

QPOs in GRMHD Simulations

Theoretical Astrophysics in Southern California

24 October 2008

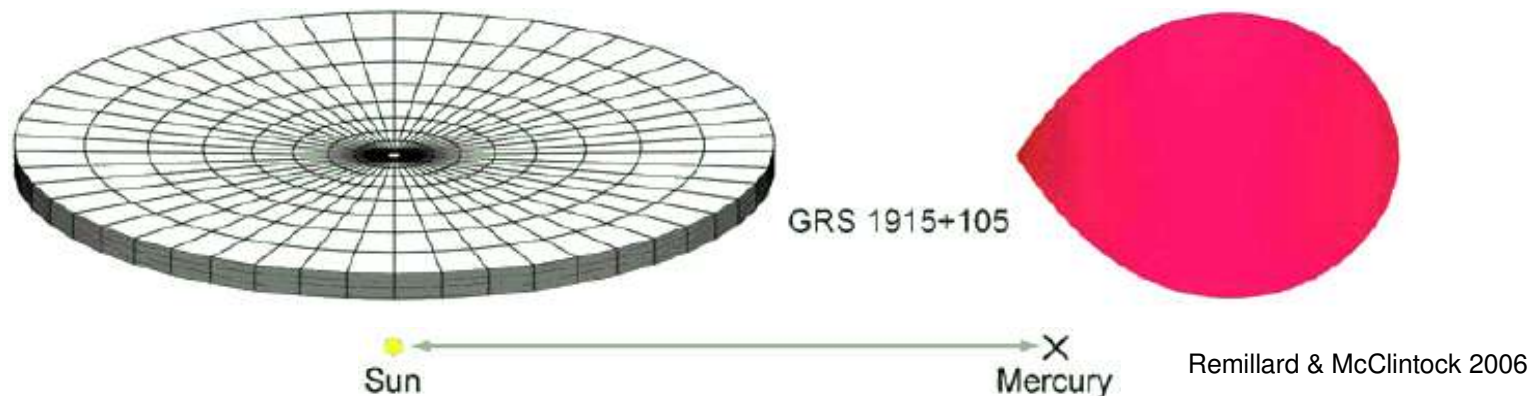
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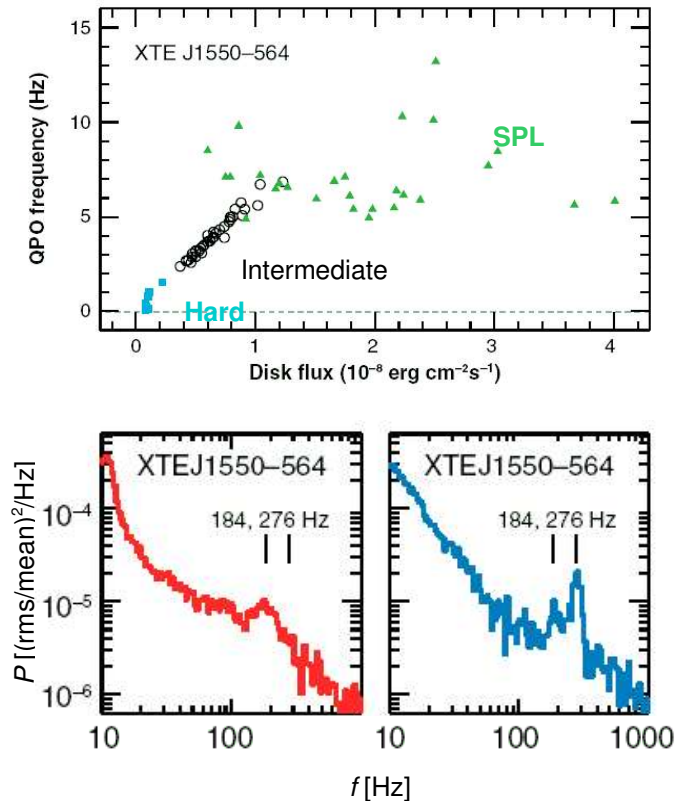
An Introduction to Black Hole X-Ray Binaries

- These binary systems include:
 - One $\sim 10M_{\odot}$ black hole primary.
 - A matter donating secondary.
- Plasma from the secondary feeds an accretion disk.
 - Dissipation of gravitational energy gives rise to disk temperatures with thermal spectra peaking in the X-rays.



Observed X-Ray QPOs

- Observations of quasi-periodic oscillations (QPOs) in the X-ray luminosities can be divided into two classes:
 - Low Frequency (0.1 to 30 Hz) QPOs:
 - QPO frequency is highly correlated with disk flux.
 - High Frequency (40 to 400 Hz) QPOs:
 - Stable frequency between successive eruption states.
 - Observed in commensurate 3:2 pairs.
- Disk v. space-time geometry?



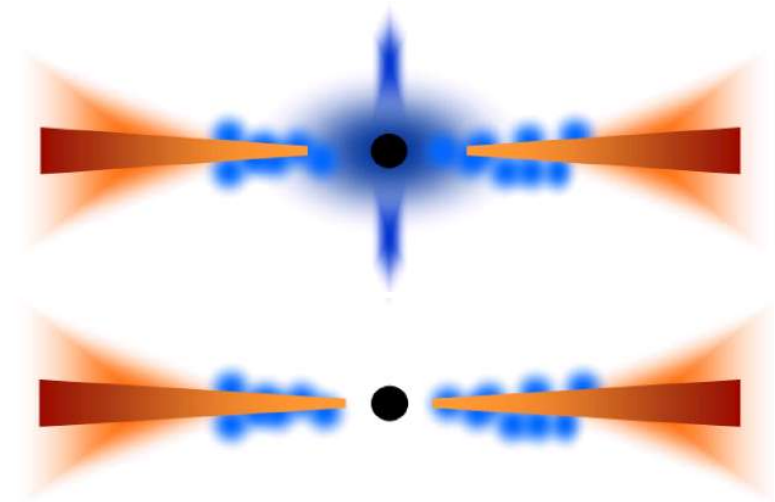
Remillard & McClintock 2006

GRMHD Simulations and QPOs

- COSMOS++ (Anninos, Fragile & Salmonson 2005):

- Fully general relativistic space-time.
- Magnetohydrodynamic (MHD) evolution.
- Global computation domain.
- Tilted and untilted disk geometries.
- No prescription for heating or cooling.

Done, Gierliński & Kubota, 2007



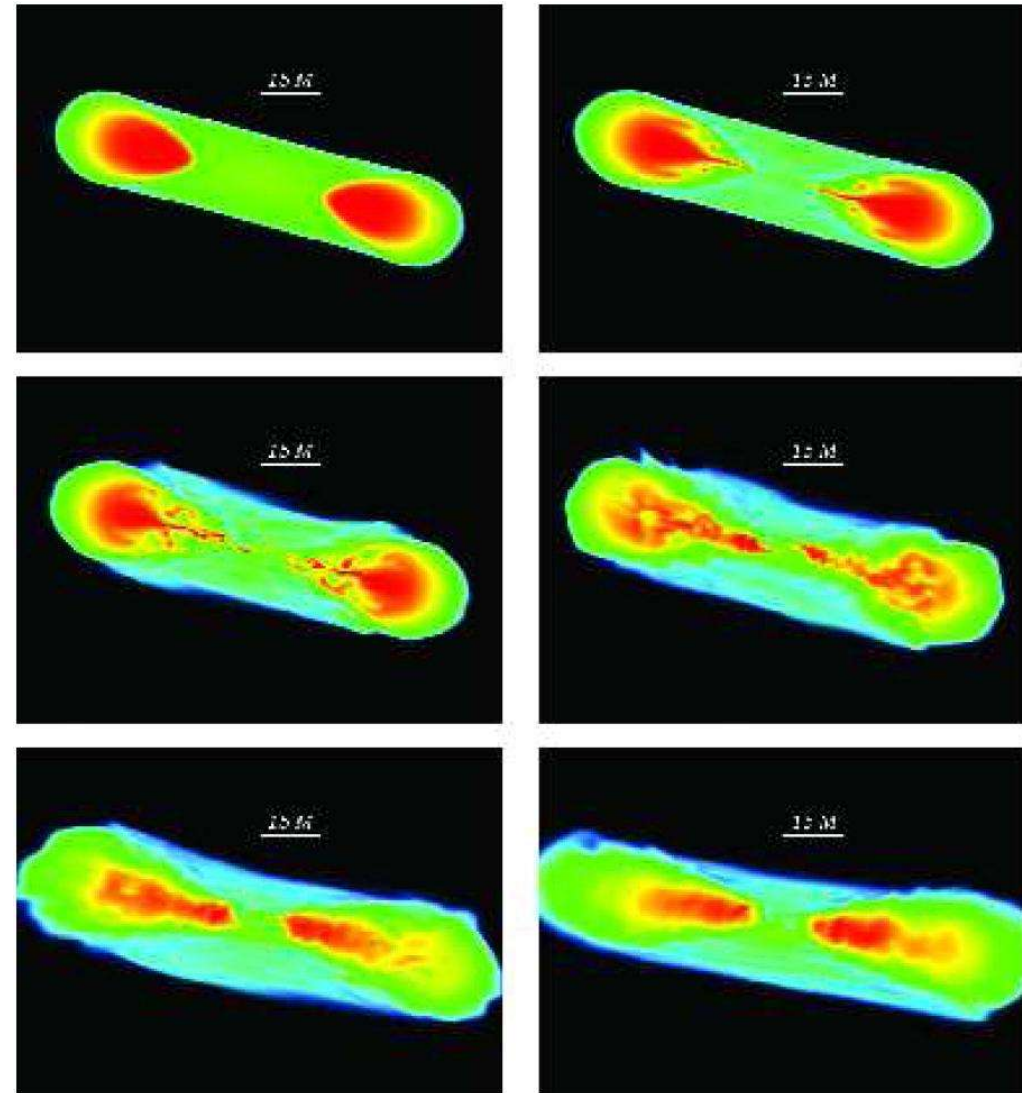
- Can we expect to succeed?

- Can we accurately simulate the necessary energetics?
- Need the captured disk dynamics be responsible for a QPO signal?

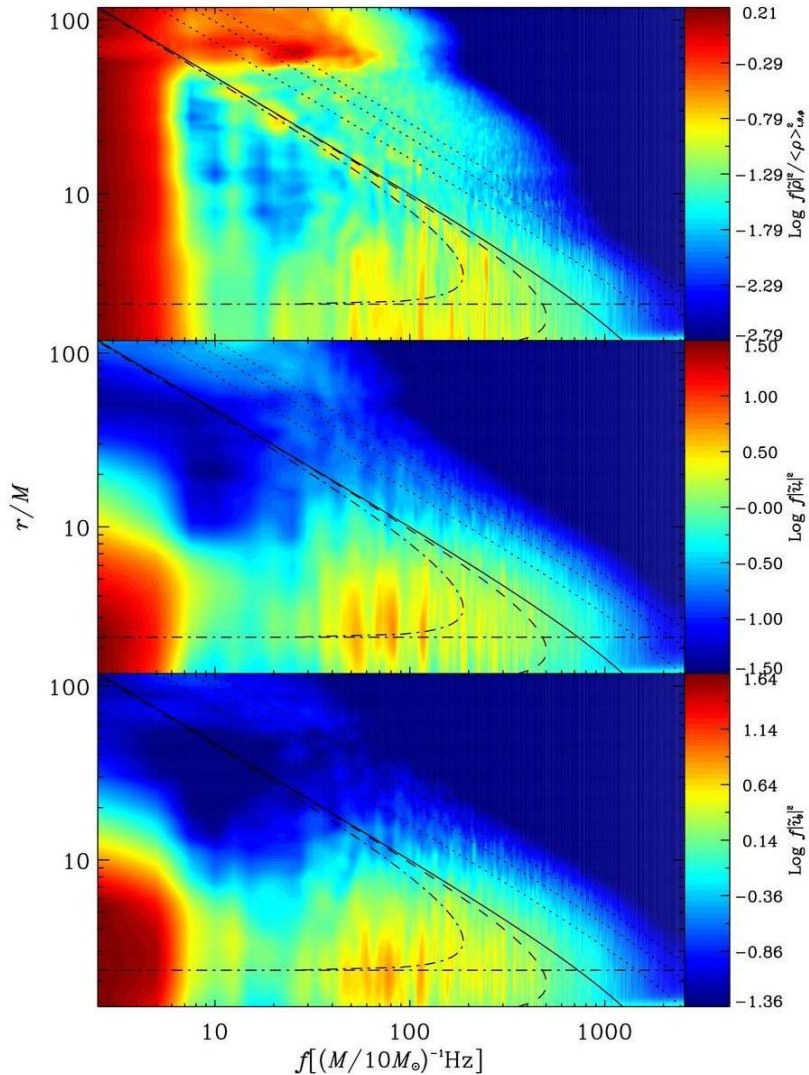
Tilted Disks and the Kerr Metric

- Tilted v. Untilted simulations:

- *A priori*, there is no evidence for alignment between BH and disk angular momenta.
- Relativistic dragging produces a bodily Lens-Thirring precession in a tilted geometry.
- The outer disk radius determines the precession period.
- Low frequency QPO candidate.



Spectral Analysis and Results



- Power Density Spectrum:
 - Shell averaged as a function of radius.
 - Three fluid variables: ρ , v_r , v_θ .
 - Over-plots of Ω (and harmonics), κ_r , κ_θ .
- Exciting Features:
 - Coherent peak in all 3 fluid variables.
 - Peaks' radial extents match inertial mode trapping regions.
 - Modes are only excited in tilted disks.
 - First HFQPO “observed” in simulation!

Theoretical Understanding

- Previous work predicts an absence of inertial modes:
 - Arras, Blaes, & Turner (2006) and Reynolds & Miller (2008) indicate the magneto-rotational instability (MRI) inhibits the growth of inertial modes.
- Our results corroborate recent theoretical work on disk warp and tilt:
 - Ferreira & Ogilvie (2008) suggest a warp or tilt in the outer disk will couple to inertial modes through an intermediate mode.
 - According to our simulations, this coupling seems strong enough to overcome MRI induced turbulence.

- Disk tilt may be essential in understanding both the low and high frequency QPOs:
 - Previous work on the turbulent suppression of inertial modes only examines the MRI as a driving mechanism for these modes.
 - Disk warp, amid MRI turbulence, appears to excite discrete inertial modes in the inner regions of the disk which exhibit a HFQPO.
 - Lens-Thirring precession of a tilted disk may give rise to LFQPO behavior.
- Hold your breath for Henisey, Blaes, and Fragile (2008)...