

Active Region Diagnostics with EIS

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Outline

- Velocity
- Line widths
- Temperature
- Density
- Fe XII photometry

Gaussian fitting

- Single Gaussians can be fit to EIS emission lines using routine eis_auto_fit.pro

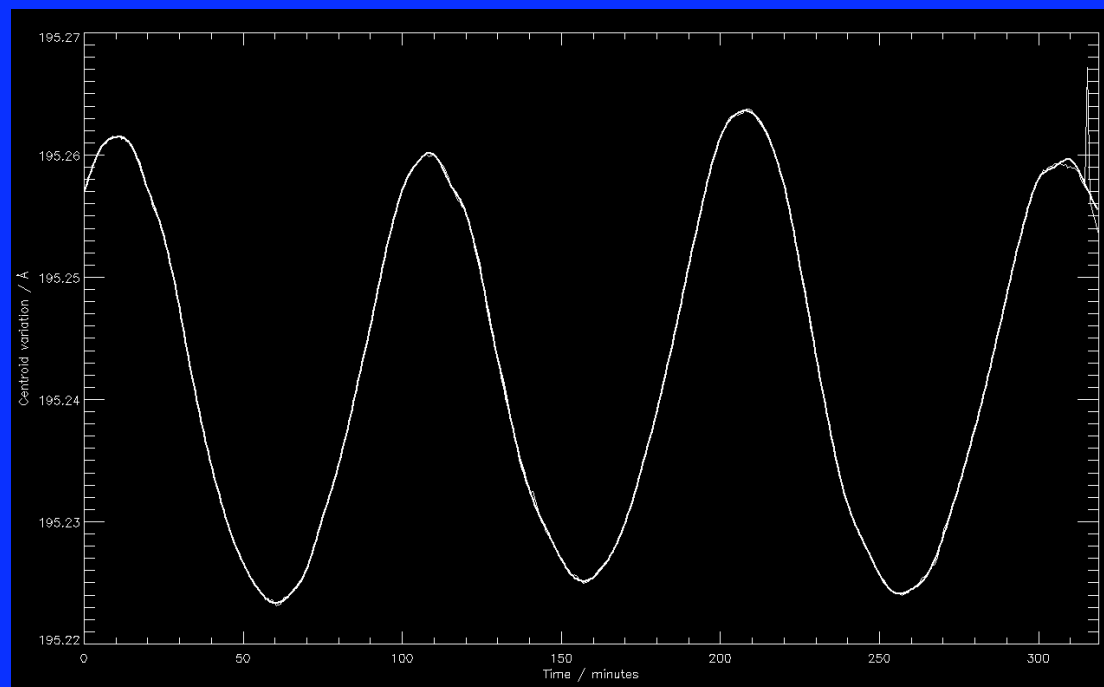
- Check out tutorial at:

http://solar.bnsc.rl.ac.uk/~young/solarb_eis/paris_tutorial/

- A multiple-Gaussian fitting is also available: eis_auto_fit_gen.pro

Velocity

- `eis_auto_fit` produces a velocity array, however needs to be corrected for instrumental effects:
 - tilt of EIS slit relative to CCD
 - orbital motion of lines on detector
- See tutorial for how to do this.

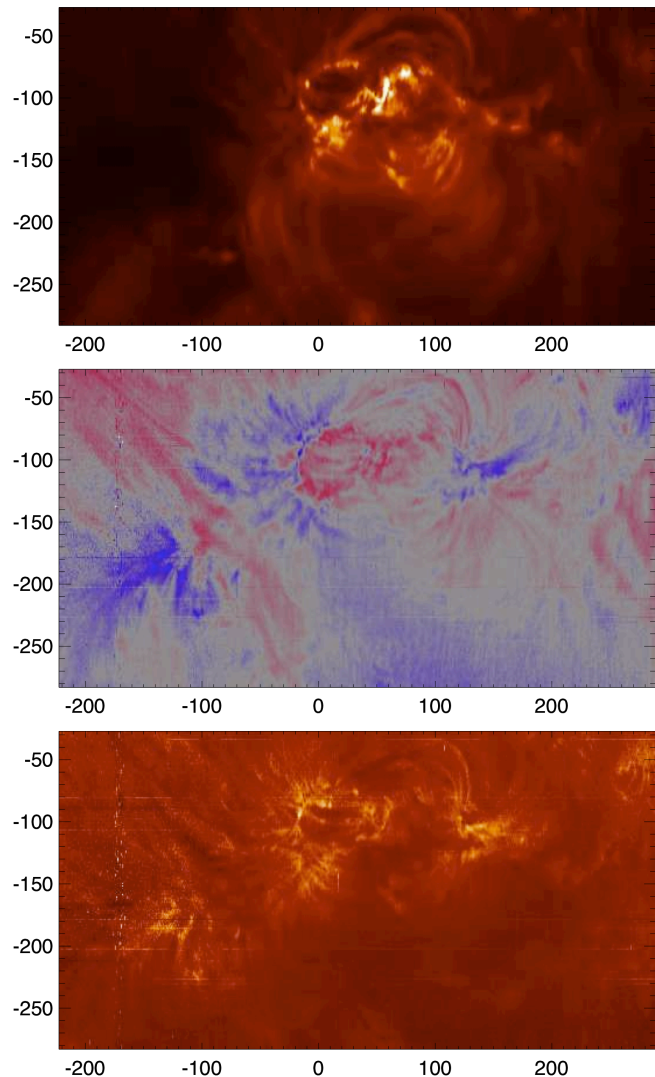


Line width

- eis_auto_fit produces line width array, but includes instrumental width
- Instrumental width:
 - around 55 mÅ
 - varies along slit by 2-3 mÅ
- No software exists for correcting instrumental width

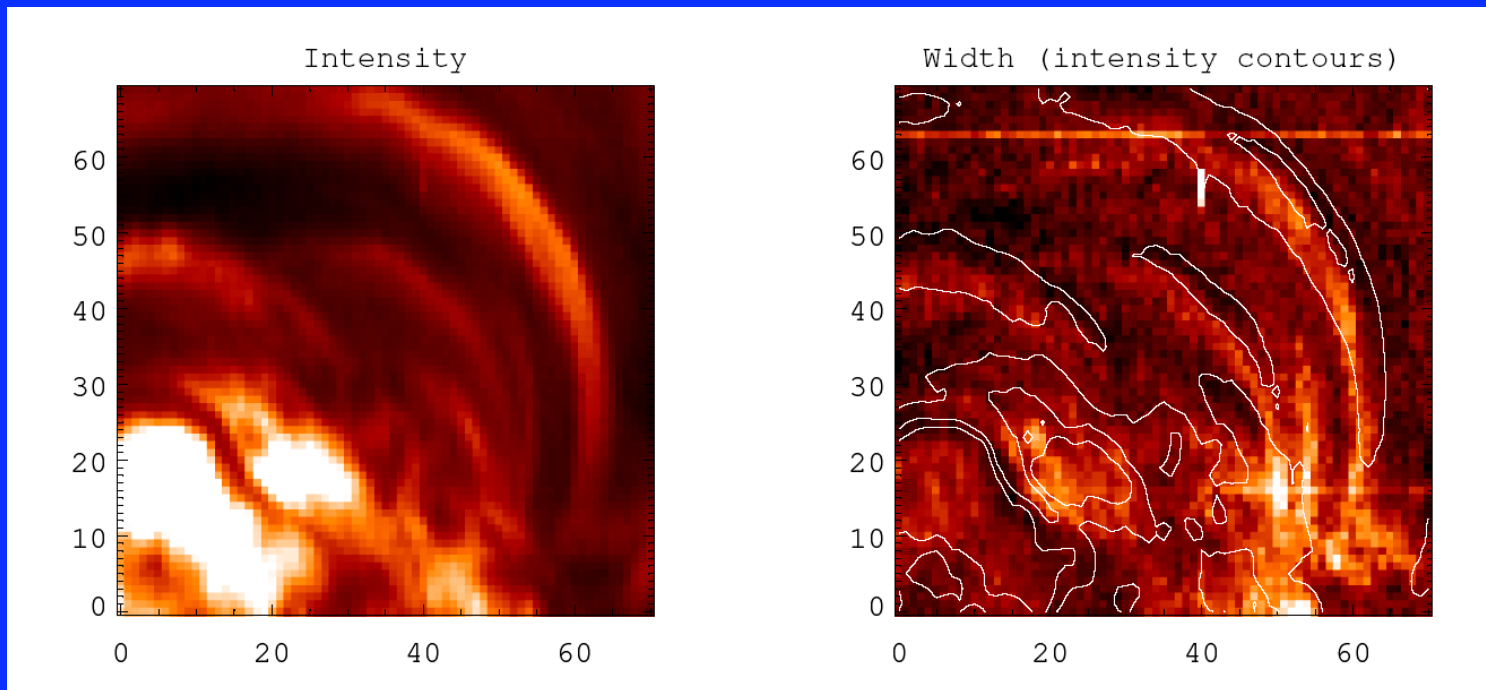
Active region maps

- Most striking feature of AR velocity and line width maps are footpoint regions showing blueshifts and large line widths
 - see Del Zanna (2008, A&A), Hara et al. (2008, ApJ), Doschek et al. (2008, ApJ)

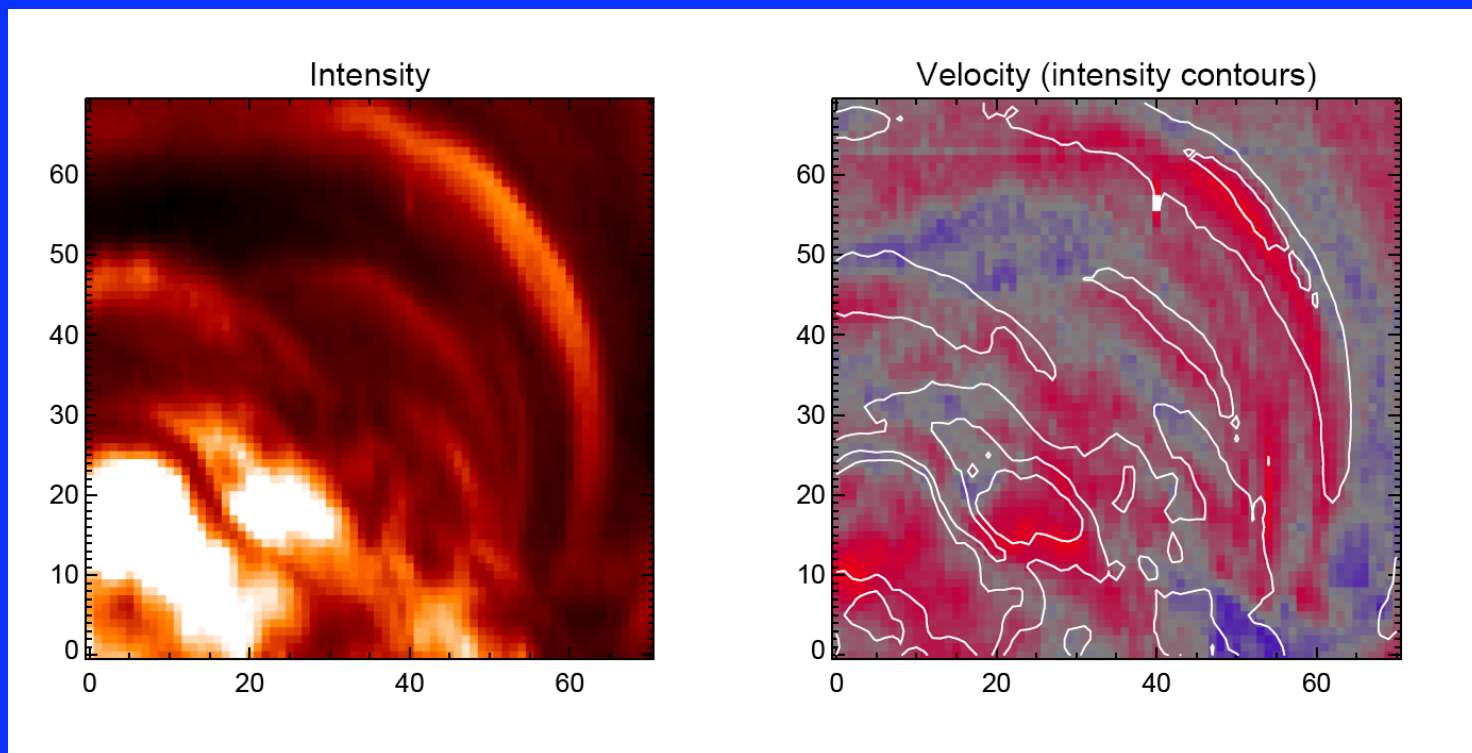


Loops

- Loops are seen in velocity and line width maps, but often appear to be different to 'intensity loops'
- see Doschek et al. (2007, ApJL)



Loops

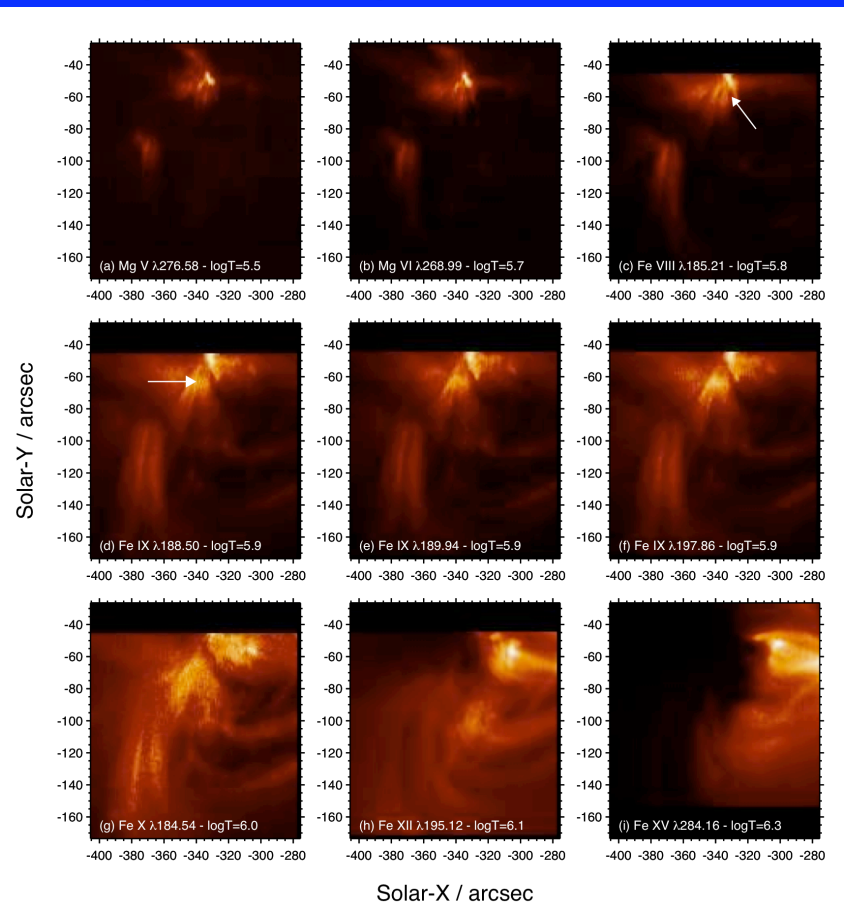


Temperature diagnostics

- Temperature is diagnosed through observing different ionization stages on an element
- Most useful element is iron
- For coronal loop work, we have complete range from stage VII ($\log T=5.6$) to stage XVII ($\log T=6.5$)

New Fe IX lines

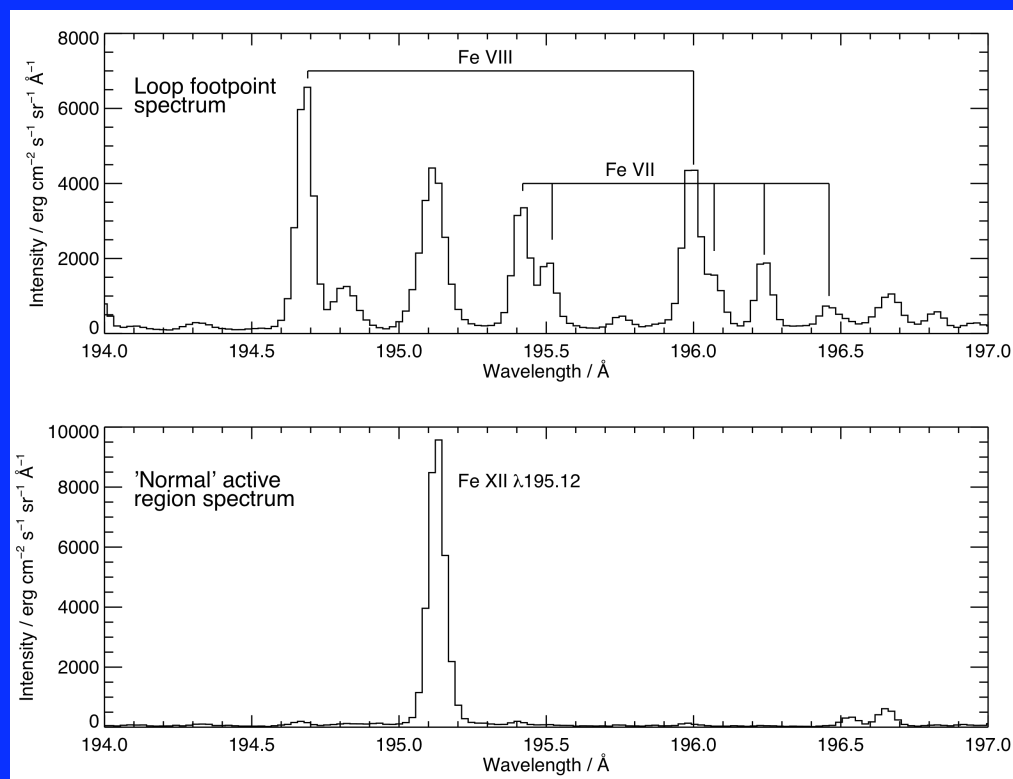
- 171 is not scientifically useful for EIS
- New lines have recently been identified (Young, arXiv:0810.5028)
- Most useful line is at 197.86 Å (unblended)



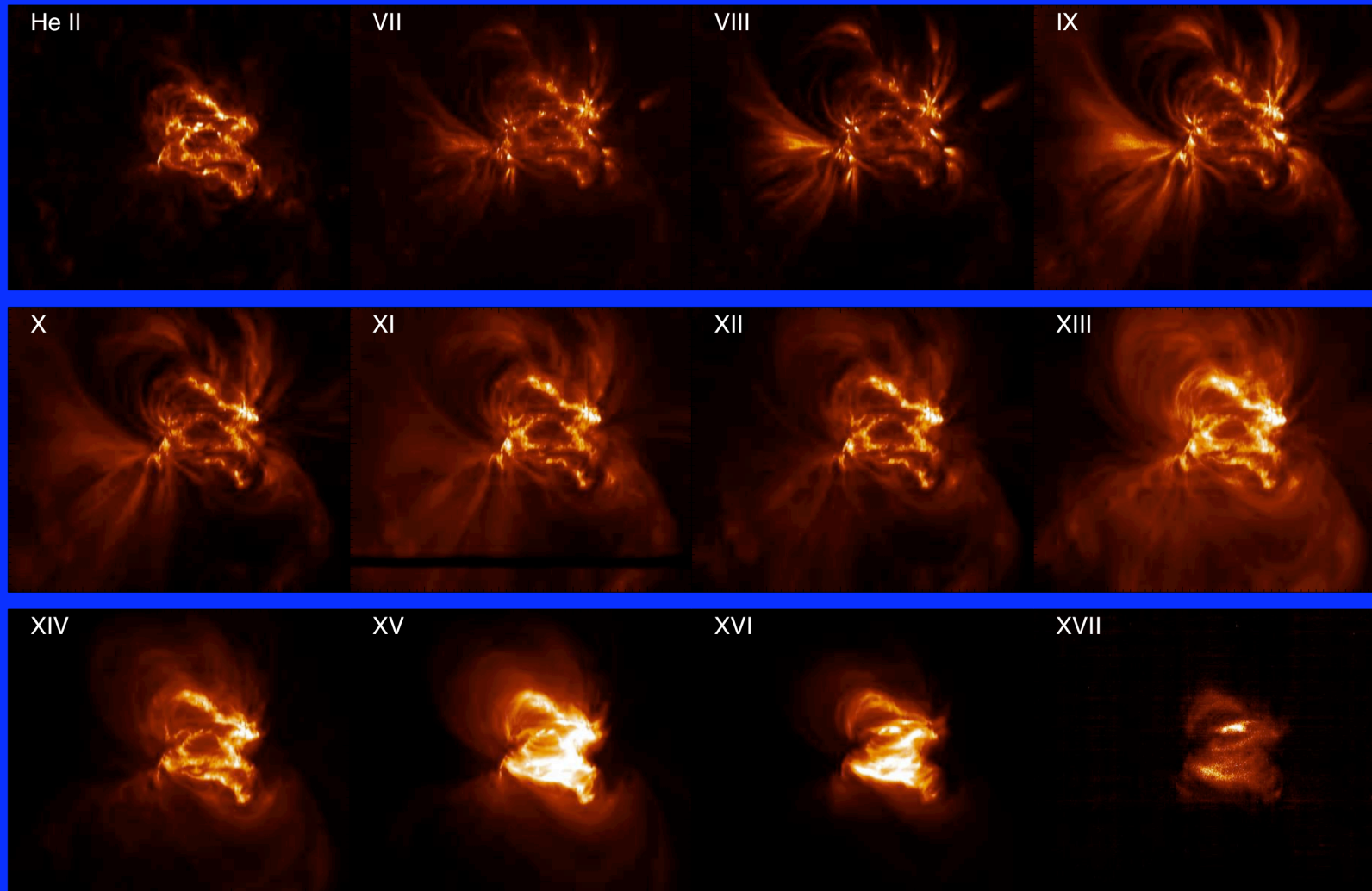
Young, arXiv:0810.5028

Fe VII – a ‘new’ ion for EIS

- A number of Fe VII lines are seen in EIS spectra
- Atomic data have only become available recently (Witthoeft & Badnell 2008)
- These allow Fe VII to be used in DEM analysis



Active region seen in 11 iron ions



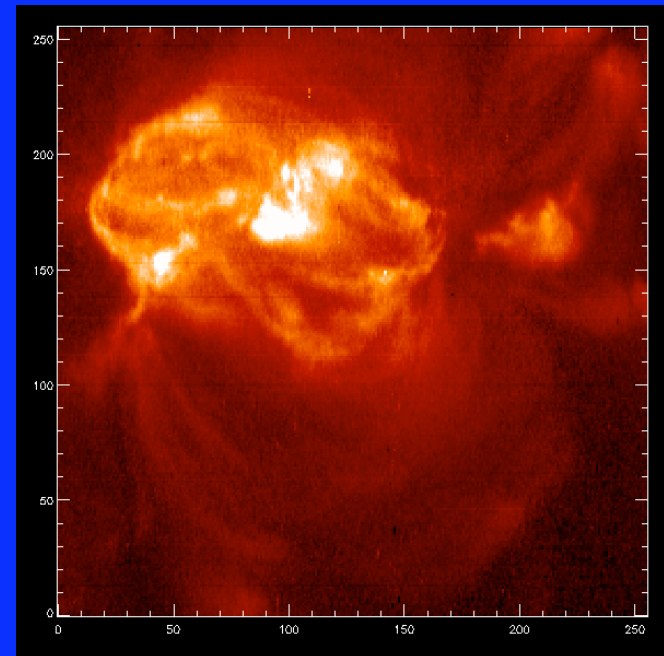
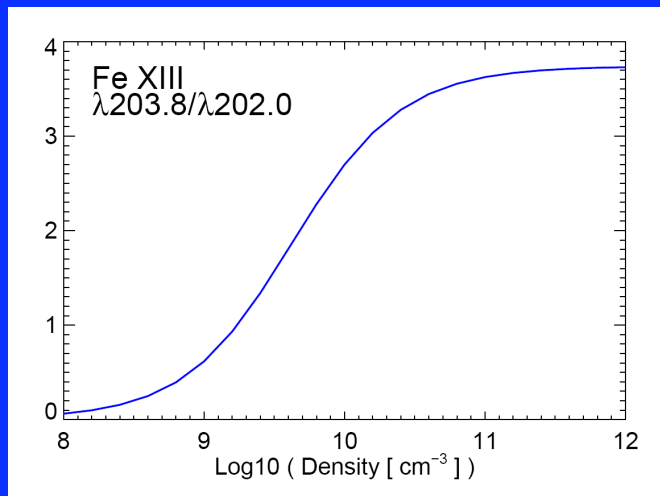
Hinode / EIS

Solar 24, Dec 2008

Dr Peter Young, NRL/GMU

Density diagnostics

- Certain emission lines from particular ions have ratios that are sensitive to the plasma density
- EIS is the first solar UV instrument to *routinely* allow high precision density measurements
 - high effective area
 - access to best coronal density diagnostics

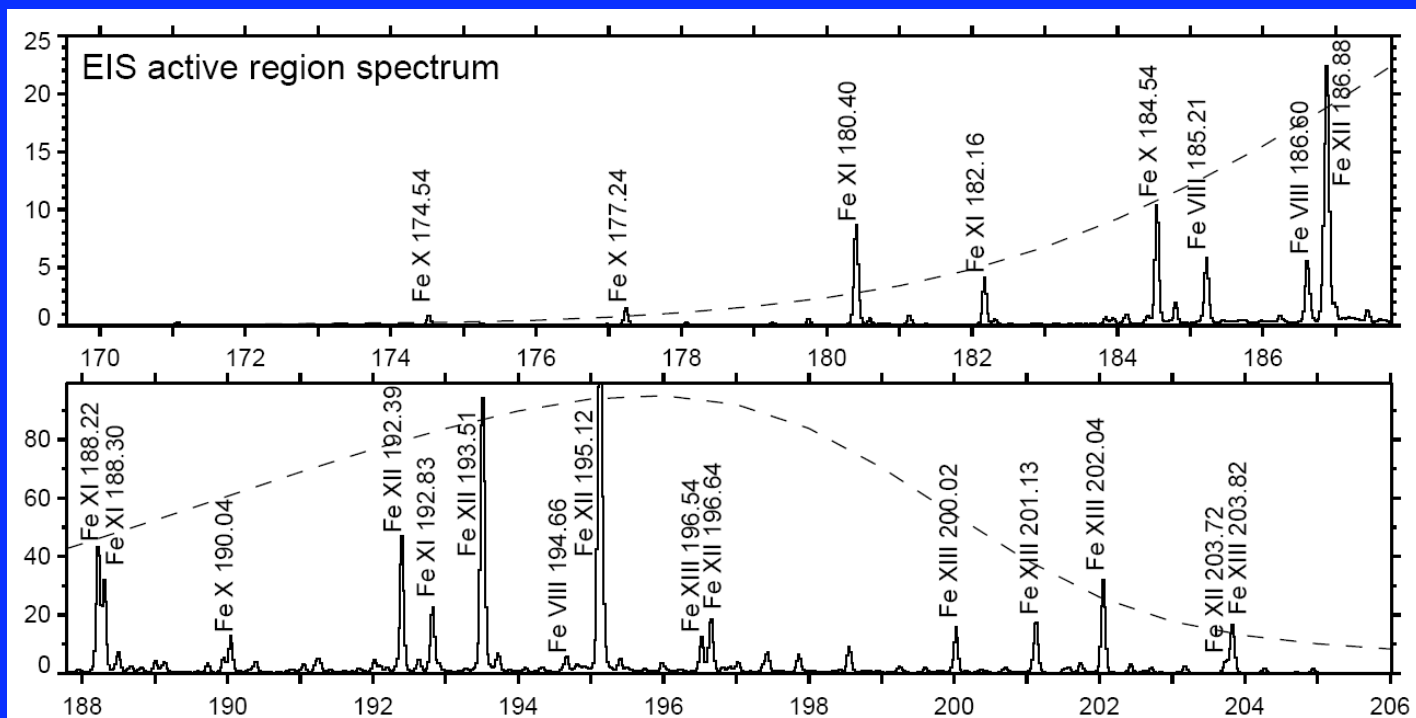


Most useful EIS density diagnostics

- Fe XII & Fe XIII
 - column depths and filling factors
- Mg VII – a cool loop diagnostic

Fe XII and Fe XIII density diagnostics

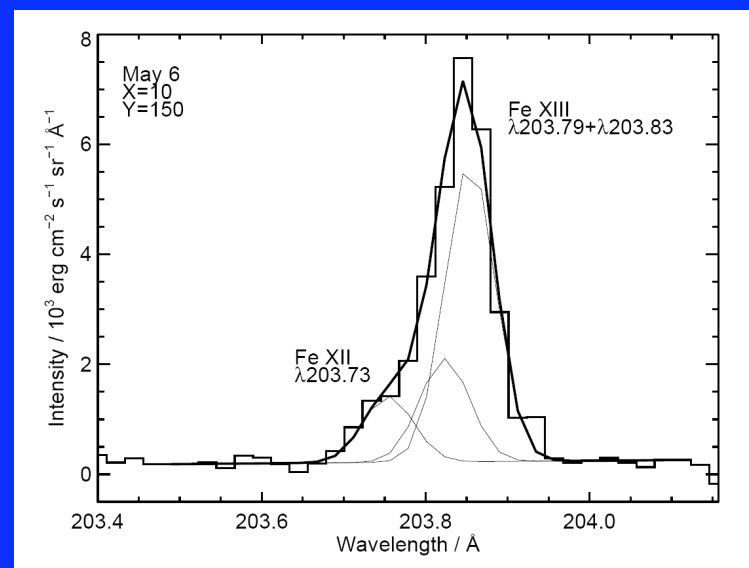
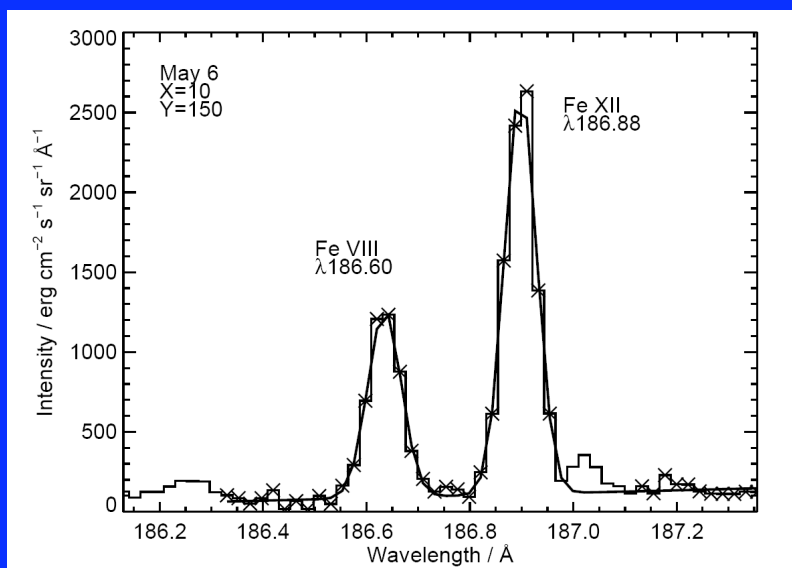
Ion	Ratios
Fe XII (logT=6.1)	$\lambda 186.88 / \lambda 195.12$ $\lambda 196.64 / \lambda 195.12$
Fe XIII (logT=6.2)	$\lambda 196.54 / \lambda 202.04$ $\lambda 203.82 / \lambda 202.04$



Young et al., 2007, PASJ
Hinode issue

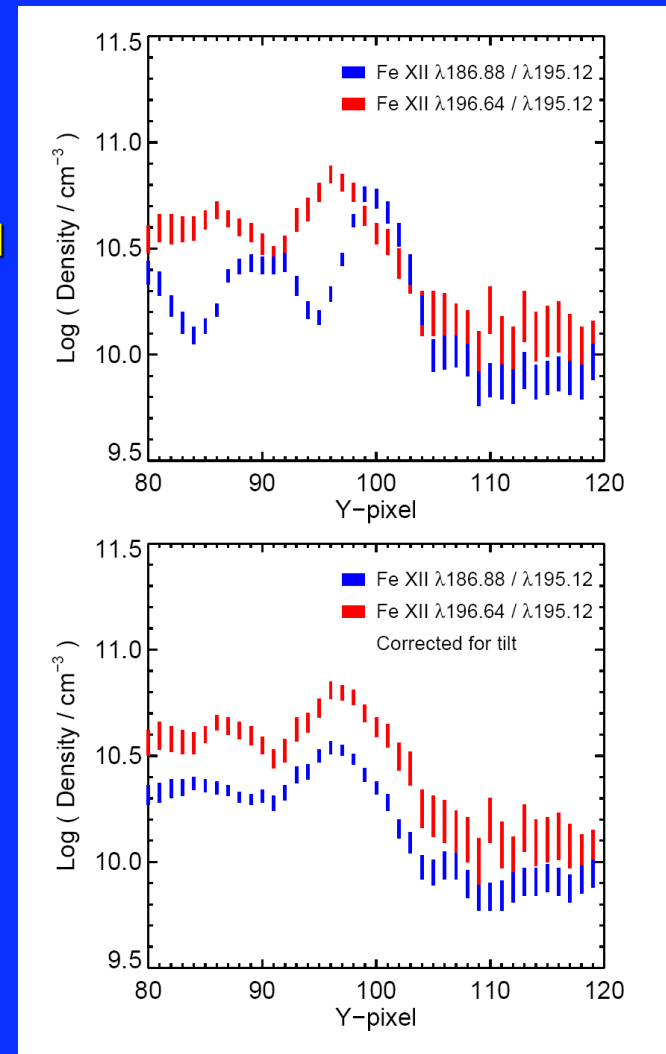
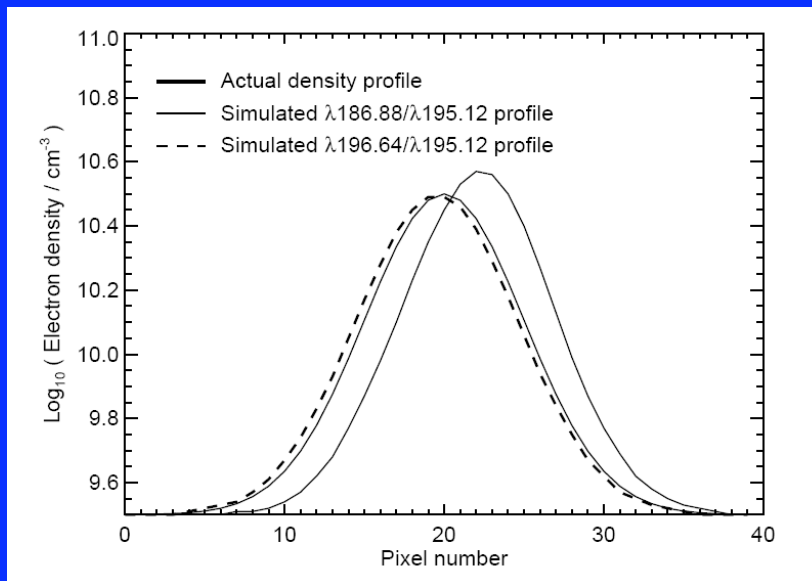
Emission line fitting

- Need robust method for automatic fitting
- Care has to be taken with blends

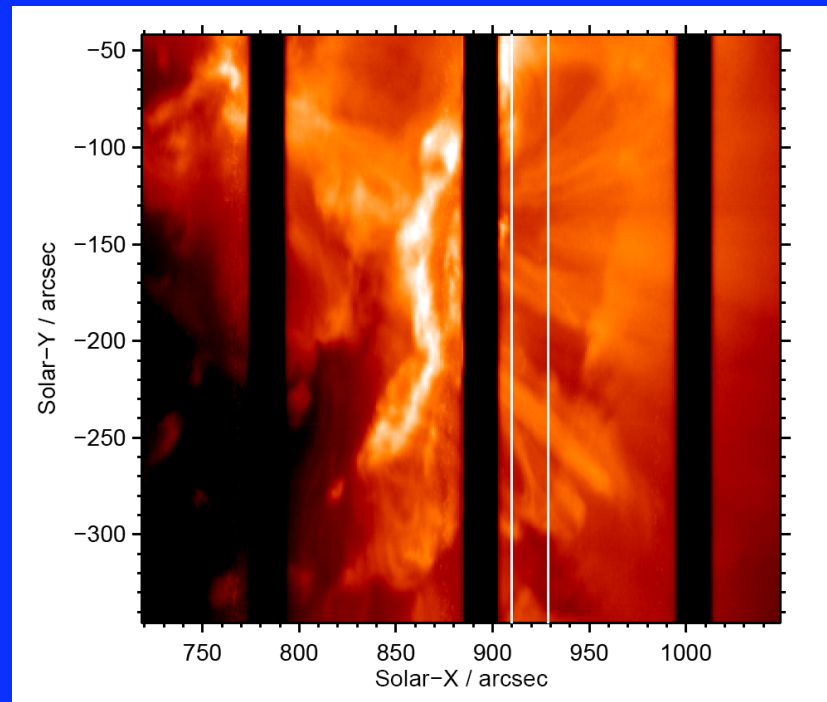


Spectral tilt

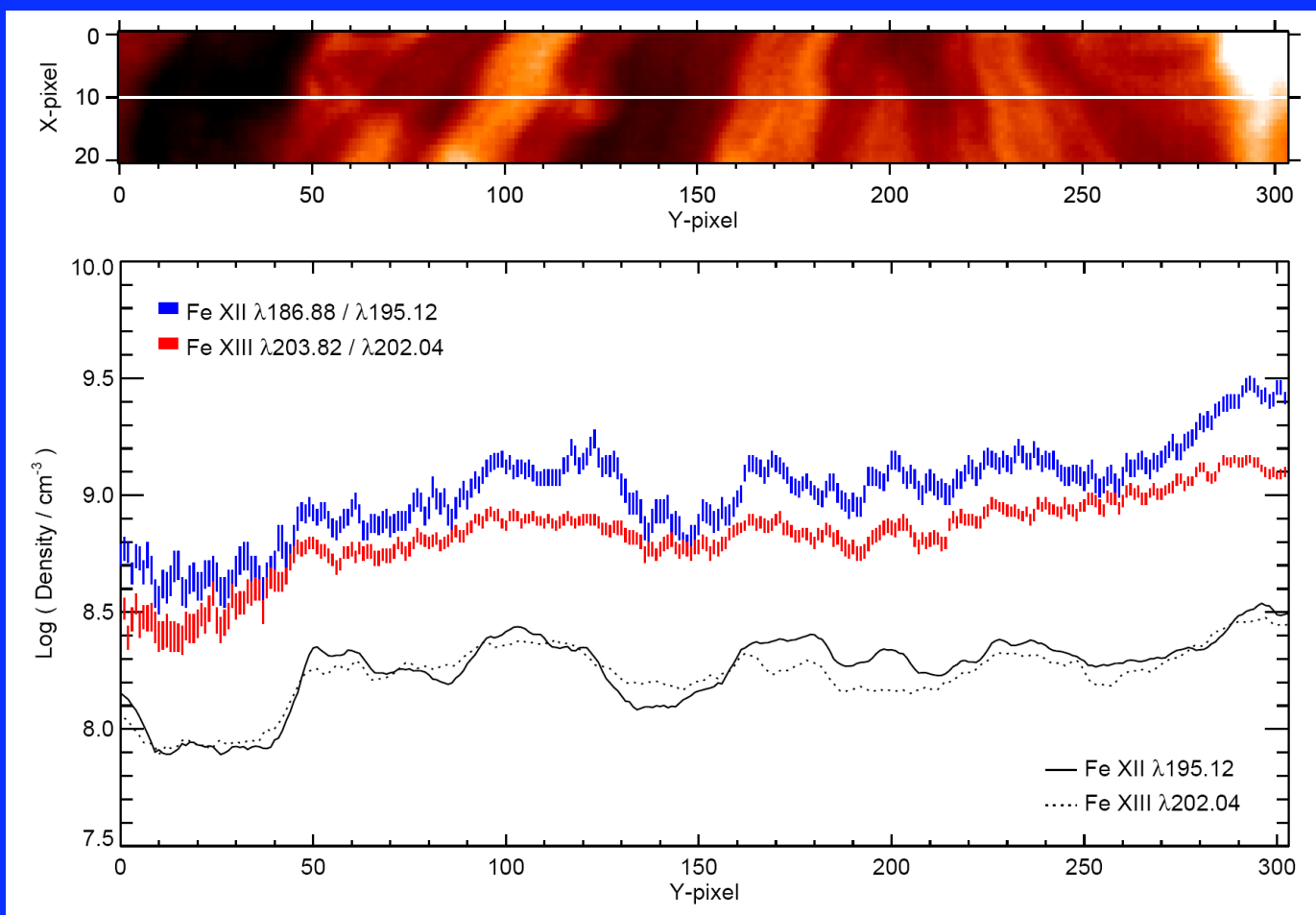
- Lines at shorter wavelengths are slightly higher on CCD than those at longer wavelengths
- Only 0.65 pixels for Fe XII 186.88 and 195.12, *but* has significant effect on derived densities



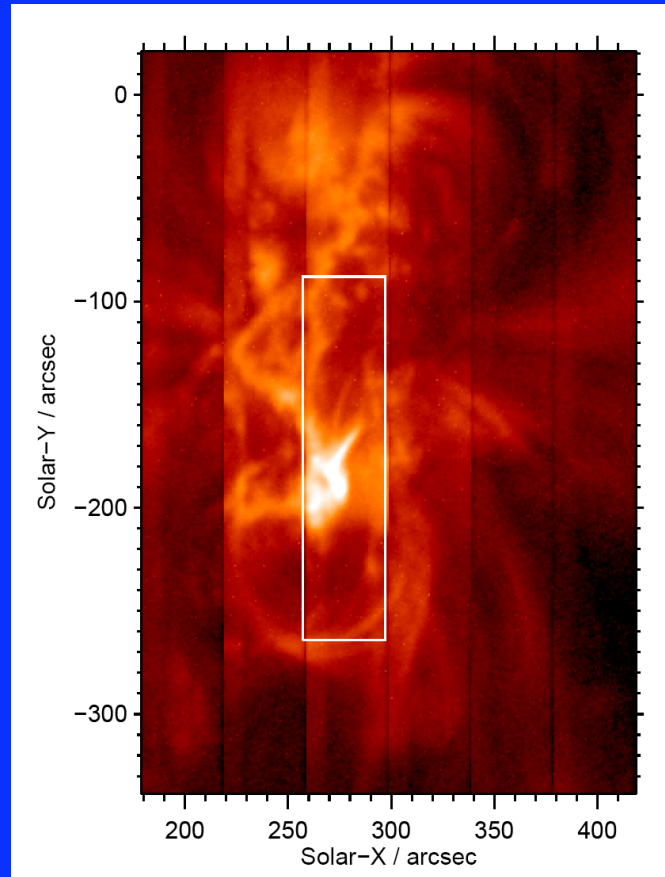
May 6 – low density data-set



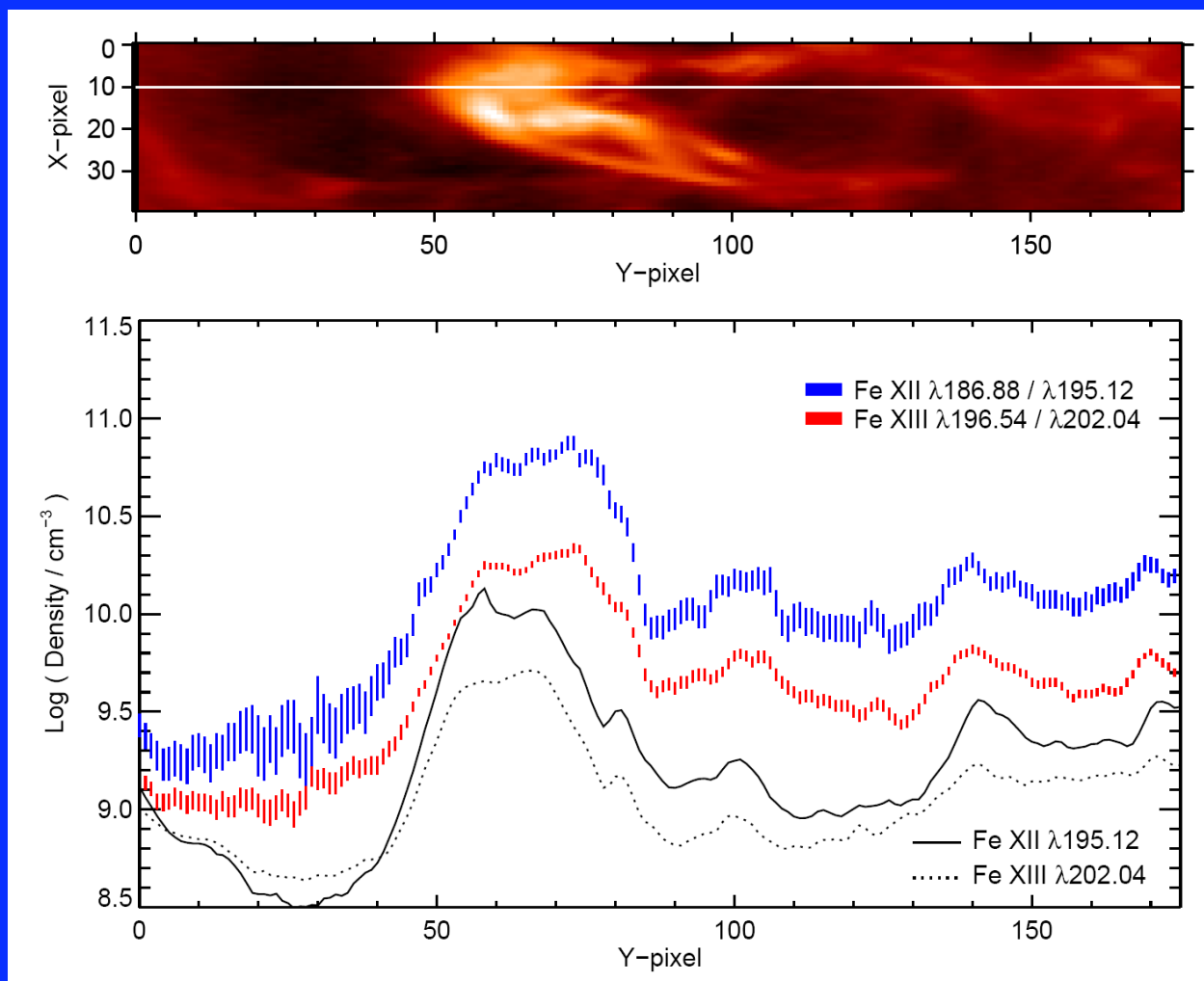
May 6 – Fe XII-XIII comparison



May 3 – high density data-set



May 3 – Fe XII-XIII comparison

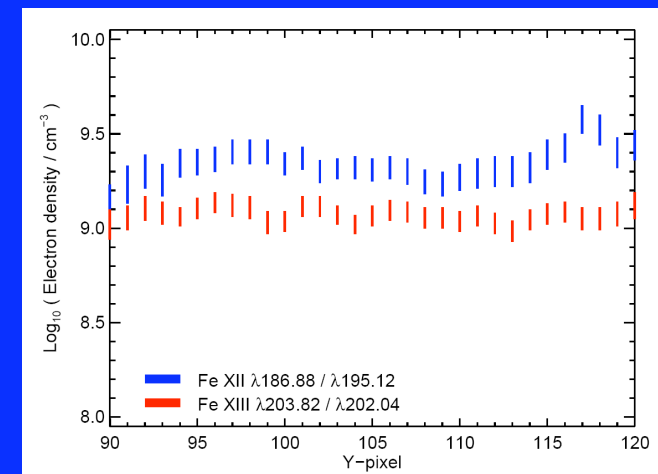
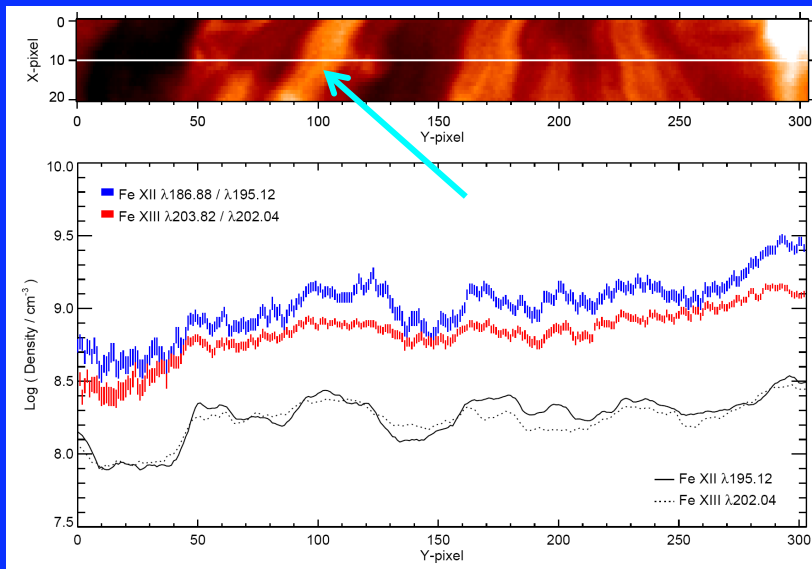


Sources of discrepancies

- Fe XII, Fe XIII differences could be due to
 - atomic data errors
 - ions formed at different temperatures
 - multiple density components along of sight

Sources of discrepancies

- Can background subtraction resolve discrepancies?



- No! Difference between XII and XIII remains the same after subtraction

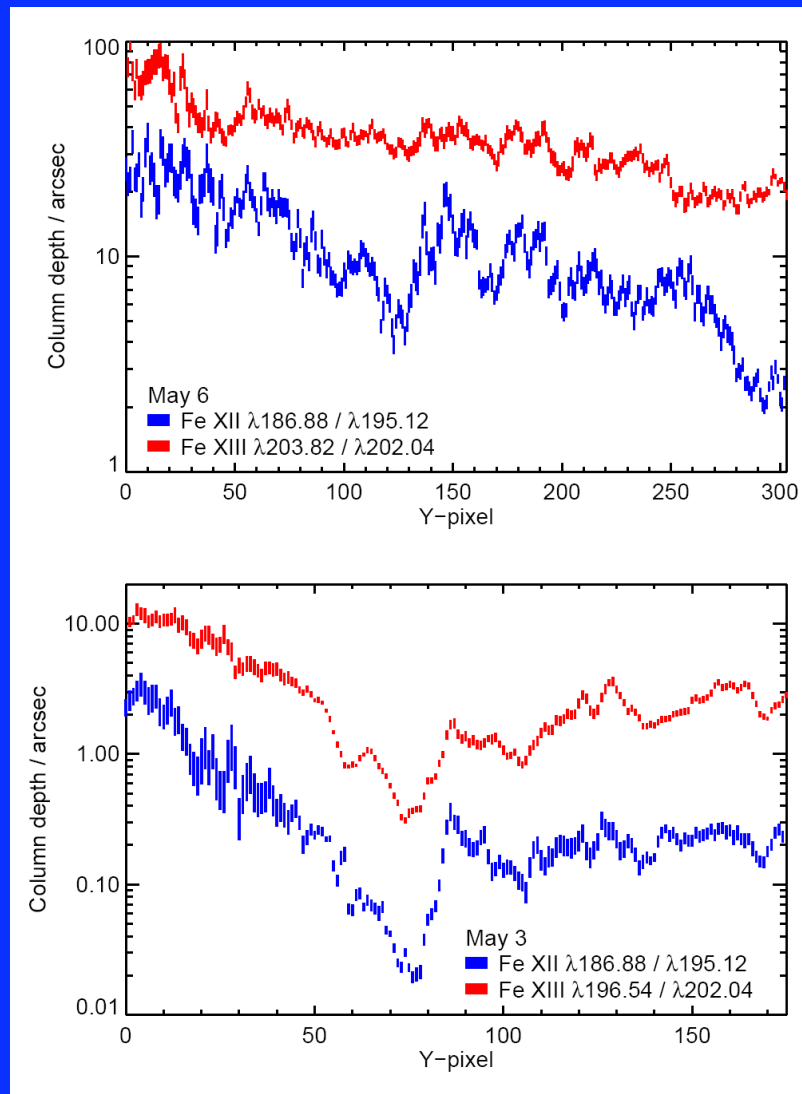
Column depths

- Can be estimated from the measured line intensities (I_{ij}) and derived densities (N_e)

$$4\pi I_{ij} = 0.83 E_{ij} A(\text{Fe}) n_j A_{ji} F(T) N_e h$$

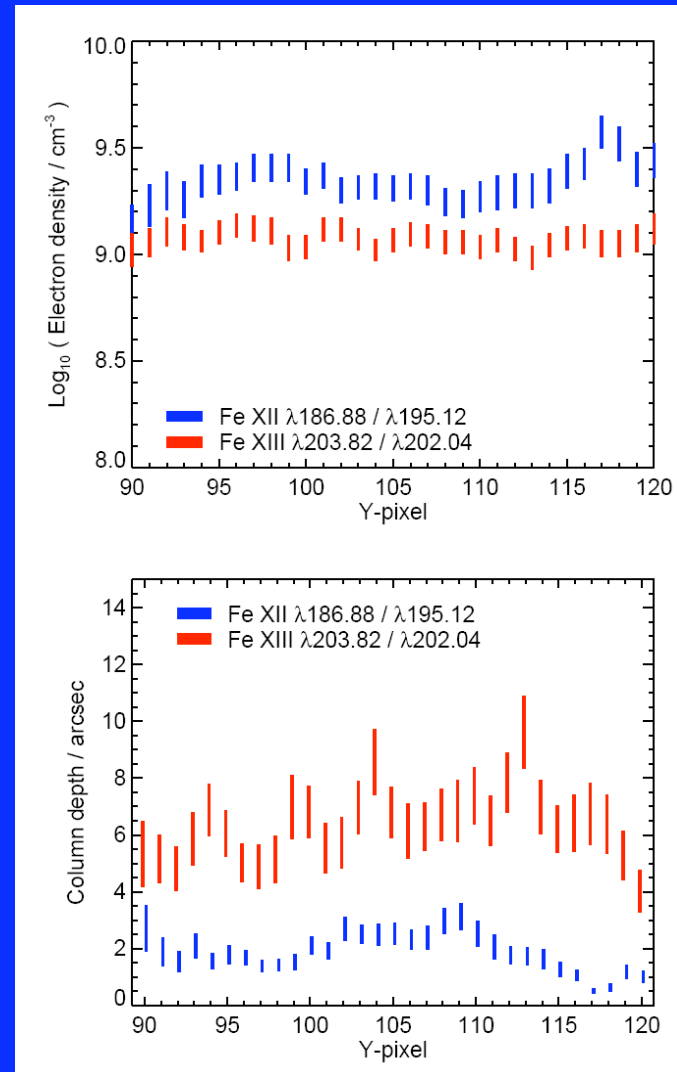
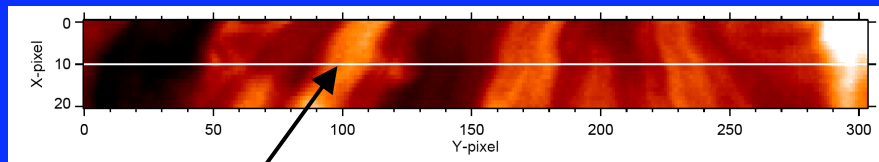
- Quantities
 - $F(T)$, ionization fraction
 - $A(\text{Fe})$, abundance of iron
 - n_j , population of upper level
 - A_{ji} , radiative decay rate
- Assumptions
 - isothermal plasma
 - coronal abundances

Column depths



Column depths for loop bundle

- Loop bundle in May 6 data-set has cross-width size of 10-15 arcsec
- How does this compare with column depths from Fe XII and Fe XIII?
- Need to subtract background level from density diagnostic lines.



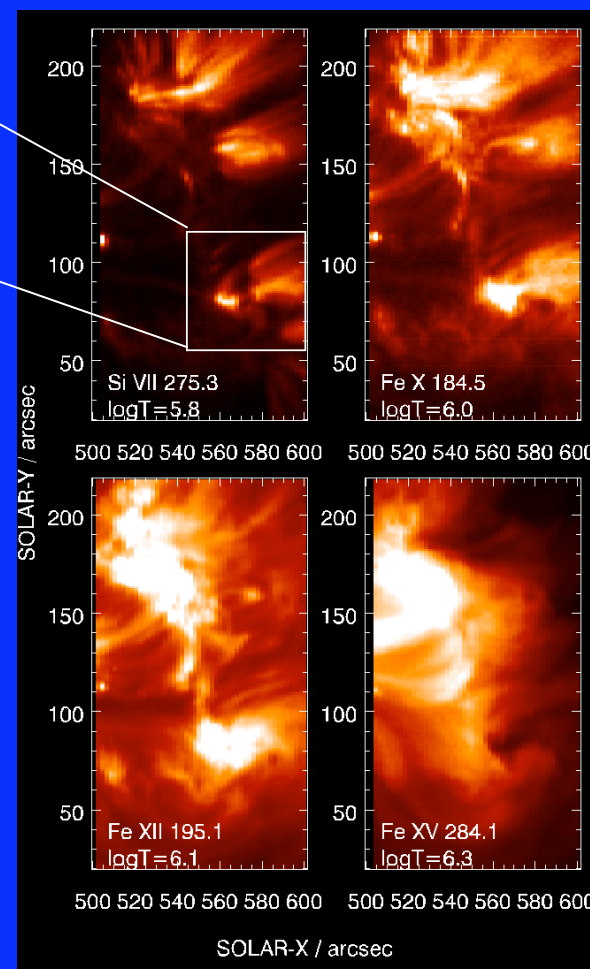
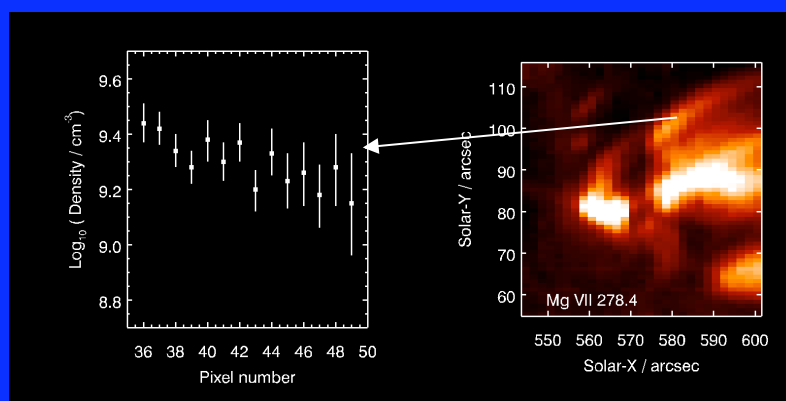
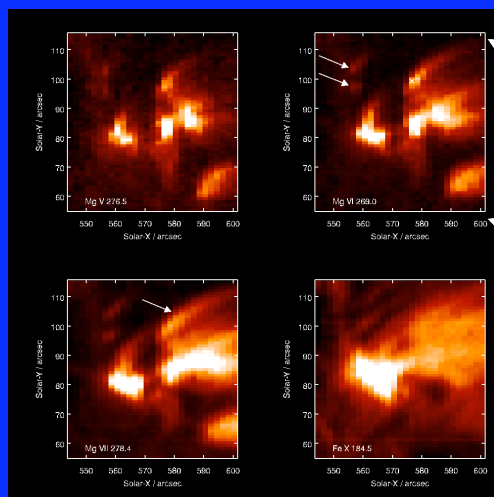
Fe XII and Fe XIII

- High precision of EIS density measurements can not be exploited until discrepancies between Fe XII and Fe XIII are understood
1. Atomic data in CHIANTI needs to be re-evaluated
 2. Comparisons with Si X (which also has a density diagnostic) in a range of conditions
 3. Study of column depths for different structures

Mg VII density diagnostic

- Lines formed at $\log T=5.8$ so very useful for cool, TRACE 171 loops

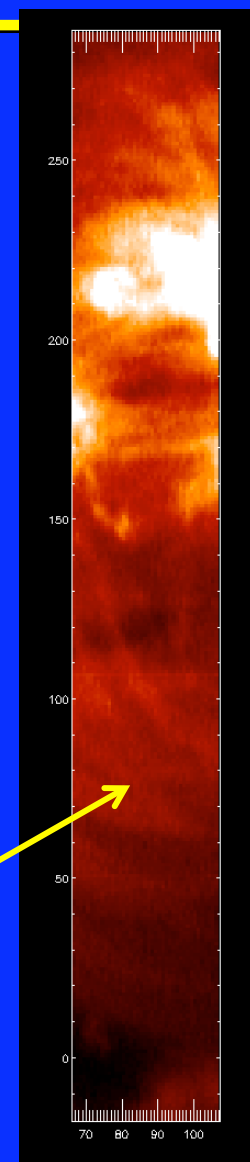
Density in loop footpoints
Young et al. (2007, PASJ)



Fe XII 195 photometry

- High sensitivity of EIS coupled with spectrally-resolved lines gives excellent possibilities for measuring small-scale fluctuations in loops
- Example: 19-Jan-2007, 3.5 hour sit-and-stare

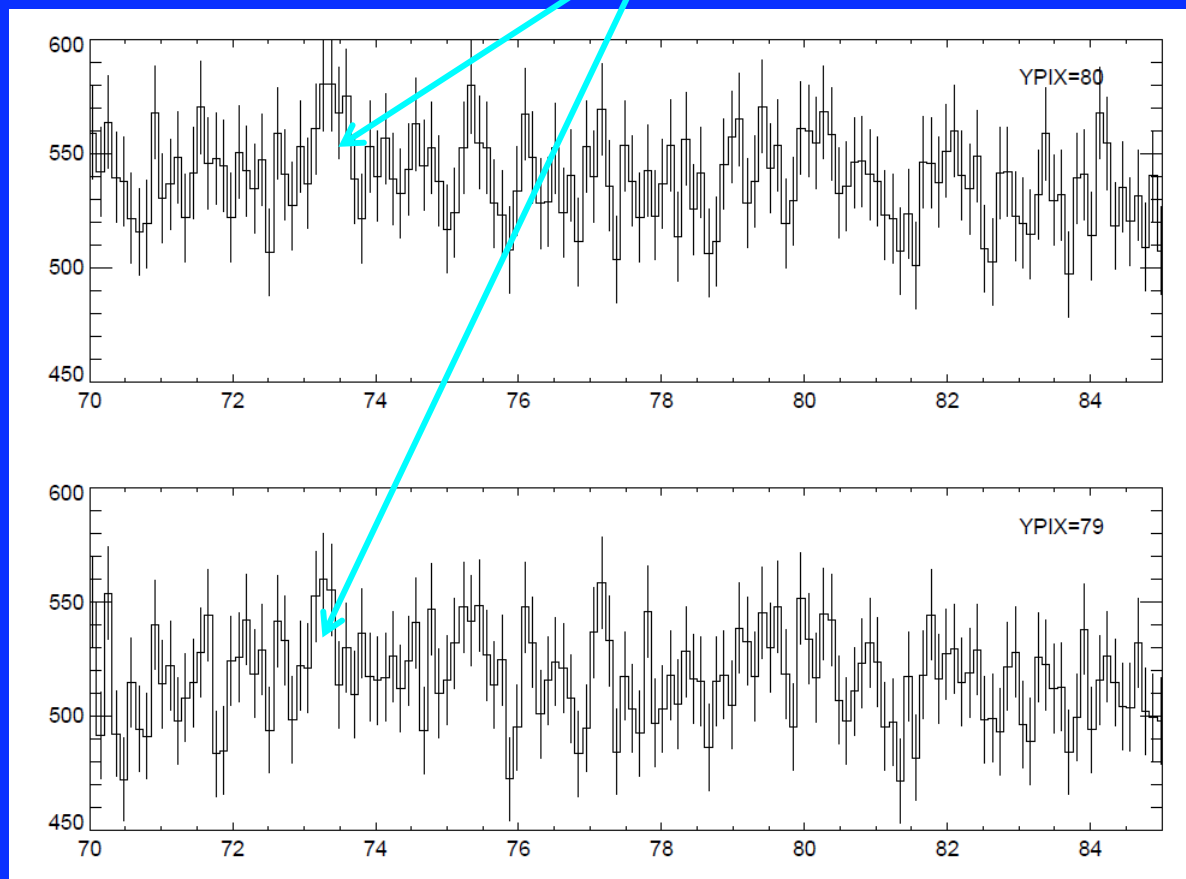
Quiescent loops



Fe XII 195 photometry

- 5 second exposures

Statistically significant 5 % intensity increase
seen in neighboring Y-pixels



List of EIS studies still to be done

- What is the relation of 'intensity', 'velocity' and 'line width' loops?
 - dynamic loops seem to be dark
- Can EIS see oscillations in TRACE 171 loops?
 - use slot to reproduce TRACE results
 - sit-and-stare to study velocity and density
- How do temperature and density vary along loops?
- Nanoflare distribution using Fe XII 195