CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

Northwestern University

GPU-Accelerated Techniques for Generating Fast EMRI Waveforms

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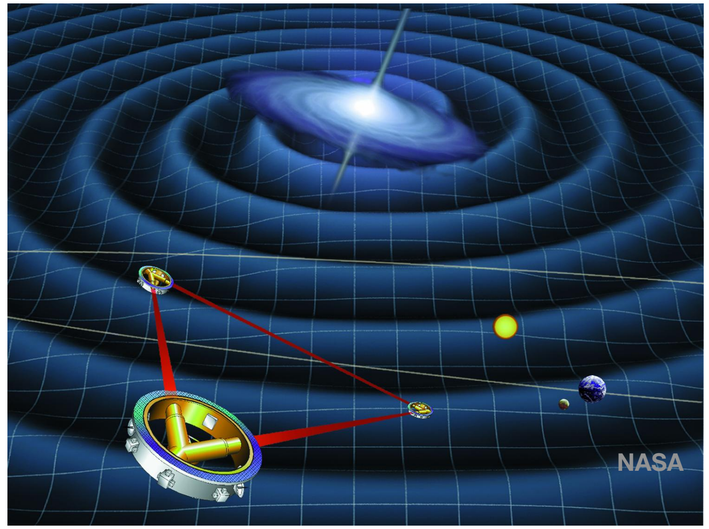
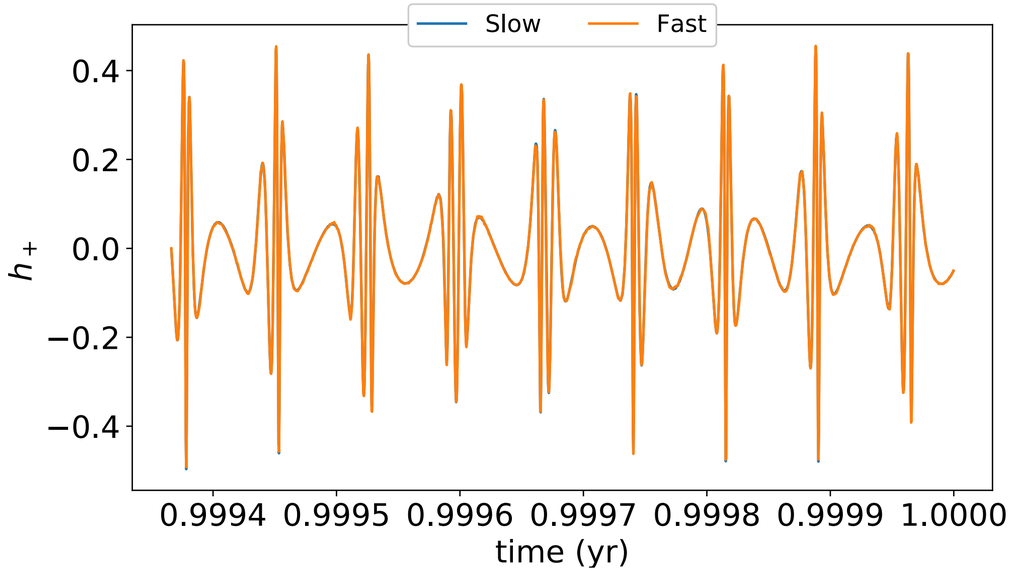
(with Alvin Chua, Niels Warburton, Scott Hughes)

Capra Meeting
June 2020

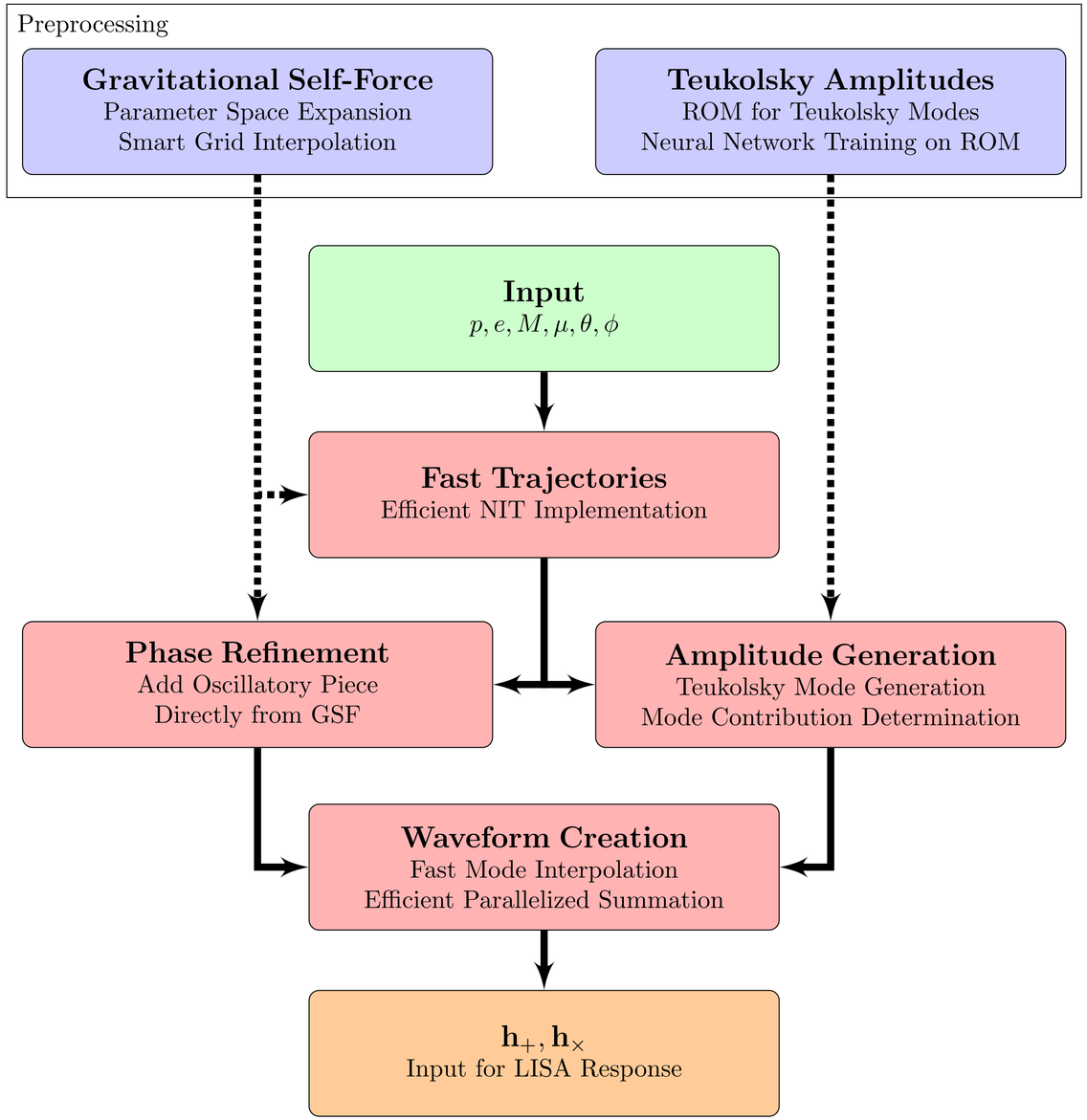


$M = 10^6 M_\odot, \mu = 10^1 M_\odot, p_0 = 10, e_0 = 0.7$



A Modular Framework

- Interchangeable pieces
- Advancements easily added
- User options for particular situations

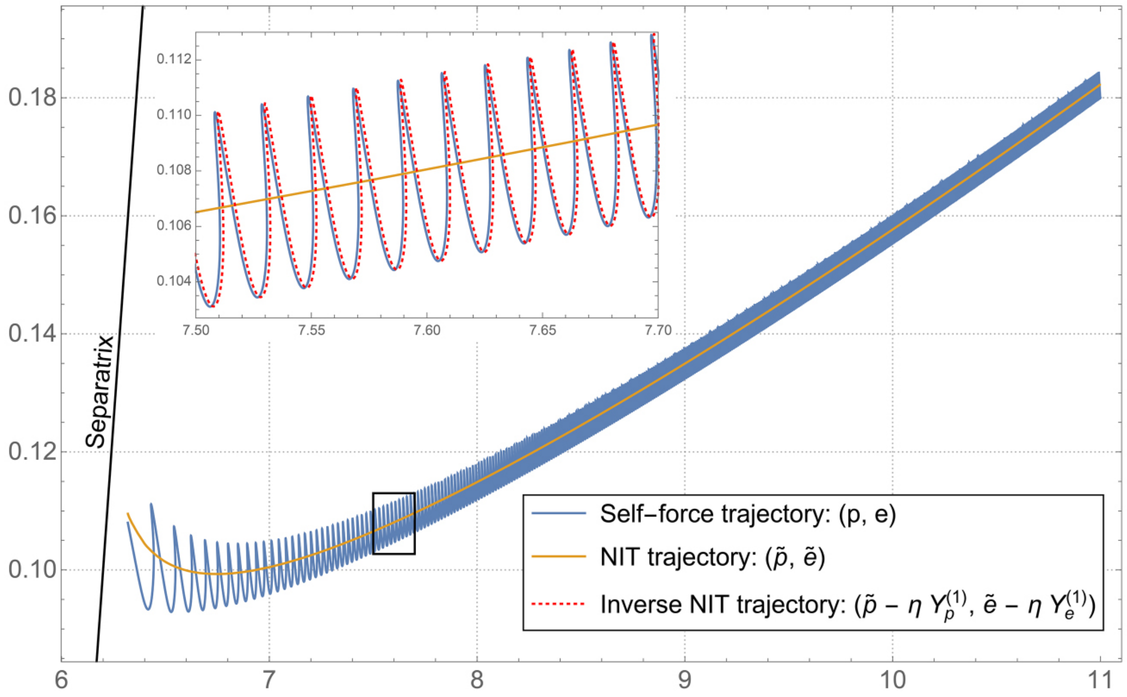


Module Options

Trajectory

- Adiabatic
  - w/ or w/o upsampling (cubic spline)
- GSF 1st-order / NIT / Two-timescale (future)
- Different integrators
  - Affects sparsity

van de Meent & Warburton 2018

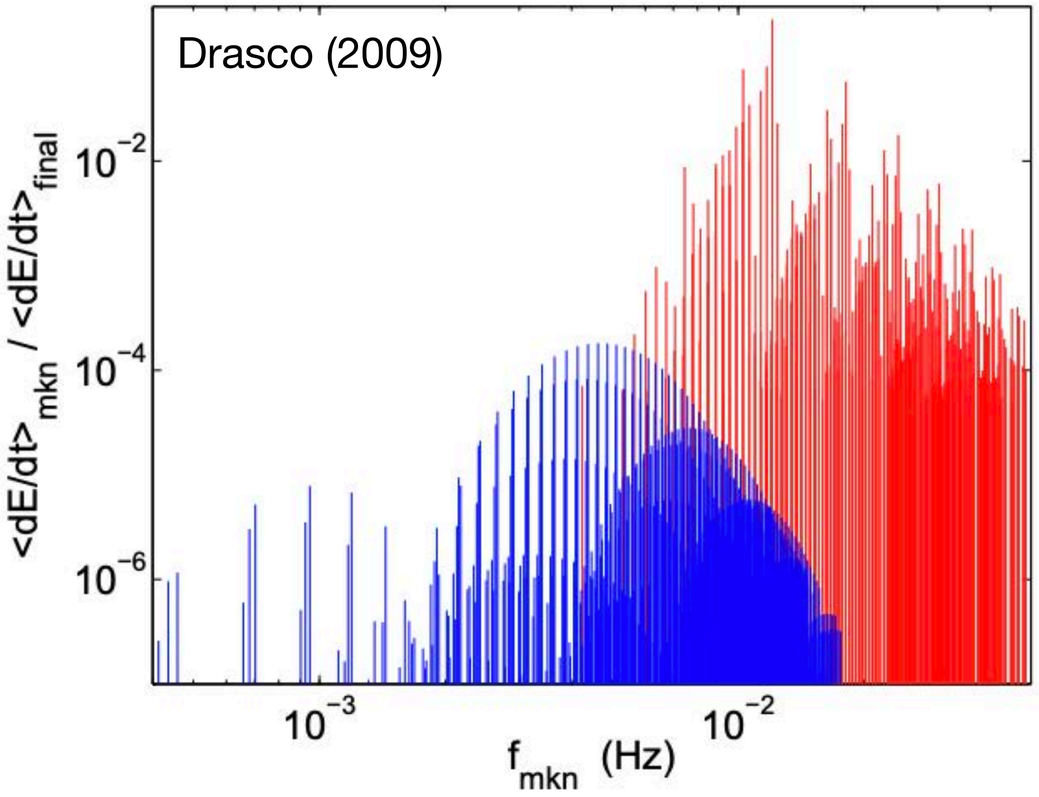


$$h(t) = \frac{1}{r}\sum_{lmn} A_{lmn}(t) e^{-i\Phi_{mn}(t)} V_{lm}(\theta, \phi)$$

Module Options

Amplitude Determination

- ROM + NN (ROMAN; Chua+2019)
- Direct 2D spline interpolation per mode (p, e)

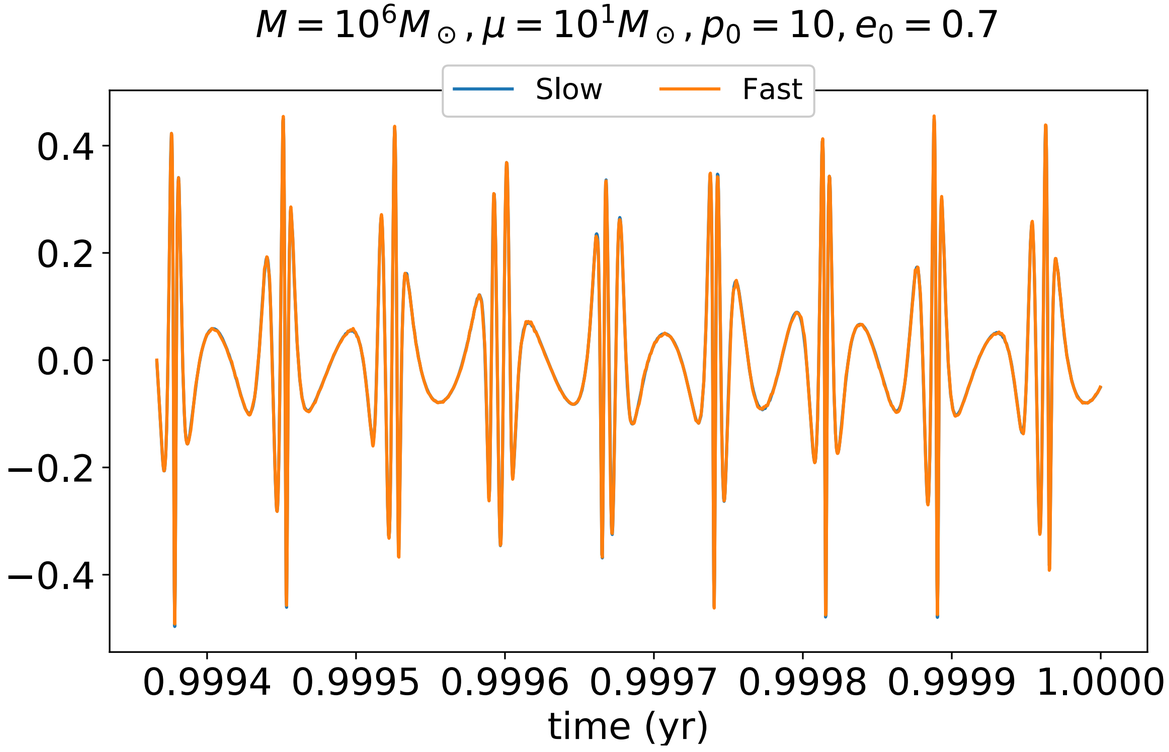


$$h(t) = \frac{1}{r}\sum_{lmn} A_{lmn}(t) e^{-i\Phi_{mn}(t)} V_{lm}(\theta, \phi)$$

Module Options

Waveform Creation

- Direct summation
- Interpolated summation (cubic spline)

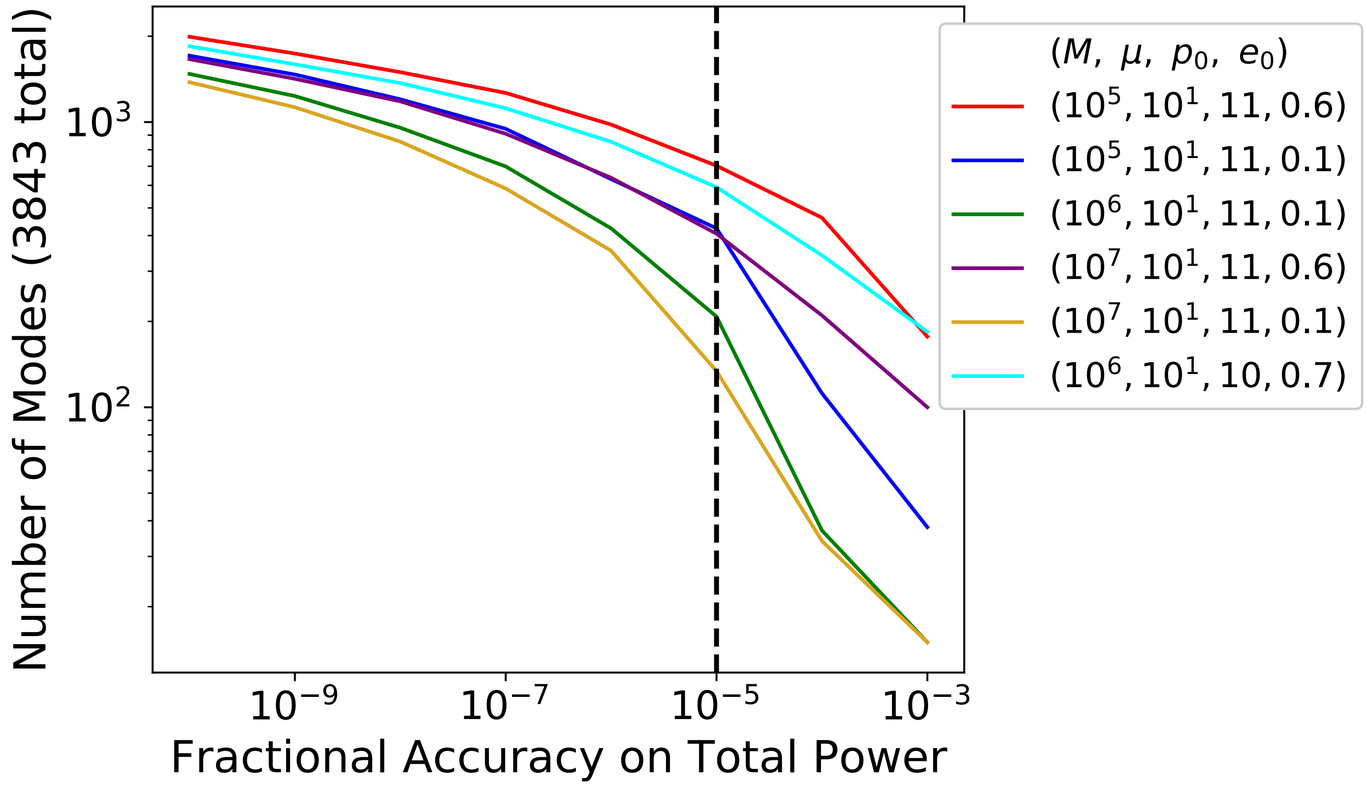


$$h(t) = \frac{1}{r} \sum_{lmn} A_{lmn}(t) e^{-i\Phi_{mn}(t)} V_{lm}(\theta, \phi)$$

Module Options

Utilities

- Mode filtering
- Spin-weighted spherical harmonics
- Overlap calculation



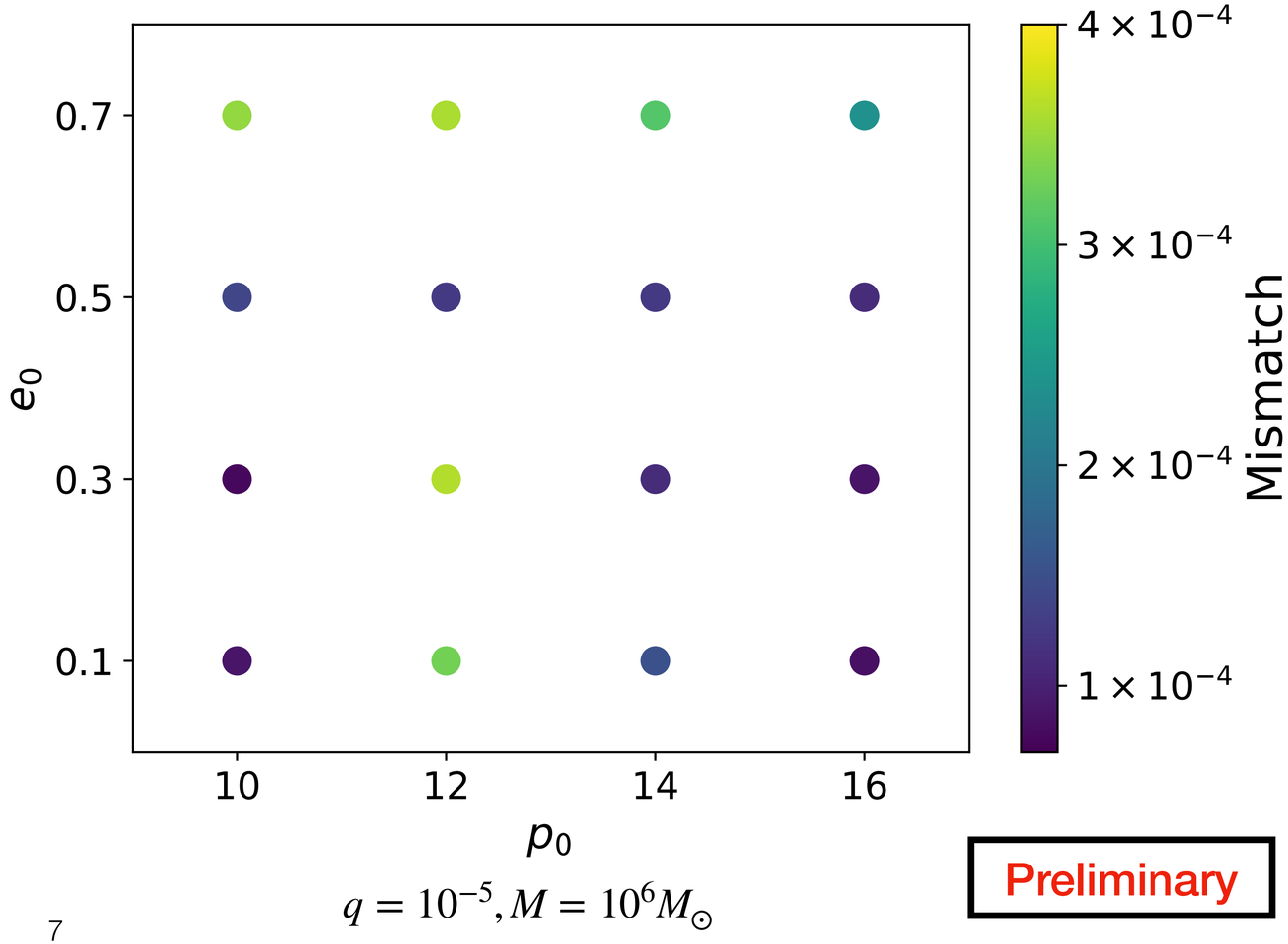
$$h(t) = \frac{1}{r}\sum_{lmn} A_{lmn}(t)e^{-i\Phi_{mn}(t)}V_{lm}(\theta,\phi)$$

Mismatch Analysis

- Normalized correlation
- ~year long inspirals
- Bias analysis in PE (future)

mismatch $\rightarrow \epsilon(a\,|\,b) = 1 - \dfrac{\rho_{a,b}}{\sqrt{\rho_{a,a}\ \rho_{b,b}}}$

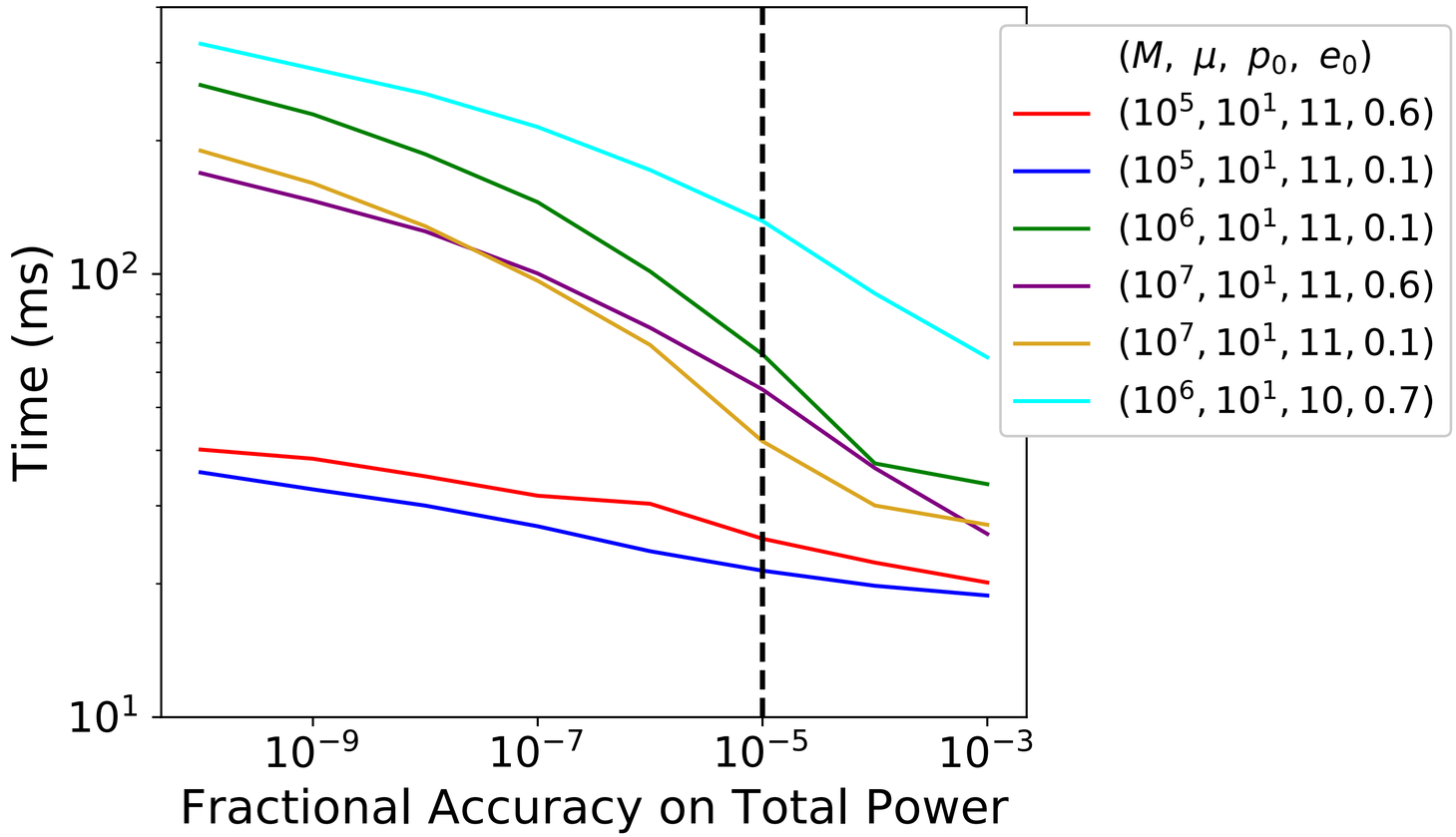
$\rho \rightarrow$ **cross-correlation**



Preliminary

Computationally Efficient Waveforms

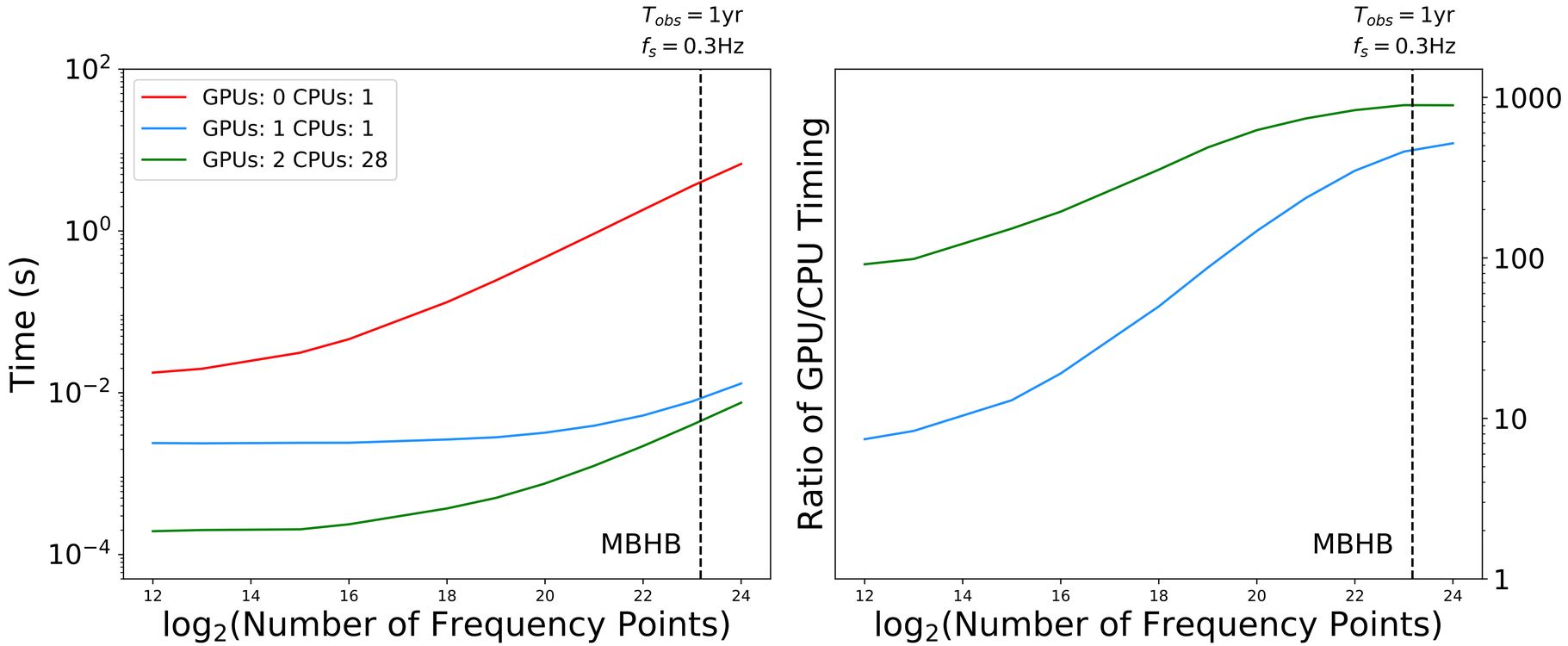
- Goal for PE: ~10s of ms
- GPU implementation
- PE: billions of waveforms



Accelerating GW Computations

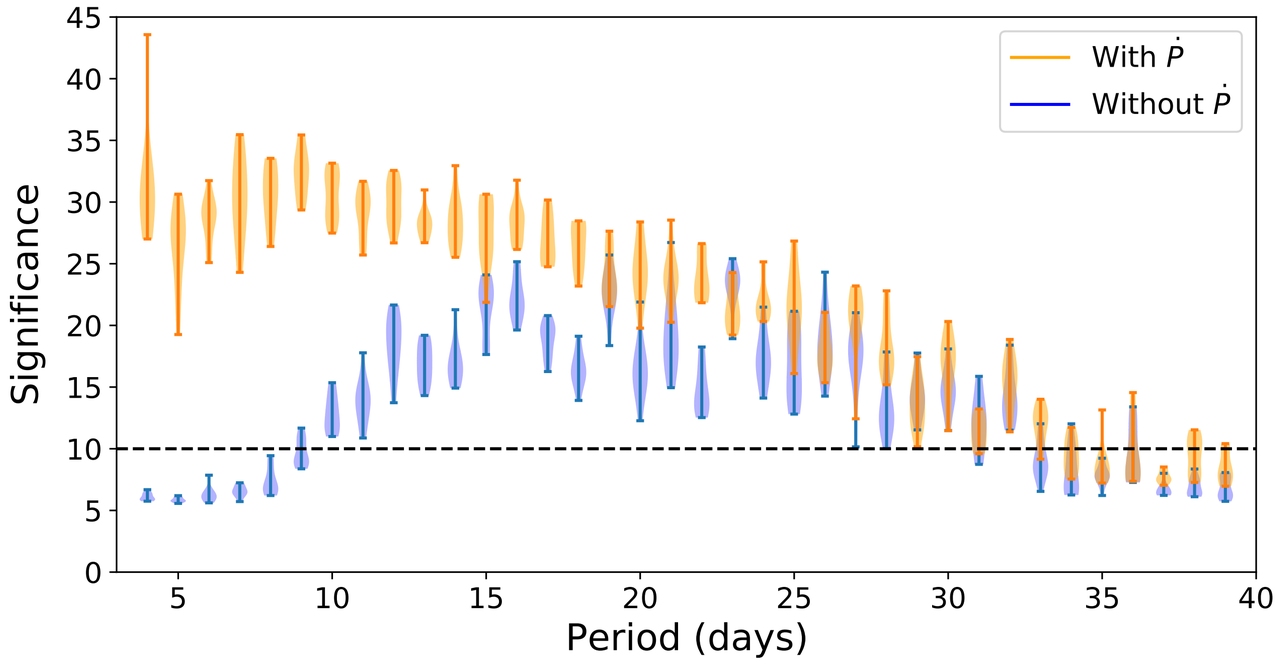
The main goal is to accelerate calculations necessary to move our science forward.

Accelerating GW Computations



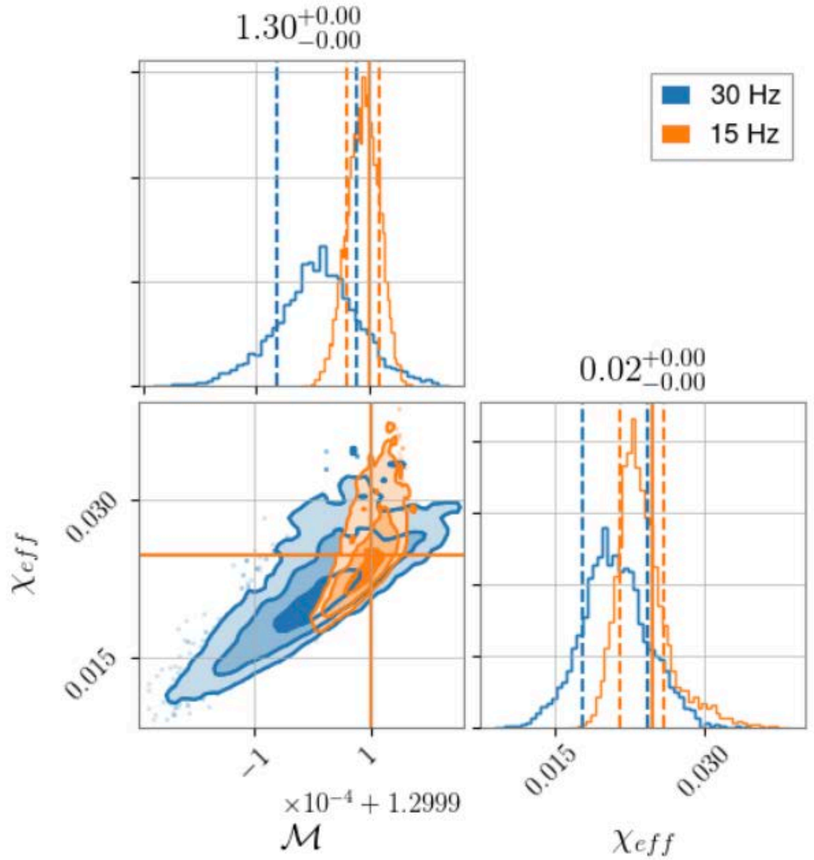
Massive black hole analysis with LISA (Katz+ 2020)

Accelerating GW Computations



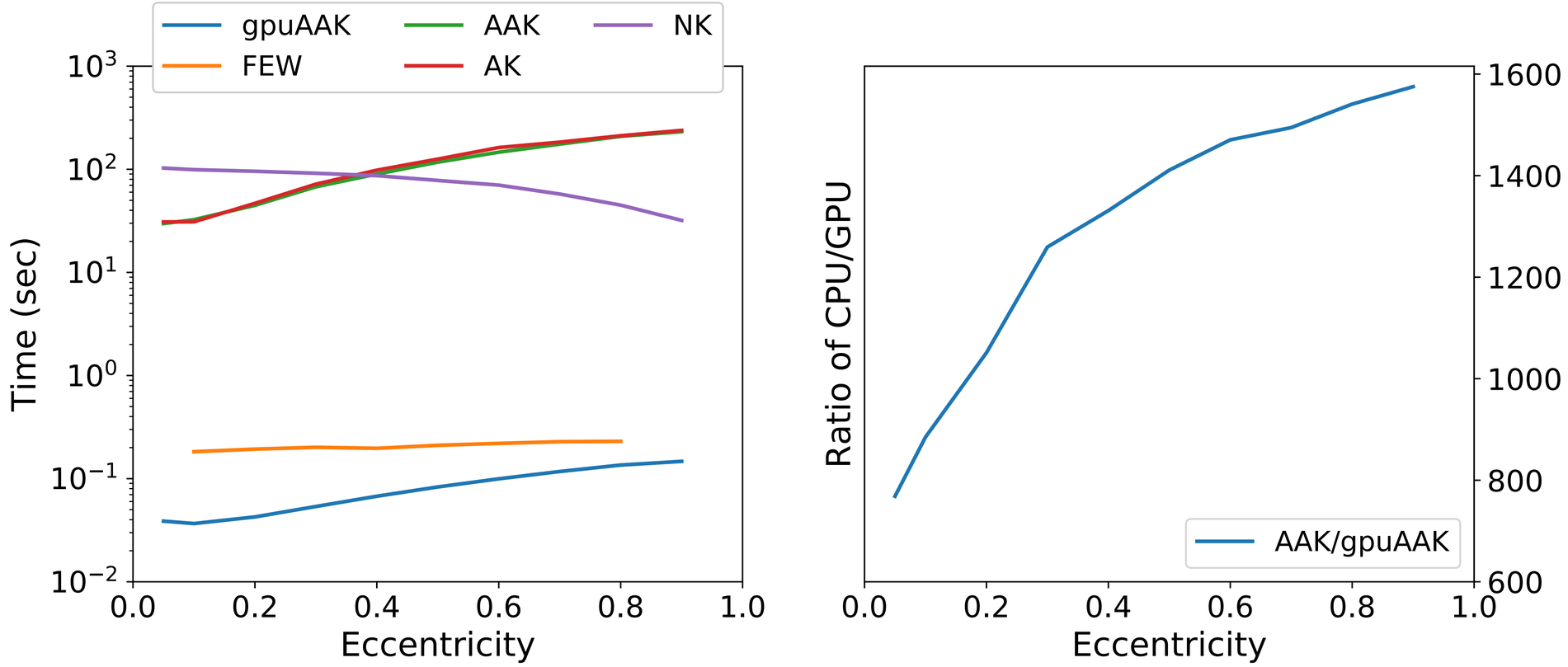
White dwarf binary search in EM surveys (Katz+ 2020)

Accelerating GW Computations



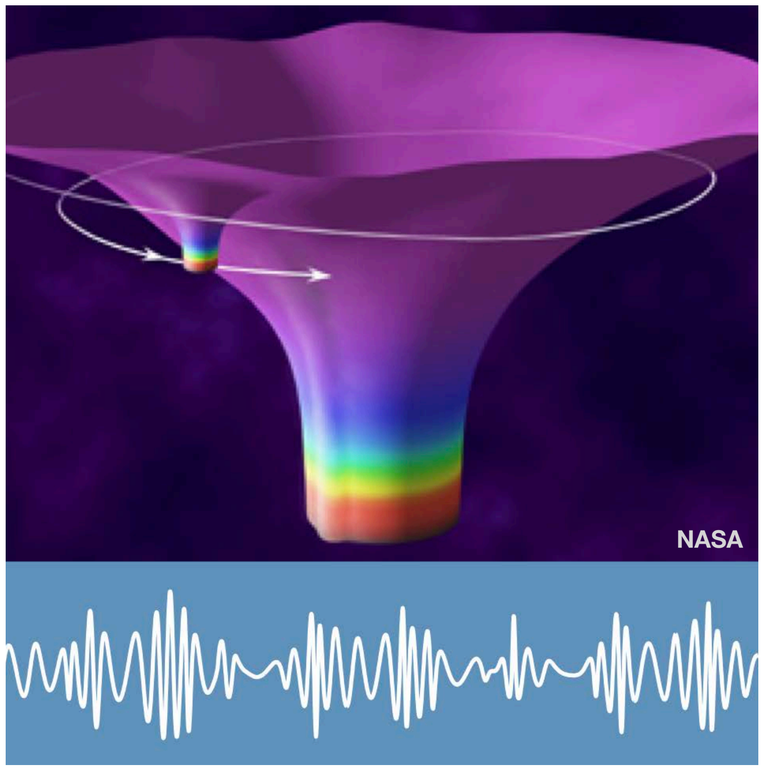
Population inference for ground-based observations (Talbot+2019, Kimball+2020)

Accelerating GW Computations



Accelerating EMRI kludge waveforms for use in data analysis

Accelerating GW Computations



- Scale Mathematica codes
- Accelerate parallelizable regions
- Further EMRI science!

Your code?

e.g. McKennon, Forrester, & Khanna (2012)

Summary

- Our framework is built to be modular and amenable to improvements.
- The observed mismatch and speed are already sufficient or close to sufficient for data analysis.
- Different computational improvements can strongly advance our science capabilities.

References

A. J. K. Chua, M. L. Katz, N. Warburton & S. A. Hughes, Rapid generation of fully relativistic extreme-mass-ratio-inspiral waveform templates for LISA data analysis, in prep.
A. J. K. Chua, C. R. Galley & M. Vallisneri, Reduced-order modeling with artificial neurons for gravitational-wave inference, Phys. Rev. Lett. 122, 211101 (2019).
M. van de Meent & N. Warburton, Fast self-forced inspirals, Class. Quantum. Grav. 35, 144003 (2018).