Black Hole Perturbation Toolkit Workshop

11th-13th March @ MIT

Niels Warburton

Goal of the Toolkit

"Our goal is for less researcher time to be spent writing code and more time spent doing physics. Currently there exist multiple scattered black hole perturbation theory codes developed by a wide array of individuals or groups over a number of decades. This project aims to bring together some of the core elements of these codes into a Toolkit that can be used by all.

Additionally, we want to provide easy, open access to data from black hole perturbation codes and calculations."

http://bhptoolkit.org

Motivation

- Lots of work to be done before LISA flies
  - see EMRI work package documents:
    https://tinyurl.com/ybsul6vs
    https://tinyurl.com/y9qt4jjh
    https://tinyurl.com/y84qxw6f
    https://tinyurl.com/emri-templates
- Stop community reinventing the wheel
- Reduce barrier to entry to help grow the field

Contributors and users

Since 2016, initial development has been led by UCD, UNC and MIT

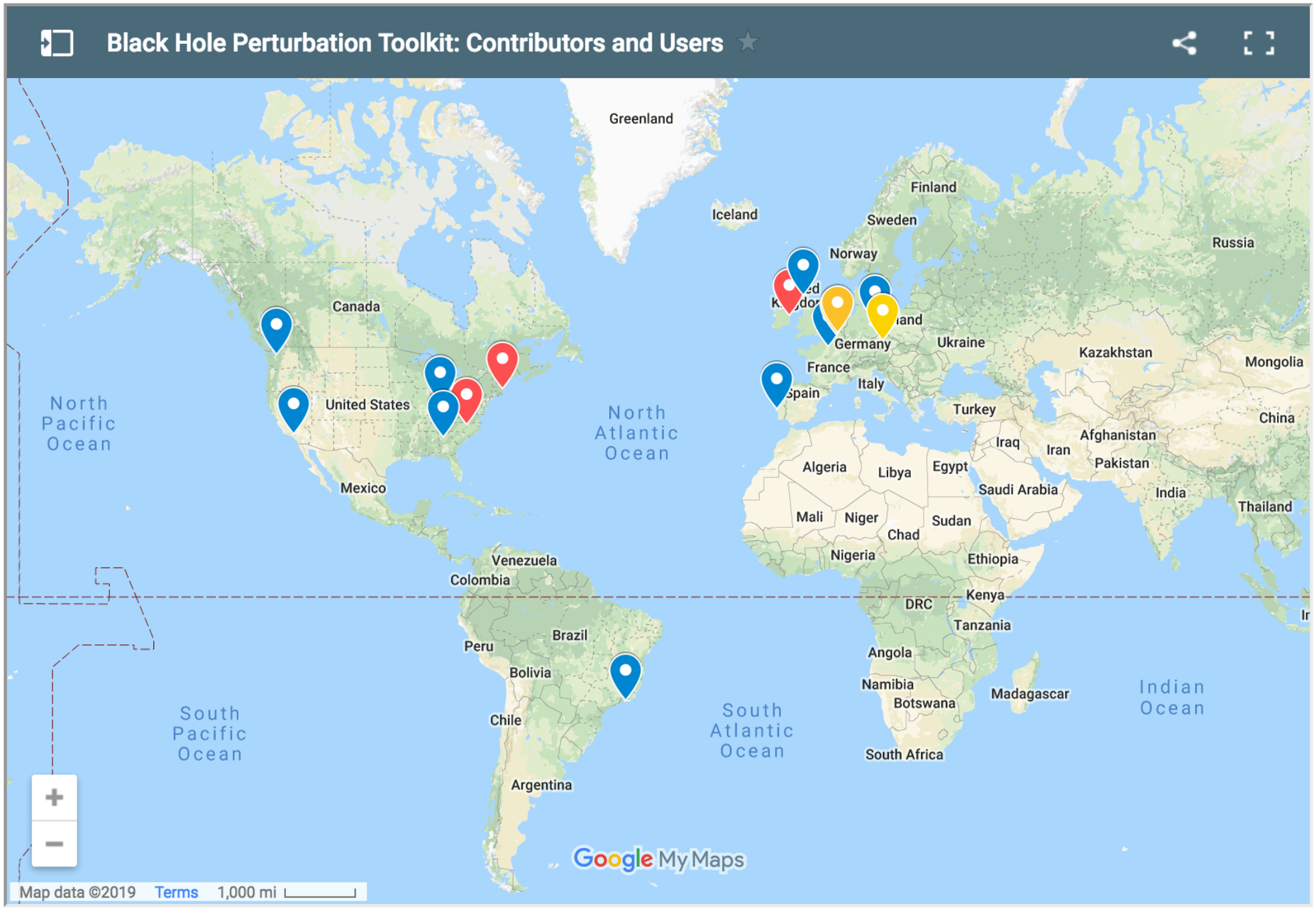
UCD DUBLIN

THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

MIT KAVLI INSTITUTE

but many other individuals have also contributed…

Contributors and users



http://bhptoolkit.org/users.html

Current modules

Code

Target 3 main languages:
- Mathematica
- C/C++
- Python

but happy to include good code in any language

Most code under MIT or GPL licences. This is something we should discuss.

Data

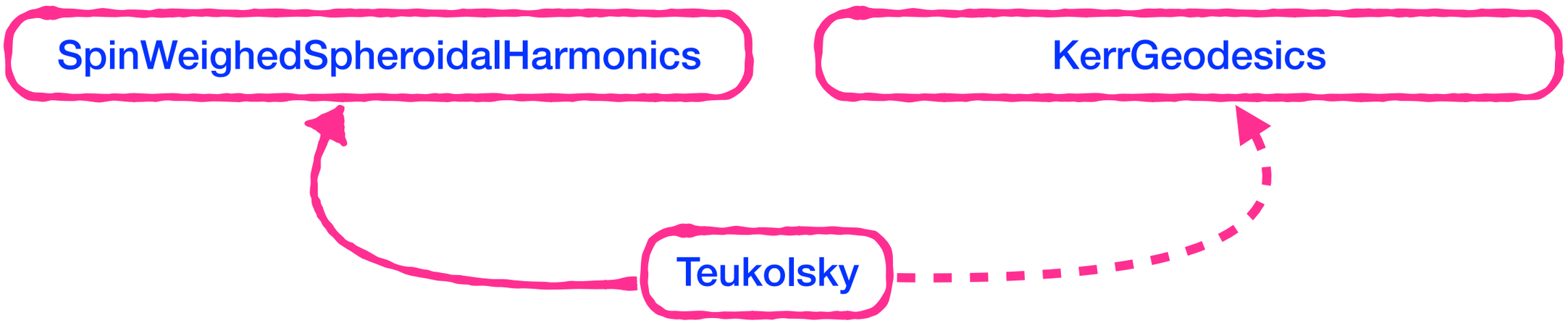
- Fluxes
- Local invariants
- High-order PN series
- Regularisation parameters

Currently most of the data is for circular, equatorial orbits

Need to discuss how to store much larger datasets for generic orbits

Current modules

Code: Mathematica



QuasiNormalModes

GeneralRelativityTensors

ReggeWheeler

Lorenz

Current modules

Code: C/C++

EMRI Kludge Suite — Kludge waveforms by Alvin Chua +

Gremlin — Teukolsky solver from Scott Hughes +

Fast Self-forced Inspirals — Self-force inspirals from Niels Warburton +

Code: Python

kerrgeodesic_gw — GWs for circular orbits by Eric Gourgoulhon +

qnm — Quasi-normal modes from Leo Stein
(not yet in the Toolkit)

Current modules

Data:

CircularOrbitData	Flux, local invariants, etc for circular orbits
PostNewtonianSelfForce	Mathematica module to load high-order Post-Newtonian series
Regularisation Parameters	Mathematica notebooks containing regularisation parameters
Mathematica Toolkit Examples	Mathematica notebooks showing example usage of various modules

Citation guideline

If you make use of any of the Toolkit in your research please acknowledge using:

> This work makes use of the Black Hole Perturbation Toolkit.

To cite the Toolkit please use this BibTeX entry (or similar). Some modules also request additional citations. Please check the documentation for individual modules.

Why cite?

A lot of researcher time and effort goes into developing the Toolkit. Acknowledging and citing this work demonstrates that it is being used which helps us secure additional funding to support further development.

Already have 7 papers that make use of or extend the Toolkit

7. “Gravitational waves from bodies orbiting the Galactic Center black hole and their detectability by LISA”, Eric Gourgoulhon, Alexandre Le Tiec, Frederic H. Vincent, Niels Warburton, arXiv:1903.02049 (*)

6. “Spin and Quadrupole Couplings for High Spin Equatorial Intermediate Mass-ratio Coalescences”, Bin Chen, Geoffrey Compère, Yan Liu, Jiang Long, Xuao Zhang, arXiv:1901.05370

5. “Spectroscopy of Extremal (and Near-Extremal) Kerr Black Holes”, M. Casals, Luís F. Longo Micchi, arXiv:1901.04586

4. “High-order asymptotics for the Spin-Weighted Spheroidal Equation at large real frequency”, M. Casals, A. C. Ottewill, N. Warburton, Proc. R. Soc. A 475:20180701 (2019), arXiv:1810.00432 (*)

3. “Gravitational self-force corrections to gyroscope precession along circular orbits in the Kerr spacetime”, D. Bini, T. Damour, A. Geralico, C. Kavanagh, M. van de Meent, Phys. Rev. D 98, 104062 (2018), arXiv:1809.02516 (*)

2. “Gravitational waves from plunges into Gargantua”, Geoffrey Compère, Kwinten Fransen, Thomas Hertog, Jiang Long, Class. Quant.Grav. 35 (2018) no.10, 104002, arXiv:1712.07130

1. “Quantum correlator outside a Schwarzschild black hole”, Cláudia Buss, Marc Casals, Phys. Lett. B776, p168-173 (2017), arXiv:1709.05990

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Workshop schedule (day 1)

- Welcome to MIT by Scott Hughes ✓
- Introduction to the Toolkit by Niels Warburton ✓

- Download and install Toolkit modules by Barry Wardell

- Overview of SpinWeightedSpheroidalHarmonics by Barry Wardell
- Overview of KerrGeodesics by Niels Warburton and Zach Nasipak
- Overview of EMRI Kludge Suite by Alvin Chua
- Overview of Gremlin by Scott Hughes
- Overview of Teukolsky and QuasiNormalModes by Barry Wardell
- Overview of GeneralRelativityTensors by Niels Warburton
- Overview of CircularOrbitData by Scott Hughes
- Overview of PostNewtonianSelfForce by Chris Munna

- Create wish list of modules (Regge-Wheeler, Lorenz gauge, generic orbit Teuk., etc)
- Create schedule of work for the next two days (code, documentation, website, etc)

Workshop schedule (days 2 and 3)

12th March

- Discuss: Coding conventions and licences
- Discuss: Data formats and storage
- Hacking: on list of software/documentation/data created the day before

- Astrophysics Colloquium @ 4pm: The Astrophysical R-process: What We Are Learning From Gravitational Waves, Dwarf Galaxies, And Stellar Archaeology

13th March

- Hacking: continue to hack on the Toolkit
- Discuss: Toolkit paper

Design APIs
Add/improve code
Test code and report bugs
Add documentation
Toolkit paper

What the Toolkit is not

Developing code to compute perturbations to black holes takes a lot of time and effort. The goal of the Toolkit is not to have each and every researcher's cutting edge code on public display, rather to build a core of software that is common to many of the codes that currently exist.