QPOs from soft gamma repeaters

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Giant flares of Soft Gamma Repeaters (SGRs)

* Magnetars are neutron stars powered by their (usually very strong) magnetic field

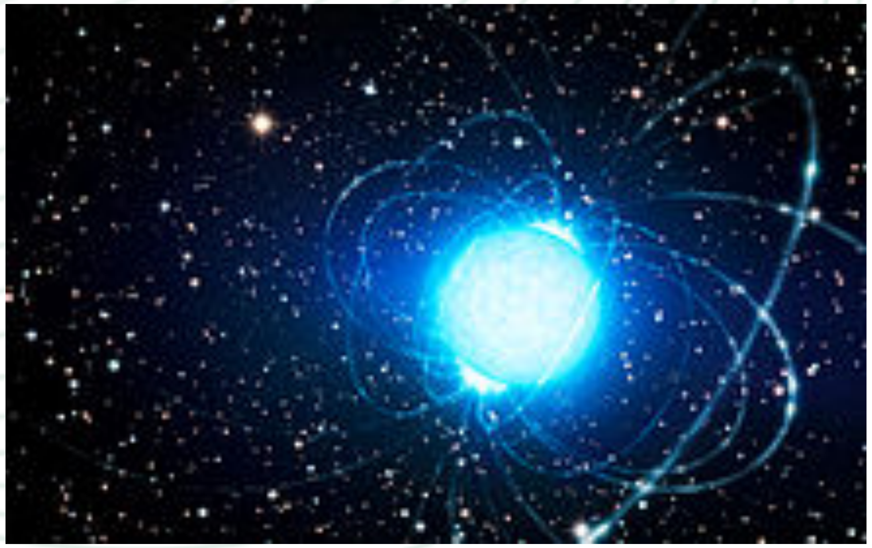
* Observations of SGRs seem to indicate that these objects are magnetars

* Only 3 giant flares have been observed so far:

  1979: SGR 0526-66 [Mazets et al, 1979; Barat et al, 1983]

  1998: SGR 1900+14 [Hurley et al, 1999]

  2004: SGR 1806-20 [Terasawa et al, 2005; Palmer et al, 2005]



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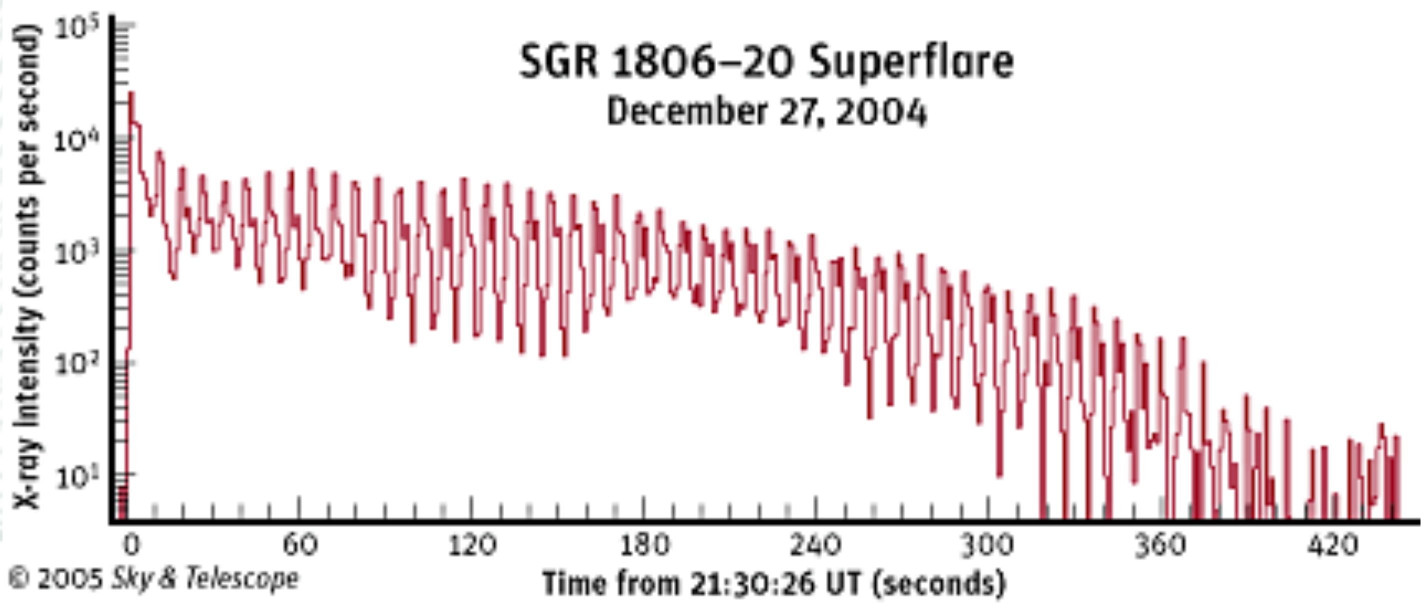
Observed Quasi-periodic Oscillations (QPOs)

* SGR 0526-66: 43.5 Hz
  [Barat et al, 1983]
* SGR 1900+14: 28, 54, 84 and 155 Hz
  [Strohmayer & Watts, 2005]
* SGR 1806-20: 18, 26, 29, 92.5, 150, 625.5 and 1837 Hz
  [Israel et al, 2005; Watts & Strohmayer, 2006; Strohmayer & Watts, 2006]

  16.9, 21.4, 36.4, 59.0, 116.3 Hz
  [Hambarayan, Neuhäuser & Kokkotas, 2011]
* Analysis of intermediate flares
  [Huppenkothen, 2014]



Possible interpretations for the QPOs

(not a comprehensive review!)

* torsional (axial) modes of the crust were a first possible explanation [Duncan, 1998]

Mode identification depends on details of modeling:

Maybe we can solve the inverse problem and learn about the EOS!

SGR 1806-20	SGR 1900+14	Torsional shear mode identification
18*		
26*		
30*	28	$n=0,\ l=2$
	53	$n=0,\ l=4$
92*	84	$n=0,\ l=6$
150		$n=0,\ l=10$
	155	$n=0,\ l=11$
625*		$n=1$
1840		$n=3$

[Watts & Strohmayer, 2007

(why are only some of the modes excited...?)

SGR 1806−20		SGR 1900+14	
f (Hz)	Mode	f (Hz)	Mode
29	$_0t_2$	28 ± 0.5	$_0t_2$
92.7 ± 0.1	$_0t_6$	53.5 ± 0.5	$_0t_4$
150.3	$_0t_{10}$	84	$_0t_6$
626.46 ± 0.02	$_1t_l$	155.1 ± 0.2	$_0t_{11}$

[Samuelsson & Andersson, 2007

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Possible interpretations for the QPOs

(not a comprehensive review!)

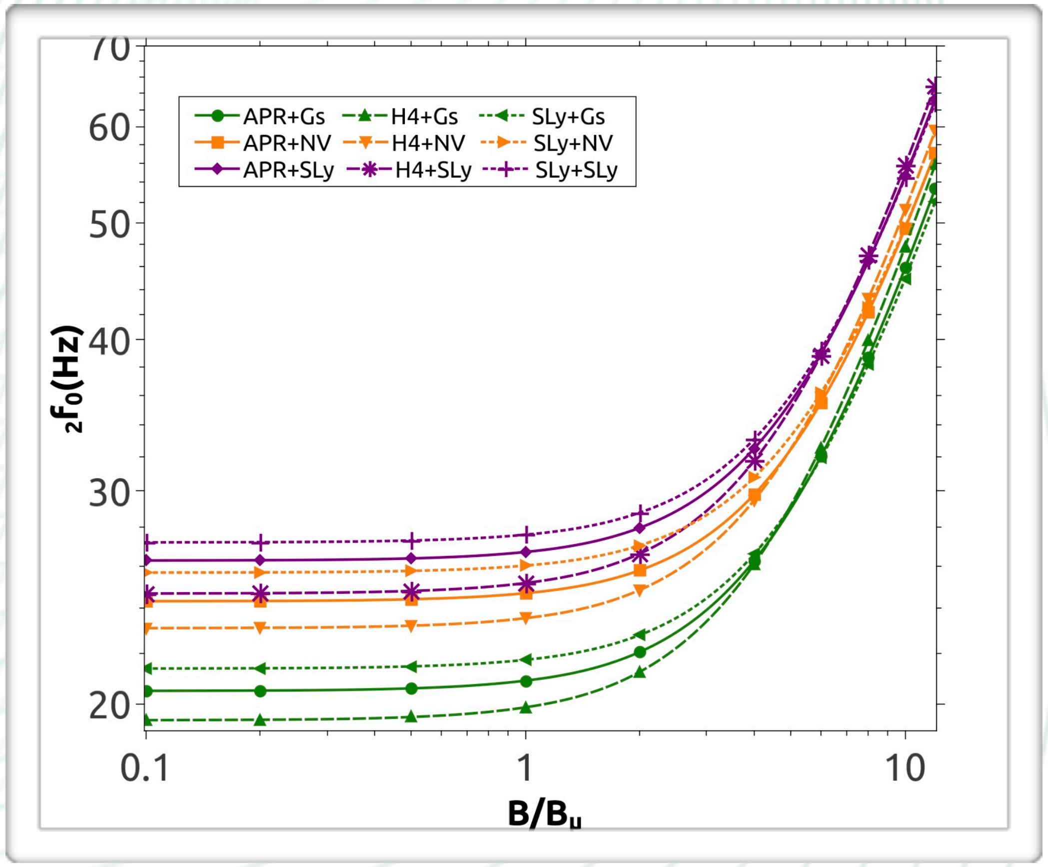
- Magnetic fields should not be neglected in the analysis! But then things get a lot more complicated...

- First, the mode frequencies change as

$$\frac{f}{f^{(0)}} \approx \left[1 + {}_2\alpha_0 \left(\frac{B}{B_\mu}\right)^2\right]^{1/2}$$

with fixed M and $B_\mu = 4 \times 10^{15}$ G

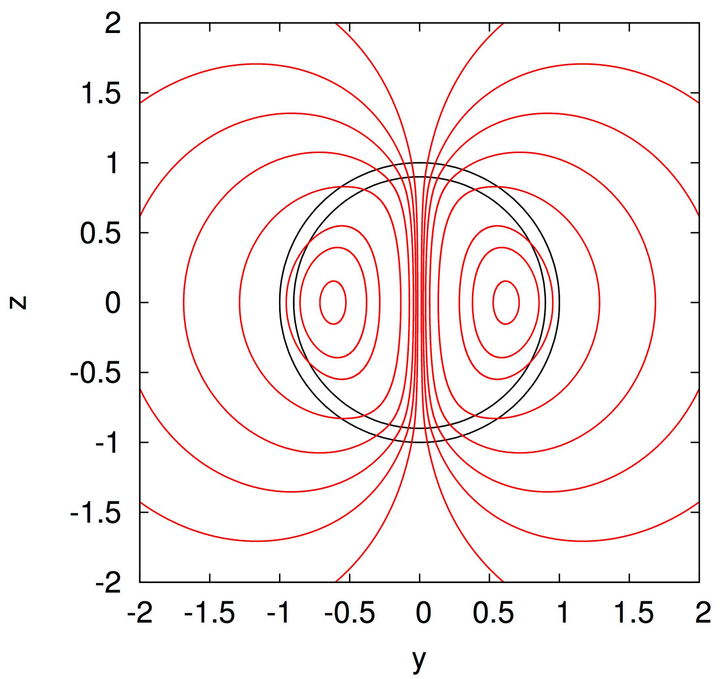
[Sotani, Kokkotas & Stergioulas, 2007]



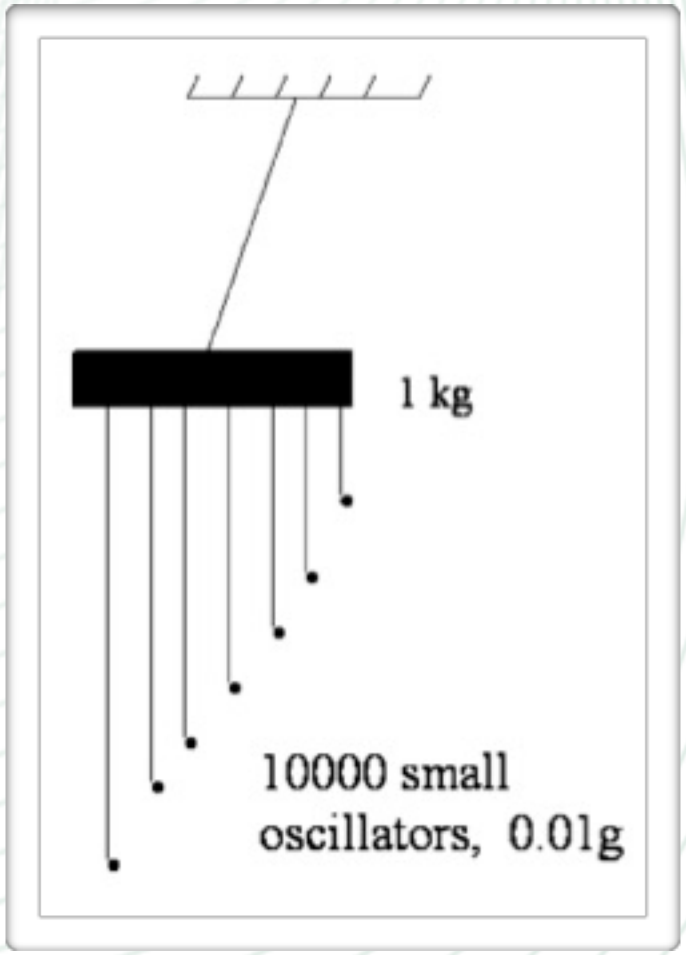
[de Souza & Chirenti, 2018]

- But it also leads to a qualitatively different picture...

Mode coupling and damping



Toy model



[Levin, 2007]

* Normal modes of the crust are quickly damped by the coupling with the MHD continuum of modes in the core [Levin, 2006]

Long term oscillation is driven by the edges of the continuum

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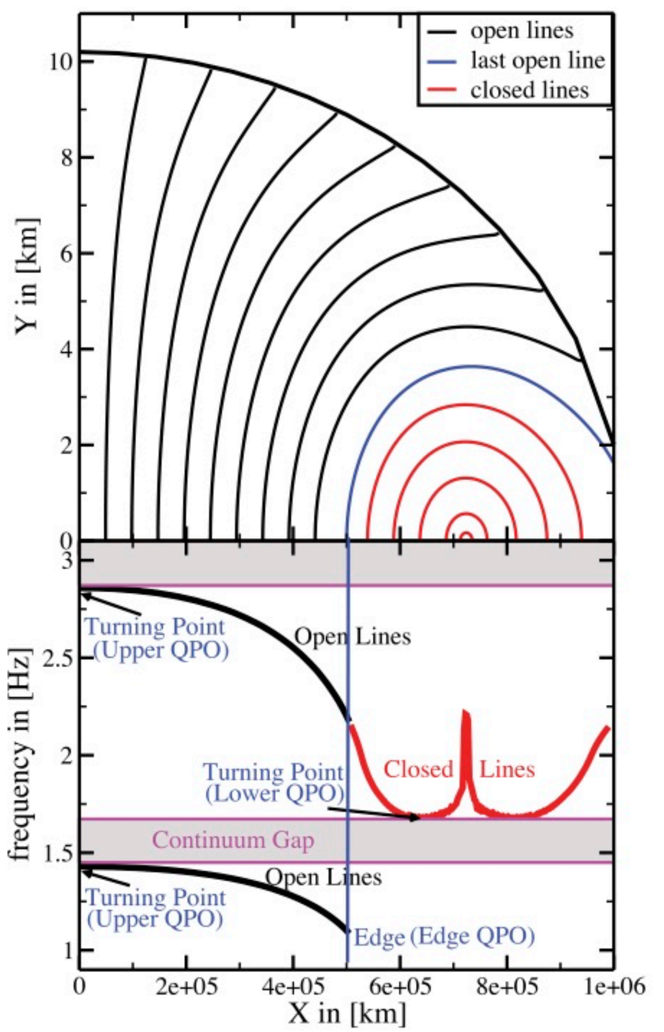
Possible interpretations for the QPOs

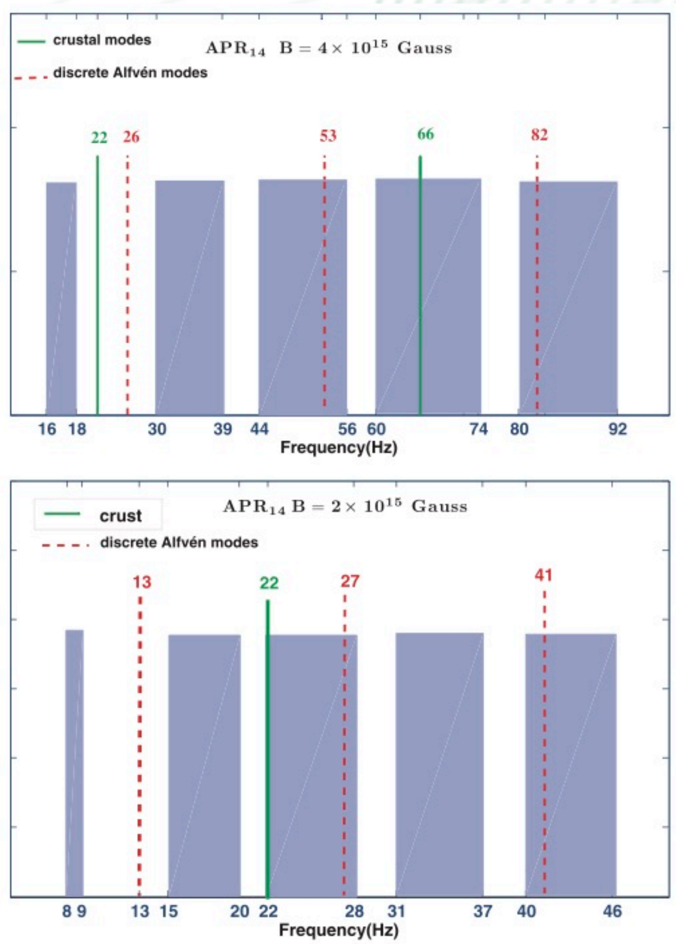
(not a comprehensive review!)

SUMMARY: it's complicated…

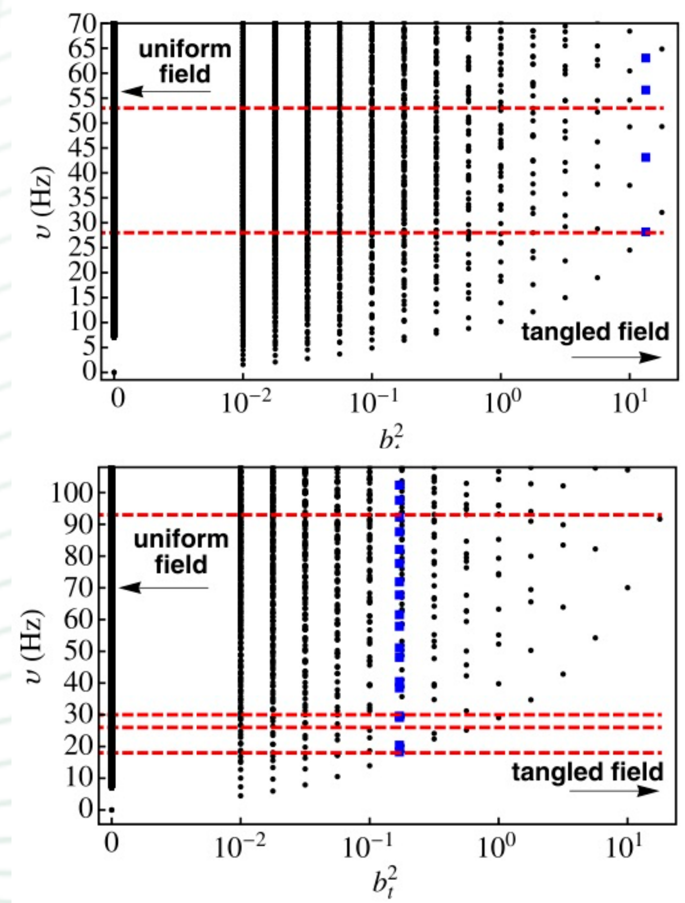
- global modes were also considered, but they have a continuous spectrum and would also be damped quickly {van Hoven & Levin 2012}
- gaps in the continuum can make the oscillations longer lived; the continuum may be further broken by the coupling of axial and polar modes, and also by other magnetic field geometries



[Gabler et al., 2012]



[Colaiuda & Kokkotas, 2012]



[Link & van Eisden, 2016]

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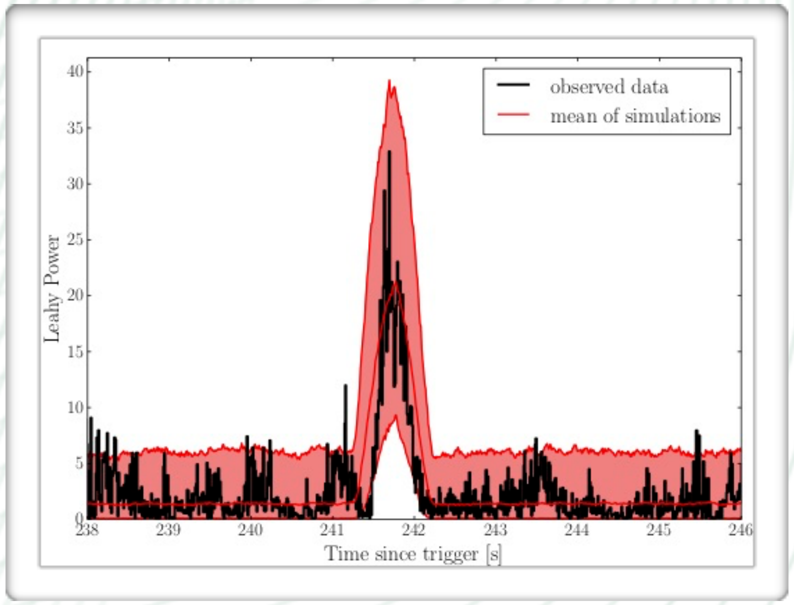
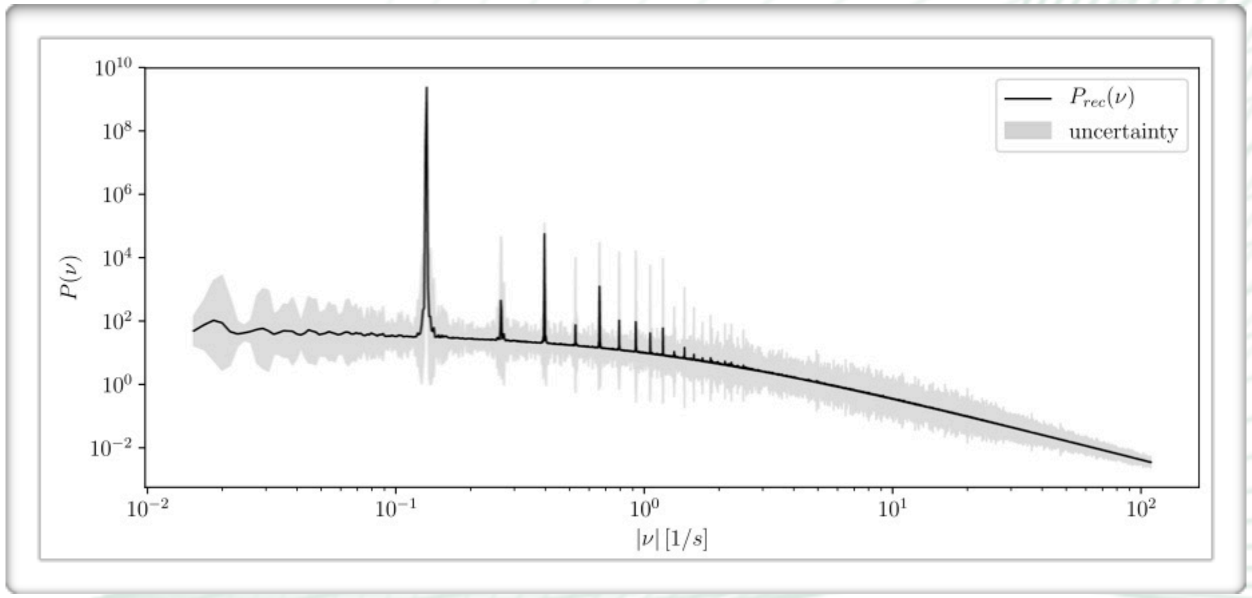
Recent re-analyses of the data

Maybe we should take another look at the data...

Huppenkothen et al. 2014
found that the 625 Hz QPO of
SGR 1806-20 was present during
only about 0.5 s during the entire signal



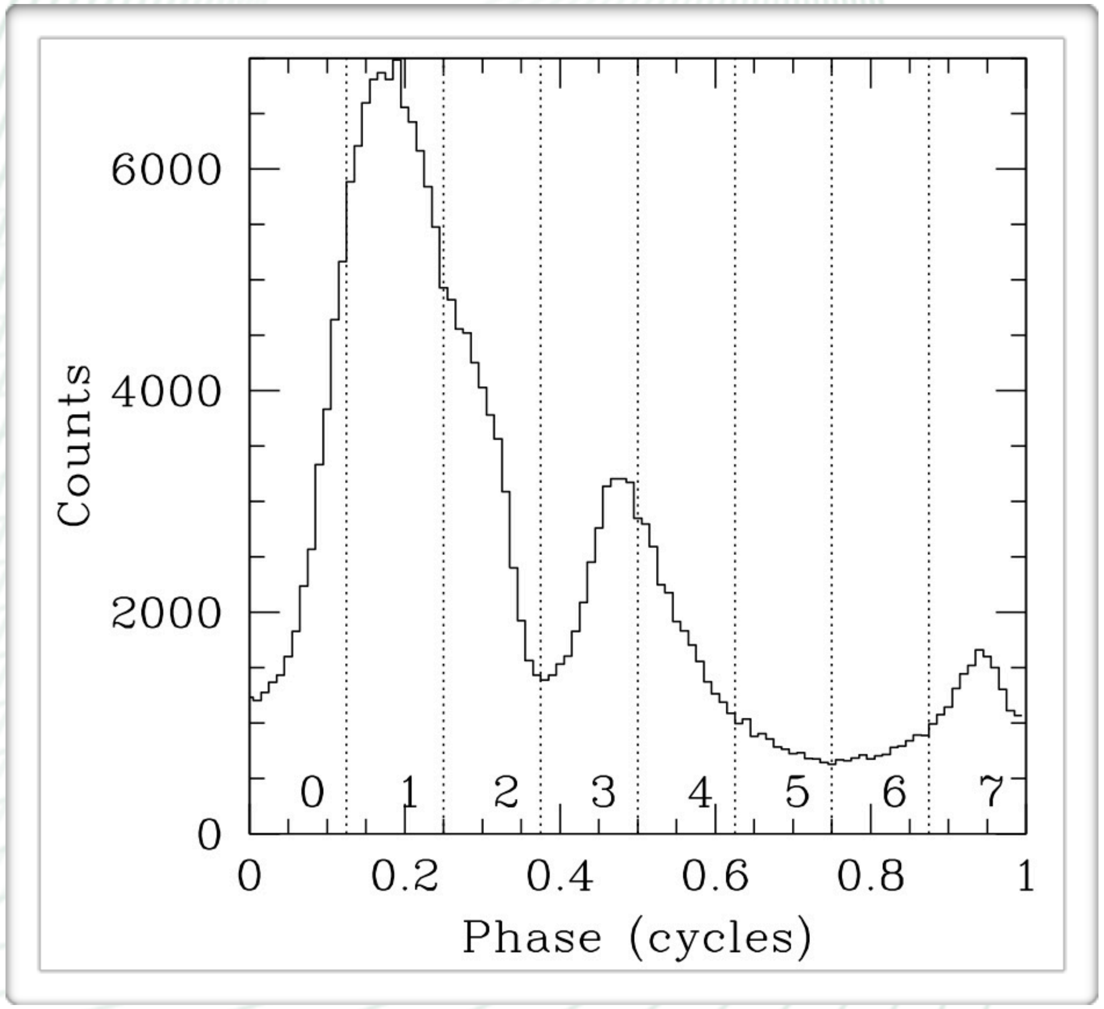


Pumpe et al. 2018 reanalyzed
the entire signal and found no
frequencies larger than 17 Hz...

Our Statistical method

SGR 1806-20 Data

* Rotational period is 7.56 s
* 1/8 of a period is 0.945 s
* We divide data into segments that start every 0.945 s and are 1 s long (368 segments)



Bayesian analysis

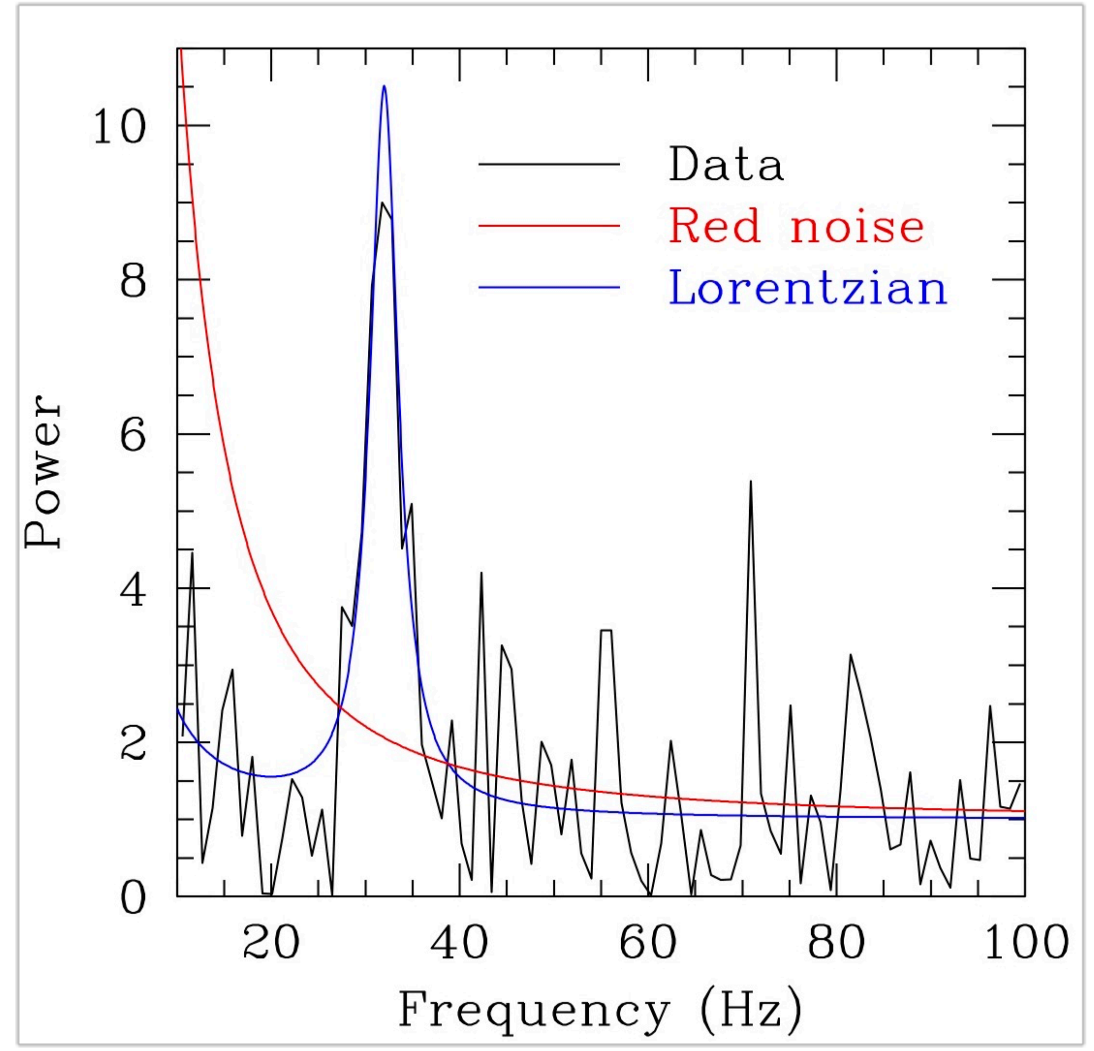
* Bayesian search for QPOs compares 2 models for the Fourier transform of each segment:

1. Red noise model

$$P_{\rm red}(f) = A(f/15\,{\rm Hz})^{-2}$$

2. Lorentzian model

$$P_{\rm Lorentz}(f) = B(f/15\,{\rm Hz})^{-2} + \frac{C}{(\Delta f)^2 + (f - f_0)^2}$$



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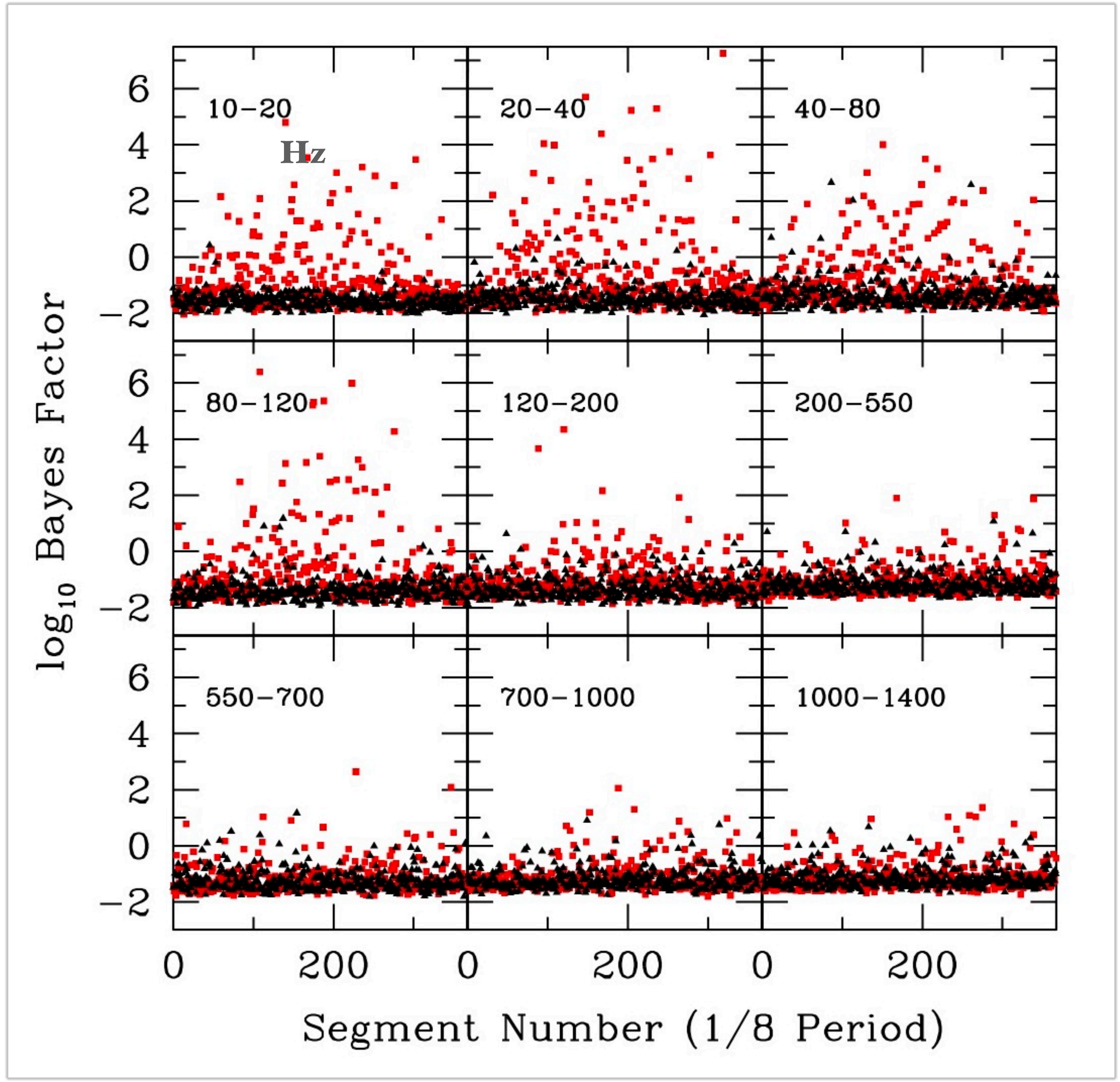
Results: general characteristics

* Black: synthetic data (no signal, noise only)

* Red: real data

* Lots of real signals, consistent with previous analyses and 3 **new** frequencies:
51.5, 97.6 and 156.6 Hz

* Almost no signals in consecutive segments!



[Miller, Chirenti & Strohmayer, 2019]

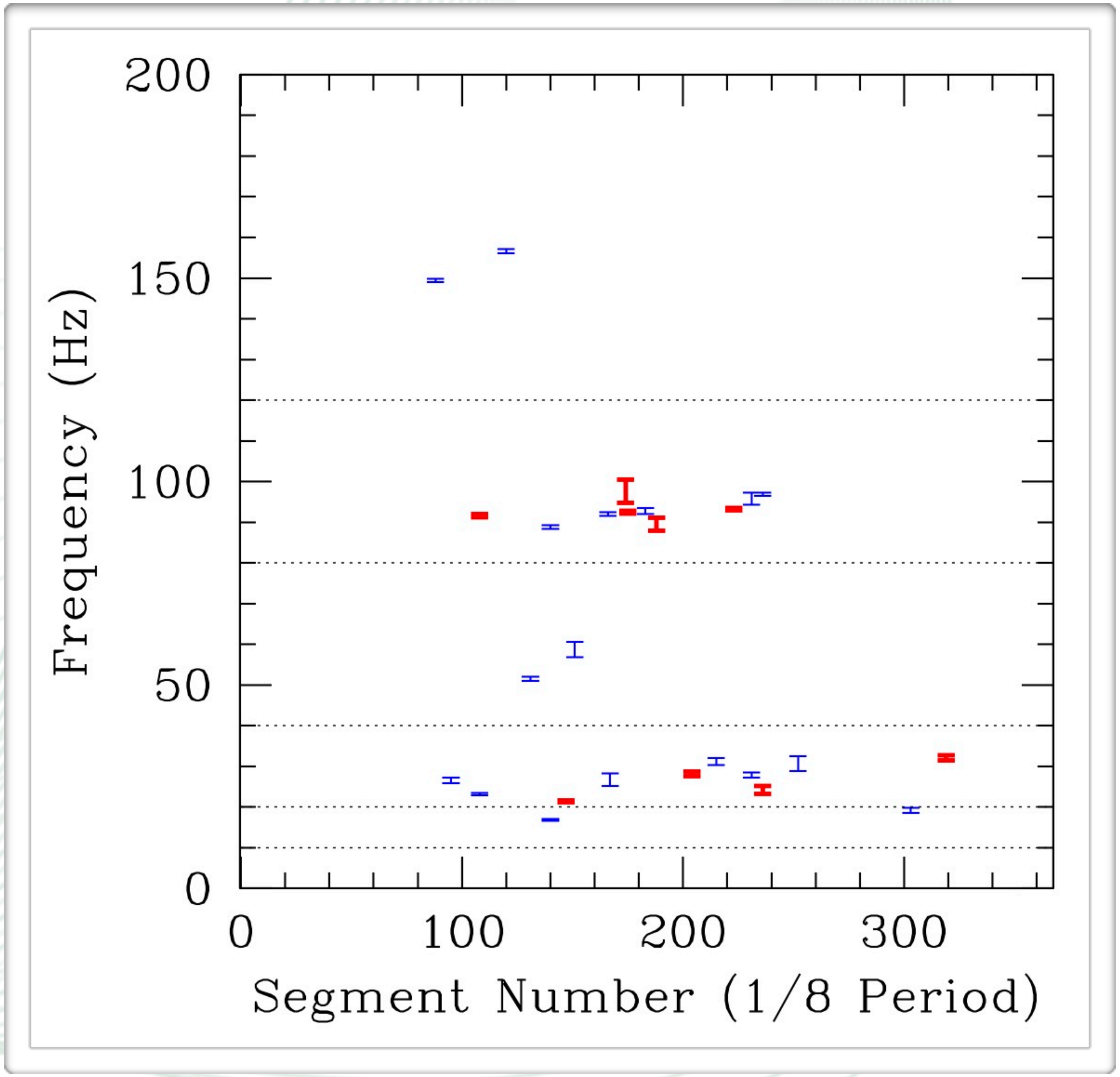
Results: persistent signals?

Blue $10^3 <$ Bayes Factor $< 10^5$

Red $10^5 <$ Bayes Factor

* **No evidence** for long lasting signals or trends in frequency evolution

* **Repeated excitations** followed by quick damping?



[Miller, Chirenti & Strohmayer, 2019]

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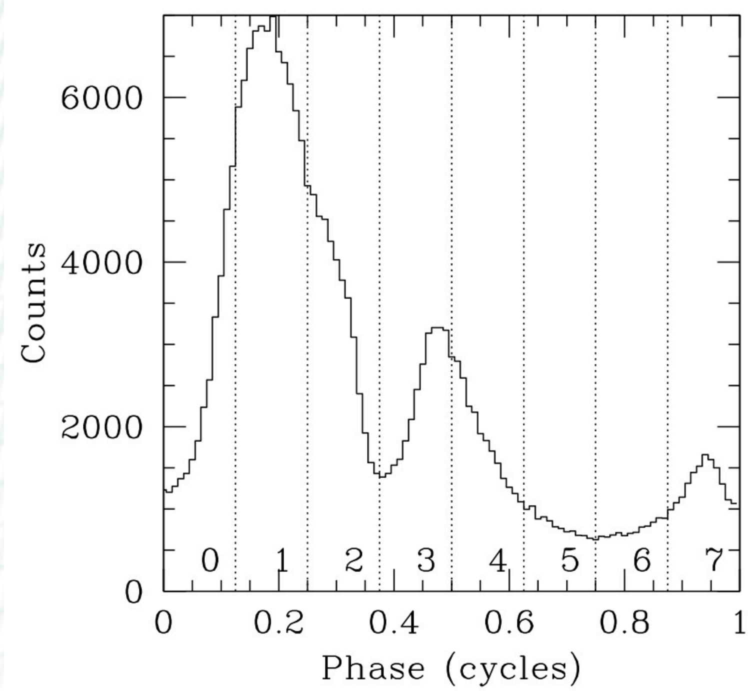
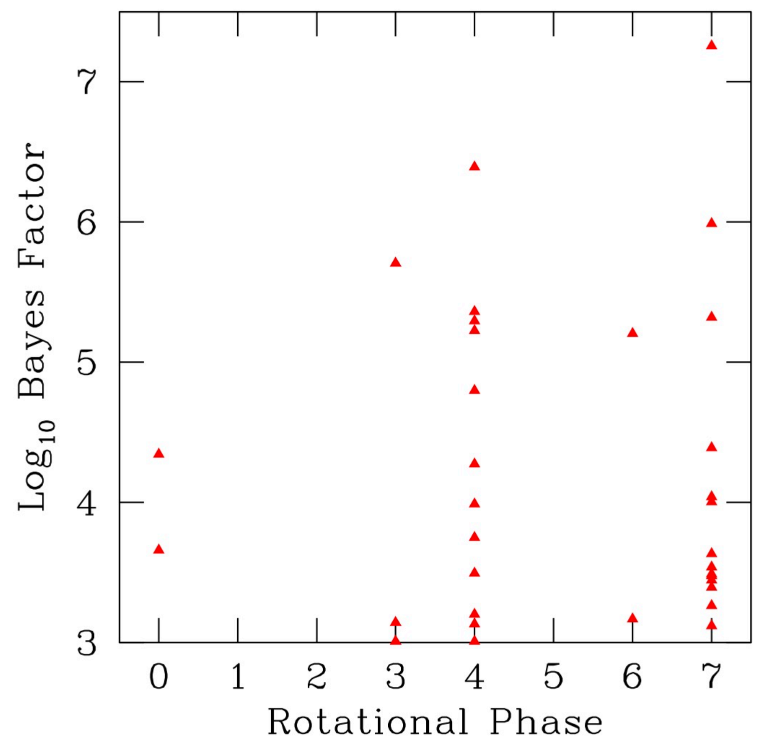
Physical mechanism?

* Obvious (but different!) rotational phase dependence

* Why? Why?! WHY?!?

* Either the crust or the magnetosphere at those phases is particularly prone to the generation of the QPOS that we see





[Miller, Chirenti & Strohmayer, 2019]

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Open questions

* what drives the giant flare?

  possible rearrangement of the magnetic field + starquake

* as the magnetic field evolves, how do the QPOs depend on the magnetic field geometry?

* what can we learn about

  the flare mechanism?

  the properties of the star?

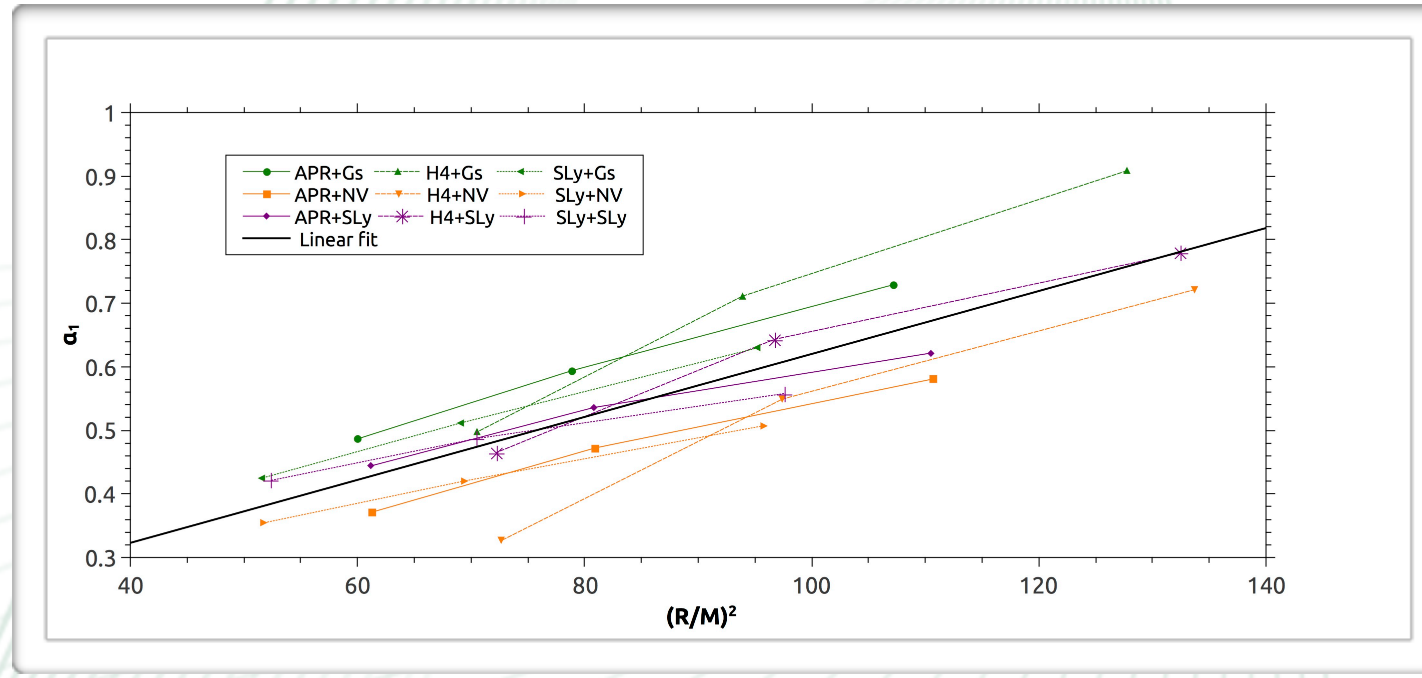
  (possible) trends in the observed frequencies?

Towards universal relations for the torsional modes of the crust

$$\frac{f}{f^{(0)}} \approx \left[1 + {}_2\alpha_0 \left(\frac{B}{B_\mu}\right)^2\right]^{1/2}$$

dependency on compactness and magnetic field geometry:

$${}_2\alpha_0 = \alpha_1 \left(1 + \alpha_2 \zeta^2\right)$$



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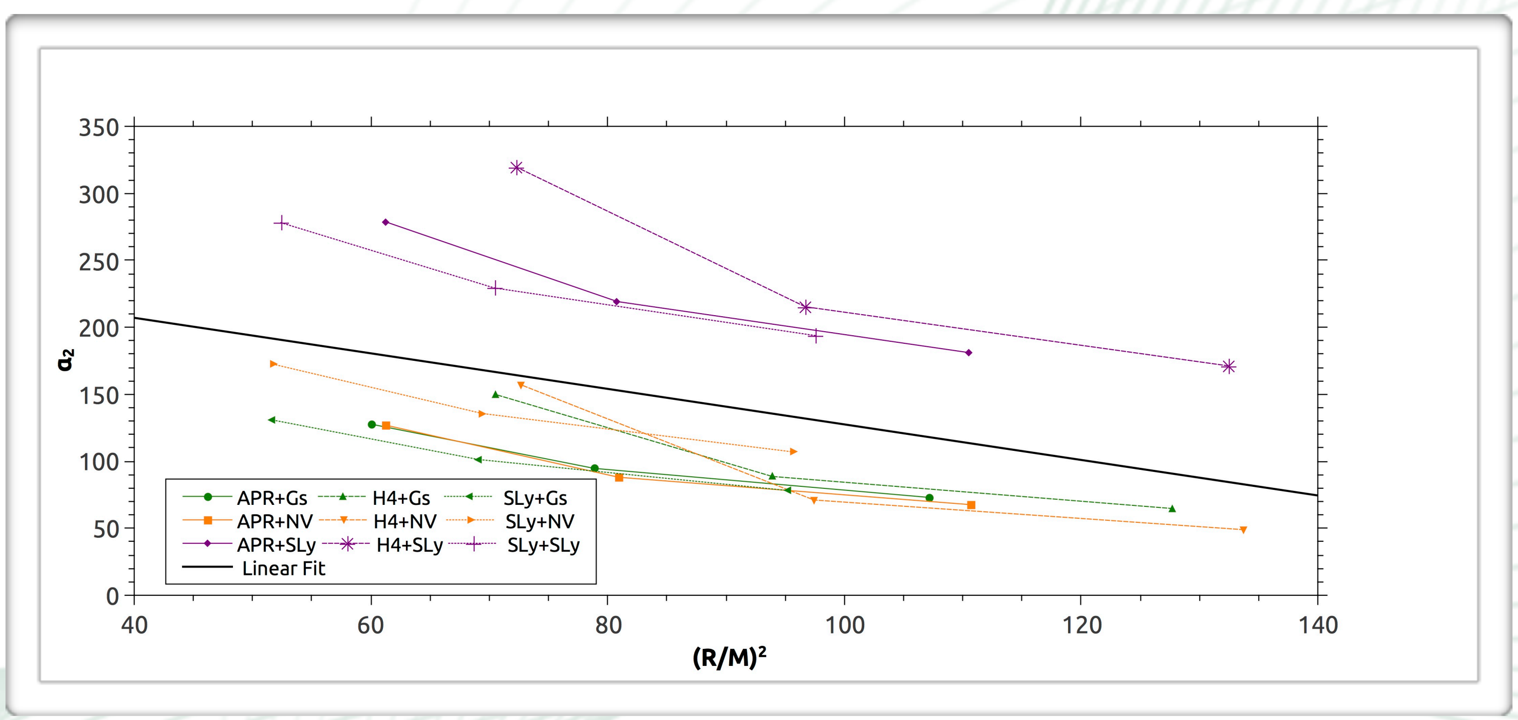

For a purely dipolar field

$${}_2\alpha_0 = \alpha_1$$

α_2 is the correction due to the toroidal component

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Conclusions and Final Remarks

* We performed a re-analysis of the data from giant flare of SGR 1806-20
* Frequencies found are consistent with previous analyses
* No persistent signals were found!
* Results consistent with fast damping of (torsional?) modes (due to coupling to the MHD continuum?) and repeated excitations (crustal healing and breaking?)
* Torsional frequencies depend on mass, EOS, crust, magnetic field strength and geometry. Solving the inverse problem will be really hard, but there is hope with progress towards universal relations!

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