Massive neutron stars as mass gap candidates

Zenia Zuraiq[1], Banibrata Mukhopadhyay[1], Fridolin Weber[2,3]
[1]Indian Institute of Science, [2]San Deigo State University, [3]University of California, San Deigo

Objective

We explore the **theoretical possibility of massive neutron stars (NSs)**

→ examining how the mass changes under different relativistic mean field NS equations of state (EOS)

→ additionally checking how adding magnetic field and anisotropy can affect the system

We use constraints on tidal deformability from observations ($\Lambda_{1.4} < 800$ and/or $\Lambda_{1.4} < 580$) and magnetic to gravitational energy ratio (E_{mag}/E_{grav}) to ensure physicality of our results.

Motivation

There exists an observational mass gap between the heaviest NSs and the lightest black holes.

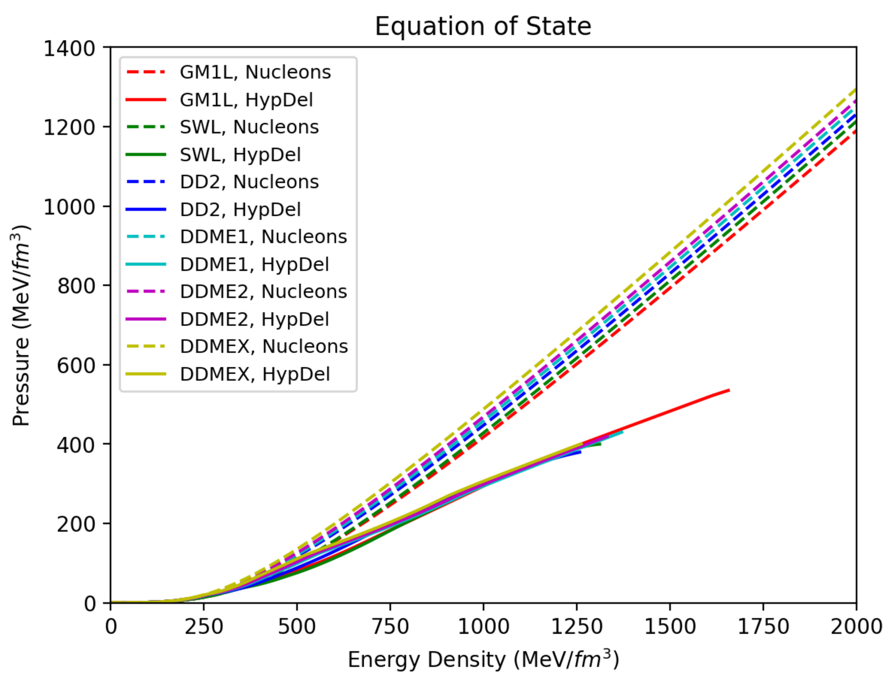
HOWEVER

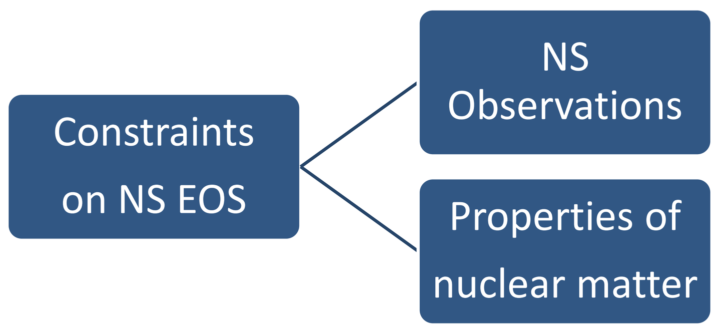
Observations like GW190814 (detected an object of mass 2.50 – 2.67 $M_\odot$) are changing this.

Massive neutron stars (> 2.5 $M_\odot$) are prime candidates to fill this mass gap!

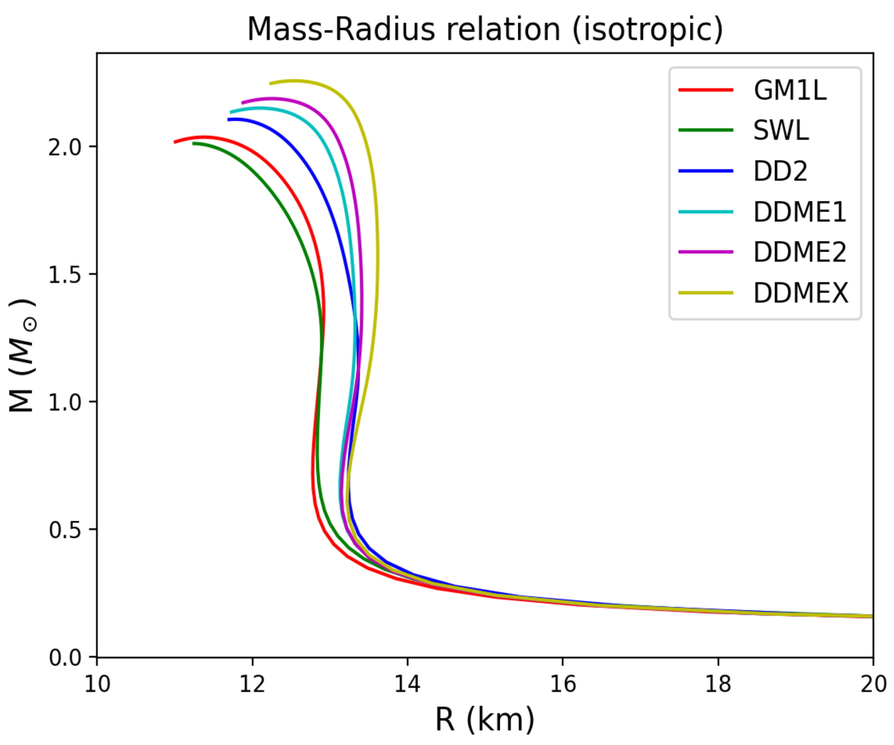
Results

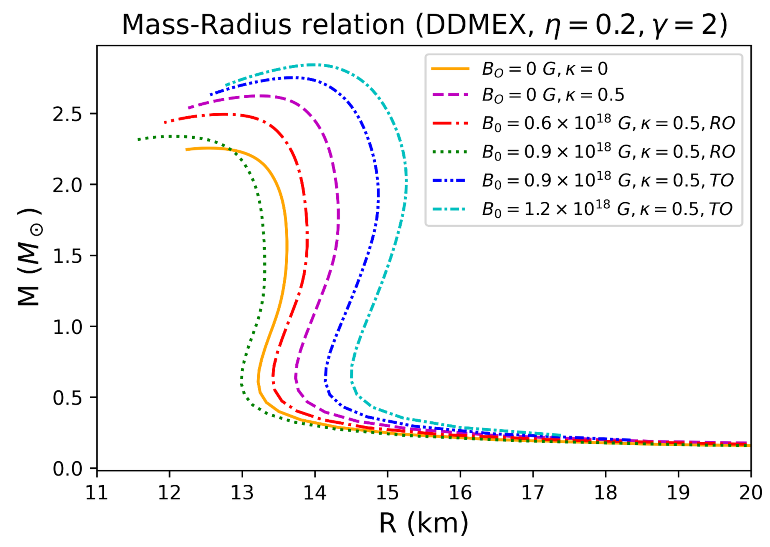
Equation of state (EOS)

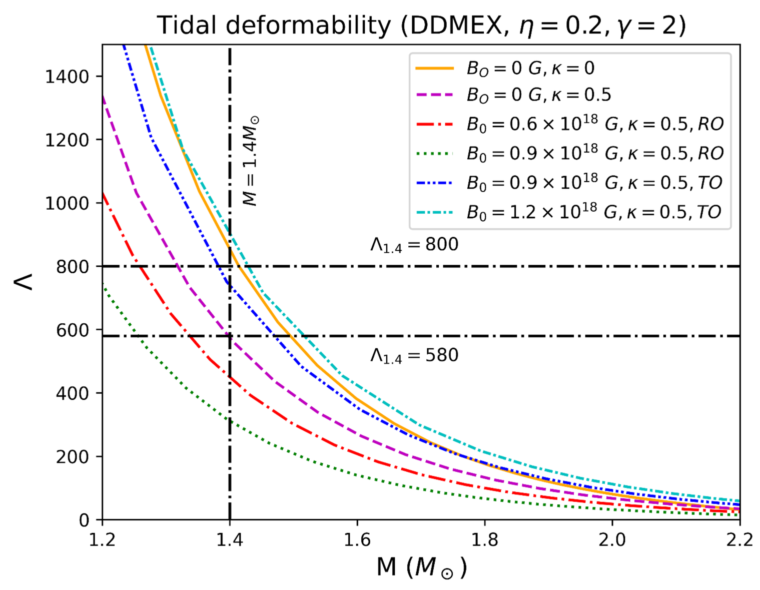


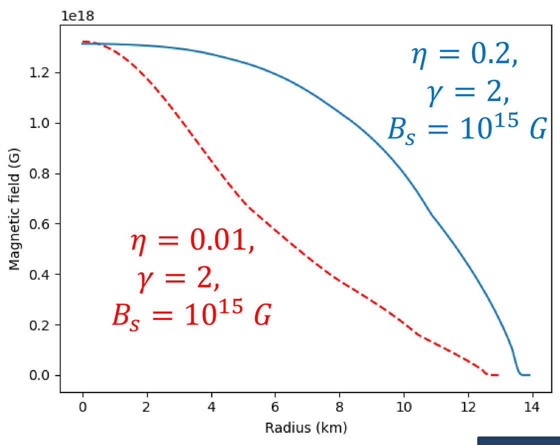


Isotropic (Pure EOS) results

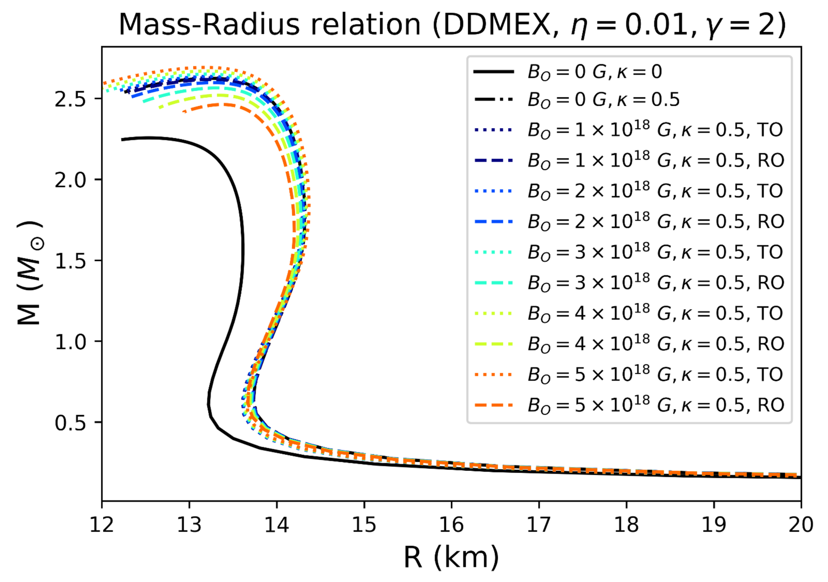


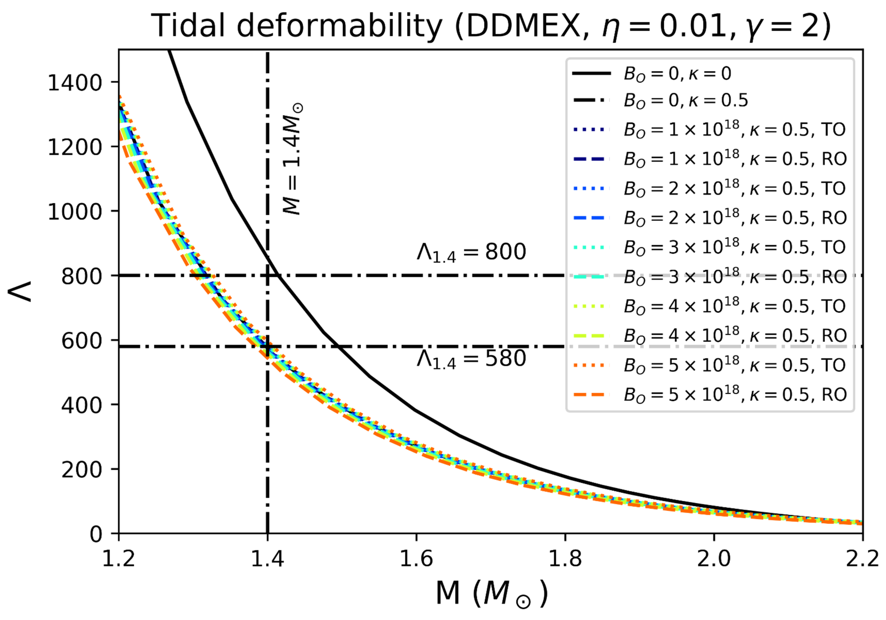






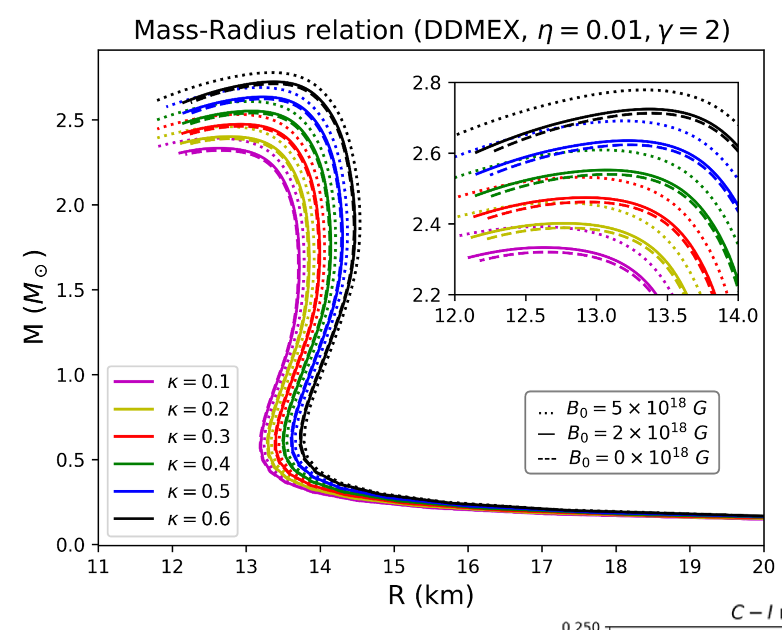
Magnetized stars with κ = 0.5

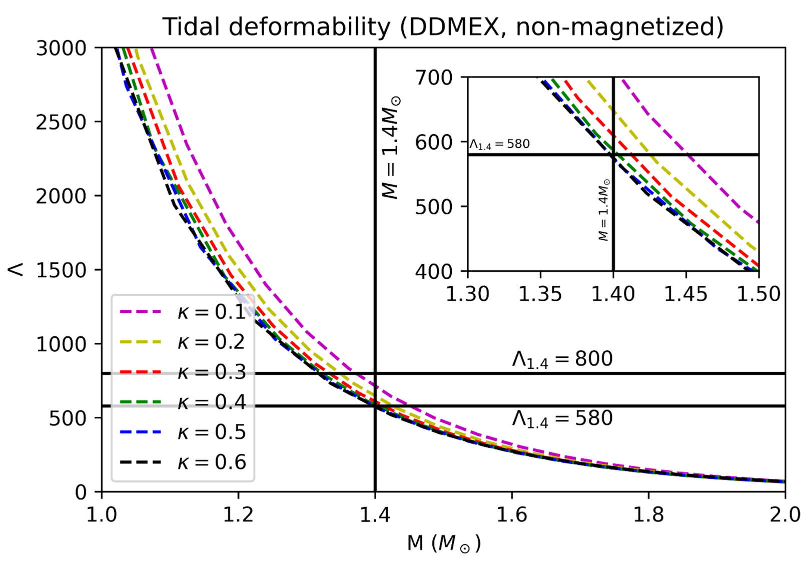




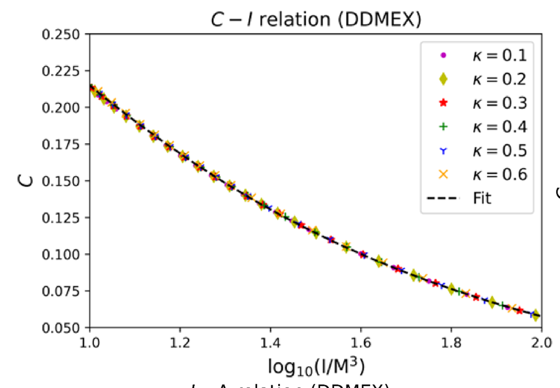
B_c (10^{18}G)	M_{max} ($M_\odot$)	R (km)	ME/GE
1.18 (TO)	2.8423	13.990	0.192
1.18 (TO)	2.6906	13.182	0.0558

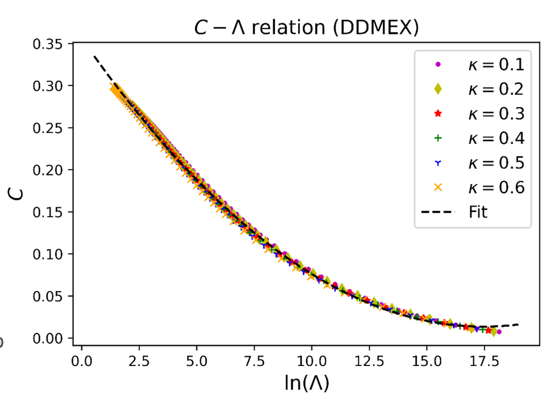
Changing κ

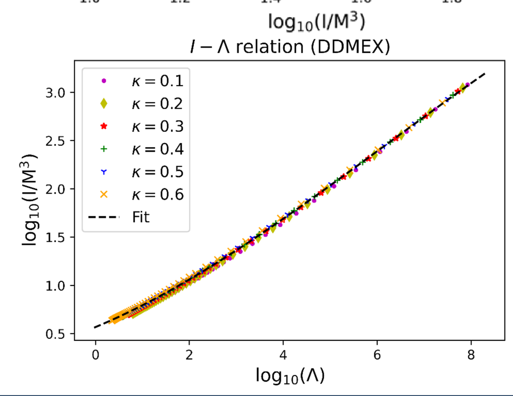




I-Love-C relations







Universal relation	Root mean square error
$C - I$	0.1626%
$C - \Lambda$	0.3721%
$I - \Lambda$	1.9505%

Formalism

Modified TOV equations

$$\frac{dm}{dr} = 4\pi r^2\left(\rho + \frac{B^2}{8\pi}\right)$$

$$\frac{dp_r}{dr} = \begin{cases} \dfrac{\dfrac{-(\rho+p_r)\left(4\pi r^3\left(p_r - \frac{B^2}{8\pi}\right)+m\right)}{r(r-2m)} + \frac{2}{r}\Delta}{\left[1 - \frac{d}{d\rho}\left(\frac{B^2}{8\pi}\right)\left(\frac{d\rho}{dp_r}\right)\right]} & \text{For radially oriented (RO) fields} \\ \dfrac{\dfrac{-\left(\rho+p_r+\frac{B^2}{4\pi}\right)\left(4\pi r^3\left(p_r + \frac{B^2}{8\pi}\right)+m\right)}{r(r-2m)} + \frac{2}{r}\Delta}{\left[1 + \frac{d}{d\rho}\left(\frac{B^2}{8\pi}\right)\left(\frac{d\rho}{dp_r}\right)\right]} & \text{For transversely oriented (TO) fields} \end{cases}$$

Deb, Mukhopadhyay & Weber (2021, 2022)

Ansatz for anisotropy

$$\Delta = \begin{cases} \dfrac{\kappa r^2\left((\rho+p_r)\left(\rho+3p_r-\frac{B^2}{4\pi}\right)\right)}{1-\frac{2m}{r}} & \text{(RO)} \\ \dfrac{\kappa r^2\left(\left(\rho+p_r+\frac{B^2}{4\pi}\right)\left(\rho+3p_r+\frac{B^2}{2\pi}\right)\right)}{1-\frac{2m}{r}} & \text{(TO)} \end{cases}$$

Bowers & Liang (1974)
Deb, Mukhopadhyay & Weber (2021,2022)

$-2/3 \leq \kappa \leq 2/3$ *(Silva et. al. (2015))*

Magnetic Field profile used

$$B(\rho) = B_s + B_0\left[1 - \exp\left\{-\eta\left(\frac{\rho}{\rho_0}\right)^{\gamma}\right\}\right]$$

Bandyopadhyay et al. (1997, 1998)

Conclusions

- Pure EOS effect not sufficient for mass gap.
- Require additional physics → magnetic field and/or anisotropy.
- Field does not necessarily increase mass → RO vs. TO. Geometry determines how mass changes with respect to that without field.
- Tidal deformability further constrains mass of NS. Strong field induced very massive NS may not satisfy tidal deformability constraint, although this result is profile-dependent. Anisotropic stars have a better chance of complying with tidal deformability constraint.

Mass gap range NSs are demonstrated to be possible, meeting all stability criteria

Contact : Zenia Zuraiq (Ph.D. Scholar and PMRF, IISc Bangalore)
zeniazuraiq@iisc.ac.in