Subtraction of Merging MBHB Signals in LISA Data

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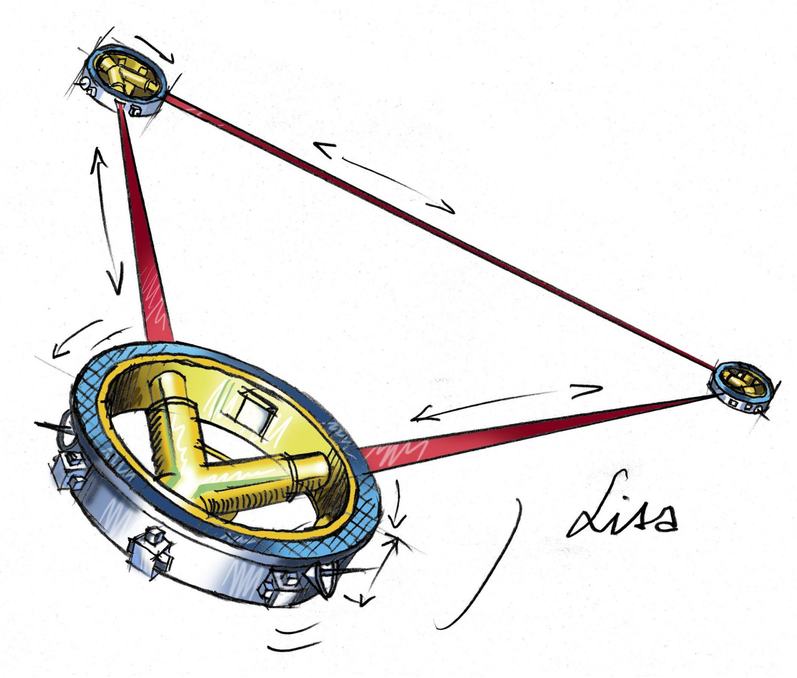
IDENTITY CARD

- Acronym: **LISA**
- Objective: Detect **gravitational waves**
- Frequency Band: 0.1 mHz - 1 Hz
- Method: Distance measurement using laser interferometry
- Configuration: 3 spacecrafts
- Arm length: 2.5 million km
- Orbit: Solar orbit
- Mission: **ESA** (NASA in collaboration)
- Status: **Adopted**
- Launch: 2035 (planned)



DATA ANALYSIS

Goals

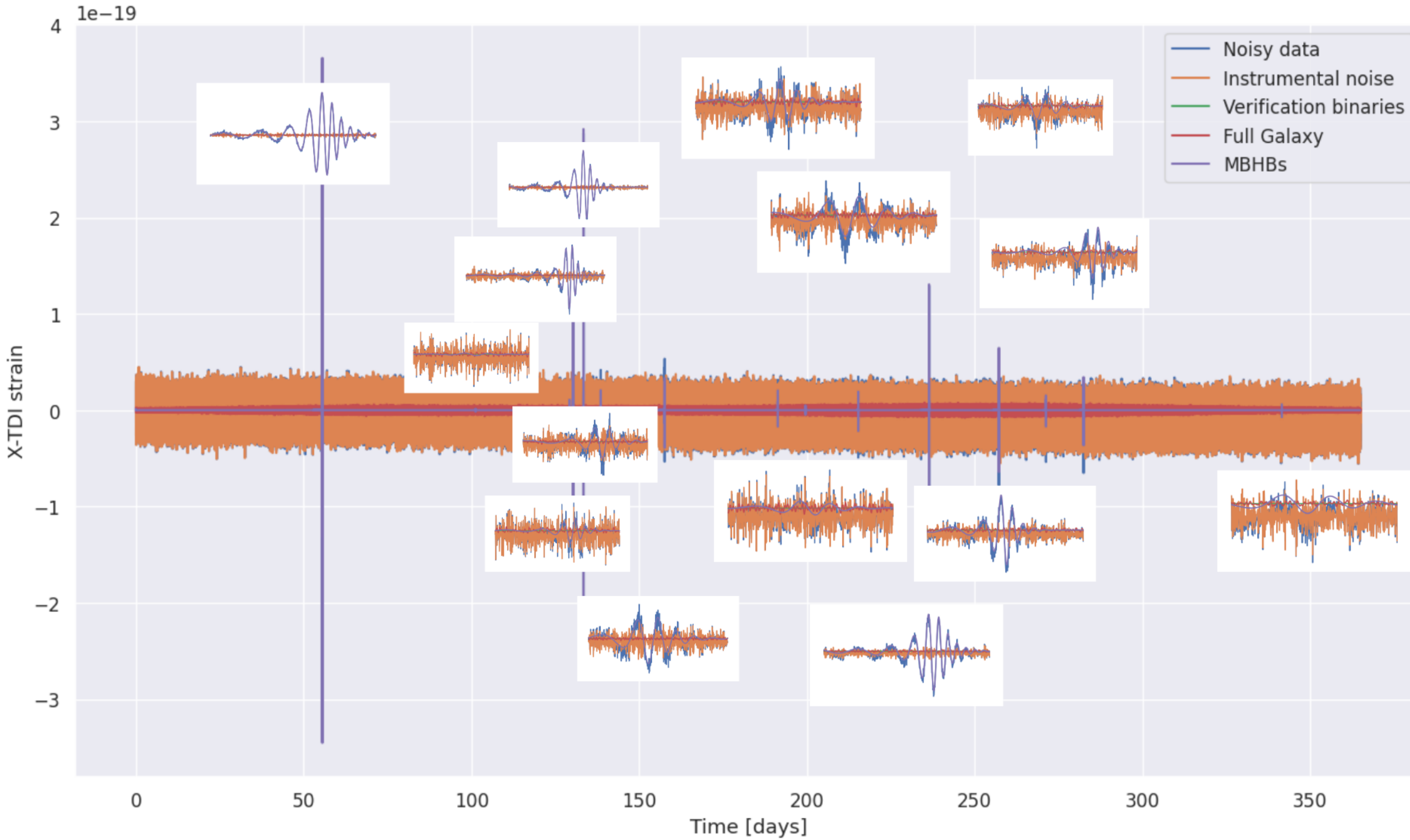
Consume the data to extract information about the astrophysical (and cosmological, etc.) sources,

- **M**assive **B**lack **H**ole **B**inaries, broadband and the loudest sources
- **G**alactic white dwarf **B**inaries, the most numerous sources
- **E**xtreme **M**ass **R**atio **I**nspirals, (among) the most challenging sources
- ...

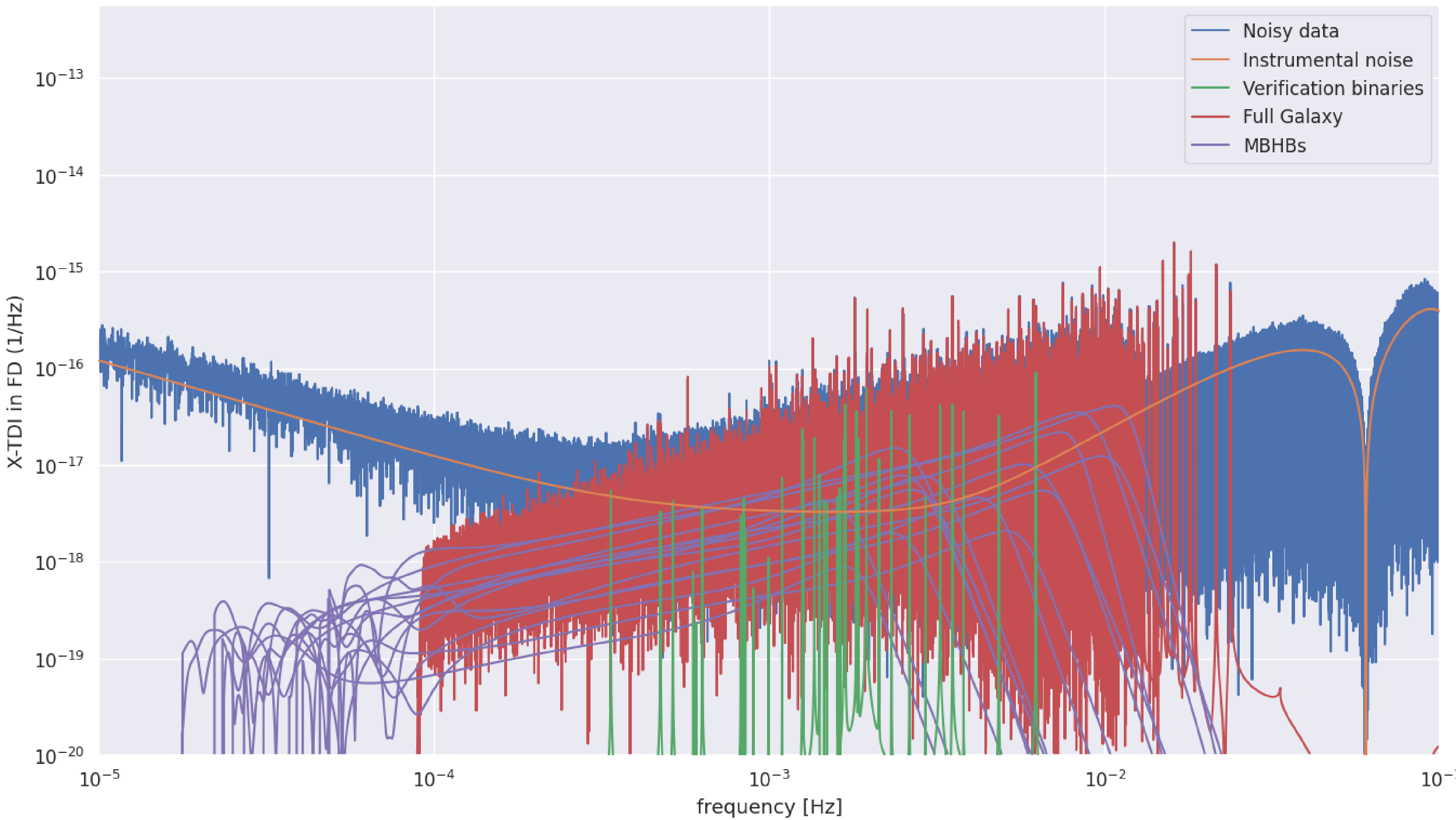
Challenges

- Signals dominate the data and overlap with each other.
- Signals will be modulated by the LISA motion.
- **MBHB** signals corrupt the noise estimation.
- Unresolved **GB** signals form a confusion noise.

SIMULATED DATA "SANGRIA"



SIMULATED DATA "SANGRIA"



Efficient Reconstruction of MBHB signals

WHY & HOW

- In a global-fit data analysis pipeline, we need the removal of **MBHB** signals to,
  - allow the **P**arameter **E**stimation for the noise model,
  - allow the **PE** for **GB**s
  - provide an initial guess of the **PE** for **MBHB**s

- Make assumptions to simplify the detector **response**:
  - frozen LISA constellation
  - long-wavelength regime
- Maximise analytically the log-likelihood ratio over parameters whenever possible
- Smartly optimise the rest
  - `VEGAS` algorithm

Nota Bene

- The **response** is how the detector reacts to the strain signal of the source and this is what can actually be measured.
- The subtraction of MBHB signals does not need to be perfect but **efficient**.

Log-likelihood Ratio

$$\log \mathcal{L} = \log \frac{p\,(d|h)}{p\,(d|h=0)} = \langle d|h \rangle - \frac{1}{2} \langle h|h \rangle \,,$$

Simplified Response

$$\begin{aligned} \tilde{h} \approx & i\sqrt{2}\sin(2\pi f L) e^{-4i\pi f L} (-6i\pi f L) e^{2i\pi f k\cdot p_0} F \tilde{h}_{\text{strain}} \\ \approx & a\tilde{H} + bi\tilde{H}, \end{aligned}$$

where $a = |F| \cos(\arg F)\,,\, b = |F| \sin(\arg F)\,,\, \tilde{H} = i\sqrt{2}\sin(2\pi f L) e^{-4i\pi f L} (-6i\pi f L) e^{2i\pi f k\cdot p_0}\, \tilde{h}_{\text{strain}}\,.$

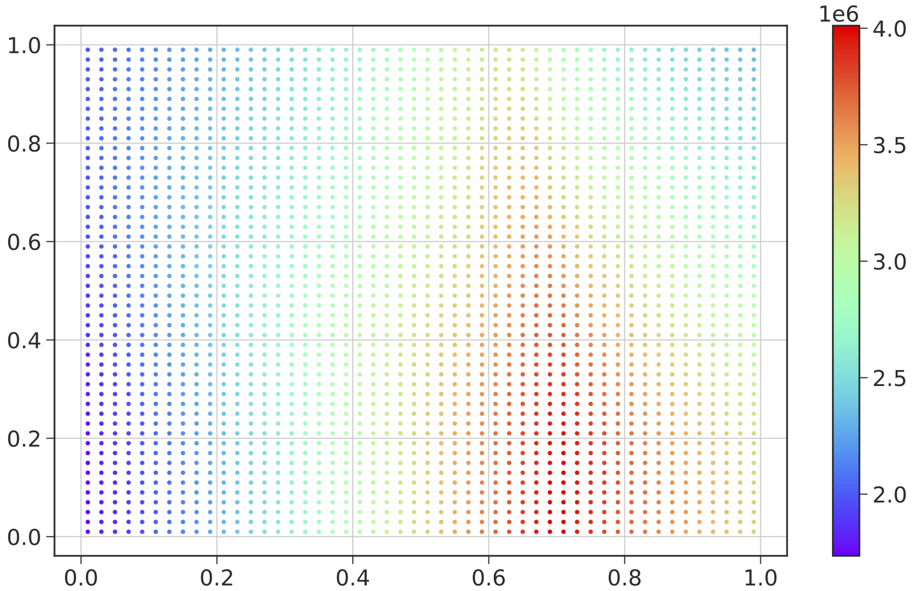
Log-likelihood Ratio (partially maximised, aka $\mathcal{F}$-statistic)

$$\log \mathcal{L}_{\max} = \frac{1}{2} \left(\frac{\langle d|H \rangle^2}{\langle H|H \rangle} + \frac{\langle d|iH \rangle^2}{\langle H|H \rangle} \right),$$

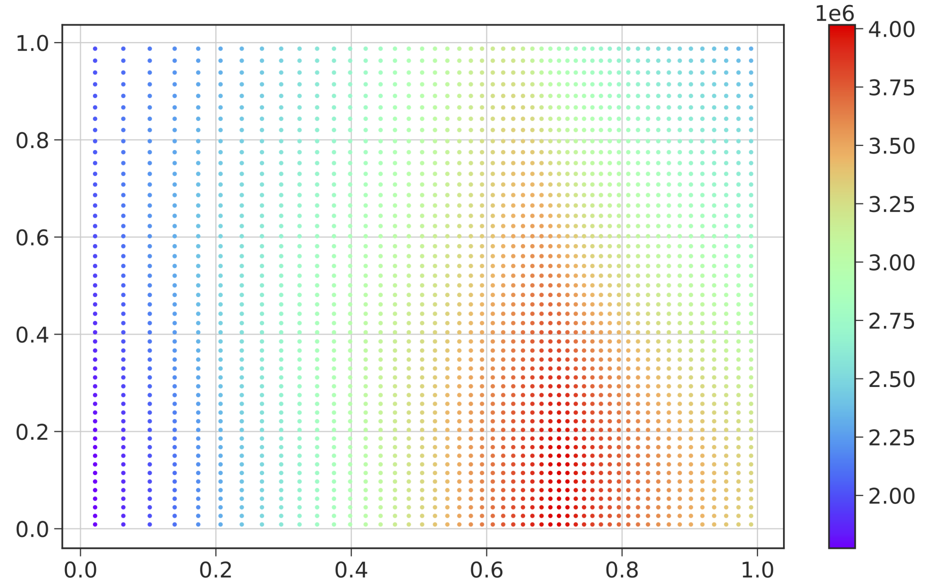
for $a = \frac{\langle d|H \rangle}{\langle H|H \rangle}\,,\, b = \frac{\langle d|iH \rangle}{\langle H|H \rangle}\,.$

VEGAS algorithm

- Monte Carlo integration algorithm invented by Peter Lepage for elementary particle physics
- Embarrassingly parallel
- We take advantage of its importance sampling feature



Initial grid

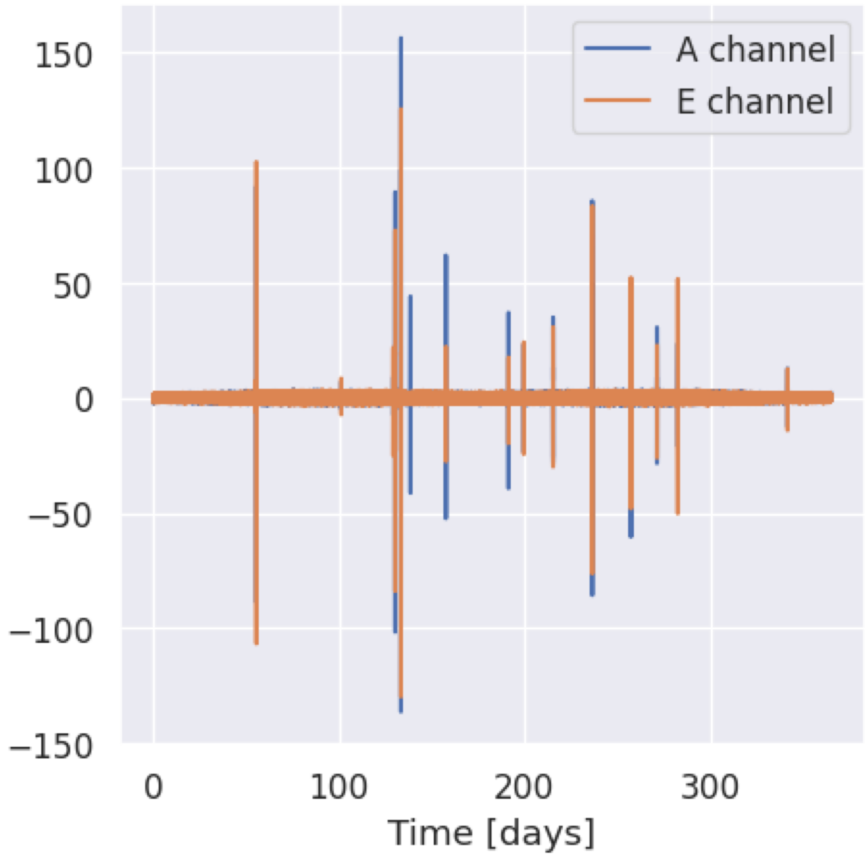


Grid after 4 iterations

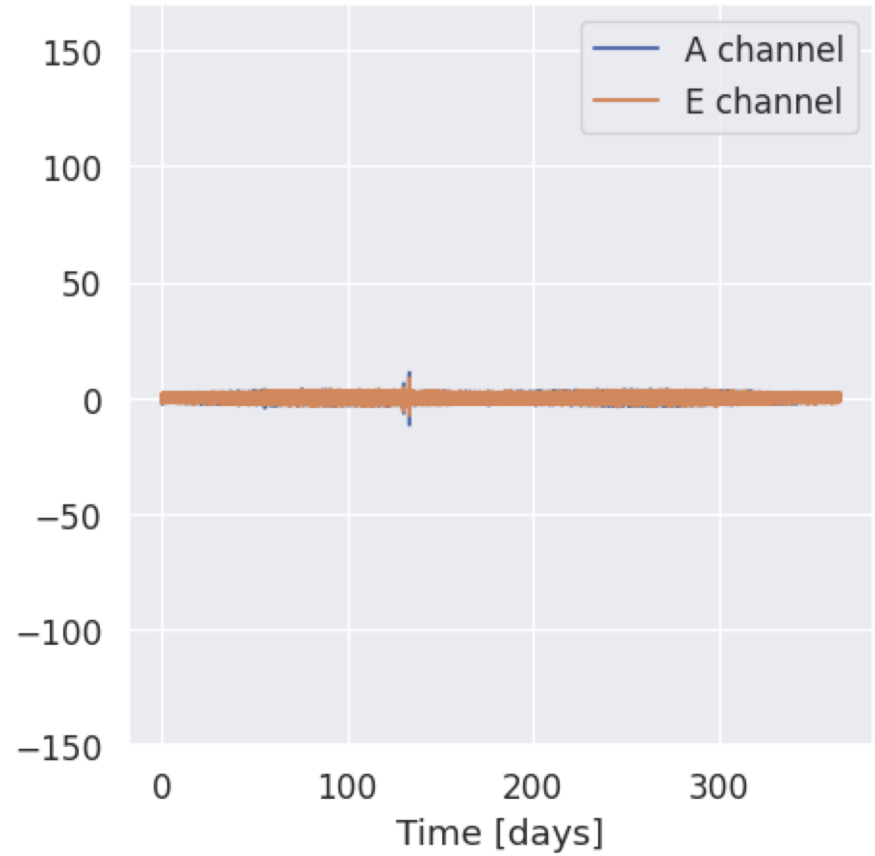
- We take the maximum of the $\mathcal{F}$-statistic over the sampled parameters

We are showing the geometry of the sampling grid in the parameter space, not the sampled points.

Subtraction Results & Conclusions



Whitened data before subtraction



Whitened data after subtraction

- The subtraction is not perfect but the residual is at the level of the noise.
- This procedure is now part of our global-fit pipeline.
- The method can also be extended for other uses, e.g., the early warning of the presence of a MBHB signal.

Thank you.