The masses of Neutron Stars

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The maximum mass of NSs

- NS are described under the theory of GR
- The hydrostatic equilibrium is described from the Tolman-Oppenheimer-Volkoff (TOV) equation

$$\frac{dp}{dr} = -\frac{Gm(r)\rho(r)}{r^2}\left(1+\frac{p(r)}{c^2\rho(r)}\right)\left(1+\frac{4\pi r^3 p(r)}{c^2 m(r)}\right)\left(1-\frac{2Gm(r)}{c^2 r}\right)^{-1}$$

$$m(r) = 4\pi\int_0^R r^2\rho(r)dr.$$

- It predicts the existence of a maximum mass, above which the star collapses into a BH
- The exact value depend on the equation of state (EoS)

An “absolute limit”

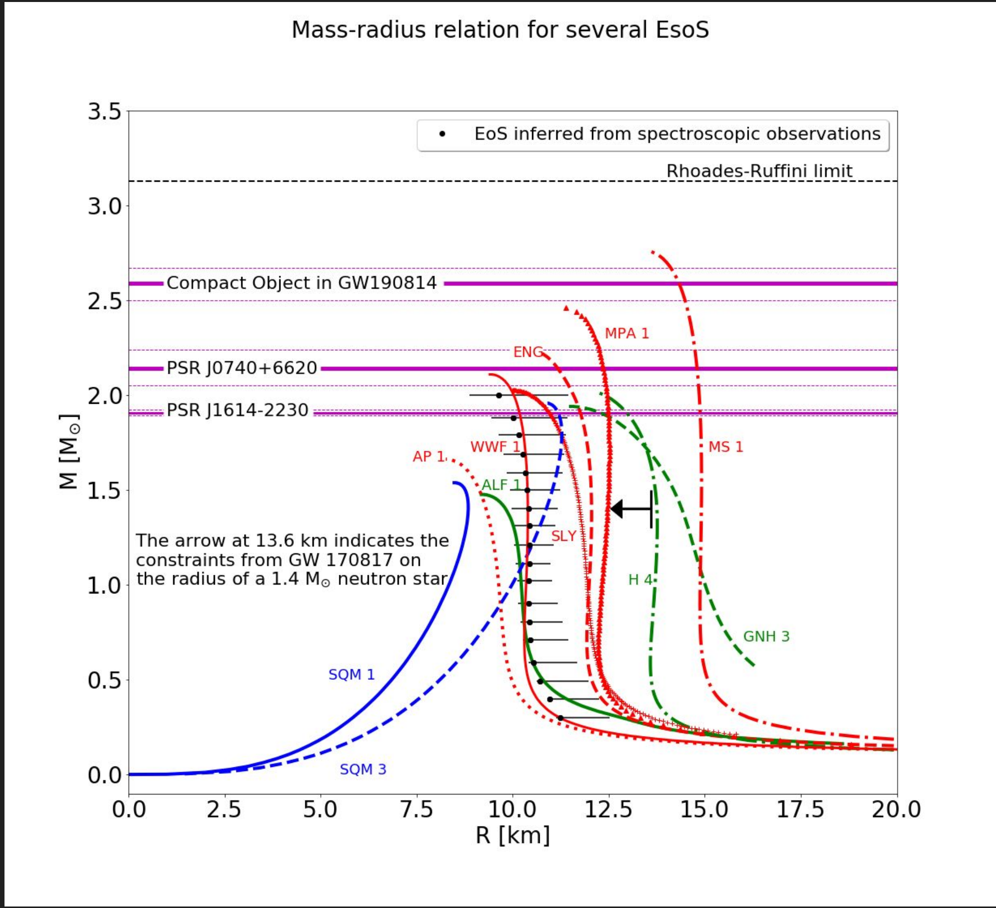
- In 1974, Rhoades and Ruffini derived an absolute limit based on a few assumptions:

$$m_{RR} \sim 3.2\ M_\odot$$

- This value is used as a safe threshold to distinguish between NSs and BHs
- Effects such as rotation and anisotropy can affect the limit (increase)

Equation of state

- We know (within some degree) how matter behaves until a certain density, correspondent with outer layers
- It's mass budget is in the core, yet undetermined
- A variety of EoS's are proposed



Strange Stars

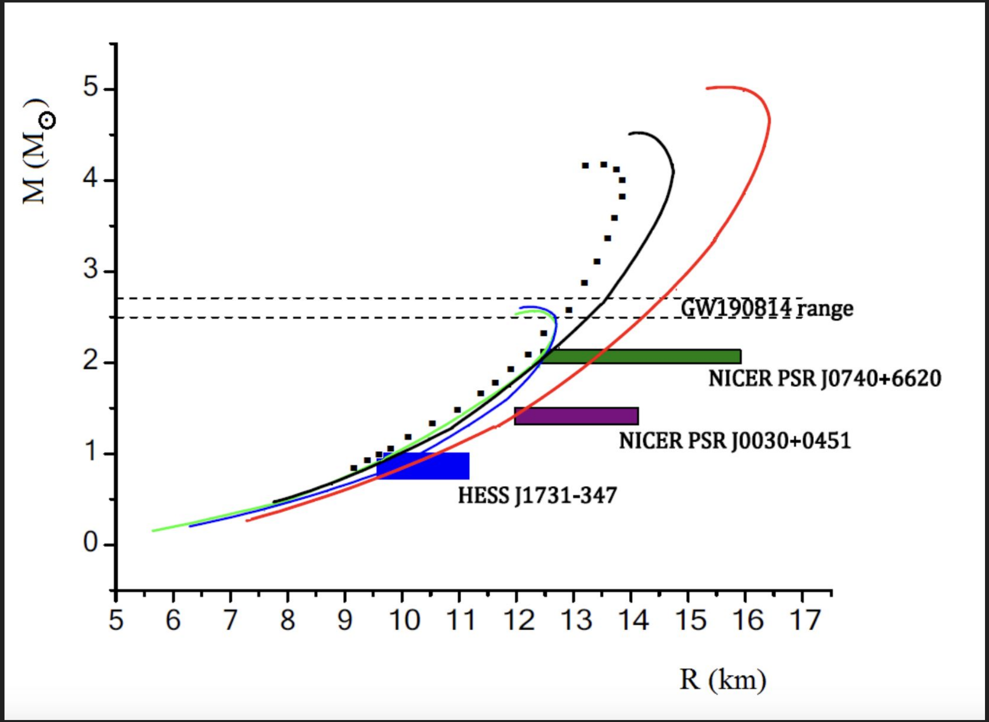
- Strange matter hypothesis: the true ground state at high densities;
- Our work: quarks in CFL state;
- Consistent both with low and high masses

HESS J1731-347 (Doroshenko et al., 2022):

$$m = 0.77^{+0.20}_{-0.17}\ M_{\odot}$$

GW190814:

$$m = 2.59^{+0.08}_{-0.09}\ M_{\odot}$$



Horvath et al. (2023)

The mass distribution

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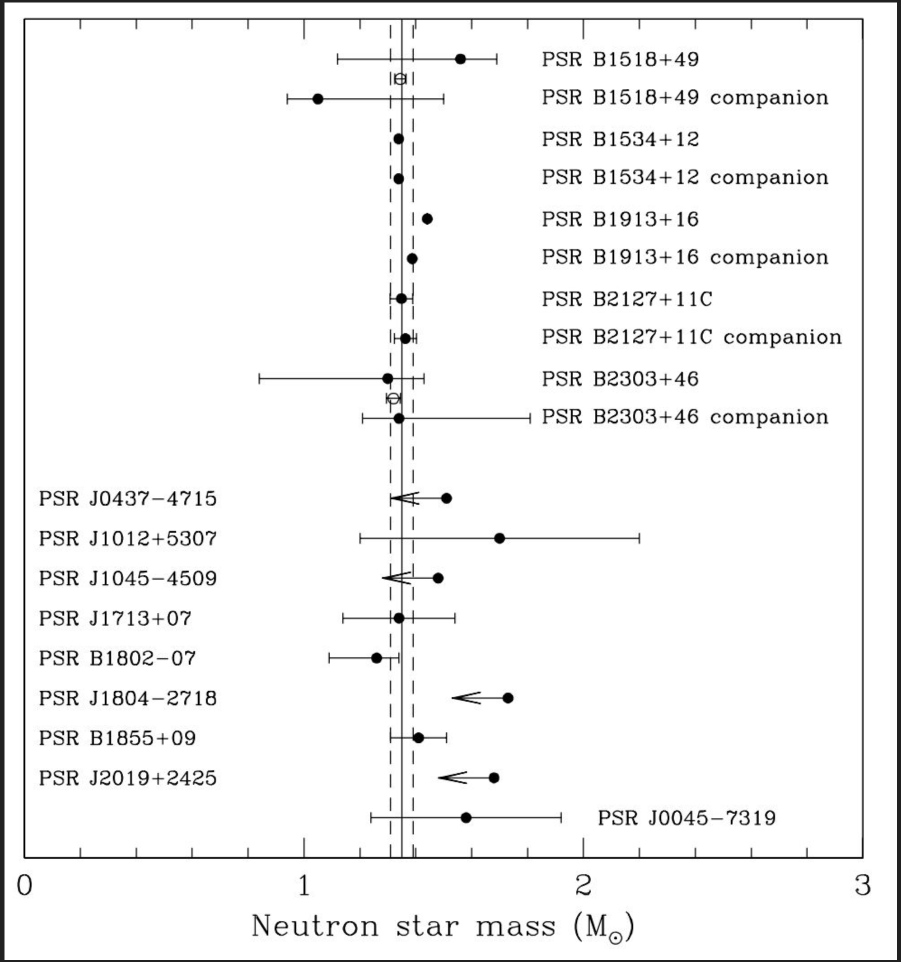
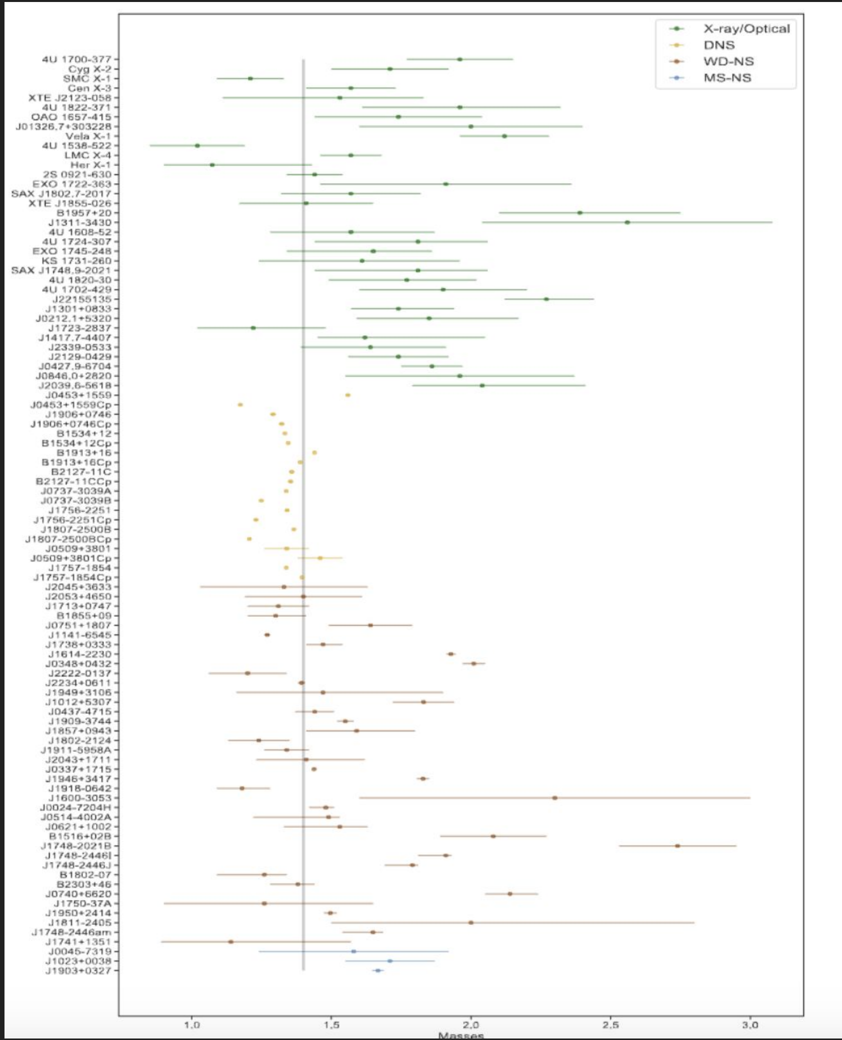
- First observations were consistent with the prediction that NSs are formed from the collapse of massive stars, when the *Fe* core mass reaches a limit
- Led to thought that stellar evolution does not allow formation of massive NSs



Thorsett & Chakrabarty (1999)



- Lightest NS: PSR J0453+1559

$$m = 1.174 \pm 0.004\ M_\odot$$

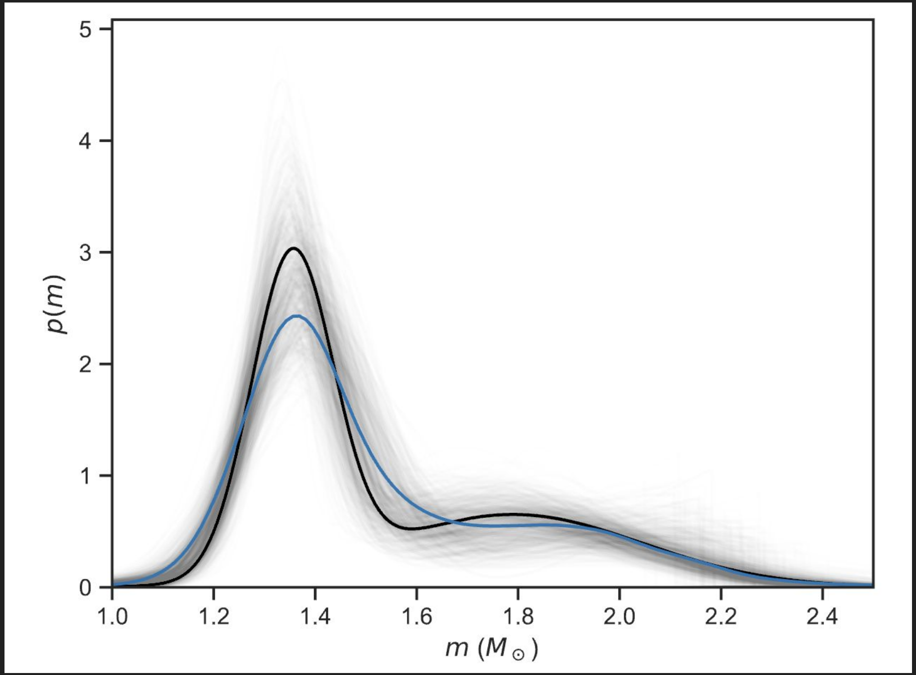
- Heaviest NS: PSR J0952-0607

$$m = 2.35 \pm 0.17\ M_\odot$$

- ~ 15 systems with NS masses potentially higher than 2 $M_\odot$
- Measurements are sensitive to inclination angle

$$M_{PSR} \propto \frac{1}{\sin^3 i}$$

The mass distribution

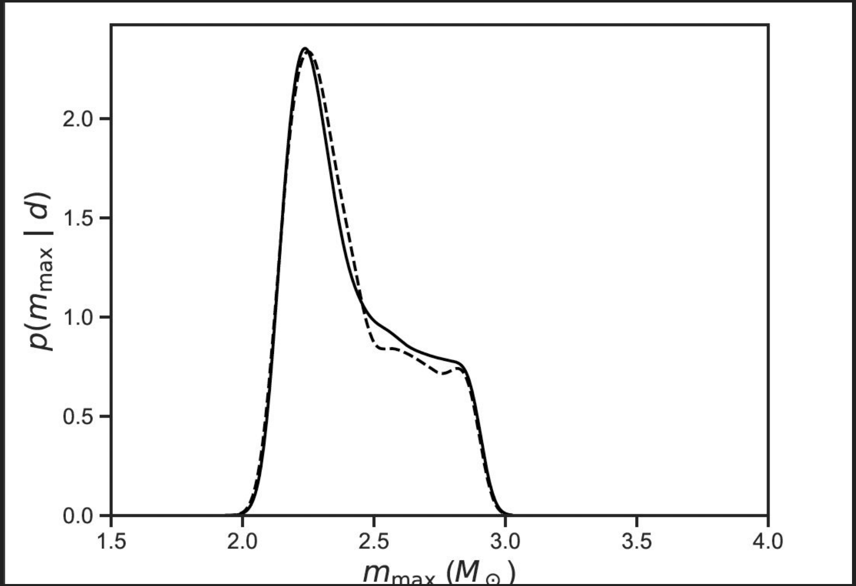


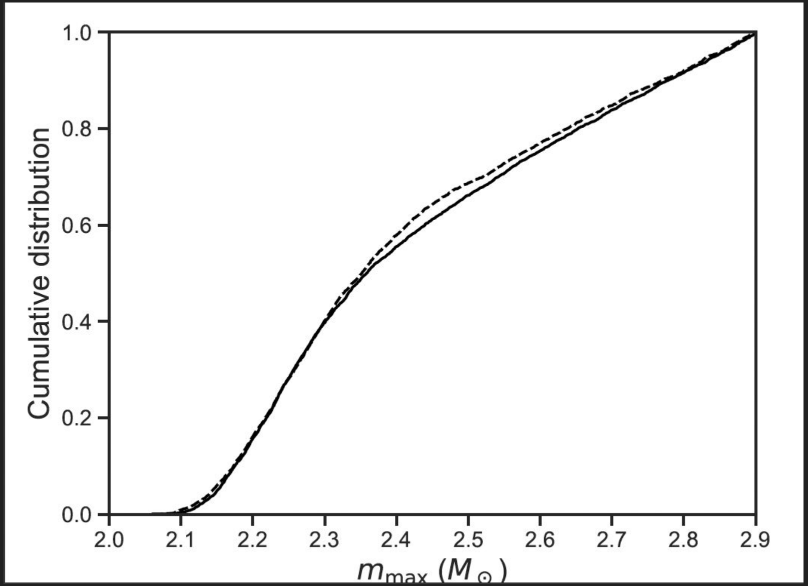
- At least two groups which differs substantially
- "Standard" scenario: light *Fe* cores
  - Suwa et al. (2018) showed that they can form NSs with $1.174\ M_\odot$
- Degenerate *OMgNe* cores: $\sim 1.25\ M_\odot$
- Massive NSs formed from heavier *Fe* cores: $\sim 1.9\ M_\odot$
- Accretion process
- Accretion Induced Collapse (AIC) and Double Degenerate AIC

Evidences of massive NS's

- GW observations raised a tension:
  - GW170817: $m_{max} \leq 2.3\ M_{\odot}$
  - GW190814: $m_{max} \geq 2.3\ M_{\odot}$

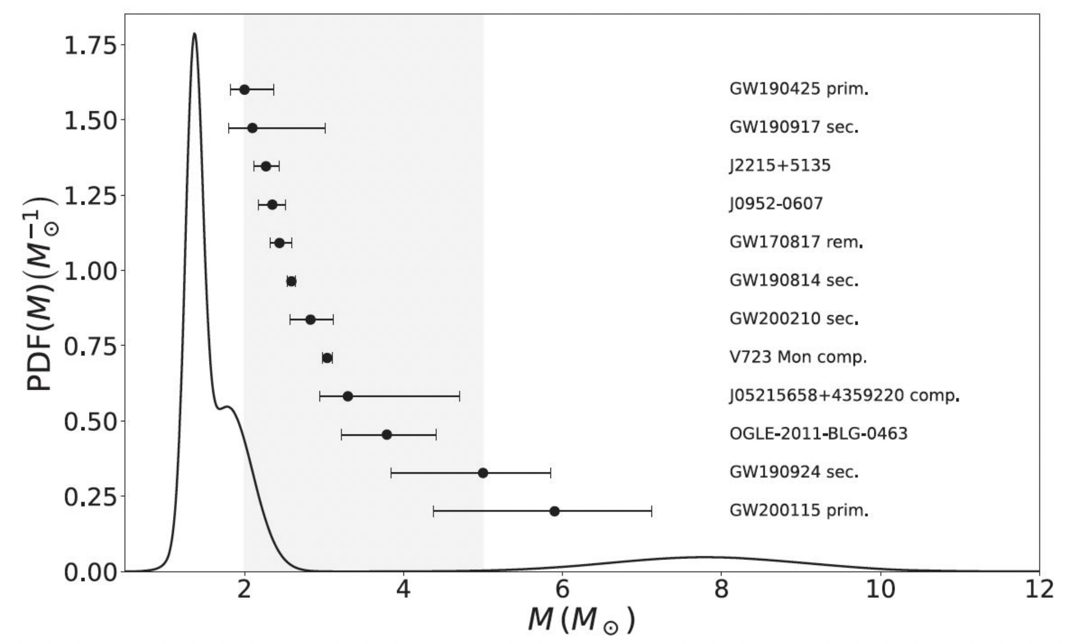
From galactic NSs

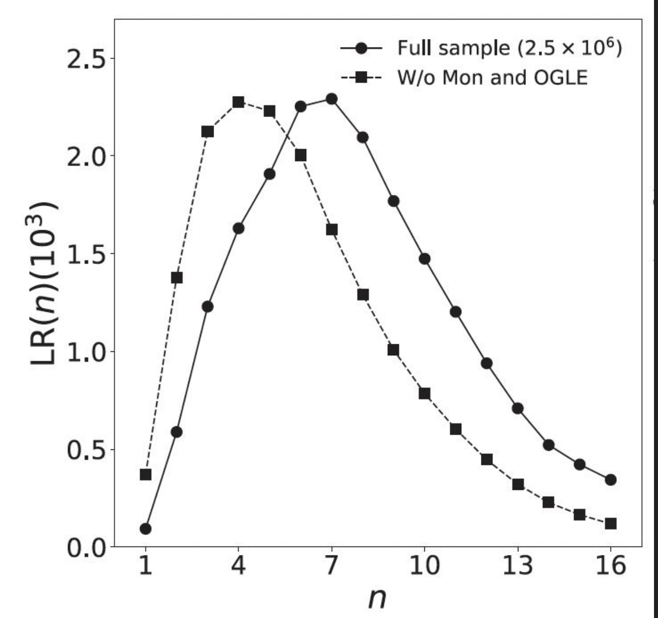




The mass gap

- Absence of compact objects in the range 2 - 5 solar masses





DoNutSS:
A Double Neutron Star System Catalogue

MAX-PLANCK-GESELLSCHAFT

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Light

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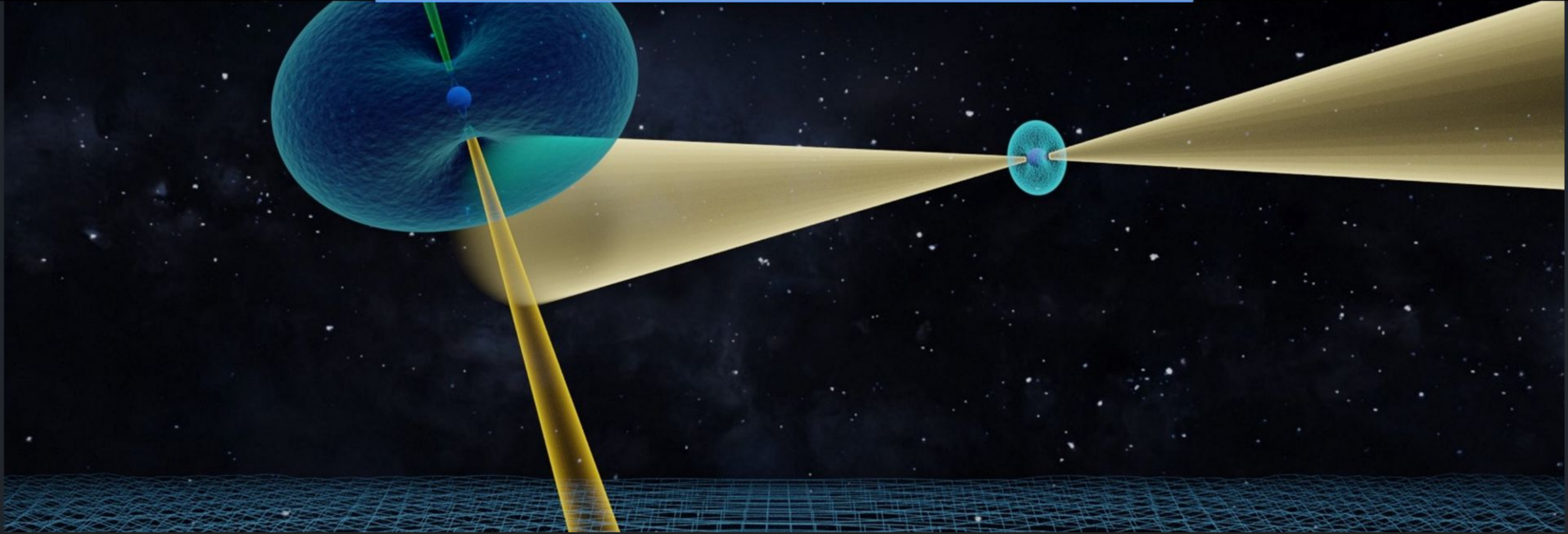

Thanks for your attention!