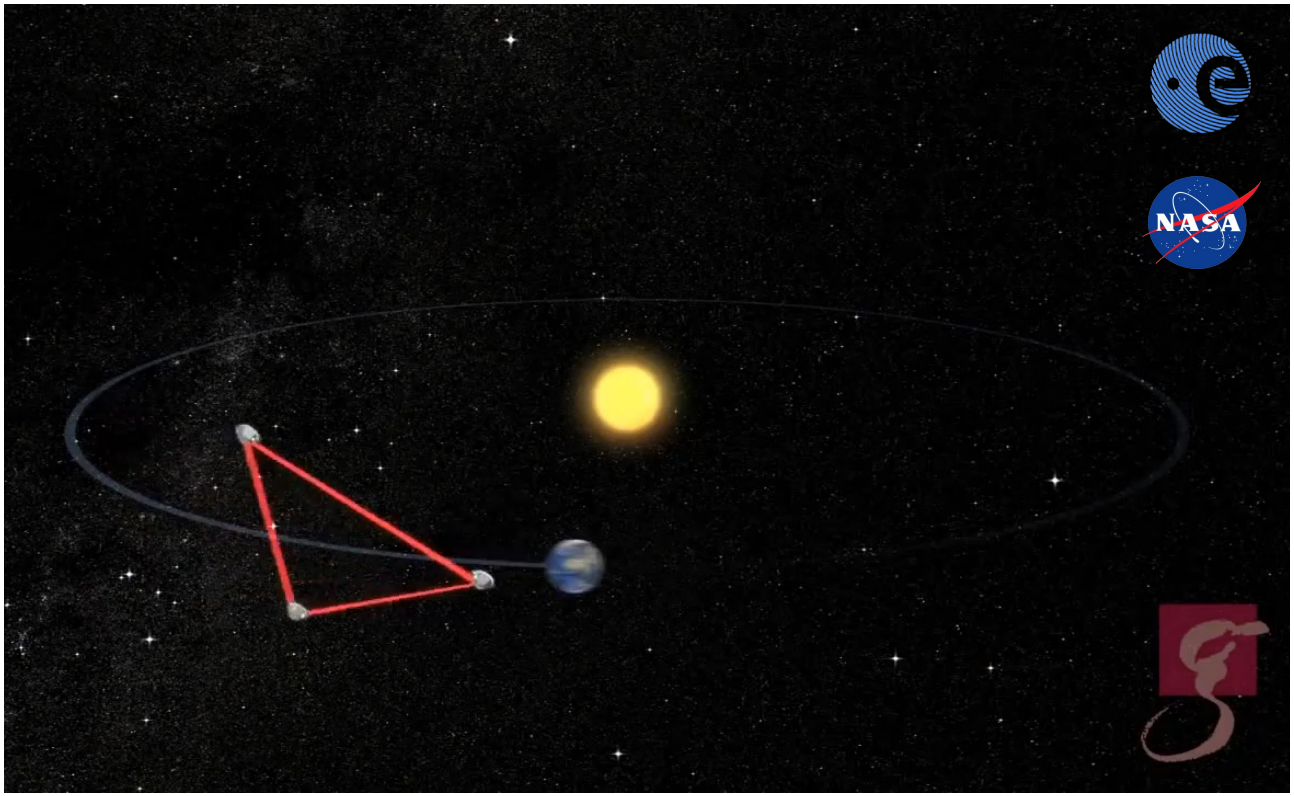
Finding EMRI Signals in Simulated LISA Data

AUGUST MULLER

Laser Interferometer Space Antenna (LISA)

- First space-based gravitational wave detector
- Begins operation in 2030s
- Constellation of 3 spacecraft in heliocentric orbit
- Large arm lengths (2.5 million km separation)



Extreme Mass Ratio Inspiral (EMRI)

- Stellar mass compact object and massive black hole
- Complicated orbit!
- Small object maps out extreme spacetime close to massive black hole
- Not yet detected (no existing techniques)

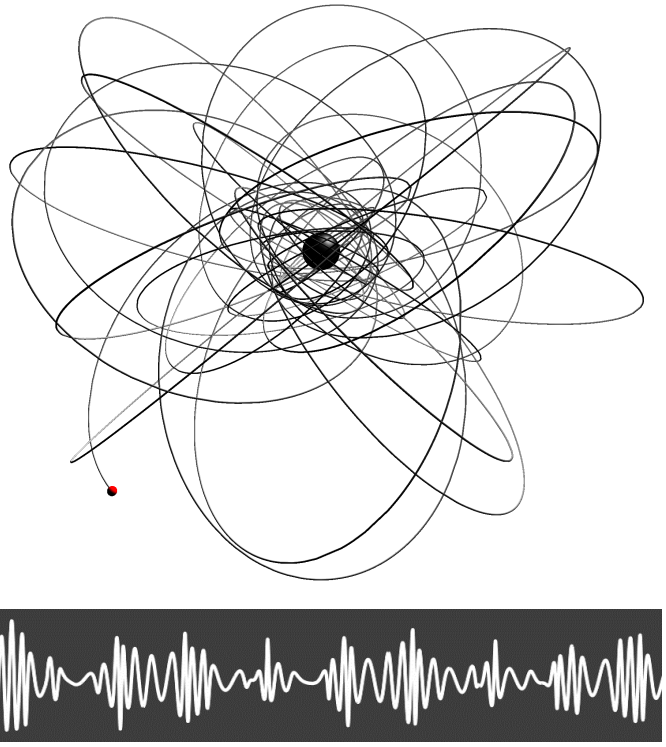
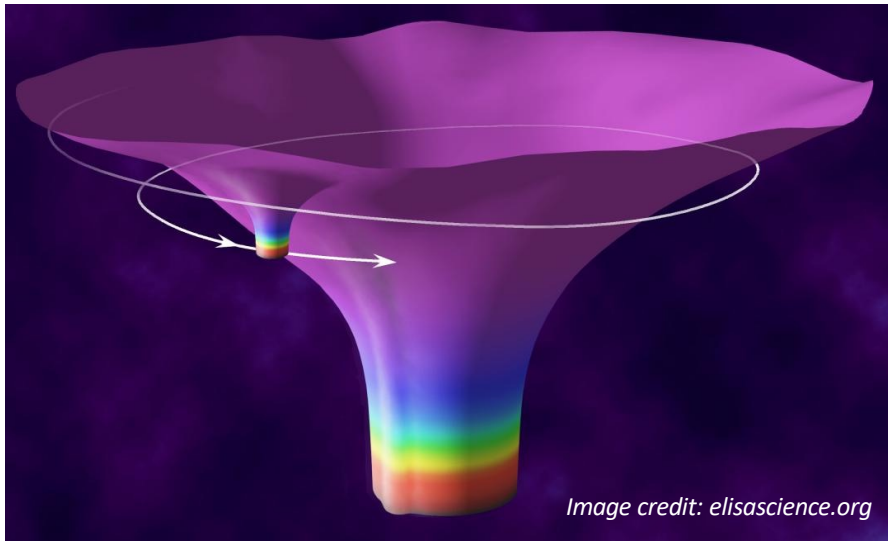


Image credits: M. van de Meent, https://lisa-ldc.lal.in2p3.fr/

Why do I care?

- Test general relativity predictions
  - Encode info about spacetime surrounding massive black hole
- Estimate cosmological parameters
  - Independent method to measure the Hubble constant (expansion rate of the universe)
- Investigate stellar populations near galactic centers
- No existing techniques for robustly detecting EMRI signals!



EMRI harmonics

- 3 independent frequencies (time evolving)

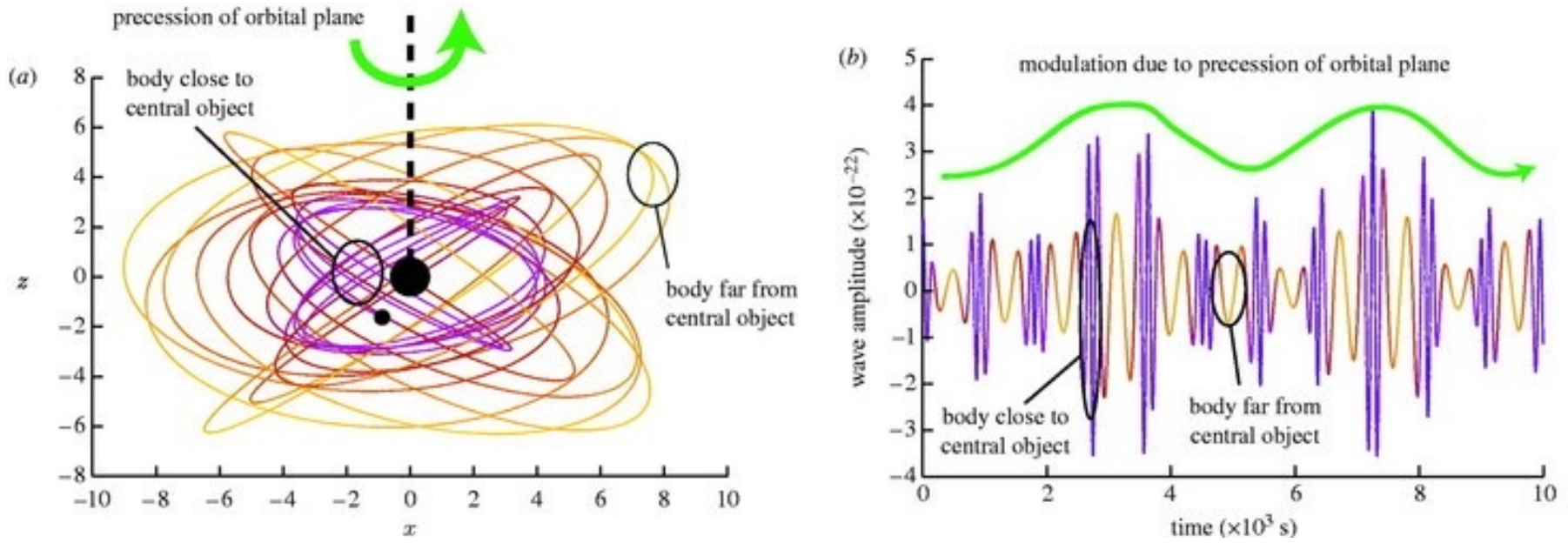
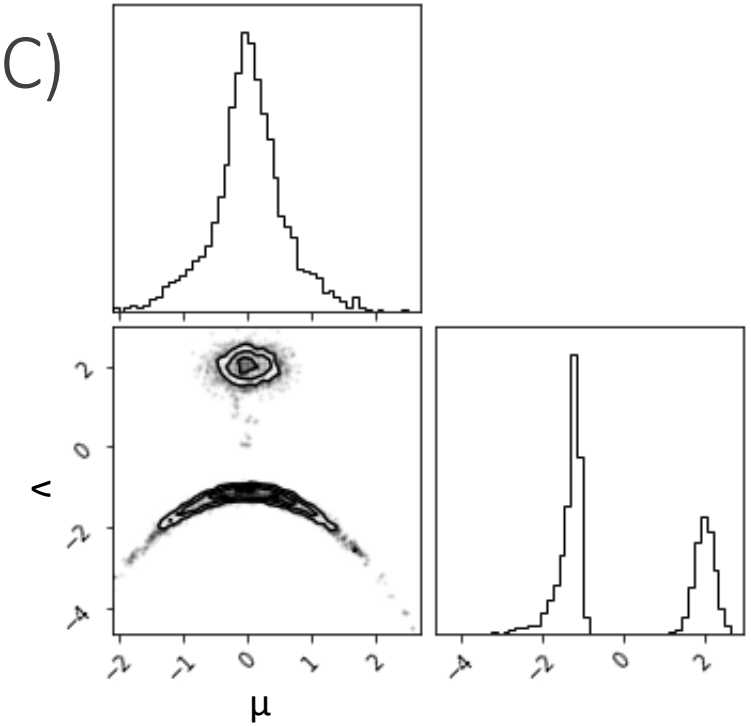


Image credit: DOI 10.1098/rsta.2008.0170

Markov Chain Monte Carlo (MCMC)

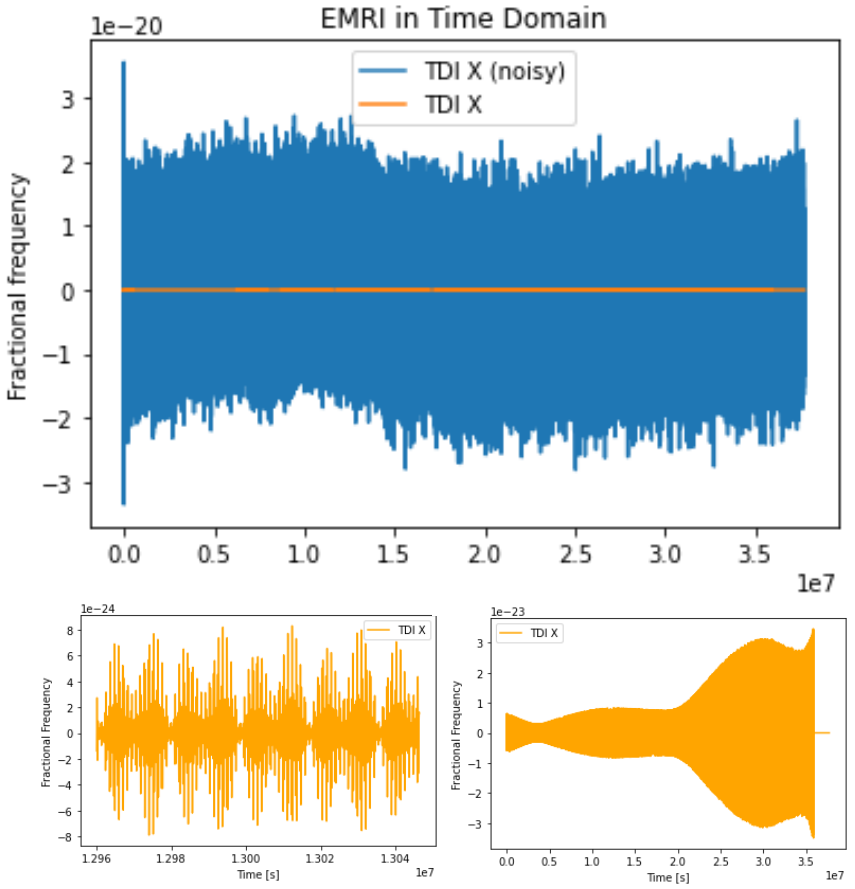
- Markov Chain = hill climbing algorithm
- Monte Carlo = run many times using random values
- Template matching (make a waveform/compare)
  - Extract EMRI parameters based on results
- Used for LIGO, other LISA source classes



$$p(\mu,\nu) = \frac{16}{3\pi}\left(e^{-\mu^2-(9+4\mu^2+8\nu)^2} + \frac{1}{2}e^{-8\mu^2-8(\nu-2)^2}\right)$$

The LISA Data Challenges

- Simulated LISA data
- Still adding more realistic noise, gaps, etc.
- LDC 1-2: EMRI injection

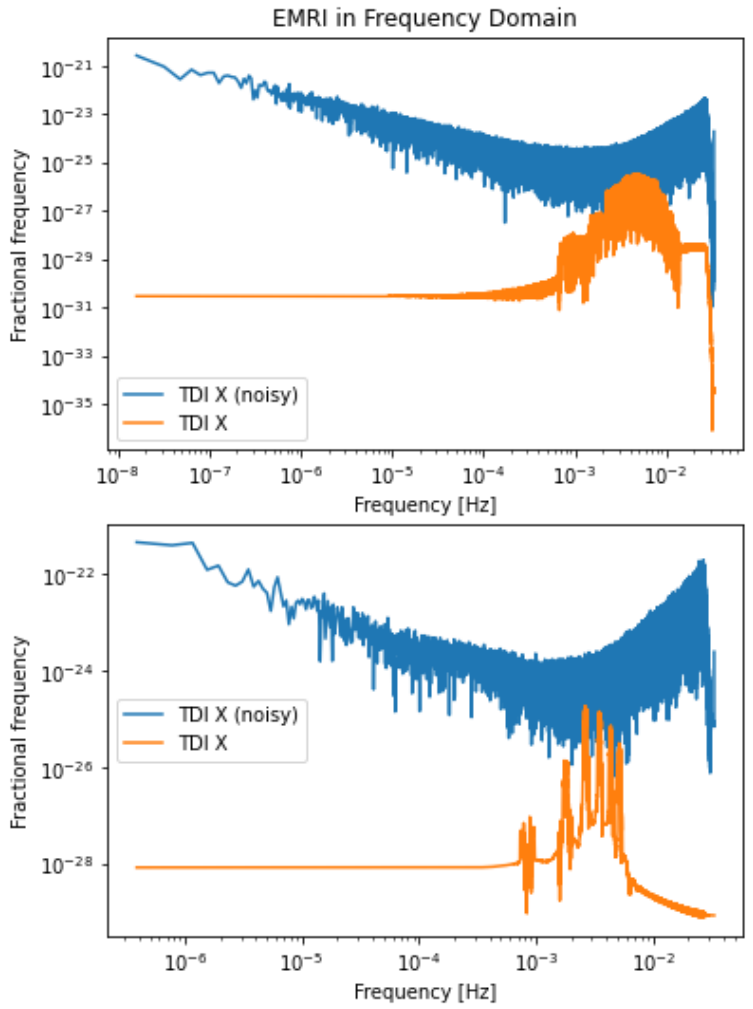


The EMRI Search

- Frequency space analysis
- 1 month segment analysis

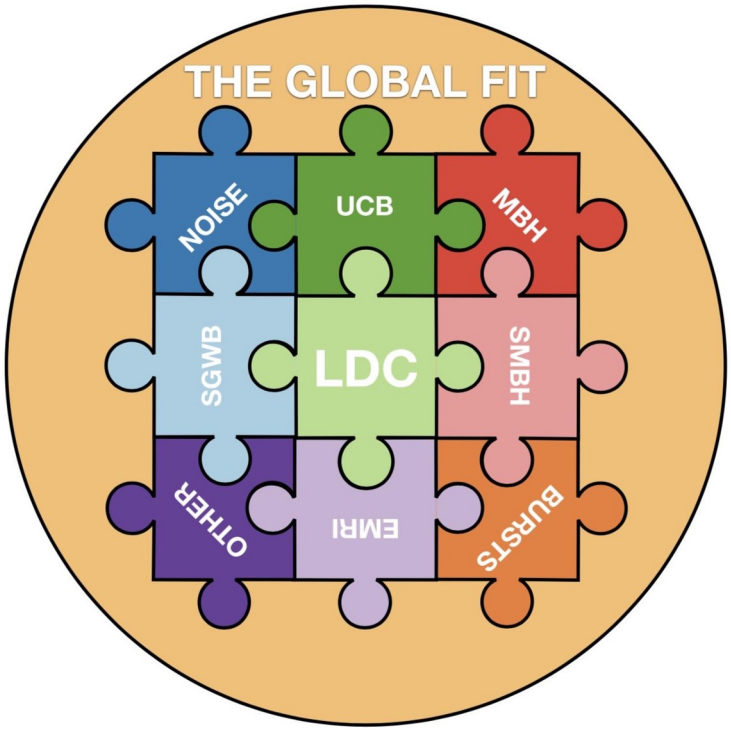
$$(a|b) = 4\mathrm{Re}\int_0^{+\infty} \frac{a(f)b^*(f)}{S_n(f)}$$

$$\ln \mathcal{L} = -\frac{1}{2}(x - x_{inj}|x - x_{inj} + y - y_{inj}|y - y_{inj} + z - z_{inj}|z - z_{inj})$$



Current Status & Future Work

- MCMC Algorithm developed (UW supercomputing cluster)
- Computationally intensive
- Template generation incomplete
    - Faster waveforms when available (FEW: arXiv 2104.04582)
- Incorporate into LISA analysis pipeline (arXiv 2301.03673)



Credit: Tyson Littenberg

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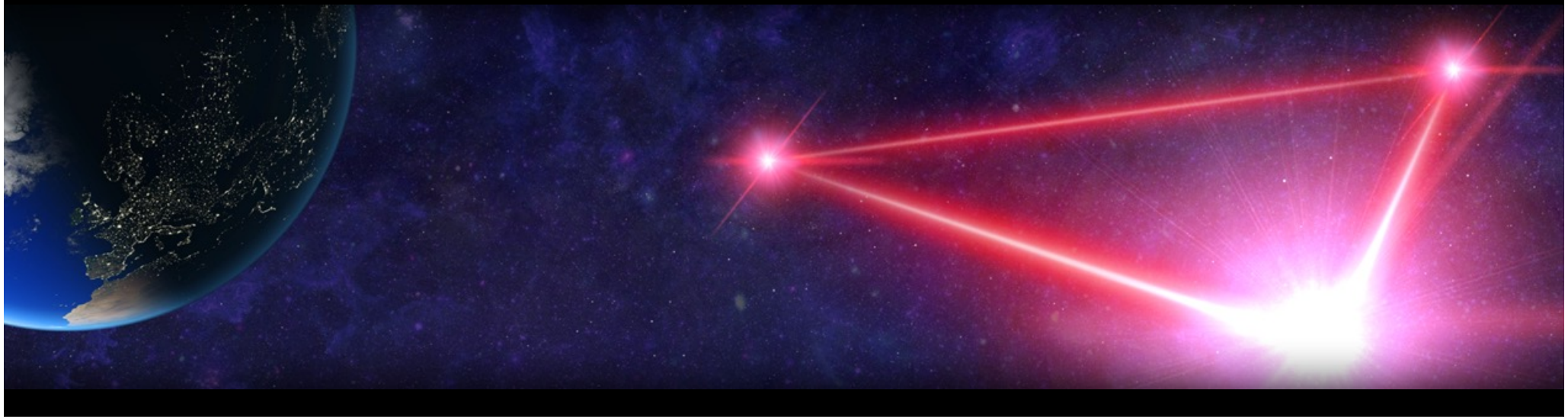

EMRI Waveforms

- Waveform generation – active area of research
- 15 parameters (mostly intrinsic, some extrinsic)

Description	Parameter	Notation	units
Sky position (SSB)	β	EclipticLatitude	Radian
Sky position (SSB)	λ	EclipticLongitude	Radian
Mass of SMBH	M	MassOfSMBH	SolarMass
Mass of compact object	μ	MassOfCompactObject	SolarMass
SMBH spin	S	SMBHspin	MassSquared
SMBH spin orient. (in SSB)	θ_K, ϕ_K	PolarAngleOfSpin	Radian
Radial orb. freq. $(t = 0)$	ν_0	InitialAzimuthalOrbitalFrequency	Hertz
Orb. mean anom. $(t = 0)$	Φ_0	InitialAzimuthalOrbitalPhase	Radian
Eccentricity $(t = 0)$	e_0	InitialEccentricity	1
Dir. of pericenter $(t = 0)$	$\tilde{\gamma}_0$	InitialTildeGamma	Radian
Azimuthal angle of orb. $(t = 0)$	α_0	InitialAlphaAngle	Radian
Inclination of orbit	Λ	LambdaAngle	Radian
Luminosity distance	D_L	Distance	Gpc
time of plunge	t_{pl}	PlungeTime	Second
-	Approximant	AK	ModelName
-	ObservationDuration	-	Seconds
-	Cadence	-	Seconds

Credit: LDC Manual