Quasi-periodic Oscillations
(the high-frequency ones)

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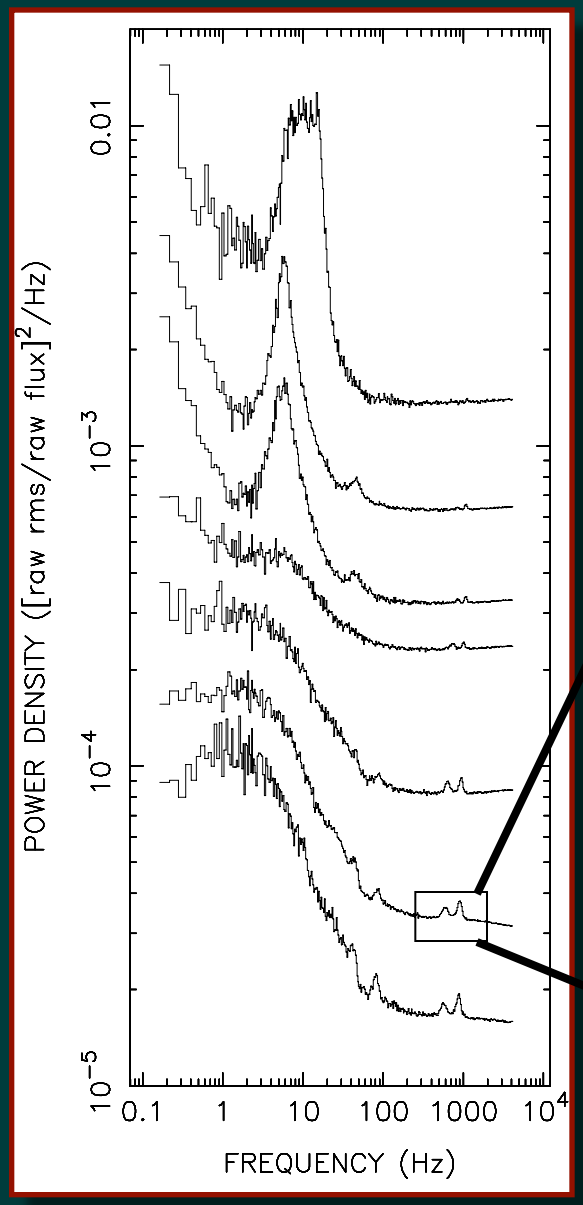
Viscous timescale:
Time it takes for a perturbation to travel through the disc.

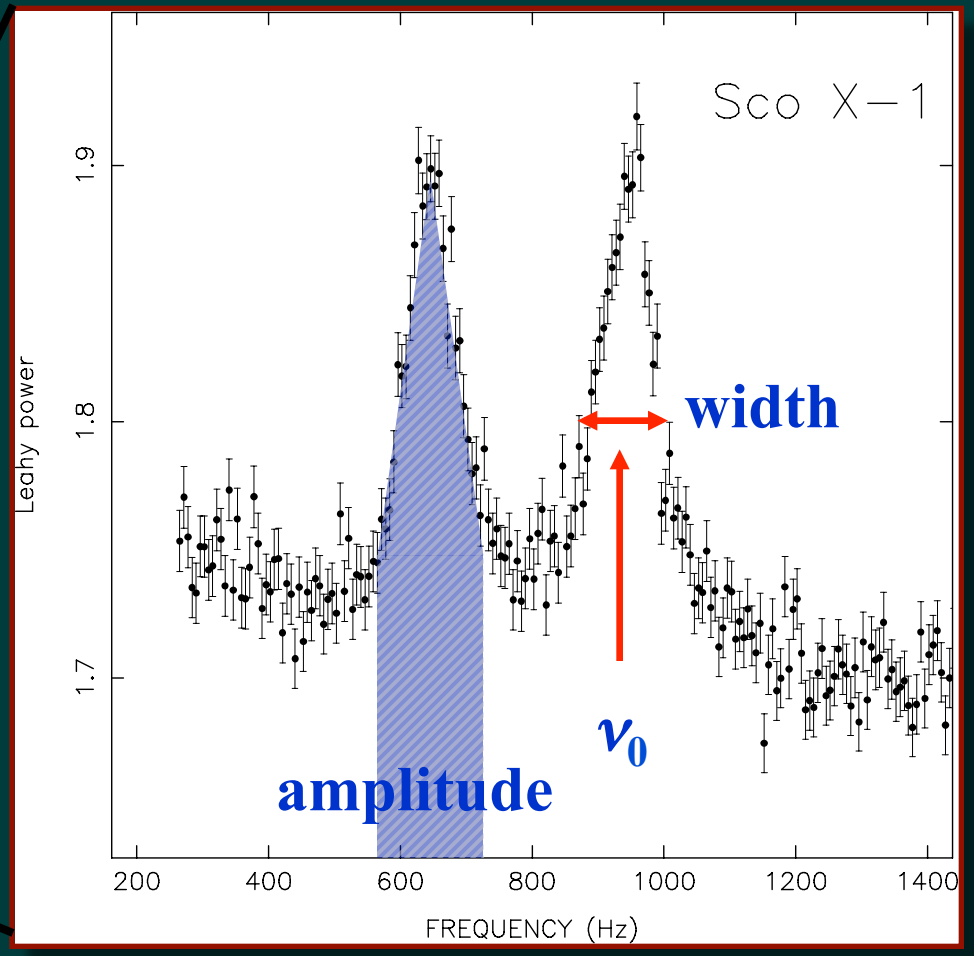
$$\tau_{\text{visc}} \propto \frac{R^2}{\alpha H c_s} \approx 10^5 \text{ s.}$$

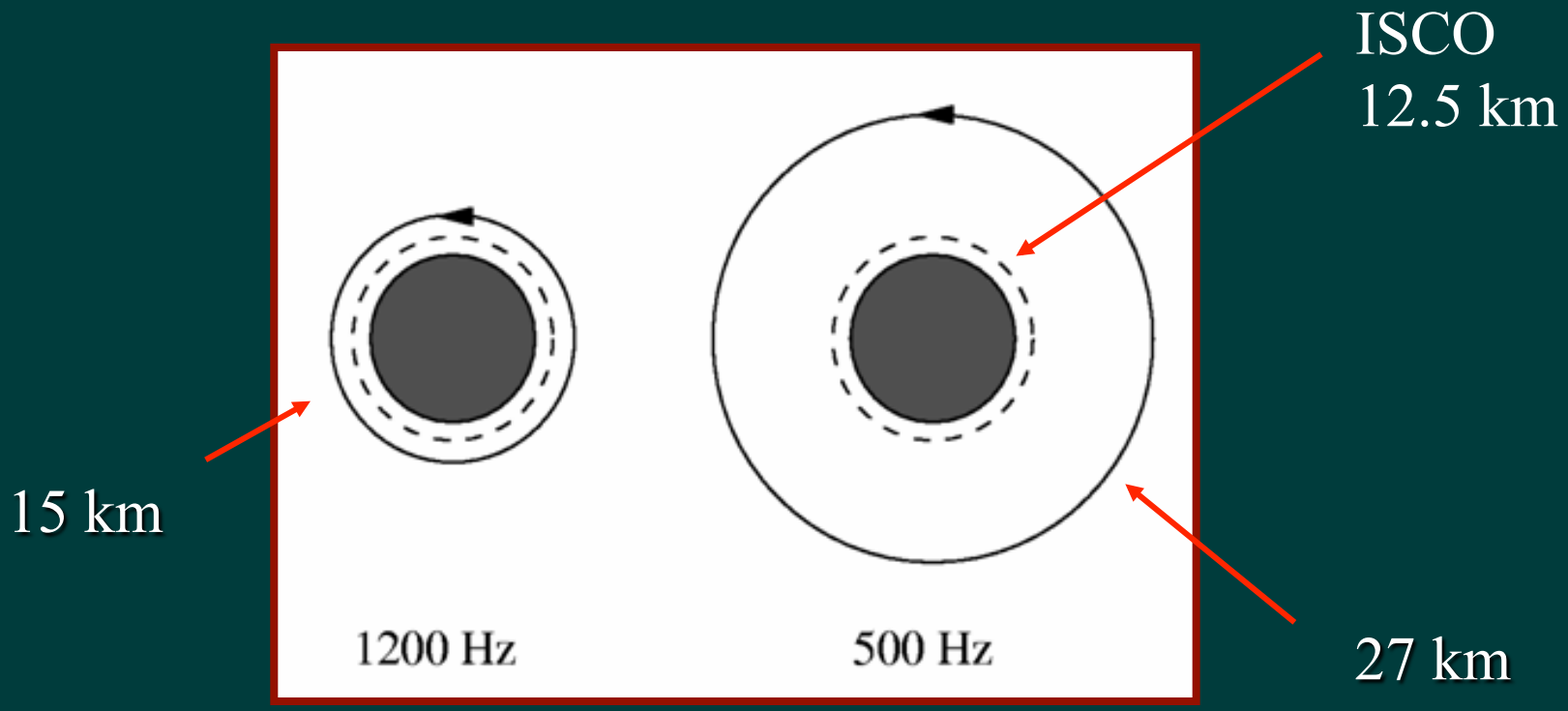
Dynamical timescale:
Crossing time close to the neutron star.

$$\tau_{\text{dyn}} \approx \frac{R_{NS}}{v_{\text{free-fall}}} = \sqrt{\frac{R_{NS}^3}{2GM_{NS}}} \approx 10^{-3} \text{ s.}$$

kHz QPOs


POWER DENSITY ([raw rms/raw flux]^2/Hz)
0.01
10^{-3}
10^{-4}
10^{-5}
0.1
1
10
100
1000
10^4
FREQUENCY (Hz)

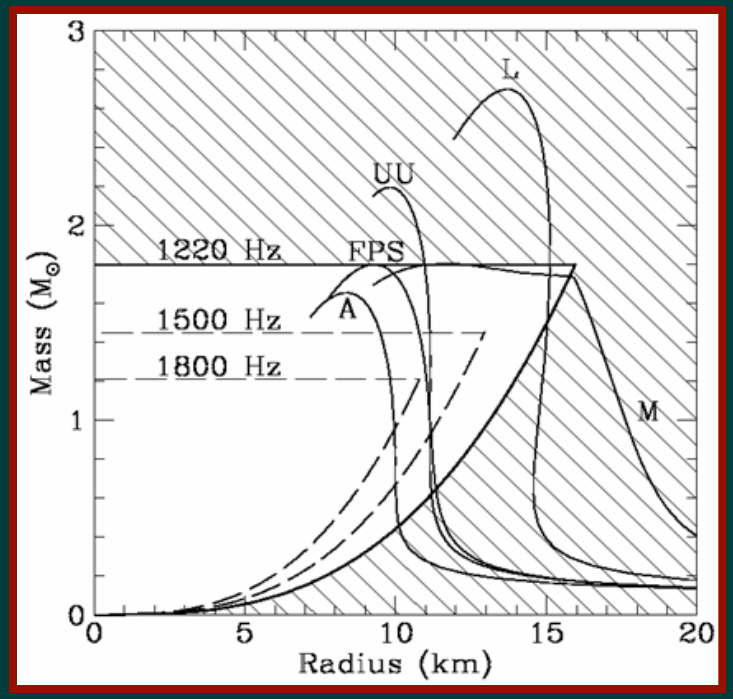

Sco X−1
Leahy power
1.9
1.8
1.7
width
ν_0
amplitude
200
400
600
800
1000
1200
1400
FREQUENCY (Hz)



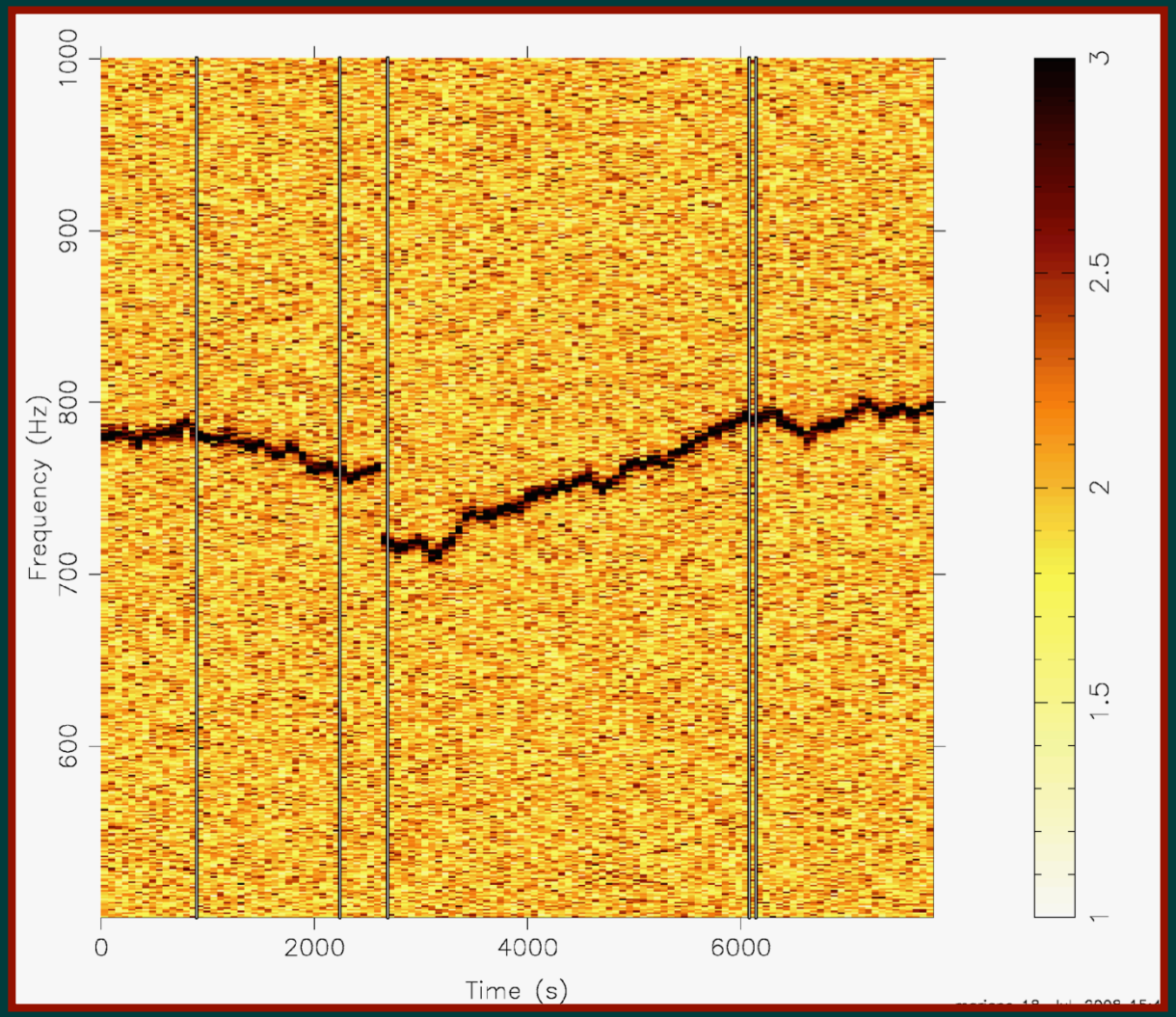
Maximum observed frequencies confirm that variability originates in regions where the gravitational field is strong (potential energy ~ rest mass energy), and GR effects are important.

Disc orbital-frequency interpretation

- In most models ν_2 orbital frequency at inner edge of Keplerian disk
- If true, this constrains neutron star mass and radius.
- QPOs vary in frequency, but remain always below ~1.2 kHz.
- An ISCO frequency of 1.2 kHz corresponds to a ~2 M_{sun} neutron star.

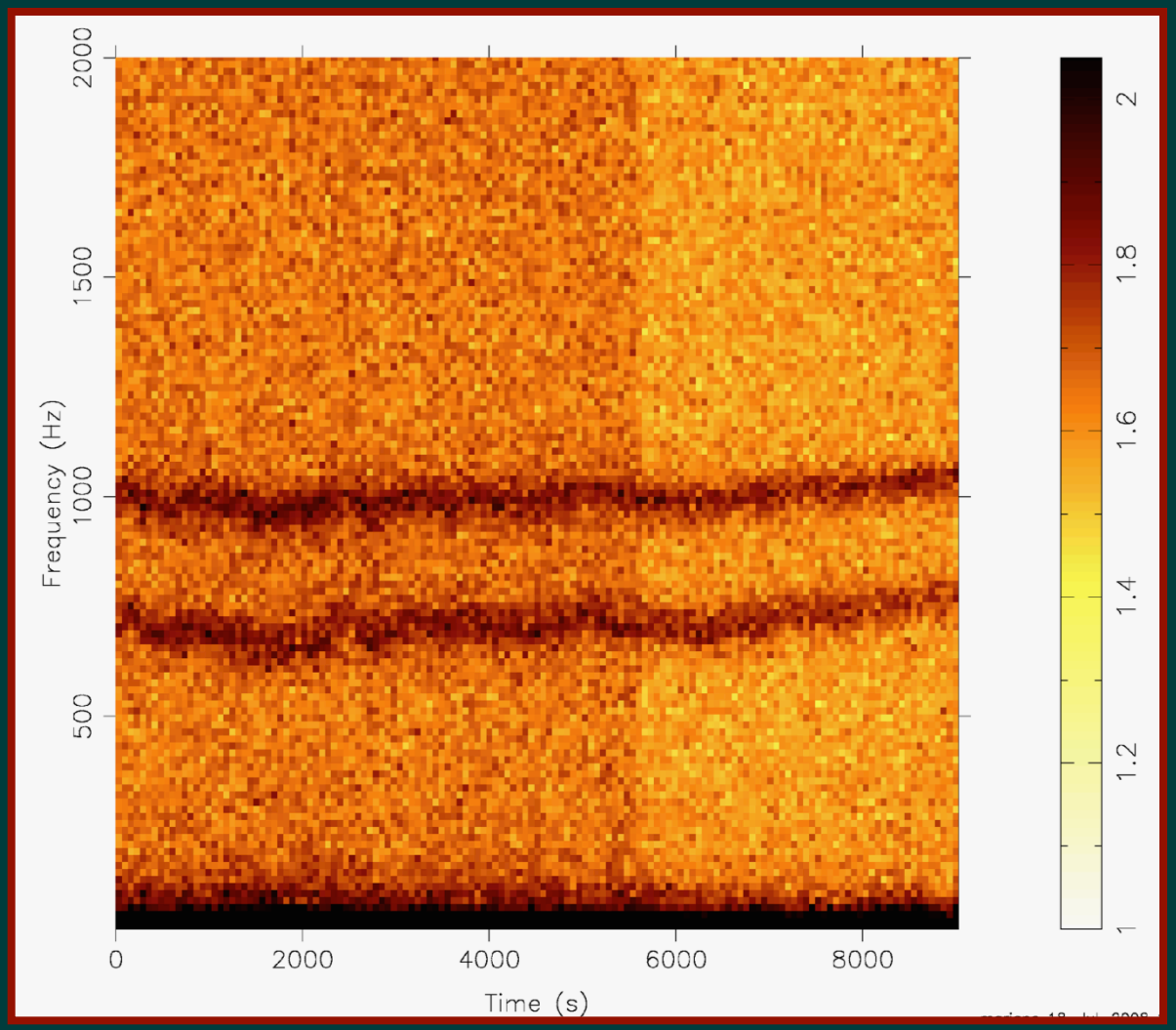


- Frequencies drift by 10-50 of Hz over ~1000 seconds.
- Probably associated to perturbation patterns moving across the accretion disc (viscous timescales).



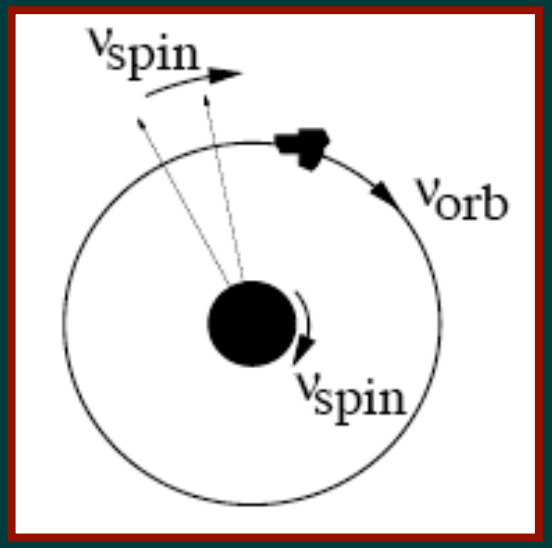
4U 1608–52

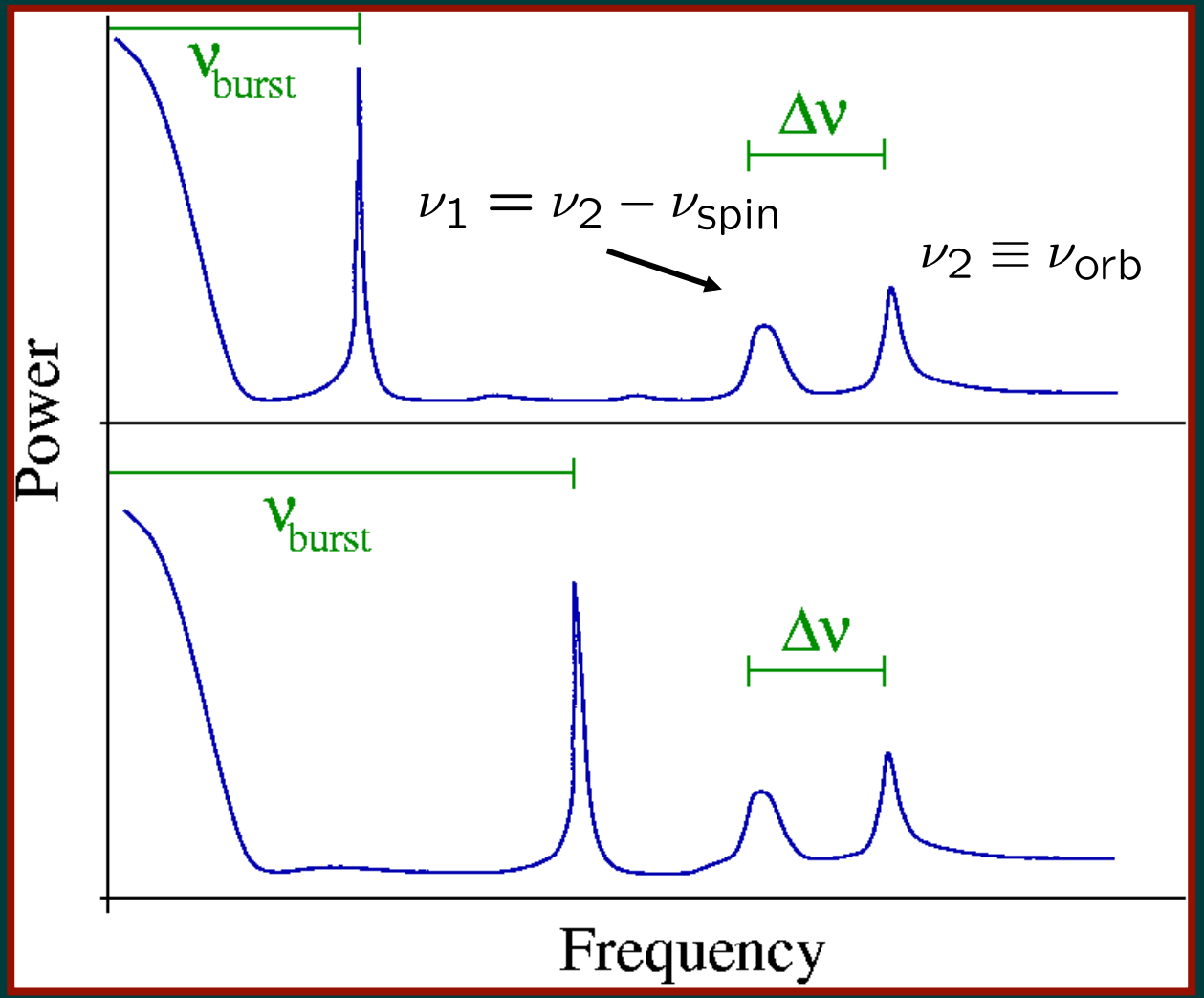
Frequencies drift, but separation remains more or less constant



Sco X–1

Beat-frequency models



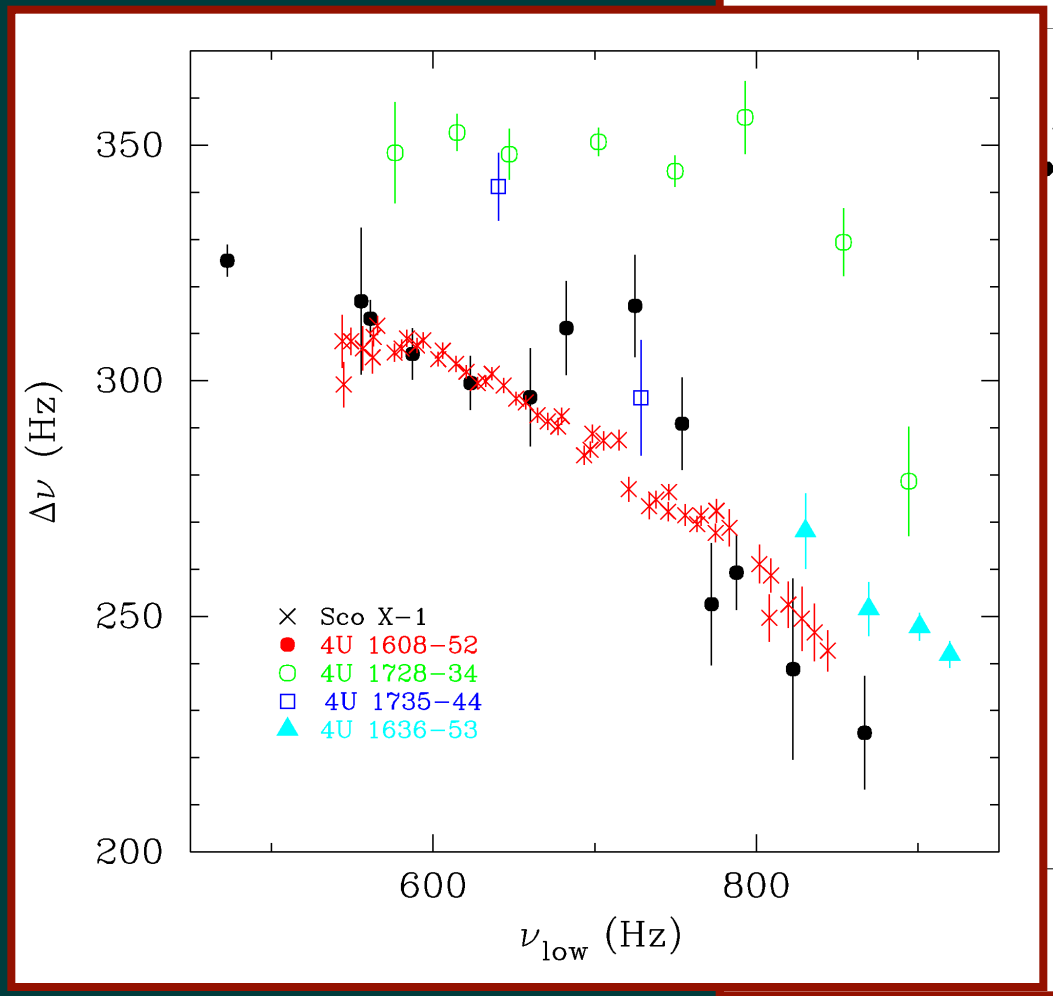


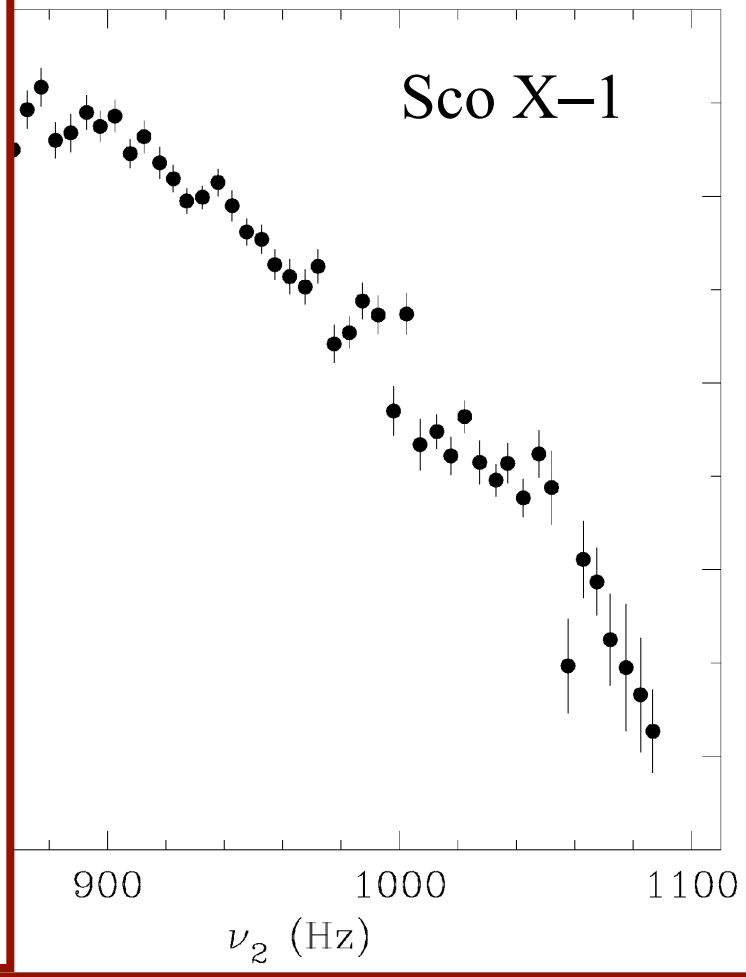
$$\nu_{burst} = \begin{cases} \nu_{spin} \\ 2 \times \nu_{spin} \end{cases} \qquad \Delta\nu = \nu_{spin}$$

SAX J1808

Miller et al.; Lamb & Miller

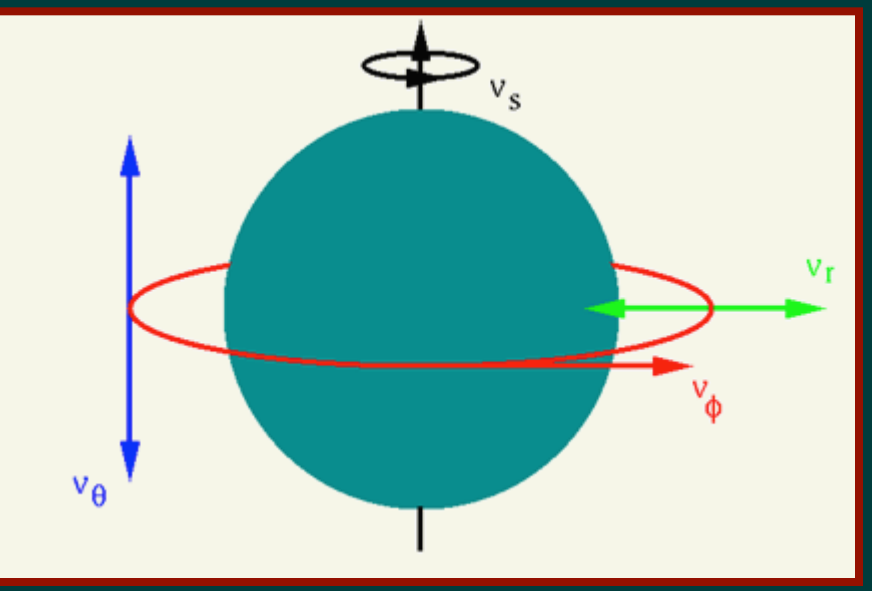
Systematic decrease of $\Delta\nu$ as $\nu_{\rm QPO}$ increase.



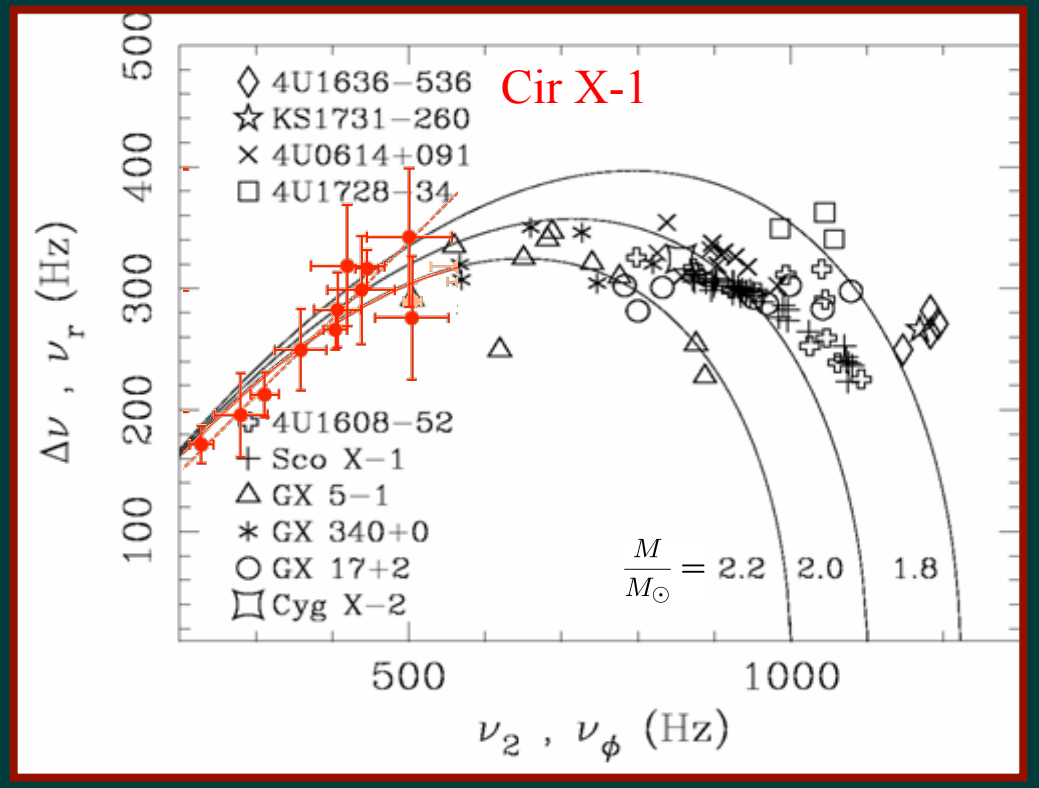


van der Klis et al.; Mendez et al.

Relativistic precession model



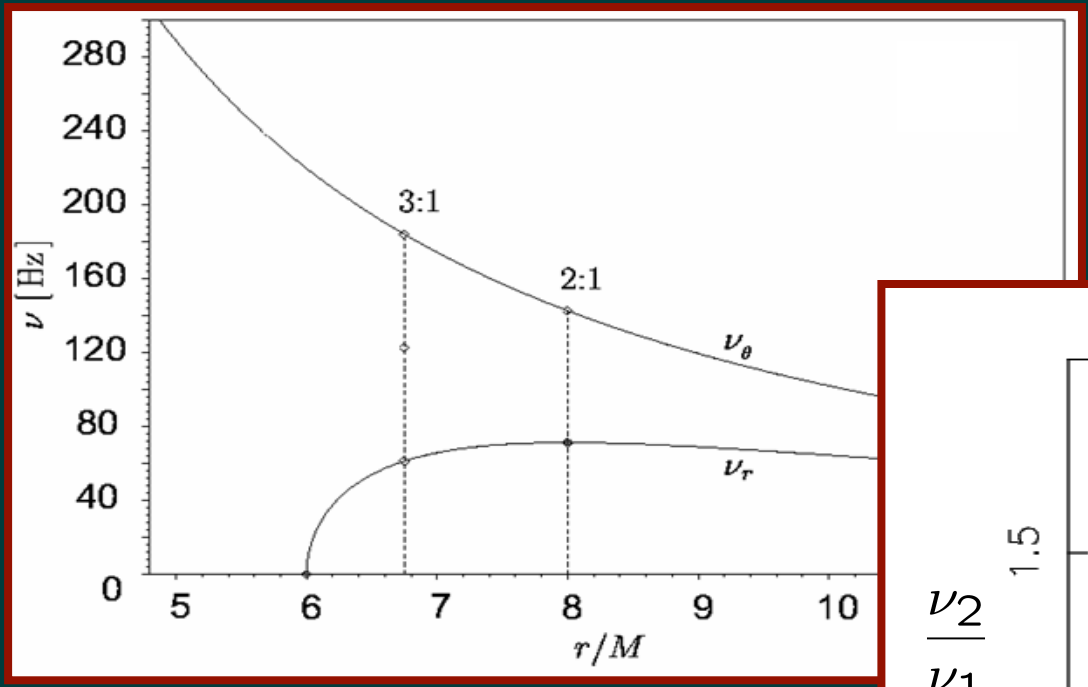
Relativistic epicycle precession frequencies.

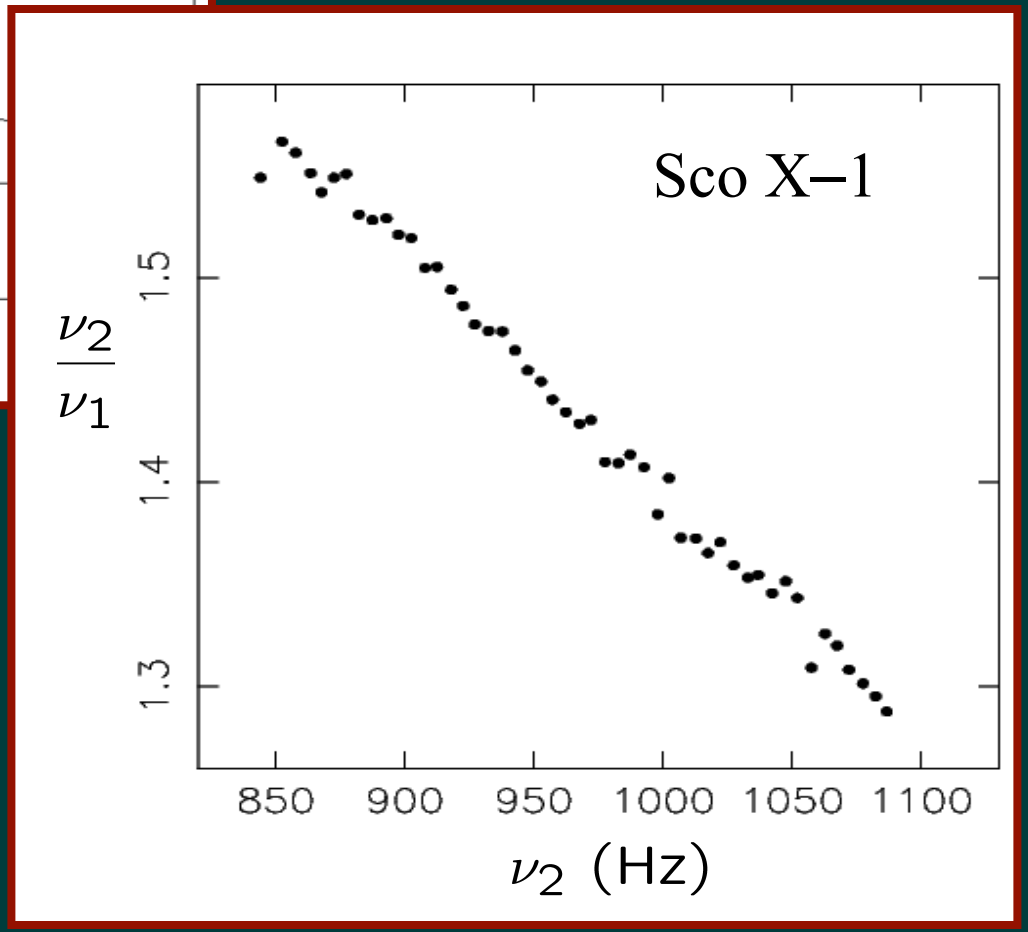


Stella & Vietri

Bouloukos et al. 2006

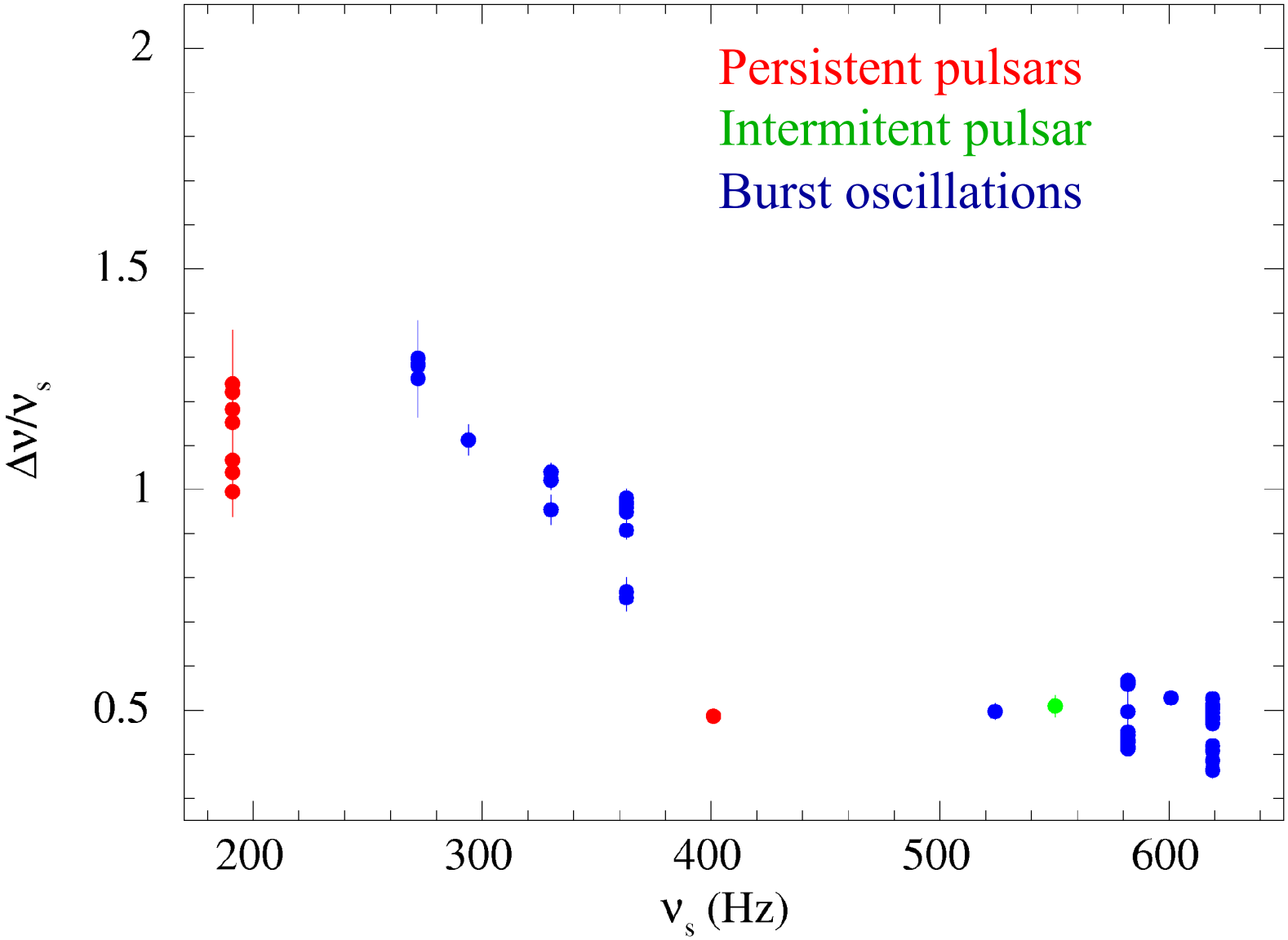
Resonance models



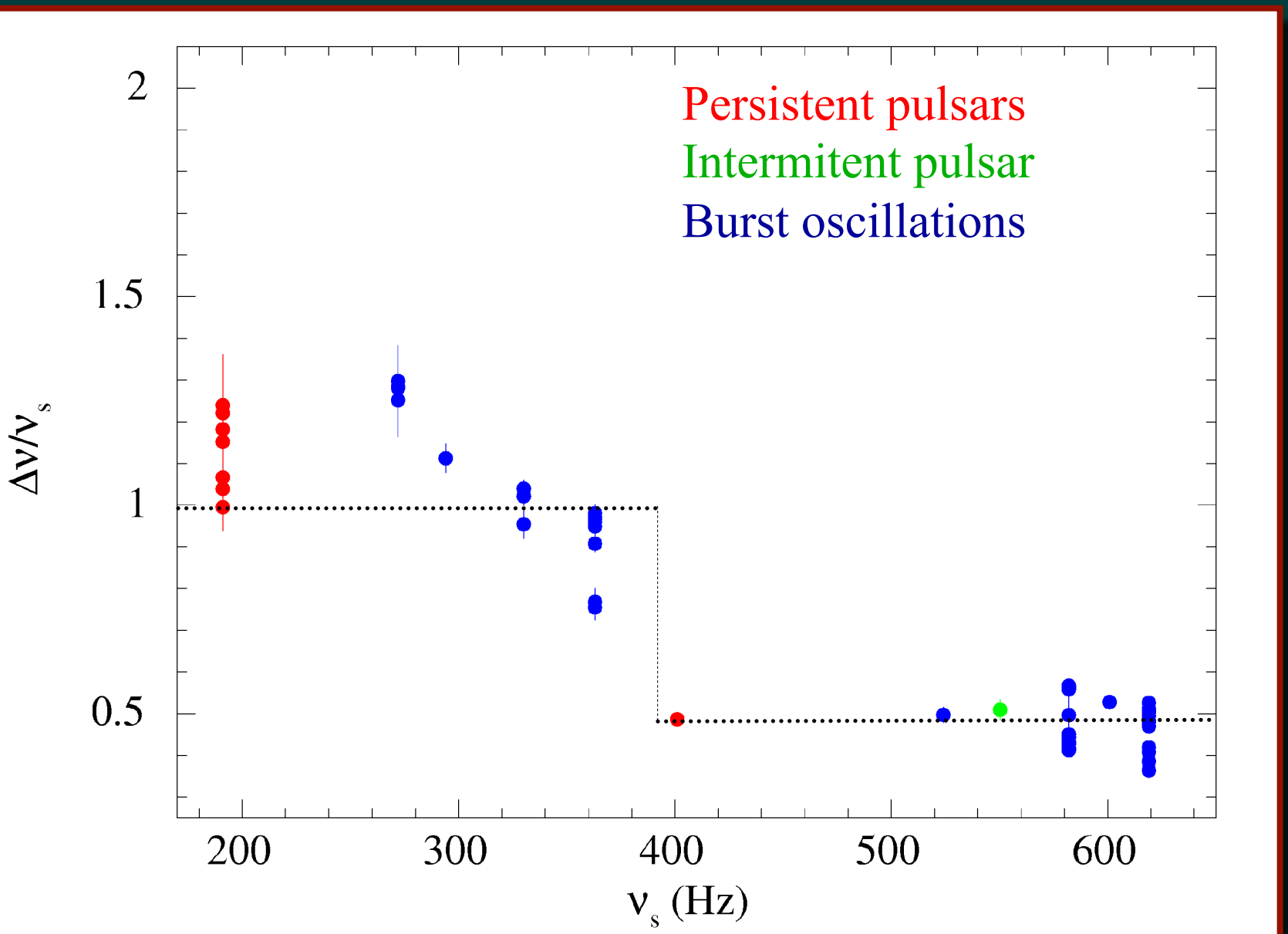


'At particular fixed radii in the disk resonances can occur between relativistic orbital and epicyclic frequencies'

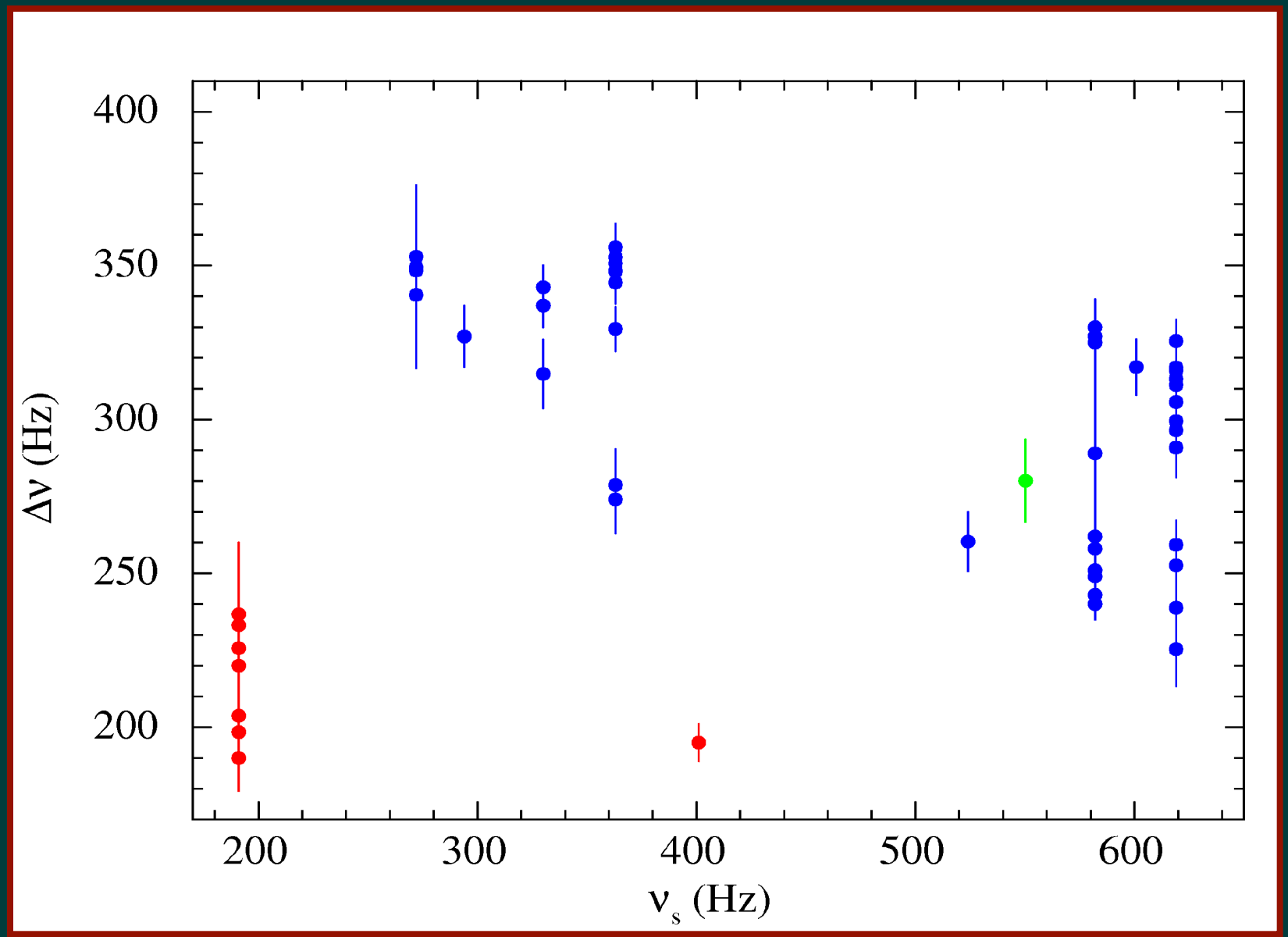
Kluzniak & Abramowicz

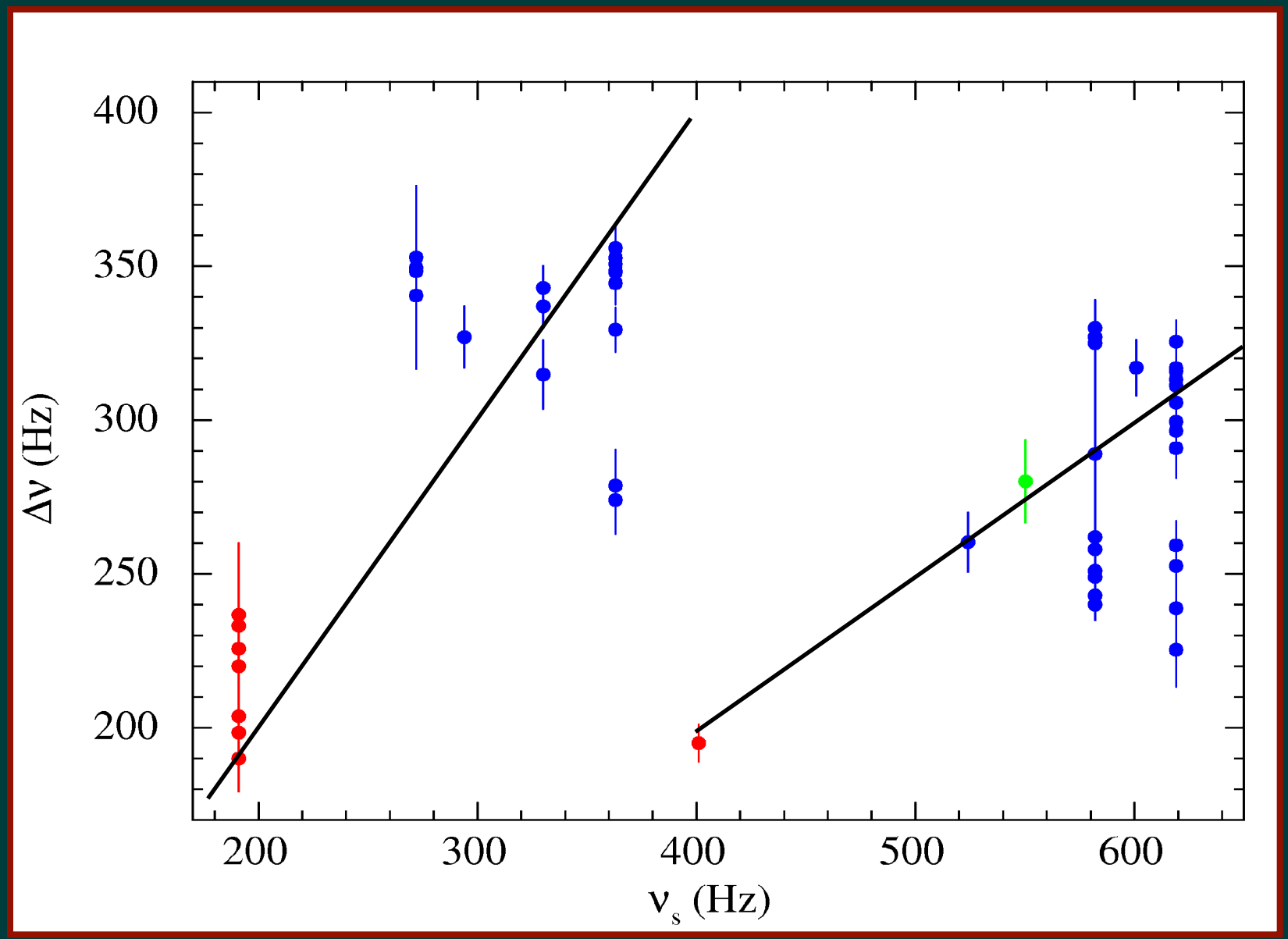


van der Klis; Mendez & Belloni

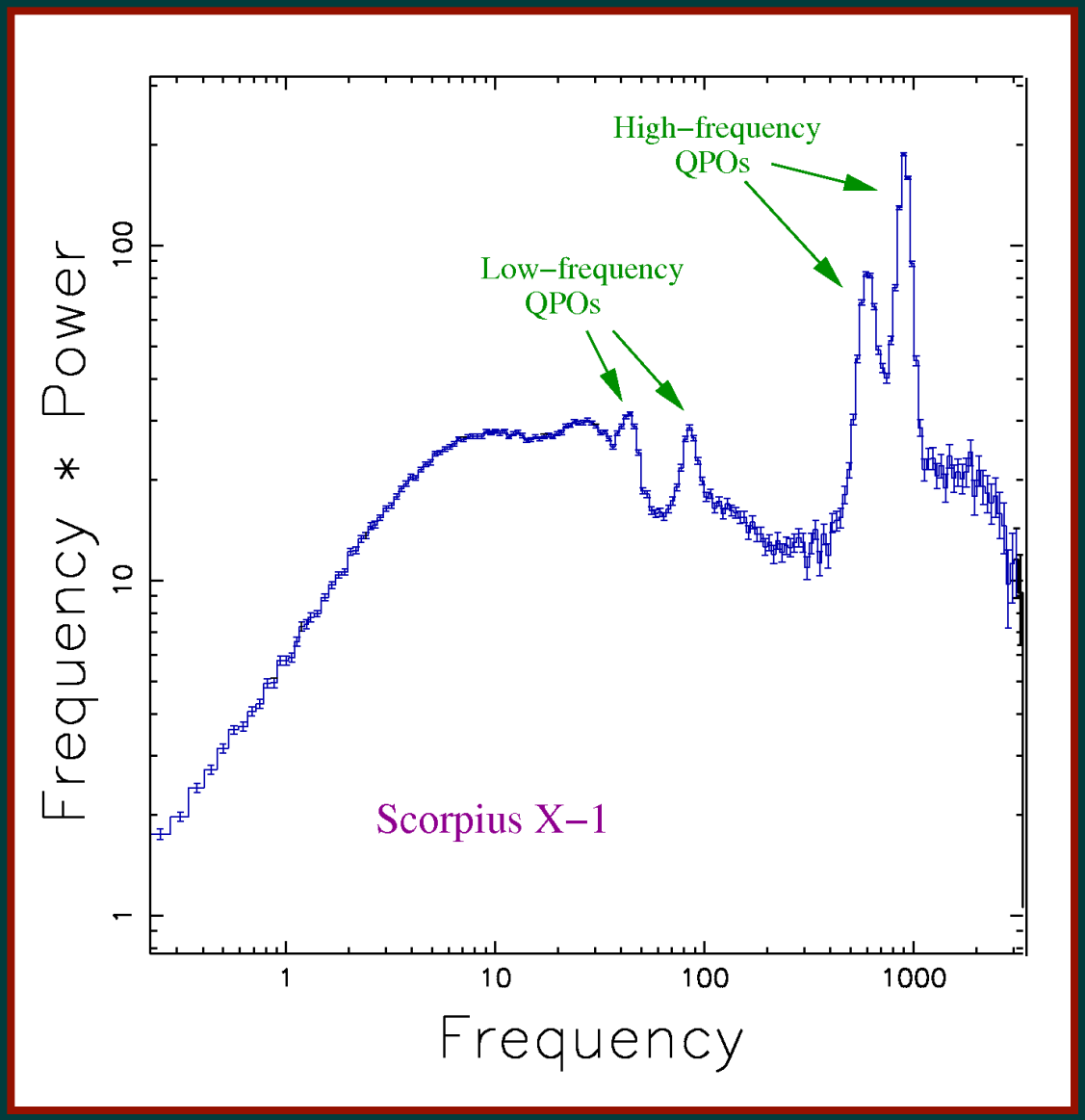


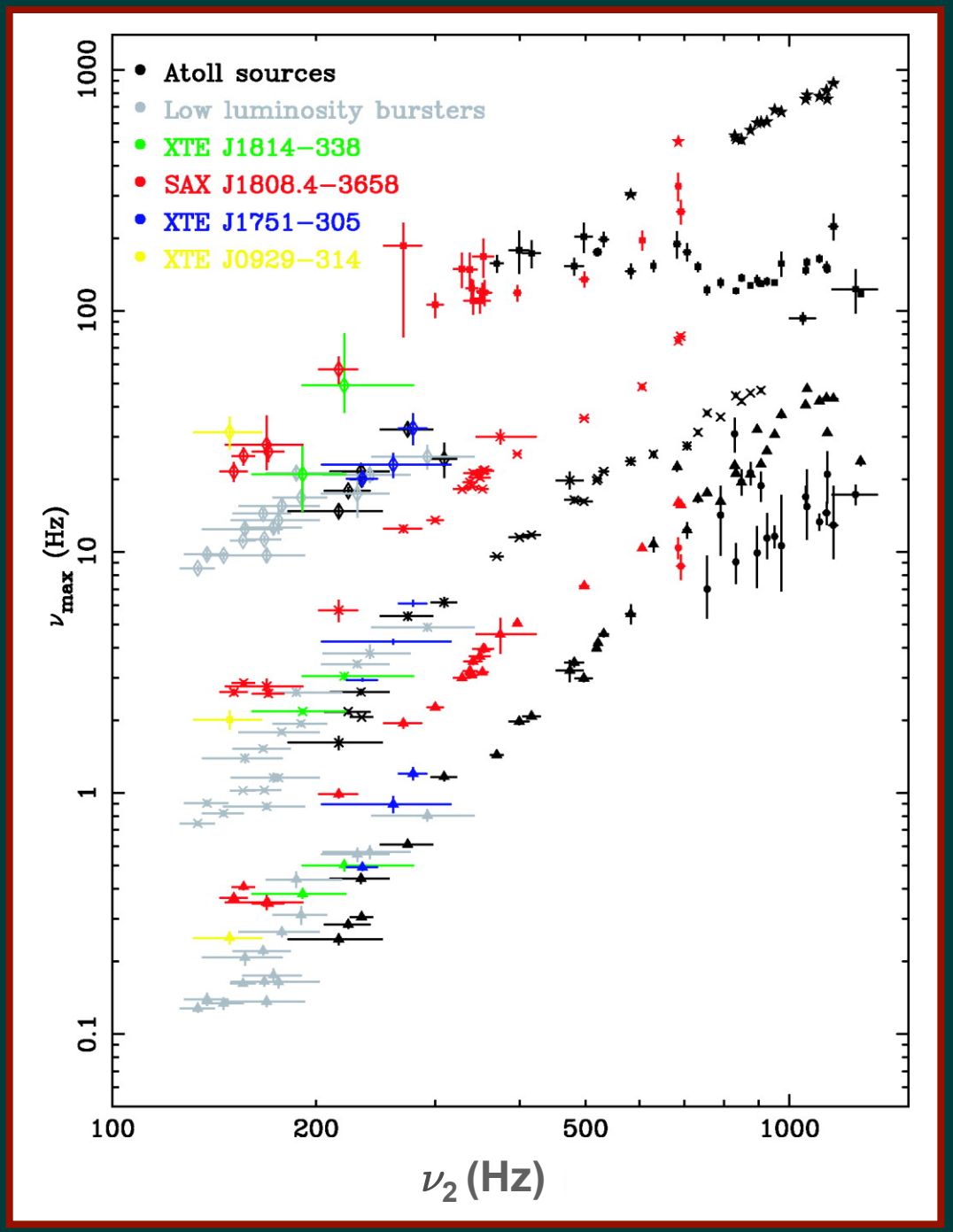
van der Klis; Mendez & Belloni


400
350
300
250
200
Δν (Hz)
200
300
400
500
600
ν_s (Hz)

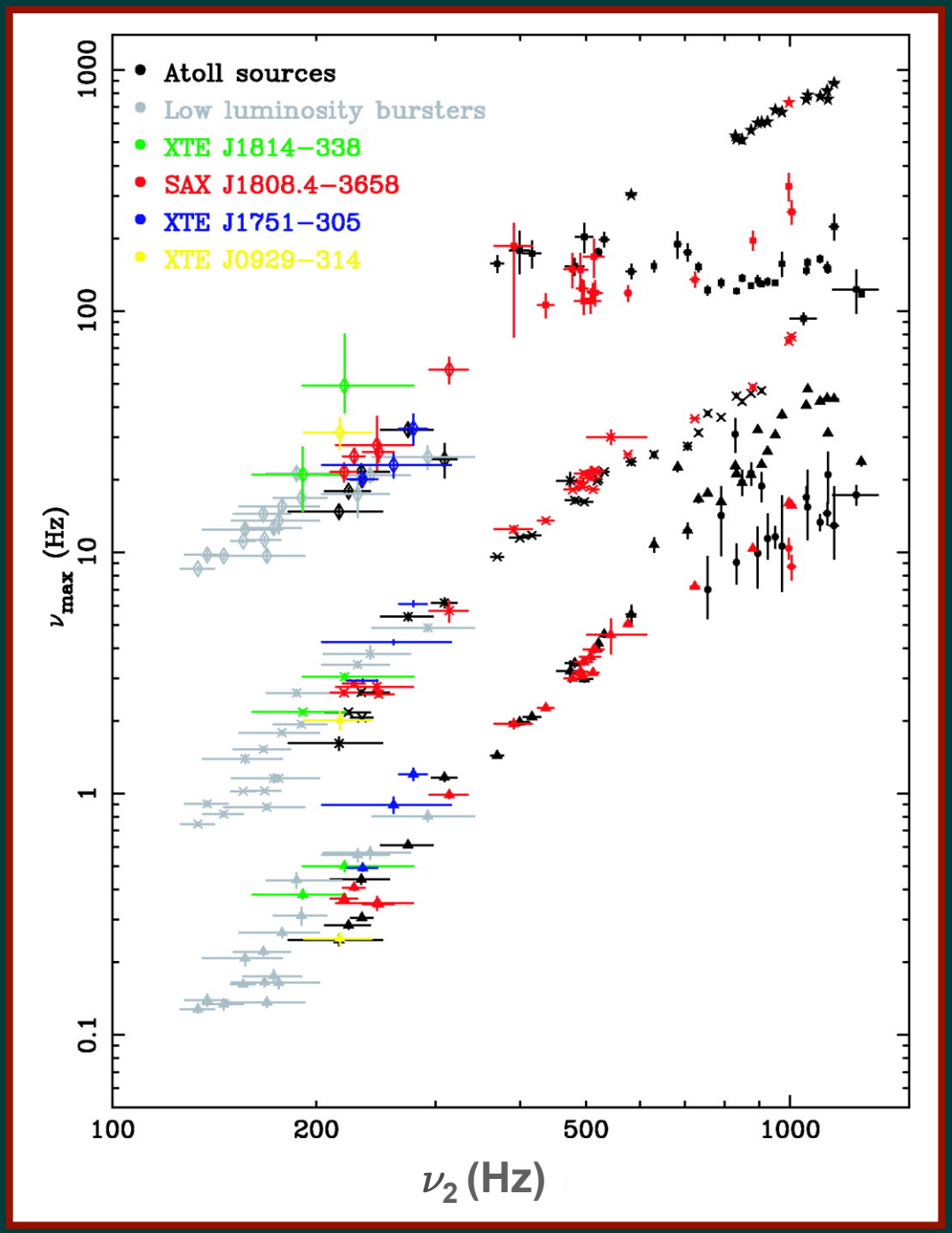

400
350
300
250
200
Δν (Hz)
200
300
400
500
600
ν_s (Hz)

Broad-band variability

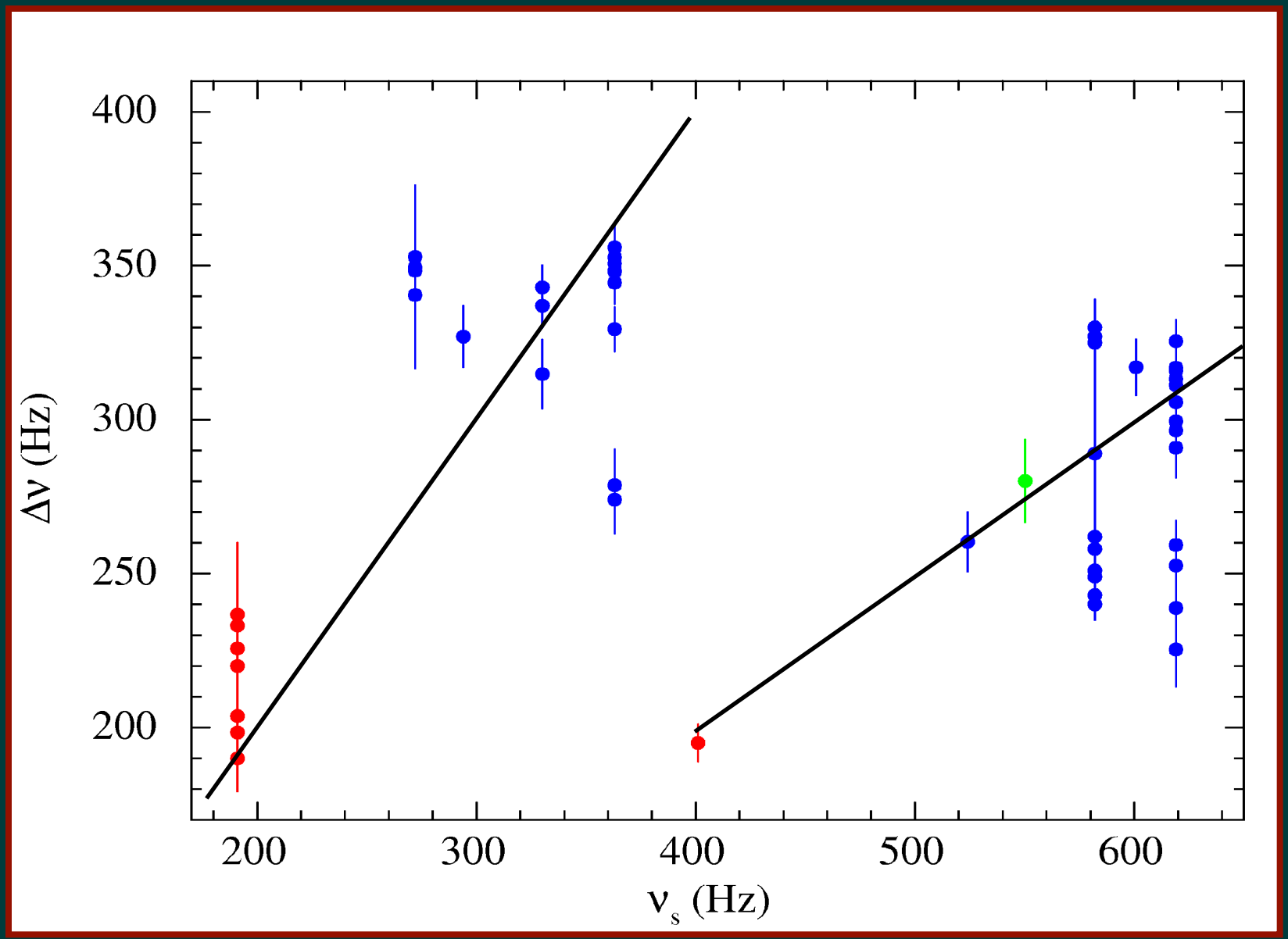




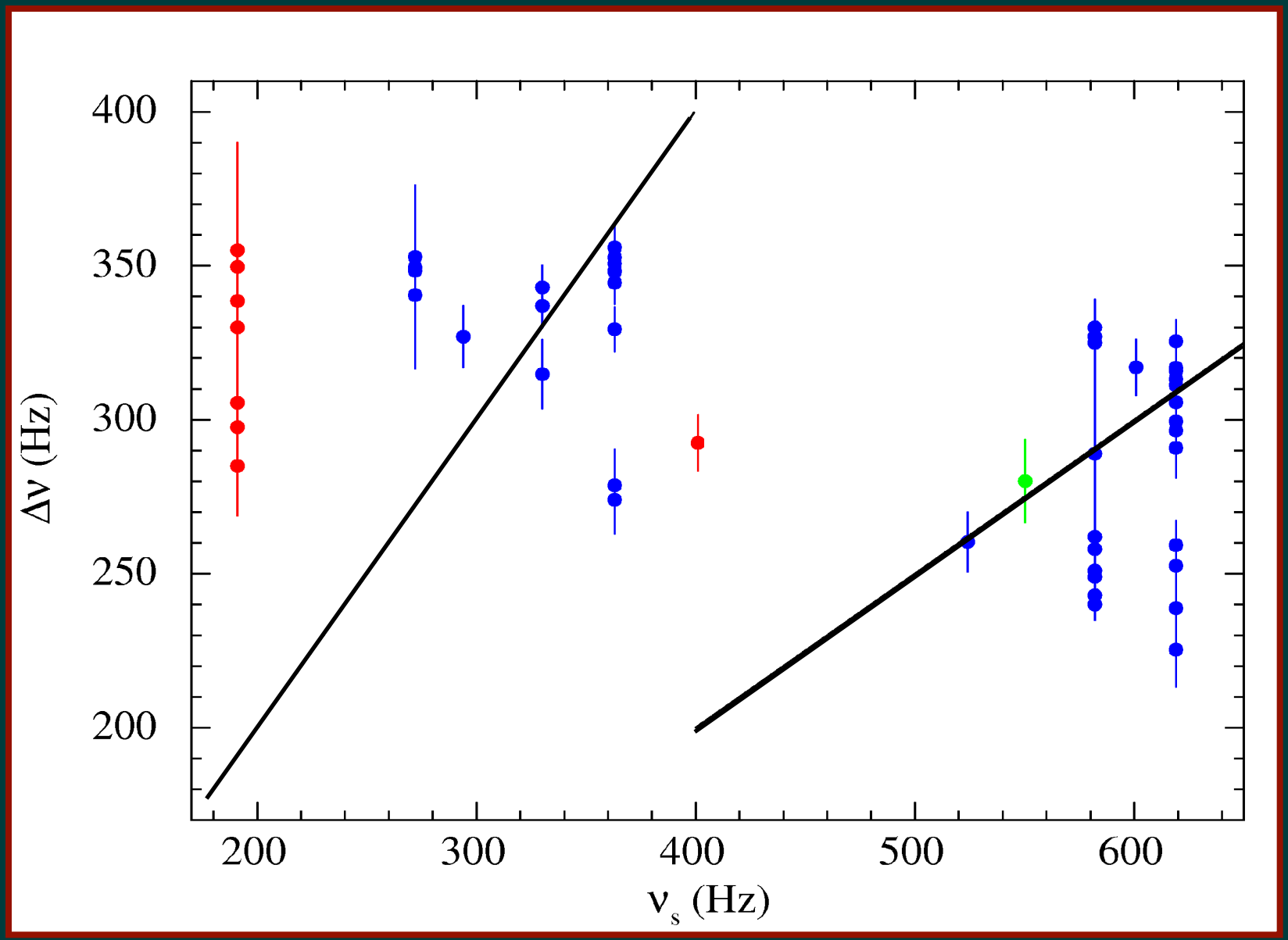
van Straaten et al.; Linares et al.; Altamirano et al.



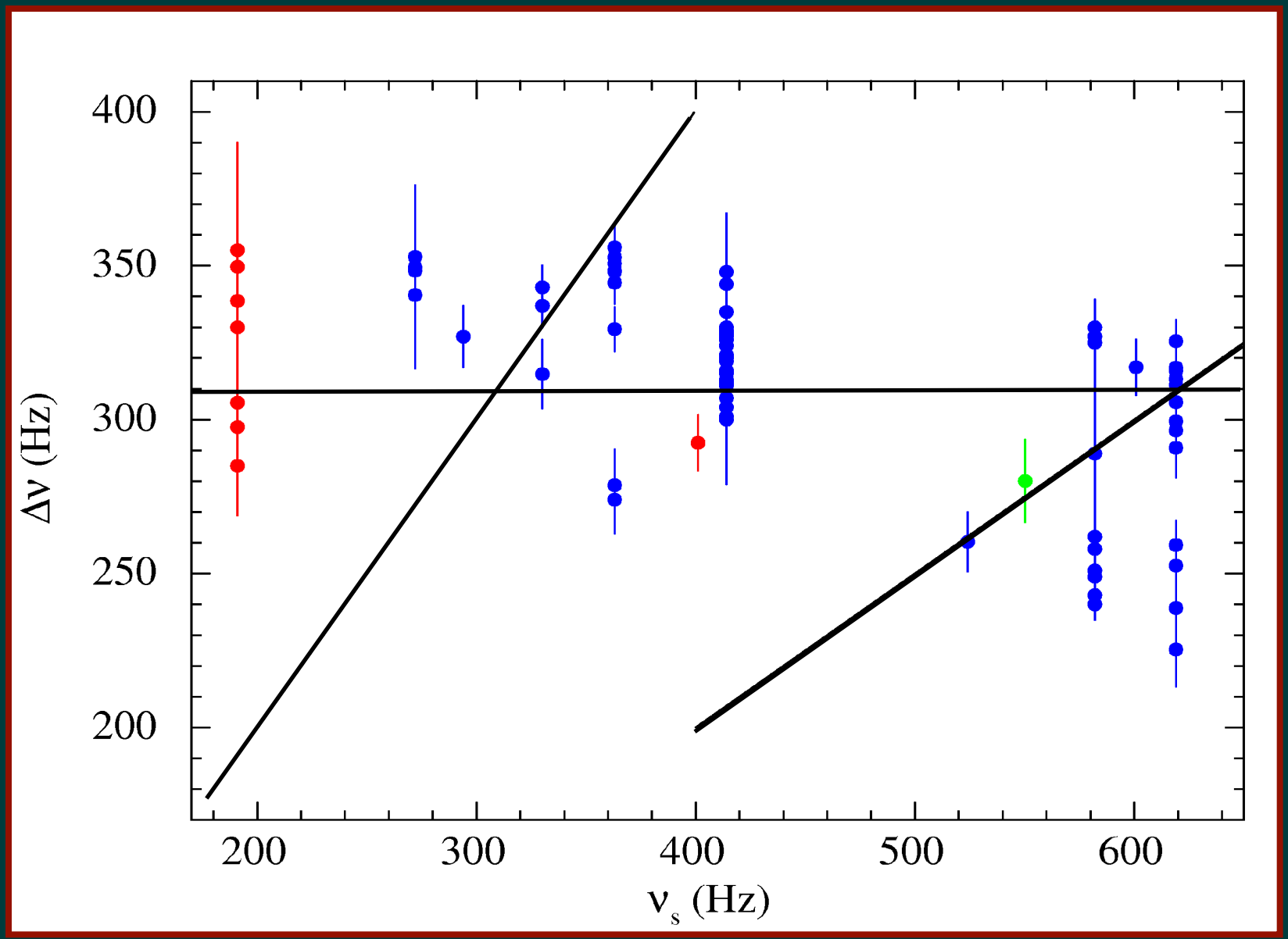
van Straaten et al.; Linares et al.; Altamirano et al.



Mendez & Belloni



Mendez & Belloni



Mendez & Belloni

Further progress: Models

– Move from epicyclic frequencies, test particles, and blobs in the disc, to full (M)HD simulations of the accretion disc in GR

– Not just QPO frequencies (dynamics), but also QPO amplitude (energetic) and coherence (lifetime)

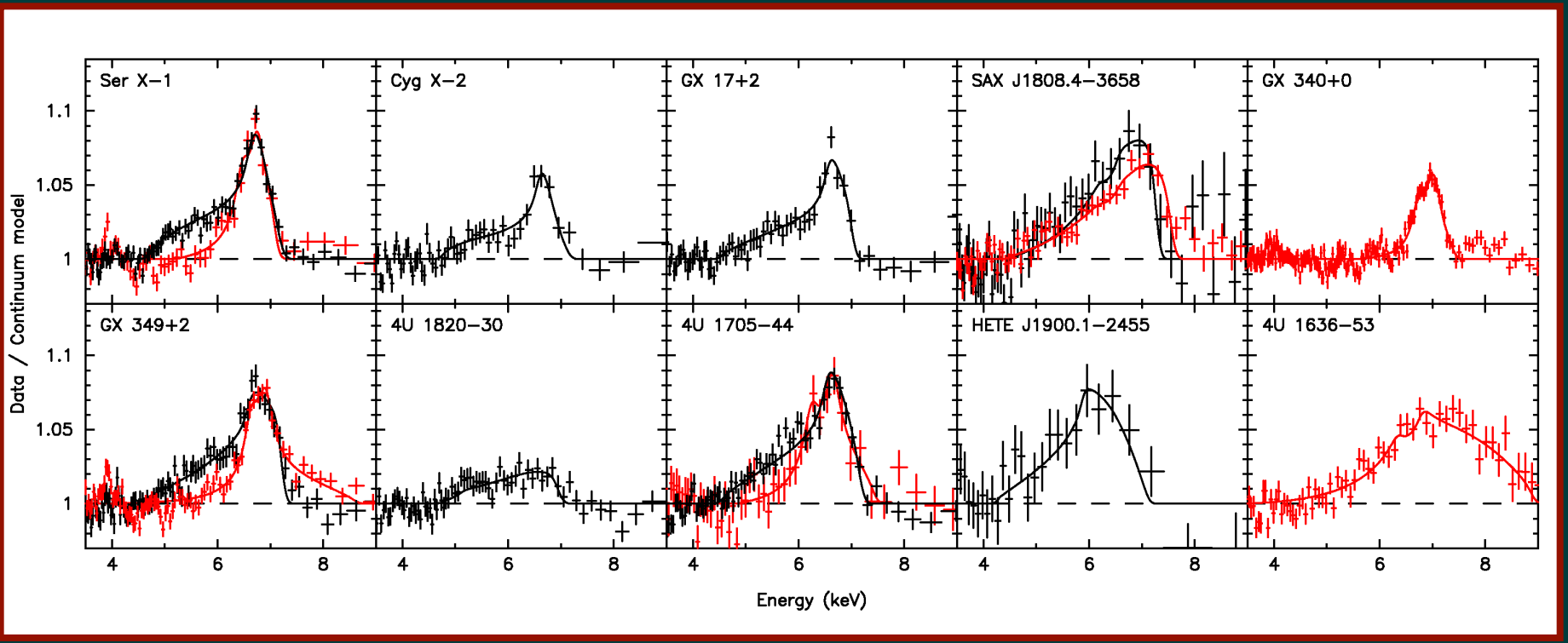
Further progress: Observations

– Find kHz QPOs in systems with spin that is either low, high, or in the gap (e.g., Ter 5, spin ~ 11 Hz)

– In one of the bright LMXBs with kHz QPOs find a spin that is either low, high or in the gap (e.g., 4U 0614+09 putative spin ~415 Hz)

ASTROSAT

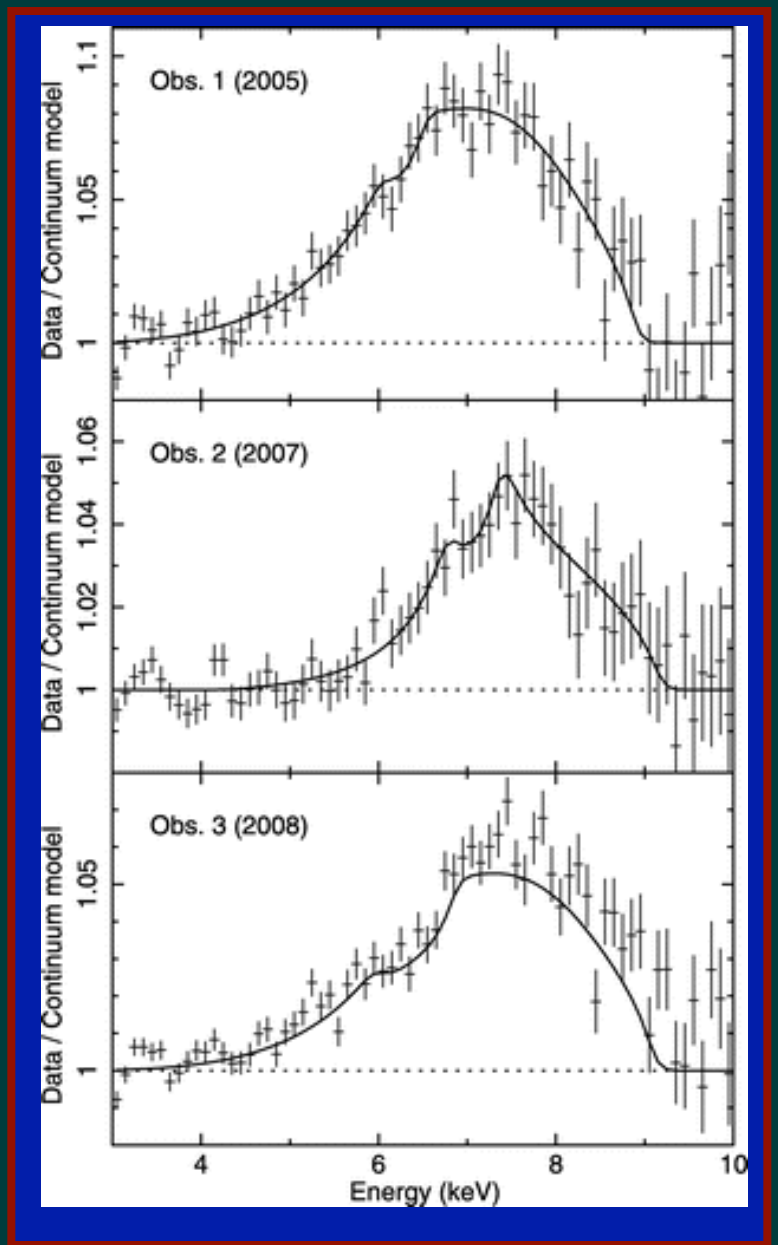
Fe line and kHz QPOs



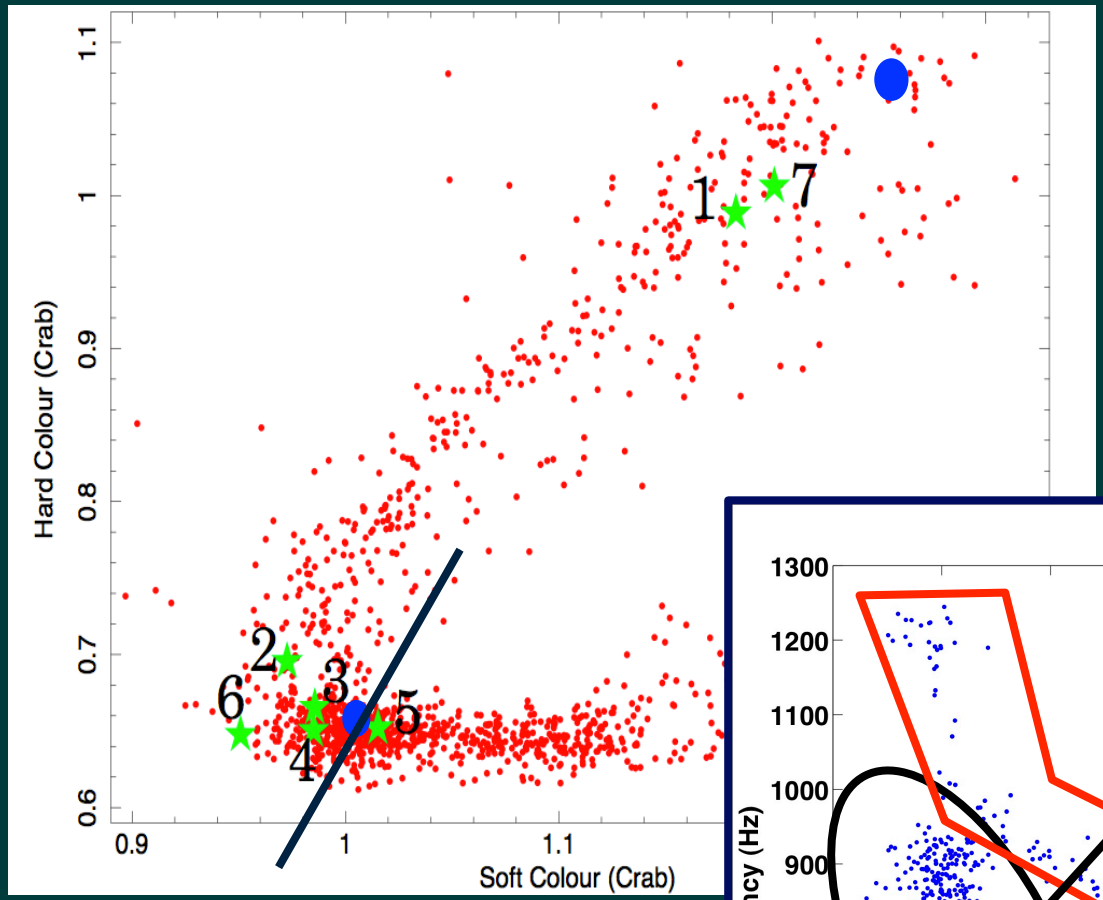
Compilation by Cackett et al.

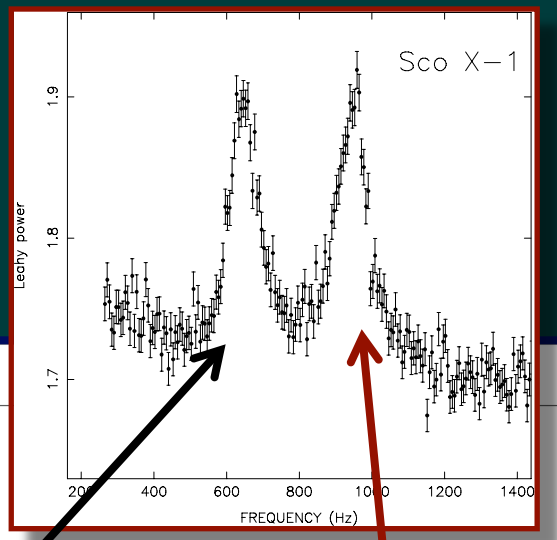
Fe line and kHz QPOs

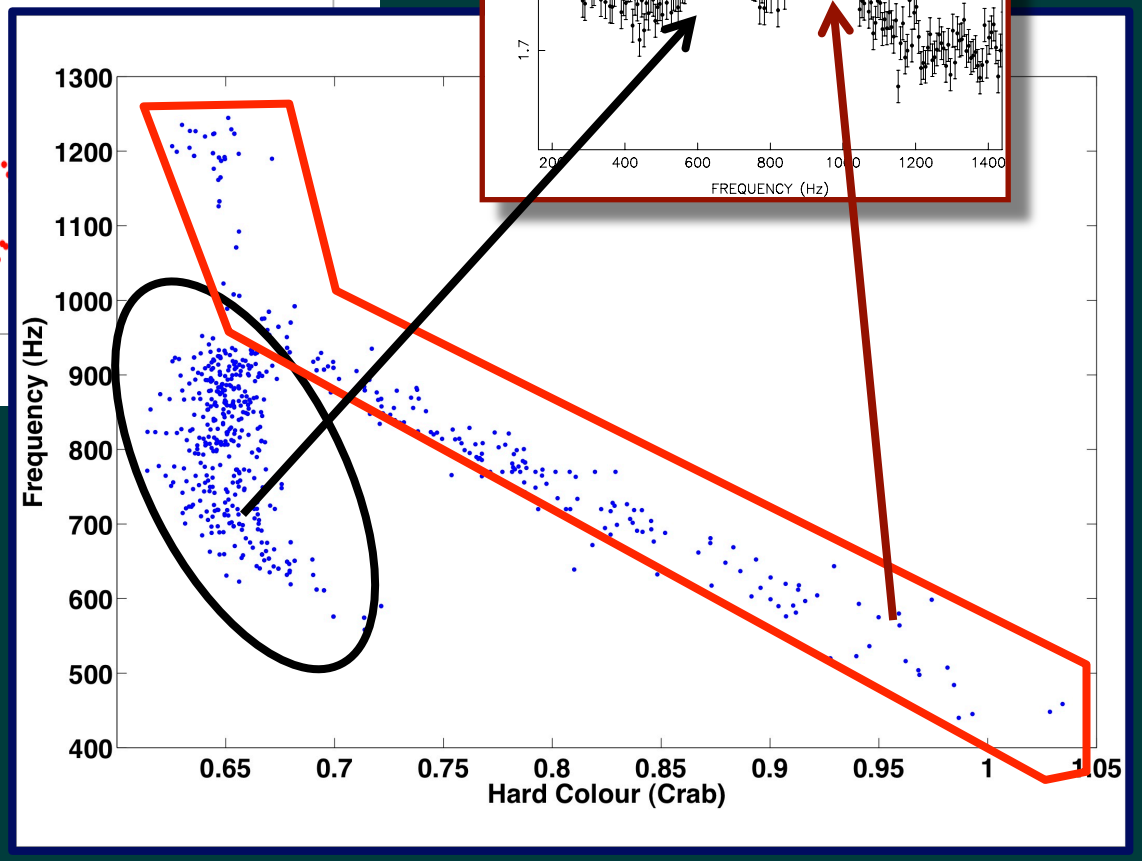
4U 1636-53



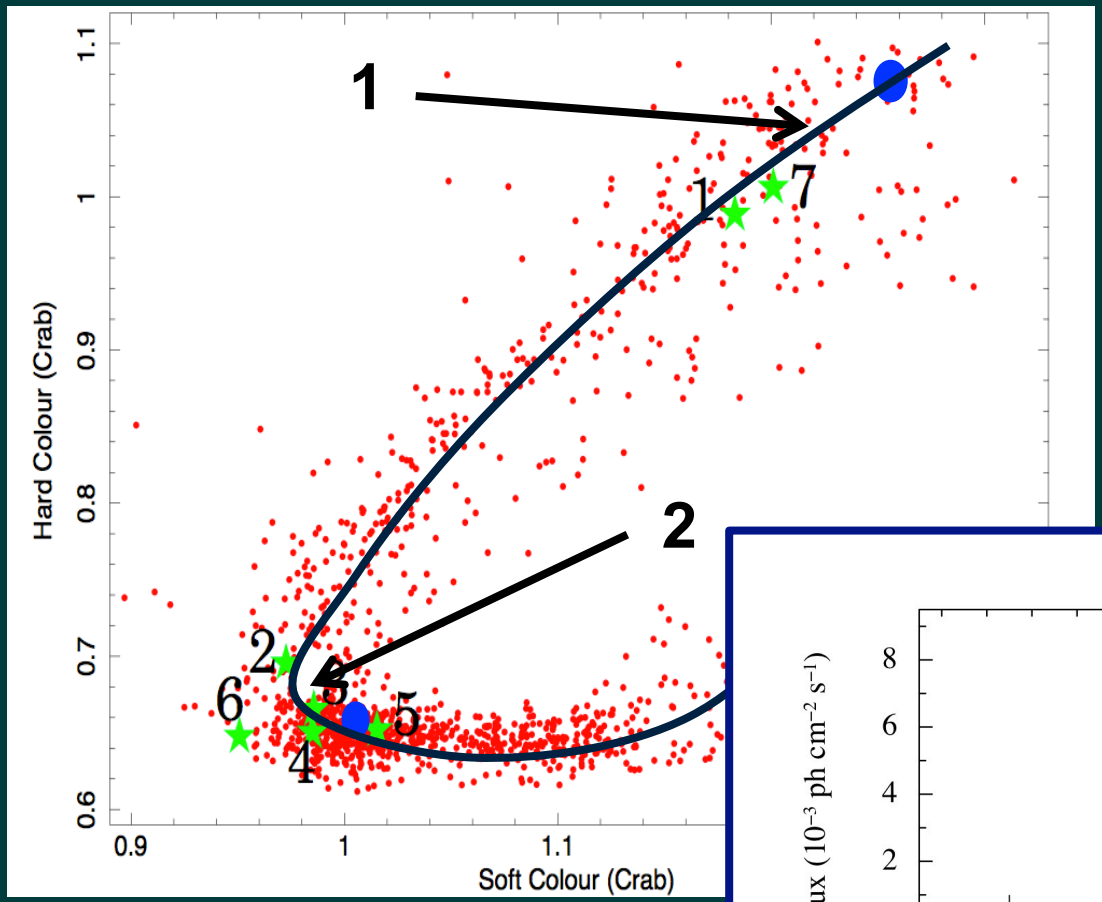
Pandel et al.

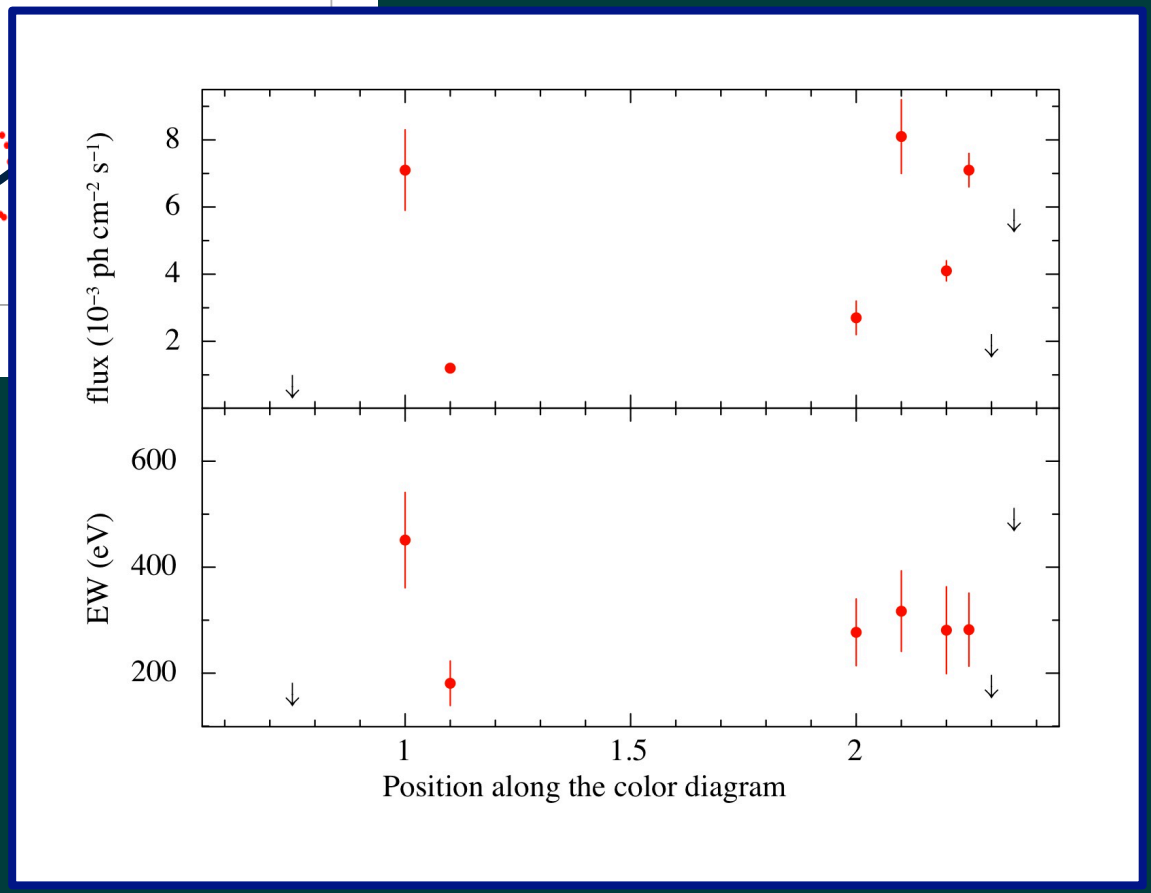






Sanna et al.; Hiemstra et al.



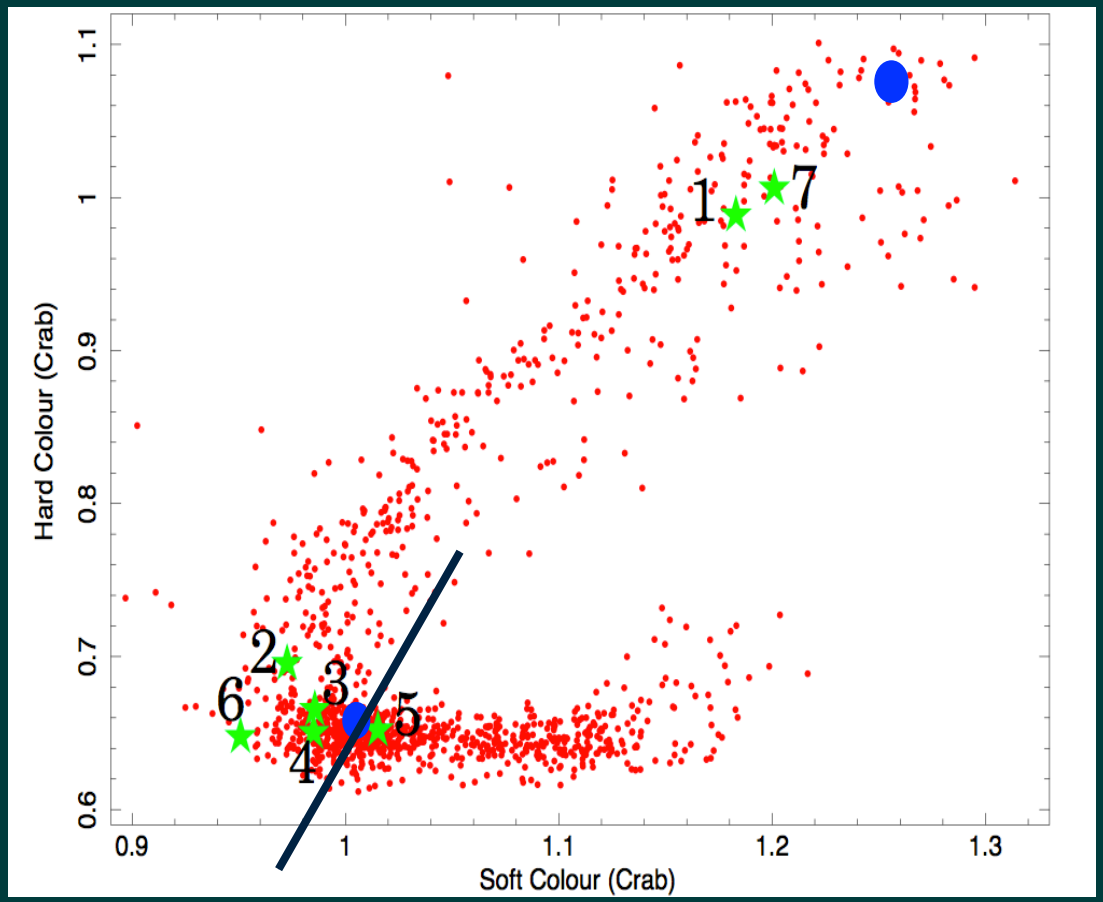


Sanna et al.; Hiemstra et al.

Perspective for ASTROSAT

– Extend detection of kHz QPOs to the softest part of the color diagram (inner disc radius is possibly the smallest)

– Simultaneous Fe line and kHz QPOs $\rightarrow$ ASTROSAT time frame should match lifetime of XMM-Newton / Suzaku.



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