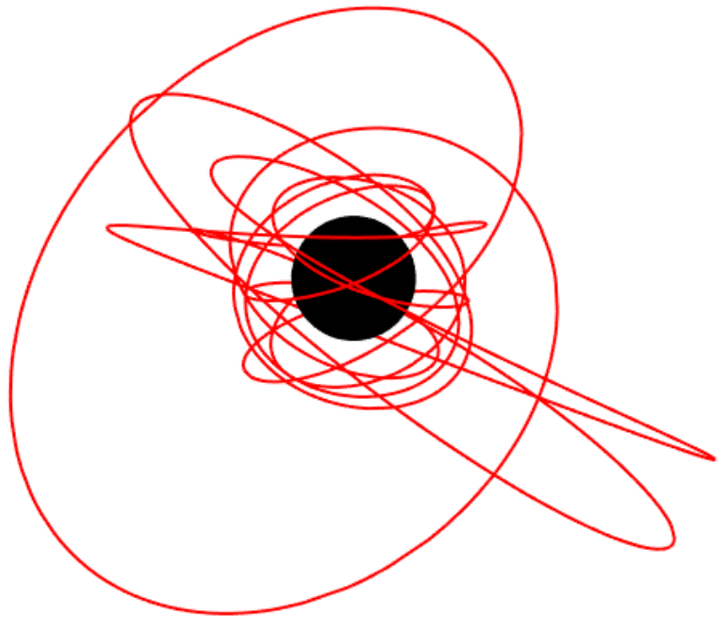
Developments at first-order



Discussion lead by Niels Warburton

23rd Capra Meeting
~~University of Texas at Austin,~~ Virtual

Discussion: overview

- What we need
- Status and challenges
- BHPToolkit update
- Slack

Three addition discussions:

- Faster GSF codes
- Covering the parameter space
- Fast waveforms

What we need at first order:

Adiabatic inspirals:

- Fluxes for point particle on generic bound orbit in Kerr
- Cover and interpolate parameter space

GSF inspirals:

- 1st-order GSF for point particle on generic bound orbit in Kerr
- Flux due to spin on the secondary for generic bound orbits in Kerr
- Cover and interpolate parameter space

What we need at first order:

For second-order:

- First-order metric perturbation everywhere in the spacetime for bound orbits in Kerr
- Derivative of the MP w.r.t. orbital elements everywhere in the spacetime, e.g., $\{\partial h/dp, \partial h/de\}$

Waveforms:

- waveform amplitudes for bound orbits in Kerr
- cover and interpolate parameter space

Computational framework that uses results from all the above

Status and challenges:

Adiabatic inspirals:
- Fluxes for point particle on generic bound orbit in Kerr
- Cover and interpolate parameter space

Fluxes:
- Can compute numerically
- Have analytic results via PN and near-NHEK expansion

Covering the parameter space:
- Need high precision interpolation (residuals $\ll 1/\epsilon$)
- Blend analytic and numerical results

Status and challenges:

GSF inspirals:
- 1st-order GSF for point particle on generic bound orbit in Kerr
- Flux due to spin on the secondary for generic bound orbits in Kerr
- Cover and interpolate parameter space

1st-order GSF:
- can numerically compute but very slowly (implementation and many more modes needed)
- No PN series as yet

Spinning secondary:
- have results for circular orbits (numerical + PN)
- No eccentric orbit results

Cover parameter space:
- Only done in Schwarzschild (by gridding)
- Don’t need such high accuracy

Status and challenges:

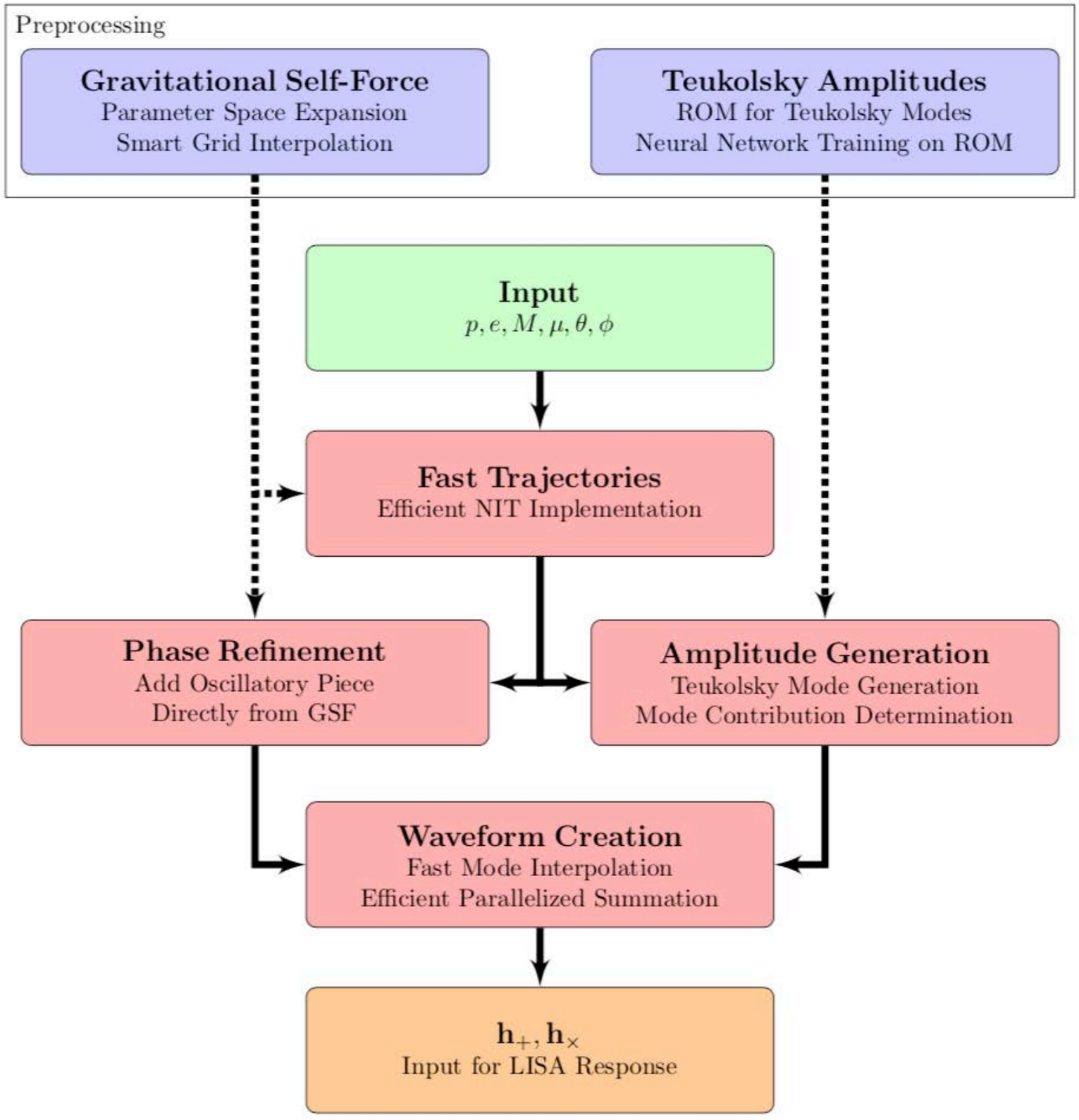
Waveforms:
- waveform amplitudes for bound orbits in Kerr
- cover and interpolate parameter space

Waveform amplitudes:
- have numerical and PN results
- Don’t need high precision (error does not accumulate)

Cover and interpolate the parameter space
- similar challenges to GSF

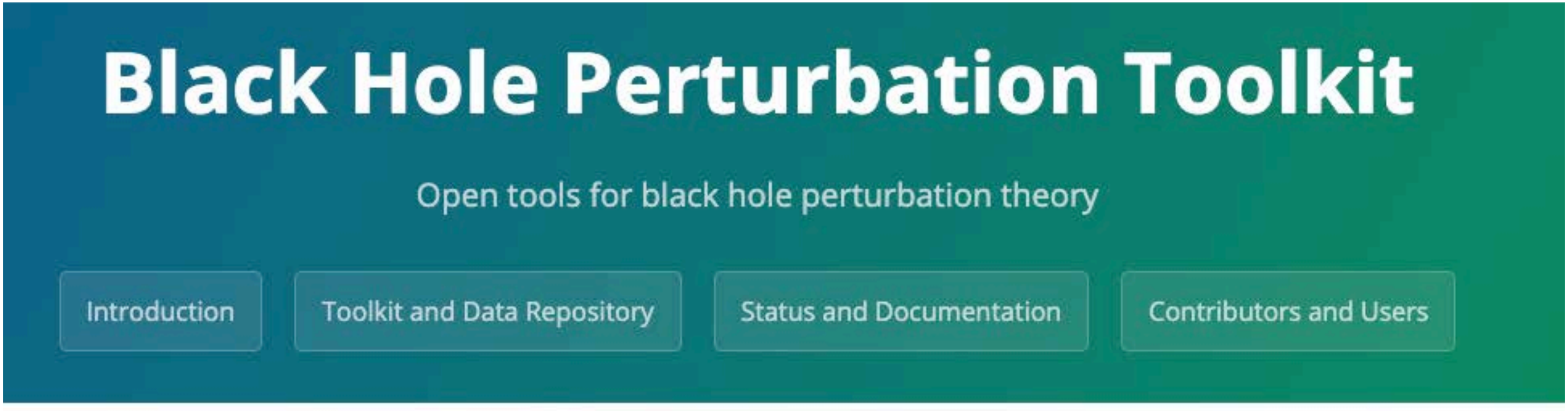
Status and challenges:

Framework:



Black Hole Perturbation Toolkit update

- Key to overcoming those challenges (and others) will be sharing code and data within the community
- Until recently there were no public Regge-Wheeler/Teukolsky codes
- The BHPToolkit is addressing this



https://bhptoolkit.org

Black Hole Perturbation Toolkit update

In the Toolkit you will find:

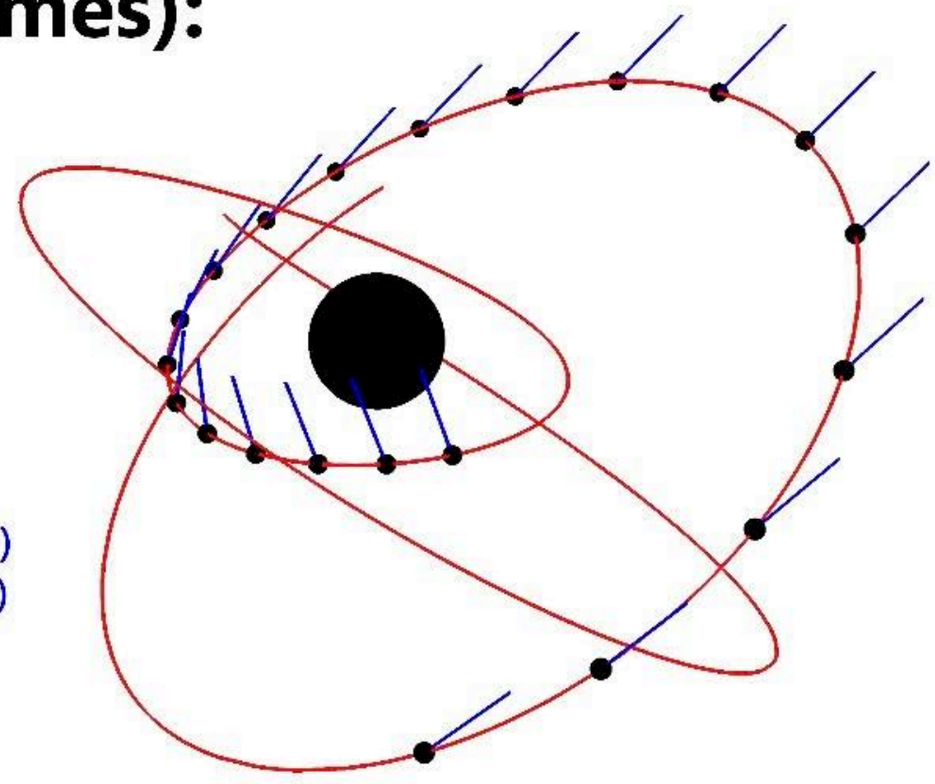
- Spin-weighted spheroidal harmonics
- Geodesics
- QNMs codes
- ReggeWheeler codes
- Teukolsky codes
- Inspiral codes (NIT)
- Waveform codes (Kludges, snapshots, surrogates)
- Self-force codes
- Data (numerical and analytic)

Black Hole Perturbation Toolkit update

- We recently held a (virtual) workshop
- Attendance: ~110 on Zoom, ~20 on YouTube

BHPToolkit Spring 2020 workshop
Monday sessions (CEST times):

12:00-12:05 - Local introduction (Vojtech Witzany and Georgios Lukes-Gerakopoulos)
12:05-12:45 - Introduction to the BHPToolkit (Barry Wardell)
12:45-13:15 - SpinWeighedSpheroidalHarmonics (Niels Warburton)
13:15-14:00 - kerrgeodesic_gw (Eric Gourgoulhon)
14:00-14:30 - Coffee break
14:30-15:15 - GeneralRelativityTensors (Seth Hopper)
15:15-16:00 - KerrGeodesics (Maarten van de Meent)
16:00-16:30 - Coffee break
16:30-17:15 - EMRI Surrogate (Scott Field)
17:15-18:00 - Quasinormal modes with qnm (in Python, Leo Stein)



All talks recorded on YouTube. See https://bhptoolkit.org/workshops.html

Monday

Time (CDT)	Speaker	Institute	Title
6:50	--		Welcome
7:00	Theo Torres	University of Sheffield	Electromagnetic self-force of a charged particle on Kerr spacetime: equatorial circular orbits Read Abstract
7:20	Leanne Durkan	University College Dublin (UCD)	On Calculating the Lorenz Gauge Metric Perturbation Read Abstract
7:40	Philip Lynch	University College Dublin	Fast Self-Forced Inspirals into a Kerr Black Hole Read Abstract
8:00	Zach Nasipak	University of North Carolina at Chapel Hill	Calculating the scalar self-force experienced during ð ‘Ÿð œf-resonances Read Abstract
8:20			Coffee
8:40	Huan Yang	Guelph University	Relativistic Mean Motion Resonance Read Abstract
9:00	Georgios Lukes-Gerakopoulos	Astronomical Institute, Czech Academy of Sciences	Impact of Resonances and Chaos on Extreme Mass Ratio Inspirals Read Abstract
9:20	Alvin Chua	Jet Propulsion Laboratory	Rapid generation of fully relativistic EMRI waveforms for data analysis Read Abstract
9:40	Michael Katz	Northwestern University	GPU-Accelerated Techniques for Generating Fast EMRI Waveforms Read Abstract

Tuesday

Time (CDT)	Speaker	Institute	Title
7:00	Adam Pound	University of Southampton	Progress toward post-adiabatic waveforms Read Abstract
9:00	Benjamin Leather	University College Dublin	A view to second-order self-force calculations for eccentric orbits Read Abstract

Wednesday

9:20	Christopher Munna	UNC Chapel Hill	Analytically expanding black hole perturbation theory quantities to high PN order Read Abstract
10:00	Oliver Long	University of Southampton	Towards a self-force calculation of the scatter angle in hyperbolic encounters Read Abstract

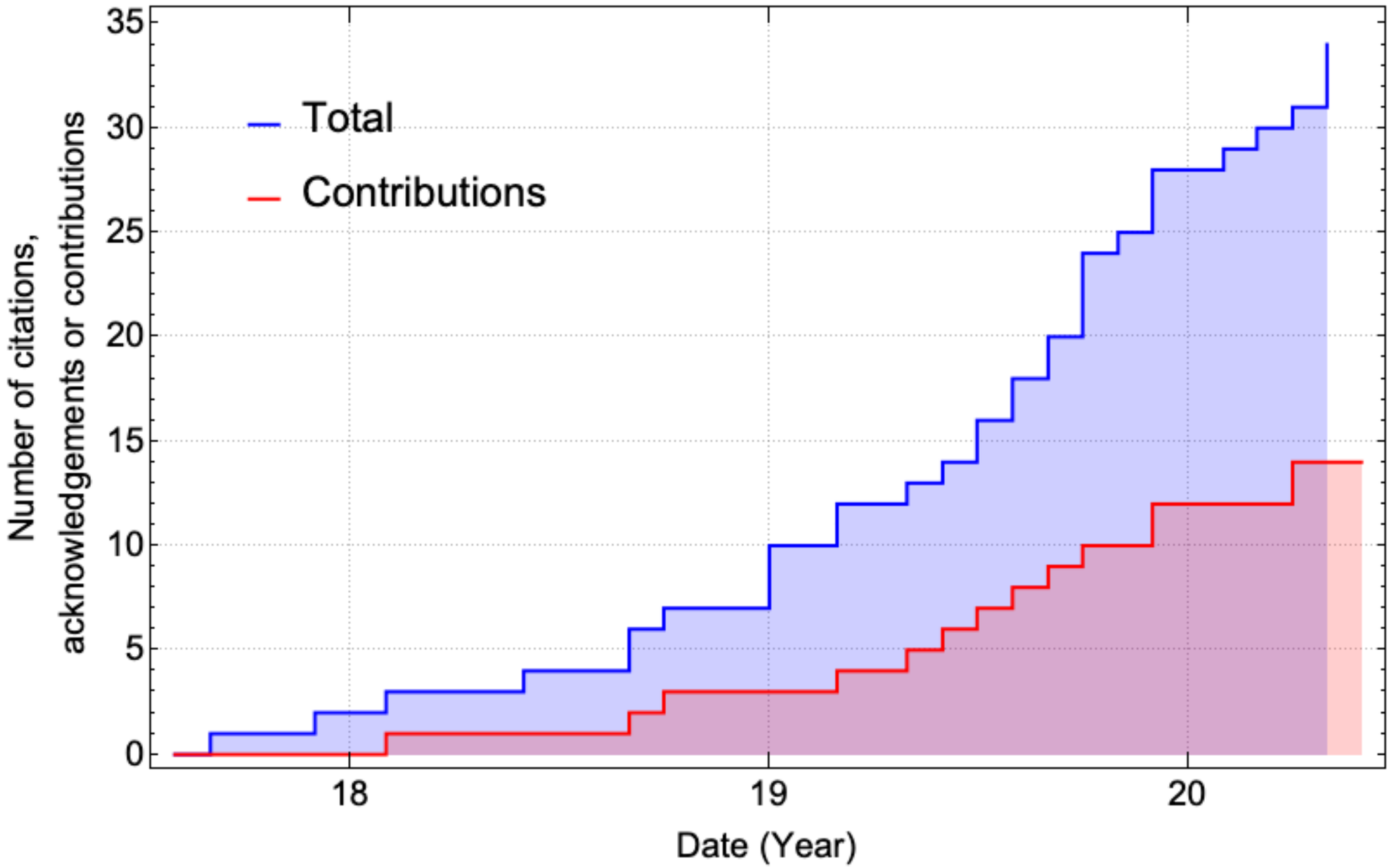
Thursday

7:40	Peter Diener	Louisiana State University	Towards the Self-consistent Evolution of a Scalar Charge Around a Schwarzschild Black Hole (yet again, again)
8:00	Samuel Cupp	Louisiana State University	Progress towards self-consistent evolution of gravitational self-force around a Schwarzschild black hole
9:20	Nur E. M. Rifat	University of Massachusetts Dartmouth	Surrogate model for gravitational wave signals from binary black hole system generated by point-particle black hole perturbation theory (ppBHPT)
9:40	Tousif Islam	University of Massachusetts (UMass) Dartmouth	Detectability and Parameter Estimation Accuracy for Intermediate-mass black holes (IMBH) with current generation detectors Read Abstract

Friday

9:00	Josh Mathews	University College Dublin	Gravitational Perturbations by a Spinning Secondary in the RW gauge Read Abstract
9:20	Gabriel Andres Piovano	La Sapienza, University of Rome	Extreme mass ratio inspirals with spinning secondary Read Abstract

Black Hole Perturbation Toolkit update



Further discussion:

- Use Slack for text-based discussion
- If you organise a video call invite everyone. Announce the call in the #capra-main channel

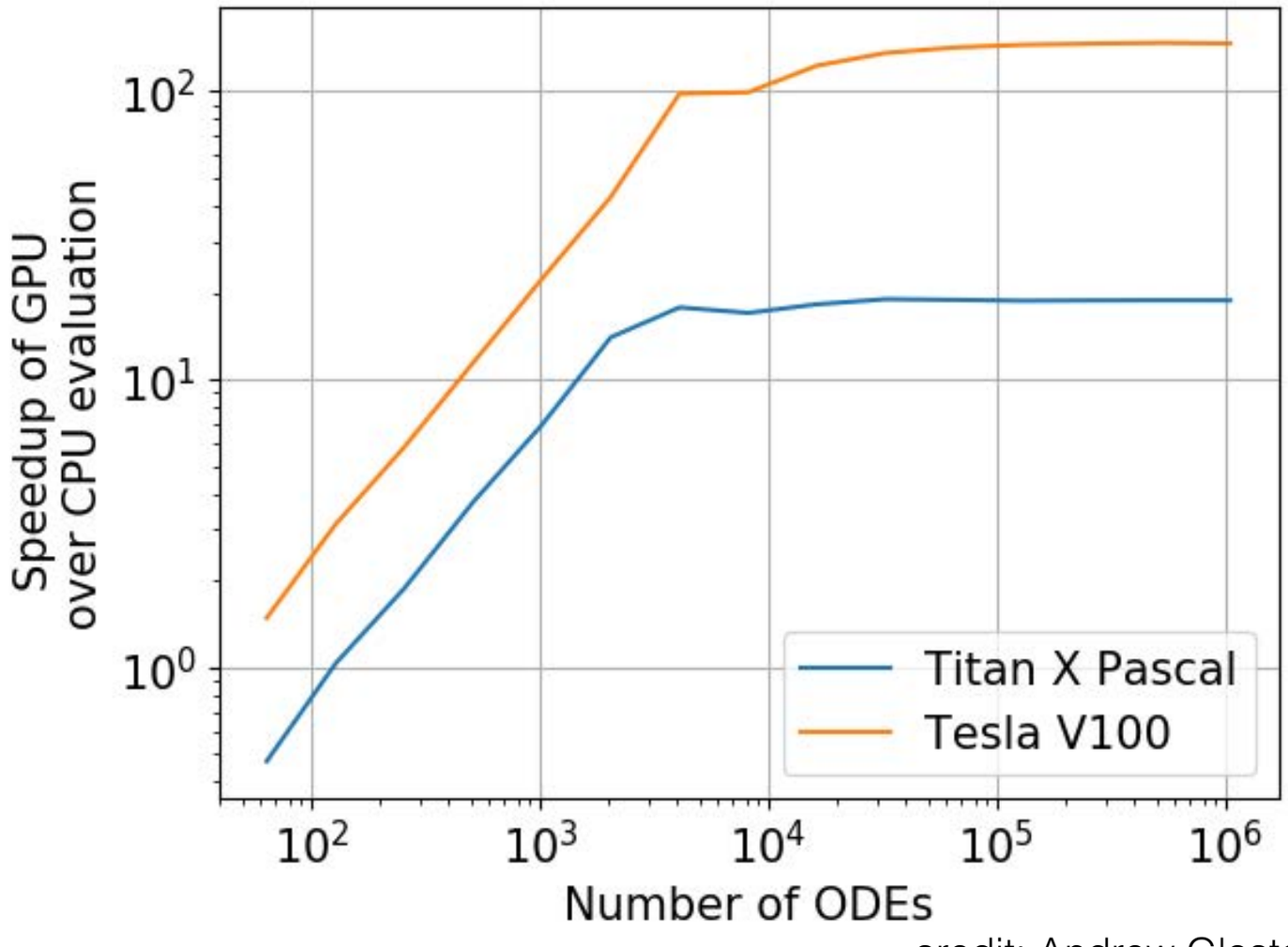
Specific discussions:

- Faster GSF codes (Now)
- Covering the parameter space (~12:00 CDT)
- Fast waveforms (~12:30 CDT)

Extra slides

GSF inspirals:

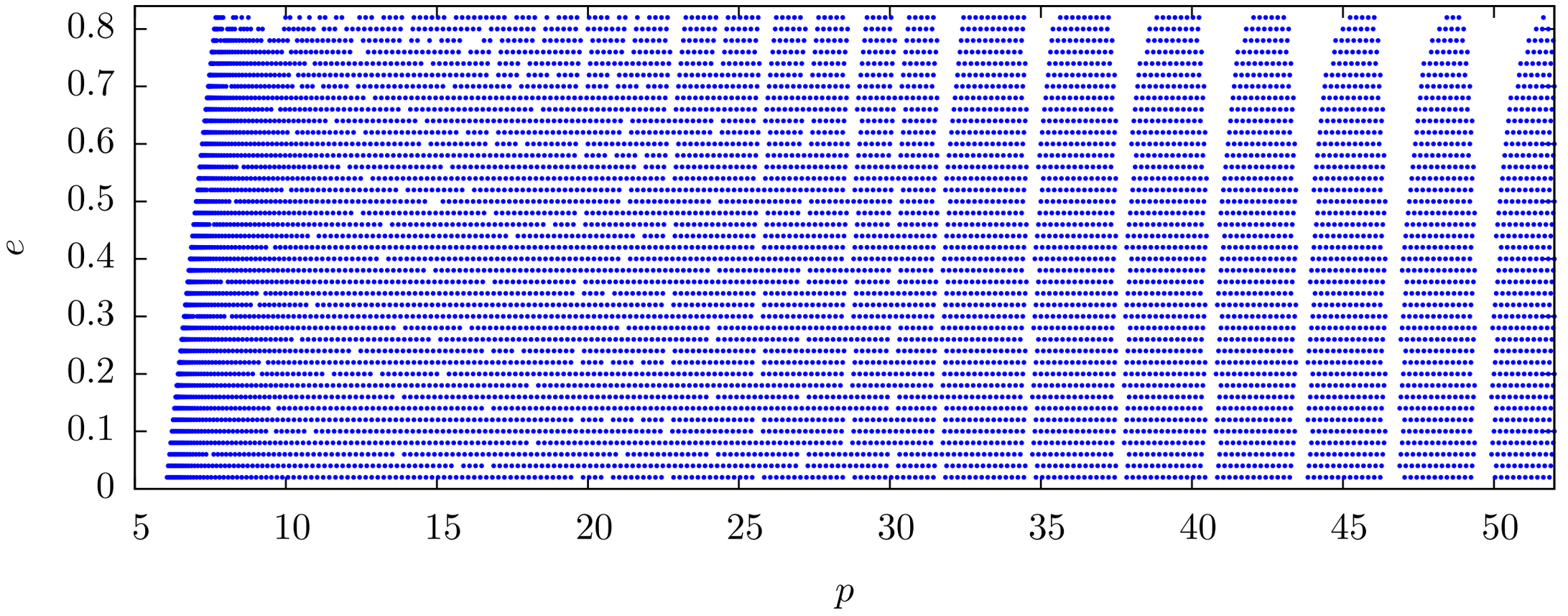
- 1st-order GSF for point particle on generic bound orbit in Kerr
- Flux due to spin on the secondary for generic bound orbits in Kerr



credit: Andrew Gloster

GPUs?

Covering the parameter space



In the past we've just grid up the parameter space

Difference precision requirements for different parts of GSF

A lot of data to curate: need good standard formats

Use analytic knowledge

Figure from Osburn, Warburton, Evans, https://arxiv.org/abs/1511.01498

Fast waveforms

- ROM + NN + GPU
- Surrogates
- other methods?

Improved phasing:

- GSF
- environmental effects
- non-GR effects

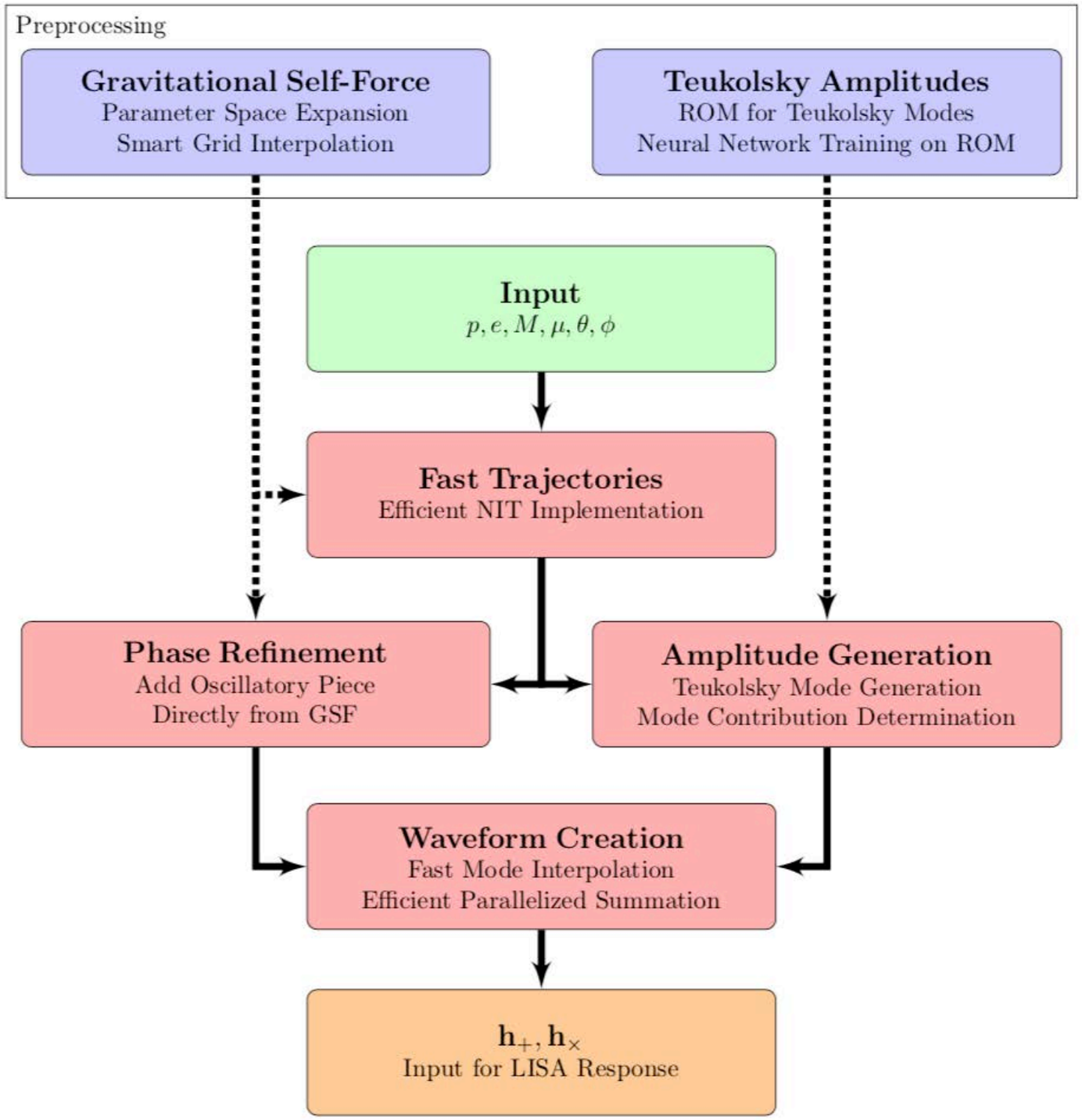


Figure from Michael Katz