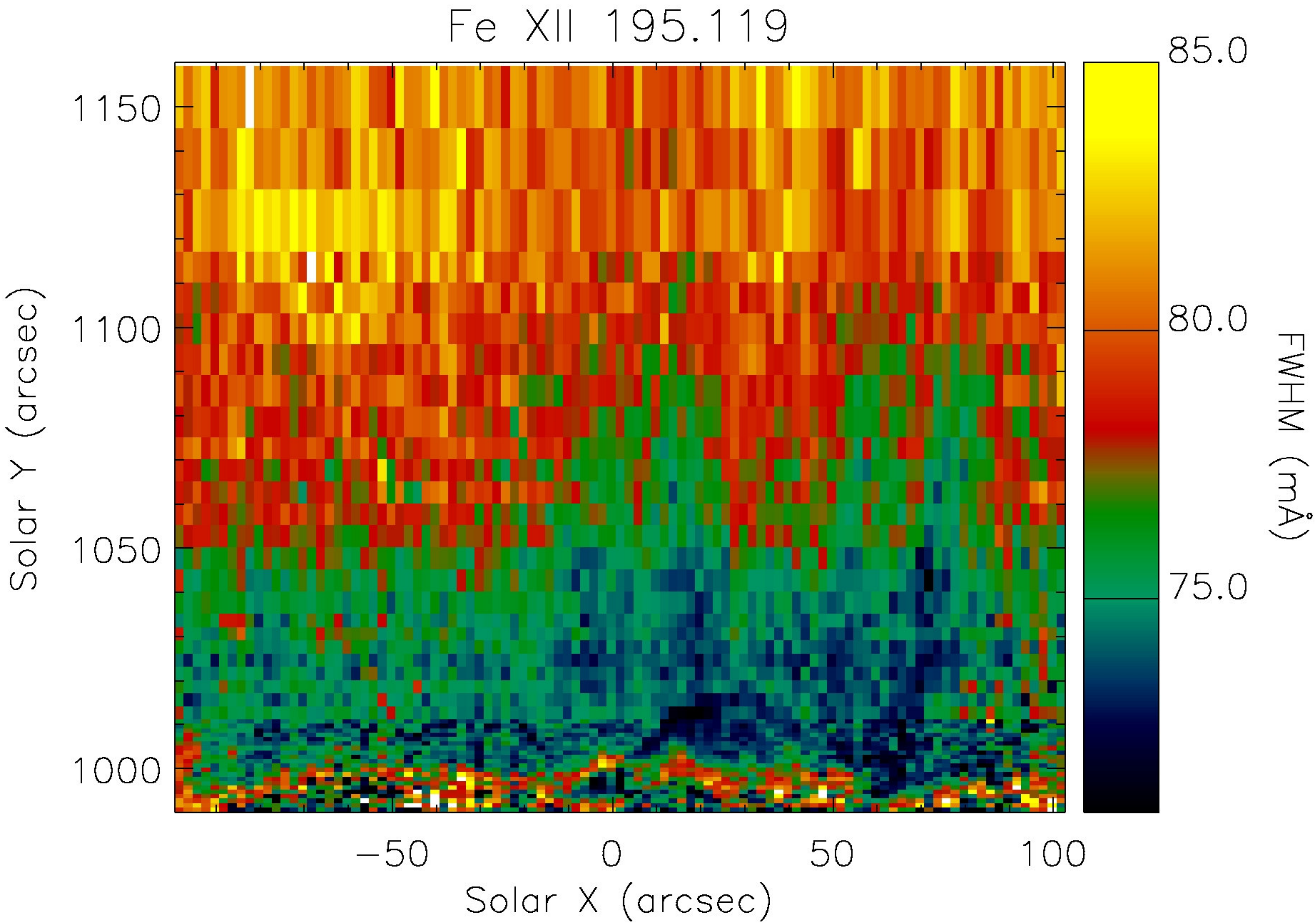
Fe XII 186.88/195.12
Solar Y (arcsec)
Solar X (arcsec)
Log (N_e/cm^{-3})
1100
1000
900
800
700
-50 0 50 100
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
Fe XII 195.119
Solar Y (arcsec)
Solar X (arcsec)
FWHM (mÅ)
85.0
80.0
75.0
70.0
65.0

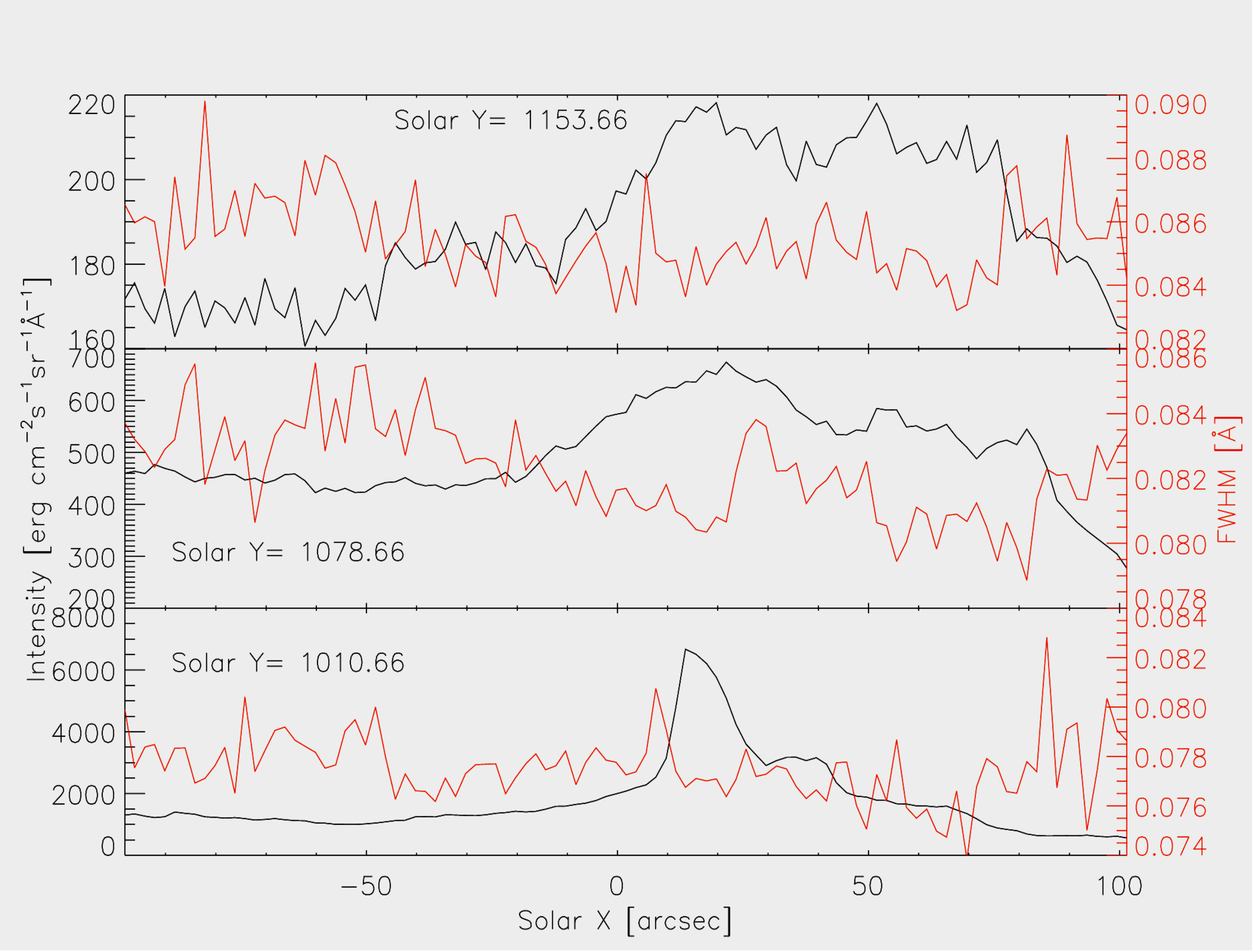

Fe XII 195.119
1150
1100
1050
1000
Solar Y (arcsec)
−50
0
50
100
Solar X (arcsec)


Fe XII 195.119
1150
1100
1050
1000
−50
0
50
100
Solar X (arcsec)
Solar Y (arcsec)
20.0
10.0
0.0
−10.0
−20.0
Doppler shift (km/s)

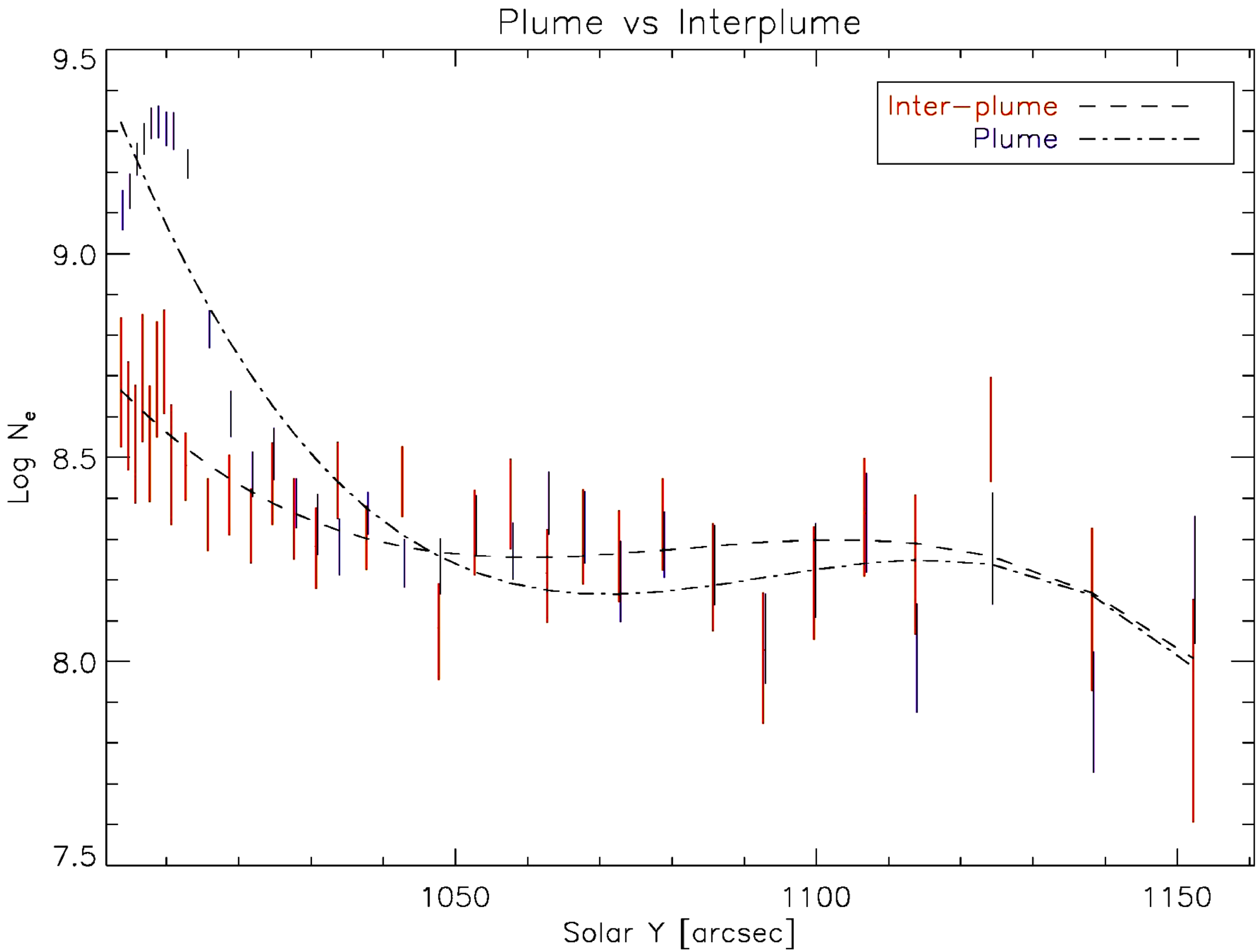


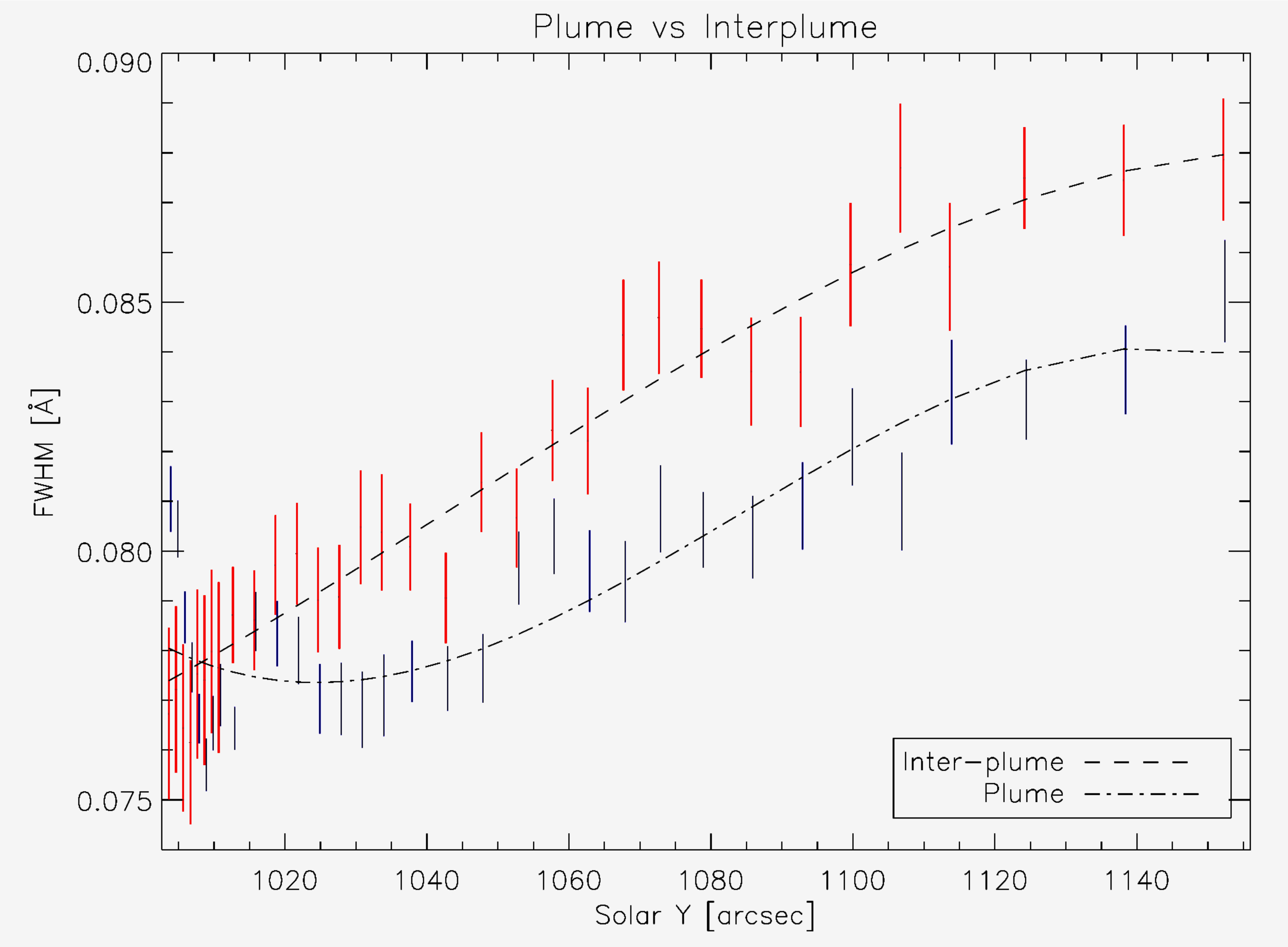
Fe XII 186.88/195.119
Solar Y (arcsec)
1150
1100
1050
1000
−50
0
50
100
Solar X (arcsec)
9.0
8.5
8.0
7.5
Log (N_e/cm^-3)

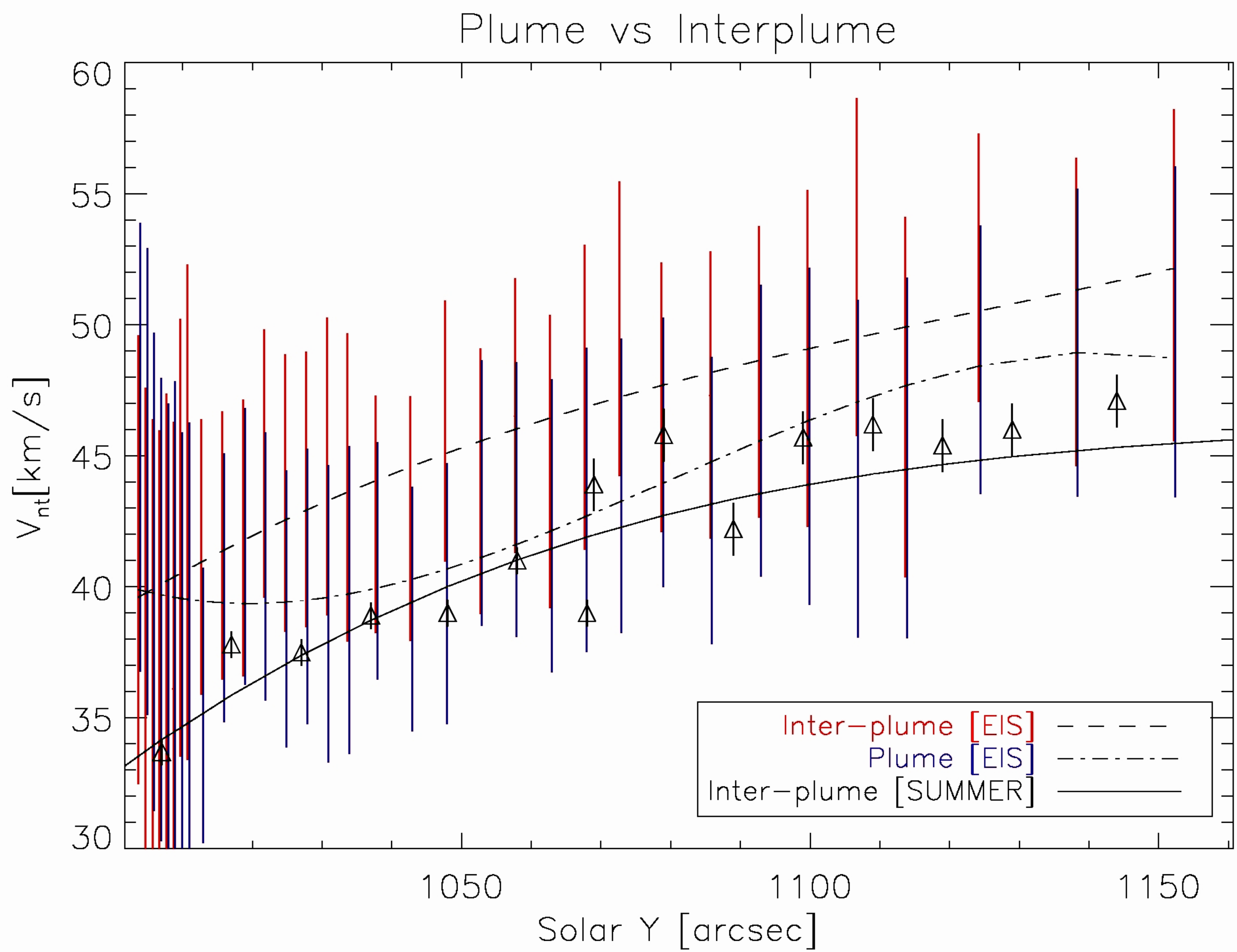

Fe XII 195.119
1150
1100
1050
1000
Solar Y (arcsec)
−50
0
50
100
Solar X (arcsec)
85.0
80.0
75.0
FWHM (mÅ)



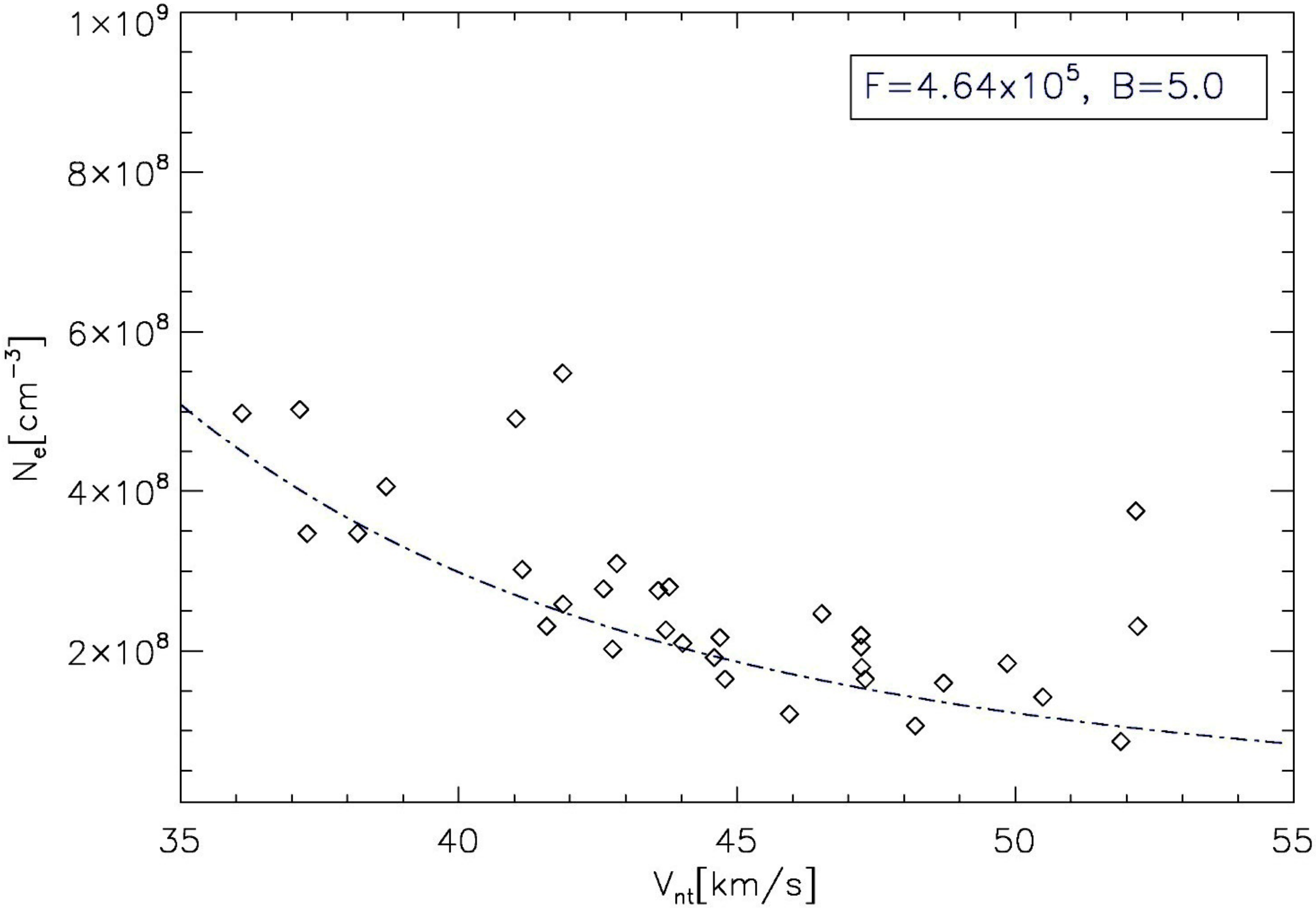
Solar Y= 1153.66
Solar Y= 1078.66
Solar Y= 1010.66
Intensity [erg cm^{-2}s^{-1}sr^{-1}Å^{-1}]
FWHM [Å]
Solar X [arcsec]
220
200
180
160
700
600
500
400
300
200
8000
6000
4000
2000
0
0.090
0.088
0.086
0.084
0.082
0.086
0.084
0.082
0.080
0.078
0.084
0.082
0.080
0.078
0.076
0.074
−50
0
50
100


Plume vs Interplume
Inter−plume
Plume
9.5
9.0
8.5
8.0
7.5
Log N_e
1050
1100
1150
Solar Y [arcsec]


Plume vs Interplume
FWHM [Å]
Solar Y [arcsec]
0.090
0.085
0.080
0.075
1020
1040
1060
1080
1100
1120
1140
Inter−plume
Plume



Plume vs Interplume
60
55
50
45
40
35
30
1050
1100
1150
Solar Y [arcsec]
V_nt[km/s]
Inter−plume [EIS]
Plume [EIS]
Inter−plume [SUMMER]



$$F = \sqrt{\frac{\rho}{4\pi}} < \delta v^2 > B$$

$$< \delta v^2 >^{1/2} \propto \rho^{-1/4}$$

Alfvén waves propagate along magnetic field lines, with wave dynamics determined by the balance between magnetic tension and fluid inertia. Pure Alfvén waves are nondispersive, so the phase and group velocities are equal, and are given by, $V_A = \frac{B}{\sqrt{4\pi\rho}}$ [Eq. 1]. V_A is phase velocity, B is the field strength and ρ is the mass density. The wave energy flux density for vertical propagation in a stratified, plane parallel atmosphere is given by the products of the wave energy density and the Alfvén velocity: $\rho\xi^2 V_A$ [Eq. 2] where ξ is the rms wave velocity. Combining Eqs. [1] and [2], the energy flux density may also be written as $F = \frac{1}{\sqrt{4\pi}}\sqrt{\rho}\xi^2 B$ [Eq. 3]. The total energy flux crossing a surface of area A is given by, $\frac{1}{\sqrt{4\pi}}\sqrt{\rho}\xi^2 BA$ If total wave energy flux is conserved as waves propagates outward, the wave amplitude has the following dependence on density, magnetic field strength and area: $\xi \propto \rho^{-1/4}/\sqrt{BA}$ If a tube carries an Alfvén wave flux and magnetic feld flux both evenly distributed over itscross sectional area A, BA is constant as the A increasesand B decreases and we get a relation $\xi \propto \rho^{-1/4}$ [Eq. 4].

Summary of line width study

Studies the comparison between plume and inter-plumes from a single observation through high resolution spectroscopic diagnostics

Inter-plumes seems to be preferred channel for the acceleration of the fast wind

The line-width variation suggests presence of waves, un-damped propagation of Alfven waves up to certain height

These results provide important initial parameters for coronal hole models

MULTI WAVELENGTH STUDY OF CH FOR THE DETECTION OF WAVES

Sit and stare observations

JOP 196 and HOP Program

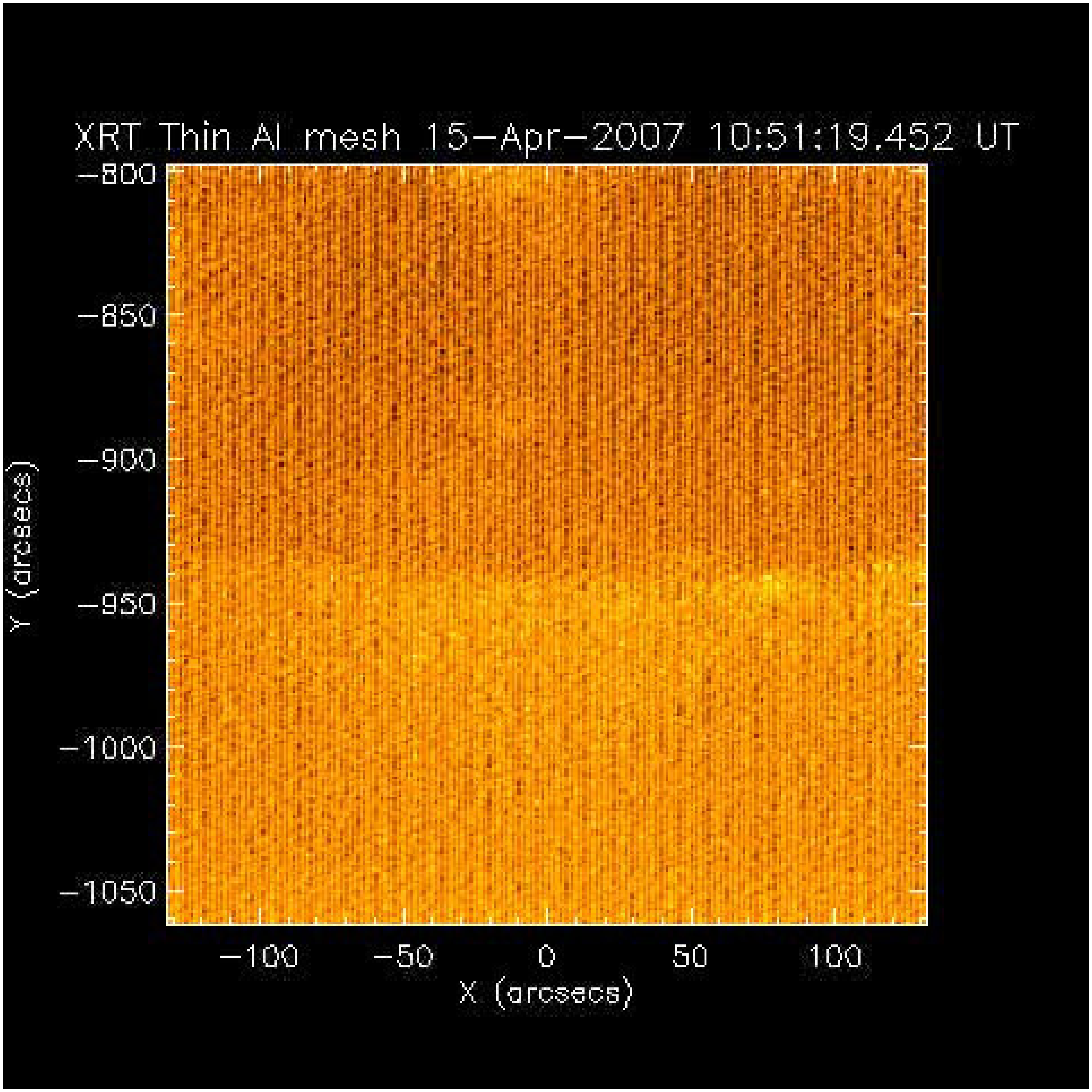
Girjesh Gupta

Indian Institute of Astrophysics

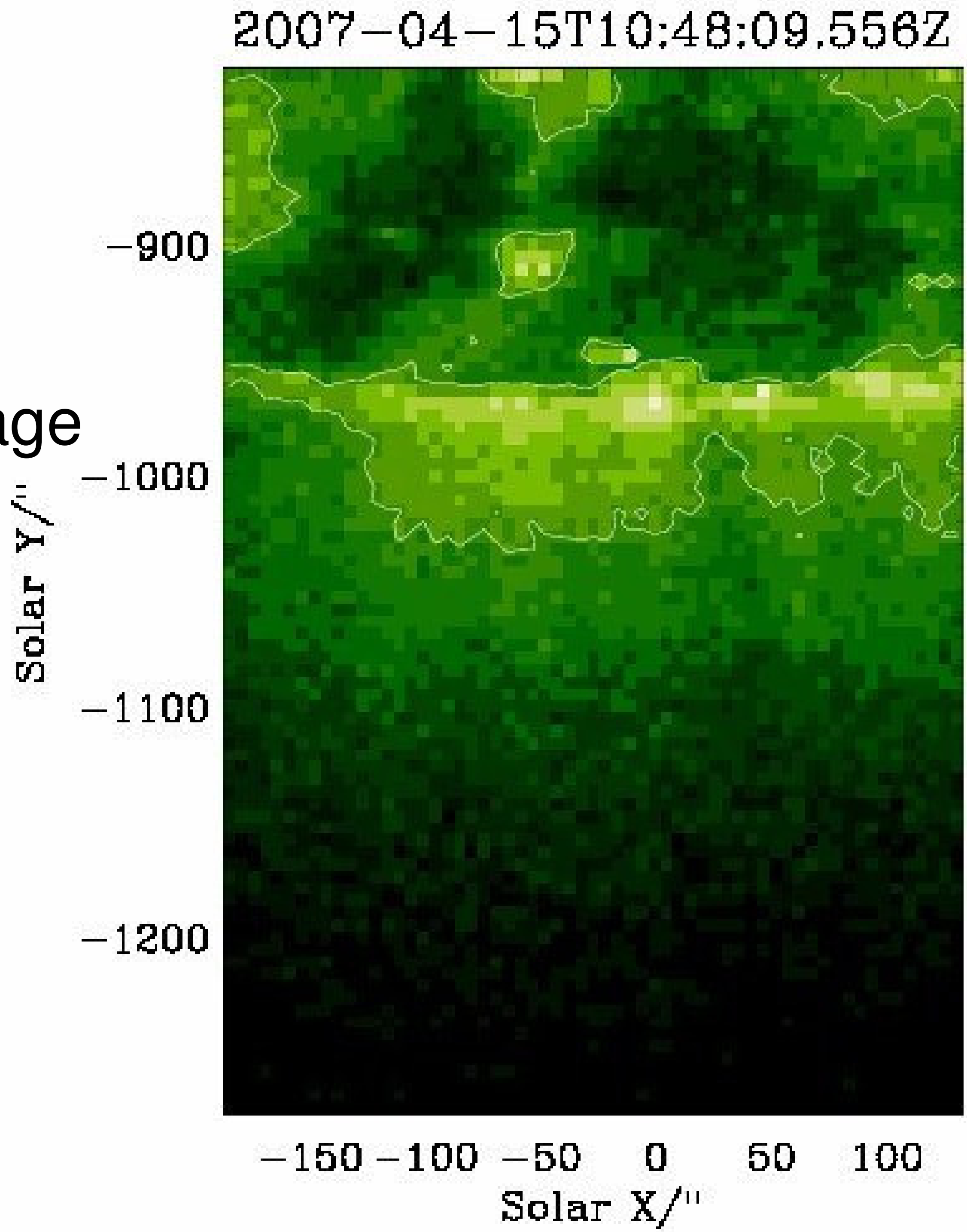
Luca Teriaca

(Max Planck Institute, Lindau, Germany)

Shinsuke Imada (NAO, Japan)

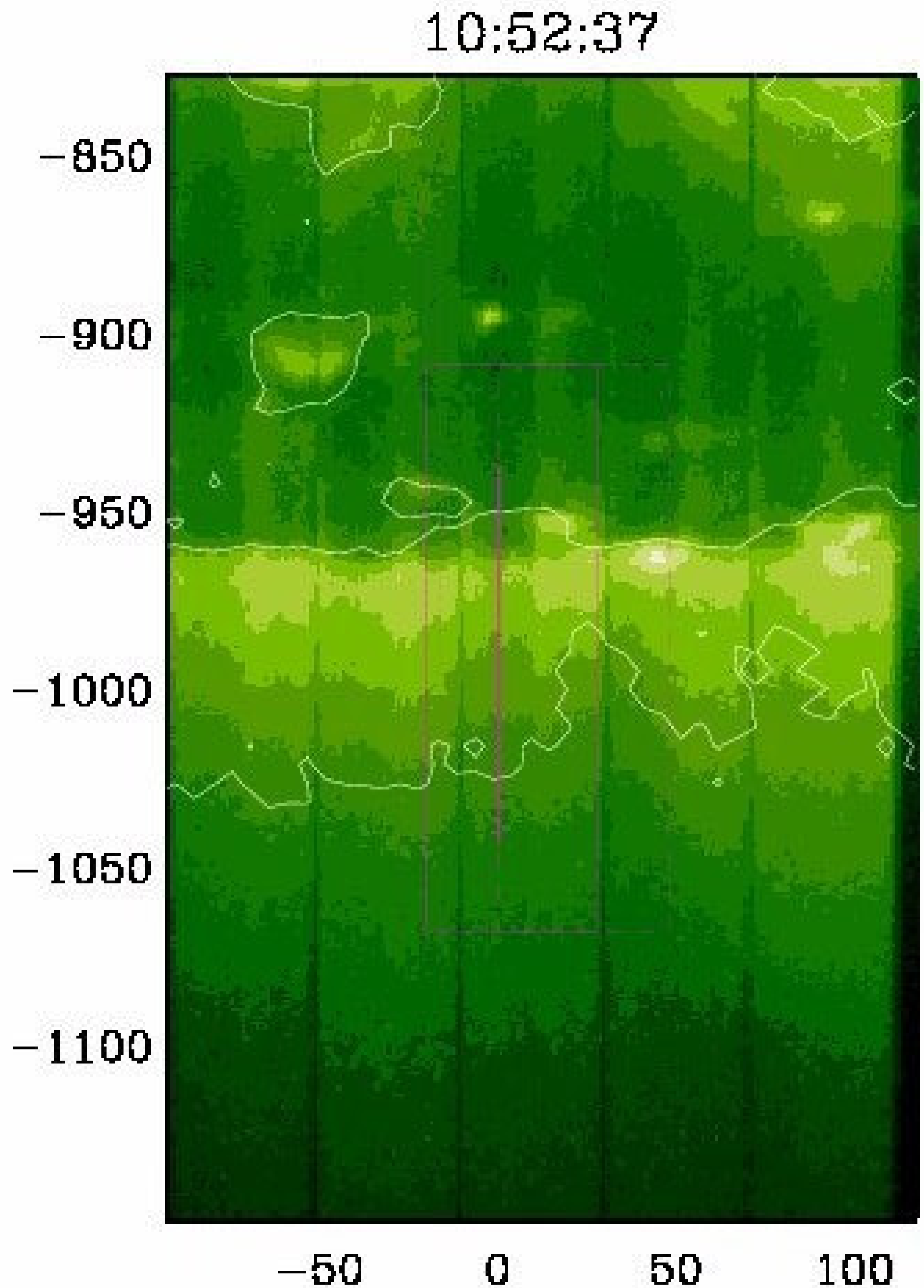

XRT Thin Al mesh 15-Apr-2007 10:51:19.452 UT
-800
-850
-900
-950
-1000
-1050
Y (arcsecs)
-100
-50
0
50
100
X (arcsecs)

EIT Image

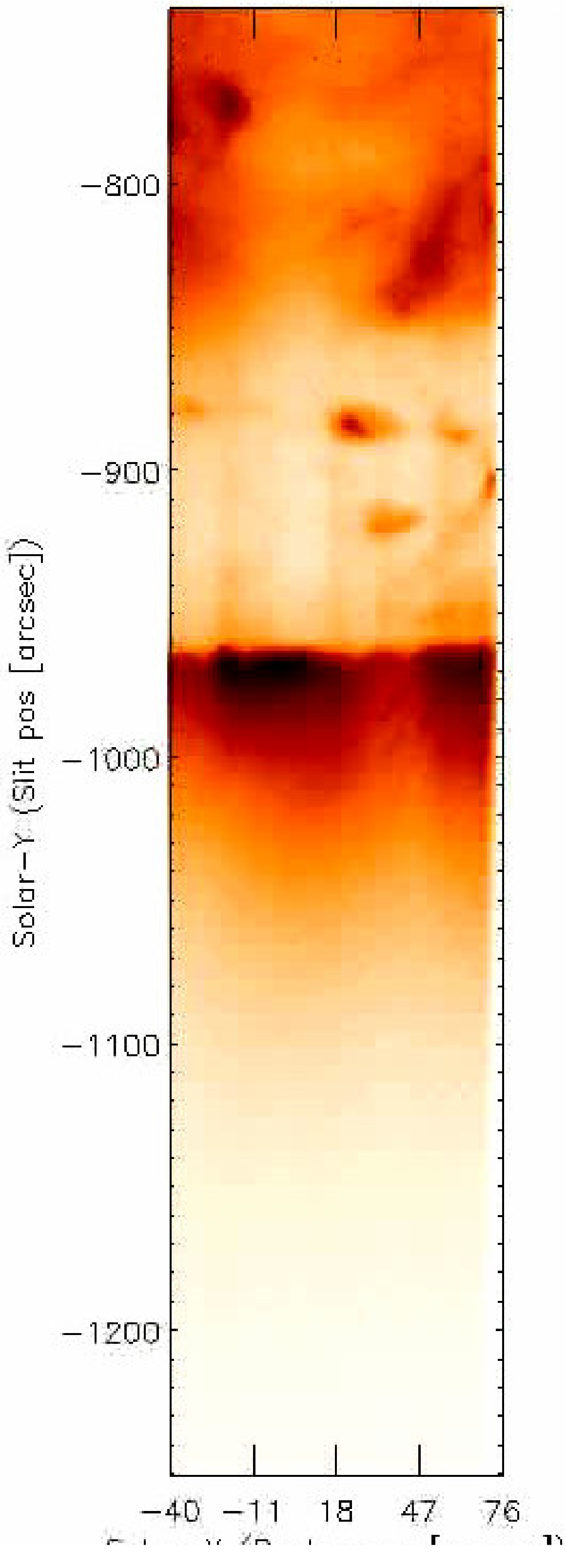


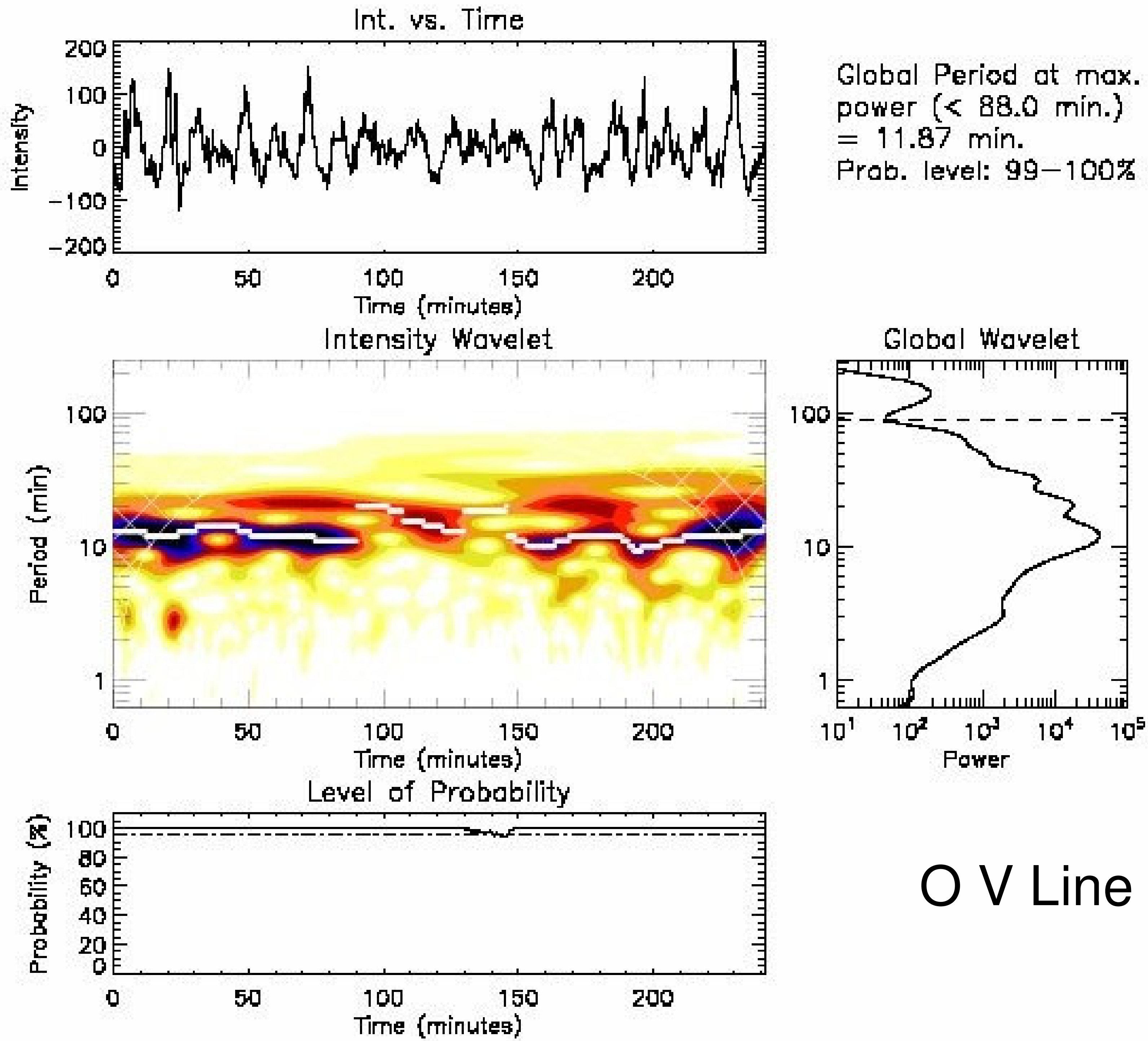
2007-04-15T10:48:09.556Z
-900
-1000
-1100
-1200
Solar Y/"
-150 -100 -50 0 50 100
Solar X/"

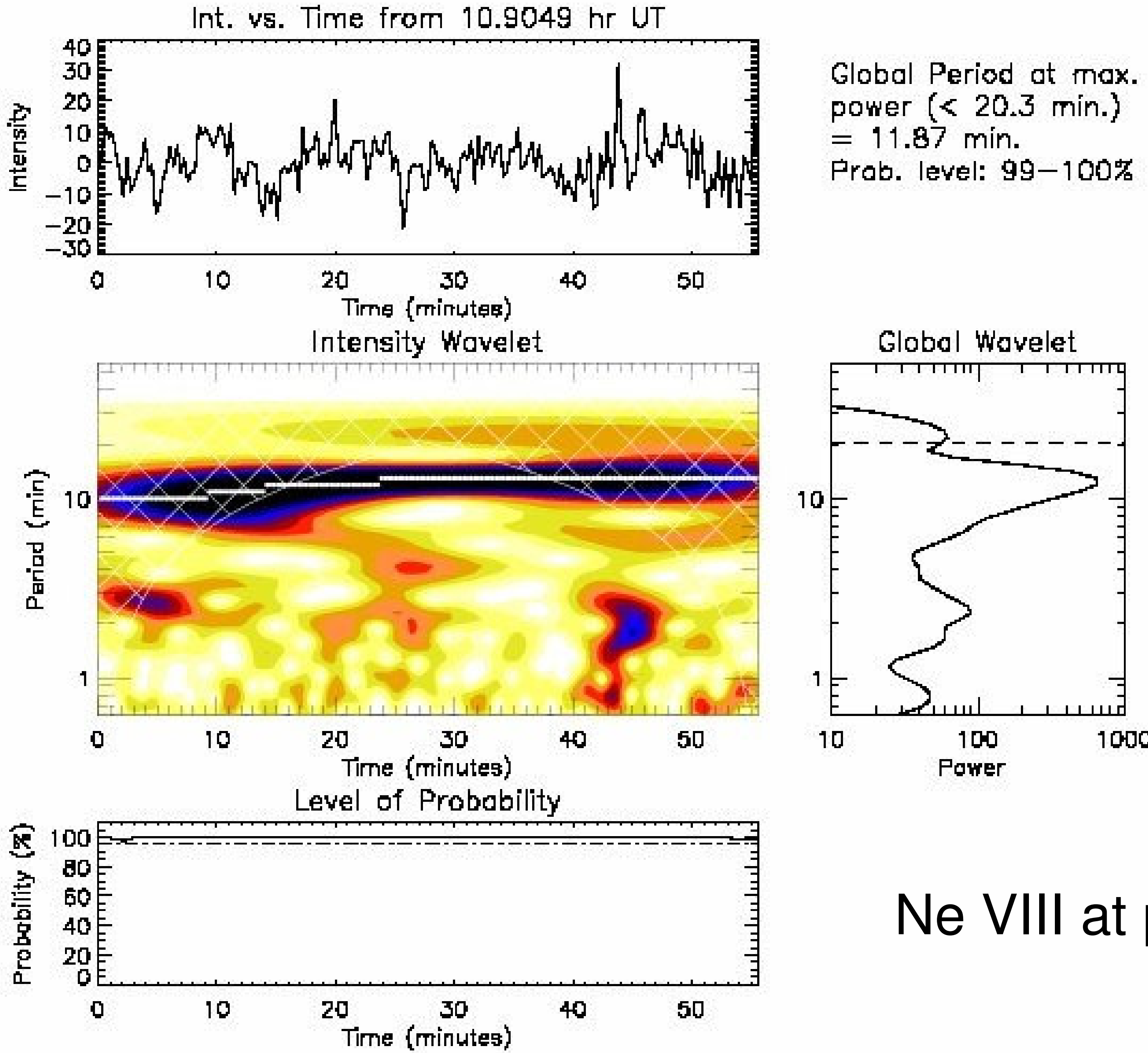
EIS Raster



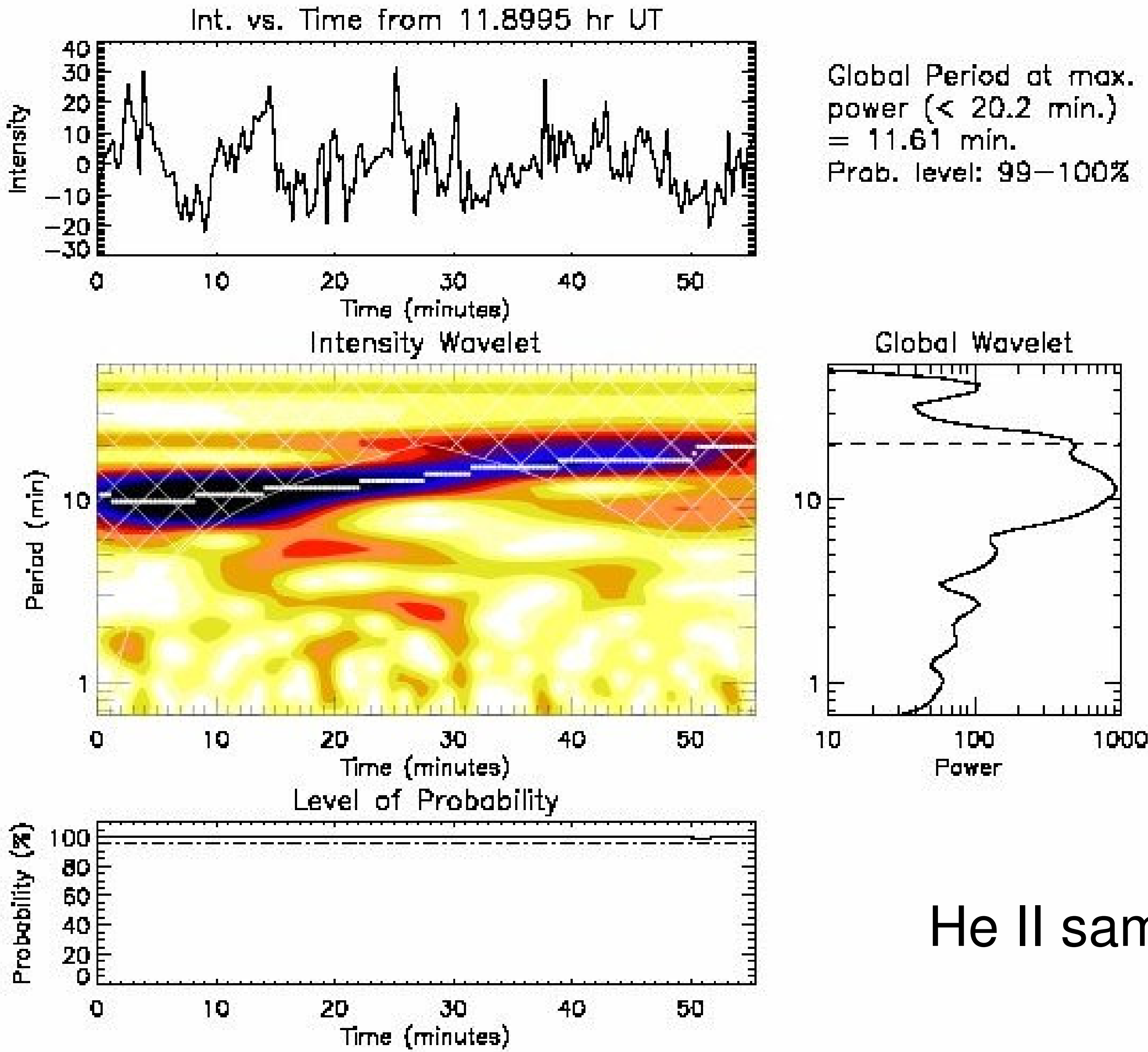
SLOT Movie
EIS




Int. vs. Time
Intensity
Time (minutes)
Global Period at max. power (< 88.0 min.) = 11.87 min.
Prob. level: 99−100%
Intensity Wavelet
Period (min)
Global Wavelet
Power
Level of Probability
Probability (%)
O V Line



Ne VIII at px 950



Int. vs. Time from 11.8995 hr UT
Intensity
Time (minutes)
Global Period at max.
power (< 20.2 min.)
= 11.61 min.
Prob. level: 99–100%
Intensity Wavelet
Period (min)
Global Wavelet
Power
Level of Probability
Probability (%)

He II same px

Conclusions:

Detected presence of oscillations and, hence, waves, in open field regions off-limb and in coronal holes. In Coronal Holes we find indications of preferred locations near loops and also at bright points, presumably the base of coronal funnels

We confirm the presence of upwardly propagating slow magnetoacoustic type waves (of the type needed to accelerate the fast solar wind)

Periodicity in the range of 10-15 mins as seen by other instruments

- *"Magnetoacoustic wave propagation in off-limb polar regions", A&A, 2006*
- *"A statistical study of wave propagation in coronal holes", A&A, 2007*