Magnetar Seismology: linking physical motion to observational effects

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Magnetars

- ~20 isolated neutron stars (NS) with
  - Slow spin periods (2-12s)
  - Rapid spin-down
  - Regular gamma-ray bursts (Soft Gamma Repeaters, SGRs)
- Some located in supernova remnants
- Young neutron stars with ultra-strong magnetic fields

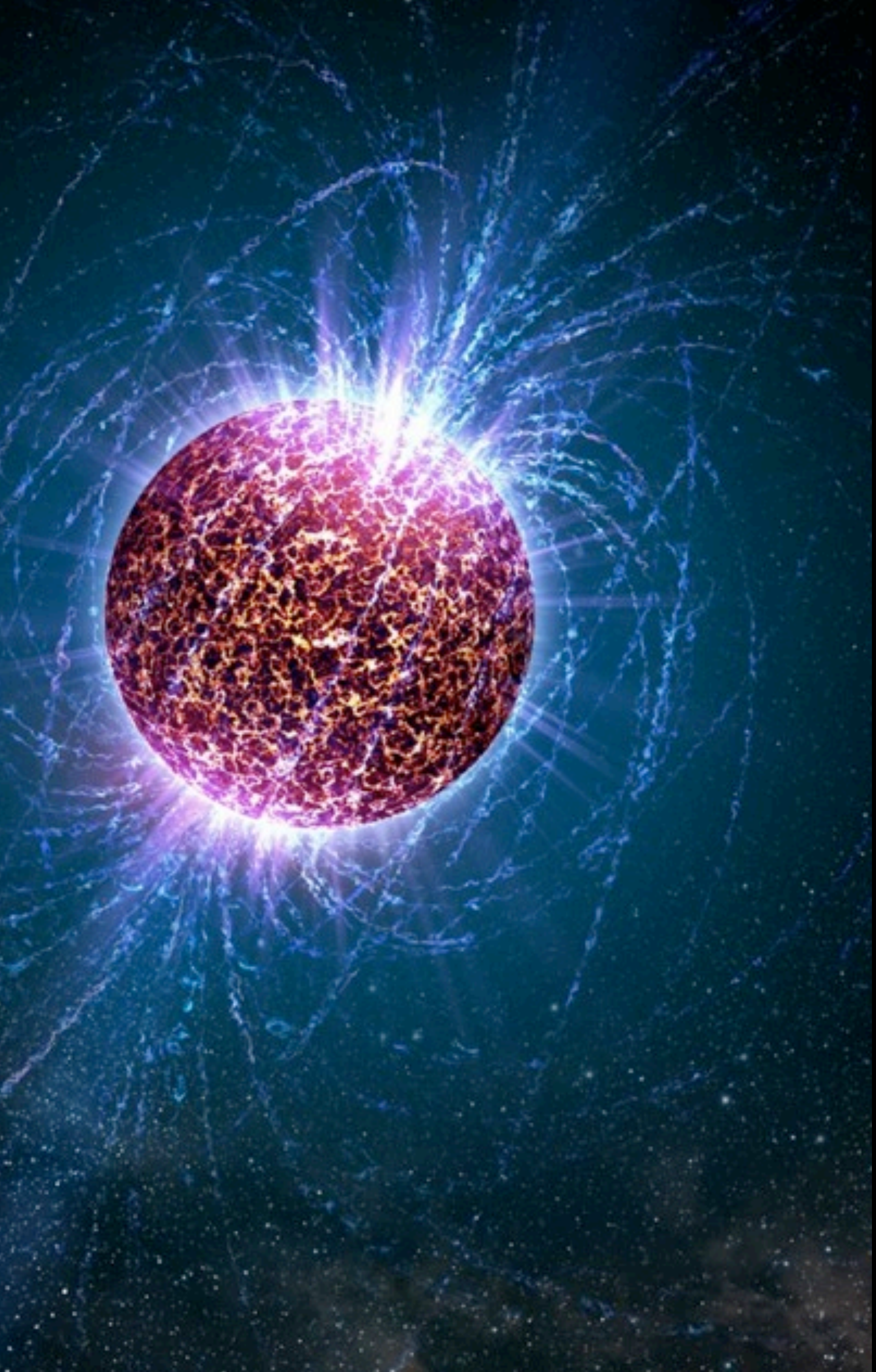
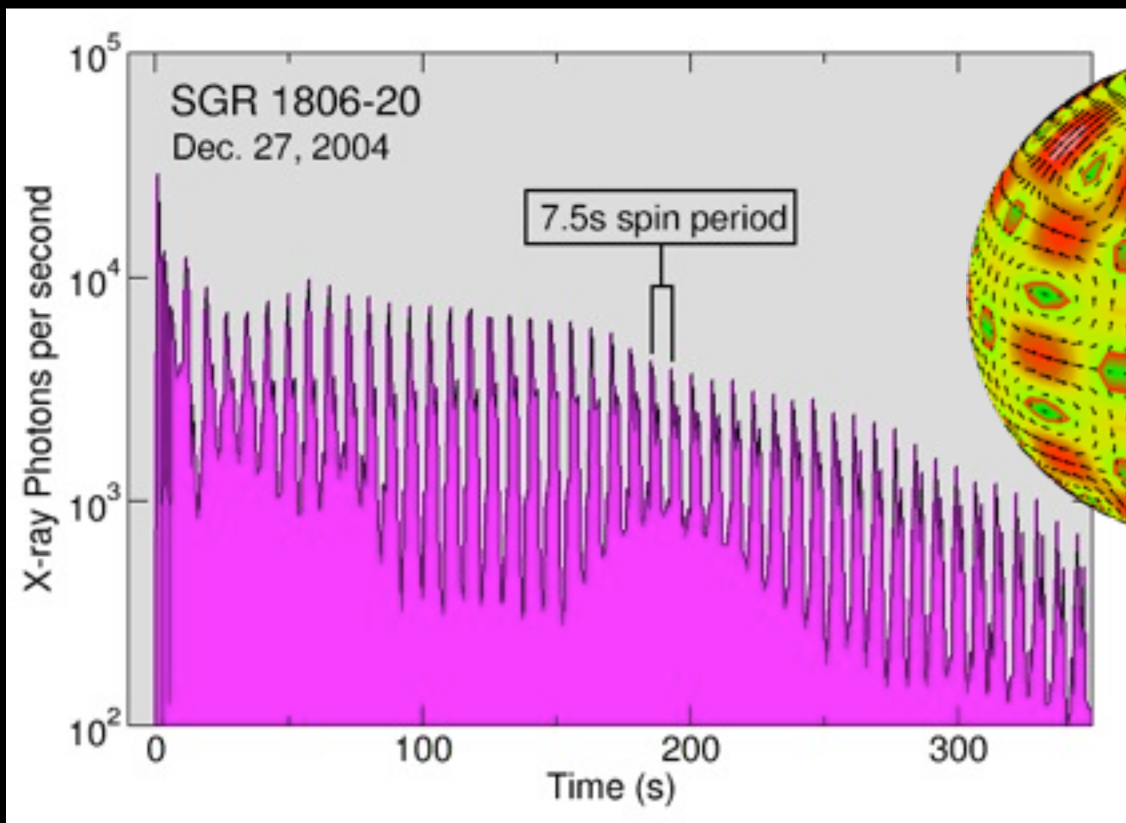
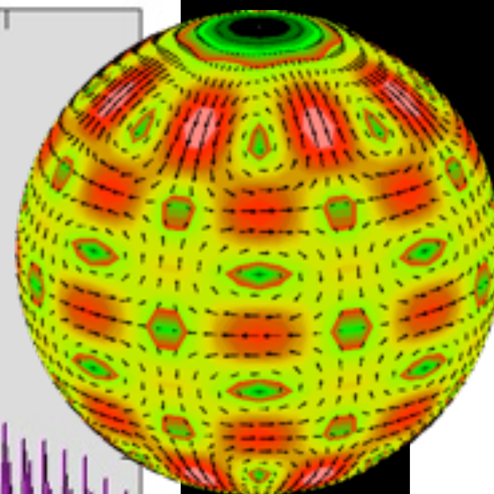
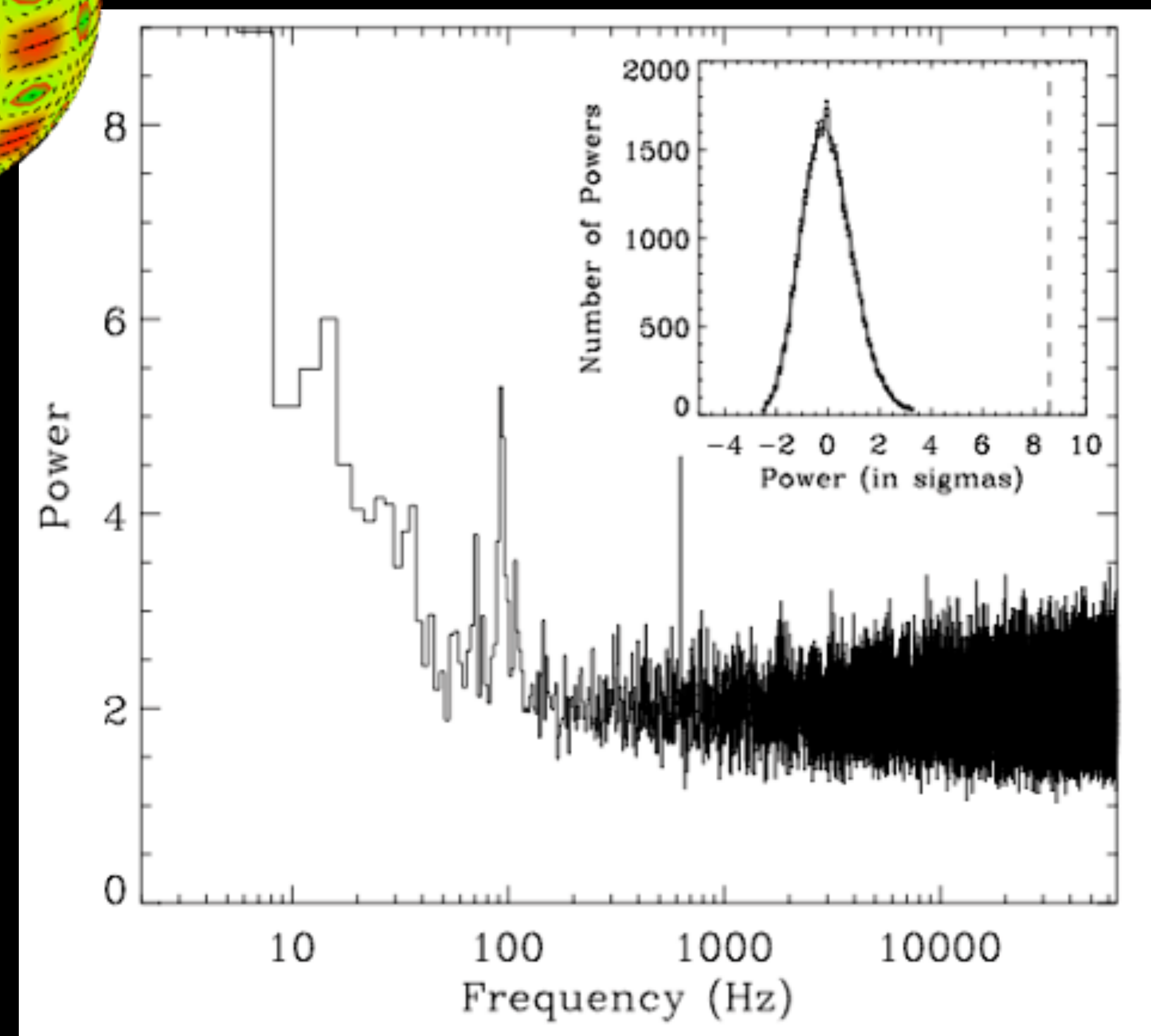


Image: Casey Reed/Penn State U

Magnetar Seismology







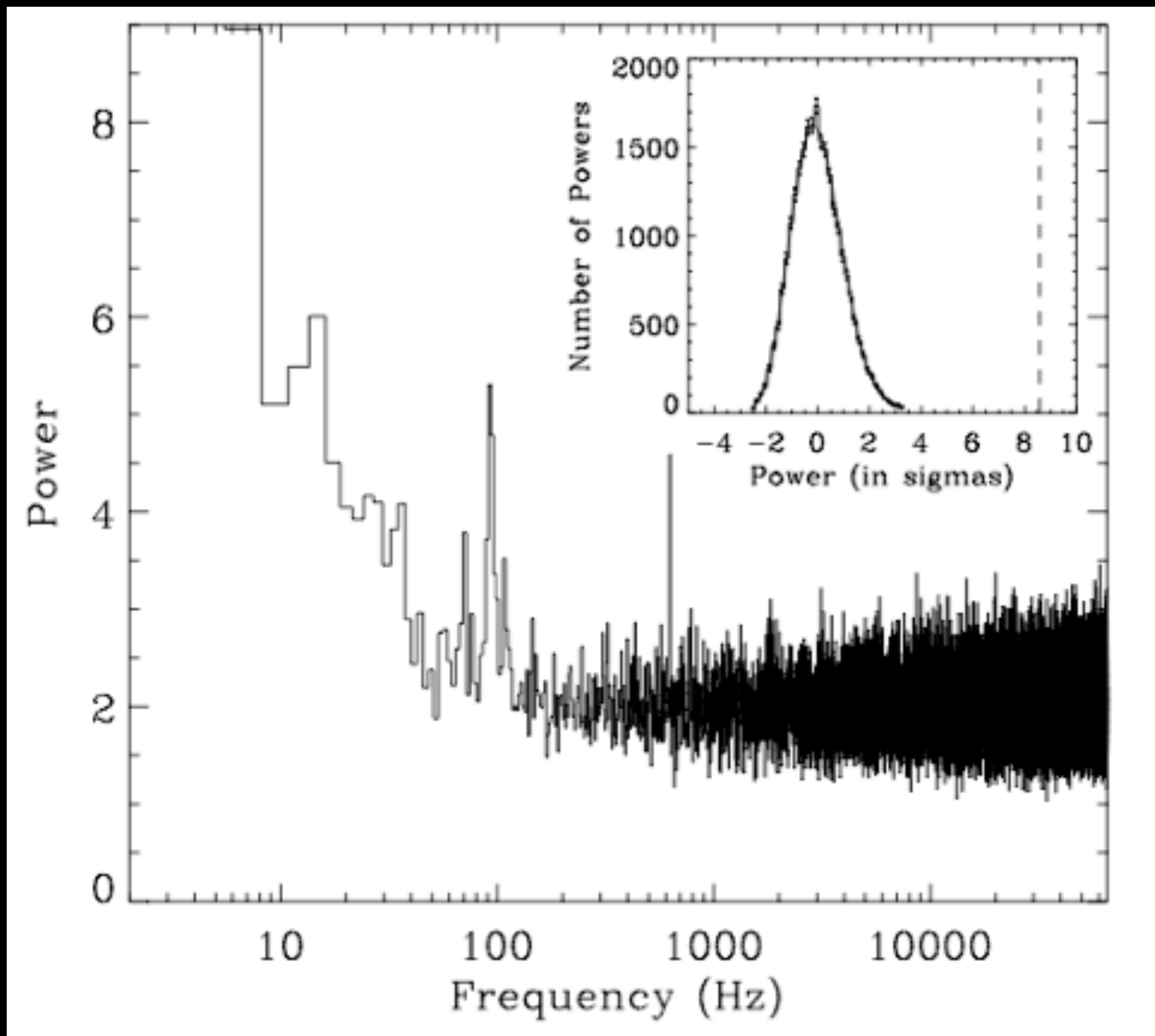
- Giant flares trigger seismic vibrations of magnetars (Israel et al. 2005, Strohmayer & Watts 2005,6, WS 2006).
- Seismic models can constrain EoS and field.

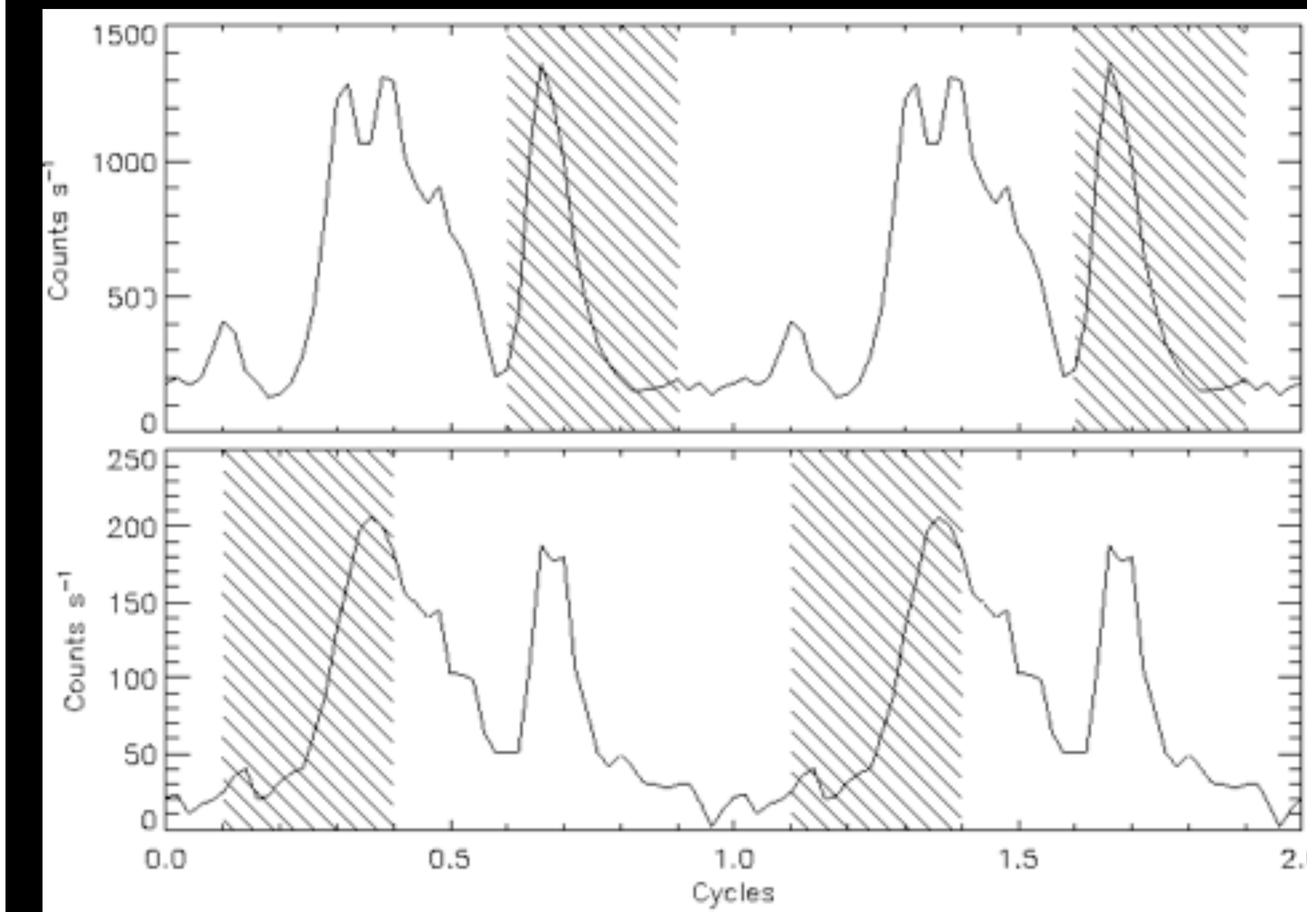
Strongest QPOs from SGR 1806-20 giant flare, Strohmayer & Watts 2006

Vidi Magnetar Project at the University of Amsterdam

- Team members: Dr. Anna Watts (PI), CD'A, Daniela Huppenkothen, Danai Antonopolou, Thijs van Putten
- Main goal: to better understand internal structure of neutron stars through astroseismology
  - search for seismic vibrations in SGRs (DH)
  - investigate connection between glitches and magnetar flares and star quakes (DA)
  - connect physical motion of star with observed radiation (CD'A, TvP)

QPO properties

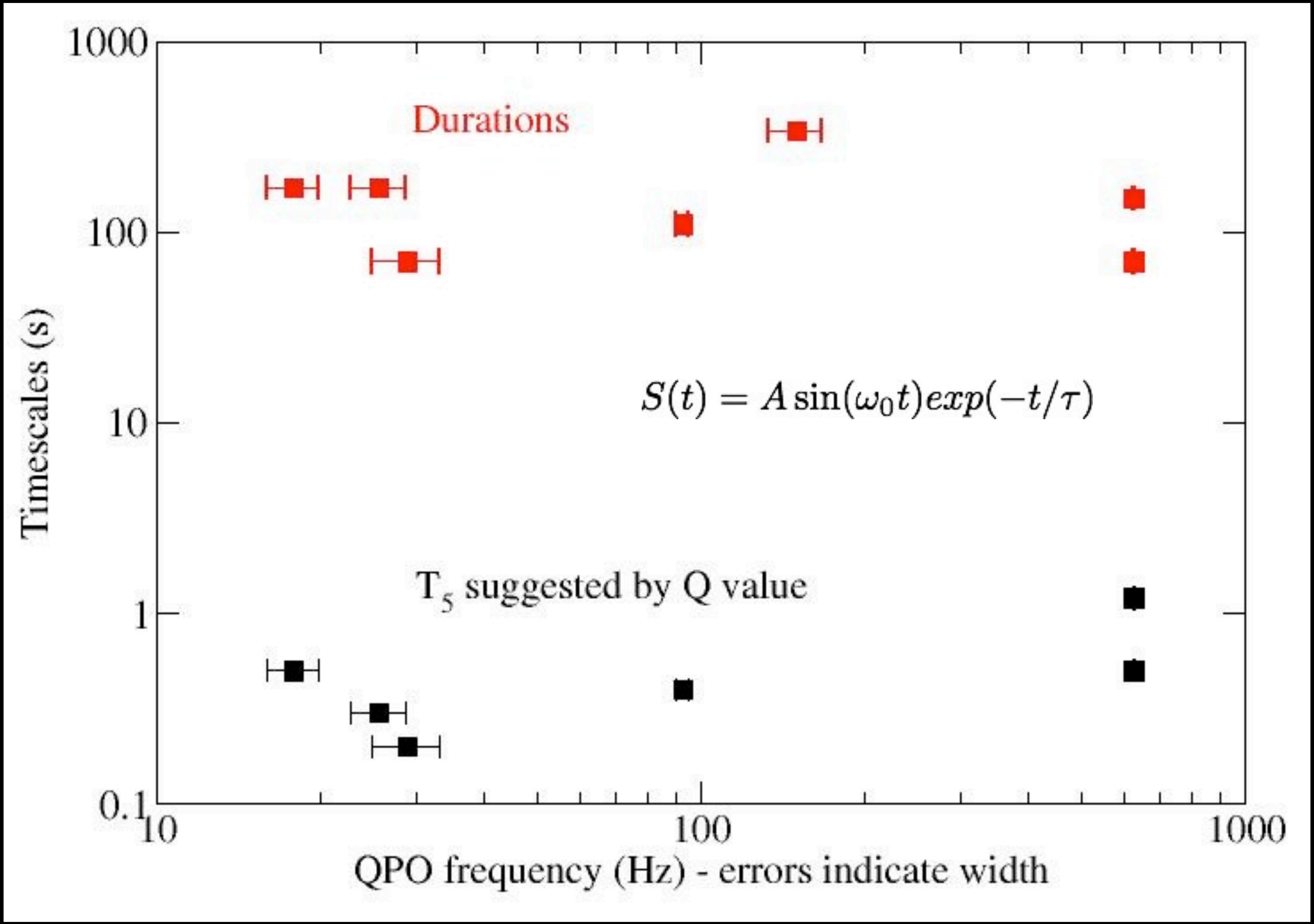




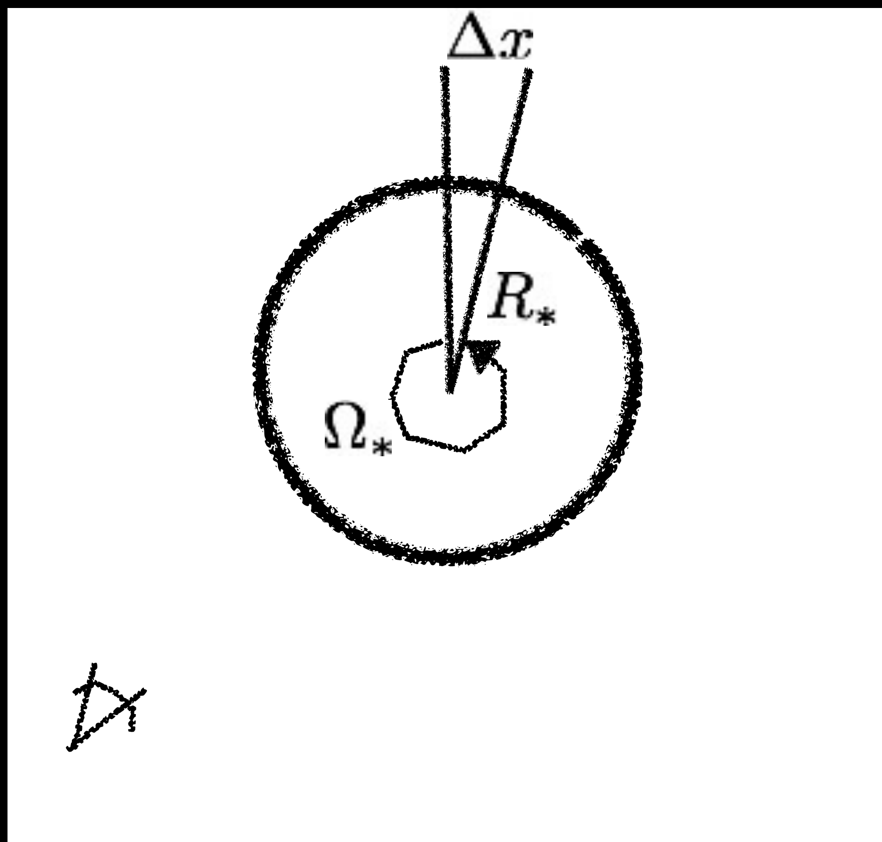
- – High Amplitude (~10-20%rms)
- – Often strongly peaked

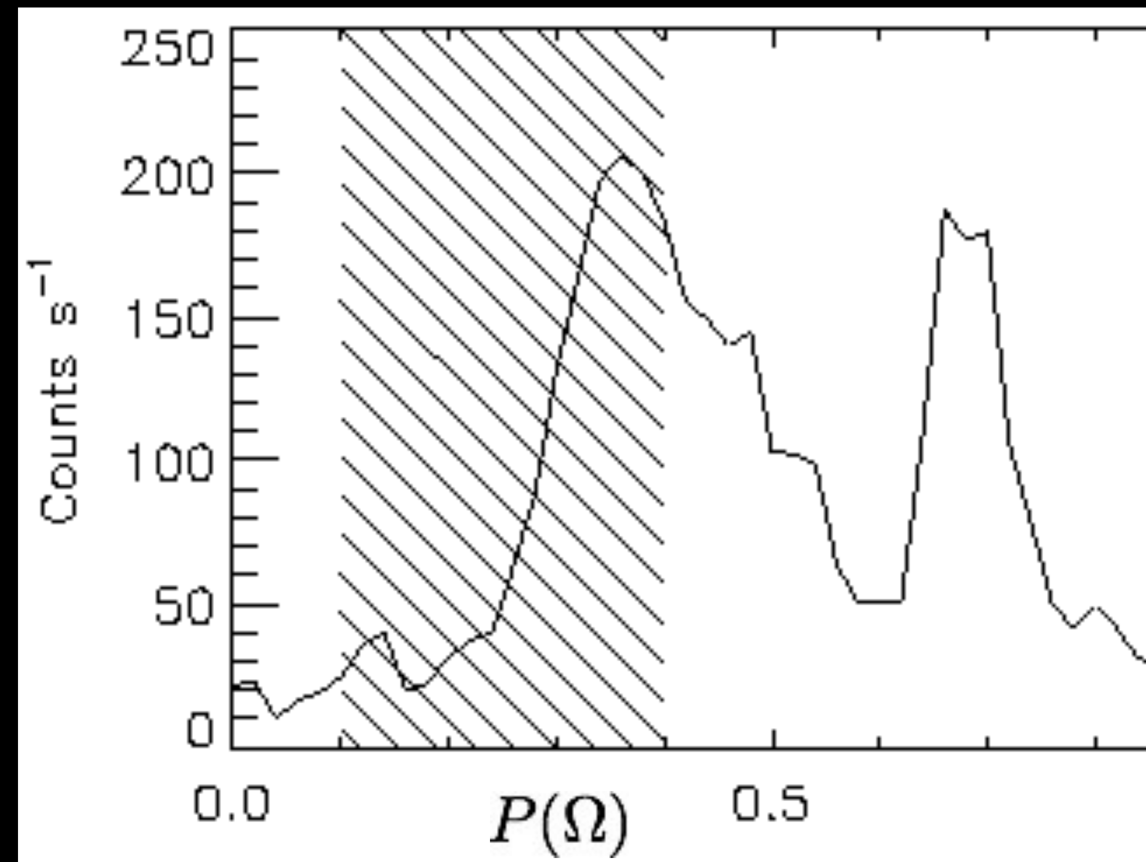
- strength of signal indicates it is not representative of physical motion in the crust (at most ~ 1R*%)
- Phase dependent signals: often linked to falling or rising light curves

Exponential Decay?



QPO model





P(Ωt) – phase profile

Transverse motion from starquake Δ*x* changes phase:

$$\Omega t \rightarrow \Omega_* t + \frac{\Delta x}{R} \sin(2\pi\nu_0 t)$$

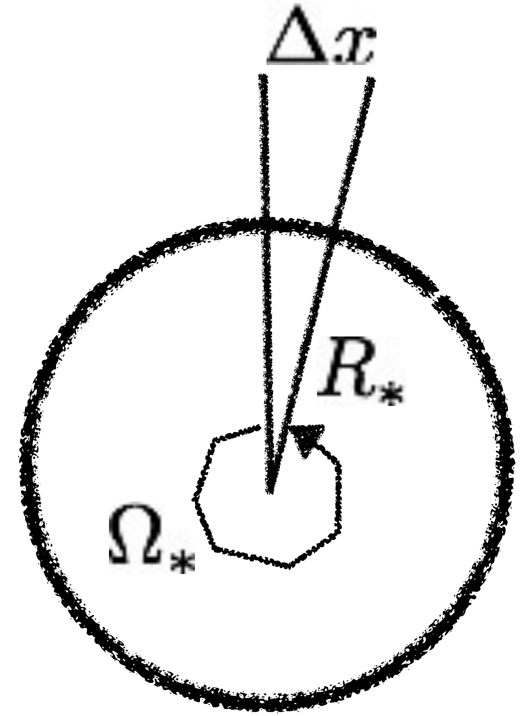
Flux profile F(t) follows from P(Ωt)

What does this imply?

QPO model II

Sinusoidal signal can be boosted by strong gradient in light profile

$$P(\Omega t) \simeq P(\Omega_* t) + \frac{\Delta x}{R}\frac{\sin(2\pi\nu_0 t)}{\Omega_*}\frac{dP}{dt}$$

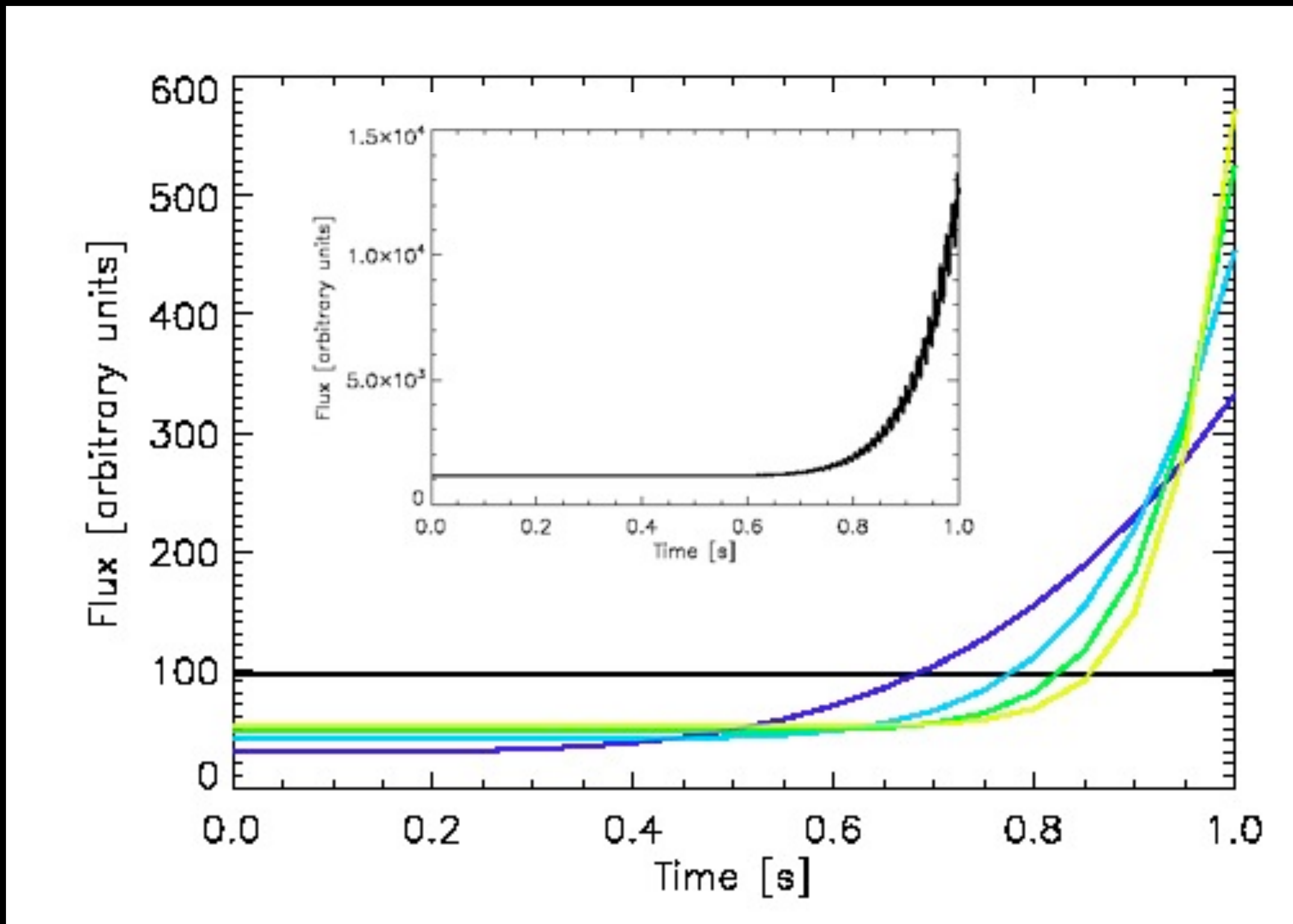


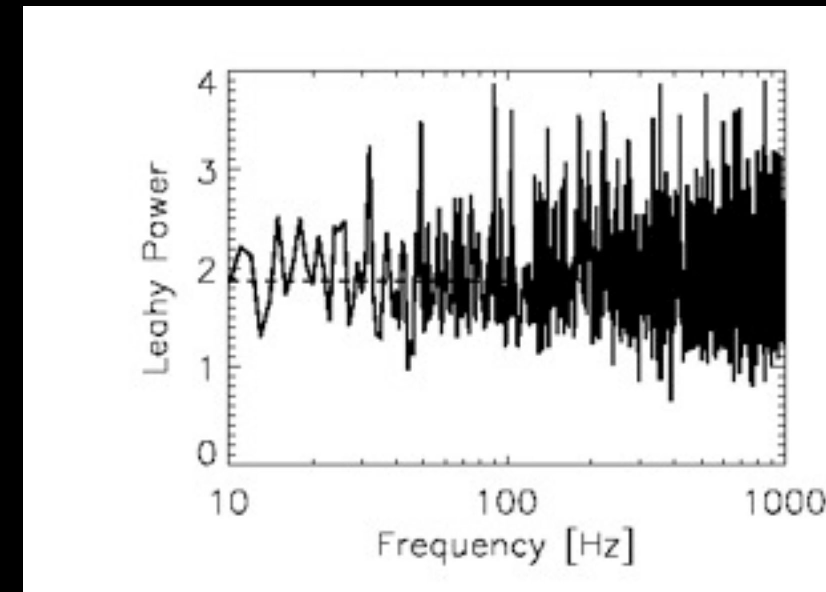
Since gradient changes, sinusoid will be broadened in power spectrum

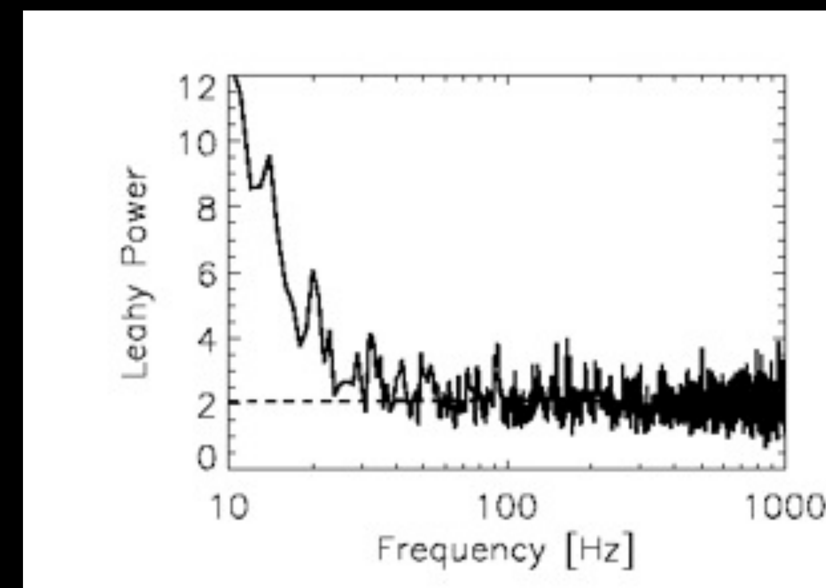
Is this effect enough to boost the ~1% motion of the crust into an observable QPO?

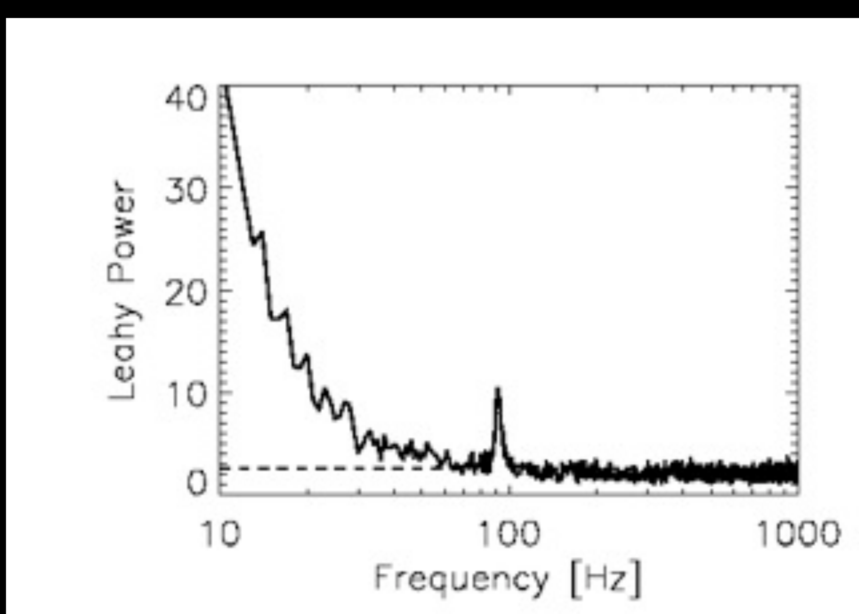
$$A_{\rm QPO} \sim \frac{8\pi\nu_0\Delta x}{R_*\Omega_*^3 N_{\rm phot}}\left(\hat{P}_0^*\left(\frac{\nu_0}{\Omega_*}\right)\hat{P}_0\left(\frac{2\nu_0}{\Omega_*}\right) - \hat{P}_0\left(\frac{\nu_0}{\Omega_*}\right)\hat{P}_0^*\left(\frac{2\nu_0}{\Omega_*}\right)\right)$$

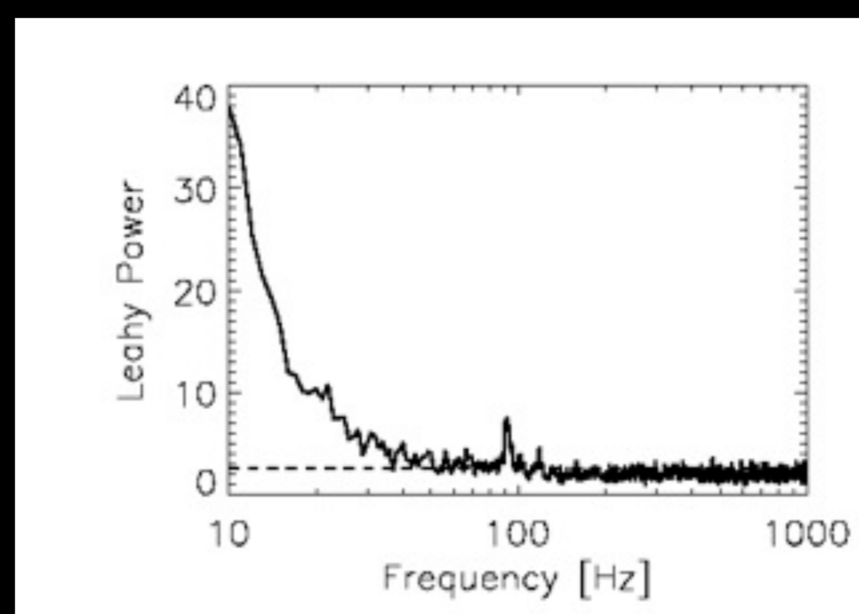
92.5Hz signal, 1% amplitude

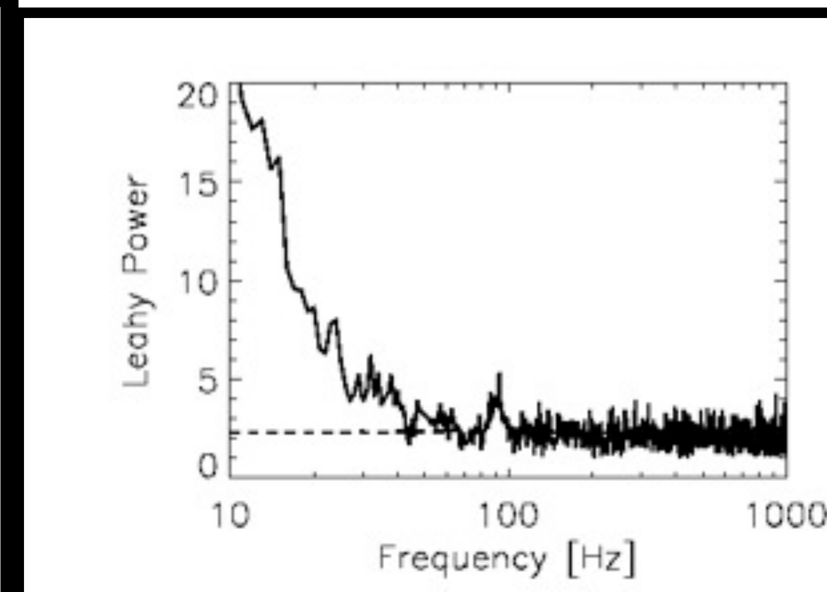




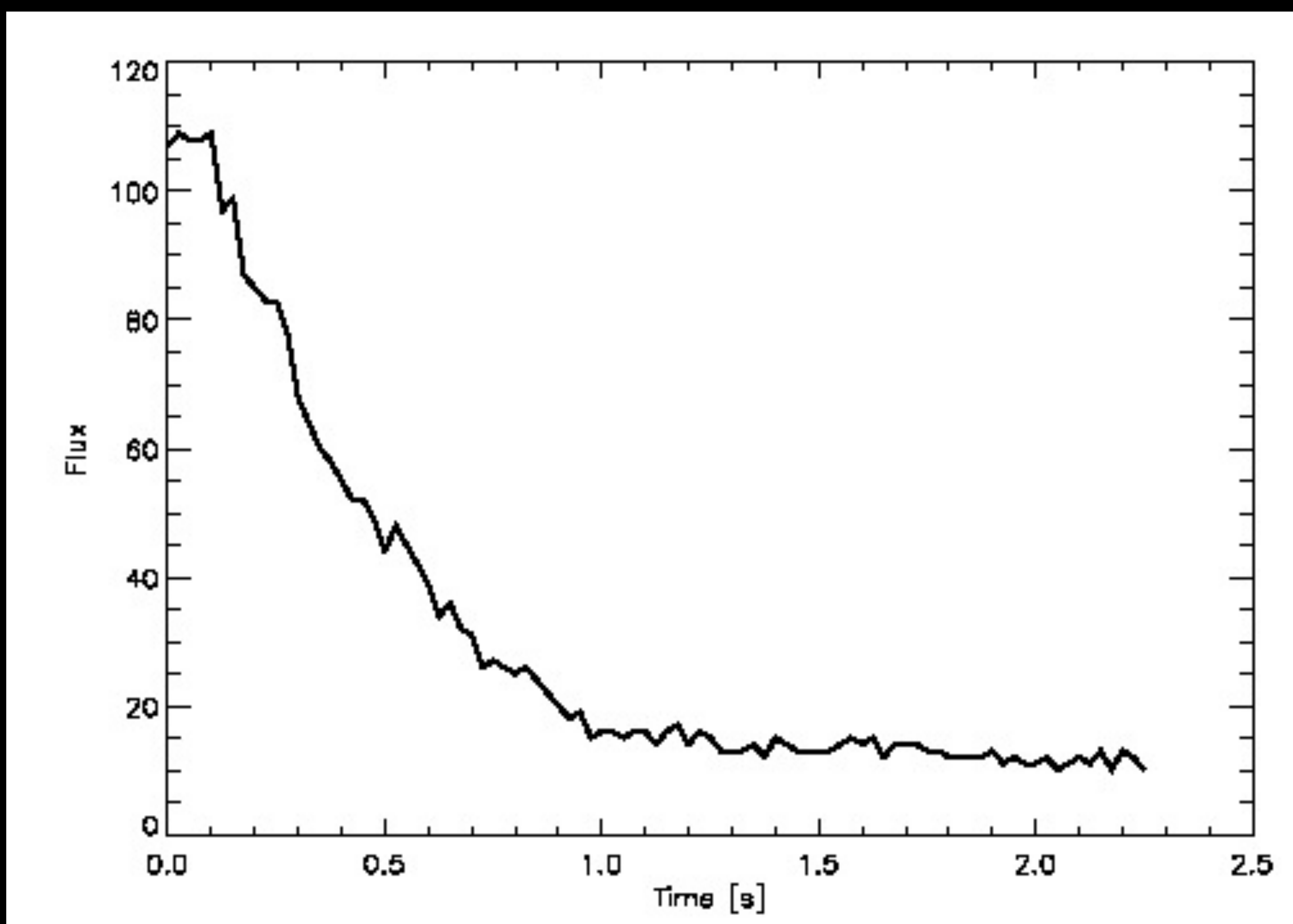








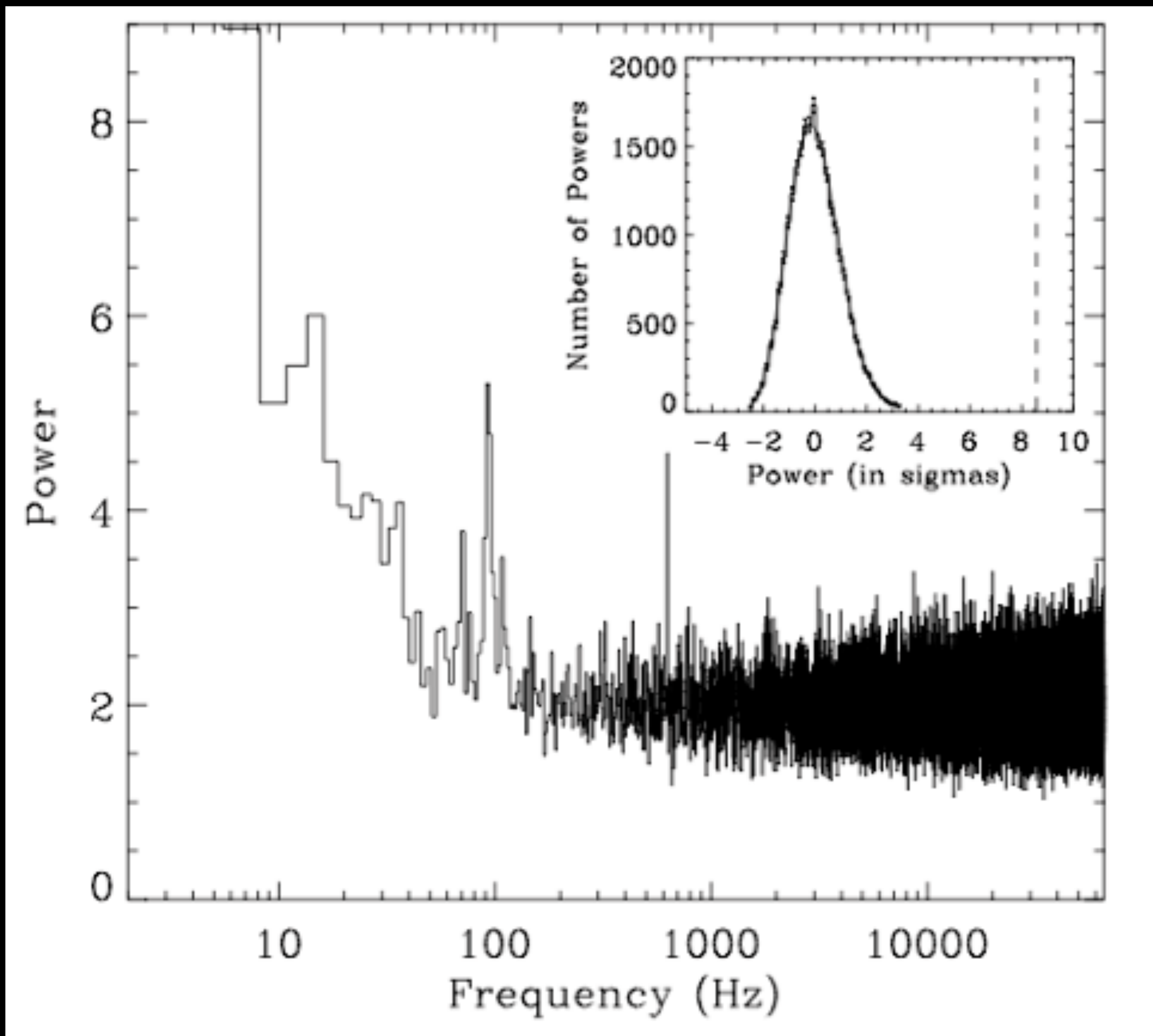
Does this work with real light curves?



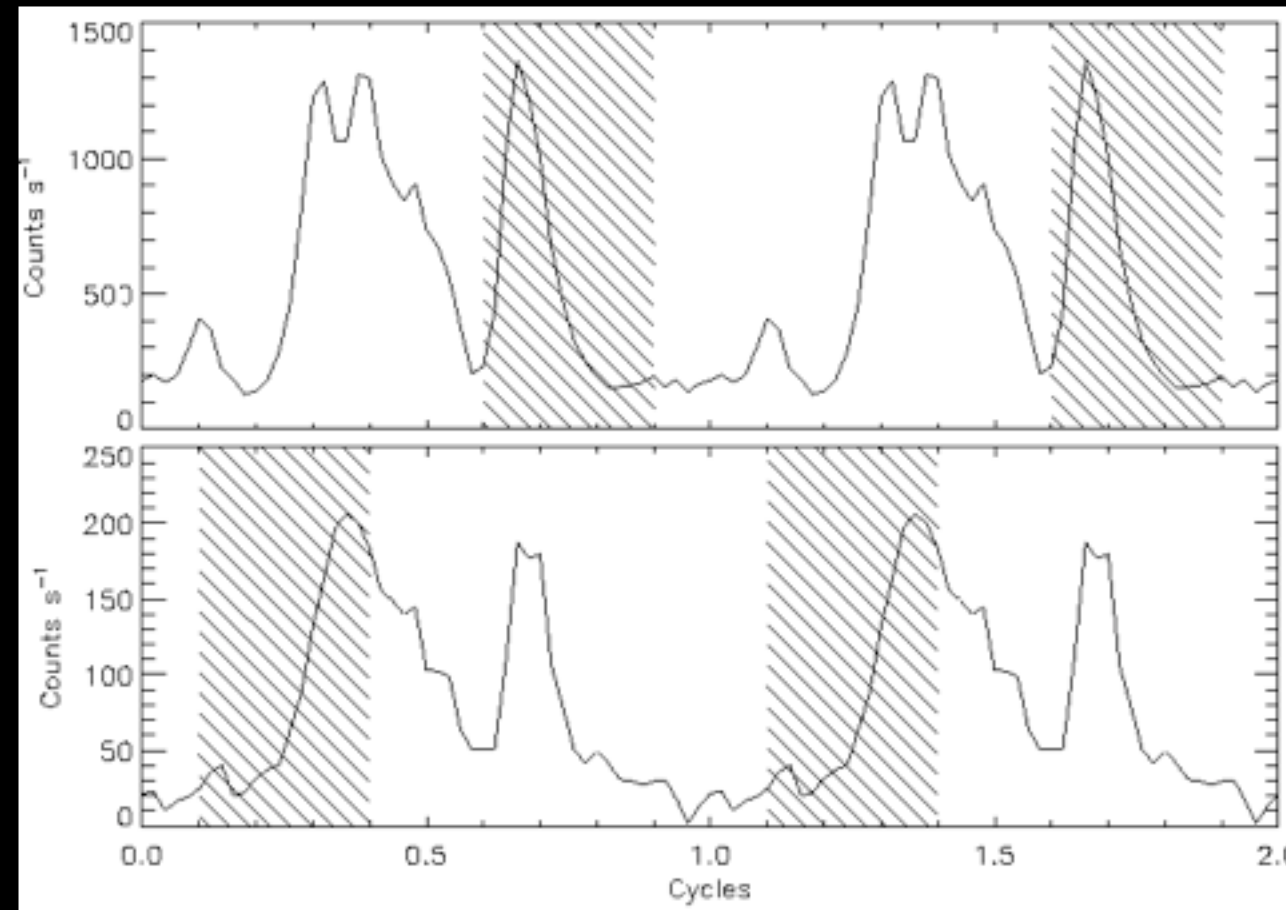
Analytic work shows need *high time resolution* for underlying light curve — ideally twice QPO frequency —Very difficult to simulate from real light curves (need to smooth to remove inherent QPOs)

Could 'hide' sharper gradients in light curve, boosting signal

Test case: Application to giant flare in SGR 1806-20

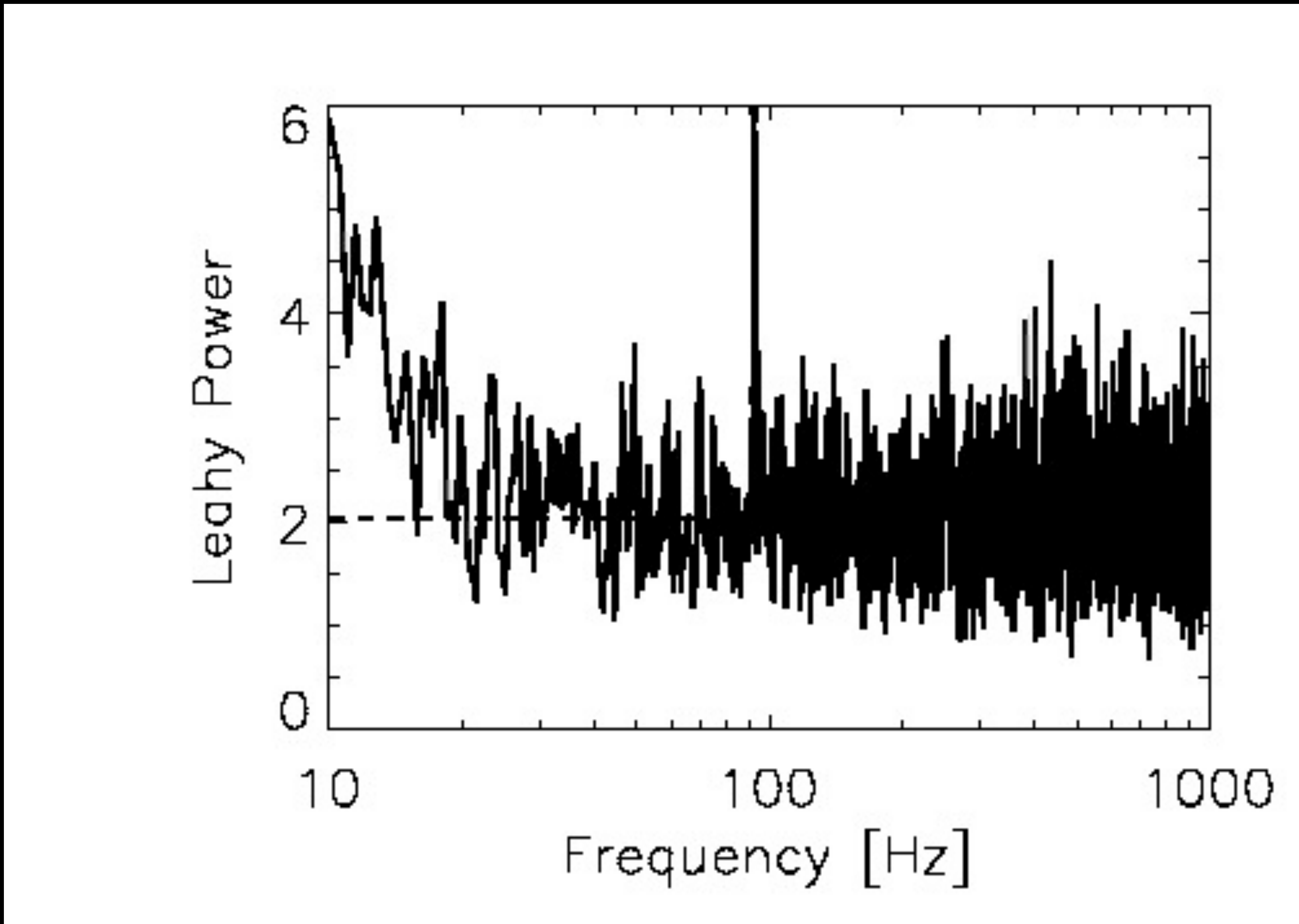


QPOs at 93Hz, 150 Hz, 625 Hz



Smooth light curve and add QPO signal on top — how strong should it be to reproduce observed amplitude

Power Spectrum



Added: 5% amplitude signal at 92.5 Hz

Do see some boosting, although likely marginal

QPO fractional amplitude: 0.053895578
Photon number: 2884.96
Q factor: 104.61030
alpha: 0.89228570
Centroid QPO frequency: 92.430713

Conclusions

- Physical motions can be boosted by strong gradients in the light curve
- Changing gradients can also broaden a sinusoidal signal into a QPO
- Need sharp gradients: presents a difficulty for simulating QPOs from real light curves, likely need to work backwards: calculate how large a gradient can be 'hidden' in the light curve
- At present, it seems unlikely to account for amplitude of some QPOs from star quakes directly, however: any rapid toroidal variation from star quake will show this boosting effect