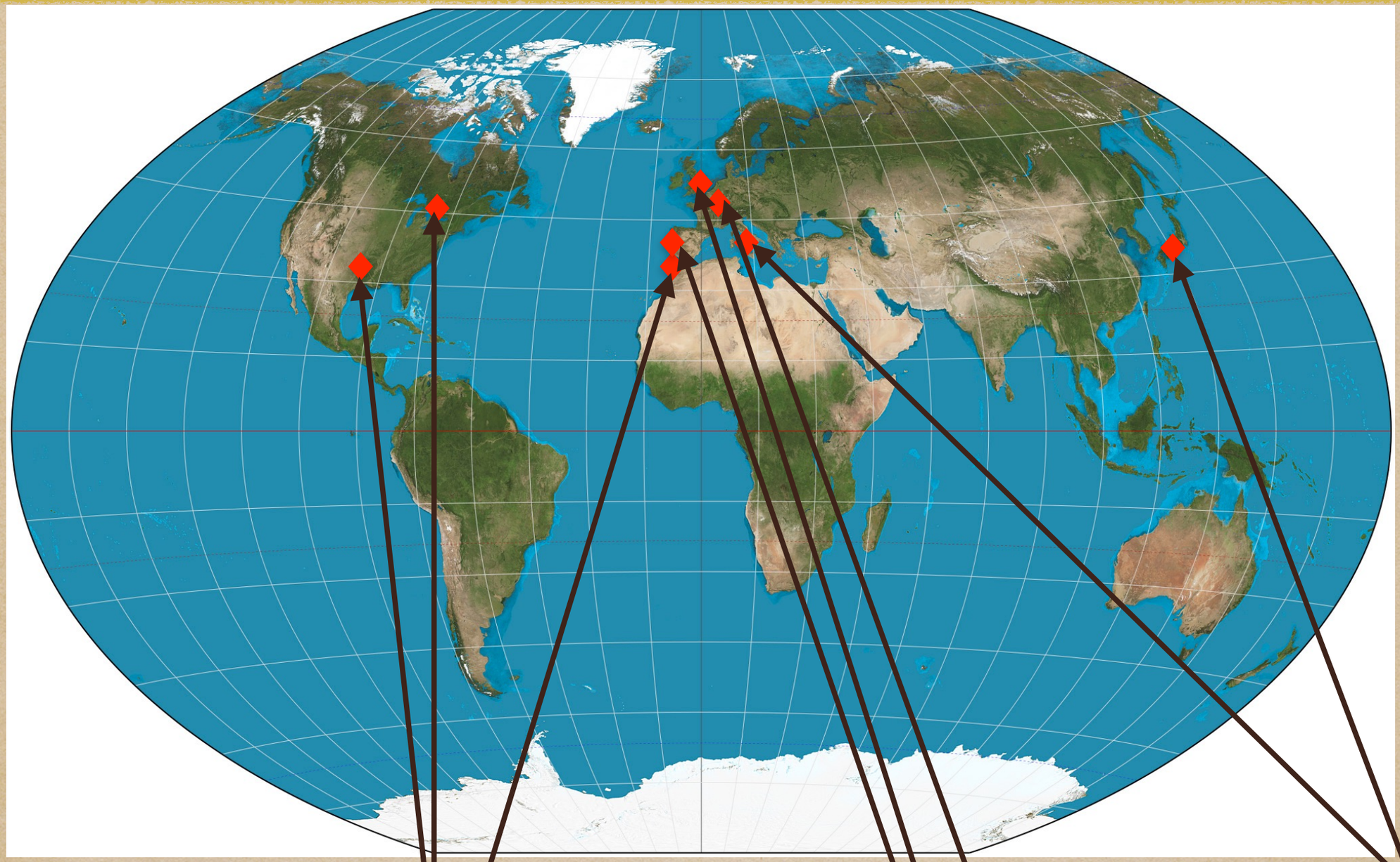
# H2020-MSCA-RISE-2015
# "StronGrHEP" 690904 Midterm Meeting

## La Sapienza University
*Rome, 22-23 Jun 2017*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 690904, from H2020-ERC-2014-CoG Grant No. "MaGRaTh" 646597, from NSF XSEDE Grant No. PHY-090003 and from STFC Consolidator Grant No. ST/L000636/1.

# Introduction

# The nodes



University of Mississippi

Perimeter Institute

IST/CENTRA Lisbon

University of Cambridge

University of Aveiro

CNRS Paris

La Sapienza, Rome

University of Osaka

# Team members

- University of Aveiro
  - Pedro Cunha
  - Carlos Herdeiro (PC)
  - Eugen Radu
  - Joao Rosa
- University of Cambridge
  - Michalis Agathos
  - William Cook
  - Markus Knutsch
  - Chris Moore
  - Roxana Rosca
  - Ulrich Sperhake (PC)
- CNRS Paris
  - Enrico Barausse (PC)
  - Antoine Klein
  - Oscar Ramos
- University of Mississippi
  - Emanuele Berti
- IST/CENTRA Lisbon
  - Laura Bernard
  - Richard Brito
  - Vitor Cardoso
  - Seth Hopper
  - Jorge Lopes
  - Masashi Kimura
  - Andrea Nerozzi
  - Vincenzo Vitagliano
- La Sapienza Roma
  - Valeria Ferrari
  - Leonardo Gulatieri (PC)
  - Paolo Pani
- University of Osaka
  - Akihiro Ishibashi
- Perimeter Institute
  - Luis Lehner

# Main Science Drivers

## ESFRI roadmap for Astronomy and Astroparticle Physics

http://www.esfri.eu/sites/default/files/20160308_ROADMAP_single_page_LIGHT.pdf

- Understand the extremes and origins of the universe
- Observe the formation of galaxies and their evolution
- Understand the formation of stars and planets
- Understand the solar system and life
- Observe gravitational waves

## Gravity is a key player!

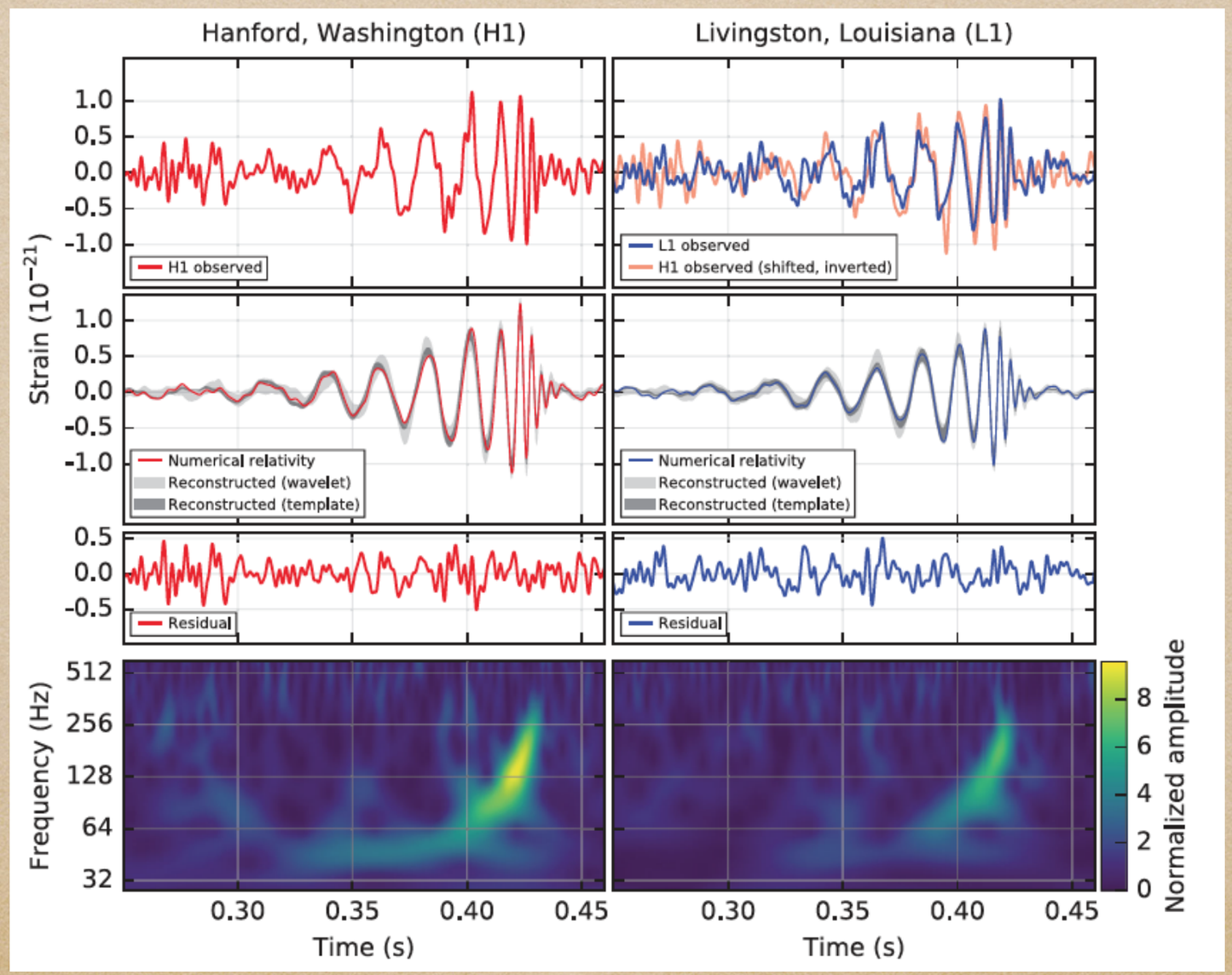
- Dark energy, dark matter? >90% of the Universe unknown!
- Gravity is unlike all other forces: Geometric! GR the final word?
- Gravitation very weak but dominates on large scales.
- New observational window: Gravitational waves

# Gravitational Waves detected!

- GW150914, GW151226, GW170104, LVT151012

  Abbott et al. 1602.03837, 1606.01210, 1706.01812

- Has (positive!) impact on our work



# Work packages

- Fundamental fields in Strong Gravity
  - Non-linear superradiant instability
  - Structure of stars with dark cores
  - Collisions of hairy black holes
  - Bounds on particle masses using gravity
- Stability of Black Holes
  - Black holes with scalar fields
  - Black holes with gauge fields
  - Shadows of single black holes
  - Shadows of black-hole binaries
- Modified Theories of Gravity
  - Compact binary waveform
  - Astrophysical Observables
  - Smoking Guns
- High-energy black-hole collisions in generic spacetimes
  - Wave extraction in axisymmetry
  - Black-hole head-on collisions
  - Wave extraction, initial data
  - Black-hole grazing collisions

# Work packages

# WP 4: High-energy black-hole collisions generic spacetimes

# Motivation: The hierarchy problem

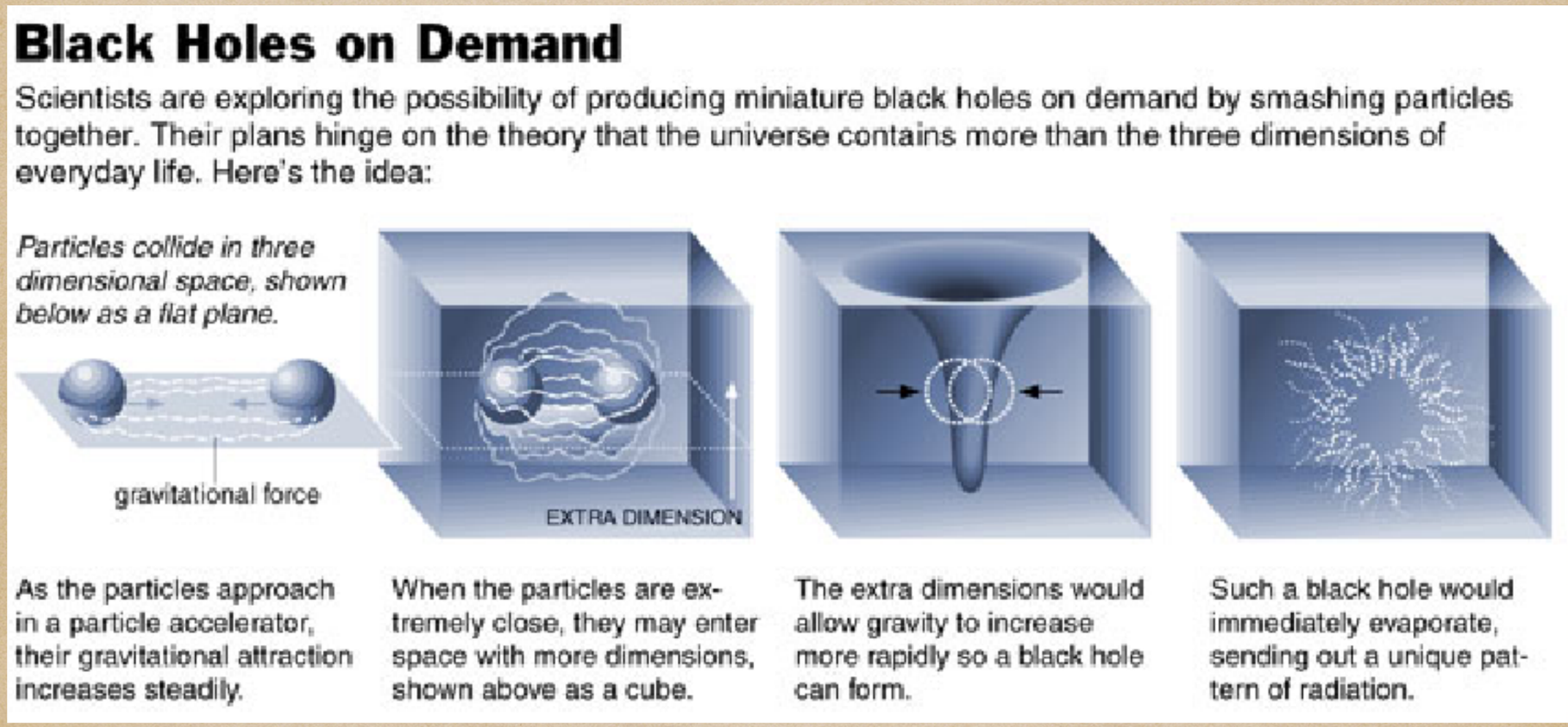
- Gravity $\approx 10^{-39}\times$ other forces
- Higgs field $\mu_{\rm obs} \approx 125\ {\rm GeV} = \sqrt{\mu^2 - \Lambda^2}$

  where $\Lambda \approx 10^{16}\ {\rm GeV} =$ grand unification energy
- Requires enormous fine-tuning

$$\frac{987654321}{123456789} = 8.0000000729$$

- Fine tuning exists:
- Or $E_{\rm Planck}$ much lower? Gravity strong at small $r$ ?
- Gravity not measured below $\sim 0.1\ {\rm mm}$ . Diluted due to
  - Large extra dimensions Arkani-Hamed, Dimopoulos, Dvali '98
  - Extra dimensions with warp factor Randall & Sundrum '99

# Motivation: TeV Gravity




- Particle collisions may form BHs

  E.g. Dimopoulos & Landsberg '01, Giddings & Thomas '01

# Deliverables and implementation

- Wave extraction in axisymmetry
  - Analytic calculation: Based on Godazgar & Reall 1201.4373
  - Numerical simulations: Modified Cartoon Cook et al 1603.00362
  - Numerical wave extraction in BH collisions Cook & Sperhake 1609.01292
- Black-hole head-on collisions
  - Equal-mass collisions from rest: Poor agreement with particle limit
  - Unequal-masses up to 1:100: Better agreement; Cook et al (in prep.)
  - Boosted collisions: 4D Sperhake et al 1511.082009; >4D Future work
  - The limit of the speed of light: Might need new initial data
- Wave extraction, initial data
  - Grazing collisions: Initial data constructed; first collisions tested
  - Wave extraction: Progressing
  - Horizon finding: Work in progress
- Black-hole grazing collisions
  - First collisions tested: It works in principle.
  - Accuracy of simulations: To be verified
  - Exploration of parameter space: Future work
  - Post-merger remnant cannot spin arbitrarily fast Figueras et al 1702.01755

# Link to secondements

- Past secondements to Perimeter institute
  - Markus Kunesch (Nov/Dec. 2016)

    Rapidly spinning BHs in higher dims. Figueras et al 1702.01755

- Past secondements to University of Mississippi
  - Michalis Agathos, Will Cook, Chris Moore, Roxana Rosca (Feb/Mar 2017)

    Black-hole collisions Cook & Sperhake 1609.01292

    Application of wave extraction Cook et al (in prep.)

    Core collapse in massive scalar-tensor theory (Work package 3)

- Future secondements
  - Osaka: Wave extraction in higher D, BH collisions, …
  - Perimeter: Collisions of hairy black holes, grazing collisions, …
  - Mississippi: Modifications of general relativity, grazing collisions, …

# Secondements

Table 1

| | | | | Period 1 | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Name | Member ID | Seconding starting month | Duration | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Carlos Herdeiro | 15 | 14 | 0.5 | | | | | | | | | | | | | | X | | | | | | | | | | |
| | 15 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Jorge Delgado | | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Pedro Cunha | 16 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| | 16 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Ulrich Sperhake | | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Michalis Agathos | 12 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| | 12 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Chris Moore | 10 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| | 10 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Will Cook | 9 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| | 9 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Markus Kunesch | 8 | 11 | 1 | | | | | | | | | | | XX | | | | | | | | | | | | | |
| | 8 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Roxana Rosca | 11 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| | 11 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Andrea Nerozzi | 6 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| Seth Hopper | 4 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 4 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| Richard Brito | 1 | 7 | 1 | | | XX | | | | | | | | | | | | | | | | | | | | | |
| Laura Bernard | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | 5 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |
| Enrico Barausse | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Oscar Ramos | 2 | 9 | 2 | | | | | | | | | XX | XX | | | | | | | | | | | | | | |
| | 2 | 21 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| Antoine Klein | 13 | 14 | 0.5 | | | | | | | | | | | | | | X | | | | | | | | | | |
| Leo Gualtieri | 14 | 14 | 0.5 | | | | | | | | | | | | | | X | | | | | | | | | | |
| | 14 | 21 | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | |
| Paolo Pani | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 21 | 0.5 | | | | | | | | | | | | | | | | | | | | | | | | |
| Jorge Lopes | 3 | 10 | 0.5 | | | | | | | | | | X | | | | | | | | | | | | | | |
| Vinc. Vitagliano | 7 | 14 | 1 | | | | | | | | | | | | | | XX | | | | | | | | | | |

# General comments

- Started a bit slowly
- To date: 13 secondement months completed
  4 half-secondement months completed
- Upcoming: About 12 more this year (Osaka, Perimeter)
- Cf. Total: 64 secondement months
- Difficulties encountered so far
  - Cambridge hit by exchange rates! GBP-EUR down $\sim 20\,\%$ since transfer
  - Frans has banned use of airnb for scientific purposes.
  - Exact timing hard to plan ahead on long time scale
  - Unexpected personnel fluctuation (one member became a pilot…)
  - Budget tricky for split secondements (multiple travel costs)
  - Total cost strongly dependent on destination country/institute

# Project management

# Reorientations of projects

- No major issues encountered as yet $\Rightarrow$ No reorientations
- Minor difficulties encountered in research work
  - BH collisions in higher dimensions: Initial data seem to saturate around $\sim 75\,\%$ of the speed of light.
    Alternative initial data presently explored.
- Positive surprises: Unexpected insight gained. E.g.
  - Potential of Gaia for gravitational wave observations
  - Instability of highly spinning BHs in 5D
  - Insight into formation of black holes through GW observations
  - Synergy with LIGO-Virgo Scientific Collaboration's GW detection

# Publications, Open access

- Publications in peer reviewed journals
  - 61 published articles
  - 9 in Physical Review Letters
  - 15 further articles under review / in print (as of Jun 19, 2017)
  - 1 conference proceedings

- Open Access
  - All articles in green open access
  - Various articles also in gold open access (e.g. U Cambridge library)
  - green open access:
    http://xxx.arxiv.org

# Selected outreach

- Talks at schools, public talks
  - Agrupamento de Escolas de Lanheses (V. Cardoso)
  - Escola Secundaria Leal da Camara + os Salesianos (V. Cardoso)
  - Adams Society, St.John's College Cambridge (U. Sperhake)
  - Cambridge University Physics Society (C. Moore)
  - Escola Secundaria de Oliveira do Bairro (C. Herdeiro)
- Blogs
  - Science News (E. Berti)

    https://www.sciencenews.org/article/ligo-snags-another-set-gravitational-waves
    https://www.sciencenews.org/article/faint-gravitational-waves-could-soon-be-ligos-radar
    https://www.sciencenewsforstudents.org/article/gravitational-waves-detected-yet-again
  - Space Daily (E. Barausse)

    http://www.spacedaily.com/reports/Discovery_of_Gravitational_Waves___What_Comes_Next_999.html
- Online outreach for students and society
  - The birth of an idea (V. Cardoso)

    https://birthofidea.tecnico.ulisboa.pt/
  - Gravitao — o Sitio de Gravitatcao (V. Cardoso)

    https://blackholes.tecnico.ulisboa.pt/gravitao/

# Selected outreach

- Newspaper, Radio etc.
  - Sara Gomes, Literatura aqui, RTP2 (2016) (V. Cardoso)
  - Kate Becker, Are Black Holes Real?, PBS (2016) (V. Cardoso)
  - The Guardian (2016) (U. Sperhake)

https://www.theguardian.com/science/2016/feb/09/watch-this-spacetime-gravitational-wave-discovery-expected

  - AM1450 KMMS (Bozeman's, Montana, Radio) (E. Barausse)

http://kmmsam.com/msu-physicist-advances-our-understanding-of-nature/

  - Attilio Ferrari, La Stampa (V. Cardoso).

http://www.lastampa.it/2016/12/22/scienza/tuttoscienze/la-prossima-odissea-sar-nel-fireball-la-sfera-di-fuoco-del-buco-nero-eBsuuiT4r2hGm1s3HZ2gmM/pagina.html

  - Joao Fernando Ramos, Journal 2, RTP2 (C. Herdeiro).

https://www.facebook.com/universidadedeaveiro/videos/1008617959195028/

  - Os 100 anos da Constante Cosmologica, RTP (C. Herdeiro)

https://www.rtp.pt/play/p384/e276130/click

- Lecturing at summer schools
  - COST New CompStar School (2016) (V. Cardoso, U. Sperhake)

# Ethics

- No ethical issues have arisen in this project