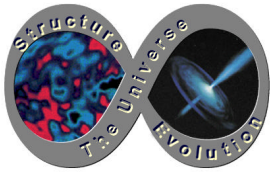


Goals of the Rossi Explorer Mission

- Prime scientific objective —
  - Investigate the fundamental properties of compact objects (white dwarfs, neutron stars, & black holes)
- Observational approach —
  - High time resolution observations of the X-rays produced near stellar surfaces and black hole horizons
- The Rossi Explorer addresses two of the three Fundamental Questions in the SEU Roadmap —
  - The cycles of matter and energy in the evolving universe
  - The ultimate limits of gravity and energy in the universe
- The Rossi Explorer addresses four of the six Research Campaigns in the SEU Roadmap —
  - The cycles in which matter and energy are exchanged
  - How gas flows in disks and how cosmic jets are formed
  - The sources of gamma-ray bursts and high-energy cosmic rays
  - How strong gravity operates near black holes and neutron stars

The Rossi X-ray Timing Explorer
A Unique Combination of Capabilities

Unprecedented capabilities to study X-ray variability on the dynamical time scales of neutron stars and black holes

- The largest X-ray telescope ever flown
- Very high time resolution (1 microsecond)
- Very high throughput (up to 150,000 counts/second)
- Broad energy coverage: 2 - 200 keV

Continuous monitoring of the X-ray sky combined with rapid response (within hours) to changes and transient events

Extremely flexible observing and scheduling support for multi-wavelength science

- Can observe any source for most of the year
- Flexible scheduling, short-notice rescheduling

New Science Results from RXTE
Probing the Extremes of Compact Objects

- Discovery of millisecond X-ray pulsars
  - 2.5 ms accretion-powered X-ray pulsar, SAX J1808-369
  - Six nuclear-powered millisecond pulsars
  - Fastest rotation-powered X-ray pulsar (16 ms), XTE J0537-6910
- Discovery of sub-millisecond X-ray brightness oscillations (kilohertz QPOs)
  - Relatively coherent (Q ~ 100)
  - Two in each source
  - Frequencies vary by hundreds of Hz
  - Frequency separation remains almost constant, close to NS spin frequency
- Important new constraints on the Mass, Radius, and Equation of State of neutron stars
  - From kilohertz QPO frequencies
  - From oscillation amplitudes during X-ray bursts
  - From harmonic content of burst oscillations
- First evidence for predictions of General Relativity in the strong-field regime
  - First evidence for innermost stable circular orbits around neutron stars
  - Possible detection of Lense-Thirring precession around neutron stars and black holes, and discovery of unsuspected Lense-Thirring precession modes of the inner disk

New Science Results from RXTE
Probing the Extremes of Compact Objects

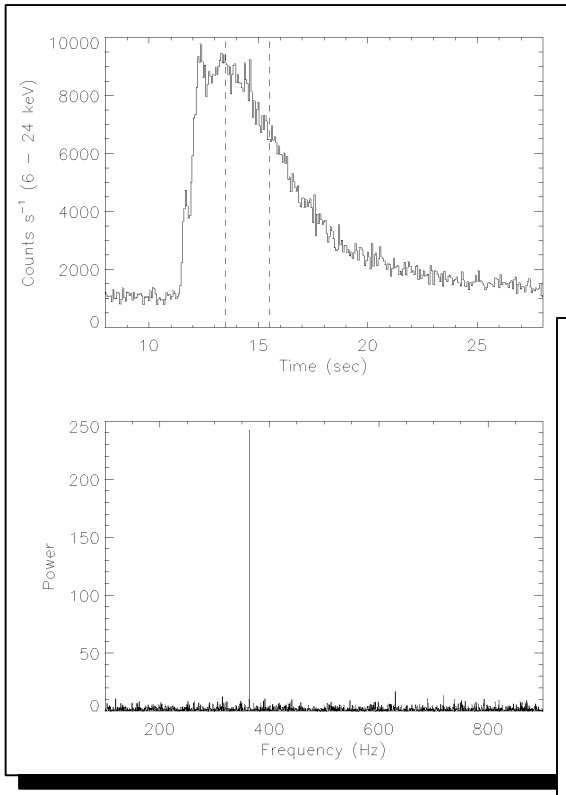
- New probes of the inner accretion disk around neutron stars and black holes
  - High-frequency QPOs
  - Rapid spectral changes correlated with other events
- First detailed studies of galactic micro-quasars
  - Discovery of three new jet systems
  - Discovery of jet-disk connection
- Discovery of a “magnetar”: a neutron star with a 10^{14}–10^{15}G magnetic field
- First determination of polar cap size on a magnetic white dwarf
- New probes of the geometry & physics of AGN using X-ray spectra above 10 keV
  - New evidence for the Unified Model of Sy I and Sy II galaxies
  - New constraints on Compton reflection (MCG-5-23-16, MCG-2-58-22, Cen A)
  - Discovery of unexpectedly long timescale variability in AGN
  - Similarity of AGN and X-ray binary power spectra (NGC 3516)
- New evidence for cosmic-ray acceleration in supernova remnants
- New understanding of X-ray variability
  - Discovery of 11 new transients
  - In-depth study of 42 outbursts in 30 different systems
  - Detection of 30 orbital or superorbital periods (12 new)

RXTE Discoveries Have Generated Widespread Public Interest

- Giant Bursts from the Bursting Pulsar (GRO J1744–28)
  - NASA Space Science Update, extensive TV, radio, and newspaper coverage
- Discovery of kilohertz QPOs —
  - HEAD press conference, extensive newspaper and radio coverage
- Possible evidence for Lense-Thirring Precession —
  - HEAD press conference, extensive TV, radio, and newspaper coverage
- First evidence for strong-field General Relativistic effects —
  - APS press conference, extensive TV, radio, and newspaper coverage
- Discovery of the disk-jet connection in microquasars —
  - NASA press release , extensive TV, radio, and newspaper coverage
- Discovery of the “missing link” millisecond accretion-powered pulsar —
  - NASA & *Nature* press releases , extensive TV, radio, and newspaper coverage
- Discovery of a “magnetar” with a ~10^{14} G magnetic field —
  - NASA & *Nature* press releases , extensive TV, radio, and newspaper coverage

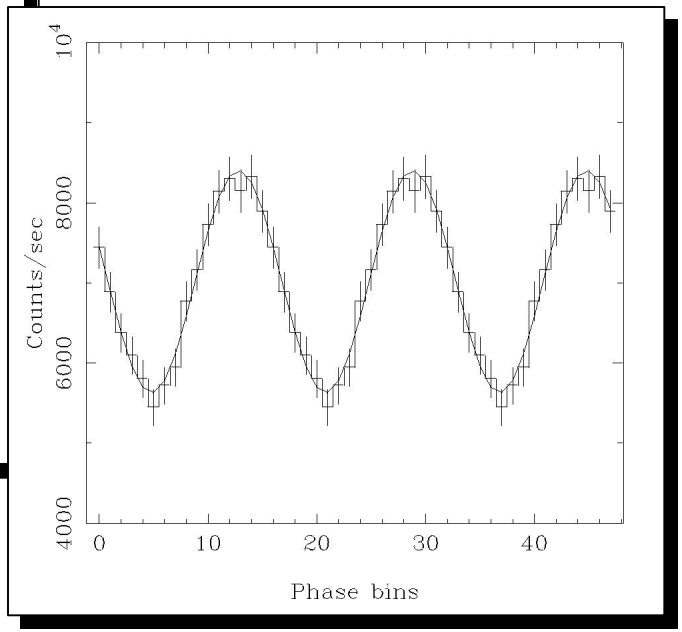
Discovery of Nuclear Powered X-ray Pulsars by RXTE

Large amplitude, millisecond oscillations in the X-ray brightness occur during thermonuclear flashes on neutron stars –



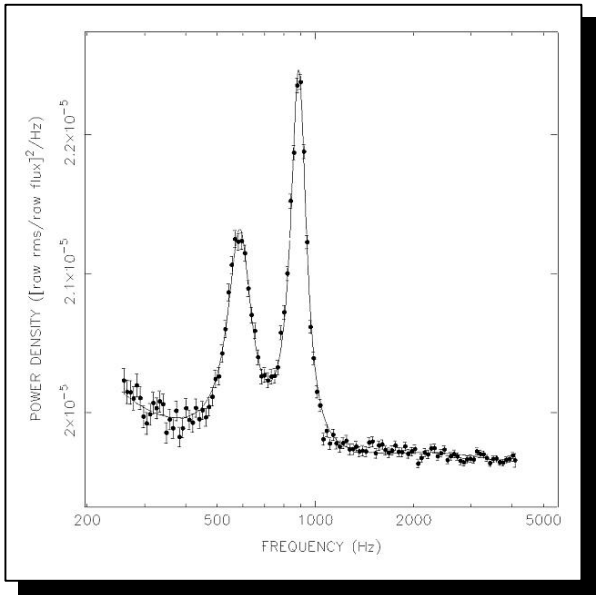
4U 1728-34

- Discovered by Strohmayer et al. (1996) using the PCA
- Observed frequencies range from 330 to 589 Hz
- Observed in a total of 6 NS-LMXBs to date
- Oscillations are highly coherent (Q ~ 1,000) in X-ray burst tails



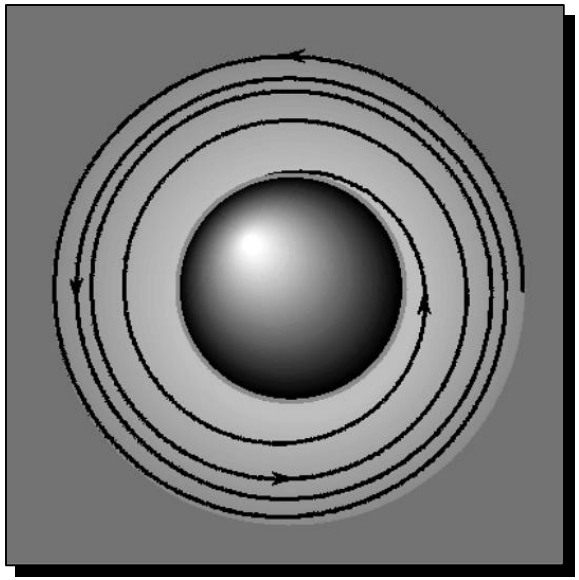
- Oscillations are likely caused by a hot spot in surface layers of neutron star
- Can be used to probe physics of thermonuclear fusion, the structure of the accreted envelope, and EOS of neutron star matter.

Discovery of Kilohertz QPOs by RXTE

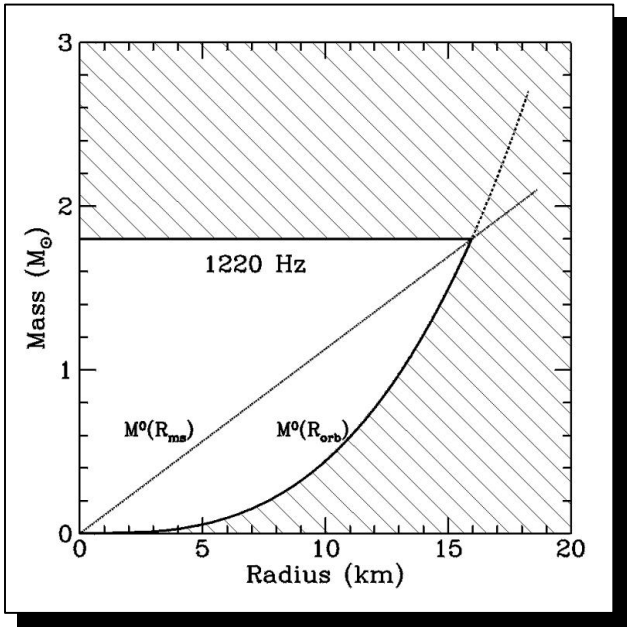


- RXTE has discovered kilohertz QPOs in 12 NS LMXBs —
  - Oscillations are remarkably coherent (Q ~ 100)
  - Two simultaneous kilohertz QPOs are often seen
  - The frequencies of the two QPOs sometimes vary by hundreds of Hz in only ~ 100–1,000 seconds
  - As the QPO frequencies vary, the frequency separation remains almost constant, close to the spin frequency

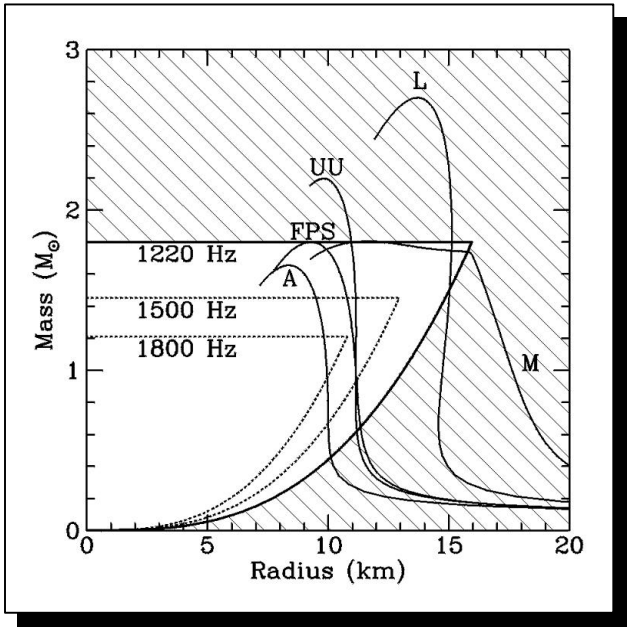
- Calculations of gas dynamics and radiation transport in full GR (Miller, Lamb, & Psaltis 1996, 1998) show how QPOs with Q ~ 100 can be generated —
  - Gas from clumps orbiting at the sonic radius spirals inward supersonically and collides with the star
  - Where gas from the clumps hits the star, the X-ray emission is brighter
  - The regions of brighter emission rotate at the sonic point orbital frequency, producing QPOs



Important New Constraints on Neutron Star Masses and Radii Using RXTE

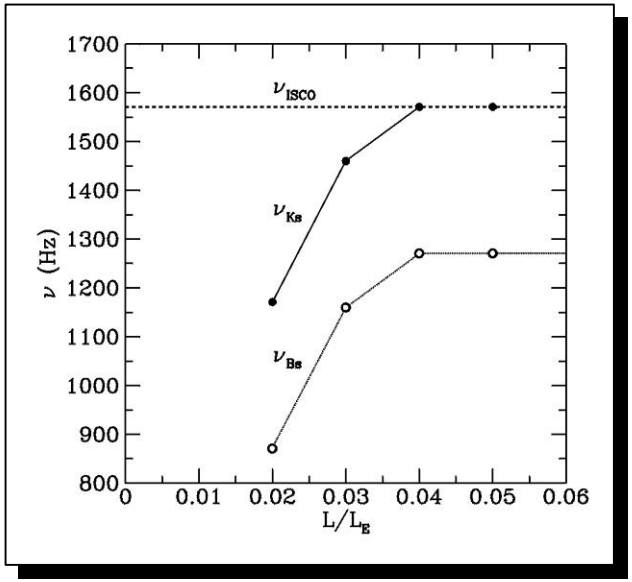


- There is strong evidence that the frequency of the upper kilohertz QPO is an orbital frequency. Hence —
  - The radius of the orbit must be larger than the radius of the neutron star (cubic constraint curve)
  - The radius of the orbit must also be as large as the radius of the innermost stable orbit (diagonal line)
  - If the radius of the orbit is *equal to* the radius of the innermost stable orbit, the mass of the star is known

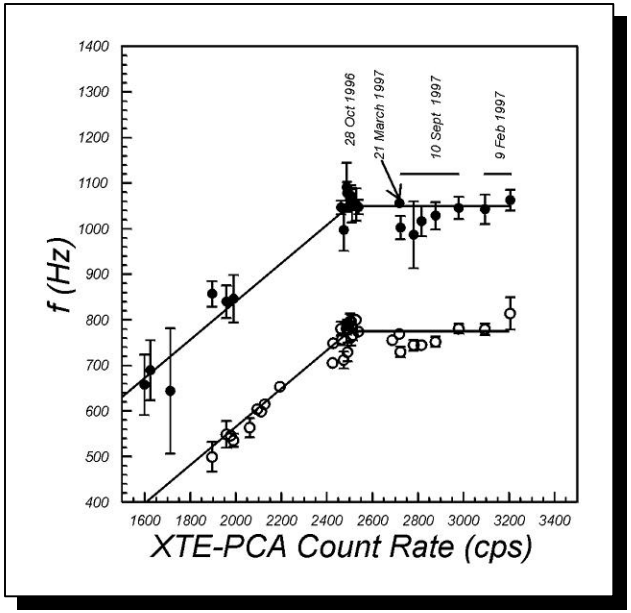


- RXTE observations provide the strictest constraints M,R constraints achieved to date —
  - Some neutron stars have radii no larger than 17 km
  - Several illustrative stiff equations of state are already close to being excluded
  - Some evidence suggests that the masses of the neutron stars that produce kilohertz QPOs are ~2 solar masses

Exploring Strong-Field General Relativity
Evidence for an Innermost Stable Orbit

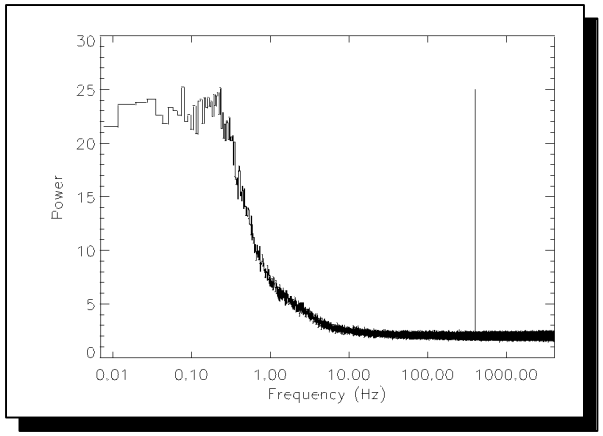


- Calculations of gas dynamics and radiation transport in full GR (Miller, Lamb, & Psaltis, 1996, 1998) predicted —
  - Sonic radius in the disk should decrease with increasing accretion rate until it reaches the ISCO and then stop
  - As a result, the frequencies of both kilohertz QPOs should first increase with L and then become constant
  - The plateau frequency of the upper kilohertz QPO is the frequency of the ISCO

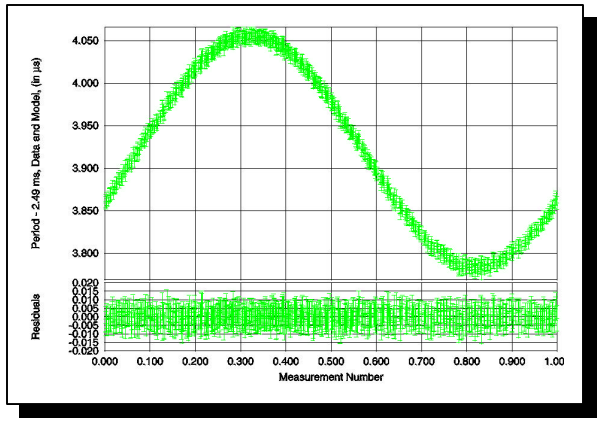


- RXTE observations of 4U 1820–30 (Zhang et al., 1998) show behavior similar to that predicted —
  - The frequencies of both kilohertz QPOs increase and then become constant with increasing countrate
  - Observations on four occasions spanning more than 10 months show the same plateau frequency
  - The plateau frequency implies a 2.3 solar mass NS
- Confirming this result will require further observations

The 2.5 Millisecond, Accreting X-ray Pulsar XTE J1808-369/SAX J1808.4-3658



400 Hz pulsations in the FFT power spectrum of XTE J1808-369

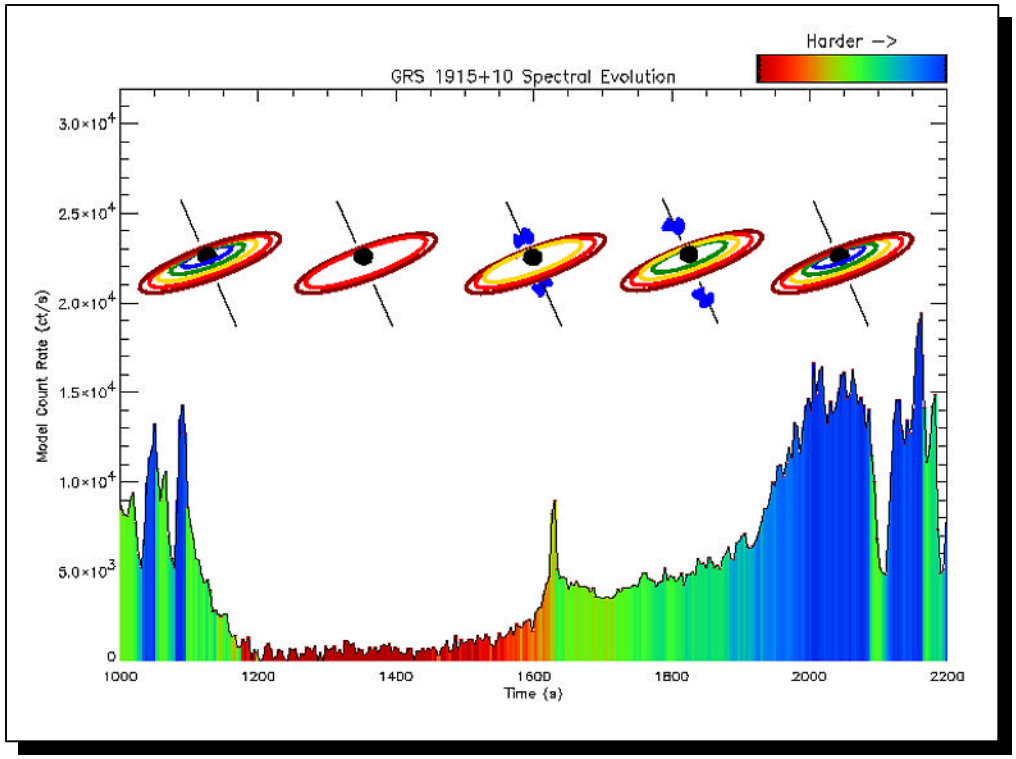


Orbital doppler shifts from XTE J1808-369 with a 2.01 hour period

- 2.5 ms coherent pulsations discovered by Wijnands & van der Klis (1998) in TOO data from PCA observations of XTE J1808-369, a previously identified transient, SAX J1808.4-3658
- Doppler shifts of pulsations show an orbital period of 2.01 hr, with a low-mass ($M_2 < 0.15\ M_\odot$) companion (Chakrabarty & Morgan 1998)
- First detection of accretion-powered X-ray pulsations *and* thermonuclear X-ray bursts in a single source
- The magnetic field is ~ 10^9 G, consistent with thermonuclear bursts and the unified model of NS-LMXBs
- XTE J1808-369 similar to the “black widow” ms radio pulsars, supporting an evolutionary link between NS-LMXBs and these radio pulsars

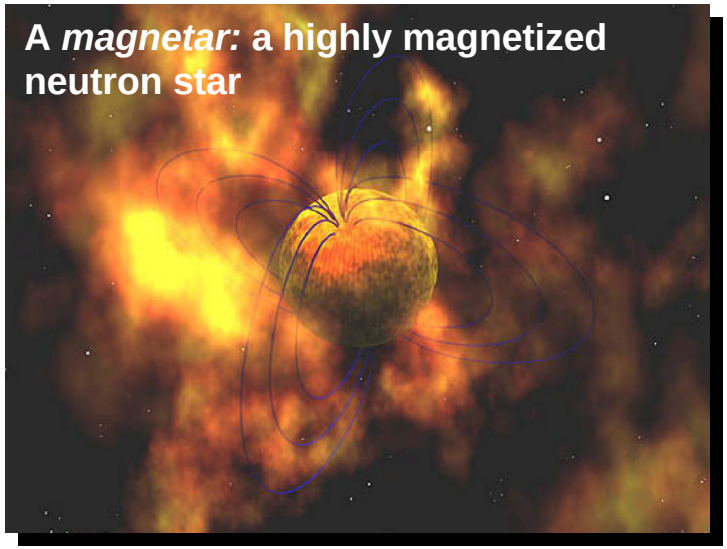
Jet-Disk Interactions in the Galactic Microquasar GRS1915+105

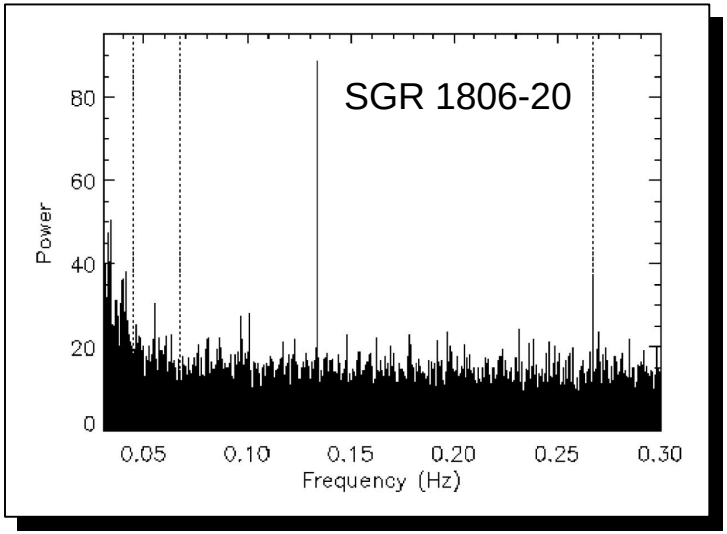
- RXTE spectra and modeling (Belloni et al., 1997) indicate that the accretion disk component "decreases dramatically" during low and quiescent states.
- RXTE data suggest that during low states the inner disk is disrupted, perhaps by the Lightman-Eardley Instability



- Simultaneous radio (Mirabel et al.) and infrared (Eikenberry) observations show that the disk disruptions are associated with radio/IR outbursts, including ejection of superluminal plasma clouds observed in the radio
- During the disk disruptions a portion of the inner accretion disk is apparently accelerated and ejected as a relativistically expanding cloud, causing a radio and IR outburst

The Soft Gamma-Ray Repeater SGR 1806-20: An X-ray Pulsar with a Superstrong Magnetic Field

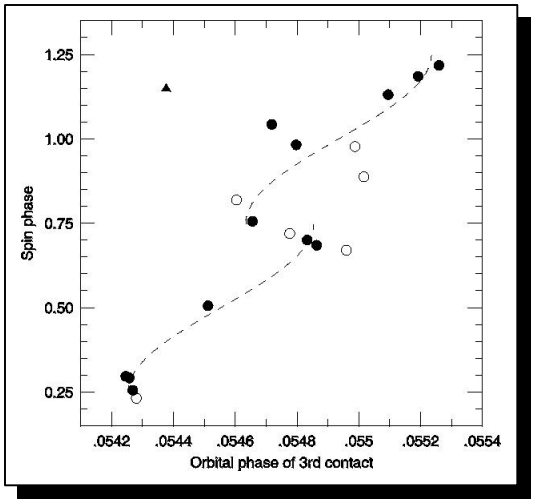


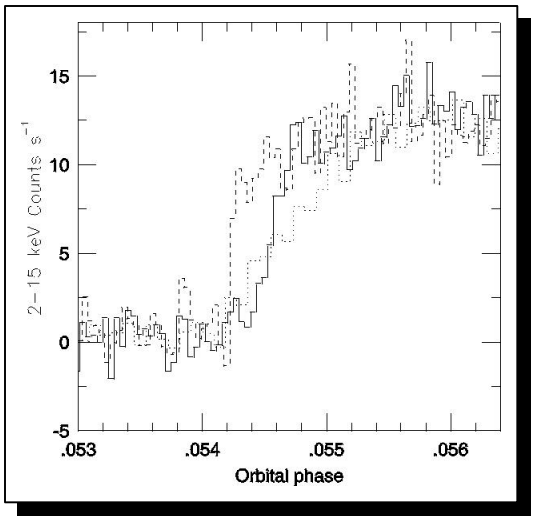


7.5 s pulsations in FFT power spectrum

- SGR 1806-20 becomes burst active in November of 1996, bursts detected with BATSE.
- 7.5 s pulsations in the persistent X-ray flux from SGR 1806-20 are discovered in PCA data by Kouveliotou et al. (1998).
- PCA data indicates a large spin down rate of ~ 9 x 10^{-4} s/yr, allowing a sensitive search to be made in ASCA data from 1993.
- Detection in ASCA data indicate a spin-down rate of 2.4 x 10^{-3} s/yr
- Long-term spin-down (ASCA to RXTE) suggest a magnetic field of 2 x 10^{14} G and an age of 8,000 yr, consistent with the age of the SNR in which the source is found.
- RXTE results suggest that the SGR burst sources are “magnetars,” neutron stars with superstong magnetic fields, as first suggested by Thompson & Duncan (1992)

Size of the Accretion Region in Magnetic White Dwarf XY Ari





- Hellier (1998) studied 20 RXTE observations of eclipse egresses of the intermediate polar XY Ari
- Timing of eclipse egresses with respect to orbital and white dwarf spin phases indicates
  - Most of the X-ray flux emerges in < 2 s, suggesting the polar caps have areas of < 0.002 of the white dwarf surface area
  - The accretion footprints are not fixed relative to the white dwarf surface, but can meander over an area < 0.01 of the surface.
  - Some of the flux arises from a larger area, suggesting that parts of both accreting poles are almost always visible.