

The temporal variability of black hole accretion disks

Chris Reynolds

(Astronomy/JSI, Univ.Maryland)

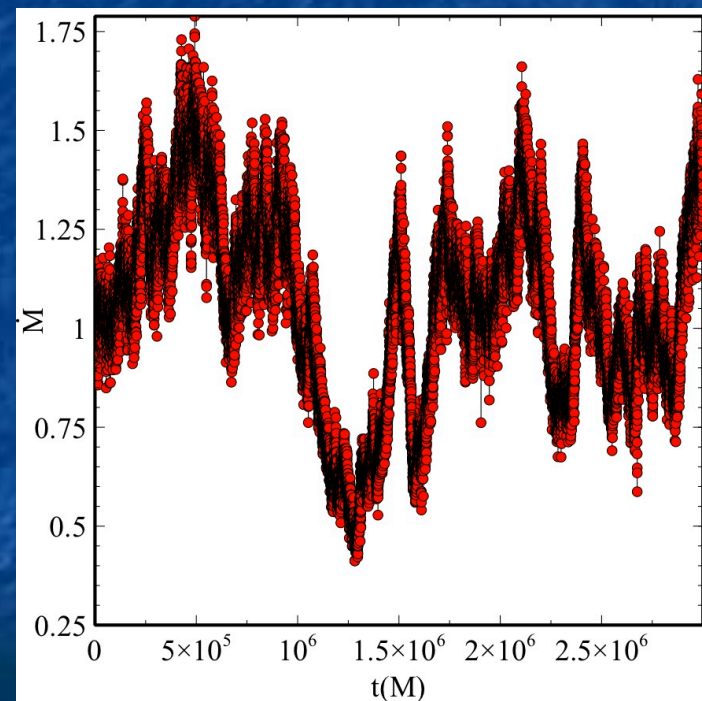
+

Phil Cowperthwaite

Drew Hogg

Cole Miller

Sean O'Neill

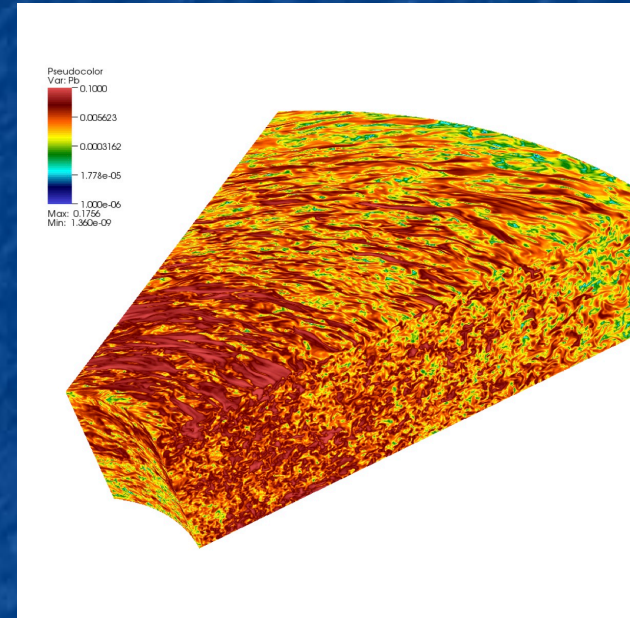


Outline

- Philosophy of this work
- Aperiodic variability
 - Structure beyond the power-spectrum
 - Assessing the “propagating fluctuation model”
- Quasi-periodic oscillations
 - Still no compelling model for HF-QPOs
 - Dynamo cycles seem generic – origin of LF-QPOs?

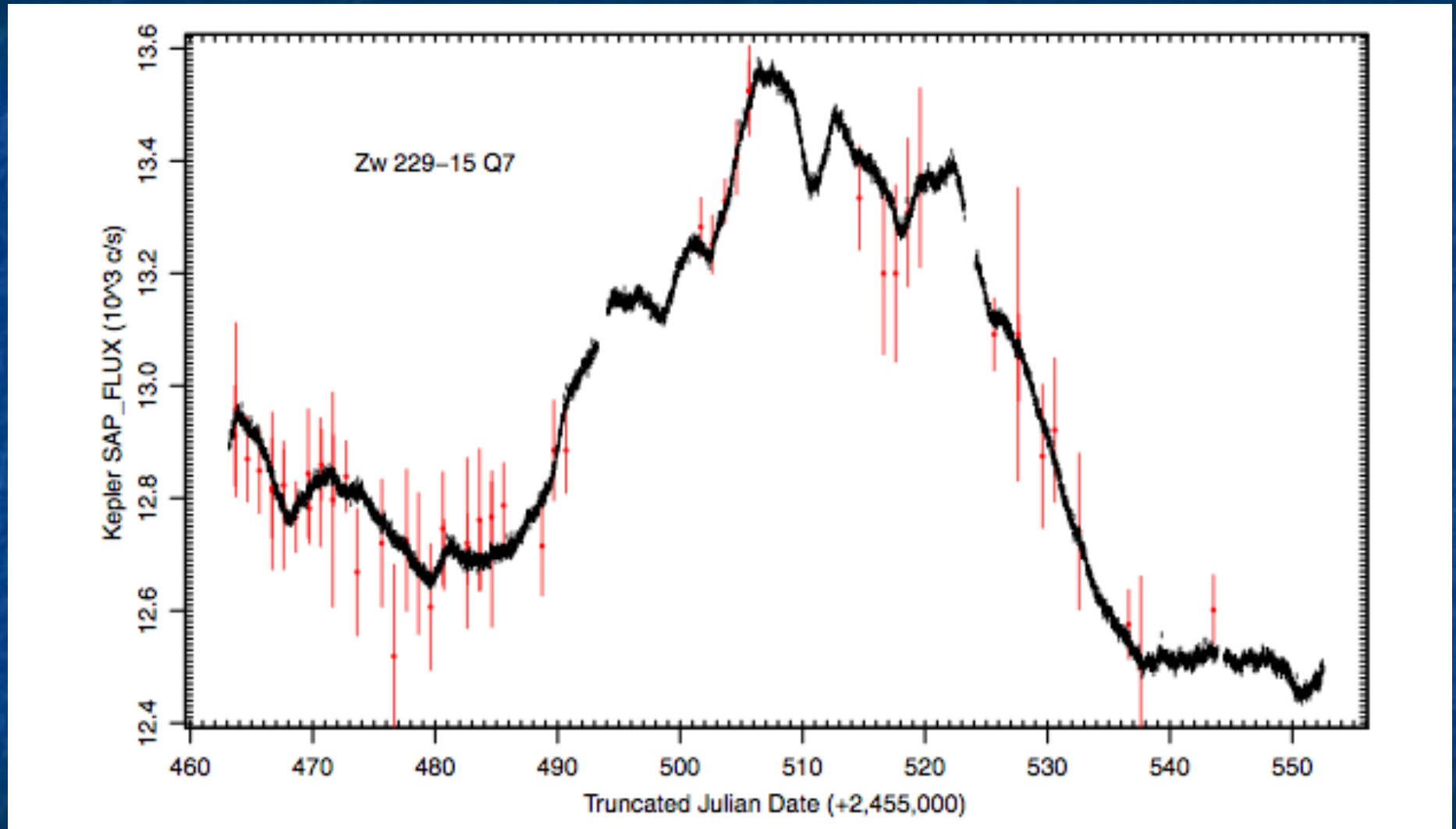
Philosophy

- Paradigm : angular momentum transport due to MRI-driven turbulence (Balbus & Hawley)
- Philosophy of this work...
 - We CANNOT yet make robust predictions of $L(v,t)$... crucial physics missing (radiation, coronal physics...)
 - Hope : dynamics somewhat decouple from thermodynamics/radiation.
 - Approach : Use MHD simulations to ask qualitative questions about the dynamics of the disk.

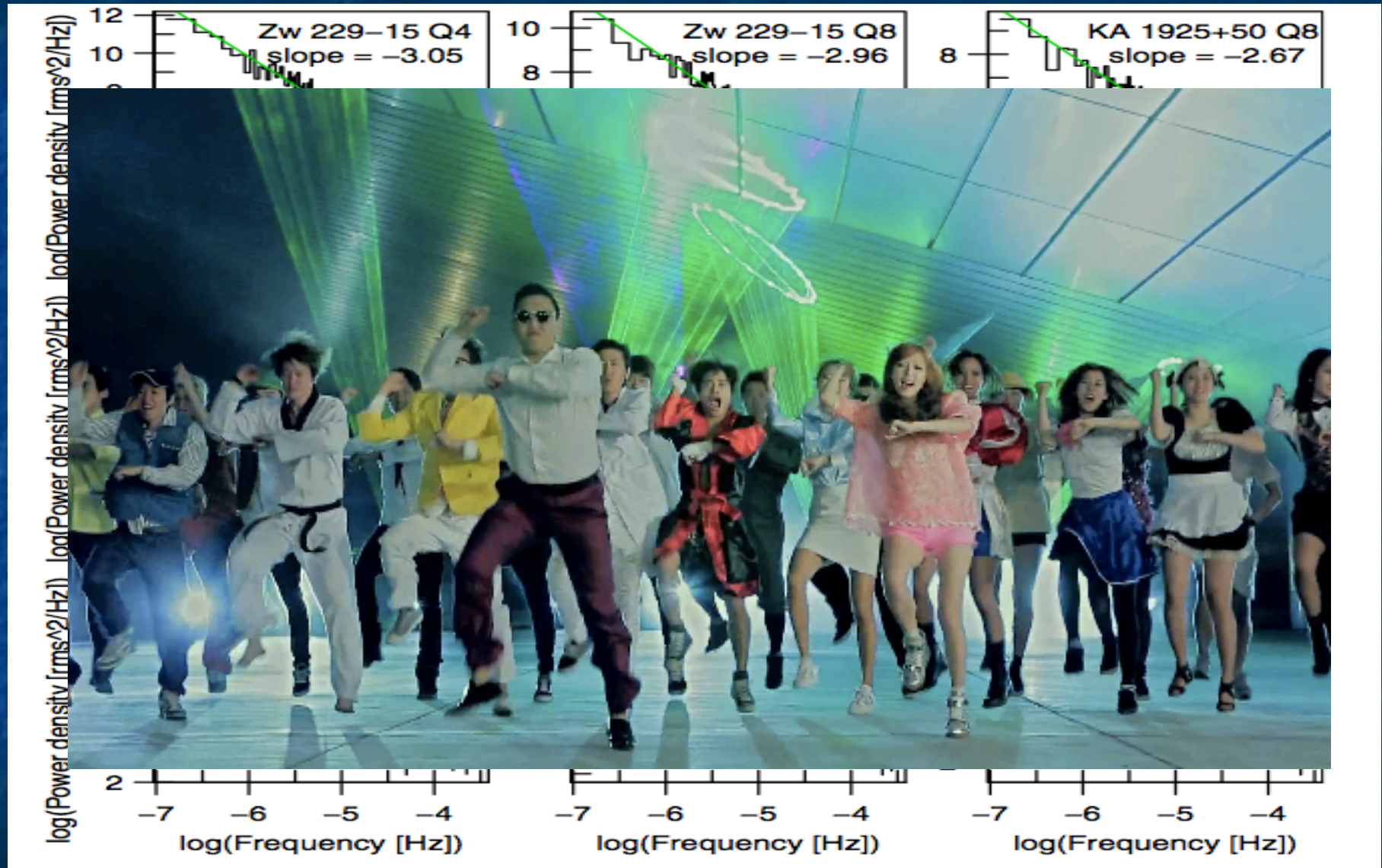


Aperiodic variability

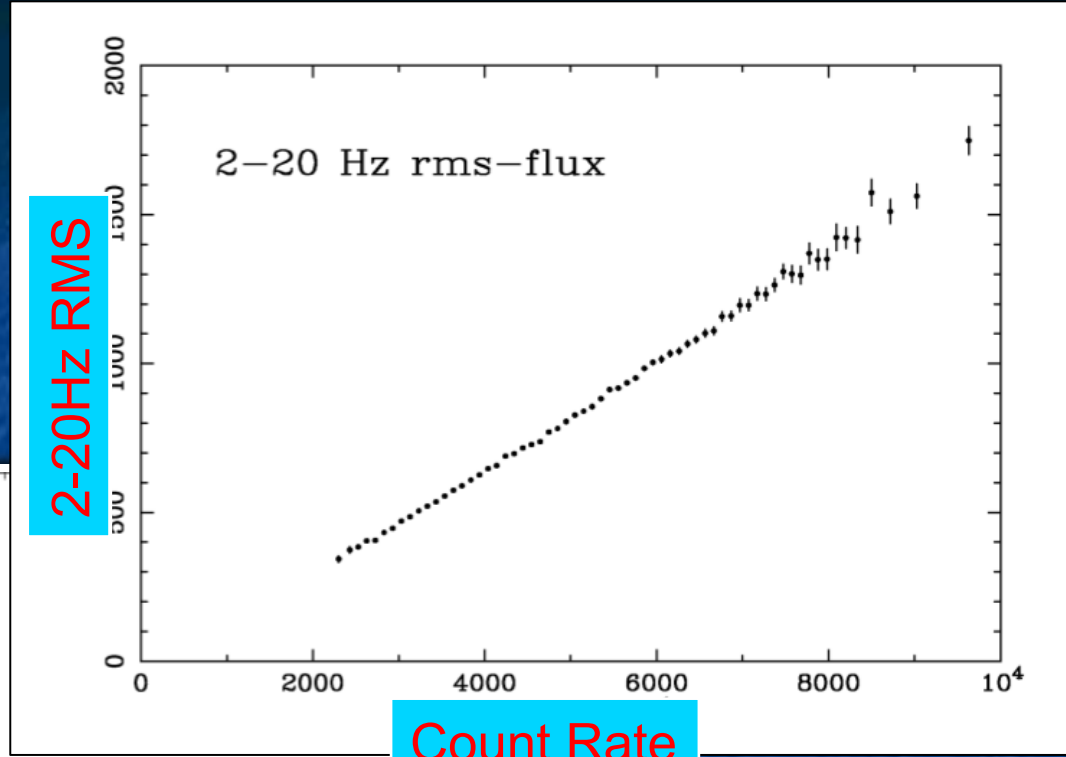
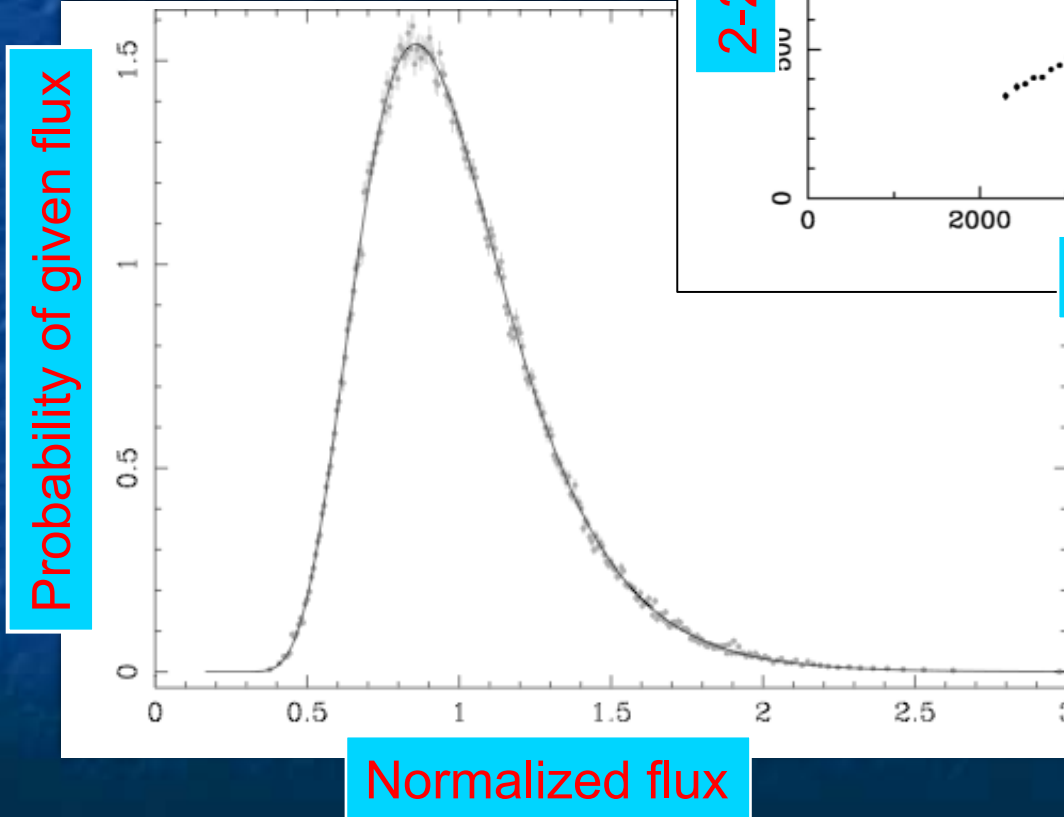
Mushotzky et al. (2011)



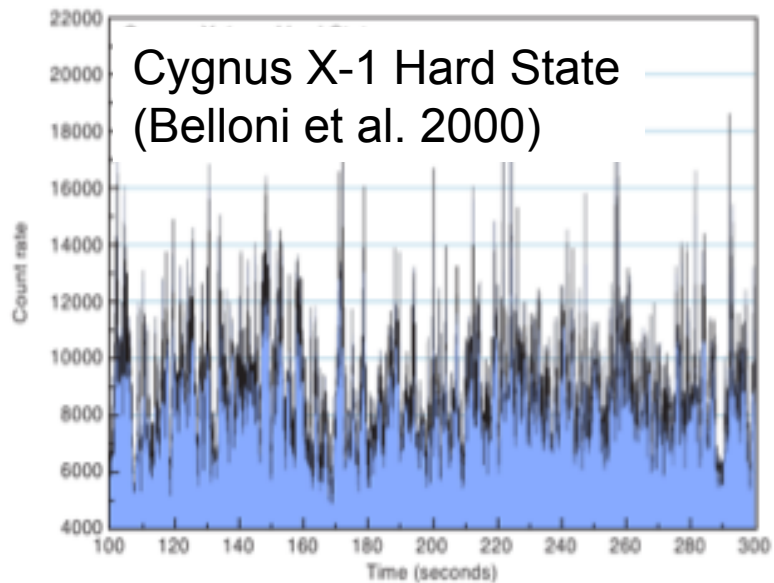
Mushotzky et al. (2011)



Cygnus X-1



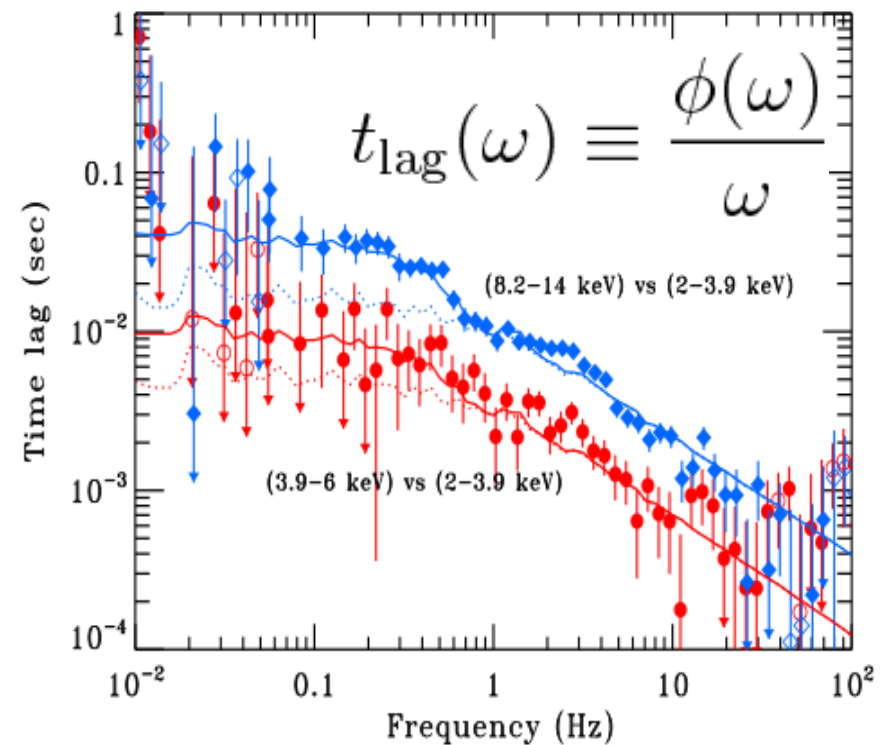
Log-normal fit (Cygnus X-1)
Low/Hard State
Uttley, McHardy & Vaughan
(2005)



Poutanen (2000); Gilfanov et al. (2000);
Nowak (2000); Uttley et al. (2011)

Findings:

- Frequency dependent time lags (almost constant phase)
- Time lags can get very long (for $M=10M_{\text{sun}}$, $10^{-2}\text{s} \approx 200r_g/c$)
- Often see log-normal variability



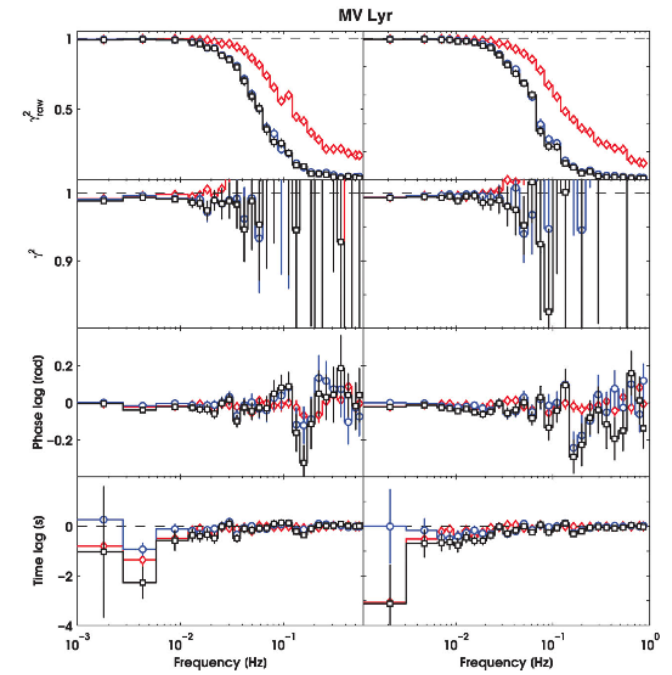
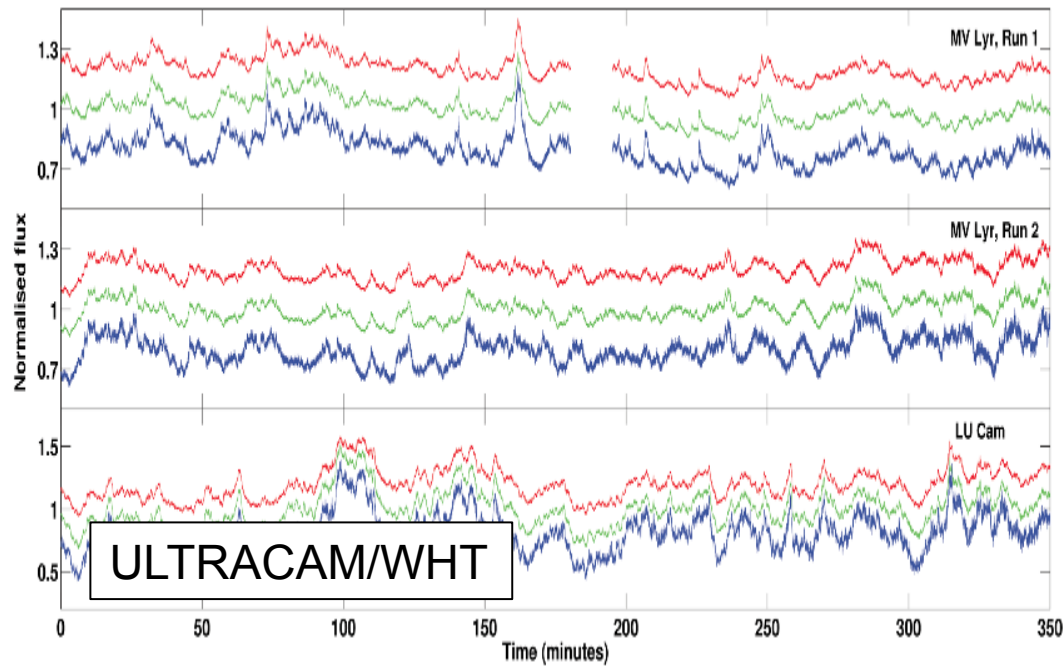
Coherence...

Computation of lags only makes sense if different realizations of the process give you a reproducible phase-lag. Assess this through the coherence function:

Break the light curve up into N segments. Then compute the **coherence function...**

$$\gamma^2(\omega) = \frac{|\langle S^* H \rangle|^2}{\langle |S|^2 \rangle \langle |H|^2 \rangle}$$

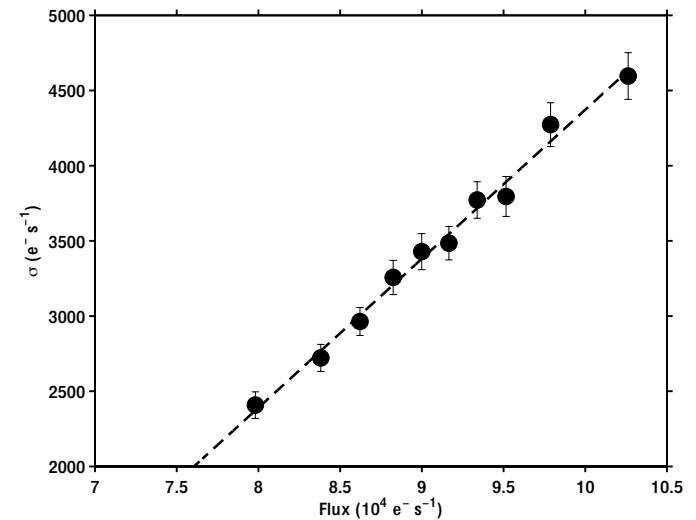
This real function of frequency ranges from 0 (completely incoherent) to 1 (completely coherent).



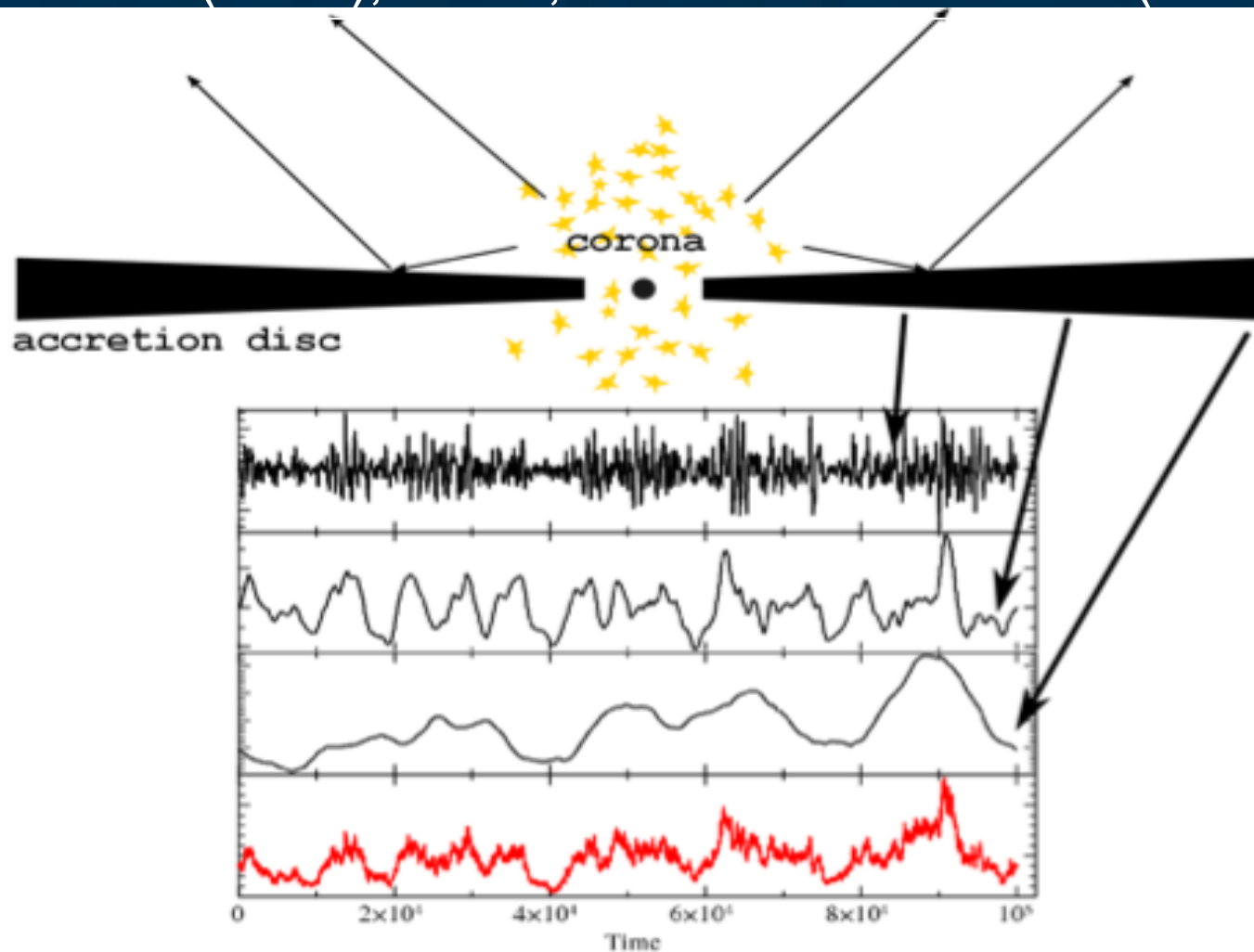
White dwarfs do it too!

Also show rms-flux relation
and frequency-dependent
time-lags

(Scaringi et al. 2013)



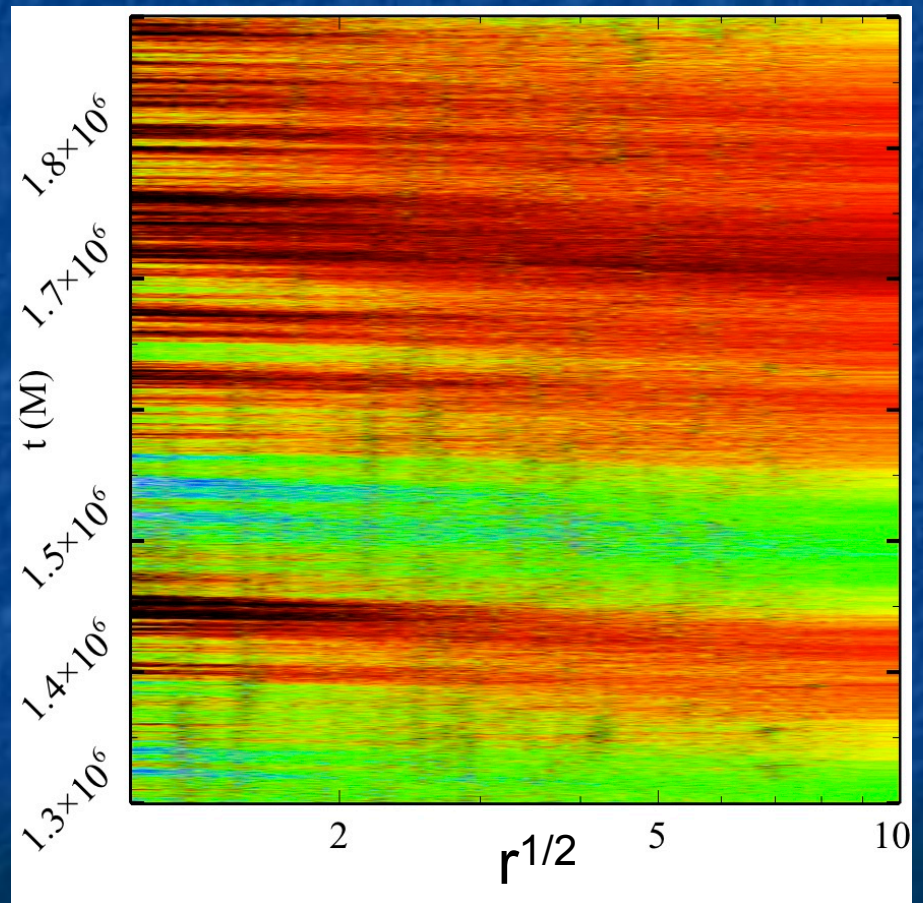
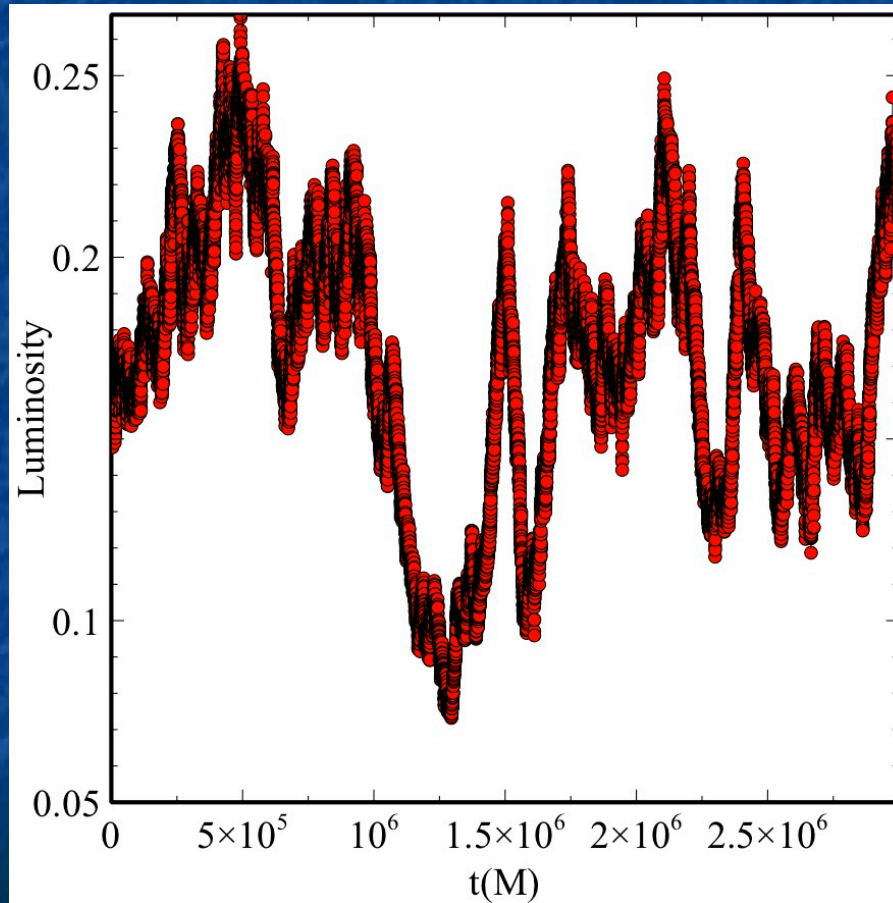
Lyubarskii (1997); Kotov, Churazov & Gilfanov (2001)

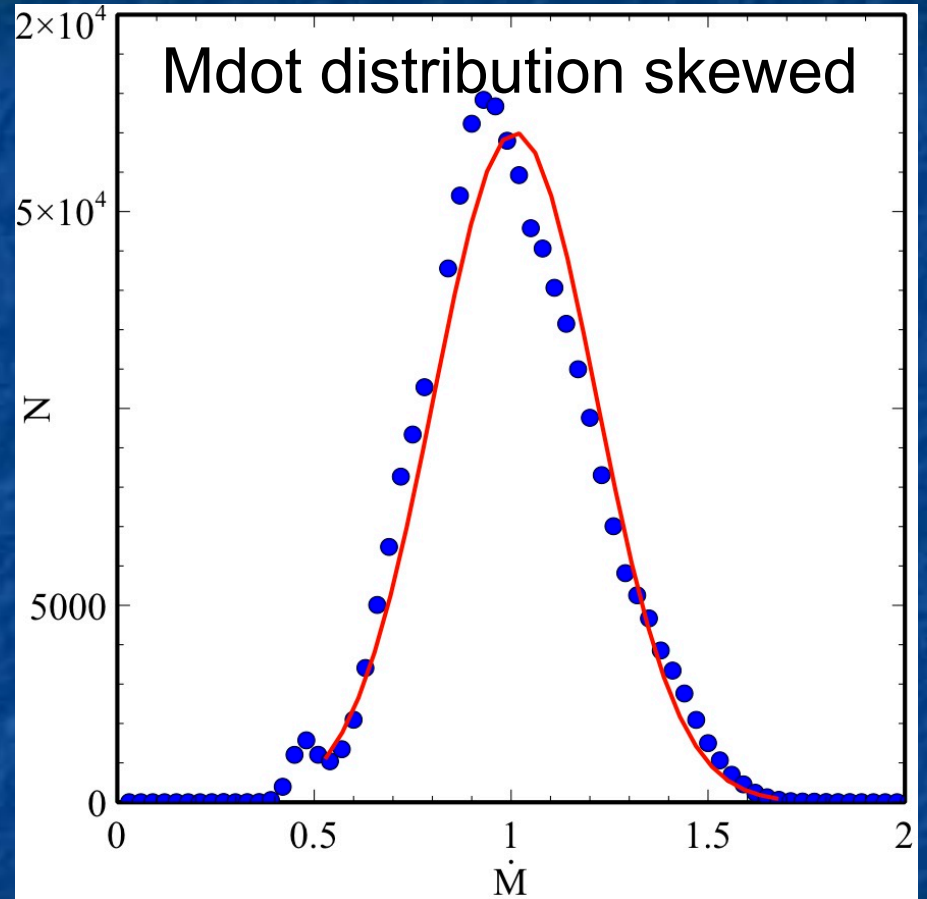
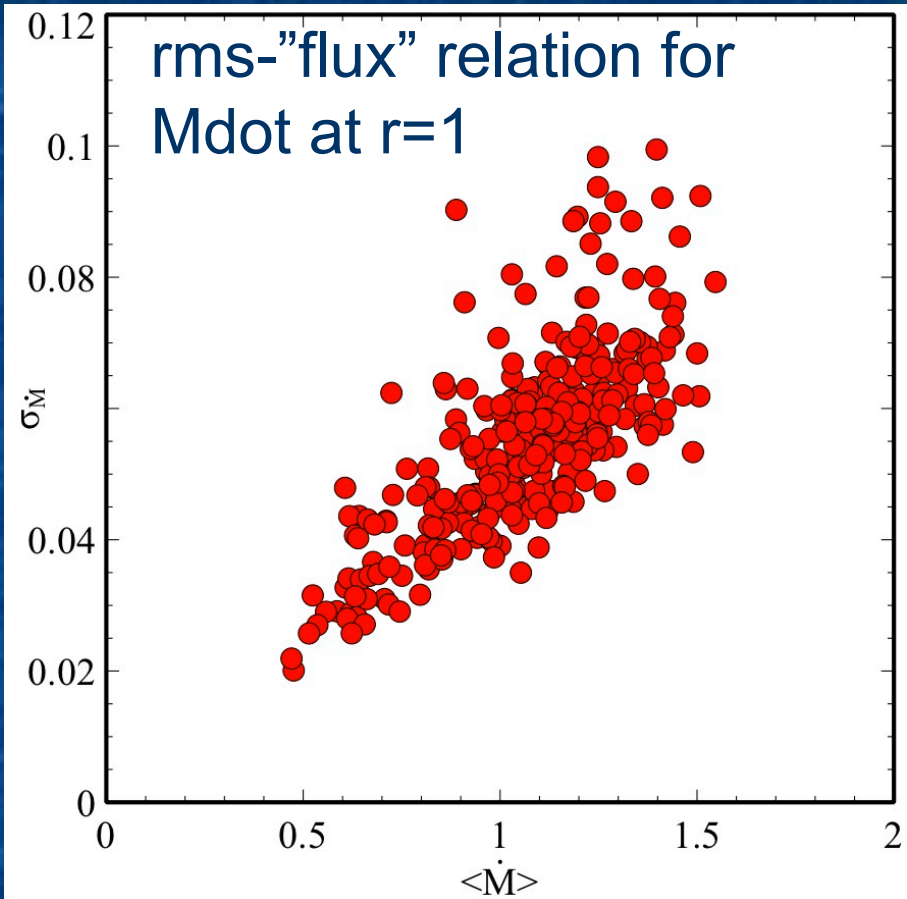


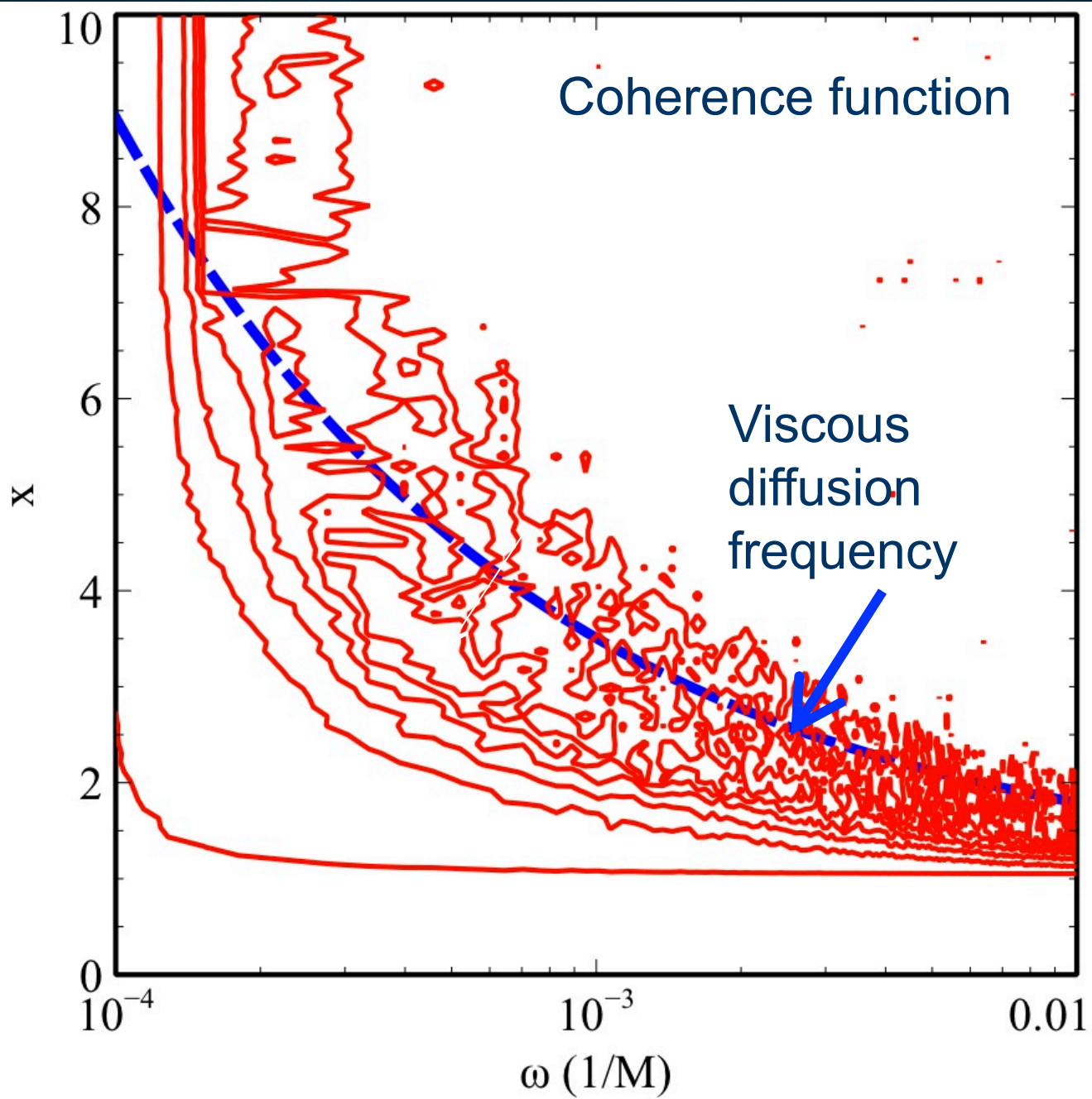
Propagating fluctuations model

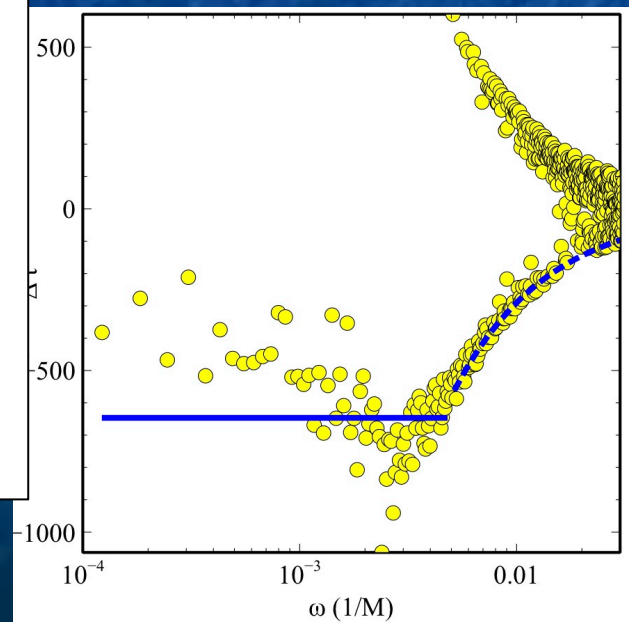
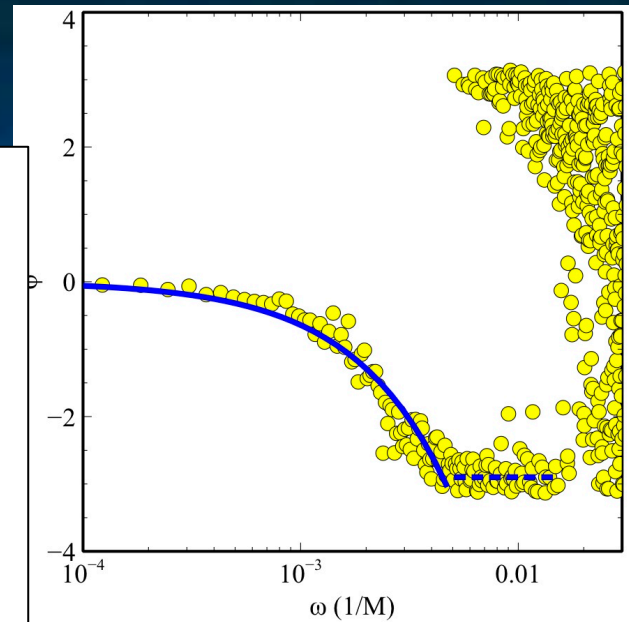
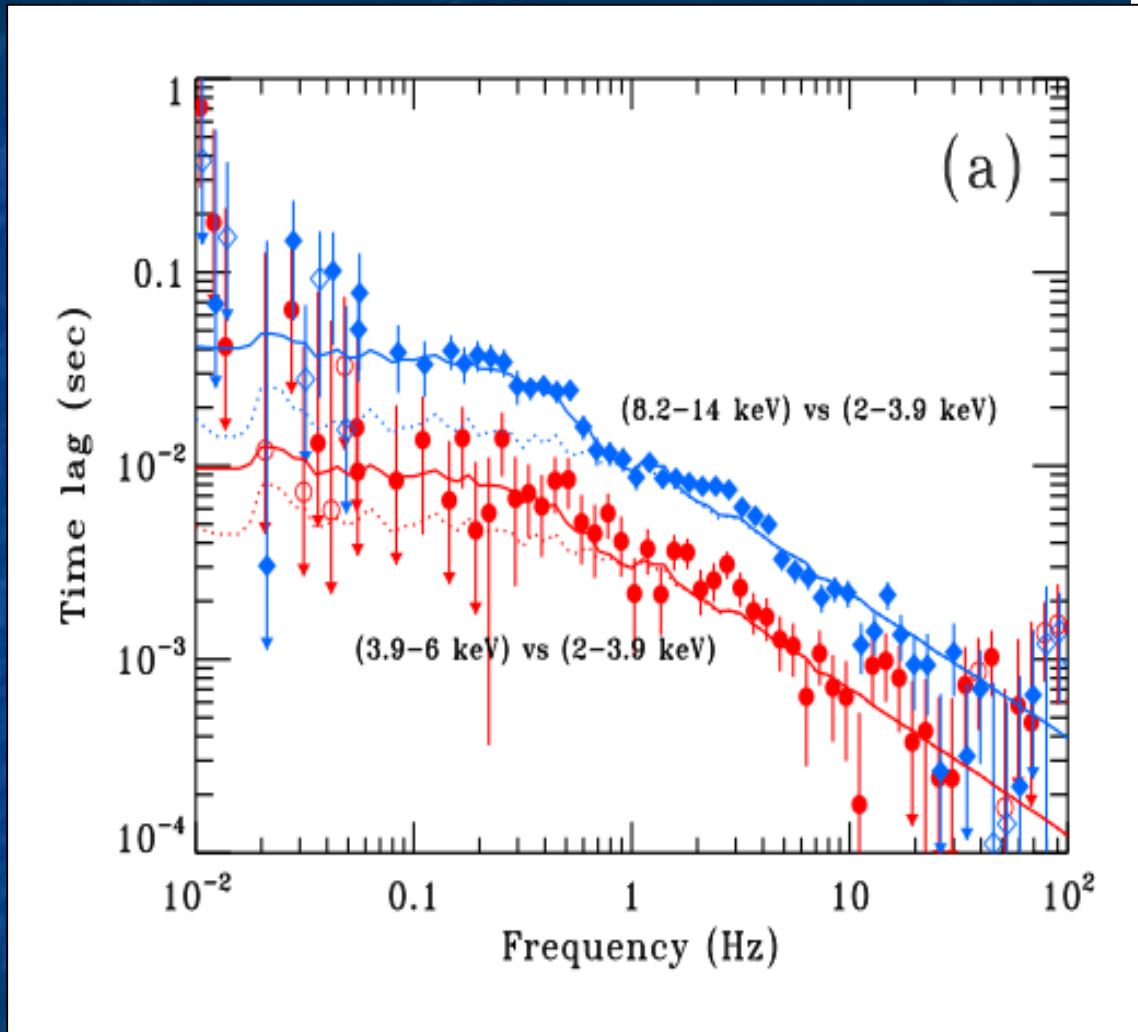
Simple 1-d accretion disk model with stochastic viscosity

Let $v=v_0(1+\beta)$, β spatially uncorrelated gaussian process with temporal coherence time = local viscous time.

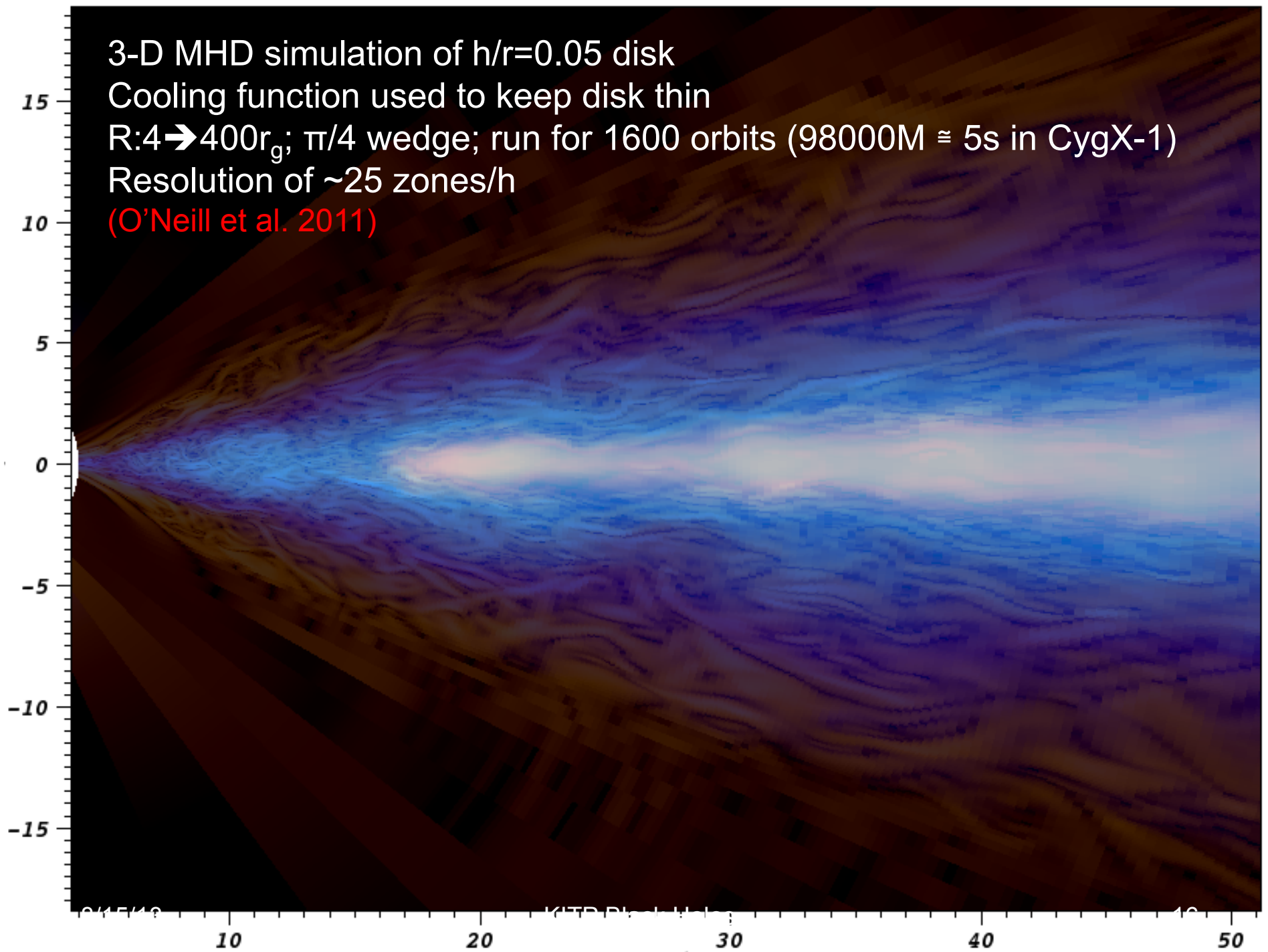




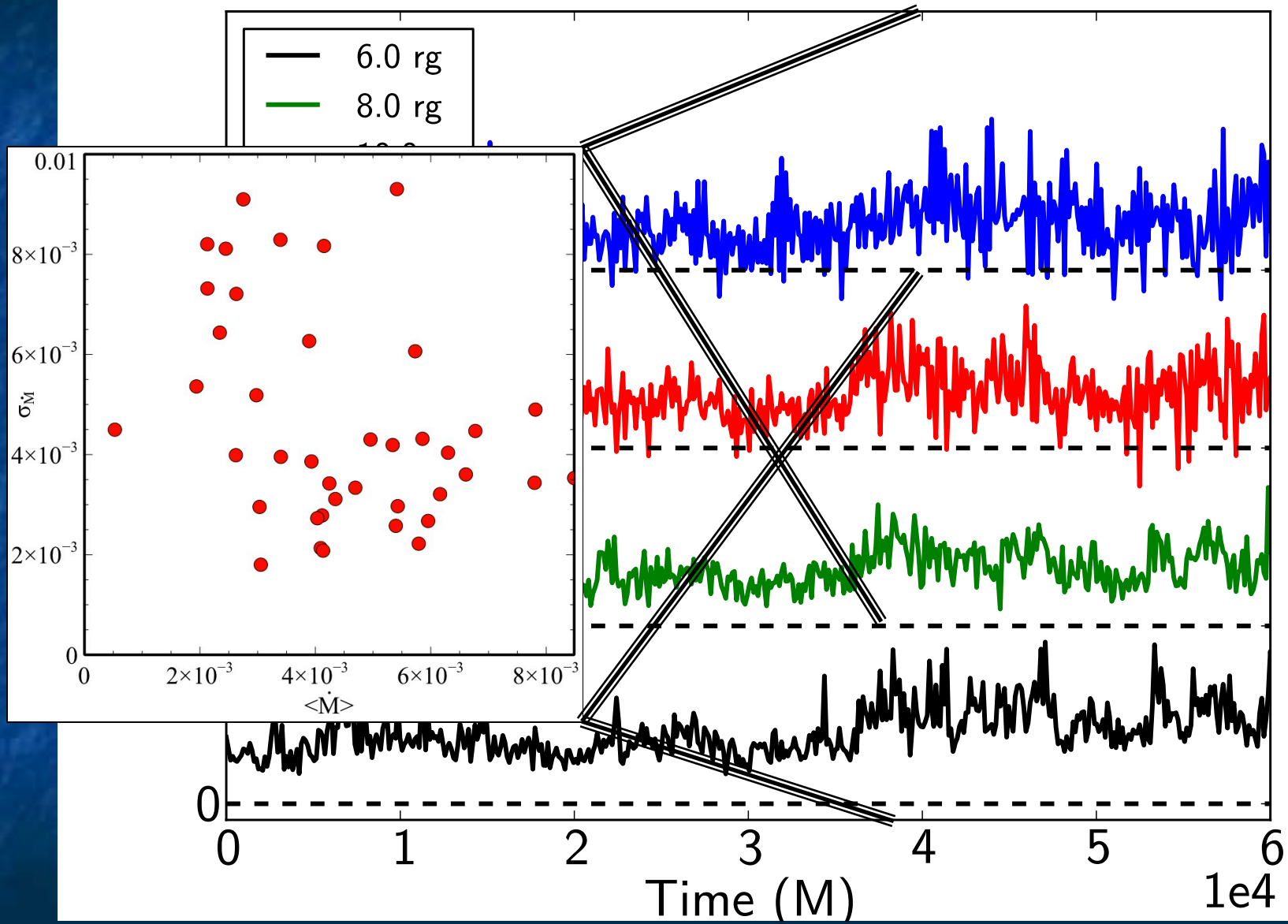


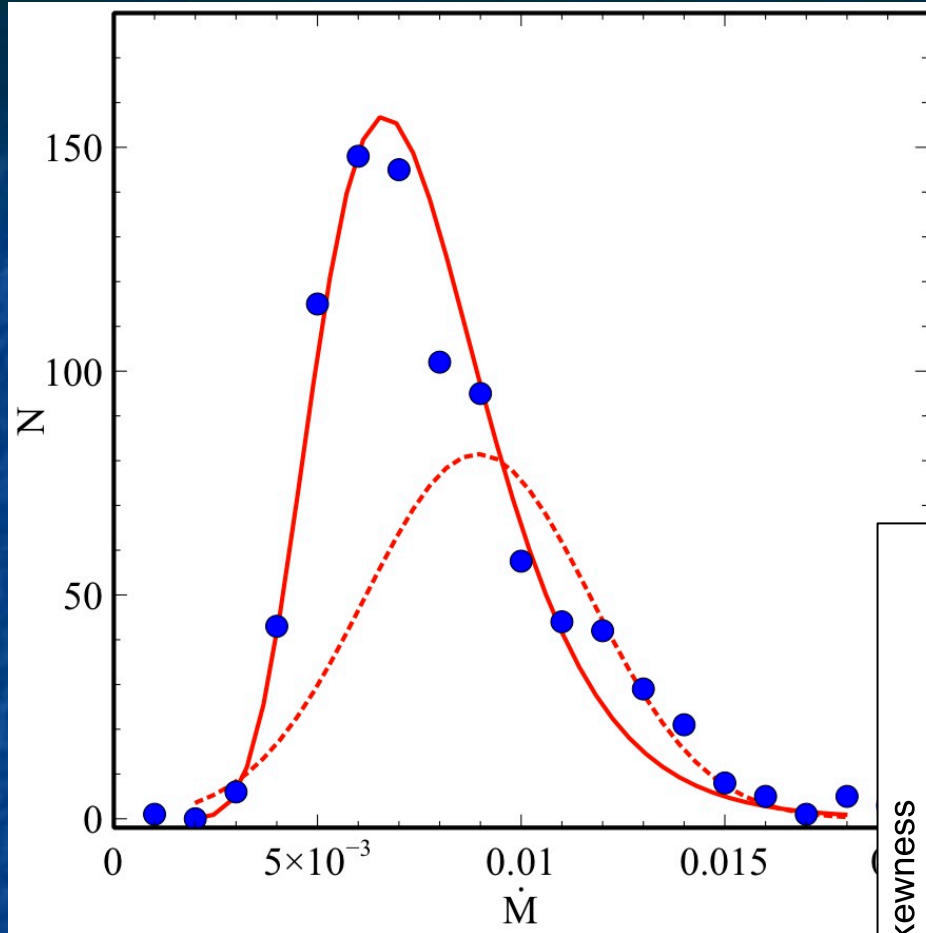


3-D MHD simulation of $h/r=0.05$ disk
Cooling function used to keep disk thin
 $R:4 \rightarrow 400r_g$; $\pi/4$ wedge; run for 1600 orbits ($98000M \approx 5s$ in CygX-1)
Resolution of ~ 25 zones/h
(O'Neill et al. 2011)

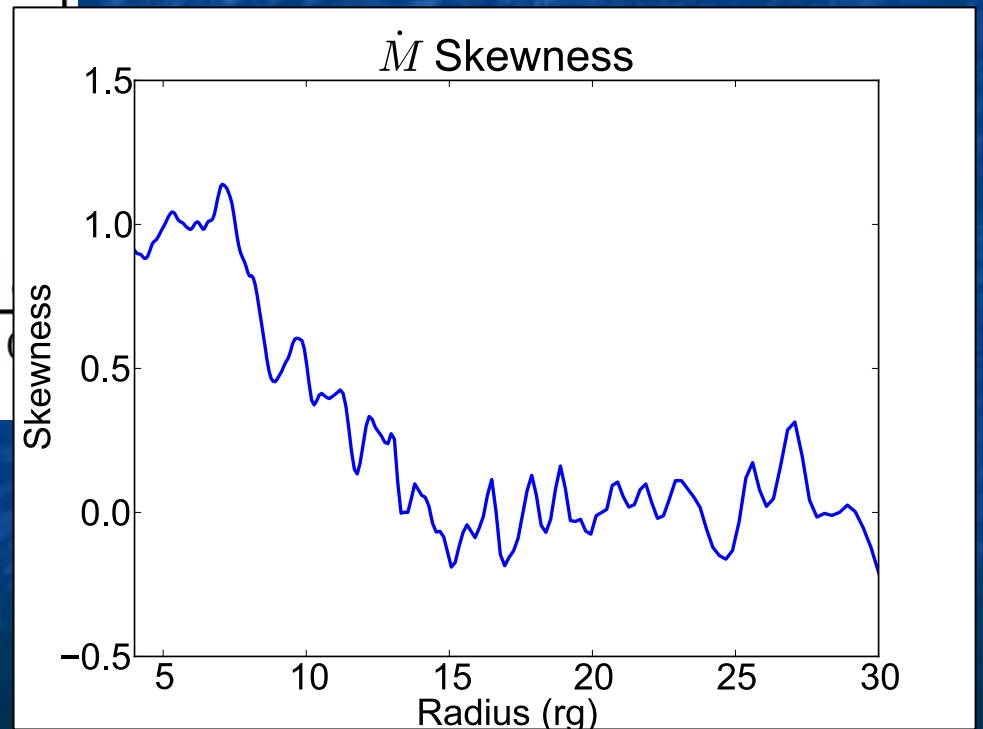


Accretion Rate (Normalized and Offset)

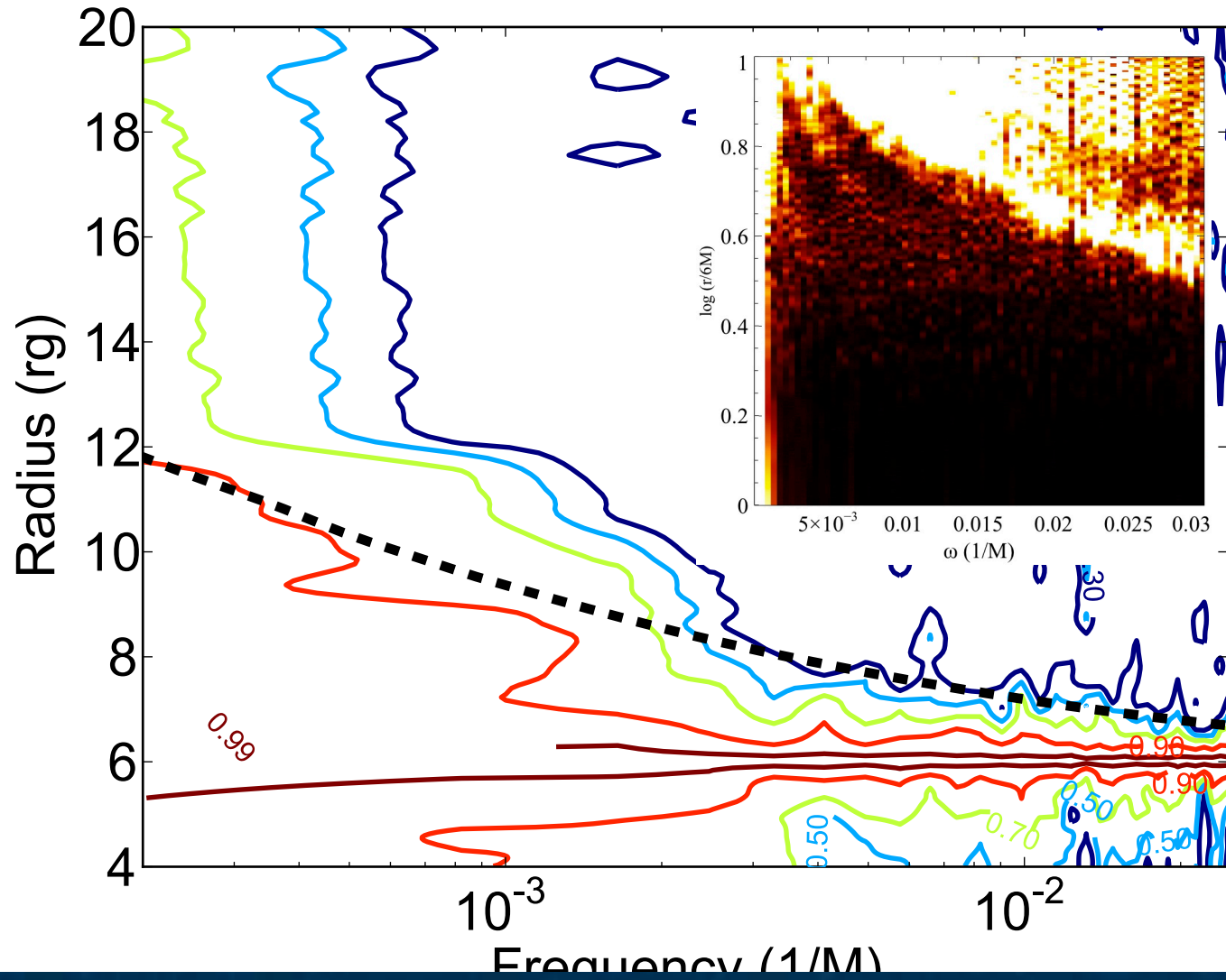


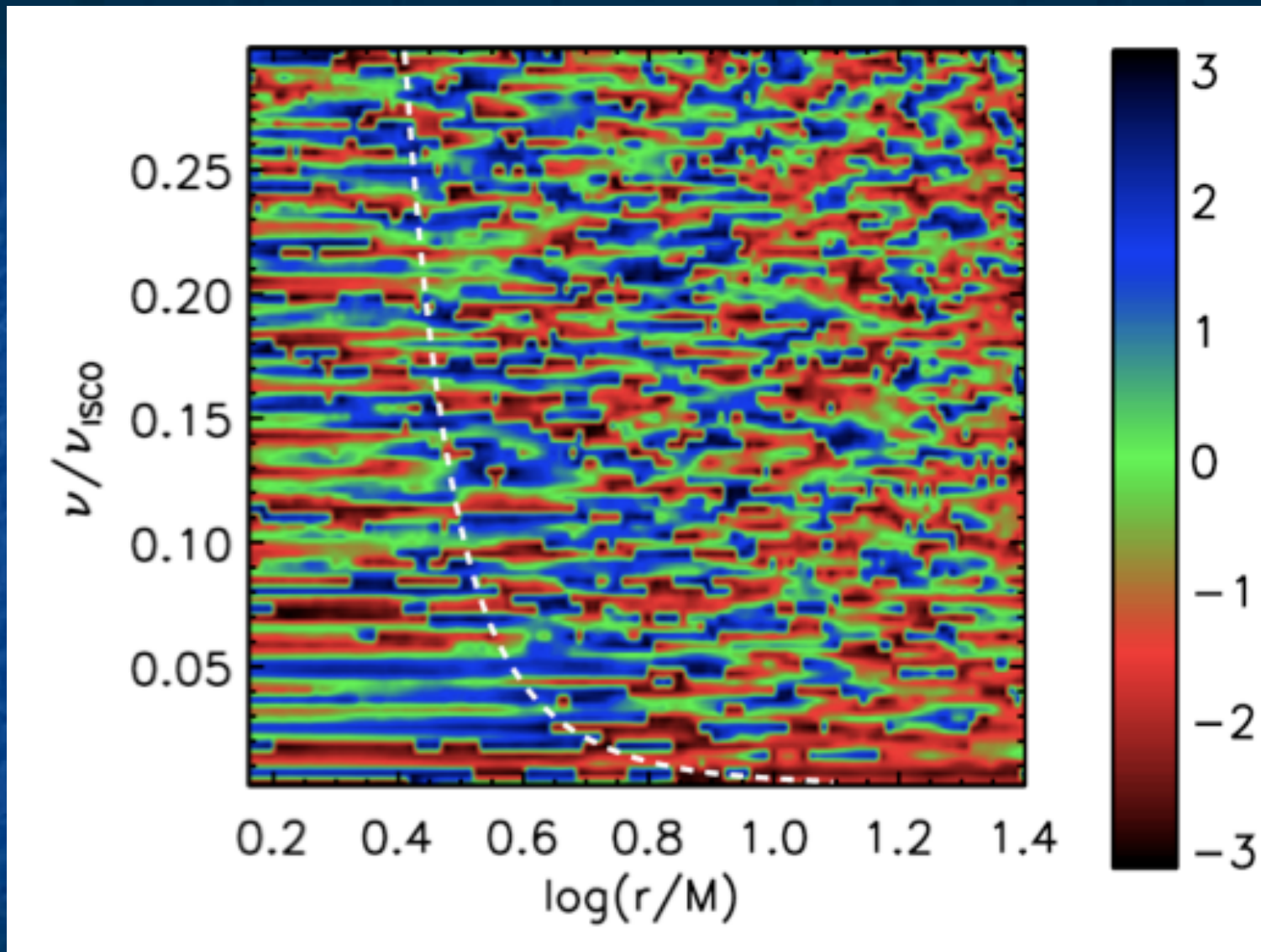


Mdot distribution becomes markedly less skewed away from the ISCO...
 doesn't seem to fit with propagating fluctuations.

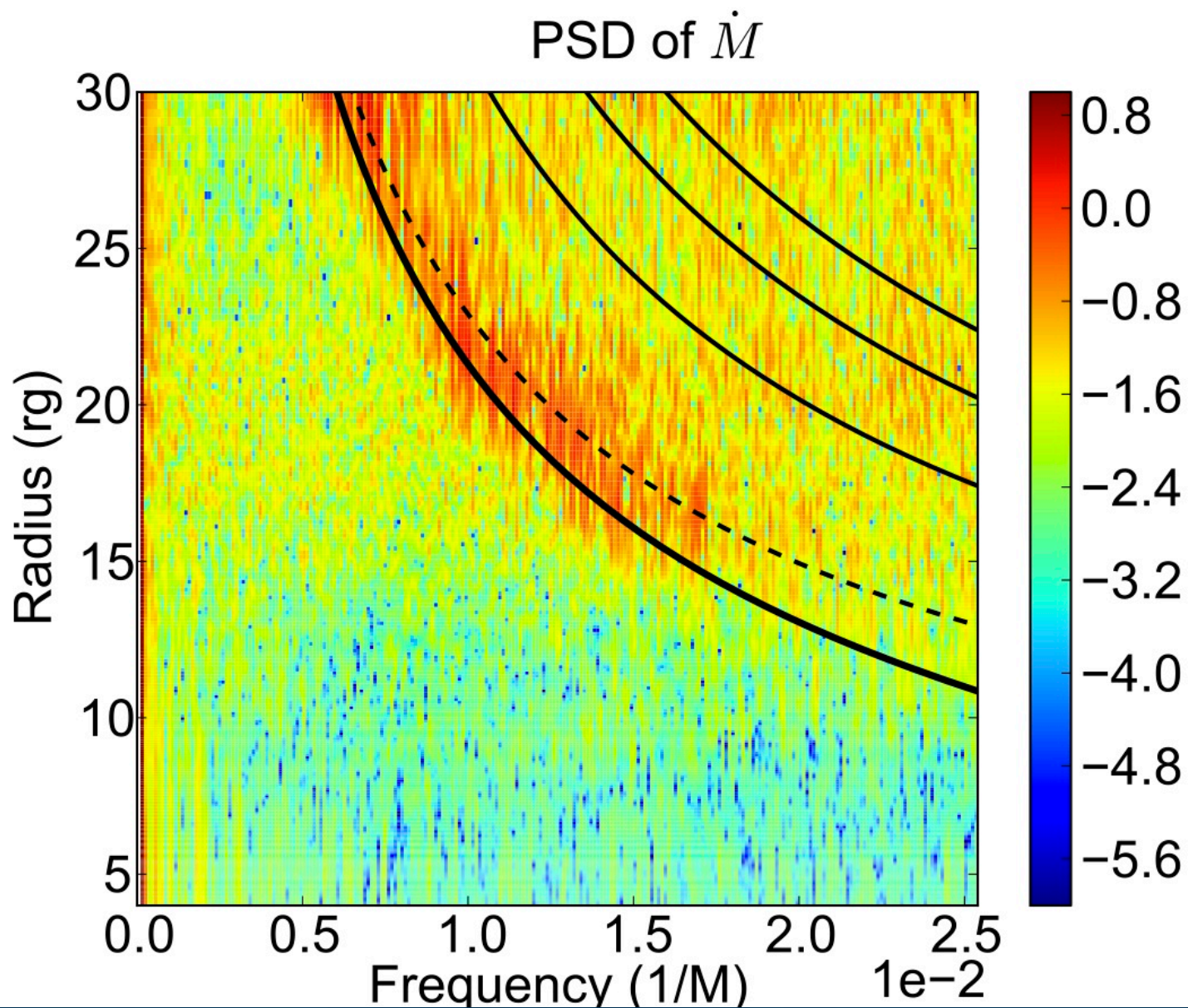


Coherence of Mdot at 6.0rg

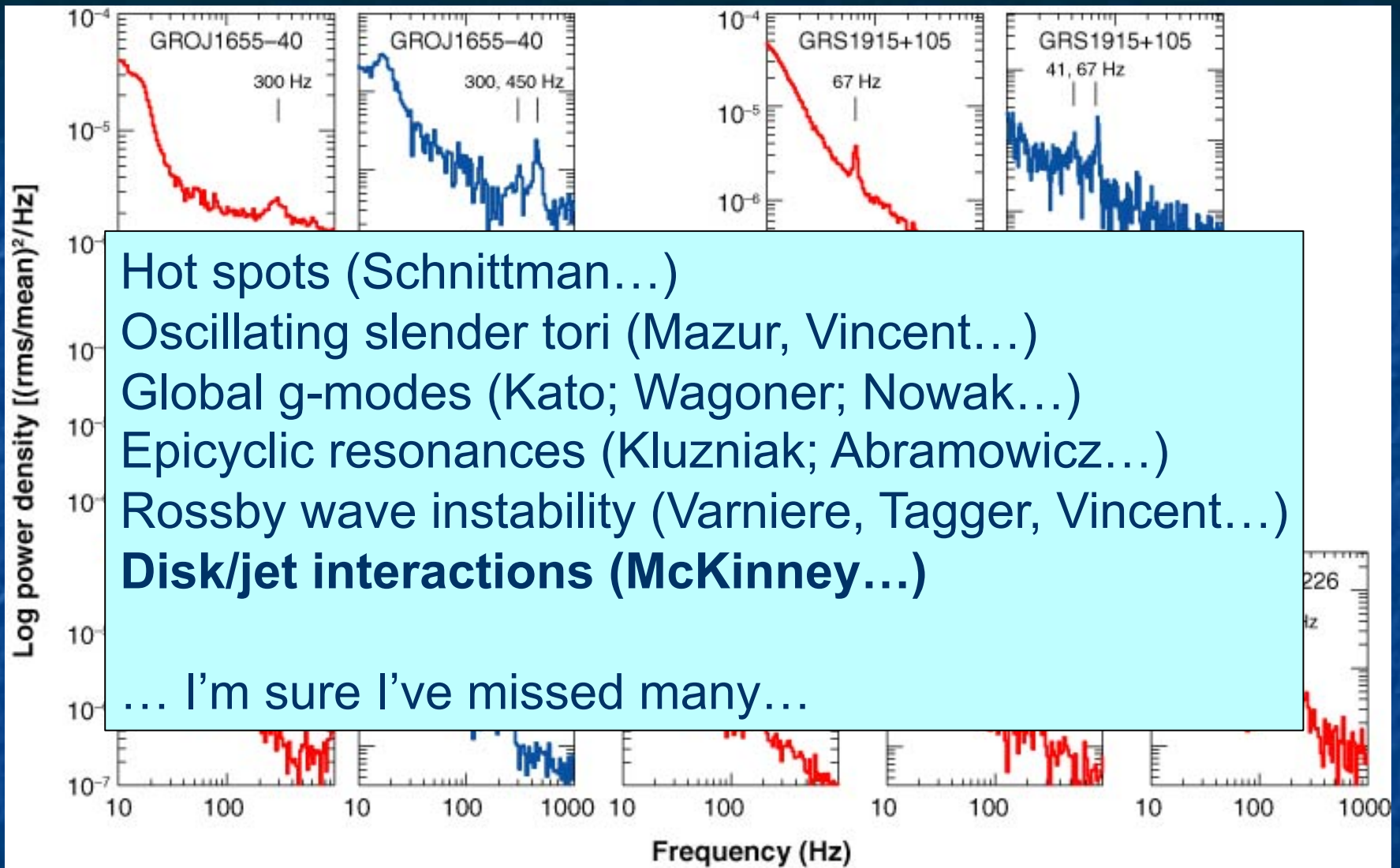




Noble & Krolik (2009)



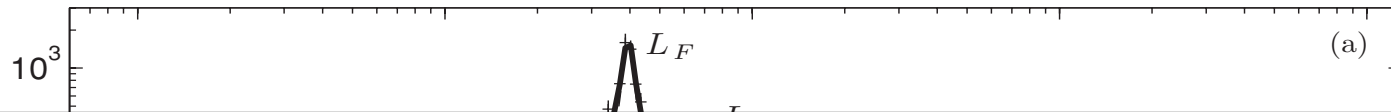
Quasi-periodic oscillations (in brief!)



AR Remillard RA, McClintock JE. 2006.
 Annu. Rev. Astron. Astrophys. 44:49–92

High-frequency QPOs

XTEJ1550-564; Rao et al. (2010)



Orbiting blobs/spirals

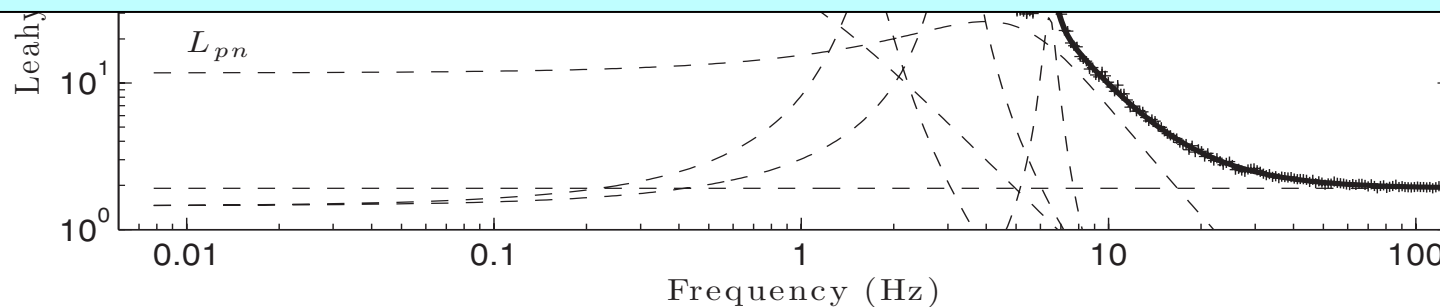
Alfven wave oscillations (Wang)

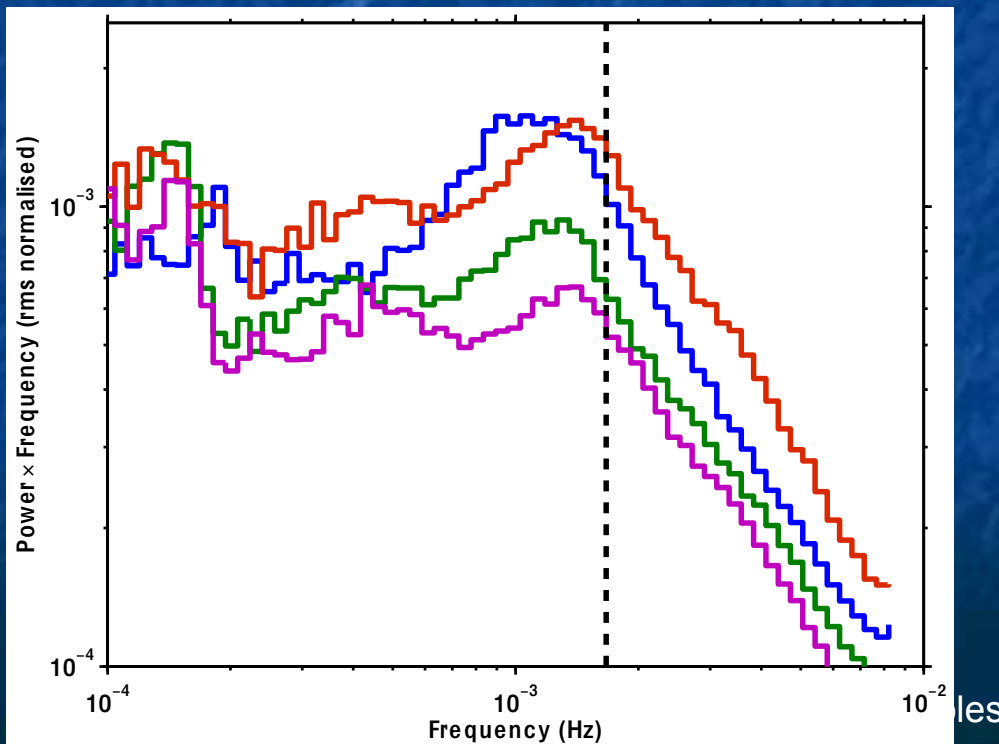
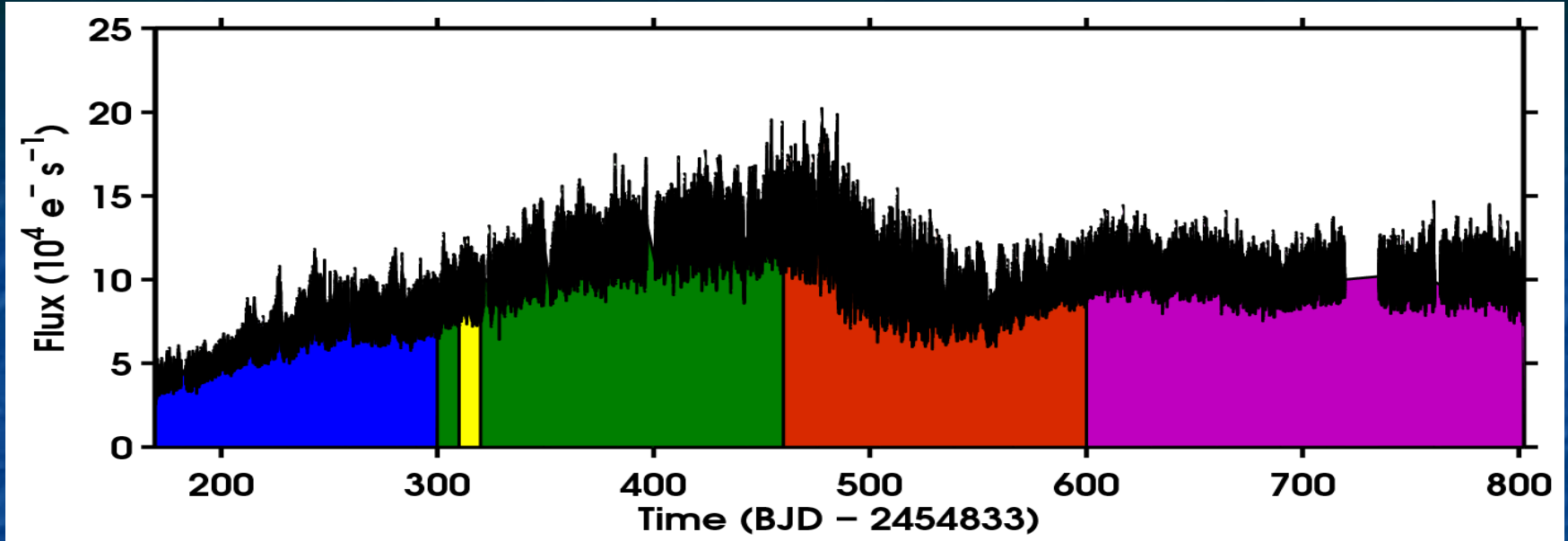
Accretion ejection instability (Tagger, Varniere...)

LT-induced precession of tilted disk (Fragile, Done...)

Dynamo cycles in MHD disks

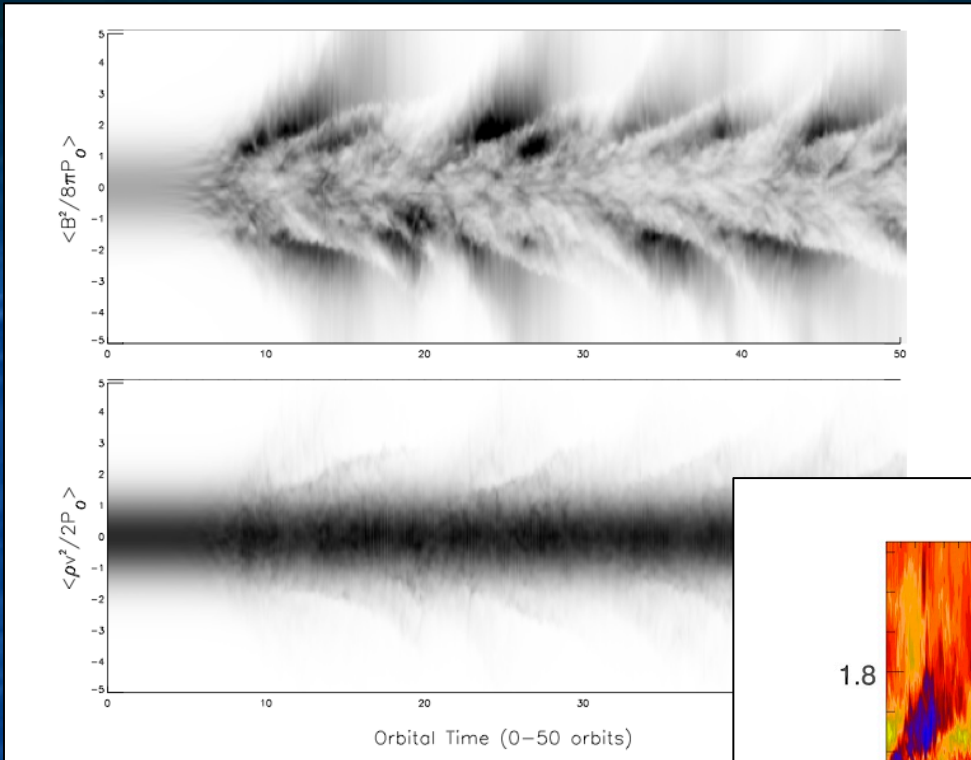
... again, I'm sure I've missed many...





White dwarfs show very similar characteristics... clearly do not need GR or rad-dom disks to get LFQPOs!

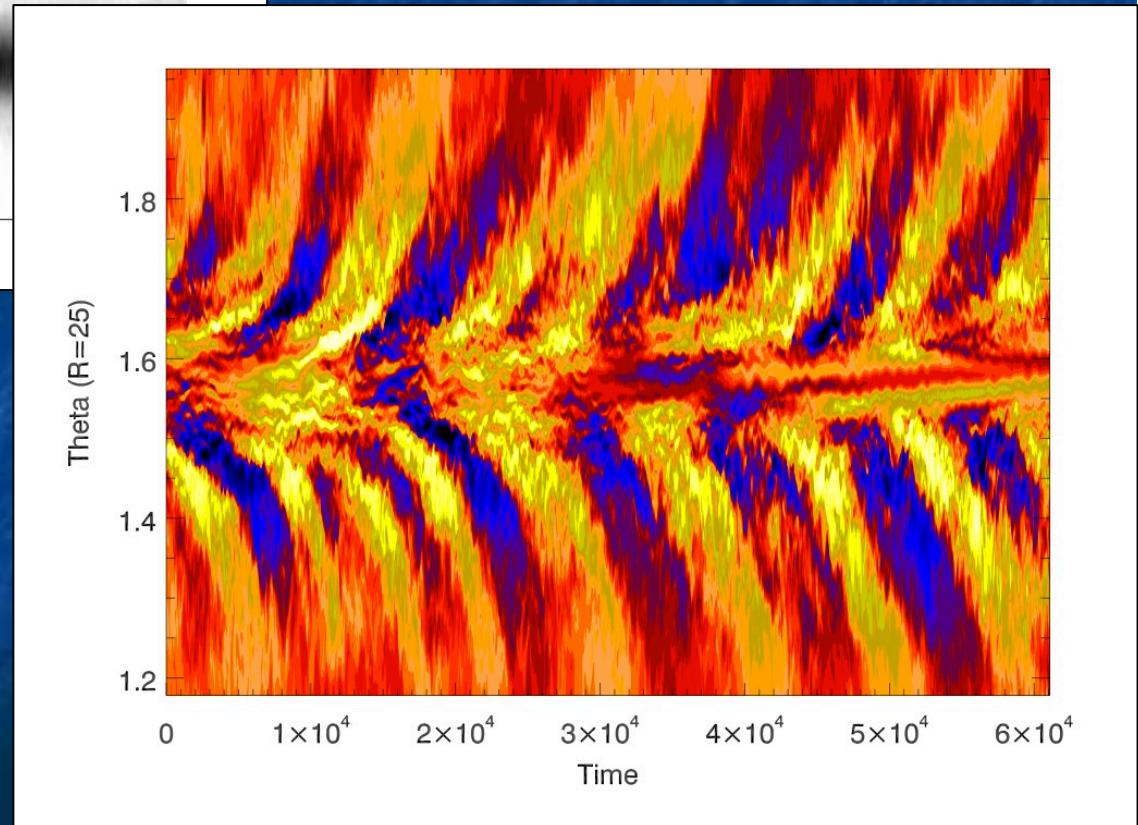
MV Lyrae w/Kepler
(Scaringi et al. 2012)

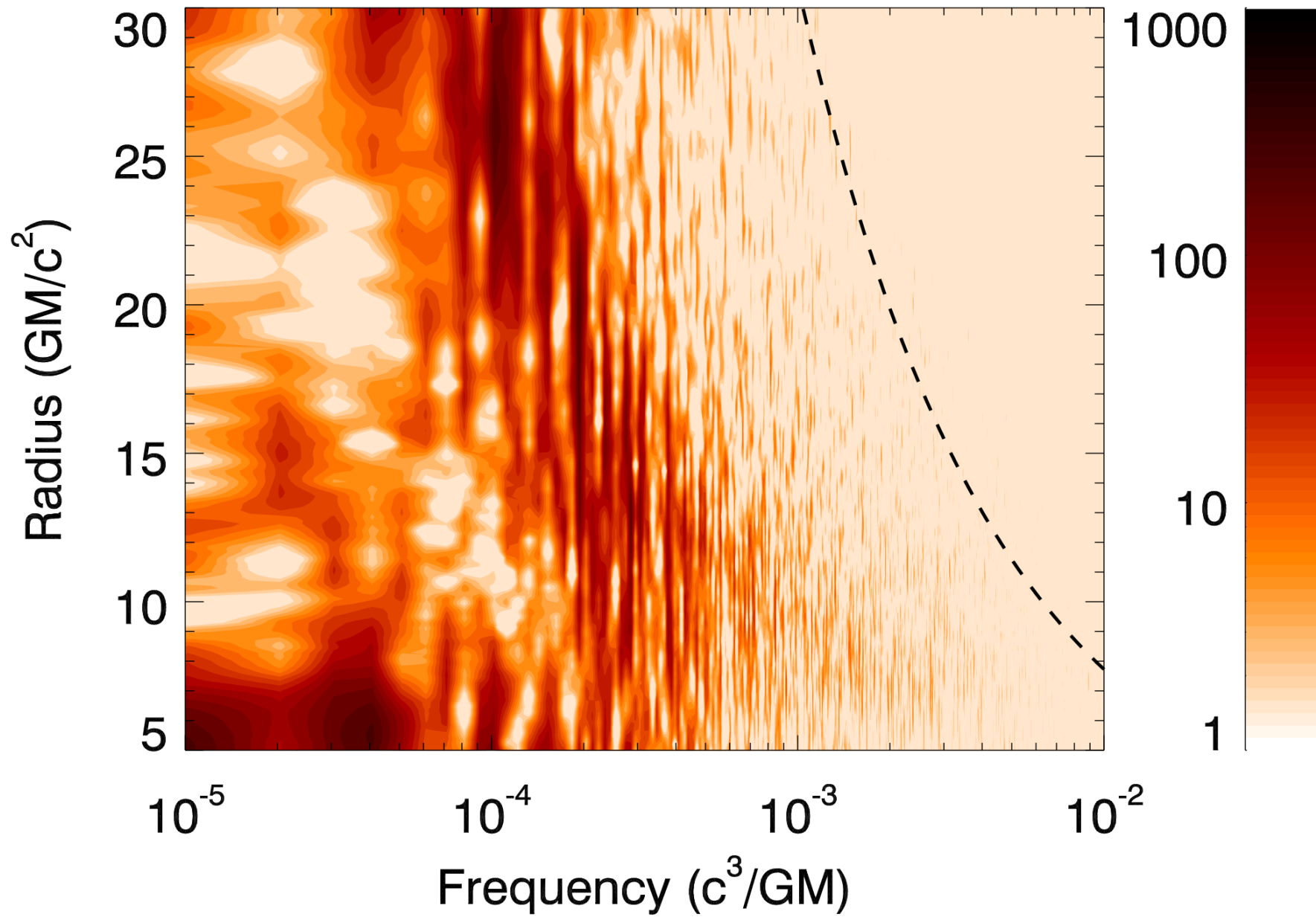


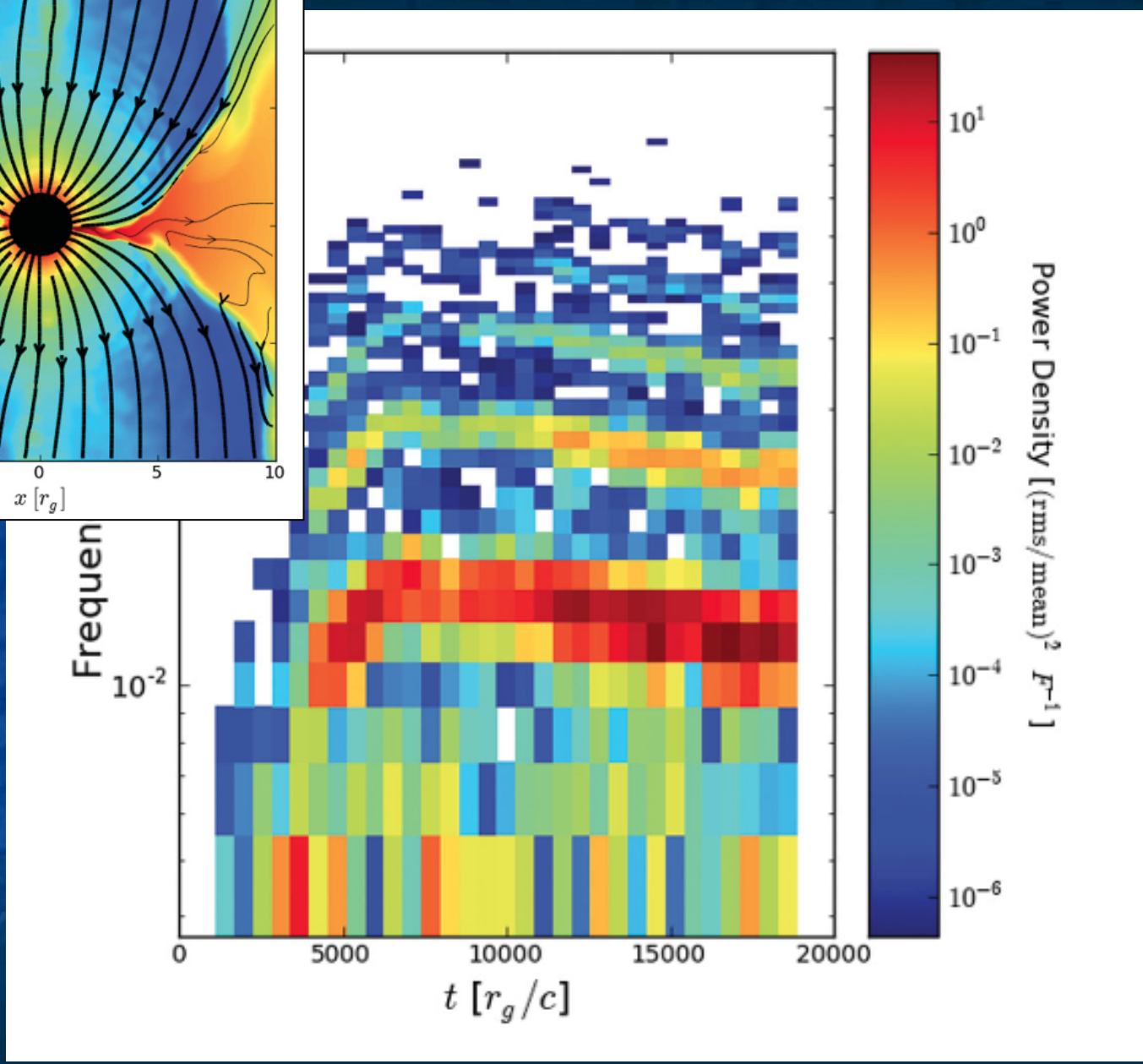
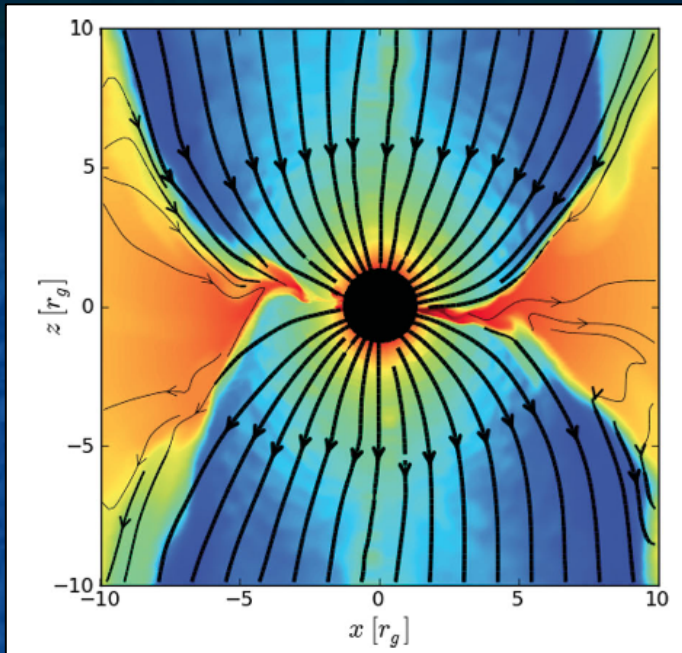
Global model
O'Neill et al. (2011)

Local model
Miller & Stone (2000)

+2 π global model
(Flock et al. 2011)







Conclusions

- MHD simulations are valuable tool to assess phenomenological variability models
- Aperiodic variability : Jury still out on propagating fluctuation model. Our MHD disk has ISCO accretion rate showing linear “rms-flux” relation, but accretion rate further out still Gaussian.
- QPOs : HFQPOs remain mysterious. Dynamo cycles are interesting possibility for LFQPOs (but then we couldn't tolerate truncated disks in low-hard states)