Long-term multi-wavelength properties of PKS 0558-504: a highly accreting black hole with a radio jet

Mario Gliozzi (GMU)

I. Papadakis (Crete), W. Brinkmann, C. Raeth (MPE),

D. Grupe (PSU), L. Kedziora-Chudczer (Sidney)

Long-term multi-wavelength data from RXTE, SWIFT, XMM, ATCA, VLBI to shed light on the nature of PKS0558-504:

Presence and role of a jet?

Accretion state (M_{BH} determination)?

Energetics?

Disk-corona interplay?

Preliminary information on PKS 0558-504

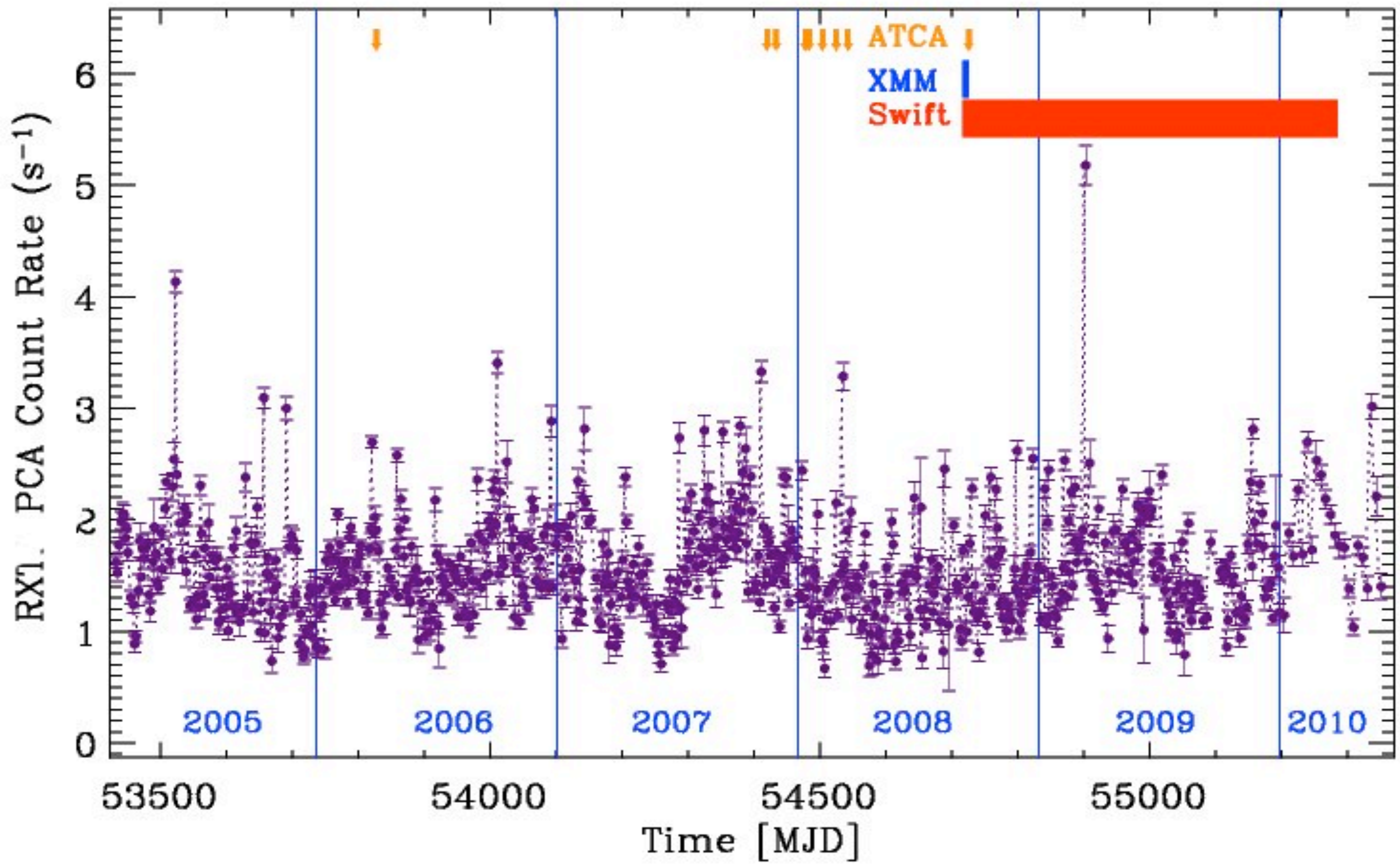
Radio-loud NLS1: R~27 [Seibert et al. 1999]

X-ray variability:
short timescales: 67% flux variation in 3′ [Remillard et al. 1991]
medium & long timescales: flux doubling in 2d [Gliozzi et al. 2000, 2007]

X-ray spectrum:
2-10 keV steep PL (Γ~2.2) + soft excess
2 Comptonization components? [Brinkmann et al. 2004; Papadakis et al. 2010]
Reflection-dominated? [Ballantyne et al. 2001; Crummy et al. 2006]

X-ray bright:
only radio-loud NLS1 bright enough for RXTE monitoring
($F_{2-10\ keV} \sim 2\times10^{-11}$ erg cm^{-2} s^{-1}, $L_{2-10\ keV} \sim 10^{45}$ erg s^{-1}):

Multi-wavelength campaign of PKS 0558-504



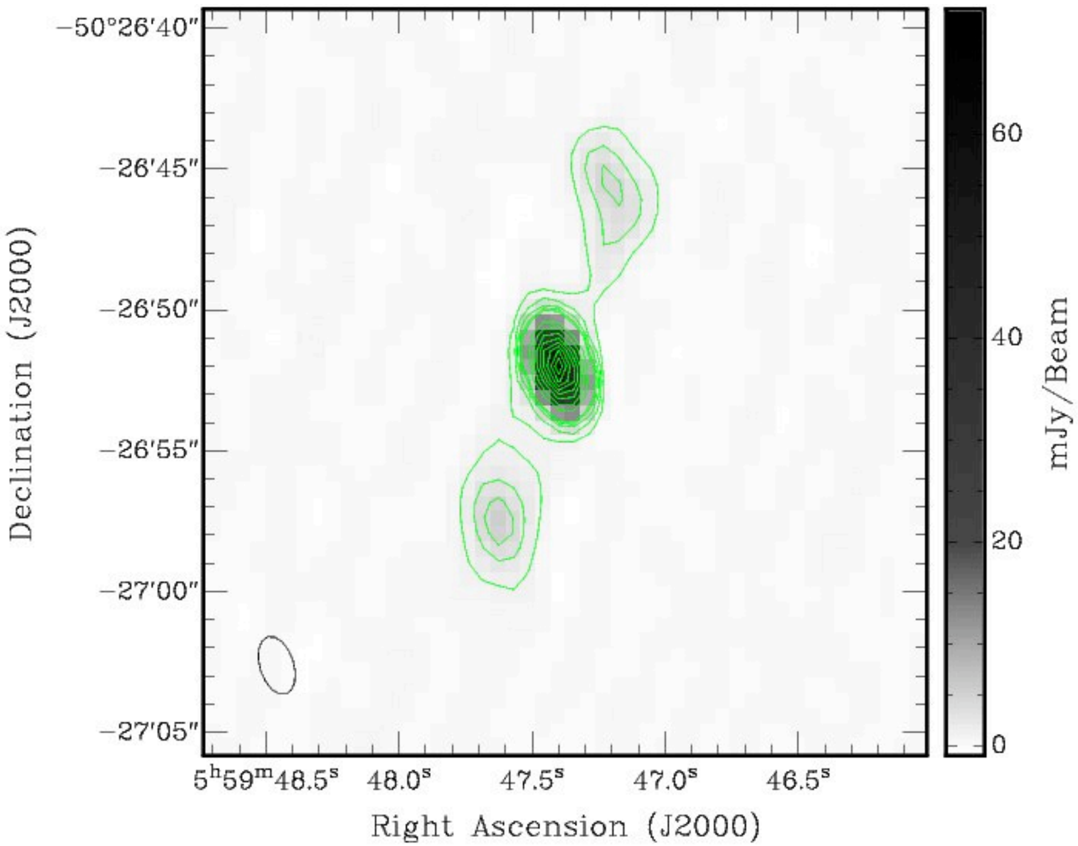
RXTE: 4 March 2005 – today **> 5 yr**

SWIFT: 7 Sept 2008 – 30 March 2010 **~1.5 yr**

XMM: 7 Sept 2008 – 17 Sept 2008 **~10 d**

ATCA: Nov 2007 – March 2008 (+ 17 Sept 2008)

A jet in PKS 0558-504?



ATCA Image at 4.8 GHz

beam=2"

1"=2.4 kpc

2 symmetric lobes resolved at ~7" from the core

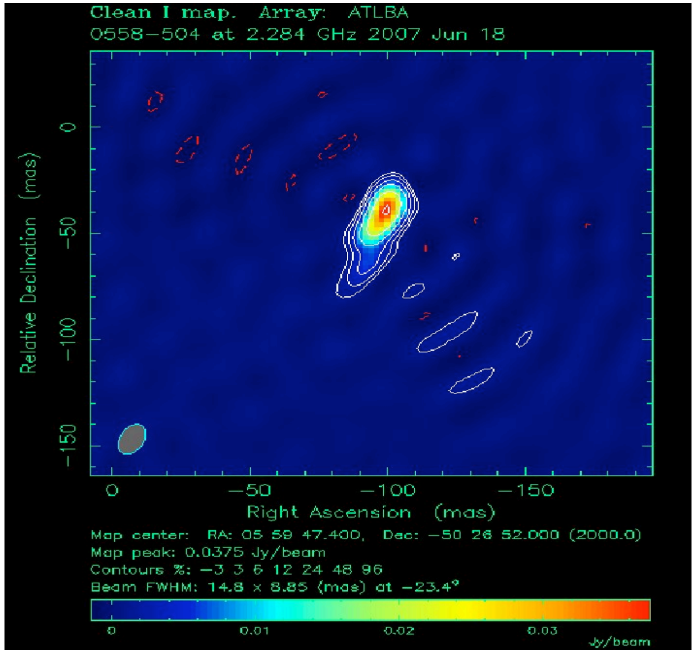
Projected linear size of full structure ~40 kpc

F_{5GHz} ~ 90 mJy,
L_{5GHz} ~ 1.7 x 10^{41} erg s^{-1}

Unusual radio structure for radio loud NLS1, generally compact or unresolved

[Yuan et al. 2008; Gu & Chen 2010]

A jet in PKS 0558-504? YES



VLBI Image

jet resolved
(R~100 pc)

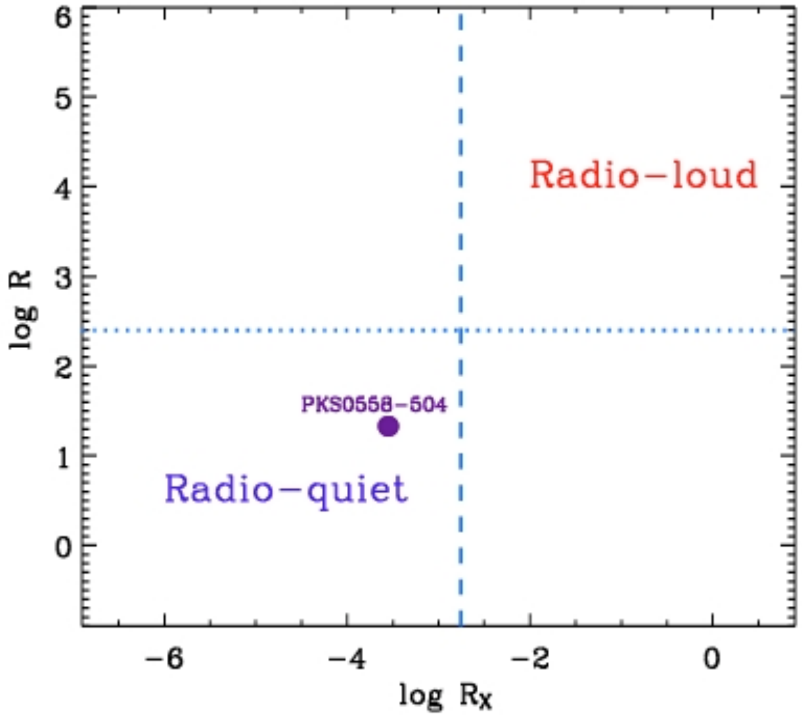
Radio Properties Summary:

* jet and lobe-like structures revealed;
* strong (F_{5GHz}~100 mJy; L_{5GHz} ~ 1.7 x 10^{41} erg s^{-1}) and variable emission;
* flat spectrum (α~0-0.5).

Role of the jet? Radio loudness

Using simultaneous radio, optical, X-ray data in Sept 2008:

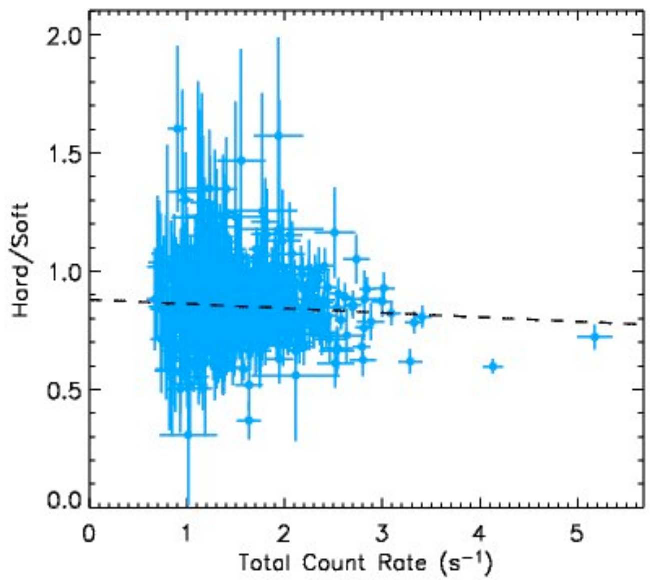
R_O~20, R_X~2x10^{-4}



Radio loudness consistent with radio-quiet Seyferts [Panessa et al. 2007]

Role of the jet? Spectral variability

Using long-term RXTE monitoring data:

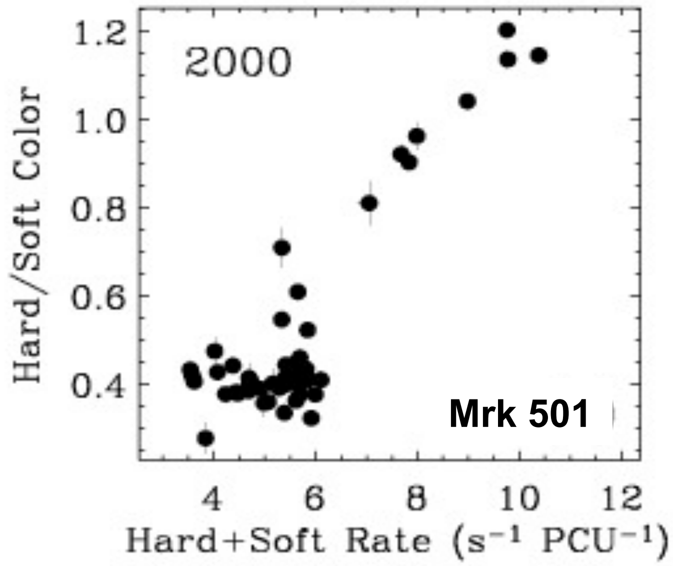


Constant trend in the hardness ratio count rate plot

Different from typical jet-dominated behavior:

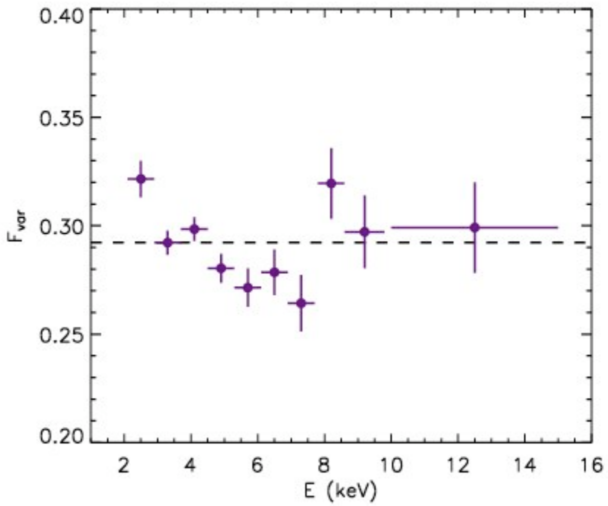
HR α ct

[Gliozzi et al. 2006]



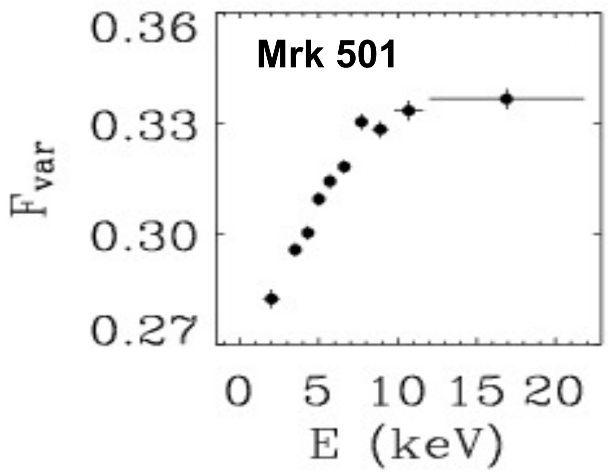
Role of the jet? Spectral variability2

Using long-term RXTE monitoring data:



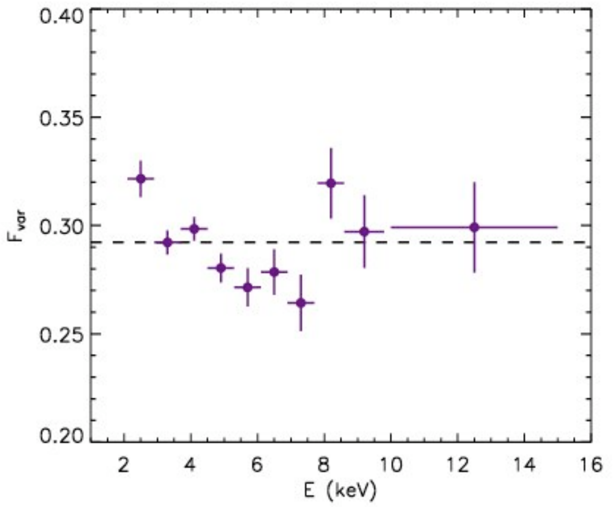
Constant trend F_{var} vs. E

Different from typical jet-dominated behavior:
$F_{var} \propto E$
[Gliozzi et al. 2006]

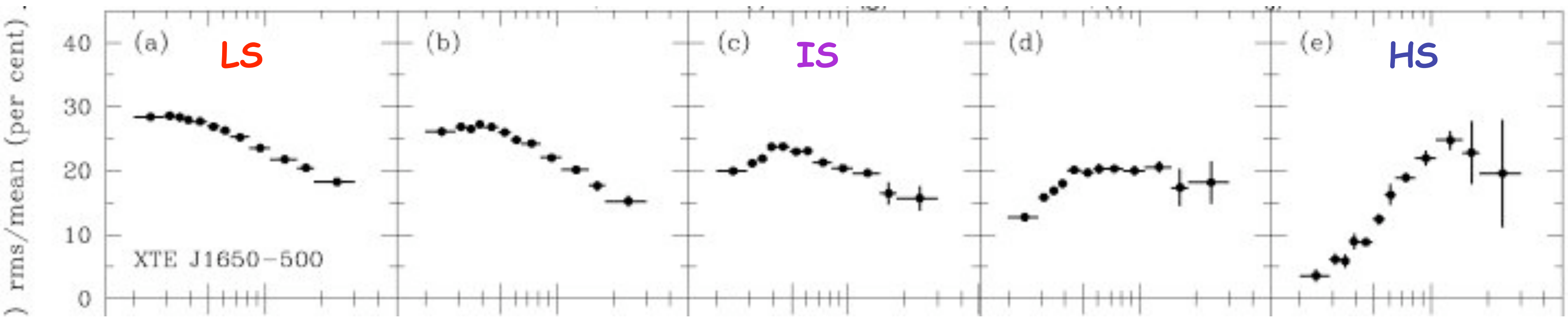


Role of the jet? Spectral variability2

Using long-term RXTE monitoring data:



Constant trend F_{var} vs. E



E [keV]

[Gierlinski & Zdziarski 2005]

Role of the jet in PKS 0558-504?

Additional constraints from X-rays and gamma-rays:

Spectral and temporal behavior typical of Seyferts:
[XMM; Papadakis et al. 2010a,b]

Non detection with Fermi-LAT
[Abdo et al. 2009]

Non detection at TeV energies with HESS:
[Giebels. 2009 private communication]

Role of the jet in PKS 0558-504?
MARGINAL

Additional constraints from X-rays and gamma-rays:

Spectral and temporal behavior typical of Seyferts:
[XMM; Papadakis et al. 2010a,b]

Non detection with Fermi-LAT
[Abdo et al. 2009]

Non detection at TeV energies with HESS:
[Giebels. 2009 private communication]

Jet contribution negligible beyond the radio band

X-rays track accretion activity

Is PKS 0558-504 unique among NLS1s?

Based on X-ray (and UV) properties:
PKS 0558-504 typical NLS1
But radio loudness?

If $R_x=L_{2-10\ keV} / L_{Radio} \sim 10^{-4}$ typical for NLS1s
most NLS1s undetected by radio surveys

PKS 0558-504 compared to other radio-loud NLS1s:
-Different radio structure (extended vs. compact);
-Lower radio loudness;
-Non detection vs. Detection at γ-rays [Abdo et al. 2009; Foschini et al. 2009]

PKS 0558-504 member of parent population of jet-dominated NLS1s

Accretion state of PKS 0558-504?

Need to determine $\lambda_{Edd} = L_{bol} / L_{Edd}$

L_{bol} derived from direct integration of SED from simultaneous Swift UVOT, XRT and XMM-Newton observations.

$L_{Edd} = L_{Edd}(M_{BH})$ derived from different M_{BH} estimate methods.

Estimate of M_{BH} for PKS 0558-504

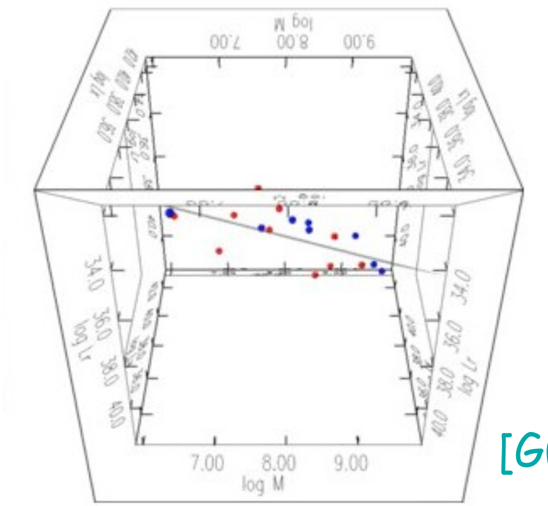
(1) Virial theorem [R=R(L); Bentz et al. 2009]:

$M_{BH} = f\ R\ \Delta v^2\ /\ G$ ~$6 \times 10^7\ M_{solar}$

but optical measurements not simultaneous and application to NLS1 questioned [e.g. Marconi et al. 2008; Decarli et al. 2008]

(2) Fundamental plane of BHs [Merloni et al. 2003; Falcke et al. 2004]:

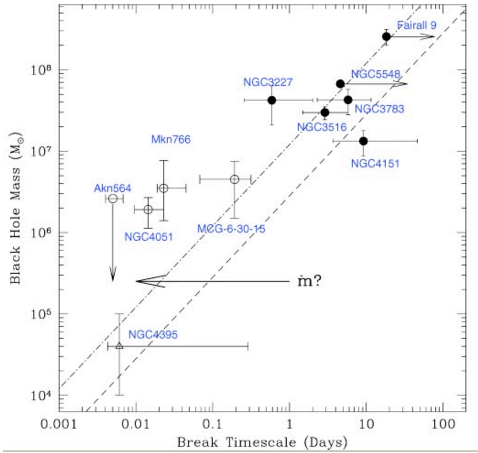
$\log M_{BH} = a\ \log L_{Radio} + b\ \log L_X + c$ ~$3 \times 10^8\ M_{solar}$



[Gueltekin et al. 2009]

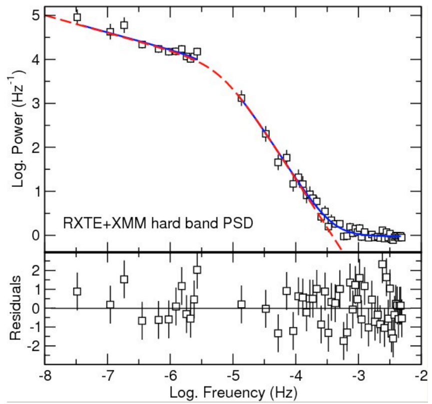
Estimate of M_{BH} for PKS 0558-504

(3) Characteristic X-ray timescale [Mc Hardy et al. 2006]:



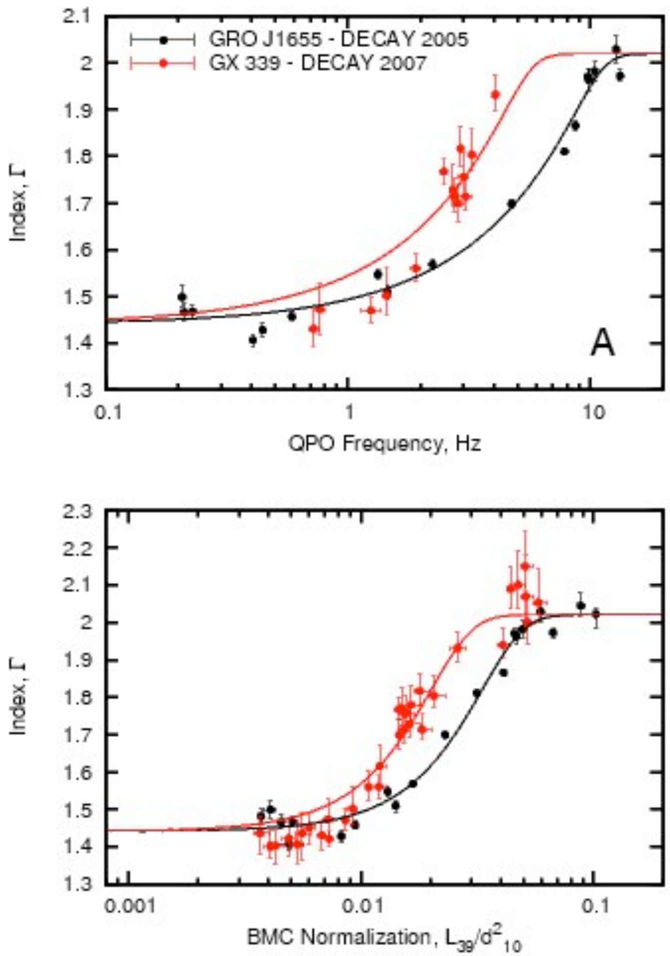
From 5yr RXTE and 5 XMM consecutive orbits [Papadakis et al. 2010b]:

$\log M_{BH} = a \log T_{break} + b \log L_{bol} + c$ $\sim 2 \times 10^8\ M_{solar}$



Estimate of M_{BH} for PKS 0558-504

(4) Scaling of X-ray spectral properties of GBHs [Shaposhnikov & Titarchuk 2009]:



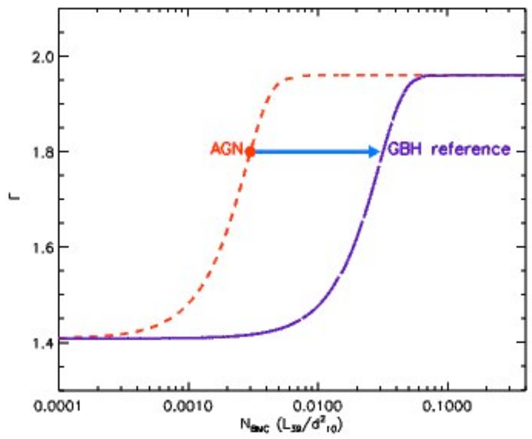
Two plots to determine M_{BH} and distance

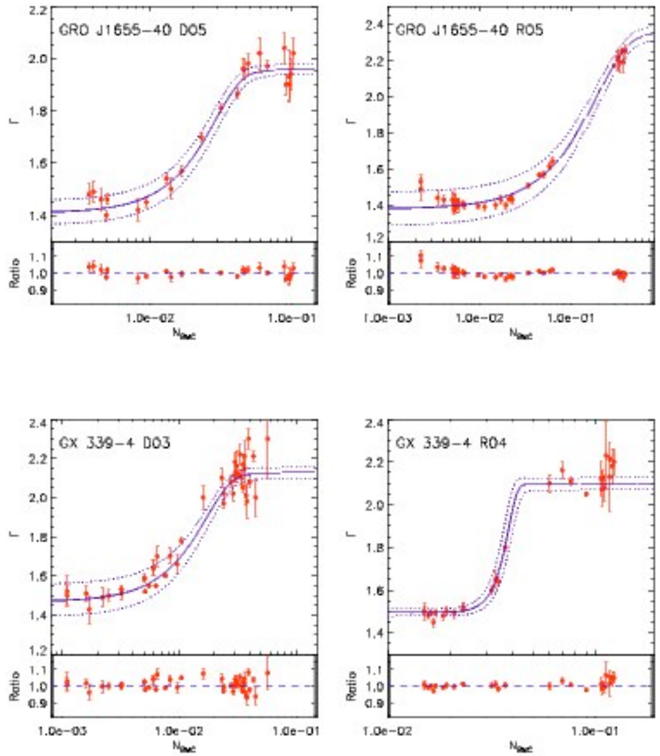
$L \sim \eta \dot{M} M_{BH}$

Estimate of M_{BH} for PKS 0558-504

(4) Scaling of X-ray spectral properties of AGN [Gliozzi et al. 2011]:

$$M_{AGN} = M_{GBH}\ (N_{AGN}/N_{GBH})\ (d_{AGN}/d_{GBH})^2$$



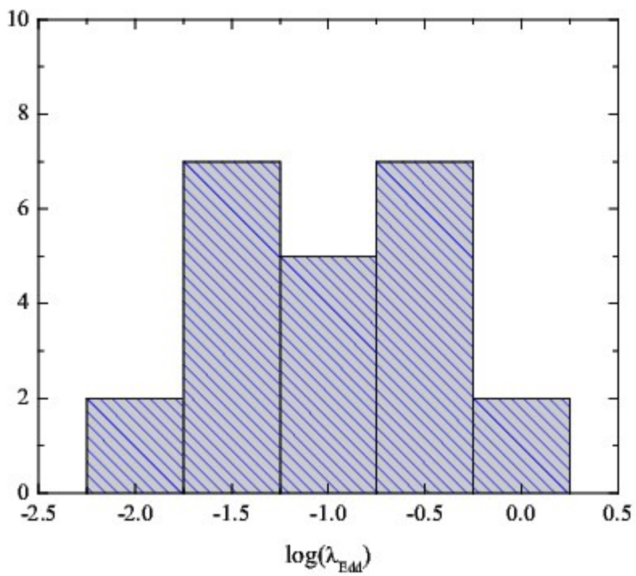


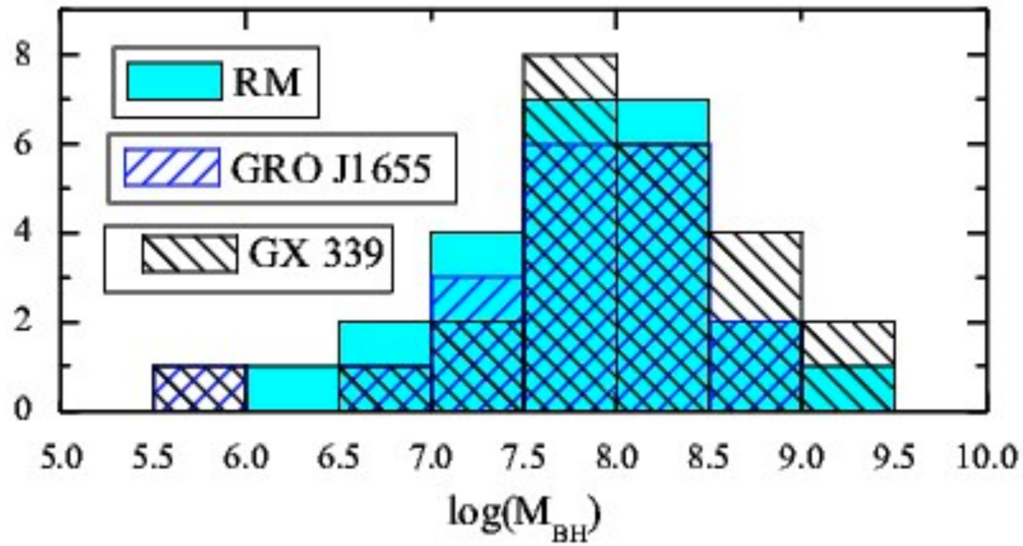
GBH references

Estimate of M_{BH} for PKS 0558-504

(4) Scaling of X-ray spectral properties of AGN [Gliozzi et al. 2011]**:**

Application to reverberation mapping sample [Peterson et al. 2004; Grier et al. 2008; Denney et al. 2010]**:**

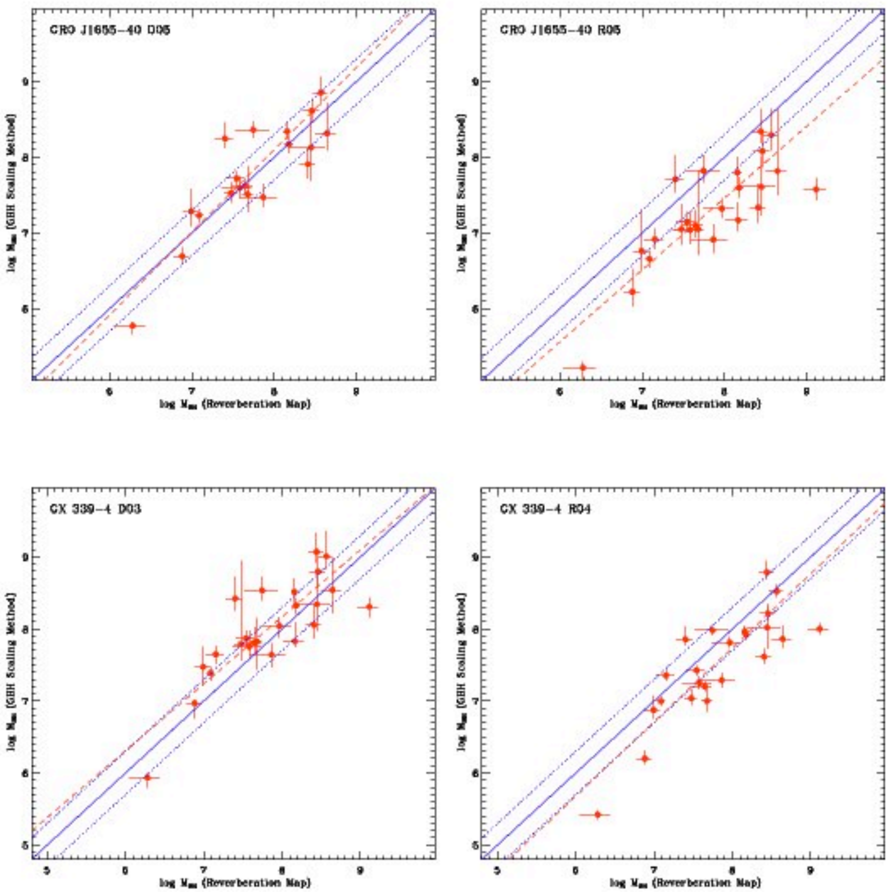




Estimate of M_{BH} for PKS 0558-504

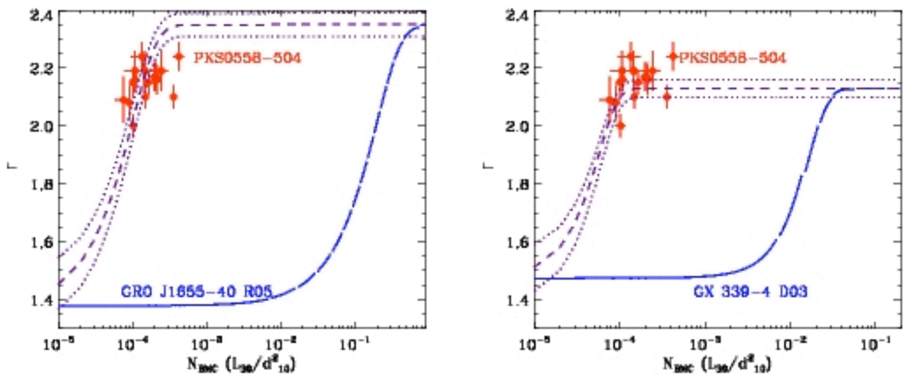
(4) Scaling of X-ray spectral properties of AGN [Gliozzi et al. 2011]:

Application to reverberation mapping sample [Peterson et al. 2004]:

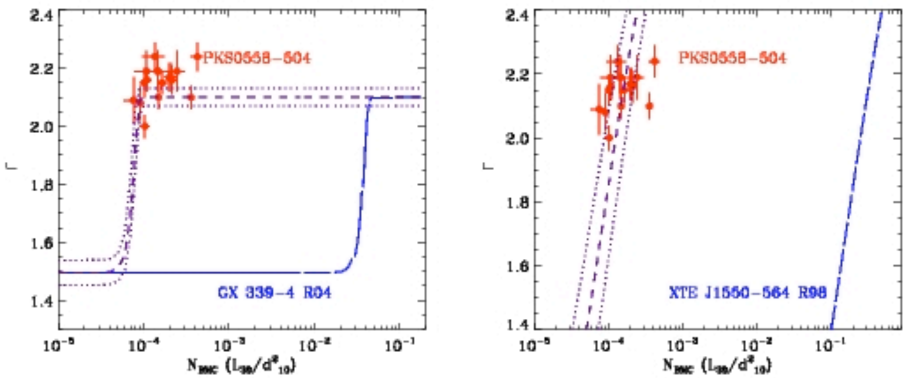


Estimate of M_{BH} for PKS 0558-504

(4) Scaling of X-ray spectral properties of AGN [Gliozzi et al. 2011]:

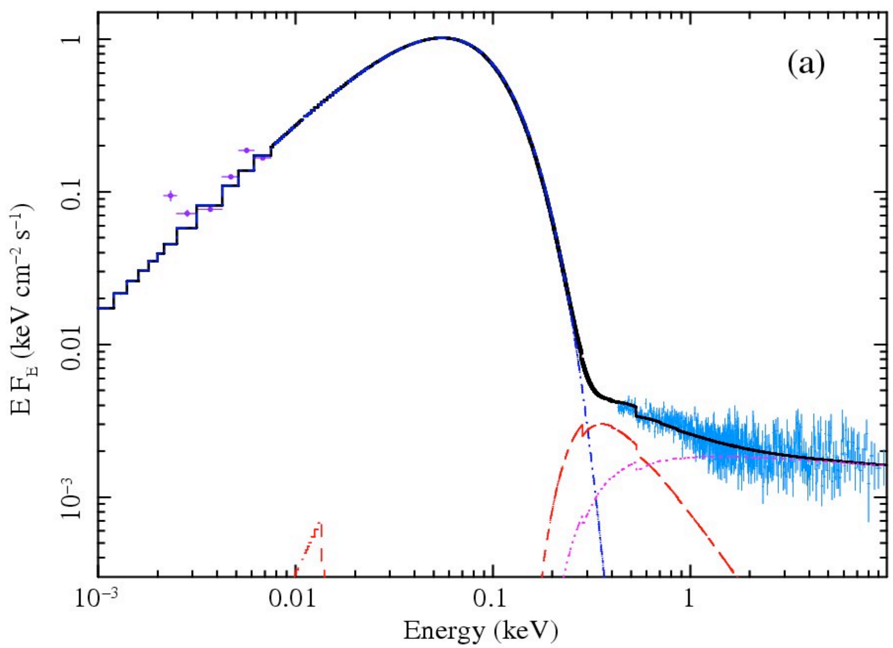


$M_{BH} \sim 3 \times 10^8 M_{solar}$



Accretion state of PKS 0558-504?

L_{bol} derived from direct integration of SED



SED dominated by a ~constant UV bump

SED variations: 10% on short timescales

L_{bol} ~ 5.5 x 10 ^{46} erg/s
(M_{BH}= 2.5 x 10^8 M_{solar})
κ_{bol} = $L_{2-10\ keV}$ / L_{bol} ~ 160

L_{bol} ~ 1.5 x 10 ^{47} erg/s
(M_{BH}= 6 x 10^7 M_{solar})

Is PKS 0558-504 highly accreting? YES

(1) Non-conservative case $M_{BH} = 6 \times 10^7 M_{solar}$:

$L_{Edd} = 8 \times 10^{45}$ erg/s

$\lambda_{Edd} \sim 20$

(2) Conservative case $M_{BH} = 3 \times 10^8 M_{solar}$:

$L_{Edd} = 3.5 \times 10^{46}$ erg/s

$\lambda_{Edd} \sim 1.5$

Super-Eddington regime

Consistency check [XMM-COSMOS survey; Lusso et al. 2010]:

$\kappa_{bol} = \kappa_{bol}(\lambda_{Edd})$

$\kappa_{bol}(1.5) \sim 150$ fully consistent with SED results

Accretion & Ejection in PKS 0558-504

PKS 0558-504 "clean" disk-jet system:
relative contributions clearly separated

Direct comparison between accretion $L_{accr} = L_{bol}$
and jet power $L_{kin} = L_{kin}(L_{Radio})$ [Merloni & Heinz 2007]

Comparison between inflow and outflow rate:

$L_{accr} = \eta \dot{M}_{in} c^2 \sim 5.5 \times 10^{46}$ erg/s

$L_{kin} = (\Gamma - 1) \dot{M}_{out} c^2 \sim 2 \times 10^{45}$ erg/s

$L_{accr} > L_{kin}$

$\dot{M}_{in} >> \dot{M}_{out}$

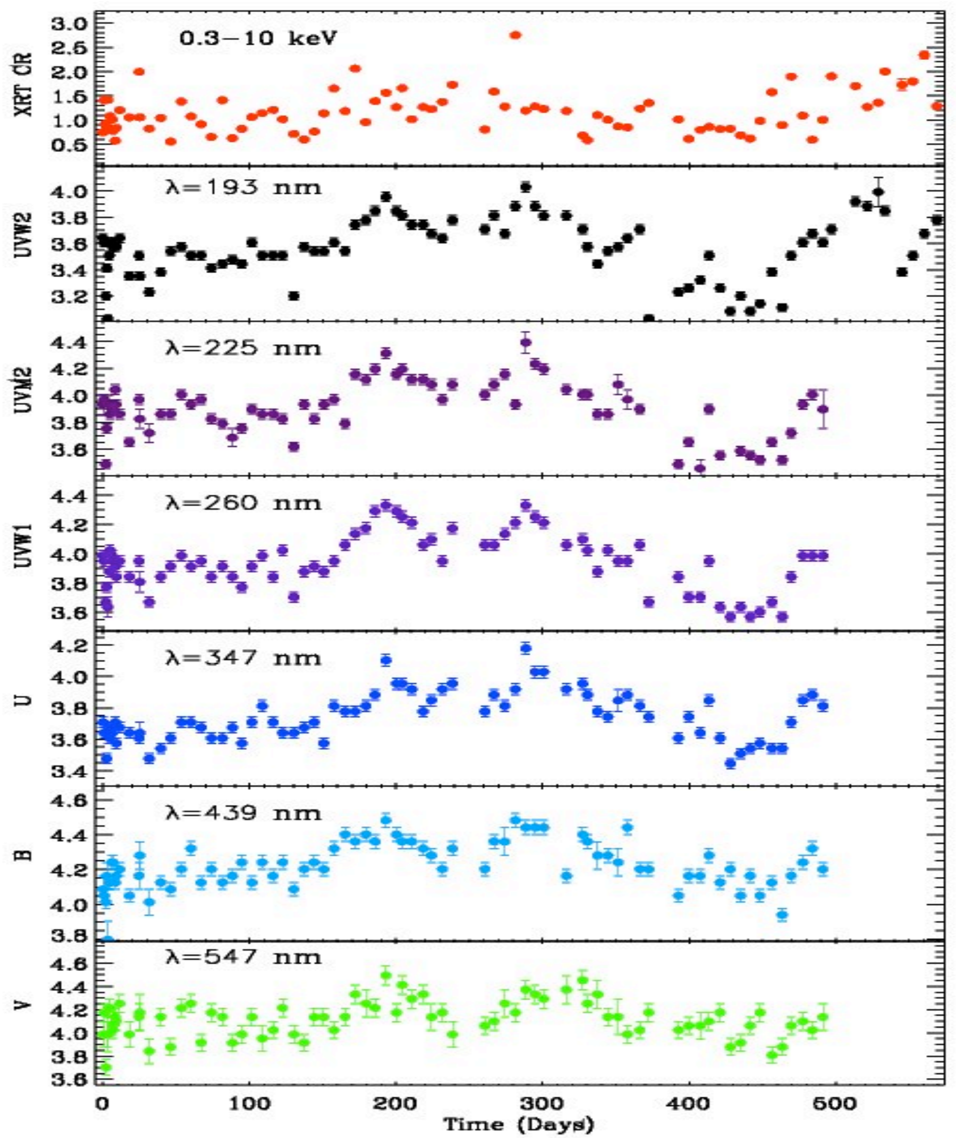
From radiation-MHD simulations of GBHs with $\lambda_{Edd} > 1$:

$L_{accr} > L_{kin}$ $\dot{M}_{in} >> \dot{M}_{out}$

in full agreement with PKS 0558-504 results [Ohsuga et al. 2009]

Multi-wavelength long-term monitoring of PKS 0558-504: Light curves

SWIFT campaign: 7 Sept 2008 – 30 March 2010

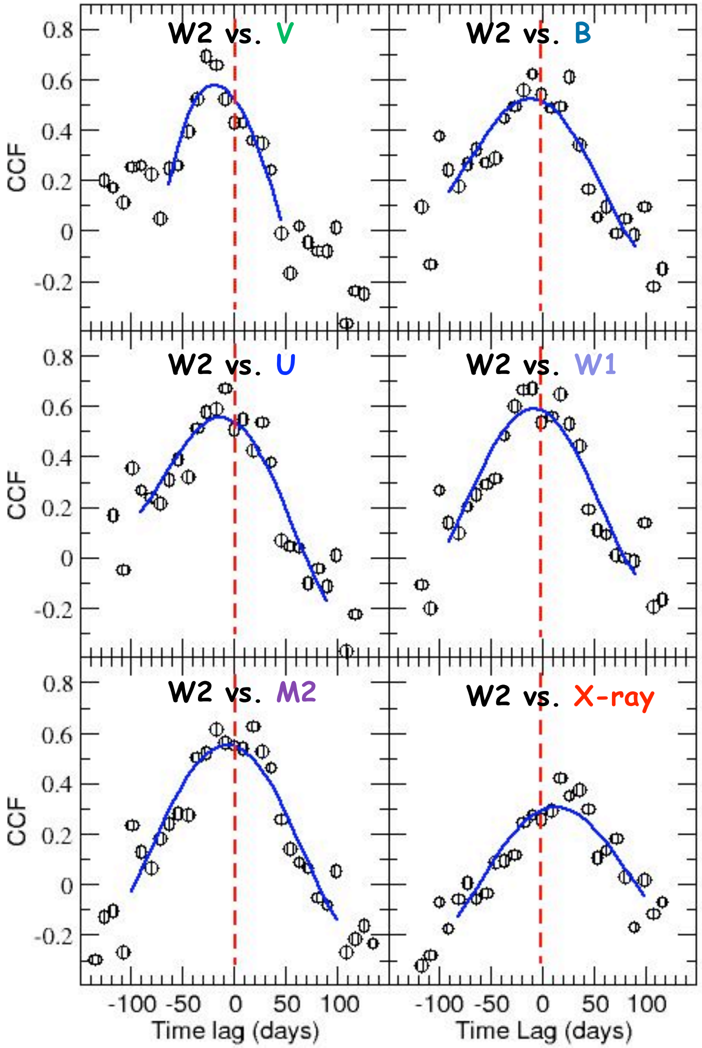


All energy bands highly variable:

$F_{var,X-ray}$~35%

$F_{var,UV}$~14%

Multi-wavelength long-term monitoring of PKS 0558-504: CCF analysis



UVW2 reference light curve:

positive lags = UVW2 leads

negative lags = UVW2 follows

Suggestive evidence of a trend: UVW2 lags optical light curves and leads the X-rays.

Propagation model favored over irradiation model.

Summary & Conclusions

* PKS 0558-504 has a radio jet (and lobes)
  but the emission unlikely jet-dominated

* Disk and jet contributions cleanly separated:
  - source accreting at super-Eddington rate
  - accretion power > jet power

* Interplay disk-corona: disk propagation favored

* "Normal" NLS1
  member of parent population of jet-dominated NLS1s

* Reminiscent of GBHs in Intermediate State