The effect of non-thermal distributions on coronal radiative losses

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Cambridge Workshop on Spectroscopy: Achievements and Future Challenges

Outline

I. **Introduction**

II. **κ–distributions**

Why κ–distributions?

Definition and basic properties

Contribution from the continuum

Bound-bound radiative losses, element contribution, Fe ions

Consequences

III. ***n*–distributions**

Why *n*–distributions?

Definition and basic properties, pseudotemperature

Bound-bound radiative losses, element contribution, Fe ions

Consequences

I. Introduction

- Emissivity ε_{ij} of a spectral line line – transition from the level i to level j in a k-times ionized element x is given by:

$$\varepsilon_{ij} = \frac{hc}{\lambda_{ij}} A_{ij} n_i = \frac{hc}{\lambda_{ij}} \frac{A_{ij}}{n_\mathrm{e}} \frac{n_i}{n^k} \frac{n^k}{n^x} A_x \frac{n_\mathrm{H}}{n_\mathrm{e}} n_\mathrm{e}^2$$

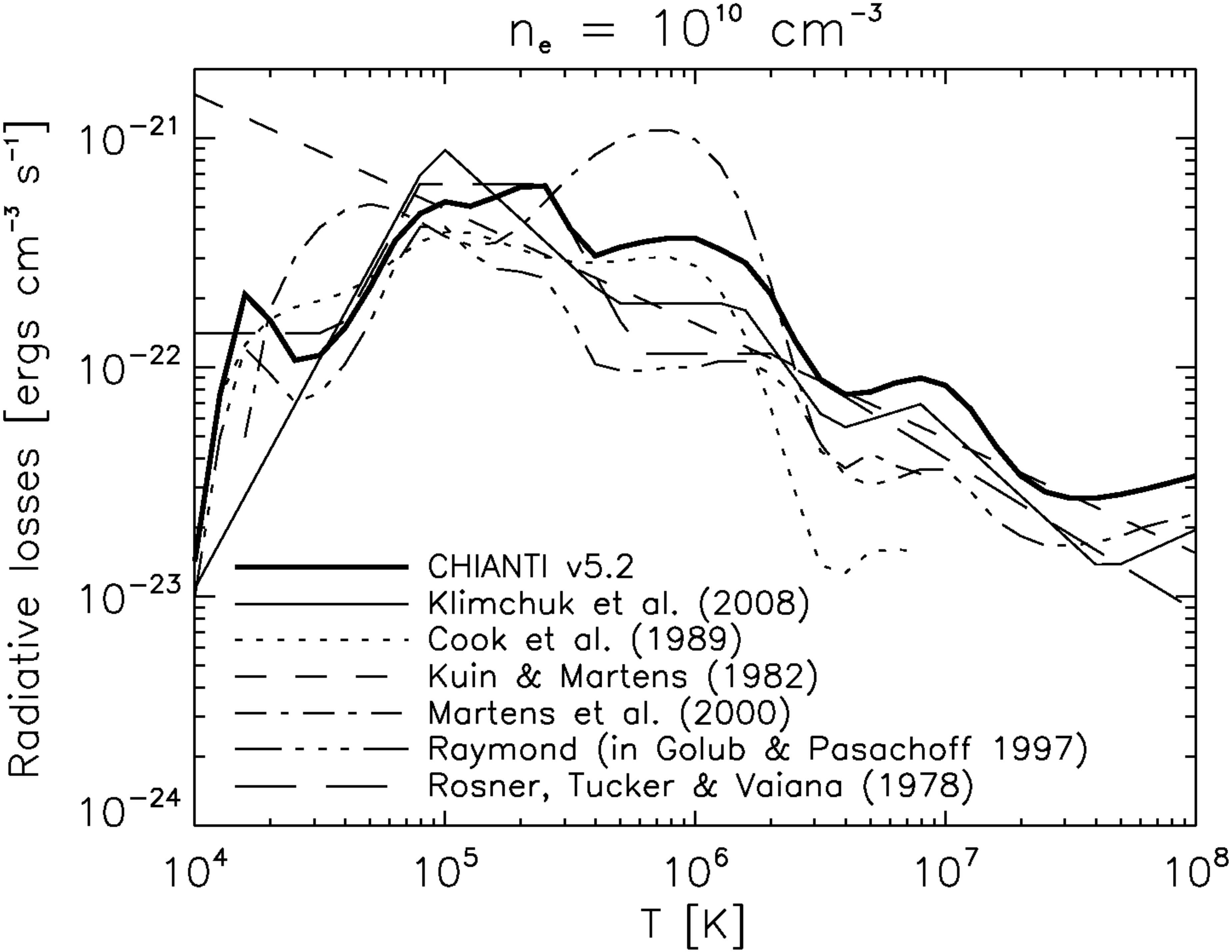
$$= G_{x,ij}(T, n_\mathrm{e}, A_x, \lambda_{ij}, \kappa) n_\mathrm{e}^2$$

- FIP effect

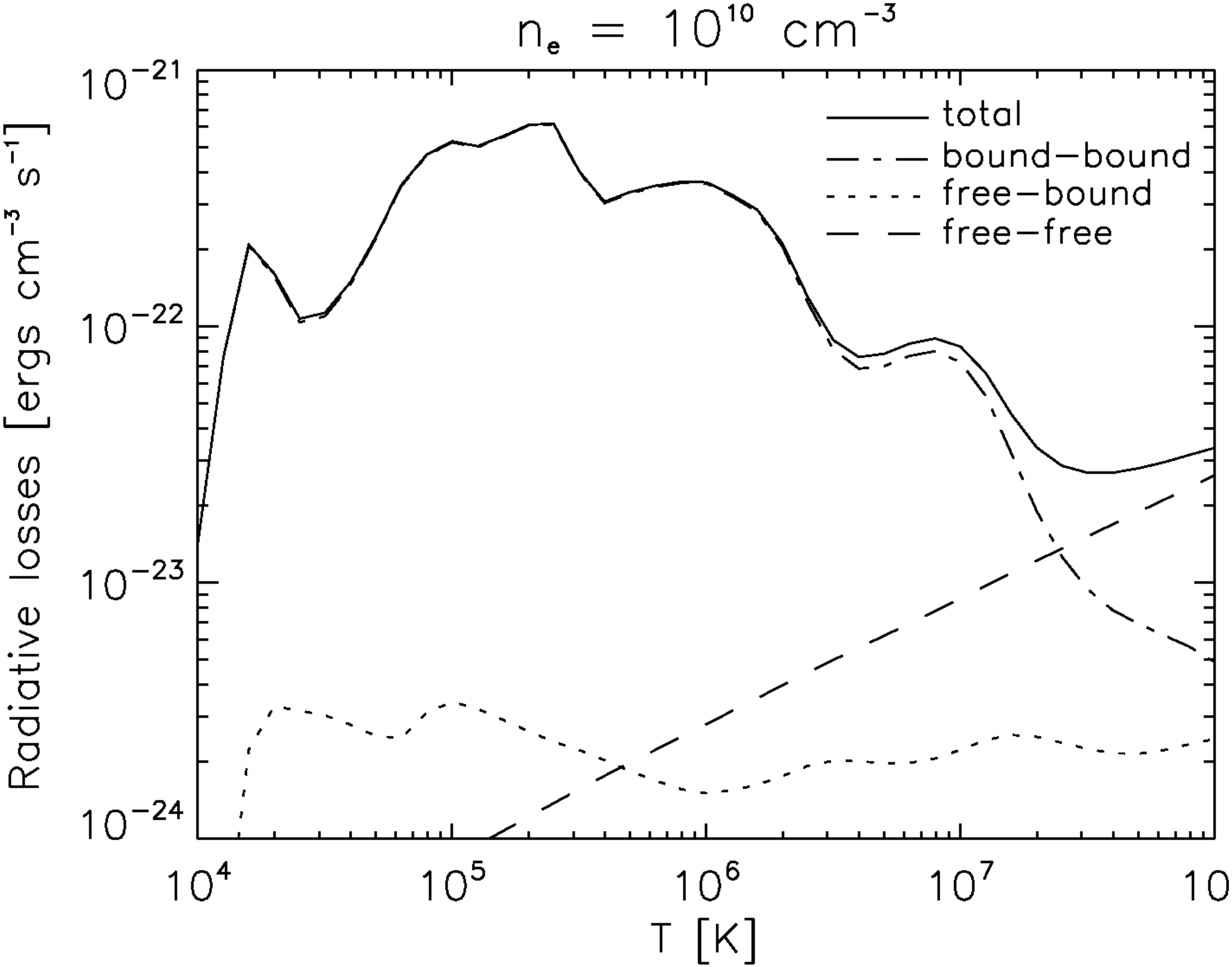
- Radiative losses E_R:

$$E_\mathrm{R}(T, n_\mathrm{e}, \kappa) = n_\mathrm{e}^2 \int \sum_{x,i,j} G_{x,ij}(A_x, \lambda_{ij}, T, n_\mathrm{e}, \kappa) d\lambda = n_\mathrm{e}^2 \Phi(T, \kappa)$$

$$-E_\mathrm{R}(T, n_\mathrm{e}, \kappa) + E_\mathrm{H} + \vec{\nabla}.\vec{F}_\mathrm{cond} = 0$$



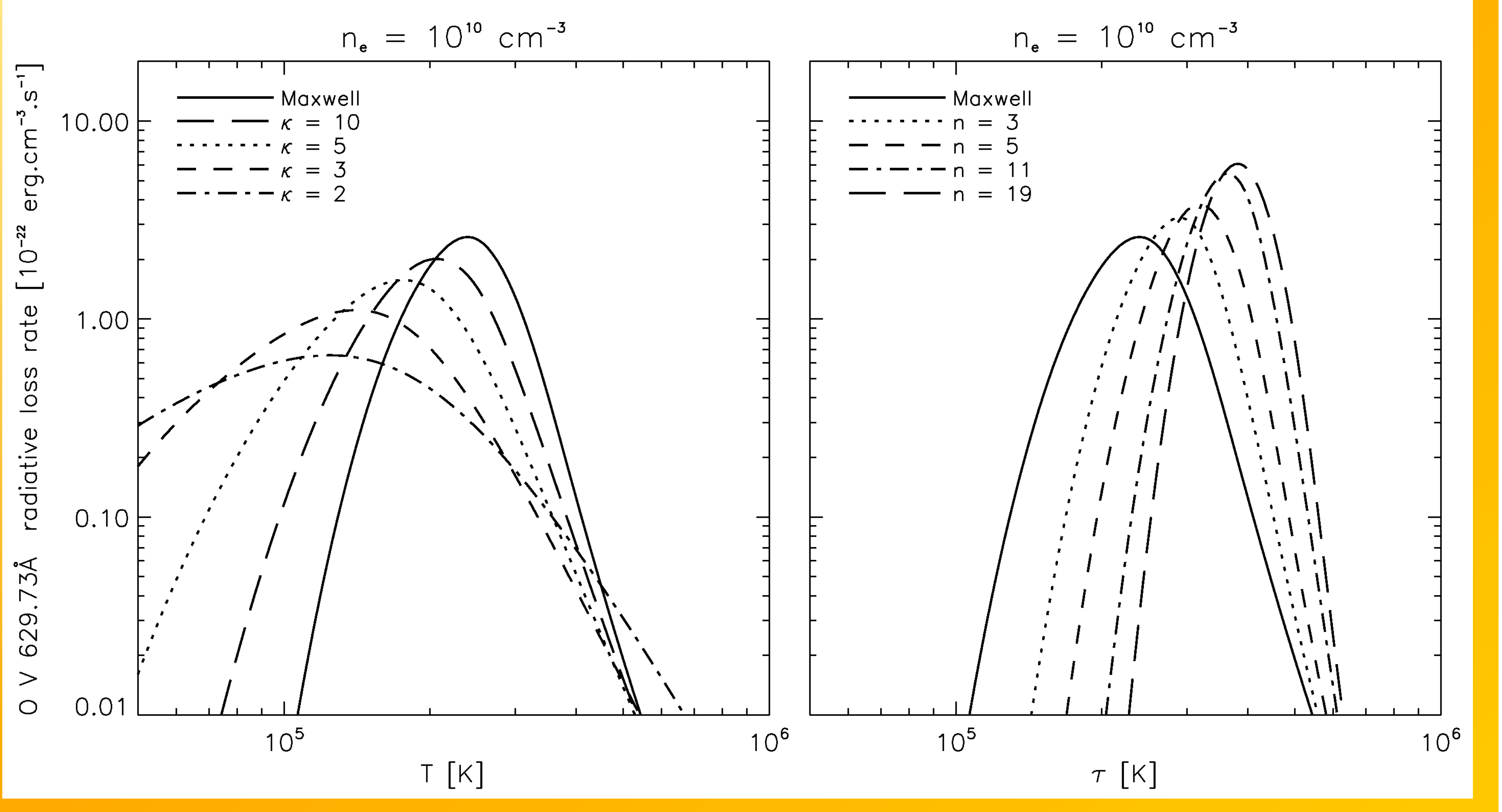
$n_e = 10^{10}$ cm^{-3}
Radiative losses [ergs cm^{-3} s^{-1}]
T [K]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^4
10^5
10^6
10^7
10^8
CHIANTI v5.2
Klimchuk et al. (2008)
Cook et al. (1989)
Kuin & Martens (1982)
Martens et al. (2000)
Raymond (in Golub & Pasachoff 1997)
Rosner, Tucker & Vaiana (1978)



$n_e = 10^{10}$ cm^{-3}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
Radiative losses [ergs cm^{-3} s^{-1}]
total
bound−bound
free−bound
free−free
10^4
10^5
10^6
10^7
10^8
T [K]

Synthetic spectra

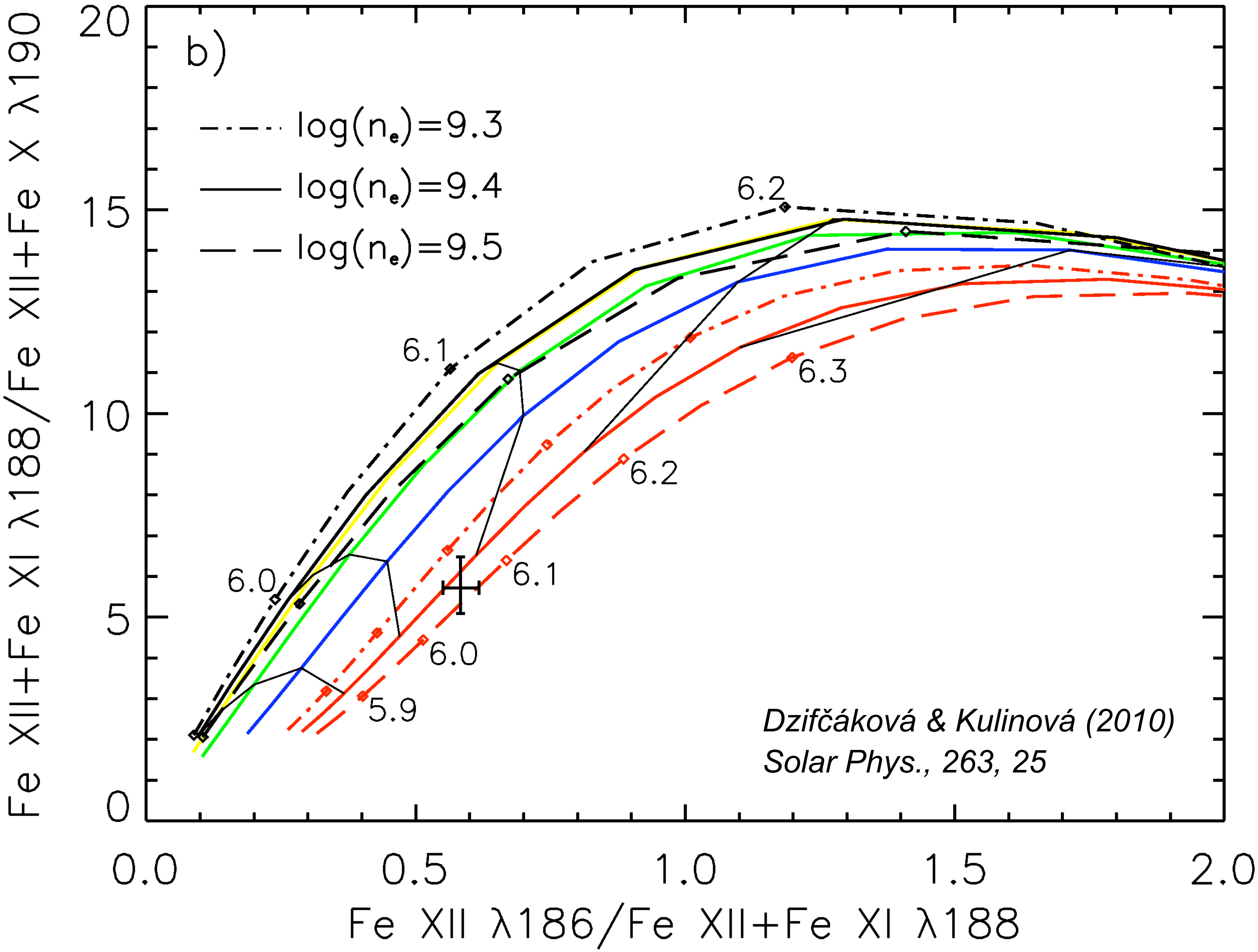
- Modification of CHIANTI, spectra for C,N,O,Ne,Mg,Al,Si,S,Ar,Ca,Fe,Ni



II. κ–distributions: why

- Study the emission – need to know about the microphysics
- Suprathermal component ("high-energy tail") present during flares and also in solar wind
- Maksimovic et al. (1997): solar wind velocity distribution is better approximated by one κ–distribution than with one or sum of two Maxwellians
- Collier (2004): if the mean particle energy is not held constant, the entropy is *not* maximalized by a Maxwellian distribution
- If the order of the mean energy conserved is, entropy is maximalized by the κ–distribution

- Dudík et al. (2009): considerable influence on the EUV filter responses
- Dzifčáková & Kulinová (2010a,b) - κ–distribution diagnosed in transition region spectra (Si III line ratios) and in flares (Fe XII line ratios)
- Their presence in AR corona is still an open question. Nevertheless...

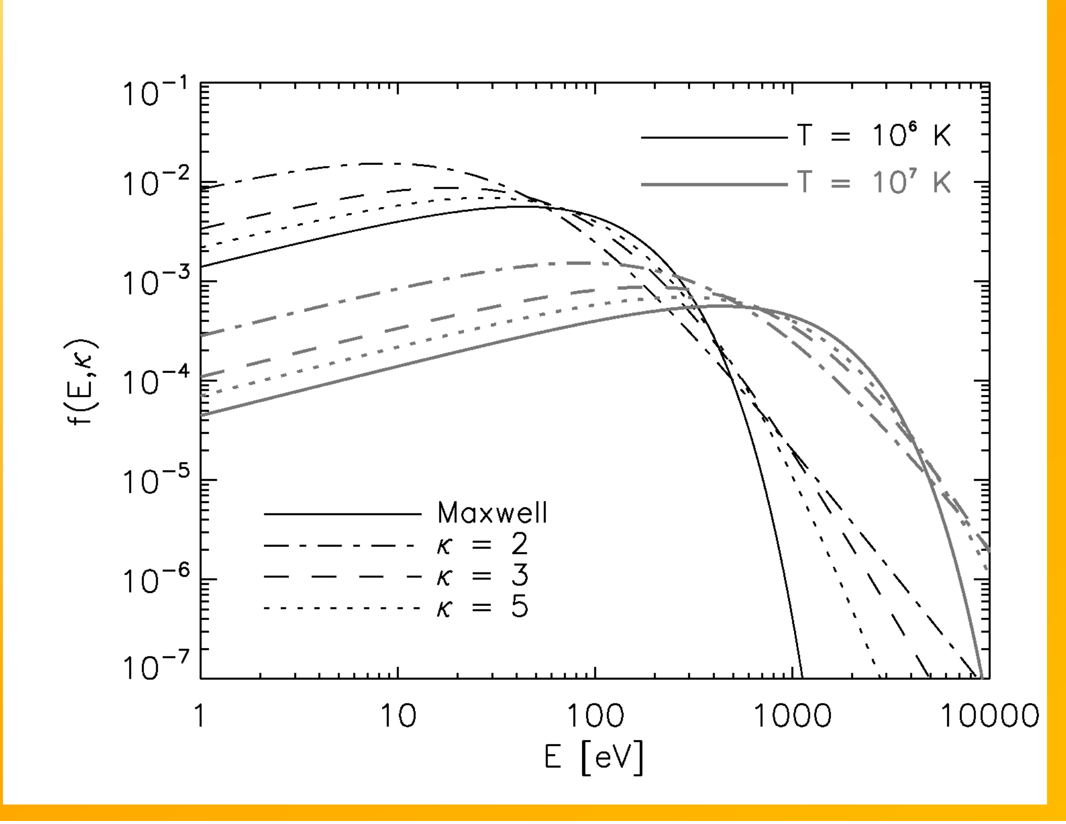


b)
log(n$_e$)=9.3
log(n$_e$)=9.4
log(n$_e$)=9.5
6.2
6.1
6.3
6.2
6.0
6.1
6.0
5.9
Dzifčáková & Kulinová (2010)
Solar Phys., 263, 25
0
5
10
15
20
0.0
0.5
1.0
1.5
2.0
Fe XII+Fe XI λ188/Fe XII+Fe X λ190
Fe XII λ186/Fe XII+Fe XI λ188

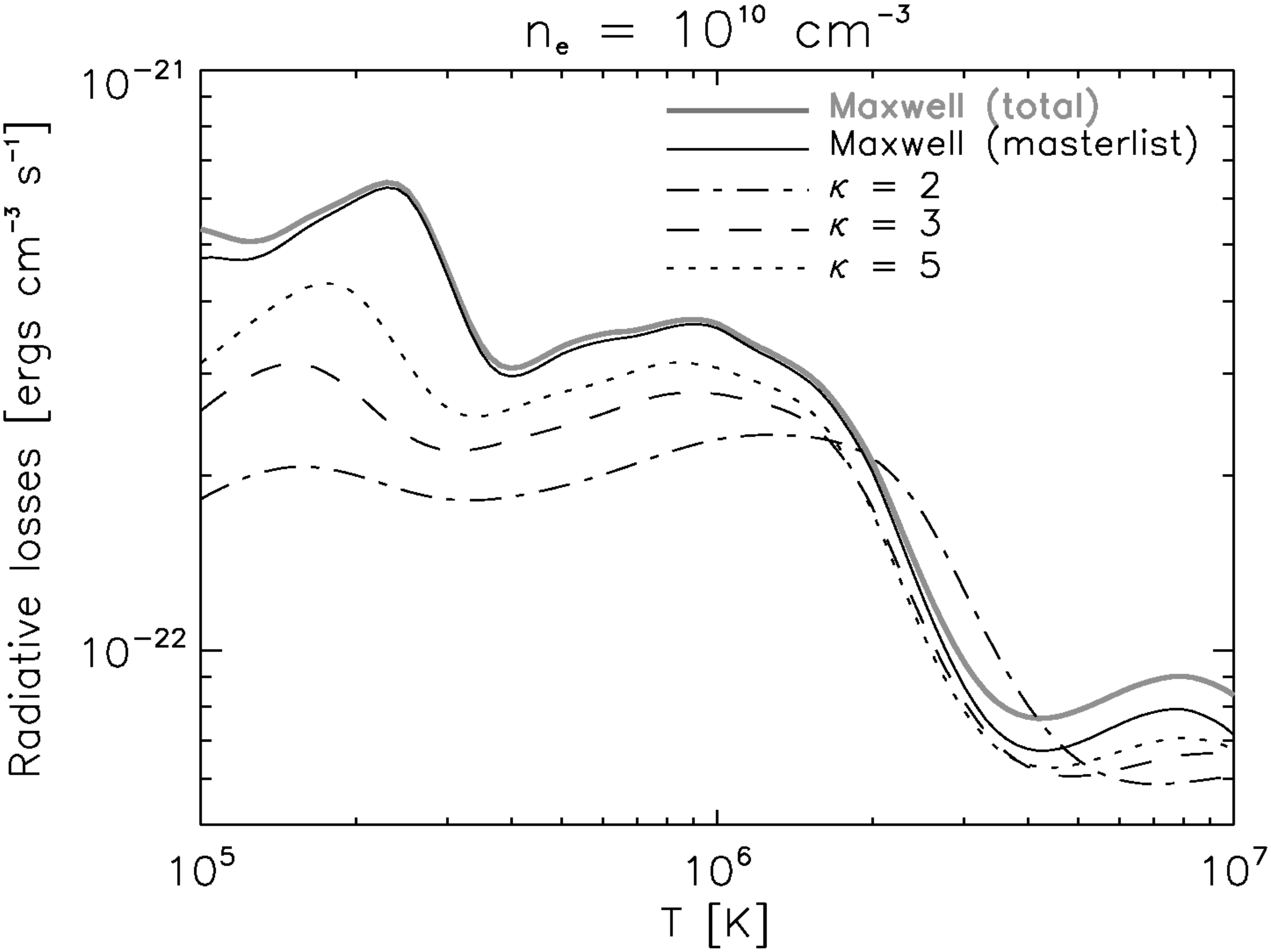
κ–distributions: definition

Owocki & Scudder (1983), Dzifčáková (2006a):

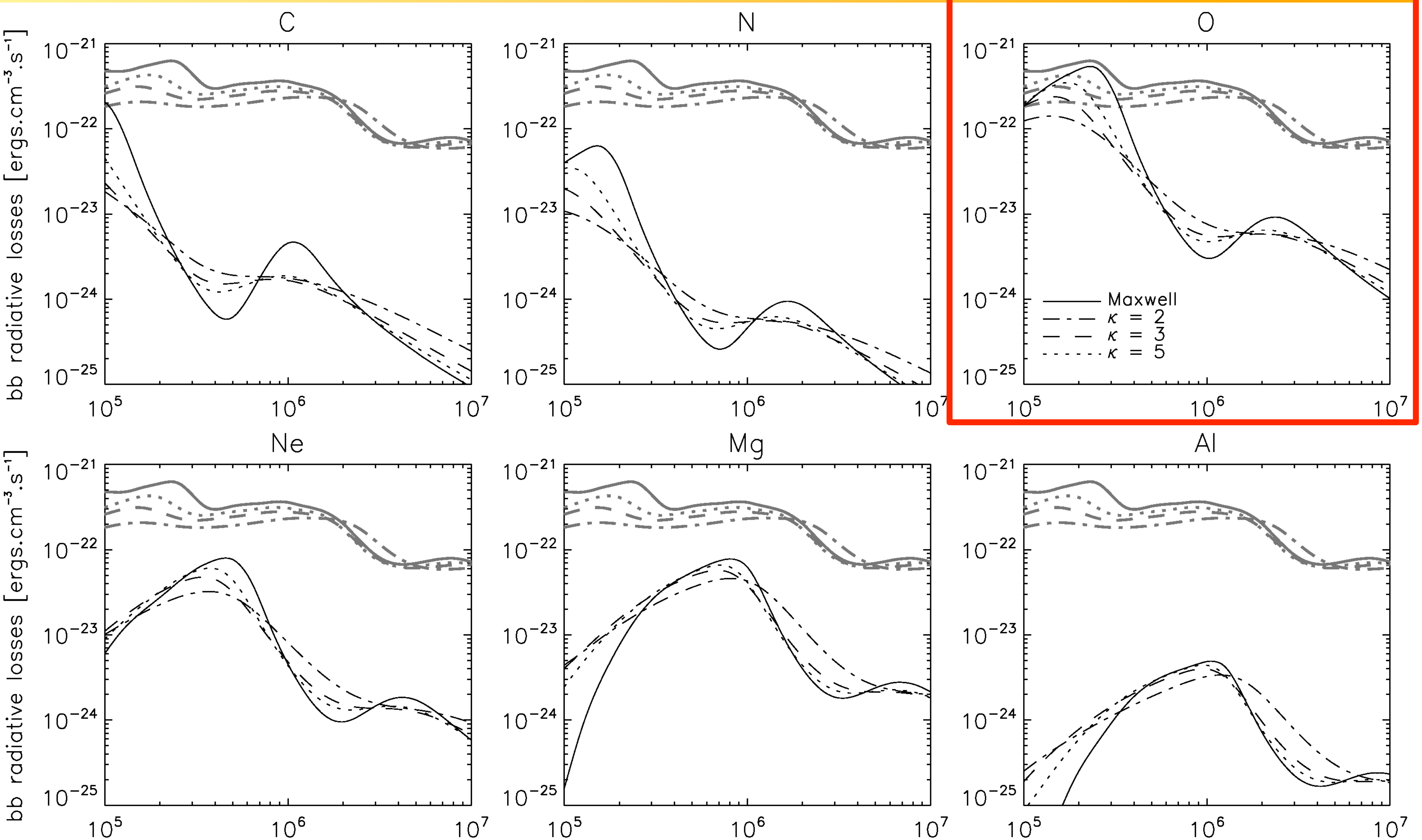
$$f(E,\kappa)dE = A_\kappa \frac{1}{\sqrt{\pi}\,(k_\mathrm{B}T)^{3/2}} \frac{E^{1/2}dE}{\left(1+\frac{E}{(\kappa-3/2)k_\mathrm{B}T}\right)^{\kappa+1}}$$

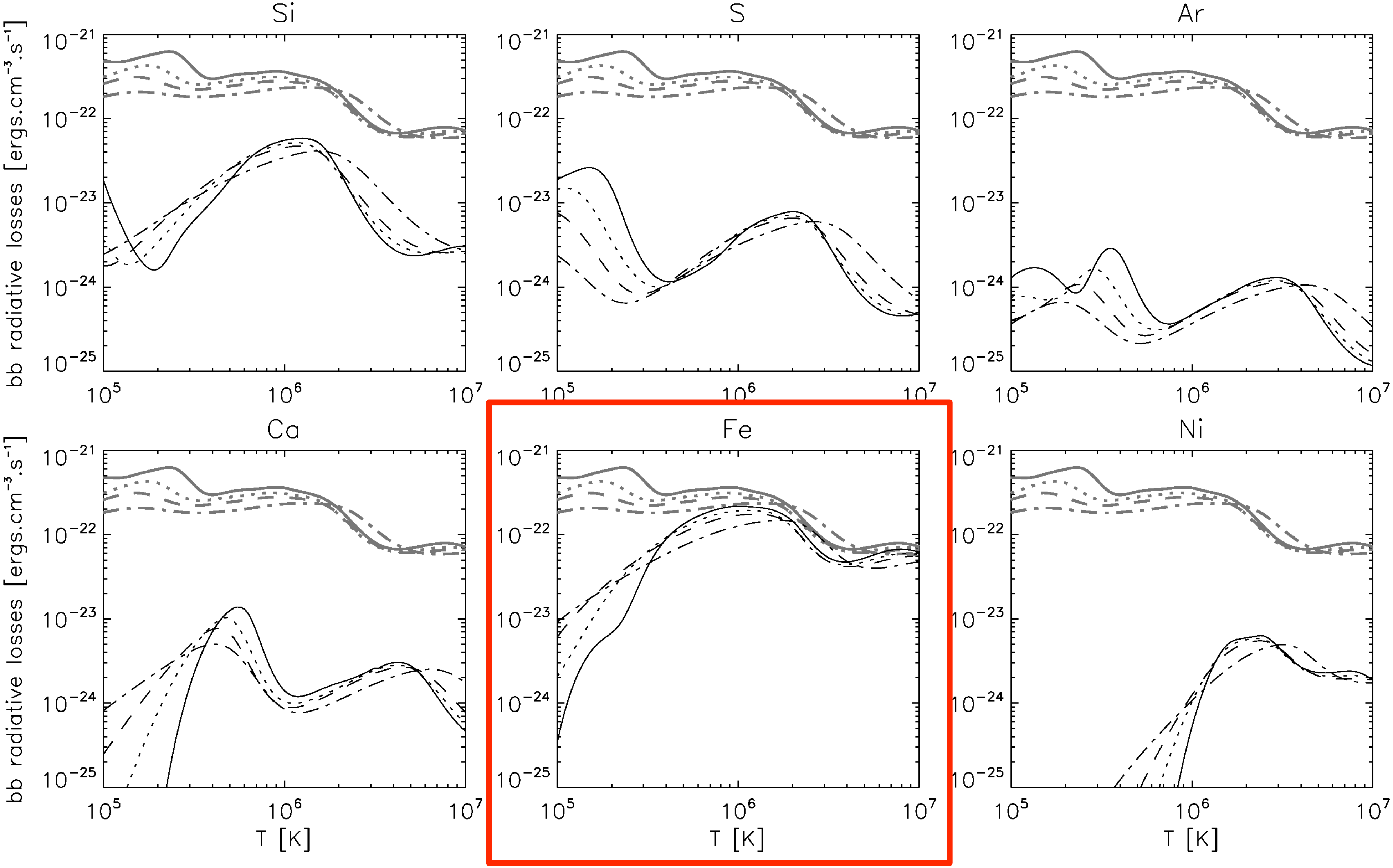


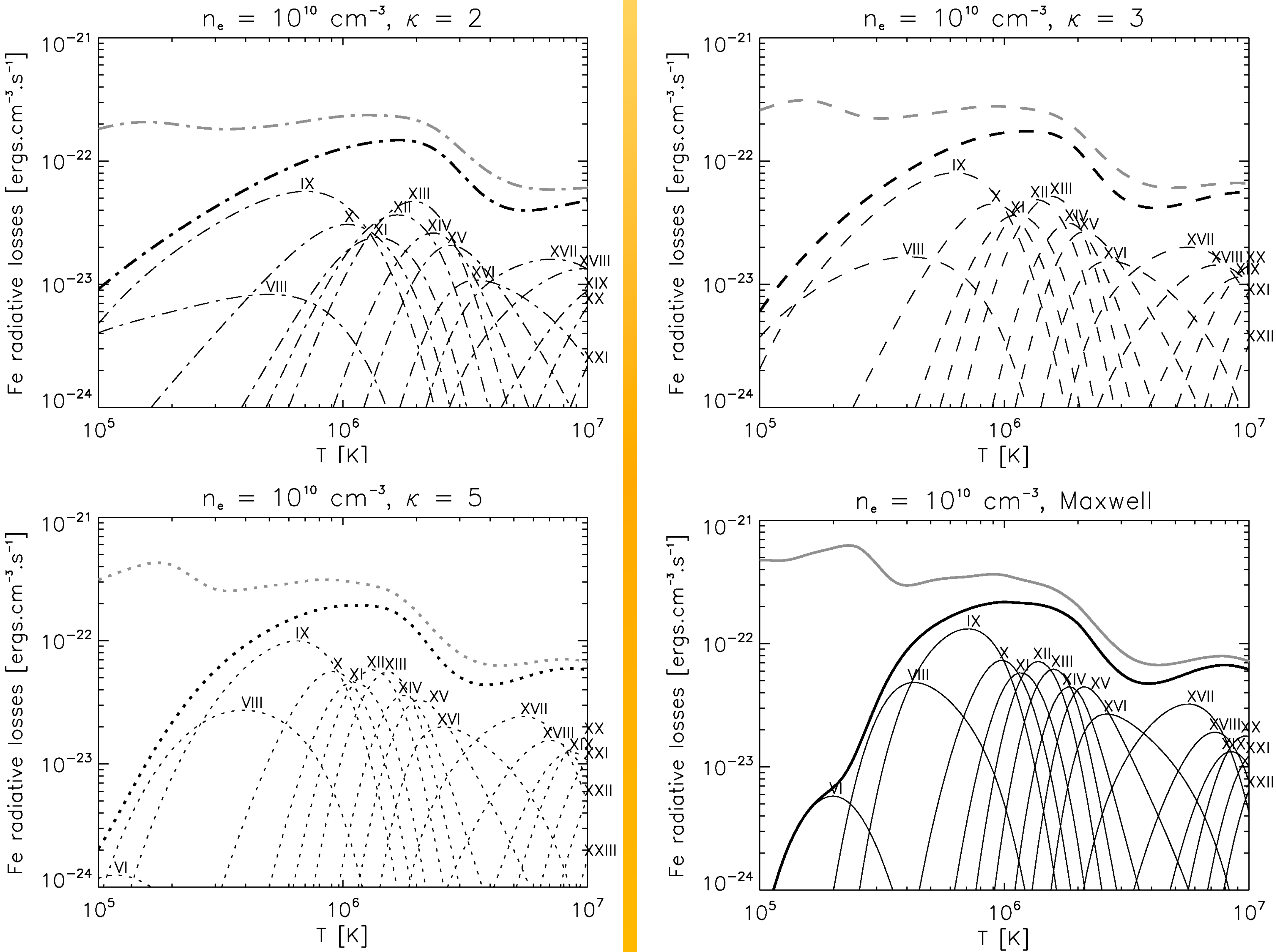
- $\kappa \to \infty$ Maxwellian distribution
- $\langle E \rangle = \frac{3}{2} k_\mathrm{B}T$
- $E_p = \frac{1}{2} k_\mathrm{B}T \frac{\kappa - 3/2}{\kappa + 1/2}$



$n_e = 10^{10}$ cm^{-3}
Radiative losses [ergs cm^{-3} s^{-1}]
10^{-21}
10^{-22}
10^5
10^6
10^7
T [K]
Maxwell (total)
Maxwell (masterlist)
κ = 2
κ = 3
κ = 5


C
N
O
Ne
Mg
Al
bb radiative losses [ergs.cm^{-3}.s^{-1}]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{5}
10^{6}
10^{7}
Maxwell
κ = 2
κ = 3
κ = 5

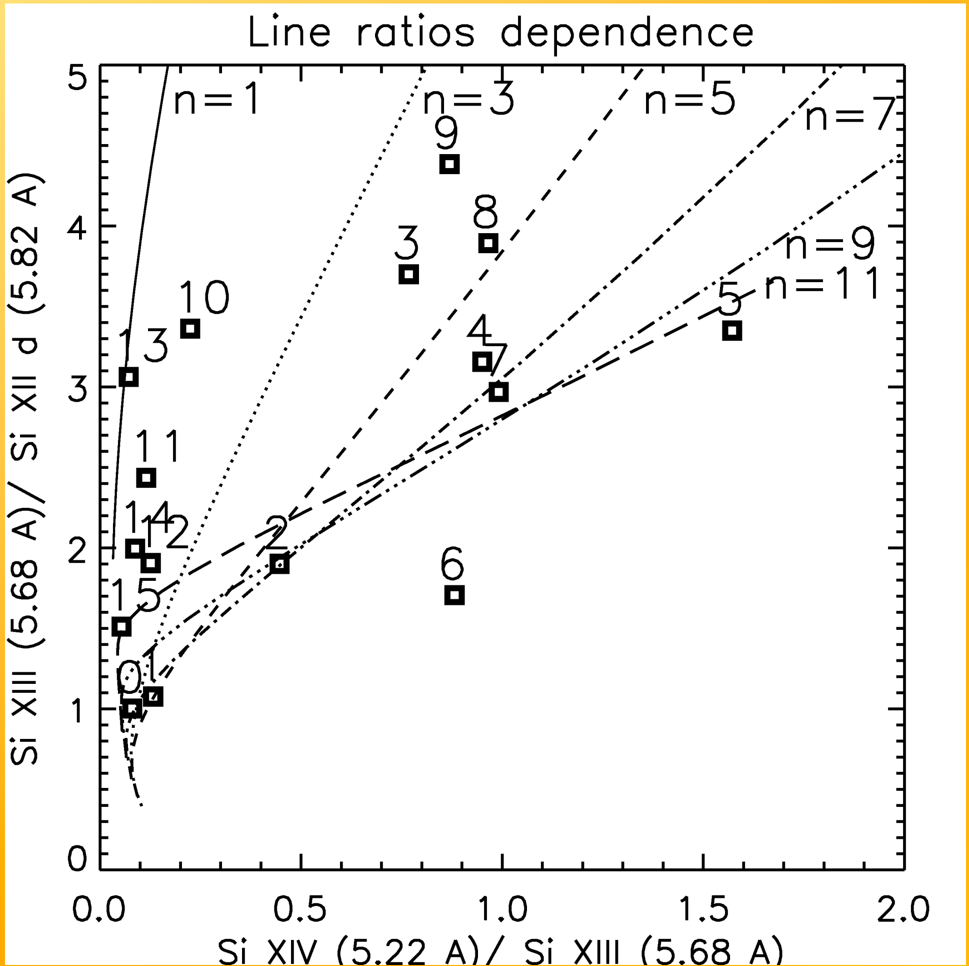

Si
S
Ar
Ca
Fe
Ni
bb radiative losses [ergs.cm^{-3}.s^{-1}]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{5}
10^{6}
10^{7}
T [K]

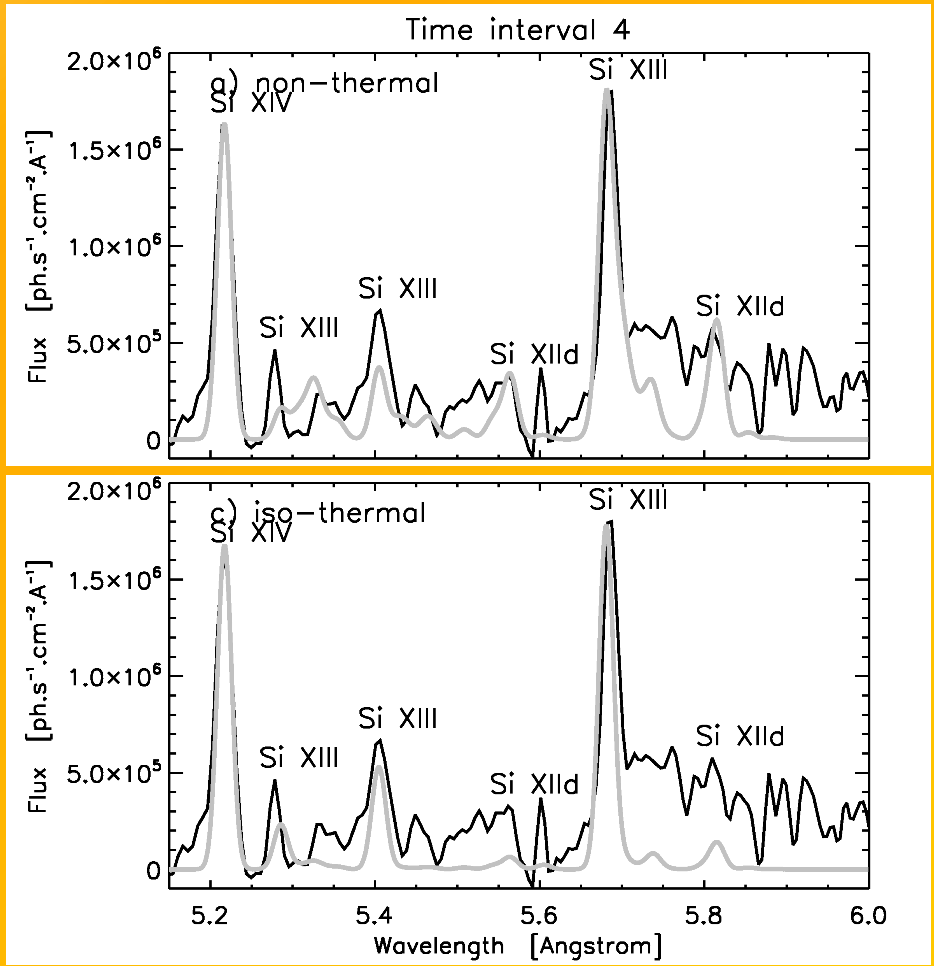


n_e = 10^10 cm^-3, κ = 2
n_e = 10^10 cm^-3, κ = 3
n_e = 10^10 cm^-3, κ = 5
n_e = 10^10 cm^-3, Maxwell
Fe radiative losses [ergs.cm^-3.s^-1]
T [K]
10^-21
10^-22
10^-23
10^-24
10^5
10^6
10^7
VI
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
XXI
XXII
XXIII

III. n–distributions: why/when

- Consistent with X-Ray spectra observed with flares (Dzifčáková et al. 2008, AA 488, 311; Kulinová et al., poster)

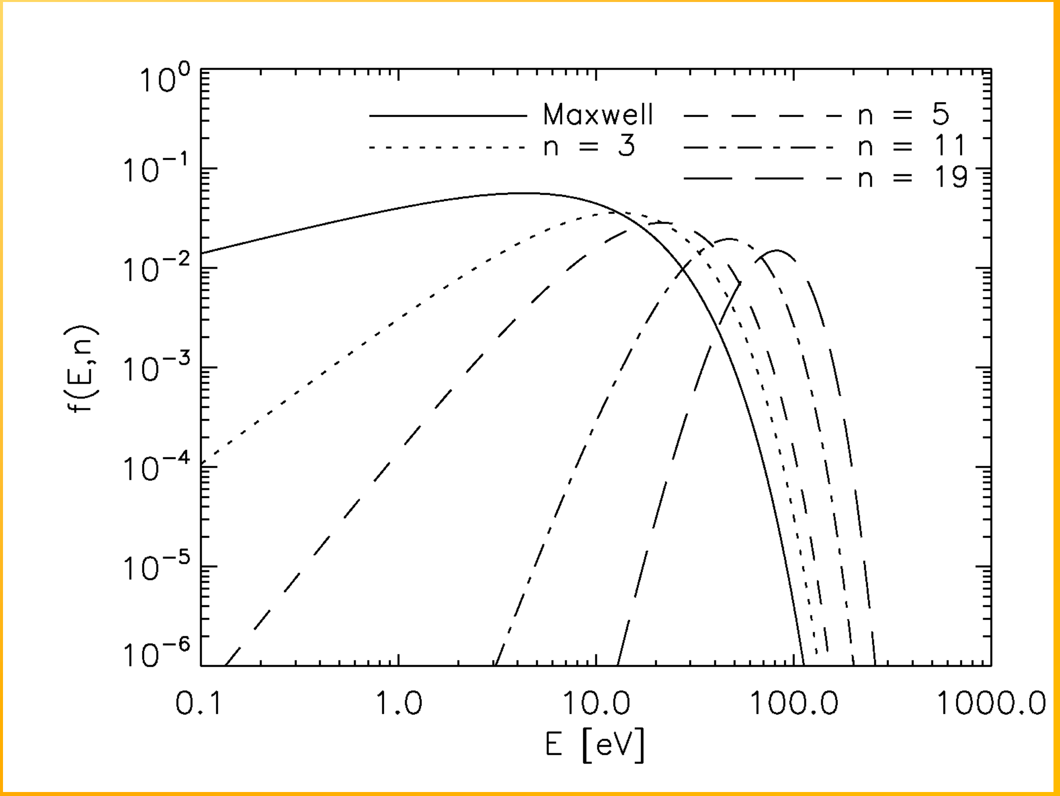




n–distributions: definition

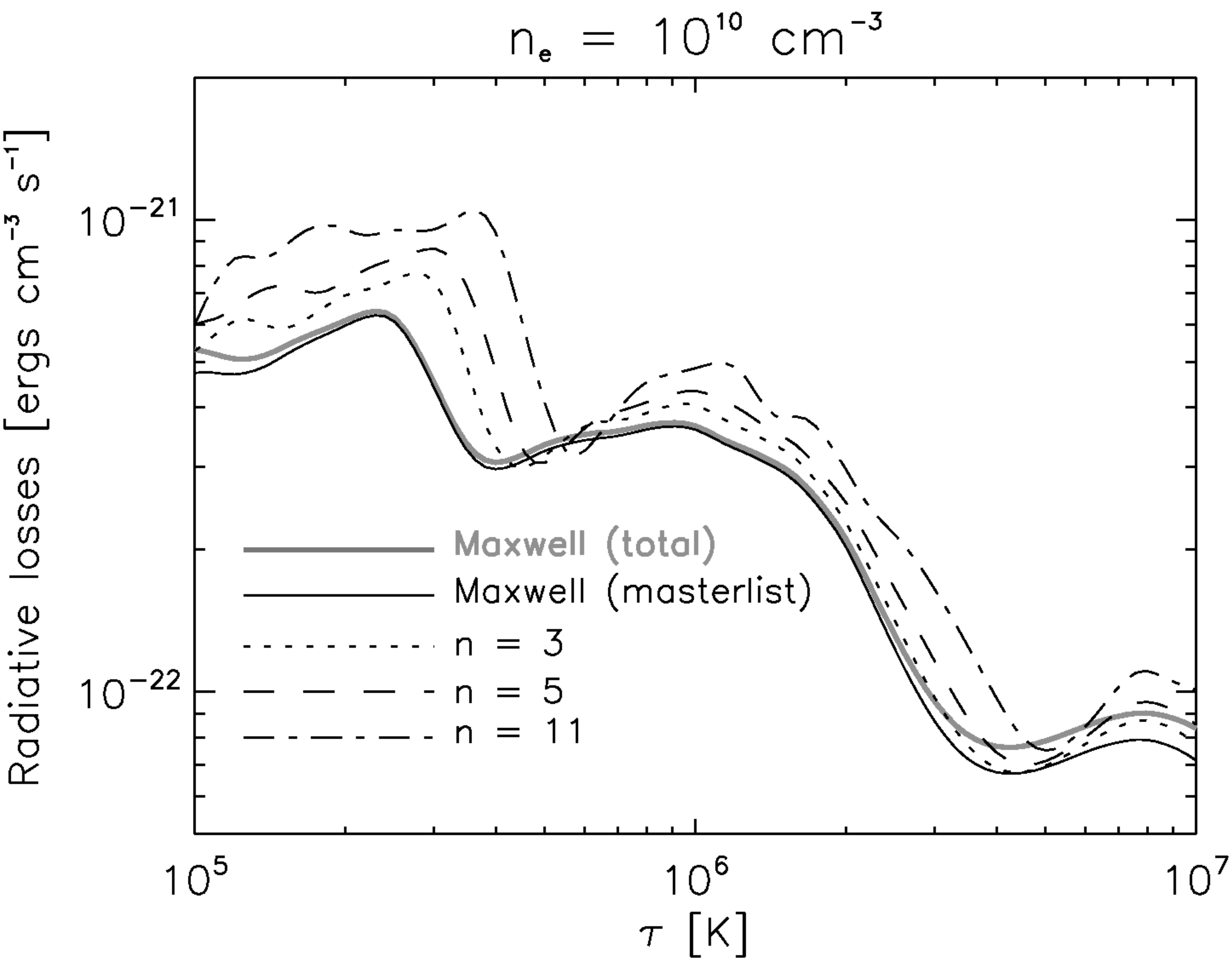
Seely, Feldman & Doschek (1987), Dzifčáková & Kulinová (2001):

$$f(E,n)dE = B^n \frac{2}{\sqrt{\pi}\,(k_B T)^{n/2+1}} E^{n/2} \mathrm{e}^{-E/k_B T} dE$$

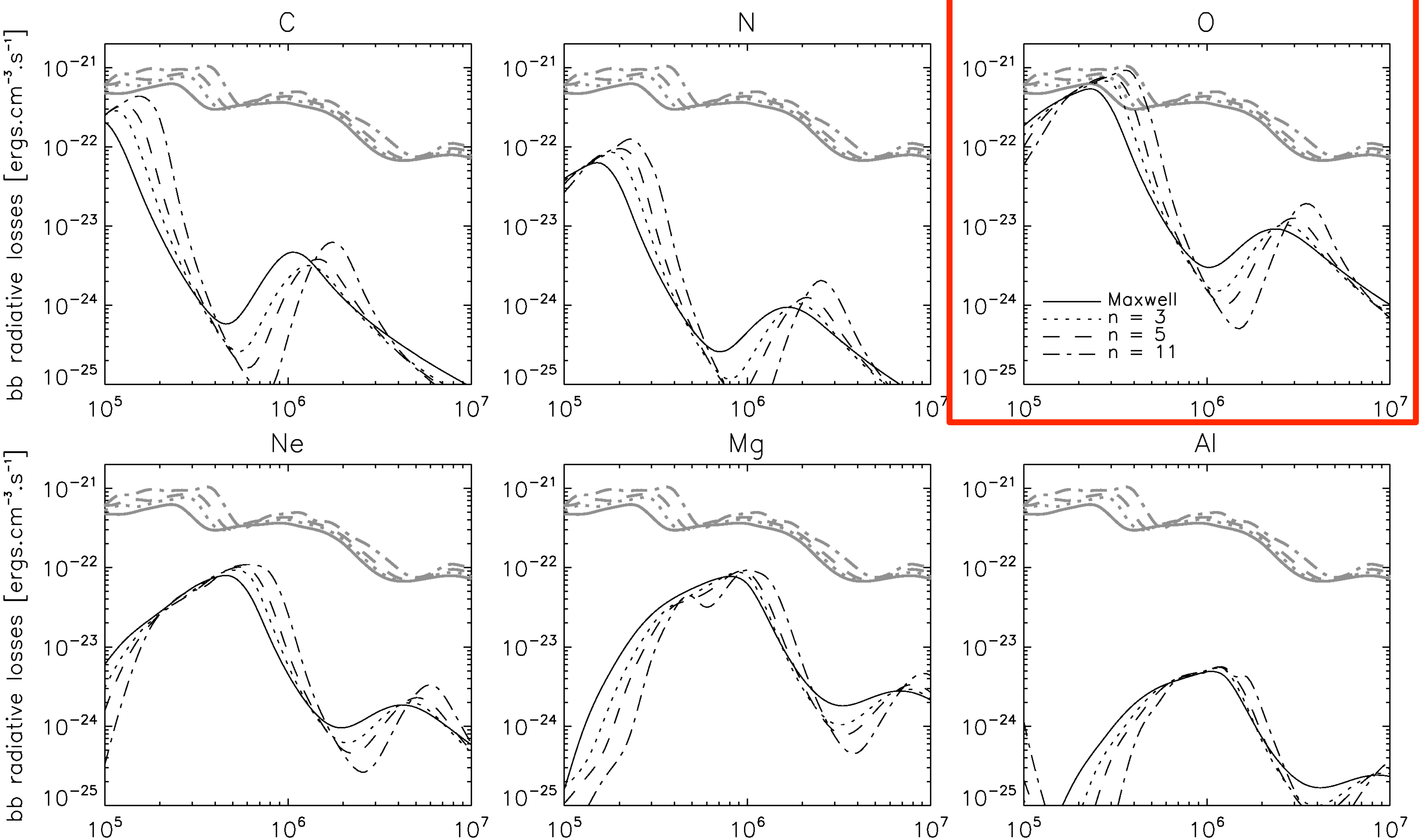


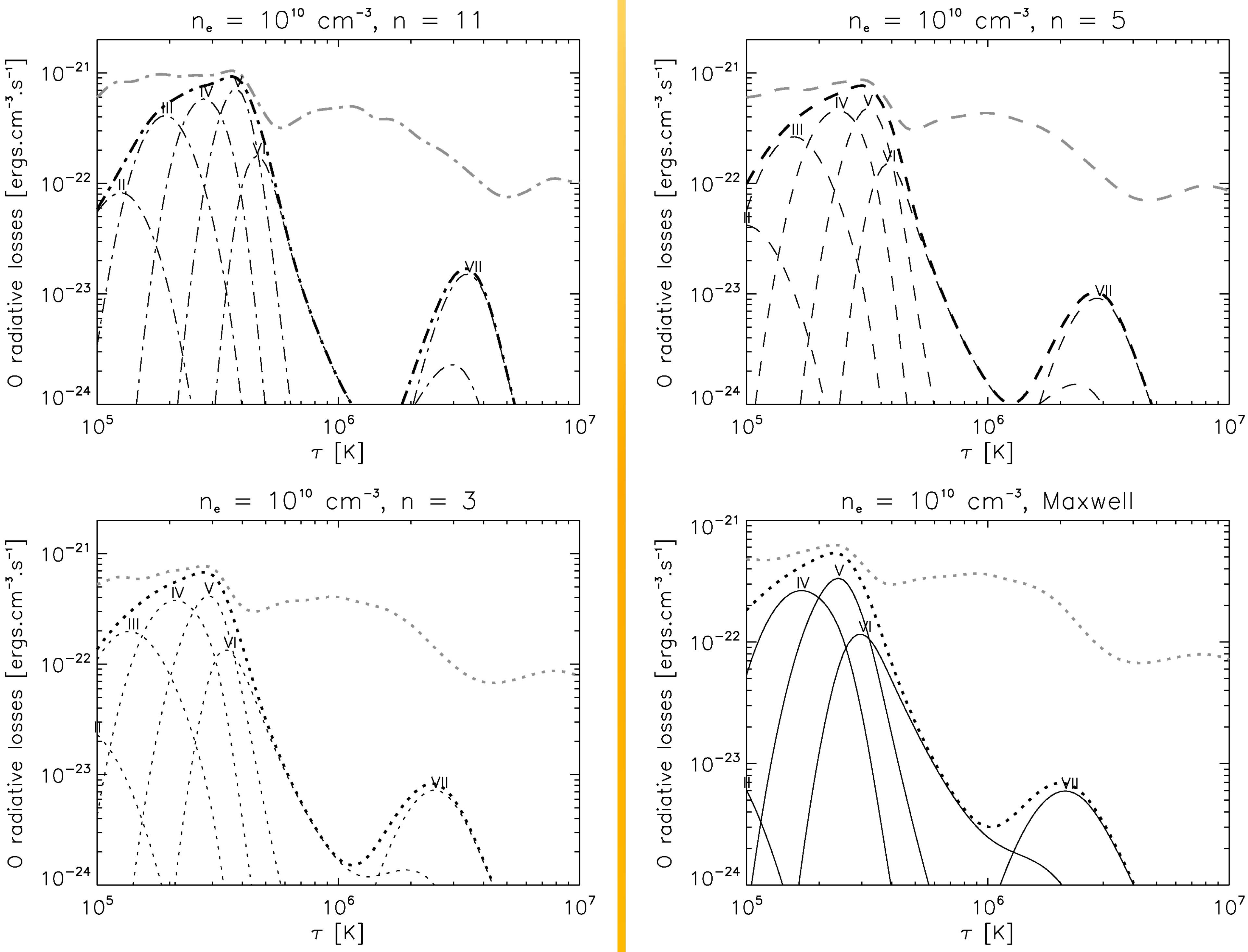
- $n = 1$ Maxwellian distribution
- $\langle E \rangle = \frac{3}{2} k_B \tau$
- Pseudo-temperature τ:

$$\tau = \left(\frac{n}{2}+1\right)\frac{2T}{3}$$

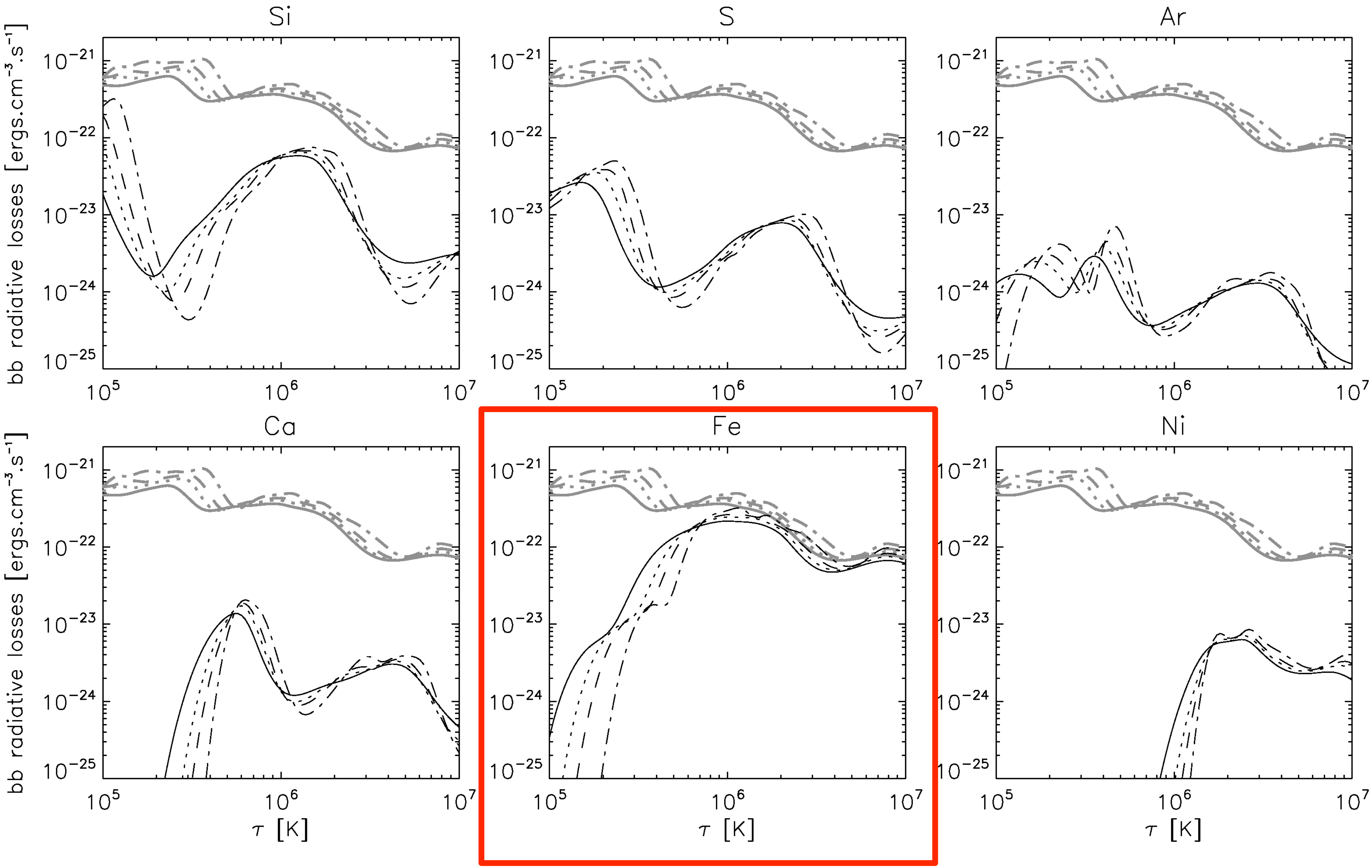


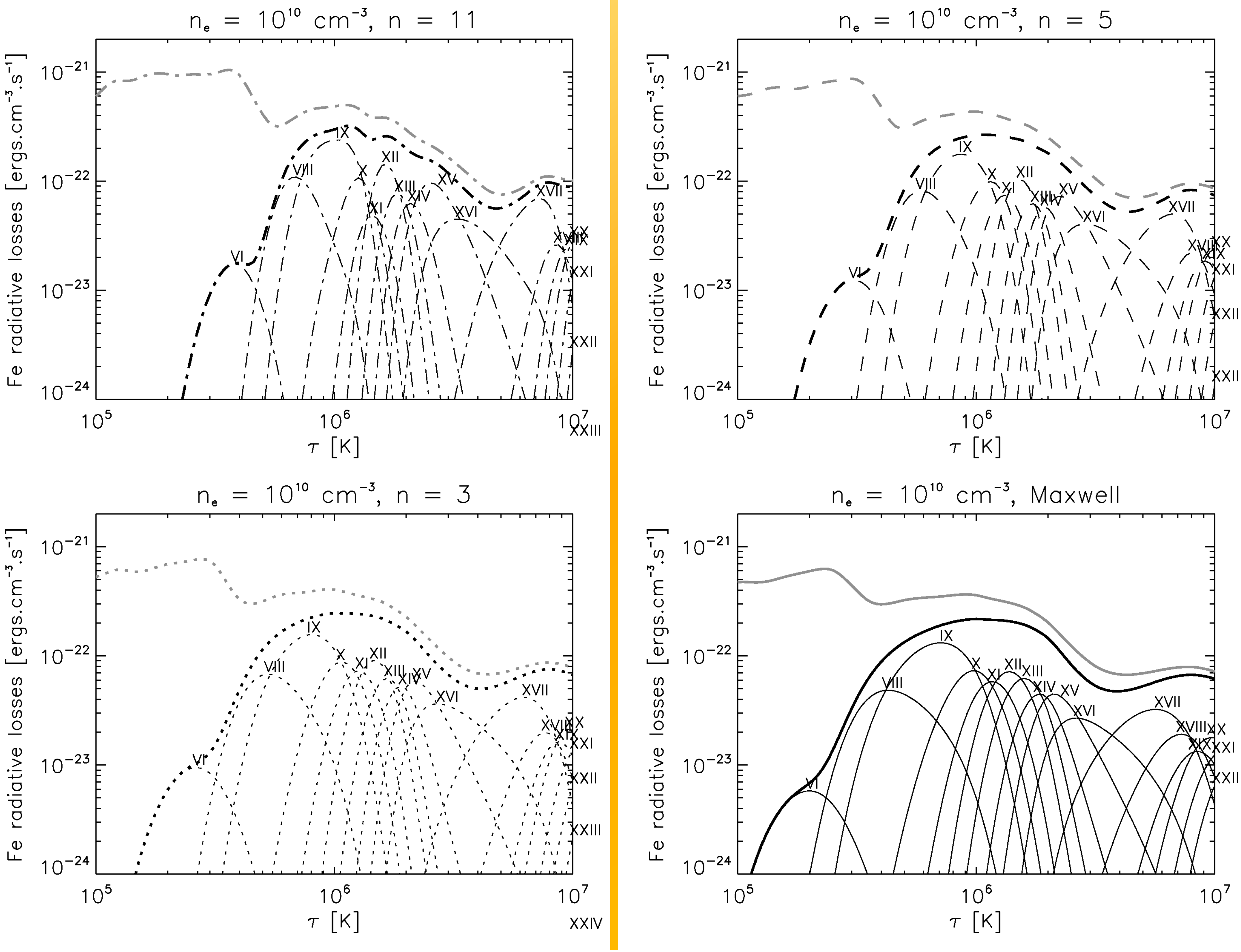
$n_e = 10^{10}$ cm^{-3}
Radiative losses [ergs cm^{-3} s^{-1}]
10^{-21}
10^{-22}
10^5
10^6
10^7
τ [K]
Maxwell (total)
Maxwell (masterlist)
n = 3
n = 5
n = 11


C
N
O
Ne
Mg
Al
bb radiative losses [ergs.cm^{-3}.s^{-1}]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{5}
10^{6}
10^{7}
Maxwell
n = 3
n = 5
n = 11



$n_e = 10^{10}$ cm^{-3}, n = 11
$n_e = 10^{10}$ cm^{-3}, n = 5
$n_e = 10^{10}$ cm^{-3}, n = 3
$n_e = 10^{10}$ cm^{-3}, Maxwell
O radiative losses [ergs.cm^{-3}.s^{-1}]
τ [K]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^5
10^6
10^7
II
III
IV
V
VI
VII


Si
S
Ar
Ca
Fe
Ni
bb radiative losses [ergs.cm^{-3}.s^{-1}]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^5
10^6
10^7
T [K]


$n_e = 10^{10}$ cm^{-3}, n = 11
$n_e = 10^{10}$ cm^{-3}, n = 5
$n_e = 10^{10}$ cm^{-3}, n = 3
$n_e = 10^{10}$ cm^{-3}, Maxwell
Fe radiative losses [ergs.cm^{-3}.s^{-1}]
T [K]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^5
10^6
10^7
VI
VIII
IX
X
XI
XII
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
XXI
XXII
XXIII
XXIV

Conclusions

- Conditions in solar corona allow for non-thermal distributions.
  We examined their influence on the radiative-loss function.

- Total radiative losses slightly lesser (up to 60%) for κ–distribution,

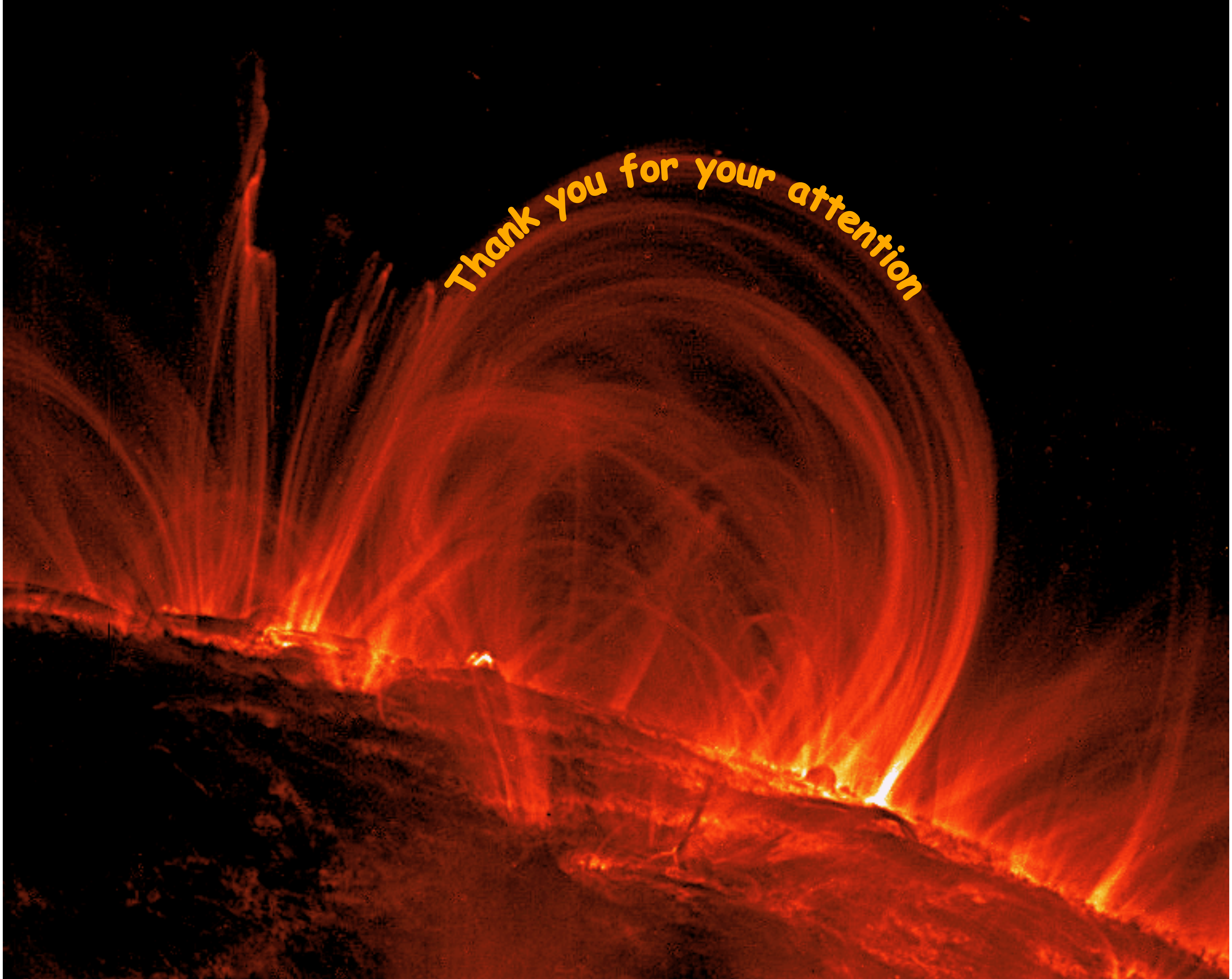
  $\Rightarrow$ lesser requirement for heating input

  higher for n–distribution

  $\Rightarrow$ cooling processes for flares

- The behavior of radiative losses copies the behavior of individual ions/ lines

- Future work: brehmsstrahlung, effect of radiation field on spectral lines


Thank you for your attention