Tidal deformabiltiy of massive neutron stars with holographic multiquark cores

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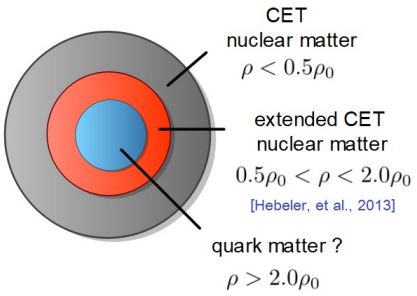
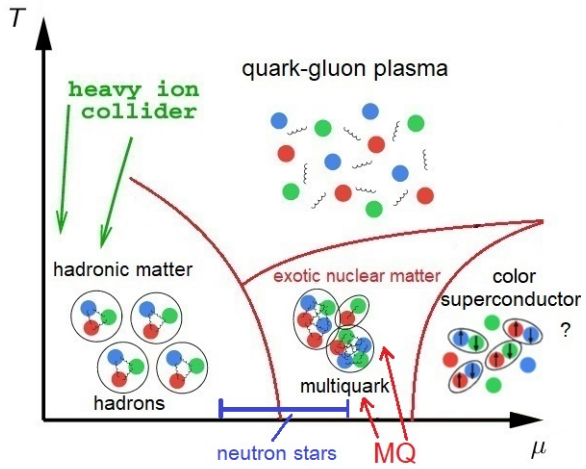
Structure of neutron stars (NS)



- NS could be divided into different layers based on $\rho_0 = 150$ MeV fm$^{-3}/c^2$.
- nuclear matter is described by chiral effective field th. (CET)
- What exactly is inside the core where $\rho \gtrsim 2.0\rho_0$?
  - A model-independent analysis [Annala, et al.,2020]
    - over 500k EoS are analyzed and compared with observational constraints
    - quark matter could exist in the cores

Conjecuture phase diagram at finite temperature T and finite quark chemical potential μ



- In the core of massive NS
  - quarks might drip
  - bound state: unclear boundary
  - effectively deconfined
- The deconfined bound state is called multiquark (MQ)
  - strongly coupled and chiral-symmetry-broken
- No exact theory for MQ
- Try holographic QCD = SU(N_c) gauge th. with a dual gravity th.
  - where N_c is large
  - not the same, but similar to $N_c = 3$

Holographic MQ state

- Holographic duality: Large N_c QCD (strongly coupled) $\leftrightarrow$ Gravity theory (weakly coupled)
- Based on Sakai-Sugimoto model [Sakai and Sugimoto, 2004; 2005],

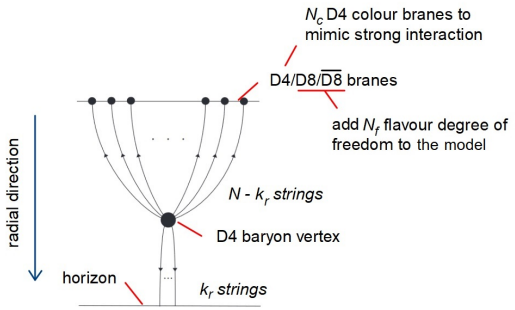
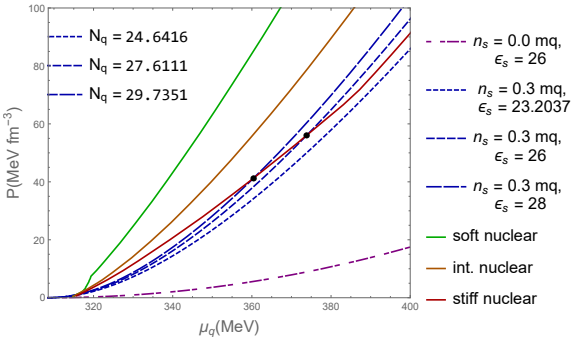
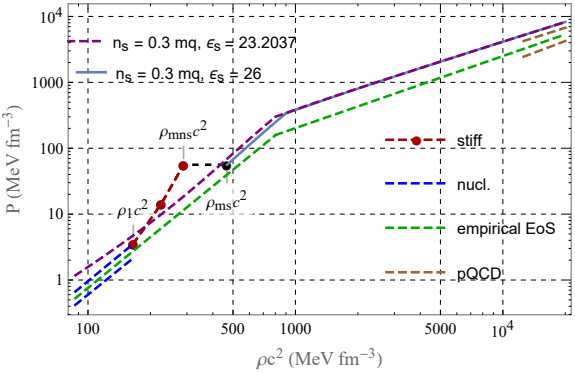


Image modified from Burikham, et al.,(2009)

- quarks $(4d) \leftrightarrow$ strings $(10d)$
- mesons $\leftrightarrow$ open strings with both ends on colour Dp-branes
- MQ $\leftrightarrow$ D4 baryon vertex with N strings attached [Burikham, et al.,2009]
  - where $n_s = k_r/N \rightarrow$ relative colour charge per multiquark
- EoS could be calculated from thermodynamics of MQ [Burikham, et al.,2010]

Possible phase transitions & EoS for massive NS with MQ core



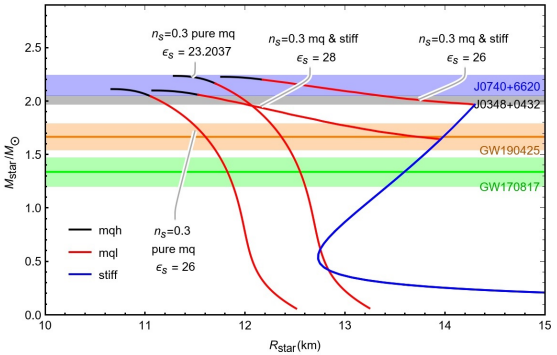


[Pinkanjanarod, Burikham, 2021]

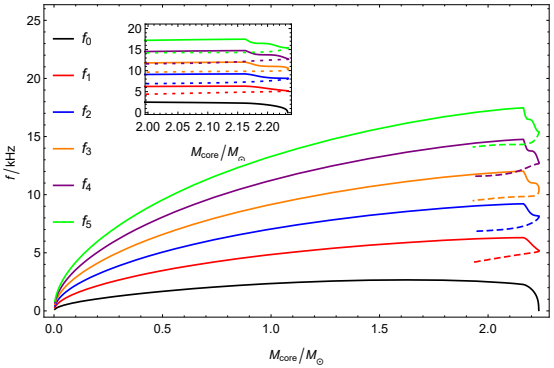
- Using cold nuclear matter EoS [Hebeler et. al., 2013]
- with holographic multiquark EoS [Burikham, Hirunsirisawat, Pinkanjanarod, 2010]
- 1^{st} order phase transition: $n_s = 0.3$ mq/stiff nuclear matter

M-R diagram of massive NS and radial pulsation of MQ cores

- Constraints from NICER
  - $M = 1.44^{+0.15}_{-0.14} M_\odot$; $R = 13.02^{+1.24}_{-1.06}$ km at $1-\sigma$ confidence level [Miller, et al., 2019, L24]



[Pinkanjanarod ,Burikham, 2021]



[arXiv:2106.13450]

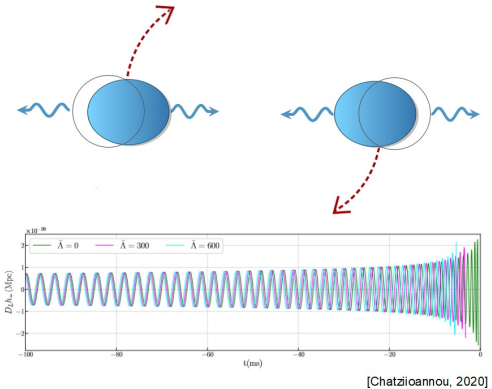
Probing NS with tidal deformability Λ

- Tidal deformability Λ from [GW170817],

$$Q_{ij} = -\Lambda \epsilon_{ij},$$

quadrupole moment Q_{ij} is deformed by external tidal gravitational field ϵ_{ij}

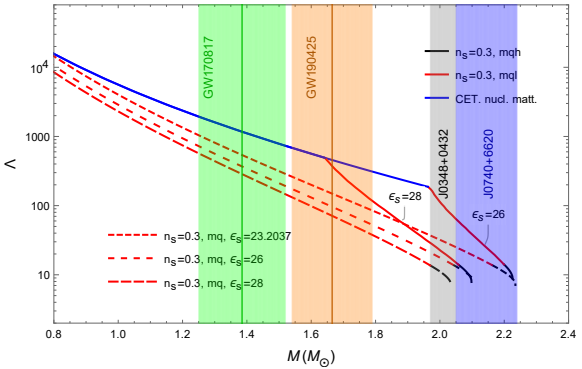
  - the greater Λ,
    the closer they are,
    the shorter period, and
    the sooner phase shifted

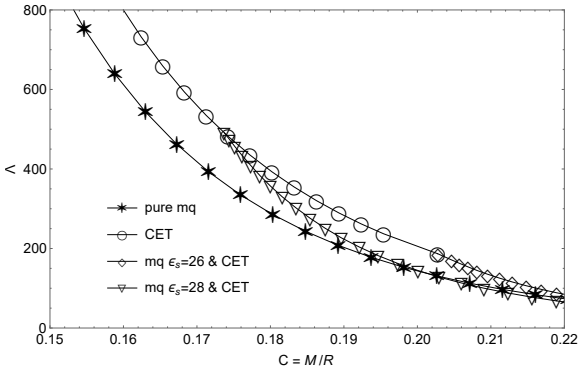


[Chatziioannou, 2020]

- $\Lambda_{1.36-1.60 M_\odot} < 800$ [GW170817]

Tidal deformation of massive NS with MQ cores,





[arXiv:2106.13450]

Conclusion

- Massive neutron stars (NS) with multiquark (MQ) cores have been studied
  - At low density, nuclear matter is described by EoS from chiral effective field theory (CET)
  - At high density, MQ could be the state of matter at the cores of NS
- The EoS of holographic MQ ($n_s = 0.3$),
  - interpolate well between the high and low-density
  - when setting $\epsilon_s = 26 - 28$ GeV/fm^3.
- 1^{st} order phase transitions between MQ and stiff nuclear matter
  - Beyond the transition density, MQ is more preferred over the stiff nuclear matter.
- M-R and tidal deformability Λ of the NS and pure MQ star have been studied
  - M-R and Λ are in agreement with the constraints from observations
- Recently, I-Love-Q relations of massive NS with MQ cores have been analyzed, and this work was submitted to [arXiv:2111.00712].