"Usin' what we got": Calculating X-ray Spectra for Non-Equilibrium Plasmas

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Abstract

It is desirable to calculate the X-ray emission spectrum from a (region of a) plasma that is not in ionization equilibrium, e.g., with application to supernova remnants, SNRs. Such a plasma will generally have ionization fractions that are not directly related to the local electron temperature and, in the case of SNR ejecta, may contain little or no H and He.

This poster describes the use of the currently available database, APED/APEC, and software, ISIS, to generate spectra for a non-equilibrium plasma that is specified by explicit densities and ionization fractions for the ions and an explicit, independent electron temperature, T_e.

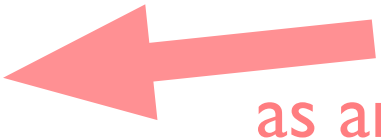
Example spectra are shown and discussed.

This approach does have some deficiencies currently, specifically: Cr lines are not in APED/C, not all relevant inner-shell lines are included, and continua spectra are not available on an ion-by-ion basis.

On a note of progress, the generalization of the ion fraction specificiation in ISIS is described and simplifies NEI plasma specification and evaluation.

Non-Equilibrium Model Examples...

* SNR Ejecta calculations
  - Badenes Type Ia models
  - Laming models for Cas A



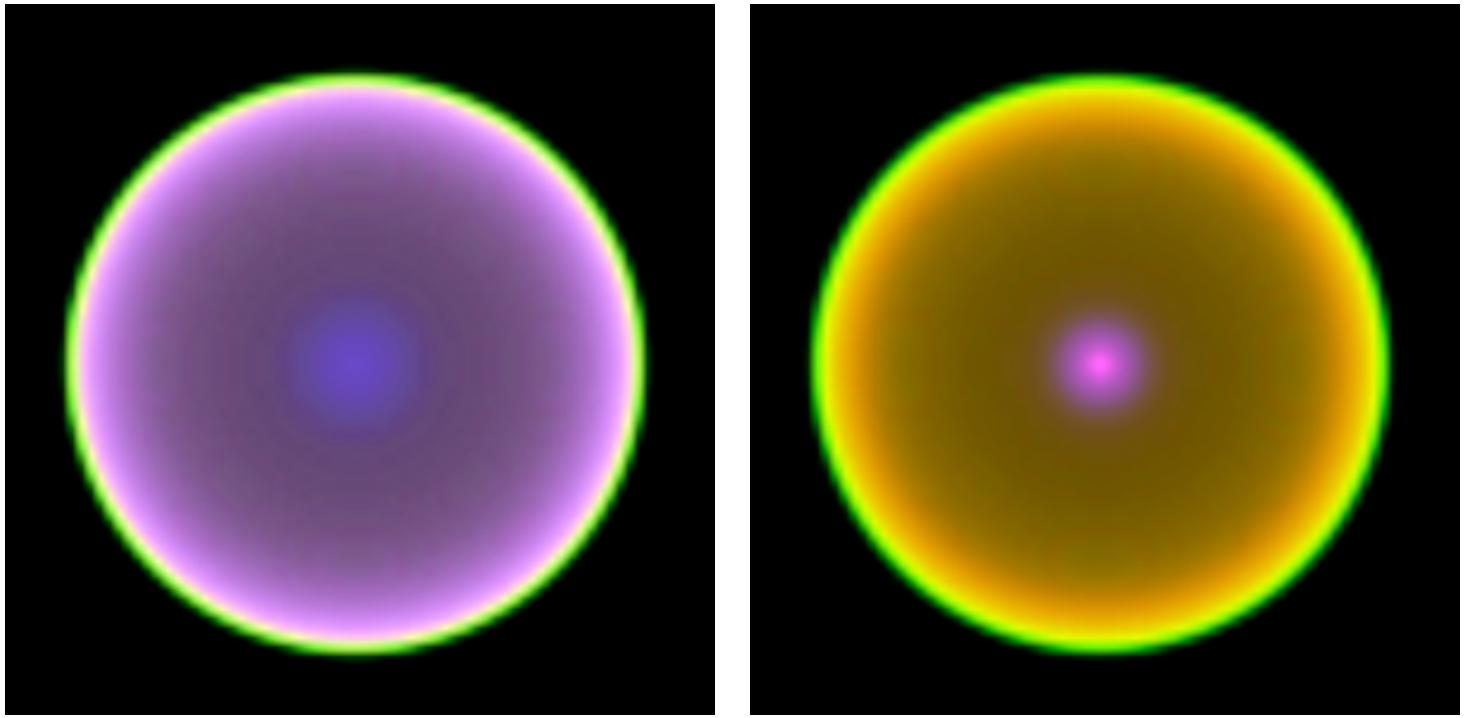
Used as as an example in the following

* Shock models
  - plane-parallel
  - Sedov solution

* "Ab initio" models
  - "Build" a model to agree with observation

Type Ia Ejecta Models

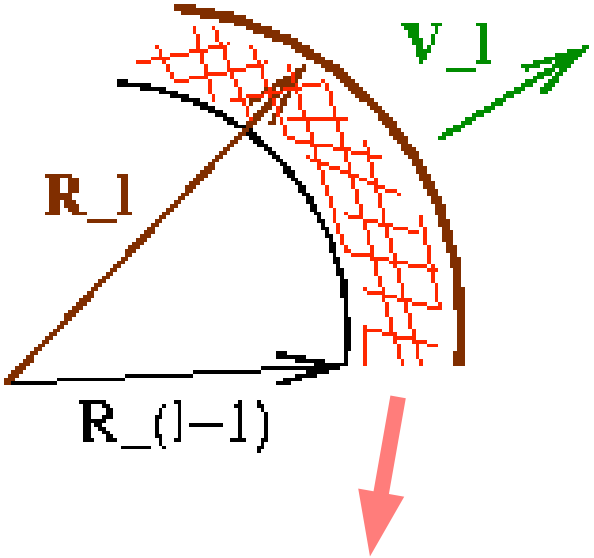
Badenes et al. 2003, ApJ 593:358-369.



2D projections* of "DDTa" and "DDTe" models at t=1000 years. R:G:B ==> Fe : Si : Ni

* Creation of these color representations of the models is not the focus of this poster - they are included here just to catch your attention. :) -dd

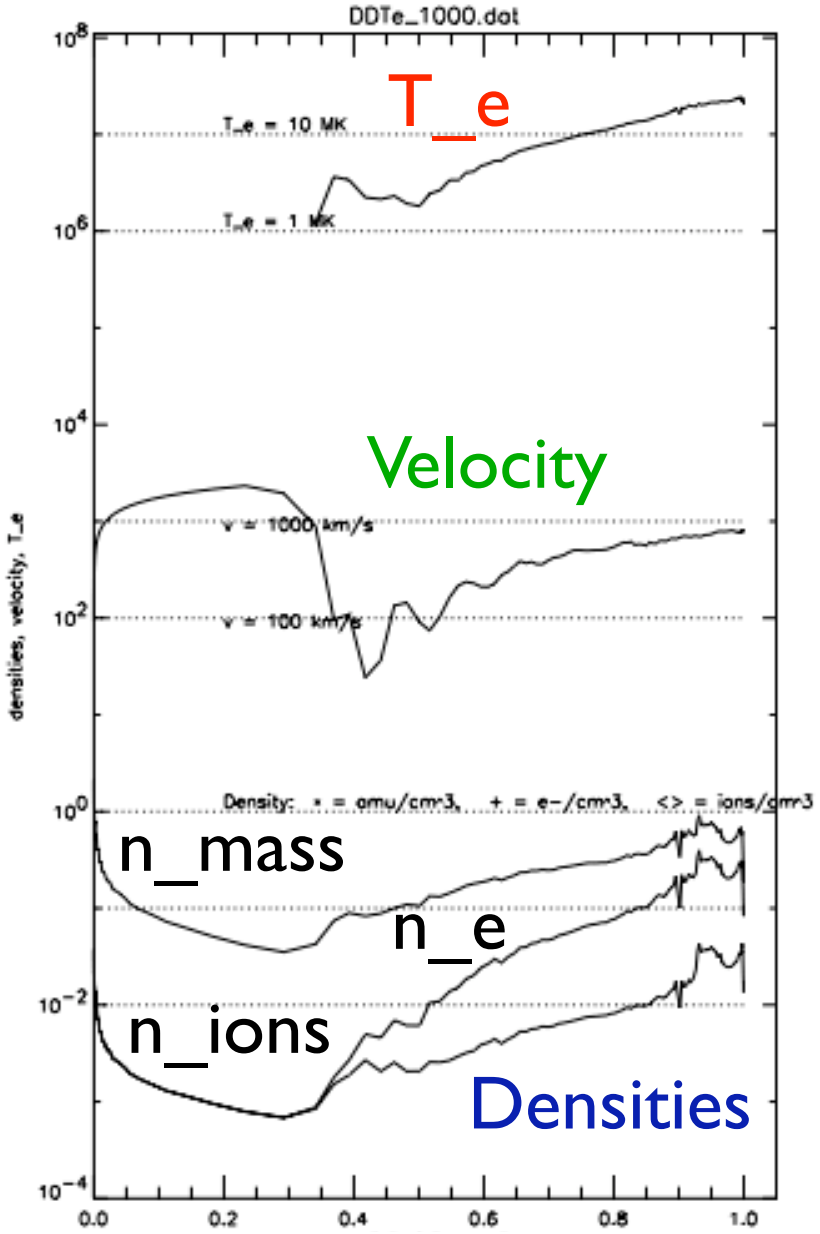
Model Parameters vs Radius (Layer)



Plasma parameters:

Ions: n_i(Z,q), T_i

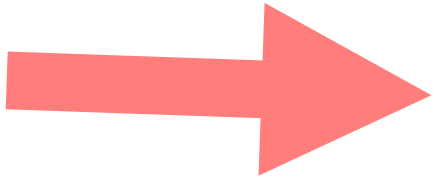
Electrons: T_e (n_e)



Transforming Parameters

Badenes' model parameters for each layer:

T_e
n_e,
n_i(Z,q)
Volume
Distance



Values input to ISIS calculation:

norm
T_e
{Zs}
{Abundances}*
ion fraction info

*e.g., w.r.t. AG89

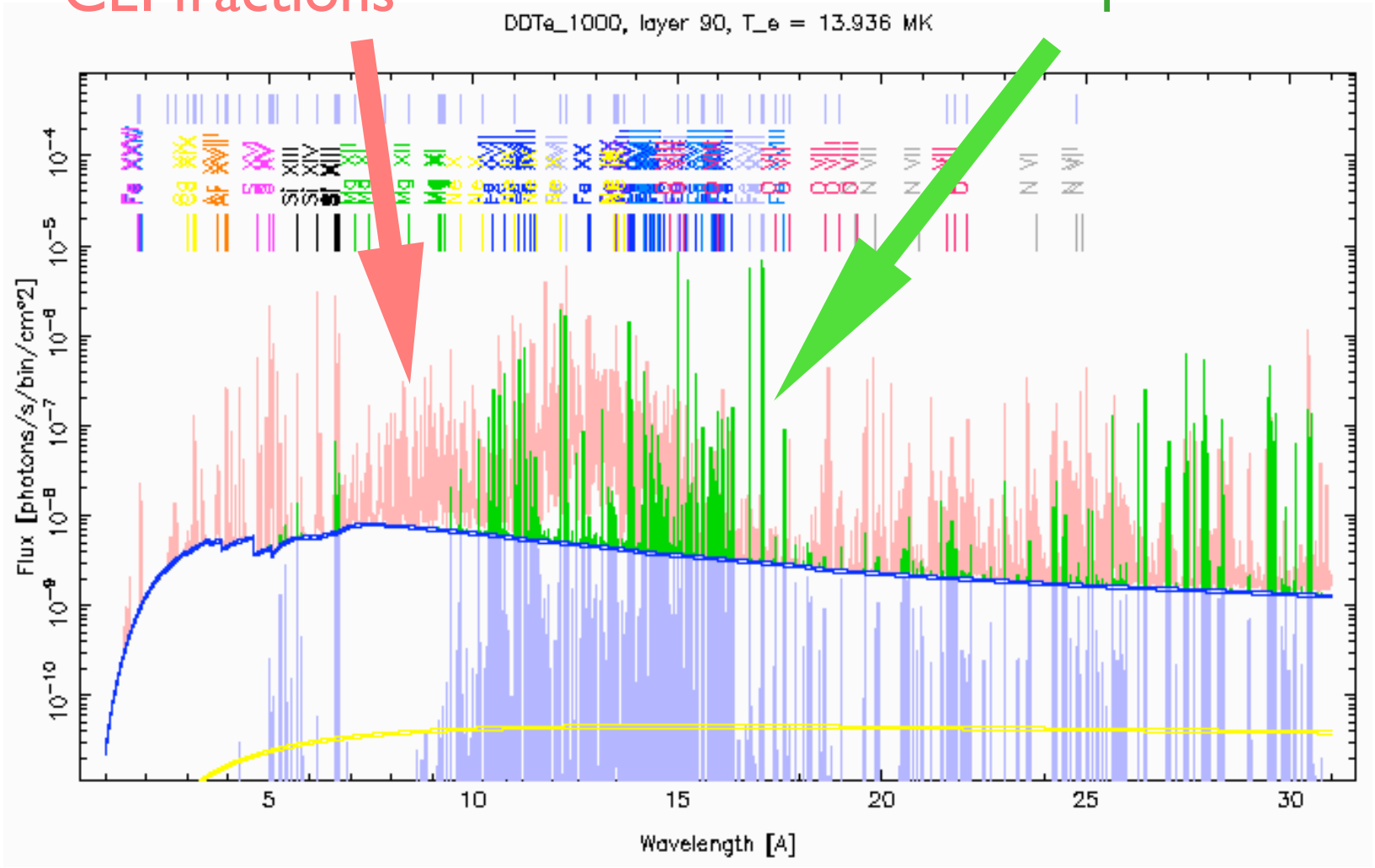
For the pedantic details see:
http://space.mit.edu/home/dd/Badenes/isis_spectra.html

Effect of Non-Equil. Ion Fractions

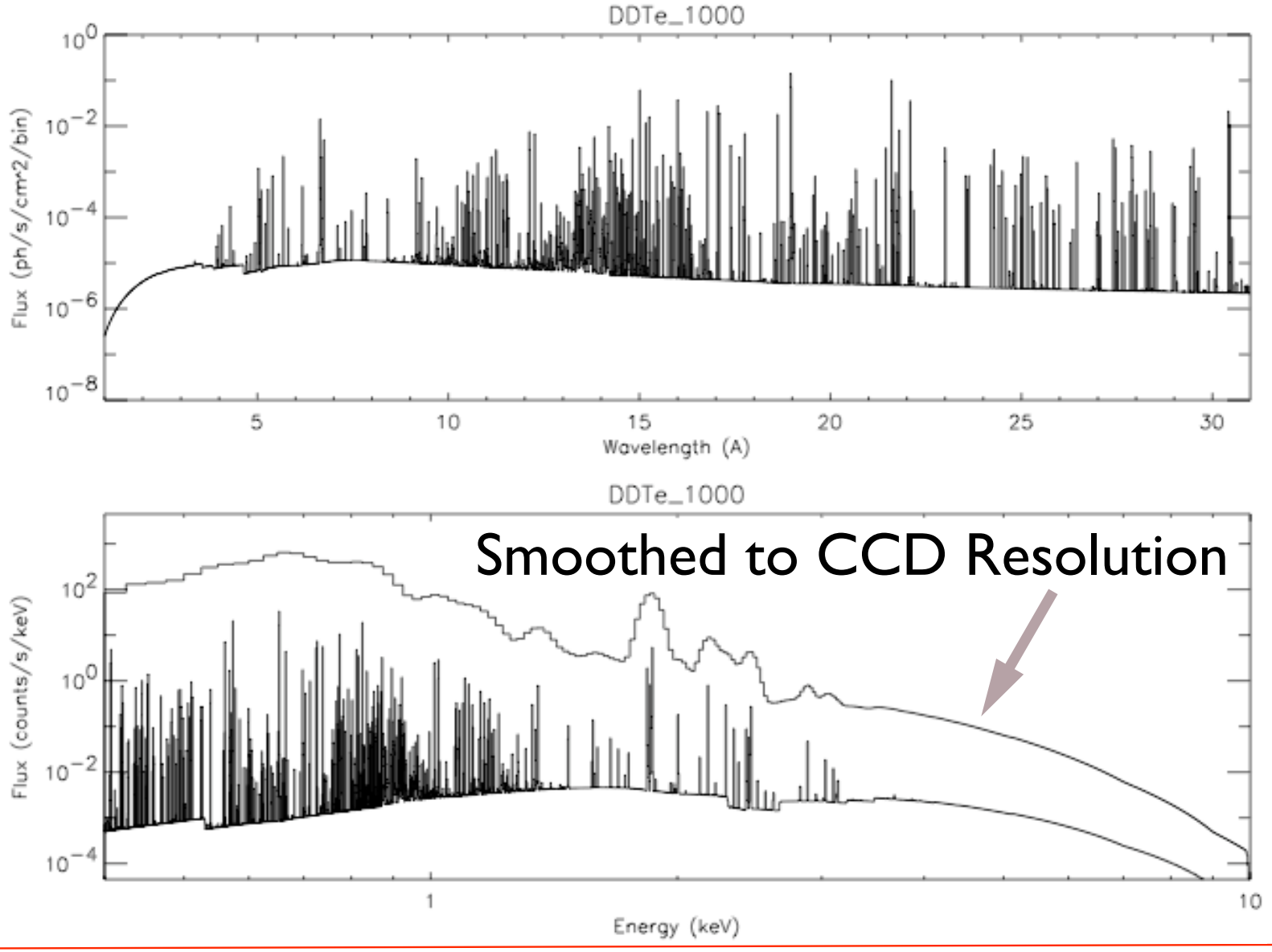
Spectrum w/ CEI fractions

DDTe, layer 90
T ~ 14 MK

Spectrum w/ non-equil. fractions

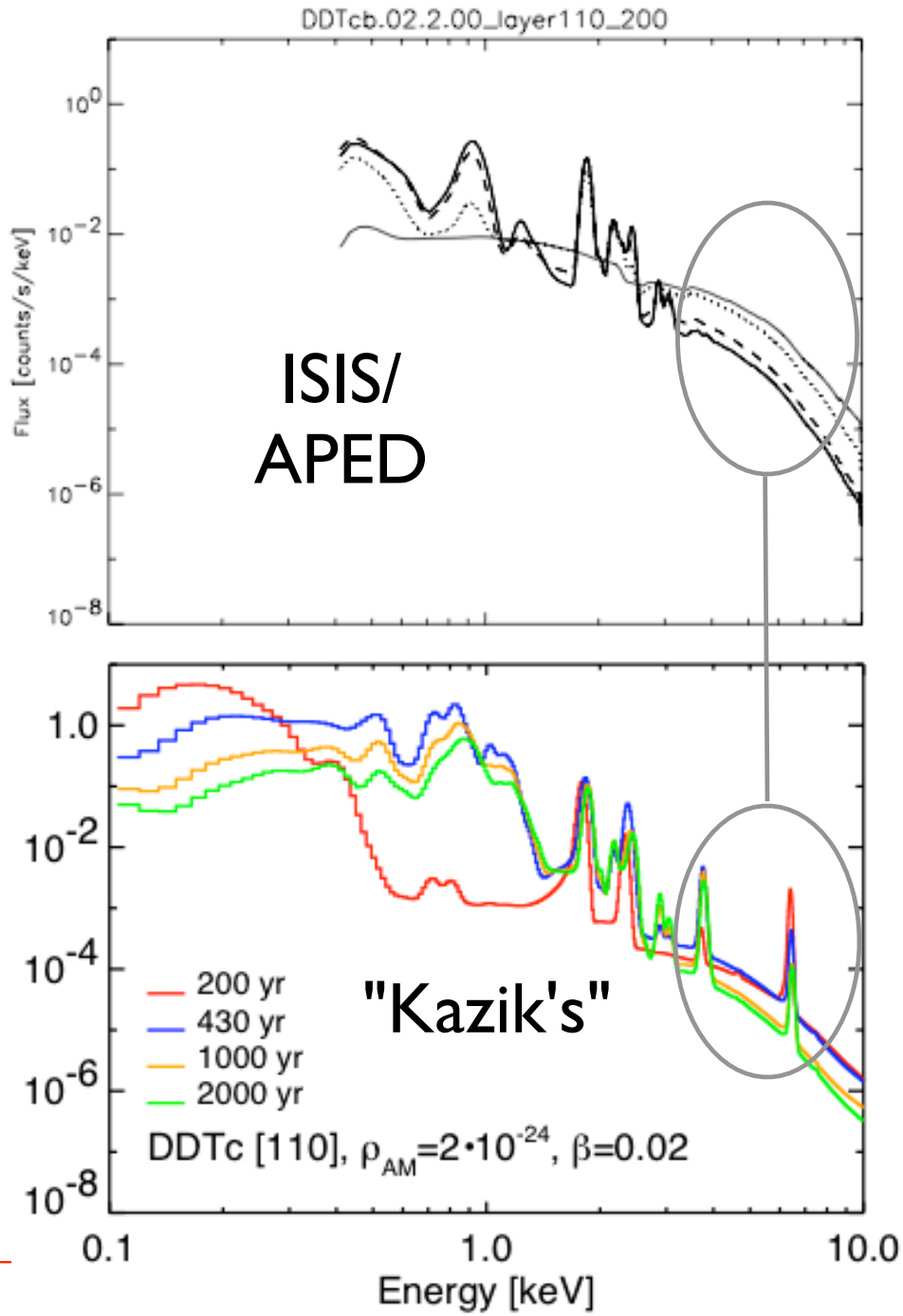


Complete Synthesized Spectrum



But... K-Shell Lines missing?

A test-case comparison of spectra created with this ISIS/APED approach to spectra created with another code (let's call it "Kazik's") shows that we are apparently missing K-shell line emission of high-Z elements --- i.e., missing inner-shell processes...



Some Naive Speculations...

Are we going about non-equilibrium plasma emission in a fruitful way ?

Non-Equilibrium
= Evolving
= Transient

The term "ion balance" may be inappropriate for a non-equilibrium plasma --- adding confusion when calculating its X-ray emission spectrum.

Instead, consider the current (instantaneous) "ion fractions" as given and calculate the emission at the present moment, ignoring evolution.

Time Scales... and an "Event" Approach for Low Densities

Time scale for ion to return to ground state

<< seconds

Time scale of our spectral measurement

10^3 to 10^6 seconds

Time scale for ion to interact with external entity (e.g., electron, ion, photon, dust grain, etc.)

> 10^7 seconds

For low-density plasmas, say n_e < 10^3, the time between external interactions for an ion is measured in years. The emission spectrum can be created as a sum over possible single "events" and their resulting emission.