

The background of the slide is a deep space image featuring a portion of the Earth in the upper left corner. Two bright, distant stars are visible, with a series of red lines connecting them, suggesting a gravitational wave signal or a path of observation. A large, bright, white and pinkish-purple energy release or explosion is centered in the lower right quadrant.

Investigating the impact of gravitational wave glitches on the parameter estimation of extreme mass ratio inspirals

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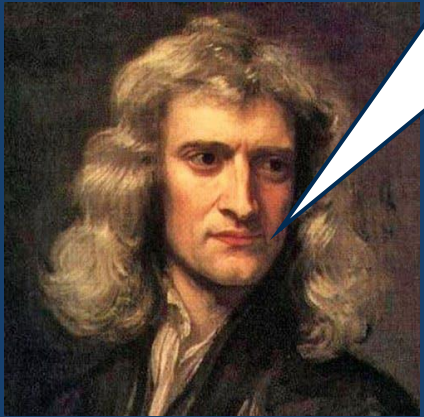


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Interpretation of gravity

- Gravity is an attractive force between two masses
- Mass is the source of gravity
- Gravity acts instantaneously

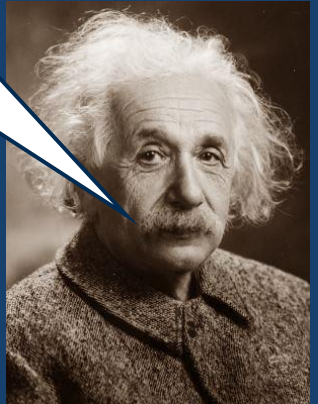
- Gravity is a curvature of spacetime
- Mass is *one* source of gravity
- Gravity does *not* act instantaneously



Classical physics

$$F = \frac{GMm}{r^2}$$

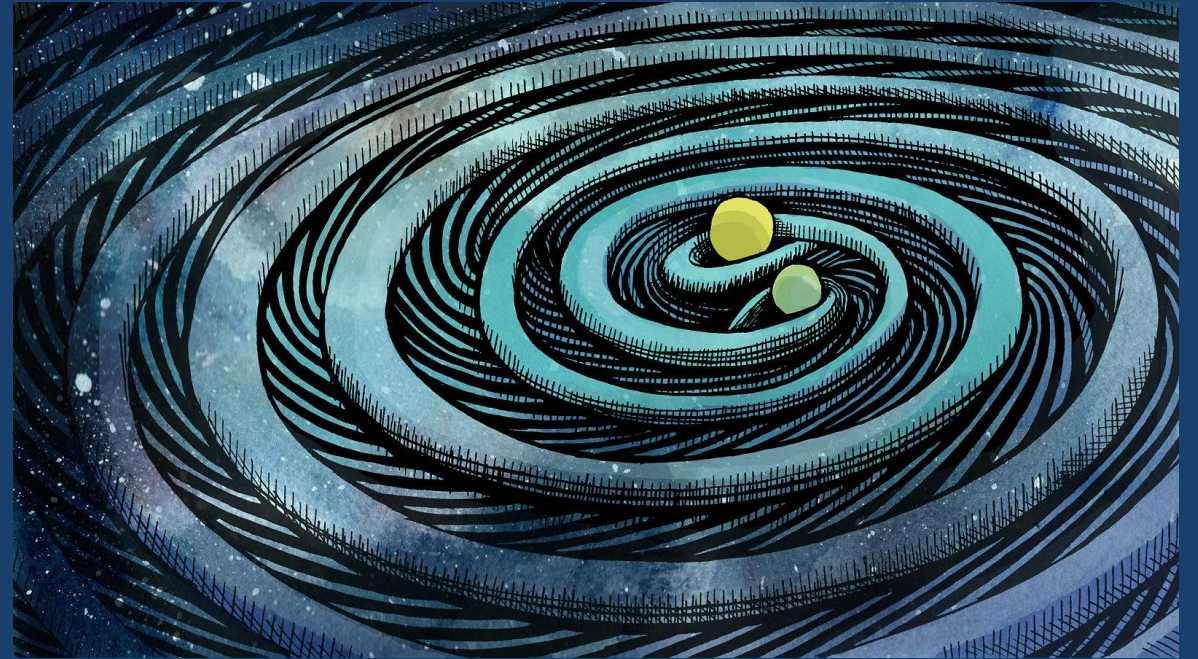
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \kappa T_{\mu\nu}$$



Modern physics

Gravitational waves

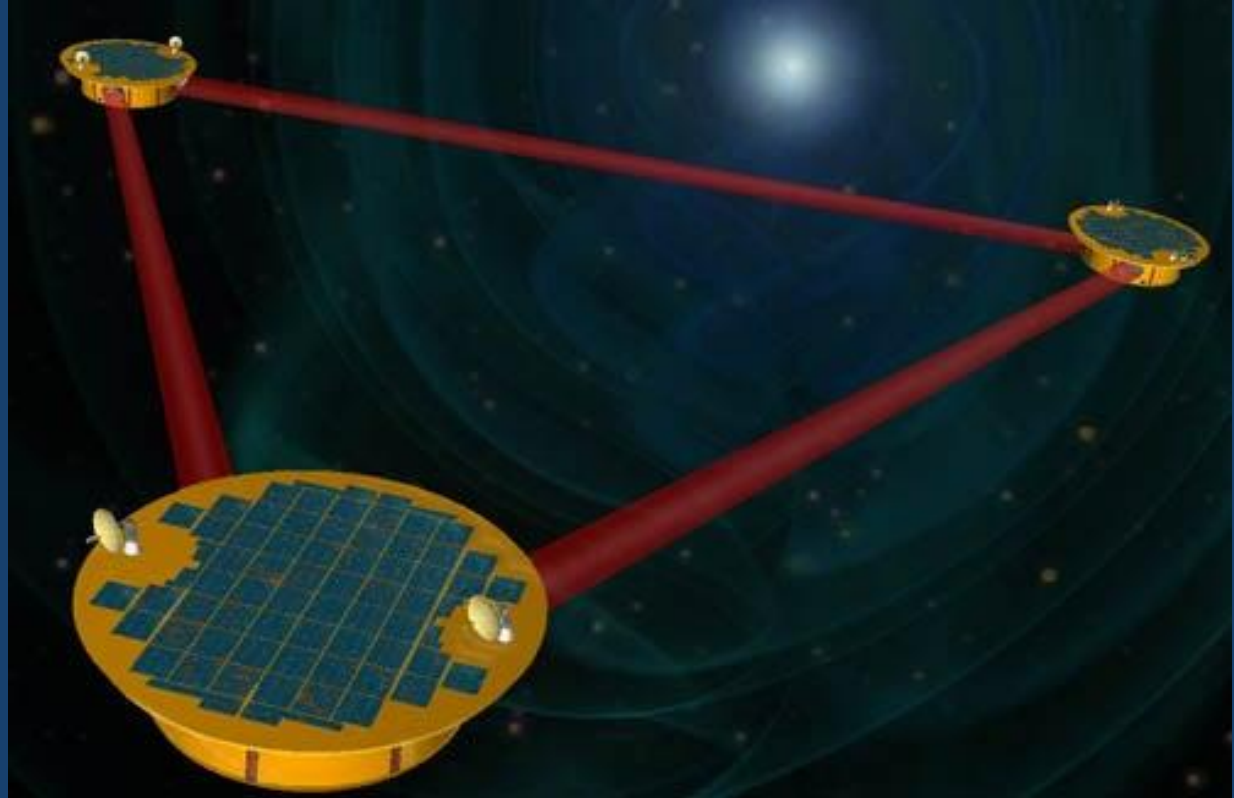
- “Ripples in spacetime” ?
- Caused by accelerating masses
- Strain $h(t)$ is usually $O(10^{-21})$
- 1st Earth-based detection in 2015 by the LIGO collaboration



No space-based detections...yet!

LISA: the space-based GW detector

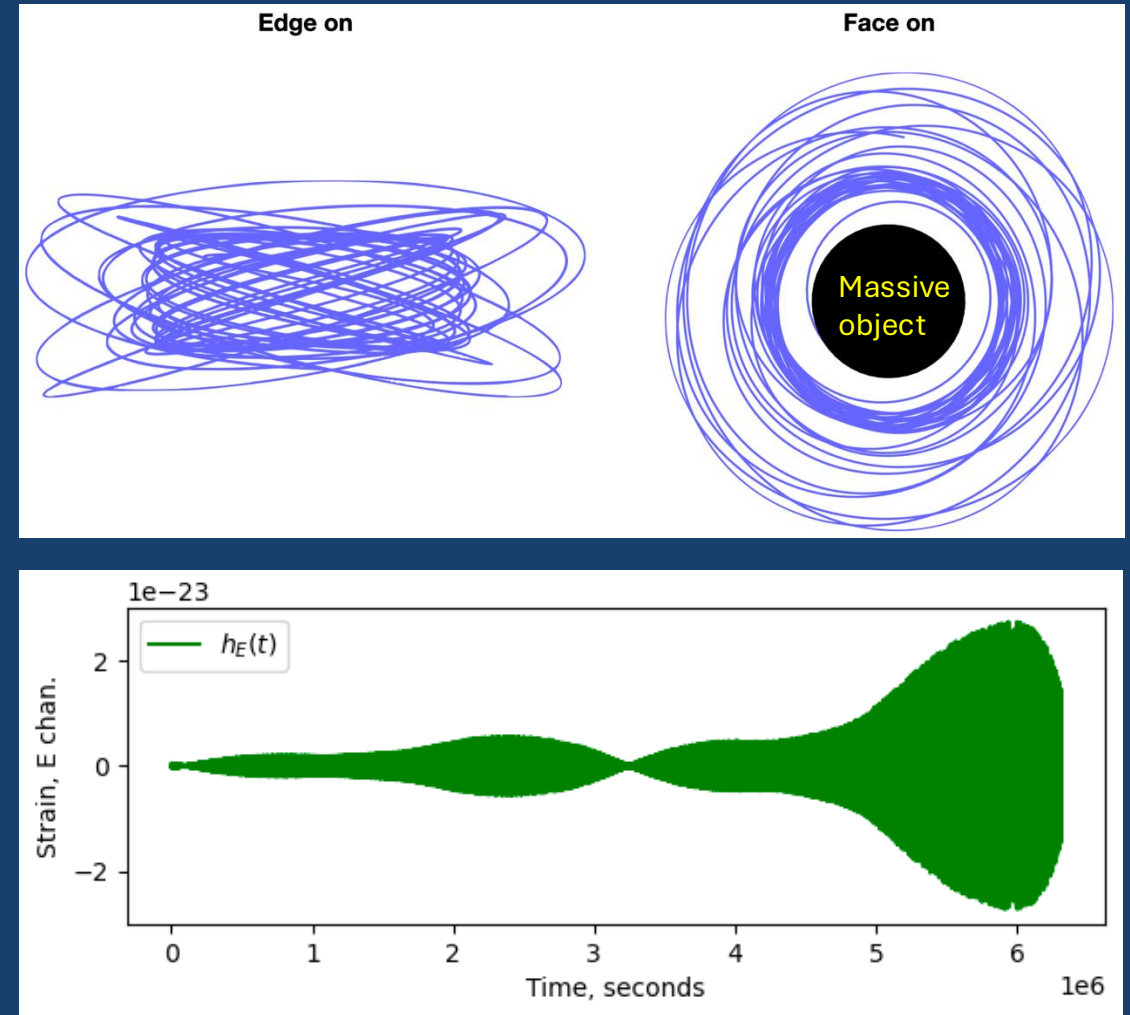
- Constellation of 3 spacecraft equipped with 6 lasers
- Trails Earth, orbits the Sun
- To be launched in the mid-2030s
- Will allow GW detections at frequencies lower than possible on Earth (0.1mHz to 1Hz)



GW source: extreme mass ratio inspiral

- Mergers of **massive** and **compact** object with mass ratio $\frac{M}{\mu} > 10^4$
- Low-amplitude, years-long GW signals
- Successful detection will permit new tests of GR, cosmology etc.

EMRI's $h(t; \bar{\theta})$ is modelled with 14 parameters e.g. masses M and μ , spin a , inclination ι , ...



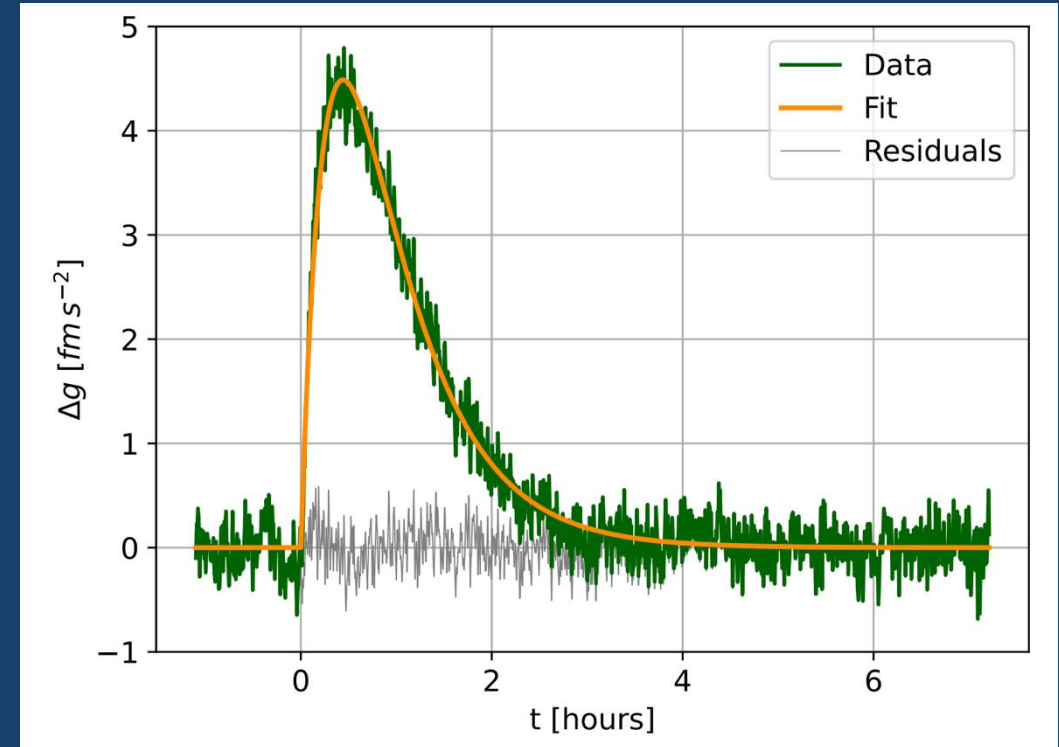
GW noise: glitches

They are:

- High-amplitude, short-duration instrumental noise
- NOT astrophysical
- Generally unexplained or coming from local disturbances to the detector

Risks that glitches pose:

- obscure or partially obscure genuine GW events
- mistaken for genuine GW events
- induce biases in GW parameter estimation



Fast Rising Exponential Decay (FRED) glitch

$$g(t; \Delta v, \tau_1, \tau_2, t_0) = \frac{\Delta v}{\tau_1 - \tau_2} \left(e^{-t'/\tau_1} - e^{-t'/\tau_2} \right) \Theta(t'), \quad t' = t - t_0$$

Δv := transferred impulse, τ_1 & τ_2 := decay/rise times, t_0 := arrival time

Goals & aims

Investigate the impact that glitches have on signal detection and parameter estimation of EMRIs.

- How do glitch backgrounds change the distribution of detected SNRs?
- How do glitch backgrounds change the posterior distributions obtained from EMRI parameter estimation?

Detecting GW events with matched filtering

Suppose **GW data** is a sum of **waveform** $h(t)$, **noise background** $n(t)$, **glitch background** $g(t)$.

$$d(t) = h(t) + n(t) + \cancel{g(t)}$$

Define the noise-weighted inner product:

$$(a|b) = 4\text{Re} \int_0^\infty \frac{\tilde{a}(f)\tilde{b}^*(f)}{S(f)} df$$

Define the detected SNR:

$$\rho_{det.} = \frac{(d|h)}{\sqrt{(h|h)}}$$

Define the optimal SNR:

$$\rho_{opt} = E(\rho_{det}) = \sqrt{(h|h)}$$

Estimating GW parameters $\bar{\theta} = (M, \mu, a, \dots)$

Use the log Whittle likelihood:

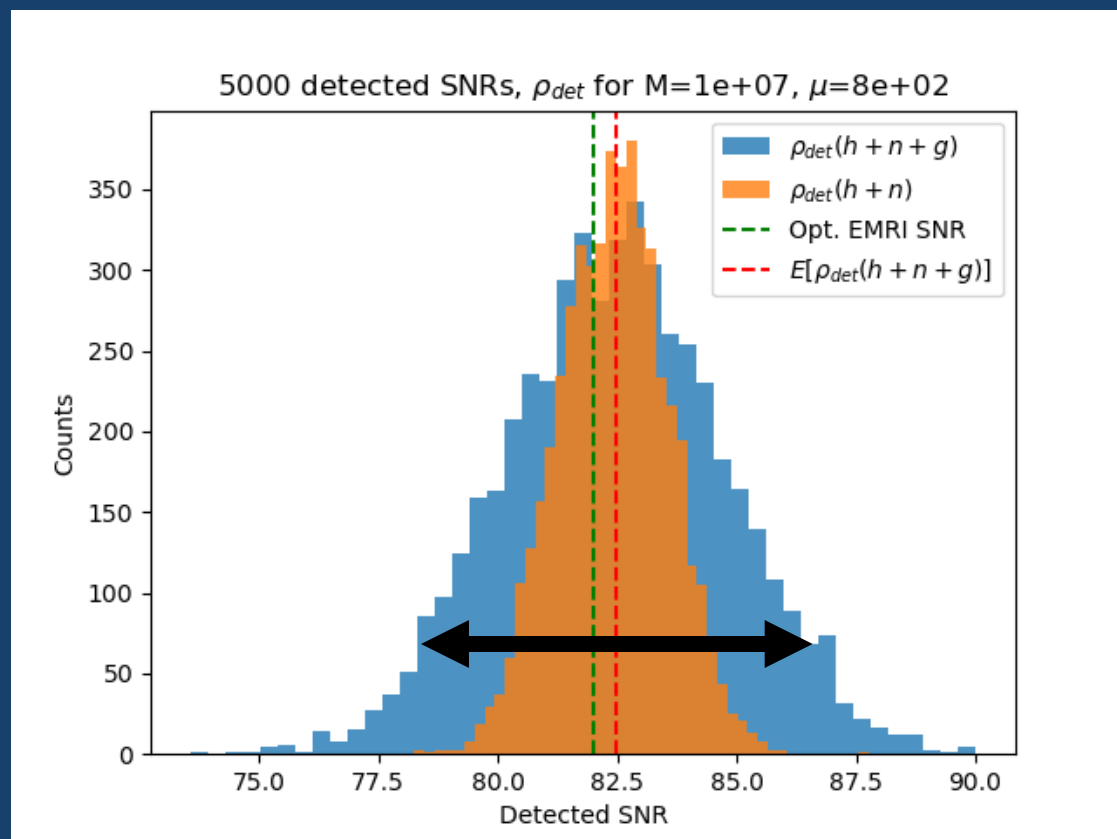
$$L(\textcolor{red}{d}(t) | \bar{\theta}) = (\textcolor{red}{d} - \textcolor{green}{h} | \textcolor{red}{d} - \textcolor{green}{h})$$

Define priors $\pi(\bar{\theta})$ for EMRI parameters, plug into Bayes' theorem:

$$p(\bar{\theta} | \textcolor{red}{d}(t)) \propto L(\textcolor{red}{d}(t) | \bar{\theta}) \pi(\bar{\theta})$$

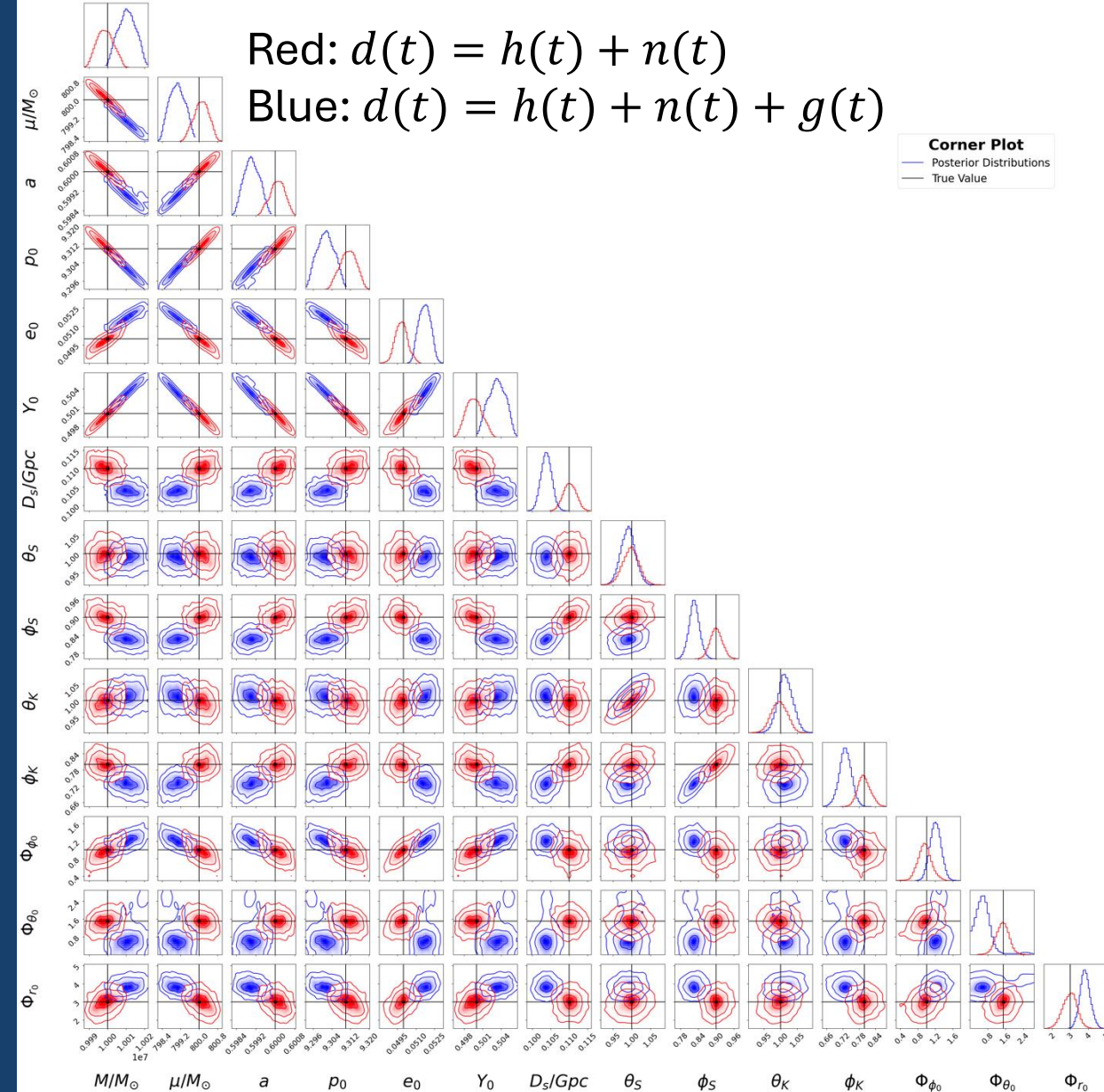
Sample the posterior with MCMC, nested sampling etc.

Results



Signal detection

25/11/2024



Parameter estimation: MCMC run

Conclusions & next steps

- Glitches may not affect signal detection that much
- Glitches lead to inaccurate EMRI parameter estimation
- There is a need to de-glitch data or fit for glitches
- Simulate more realistic glitch backgrounds