

tfwaves: a time-frequency representation for long-lived signals of LISA

Results on EMRIs (and SOBHB!)

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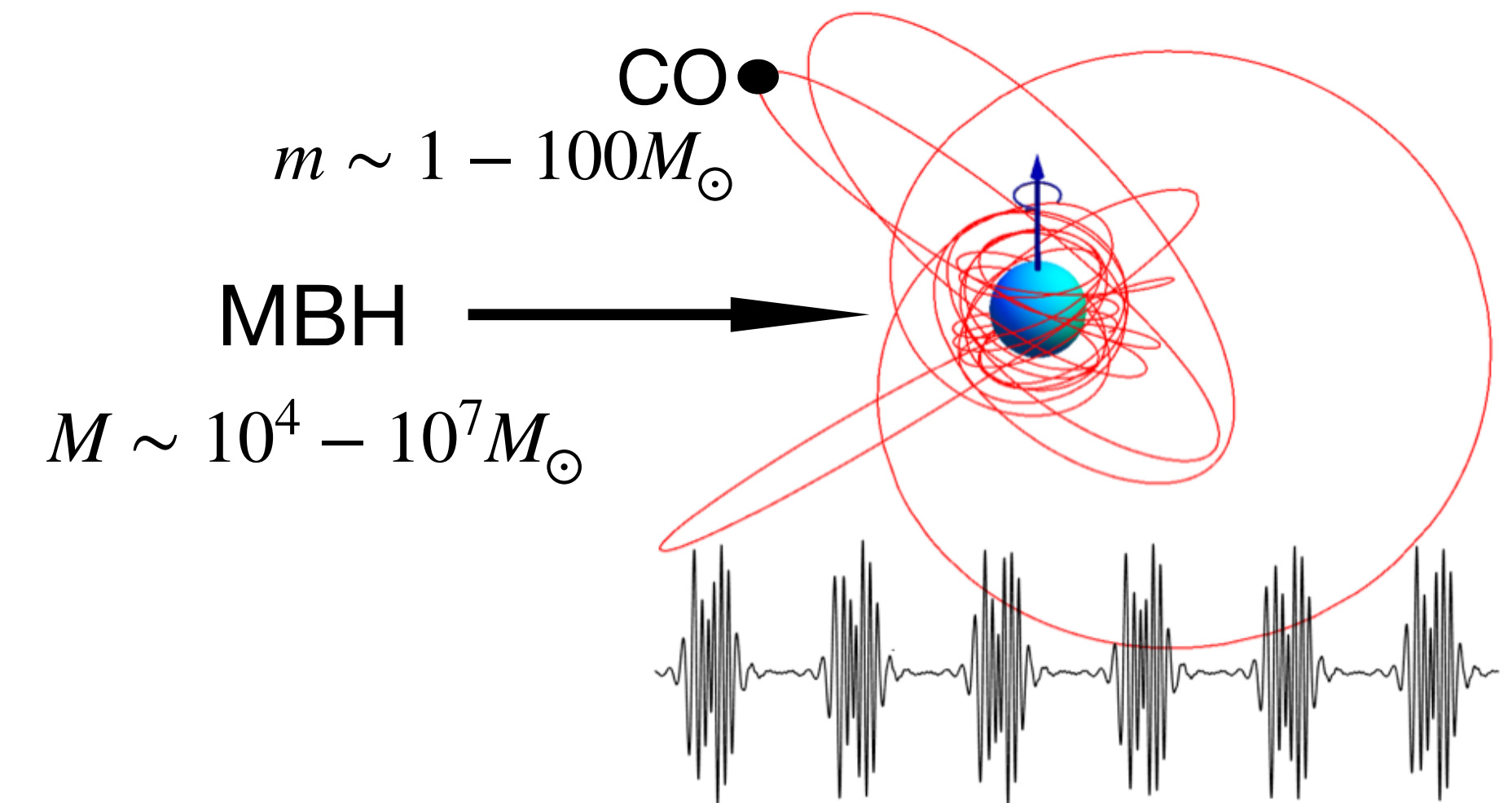


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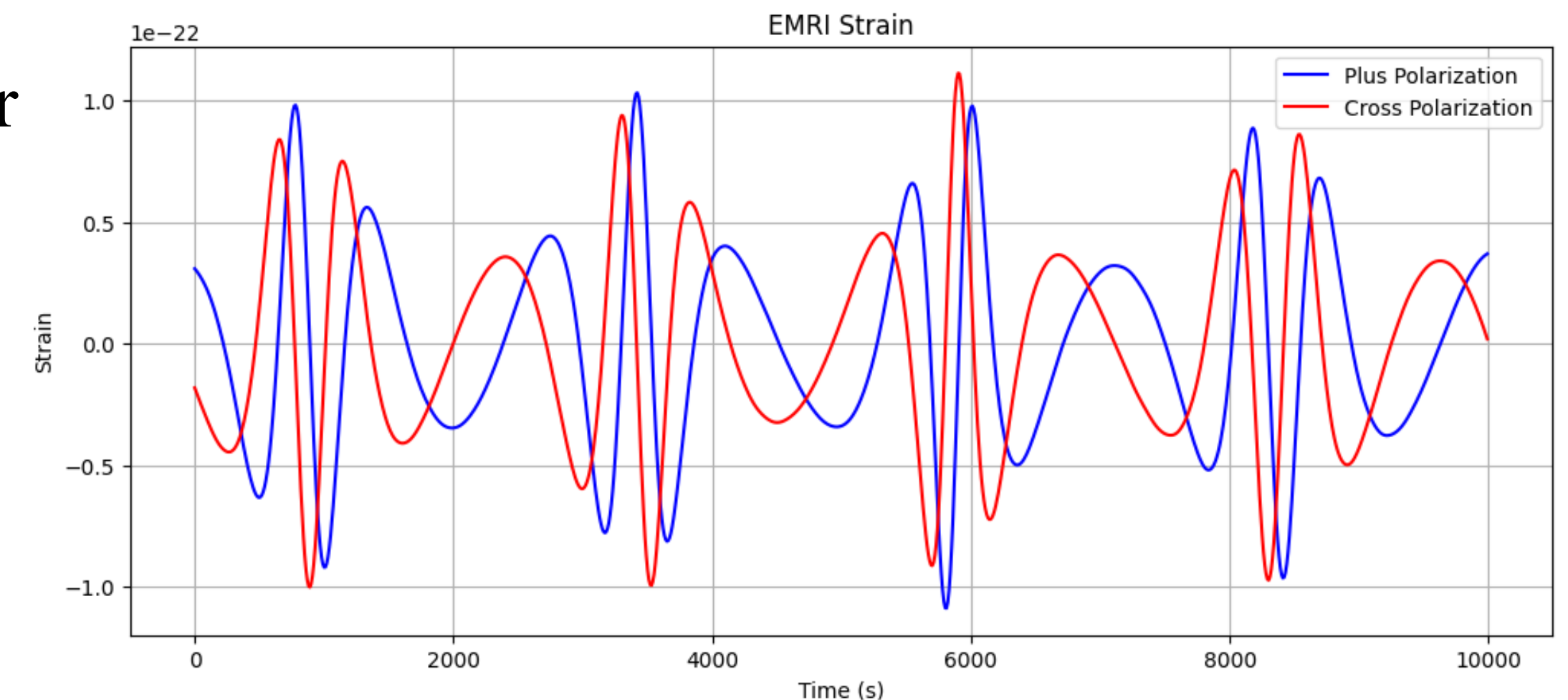


Extreme Mass Ratio Inspiral (EMRI) & Waveform

- Compact Object (CO) + Massive Black Hole (MBH) = EMRI
- Inspirals very slowly, so it is precise probe to study the central black hole.
- Orbits are highly eccentric and relativistic.
- The waveform exhibits many harmonics.
- Signal builds up slowly, in a 14 -17 dimensional parameter space.
- A fully coherent template bank would need $\sim 10^{40}$ templates, so search is challenging.



V. Cardoso et al., arXiv:1908.11390



Why Time-Frequency ?

- Distinguishable mode by mode .
- Inclusion of noise non-stationarities.
- Sparse representation in time-frequency plane.

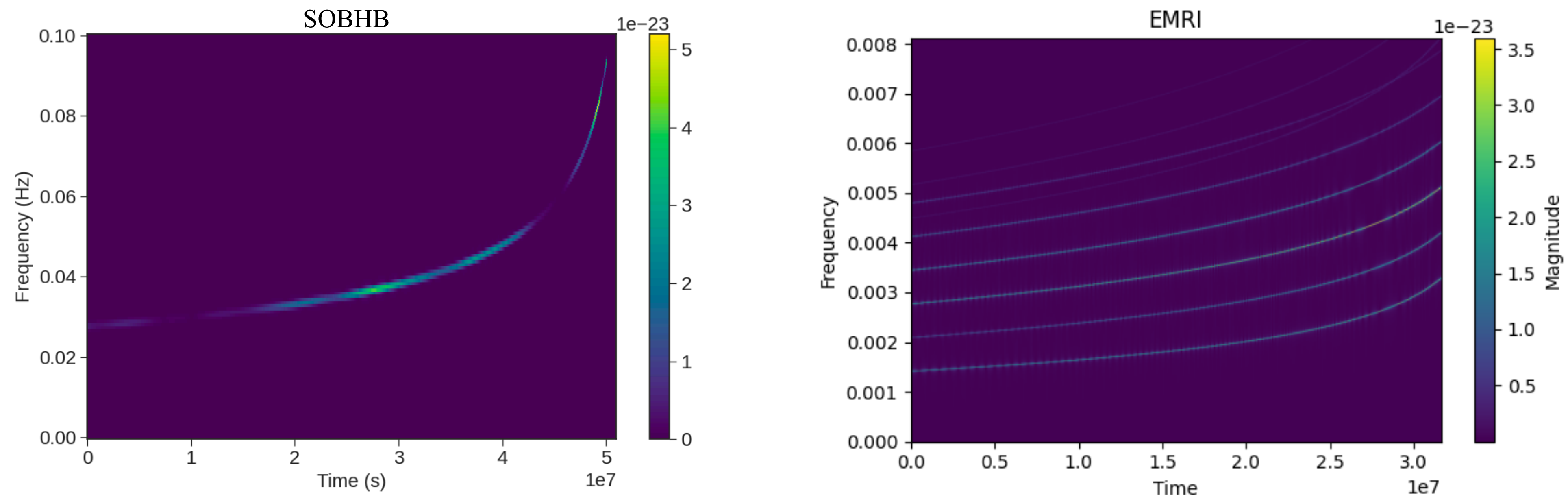


Figure: Time-frequency map of SOBHB and EMRI

Foundations

- Mode-by-mode decomposition in amplitude/phase:

$$h(t) = \frac{\mu}{d_L} \sum_{l,m,n} A_{lmn}(t) {}_{-2}Y_{lm}(\theta, \phi) e^{-i\Phi_{mn}(t)}$$

- Taylor expansion of amplitude and phase:

A. Time domain:

$$A(t) \approx A(\tau)$$

$$\Phi(t) \approx \Phi(\tau) + 2\pi f(\tau)(t - \tau) + \pi \dot{f}(\tau)(t - \tau)^2$$

B. Frequency domain:

$$A(\nu) \approx A(f)$$

$$\Phi(\nu) \approx \Phi(f) + 2\pi\tau(f)(\nu - f) + \pi\tau'(f)(\nu - f)^2$$

- Analytical maps $(A, \Phi) \mapsto (h_+, h_\times)$ and/or $(A, \Phi) \mapsto$ **LISA Instrumental Response**
- Short Time Fourier Transform (STFT) of $y(t) = F(t)h(t + d(t))$ [Marsat & Baker 2018] using **Fresnel Kernel**.

Which harmonics are kept

- **FastEMRIWaveform** (FEW) mode selector at threshold $\varepsilon = 10^{-2}$, then keep the harmonics above 1 % of the squared SNR: the dashed line.

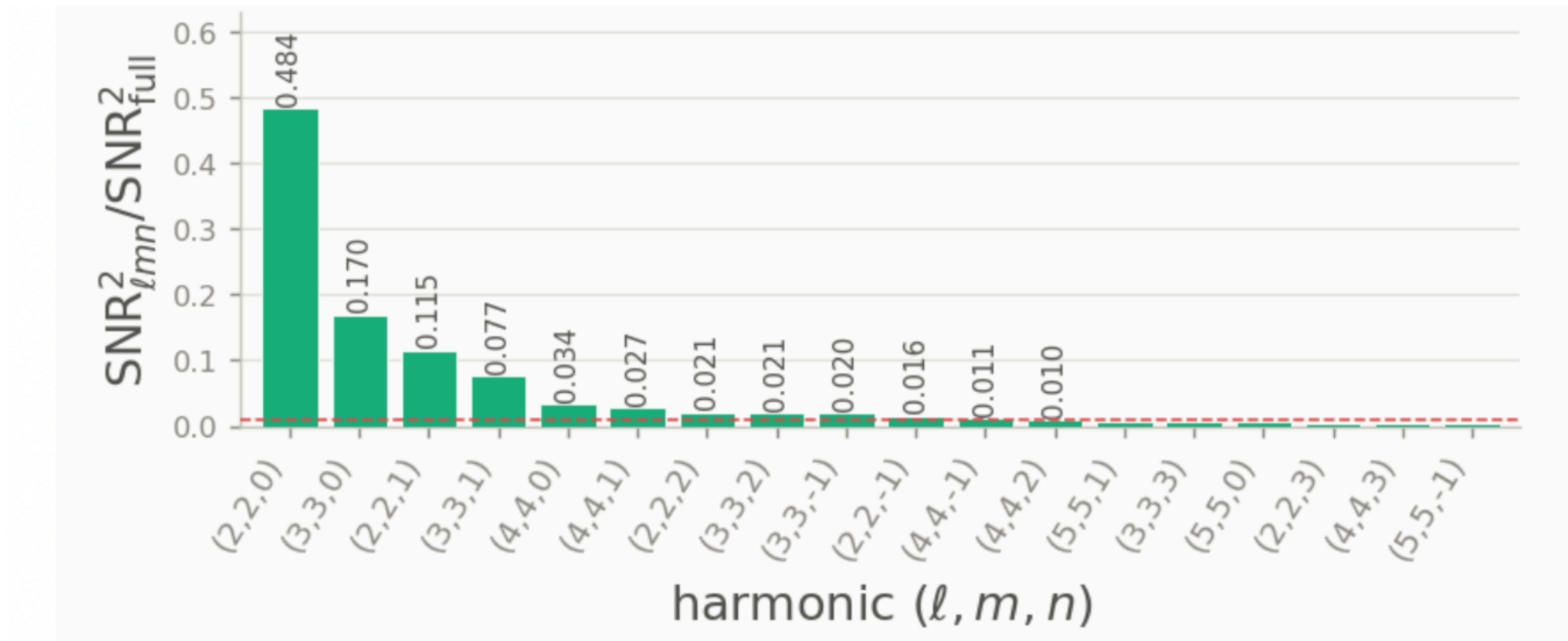
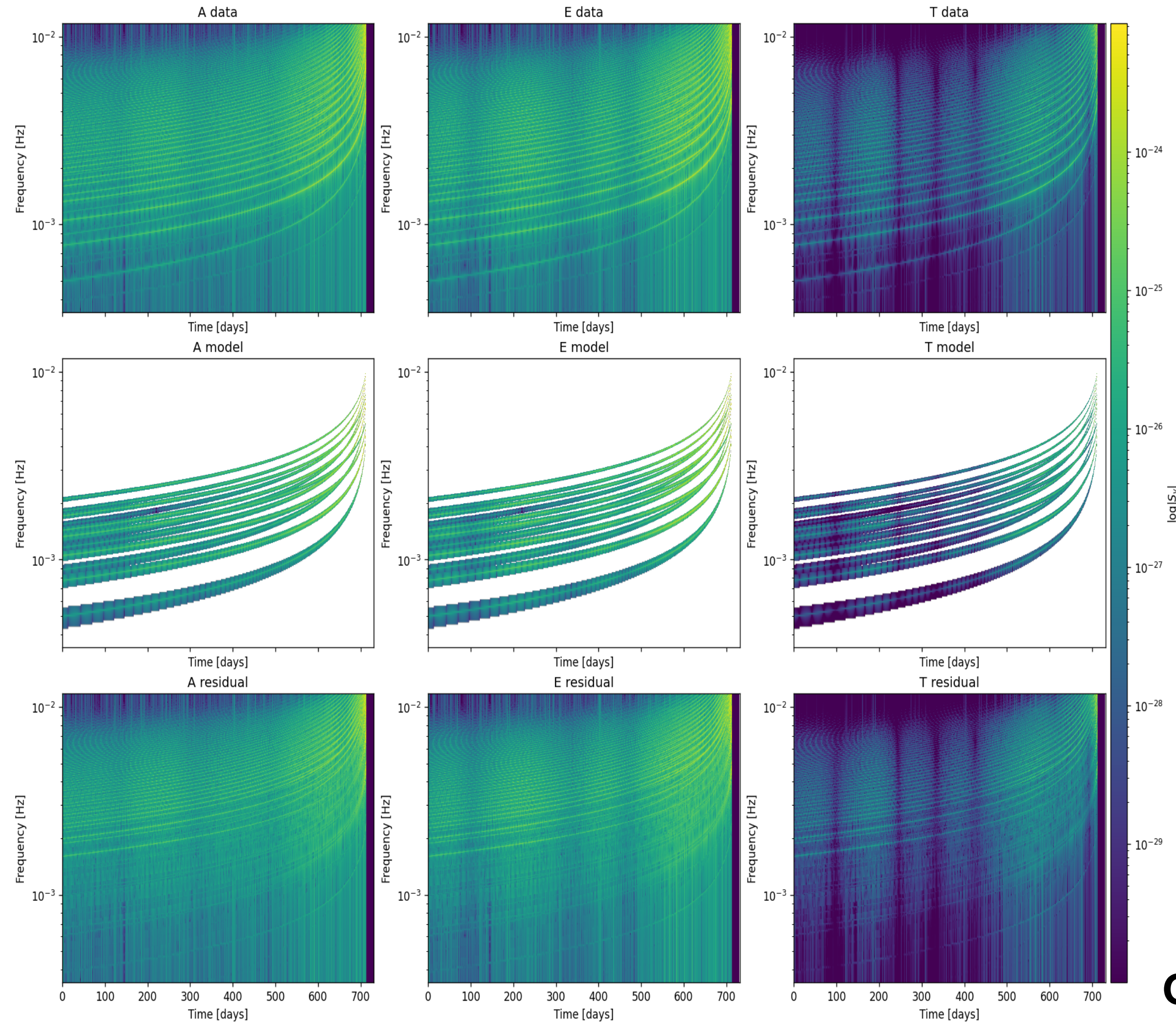


Figure: Per-harmonic contribution to the squared signal-to-noise ratio

Time-frequency map of EMRI

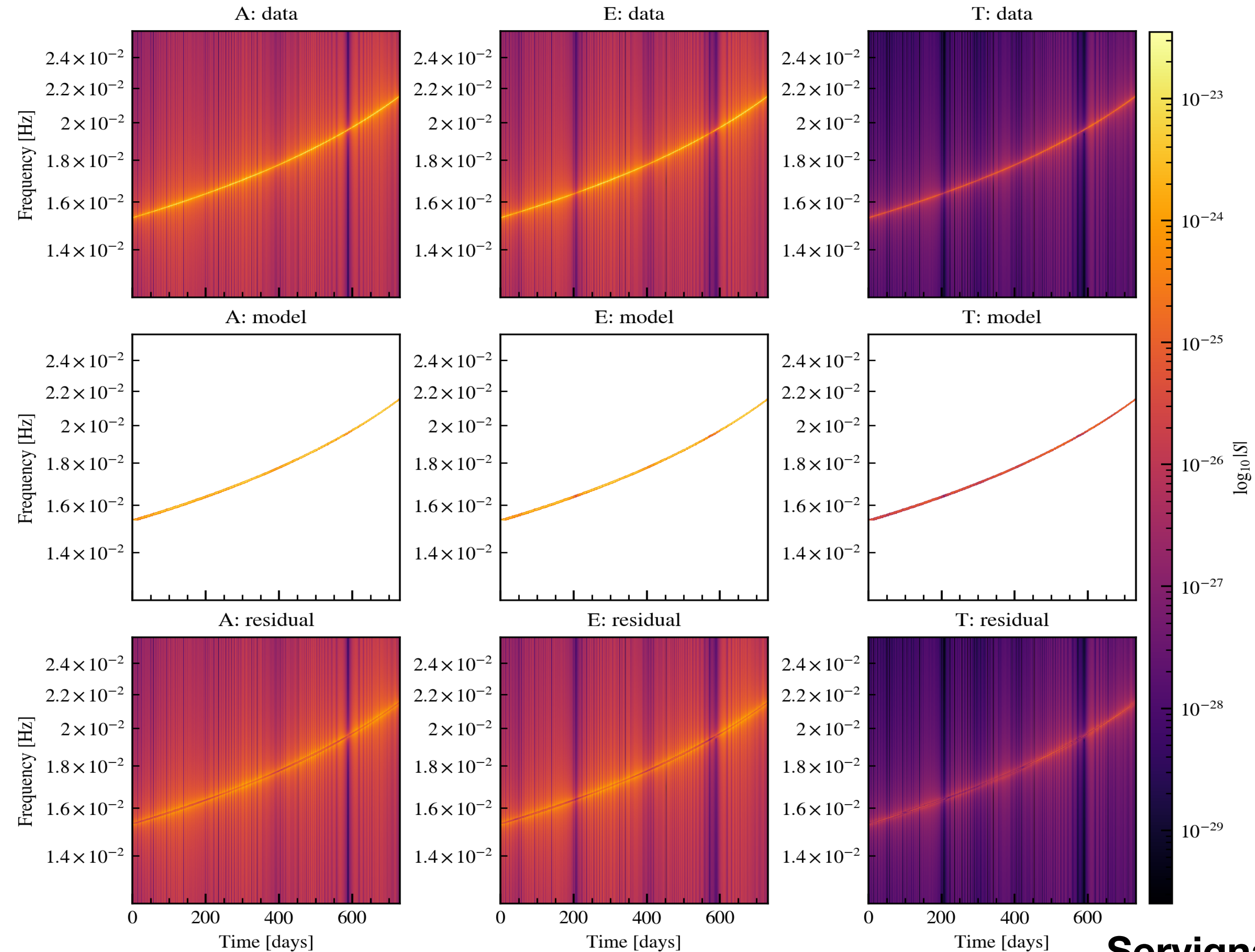
- GW Response Data
- GW Response Model
- Residual



Ghosh et al. (in prep)

Time-frequency map of SOBHB (Credit : @Gaël Servignat)

- GW Response Data
- GW Response Model
- Residual



Servignat et al. (in prep)

Overlaps

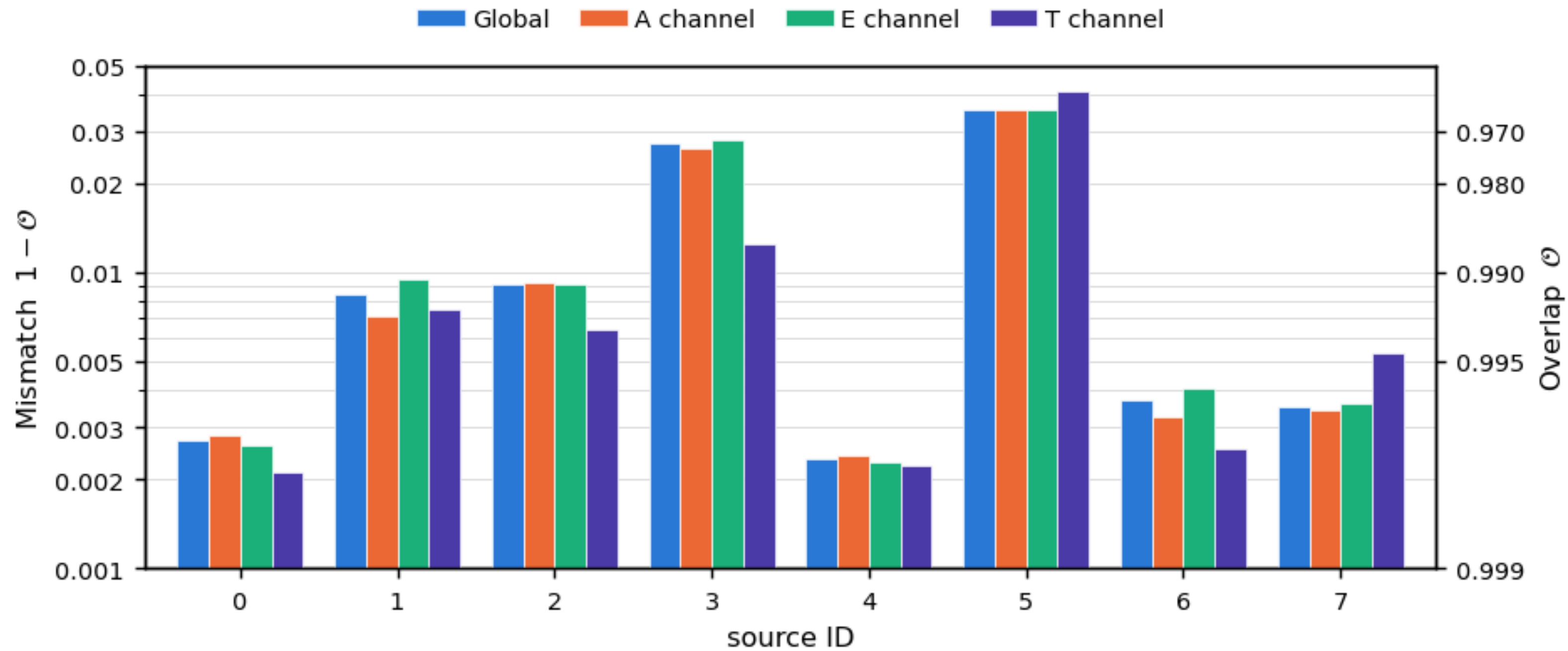
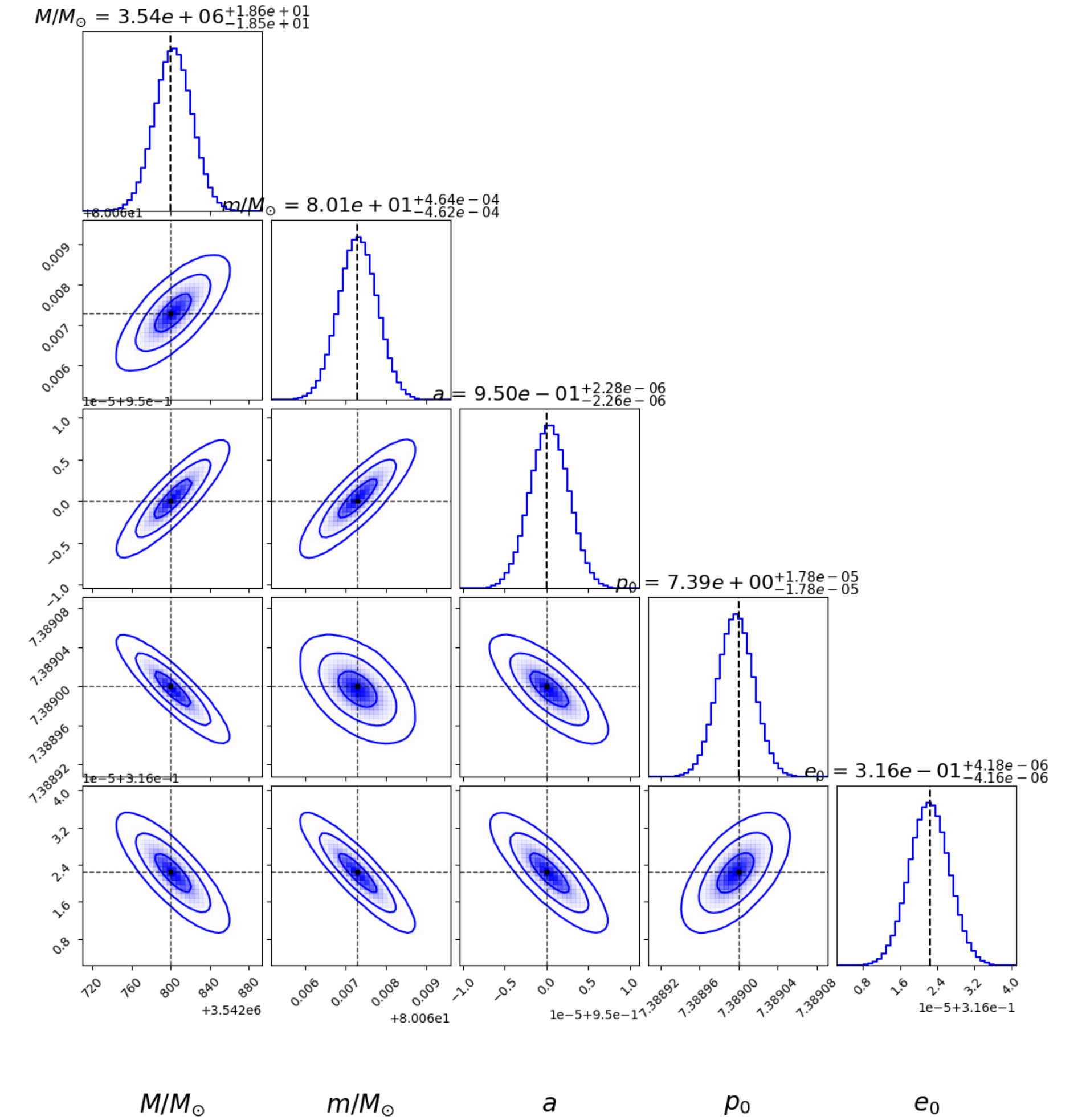
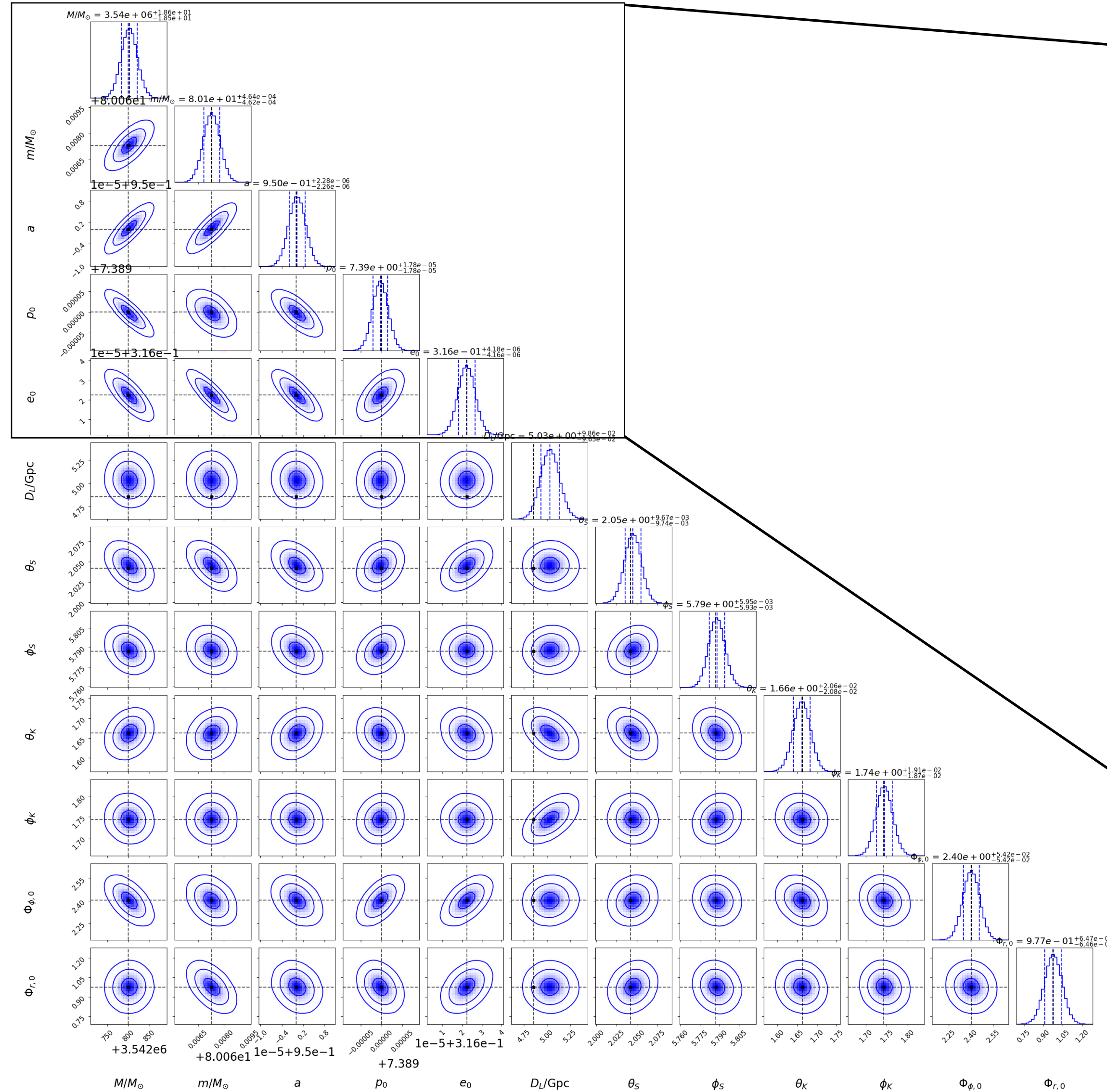


Figure: Mismatch $1 - O$ (left axis) and overlap O (right axis) on the model support, all channels together and A, E, T separately.

Ghosh et al. (in prep)

Noiseless PE



Ghosh et al. (in prep)

Conclusions and Future work

- LISA time-frequency response for any time-domain waveform.
- Noiseless parameter estimation for EMRIs & SOBHBs.
- Implemented in Numpy version [tfwaves](#) and JAX version [jaxtfwaves](#), both public.
- **To be incorporated in globalfit pipeline Gee-Moo (APC): stay tuned!**
- **Semi-coherent or hierarchical EMRI search on the sparse support (maybe)!**

Thanks for your attention

Questions & Discussion

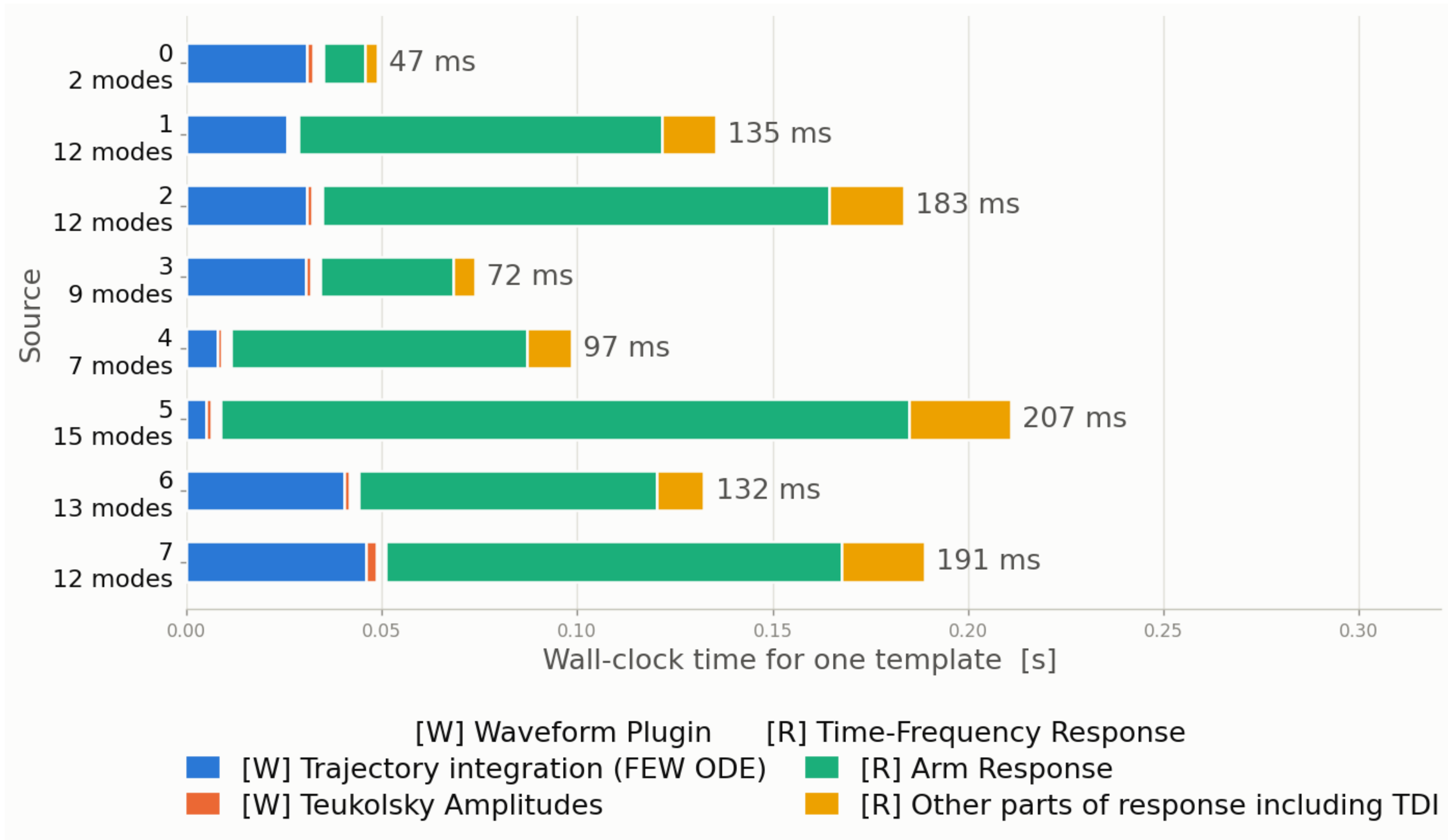
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Cost



Ghosh et al. (in prep)