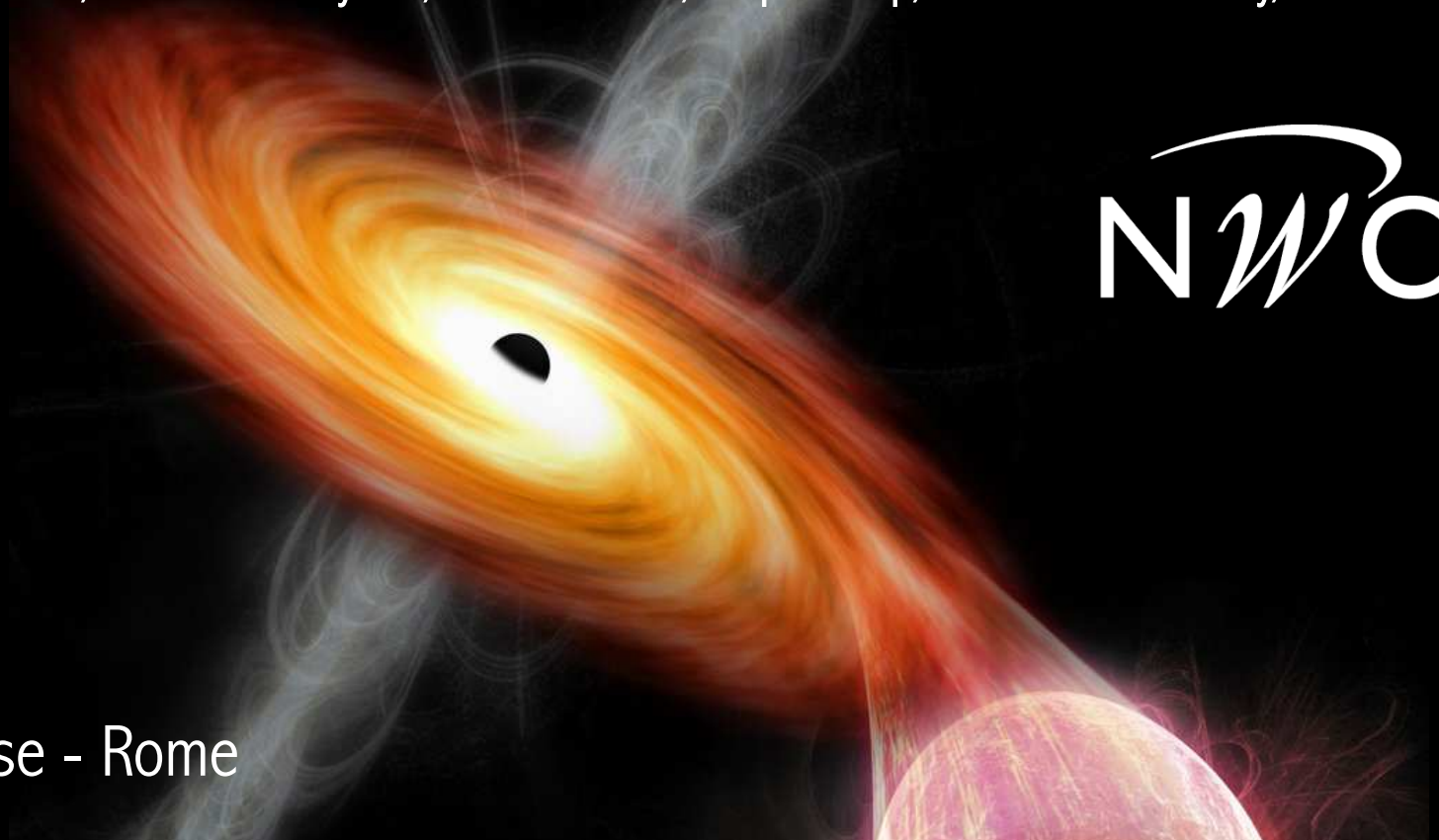
Probing general relativistic precession with tomography and polarimetry

Adam Ingram

Michiel van der Klis, Matt Middleton, Chris Done, Diego Altamirano, Phil Uttley, Magnus Axelsson, Tom Maccarone, Juri Poutanen, Henric Krawczynski, Matthew Liska, Casper Hesp, Sasha Tchekhovskoy, Sera Markoff



NWO

X-ray Universe - Rome

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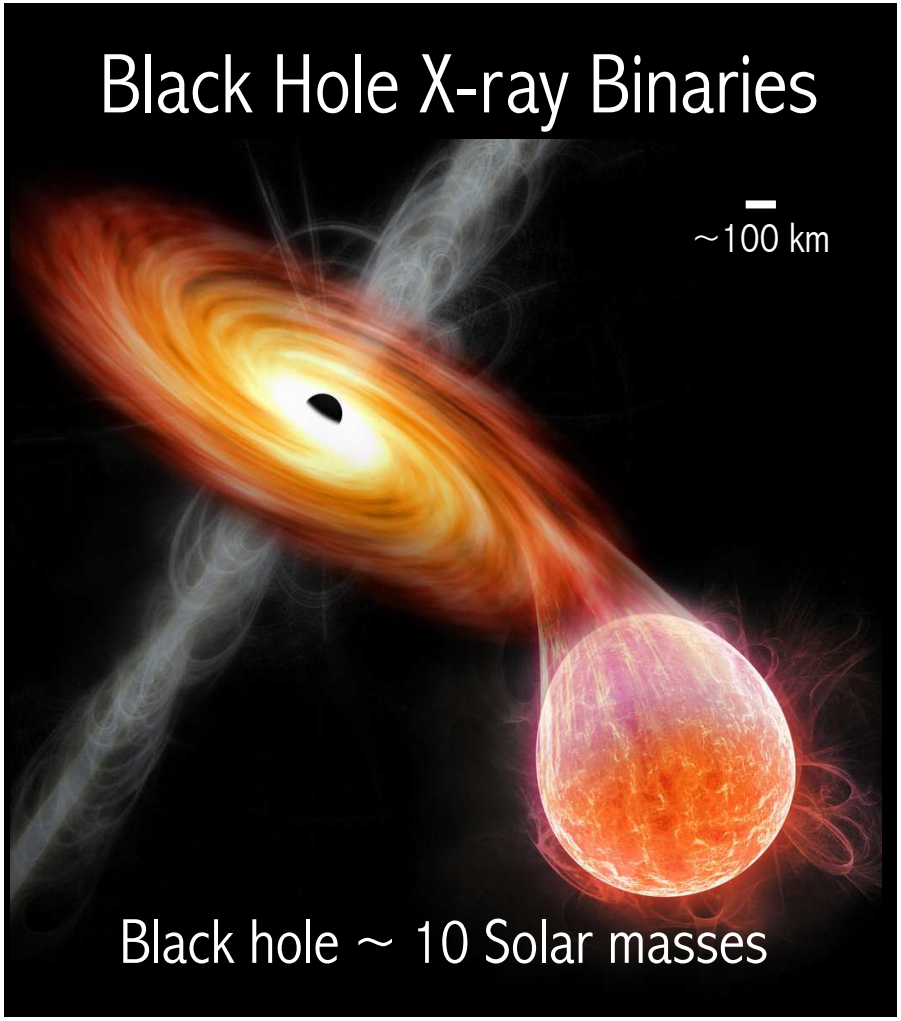
Black hole X-ray binaries



- Unique laboratories for strong field GR
- Probe relativistic motions of orbiting material in strong gravitational fields
- Too small to directly image

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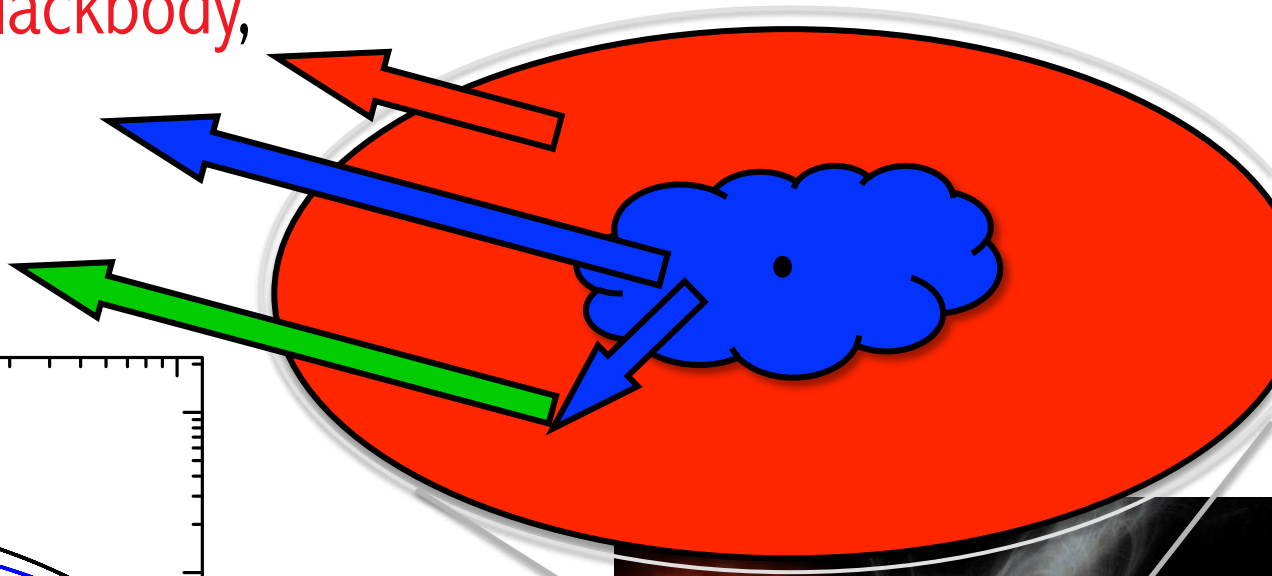
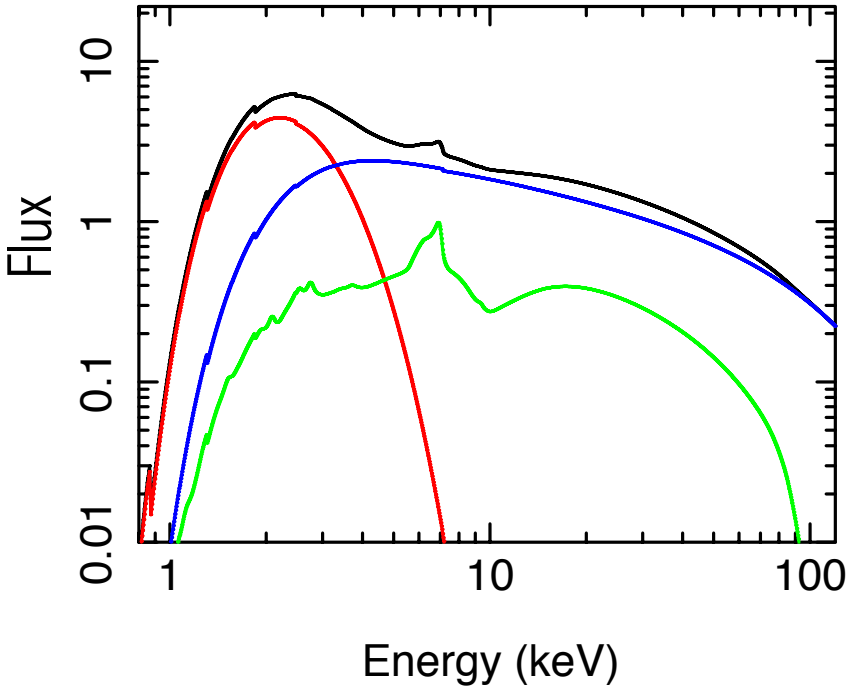
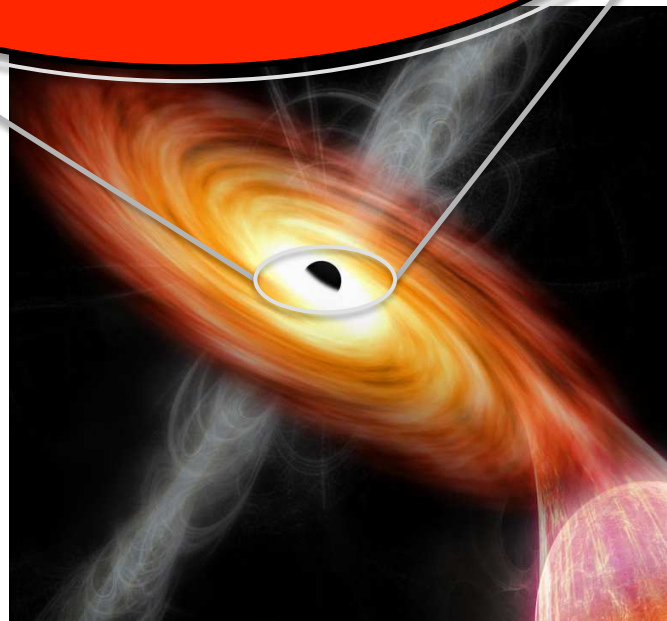
Black hole X-ray binaries

Multi-temperature blackbody,
Comptonisation and
Reflection







e.g. Done, Gierlinski & Kubota (2007)

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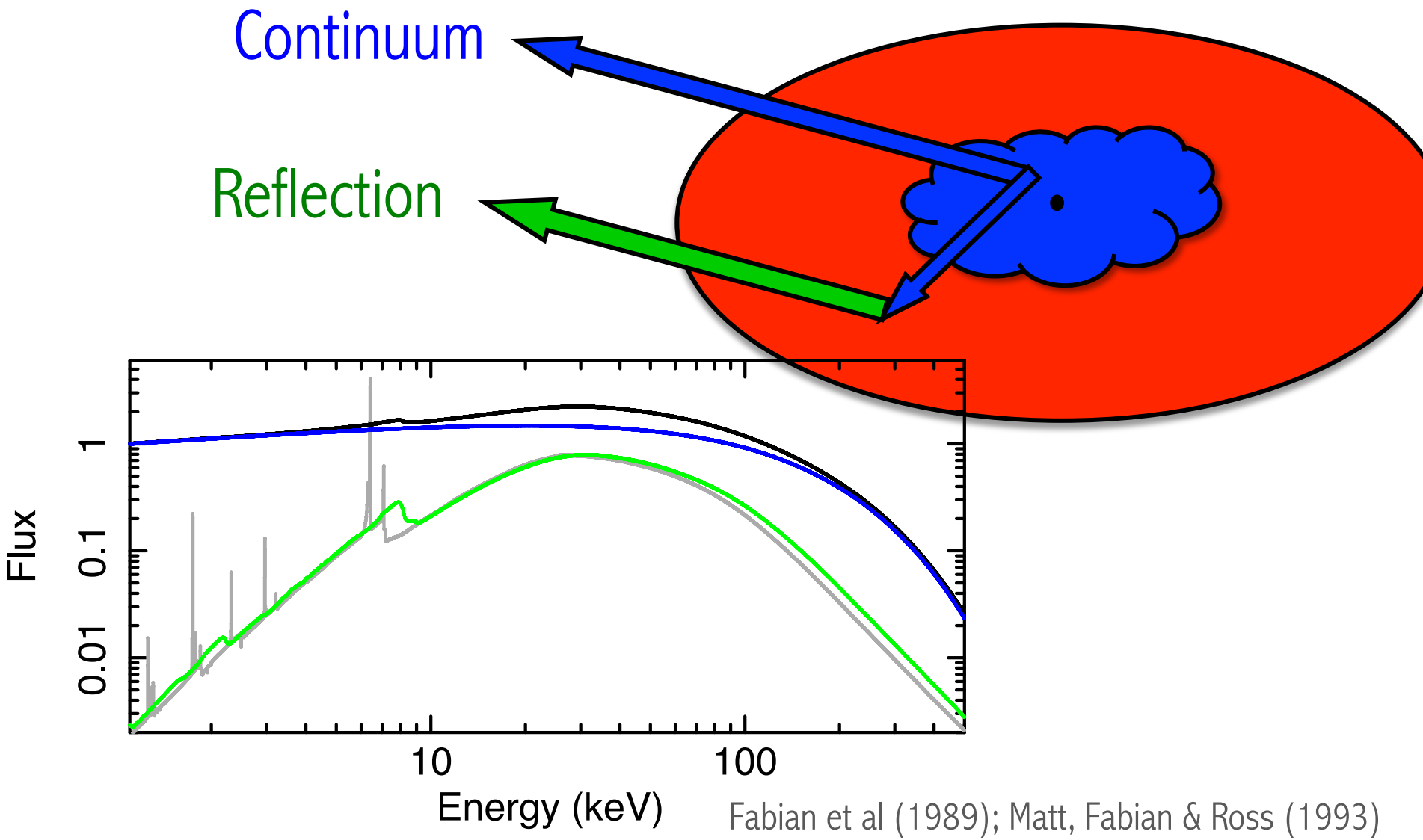
Reflection



Fabian et al (1989); Matt, Fabian & Ross (1993)

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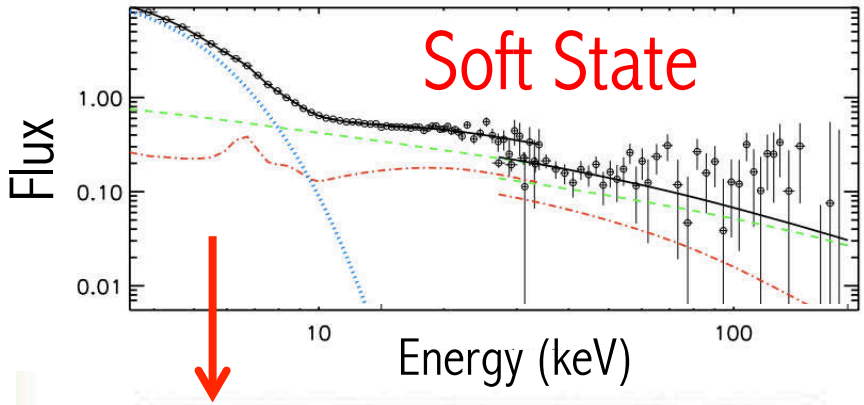
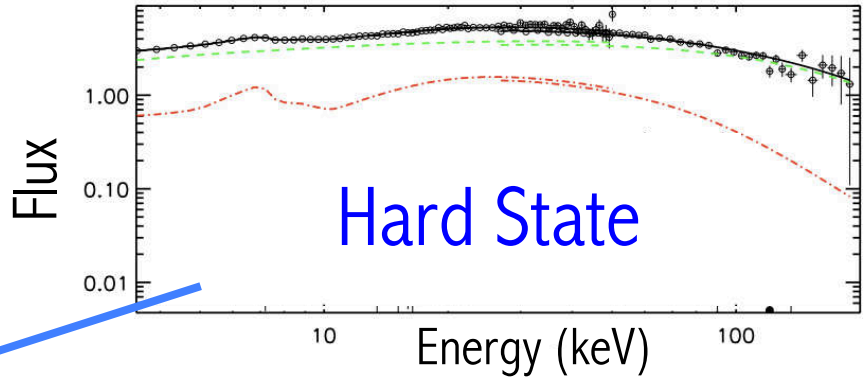
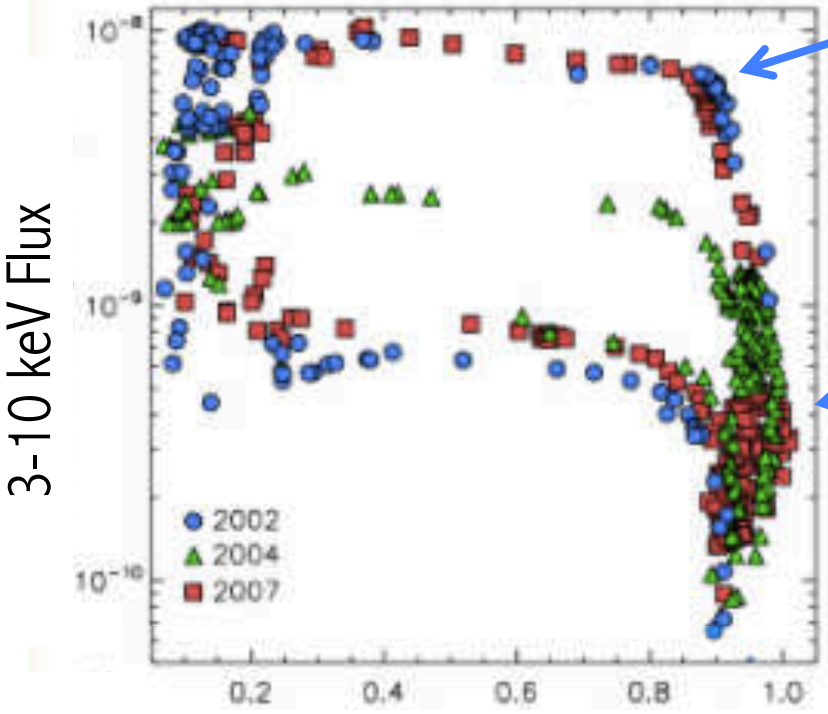
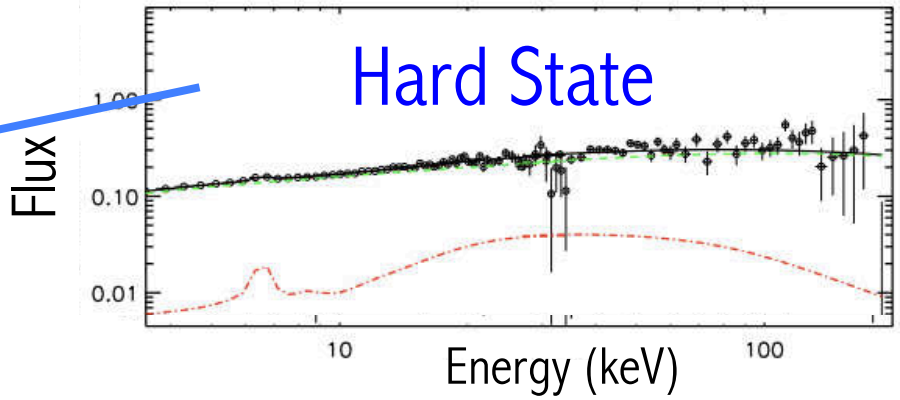
Spectral states









e.g. Done, Gierlinski & Kubota (2007); plots: Plant et al (2014)

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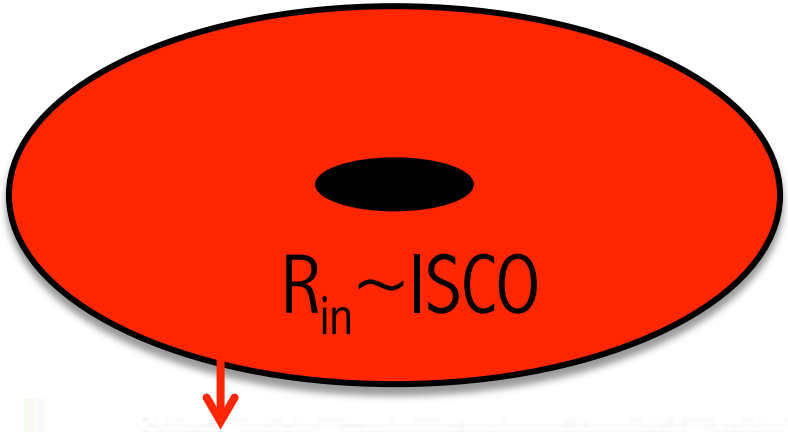
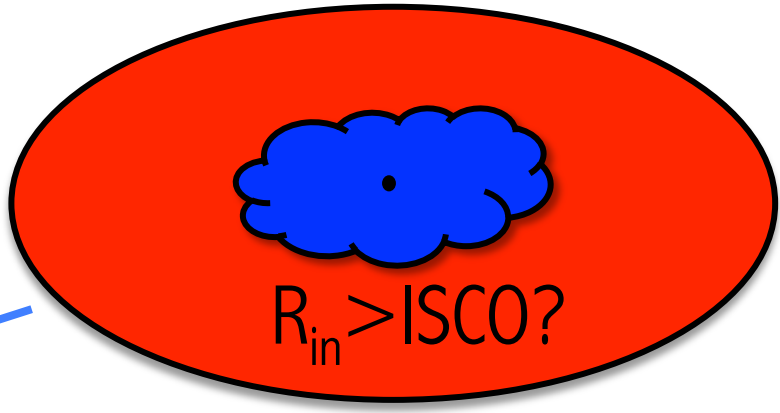
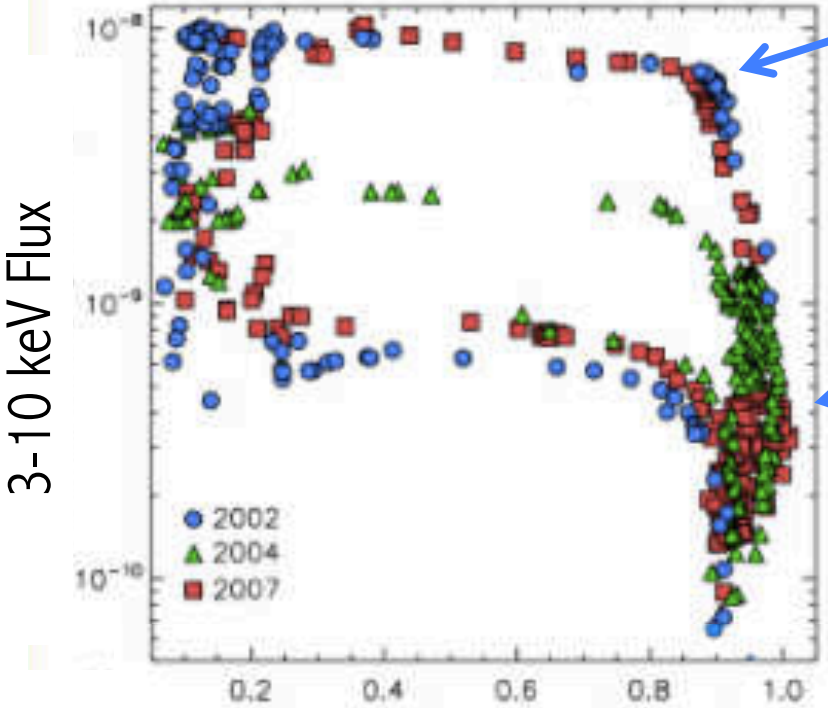
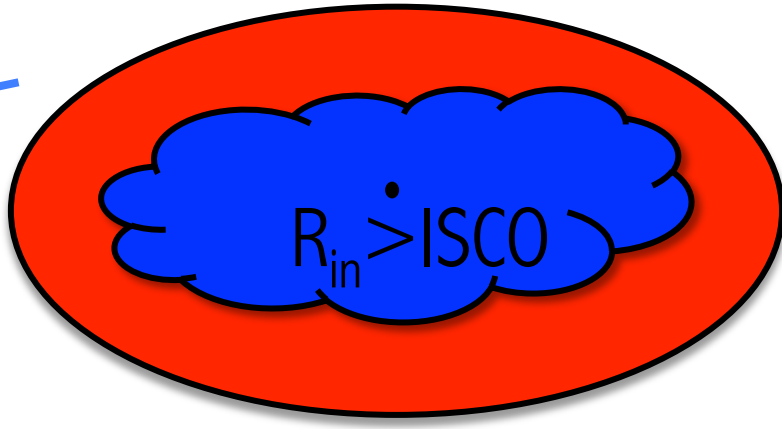
Spectral states









e.g. Done, Gierlinski & Kubota (2007); plots: Plant et al (2014)

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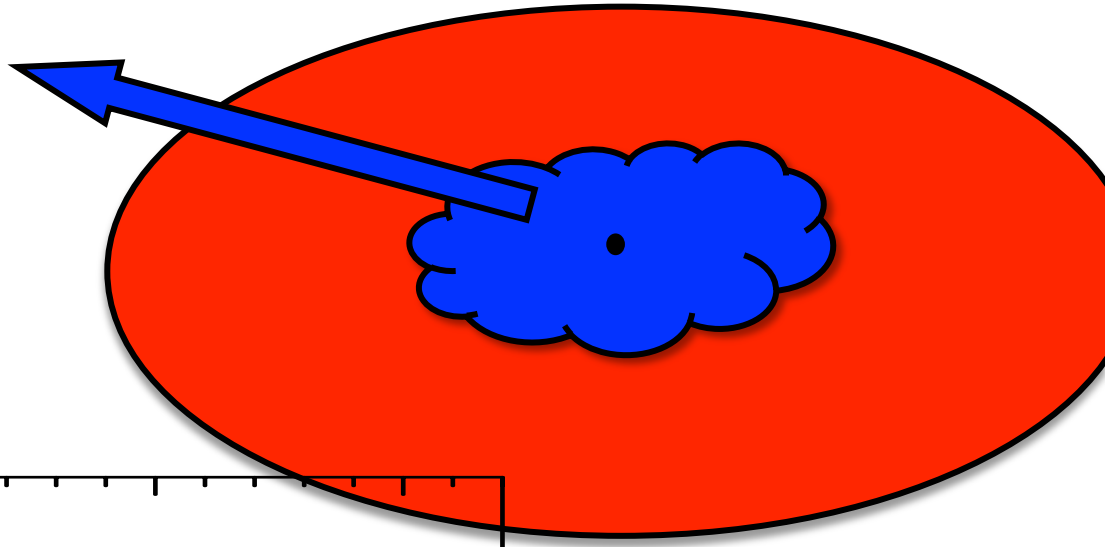
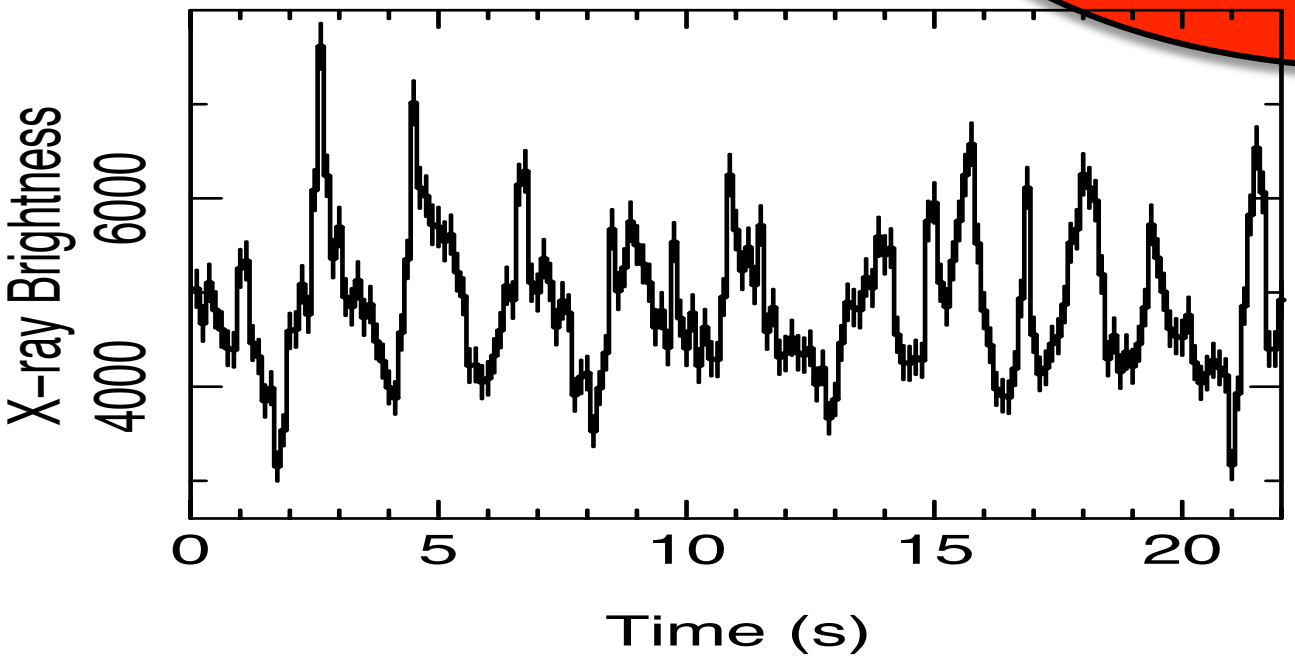
Quasi-periodic oscillations (QPOs)

QPO period moves from
~ 10 – 0.1 s
as spectrum gets softer





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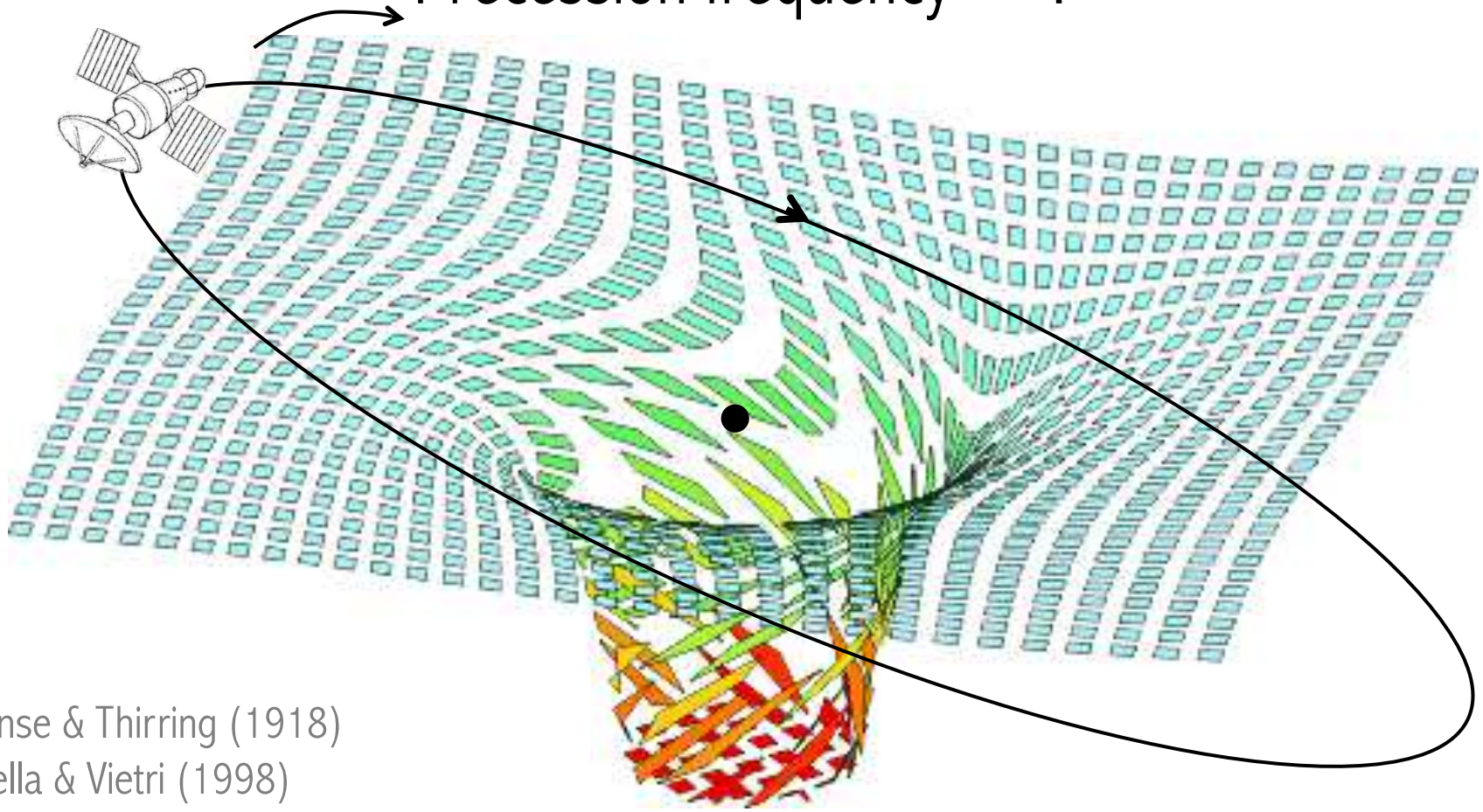
Frame dragging

The spin of the black hole influences the satellite orbit

Precession frequency $\sim r^{-3}$



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

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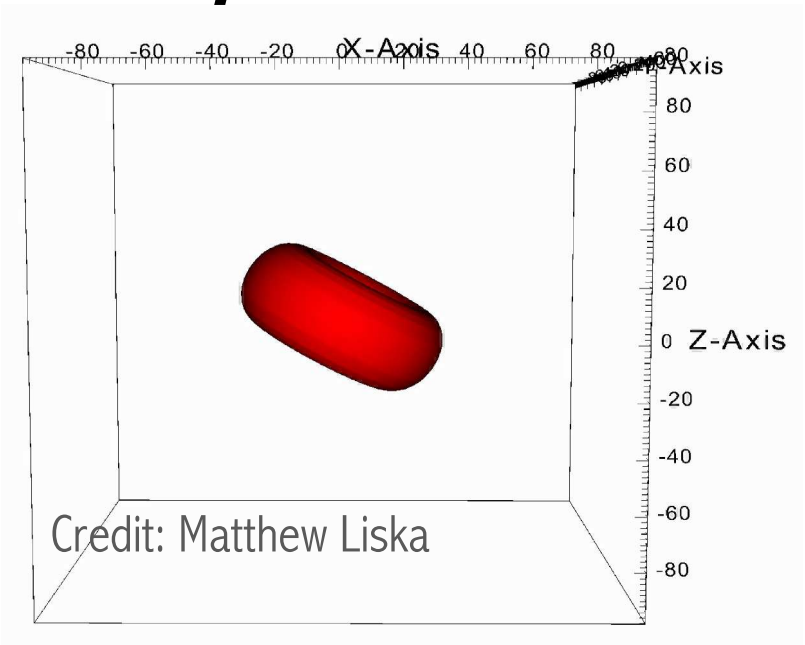
Frame dragging

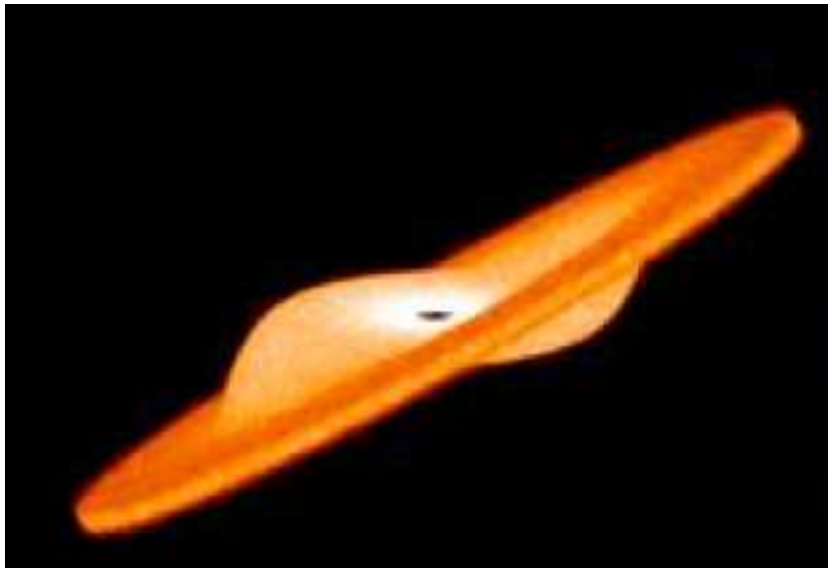
H/R > α



Solid body precession at average LT frequency

Fragile et al (2007); Liska et al (in prep)

H/R < α



Viscosity aligns inner regions with the BH and outer regions with the binary partner

Bardeen & Petterson (1975)

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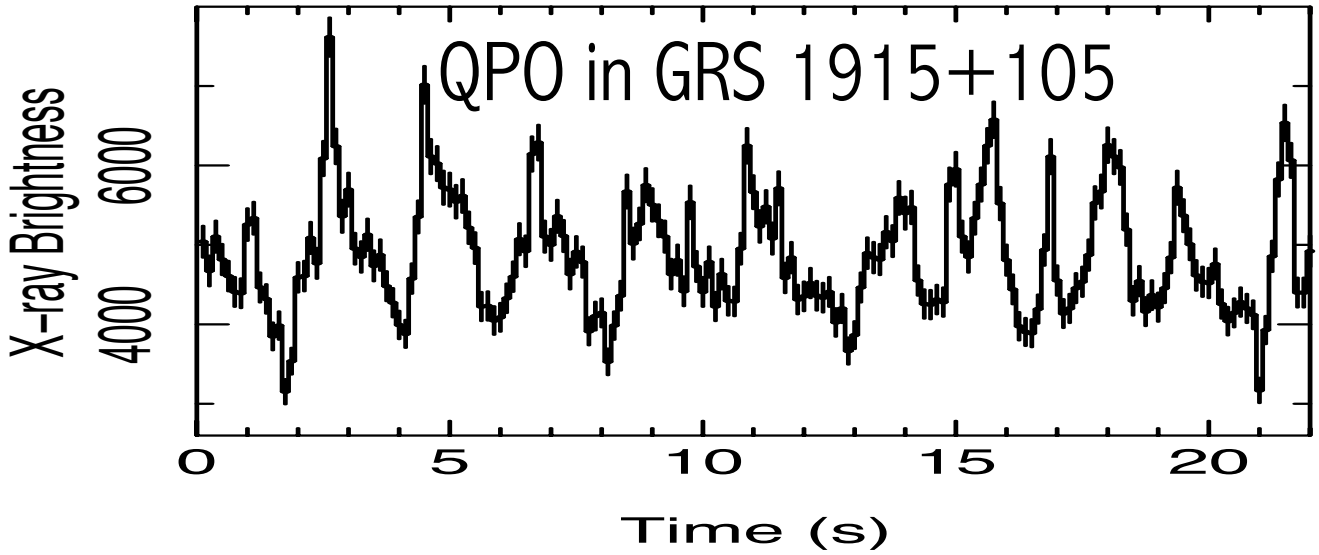
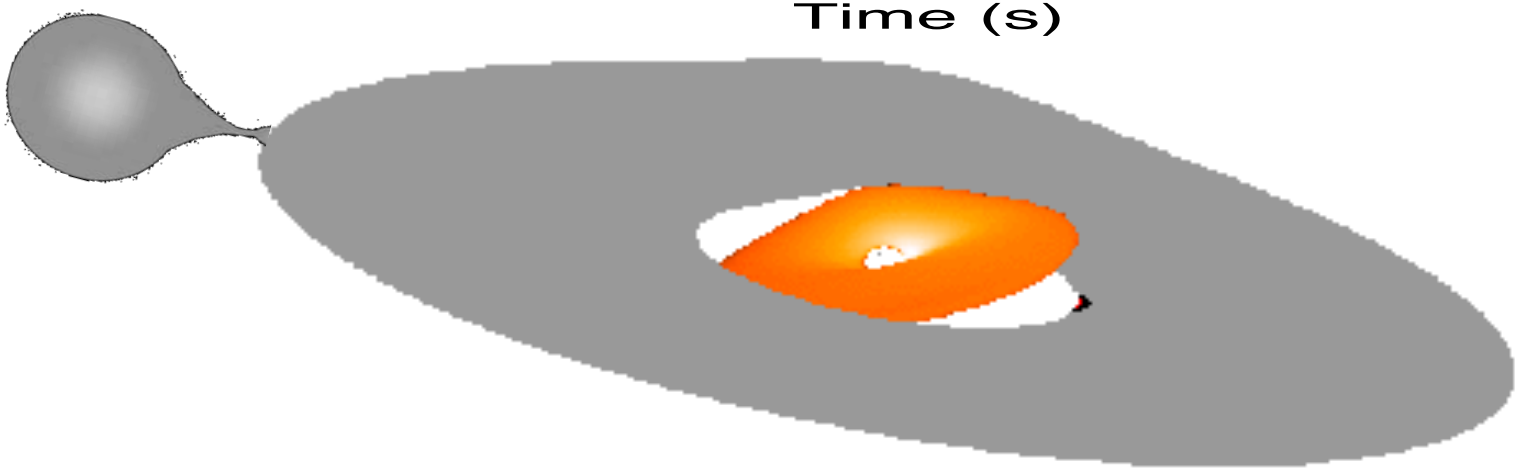
Frame dragging





Ingram, Done & Fragile (2009)

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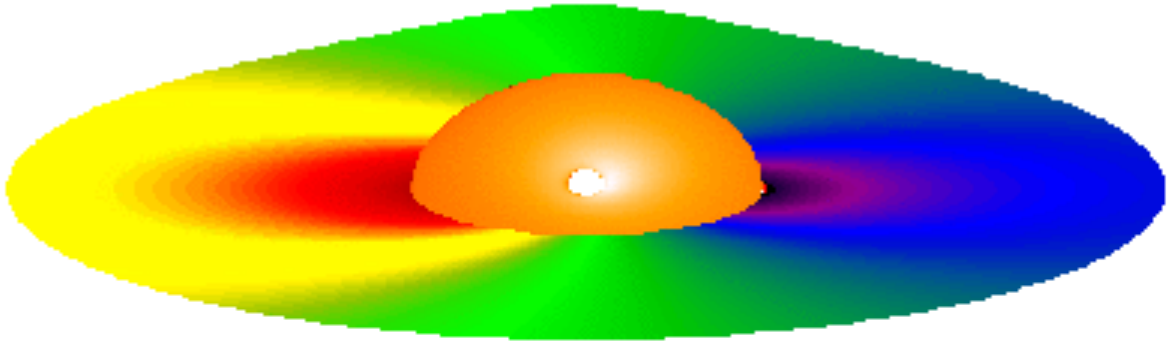
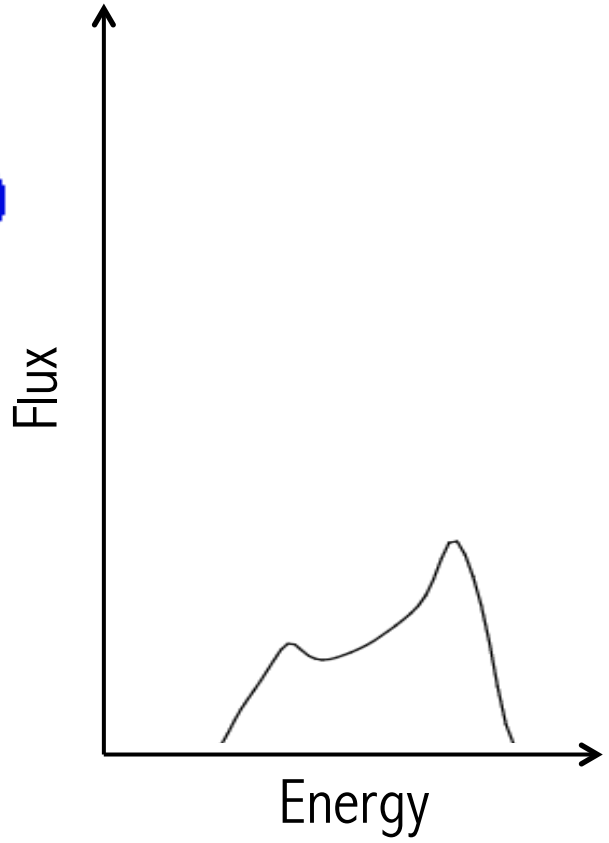
Frame dragging

Tell-tale sign of precession: a rocking iron line





https://www.youtube.com/watch?v=e1QmLg5mGbU

Ingram & Done (2012); Schnittman et al (2006)

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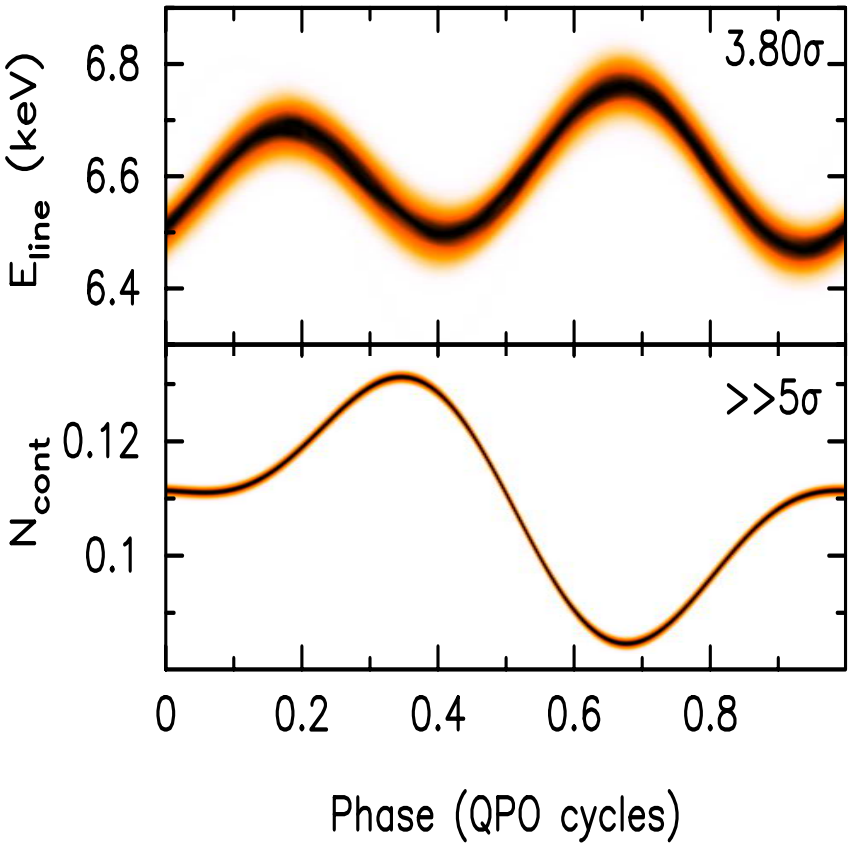
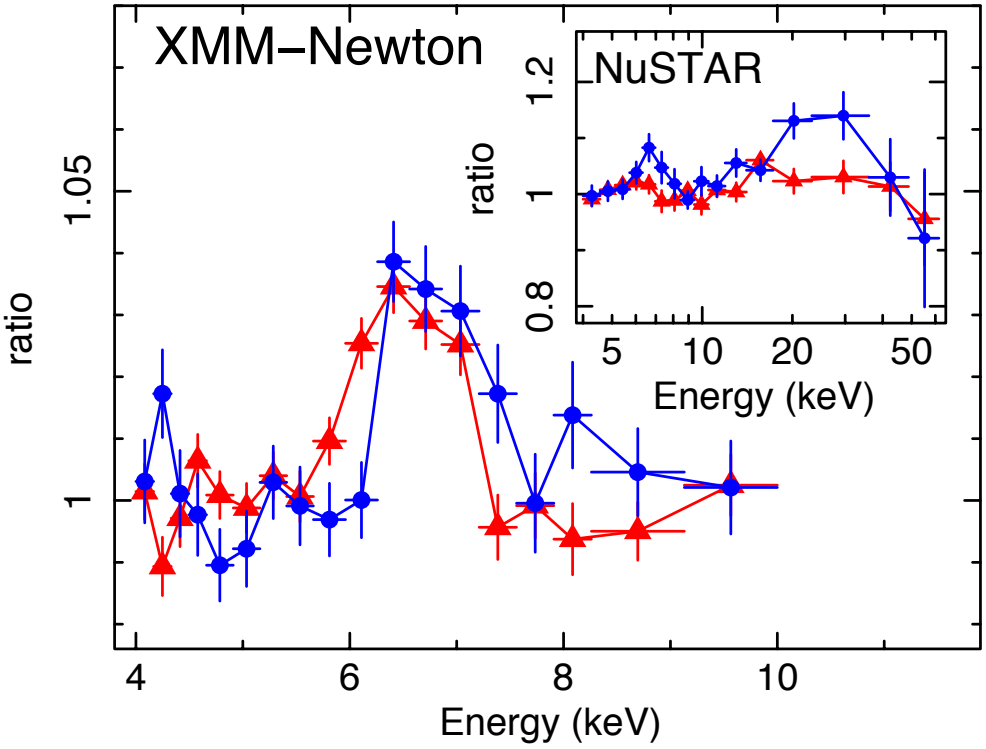
Precession in H 1743-322





Ingram et al (2016)

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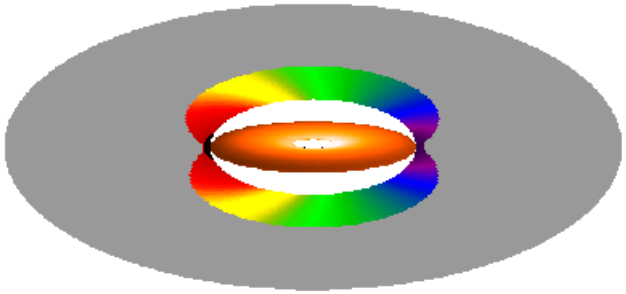
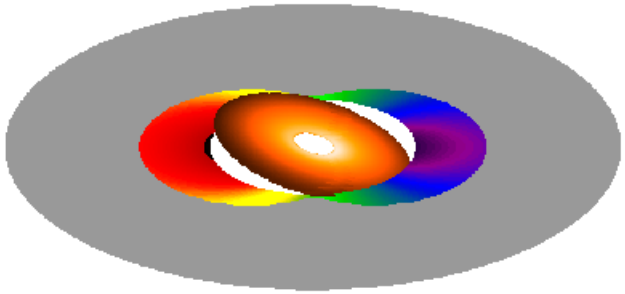
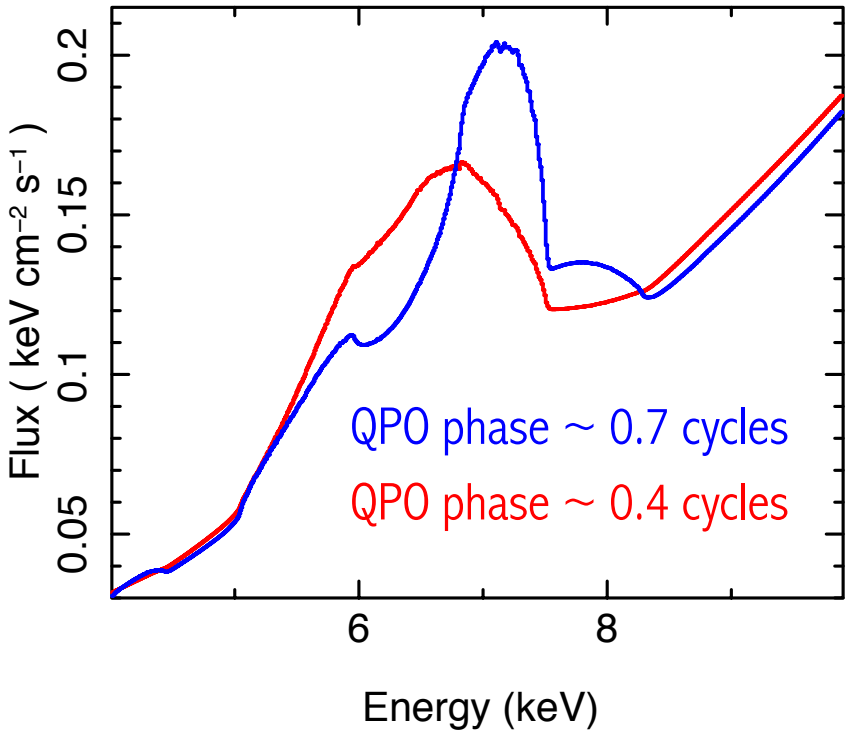
Interpretation

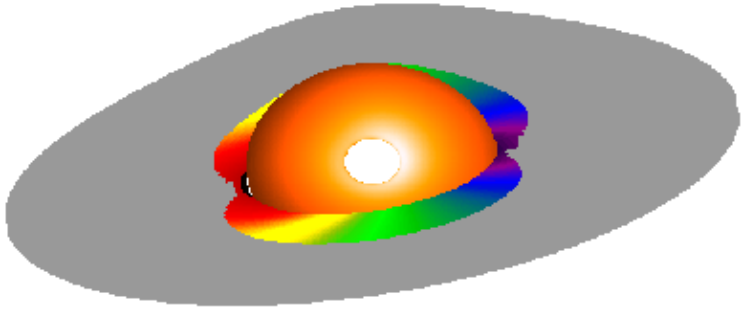
QPO phase ~ 0.4 cycles

QPO phase ~ 0.7 cycles



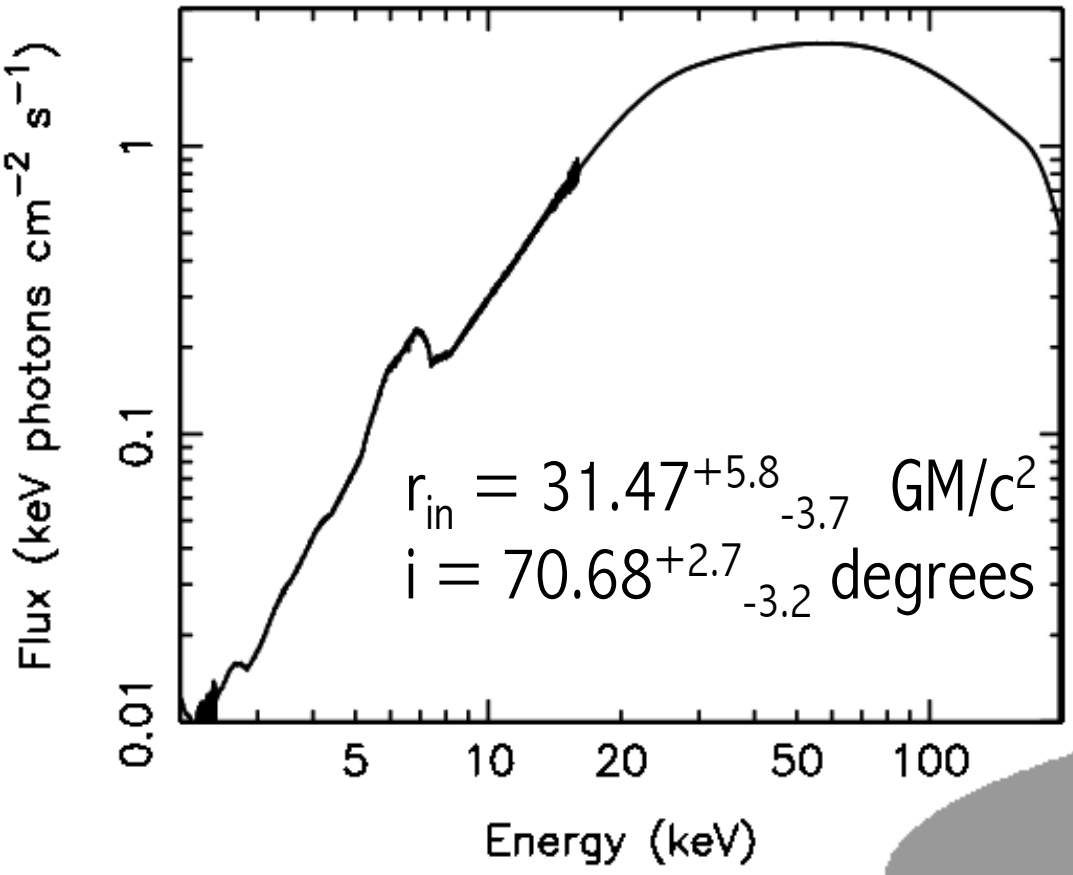






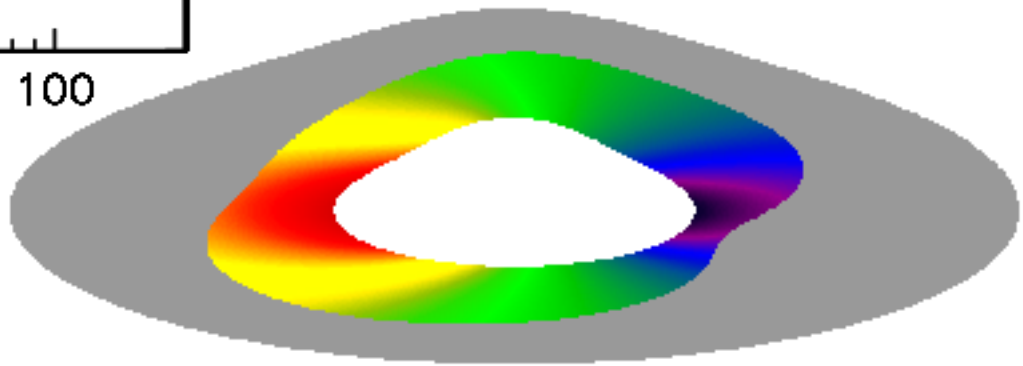
Ingram et al (2017)

Tomographic modeling



Parameterize disk illumination:

$$I_{E_e}(r,\phi,\gamma) \propto$$
$$r^{-q} \quad \left\{1 + A_1 \cos^2\left[(\gamma - \phi + \phi_1)/2\right]\right.$$
$$+ \quad \left. A_2 \cos^2\left[\gamma - \phi + \phi_2\right]\right\} I_{E_e},$$



https://figshare.com/articles/Tomographic_modelling_of_H_1743-322/3503933 Ingram et al (2017)

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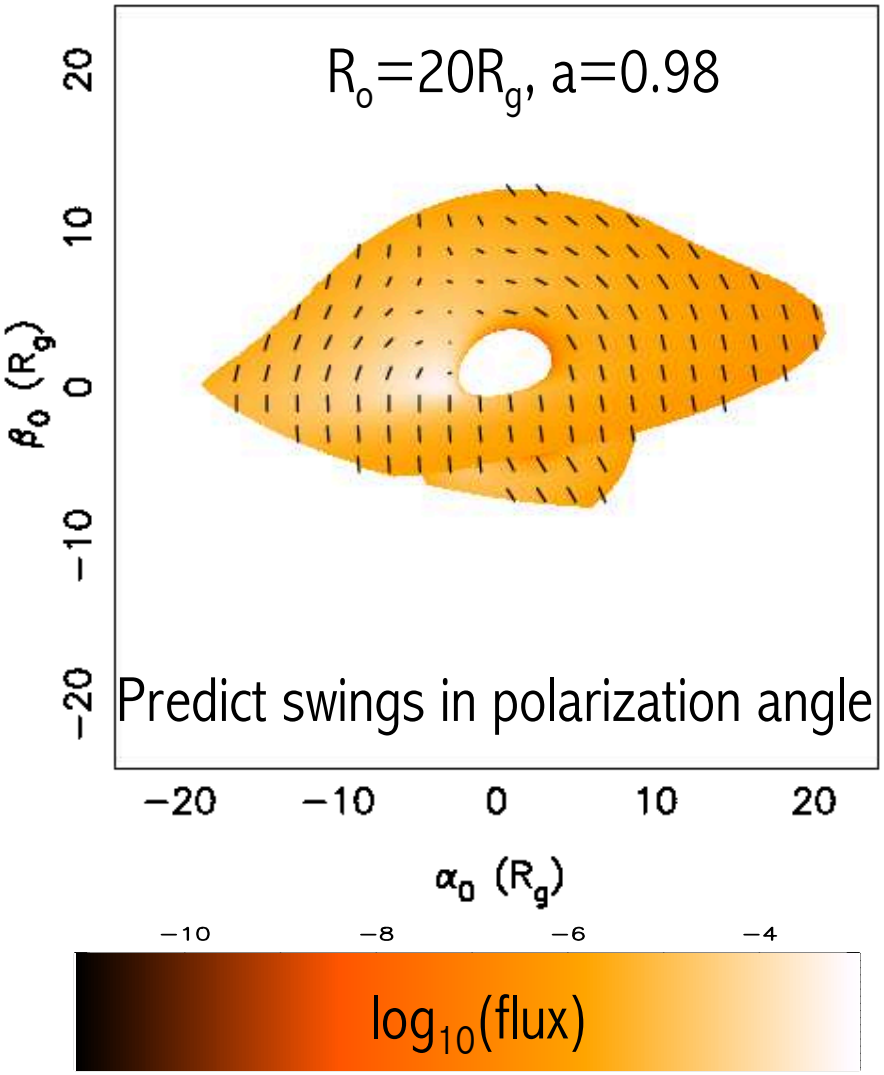
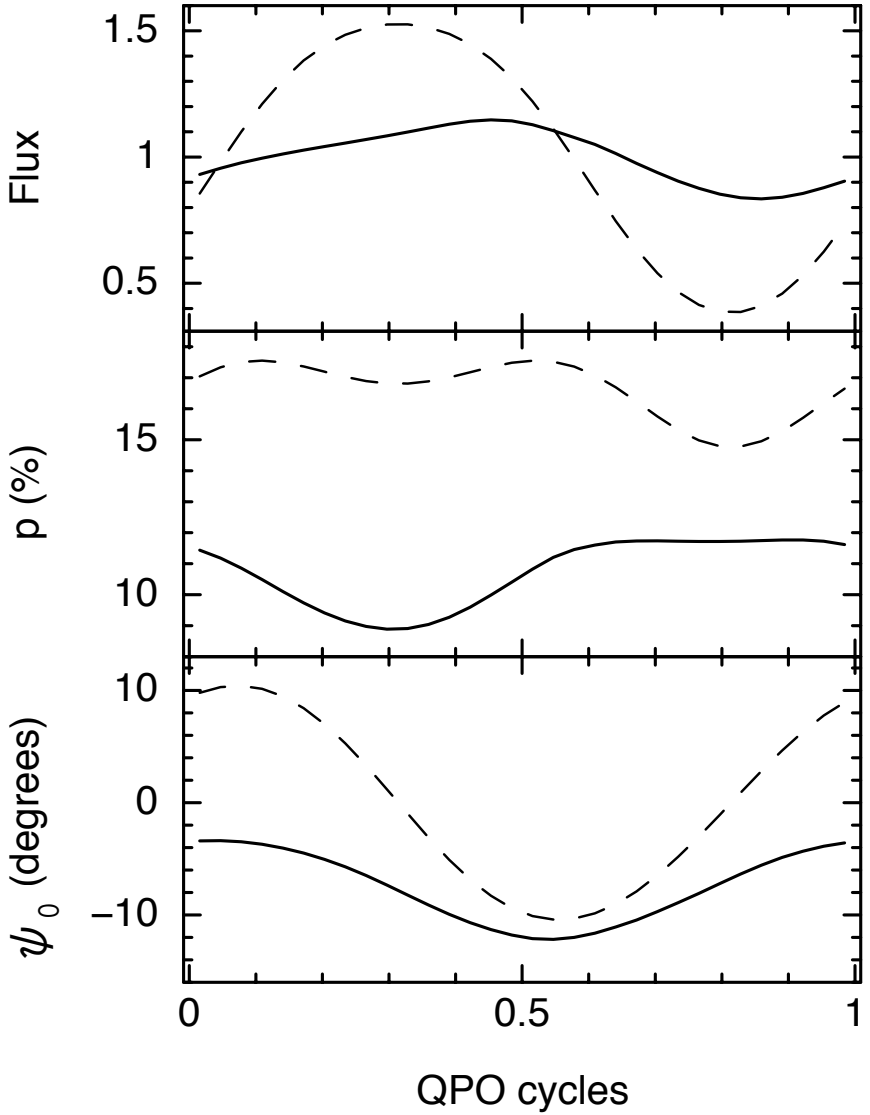
Polarization





www.youtube.com/watch?v=ieZYYfCapJg&feature=youtu.be

Ingram et al (2015)

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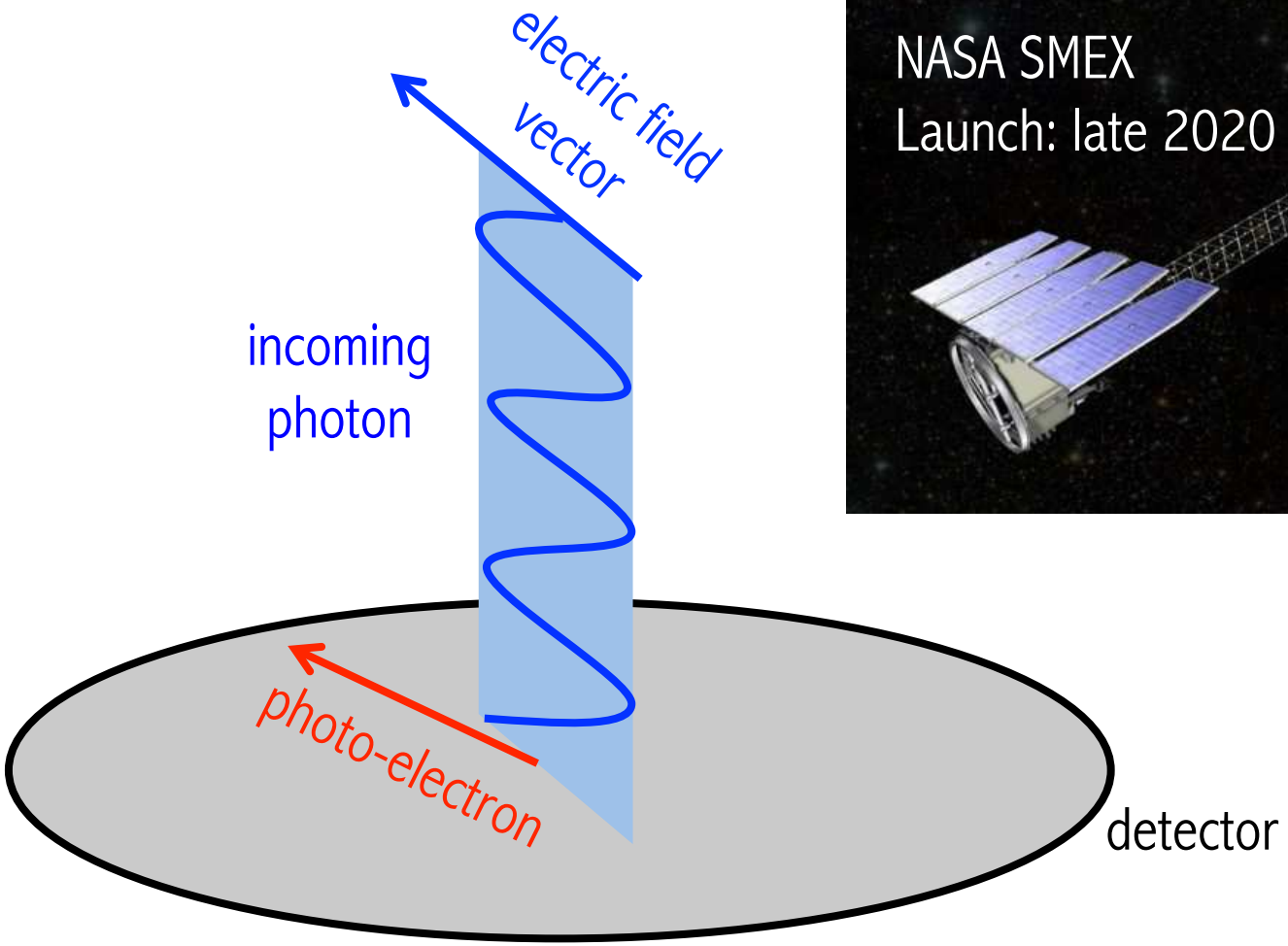
X-ray polarimetry-timing



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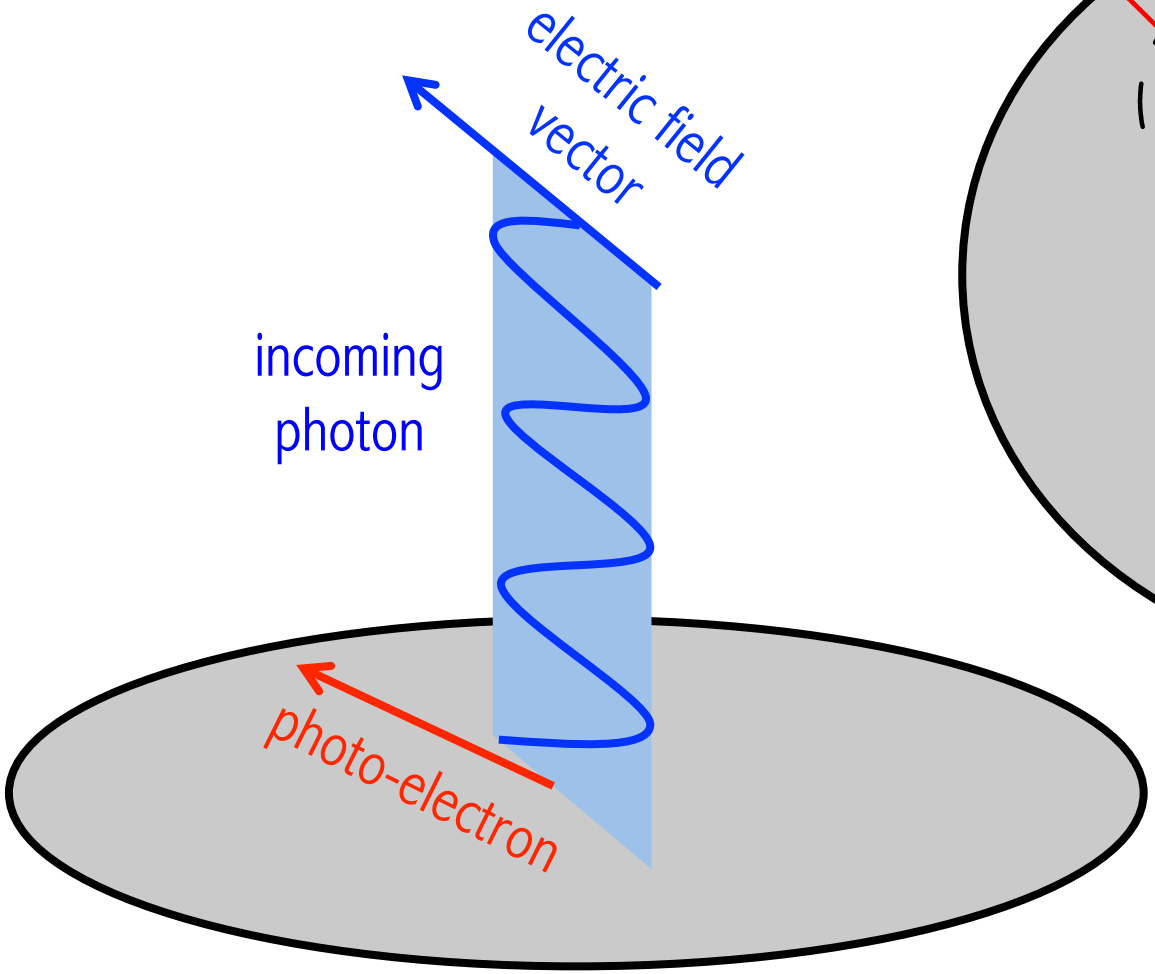
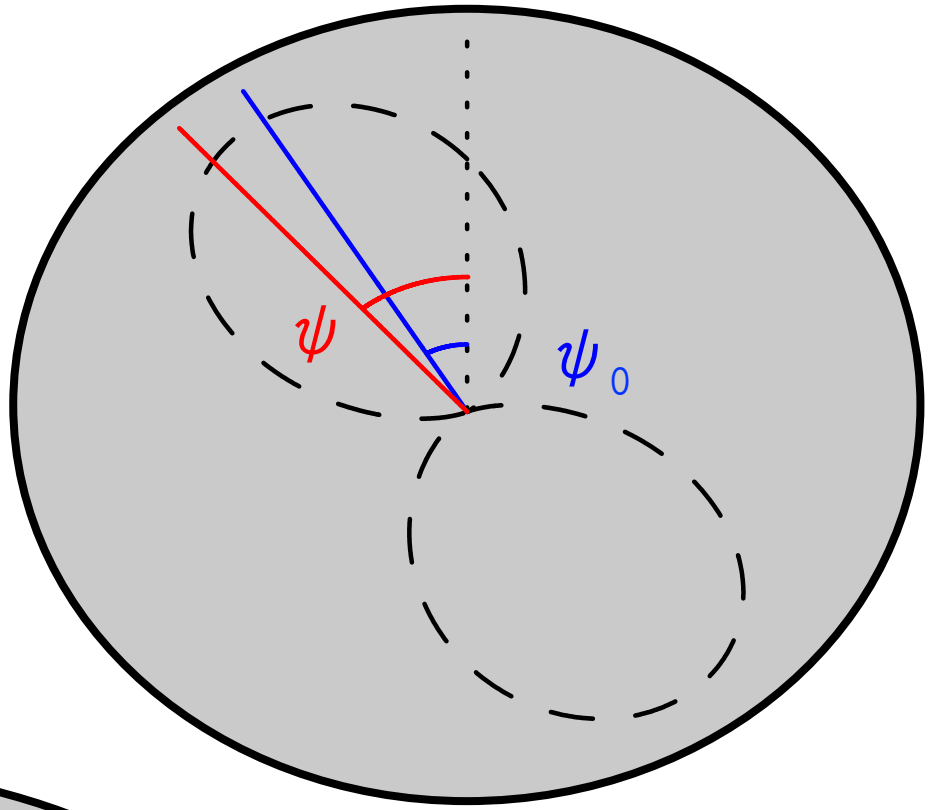
X-ray polarimetry-timing

ψ_0 = polarisation angle

ψ = modulation angle



North on projected sky



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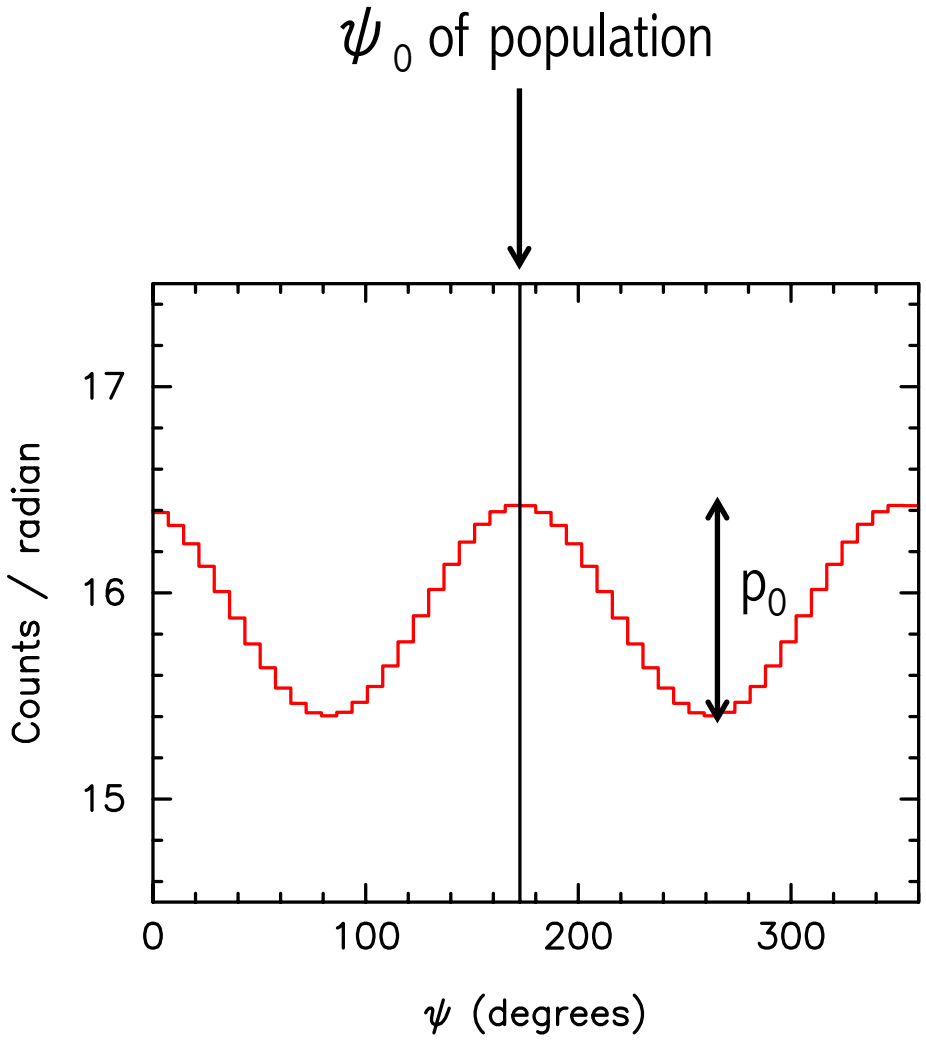
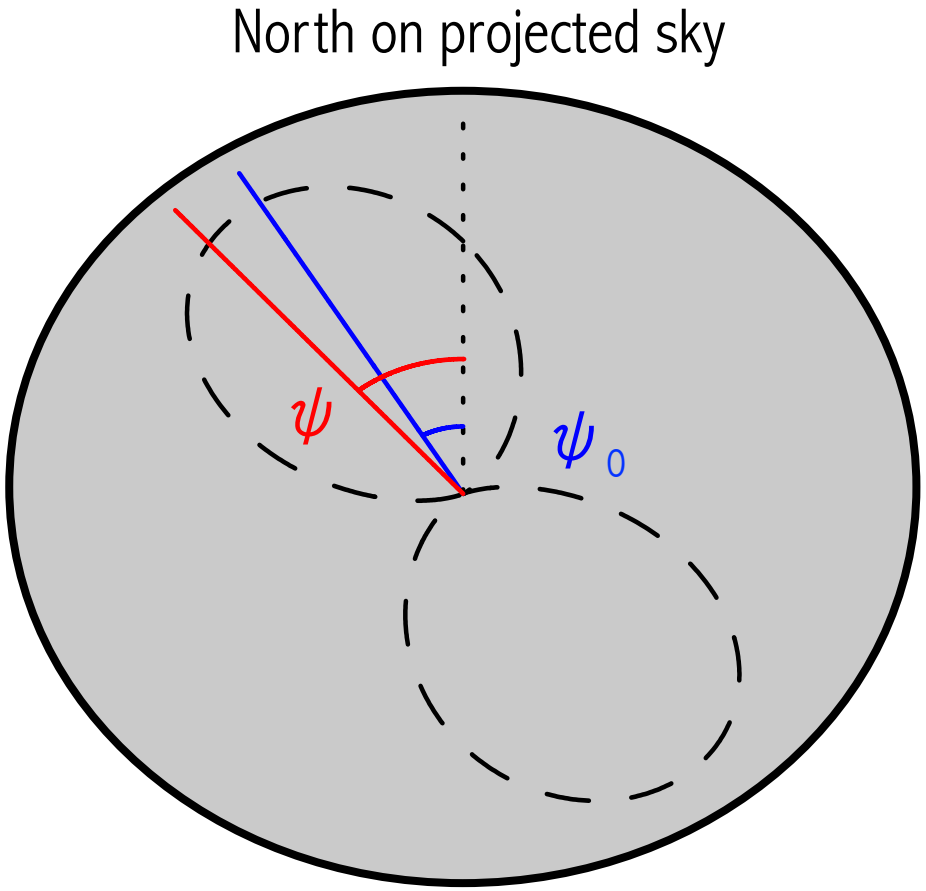
X-ray polarimetry-timing





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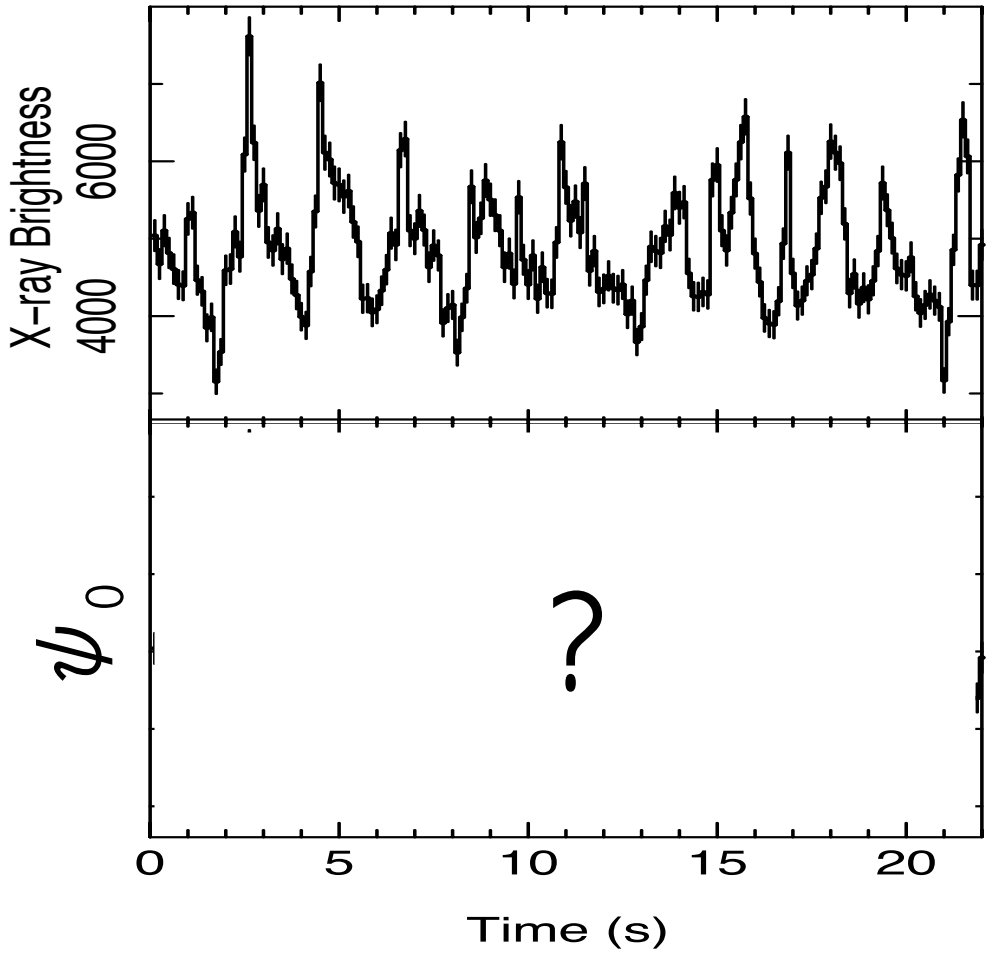
X-ray polarimetry-timing



Can we make a time series?

- IXPE count rate ~ 100 c/s
- p_0 of source < ~10%
- Integration time:

  T ~ 4 minutes!

So can't probe variability on timescales of seconds ☹

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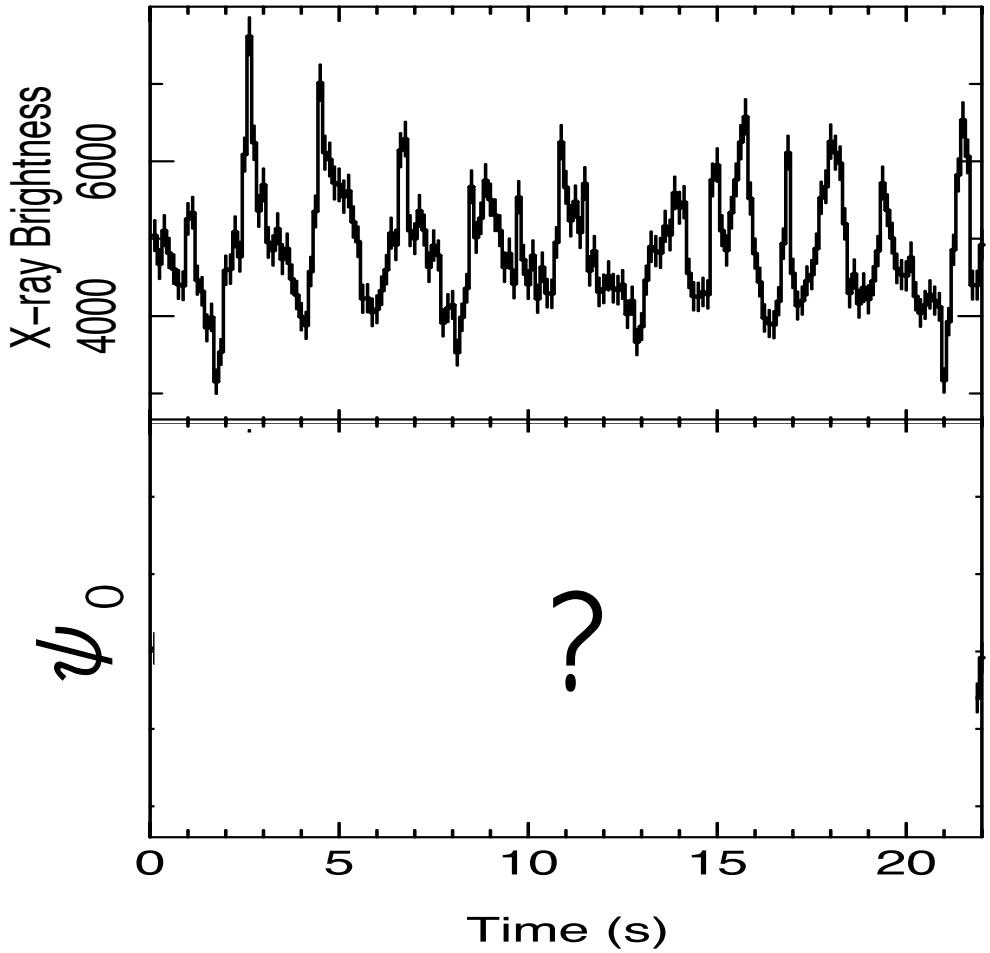
X-ray polarimetry-timing



Can we make a time series?

- IXPE count rate ~ 100 c/s
- p_0 of source < ~10%
- Integration time:

  T ~ 4 minutes!

Can use phase-folding for periodicities like pulses, but NOT for QPOs and noise ☹

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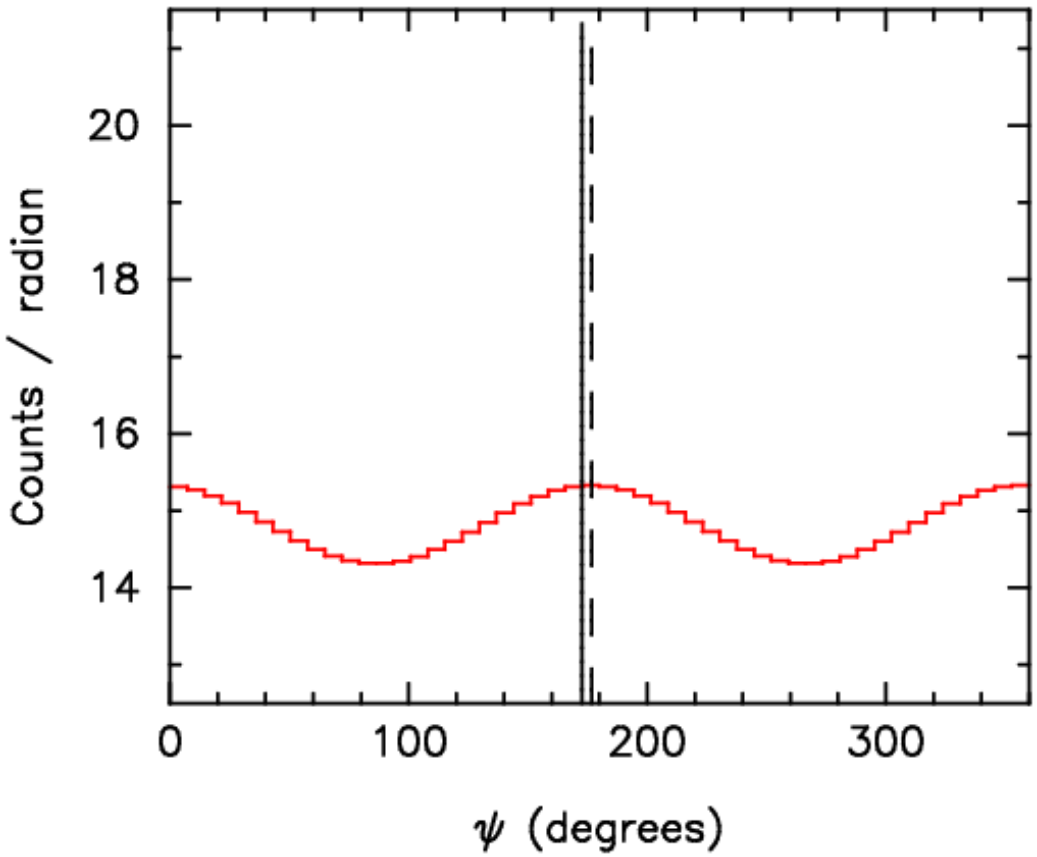
X-ray polarimetry-timing



ψ_0 varies: peak of distribution varies

p_0 varies: amplitude of distribution varies

Ingram & Maccarone (in prep)

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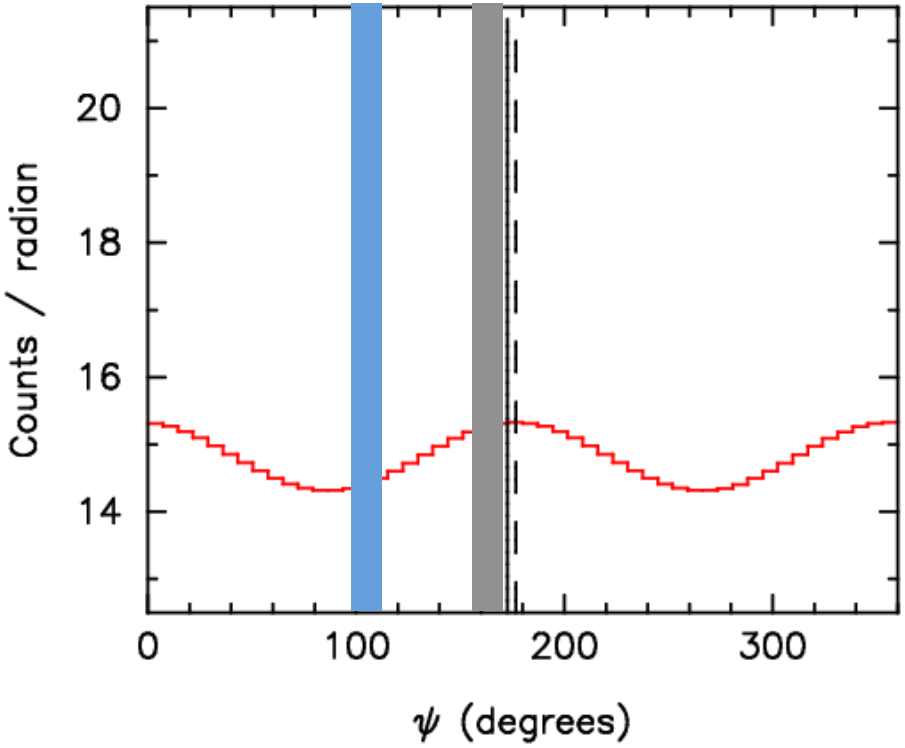
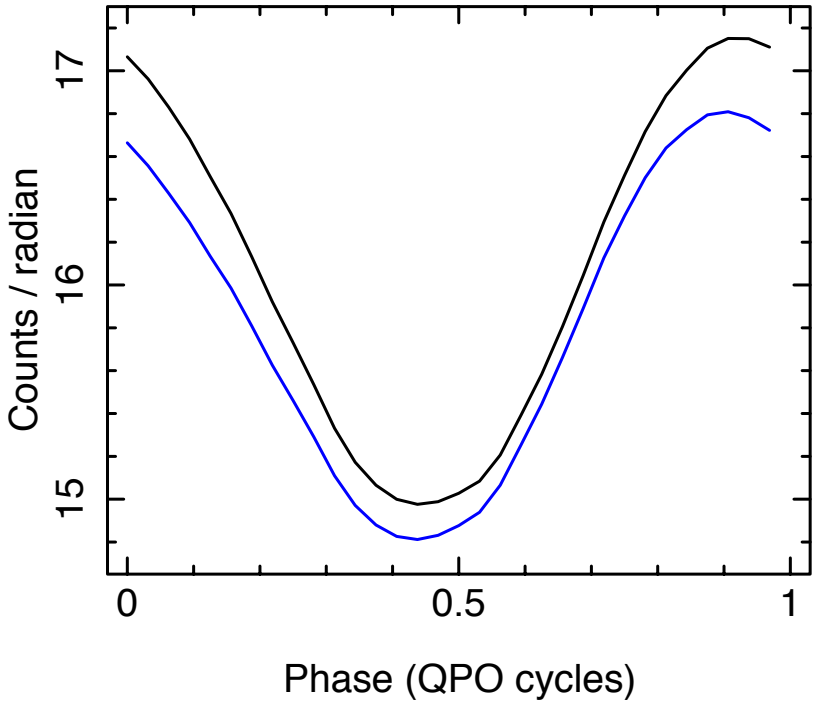
X-ray polarimetry-timing





Can measure the amplitude and phase of each of these light curves using standard cross-spectral techniques

Ingram & Maccarone (in prep)

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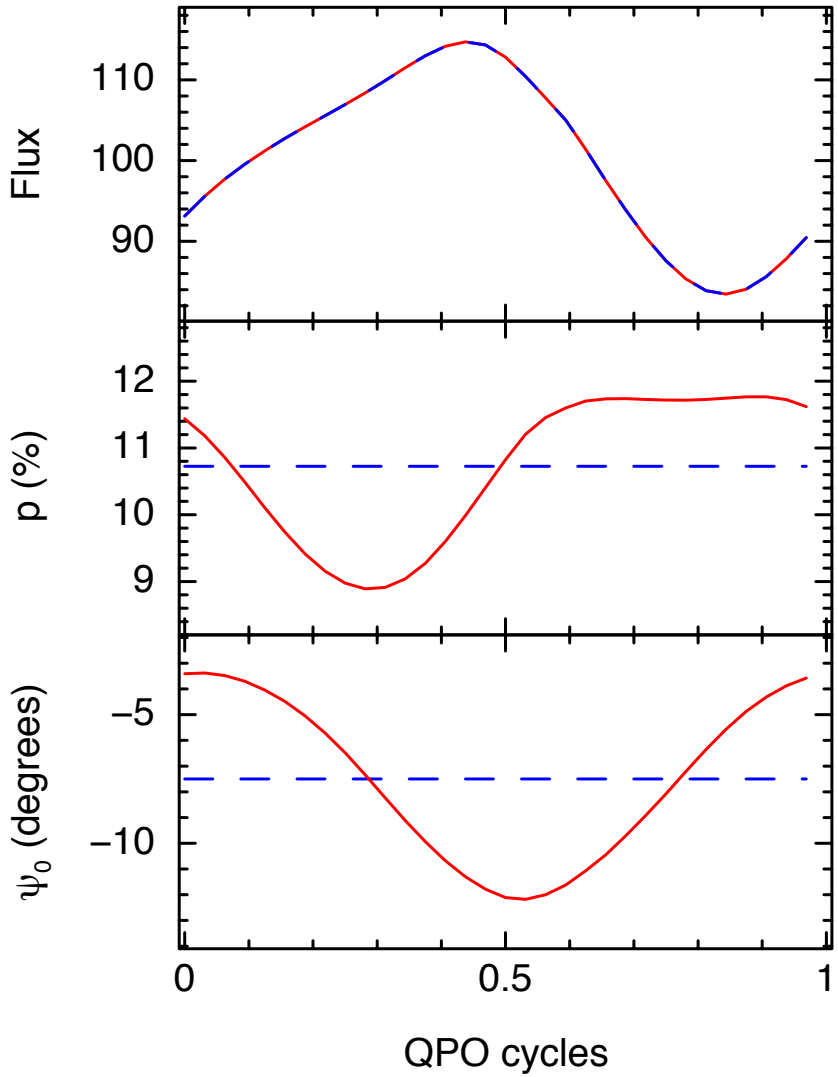
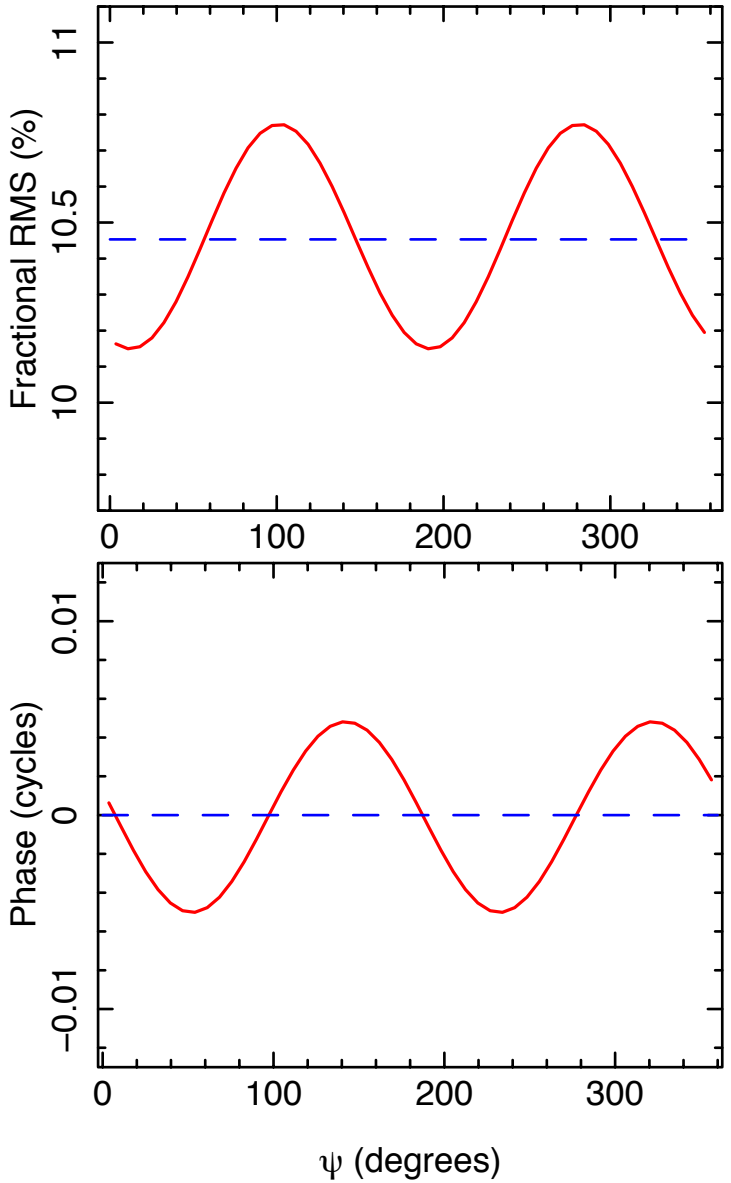
X-ray polarimetry-timing





Ingram & Maccarone (in prep)

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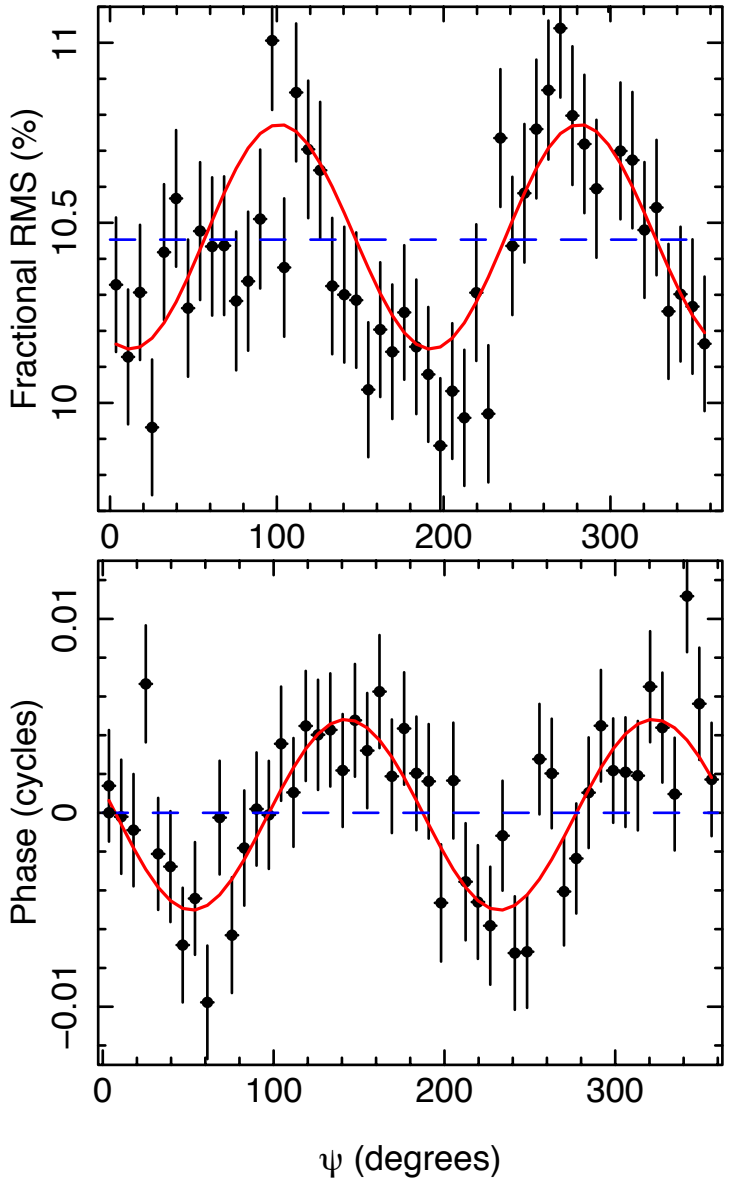
X-ray polarimetry-timing

Simulated 200 ks IXPE exposure:

Proposed missions:

XIPE (ESA M4 candidate): 2× area = even better

eXTP (Chinese-led): 2-5× area + large area detector = even better still!



Ingram & Maccarone (in prep)

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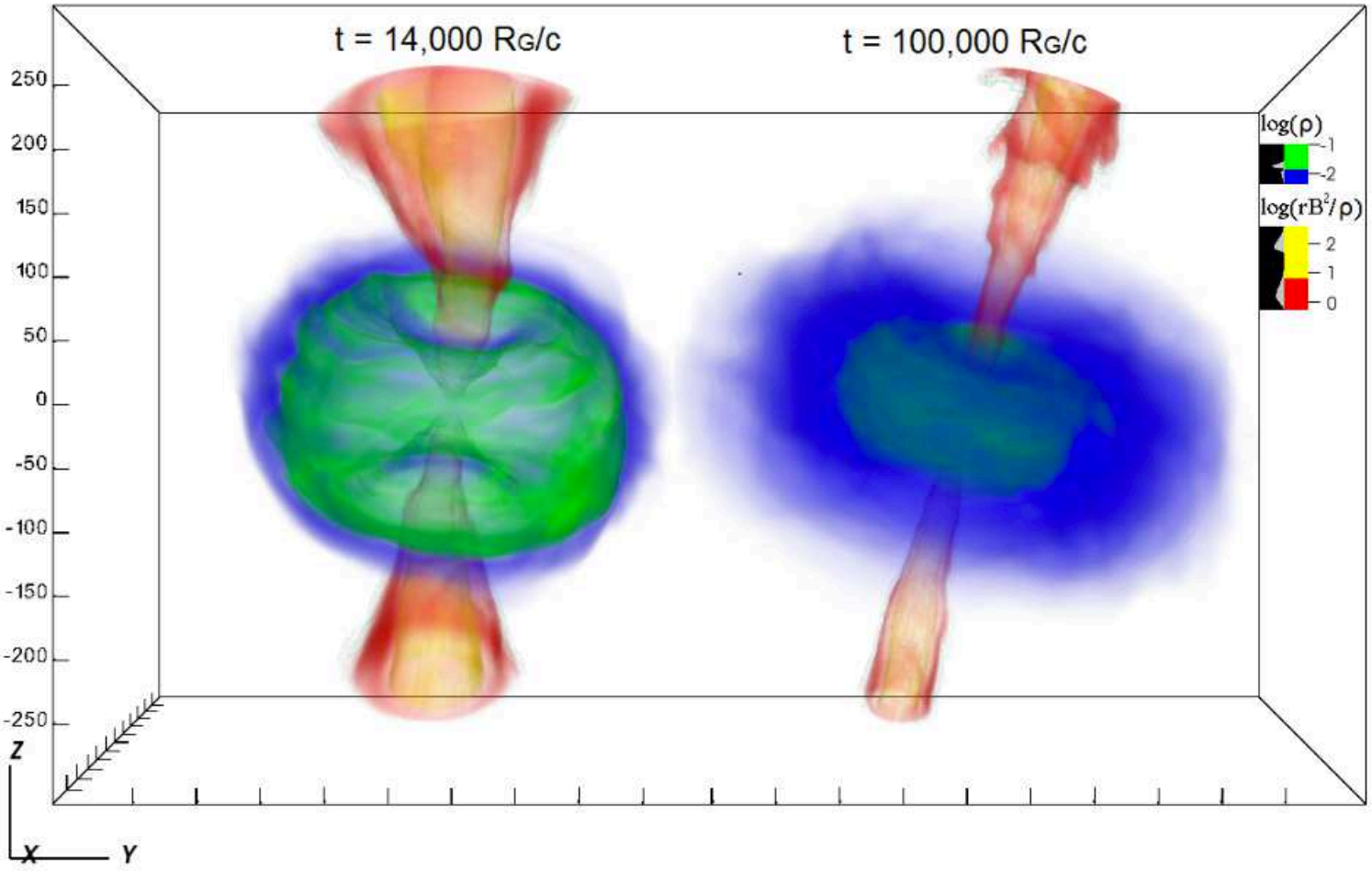
Jet precession



Liska, Hesp, Tchekovskoy, Ingram et al (in prep)

Conclusions

- The centroid energy of the iron line in H 1743-322 is modulated on the QPO frequency => LT precession!
- First instance of tomographic mapping
- X-ray polarimetry-timing provides orthogonal test and powerful probe of the accretion geometry
- This should be possible with IXPE
- XIPE and eXTP will be even better!
- Method not just for QPOs: any kind of stochastic variability!
- Predict jet precession with high-res GRMHD simulations