

INTRODUCTION

We model **slowly rotating neutron stars in massive scalar–tensor gravity**, improving boundary and surface treatments to accurately show that scalarized stars can support significantly higher masses than GR predicts.

MOTIVATION

- **Why scalar–tensor gravity?** Strong-field deviations compatible with weak-field constraints.
- **Why a scalar field?** Scalar degrees of freedom arise in extensions of GR.
- **Why neutron stars?** They probe strong-field gravity.
- **Why a massive scalar?** A finite interaction range can weaken binary-pulsar constraints.

FRAMEWORK

Conformal rescaling

Jordan frame
Matter minimally coupled

$$\bar{g}_{\mu\nu} = A^2(\varphi)g_{\mu\nu}$$

Einstein frame
Convenient gravitational equations

Model parameters

$\beta < 0$: strength of scalarization.

m_φ : scalar mass.

Interaction range:

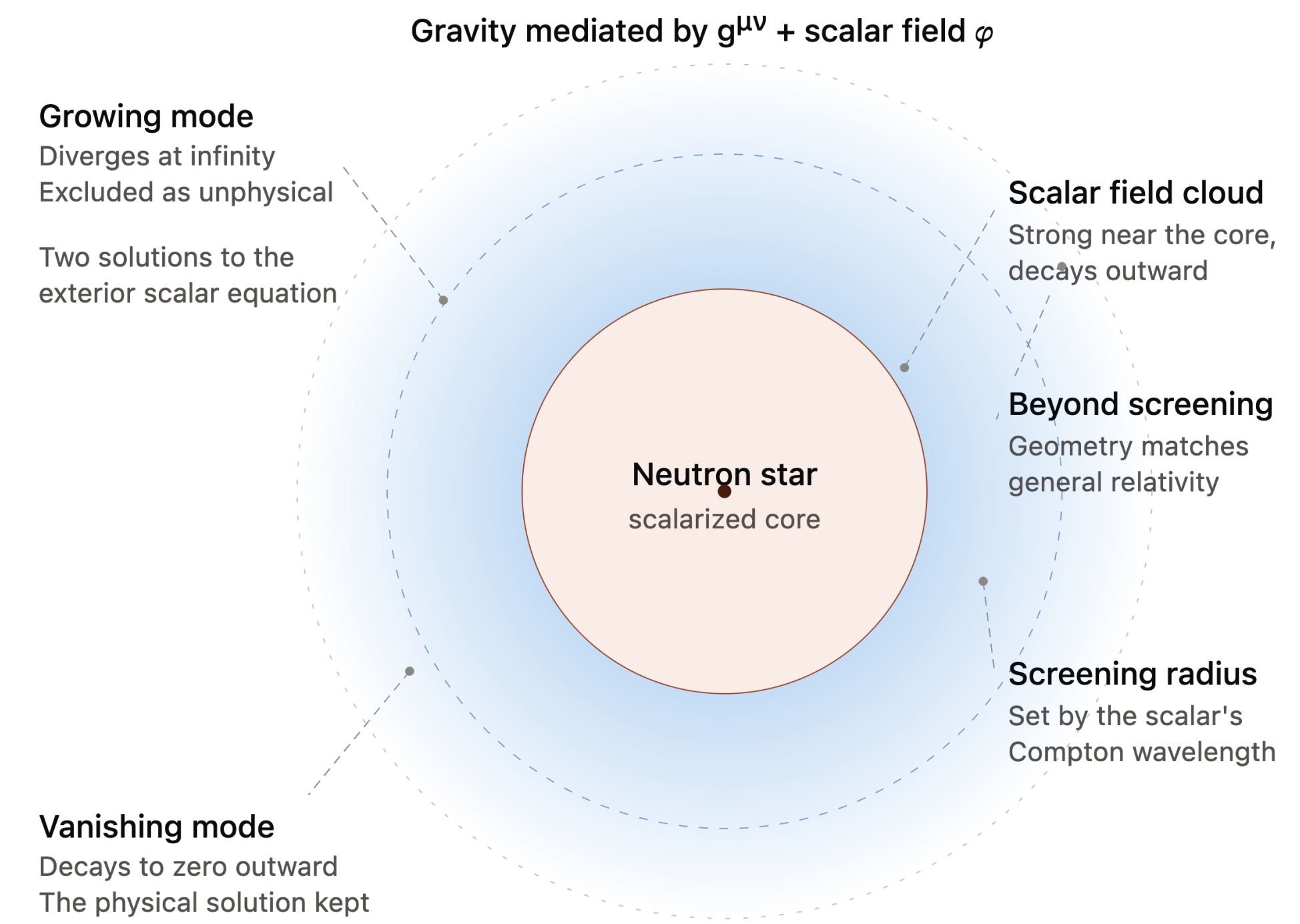
$$\lambda_\varphi = 1/m_\varphi.$$

Massive Damour–Esposito–Farèse model

$$A = e^{\beta\varphi^2/2}, \quad \alpha = \beta\varphi, \quad V = 2m_\varphi^2\varphi^2$$

Vary the action with respect to φ : $\square\delta\varphi = m_{\text{eff}}^2\delta\varphi$

$$4\pi G|\beta|(\epsilon - 3\bar{p}) > m_\varphi^2 \implies m_{\text{eff}}^2 < 0 \implies \text{spontaneous scalarization}$$



Massless scalar
 $\sim 1/r$

Massive scalar
 $\sim e^{-m_\varphi r}/r$

NUMERICAL METHOD

EOS: APR(PCHIP)
+ Parameters(P_c, β, m_φ)

Initial ν_c and φ_c
guess

Integrate interior ODE
 $P, m, \varphi, \nu, \frac{d\varphi}{dr}, \omega, \omega'$

Match exterior
solution

**Robin outer
boundary condition**

Shooting convergence
(Nelder–Mead)

**Stellar surface
extraction**

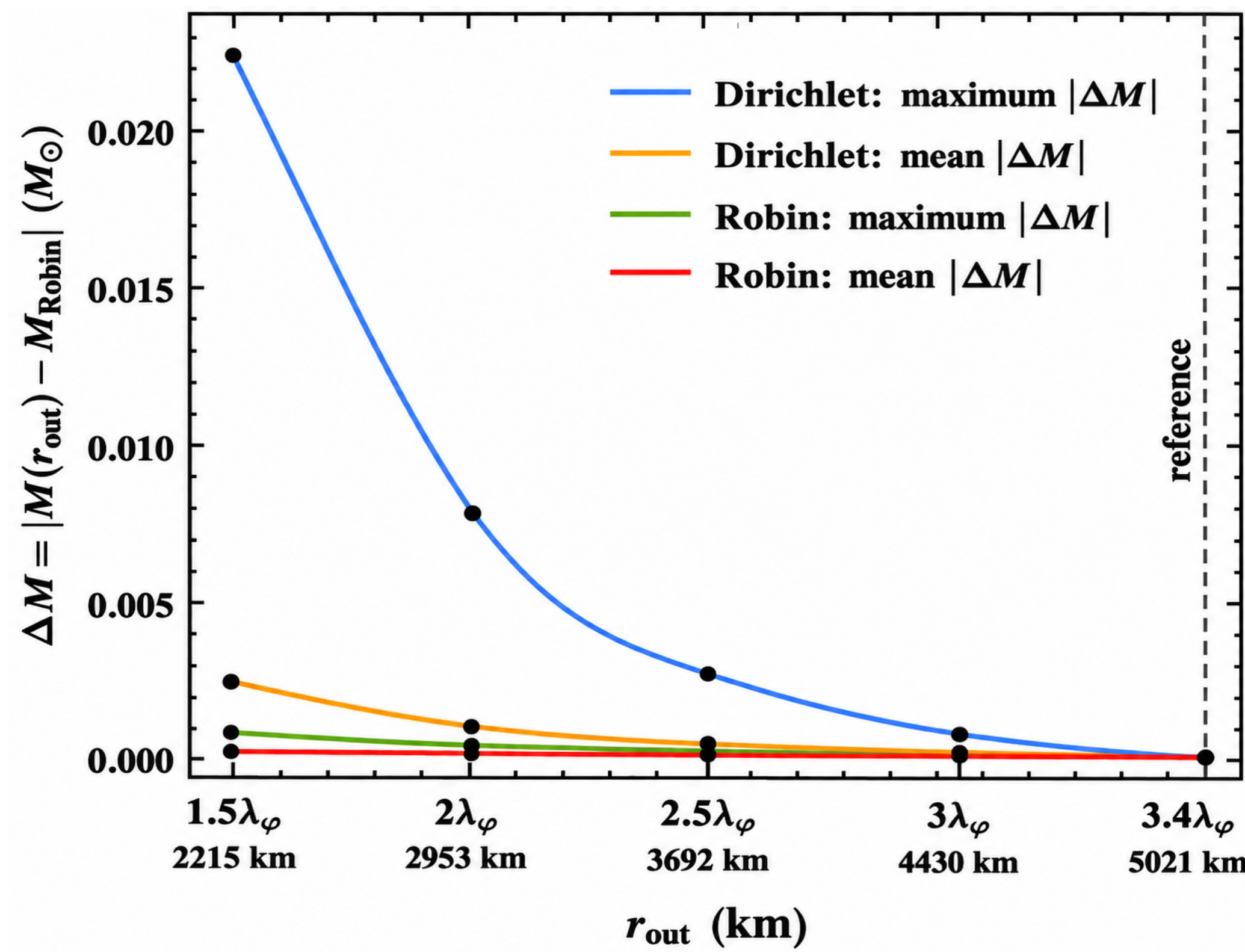
not converged: update the central guess

1 | ROBIN OUTER BOUNDARY CONDITION

Dirichlet — Artificially truncates the scalar tail at a finite radius: $\varphi(r_{\text{out}}) = 0$

Robin — Matches the slope of the physical Yukawa tail: $\varphi(r) \simeq (Q_s/r) e^{-m_\varphi r}$.

$$\varphi'(r_{\text{out}}) + \left(m_\varphi + \frac{1}{r_{\text{out}}}\right)\varphi(r_{\text{out}}) = 0$$



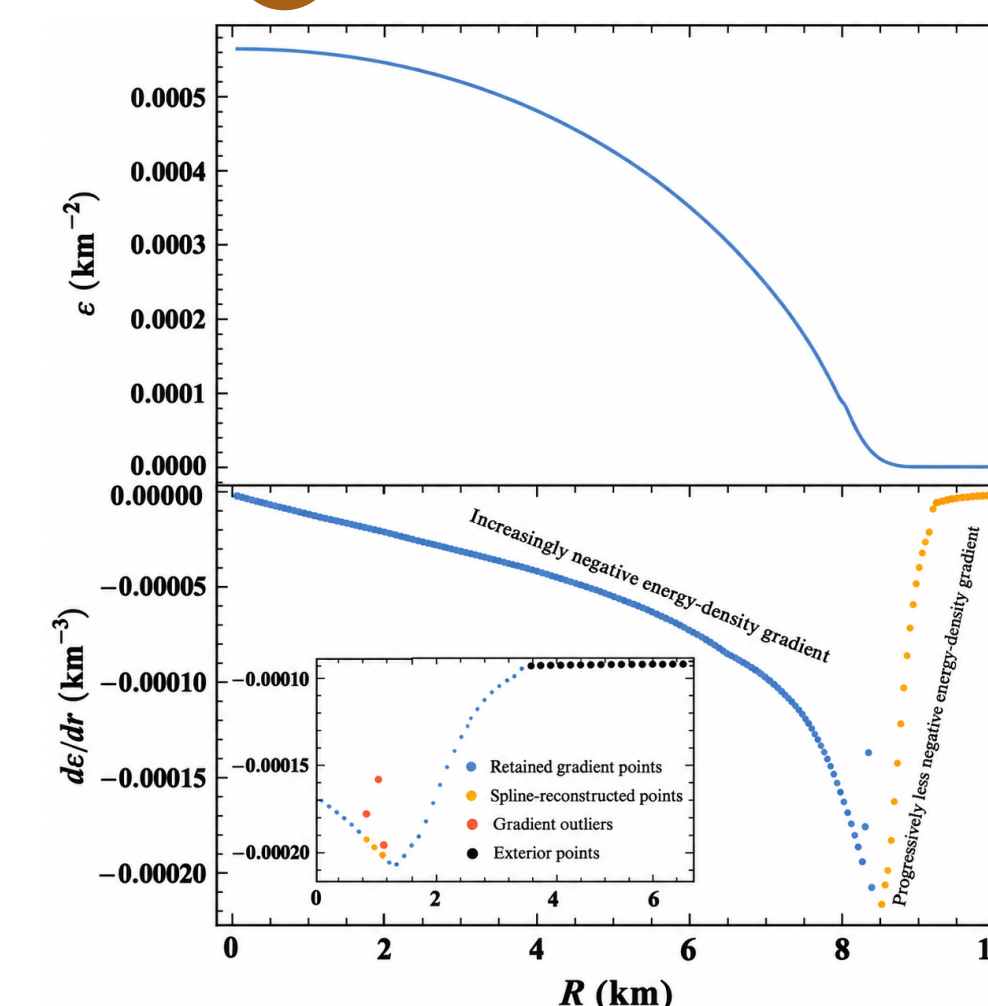
Outer-boundary sensitivity reduced by more than an order of magnitude:
Dirichlet $\sim 10^{-2} M_\odot$, **Robin** $< 10^{-3} M_\odot$.

2 | STELLAR-SURFACE RECALIBRATION

$\beta = -10$, $m_\varphi = 0.0050$

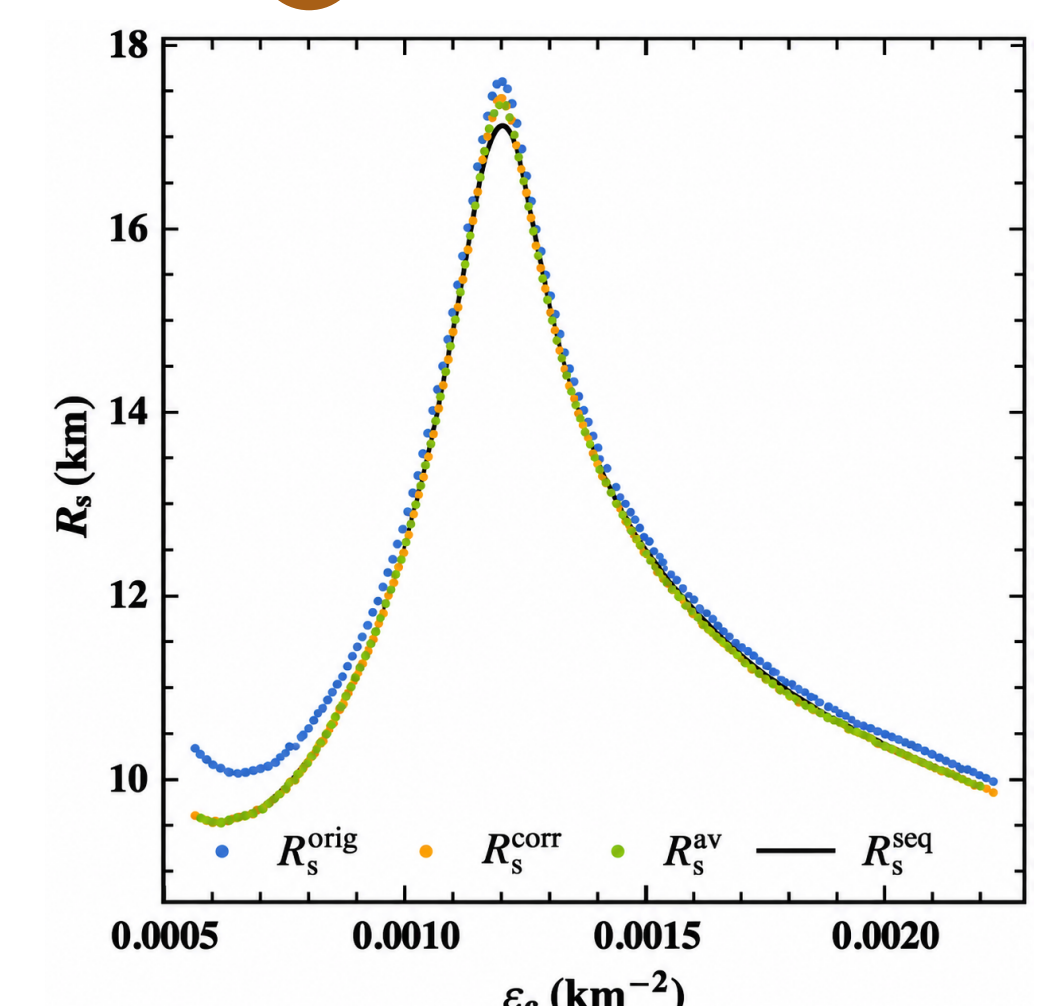
Smooth the residual, not the physical peak.

1 Identify surface



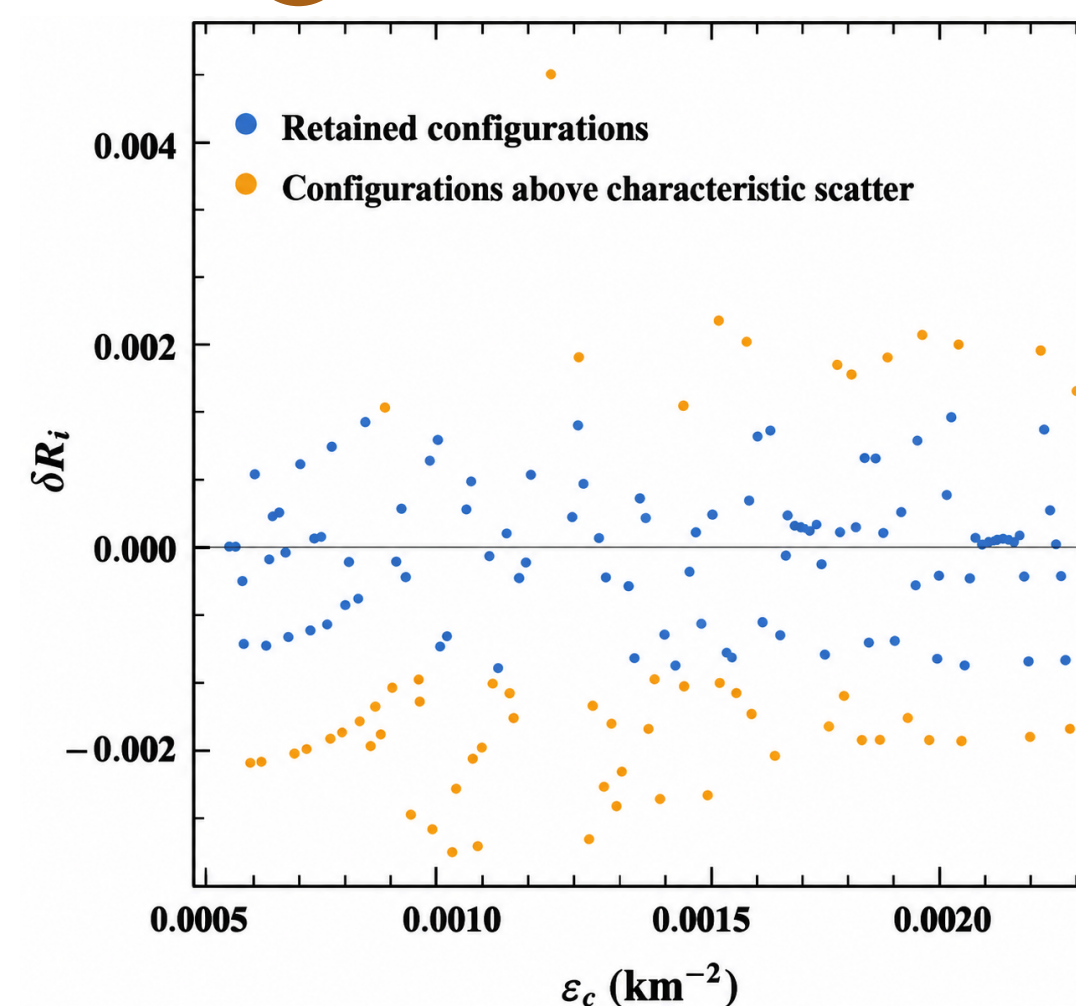
The minimum of the finite difference $d\epsilon/dr$ locates the surface.

2 Correct locally



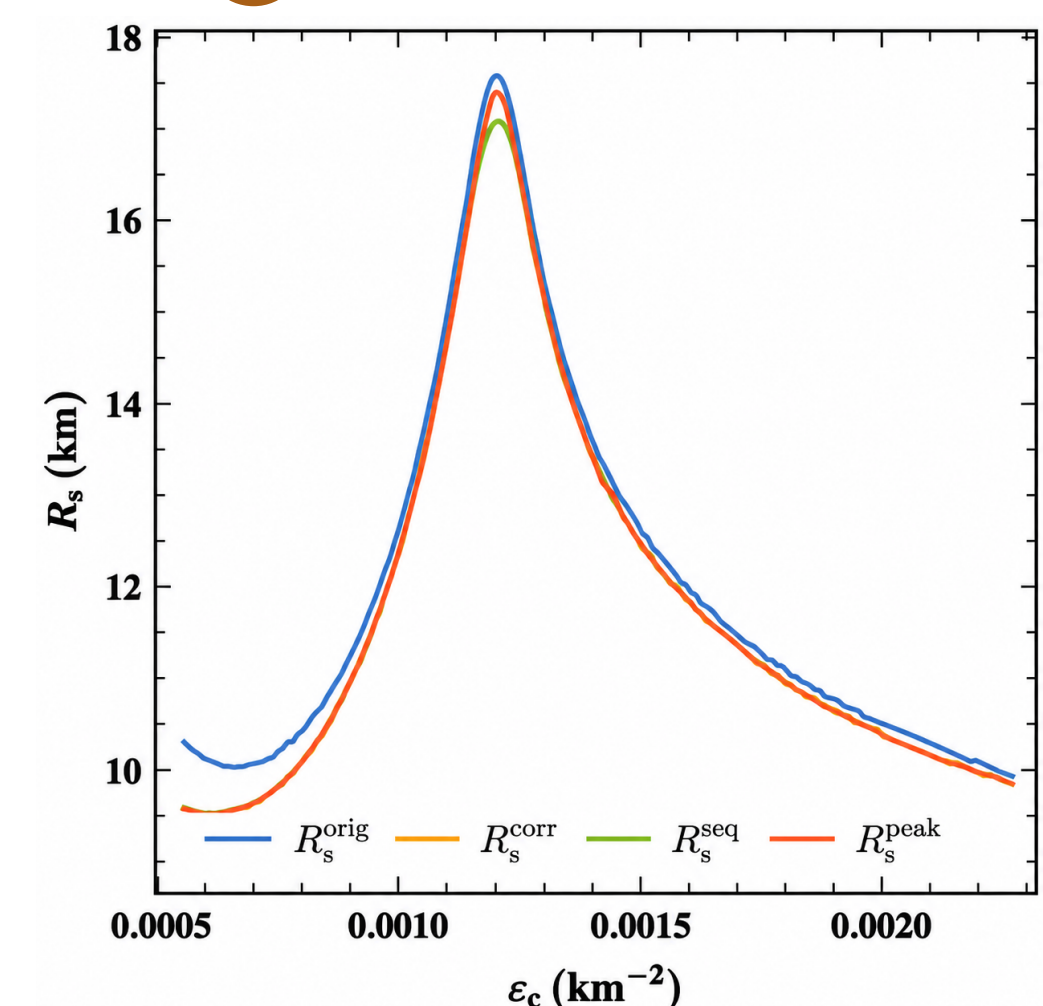
$R_s^{\text{orig}}, R_s^{\text{corr}}, R_s^{\text{av}}, R_s^{\text{seq}}$: original, locally corrected, moving-average and sequence-recalibrated radii.

3 Select & smooth



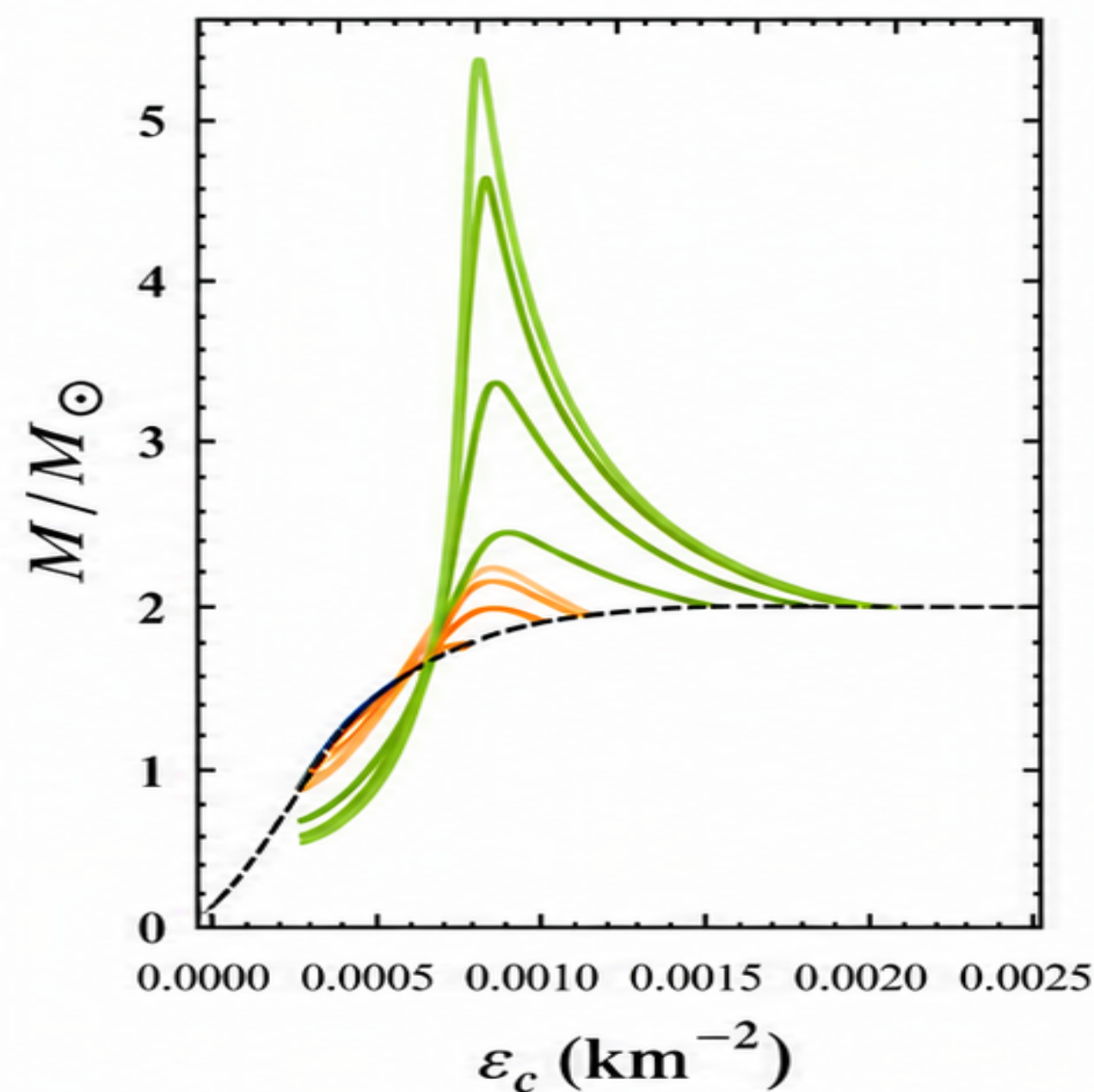
Configurations with $|\delta R_i| \leq |\delta R|$ are kept for interpolation (blue); larger deviations are excluded (orange).

4 Preserve the peak

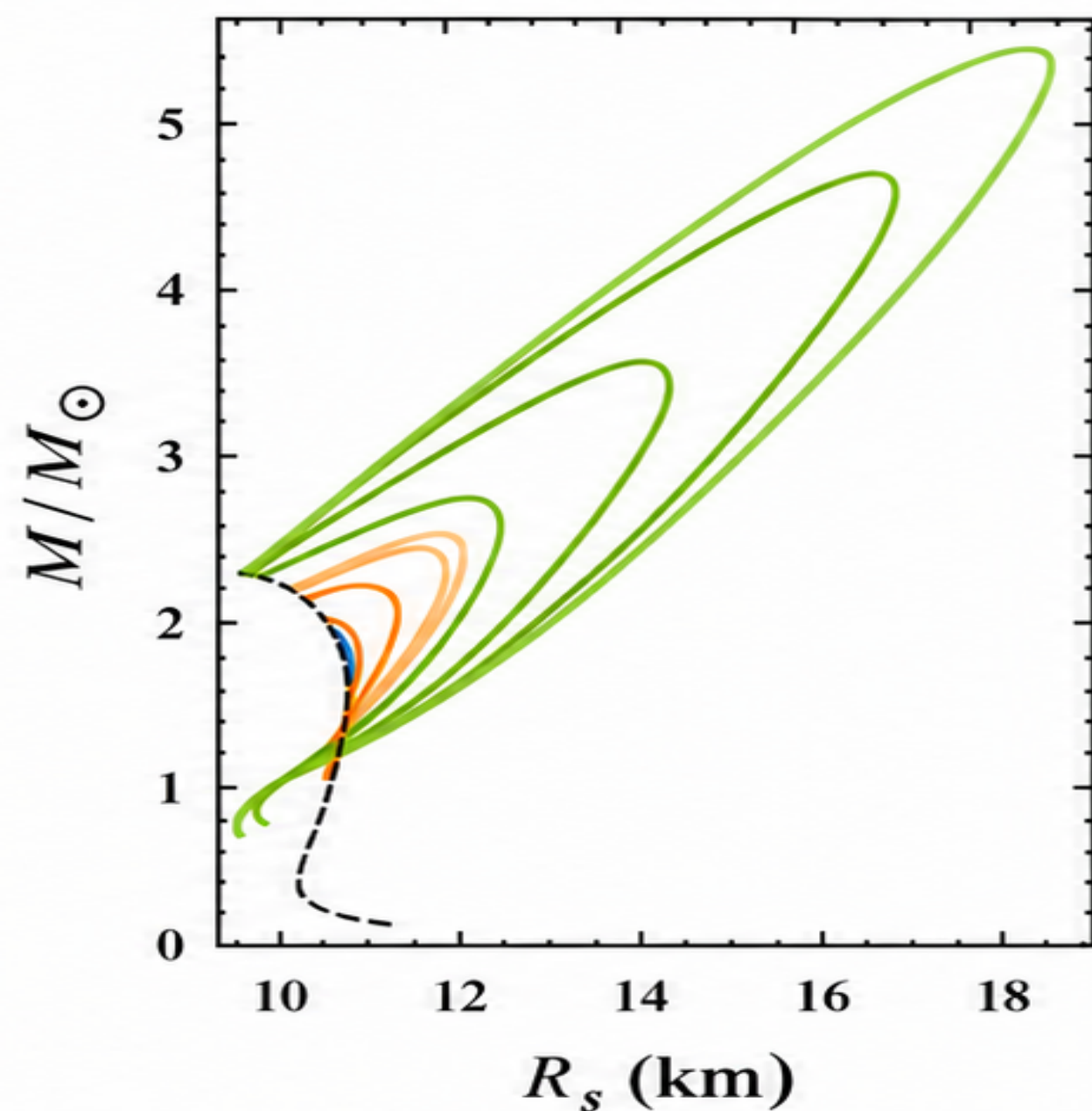


The smoothed sequence sets the baseline; only the smoothed residual is restored near the maximum.

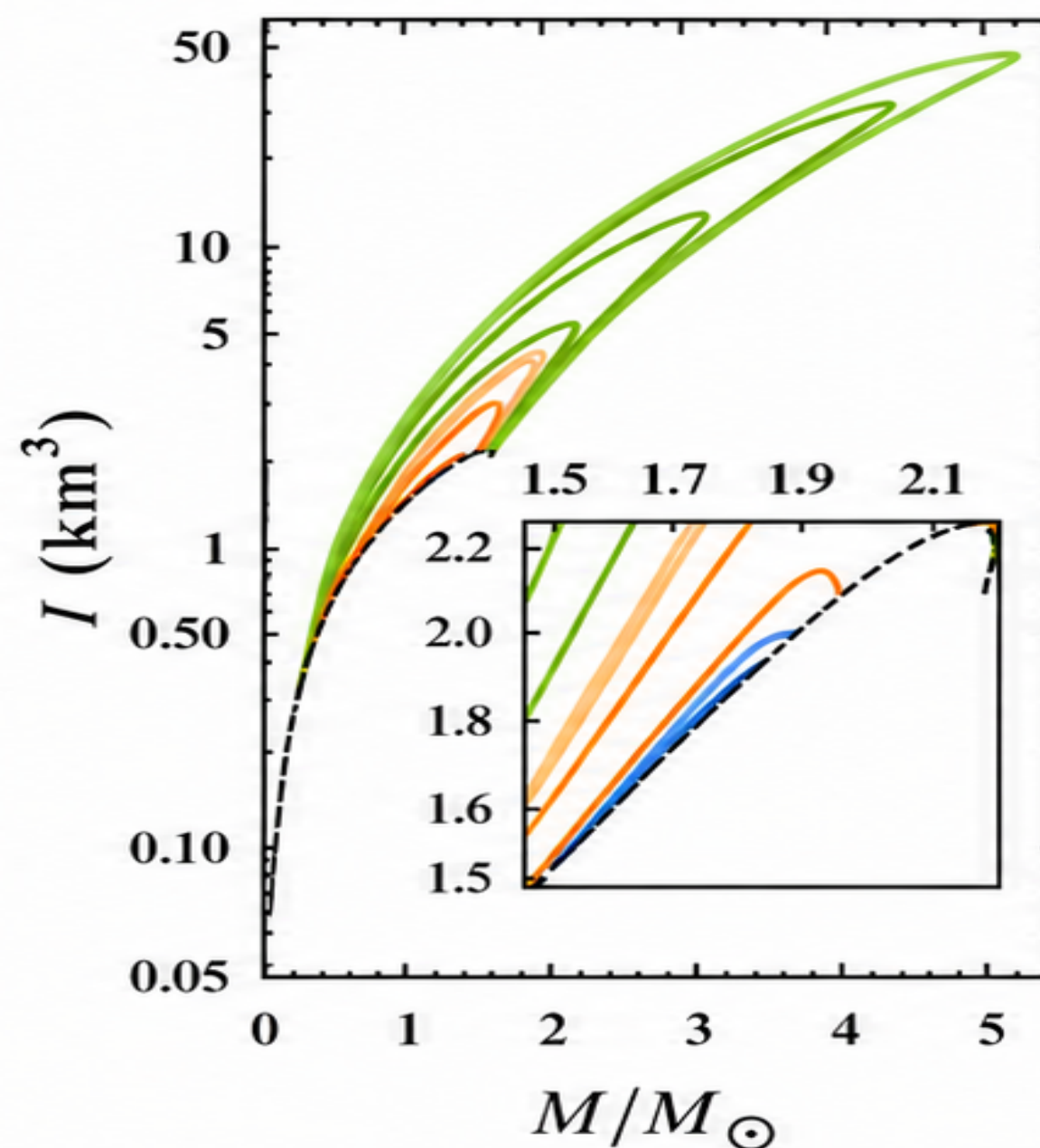
RESULTS



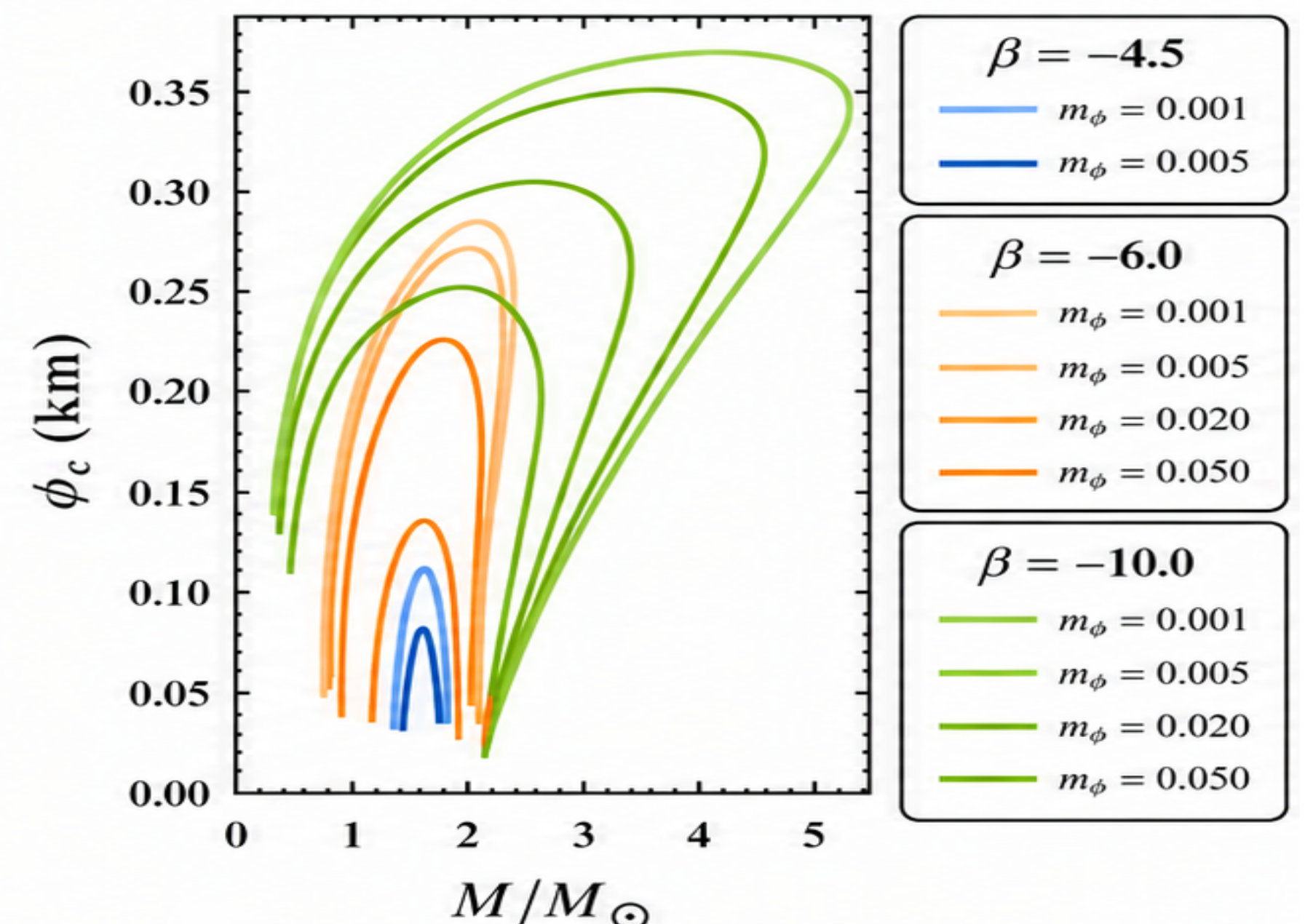
(a) Mass vs central energy density



(b) Mass vs radius



(c) Moment of inertia vs mass



(d) Central scalar field vs mass

- **What enhances scalarization?** More negative β .
- **What suppresses scalarization?** Increasing m_φ .

- **What changes?** Stellar properties.
- Dashed black curves represent general relativity.

CONCLUSIONS

- **Robin boundary condition** reproduces the physical Yukawa tail and strongly reduces finite-boundary sensitivity.
- **Surface recalibration** suppresses numerical radius fluctuations without erasing genuine physical maxima.
- **Scalarization** is strongest for more negative β and smaller m_φ , producing the largest departures from GR.

NEXT STEPS

- Tidal Love numbers and universal relations.
- Bayesian analysis.