Cosmic Tsunamis in Modified Gravity

scalar waves wrecking screening mechanisms

David F. Mota

With R. Hagala and C. Llinares
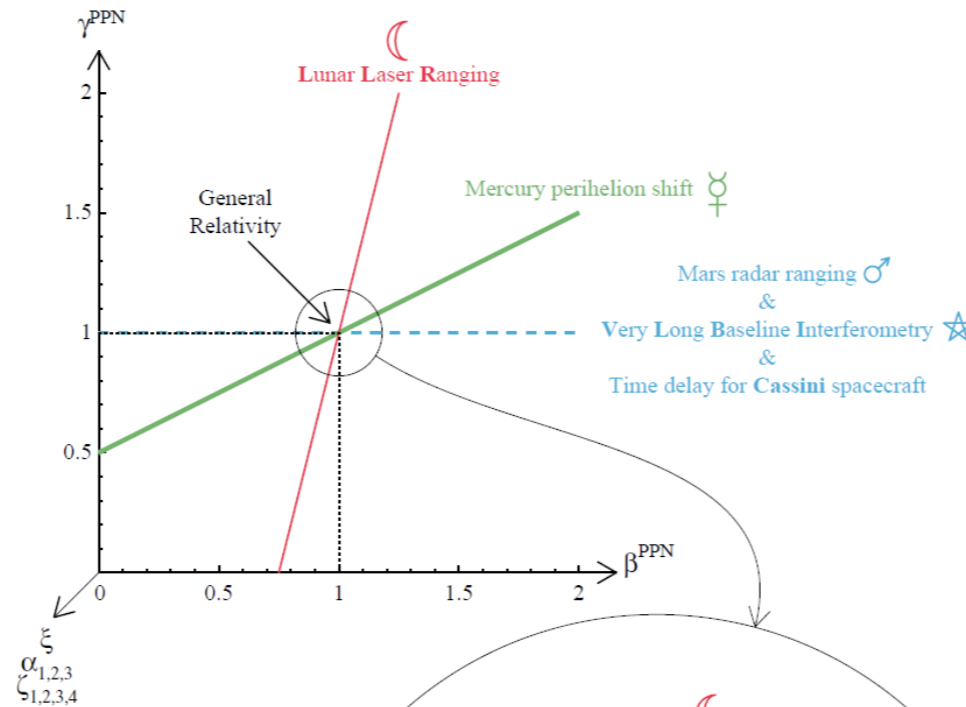
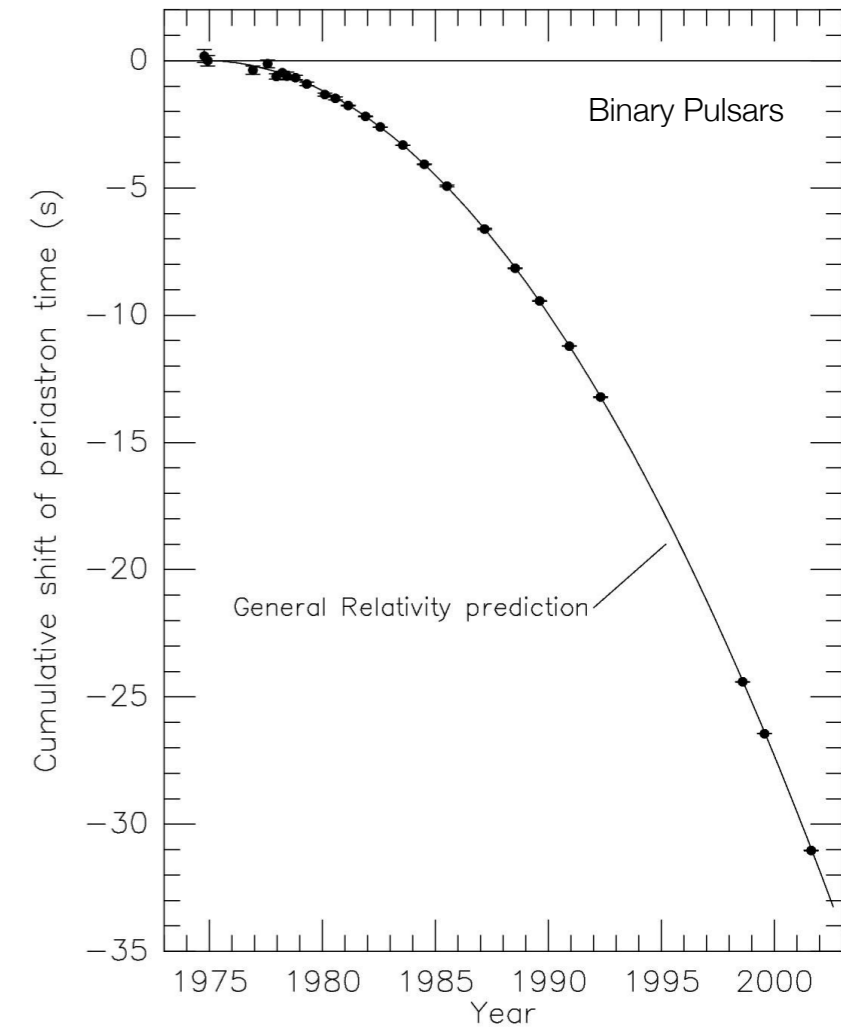# *Extending General Relativity*
Light degree of freedom driving acceleration
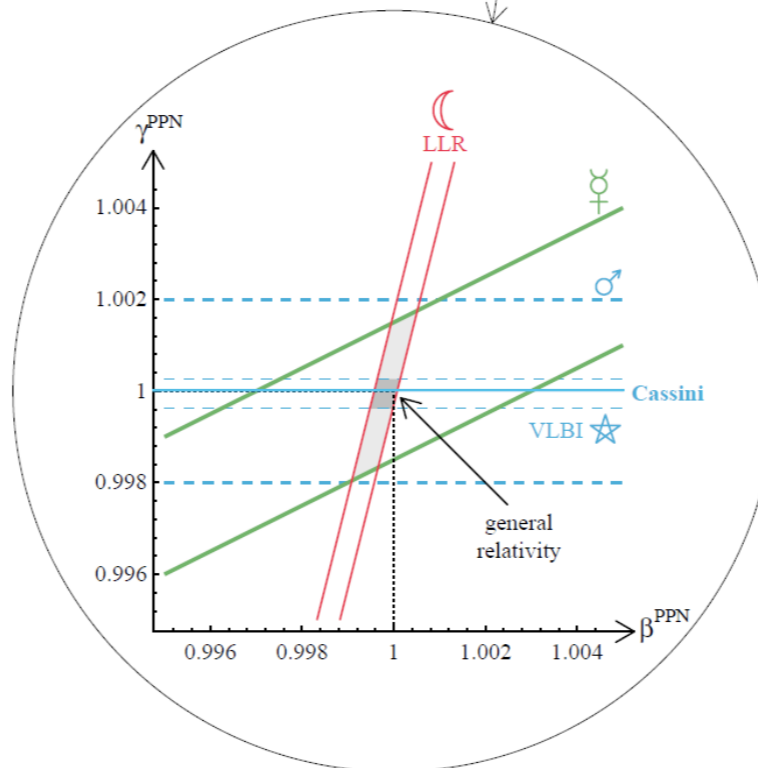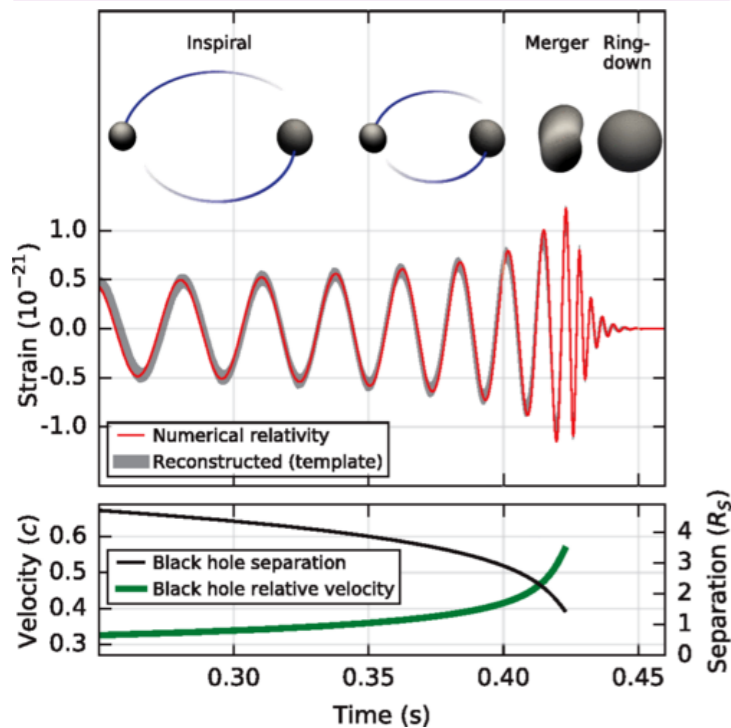
Screening Mechanisms!

Solar System Bounds

Astrophysical Bounds

Strong field Bounds

Screening Mechanisms in Scalar-Tensor Gravity
Suppressing the Yukawa Potential

$$\mathcal{L} = -\frac{1}{2}Z^{\mu\nu}(\phi, \partial\phi, ...)\partial_\mu\phi\partial_\nu\phi - V(\phi) + g(\phi)T^\mu_\mu$$

1. Weak coupling

2. Large mass

$$V(r) = -\frac{g^2(\bar{\phi})}{Z(\bar{\phi})c_s^2(\bar{\phi})}\frac{e^{-\frac{m(\bar{\phi})}{\sqrt{Z(\bar{\phi})}c_s(\bar{\phi})}r}}{4\pi r}\mathcal{M}$$
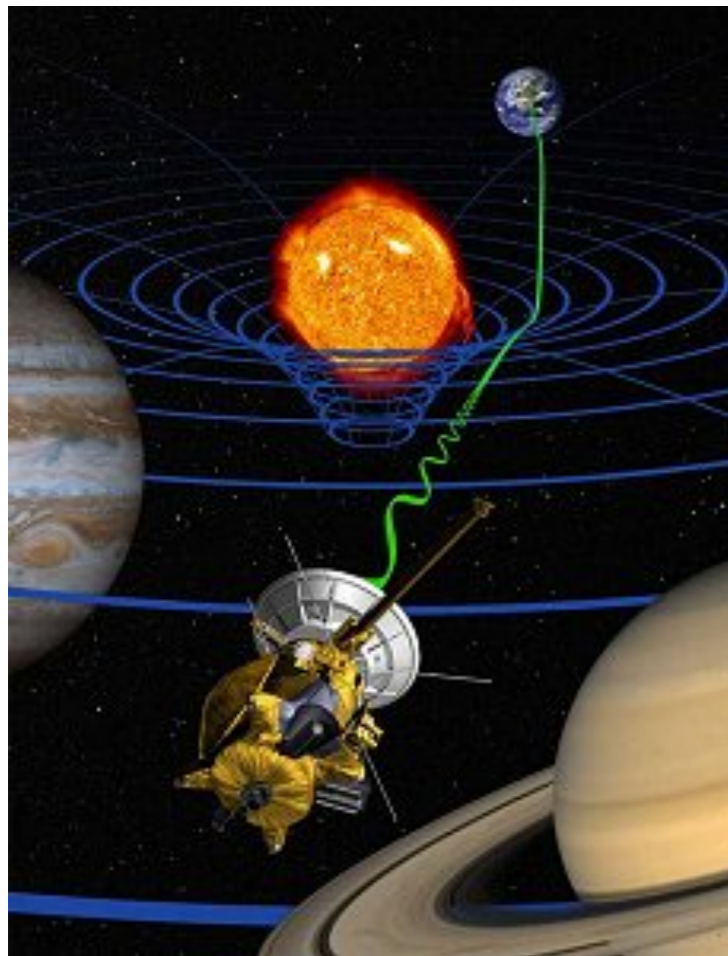
3. Large inertia

Efficiency crucial to evade gravity constraints

Constrains on Modified Gravity
Post-Newtonian Parameter

$$ds^2 = (-1 + 2\frac{GM}{r})\,dt^2 + (1 + 2\gamma\frac{GM}{r})\,dx^2$$

"How much space is curved by a unit rest mass"

$$\gamma - 1 = (2.1 \pm 2.3) \times 10^{-5}$$

$$\gamma - 1 = 0, \qquad \text{GR}$$

$$\gamma - 1 = -\frac{\phi^2}{M^2}\frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2})}$$

Computing the profile of the field in the solar system

$$S = \int \mathrm{d}^4 x \sqrt{-g} \left(\frac{M_{\mathrm{Pl}}^2}{2} R - \frac{1}{2}(\partial\phi)^2 - V(\phi) \right) + S_{\mathrm{matter}} \left[A^2(\phi) g_{\mu\nu}, \psi \right]$$

- Scalar field equation of motion

$$\ddot{\phi} + 3H\dot{\phi} - \frac{1}{a^2}\nabla^2\phi = -V_{\mathrm{eff},\phi}(\rho, \phi)$$

- A damped **wave equation**

Quasi-static approximation

Field profile does not change in virialised/quasi-static systems

- Scalar field equation of motion

$$\frac{1}{a^2}\nabla^2\phi = -V_{\text{eff},\phi}(\rho, \phi)$$

- **Quasi-static** approximation

$$S = \int \mathrm{d}^4x\sqrt{-g}\left(\frac{M_{\text{Pl}}^2}{2}R - \frac{1}{2}(\partial\phi)^2 - V(\phi)\right) + S_{\text{matter}}\left[A^2(\phi)g_{\mu\nu}, \psi\right]$$

Quasi-static approximation
Field profile does not change in virialised/quasi-static systems

- Scalar field equation of motion

$$\frac{1}{a^2}\nabla^2\phi = -V_{\mathrm{eff},\phi}(\rho,\phi)$$
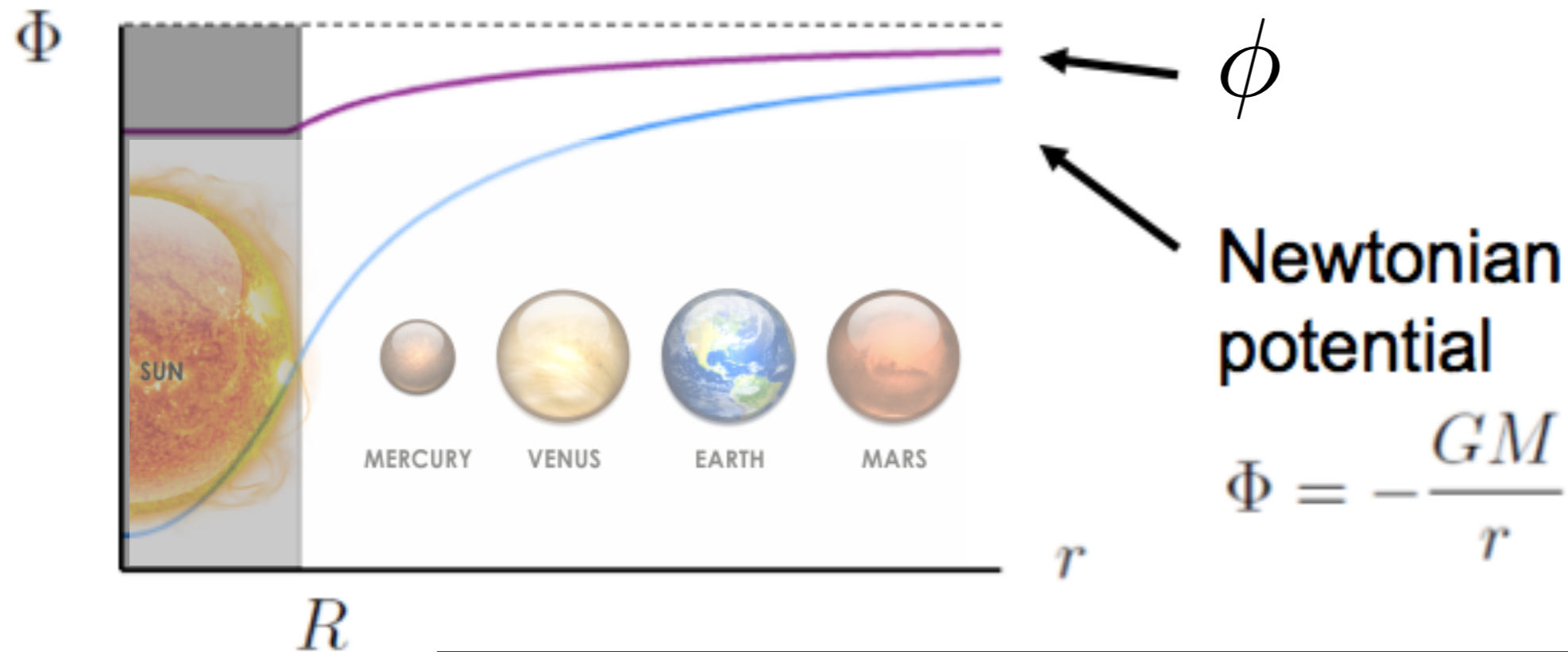
- **Quasi-static** approximation

ϕ

Newtonian

Φ

r
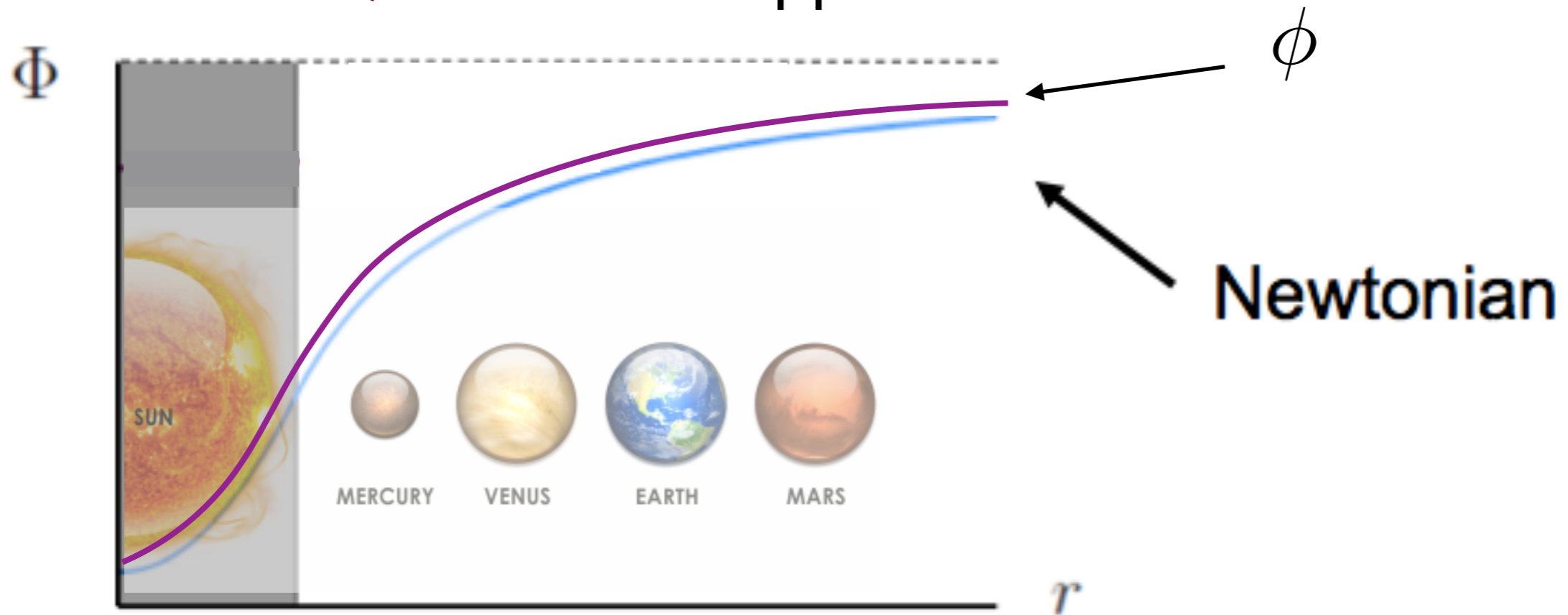
R

$$\gamma - 1 = -\frac{\phi^2}{M^2}\frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1+\frac{\phi^2}{M^2})} \ll 1$$

Screening mechanism suppress field value and gradient

$$\vec{a} = -\vec{\nabla}\Phi - \boxed{\frac{d \ln A(\phi)}{d\phi} \vec{\nabla}\phi}$$

$$\boxed{F_\phi \ll F_N}$$

ϕ

Newtonian potential

$$\Phi = -\frac{GM}{r}$$

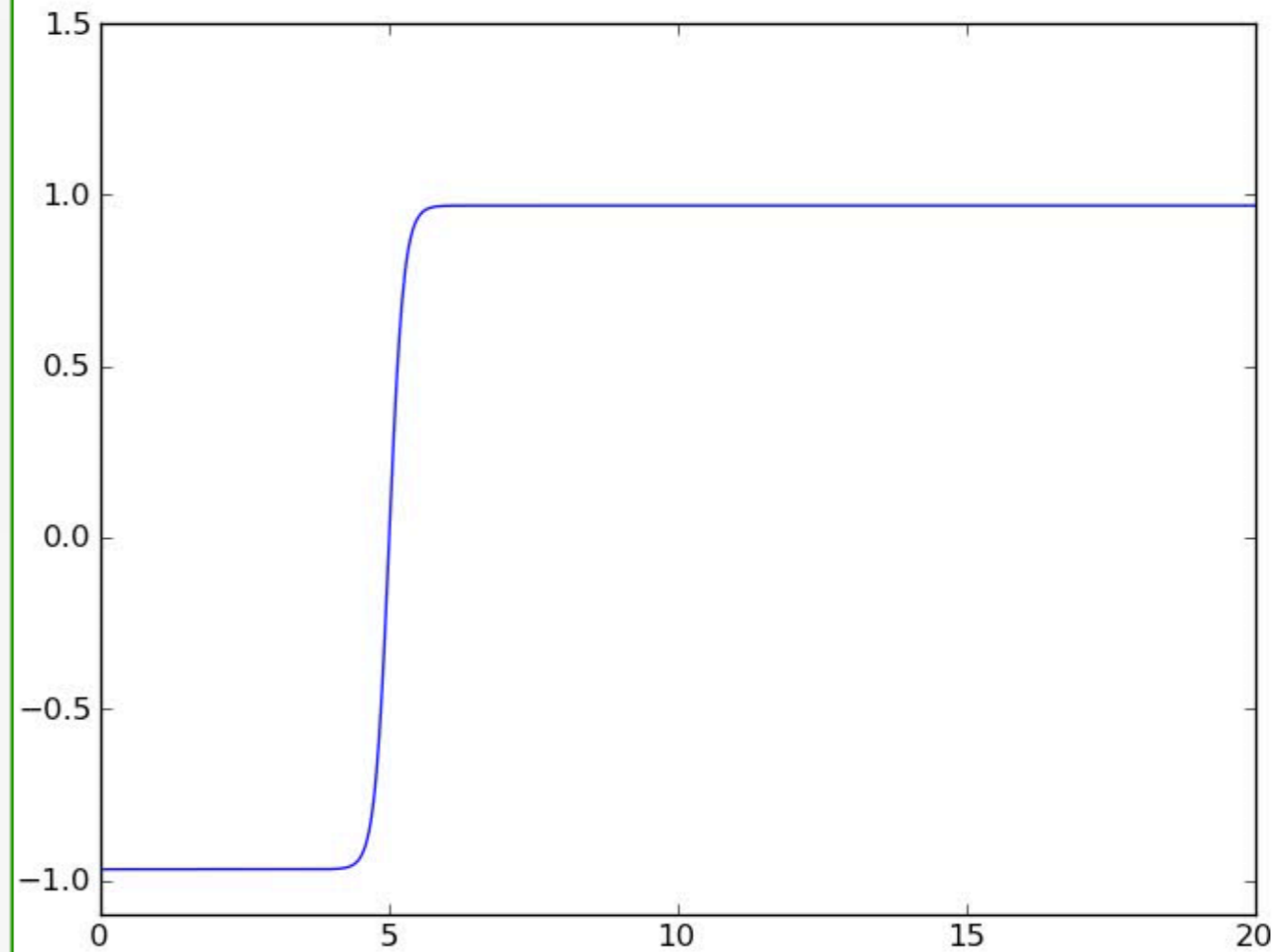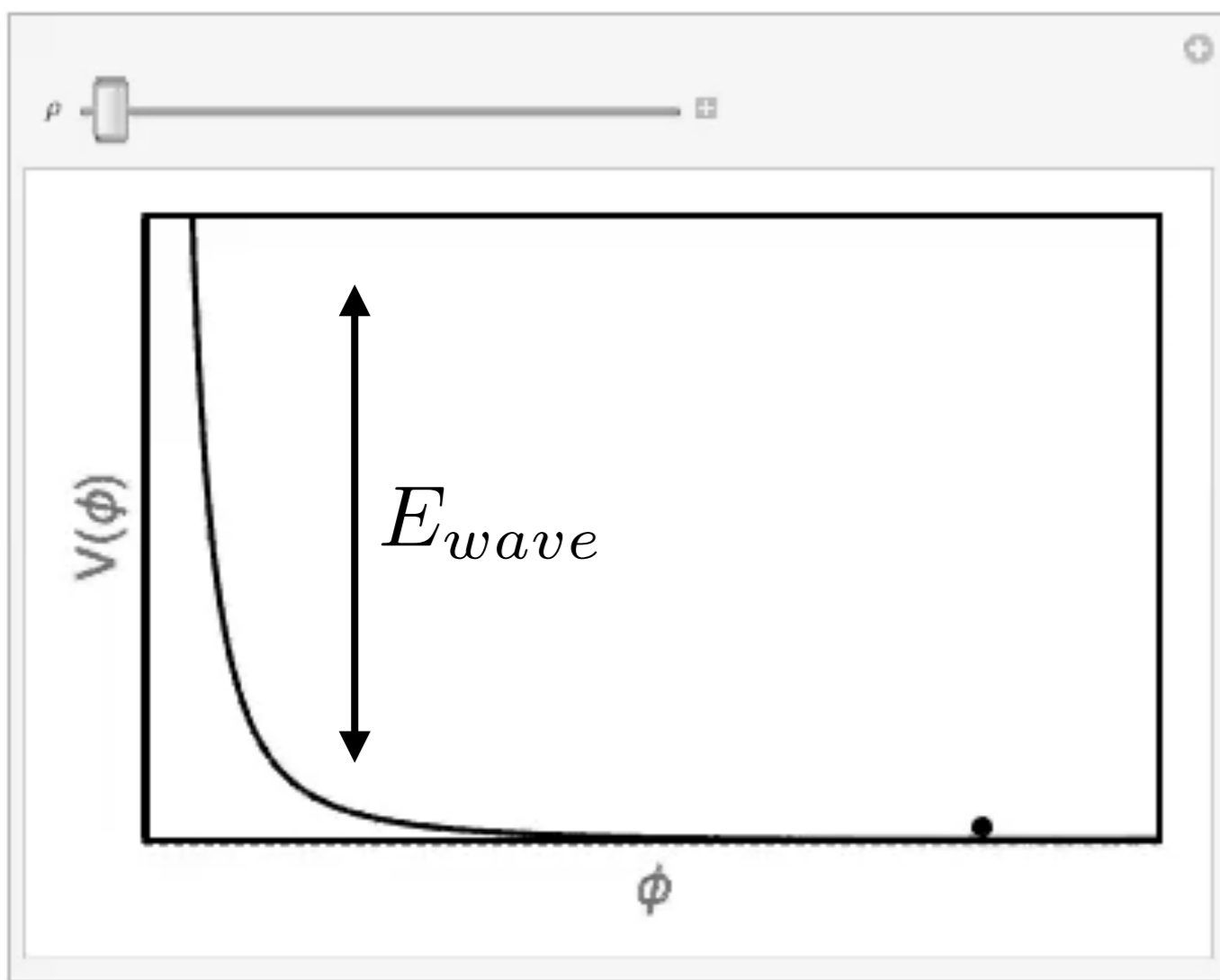$$\gamma - 1 = -\frac{\phi^2}{M^2} \frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2})} \ll 1$$

Waves from Supernovae

Chameleon Potential
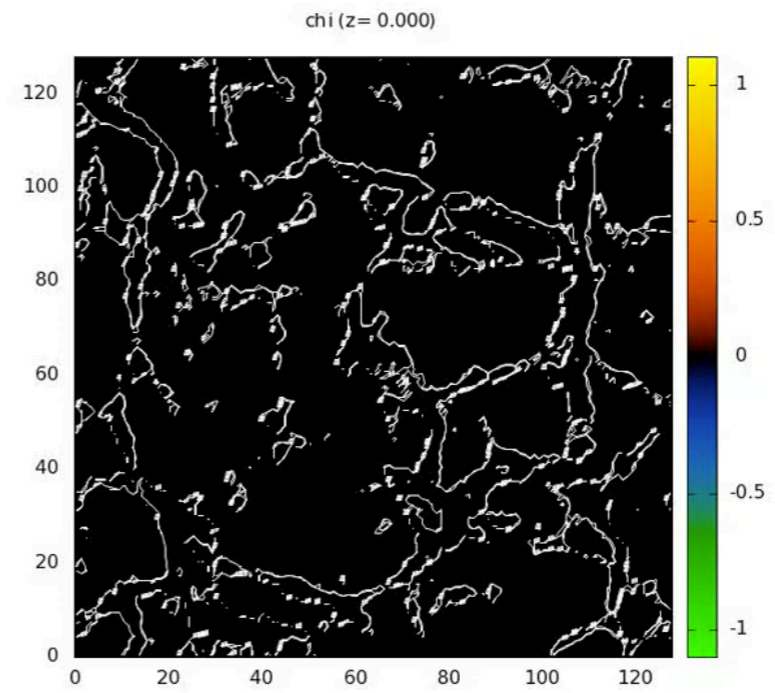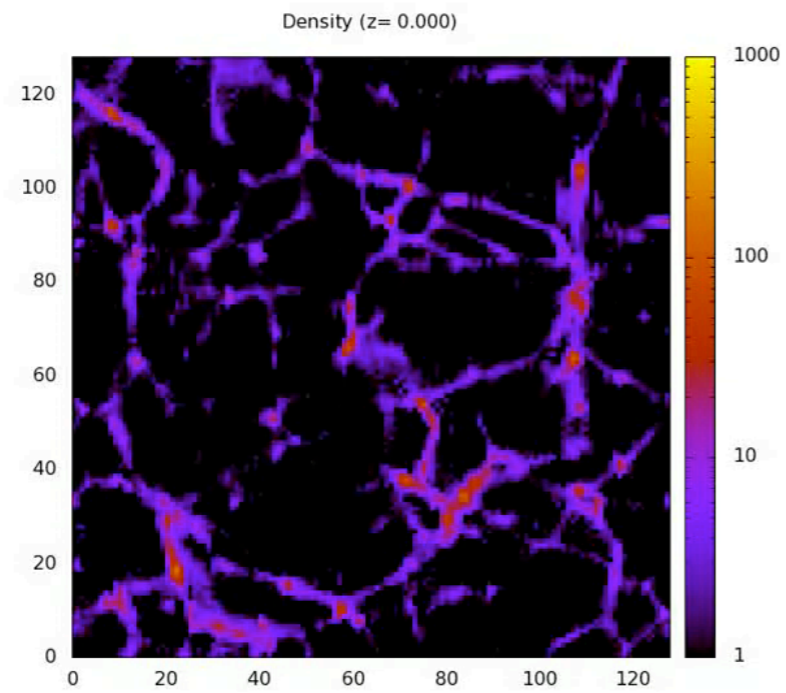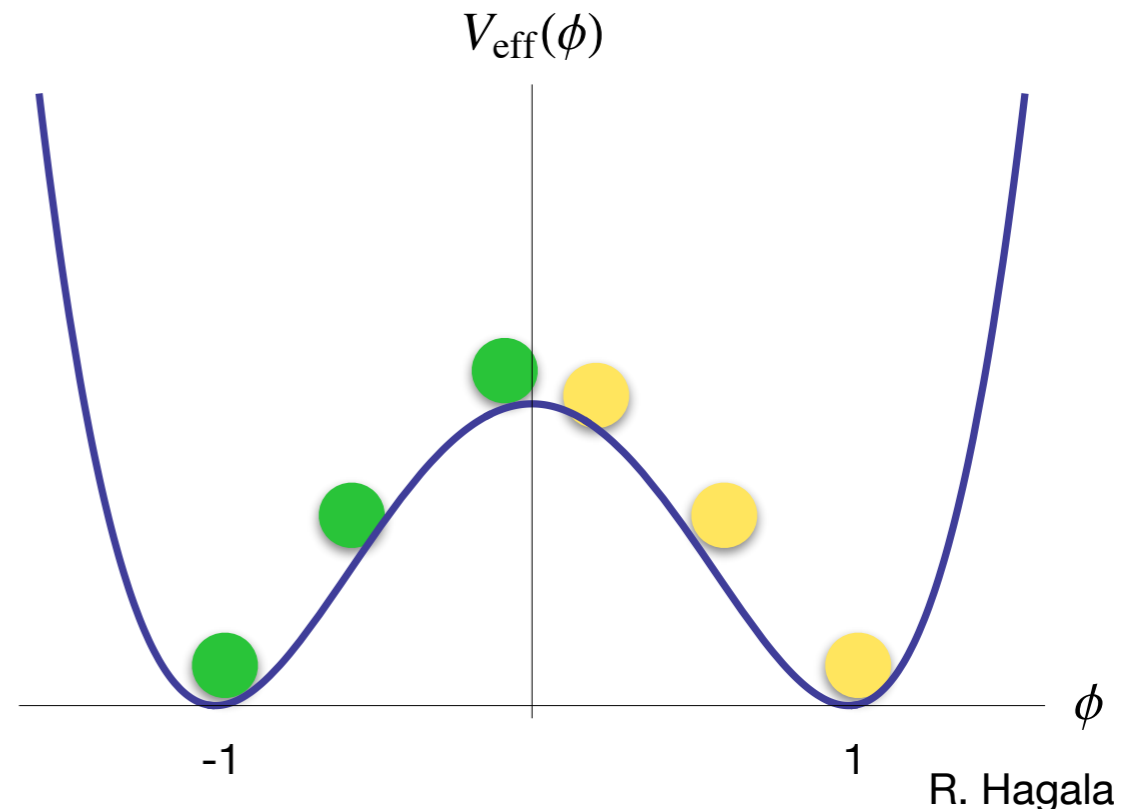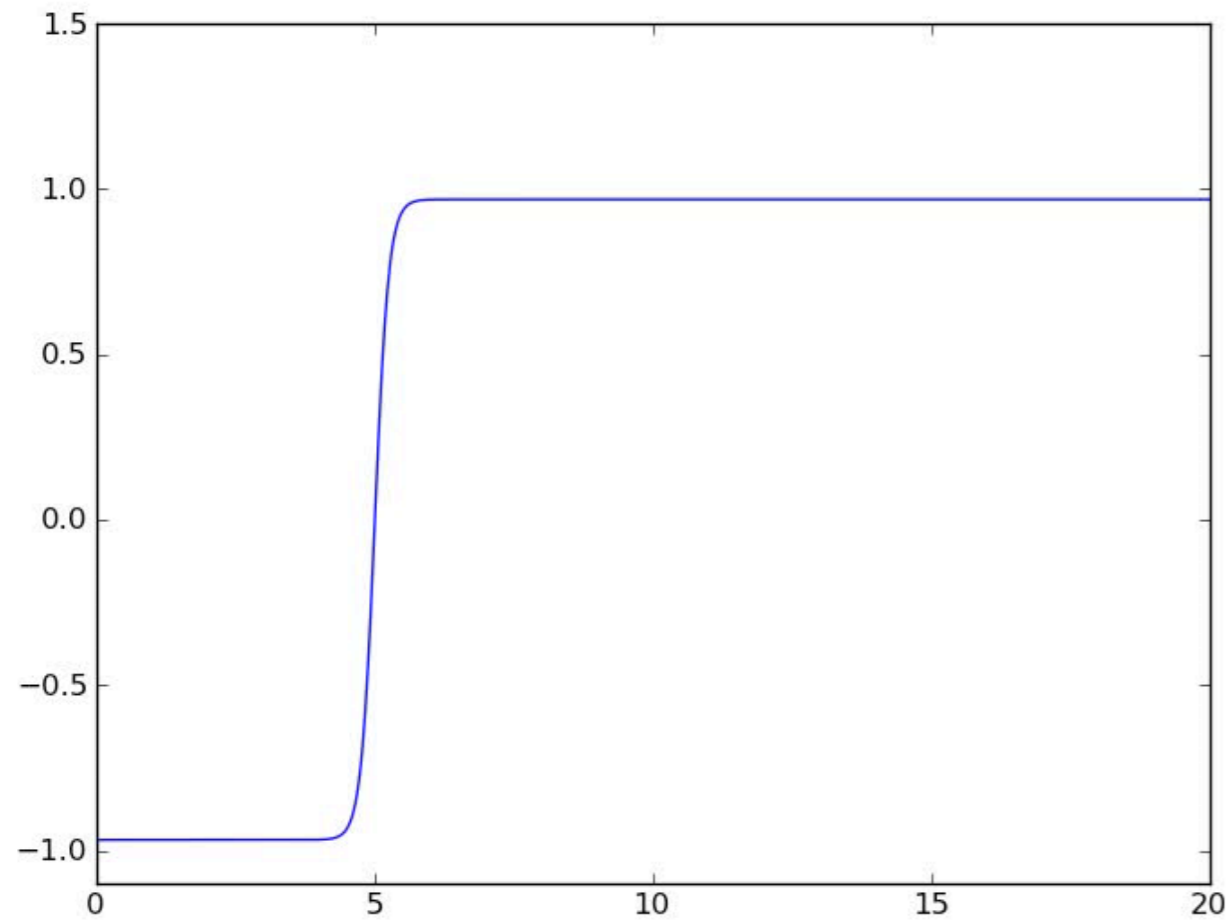

E_{wave}

$V(\phi)$

ϕ

Profile of field

Waves from collapse of domain walls

Density (z= 0.000)   chi (z= 0.000)

Profile of field

$V_{\mathrm{eff}}(\phi)$

ϕ

-1   1

R. Hagala

Cassini bound

Distance from milky way centre

Solar System

$$\gamma - 1 = -\frac{\phi^2}{M^2} \frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2})}$$

Cassini bound
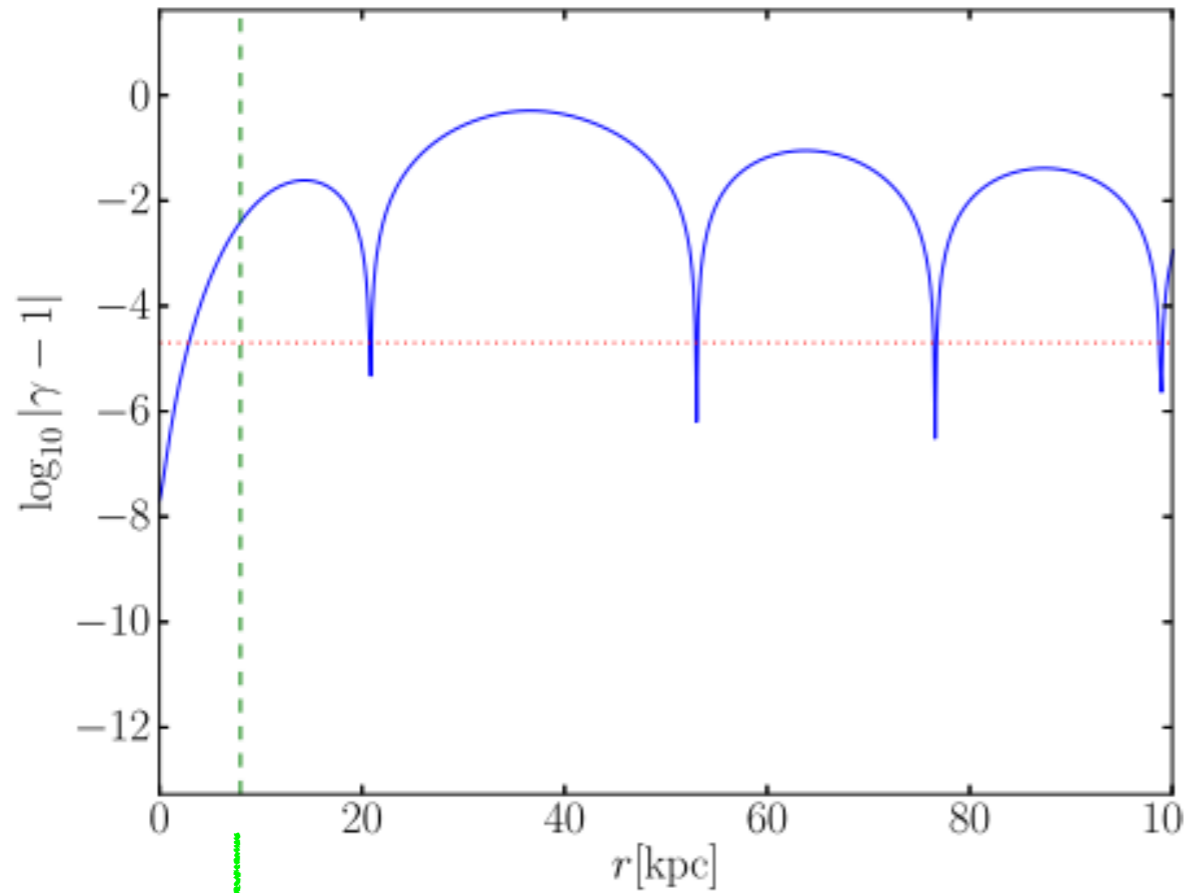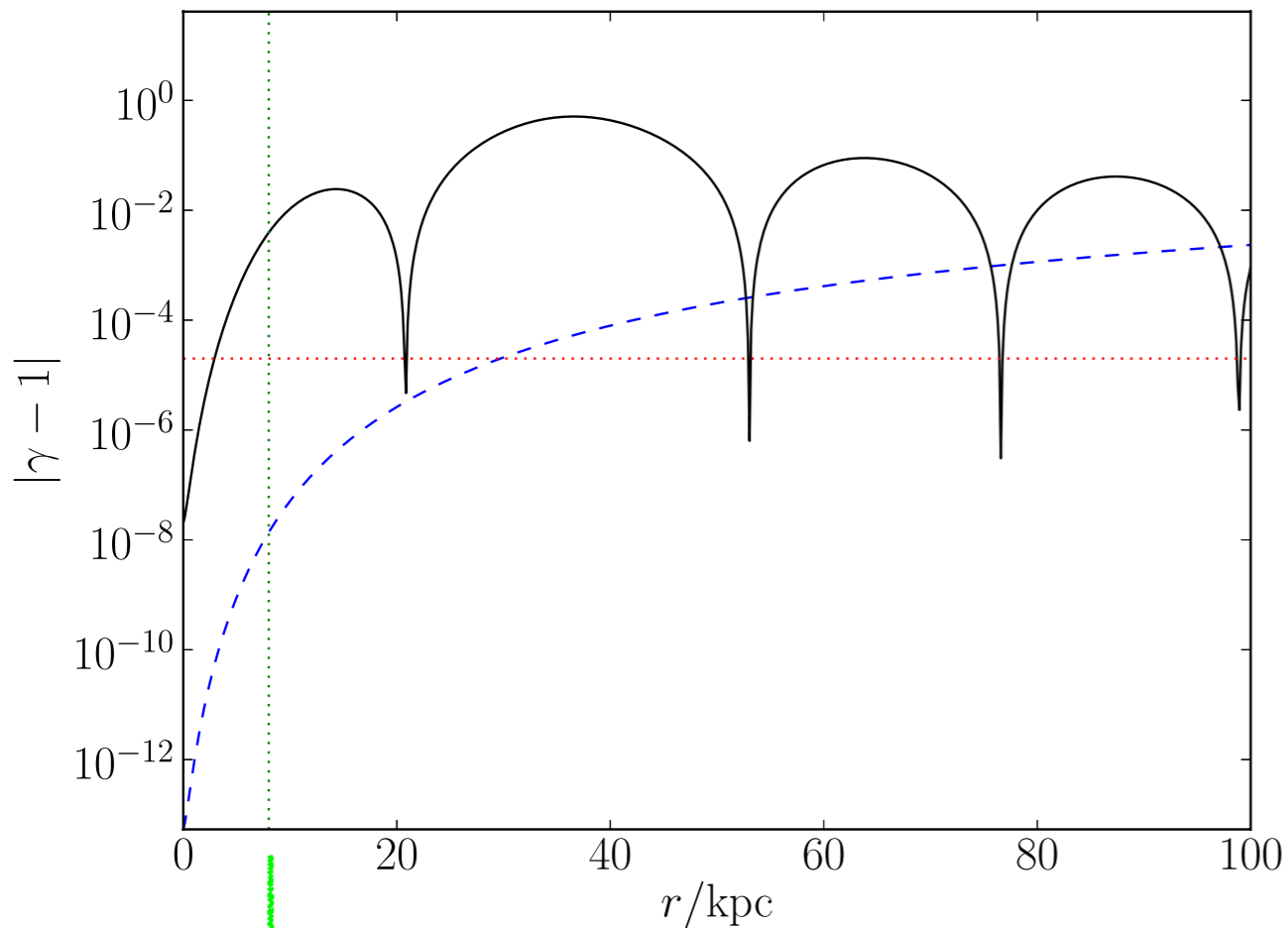
Distance from milky way centre
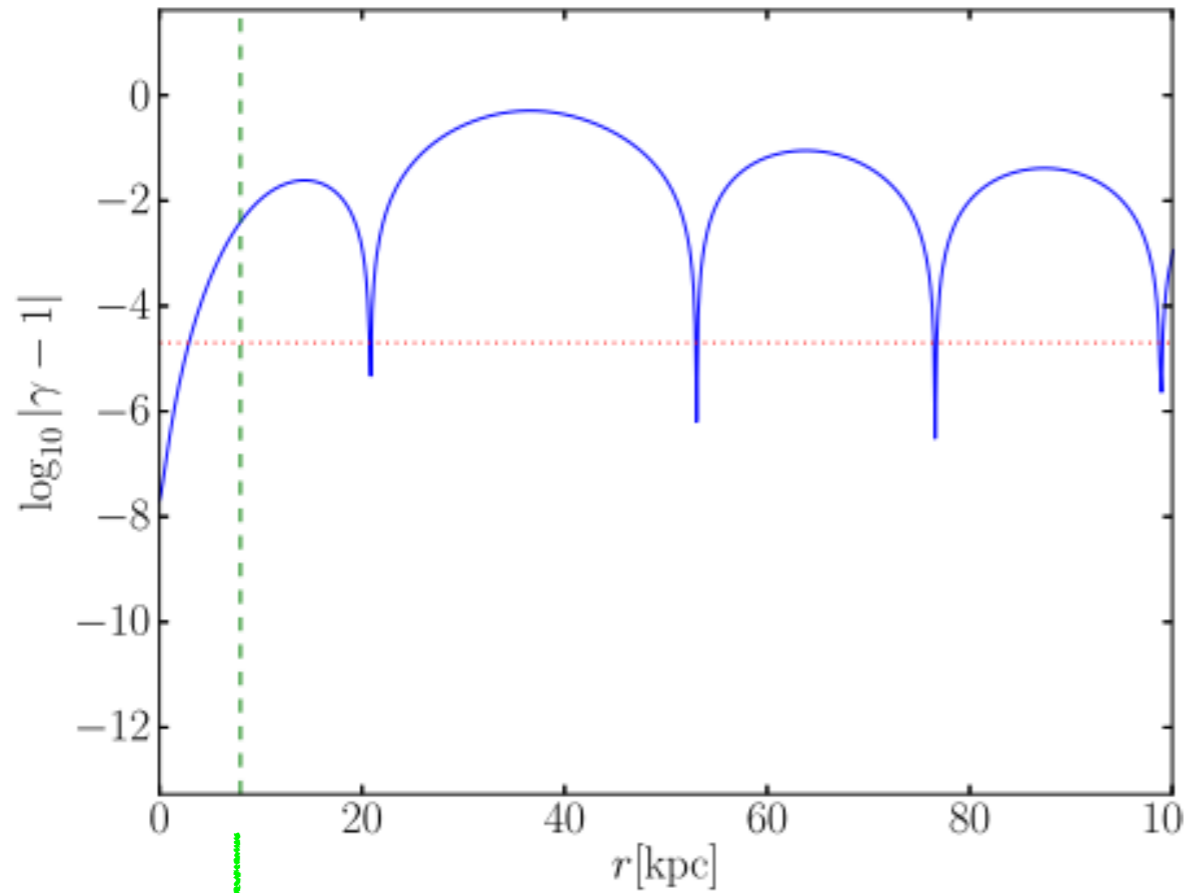
Solar System

$$\gamma - 1 = -\frac{\phi^2}{M^2} \frac{2}{\frac{\phi^2}{M^2} + 2\Psi\left(1 + \frac{\phi^2}{M^2}\right)}$$

Distance from milky way centre

Cassini bound

$$\gamma - 1 = -\frac{\phi^2}{M^2}\frac{2}{\frac{\phi^2}{M^2} + 2\Psi(1 + \frac{\phi^2}{M^2})}$$
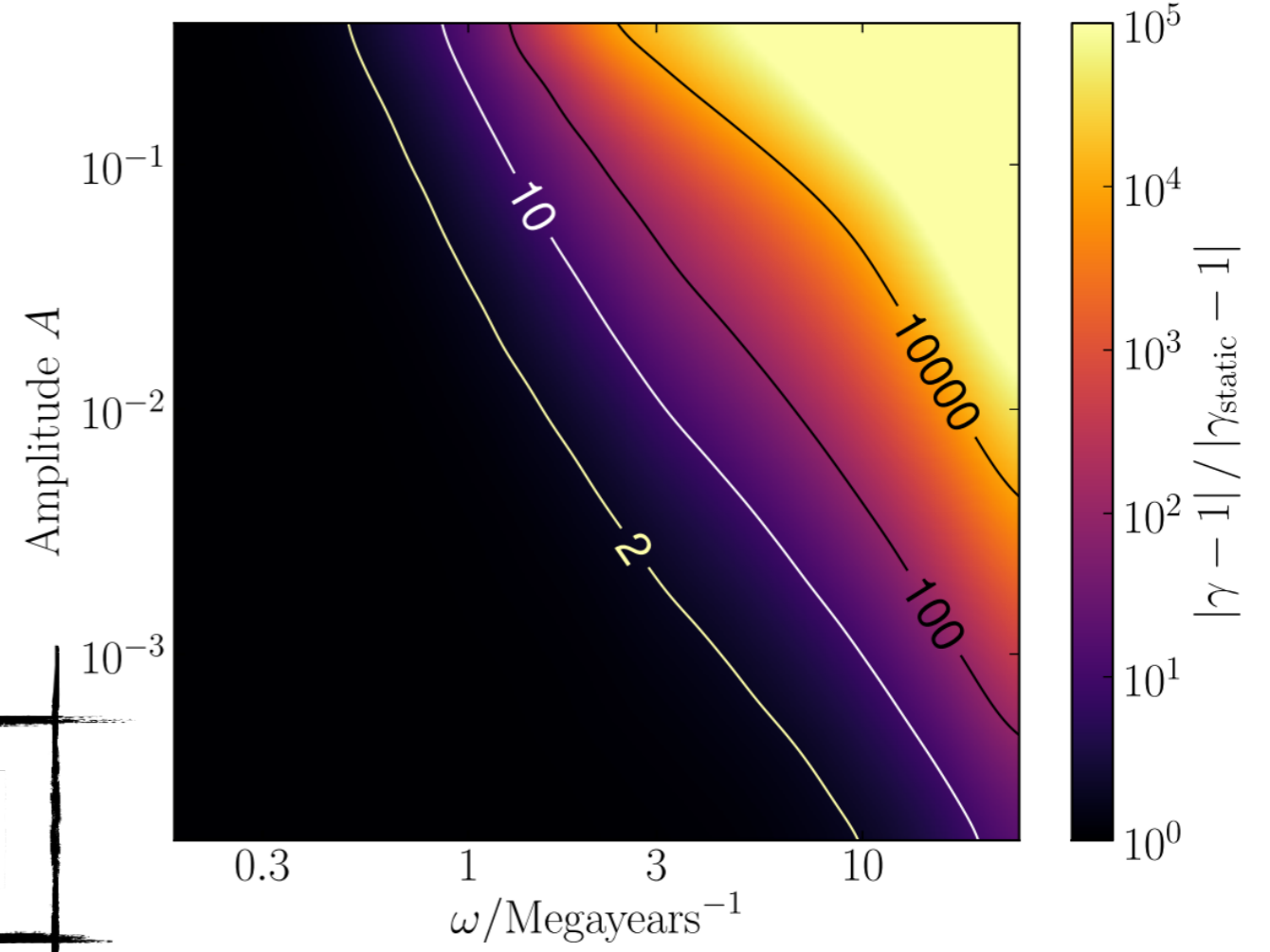
Solar System

Screening disrupted!

Scalar waves increase the PPN parameter and fifth force several orders in magnitude!

Oscillations are a smoking gun!

Summary

‣ A light extra degree of freedom in the gravity sector is viable only if a screening mechanism is efficient to suppress it at local scales

‣ The viability and efficiency of screening mechanism generally relies on the quasi-static approximation

‣ Astrophysical events can create waves and the quasi-static approximation is no longer valid

‣ Waves diminish the screening mechanism efficiency in several orders of magnitude reducing the viability of many modified gravity theories