Title: Binary Black Hole Mergers beyond General Relativity - Part 1

Speakers: Maria Okounkova

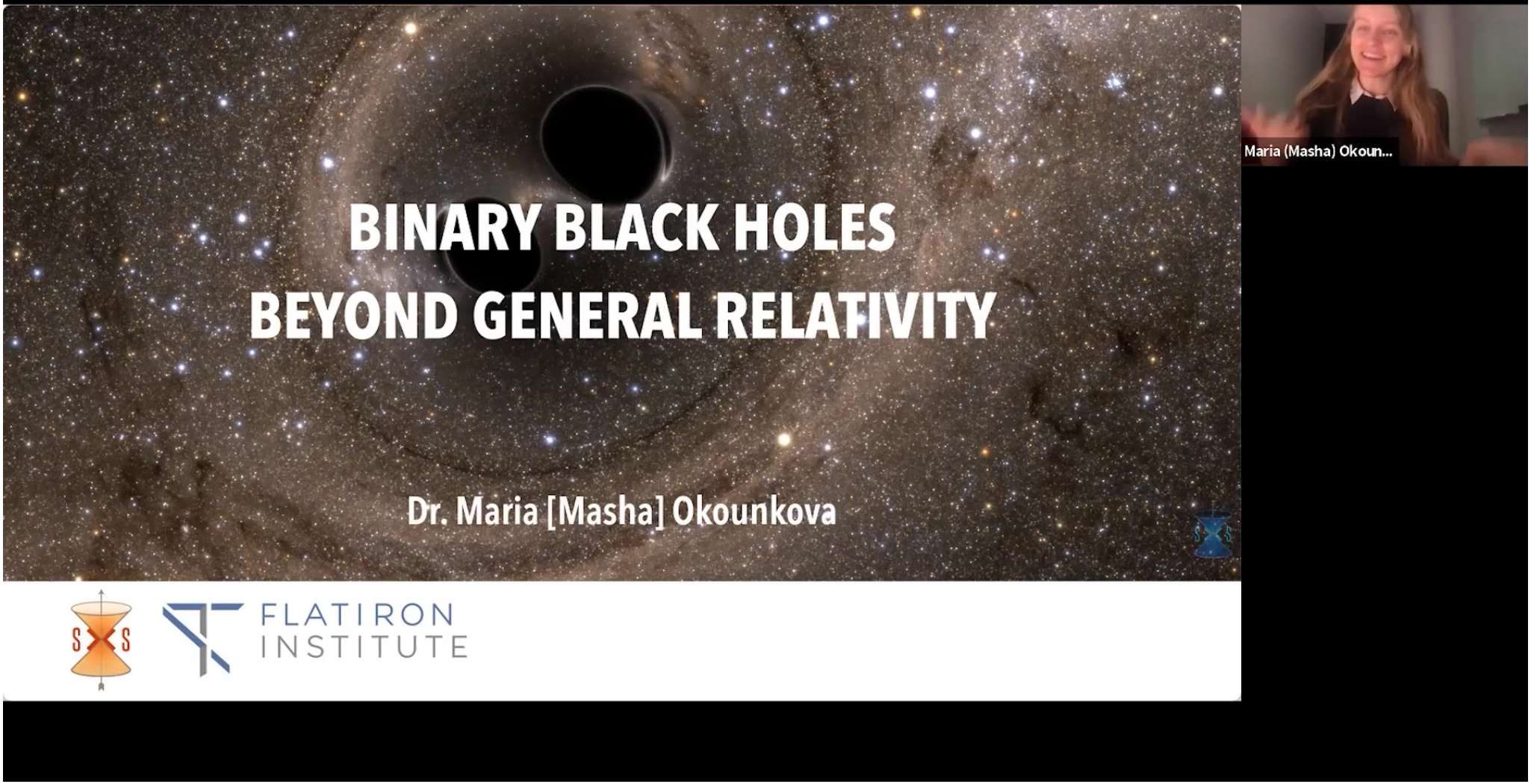
Series: Strong Gravity

Date: September 23, 2021 - 1:00 PM

URL: https://pirsa.org/21090020

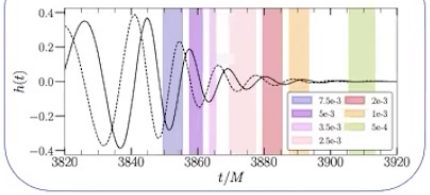
Abstract: At some length scale, Einstein's theory of general relativity (GR) must break down and be reconciled with quantum mechanics in a quantum theory of gravity. Binary black hole mergers probe the strong field, non-linear, highly dynamical regime of gravity, and thus gravitational waves from these systems could contain beyond-GR signatures. While LIGO presently performs model-independent and parametrized tests of GR, in order to perform model-dependent tests, we must have access to numerical relativity binary black hole waveform predictions in beyond-GR theories through full inspiral, merger, and ringdown. In this talk, I will discuss our results in producing full numerical relativity waveforms in beyond-GR theories, including dynamical Chern-Simons gravity and Einstein dilaton Gauss-Bonnet gravity, and performing gravitational wave data analysis on these waveforms.

Zoom Link: https://pitp.zoom.us/j/97878046362?pwd=cmZySjVIdU15VmxWM1J5bnBpQkpvQT09

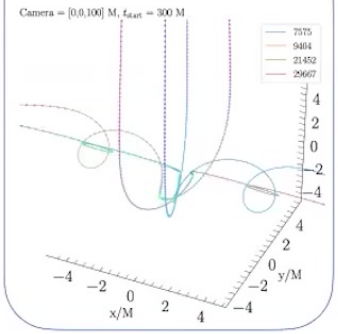

BINARY BLACK HOLES
BEYOND GENERAL RELATIVITY
Dr. Maria [Masha] Okounkova
FLATIRON
INSTITUTE
Maria (Masha) Okoun...

My research [numerical relativity]

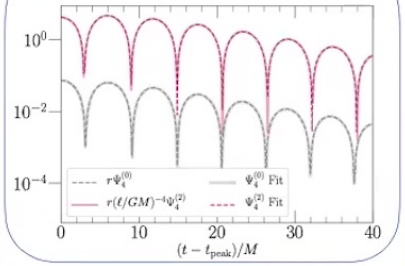
The onset of BBH ringdown



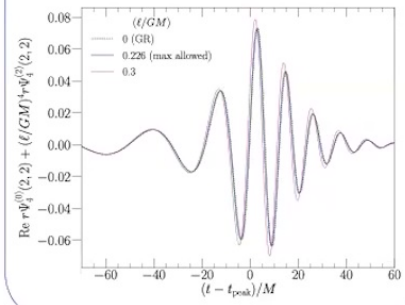
Tracing BBH mergers



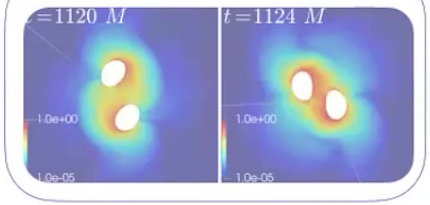
Black hole quasi-normal modes



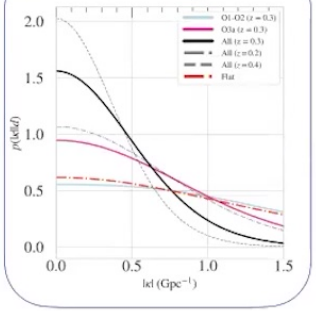
BBH mergers beyond general relativity



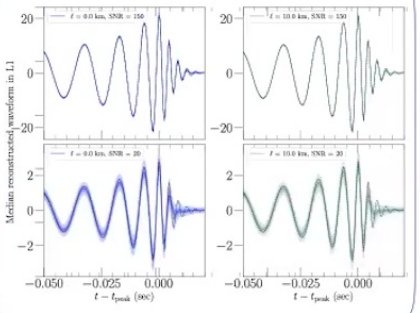
BBH spacetime non-linearities



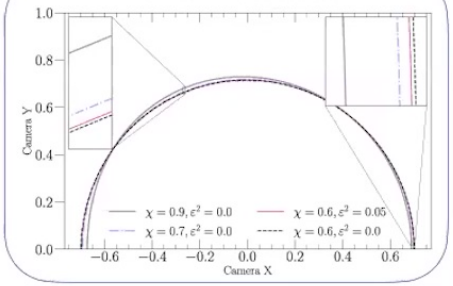
GW Birefringence



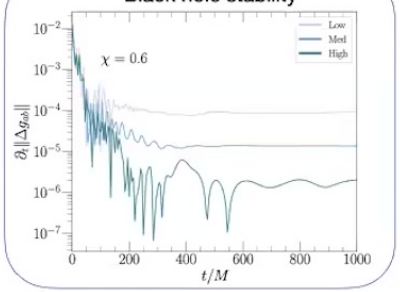
Testing GR with gravitational waves



Black hole shadows



Black hole stability



My research [numerical relativity]

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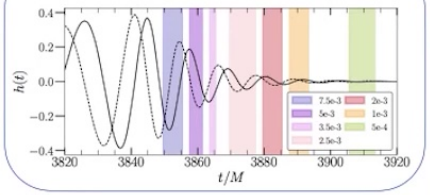

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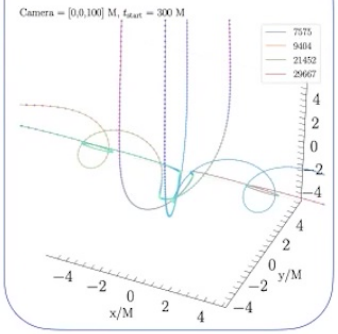

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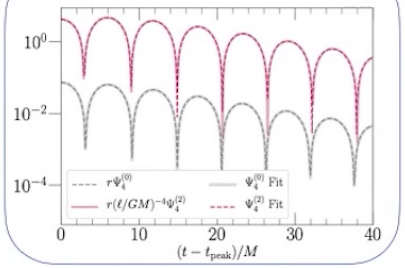

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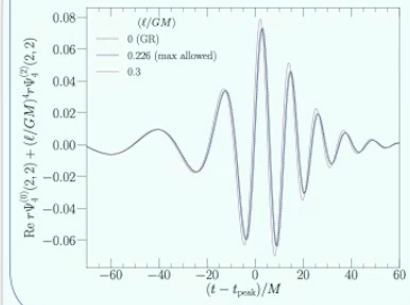

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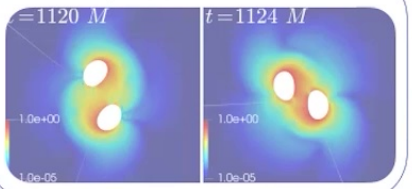

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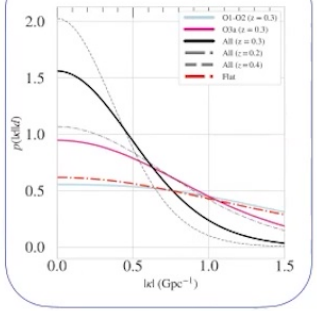

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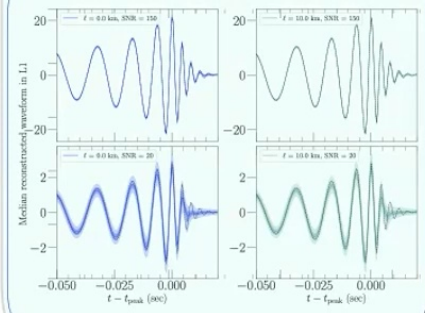

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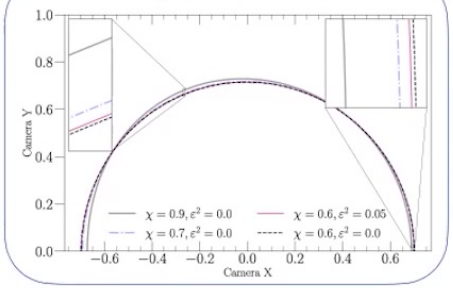

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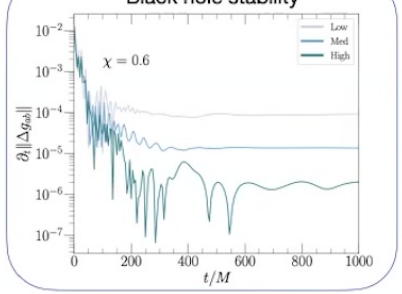
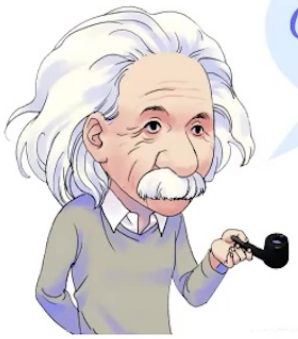




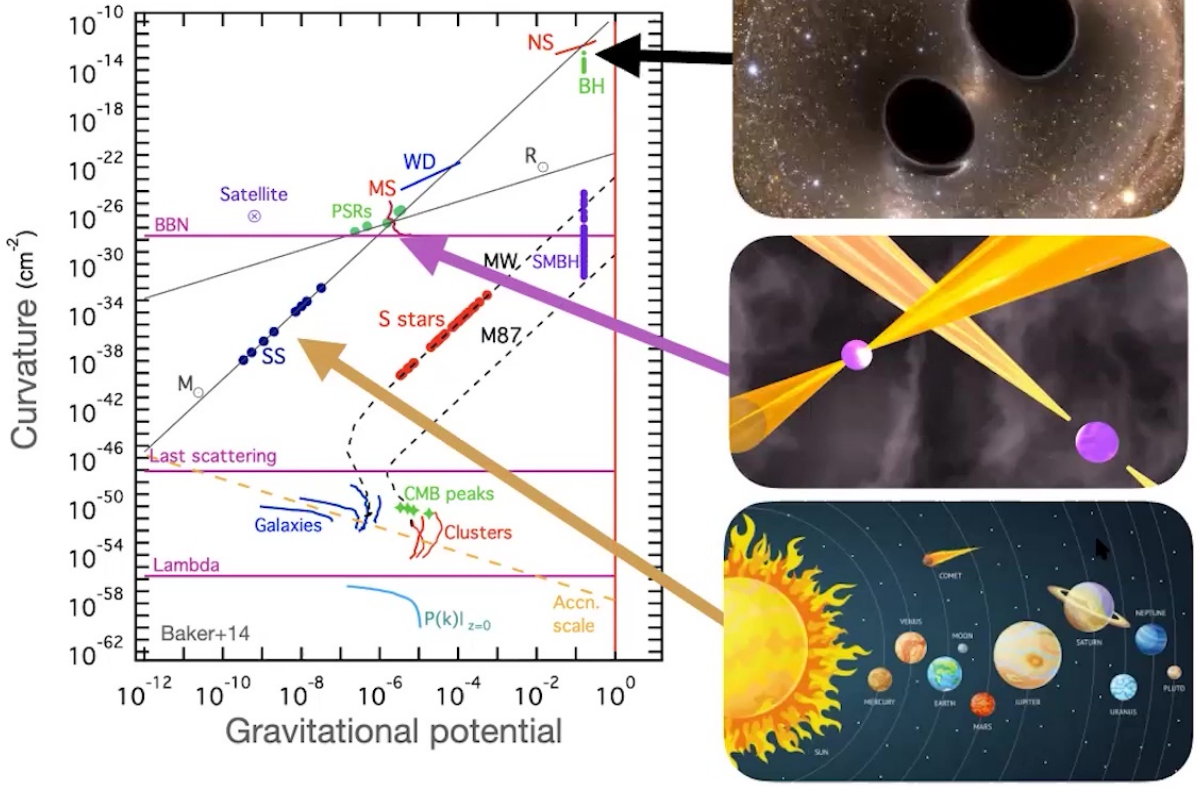
$$G_{ab} = 8\pi T_{ab}$$

Why do you spend so much time testing GR?
We *know* that the theory is right.

Nature isn't classical

Can we observe gravity beyond GR?

Looking for extreme gravity



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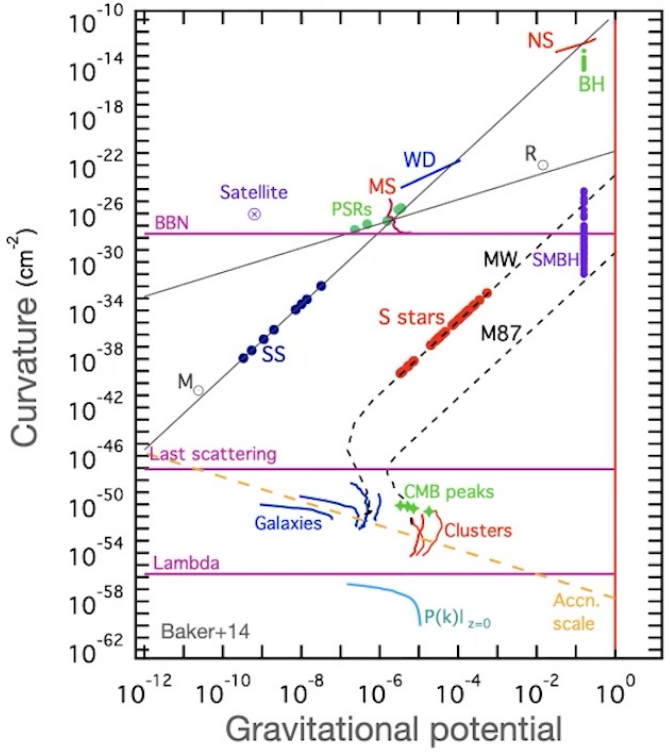
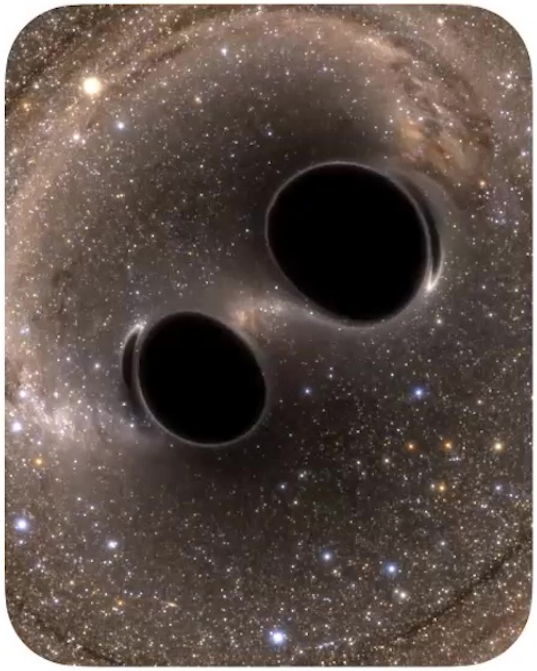
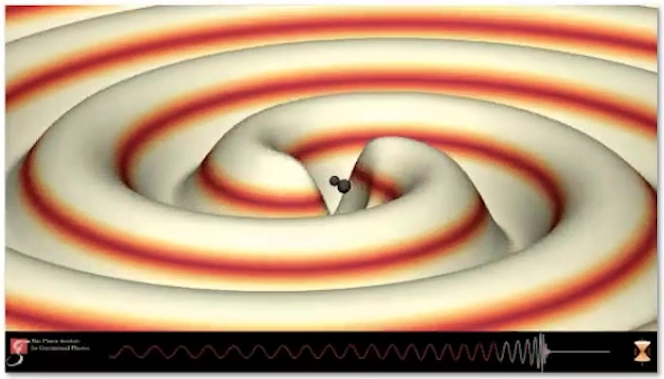


Our best laboratory

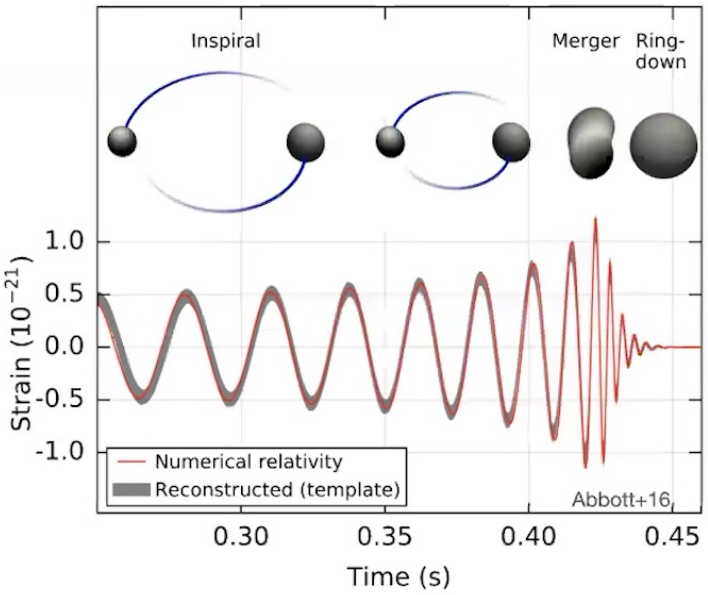


Binary black hole mergers:



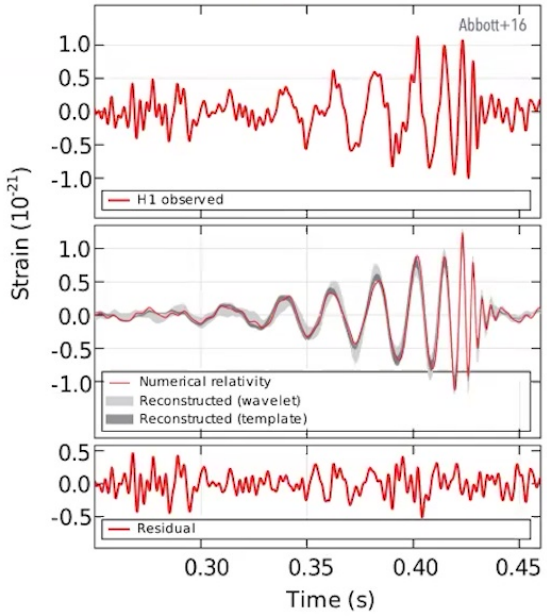
Probe the non-linear,
highly dynamical,
strong-field regime of gravity

Gravitational waves:



Looking for beyond-GR physics with GWs

Null tests



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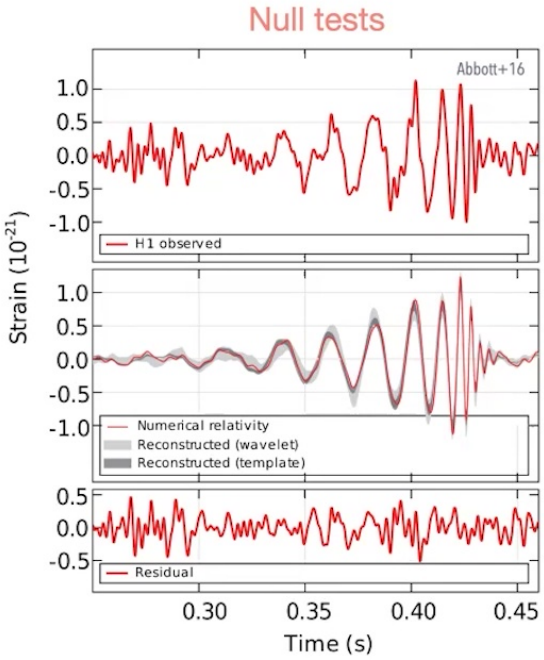

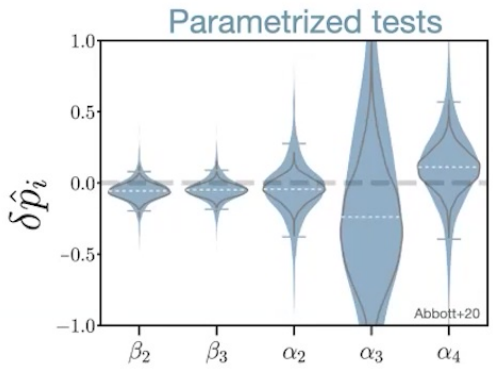

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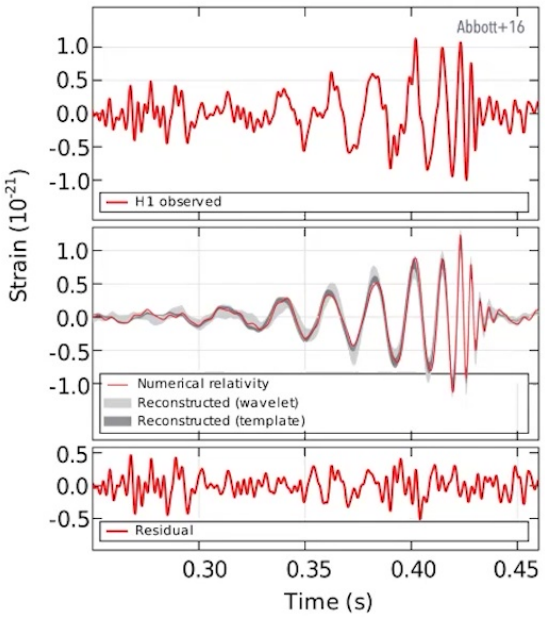
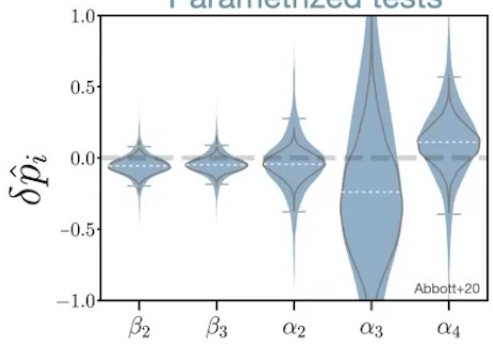
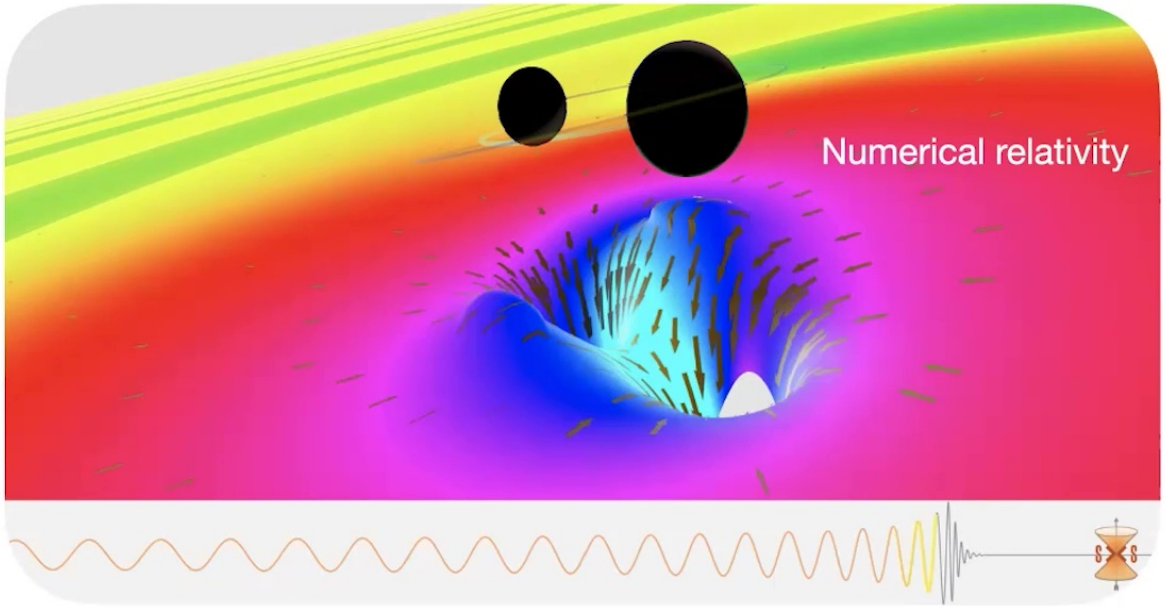


Parametrized tests



Missing model-dependent tests

Missing beyond-GR gravitational waveforms → Let's make them!



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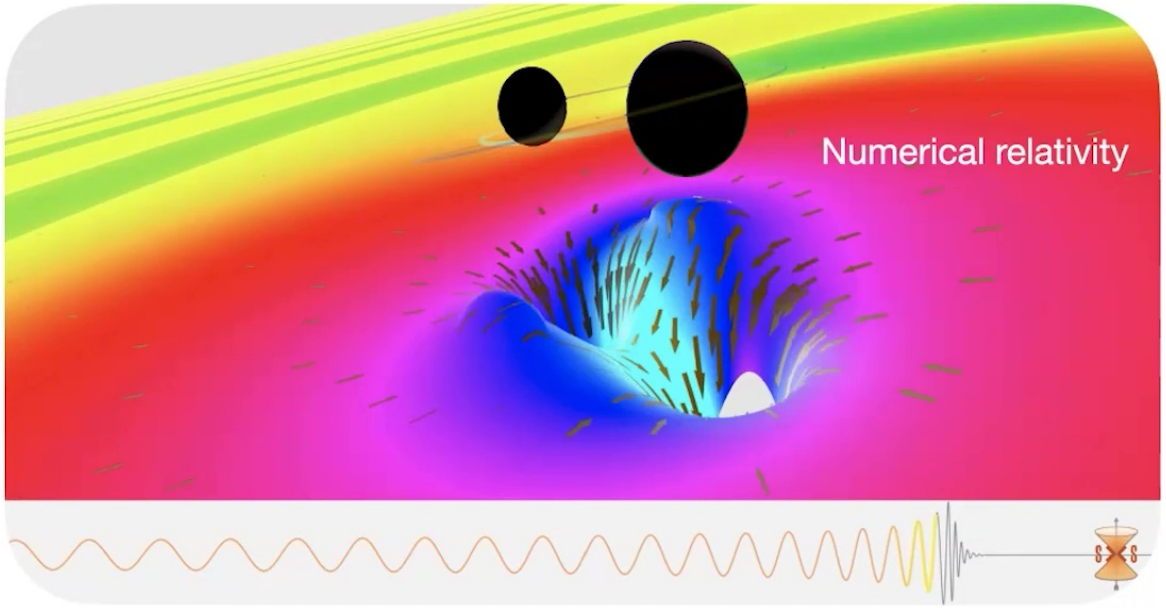
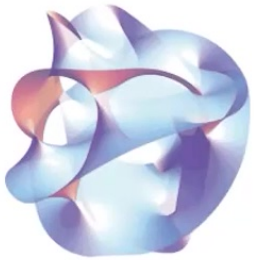
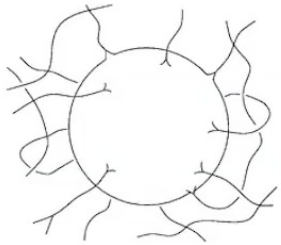


Numerical relativity beyond general relativity

Choosing beyond-GR theories



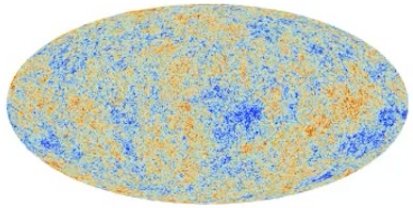


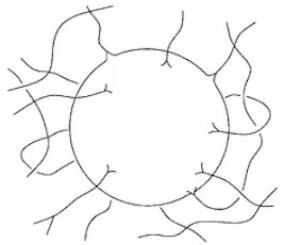
Beyond-GR effective field theories

$$\int d^4x\sqrt{-g}\,\left(R+\varepsilon^2\mathcal{R}^2+\varepsilon^4\mathcal{R}^3+\ldots\right)$$

Dynamical Chern-Simons gravity

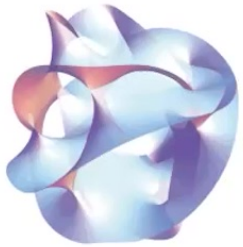
$$S = \int d^4x\sqrt{-g}\left(R - \ell^2\vartheta\ ({}^*R_{abcd}R^{abcd}) - \frac{1}{2}\partial_a\vartheta\partial^a\vartheta\right)$$

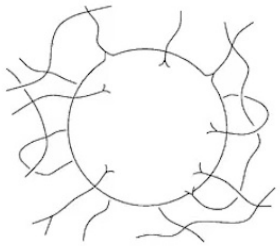




Einstein dilaton Gauss-Bonnet gravity

$$S = \int d^4x\sqrt{-g}\left(R + \alpha e^{\vartheta}(R_{abcd}R^{abcd} - 4R_{ab}R^{ab} + R^2) - \frac{1}{2}\partial_a\vartheta\partial^a\vartheta\right)$$

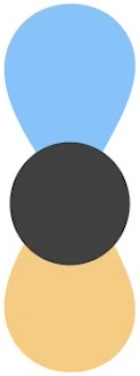




Dynamical Chern-Simons gravity

$$\ell^2 \vartheta \, ({}^*R_{abcd}R^{abcd})$$

Schwarzschild ✓ Kerr ✘



ϑ Dipole

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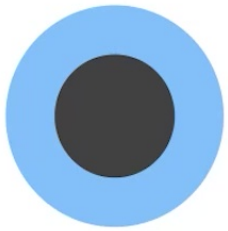

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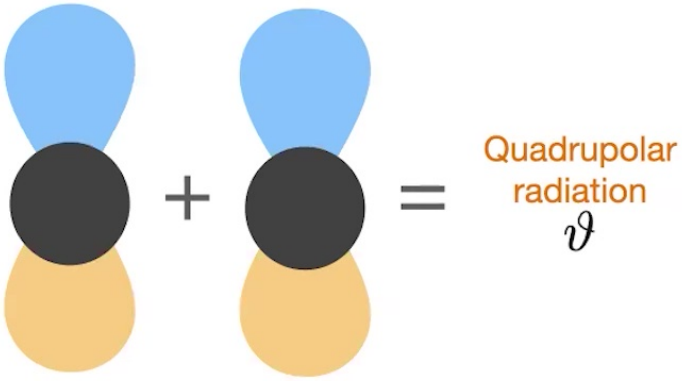

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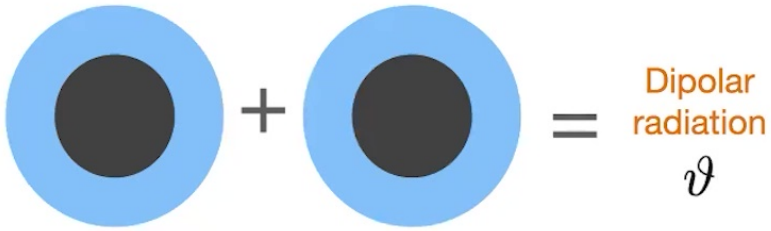

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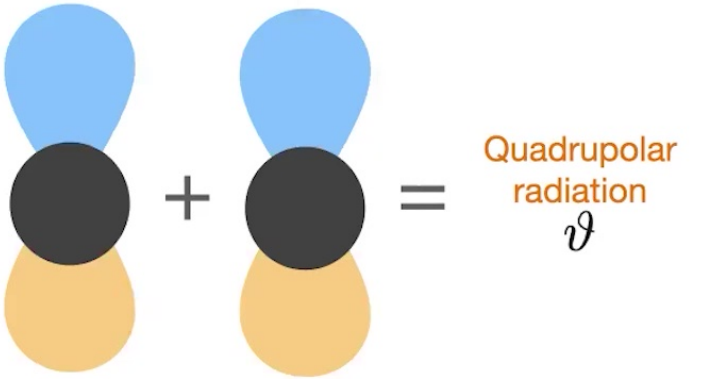

Quadrupolar radiation ϑ

ϑ Dipole

+2 PN order correction

Einstein dilaton Gauss-Bonnet gravity

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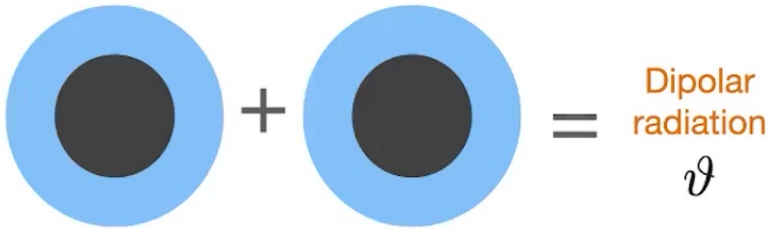
Schwarzschild ✘ Kerr ✘



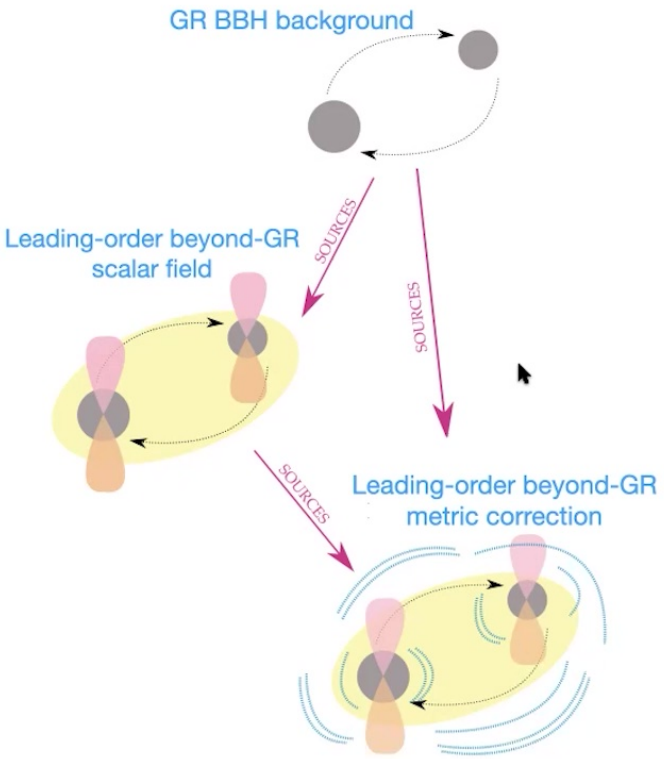
Dipolar radiation ϑ

ϑ Monopole

-1 PN order correction

What we've done: The first BBH merger waveforms in higher-curvature theories of gravity

Our method: order reduction-scheme



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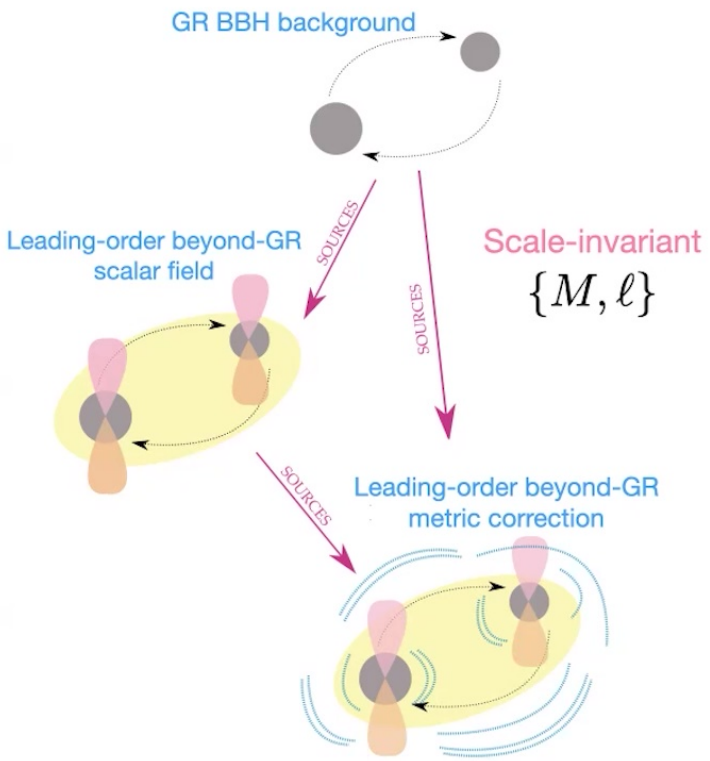

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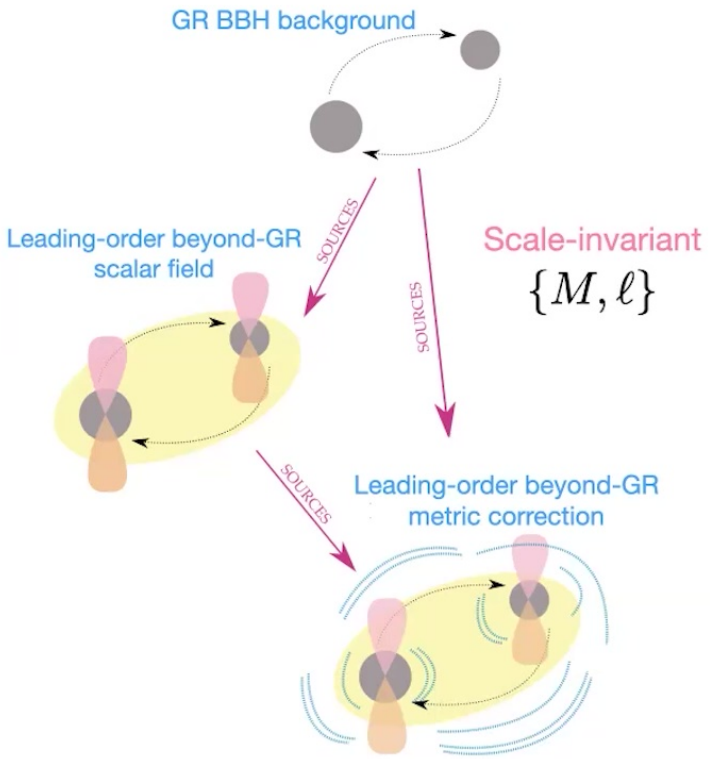
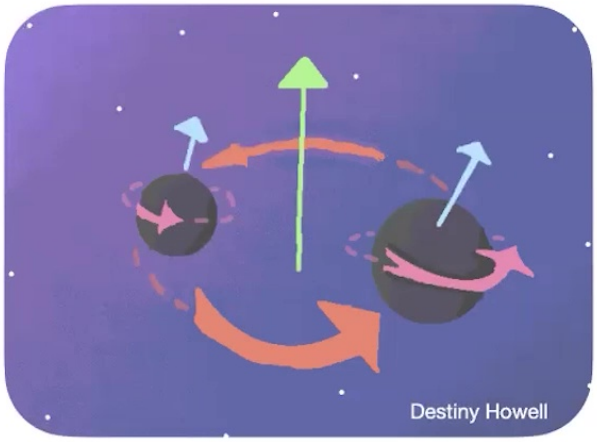


1. Okounkova et al. Phys. Rev. D 96:044020: dCS scalar field evolution
2. Okounkova et al. Class. Quant. Grav: dCS Initial data and black hole shadows
3. Okounkova et al. Phys. Rev. D 99:044019: beyond-GR evolution methods, stability of rotating black holes in dCS
4. Okounkova Phys. Rev. D 100:124054: Stability of rotating black holes in EdGB
5. Okounkova et al. Phys. Rev. D 100:104026: Binary black hole collisions in dCS
6. Okounkova et al. Phys. Rev. D 101:104016: GW150914 in dCS
7. Okounkova Phys. Rev. D 102:084046: GW150914 in EdGB

1. Waveforms
2. What we've learned
3. What we're going to do in the coming decades

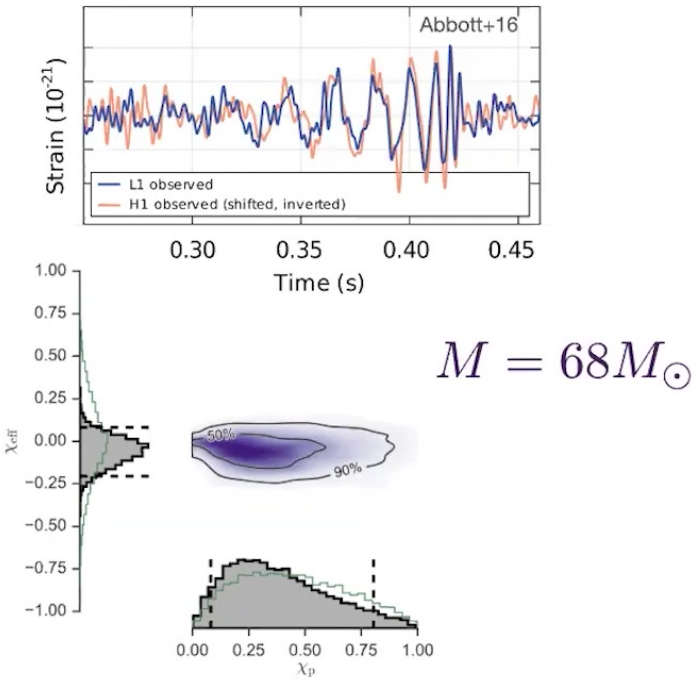
Choosing BBH parameters to simulate



Scale-invariant

$\{M, \ell\}$

GW150914 parameters



$M = 68M_{\odot}$

The first BBH merger waveforms in higher-curvature theories of gravity