

Imaging Black Hole QPO Models

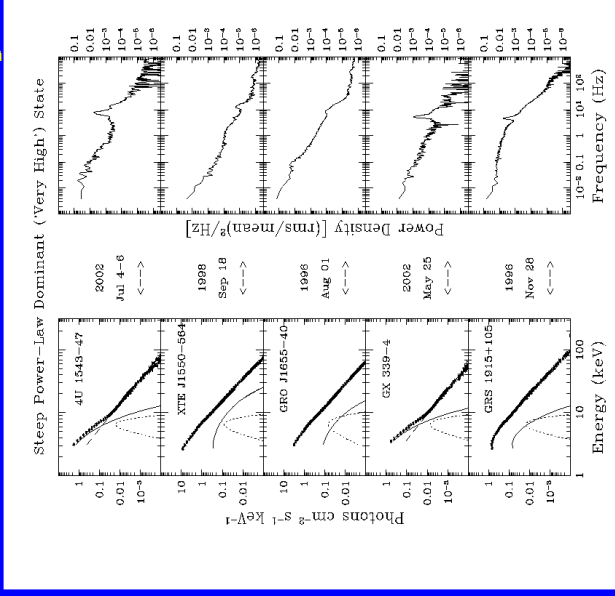
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KITP Jets/Disks Conference
Santa Barbara, CA
May 25, 2005

Outline

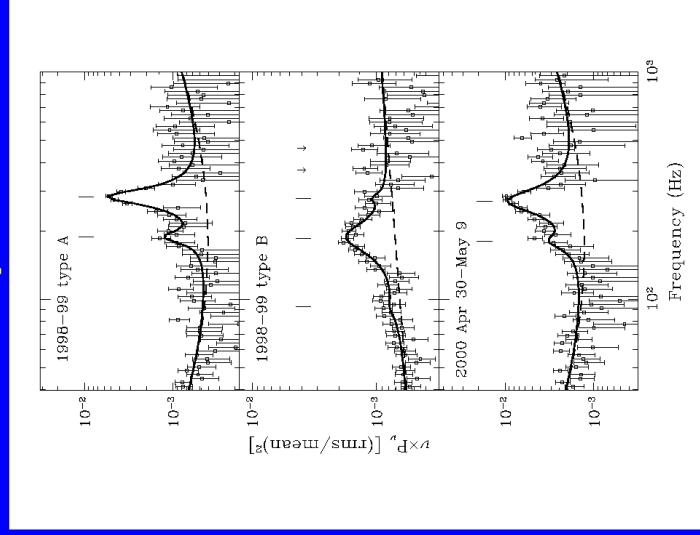
- Motivation
- Ray Tracing in Kerr Metric
- Example Models
 - Geodesic Hot Spot
 - Precessing Ring
 - Oscillating Torus
- The Future....

RXTE observations of black holes in the steep power law state show a variety of QPOs



McClintock & Remillard (2005)

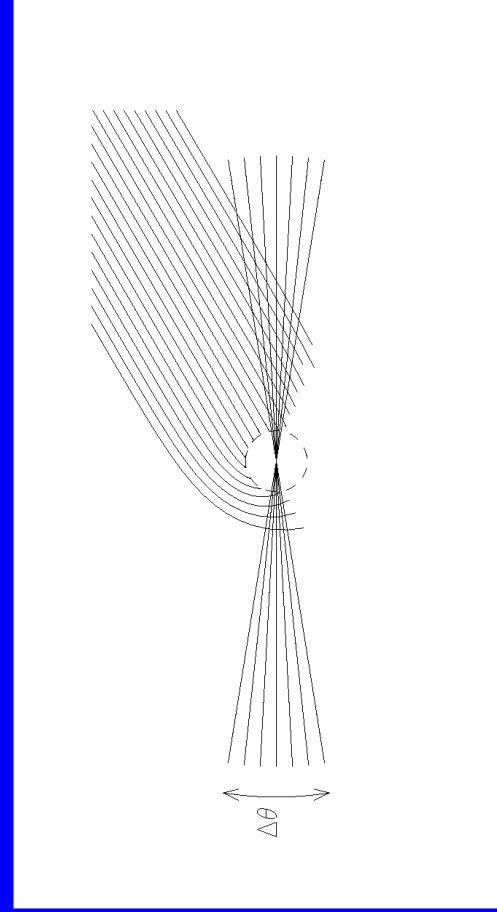
Many of the high frequency QPOs appear at commensurate frequencies with integer ratios



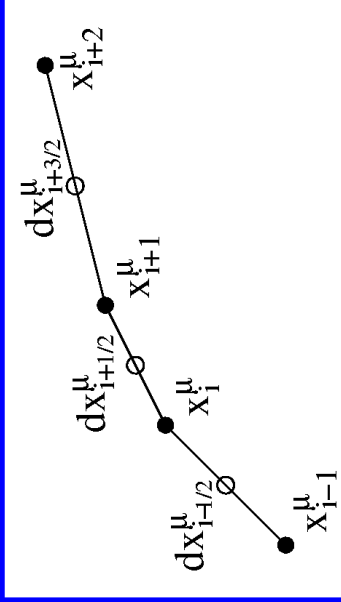
- XTE J1550-564
- GRO J1655-40
- Miller et al. (2001)
- Remillard et al. (2002)
- GRS 1915+105
- Remillard et al. (2003)
- H1743-322
- Homan et al. (2005)

Ray Tracing

We ray-trace photons backwards in time from a distant observer through a fixed grid



The relativistic radiative transfer equation is solved along the photon path length

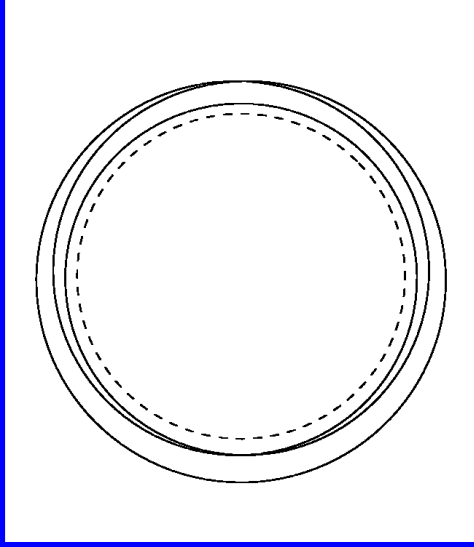


$$\frac{dI_\nu}{ds} = \left(\frac{\nu}{\nu'}\right)^2 j'_\nu - \left(\frac{\nu'}{\nu}\right) \alpha'_\nu I_\nu$$

Rybicki & Lightman (1979)

Geodesic Hot Spot Model

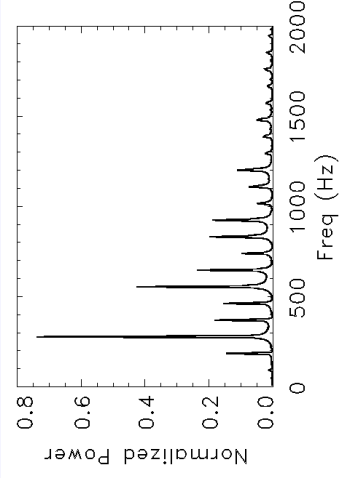
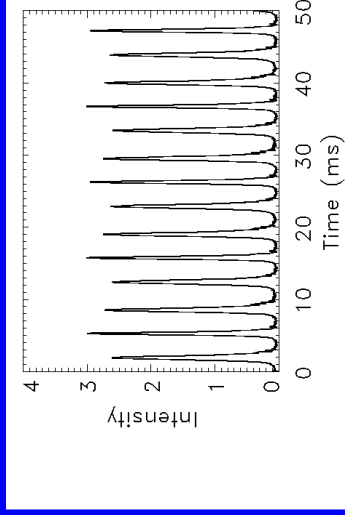
Light curves are calculated by integrating
emission from hot spots orbiting along
geodesic orbits



The X-ray light curves are characterized by the
relative power in each of the beats and
harmonic overtones

$$M = 10M_{\odot} \quad a/M = 0.5 \quad r/M = 4.887$$

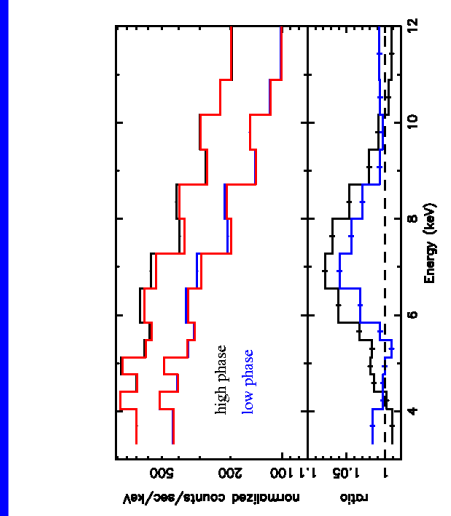
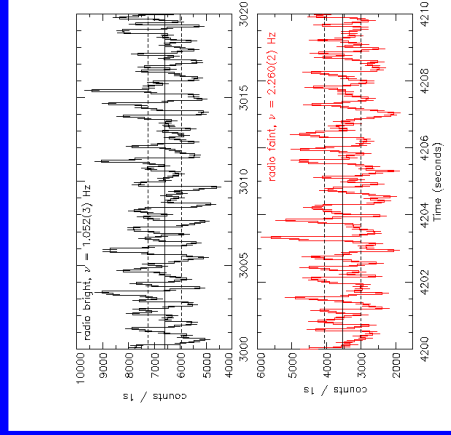
$$\nu_{\phi} = 285 \text{ Hz} \quad \nu_r = 95 \text{ Hz}$$



Schnittman & Bertschinger (2004)

Precessing Ring Model

The geodesic ring model has been used to explain recent observations of GRS 1915+105



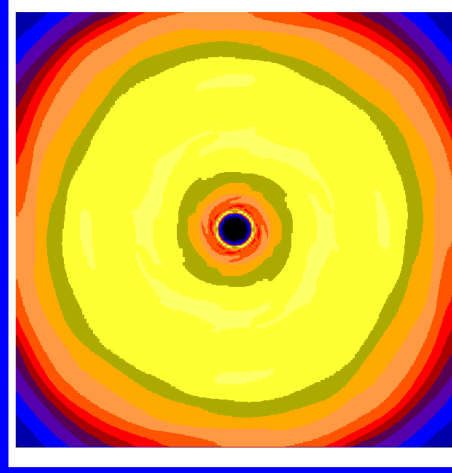
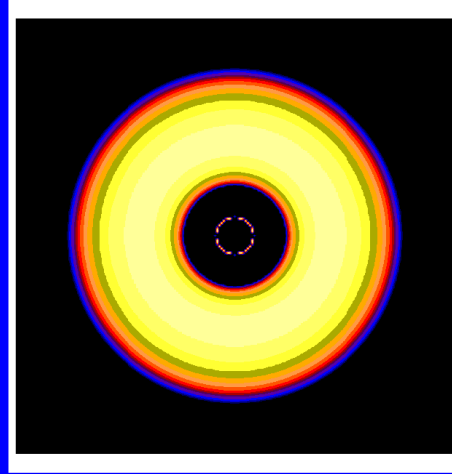
Miller & Homan (2005)

Oscillating Torus Model

Rezzolla, Yoshida, Maccarone, & Zanotti (2003)
 Rezzolla, Yoshida, & Zanotti (2003)
 Zanotti, Rezzolla, & Font (2003)

The Future

light curves and spectral lines from global MHD simulations



De Villiers & Hawley (2003)
 De Villiers, Hawley, & Krolik (2003)
 Hirose, Krolik, De Villiers, & Hawley (2004)
 De Villiers, Hawley, Krolik, & Hirose (2005)
 Krolik, Hawley, & Hirose (2005)

Additional Features

- Electron Scattering
- More Detailed Emission Models
- Higher Resolution, Parallel Implementation
- More QPO Models!!