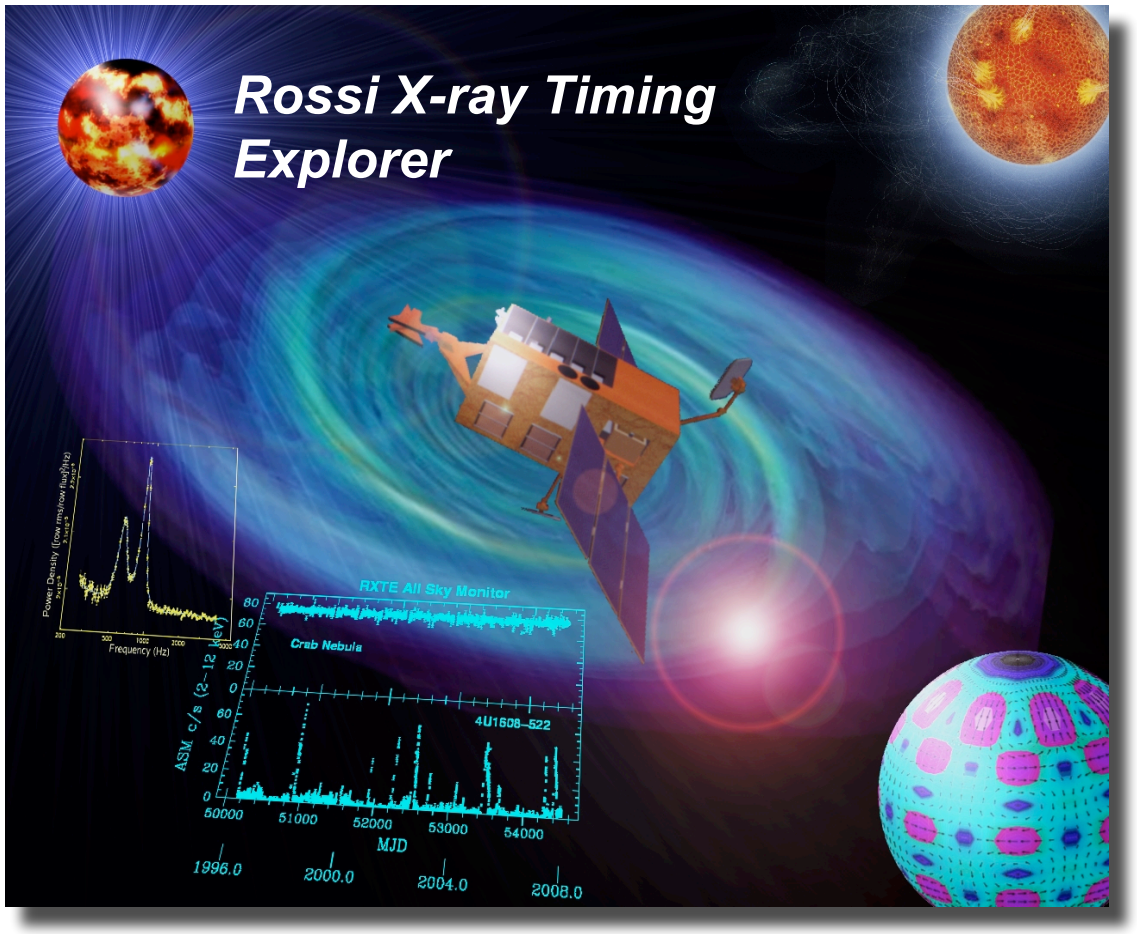
Presentation to the 2008 Senior Review of Mission Operations and Data Analysis



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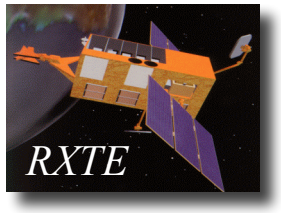
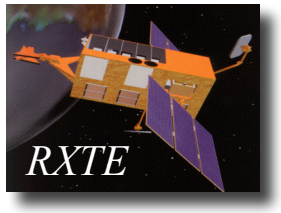
Reasons to Continue RXTE



- RXTE's large area sub-millisecond timing capability remains unique.
- RXTE's observing flexibility remains unduplicated.
- RXTE's broad spectral band is valuable as a constraint on narrow band, high resolution spectra.
- RXTE continues to be productive at low cost; 3 invited and >33 contributed papers at recent AAS/HEAD meeting; major contributions at COSPAR 2008.
- RXTE observations are highly sought after to support many multi-wavelength and multi-mission observing programs.
- Anticipated multi-mission opportunities during the 2009-2011 period represent new science (combining timing and spectra, and unprecedented energy coverage).
- New Core Science Program will provide important additional public access to data.

Recent Science Highlights



Neutron Stars

- Discovery of a 70.5 ms, energetic pulsar associated with a TeV (HESS) source (ATels from 2008 Feb and Mar, ApJ paper in press).
- Discovery of a magnetar/rotation-powered pulsar transition object.
- Discovery of intermittent accreting millisecond pulsars (AMPs, HETE J1900.1-2455, SAX J1748.9-2021, Aql X-1).
- Millisecond pulsar spin down between outbursts and orbital period growth too fast for gravitational radiation alone (SAX J1808.4-3658).

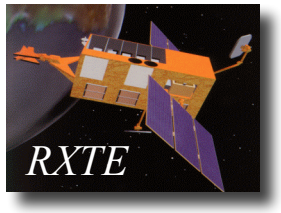
SMBHs

- Tracking the injection of plasma blobs in the BL Lac jet (Nature 2008).

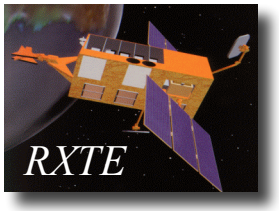
Galactic BHs

- Measurement of inner disk radii in low-hard state (in coordination with Swift and XMM-Newton).
- Spin and mass measurements for black holes in progress, and the lightest known black hole (XTE J1650-500, 3.8 $M_{\odot}$).

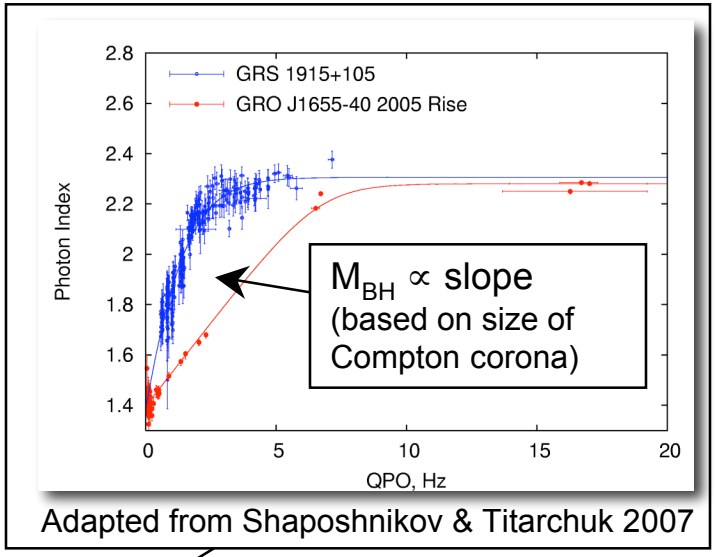
RXTE Impact: “Pipsqueak” Black Hole Makes Big Media Splash



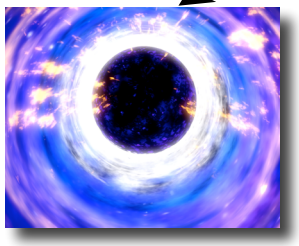
Fundamental Black Hole Parameters



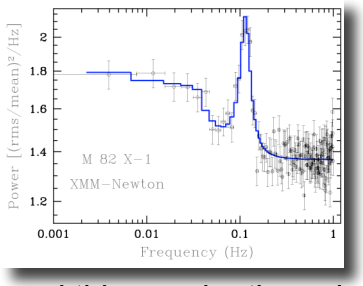
Measuring BH Mass



Adapted from Shaposhnikov & Titarchuk 2007



XTE J1650-500:
Low-mass black hole

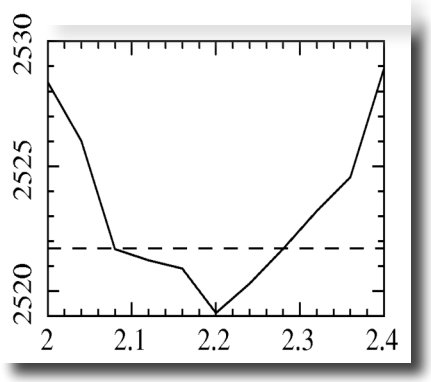


… and this may be the only mass measurement method that works for large numbers of putative intermediate-mass BHs

Uses RXTE's unique combination of spectral and timing capabilities

Measuring BH Spin

Improved Reflection Models



New (2008 Apr.) RXTE+XMM result:
GX 339-4 BH spin measured to be 0.92±0.04 (Reis, Fabian et al. 2008, subm.)

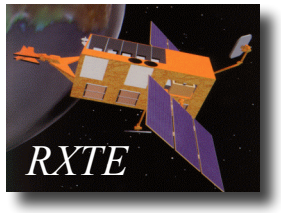
Fitting the Continuum with Relativistic Disk Models

McClintock et al. (2006) find $a_* > 0.98$ for GRS 1915+105

Don't forget about the kHz QPOs

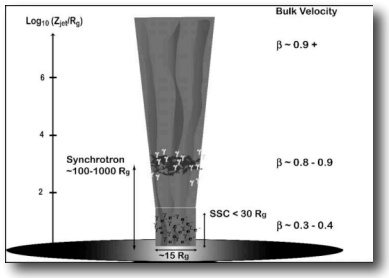
450/300 Hz QPO pairs in GRO J1655-40 indicate $a_* = 0.4$-0.9.

Disk/Jet Coupling in Black Hole Systems



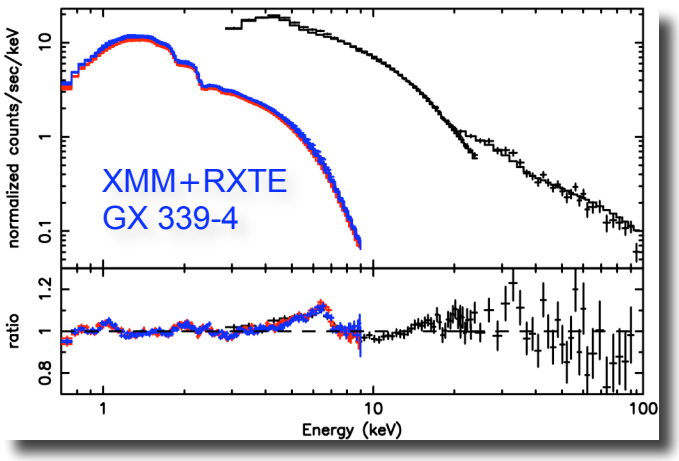
- For Galactic black holes, only the hard state has a steady jet.
- RXTE is key to the on-going debate concerning the hard state geometry.

Can the base of the jet subsume the role of the corona? (Markoff, Nowak, & Wilms 2005)



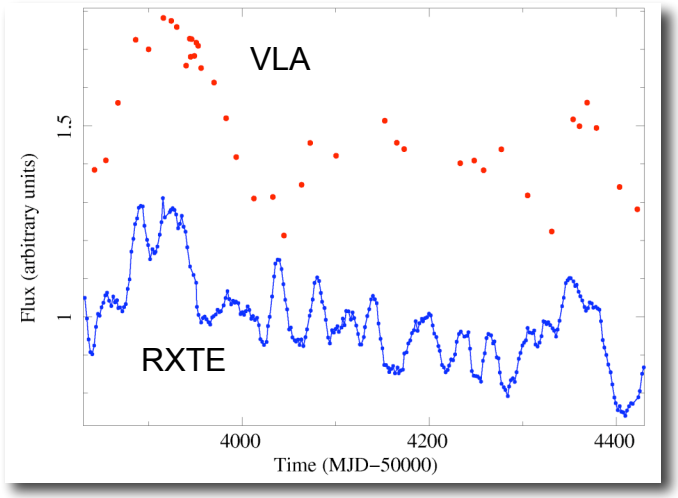
• The Miller et al. (2006) GX 339-4 study marks the first time relativistic models have been applied to the hard state (R_{in}/R_g = 4.0 ± 0.5).

• RXTE (PCA+HEXTE) provides critical bandpass coverage with the highest statistical quality.



Using RXTE's broad spectral band

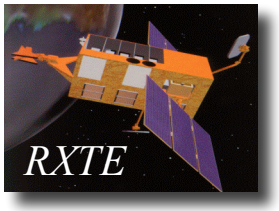
Progress is also being made on Seyfert AGN via RXTE, radio, optical monitoring

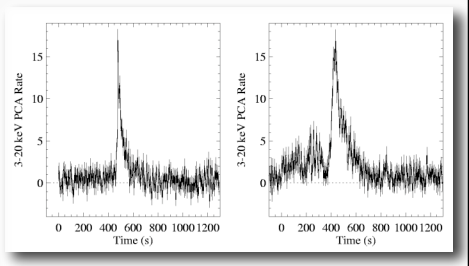


X-ray (RXTE) and radio (VLA) light curves for NGC 7213 correlated with a delay of <20 days (Uttley et al., in prep.)

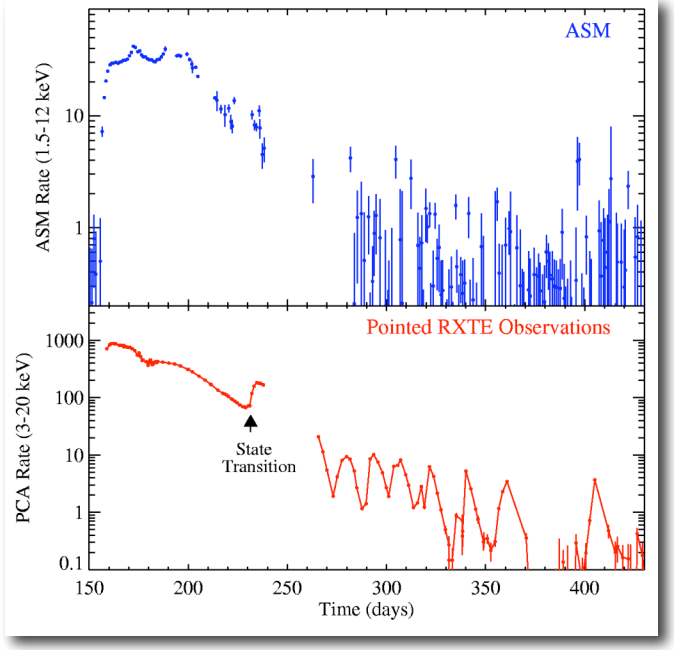
RXTE also important for Blazar studies, especially with the upcoming GLAST launch

RXTE Capabilities for Observations of Galactic Black Holes at Low Luminosities

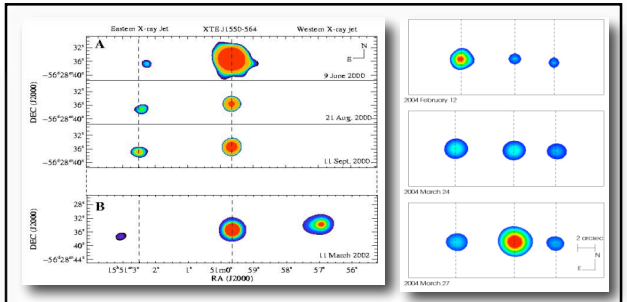




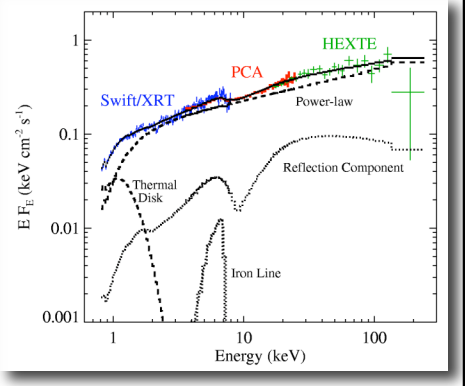
"Hidden" black hole X-ray bursts discovered by RXTE



RXTE ASM and PCA light curves for the low-mass Galactic black hole XTE J1650-500

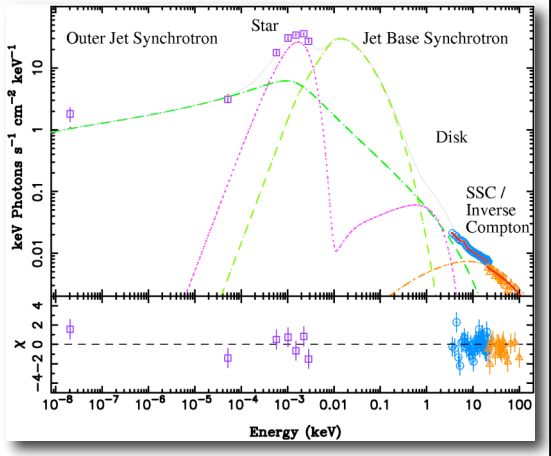


X-ray jet discovery with Chandra. Approved 08/09 TOO program.



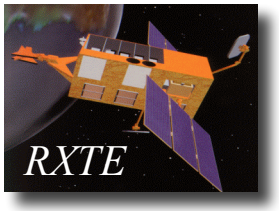
Smeared reflection features (in the hard state) with Swift. Approved TOO programs with Swift, XMM-Newton, and Suzaku in 2008/2009.

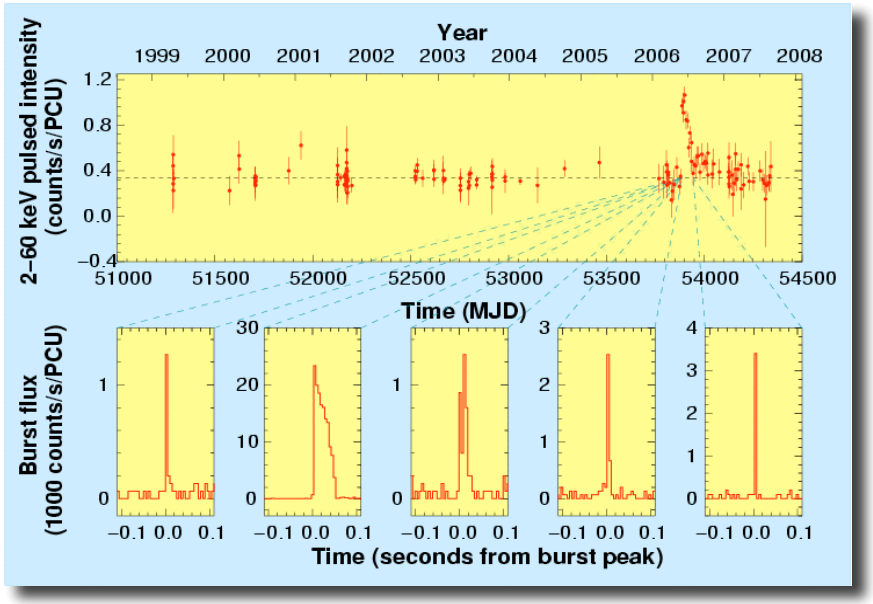
Using RXTE's flexibility and providing multi-wavelength and multi-mission support.

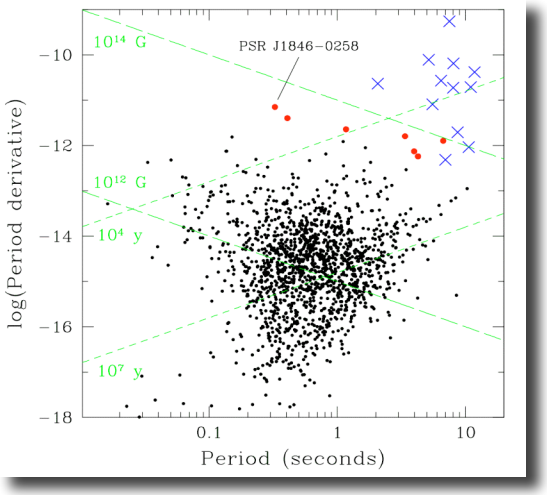


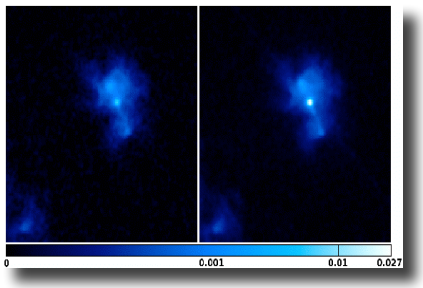
Compact "radio" jet emission detected in infrared with Spitzer, maybe X-ray, will it be seen by GLAST?

RXTE Discovers First Magnetar-like X-ray Emission from a Rotation-powered Pulsar





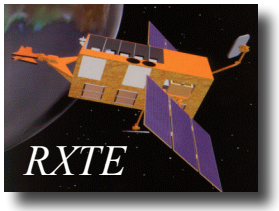


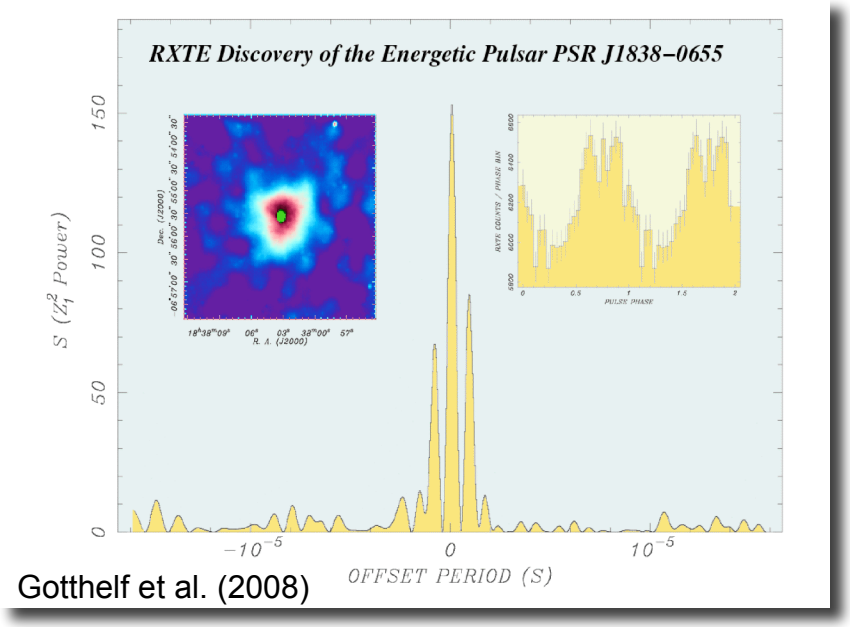


Gavriil et al. (2008)

- A key question: at what magnetic field strength does magnetar behavior begin, and why?
- Until recently, no rotation-powered pulsar had ever exhibited magnetar properties (bursts, flares, and dramatic changes in pulse timing).
- Gavriil et al. (2008) found the first magnetar-like bursts, and a pulsed flux flare from a rotation-powered pulsar (PSR J1846-0258 in Kes 75).
- *Chandra* imaging also revealed the flare in total intensity.
- PSR J1846-0258 is the first pulsar - magnetar transition object! Indicates that magnetar behavior can exist over a much wider range of inferred field strengths than previously thought.
- **Future RXTE observations will target a larger sample of high-field pulsars.**

Discovery of Pulsar AX J1838-0655: A Pulsar Wind Nebula -- TeV Association

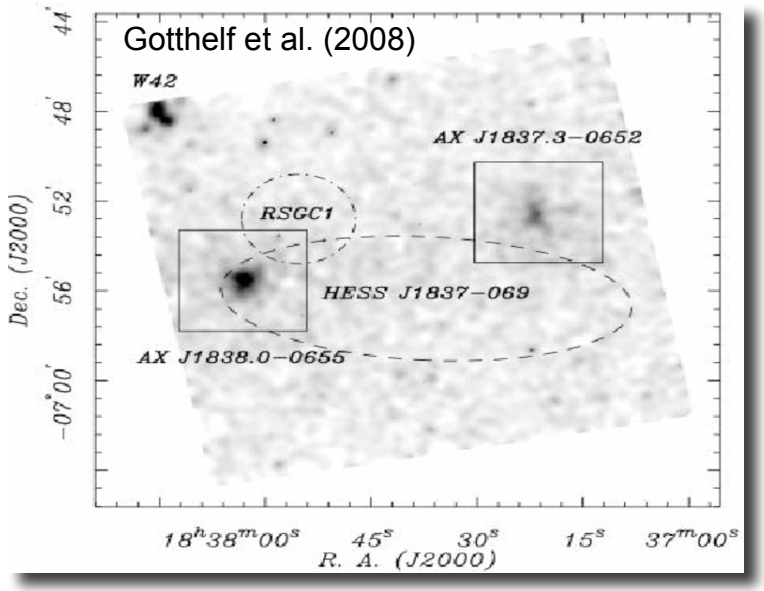




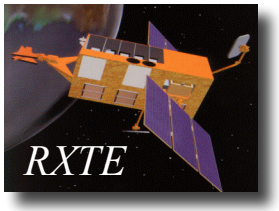
Gotthelf et al. (2008)

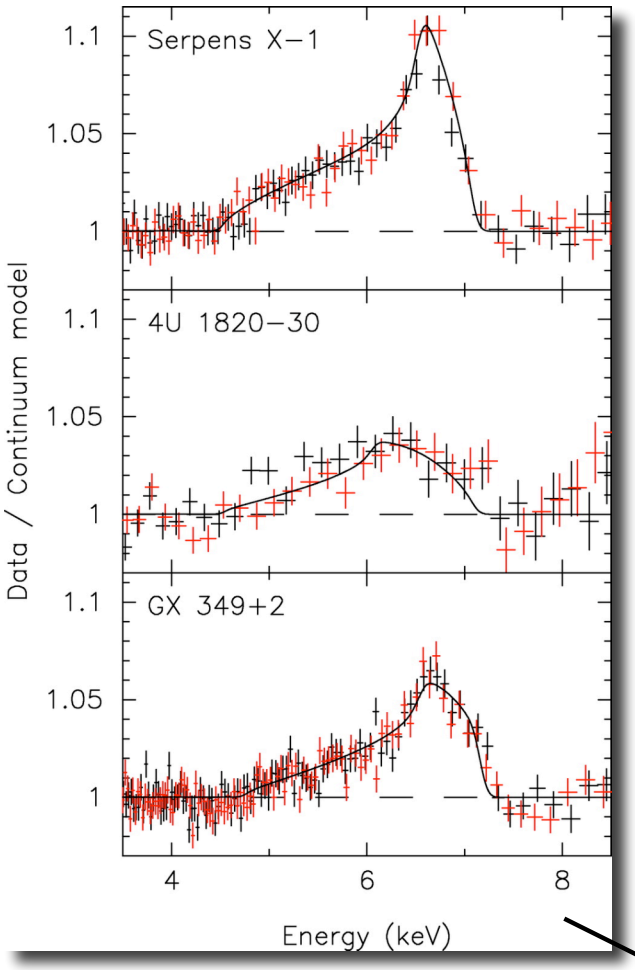
- RXTE recently discovered 70.5 ms pulsations from AX J1838.0-0655, and also measured the spin-down rate, indicating a young, energetic pulsar (Gotthelf et al. 2008; Kuiper et al 2008).
- **Future RXTE observations will confirm new pulsar - TeV associations, and constrain the energetics of the PWN.**

- HESS observations have discovered several extended TeV sources apparently coincident with pulsar wind nebulae (PWN; Aharonian et al. 2006).
- Some HESS sources are suspected PWN, but pulsar detections are lacking.
- HESS J1837-069 is coincident with AX J1838.0-0655, a PWN recently imaged with CHANDRA.



New Neutron Star Mass Estimates from Relativistic Fe Lines and Kilohertz QPOs





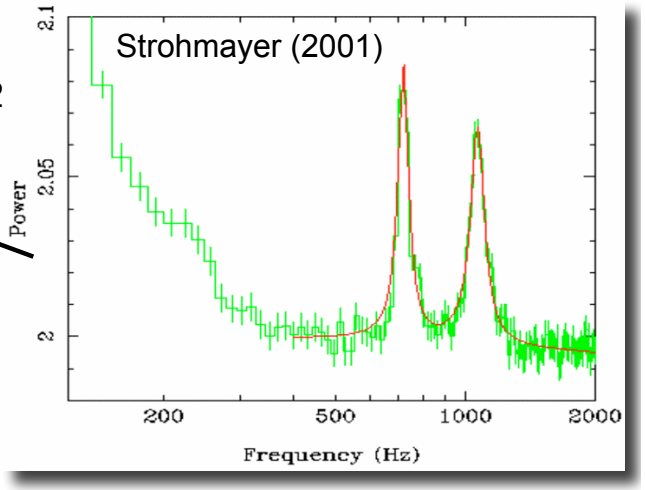
Cackett et al. (2008)

- Recent *XMM-Newton* and *Suzaku* observations have found relativistic Fe lines in several accreting neutron star binaries (Bhattacharyya & Strohmayer 2007; Cackett et al. 2008).
- Both Fe line profiles and kHz QPO frequencies provide inner disk diagnostics.
- Simultaneous QPO and Fe line detections can provide a new way to estimate the stellar mass.
- **Suzaku observations of Cyg X-2, 4U 1820-30, and GX 340+0 approved. RXTE will provide required simultaneous coverage.**

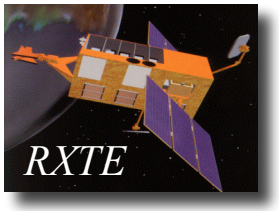
$$\nu_{orb} = (1/2\pi)\,(GM_{ns}/r^3)^{1/2}$$

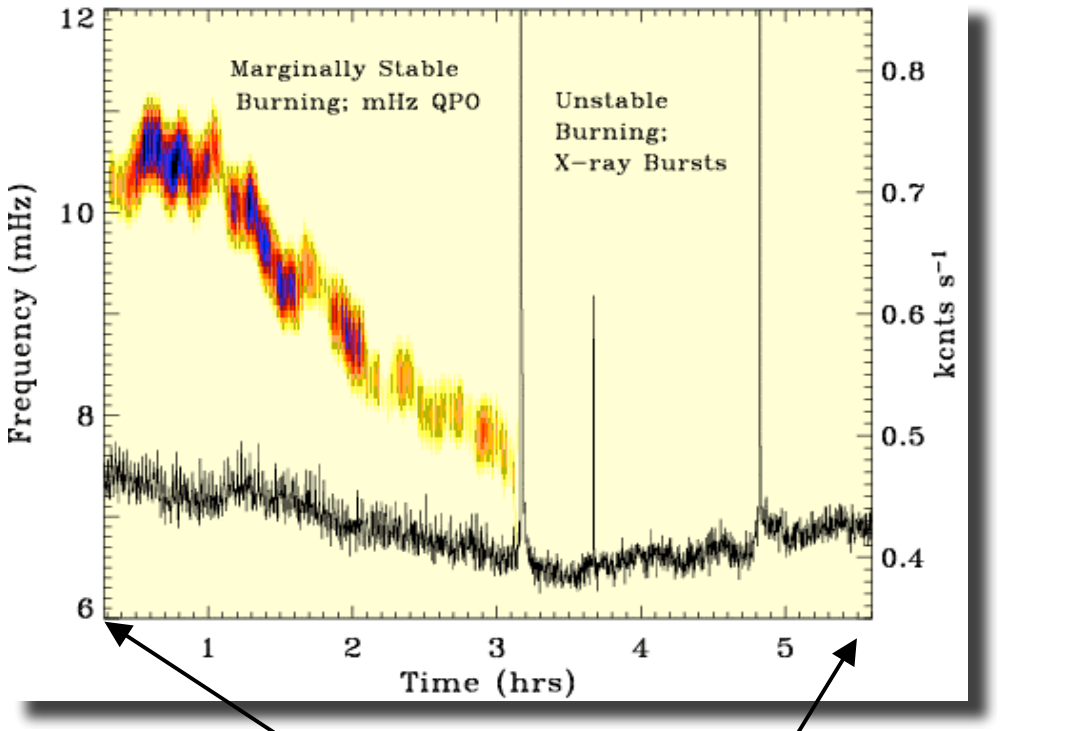
$$M_{ns} = \nu_{orb}^{\,3} / (2\pi G \nu_{orb})$$

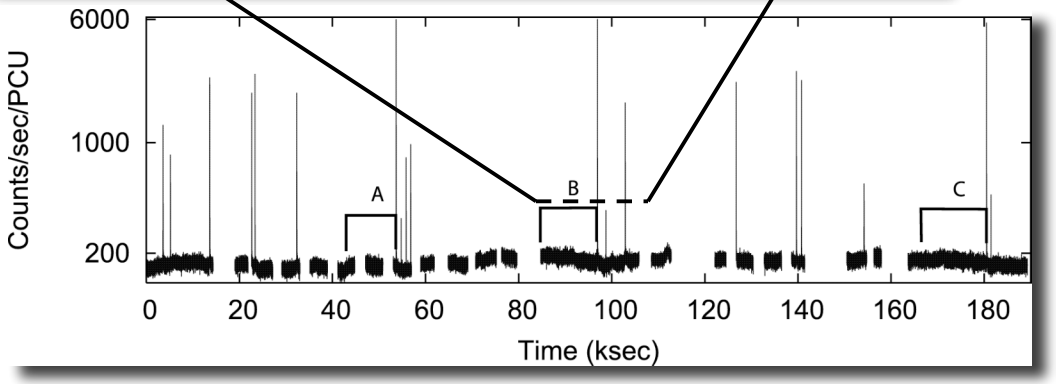
$$\nu_{orb} = (GM_{ns}/r)^{1/2}$$



Marginally Stable Nuclear Burning: A New Probe of Neutron Stars

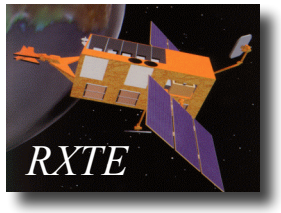






- RXTE observed mHz QPOs from several accreting LMXBs (eg., 4U 1636-53; Revnivtsev 2001; Altamirano et al. 2008).
- Theory predicts marginally stable burning (quasi-periodic) when the accretion rate is near the critical rate for instability (Heger et al. 2007).
- Approach to instability directly seen for first time with RXTE: mHz QPO drops below 8 mHz, X-ray bursts occur!
- mHz QPO frequency has dependence on surface gravity $\propto M/R^2$ as well as composition. Can probe surface physics and structure.
- **Future goals: observe marginally stable burning in more objects, in particular, helium accretors for which composition is known.**

New Program Elements



- Observations correlated with GLAST for AGN and Galactic sources:

  RXTE Cycle 12 includes 7 programs for multiple targets;

  GLAST Cycle 1 includes 3 programs requiring RXTE and many for which RXTE would be likely to provide X-ray coverage;

  RXTE timing of radio-quiet X-ray pulsars will enable GLAST studies;

  RXTE Cycle 13 is expected to include similar proposals.

- Observations correlated with upgraded TeV observatories:

  Veritas, HESS, MAGIC are pursuing coordination with RXTE.

- Immediate public accessibility of "core program" observations:

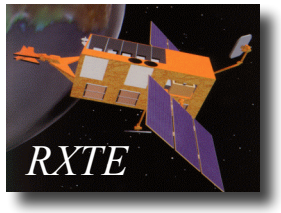
  PCA scanning of the Galactic bulge provides triggers and context;

  follow-up observations of new Galactic sources find their nature;

  dense observations of new and recurrent AMPs and BH transients have application to many physics questions.

- Transfer to Multi-mission Operations Center to reduce costs.

Cost Reductions



Manpower (Full Time Equivalents):

	1997 (Peak)	2004	2008	2009	2010
Mission Ops	16.0	10.00	6.6	5.5	4.5
SOF	12.00	3.50	2.3	2.3	2.3
GOF	16.00	3.45	1.4	1.4	1.4
ITs	33.00	10.88	6.5	6.4	6.1
Total	77	27.8	16.8	15.6	14.3
Total (real yr K$):	7718+	5844	2355*	1425*	3105

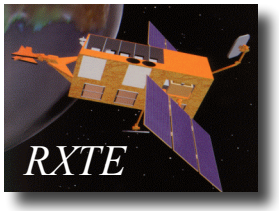
+ 1997 is not full cost, GO not included.

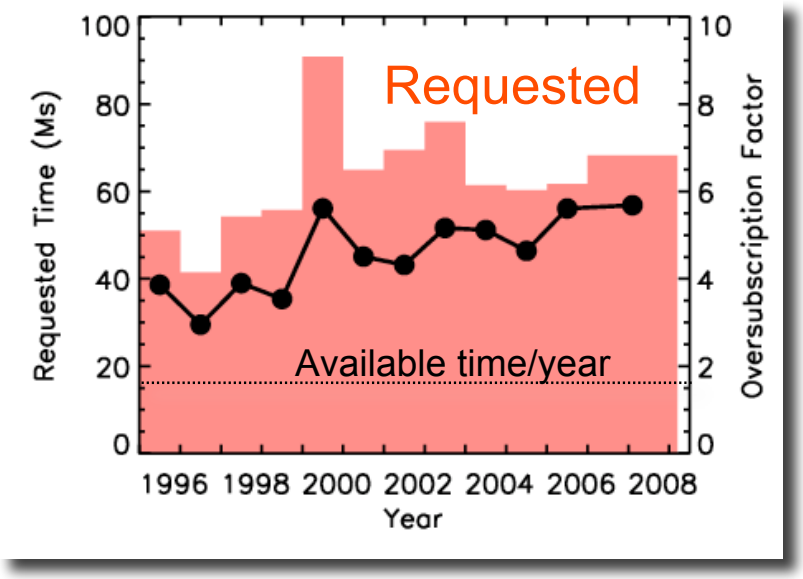
* Carryover allowed operations with low new funding.

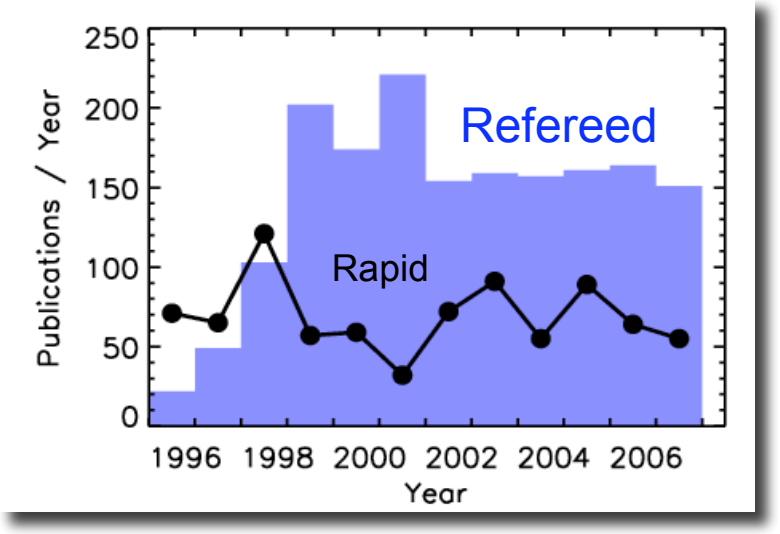
Change enabling cost reduction:

•Operations	24x7	12x7(auto)	8x6	8x5	Multi-mission
•Science processing	tapes, by XSDC	internet, by GOF			
•Spacecraft info	FDF, Pacor		by MOC		
•Help desk	full	reduced	bare (PI teams supplement)		

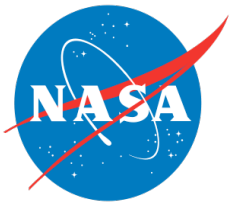
RXTE Remains Popular and Productive



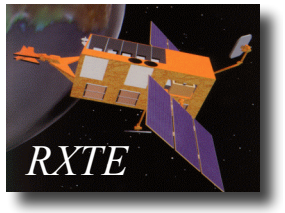




- 153 Cycle 12 proposals.
- 361 unique PIs (AO 1-12).
- 6.8 TB (4 x archive) downloaded in 2007.
- Publication rate (refereed) remains high and steady at ~160 per year.
- Rapid notifications (Atel, IAUC, GCN) fluctuate at about 60 per year.
- Conference reports remain significant at 85 per year.
- High-impact citation rate: ~15 citations/paper (2004-2006, of papers published in 2003; Trimble 2007).
- 7 press releases since April 2006.
- 82 PhD theses.



Hardware Status



- Changes have been relatively minor since the 2006 review.
- The hardware during the next few years should be substantially the same as that used to obtain the recent results.
- One Proportional Counter Unit (1250 cm^2) has shown no faults.
- One counter reaches background limits in 1000 s for AGN (0.2 mCrab) and for the Galactic bulge scans (1 mCrab).
- Duty cycles of 20% for each of the other PCUs enables 2-3 PCUs for most galactic timing studies, 4 or 5 occasionally.
- HEXTE Cluster B (rocking) provides a background model for Cluster A (not rocking).
- Partial loss of ASM sensitivity is possible, but the PCA scans go deeper for the Galactic bulge, and ASM all-sky coverage would remain.