Emission- & Absorption-Measure Distributions

High Resolution X-Ray Spectroscopy: Towards *XEUS* and *Con-X*
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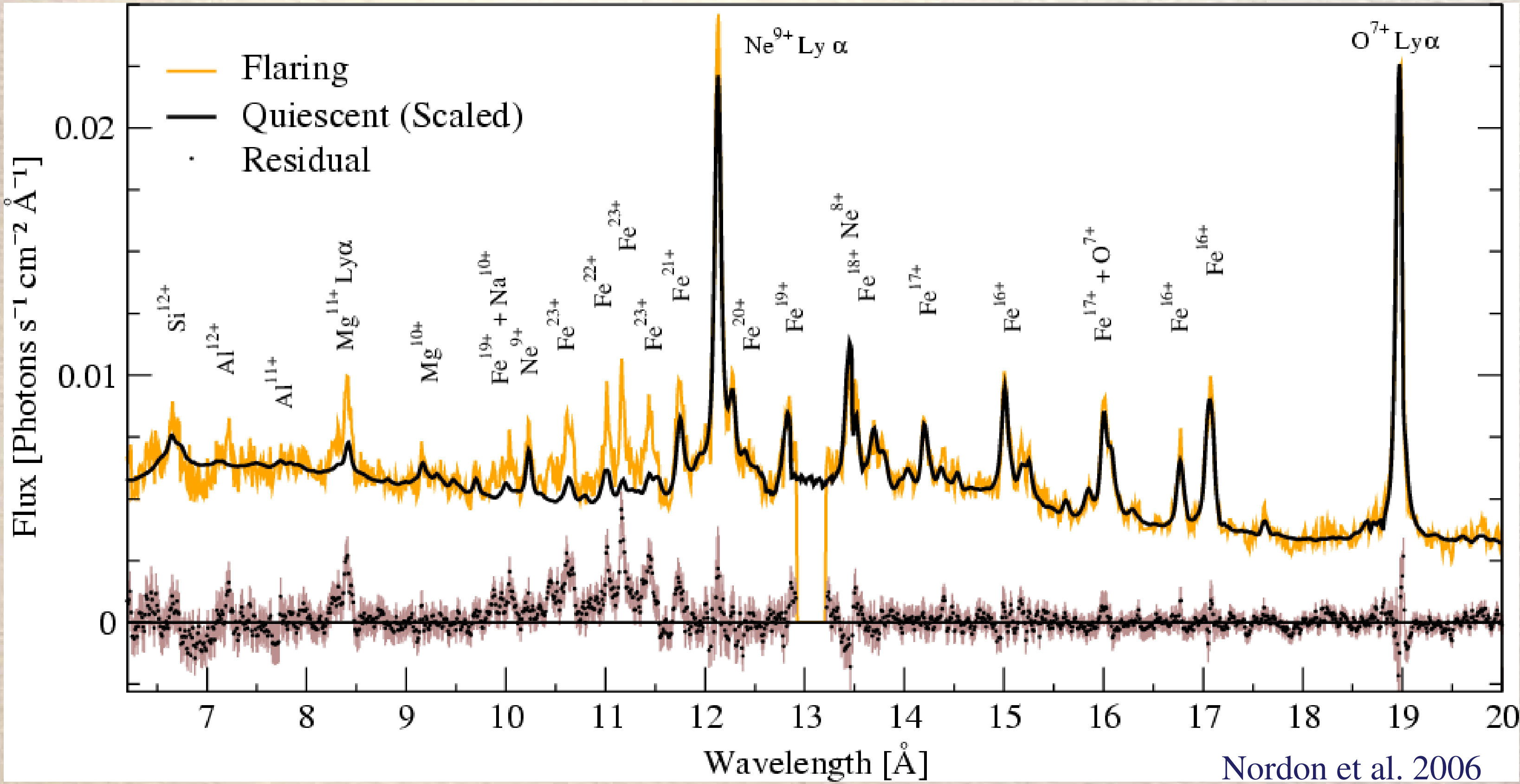
Outline

- Emission Spectra
  - EMD and why we want it
  - Fundamental Limitations
  - Results from coronal flares
- Absorption Spectra
  - Measured quantities
  - Absorption Measure Distribution (AMD)
  - Results for AGN outflows
- Conclusions

Emission Line Spectra



Nordon et al. 2006

Line Flux: Reminder

- Fundamental plasma quantity:
  photons emitted per second per cm^3: $n_j A_{ji}$
- In the steady state coronal approximation:
  What comes up must come down:
  $n_j A_{ji} = n_e n_i Q_{ij}(T_e)$, $n_i = n_q$, plus cascades
- In astrophysical terms:

atomic physics   plasma physics   chemistry

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

since $(n_j / n_q) \sim n_e$, the $F_{ji} \sim n_e n_H \sim n^2$

- For observed line flux F_{ji} now
  divide by $4\pi d^2$ and integrate over volume

Emission Measure

- Now,

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- For an isothermal, isochemical plasma,

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are needed to see this picture.

- However, steady state coronal plasma CANNOT in reality be isothermal, so

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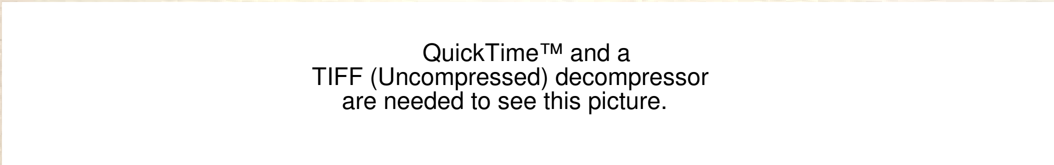
are needed to see this picture.

The EM Distribution

- So, what we are seeking is:

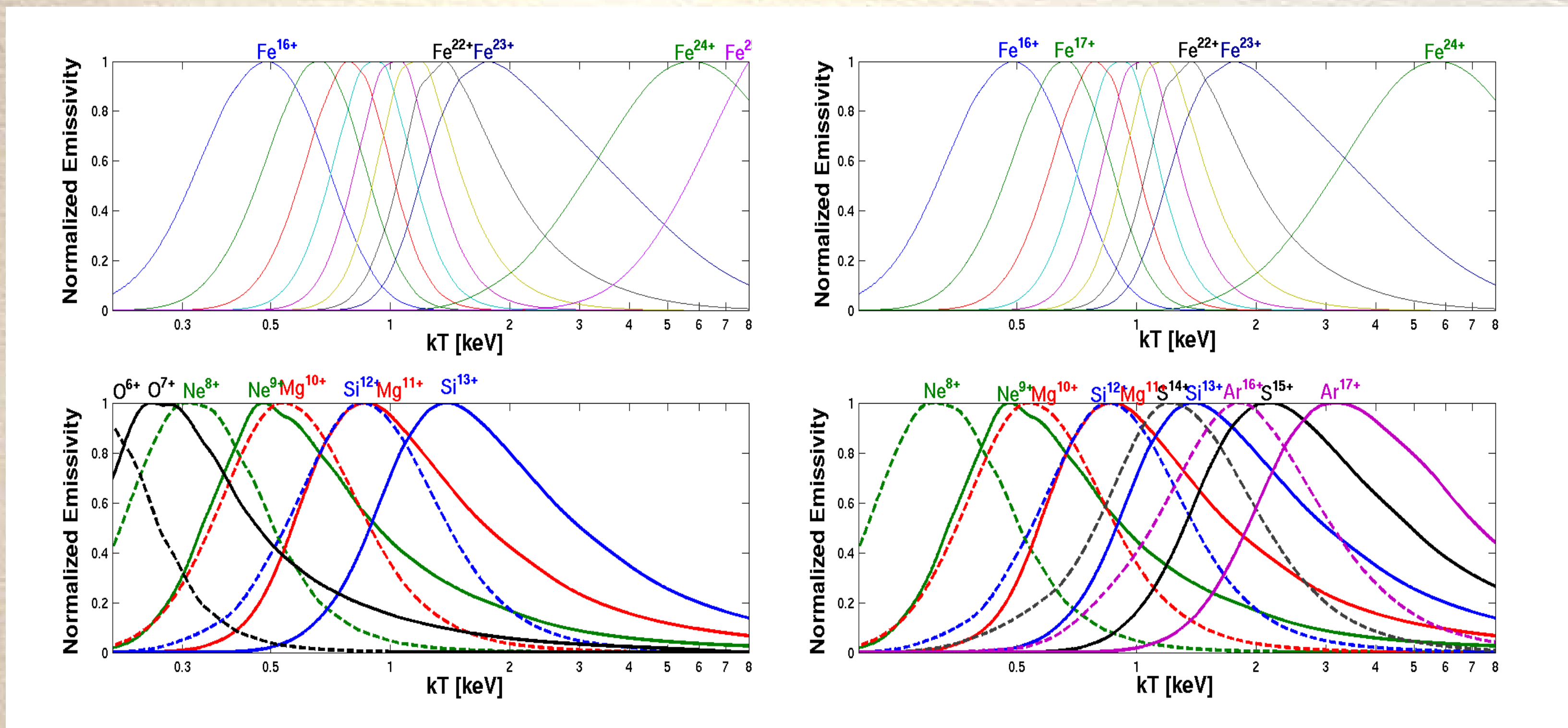


- In general, the derivation of the EMD is subject to confusion due to the entanglement of thermal and chemical contributions ($F_{ji} \sim A_Z EMD$)
- The X-ray band is unique in its richness: Fe-L comes to the rescue providing an abundance-free distribution (also, line ratios between ions)
- Once the EMD profile is known, normalizations for different elements yield the ABUNDANCES

Ionic Distributions

RGS+EPIC

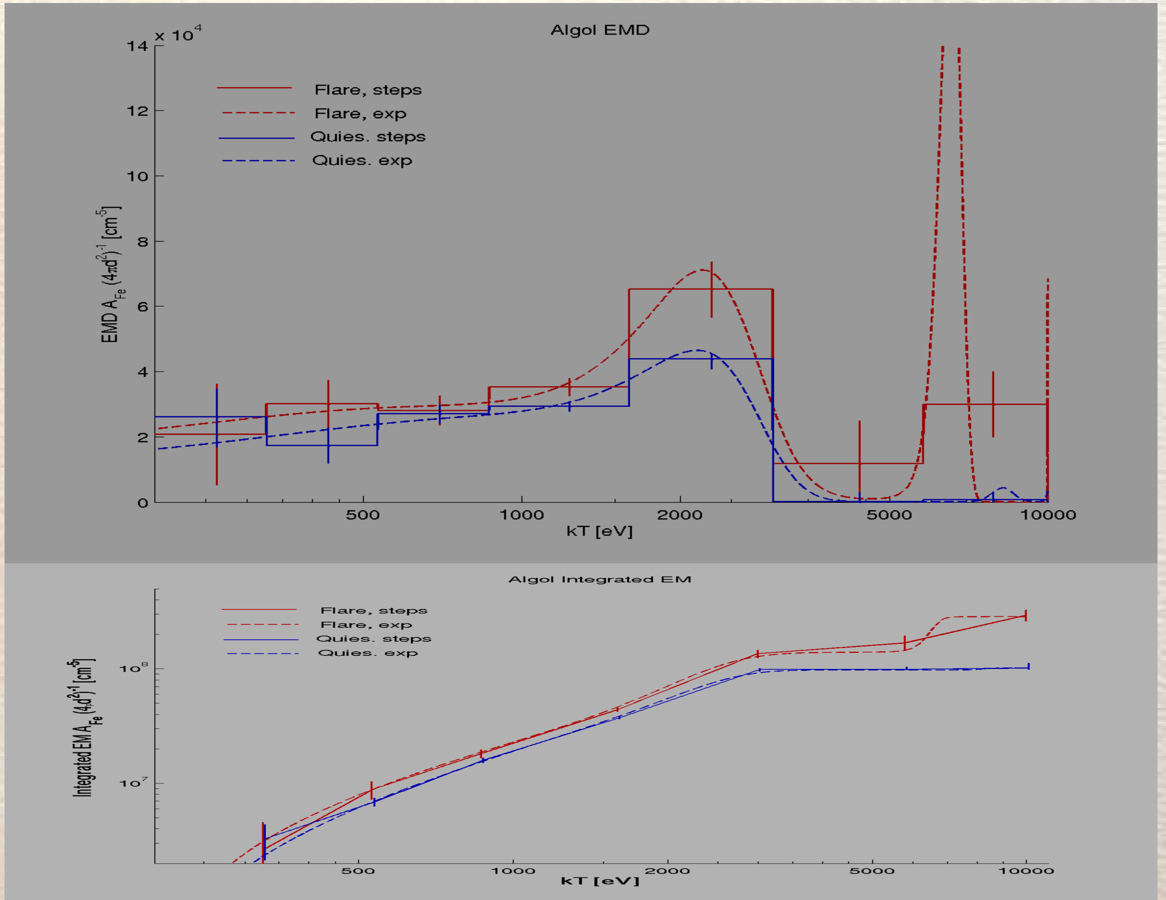
LETGS



Finding the EMD: The Inversion Problem

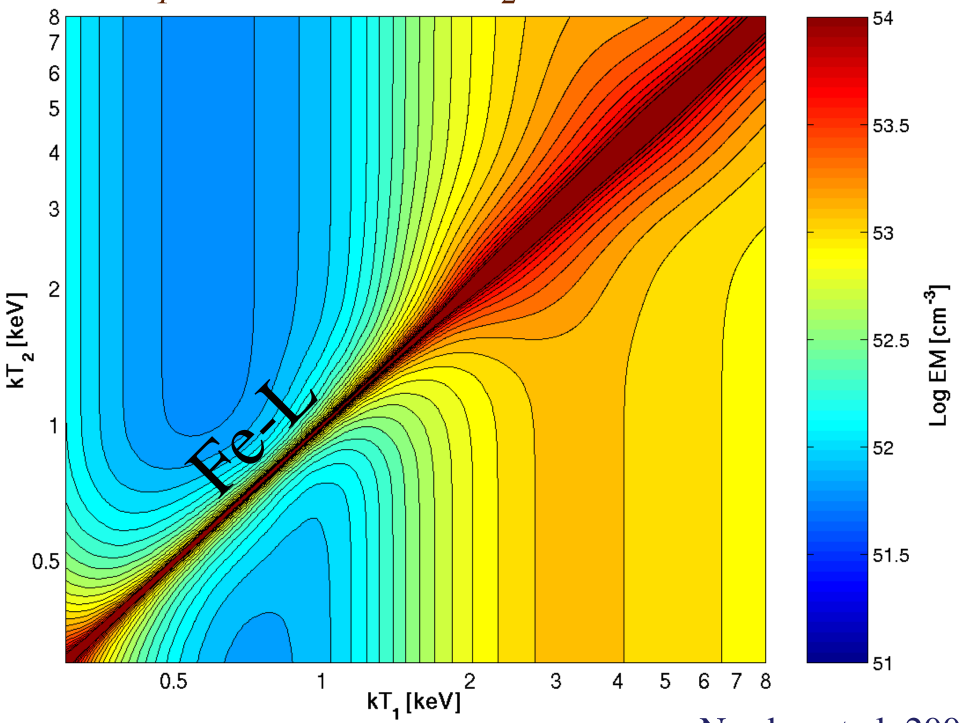
- Degeneracy is inherent even for high-accuracy measurements
  - Solution is non-unique
  - No physics to hint at the EMD shape
  - No escape from width of line emissivity curves
  - EMD variations on small temperature scales produce indistinguishable spectra
- Solution: fit for average EMD in *T*-bins
  - Produces meaningful, well localized errors
  - Limited temperature resolution
  - Dependent on ionization balance (e.g., Gu 2003)

Different EMD Shapes



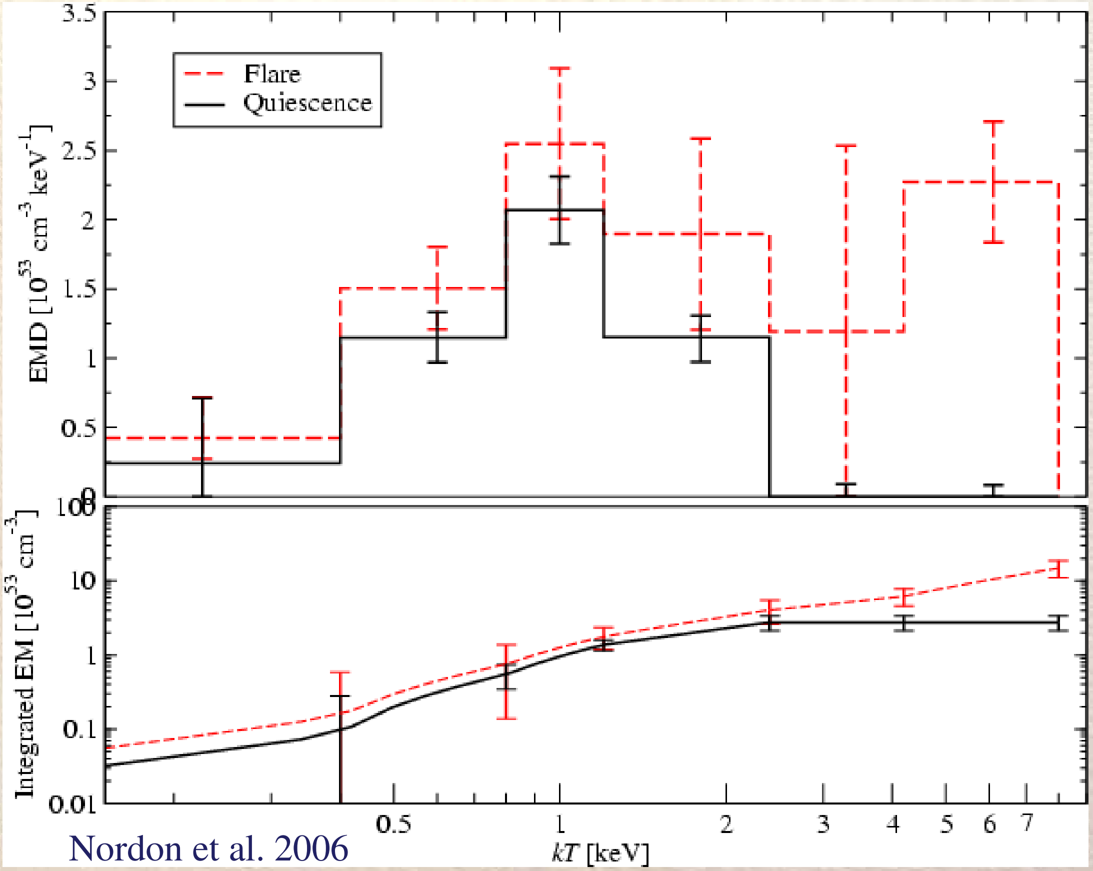
The Desire for EMD Confidence Dictates Low *T*-Resolution

How far can one go from T_1 to T_2 to compensate for $\delta EMD(T_1)$ with $\delta EMD(T_2)$ (to within $\Delta X^2 < 1$)?



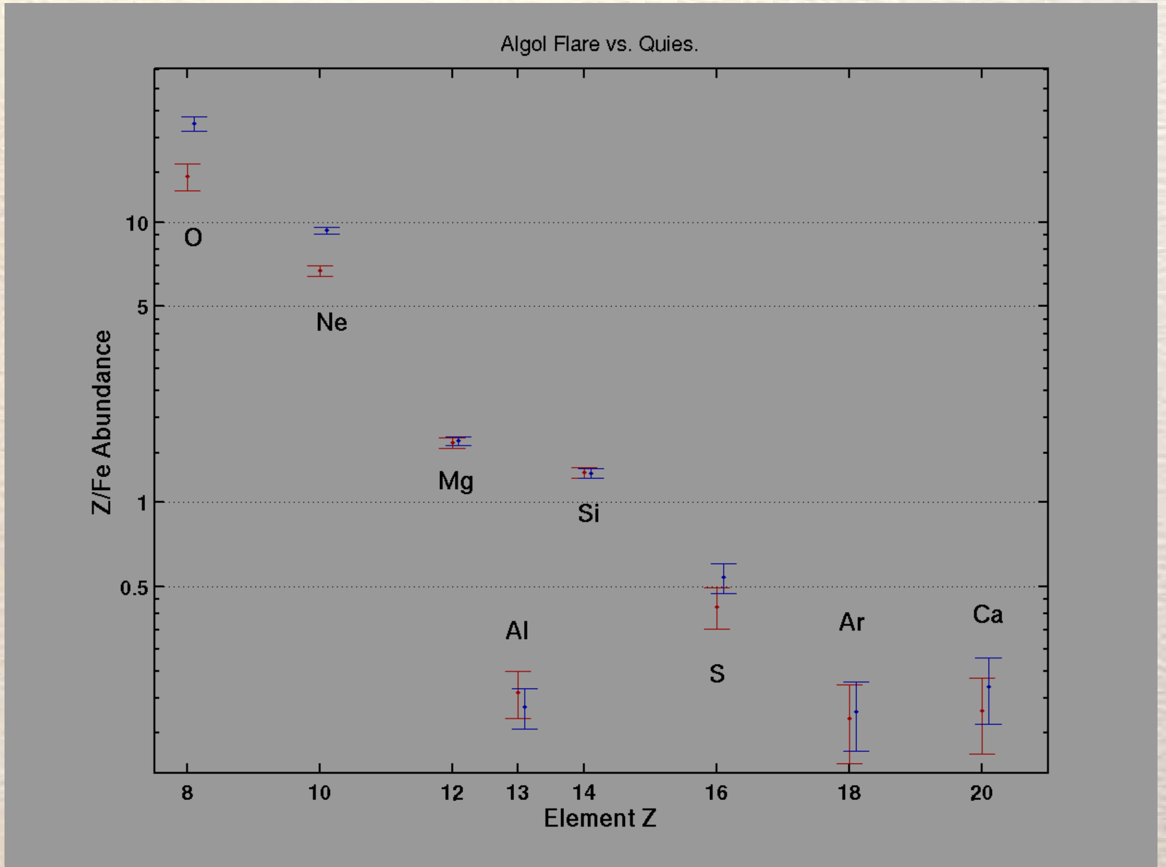
Nordon et al. 2006

Some Results:
Giant Flare on σ Gem

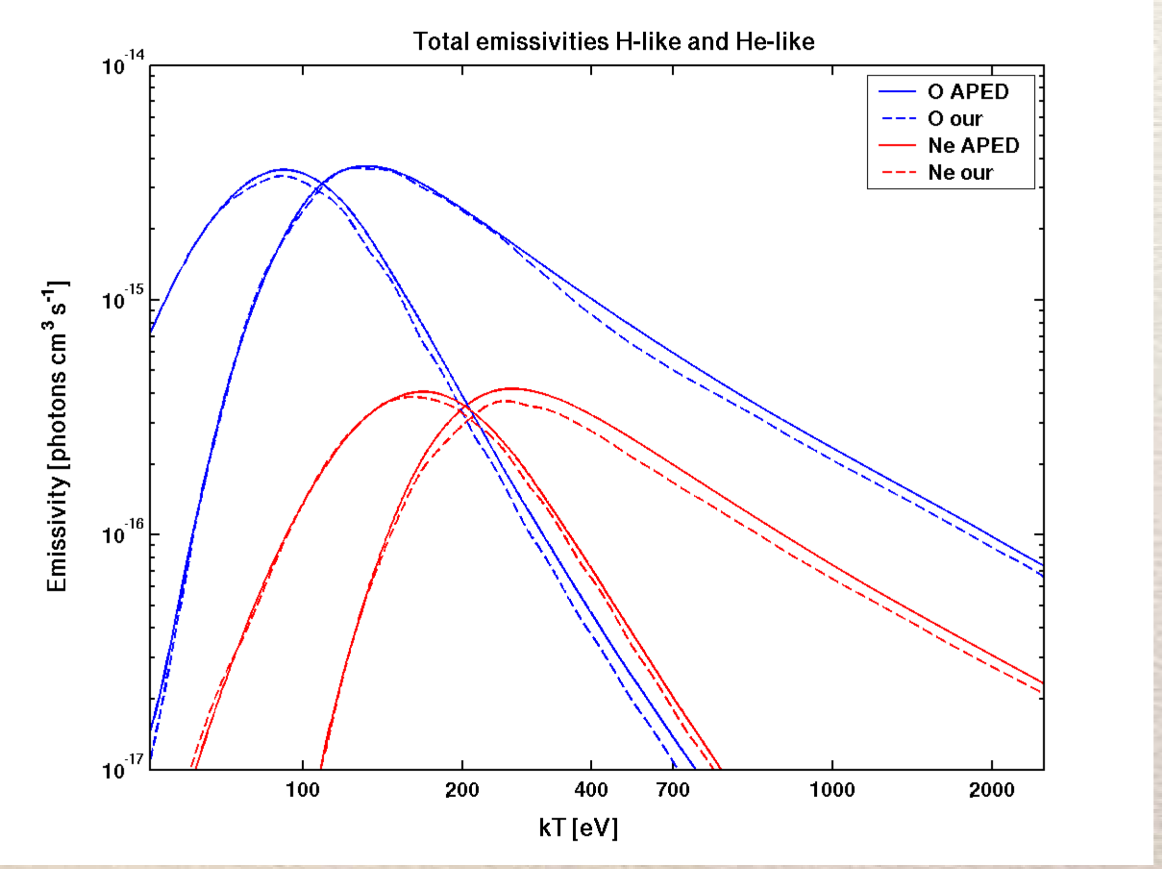


Nordon et al. 2006

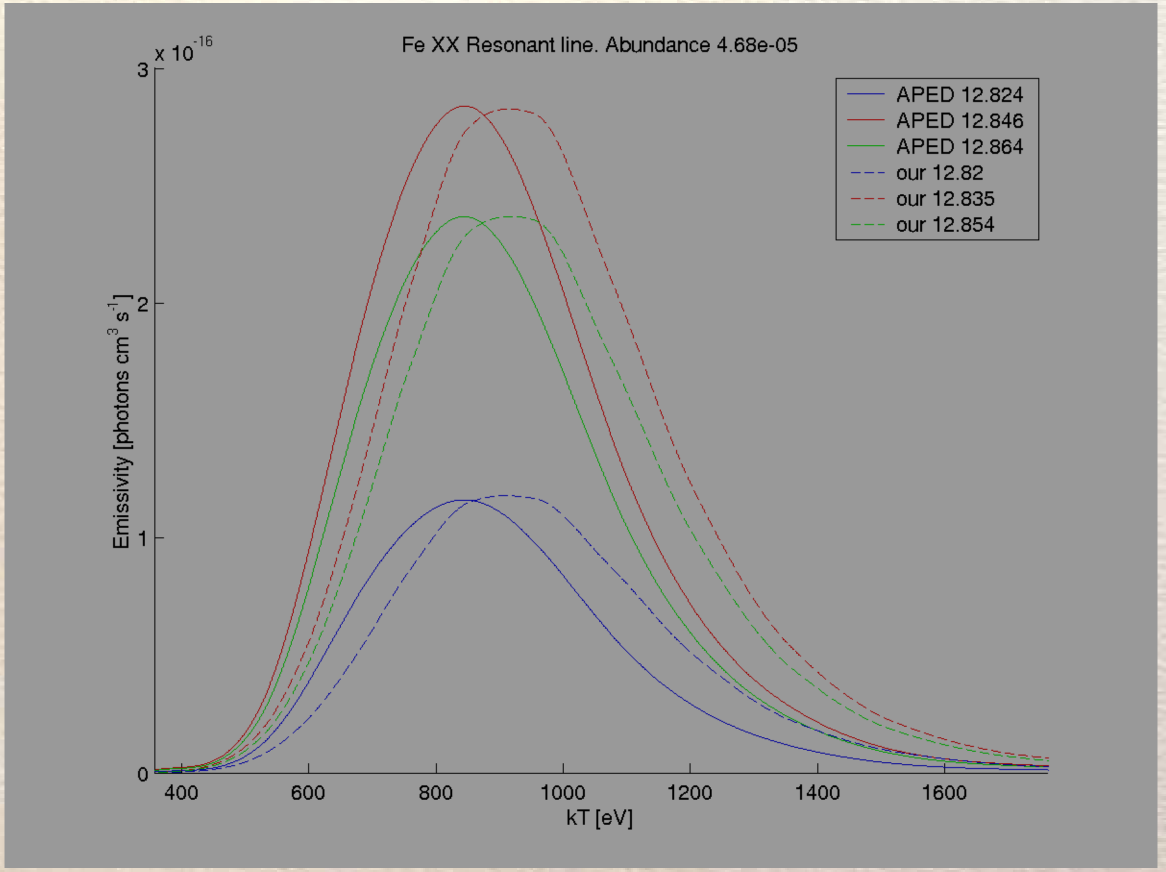
Abundances
Flare vs. Quiescence



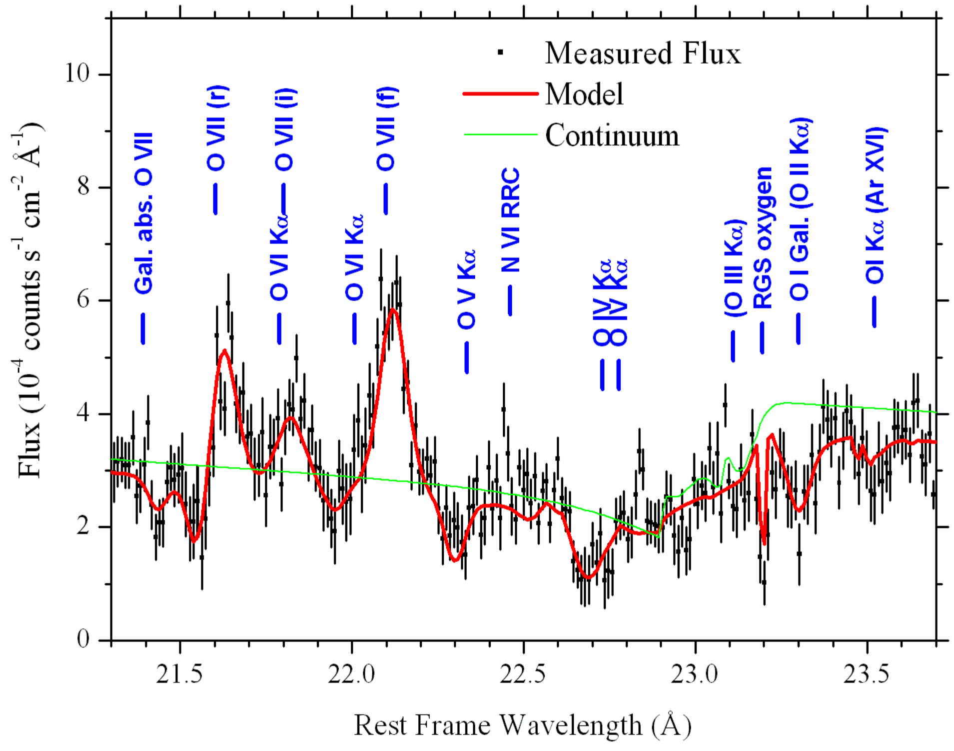
Atomic Data? Sanity Check



and Fe-L, e.g. Fe^{+19}



What about Absorption?



Absorption: The Same, but Slightly Different

- Measured quantity: Equivalent width and optical depth of (several) lines & edges (partial covering can complicate things considerably).
- Fundamental plasma quantity:
  Optical depth and ionic column density $\tau_{ij} = N_{ion}\sigma_{ij}$

$$N_{ion} = \int_{r_{min}}^{r_{max}} n_q dr$$

- Again, all ions are essentially in their ground state and in astrophysical terms:

$$n_q = \left(\frac{n_q}{n_Z}\right)\left(\frac{n_Z}{n_H}\right) n_H = f_q(\xi) A_Z n_H$$

- Ionization parameter QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture. replaces T_e
- Thus: for isochemical, isothermal (iso-ξ) absorber:
  one obtains an Equivalent $N_H = N_{ion} / f_q A_Z$

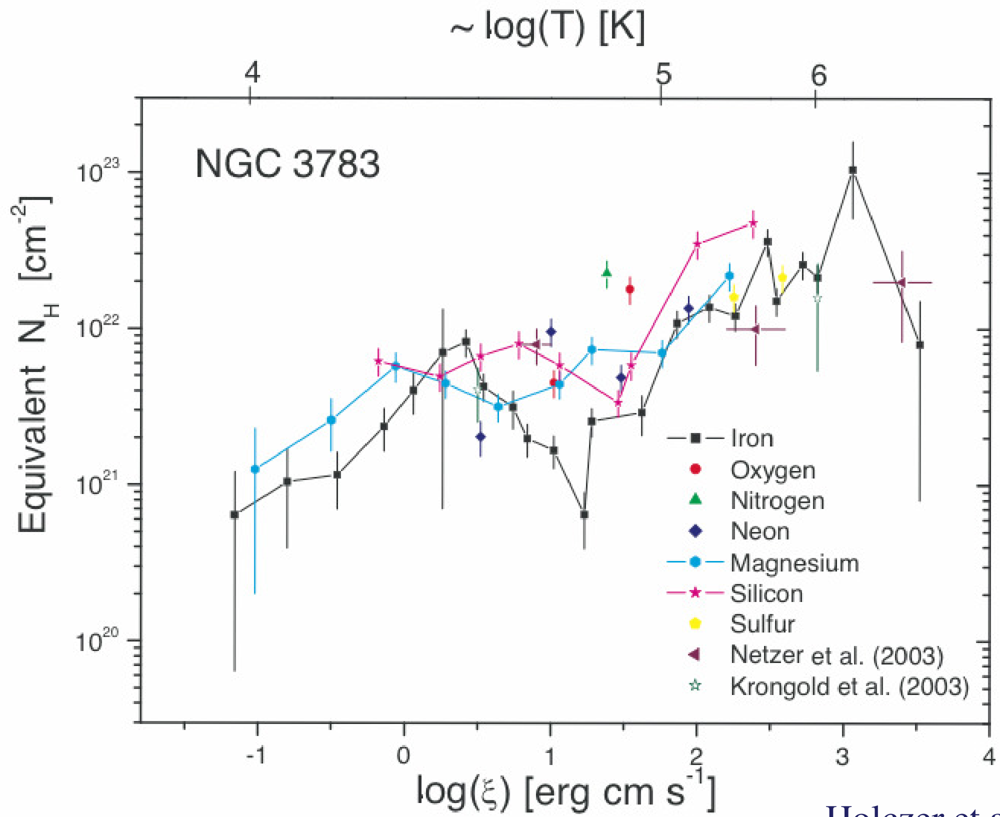
In Fact, N_H is Distributed

- An isothermal plasma near an intense ionization source (quasar) is even less likely than an isothermal coronal plasma.
- There must be an Absorption Measure Distribution (AMD):

$$N_H = \int \frac{dN_H}{d\xi}(\xi)d\xi \equiv \int AMD(\xi)d\xi$$

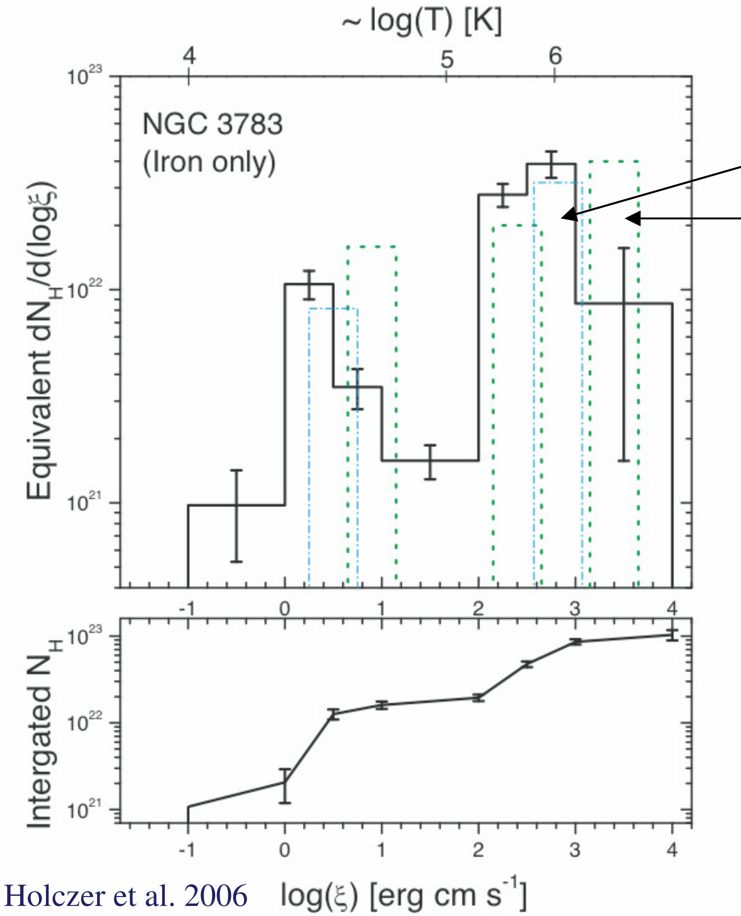
- SRON group (Steenbrugge, Costantini) has explored power-law AMDs (for NGC 5548, Mrk 279), but see talk by Goncalves
- Again, in the AMD derivation there can be confusion due to the entanglement of thermal and chemical contributions ($N_{ion} \sim A_Z AMD$)
- In absorption, the X-ray band is even more all-inclusive
- Inner-shell absorption reveals ALL CHARGE STATES (barring bare)
- Particularly, 26 ions of Fe allow for an abundance-free AMD analysis relying on T and $f_q(\xi)$ (XSTAR by T. Kallman)

Individual Ionic Column Densities



Holczer et al. 2006

Reconstructing The AMD

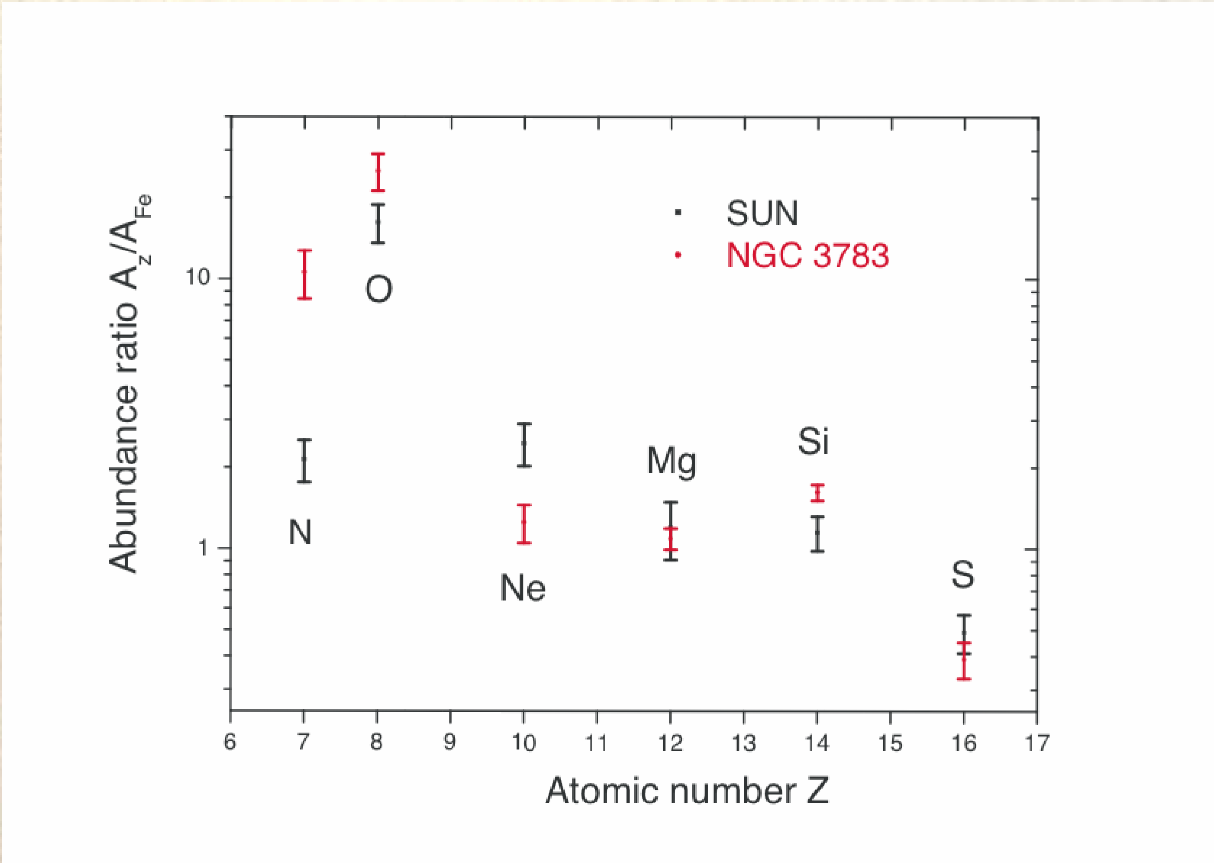


Krongold et al.

Netzer et al.

Holczer et al. 2006

Abundances (more reliable than emission)



Conclusions

- Astrophysical X-ray plasmas are generally NOT isothermal
- There always is a distribution: EMD or AMD
- The EMD and AMD play a role in comparative studies
- Essential for reliable abundance determination
- The EMDs/AMDs happen to be rather broad, thus few-T models do not usually represent the EMD/AMD correctly
- In the absence of a physical model for the EMD or AMD, the best representation is a step function, which allows for local well-constrained error estimates
- L-shells provide powerful diagnostics, but T- or ξ– resolution is limited by fundamental physics; the ionic distributions
- To that end, the ionization balance (atomic data) is key

THANK YOU
FOR YOUR ATTENTION

Stability Analysis