Astronomical Institute of the Czech Academy of Sciences

KAPPA package - the latest update

E. Dzifčáková[1], J. Dudík[1], J. Lörinčík[1,2], A. Zemanová[1]

[1]*Astronomical Institute of the Czech Academy of Sciences, Fričova 298, 251 65 Ondřejov, Czech Republic*

[2]*Institute of Astronomy, Charles University, V Holešovičkách 2, 18000 Prague 8, Czech Republic*

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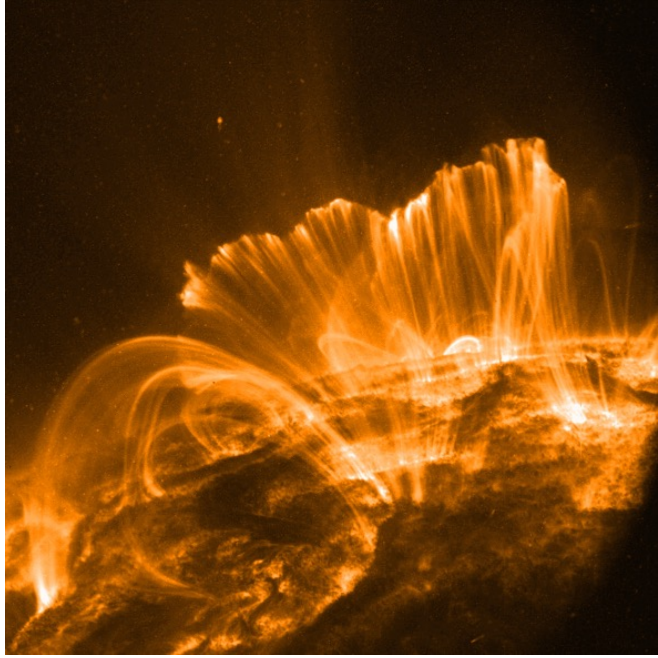
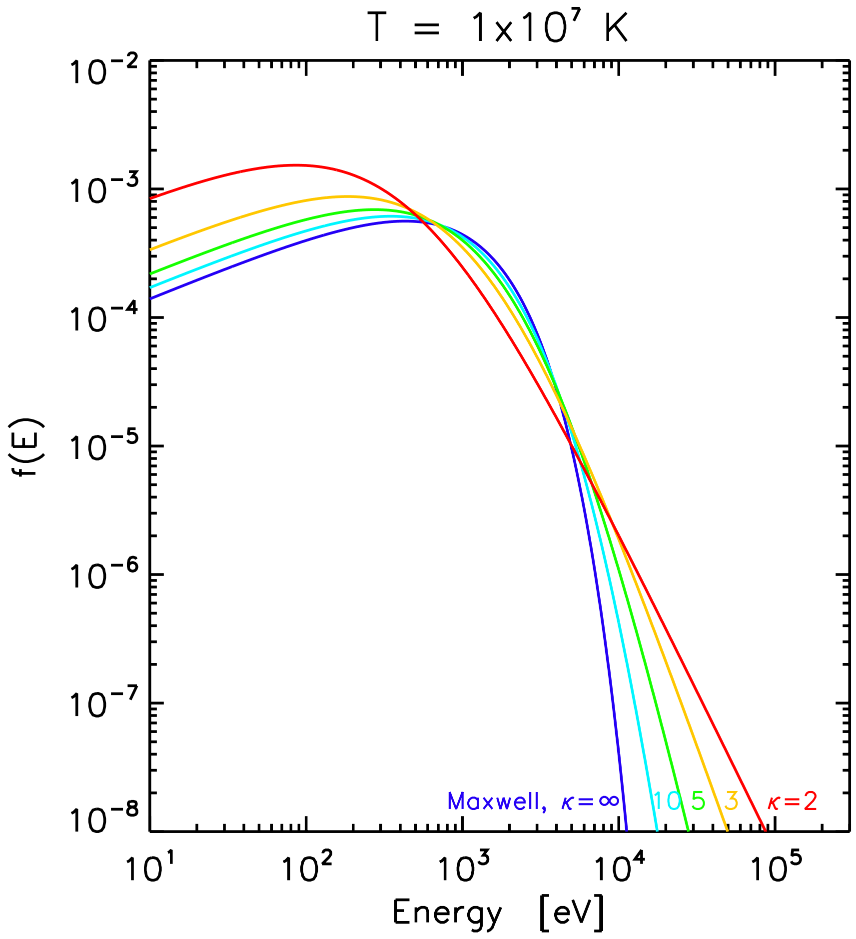
Motivation



- plasma emission analysis – we need to know microphysics
- non-equilibrium processes affect observed plasma parameters
- “high-energy tail” - solar flares and solar wind
- flares - κ-distributions supported by the stochastic acceleration models (e.g. *Bian et al. 2014*)
- coronal sources of X-ray emission can be described by κ-distributions (e.g. *Kašparová & Karlický 2009; Oka et al. 2013, 2015; Battaglia et al. 2015*)
- physical background of the κ-distributions is well established (e.g. *Livadiotis 2017*) and connected with extensive statistical mechanics (*Tsallis 1988, 2009*)
- distributions with an enhanced high energy tail can be formed in corona due to heating (micro-flares or waves)
- high–energy particles affect the ionization and excitation state -> changes in the line intensities

Kappa-distribution



The κ-distributions with a constant temperature of T = 10^7K. The values of κ are indicated by colors. The κ-distributions have the same mean energy of particles.

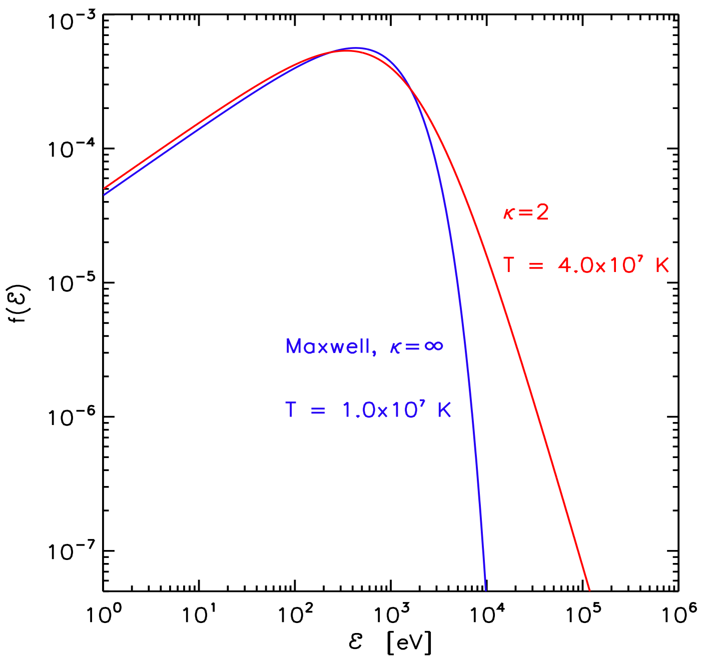
$$f_\kappa(E) = A_\kappa \frac{2E^{1/2}dE}{\pi^{1/2}(kT)^{3/2}}\left(1+\frac{E}{(\kappa-1.5)kT}\right)^{-(\kappa+1)}$$

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

$$p = nkT$$

$$E \to \infty:$$

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

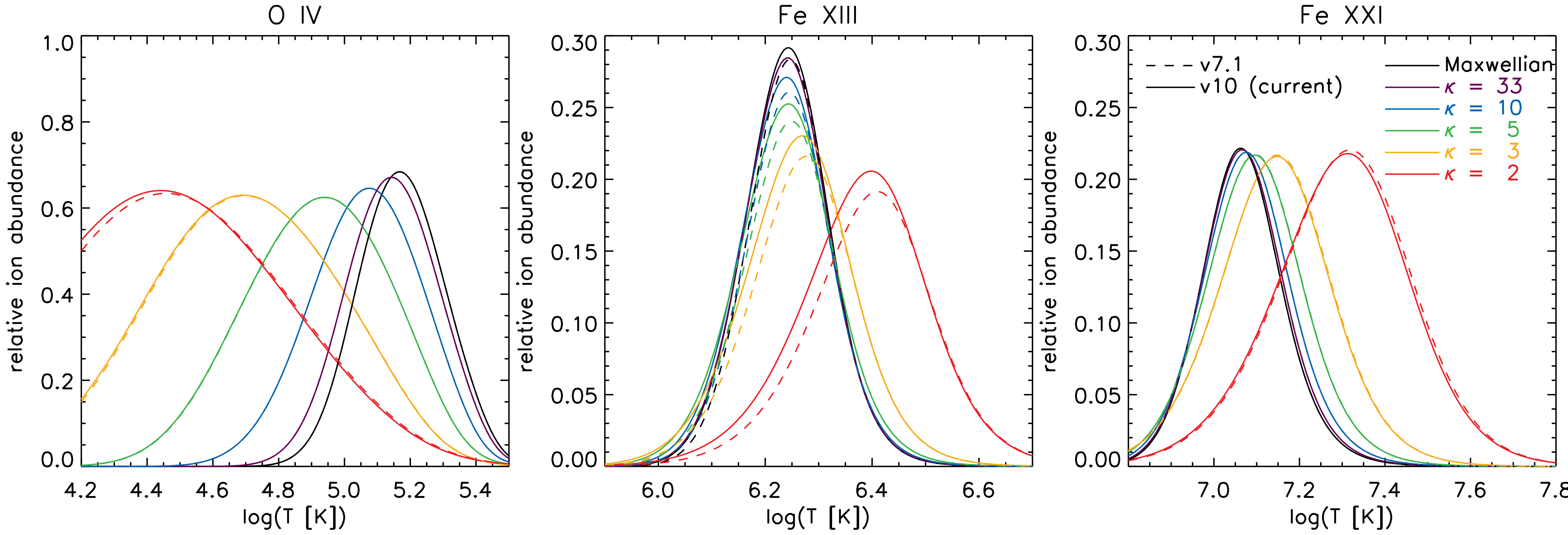


The Maxwellian distribution *(blue)* and κ-distribution with κ=2 *(red)* with the same temperature corresponding to their cores, $T_{c,Mxw} = T_\kappa\, \kappa / (\kappa - 1.5)$.

KAPPA package

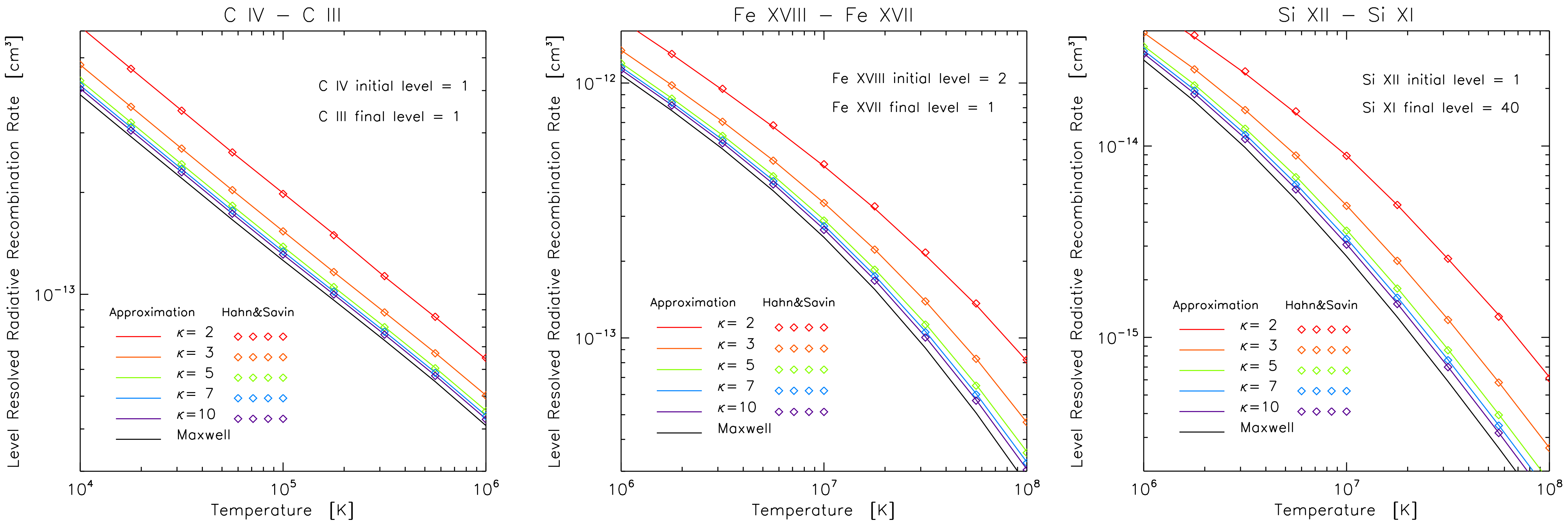
- KAPPA package (http://kappa.asu.cas.cz/) is a database and software package for calculations of optically thin synthetic spectra for non-thermal kappa-distributions in the solar transition region or in the corona
- New version of the KAPPA is based on the CHIANTI database and software version 10 (*Del Zanna et al., 2021*)
- Following CHIANTI 10, KAPPA package now contains numerous and significant improvements:
  - updated rate coefficients for ionization, recombination, ionization equilibria, and especially excitation,
  - terms of departing from the coronal approximation: ionization and recombination from/to excited levels that modify the level population (two ions model)
- Excitation rates are for κ-distributions are calculated from Maxwellian rates using approximation functions depending on the type of transition (*Burgess and Tully, 1992*). The method was tested by *Dzifčáková & Mason (2008)*
- The effect κ-distribution on the excitation rates depends on the type of atomic transition and ratio of the excitation energy to temperature. These changes are manifested in observed spectrum and allow us to diagnose κ-distributions

Ionization equilibrium



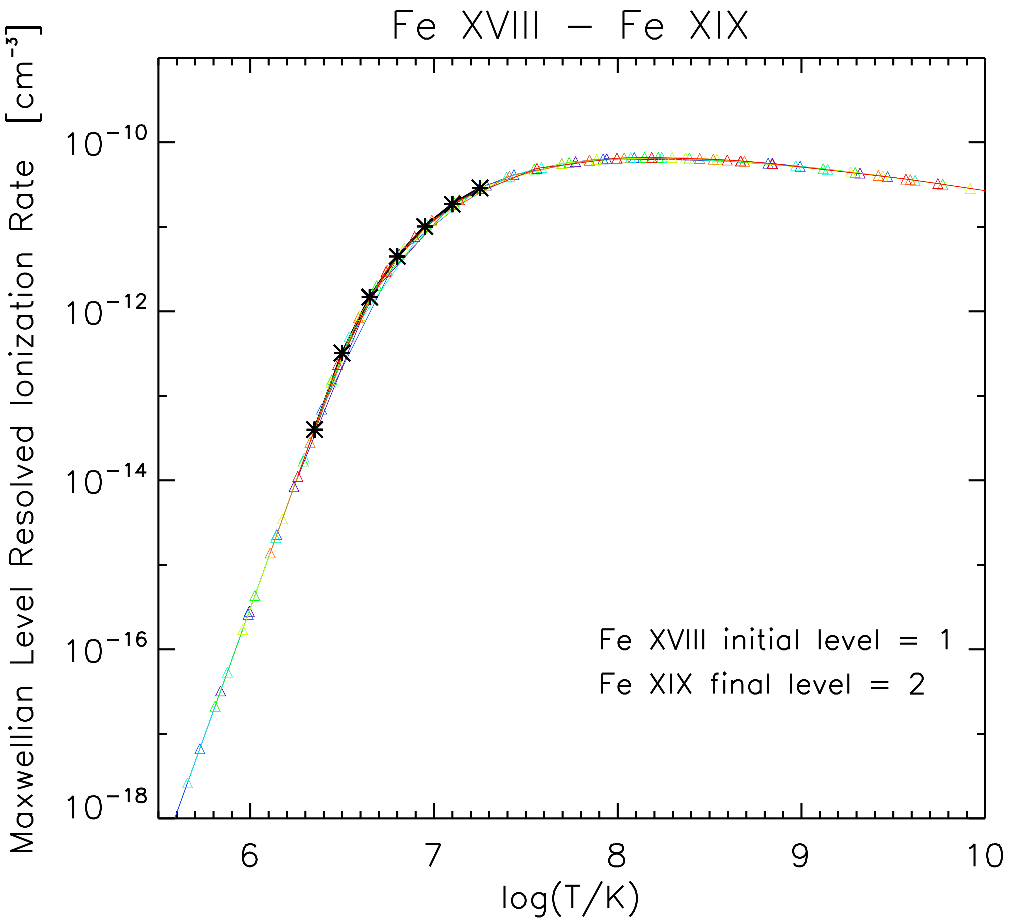
Behavior of the relative ion abundances with κ. O IV from the transition region (left), Fe XIII, a coronal ion, and Fe XXI, which occurs during solar flares. Different colors denote different values of κ. Full lines correspond to new calculations in the current version of KAPPA (and CHIANTI version 10), while the dashed ones show calculations from the previous version of KAPPA (CHIANTI version 7.1).

Level resolved recombination rates

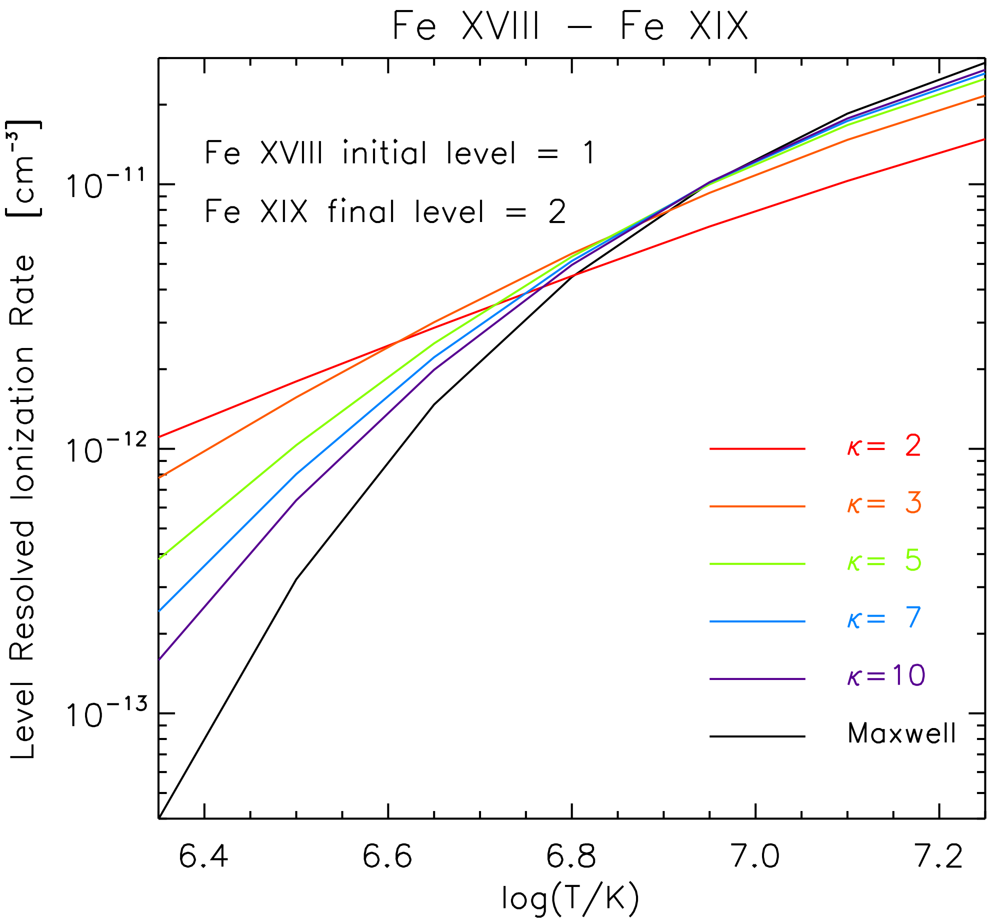


Comparison of level resolved radiative recombination rate calculated using our approximations (full lines) with the approximation of Hahn & Savin (2015) (diamonds) for transition from ground level $1s^2\ 2s\ ^2S_{0.5}$ of C IV to ground level $2s^2\ ^1S_0$ of C III (*left*), from initial level $2p^5\ ^2P_{0.5}$ of Fe XVIII to ground level $2p^6\ ^1S_0$ of Fe XVII (*middle*), and from ground level $1s^2\ 2s^2\ ^2S_{0.5}$ of Si XII to level $2p\ 3d\ ^3D_3$ of Si XI (*right*). Individual colors represent different value of κ

Level resolved ionization rates

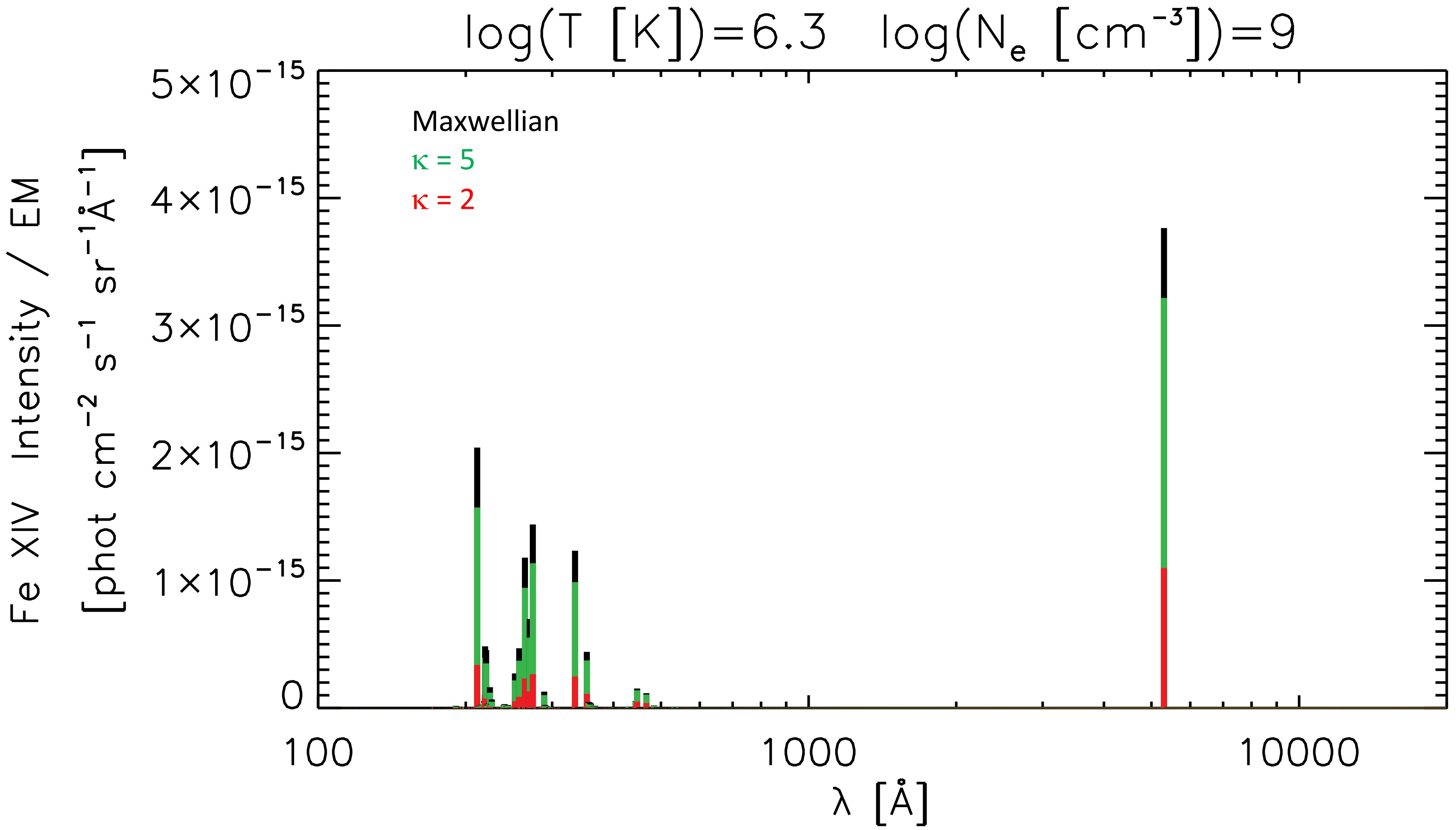


Extrapolation of level resolved ionization rate from ground level of Fe XVIII to level $2s^2\ 2p^4\ ^3P_0$ of Fe XIX. Black points correspond to rates tabulated in CHIANTI, while colored points denote temperatures for which Maxwellian rates are required to calculate the rates for κ-distributions using the by Hahn & Savin (2015) approximation.



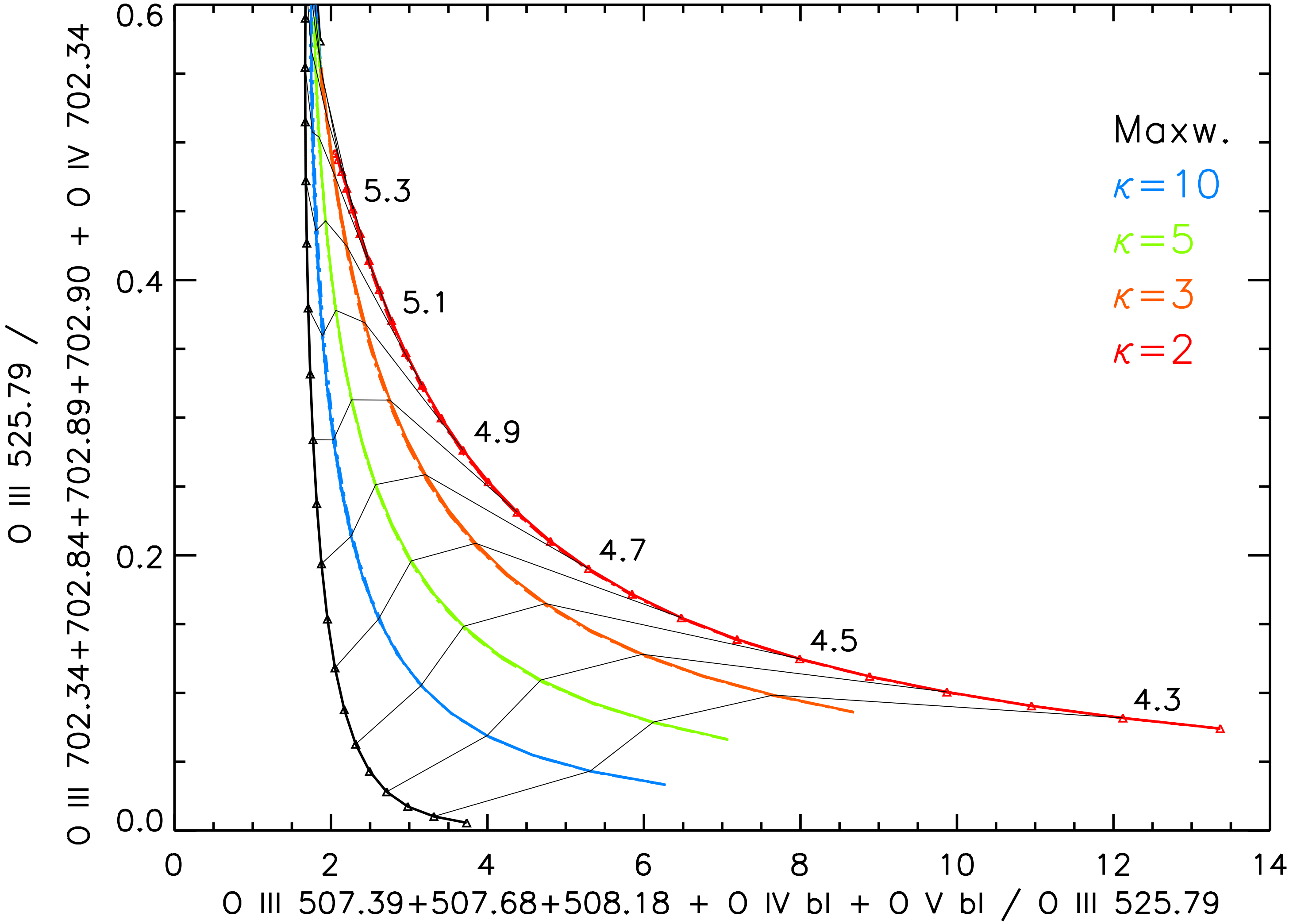
Ionization rates from ground level of Fe XVIII to level $2s^2\ 2p^4\ ^3P_0$ of Fe XIX for different κ-distributions calculated by Hahn & Savin (2015). Individual colors represent the value of κ.

Fe XIV Spectrum



Synthetic Fe XIV spectrum (photon units) from EUV to the infra-red spectrum. Individual colors represent the value of κ. The spectra are plotted for a constant log(*T* [K]) = 6.3 and constant log(*N*e [cm−3]) = 9.0. An emission measure of unity is assumed.

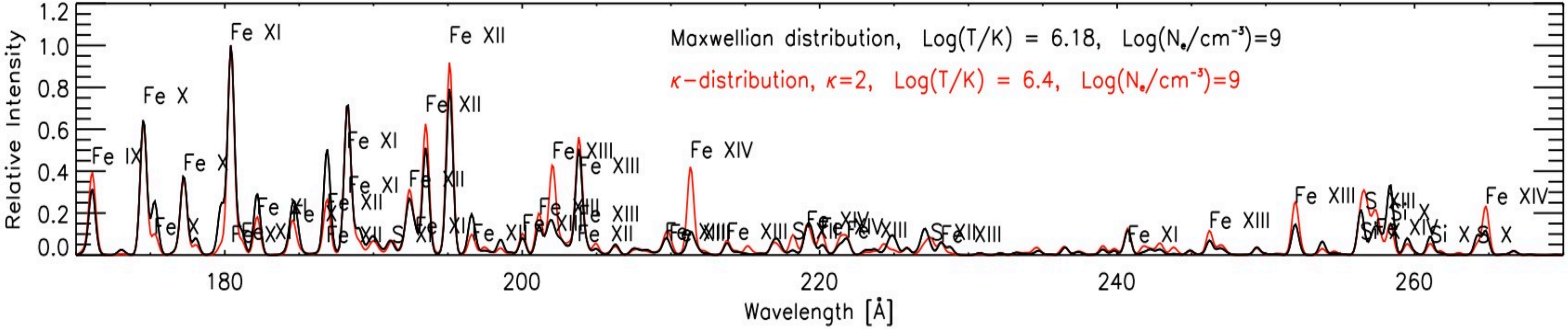
Diagnostics - SPICE



Example of ratio-ratio diagram (involving two line intensity ratios) sensitive to both *T* and κ, involving the O III lines together with their blends. The gray lines denote isotherms, with the values of log(*T* [K]) indicated.

This ratio-ratio diagram shows high to the κ-distributions:
a factor of **4** for log(T [K]) = 4.5!

Thank you very much!



Sofware and database: http://kappa.asu.cas.cz/

Dzifčáková *et al.*, 2021, "KAPPA: A Package for Synthesis of Optically Thin Spectra for the Non-Maxwellian κ-Distributions II. Major Update to Compatibility with CHIANTI version 10", *submitted to ApJS*