Constraining spontaneous scalarization with neutron star mass-radius relationship

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Spontaneous Scalarization

Action for the Damour-Esposito-Farèse model

$$S = \frac{1}{16\pi}\int d^4x\sqrt{-g}(R - 2g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - 2m_\phi^2\phi^2) + S_{\mathrm{m}}[\psi_{\mathrm{m}}, A^2(\phi)g_{\mu\nu}] \quad (1)$$

Non-minimal coupling. $\tilde{g}_{\mu\nu} = A^2(\phi)g_{\mu\nu}$ is the physical metric used by observers (Jordan frame)

Use $A = e^{\beta\phi^2/2}$, $\beta < 0$

Spontaneous Scalarization

Field equations:

$$R_{\mu\nu} = 8\pi(T_{\mu\nu} - \frac{1}{2}g_{\mu\nu}T) + 2\partial_\mu\phi\partial_\nu\phi + m_\phi^2\phi^2 g_{\mu\nu} \qquad (2)$$

$$\Box\phi = -4\pi\beta\phi T + m_\phi^2\phi \qquad (3)$$

$\phi = 0$ is a solution: equivalent to GR

But, GR solution is unstable (tachyonic instability)
$\Longrightarrow$ spontaneous scalarization

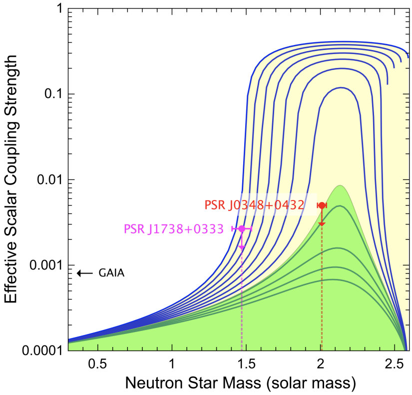
Spontaneous Scalarization

Massive scalar-tensor theory appealing because:

- Large deviations from GR in the strong field regime.
- Far field dies off fast enough to pass weak field tests.

Spontaneous Scalarization

Previously, $m_\phi = 0$ case was examined. Most of the β range ruled out by binary measurements. Remaining only small deviations from GR.



[J. Antoniadis *et al.*, 2013]

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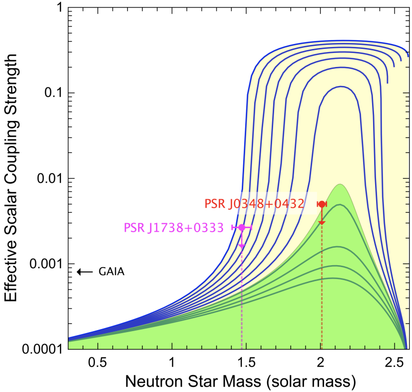


[J. Antoniadis *et al.*, 2013]

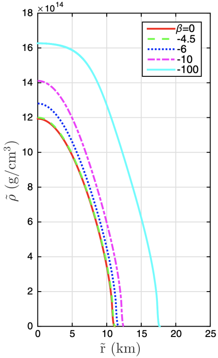
Introducing mass screens the scalar field:

$$\phi(r = \infty) \sim \frac{1}{r} \tag{4}$$

$$\downarrow m_\phi \neq 0$$

$$\phi(r = \infty) \sim \frac{e^{-2\pi r/\lambda_\phi}}{r} \tag{5}$$

Spontaneous Scalarization



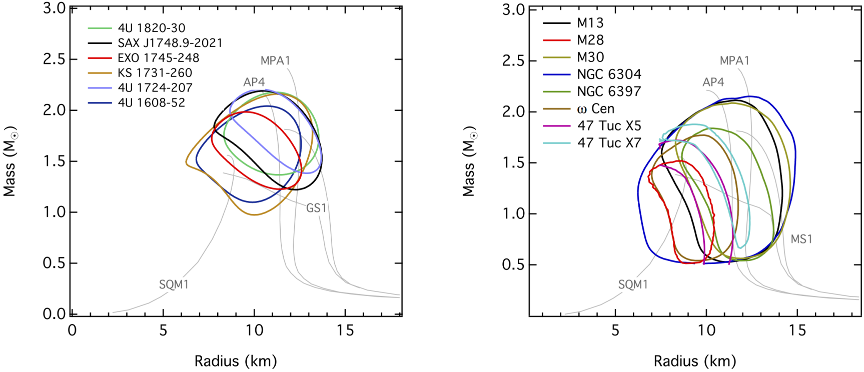
[F. M. Ramazanoğlu and F. Pretorius, 2016]

With $m_\phi \neq 0$, β is again unconstrained. How can we constrain β?

Changing β changes the NS structure radically. $\Longrightarrow$ Use the mass-radius relation.

Neutron Star Mass-Radius Relationship

Observed *M*-*R* likelihoods for neutron stars



[F. Özel *et al.*, 2016]

Neutron Star Mass-Radius Relationship

Given an equation of state, solutions form a one parameter family with the central pressure p_c. For each (β, m_ϕ), find the mass-radius relationship $M = M(R)$ by varying p_c

We need an equation of state $\rho = \rho(p)$. For now, fix an equation of state and focus on (β, m_ϕ); rough upper limit on β

Posterior Likelihoods From Neutron Star Data

Likelihoods for (β, m_ϕ), given experimental data

$$P(\beta, m_\phi \mid \text{data}) = C_1 P(\text{data} \mid \beta, m_\phi) P_\text{p}(\beta) P_\text{p}(m_\phi) \tag{6}$$

$$P(\text{data} \mid \beta, m_\phi) = C_2 \prod_{i=1}^{N} \int_{M_\text{min}}^{M_\text{max}} P_i(M, R(M) \mid \beta, m_\phi) P_\text{p}(M) dM \tag{7}$$

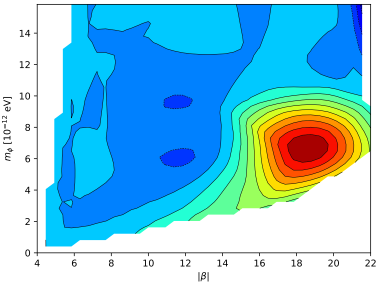
P_p: prior distribution. Use two kinds of distributions:

- Flat prior
- Flat-in-log prior

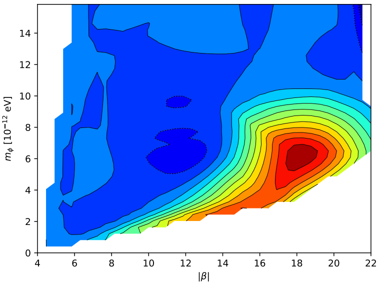
Preliminary Results

2H equation of state [J. S. Read *et al.*, 2009]

Flat prior



Flat-in-log prior



Further Reading

- T. Damour and G. Esposito-Farèse, Phys. Rev. Lett. **70**, 2220 (1993).
- J. Antoniadis *et al.*, Science **340**, 1233232 (2013).
- F. M. Ramazanoğlu and F. Pretorius, Phys. Rev. D **93**, 064005 (2016).
- F. Özel *et al.*, Astrophys. J. **820**, 28 (2016).
- J. S. Read *et al.*, Phys. Rev. D **79**, 124033 (2009).

THANK YOU!