# Waveforms in LDC and beyond

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# Main driver

- Simulations
  - Speed is not essential
  - We need h+, hx in solar system barycenter
  - Numerically produce TDIs using interpolation
  - Restrictions: ability to analyze the data (existence of the fast version). Biases could be studied in simpler (noiseless) way

- Analysis: fast fast fast
  - Easy/fast to apply response
  - We generate (often) TDI directly: use phase and amplitude with response function
  - Availability: code easy to adapt to our need for sampling
    - MBHBs: we define some parameters at merger
    - EMRIs: some parameters defined at plunge

# Galactic binaries (GBs)

- The signal is almost monochromatic
  - Taylor expansion of the phase: A Sin($\phi_0 + \omega t + \dot{\omega} t^2/2$)
  - Doppler modulation: harmonics ot 1/year in frequency domain
- Several versions of response
  - The response is generated in the time domain with a large time step (weeks), assuming the GW signal is emitted at the nearest Fourier bin. Then response is transformed in freq. domain and shifted.
- Complications:
  - Hierarchical triplets: accelerated c.o.m.
  - Eccentric binaries
    - Periapsis precession
    - Harmonics of mean anomaly in the freq. Domain
  - Finite size effects?

# MBHBs

- We currently use PhenomHM waveforms
  - Circular, no orbital precession
    - Easy to apply response: harmonic by harmonic in frequency domain
    - We use stationary phase to associate time and frequency, and assume "frozen" LISA at the merger (few hours)
  - Many degeneracies (especially without higher modes (HM))
  - Quite fast to generate
- We need waveforms for eccentric and precessing binaries + long (between a month* and few hours with cadence 10 sec)
  - Response is the main issue: response is a function of time and instantaneous frequency
  - Multi-voice: many harmonics at the same instance.
  - Apply response in time domain (interpolation), GPU?
- Fast likelihood:
  - "Heterodyning" ($s-h_{appr}$) if approximation is reasonable, we remove the fast oscillating part of the signal: low frequency -> fewer points.

# EMRIs

- FEW package
  - Schwarzschild eccentric based on the interpolated self-force
  - AAK5PN: mapping AK onto proper geodesic. Generic orbit
  - Many harmonics (beatings of three slowly evolved orbital freqs.)
  - Do not cover the whole parameter space (but most of it), ecc<0.7
- Response
  - GPU in time domain, or harmonic-by-harmonic
- Need fast and realistic waveform (self-force) for generic orbits
- Simulated data to be released
  - AAK and Schwarzschild:
  - Priors: AAK e(t=0) U[0.1, 0.4], e(t=plunge) U[0-0.3], use a reference time/frequency
  - Schwarzschild e(t=0) < 0.7,   separatrix + a bit [7*(6 +2e(t=0)) - 41.9 < p0 < 14*e0 + 0.1]  ->  p0 < 16+ 2e(t=0)
  - 1e5<M_mbh < 3e6, 5<mu<50,    mu/M <1e-4
  - 15< SNR <75
  - AAK:   0.2<S<0.9,     0.99>|cos(incl)|>0.45
  - Cadence 10 sec
  - Duration: 2 years, 1 EMRI plunge within  6 months, 2nd in the 1-2 years and 3rd plunges outside 2 years
  - Orbit truncated Keplerian (fixed armlength)
  - TDI2.0

# StBBH: stellar mass BBHs

- Based on spin-aligned PhenomD
  - Mildly relativistic
  - Assume circular orbit (wrong assumption)
  - Use SPA
  - long-lived, could be multiband: leaving LISA band during observation period
  - Response could be applied in freq. domain (doppler modulation, non-trivial response at high freq.)
- Recently released dataset
  - 8 sources: Do It Yourself
    - 3 multiband
    - 2 years, 5 sec cadence, TDI2.0
- Need eccentric waveforms
  - Long duration
  - The eccentricity could be large

# What else...

- Unification of notations and referring to a single preferred frame
- Non-stationary noise
  - Time-frequency formulation of matched filtering
- Burst-like GWs (binaries)
  - Hyperbolic orbits
  - Very high eccentricity
- Fast waveforms (with response)/fast likelihoods
  - Machine learning techniques?