Mapping the inner accretion region of AGN with X-ray variability

William Alston

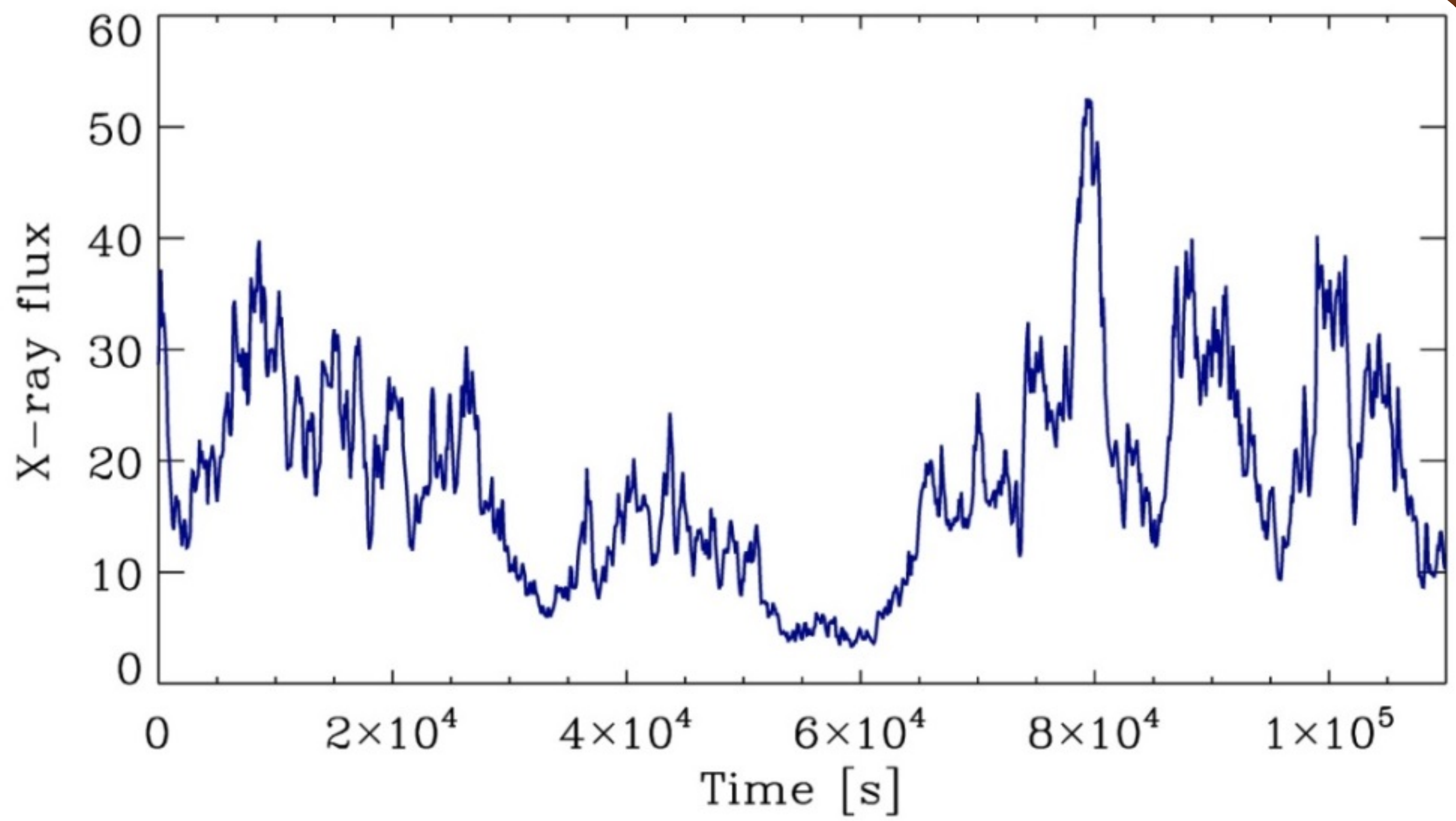
Andy Fabian, Douglas Buisson, Michael Parker, Ciro Pinto, Anne Lohfink, Erin Kara, Phil Uttley, Dan Wilkins, Michal Dovciak, Matt Middleton, Dom Walton, Jiachen Jiang, Barbara DeMarco, Ed Cackett, Abdu Zoghbi, Andy Young, Giovanni Miniutti

STRONGGRAVITY
EU FP7-SPACE research project 312789
2013 - 2017

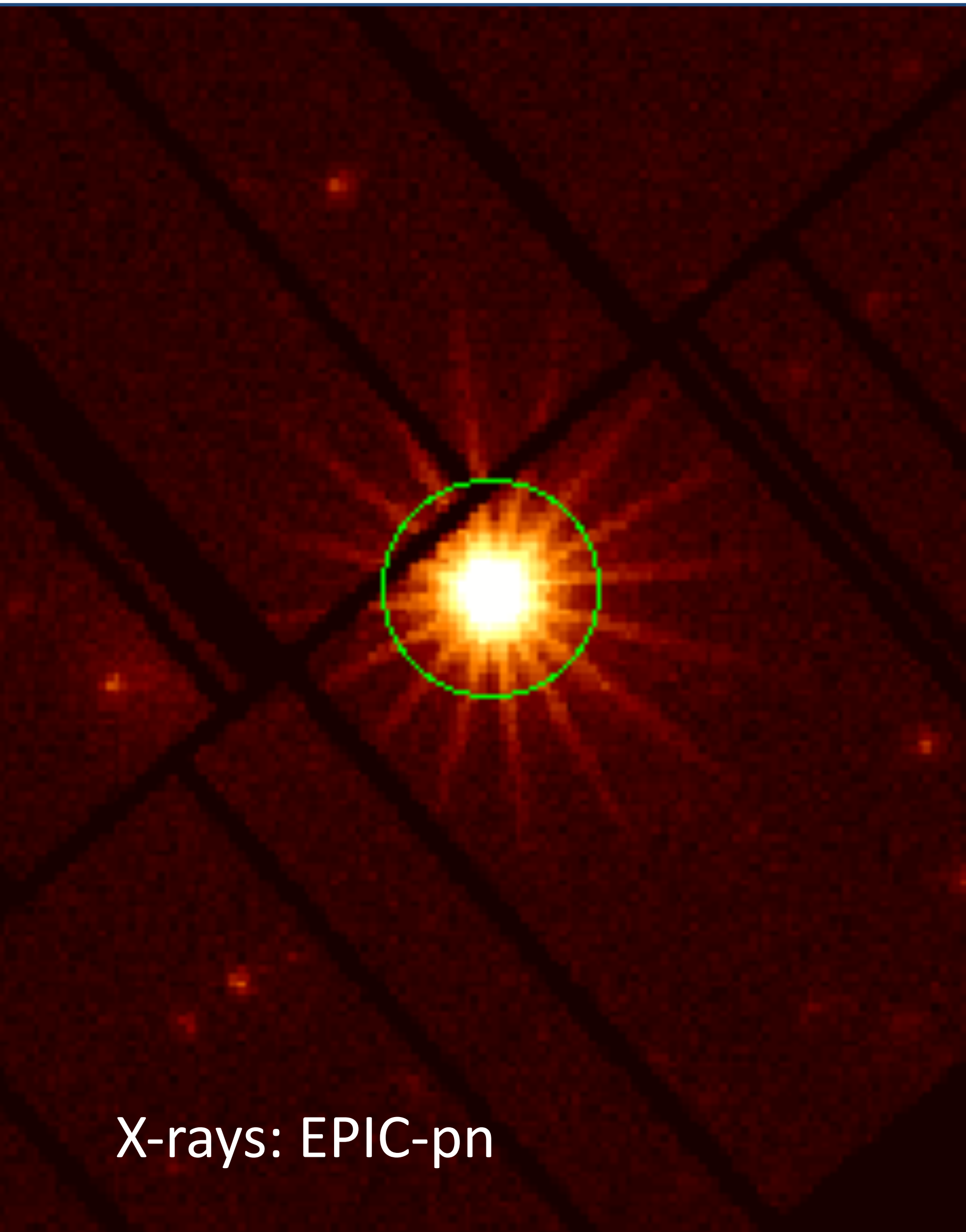
ioa
Cambridge X-Ray Astronomy

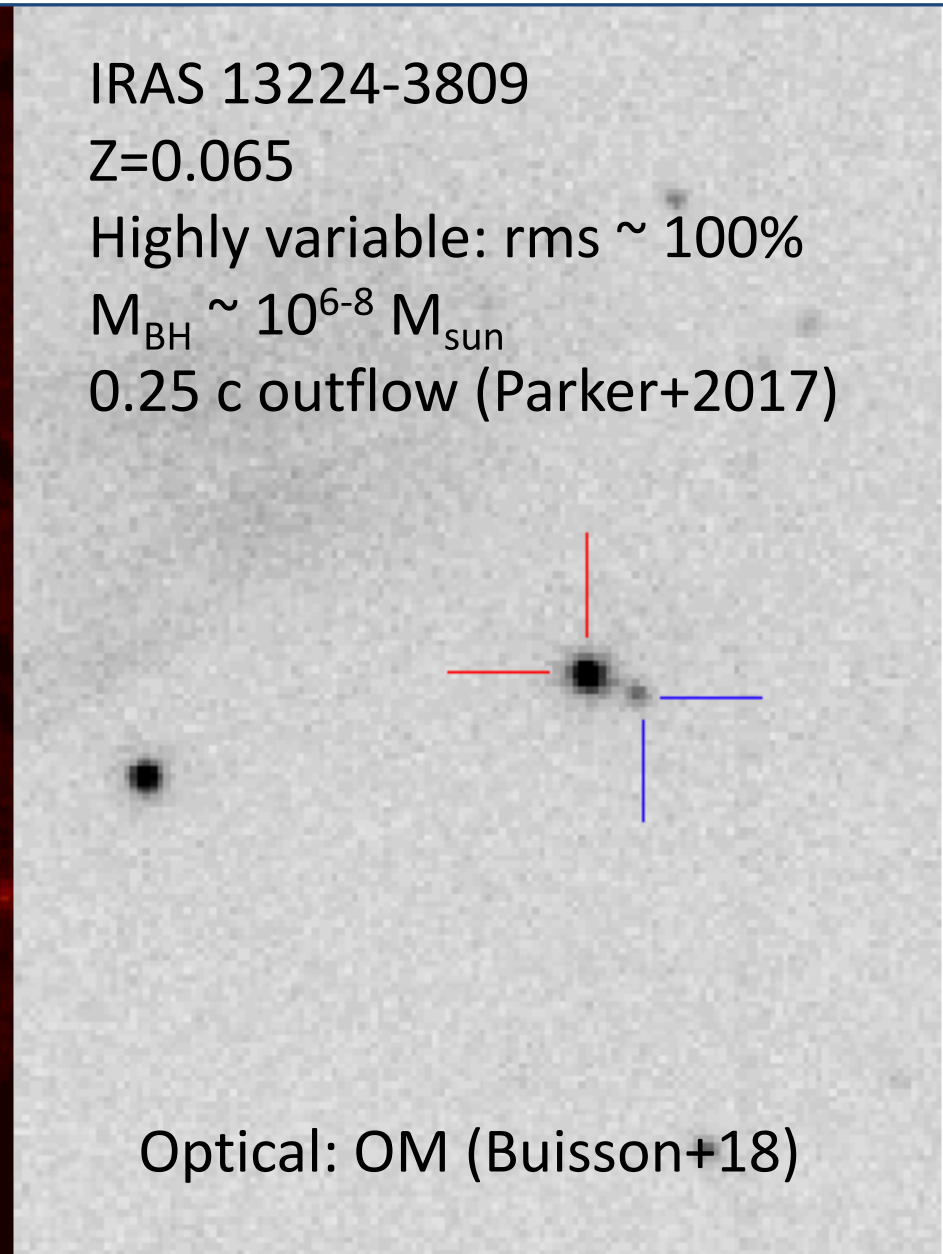
Most-rapid variations seen in X-rays

$t_{dynamical} \sim 500$ s at 6 R_g for $M_{BH} = 10^6\ M_{sun}$

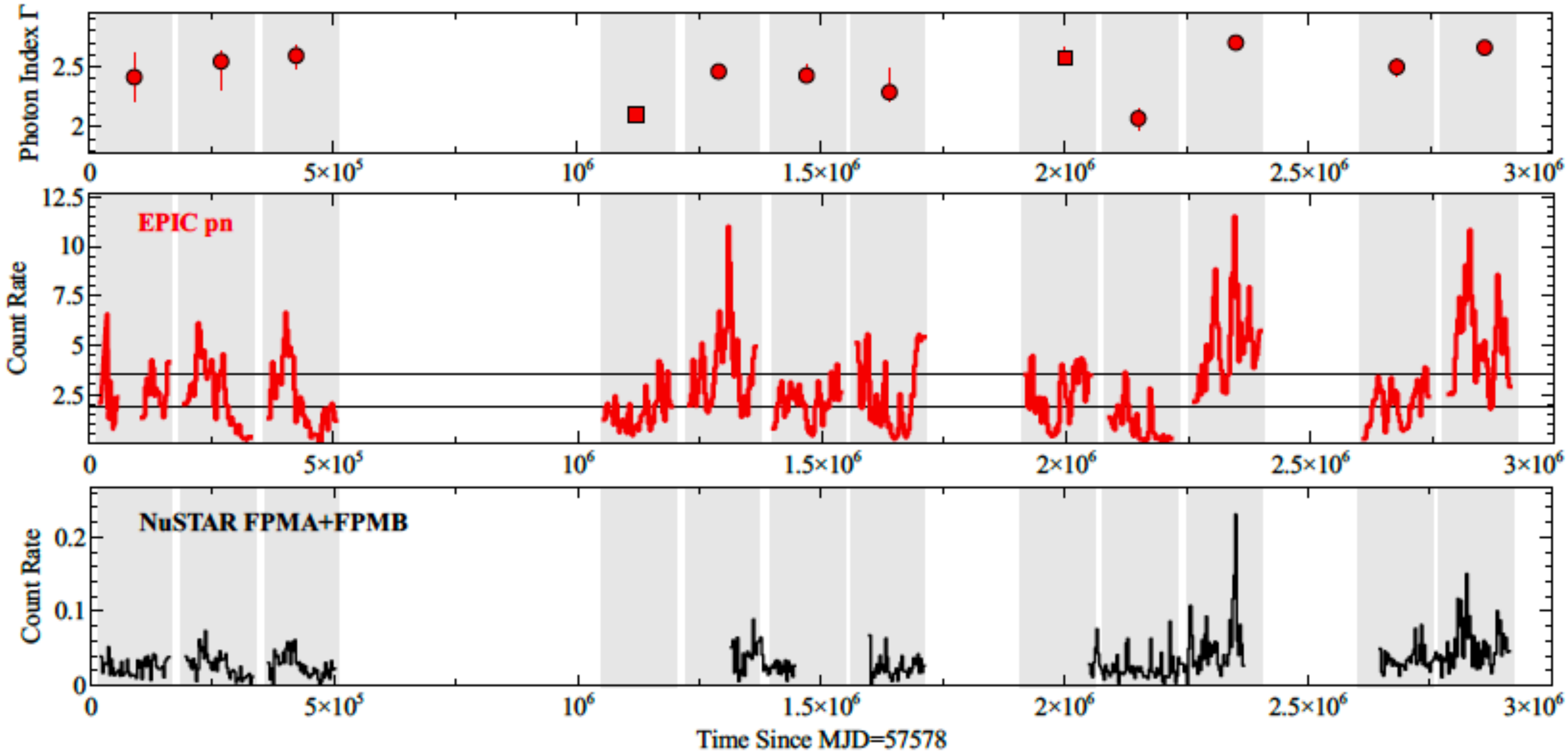


1.5 Ms XMM-Newton obs in 2016





IRAS 13224-3809: 30 days



Parker et al 2017a,b; Pinto et al 2018;
Buisson et al 2018; Jiang, et al, in press; WA et al, sub

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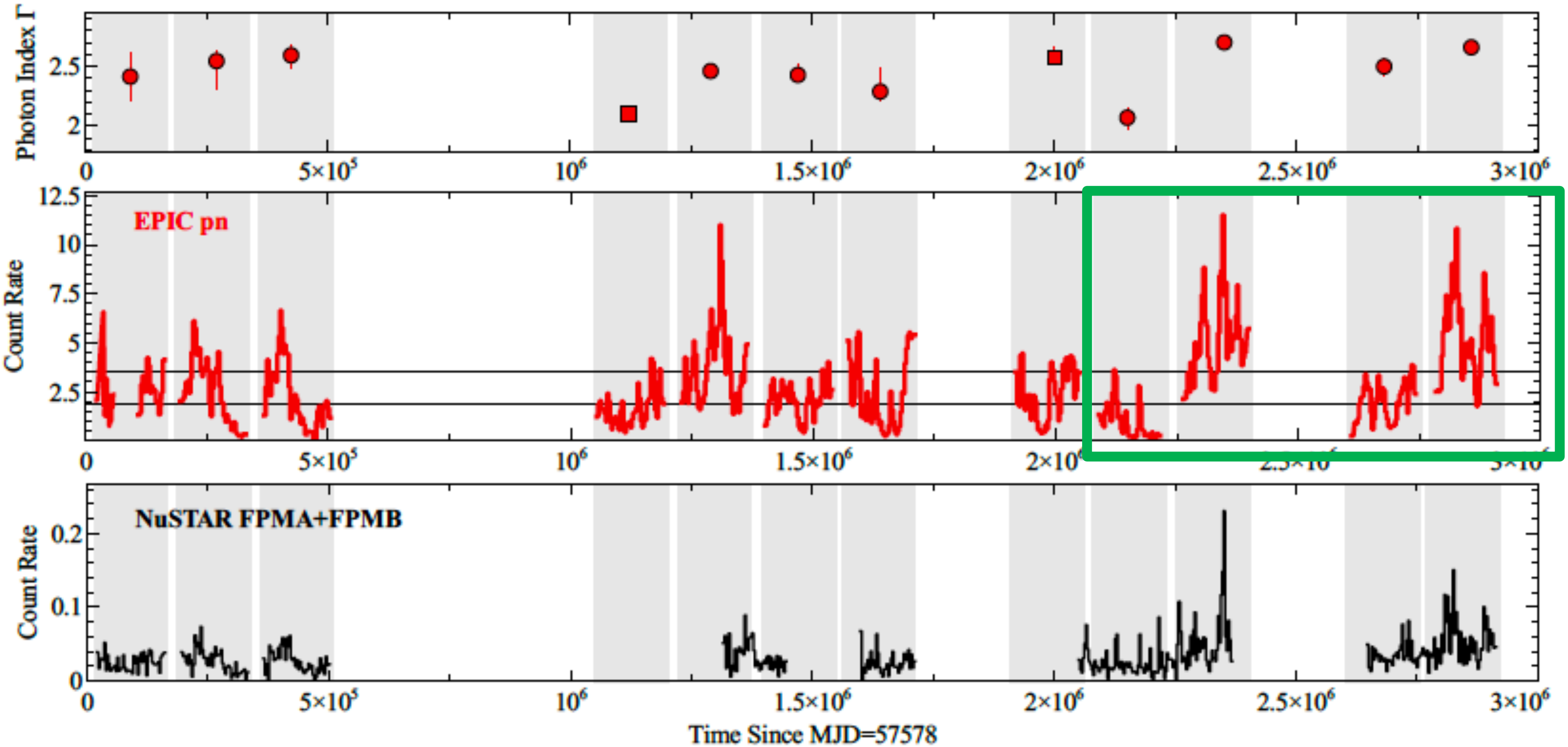

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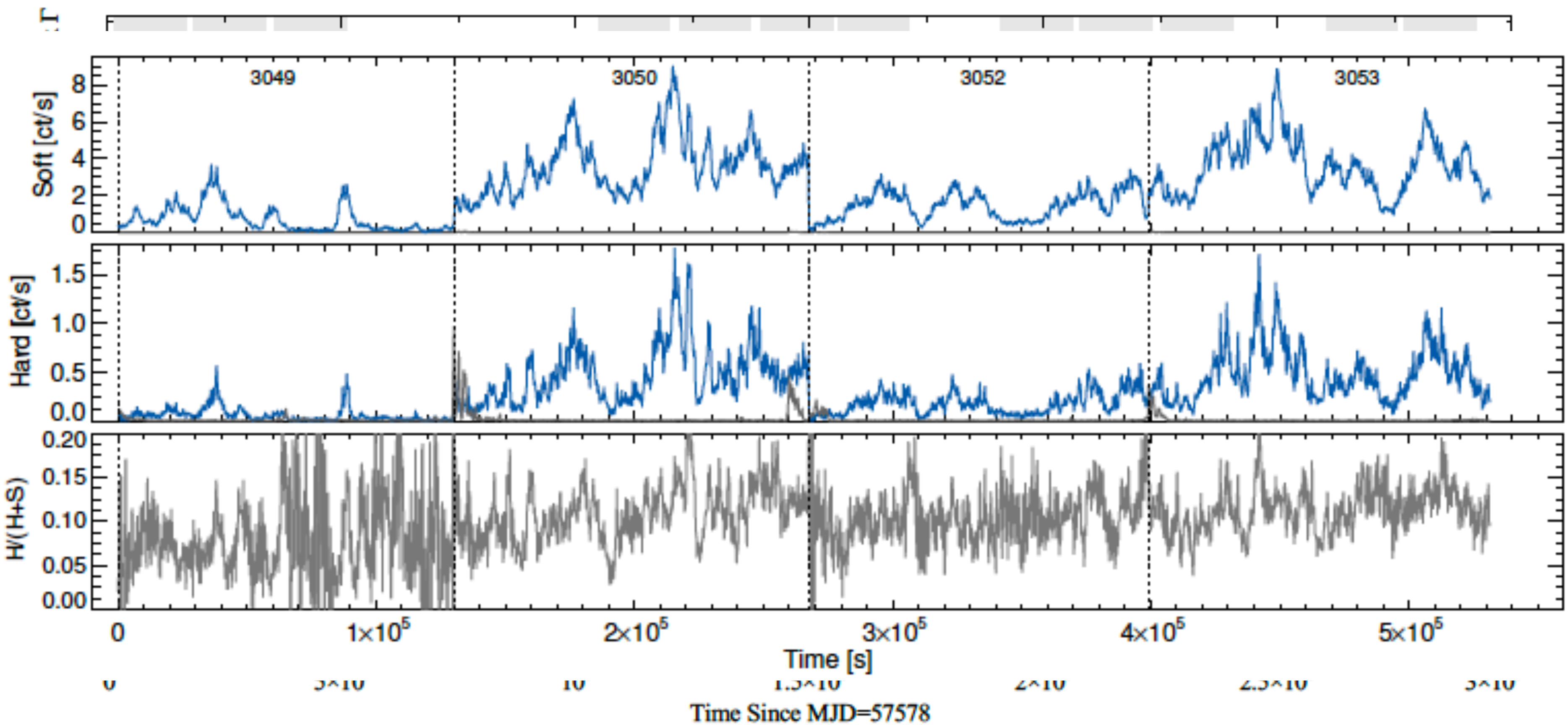

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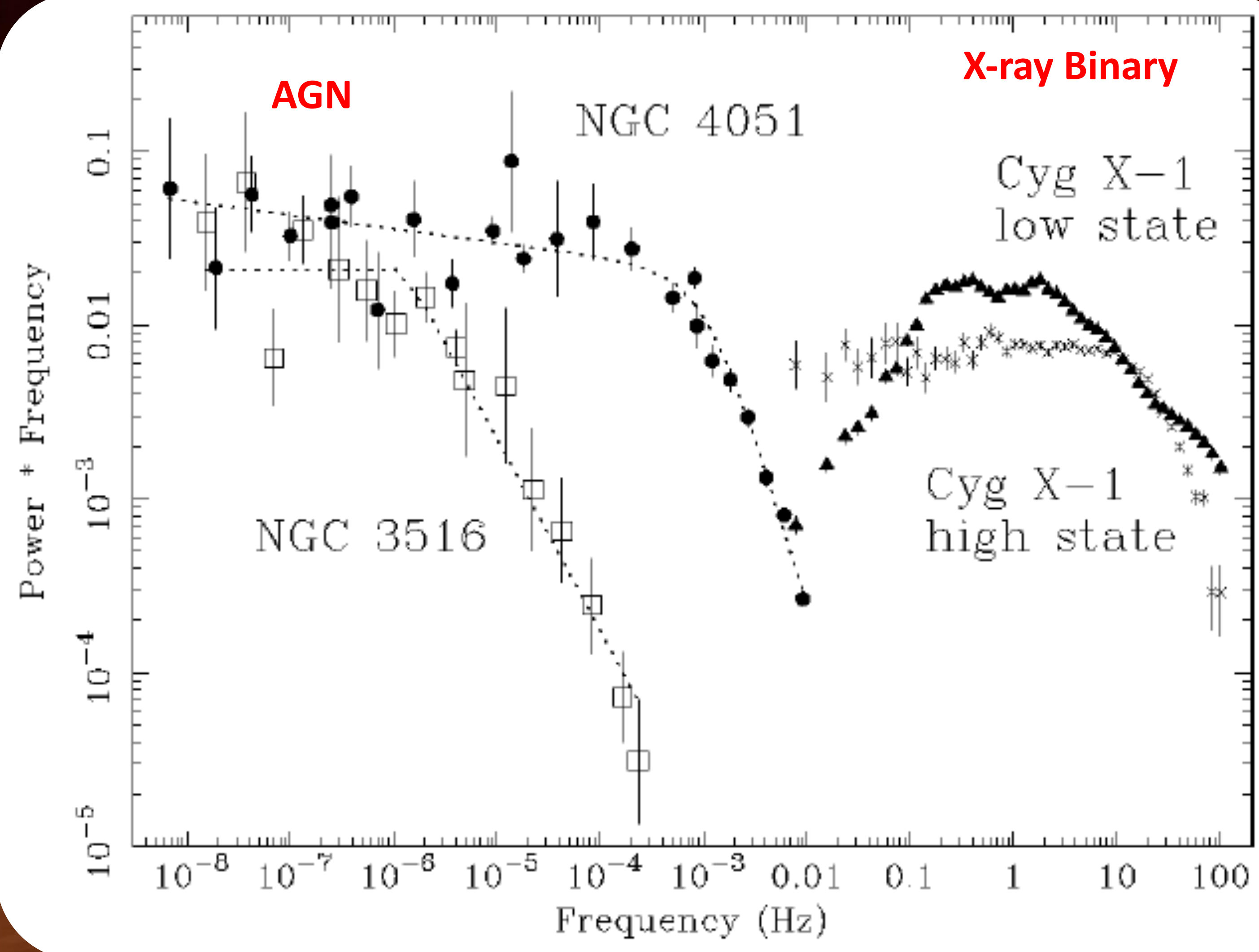
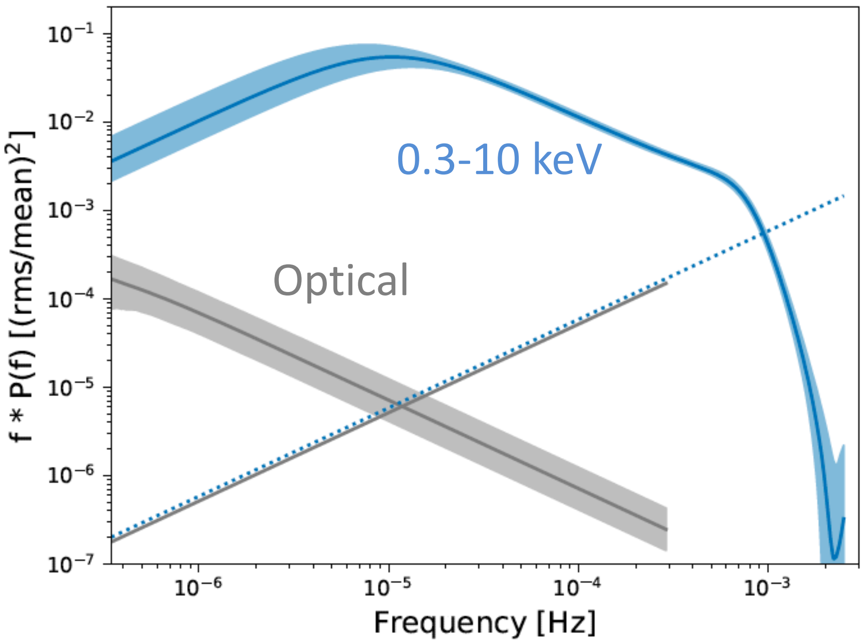
Power Spectral Density (PSD)
- variability amplitude as a function of temporal frequency

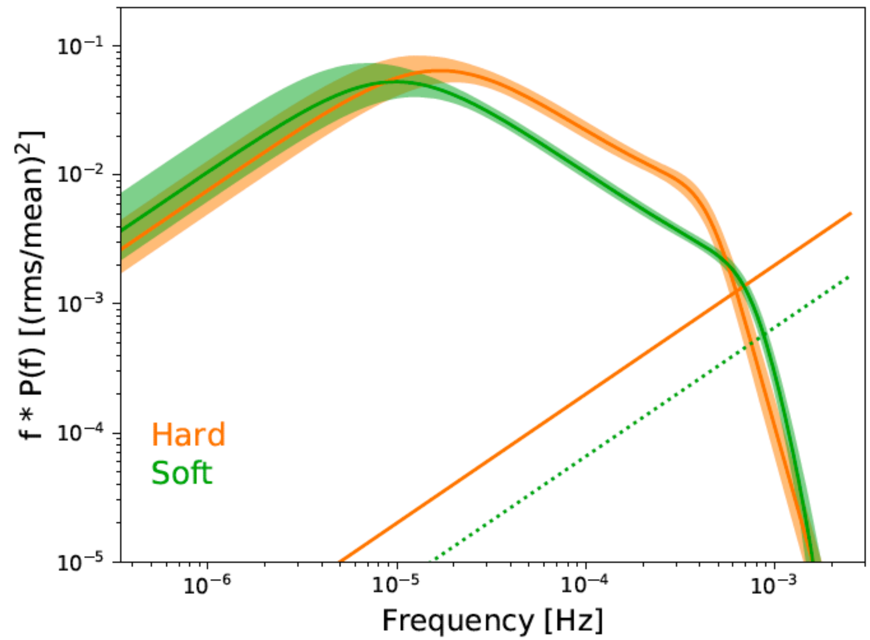


See also talks by Ponti, DeMarco

Long-term PSD

CARMA modelling of 30 day full light curve
(continuous auto-regressive moving average; Kelly et al 2014)
Works for gappy data
Models PSD as sum of Lorentzians

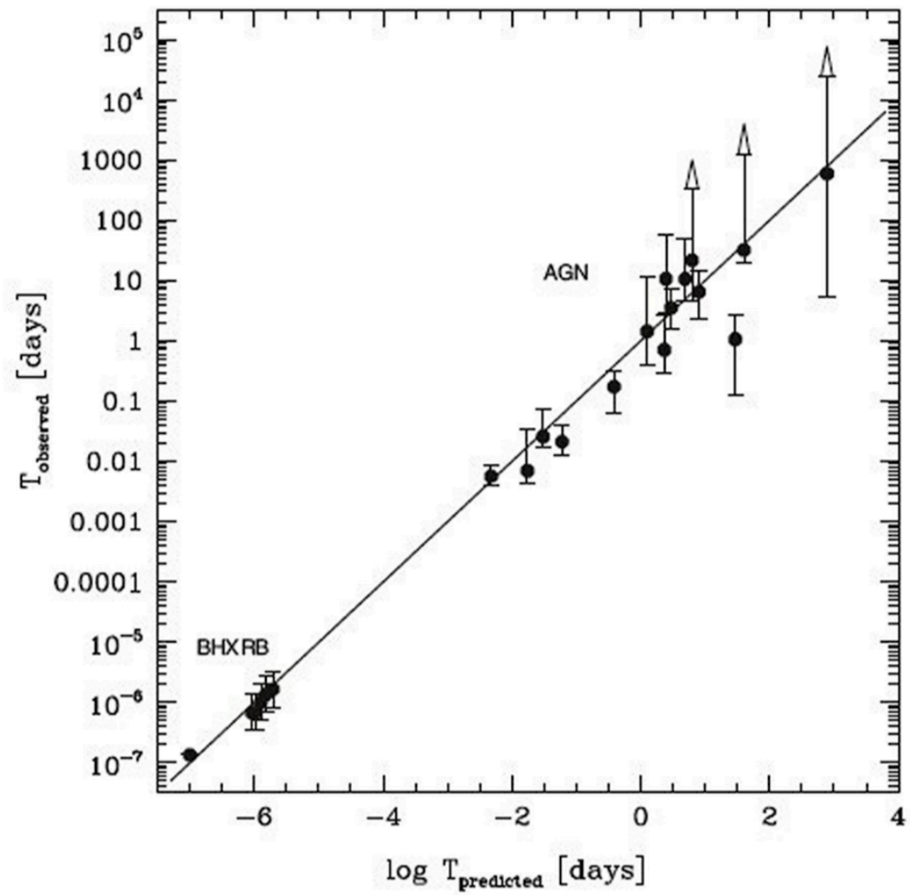




Low frequency roll over seen in one other AGN: Ark 564 (McHardy et al 2008)

Alston et al, sub

BH mass – PSD break relation



Relation between BH mass and high frequency PSD break timescale observed for many Type 1 AGN and BH XRBs

$$\log(T_b) = A\log(M_6) + B\log(L_{44}) + C$$

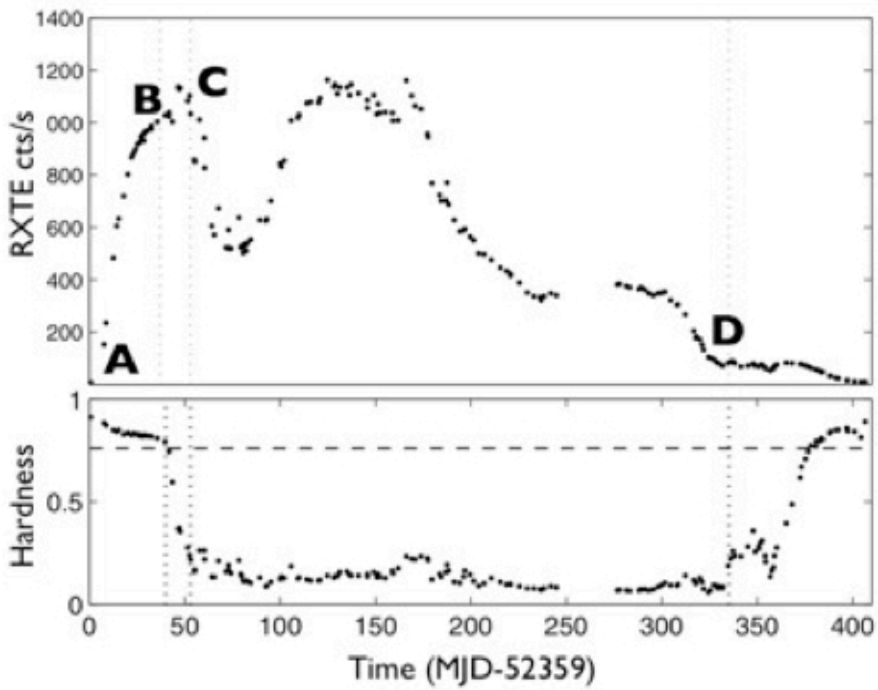
IRAS 13224:
T_b = 0.012 days
L_{bol} = 4 x 10^{44} ergs s^{-1} (Buisson+18)

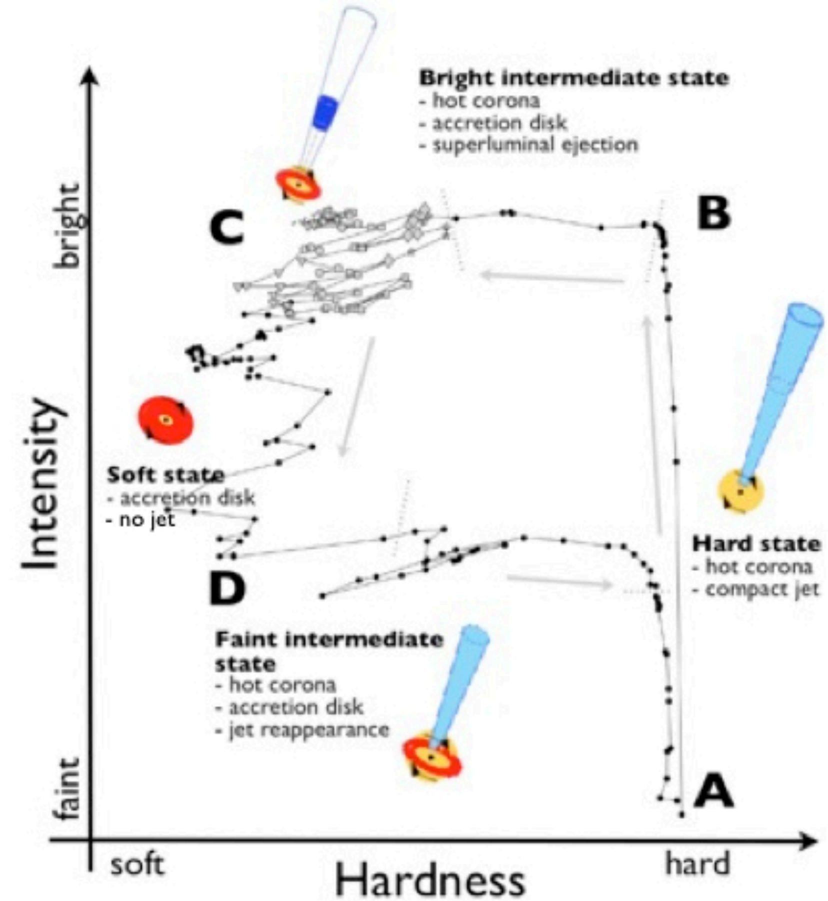
M_{BH} = 2 x 10^6 M_{sun}
m_{Edd} $\gtrsim$ 1-3

McHardy et al 2006
Gonzalez-Martin & Vaughan 2012

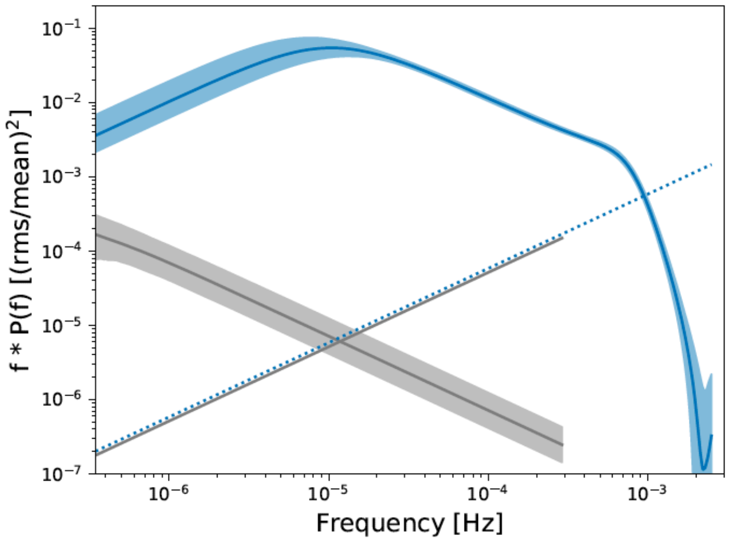
Accretion state analogue

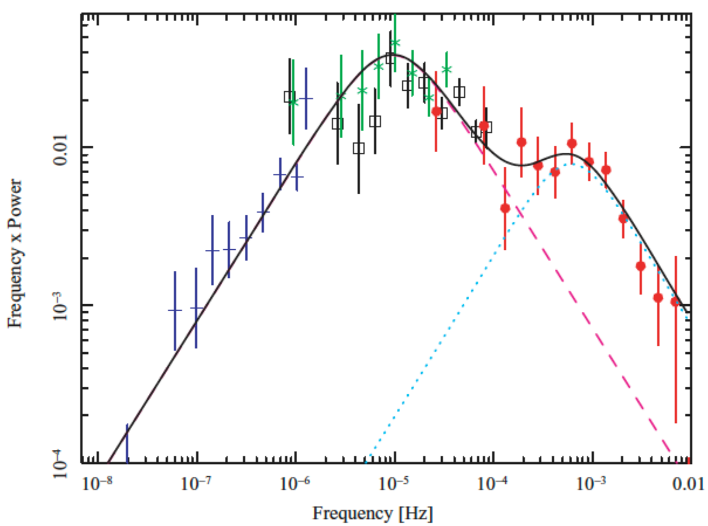
BH XRBs have distinct PSD shapes for particular accretion states

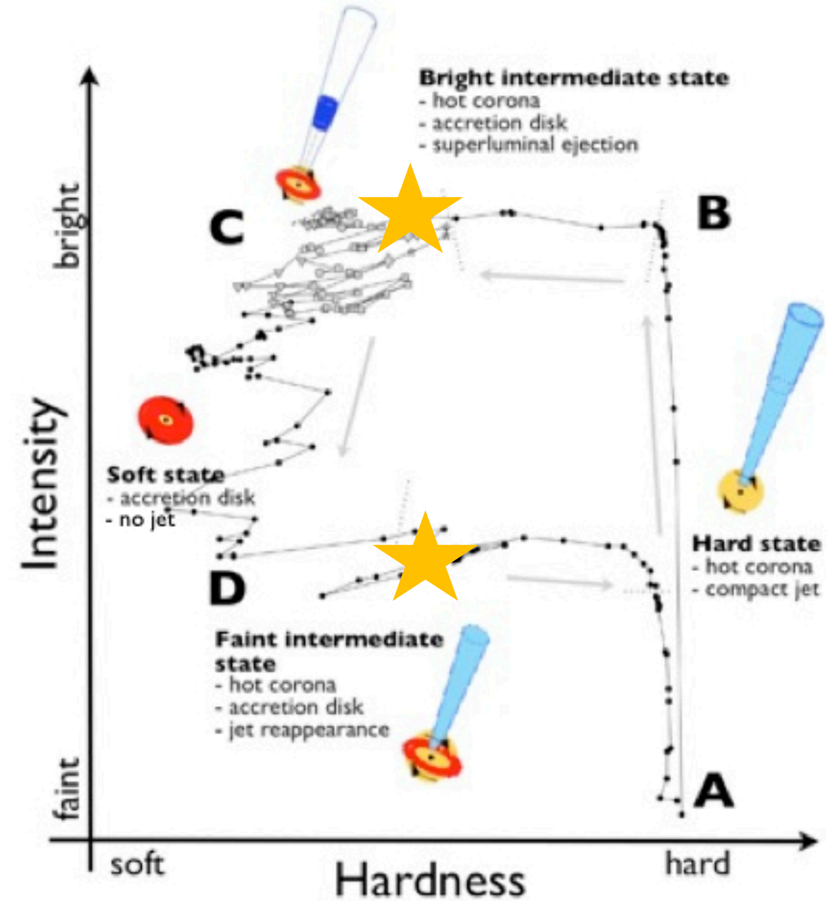




Accretion state analogue





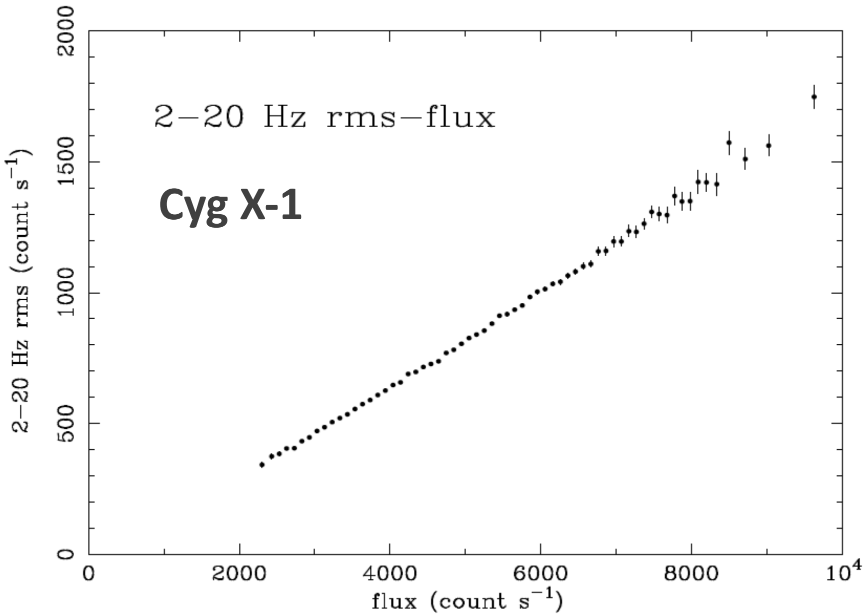


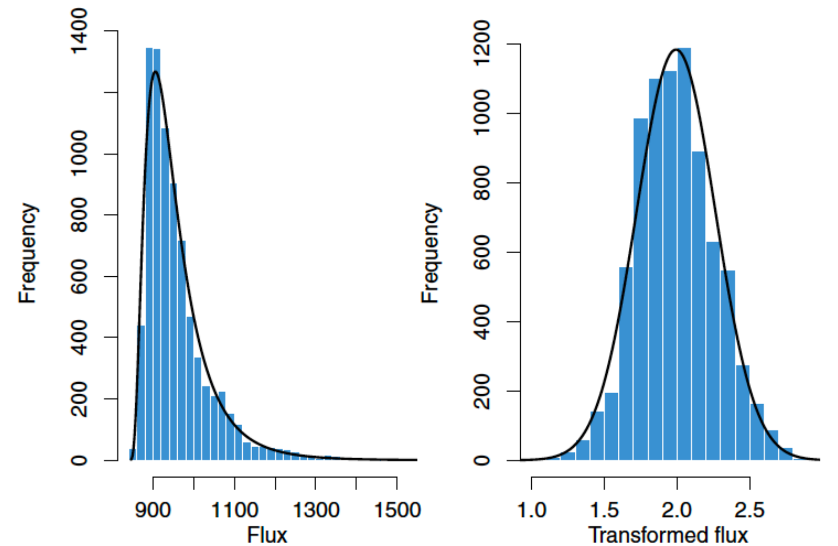
Low frequency roll over seen in one other AGN: Ark 564 (McHardy et al 2008)

Also accreting at Eddington

Therefore Very High/Intermediate state

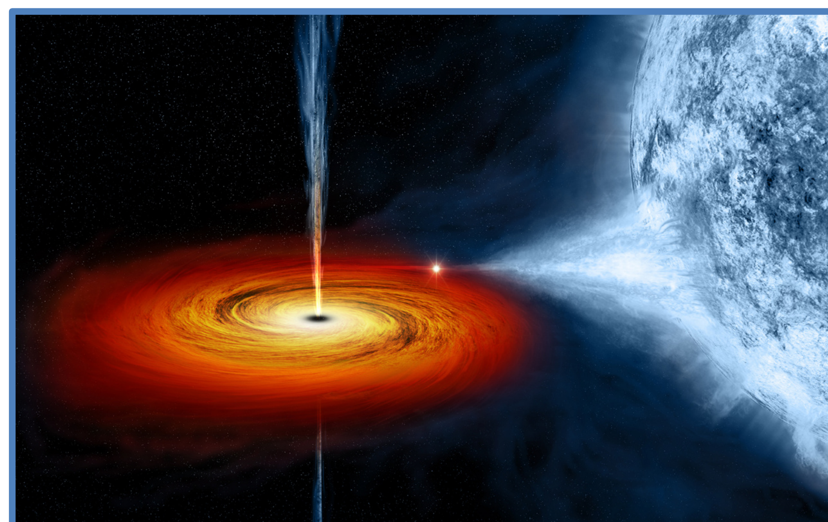
Rms-flux relation: linear



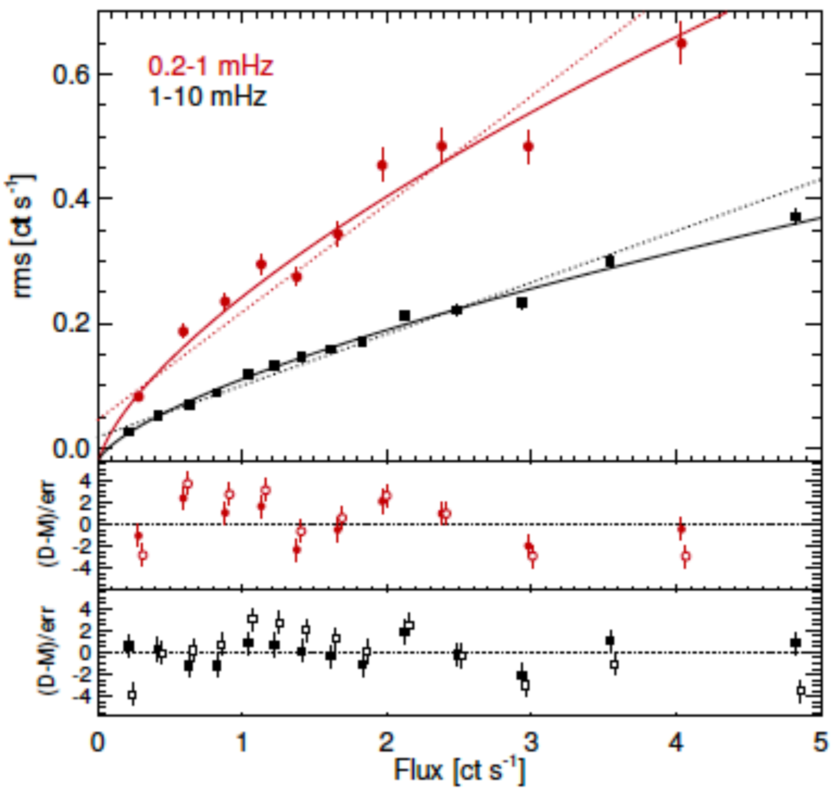


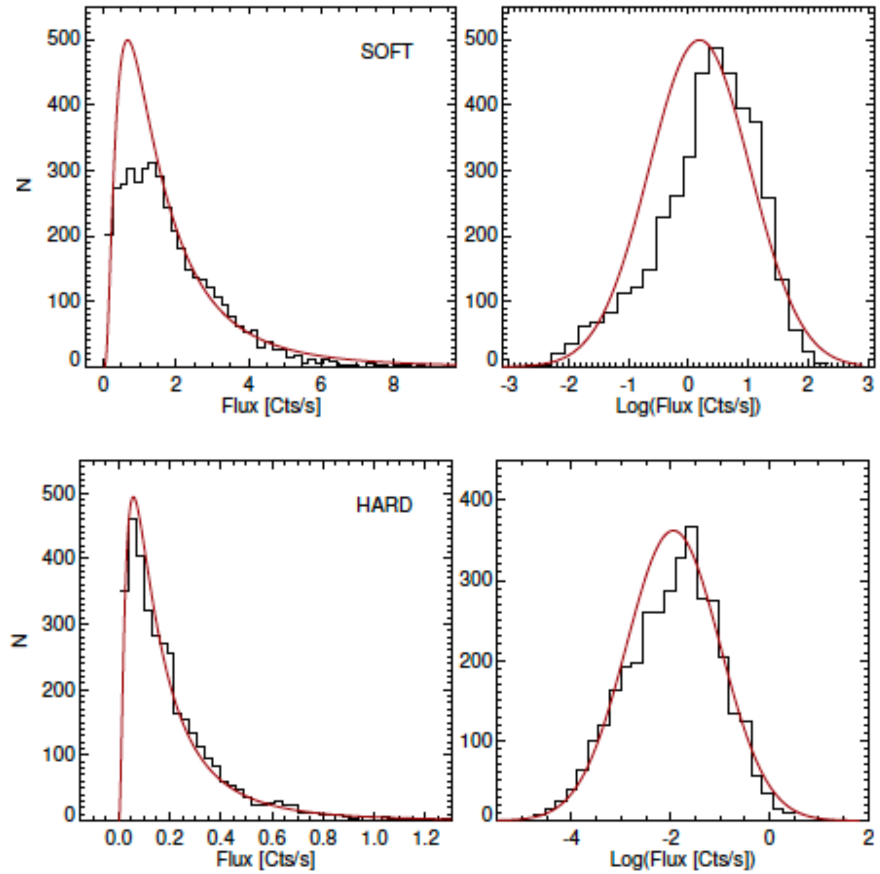
- Universal signature of accretion: WDs, YSOs, XRBs, AGN
- Tells us variability process is multiplicative, not additive
- Consistent with propagation of fluctuations model

e.g. Uttley + 2005, Vaughan + 2011



IRAS 13224-3809: rms-flux relation





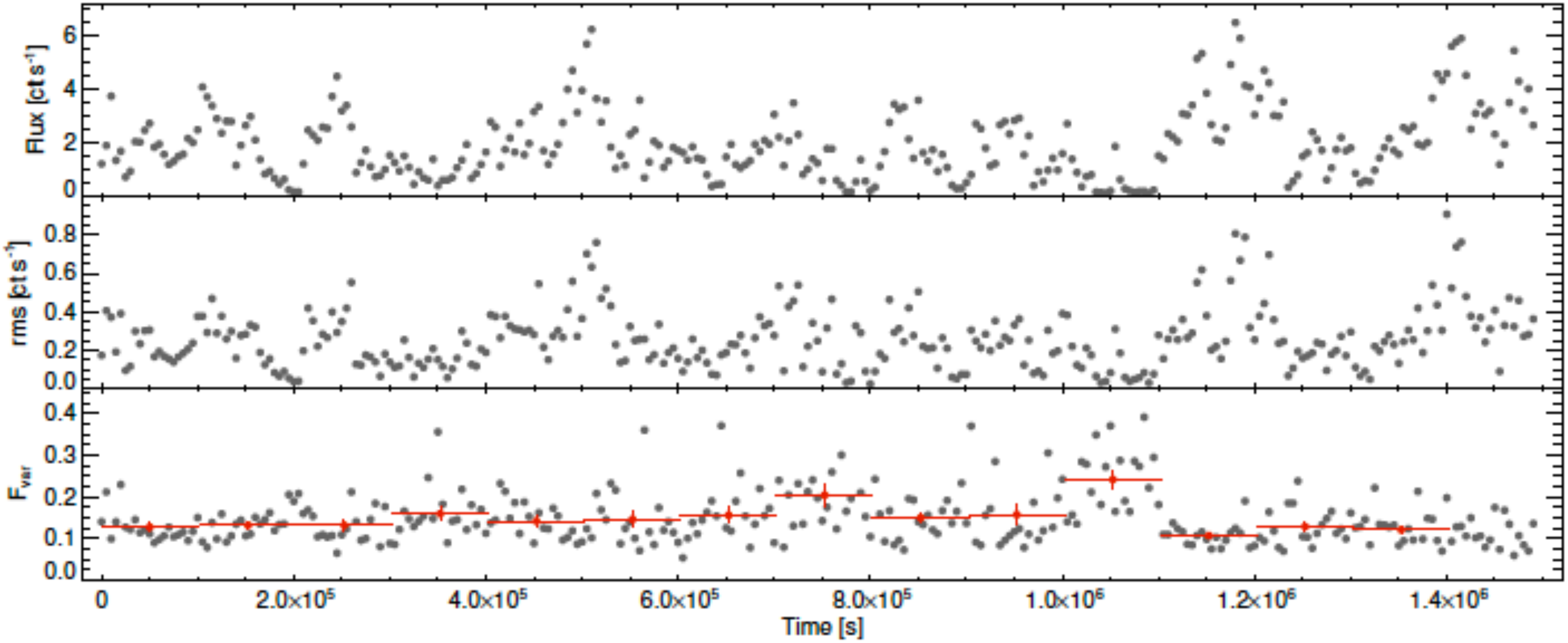
Poor fit to linear model

$\sim F^{\alpha}$, with $\alpha = 2/3$

Corresponds to power law transformation of a Gaussian process

IRAS 13224-3809: stationarity

Stationary process: well defined mean and variance on long timescales

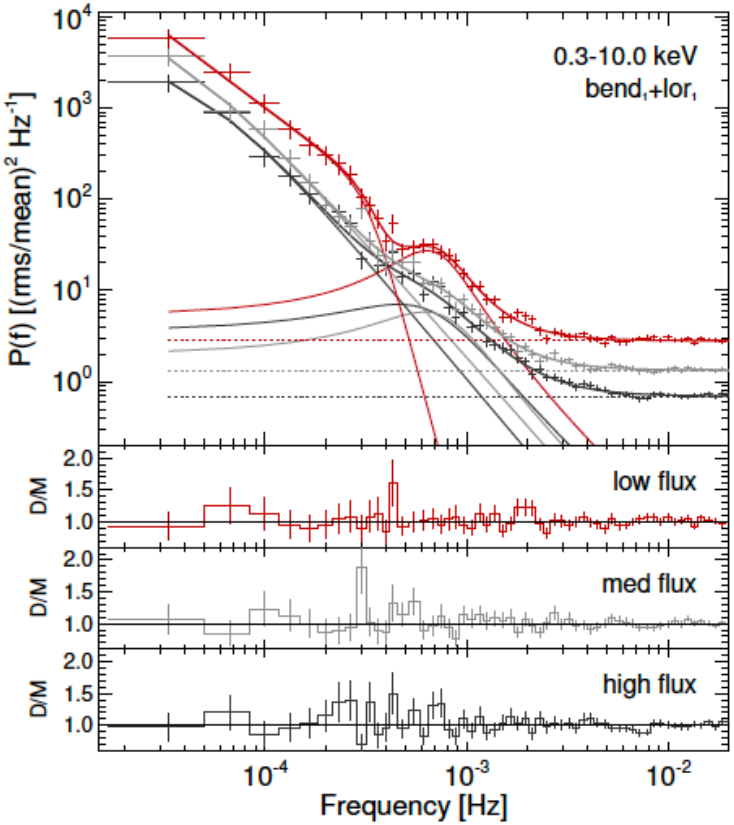


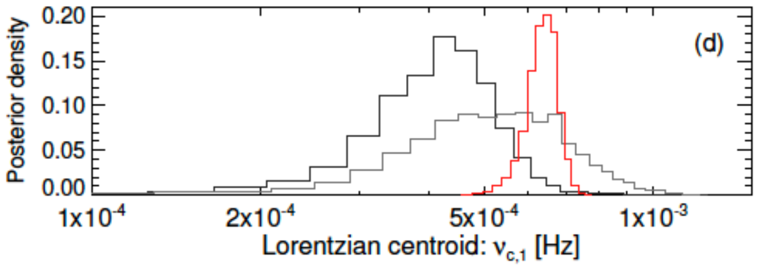
Fractional variability should remain constant for stationary process

- Factors out rms-flux relation

Alston et al, submitted

Inner disc radius vs m_dot





McHardy relation:

$$\log(T_b) = A\log(M_6) + B\log(L_{44}) + C$$

$$\dot{m}_E \approx L_{bol}/L_E$$

$$T_B \approx M_{BH}^{1.12} / \dot{m}_E^{0.98}$$

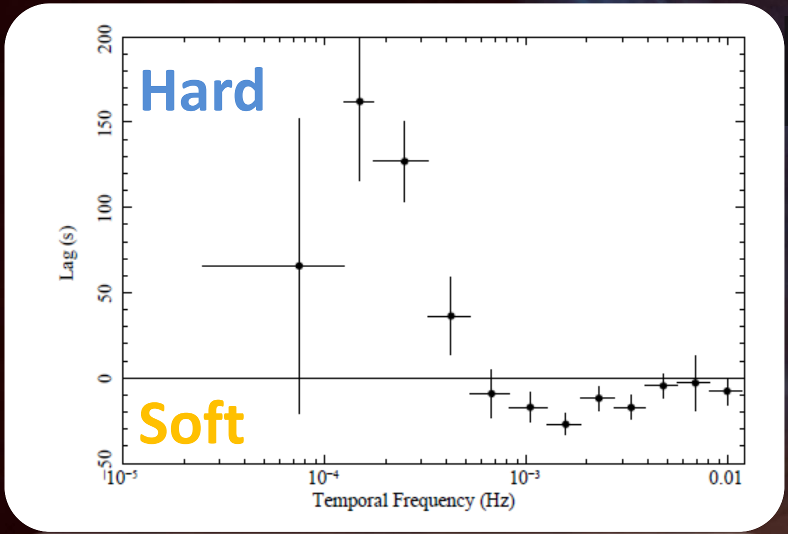
Assume HF break related to inner disc – e.g. thermal/viscous timescale

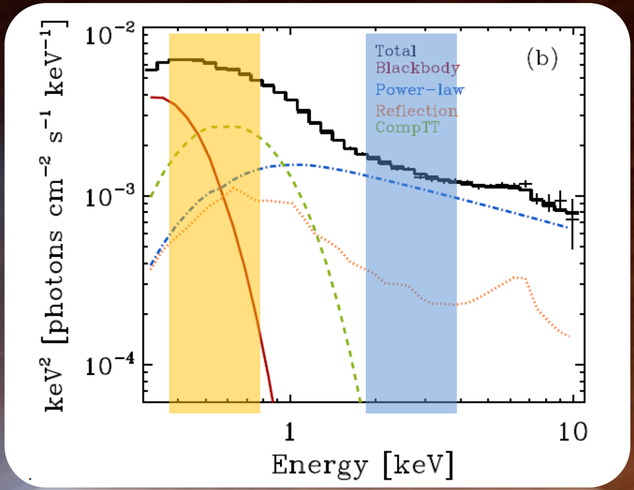
$$R_{disk} \propto \dot{m}_E^{-2/3}$$

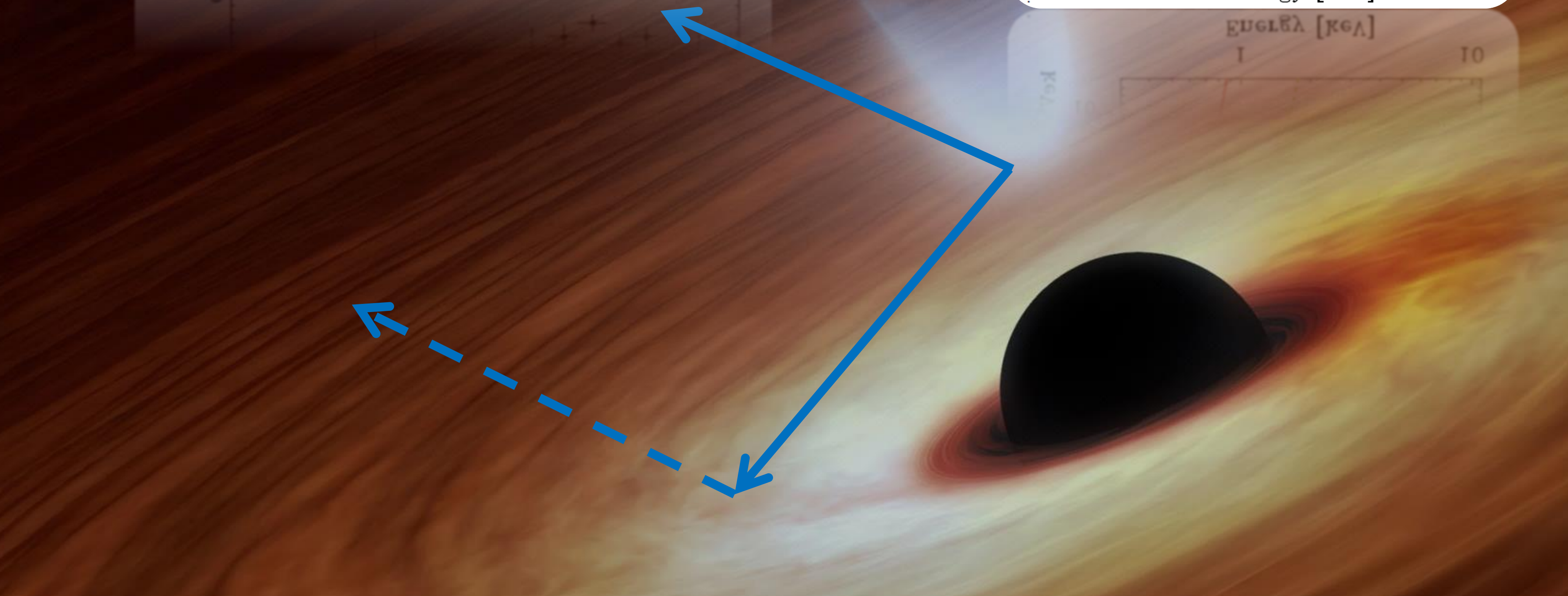
May be observing break timescale decreasing with flux (m_dot)

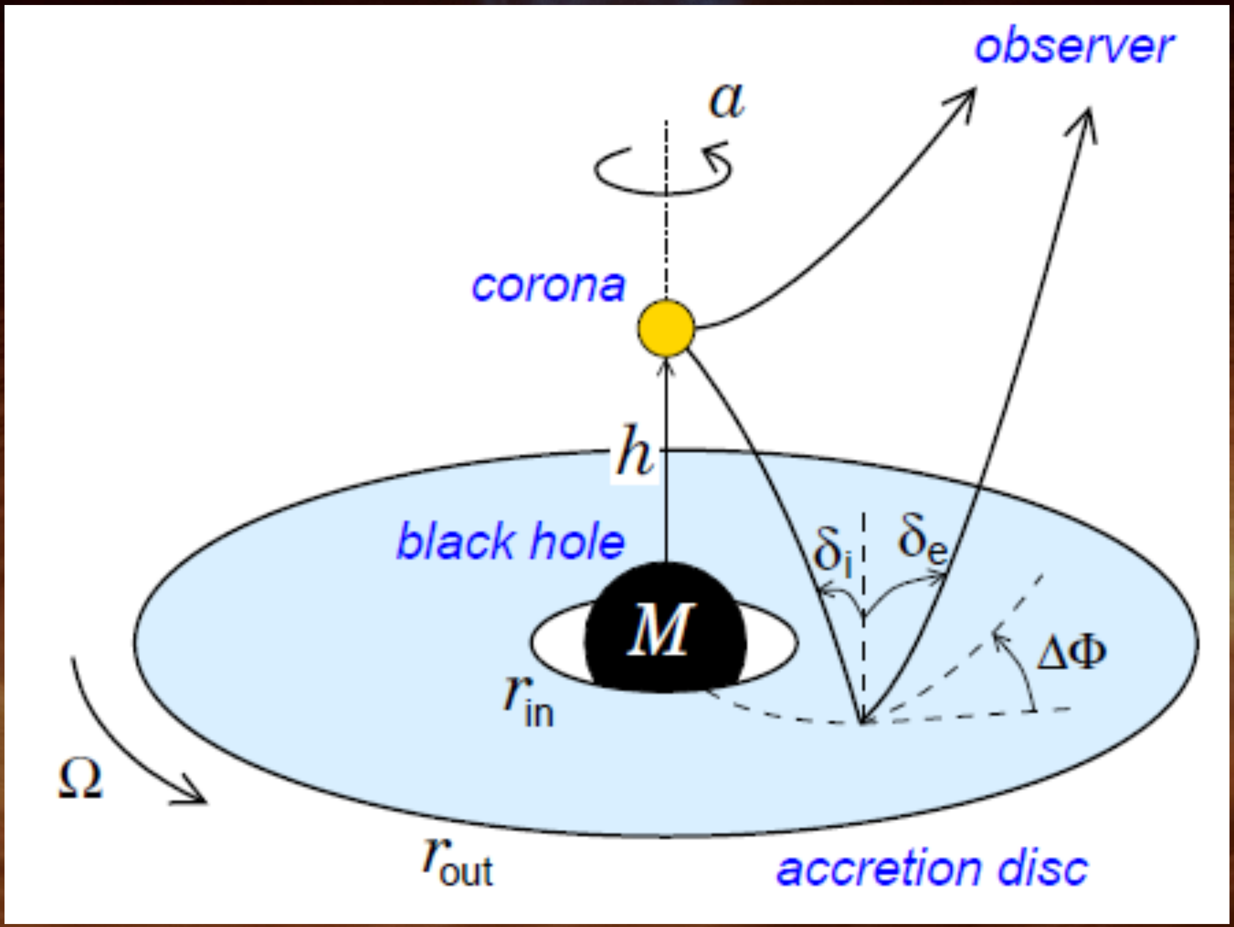
Alston et al, sub

AGN time lags:









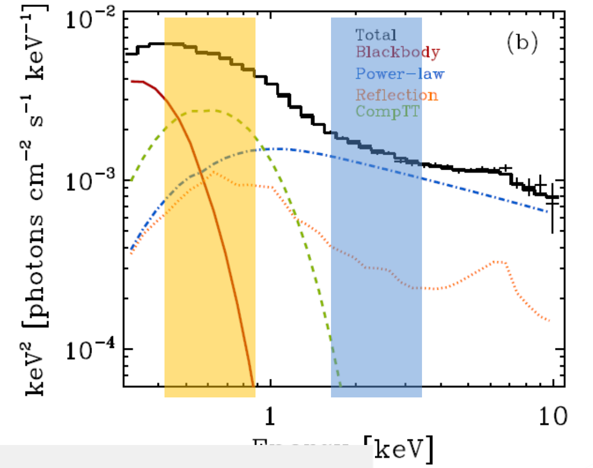
See also talk by Caballero-Garcia

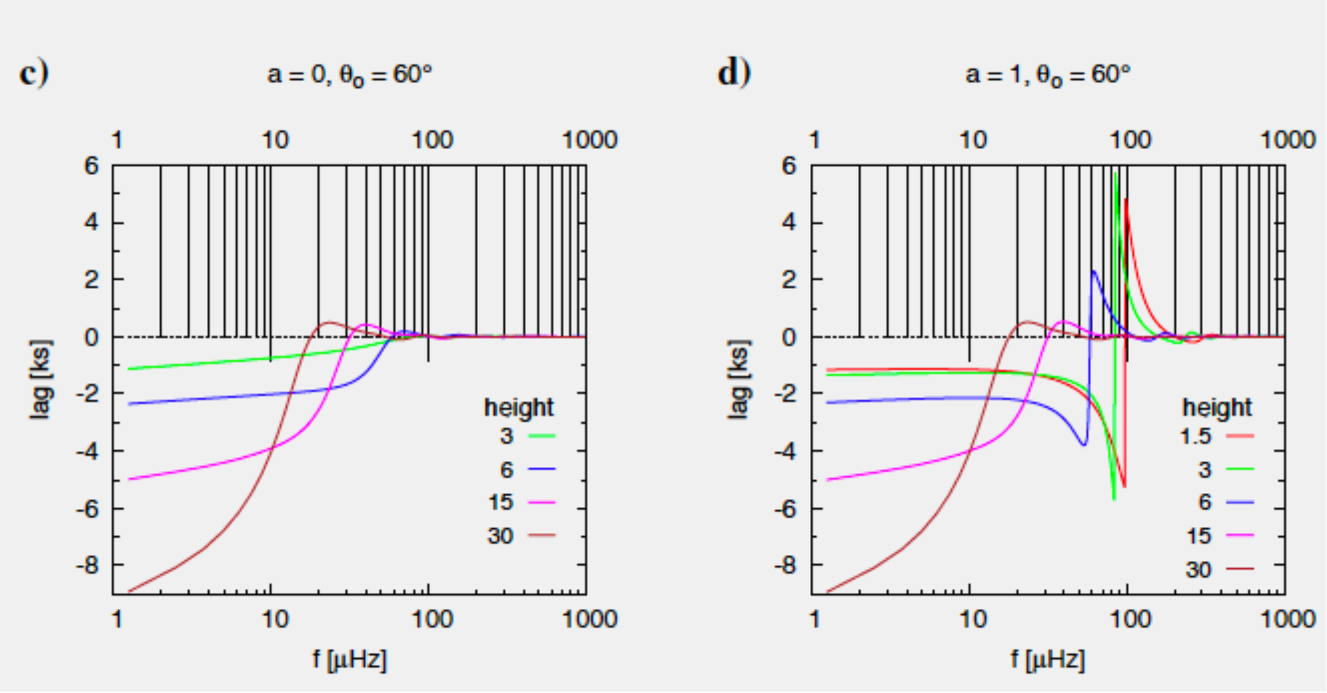
Modelling time lags

Transfer function   Response function

$$\Gamma(\nu) = \int_{-\infty}^{\infty} \psi_{\mathcal{E}}(t) \exp(-i2\pi\nu t) dt,$$

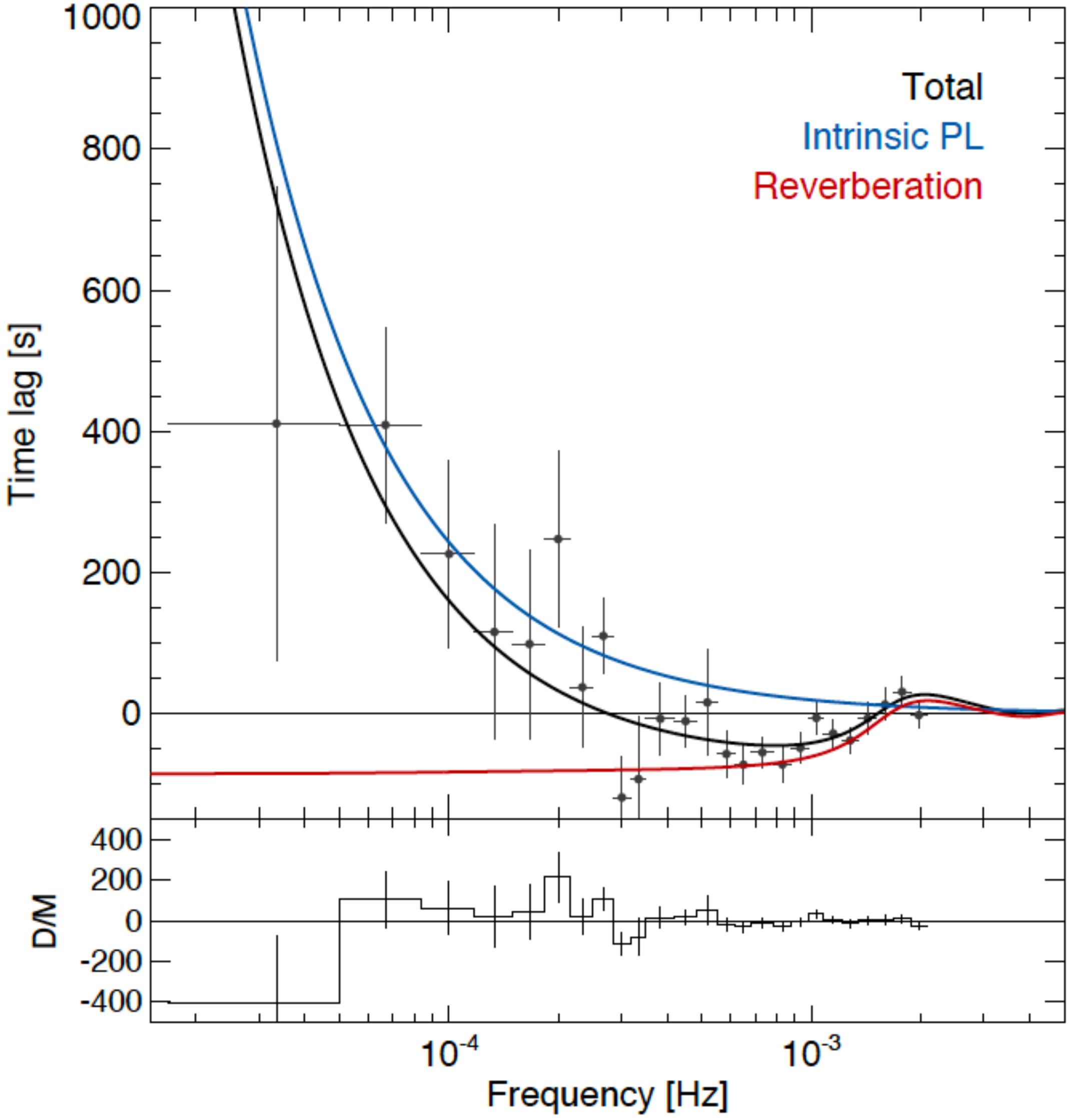
Requires reflection spectrum to obtain weighting in each energy band





Dovciak, et al (2014)

Modelling time lags

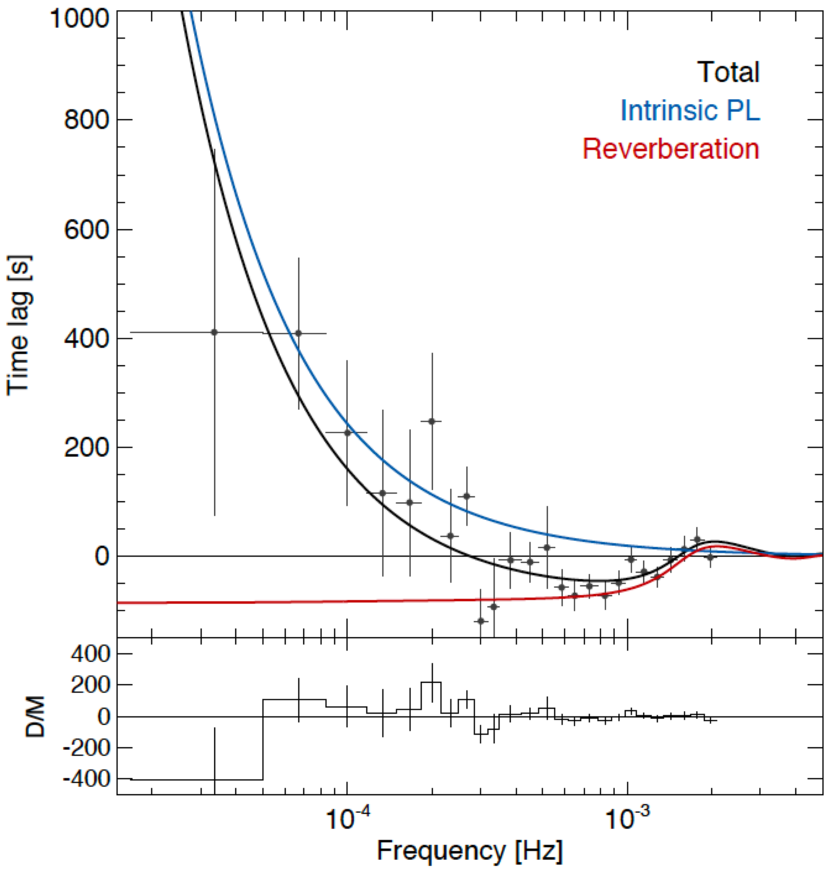


From spectra:
Disc density
emissivity

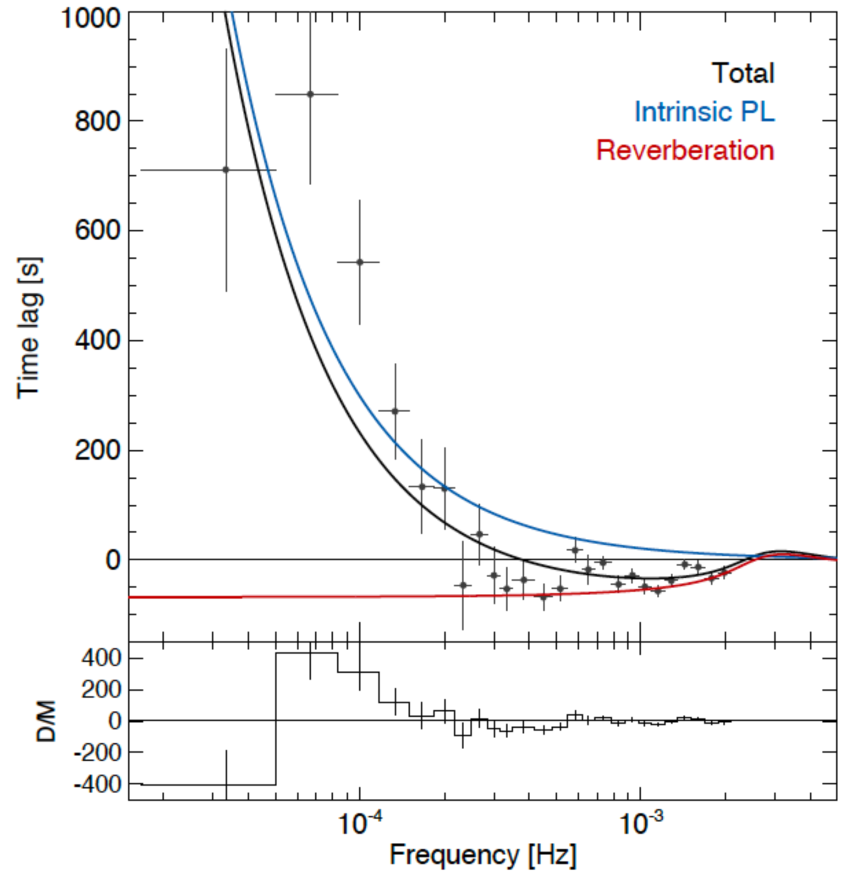
Free parameters:
$M_{BH} = 2 \times 10^6\ M_{sun}$
Spin = 0.99
height = 5 Rg

Modelling time lags

Low flux



High flux



Source height increases with flux

But… poor fit to high flux data……….

Modelling of intrinsic lag not correct?

Summary

- X-ray variability is important for understanding accretion processes
- 1.5 Ms (+500 ks) campaign on IRAS 13224-3809
  - Unprecedented look at inner accretion region
- Non-stationarity on ~few 100 ks timescales
- Non-linear rms-flux relation
  - Fractionally more variable at low source flux
- PSD low frequency break + accretion rate
  - VH/Intermediate state analogue
- M_{BH} from HF break
- Modelling lags with single lamppost model
  - High spin and similar mass to break method