Power-Colours

POWER SPECTRAL COMPARISON MADE EASY

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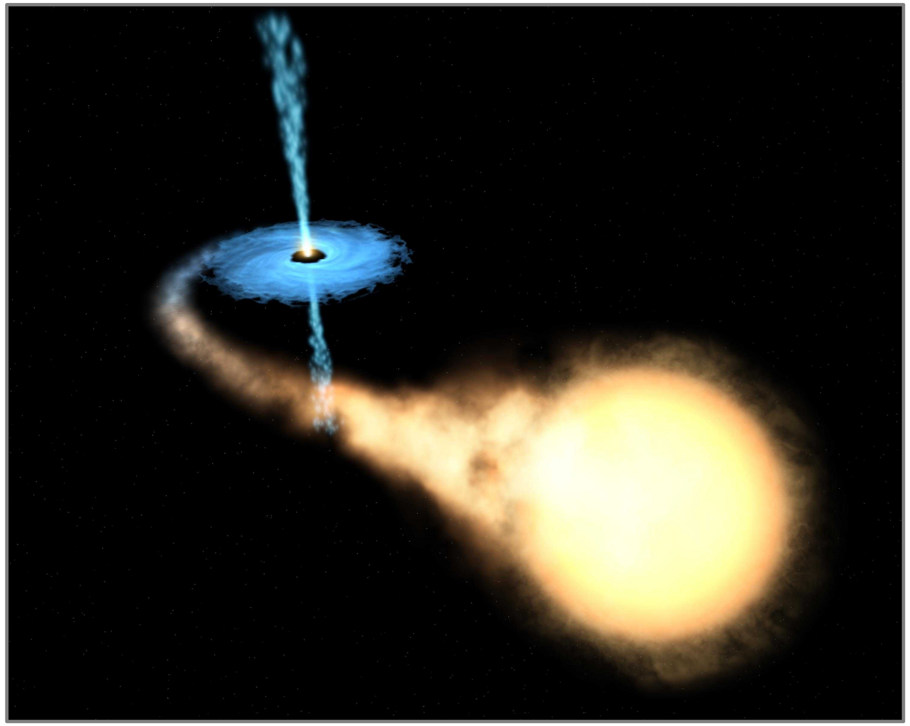
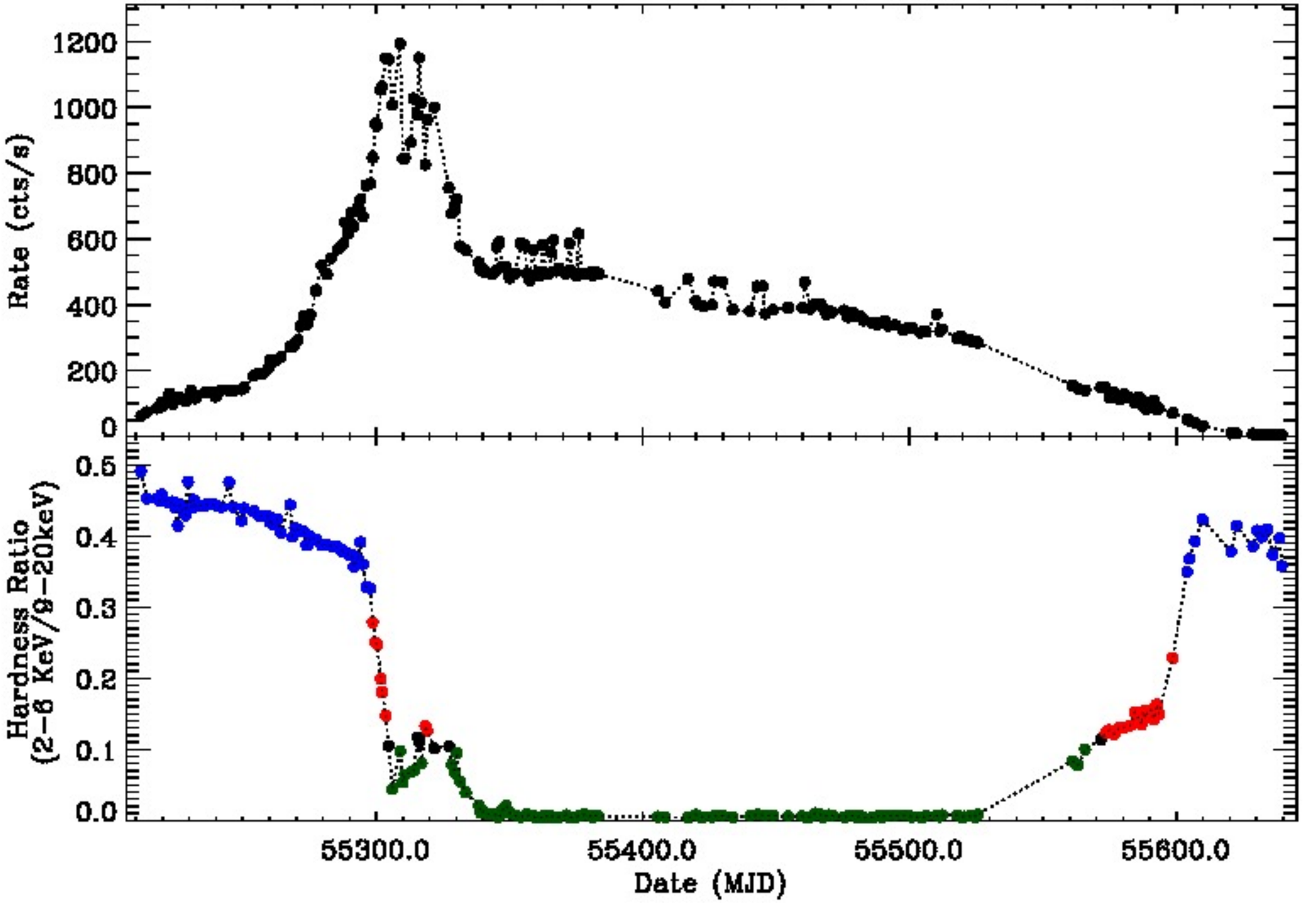
Black Hole X-ray Binaries

- Stellar Mass Black Holes with a Stellar Companion
- Can be transient or persistent X-ray sources
- Significant changes in the accretion structure observed over time
- Difference in both Energy Spectral and Timing properties caused by these changes separate observations into various source “states”



How does the Variability Change?

Energy Spectra



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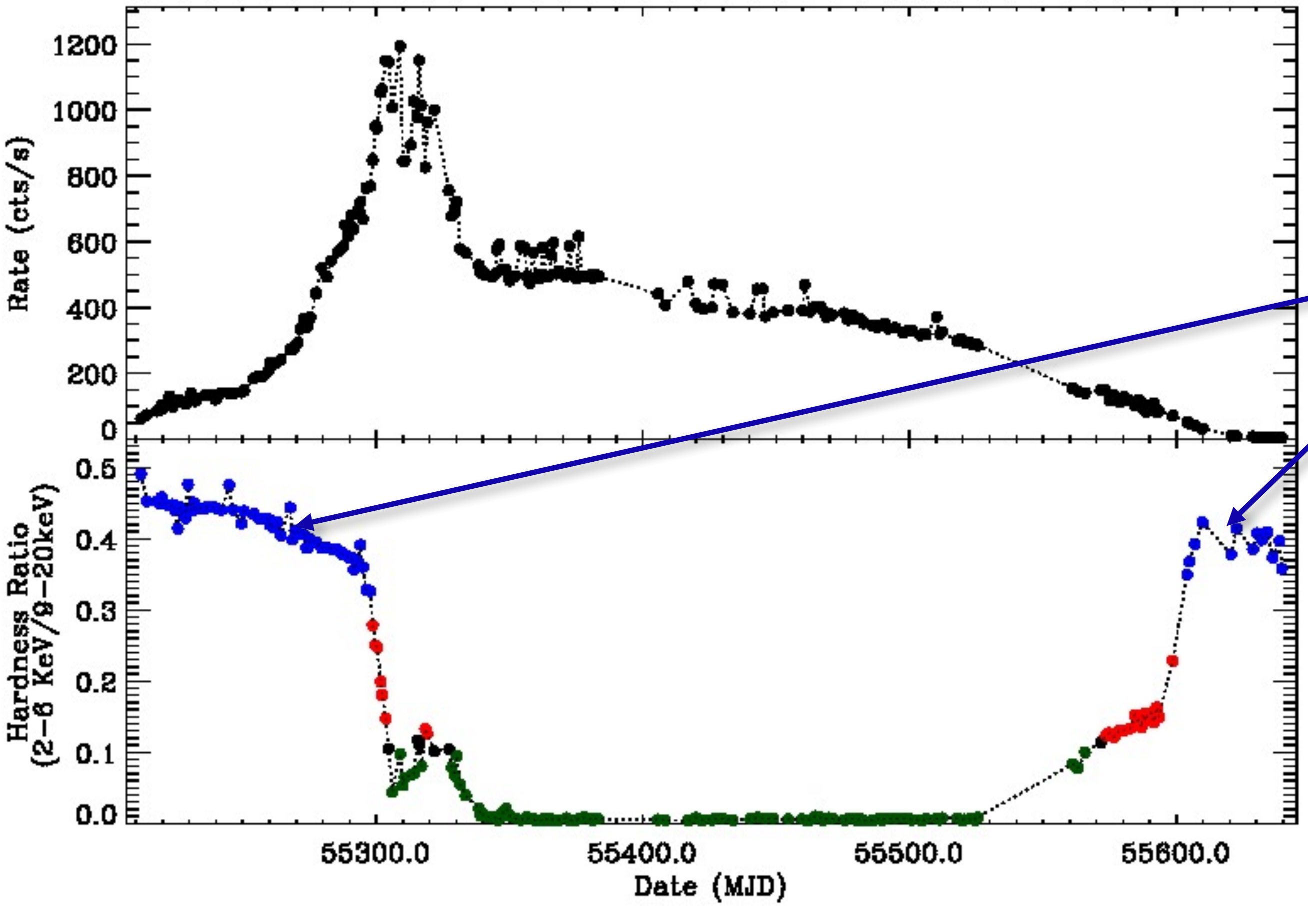

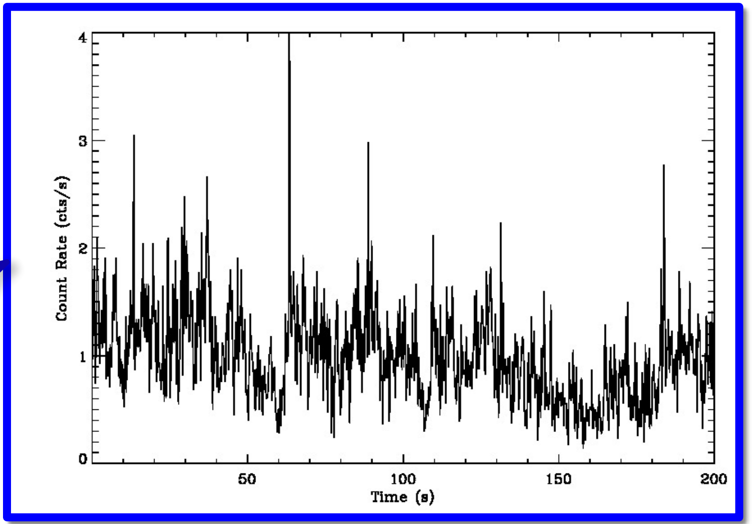

Hard State:
Strong Variability over a large range of timescales

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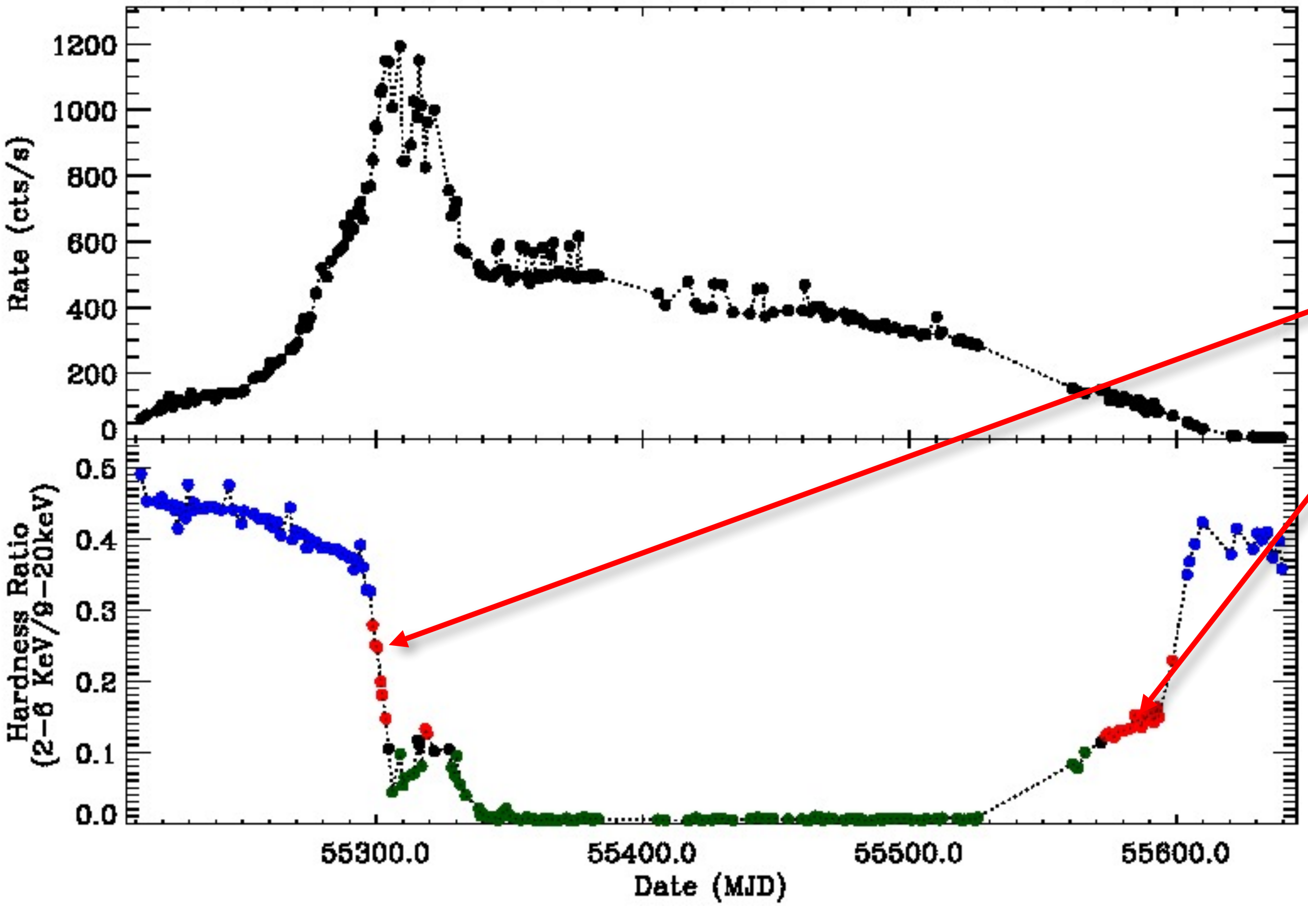
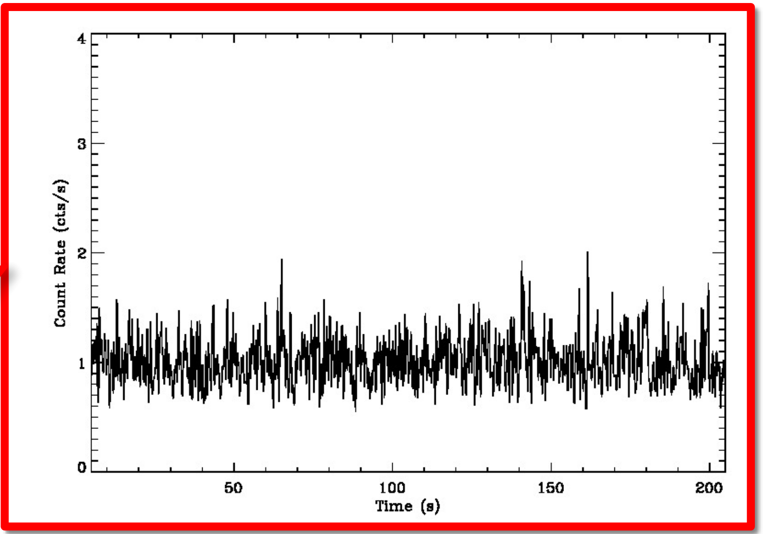
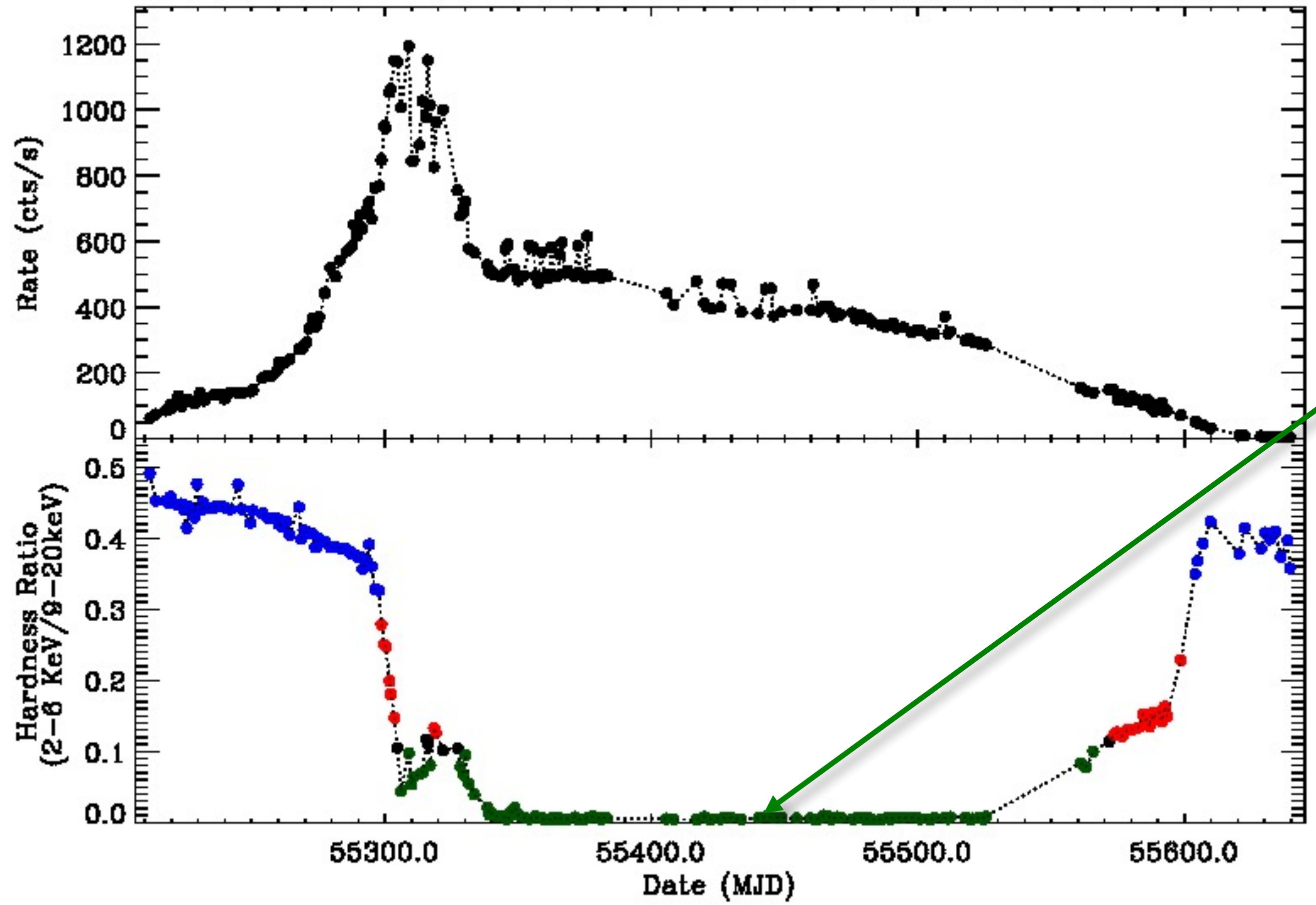


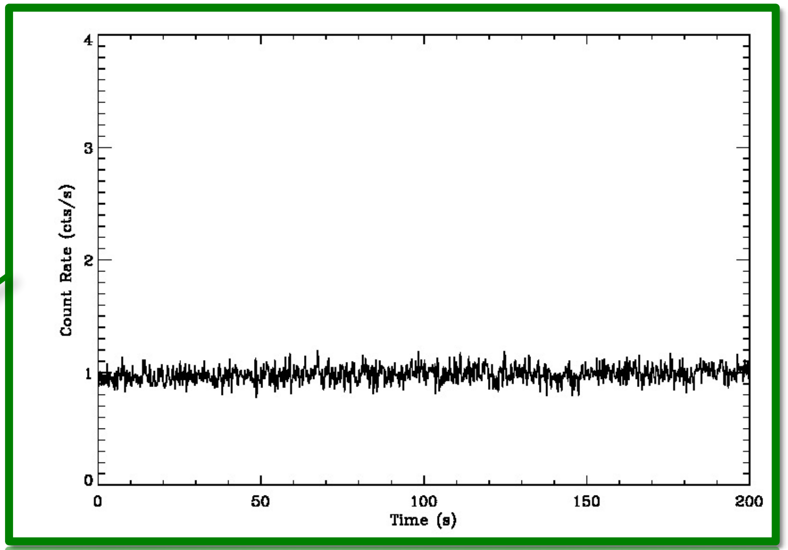


Hard Intermediate State:
Strong short term variability

How does the Variability Change?

Energy Spectra

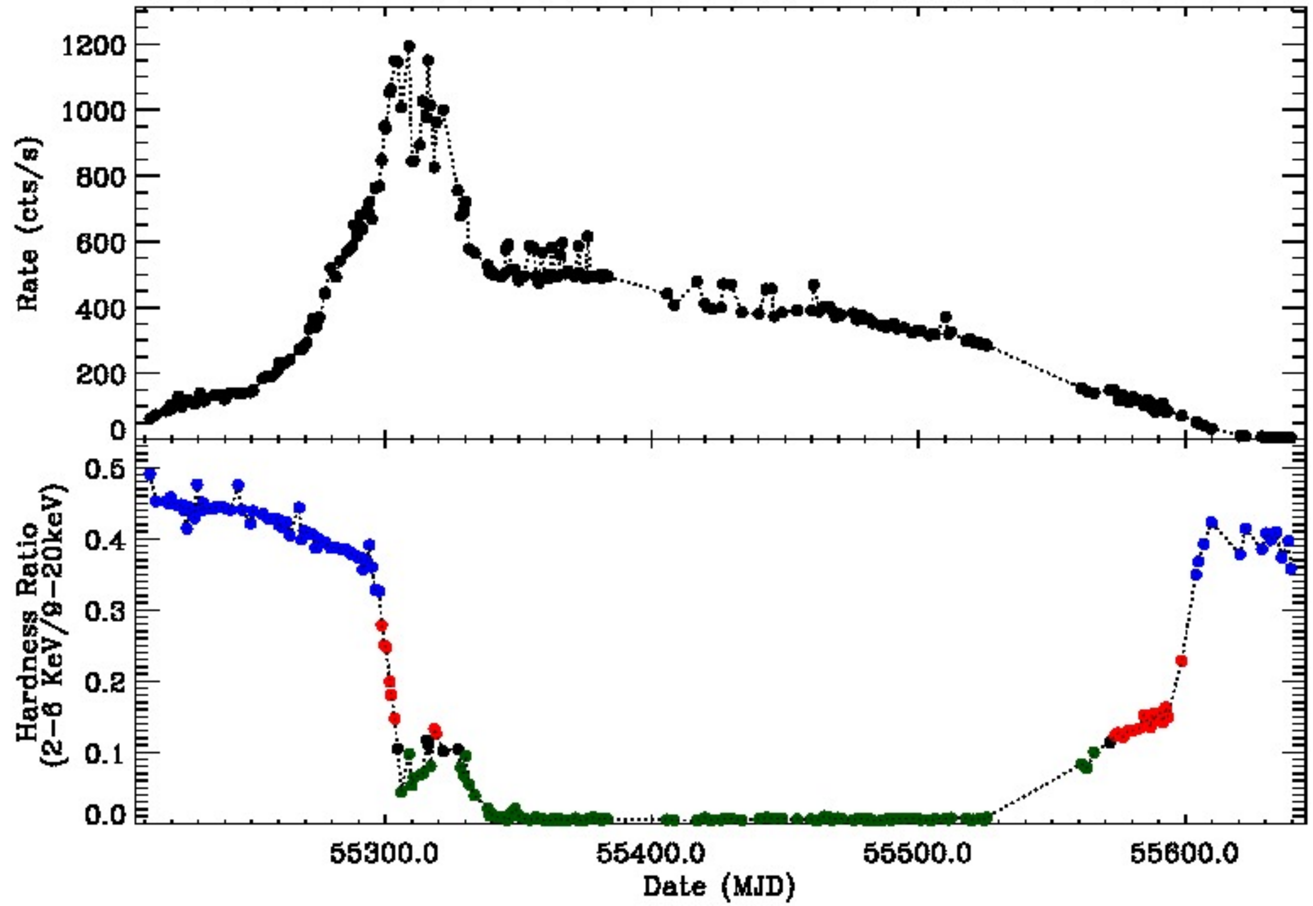


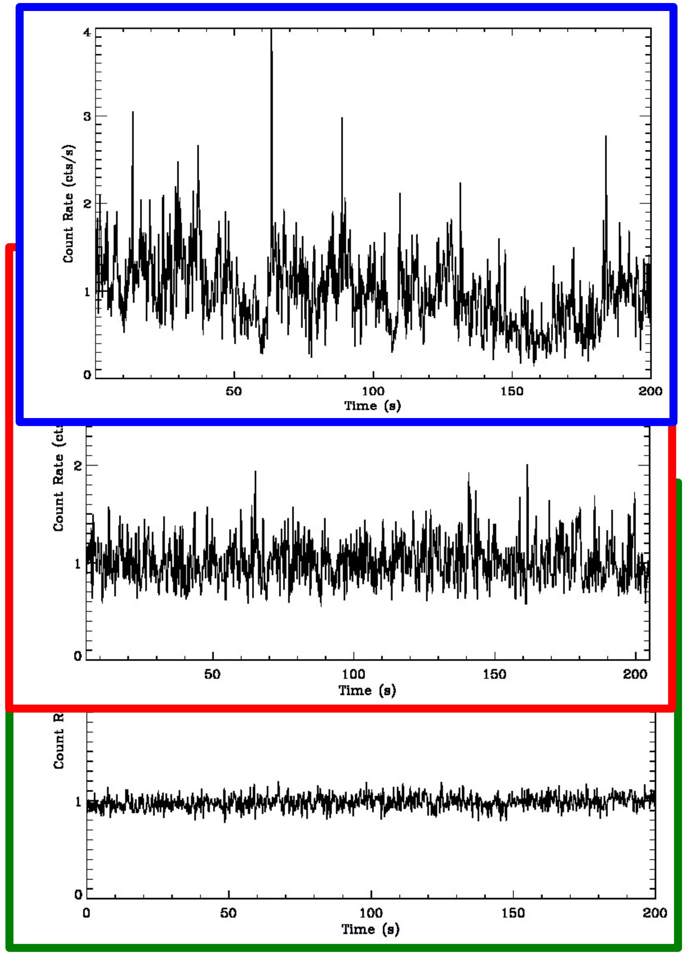


Soft States:
Small amount of variability over all timescales

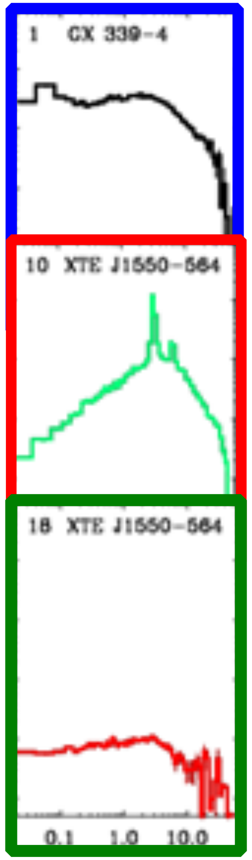
What are Spectral States?

Energy Spectra





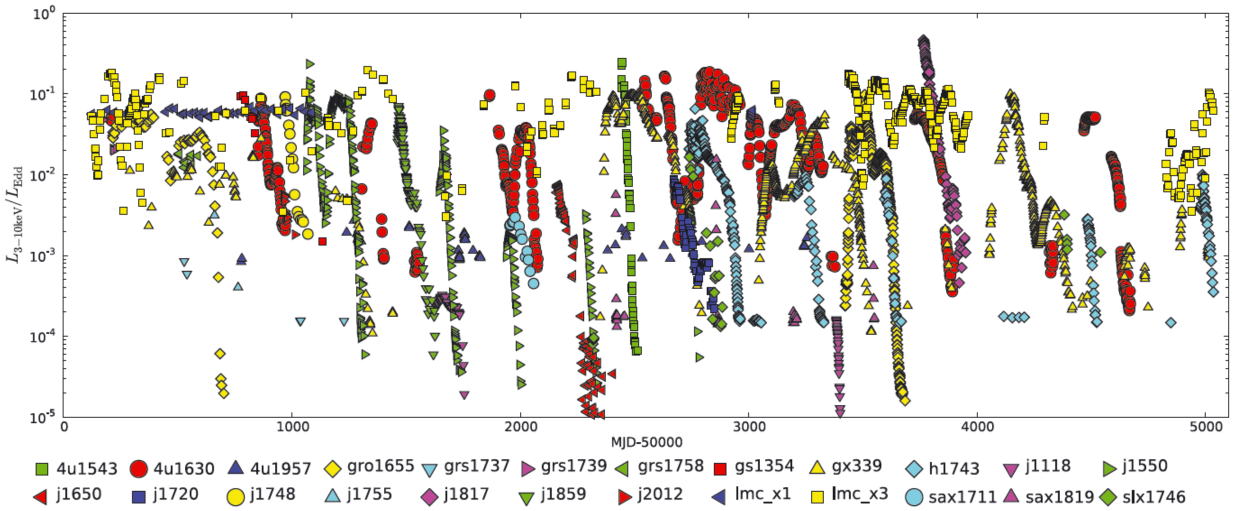
Power



Frequency (Hz)

Why create a new method to compare variability properties?

- 16 Years of RXTE data provides ~6000 observations of Stellar Mass Black Holes alone
- Manual Classification is time consuming and subjective
  - Fitting with no underpinning physics
- Current rapid classification methods work well for single sources but poorly across different objects
- Mass classification allows for a more holistic look at all source properties



Dunn et. al. (2010)

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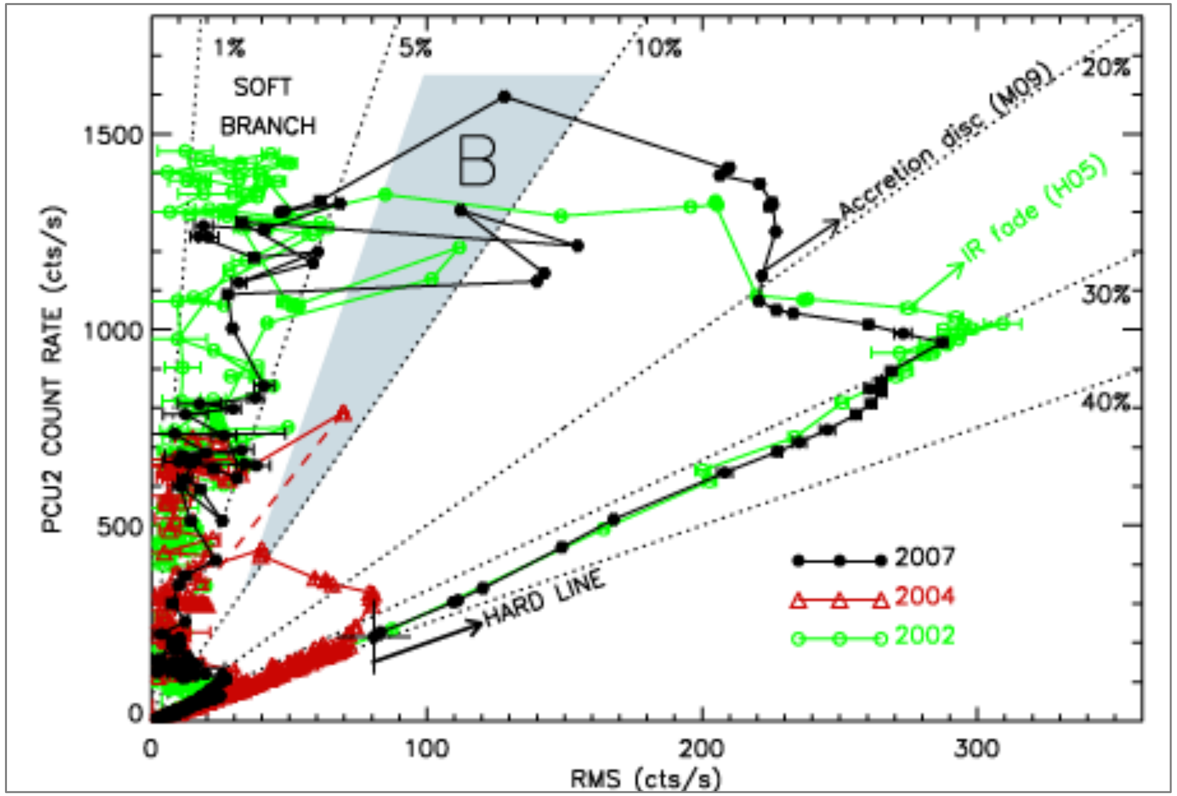

Munoz-Darias et. al. (2011)

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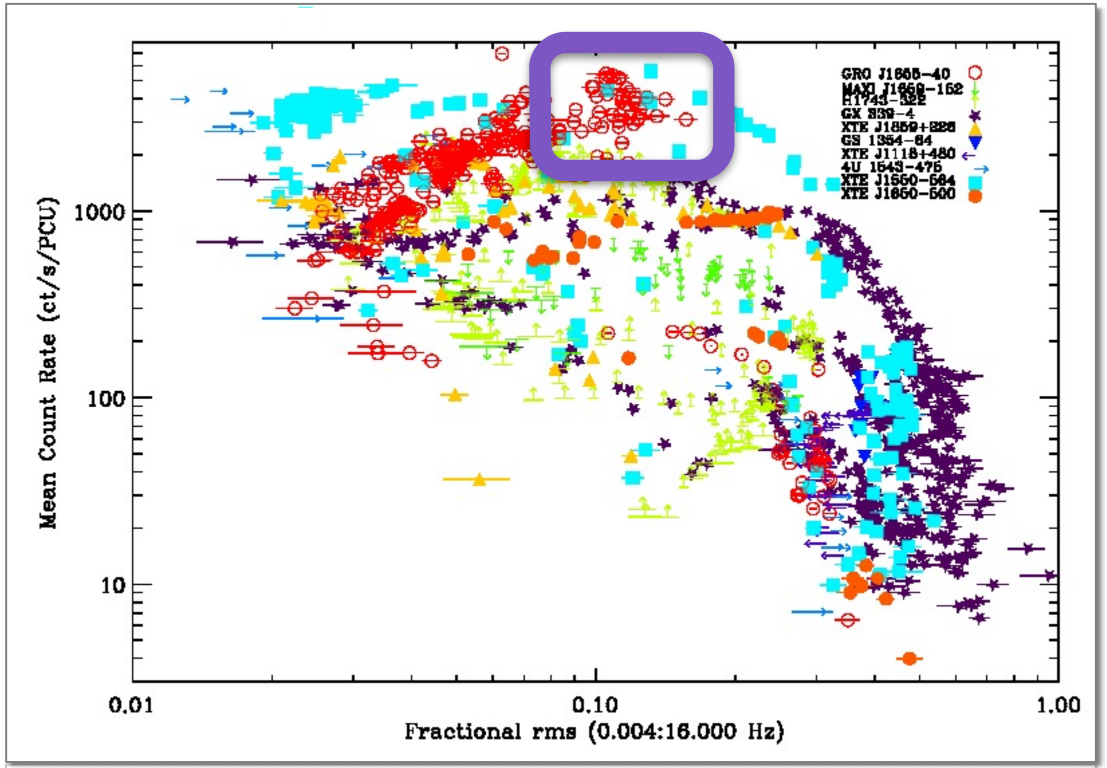
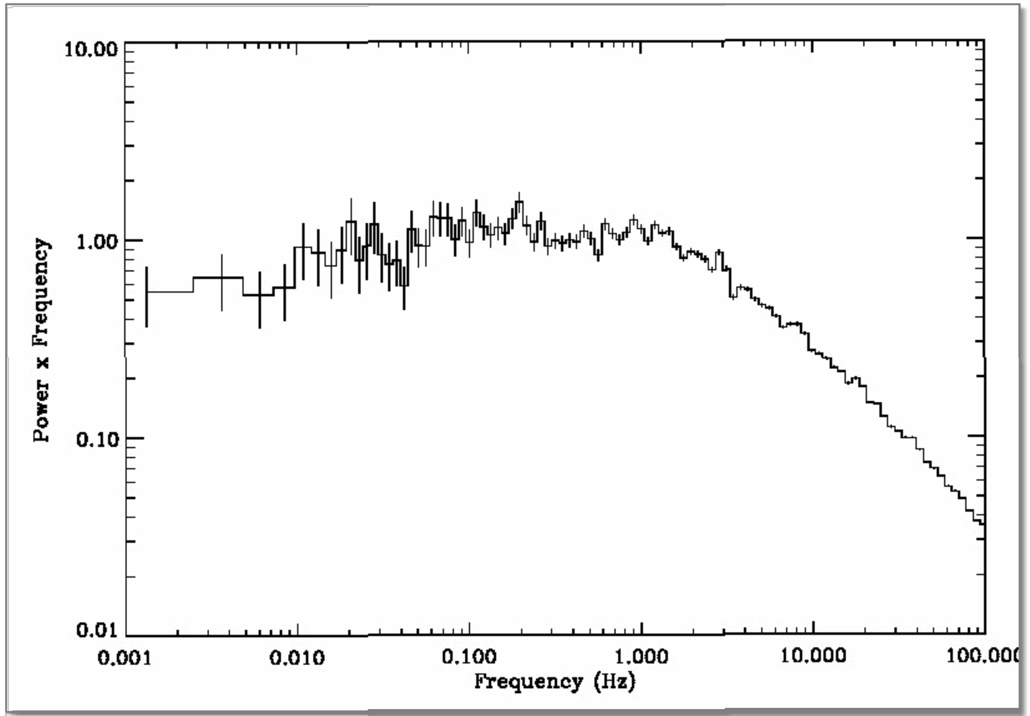


Defining power colours

- Energy spectral colours refer to ratios of flux in different energy bands
- Power spectral colours are ratios of variance measured over different timescales

- Power spectra map how much the X-rays from a source vary on different timescales



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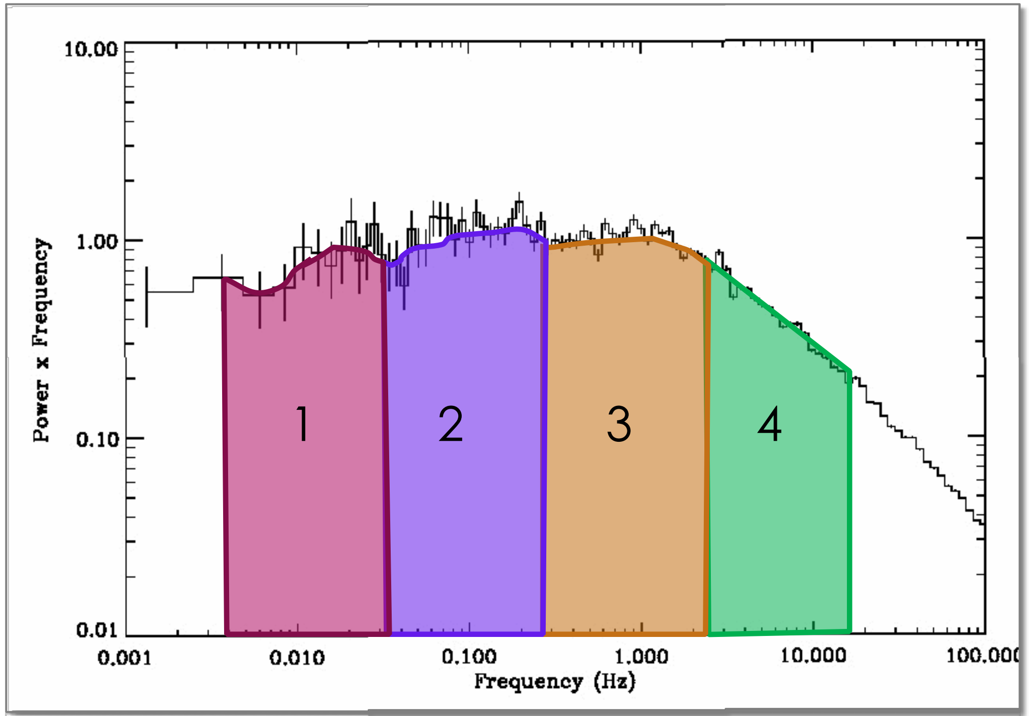
- Power spectra map how much the X-rays from a source vary on different timescales
- Chosen Ratios are 2/4 vs. 3/1

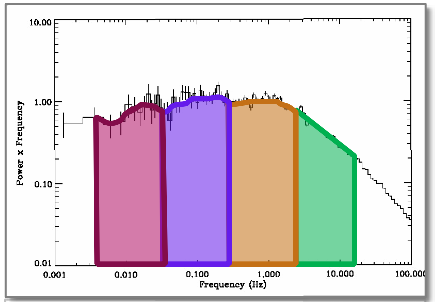


The power colour-colour plot

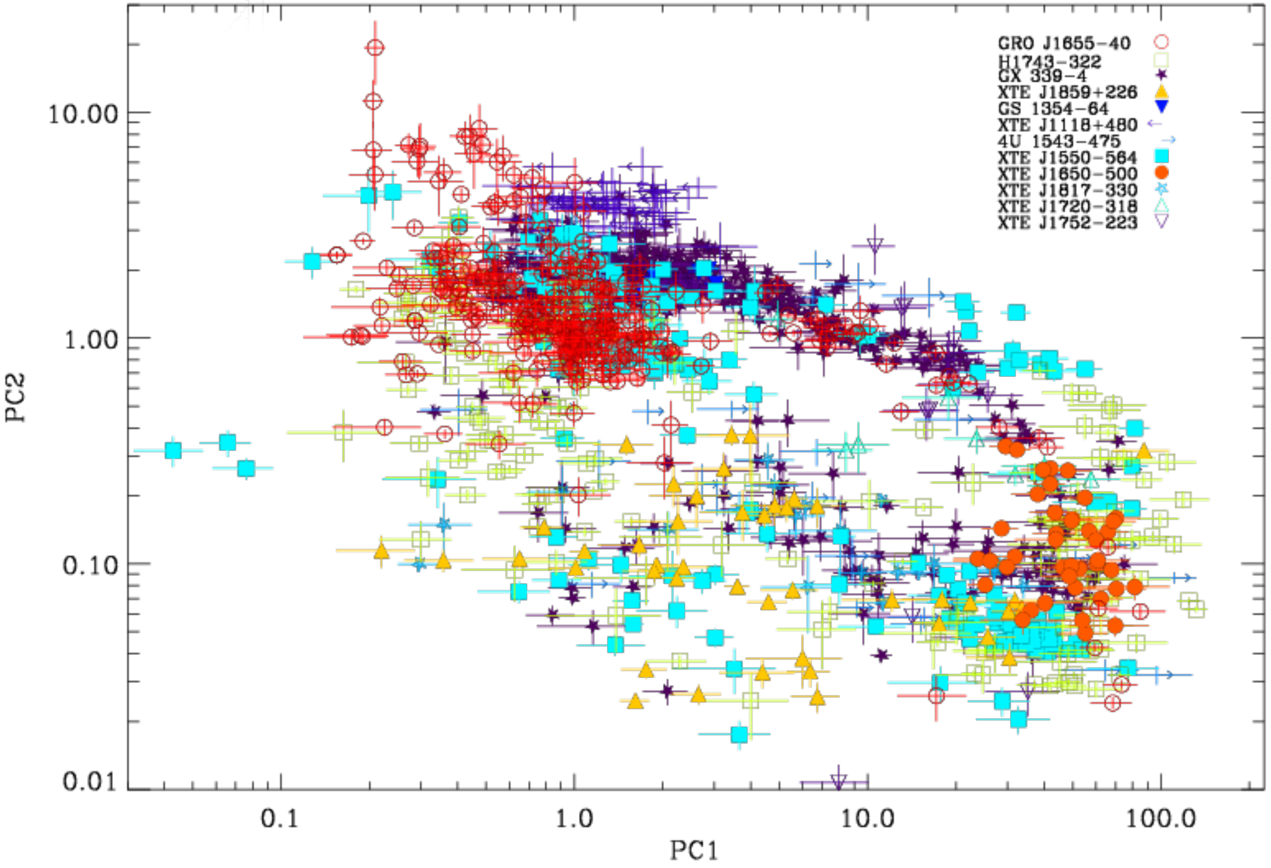
Consistency observed between behaviour of many different objects

Single path followed (excluding intermediate states)

Path can be parameterised (to an extent)



2/4

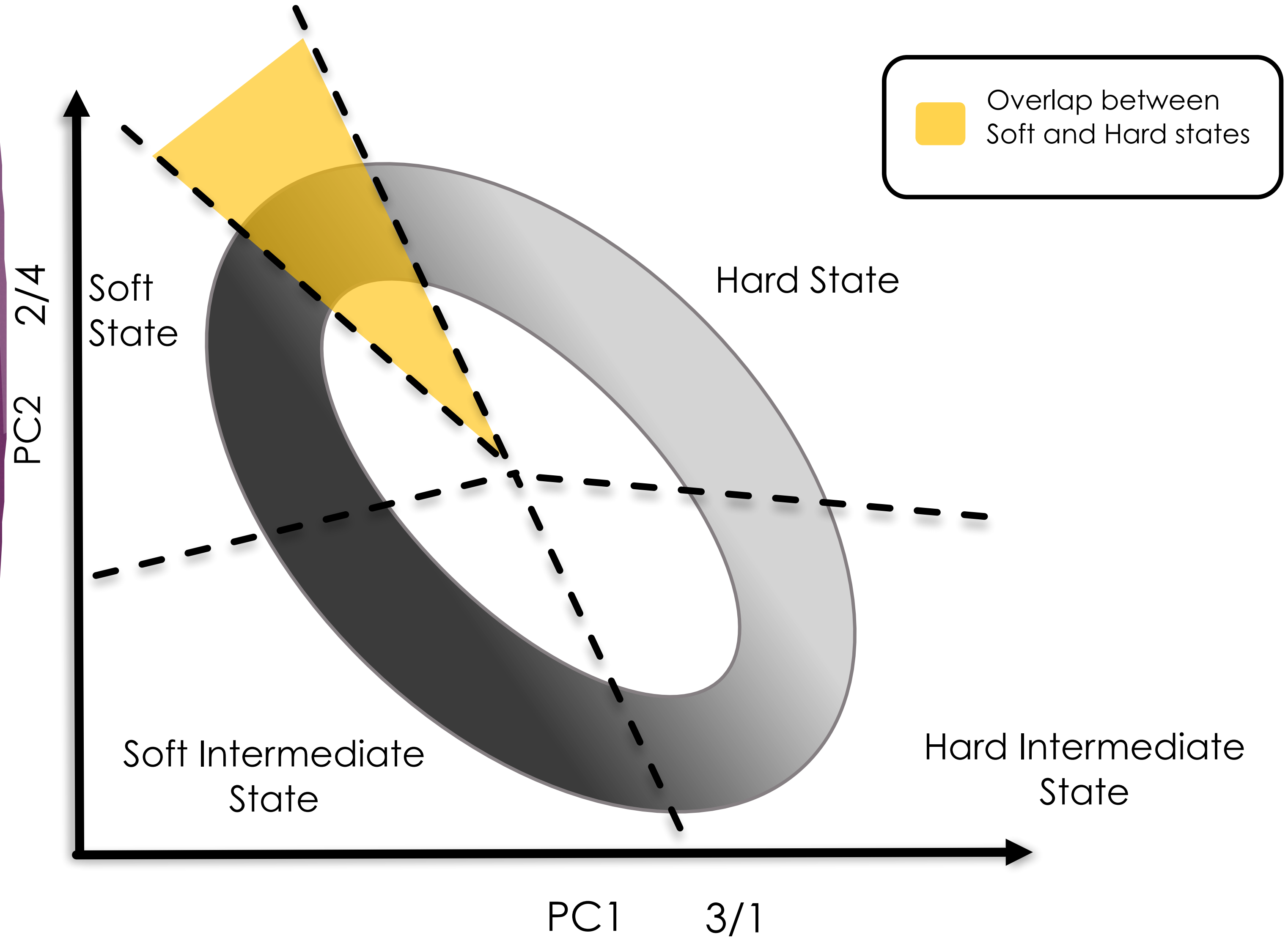


3/1

Finding states around the loop

Observations with similar power-spectral shape can be easily selected

Path can be described using the diagram



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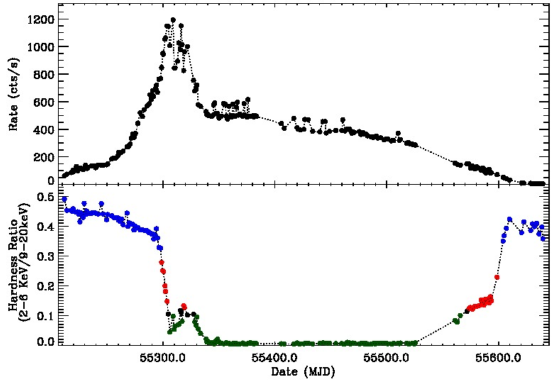

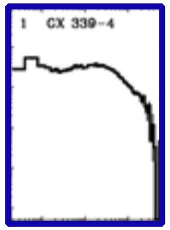

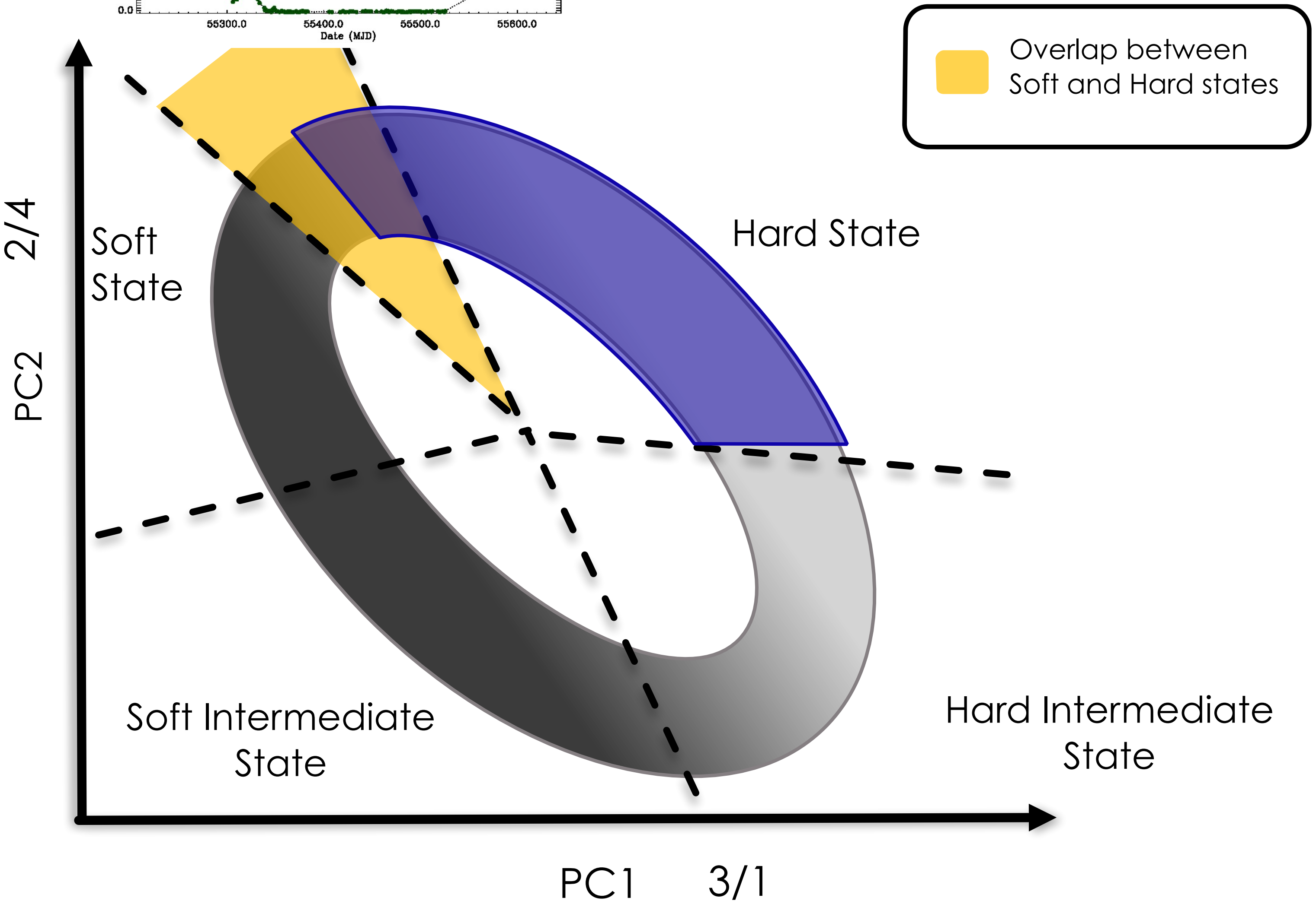

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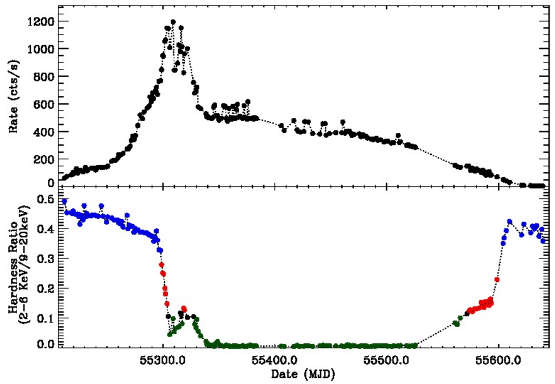

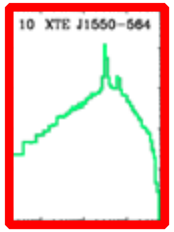

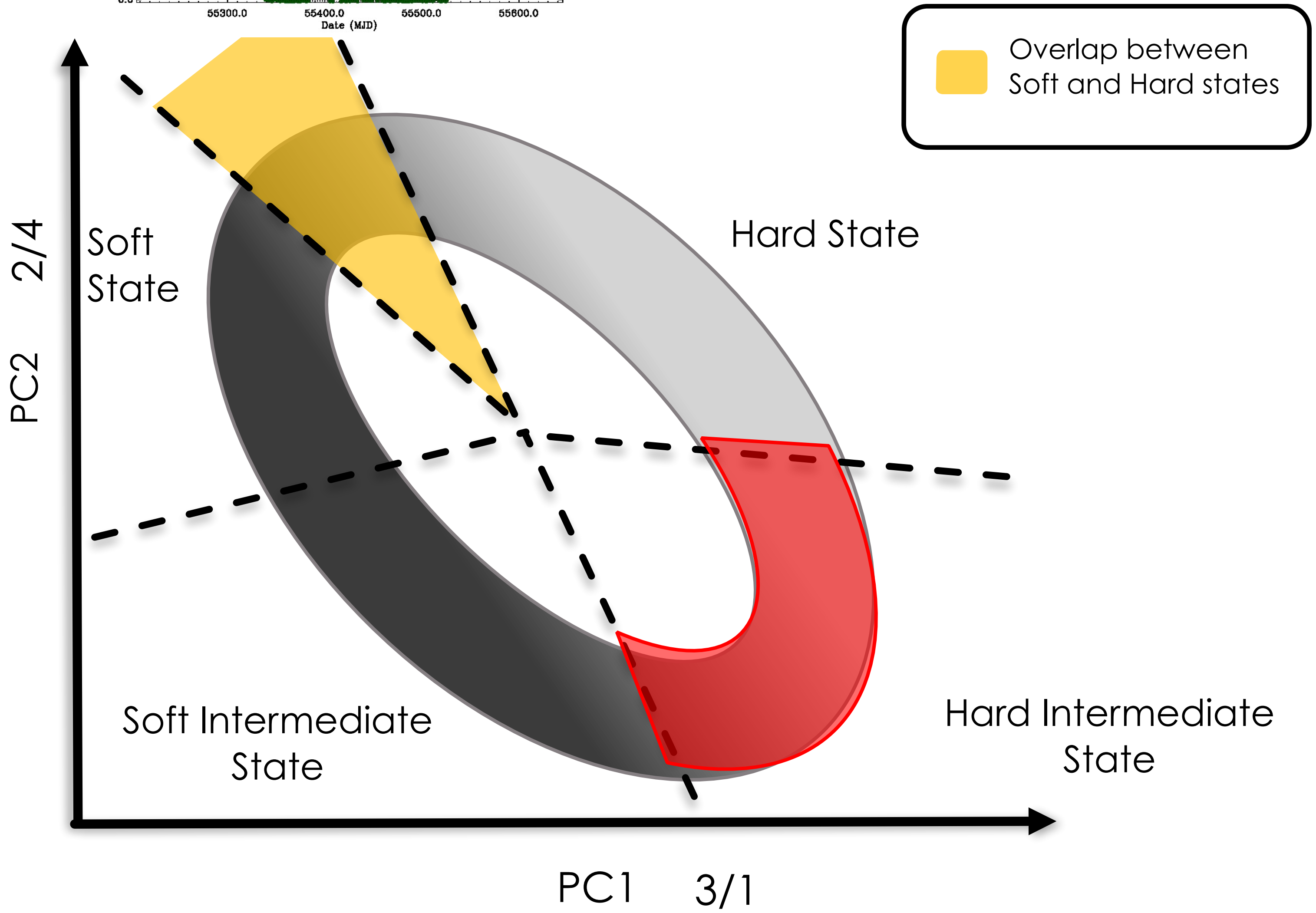

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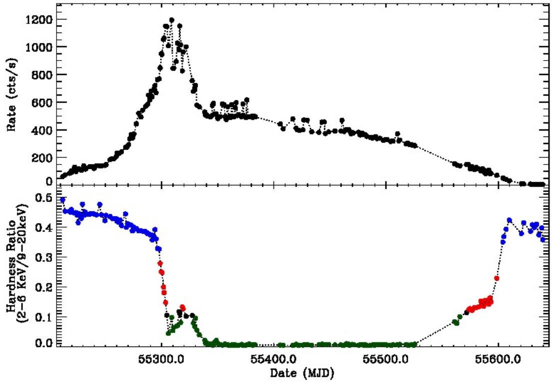

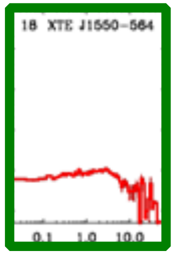

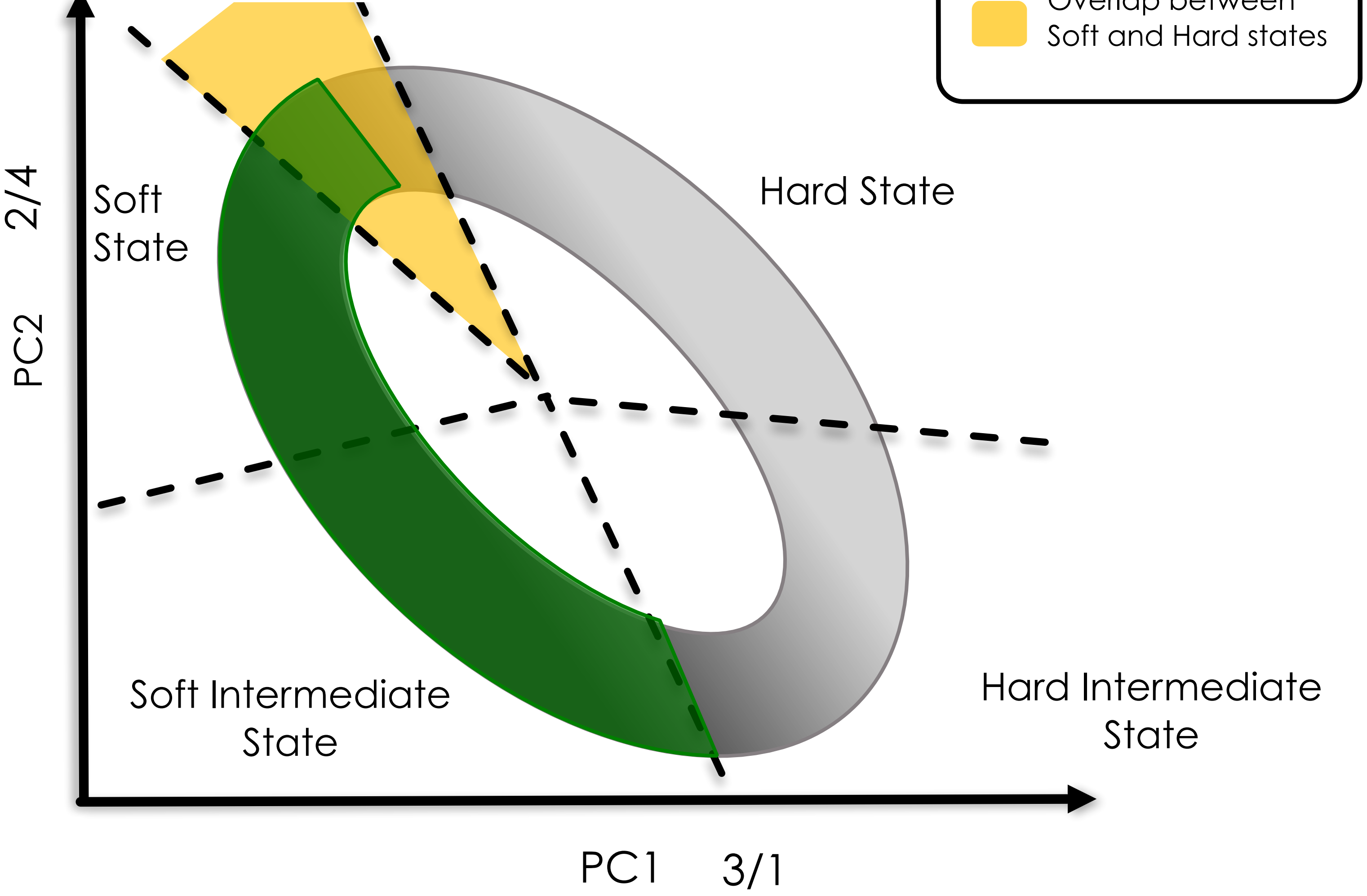

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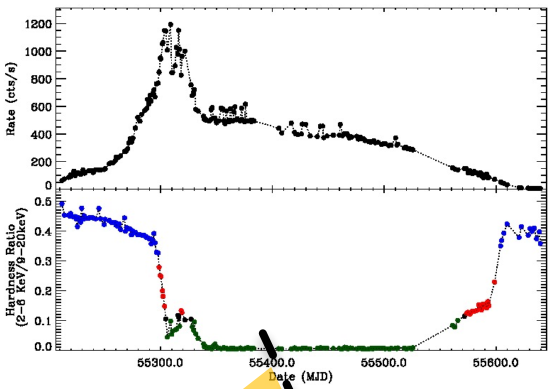
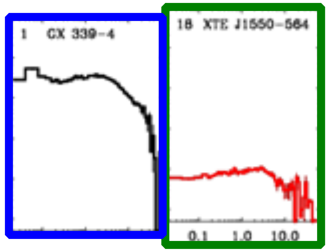
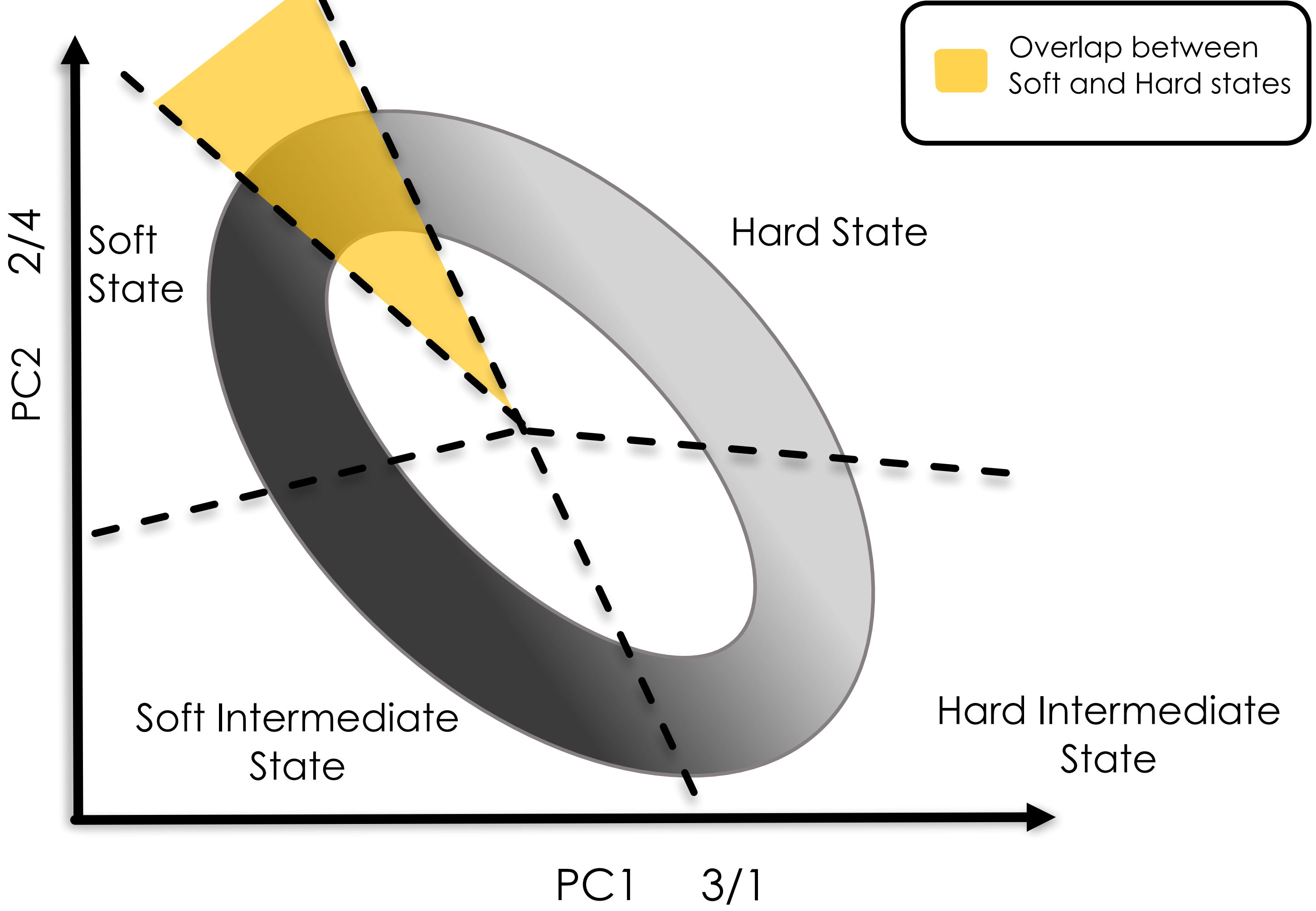






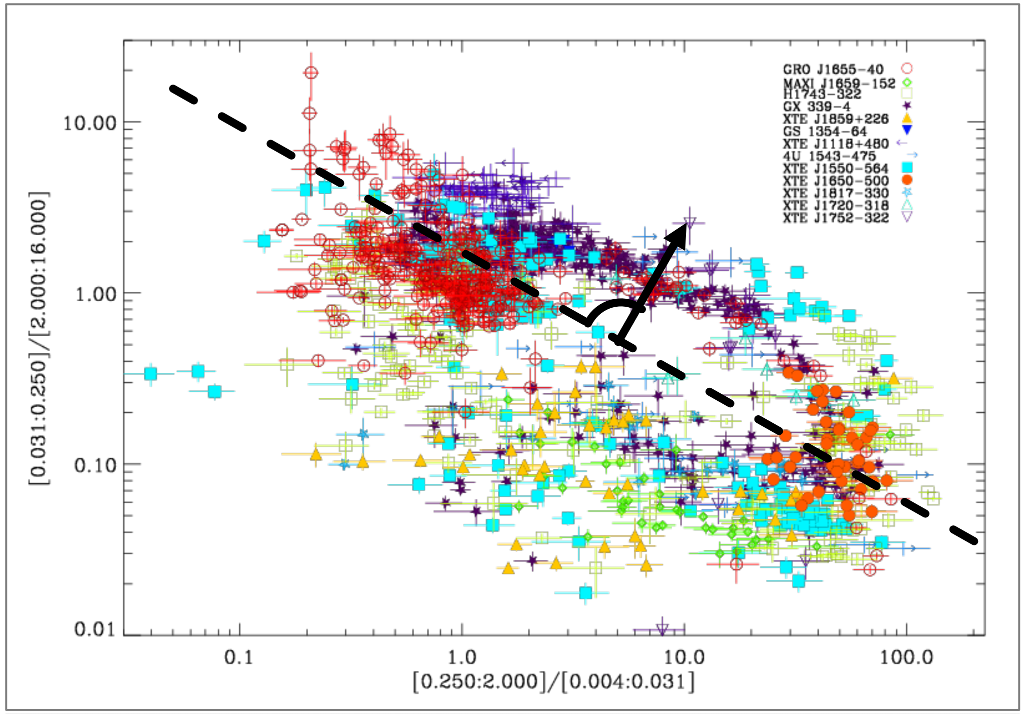
Parameterising the power-colour-colour plot

- Parameterising the location of points on the power colour-colour diagram allows for property comparison
- Define a power colour angle around the path or "Hue"

Method:

- Find a centre of mass
- Calculate dot products between vectors to points and a semi-major axis

Start here



Broad band noise is not inclination angle dependent

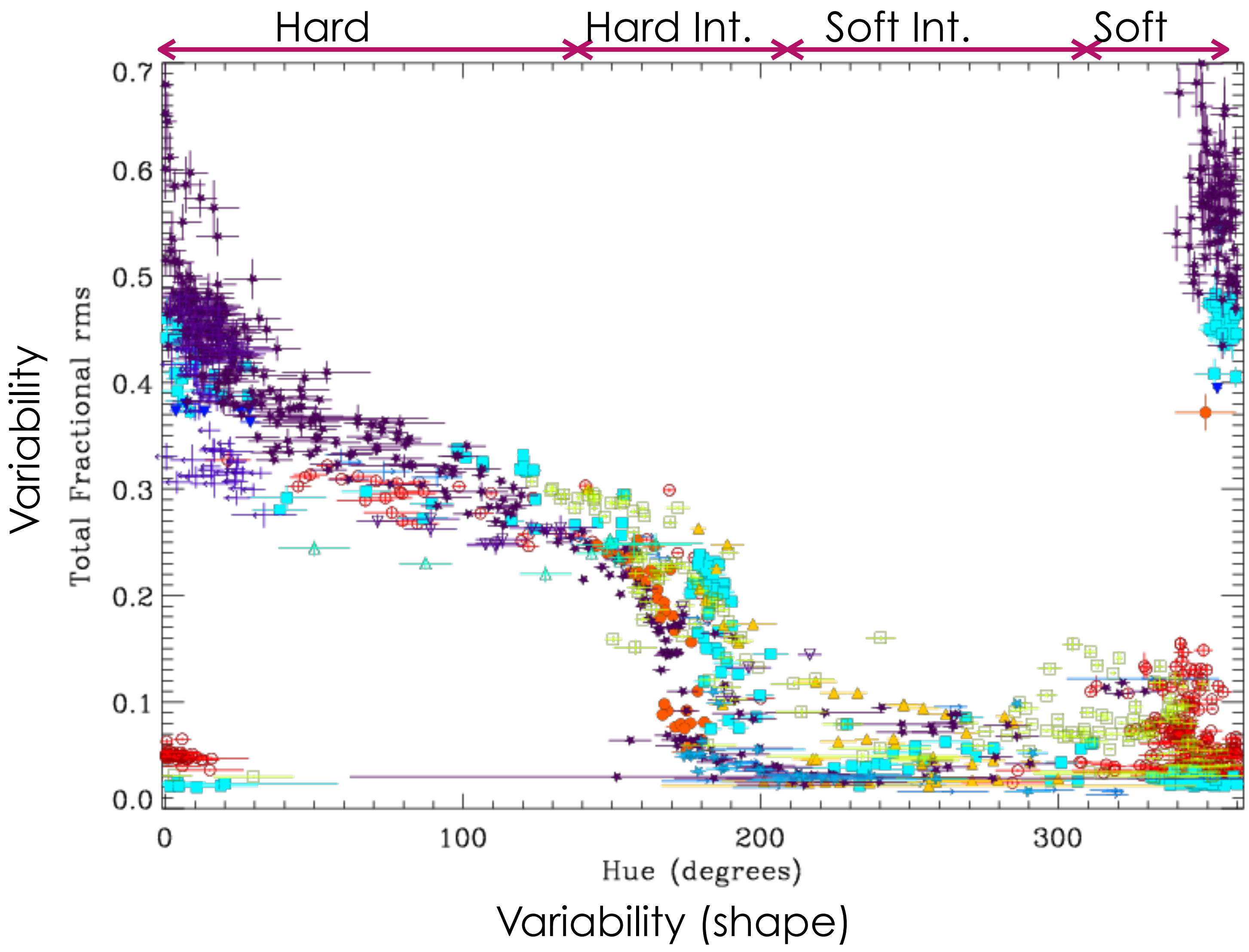
Initial slight shift in hue observed between high and low inclination objects – QPOs?

Removal of QPOs from the lightcurves removes this shift

Fractional rms of broad-band noise does not depend on inclination

See also Poster and Paper by Motta et. al. (2014)

ArXiv: 1405.7293



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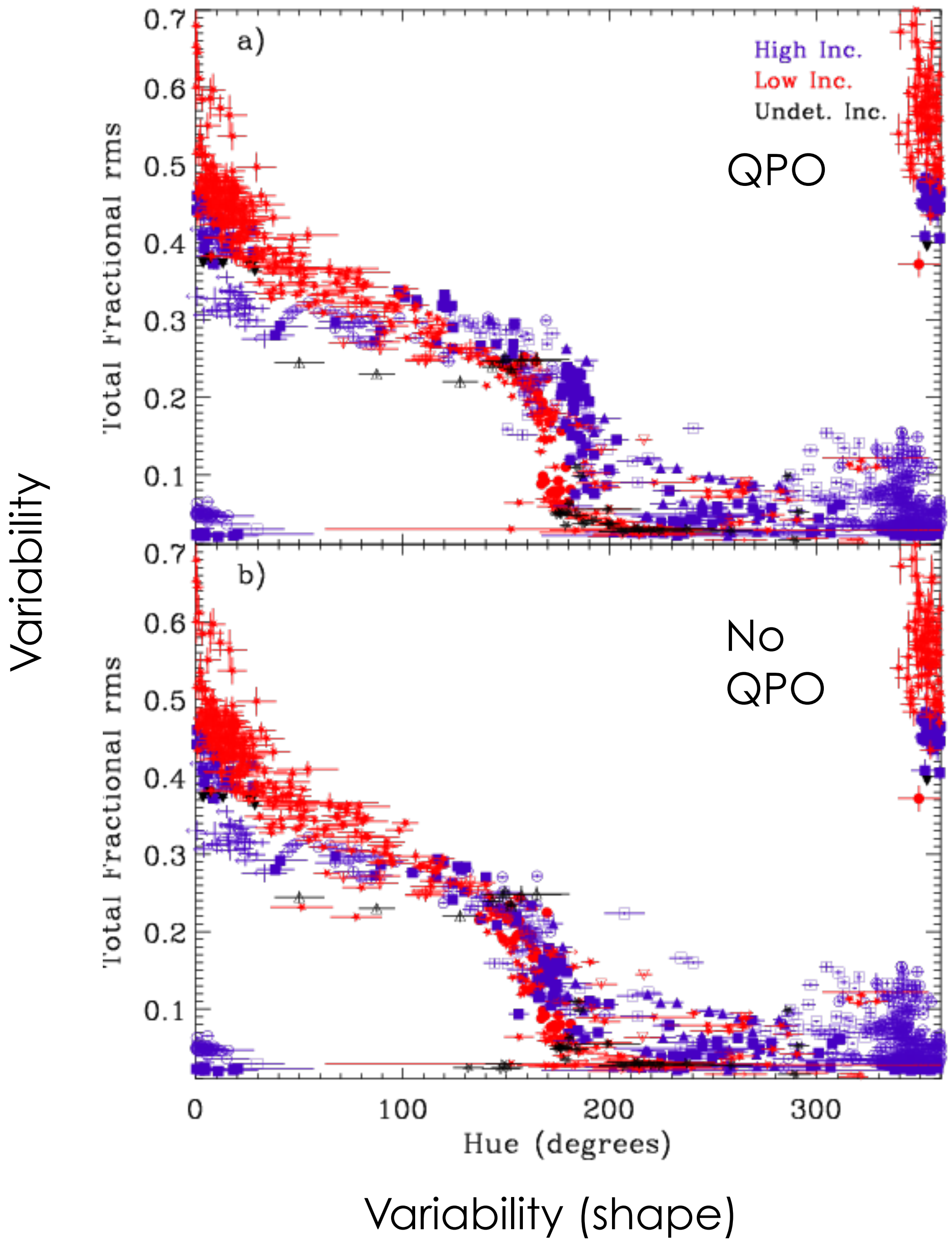


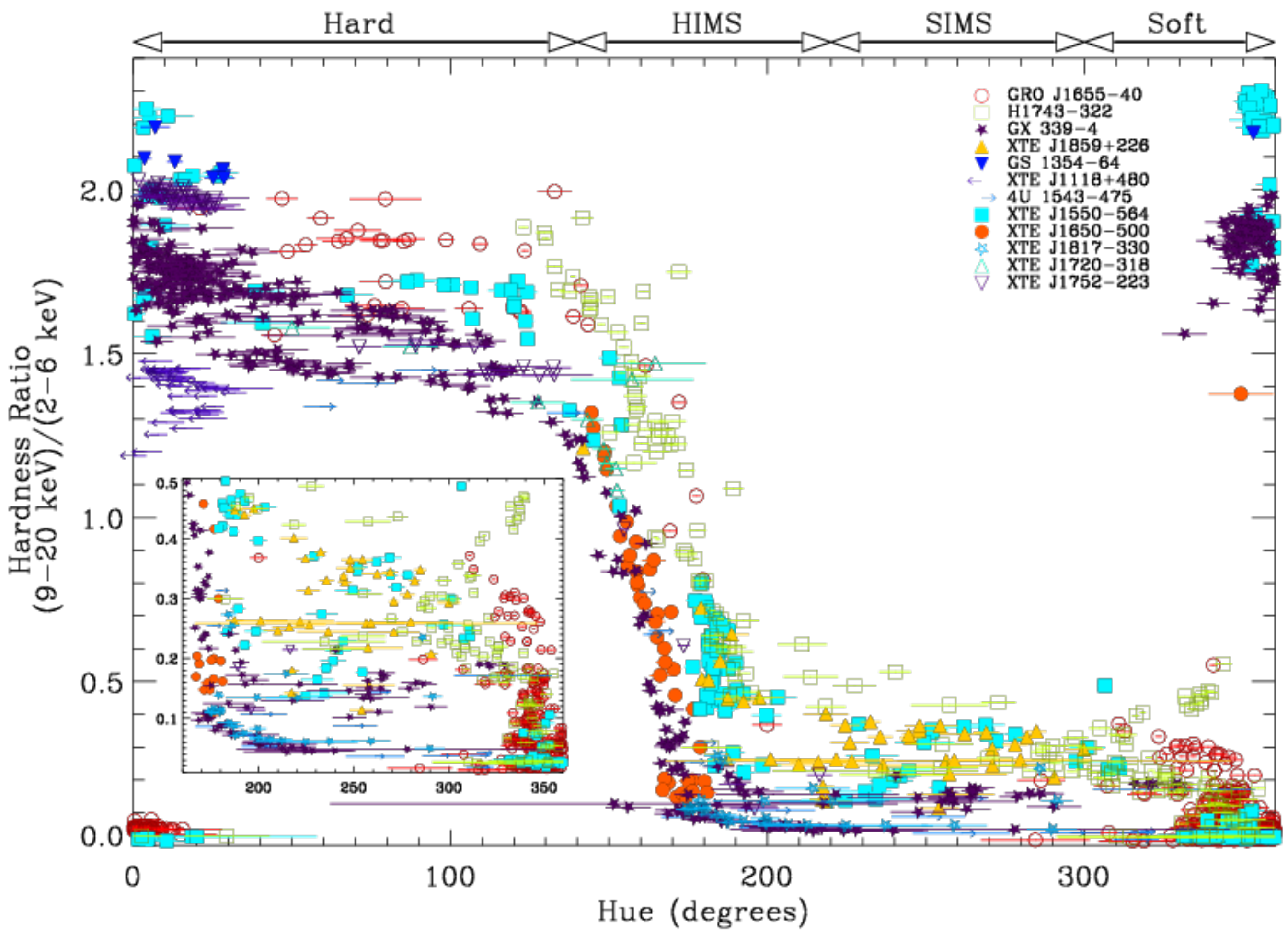
Direct Comparison of Spectral properties

We can now directly compare Energy and Power spectral properties

Plot angle around the power colour-colour diagram against Energy spectral hardness

Significant spread observed

Energy Spectra



Variability

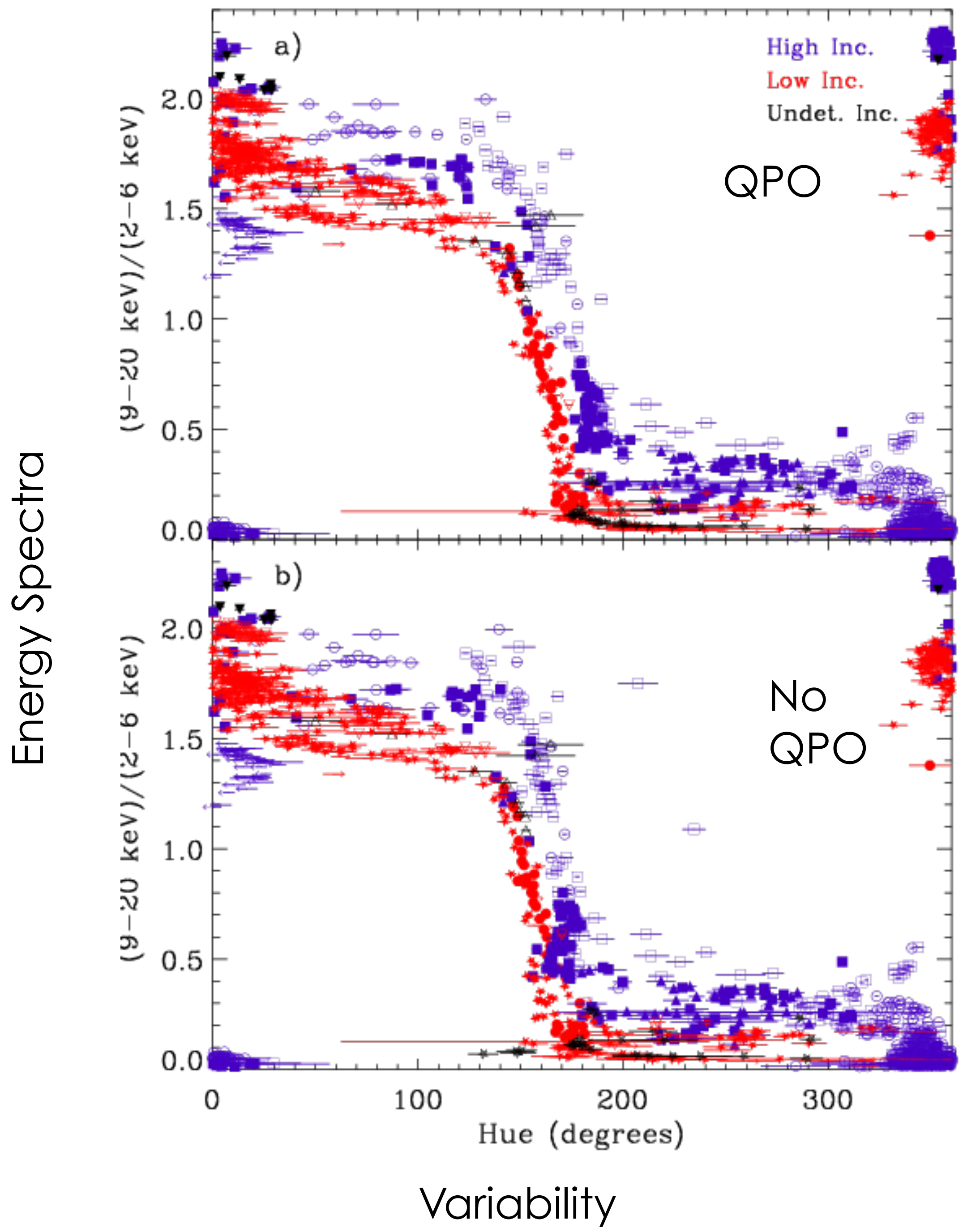
Higher inclination angle objects are harder

Recent work by Munoz-Darias et. al. (2013) showed that high inclination objects are harder than those inclined at a lesser angle

Colour code into two inclination angle groups

Red: > 60 degrees

Blue < 60 degrees



A higher optical depth for highly inclined sources?

Separation in Energy Spectral hardness extends to the hard state when we compare power spectra

Accretion flow consists of cool thin disc and hot thick inner flow

Optical depth is higher through more material

Could simply be a result of this difference in los

$$\frac{I}{I_0} = e^{-\tau}$$

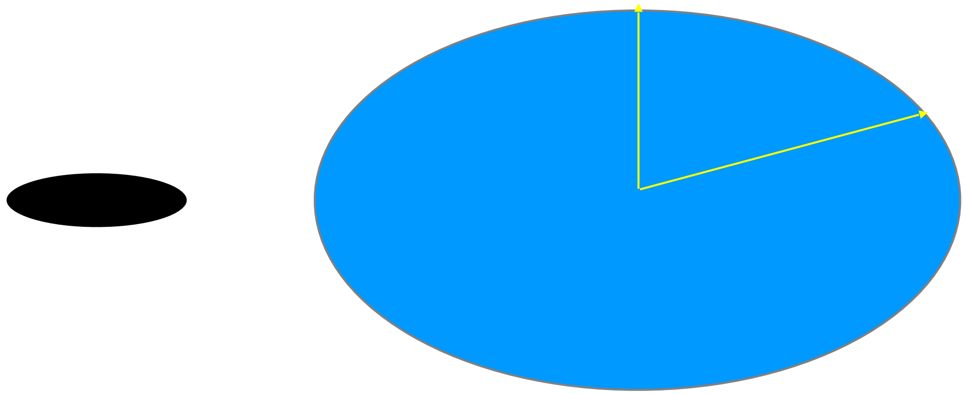
Mean High inclination 70°
Mean Low inclination 44°

Estimated ratio of optical depths from HR:

$$\frac{\tau_{hi}}{\tau_{lo}} \approx 1.33$$

Estimated difference in ratio under plane-parallel geometry:

$$\frac{\tau_{hi}}{\tau_{lo}} \approx 2.1$$



Hot optically thin corona

Conclusions

- Power colour-colour plot is a powerful new tool in analysis arsenal
- Allows us to directly compare observations with similar power spectral properties for the first time
- Can be extended to a wide range of analyses
- Also works for different object types
- Reveals that High inclination objects appear harder than lower inclination ones
  - Due to higher optical depth along different lines of sight?

For further discussion and results see ArXiv preprints: 1405.2024 and 1405.2026