GW190814: On the properties of the secondary component of the binary

by

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Based on arXiv: 2008.01582 & arXiv: 2010.02090

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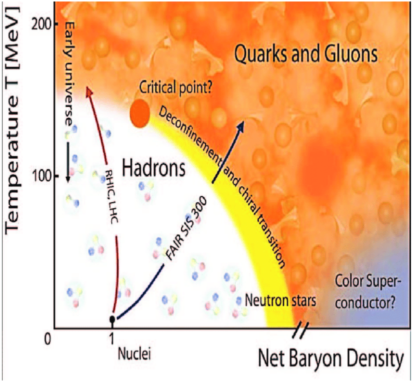
Introduction



Credit: *P. Bicudo*

- One of the key challenges of current astrophysics is to constrain the Equation of state (EoS) of neutron star (NS)
- NSs have very high density ($\sim 10^{15} \mathrm{gcm}^{-3}$) and low temperature ($\sim 10^7$ K)
- Lab experiments, particle accelerator cannot produce such material
- Only astrophysical observations can probe NS EoS

EoS parameterization and Bayesian statistics

- Posterior distribution of EoS parameters θ

$$P(\theta|d) = \frac{P(d|\theta)\times P(\theta)}{P(d)} = \frac{\Pi_i P(d_i|\theta)\times P(\theta)}{P(d)}$$

  where $d = \{d_{\rm GW}, d_{\rm x-ray}, d_{\rm radio}\}$

- We improve piecewise-polytope (PP) parameterization combining information coming from our nuclear physics knowledge.
  - In outer crust BPS EoS is used
  - Then below $1.25n_0$ saturation properties of nuclear matter is used

$$e_0(\rho,\delta) \approx e_0(\rho) + e_{sym}\delta^2$$
$$e_0(\rho) = e_0(\rho_0) + \frac{K_0}{2}\chi^2$$
$$e_{sym}(\rho) = e_{\rm sym}(\rho_0) + L\chi + \frac{K_{\rm sym}}{2}\chi^2$$

    $\delta = \text{"symmetry parameter"} = (\rho_{\rm n} - \rho_{\rm p})/\rho$,
    $\chi = (\rho - \rho_0)/3\rho_0$
  - At high densities PP parameterization is used

Constraint based on present observations: GWs+NICER

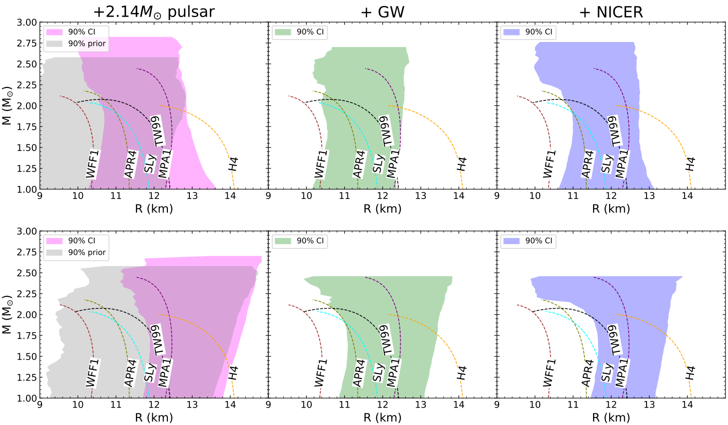
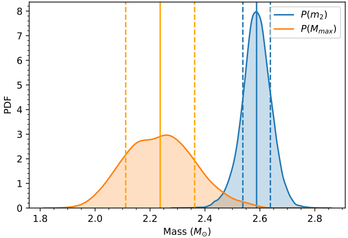


Figure: PP based result (in upper panel), hybrid nuclear+PP model (in lower panel)

BB+20, arXiv: 2008.01582

GW190814: Lightest BH or heaviest NS?

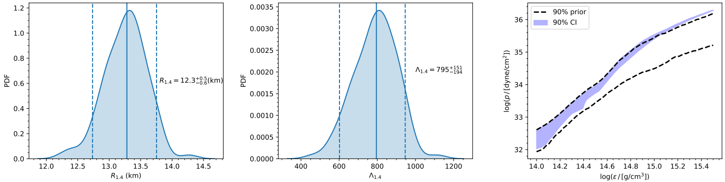
- Used EoS posterior samples from Bhaskar+(2020) to get $P(M_{\mathrm{max}})$
- Used publicly available LVC posterior of GW190814
- $P(m_2 > M_{max}) = .99$, BH = 99%, NS=1%



- rapid rotation can increase NS mass upto 20% ⇒ another possibility

BB+20, arXiv: 2010.02090

Properties assuming slowly rotating NS



- GW170817, GW190425 and NICER data are combined
- Full posterior of secondary mass of GW190814 is used as maximum mass threshold
- bound on $R_{1.4}$, $\Lambda_{1.4}$ agrees with LVC paper, Essick+(2020), INGO+(2020)
- Stringent constraint on high-density EoS

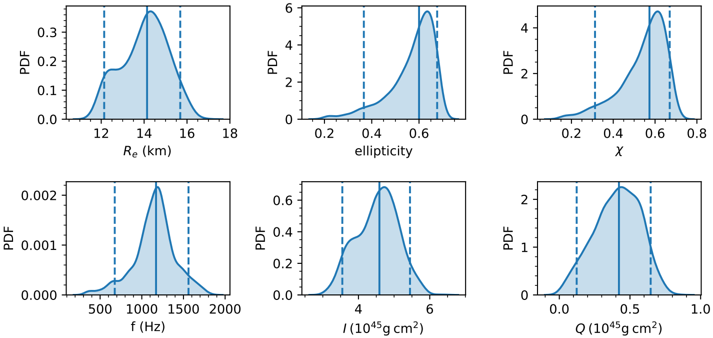
Inference technique assuming rapidly rotating NS

- Cromartie pulsar, GW170817, GW190425 and NICER data are used as nonrotating NS
- Used a universal relation found by Breu and Rezzolla, 2016.

$$M_{\rm max}^{\rm rot} = M_{\rm max}^{\rm TOV}\left(1 + a_1\left(\frac{\chi}{\chi_{\rm kep}}\right)^2 + a_2\left(\frac{\chi}{\chi_{\rm kep}}\right)^4\right)$$

- Using Bayesian inference we simultaneously sample EoS parameters and $\chi/\chi_{\rm kep}$
- These posterior samples are then used as input in RNS code to deduce several properties of the secondary
- Error introduced by universal relation is marginalized over in our calculation.

Properties assuming rapidly rotating NS



Could be the fastest rotating NS!

R-mode instability and NS temperature

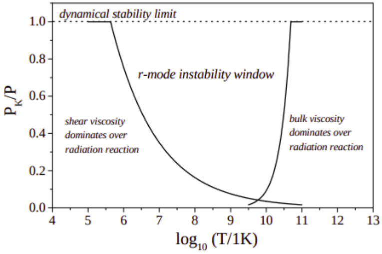


Fig. 3. The critical rotation rates at which shear viscosity (at low temperatures) and bulk viscosity (at high temperatures) balance gravitational radiation reaction due to the r-mode current multipole. This leads to the notion of a "window" in which the r-mode instability is active. The data in the figure is for the $l = m = 2$ r-mode of a canonical neutron star ($R = 10$ km and $M = 1.4M_\odot$ and Kepler period $P_K \approx 0.8$ ms).

Credit: *Andersson et. al. 2000*

R-modes and superfluid mutual friction

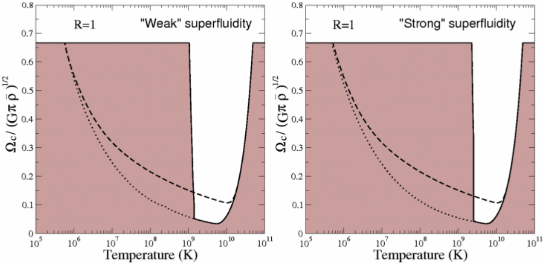
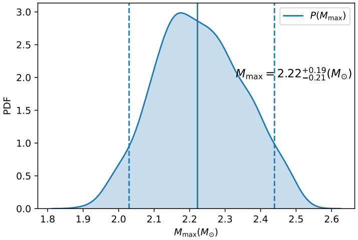


Figure 4. The r-mode instability window for $\varepsilon_p = 0.6$, calculated as a function of core temperature T and for $\mathcal{R} = 1$ in the 'weak' (left-hand panel) and 'strong' (right-hand panel) superfluidity cases. We consider a star with $M = 1.4\,M_\odot$ and $R = 10$ km. The dotted line indicates the shape the instability window has if we ignore mutual friction, while the dashed line indicates the effect that the Ekman layer at the base of the crust would have on the instability region. The results show that, when $\mathcal{R} = 1$, the mutual friction is strong enough to suppress the r-mode instability completely as soon as the core becomes superfluid.

Credit: *Haskell et. al. 2009*

What if secondary of GW190814 is a BH

- We assume population of NS and BH do not overlap
- Then if secondary is a BH, it would place a limit on on $M_{\max}$
- Assuming these two hypothesis we re-calculate the EoS posterior and corresponding distribution on $M_{\max}$ is shown here



Summary and Future plans

- We have developed a hybrid EoS formulation which connects low density nuclear physics information with a generic parameterization at higher densities
- Novel constraint on NS EoS is obtained combining multiple astrophysical observations
- Our analysis on GW190814 provides interesting inference on the properties of "mass-gap" event
  - Only $\sim 1\%$ probablity to be a nonrotating NS−−if true−− very stiff EoS for NS
  - Under rotating NS hypothesis it qualifies as fastest rotating NS observed ever!
  - Need extreme conditions to become NS (both rotating and nonrotating)−−The object is more likely to be a BH
- Any upcoming astrophysical observations can be used to put further constraints on NS EoS

Questions ?