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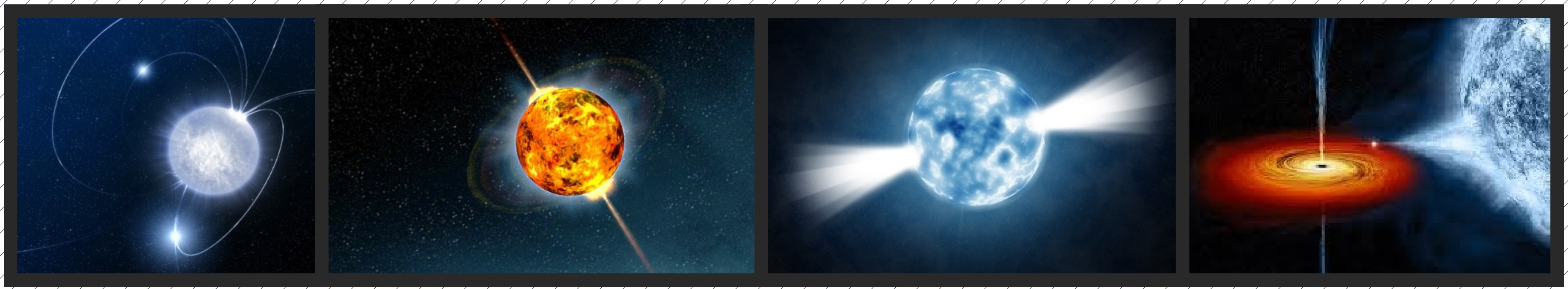

THE CRITICAL STRAIN ANGLE IN THE NEUTRON STAR CRUST

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TÜBİTAK

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Layers of the NS Crust:

$\rho_{drip} = 4\times10^{11}$ gcm^{-3}

Outer Crust: **Ions arrayed in (probably bcc) Coulomb lattice + gas of degenerate electrons**

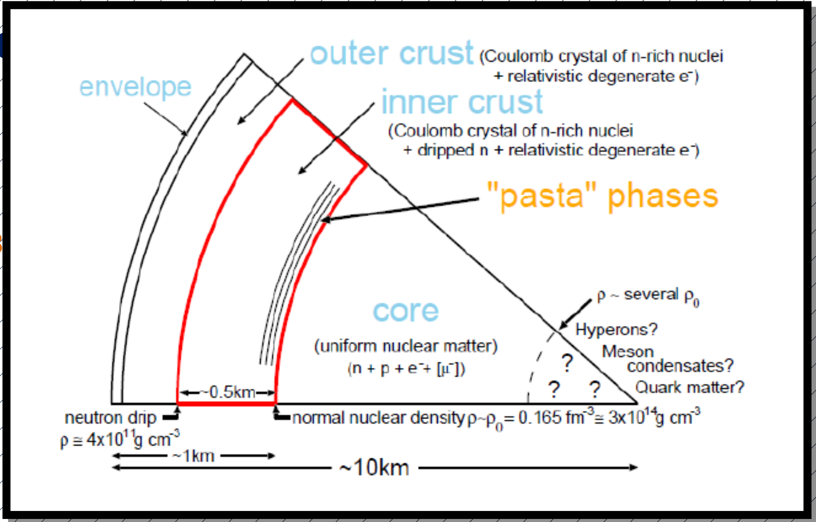
Inner Crust **($\rho>\rho_{drip}$): Neutron rich, Lattice of nuclei+electrons + free neutrons**

Screening effe

spacing)

At the highest densities (ρ ~10^{14} gcm^{-3}

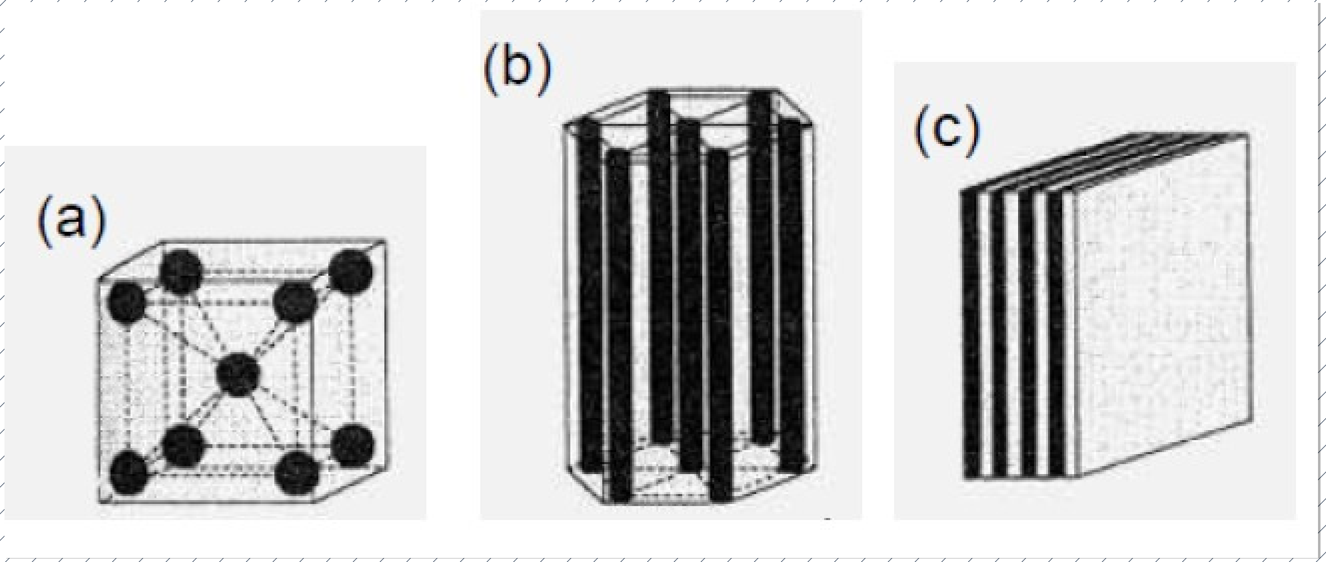
- **'Nuclei' start to 'touch'**
- **Competition between Coulomb re**
  Nuclear attraction



Nuclear Pasta: **Spherical, spaghetti-like rods, lasagna-like slabs**

(Ravenhall, Pethick&Wilson-1983)

(Hashimoto, Seki, Yamada- 1984)



tion modes, gravitational wave emission, magnetar giant flares, glitch

Glitch and Crustquakes:

- **Sudden change in rotation rate and spindown rate with no correlated change in pulsar's electromagnetic signature**
  (*exceptions: i.e. PSR J1119-6127, 1E 2259+586, J1846-0258*)

- **internal changes of the neutron star:**

  -structural(crustquakes)

  -angular momentum exchange between star's components (vortex unpinning)

$$\frac{\Delta\Omega}{\Omega} \sim 10^{-9} - 10^{-6}$$

$$\frac{\Delta\dot{\Omega}_c}{\dot{\Omega}_c} \sim 10^{-5} - 10^{-3}$$

- Stresses in the crust induced by spinning down of the star
- Readjusting to more spherical form that a fluid star would follow
- Reduction in crust's moment of inertia
- Increase in angular velocity by conservation of angular momentum

Glitch!

$$\left|\frac{\Delta I}{I}\right| = \frac{\Delta \Omega}{\Omega} = \frac{\Delta \dot{\Omega}}{\dot{\Omega}_c}$$

- explains small glitches (i.e. Crab, PSR J0537-6910), but inadequate for larger glitches (Vela)

Time between glitches does not fit pure superfluid unpinning model.

Glitches are probably not pure superfluid events.

Crustquakes trigger , superfluid amplifies.

ical (breaking) strain angle:

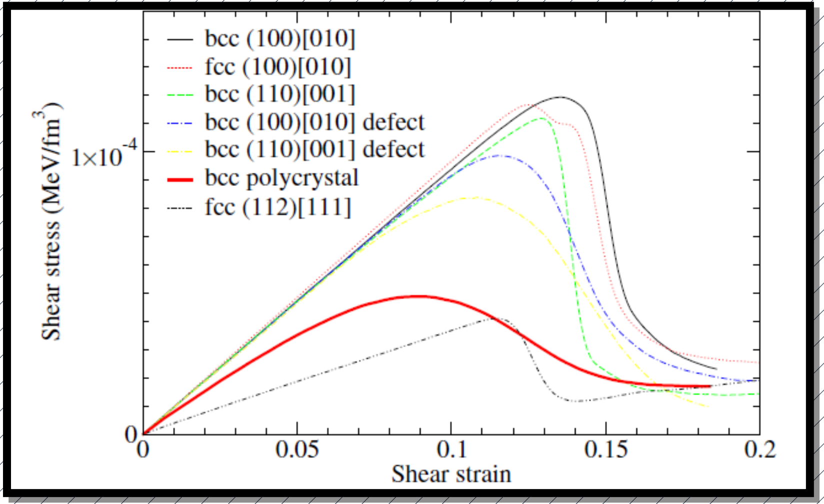
chowski&Welch(1970) : **$10^{-5}<\theta_{cr}<10^{-3}$** (doing analogy with terrestrial crystal

Pines(1985) : **$\theta_{cr}\sim10^{-2}$-10^{-1}** (pure Coulomb lattice, fine structure

itz&Kadau(2009) : **$\theta_{cr}\sim10^{-1}$** (based on molecular dynamics simu
-for outer crust, $\rho\sim10^{13}$ gcm^{-3})

- **It is too hard for the crust to fracture along faults, but rather it fails collectively**

- **Crust is very strong and can support large mountains so that their gravitational wave radiation might be detectable**



Estimating θ_{cr} for all layers of NS crust *(Akbal&Alpar 2016-to be submitted)*

Hypothesis – $\theta_{cr} \sim |E_C|/E_K$

Dimensionless value of the ratio total Coulomb energy to the relativistic electrons' kinetic energy is relevant to this critical value:

$$|E_C| = \int_{cell} (E^2/8\pi) d\tau. \quad E_K = Z(3/4)\hbar c k_F$$

Wigner-Seitz cell approximat
Z electrons and Z protons

$$\theta_{cr}^{sph} \sim \frac{2}{5}\left(\frac{4}{9\pi}\right)^{1/3} Z^{2/3}\alpha\left(\frac{2r_c}{R} + \frac{R^2}{r_c^2} - 3\right),$$

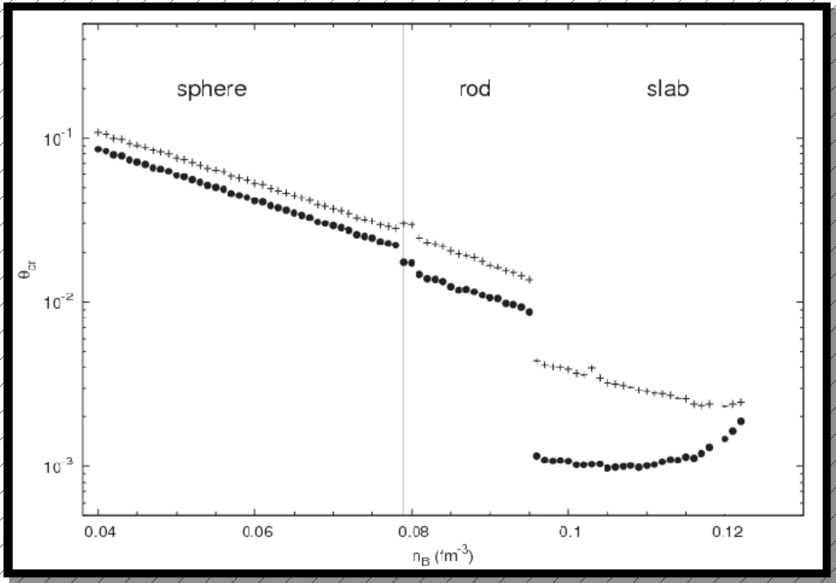
$$\theta_{cr}^{rod} \sim \frac{4}{3(3\pi)^{1/3}}\lambda^{2/3} r_c^{2/3}\alpha\left(ln\left(\frac{r_c}{R}\right) - \frac{1}{2} + \frac{R^2}{2r_c^2}\right),$$

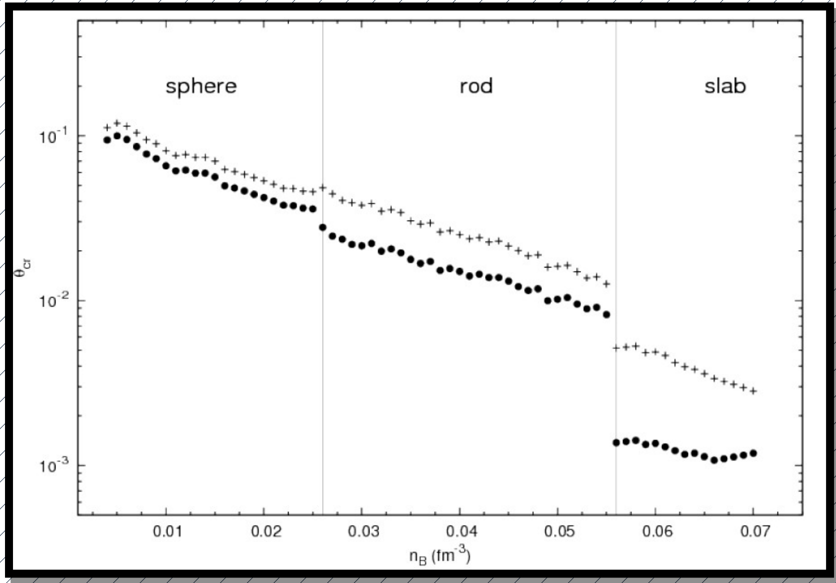
$$\theta_{cr}^{slab} \sim \frac{2}{9}\left(\frac{\pi}{3}\right)^{1/3}\sigma^{2/3} r_c^{1/3}\alpha\left(r_c - \frac{11R}{8} + \frac{R^2}{2r_c}\right).$$

$\lambda = Z/r_c$

$\sigma = Z/r_c^2$

R and r_c values obtained by Iida et al. 2001 and Maruyama et al. 2005





- Our estimation (**θ_{cr}=4.4x10^{-2}**) is also in agreement with Horowitz&Kadau(2009) that obtains **θ_{cr}=8x10^{-2}** for bcc polycrystal orientation in outer layer.

Minimum Glitch Size in Crab:

Neutron star glitches have a substantial minimum size

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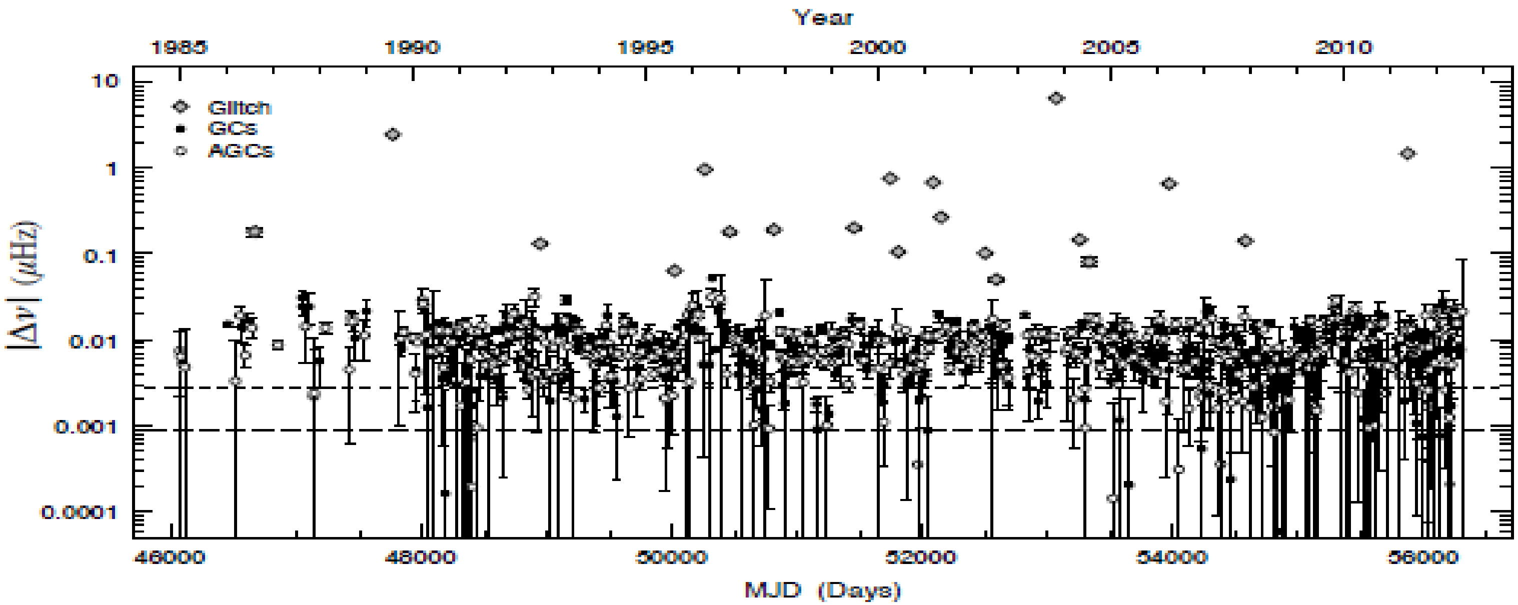
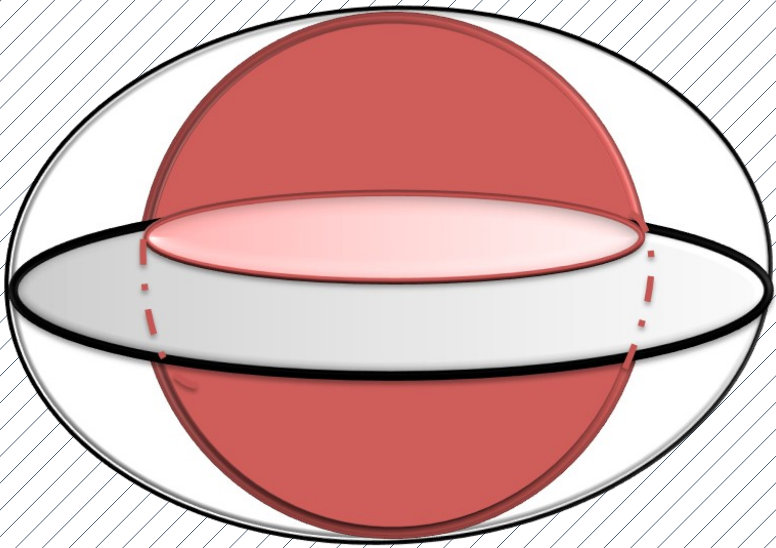


Figure 3. Time sequence of glitches, glitch candidates (GCs) and anti-glitch candidates (AGCs). Horizontal lines indicate the detection limits (Eq. 2) for $|\Delta\dot{\nu}| = 1 \times 10^{-15}\,\mathrm{Hz\,s^{-1}}$ (long dashed) and $10 \times 10^{-15}\,\mathrm{Hz\,s^{-1}}$ (short dashed). The low number of detections between the years 1985 and 1990 is caused by the presence of short gaps with no observations.

Preliminary results (Akbal&Alpar 2016 -ongoing)



A ring including many plates moves inward

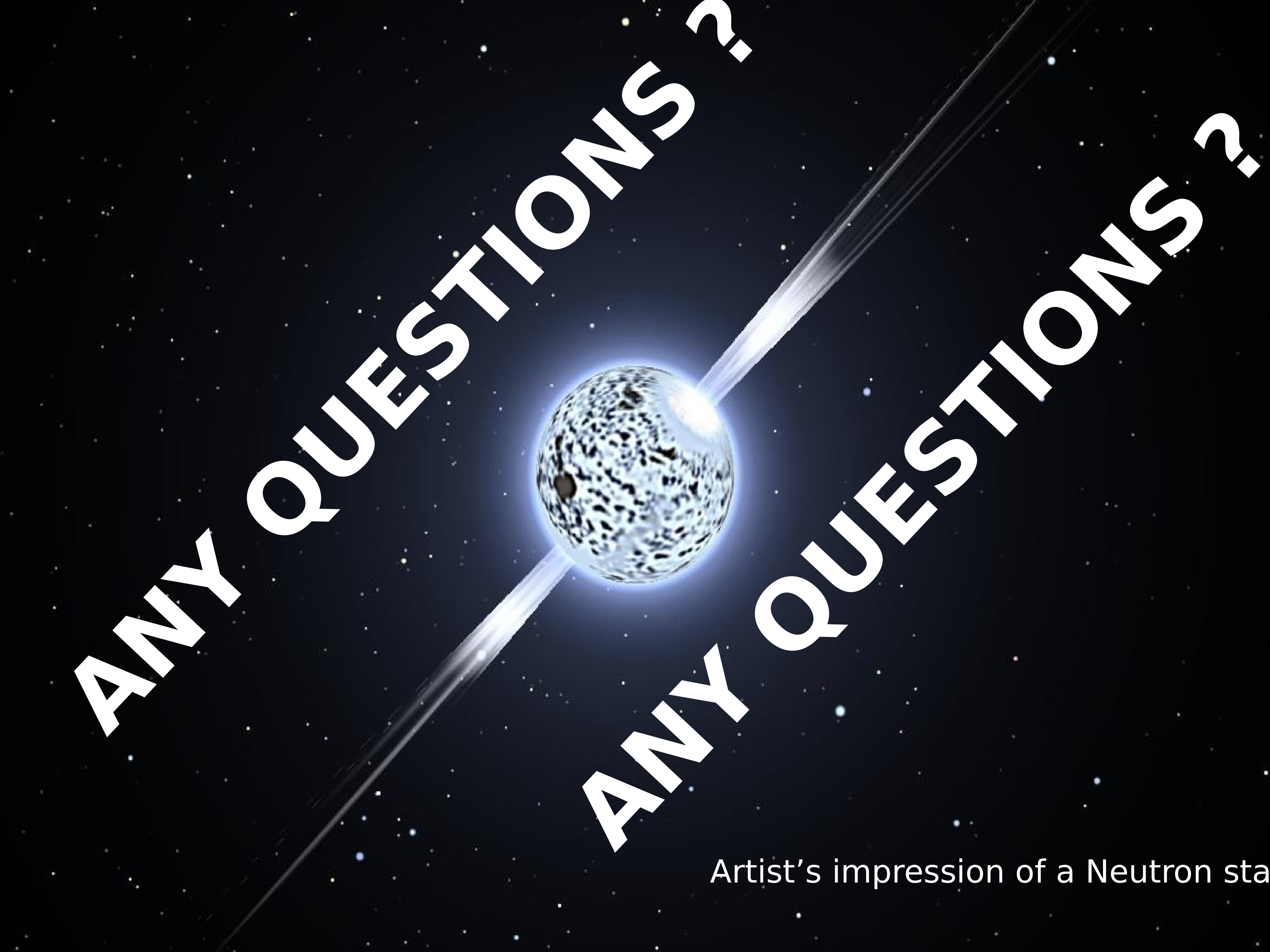
D: plate size

h: crust thickness

$$\Delta\nu = 0.05\ \mu\mathrm{Hz},\ \Delta\Omega/\Omega = 1.7 \times 10^{-9}$$

$$\frac{\Delta\Omega}{\Omega}|_{min} = \frac{\Delta I}{I} \propto f\left(\frac{D}{h}\right) \propto f(\theta_{cr})$$

$$\theta_{cr} \sim \frac{D_4 \times 10^4}{h_5 \times 10^5} \sim 3.3 \times 10^{-2} \frac{1}{h_5} \left(\frac{(M/M_S)}{\rho_{c,13} h_5 f}\right)^{1/2}$$



Artist’s impression of a Neutron sta