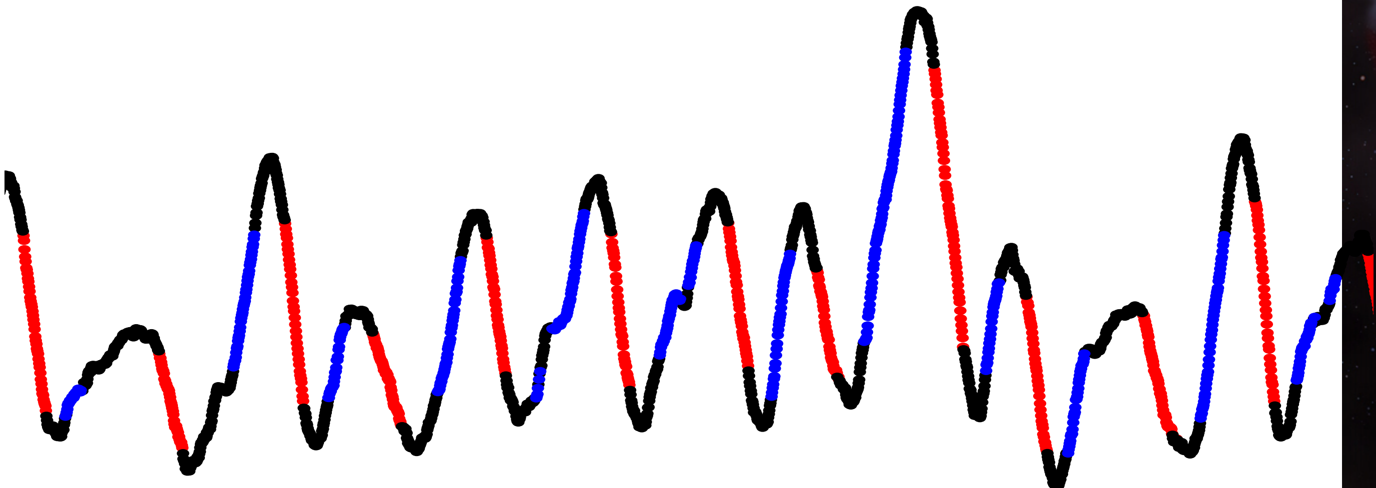
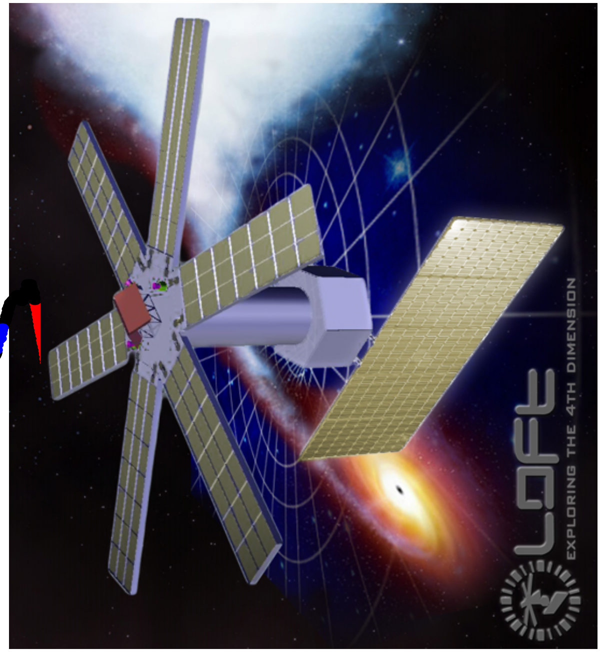
Uncovering the QPO mechanism with LOFT

Adam Ingram





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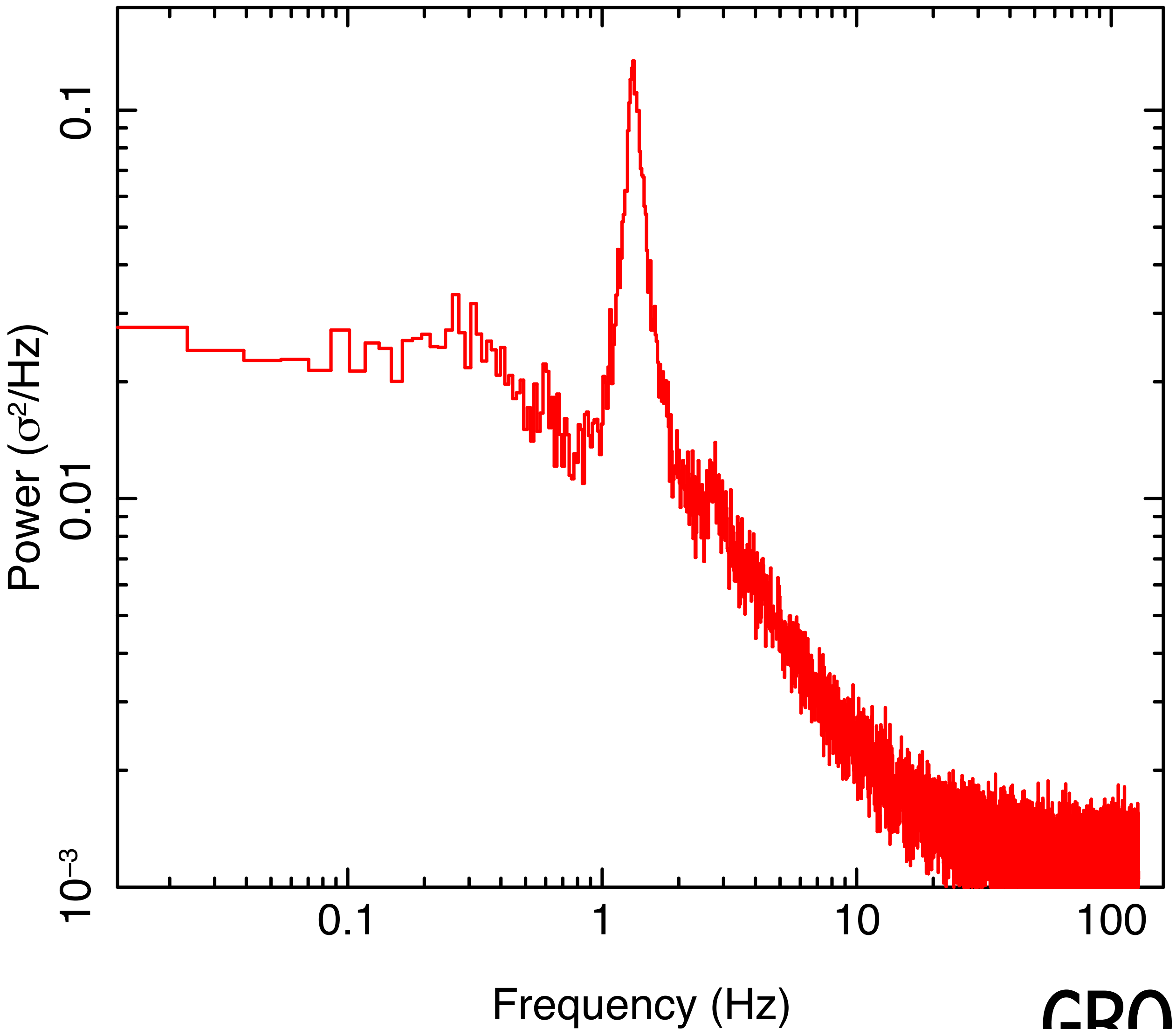
Lucy Heil, Chris Done, Michiel van der Klis,
P Chris Fragile, Phil Uttley

First UK LOFT Science Meeting
London, 2013 June 24-25

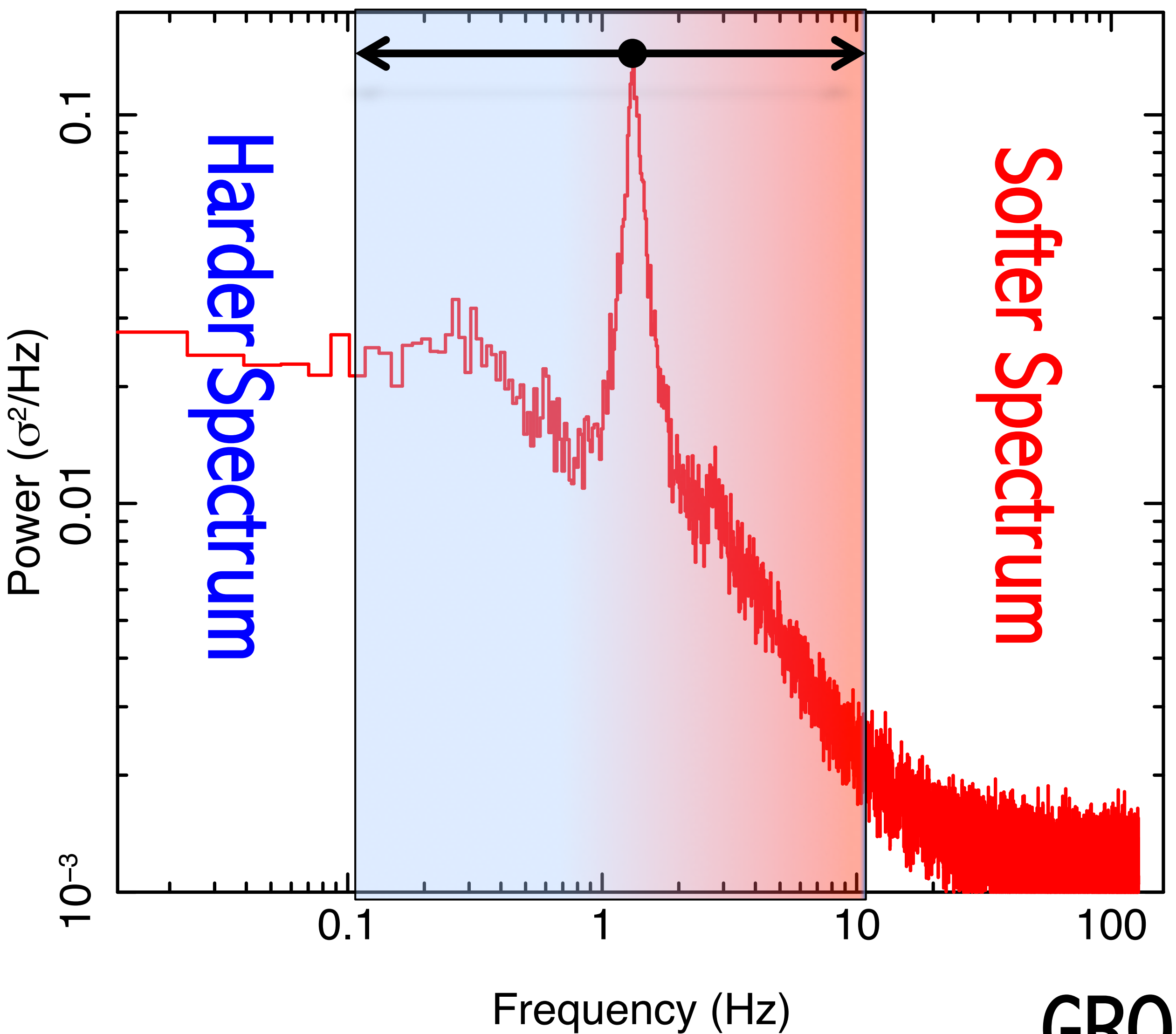
Science & Technology Facilities Council
UCL
Royal Astronomical Society

Low frequency QPOs



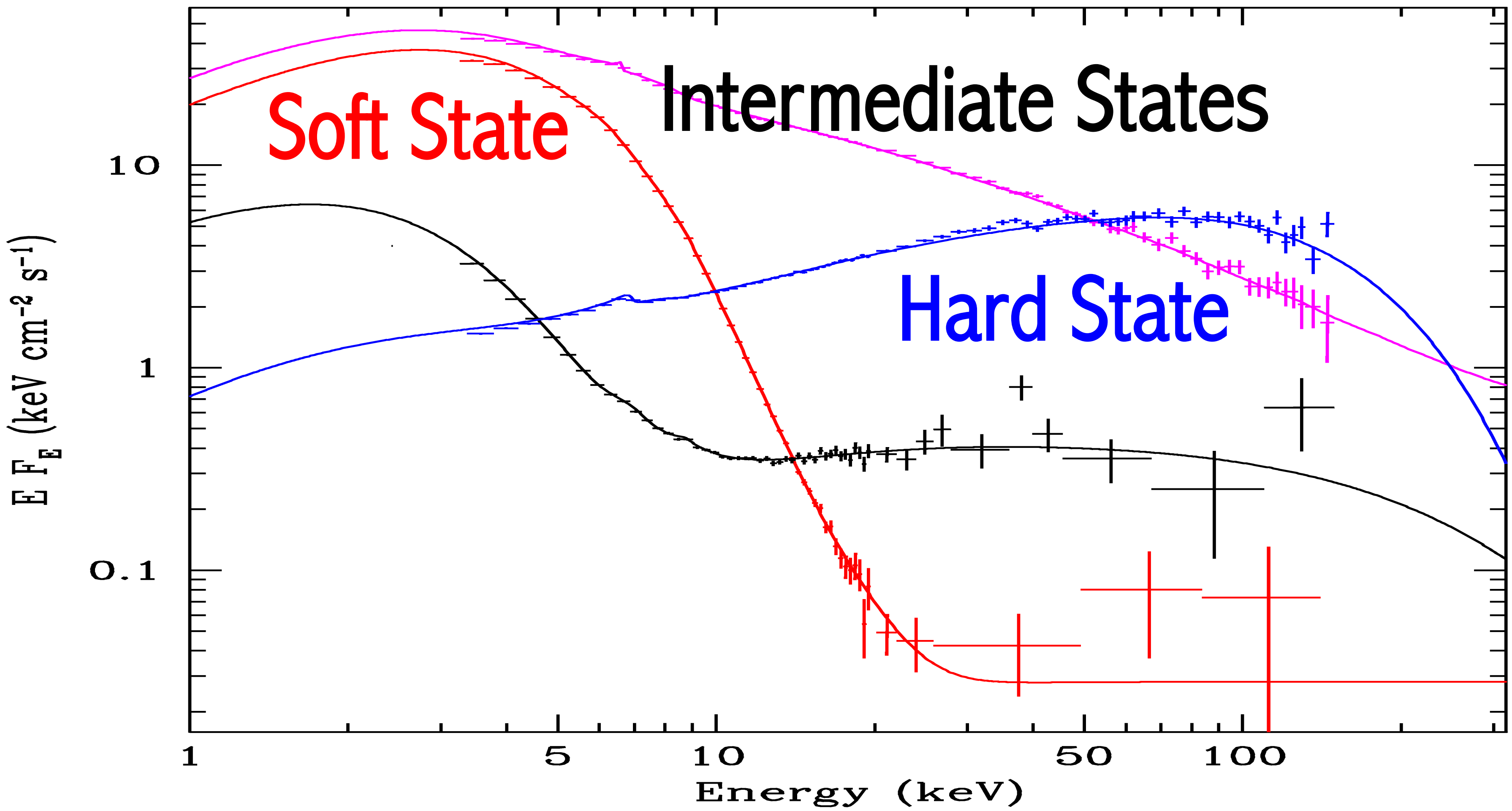
GRO 1655-40

Low frequency QPOs



GRO 1655-40

Truncated disk model



Done, Gierlinski & Kubota (2007)

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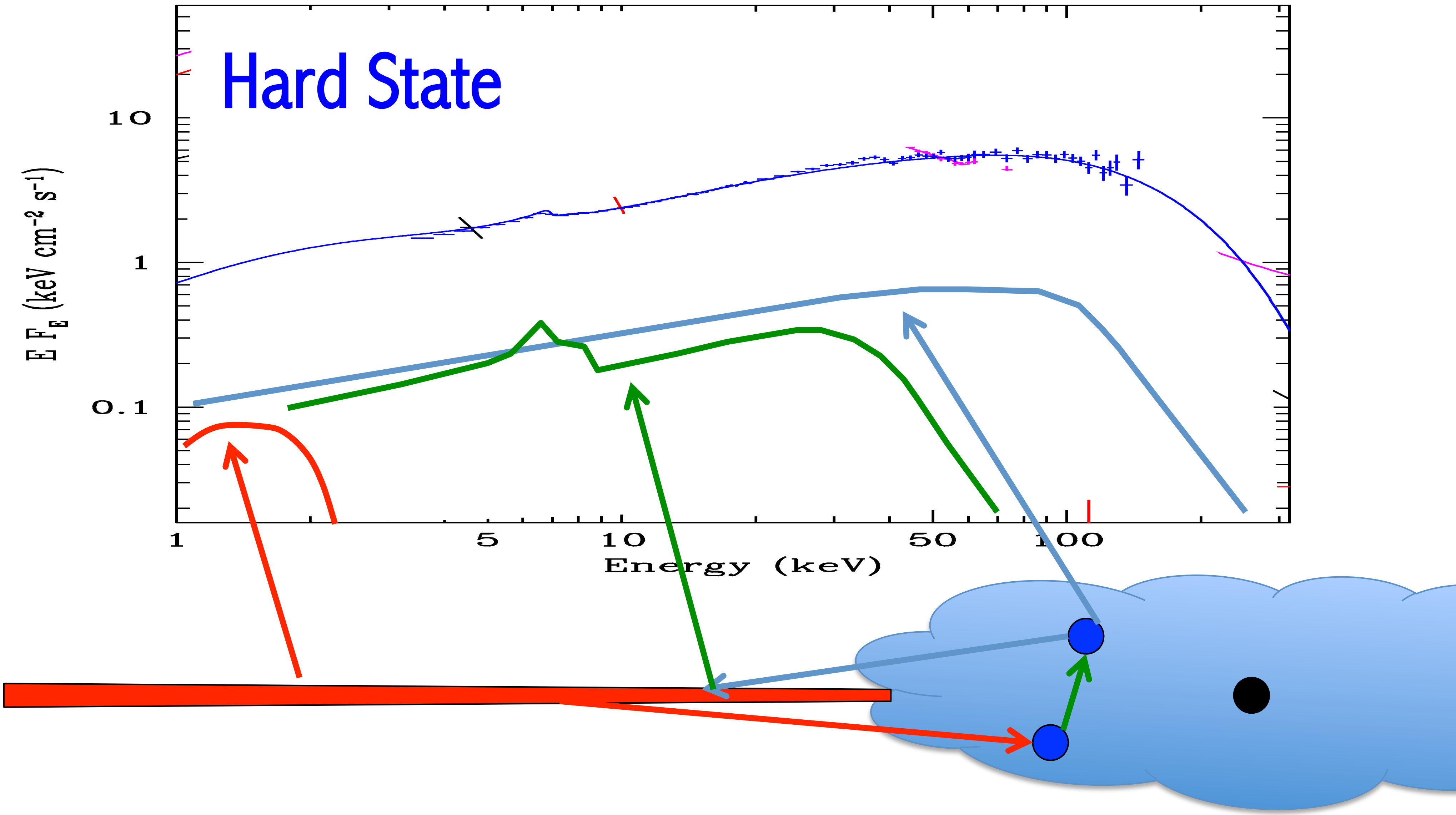
Truncated disk model



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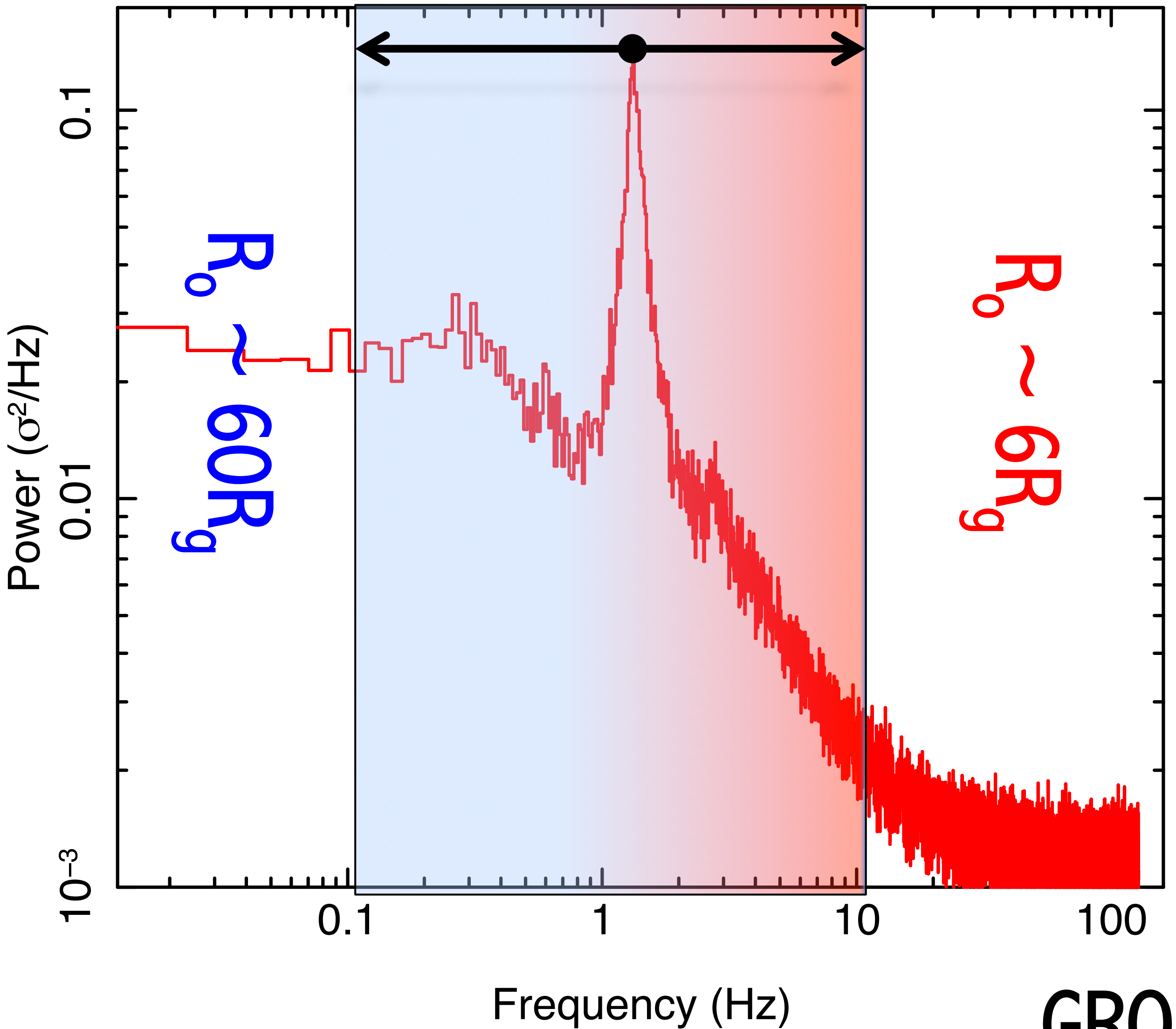
Truncated disk model

R_o = Truncation Radius



GRO 1655-40

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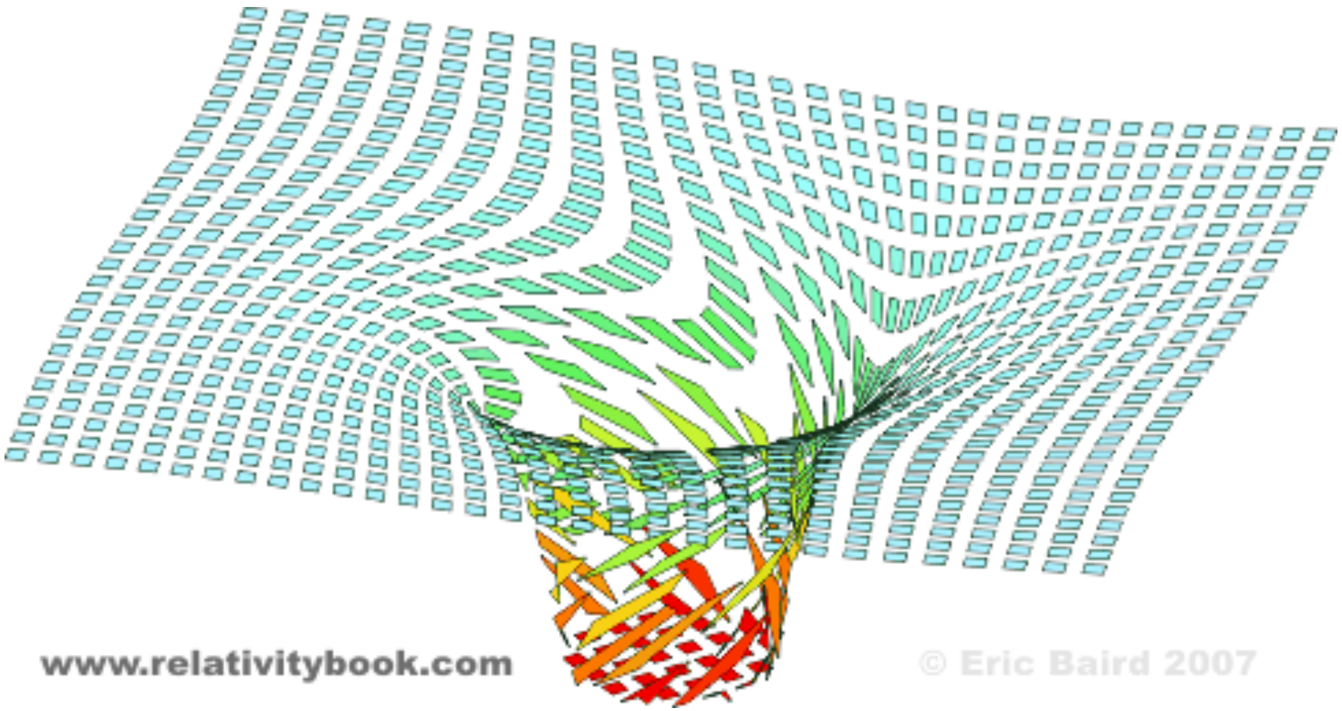
Frame dragging



Lense & Thirring (1918); Stella & Vietri (1998)

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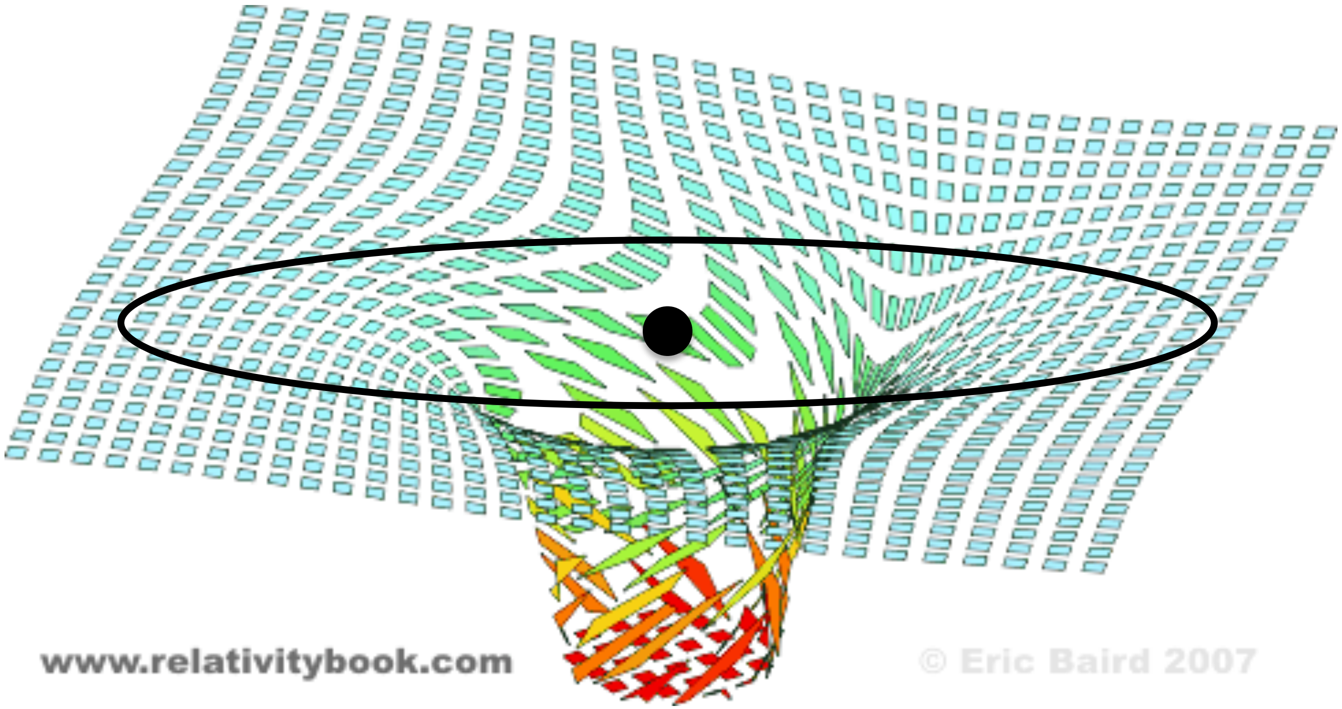
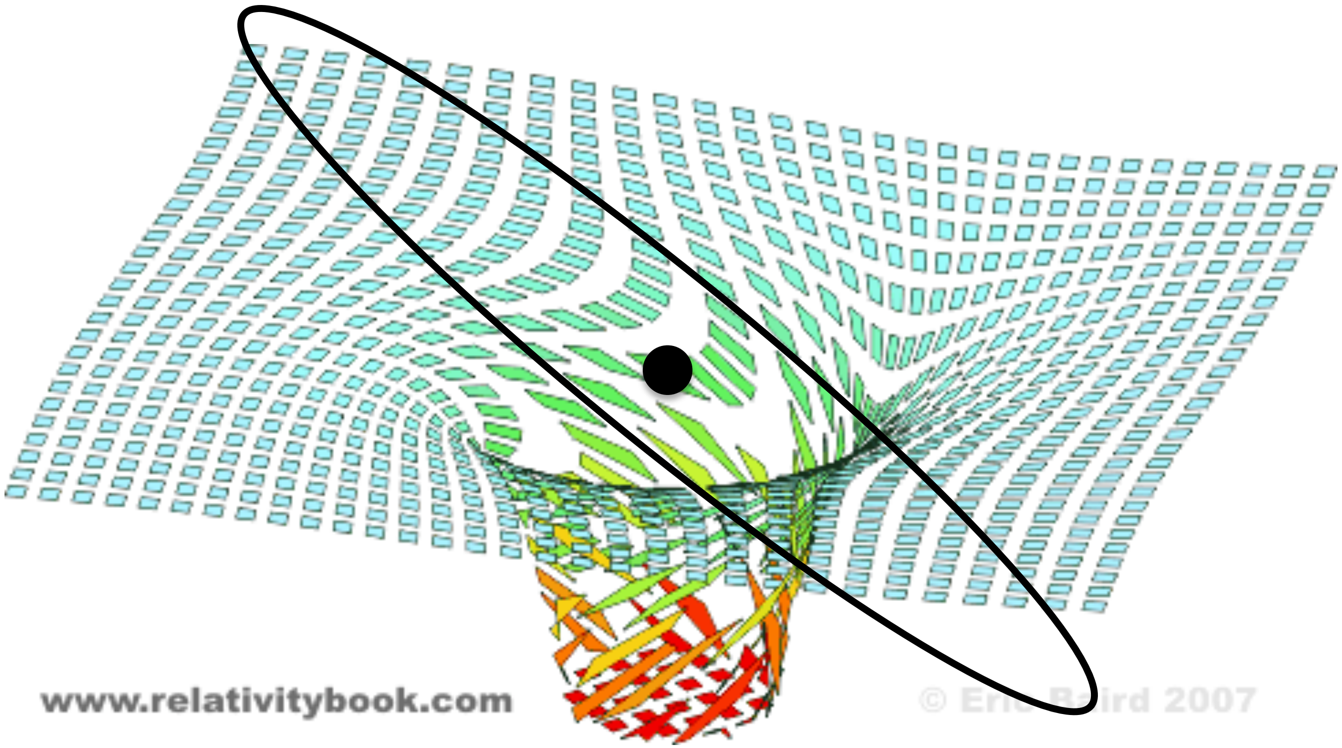
Frame dragging



Lense & Thirring (1918); Stella & Vietri (1998)

Frame dragging



Lense & Thirring (1918); Stella & Vietri (1998)

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Frame dragging

m = 1 HFGM Mode

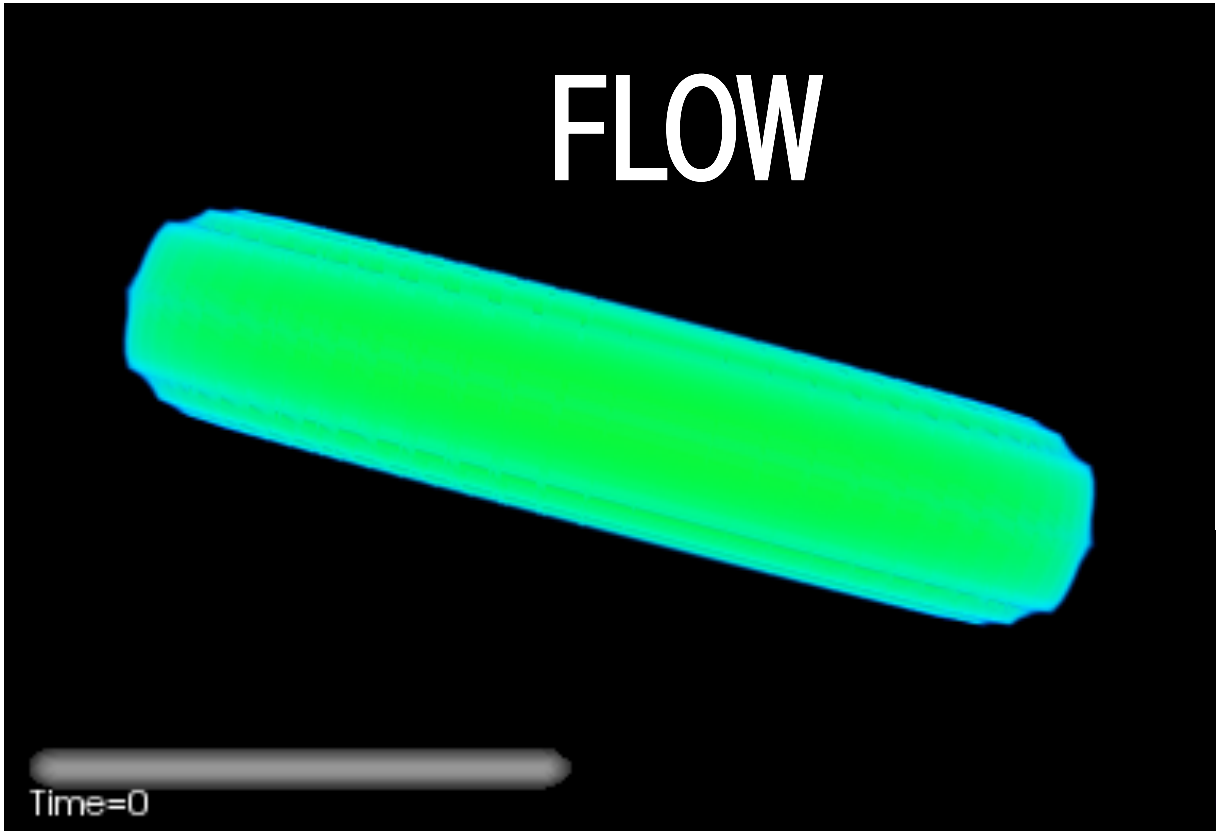
Frequency = 29 Hz

Growth Rate = –0.6 Hz

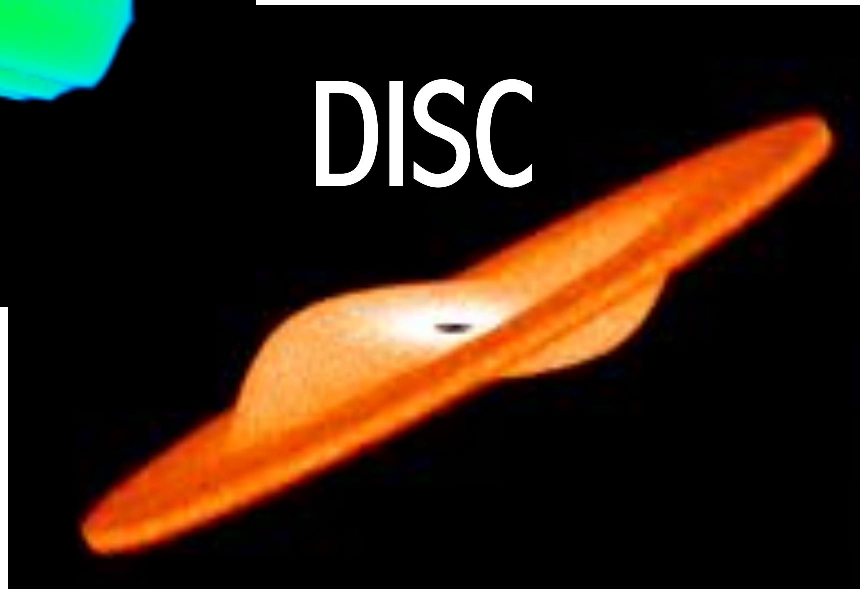
Q = 48

Markovic´, Lamb, Duez, Engelhard, Fregeau & Huffenberger

Frame dragging

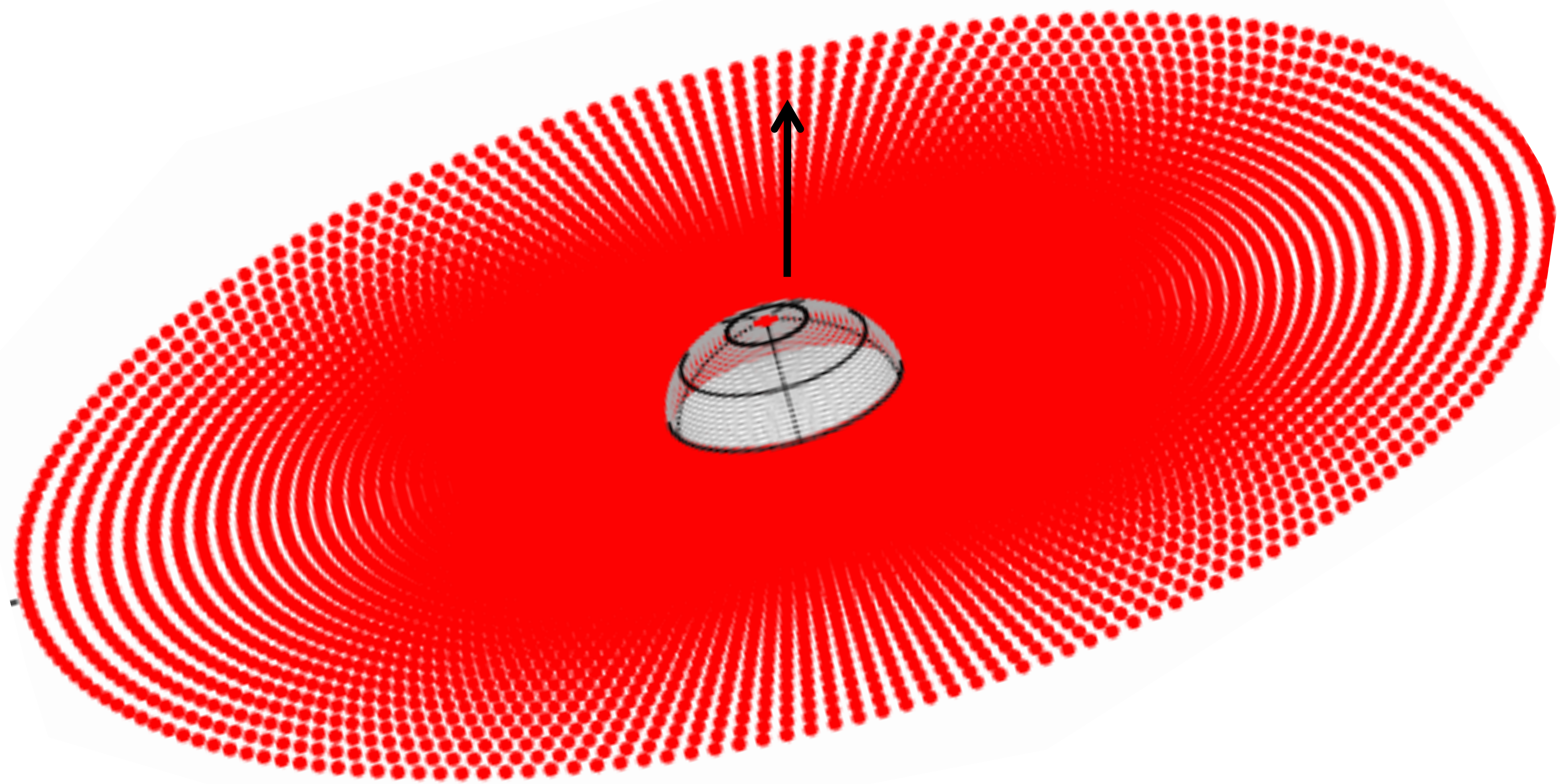


Fragile et al (2007)

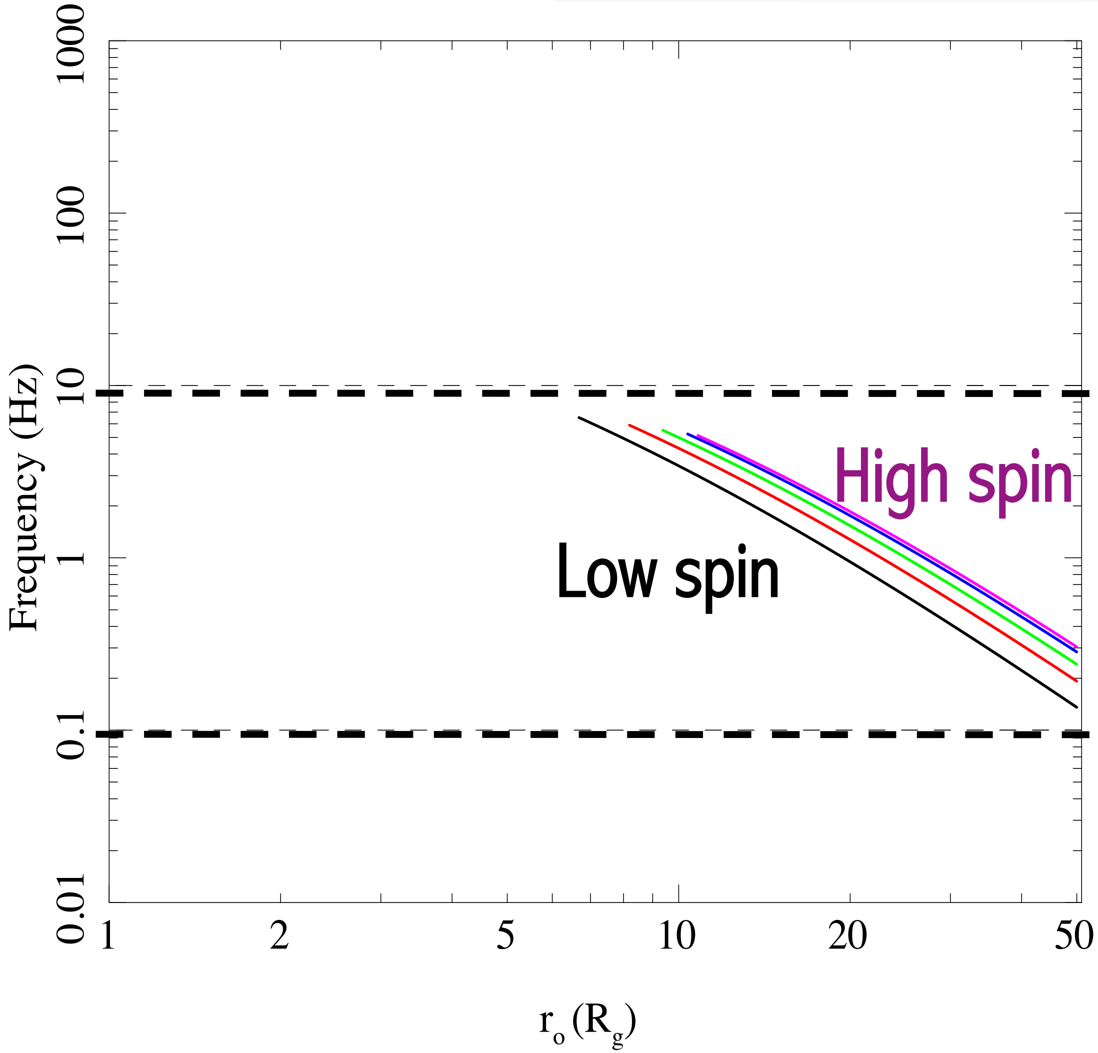


Bardeen & Petterson (1975)

Frame dragging



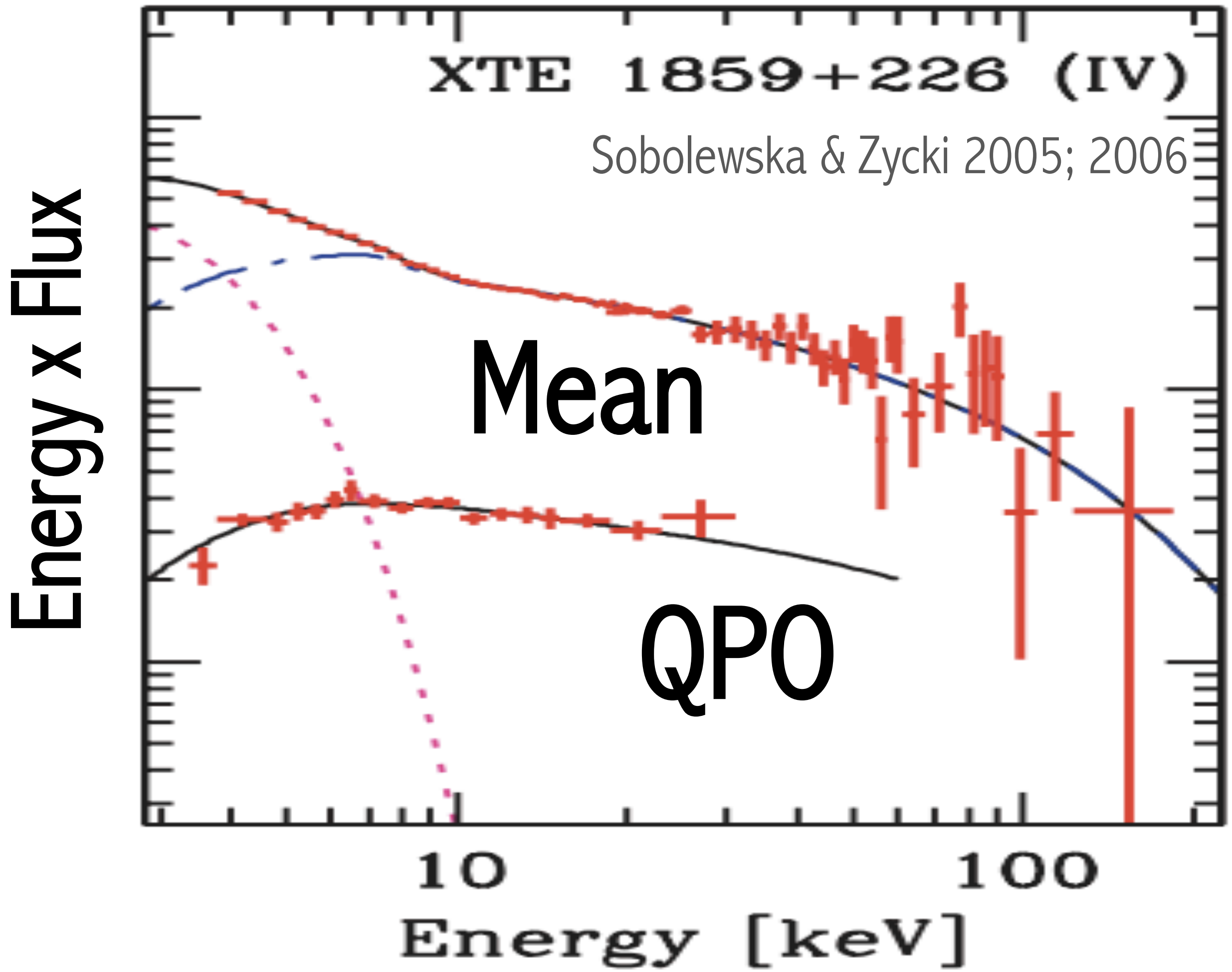
Frame dragging



The frequencies match

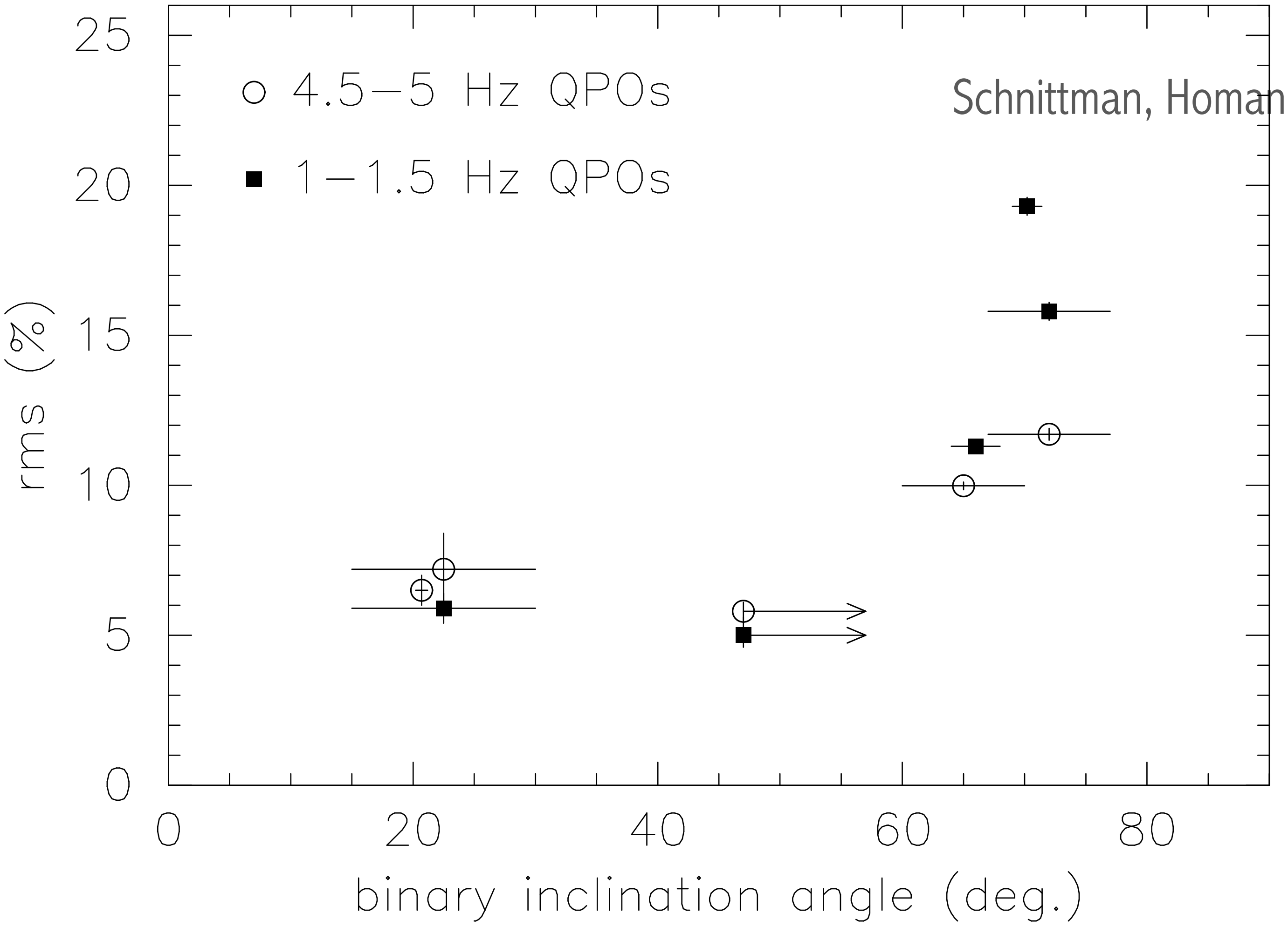
Ingram, Done & Fragile (2009)

Frame dragging



The QPO modulates the power law emission

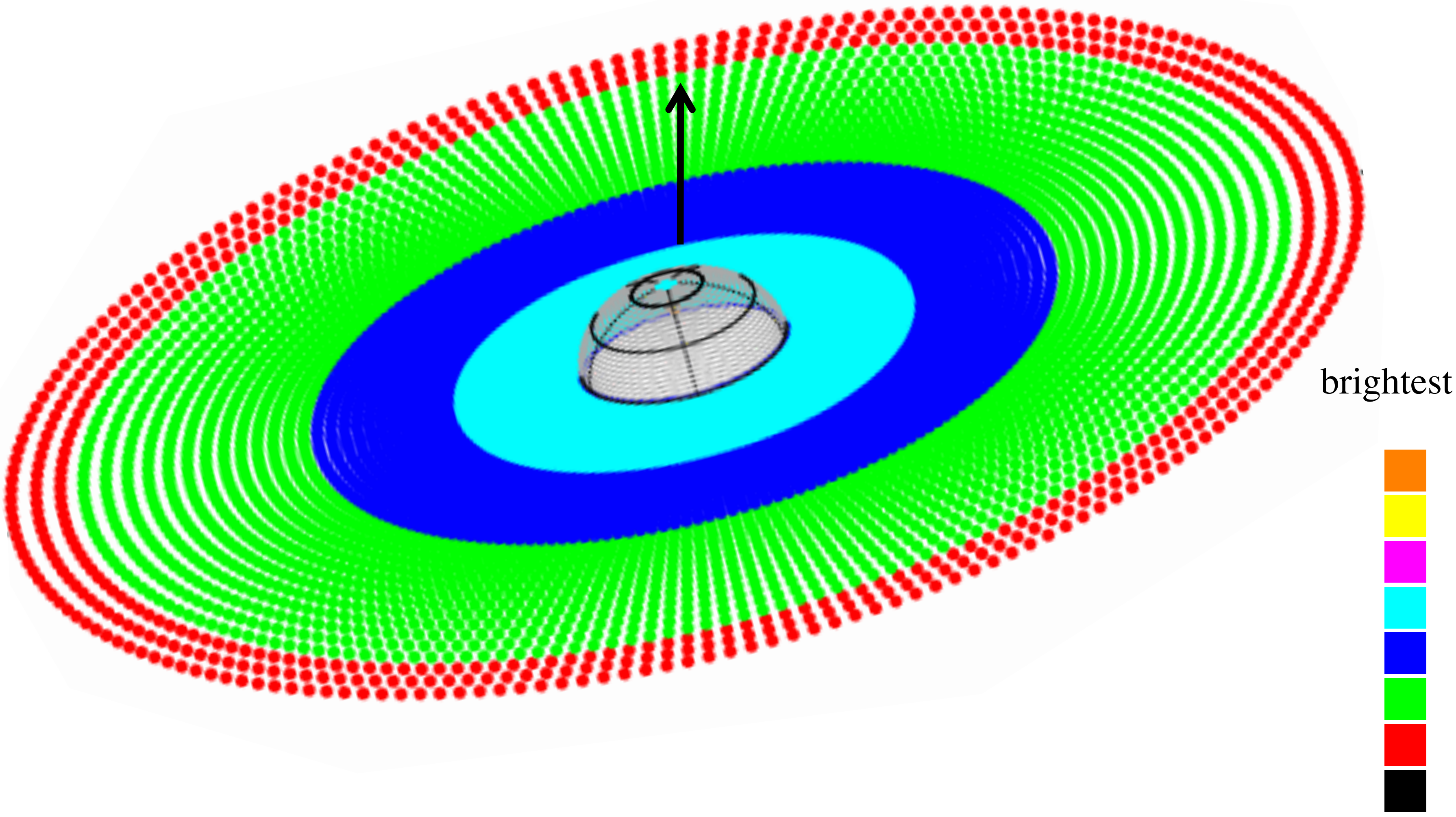
Frame dragging



Schnittman, Homan & Miller (2006)

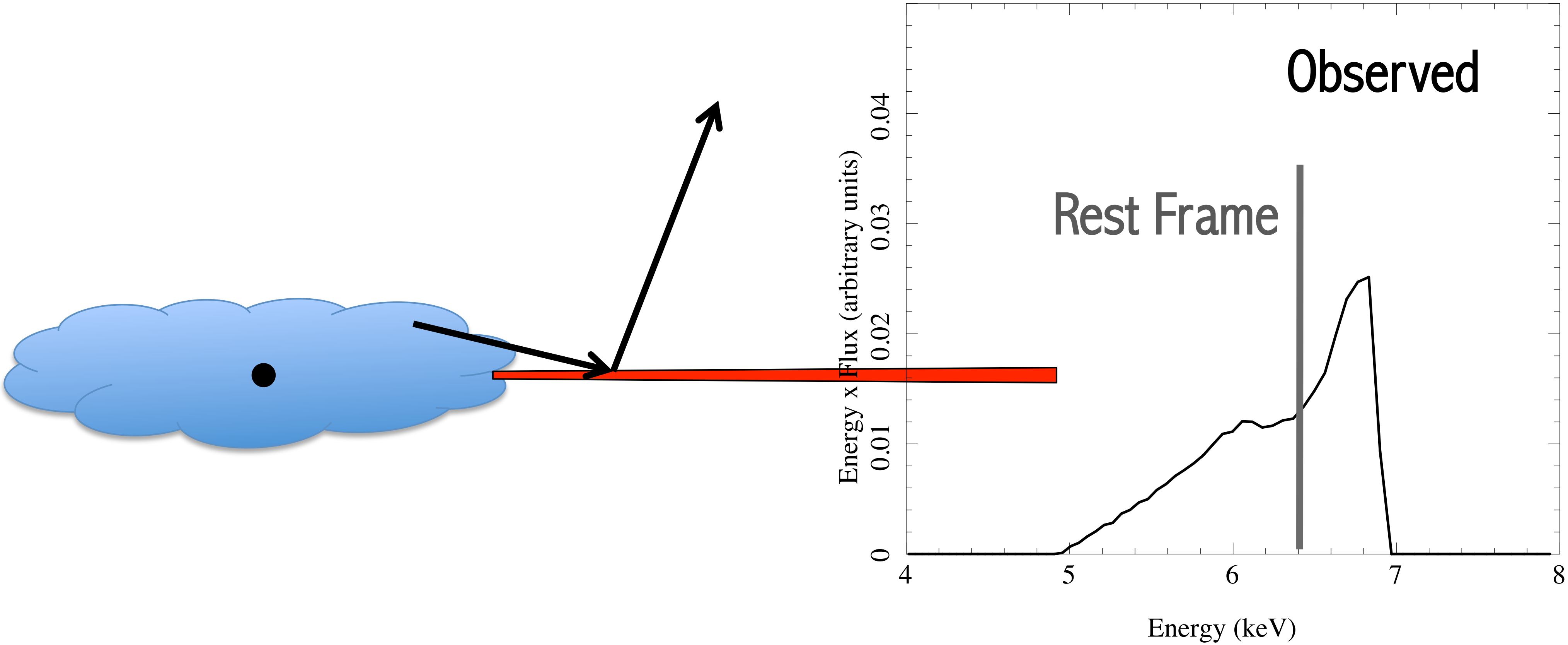
The QPO amplitude depends on inclination angle

Testing precession



Ingram & Done (2012b)

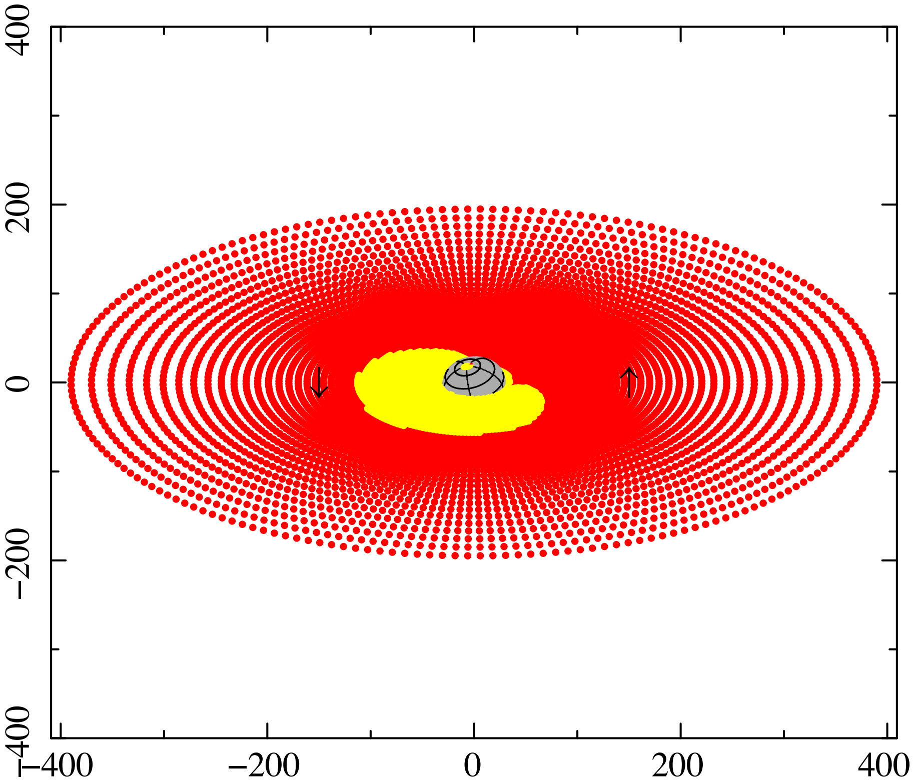
Testing precession

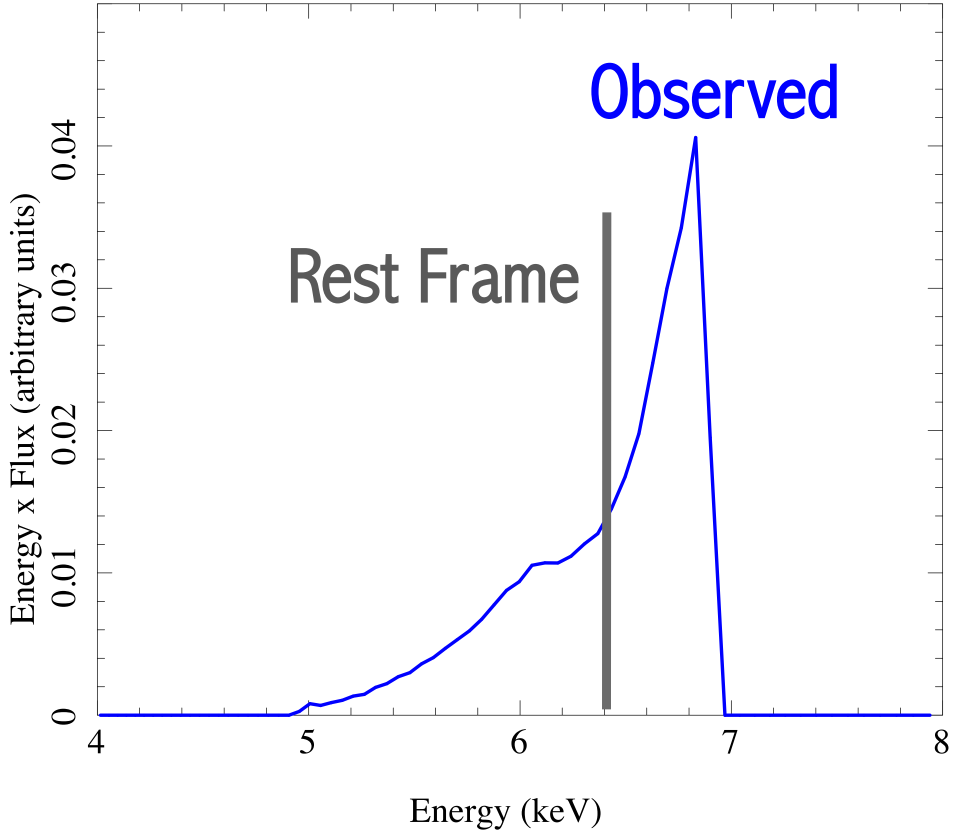


Ingram & Done (2012b)

Fabian et al (1989)

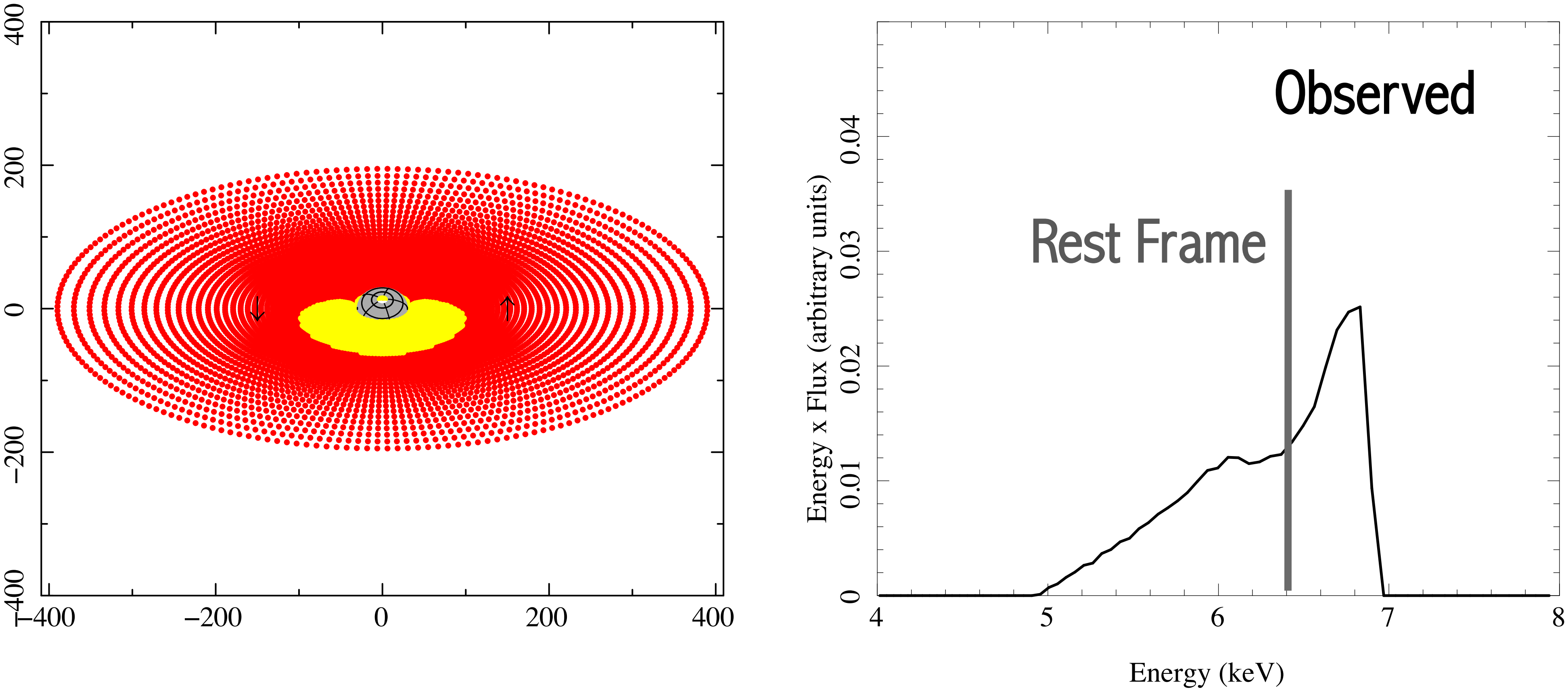
Testing precession





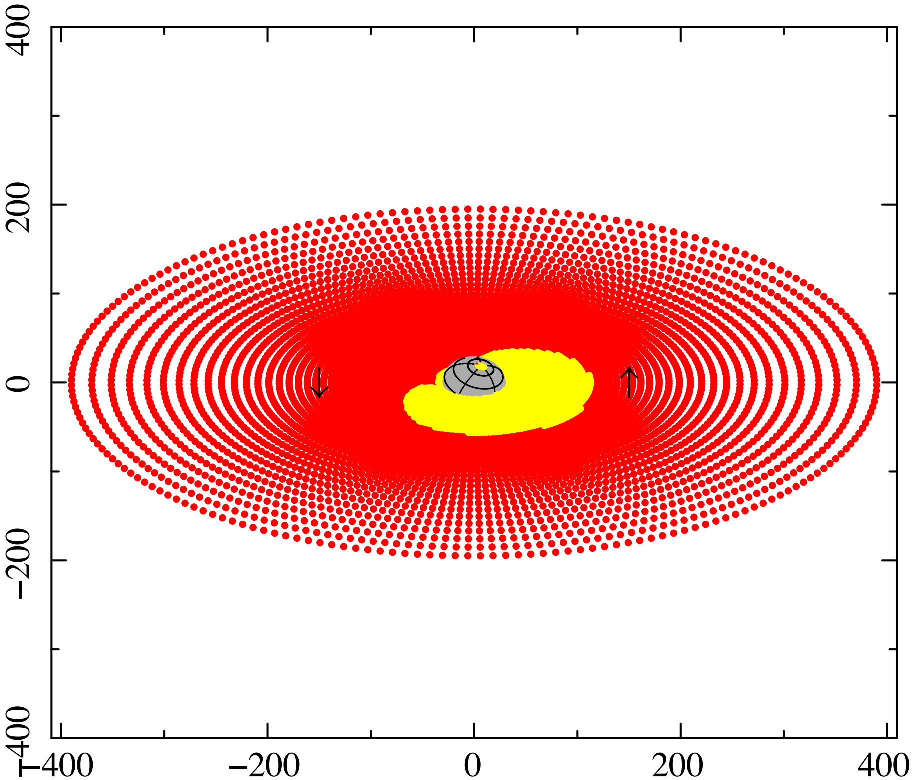
Ingram & Done (2012b)

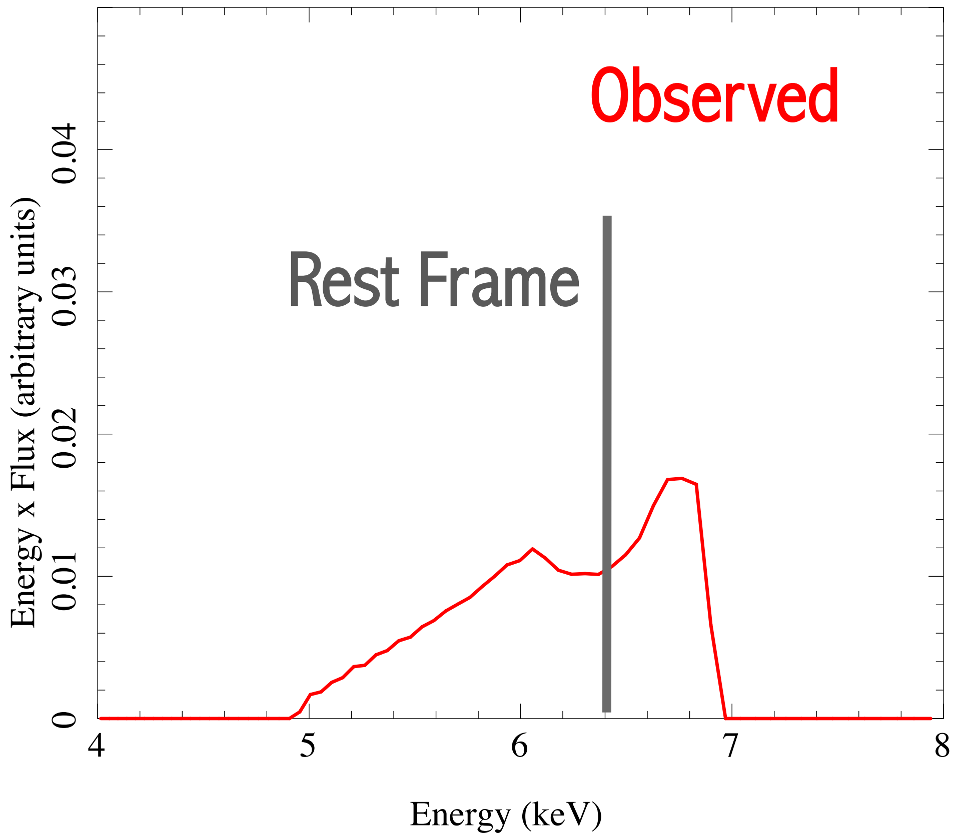
Testing precession



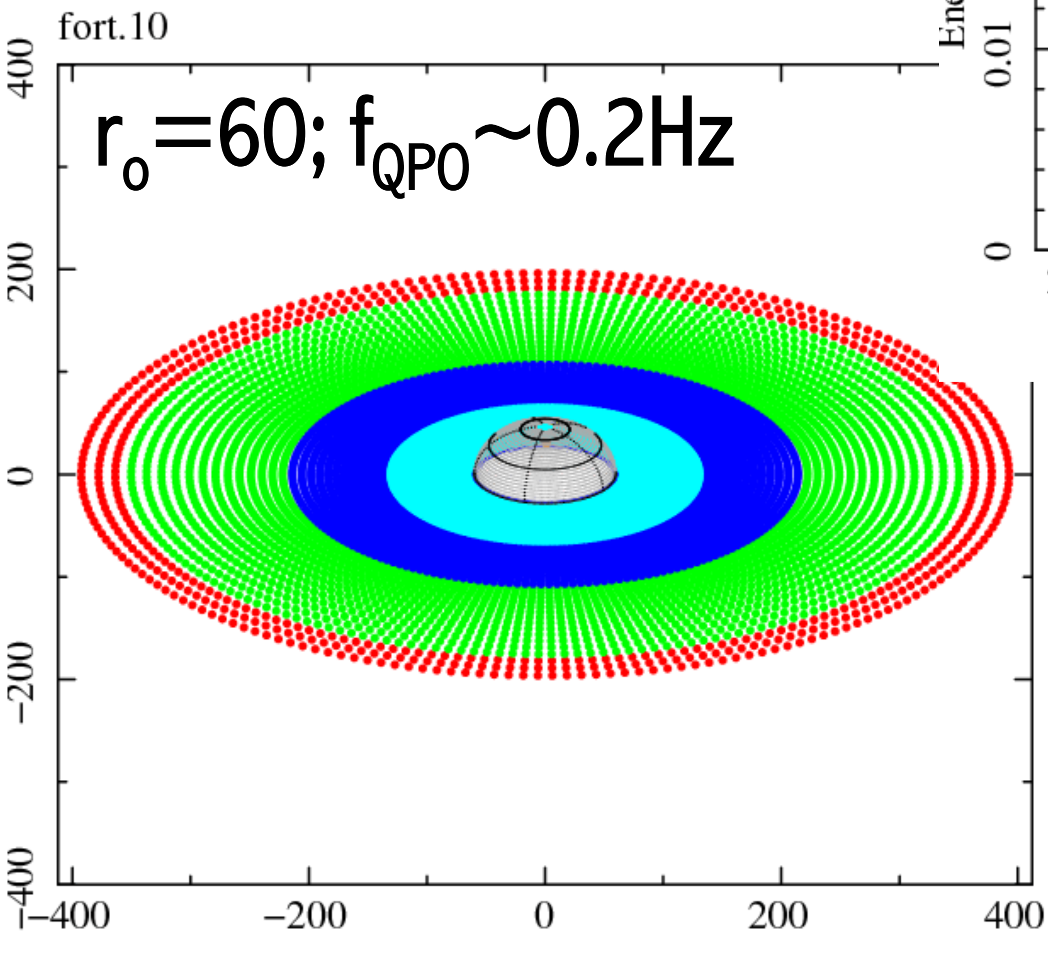
Ingram & Done (2012b)

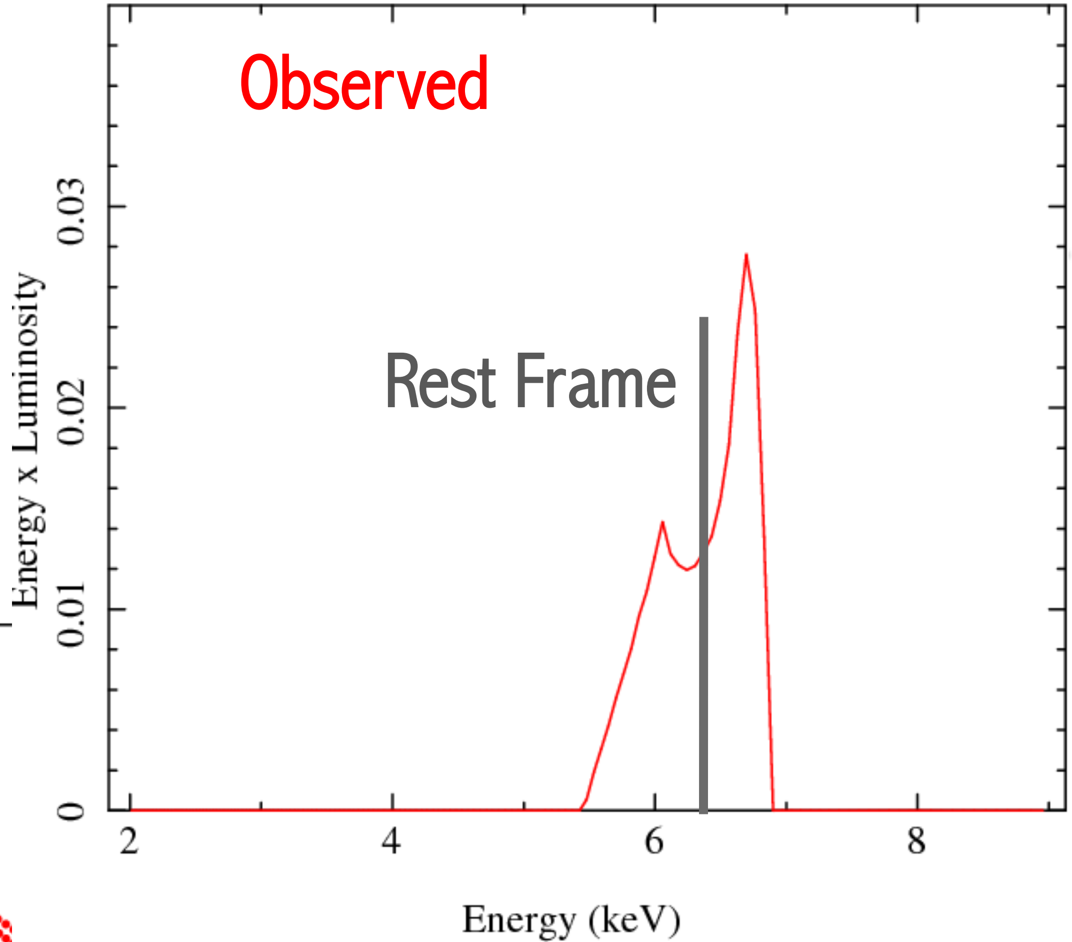
Testing precession





Ingram & Done (2012b)





Ingram & Done (2012b)

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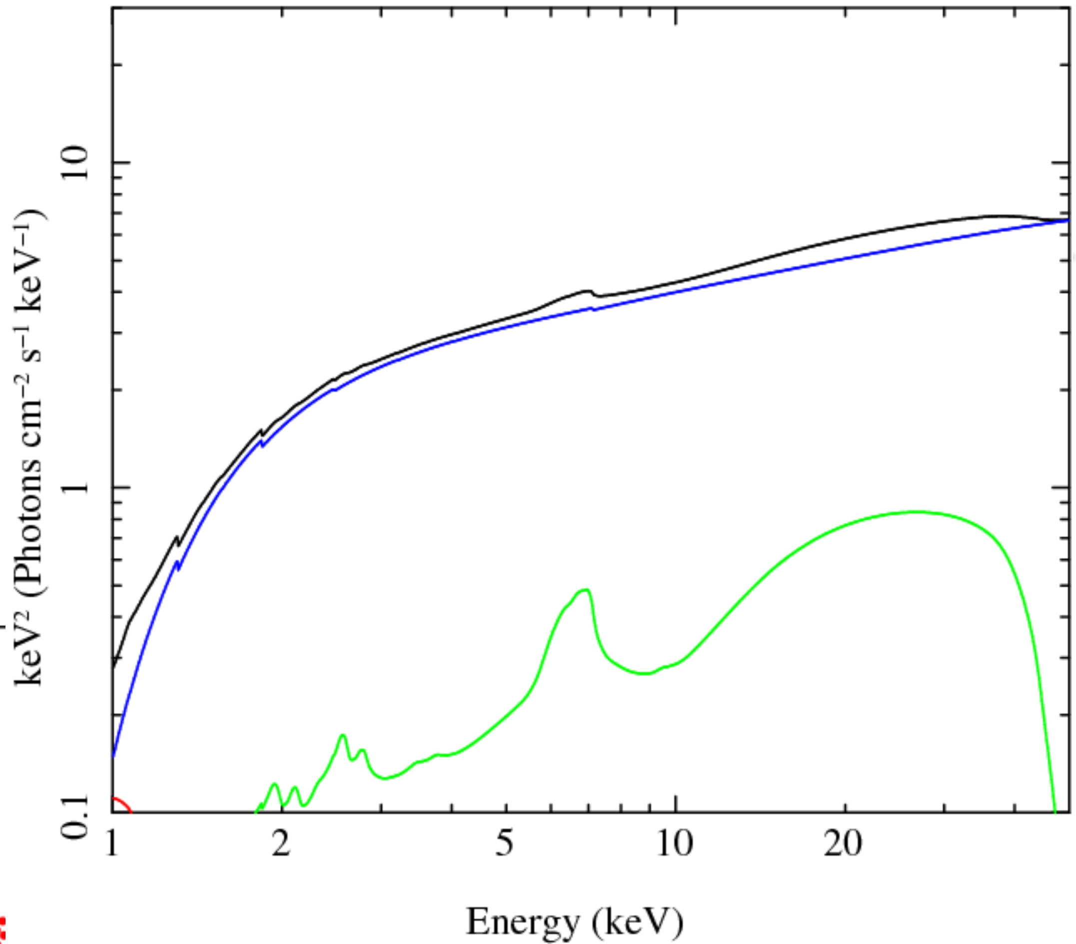
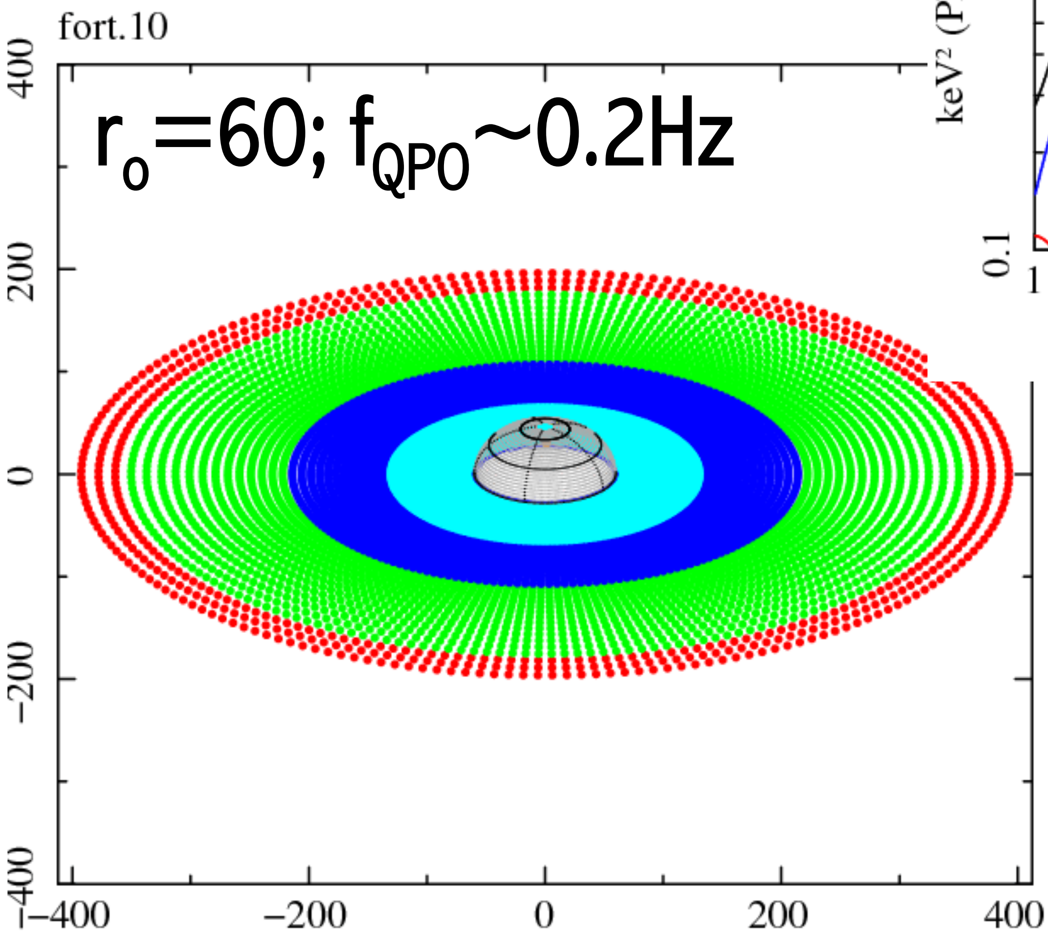


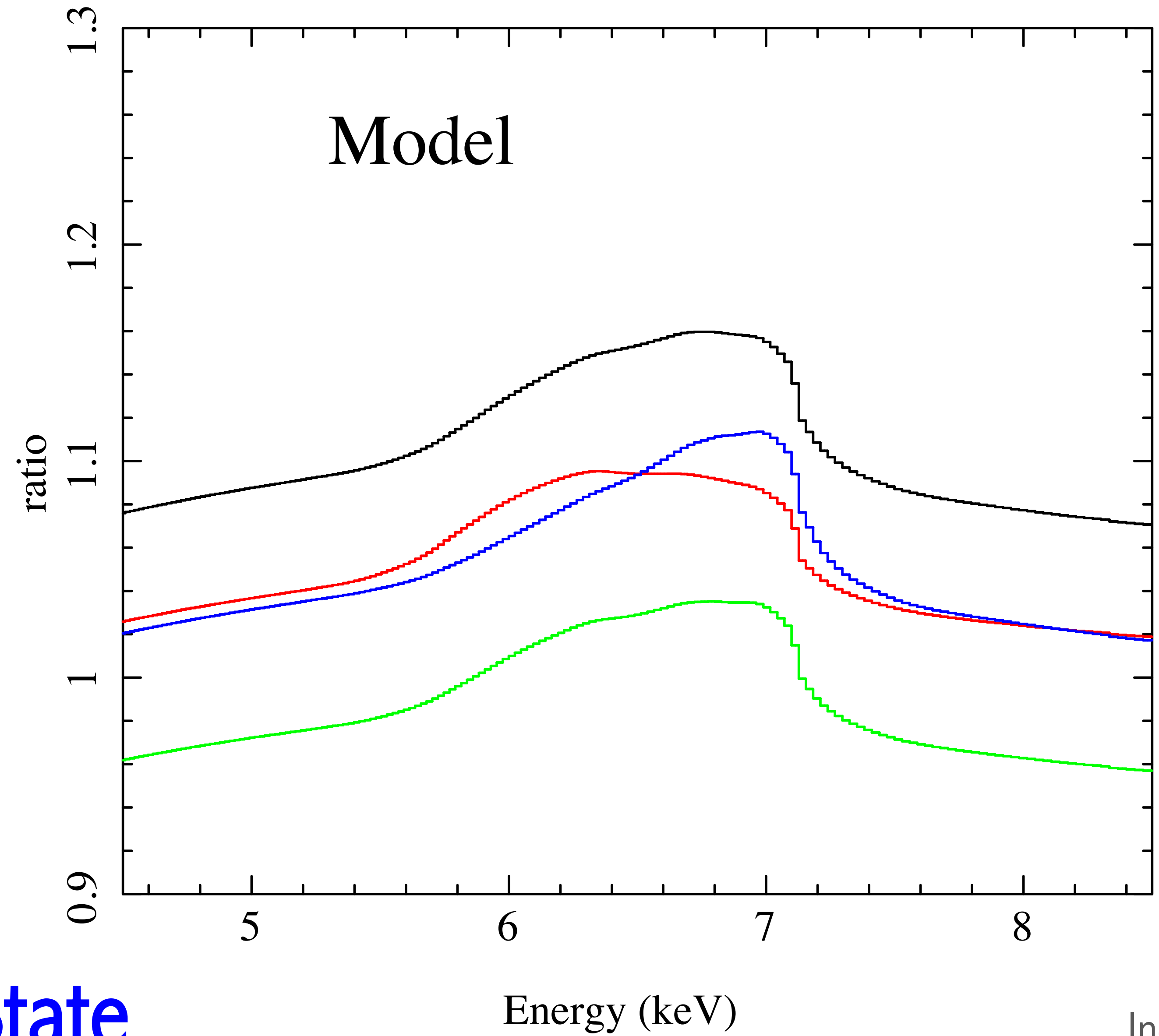


Full spectral model

-Continuum oscillates (NTHCOMP)

-Reflection spectrum shifts in energy (RFXCONV; Ross & Fabian 2005; Kolehmainen & Done 2011)

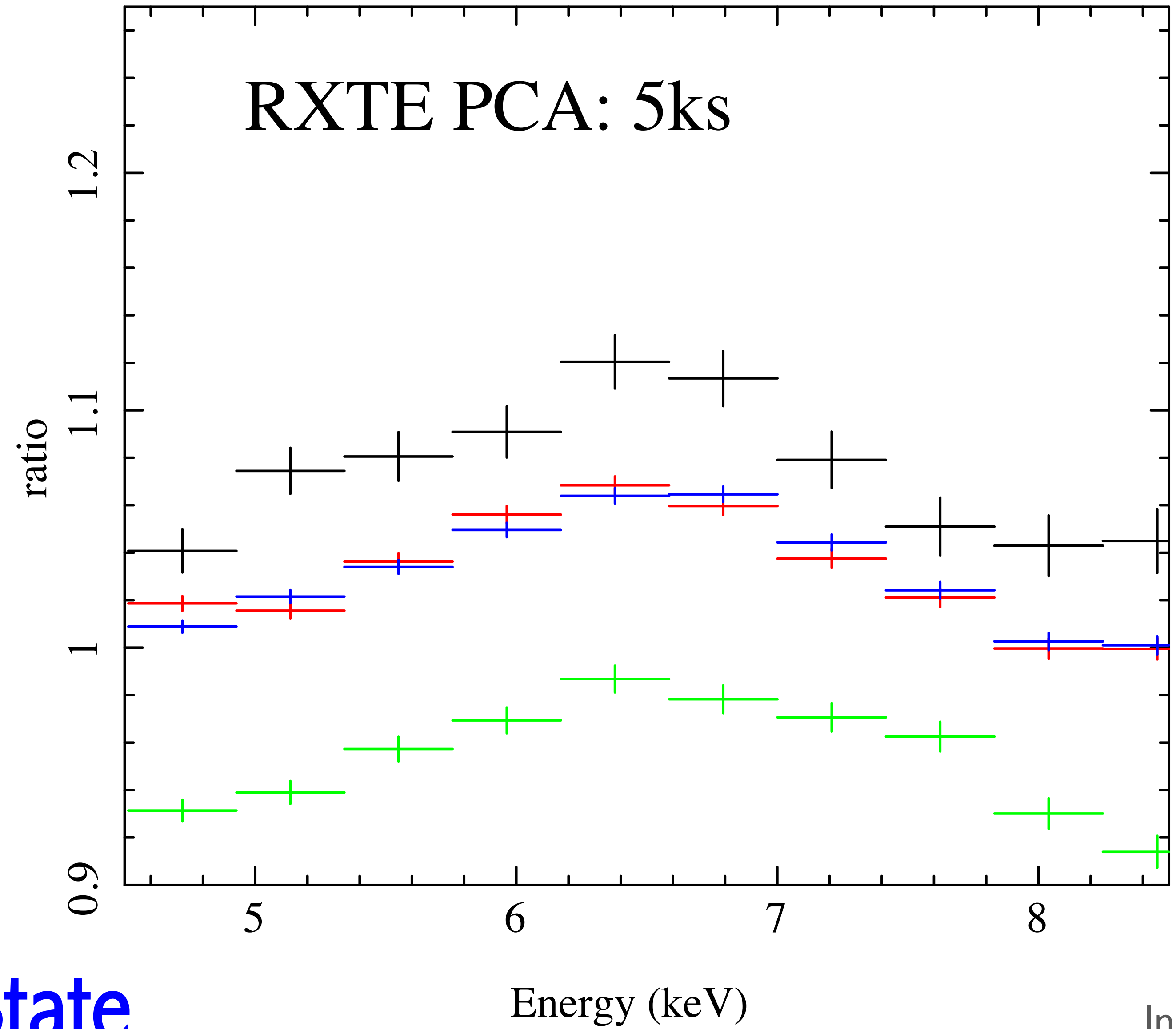
Testing precession



Hard State

Ingram & Done 2012b

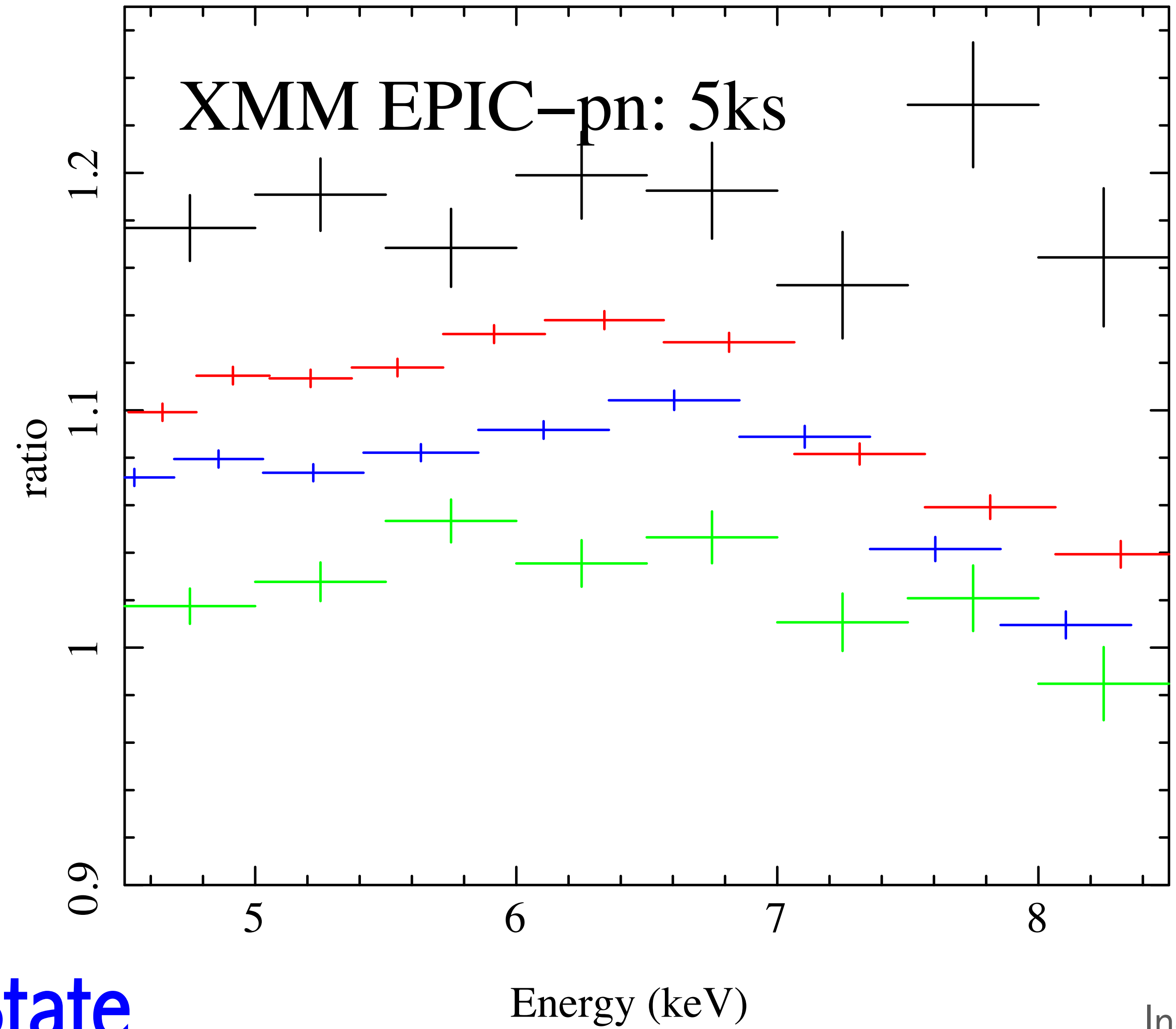
Testing precession



Hard State

Ingram & Done 2012b

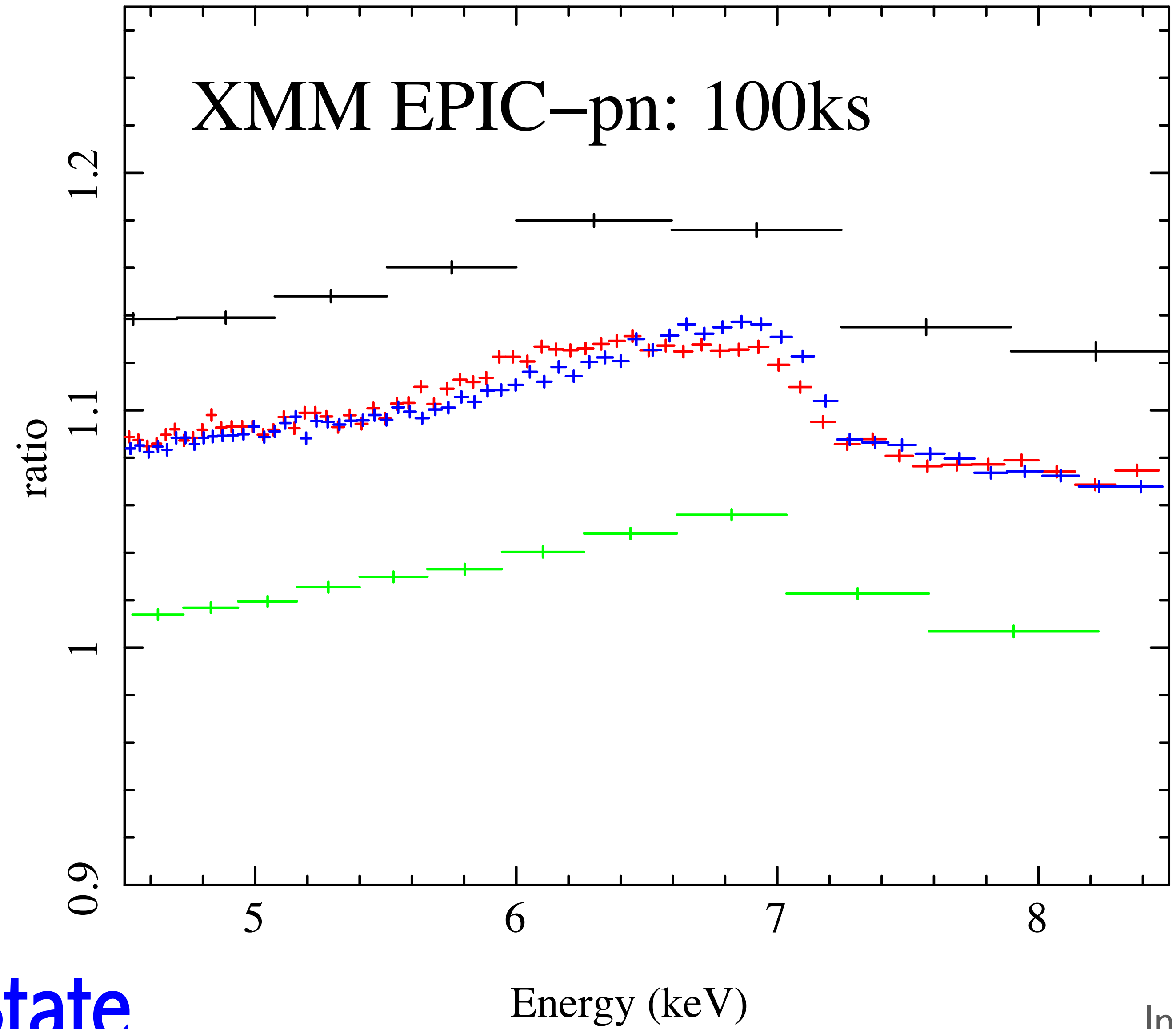
Testing precession



Hard State

Ingram & Done 2012b

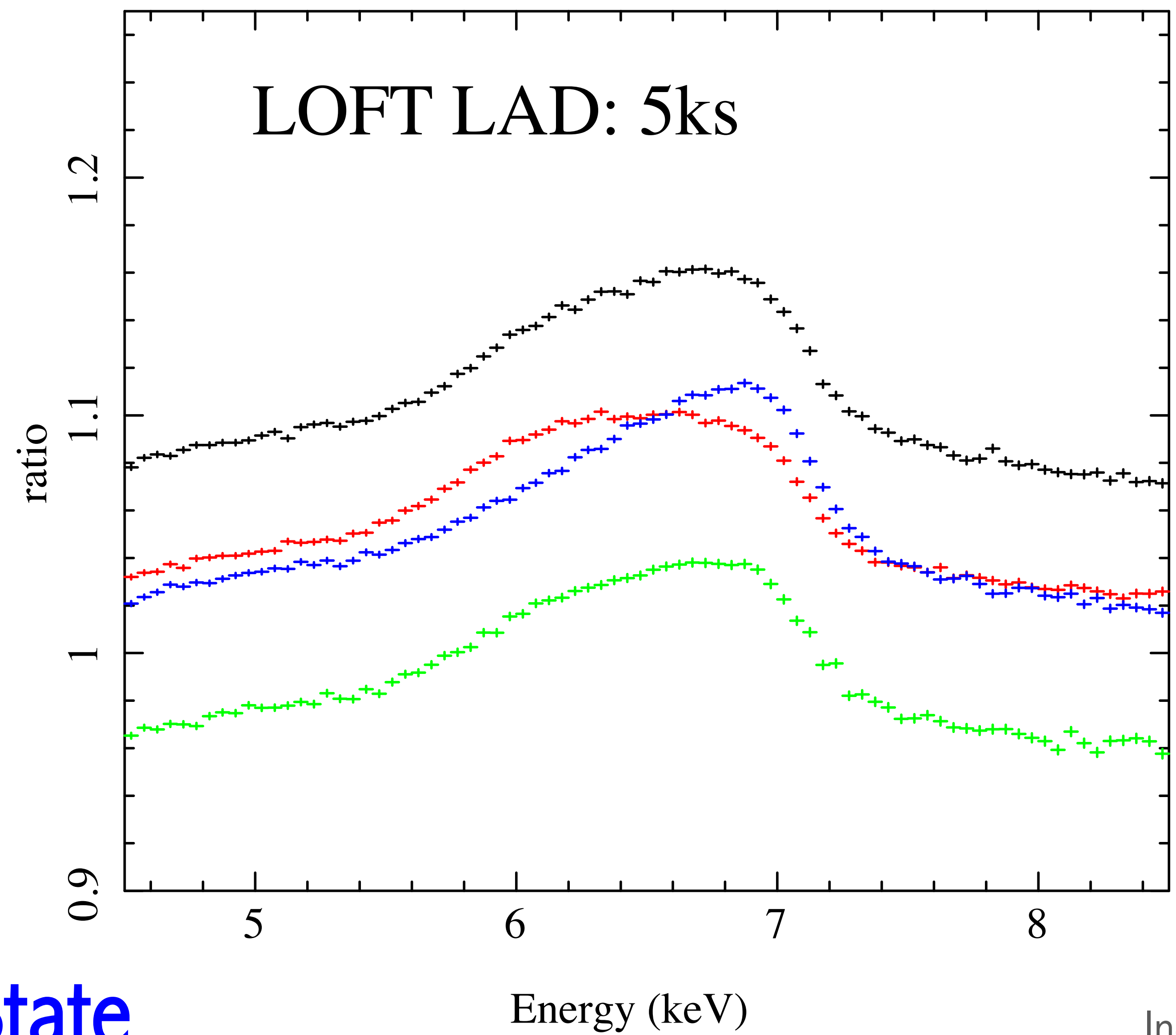
Testing precession



Hard State

Ingram & Done 2012b

Testing precession

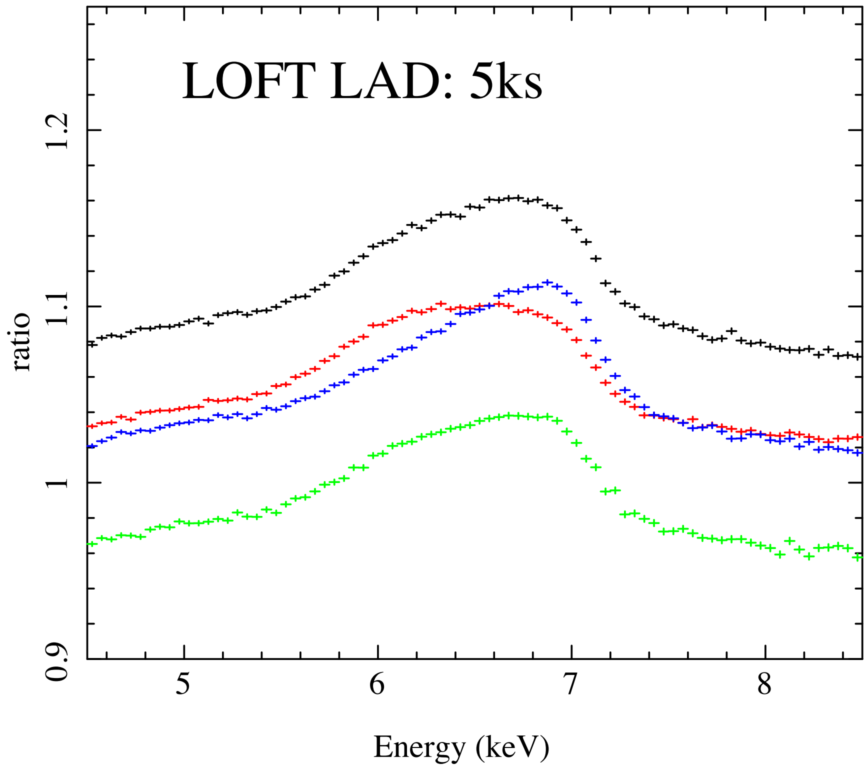


Hard State

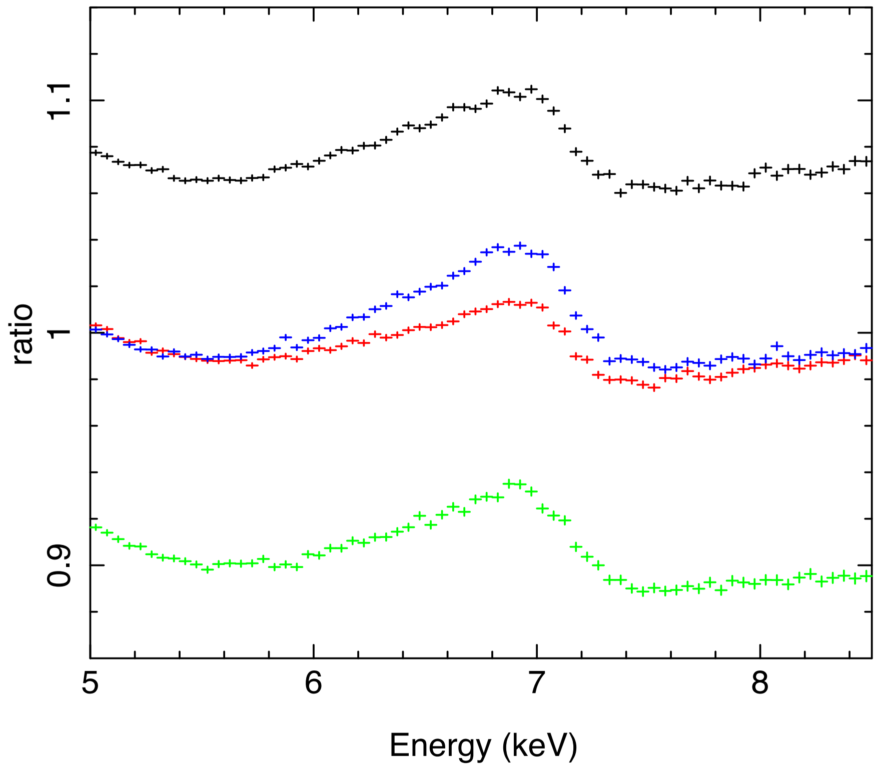
Ingram & Done 2012b

LOFT

Hard State



Intermediate State

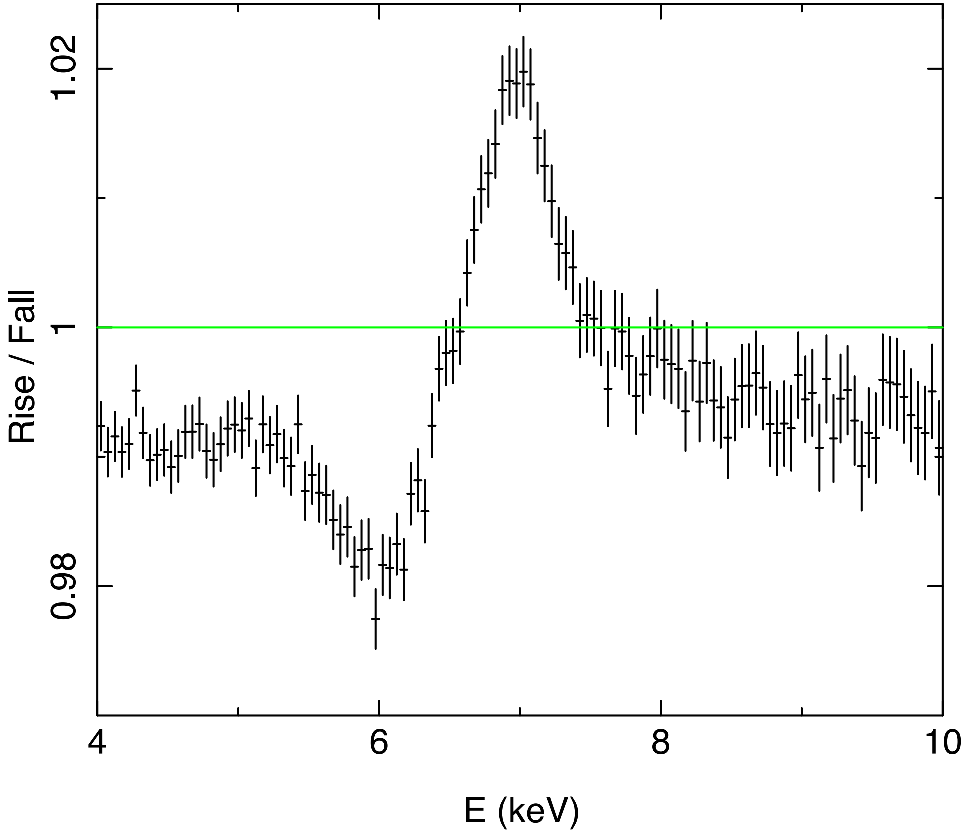


Ingram & Done 2012b

LOFT

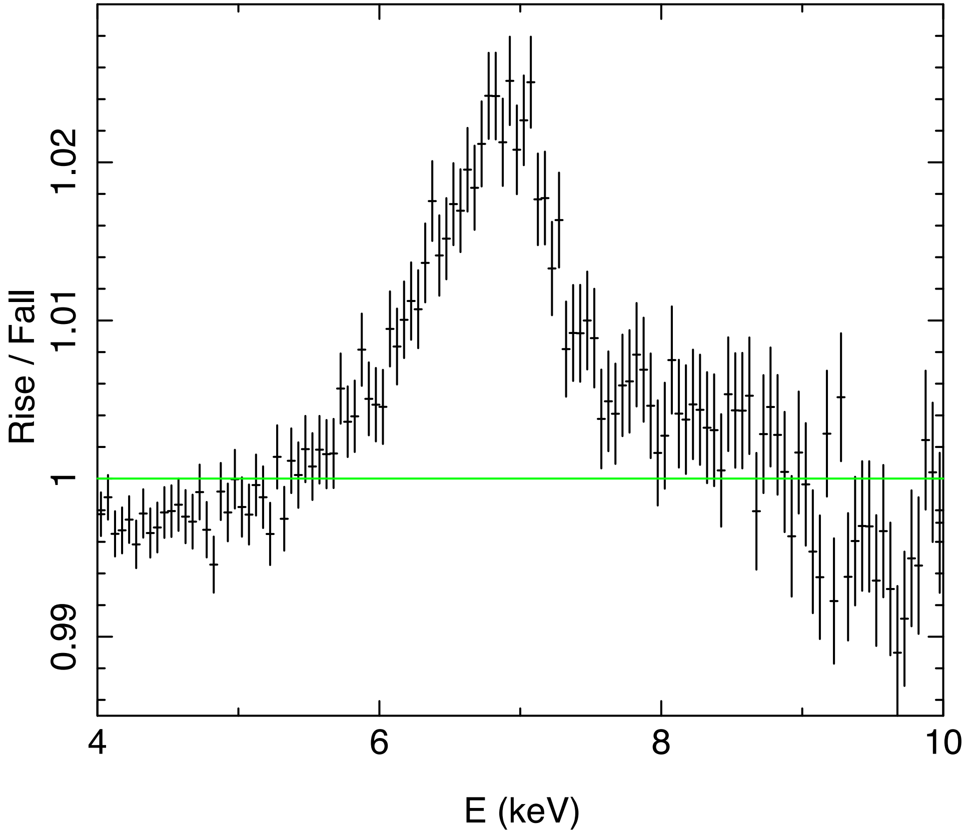
Hard State

$r_o = 60; i = 60$

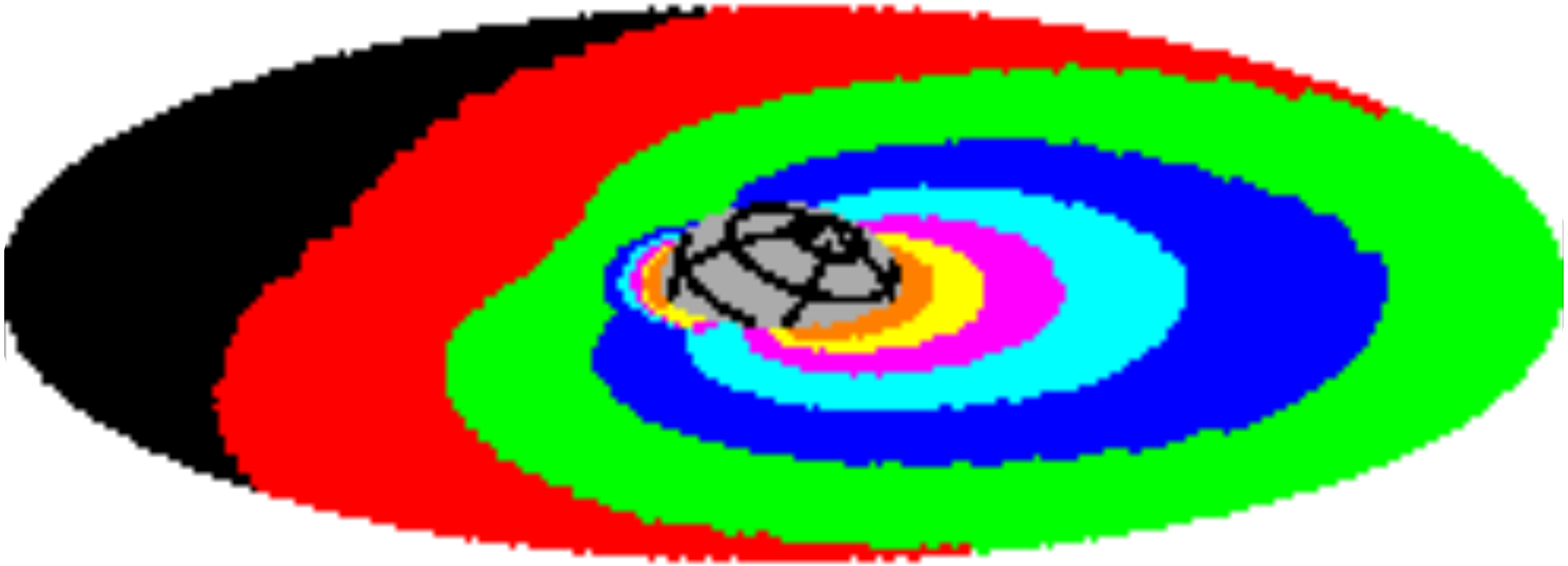


Intermediate State

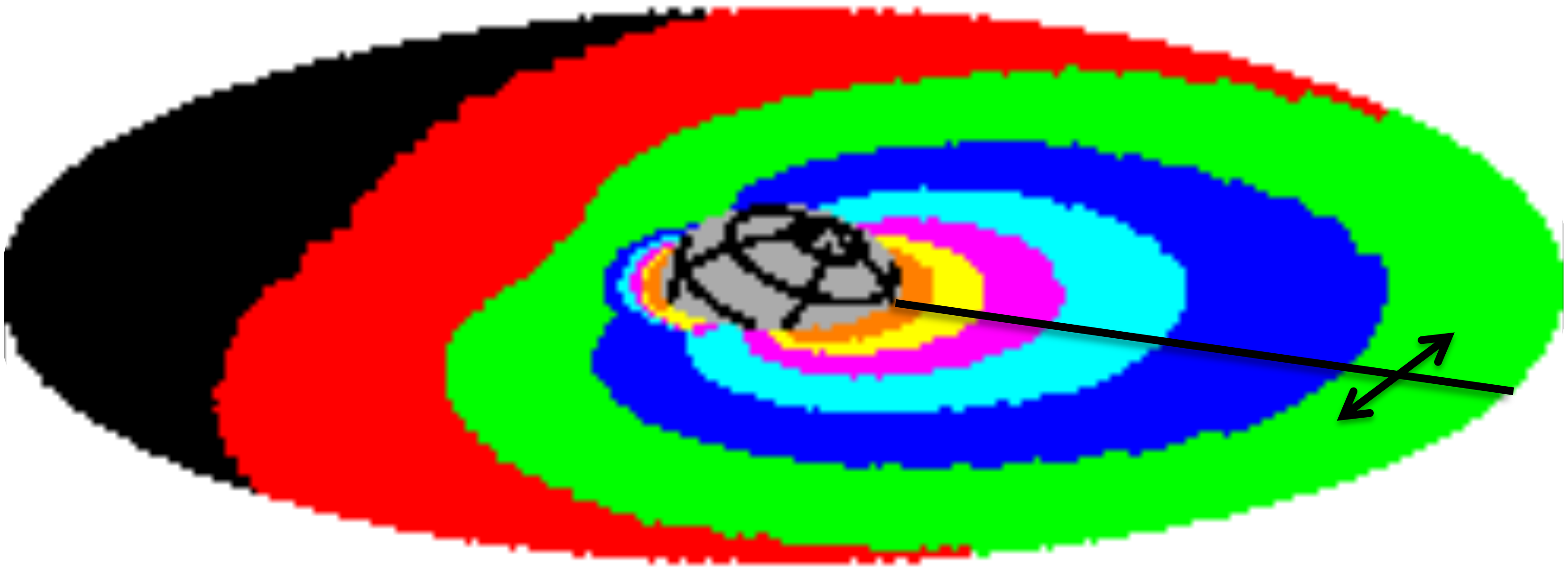
$r_o = 7; i = 60$



LOFT



LOFT



LOFT

$$I(r,\phi) \sim r^{-q}\left[A\exp\left(\frac{\phi^2}{2\Delta^2}\right)+B\right]$$

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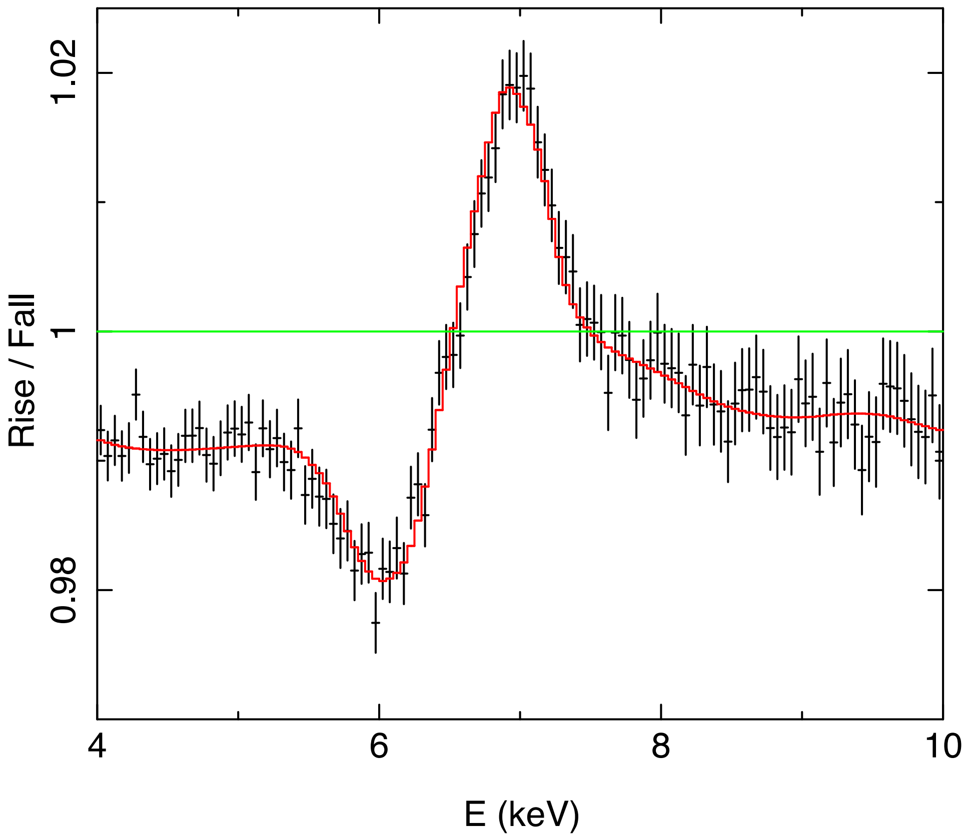
LOFT

Hard State

r_o = 60; i = 60

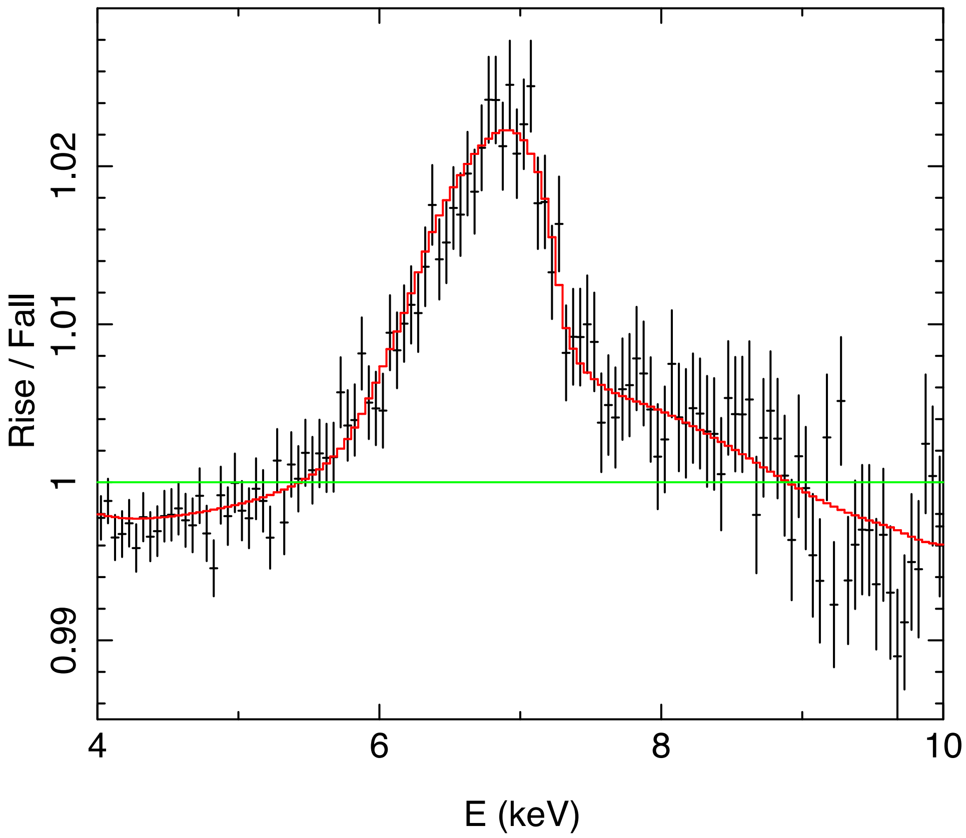
r_o = 52.9±3.3; i = 59.8±3.0



Intermediate State

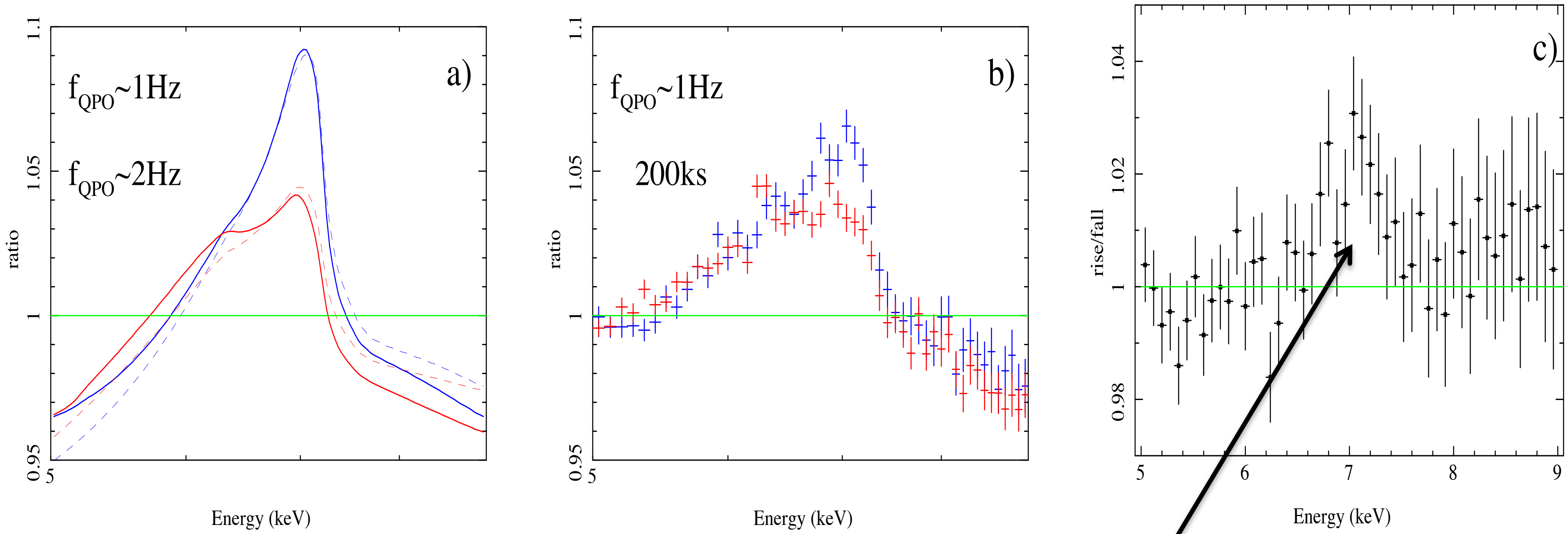
r_o = 7; i = 60

r_o = 6.4±0.2; i = 54.5±0.3



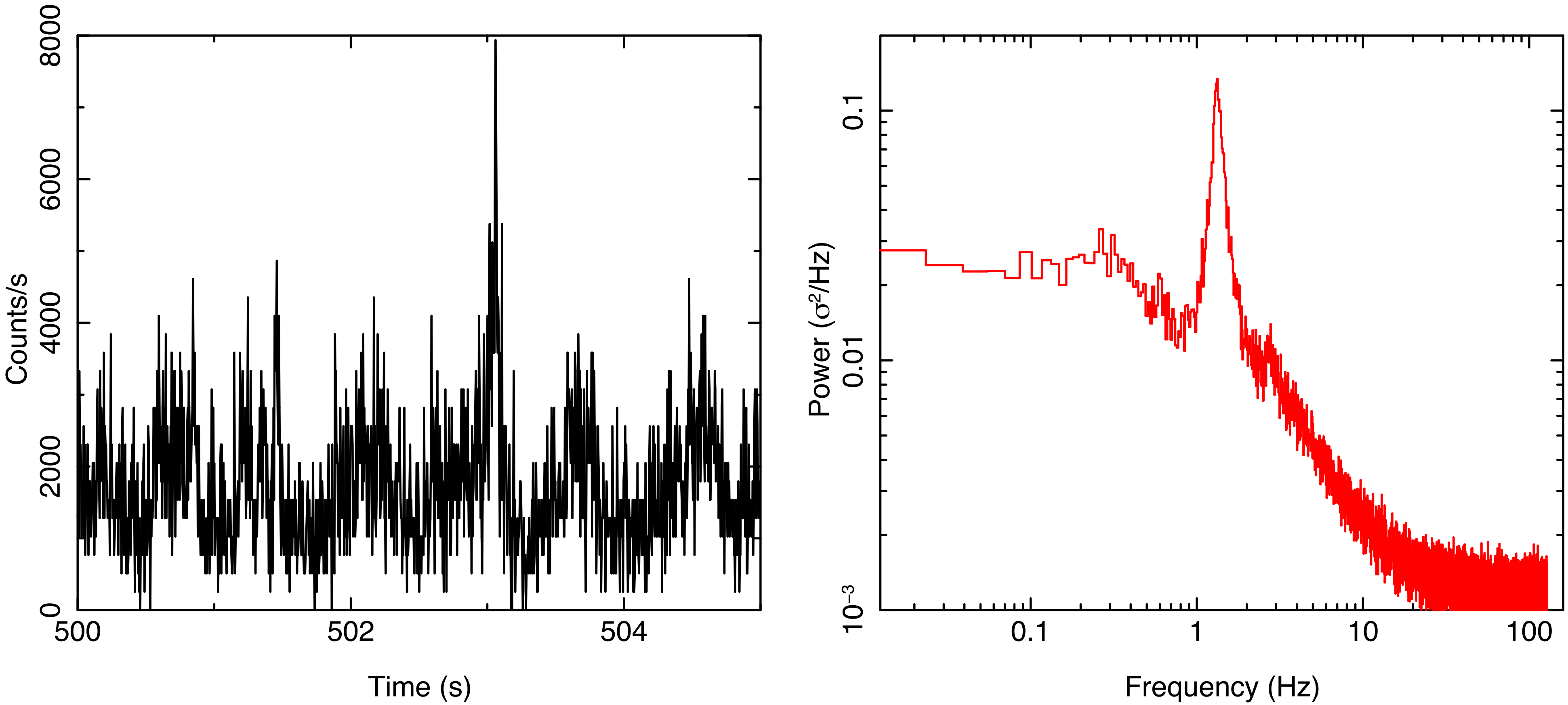
XMM

r_o=30; f_{QPO}~1Hz - `sweet spot'



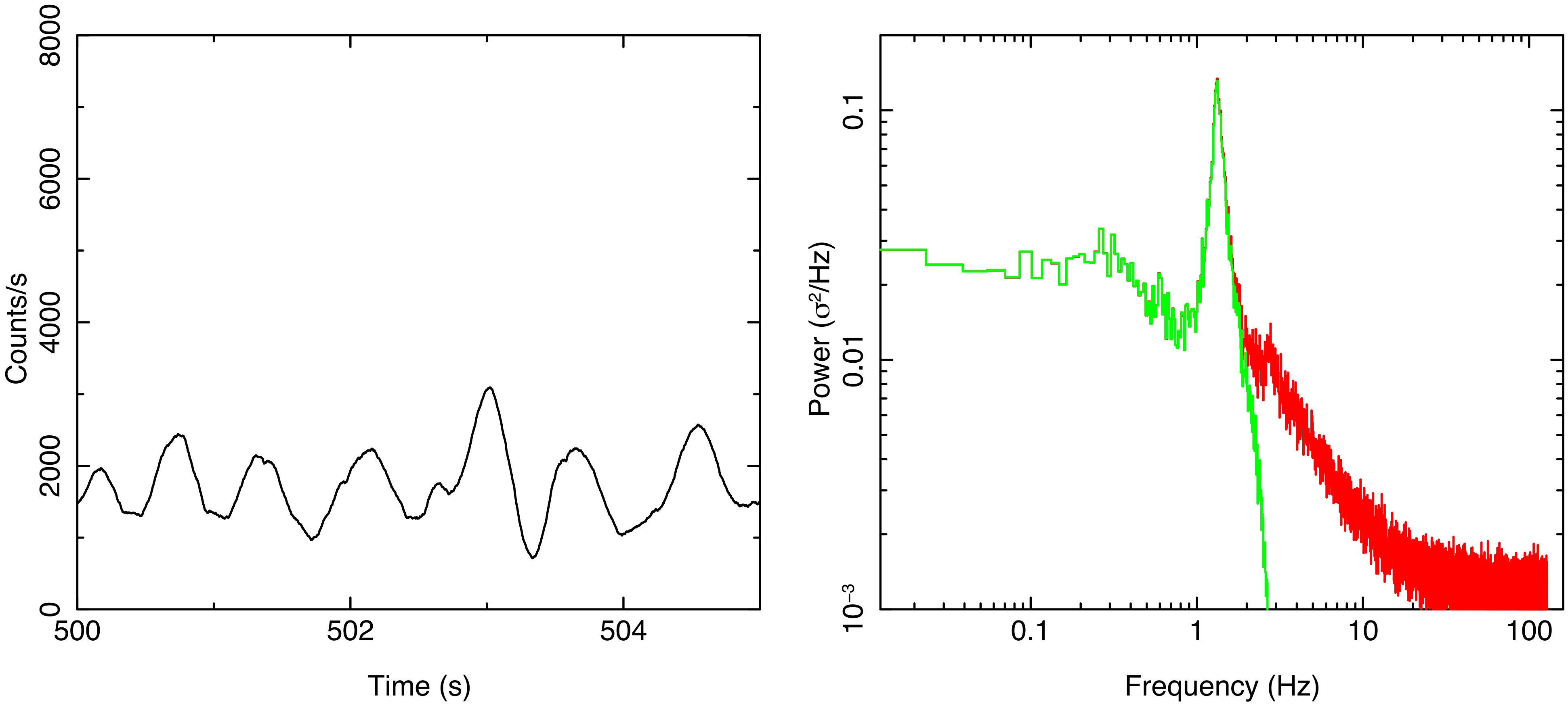
4.7σ feature

RXTE / Phase binning



RXTE / Phase binning

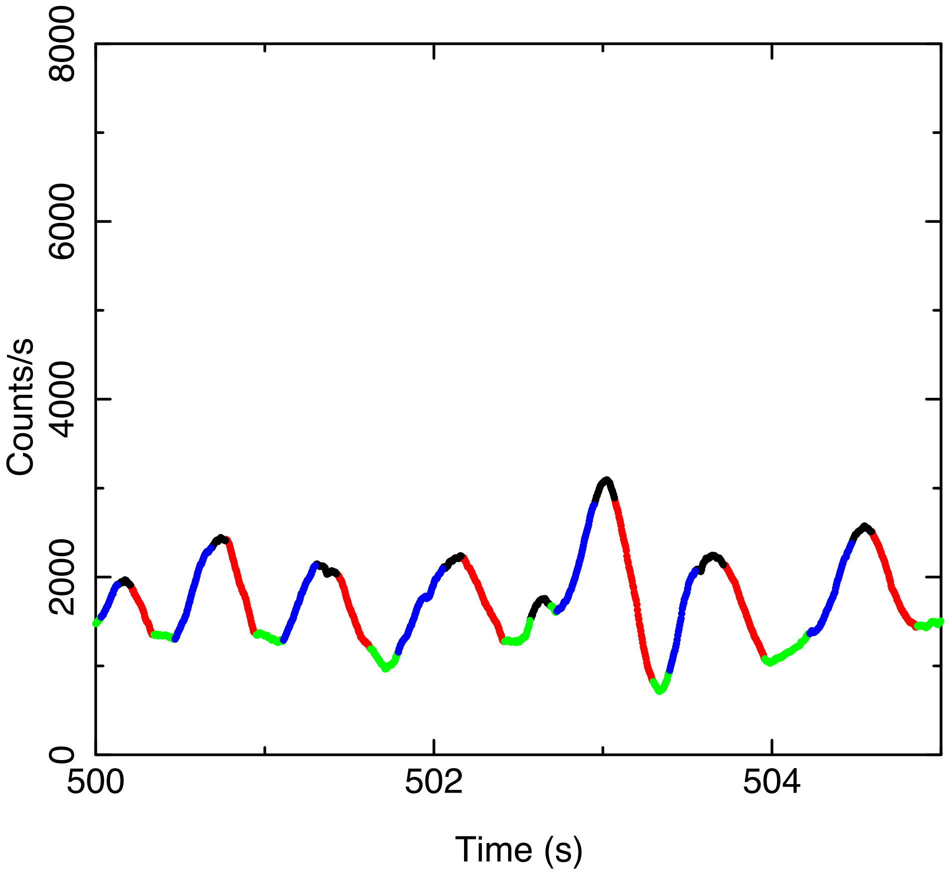
Savitsky-Golay filter



Ingram et al (in prep)

RXTE / Phase binning

4 phase bins: max, fall, min, rise



Ingram et al (in prep)

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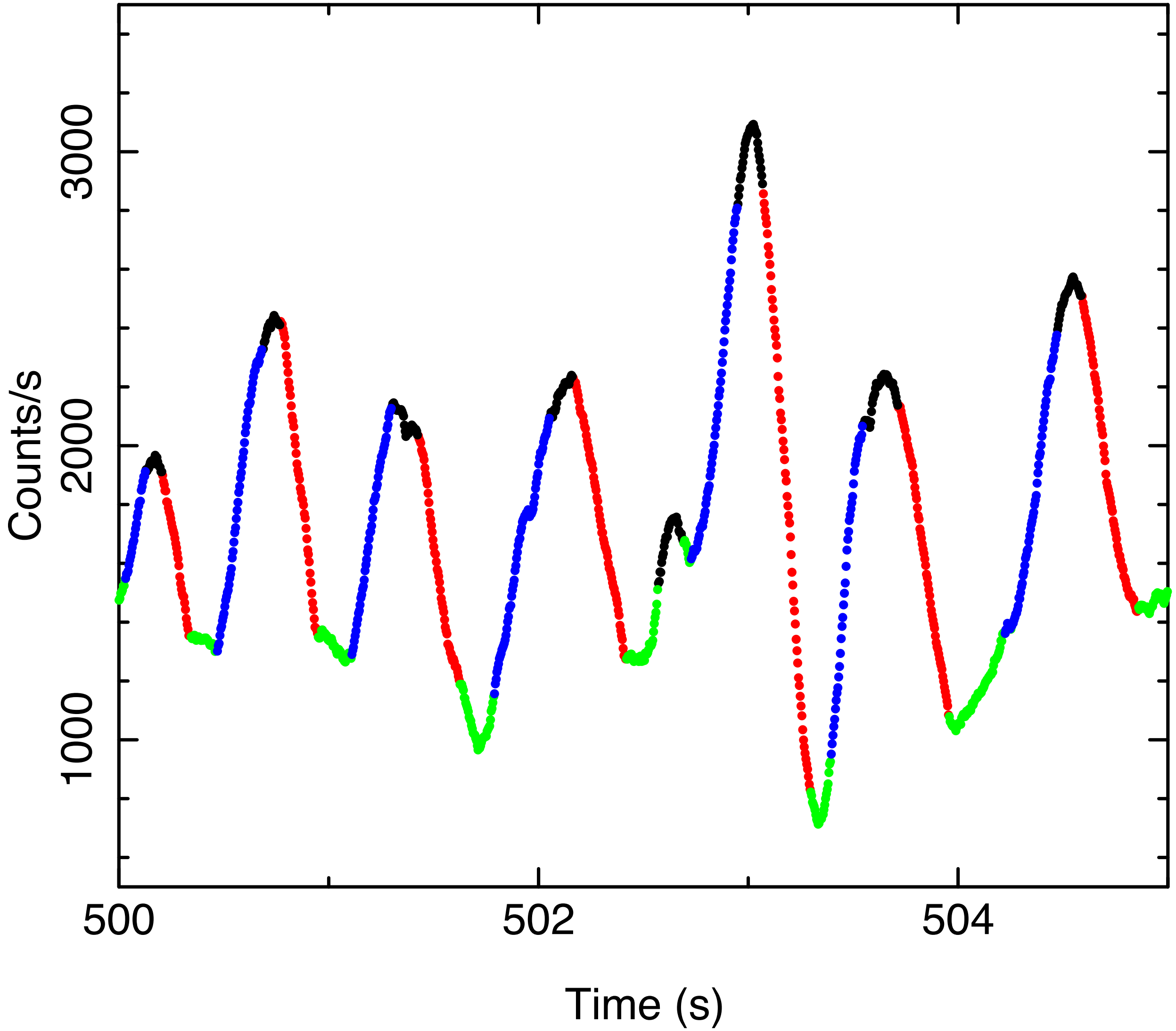
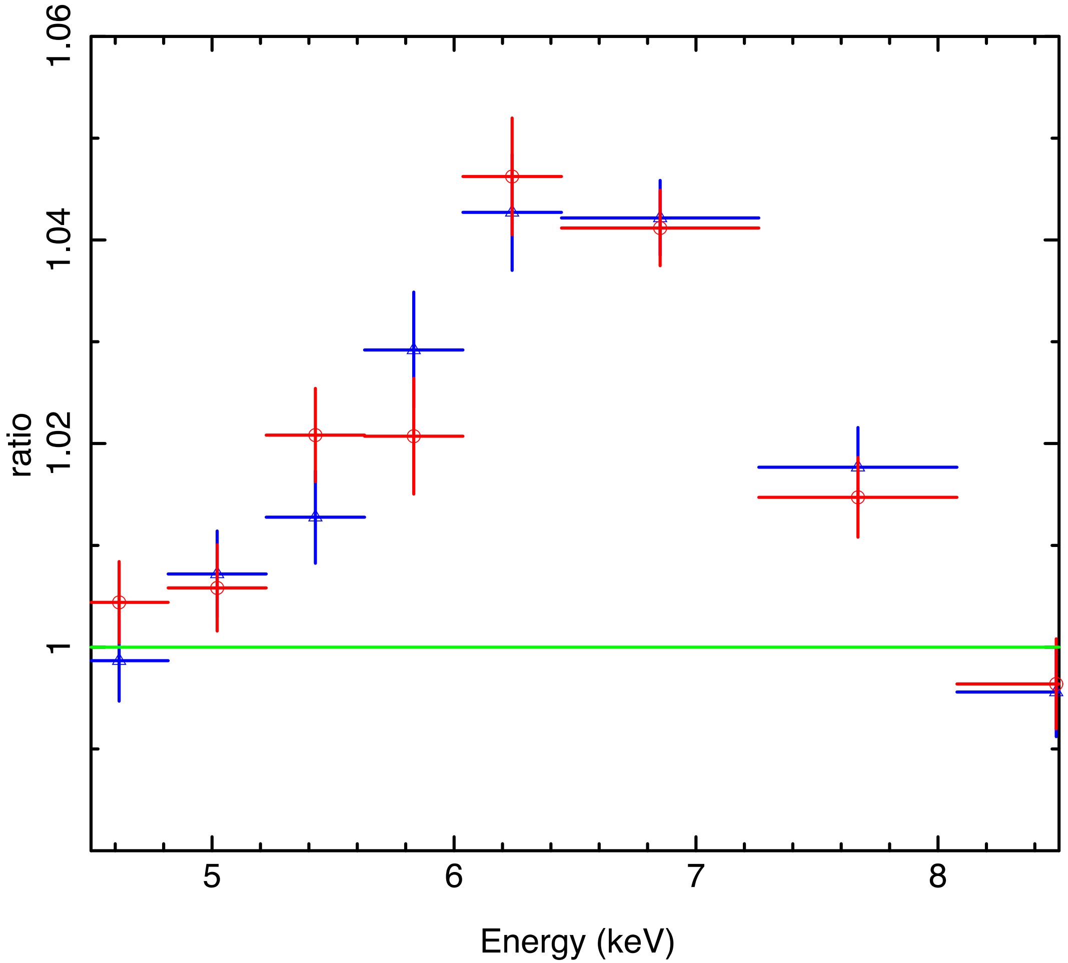
RXTE / Phase binning



Ingram et al (in prep)

RXTE / Phase binning

... so can phase bin but need LOTS of counts:



GRO 1655-40; QPO~2Hz

Ingram et al (in prep)

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RXTE / Phase binning

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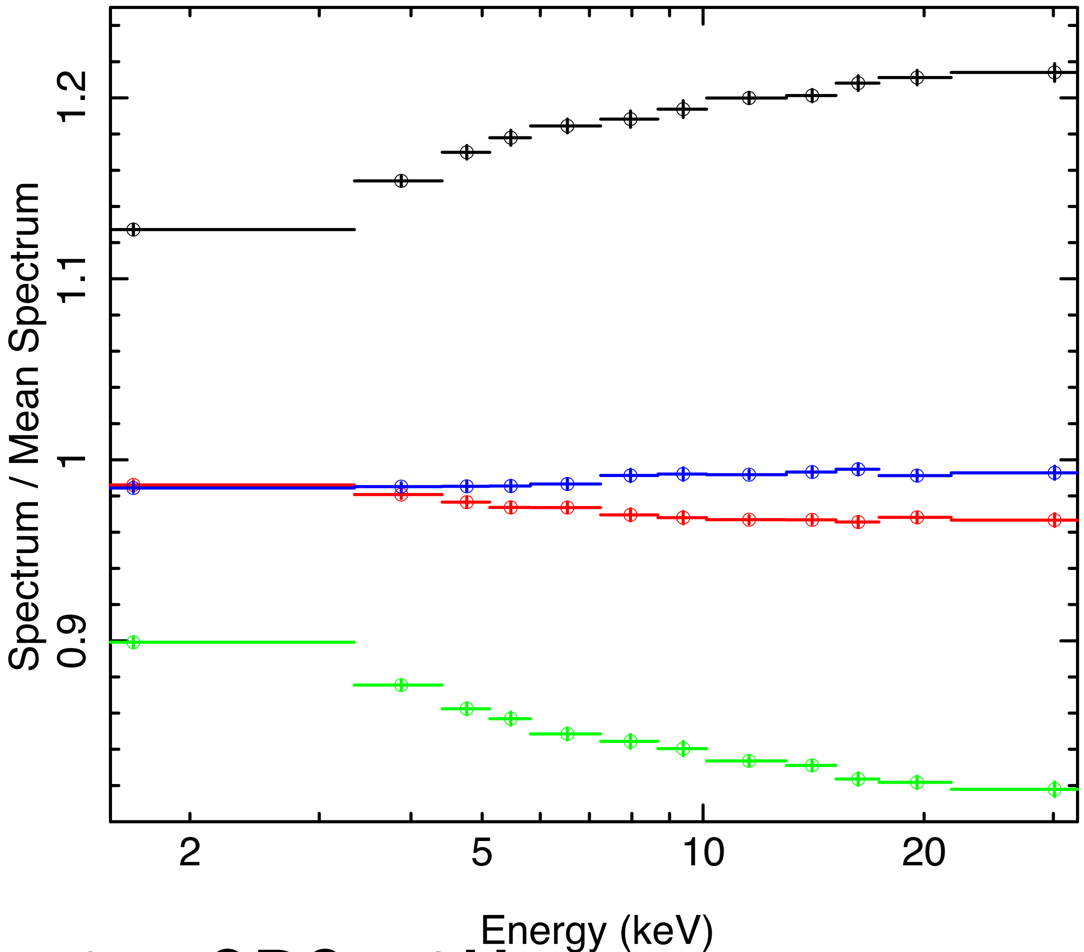

GRS 1915+105; QPO~2Hz

Ingram et al (in prep)

RXTE / Phase binning

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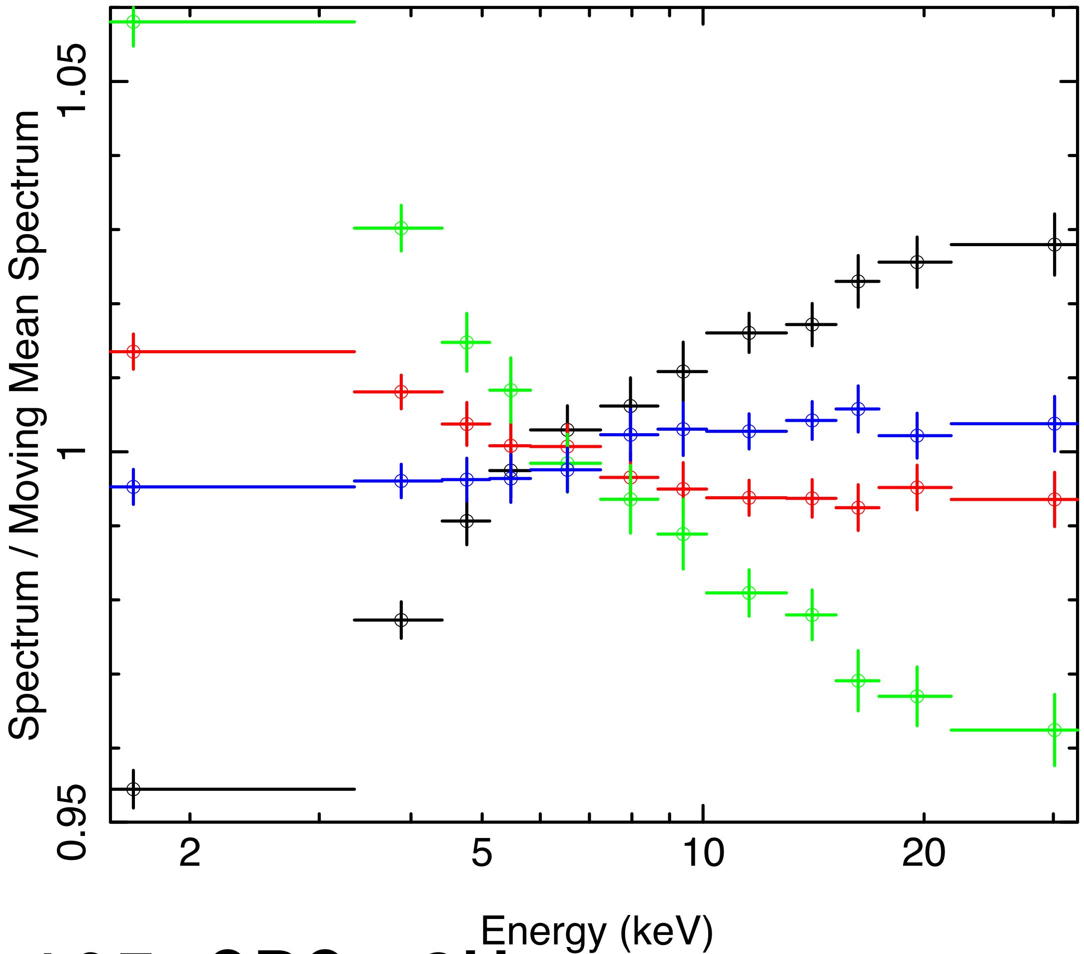

GRS 1915+105; QPO~2Hz

Ingram et al (in prep)

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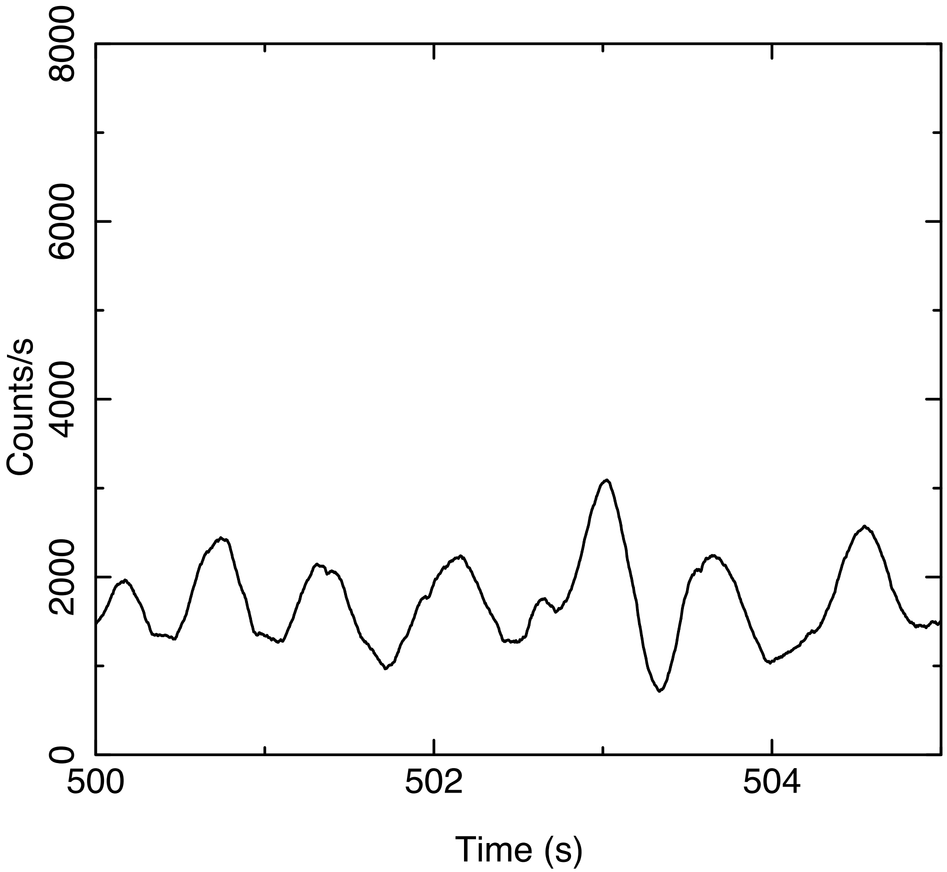
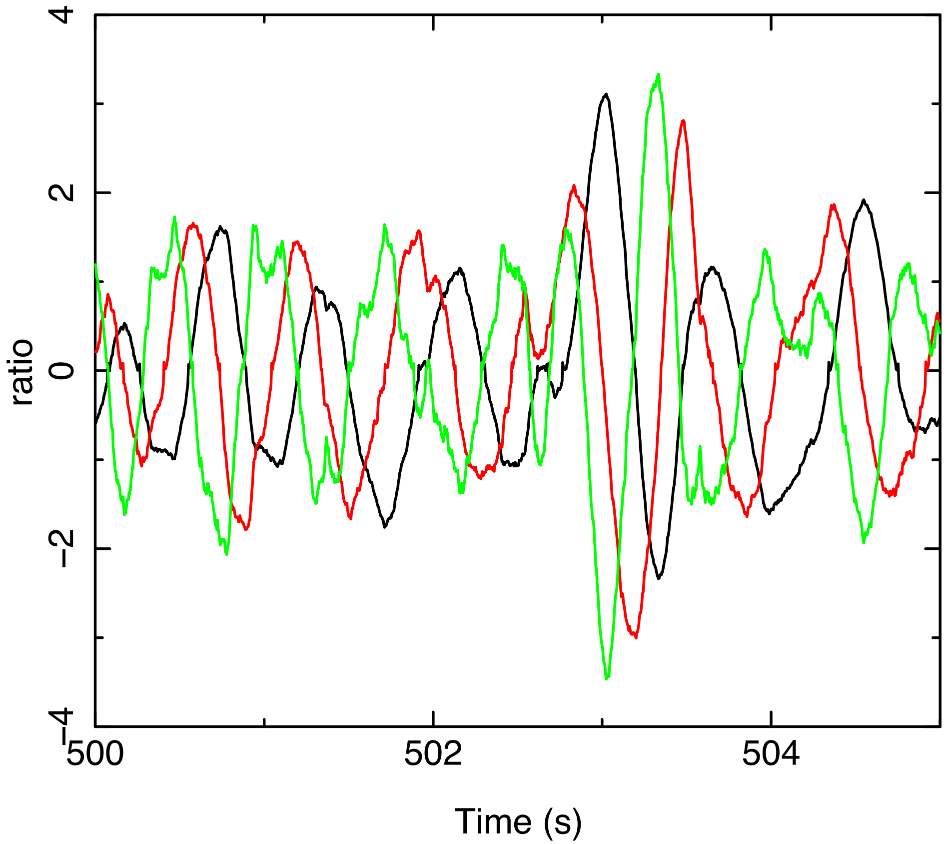
Conclusions

- If QPOs are due to precession, the iron line will rock on the QPO frequency
- LOFT will be able to detect this easily
- This will provide a very good diagnostic for inclination and disc inner edge
- Phase binning the QPO is possible now
- …but need *very* long exposures

RXTE / Phase binning

Savitsky-Golay filter: calculate the nth derivative

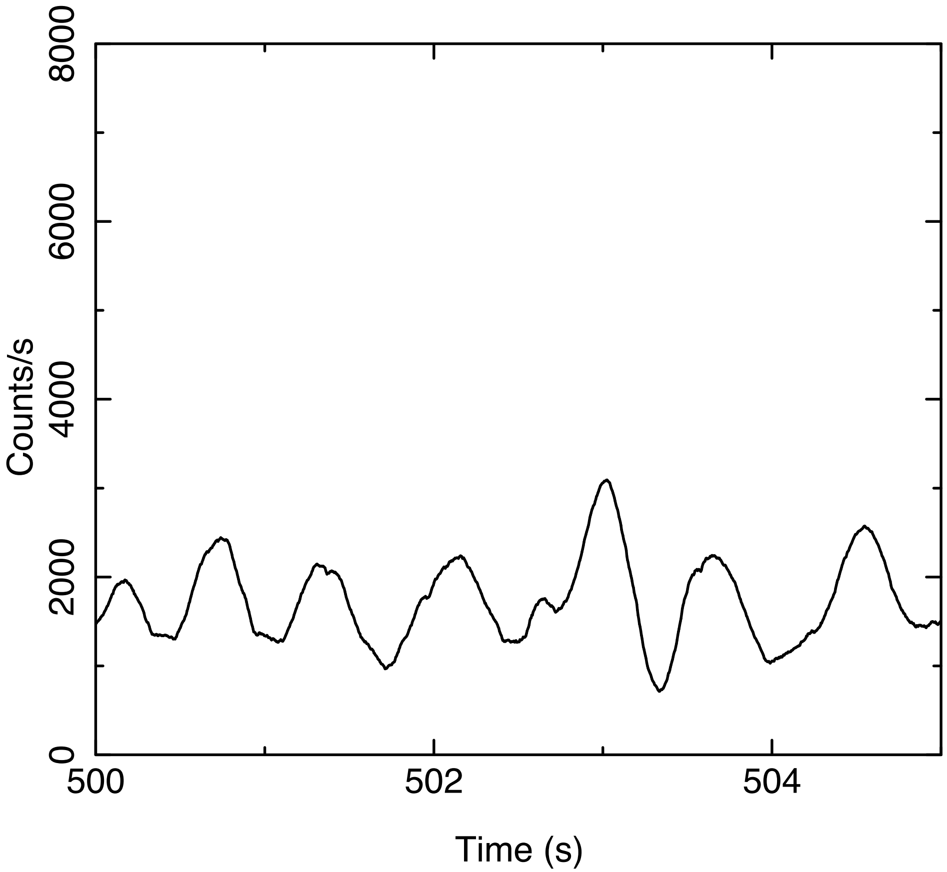


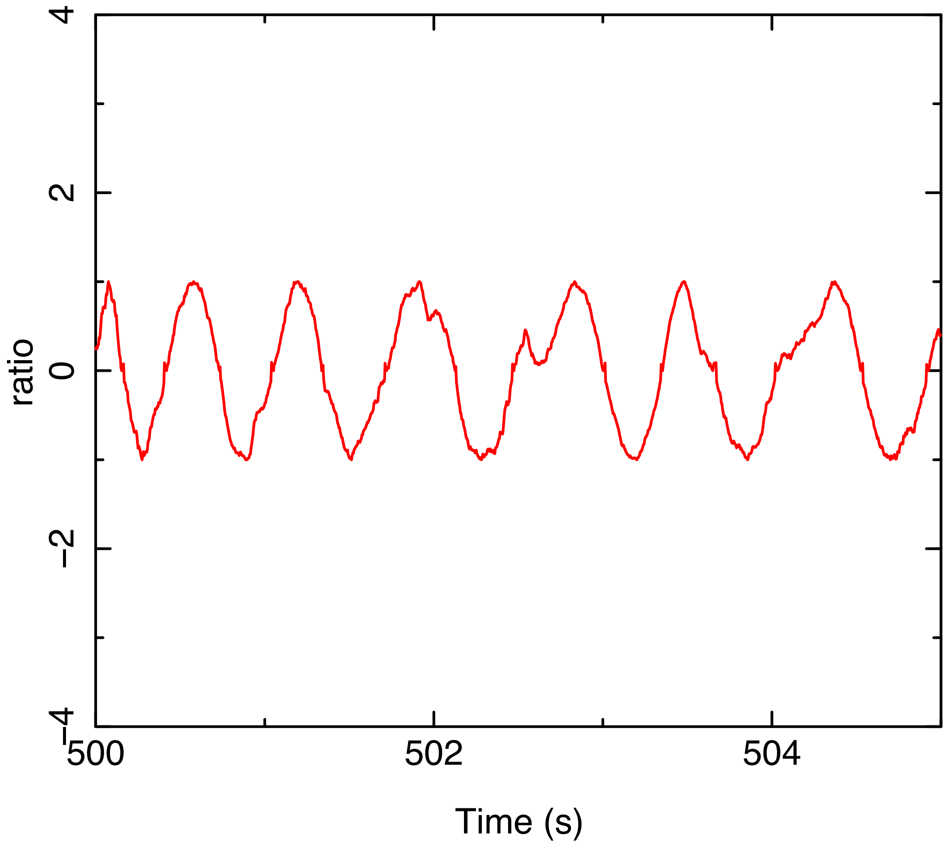


Ingram et al (in prep)

RXTE / Phase binning

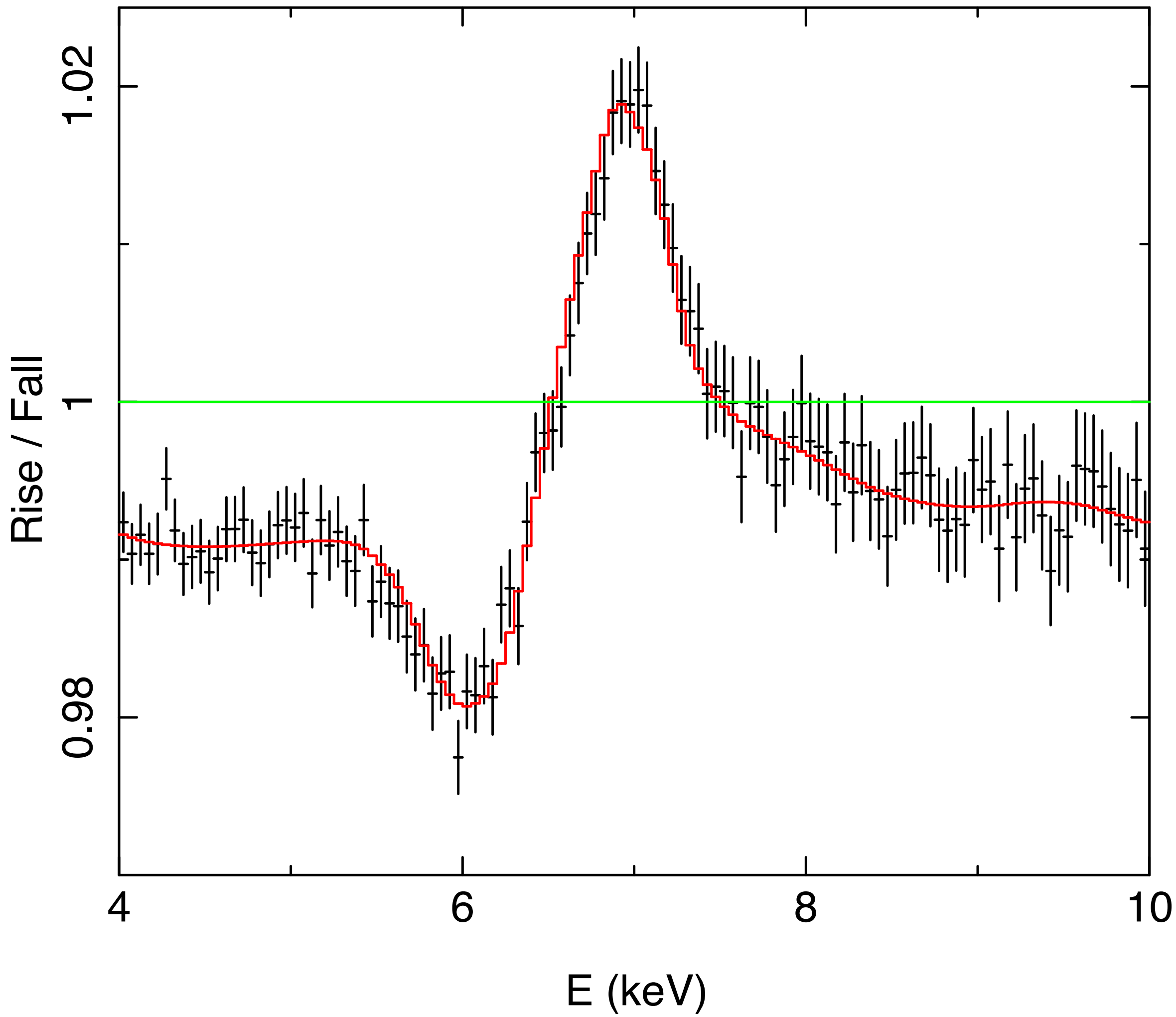
Normalise each half-cycle of the 1st derivative to classify phase



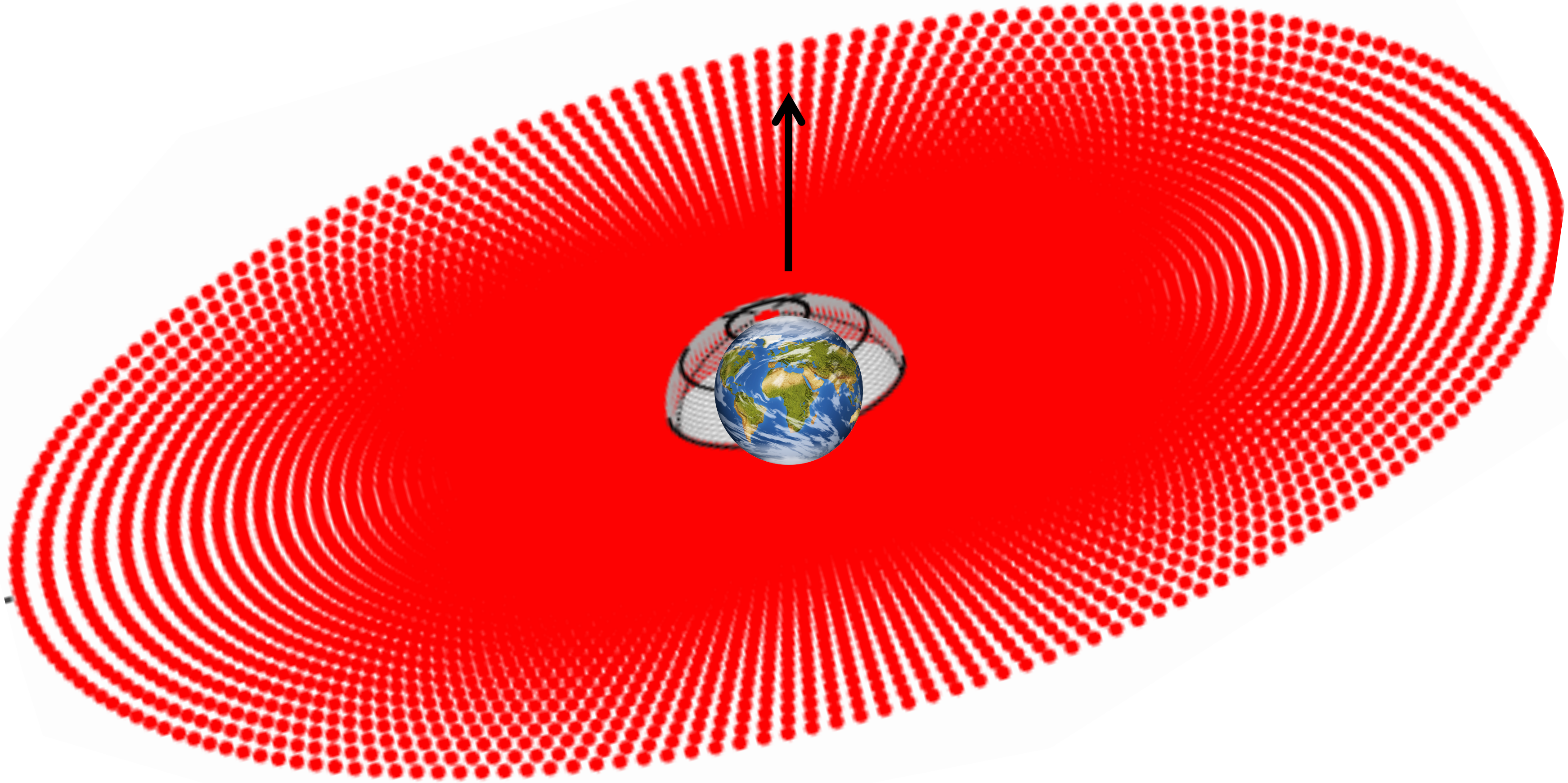


Ingram et al (in prep)

Conclusions

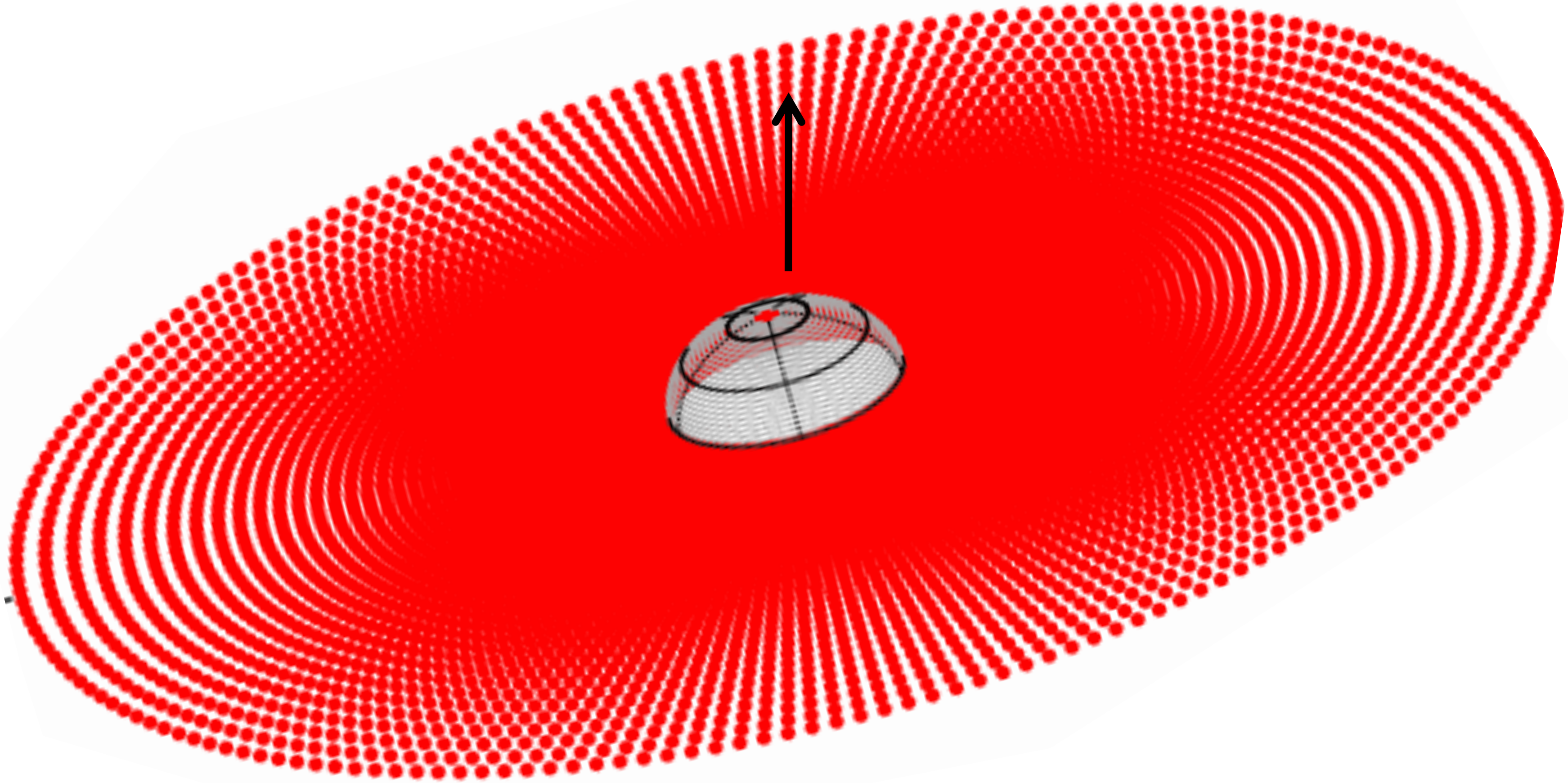


RXTE / Phase binning



GRS 1915+105

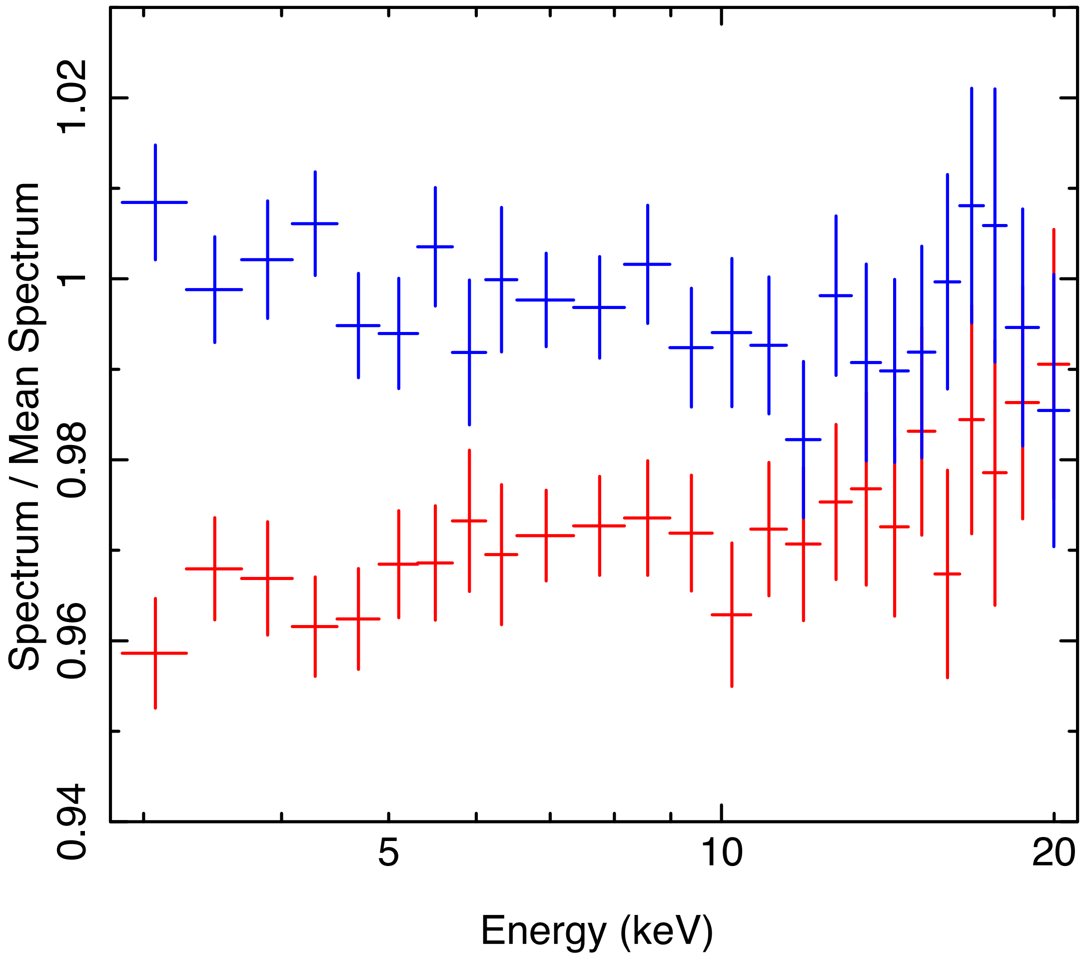
RXTE / Phase binning



GRO 1655-40

RXTE / Phase binning

… so can phase bin but need LOTS of counts:



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RXTE / Phase binning

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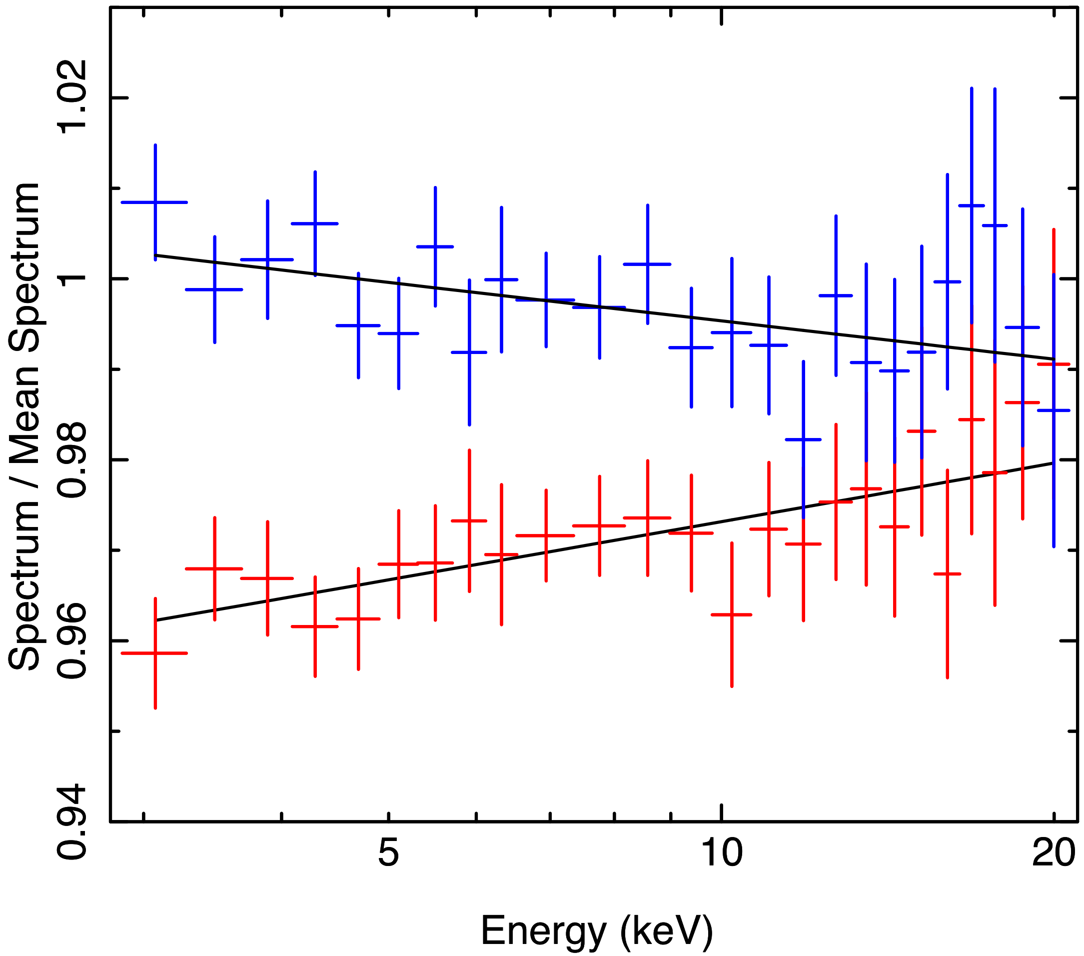
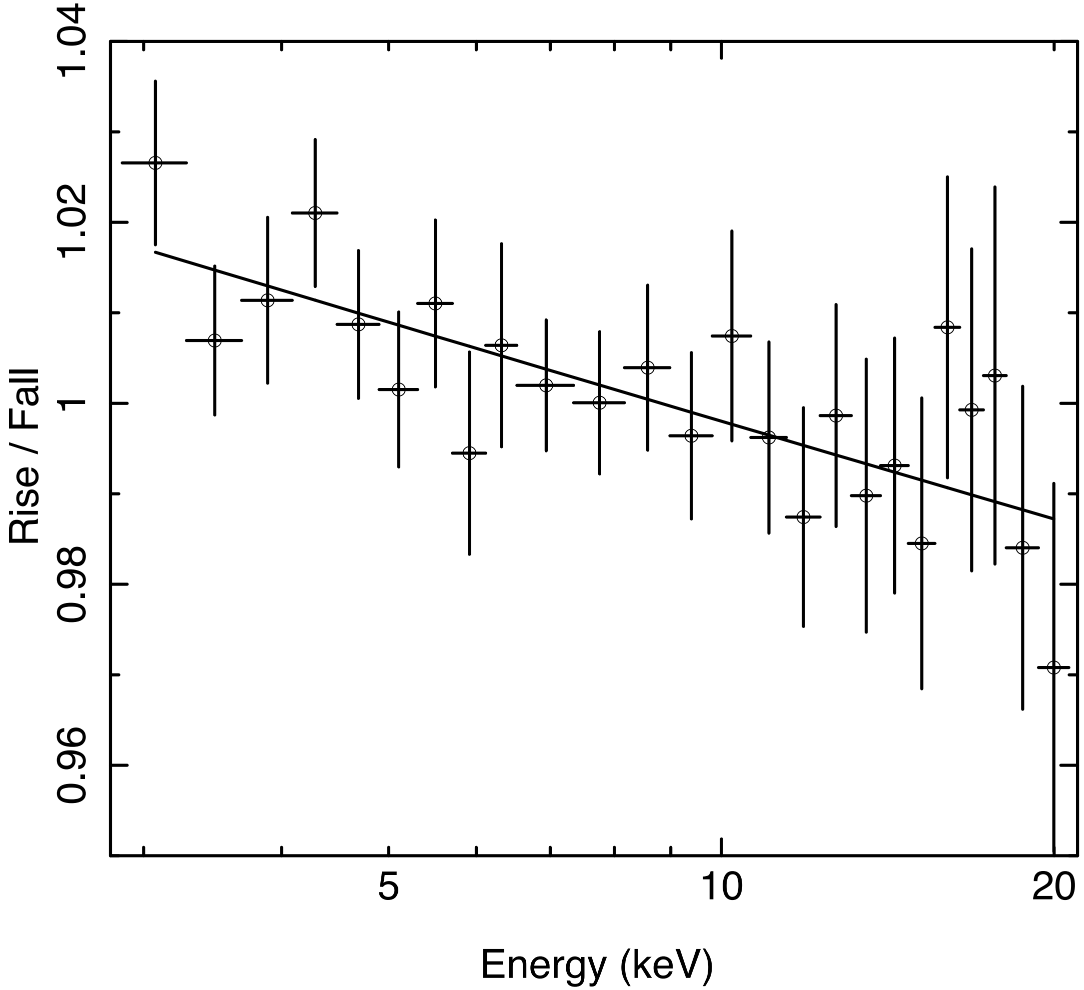


… but both consistent with a constant

RXTE / Phase binning

… so can phase bin but need LOTS of counts:



RXTE / Phase binning

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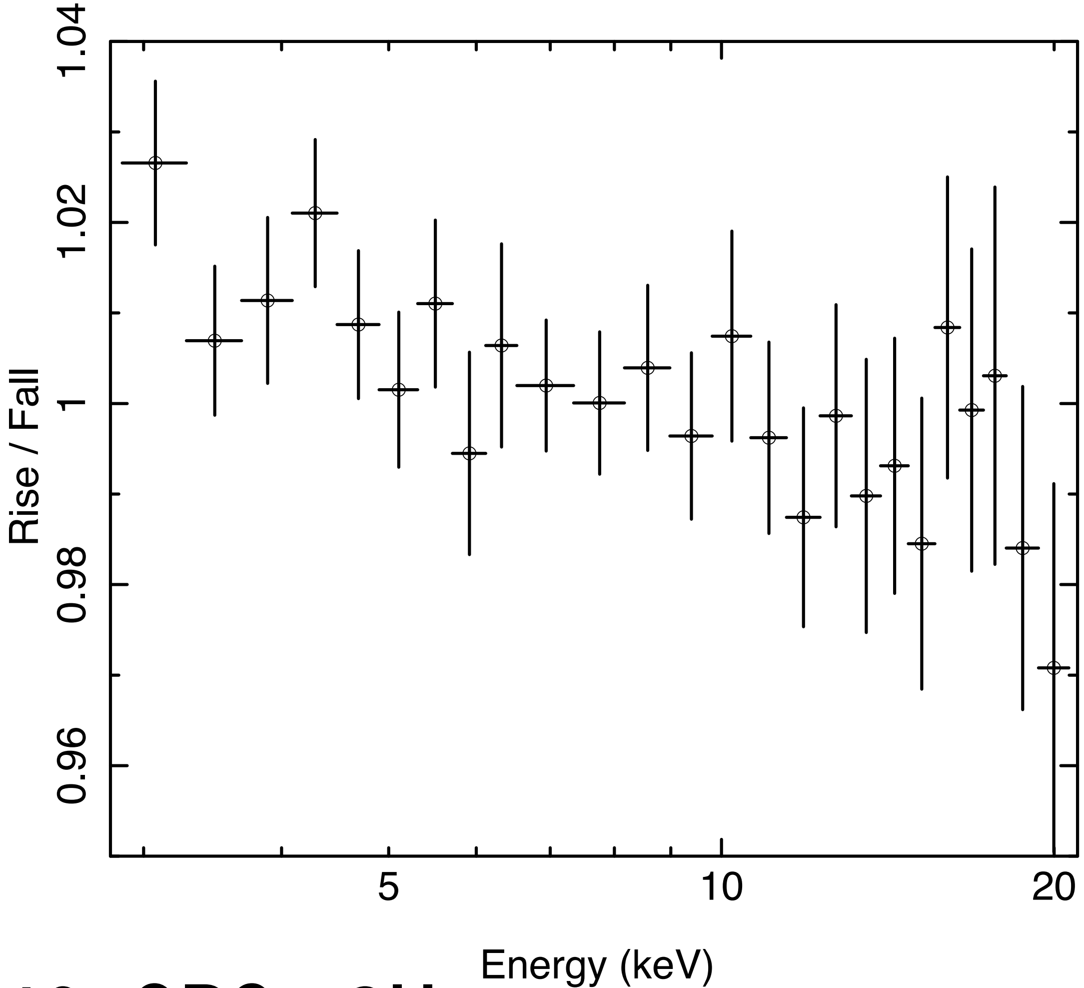

GRO 1655-40; QPO~2Hz

Ingram et al (in prep)

RXTE / Phase binning

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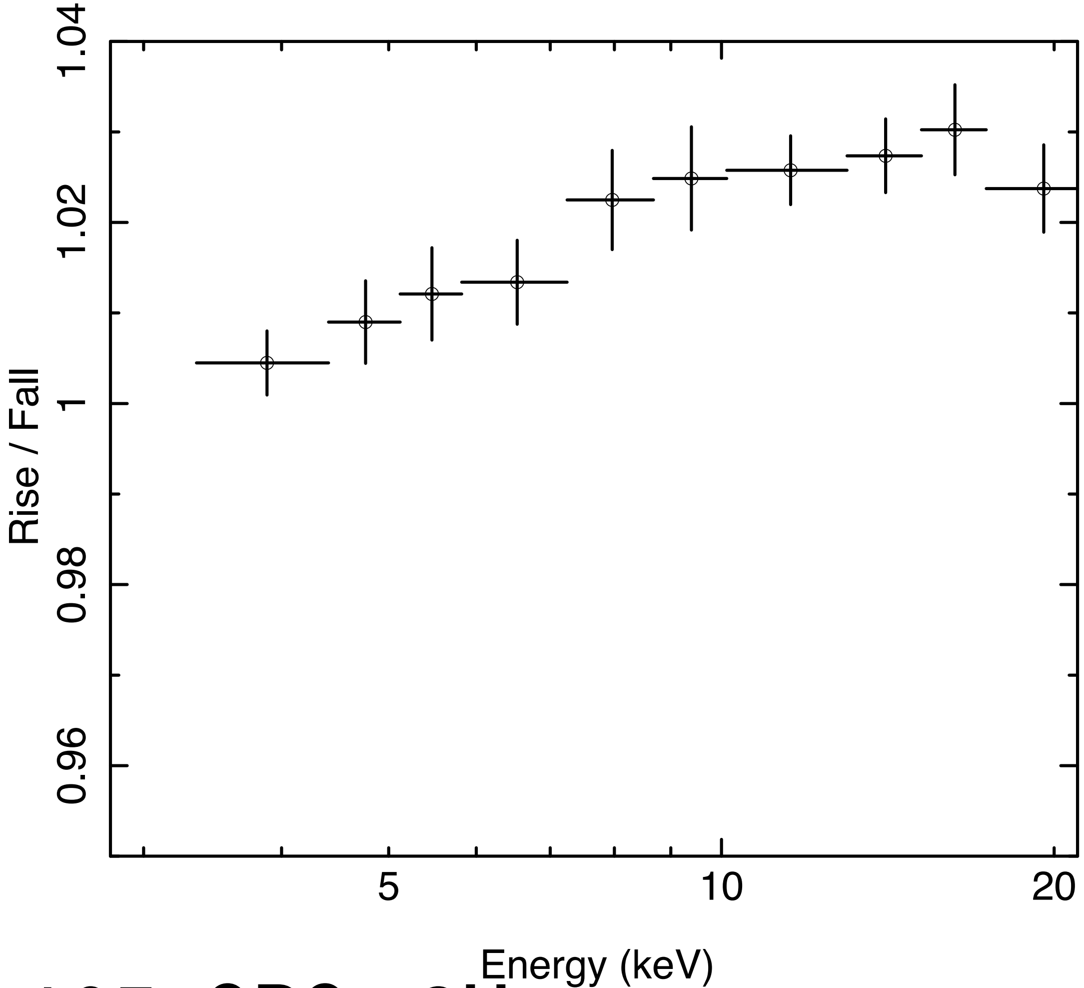

GRS 1915+105; QPO~2Hz

Ingram et al (in prep)

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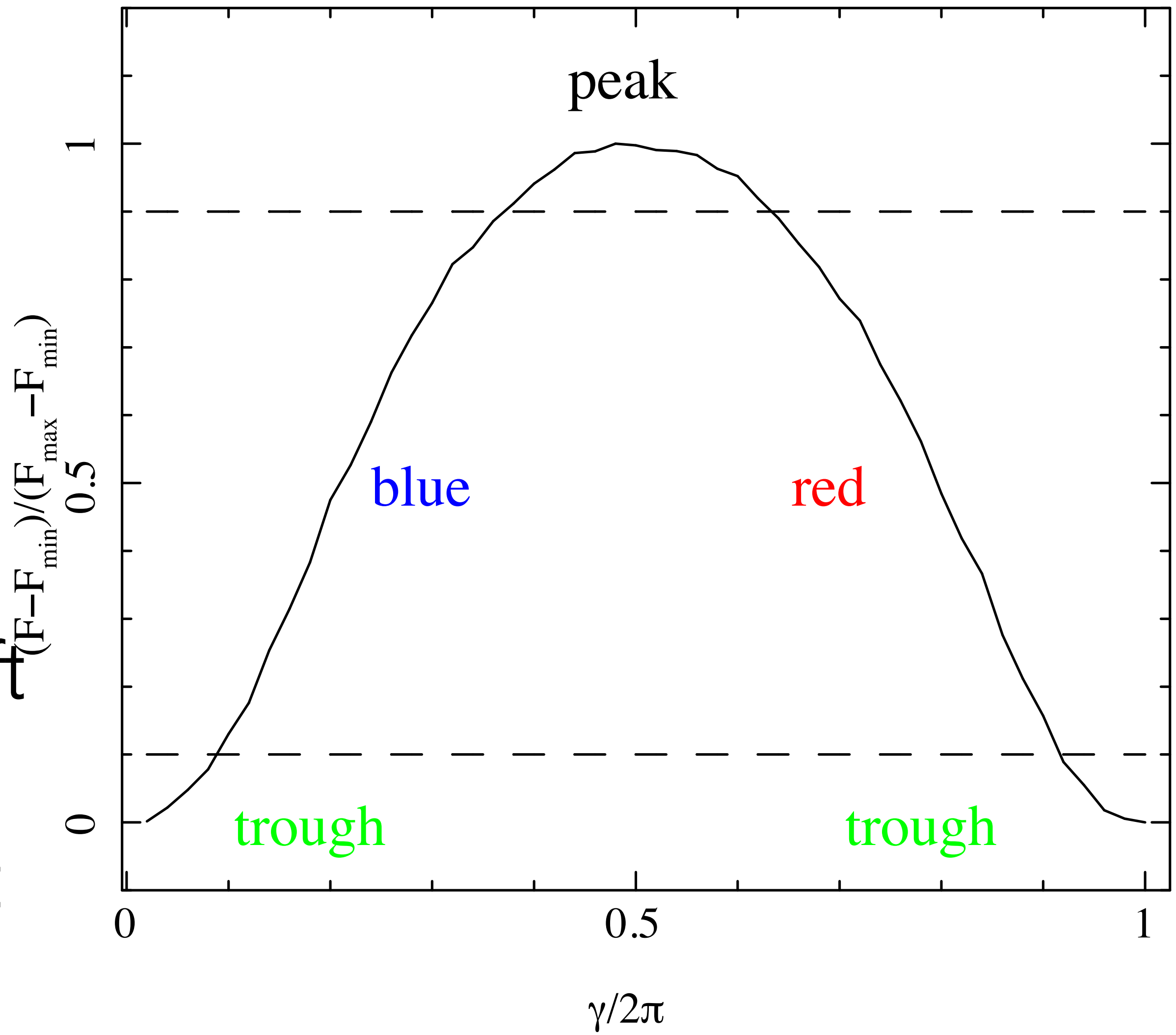
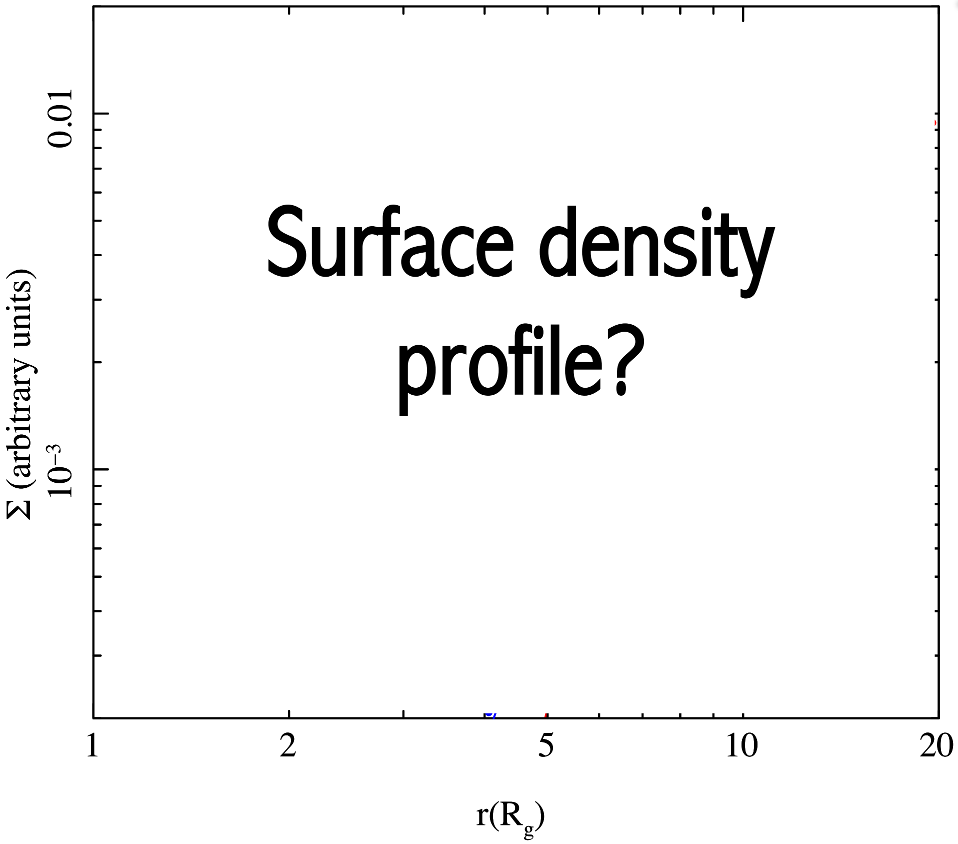
Testing precession

- 2-20 keV light curve of this model
- Apply a flux selection to find the QPO peak and trough
- The rising section will have maximum blue shift
- The falling section will have maximum red shift

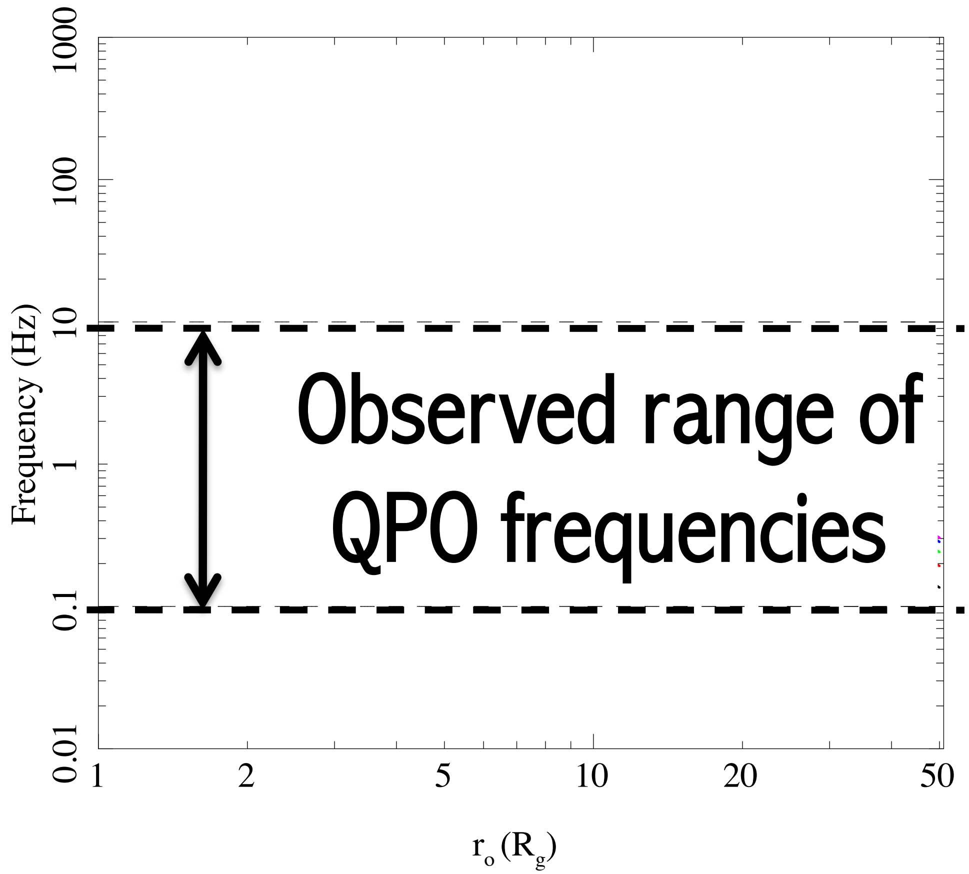


Ingram & Done 2012b

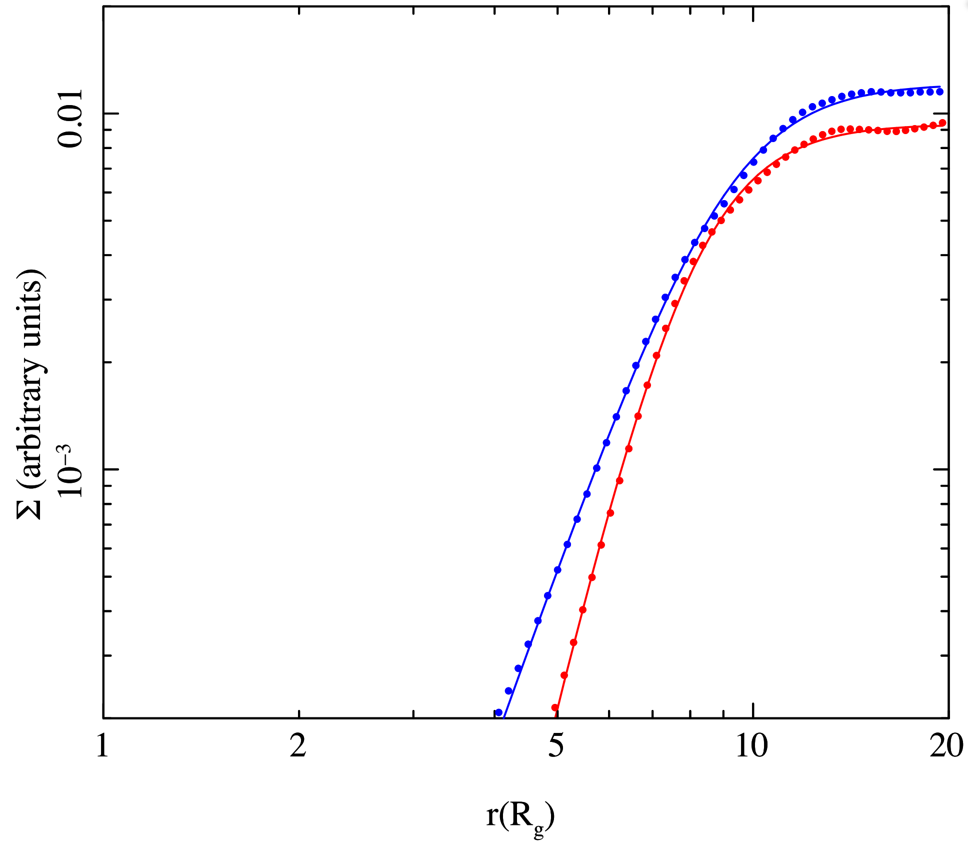
Frame dragging



Ingram, Done & Fragile (2009)
Fragile et al (2007)



Frame dragging



Ingram, Done & Fragile (2009)
Fragile et al (2007)