Testing Modified Gravity with Merging Neutron Stars

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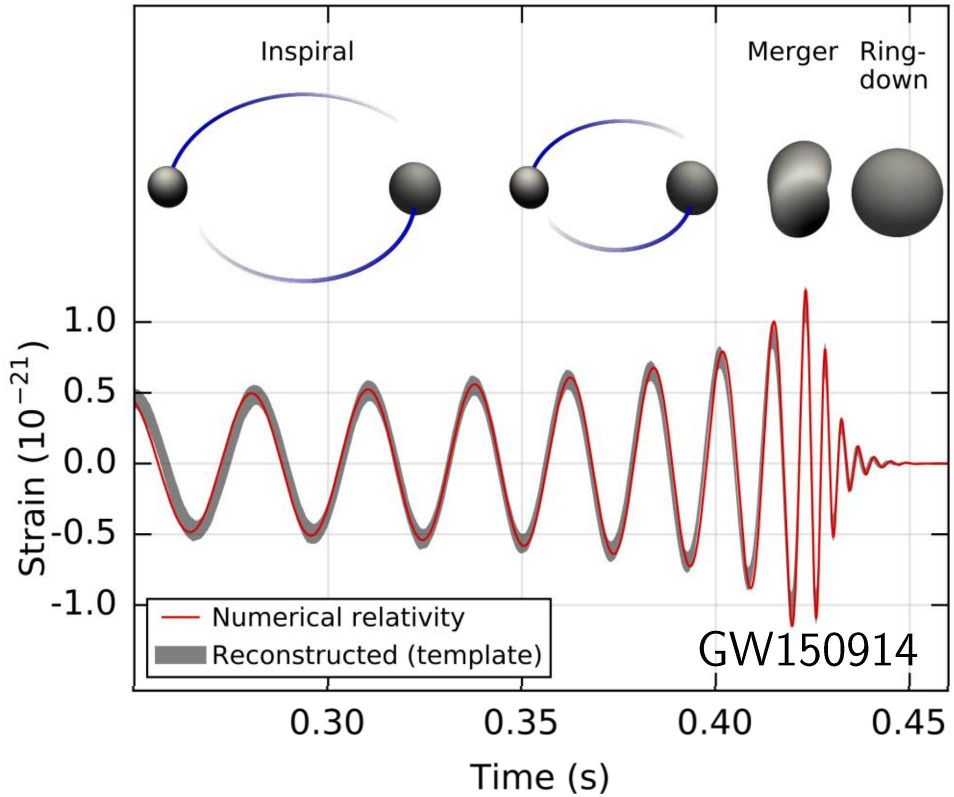
Introduction

Motivation: Test modifications of GR at extreme conditions

→ Merging black holes and neutron stars

→ Target of gravitational wave detectors such as LIGO



Adapted from: [www.ligo.org/science/faq.php]

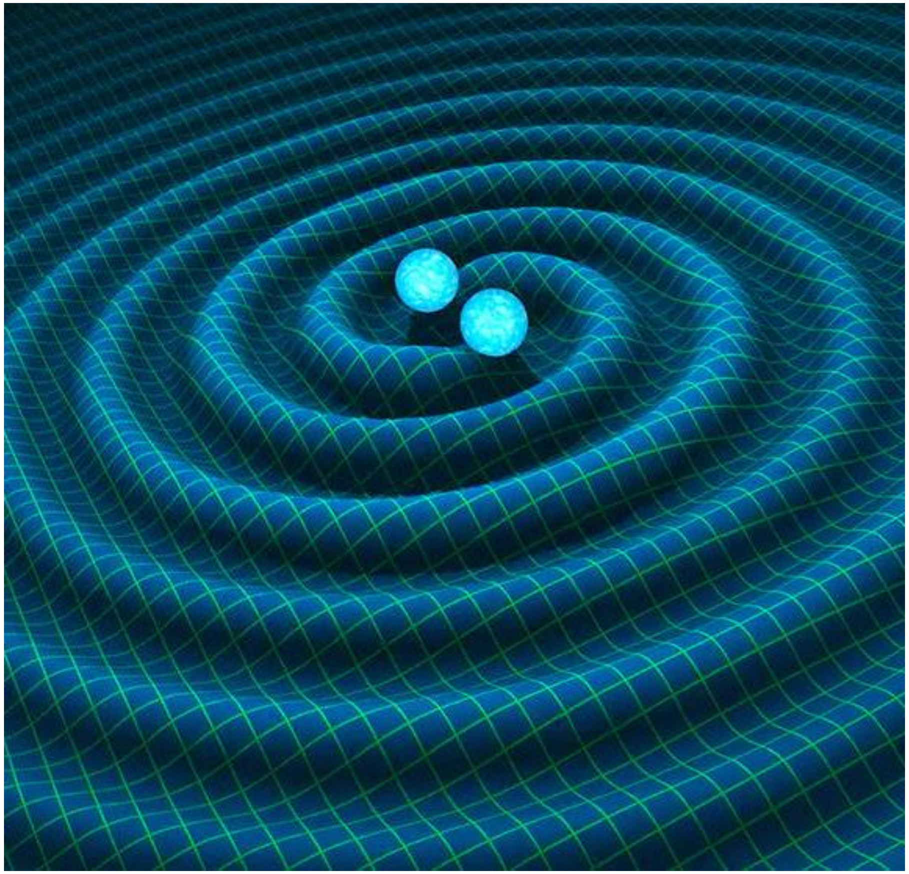
Introduction

Toy model: Simplest model of $f(R)$ modified gravity:

R^2 gravity
$=$ GR $+$ a scalar field

$\longrightarrow$ Scalar field couples to matter

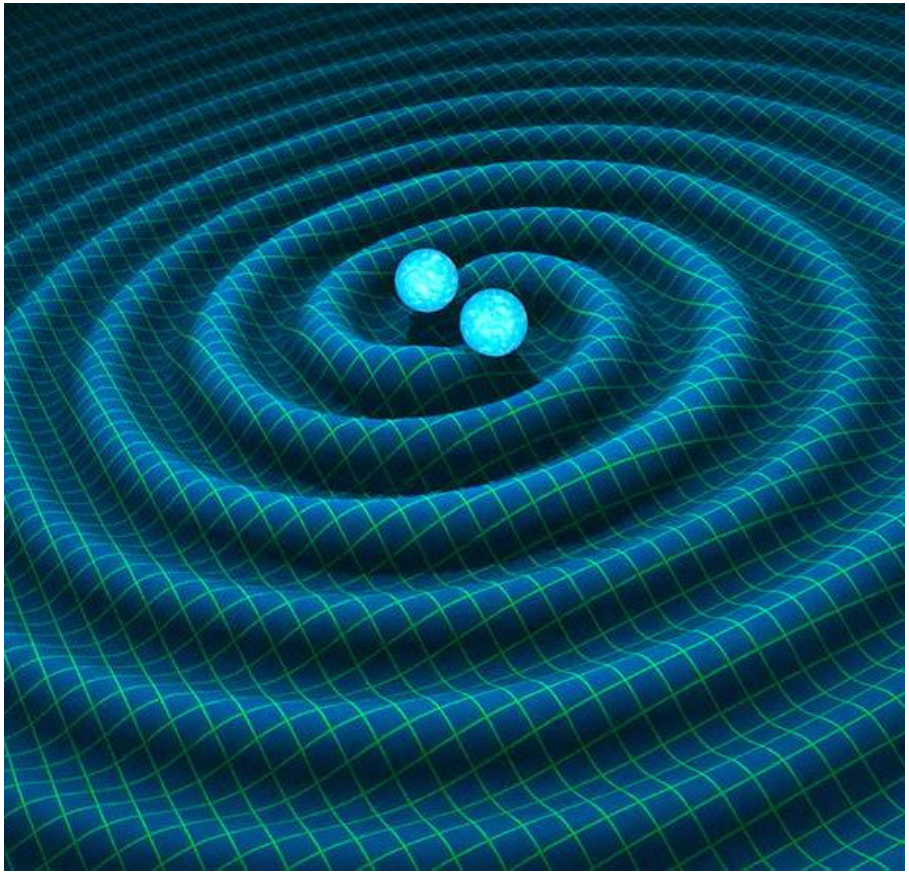
$\longrightarrow$ Merger history differs from GR only for neutron stars



[R. Hurt/Caltech-JPL]

Introduction

→ "Testing Modified Gravity with Merging Neutron Stars"



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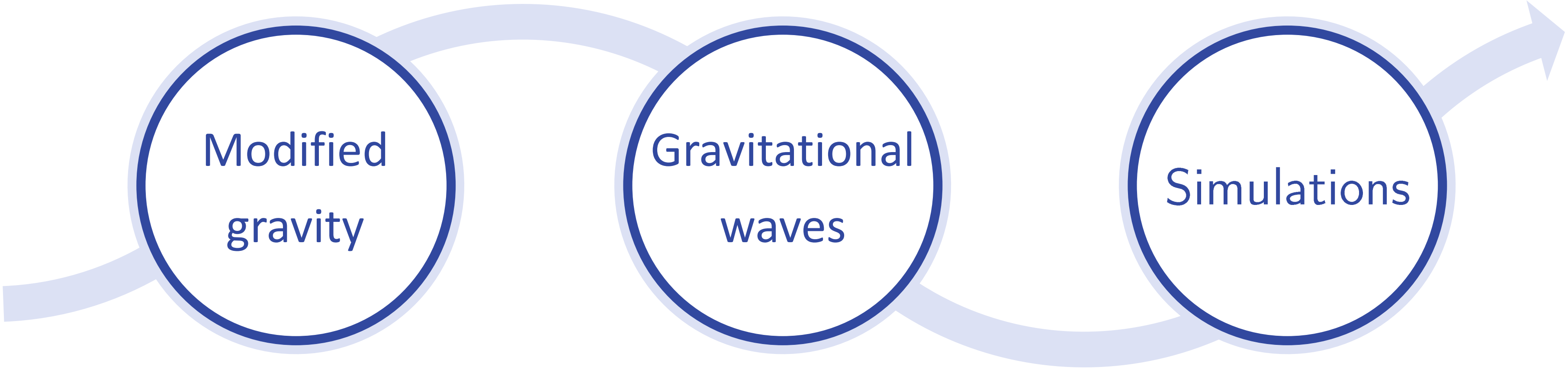
Outline

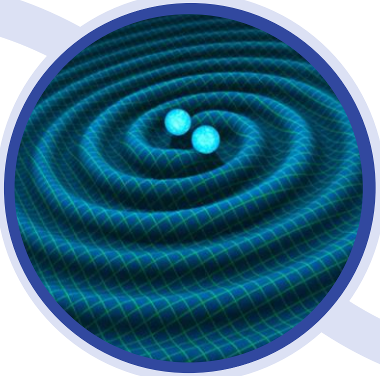


Outline

Gravitational waves

Simulations

Outline



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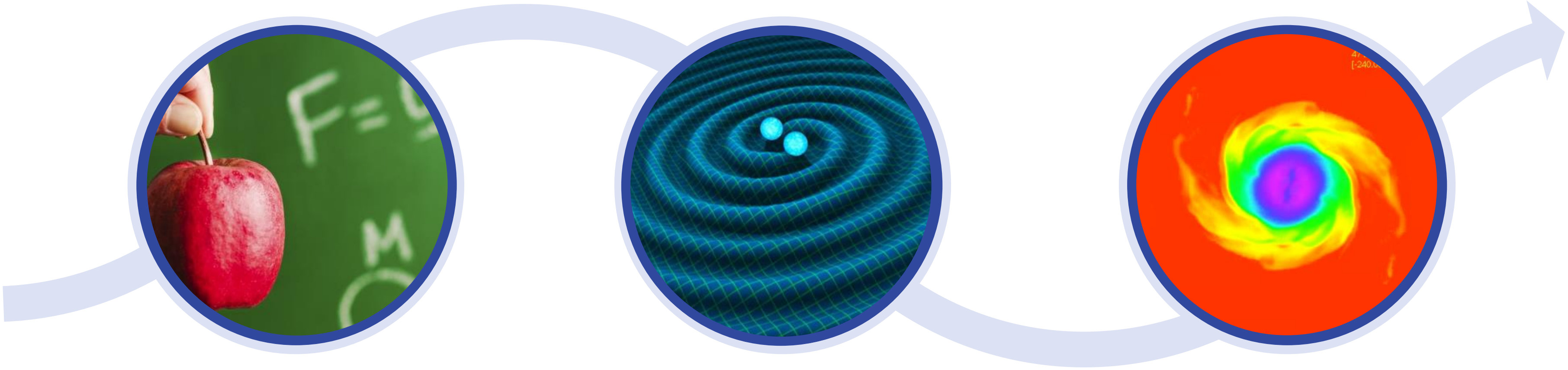

Modified

gravity

$f(R)$ gravity

- Generalizes Einstein-Hilbert action of GR:

$$S \sim \int d^4x \sqrt{-g}\, R + S^M$$

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R^2 gravity

- Function in the generalized action:

$$f(R) = R + a_2 R^2$$

[Staykov et al., '14]

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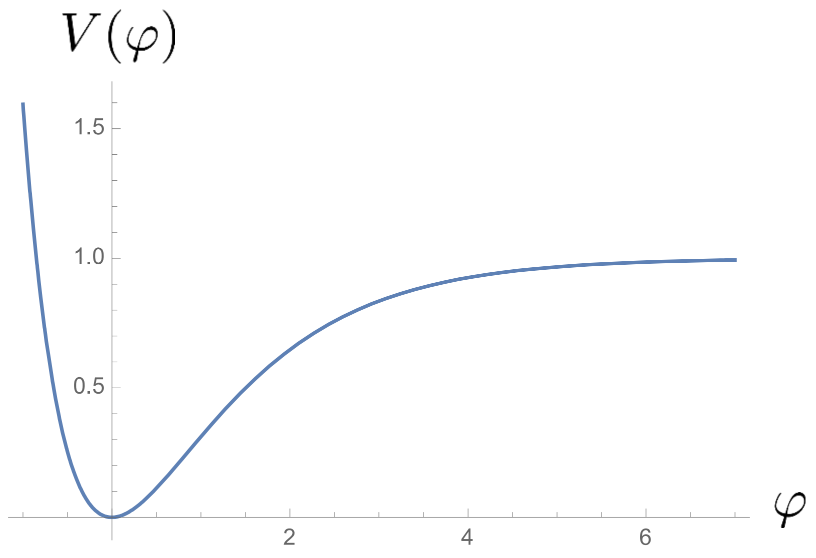
$\longrightarrow$ Scalar potential:

$$V(\varphi) \sim \frac{1}{a_2}\left(1 - e^{-c\varphi}\right)^2$$



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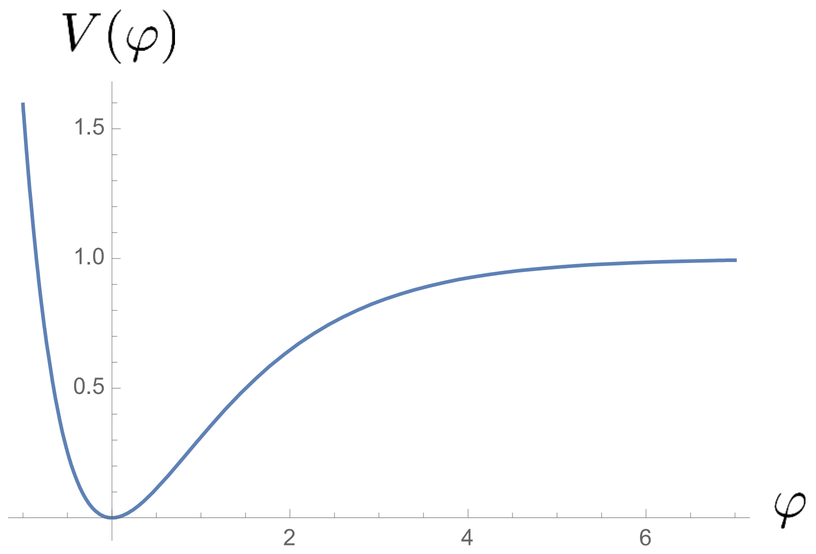

$\longrightarrow$ Scalar mass:

$$m_\varphi = \sqrt{\frac{1}{6a_2}}$$

R^2 gravity

- Equation of motion for φ:

$$\Box\varphi = V'(\varphi) + \frac{1}{2}c\,\tilde{T}^{\mu}_{\mu}$$

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Gravity + neutron star ρ, p

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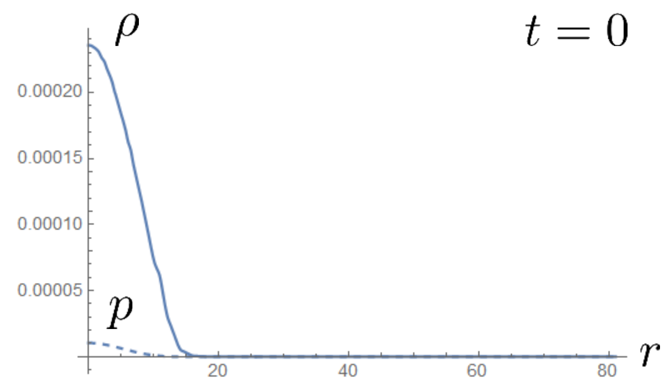

[www.had.liu.edu/] [www.lorene.obspm.fr]

R^2 gravity

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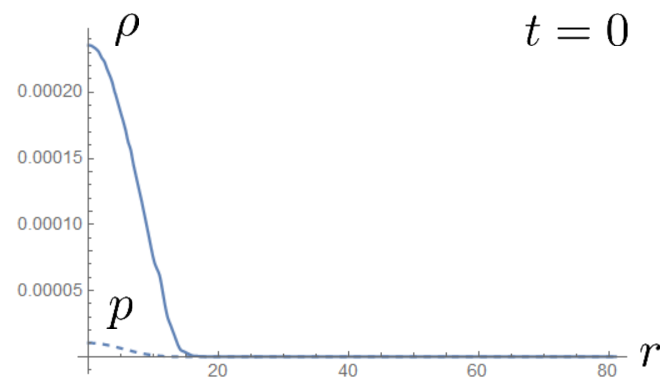
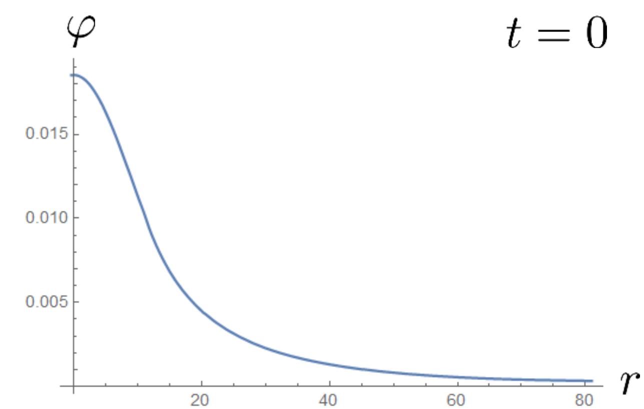
Gravity + neutron star ρ, p

$\longrightarrow$ Static scalar profile:

$$\varphi \sim \alpha M \frac{e^{-m_\varphi r}}{r}$$

(α: scalar charge)





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R^2 gravity

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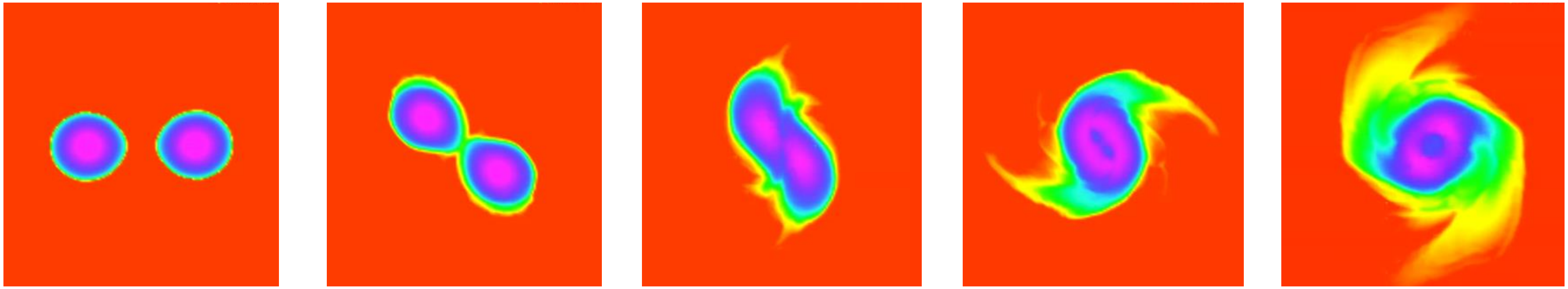
$\longrightarrow$ Changes dynamics of merging neutron stars



[Barausse et al., '12] [Palenzuela, et al., '12]

R^2 gravity

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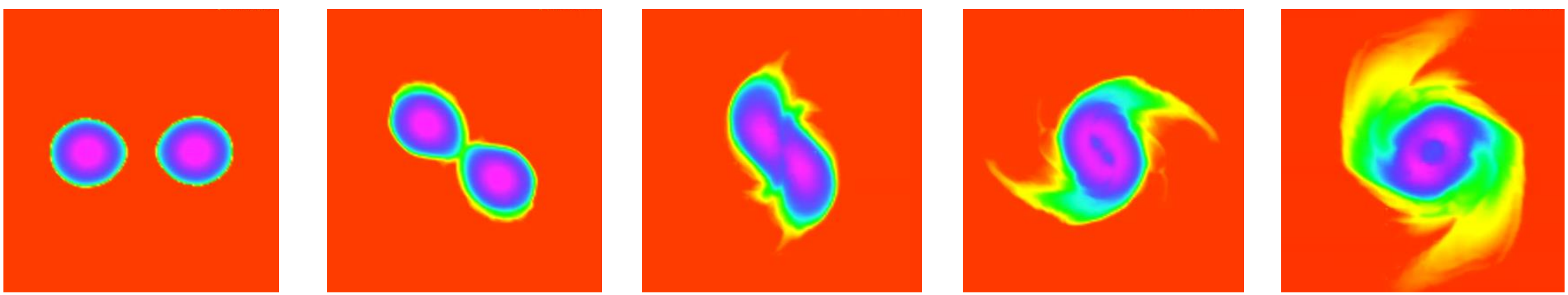
$\longrightarrow$ Changes dynamics of merging neutron stars

$\longrightarrow$ Changes GW signal



[Barausse et al., '12] [Palenzuela, et al., '12]

Gravitational

waves

GW signal

Energy emitted in gravitational + scalar radiation:

$$\frac{dE}{dt} = \frac{dE_{\mathrm{g}}}{dt} + \frac{dE_{\varphi}}{dt}$$

GW signal

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$\longrightarrow$ Characteristic strain:

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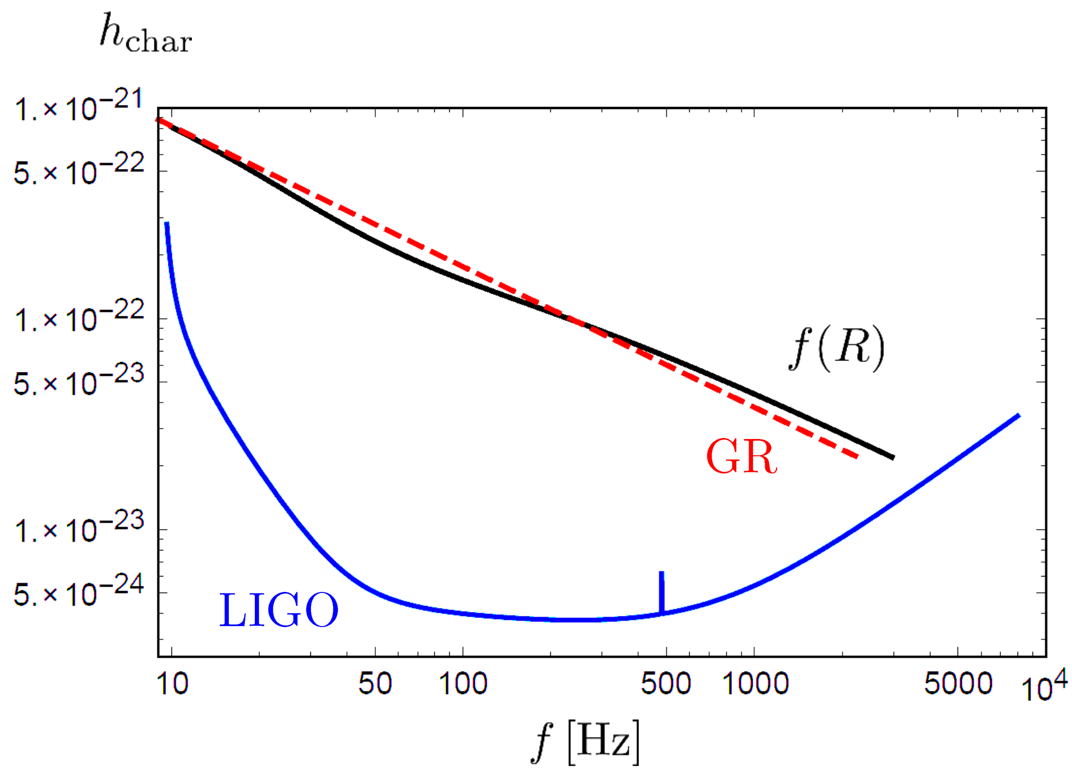

$m_\varphi = 3.98 \cdot 10^{-6}\,\mathrm{m}^{-1}$,

$\alpha \equiv \alpha_1 = \alpha_2 = 0.89,\; M_1 = M_2 \equiv 1.25 M_\odot$

[dcc.ligo.org/LIGO-T0900288/public]

Detectability

Signal-to-noise ratio:

$$\langle \, \mathrm{SNR}^2 \, \rangle = 4 \int_0^\infty \frac{|h_{\mathrm{char}}(f)|^2}{S_n(f)} \, df$$

[Allen et al., '14]

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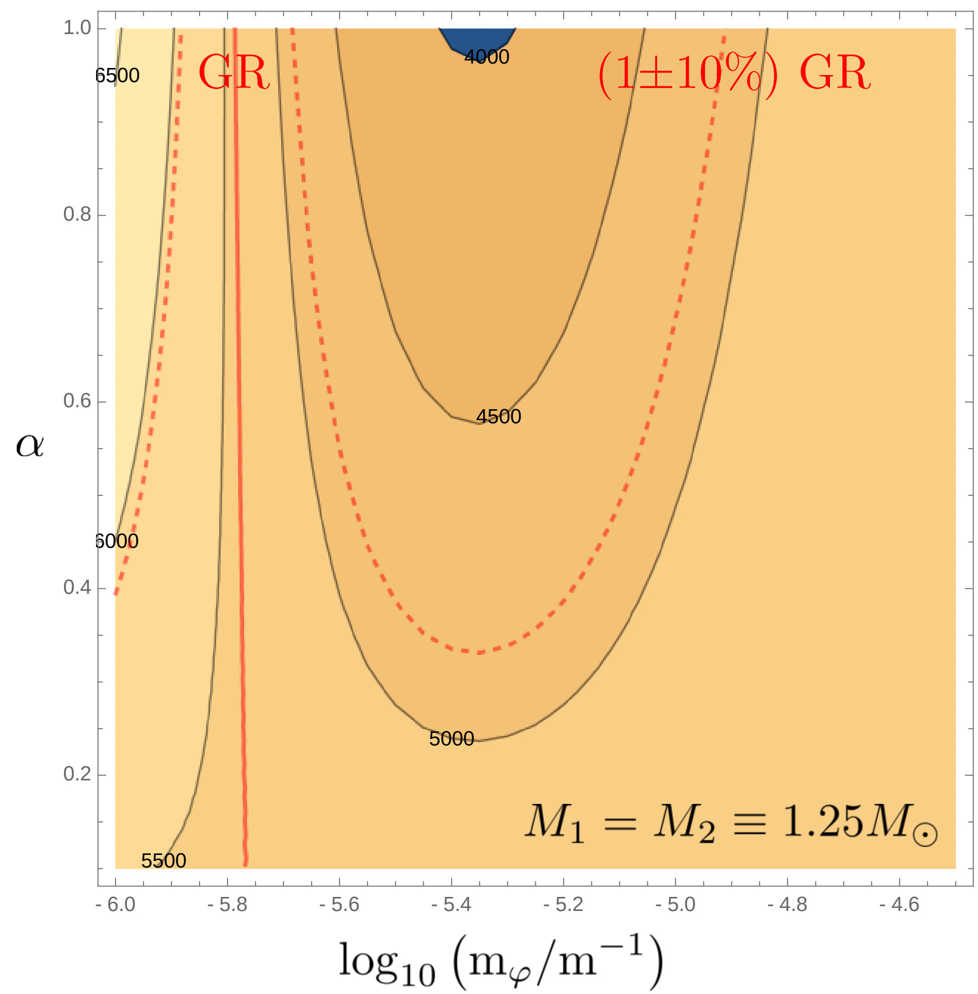
→ Clear deviations from GR in a wide range of parameter space



Conclusions

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Motivation: Test modifications of GR at extreme conditions

$\longrightarrow$ Merging neutron stars

Toy model: Simplest model of $f(R)$ modified gravity

$\longrightarrow$ R^2 gravity = GR + scalar field

Conclusions

Results: Significant deviations of GW signal from GR

$\longrightarrow$ Detectable with LIGO

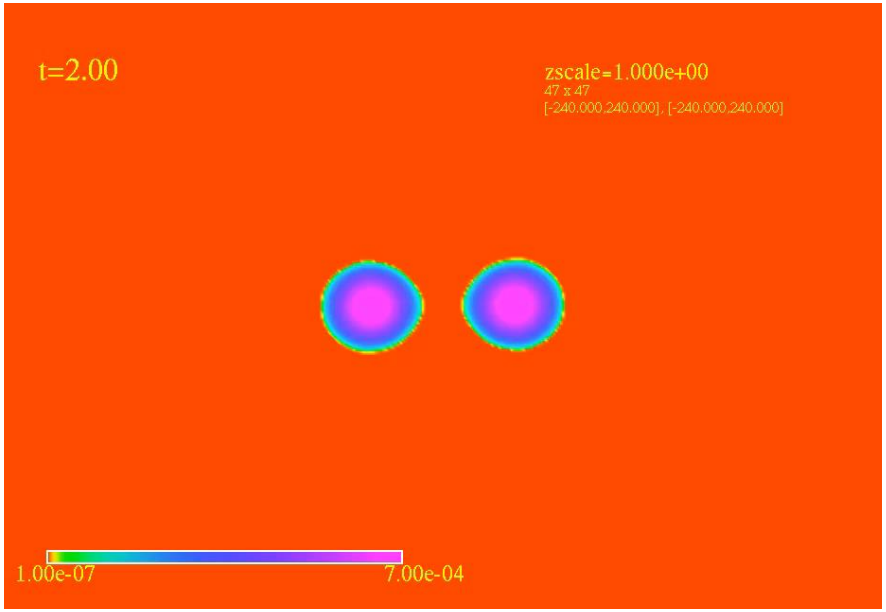
Outlook: New interesting features of scalar field discovered in simulations

$\longrightarrow$ More to explore!

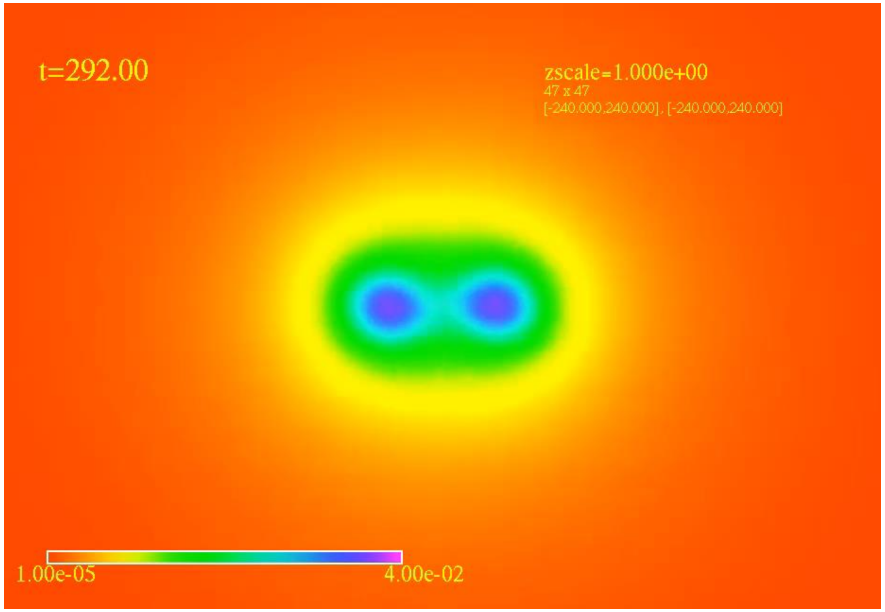
Simulations

Simulations

Neutron star density ρ



Scalar field φ



$$M_1 = M_2 \equiv 1.2 M_\odot,\; a_2 = 1.09 \cdot 10^9\,\mathrm{m}^2$$

[www.had.liu.edu/] [www.lorene.obspm.fr] [Barausse et al., '12] [Palenzuela, et al., '12]

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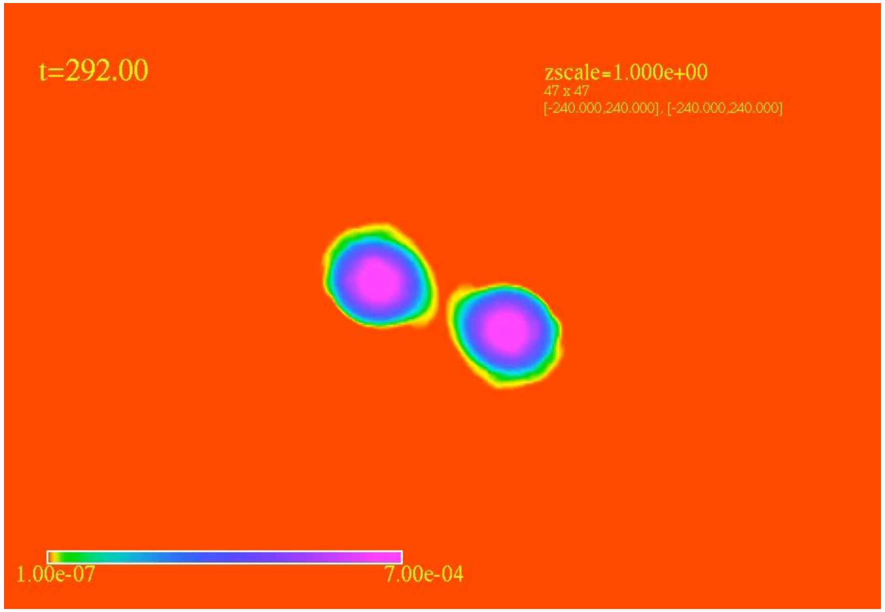

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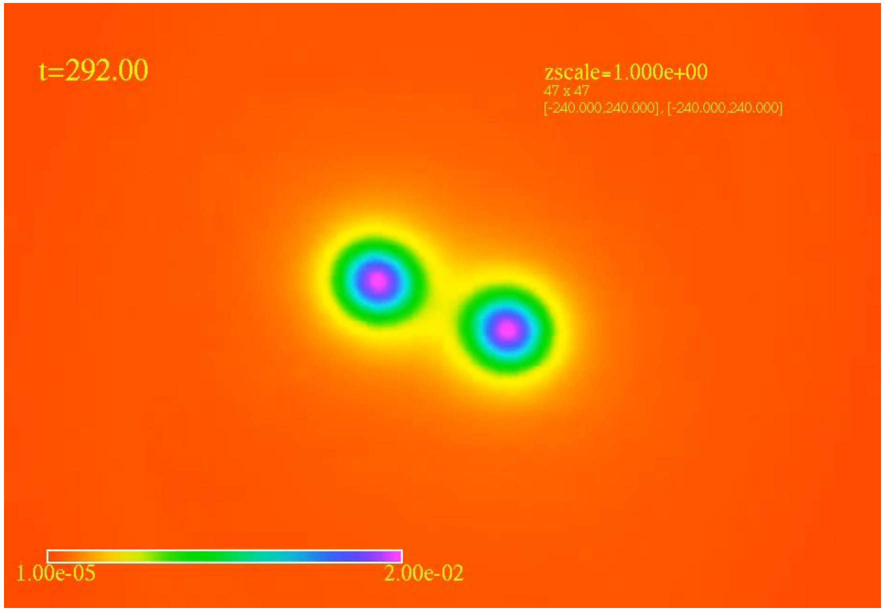


$$M_1 = M_2 \equiv 1.2 M_\odot, \; a_2 = 2.18 \cdot 10^7 \, \mathrm{m}^2$$

[www.had.liu.edu/] [www.lorene.obspm.fr] [Barausse et al., '12] [Palenzuela, et al., '12]

Thank you for your attention!

Backup

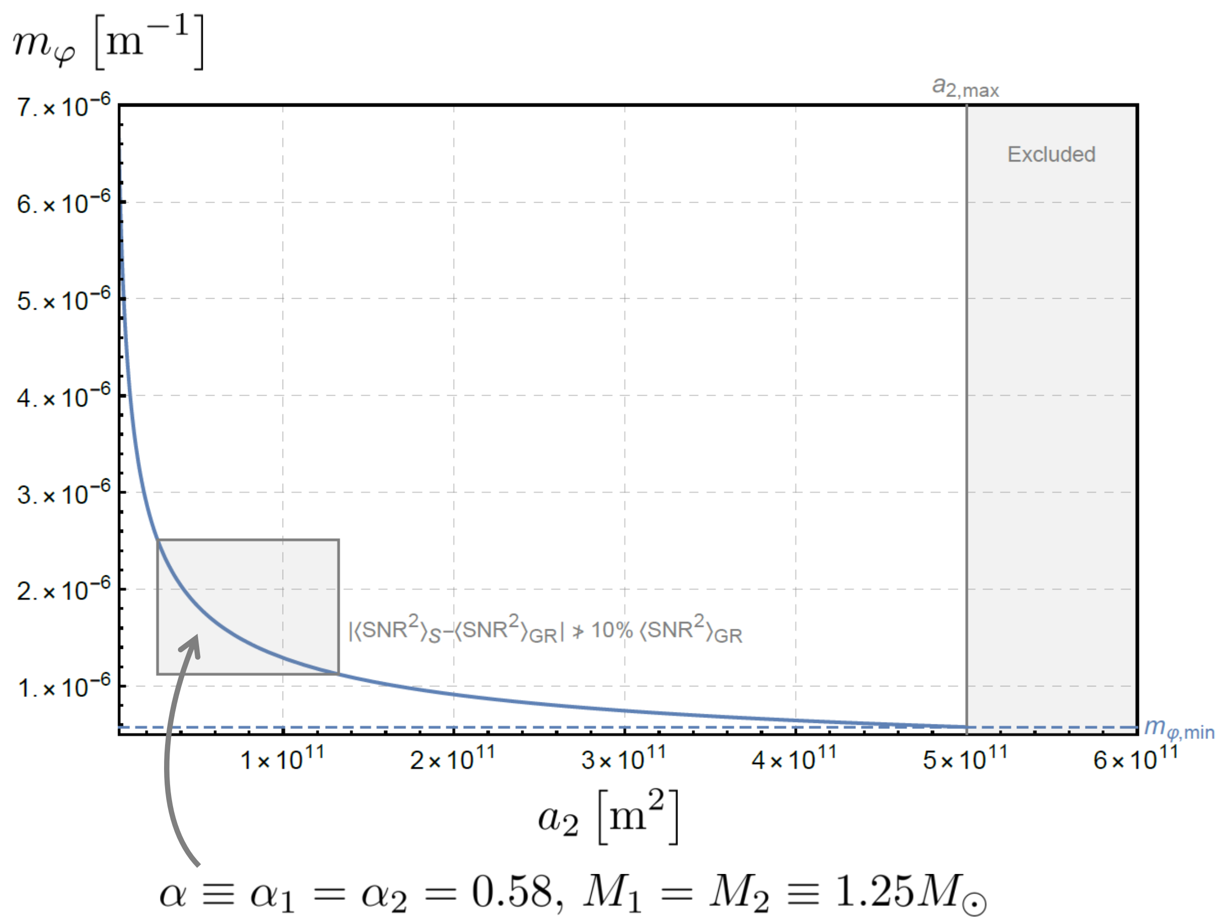
Experimental constraints on a_2

Tightest constraint from solar-system tests:

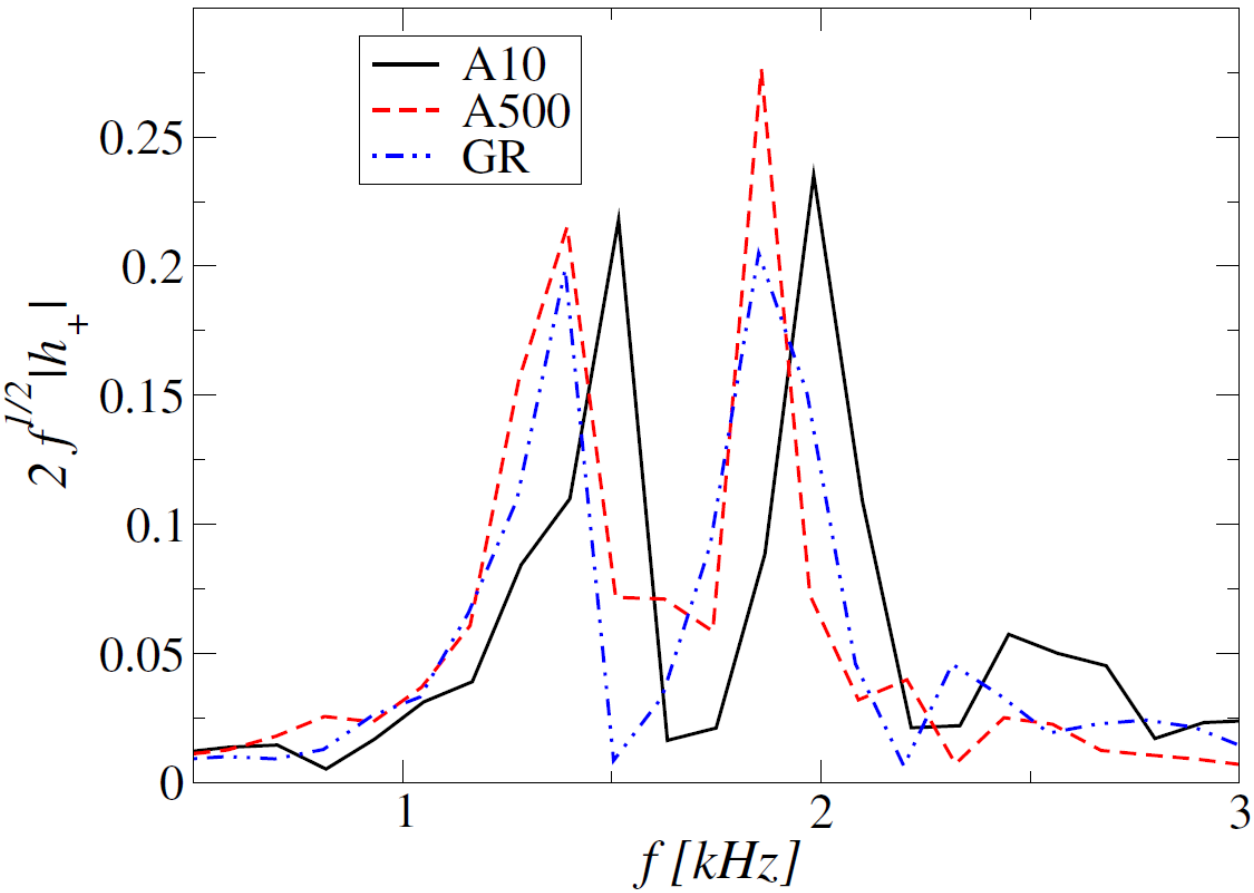
$$a_2 \lesssim 5 \cdot 10^{11}\,\mathrm{m}^2$$

[Naf, Jetzer, '10]

$\longrightarrow$ Can be fulfilled!



Square root of power spectral density for the after-merger state



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