Dynamically scalarizing binary neutron stars

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Phys. Rev. **D96** 084019 (2017)

Scalar-tensor theories

Jordan Frame: test particles follow geodesics of $\tilde{g}_{\mu\nu}$

$$\tilde{m}_{\text{test}}(\phi) = \tilde{m}_{\text{test}}$$

$$S = \int d^4x \frac{\sqrt{-\tilde{g}}}{16\pi} \left(\phi \tilde{R} - \frac{\omega(\phi)}{\phi} \tilde{g}^{\mu\nu} \nabla_\mu \phi \nabla_\nu \phi \right) + \sum_A \int d\tau_A \tilde{m}(\phi)$$

Mass of self-gravitating objects depends on ϕ
(violation of the strong equivalence principle)

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$$g_{\mu\nu} = \phi \, \tilde{g}_{\mu\nu}$$

$$\varphi = \tfrac{1}{2} \int d(\log \phi) \sqrt{3 + 2\omega(\phi)}$$

Mass of self-gravitating objects depends on ϕ (violation of the strong equivalence principle)

Einstein Frame: φ minimally couples to $g_{\mu\nu}$

$$S = \int d^4x \frac{\sqrt{-g}}{16\pi} \left(R - 2g^{\mu\nu} \nabla_\mu \varphi \nabla_\nu \varphi \right) + \sum_A \int d\tau_A \, m_A^{(E)}(\varphi)$$

$$m_{\text{test}}^{(E)}(\varphi) = \tilde{m}_{\text{test}} \, e^{\beta\varphi^2/2}$$

Dynamical scalarization

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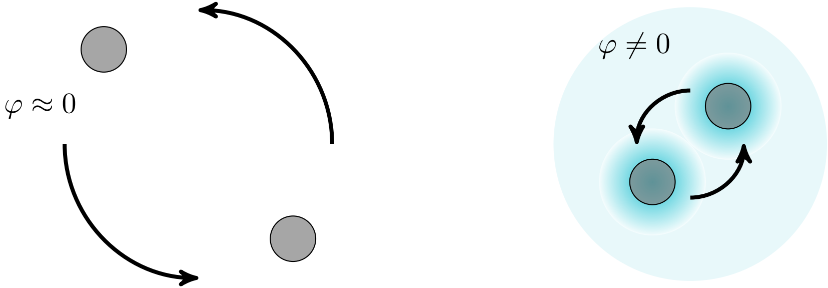
Dynamical scalarization can occur in binary neutron stars when $\beta \lesssim -4.3$



Problem: Post-Newtonian expansion breaks down for dynamical scalarization

Dynamical scalarization

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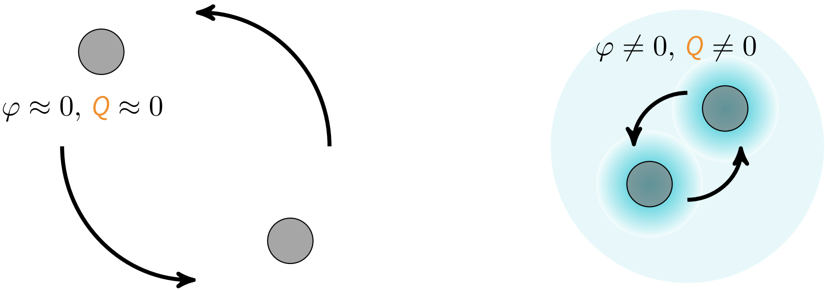


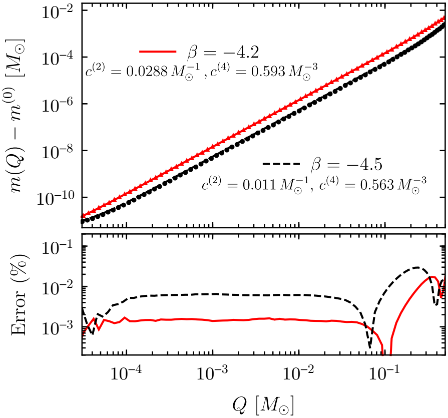
Problem: Post-Newtonian expansion breaks down for dynamical scalarization

New insight: We introduce the "free energy" $m(Q) = m^{(E)}(\varphi) + Q\,\varphi$ [Damour+ 1996]

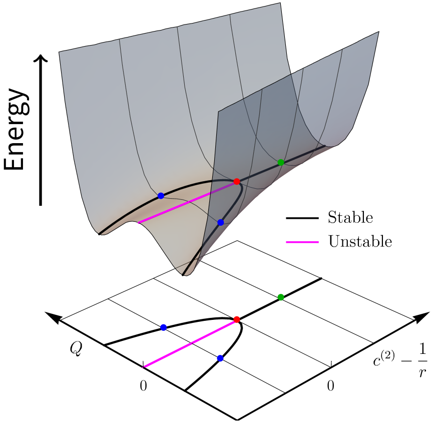
An effective action ansatz

From the symmetry $\varphi \to -\varphi,\ Q \to -Q$ of the theory, a reasonable ansatz during the adiabatic inspiral is

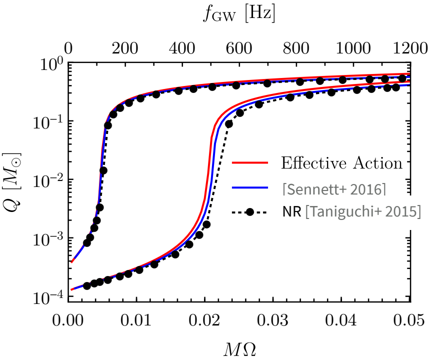
$$m(Q) = m^{(0)} + \frac{c^{(2)}}{2!}Q^2 + \frac{c^{(4)}}{4!}Q^4$$



Consequences of the model



Dynamical scalarization is a second-order phase transition



Reasonable agreement with numerical relativity calculations

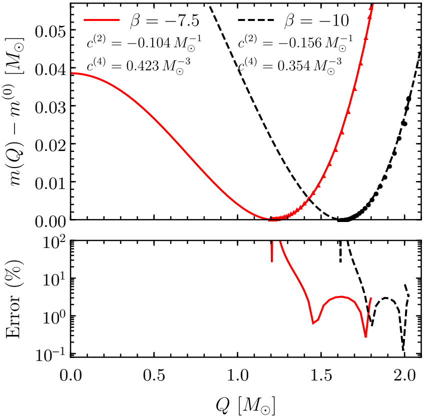
All of the interesting non-GR physics is encapsulated in a simple effective action

Backup slides

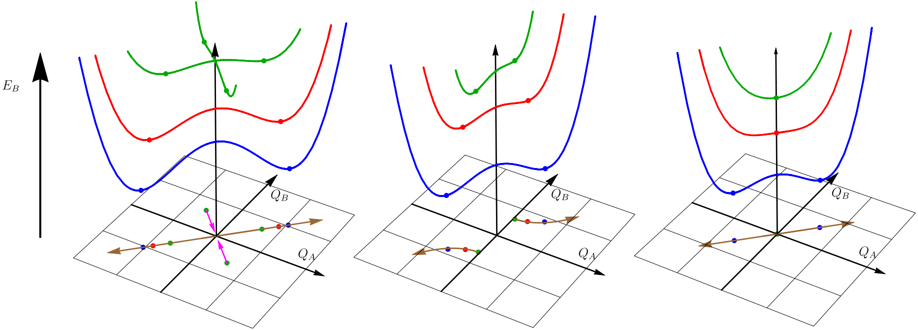
Spontaneous scalarization

Spontaneous scalaraization can be modeled with the same effective ansatz, but with $c^{(2)} < 0$

$$m(Q) = m^{(0)} + \frac{c^{(2)}}{2!}Q^2 + \frac{c^{(4)}}{4!}Q^4$$



Asymmetric binaries



Spontaneous scalarization
$c_A^{(2)} < 0,\ c_B^{(2)} < 0$

Induced scalarization
$c_A^{(2)} > 0,\ c_B^{(2)} < 0$

Dynamical scalarization
$c_A^{(2)} > 0,\ c_B^{(2)} > 0$