Novel Scalings of Neutron Star Mass, Radius, and Tidal Deformability for Probing the Core Equation of State

Bao-Jun Cai (Fudan University), 7/6/2026

CosPA2026/ACGRG13

IPAD-TOV: Intrinsic and Perturbative Analyses of Dimensionless TOV Equations

$$\frac{\mathrm{d}}{\mathrm{d}\widehat{r}}\widehat{P} = -\frac{\widehat{\varepsilon}\widehat{M}}{\widehat{r}^2}\frac{(1+\widehat{P}/\widehat{\varepsilon})(1+\widehat{r}^3\widehat{P}/\widehat{M})}{1-2\widehat{M}/\widehat{r}}; \quad \frac{\mathrm{d}}{\mathrm{d}\widehat{r}}\widehat{M} = \widehat{\varepsilon}\widehat{r}^2 \qquad E(\rho,\delta) \approx E_0(\rho) + E_{\rm sym}(\rho)\delta^2$$

How to perturbe?

top-down
(strong-field gravity in GR)
(nuclear model independent)

$$\frac{M_{\rm NS}}{R} \leftrightarrow \frac{P}{\varepsilon} \leftrightarrow \frac{\mathrm{d}P}{\mathrm{d}\varepsilon} \leftrightarrow \frac{\mathrm{d}\ln P}{\mathrm{d}\ln\varepsilon}$$

$$\widehat{P} = P/\varepsilon_{\rm c} \approx \mathrm{X} + b_2\widehat{r}^2 + b_4\widehat{r}^4 + \cdots$$
$$\widehat{\varepsilon} = \varepsilon/\varepsilon_{\rm c} \approx 1 + a_2\widehat{r}^2 + a_4\widehat{r}^4 + \cdots$$
$$\widehat{M} \approx \frac{1}{3}\widehat{r}^3 + \frac{1}{5}a_2\widehat{r}^5 + \frac{1}{7}a_4\widehat{r}^7 + \cdots$$

$$\mathrm{X} \equiv P_{\rm c}/\varepsilon_{\rm c}, \ \mu \equiv \widehat{\varepsilon} - 1$$

$$\mathcal{U}/\mathcal{U}_{\rm c} \approx 1 + \sum_{i+j\geq 1} u_{ij}\mathrm{X}^i\mu^j$$

(double-element expansion)

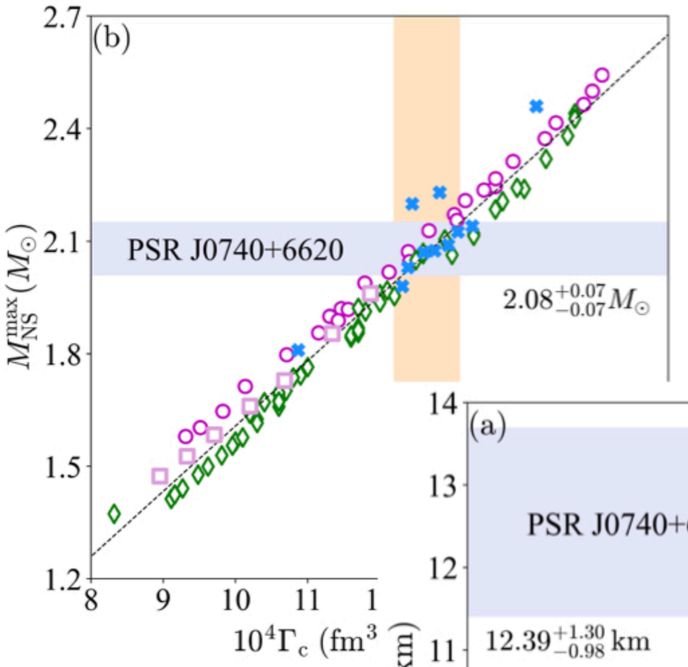
numerical — input dense matter EOS

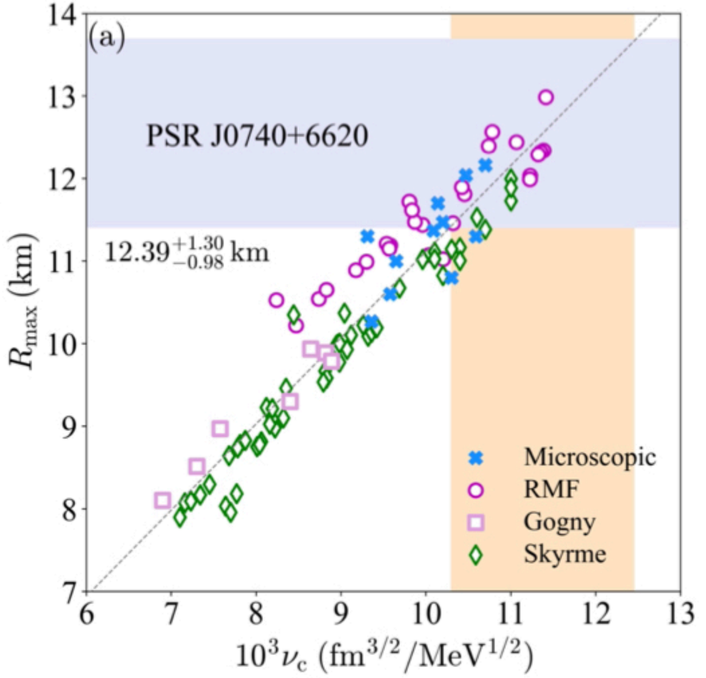
physical ingredients mechanisms on EOS

- others,...
- inference algorithms
- astrophysical data
- heavy ion collision data
- transitions, exotic particles
- nuclear structure quantities
- nuclear model selected
- CEFT (χEFT): low-density

bottom-up
(based on model construction)

⋆ ultimate goal: core/central EOS in NSs

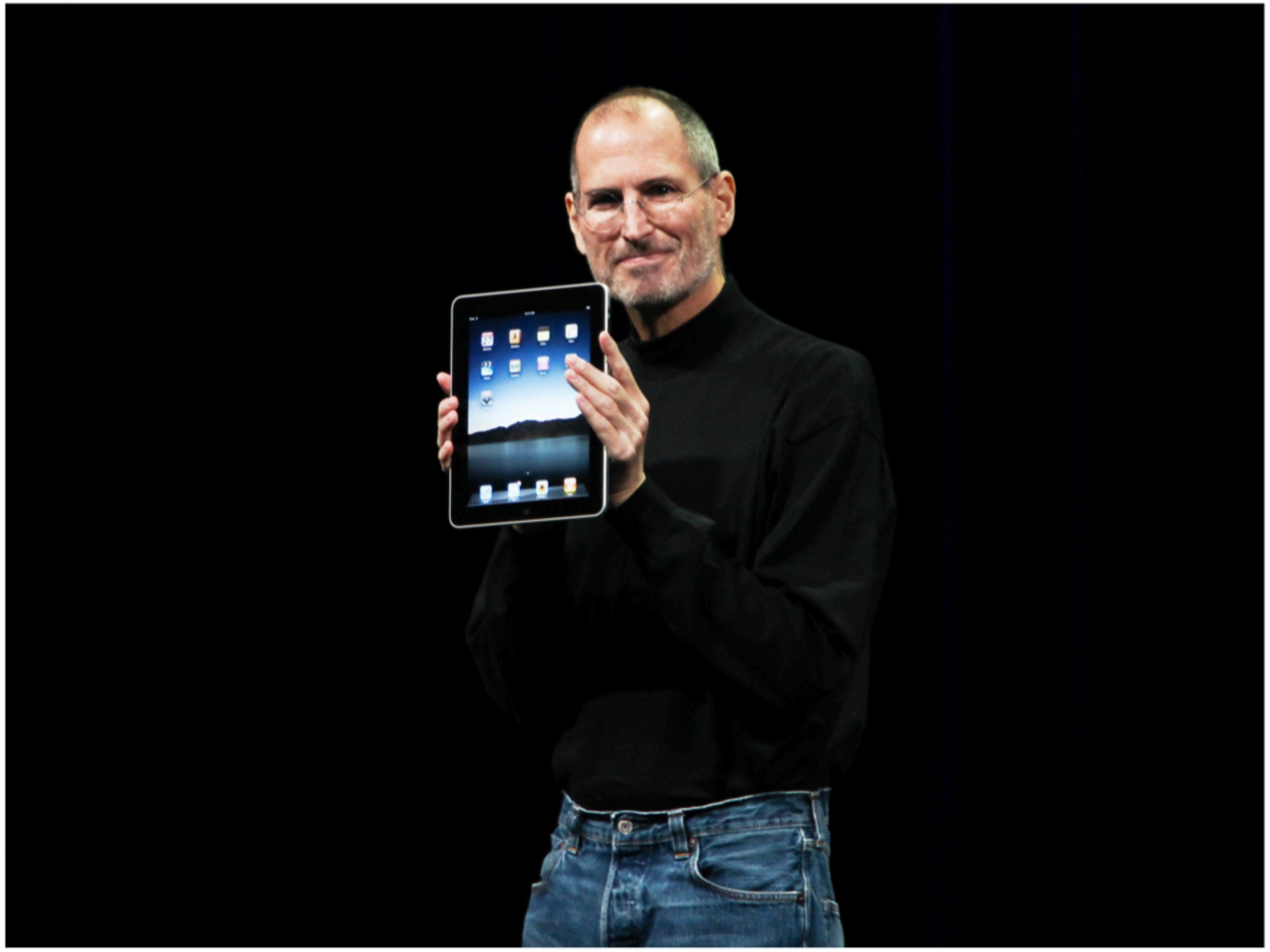




$M_{\rm NS}, R, \Lambda, \cdots$
↔EOS quantities

arXiv:2306.08202
arXiv:2501.18676
arXiv:2606.21402

IPAD-TOV: analogy to Apple's IPAD



Steven Paul Jobs (2/24/1955-10/5/2011)

English meaning of Apple's iPad from Cambridge Dictionary: a brand name for a tablet (aka, small computer) that is controlled by touch rather than having a keyboard.

In our IPAD-TOV approach, properties of supra-dense NS matter governed by the TOV equations are probed perturbatively without using a specific input model EOS.