Probing the inner accretion region of IRAS 13224-3809

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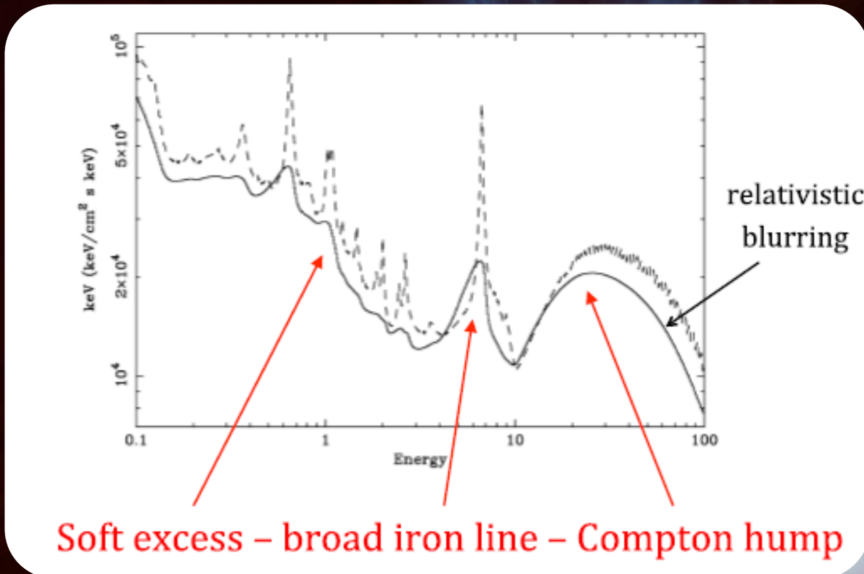
+VLP collaboration

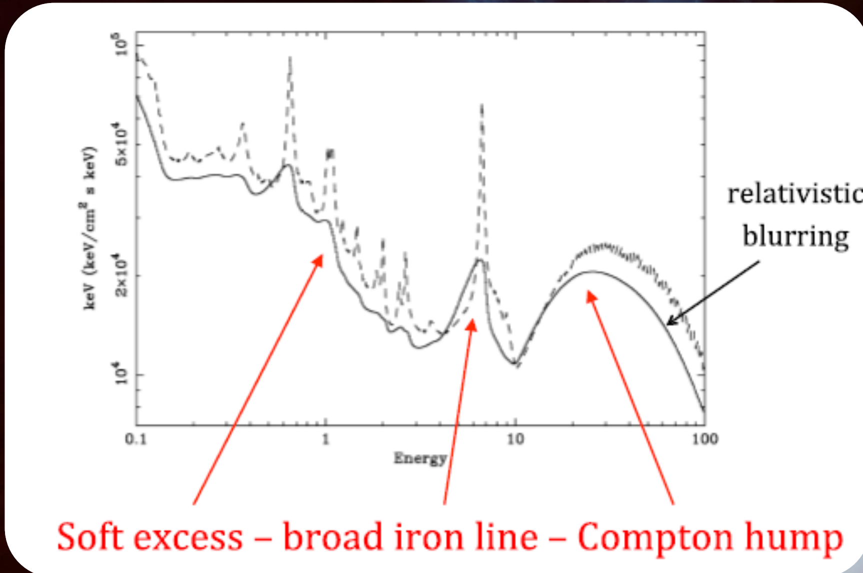
STRONGGRAVITY
EU FP7-SPACE research project 312789 2013 - 2017

Pune
18-12-17

Cambridge X-Ray Astronomy



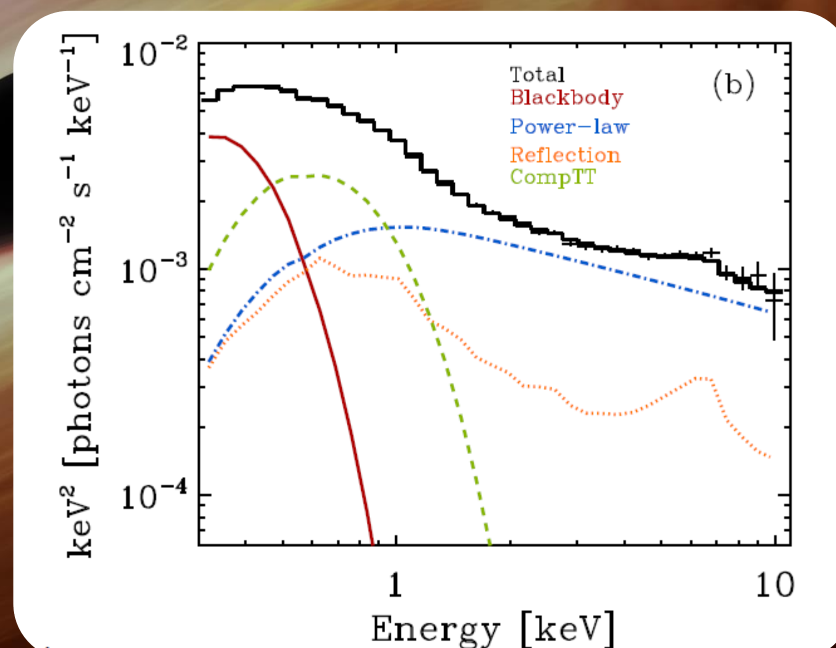
Iron Kα (6.4 keV) and blurring of reflection spectrum can be used to constrain BH spin (see e.g. Reynolds & Fabian 2000)

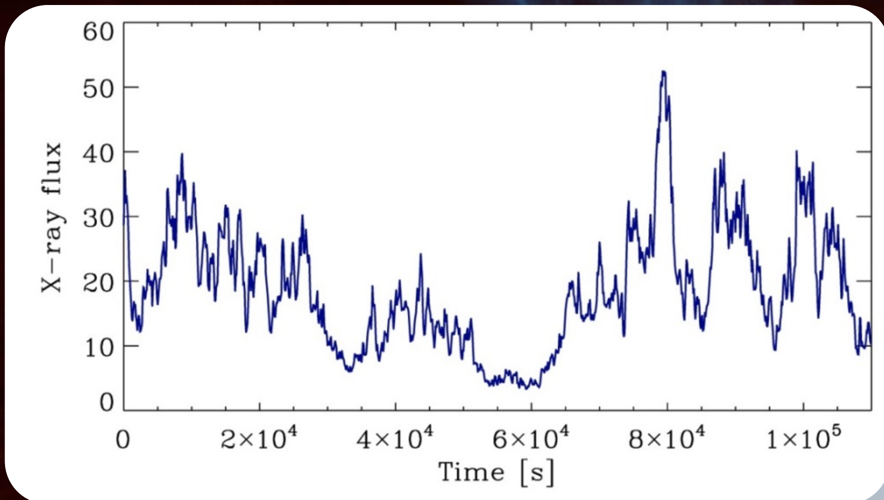


Iron Kα (6.4 keV) and blurring of reflection spectrum can be used to constrain BH spin (see e.g. Reynolds & Fabian 2000)

But, AGN spectra are messy, particularly below 1 keV

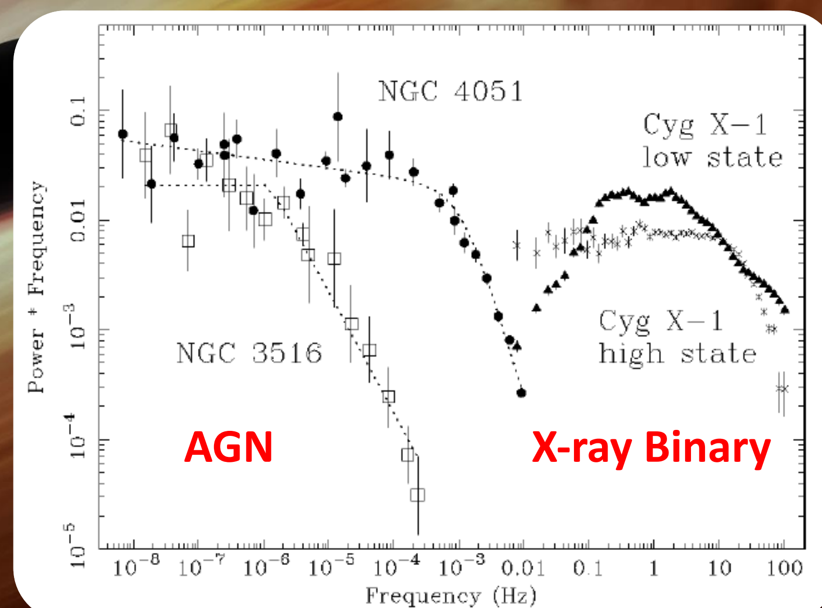
=> Want to use spectral variability to understand variable emission components





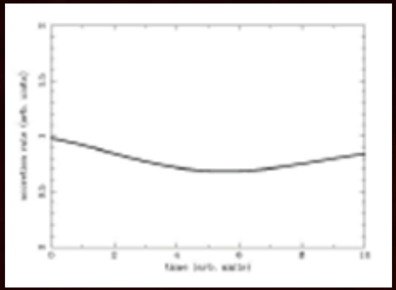
Variable in all wavebands and on all timescales. Largest, most-rapid variations seen in X-rays

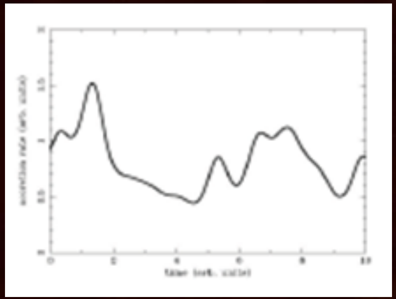
Variability amplitude as a function of temporal frequency

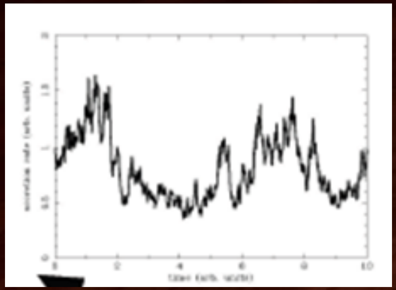


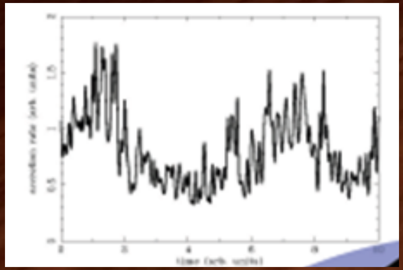
Propagation of mass accretion rate fluctuations

Modulation of independent frequencies (e.g. Arevalo & Uttley 2006)

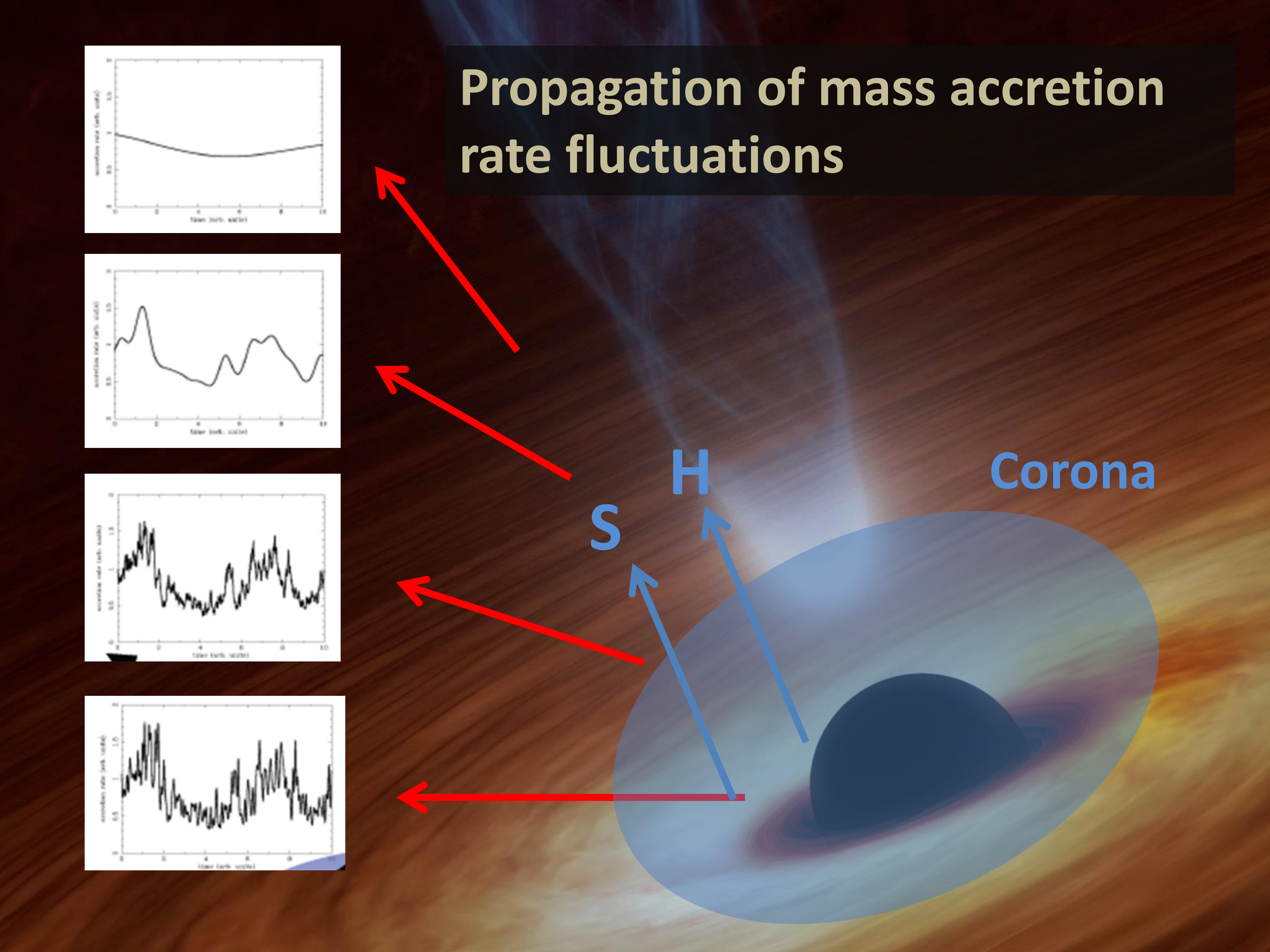




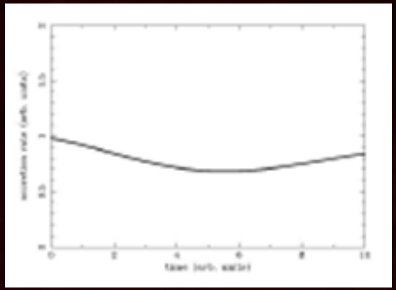


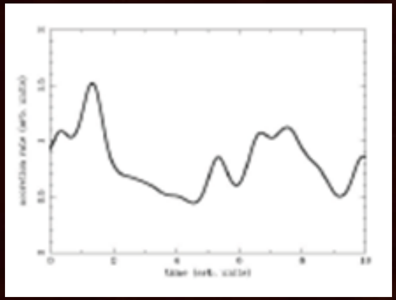


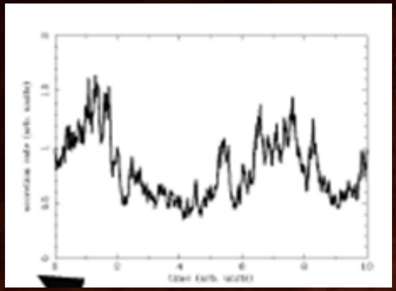
Propagation of mass accretion rate fluctuations

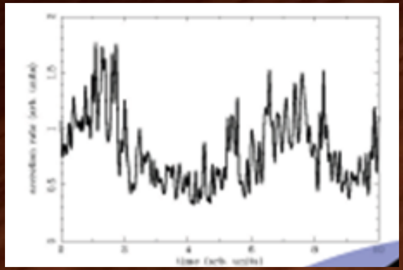


Propagation of mass accretion rate fluctuations



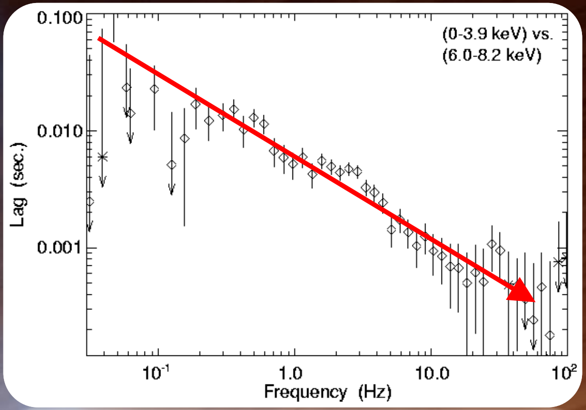




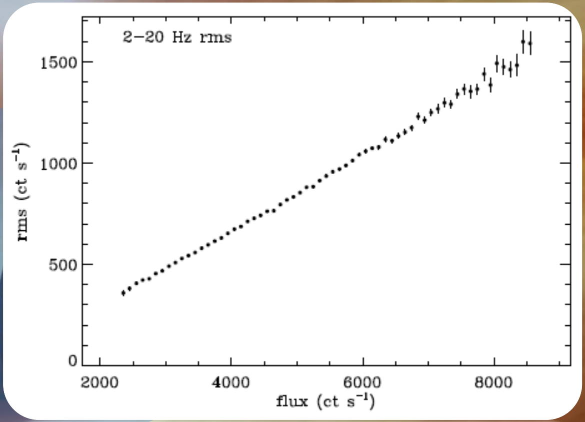


H

S

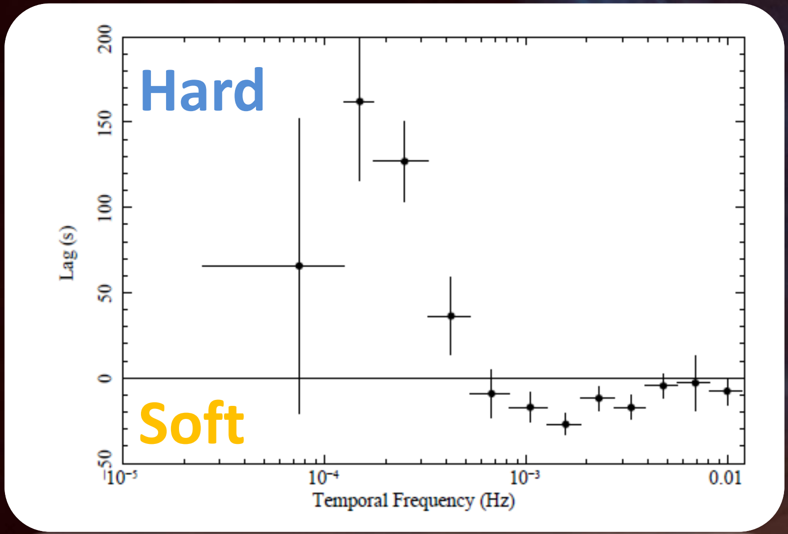


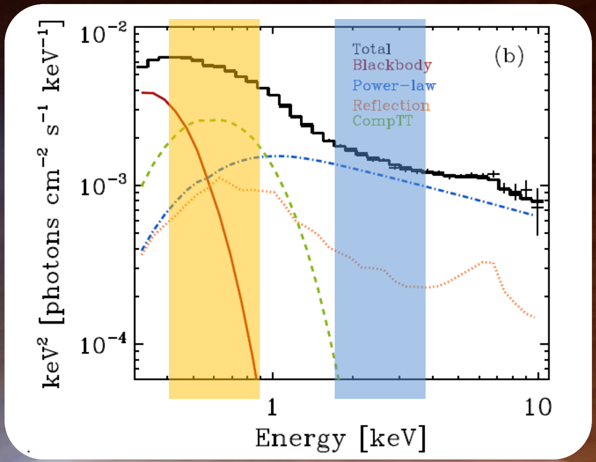
Hard band lags

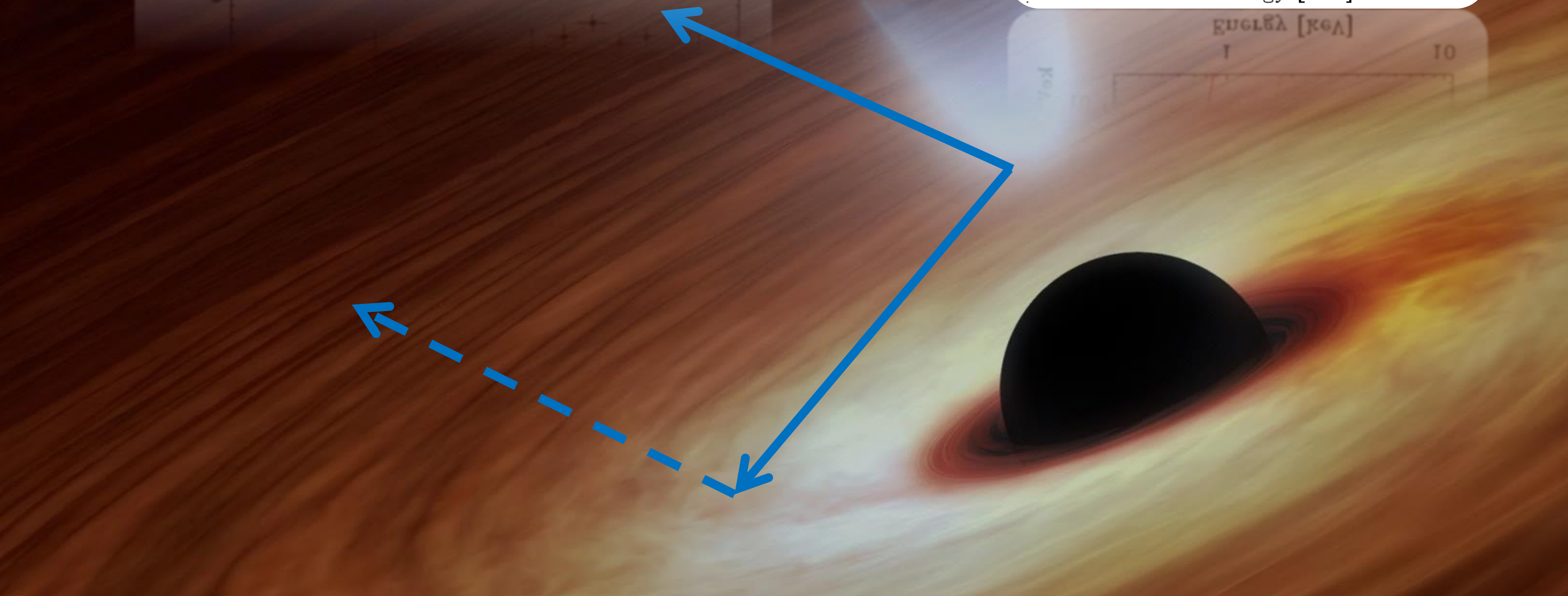


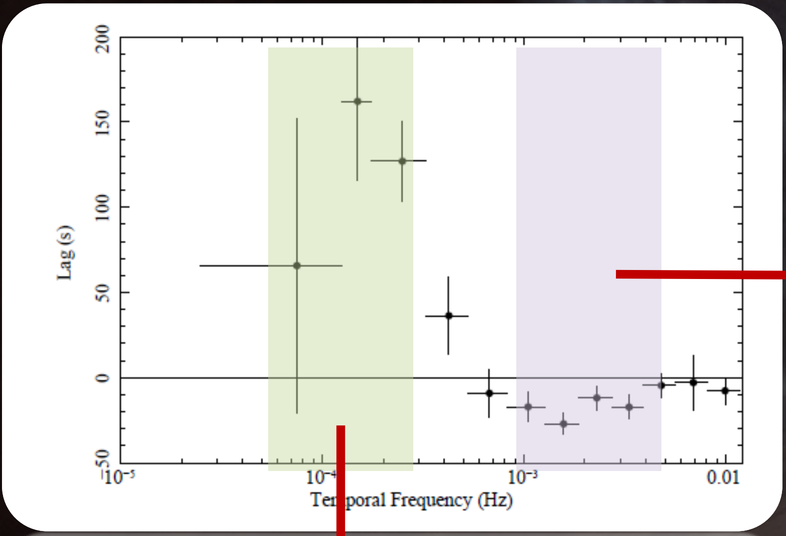
rms-flux relation

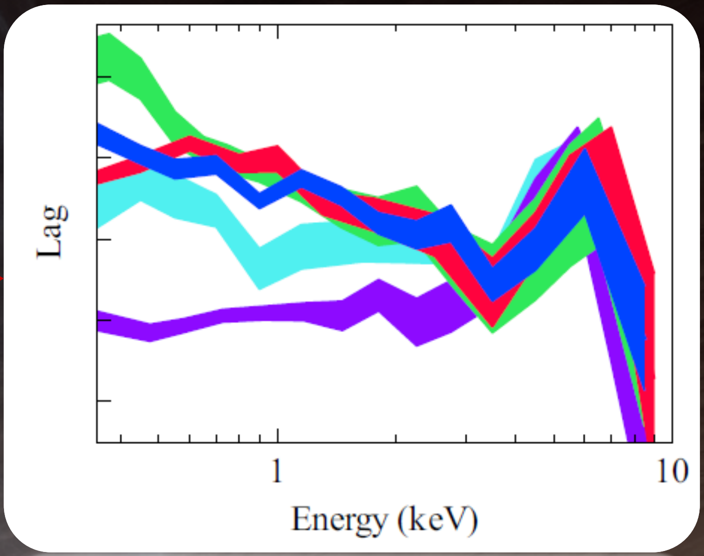
AGN lags:

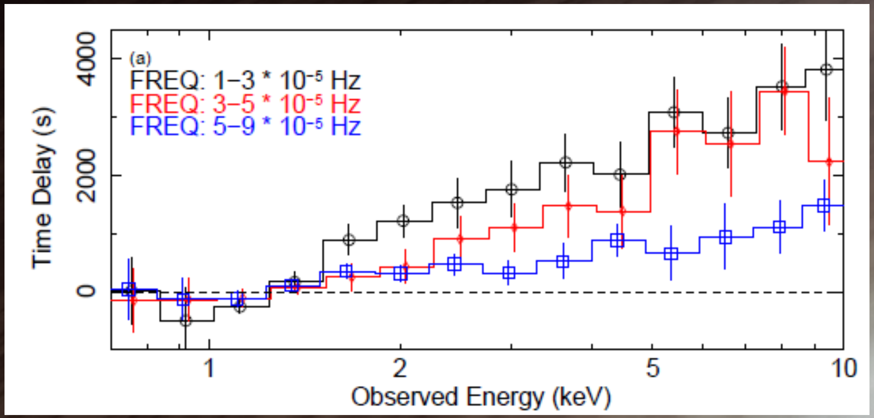

Hard
Soft
Lag (s)
200
150
100
50
0
-50
10⁻⁵
10⁻⁴
10⁻³
0.01
Temporal Frequency (Hz)

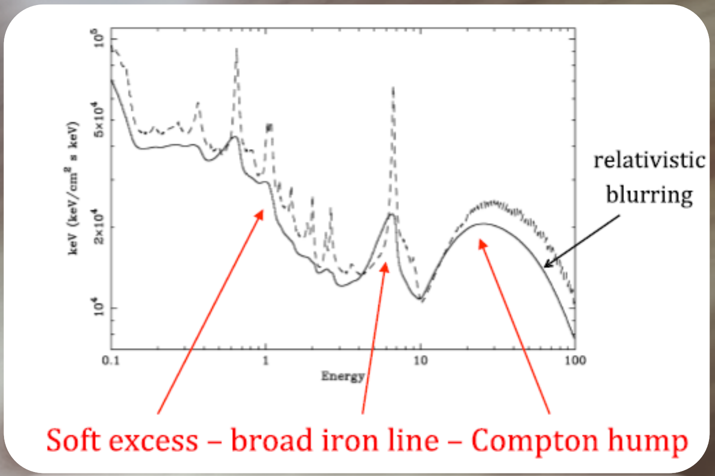

Total
Blackbody
Power−law
Reflection
CompTT
(b)
keV² [photons cm⁻² s⁻¹ keV⁻¹]
10⁻²
10⁻³
10⁻⁴
1
10
Energy [keV]



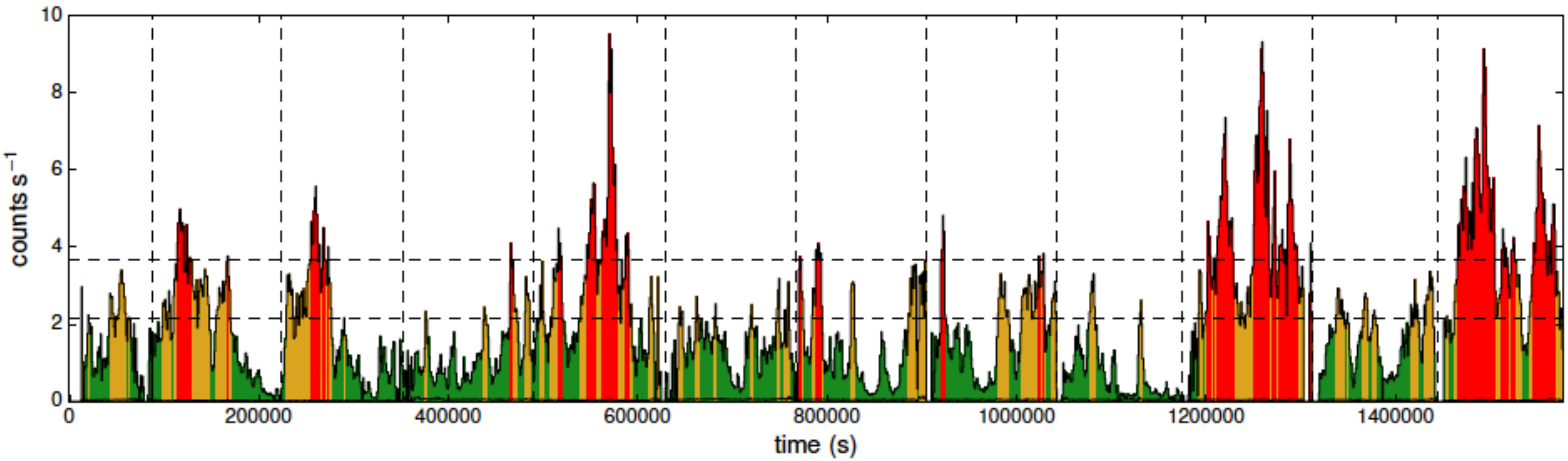

Lag (s)
Temporal Frequency (Hz)
200
150
100
50
0
-50
10^{-5}
10^{-4}
10^{-3}
0.01


Lag
Energy (keV)
1
10


(a)
FREQ: 1–3 * 10^{-5} Hz
FREQ: 3–5 * 10^{-5} Hz
FREQ: 5–9 * 10^{-5} Hz
Time Delay (s)
4000
2000
0
1
2
5
10
Observed Energy (keV)

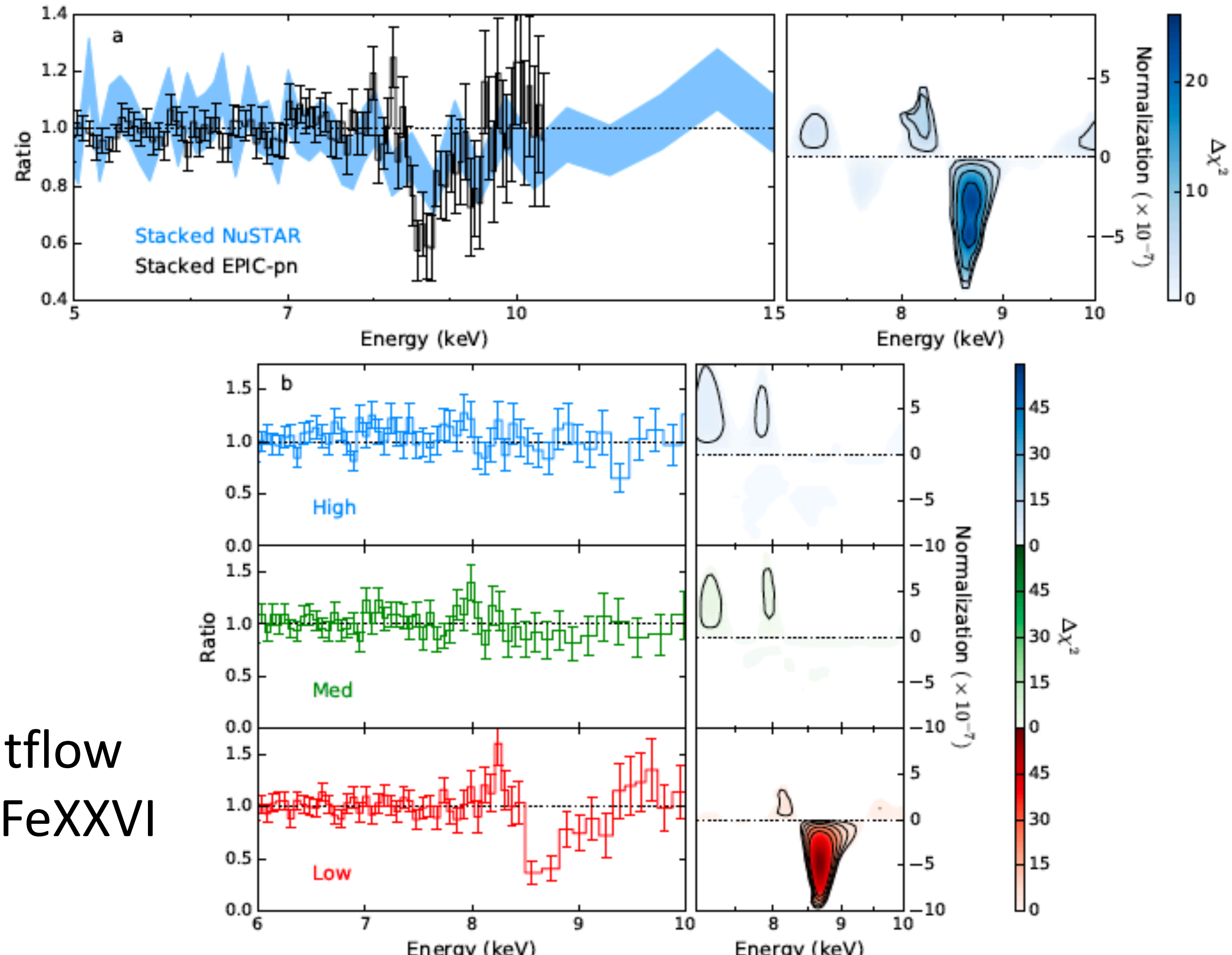

relativistic
blurring
keV (keV/cm^2 s keV)
Energy
0.1
1
10
100
Soft excess – broad iron line – Compton hump

IRAS 13224-3809: ultrafast outflow



Parker et al (2017)

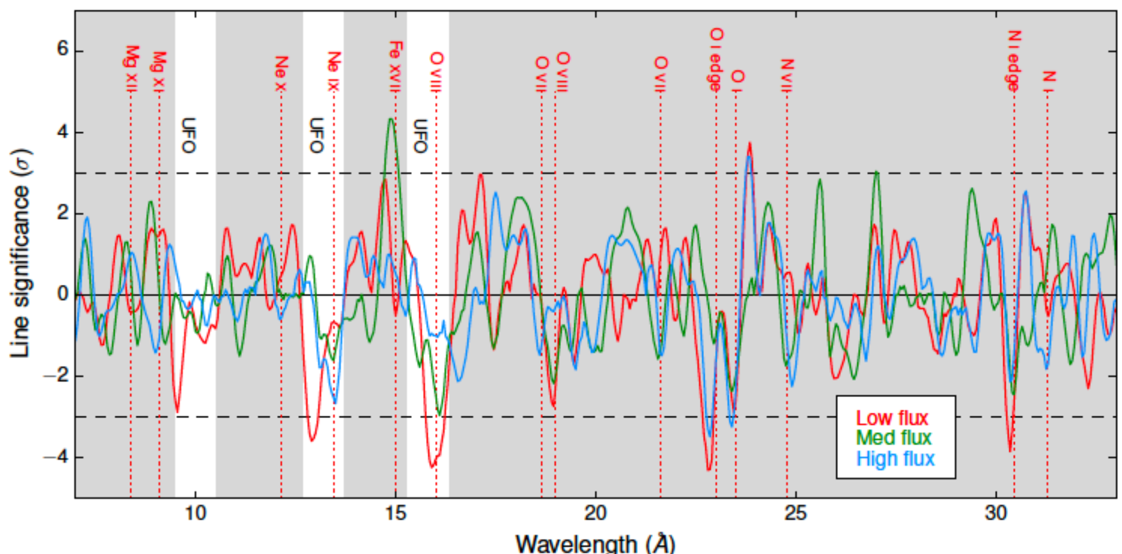
IRAS 13224-3809: ultrafast outflow



~0.24c outflow
FeXXV or FeXXVI

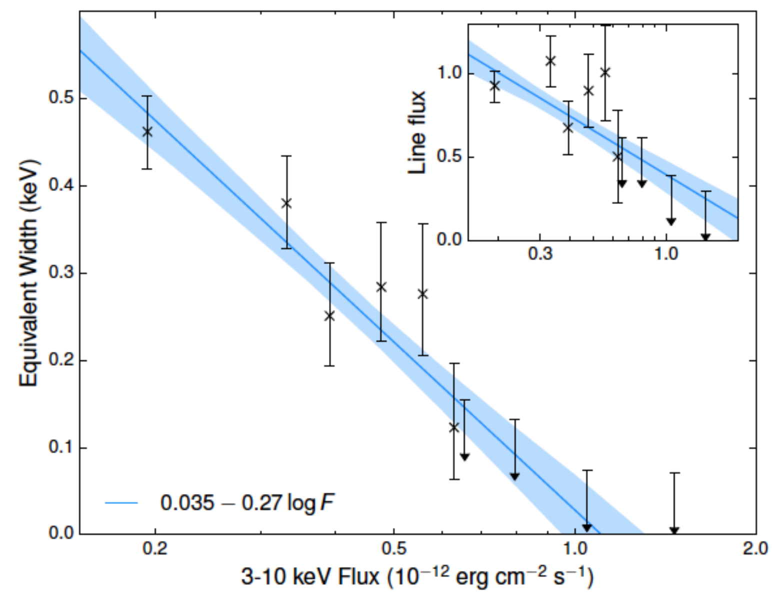
Parker et al (2017)

IRAS 13224-3809: ultrafast outflow



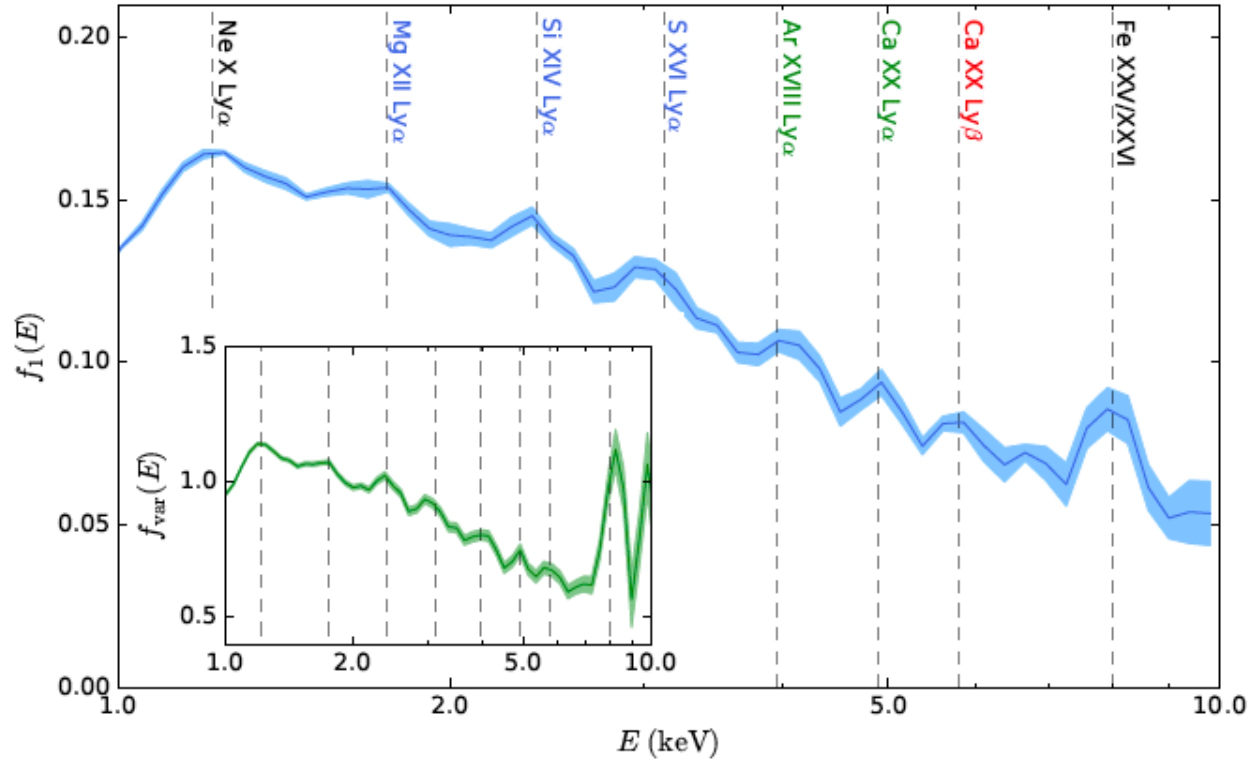
Features observed in RGS

Line strength varies with continuum luminosity



Parker et al (2017)

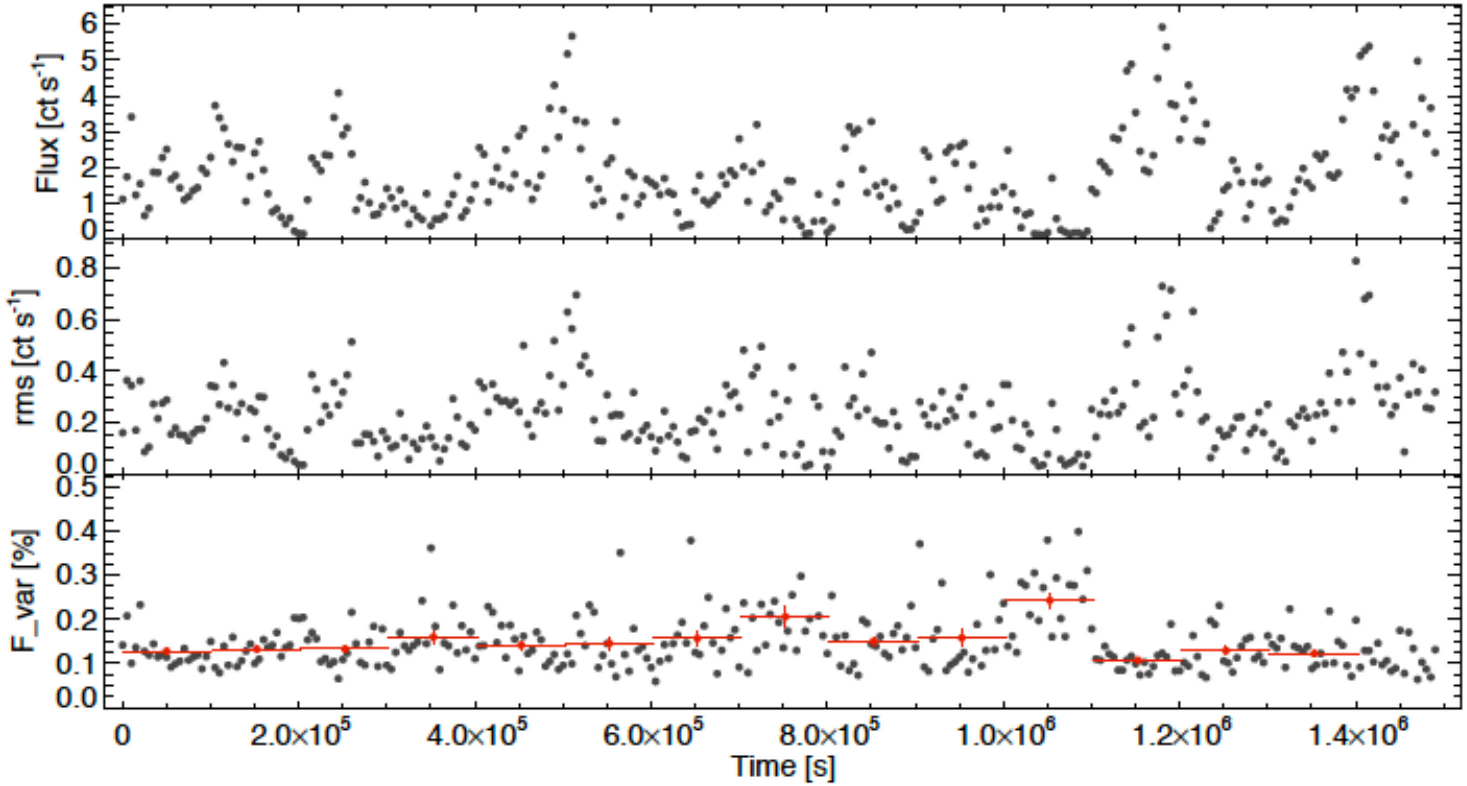
Outflow variability: PCA



- **10 ks bins**
- **Peaks in variability corresponding to the strongest absorption lines of the UFO model**

Parker et al (2017)

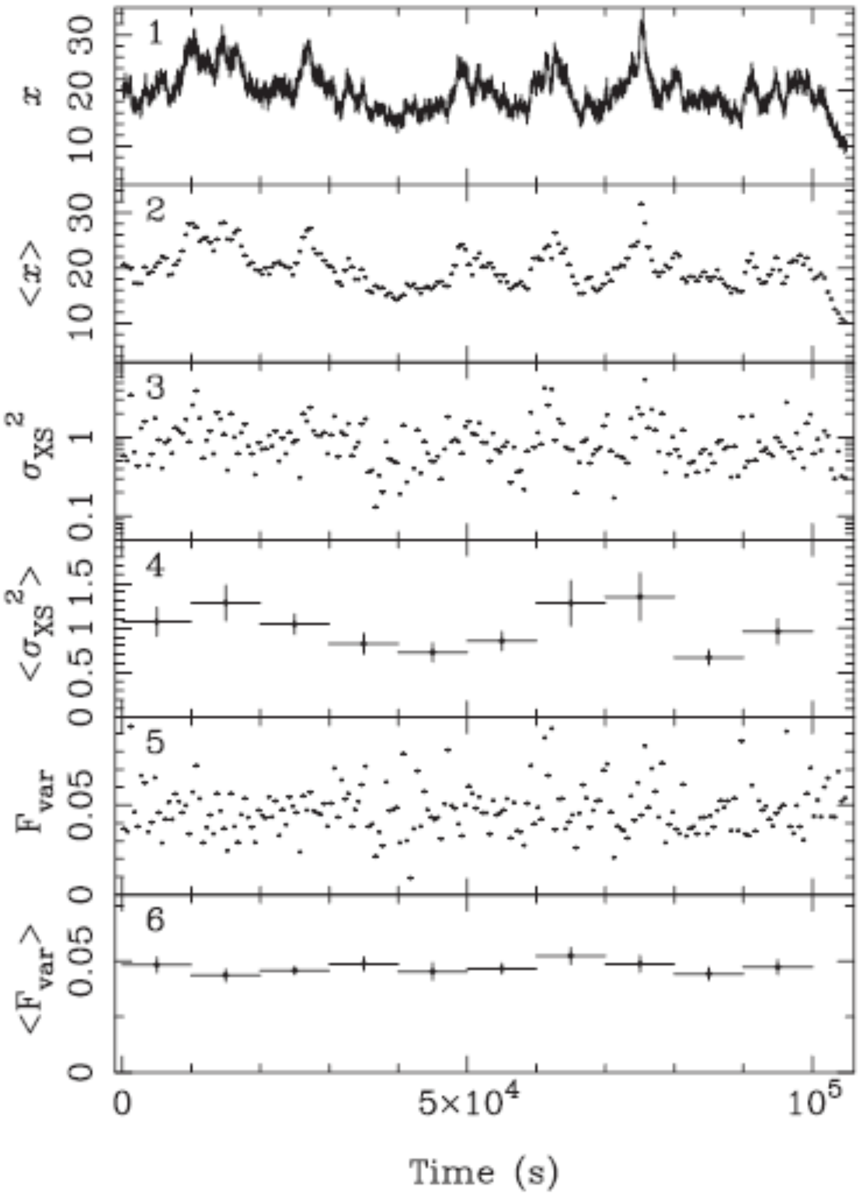
IRAS 13224-3809: stationarity

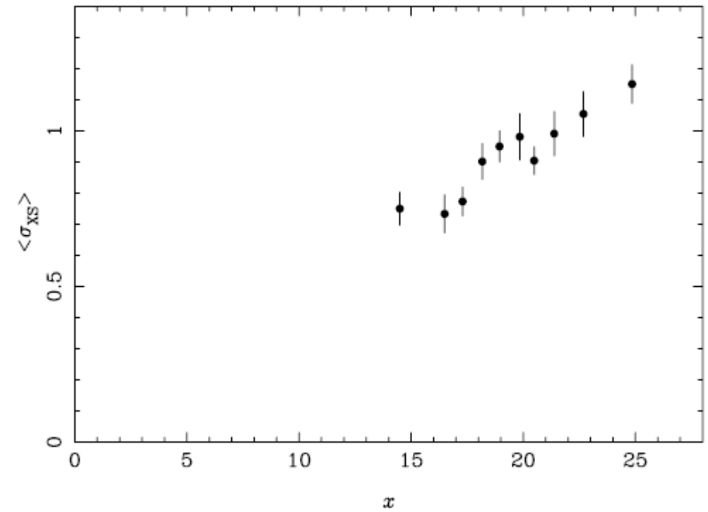


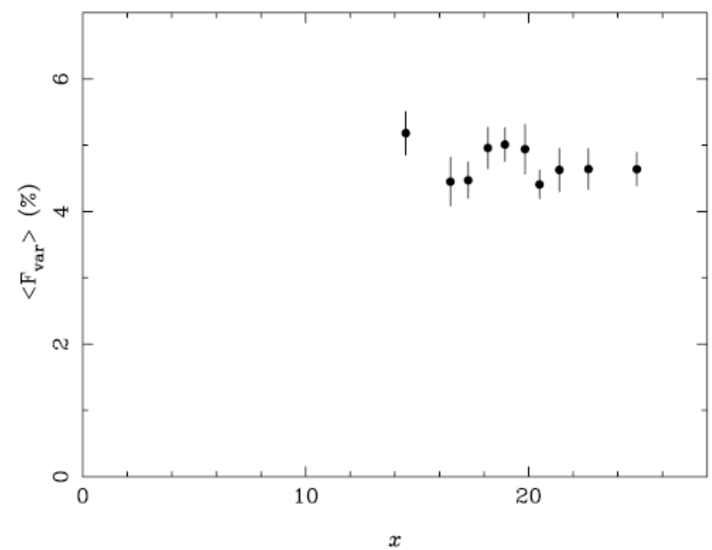
Fractional variability should remain constant for stationary process

Alston et al, in prep

Rms-flux relation

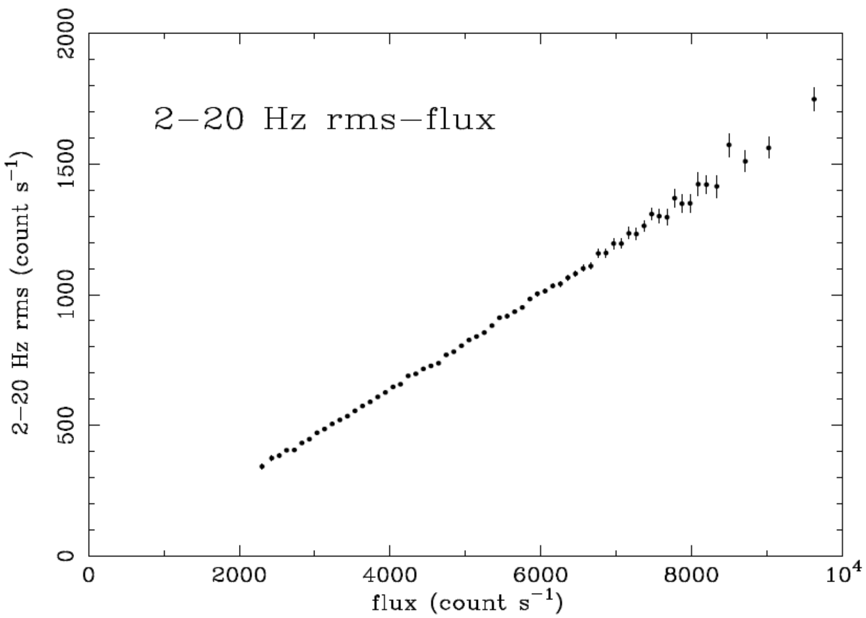


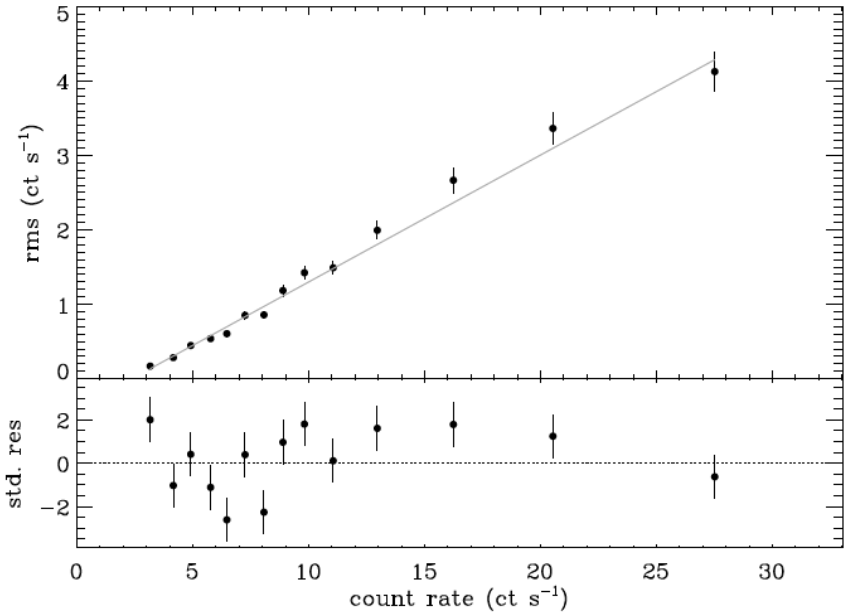




Mrk 766 - Vaughan et al (2003)

Rms-flux relation: linear



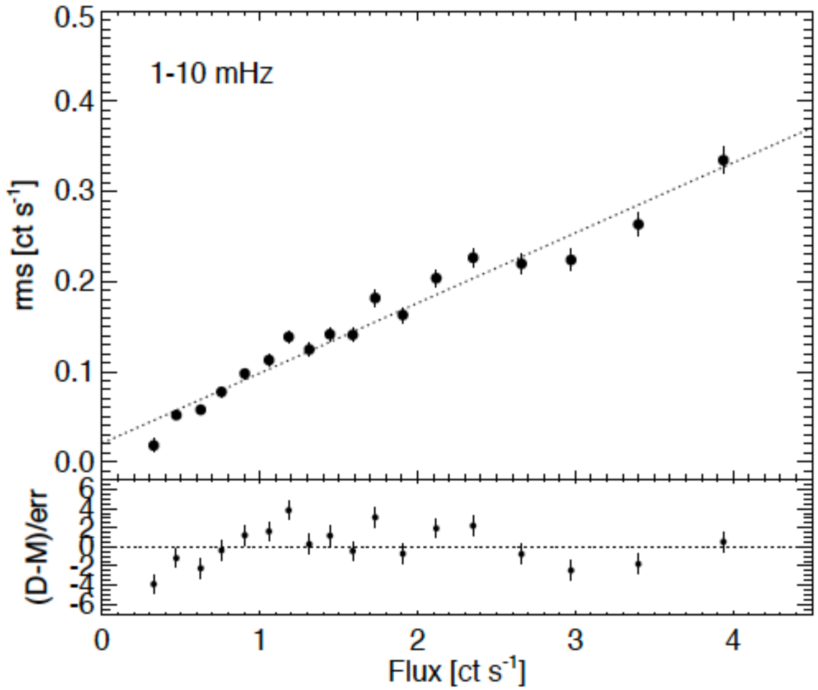


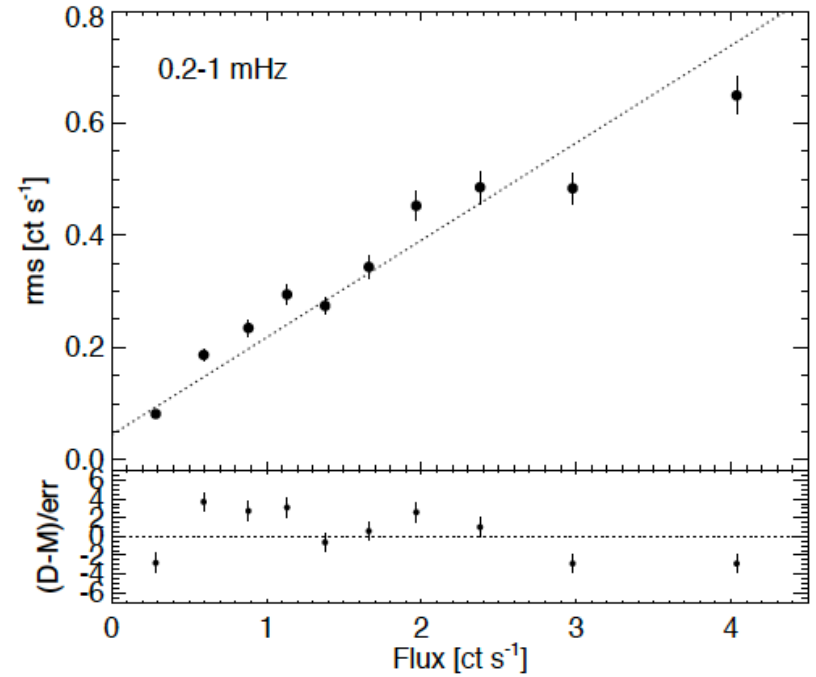
Cyg X-1

NGC 4051

e.g. Uttley + 2005, Vaughan + 2011

IRAS 13224-3809: rms-flux relation

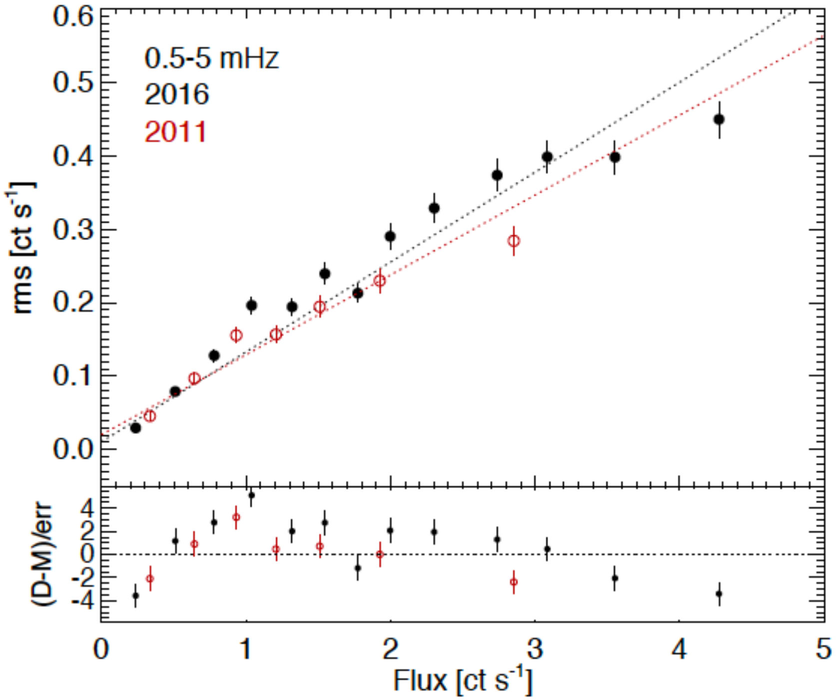


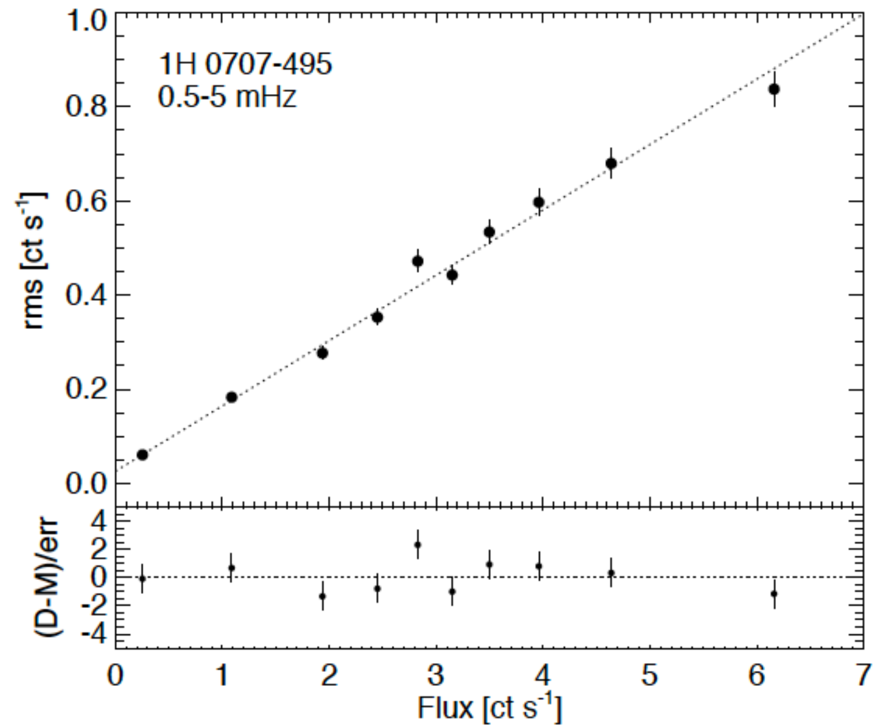


Poor fit to linear model
Seen at all frequencies and energies

Alston et al, in prep

IRAS 13224-3809: rms-flux relation



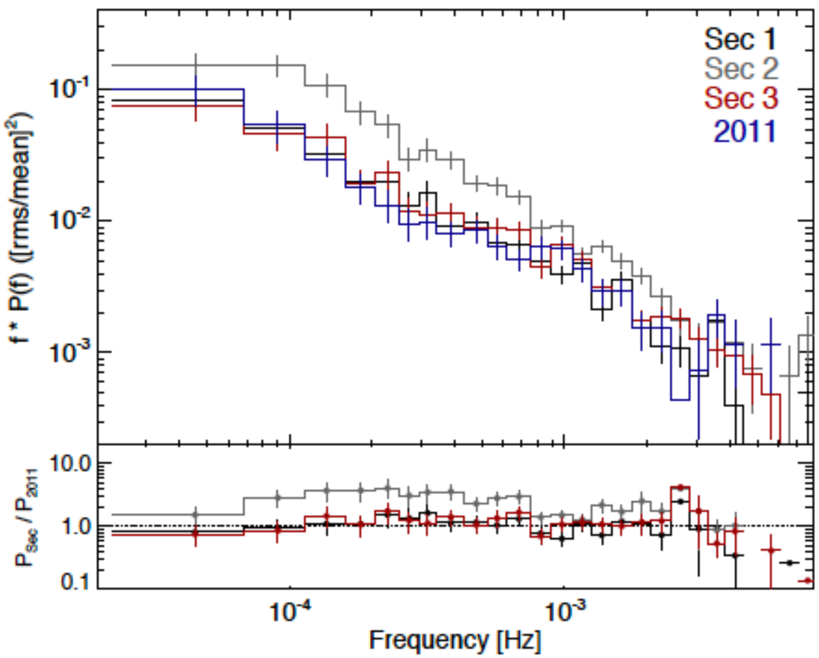


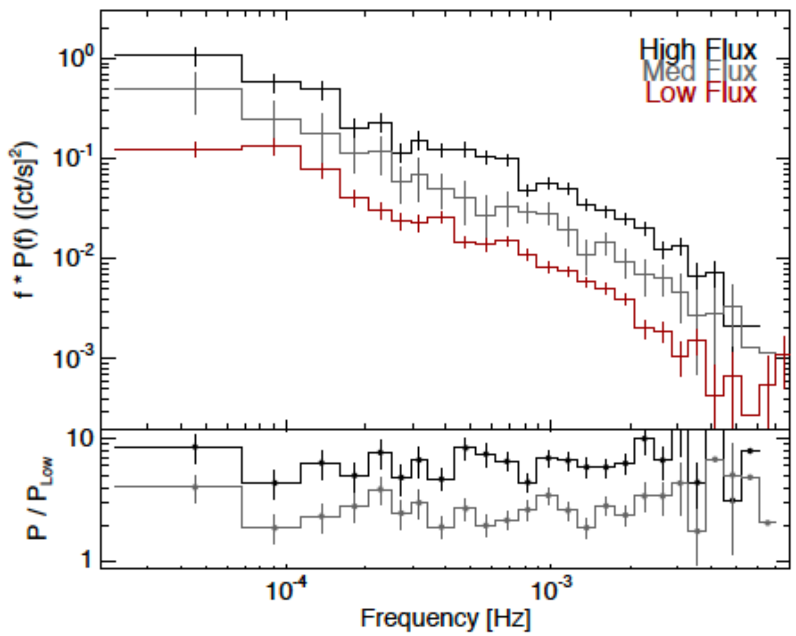
New vs old data

Similar NLS1 with 1.3 Ms data

Alston et al, in prep

IRAS 13224-3809: PSD





Change in shape seen in fractional units

Indicates non-stationarity

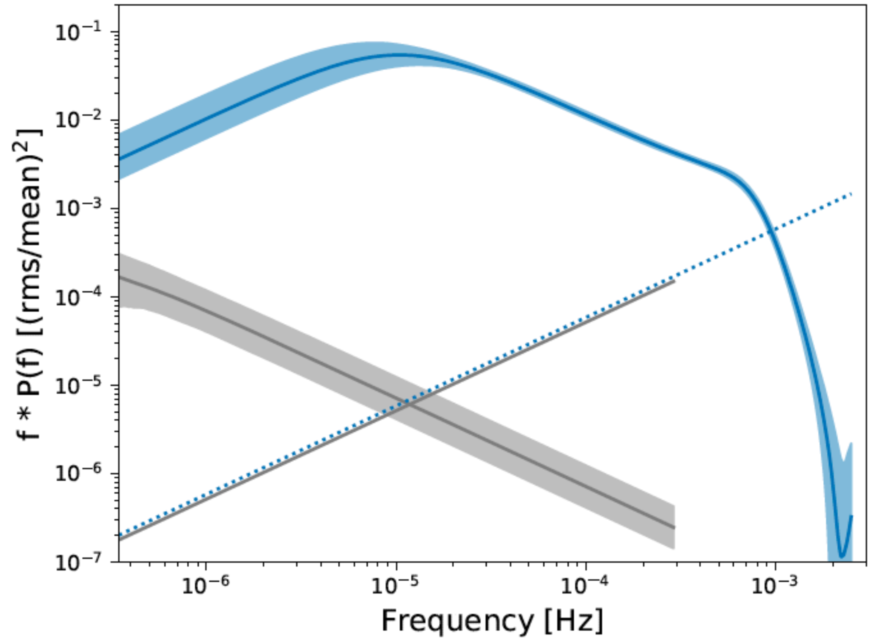
Subtler changes in shape in fluxed PSD

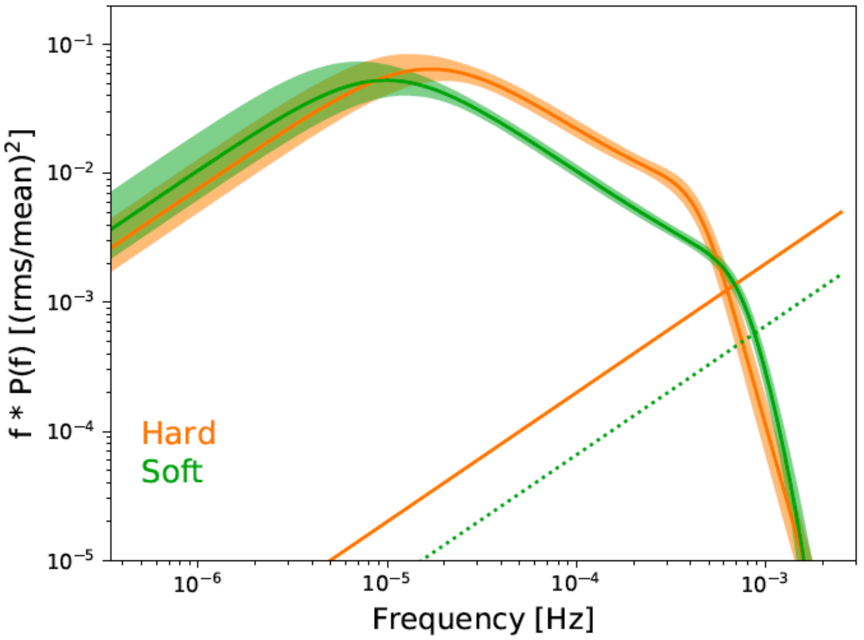
Suggests non-stationarity is related to changes in epoch, not simply flux

Alston et al, in prep

Long-term PSD

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

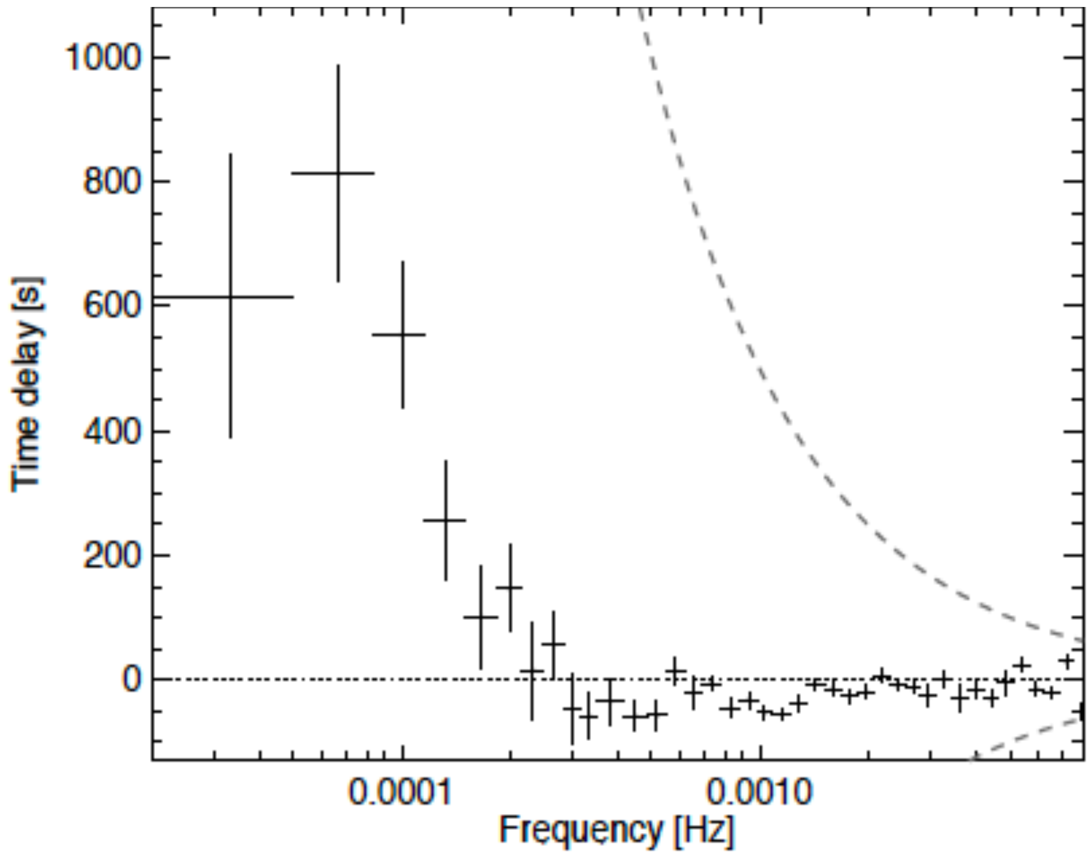




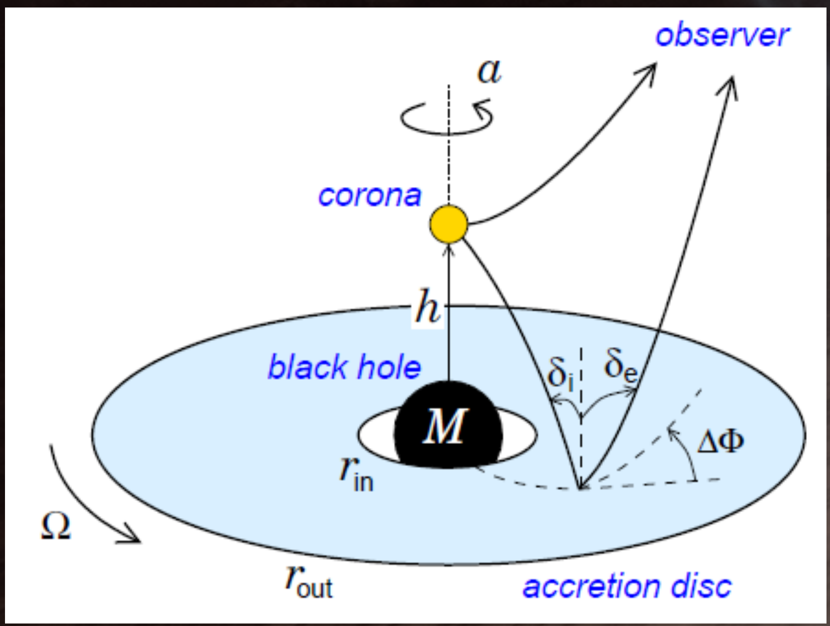
Alston et al, in prep

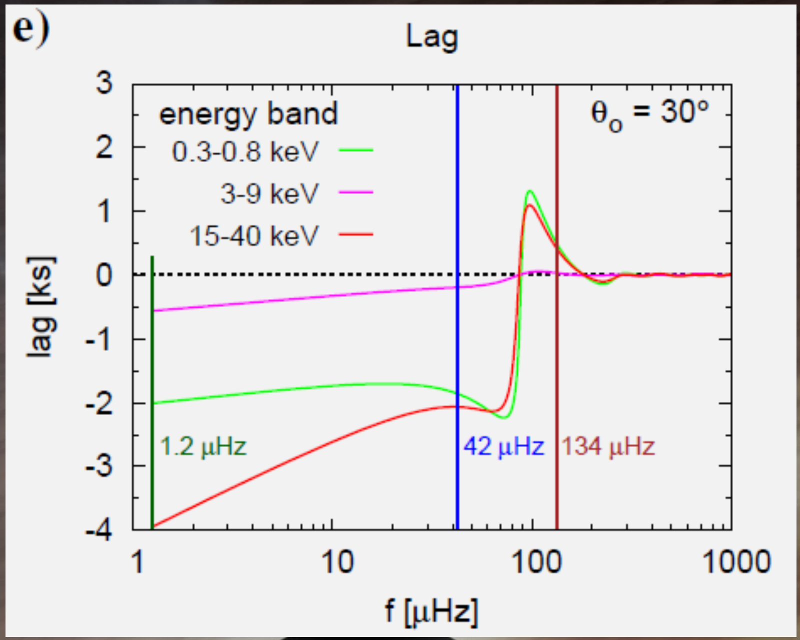
IRAS 13224-3809: lags

1.5 Ms data
0.3-1 vs 1.2-4.5 keV



Alston et al, in prep





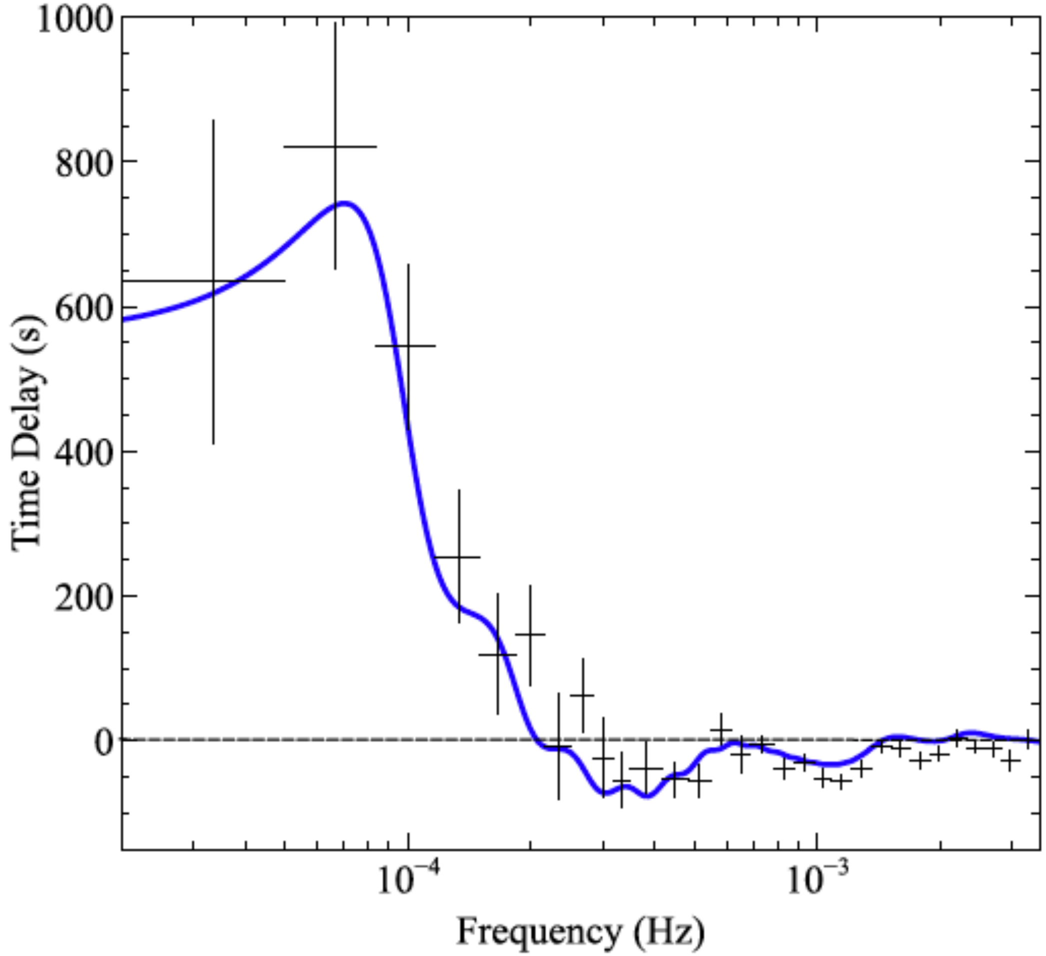
Dovciak, WA, et al (2014)

Chainakun et al (2016)

Modelling time lags

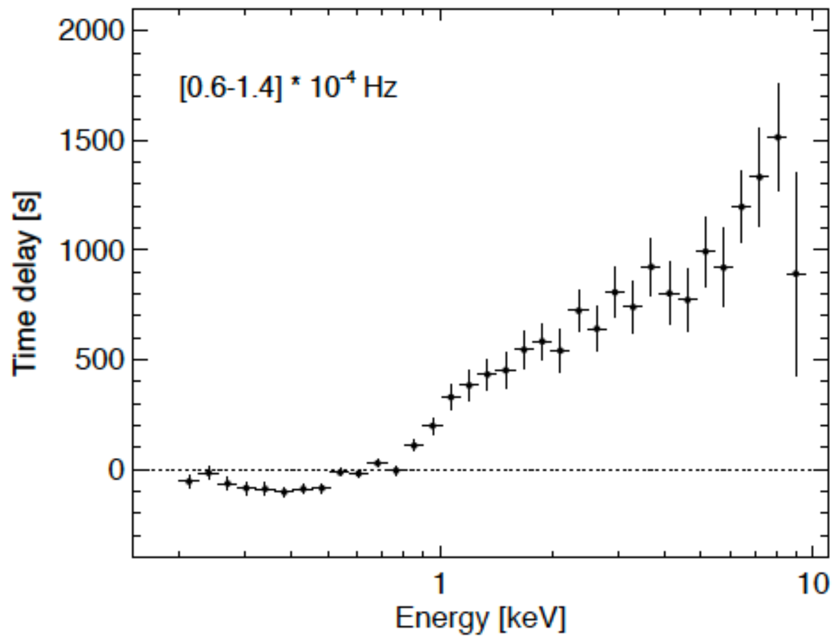
Can't get a good fit with one corona model (KYNrev; Dovciak)

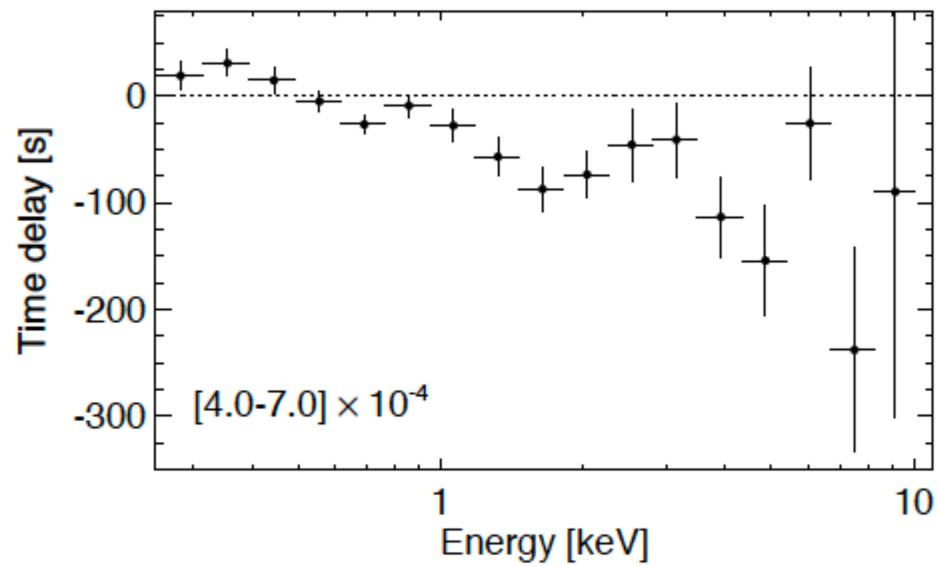
Using two corona model of Chainkun & Young



Alston et al, in prep

IRAS 13224-3809: lag energy



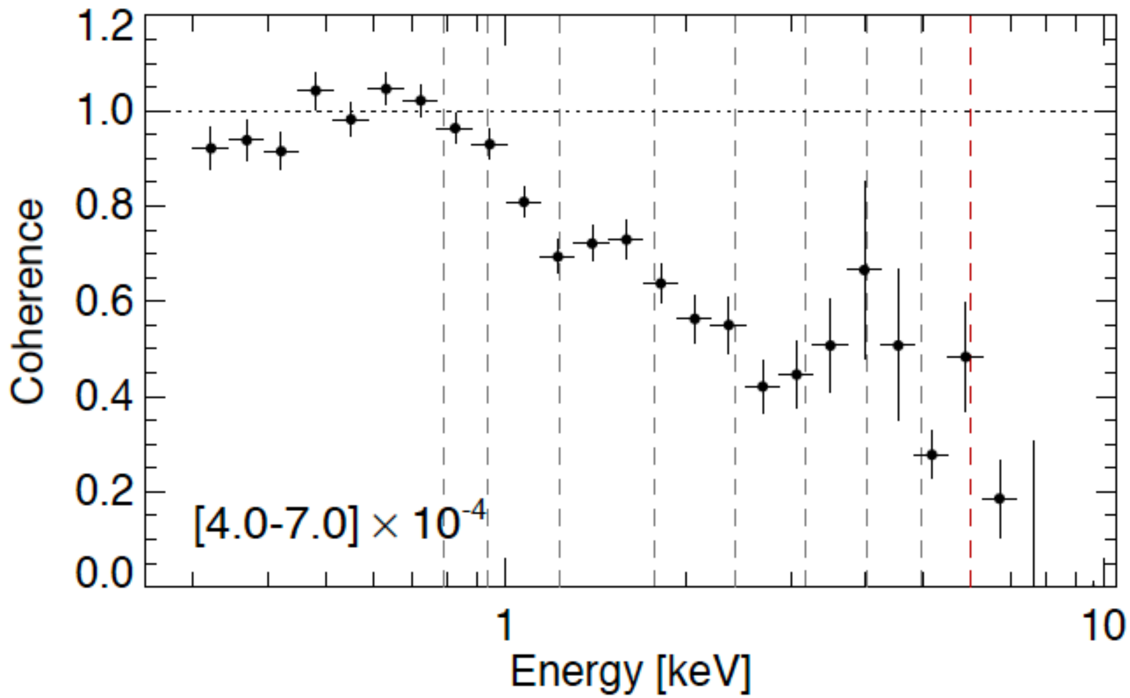


Low frequency: hard lags

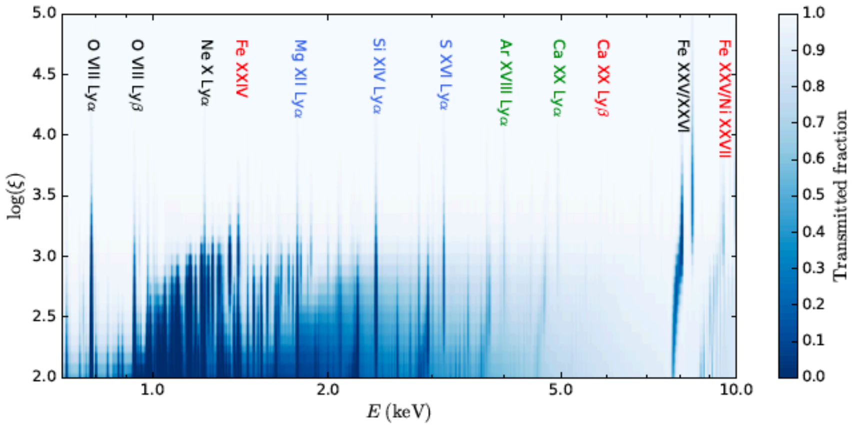
Possible FeK lag
High flux segments

Alston et al, in prep

IRAS 13224-3809: coherence



Warmabs sim

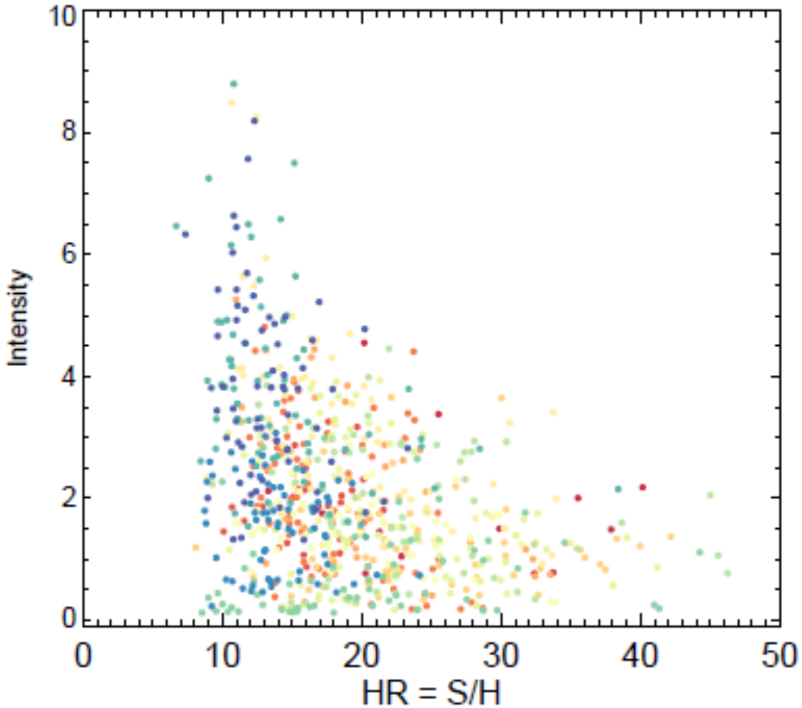


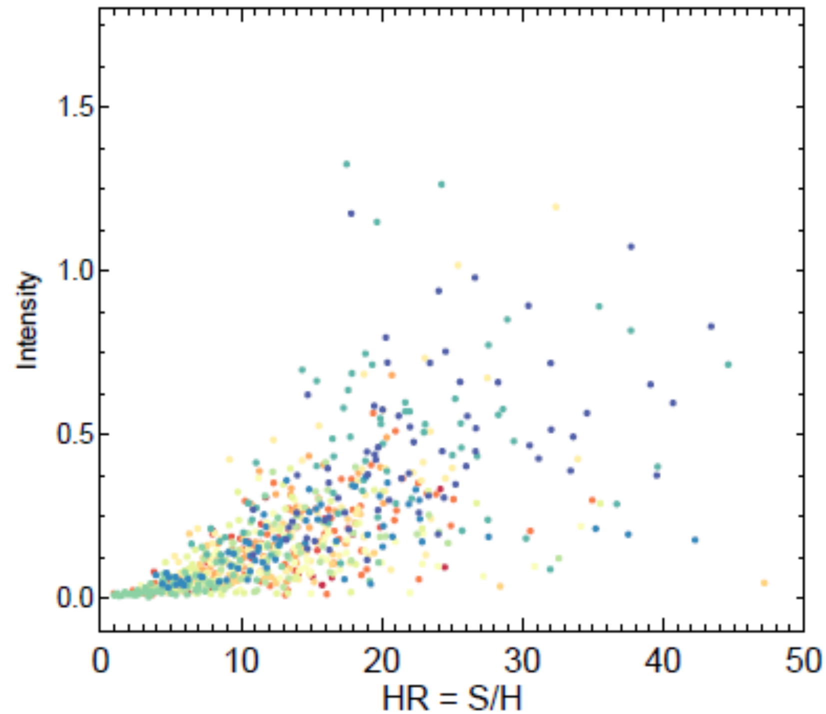
Alston et al, in prep

Summary

- 1.5 Ms campaign on IRAS 13224-3809
  - Unprecedented look at inner accretion region
- 0.26c outflow
  - Ionisation changes with flux
- First non-linear rms-flux relation observed
  - Truly non-linear relation?
  - Drift in gradient over time?
- PSD shows LF break
- Modelling lag-f with two corona model
- Lags/ Fe K reverberation complicated by wind?

Complex spectral variability





- 0.3-1 vs 1.5-6 keV
- 1.2-4 vs 5-10 keV

- NLS1s typically show softer when brighter behaviour

Cross spectrum

FT of two evenly sampled time series
e.g. soft and hard bands
Average over e.g. 10 ks segments

$$x(t), y(t) \longrightarrow X(f), Y(f)$$

Complex valued "cross spectrum"

$$\begin{aligned} C_{xy} &= X^*(f)Y(f) \\ &= |X||Y|e^{i(\phi_y - \phi_x)} \end{aligned}$$

Coherence (between 0 - 1)
linear correlation as a function of *f*

$$\gamma^2(f) = \frac{\left|\langle C_{xy}(f)\rangle\right|^2}{\langle |X(f)|^2\rangle\langle |Y(f)|^2\rangle}$$

Phase delay

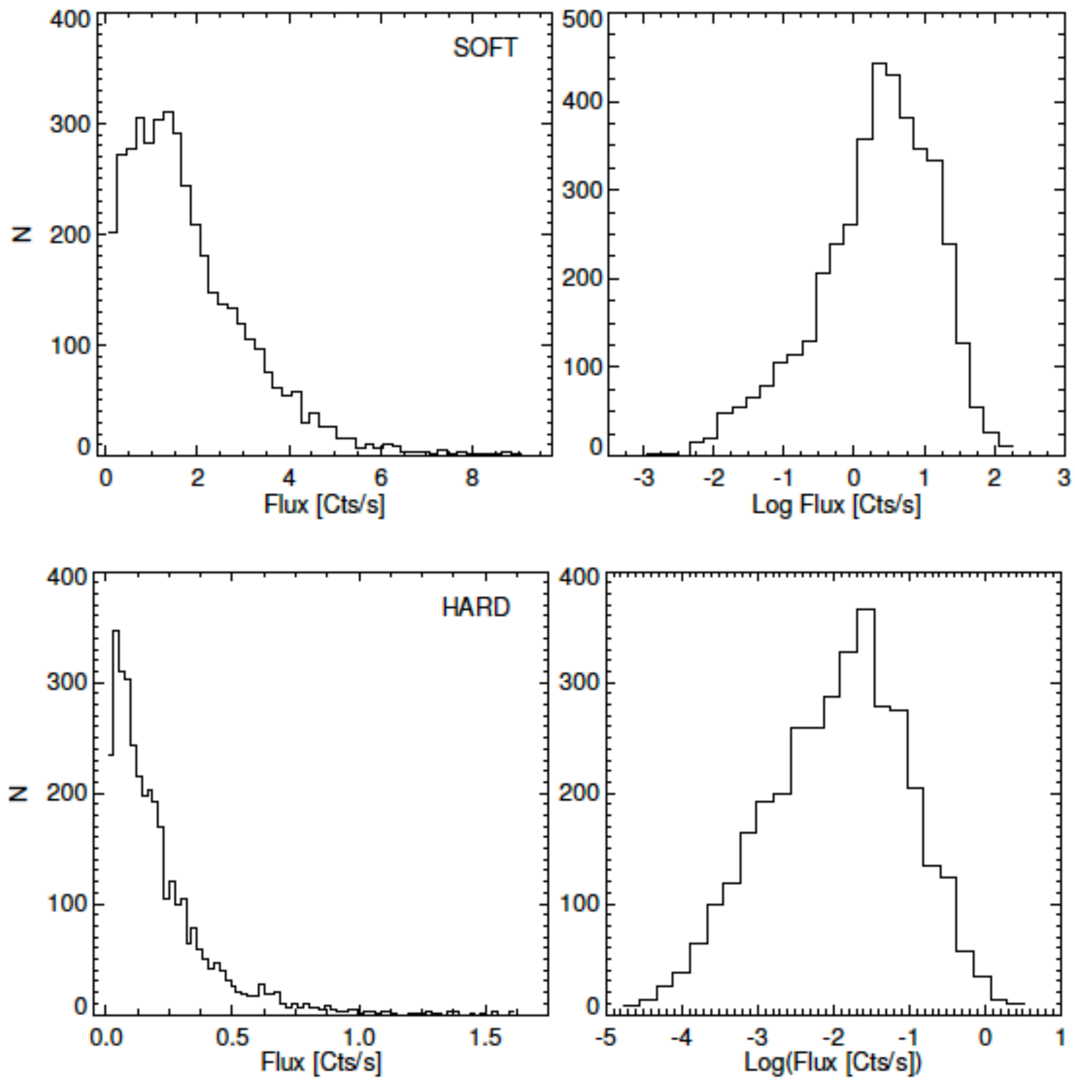
$$\phi(f) = \arg\left(\langle C_{xy}(f)\rangle\right)$$

Time delay

$$\tau(f) = \frac{\phi(f)}{2\pi f}$$

Flux distribution

Kjhb
kjb



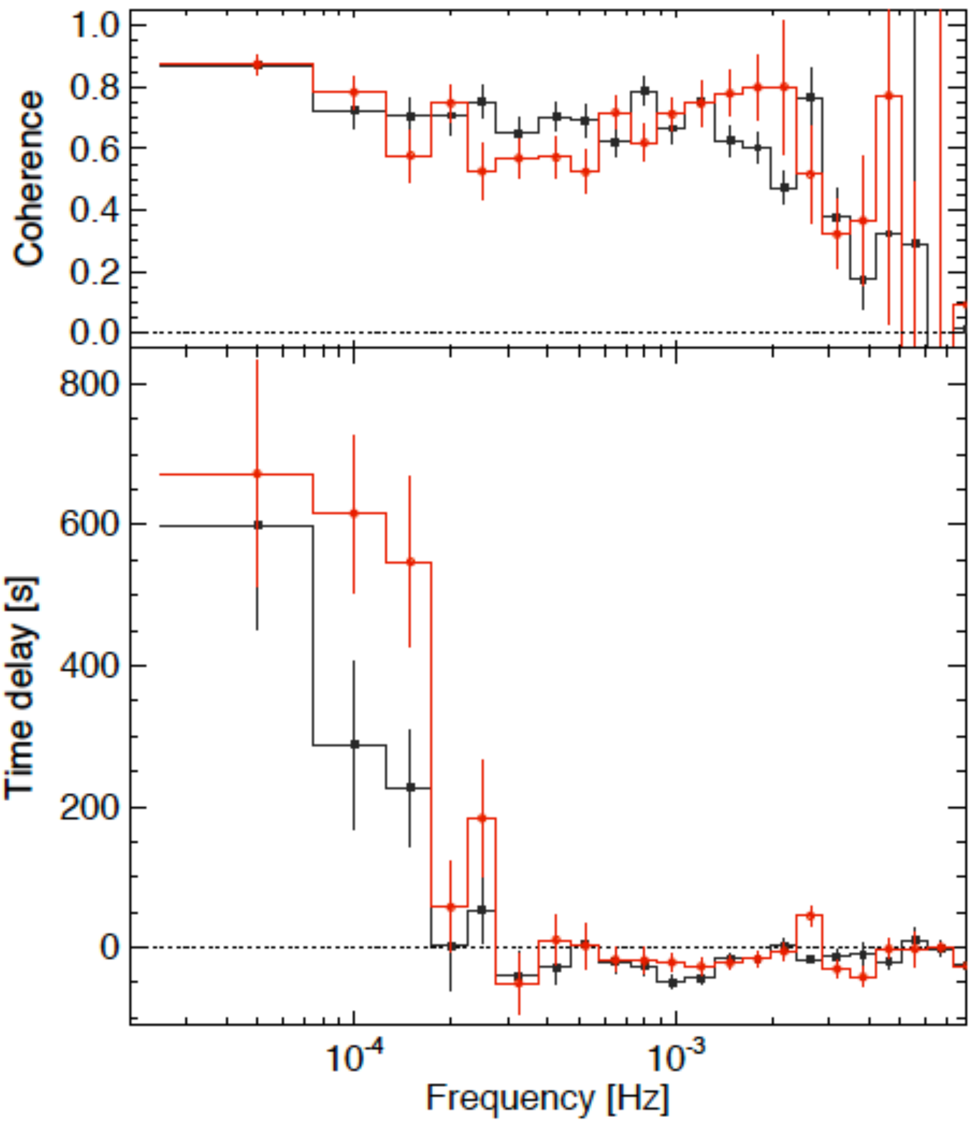
Alston et al, in prep

IRAS 13224-3809: lags

0.3-1 vs 1.2-4.5 keV

Sec 1+3 (1Ms)
Sec 2 (500ks)

Subtle changes in lags and coherence



Alston et al, in prep

Kjhb
kjb

Alston et al, in prep