AtomDB: Atomic Data for X-ray Astronomy

Adam Foster[1], Hiroya Yamaguchi[1], Li Ji[2], Randall Smith[1]
Nancy Brickhouse[1]

1 - Harvard-Smithsonian Center for Astrophysics, Cambridge, MA
2 - Purple Mountain Observatory, Nanjing, China

Types of Plasma

Collisionally ionized

- $k_b T$ ~ Ionization energy
- Models include AtomDB, SPEX, CHIANTI
- Many emission lines, if optically thin

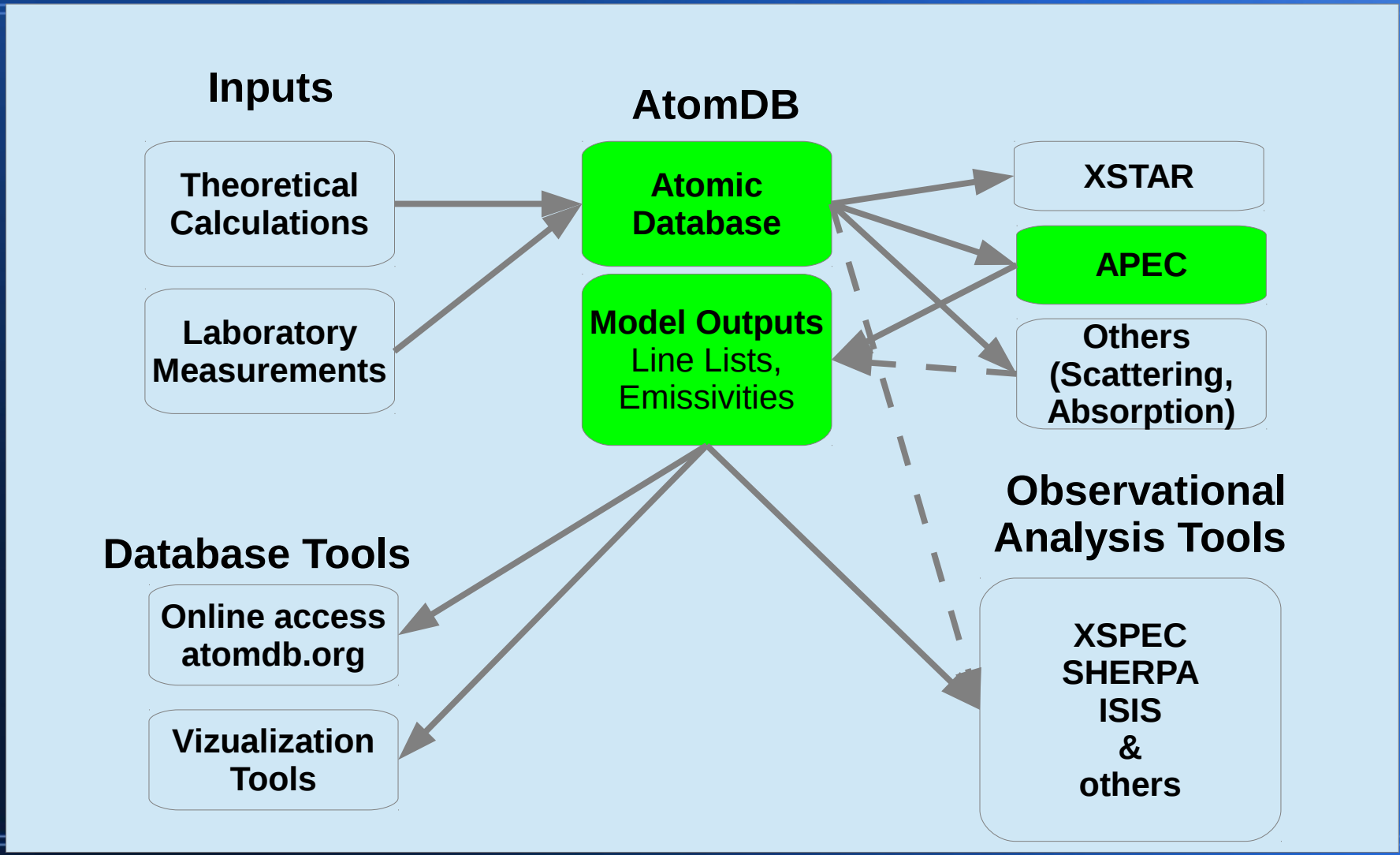
Photoionized

- $k_b T$ < Ionization energy
- Models include XSTAR, CLOUDY
- Relatively few emission lines, many absorption features

Types of Collisional Plasma Model

- Coronal/Nebular
  - Low density ($N_e < 10^{14}$-$10^{16}cm^{-3}$)
  - All excitations return to the ground state
- Collisional-Radiative
  - Moderate [high] density (10^{14} -$10^{23}cm^{-3}$)
  - Collisions from long lived (“metastable”) states can be significant
- Local Thermodynamic Equilibrium (LTE)
  - Very high density
  - Populations determined by Boltzmann factor

AtomDB


Inputs
Theoretical Calculations
Laboratory Measurements
AtomDB
Atomic Database
Model Outputs
Line Lists, Emissivities
XSTAR
APEC
Others (Scattering, Absorption)
Database Tools
Online access atomdb.org
Vizualization Tools
Observational Analysis Tools
XSPEC
SHERPA
ISIS
&
others

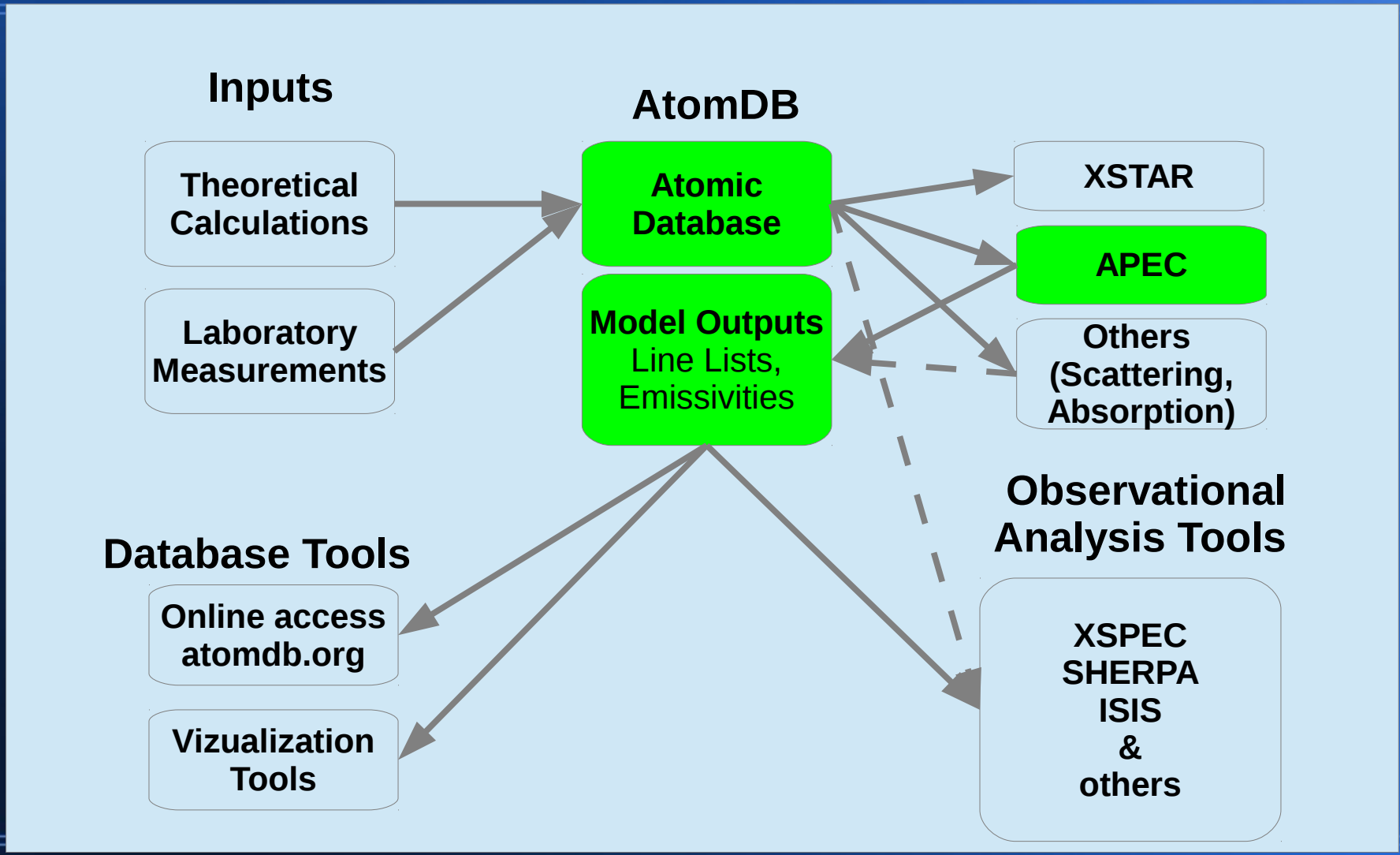
APEC models

Well know from XSPEC, Sherpa etc. (apec, vapec, vvapec...)

- AtomDB group:
  - Calculates emission per element
  - 51 temperatures (10^4K to 10^9K)
  - Save emissivity in 51 block FITS file (~50MB)
- XSPEC/Sherpa:
  - Read in FITS files, interpolate to desired T_e, sum emission.

$$I = \varepsilon(T_e) N_e N_i$$

AtomDB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ATOMDB Atomic Data for Astrophysicists

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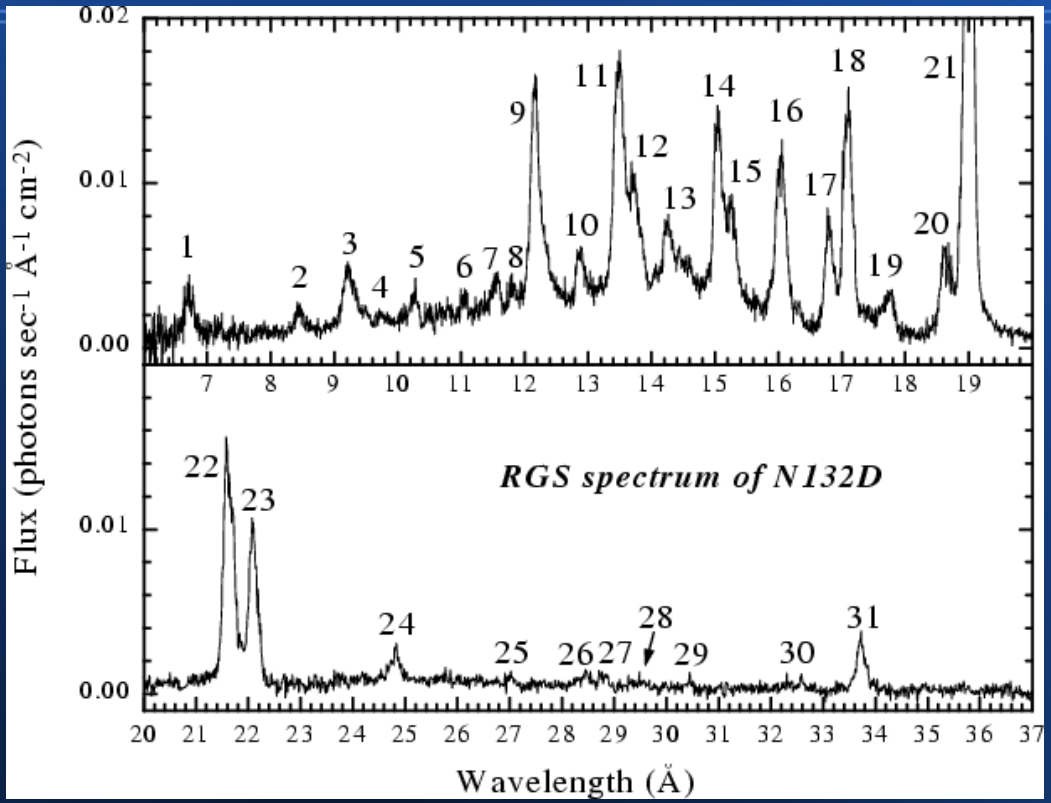
Searching for lines between 7.3 and 7.7 Å

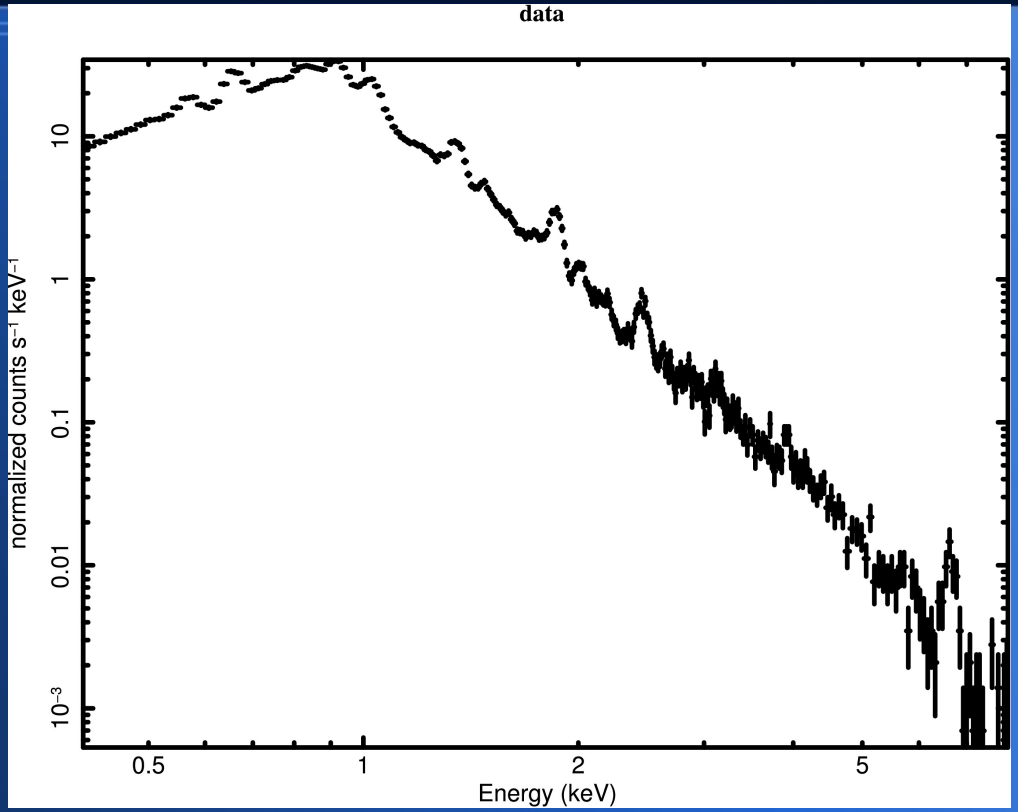
9 lines found.

Ion	Wavelength Å	Upper Level	Lower Level	Emissivity ph $cm^3 s^{-1}$	Te peak K	Relative Intensity
Mg XI	7.310	37	1	2.205e-18	6.310e+6	0.34
Fe XXIV	7.370	19	2	2.415e-18	1.995e+7	0.37
Fe XXIV	7.437	20	3	4.432e-18	1.995e+7	0.68
Fe XXIV	7.457	16	3	1.757e-18	1.995e+7	0.27
Fe XXIII	7.472	176	5	2.442e-18	1.585e+7	0.37
Mg XI	7.473	23	1	4.611e-18	6.310e+6	0.70
Fe XXIII	7.478	104	1	6.550e-18	1.585e+7	1.00
Fe XXIII	7.498	168	5	1.496e-18	1.585e+7	0.23
Fe XXII	7.681	233	1	3.472e-18	1.259e+7	0.53

“High Resolution”

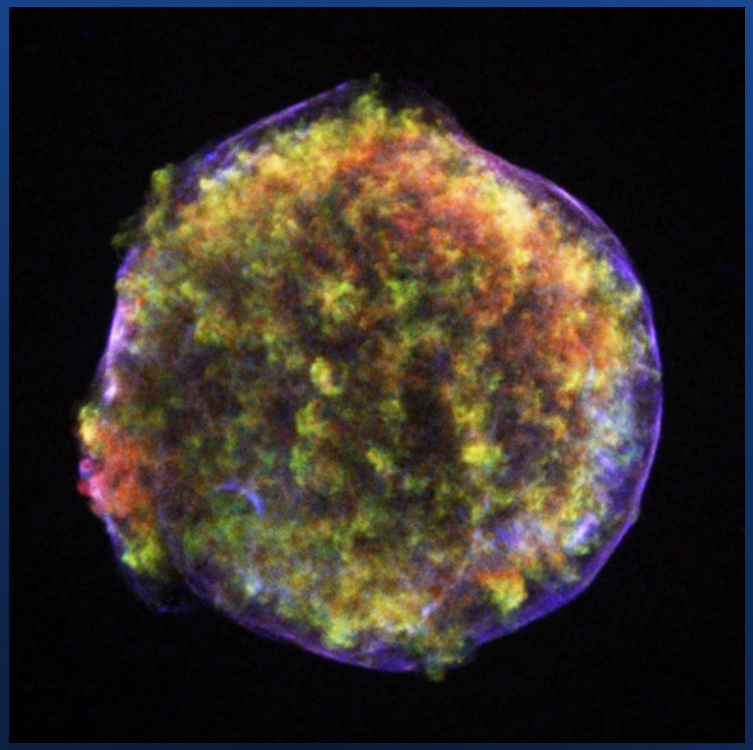


XMM RGS (Grating)

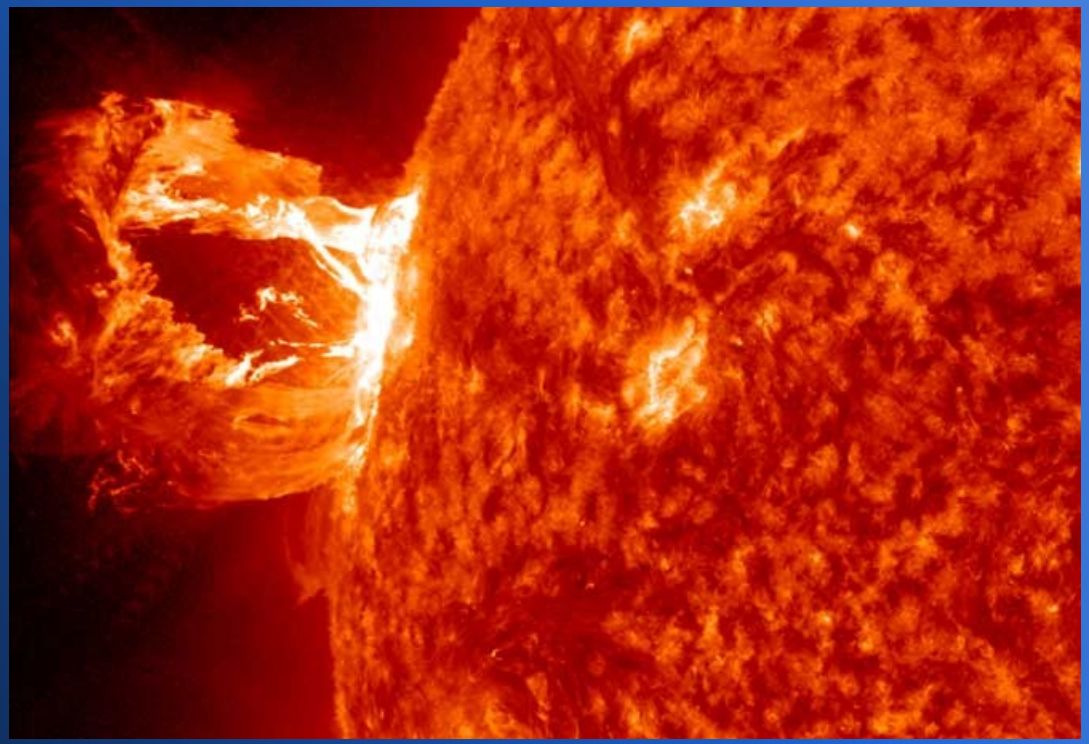


XMM MOS (CCD)

Astrophysical Non-Equilibrium Plasma



- Supernova Remnant



- Solar Flare

CIE vs NEI

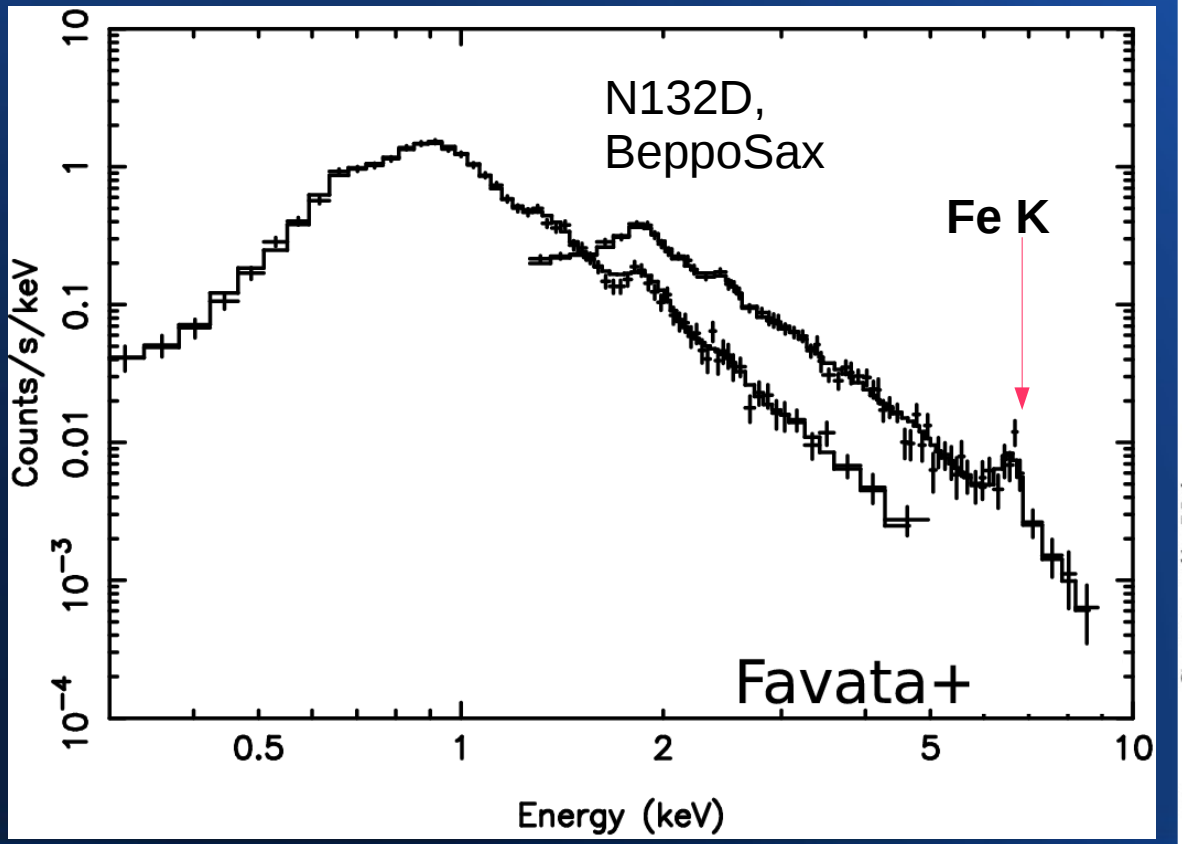
$$\frac{dN^{+z}}{dt} = N_e\left(S^{+z-1}(T_e)N^{+z-1} + \alpha_{+z+1}(T_e)N^{+z+1}\right) - N_e\left(S^{+z}(T_e)N^{+z} + \alpha_{+z}(T_e)N^{+z}\right)$$

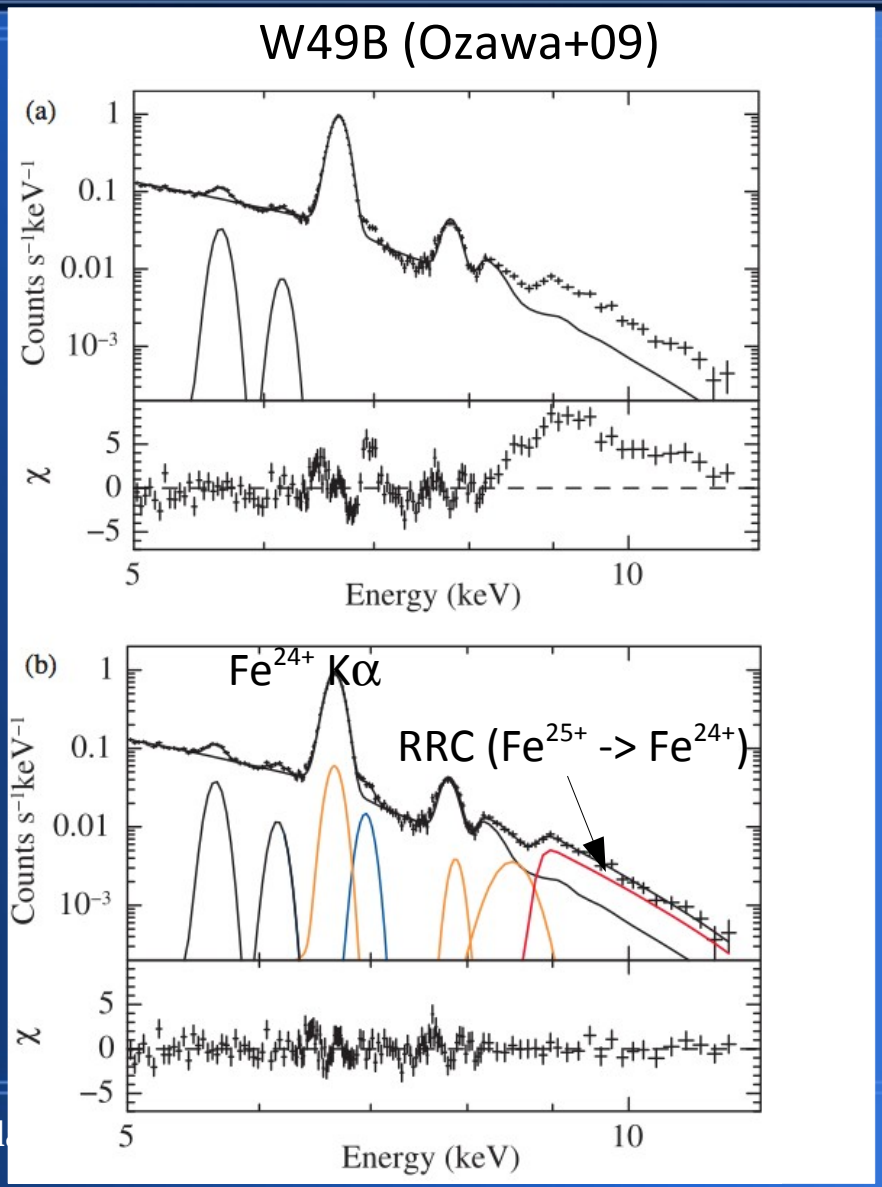
- Collisional ionization equilibrium: $dN^{+z}/dt = 0$

  → Ion+Rec (to ion) = Ion + Rec (from ion)

- Non equilibrium plasma (NEI, NIE) simply means $dN^{+z}/dt \neq 0$
  - Can be ionizing or recombining

And their spectra...



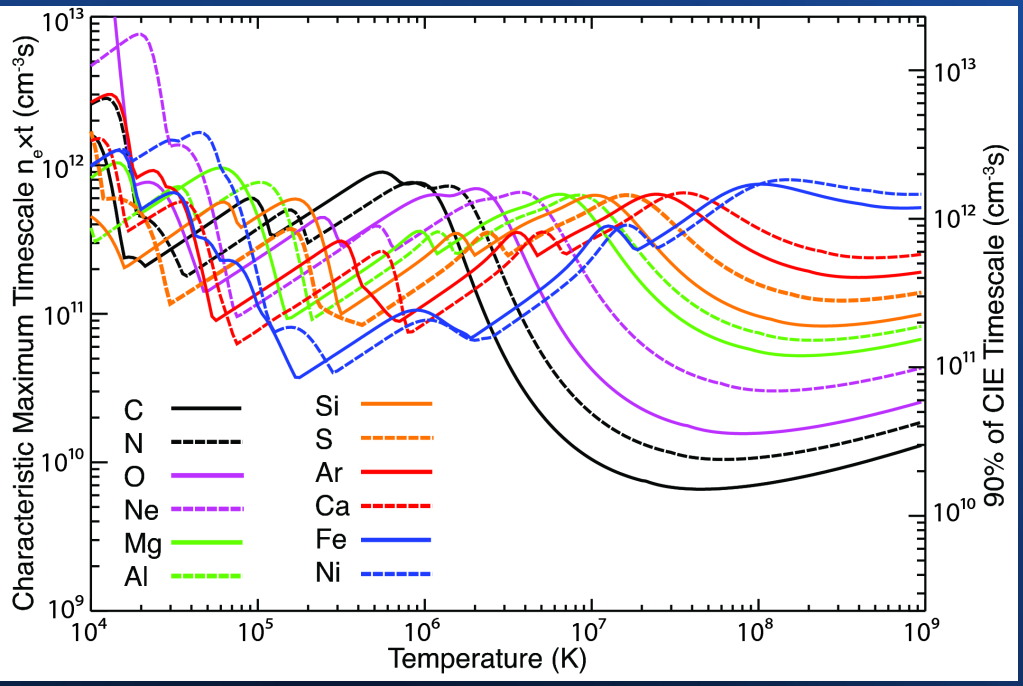


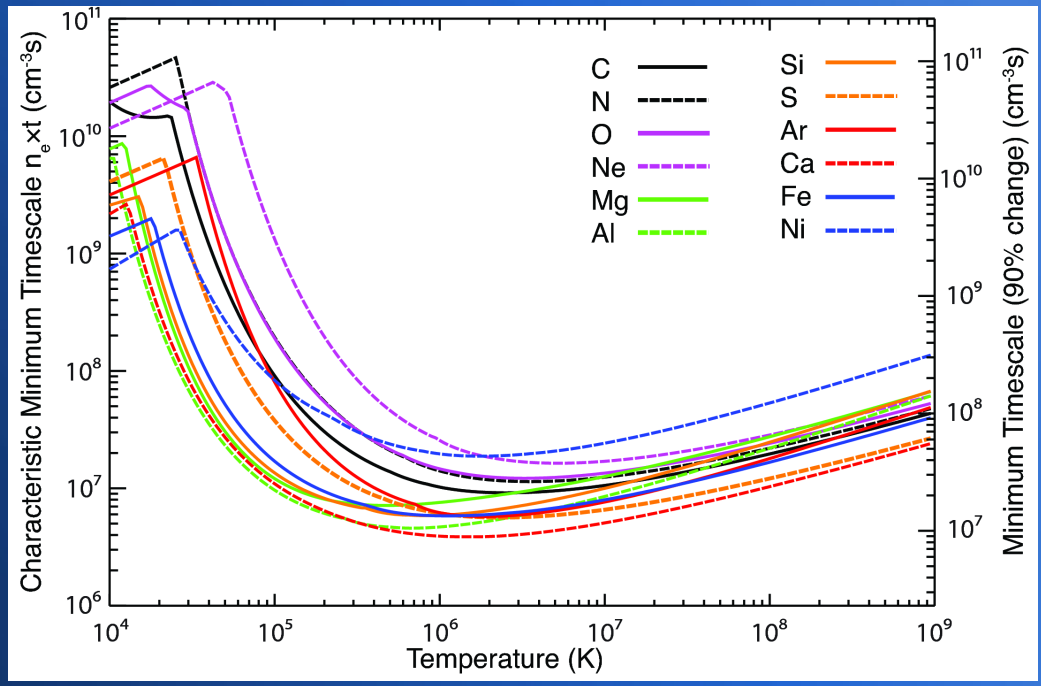
When do we care about NEI?

Solve ion balance matrix:

$$\frac{dN^{+z}}{dt} = N_e\left(S^{+z-1}(T_e)N^{+z-1} + \alpha_{+z+1}(T_e)N^{+z+1}\right) - N_e\left(S^{+z}(T_e)N^{+z} + \alpha_{+z}(T_e)N^{+z}\right)$$

NEI timescales

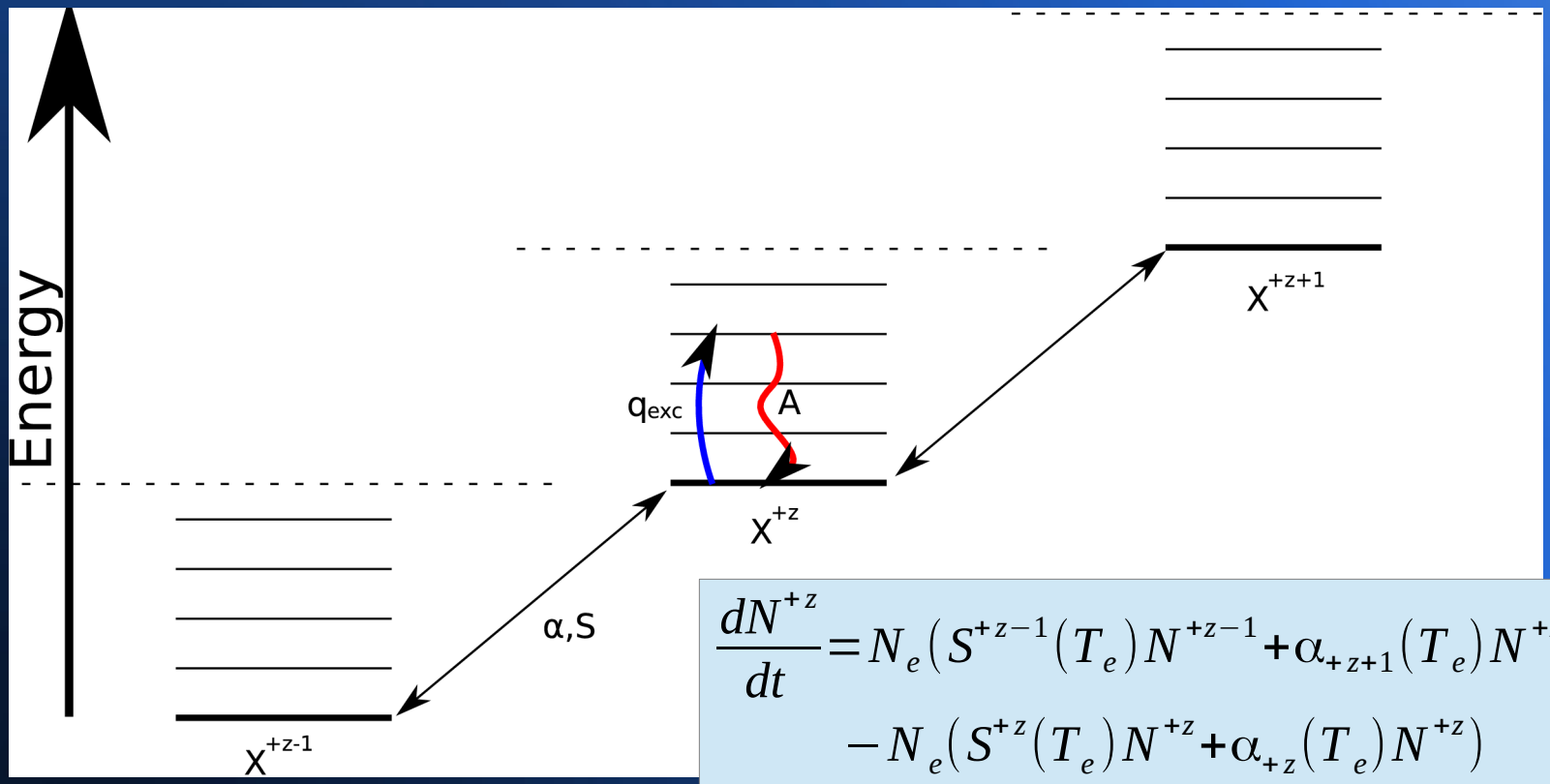




Smith & Hughes 2010

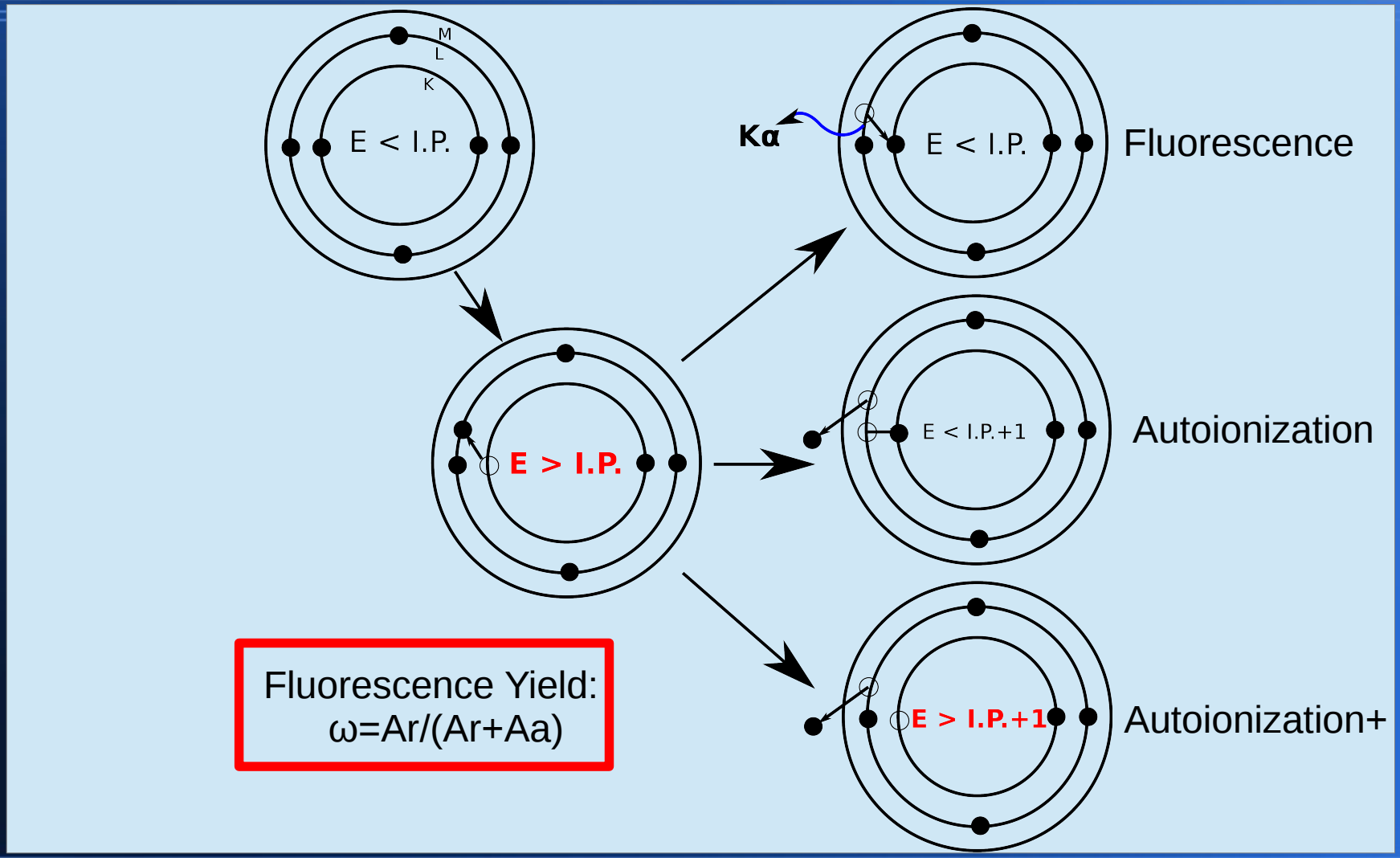
Solving for 1/e or 90% transition times show that NEI matters for ~$10^8 < n_e t < 10^{12}$

Collisional-Radiative Modeling

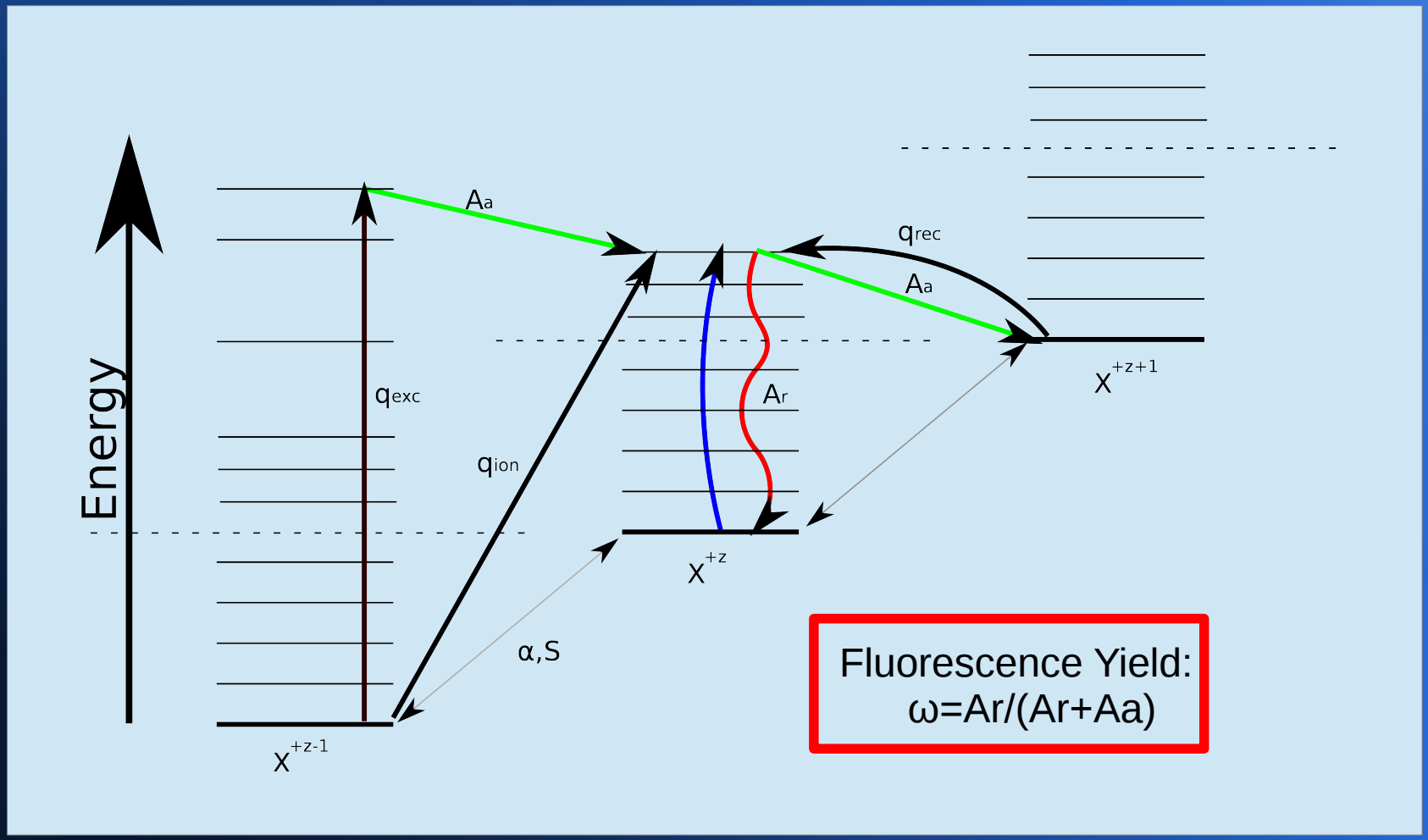


$$\frac{dN^{+z}}{dt} = N_e\left(S^{+z-1}(T_e)N^{+z-1} + \alpha_{+z+1}(T_e)N^{+z+1}\right) - N_e\left(S^{+z}(T_e)N^{+z} + \alpha_{+z}(T_e)N^{+z}\right)$$

Inner Shell Processes



Autoionizing state processes



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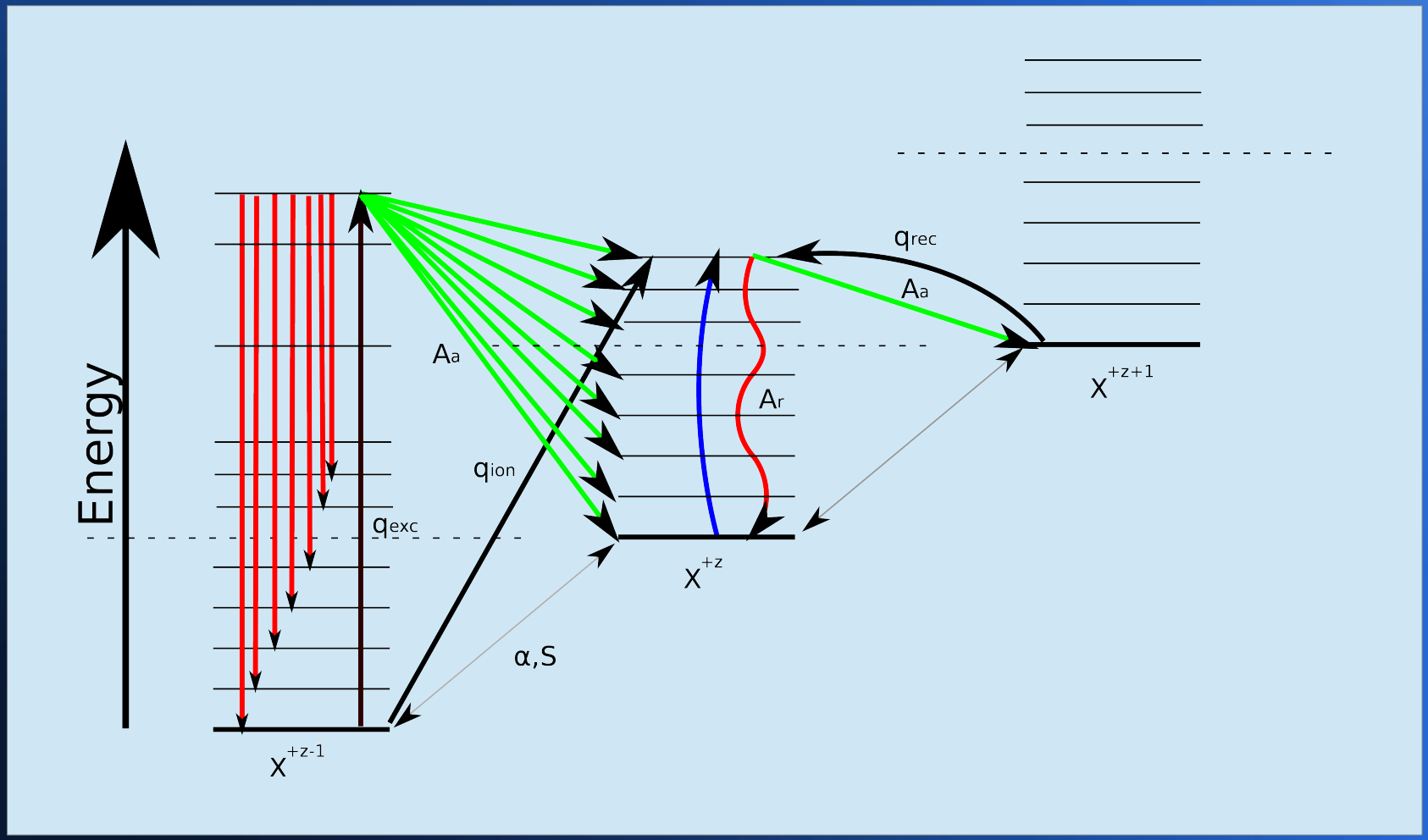
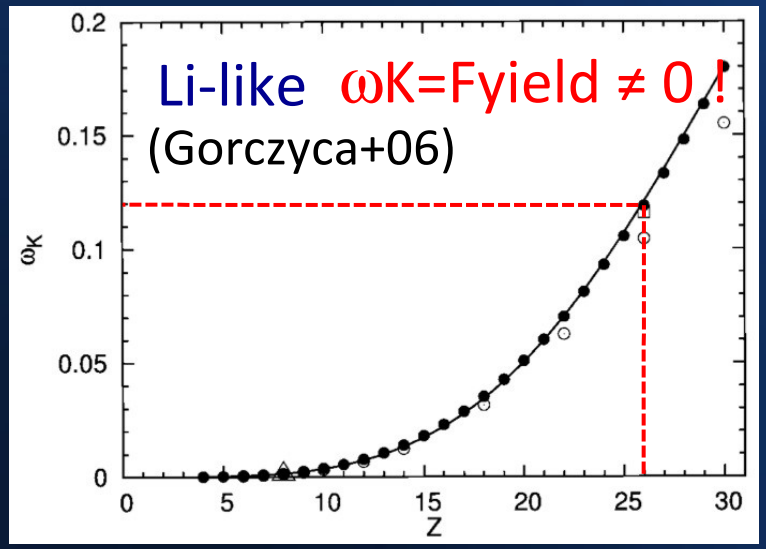


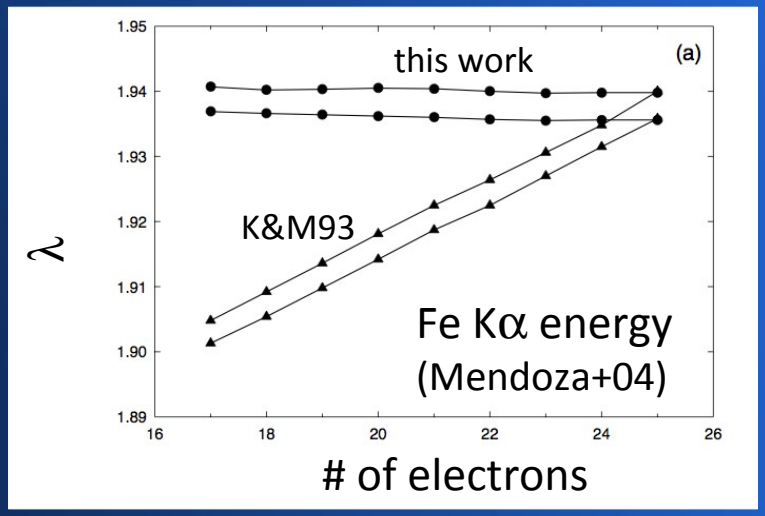
NEI models in XSPEC

- No fluorescence line data in AtomDB
- Widely used NEI model (Borkowski+ 2001) based on old AtomDB (v1.3.1)
- Fits to experimental data for inner-shell ionization (Beigman+1996)
- Uses Kaastra & Mewe (1993) data for Auger yields

Kaastra & Mewe data

- Kaastra & Mewe obtained Auger yields by extrapolating from experimental values for singly ionized ions. (Danger!)
- Neglect of configuration interaction lead to some large errors, e.g. Be-like ions with fluorescence yield=0

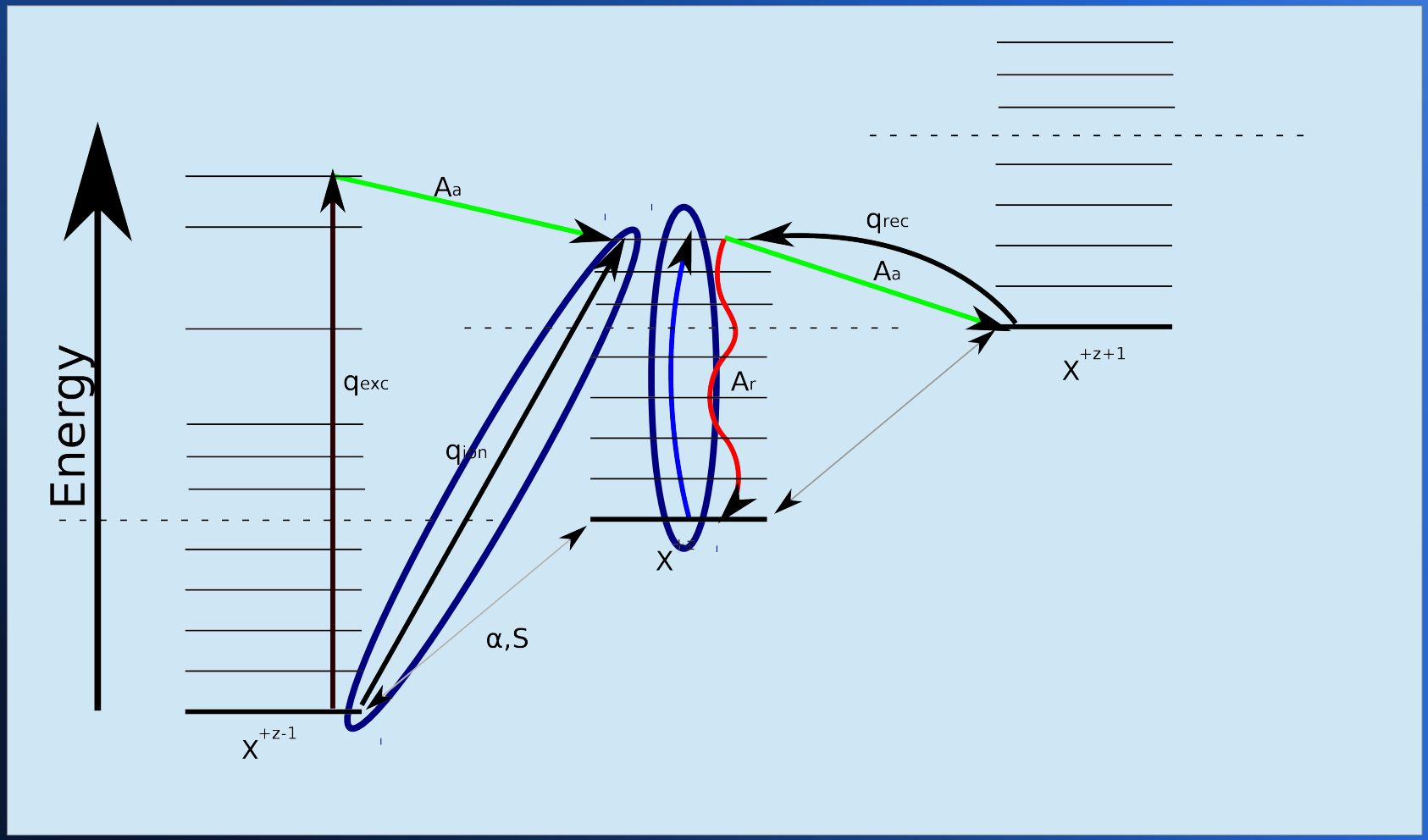




Newer Fluorescence Yield Data

	Fe I-XVI	XVII-XXIV	Ni I-XVIII	XIX-XXVI	Cr, Mn
Ar, Aa	Palmeri+03a Mendoza+04	Gorczyca+03;06 Hasoglu 08 (thesis)	Palmeri+08a		Palmeri+12
λ (Kα)		Palmeri +03b			
λ (Kβ)		Eriksen 2012	(not detected)	Eriksen 2012	(not detected)
x-sec (EII)	phenomenological formula (Haque+06)				
x-sec (EIE)	(IRON Project)				

Populating These Levels



Inner Shell Excitation

- R-matrix data for Li-like and Na-like systems provided by Liang+2009,2011
- Large scale FAC runs performed by Kris Eriksen for Fe XVII-XXIV
- For other ions, data is immediately sketchier/missing

Stopgap solution

Flawed data better than no data*

- Run FAC (unoptimised – speed is of the essence)
- Get full set of excitation, ionization, radiative and Auger rates.
- Where possible, compare with literature values, and replace/scale.
- Release model
- Get lots of “suggestions”
- FIX!

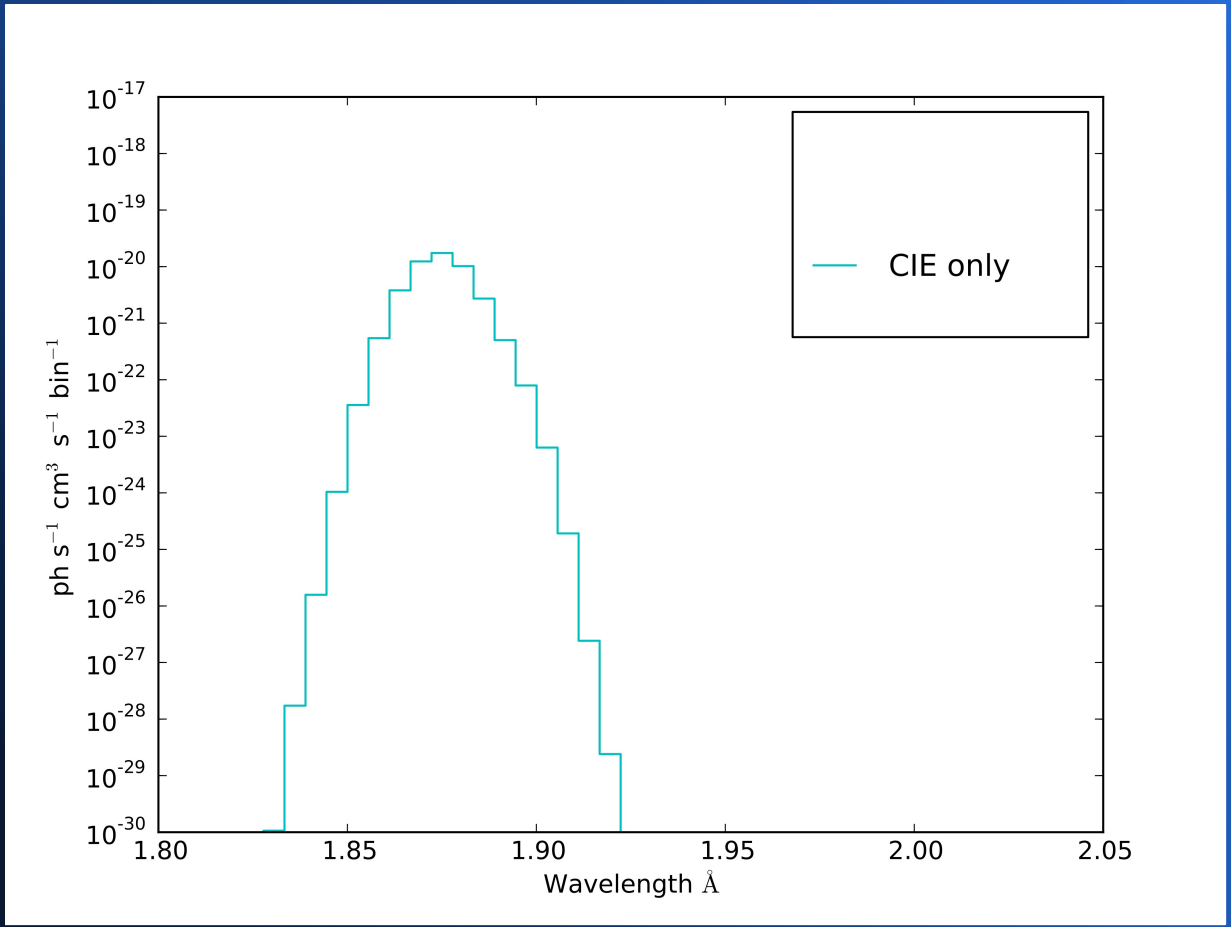
* - within reason

Inner Shell Ionization

- Total ionization cross sections available
- Inner shell direct ionization harder to come by
- Patchy data at best...

Li-like Fe

Te = 10keV
Ne = 1cm^{-3}
Time = 10^{11}s



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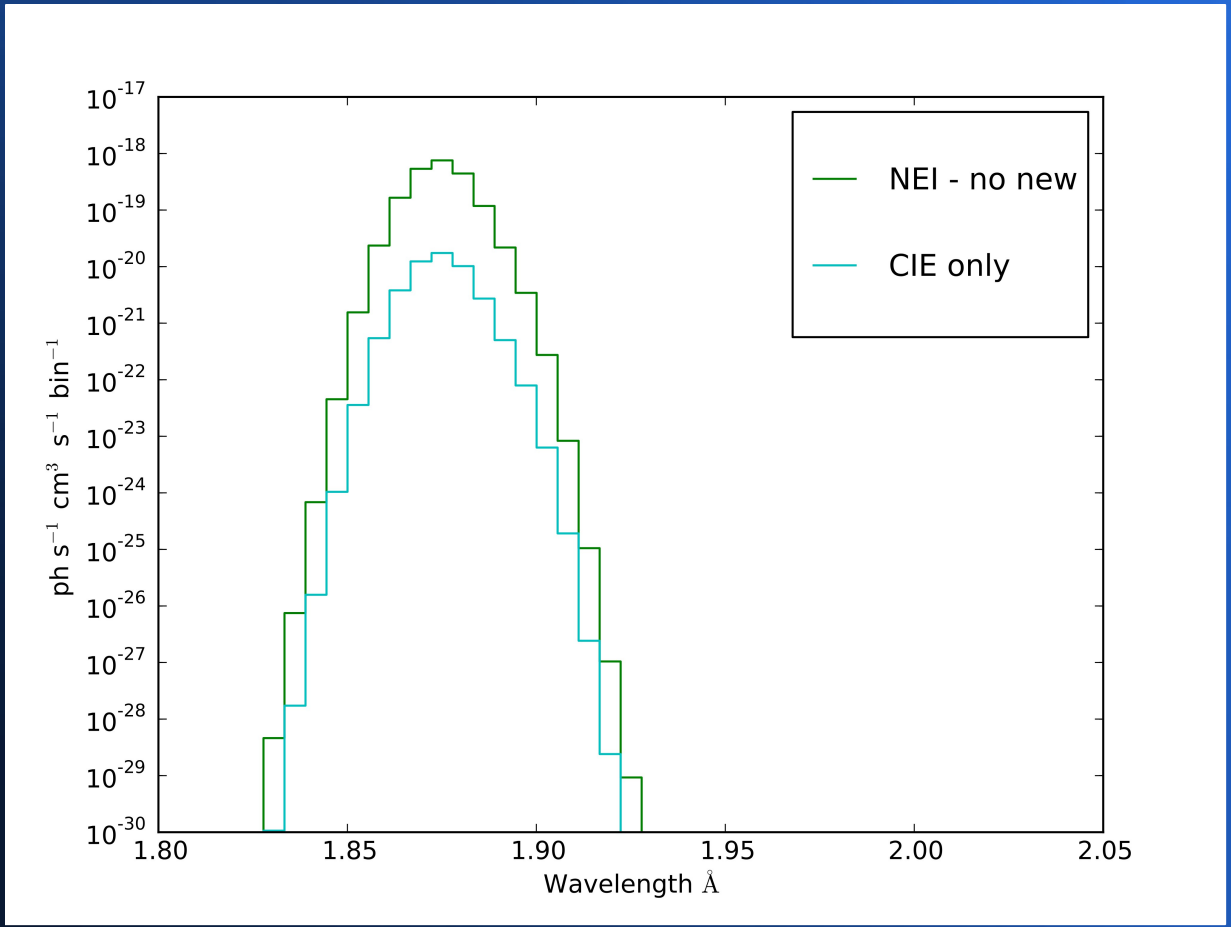

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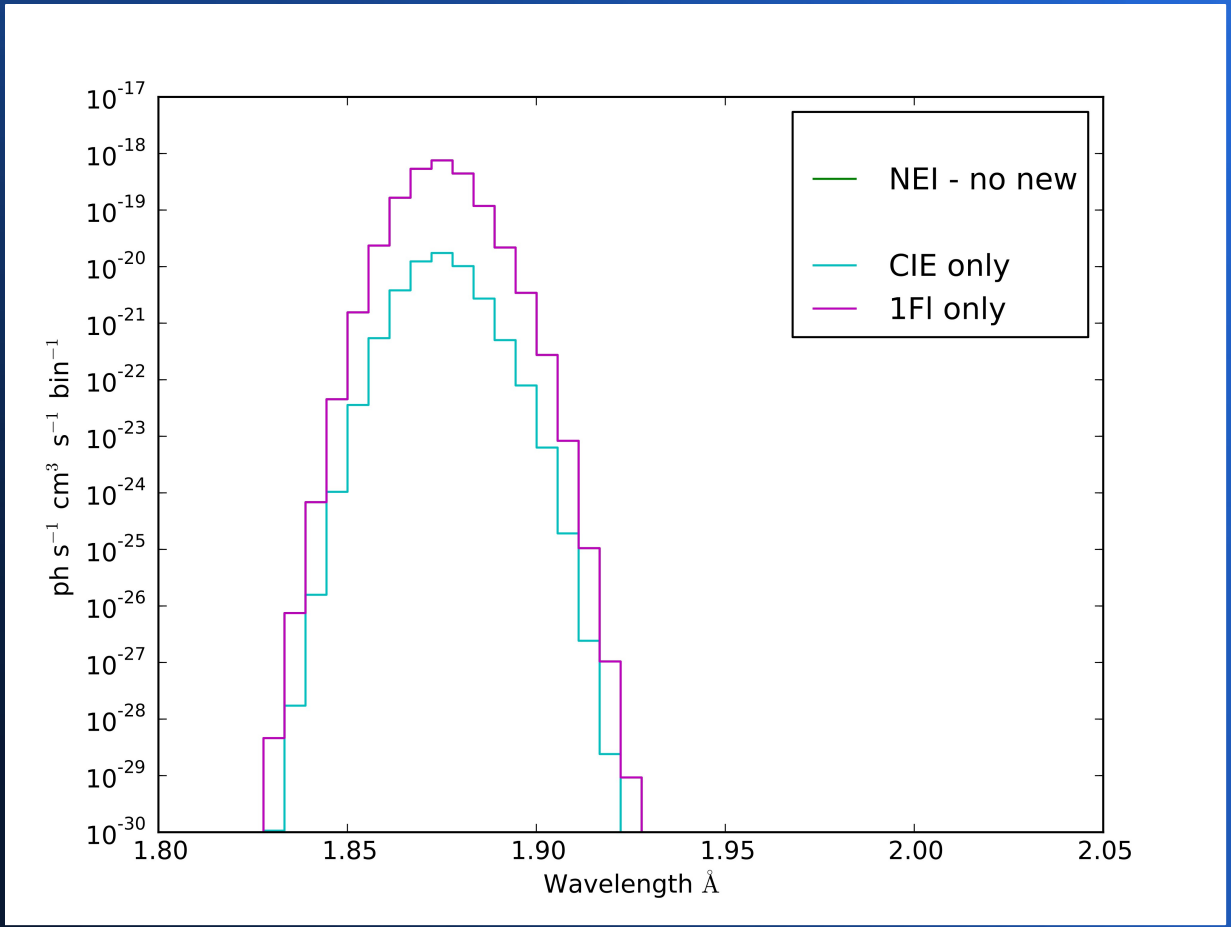

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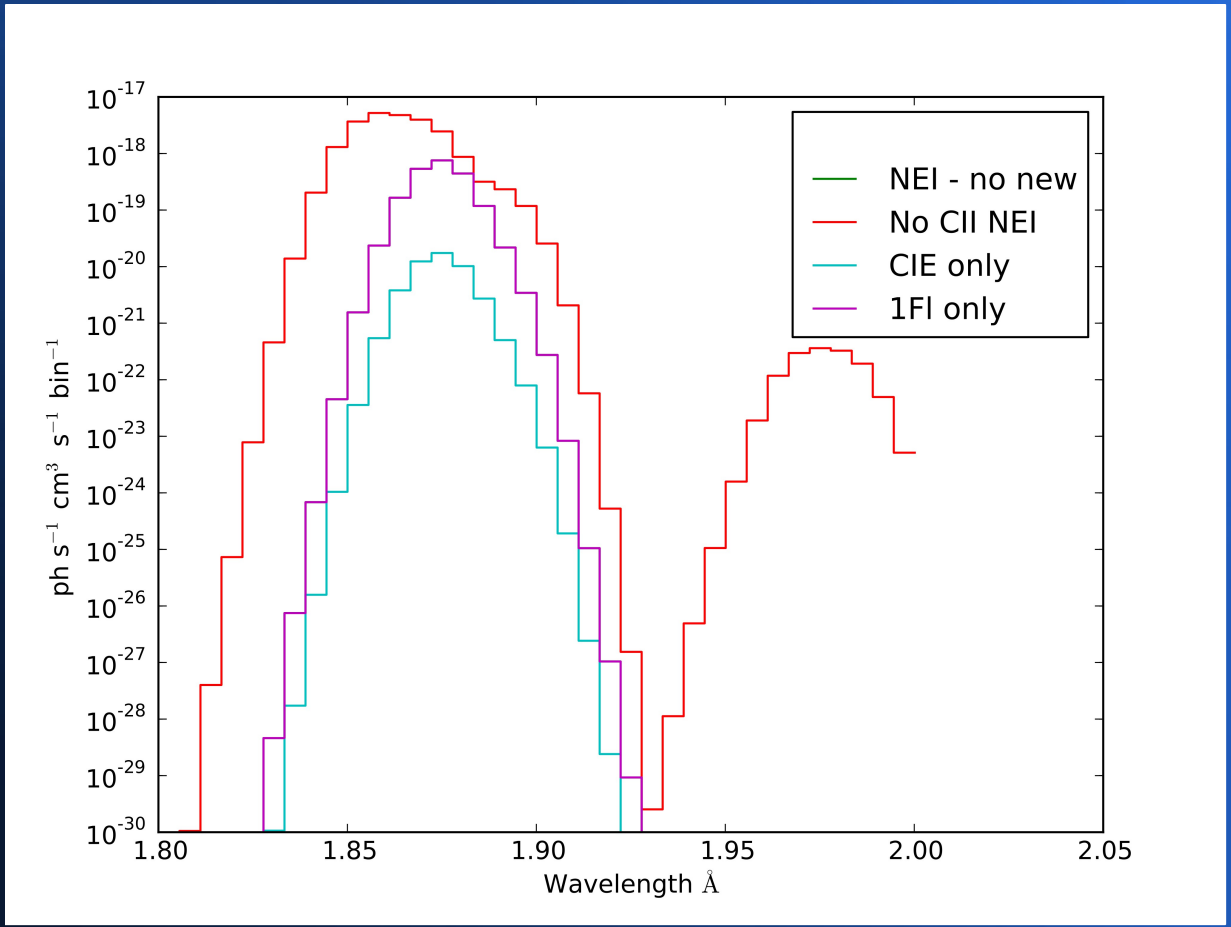

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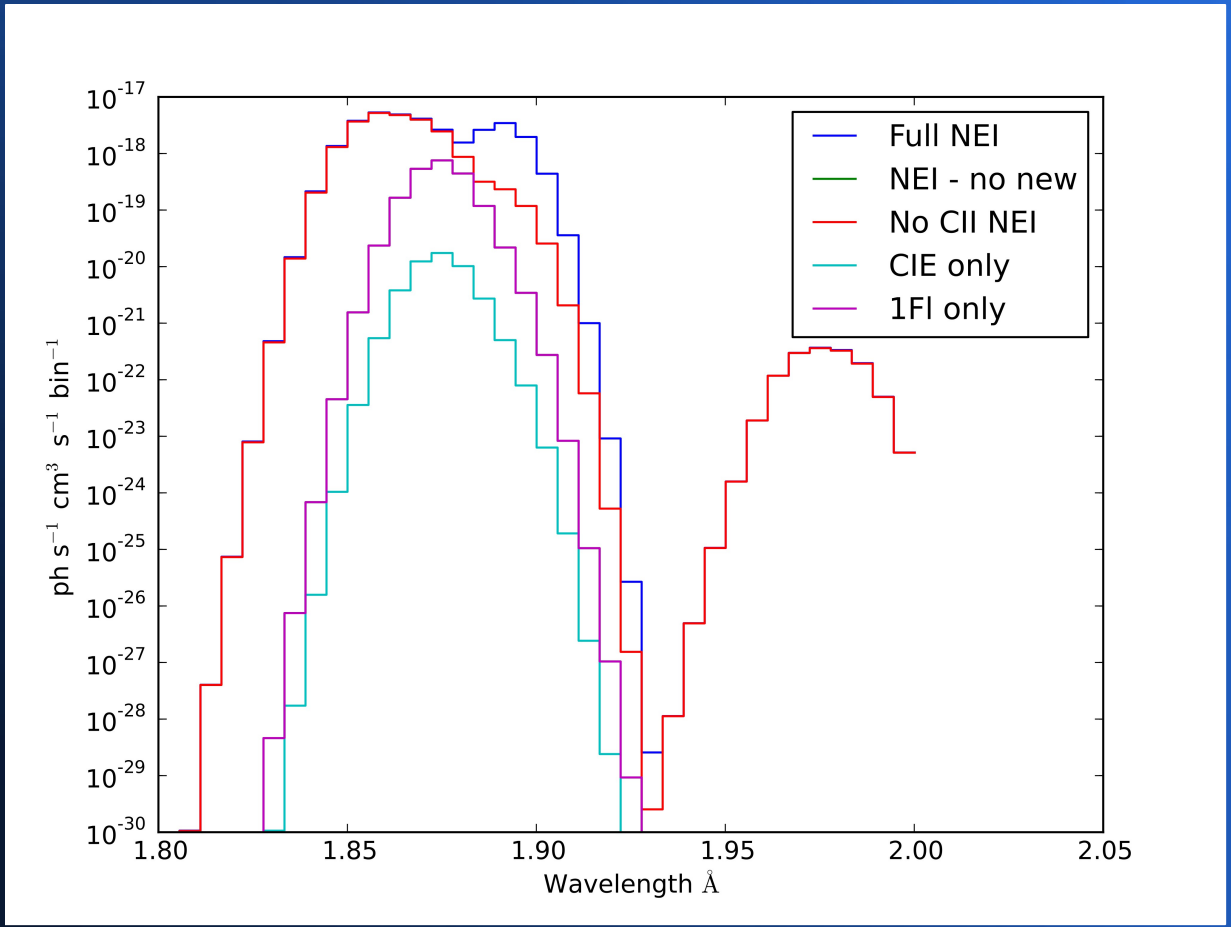


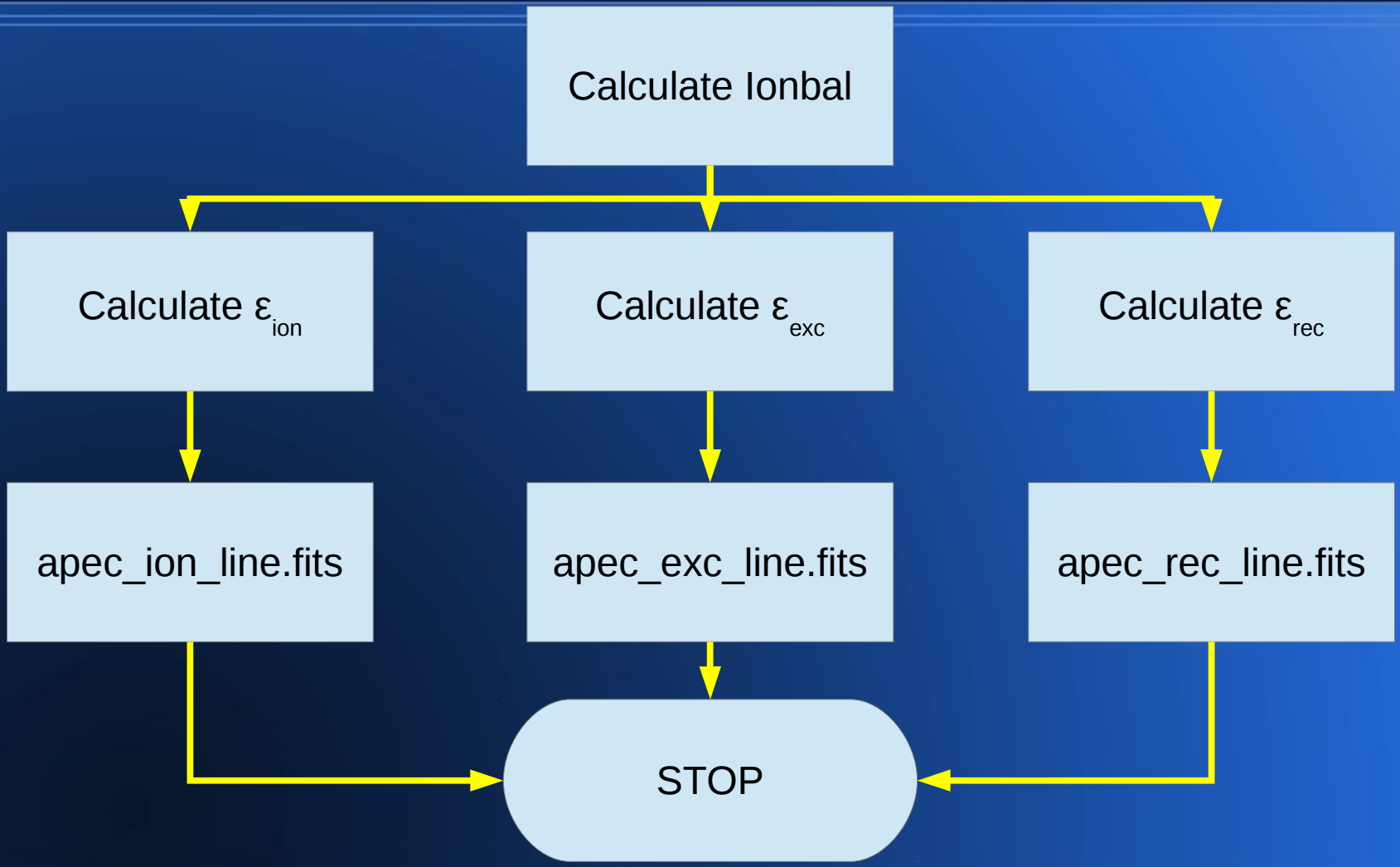
Practical considerations

APEC already capable of NEI plasma calculations

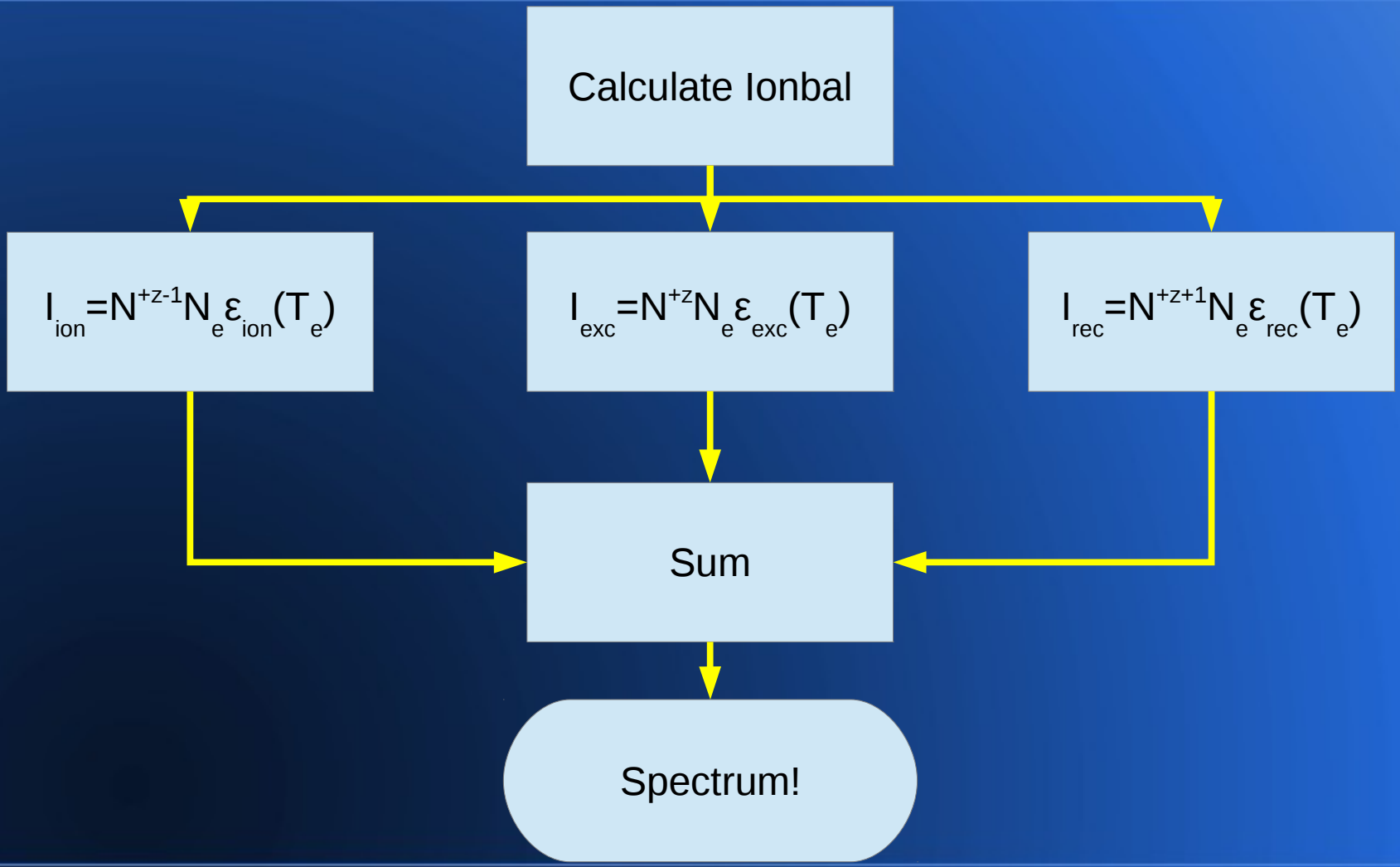
Practical issues due to ionization balance changes:

- No typical ion distribution
- Previous approach → HUGE files (50MB * 50 = 2.5GB)

APEC NEI Calculation



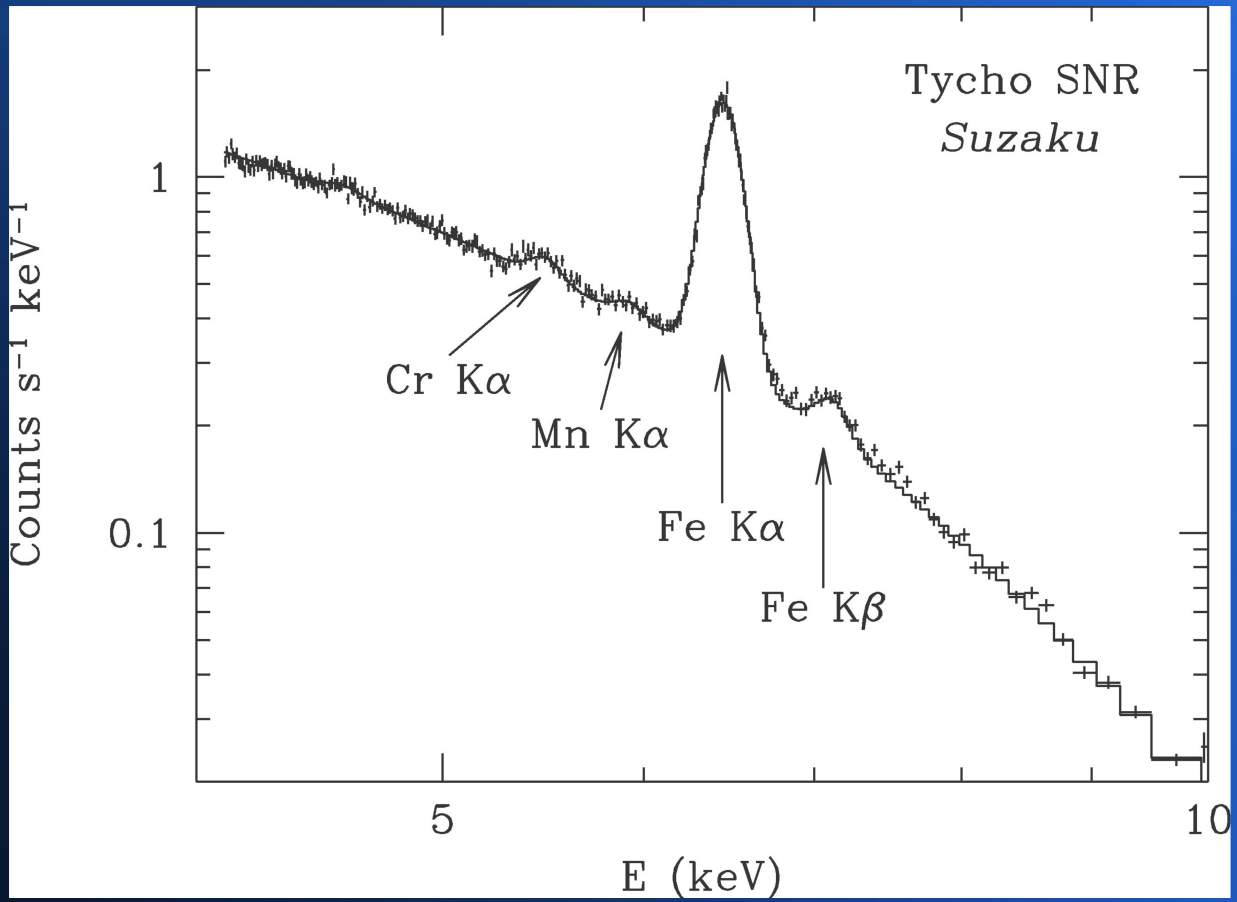
XSPEC model


Calculate Ionbal
$I_{ion}=N^{+z-1}N_e\varepsilon_{ion}(T_e)$
$I_{exc}=N^{+z}N_e\varepsilon_{exc}(T_e)$
$I_{rec}=N^{+z+1}N_e\varepsilon_{rec}(T_e)$
Sum
Spectrum!

Progress

- FAC data has been generated for iron
- APEC code updated
- First model created
- Still evaluating/fixing data.
- Concentrating on Fe (all ions) first.
- Anyone with better data welcome to mention it now...

Not just iron...



7-sigma detections

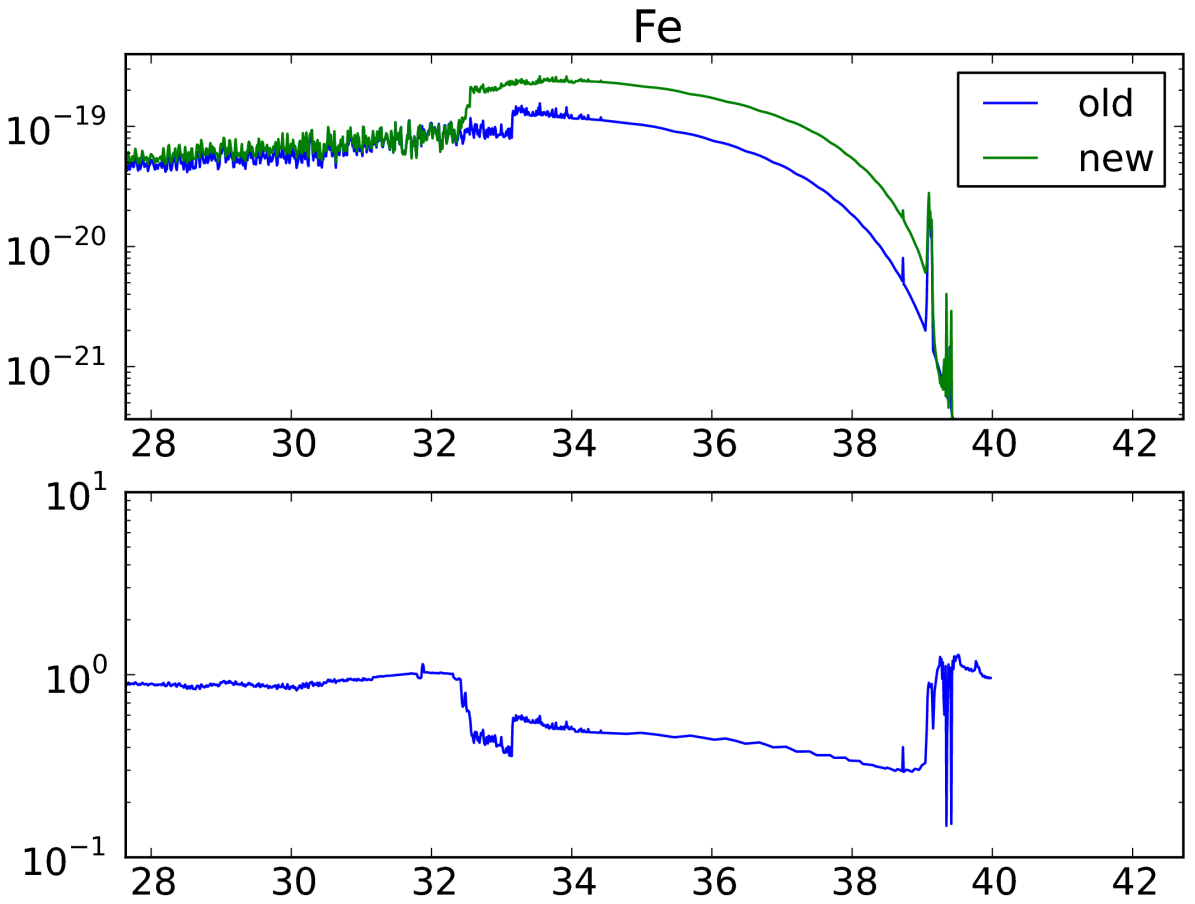
Tamagawa+2009, Badenes+2008

Other Projects

Merging XSTAR into AtomDB

Merged XSTAR photoionization data into AtomDB

- Used by APEC to calculate Radiative Recombination Continuua.
- Will be used by future version of TBABS



New Data Formats

Existing		New	
IR	ionization & rec rates	PI	Photoionization cross sects
LV	energy levels	AI	Autoionization rates
LA	A-values, wavelengths	CI	Inner shell ionization rates
EC	electron collision data		
PC	proton collision data		
DR	dielectronic satellite lines		