Diagnostics of non-Maxwellian κ-distributions in Hinode/EIS active region spectral atlas

Juraj Lörinčík[1,3], Jaroslav Dudík[1], Giulio Del Zanna[2], Elena Dzifčáková[1]

1 – Astronomical institute of the Czech Academy of Sciences, Ondřejov, Czech Republic

2 – DAMTP, CMS, University of Cambridge, Cambridge, UK

3 – DAPEM, FMPH UNIBA, Bratislava, Slovakia

8TH CORONAL LOOPS WORKSHOP, PALERMO, 2017

We report on analysis of a Hinode/EIS spectral atlas of the active region NOAA 11692 observed on 2013 March 15. We selected spatial boxes containing two coronal warm loops and coronal moss as well as neighboring background areas. The spectra were averaged in order to improve photon statistics due to the excluding missing pixels. Spectra of Fe XI-XV lines needed for plasma diagnostics were fitted and calibrated with the in-flight calibration of Del Zanna (2013, A&A, 555, 47).

Diagnostics of density and κ-distributions was performed from observed ratios of line intensities (Dudík et al. 2015, ApJ, 807, 123). Diagnostic ratio-ratio diagrams use state-of-art atomic data from Chianti v. 8. Density diagnostics using various ratios indicate averaged density of log (ne cm^{-3}) = 9.25 for loops and log (ne cm^{-3}) = 9.6 for moss. Diagnostics of κ-distributions resulted in strongly non-Maxwellian loops with $\kappa \leq 2$ and moss with $\kappa \leq 4$.

Astronomický ústav AV ČR

UNIVERSITY OF CAMBRIDGE

1. Introduction

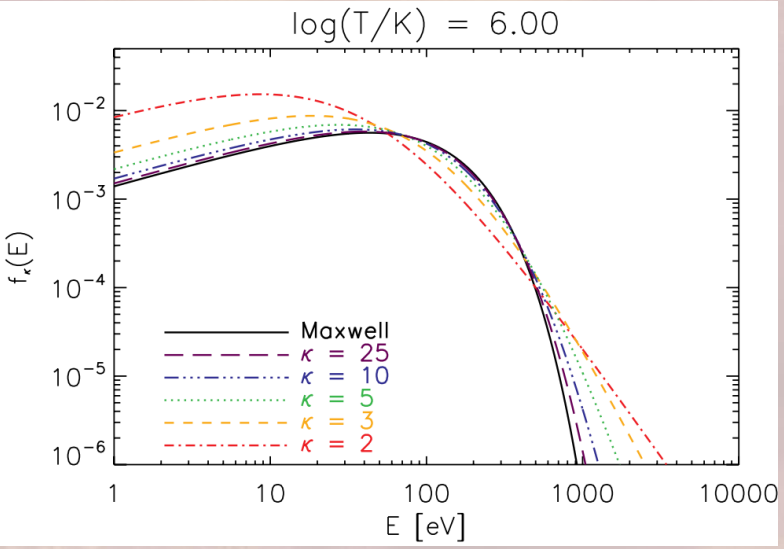
- Plasma in the solar corona – ionization/recombination and excitation/de-excitation processes out of equillibrium
- Treated here by the electron kappa distributions
- κ encodes the system's departure of equllibrium
- Already observed in
  - Solar wind – Maksimovic et al. (1997)
  - Transition region – Dzifčáková & Kulinová (2011)
  - Flares – Kašparová & Karlický (2009)
  - Transient coronal loop – Dudík et al. (2015)
- Dzifčáková & Kulinová (2010) and Mackovjak (2013) – method of diagnostics of κ using ratio-ratio diagrams
- Here, we
  - Introduce observation of an active region
  - Describe basic steps of data reduction
  - Diagnose density in two coronal loops and moss
  - Diagnose κ and T
  - Check the instrument's in-flight calibration

Electron κ-distributions

$$F(E,\kappa) = A_\kappa \frac{2}{\sqrt{\pi}(k_B T)^{3/2}} \frac{E^{1/2}}{\left(1+\frac{E}{(\kappa-1.5)k_B T}\right)^{\kappa+1}}$$

$$A_\kappa = \frac{\Gamma(\kappa+1)}{(\kappa-0.5)(\kappa-1.5)^{3/2}}$$

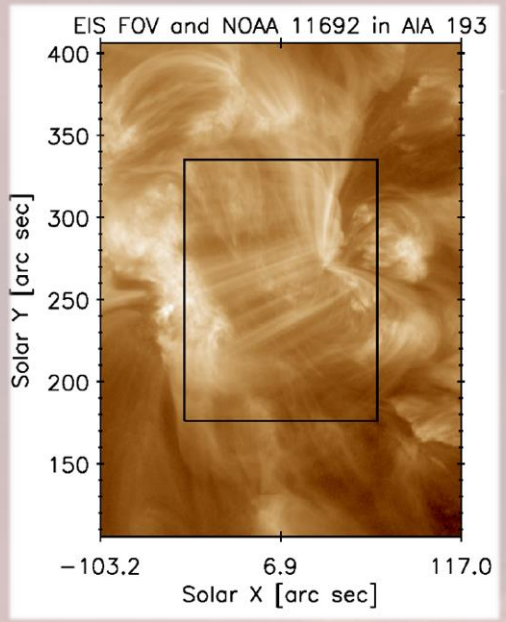
- $\kappa \rightarrow \infty$ – thermodynamic equillibrium
- $\kappa \rightarrow 3/2$ – furthest departure from equillibrium



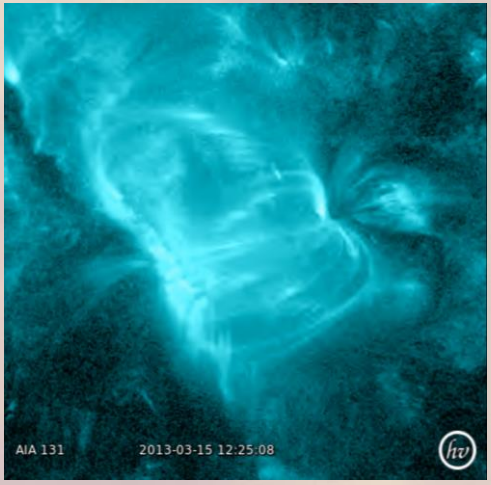
Kappa distribution for selected values of κ. From Dudík et al. (2015).

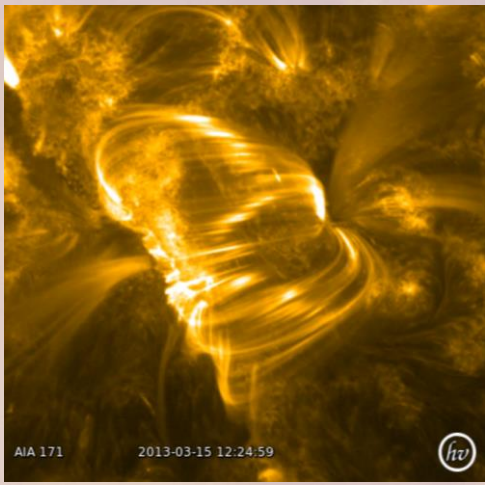
2. Observation

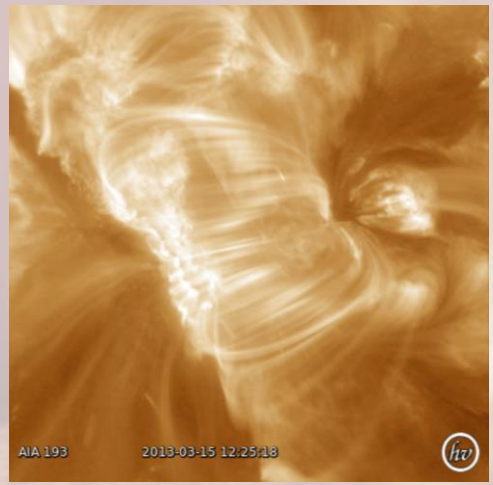
- EIS spectral atlas – full range of instrument's λ
- 120'' x 160'' section of the AR 11692
- Non-flaring during the observation
- 30s exposure time

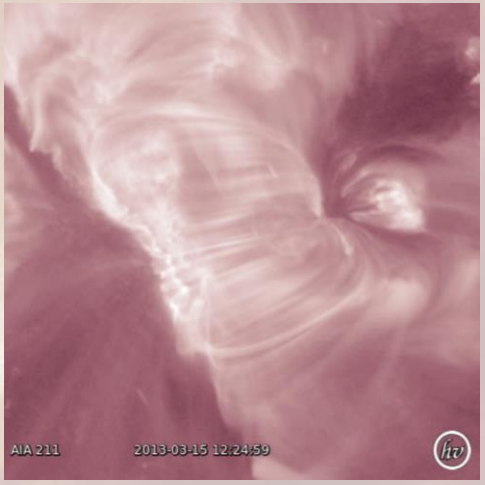


EIS FOV (black frame) drawn in the *SDO*/AIA 193Å filter channel picture of the active region.









Active region NOAA 11692 observed in 131Å, 171Å, 193Å, and 211Å filter channels of *SDO*/AIA.

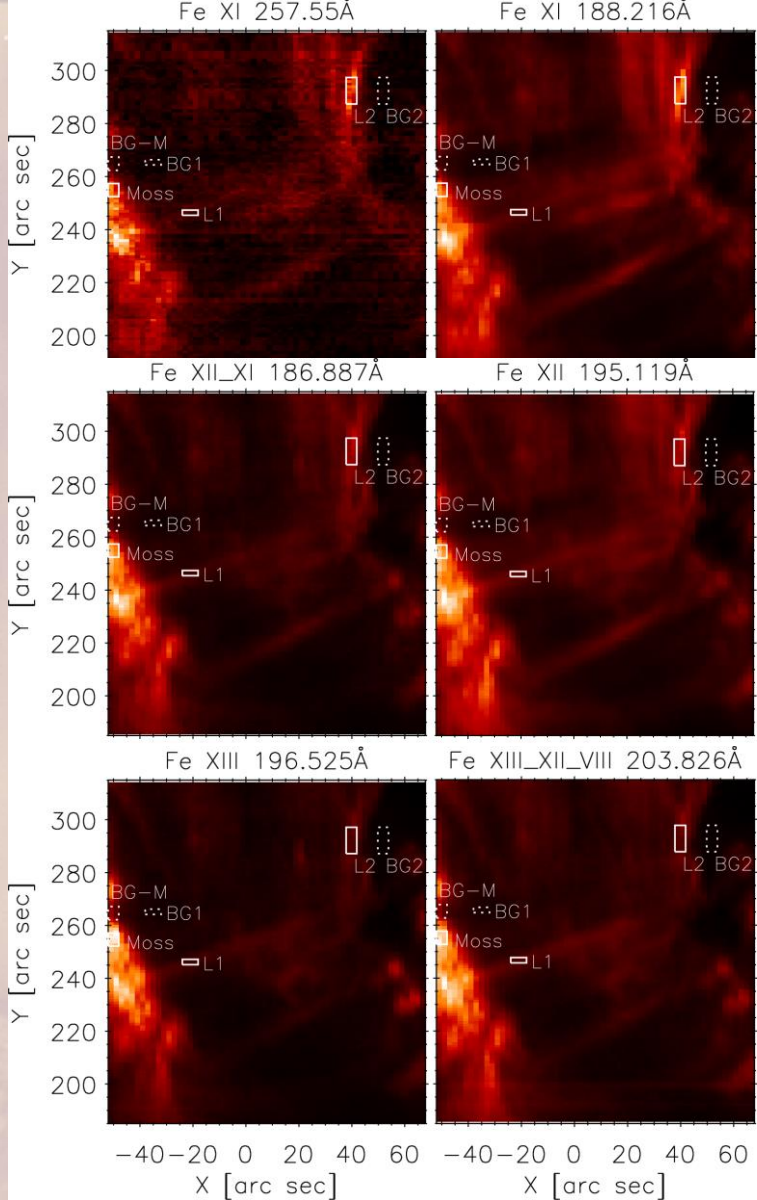
2. Data reduction

1. *Hinode*/EIS and *SDO*/AIA co-aligning
2. Processing
   - ✓ EIS_PREP
   - ✓ Geometrical corrections
   - ✓ MP exclusion
   - ✓ Intensity averaging in spatial boxes
     - Loop L1, 2 x 3 pixels
     - Loop L2, 2 x 10 pixels
     - Moss, 2 x 5 pixels
3. Data fitting – *XCFIT*
4. Data calibration – Del Zanna (2013)
5. Subtraction of the background intensity

Fe XI

Fe XII

Fe XIII



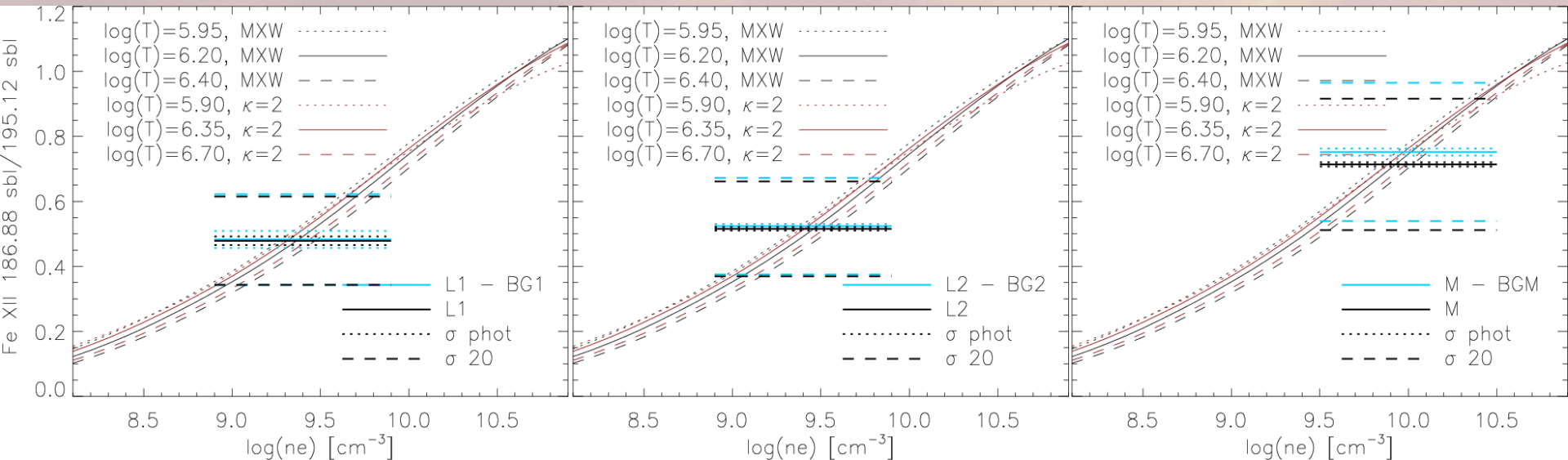
EIS FOV drawn in the centroid of selected spectral lines

3. Diagnostics I. – density

- Needed to be done a priori to diagnostics of κ
- Fe XI – Fe XIV line ratios
- Fe XIV: sufficient counts only in the moss
  - ➢ Also problems with calibration and blends

		L1-BG1		L2-BG2		M-BGM	
Line	Ratio	Observed	1-σ_{phot}	Observed	1-σ_{phot}	Observed	1-σ_{phot}
Fe XI	182/188	8.5–8.6	8.2–9.1	9.0–9.3	8.9–9.3	9.2–9.5	9.1–9.6
Fe XII	186/195	9.3–9.5	9.2–9.6	9.4–9.6	9.4–9.6	10–10.1	10–10.1
Fe XIII	196/202	9.0–9.3	8.9–9.4	8.9–9.3	8.9–9.3	9.2–9.6	9.2–9.6
Fe XIII	203/202	9.1–9.4	9–9.5	9.1–9.4	9.1–9.4	9.4–9.7	9.4-9.7
Adopted			9–9.5		8.9–9.6		9.2–10

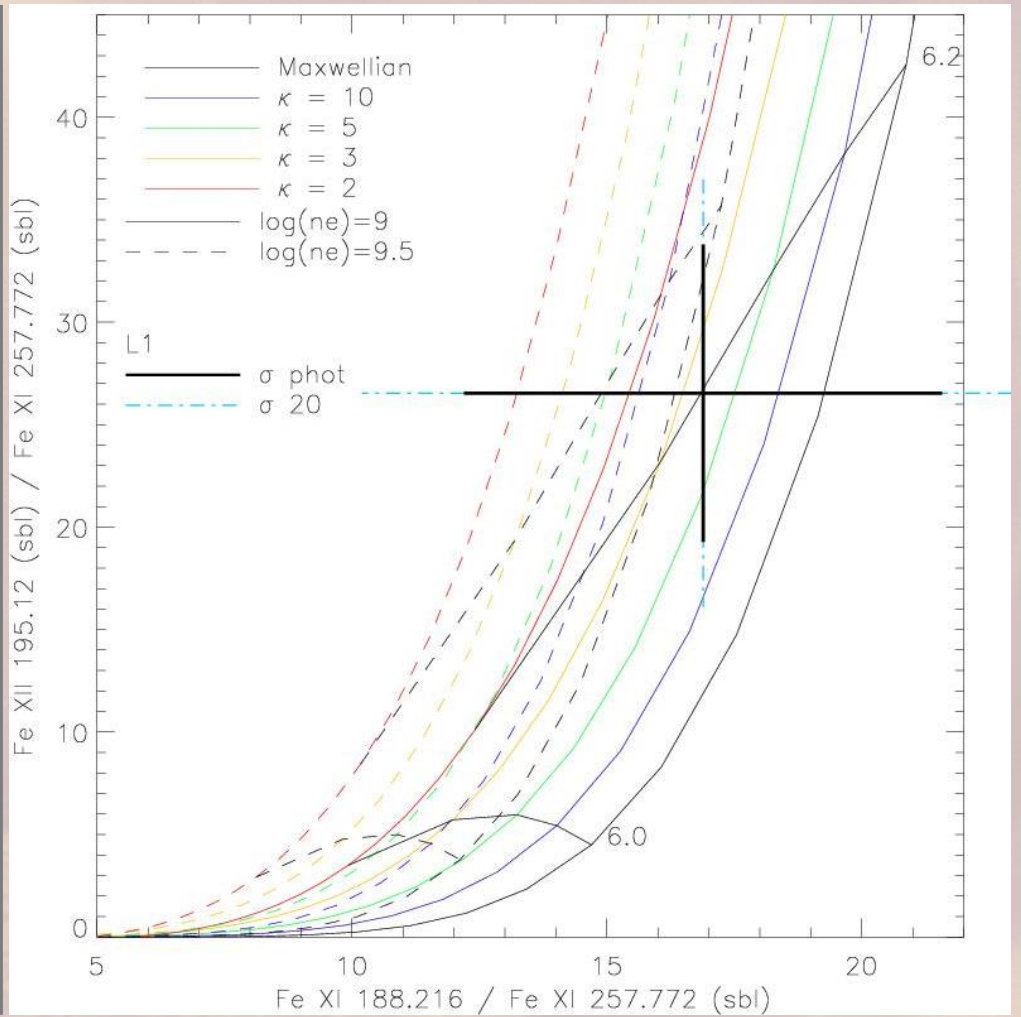
Density diagnostics using the Fe XII 186.9Å /195.12Å line ratio. Red and black curves represent synthethic ratios calculated for different *T* and κ, horizontal blue and black lines stand for the observed ratios with and without subtracted background, respectively.



3. Diagnostics II. – κ-distributions: a method & L1

- Ratio-ratio diagrams constructed for a diagnosed N_e
- EIS: multi-channel diagnostics
- Combining Fe XI and Fe XII lines from the SW channel of EIS with Fe XI 257.55Å and 257.77Å lines
- These in R_X and R_Y or only in R_X

  – to check the instrument's calibration

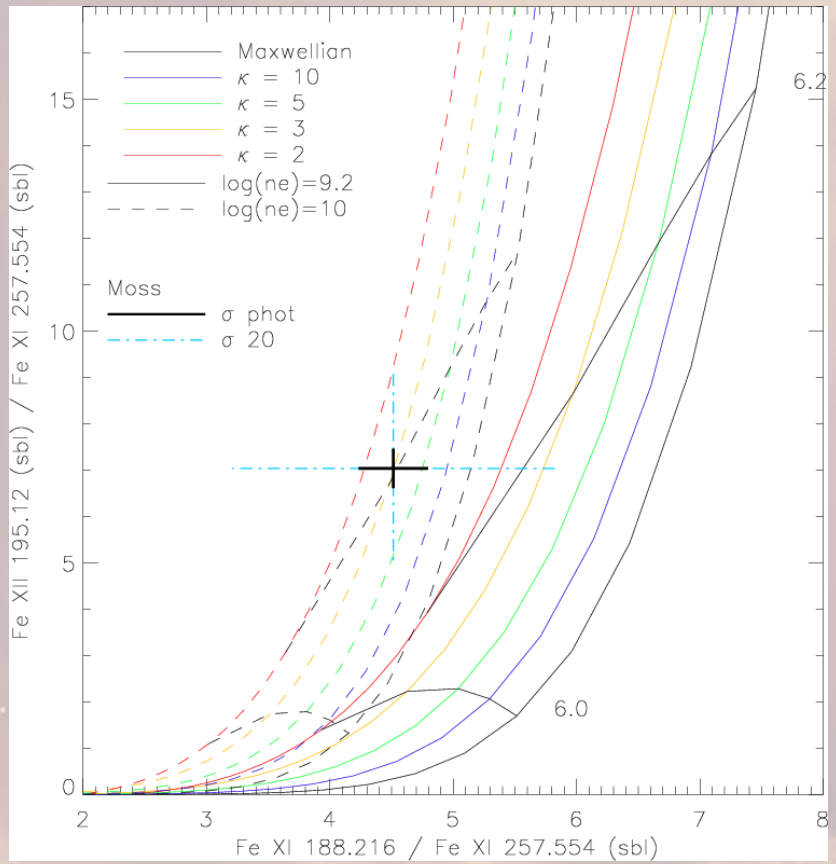


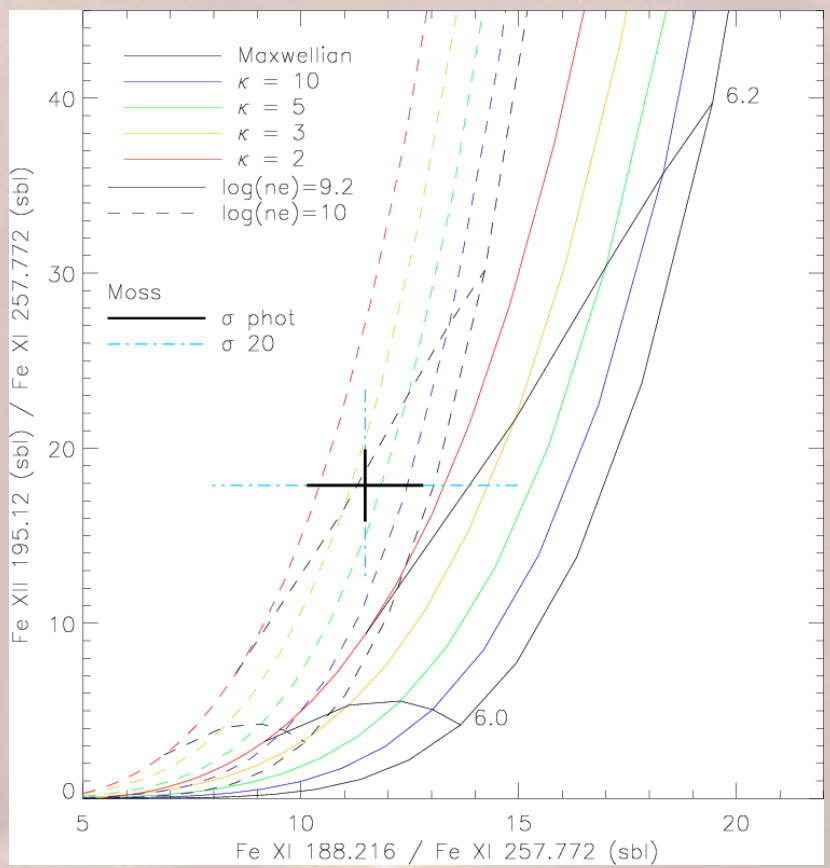
Ratio-ratio diagram used for diagnostics of *κ*. Theoretical ratios (dashed and solid color lines) are plotted as functions of *κ* (dashed and solid color lines) and *T* (dashed and solid black lines).

Color coding stands for *κ*-distributions with different value of *κ*.

Crosses represent observed ratios, with 1-σ_{phot} and σ_{20} uncertainties (black and blue color, respectively).

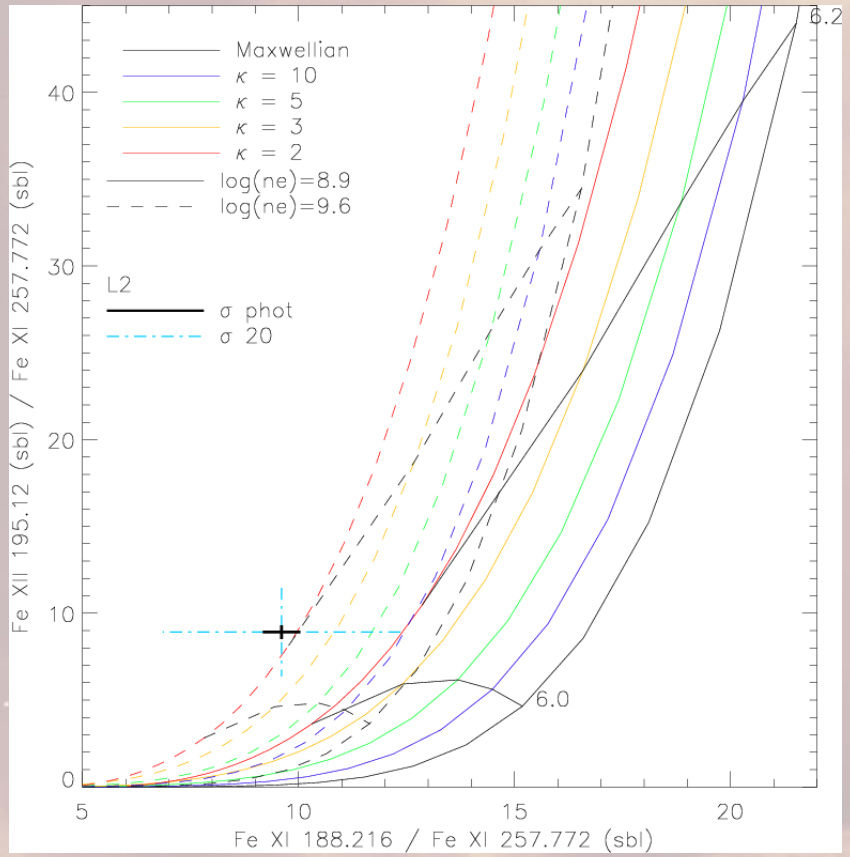
3. Diagnostics II. – κ-distributions: moss

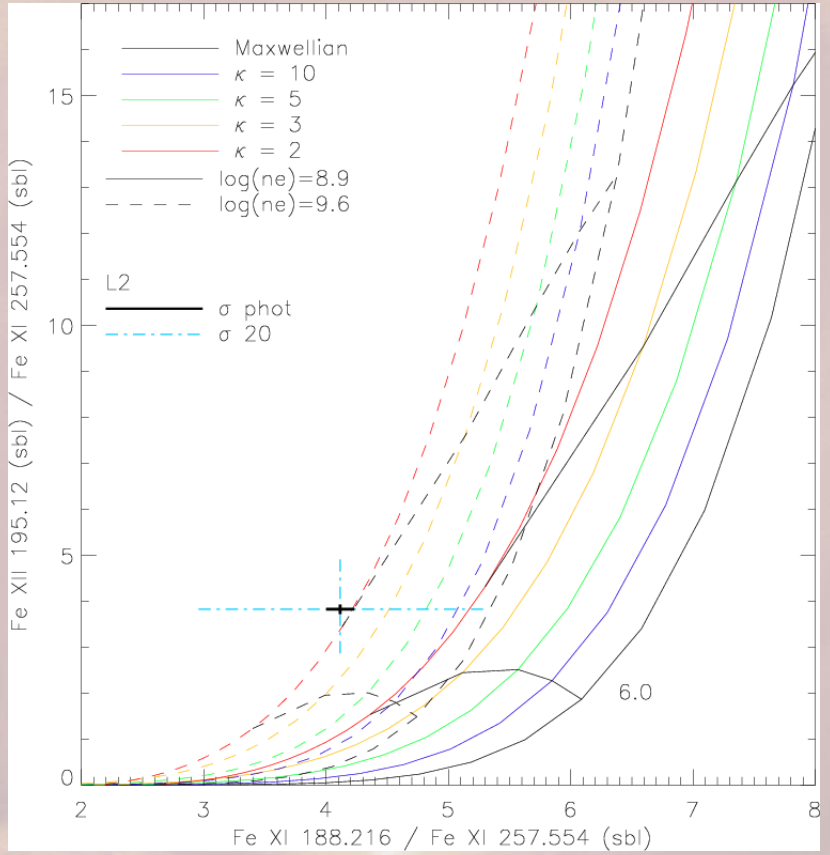




- Color solid and dashed curves: theoretical ratios, black solid and dashed curves: isotherms
- Black and blue dashed cross – observation and its uncertainties

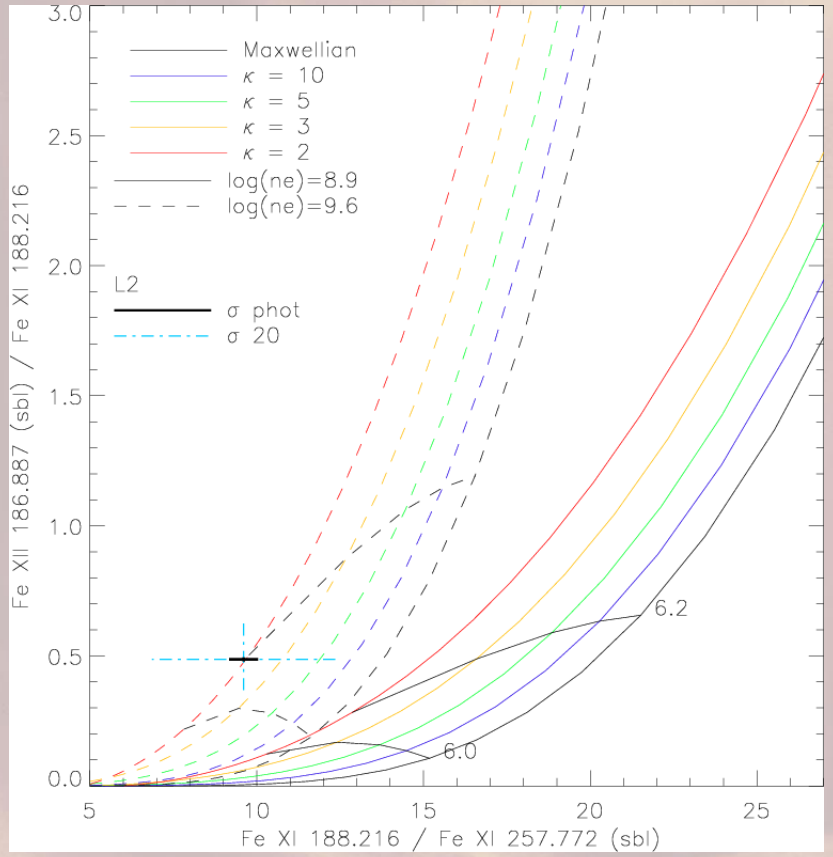
3. Diagnostics II. – κ-distributions: L2

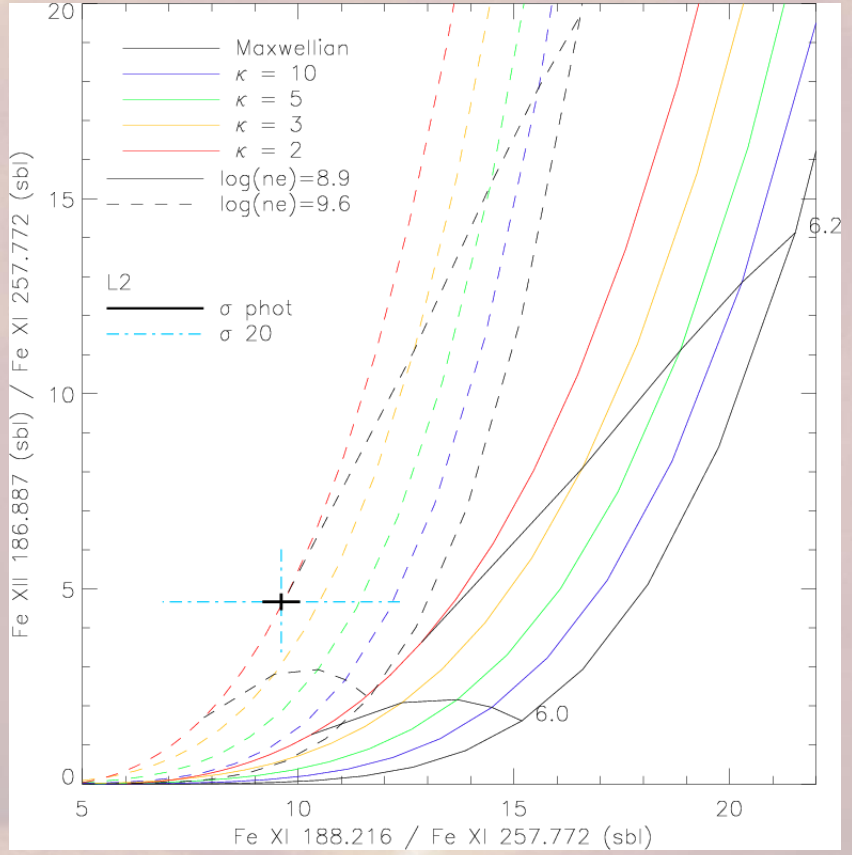




- Color solid and dashed curves: theoretical ratios, black solid and dashed curves: isotherms
- Black and blue dashed cross – observation and its uncertainties

4. Diagnostics of κ and instrument calibration





- Color solid and dashed curves: theoretical ratios, black solid and dashed curves: isotherms
- Black and blue dashed cross – observation and its uncertainties

5. Summary

- Goal of this work was to diagnose non-maxwellian κ-distribution in the Hinode/EIS spectrum
- We found and processed atlas observation of active region
- Data were fitted and obtained line intensities calibrated using the GDZ in-flight calibration routine
- Density in the loops and moss was diagnosed, also with ratios involving lines of Fe XIV as
  L1: $\log(N_e\ [cm^{-3}]) = 9 – 9.5$, L2: $\log(N_e\ [cm^{-3}]) = 8.9 – 9.6$, M: $\log(N_e\ [cm^{-3}]) = 9.2 – 10$
- Diagnostics was performed using ratios involving Fe XIV lines
  – important to resolve and get rid off blends in the future
- Results of diagnostics of non-maxwellians
  L1: non-maxwellian plasma, L2: $\kappa \leq 2$, Moss: $\kappa \in (3 – 5)$
- Del Zanna (2013) in-flight calibration sufficiently precise for diagnostics of κ
  20% calibration uncertainty rather over-estimated

To be done

- Diagnostics of κ in QS
- DEM