Giving Spectral Modelers an f

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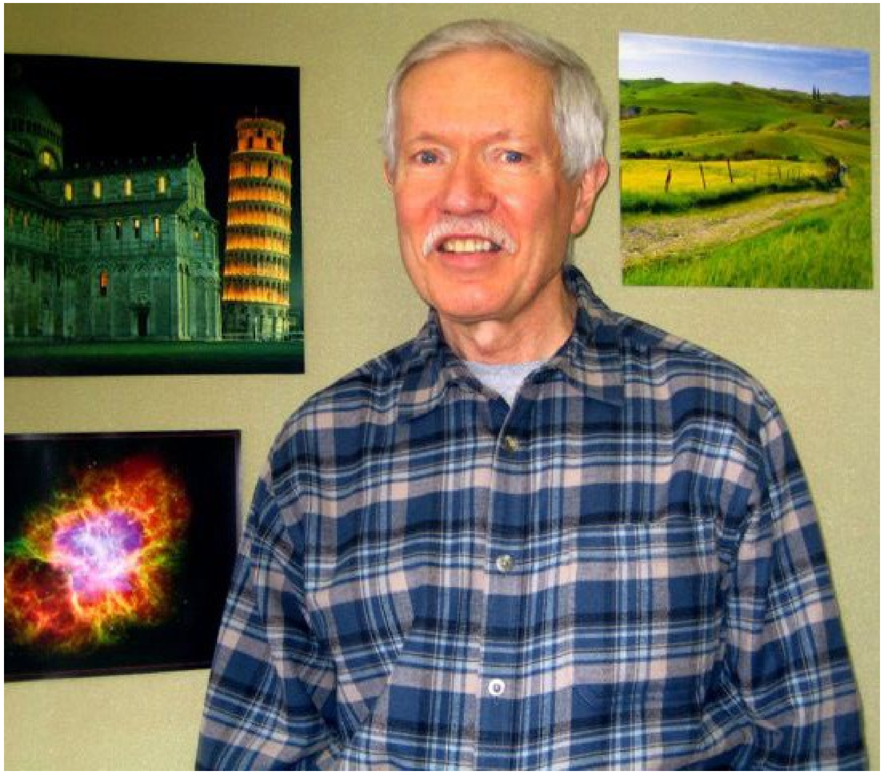
Accretion in Stellar Systems, Aug. 10, 2018

Colaborators: Samer El-Abd, Jeff McClintock, …

credit: Don Dixon

Things I will remember about working with Jeff:

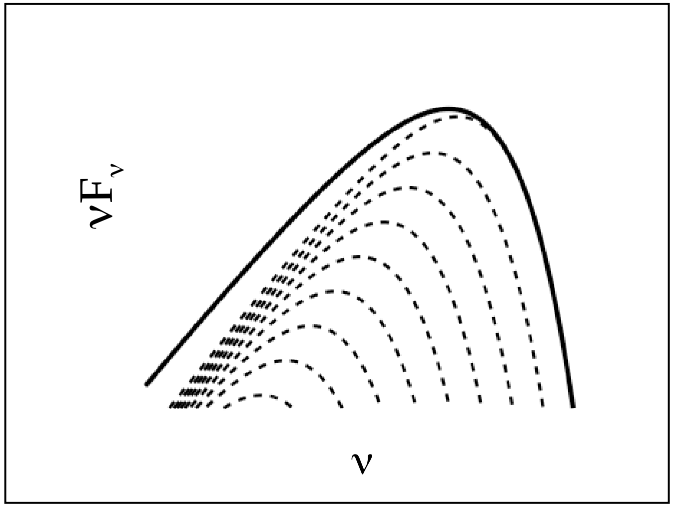
- Valued my work on accretion disk spectra, promoted it, included me in the effort, encouraged me, and advocated for me
- He was determined both to make it work and get it right
- He was always enthusiastic and wonderfully persuasive



Color-corrected Blackbodies

Integrate over radii with different temperature: a multitemperature blackbody:

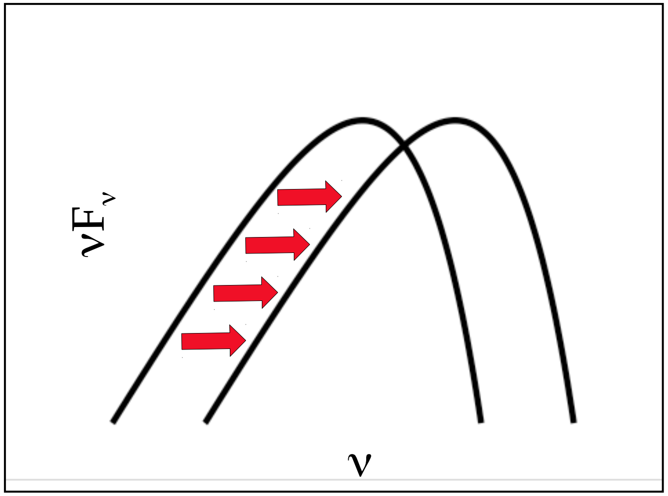
$$T \propto r^{-3/4}$$



Essentially the DISKBB model (Mitsuda+ 1984)

Electron scattering and atomic opacity cause deviations from blackbody: sometimes approximated as a “color-corrected” blackbody (Shimura & Takhara, 1995):

$$I_\nu = \frac{1}{f^4} B_\nu(fT)$$



Disk Spectral Models

Self-consistent models of spectra at the disk surface must perform stellar atmospheres-like calculations:

•Solve for hydrostatic equilibrium

$$-\frac{\partial P_{\rm tot}}{\partial z} = \rho \Omega^2 z$$

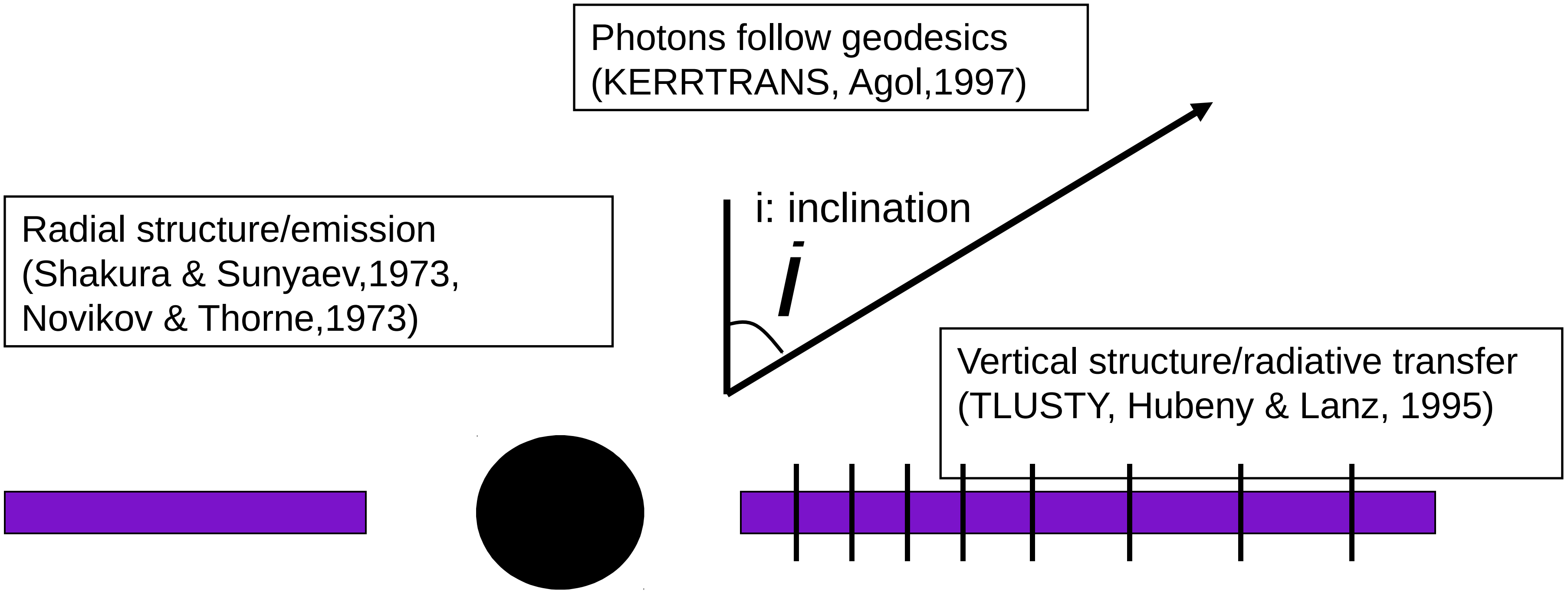
•Solve for radiative equilibrium

$$\nabla \cdot F = \epsilon$$

•Solve equations of radiative transfer and statistical equilibrium (with Compton scattering, Bremsstrahlung, and atomic opacities)

Solving large system of coupled PDE’s: typically involves iterative methods (complete linearization, accelerated lambda iteration)

BHSPEC



Photons follow geodesics
(KERRTRANS, Agol,1997)

Radial structure/emission
(Shakura & Sunyaev,1973,
Novikov & Thorne,1973)

Vertical structure/radiative transfer
(TLUSTY, Hubeny & Lanz, 1995)

Thin Disk Model Parameters

M: black hole mass

L/L_{edd}: luminosity/accretion rate

a_*: black hole spin

α: stress parameter

Annuli Parameters

surface density

gravity ($g = \Omega^2 z$)

effective temperature

KERRBB vs BHSPEC

Similarities:

- Both models assume F(R) based on Novikov-Thorne Both trace geodesics and include frequency shifts to get spectrum far from disk

Differences:

- BHSPEC uses spectrum computed using TLUSTY to obtain spectra at disk surface, ignores returning radiation
- KERRBB uses color-corrected blackbody, includes returning radiation

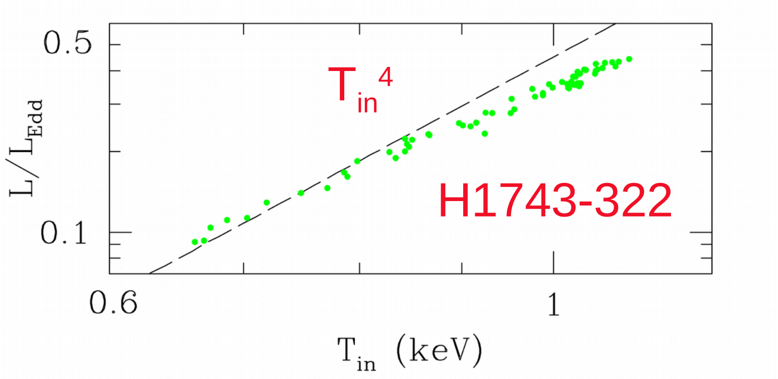
Which should we use to measure spin?

Jeff’s solution: both – fit BHSPEC with KERRBB to find f and use with returning radiation in KERBB

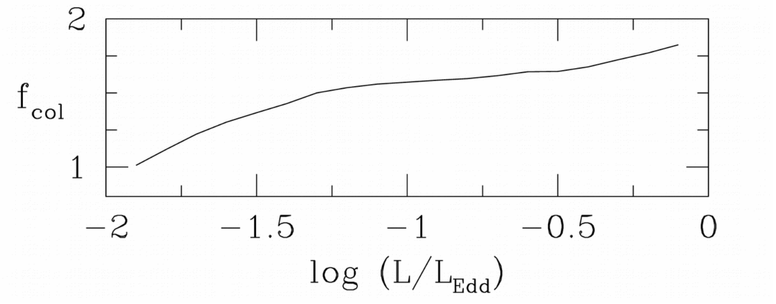
Using f

Using multitemperature blackbody one finds $L \sim T^4$, where $T=T_{in}$.

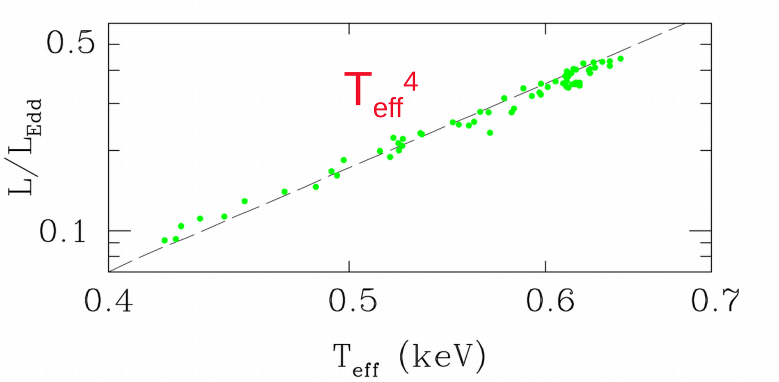
Radius is nearly (but not exactly) constant



Shafee et al. (2006)



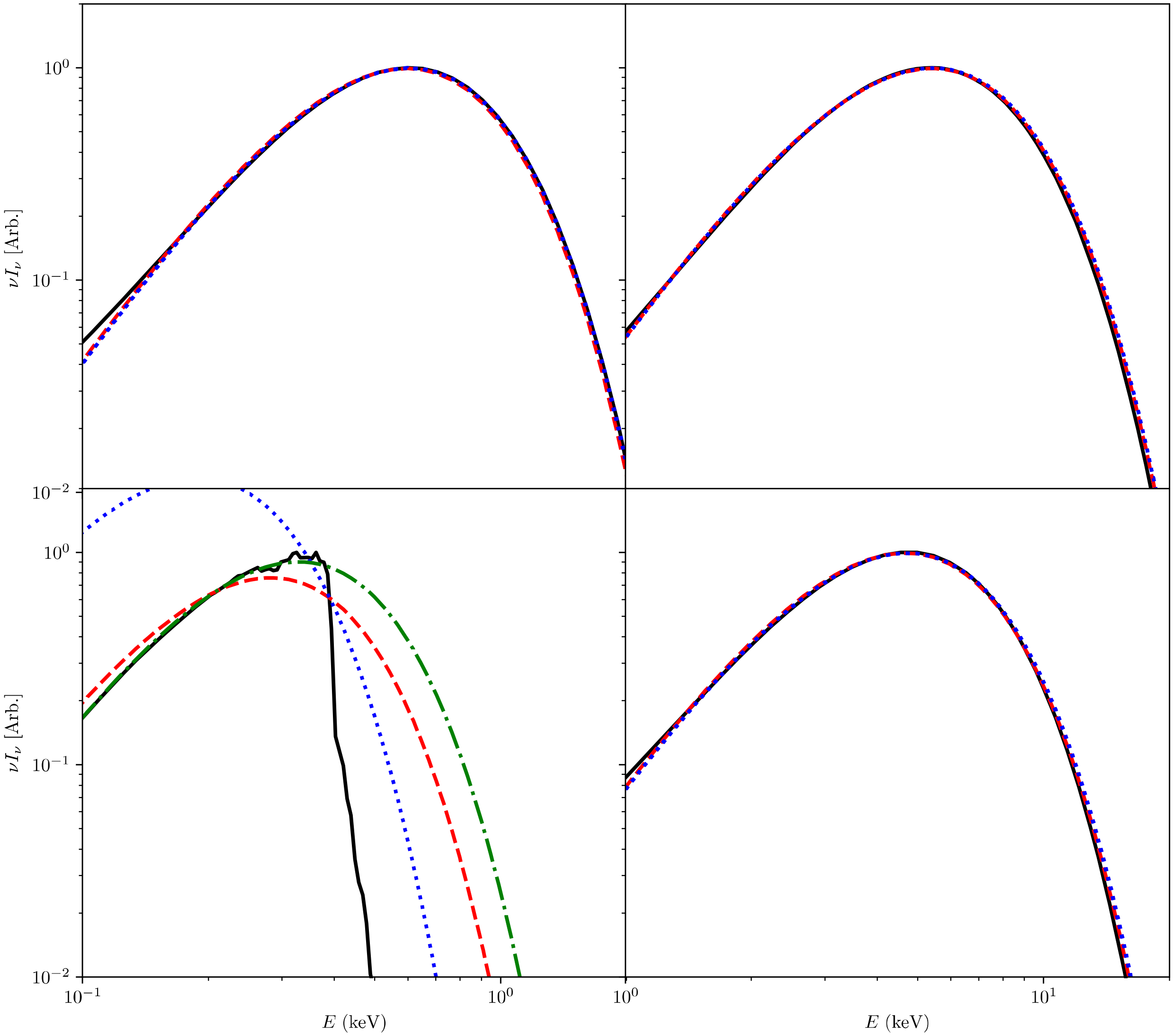
Use a color correction f to “correct” the relations: $T_{eff}=T_{in}/f$

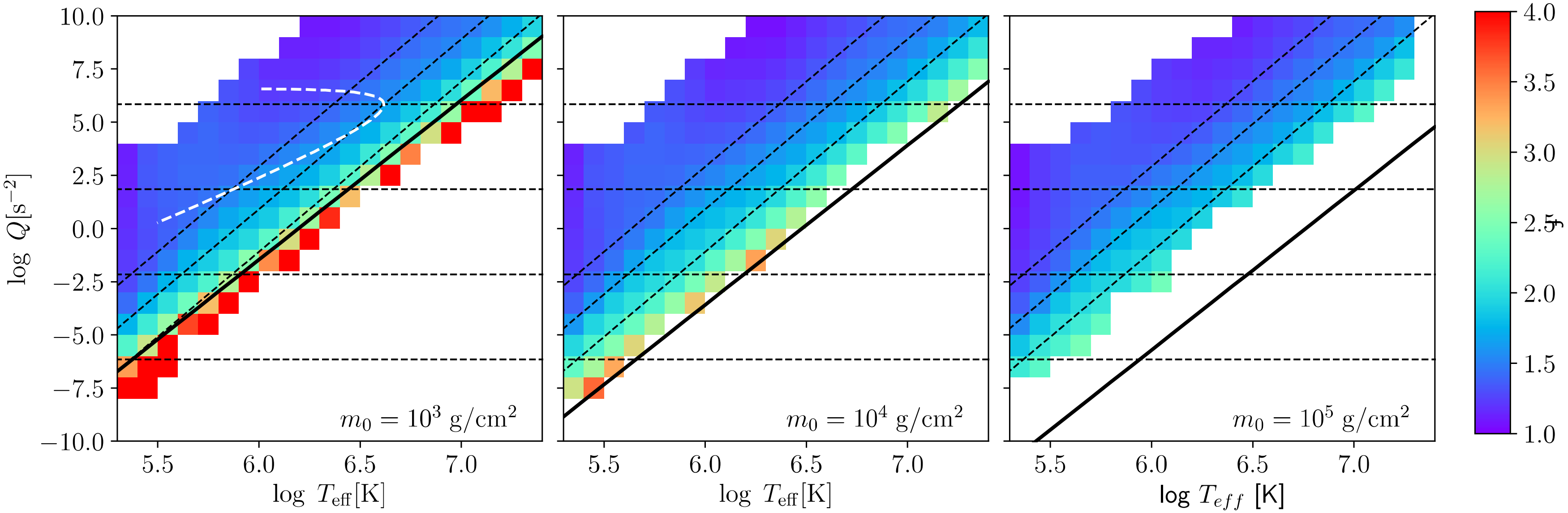


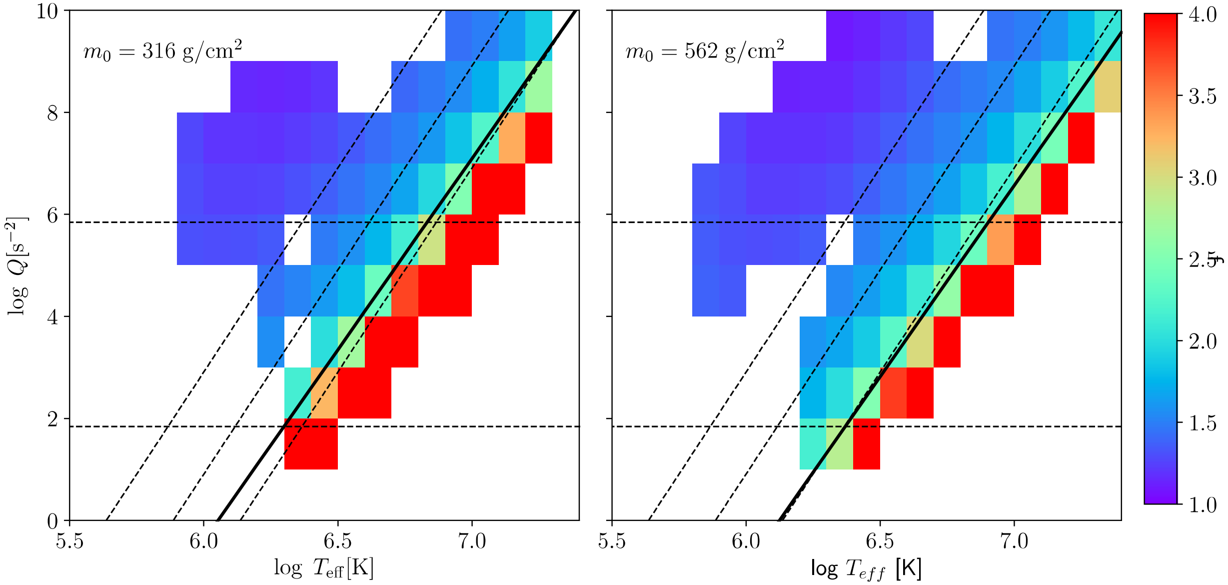
Implied radius is now constant!

Estimating f for individual Annuli

Value of f relatively unambiguous for models that look like color corrected blackbodies but not those that don’t look like color corrected blackbodies.







Parameters:

Q: $g = Q z$ ($= \Omega^2$)

$T_{\rm eff}$: $F = \sigma T_{\rm eff}^4$

$m_0 = \Sigma / 2$

What happens if a disk doesn’t emit enough photons to match the energy that is being released by accretion?

It heats up!

Photon Starvation

What happens if a disk doesn't emit enough photons to match the energy that is being released by accretion?

It heats up! Balance of photons and flux occurs for

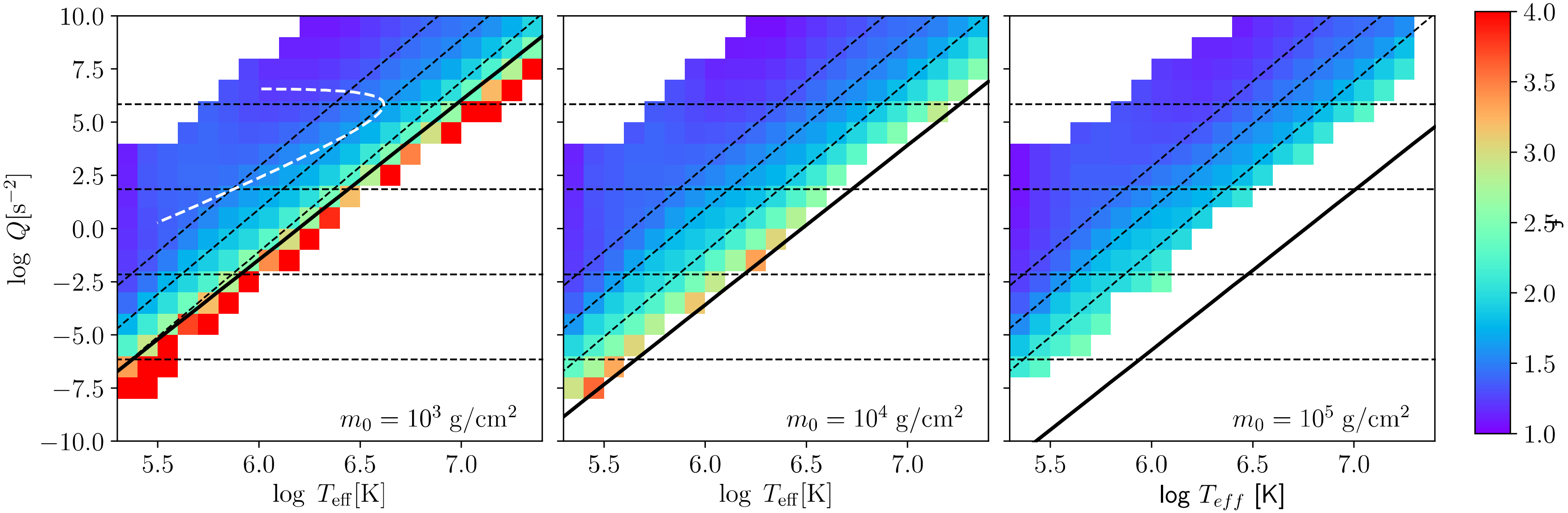
$$\eta_{\mathrm{ff}} H = \sigma_{\mathrm{sb}} T_{\mathrm{eff}}^4$$

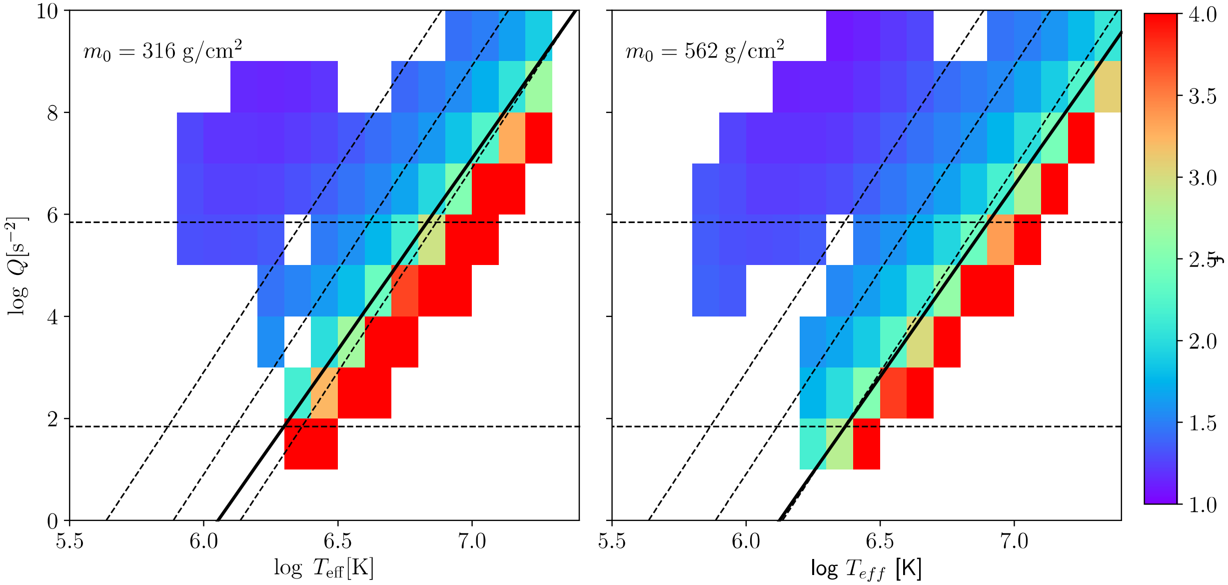
with:

$$H = \frac{\kappa_{\mathrm{es}} \sigma_{\mathrm{sb}} T_{\mathrm{eff}}^4}{cQ} \quad T \simeq (\kappa_{\mathrm{es}} m_0)^{1/4} T_{\mathrm{eff}} \quad \rho \simeq \frac{m_0}{H}$$

Gives:

$$Q = \frac{m_p^2 \kappa_{\mathrm{es}}^{7/8} \sigma_{\mathrm{sb}}^2}{\eta_0 c} \frac{T^{7.5}}{m_0^{2.125}}$$



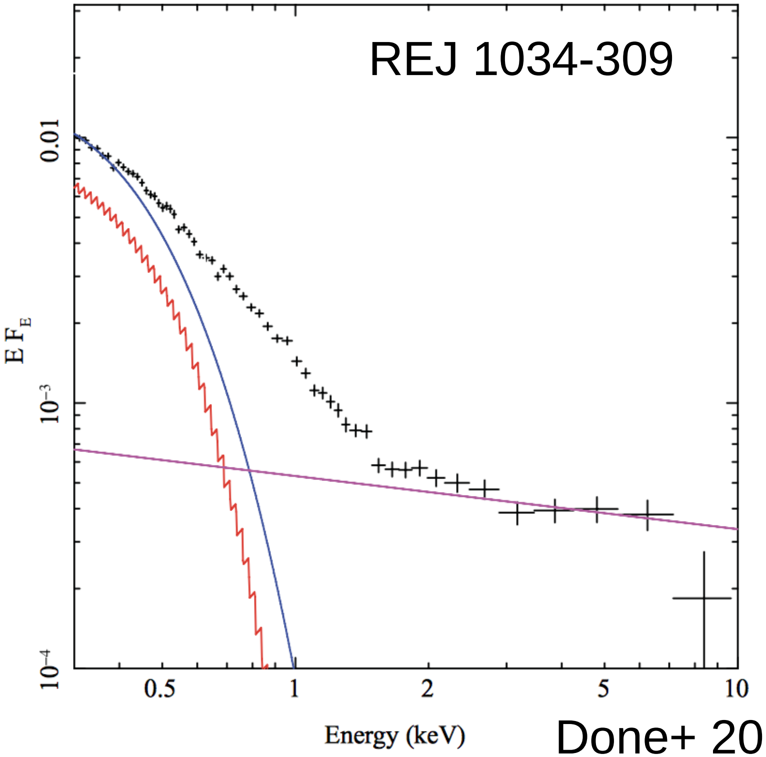


Spectral hardening factors only get large when disk becomes photon starved!

Where Might this Be Important?

Soft X-ray excess

For supermassive black holes with M ~ 10^6 M_{sun}, emission from inner accretion disk might reach soft X-ray, but soft excess would seem to require larger f than α-disk models predict



Done+ 2012

Low/hard state X-ray binaries

Some interpretations of low/hard spectral states require disk has f > 2 (see e.g. Reynolds & Miller, 2013; Salvesen+ 2013)

Summary

- We use TLUSTY models to explore variation of spectral hardening over large range of parameters
- We find that f ~ 1.4 – 2 over the range of accretion rates and masses in X-ray binaries
- AGN are expected to have larger f than X-ray binaries at the same accretion rate.
- Large values of f (>2) are found when disks become photon starved, which happens at accretion rates below Eddington for mass surface densities below about 1000 g/cm^2

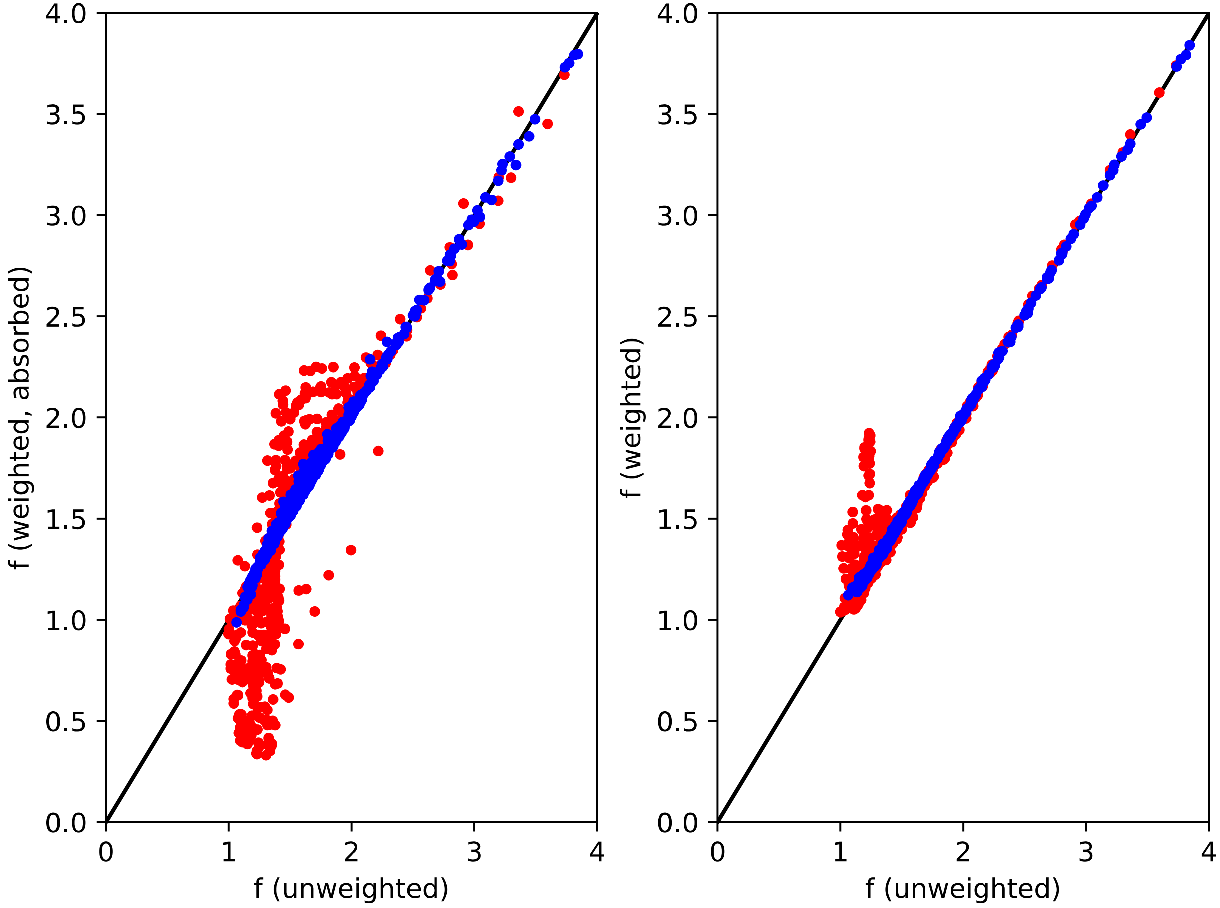
Estimating f for individual Annuli

Red: peak below 0.5 keV
Blue: peak above 0.5 keV

No single way to fit a color corrected blackbody to our models.

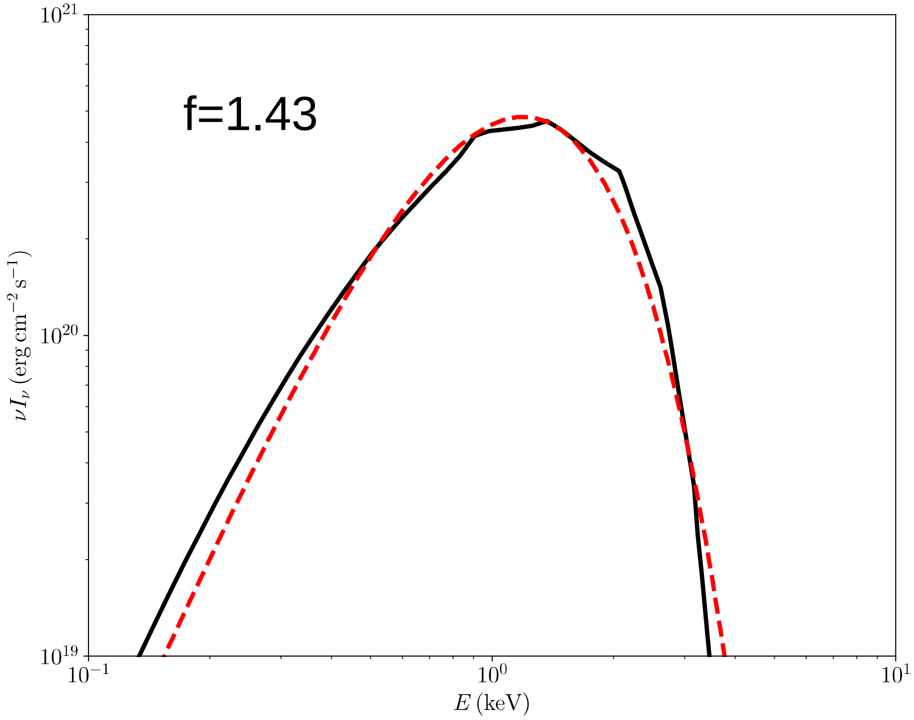
Could include:

- Absorption
- Weight by counts
- Instrument response

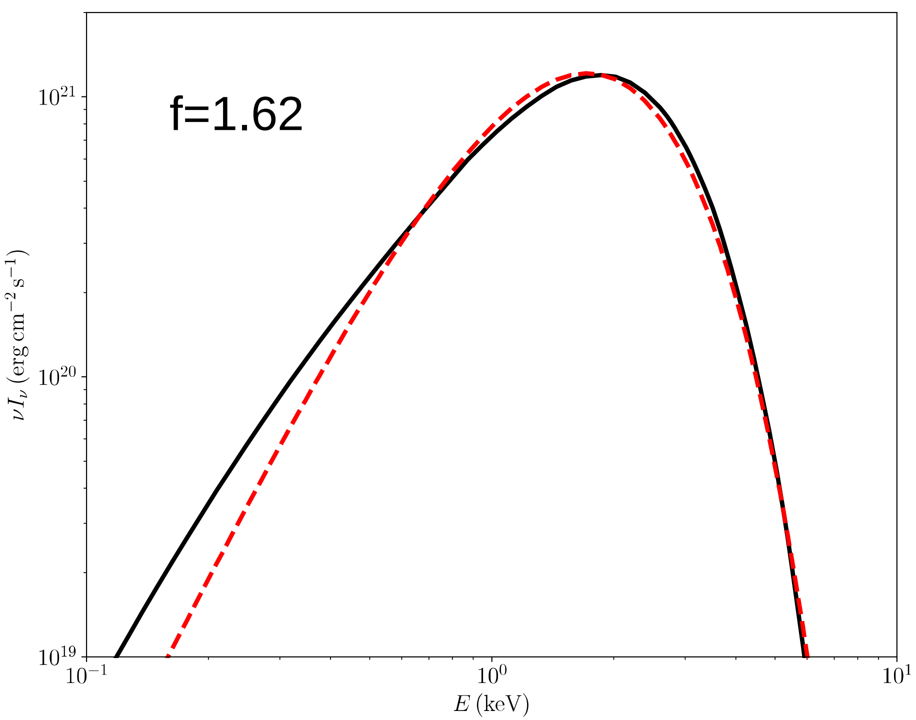


Effect of Coronal Dissipation

80% dissipation in corona



0% dissipation in corona



Merloni, Fabian, and Ross (2000) concluded that putting a fraction of dissipation in corona would make the disk spectrum harder. Our results go the opposite way. Taking dissipation out of the disk makes it colder, which reduces f!