Continuous Gravitational Waves and SETI

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Continuous GW and SETI

- The search for natural continuous gravitational wave signals
- Speculate briefly on artificial GW transmitters.
- Focus on ground based detector frequency band from 10 Hz to few kHz.

These are historic times with the opening of the gravitational wave sky

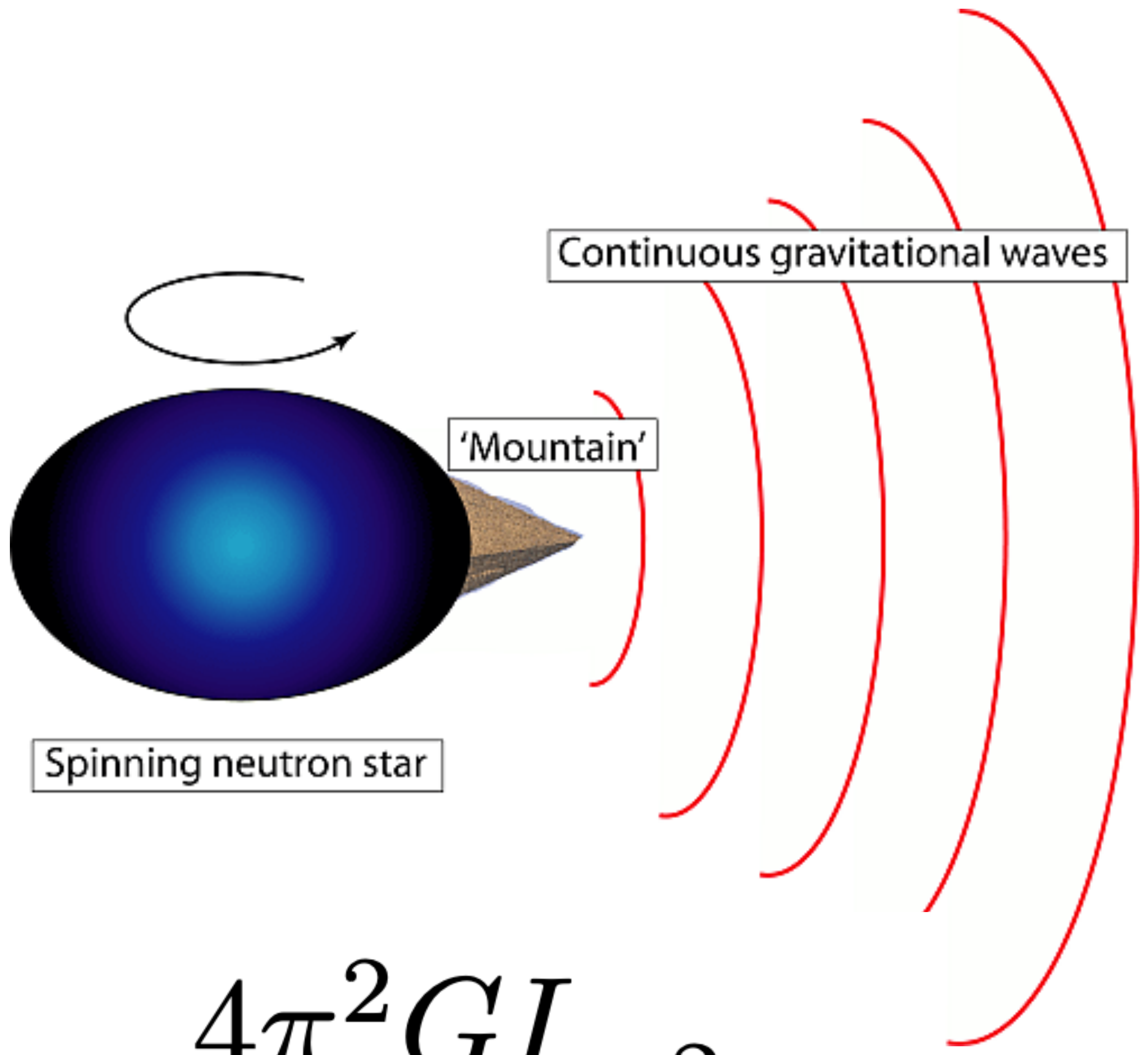
Galileo's Sky
Telescopes opened vast EM sky for 4 centuries.

Gravitational Wave Sky
Seen mergers of black holes and neutron stars

What else is out there?
Galileo discovered mountains on the moon. Can we find mountains on neutron stars?

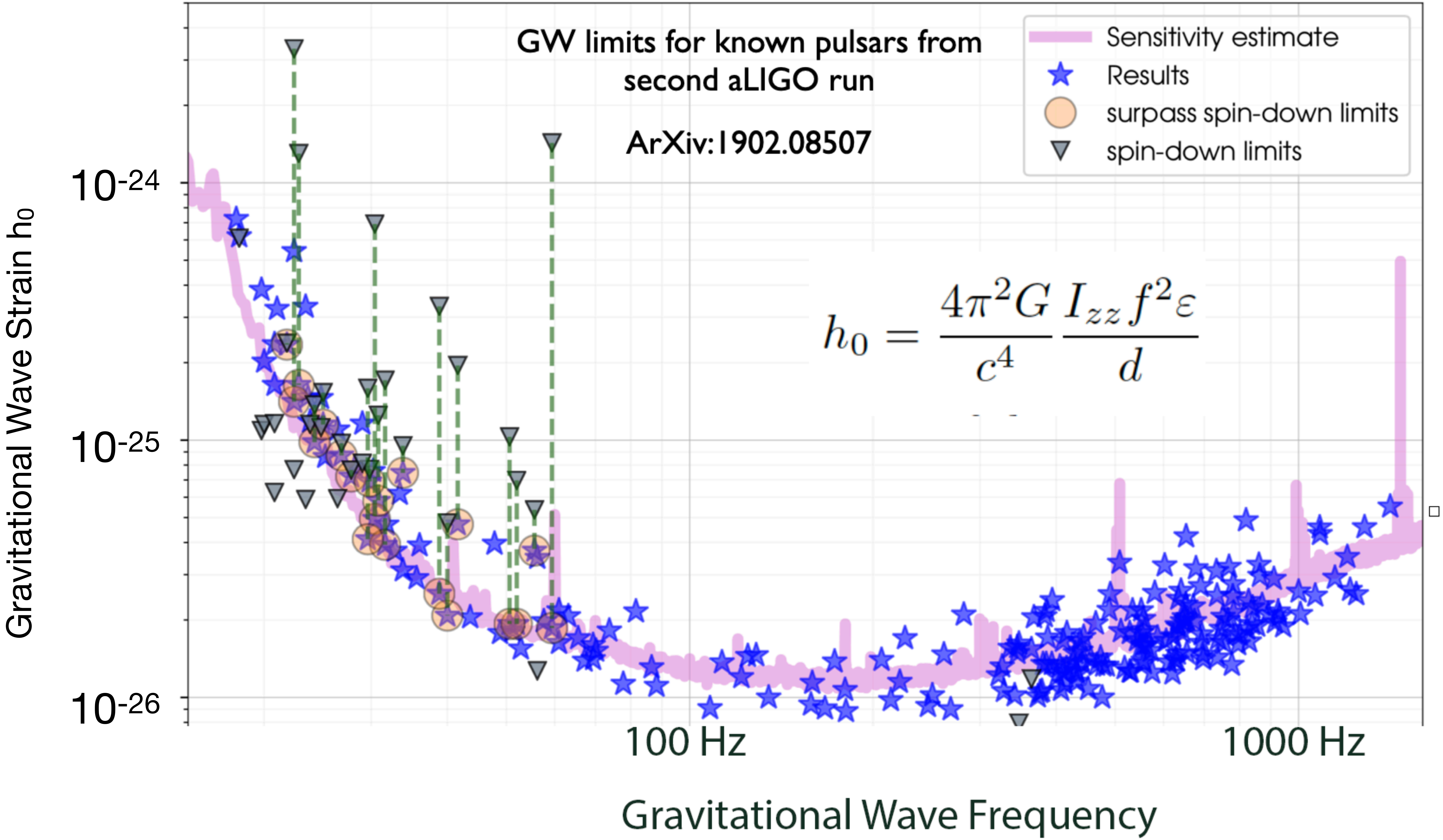
Gravitational waves from NS mountains

- Rotating, non-axisymmetric neutron star efficiently radiates gravitational waves.
- GW strain h_0=ΔL/L depends on GW frequency f_{GW} (twice rotational f) and distance to star *d*.
- Important unknown is **ellipticity** ε. Fractional difference in moments of inertia (z is rot. axis)
- Many ongoing searches for GW from known and unknown NS. Often computationally limited.
- Gain sensitivity to weak signals by integrating ***coherently*** for long observation times.



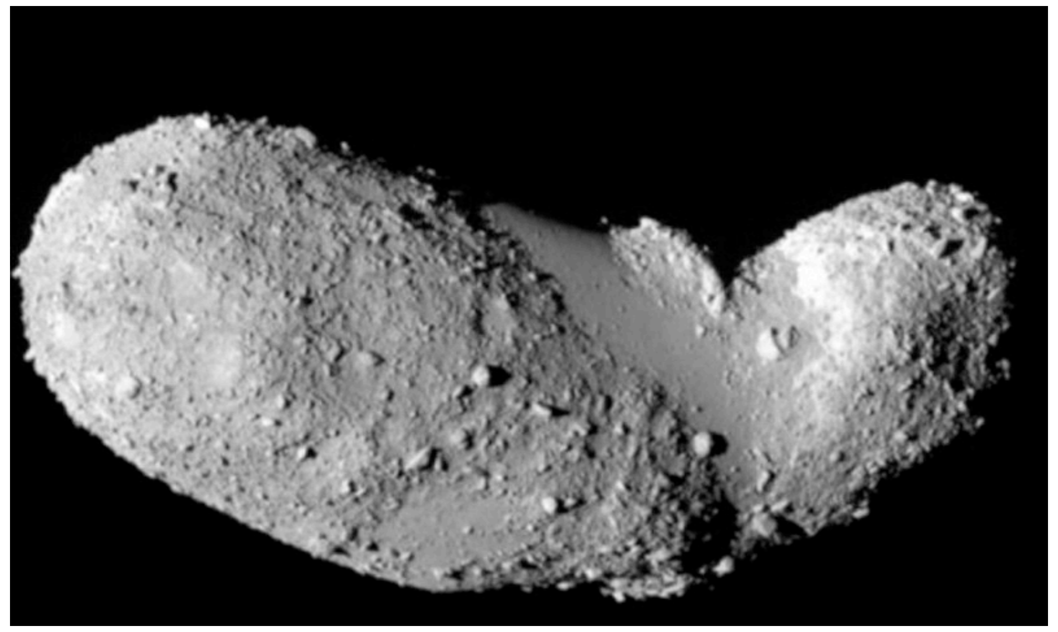
$$h_0 = \frac{4\pi^2 G I}{c^4 d} f_{GW}^2 \varepsilon$$

$$\varepsilon = \frac{I_{xx} - I_{yy}}{I_{zz}}$$

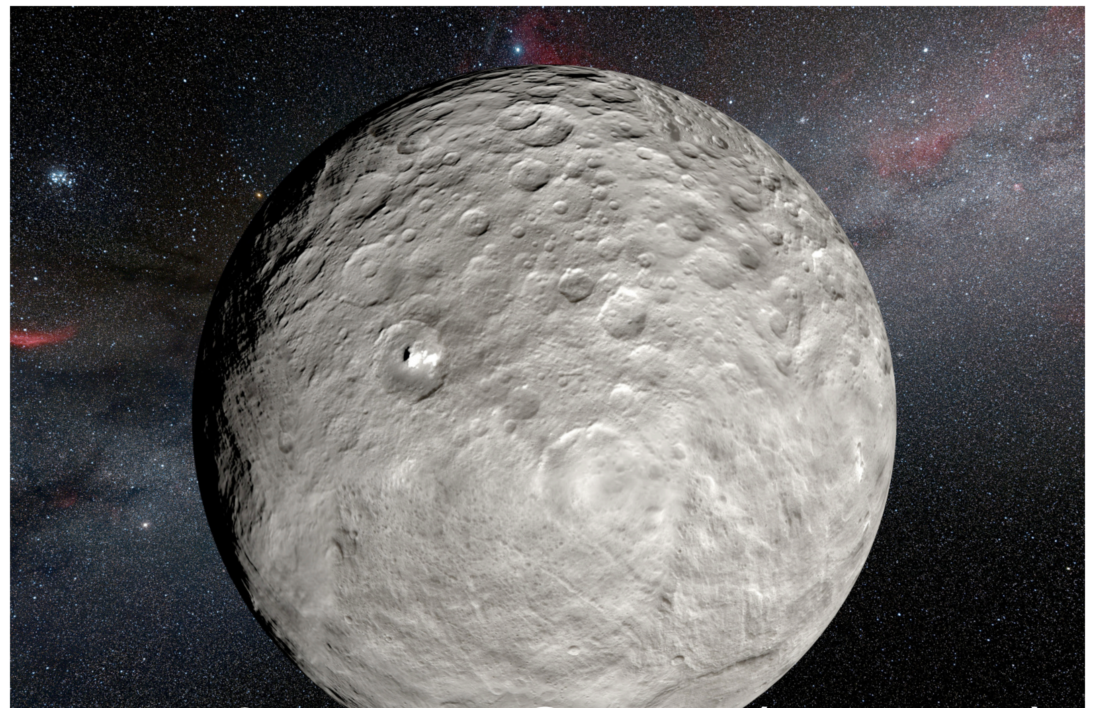

GW limits for known pulsars from second aLIGO run
ArXiv:1902.08507
Sensitivity estimate
Results
surpass spin-down limits
spin-down limits
$$h_0 = \frac{4\pi^2 G}{c^4} \frac{I_{zz} f^2 \varepsilon}{d}$$
10^{-24}
10^{-25}
10^{-26}
Gravitational Wave Strain h_0
100 Hz
1000 Hz
Gravitational Wave Frequency

Maximum ellipticity

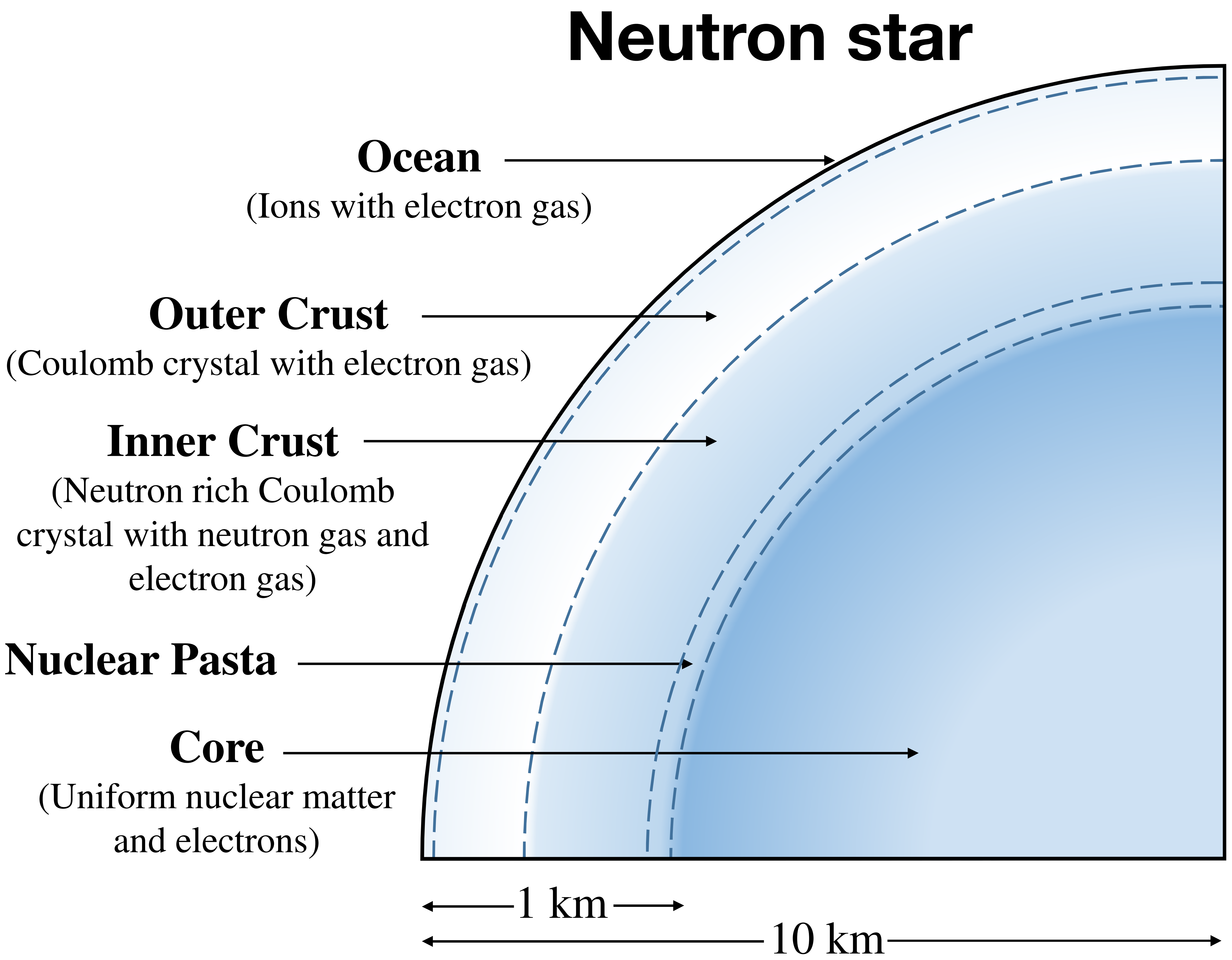
- Maximum ellipticity of a body is ~strength of rocks / strength of gravity.
- Example: asteroids with weak gravity can have large ellipticity while dwarf planets have strong gravity and a small ellipticity.
- NS crust can support $\varepsilon \sim 10^{-6}$ [PRL**121**, 132701].
- GW transmitter depends on ***material strength.*** Put mass on a stick and shake vigorously. Need both a large mass and a strong stick.



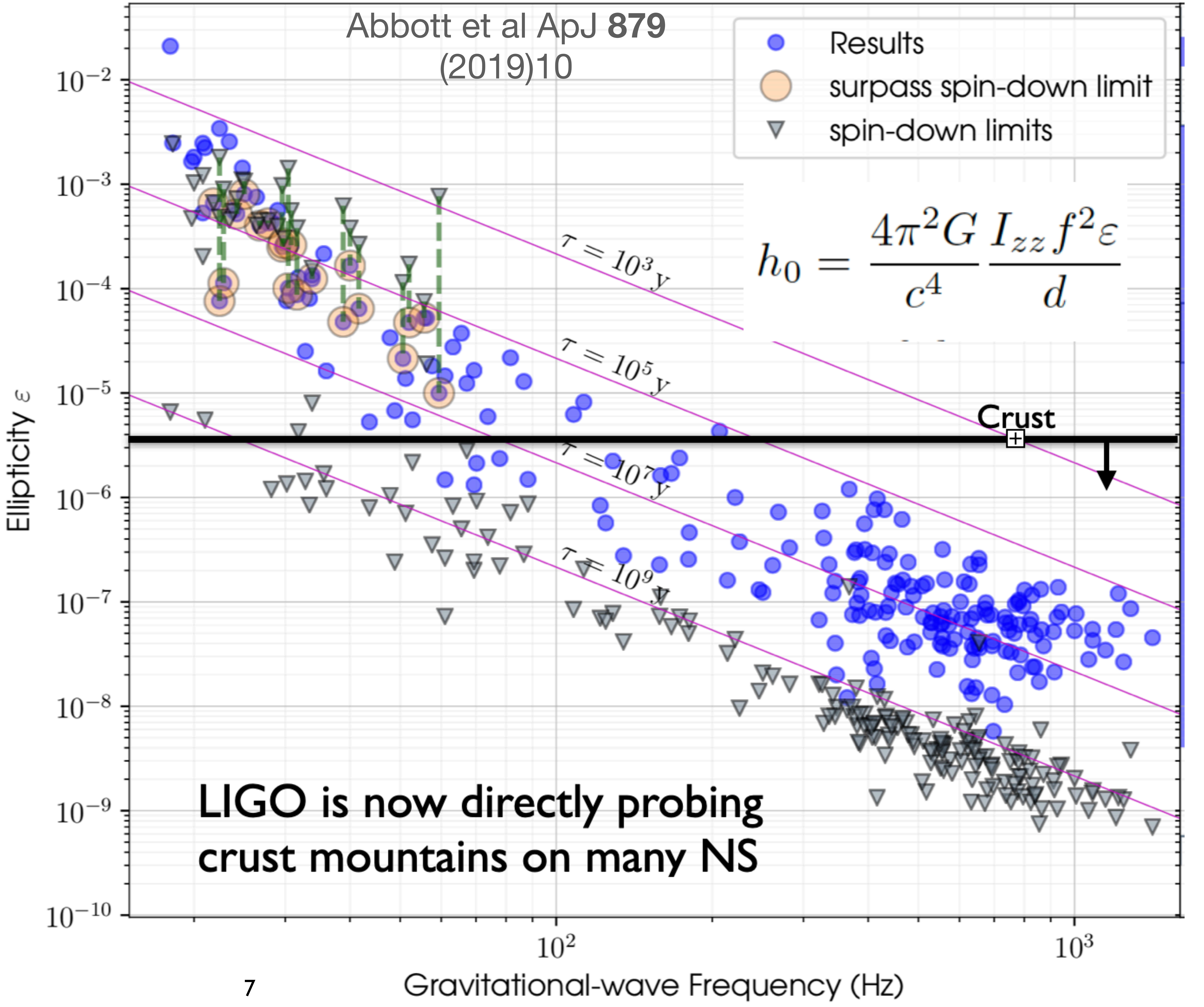
Asteroid Itokawa (~300 m)



Dwarf planet Ceres (940 km)



- **Maximum possible 'mountain'**: depends on strength of the crust. Our crust can support **ϵ < few x 10^{-6}**.
- **Mountain building mechanisms**: does nature actually build big mountains on a given star? Hard astrophysical, planetary science … problem.
- **Many ongoing LIGO searches** for continuous GW from rotating NS. No detections yet. Best present GW limit $\varepsilon<6\times10^{-9}$. This is significantly smaller than maximum possible mountain.



Match Filter Searches

- Need a very detailed model of GW signal in order to find it. Can only find what you know to look for!

- Know or guess **many parameters**: frequency (f_0), spin down (f'), 2nd derivative (f"), sky position (Ra, Dec to remove doppler shifts), orbital parameters for binary system …

- Need accuracy within one rotation over ~ 1 year observing time (~100 Hz for 10^7 sec -> need 1 part in 10^9). Can require very large number of trials.

- Alternatively, less sensitive **partially coherent search** with shorter coherence time and adding additional data incoherently.

What is Einstein@Home?

Einstein@Home uses your computer's idle time to search for weak astrophysical signals from spinning neutron stars (often called pulsars) using data from the LIGO gravitational-wave detectors, the MeerKAT radio telescope, the Fermi gamma-ray satellite, as well as archival data from the Arecibo radio telescope.

Learn more

JOIN NOW

User of the day
JERICKO

Over 500,000 volunteers and counting.
WINDOWS MAC LINUX

Einstein@Home Progress
(Credits per day)

Update On "Einstein@Home: Pulsar Seekers"
March 14, 2025

Dear Einstein@Home volunteers,

You may remember that we...

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Einstein@Home Is Twenty Years Old Today!
February 19, 2025

I want to congratulate all of our Einstein@Home volunteers, developers, and scientists: our project is 20 years old today. We officially launched ...

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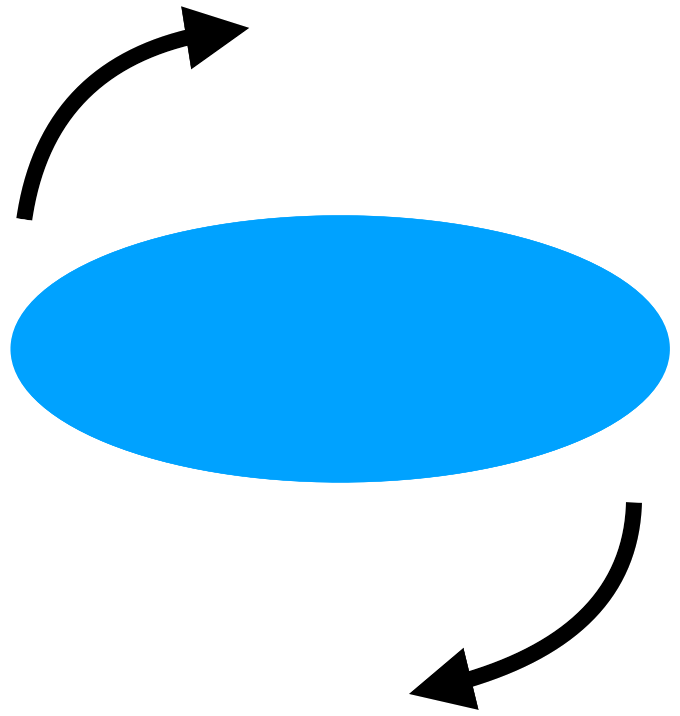
Artifical GW Transmiter

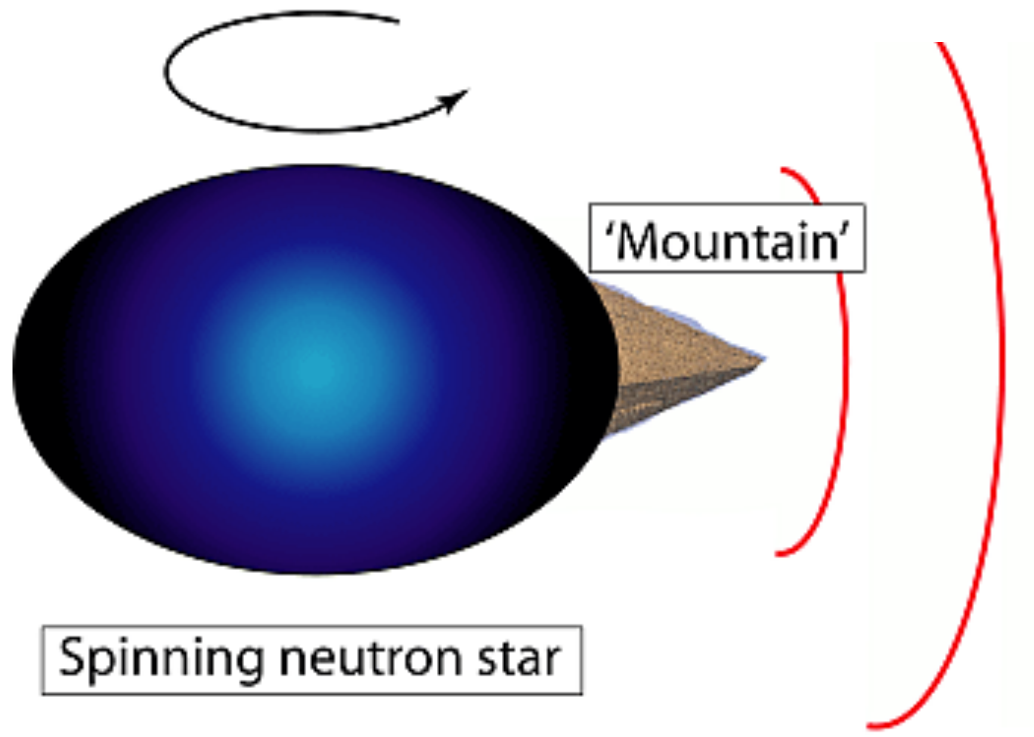
- Signal falls as 1/distance, helps very long distance communication.
- A massive deformed rotator is a GW transmitter. Need large mass, high density and great mechanical strength. May not need much power to keep rotating. (Millisecond pulsars can keep spinning for billions of years.)



- Perhaps change moment of inertia to frequency modulate the signal.
- You won't like the required mass, density, and strength of the rotator!
- Focused on frequencies > 10 Hz for ground based detectors. Space based (LISA) or Lunar detectors sensitive to lower frequencies.

Continuous GW and SETI

- Rotating neutron stars with small deformations are promising sources of continuous GW.
- Many ongoing searches of LIGO data for continuous GW signals. No detections yet.
- Need to know or guess many parameters to find signal.
- Can SETI expertise help us find these very weak and very unknown signals? Or will we fail because of limitations of our imagination?



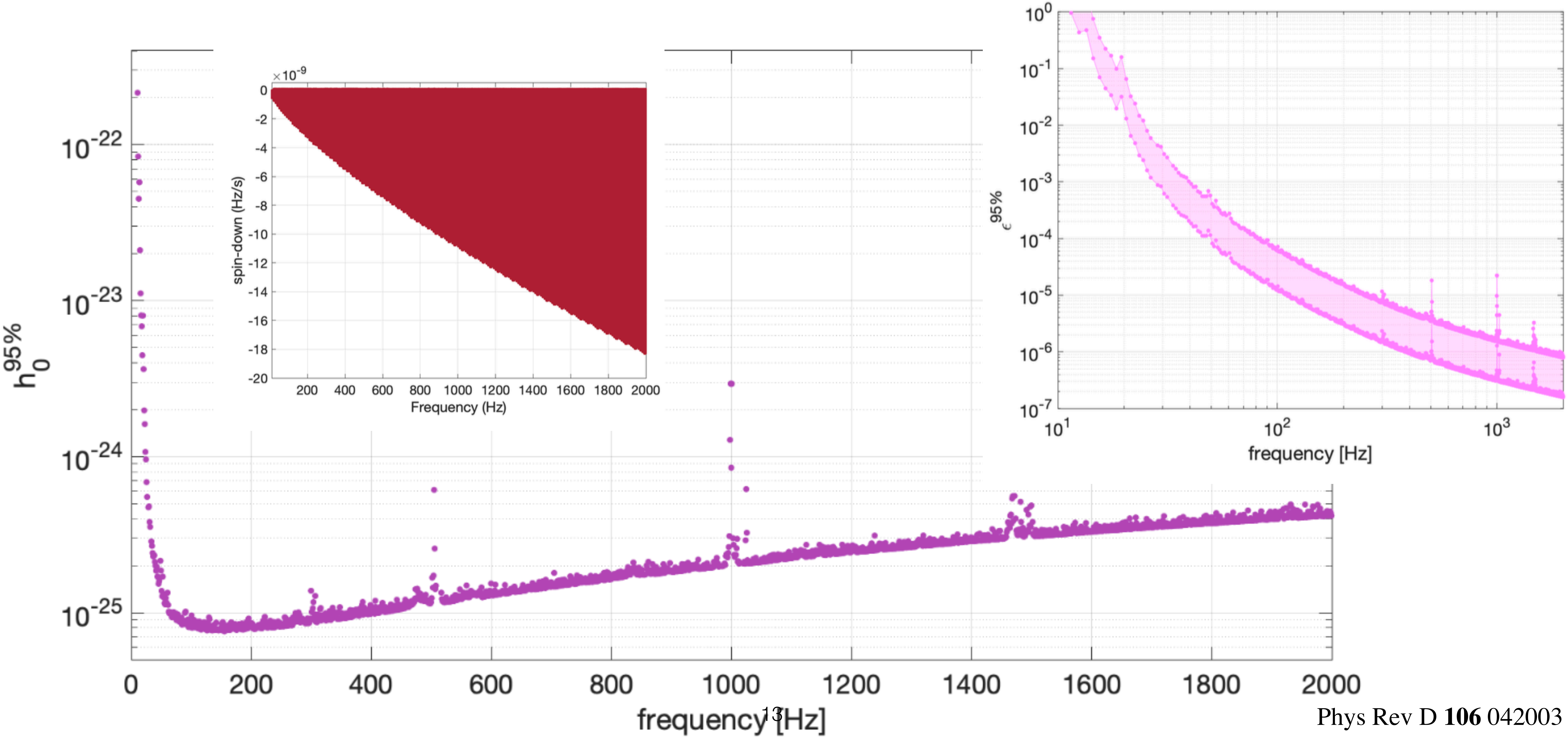
Unknown Neutron Stars

- Can search for known NS with known parameters (easiest), or known directions (such as galactic enter) with unknown parameters (frequency…) or unknown stars with unknown parameters (hardest).

- Only know a few thousand NS (mostly radio pulsars) out of ~10^8 NS in galaxy. Vast majority of galactic NS unknown.

- Variety of different kinds of NS with tradeoffs for GW searches: young and energetic (Crab), fast spinning recycled, rapidly accreting, unknown (very numerous)…

GW from Galactic Center



Phys Rev D **106** 042003

Searches for Continuous-Wave Gravitational Radiation

- Keith Riles

- Now that detection of gravitational wave signals from the coalescence of extra-galactic compact binary star mergers has become nearly routine, it is intriguing to consider other potential gravitational wave signatures. Here we examine the prospects for discovery of continuous gravitational waves from fast-spinning neutron stars in our own galaxy and from more exotic sources. Potential continuous-wave sources are reviewed, search methodologies and results presented and prospects for imminent discovery discussed.

- Living Reviews in Relativity. 176 pages, 39 figures

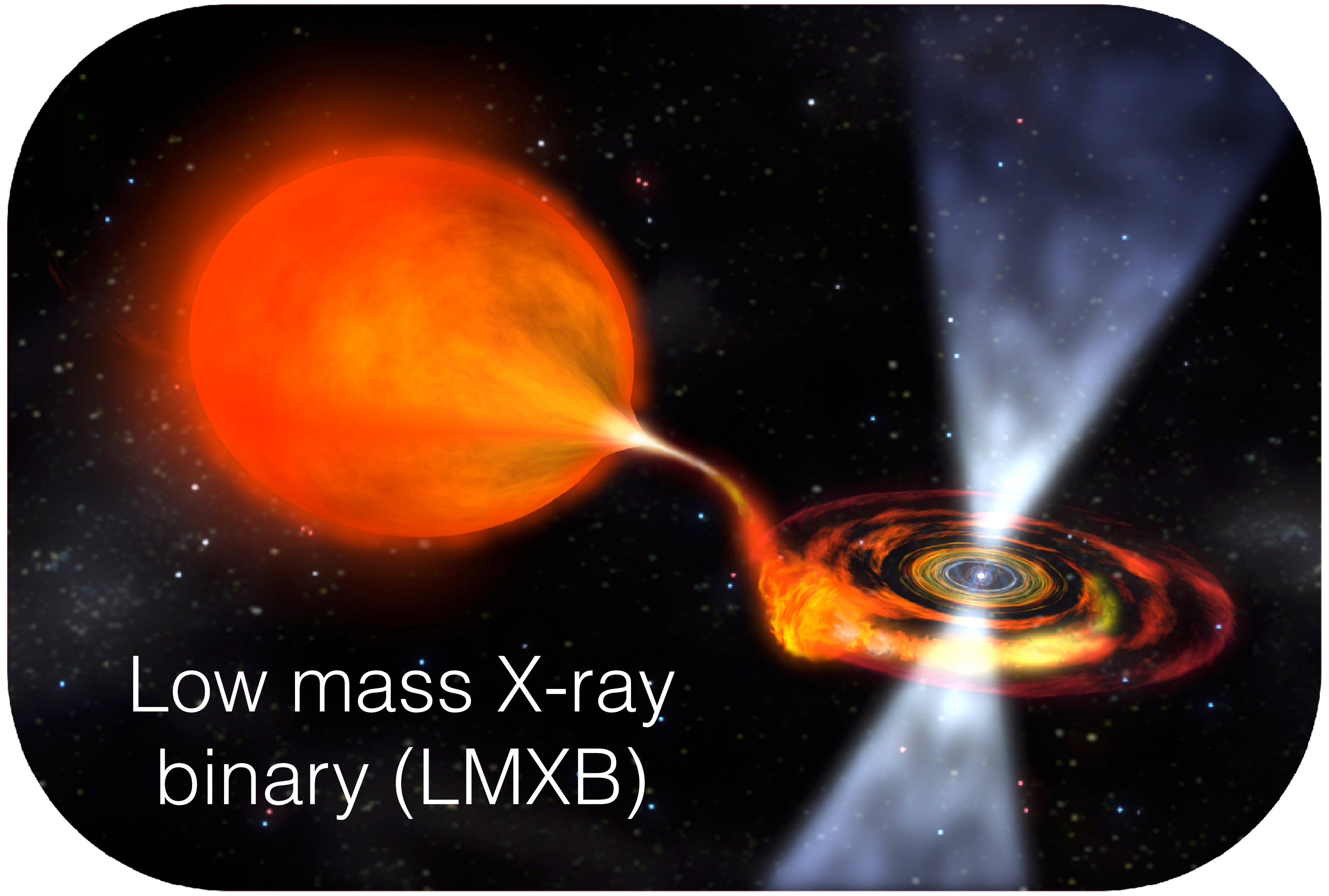
- arXiv:2206.06447

Why don't NS spin faster?

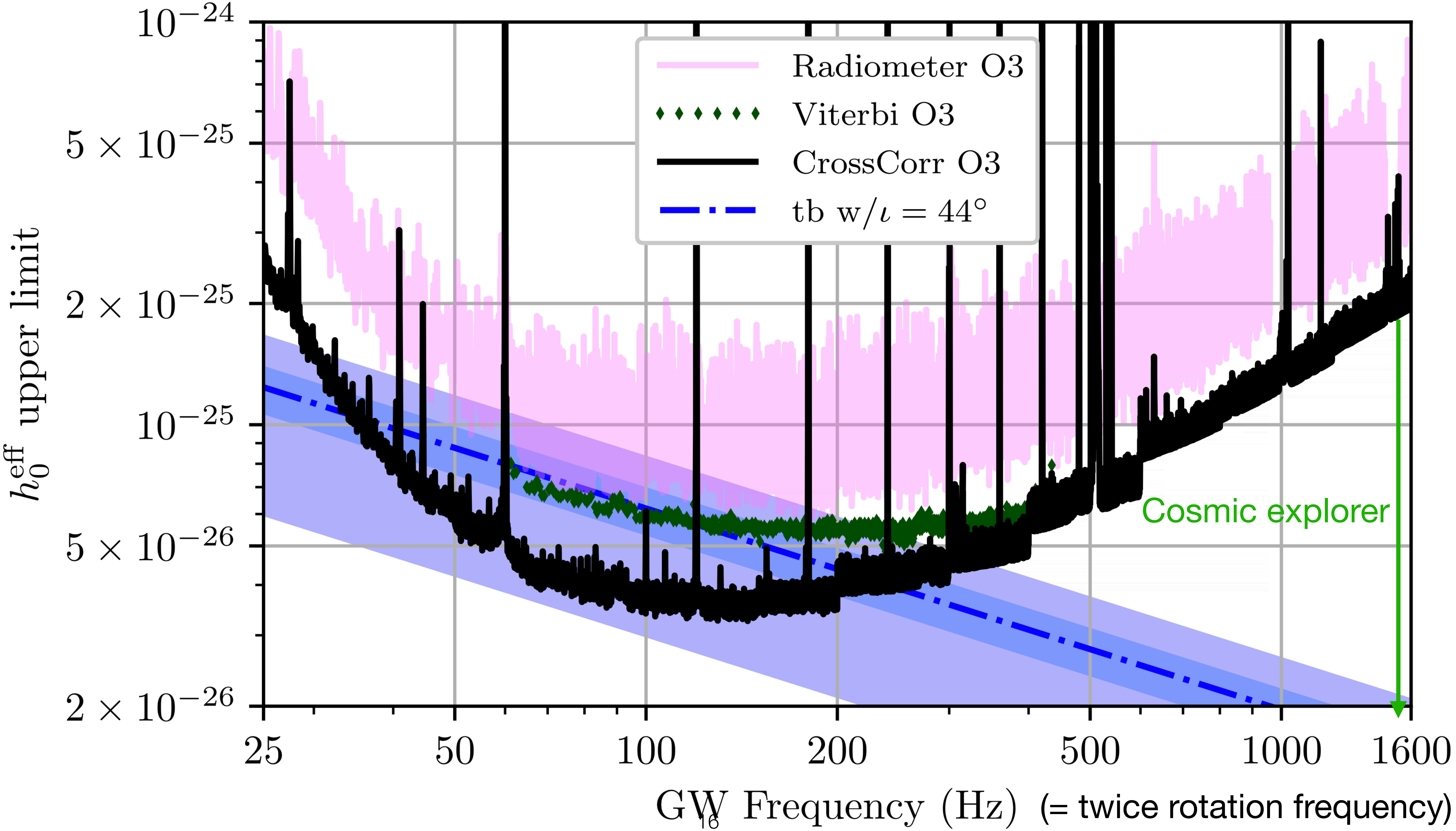
- Fastest observed star spins at 716 Hz. This is about 1/2 of Kepler breakup frequency (where centrifugal force balances gravity).

- Accretion spins up neutron stars until the crust *breaks*. Hypothesis: This broken crust is *deformed* with a nonzero quadrupole moment so gravitational wave radiation prevents the star from spinning up further.

- Finite element simulations find crust breaks near observed speeds. *ApJL* **978** L8 (2025) with **Jorge Morales**.



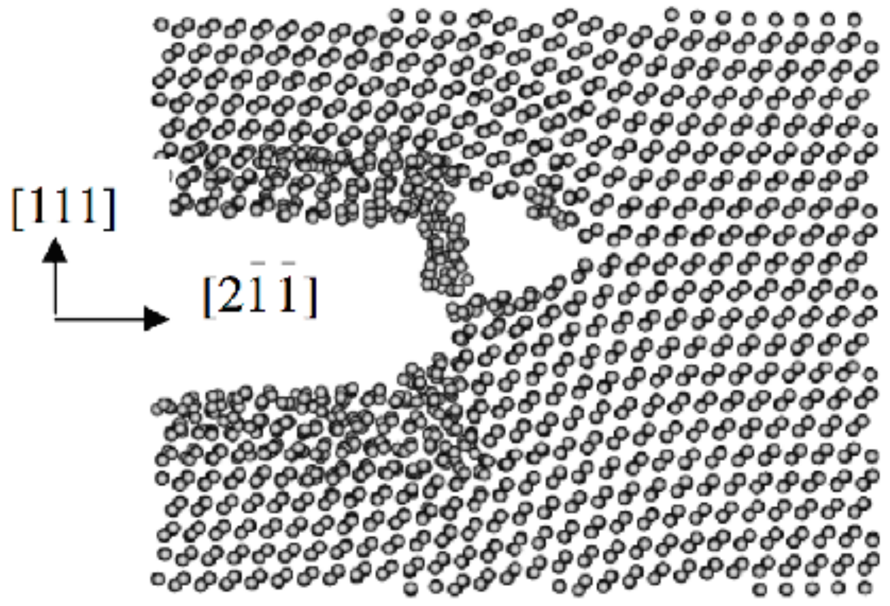
LIGO observations of Scorpius X-1



Crust Strength and Neutron Star Mountains

- Material Scientist Kai Kadau (LANL) and I simulated breaking stress of NS crust including impurities, dislocations, grain boundaries… *We find NS crust is the strongest material known, ten billion times stronger than steel.*

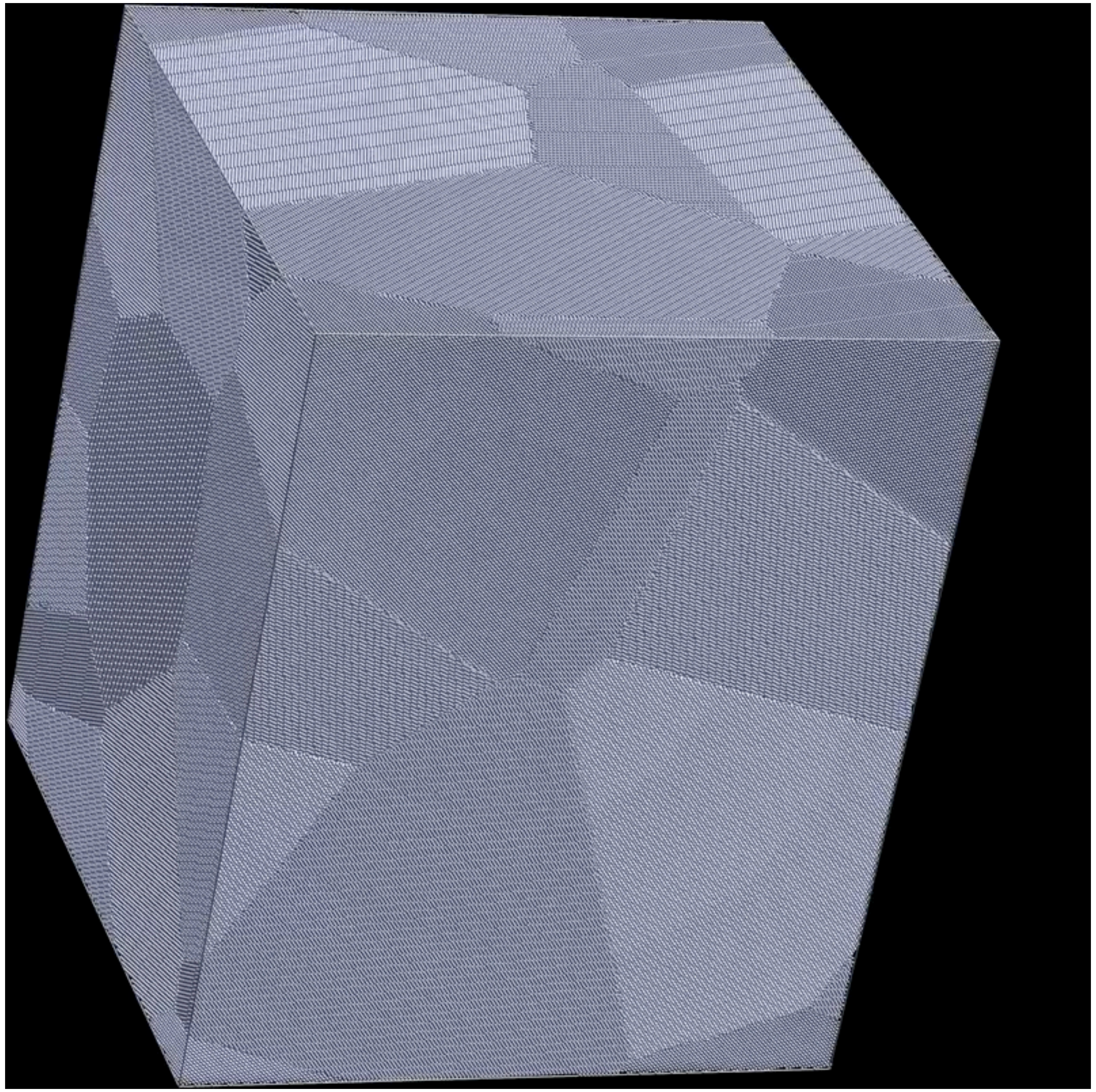
- For **conventional materials,** impurities, dislocations, grain boundaries… can nucleate cracks. Often material *fractures* at a strain (fractional deformation) σ << 0.1



MD simulation of crack propagation (fracturing) in Silicon. Neutron star crust does not fail this way.

- **Neutron stars:** High pressure prevents void formation and fractures. Crust is very strong even with defects, impurities, dislocations, grain boundaries…. Breaking strain very large $\boxed{\sigma \sim 0.1}$ Strong crust can support larger ellipticity.

- Recent results: Baiko+Chugunov, reproduce MD with semi-analytical approach, MNRAS **480**, 5511. Caplan et al, nuclear pasta also strong, PRL **121**, 132701.



MD simulation of crust breaking, with 13 million ions. Red color indicates deformation of lattice. PRL **102**, 191102 (2009)

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