Density diagnostics derived from the O IV and S IV lines observed by IRIS

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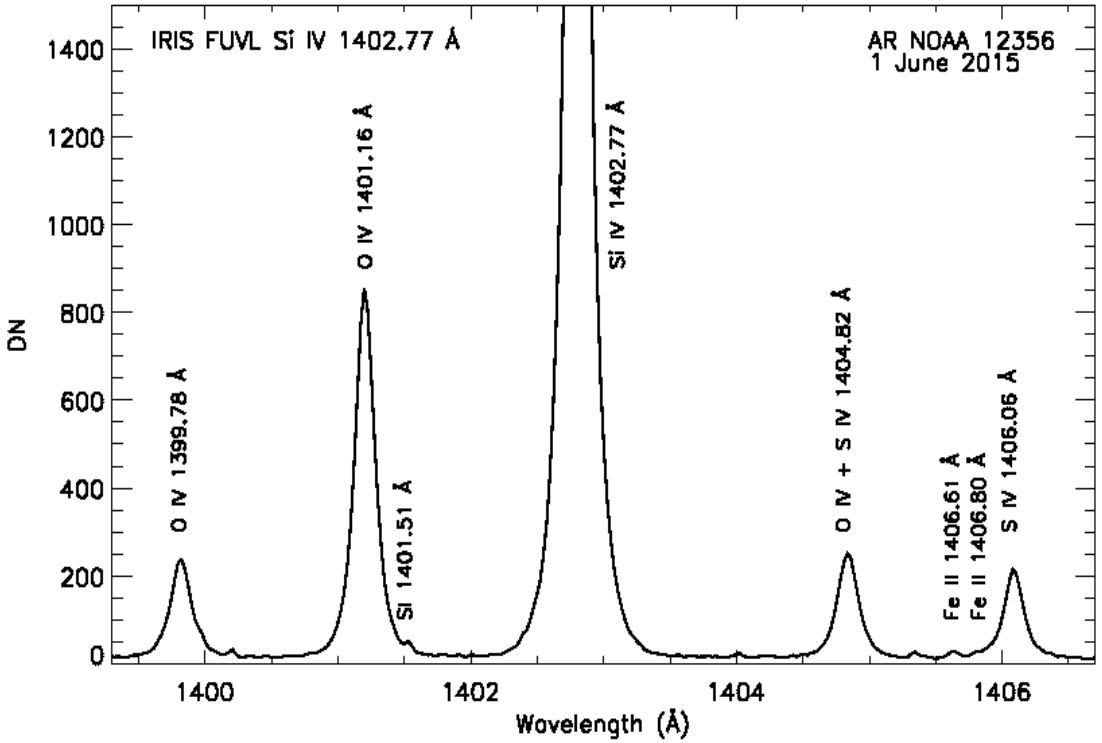
Outline

- The IRIS OIV and SIV lines as density diagnostics
- The density diagnostic method
- Results:
  - Active Region (AR) loop
  - X class flare on 22 June 2015
- The effect of high densities in the atomic calculations
- Conclusions

The IRIS TR lines around 1400 A



Intercombination (low *A*–values) lines :

- OIV multiplet (T~ $10^{5.15}$ K)
  1399.78, 1401.16 and 1404.81 Å
- SIV (T~ $10^{5.0}$ K):
  1406.06 and 1404.85 Å
- The line ~ 1404.8 Å is a blend of OIV and SIV, the blend can be estimated knowing the plasma density.

Si IV **allowed (high *A*–value) transition** (T ~ $10^{4.9}$ K)

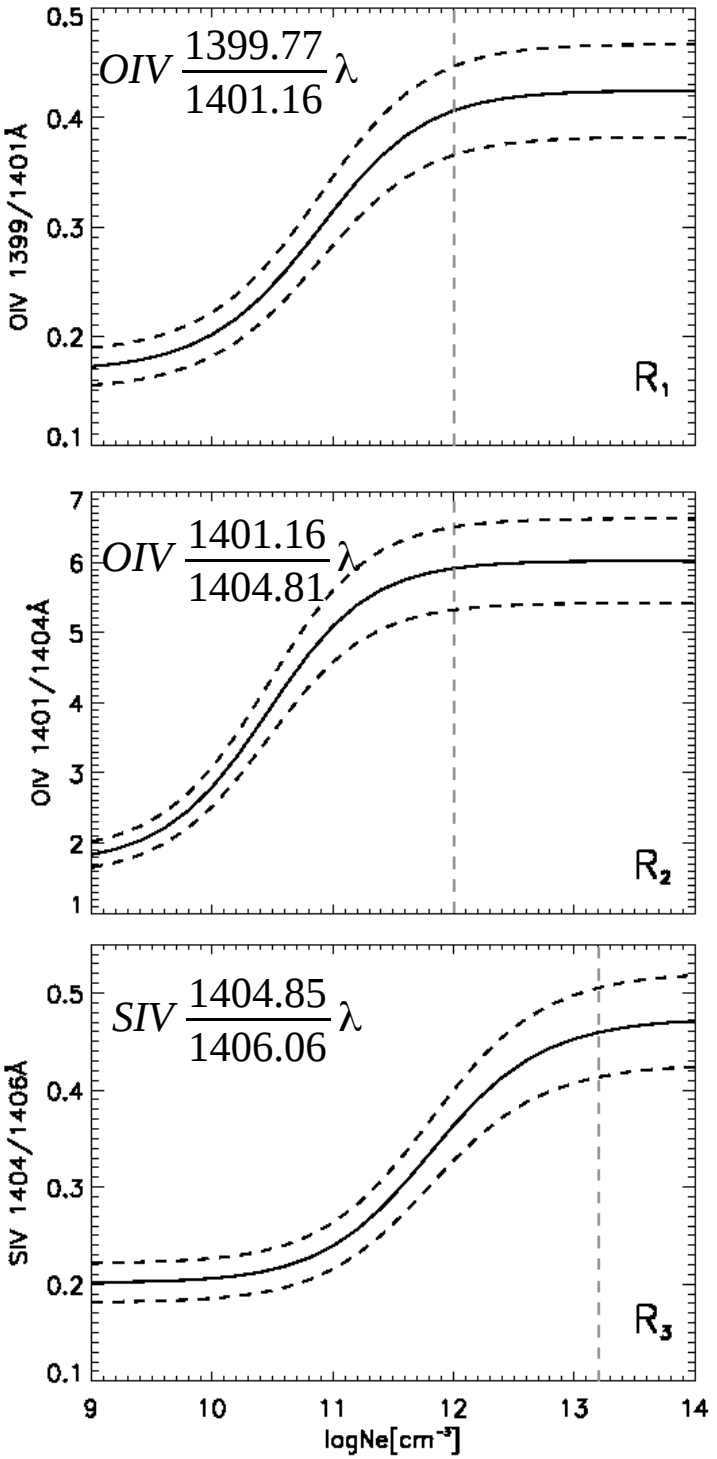
- Density diagnostics based on SiIV/OIV ratio are problematic (Hayes&Shine87):
  - formed at quite different temperatures
  - allowed/semi forbidden transitions
  - low/high FIP elements
  - different behaviour in non equilibrium ionization
- The O IV and S IV lines can provide very good density diagnostics (e.g., Flower75, Bathia80)

The OIV–SIV lines

- OIV line ratio density sensitive between 10^{10}–10^{12} cm^{-3}
- SIV line ratio between 10^{11}–$10^{13.2}$ cm^{-3}
- Density diagnostics based on OIV-SIV lines:
  In pressure equilibrium, should give similar densities
- Discrepancies were identified by Keenan, 2002 to be due to:
  - atomic data
  - blends/limited spectral resolution
  - OIV+SIV blend difficult to estimate

  However, **some discrepancies still remained** (Del Zanna, 2002) .
- New IRIS observations, revised atomic data:
  - OIV (CHIANTI v8, Del Zanna+2015)
  - SIV (Del Zanna&Badnell 2016)

=> can these discrepancies now be solved?



Density diagnostics method

The intensity of an optically thin spectral line can be expressed as:

$$I \propto \int_h G_{th}(T, N_e) N_e^2 dh$$

where

$$G_{th}(T, N_e) = \frac{N(X_j^{+m})}{N(X^{+m})} \cdot \frac{N(X^{+m})}{N(X)} \cdot 0.83 \cdot Ab(X) \cdot \frac{A_{ji}}{N_e}$$

We adopt an **emissivity ratio (ER) method:**

compare the observed intensity I_{obs} and the theoretical contribution function $G_{th}(T, N_e)$ of a set of lines as a function of density

$$ER(T, N_e) = \frac{I_{obs}}{G_{th}(T, N_e)} \cdot C$$

For an almost iso-density plasma, the ratios ER(T, N_e) should consistently intersect at the same value, giving the density N_e of the emitting plasma source (similarly to L-function ,Landi&Landini97).

This method allows a better identification of possible discrepancies or anomalies

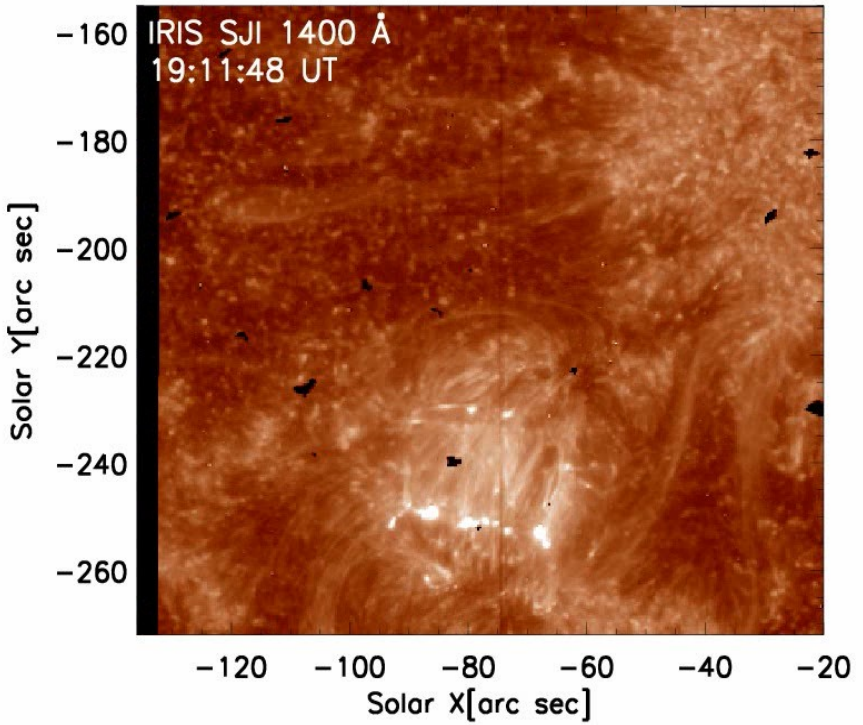
Case study1: AR 12356

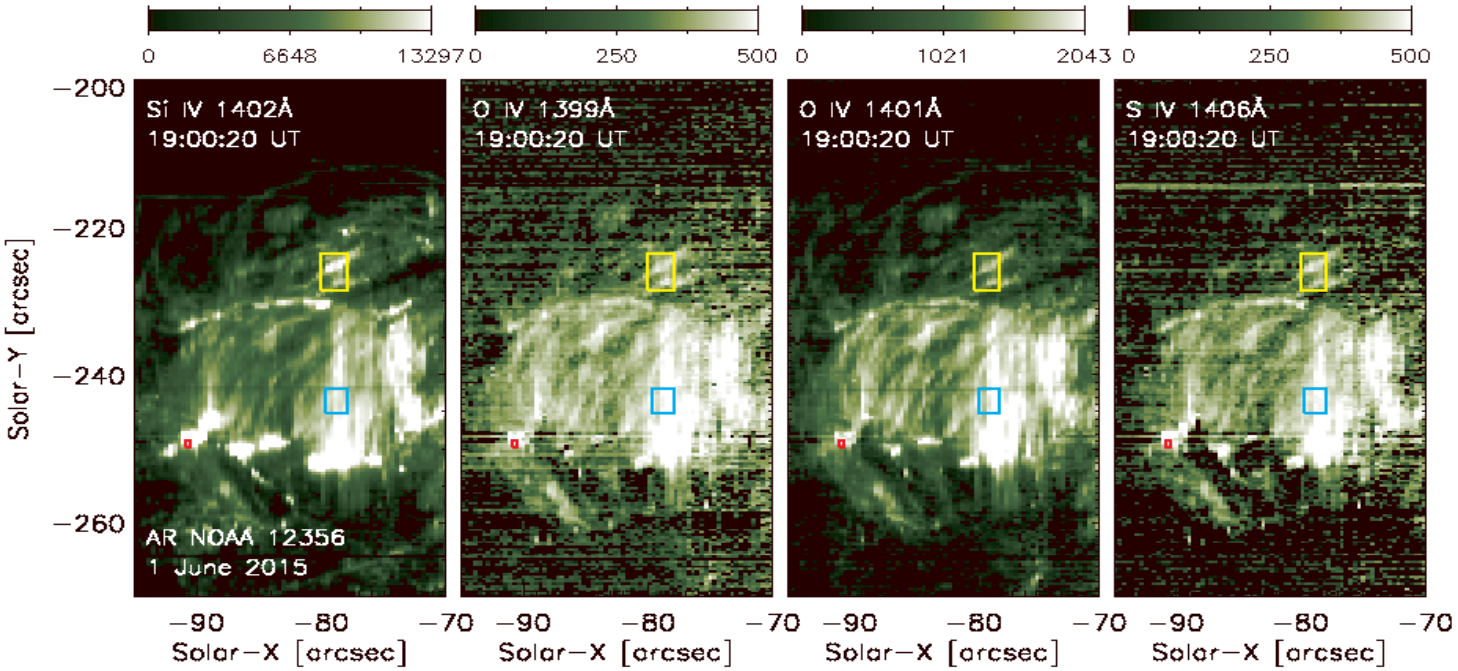
IRIS observation:

Large 60 s exposure raster on the AR 12356

Three features observed in the AR :

- **loop (blue)**
- plage (yellow)
- brightening (red)





Top: IRIS SJI 1400 Å image with IRIS spectrograph FoV

Left: intensity maps in the TR lines observed by the IRIS Spectrograph

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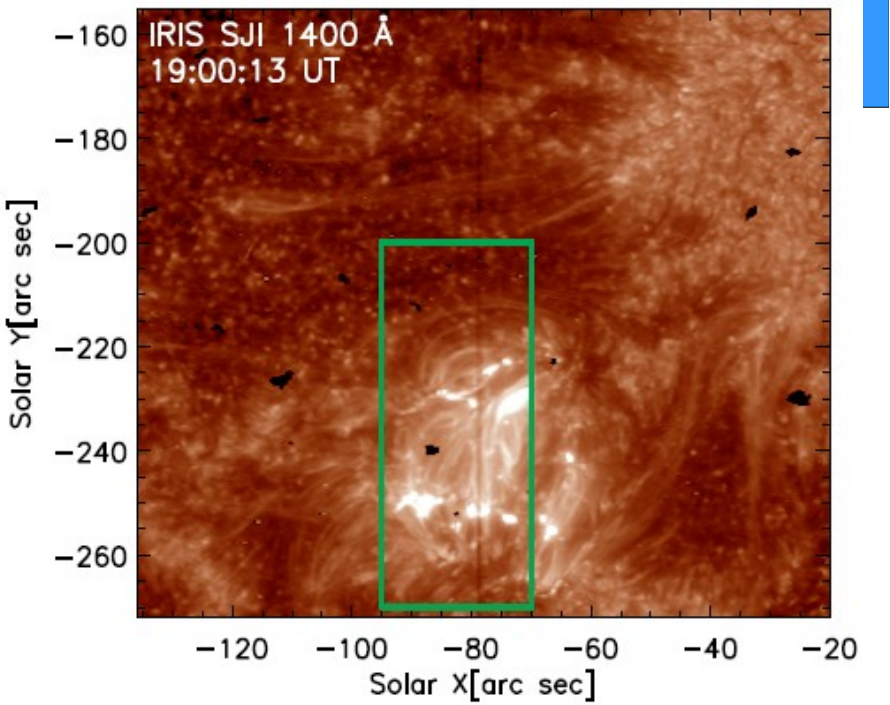

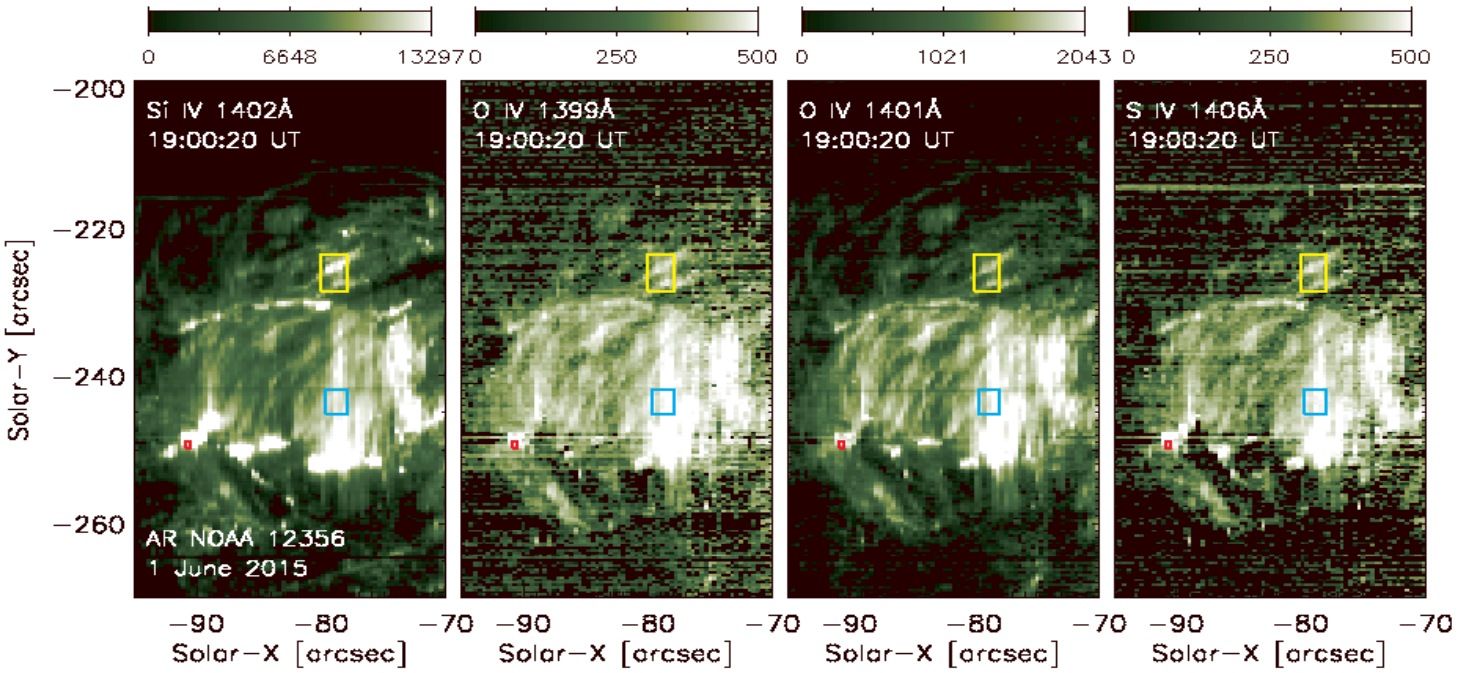

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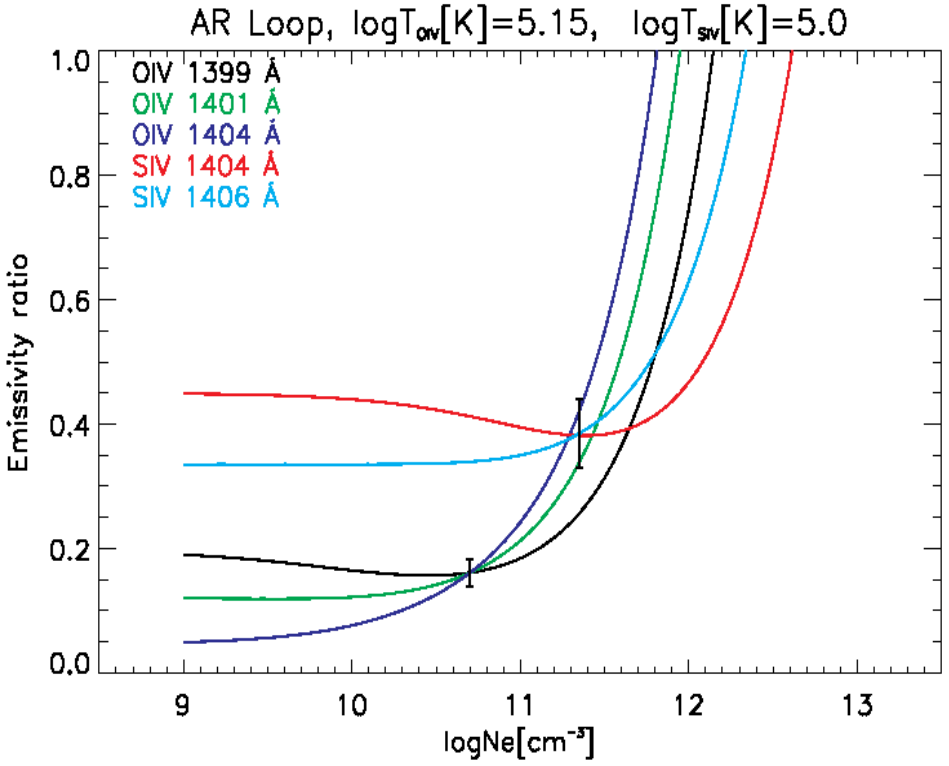
Left: intensity maps in the TR lines observed by the IRIS Spectrograph

Emissivity ratio method in AR loop (1/2)



Still factor ~4 discrepancy in density.

- OIV 1404 and SIV de blended using the density measured by the OIV 1399/1401λ ratio

- $G_{th}(T,N_e)$ obtained assuming:

  -equilibrium conditions

  -peak temperature of formation for each ion:

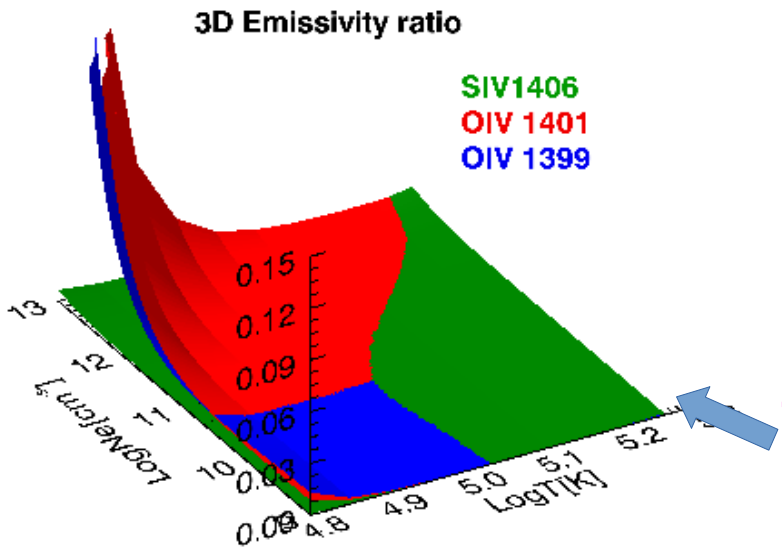
  $T_{max}=10^{5.15}$ K for OIV; 10^5 K for SIV

  -ionization fraction calculated in CHIANTI v8

  (low density approximation)

- Error bars take into account the errors on atomic data (~10%) and on the line intensities (~10%)

Emissivity ratio method in AR loop

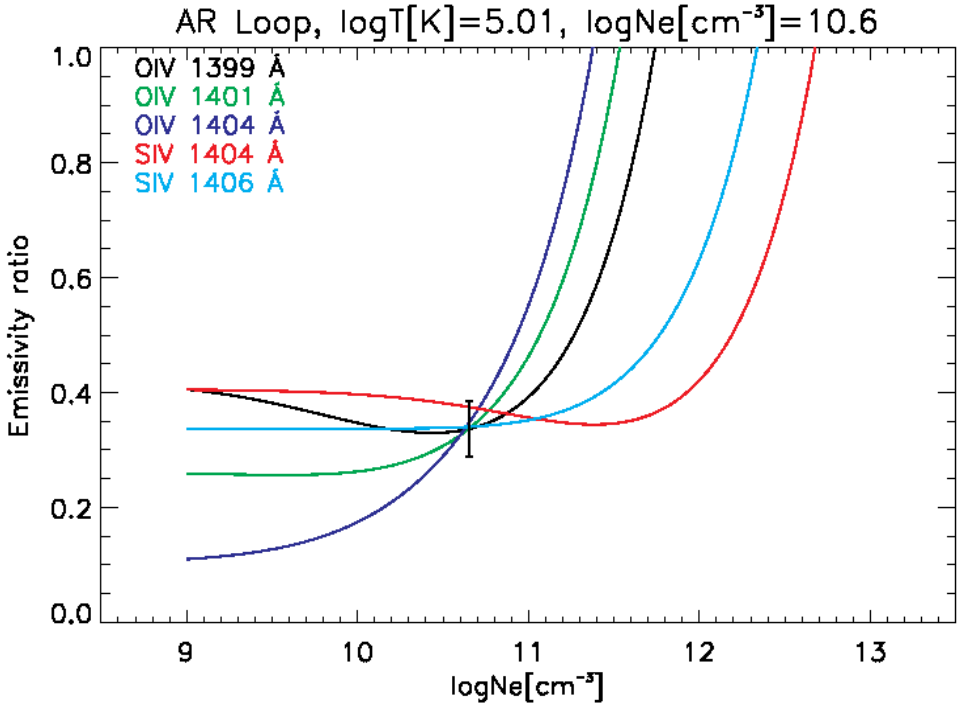


Looking for a unique temperature and density value which can explain the observed line intensities

=> extension of the ER method to 3D in the temperature space.

(NB. 3D method only using independent lines)

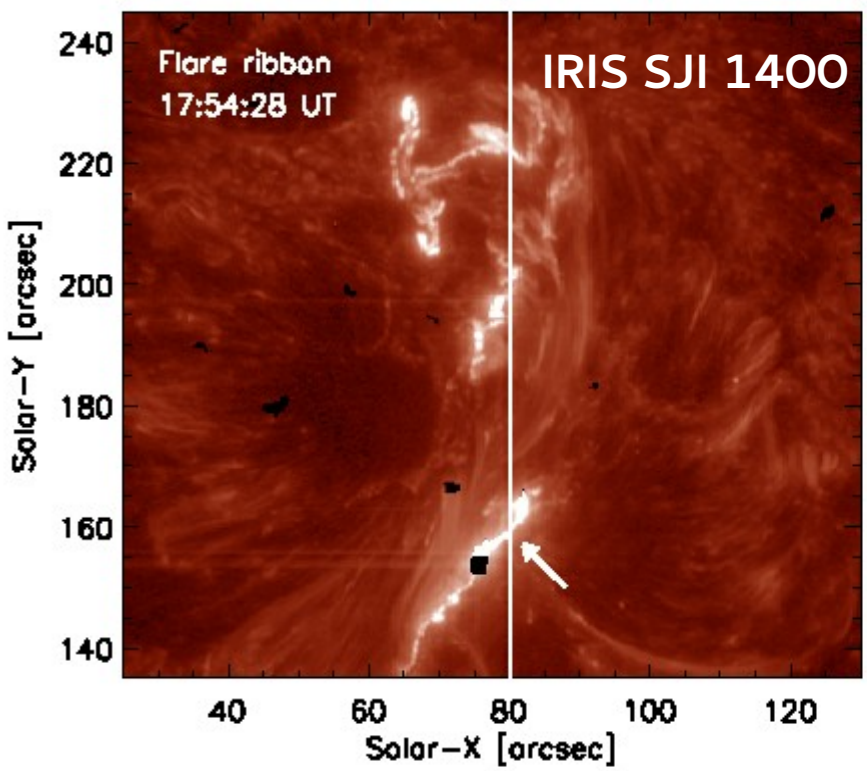
The 3D ER plot is consistent with a plasma being at a temperature of ~10^5 K and density $10^{10.6}$ cm^{-3}

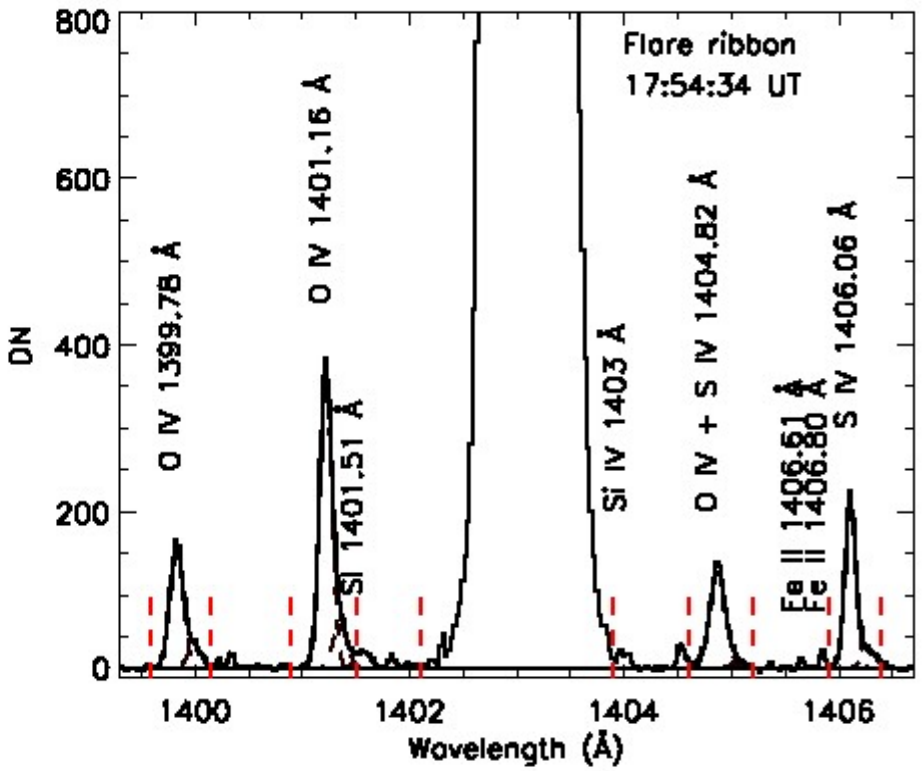


ER plot where same temperature **($T=10^{5.01}$ K)** has been assumed for both ions

All the ER curves (including the curves for the OIV and SIV 1404 Å lines) now consistently intersect

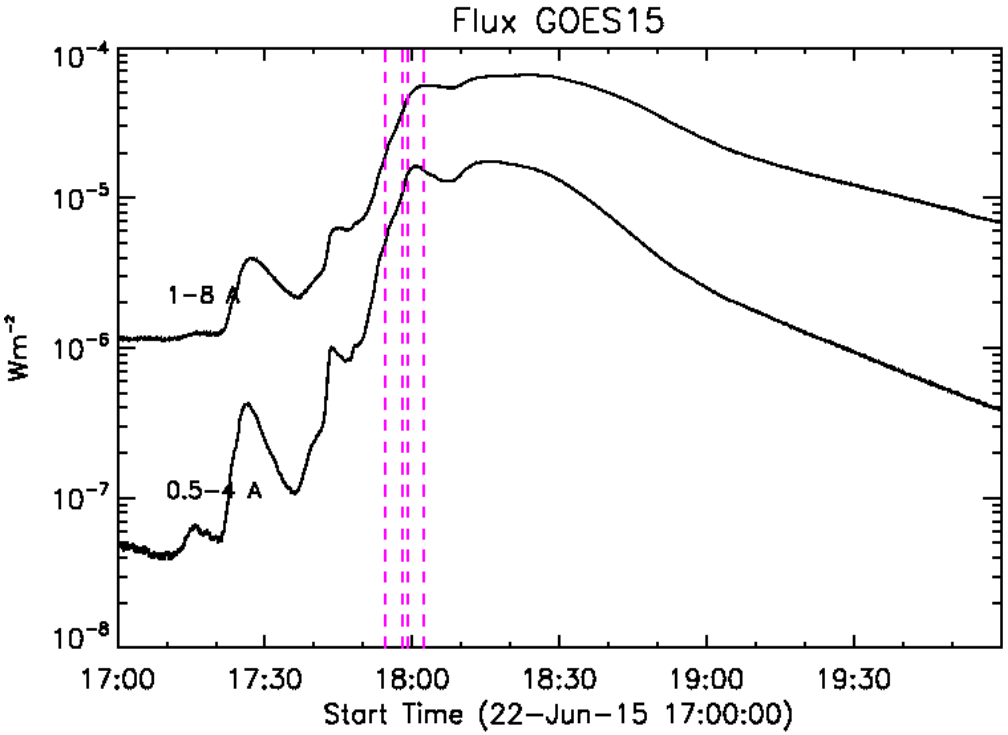
Case study 2: 22 June 2015 X class flare

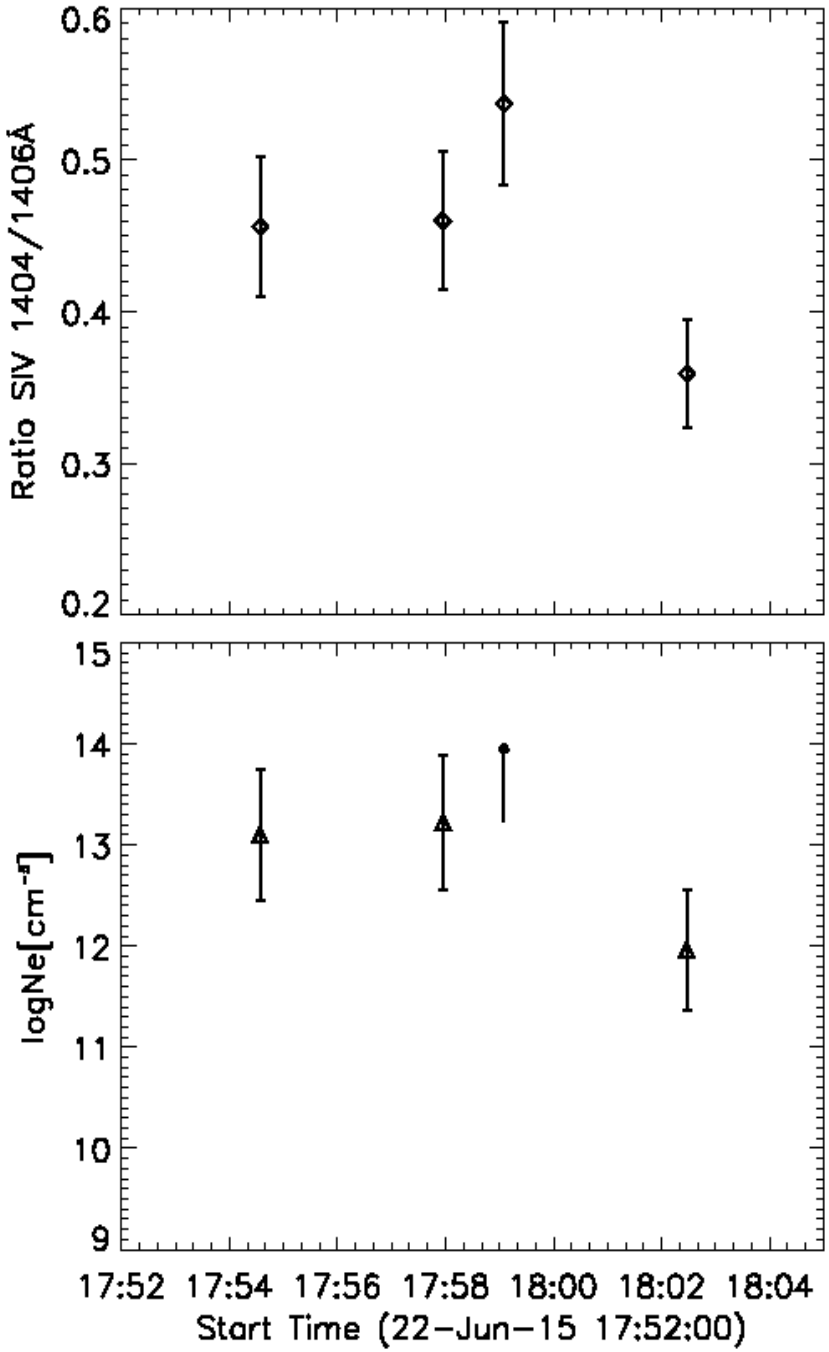




- Density diagnostics at the flare footpoints over time during the impulsive/peak phase
- SIV enhanced as a result of the high electron number density
- The OIV line ratios reach the high density limit ($10^{12}cm^{-3}$) in this case => **the OIV+SIV line can then be reliably de blended**
- The SIV ratio is sensitive to higher density values and can be used as a density diagnostic

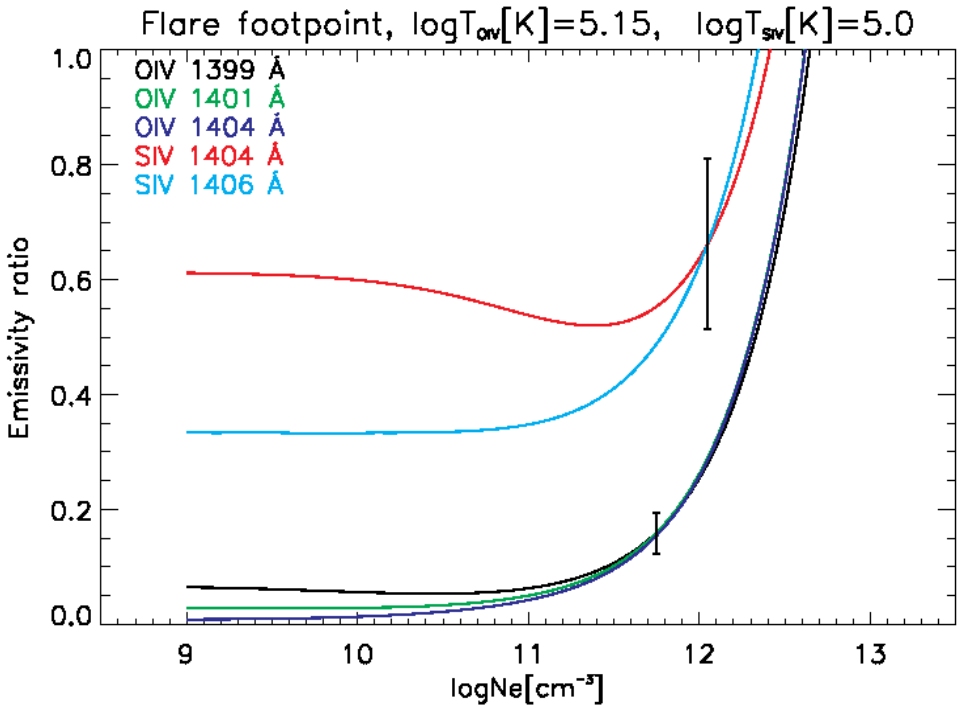
Density diagnostics in the 22 June 2015 flare

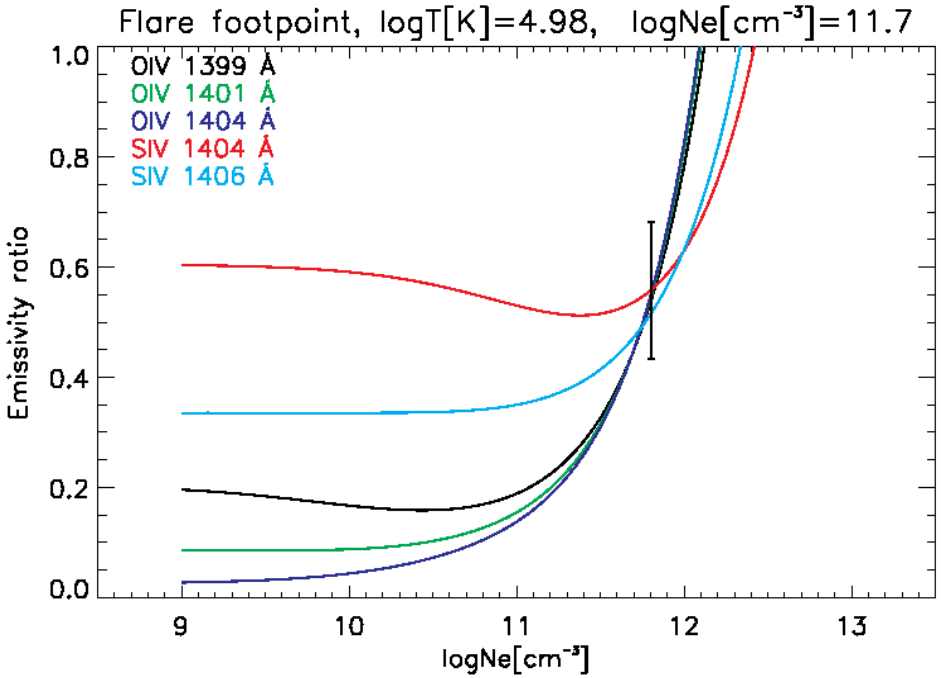




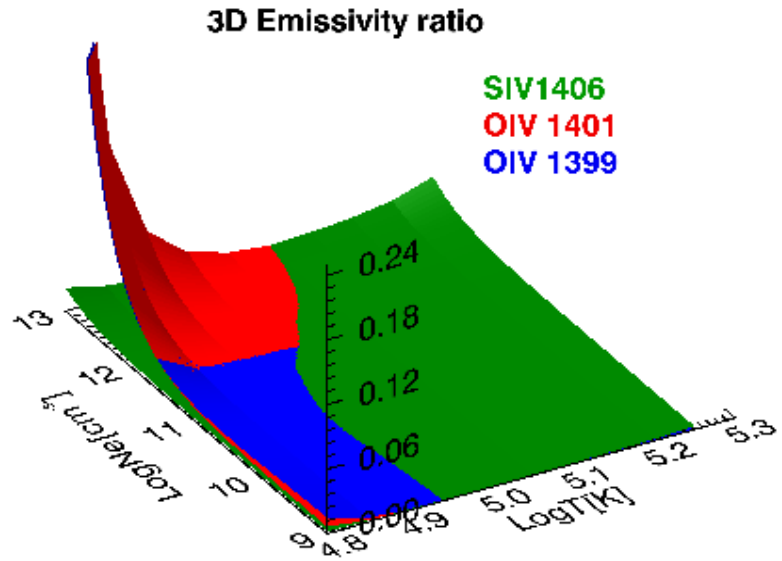
- 4 density measurements (pink vertical lines)
- The SIV shows densities as high as 10^{13} cm^{-3}or more
- The emissivity ratio with OIV and SIV can be only be applied for the last measurement (Ne <10^{12} cm^{-3})

Emissivity ratio method in flare

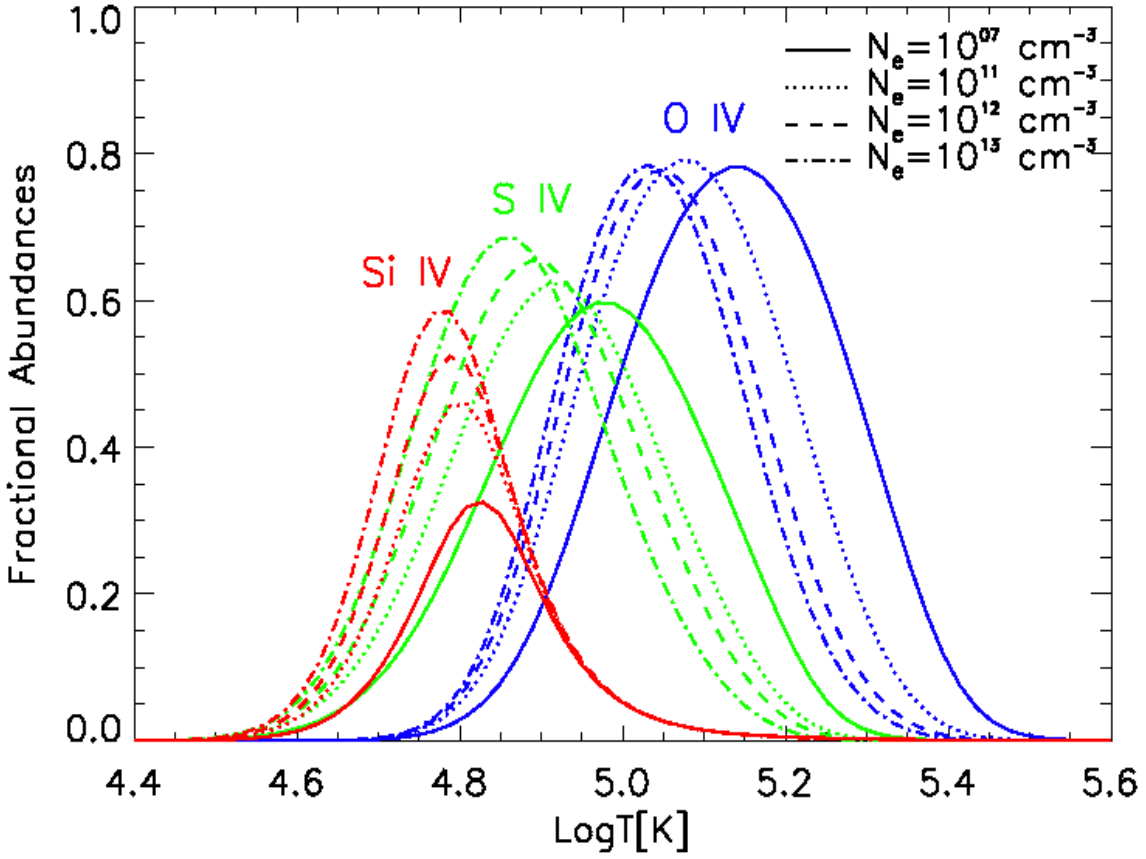




- Discrepancy assuming peak formation temperature for the two ions (T_{max}=$10^{5.15}$ K for OIV; 10^5 K for SIV)
- The discrepancy is again resolved if we assume the same temperature for the two ions (from the 3D ER plot)
- The ER plots are consistent with a plasma density of ~$10^{11.7}$ cm^{-3} and temperature of ~$10^{4.98}$ K just after the peak of the flare



Density effects on fractional ion abundance



- Two main effects become important at high densities:
  -suppression of the dielectronic recombination (DR)
  - ionization from metastable states
- Including these effects in the atomic calculations causes a shift in the temperature formation of the ions towards lower values
- **However, the density diagnostics are not significantly affected**

Fractional ion abundances calculated using atomic data from **OPEN–ADAS (Atomic Data and Analysis Structure; www.open.adas.ac.uk)**

Conclusions

- The OIV/SIV lines can provide useful information on the electron number density of the plasma from which they are emitted.

- Discrepancies in the density diagnostics provided by the two ions separately can be solved using the new **3D emissivity ratio method**, which is consistent with a plasma being on average isothermal. This can be justified considering that we are observing either loops or (flare) loop footpoints.

- An electron number density of around **10^{11} cm^{-3}** and an isothermal temperature of **~ $10^{5.01}$ K** are found in the **AR loop**.

- Very high densities around **10^{13} cm^{-3}** or above are found at the footpoints of an **X class flare** during the impulsive phase by using the SIV line ratio.

- The **high density effect** needs to be taken into account in the atomic calculations. While the ion temperatures are shifted to lower values, the density diagnostics are not significantly affected.

- *"Density diagnostics derived from the O IV and S IV intercombination lines observed by IRIS"*, A&A accepted, 2016.