AGN Variability

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Variable AGN 2017

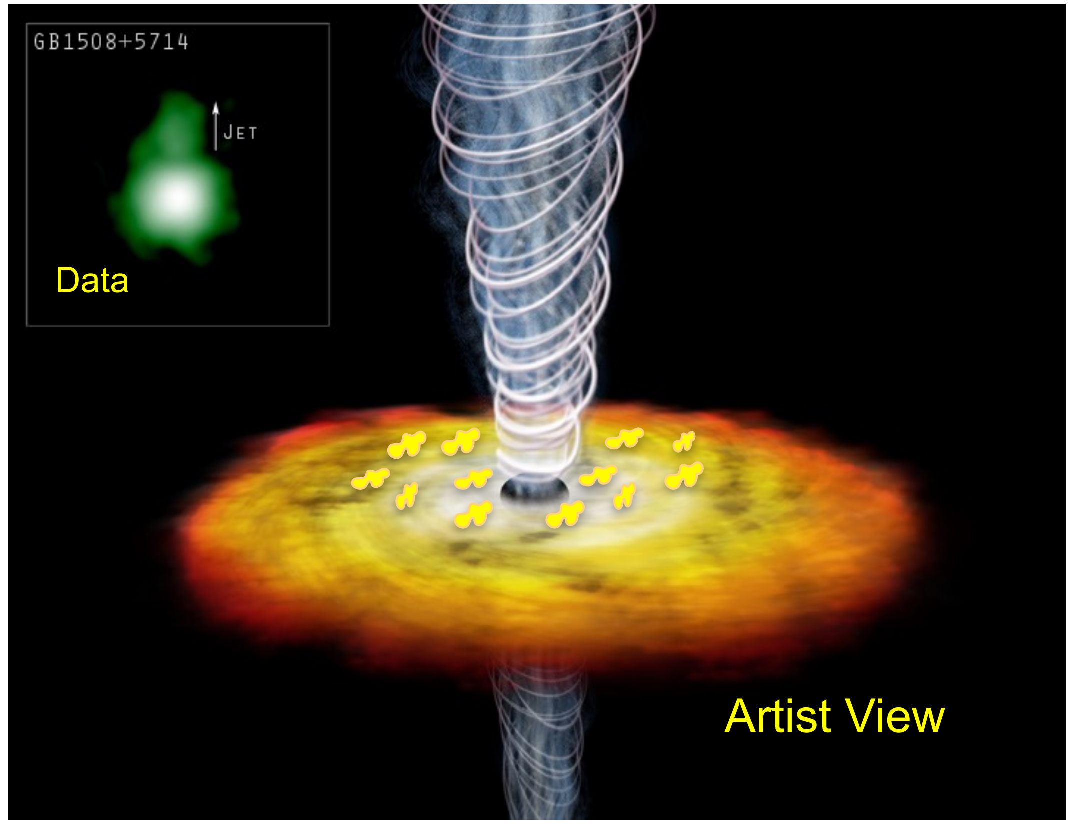
- What do we know about AGN variability in general?
- Are changing-look AGN and TDEs the extreme tail end of this distribution?
- How can we extend theoretical progress to learn about regular to extreme variability in AGN?
- What can changing-look AGN, TDEs, and microlensing teach us about the theory of accretion physics and the AGN/galaxy connection?
- How can we devise strategies to most efficiently look for these phenomena with the upcoming generation of multi wavelength telescopes, including Pan-STARRS, PTF/ZTF, LSST, eROSITA, SKA, WFIRST?

Variable AGN 2017

- Observations:
  - surveys - finding extreme objects
  - tidal disruption events
  - changing look quasars
  - reverberation
  - microlensing
  - spectroscopy
- Analysis methods:
  - power spectra
  - structure function
  - time series - damped random walk (DRW), CARMA
- Theory:
  - AGN structure - disk, corona, clouds, torus, outflows
  - emission processes - continuum, emission lines, photoionization
  - physical processes - fueling, instabilities

AGN Model Components

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



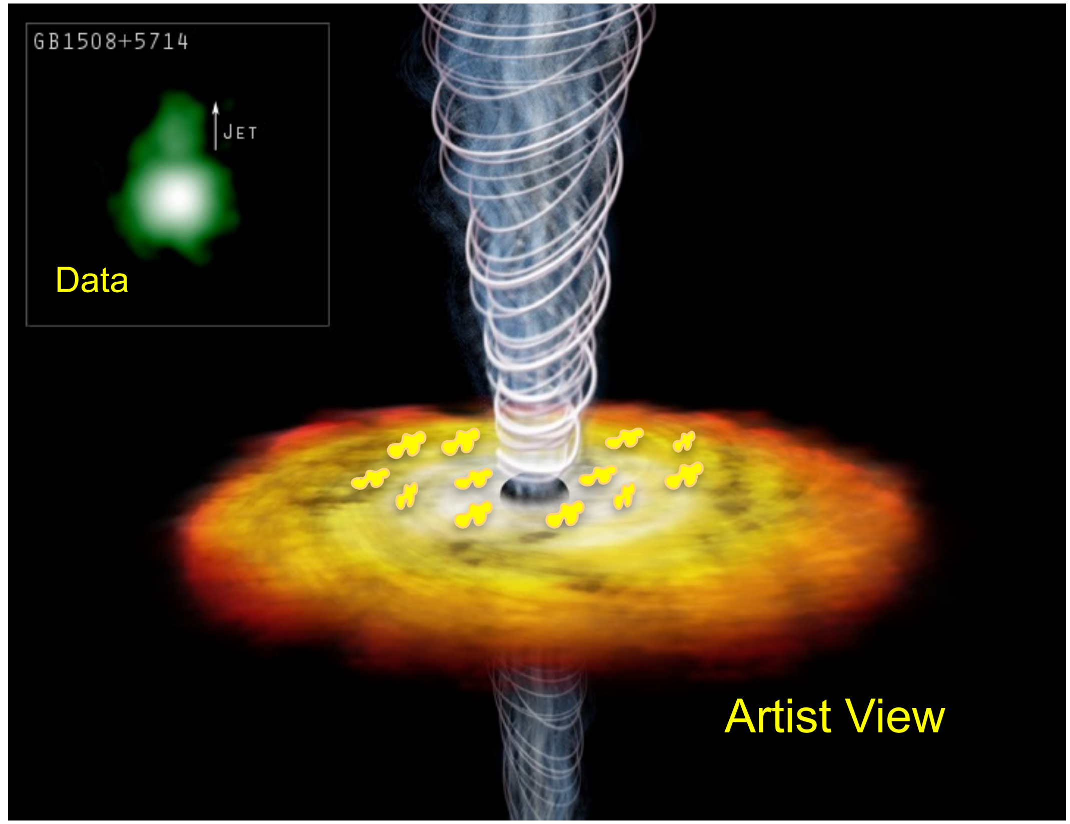
Black Hole gravity is fundamental to the AGN Power

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, evolution, black hole growth etc.

AGN Variability

- On the line of site
  - Occultation events - clouds, torus, outflows, BAL
  - Microlensing
- Intrinsic to the AGN
  - Optical/UV emission
    - Continuum - Accretion flow
    - Emission lines - BLR
    - Photoionization
  - X-rays
    - Corona, hot plasma
    - Outflows (also in radio, γ-rays)
    - Reflection/irradiation
- Dramatic events?
    - TDE
    - Mergers (Haiman 2017)
    - ??



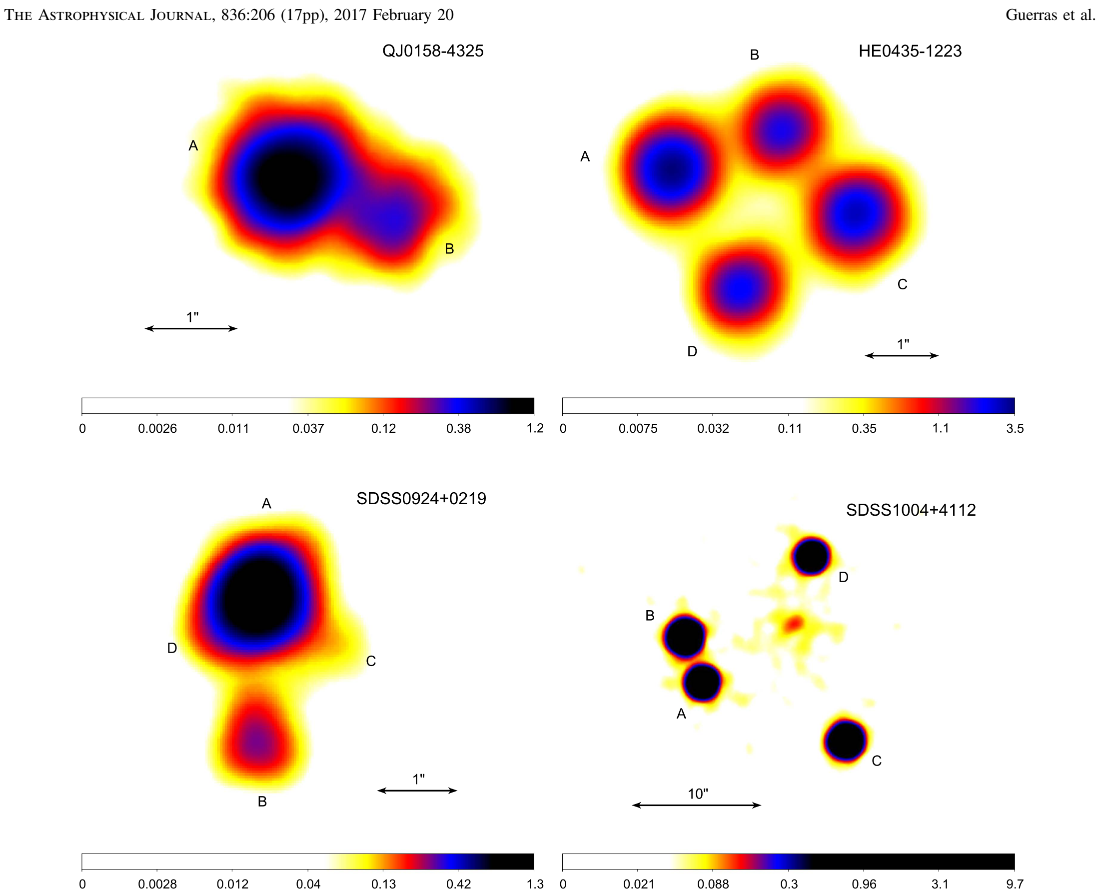
Microlensing
Constraints on Geometry

- 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

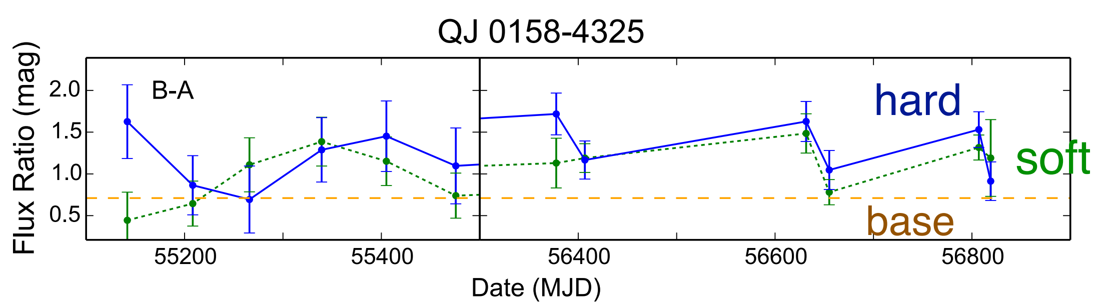
- References: Kochanek 2004, Pooley et al. 2007, Morgan et al 2010, 2012, Mosquera and Kochanek 2011, Chartas et al 2016,

Microlensing

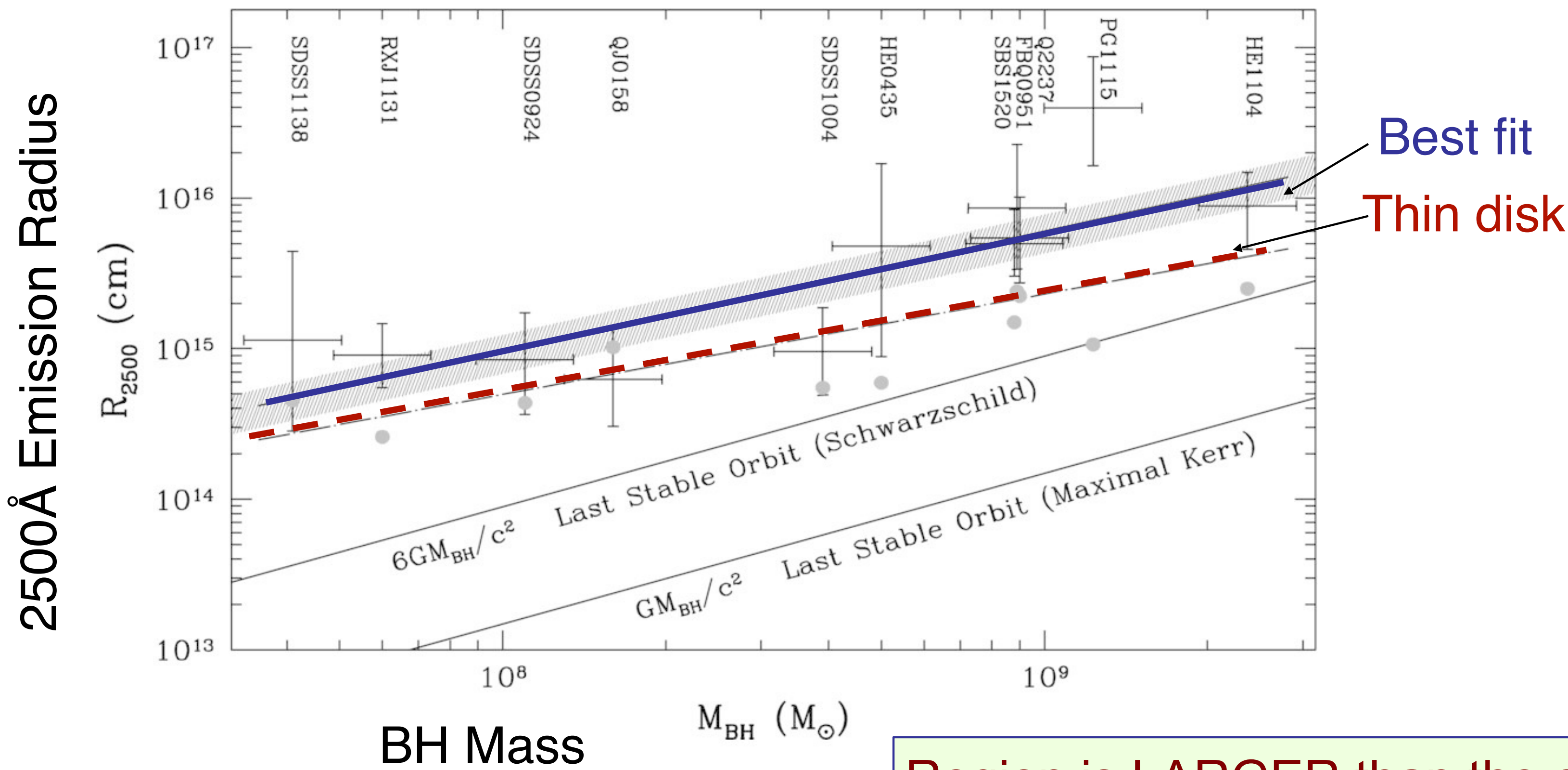
X-ray Images of Lensed Quasars observed with Chandra



Guerras et al. 2017



Microlensing Constraints
Size of the Optical Emission Region

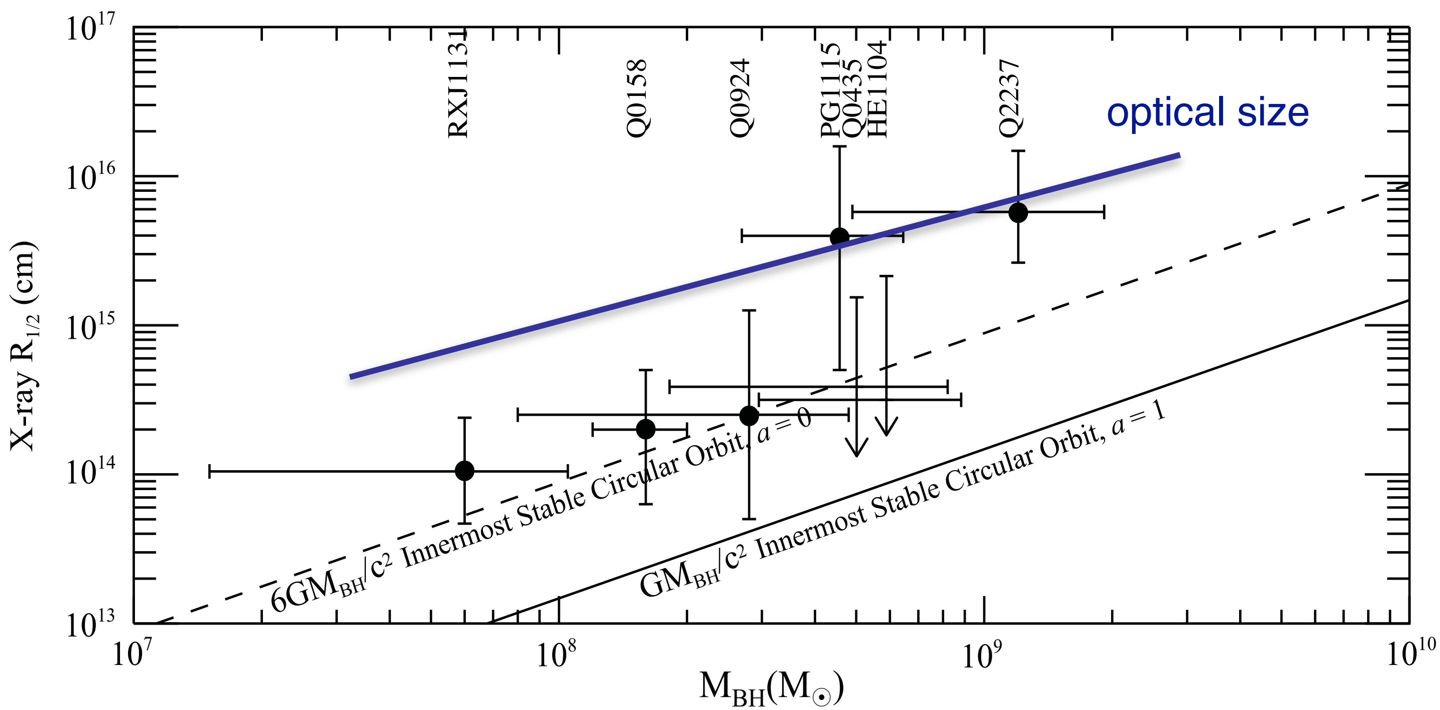


Region is LARGER than the one predicted by the standard Shakura-Sunyaev disk

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

Size of the X-ray Emission Region

X-ray Emission Size



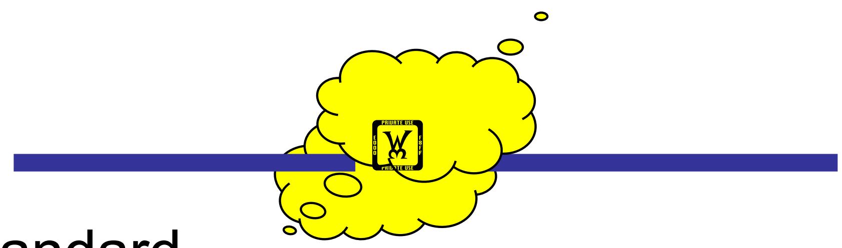
BH Mass

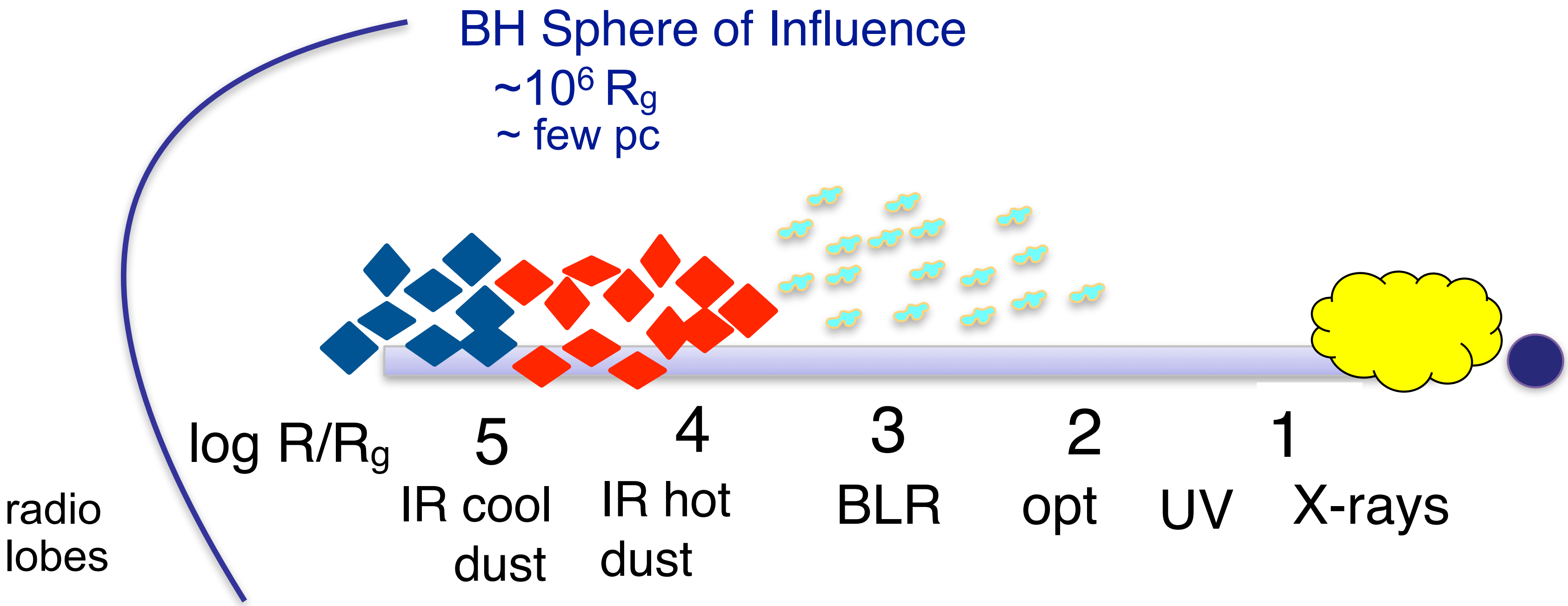
Chartas et al. 2016, 2017

Disk truncation? Fe Kα line at $R < 8.5 r_g$

AGN (Quasars) Innermost geometry

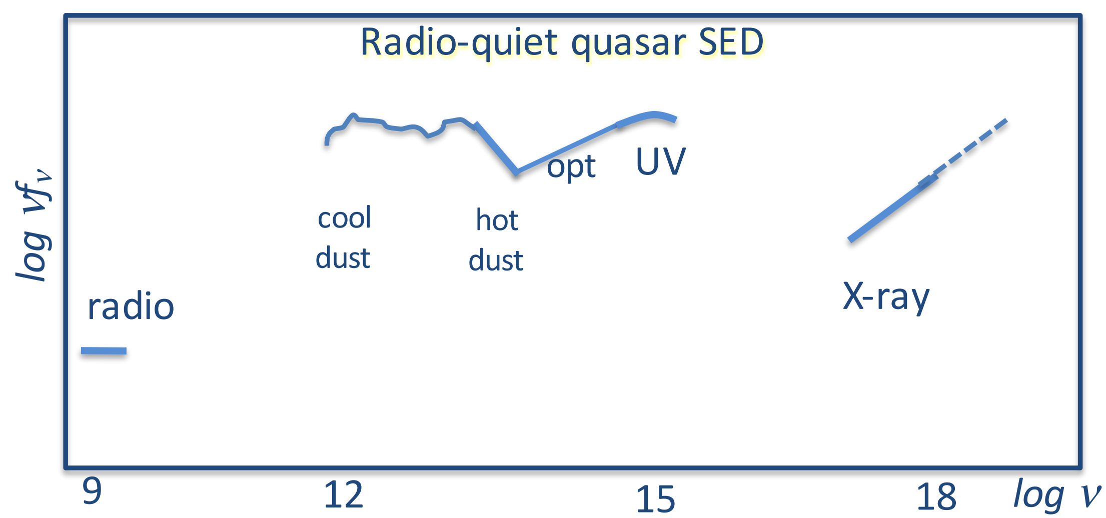
- Corona (X-rays) is more compact than the optical-UV (disk)
- Optical-UV disk more extended than the standard thin disk.





Simple?

Reverberation studies



Elvis et al. 1994

Credit:
Martin Elvis

AGN Timescales

- Light crossing time at 100 r_s

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

- Orbital

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

- Thermal (note the viscosity dependence)

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

$R_{100r_S} = R\ /100r_S$ - radius in $100r_s = 2\ GM_{bh}/c^2$

$M_8 = M_{bh}\ /10^8 M_{sun}$

Note => $t_{th} \sim (h/r)^2 t_{visc}$

Accretion Disk Instabilities

Stability curve

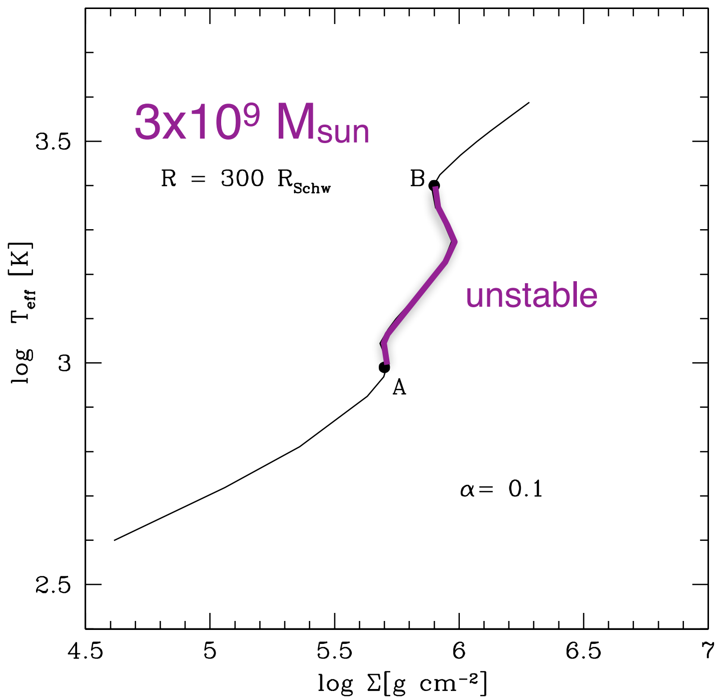


FIG. 2.—Stability curve calculated for the disk around a supermassive black hole of $M = 3 \times 10^9\ M_\odot$ at the radius $R = 300R_{\rm Schw}$. The viscosity parameter is $\alpha = 0.1$. Point A is the starting point of the ionization instability cycle, and the instability ends at point B.

Ionization Instability zone

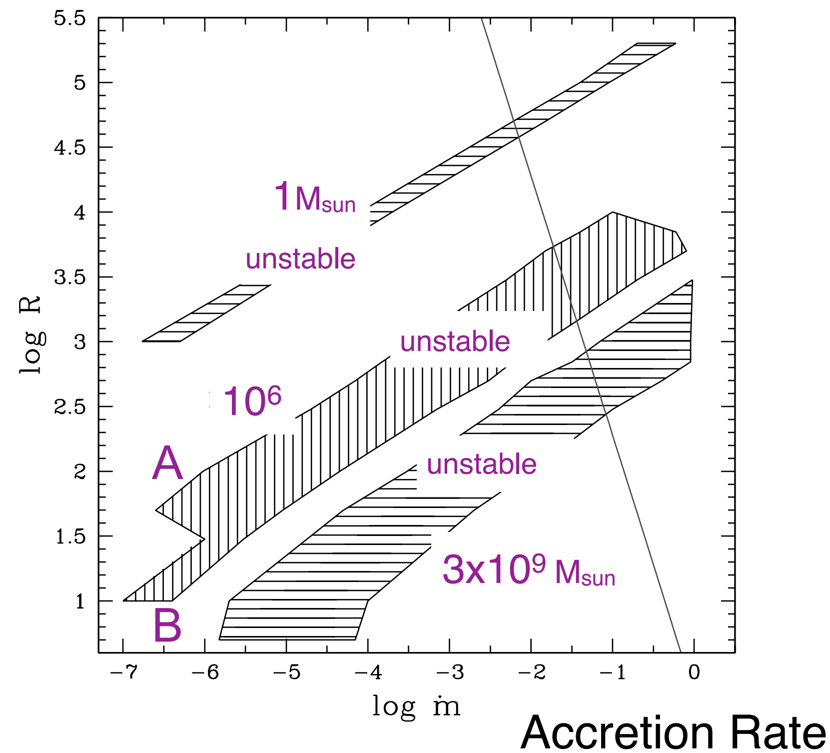
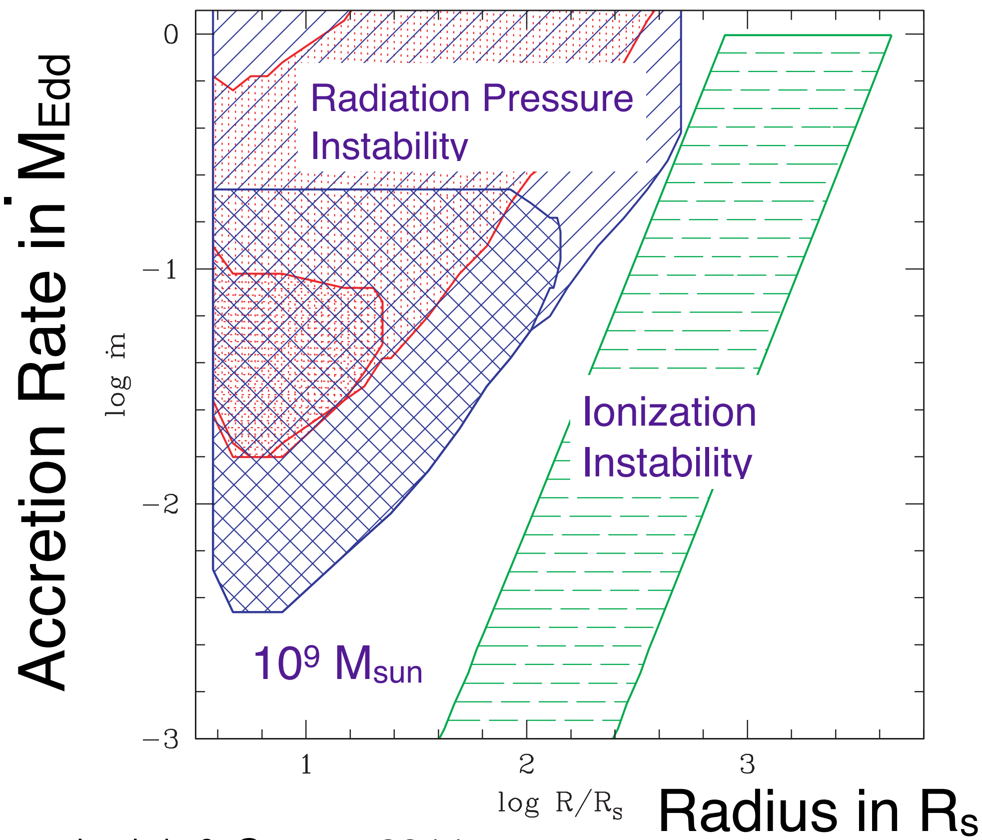


FIG. 3.—Radial extension of the ionization instability zone as a function of the accretion rate. The contours correspond to the turning points A and B on the S-curve (see Fig. 2). The thick solid line marks the transition radius, resulting from the ADAF prescription (see text). The black hole mass is $M = 1\ M_\odot$ (*top contour*), $10^6\ M_\odot$ (*middle contour*), and $3 \times 10^9\ M_\odot$ (*bottom contour*). The viscosity parameter is $\alpha = 0.1$.

Siemiginowska, Czerny & Kostyunin 1996
Janiuk, Czerny, Siemiginowska & Szczerba 2004
Menou & Quataert 2001

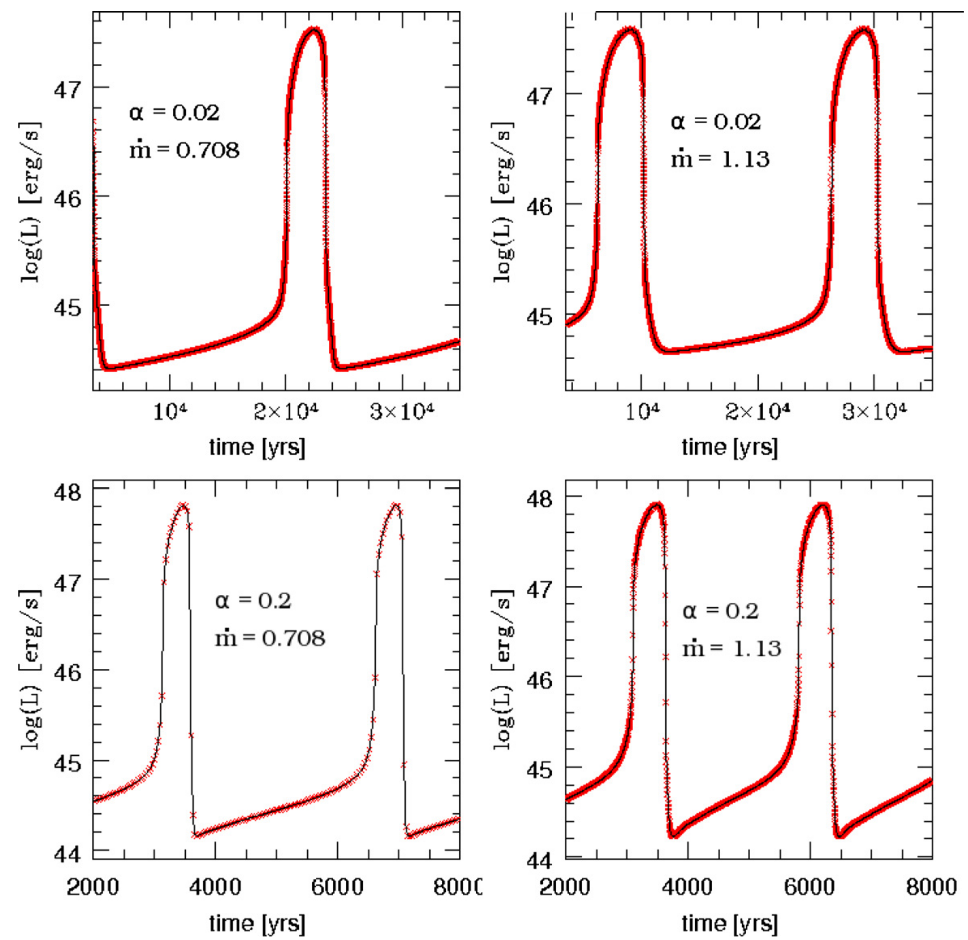
Accretion Disk Instabilities



Janiuk & Czerny 2011

Outbursts due to RP instability

10^8 M_{sun}



Czerny, Siemiginowska et al. 2009

AD Radiation Pressure Instabilities

Outbursts Durations

viscosity

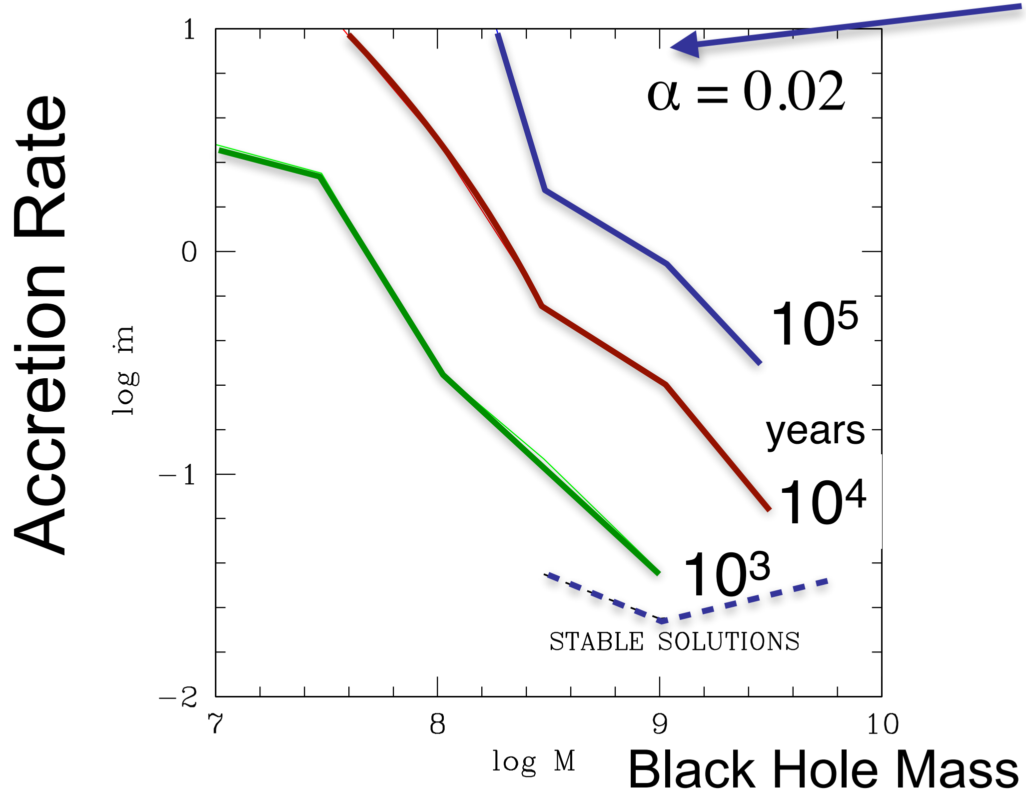


Figure 4. Contour maps of the constant outburst duration time, in the black hole mass vs. accretion rate (Eddington units) plane. The outburst durations are given for each curve in years. The viscosity parameter is taken as $\alpha = 0.02$.

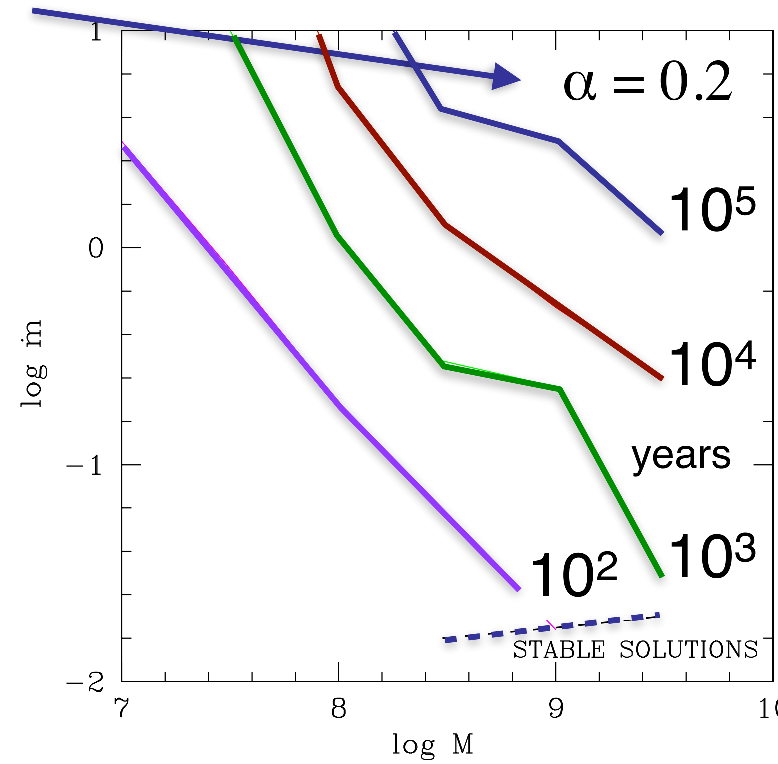
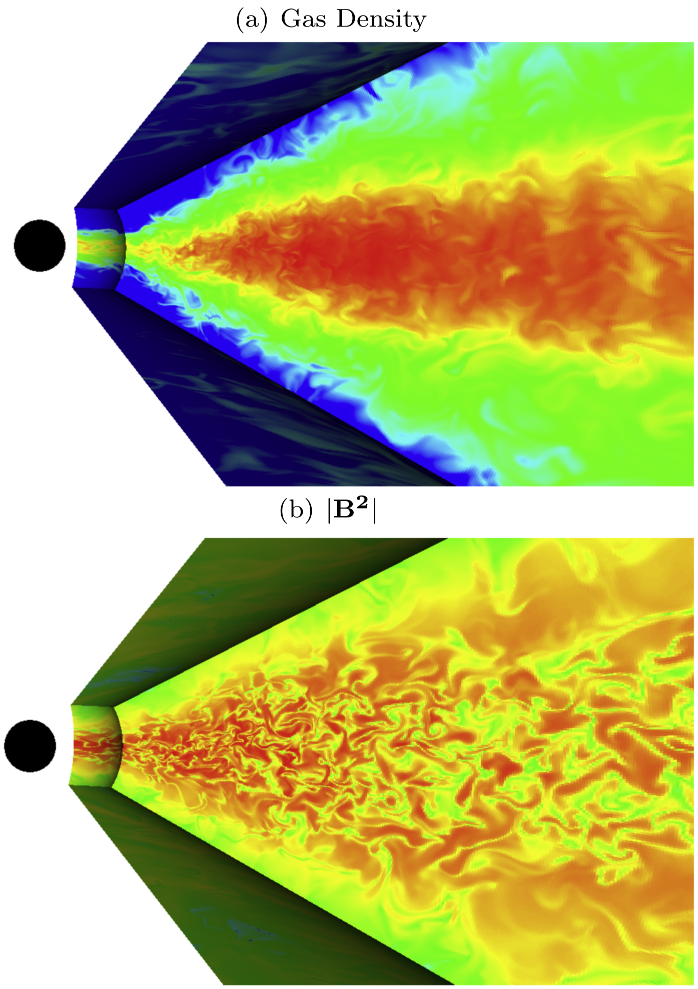
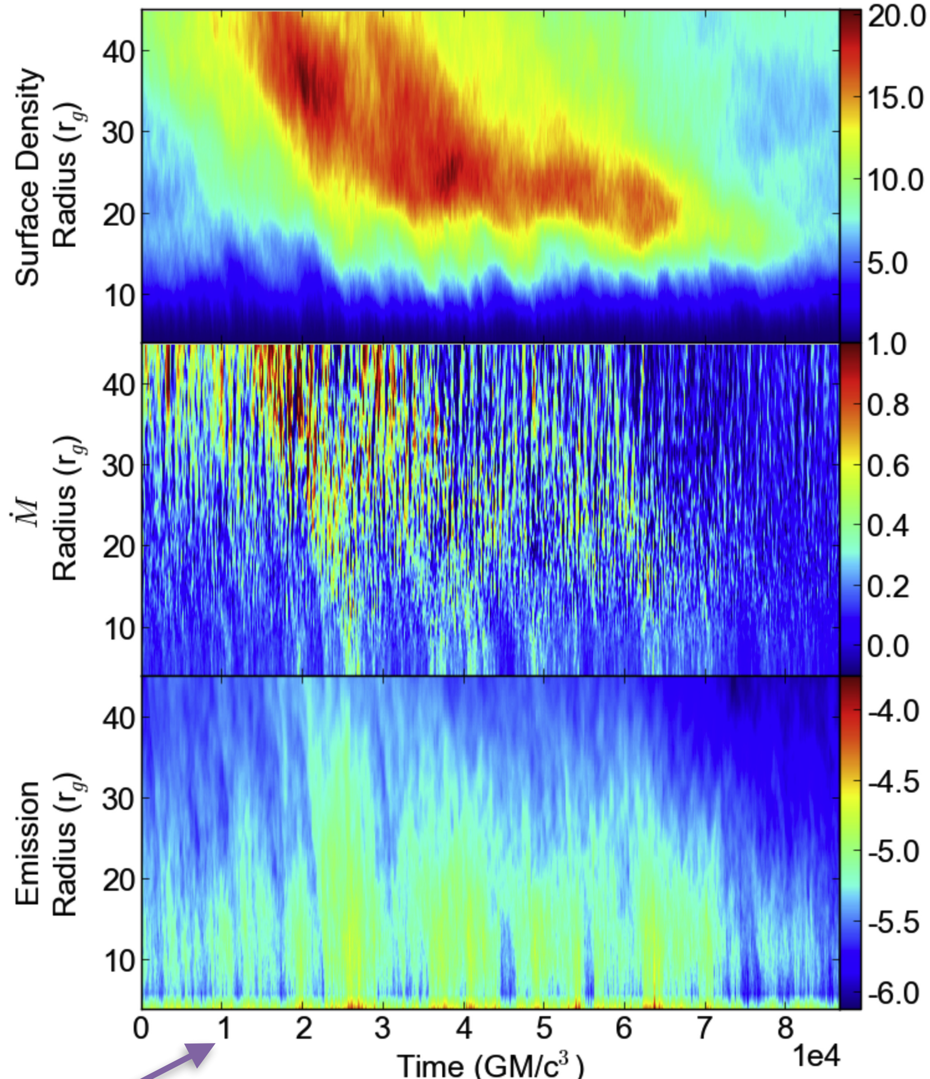


Figure 5. Contour maps of the constant outburst duration time, in the black hole mass vs. accretion rate (in Eddington units) plane. The outburst durations are given for each curve in years. The viscosity parameter is taken as $\alpha = 0.2$.

Czerny, Siemiginowska et al. 2009

Propagating Fluctuations in Accretion Disk Global Simulations



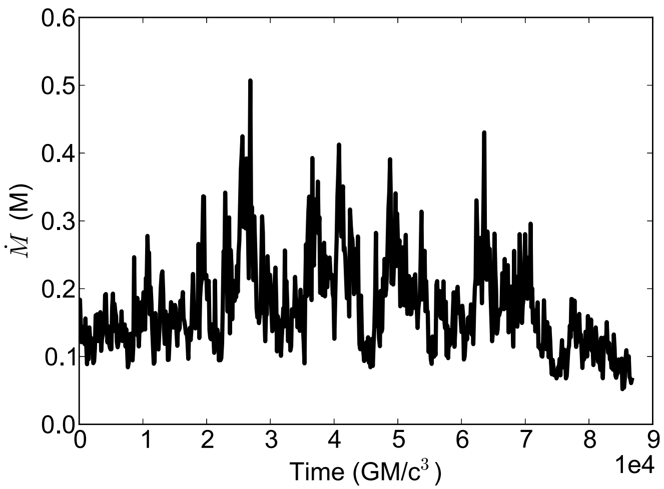


5e5 sec for 10^7 Msun

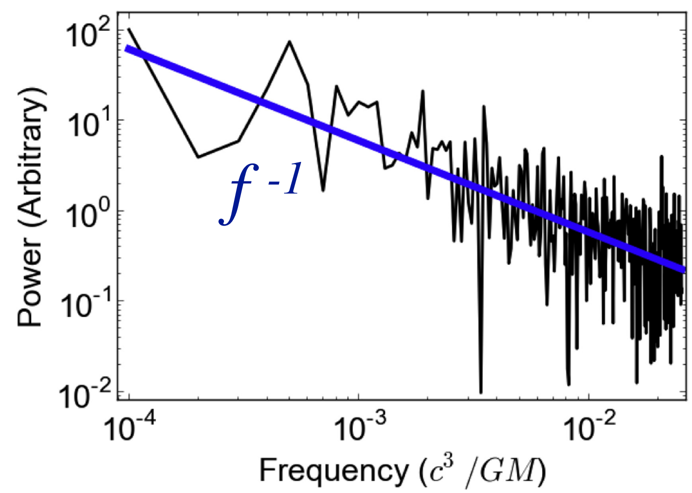
Hogg & Reynolds 2016

Propagating Fluctuations in Accretion Disk Global Simulations

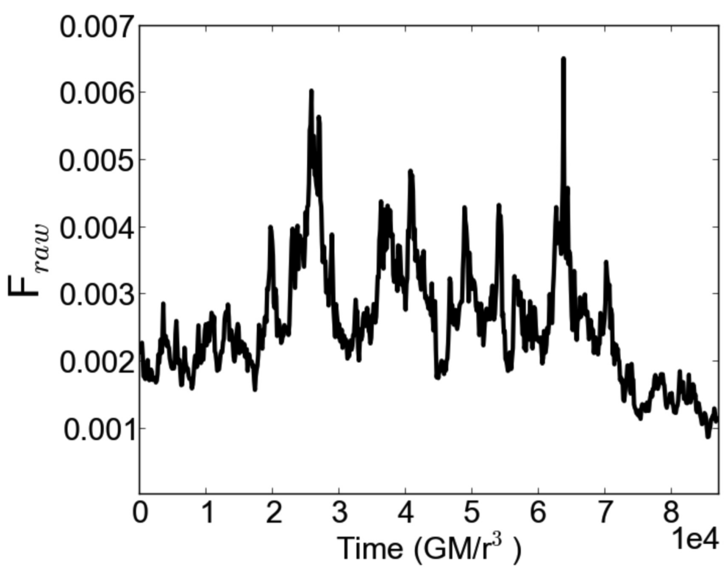
(a) $\dot{M}$ at ISCO



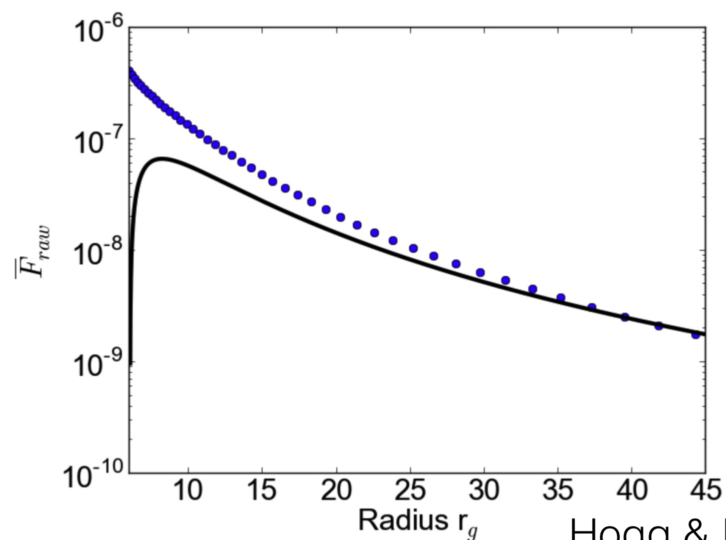
(b) PSD of $\dot{M}$ at ISCO



(a) Synthetic Light Curve



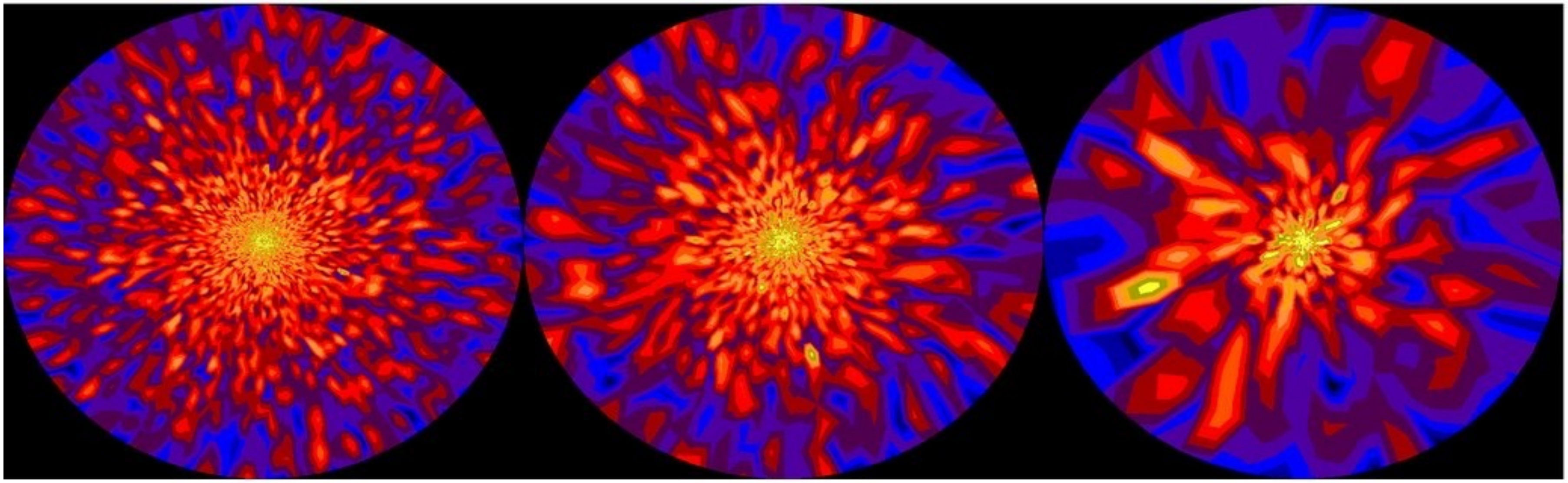
(b) Average Disk Emission Profile



Hogg & Reynolds 2016

Stochastic View of the Accretion Disk

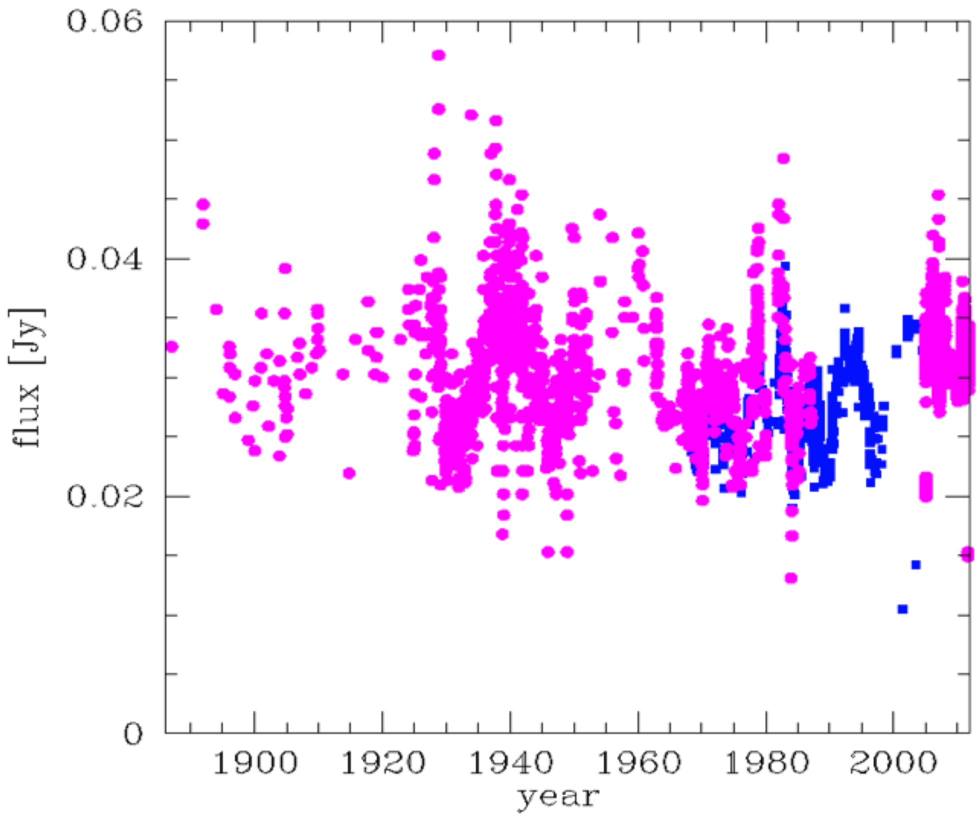
Dexter and Agol 2011 ApJ 727 L24

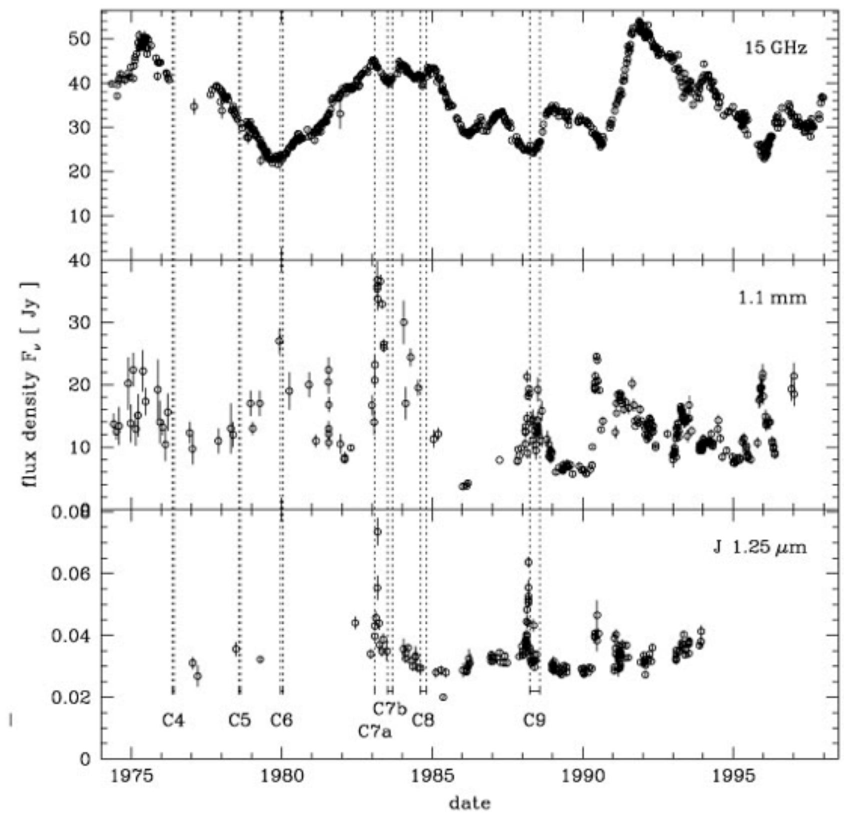


n=2200 n=550 n=140

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.

Long-term Quasar Variability





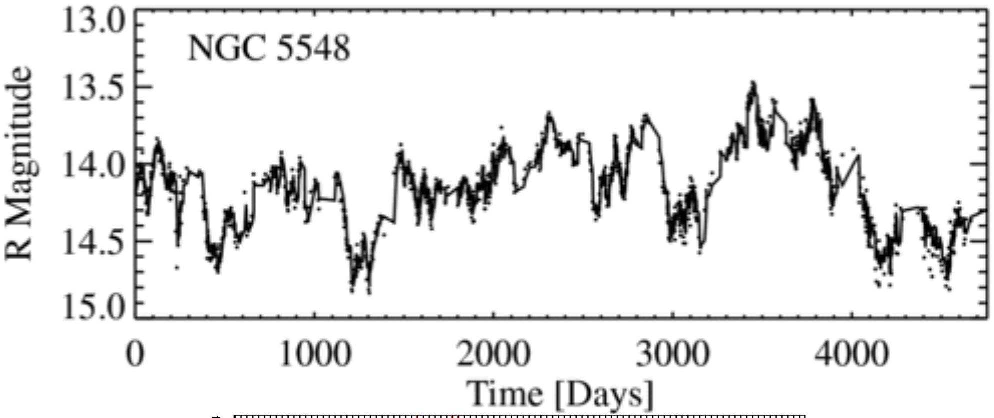
3C 273 Optical Variations
>100 years

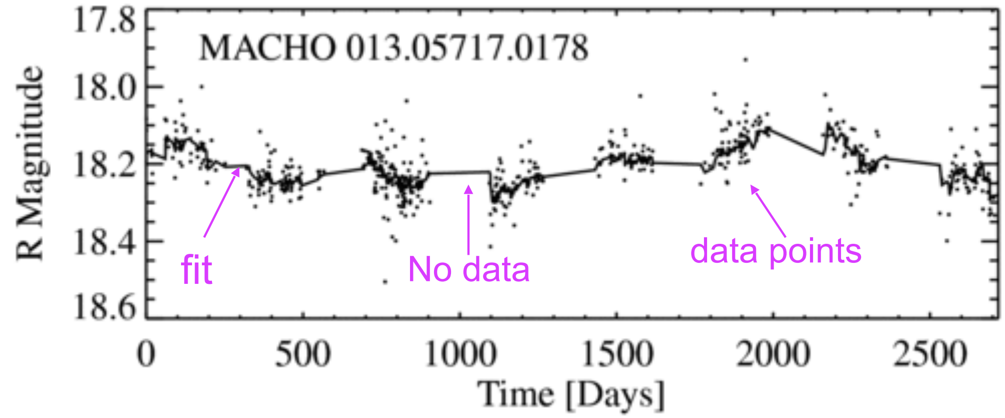
Radio Outbursts

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

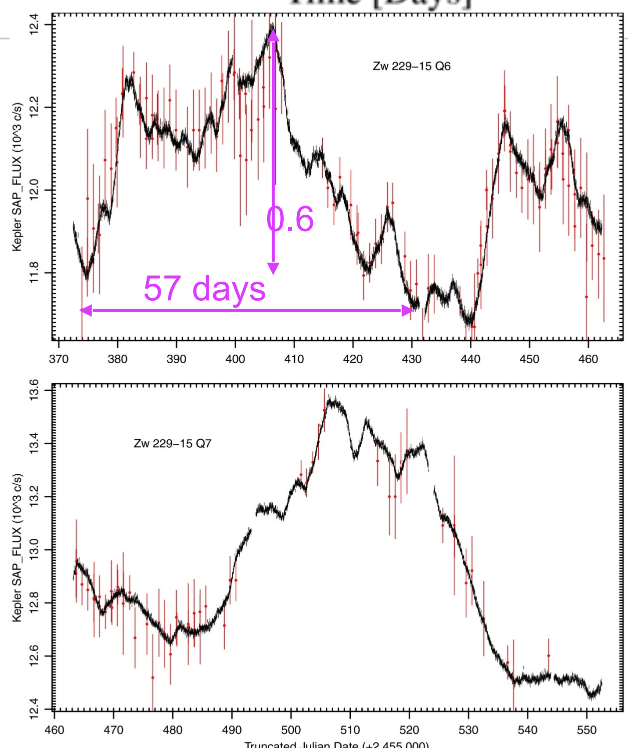
Optical Intrinsic Variations





Kelly, Bechtold & Siemiginowska 2009

Kepler Flux



Mushotzky et a 2011

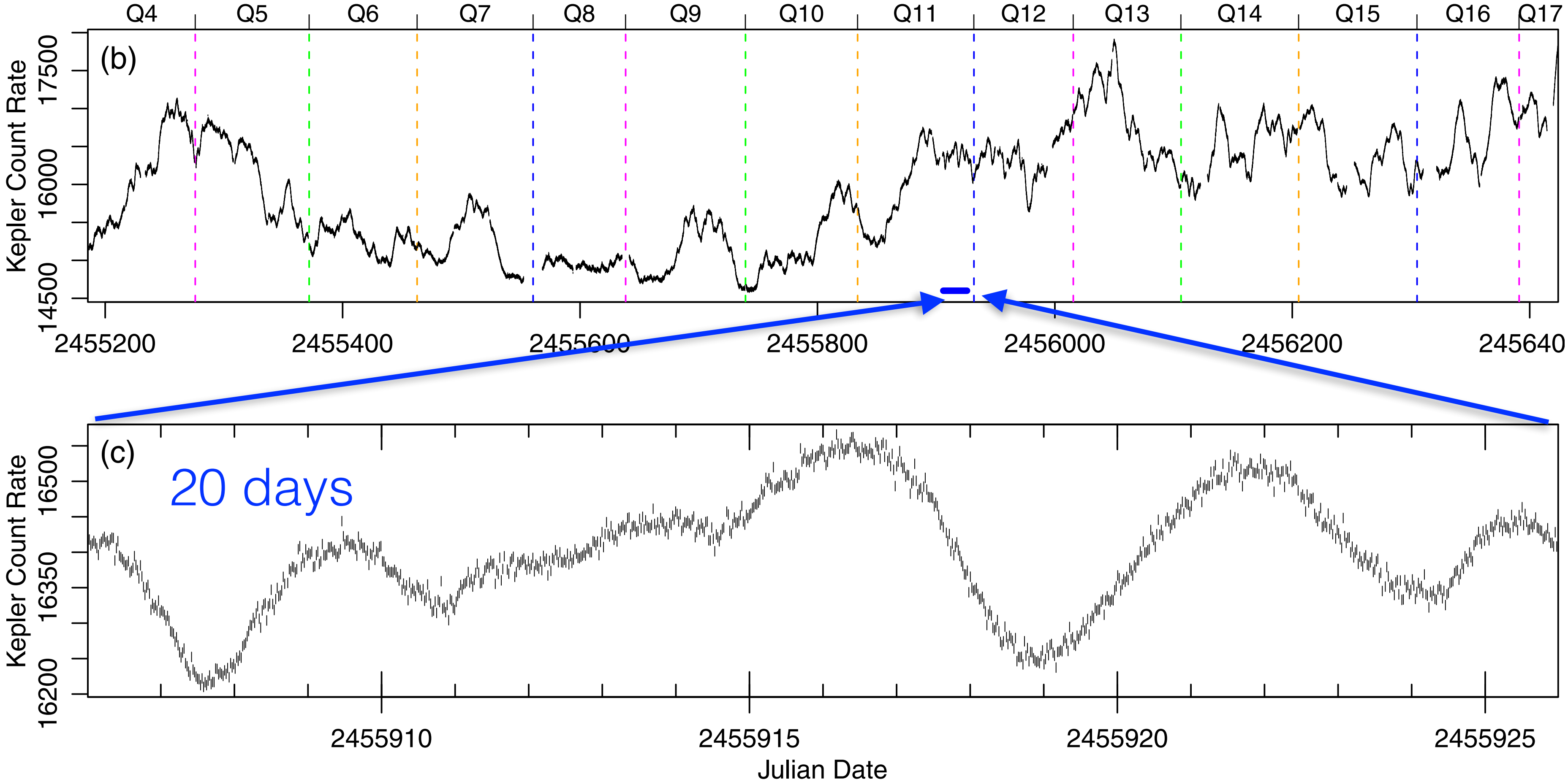
~90 days

- 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

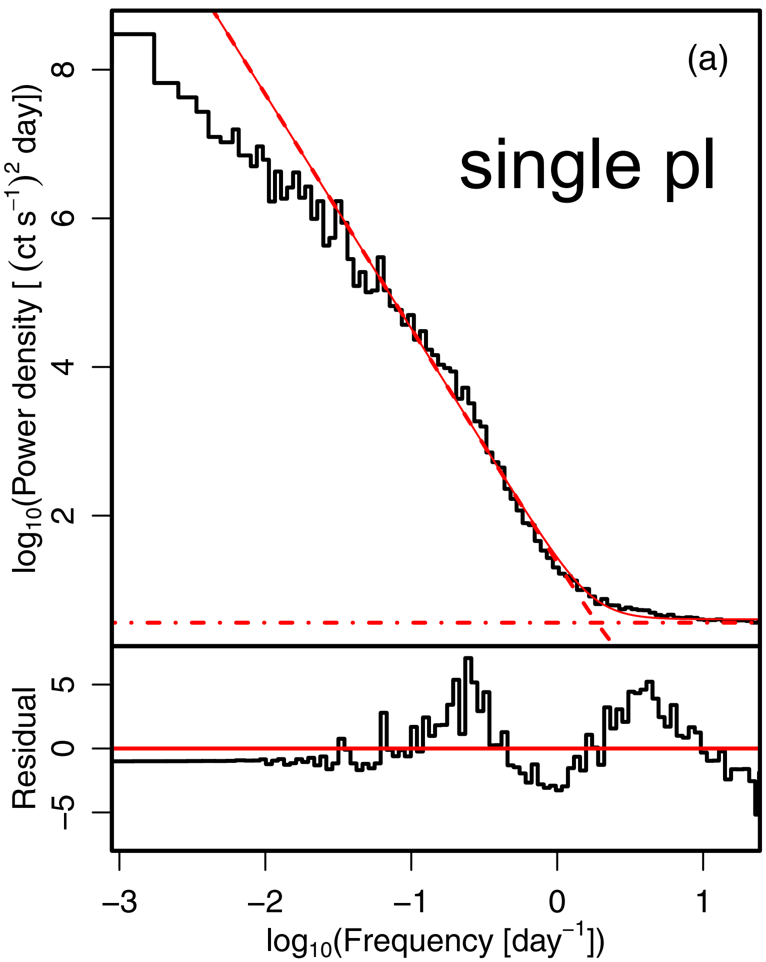
Zw 229-15

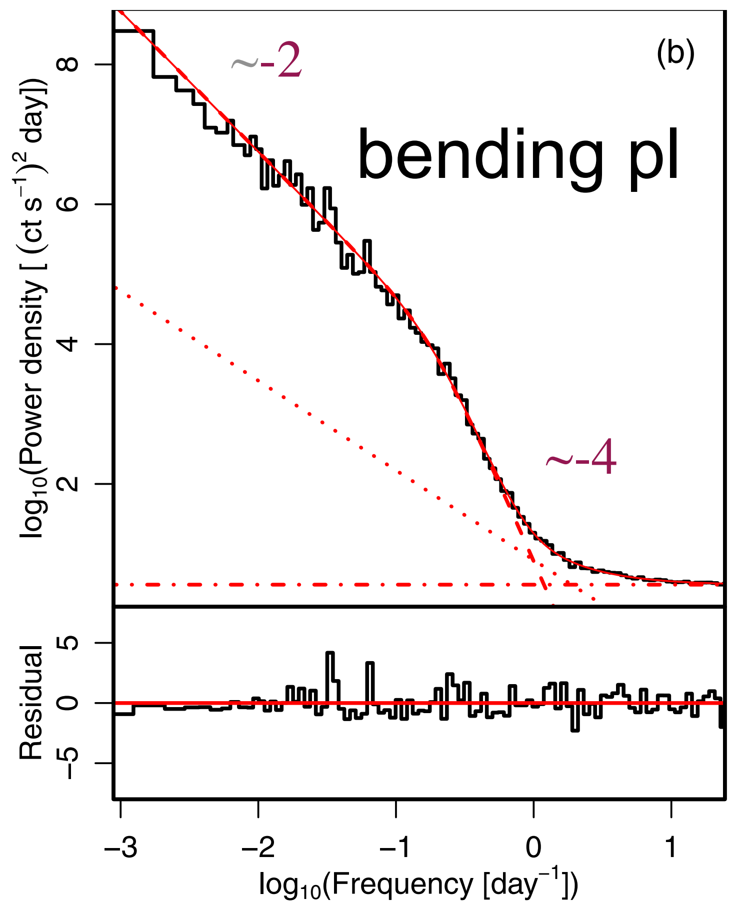
Kepler LC



Edelson et al 2014

Power Spectrum ZW 229-15



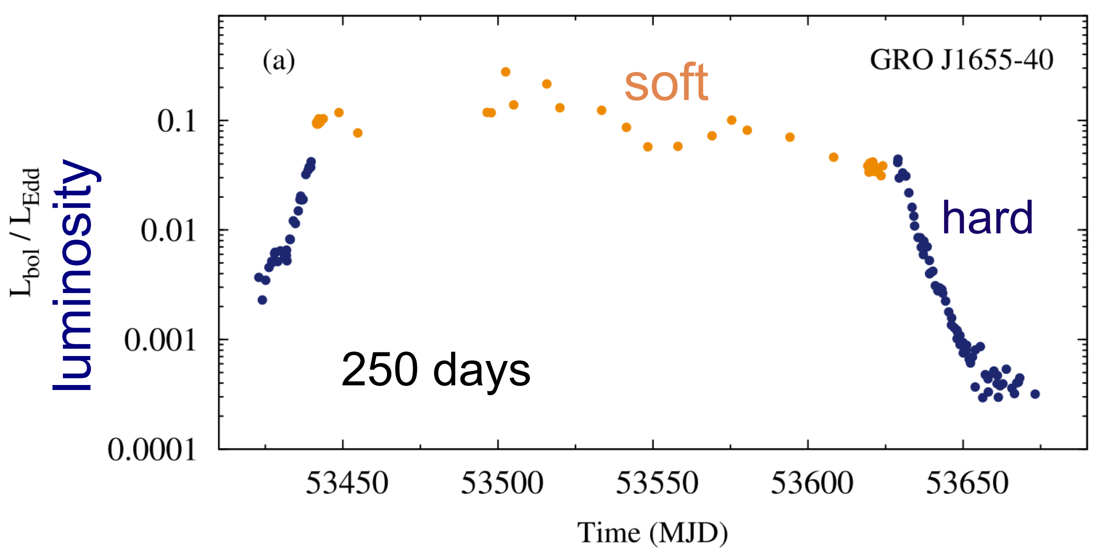


Edelson et al 2014

also CARMA model - bend at ~ 5 days

- Short timescales - within one observations
- Long timescales - monitoring observations
- Surveys - extreme variability

Galactic Binary Black Holes: State Transitions



Sobolewska, Siemiginowska & Gierlinski 2011

$M_{bh} \sim 10\ M_{sun}$

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

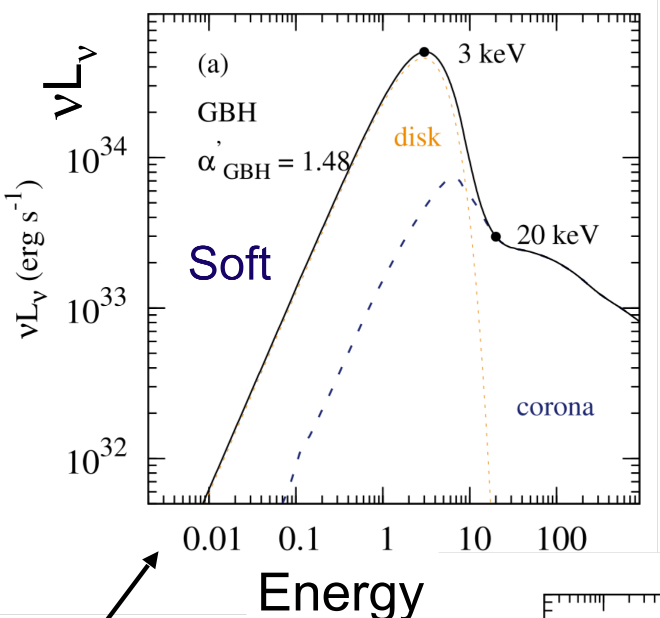
1 year => 10^7 years for AGN 10^8 M_{bh}

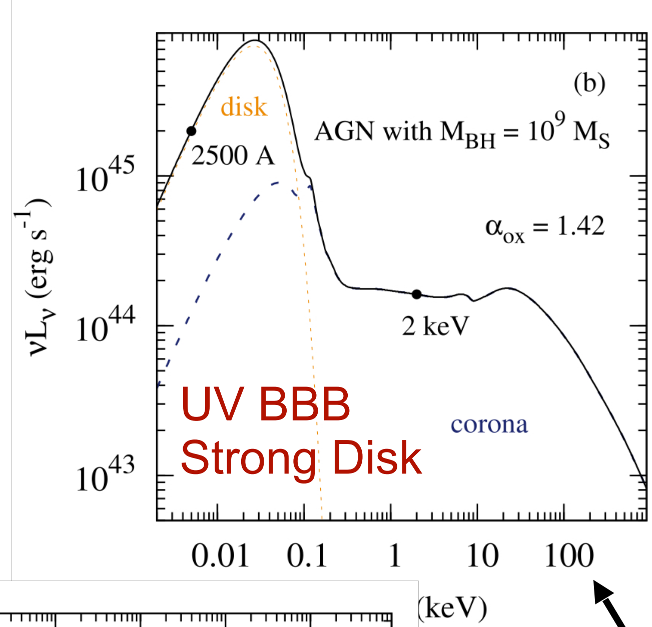
more from Jason Dexter today

Spectral Similarities

Blackbody + Power law
Disk + Corona

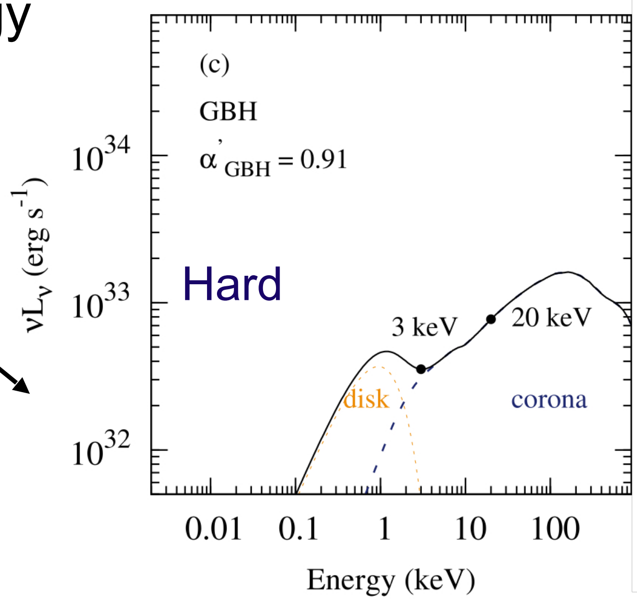
$T_{eff}(\text{disk}) \sim M_{BH}^{-1/4}$

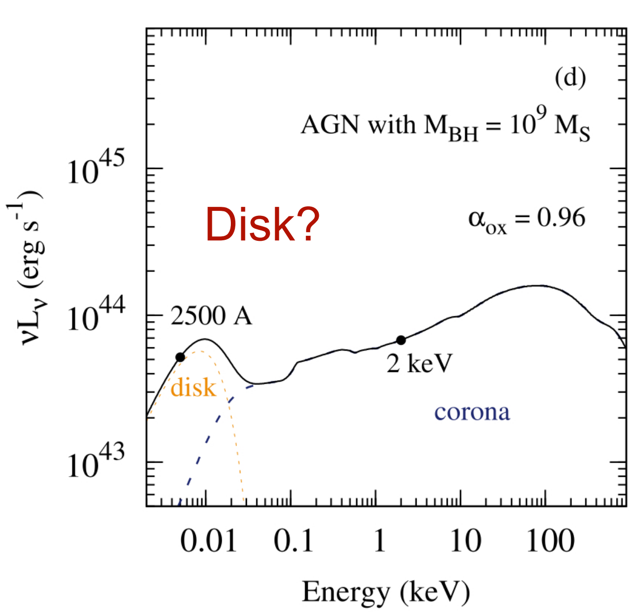




GBH X-rays

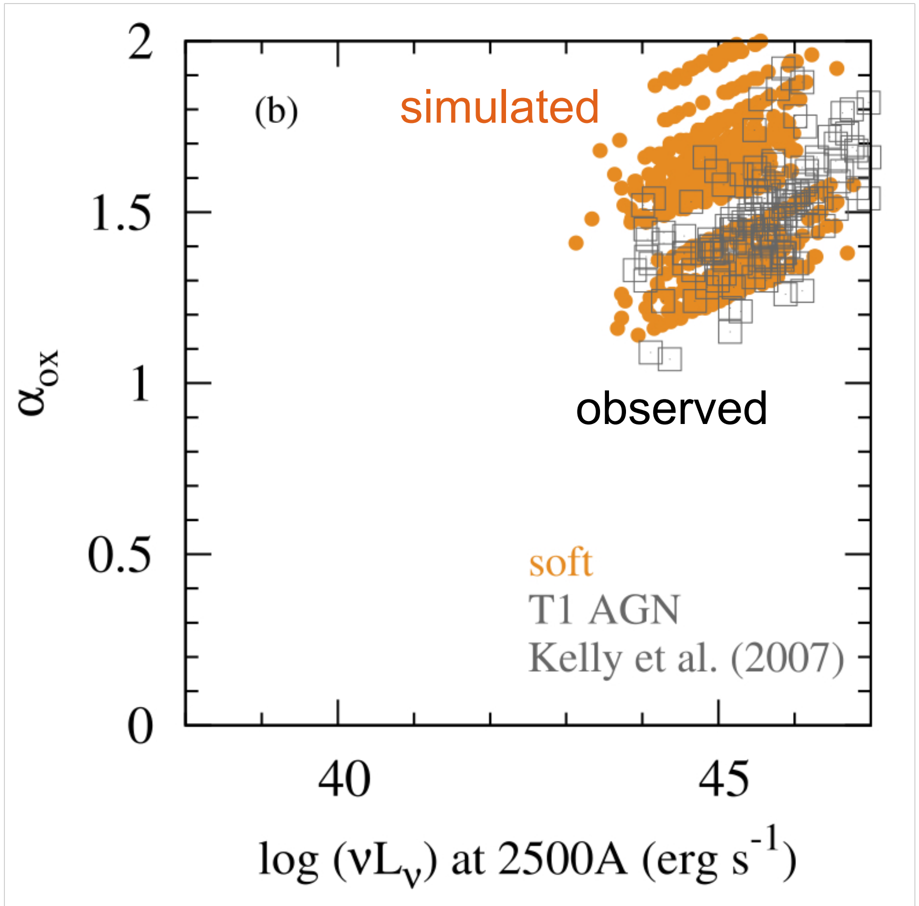
AGN opt-UV

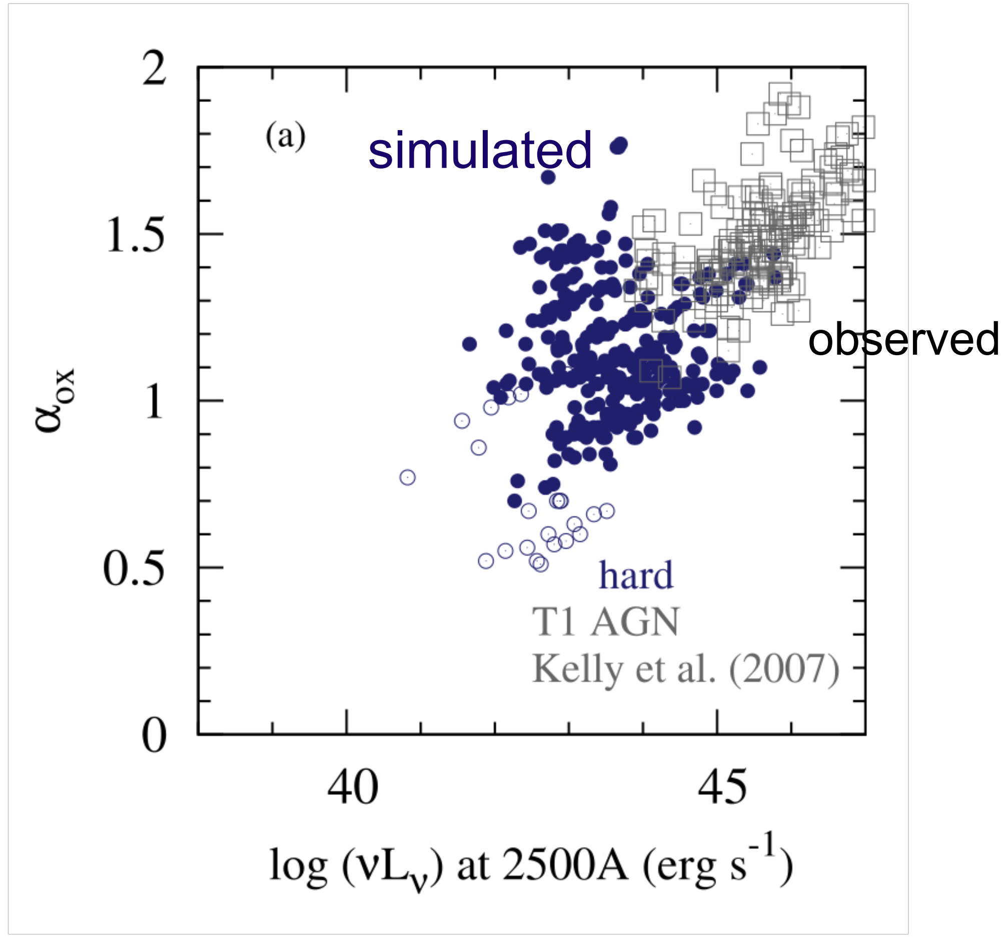




Sobolewska, Siemiginowska & Gierlinski 2009, 2011

Type 1 AGN in Soft State





Sobolewska, Siemiginowska & Gierlinski 2009, 2011

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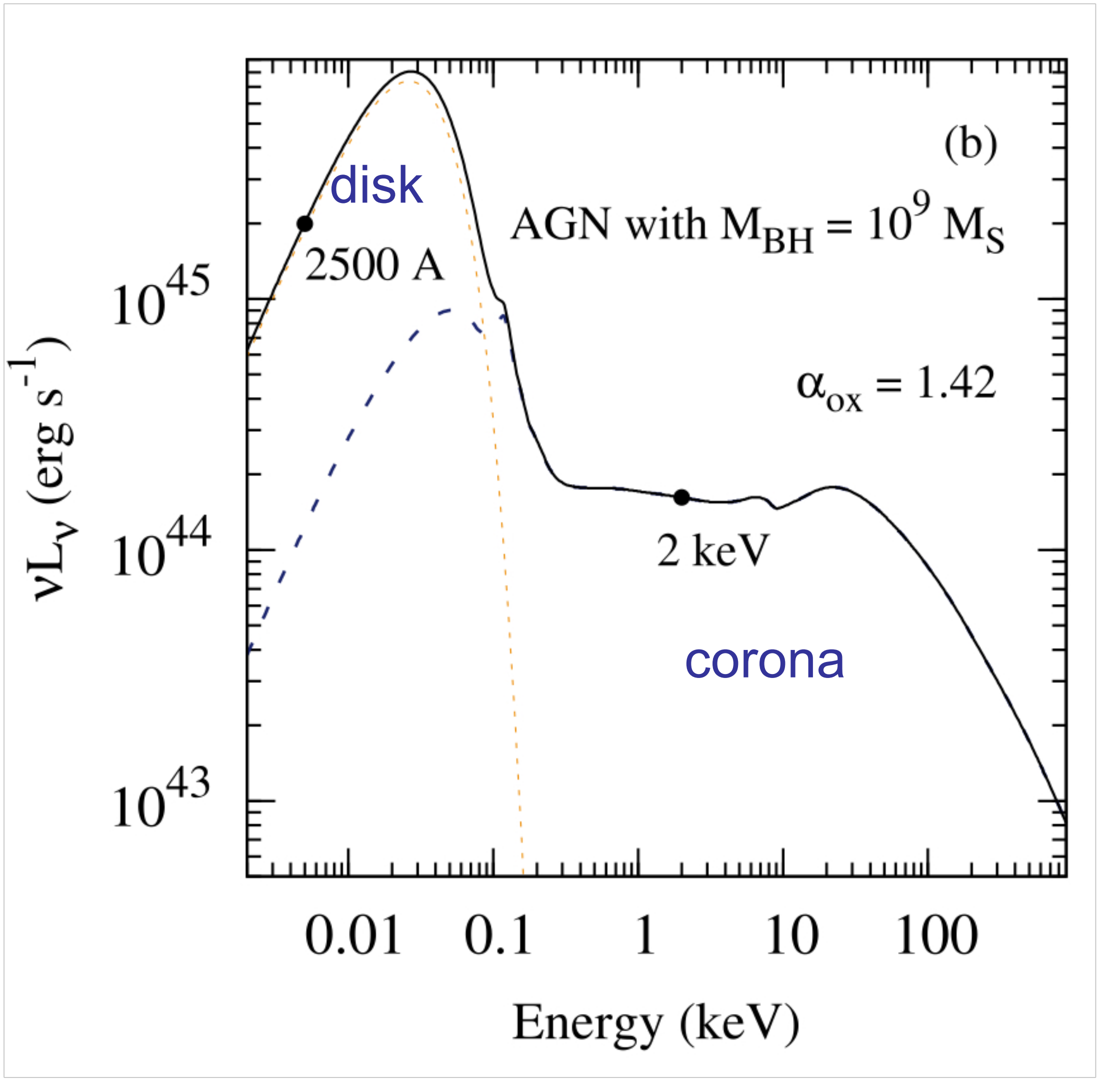
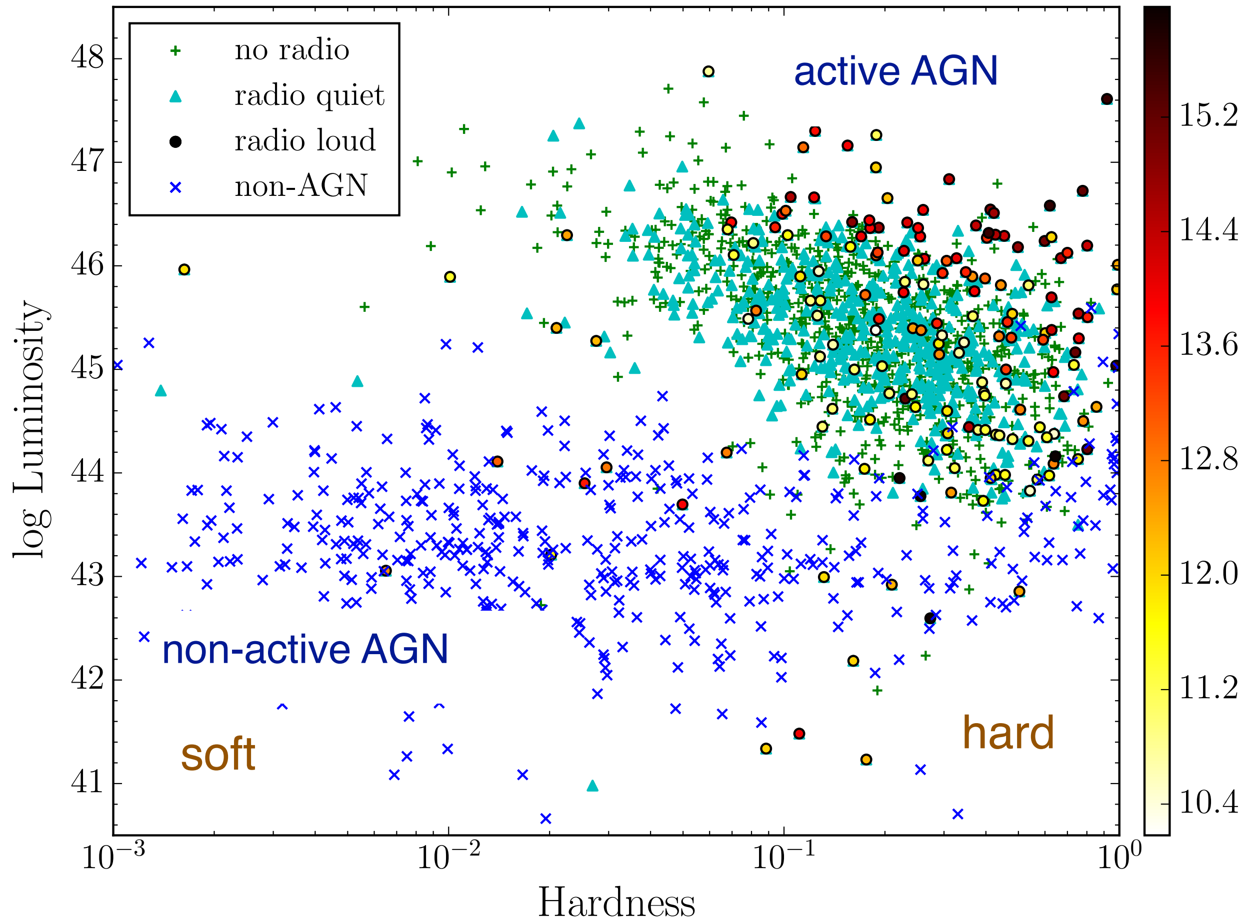


Optical-UV - disk

X-rays - corona

X-ray hardness and Radio-Loudness



Hardness = L_p/L_p+L_d

L_p - 0.1-100 keV - corona

L_d - disk

Svoboda, Guainazzi & Merloni 2017 (arXiv:1704.07268)

Koerding et al 2006

Summary

- Complex Emission
- Microlensing constraints on the geometry - not a standard disk
- Disk Instabilities   - Radiation/Ionization
- Similarities to XRB?
- Finding targets to constrain the physics - surveys? evolution?
- Kepler light curves probe the broad range of timescales
- Discussion at the meeting - reverberation, TDE, scaling, methods
- Theory?

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