Resonance Excitation
and
Dielectronic Recombination
as
Line Formation Processes for Iron L-shell Ions
in
Collisional and Photoionized Plasmas

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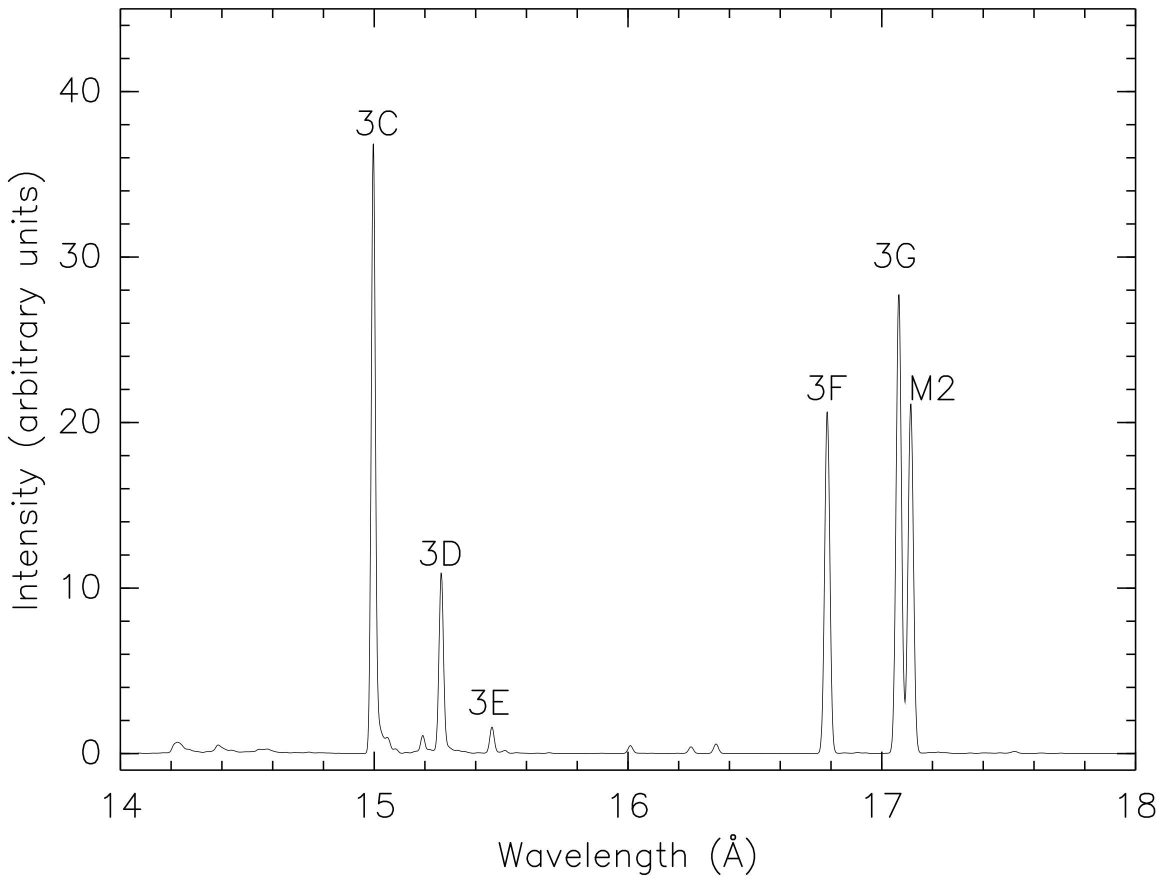
Motivation—The Case of Fe XVII

- $3d - 2p$ lines. 3C (15.01Å), 3D (15.26Å) and 3E (15.46Å). Mostly due to direct excitation from ground state.
- $3s - 2p$ lines. 3F (16.78Å), 3G (17.05Å) and M2 (17.10Å). Mostly due to radiative cascades.
- 3C/3D ratio—Opacity effects?
- 3F+3G+M2/3C ratio. > 2 in observations, < 2 in models.

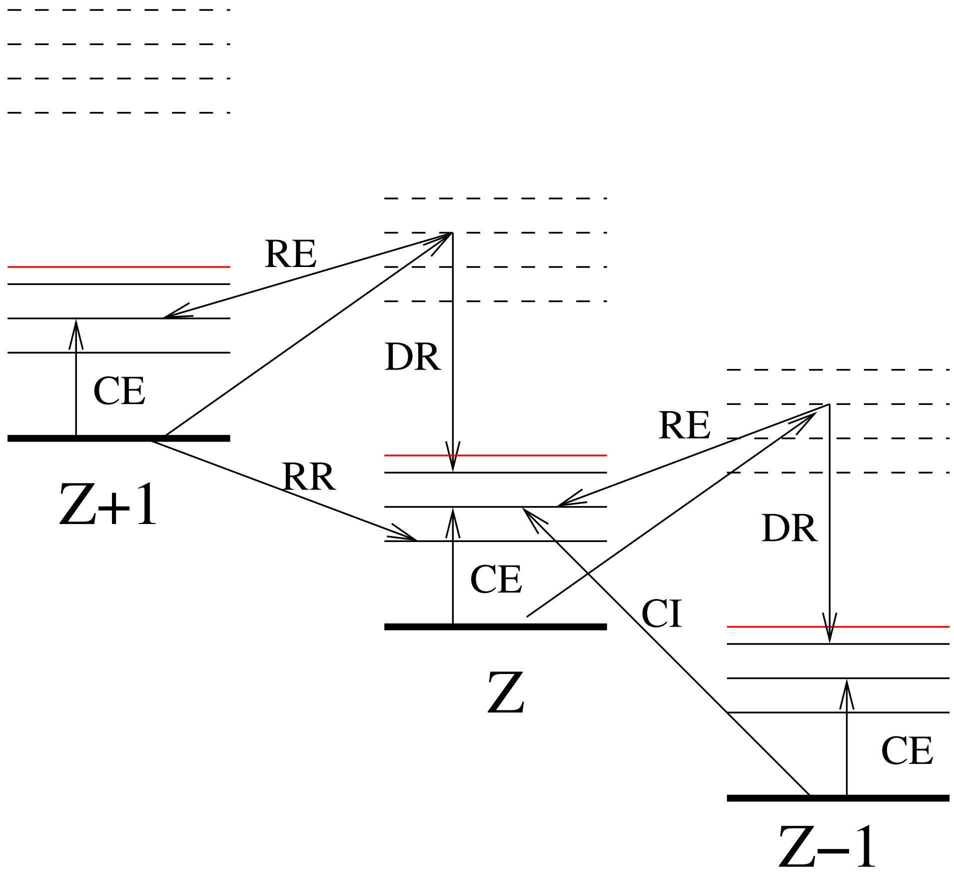
Fe XVII $3 \rightarrow 2$ spectrum



Commonly Used Single-Ion Models

- For collsion-dominated plasmas, only collisional excitation (CE) as line formation processes.
- For photoionization-dominated plasmas, radiative recombination (RR) is included.
- At low electron densities, coronal models are used. Collisional coupling between excited states is ignored.
- No coupling between different charge states, except in the calculation of ionization balance.

Multi-Ion Models



Resonance Types

- $\Delta N = 0$—$2lnl'$. Important at Low Temperatures.
- $\Delta N = 1$—$3lnl'$.
- $\Delta N = 2$—$4lnl'$.
- KLnl'—K-shell satellites.

The Flexible Atomic Code

- Relativisitc.
- Multi-configurational.
- Continuum processes based on distorted-wave approximation.
- Resonances treated in isolated, independaent process approximation.
- Large scale spectral modeling.
- Exist in public domain, ftp://space.mit.edu/pub/mfgu/fac/

Comparison With Hullac—Fe XVII (600 eV)

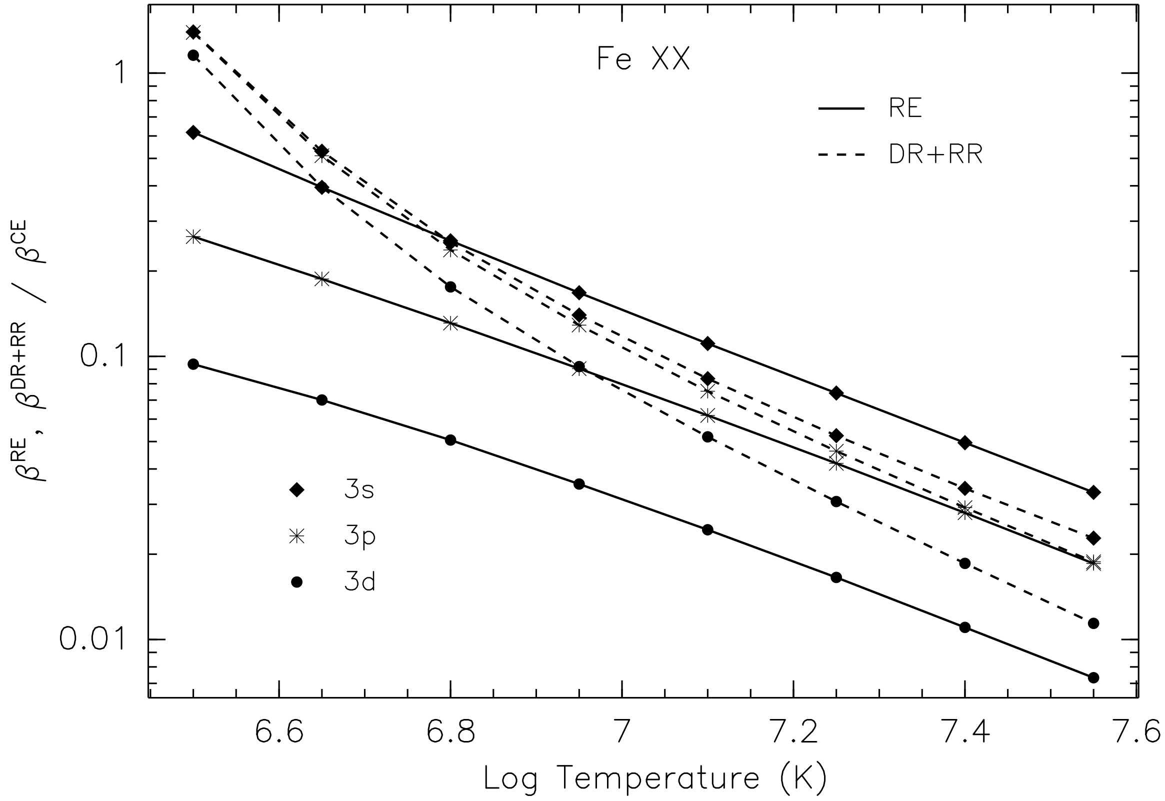
Process	Line Power(10^{-12} cm^3 s^{-1})					
	3C	3D	3F	3G	M2	
CE only	37.4	10.9	17.1	21.2	14.4	Doron&Behar
	40.9	11.2	18.9	23.3	14.4	Present
RE	0.0	0.0	2.0	2.7	2.3	
	0.5	0.5	3.5	5.7	4.4	
DR+RR	0.2	0.2	1.4	1.9	5.0	
	0.1	0.2	0.9	2.3	5.0	

Ionization balance from Mazzotta et al. (A&AS, 133, 403).

Results for Other Iron L-shell Ions

- Effective rate coefficients. $I = \int n_e n_z \alpha dV$.
- $\sum \alpha^{RE}(3s-2p)/\sum \alpha^{CE}(3d-2p)$.
- $\sum \alpha^{Rec}(3s-2p)/\sum \alpha^{CE}(3d-2p)$, Rec = DR + RR.
- RR effects negligible for collision-dominated plasmas in ionization equilibrium.
- DR and RE important for Fe XVII—XX. Effects small for higher charge states.

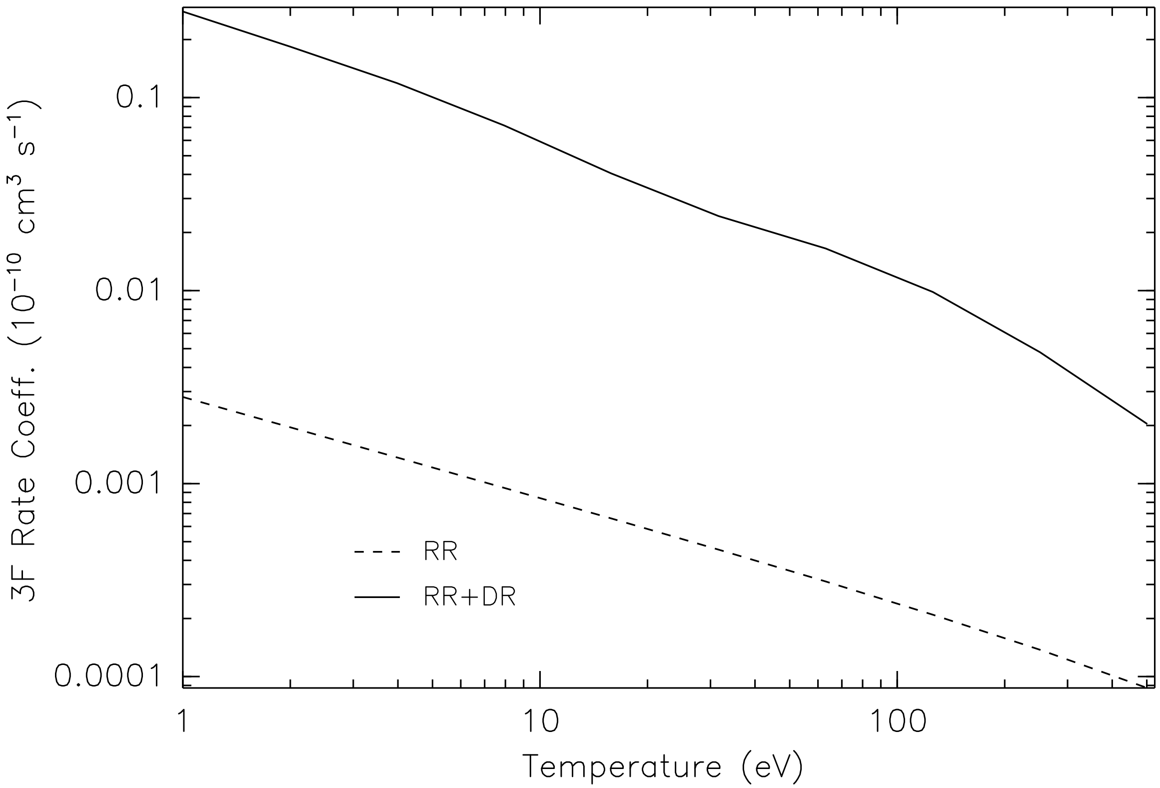
Example—Fe XX



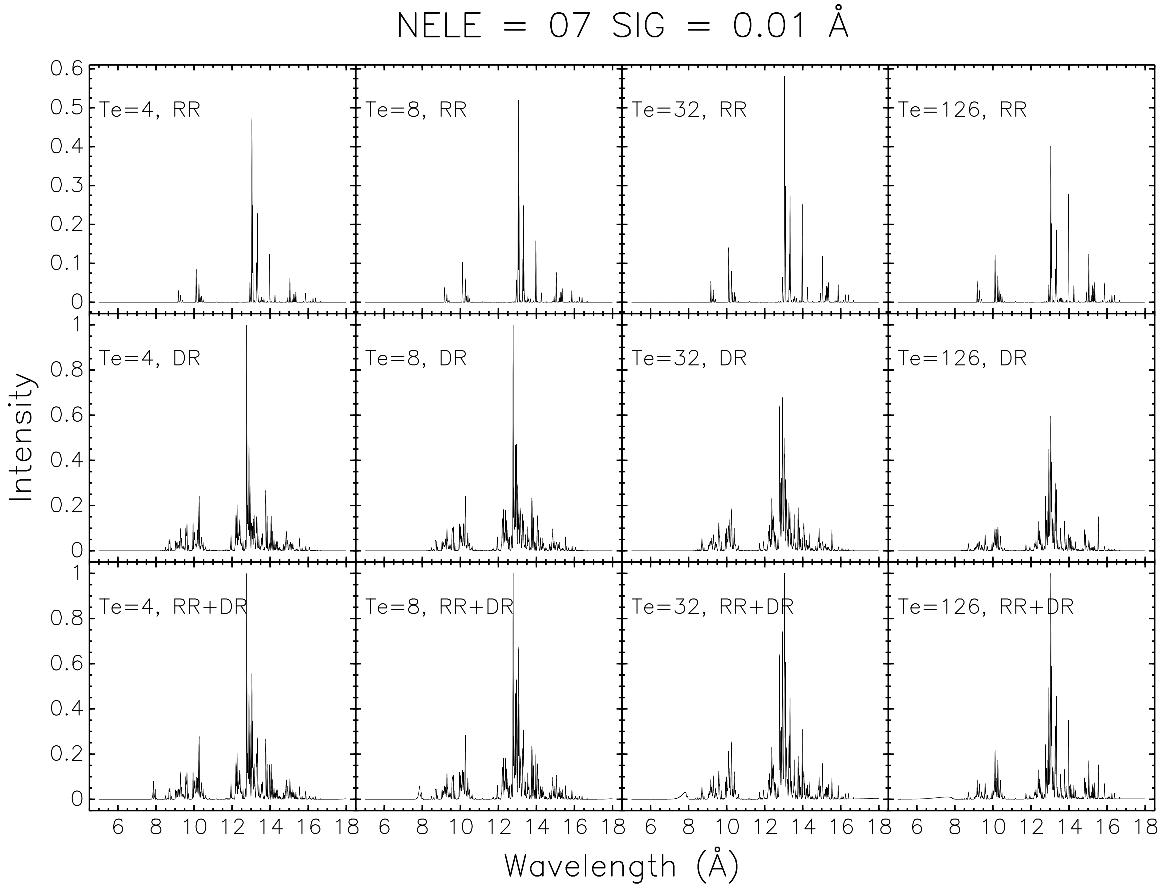
Photoionization-dominated Plasmas

- X-Ray Binaries, AGNs.
- Low temperature. a few tens of eV for Fe L-shell.
- Emission dominated by radiative cascades following recombination and photoexcitation.
- Only RR is relevant for K-shell ions.
- $\Delta N = 0$ DR important for Fe L-shell.

Example—Fe XVII line 3F



Example—Fe XX Spectra



Summary

- Multi-ion models necessary to account for indirect line formation.
- RE and DR most important for Fe XVII—XX in collision-dominated plasmas.
- Emission following $\Delta N = 0$ DR comparable with RR for Fe L-shell ions in photoionization-dominated plasmas.