Cool Stars 17 Splinter Session
Non-thermal processes in coronae and beyond
Barcelona, Spain
24-29 June 2012

How Atomic Rate Uncertainties Affect Fits to X-ray Spectra

Nancy S. Brickhouse

Harvard-Smithsonian Center for Astrophysics

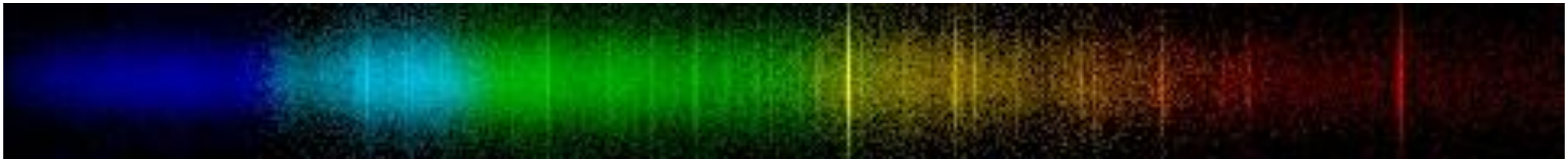
Acknowledgments to Randall Smith and Adam Foster.

This talk is based on benchmarking ATOMDB.

How Atomic Rate Uncertainties Affect Fits to X-ray Spectra

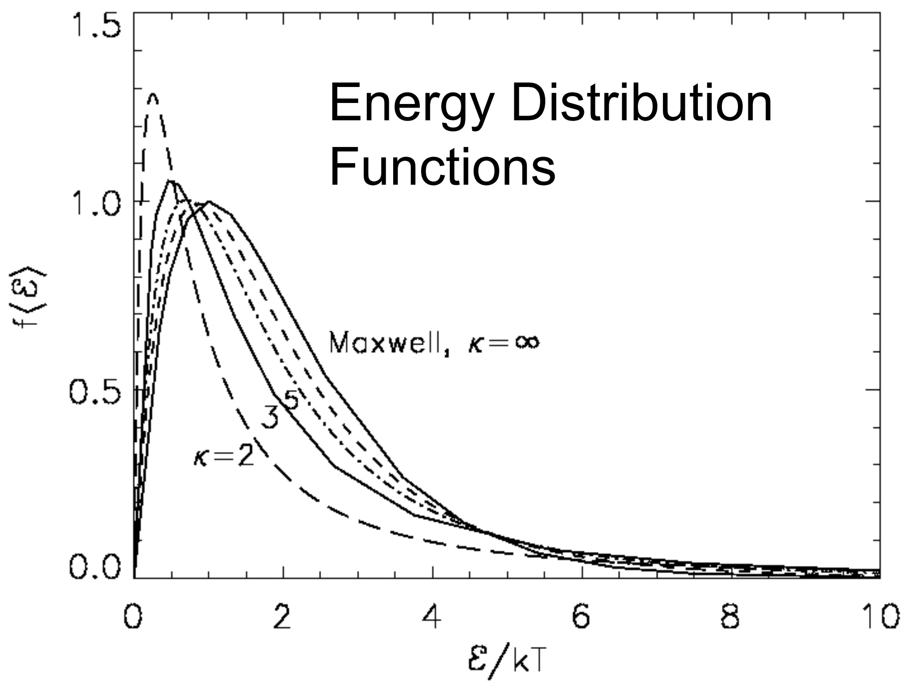
OR

If I can’t find a model that fits my data, have I discovered exotic physics?



Outline

- The Coronal Model: Thermal Plasma in Collisional Ionization Equilibrium (CIE) and Beyond
- Guide to Atomic Rate Uncertainties
- Young Stellar Spectra
- Interpreting the Diffuse Emission in SF Regions
- Some Words about Charge Exchange
- Lessons



Thermal Plasma or Non-thermal (exotic)?

• **Plasma temperature is defined for gas in thermal equilibrium, for which the most probable velocity distribution is the Maxwellian.**

➔Examples of non-thermal plasmas are particle beams, bumps on tails, Kappa distributions.

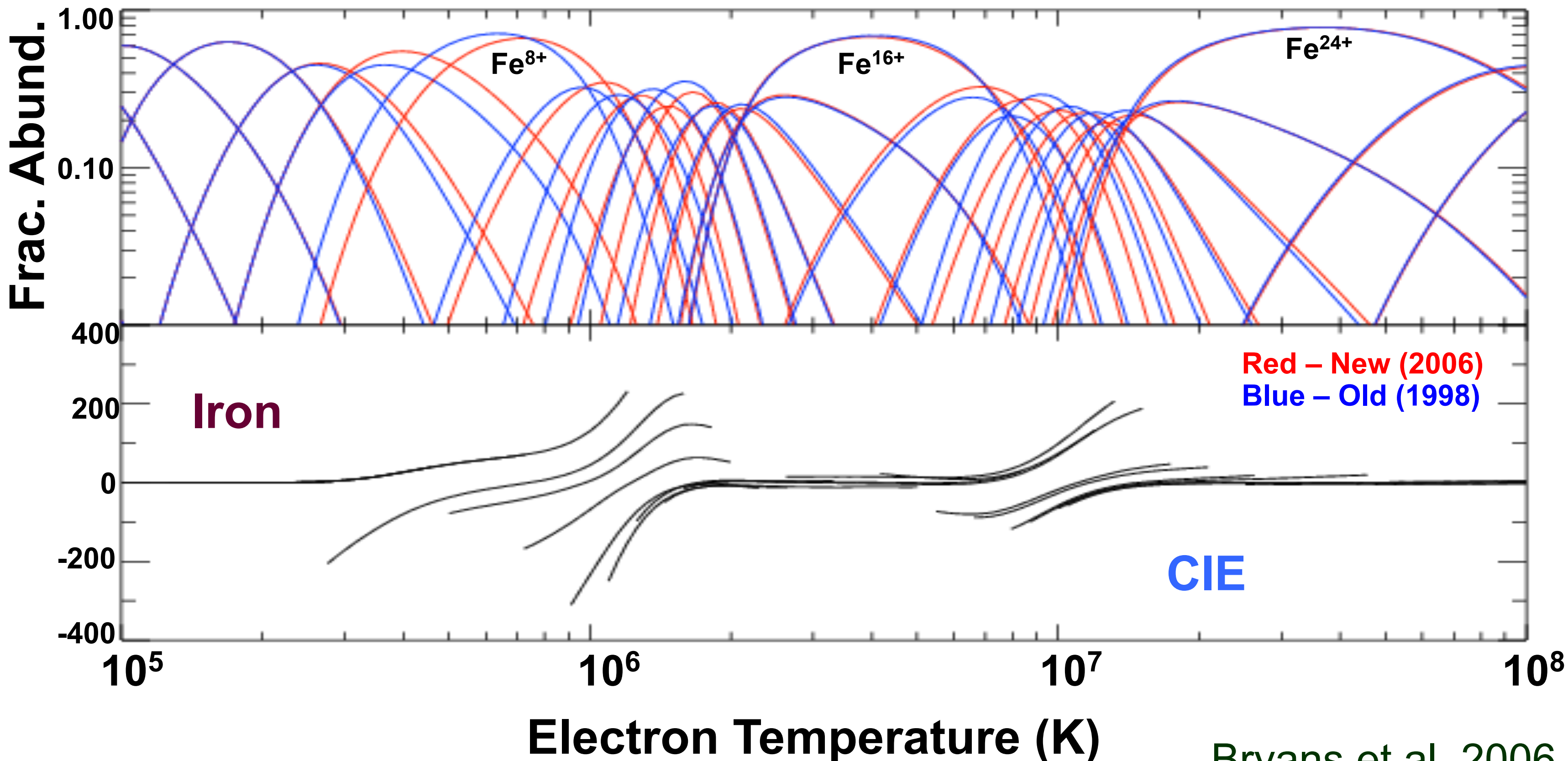
• **Particles of similar mass equilibrate with each other, so e− with e− and p with p first, and then with each other.**

➔$T_e \neq T_p$

CIE or Non-Equilibrium Ionization?

• **Ionization equilibrium occurs when collisional ionization by electron impact balances collisional and radiative recombination processes**

➔**For short times and/or at low densities the ionization state has not reached its equilibrium value and thus does not reflect T_e.**



Bryans et al. 2006

Line Emission from Collisional Excitation or something else more exotic?

In the "coronal" limit the electron density N_e is low enough that most of the level population is in the ground state.

Flux = $\sum \varepsilon (T_e)\, EM(T_e) / (4 \pi R^2)$, where

R is the distance,

$EM(T_e) = \int N_e N_H dV$ is the emission measure, and

$\varepsilon (T_e)$ is the emissivity. It depends on a lot of atomic physics, e.g. ionization and recombination rates and collisional excitation rates

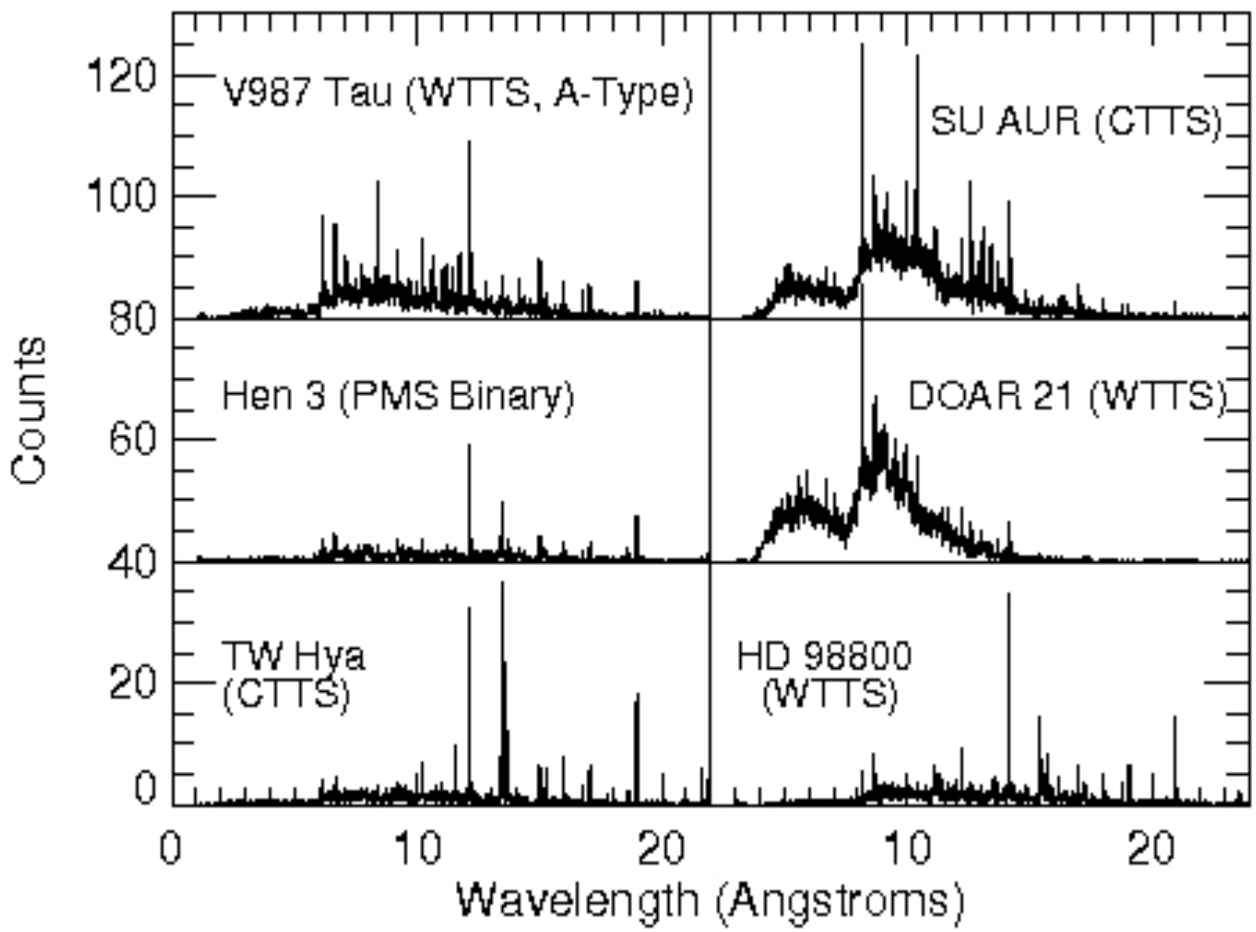
➔Level population by other methods (recombination to an upper level, fluorescence) and metastable levels with long lifetimes give interesting diagnostics for exotic processes.

Guide to Atomic Rate Uncertainties

	Typical	Possible
• Collisional excitation	20 to 30%	5 to 10%
• Radiative decay	20 to 30%	5 to 10%
• Collisional ionization	20%	10%?
• Radiative recombination	25%	?
• Dielectronic recombination	30 to 50%	?
• 2-photon emission	25%?	
• Bremsstrahlung	2%	
• Wavelengths	0.05 to 2%	0.003%

- Missing processes (e.g. recombination to upper levels)
- Missing lines (described by Beiersdorfer)

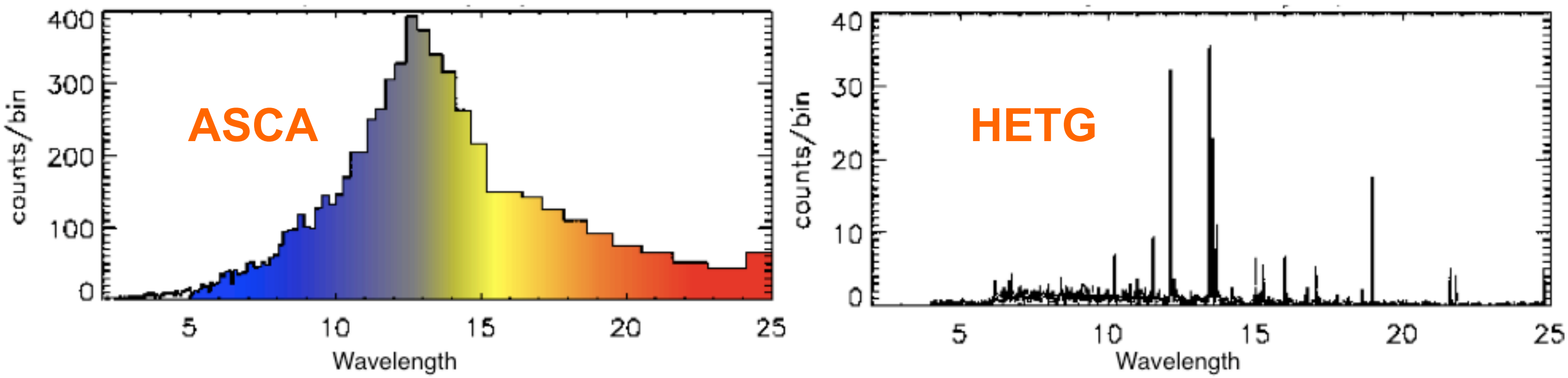
How complicated can it get?
Star formation is pretty messy.



- **Hard X-rays: corona**
- **Soft X-rays: corona, jet, shock**
- **Absorption by: ISM, disk, accretion stream, nebula**

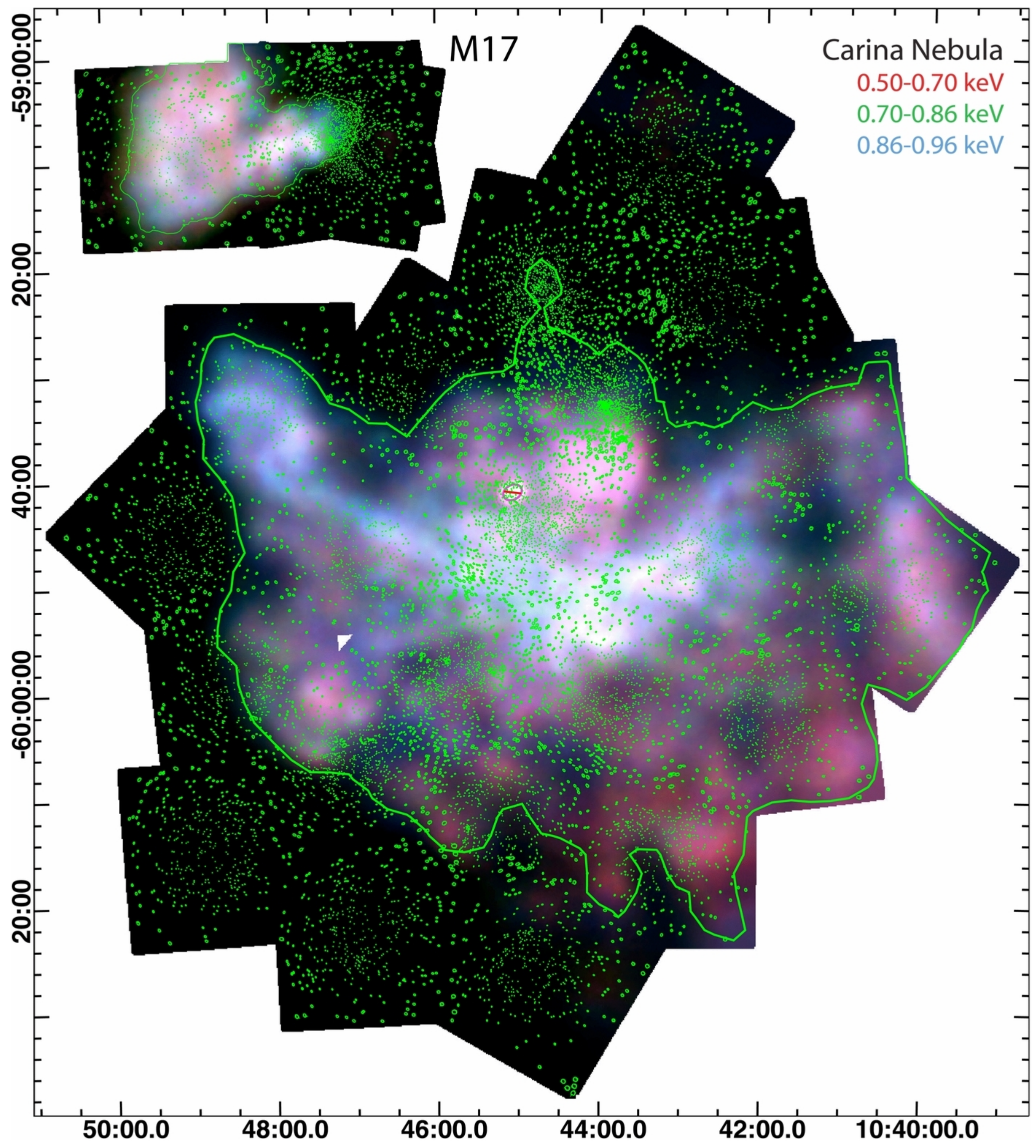
Sample of young star spectra from the Chandra HETG

Furthermore, extended emission and crowded fields cannot be observed with optimal spectral resolution.

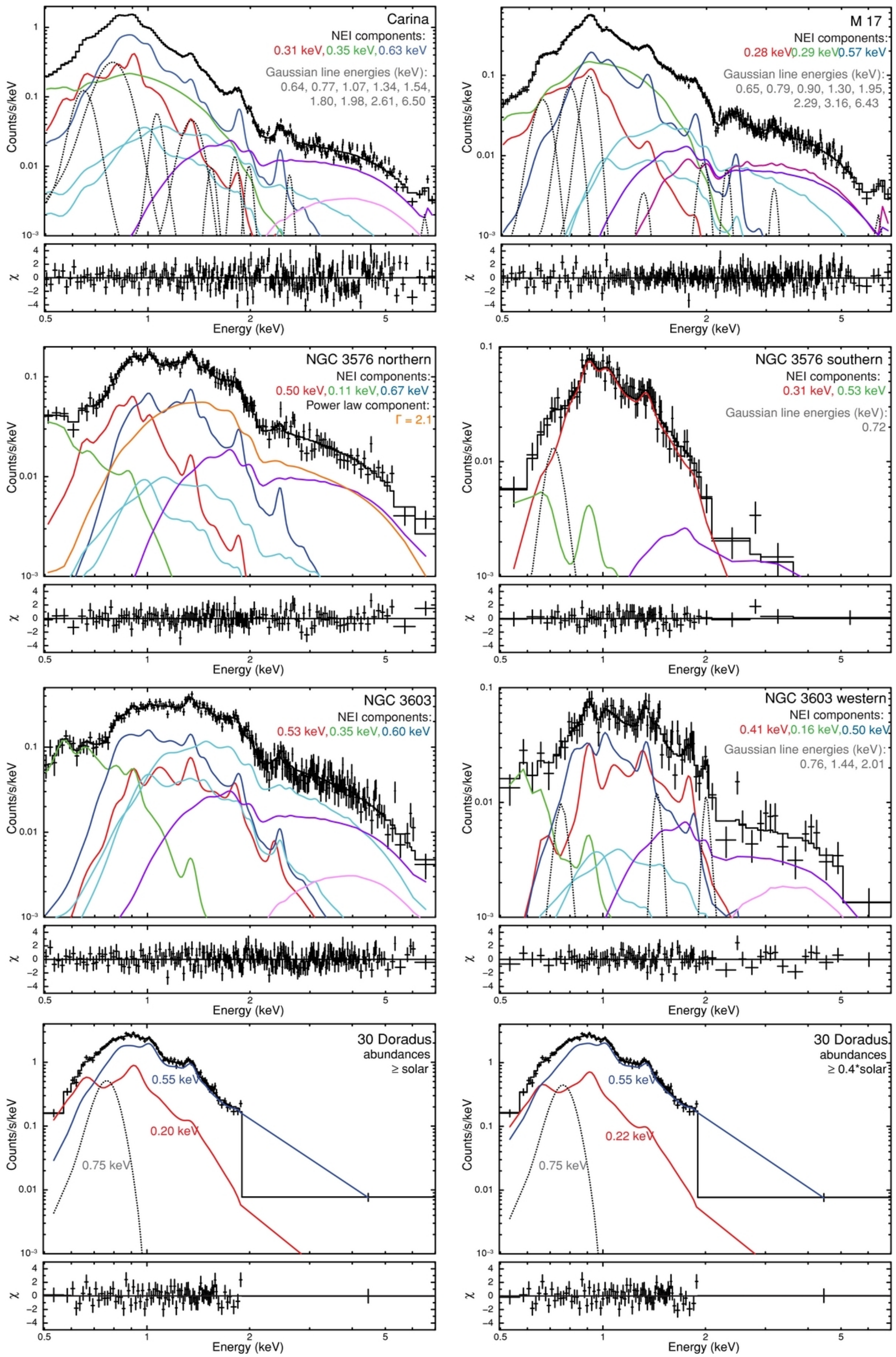


- **CCD vs Grating for the same star (TW Hya)**

And it gets worse. The diffuse nebular emission processes are not all known (e.g. photoionization from hot stars, fast wind shocks?)



From Townsley et al. 2011, ApJS 194 16



Special thanks to Leisa Townsley for asking.

Even with several model components including complex physics, there are many residuals. Are they interesting?

Many of them are near strong lines, suggesting atomic data problems.

Some of the very large problems may be in the absorption models.

From Townsley et al. 2011, ApJS 194 16

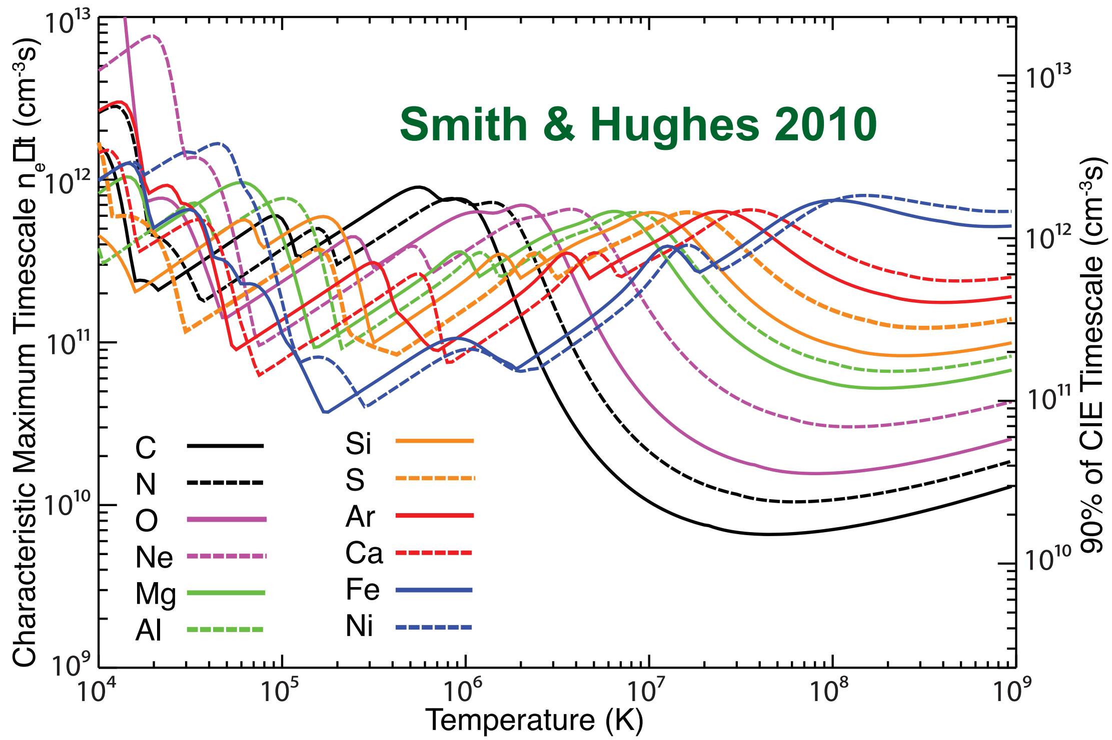
Some Words about Charge Exchange (CX)

- "Highly ionized plasmas don't wait." (R. K. Smith)

- Dominance of CX occurs w/ ionized metals, neutral hydrogen, and a rapid transition region.

- However, charge neutrality in a stellar wind means that electronic recombination will occur over short distances.

- CX allows only ~2 X-ray photons, whereas CE keeps going.



- Both recombination processes lead to large G-ratios and large Ly α /Ly β Ratios.

- Absence of Radiative Recombination Continua in CX the main distinction.

Lessons

- Thermal plasma in CIE does not provide much spectral information on heating, dynamics, feedback.

- Atomic rate uncertainties > calibration and statistical errors.

- Uncertainties in the charge state balance can lead to inconsistencies in global models.

- Residuals near strong lines are likely related to atomic rate uncertainties. Complex absorption effects will exacerbate this.

- Departures from Maxwellian and CIE will be difficult to establish at CCD resolution.

- Such departures, if established through resolved line ratios with accurate atomic rate data, are critical to getting to the interesting physics.