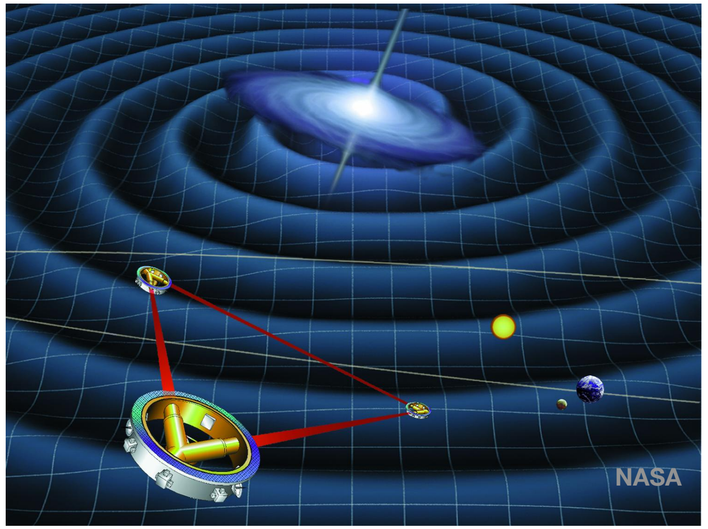
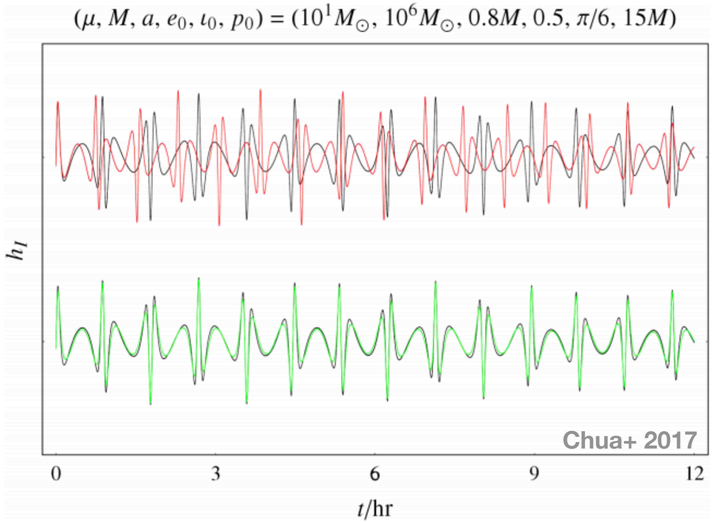
Data analysis calculations with the EMRI Kludge Suite

Michael Katz and Alvin Chua

BHPT Virtual Workshop
25-27 May 2020





Overview of EMRI Kludge Suite

(Our personal) definition of a kludge waveform model:

- Semi-relativistic: Uses flat-space approximations, not self-consistent
- Extensive: Generic Kerr orbits, extrinsic parameters
- End-to-end: Parameters -> trajectory -> orbit -> waveform -> response
- Fast: Feasible for bulk use in data analysis algorithms

Three models implemented in EMRI Kludge Suite:

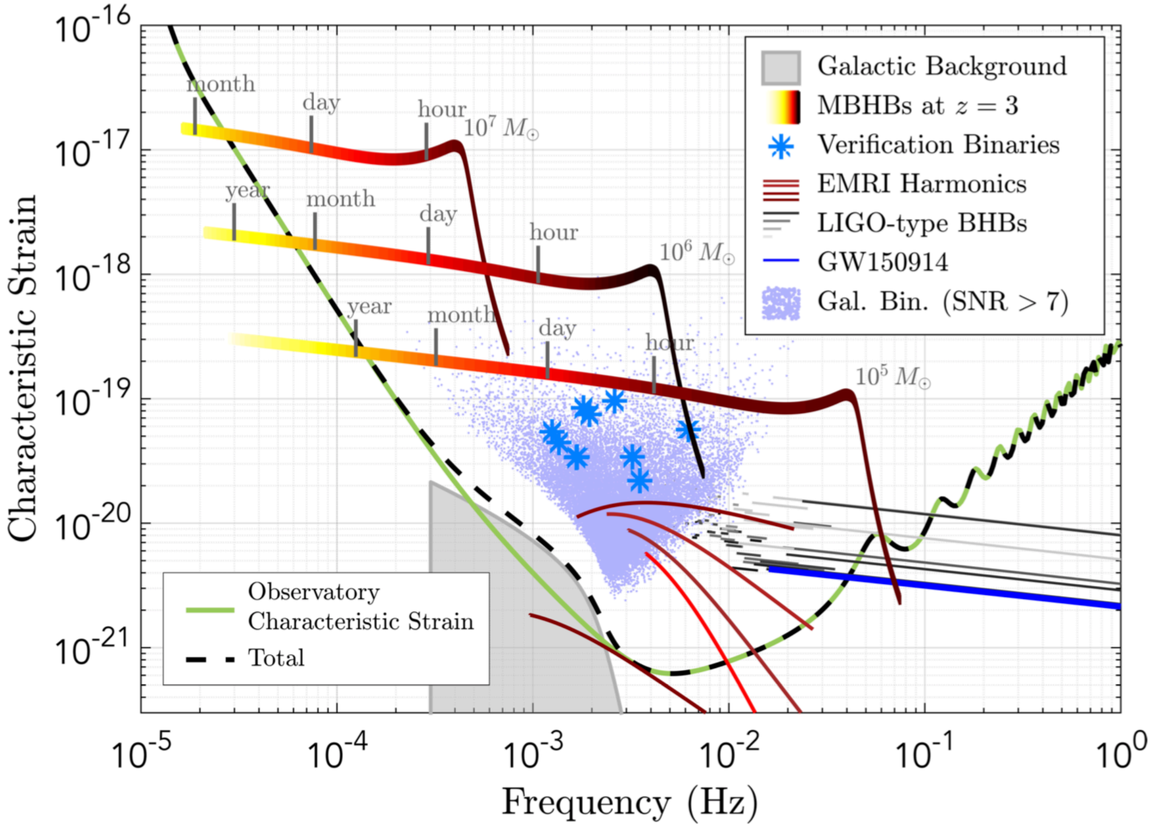
- Analytic kludge (AK): Barack & Cutler, 2004
- Numerical kludge (NK): Babak, Fang, Gair, Glampedakis & Hughes, 2007
- Augmented analytic kludge (AAK): Chua & Gair, 2015

Overview of EMRI Kludge Suite

Model	Trajectory	Orbit	Waveform/response	Accuracy	Speed
AK	- Mixed-order PN fluxes	- Evolving Keplerian ellipses	- Peters-Mathews approximation to quadrupole - Fixed-and-equal-arm response (TDIs)	- Instantaneous frequencies too high - Schwarzschild plunge handling - Qualitative use only	- Fast, but less speedup over NK for shorter waveforms or more eccentric orbits
AAK	- 3PN O(e^6) fluxes - Locally fitted to NK trajectories	- Evolving Keplerian ellipses - Instantaneous frequencies mapped to Kerr	- Peters-Mathews approximation to quadrupole - Fixed-and-equal-arm response (TDIs)	- Phase-accurate w.r.t. NK waveforms, for 2-6 months - Approximate Kerr plunge handling	- Same as AK, but slightly faster due to streamlining - GPU implementation available (fast)
NK	- Mixed-order PN fluxes - Fitted to adiabatic trajectories	- Evolving Kerr geodesics	- Quadrupole - Long-wavelength response (h_I,II)	- Phase-accurate w.r.t. adiabatic waveforms, down to 2-3 r_ISCO - Kerr plunge handling	- Order of magnitude slower than AK/AAK on average

LISA Data Analysis

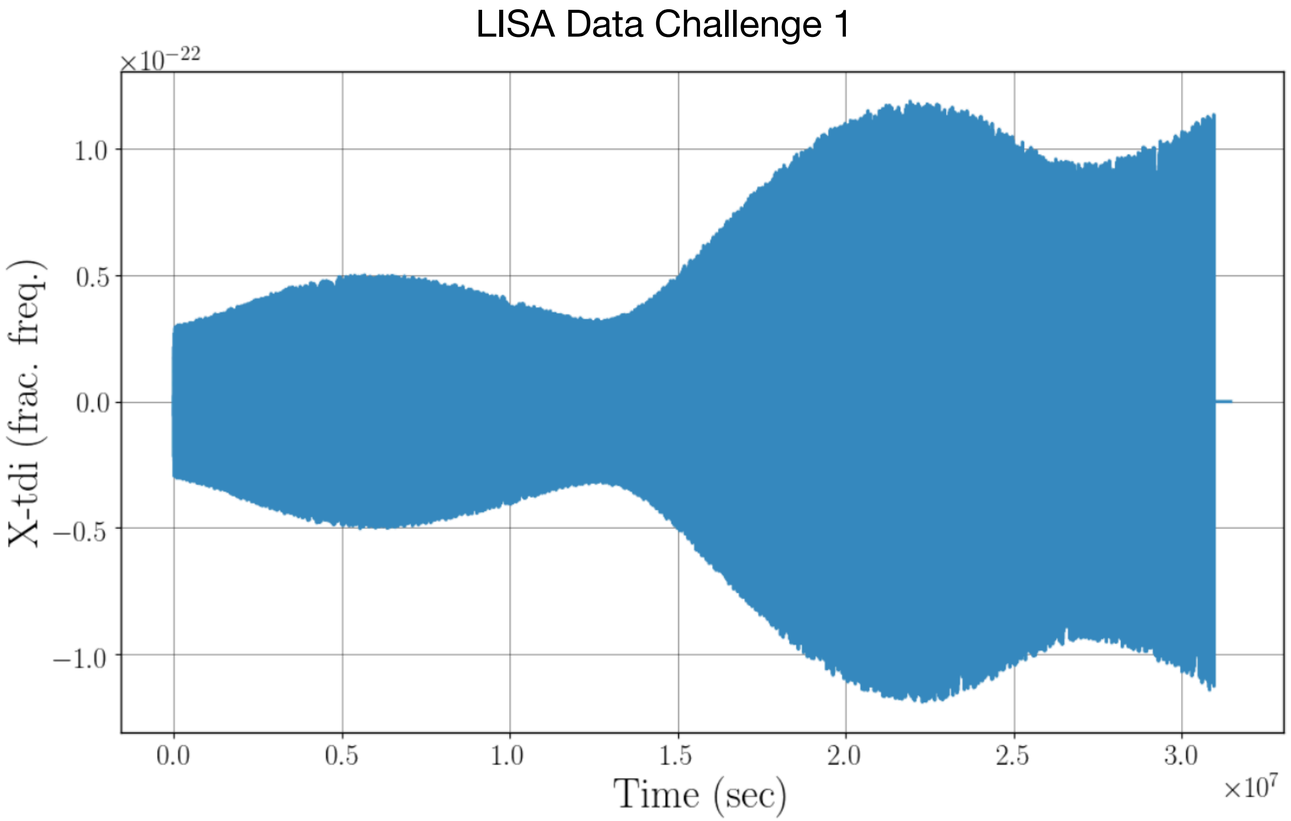
- Goal: find sources, extract accurate parameters, test GR, etc.
- Overlapping Signals
- Data stream never void of sources (harder to estimate noise)
- Non-stationary noise, non-Gaussian noise (glitches), data gaps, etc.



Amaro-Seoane et al 2017

Parameter Estimation for EMRIs

- Long signals (~yr)
- Requires many cycles for detection
- Difficult search and PE
- Need to move towards more accurate waveform models (beyond kludges)



Link: https://lisa-ldc.lal.in2p3.fr/ldc

Calculating the Signal-to-Noise Ratio (SNR)

$$< a | b > = 2 \int_{-\infty}^{\infty} \frac{\tilde{a}(f)^* \tilde{b}(f) + \tilde{a}(f) \tilde{b}(f)^*}{S_n(f)} df$$

$$\rho_a = \sqrt{< a | a >}$$

$\rho \rightarrow$ **SNR**

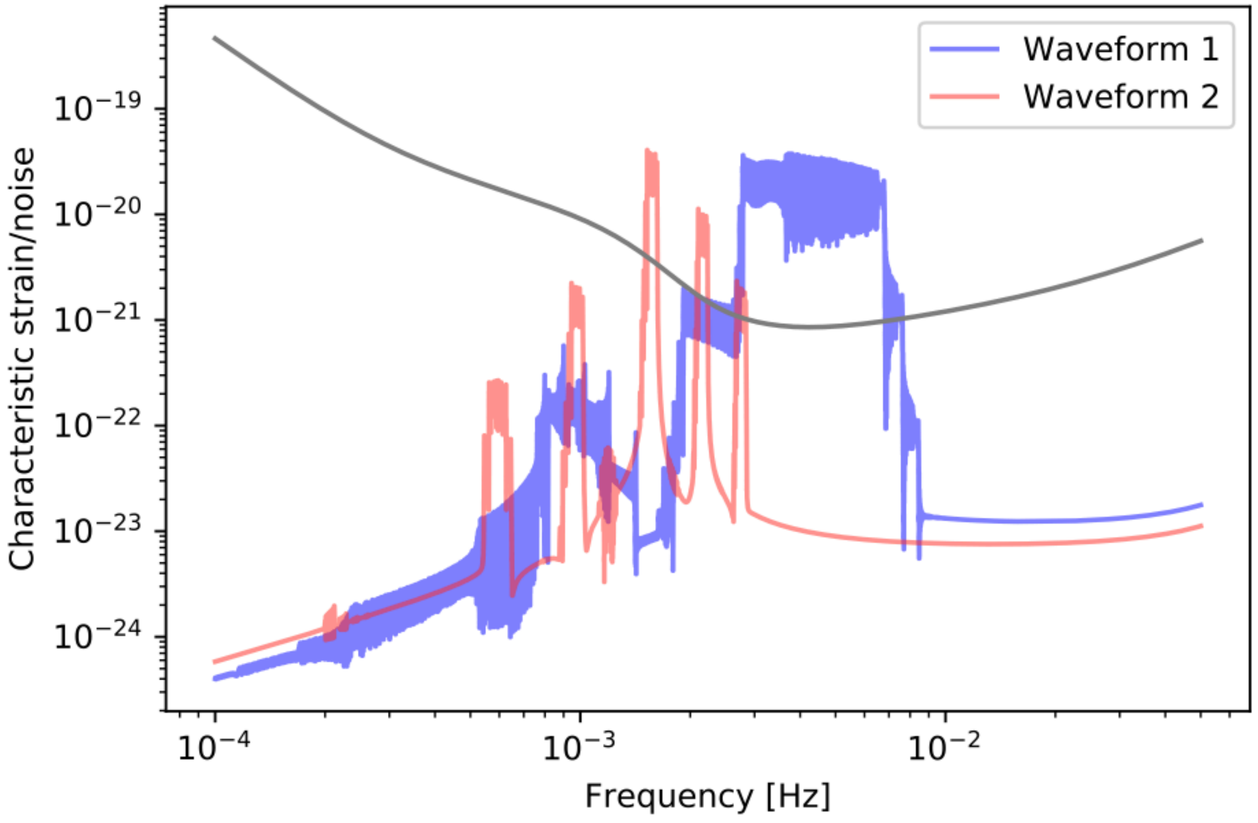
$a(t) \rightarrow$ **Time-Domain Strain Signal**

$b(t) \rightarrow$ **Another Time-Domain Strain Signal**

$\tilde{a}(f) \rightarrow$ **Fourier Transform of** $a(t)$

$S_n(f) \rightarrow$ **Power Spectral Density of the noise**

Estimating the SNR by eye



What we will cover in this notebook:

1. The LISA sensitivity curve
2. Generating AAK waveforms
3. Calculating optimal SNRs
4. Comparing EMRIs across parameter space