Variable AGN as probes of accretion physics

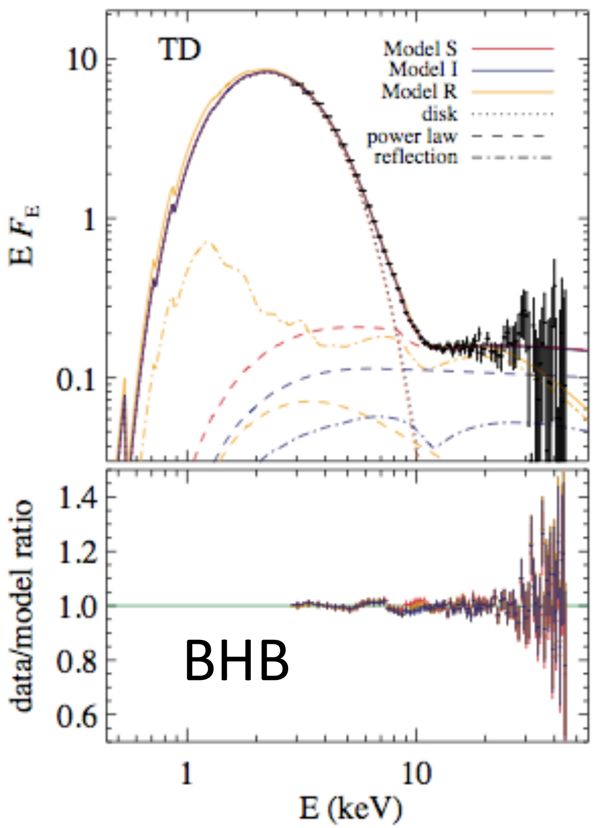
Jason Dexter

MPE Garching

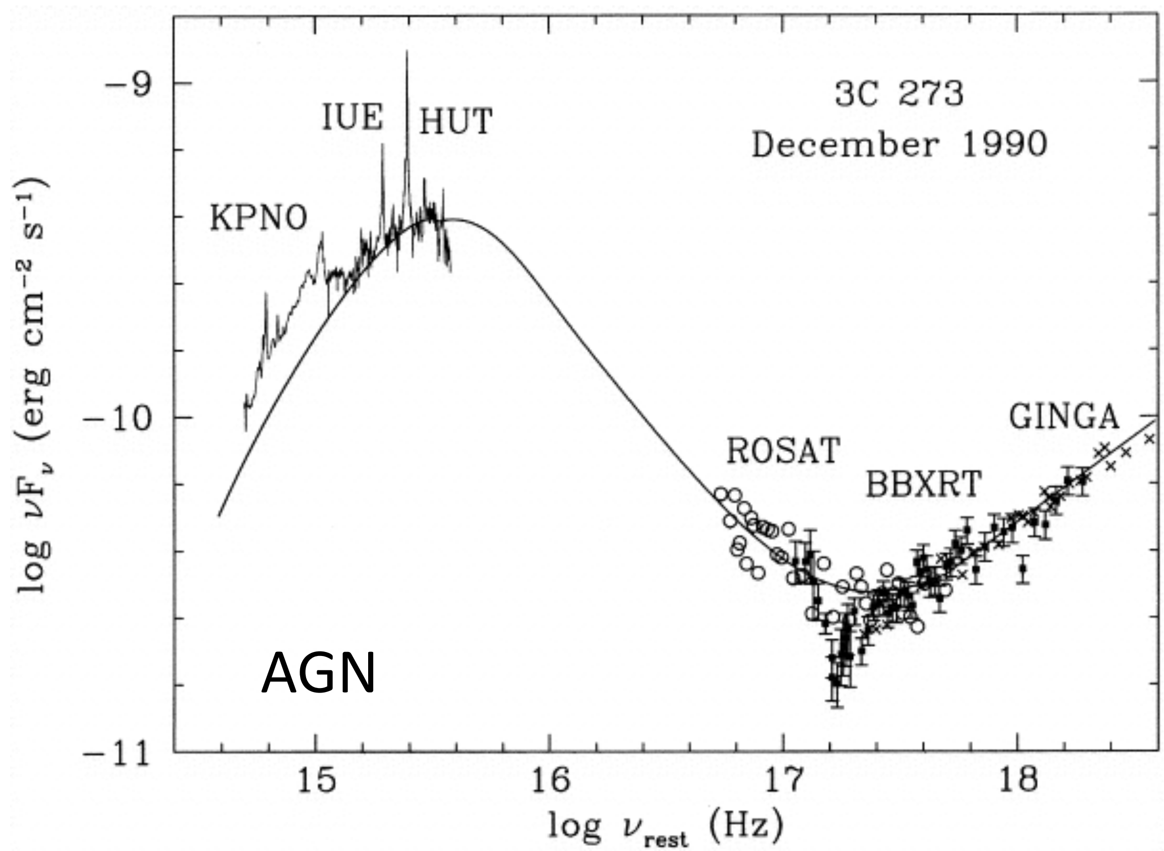
with Eric Agol, John Ruan, and the CARS team

L, T_{eff} agree with thin disk theory

- L ~ 0.1 mdot c^2, T_{eff} ~ $mdot^{1/4}$ $M^{-1/4}$
  (Shakura & Sunyaev 1973)



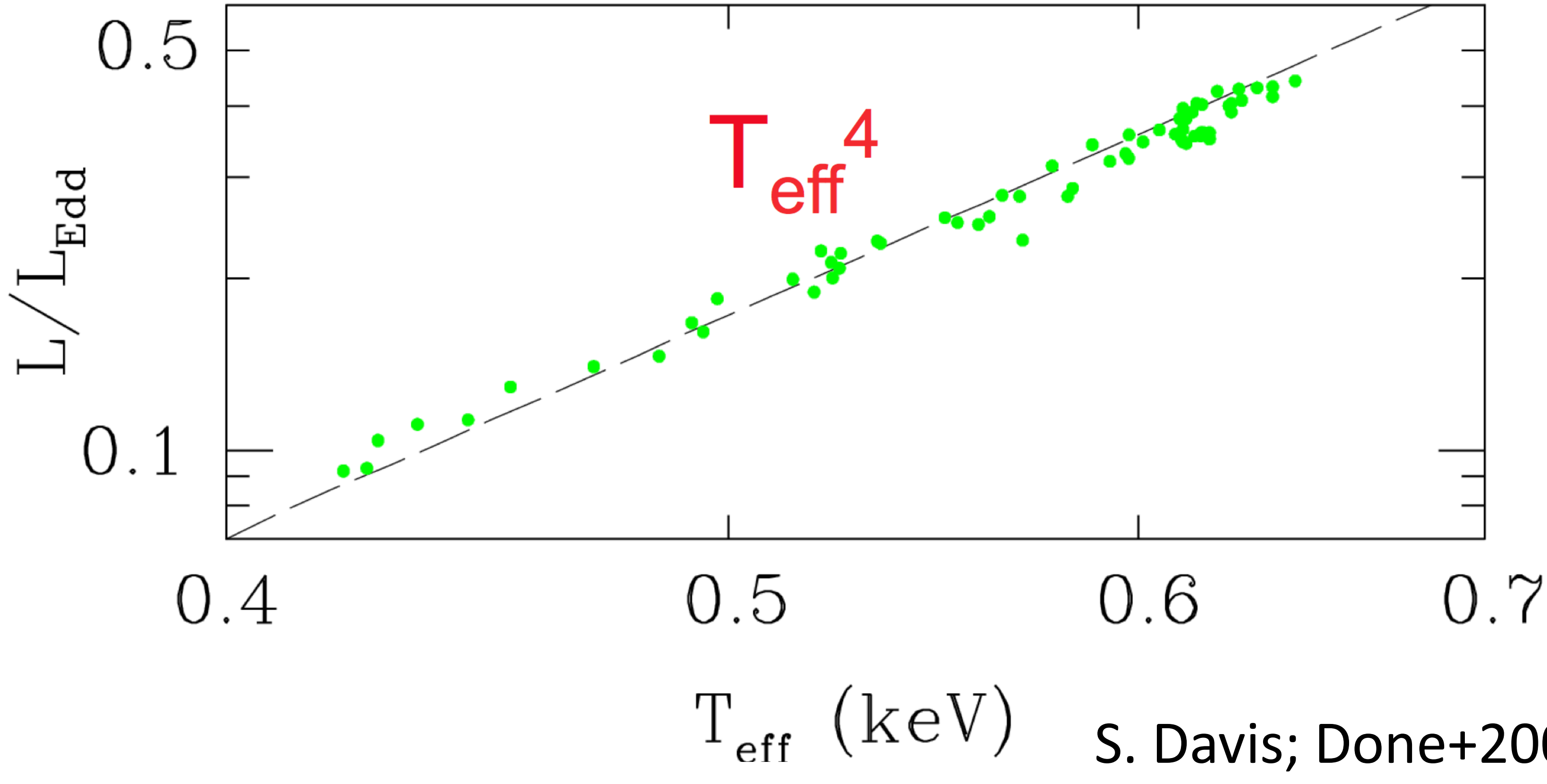
Steiner+2010



Kriss+1999

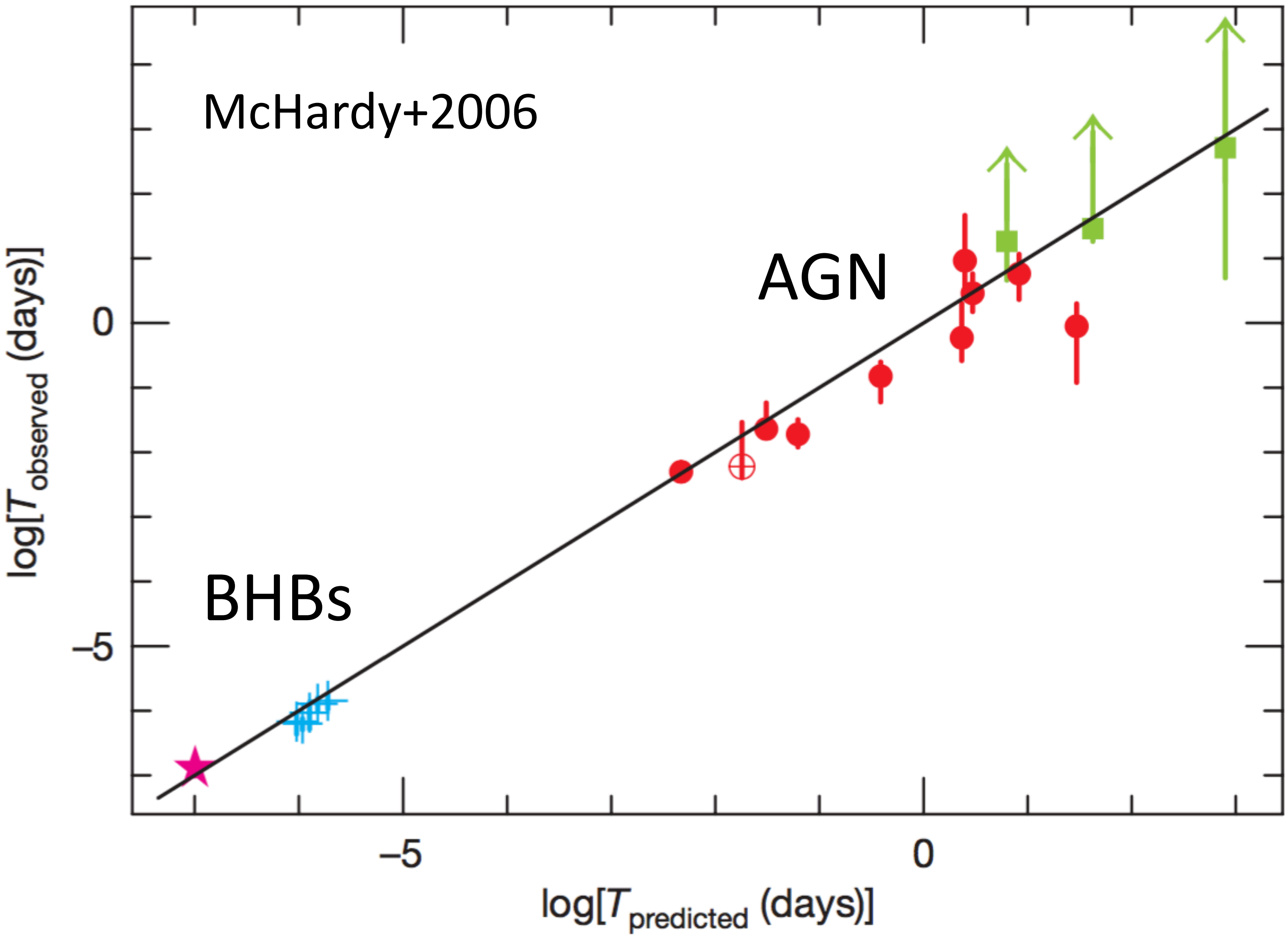
L ~ T_{eff}^4 in binaries

- Optically thick at constant R_{in}



S. Davis; Done+2007

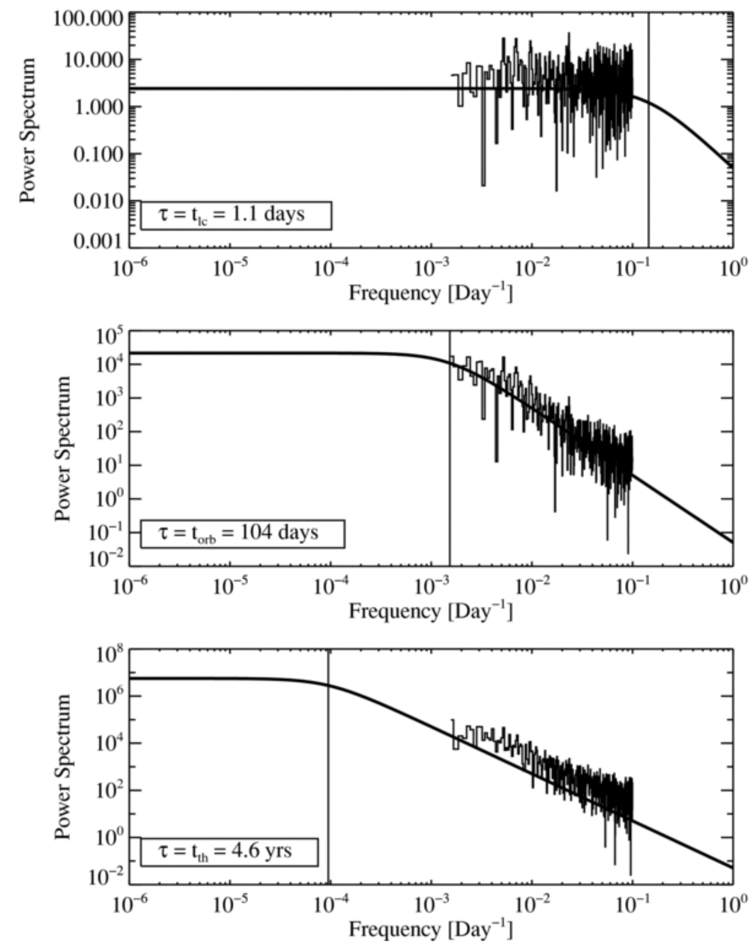
X-ray var: accretion is scale free?



Optical var: not (only?) viscous propagation

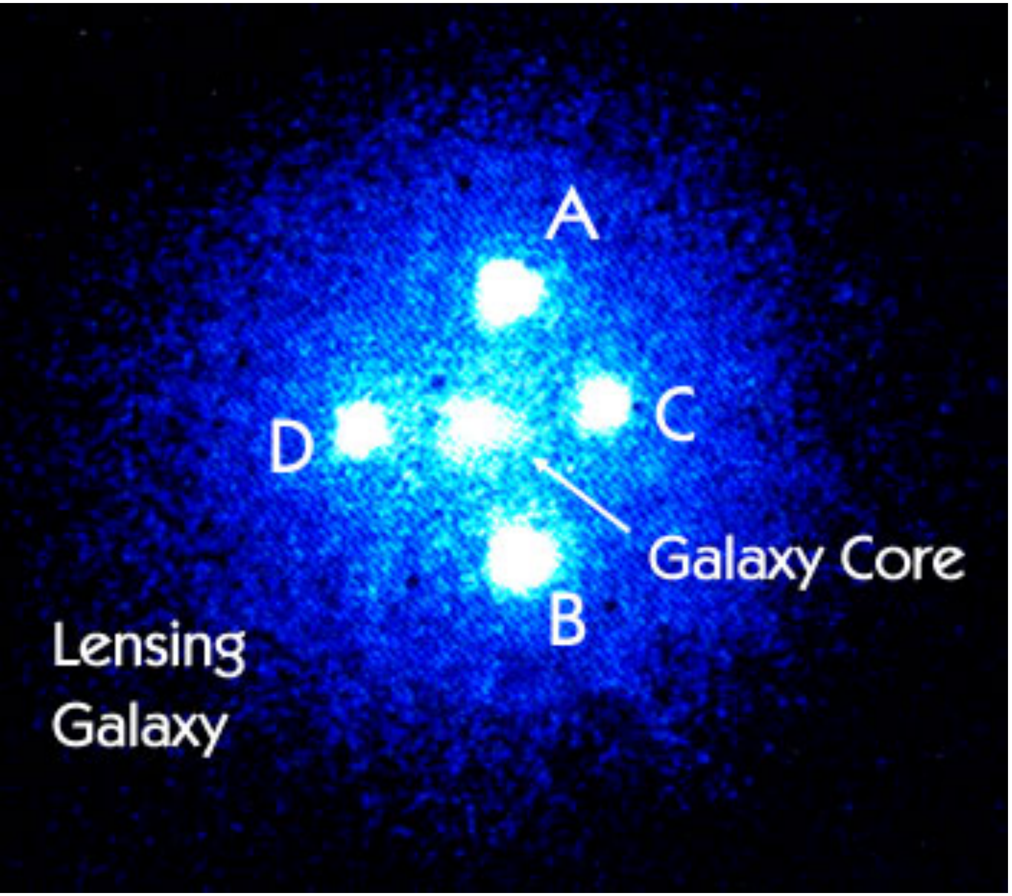
- Saturation timescales ~ 100 d (Collier & Peterson 2001, Kelly+2009, MacLeod+2010, Kozlowski+2010)

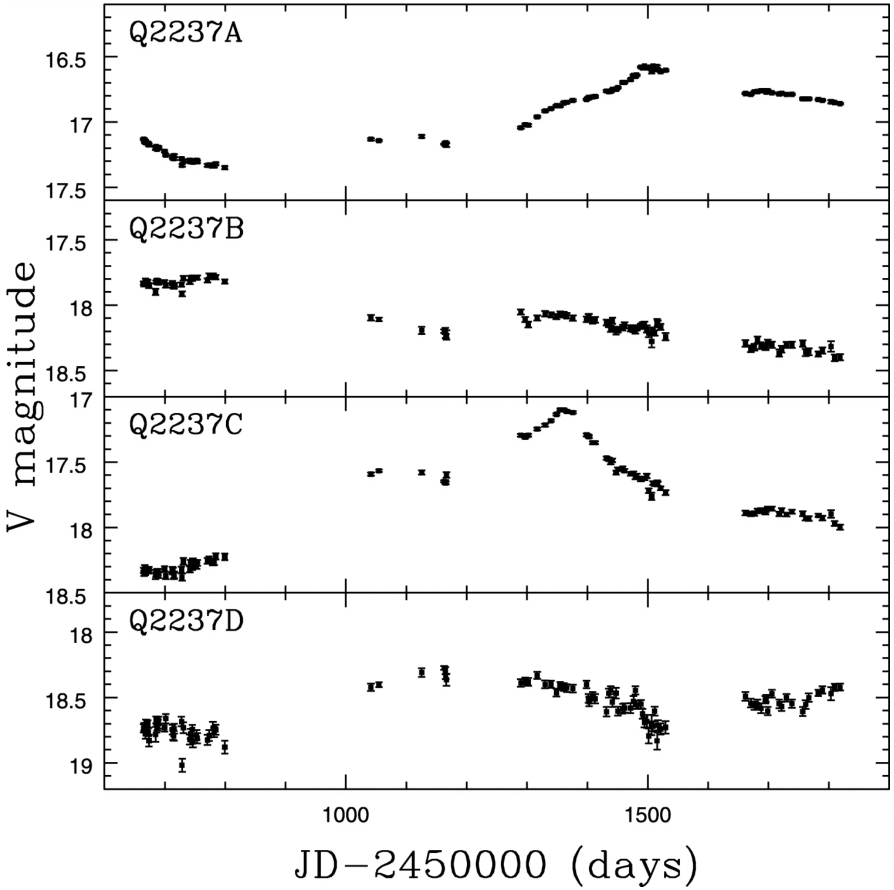
- $t_{inflow} > 10^3$ yr; t_{therm} ~ 1 yr
- Unlike X-rays in BHBs!



Kelly+2009

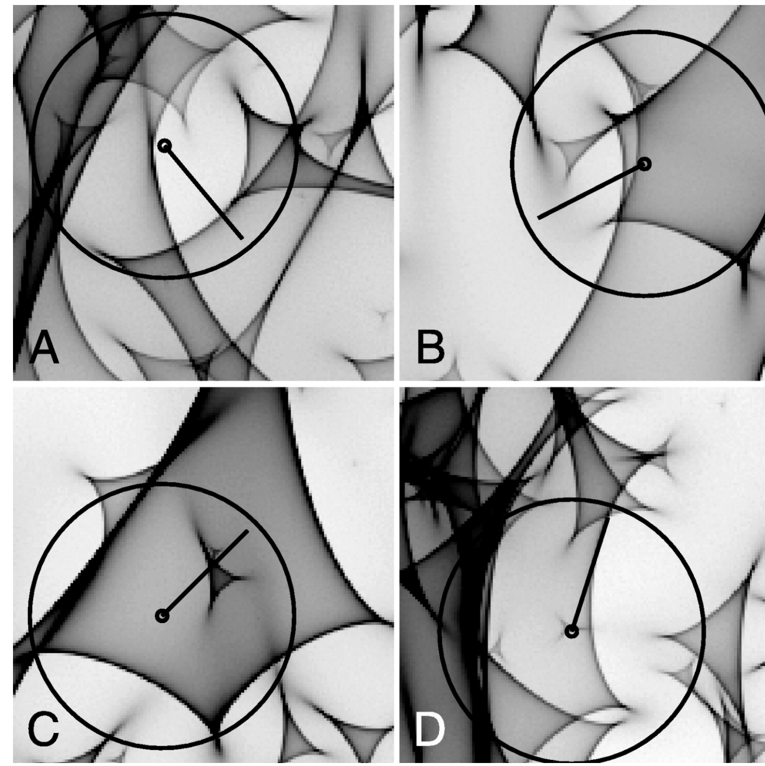
Microlensing measures disk size





AGN Disks are factor ~4 too big

- Larger disk → smaller variations
- Sizes too large by 0.6 ± 0.3 dex! (Morgan+2010)
- Independent of M, Mdot

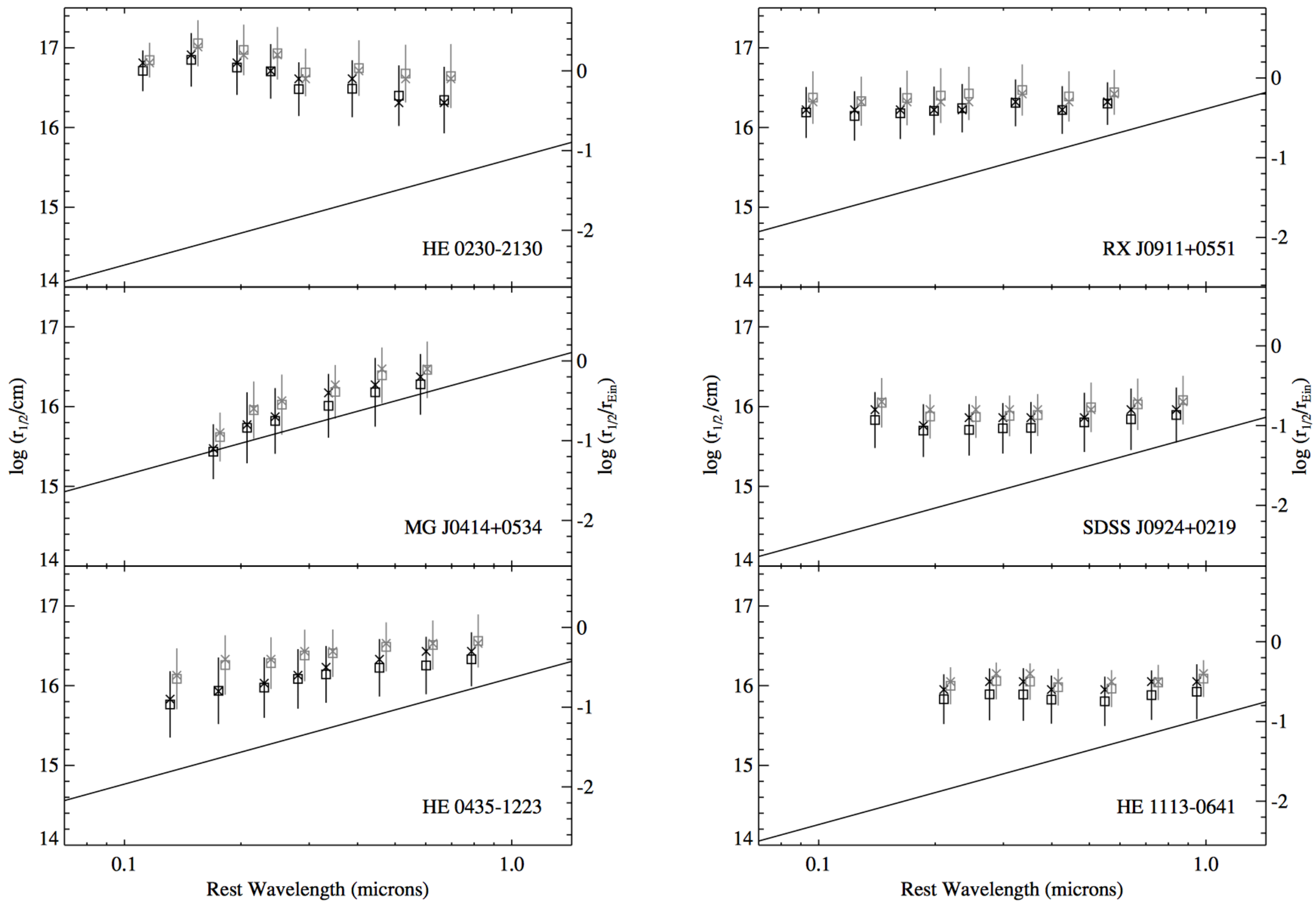


Kochanek 2004

Mapping disks with microlensing

X-ray size ~ 10 r_g, optical ~ 70 r_g (e.g. Dai+, Chartas+)

Size

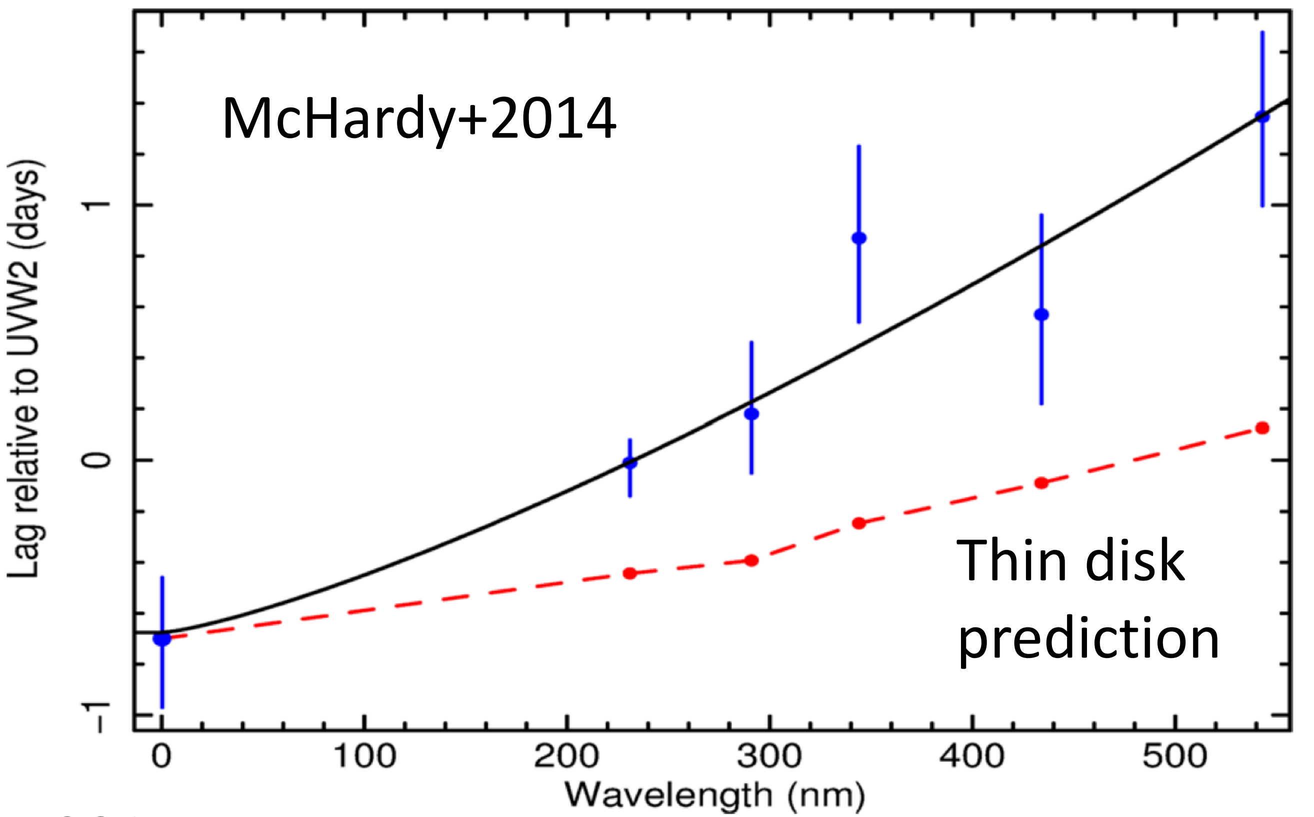


Wavelength

Blackburne+ 2011

Mapping disks with reverberation

- lags relative to UV ~ emission size, again disk is too large

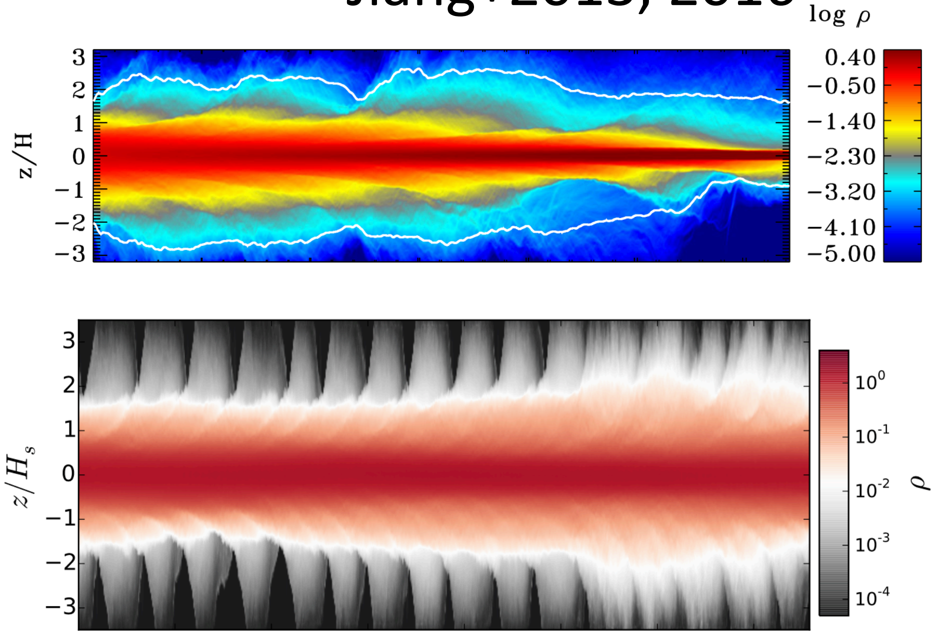


also Jiang+2017

Recent attempts to save disk models

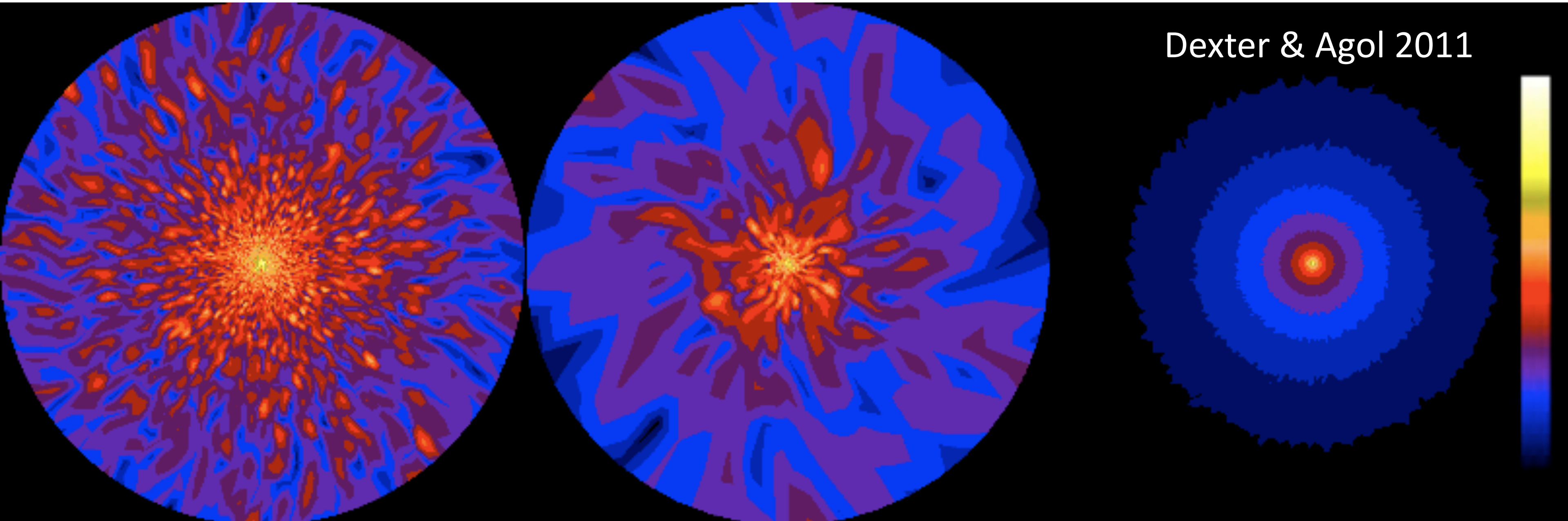
- Inhomogeneous disks
  (Dexter & Agol 2011)
- Disk is reprocessed
  (Lawrence 2011)
- Iron opacity
  - Outflows
    (Laor & Davis 2014)
  - Thermal stability
    (Jiang+2013, 2016)
- Tenuous atmospheres (Hall+)
- C. Done talk / optxagnf

Jiang+2013, 2016

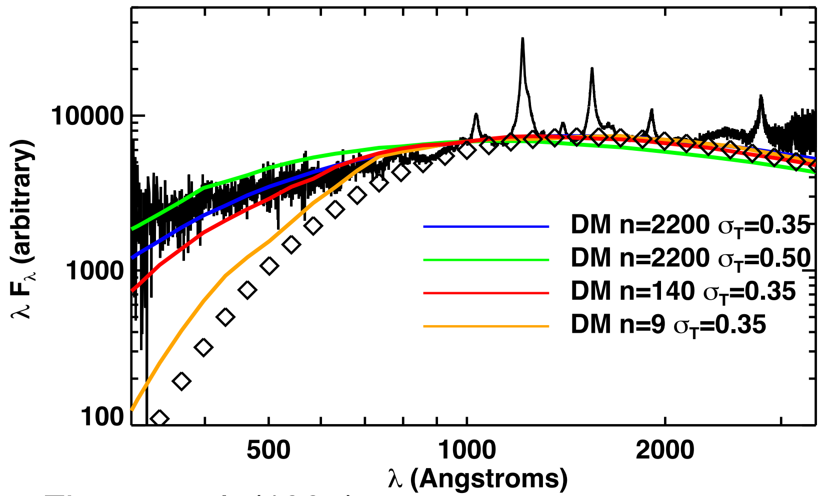


Inhomogeneous disks

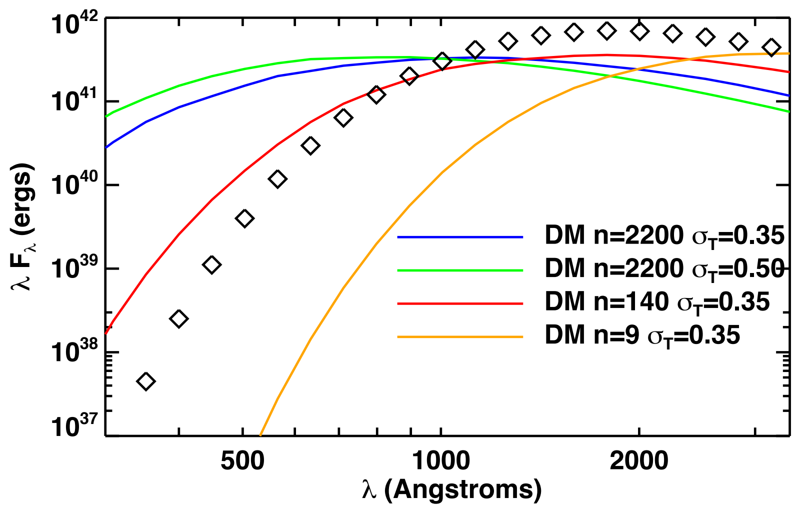
- "Disk" as zones with varying $T(\phi,t)$
- Keep thin disk on average: $\langle \sigma T^4 \rangle_{\phi,t} = F(r)$
- Can match observations for large fluctuations
- Variations: BHBs (Dexter & Quataert 2012), Cai+2016



Inhomogeneous disks

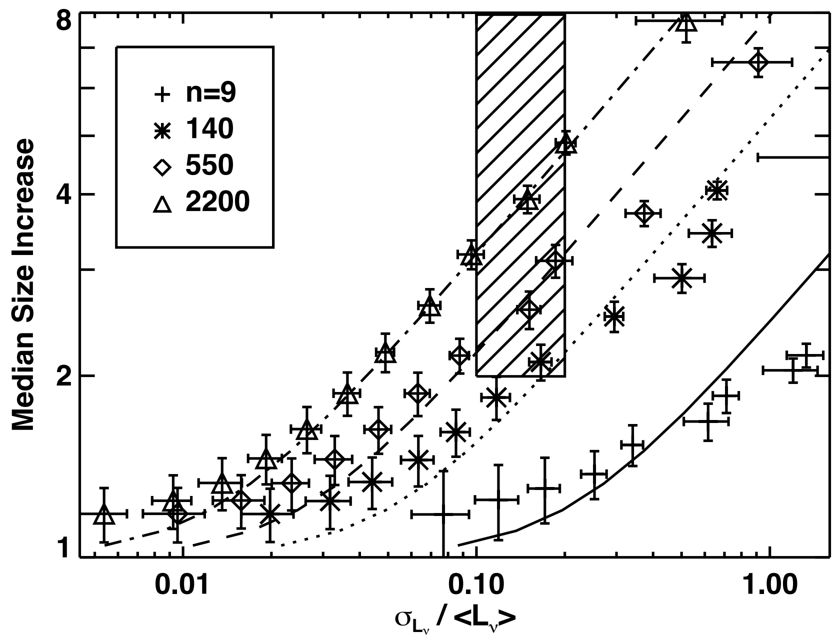


Zheng et al. (1997)



n – number of zones per octave in radius

σ_T - Amplitude of fluctations in dex

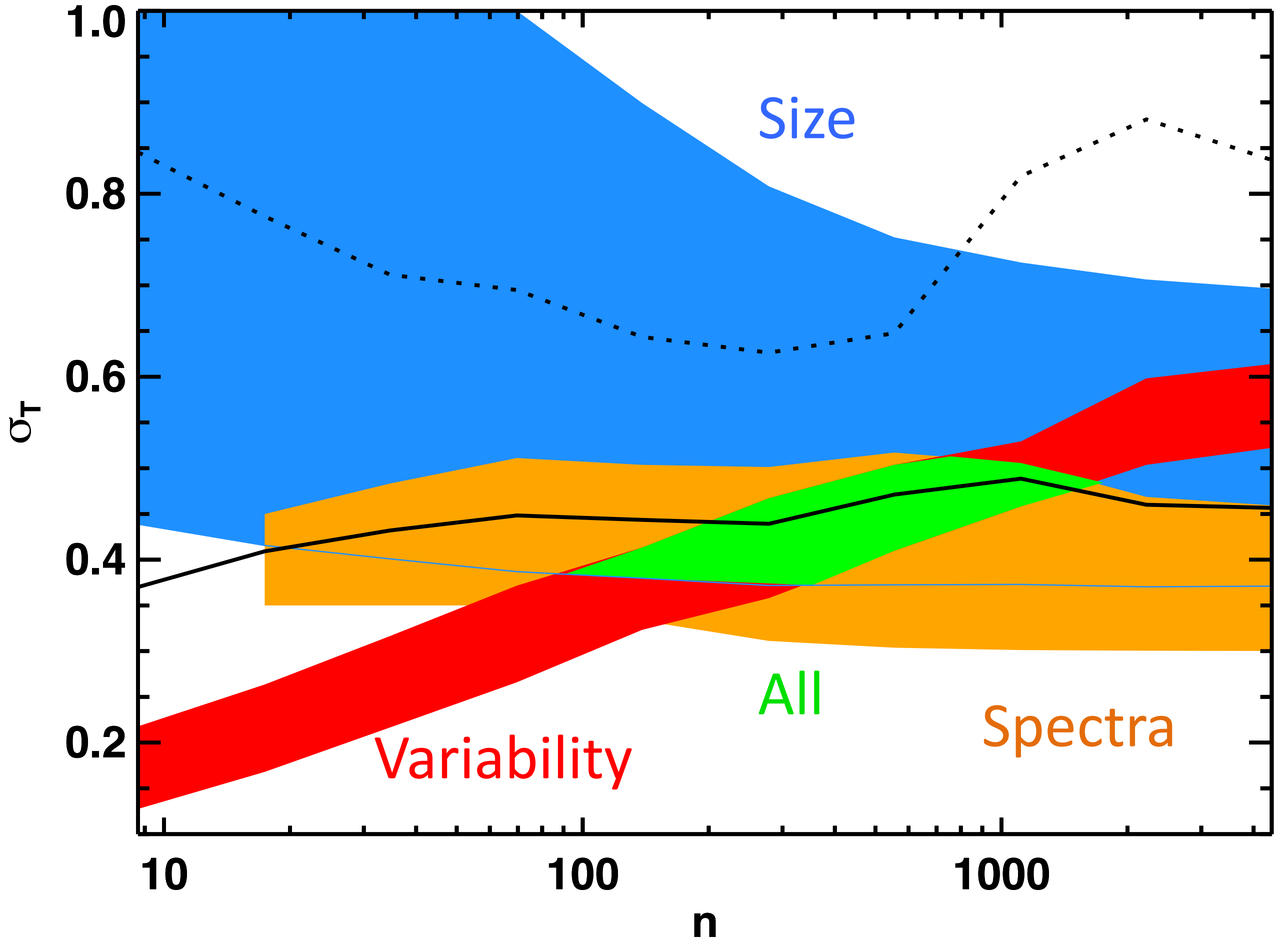


Dexter & Agol 2011

Inhomogeneous disks

n – number of zones per octave in radius

σ_T - Amplitude of fluctations in dex



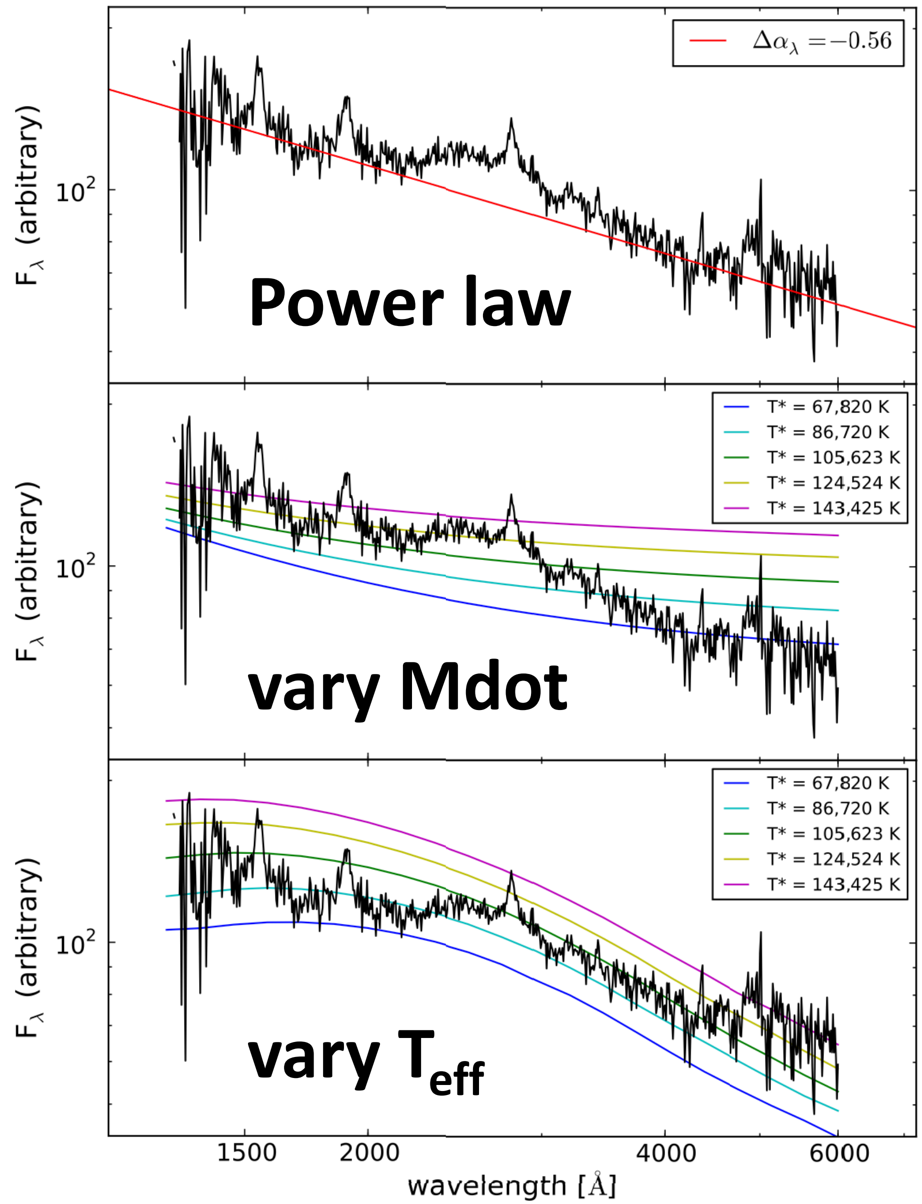
Need fluctuations of ~0.4 dex in small regions

SDSS quasar spectral variability

Ruan+2014

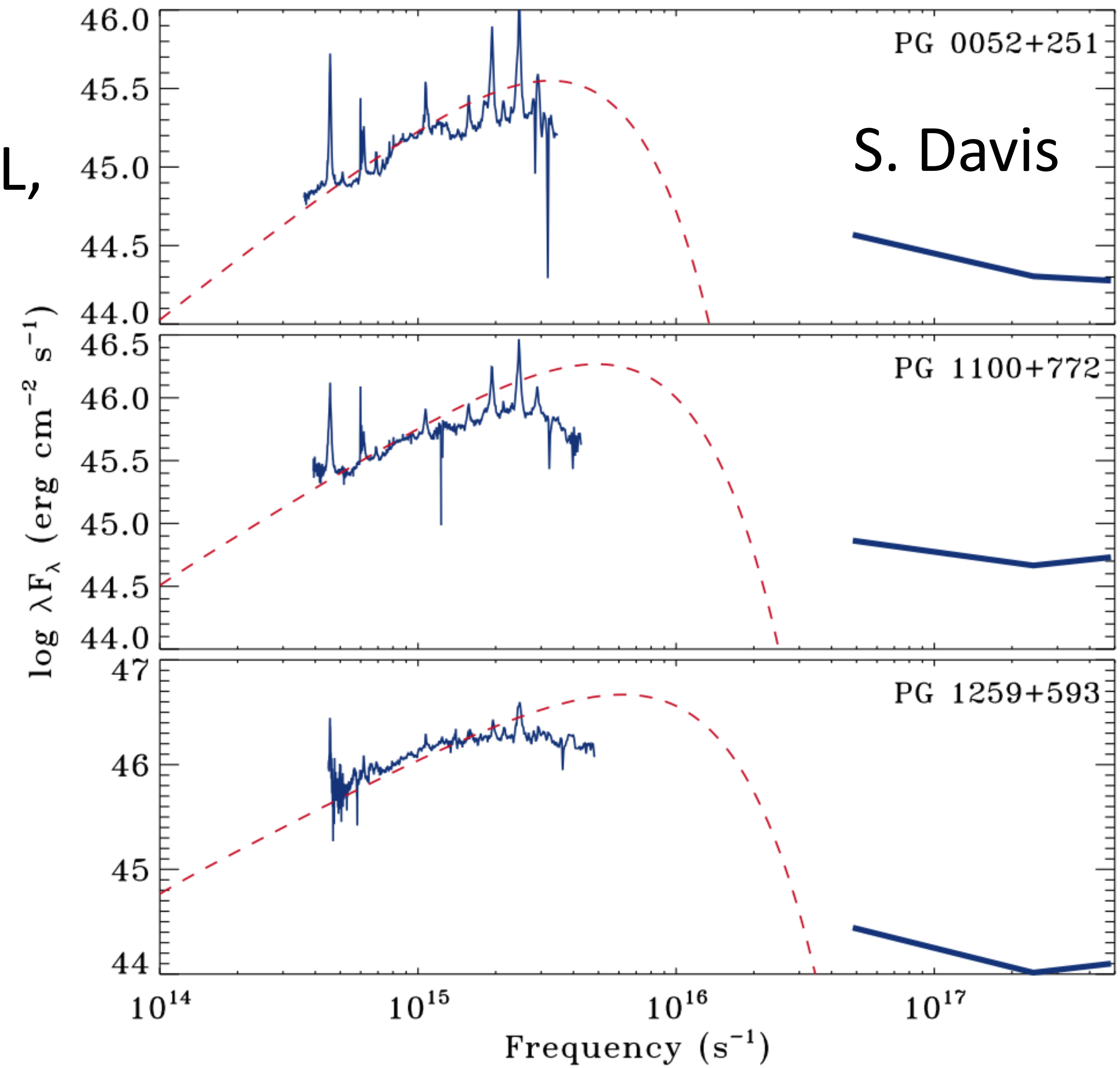
- Changes in Mdot don't match variable spectrum (also Sun+, Meusinger+; but Hung+)

- Need large T fluctuations!



Constant T_{eff} in AGN

Factor ~ 10 in L, peak ~ 1000 A

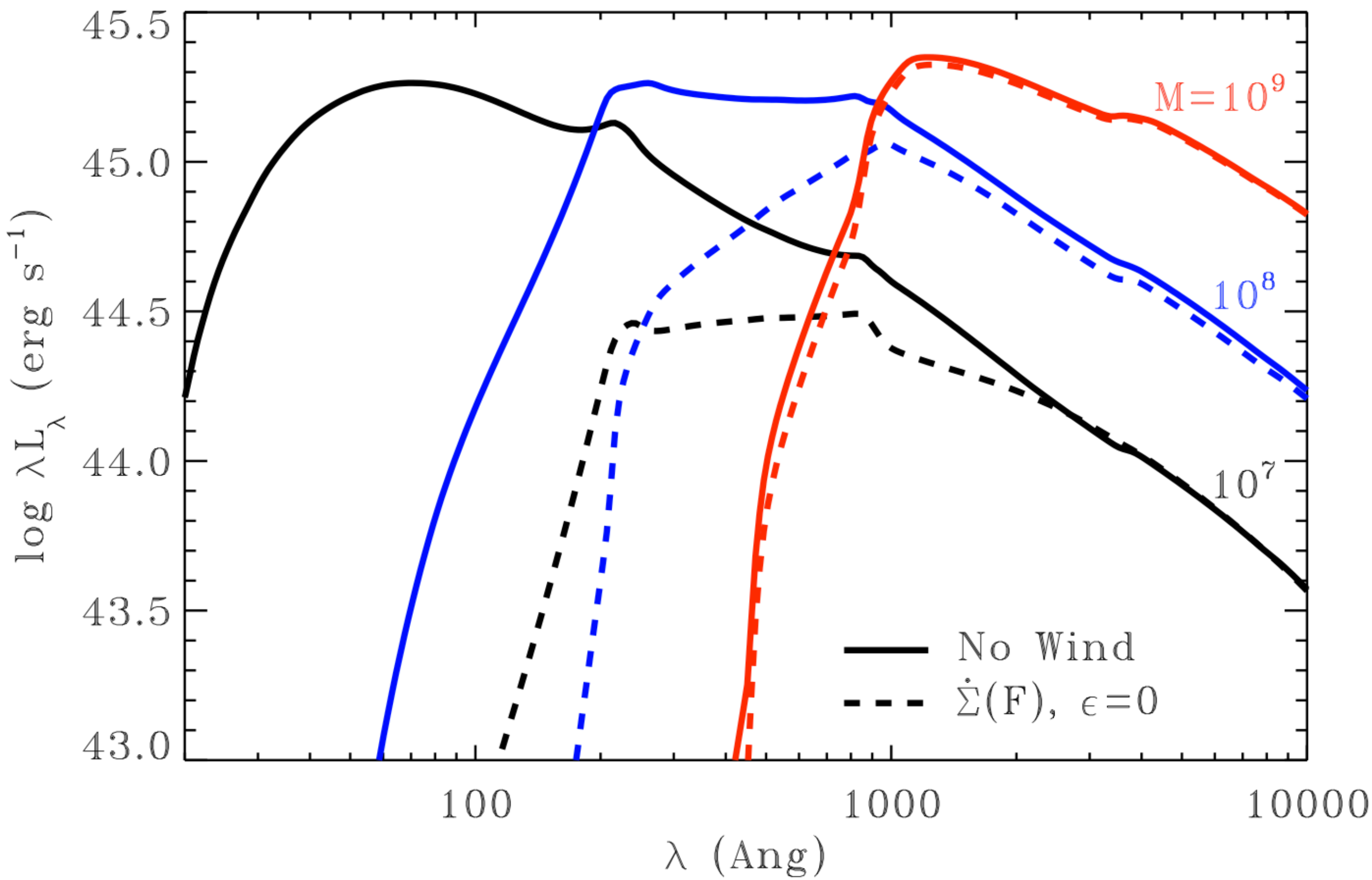


Increasing L ↓

Data: Brotherton+, Brandt+

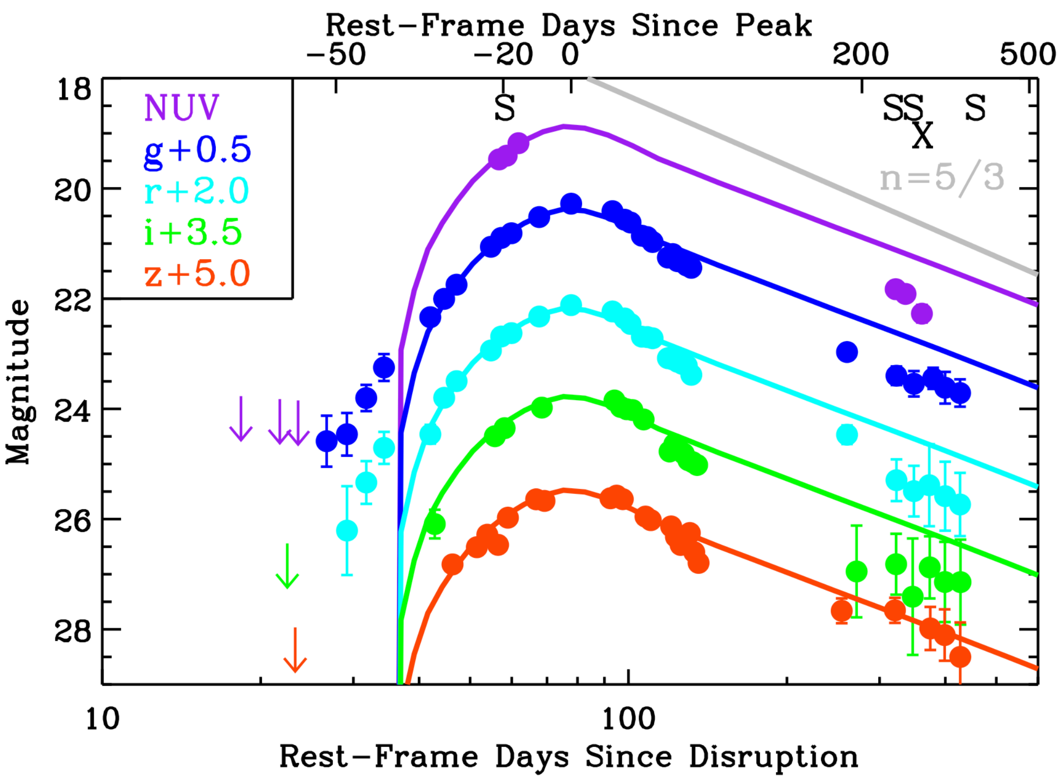
Massive outflows?

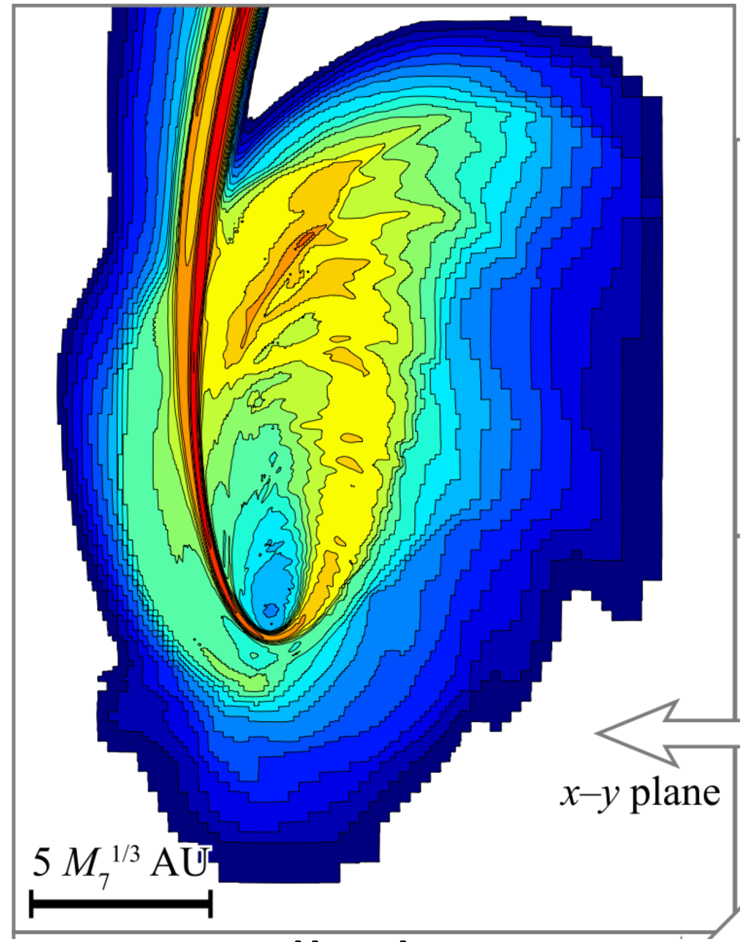
- Laor & Davis 2014:
  scale line-driven winds from O stars to AGN



Similar problem in optical TDEs?

Gezari+2012





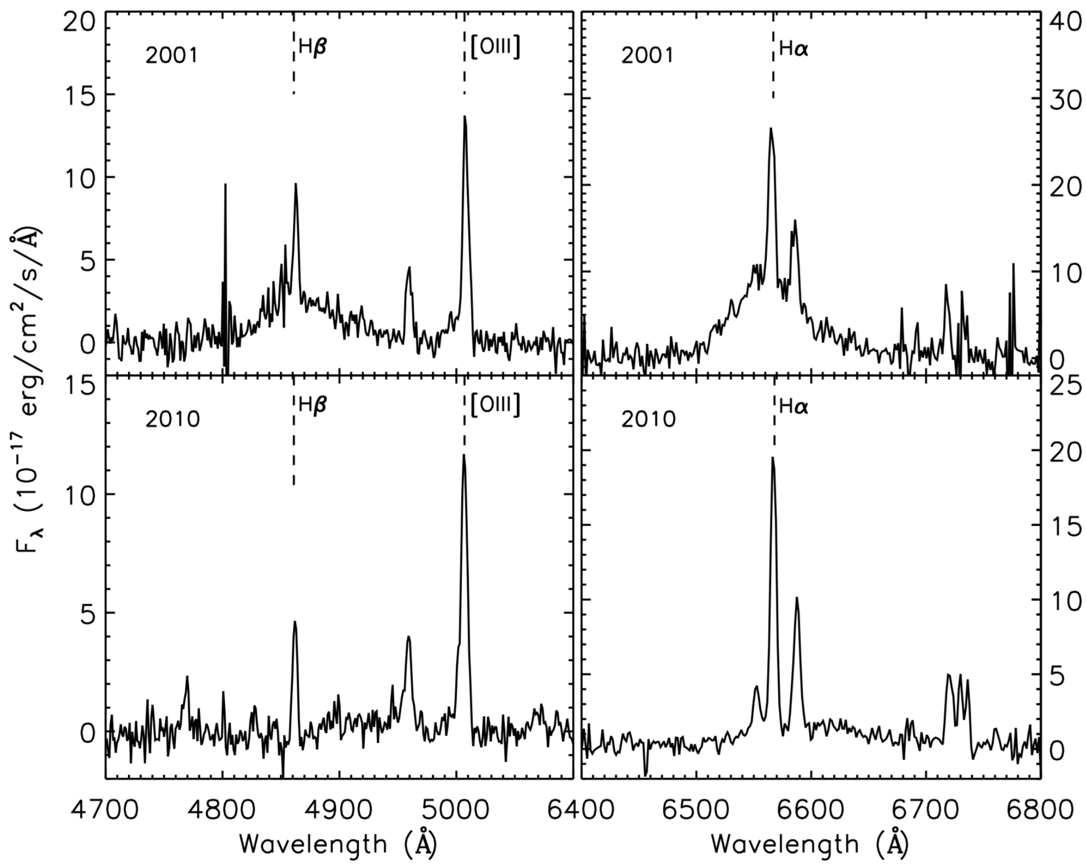
Guillochon+2014, Roth+2015, Miller 2015

Changing look AGN can help

- Type 1 ⬌ 1.9 with factor ~10 changes in L on year timescales

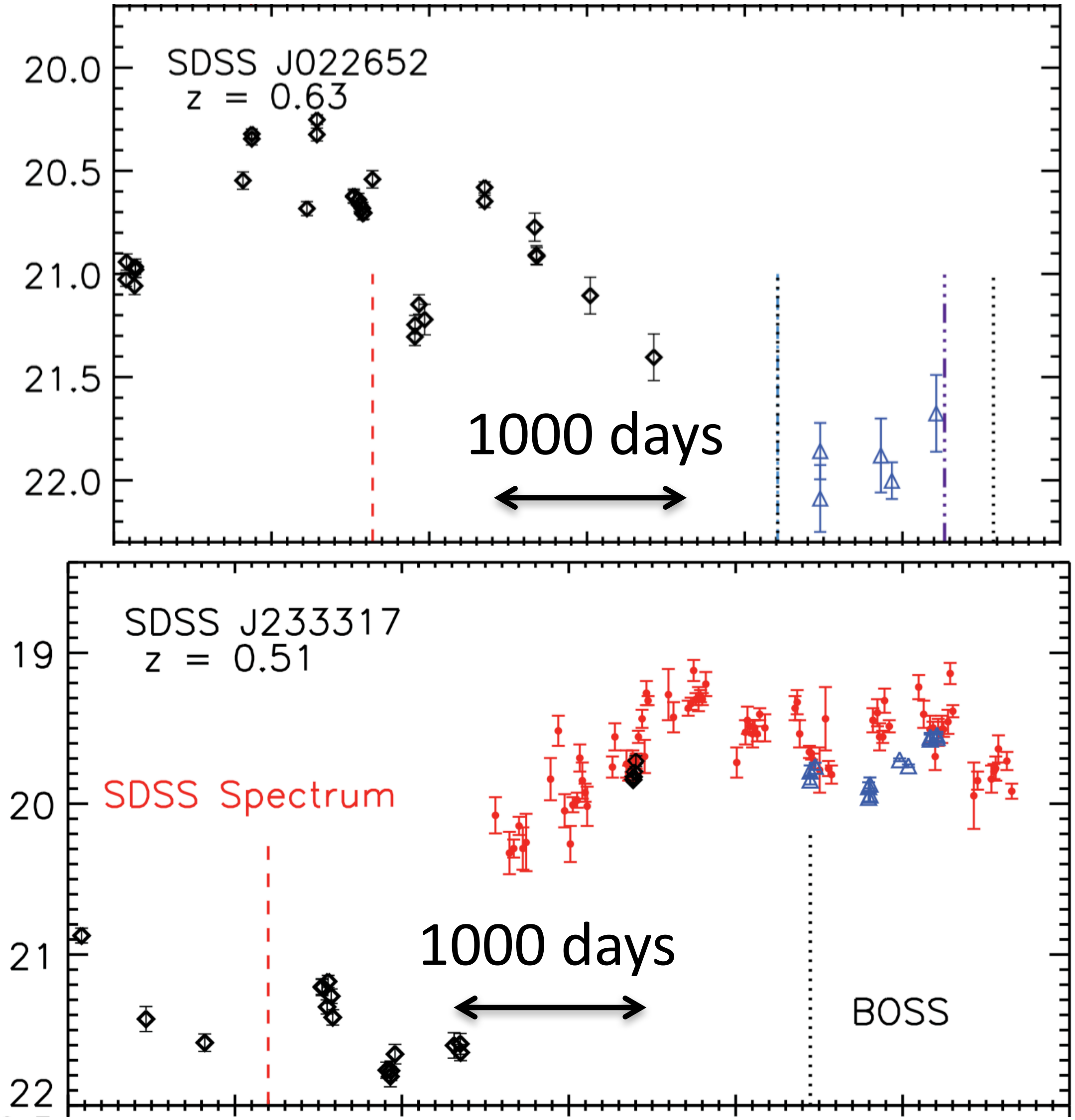
Before

After



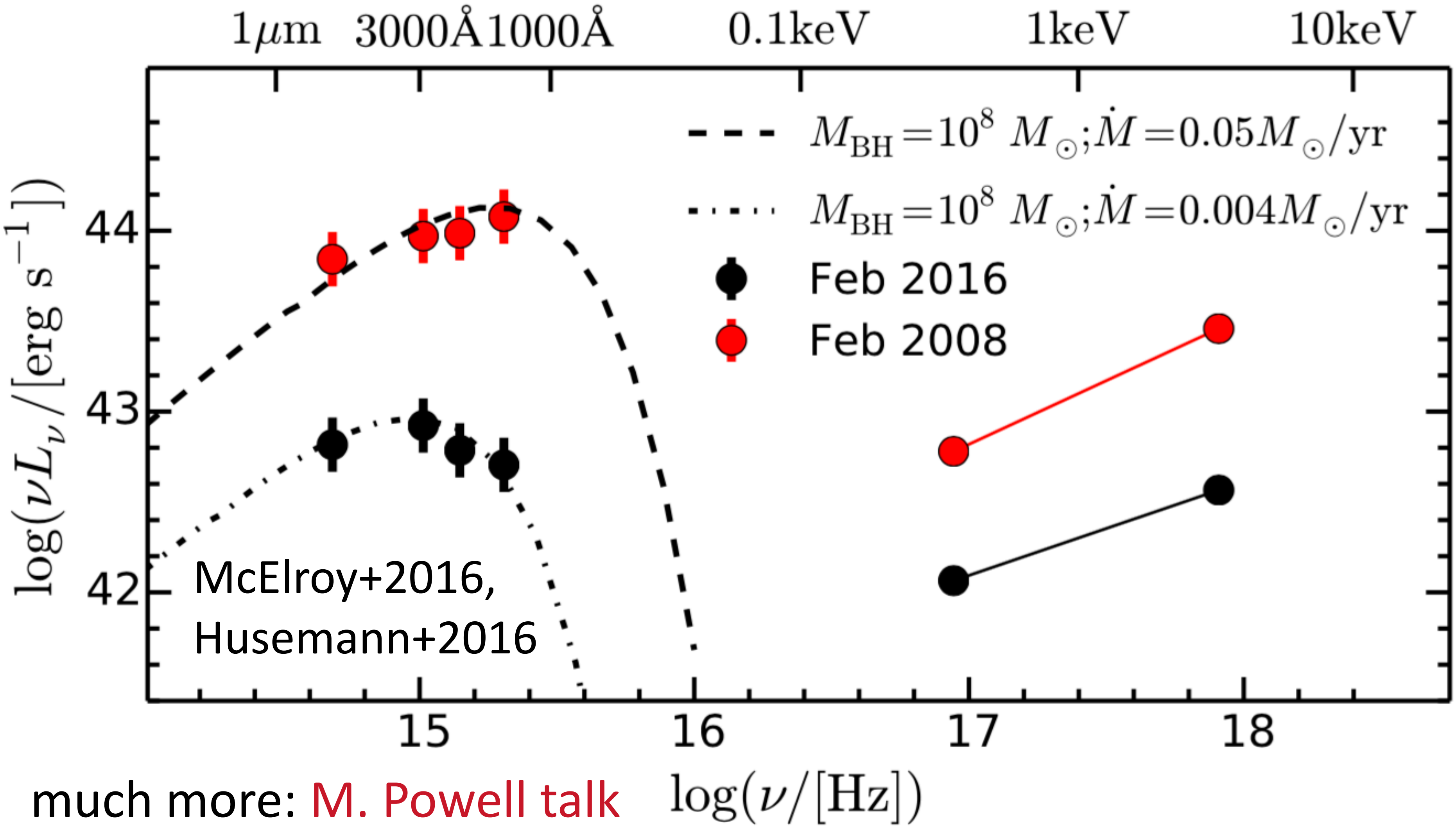
LaMassa +2015

Rapid changes in intrinsic L



MacLeod +2016

Mrk 1018: T_{eff} down with L!



much more: M. Powell talk

Year timescales are fast

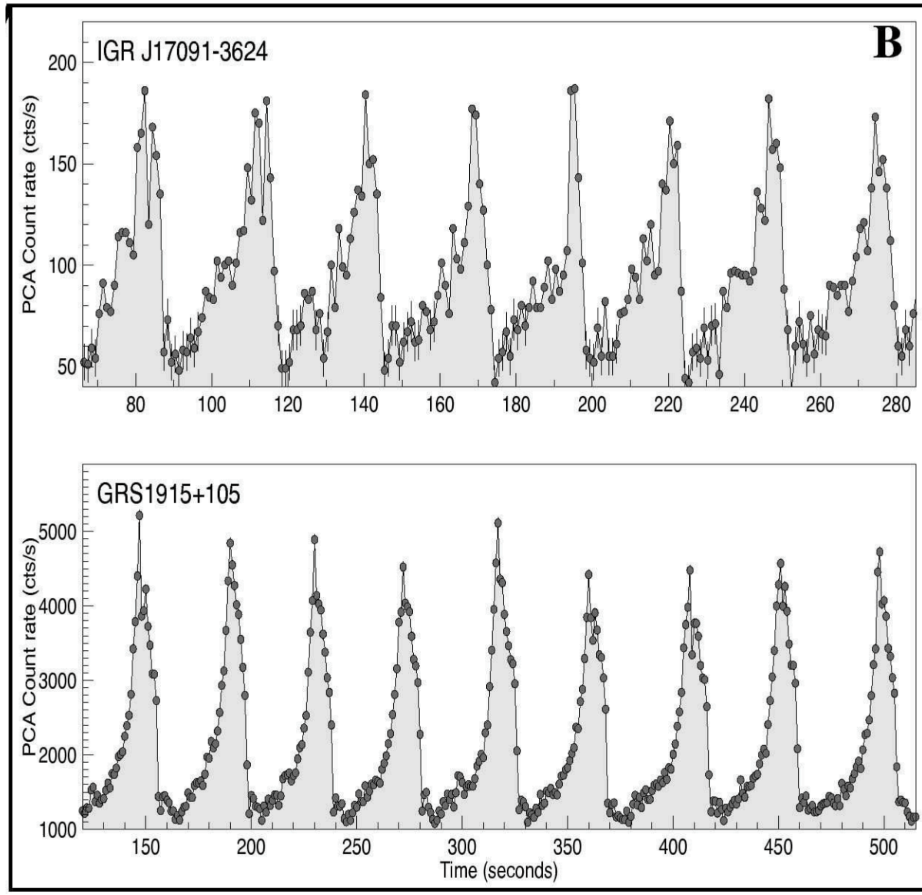
- Inflow could explain off(?) but not on
- Related to thermal instability? (Jiang+2016)

$$t_{\rm infl} = 1300{\rm yr}\left[\frac{\alpha}{0.1}\right]^{-1}\left[\frac{\lambda_{\rm Edd}}{0.005}\right]^{-2}\left[\frac{\eta}{0.1}\right]^{2}\left[\frac{r}{10r_{\rm g}}\right]^{7/2}\left[\frac{M_8}{2.0}\right]$$

$$t_{\rm th} \simeq 0.5{\rm yr}\left(\frac{\alpha}{0.1}\right)^{-1}\left(\frac{\rm M_{BH}}{10^8 M_\odot}\right)\left(\frac{\rm R}{100R_S}\right)^{3/2}$$

Like weird X-ray binaries?

- Too fast for BHB state transitions (~days-weeks)
- Limit cycles in GRS 1915+105 and 2 others (Belloni+1997, Neilsen+2011, Altamirano+2011, Bagnoli+2015)
- $L \sim L_{edd}$ not needed



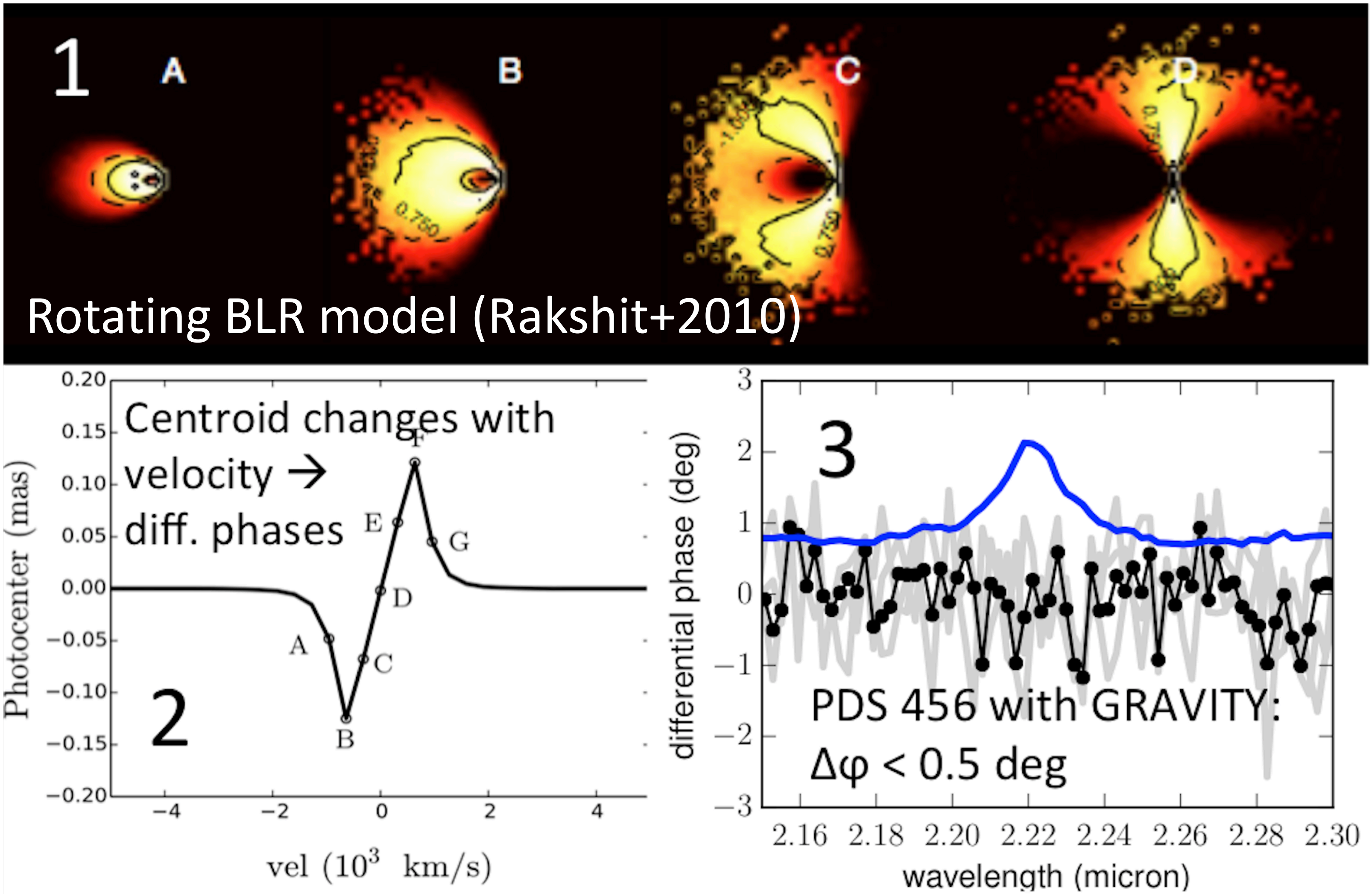
Altamirano+2011

Summary

- Disk theory works well for BHBs but not AGN
- Large temperature fluctuations, massive winds, ?
- Changing look AGN as a time-resolved view of a changing accretion process
  - Why factor ~10?
  - Do broad line changes make sense?

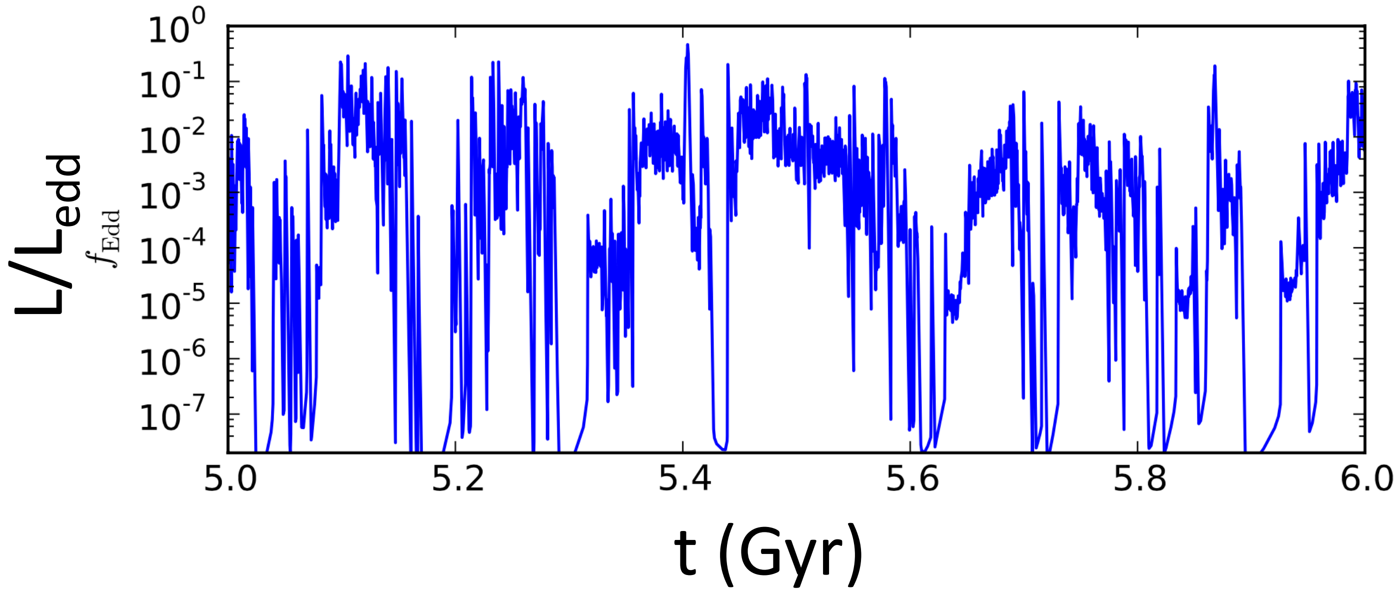
GRAVITY: spatially resolve the BLR

- ~10 microarcsecond opt. interferometry



Not related to AGN duty cycle?

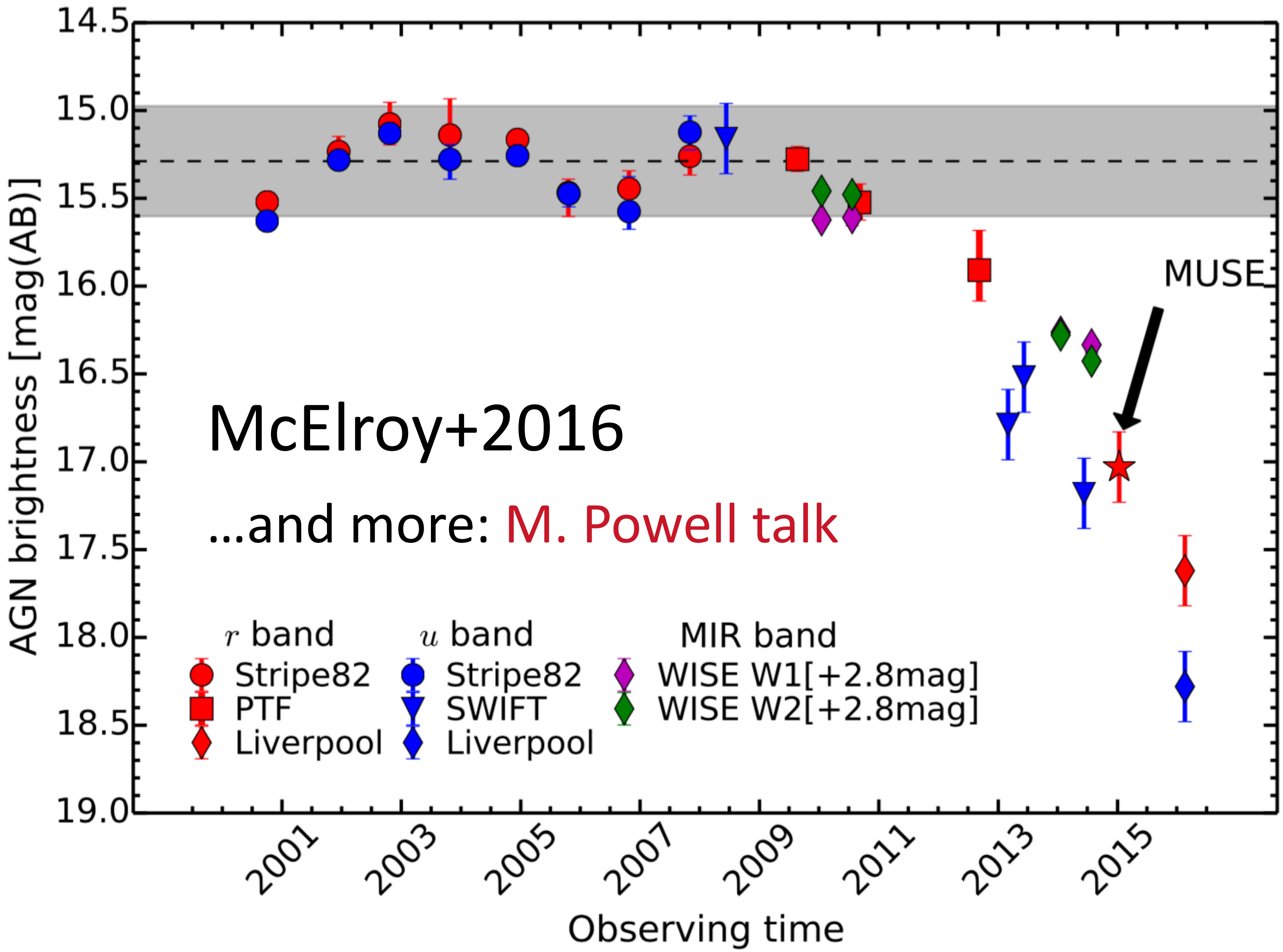
- $t_{AGN} \sim 10^{4\text{-}5}$ yr, $t_{CL} \sim$ few yr,
  $f_{CL} = t_{CL}/t_{AGN} \sim 10^{-4}$



Novak+2011

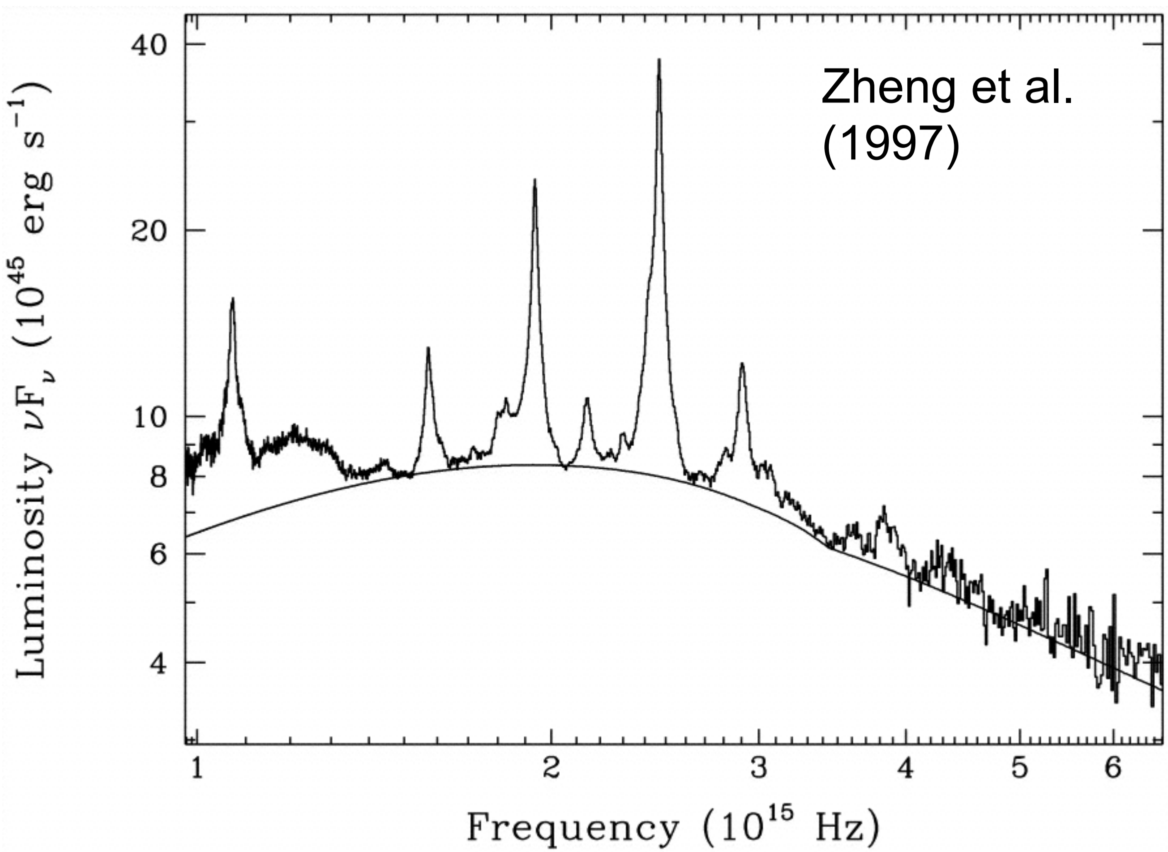
- Not for Mrk 1018: $L_{max}/L_{min} \sim 10$, $t_{high} \sim 30$ yr
- Others?

Mrk 1018: 30 year cycle?



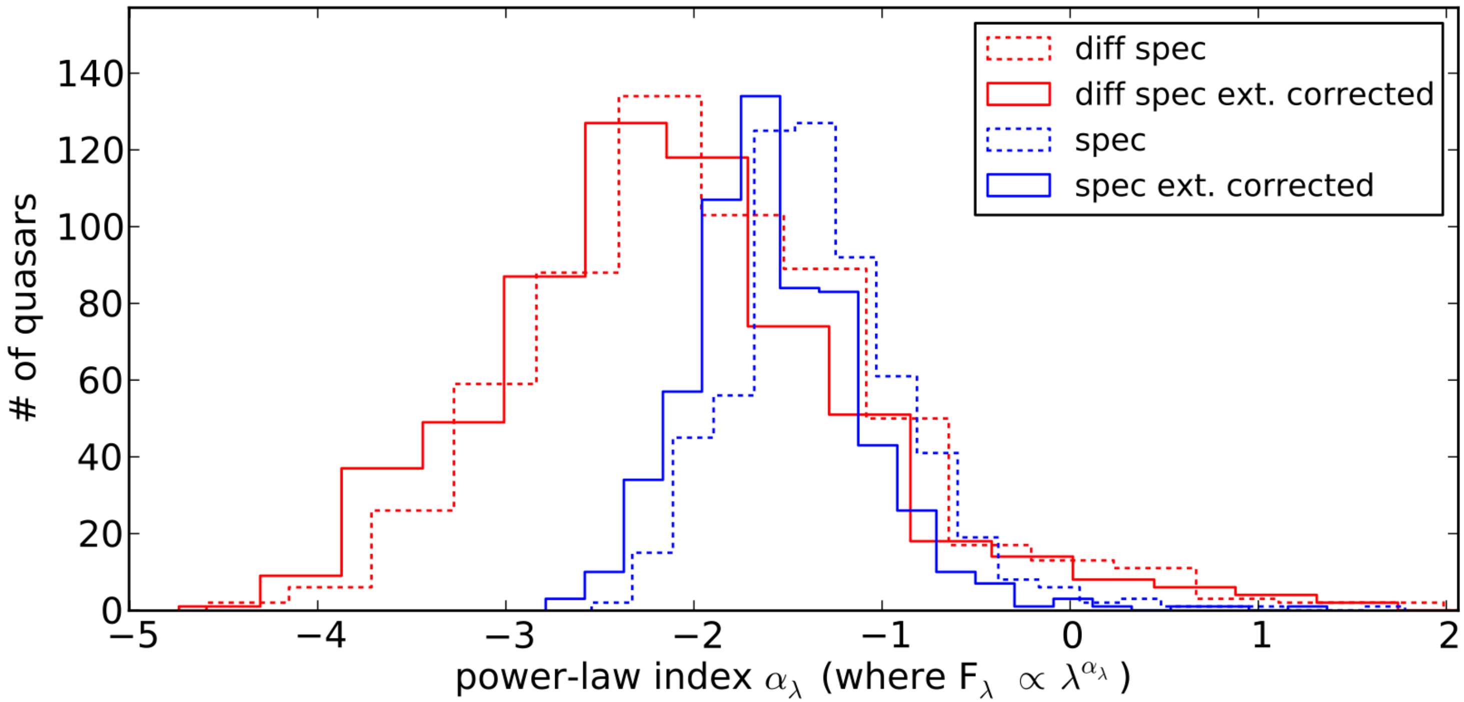
α- model issues: optical/UV Spectra

- Spectra are broader than a multi-T blackbody

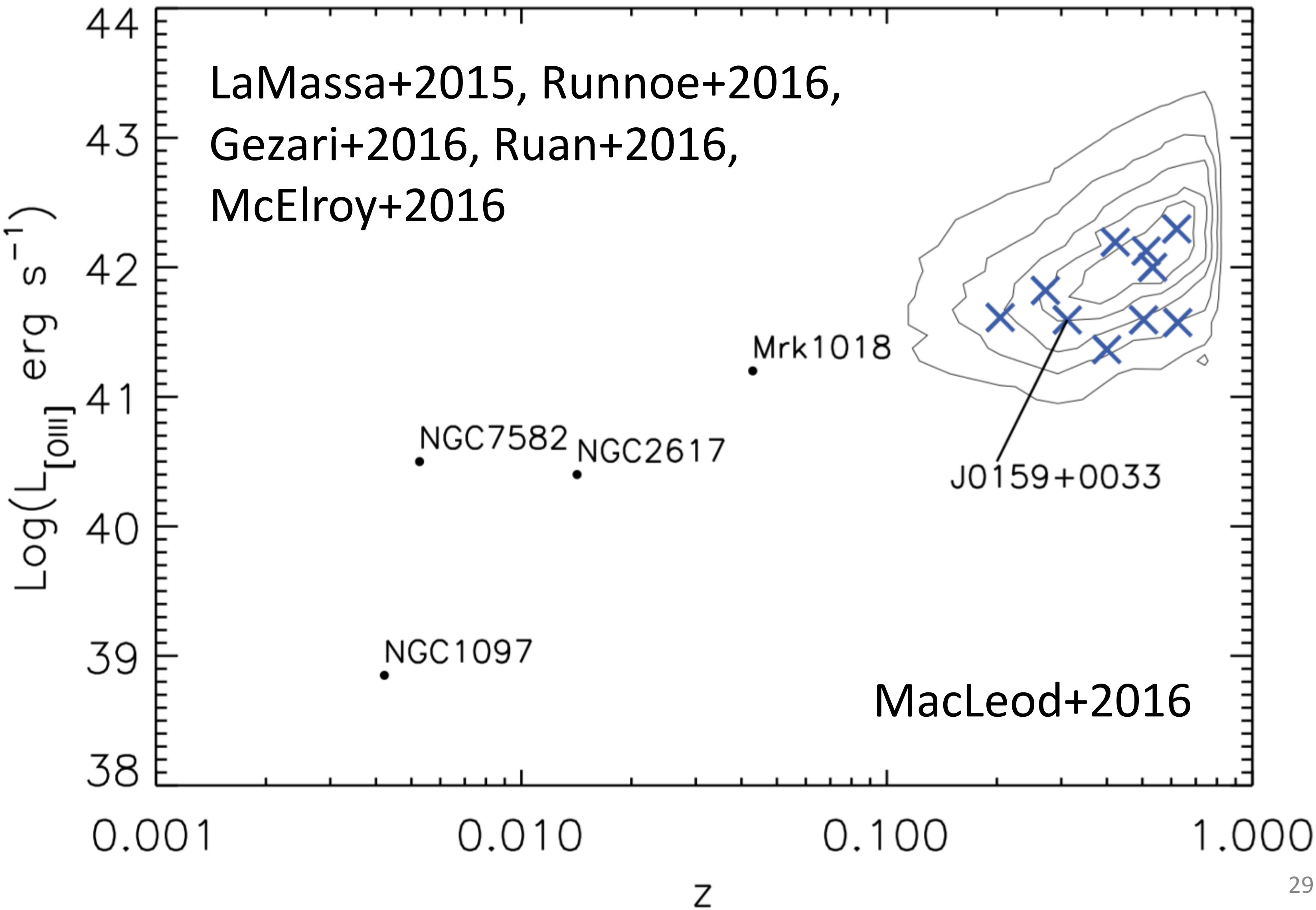


Quasar spectral variability

- Ratio of repeat SDSS spectra showing variability (Ruan+2014)



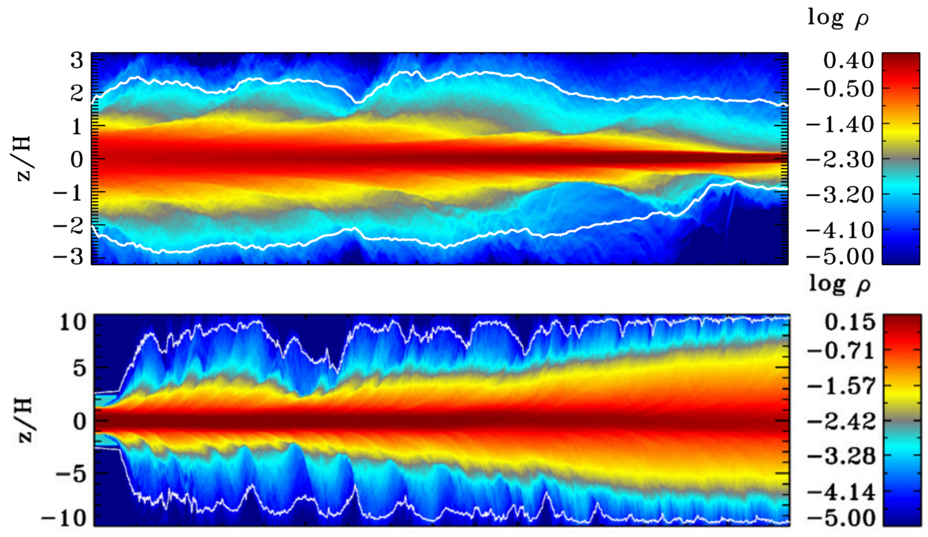
~10 objects known



Are large T fluctuations realistic?

- Observations: σ_T = 0.35-0.50
- MRI: Too small? ($\sigma_T \approx$ 0.1-0.2)
- Thermal/inflow: simulations underway…

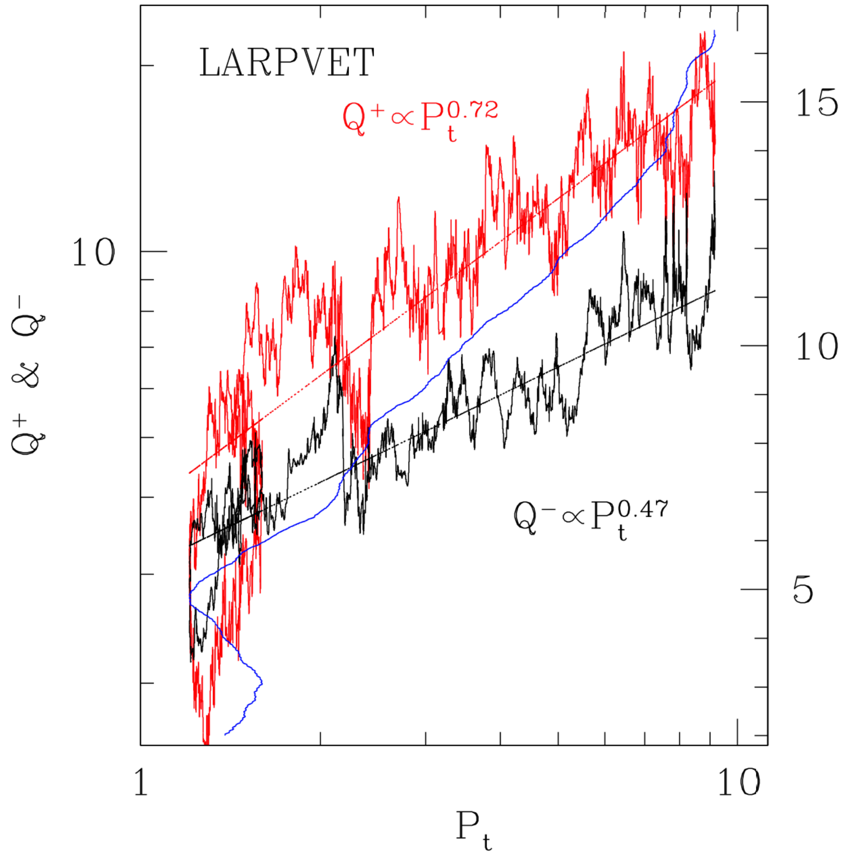
- Or: magnetically supported disk (Begelman & Pringle 2007)



Jiang+2013

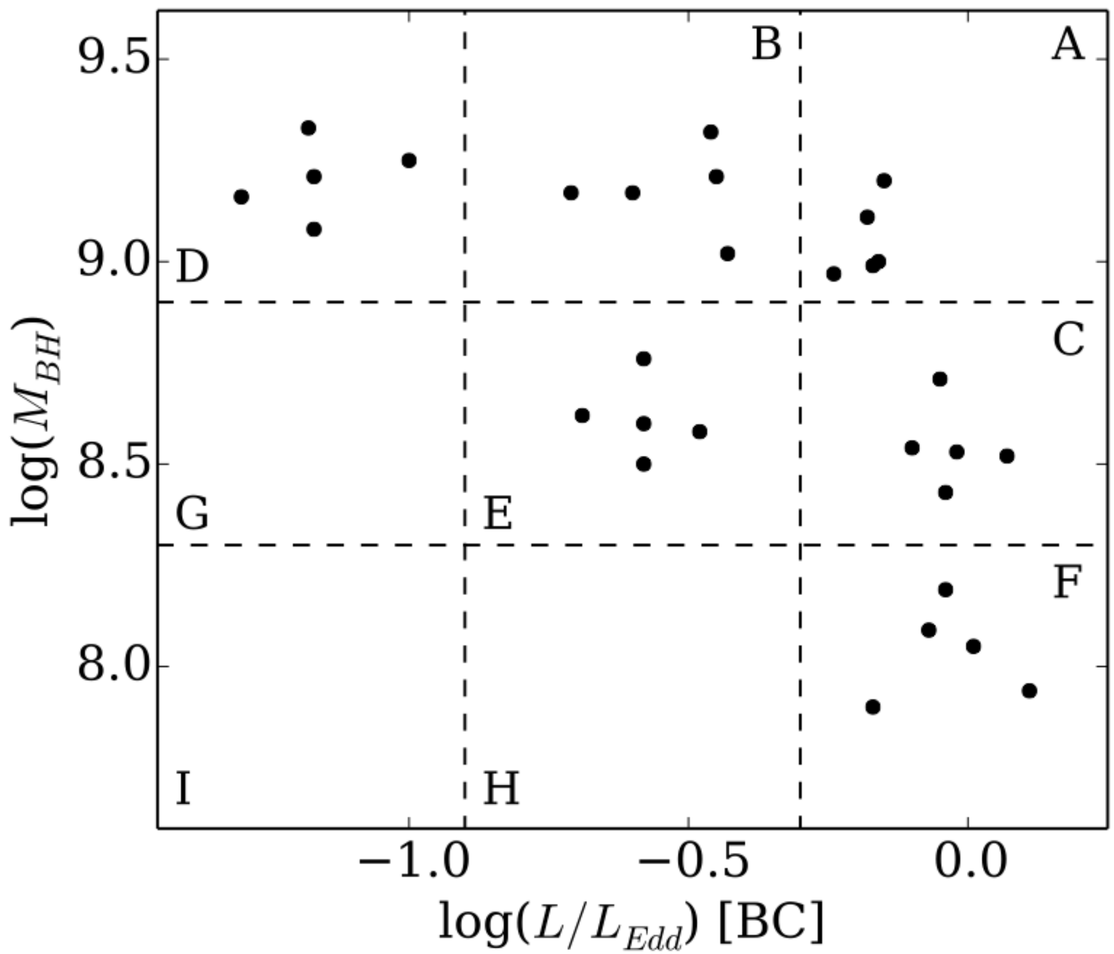
Thin disks in AGN are unstable

- Thermal instability: Heating stronger function of T than cooling
- Inflow instability: Surface density inversely proportional to accretion rate



Jiang et al. (2013)

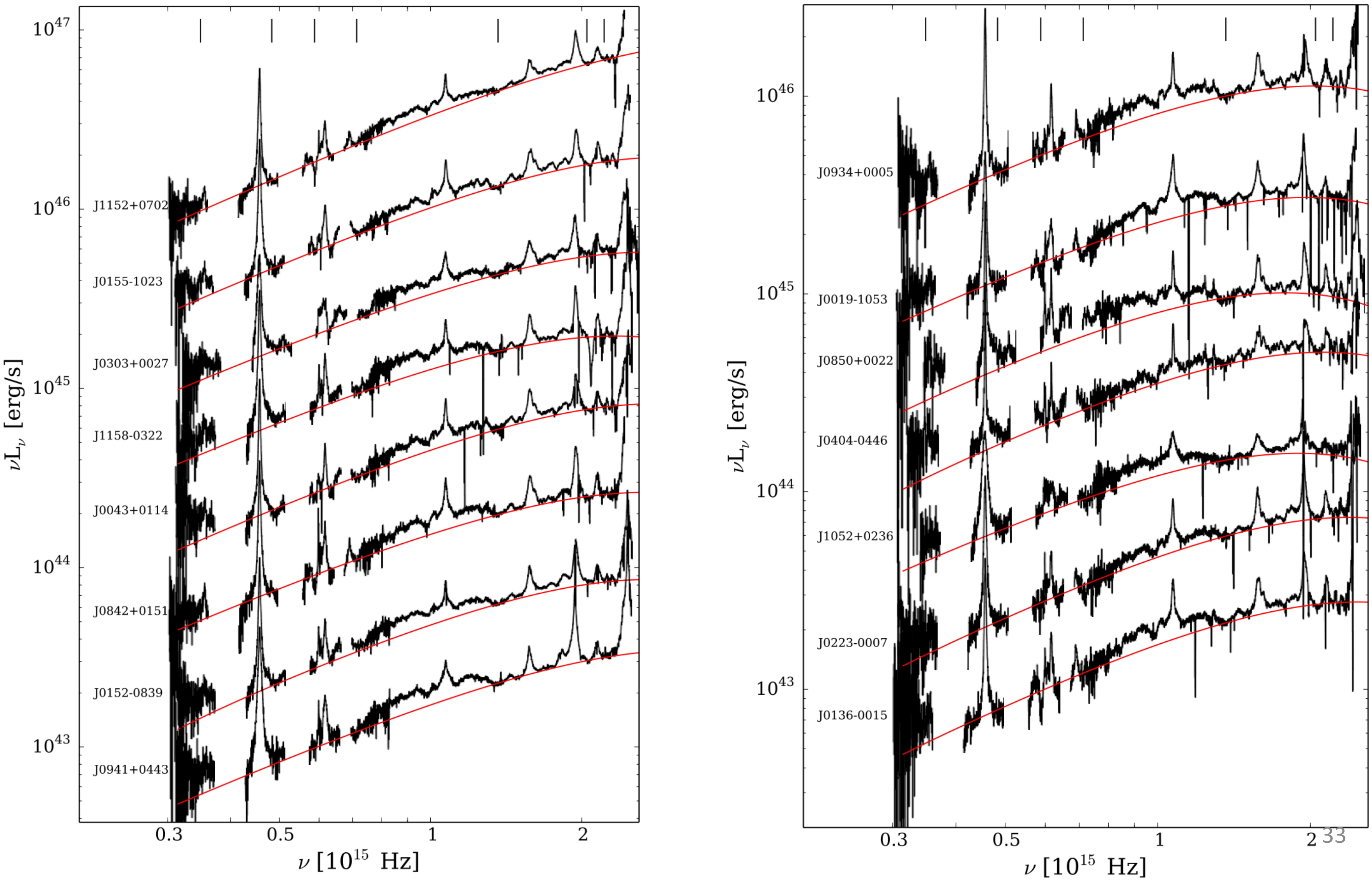
AGN spectral fits with disk models



Cappelupo +2015

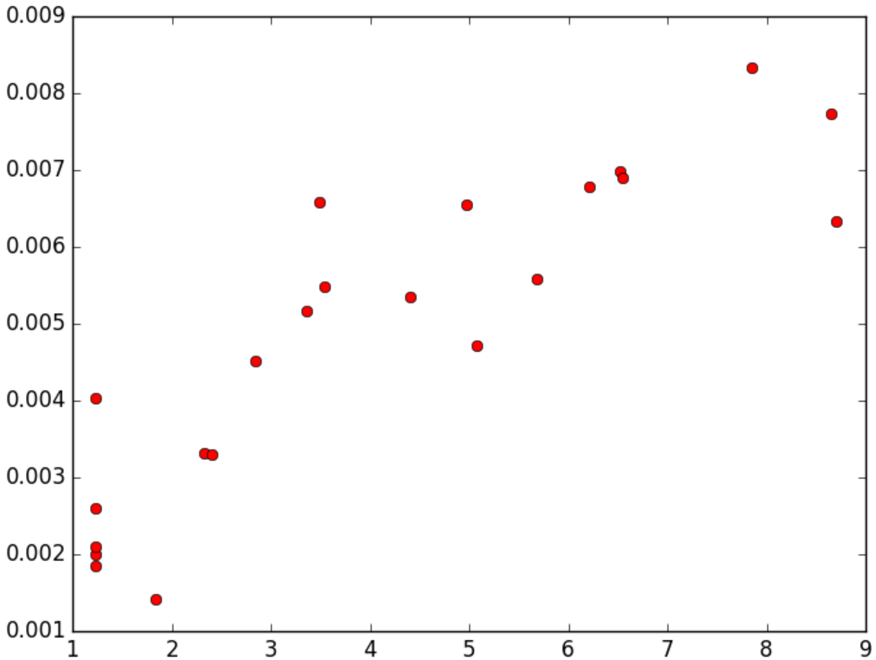
T_{eff} ~ (mdot / M $R^3)^{1/4}$, fit gives R → BH spin

Disk models fit, but similar T_{eff}

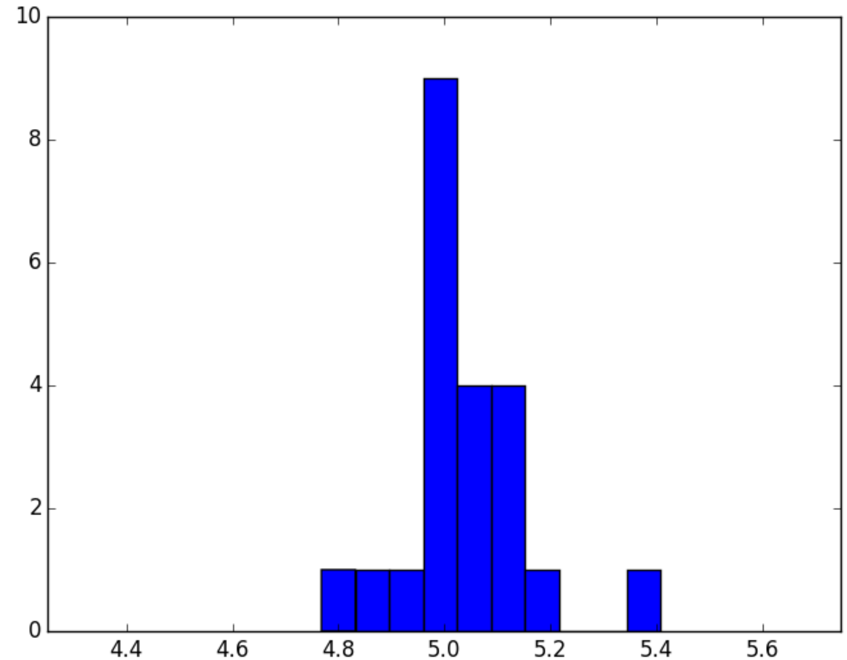


Best fit spin correlates with mdot/M, keeps T_{eff} ~ const

mdot/M

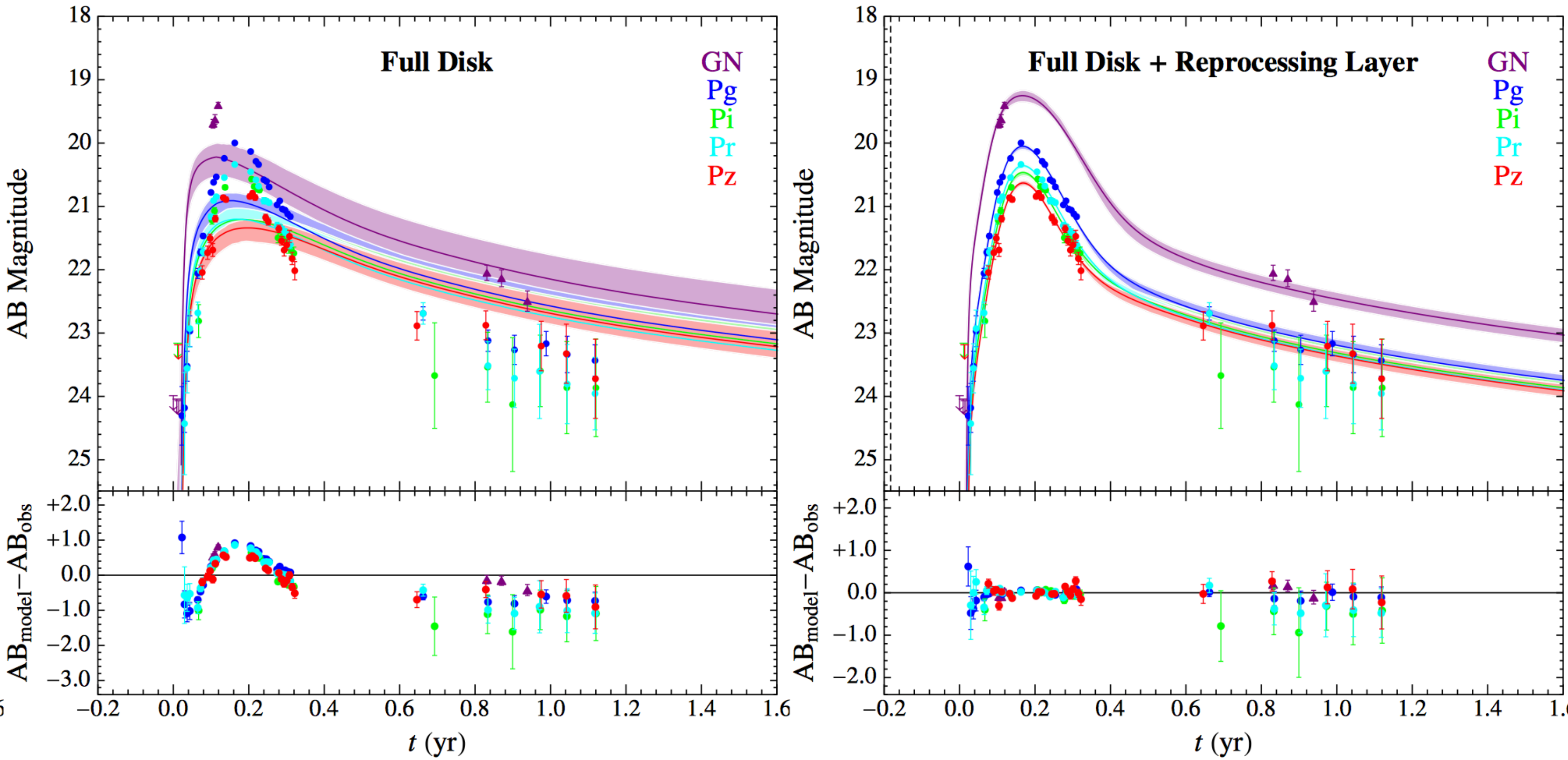


Inner radius



$T_{eff} \sim (\mathrm{mdot} / M R^3)^{1/4}$

TDEs: L_{opt} is not from a disk

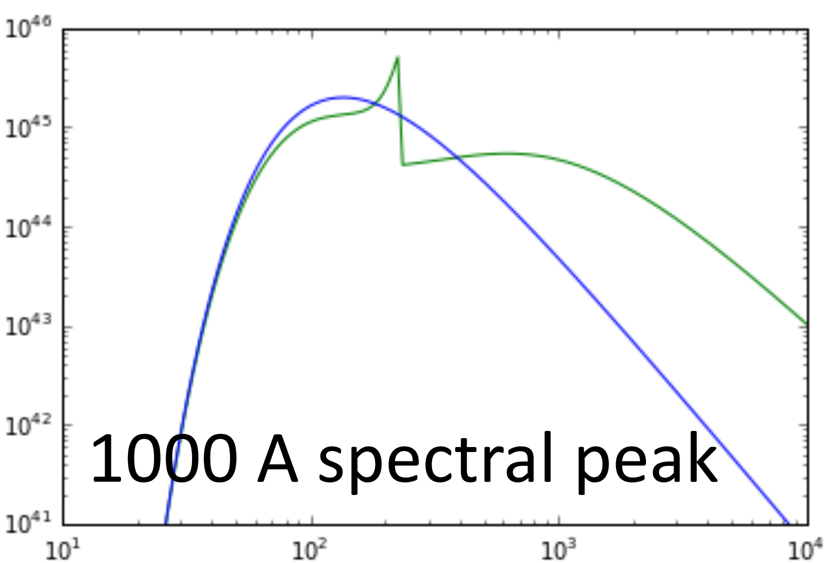


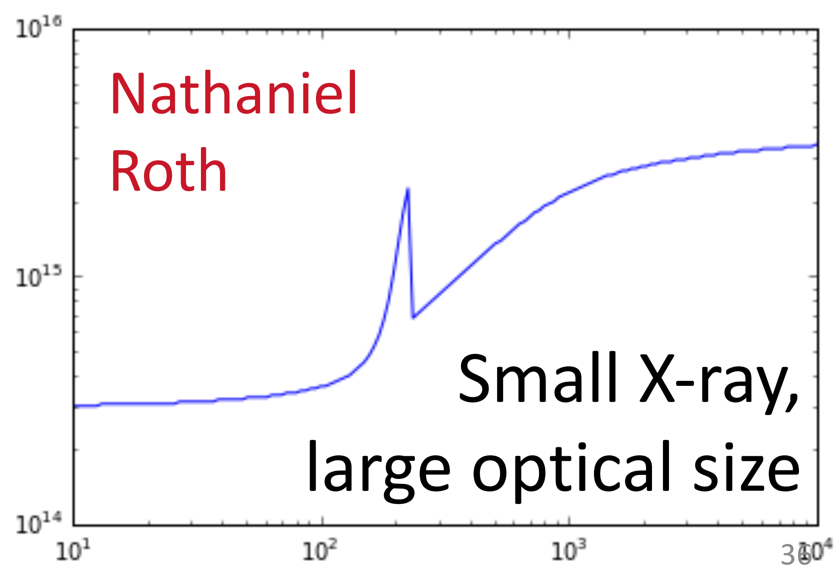
Guillochon+2014

Could this work in AGN?

- Require high L_X to ionize everything
- Solve for L_{opt} from re-processing:

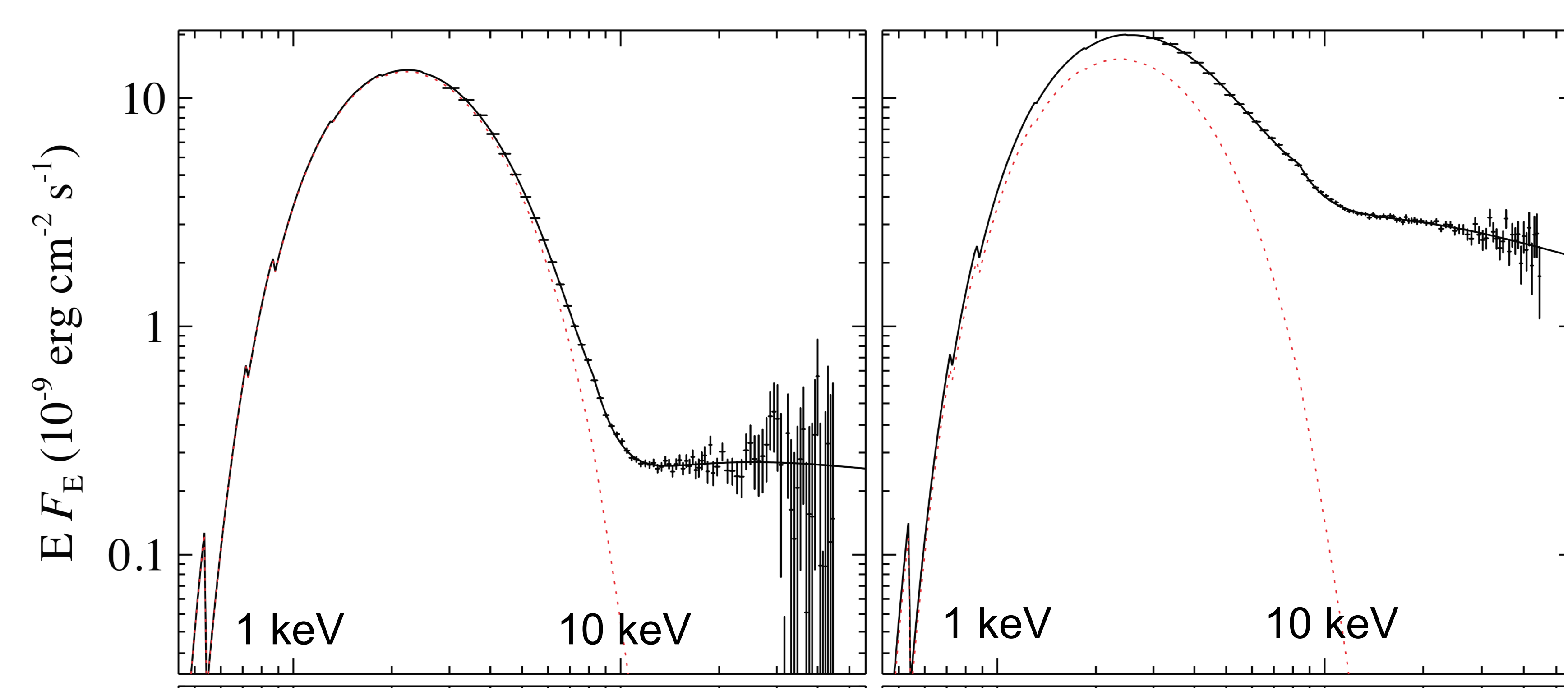
$$L_{\rm opt} \simeq 10^{43} \left(\frac{L_X}{10^{45}\ \rm ergs\ s^{-1}} \right)^{5/32} \left(\frac{r_{\rm in}}{10^{14}\ \rm cm} \right)^{39/32} \left(\frac{r_{\rm out}}{10^{15}\ \rm cm} \right)^{3/16} \rm ergs\ s^{-1}$$





Soft state BHBs

- Standard interpretation: static disk with variable “corona” (power law)

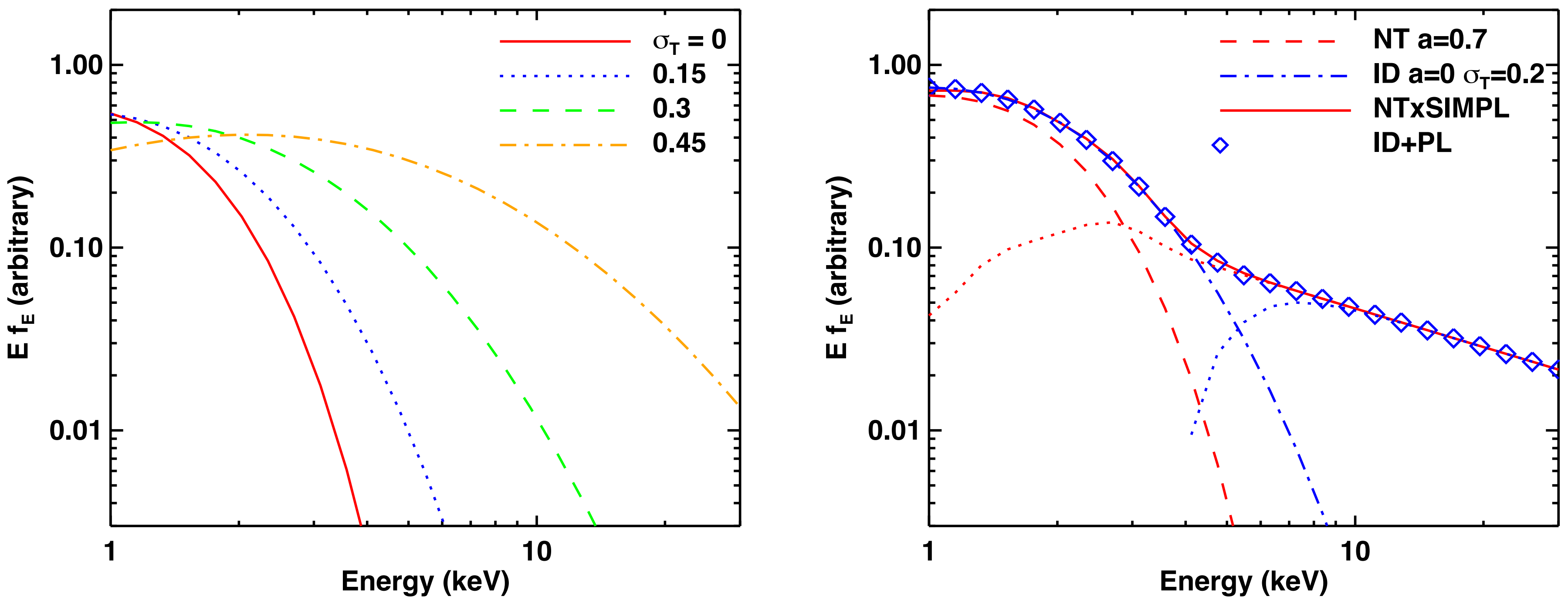


McClintock et al. (2011)

Inhomogeneous Disks in BHBs?

- Alternative: larger fluctuations cause spectra to appear less thermal

Dexter & Quataert (2012)



Black Hole Accretion

- Powers brightest objects in Universe
- Black hole/galaxy, mass & spin evolution