AGN Variability Mechanisms

Aneta Siemiginowska

Harvard-Smithsonian Center for Astrophysics

Collaboration with:

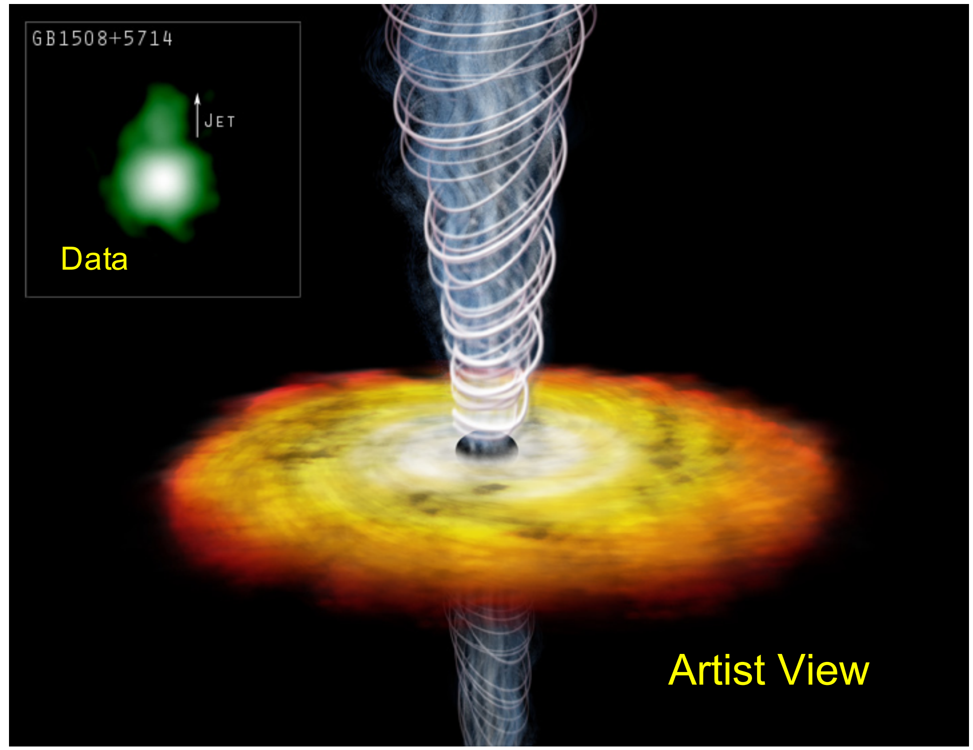
Brandon Kelly (former Hubble Fellow at CfA, now UCSB)
Malgorzata Sobolewska (post-doc at CfA)
Bozena Czerny (CAMK, Warsaw)

Outline

- AGN model
  - Components, emission, variability
- Variability analysis
  - Microlensing constraints
  - Scaling with black hole mass
  - Simulating light curves
- Conclusions and future

AGN Model Elements

- Accretion Disk
- Hot corona
- Torus
- Clouds
- Relativistic Jet



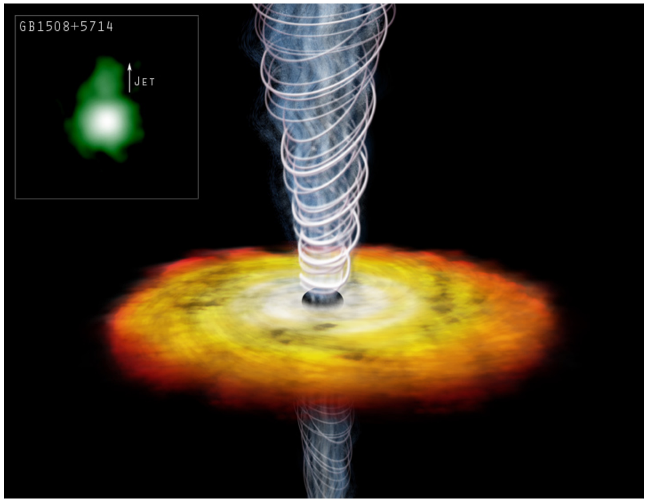
Black Hole gravity is fundamental to the AGN Power

Why AGN variability?

- AGN primary emission is not resolved!
- The variability allows us to “look inside” the AGN and:
  - constrain the emission region size
  - learn about energetics of the system
  - understand the AGN Physics, e.g. viscosity constraints, connection between different emission sites

Variability

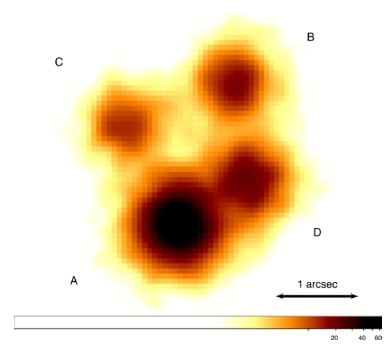
- On the line of site
  - Occultation events - clouds, torus, wind
  - Microlensing
- Intrinsic to the AGN
  - Optical emission
    - » Continuum - Accretion flow
    - » Emission lines - BLR
  - X-rays
    - » Corona, hot plasma
    - » Outflow (also in radio, γ-rays)
    - » Reflection



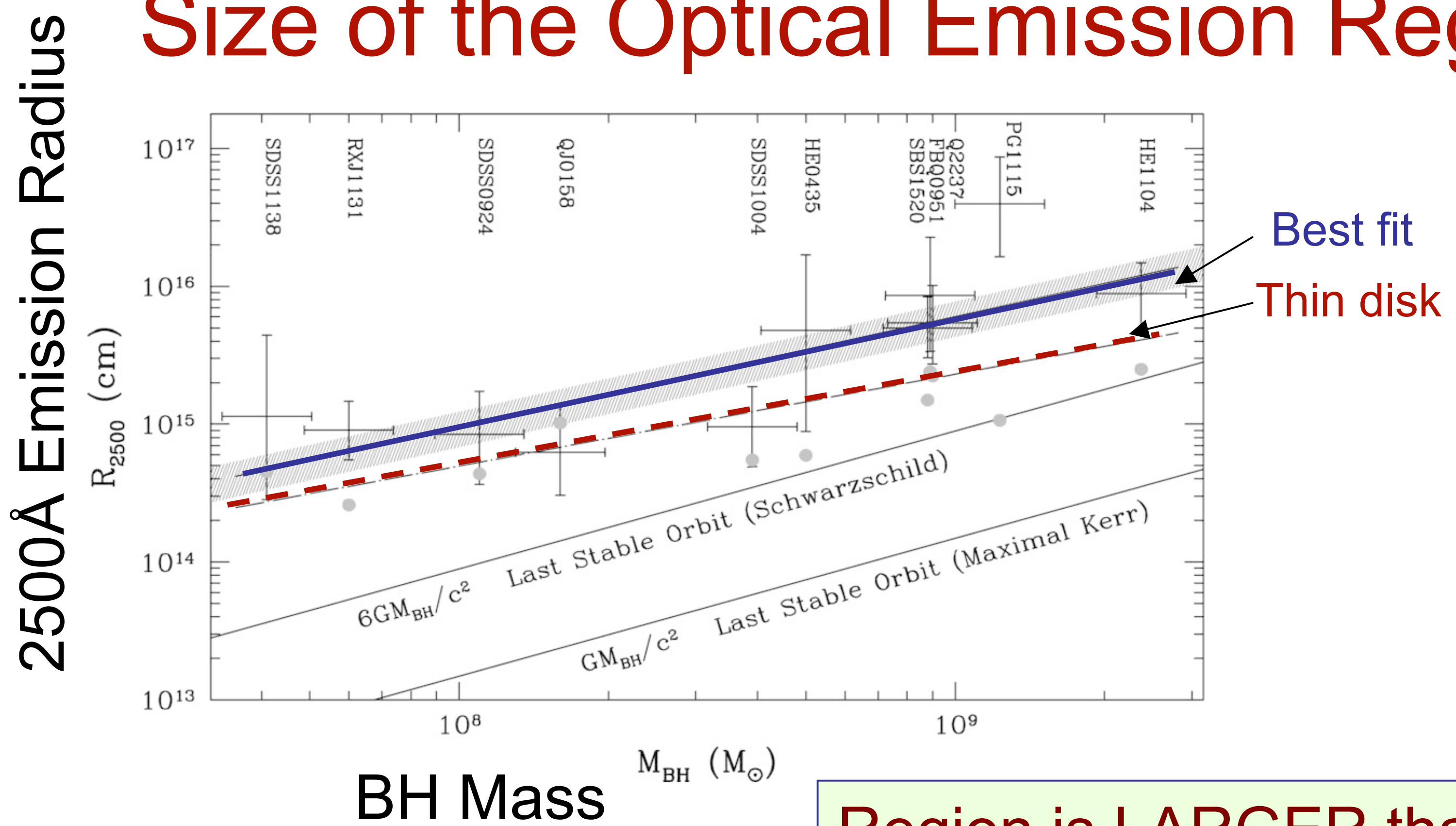
Microlensing
Constraints on Geometry

- Source of the variability external to the AGN
- Monitoring multiple quasar images gives the best observational constraints on the emission sites in optical-UV and X-rays *(see Andy Lawrance talk)*

- References: Kochanek's group, Pooley et al 2007



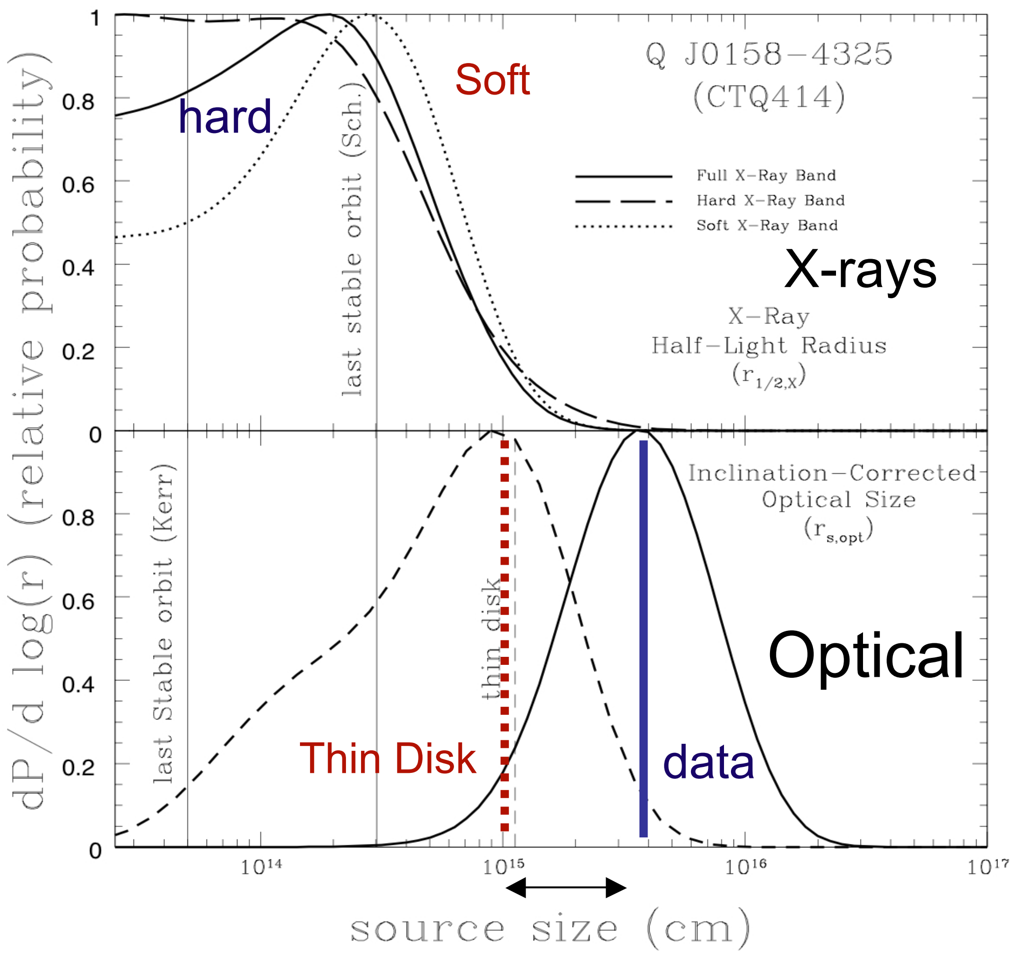
Microlensing Constraints
Size of the Optical Emission Region



Pooley et al 2007, Morgan et al 2010, 2012
Mosquera et al 2011

Region is LARGER than the one predicted by the standard Shakura-Sunyaev disk

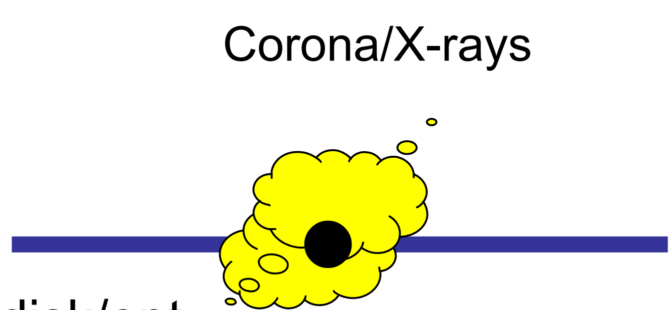
Constraints on X-ray/Optical Geometry



Morgan et al. 2012

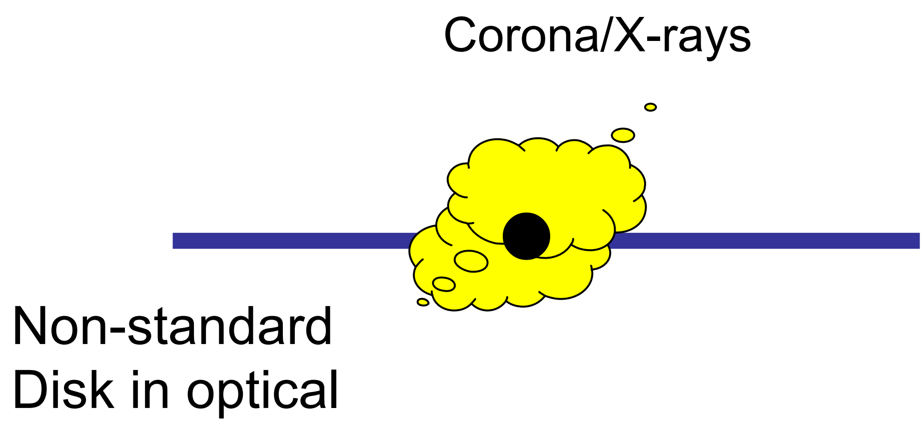
X-ray emission regions more compact and located closer to the Black Hole than the optical emission regions of the disk.

Geometry

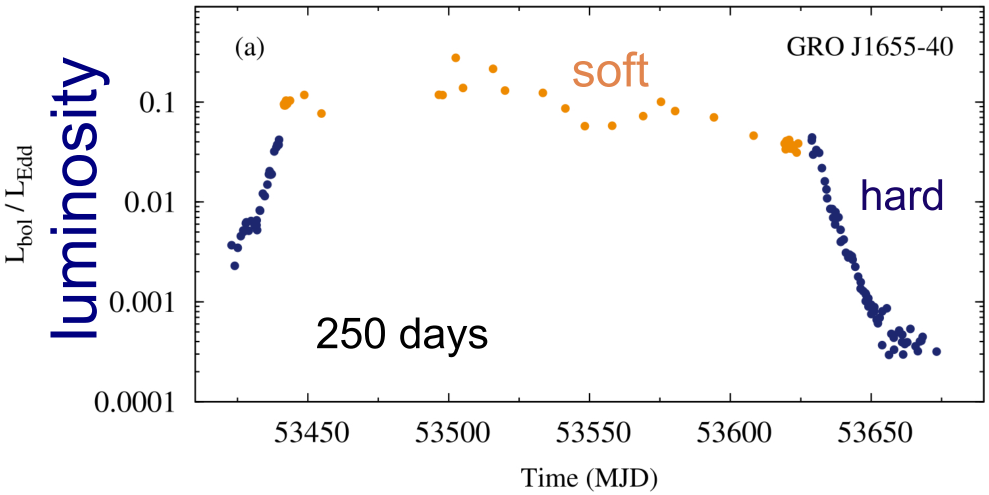


AGN (Quasars) geometry

- Corona (X-rays) is more compact than the optical-UV (disk)
- Optical-UV disk more extended than the standard thin disk.



Galactic Binary Black Holes: State Transitions



Sobolewska, Siemiginowska & Gierlinski 2011

GBH full outburst during a year in X-rays (here XTE data) shows a large increase in bolometric luminosity and a significant variation in the X-ray spectrum

1 year => 10^7 years for AGN 10^8 M_{bh}

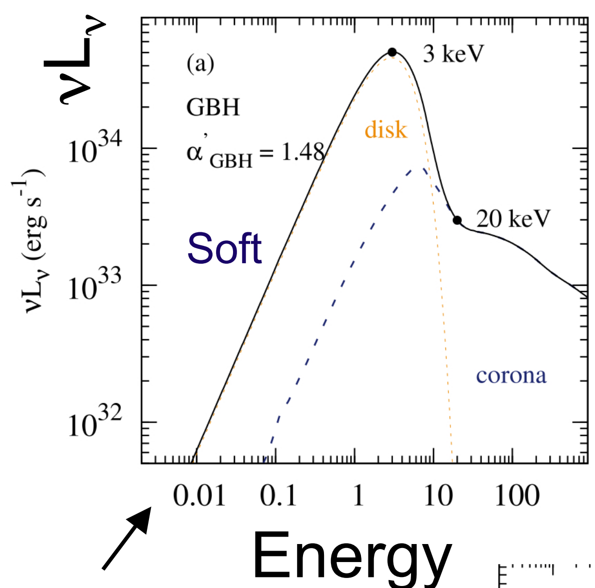
also in Van Velzen talk

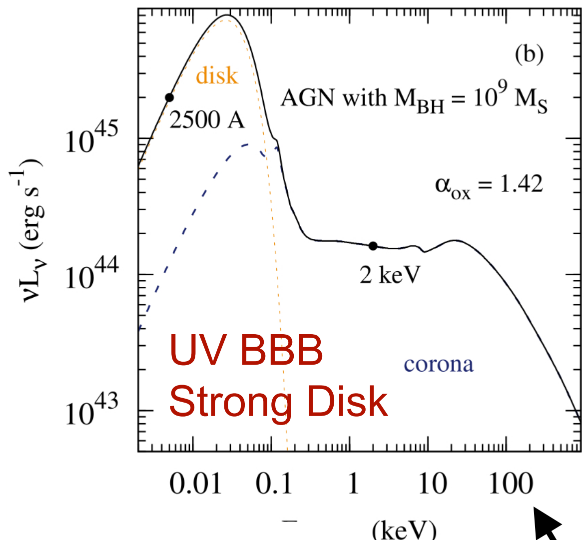
Spectral Similarities

Blackbody + Power law

Disk + Corona

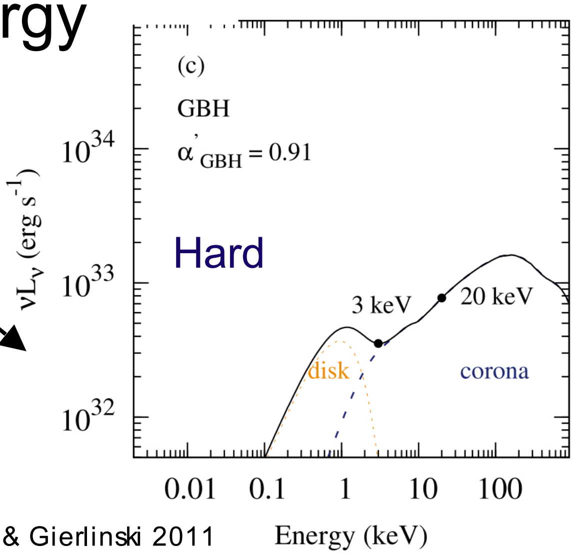
$T_{eff}(\text{disk}) \sim M_{BH}^{-1/4}$

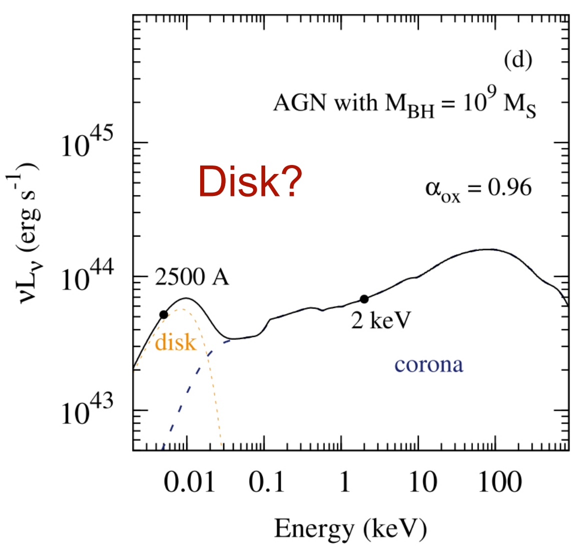




GBH X-rays

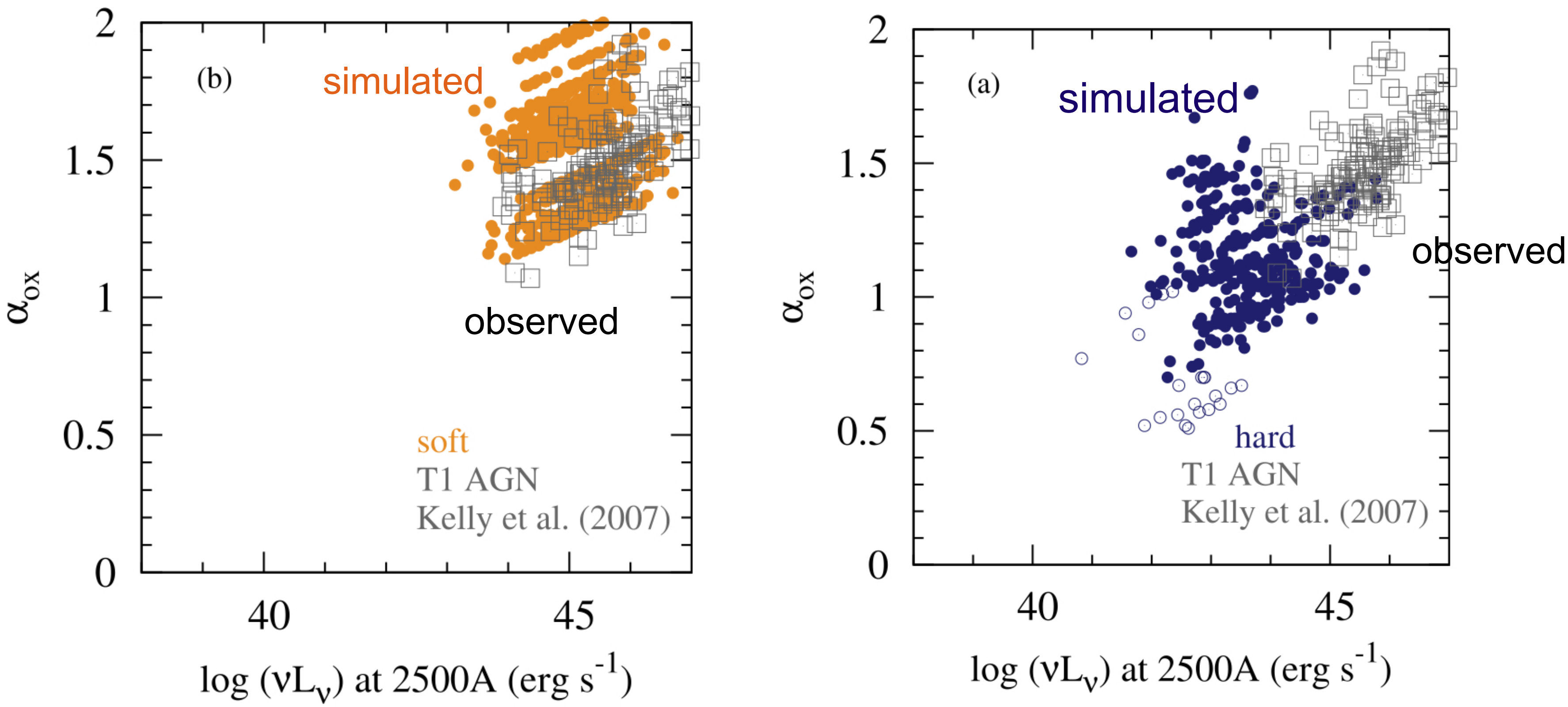
AGN opt-UV





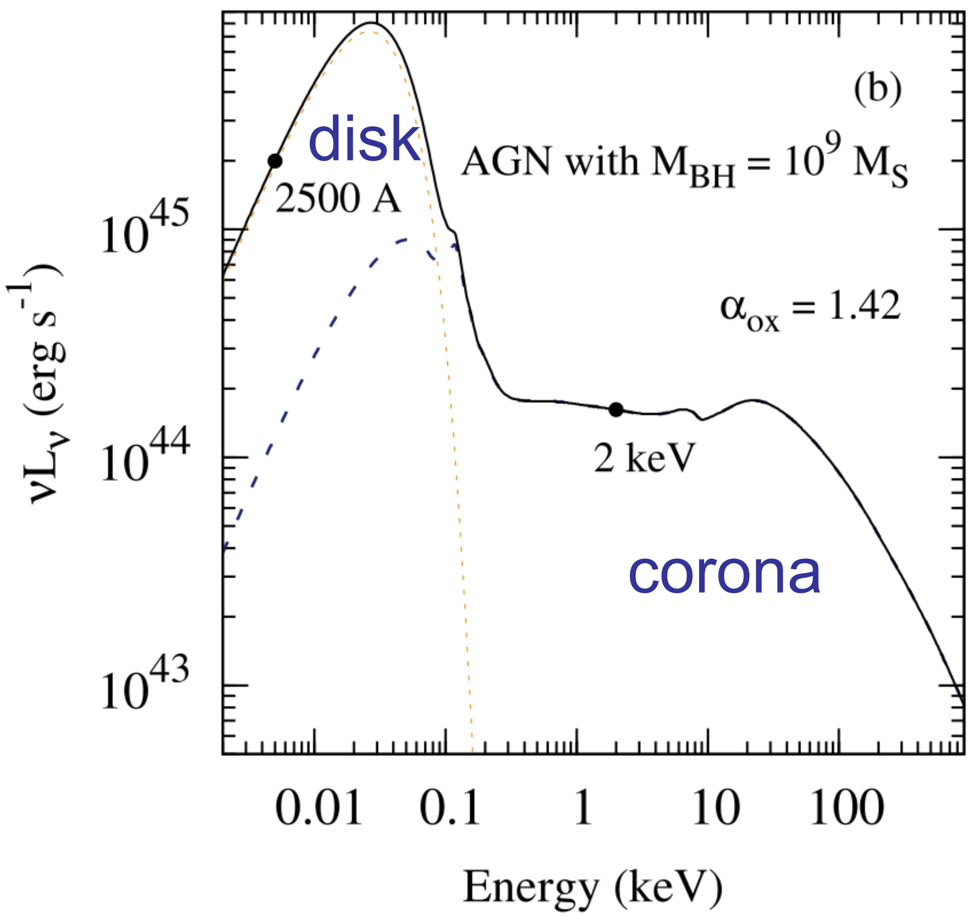
Sobolewska, Siemiginowska & Gierlinski 2011

Type 1 AGN in Soft State



Sobolewska, Siemiginowska & Gierlinski 2011

Type 1 AGN in Soft State



Optical-UV - disk

X-rays - corona

AGN Timescales

- Light crossing time at 100 r_s

$$t_{lc} = 1.1\ M_8 R_{100rs}\ days$$

- Orbital

$$t_{orb} = 104\ M_8 (R_{100rs})^{3/2}\ days$$

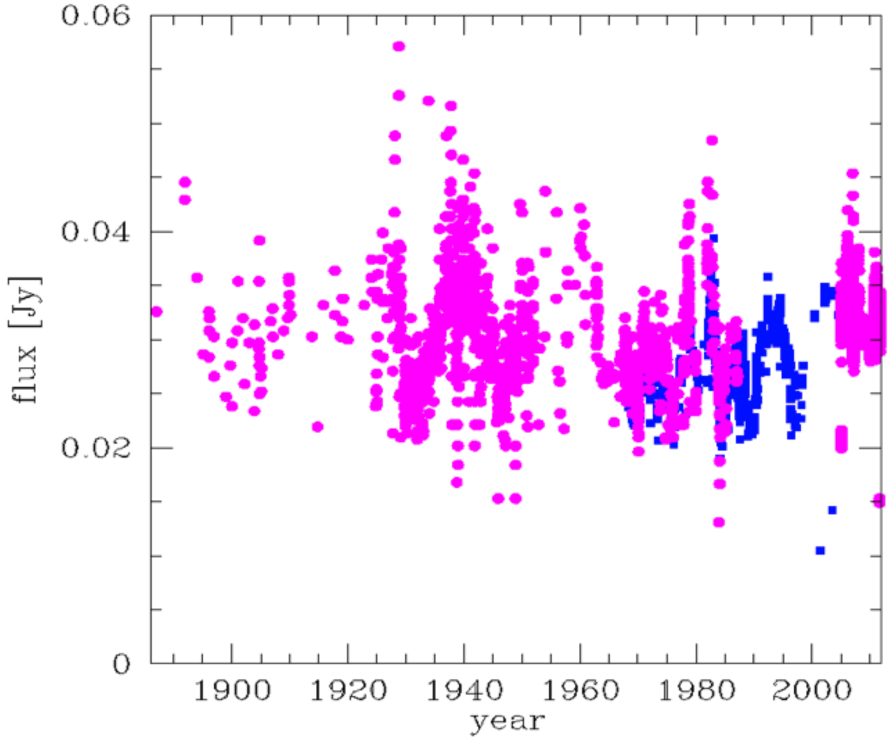
- Thermal (note the viscosity dependence)

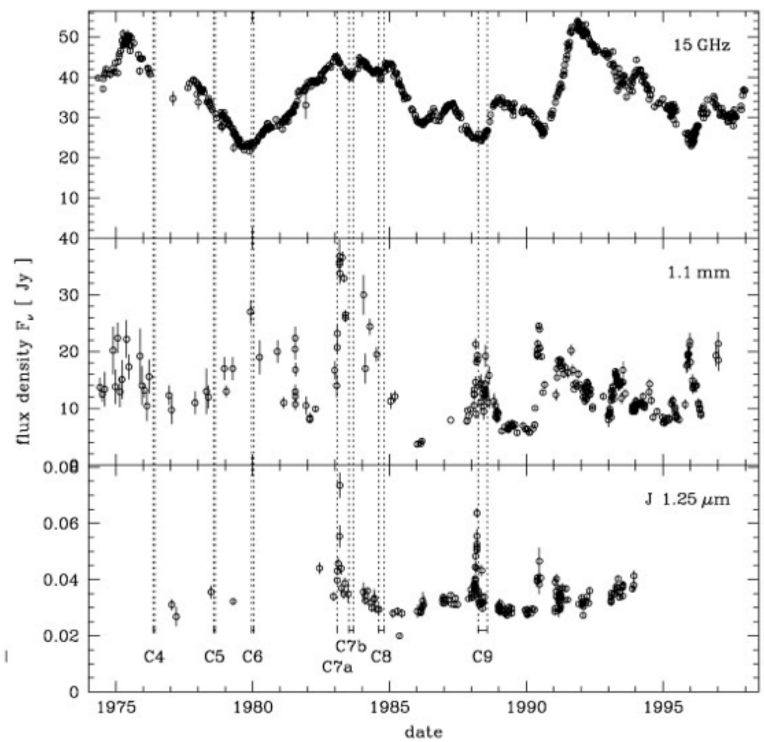
$$t_{th} = 4.6\ (\alpha_{0.01})^{-1}\ M_8 (R_{100rs})^{3/2}\ years$$

$R_{100rS} = R/100r_S$ - radius in $100r_s = 2\ GM_{bh}/c^2$
$M_8 = M_{bh}/1e8M_{sun}$

Long-term Quasar Variability

Soft State





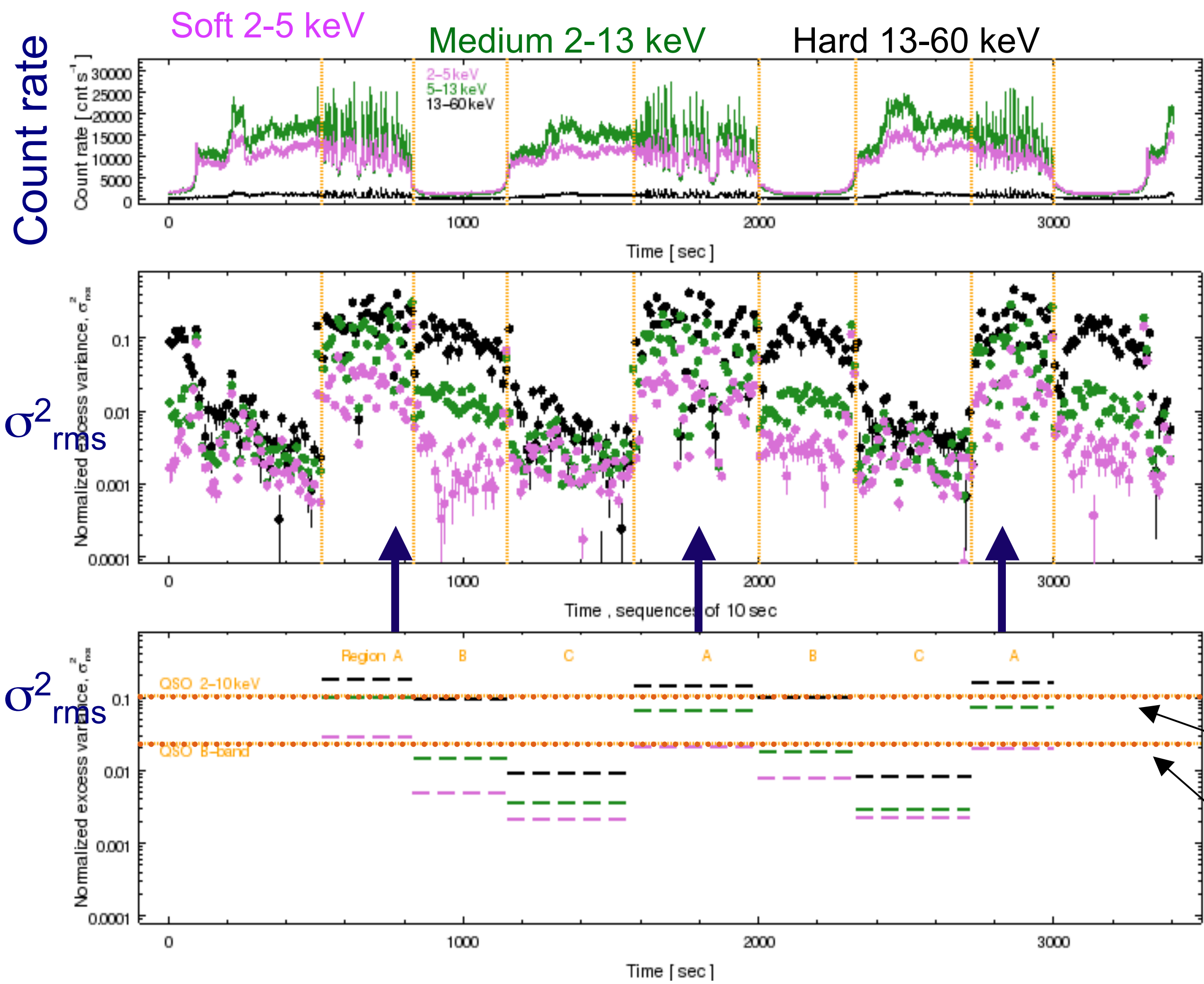
3C 273 Optical Variations
>100 years

Radio Outbursts

Outbursts in radio typically every 8.1 year (Zhang 2010)
Outbursts are accompanied by ejections of superluminal blobs

http://ned.ipac.caltech.edu/level5/March02/Courvoisier/Cour6_2.html

Variability: Scaling with BH Mass



GRS1915+105
X-ray variations
in microquasar

M_{BH}~14 M_{sun}
High accretion rate ~ M_{Edd}

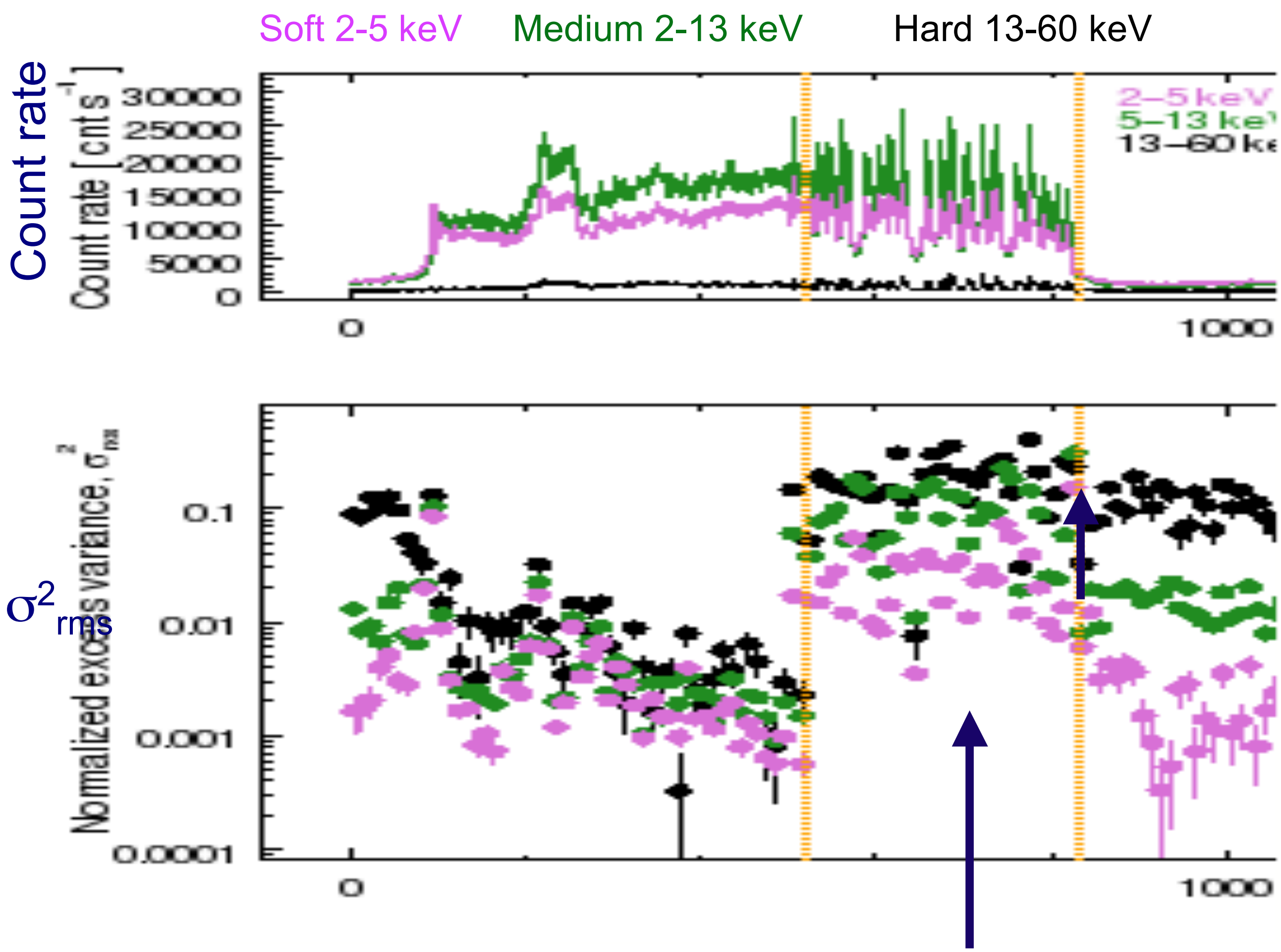
M_{BH}~8x10^8 M_{sun}

Time ~ M_{bh}
10 sec => ~18 yrs

3C 273
X-rays - corona/jet
Optical - disk

Sobolewska et al 2012 in preparation

Variability: Scaling with BH Mass

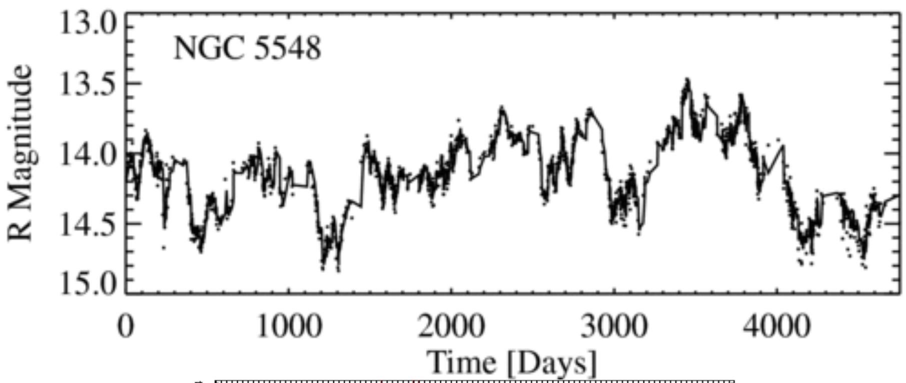


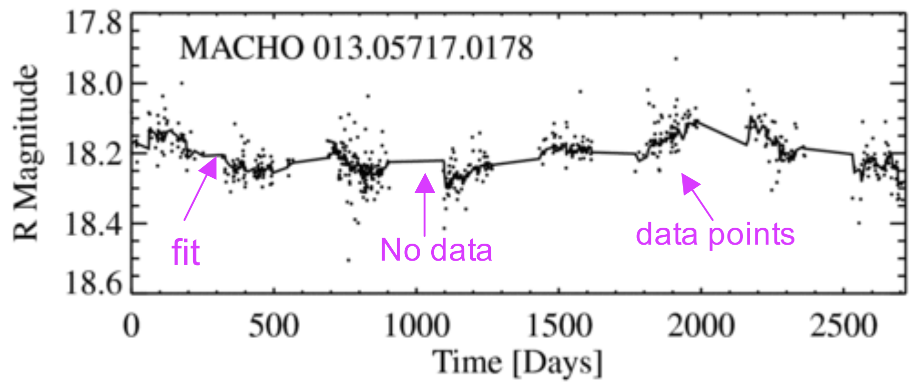
Time ~ M_{bh}

10 sec => ~18 yrs

Sobolewska et al 2012 in preparation

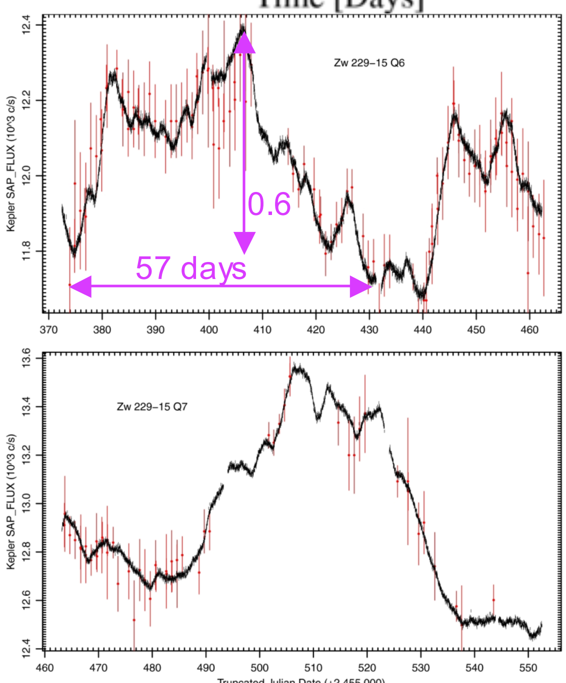
Optical Intrinsic Variations





Kelly, Bechtold & Siemiginowska 2009

Kepler Flux

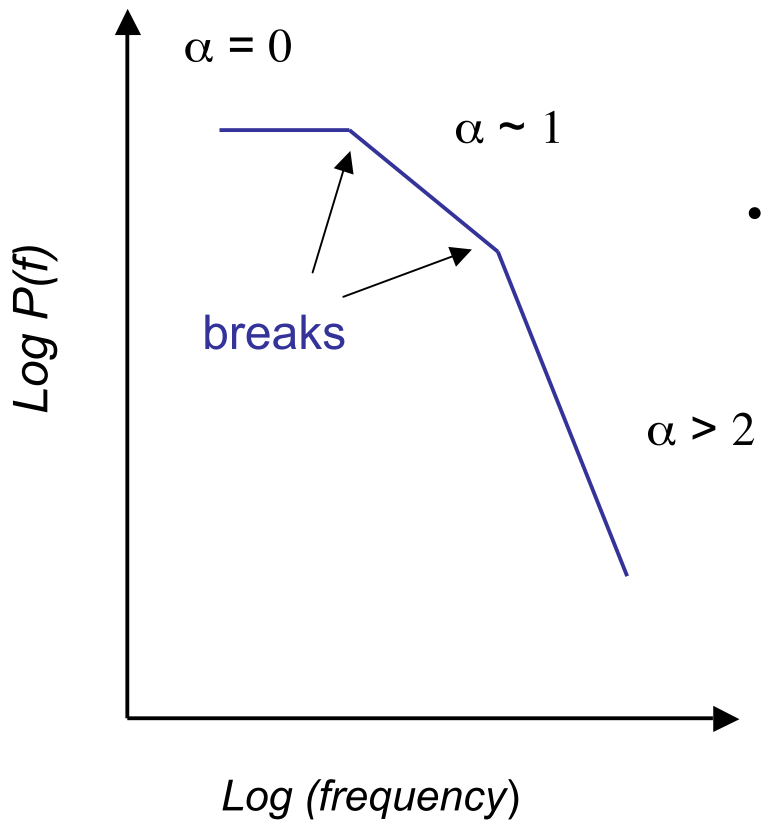


Mushotzky et a 2011 ~90 days

- Good optical data covering a few years
  MACHO, OGLE, AGN Watch, PanSTARRS
- Continuum variations on long and short times
- Relatively small amplitude (10-20%)
- No periodic variations

The best sampled optical light curves (every 30 min)
from *Kepler* - only a few AGN known
Probe orbital timescales to thermal timescales

Modeling AGN Variability: PSD



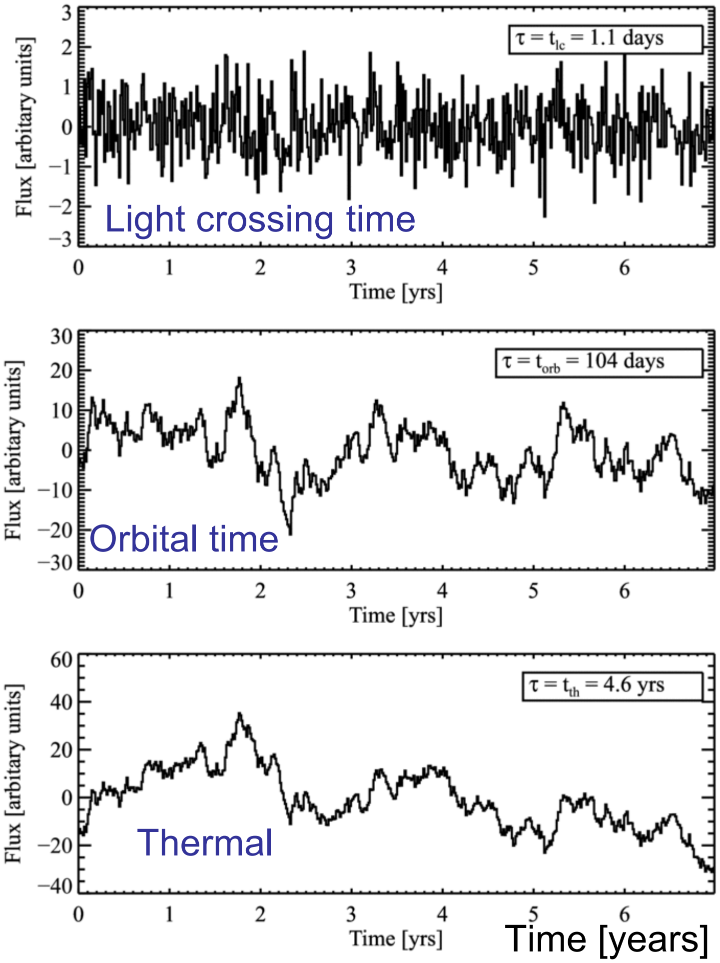
- PSD modeling:
  - Non-parametric
  - good for quantifying the variability (e.g. characteristic time-scales)
- But has several limitations:
  - limited in discriminating between variability models
  - Shape evolves with time, e.g. dramatic changes between different spectral states
  - Light curves have a finite duration time and often non-uniform sampling causing windowing effects
  - Power from low frequency can leak into high frequency (e.g. red noise leak) and from high frequency to low frequency (aliasing)
  - Periodicity in the optical data due to observational constraints by the Earth orbit etc.

see Uttley & McHardy 2001, Uttley et al. 2002, Vaughan et al. 2003, Uttley et al. 2005

Modeling Variability: Time-series

- Assume that the observed variations are generated by an underlying stochastic process - a parametric model
- Observations are different realizations (samples) from that process
- Main goal: determine the NATURE of the physical system responsible for that process.
- Modeling the data (light curves) directly is free of the windowing effects.
- Gives unbiased estimates of the characteristic timescales and variance of the process.
- Needs a parametric model for a light curve - use CAR (continuous auto-regression or OU) - characteristic frequency, rate of perturbations and amplitude

Simulating Optical Lightcurves



$M_{BH} = 10^8 M_{sun}$ and with different timescales
7 years, sampled every 5 days

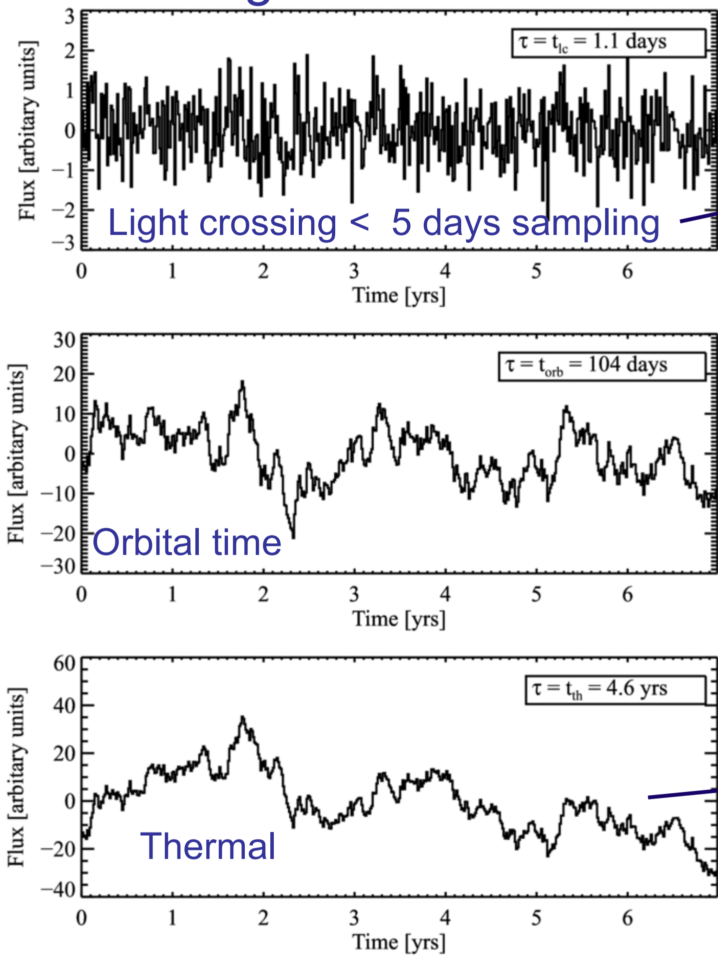
Kelly, Bechtold & Siemiginowska, 2009 ApJ 730 52

- Simple Stochastic process
- $P(f) \sim f^{-2}$ are consistent with damped random walk
- $P(f)$ - Break at the characteristic timescale of the process
- Possible link to physical parameters:

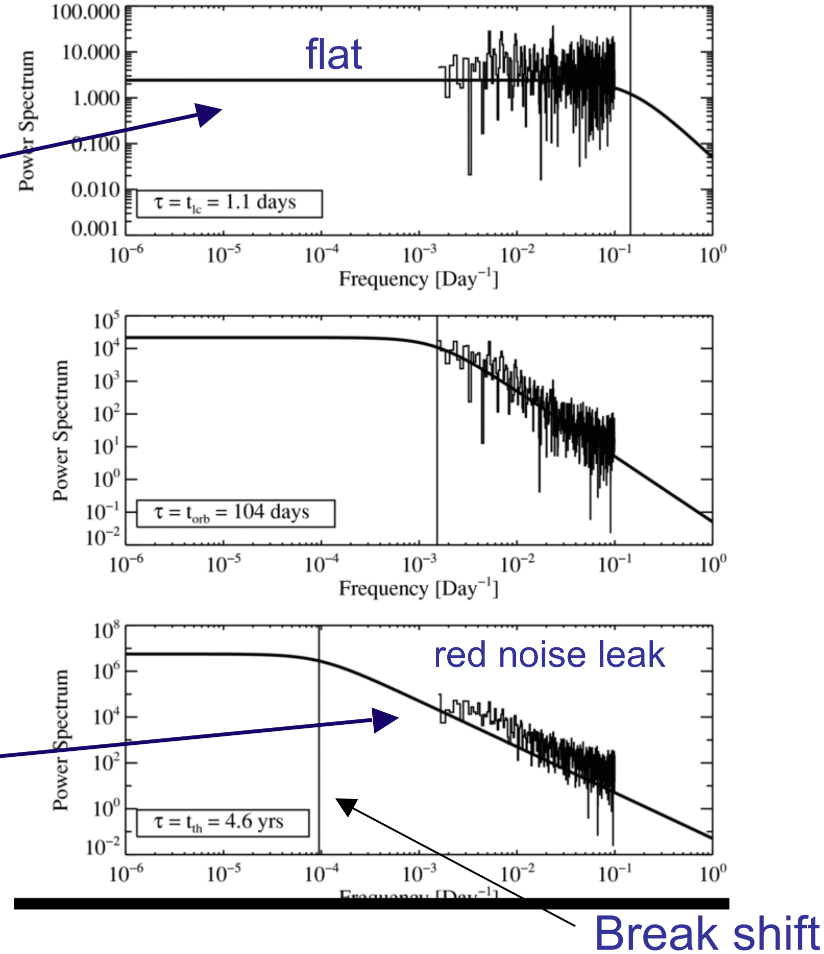
- Characteristic frequency, i.e. relaxation time of the process, might relate to the time required for diffusion to smooth out local accretion rate perturbations
- Amplitude of the driving noise, variability resulting from local turbulence or other perturbations to the magnetic field etc.

Simulating Optical Lightcurves

CAR Lightcurves



Power Spectrum



$M_{BH} = 10^8\ M_{sun}$ and with different timescales
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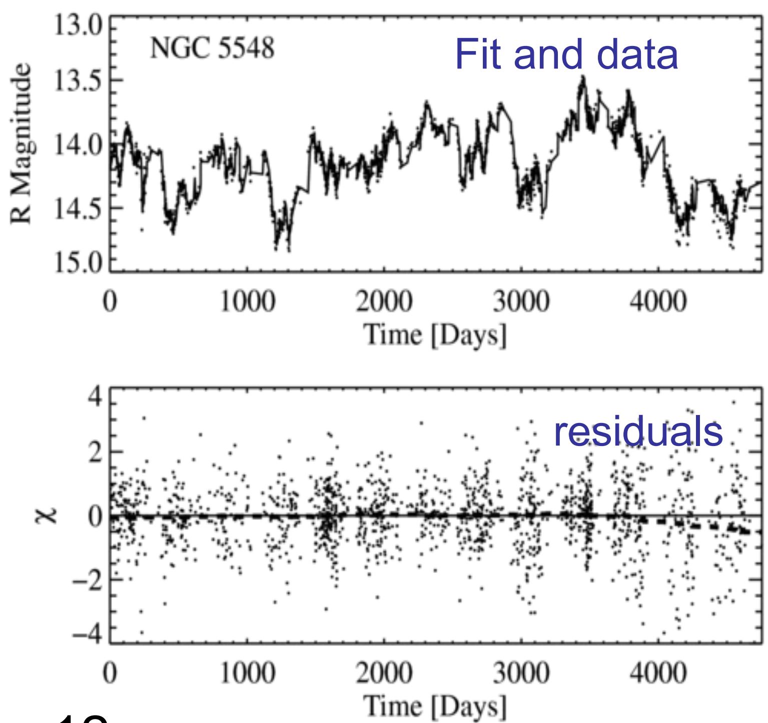
Kelly, Bechtold & Siemiginowska, 2009 ApJ 730 52

Modeling Optical Light curves

NGC 5548

R Magnitude



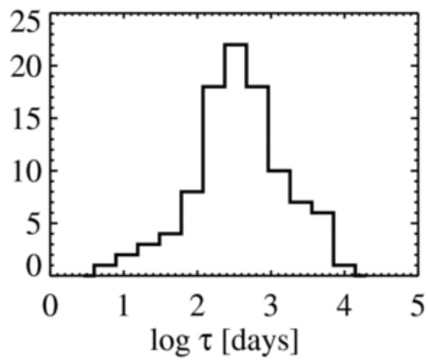
~12 years

- 100 quasars with optical light curves
- Defined likelihood and performed MCMC analysis to model the observed light curves using Bayesian methodology.
- Best fit light curve, characteristic timescales and variability parameters
- NGC 5548 fit with the characteristic timescale of 214 days

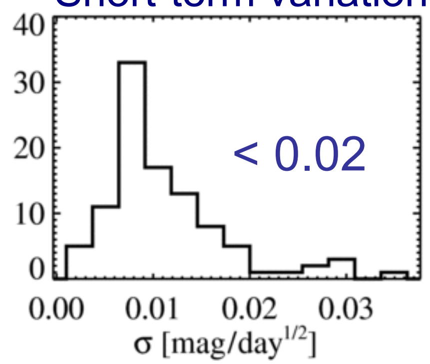
Modeling Optical Light curves

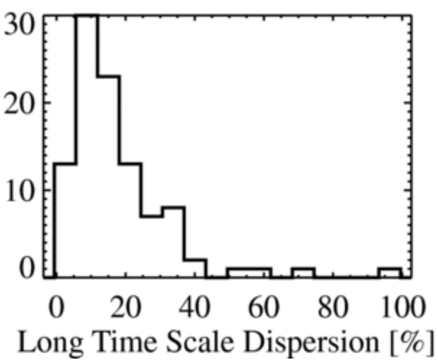
Sample of 100 quasars: MACHO, PG sample, AGN Watch

timescale 10-10^4 days

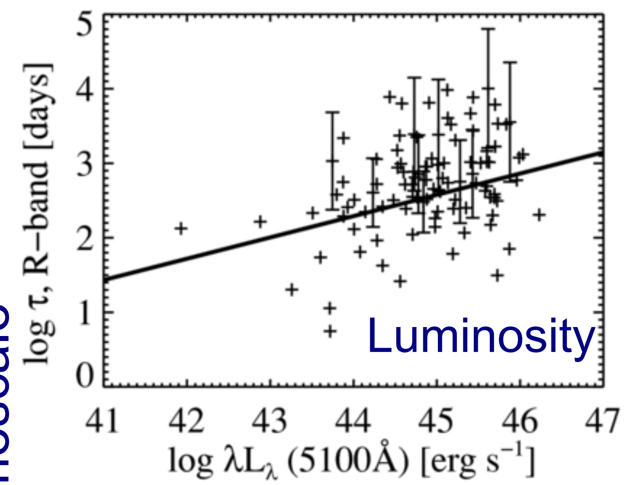


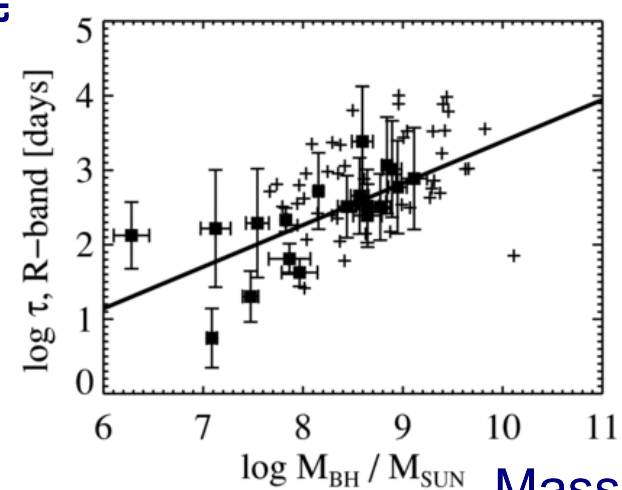
Short-term variations





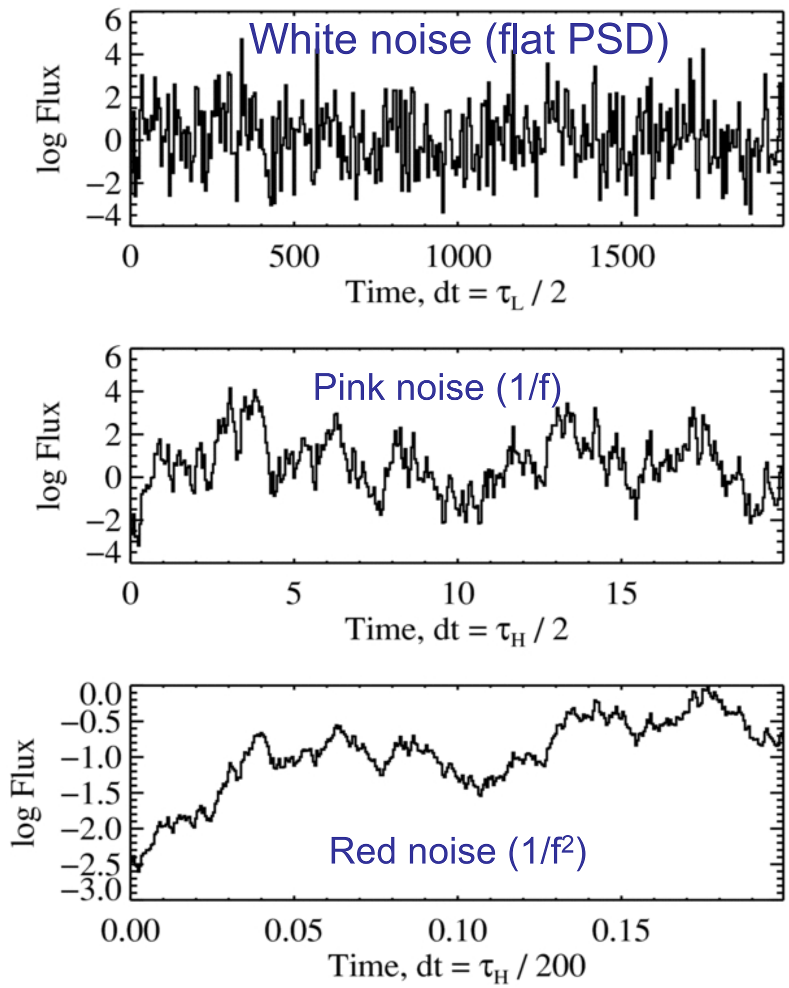
timescale





Mass

Simulating X-ray Light curves



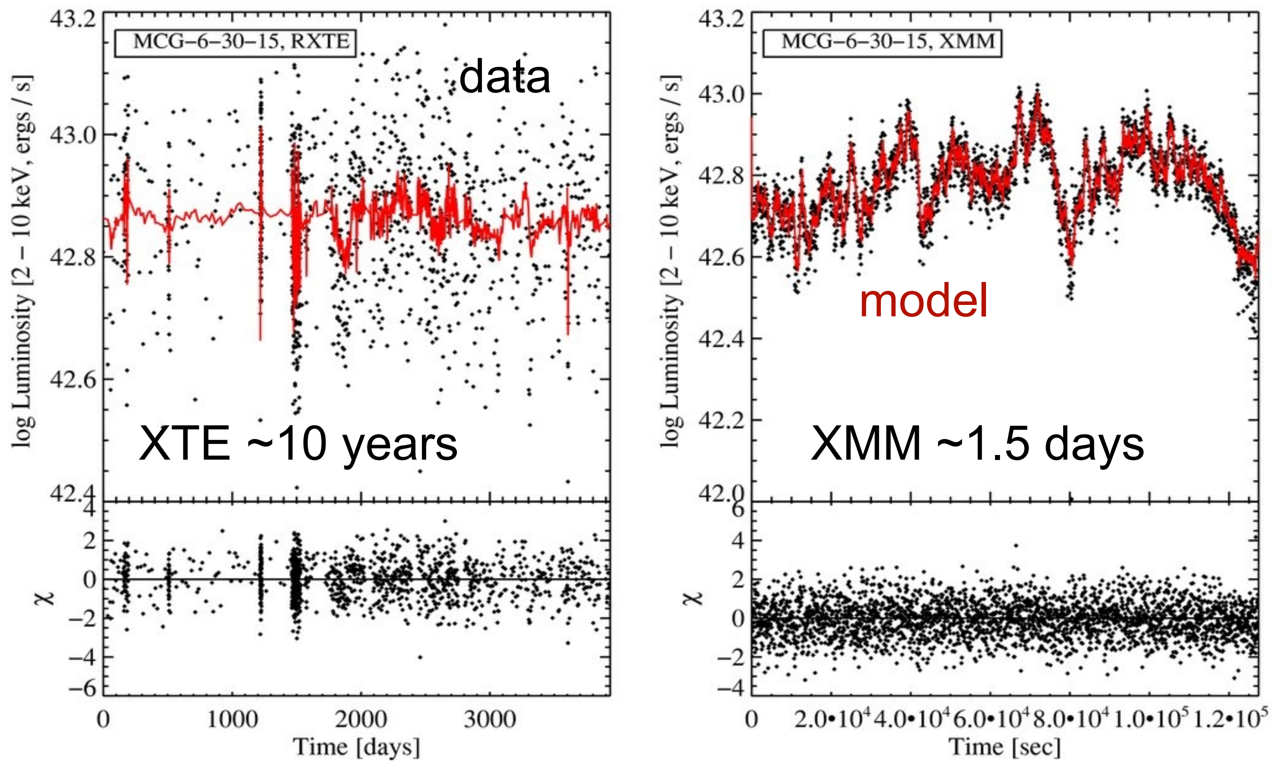
Kelly, Sobolewska & Siemiginowska, 2011 ApJ 730 52

- X-rays from hot corona
- **Two breaks in PSD** =>
  two characteristic timescales
- **Linear Combination** of Stochastic processes
- Model light curves - Likelihood analysis
- Model applied to 10 local AGN
- Long timescales with XTE (Sobolewska & Papadakis 2009) and short timescales with XMM-Newton

Observations probe different parts of the same process

Modeling X-ray Variability

MCG-6-30-15

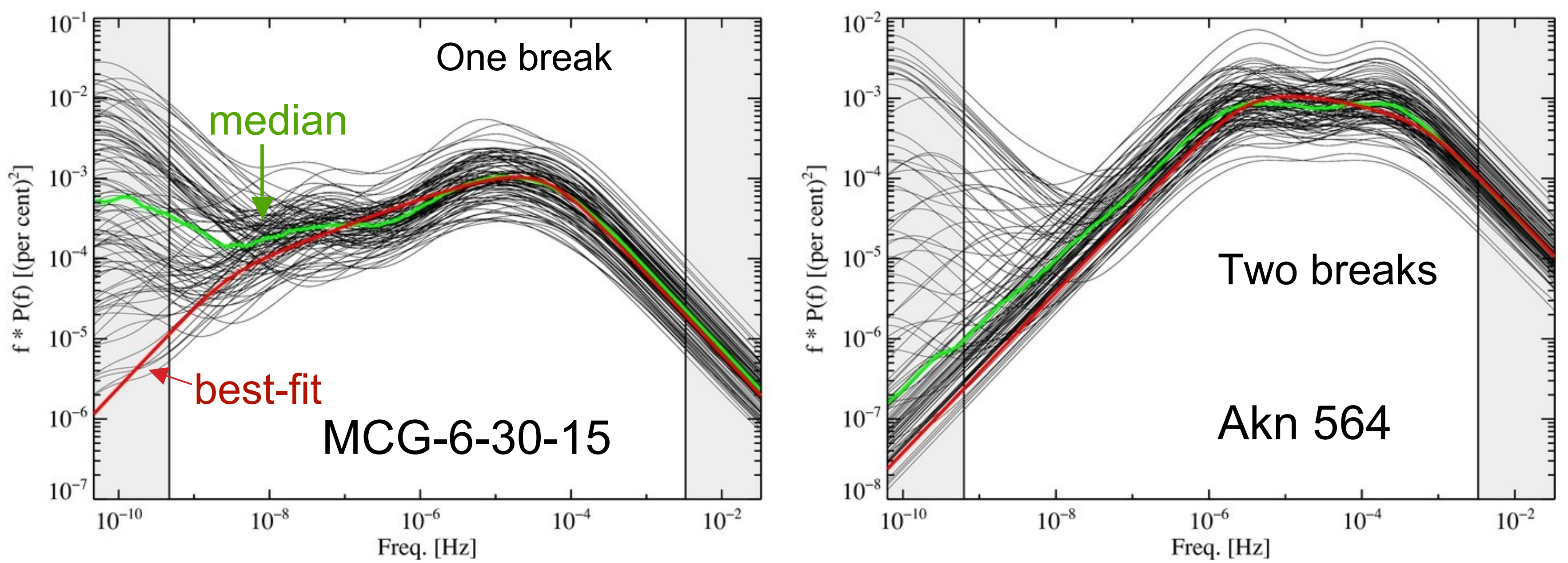


Time [days] Time [sec]

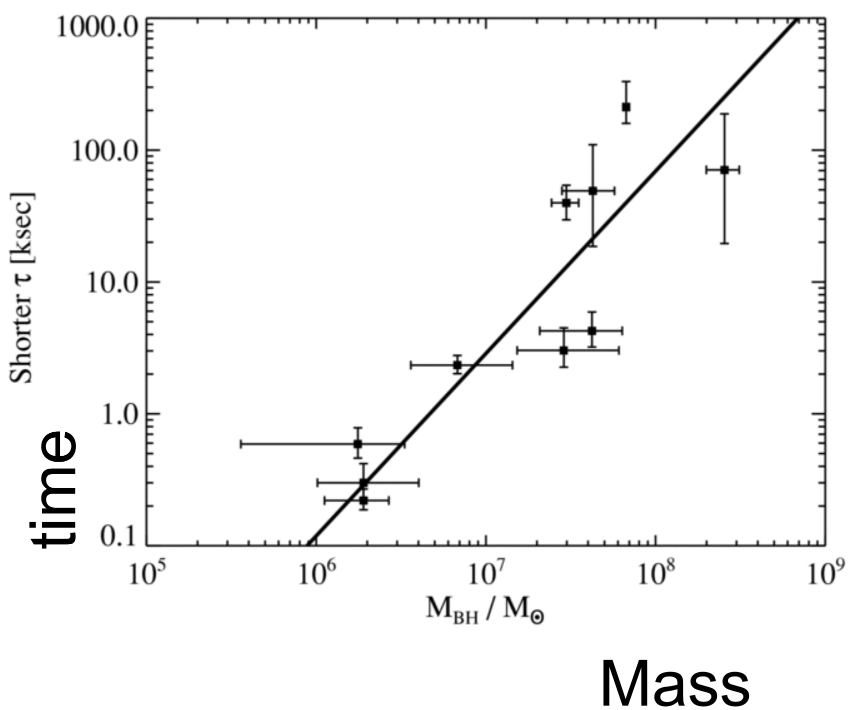
Kelly, Sobolewska & Siemiginowska, 2011 ApJ 730 52

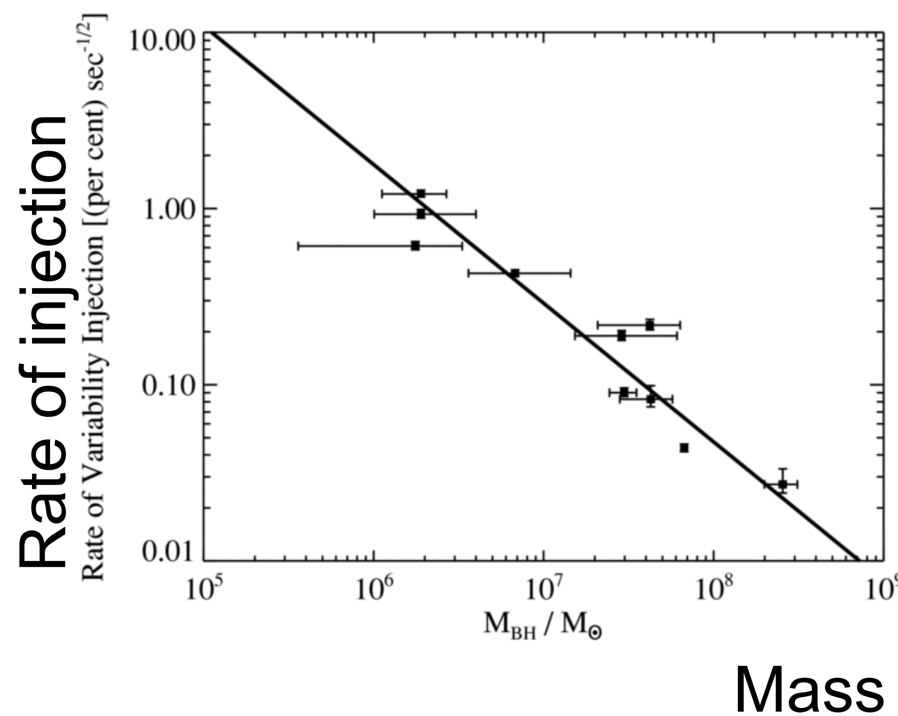
Modeling X-ray Variability

100 realizations of the PSD given the observed lightcurves



Modeling X-ray Light Curves



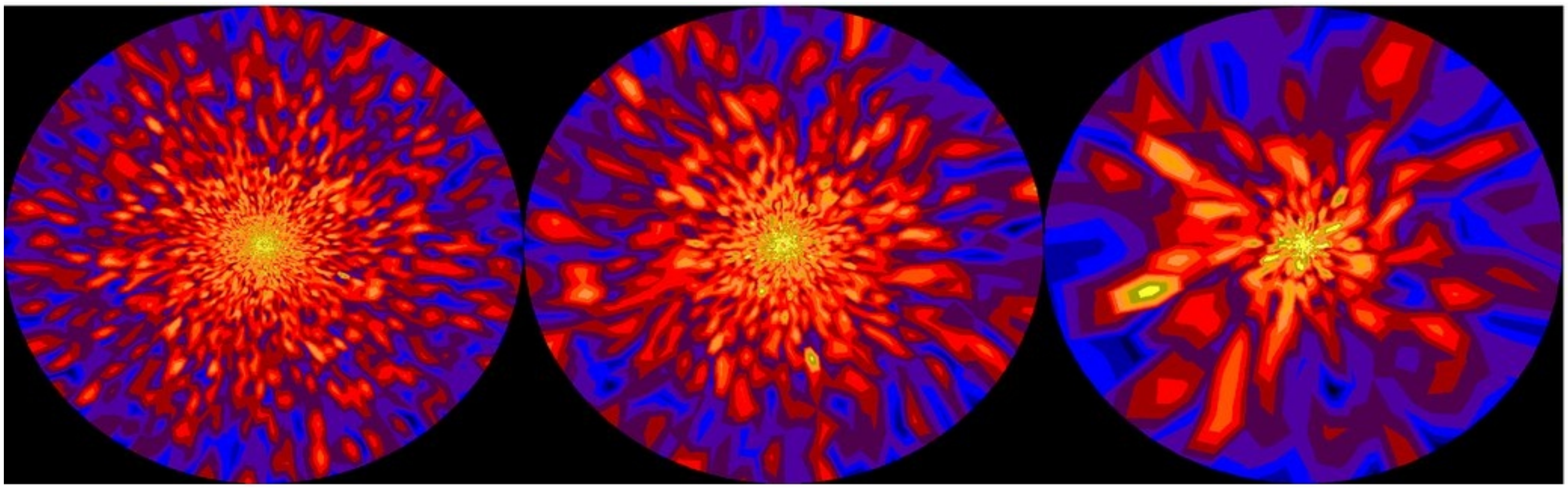


Modeling Light Curves: Summary

- Variations consistent with the stochastic process -perturbations to the luminosity could be caused by magnetic turbulence.
- Perturbations smoothed on the timescales shorter than the orbital or thermal timescales
- Timescales correlates with M_{bh} and luminosity
- Significant anticorrelation between M_{bh} the amplitude of the driving noise => very good constraints on the mass.
- Both short and long-term observed light curves due to the same process.
- Orgin of optical and X-ray variations partially shared.
- Mixed stochastic process describes the evolution of viscous, thermal and radiative perturbations

Stochastic View of the Accretion Disk

Dexter and Agol 2011 ApJ 727 L24



n=2200 n=550 n=140

Temperature maps assuming that Temp(ϕ, r, $time$) follows a damped random walk in each independent zone n assuming the local temperature characteristic timescale of 200 days.

Outbursts, Flares and Shortest Timescales

- Jet activity - large amplitude, rapid rise and short durations - not described by the stochastic random walk in linear regime
- Best observational examples can be found in gamma-rays and TeV
- Kepler optical variations - probe dynamical timescales, data not consistent with the linear regime

Conclusions

- AGN Type 1 in Soft State
- Microlensing constraints on the geometry - not a standard thin disk
- Optical variations on long times consistent with a random process
- Characteristic timescales consistent with thermal and orbital times.
- Physical process? Instabilities - *see Agnieszka Janiuk talk.*
- Recent Kepler light curves probe the shortest timescales, close to the light-travel time - not consistent with the stochastic process, indicate a non-linear behaviour.
- Variability can be used to measure the BH mass.
- Long term light curves needed