KAPPA Package: Multi-Ionization and Suppression of Dielectronic Recombination for the Ionization Equilibria of Kappa Distributions

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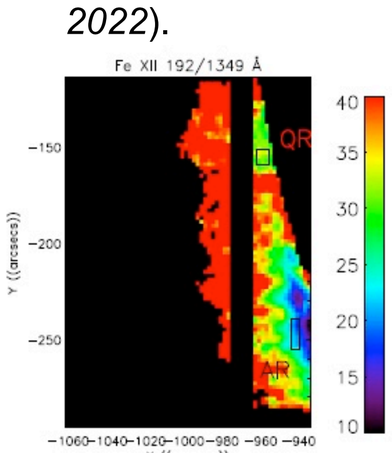
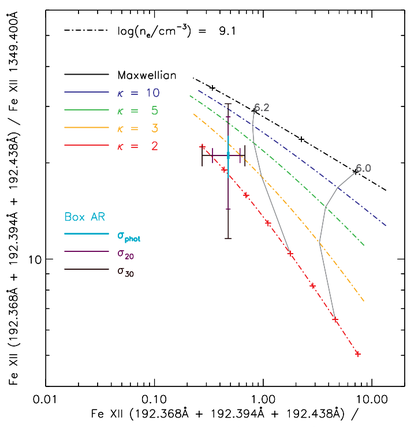
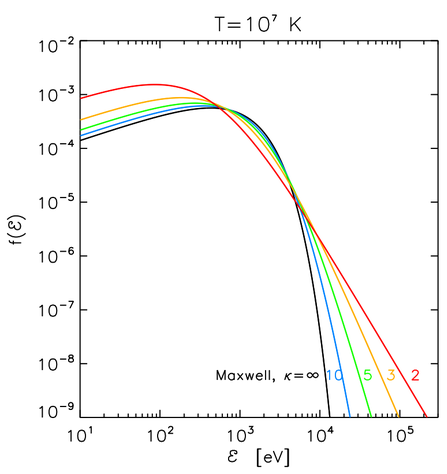
Motivation

- Supra-thermal component ("high-energy tail") of the particle distribution is observed in flares and solar wind (*Maksimovic et al., 1997 GeoRL 24, 1151; Livadiotis et al., 2018, ApJ 853, 142*).
- Non-Maxwellian distributions with a high energy tail – result of the strong gradient temperature and/or density (e.g. *Roussel-Dupré 1980; Shoub 1983; Bradshaw et al. 2012*), heating, reconnection (*e.g. Testa et al. 2014; Klimchuk 2010; Gontikatis et al. 2013*), presence of some type of waves (*e.g. Vocks & Mann 2003; Vocks et al. 2008).*
- κ-distribution with κ=2-3 was diagnosed in the solar active region (*Del Zanna et al., 2022*).





Non-thermal κ-distribution



$$\langle E_\kappa \rangle = \frac{3}{2} kT$$

$$p = nkT$$

$$E \to \infty:$$

$$f(E) \approx const. \times E^{-(\kappa+0.5)}$$

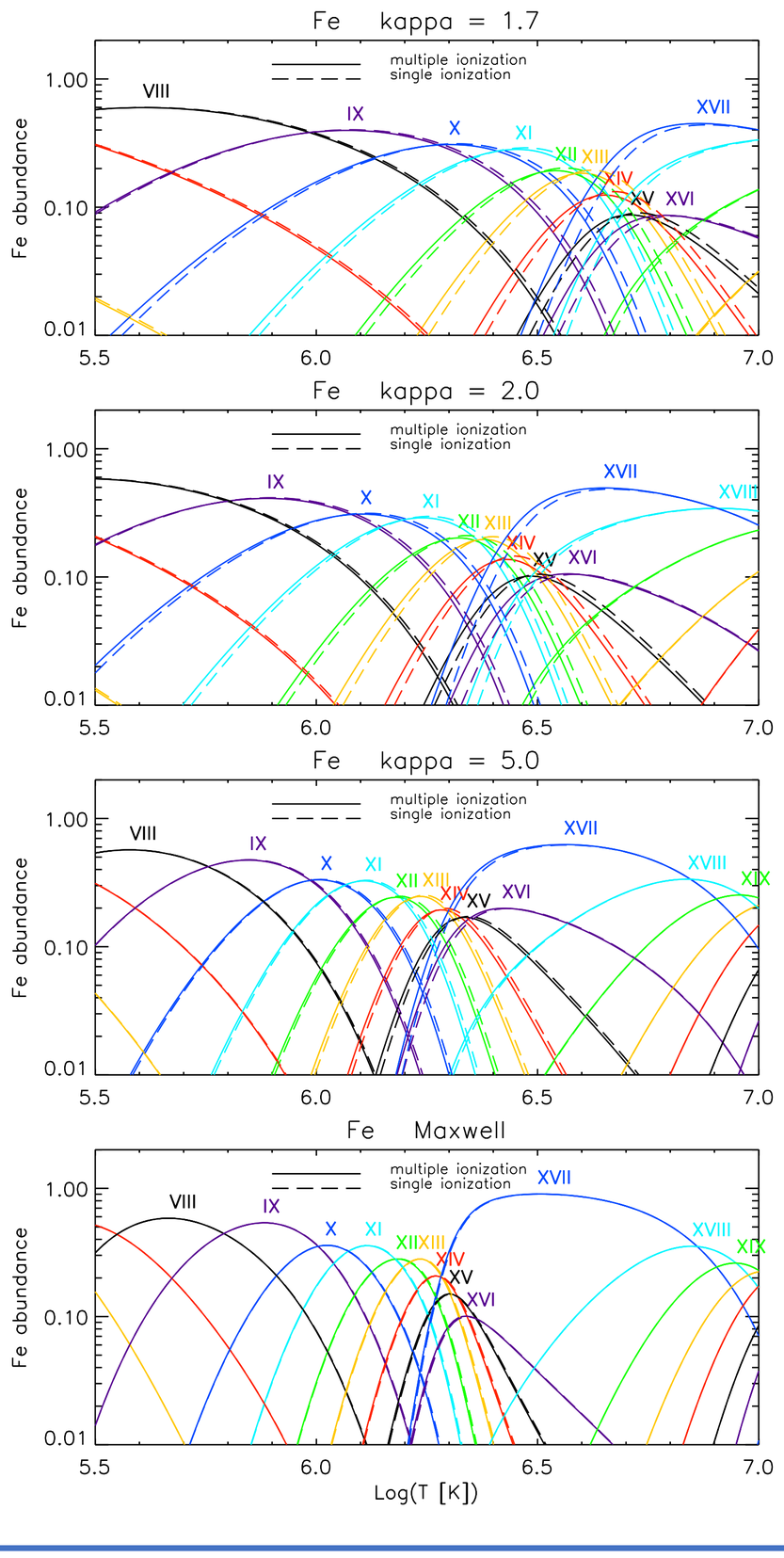
Strong nonthermal k-distribution becomes Maxwellian for $\kappa \to \infty$.

Maxwellian distribution (black line) and κ-distributions for κ = 2 (red), 3 (orange), 5 (green), and 10 (blue line).

Ionization equilibria with multi-ionization

Data: Hahn *et al*. (2017)

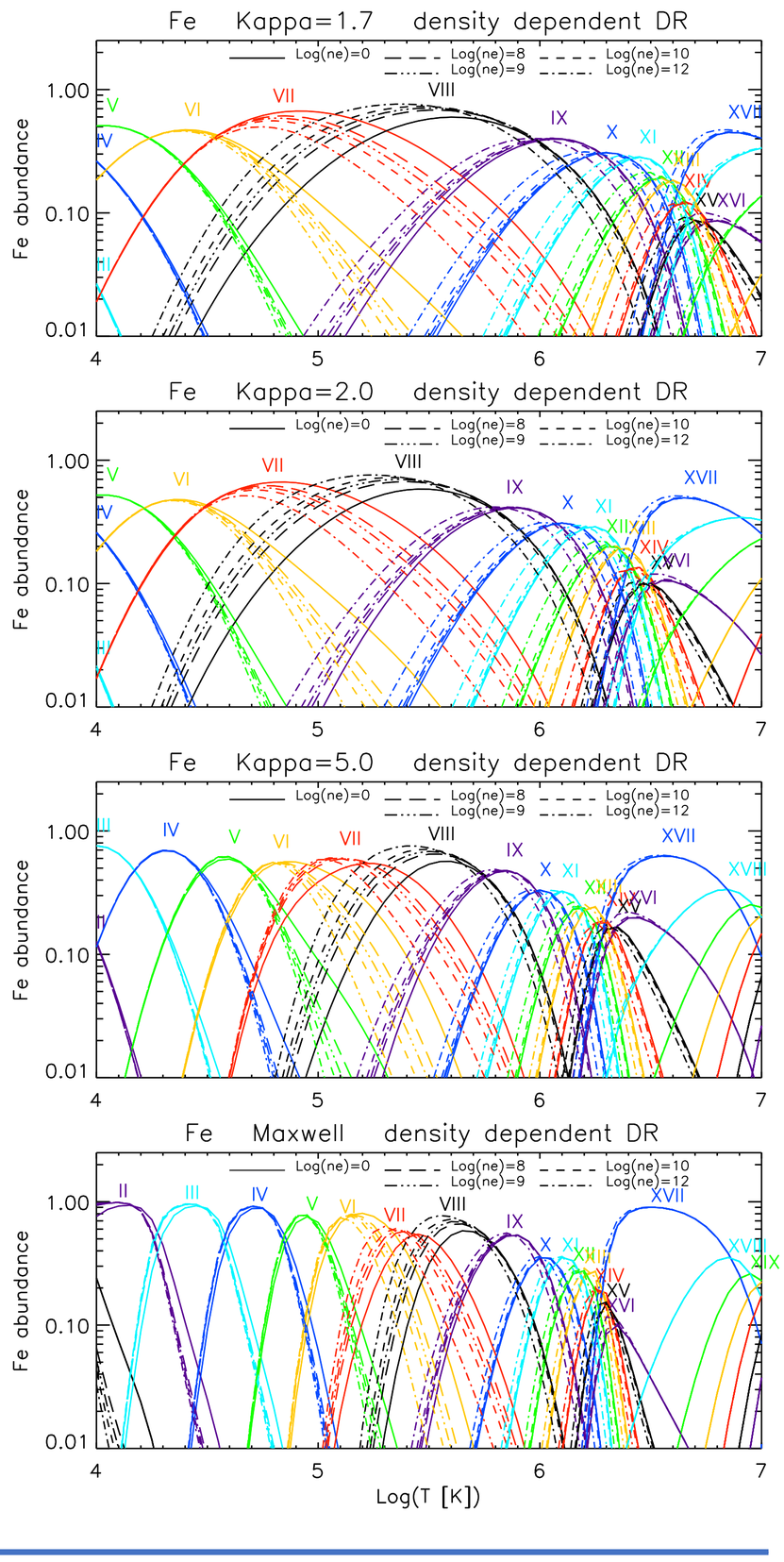
Effect of the multi-ionization on the ionization equilibrium for κ-distribution increases with decreasing κ. it is different for different element and ions. For Maxwellian distributions, this effect can be usually neglected.



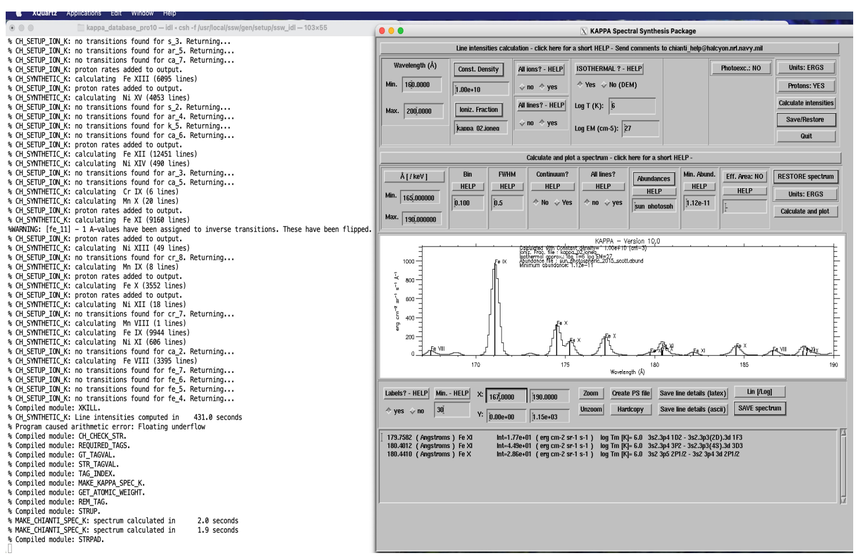
Density suppression of dielectronic recombination

Data: Nikolić *et al*. (2013, 2018)

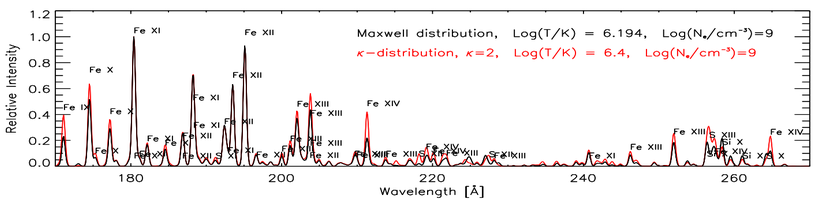
Suppression of dielectronic recombination is similar for κ-distributions and Maxwellian distribution and it is different for different element and ions. The most affected are transition region ions.



KAPPA package



- KAPPA package (*http:/kappa.asu.cas.cz*) was developed to synthesise optically thin line and continuum spectra for non-thermal κ-distributions.
- KAPPA database contains the ionization and recombination rates together with new density dependent ionization equilibria for κ = (1.7; 33). Tools for calculation of synthetic line and continuum intensities are provided and described.
- KAPPA package is based on the freely available CHIANTI database and software. Latest version (*Dzifčáková et al. 2023, ApJS 269, 45)* corresponds to the latest CHIANTI database 10.1 and includes the software improvements of CHIANTI 10.2 for the calculation of the synthetic spectra (*Del Zanna et al., 2021, ApJ, 909, 38*). Extended KAPPA database contains all atomic data necessary for the calculation of the synthetic spectra for κ-distributions to reduce confusions when using different versions of CHIANTI.



Synthetic EIS spectrum calculated for the Maxwellian distribution (black line) and κ-distributions for κ = 2 (red) using KAPPA package. The ratio of intensity of Fe XI 180.40 Å line to Fe XII 195.12 Å line is the same for both distributions.

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