Time variability of radio-quiet AGN. Theory

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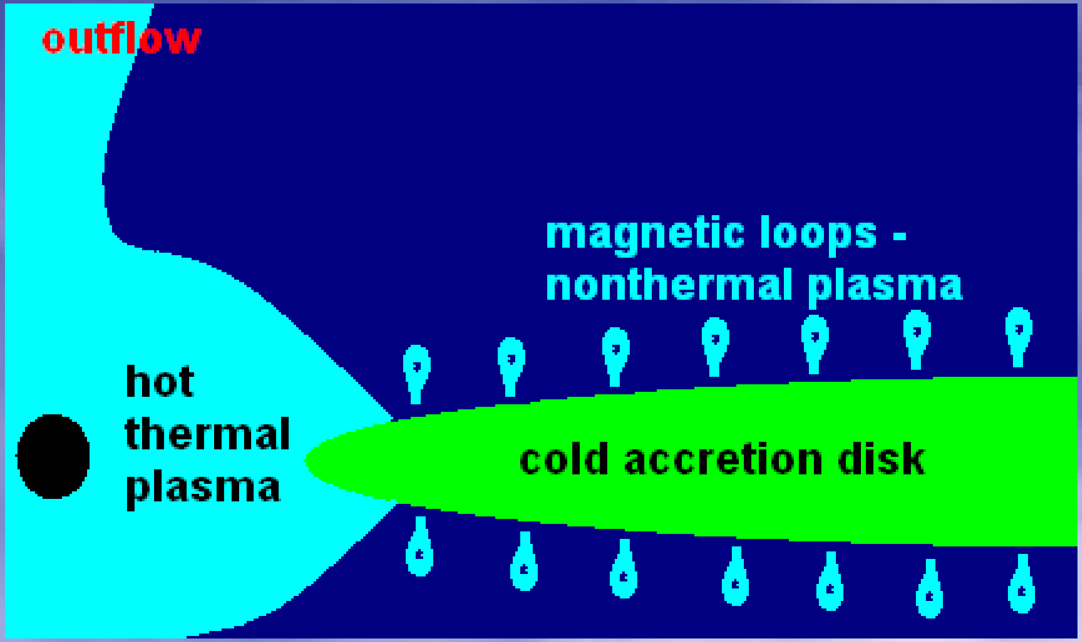
Outline

- Flow geometry
- Basic timescales in alpha disks
- Basic instabilities in alpha disks
- Nature of viscosity, instabilities in MHD simulations
- Disk – hot medium interaction and its effect on the time variability
- Hot medium origin

Flow geometry



High L/L_{Edd} – disk approaching black hole, spectra disk-dominated

Low L/L_{Edd} – disk retreating, spectra dominated by hot thermal plasma

Flow geometry

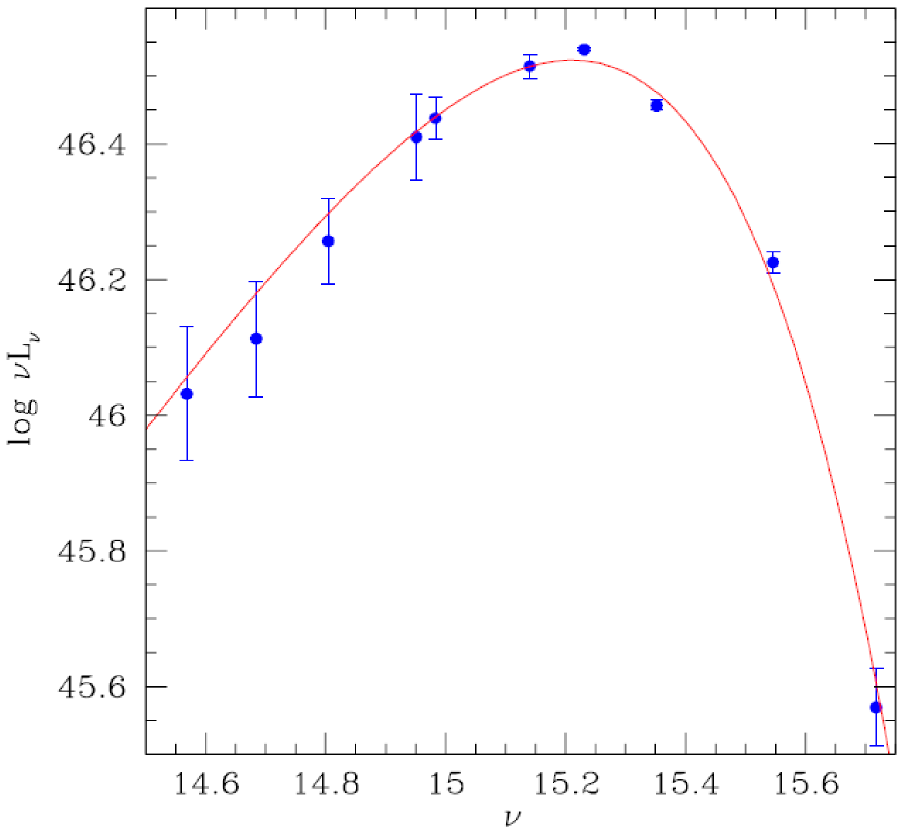


Figure 3. The best fit of the Kerr black body disk to the spectrum, assuming $M = 2.7 \times 10^9 M_\odot$: $\dot{m} = 0.135$, $a = 0.46$, $\cos i = 0.97$ (continuous line) and photometric points (dots with marked errors) for SDSS J094533.99+100950.1.

An example of disk-dominated spectrum: WLQ SDSS J094533.99+100950.1

(Hryniewicz et al., in preparation)

Basic timescales in alpha disks

Viscous torque = alpha*Ptot

$$t_{dyn} = \Omega_K^{-1}$$

$$t_{dyn} = 10^4 (\frac{r}{3R_{Schw}})^{3/2} (\frac{M}{10^8 Ms}) \quad [s]$$

Orbital motion

$$t_{th} = t_{dyn} (\frac{1}{\alpha})$$

$$t_{th} = 10^5 (\frac{0.1}{\alpha}) (\frac{r}{3R_{Schw}})^{3/2} (\frac{M}{10^8 Ms}) \quad [s]$$

Optical variability ?

$$t_{visc} = 10^7 (\frac{0.1}{\alpha}) (\frac{h}{0.1r})^2 (\frac{r}{3R_{Schw}})^{3/2} (\frac{M}{10^8 Ms}) \quad [s]$$

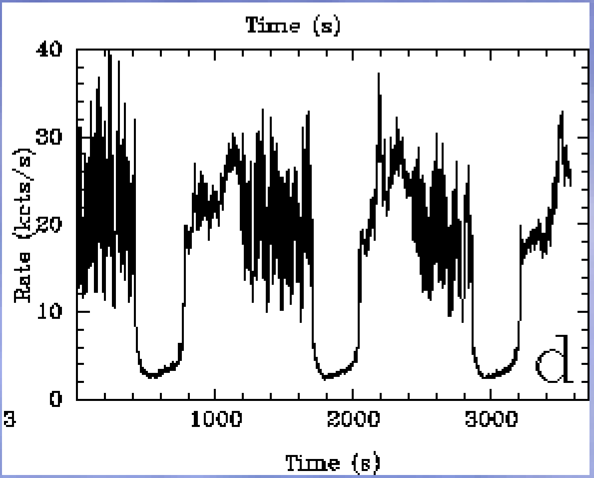
Evolution of surface density

Basic instabilities in alpha disks

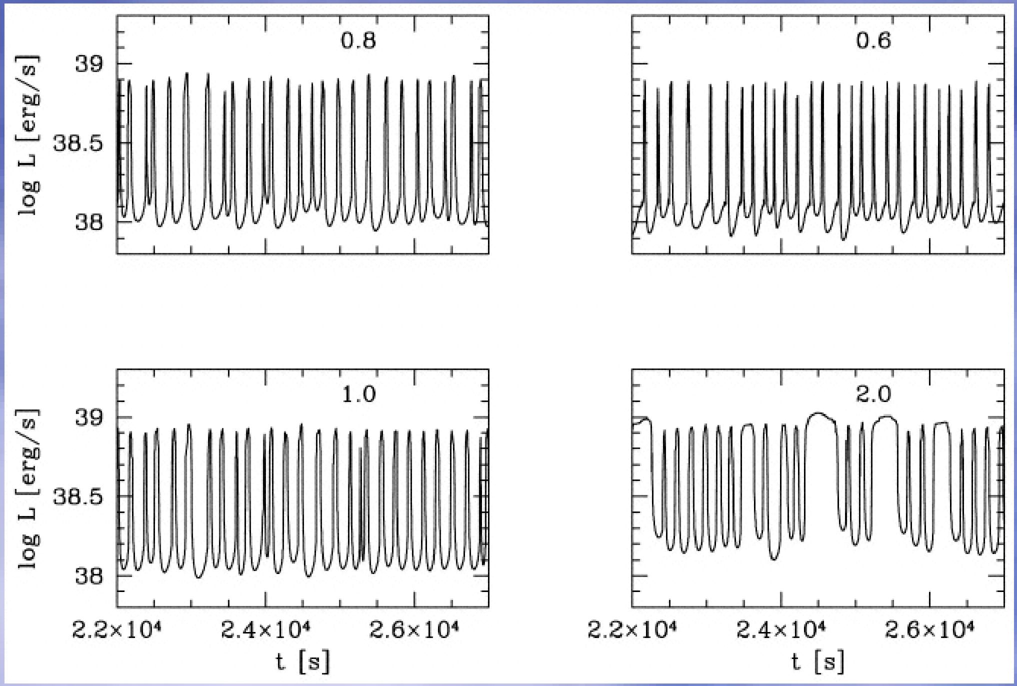
- Radiation pressure instability (inner disk)
- Ionization instability (middle disk)
- Gravitational instability (outer disk)

Radiation pressure instability

GRS 1915+105 is the only galactic source showing (occasionally) this instability.

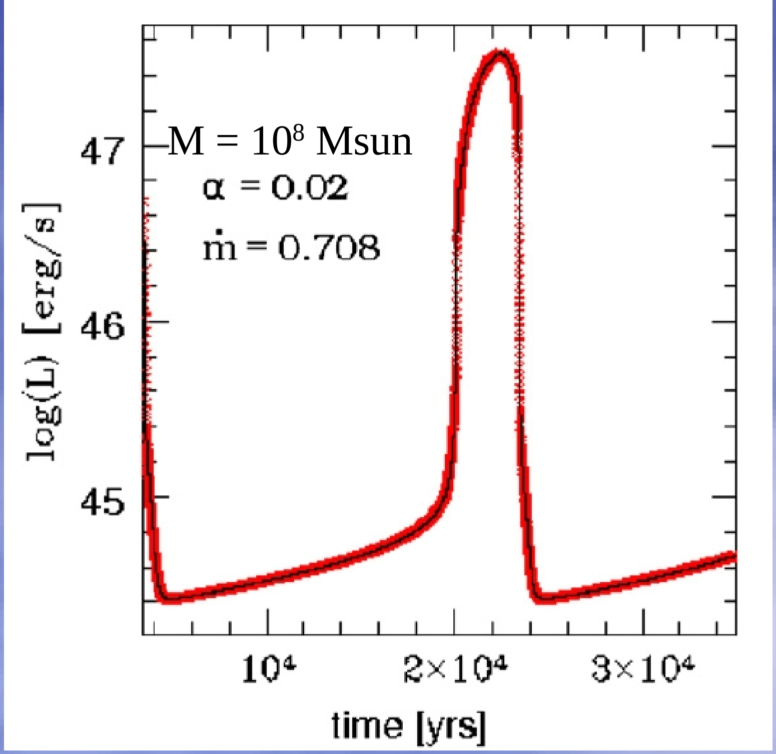


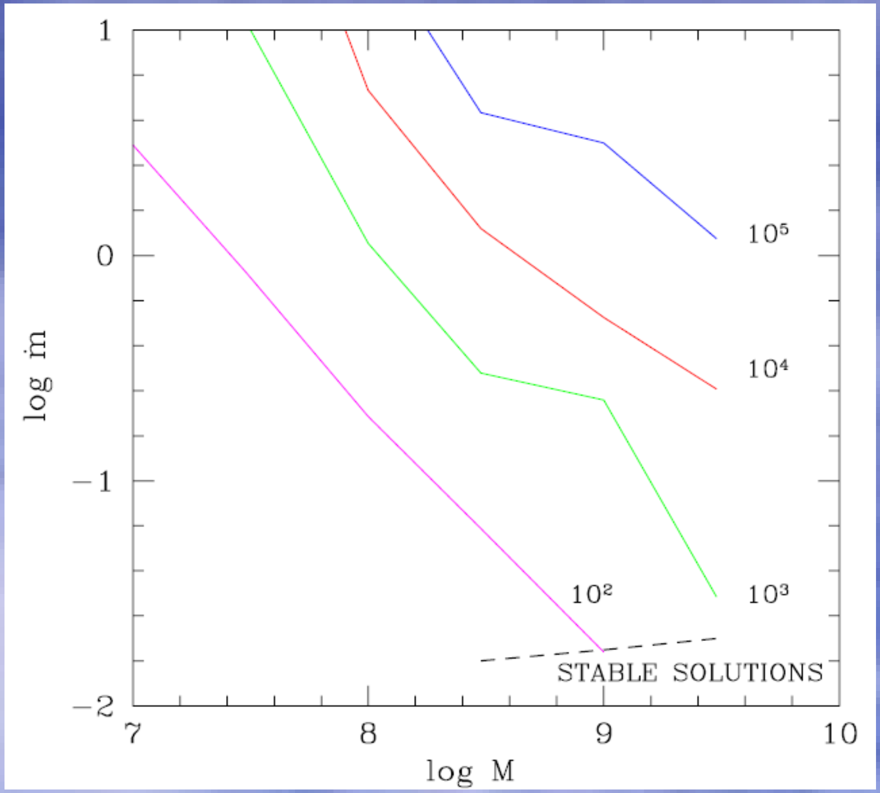
example of GRS 1915+105 lightcurve from Belloni et al. (2000)



Model of the disk time evolution in GRS 1915+105 (Janiuk et al 2000). Model explains the lack of state transitions from C to B.

Radiation pressure instability

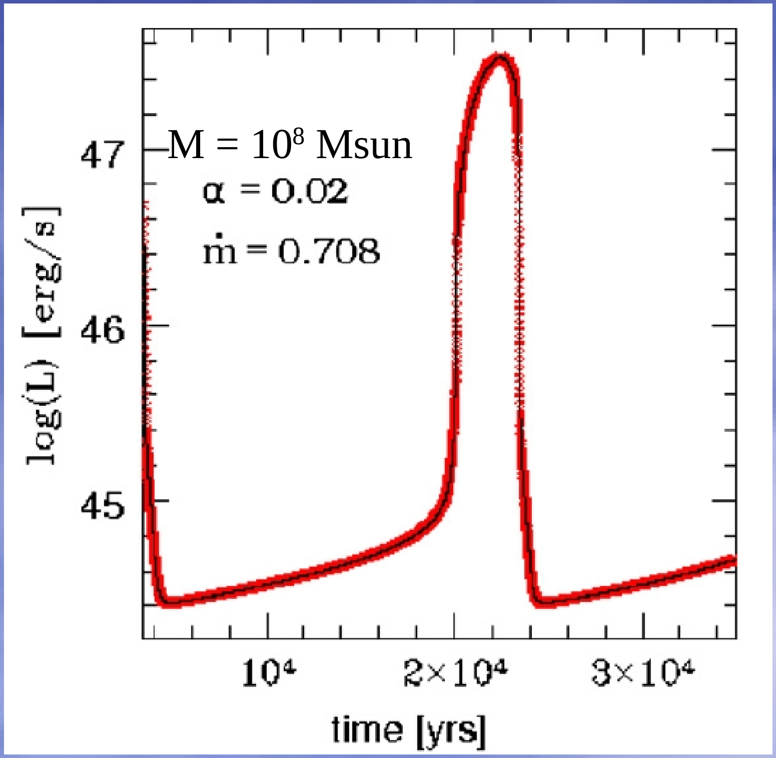




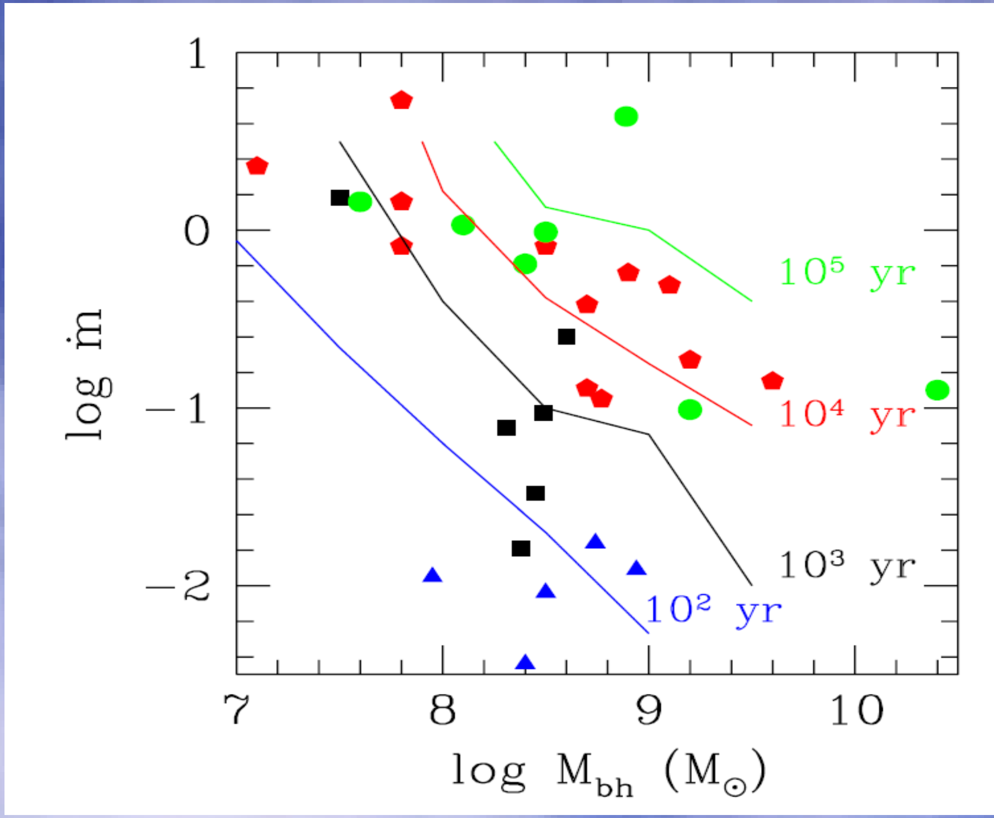
Czerny et al. 2009

Predicted outburst duration

Radiation pressure instability

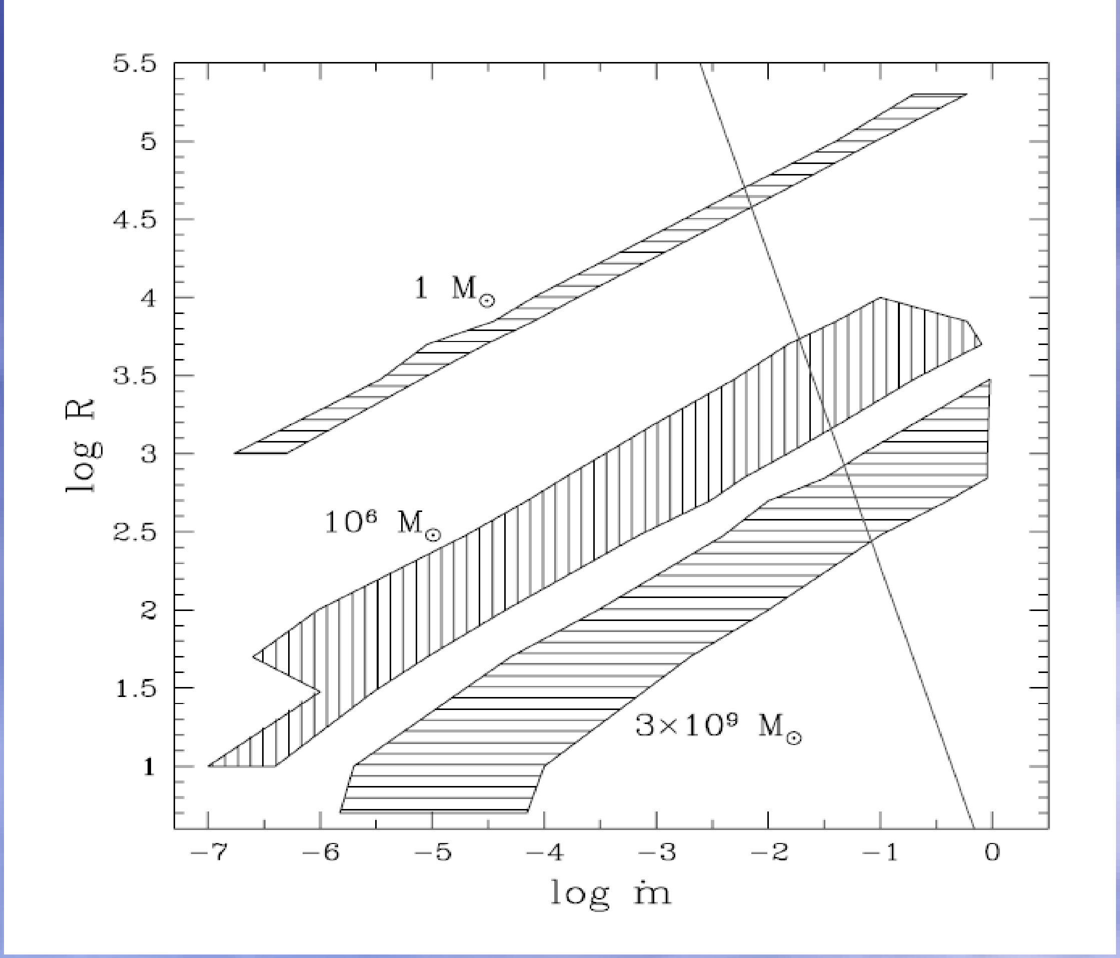


Czerny et al. 2009



Predicted outburst duration combined with BH masses, luminosities and ages of Young Radio Sources, Wu 2009

Ionization instability

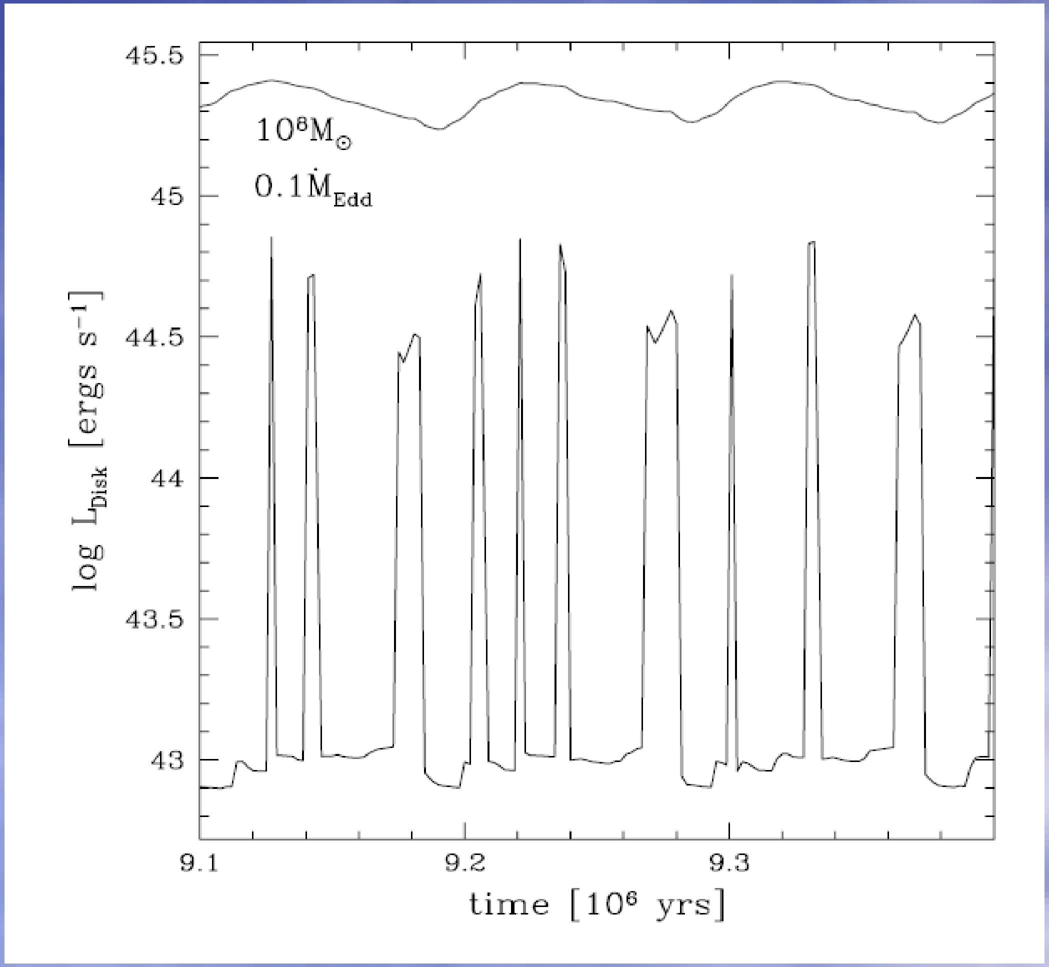


Responsible for X-ray novae and dwarf novae outbursts.

May operate in AGN

Janiuk et al. 2004

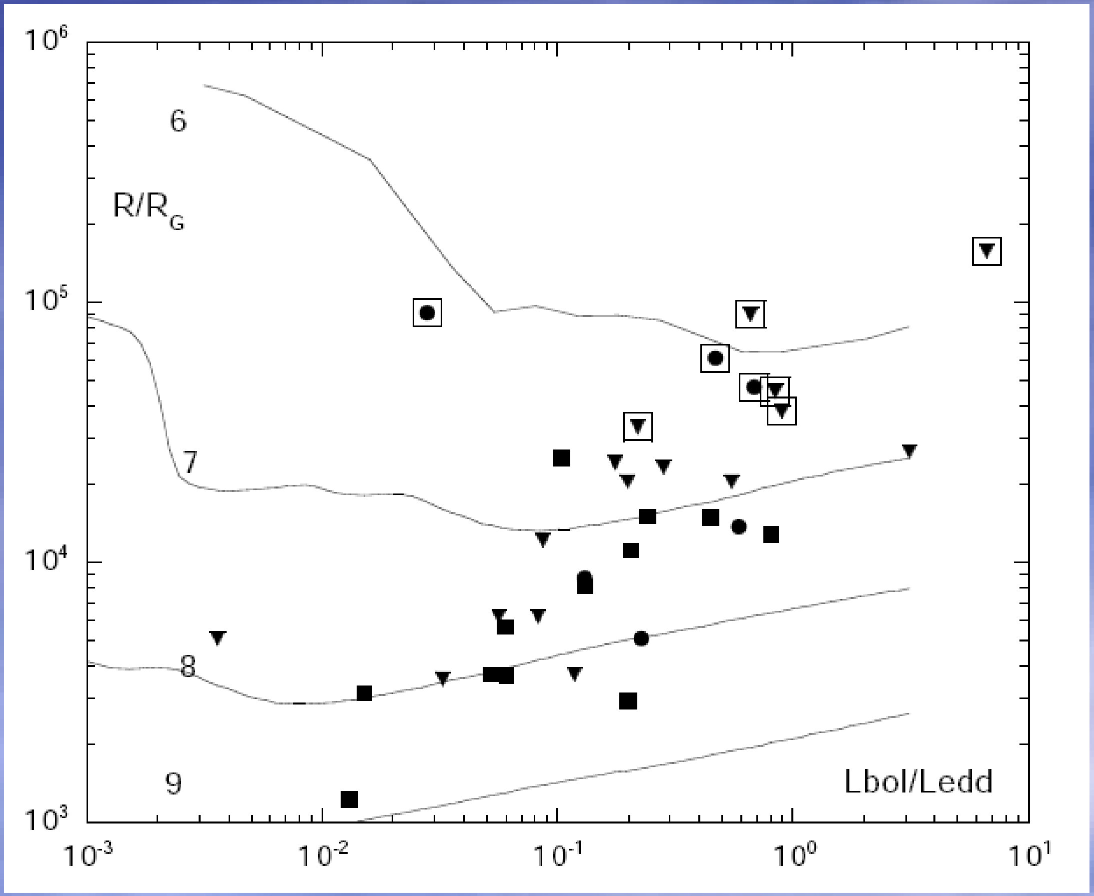
Ionization instability



- Upper curve: whole disk
- Lower curve: evaporated disk
- interesting for intermittent activity

Janiuk et al. 2004

Gravitational instability

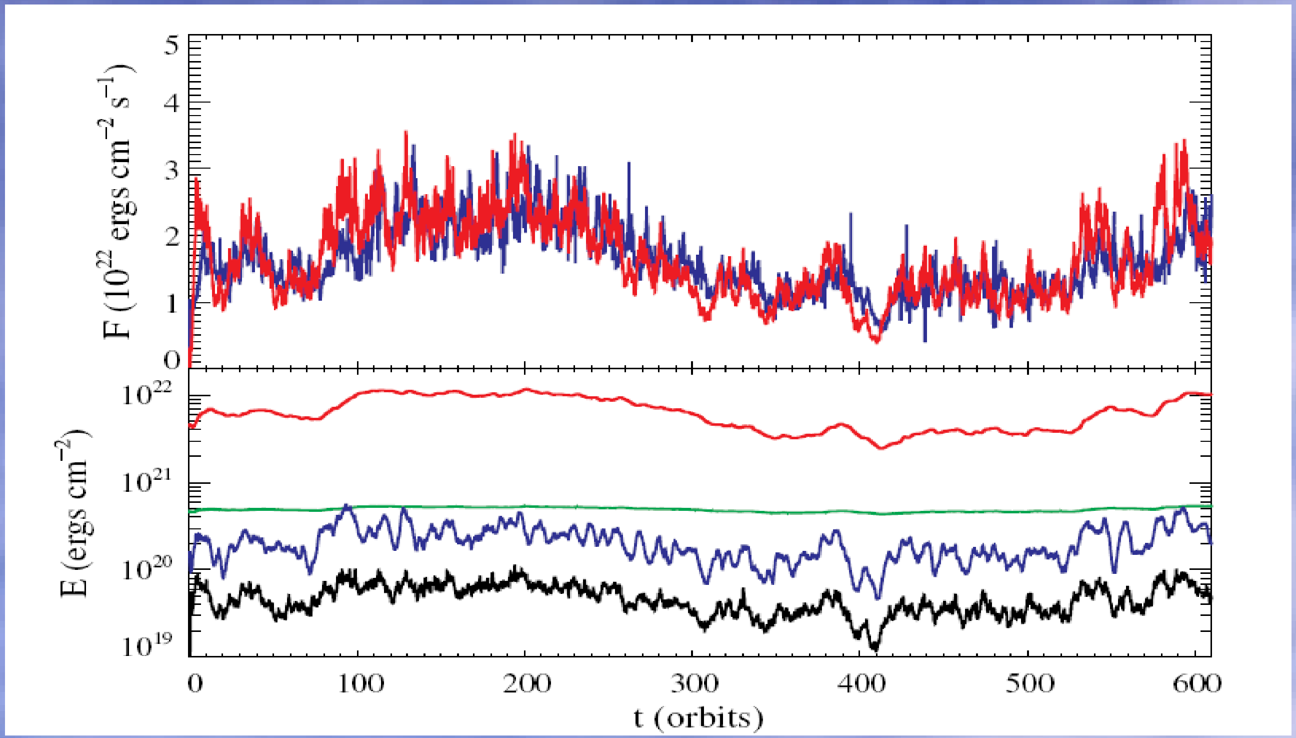


May:
-generate stars
-speed up inflow
-determine BLR

Collin & Hure 2001

Nature of viscosity

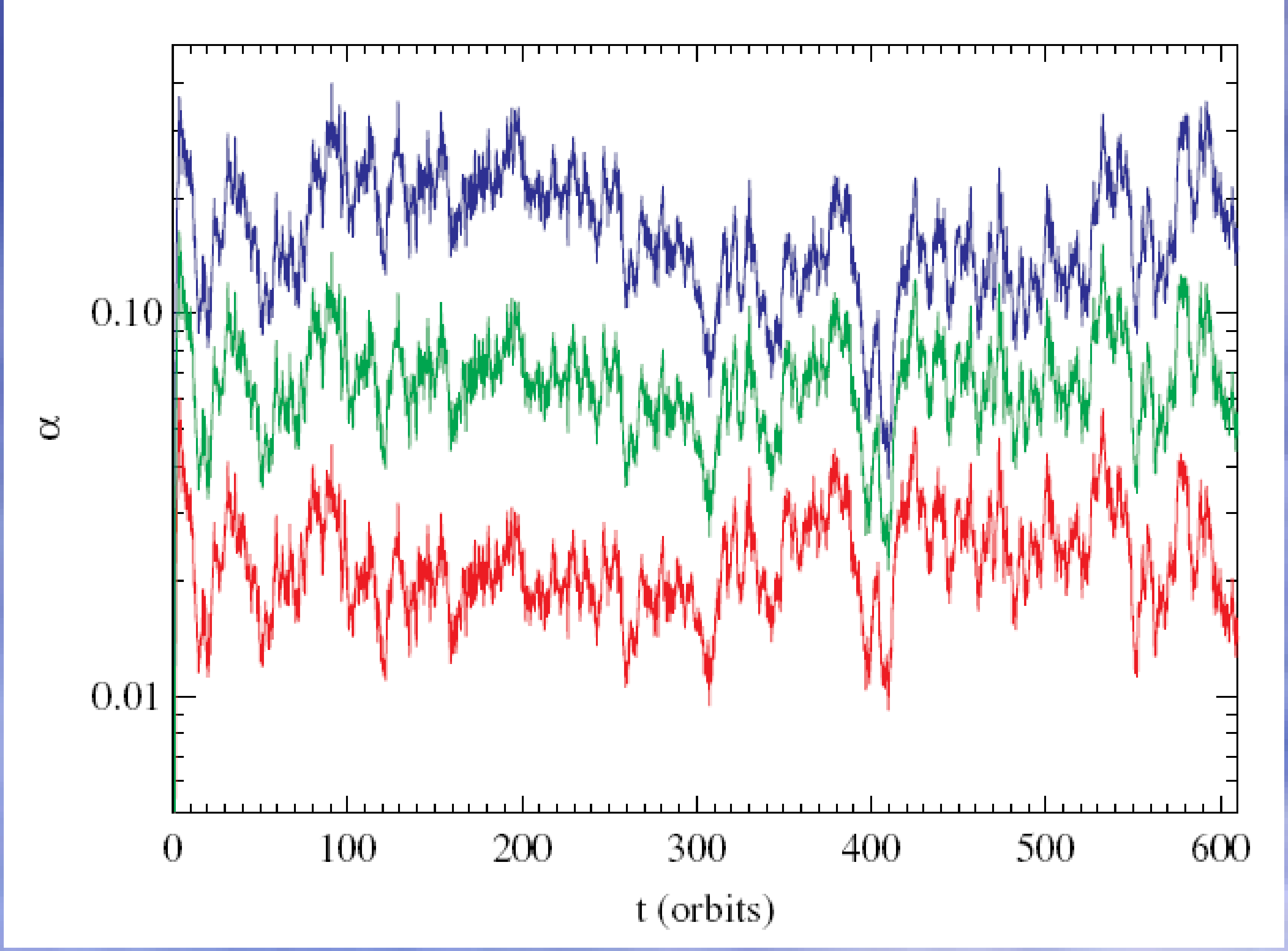
Magneto-rotational instability, Balbus & Hawley



3D simulations show that this leads to additional faster variability in 'thermal' timescale

Hirose et al. 2009

Nature of viscosity

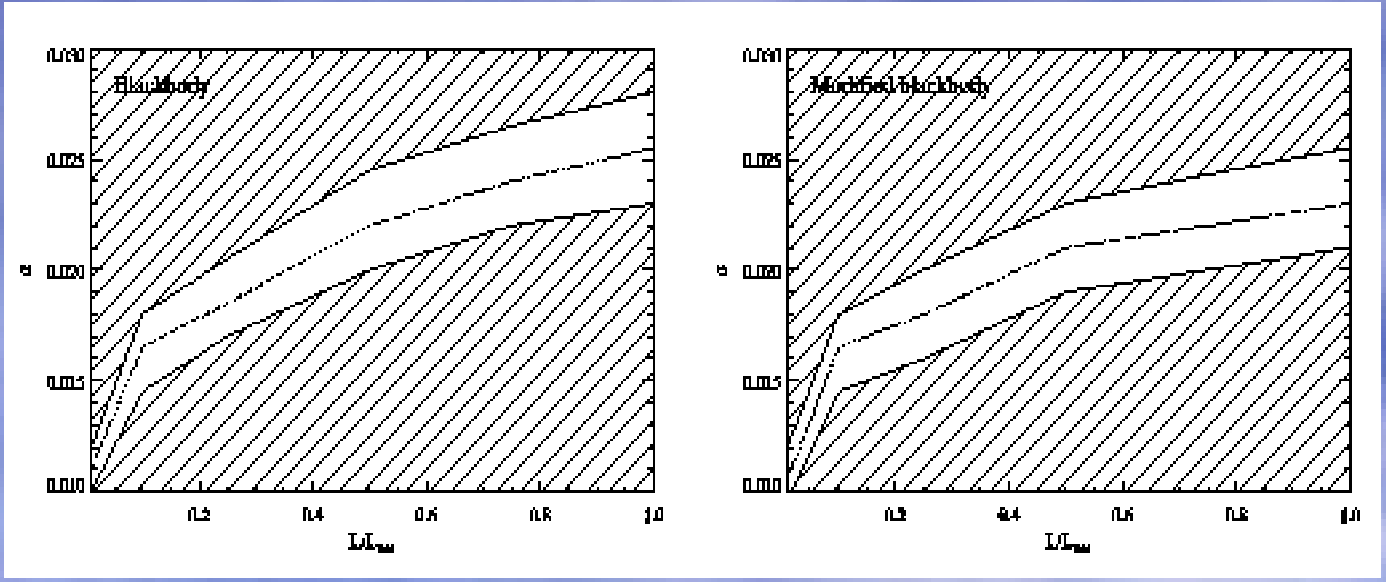


Hirose et al. 2009

Nature of viscosity

If optical fluctuations in quasars are interpreted as thermal timescale, Starling et al. 2004 obtain:

$$\alpha \sim 0.02$$



Nature of viscosity

Are optical variations in quasars in the timescales of days, down to intra-night micro-variability, due to MRI?

NO

YES

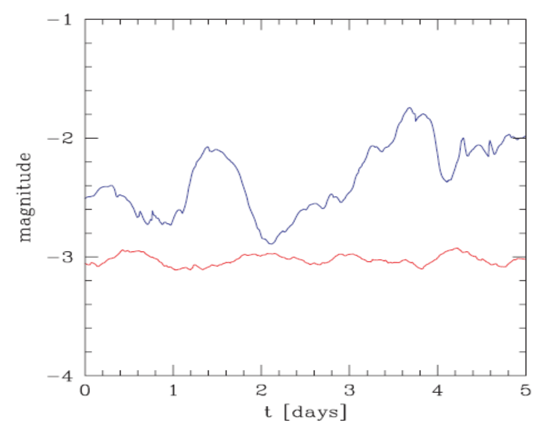
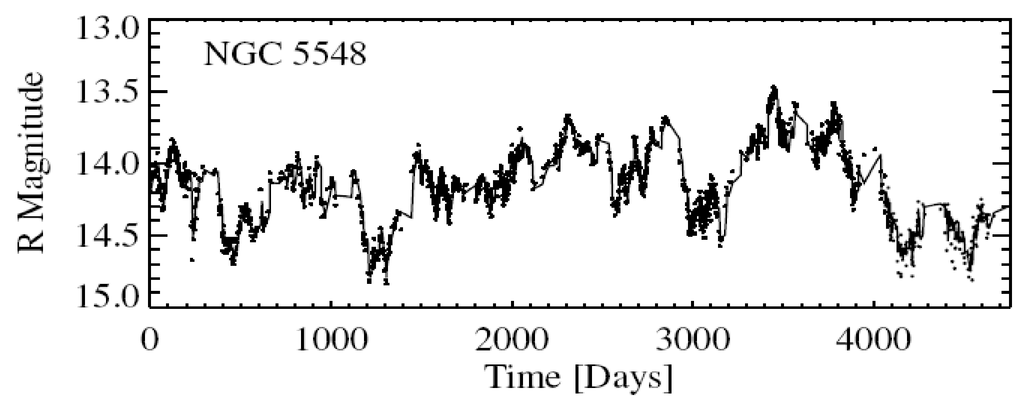


Figure 3. The light curves expected from the local MRI developments at 10 $R_{\rm Schw}$ radius around a 10^7 $M_\odot$ black hole for 36 (upper blue curve) and 360 (lower red curve) coexisting magnetic cells.



Czerny et al. 2008

Kelly et al. 2009

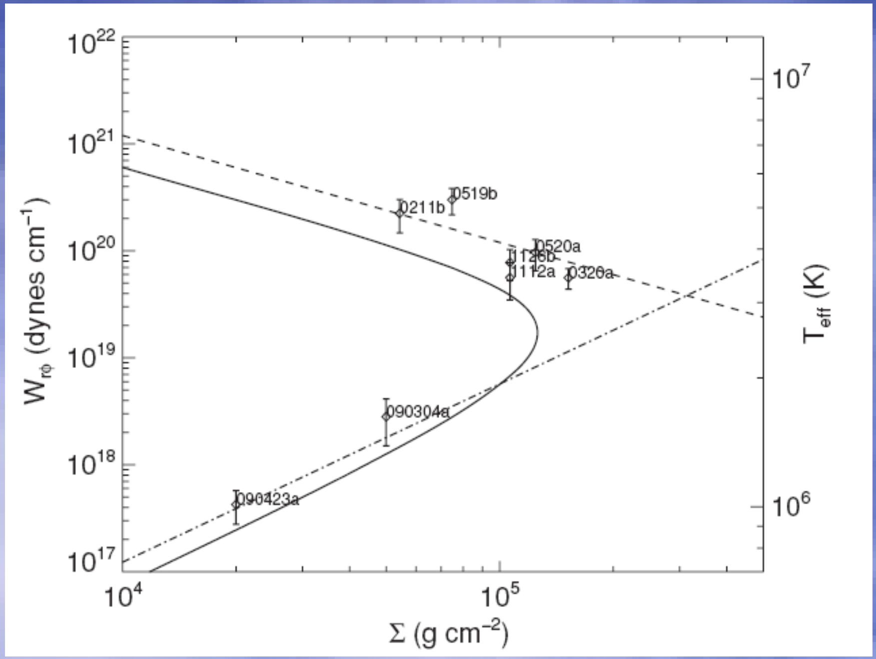
Nature of viscosity

The key question to MRI: is radiation pressure instability operating?

No

May be...

"The magnetic energy and pressure do scale together as suggested by the dimensional analysis underlying the alpga model, but it is not necessarily because the pressure directly forces the magnetic energy..."

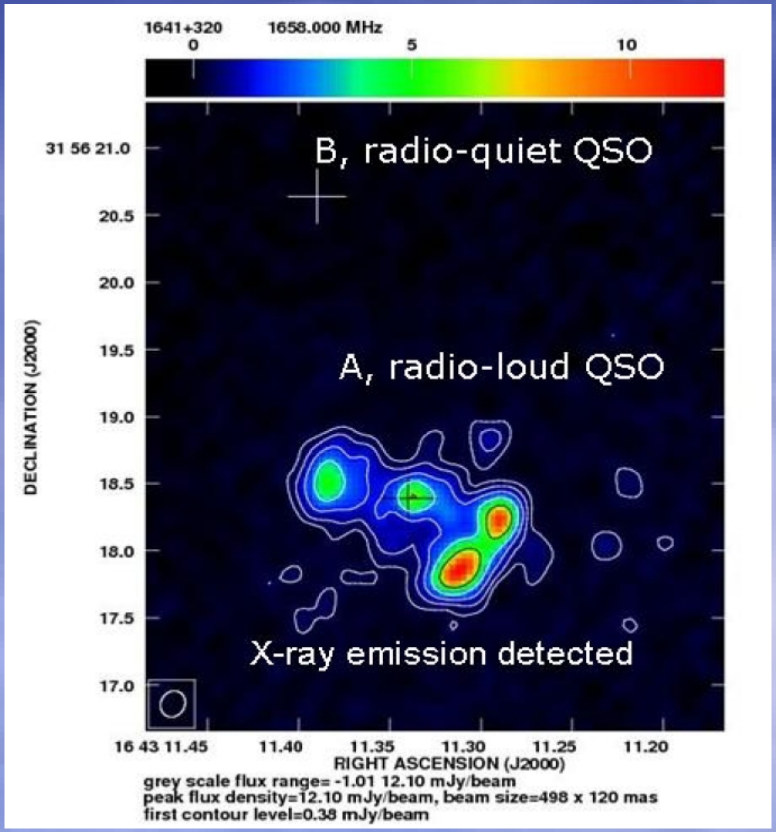


Hirpse, Krolik & Blaes 2009, January

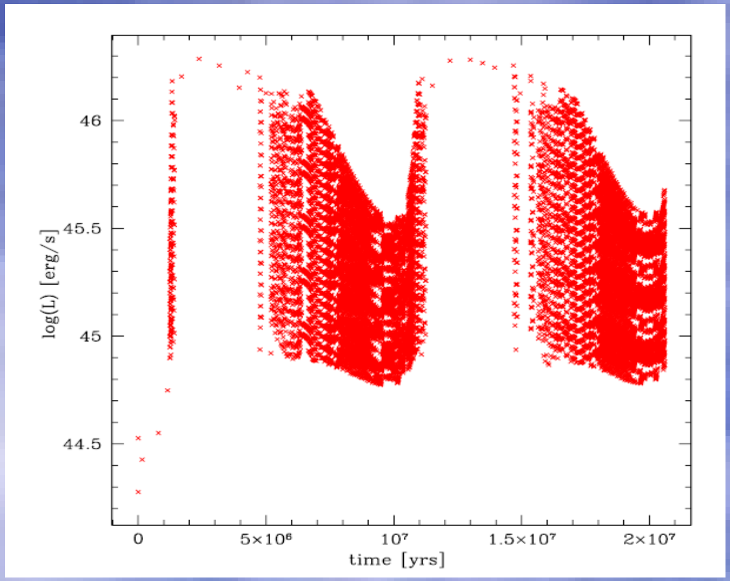
Hirose, Blaes & Krolik 2009, October

Nature of viscosity

Instabilities are sensitive to boundary conditions. Example.

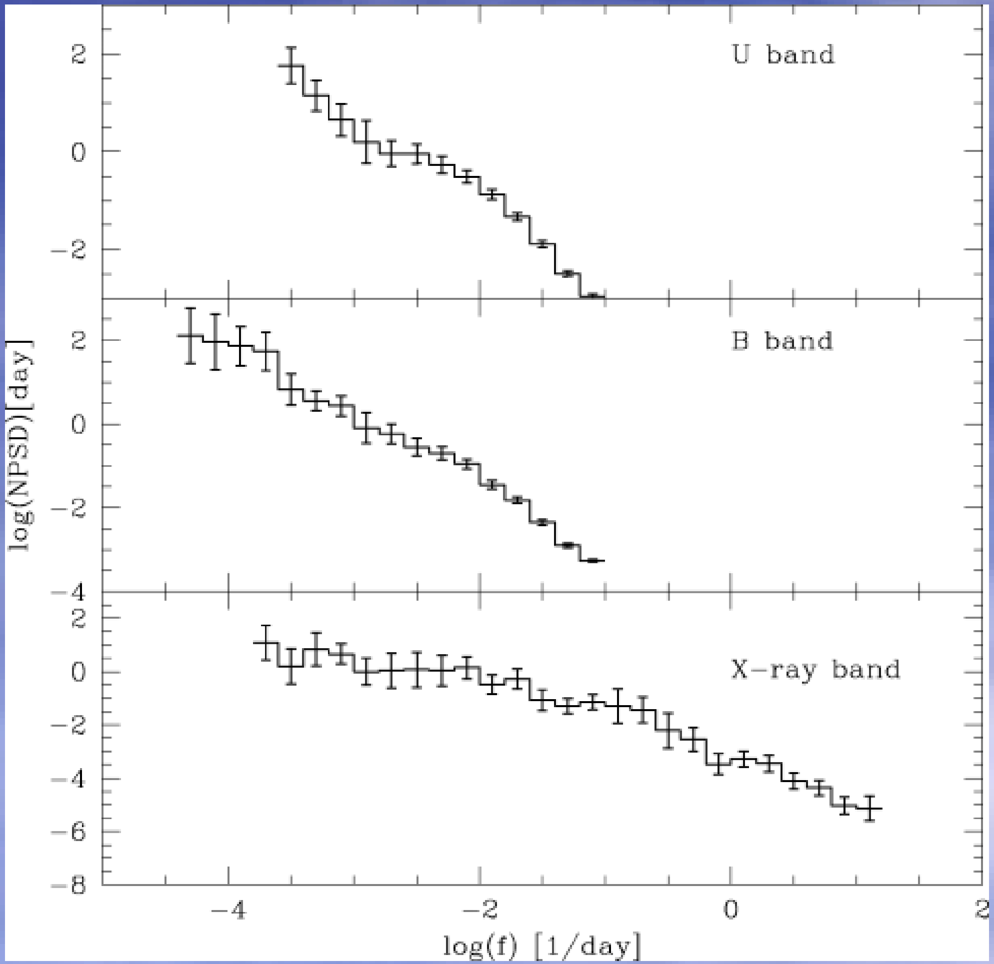


Instability with sinusoidal accretion rate at the outer edge; stable states close to maximum.



Kunert-Bajraszewska & Janiuk, in preparation

Disk-hot medium interaction



- X-ray irradiation of the disk – variable X-rays lead to variable optical/UV flux
- local disk fluctuations - accretion rate perturbation – variable optical flux leads to variable X-ray flux (propagation model of Lyubarsky 1997)

NGC 4151; Czerny, Doroshenko et al.. 2003

Disk-hot medium interaction

6 *Gaskell*

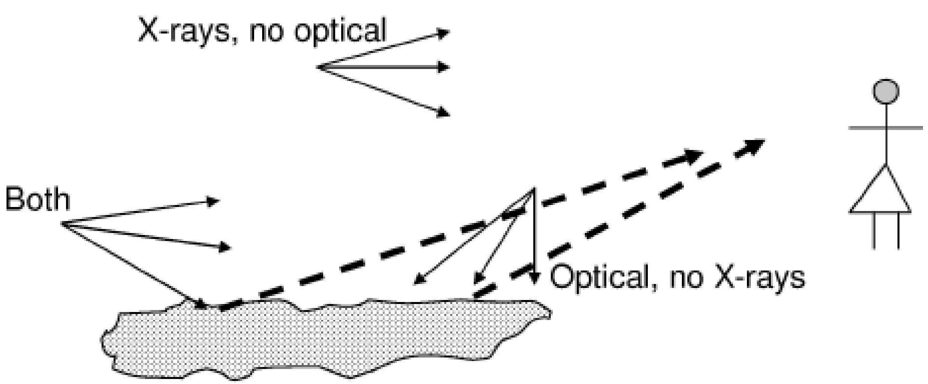


Figure 5. A schematic illustration of possible effects of directional emission of X-rays and high-energy particles on short-term X-ray and optical variability. The X-ray emission at the top happens to be towards the observer but mostly misses the reprocessing surface. The emission on the left is aimed towards the observer, but also hits a reprocessing surface and produces enhanced optical emission. The X-rays on the right are not directed at the observer, but do hit the reprocessing surface. The observer only sees the reprocessed radiation in this case.

Short timescales: X-ray irradiation

Anisotropic emission model, Gaskell 2006

Disk-hot medium interaction

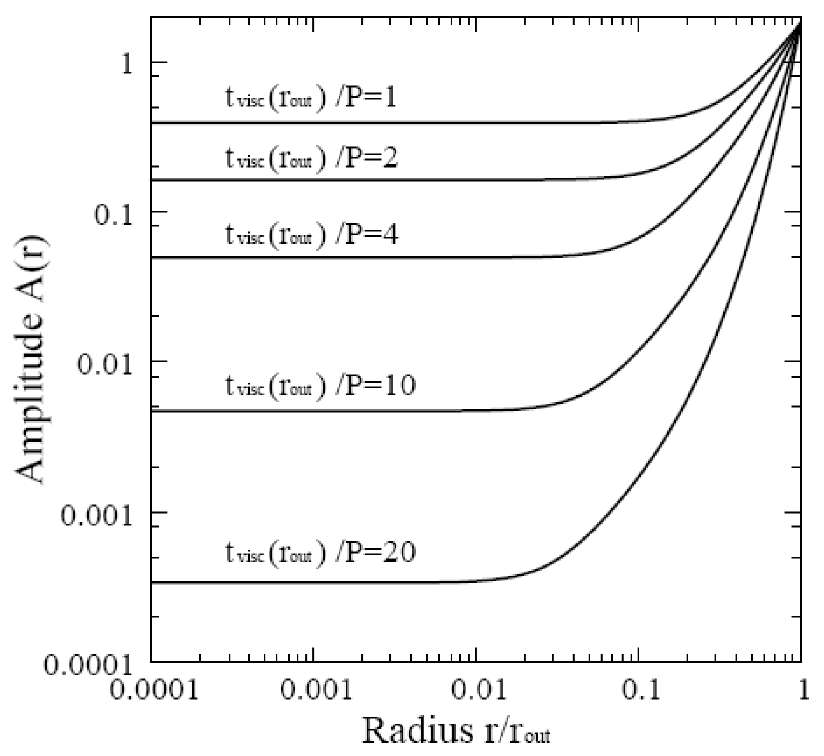


Figure 7. The amplitude of the steady-state periodic variability of the mass flow rate as a function of the radius, $A(r)$, for a number of values of $t_{\rm visc}(r_{\rm out})/P$. The parameters are $n = 3/4$, $r_{\rm out}/r_{\rm in} = 10^4$ and the amplitude of the sinusoidal modulation is $A(r_{\rm out}) = 1.8$.

Damping is very strong if the modulation timescale is shorter than the viscous timescale.

Zdziarski et al. 2010

Disk-hot medium interaction

Faster propagation: accreting corona model

Process can be modeled using Markoff chain (e.g. King et al. 2004) but considerable arbitrariness is involved.

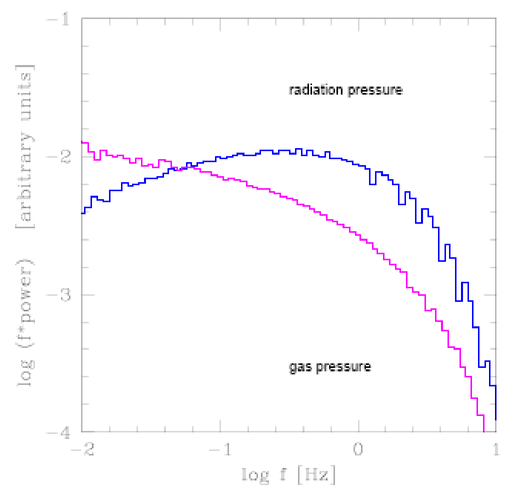


Fig. 1. Power spectrum density for the radiation-pressure dominated and gas-pressure dominated disk if the dynamo cells scale with the disk thickness (models Aa-rad and Aa-gas from Table 1).

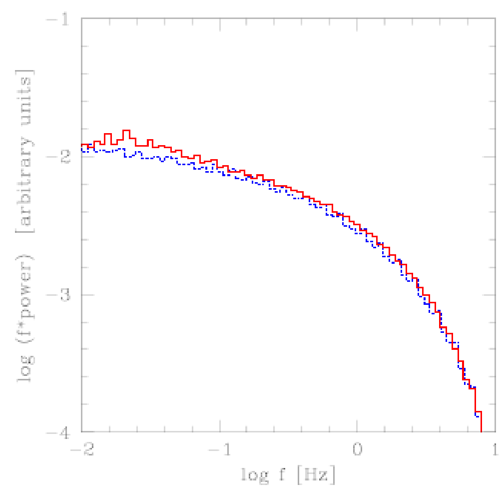


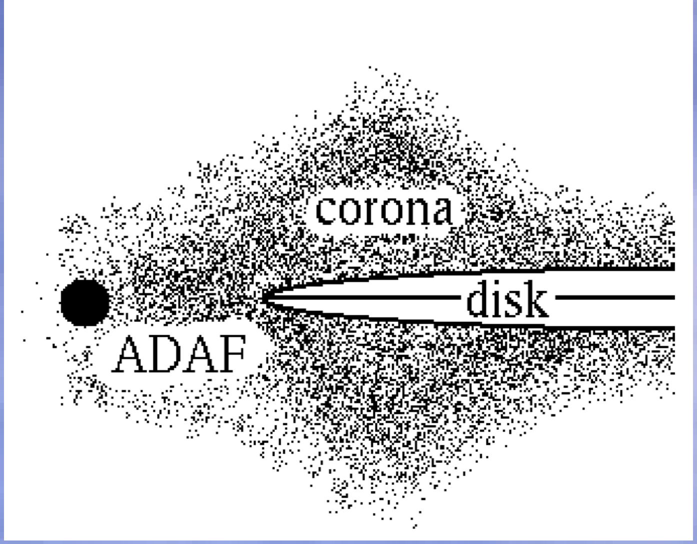
Fig. 2. Power spectrum density for the radiation-pressure dominated (dotted histogram) and gas-pressure dominated (solid histogram) disk if the dynamo cells scale with the disk radius. Random location of cells (models Ab-rad and Ab-gas from Table 1).

Hot medium origin

- Failed jet/lampost model
- Inner ADAF/IRAF
- Anchored magnetic flares
- Disk evaporation/condensation – accreting corona
- Inflow of ionized material

Hot medium origin

Most advanced model: disk evaporation/condensation (Meyer & Meyer-Hoffmeister 1994 +)



Rozanska & Czerny 2000

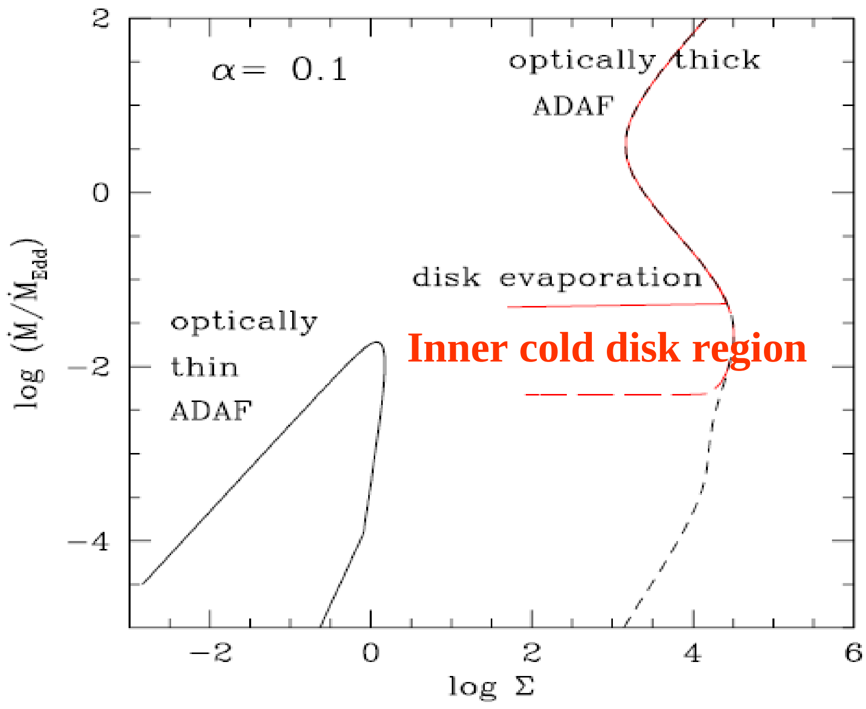
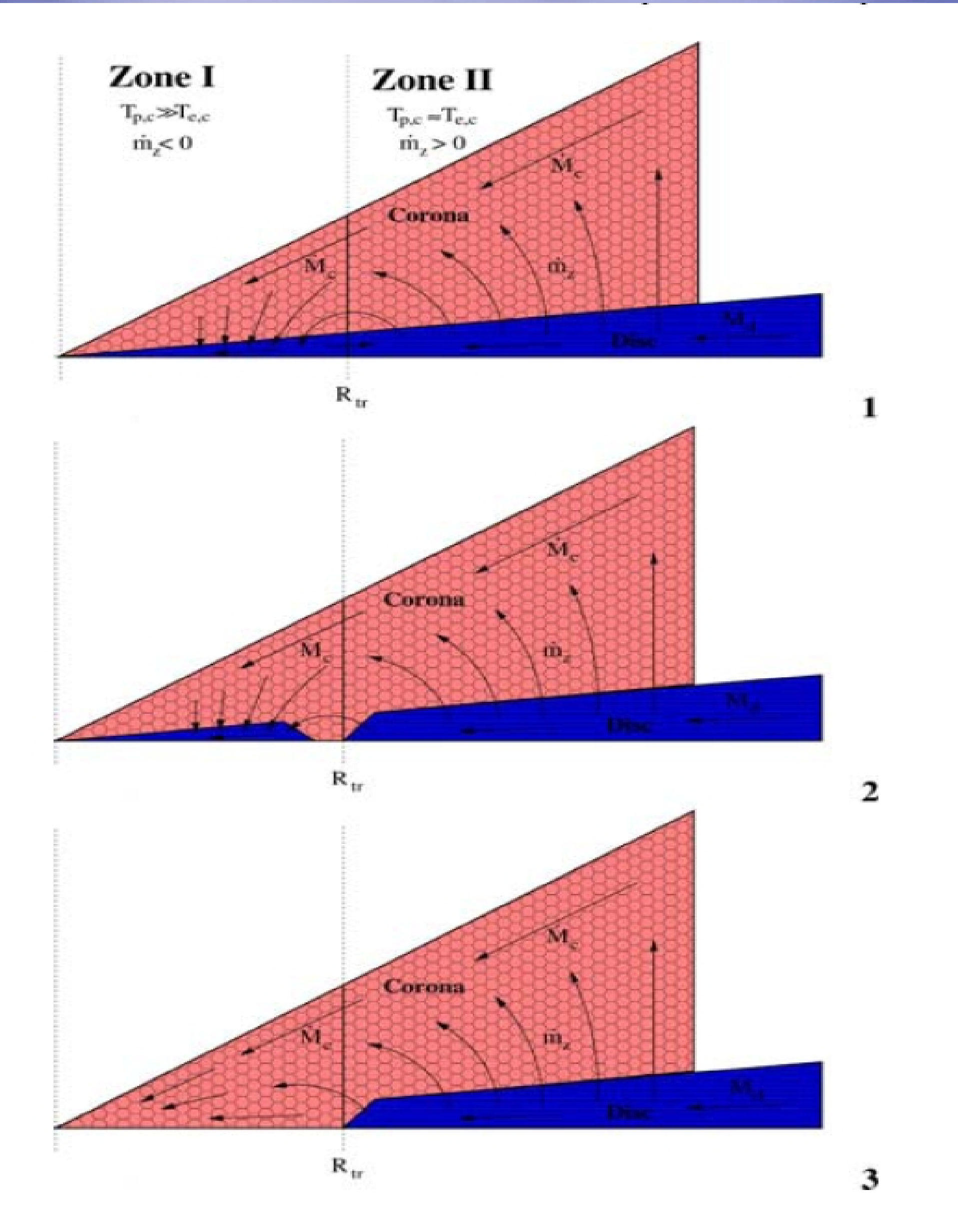


Fig. 16. The relation between the accretion rate and the surface density of the disk/corona system at $10R_{\rm Schw}$ for the viscosity parameter $\alpha = 0.1$ in case of irreversible ADAF transition (continuous line) and with secondary disk rebuilding (long dashed line). Short-dashed line shows the standard Shakura-Sunyaev model supplemented with advection essential at high accretion rates, calculated for $M = 10^8 M_\odot$ - slight wiggles of the gas dominated lower branch are caused by bound-free opacities. Continuous line in the lower right part of the diagram shows solution for an optically thin flow (Narayan & Yi 1995b, Abramowicz et al. 1995), computed using the code of Zdziarski (1998).

Hot medium origin

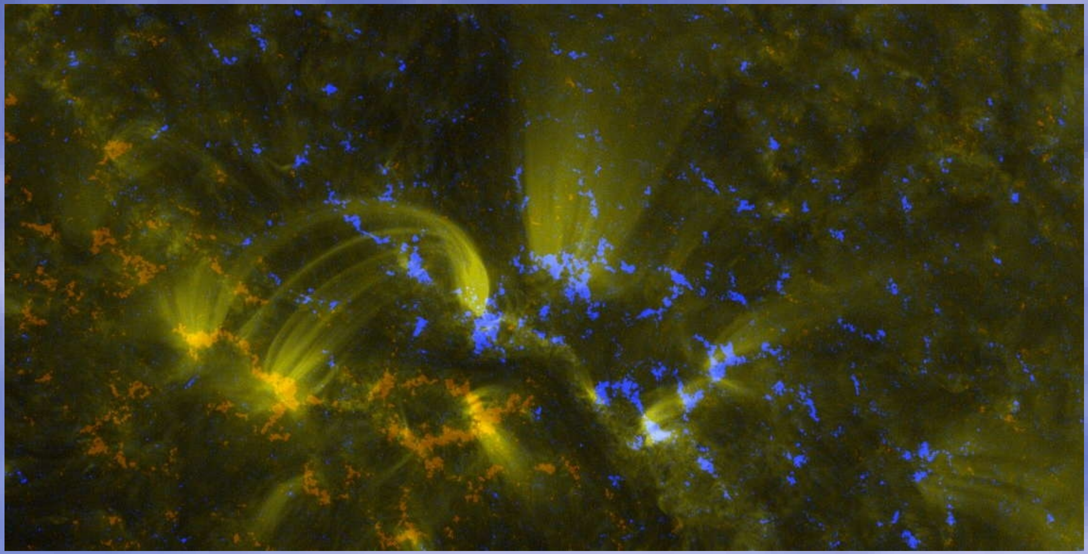
Complete time evolution of a disk with two-temperature corona; disk condensation/evaporation due to conduction and radiative processes; low accretion rate.



Mayer & Pringle 2007

Conclusion:

We should borrow much more physics from the solar corona in order to understand multi-phase AGN medium...



Solar Dynamics Observatory, Hotshot for July 16, 2010