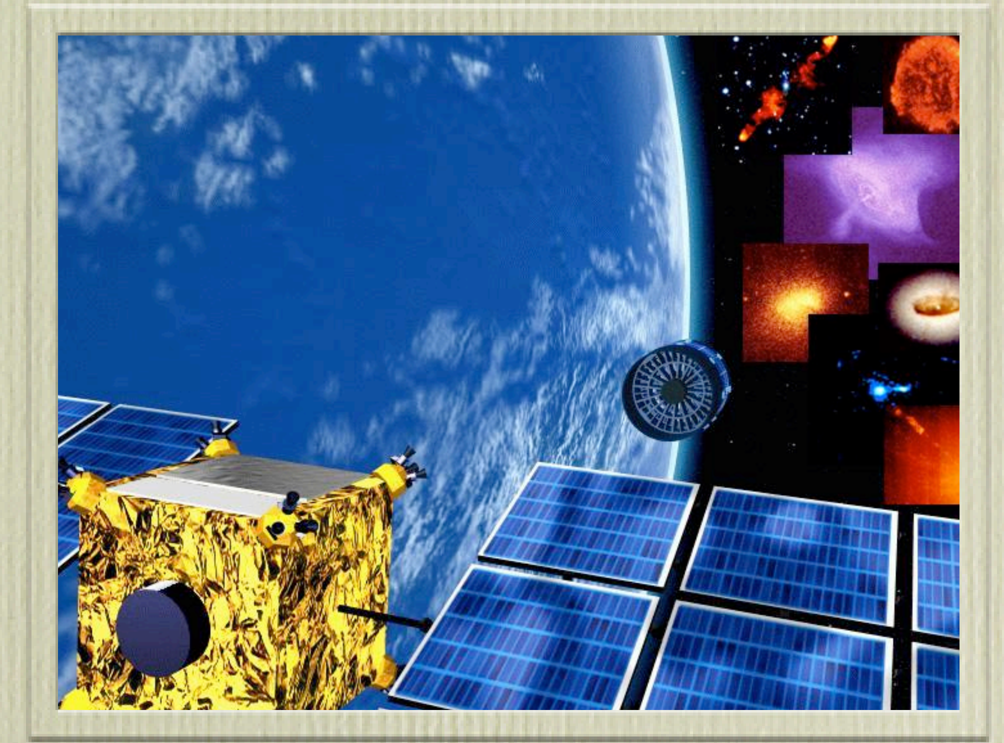
Fast X-ray timing and Spectroscopy with PERXEUS



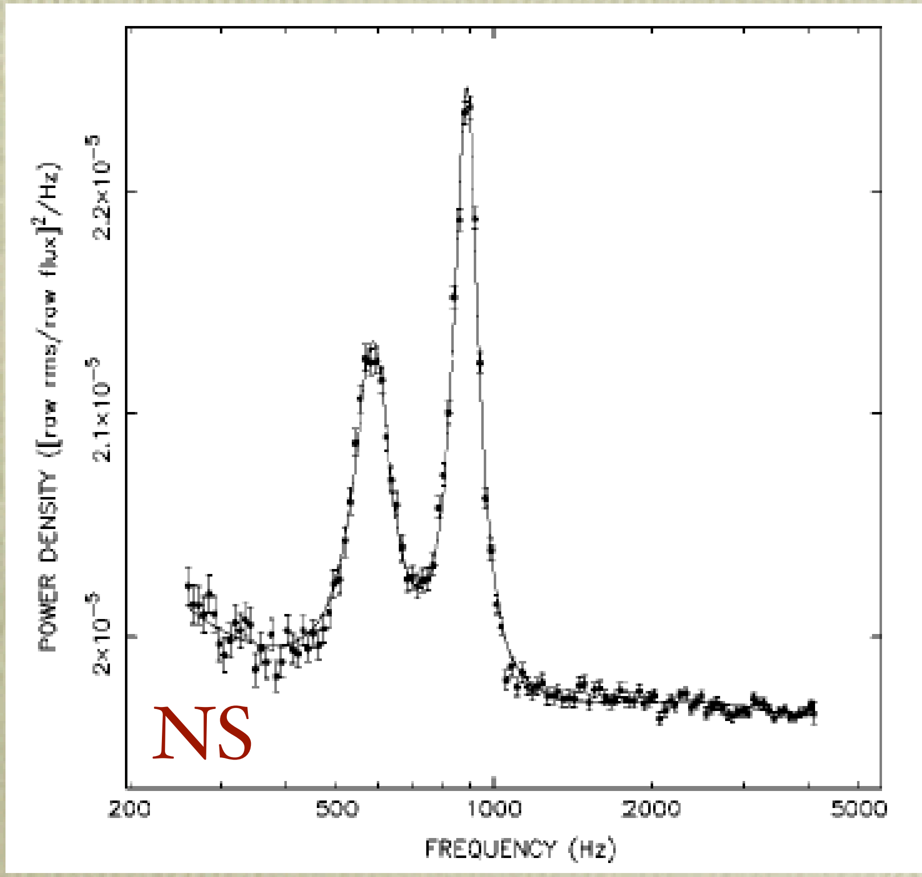
J.L. Atteia, D. Barret, T. Belloni, G. Bignami, H. Bradt, L. Burderi, S. Campana, A. Castro-Tirado, D. Chakrabarty, P. Charles, S. Collin, S. Corbel, C. Done, G. Dubus, M. Gierlinski, J. Grindlay, A. Fabian, R. Fender, E. Gourgoulhon, J.M. Hameury, C. Hellier, M. van der Klis, E. Kendziorra, W. Kluzniak, E. Kuulkers, S. Larsson, J.P. Lasota, P. Lechner, T. Maccarone, D. de Martino, K. Menou, S. Mereghetti, C. Miller, F. Mirabel, M. Nowak, J.F. Olive, S. Paltani, R. Remillard, J. Rodriguez, R. Rothschild, R. Staubert, G. Skinner, L. Stella, L. Strüder ,T. di Salvo, R. Sunyaev, M. Tagger, M. Tavani, L. Titarchuk, G. Vedrenne, N. White, R. Wijnands, J. Wilms, A. Zdziarski, W. Zhang

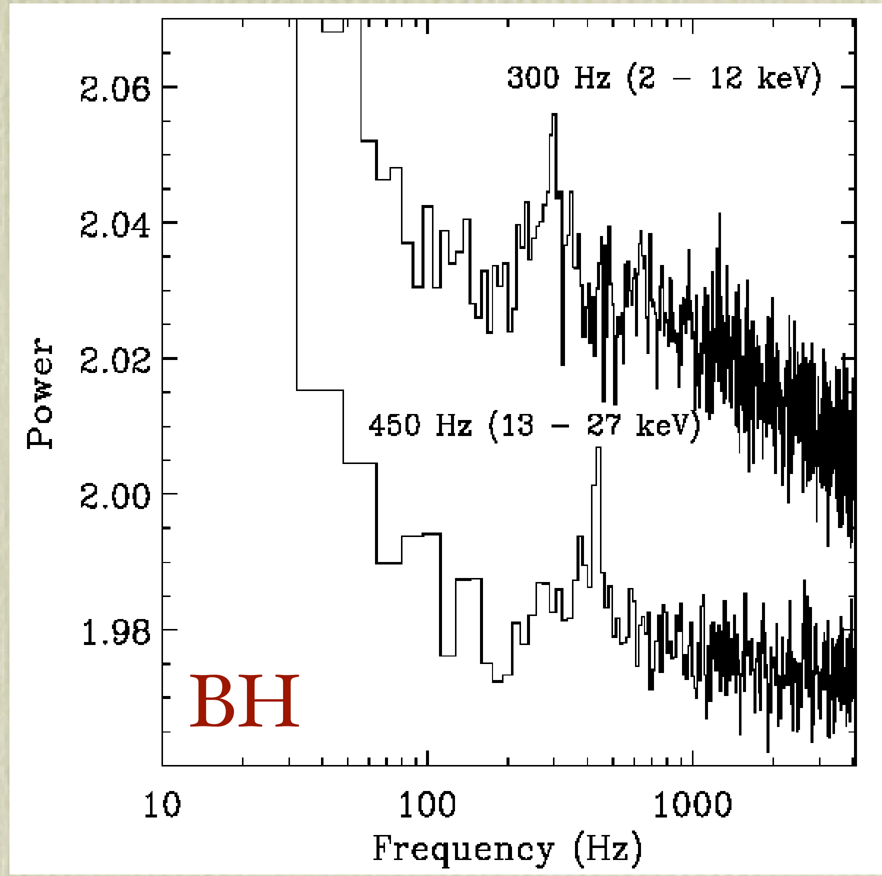
Outline

- Fast X-ray Timing and Spectroscopy probing the strong field region
- Bringing X-ray astronomy to fundamental physics: constraining the equation of state of matter at supra-nuclear matter with weakly magnetized accreting neutron stars
- Pushing beyond RXTE: why a 10 m^2 class X-ray mission like PERXEUS is necessary
- A possible detector implementation for a fast timer on PERXEUS

Millisecond time variability

- The Rossi X-ray Timing Explorer has demonstrated that the X-ray emission from X-ray binaries varies on the dynamical time scales of their accretion flows

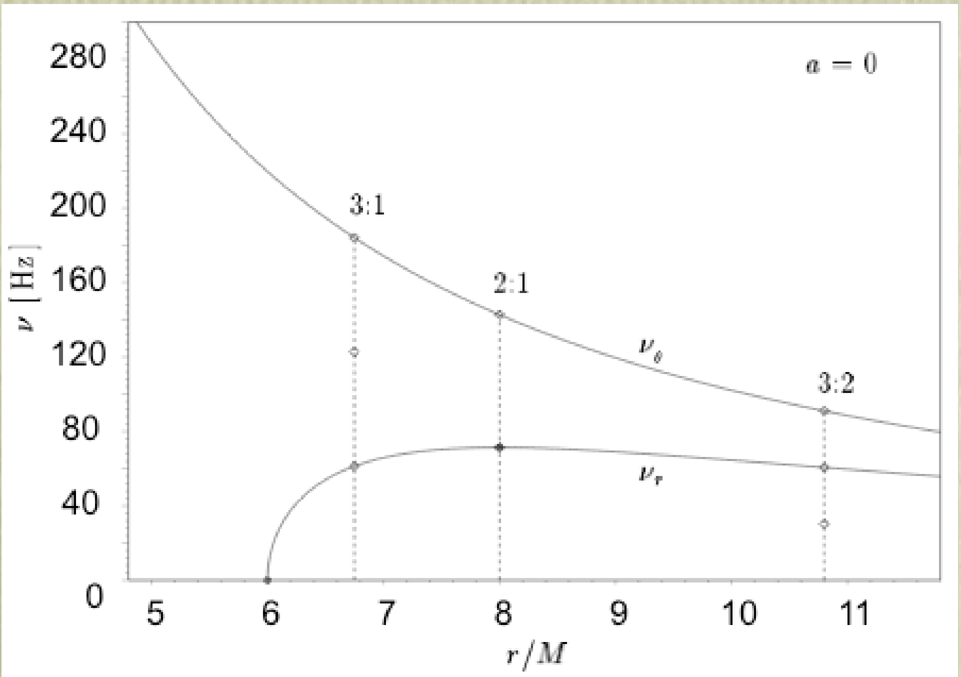


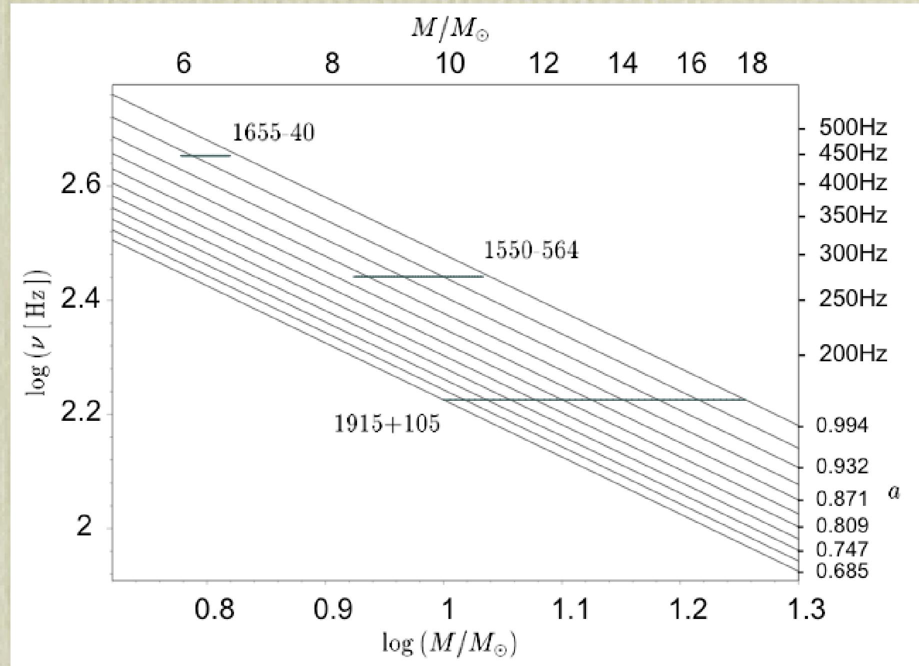


Van der Klis (2001) - Remillard & McClintock (2004)

BH QPOs and resonance

- Pairs of QPOs in 3 out of 4 microquasars come with a 3:2 ratio (450&300 Hz), suggesting non-linear resonance
- Pairs of modes attain high amplitudes in the disk where their frequencies have ratios equal to ratios of small integers



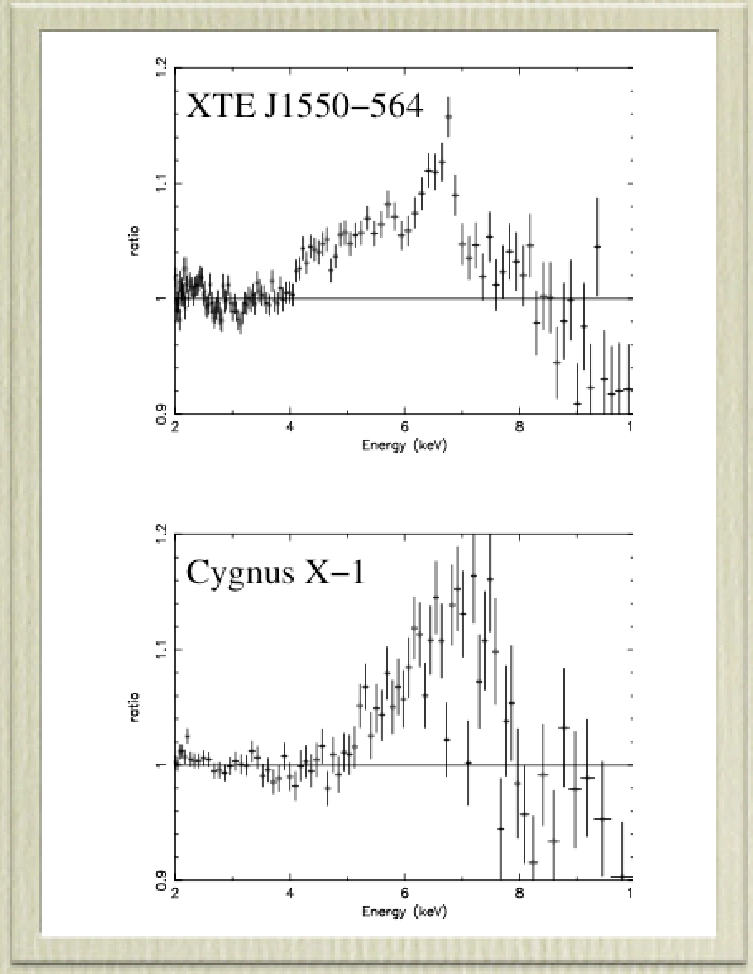


Abramowicz & Kluzniak (2004) - Abramowicz et al. (2004)

X-ray spectroscopy

Broad relativistic Iron lines are seen in the X-ray spectra of accreting black holes: XMM-Newton, Chandra, ASCA

- Irradiation of the inner disk produces a Fe line
- Gravitational redshift
- Doppler shifts
- Similarities with lines in AGNs



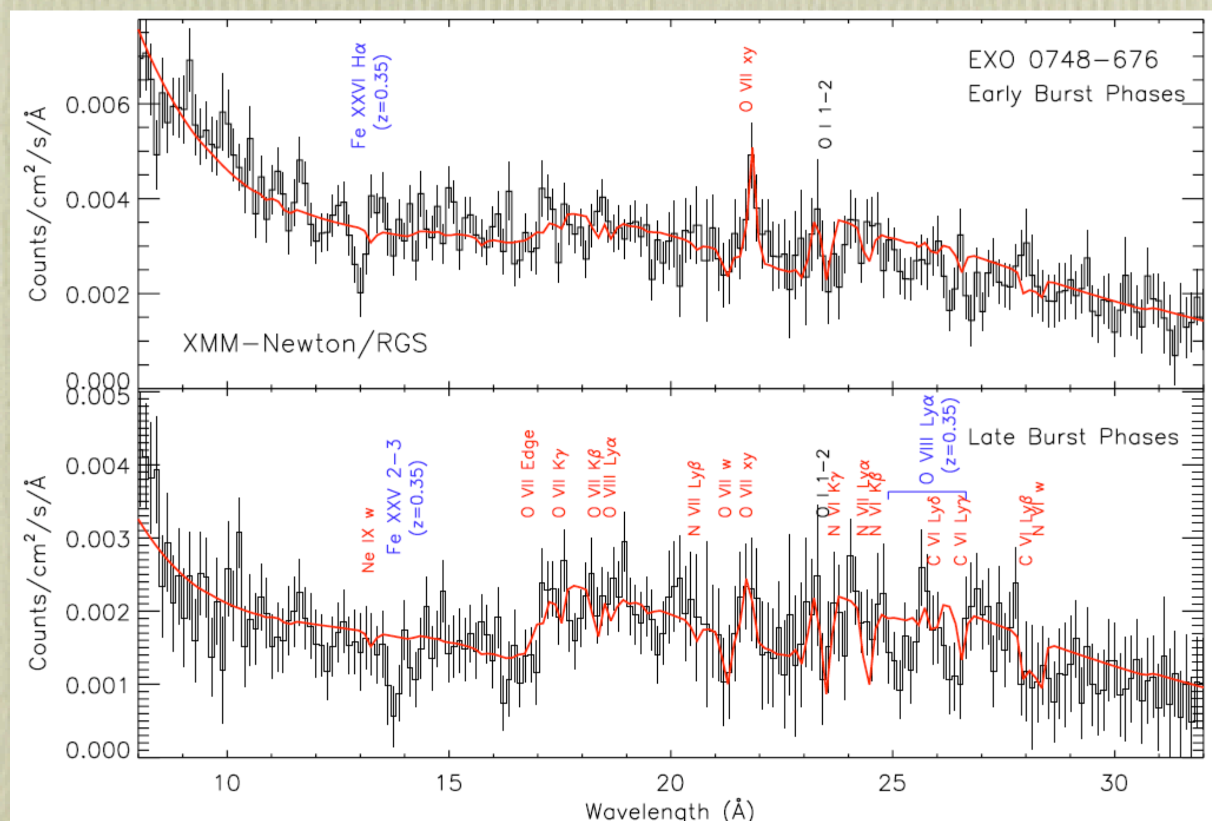
Constrains the BH spin & dynamics of the inner flow

Miller & Fabian (2004)

1. Constraining the EOS of nuclear matter

- Absorption lines in X-ray bursts

XMM-Newton RGS

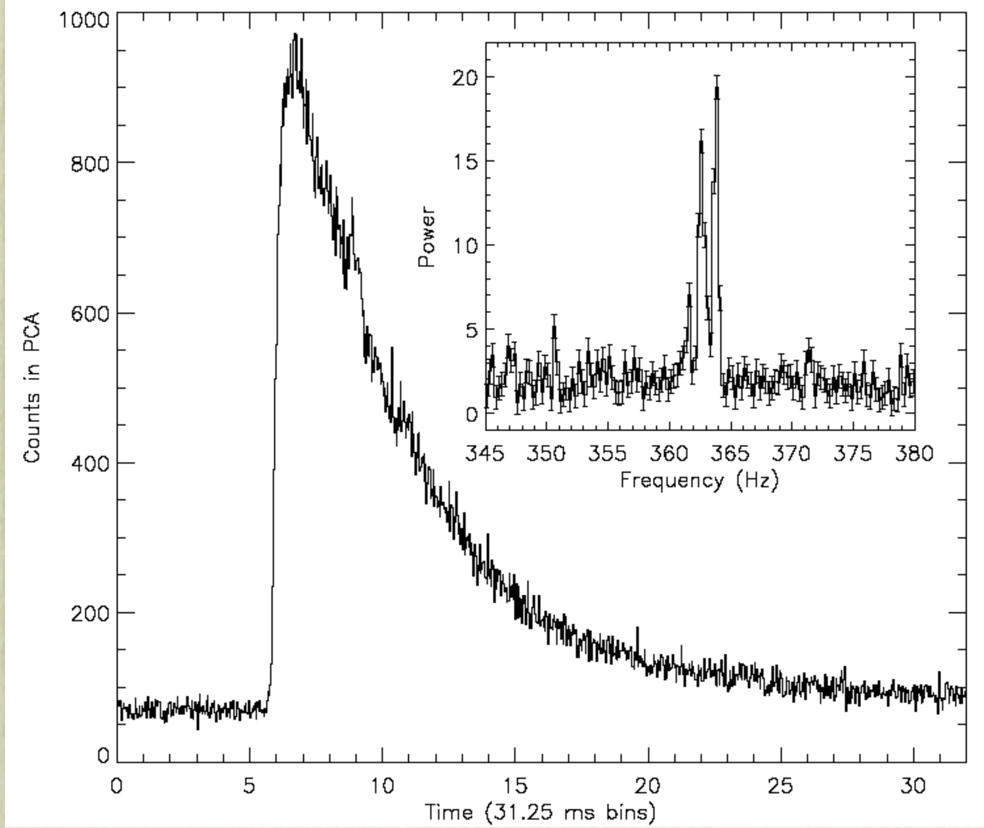


$$1 + z = (1 - 2\beta)^{-1/2} (\beta \text{ stellar compactness})$$

Cottam et al. (2003)

2. Constraining the EOS of nuclear matter

- Waveform fitting of the X-ray burst oscillations: hot spot rotating at the neutron star spin frequency

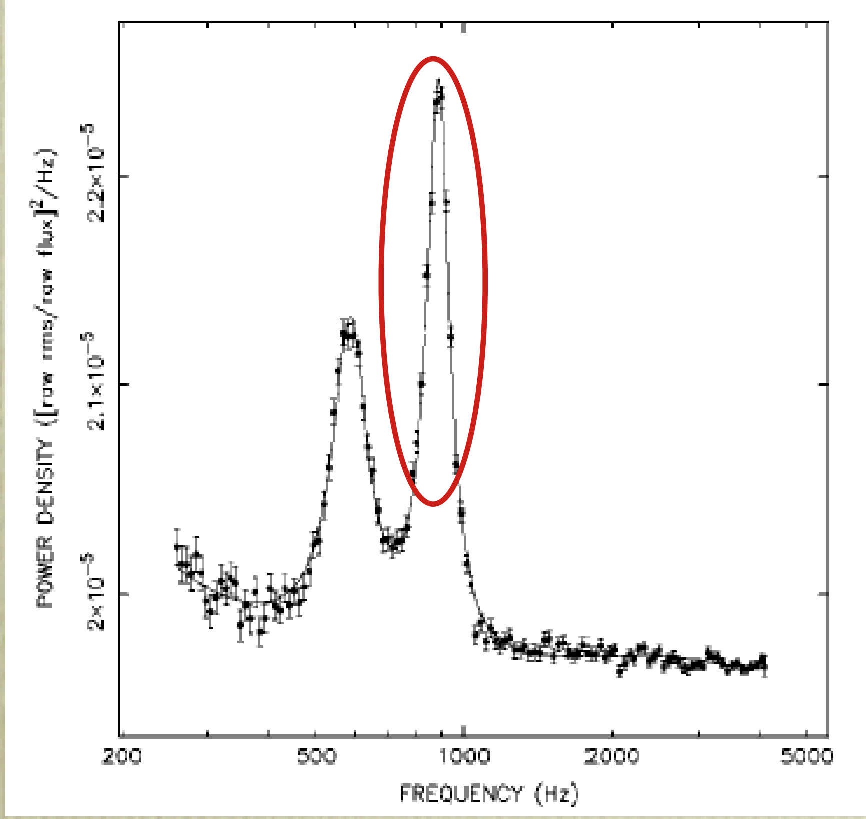


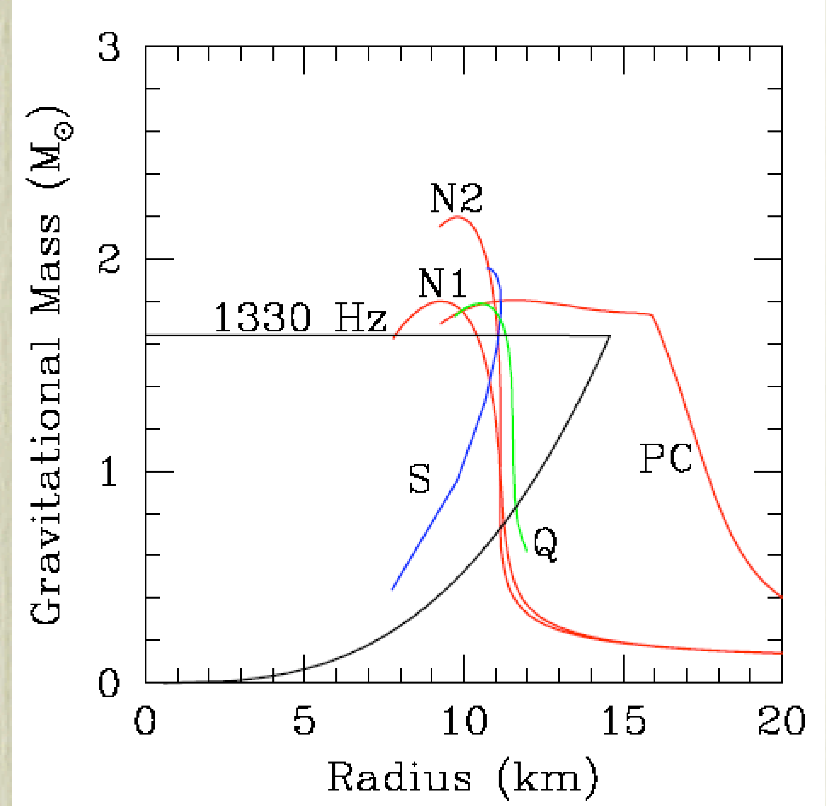
Strohmayer et al. (1996) - Strohmayer & Bildsten (2004)

3. Constraining the EOS of nuclear matter

- High frequency QPOs

$$\nu_{\rm upper} \approx \nu_{\rm orb} - R_{\rm orb} > R_{\rm ISCO}(= \frac{6GM}{c^2}) \text{ and } R_* < r_{\rm orb}$$





Miller C. (2004)

Beyond Rossi

- Was EINSTEIN wrong or right? Testing General Relativity in the strong field regime: existence of an innermost stable circular orbit, dragging of inertial frames, ...
- How do black holes form and evolve?: constraining their spins and accretion flows,...
- How do stellar mass and super-massive black holes compare?
- What's the equation of state of matter at supra-nuclear density? do strange stars exist?

Why do we need ~10 m²?

$$n_\sigma = \frac{1}{2}\frac{S^2}{B+S} r_s^2 \left(\frac{T}{\Delta\nu}\right)^{1/2}$$

$$\mathrm{S_{PERXEUS}} \sim 50 - 100\ \mathrm{S_{PCA}}$$

S: Source count rate
B: Background rate
T: PDS integration time

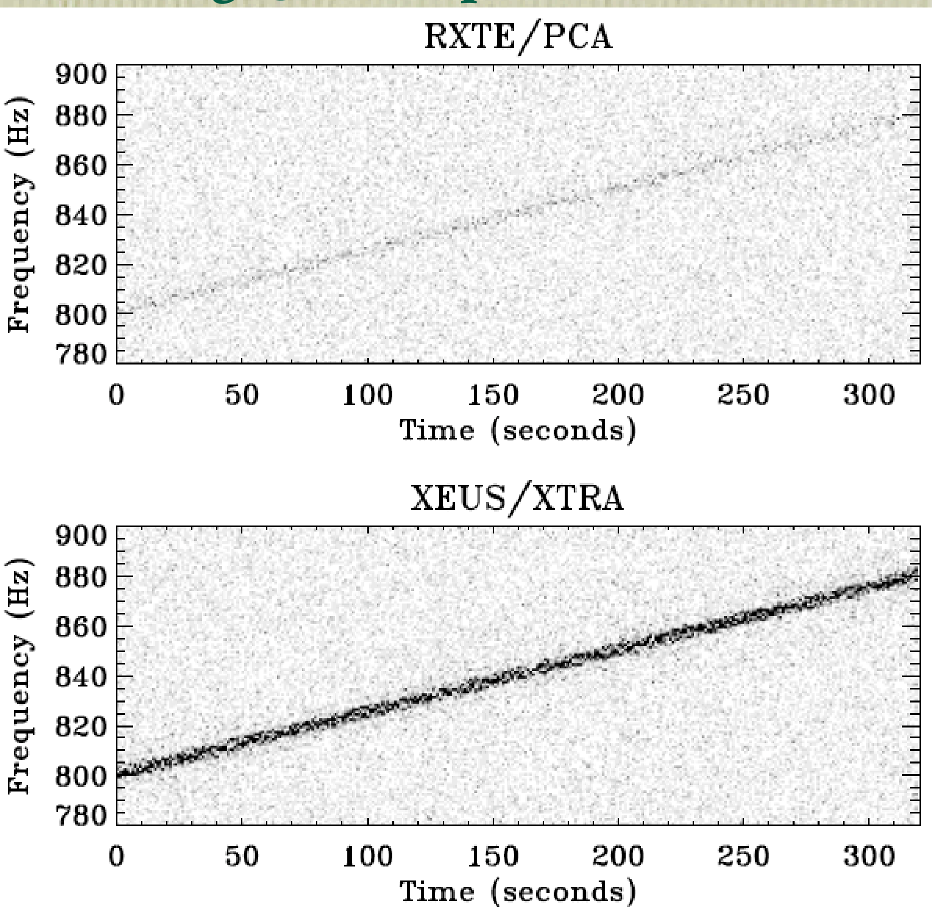
$$5\sigma\ \mathrm{PCA} \Longrightarrow 250 - 500\sigma \mathrm{PERXEUS}$$

$$\mathrm{T_{PERXEUS}} < \frac{\mathrm{T_{PCA}}}{2500}$$

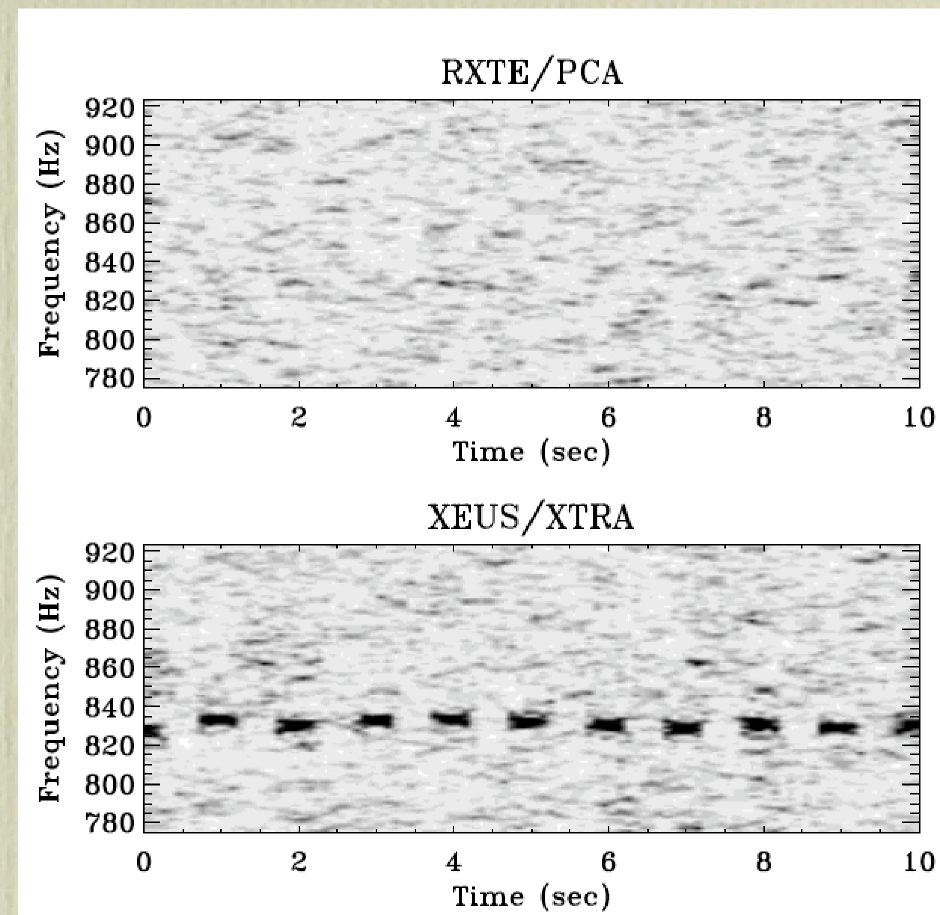
What QPOs really are

45000 counts/s (20xPCA)

Following QPO frequencies



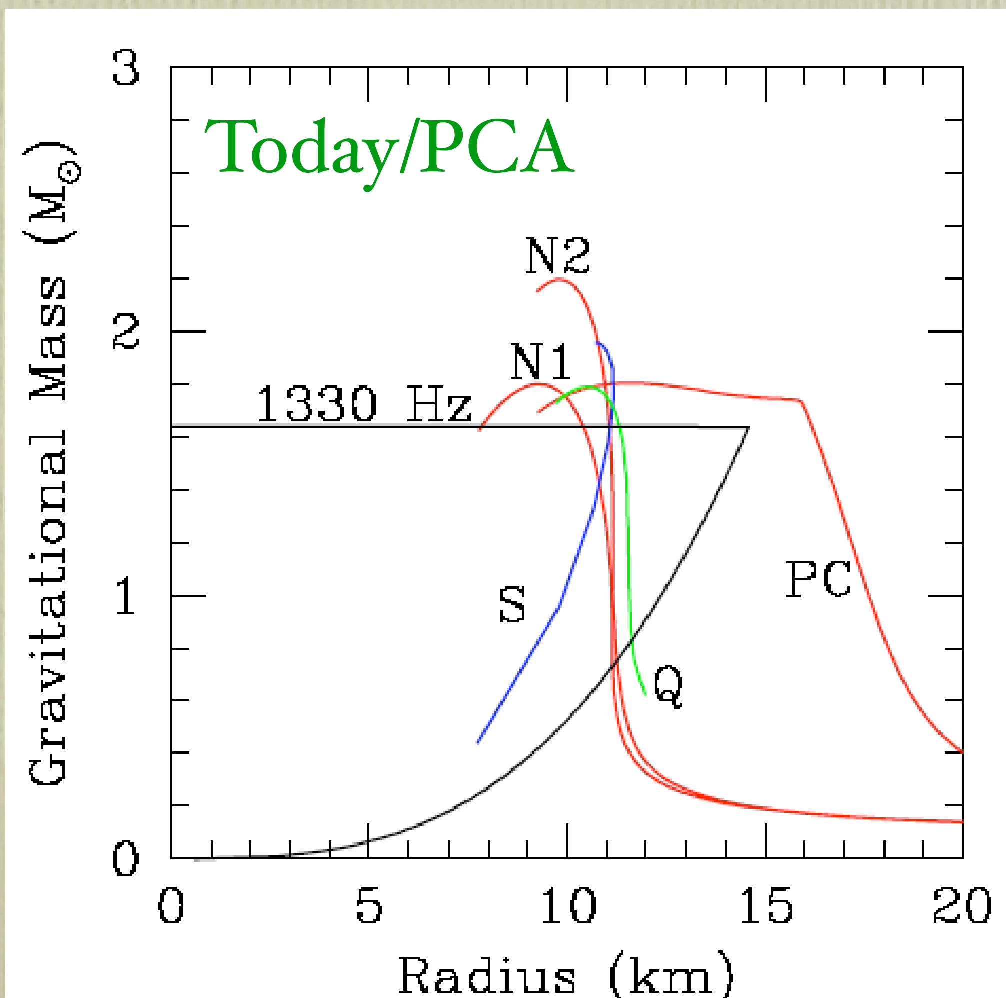
In the time domain

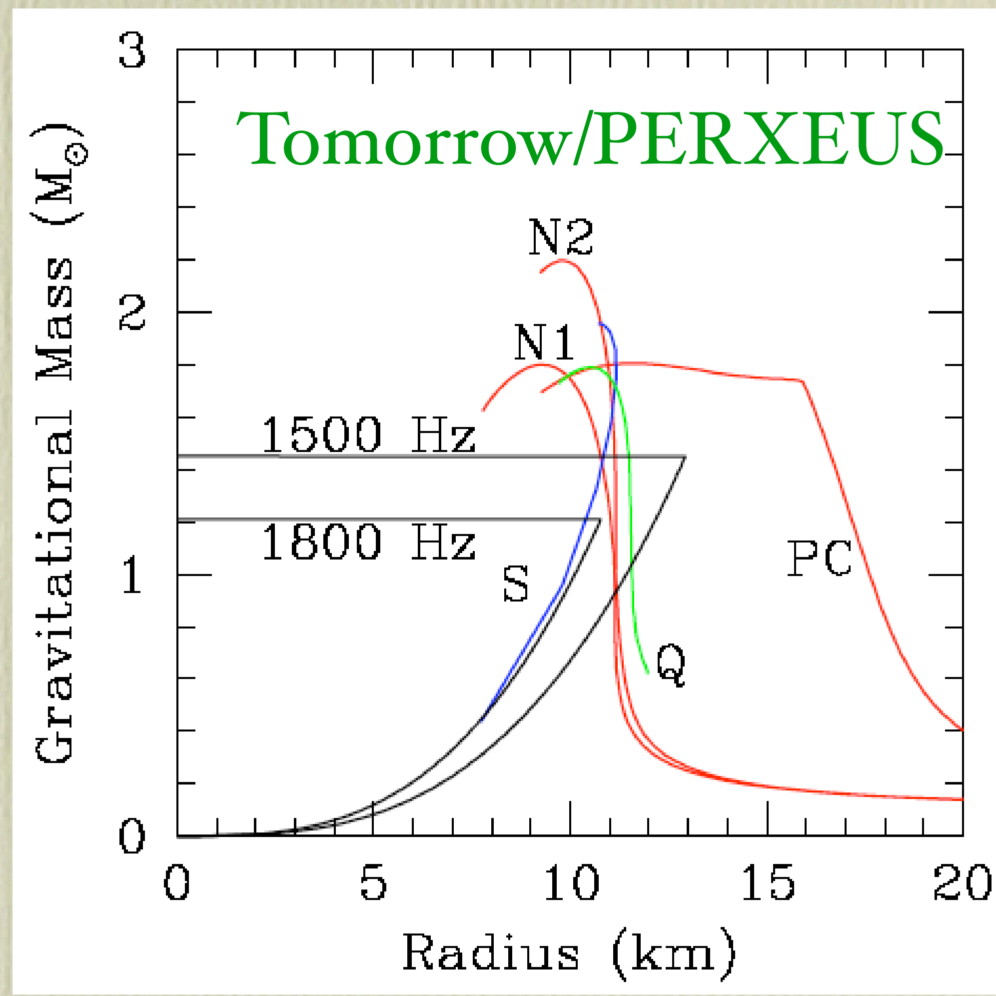


Barret (2004)

Searching higher frequency QPOs

$$\nu_{\rm upper} \approx \nu_{\rm orb} - R_{\rm orb} > R_{\rm ISCO}(= \frac{6GM}{c^2}) \text{ and } R_* < r_{\rm orb}$$

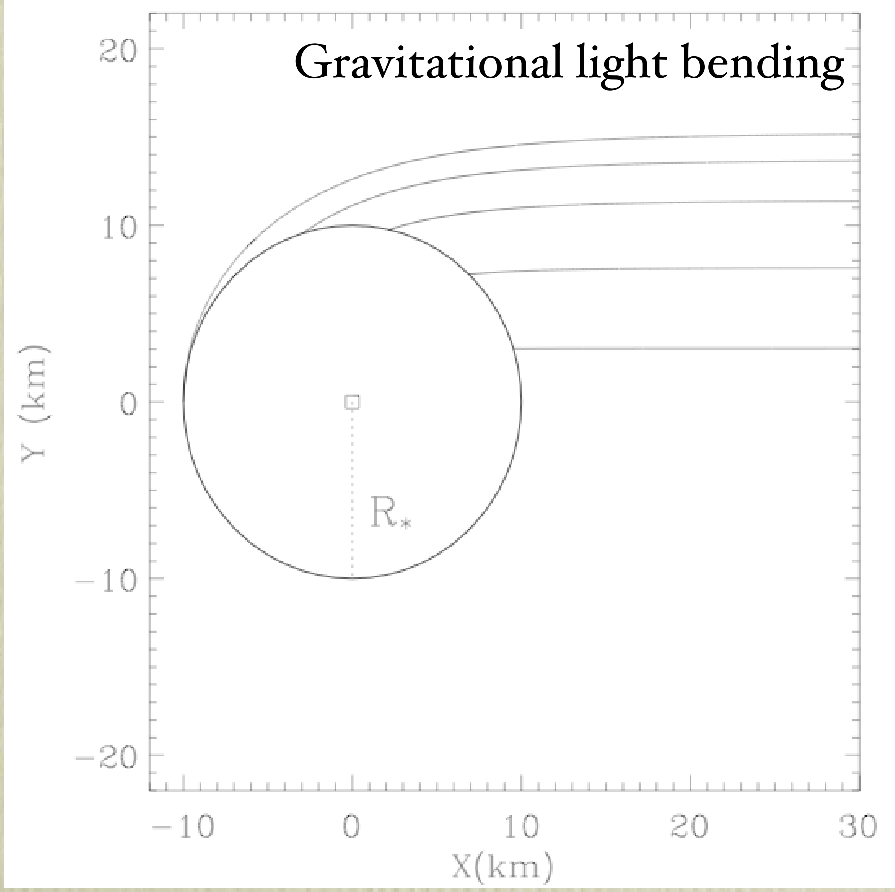




Miller C. (2004)

Modeling burst oscillations

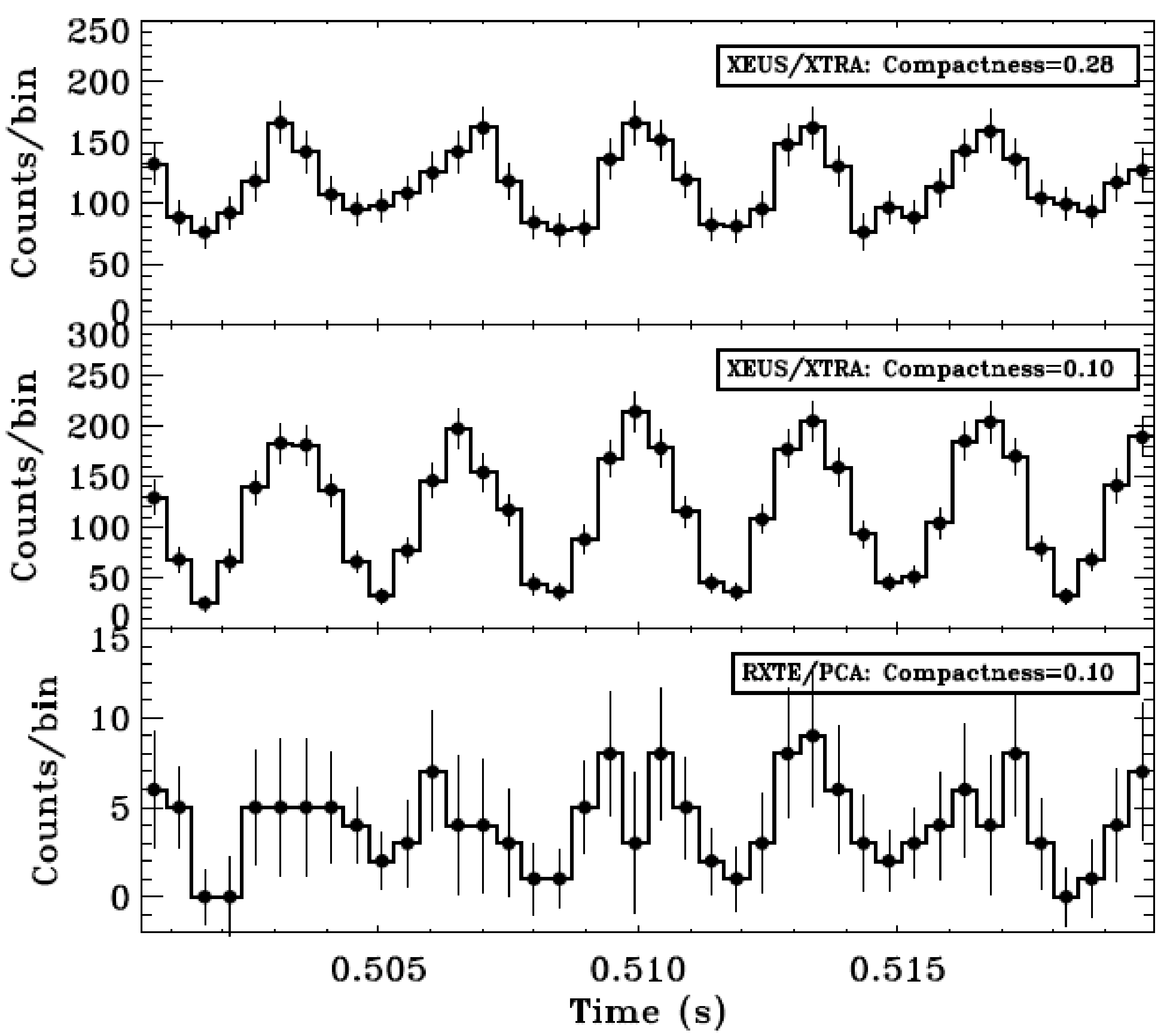
- External spacetime is the Schwarzchild metric
- Blackbody surface emission
- Relativistic beaming and aberration due to stellar rotation
- Initial location, angular size and growth rate of the hot spot



Strohmayer (2004)

Seeing individual oscillations

400000 counts/s (20xPCA)

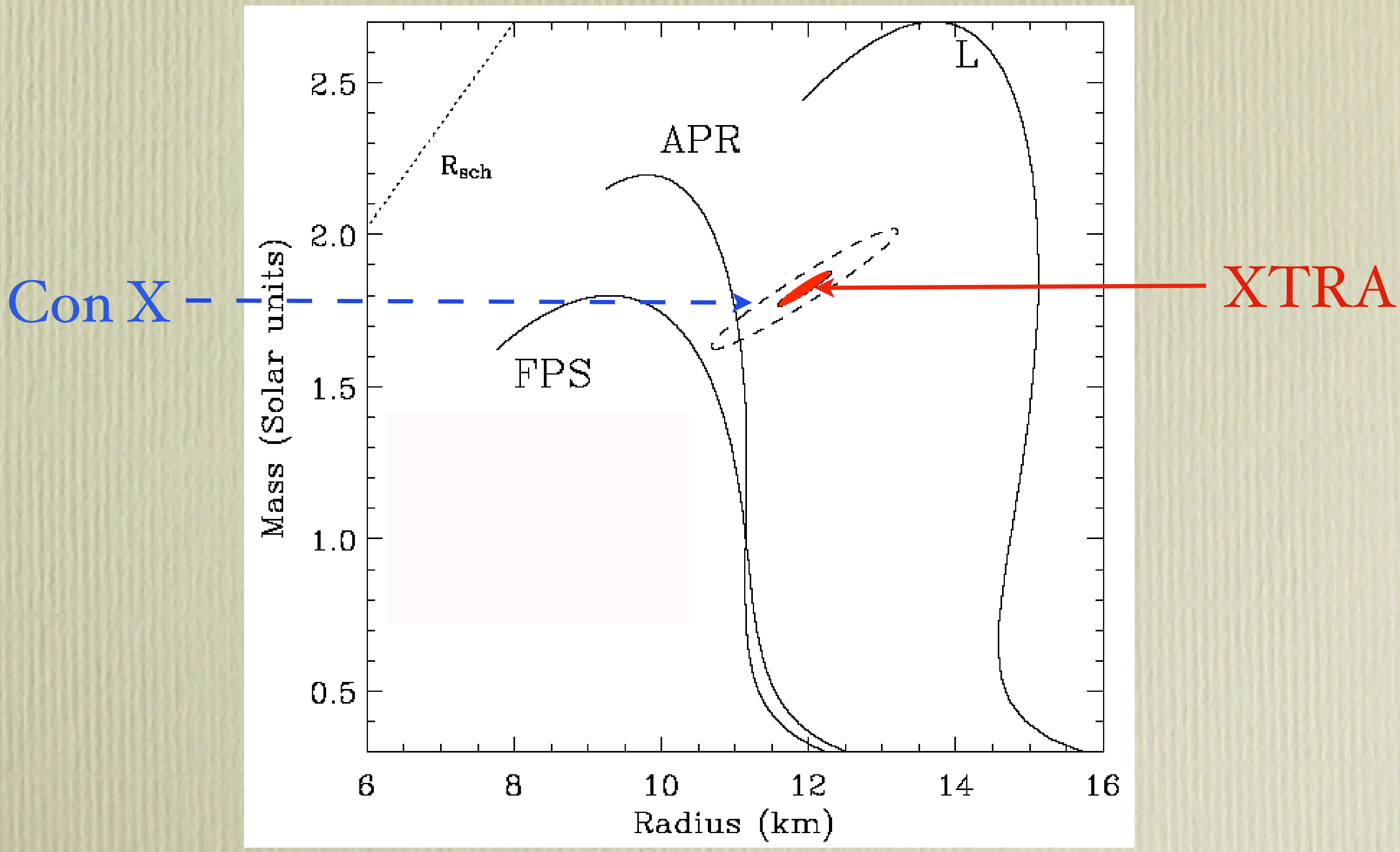


Compactness

PCA

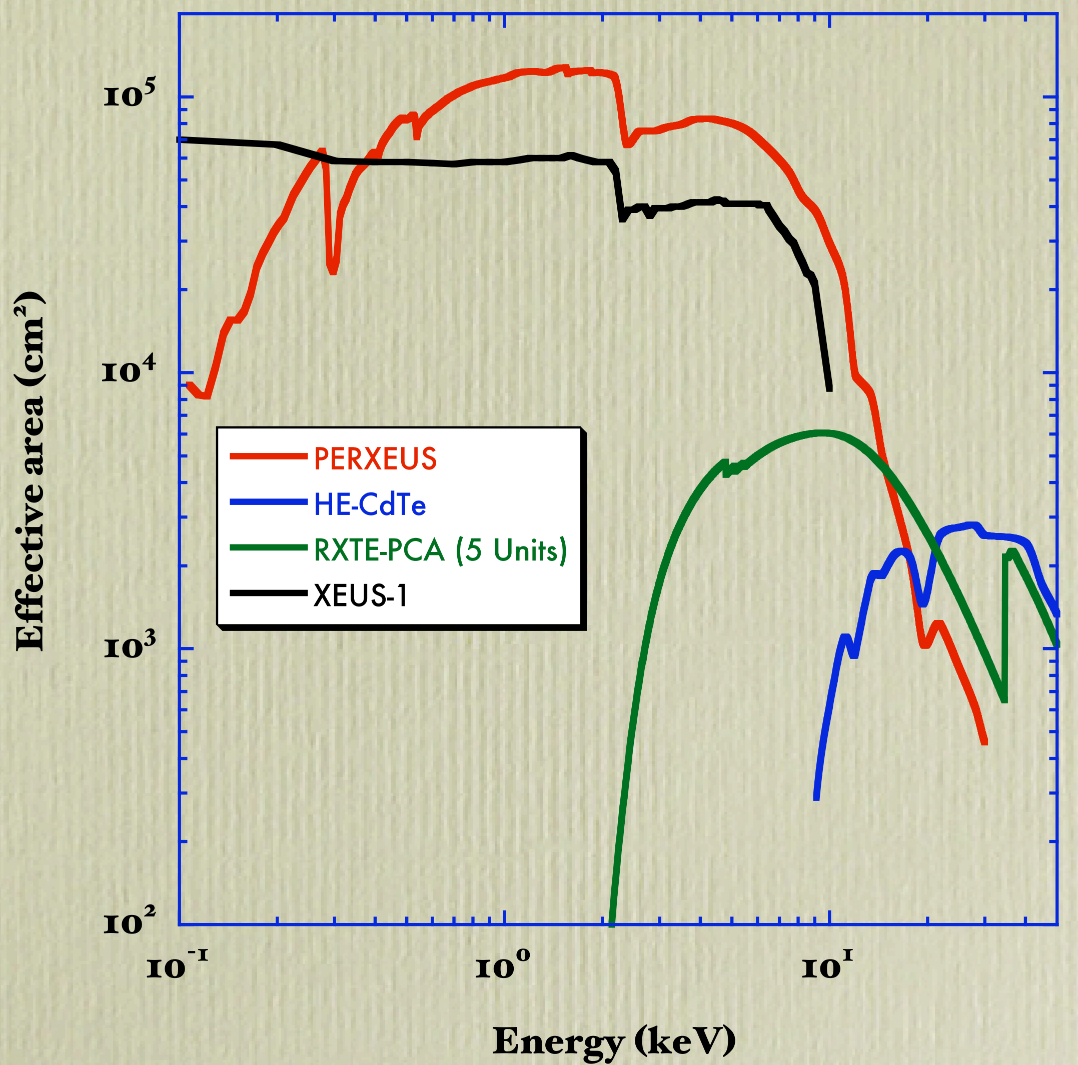
Barret (2004)

Constraining the EOS



Adapted from Strohmayer (2004)

Effective area & count rates

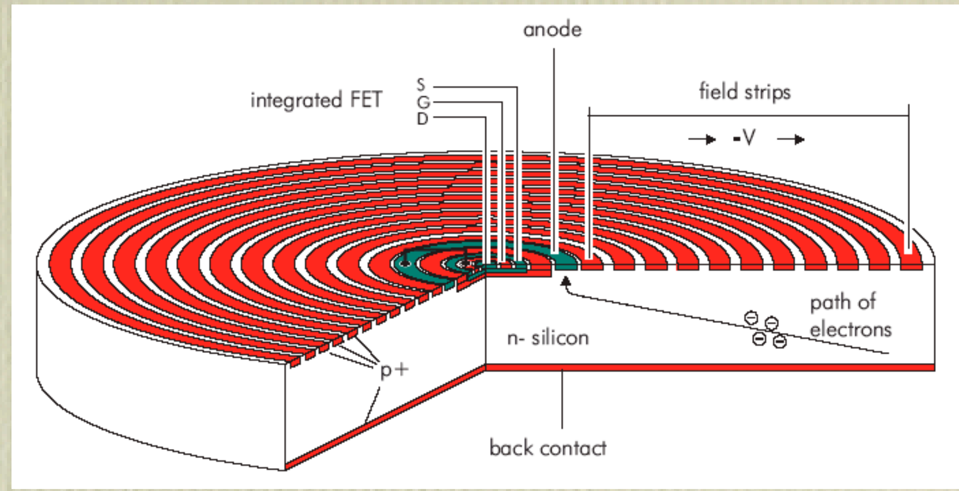


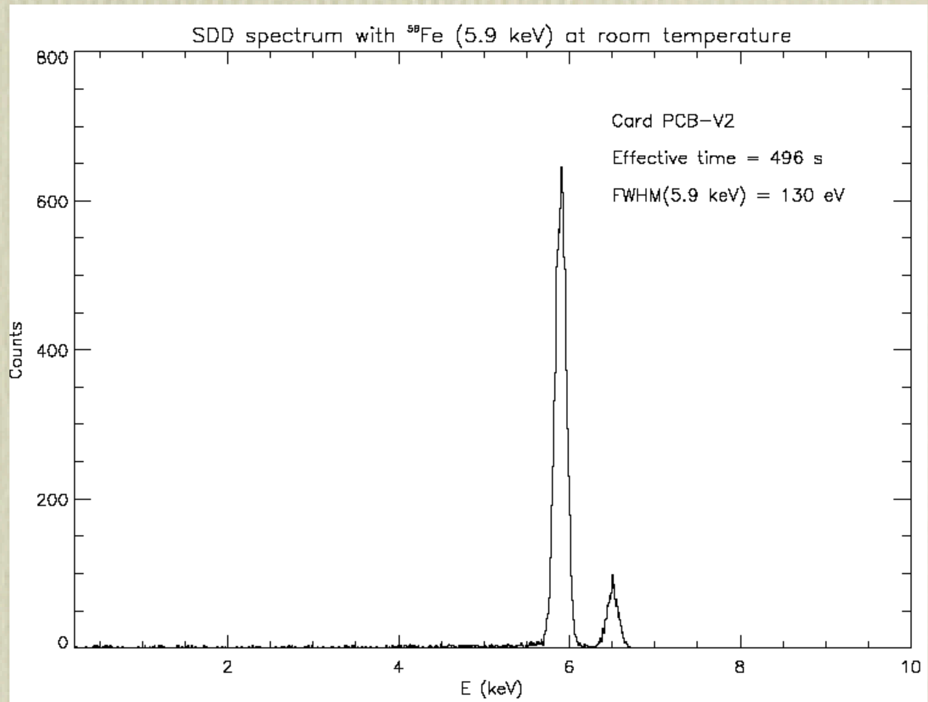
Crab $\sim$ 1 Mcounts/s

Courtesy of A. Parmar

Silicon drift detector

- High resistivity n-type fully depleted Silicon
- Small output capacitance due to the small size of the anode
- High count rate capabilities
- Good energy resolution (130 eV at room temperature)

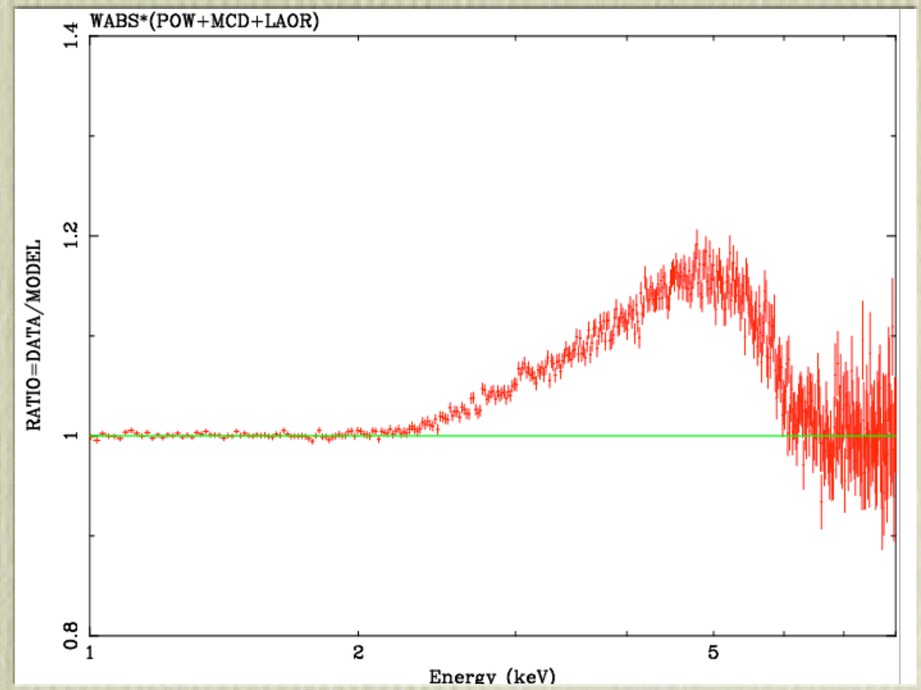




Strüder (2001) - Lechner (2001) - Leutenegger et al. (2001)

Seeing lines on short time scales

100 seconds - PERXEUS

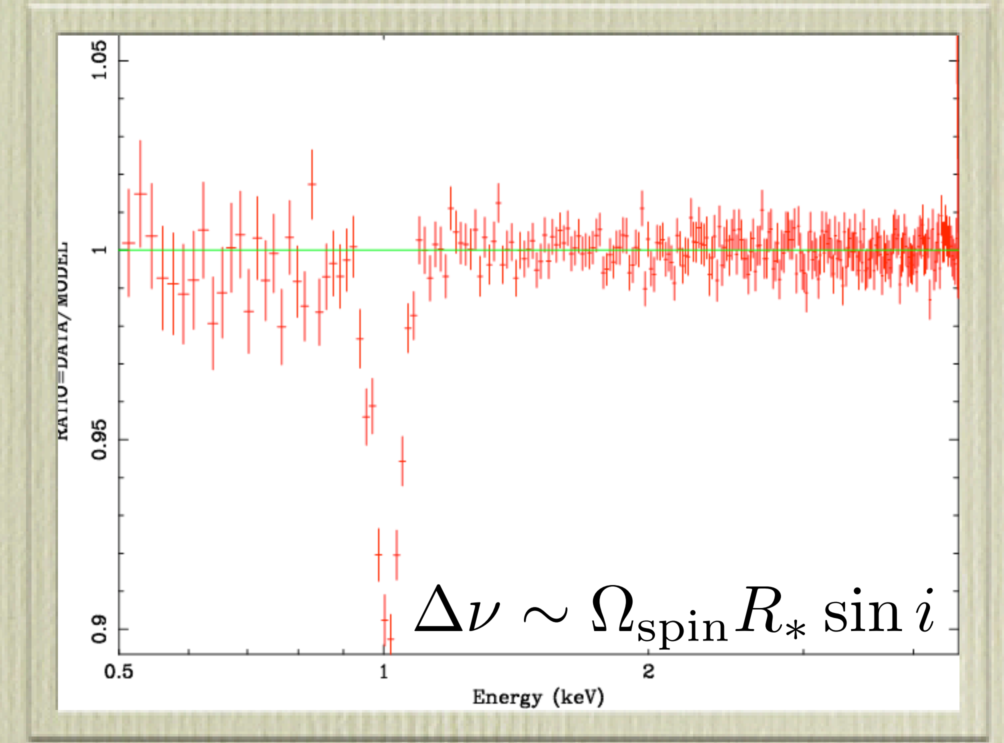


Laor Line above a complex power law and disk blackbody continuum

Miller et al. (2004)

X-ray burst absorption lines

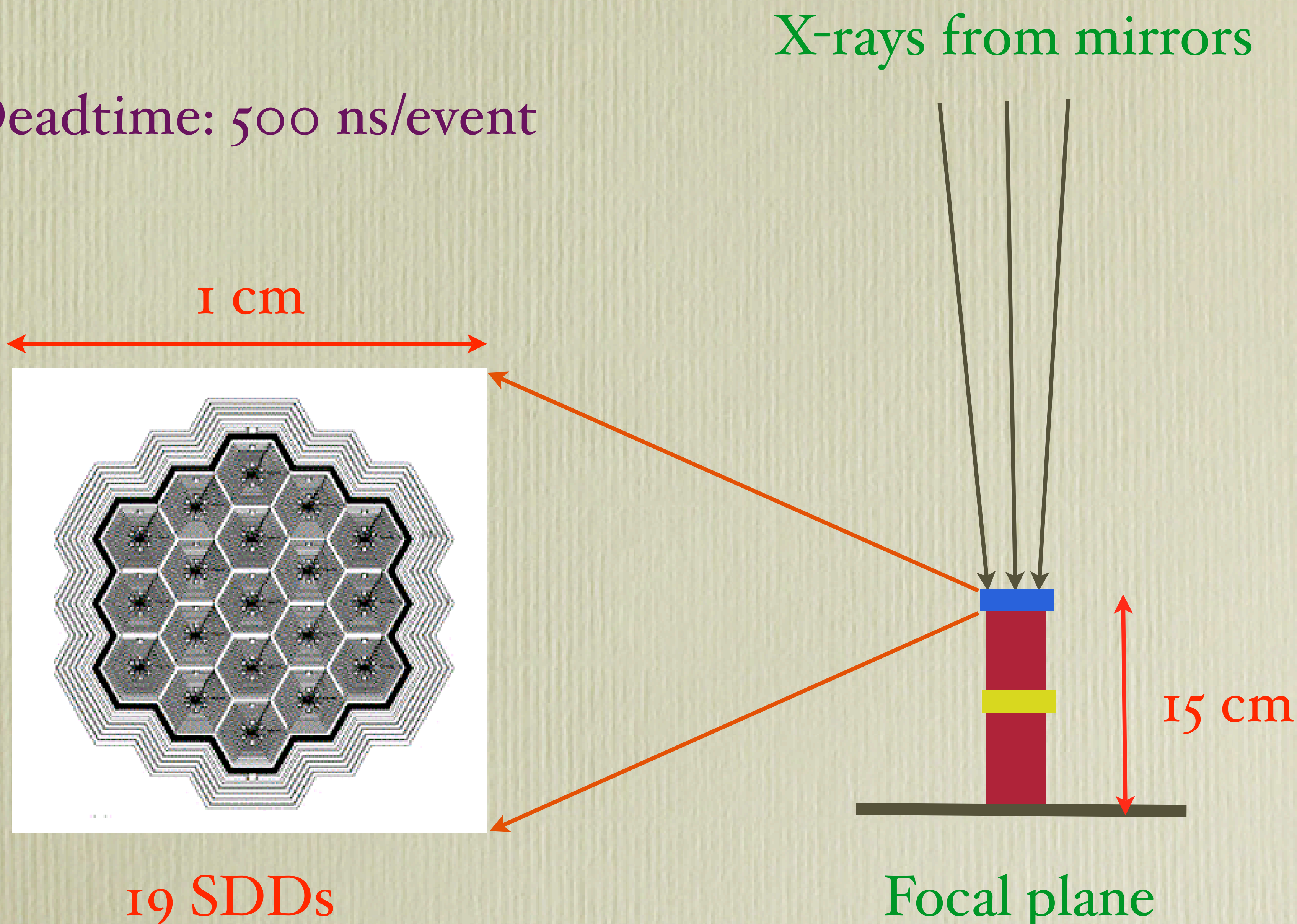
10 seconds (PERXEUS)



X-ray burst (Eddington limit at 3 kpc): 1 keV absorption line of 10 eV equivalent width

Detector implementation

Deadtime: 500 ns/event



Deadtime, packaging, on-board data processing, telemetry to be studied: MPI, Tübingen, ROENTEC,

Conclusions

- Probing General Relativity in the strong field regime and constraining the equation of state of matter at supra-nuclear density using fast X-ray timing and spectroscopy can be achieved with the effective area of the PERXEUS mission
- There are ways of implementing a fast timing detector capable of observing the brightest sources of the sky with existing technology