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ASTRONOMICAL INSTITUTE ANTON PANNEKOEK

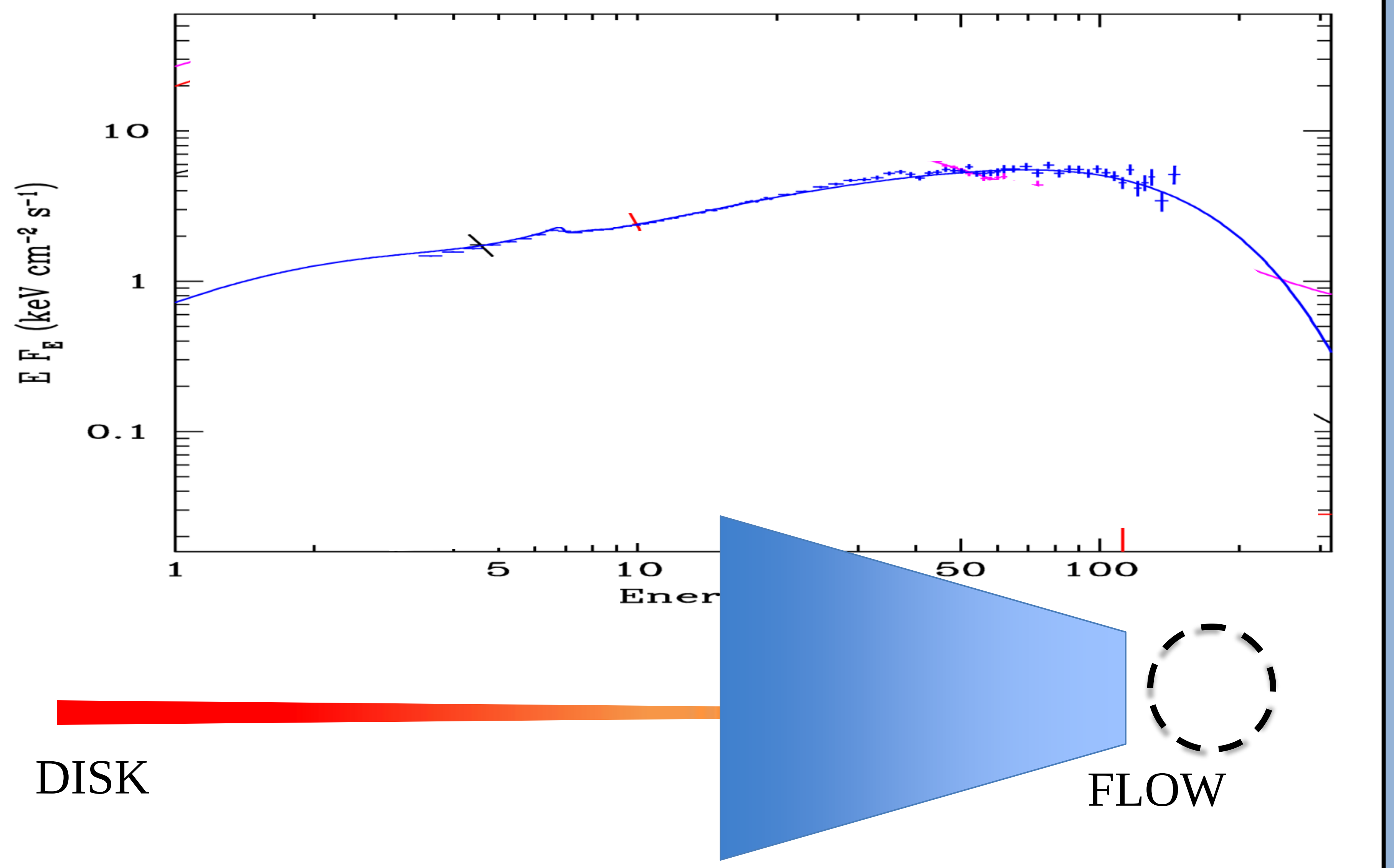
LOFT EXPLORING THE 4TH DIMENSION

A UNIQUE TEST FOR A RELATIVISTIC PRECESSION ORIGIN OF THE LOW FREQUENCY QPO IN

Adam Ingram, Chris Done, Luigi Stella, Sergio Campana, Michiel van der Klis, P Chris Fragile

Talk - 19th June 2012

Truncated disk model



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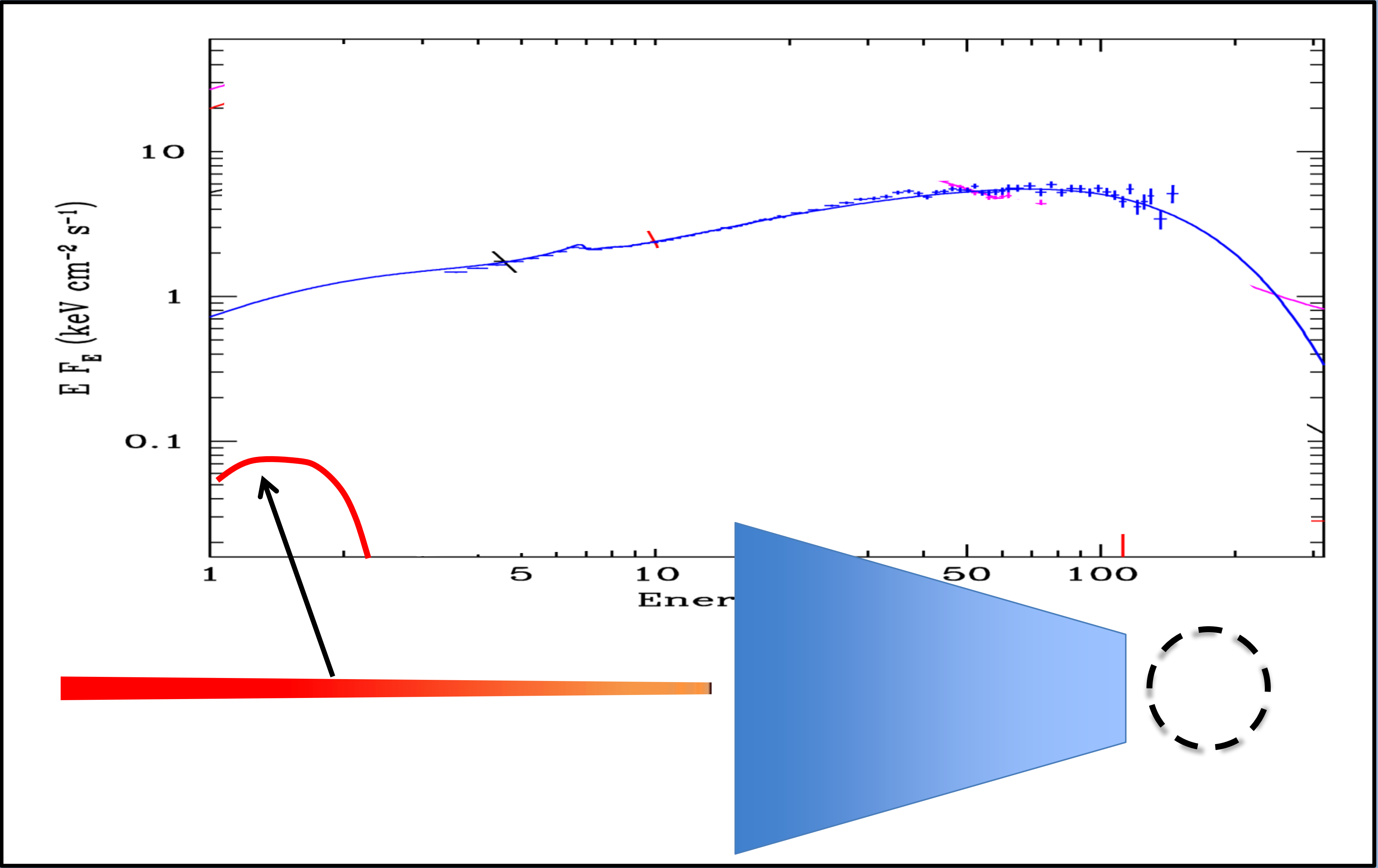

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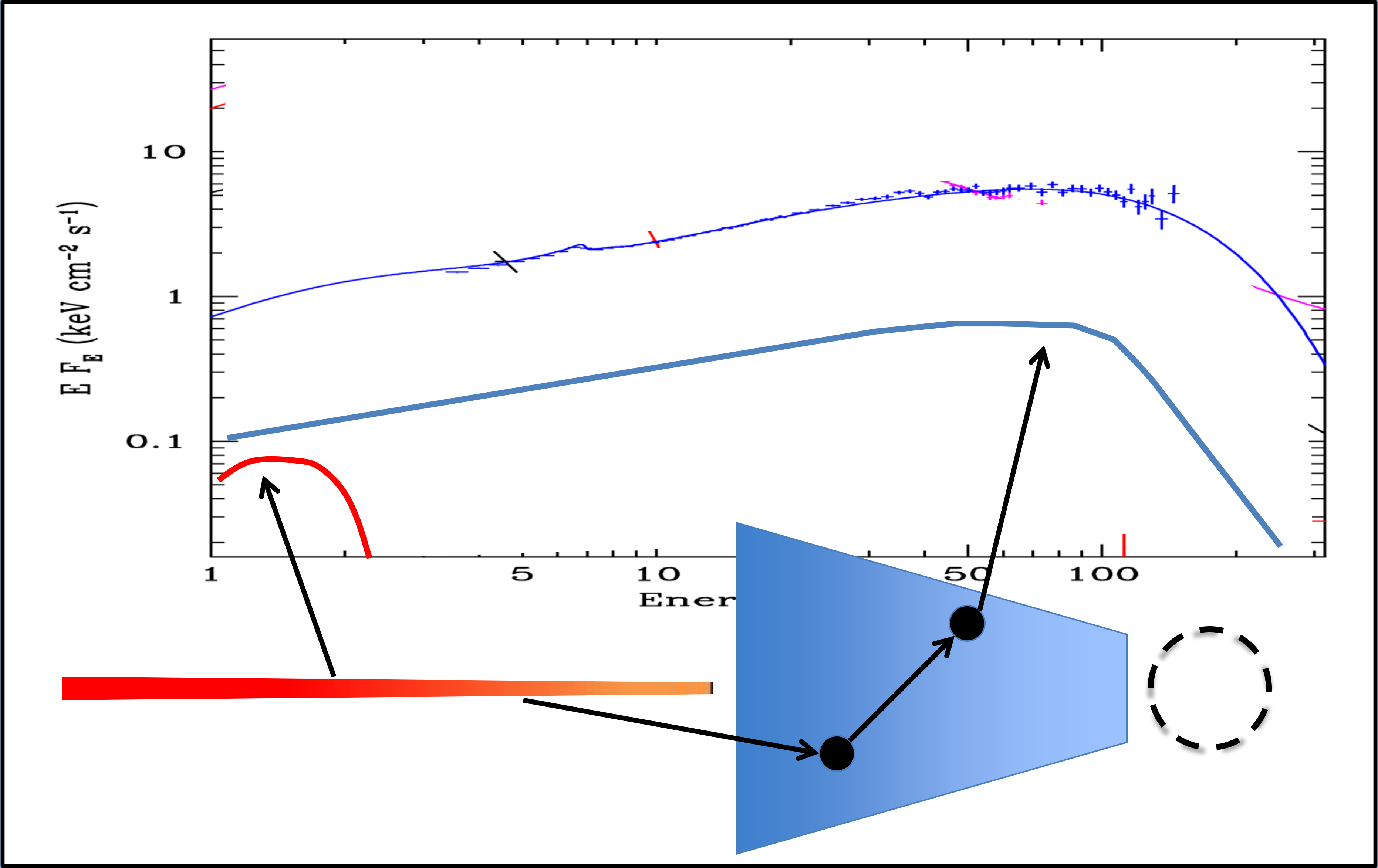

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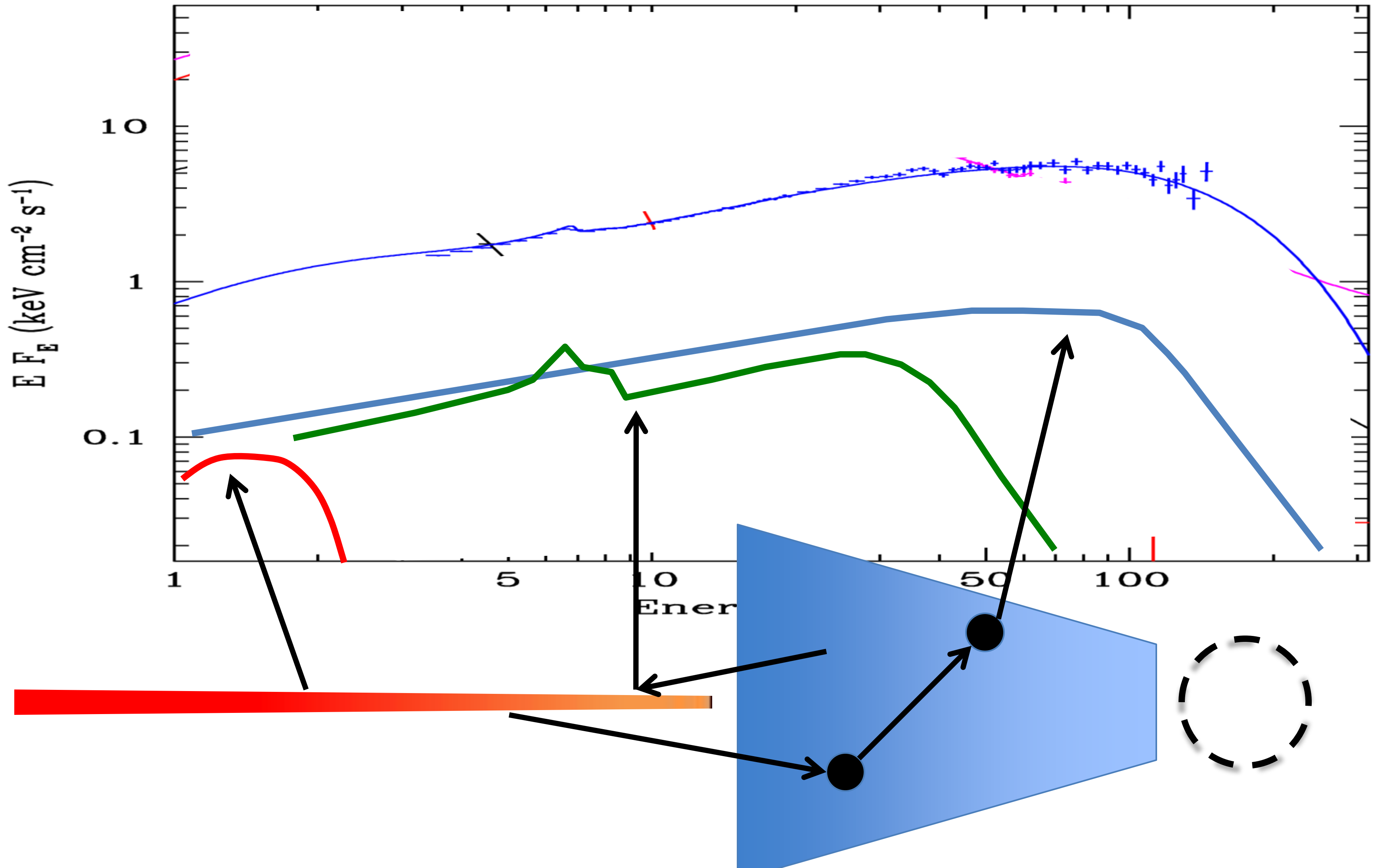

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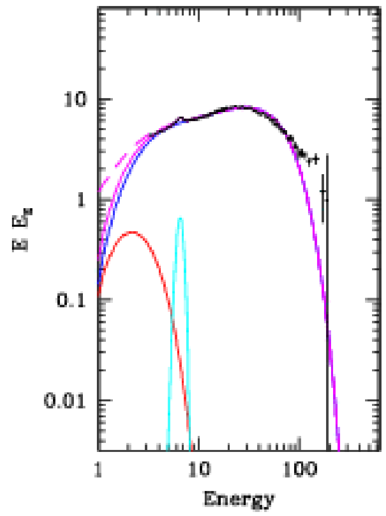
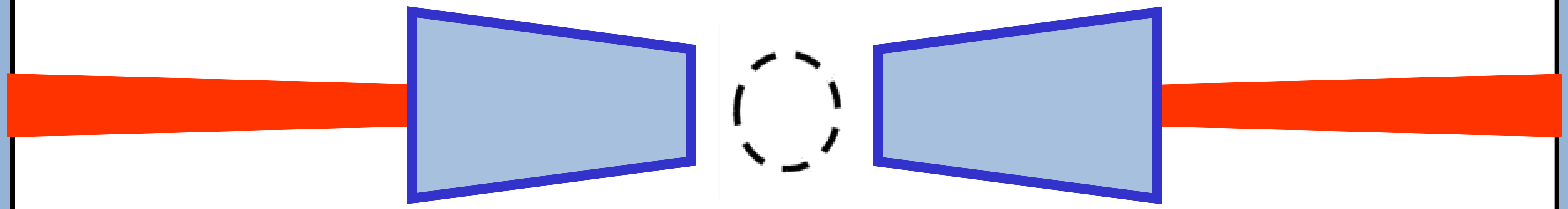


XTE J1550-564



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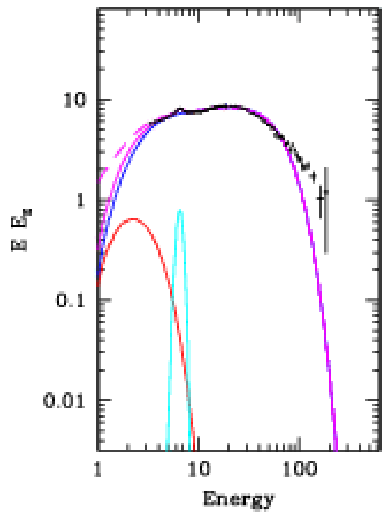

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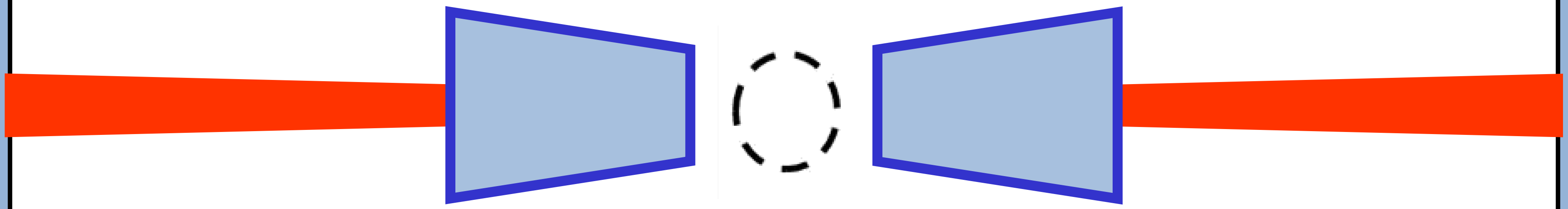

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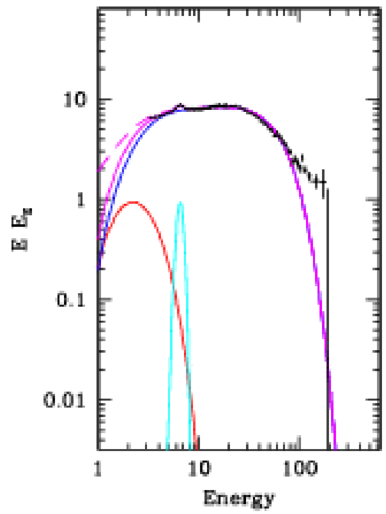

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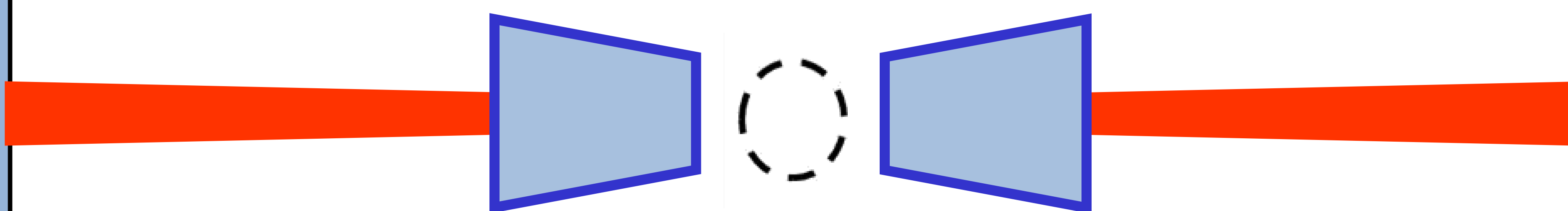

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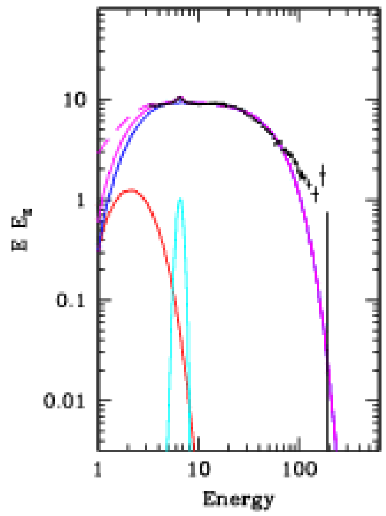

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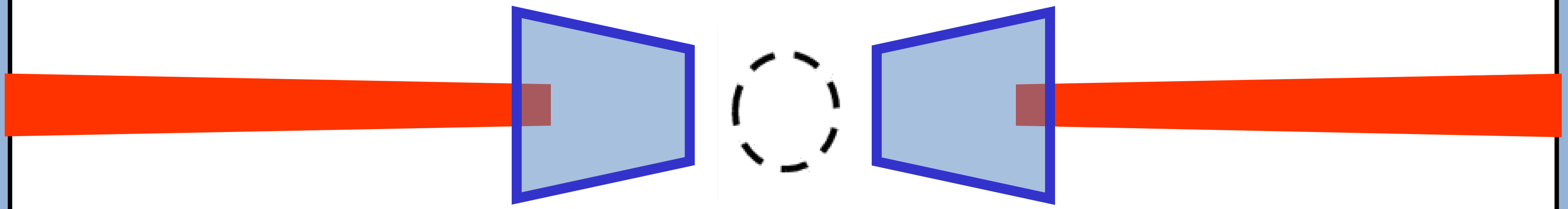

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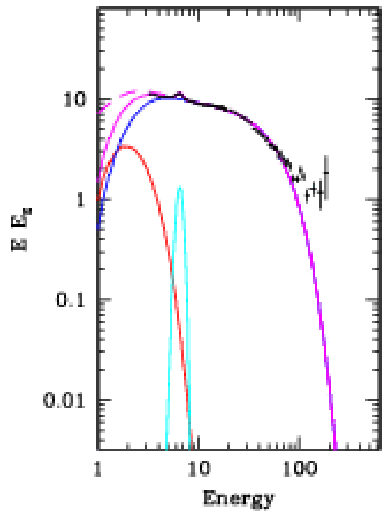

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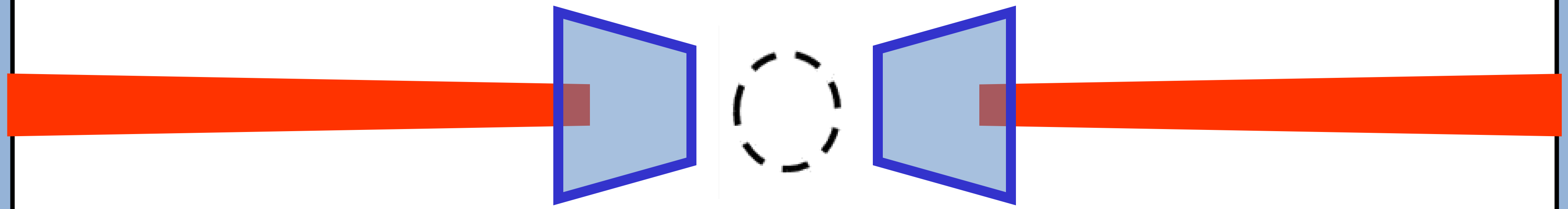

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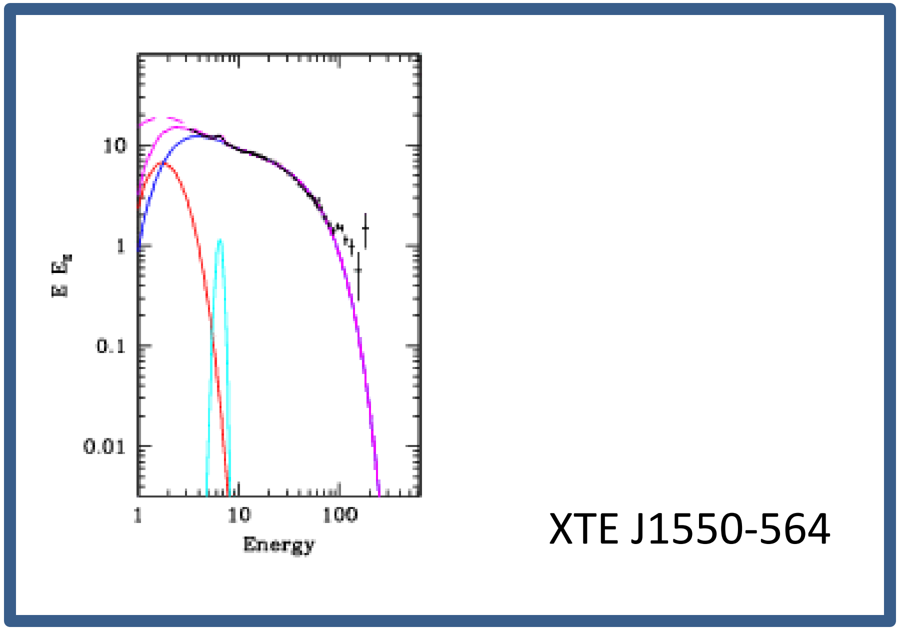

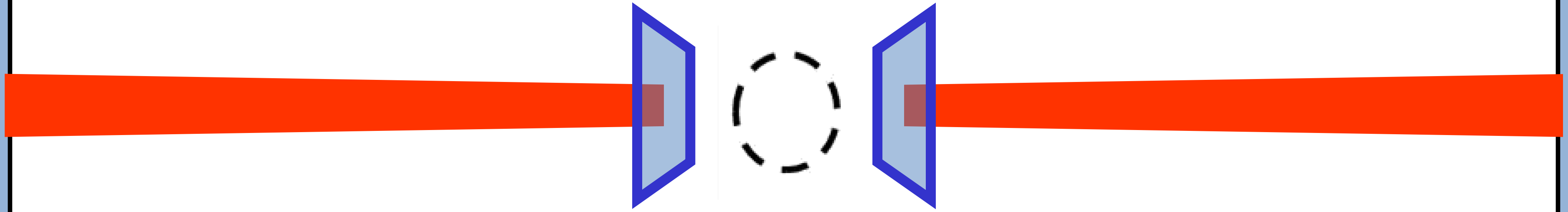

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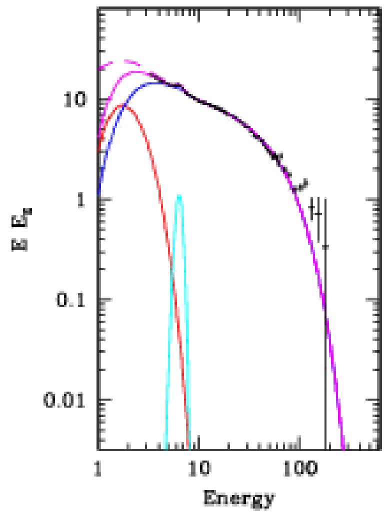

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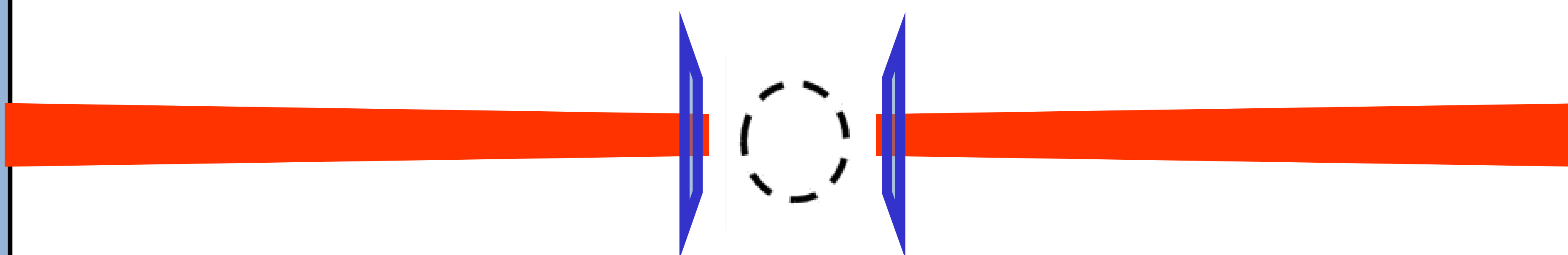

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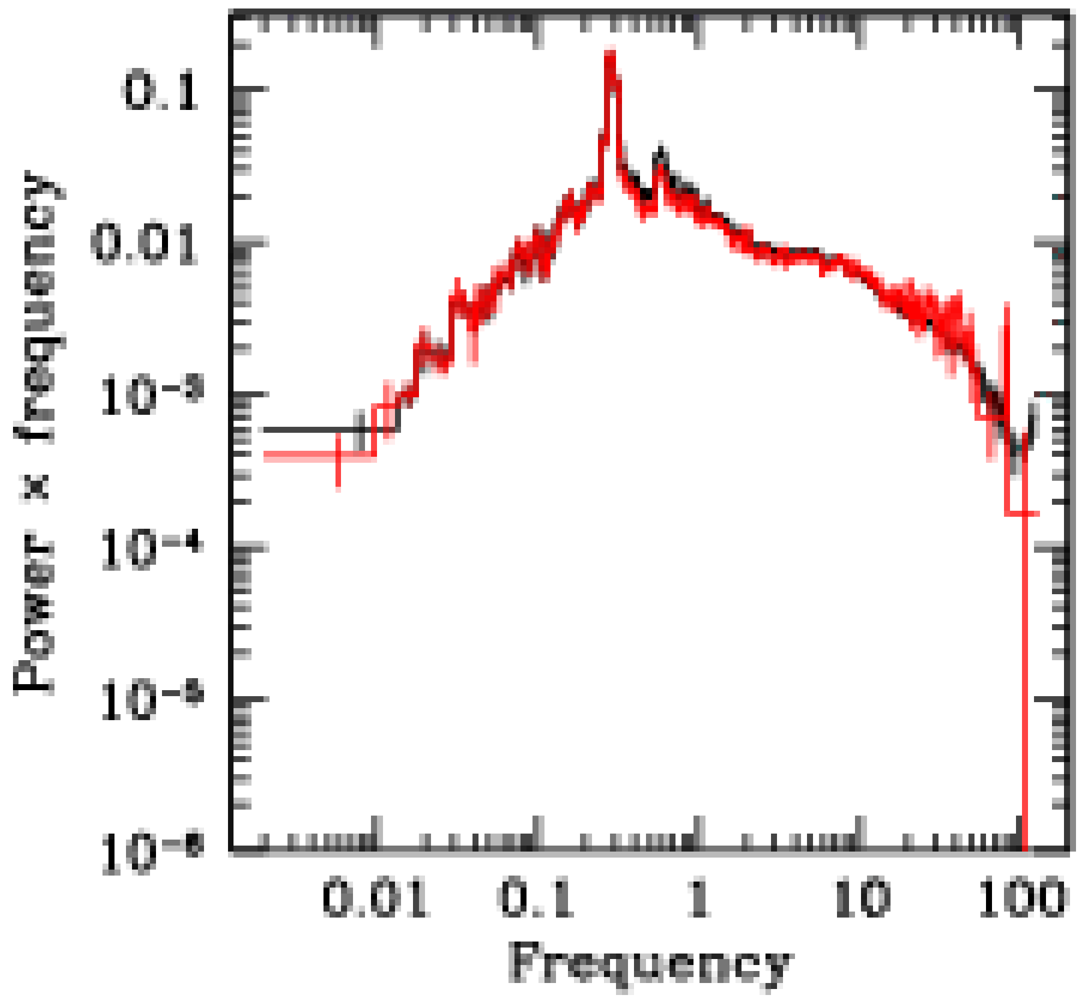
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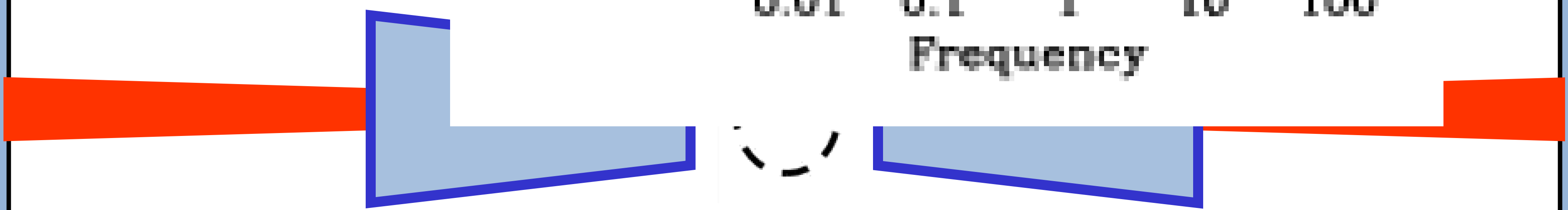
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0.01
0.1
1
10
100
Frequency



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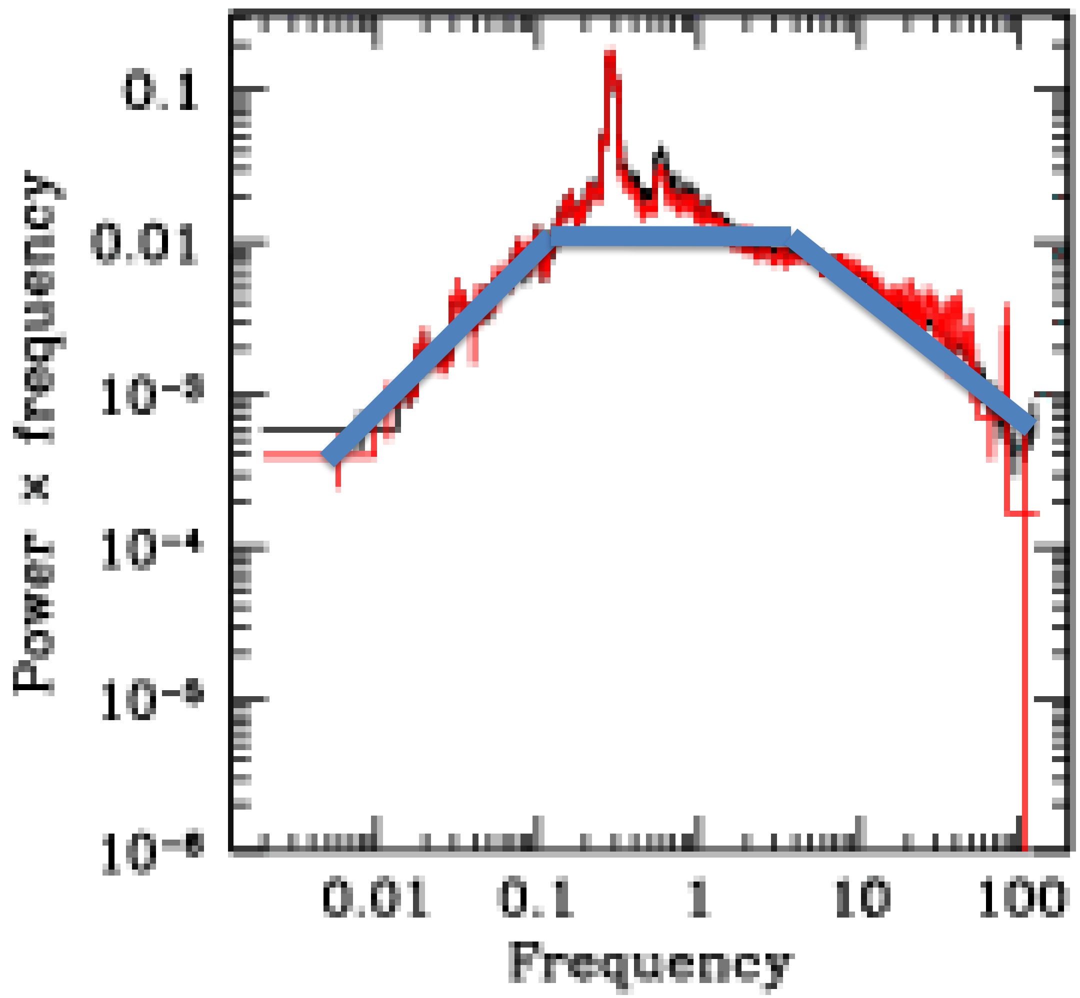

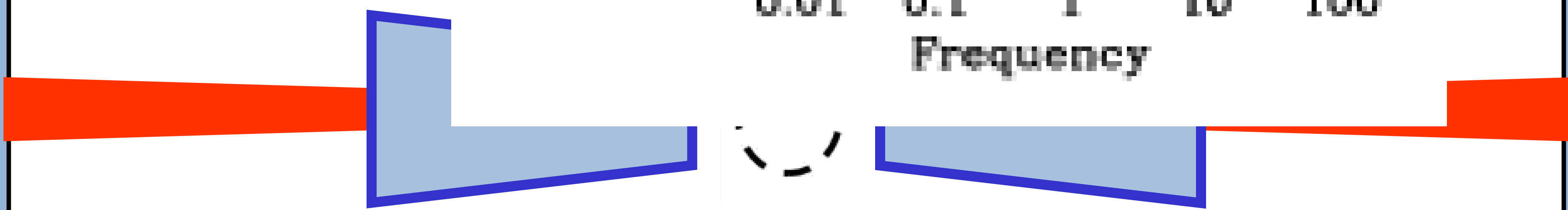

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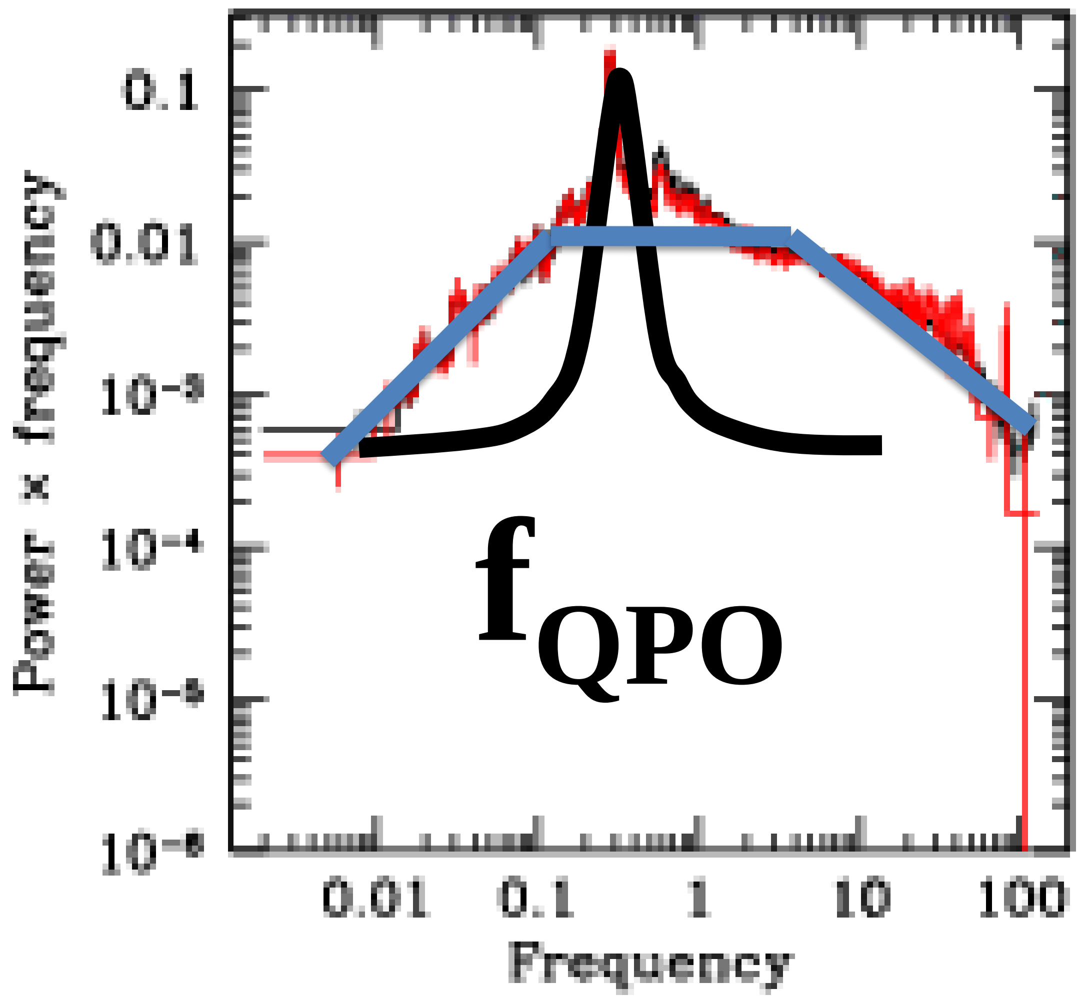
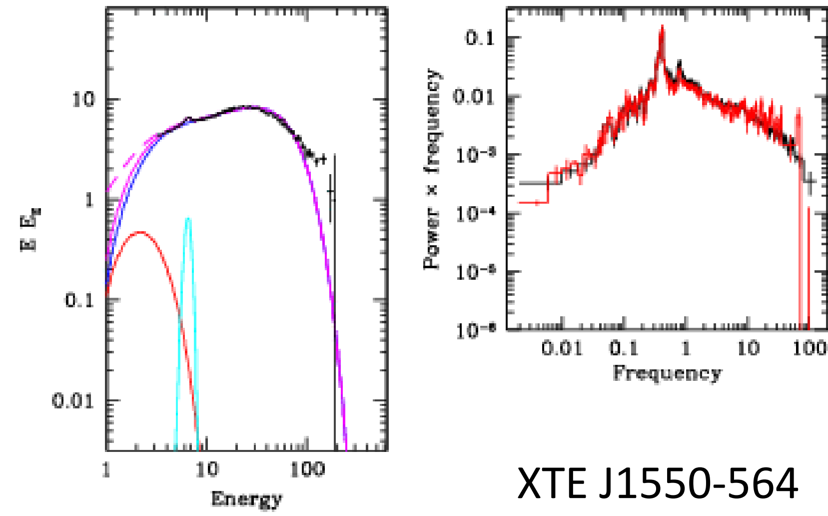
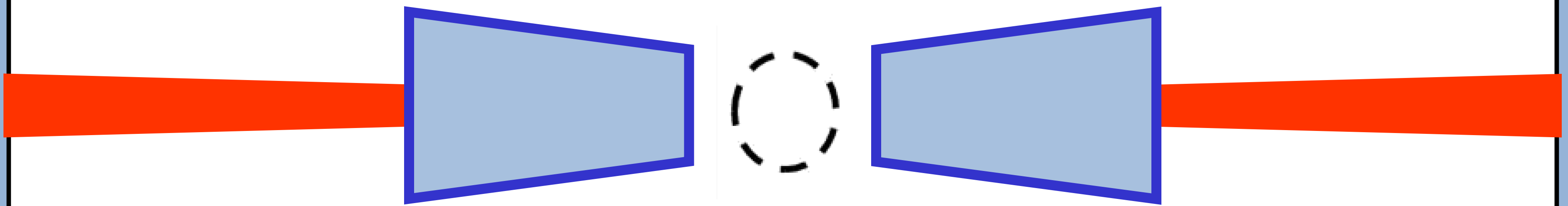


Truncated disk model



XTE J1550-564 [3]



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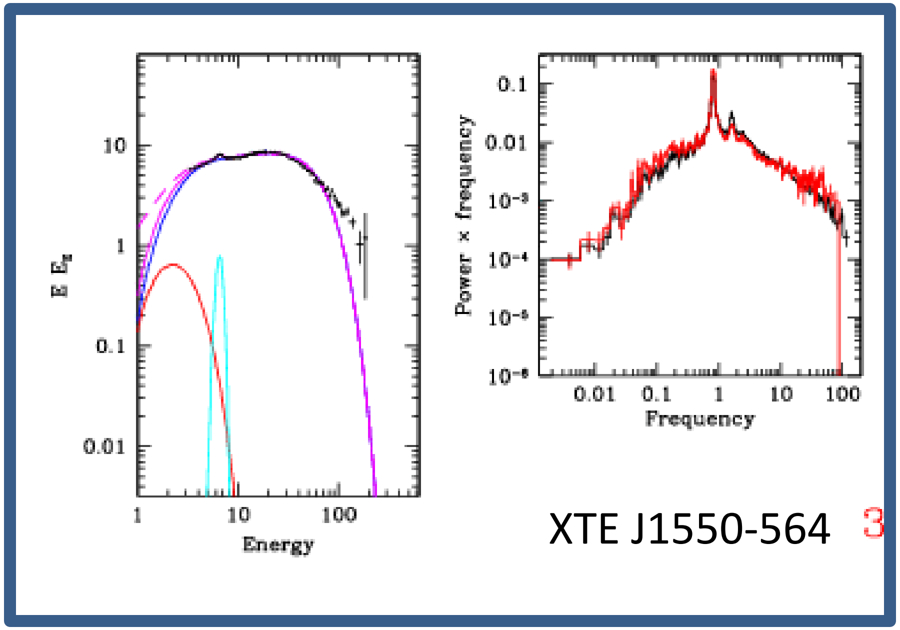

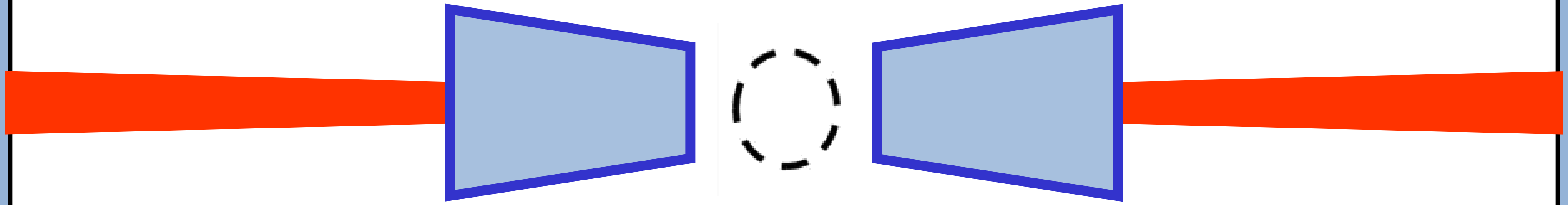

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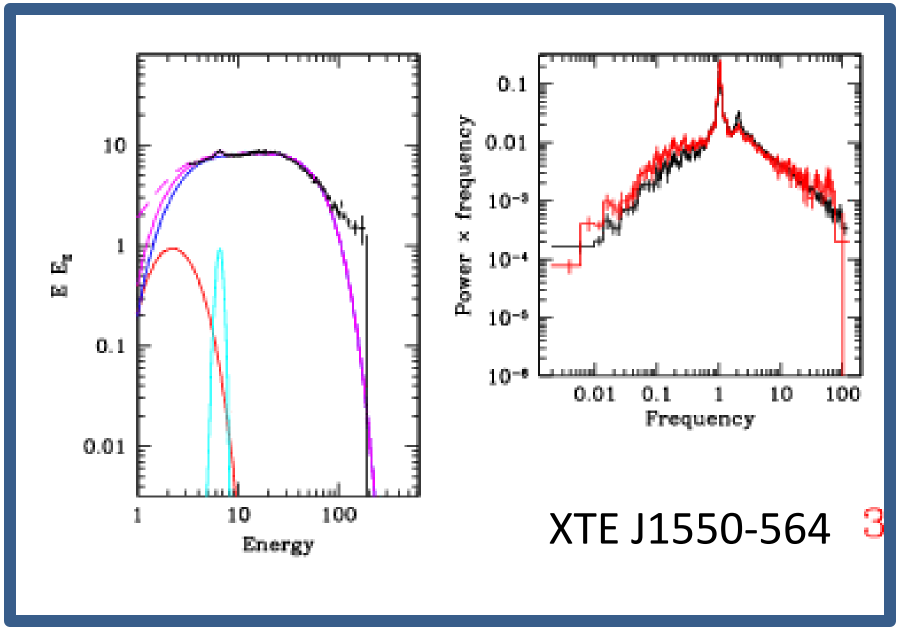

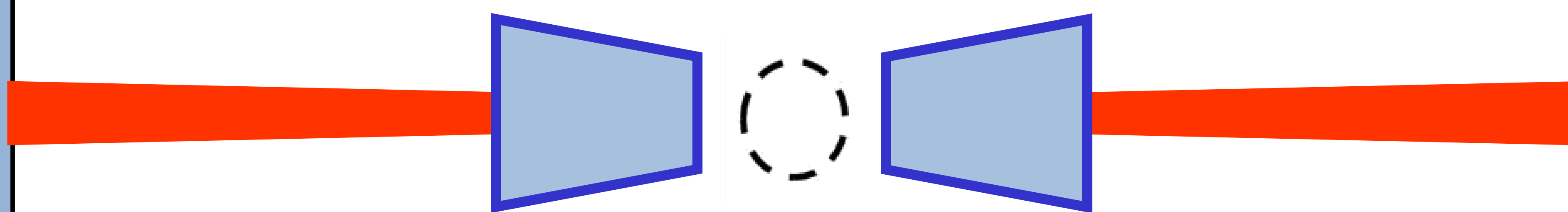

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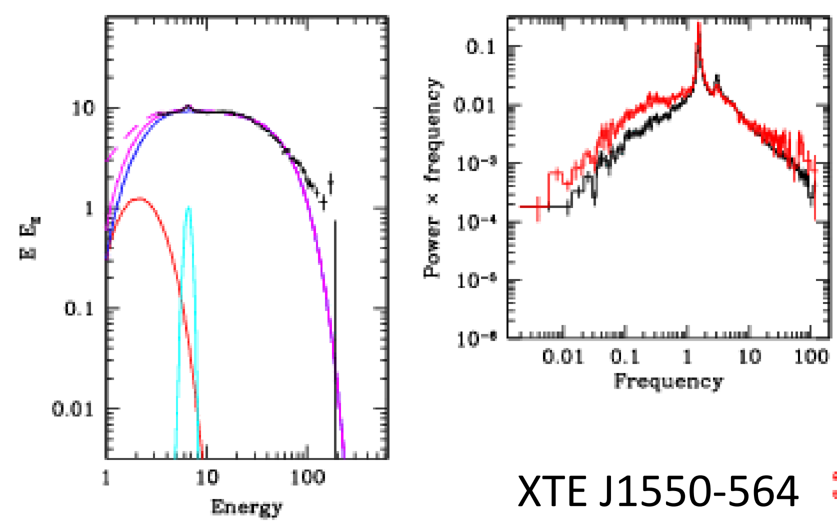
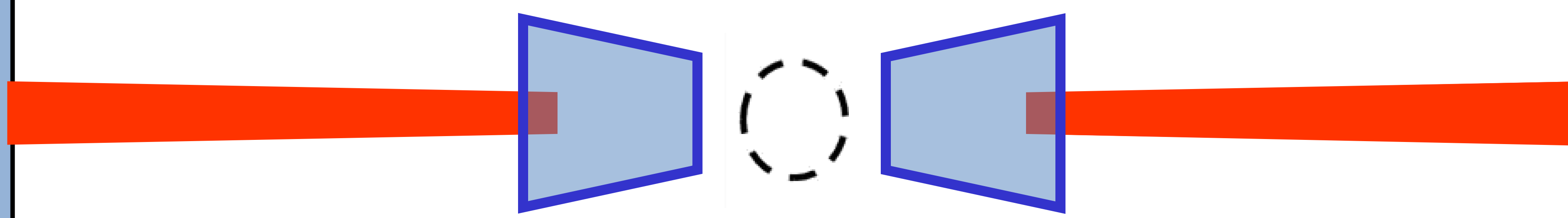


XTE J1550-564 3



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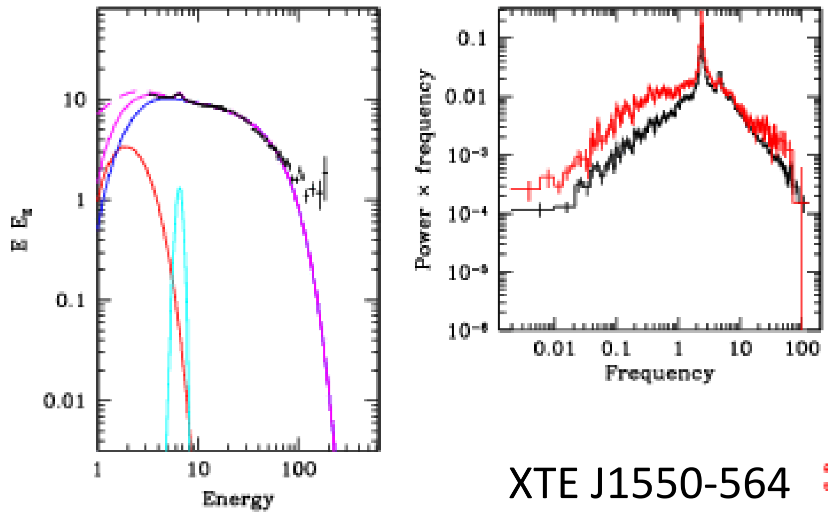

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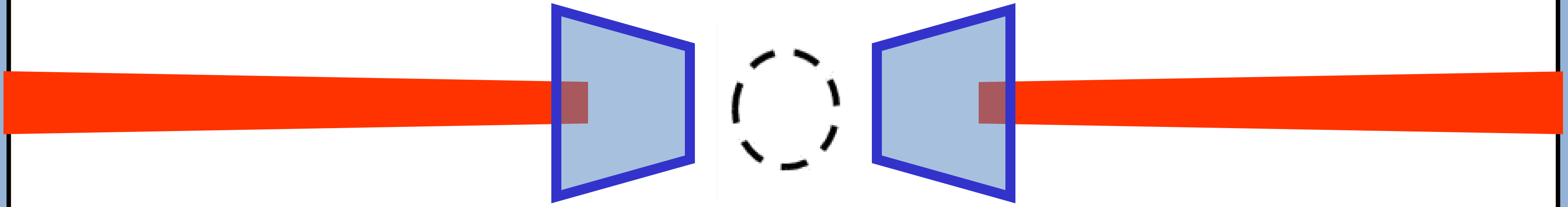

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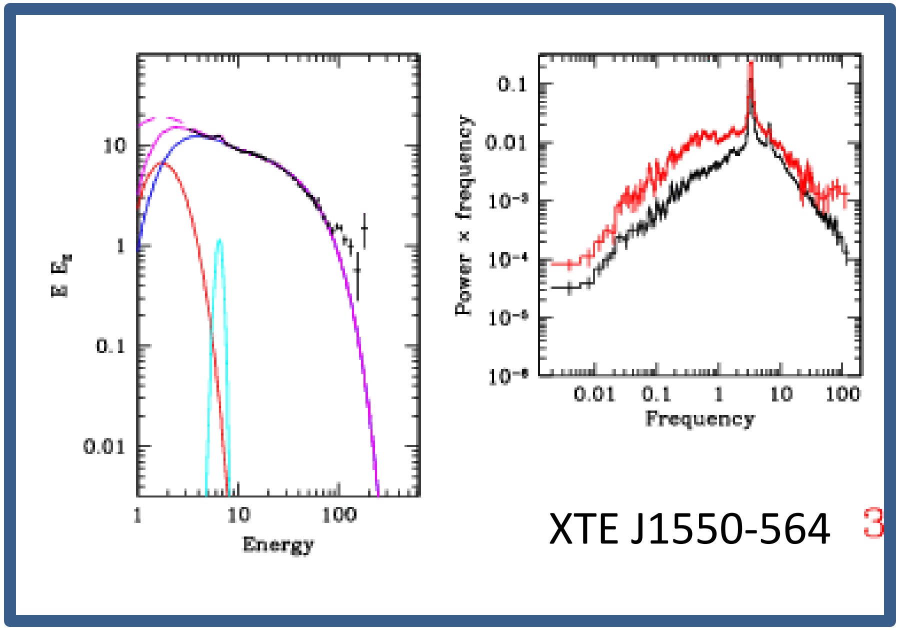

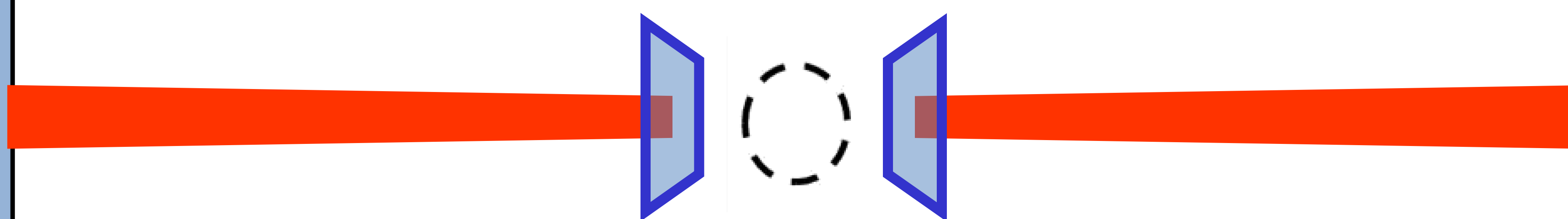

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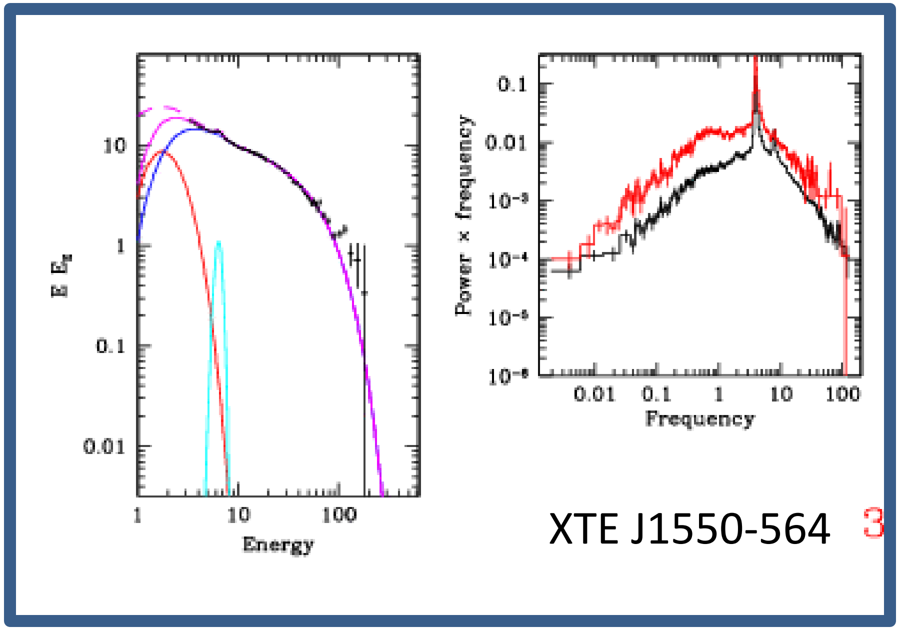
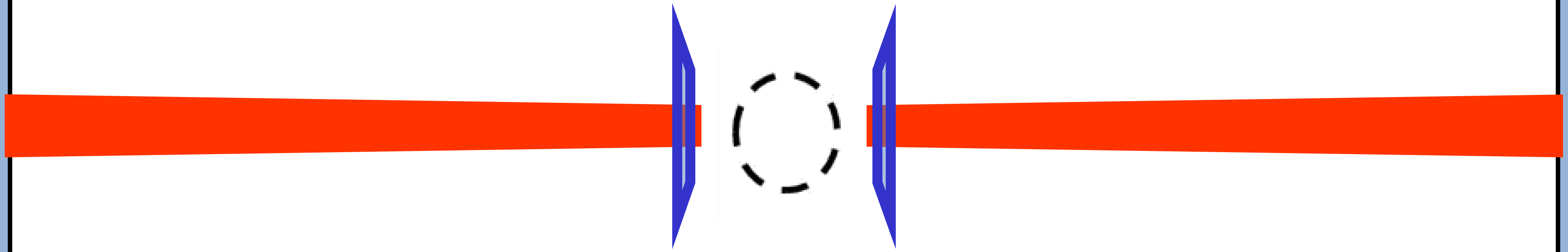
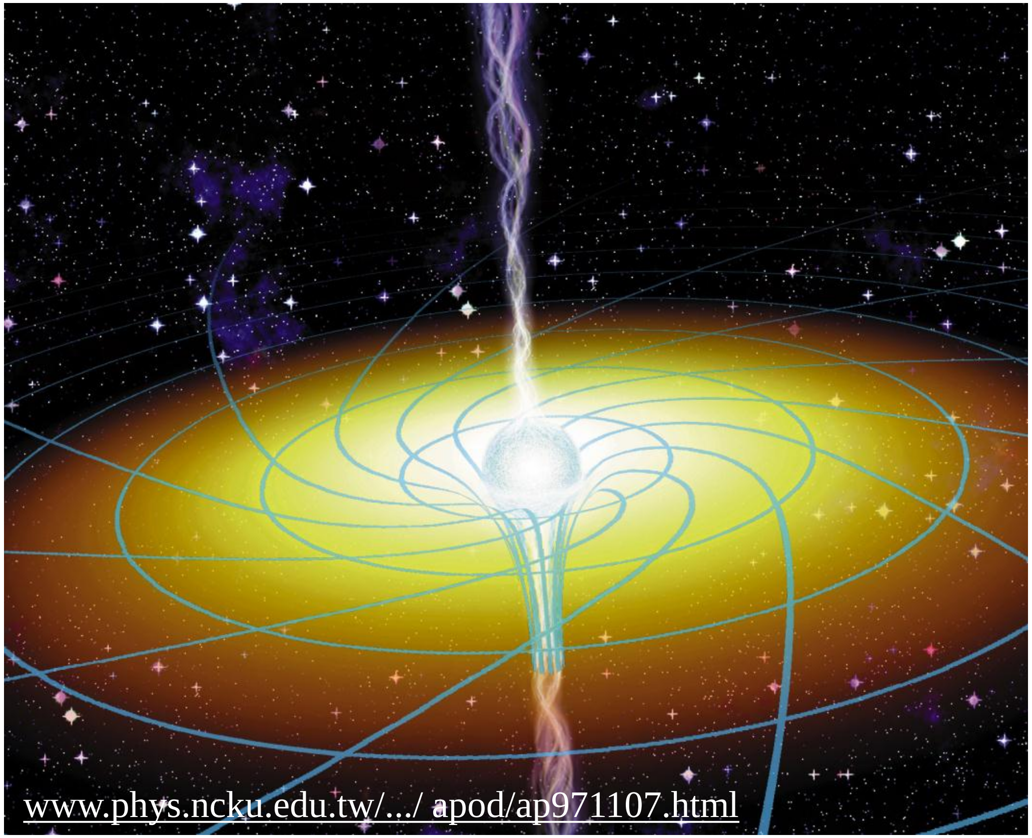




So can we explain the **QPO** with the truncated disk model?

Lense-Thirring precession



- Asymmetric potential => precession of particle orbits

  …Lense-Thirring precession

Stella & Vietri 1998; Markovic´ & Lamb 1998

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Lense-Thirring precession

m = 1 HFGM Mode

Frequency = 29 Hz

Growth Rate = –0.6 Hz

Q = 48

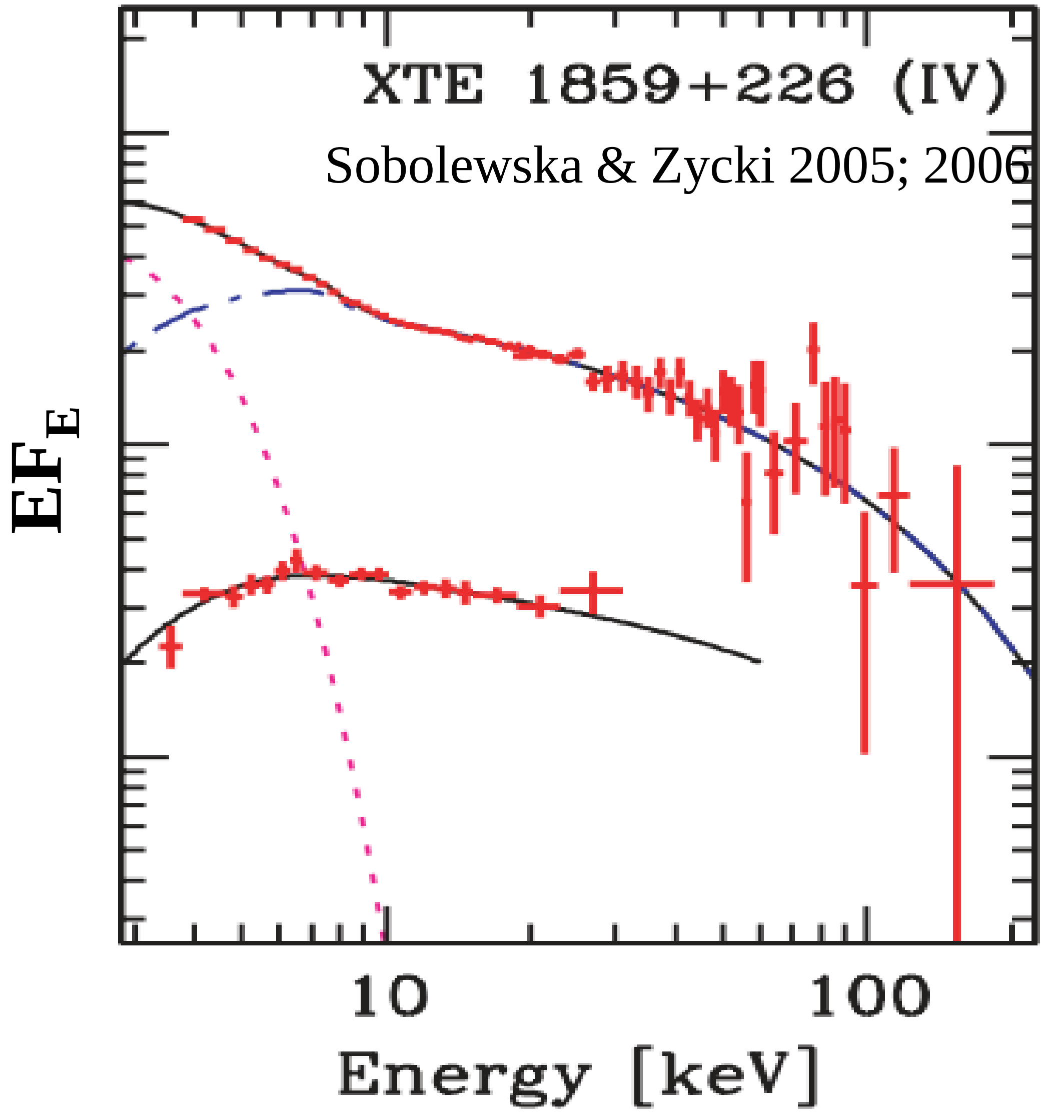
- Asymmetric potential => precession of particle orbits

…Lense-Thirring precession

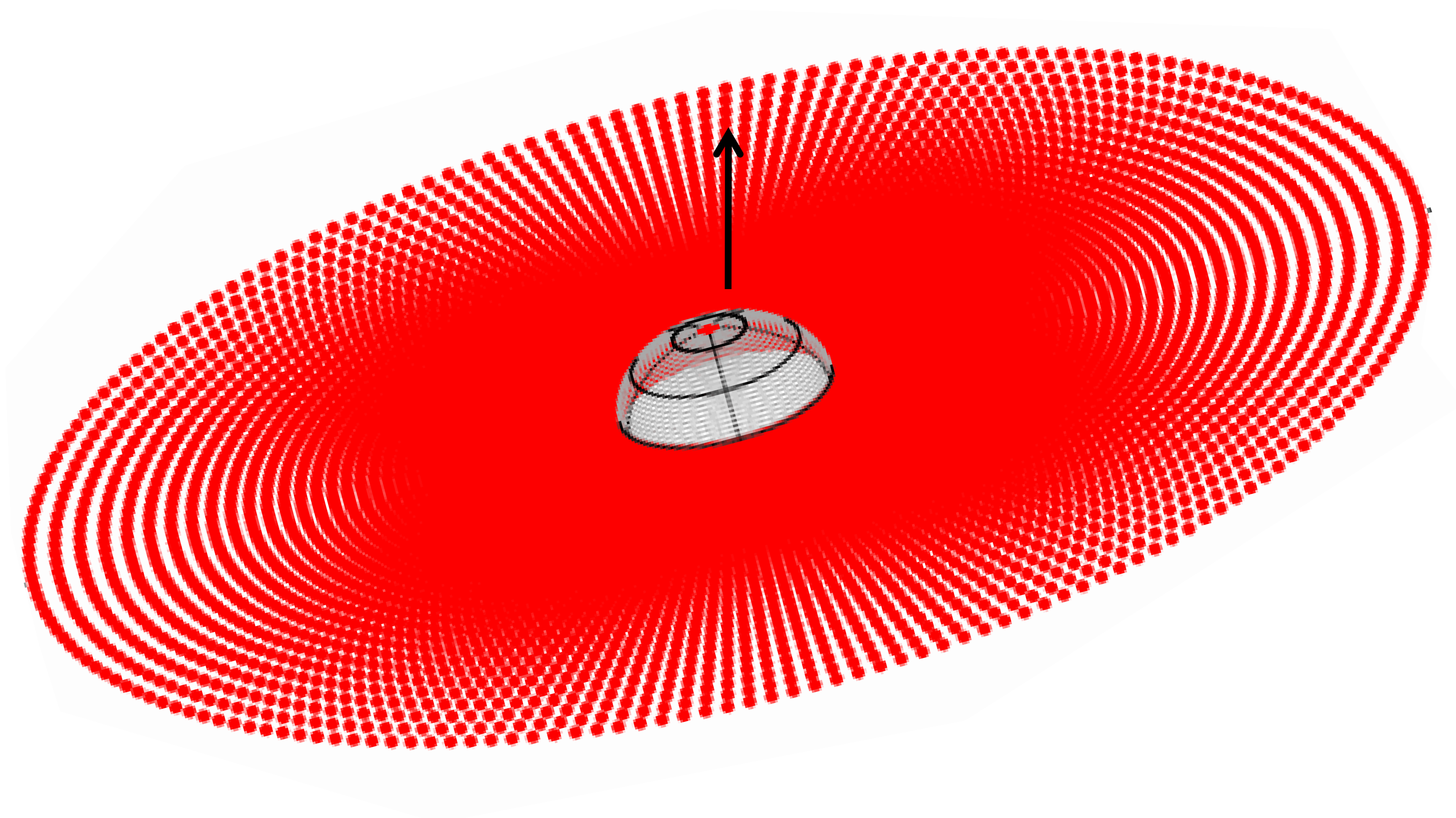
Markovic´, Lamb, Duez, Engelhard, Fregeau & Huffenberger

Lense-Thirring precession

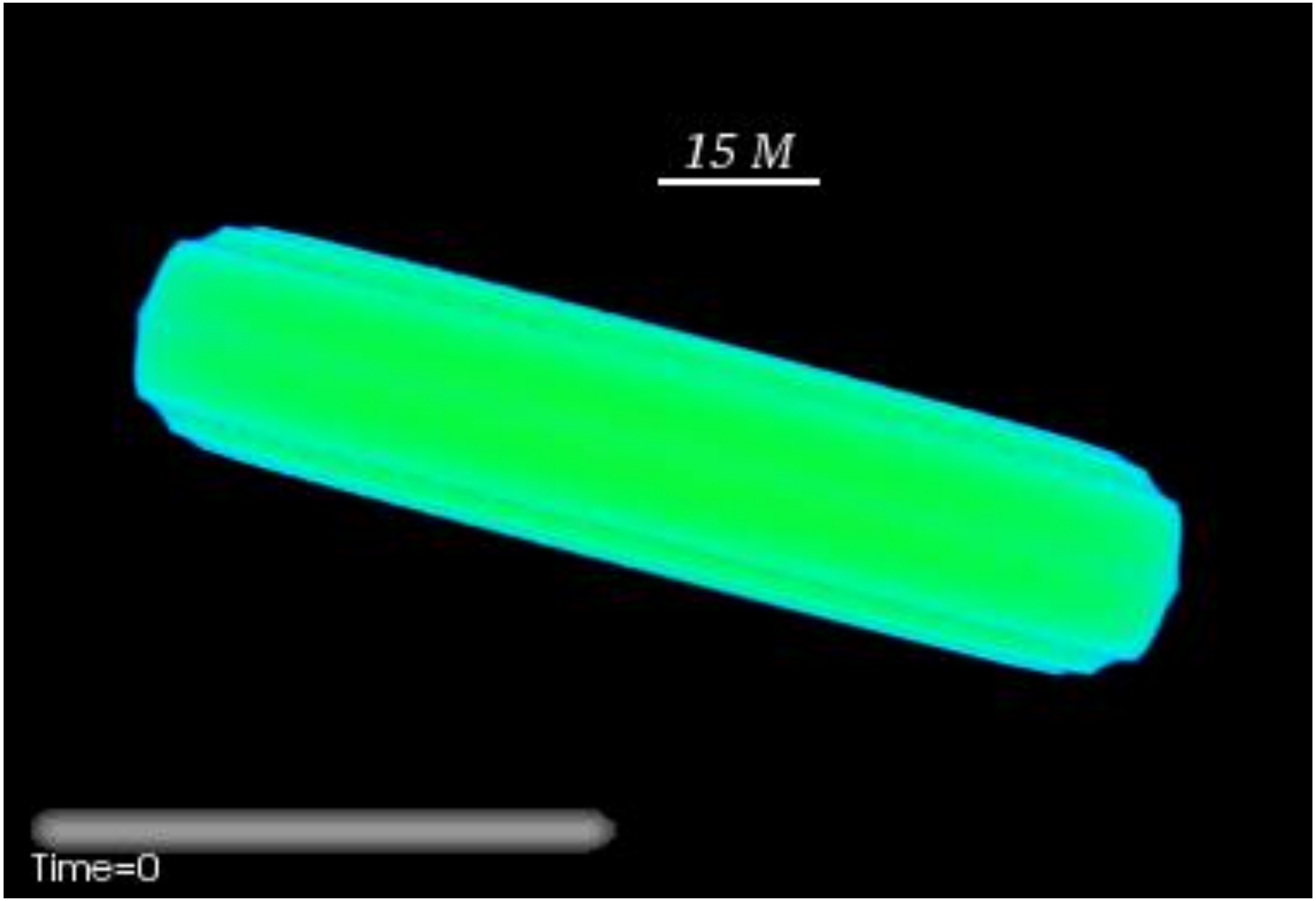
- QPO is observed in the Comptonized tail
- Need a model that ties the QPO to the tail



Lense-Thirring precession

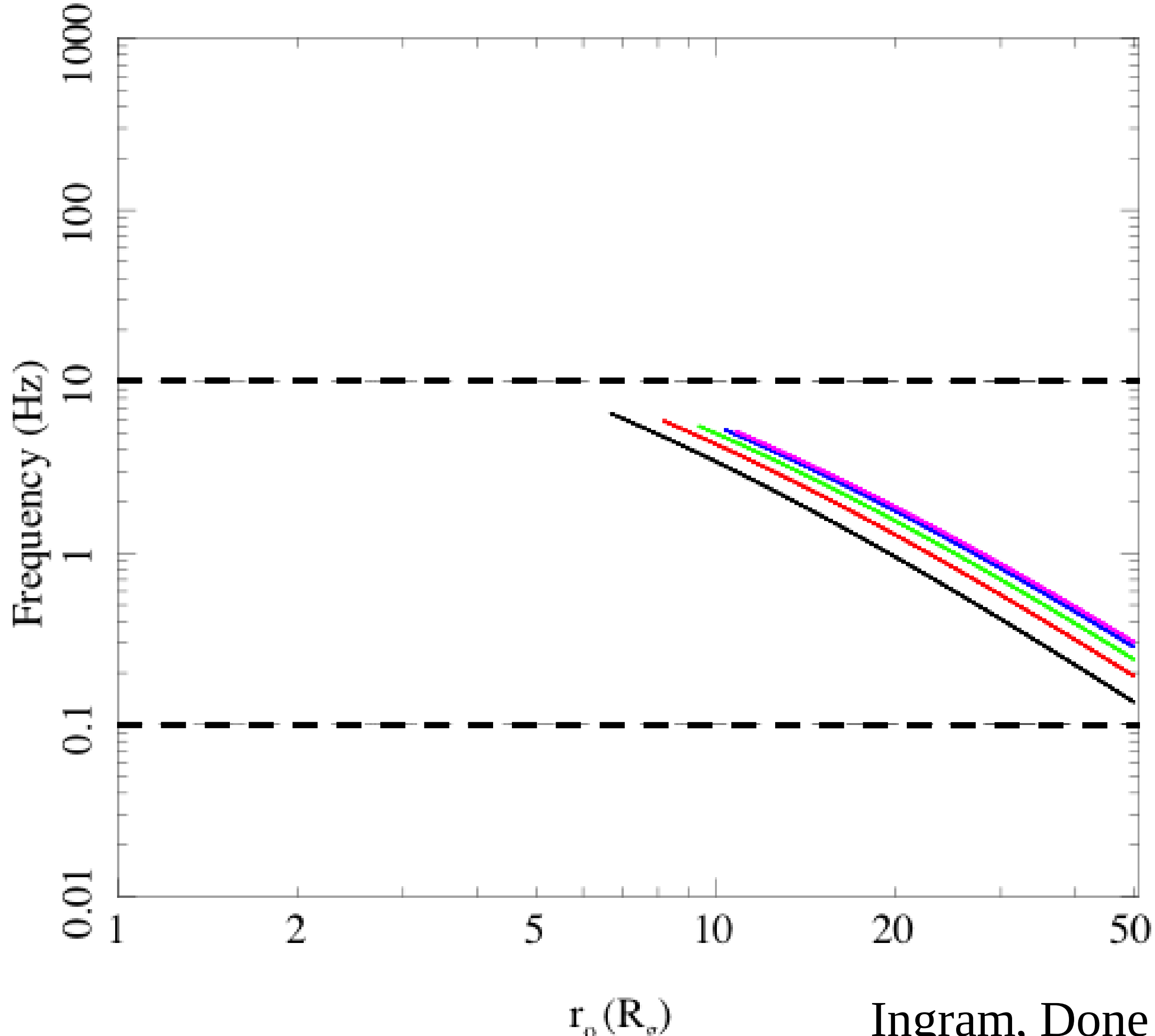


Lense-Thirring precession



Fragile et al 2007

Lense-Thirring precession

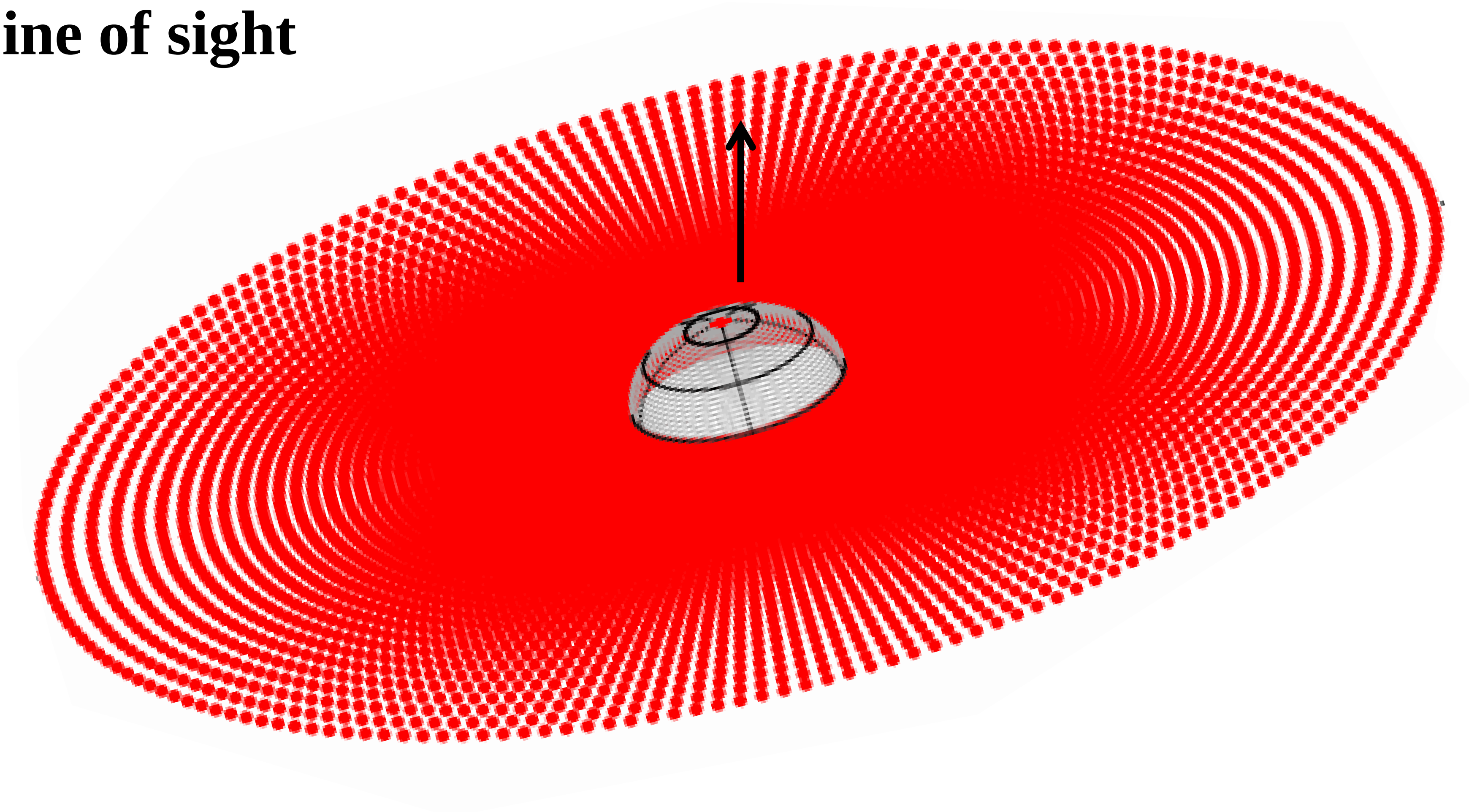


Ingram, Done & Fragile 2009

Testing precession – phase behavior of the QPO

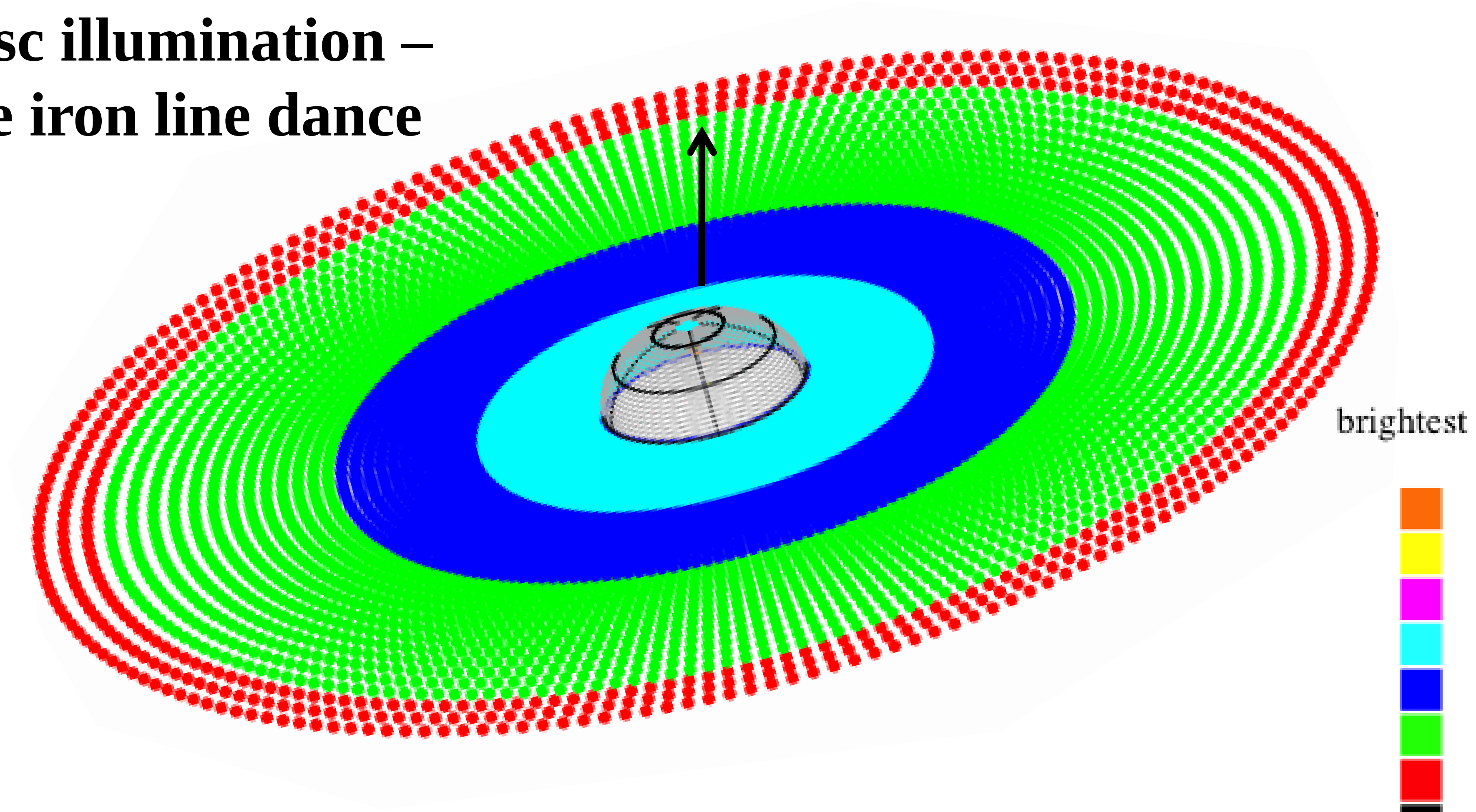
Testing precession

Line of sight



Testing precession

Disc illumination –
the iron line dance

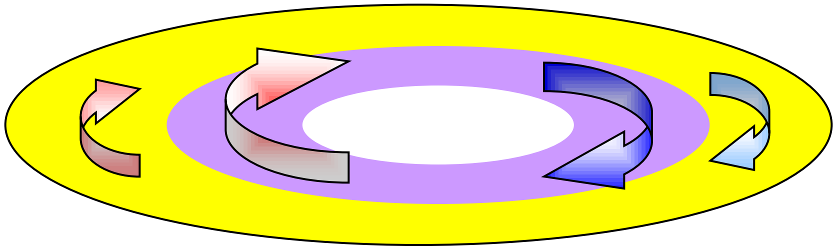


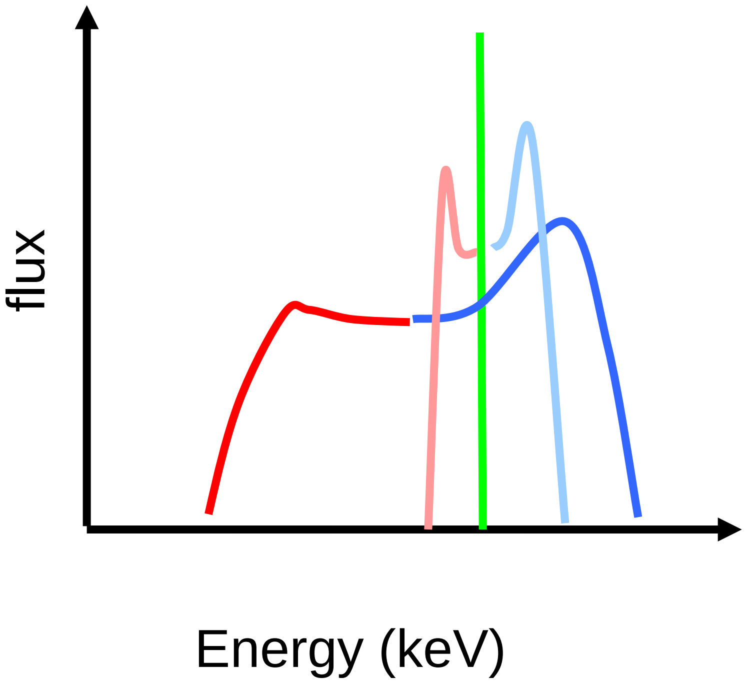
Testing precession

Emission from side of disc coming towards us:

- Doppler blue shifted
- Beamed from length contraction
- Time dilation as fast moving (SR)
- Gravitational red shift (GR)

Fe Kα line from irradiated disk should be broad and skewed

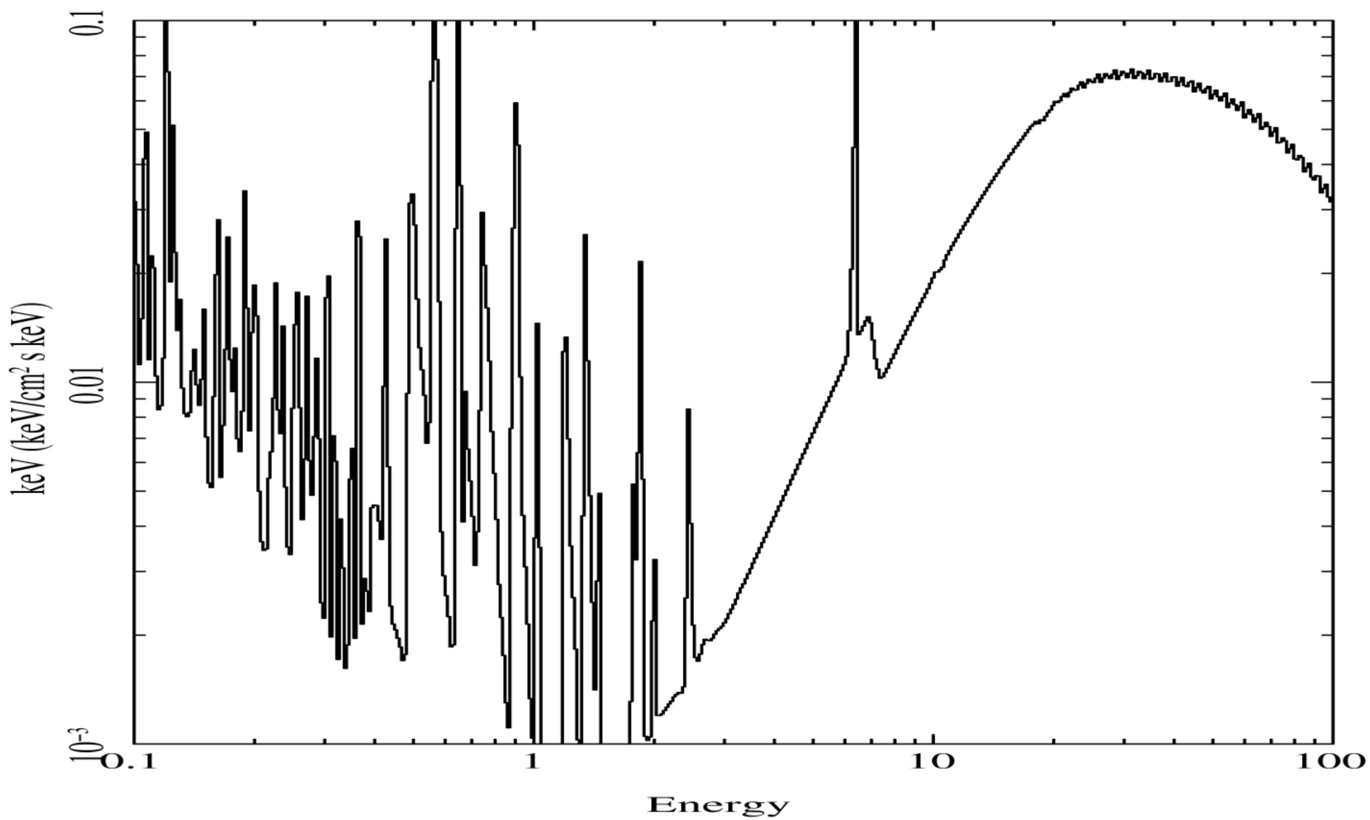




Fabian et al. 1989

Testing precession

Doppler boosting and relativistic effects smear and broaden the line



Testing precession

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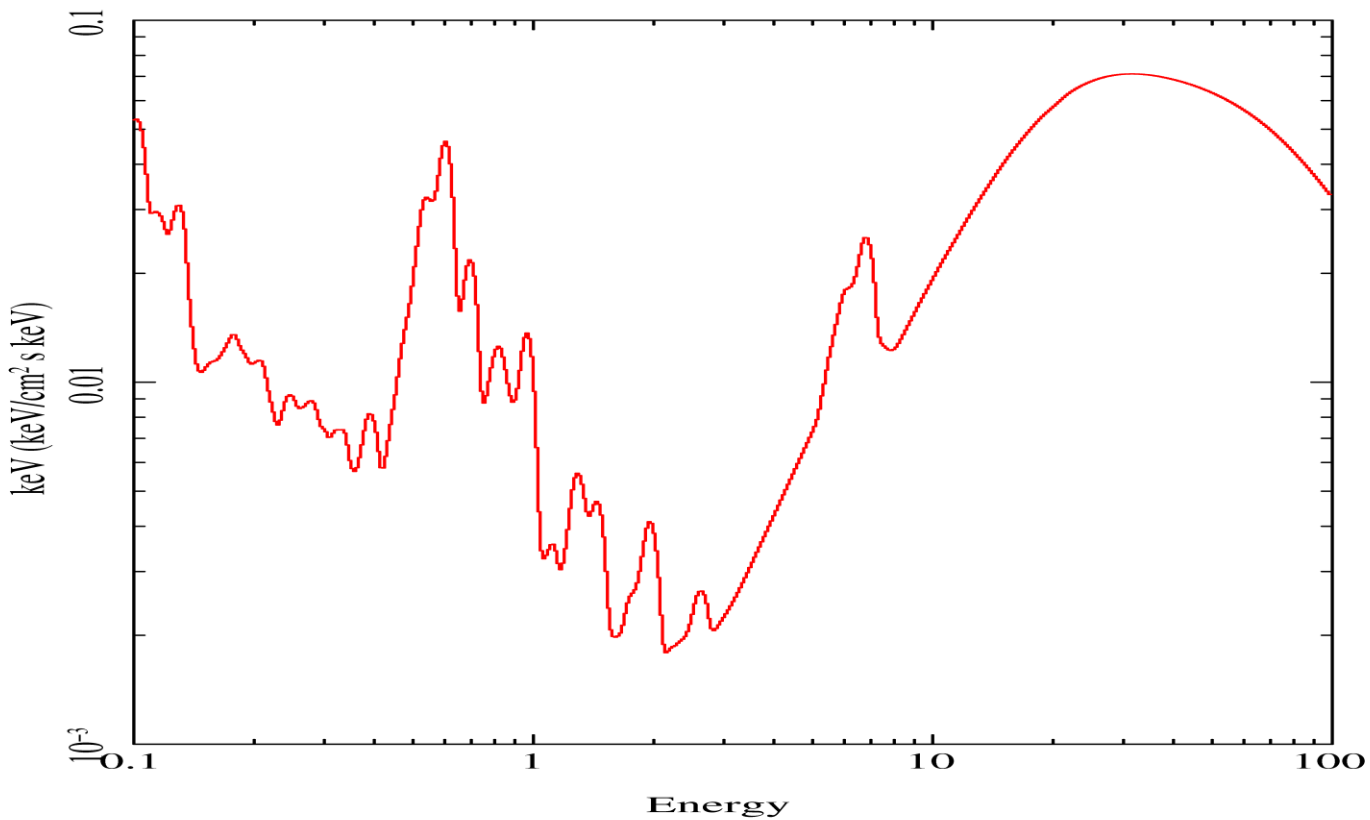
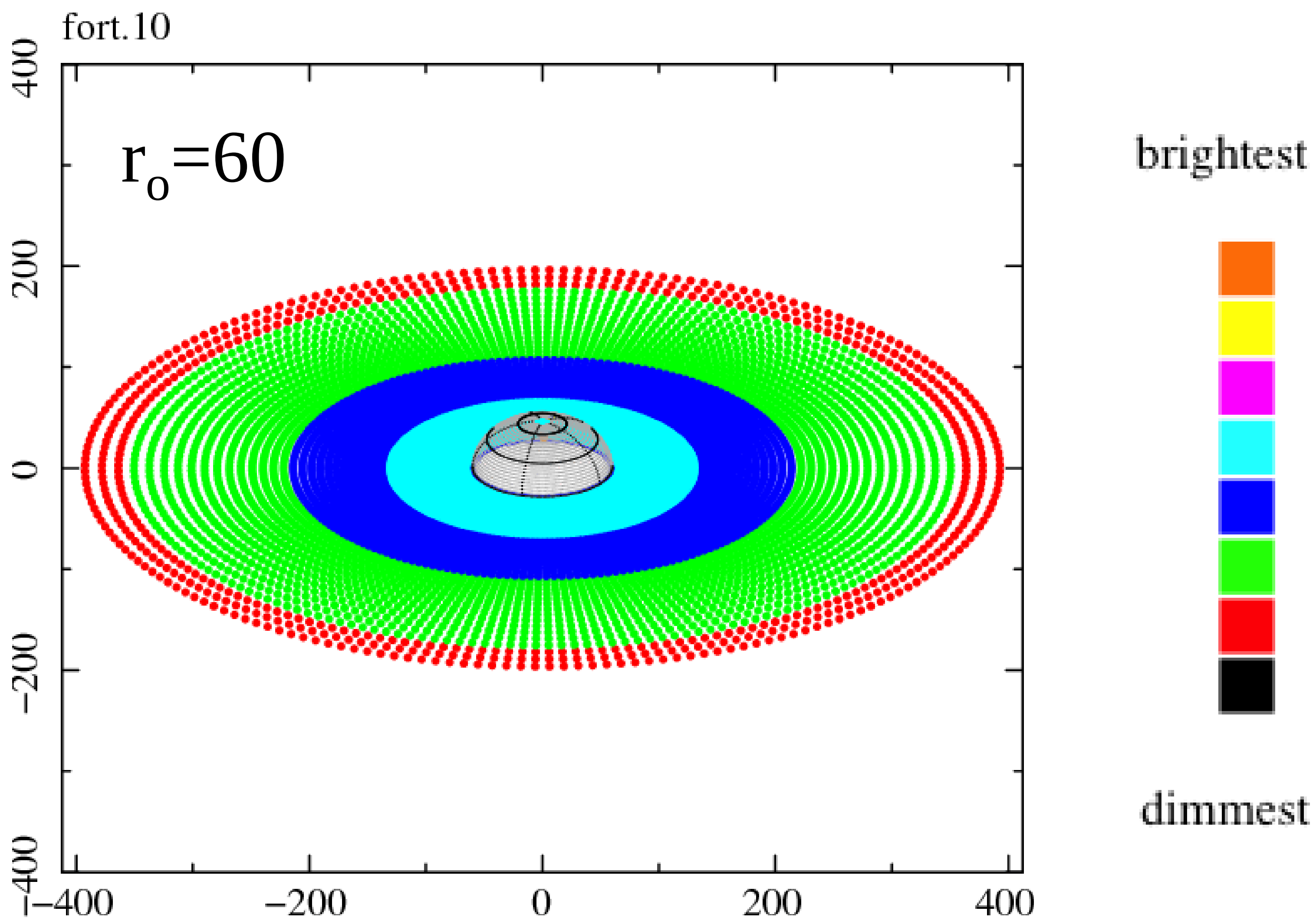


Testing precession



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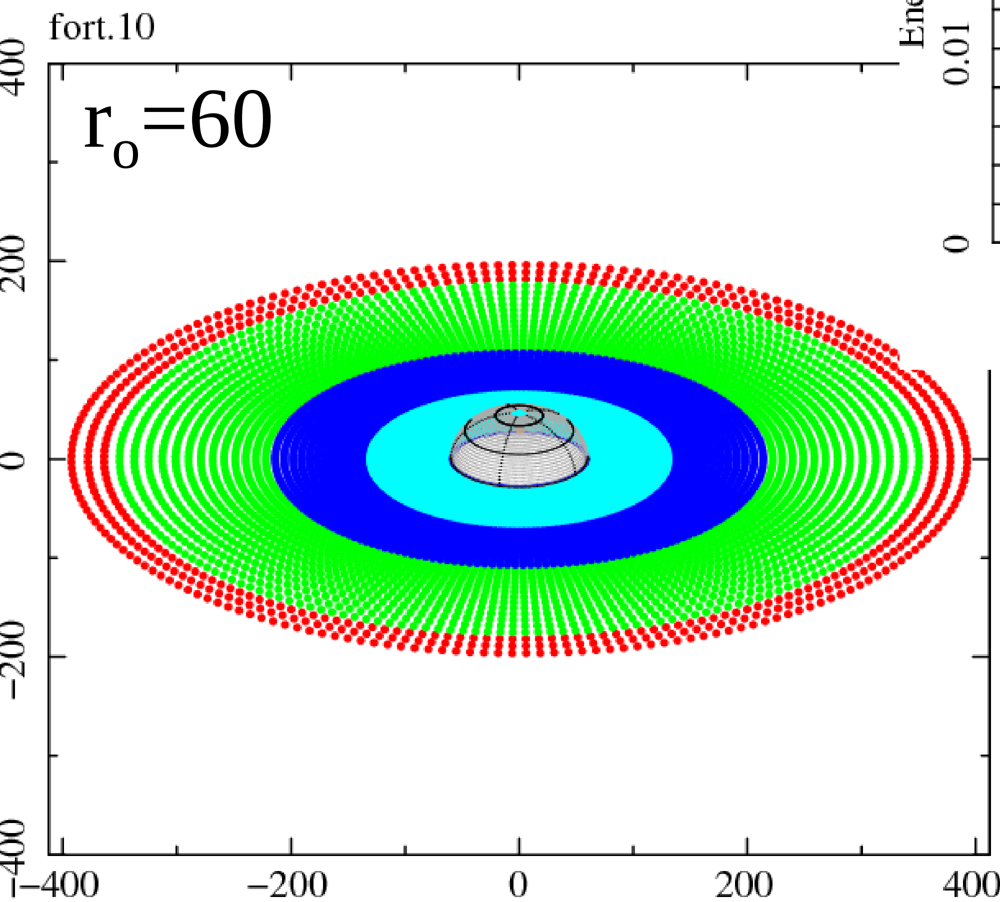
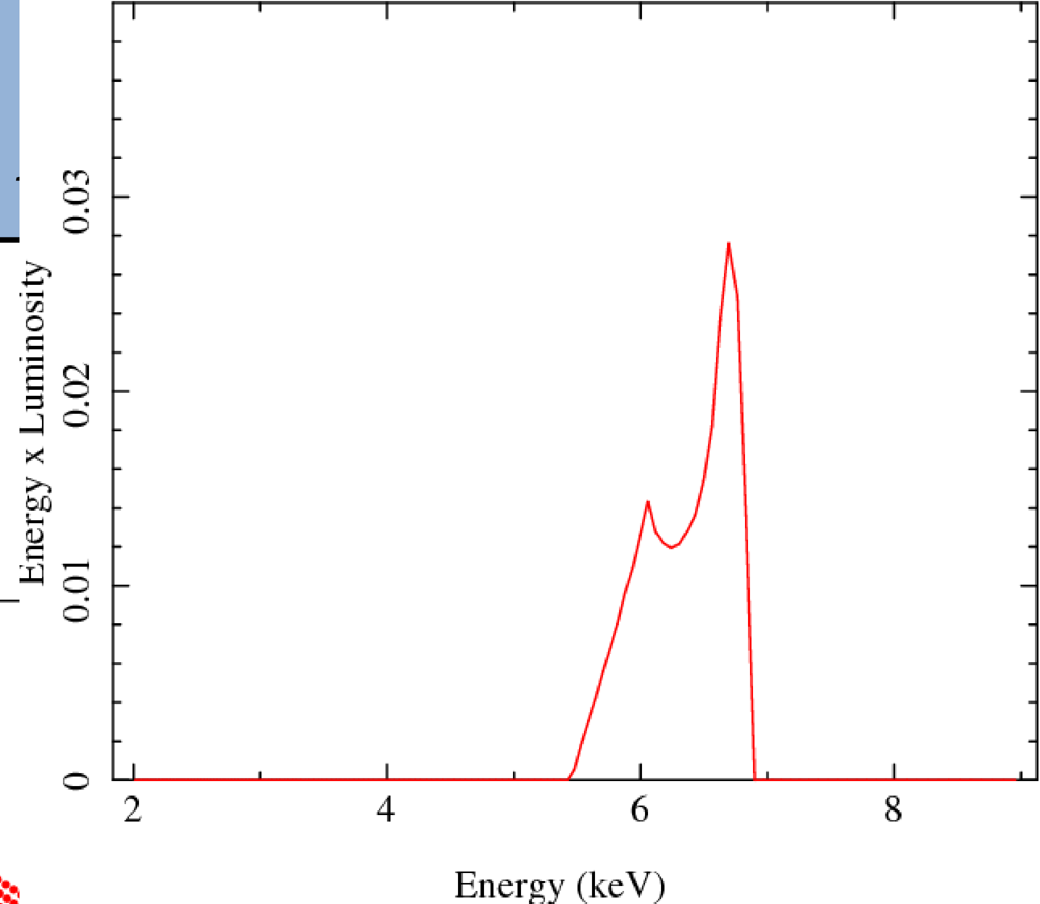
Testing

Ingram & Done 2012b

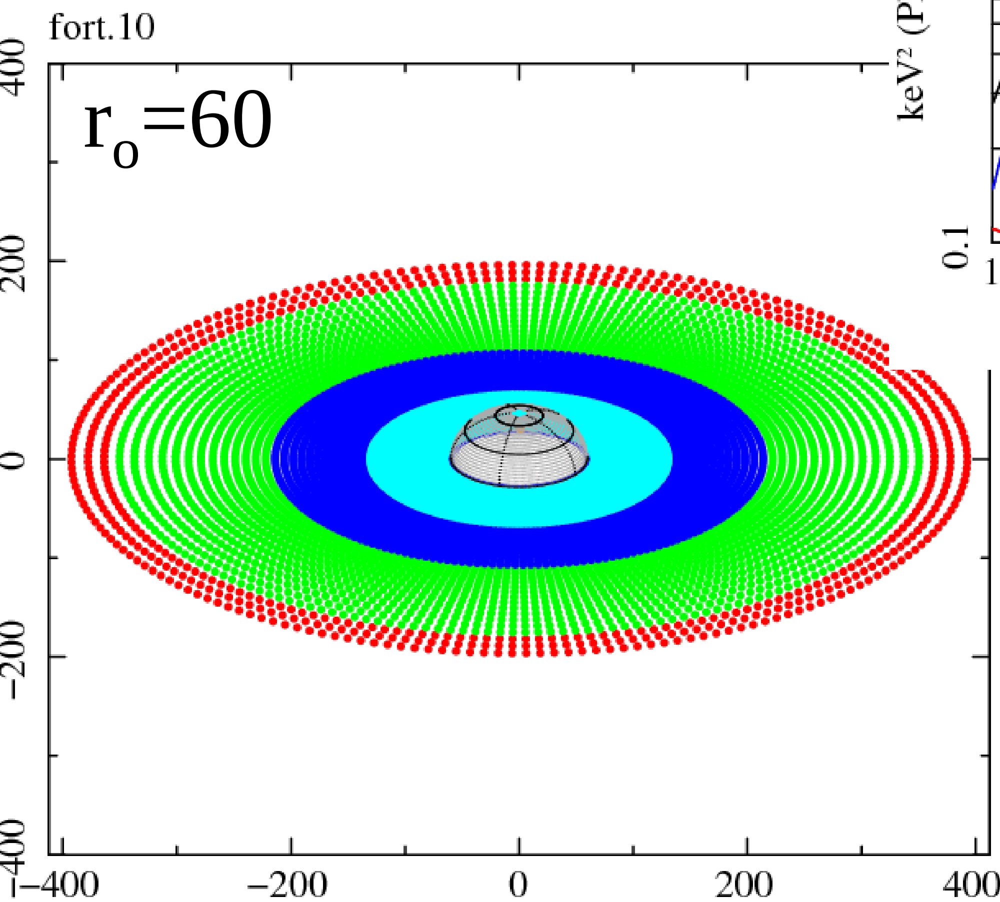


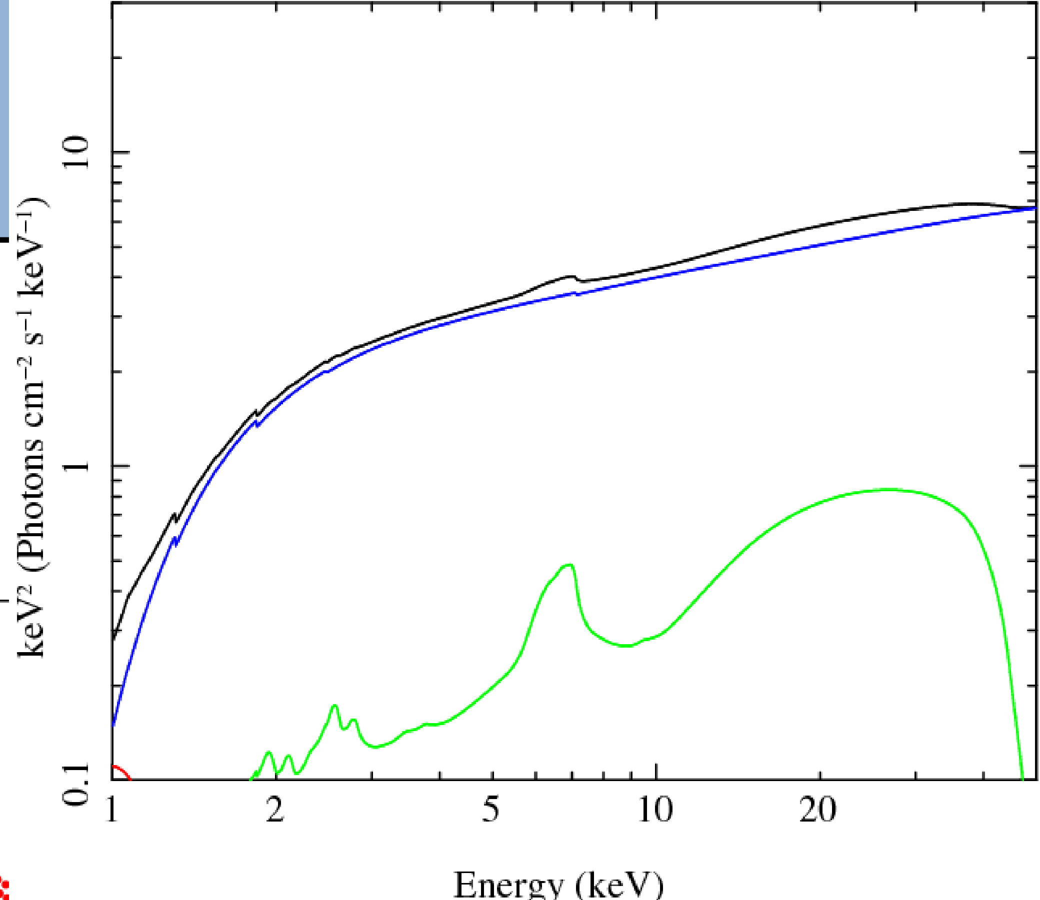


Delta function iron fluorescence at 6.4keV

Testing

Ingram & Done 2012b





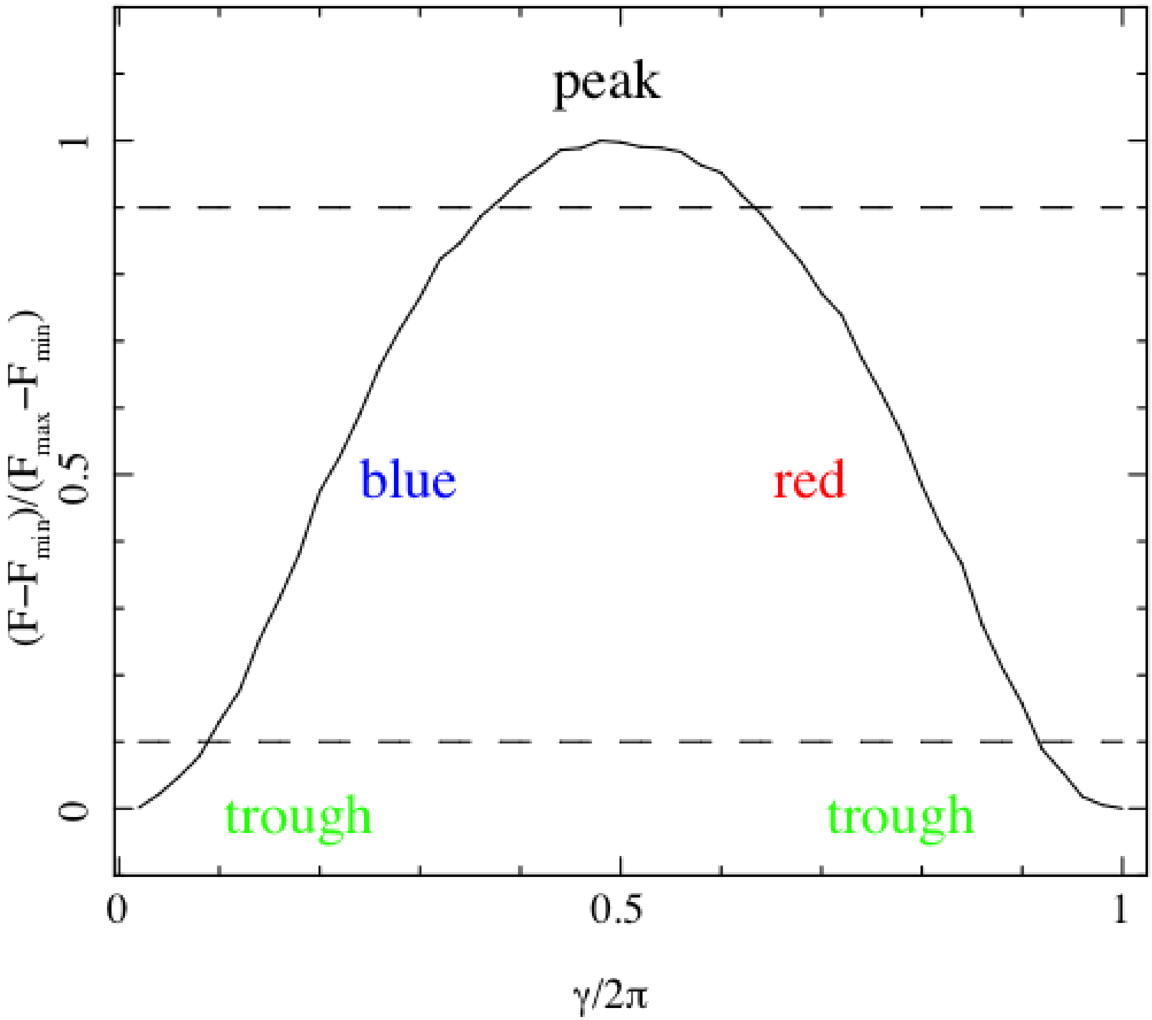
Full spectral model

-Continuum oscillates (NTHCOMP)

- Reflection spectrum shifts in energy (RFXCONV) (Ross & Fabian 2005)

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



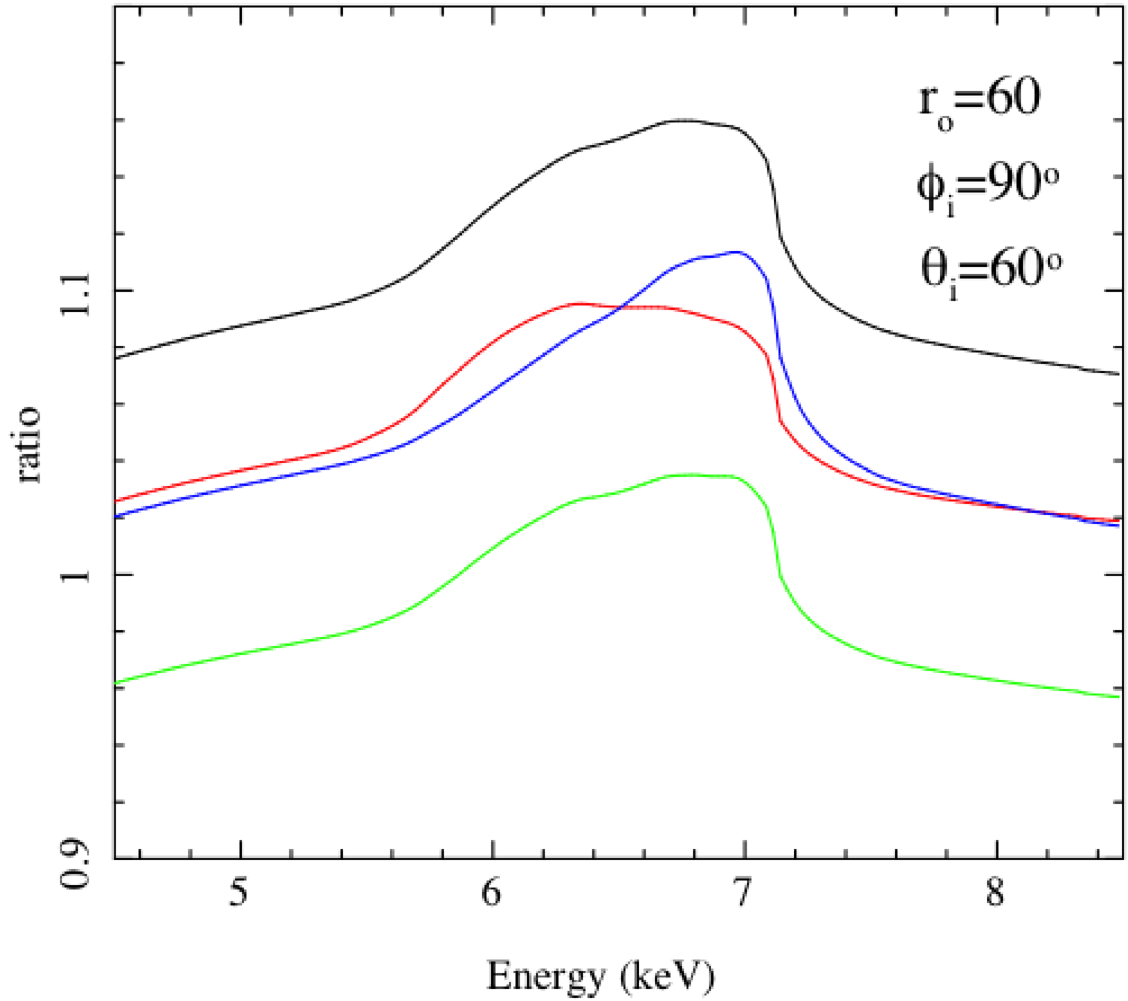
Ingram & Done 2012b

Testing precession

- Plot the spectrum for each of the 4 phase bins

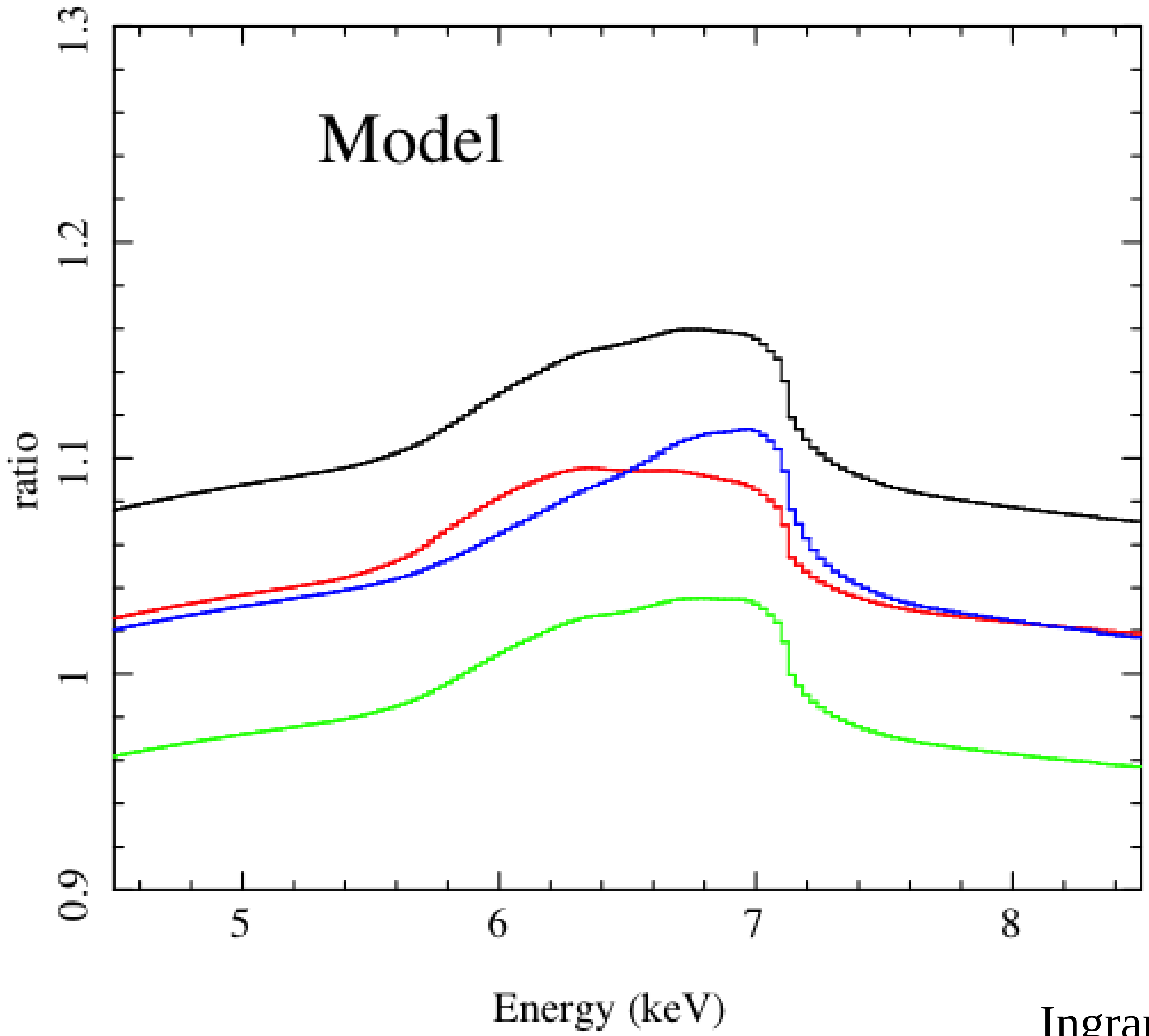
- Black: peak
- Red: fall
- Green: trough
- Blue: rise

- Ratio to a $\Gamma=1.6$ power law



Ingram & Done 2012b

Testing precession



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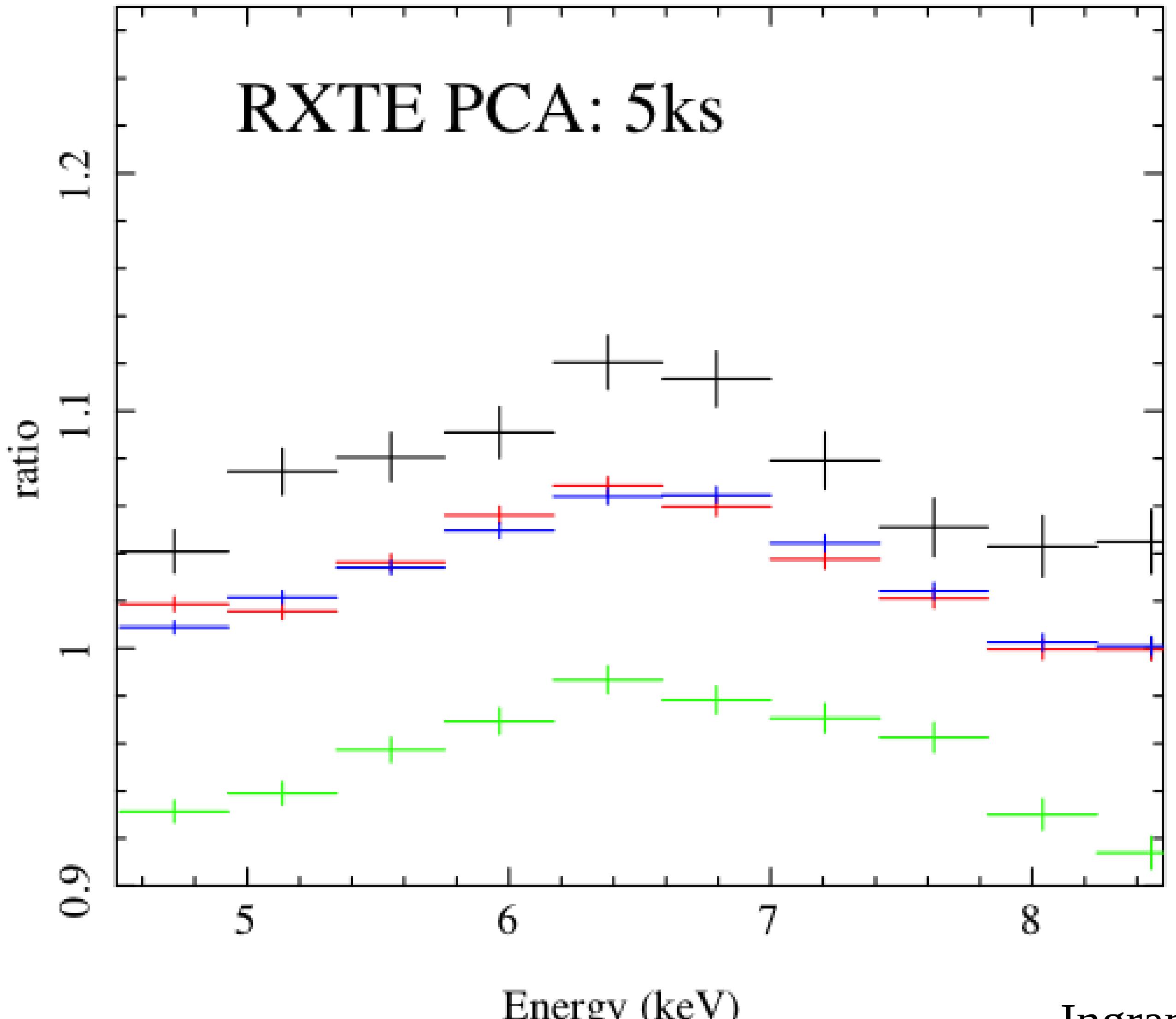

Ingram & Done 2012b

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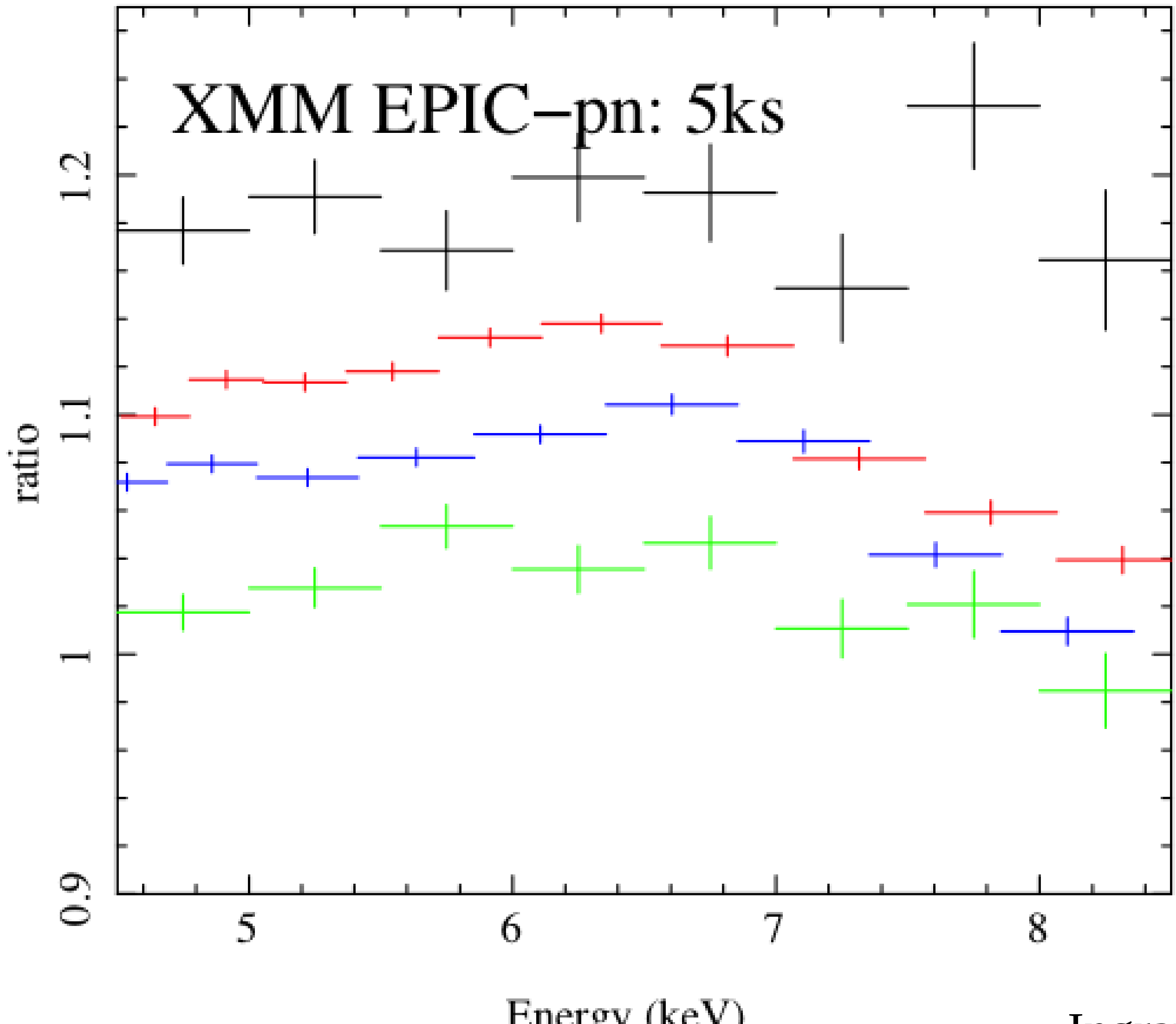

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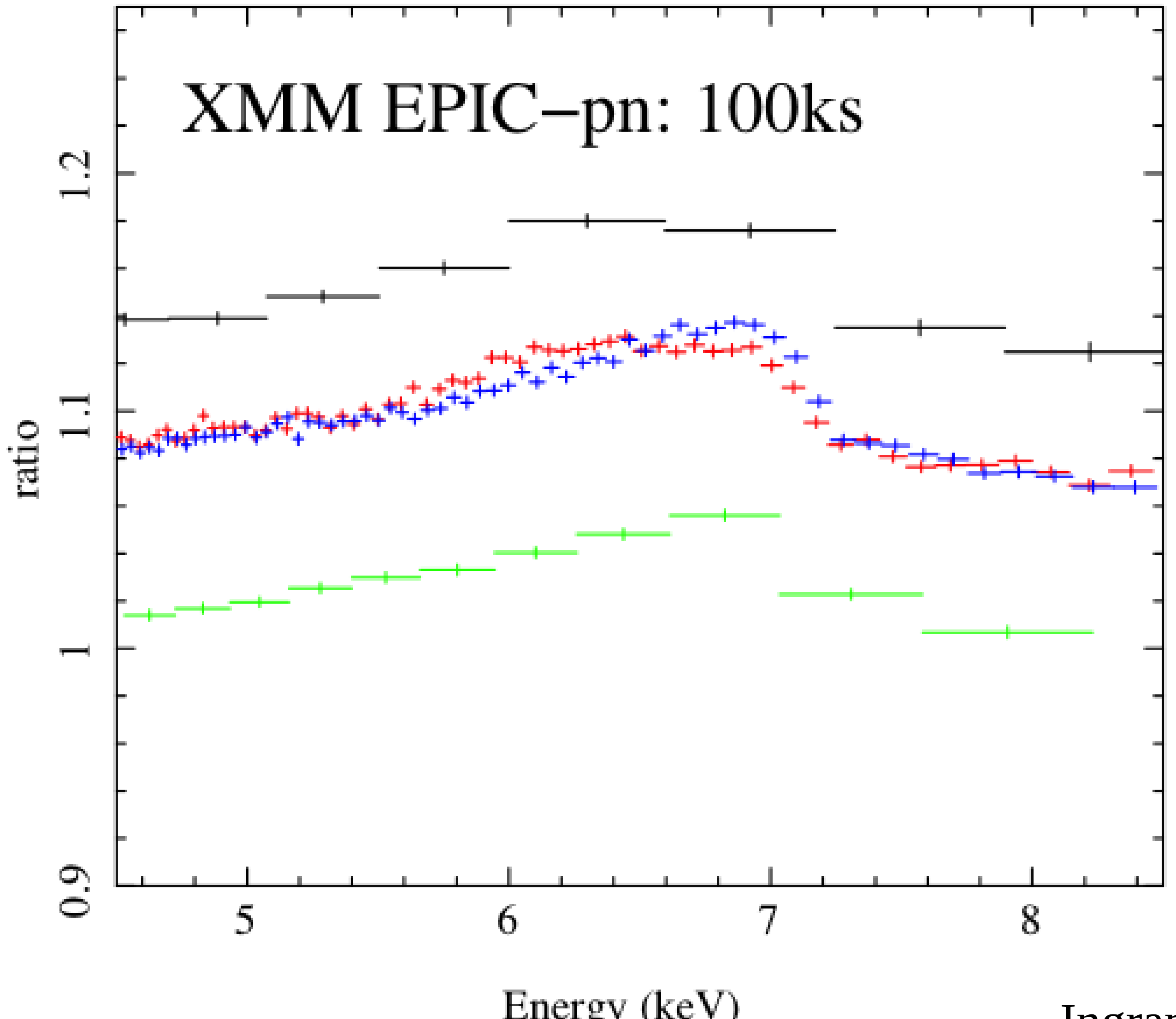

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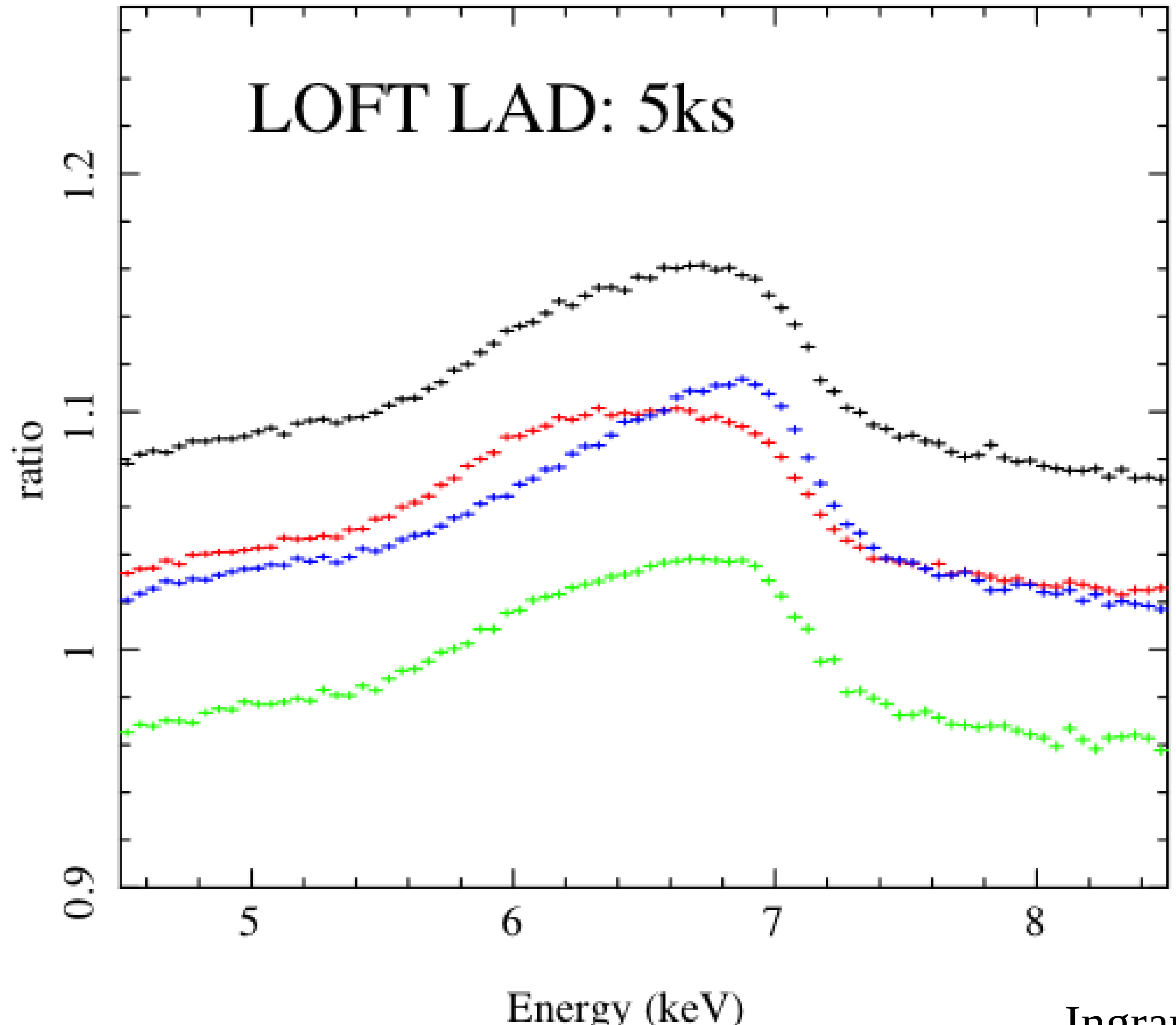

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Conclusions

- Lense-Thirring precession model can predict QPO frequencies for black holes as a class
- Precession causes a rotating illumination pattern which causes the iron line to rock between red and blue shift
- Reddest spectrum is the fall (after peak) and bluest spectrum is the rise (after trough)
- It may be possible to observe this with long exposures on current instruments but LOFT will *revolutionize* the field!

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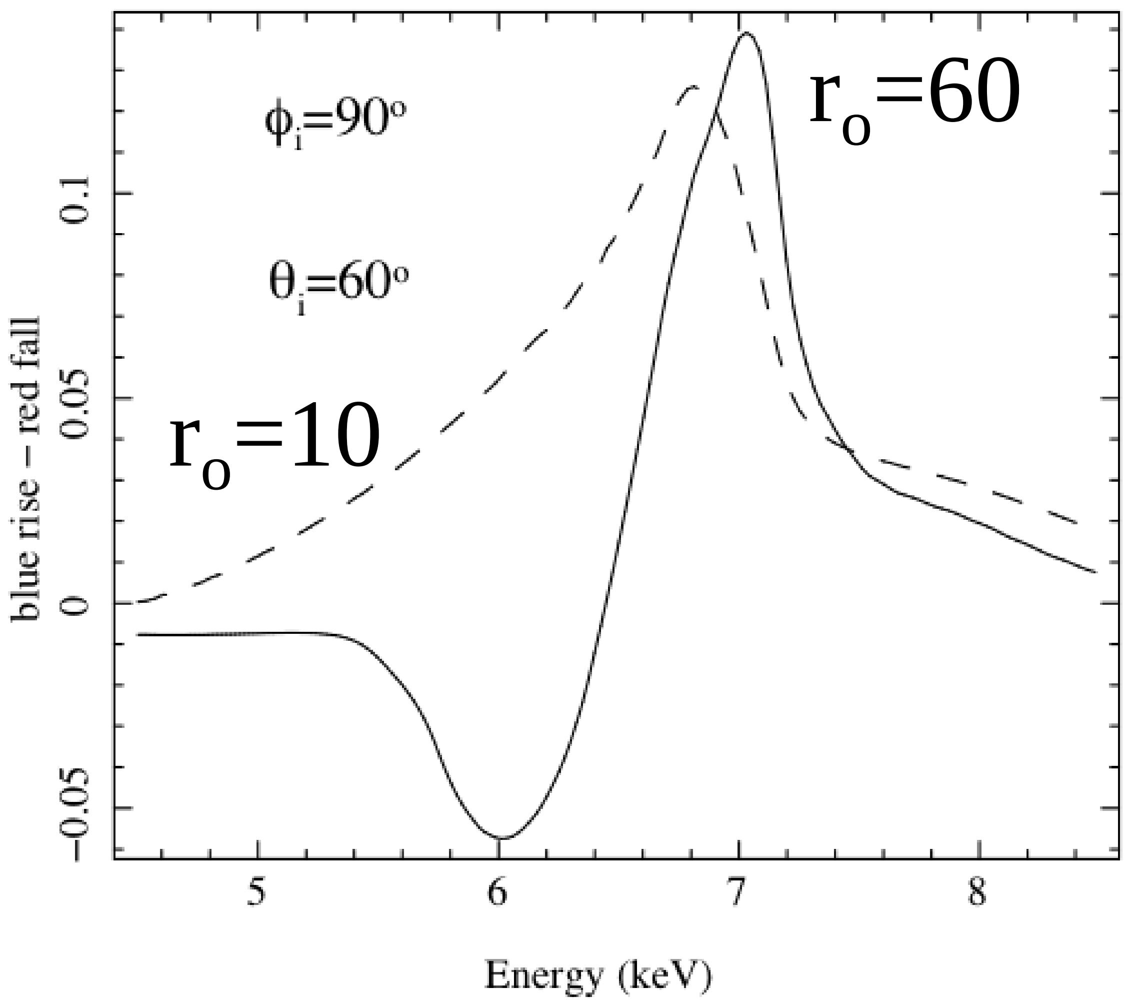
Testing precession

- Take difference spectrum of (blue rise - red fall)
- For $r_o=60$, get 'red dip' and 'blue trough'
- For $r_o=10$, no red dip due to strong Doppler boosting in the inner regions
- => Potentially a robust diagnostic for disc truncation

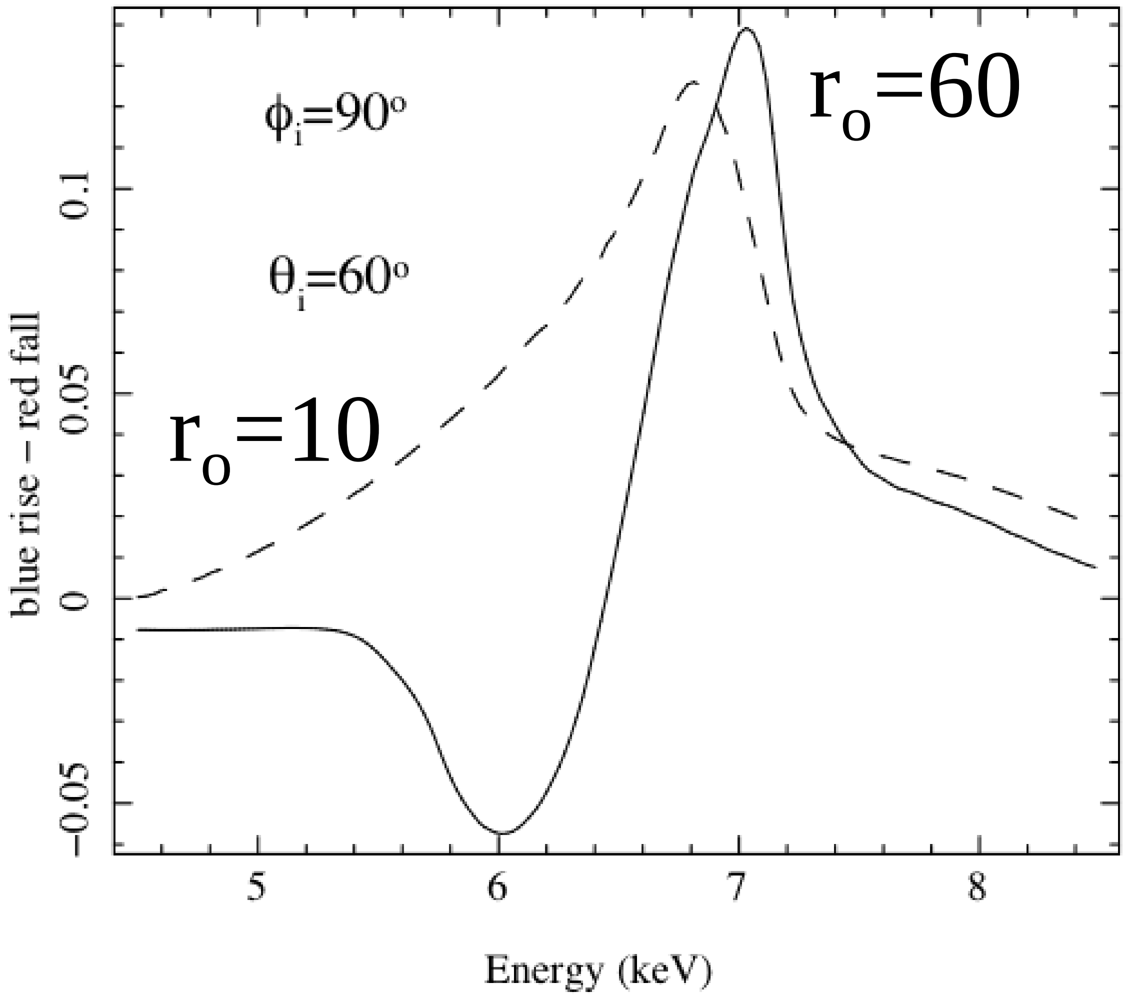


Ingram & Done 2012b

Testing precession

- Real smoking gun for LT precession is red dip

- => Need to look in the low/hard state



Ingram & Done 2012b

Broadband noise

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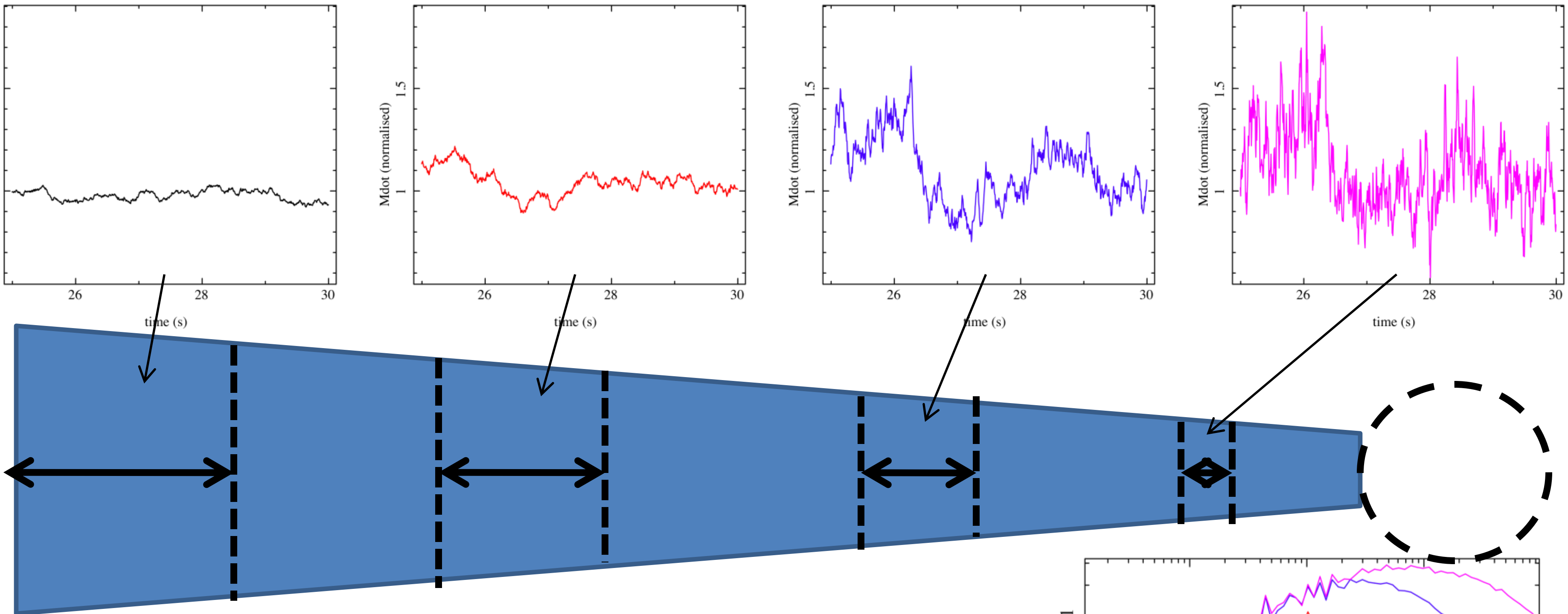
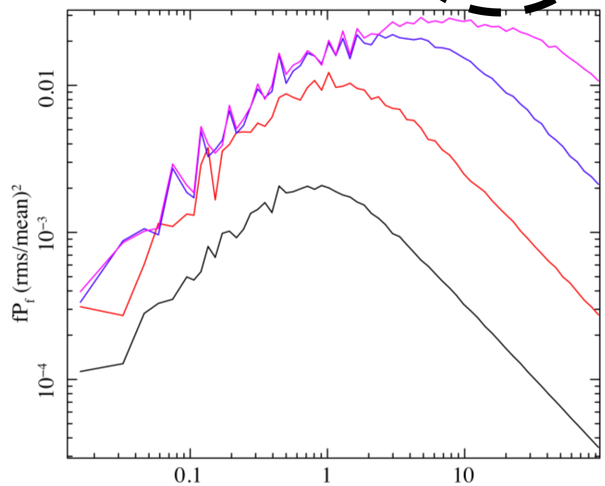
Propagating fluctuations



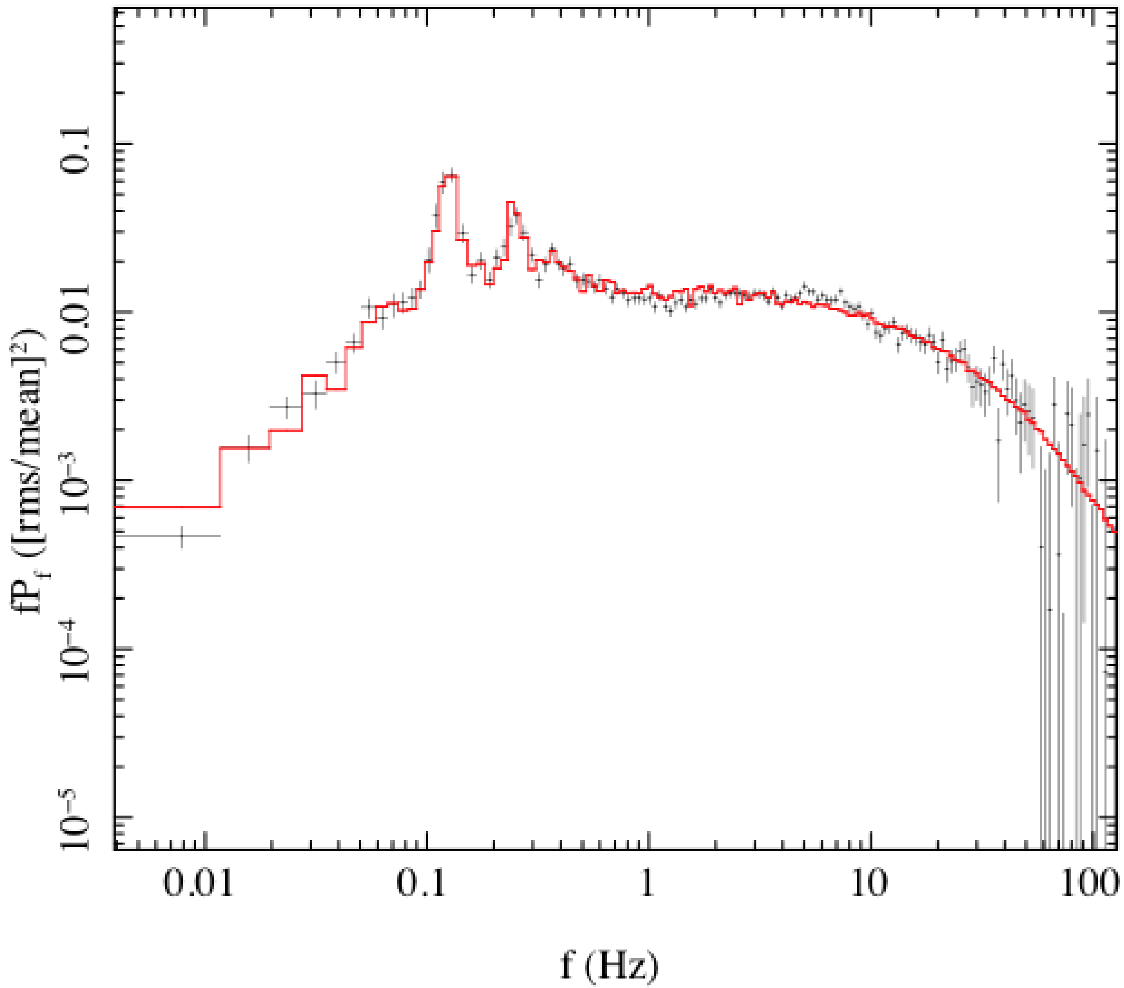


This gives the noise spectrum EMMITED at each annulus

Lyubarskii 1997; Arevalo & Uttley 2006, Kotov et al 2001

Fitting to XTE J1550-564

r_o=68.0



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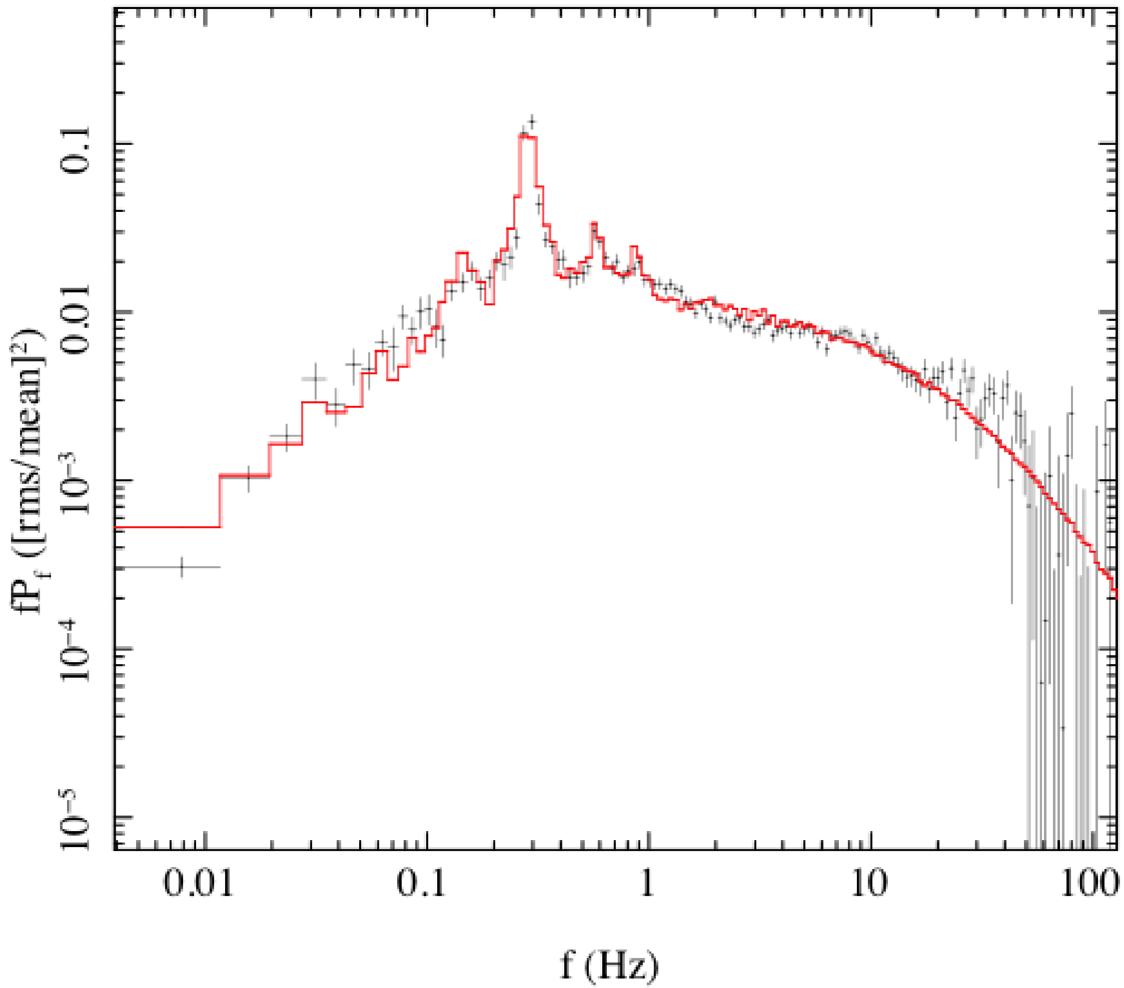
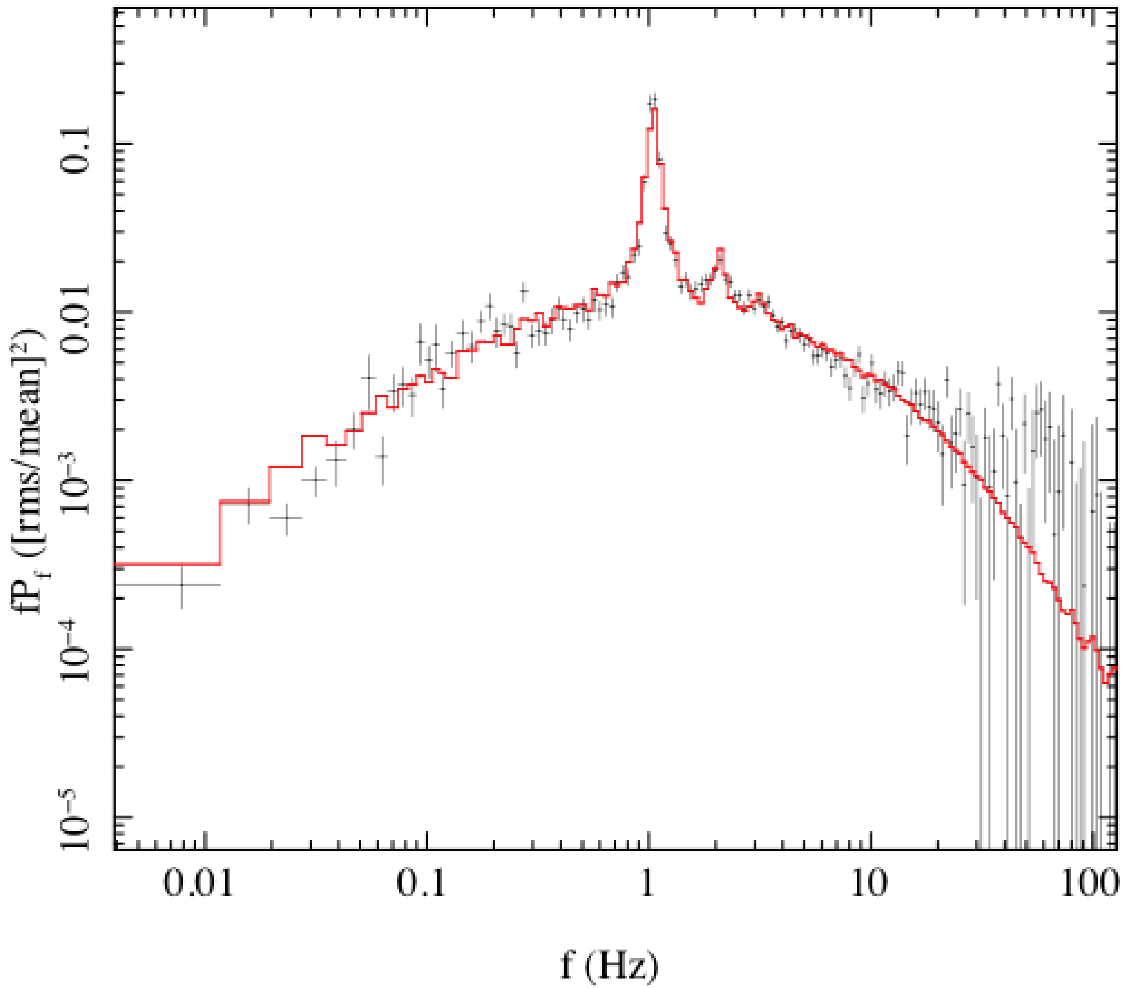
Fitting to XTE J1550-564

r_o=45.7



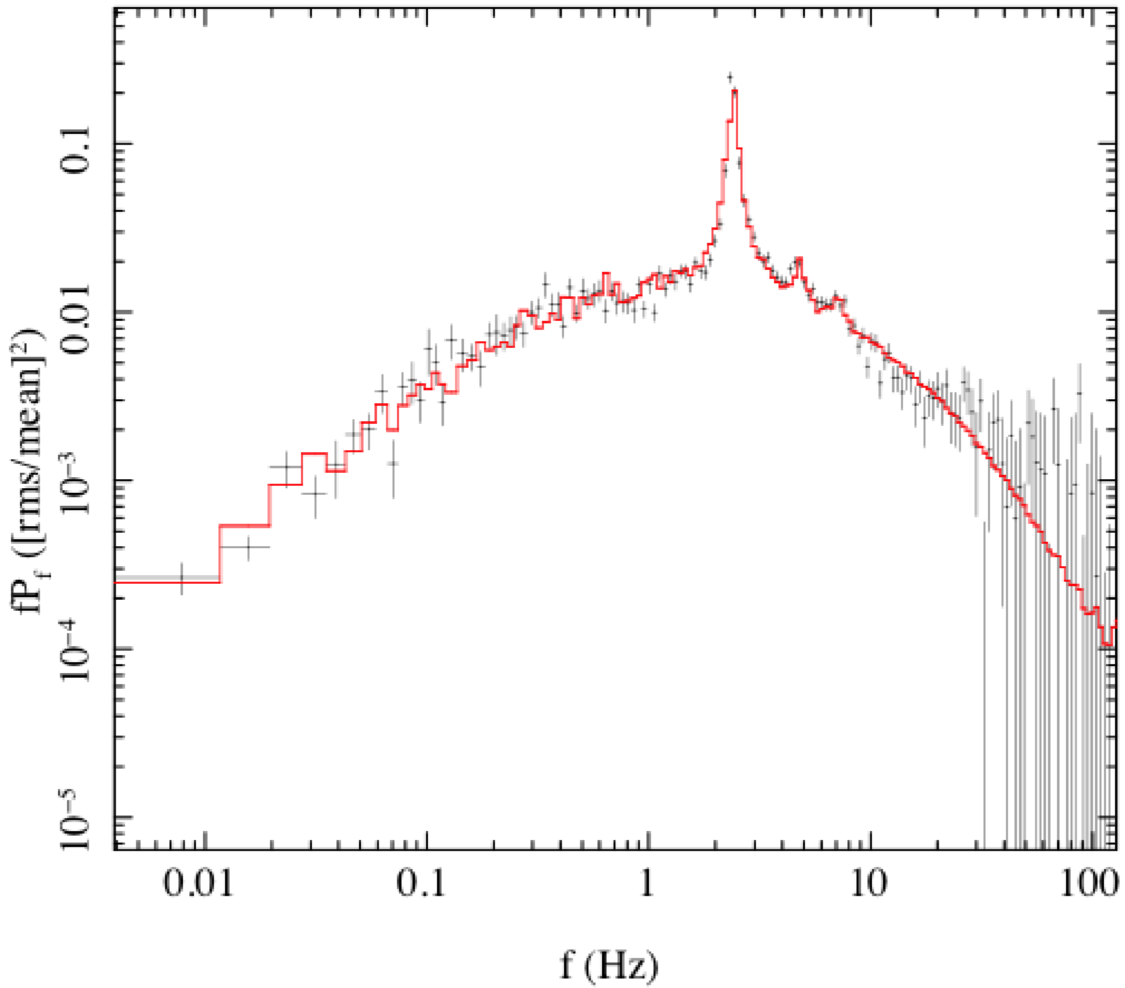
Fitting to XTE J1550-564

r_o=25.0



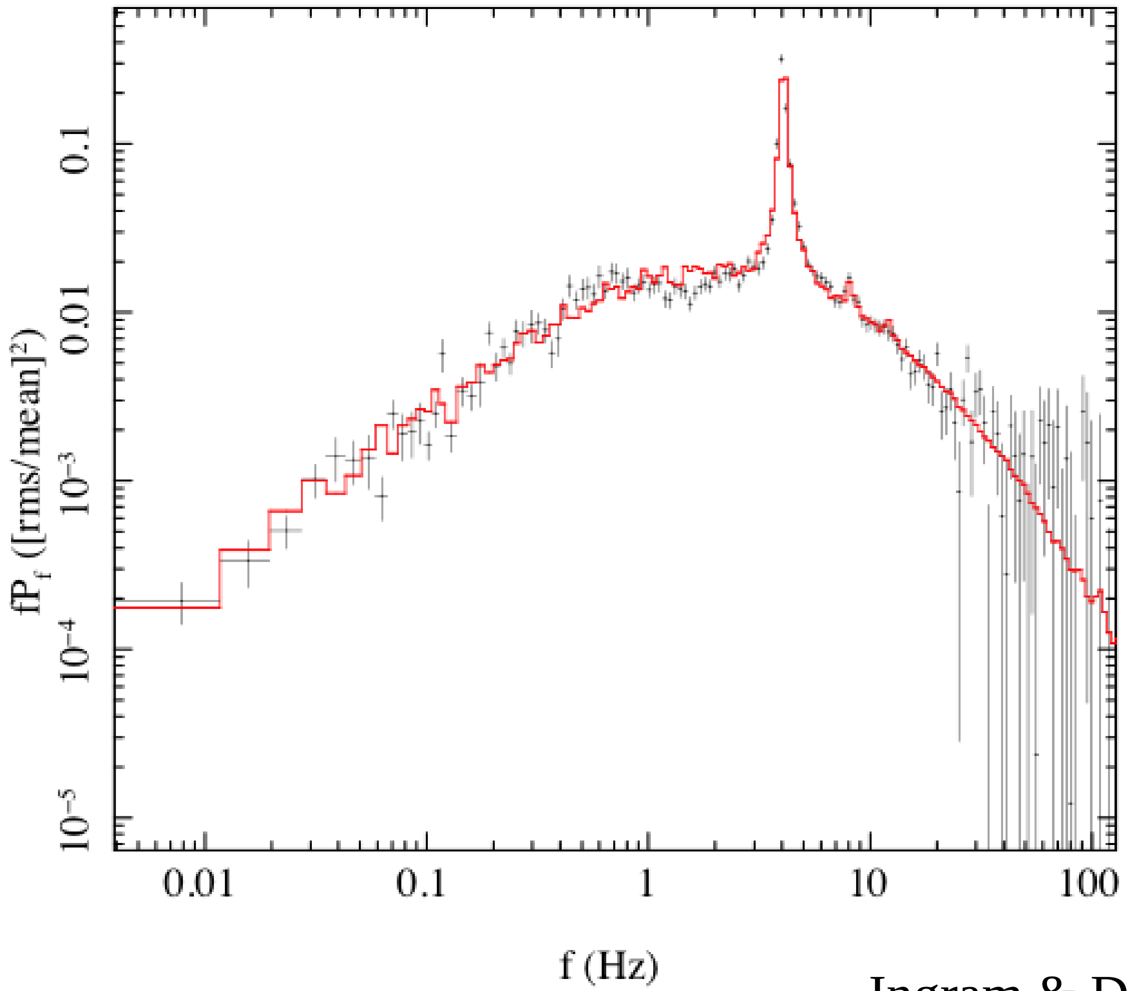
Fitting to XTE J1550-564

r_o=16.3



Fitting to XTE J1550-564

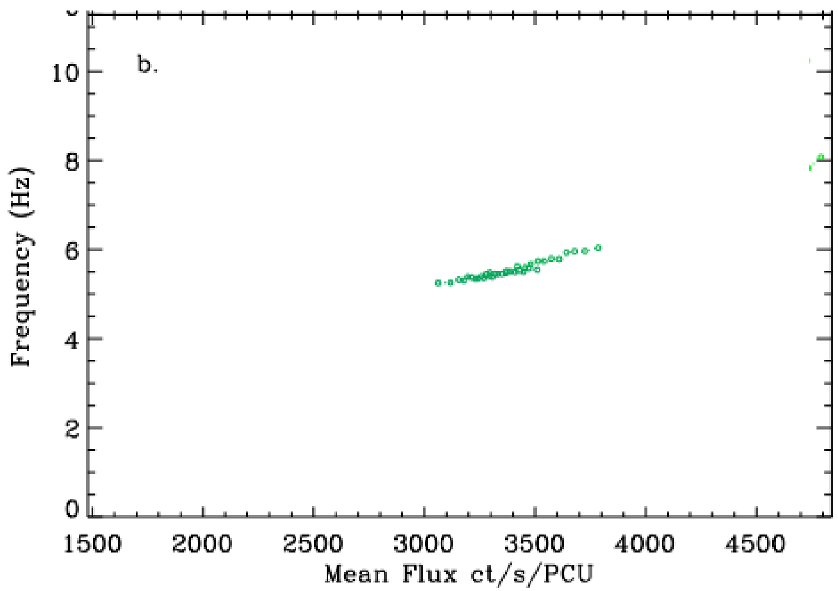
r_o=12.8

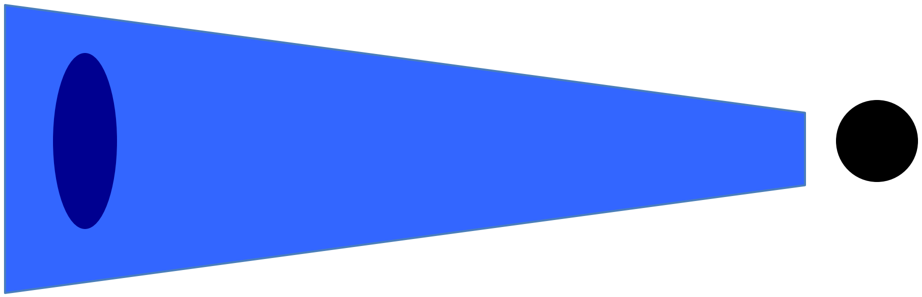


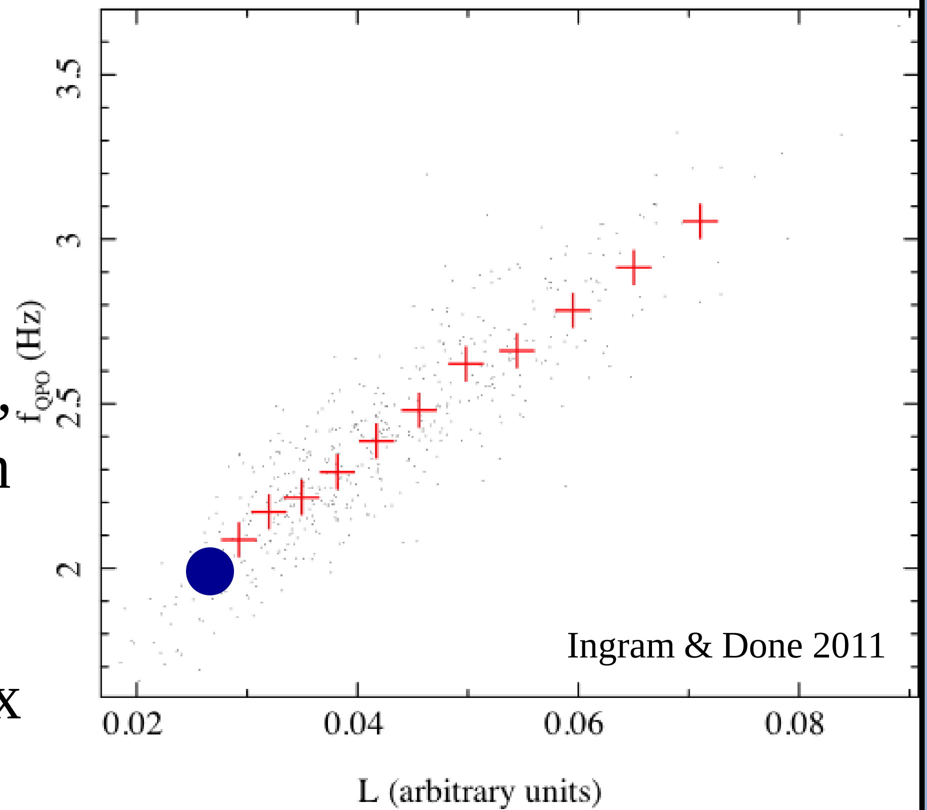
PROPFLUC
Ingram & Done 2011; 2012a

Frequency jitter

Heil, Vaughan & Uttley 2011





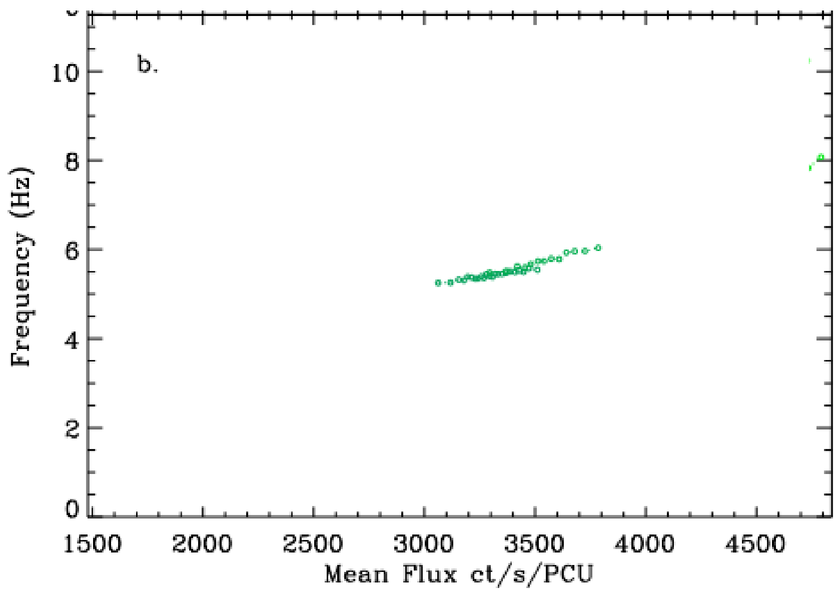


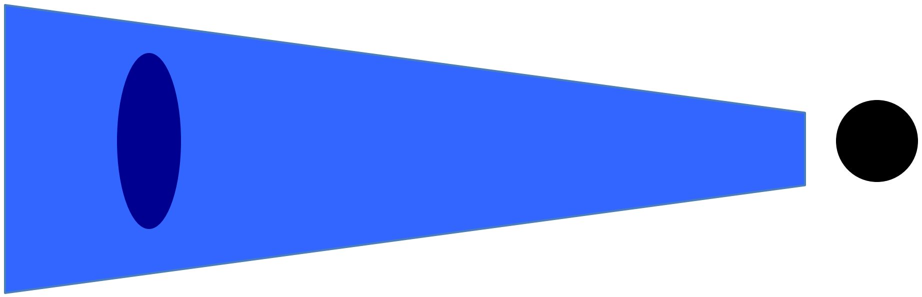
Ingram & Done 2011

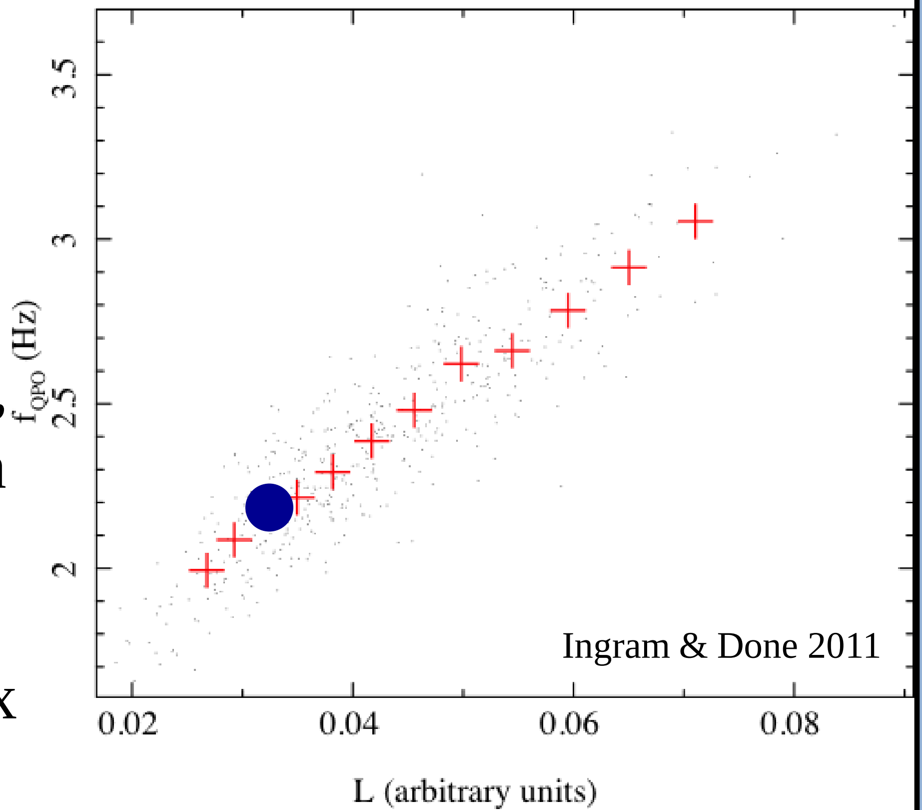
- On short timescales (3s segments), the QPO frequency correlates with the source flux
- Our model *predicts* this because both precession frequency and flux depend on mass accretion rate

Frequency jitter

Heil, Vaughan & Uttley 2011







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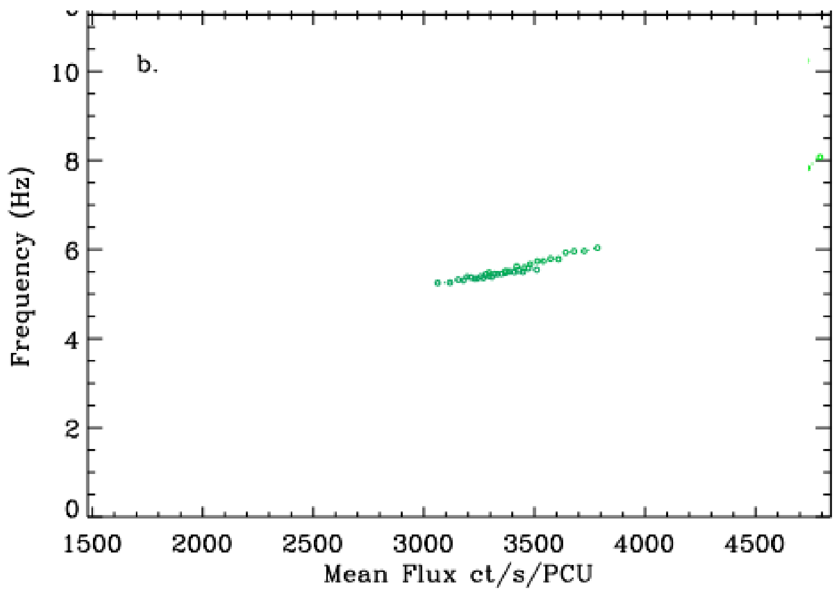
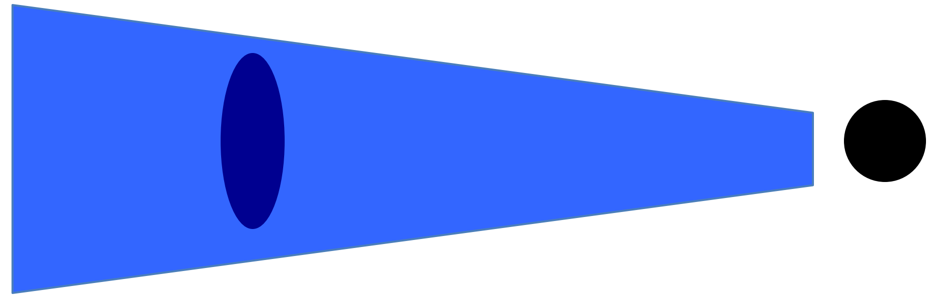
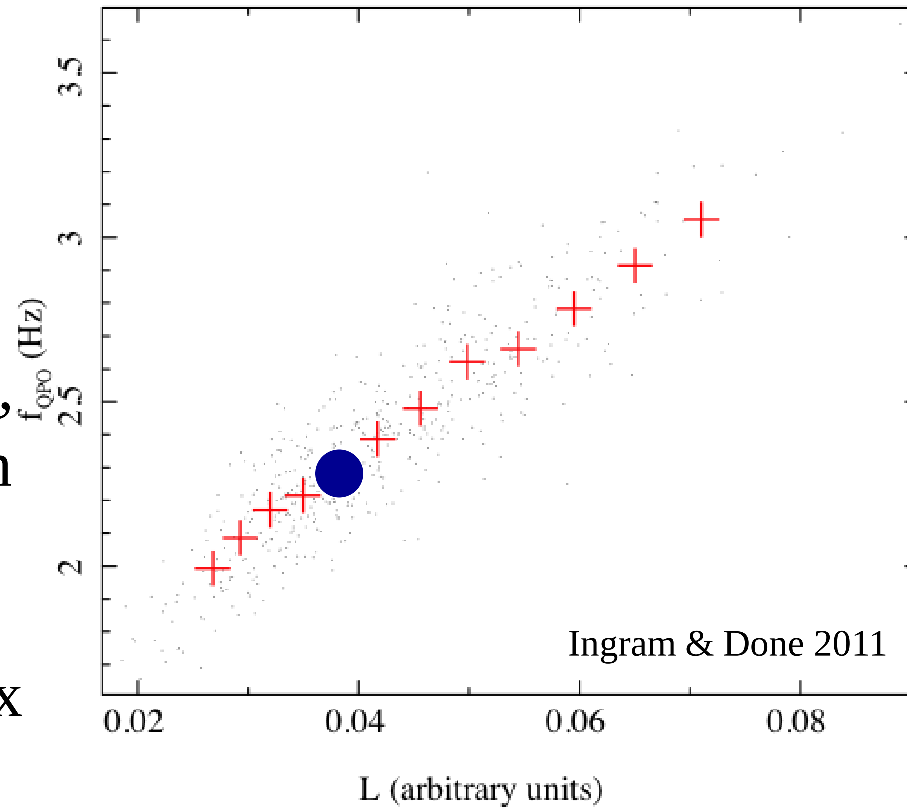
Heil, Vaughan & Uttley 2011







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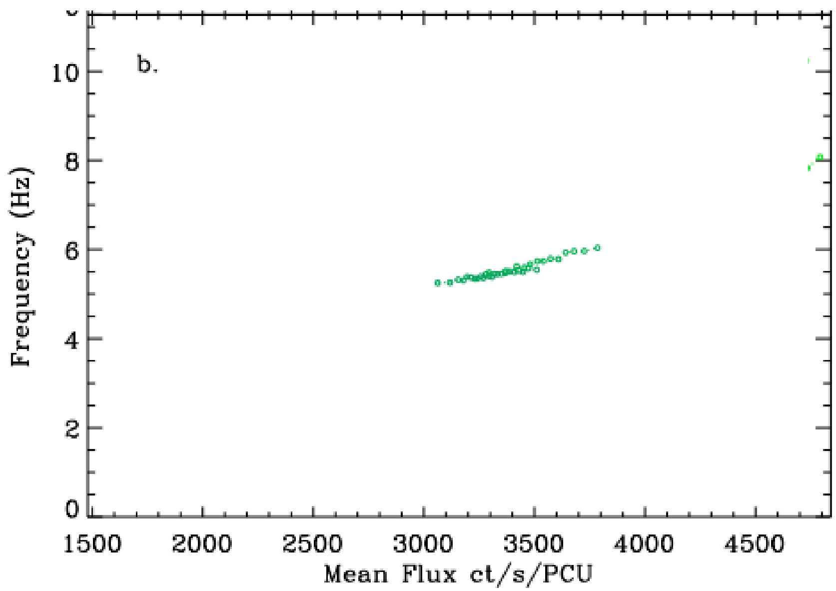

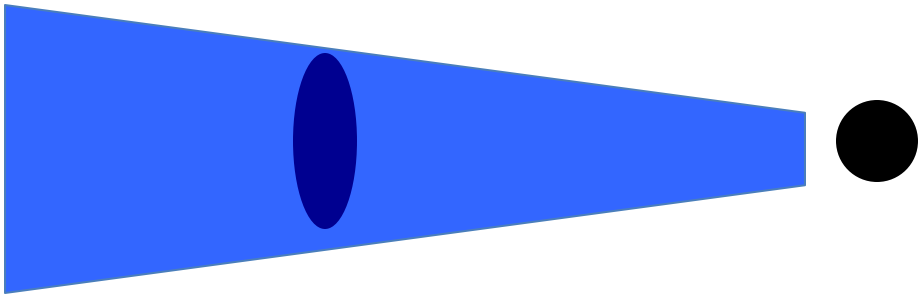

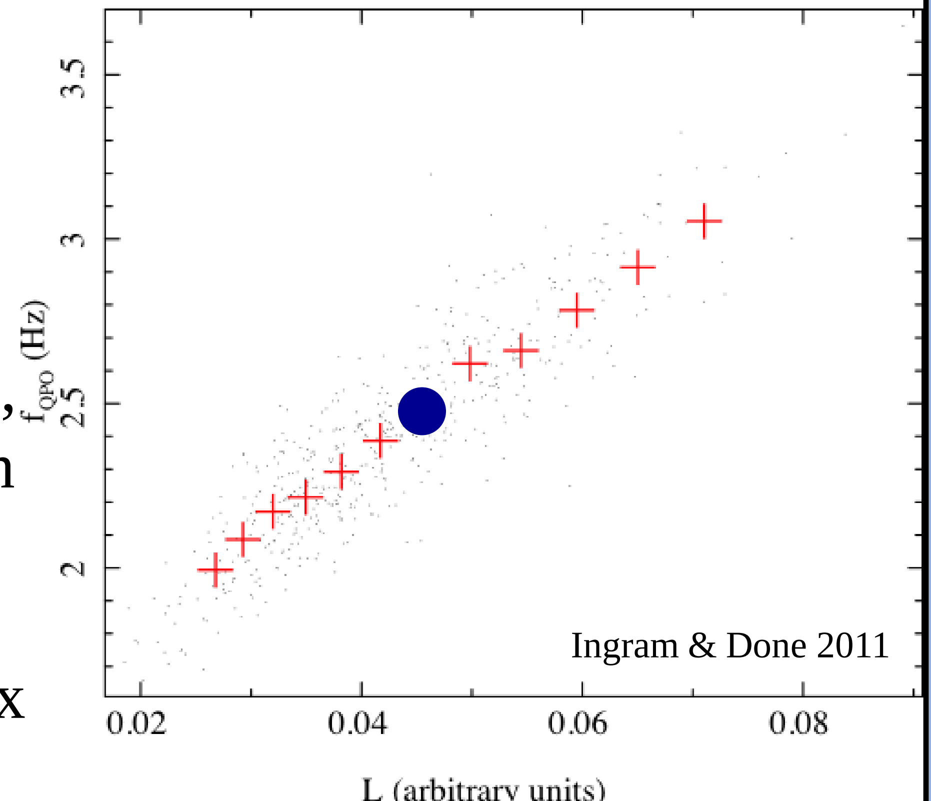

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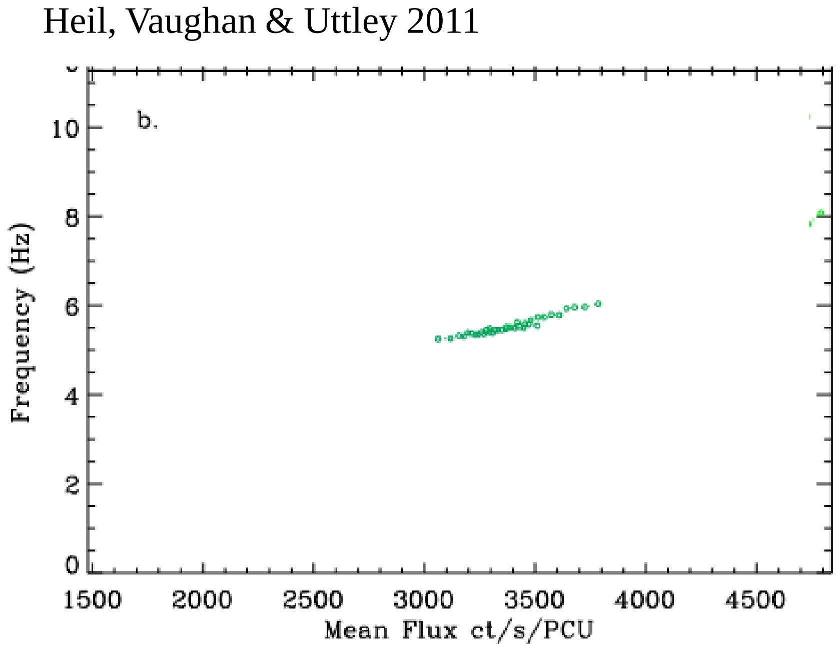
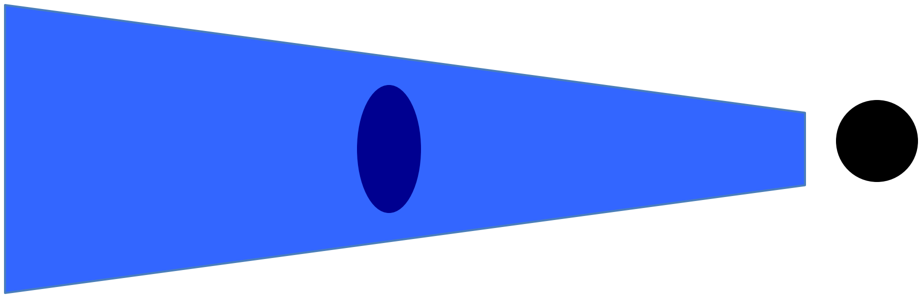
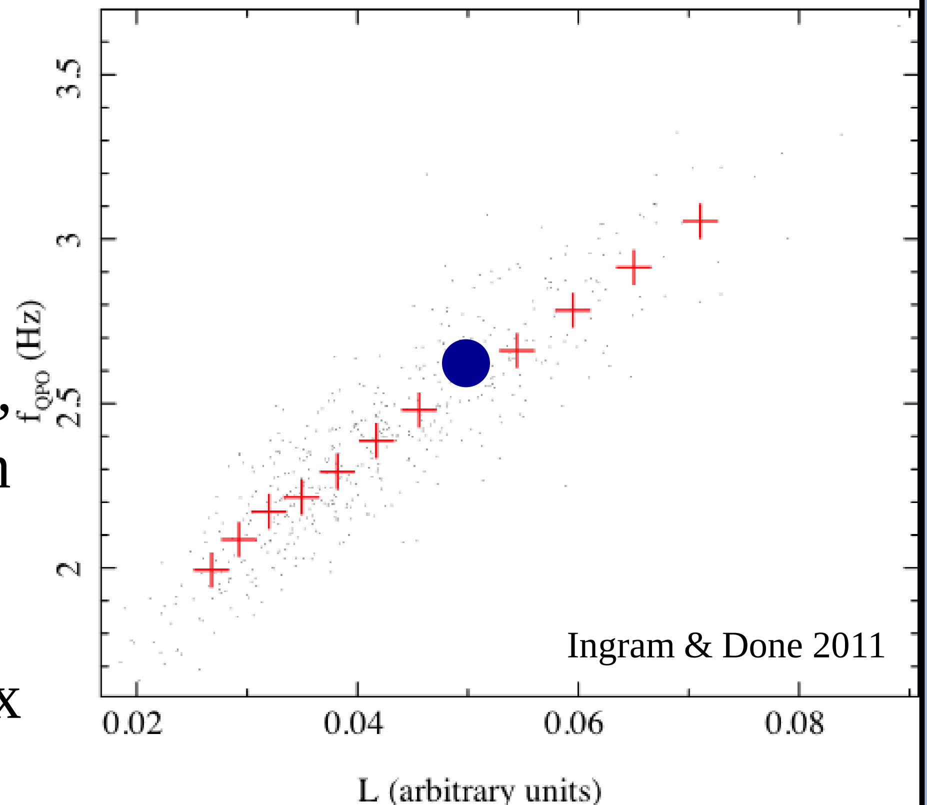
Frequency jitter







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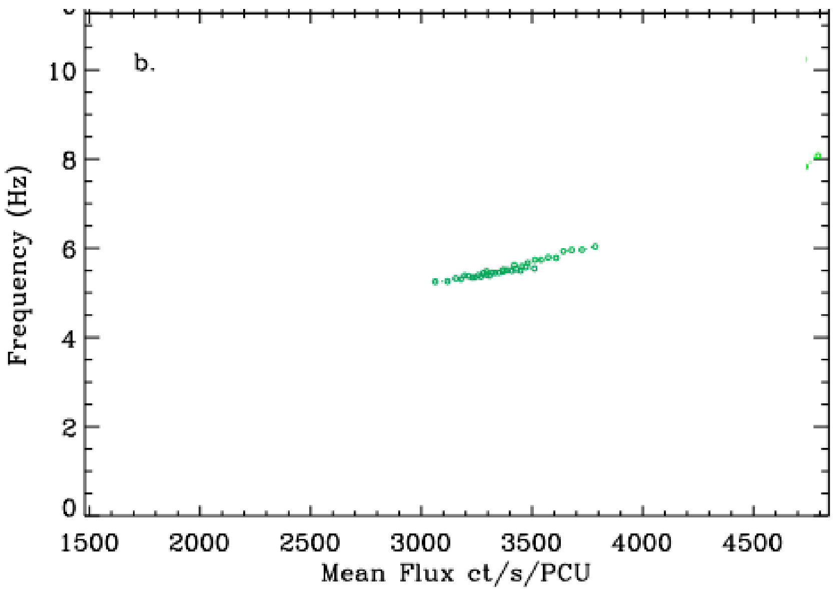
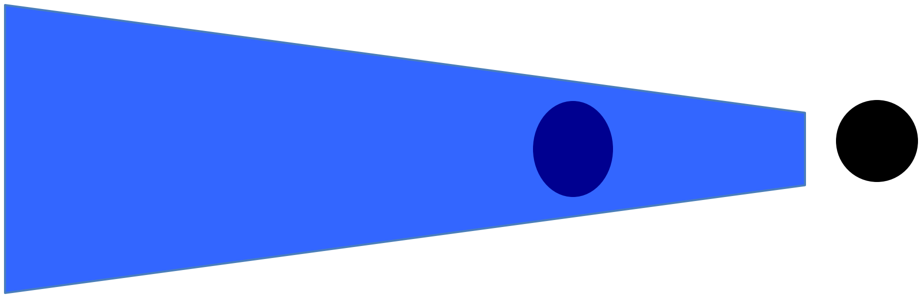
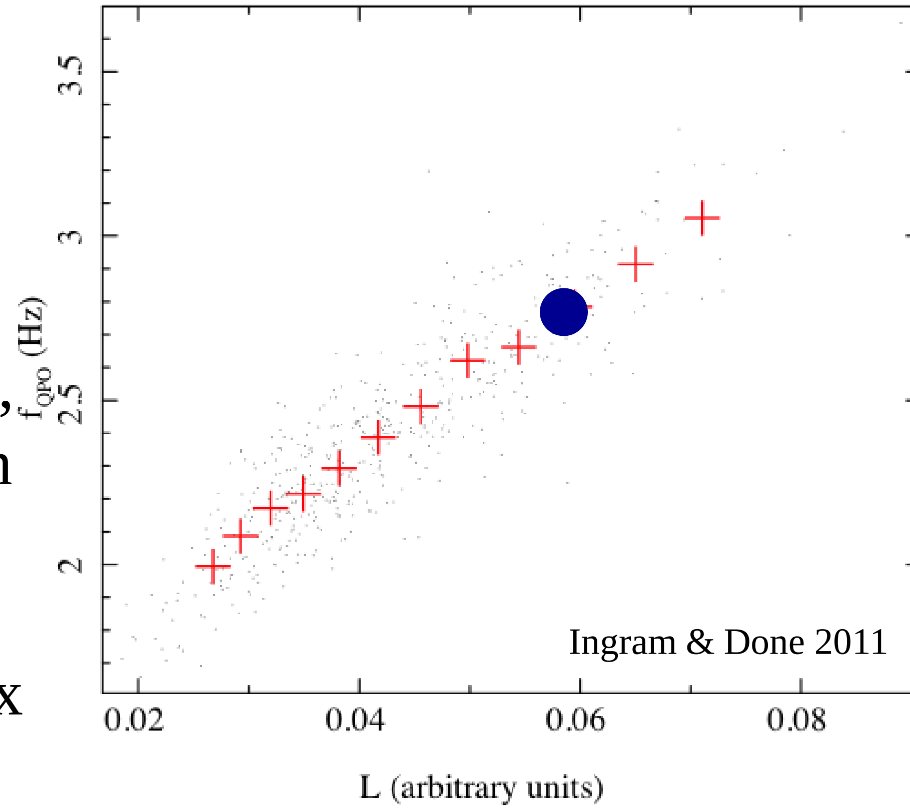
Frequency jitter

Heil, Vaughan & Uttley 2011







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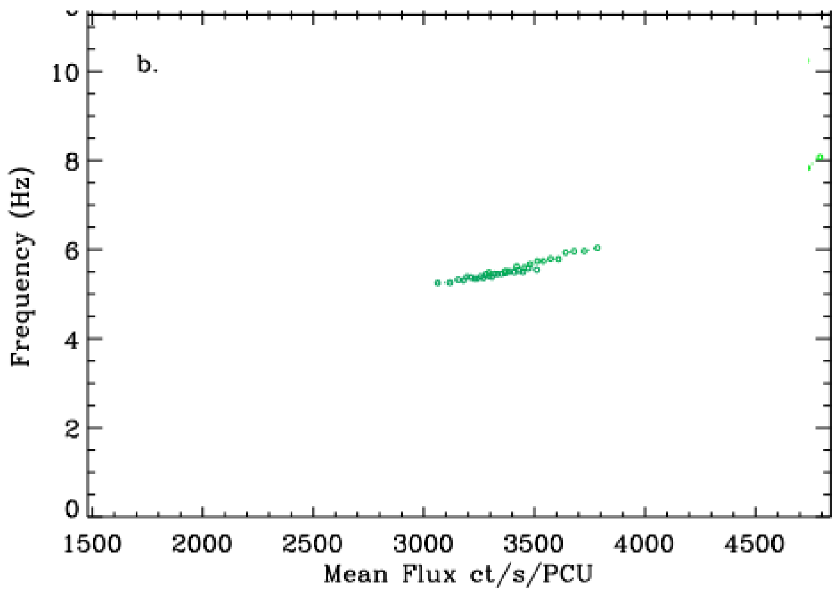

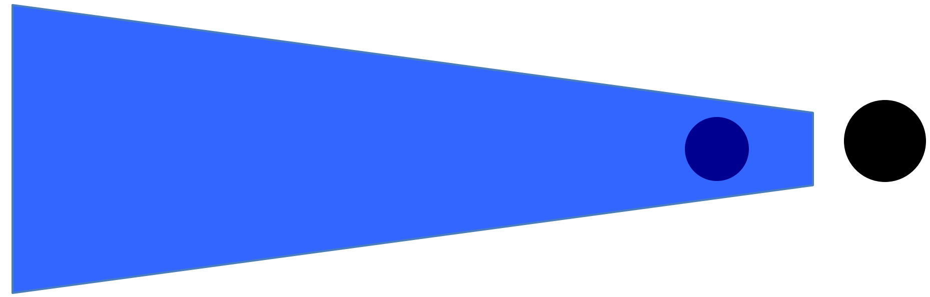

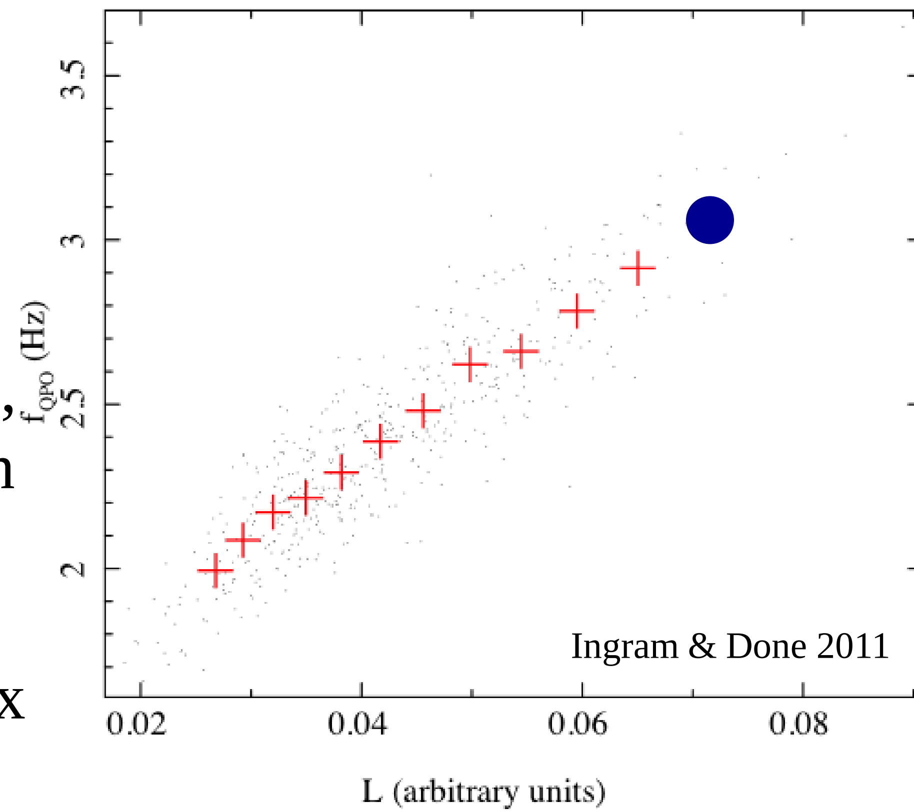

Ingram & Done 2011

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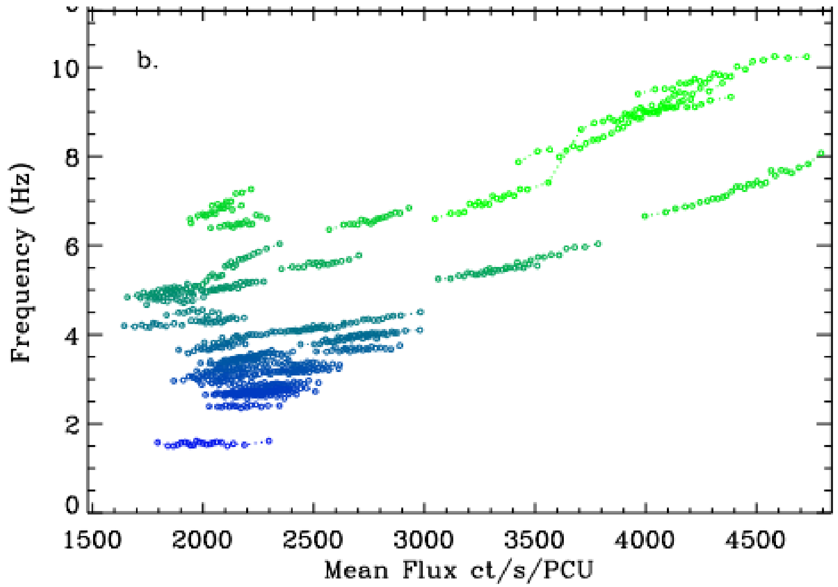
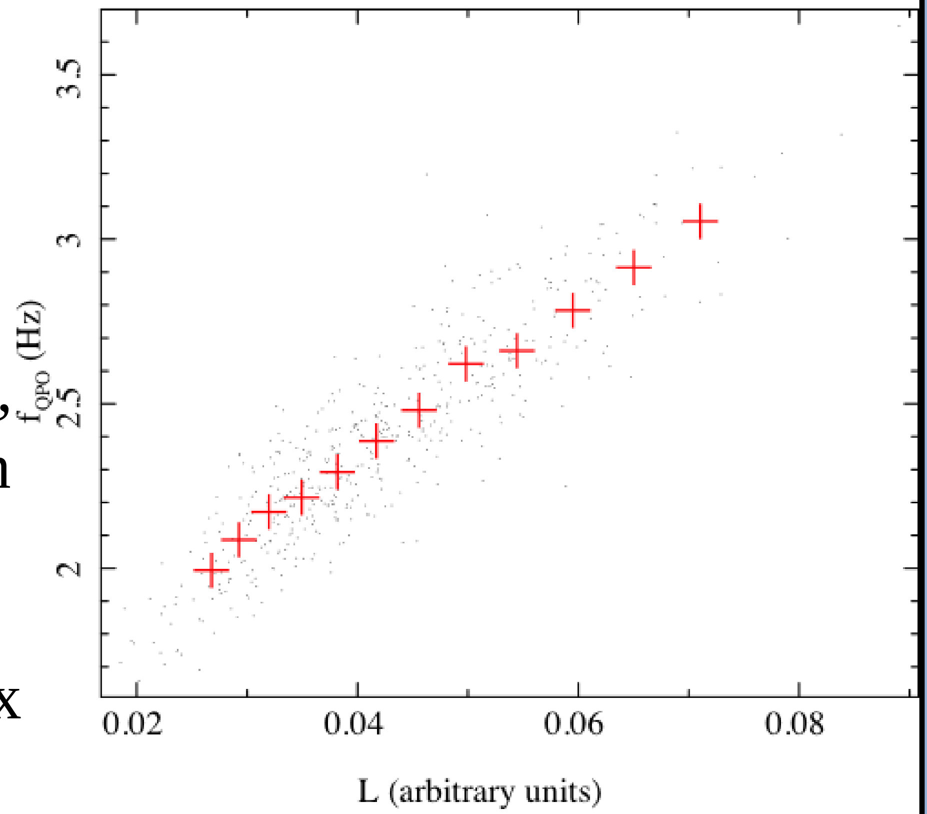
Frequency jitter



Heil, Vaughan & Uttley 2011

Ingram & Done 2011



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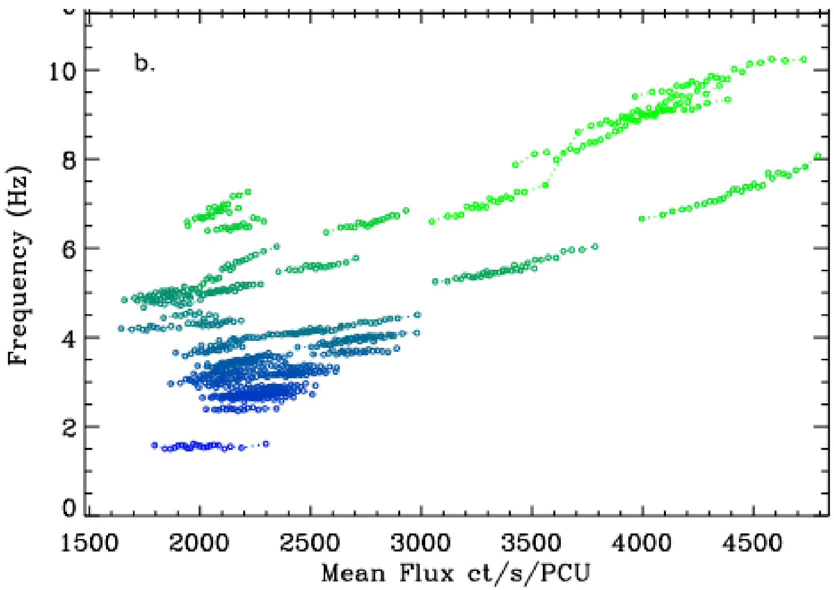
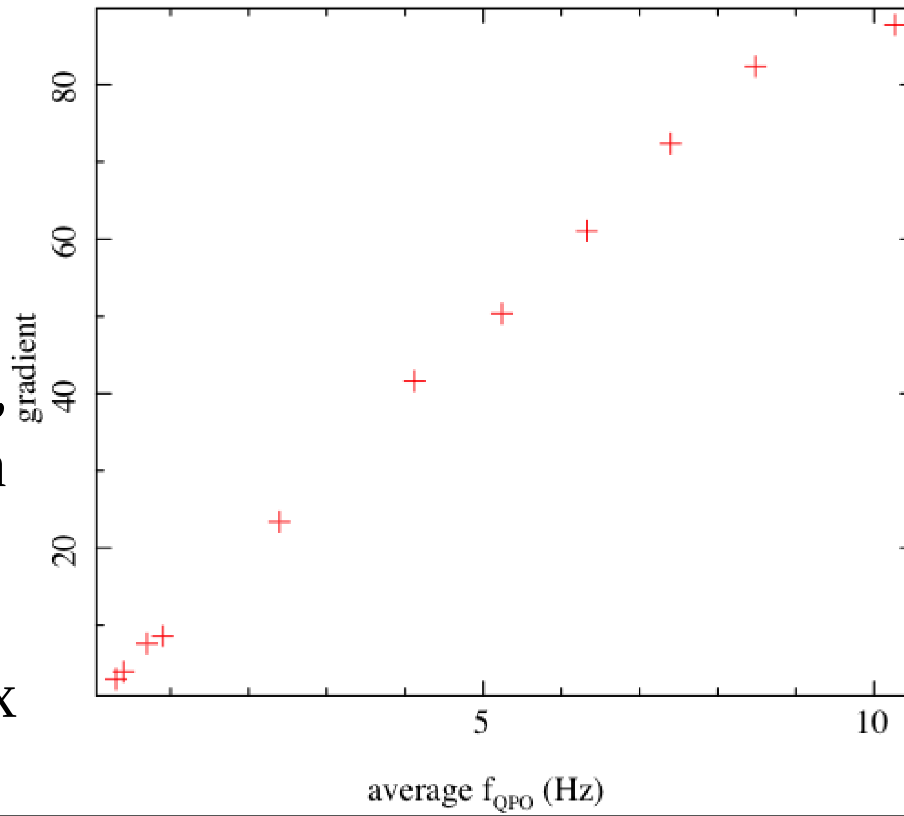


Heil, Vaughan & Uttley 2011

Ingram & Done 2011



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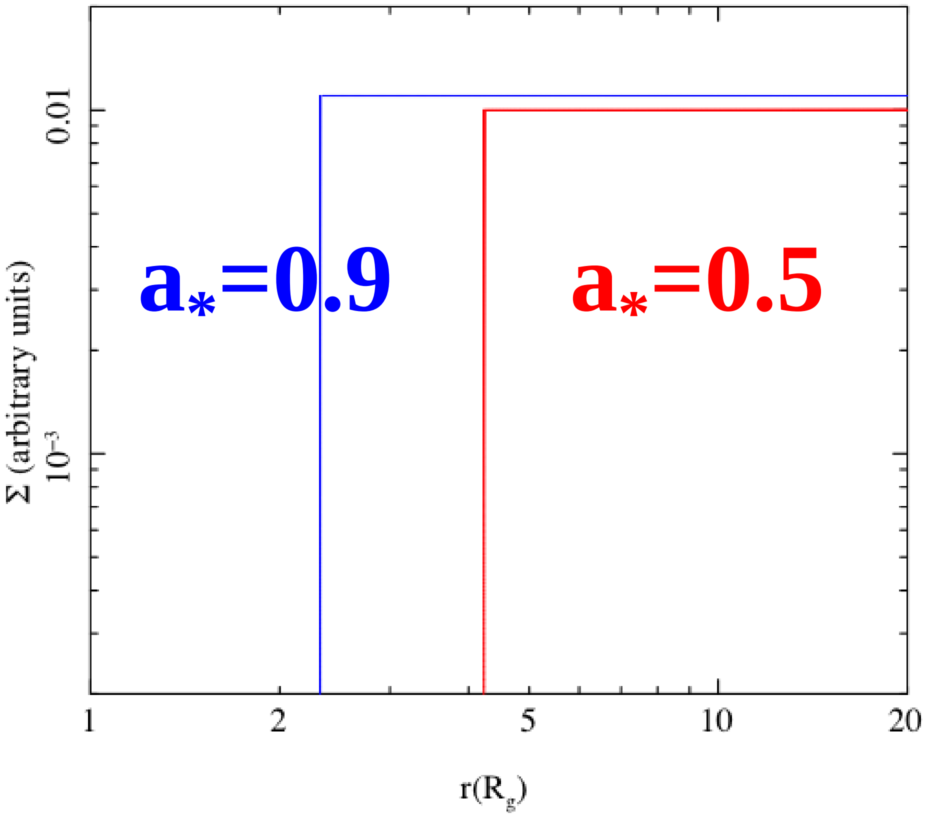
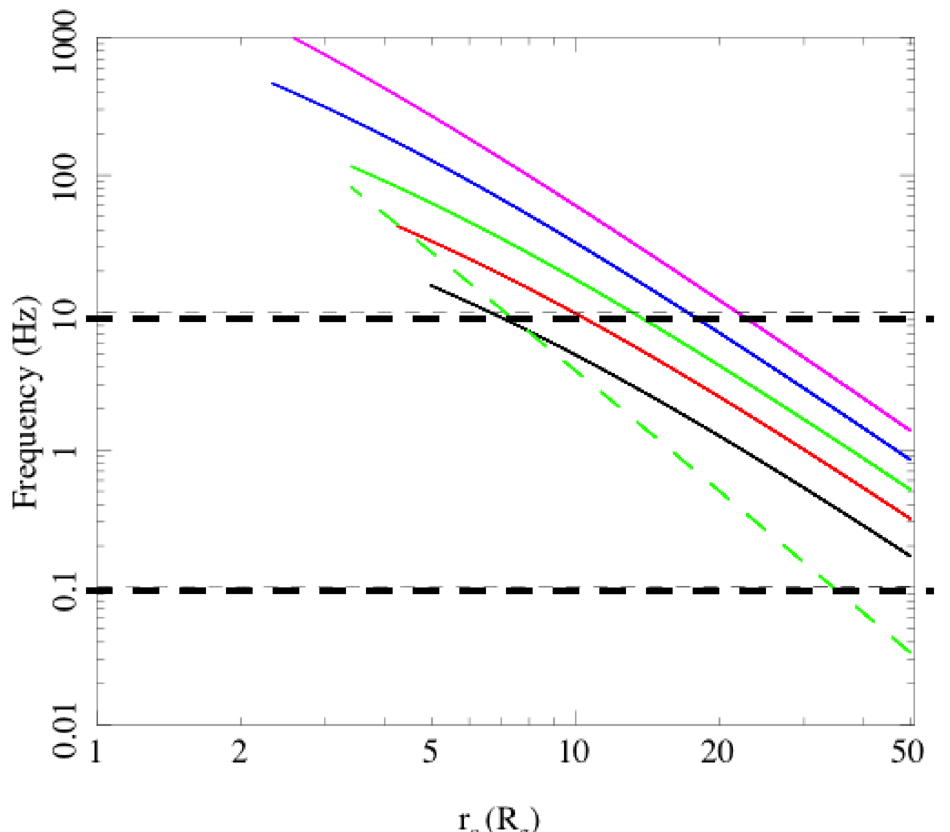
Lense-Thirring precession



Ingram, Done & Fragile 2009



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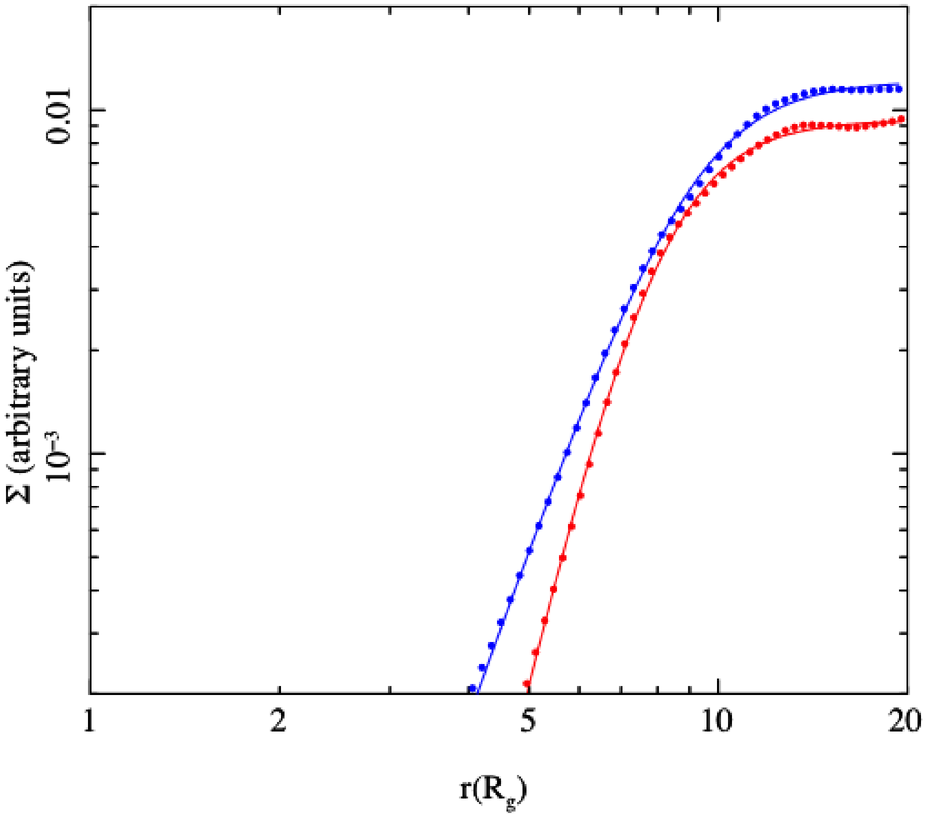

Ingram, Done & Fragile 2009
Fragile et al 2007