Working Group 2: Introduction and Overview

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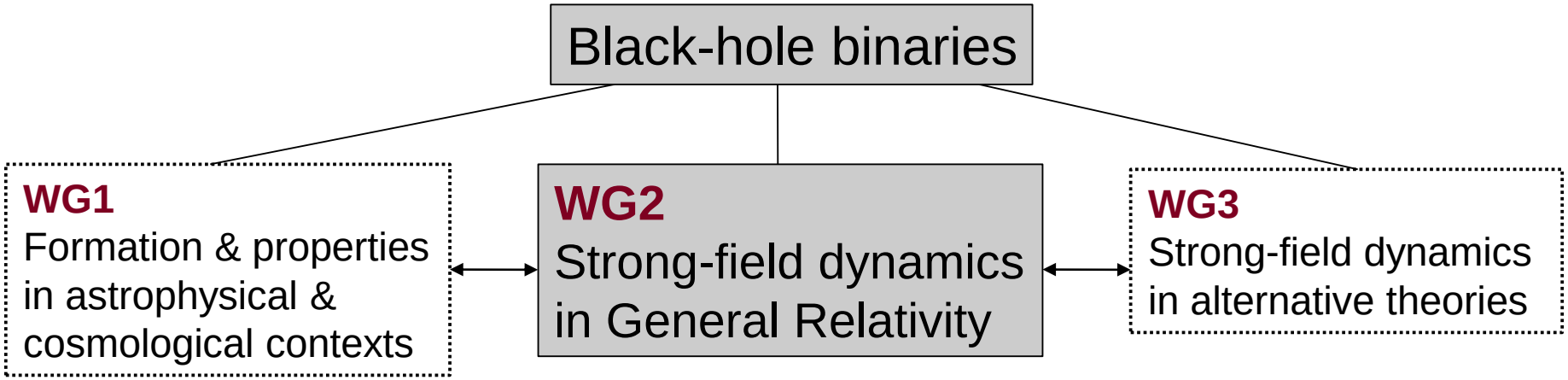
Outline

- Scope and structure of WG2
- Role & status of signal models in GW astronomy
- Review of modelling challenge
- Review of main approaches

Remit/scope of Working Group 2



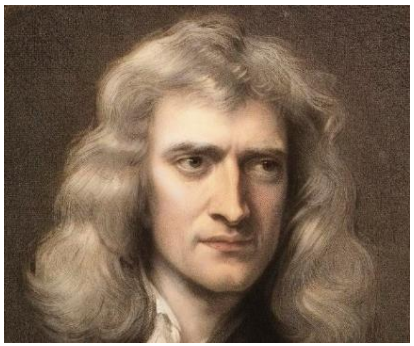
Remit/scope of Working Group 2

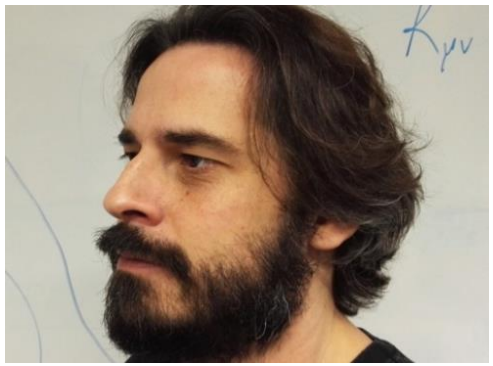
Black-hole binaries

WG1
Formation & properties in astrophysical & cosmological contexts

WG2
Strong-field dynamics in General Relativity

WG3
Strong-field dynamics in alternative theories





Topical subgroups

- Perturbation methods [Barry Wardell]
- Post-Newtonian & post-Minkowskian methods [Alexandre Le Tiec]
- Numerical Relativity (astro) [Patricia Schmidt]
- Numerical Relativity (HEP) [Ulrich Sperhake]
- Effective and phenomenological methods [Tanja Hinderer]
- Source models & the data-analysis challenge [Jonathan Gair]

- **White paper in preparation reviews progress & prospects**

Role & status of signal models in GW astronomy

Consider :

1. GW150914 was first identified using a template-free search algorithm. But subsequent BBH events, which were less bright, would have likely been altogether missed without signal models.

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Source models are important for identification and interpretation of signals
(not only, but especially, for binary sources)

Role & status of signal models in GW astronomy

Consider :

2. For BBH signals detected so far, systematic error from deficiencies in current signal models is only marginally smaller than error from instrumental noise statistics. It would dominate total error budget for some potential sources (and already does, for binary NS GW170817).

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It is important to improve fidelity and accuracy of existing models

Role & status of signal models in GW astronomy

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3. Even with a perfectly accurate model at hand, analysis of GW170817 would not have been possible within the timescale of weeks in which it was carried out, without a suitable reduced-order representation of the model, necessary to make such analysis computationally manageable.

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It is important to devise computationally efficient representation of models for data-analysis purposes

Role & status of signal models in GW astronomy

Consider :

4. Identification and parameter extraction of EMRIs and IMRIs in the LISA data highly reliant on phase-coherent matched filtering against accurate waveform templates. No reliable waveform models exist for EMRIs and IMRIs as of yet.

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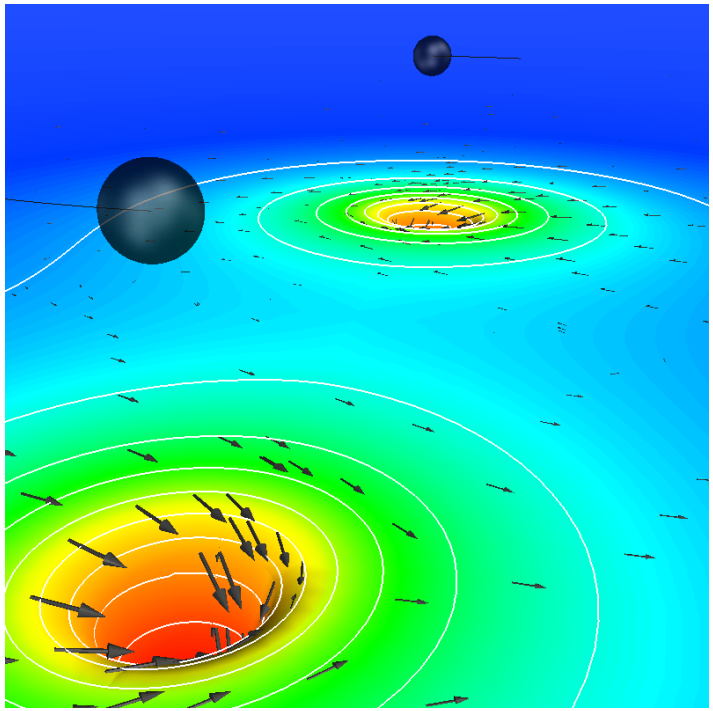
It is important to develop those!

The binary black hole problem in GR

Solve

$$G_{\mu\nu}(g_{\alpha\beta}) = 0$$

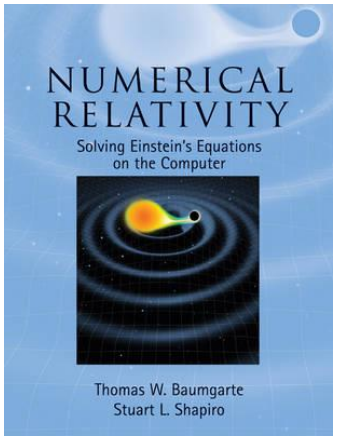
for the metric $g_{\alpha\beta}$ of spacetime,
with suitable initial & boundary conditions.

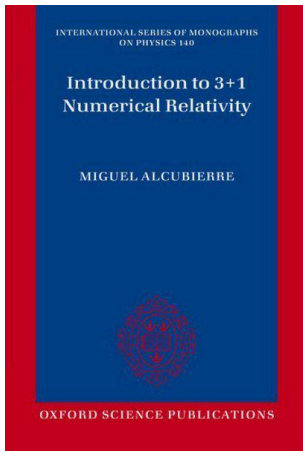


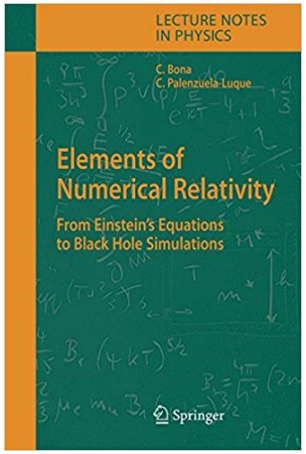
[H. Pfeiffer]

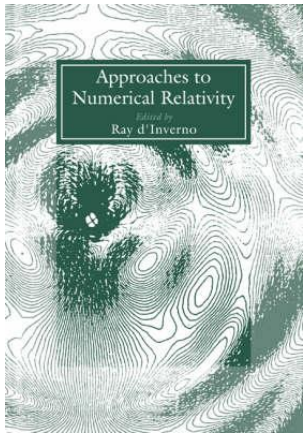
Why is it so hard?

- Choice of gauge & evolution variables; stability
- Singularities
- Where are the (apparent) horizons?
- Initial conditions
- Extraction of observable waveforms & BH properties
- Multiple scales
- ...
- Computational cost

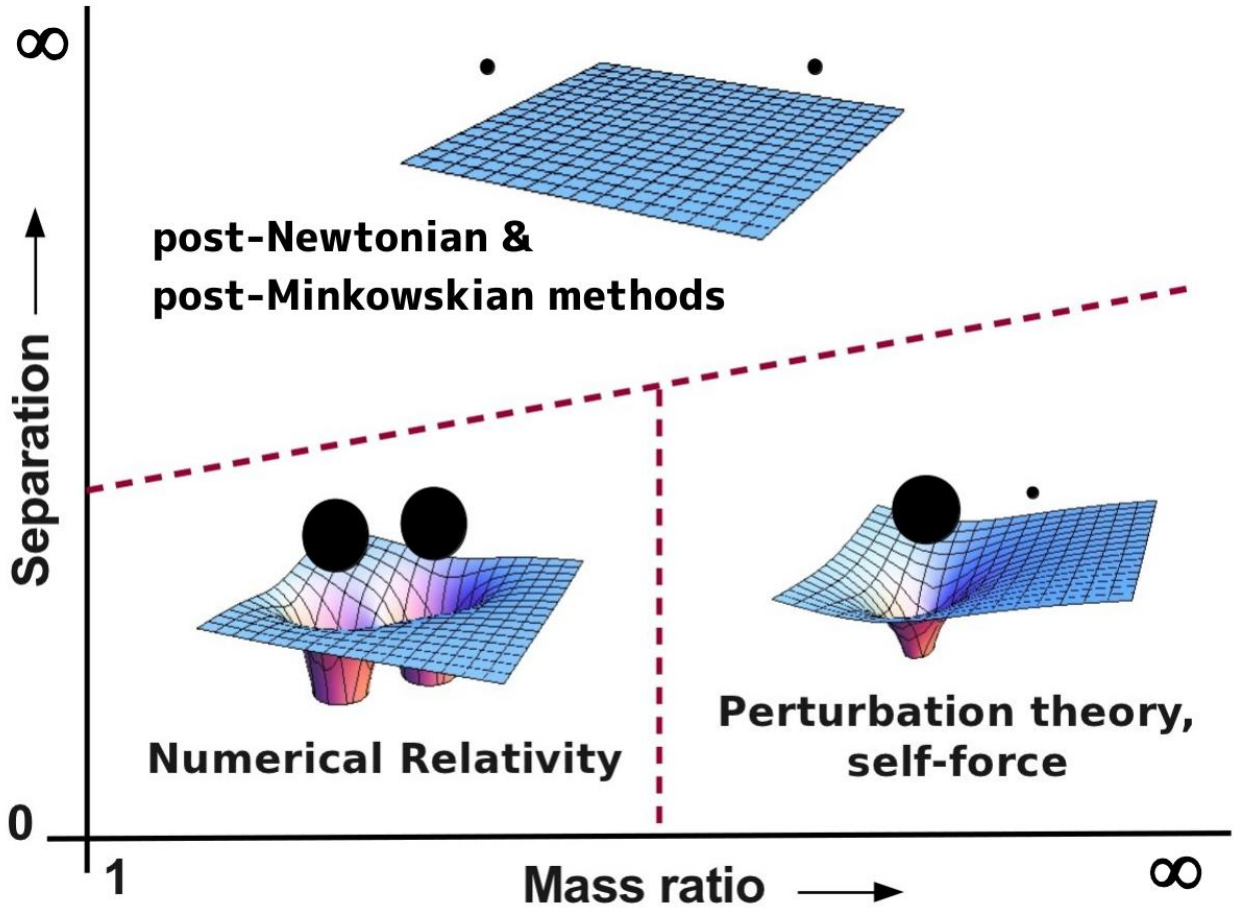




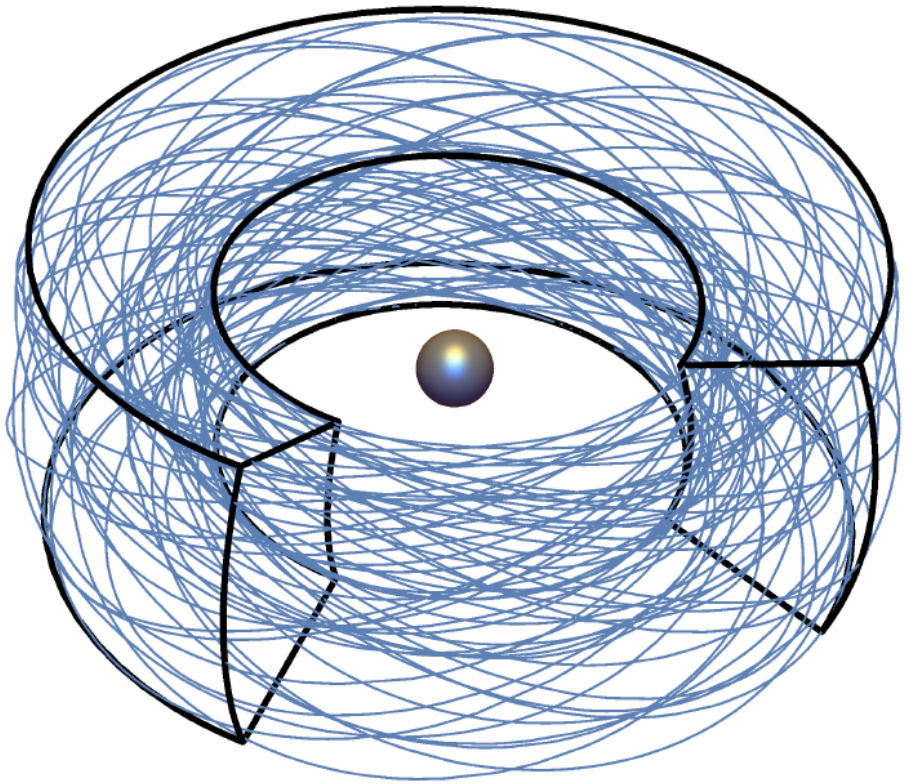




Domains of the binary black hole problem in GR

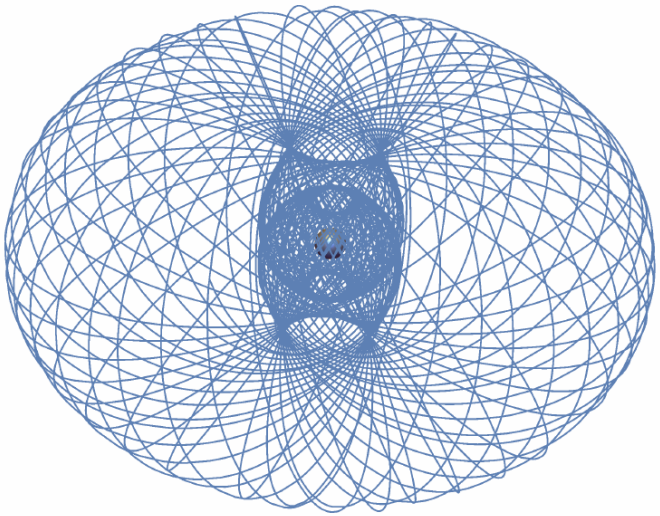


EMRIs: a unique modelling challenge

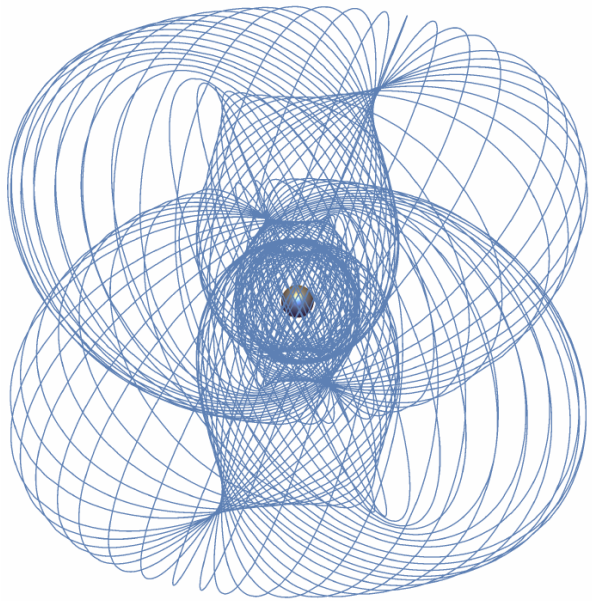


- $\sim 10^5$ wave-cycles in the LISA band, all within the inner $\sim 5r_{\rm S}$.
- To model with sub-radian accuracy must account for back-reaction force through 2nd-order in self-force expansion.

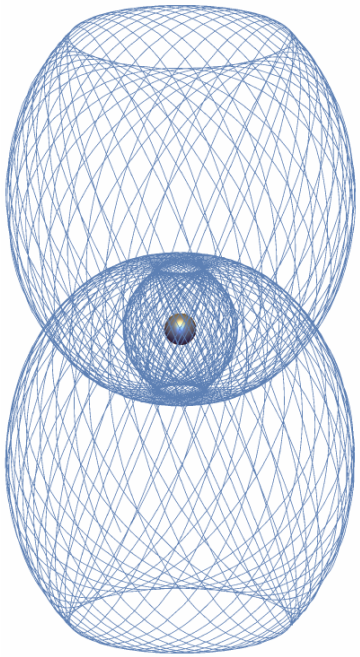
Transient resonances in EMRIs



$\lambda = 20°$



$\lambda = 45°$



$\lambda = 90°$

3:2 resonant orbits of same parameters (semilatus rectum, eccentricity, inclination) but different resonant phase λ.

From Einstein's equations to search templates

"Systematic" treatments

- Numerical relativity
- Post-Newtonian theory
- Self-force theory
- (EFT-inspired techniques)

$\rightarrow$

Effective-field & Phenomenological models

- Effective One Body (EOB)
- Phenomenological waveforms
- EMRI Kludges

$\downarrow$

Reduced-order representation

$\downarrow$

Search templates

Other applications of Numerical Relativity

- Critical behavior in gravitational collapse (Choptuik 1992,. . .)

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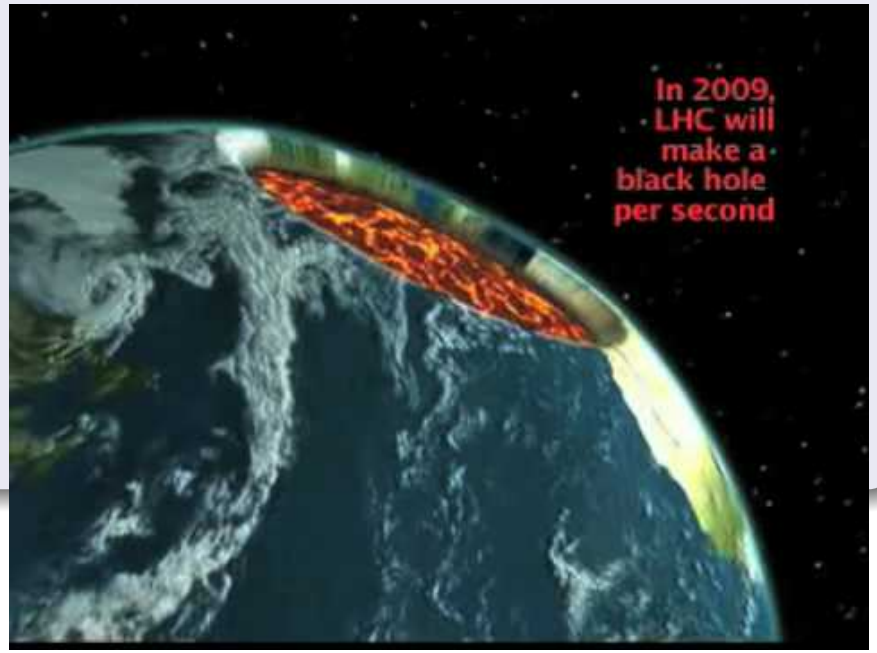
- BHs in $D > 4$ and in dS/AdS
- BHs in particle collisions (LHC or cosmic rays); TeV gravity?



Rest of morning programme

09:30-10:00 **Barry Wardell:** Perturbation methods & self-force

10:00-10:30 **Alexandre Le Tiec:** Post-Newtonian methods

10:30-11:00 *Coffee*

11:00-11:30 **Particia Schmidt:** Numerical Relativity in astrophysics

11:30-12:00 **Ulrich Sperhake:** Numerical Relativity in fund. physics

12:00-12:30 *Discussion*