On the possibility to diagnose the κ- distributions from the Hinode/EIS spectra

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Overview

1. Introduction & Motivation
2. κ-distributions
3. EUV diagnostics of the κ-distributions
   - Method
   - Density diagnostics
   - κ-distributions diagnostics
4. Conclusions

1. Introduction & Motivation

- The κ-distributions were detected in the interplanetary plasma → are they present in the solar corona?
- The type of distribution affects intensities of the spectral lines → can we diagnose it from the spectroscopic data?
- Data and theory are required (Hinode/EIS and modified CHIANTI)

2. κ-distribution

A non-Maxwellian distribution of particle energies

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

A_κ – normalization const.

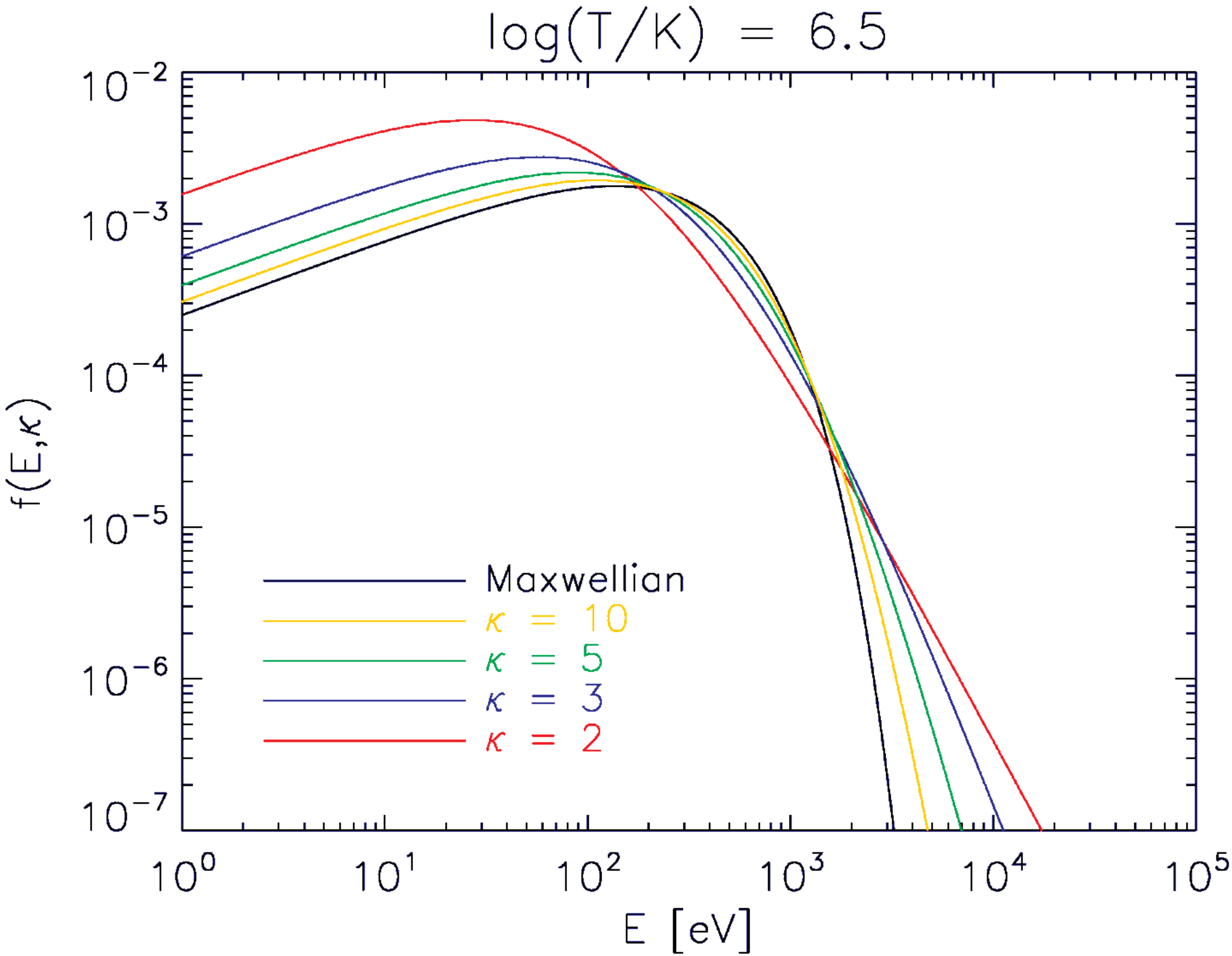
T a κ – parameters of distribution

E – electron kinetic energy

Owocki & Scudder (1983)

κ → ∞: Maxwellian distribution

κ → 3/2: the highest deviation from Maxwellian distribution



log(T/K) = 6.5
f(E,κ)
E [eV]
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^0
10^1
10^2
10^3
10^4
10^5
Maxwellian
κ = 10
κ = 5
κ = 3
κ = 2

Successful diagnostics

- Maksimovic et al. (1997 a, b); Zouganelis (2004, 2005, 2008) – in the solar wind
- Decker et al. (2005) – in the outer heliosphere
- Dialynas et al. (2009) – in the Saturnian magnetosphere
- Pinfield et al. (1999); Dzifčáková & Kulinová (2011)

  – in the solar transition region
- Lee et al. (2012) – line profiles, ion distribution in the solar corona

3. EUV diagnostics of the electron κ -distributions

- Dzifčáková & Kulinová (2010) – Fe lines
- Investigated lines: Al, Ar, Ca, Mg, Ni, O, S, Si
- **Synthetic intensities** of lines

  $\log(T/\mathrm{K}) = 5.0 - 7.5$; $\log(n_e/\mathrm{cm}^{-3}) = 8 - 12$;

  Maxwellian and κ = 10, 5, 3, 2 distribution
- **Observed intensities**

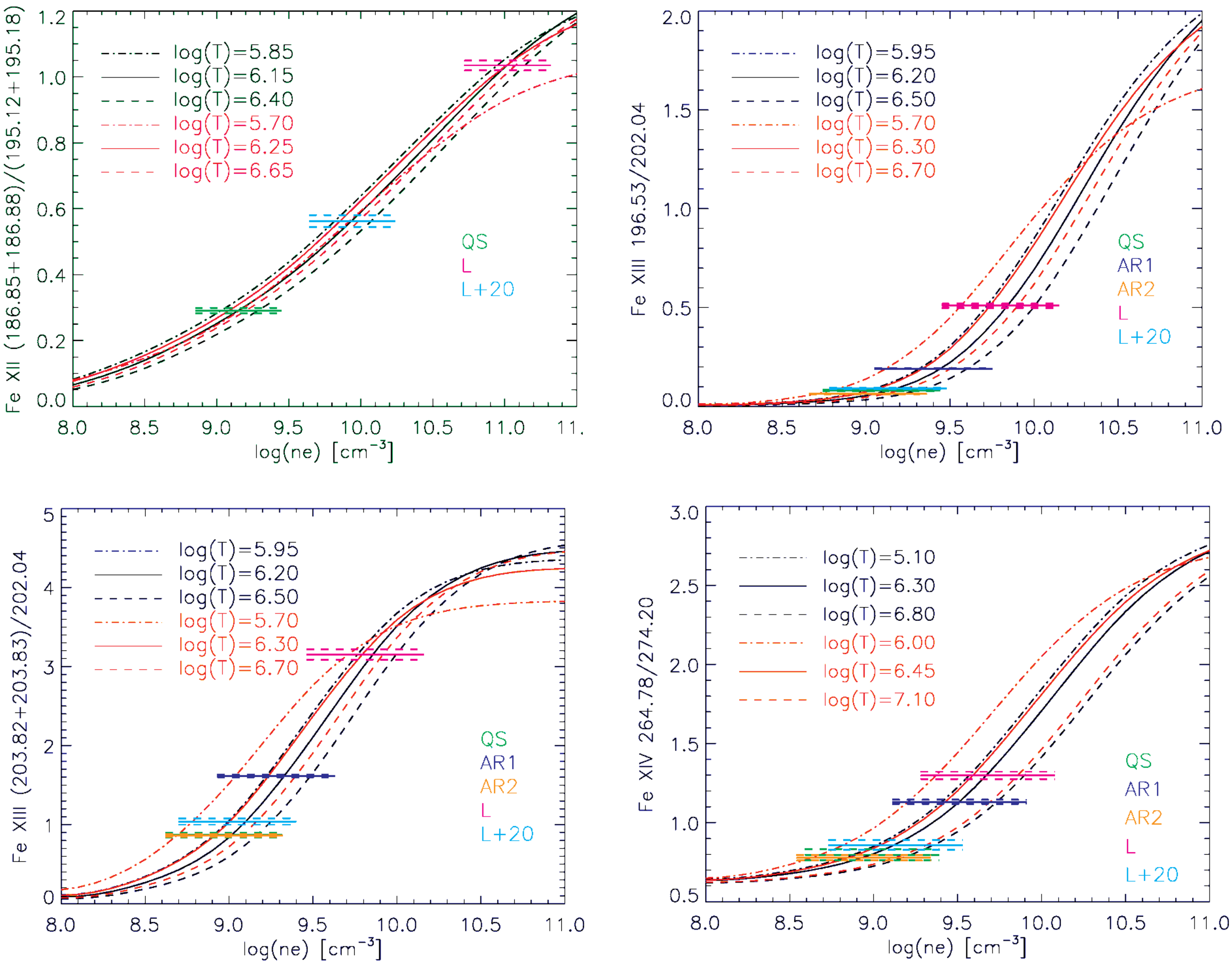
  Hinode/EIS: 170 – 210 Å and 250 – 290 Å

  QS, AR1, AR2, L and L+20" (Brown et al., 2008)

Density diagnostics

Ion	Ratio	$\log(T_{max}/K)$		Density range
		Maxwell	$\kappa = 2$	$\log(n_e/cm^{-3})$
~~Si X~~	~~261.06 / 258.37~~	~~6.15~~	~~6.20~~	~~8 – 9.5~~
~~S X~~	~~196.81 / 264.23~~	~~6.15~~	~~6.20~~	~~10 – 12~~
Fe XII	(186.85 + 186.88) (*bl* S XI)/(195.12 + 195.18)	6.15	6.25	8 – 11.5
Fe XIII	196.53 / 202.04	6.20	6.30	9 – 11
Fe XIII	(203.82 + 203.83) / 202.04	6.20	6.30	8.5 – 10.5
~~S XI~~	~~190.36 / 191.27 (*bl** Fe IX)~~	~~6.25~~	~~6.30~~	~~10 – 12~~
~~S XI~~	~~(285.82 + 285.85) / 281.40~~	~~6.25~~	~~6.35~~	~~8 – 10~~
Fe XIV	264.78 (*bl Fe* XI) / 274.20 (*bl* Si VII)	6.30	6.45	8.5 – 11
~~Ni XVI~~	~~194.05 / 185.23 (*bl** Fe VIII)~~	~~6.40~~	~~6.60~~	~~9.5 – 11.5~~
~~Ar XIV~~	~~191.40 / 194.40~~	~~6.50~~	~~6.70~~	~~10.5 – 12~~

Line ratios proposed by Young (2007)

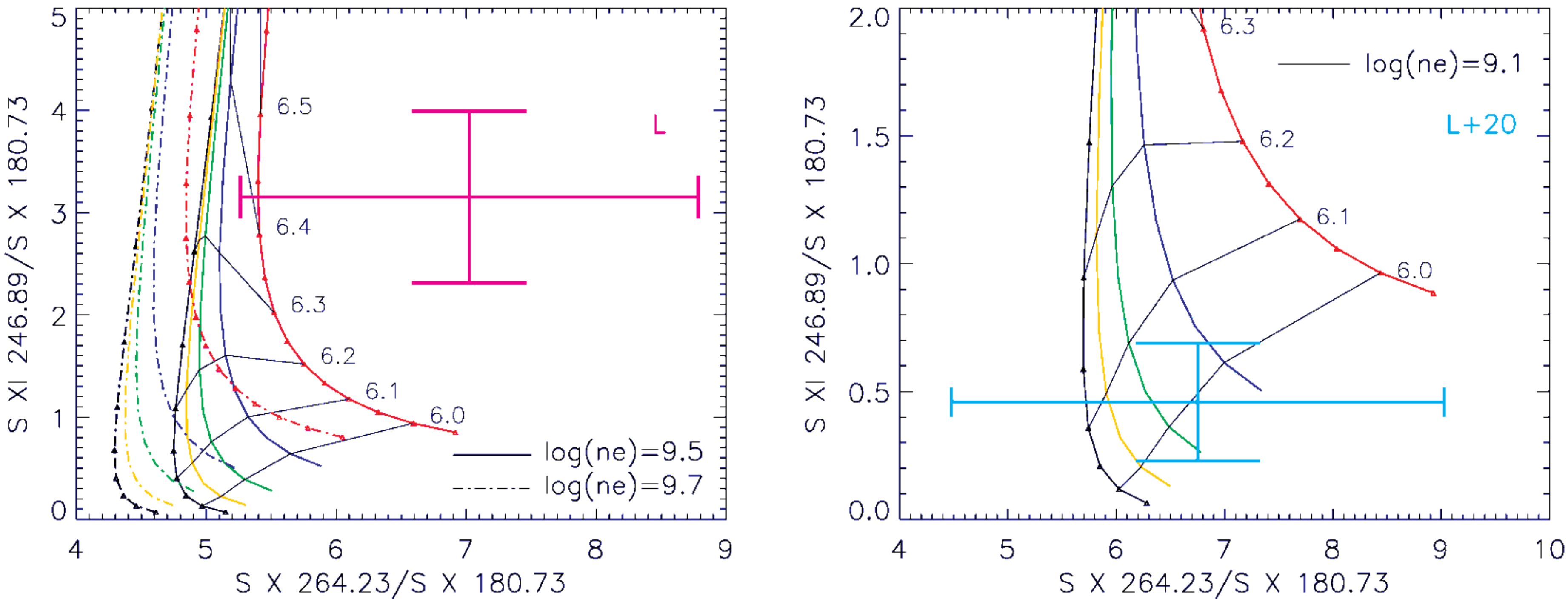


Fe XII (186.85+186.88)/(195.12+195.18)
log(T)=5.85
log(T)=6.15
log(T)=6.40
log(T)=5.70
log(T)=6.25
log(T)=6.65
QS
L
L+20
log(ne) [cm^{-3}]
Fe XIII 196.53/202.04
log(T)=5.95
log(T)=6.20
log(T)=6.50
log(T)=5.70
log(T)=6.30
log(T)=6.70
QS
AR1
AR2
L
L+20
log(ne) [cm^{-3}]
Fe XIII (203.82+203.83)/202.04
log(T)=5.95
log(T)=6.20
log(T)=6.50
log(T)=5.70
log(T)=6.30
log(T)=6.70
QS
AR1
AR2
L
L+20
log(ne) [cm^{-3}]
Fe XIV 264.78/274.20
log(T)=5.10
log(T)=6.30
log(T)=6.80
log(T)=6.00
log(T)=6.45
log(T)=7.10
QS
AR1
AR2
L
L+20
log(ne) [cm^{-3}]

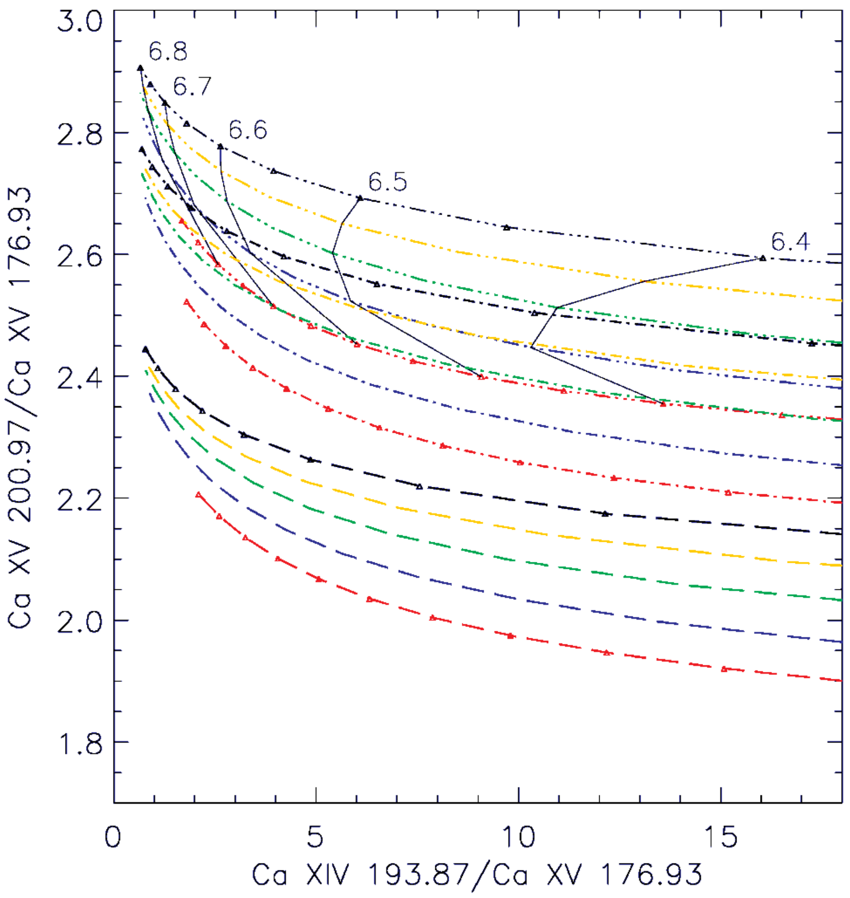
Density diagnostics – Fe ratios

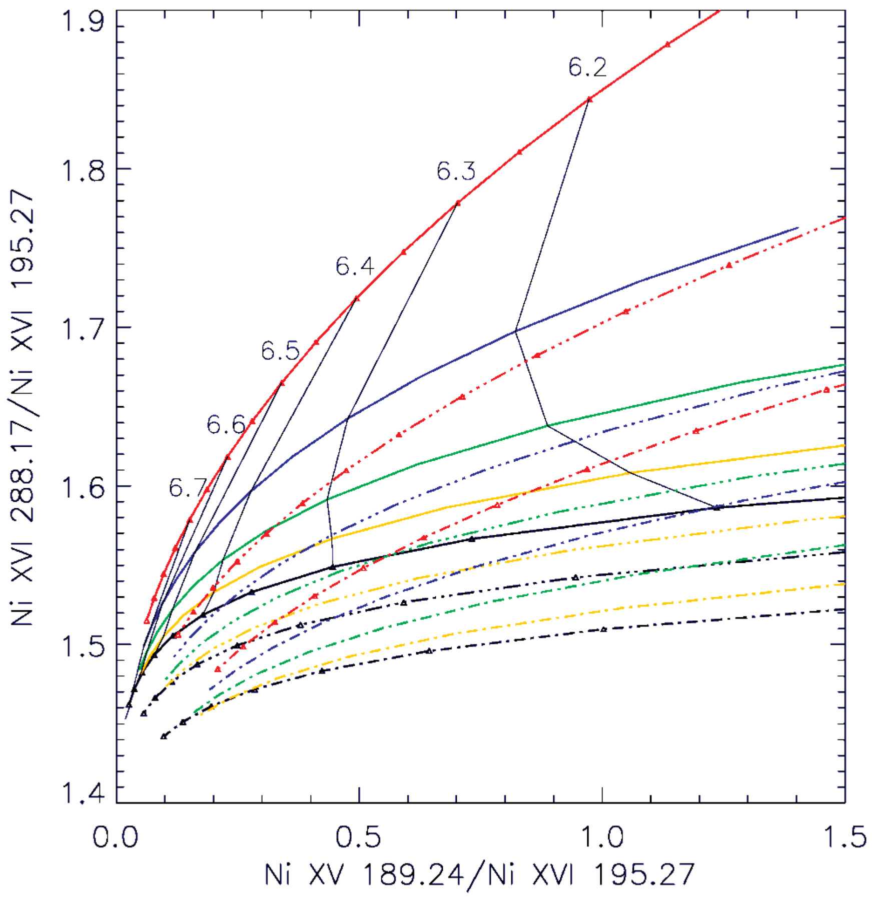
Ratio	Distr.	QS	AR1	AR2	L	L+20
Fe XII						
(186.85+186.88)/	Mxw	$9.15^{+0.17}_{-0.15}$	saturated	saturated	$^{\dagger}11.02^{+0.16}_{-0.11}$	$^{\dagger}9.93^{+0.18}_{-0.16}$
(195.12+195.18)	$\kappa = 2$	$9.09^{+0.15}_{+0.04}$	saturated	saturated	$^{\dagger}11.03^{\ddagger}$	$^{\dagger}9.85^{+0.17}_{+0.09}$
Fe XIII	Mxw	$9.14^{+0.19}_{-0.15}$	$9.45^{+0.16}_{-0.13}$	$9.06^{+0.19}_{-0.14}$	$9.85^{+0.17}_{-0.14}$	$9.18^{+0.19}_{-0.14}$
196.53/202.04	$\kappa = 2$	$9.03^{+0.19}_{-0.25}$	$9.34^{+0.17}_{-0.22}$	$8.96^{+0.18}_{-0.25}$	$9.74^{+0.18}_{-0.18}$	$9.07^{+0.18}_{-0.25}$
Fe XIII						
(203.82+203.83)/	Mxw	$9.02^{+0.17}_{-0.12}$	$9.33^{+0.17}_{-0.11}$	$9.02^{+0.16}_{-0.12}$	$9.86^{+0.16}_{-0.12}$	$9.10^{+0.17}_{-0.12}$
202.04	$\kappa = 2$	$8.92^{+0.18}_{-0.24}$	$9.24^{+0.17}_{-0.20}$	$8.92^{+0.17}_{-0.23}$	$9.80^{+0.15}_{-0.13}$	$9.01^{+0.18}_{-0.24}$
Fe XIV	Mxw	$8.99^{+0.32}_{-0.21}$	$9.51^{+0.24}_{-0.11}$	$8.94^{+0.28}_{-0.17}$	$9.68^{+0.24}_{-0.13}$	$9.13^{+0.29}_{-0.17}$
264.78/274.20	$\kappa = 2$	$8.91^{+0.36}_{-0.32}$	$9.43^{+0.28}_{-0.23}$	$8.86^{+0.32}_{-0.27}$	$9.60^{+0.28}_{-0.25}$	$9.05^{+0.33}_{-0.29}$
mean	Mxw	$9.08^{+0.21}_{-0.15}$	$9.44^{+0.19}_{-0.12}$	$9.01^{+0.21}_{-0.14}$	$9.80^{+0.19}_{-0.13}$	$9.14^{+0.22}_{-0.15}$
	$\kappa = 2$	$8.99^{+0.22}_{-0.30}$	$9.34^{+0.22}_{-0.22}$	$8.91^{+0.23}_{-0.25}$	$9.72^{+0.20}_{-0.17}$	$9.04^{+0.24}_{-0.26}$

Diagnostics of κ – density dependent

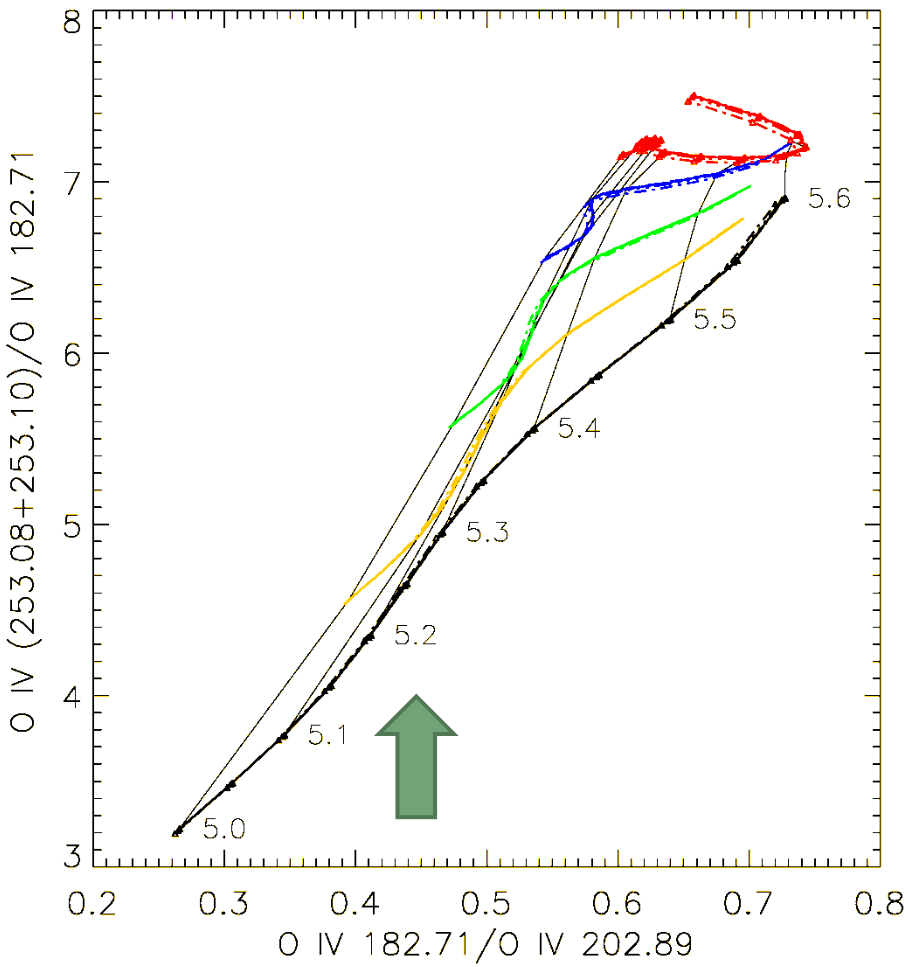


Diagnostics of κ – density dependent



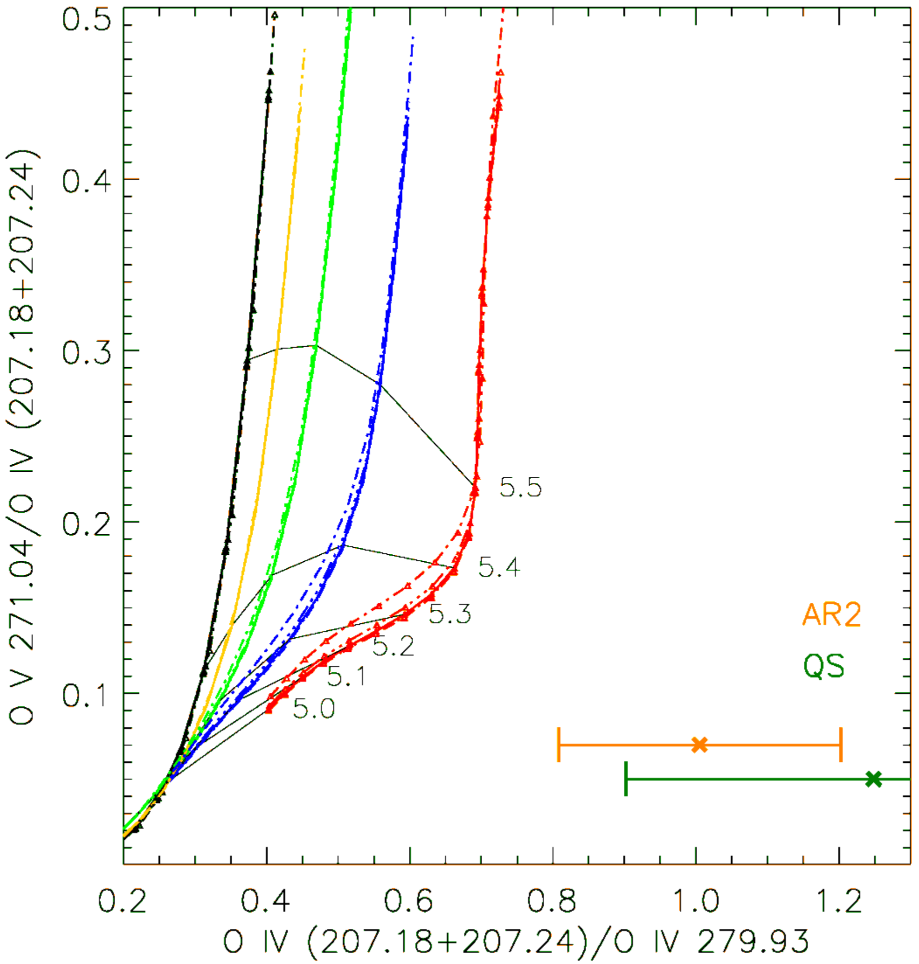


Diagnostics of κ – density independent



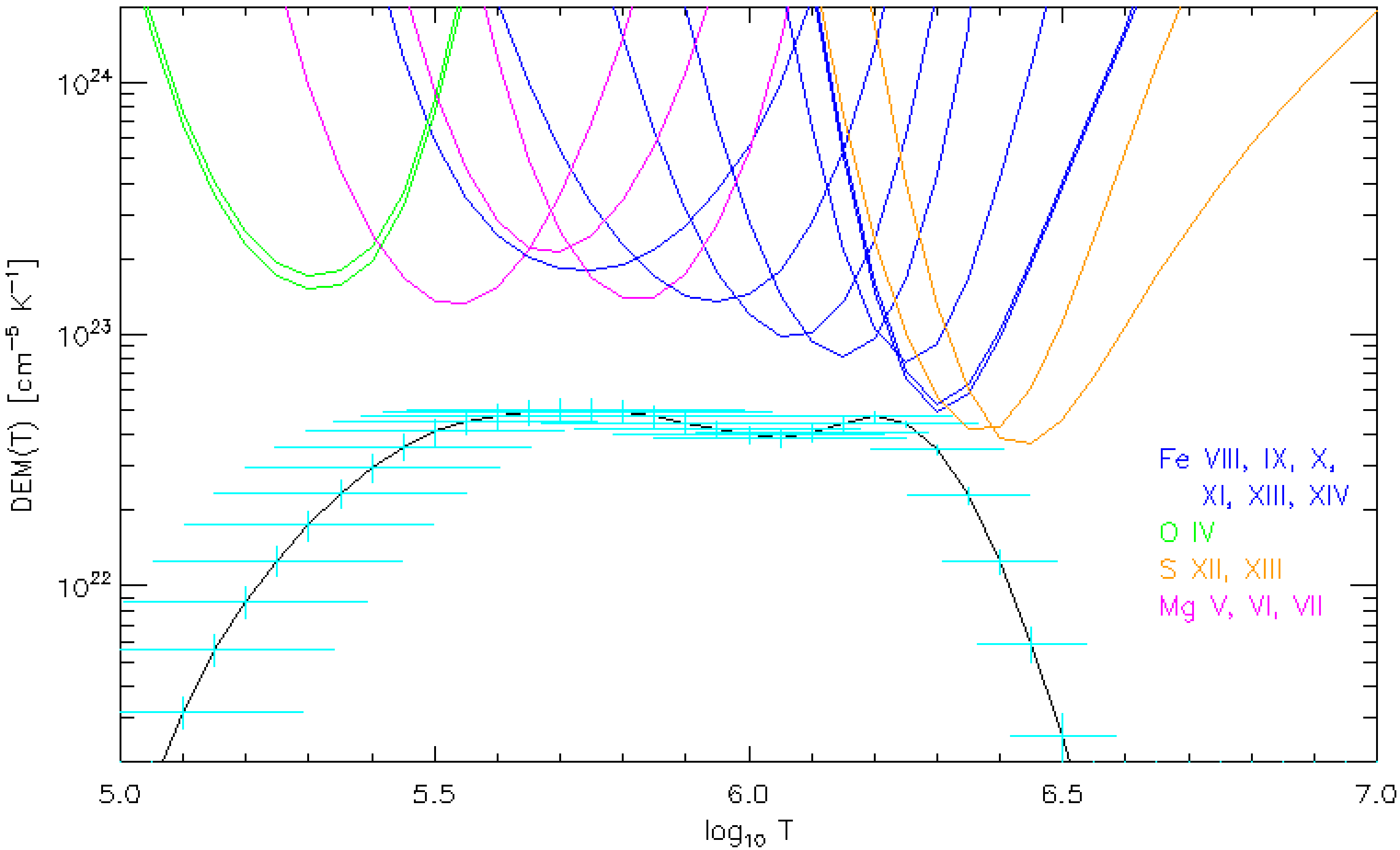
- Density independent
- Single-ion diagnostics
- Great diag. opportunity
- O IV log(T_{max}/K) = 5.2
- Weak lines – long exposures are required

Diagnostics of κ – density independent



- Data only for 1 ratio on x-axis
- The distribution is unlikely to be Maxw.
- Blend with Mg IX 207.2 Å lines

DEM analyse => the removing of blends



Maxwellian DEM for AR2. Regularized inversion method (Hannah & Kontar (2012))

Suitable line ratios for the κ – distr. diagnostics

Pairs of the line ratios *(wavelength in Å)*
O IV 182.71 / O IV 202.89† – O IV (207.18 + 207.24) / O IV 202.89†
O IV 182.71 / O IV 202.89† – O IV (207.18 + 207.24) / O IV 203.04
O IV 182.71 / O IV 202.89† – O IV (253.08 + 253.10)‡ / O IV 182.71
O IV 182.71 / O IV (271.57 + 271.58) – O IV (207.18 + 207.24) / O IV 182.71
O IV (207.18 + 207.24) / O IV 279.93 – O V 271.04 / O IV (207.18 + 207.24)
O IV (207.18 + 207.24) / O IV 279.93 – O V 271.04 / O IV 279.93
Ca XIV 193.87 / Ca XV 176.93 – Ca XV 200.97 / Ca XV 176.93
Ca XIV 193.87 / Ca XV 176.93 – Ca XV 200.97 / Ca XV 182.87♮
Ni XV 189.24 / Ni XVI 195.27♯ – Ni XVI 288.17 / Ni XVI 195.27
S X 264.23 / S X 180.73 – S X 264.23 / S XI 246.89
S X 264.23 / S X 180.73 – S X 246.89 / S XI 180.73

4. Conclusions

- Proposed the diagnostic method of the *κ, T,* n_e
- Used CHIANTI and data from Hinode/EIS
- Choose useful EUV line ratios for the diagnostics
- Try to diagnose presence of κ-distribution
- Proper data are needed – EIS proposal in progress
- DEM for κ-distributions are planned

Answers

- Are κ-distributions present in the solar corona?

  Probably – new data are required

- Can we diagnose κ-distributions from the spectroscopic data?

  YES – take care about all possible errors

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Thank you for your attention