Global properties of rotating neutron stars via matched QCD equations of state

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8 December 2016

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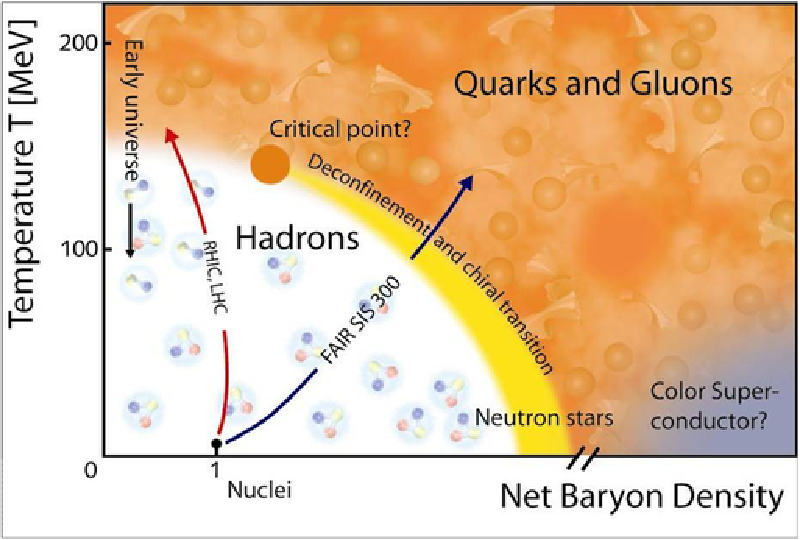
Outline

1. Matching: the idea
2. Kurkela et al. 2014 matched EOS band
3. Applications to rotating NSs

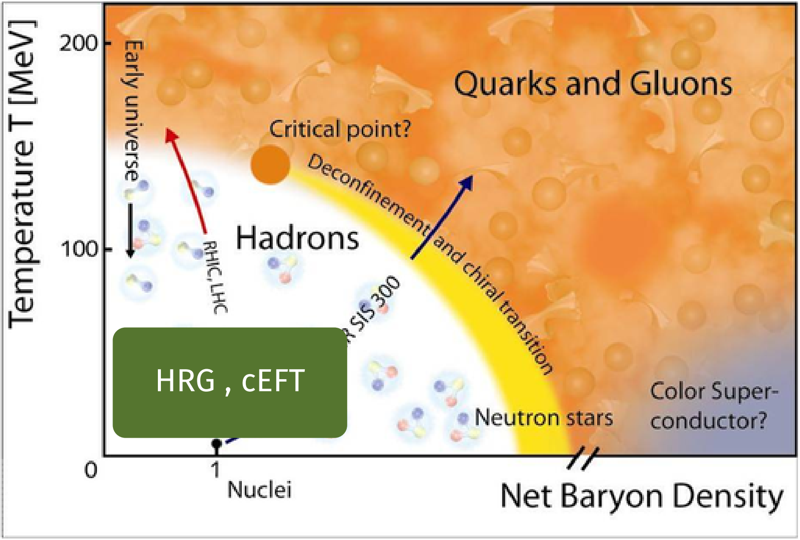
Matching: the idea

QCD matter



Source: Compressed Baryonic Matter (CBM) experiment

QCD MATTER



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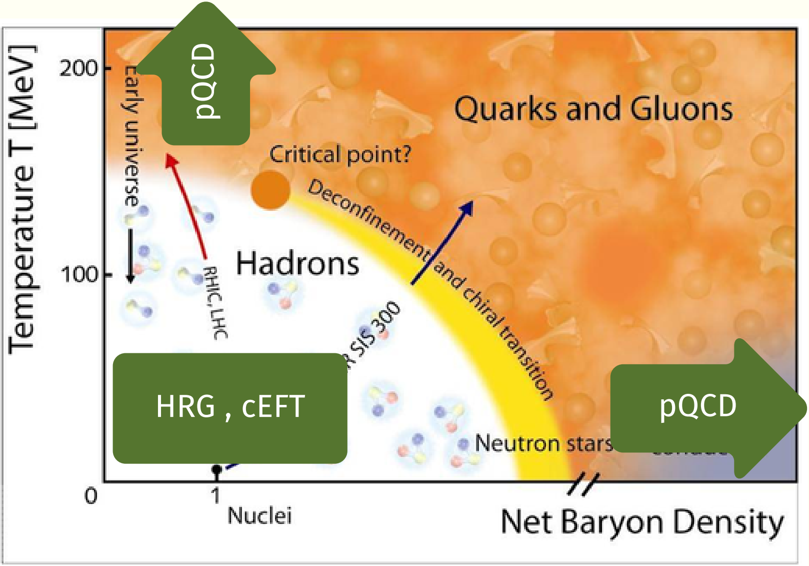

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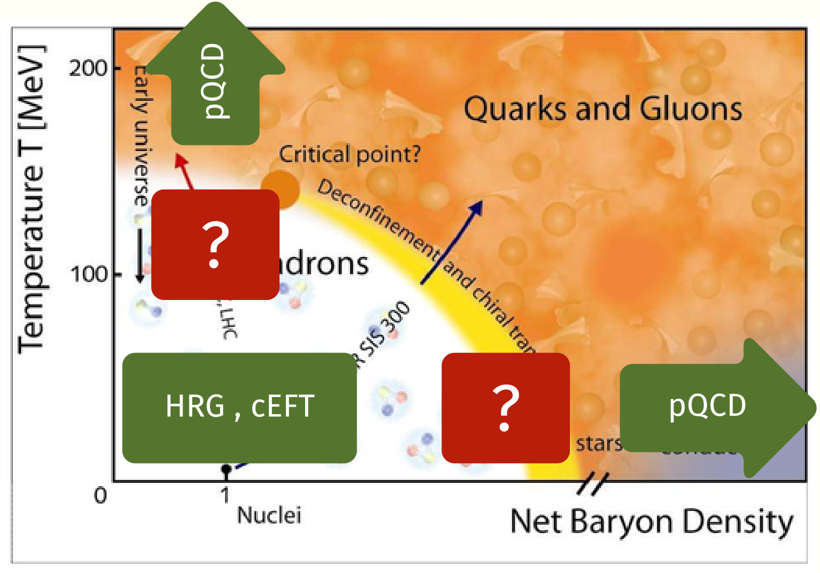

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- This philosophy, applied to the QCD phase diagram at $T = 0$ can shed light on NSs and their properties.

Kurkela et al. 2014 matched EOS band

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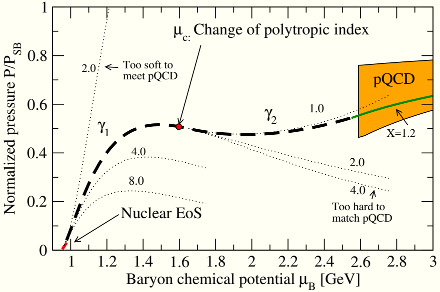
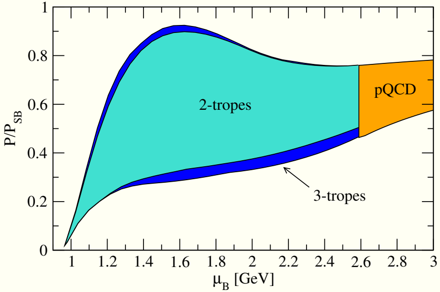
- Kurkela et al. 2014 have matched **cEFT** (Tews et al. 2013) to **pQCD** (Fraga et al. 2014, Kurkela et al. 2010) with 2-3 interpolating polytropes: $P(n) \propto n^{\gamma}$

- Thermodynamic consistency, subluminality, matching to pQCD, place stingent constraints on values of matching indices and locations.

Kurkela, Fraga, Schaffner-Bielich, and Vuorinen, Astrophys.J. 789 (2014) [arXiv:1402.6618], Fraga, Kurkela, and Vuorinen, Eur.Phys.J. A52 (2016) [arXiv:1508.05019]

- Solutions for $\gamma_1 \in [2.23, 9.2]$, and $\gamma_2 \in [1.0, 1.5]$, change in polytropic index at $\mu^* \in [1.08, 2.05]$ GeV.





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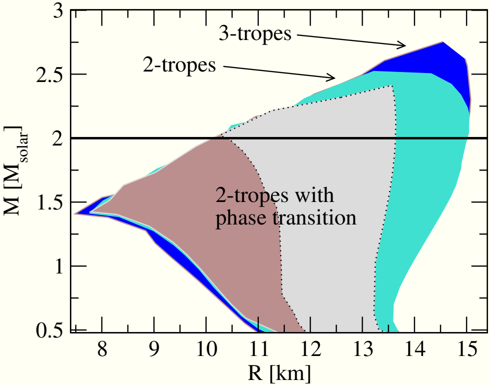
Kurkela et al. 2014 EOS band

- Used EOS band to construct rotating NS. (With $2M_\odot$ constraint.)



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Applications to rotating NSs

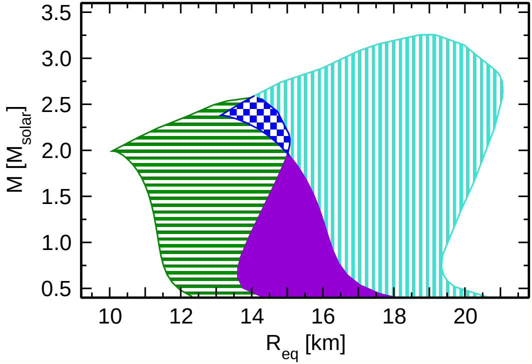
Applying EOS to rotating NSs

- Used $P(\epsilon)$ of Kurkela et al. 2014 with the publically-available RNS code to construct NSs with any ω below the mass-shedding (Kepler) limit.

- Looked at various relations:
  - M-R_e
  - M-f
  - R_e-f (for $1.4M_\odot$ star)
  - I-R_e (for the double pulsar PSR J0737-3039A)

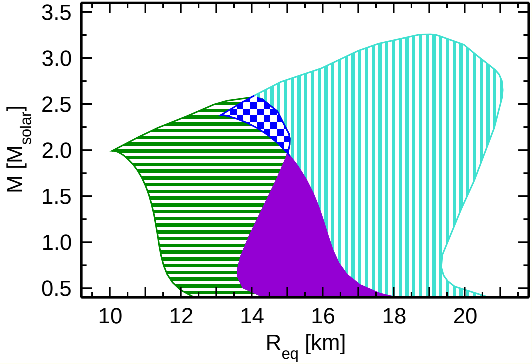
Plots

Mass-equatorial radius



Green region: nonrotating. **Light blue region:** mass shedding.

TG, Astrophys.J. 832 (2016) [arXiv:1605.08067]



Green region: nonrotating. **Light blue region:** mass shedding.

- Maximum nonrotating mass is $2.5 M_\odot$; rotating is $3.25 M_\odot$
- Maximum allowed radius is 21km.

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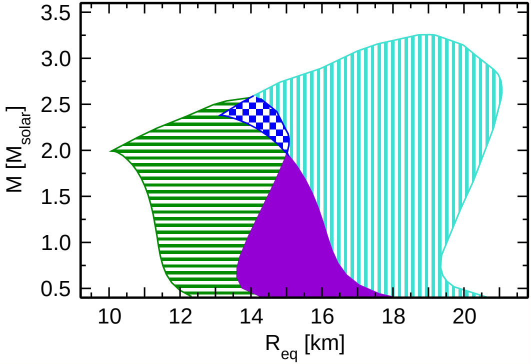

Green region: nonrotating. **Light blue region:** mass shedding.

- Maximum nonrotating mass is $2.5M_{\odot}$; rotating is $3.25M_{\odot}$
- Maximum allowed radius is 21km.
- The same EOS forms the boundaries for both the rotating and nonrotating regions.

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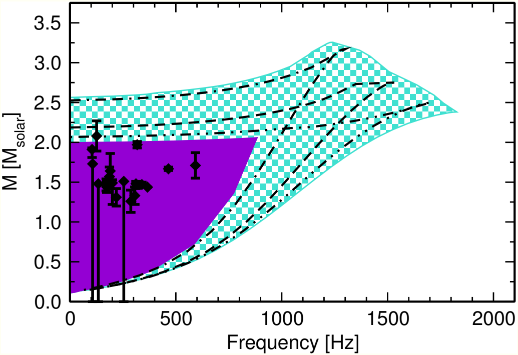
Mass-frequency



Purple region: allowed for all EOSs. **L. blue region:** allowed for only some EOSs. **Dashed lines:** sample EOSs. **Data points:** NSs with $f > 100$Hz, from Haensel, Bejger, Fortin, and Zdunik, 2016.

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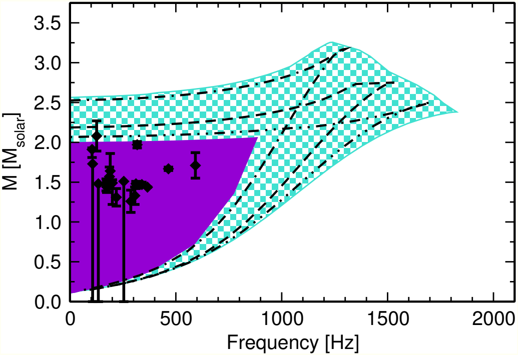

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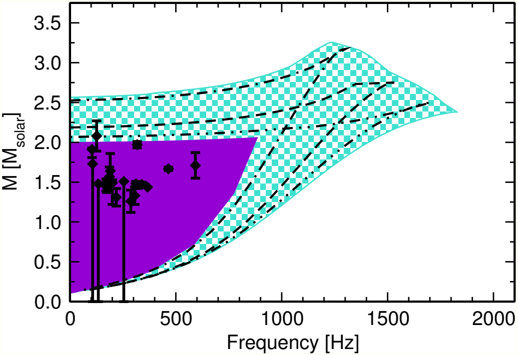

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- One star (B1516+02B) cuts slightly into the top band, though not really a rotation constraint.
- f constraint: upper-right corner of purple region: $f > 883$Hz will start eliminating EOSs.
- lower-f NSs could also rule out EOSs if their masses were sufficiently low (e.g., $f = 716$Hz starts constraining for $M > 1M_\odot$)

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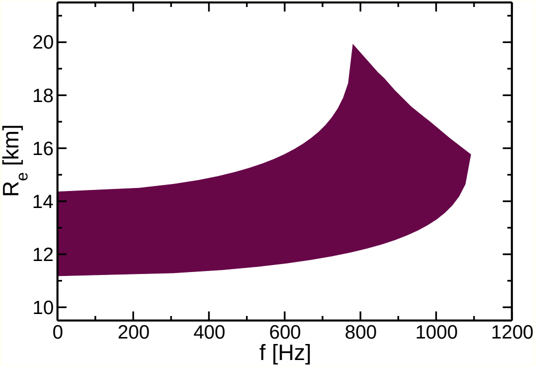
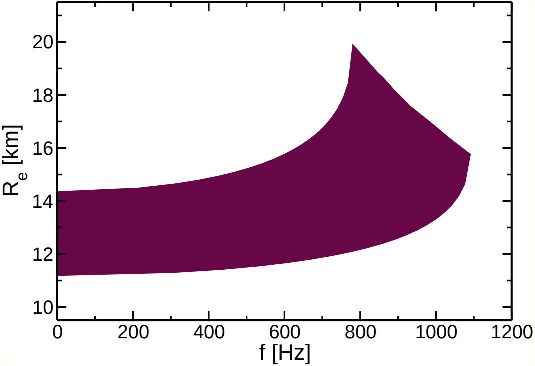
Equatorial radius-frequency



Allowed region of $R_e(f)$ curves for a $1.4M_\odot$ star.

Equatorial radius-frequency



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- Largest f that all EOSs can support is $f = 780Hz$.
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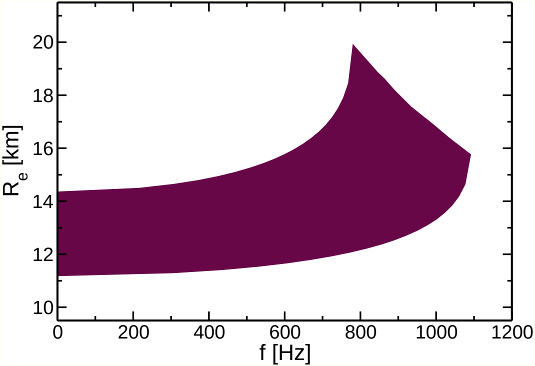

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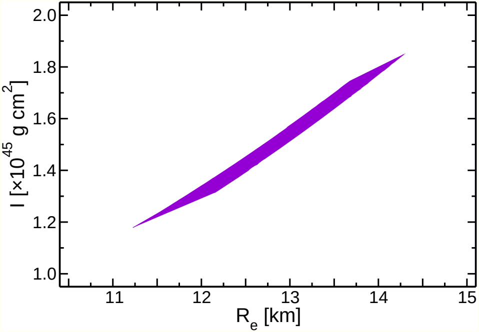
- Largest f that all EOSs can support is $f = 780 Hz$.
- Plot serves as a prediction for observational astronomers.
- When consistent, reliable data of NS radii are available, plot could be overlaid with observational data to further constrain the QCD EOS.

I-R_e for the double pulsar PSR J0737-3039A



Allowed region of (I, R_e) points for PSR J0737-3039A.

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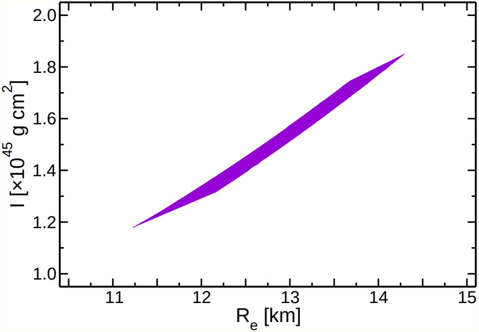

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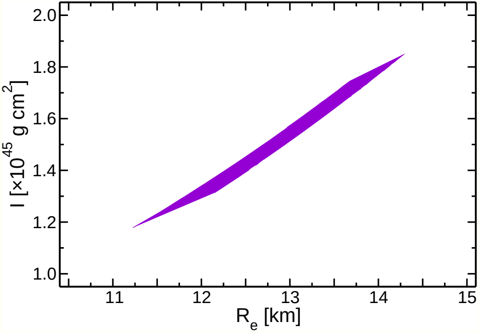

Allowed region of (I, R_e) points for PSR J0737-3039A.

- Strongly correlated: measuring I with 10% precision determines R_e to $\pm$0.5km within this approach.
- All EOSs fall on "vertical" edges, so a measurement of I, even to low precision, would have large effect on EOS band.

TG, Astrophys.J. 832 (2016) [arXiv:1605.08067]

$$\text{e.g.} \quad I = (1.5 \pm 0.15) \times 10^{45} g \cdot cm^2$$

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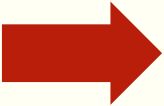

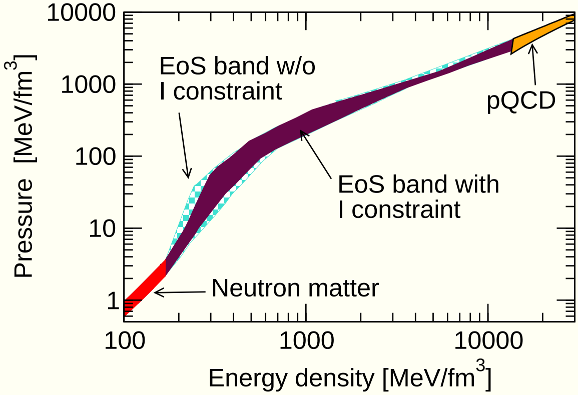

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Summary

- No **fully first-principles** approach to the QCD EOS currently exists to apply to NSs.

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- Kurkela et al. 2014 matching can be applied to **rotating** NSs, and allows for other comparisons to observation:
  - ***M*-*f* regions** most directly connect to current observations and can lead to future EOS-constraint. (Future R_e–f also?)
  - **Most stringent constraints** on EOS band would come from even a relatively imprecise measurement of I of the double pulsar PSR J0737-3039A.

Thank you!