Gravitational waves from the pulsar glitch recovery period

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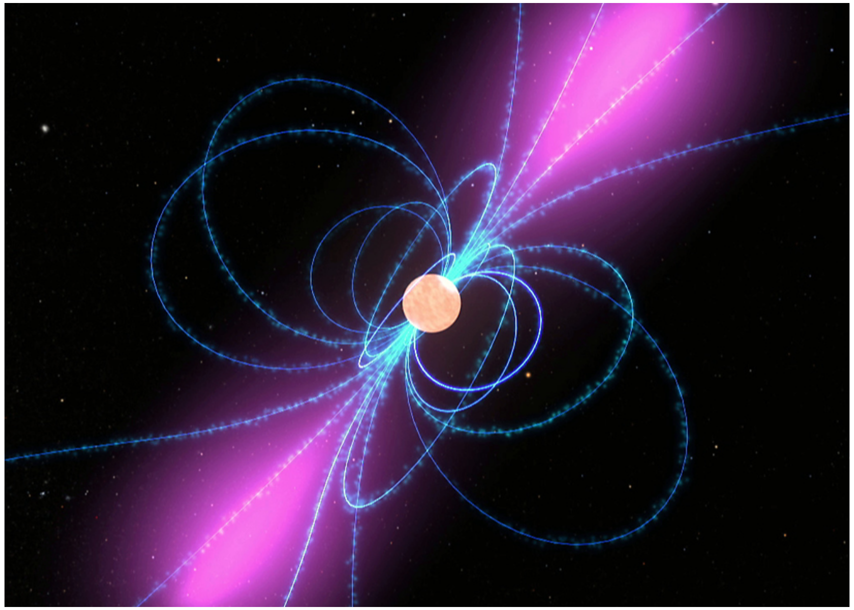
Overview

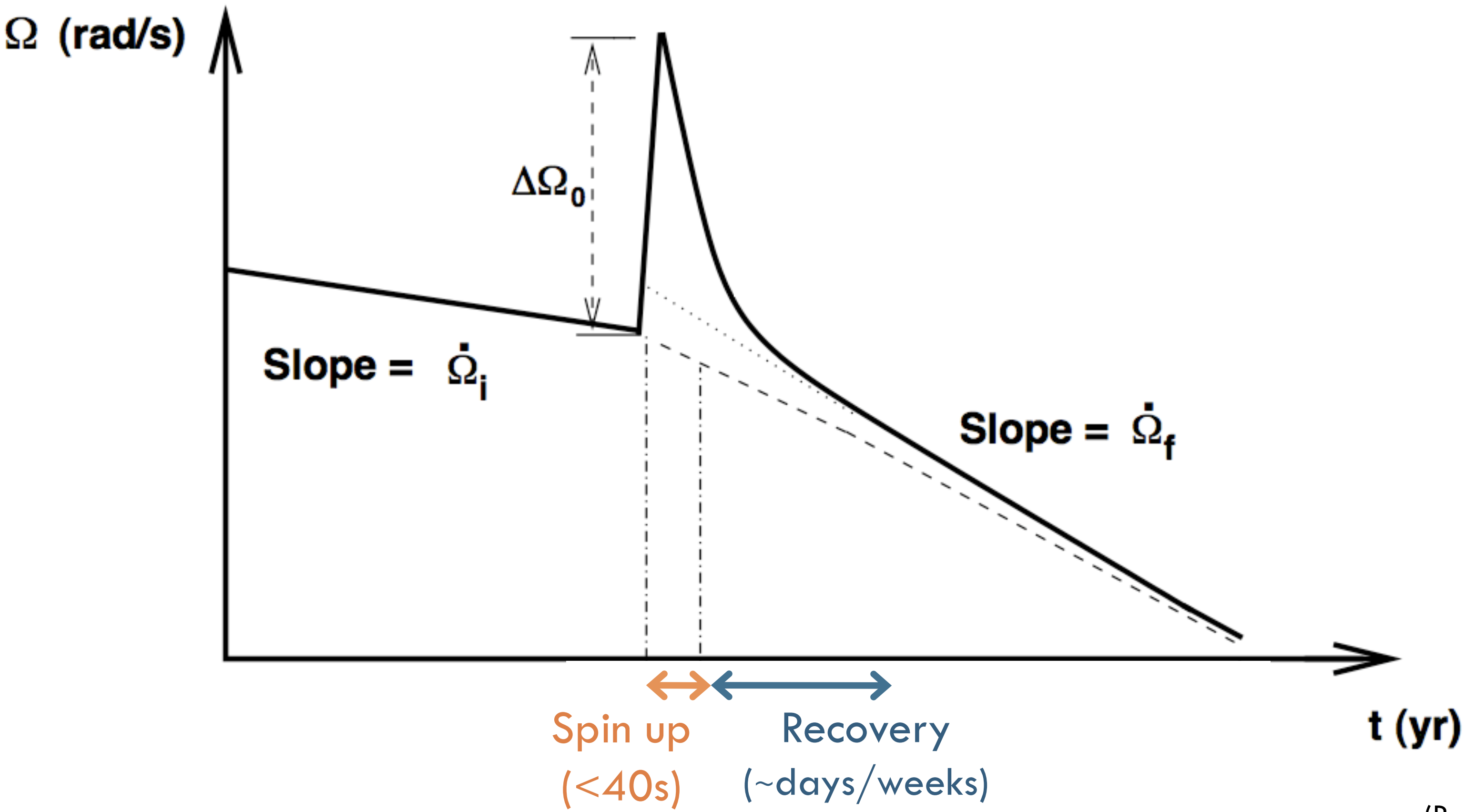
- Different types of signal from a pulsar glitch
- Calculate GW signal using simple model of a glitch
- Estimate signal-to-noise ratio for ET
- Compare the conventional and xylophone configurations for a glitch search
- Blind searches for unseen glitches
- Determine properties of interior from observations

Pulsars and glitches

- Rapidly rotating neutron stars
  - "Lighthouse effect"
- Extremely accurate timing of pulses (up to 1 part in 10^{15})
- Occasional timing irregularities: **glitches**
  - $10^{-11} < \delta\Omega/\Omega < 10^{-4}$

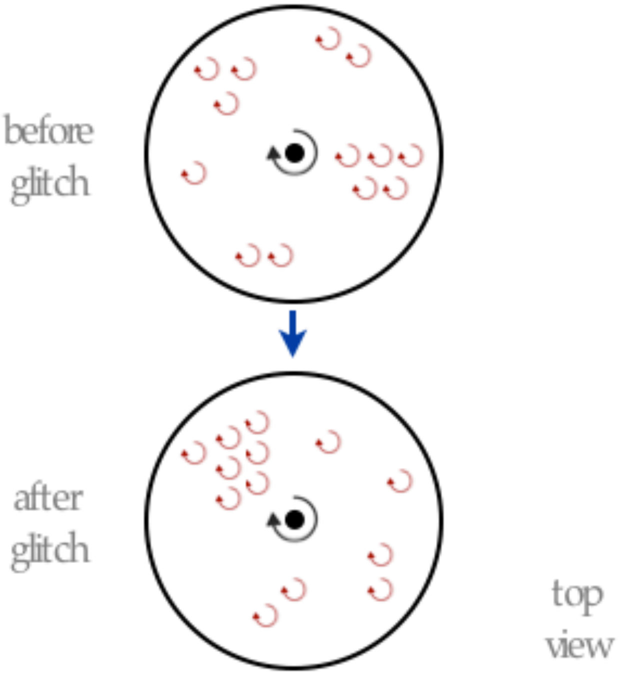


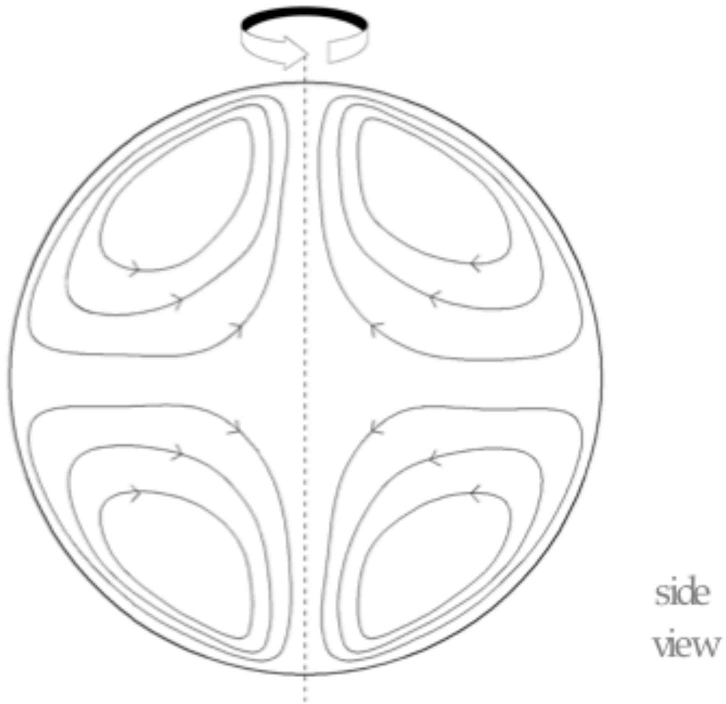
Anatomy of a glitch



(Peralta 2006)

Types of GW signal





Burst Signal (< 40 sec)

Microphysics (inhomogeneous vortex rearrangement)

Continuous Signal (days/weeks)

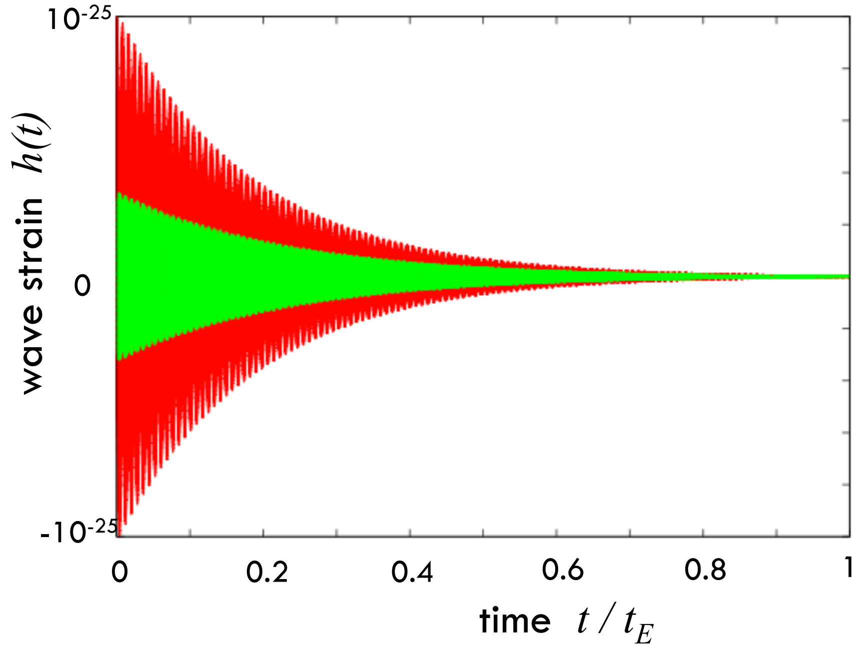
Macrophysics (nonaxisymmetric circulation during relaxation)

Glitch model

- Model NS as cylinder with solid crust, fluid interior
  - allows analytic solutions, stratification
- Glitch: step increase in crust $\Omega \to \Omega + \delta\Omega$
- Interior is spun up to match crust via the process of **Ekman pumping**
- Nonaxisymmetric interior spin-up flow → GW

Continuous GW signal

- Signal at f_* and $2f_*$
- Continuous source
  - long decay time-scale
  - coherent integration increased signal-to-noise
- Contains information about the properties of the pulsar interior



Detectability with ET

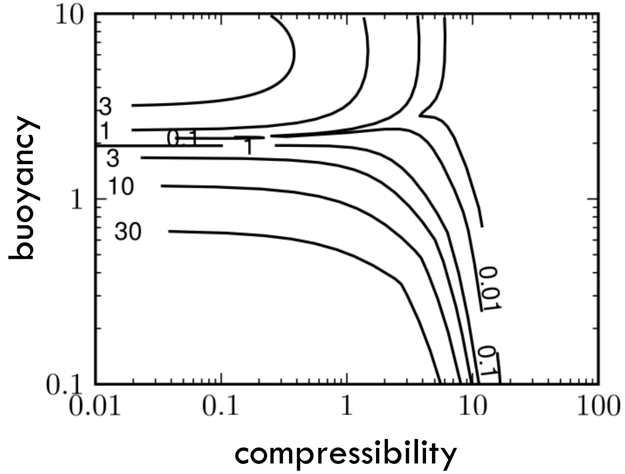
Characteristic wave strain

$$h_0 = 6 \times 10^{-26} \left(\frac{\delta\Omega/\Omega}{10^{-4}}\right) \left(\frac{f_*}{10^2\ \mathrm{Hz}}\right)^3 \left(\frac{D}{1\ \mathrm{kpc}}\right)^{-1}$$

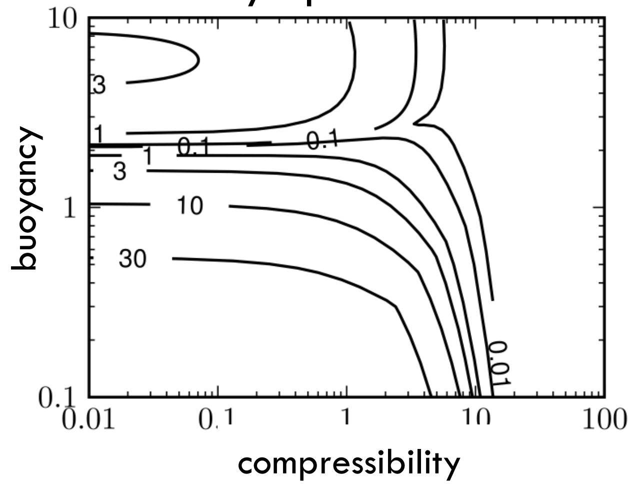
Signal-to-noise ratio for integration over glitch recovery period

- $f_* = 100$ Hz
- $\delta\Omega/\Omega = 2\times10^{-4}$
- distance = 1 kpc

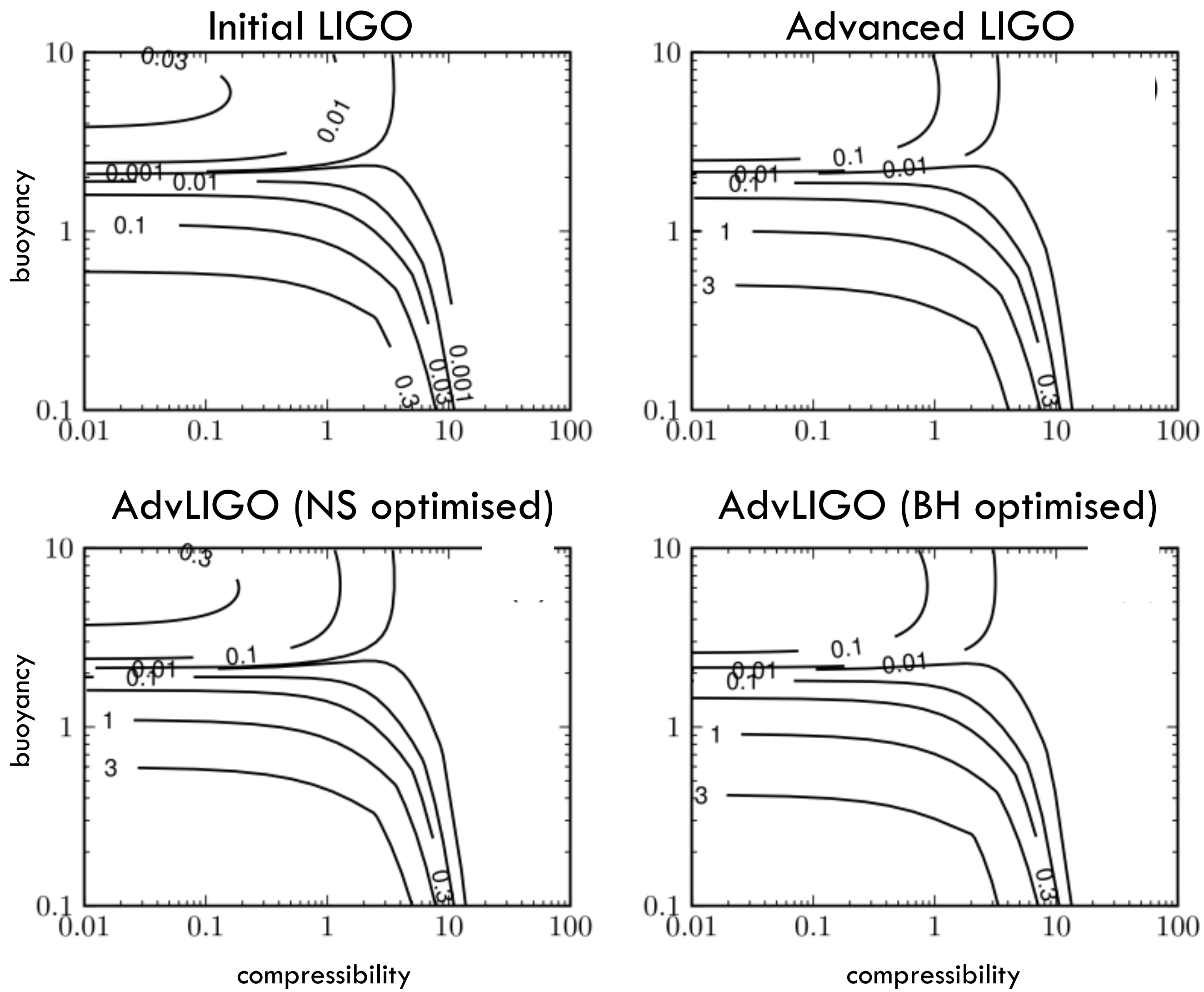
Conventional ET



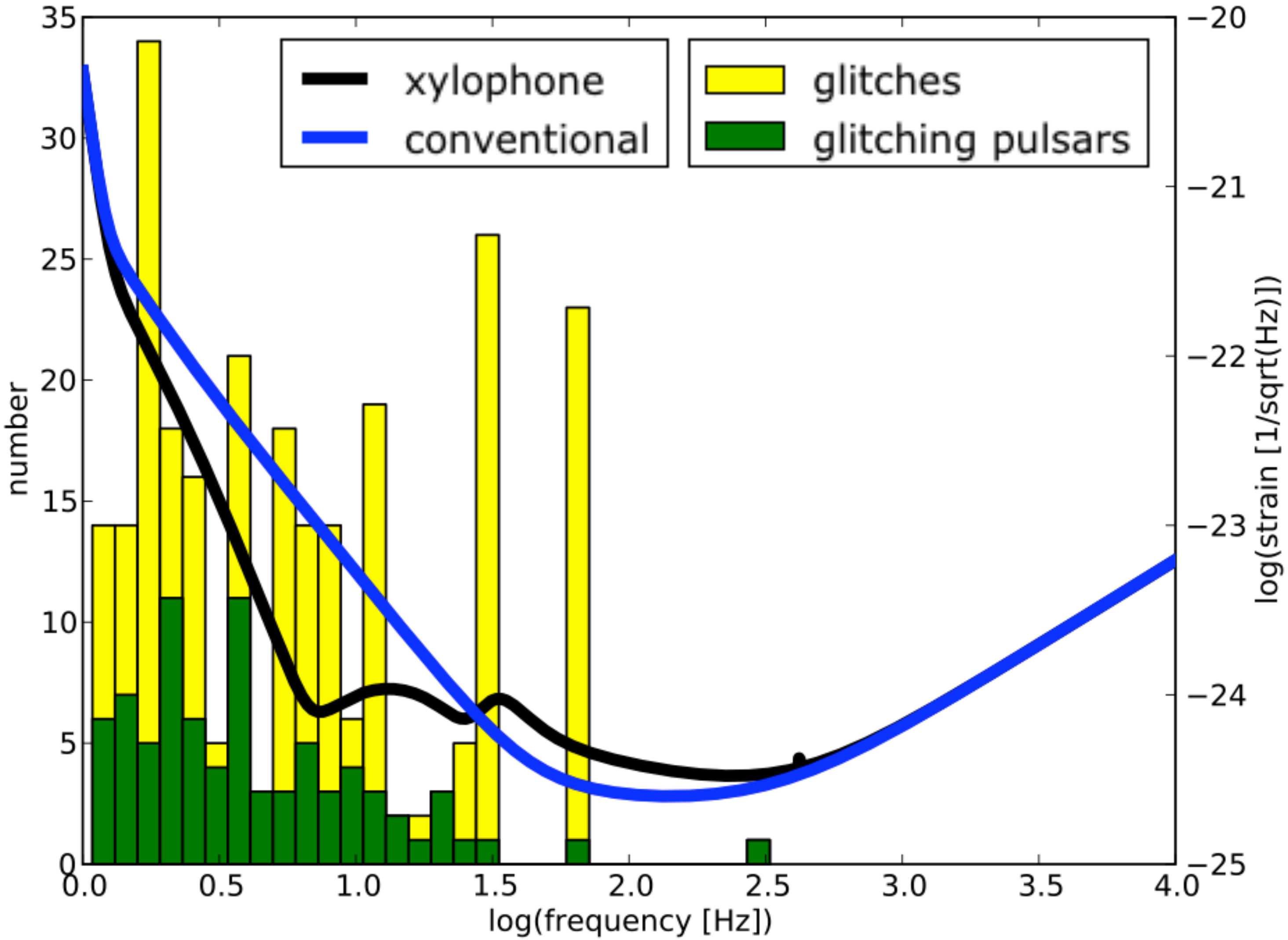
Xylophone ET



LIGO (for comparison)

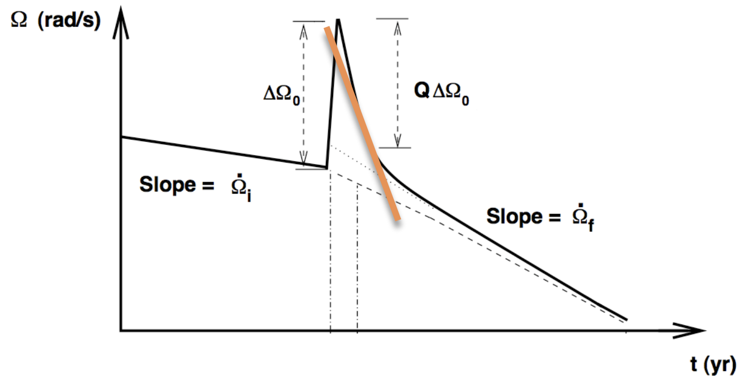


Conventional vs xylophone ET



Detectability Concerns

- $h_0 \propto f_*^3 \rightarrow$ more common, low frequency glitches have smaller wave strain
- Larger frequency derivative than usual during relaxation period



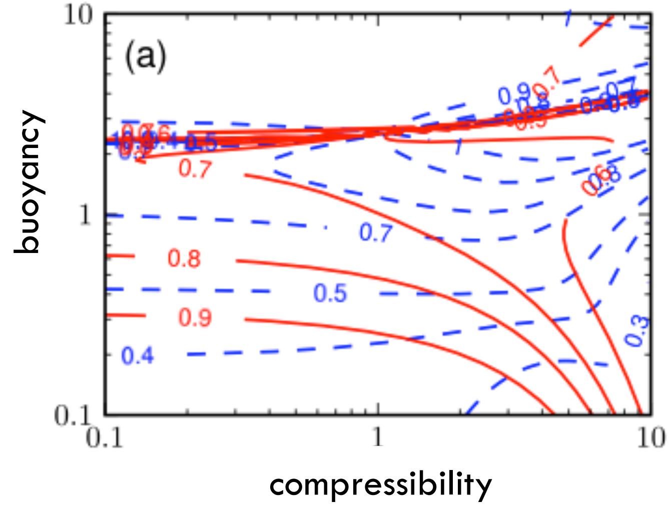
Blind Search

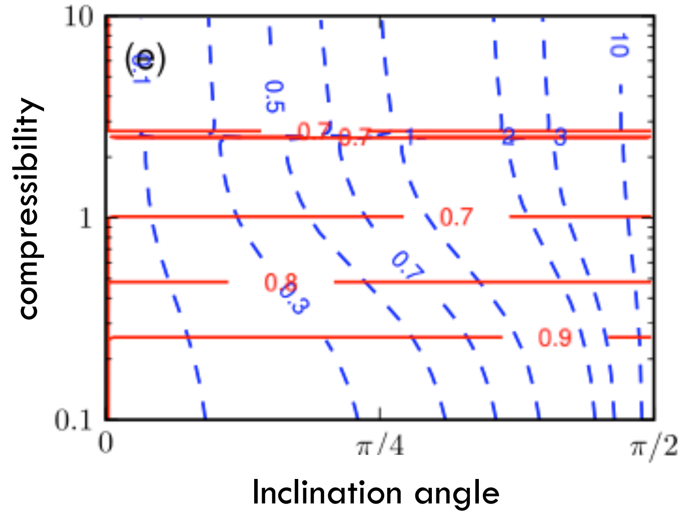
- Around 300 glitches observed from ~ 100 pulsars (out of the ~ 2000 pulsars known)
- Estimated galactic population of 10^9 neutron stars, closest expected at distance of 8 pc
- Must be nearby, unseen glitches that are detectable (maybe even with LIGO currently?)
- Difficult to search for: unknown position, relaxation, and timing of event (however SKA, etc in future…?)

Nuclear properties from GW signal

Extract properties of bulk nuclear matter in neutron star interior

- compressibility
- viscosity
- buoyancy
- inclination angle





Contours of constant amplitude ratio (blue) and width ratio (red) of Fourier spectrum peaks at f_* and $2f_*$ for plus polarisation.

Terrestrial Experiments

- Neutron radius measurements for lead (PREx)
- Heavy-ion collisions (RHIC)
  - Viscosity ~ quantum lower bound

Table 1. Experimental and theoretical results for compressibility, viscosity and Brunt-Väisälä frequency.

Quantity	Experiment/Theory (E/T)	Result	Dimensionless	Reference
K	Au+Au and C+C collisions (~ GeV) (E)	$\kappa \approx 200$ MeV	$K = 0.97$	1, 2
	nuclear resonances (E)	$\kappa \approx 240$–270 MeV	$K = 0.72$–0.81	3, 4
	nuclear symmetry energy (E)	$\kappa = 210$ MeV	$K = 0.93$	5, 6
E	Au+Au collisions (200 GeV) (E)	$\eta/s \approx \hbar/4\pi k_B$	$E = 8 \times 10^{-20}$	7, 8
	neutron-neutron scattering (T)	$\eta = 2 \times 10^{20}$ g cm^{-1} s^{-1}	$E = 5 \times 10^{-9}$	9
	electron-electron scattering (T)	$\eta = 6 \times 10^{20}$ g cm^{-1} s^{-1}	$E = 1 \times 10^{-8}$	9
	quark-quark scattering (T)	$\eta = 5 \times 10^{15}$ g cm^{-1} s^{-1}	$E = 1 \times 10^{-13}$	10
N	chemical composition (T)	$N_* \sim 500$ s^{-1}	$N = 0.8$	11, 12
	centrifugal correction (T)	$N = 0.32$-0.84	$N = 0.32$-0.84	13

(1) Sturm et al. (2001), (2) Hartnack et al. (2006), (3) Vretenar et al. (2003), (4) Piekarewicz (2004), (5) Chen et al. (2005), (6) Li et al. (2008), (7) Adler et al. (2003), (8) Adare et al. (2007), (9) Cutler & Lindblom (1987), (10) Jaikumar et al. (2008), (11) Reisenegger & Goldreich (1992), (12) Lai (1994), (13) Passamonti et al. (2009)

Summary

- Continuous gravitation radiation during glitch recovery period
- Estimate signal-to-noise ratio for ET

  → large glitches detectable
- Many nearby, unseen glitches with strong signals
- Learn new information about pulsar interior from future GW observations