Continuous-wave gravitational radiation from pulsar glitch recovery

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Talk Outline

Pulsar glitches as a potential gravitational wave source

Brief details of glitch model and calculation

Detectability estimates for Einstein Telescope

Determining pulsar interior properties

Pulsars as GW sources

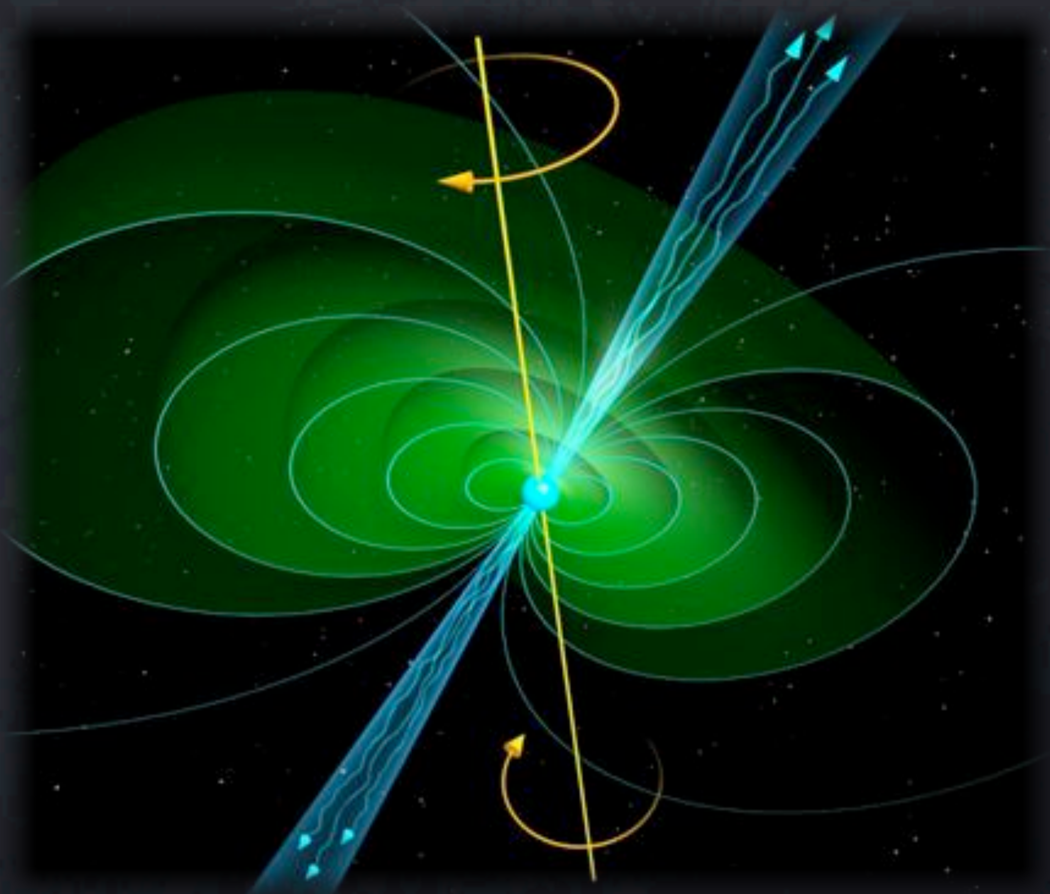
Frequencies in sensitivity sweet spot of detectors

Extremely accurate timing (up to 1 part in 10^{15}) allowing coherent search

Nuclear density objects

$$\frac{1.4\mathrm{M}_\odot}{(10\ \mathrm{km})^3} \approx \frac{m_\mathrm{n}}{(h/m_\mathrm{n}c)^3}$$

Complicated structure: solid crust, fluid interior



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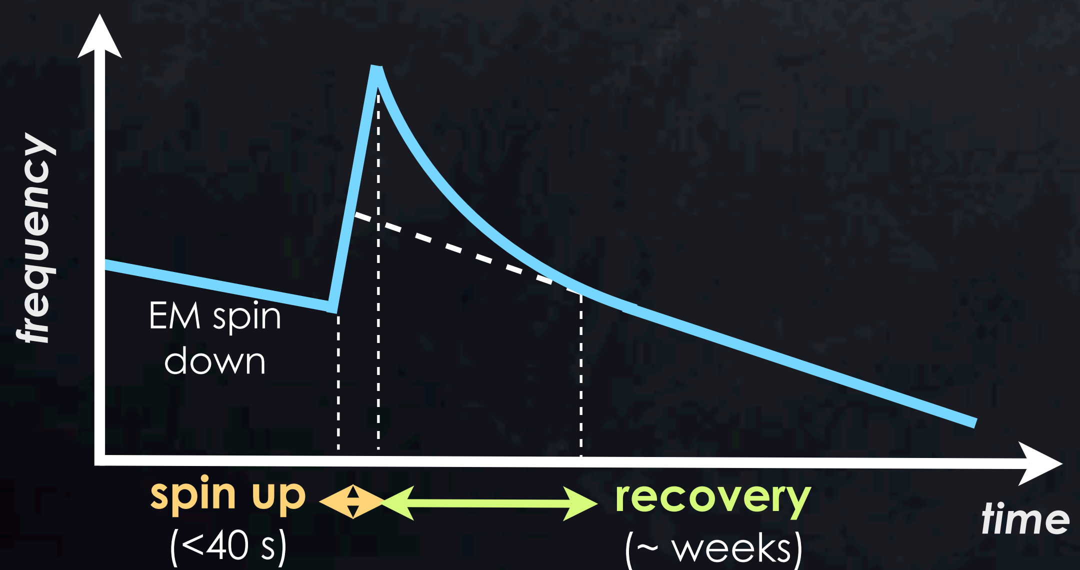
Pulsar Glitches

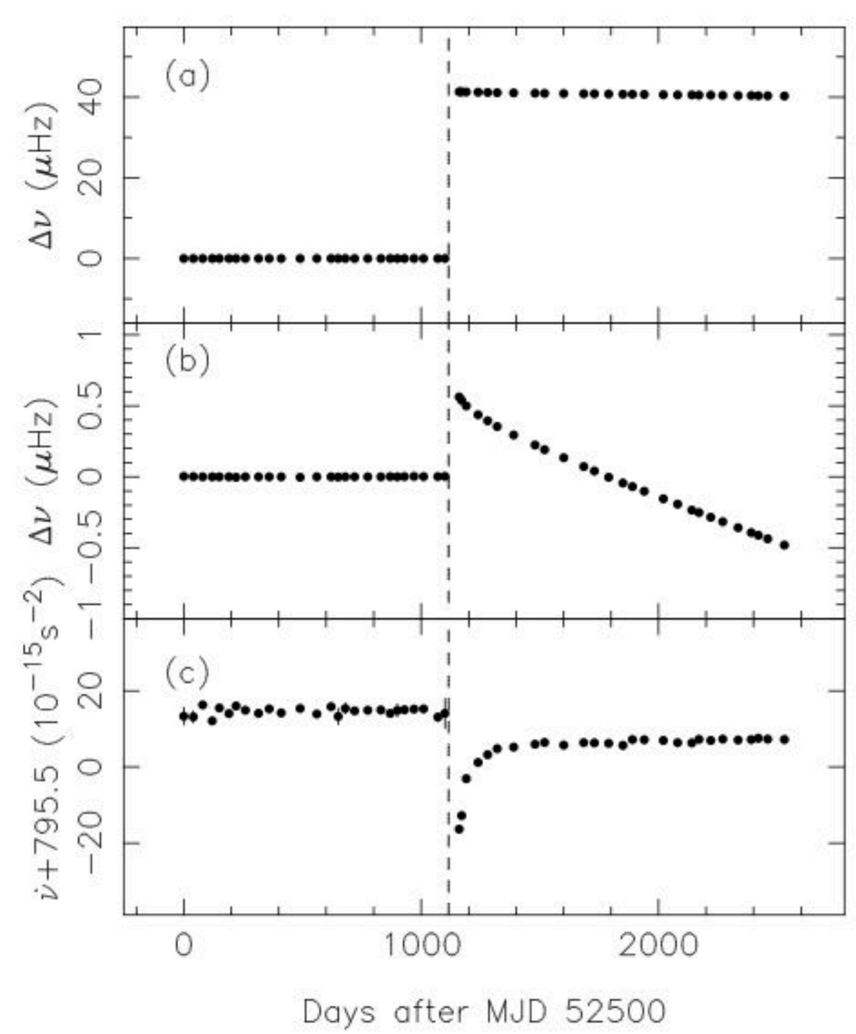
Sudden increase in spin frequency → **glitch**

'Exponential' recovery of crust and core to new spin state

285 glitches in 101 objects,
$10^{-11} < \Delta\nu / \nu < 10^{-4}$



2005 glitch PSR B2334+61



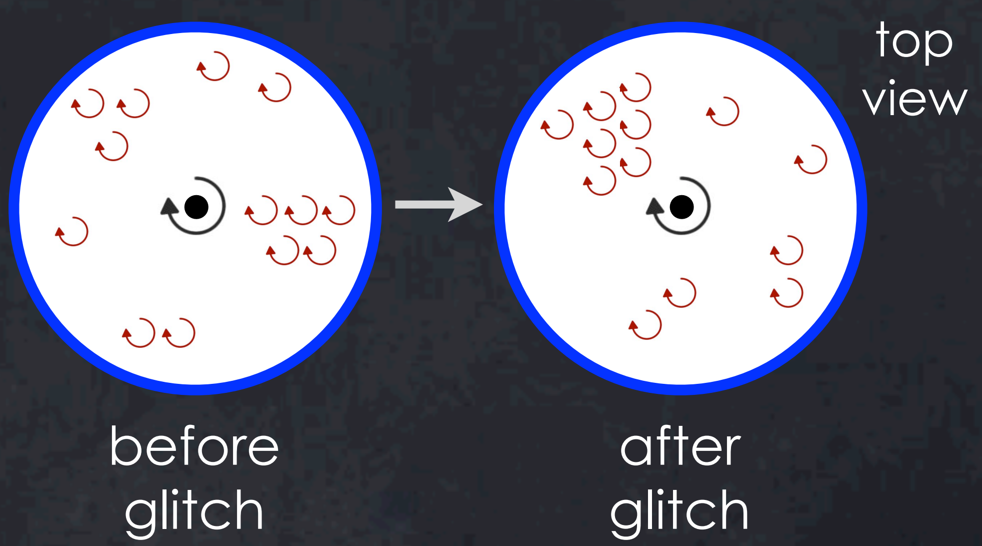
Yuan et al (2010)

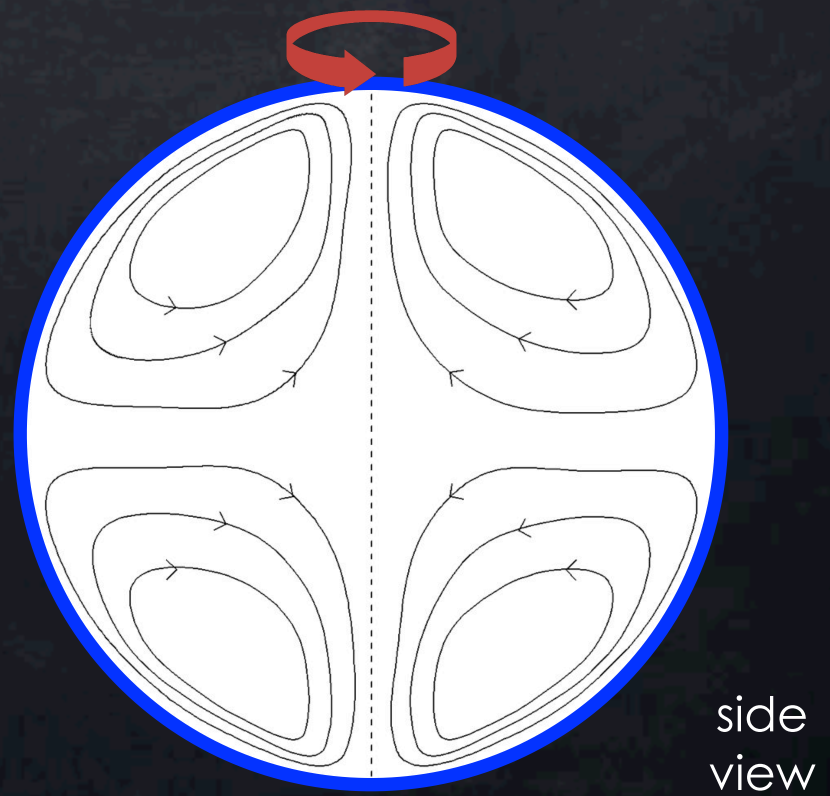
Glitch GW Signals

Glitches nonaxisymmetric:
self organised critical systems
inhomogeneous on all scales

Burst signal during spin up
(< 40 s): microphysics of vortex
pinning and rearrangement

Continuous signal throughout
recovery phase (~ weeks):
large scale circulation excited
by differential rotation
between crust and core





Glitch Model

Simple NS model: rigid, cylindrical crust

Fluid interior: viscosity E, compressibility K, stratification K_s (buoyancy N)

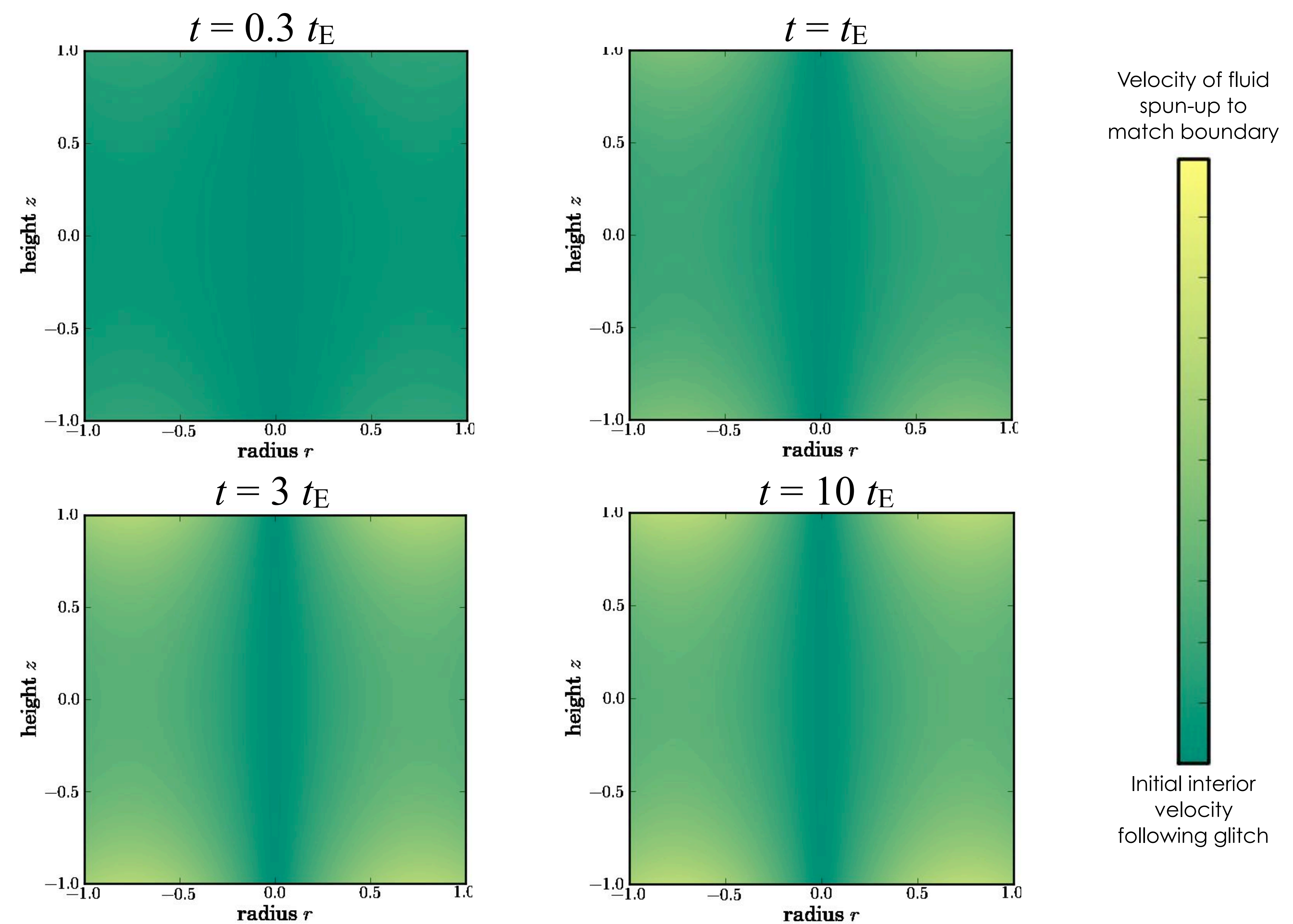
Model glitch as a step increase in crust angular velocity: $\Omega \rightarrow \Omega + \delta\Omega$

Assume glitch triggers initial nonaxisymmetric state

Solve linearised Navier-Stakes equations

Spin-Up Flow

Azimuthal velocity v_φ in rotating frame

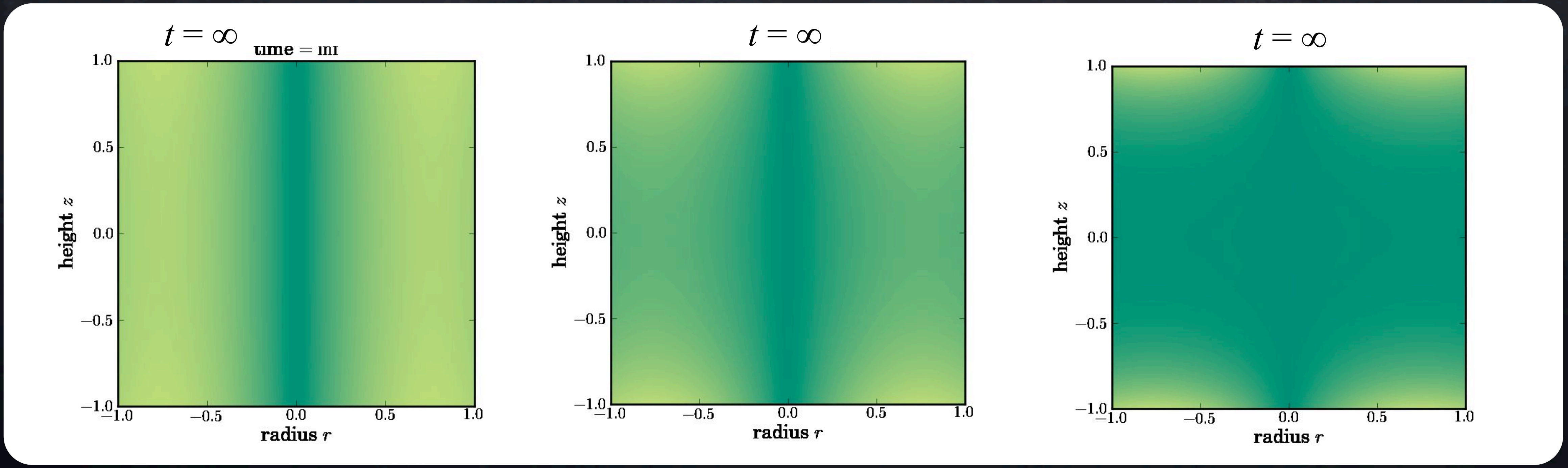


Spin-up Flow Penetration

Buoyancy force from stratification gradient opposes vertical flow along sidewall, reduces spin-up flow depth

Compression of fluid element decelerates vertical flow

Spin-up volume and time modified by interior properties



$N = 0.3$ $N = 1$ $N = 3$

Stratification (buoyancy) parameter

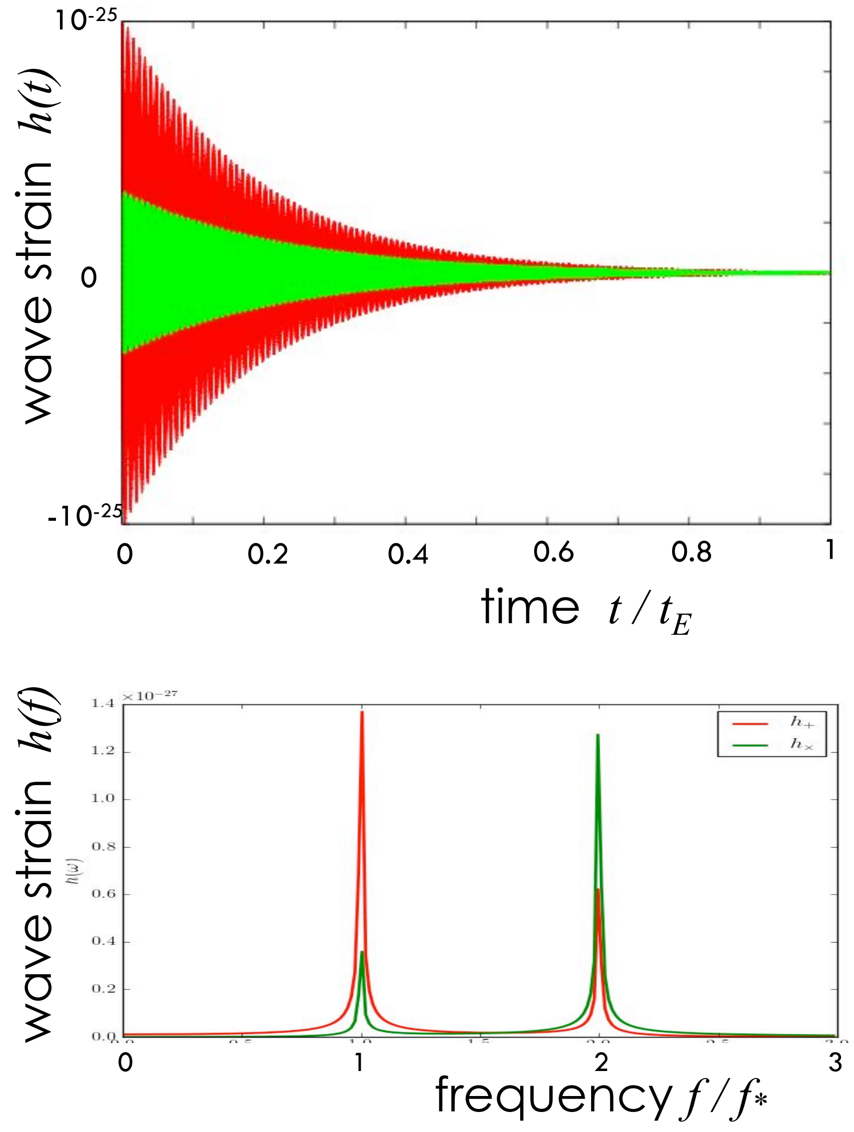
GW Signal

Nonaxisymmetric interior flow → gravitational radiation

Calculate GW signal from current quadrupole moment (mass quadrupole is smaller)

Signal at f_* and $2f_*$

Signal decays exponentially on modified Ekman (recovery) timescale



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

Detectability

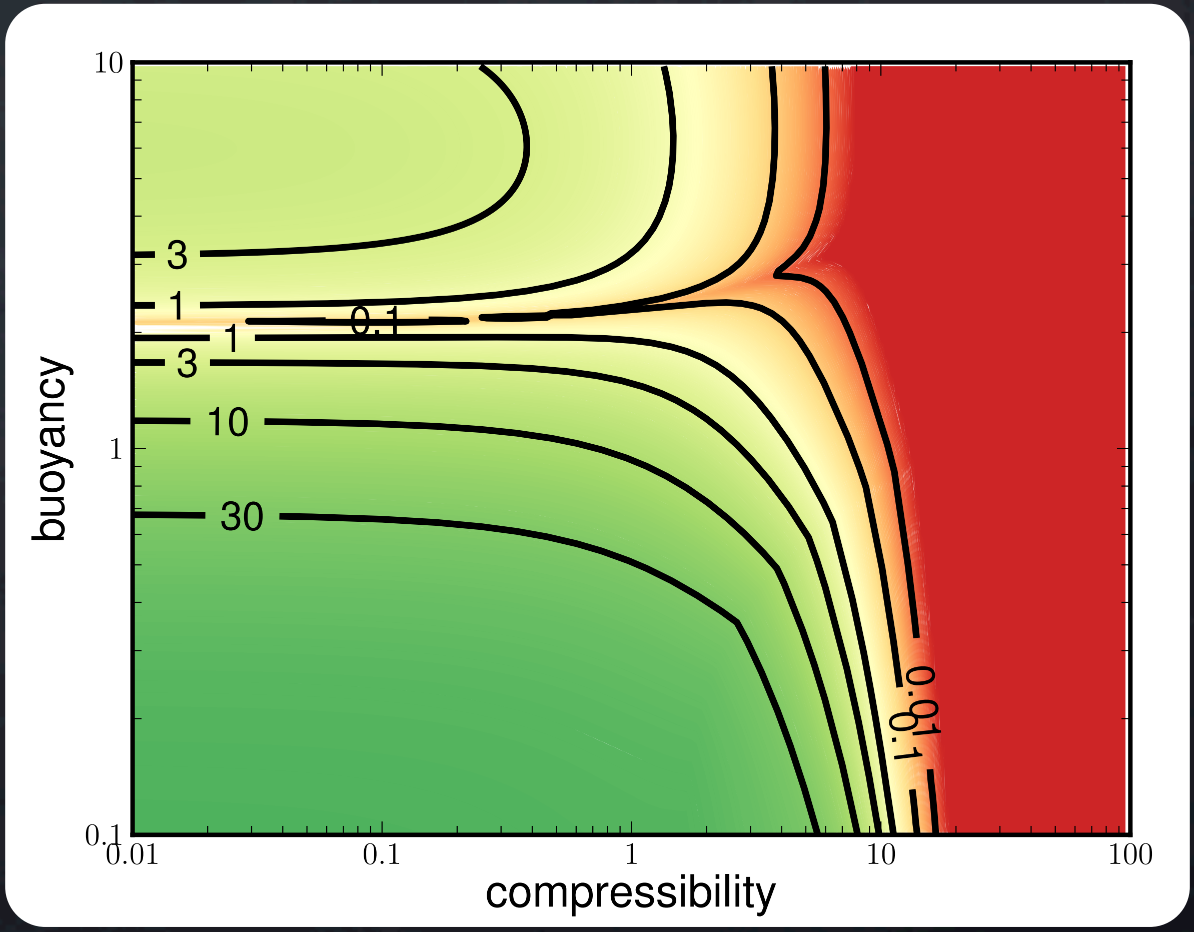
Radio observations trigger search and provide frequency

Coherent integration over recovery period

Average over sky position, polarisation angle and inclination angle

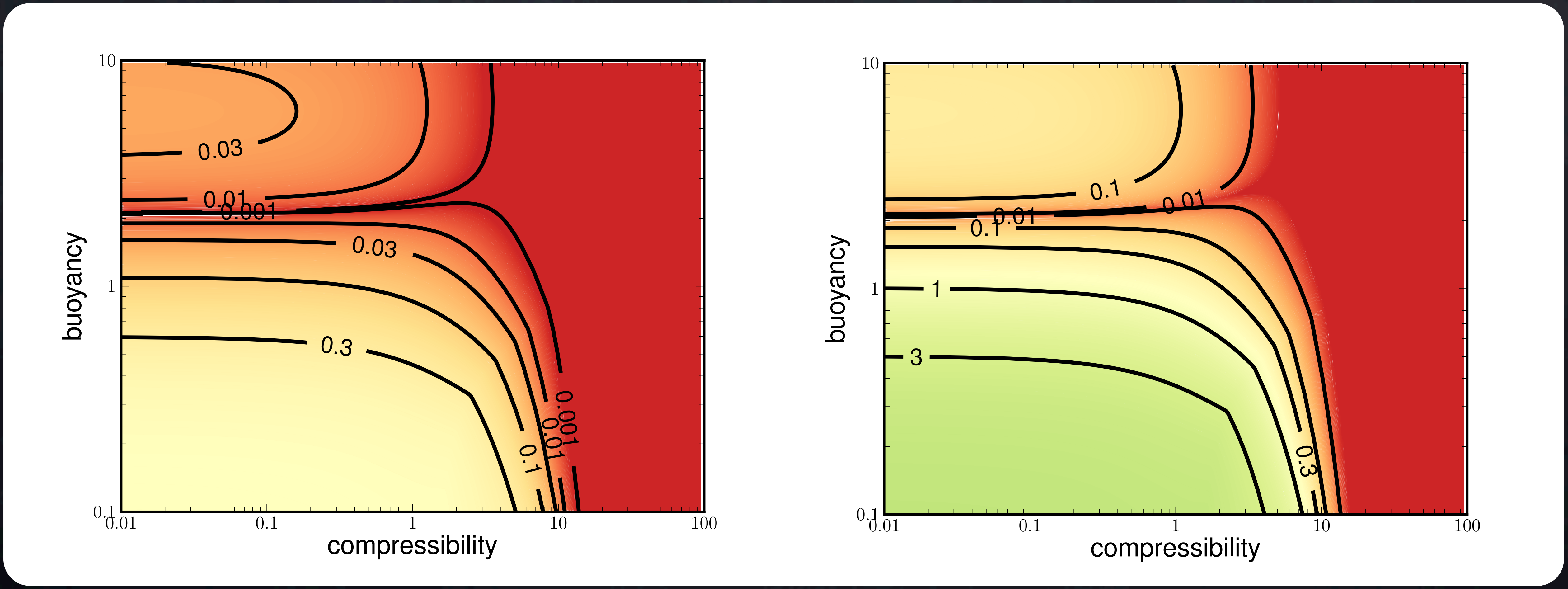
Source: distance = 1 kpc, $f_* = 100$ Hz, $\delta\Omega / \Omega = 10^{-4}$

Signal-to-noise ratio contours for ET



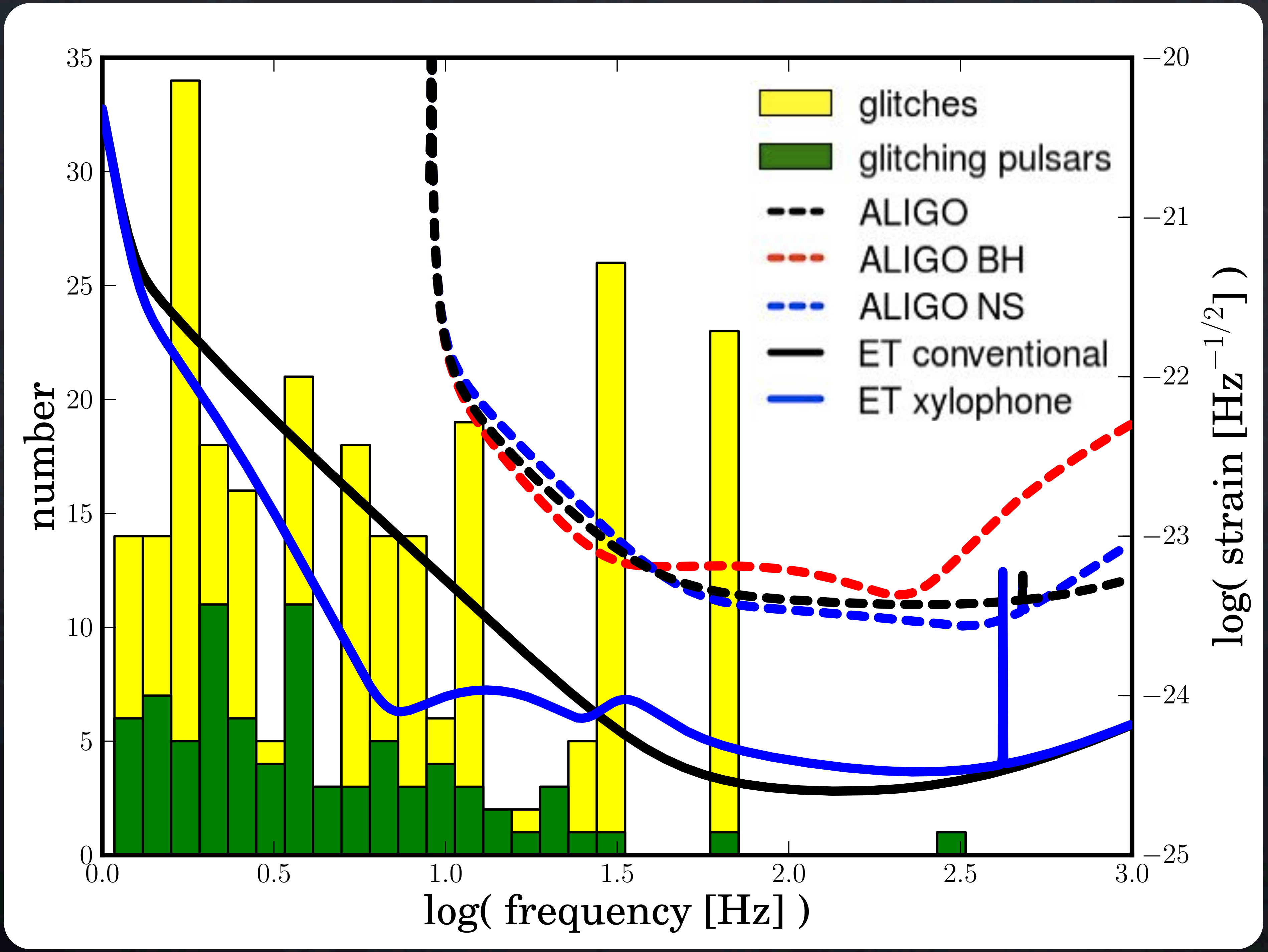
Detectability with LIGO

LIGO | Advanced LIGO



Source: distance = 1 kpc, $f_* = 100$ Hz, $\delta\Omega / \Omega = 10^{-4}$

ET vs LIGO


glitches
glitching pulsars
ALIGO
ALIGO BH
ALIGO NS
ET conventional
ET xylophone
number
log(frequency [Hz])
log(strain [Hz$^{-1/2}$])
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
2.0
2.5
3.0
−20
−21
−22
−23
−24
−25

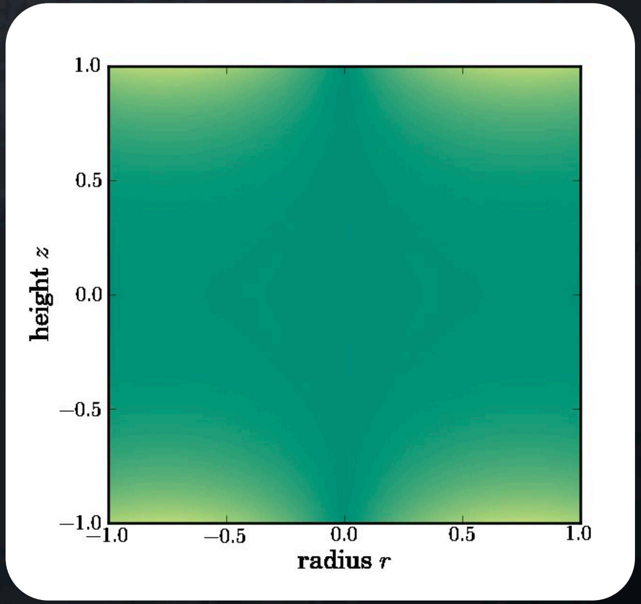
Remnant Flow & Unseen Glitches

10^9 galactic NS → many unseen glitches (285 glitches observed from ~ 2000 pulsars

Very difficult to search without EM trigger

Persistent GW signal in recently ($<10^4$ yr) differentially rotating NS?

Remnant flow contains information on rotation history of star?



Nuclear Equation of State

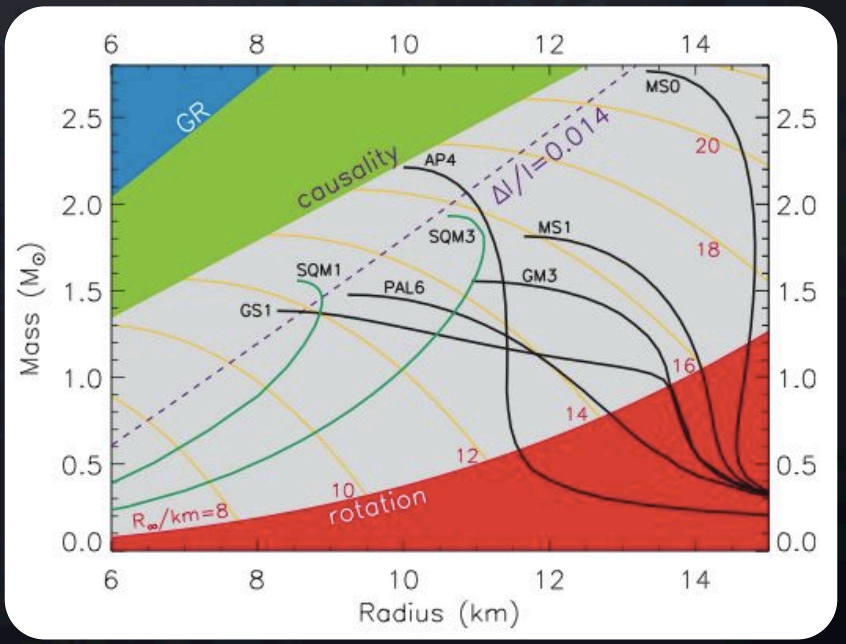
Terrestrial experiments:

Relativistic Heavy Ion Collider (RHIC)
Au+Au collisions at GeV energies
- high compressibility
- viscosity ≈ quantum lower bound

Parity Radius Experiment (PREx)
measure neutron skin thickness in lead

Astrophysical observations:

Simultaneous mass and radius measurement (~10^{57} neutrons, ~ MeV)



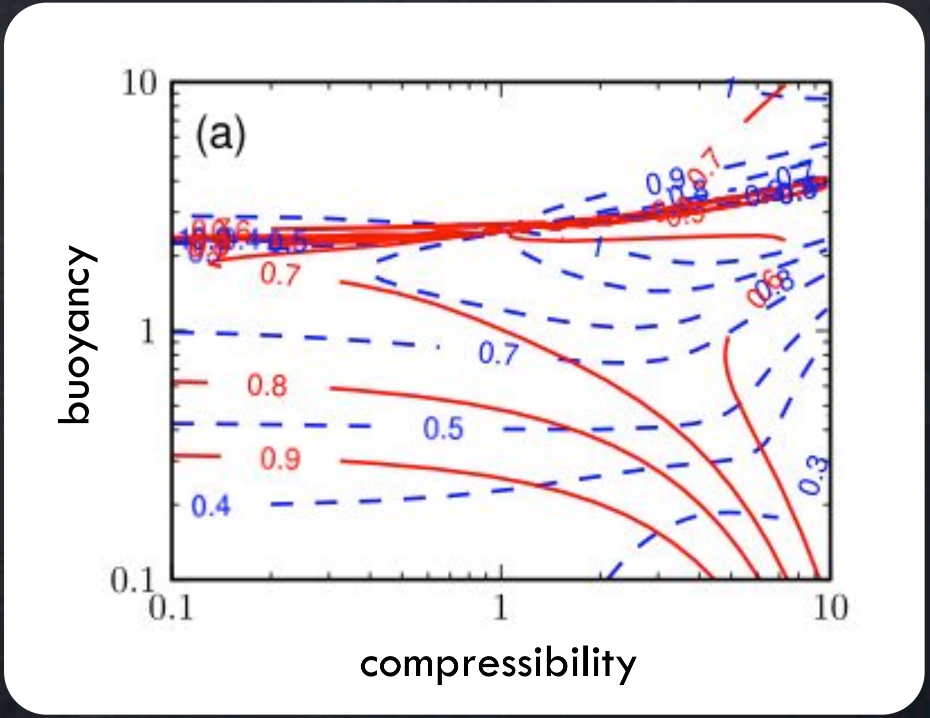
(Lattimer & Prakash 2004)

Extracting Nuclear Properties from GW

GW signal directly probes neutron star interior

Infer viscosity from the recovery timescale

Extract viscosity, compressibility, stratification and inclination angle from GW data



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

Summary

Pulsar glitches, or otherwise differentially rotating neutron stars, are a source of gravitational waves

Largest glitches detectable with ET

More glitches observed at lower frequencies (<40 Hz)
→ dual-band ‘xylophone’ configuration advantageous

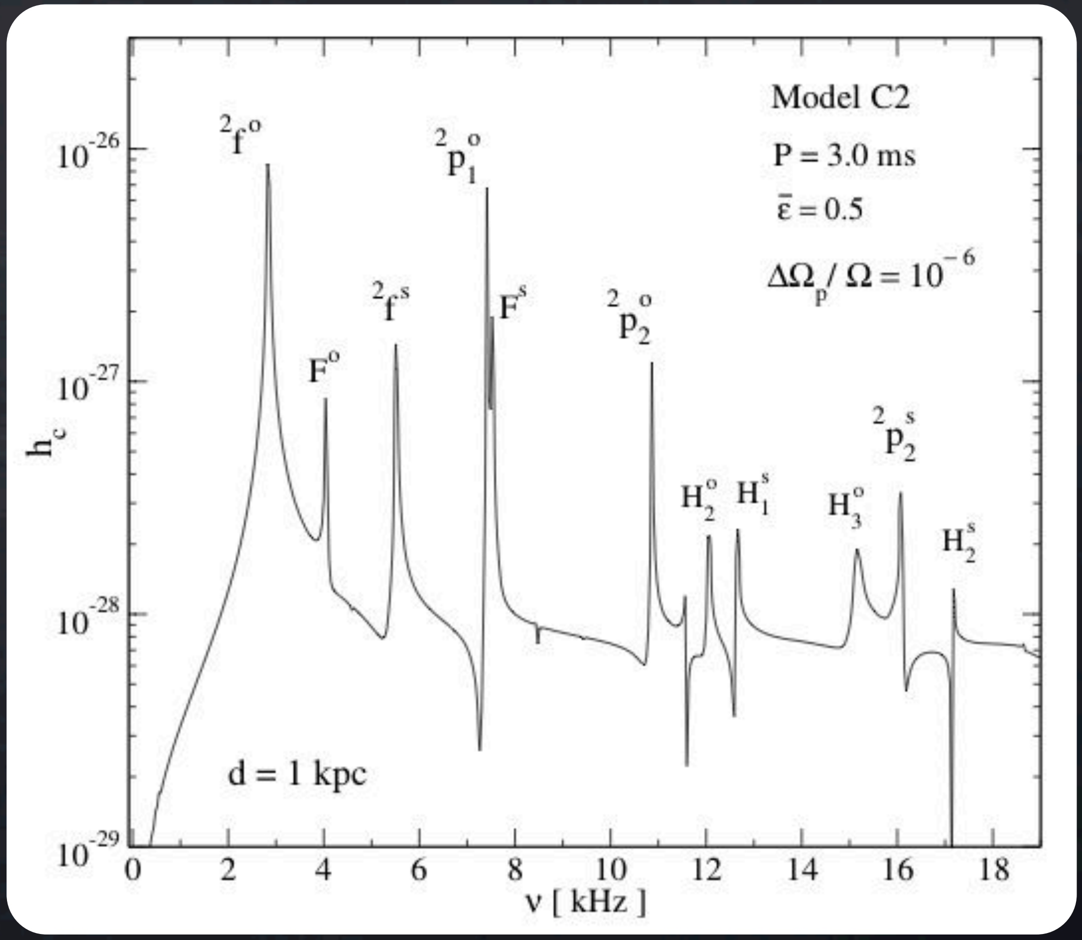
Extract properties of neutron star interior matter from future gravitational wave observations

Supplementary Slide

Burst signal:
Sidery, Passamonti & Andersson (2010)

Two fluid star, entrainment

Vibrational modes (f-mode, p-modes, etc) damped rapidly (seconds)



Sidery et al (2010)