Fundamental Physics panel discussion

@ Gravity Shape Pisa
University of Pisa, 23 October 2024

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GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

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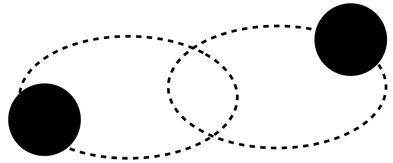
MARIE CURIE ACTIONS

Waveform modelling in vacuum GR

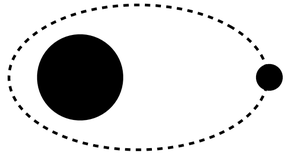
pN/EOB



- Inspiral: high-pN/EOB expansion
- Ringdown: superposition of (ℓ, m, n) exponentially damped sinusoids
- IMR hybrid models with NR

- Modelling of quadratic quasinormal modes (QNMs) and nonlinearities
- Ringdown amplitudes for spin-precessing binaries
- Limited NR modelling

Self-Force



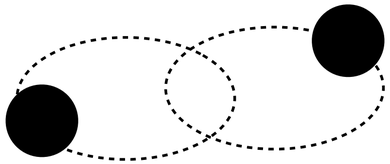
- 1PA calculations advancing for generic orbits
- 1PA energy flux & waveforms for non-spinning binaries in quasi-circular orbits

- 1PA waveforms for spinning and generic orbits
- Resonances

- Spin of the secondary?
- Quadrupole of the secondary?

Waveform modelling beyond vacuum GR

pN/EOB



- 3pN inspiral for scalar-tensor and Einstein-scalar-Gauss-Bonnet (sGB) gravity
- 1pN correction for dynamical friction

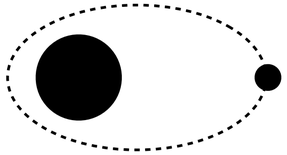
- Love numbers and quadrupole moments for black holes in sGB and dynamical Chern-Simons (dCS), and horizonless compact objects (boson stars, gravastars)

- Fast rotating QNM spectrum for sGB and Effective Field Theories (dCS hopefully soon)
- Slowly rotating solutions for restricted set of theories (GB family mostly)
- QNM spectrum for specific models of horizonless compact objects

- IMR waveforms beyond GR in ESGB gravity
- NR waveforms of horizonless compact object mergers (boson stars)
- Limited NR modelling beyond GR
- Missing link between NR and analytical templates

Waveform modelling beyond vacuum GR

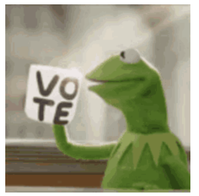
Self-Force



- 0PA correction for scalar fields & EFT theories
- flux calculations for scalar clouds and horizonless compact objects

- no calculations beyond 0PA (do we need them?)
- no ab-initio finite-size effect calculations, deviations on the multipolar structure

Waveform modelling beyond vacuum GR



Which astrophysical sources are more promising to test general relativity and look for possible deviations from it?

Massive black hole binaries

Extreme mass ratio inspirals

Other

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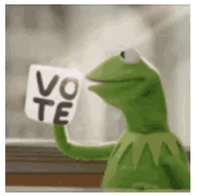
Waveform modelling beyond vacuum GR



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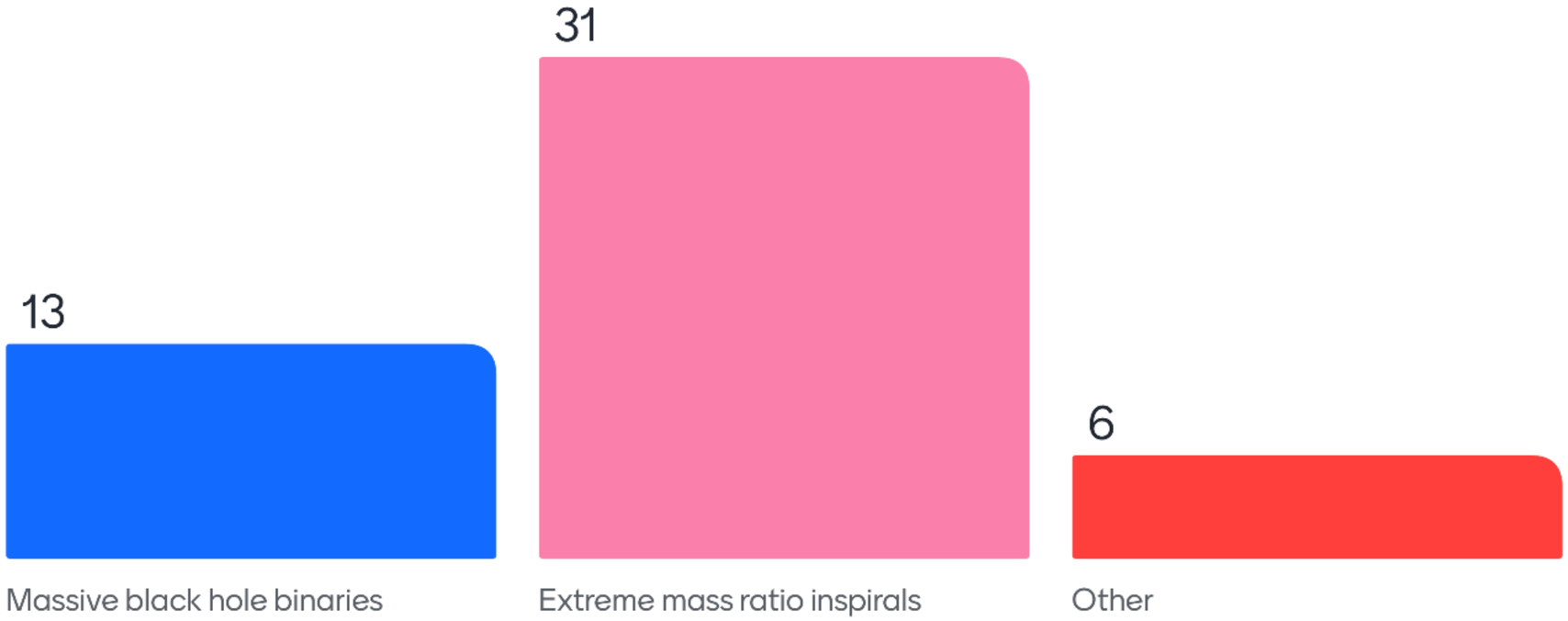


Testing approach

How do we test deviations from vacuum GR?

Agnostic

- flexible & immediately applicable
- applicable to the coalescence phases
- useful for non-vacuum/beyond-GR/ECOs
- mostly pN based for the inspiral and QNM-based for the ringdown

- many parameters to add
- degeneracies for non-vacuum/beyond-GR/ECOs
- physical mapping requires specific models (aka false d.o.f. and *what if* we detect something)
- no parametrization for SF (but1 case)

Model specific

- superior in constraining power
- IMR waveforms
- inclusion of non-perturbative effects

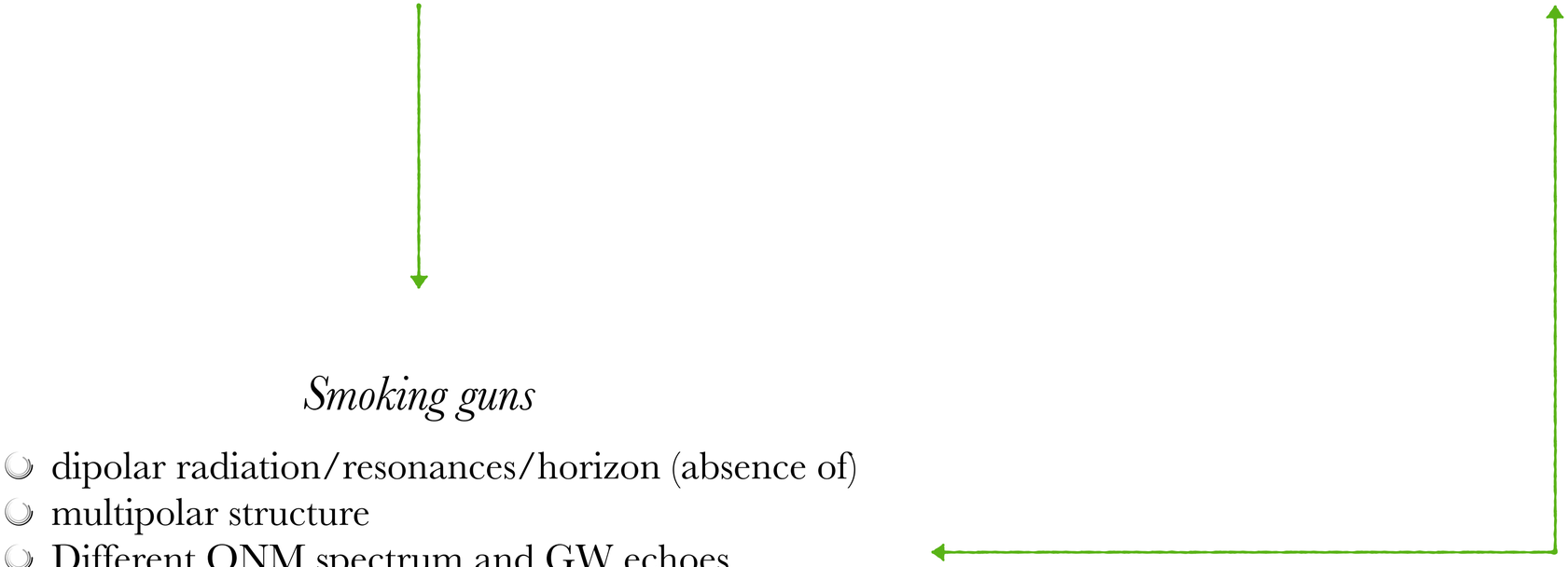
- Numerically expensive
- Case-by-case analytical models

Testing approach

How do we test deviations from vacuum GR?

Agnostic

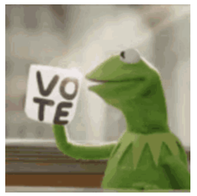
Model specific



Smoking guns

- dipolar radiation/resonances/horizon (absence of)
- multipolar structure
- Different QNM spectrum and GW echoes
- indirect constraints (super radiance)

Testing approach



How do we test deviations from vacuum GR?

Agnostic *Model specific*

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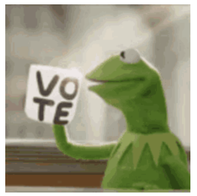
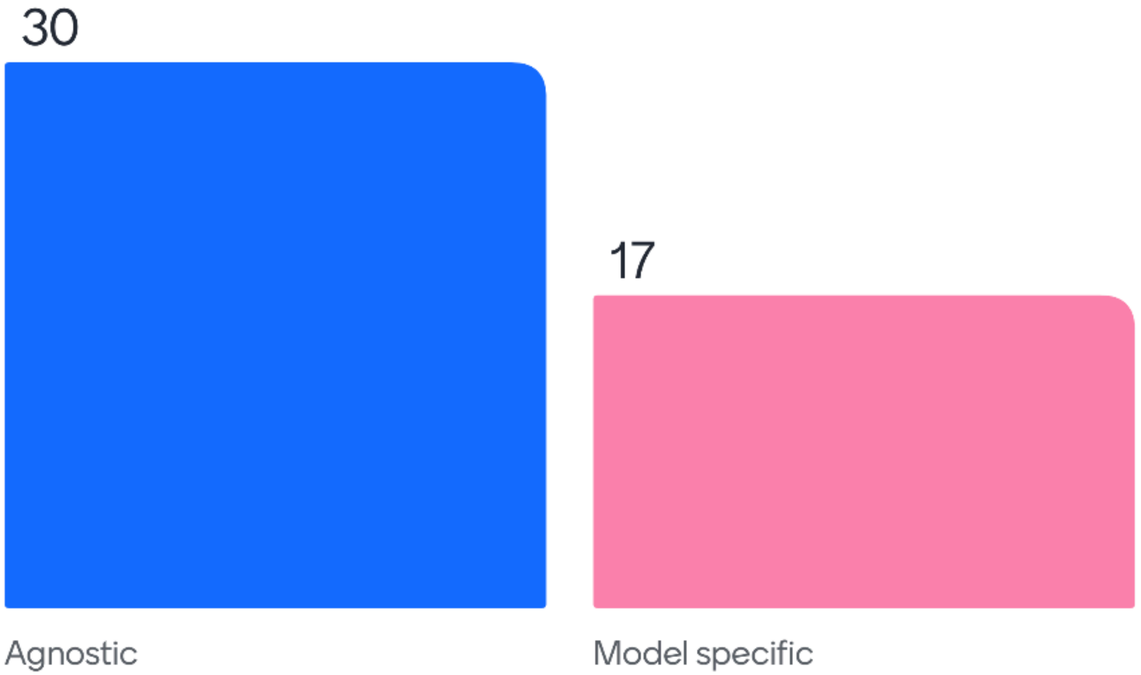
Given current and future constraints <u>before</u> 3G & LISA, how do we move?

- running out of theories and models

Testing approach

How do we test deviations from vacuum GR?





Systematics

How do we address false violations if we detect something?

possible cause of systematics

Due to Noise Artifacts?	Caused by Waveform Systematics?	Due to Astrophysical Causes?
Non-Stationarity	Missing Physics Eccentricity Tides, Viscosity Kicks Ringdown Modes	Gravitational Lensing
Non-Gaussianity, Glitches		Environments
Overlapping Signals		Mistaken Source Class
Data Gaps, Detector Calibration	Inaccurate Modelling	Astrophysical Population

A. Gupta +, 2405.02197

Which sources of systematics are more important and should be tackled in priority order?

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Systematics

Which sources of systematics are more important and should be tackled in priority order?

environmental effects
tgr-specific sel effects
environment
inaccurate modelling
sources
missing physics
waveforms
inaccurate waveforms
overlapping signals
noise non-gassianity
non-stationarity
non-statuonary noise
waveform systematics
frequencies
global fit
environments
coverage of model space
glitches
astrophysical populations
eccentricity
mistaken source
calibration
astrophysics
precession
populations
noise
detector calibration
noise non-stationarity
non stationarity
decaffinated beverages
waveforms eccentricity