GLOBAL PROPERTIES OF NEUTRON STARS WITH QCD EQUATIONS OF STATE

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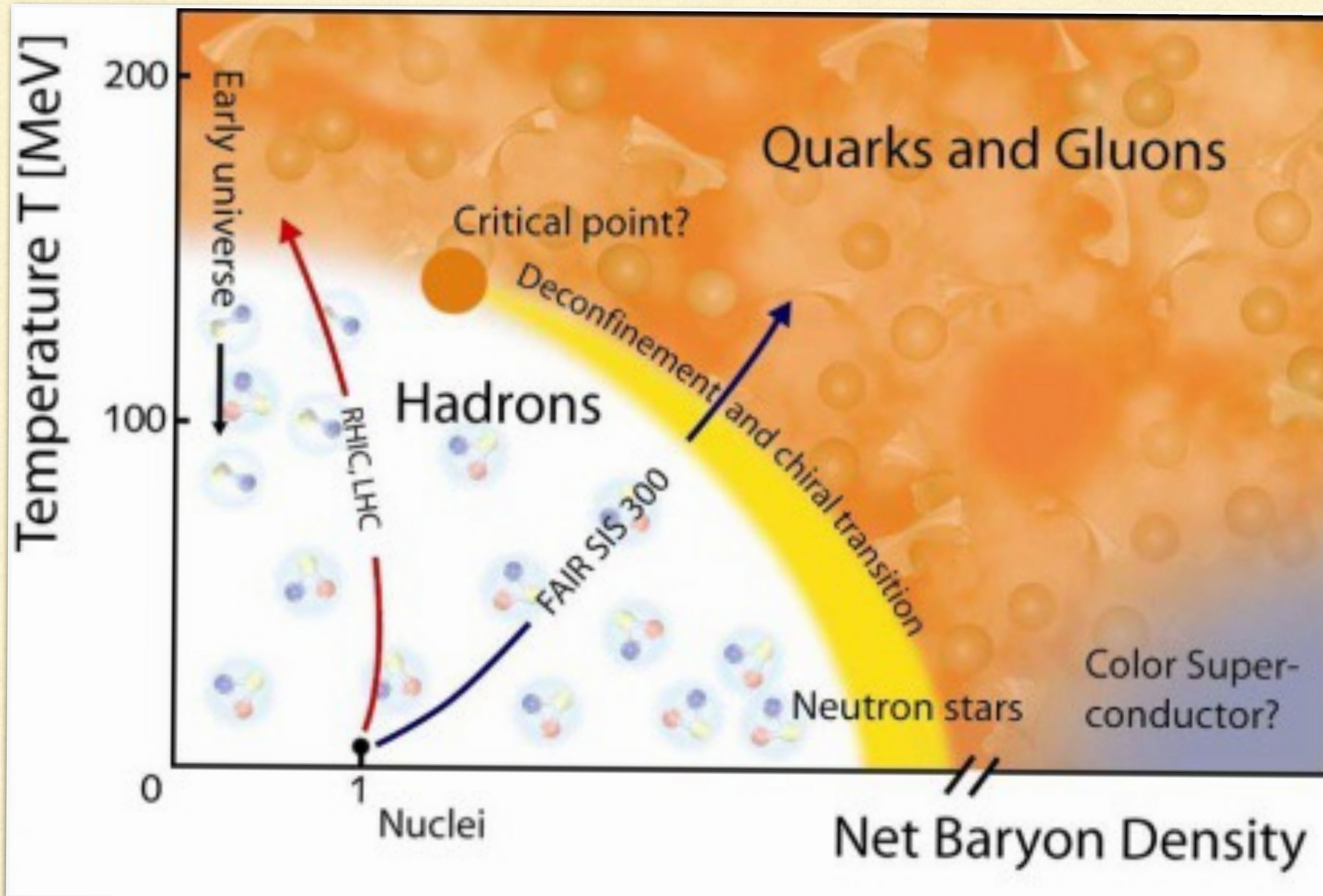
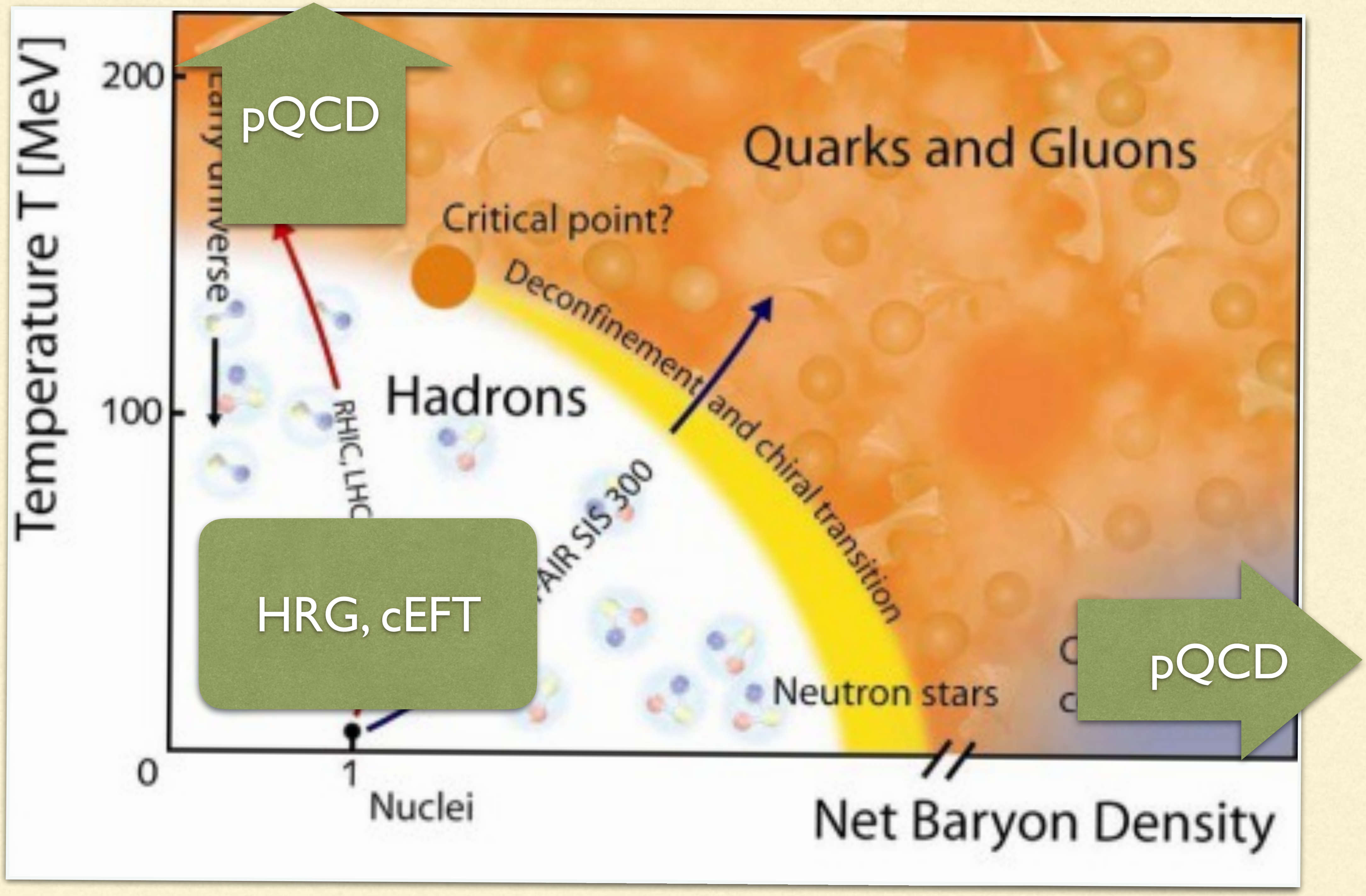
23 May 2016

QCD MATTER



Source: Compressed Baryonic Matter (CBM) Experiment

NUCLEAR MATTER



Source: Compressed Baryonic Matter (CBM) Experiment

- Matching two (controlled) **perturbative** regimes can give us information about the complex, **nonperturbative** regime in between.

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

OUTLINE

- PHILOSOPHY & MOTIVATION
- KURKELA et al. EOS BAND
- APPLYING EOS to ROTATING NSs

KURKELA et al. EOS BAND

Kurkela, Fraga, Schaffner-Bielich, and Vuorinen (arXiv:1402.6618)

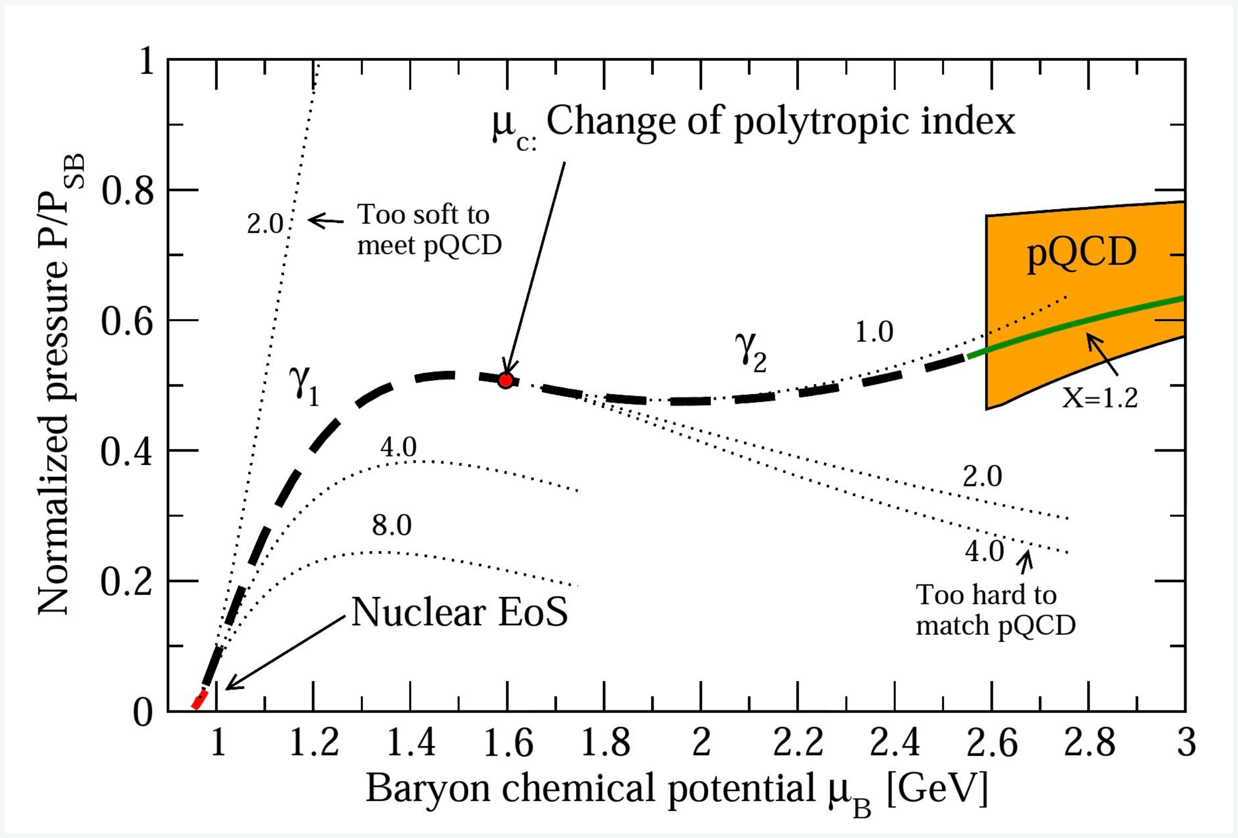
KURKELA et al. EOS BAND

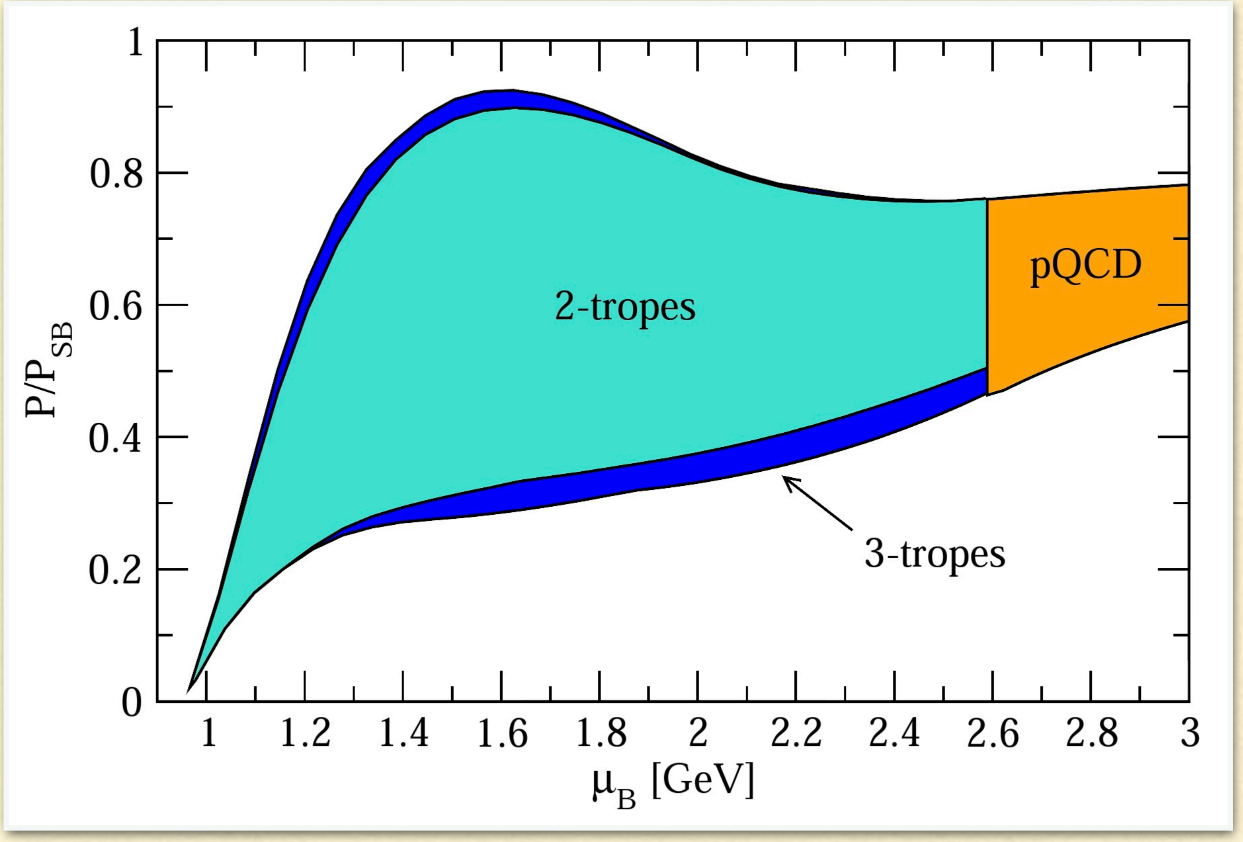
- Kurkela, et al. have matched cEFT [Tews et al., 2013] to pQCD [Fraga et al. 2014, Kurkela et al. 2010] with 2-3 interpolating polytropes. ($P(n) = \text{const.}\ n^{\gamma}$)
- Thermodynamic consistency, subluminality, matching to pQCD, place stringent constraints on values of matching indices and locations.

Kurkela, Fraga, Schaffner-Bielich, and Vuorinen (arXiv:1402.6618)

KURKELA et al. EOS BAND

- 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.

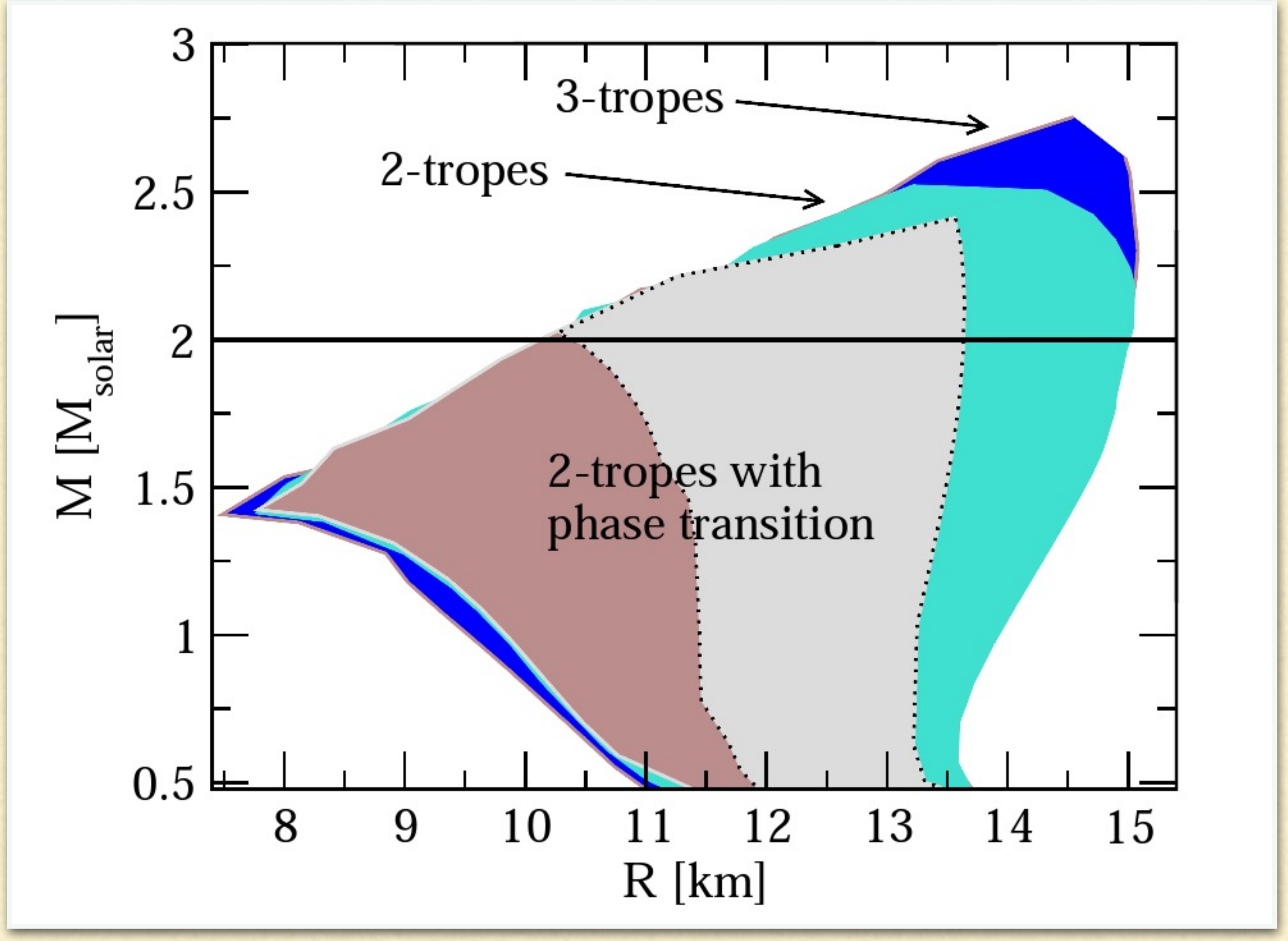




Kurkela, Fraga, Schaffner-Bielich, and Vuorinen (arXiv:1402.6618)

Kurkela et al. EOS band

- They used EOS band to construct rotating NSs. (With $2M_S$ constraint.)



Kurkela, Fraga, Schaffner-Bielich, and Vuorinen (arXiv:1402.6618)

APPLYING EOS to ROTATING NSs

[arXiv soon]

APPLYING EOS to ROTATING NSs

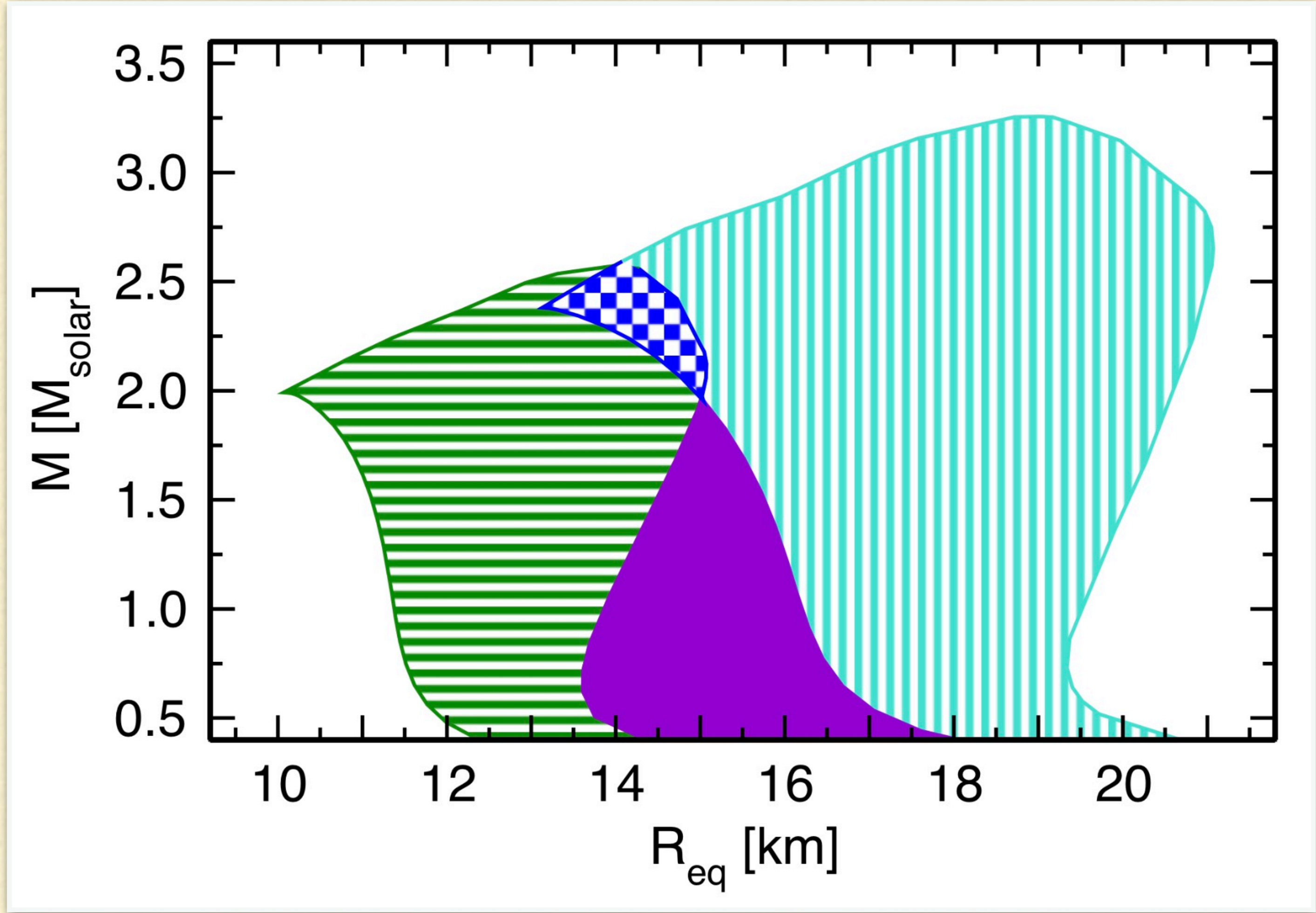
- Used P(ε) of Kurkela et al. with the publicity available RNS code to construct NS with any ω below the mass-shedding limit.

- Looked at various relations: *M–R*, *M–f*, *Re–f* (for 1.4*Ms*-star), *I–Re* (for the double pulsar PSR J0737-3039A)

[arXiv soon]

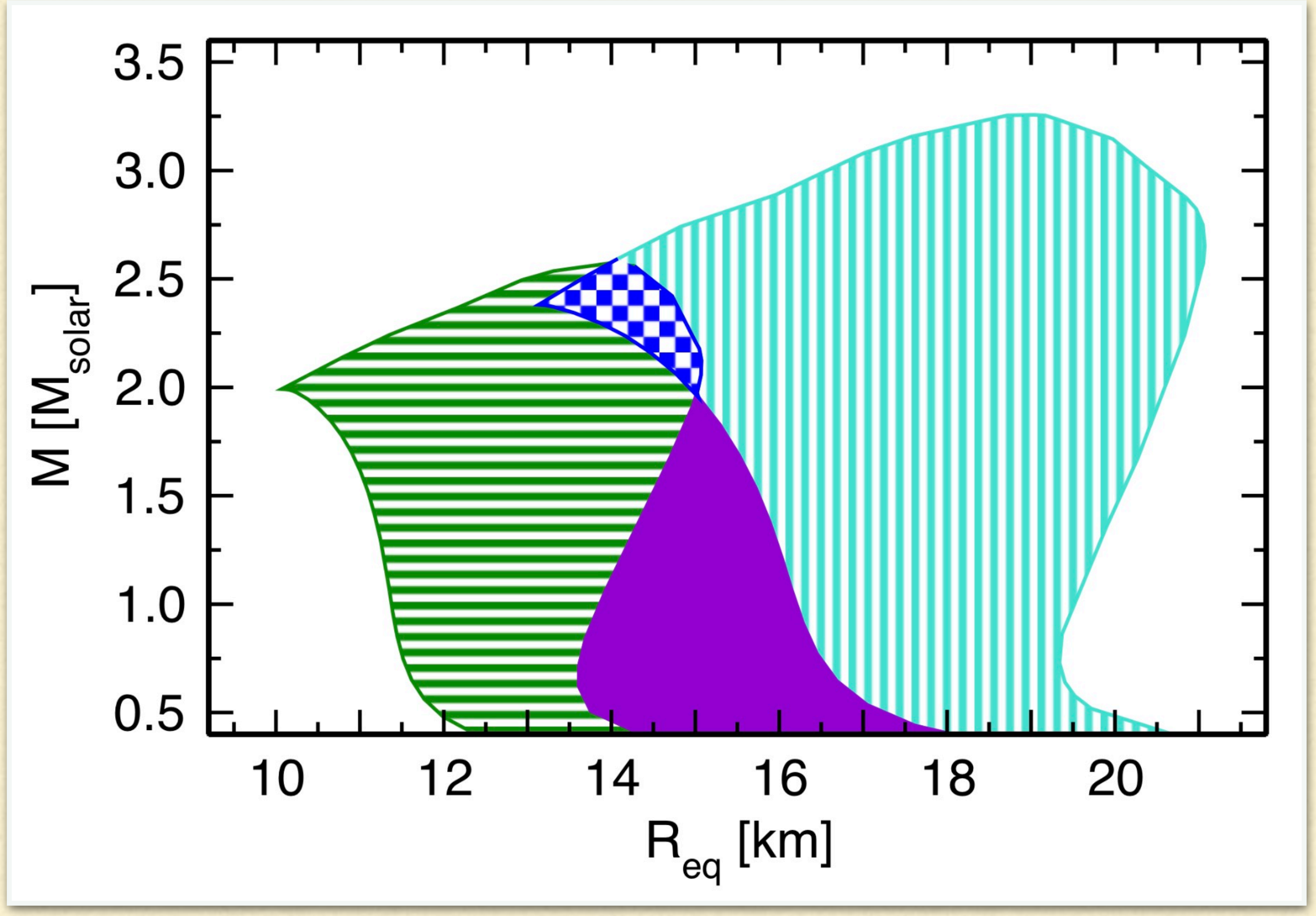
Plots

Mass–equatorial radius



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

Mass–equatorial radius



- Maximum nonrotating mass is 2.5*Ms*, rotating is 3.25*Ms*.
- Maximum allowed radius is 21km.

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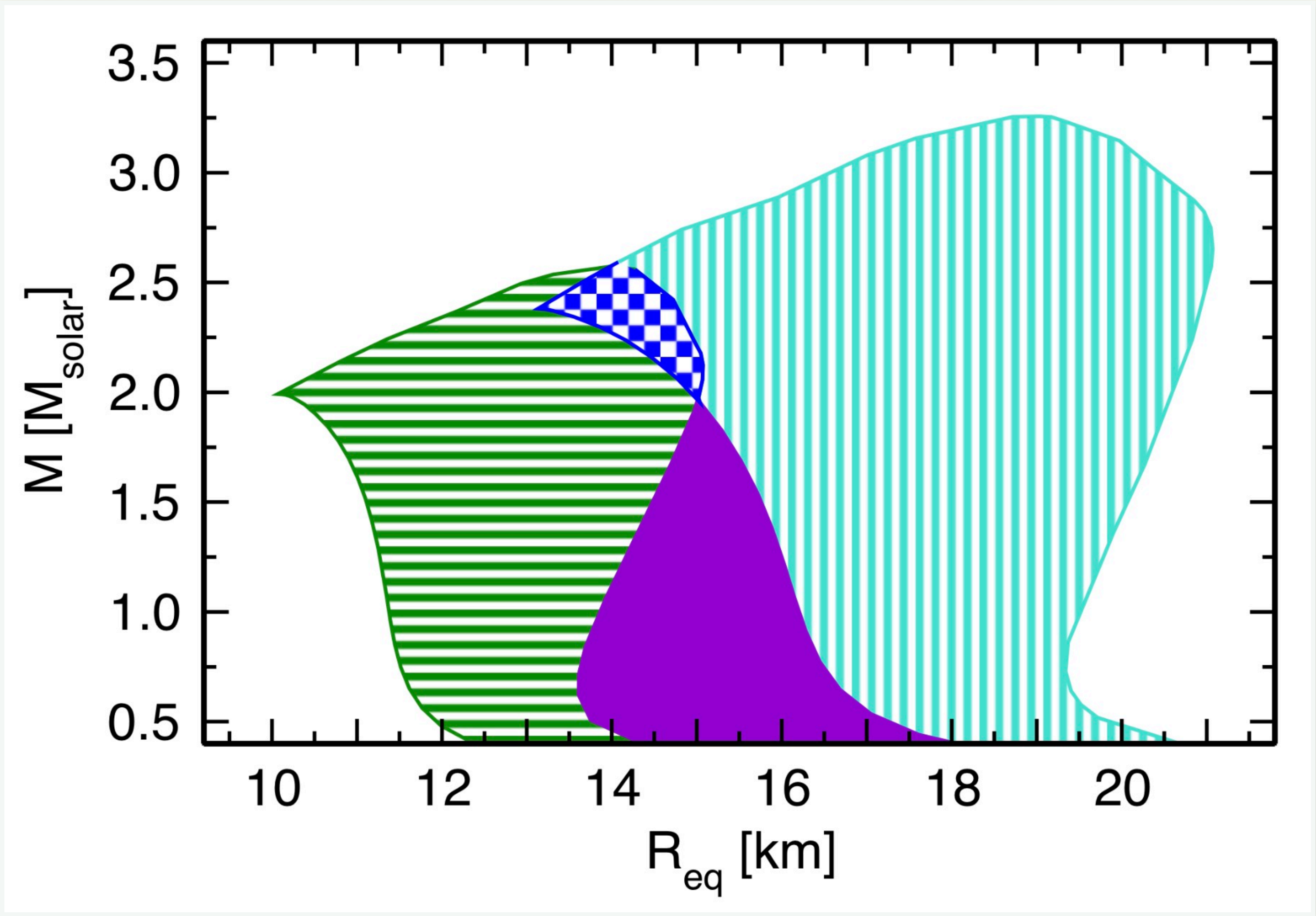
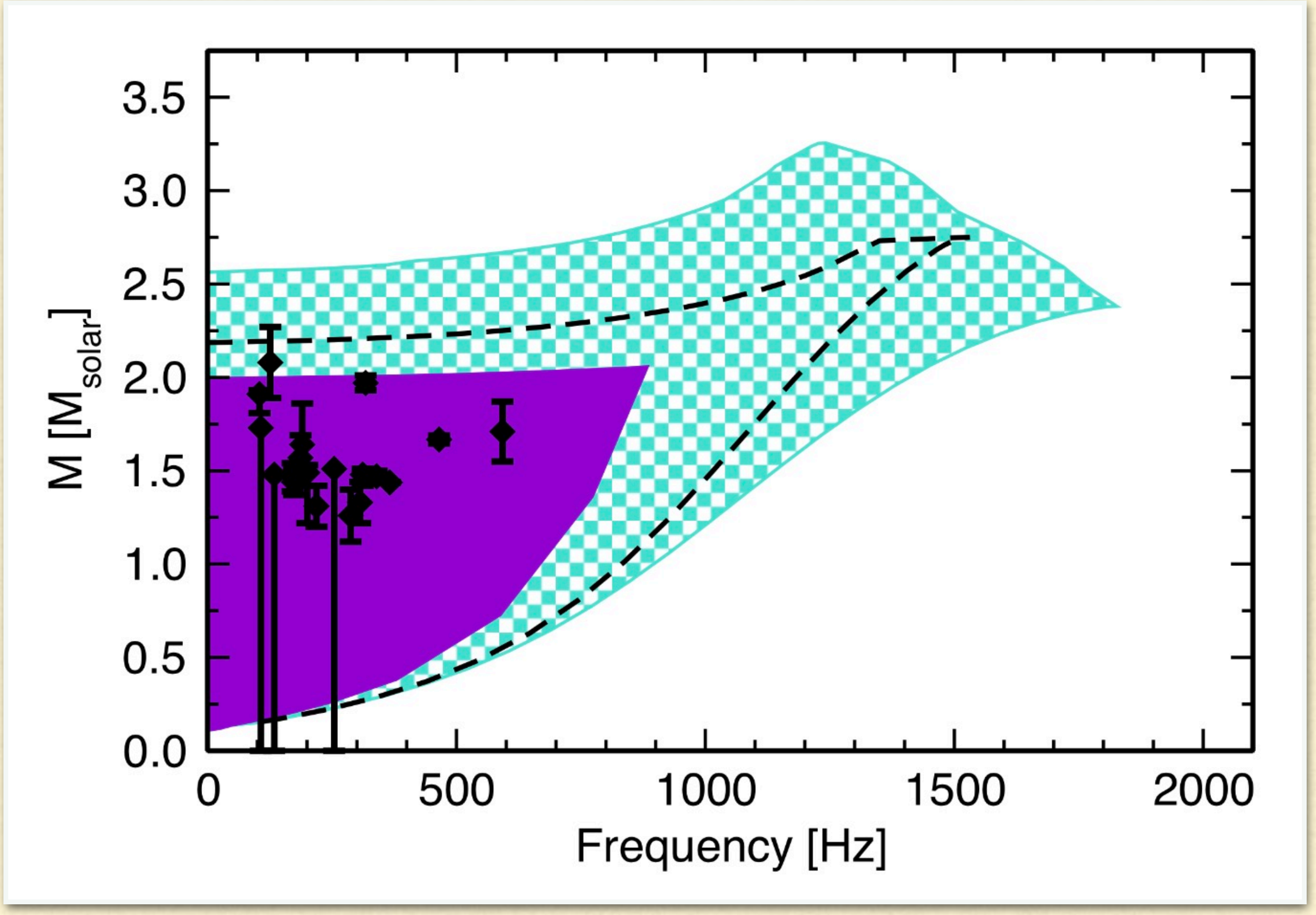
Mass–equatorial radius



- Maximum nonrotating mass is 2.5*M*s, rotating is 3.25*M*s.
- Maximum allowed radius is 21km.
- The same EOS forms the boundaries for both the rotating and nonrotating.

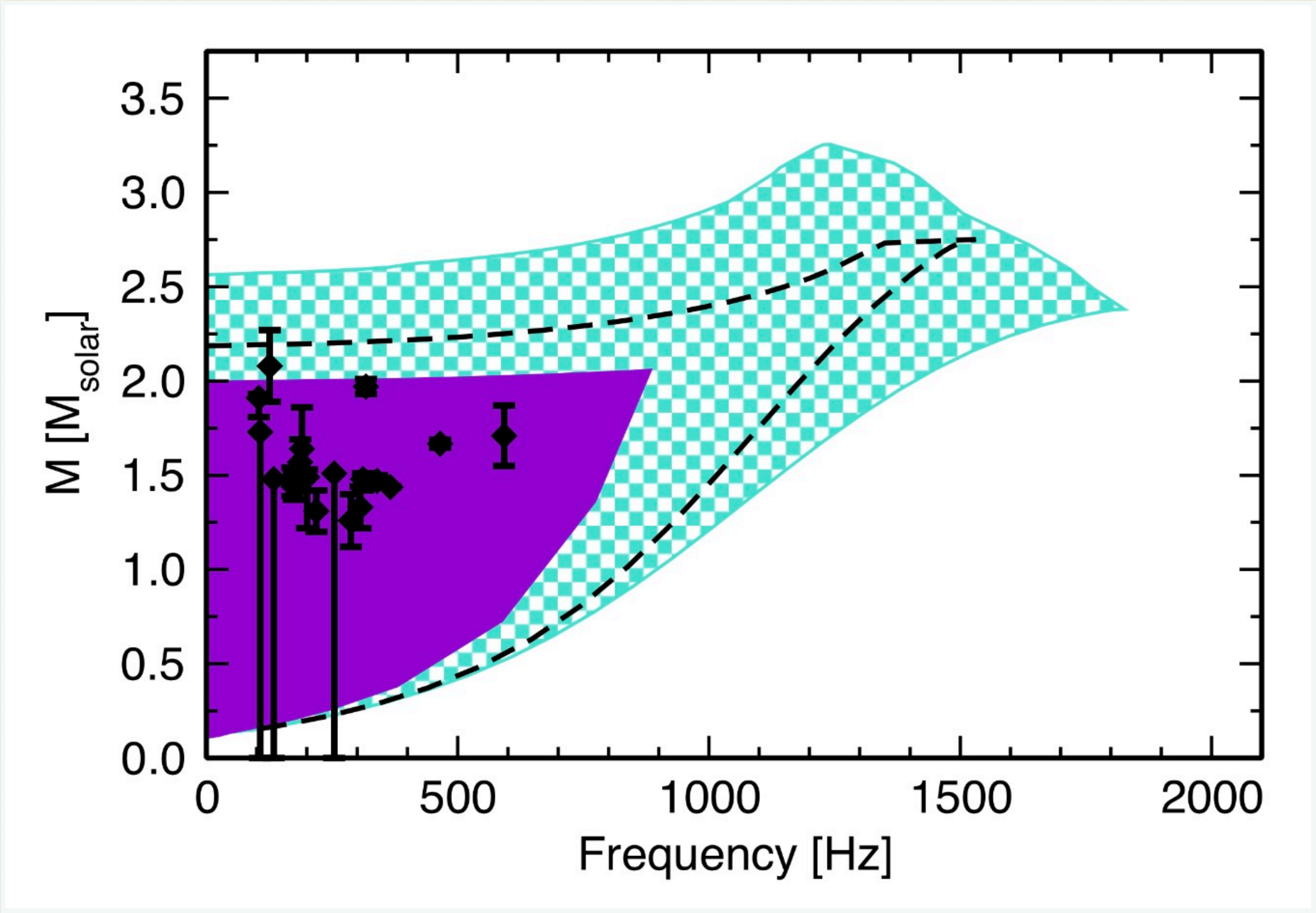
Green region, nonrotating. **Light blue region**: mass-shedding.

Mass–frequency



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

Mass–frequency



- One star (B1516+02B), cuts slightly into the top band, though not really a rotation constraint.

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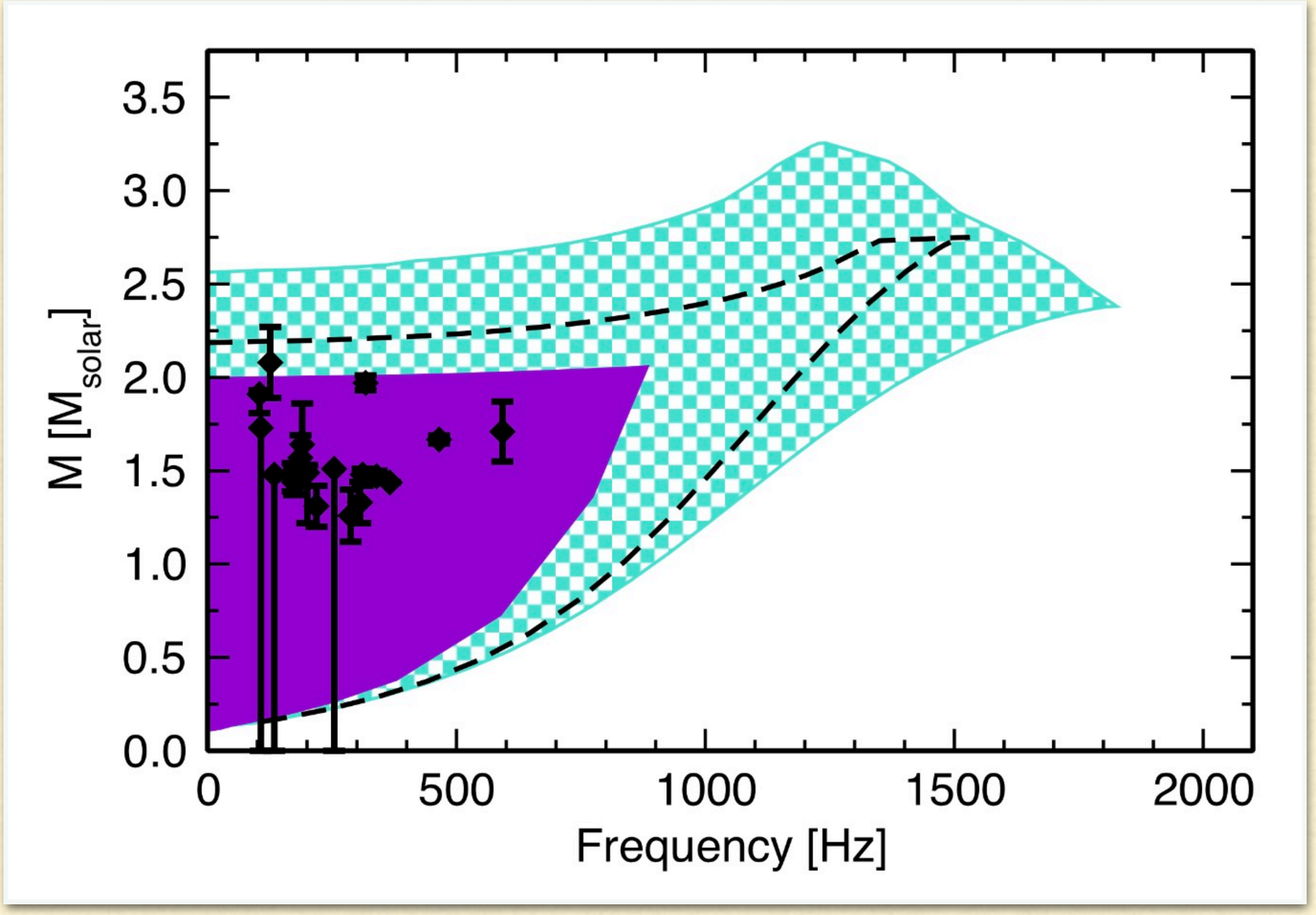

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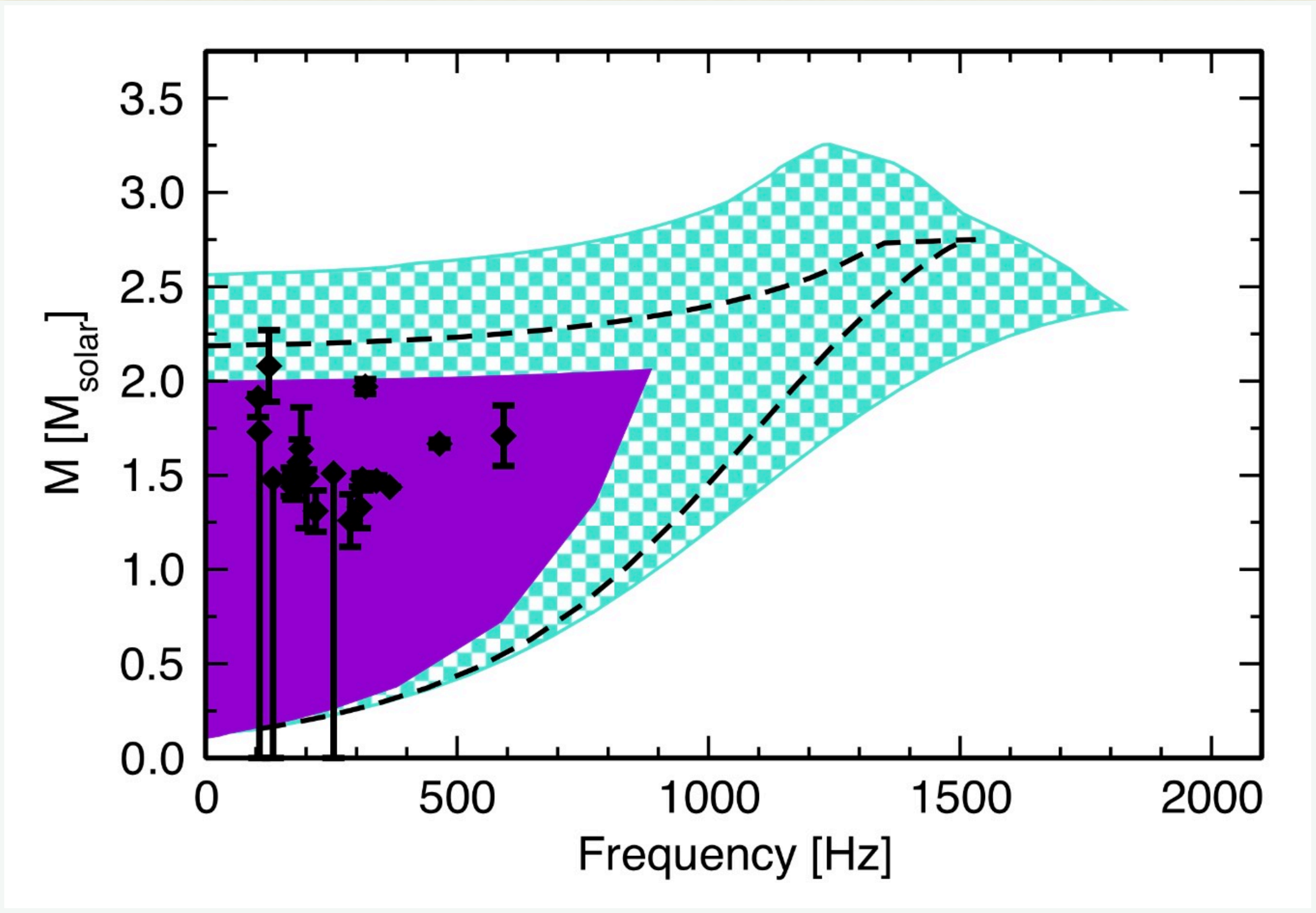
- *f* constraint: upper-right corner of purple region: *f* > 883Hz will start elimination EOSs.

Mass–frequency



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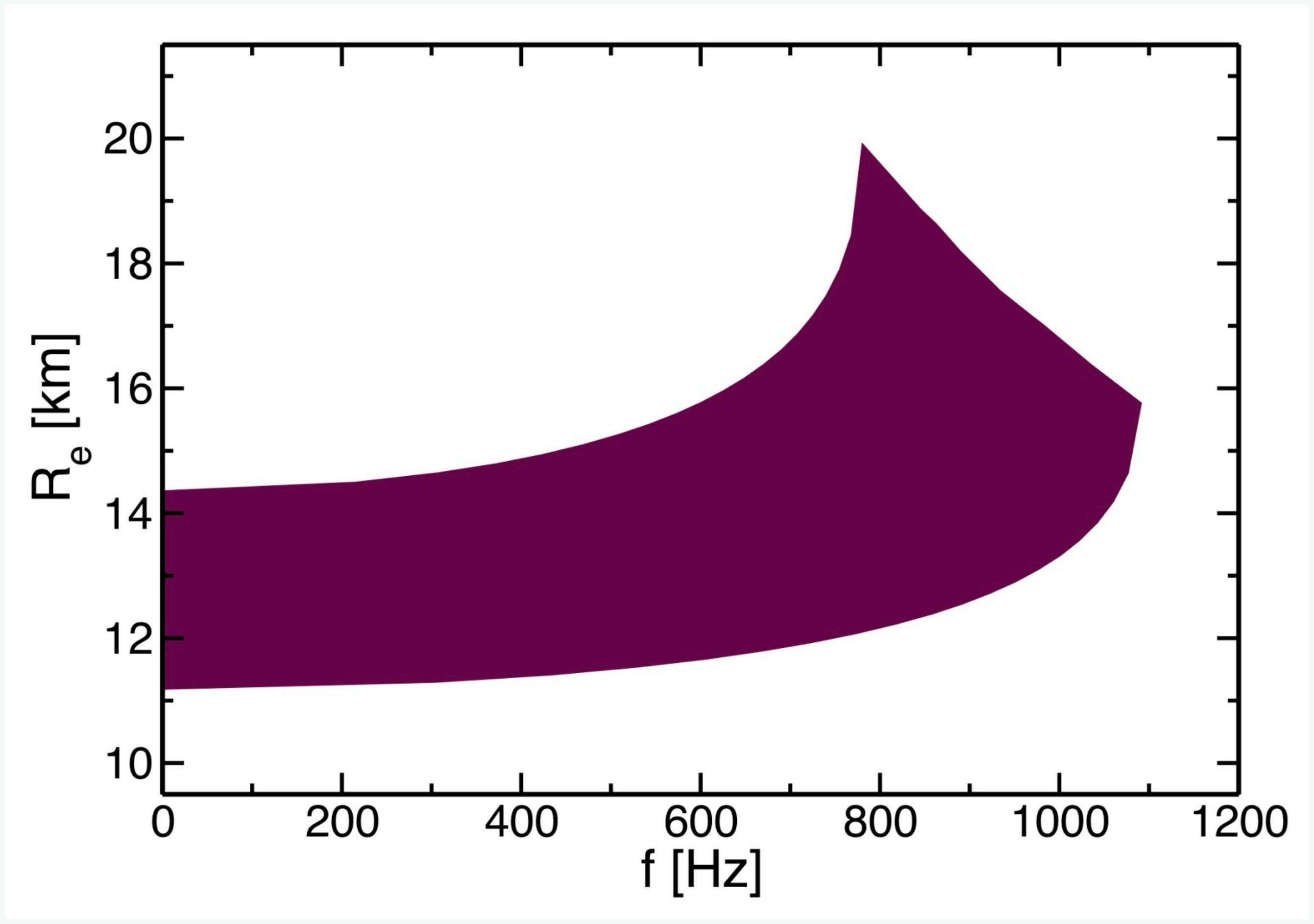
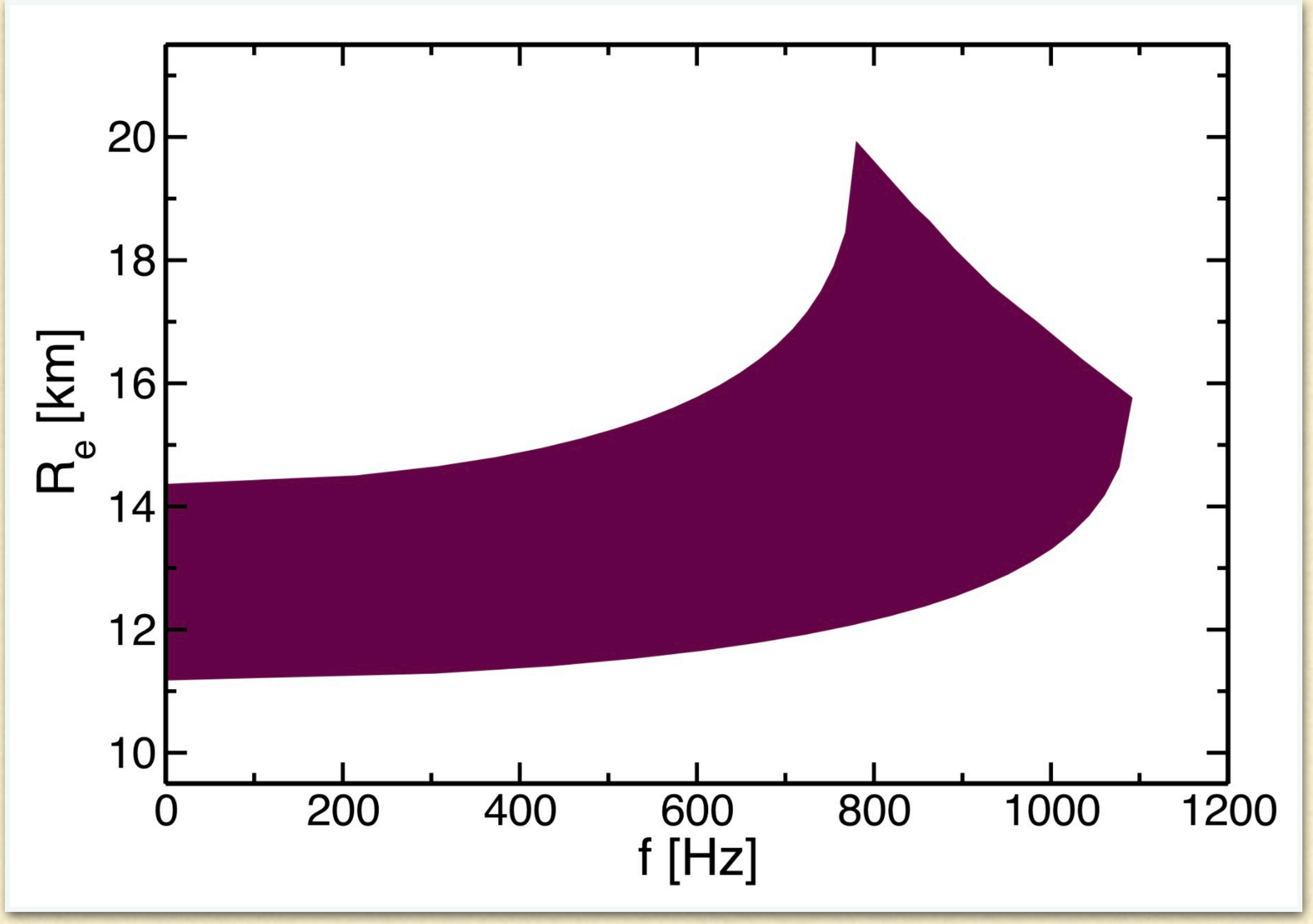
- One star (B1516+02B), cuts slightly into the top band, though not really a rotation constraint.
- *f* constraint: upper-right corner of purple region: *f* > 883Hz will start elimination EOSs.
- lower-*f* NSs could also rule out EoSs if their masses were sufficiently low (e.g., *f* = 716Hz starts constraining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

Equatorial radius–frequency



Allowed region of $R_e(f)$ curves for a $1.4 M_S$ star.

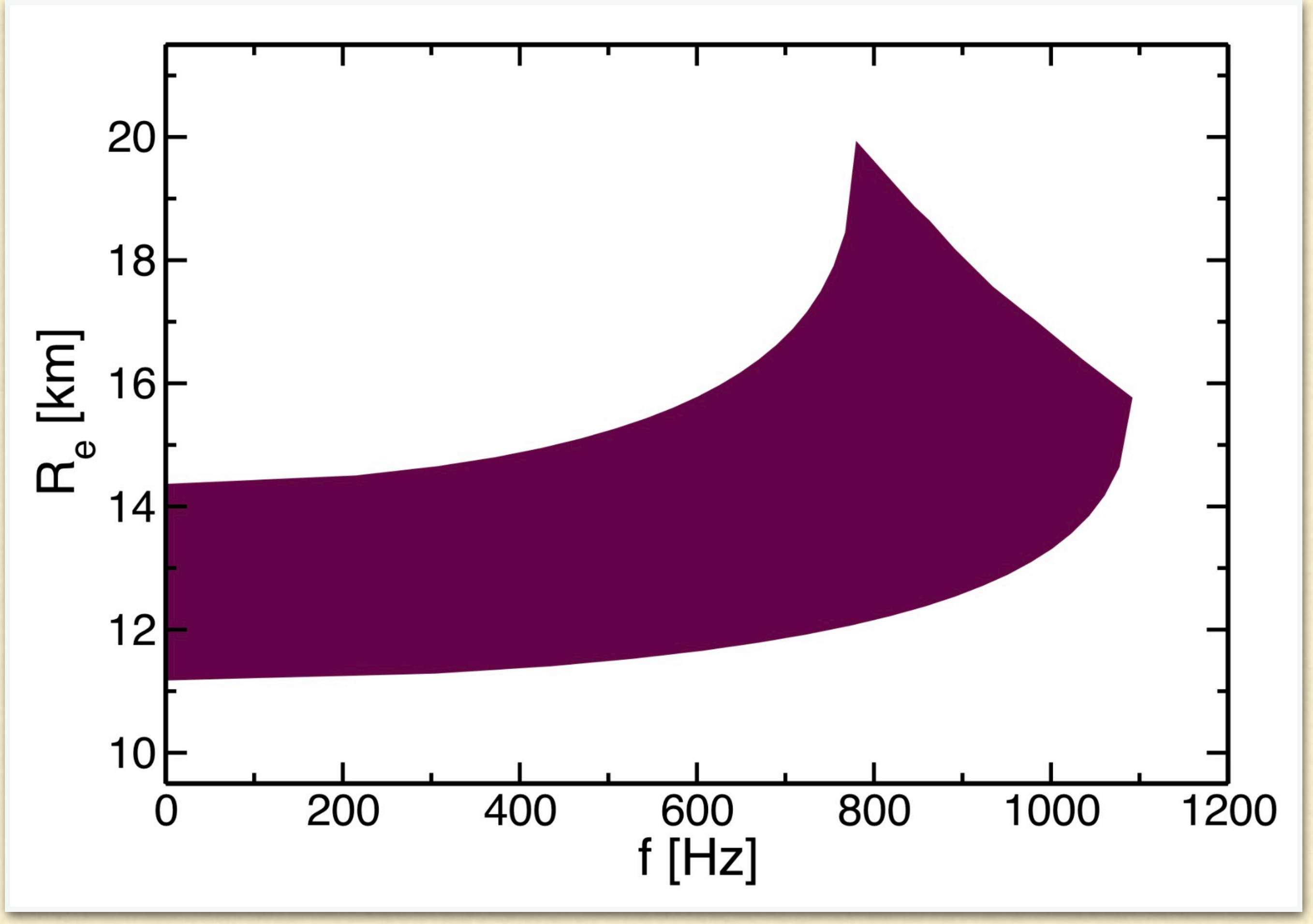
Equatorial radius–frequency



Allowed region of $R_e(f)$ curves for a $1.4M_s$ star.

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

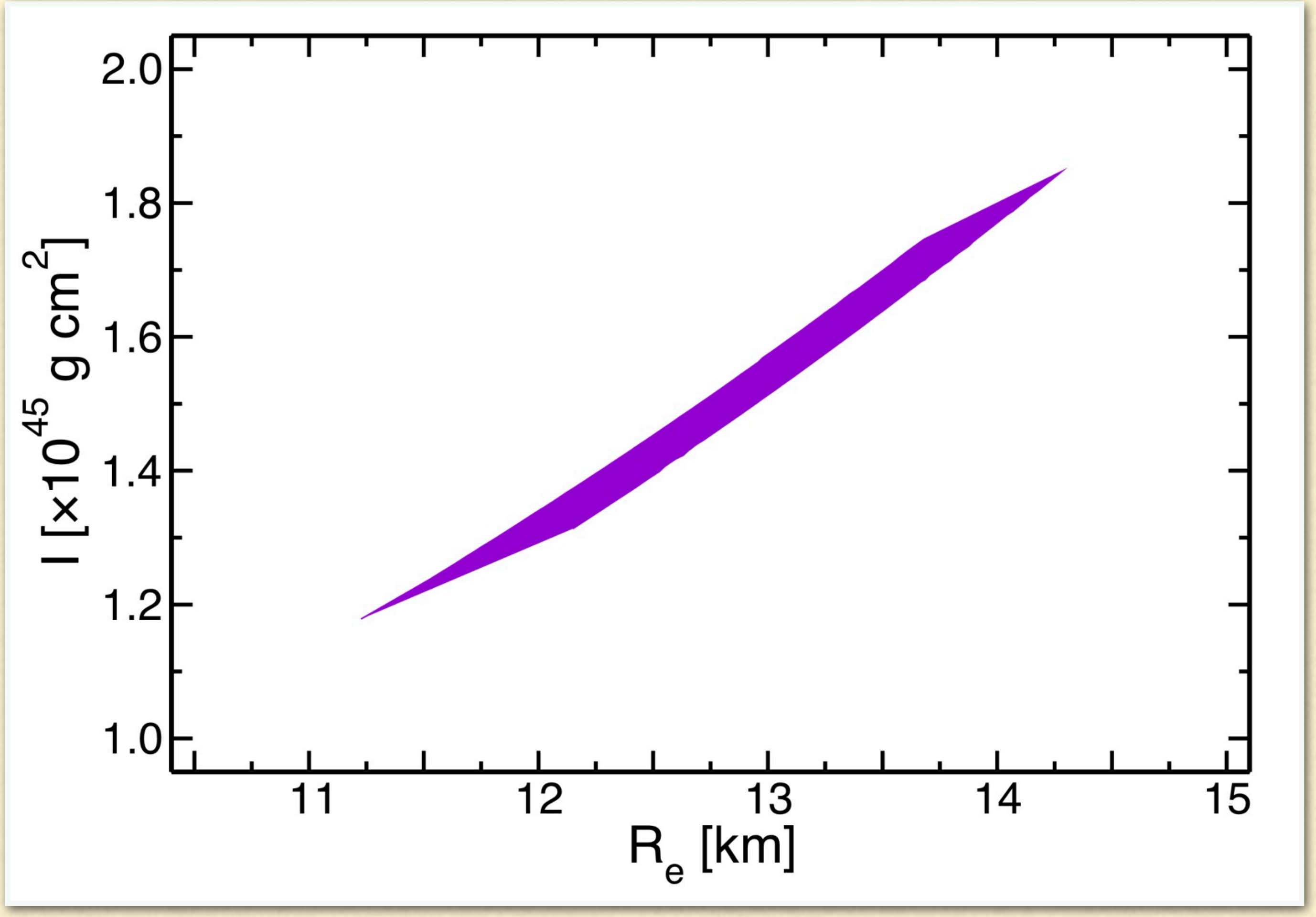
Equatorial radius–frequency



Allowed region of $R_e(f)$ curves for a $1.4M_s$ star.

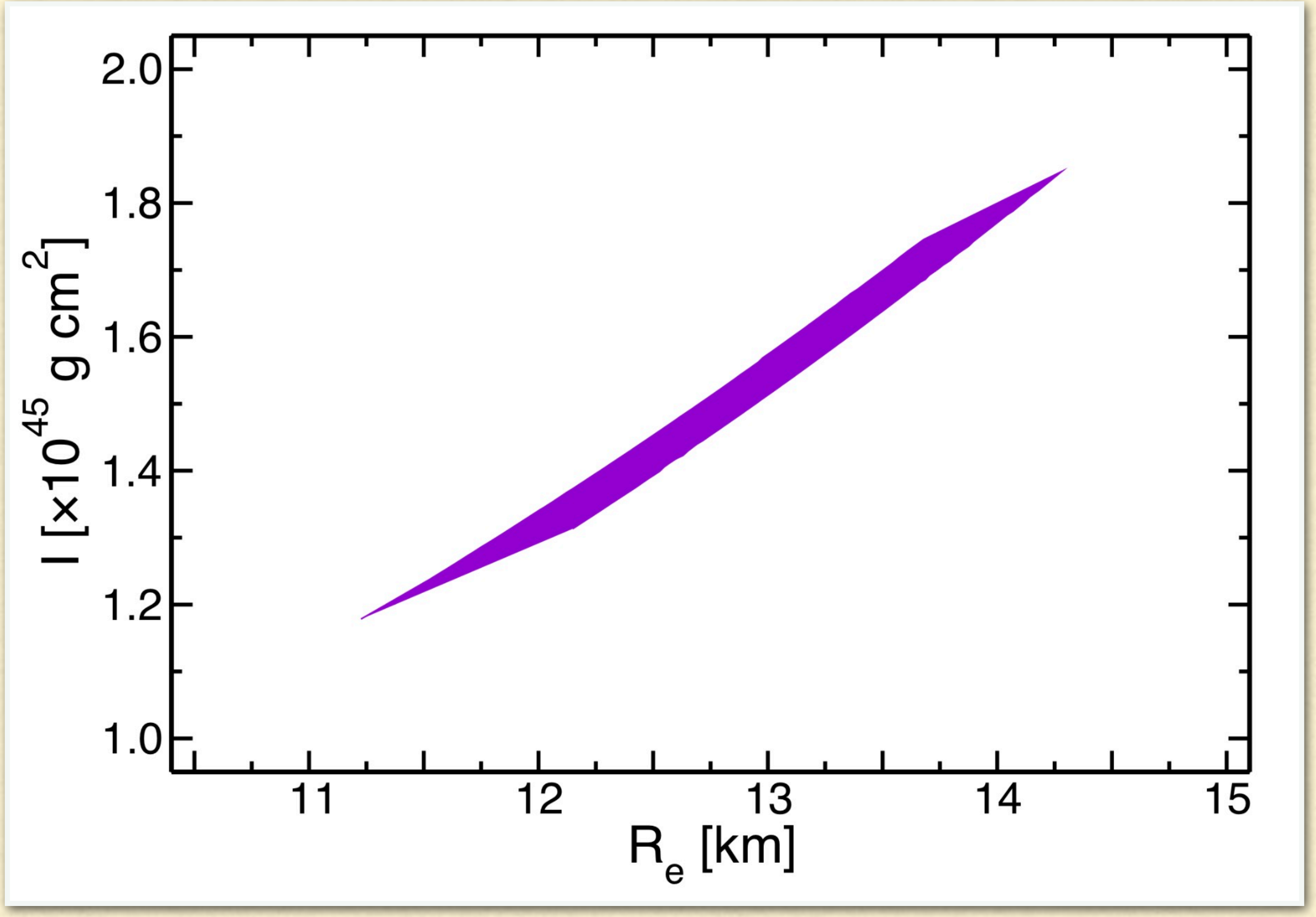
- Largest f that all EOSs can support is f = 780Hz.
- Plot serves as a prediction for observational astronomers.
- When consistent, reliable data of NS radii are available, plot could be overlaid with observational data to further constrain the QCD EOS.

I–*R*e for the double pulsar PSR J0737-3039A



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

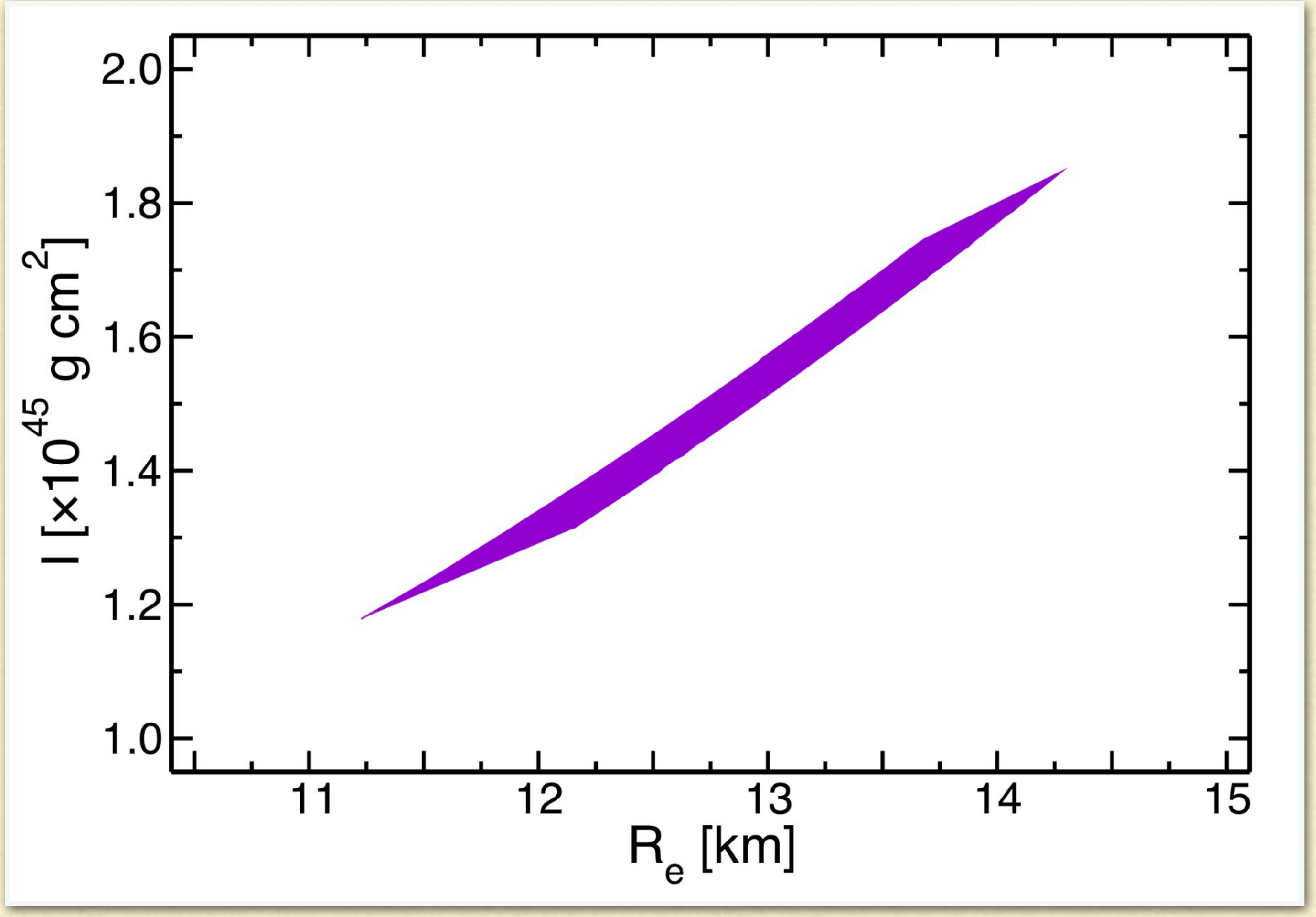
I–*R*e for the double pulsar PSR J0737-3039A



Allowed region of (*I*, *R*e) points for PSR J0737-3039A.

- Strongly correlated: measuring *I* with 10% precision determines *Re* to +/- 0.5km.

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

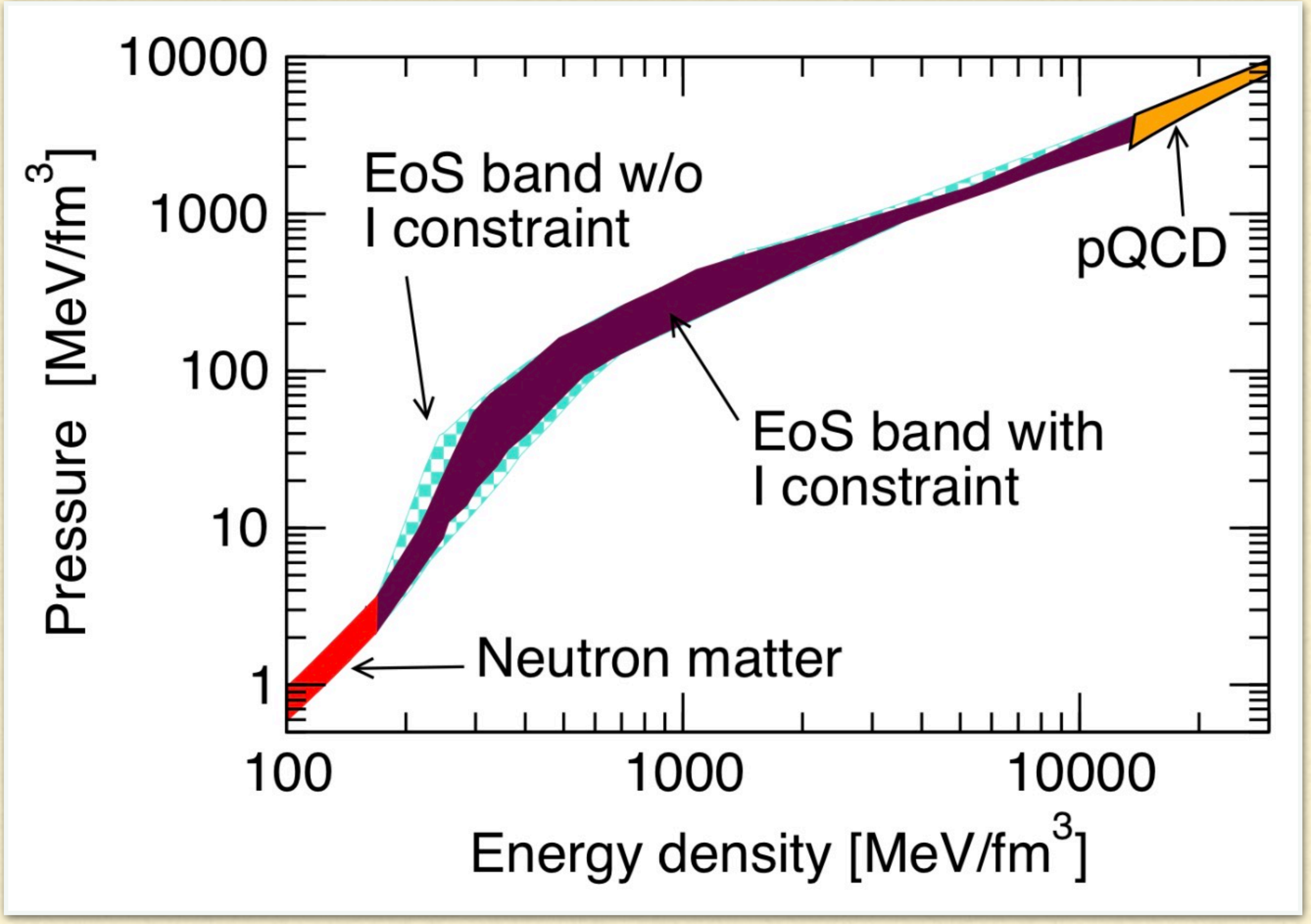


Allowed region of (*I*, R_e) points for PSR J0737-3039A.

- Strongly correlated: measuring *I* with 10% precision determines *Re* to +/- 0.5km.
- All EOSs fall on "vertical" edges, so a measurement of *I*, even to low precision, would have large effect on EOS band.

e.g. $\boxed{I = (1.5 \text{ +/- } 0.15) \times 10\text{^}45 \text{ g cm}^2}$

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



SUMMARY

- cEFT+pQCD matching of (1402.6618) 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-constraints. (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.