Testing General Relativity by looking for scalar gravitational waves

Jérôme Novak
DARC – CNRS

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Motivations

Tensor-scalar theories naturally arise in many attempts to quantify gravity, from Kaluza-Klein to string theory
$\hookrightarrow$ weak energy limit: spin 2 field + spin 0 field(s)

Best alternative theories:

- metric theories
- well motivated (natural)
- generalization of GR

Damour & Esposito-Farèse, 1992

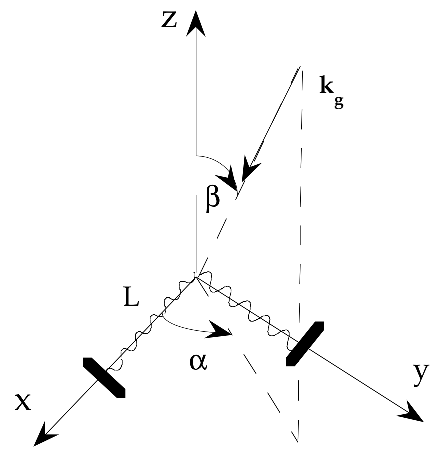
Within this framework, how far are we from General Relativity?

Detection by laser interferometers

Generation and propagation of gravitational waves similar to those of General Relativity (transverse waves)

tensor wave $h_{\mu\nu}$(as in GR) + scalar wave(s) φ

Interaction with interferometric detectors:



$$\delta\left(\phi_x - \phi_y\right) = -2\alpha_0 L\varphi(t)\cos(2\alpha)\sin^2\beta$$

Wagoner & Kalligas, 1997

Parameter space of the tensor-scalar theory

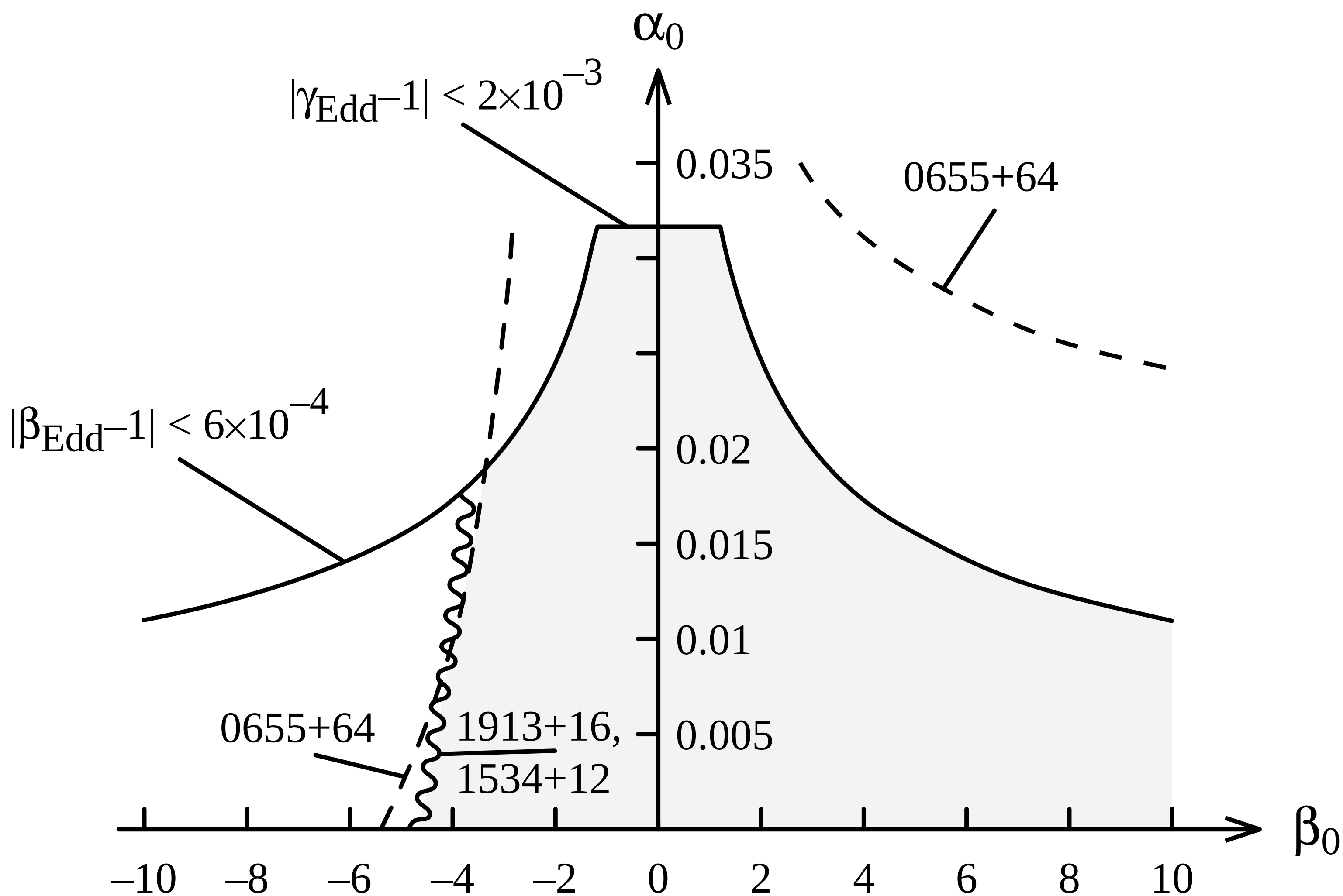
$$
\begin{aligned}
R^*_{\mu\nu} - \frac{1}{2} g^*_{\mu\nu} R^* &= 2q^*_\pi T^*_{\mu\nu} + 2\partial_\mu\varphi\partial_\nu\varphi - g^*_{\mu\nu} g^{\rho\sigma}_* \partial_\rho\varphi\partial_\sigma\varphi \\
\Box_{g_*}\varphi &= -q^*_\pi \alpha(\varphi) T_*
\end{aligned}
$$

Coupling function $\alpha(\varphi) = \alpha_0 + \beta_0 \times \varphi$

General Relativity $\iff$ $\alpha_0 = 0$ and $\beta_0 = 0$

Constraints by solar-system experiments and binary pulsar timing:

$$\alpha_0^2 < 10^{-3},\ |\beta_0|\alpha_0^2 < 7 \times 10^{-4}$$



Damour & Esposito-Farèse, 1996

Possible astrophysical sources

- collapse of a neutron star to a black hole (Novak, 1998a)
- transition of a neutron star to a strong scalar field state (Novak 1998b)
- supernova collapse to a neutron star (Novak & Ibañez, 2000)

$$h_S(t) = \frac{2}{d}\alpha_0 \left(R(\varphi(R) - \varphi_0)\right)$$

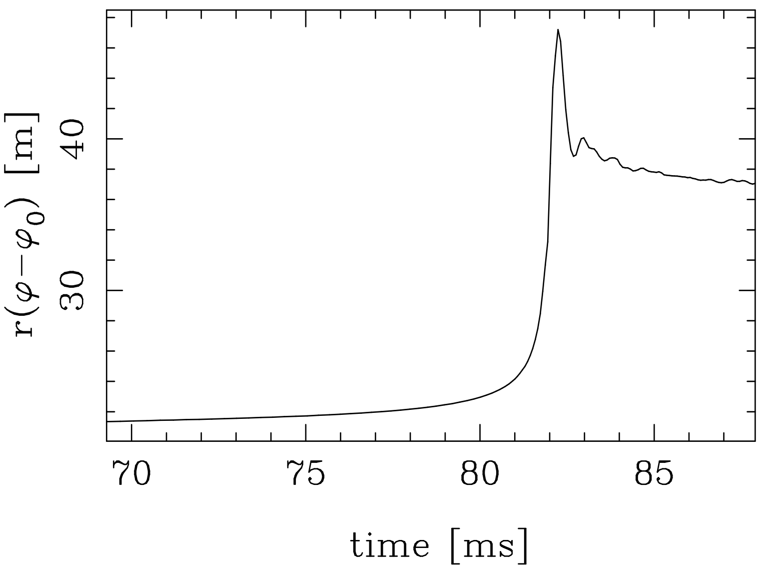
$$h_S(t) \sim \frac{\alpha_0^2}{d}$$

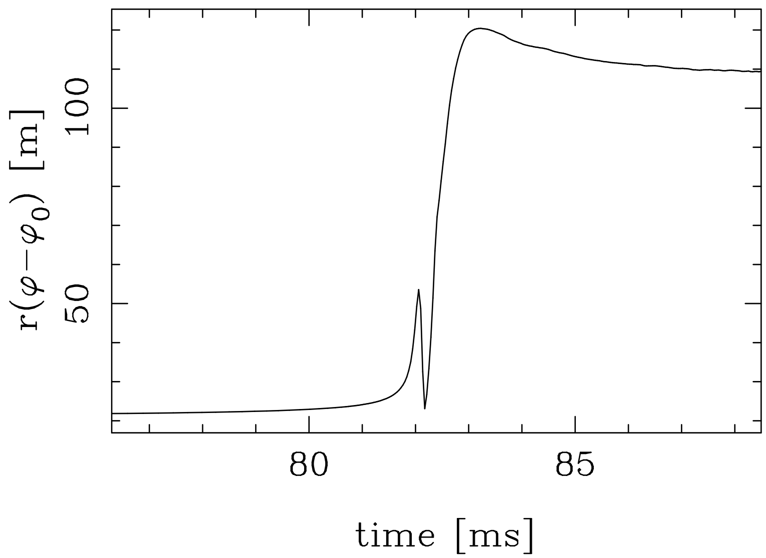
Characteristic frequencies $\sim 700 \to 1200$ Hz

Supernova collapse

$\alpha_0 = -0.01$, $\beta_0 = -4$,
$\rho_{\rm bounce} = 1.5\ \rho_{\rm nuc}$, $S = 1$

$\alpha_0 = -0.01$, $\beta_0 = -4$
$\rho_{\rm bounce} = 15\ \rho_{\rm nuc}$, $S = 5$





$M_g = 1.2 M_\odot$, $N_{\rm min} = 0.7$,
$E_{rad} = 2.3\ 10^{-3}$ FOE

$M_g = 1.1 M_\odot$, $N_{\rm min} = 0.4$,
$E_{rad} = 5.8\ 10^{-2}$ FOE

We can *see* type II supernovæ(SN1987A, SN1993J, SN1997D...)

$$\tilde{h_S}(\text{SN87a}) \simeq 1.3 \times 10^{-19} \alpha_0^2 \ [\text{Hz}^{-1/2}]$$

$\Rightarrow$ An absence of scalar wave detection gives constraints on α_0.

$\Rightarrow$ A detection would be a revolution for the modeling of gravity...