Anisotropic neutron star crust, solar system mountains and gravitational waves

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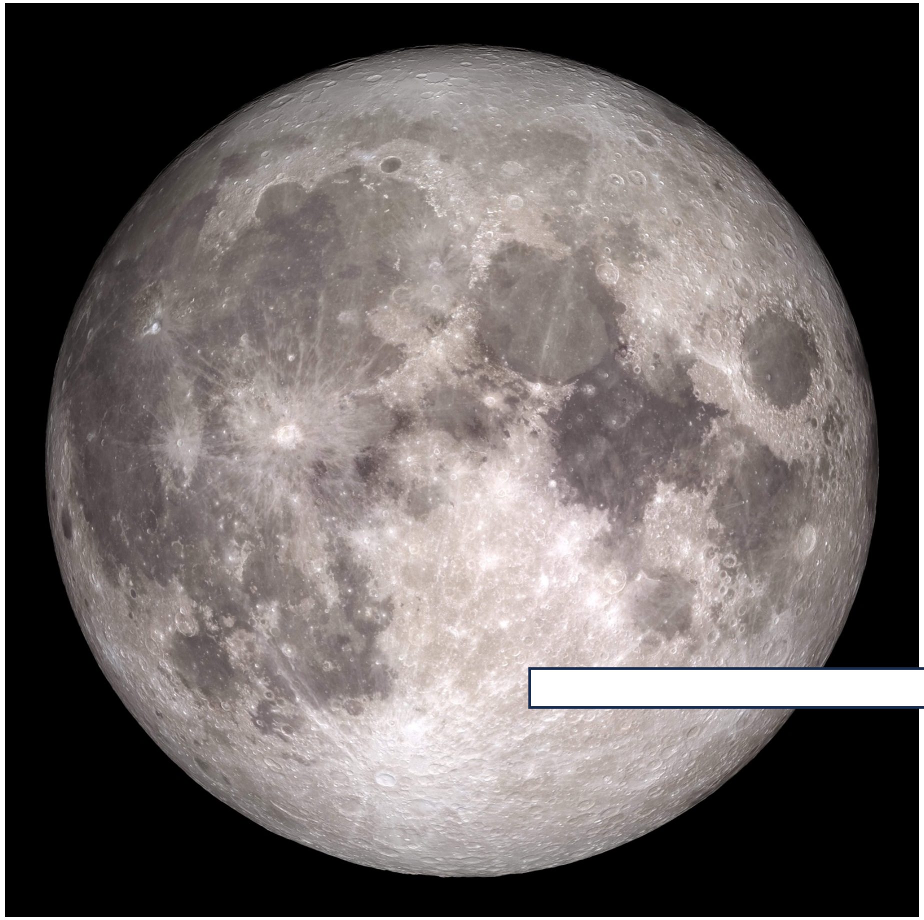
Indiana University and Max Planck Institute for Gravitational Physics (Albert Einstein Institute)
Supervisor: Charles J. Horowitz

1609, Galileo, and the Moon

Credit: NASA

1609, Galileo, and the Moon



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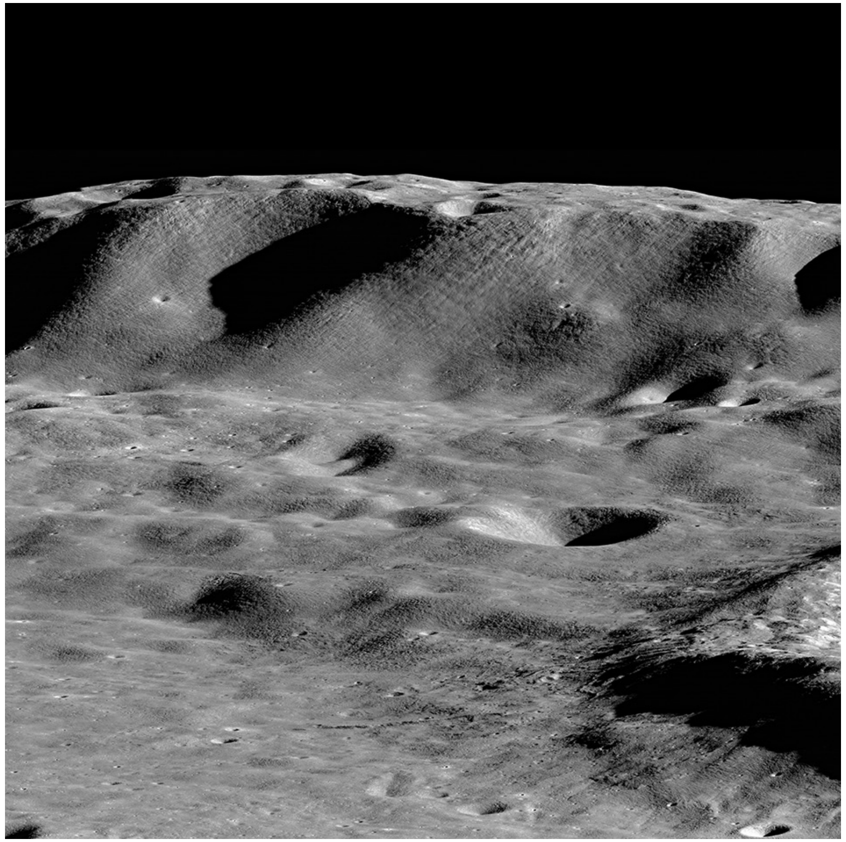

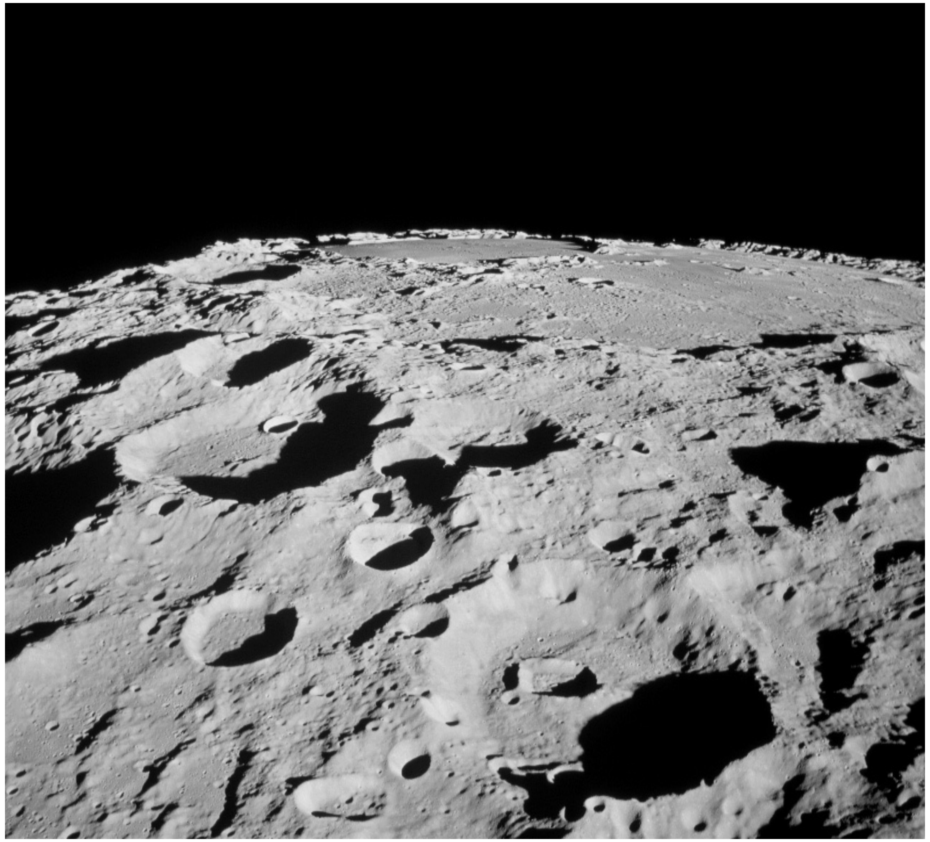

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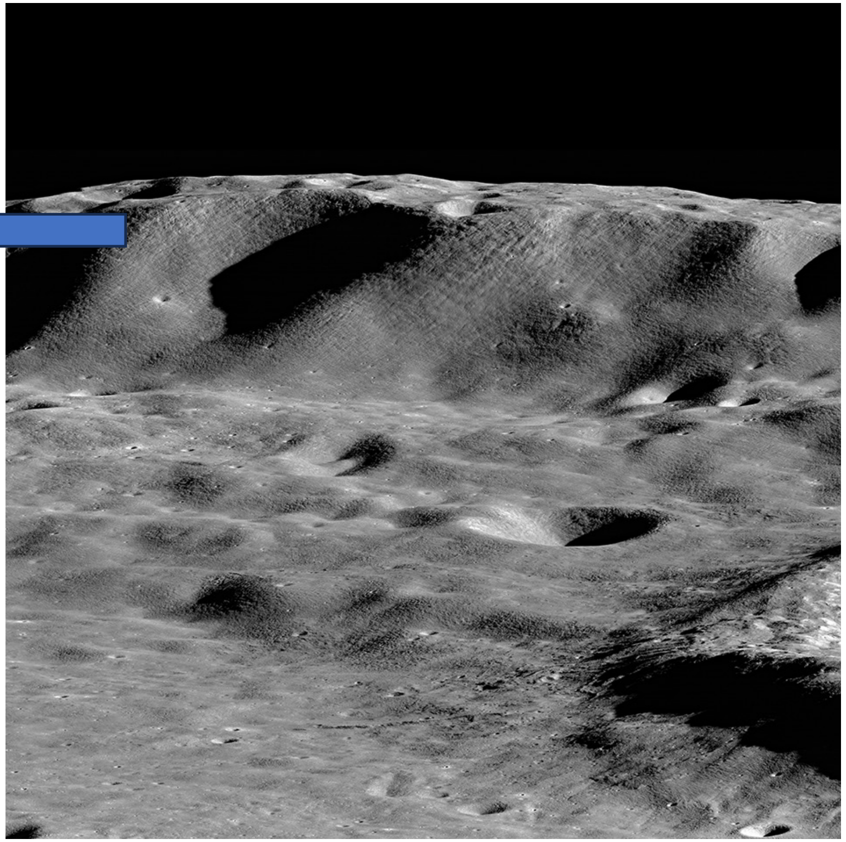
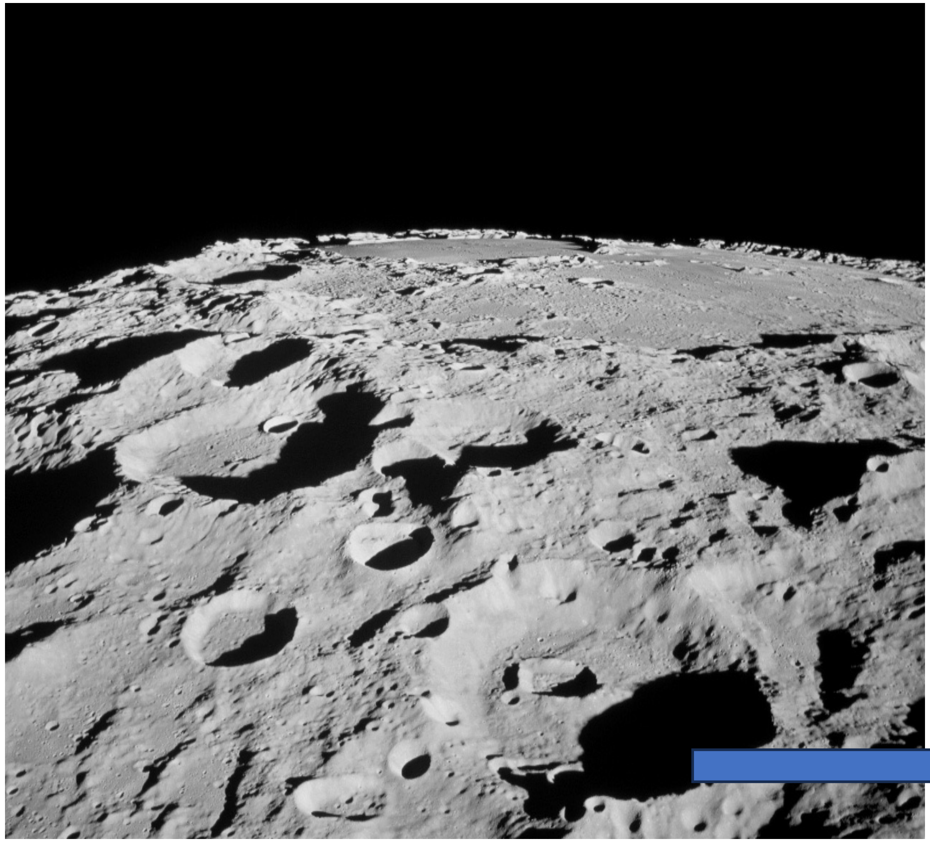
1609, Galileo, and the Moon

Mountains





Craters

Credit: NASA

Fast forward 414 years …

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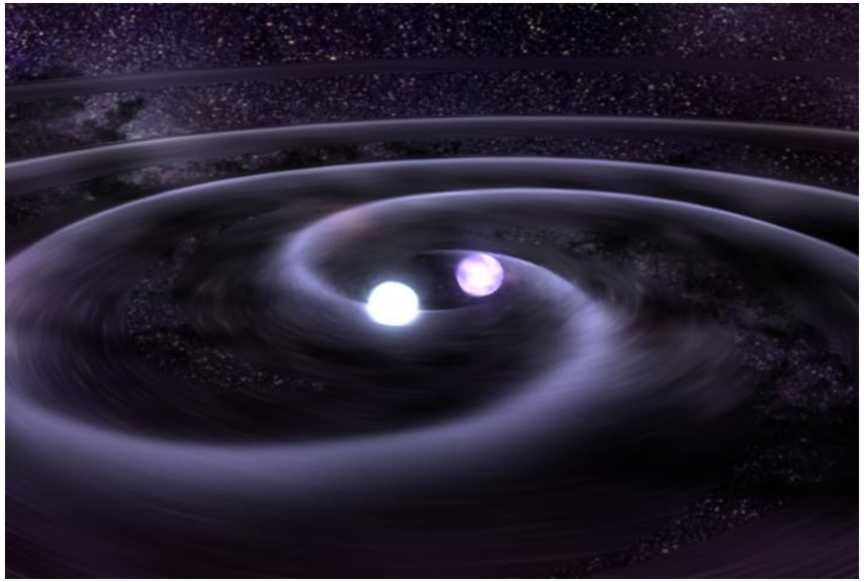

Credit: NASA Goddard Space Flight Center

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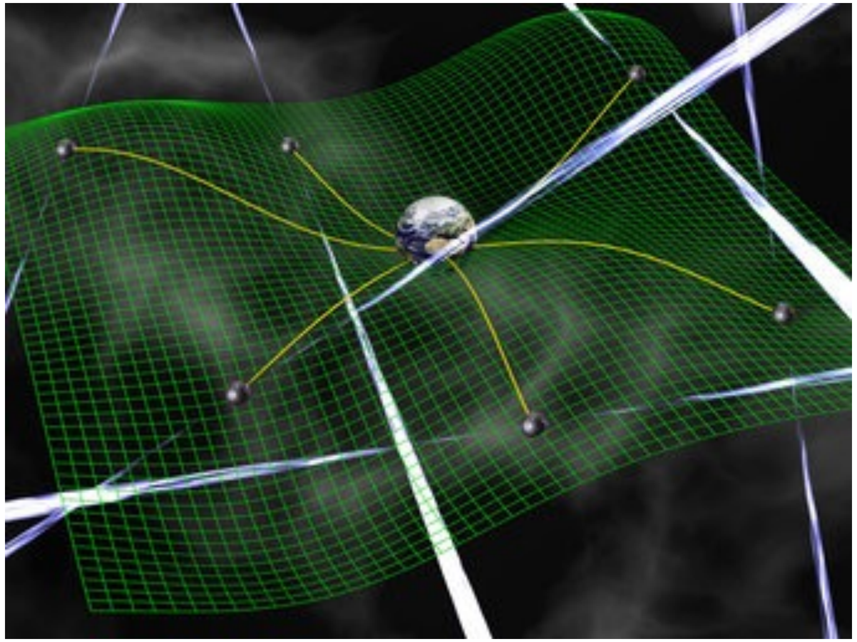

Credit: Max Planck Institute for Radio Astronomy

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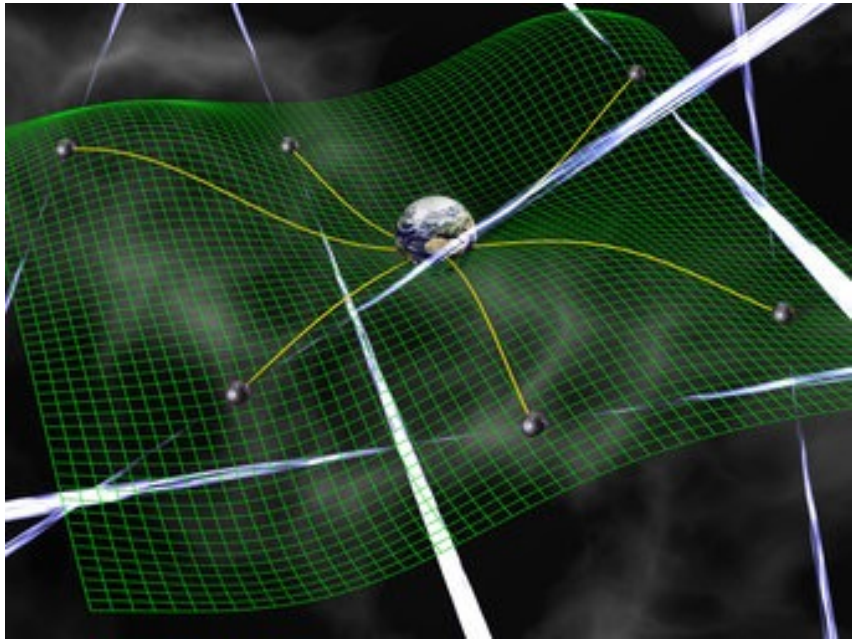

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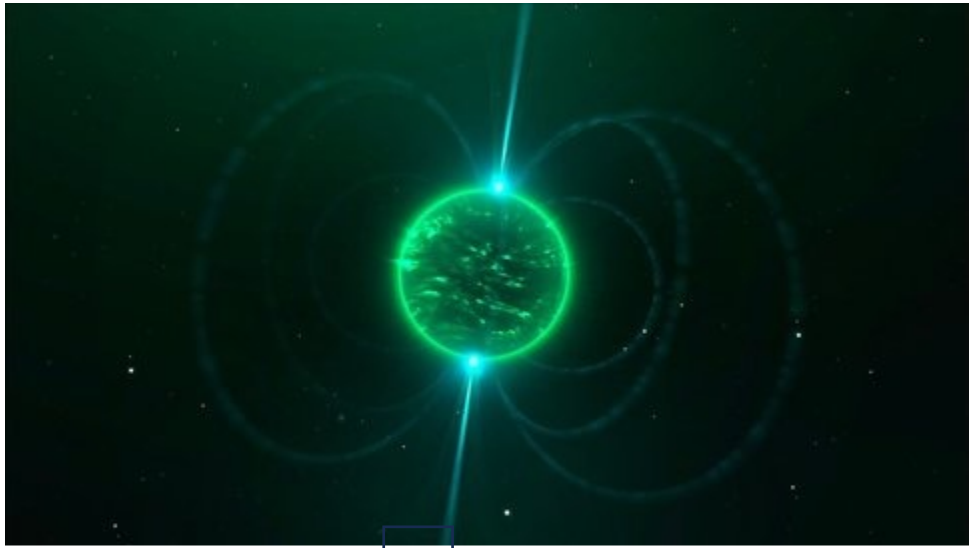

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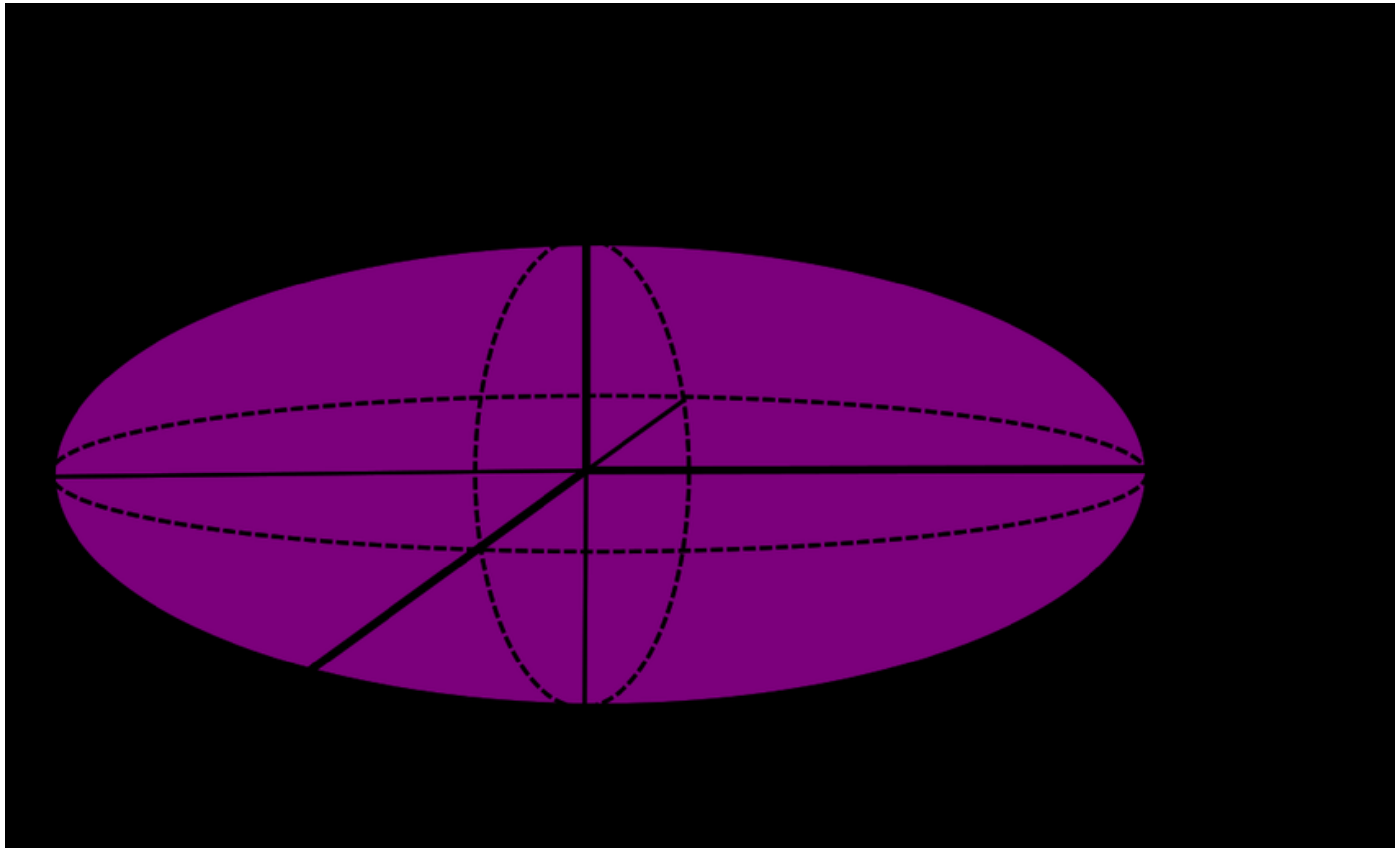
Credit: M.A. Papa MPI for Gravitational Physics, Hannover

Continuous Gravitational Waves from Neutron Stars Mountains



Credit: Magdalena Sieniawska and Michal Bejger

Interesting Range of Ellipticities

$\epsilon_{max} = few \times 10^{-6}$ (for instance, see Ushomirsky et. al. 2000, Gittins et. al. 2021, Morales et. al. 2022)

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Credit: Verisatum

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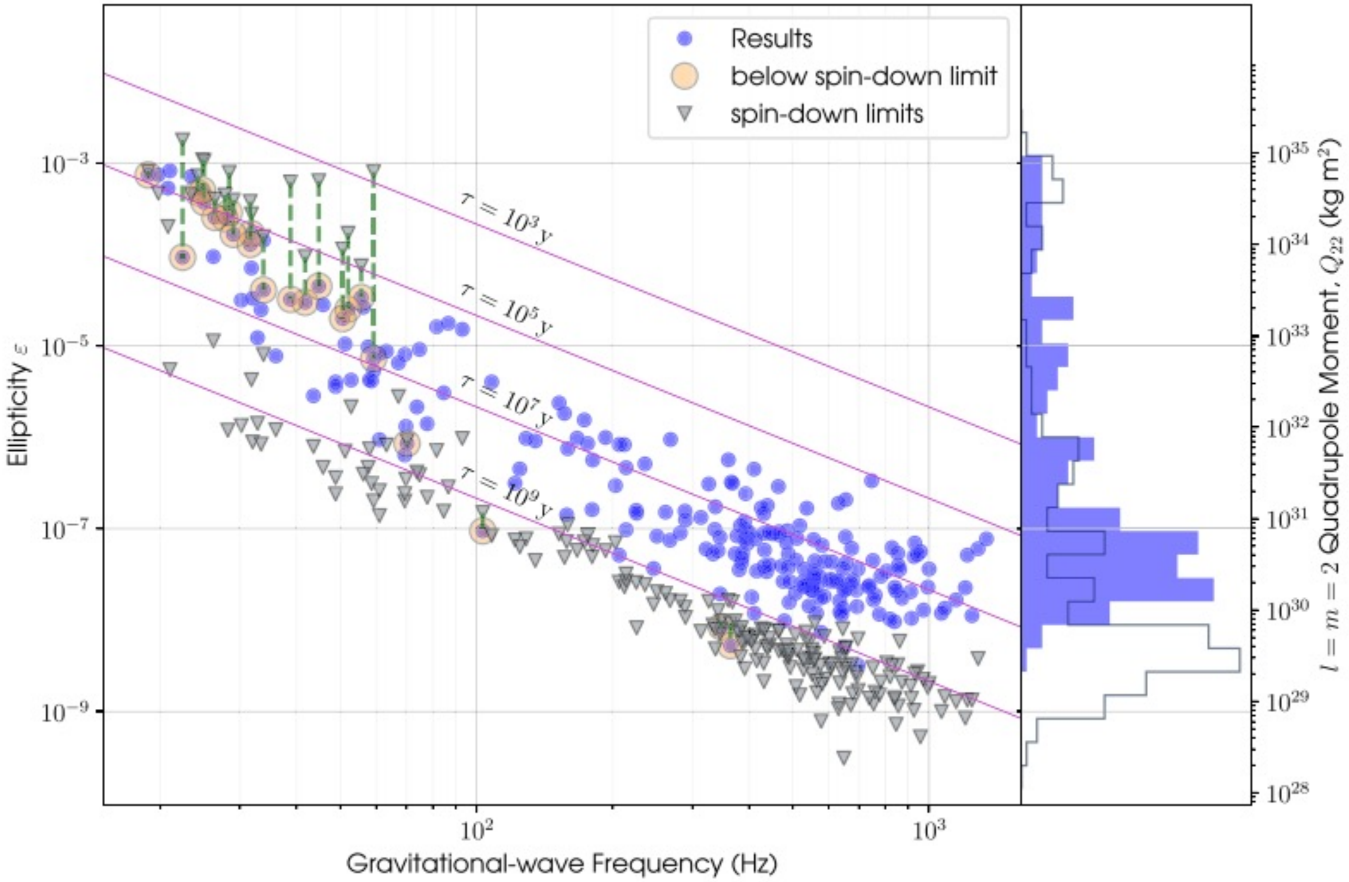

R. Abbott et al., Searches for Gravitational Waves from Known Pulsars at Two Harmonics in the Second and Third LIGO-Virgo Observing Runs, ApJ 935, 1 (2022).

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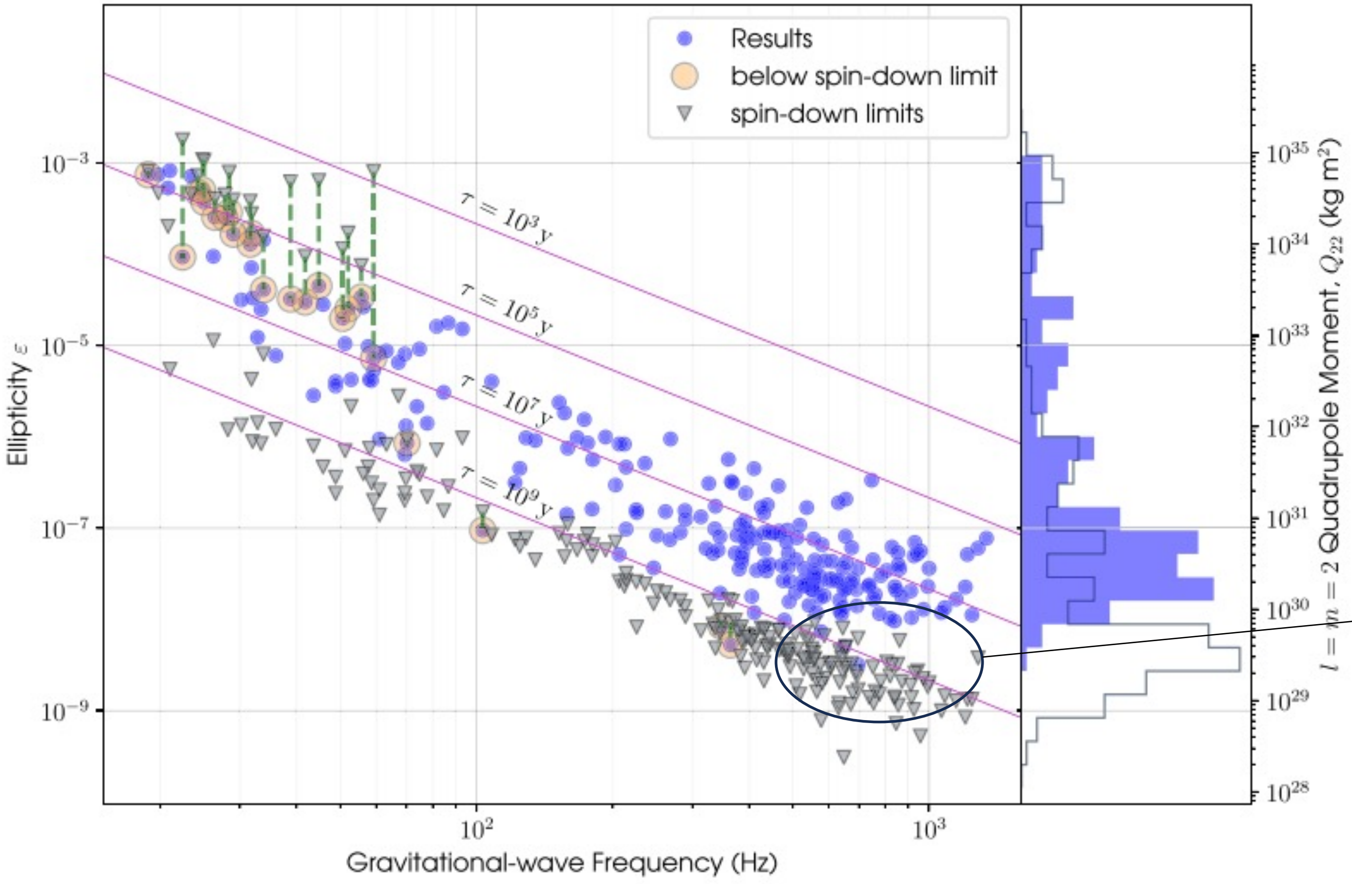

$\epsilon_{min} \sim few \times 10^{-9}$

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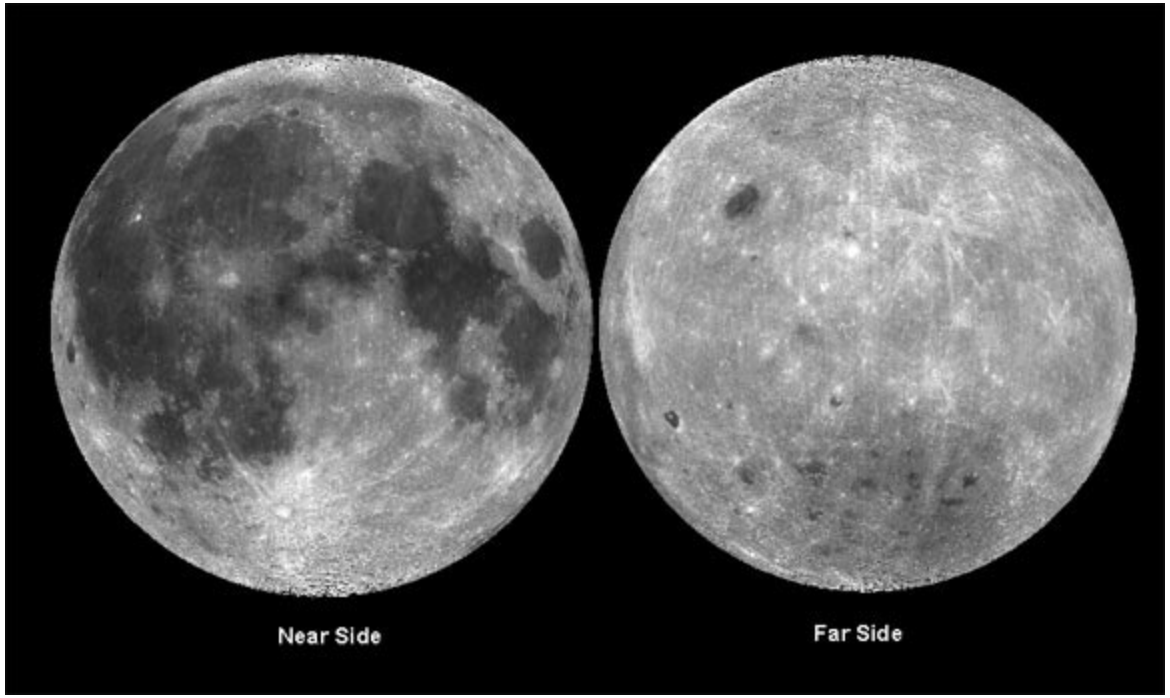
Analogies from Solar System Planets and Moons

1. Diversity

2. Large Scale Asymmetries



Credit: NASA

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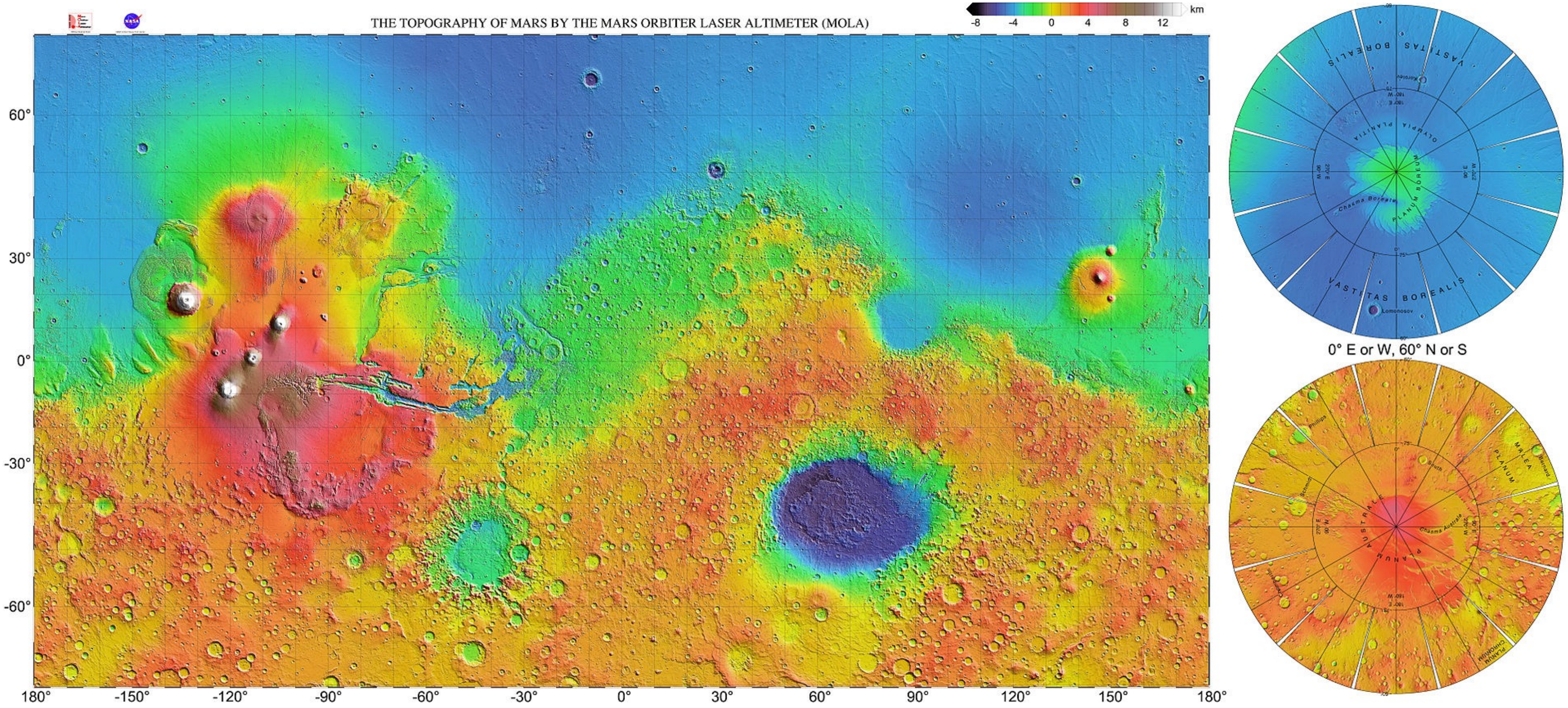
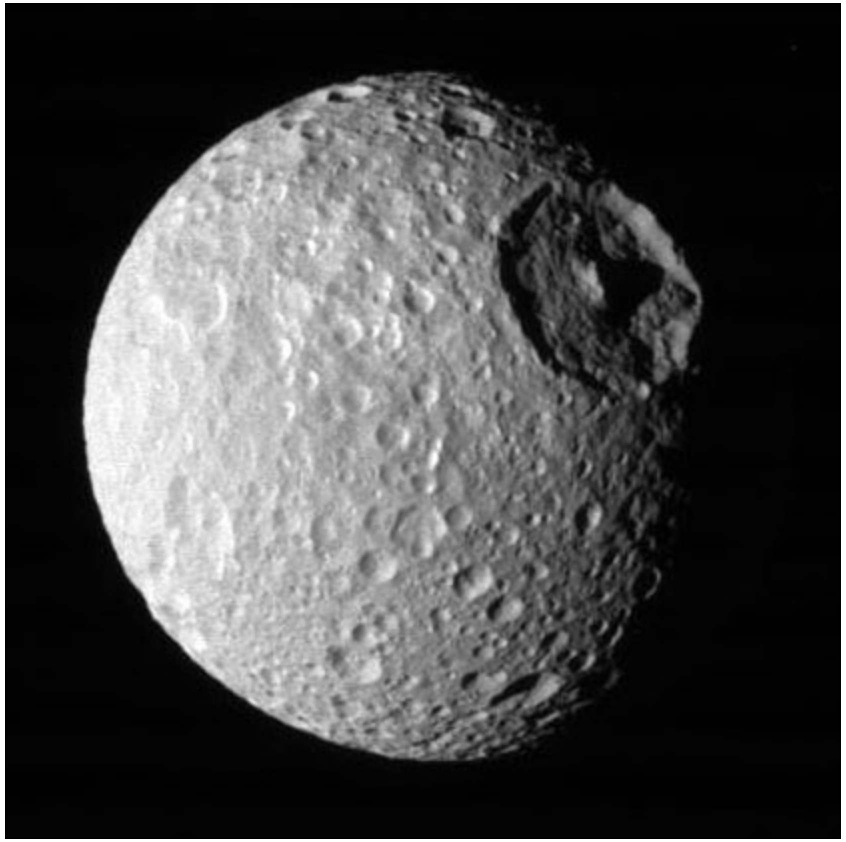


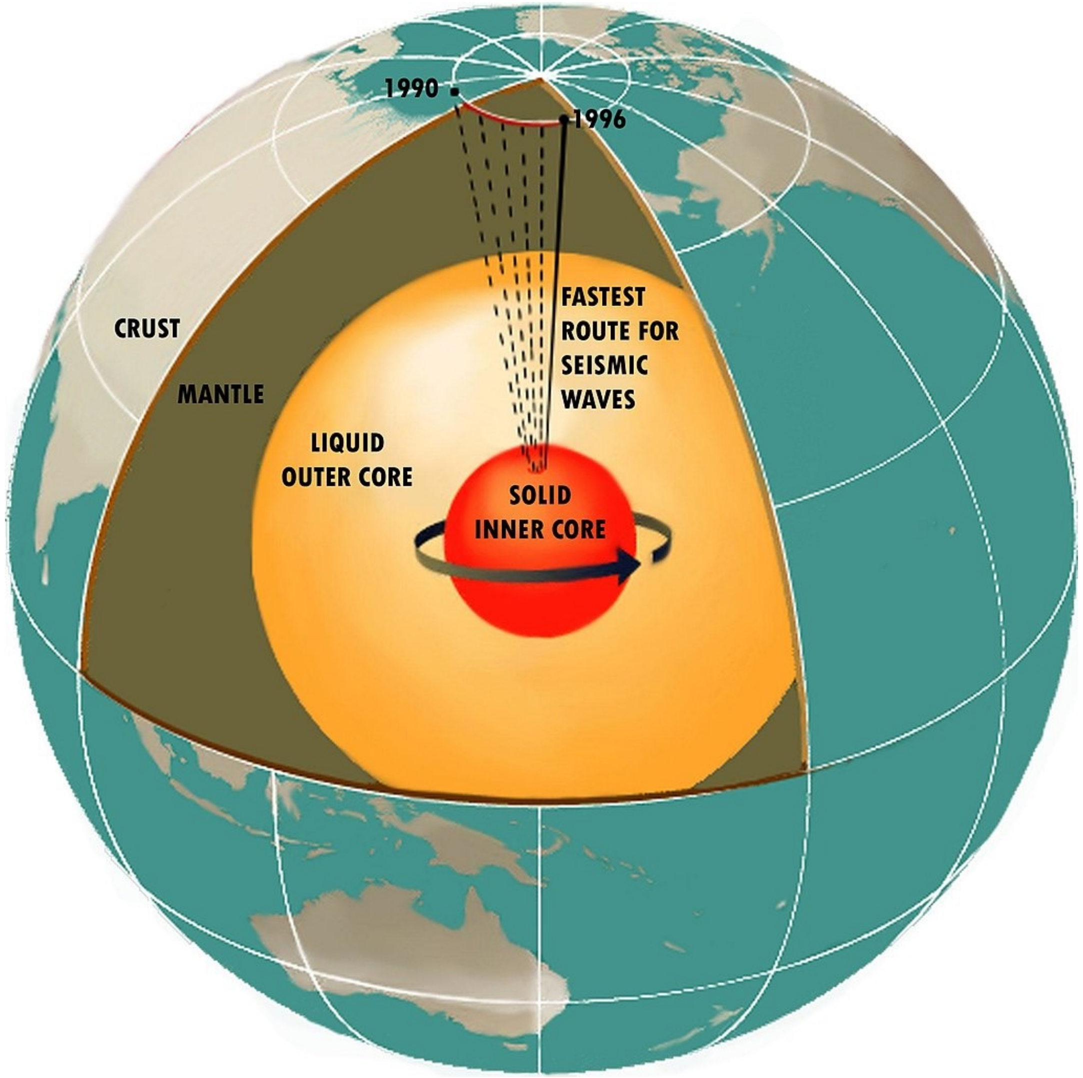
Credit: NASA

3. Scars



Credit: Cassini, NASA/ESA/ASI

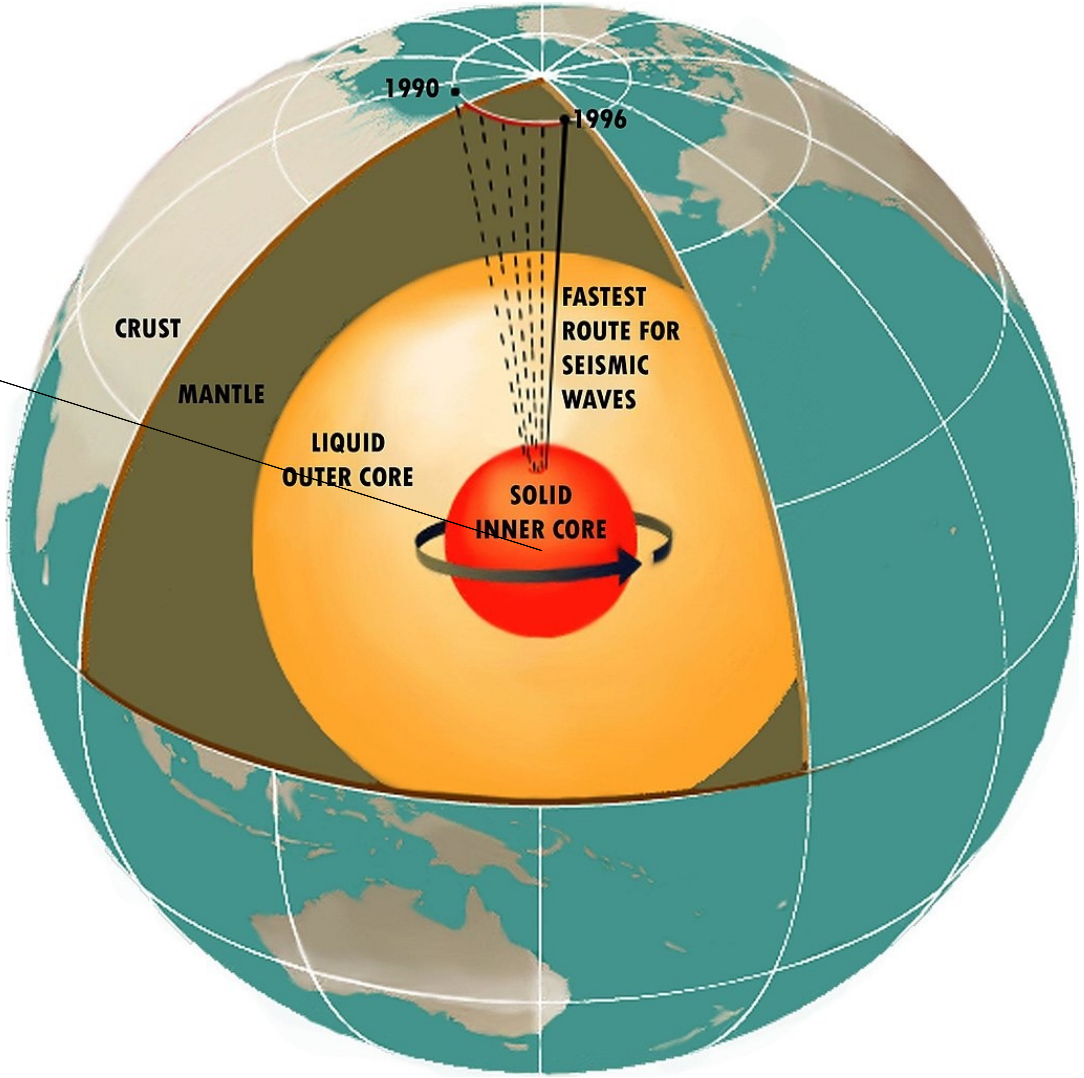
4. Anisotropies



Credit: Dixon Rohr, NASA

4. Anisotropies

$$\langle \phi \rangle \sim 10^{-5}$$



Credit: Dixon Rohr, NASA

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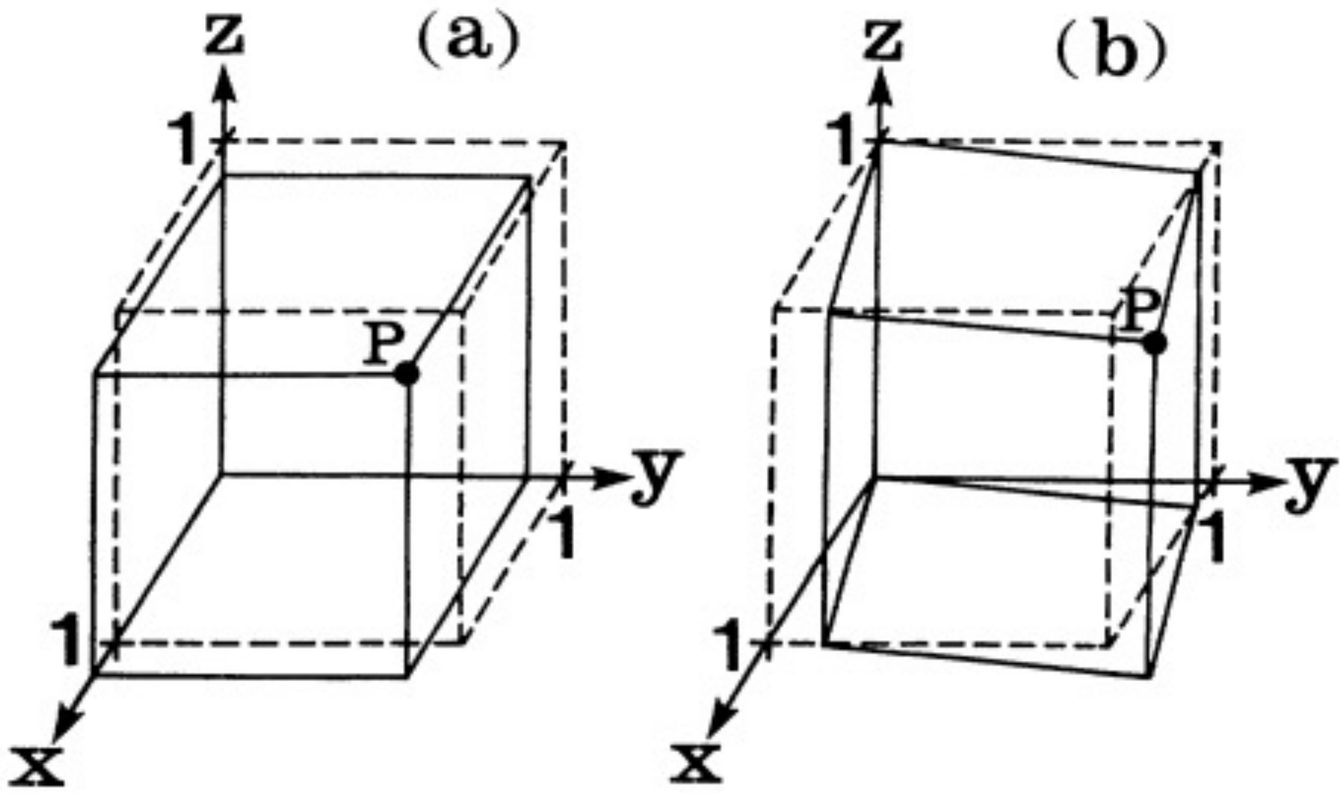

Shuji Ogata and Setsuo Ichimaru, Phys. Rev. A 42 (1990) 4867.

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$$\mathcal{E} \sim (0.10)(0.10)(0.10) \text{x} \mathcal{E}_{max}$$

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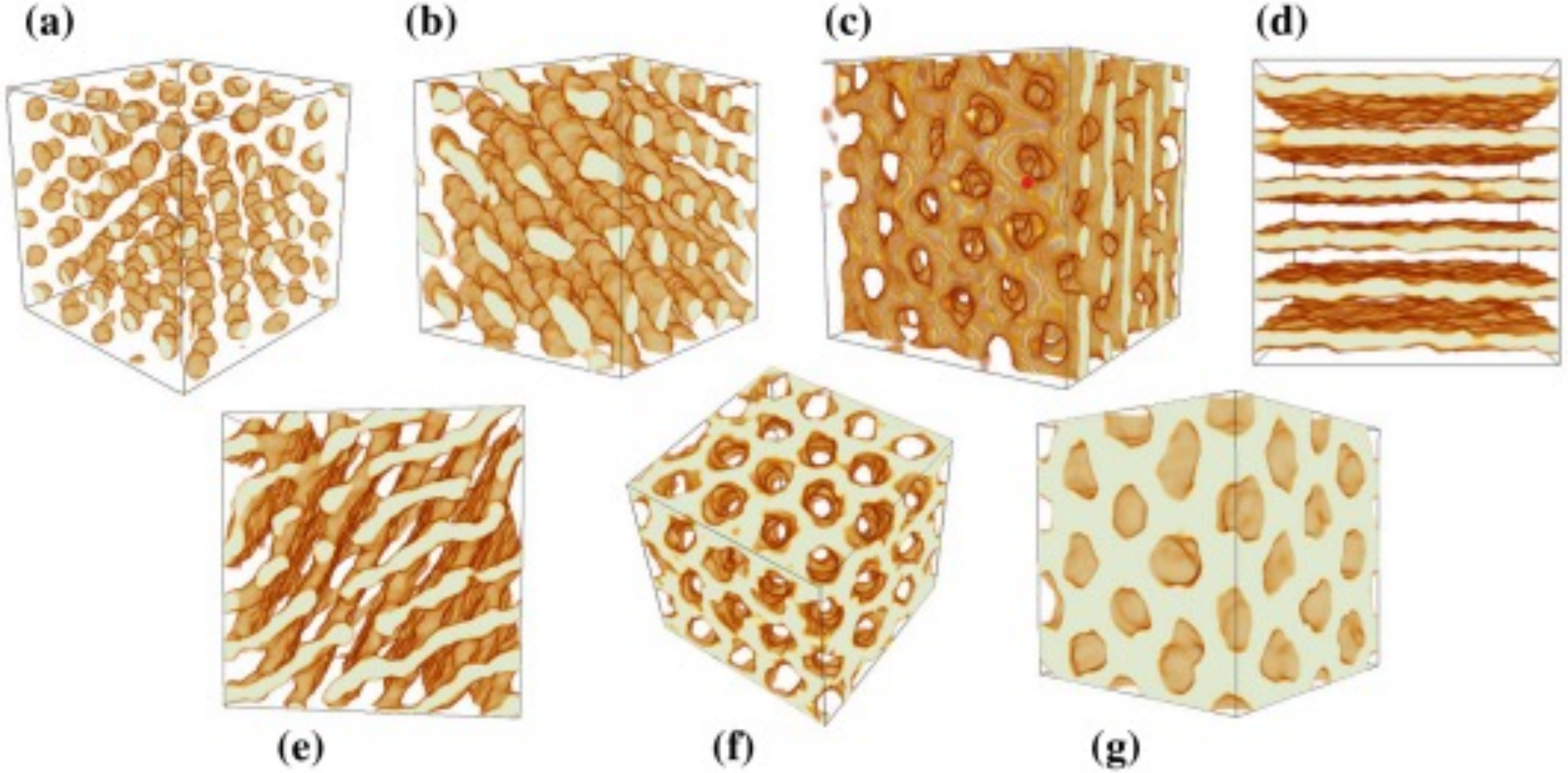

M. E. Caplan and C. J. Horowitz, Colloquium: Astromaterial science and nuclear pasta, Rev. Mod. Phys. 89, 041002 (2017).

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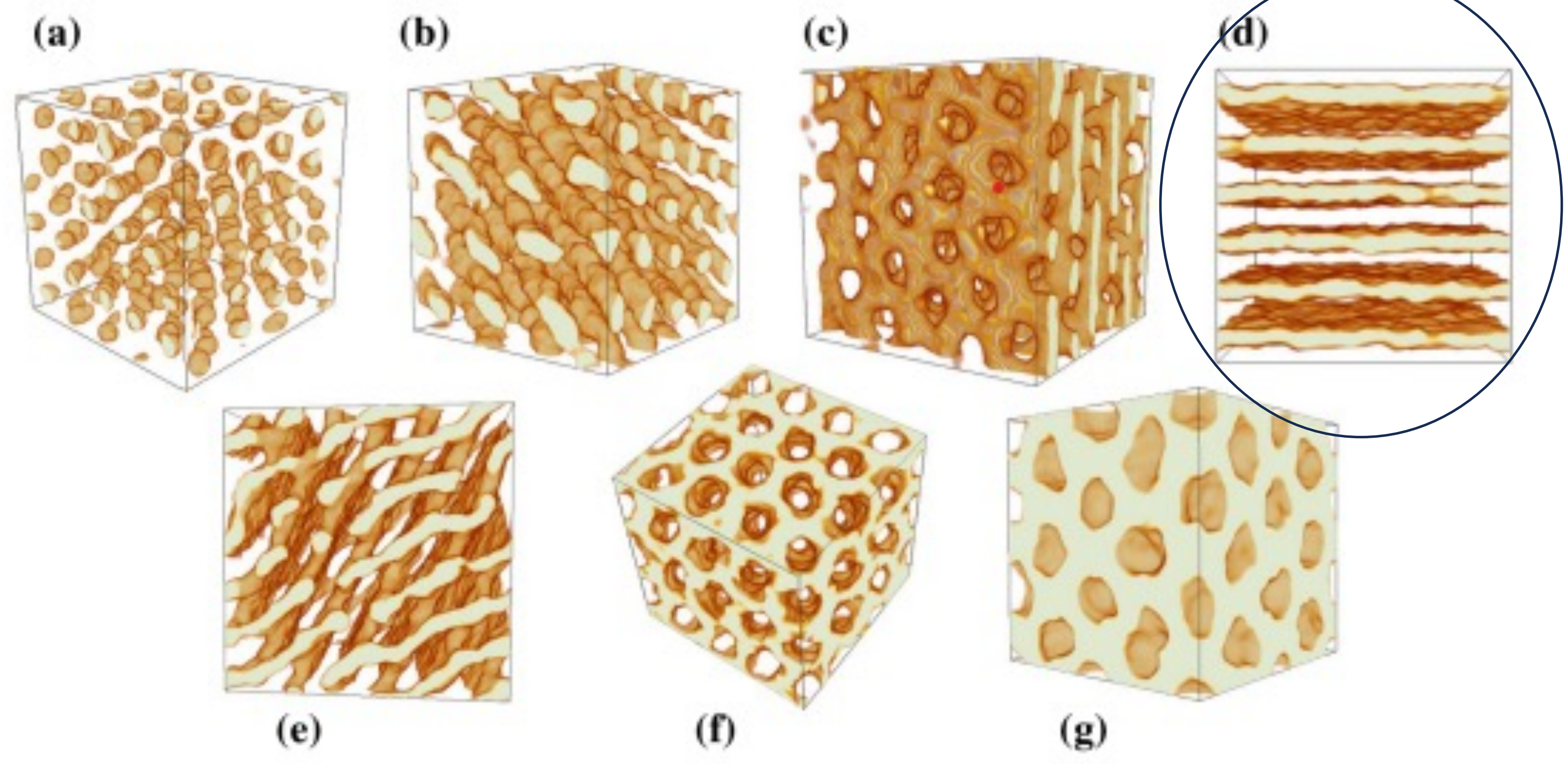

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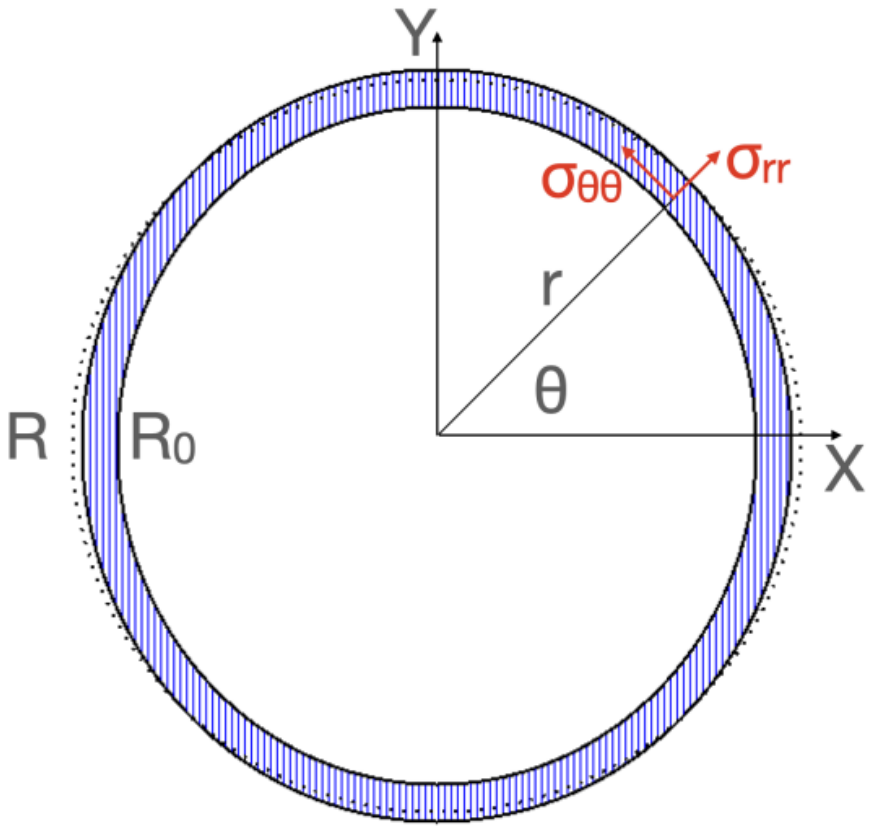
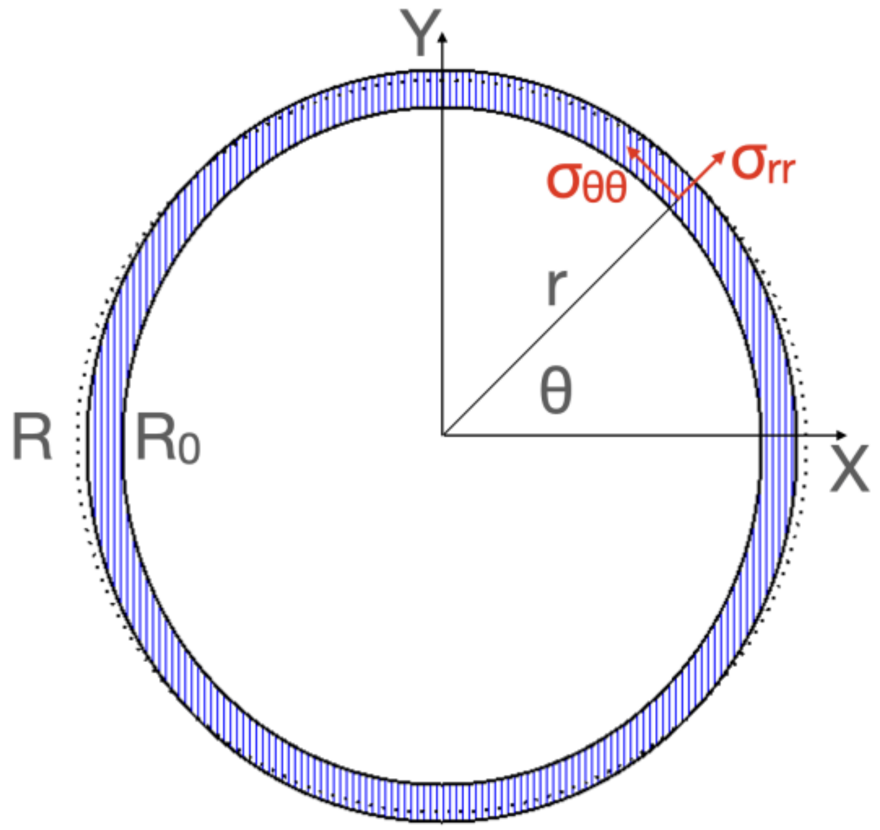


FIG. 1. Cut through the equatorial plane of a rotating star. The crust extends from R_0 to R and is slightly anisotropic in the X direction.

4. Anisotropies

$$\epsilon \approx \frac{m_{cr}}{M}\langle\phi\rangle\frac{\Omega^2-\Omega_0^2}{\Omega_K^2}$$



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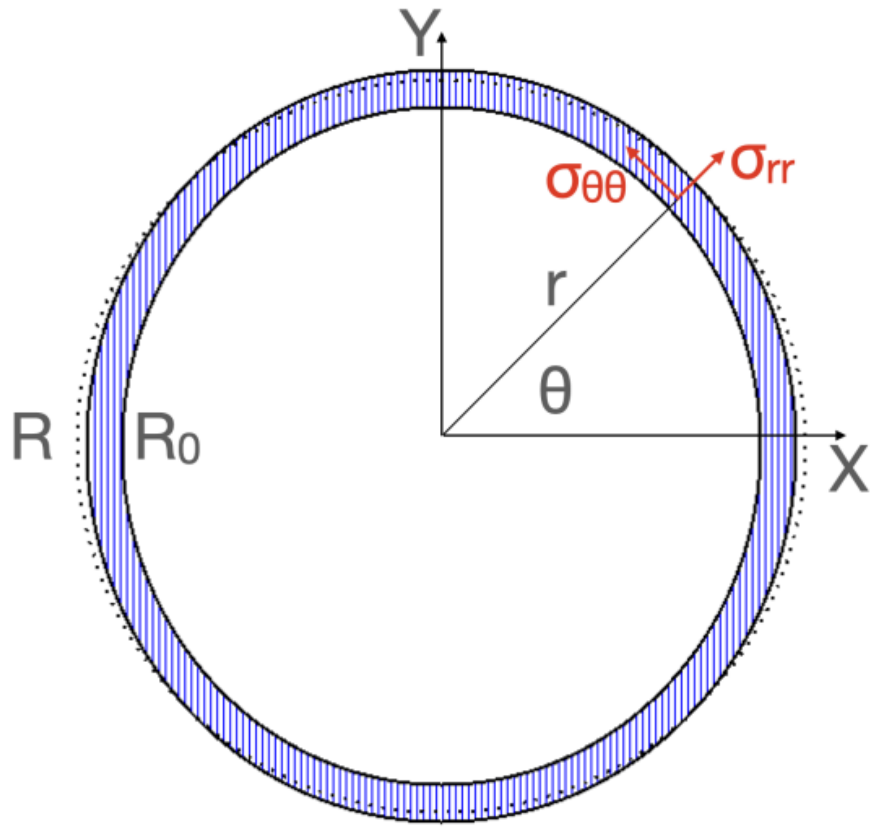

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$$n \neq 5$$

$$n = 5 + 4\frac{\Omega^2}{\Omega^2 - \Omega_0^2}$$

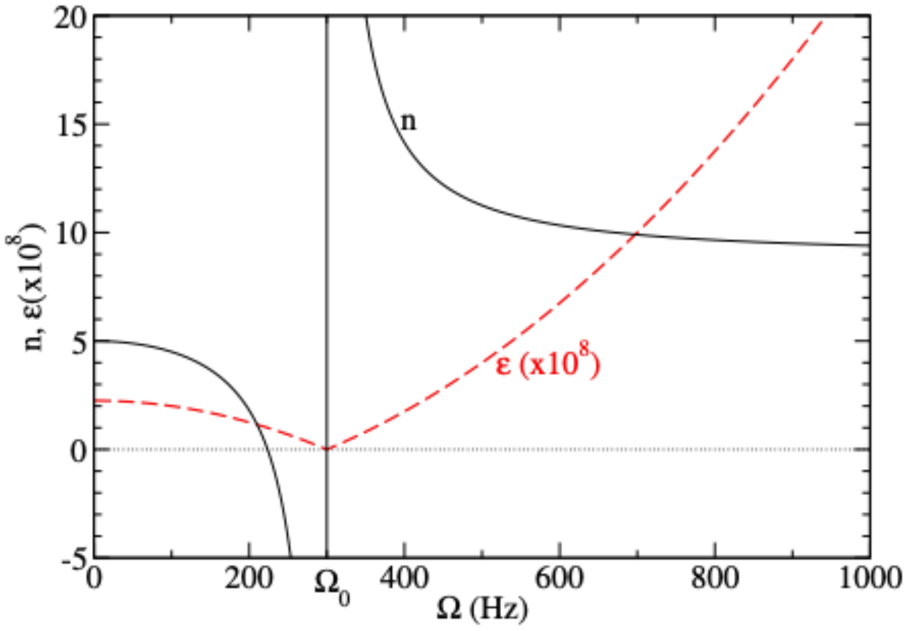

FIG. 2. Breaking index n (solid black curve) and ellipticity ϵ (dashed red curve) vs rotational frequency Ω assuming the crust froze while the star was rotating at $\Omega_0 = 300$ Hz.

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$$\langle \phi \rangle \ \epsilon \ (10^{-4}, 10^{-5})$$

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$$\langle \phi \rangle \sim 10^{-6}$$ → Minimum ellipticity in ms pulsars

- *G. Ushomirsky, C. Cutler, and L. Bildsten, Deformations of Accreting Neutron Star Crusts and Gravitational Wave Emission, Mon. Notices Royal Astron. Soc. 319, 902 (2000).*
- *G. Woan, M. D. Pitkin, B. Haskell, D. I. Jones, and P. D. Lasky, Evidence for a Minimum Ellipticity in Millisecond Pulsars, ApJ Lett. 863, L40 (2018).*

Conclusions

- **Detectable NS mountains** are non-axisymmetrical, large scale, and long lived deformations on NS crust
- The maximum ellipticity for a canonical NS is a few times 10^{-6}
- Solar System bodies and their mountains give us ‘ground truths’ that support the existence of detectable neutron star mountains
- The braking index for gravitational radiation of mountains is not necessarily 5
- Macroscopic anisotropy on the crust of rapidly spinning NS can give rise to interesting ellipticities that can explain both accretion torque balance and minimum ellipticity, and that *can be detected in the near future*