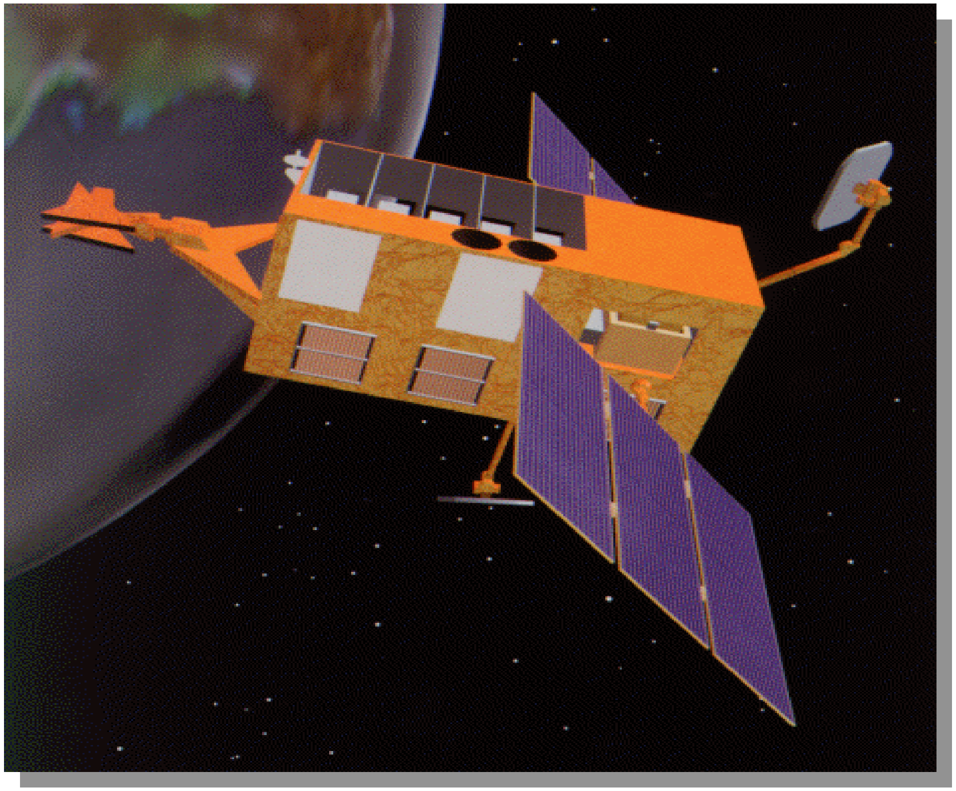
RXTE

Presentation to the 2002 Senior Review of Mission Operations and Data Analysis

Frederick Lamb
University of Illinois
Chairman, RXTE Users Group



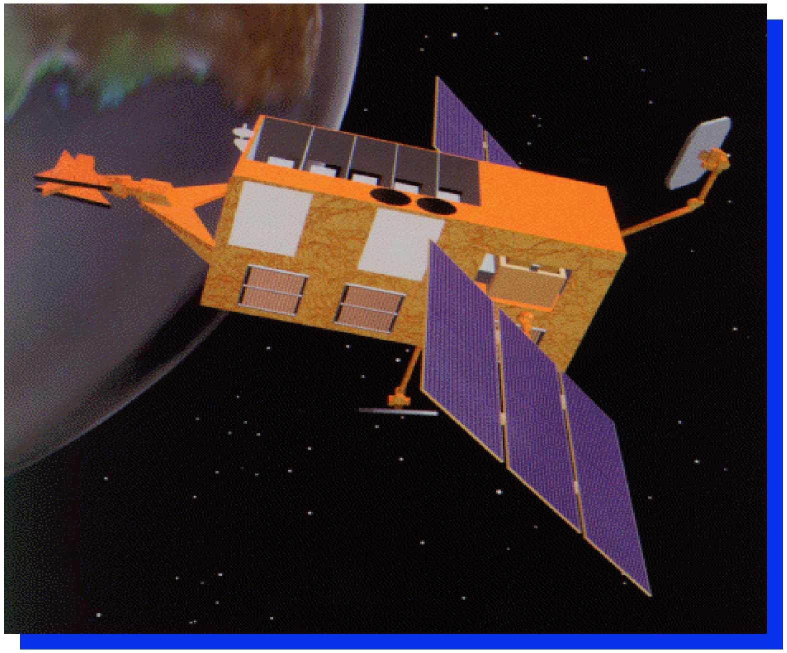
The Rossi X-Ray Timing Explorer

RXTE

Addresses Fundamental Astrophysics Questions with Unique Capabilities

RXTE addresses many fundamental questions, including –

- Gravitational physics in the strong-field regime
- Physics of ultradense matter and ultrastrong magnetic fields
- Mass inflows and outflows in accretion-powered systems



RXTE has capabilities unmatched by any other current or planned mission –

- Large collecting area and low background
- Broad (2-200 keV) energy coverage; will provide the only coverage above 10 keV
- Provides timing from 1 μs to 10 Ms
- Continuous monitoring of the X-ray sky
- Rapid response (15 min) when necessary for new sources and changes in known sources
- Highly flexible (even “last-minute”) scheduling, excellent coverage of the night sky
- Uniquely high telemetry rates
- Sophisticated onboard data processing

RXTE Rationale for Continuing the Mission

- RXTE has many unique capabilities
- These capabilities are continuing to yield major discoveries that address fundamental questions
- Follow-up observations are critical to capitalize on these discoveries and to resolve outstanding questions
- Coordinated observations with Chandra, XMM-Newton, INTEGRAL, and the new TeV observatories will increase greatly the scientific yields of all these efforts

RXTE

Some Major Scientific Discoveries and Accomplishments Since June 2000

- Sidebands on kilohertz QPOs in neutron stars
- Pairs of stable high-frequency QPOs in black holes
- Firmer evidence for black holes with significant spin
- Evidence for 3:2 frequency relation of black hole QPOs
- Superbursts from neutron stars
- Two more millisecond accretion-powered pulsars (making 3 total)
- Strong correlation of X-ray and TeV flaring in blazars
- Evidence for SGR-like bursts from an anomalous X-ray pulsar
- Large glitches in the spin of the fastest rotation-powered pulsar
- Discovery of additional pulsars with cyclotron resonance lines

RXTE

Some Major Scientific Discoveries and Accomplishments Since June 2000

Events Last Month (May 2002)

- Discovery of a third millisecond accretion-powered pulsar (XTE J0929–314, ν_{spin} = 185 Hz)
- Discovery of a new black hole candidate (XTE J1908+094)
- Simultaneous very strong X-ray and TeV flare in 1ES 1959+650
- Strong X-ray flare in Eta Carinae
- X-ray and radio observations of unusually strong optical flaring of the black hole SAX J1819.3–2525 = V4641 Sgr
- Largest outburst of black hole candidate GX 339–4 since 1988, revealing microquasar behavior (Belloni et al. 2002)

(10 RXTE IAU Circulars in May)

RXTE Productivity and Guest Observing Budget

RXTE Publications

- The yearly rate of RXTE-related refereed publications has increased by a factor ~ 10 from 1996 to 2001
- More than 730 refereed papers and 430 IAU Circulars have now been published
- More than 2,000 RXTE-related papers have been published to date (~ 1,000 since the 2000 Senior Review)

Requested Budget for Guest Observations

- The 1998 Senior Review recommended that $1,000 k be transferred from the RXTE budget to the ADP budget to support RXTE and other observations via this program
- For AO-8 we are requesting an average of $10 k for successful RXTE observing proposals, which amounts to $700k per year

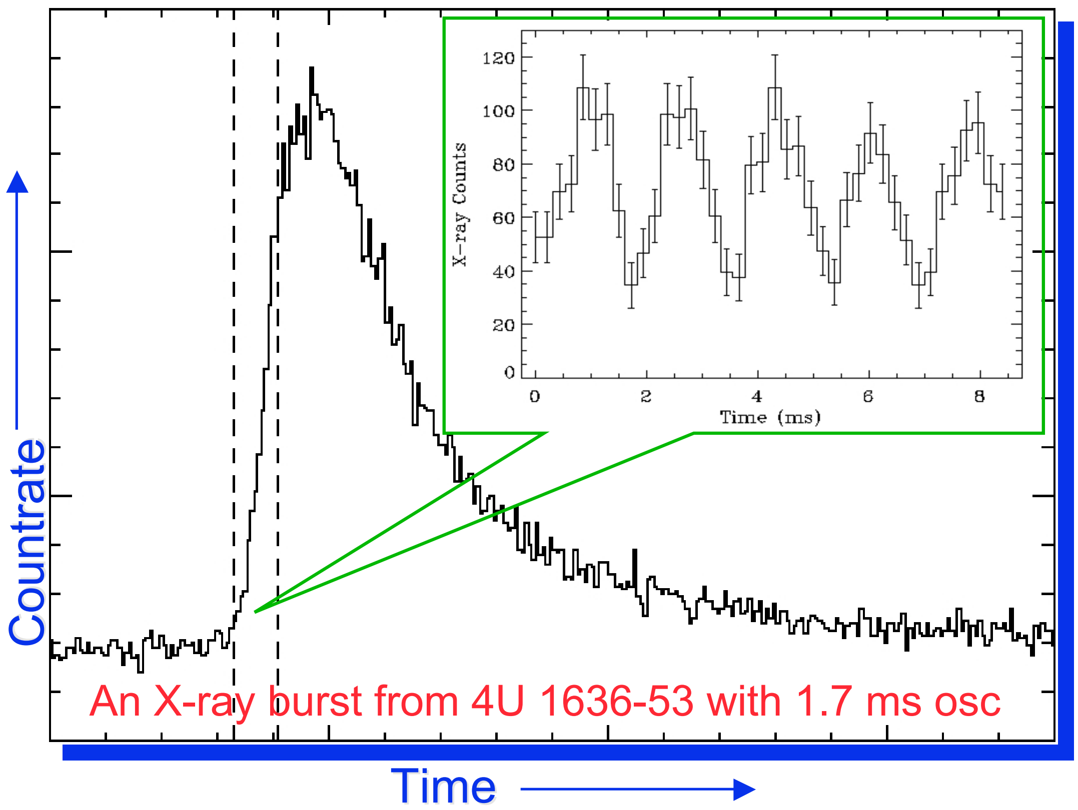
RXTE # Productivity and Guest Observing Budget

Differences in AO-7 Operation Mode

- Less reluctance to interrupt non-TOO's (60% more TOO observing time during the first 3 months of AO-7 than in AO-6)
- Greater confidence in the value of short observations and skill at planning are making possible more extensive monitoring programs
- Chandra and XMM-Newton coordinated observations are more common (~20% of the total)
- Chandra cycle 5 TACs will be able to allocate 500 ksec of RXTE time

Justification of the Requested Budget

- The requested yearly budget is only ~ 40% of the average budget over the first 5 years of the mission
- The requested budget has (very modest) support for GOs
- Support for a postdoc to maintain the ASM calibration
- 50% of a programmer to revise the software to protect the unique scheduling capability of RXTE



Physics of Nuclear Burning and Neutron Star Dynamics from X-ray Burst Oscillations

Ignition begins at a single point, creating a bright spot.

As the bright spot rotates with the star, we see X-ray oscillations.

The oscillation frequency varies systematically during a burst.

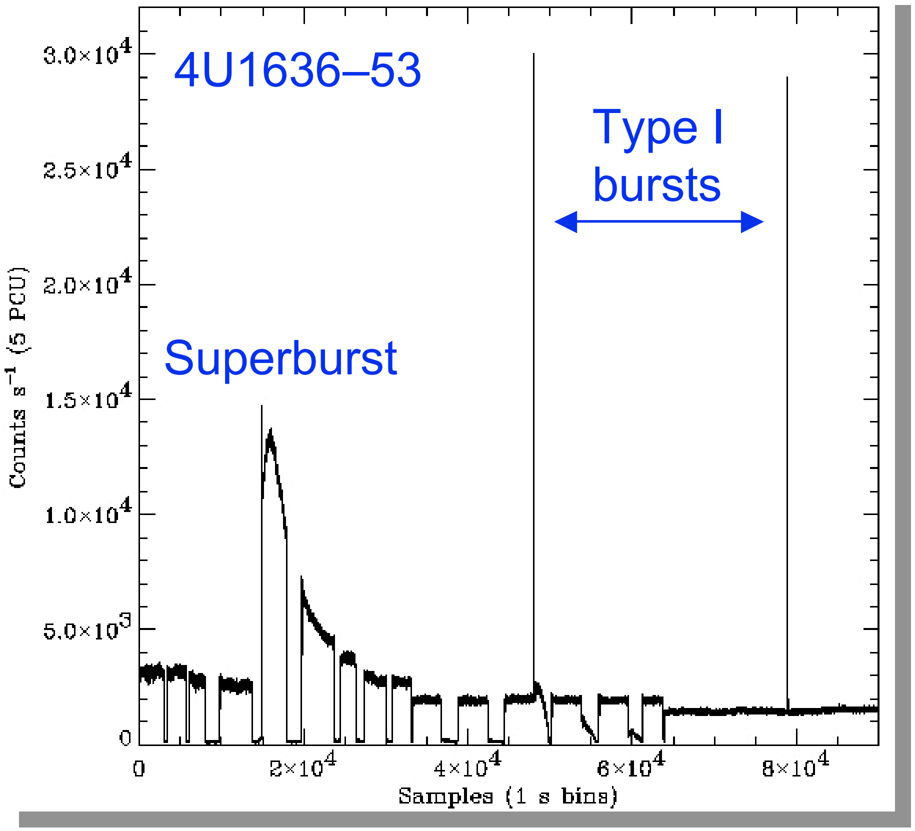
(Strohmayer et al. 1996, 1998)

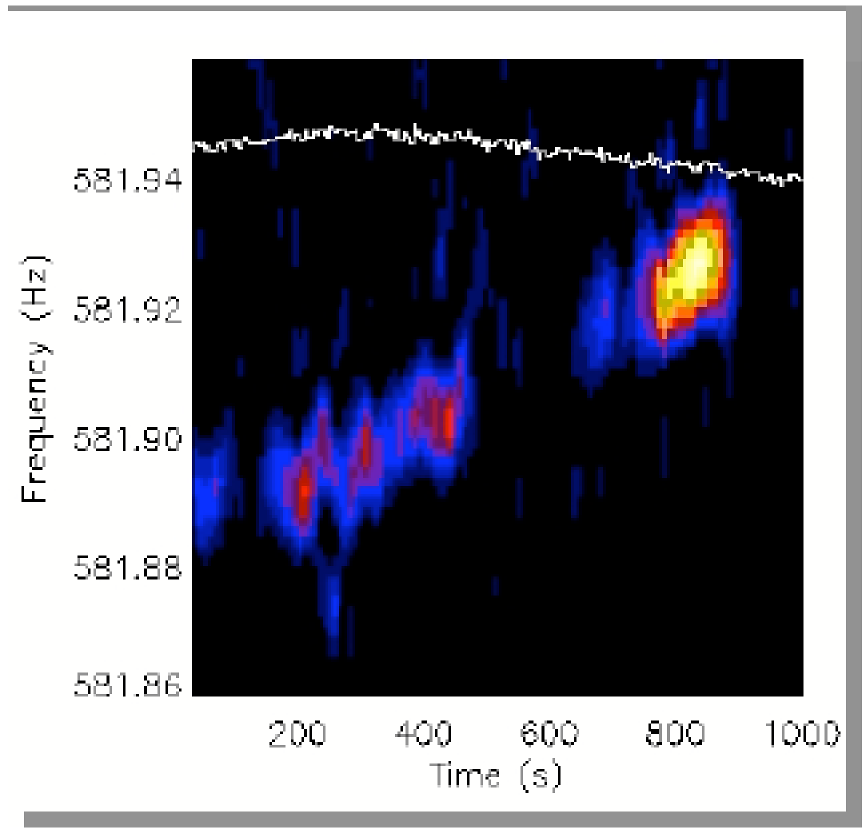
Implications for physics of neutron stars and nuclear burning –

- **The oscillations imply spin rates ~ 250–350 Hz, as expected from magnetic equilibrium.**
- **The oscillations in burst tails require confinement, possibly by the magnetic field.**
- **Oscillation amplitudes and waveforms constrain neutron star compactness (M/R).**

RXTE

Discovery of "Superbursts" With Nearly Stable Periodic Oscillations

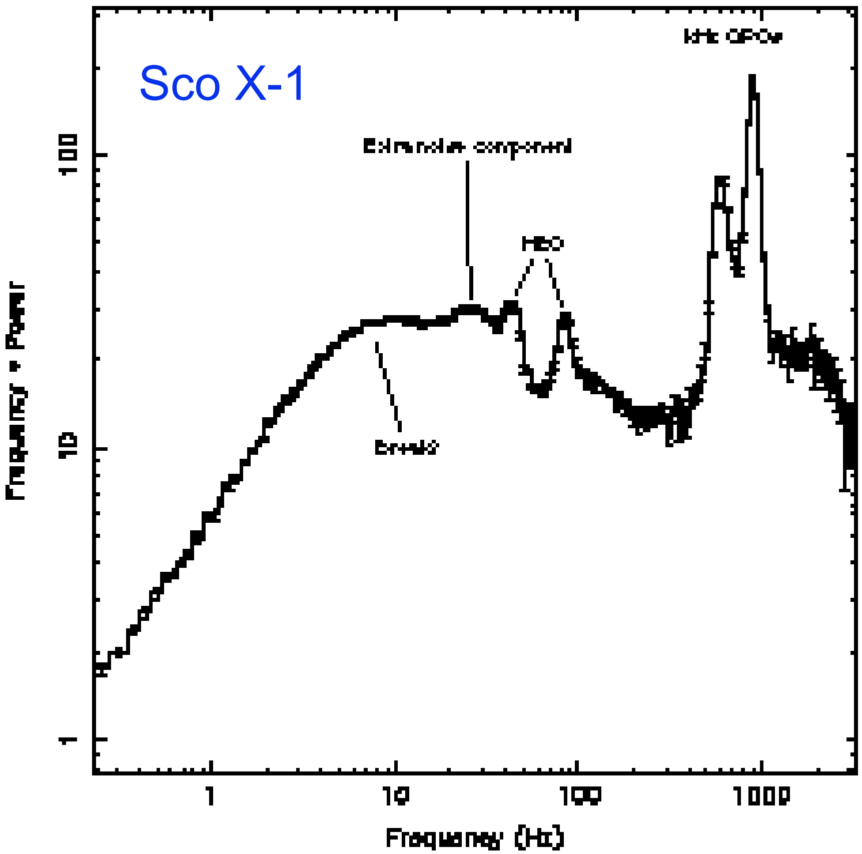




- Duration and total X-ray energy is ~ 1,000 times that of Type I X-ray bursts
- So far seen in five neutron stars. ASM saw 2 superbursts from 4U1636–53.
- Nuclear energy release occurs at much greater depths than in Type I bursts

RXTE

Kilohertz Quasi-Periodic X-ray Brightness Oscillations in Accreting Neutron Stars



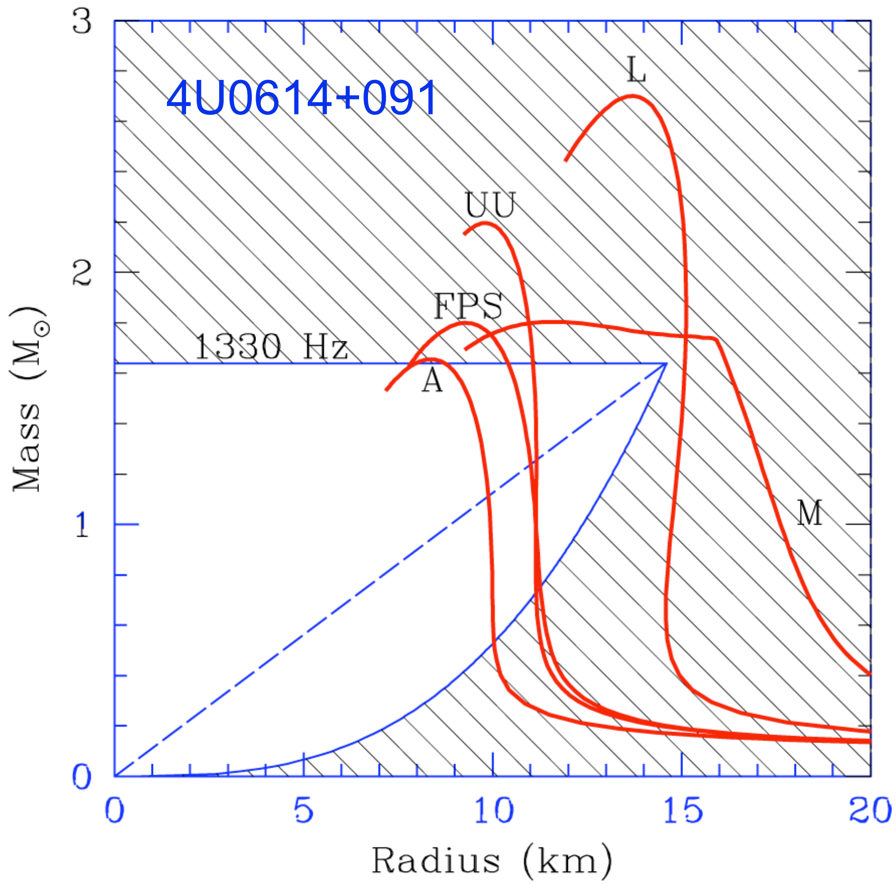
X-ray flux power density spectrum observed by Wijnands et al. (1998)

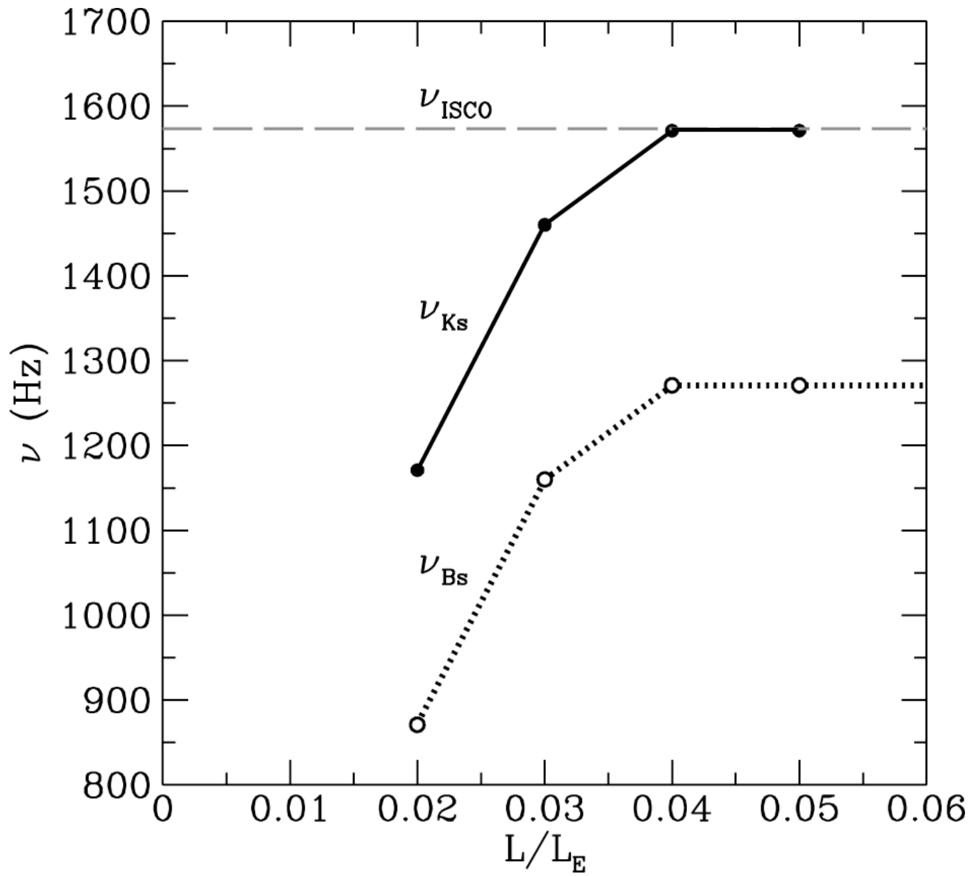
Key kilohertz QPO properties –

- Observed in > 20 neutron stars
- High coherence ($\nu/\delta\nu$ ~ 30–200)
- Two principal oscillations
- Their frequency separation $\Delta\nu$ remains fairly constant, about equal to the neutron star spin frequency
- The frequencies of the kHz QPOs can vary by several hundred Hz within ~ 100–1,000 seconds

RXTE

Constraints on Properties of Dense Matter
Evidence for General Relativistic Effects

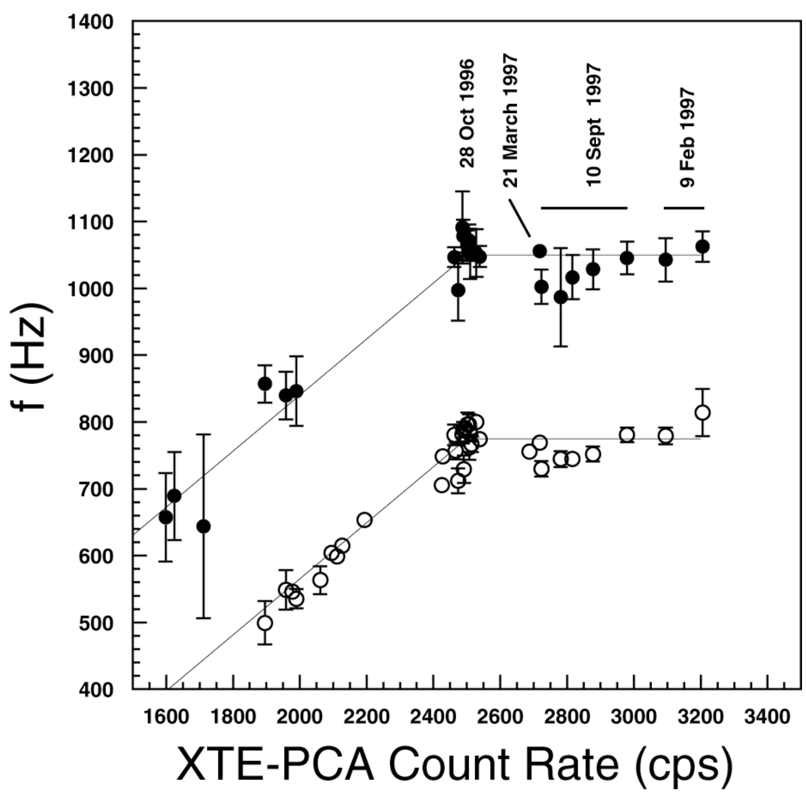


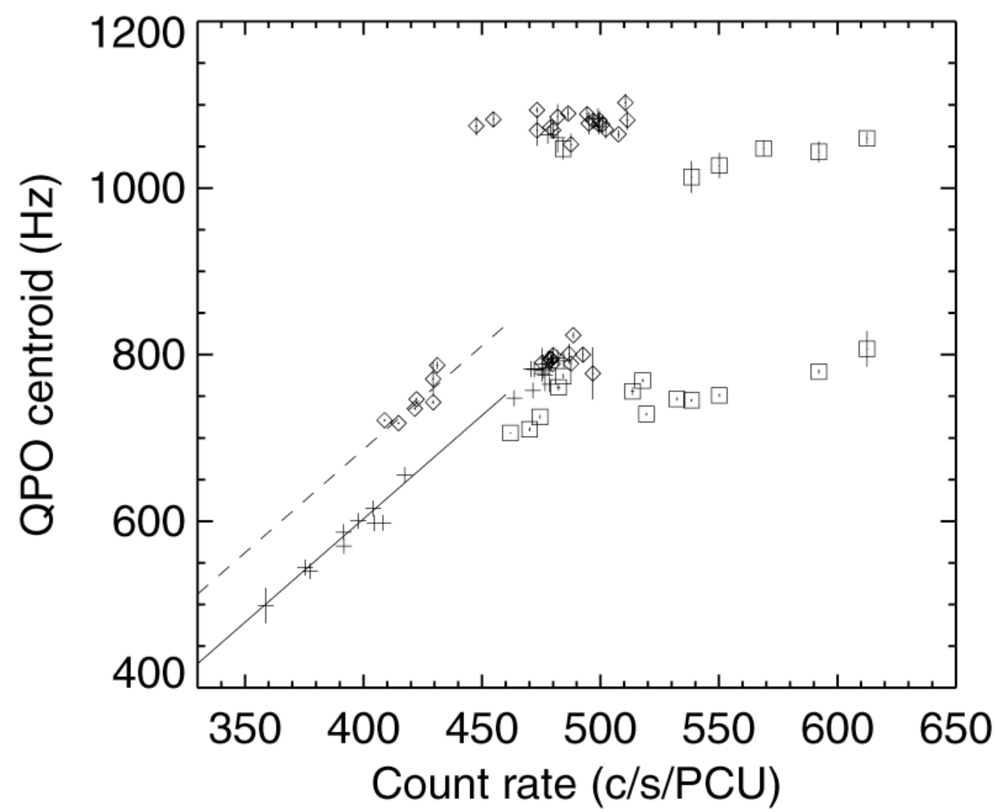


Left: Comparison of upper kilohertz QPO frequency with NS EOS
Right: ISCO signature predicted by Miller, Lamb, and Psaltis (1998)

RXTE

Evidence for the Predicted ISCO Signature Observed in 4U1820–30



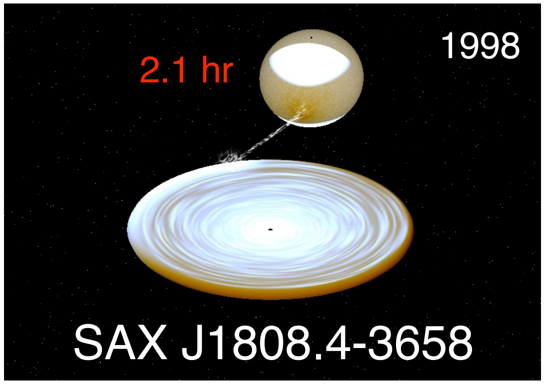


Left: QPO frequencies vs. countrate during 1996–97 (Zang et al. 1998)

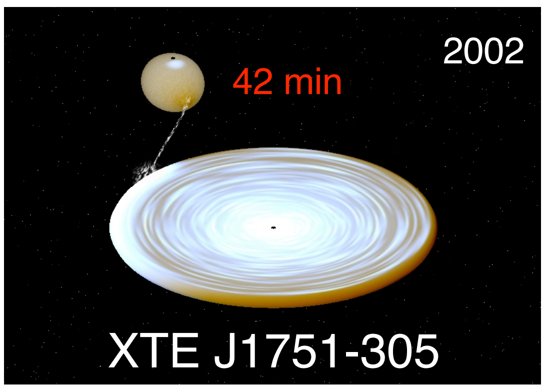
Right: QPO frequencies vs. countrate during 1998 (Kaaret et al. 1999)

RXTE

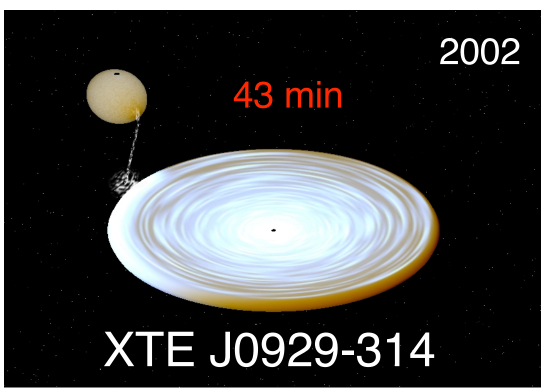
Discovery of Three Accretion-Powered Millisecond Pulsars in Ultracompact Systems



ν_{spin} = 401 Hz, f(M) = 3.9 x 10^{-5} $M_{\odot}$



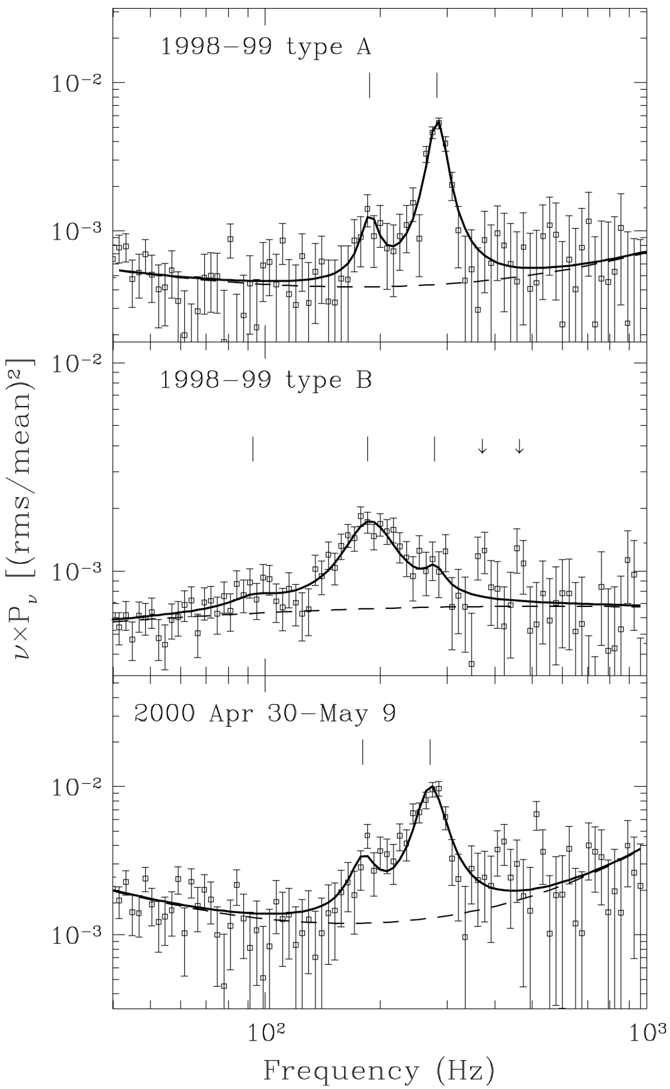
ν_{spin} = 435 Hz, f(M) = 1.3 x 10^{-6} $M_{\odot}$



ν_{spin} = 185 Hz, f(M) = 2.7 x 10^{-7} $M_{\odot}$

RXTE

Discovery of Pairs of High-Frequency QPOs in Galactic Black-Hole Candidates



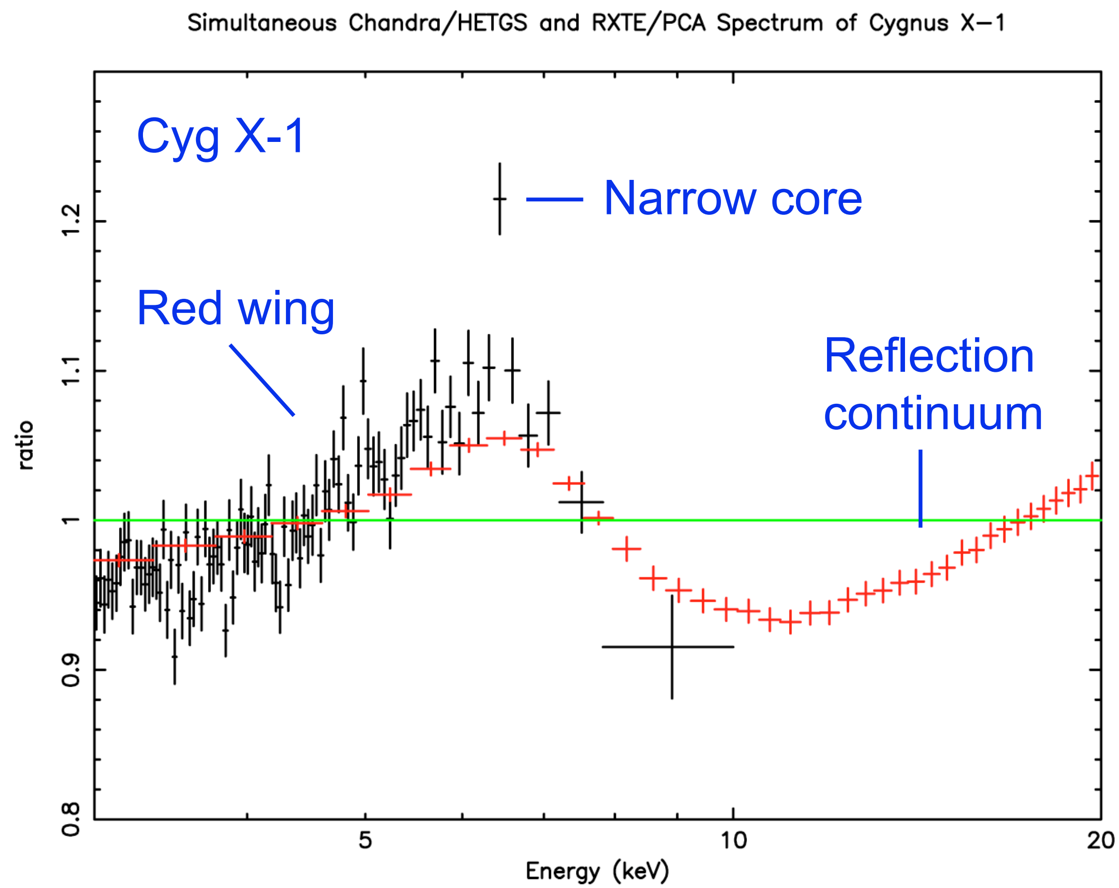
Stable frequencies, with evidence for 3:2 frequency ratios

QPOs are strongest at photon energies greater than 10 keV

Amplitude ratios change systematically with X-ray spectral state

RXTE

Coordinated RXTE & Chandra Observations of Fe Lines in Galactic Black-Hole Candidates



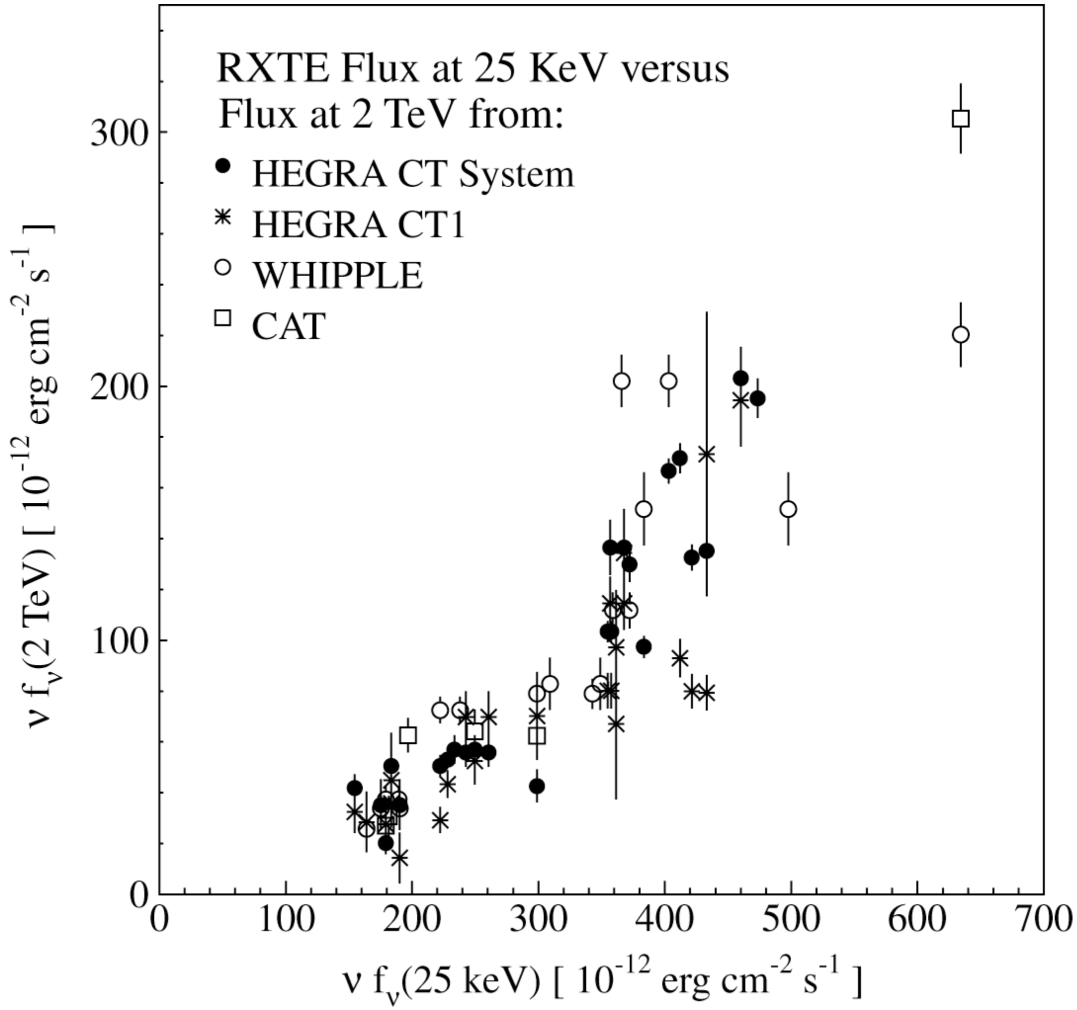
Miller et al. (2002)

- RXTE/PCA and Chandra/HETGS line spectra agree well
- The Fe line is broad with a very narrow central component
- The reflection continuum is very clear in the RXTE spectrum

RXTE

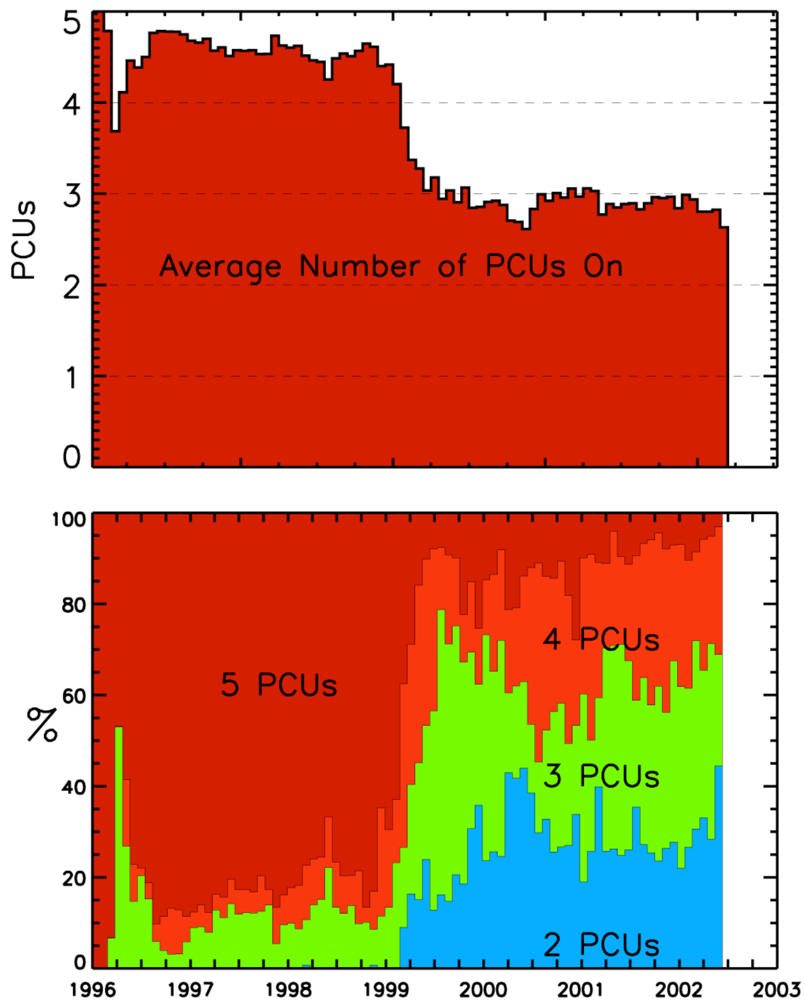
Discovery of Strong Positive Correlation Between X-ray and TeV Flaring

Mk 501 (Krawczynski et al. 2002)



Further coordinated observations with TeV observatories are a major focus of the observing program in the current AO-7 observing cycle

RXTE Health of the Proportional Counter Array



PCU performance has been stable over the past 18 months

On average, 3 PCUs are in use at any one time

All 5 PCUs are used when needed