High-Frequency Gravitational Waves from Phase Transitions in Nascent Neutron Stars

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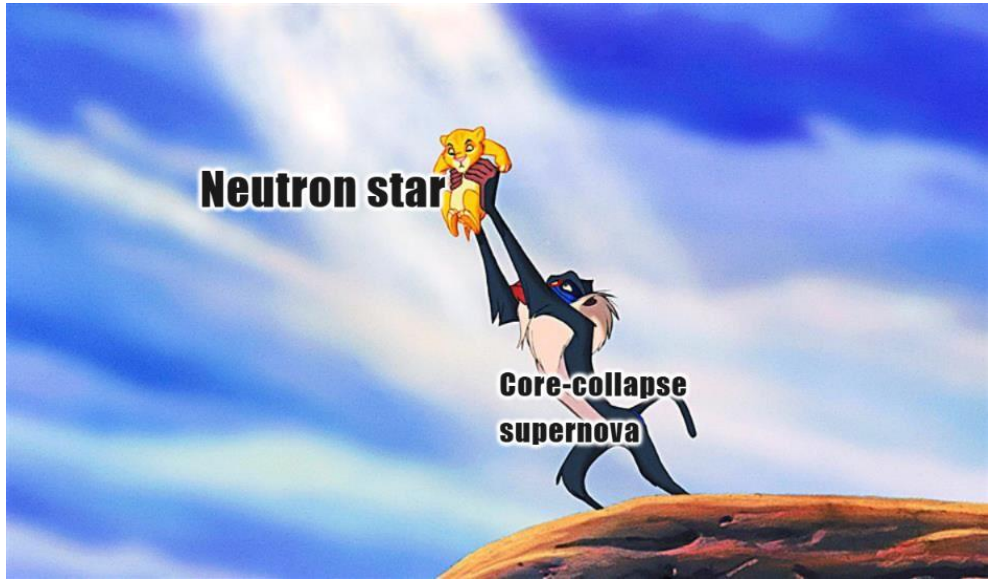
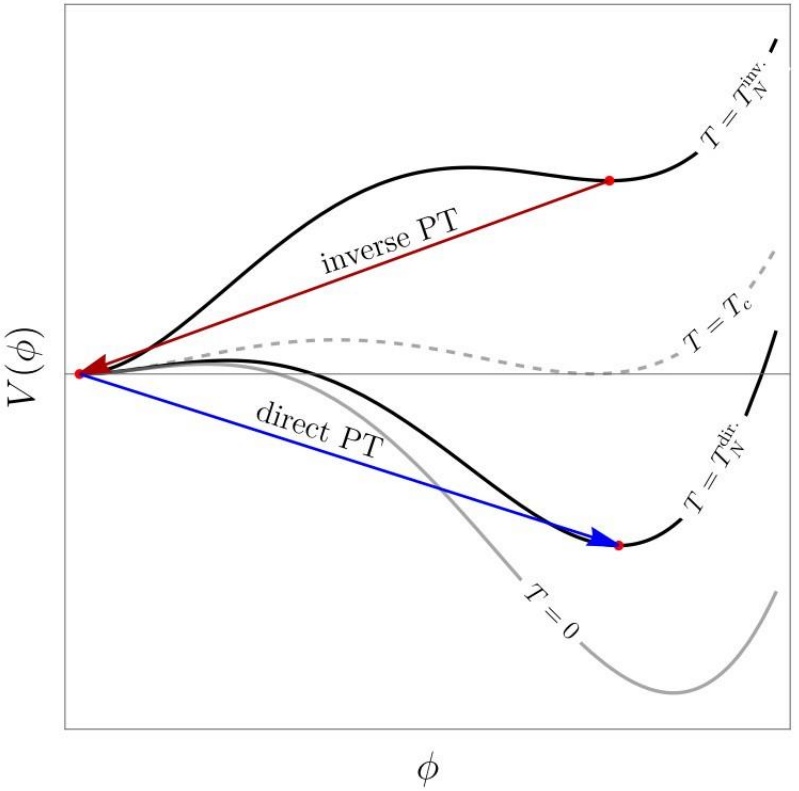
Introduction



- Core could consist of deconfined quark matter
- Phase transition from hadronic matter to quark-gluon plasma



Barni, Blasi, Vanvlasselaer, arXiv:2406.01596v2

- If 1st order, bubble nucleation => gravitational wave signal in MHz band
- Unique opportunity for high-frequency GW detectors to probe extreme regime of QCD

Characteristic Strain

$$h_c^2 = \frac{8\pi G}{2\pi^2}\frac{\rho_{GW}}{f_p^2}$$

$$h_c^2 = \frac{(8\pi G)^2}{2\pi^2}\frac{1}{f_p^2}(e+p)^2 \bar{U}_f^{\,4} t R \tilde{\Omega}_{GW}$$

- Peak frequency (~MHz, depends on bubble separation)
- Energy density and pressure (from neutron star equation of state)
- Root mean square fluid velocity (from bubble dynamics and phase transition strength)
- Time duration of the source (min. of light crossing time and shock formation time)
- Mean bubble separation (from timescale of phase transition and bubble wall velocity)
- Efficiency of gravitational waves from sound waves (from previous numerical simulations)

Also:

- Suppressed if phase transition is stalled/incomplete

Pipeline

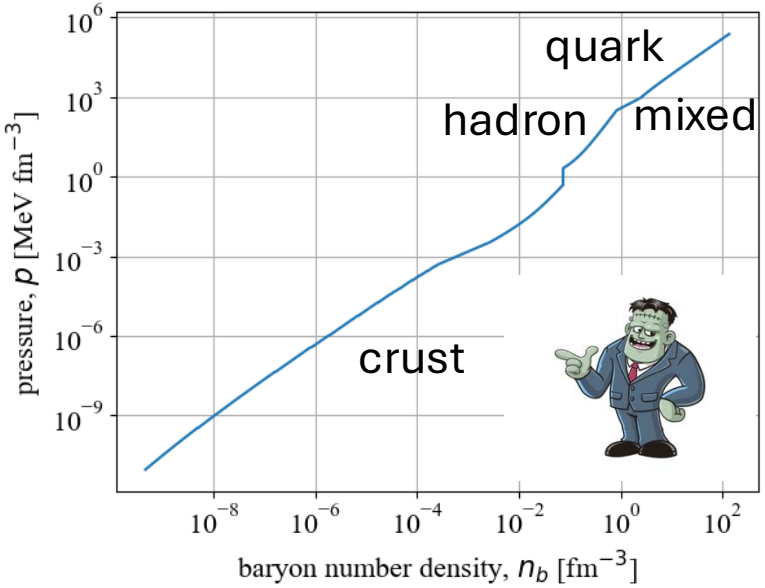
Define equation of state

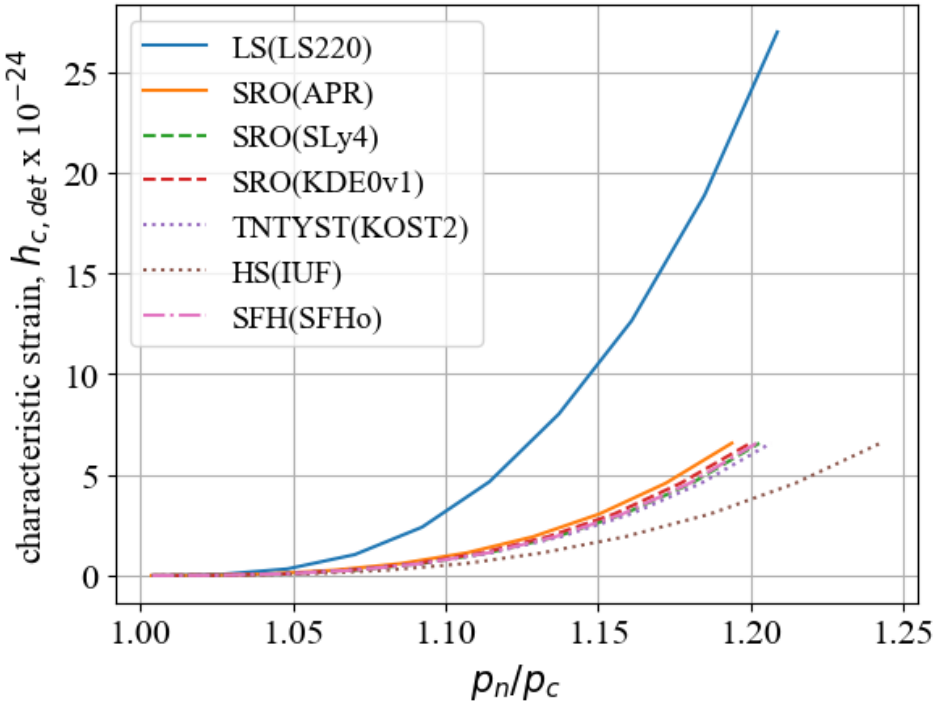
(critical pressure, phase transition strength, input for TOV solver)

Solve TOV equations

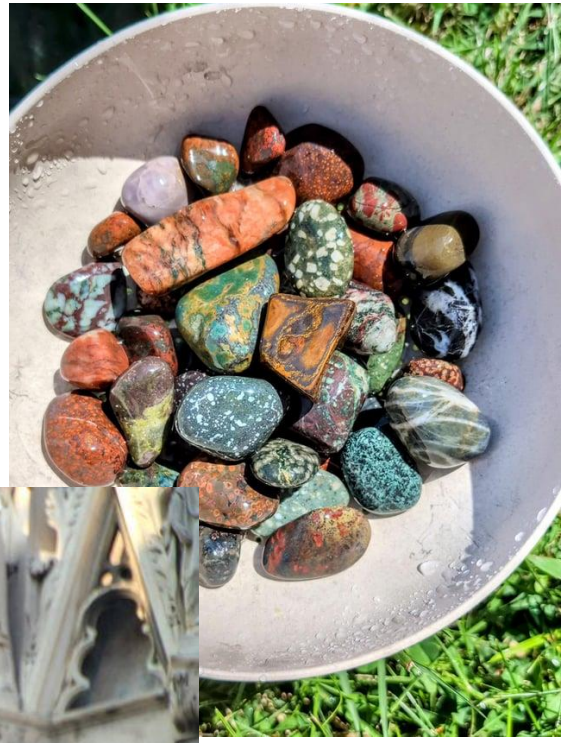
(mass-radius relation, size of quark core)

Calculate bubble wall velocity



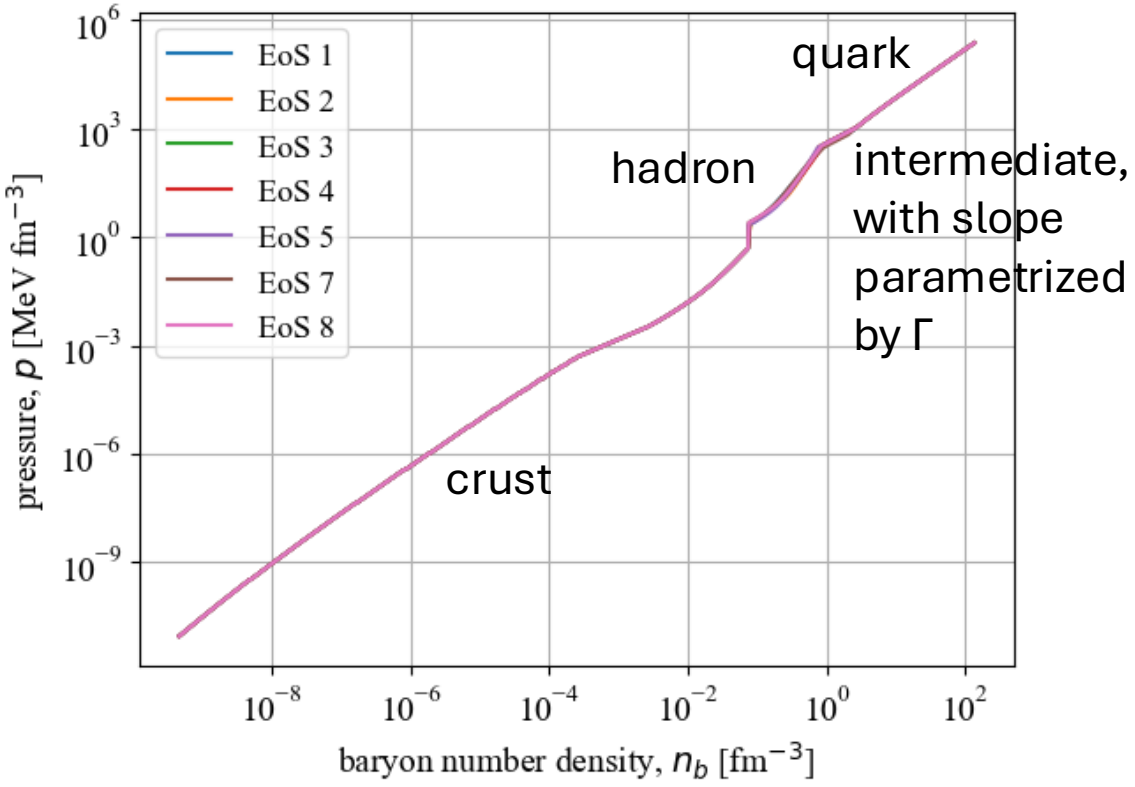


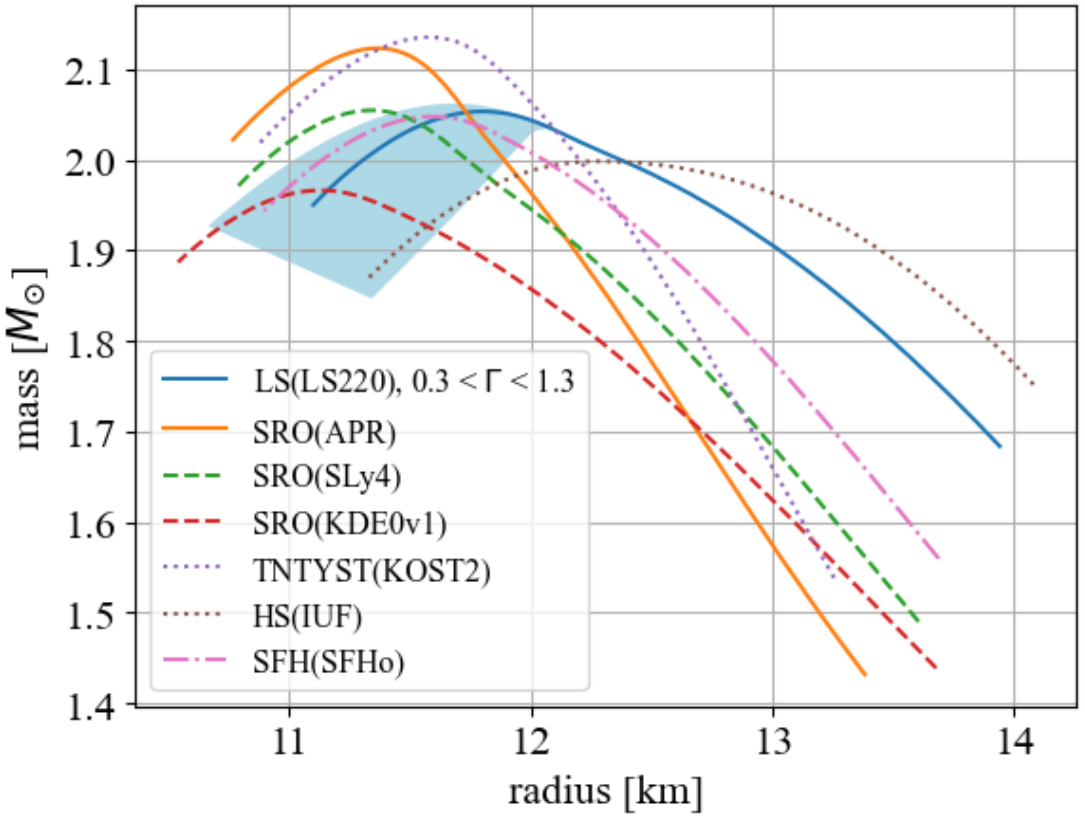
Thank you!

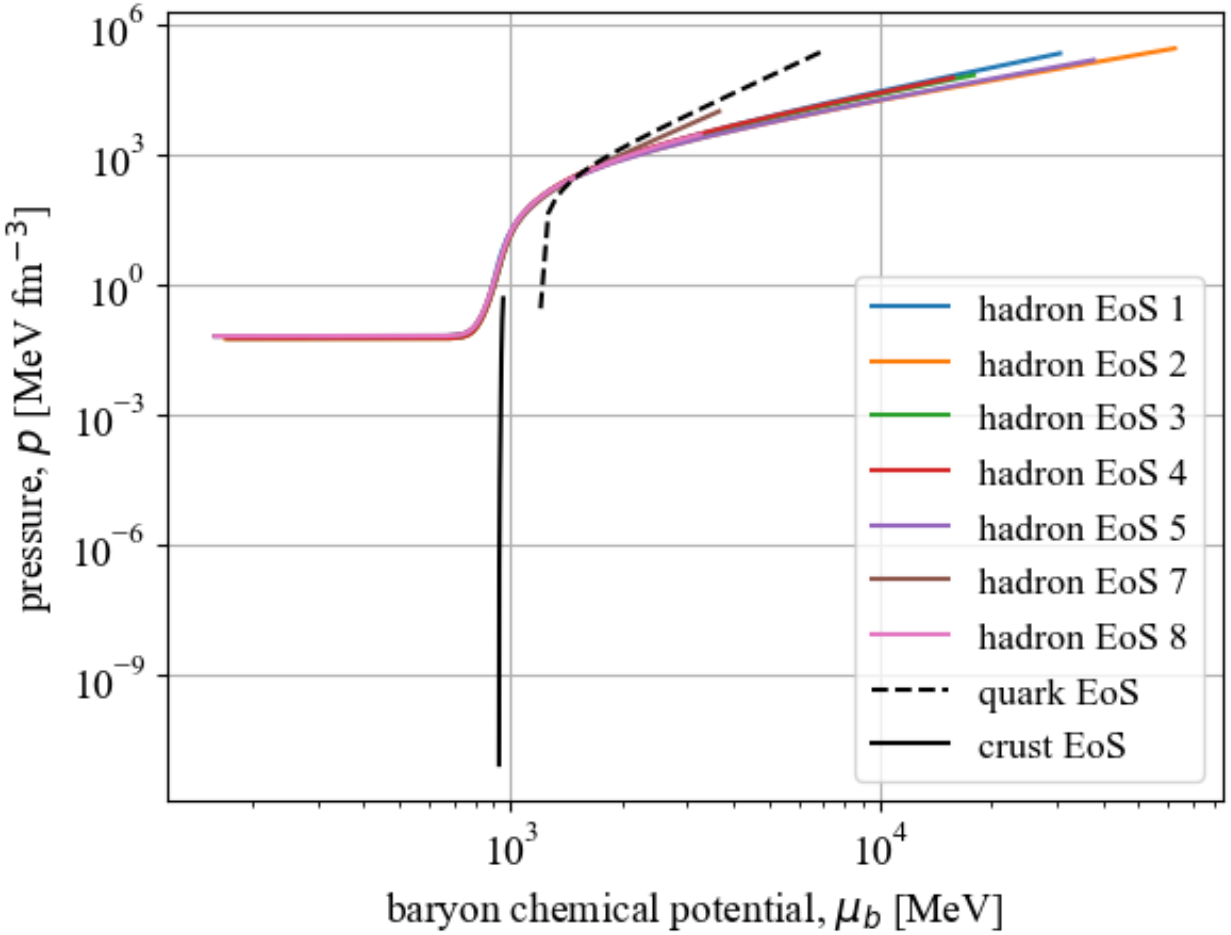


Neutron Star Model

- Need equation of state (EoS) to determine relation between pressure, energy density, baryon number density, and chemical potential
- Solve Tolman–Oppenheimer–Volkoff equations to get mass-radius relation and size of quark core






pressure, p [MeV fm^{-3}]
10^{6}
10^{3}
10^{0}
10^{-3}
10^{-6}
10^{-9}
10^{3}
10^{4}
baryon chemical potential, μ_b [MeV]
hadron EoS 1
hadron EoS 2
hadron EoS 3
hadron EoS 4
hadron EoS 5
hadron EoS 7
hadron EoS 8
quark EoS
crust EoS