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
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)
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
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

<table>
<thead>
<tr>
<th>Ion</th>
<th>Ratios</th>
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<tbody>
<tr>
<td>Fe XII</td>
<td>(\lambda_{186.88} / \lambda_{195.12})</td>
</tr>
<tr>
<td>(logT=6.1)</td>
<td>(\lambda_{186.64} / \lambda_{195.12})</td>
</tr>
<tr>
<td>Fe XIII</td>
<td>(\lambda_{196.54} / \lambda_{202.04})</td>
</tr>
<tr>
<td>(logT=6.2)</td>
<td>(\lambda_{203.82} / \lambda_{202.04})</td>
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EIS active region spectrum

Young et al., 2007, PASJ Hinode issue

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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
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

May 6
- Fe XII λ186.88 / λ195.12
- Fe XII λ203.82 / λ202.04

May 3
- Fe XII λ186.88 / λ195.12
- Fe XIII λ196.54 / λ202.04

Solar 24, Dec 2008
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**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