

tfwaves, a Python package for time-frequency representation of LISA signals

Results on EMRIs (and stBHB!) · Saptarshi Ghosh, Gaël Servignat,
Quentin Baghi · Astroparticule & Cosmologie, Paris

EMRI Search and Inference within the LISA Global Fit - Part II —
Singapore, 13 July 2026



01

SECTION

Underlying Principles

And how to use tfwaves

Underlying Principles

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

$$h = \sum_{\ell m} {}_{-2}Y_{\ell m} h_{\ell m}$$
$$h_{\ell m} = A_{\ell m} e^{-i\Phi_{\ell m}}$$

- **Taylor expansion ($x = f$ or τ):**

$$A(x) = A(x^*)$$

$$\Phi(x) = \Phi(x^*) + (x - x^*)\Phi'(x^*) + \frac{1}{2}(x - x^*)^2\Phi''(x^*)$$

- **Derivation of analytical maps** $(A, \Phi) \mapsto (h_+, h_\times)$ **or** $(A, \Phi) \mapsto (\text{TDI})$.
STFT $\{y(t)\}(\tau, f)$ where $y(t) = F(t)x(t + d(t))$ (Fresnel kernel formalism)

Underlying Principles

- Rectangular window (Tukey to be added)
- T-f track localisation using phase
- LISA response implemented in time-frequency
- Sparsity accelerates computations
- Implemented in Numpy (<https://gitlab.in2p3.fr/lisa-apc/tfwaves>) and JAX (<https://gitlab.in2p3.fr/servignat/jaxtfwaves>), both public.

As a user: implement a plugin

- **Express $h_{+/\times}$ in the SSB:**

$$h_{+/\times}^{\text{SSB}}(t) = \sum_{\ell, m \geq 0} 2\Re(\mathcal{K}_{\ell m}^{+/\times} A_{\ell m}(t) e^{-i\Phi_{\ell m}(t)}) \quad (\text{time domain})$$

$$h_{+/\times}^{\text{SSB}}(t) = \sum_{\ell, m \geq 0} K_{\ell m}^{+/\times} A_{\ell m}(f) e^{-i\Phi_{\ell m}(f)} \quad (\text{freq domain})$$

- **The Waveform class of `tfwaves` exposes the API:**
 - `compute_amplitudes` (outputs $A_{\ell m}$)
 - `compute_phases` (outputs $\Phi_{\ell m}$)
 - `compute_frequencies/compute_times` (derivatives of $\Phi_{\ell m}$)
- **One EMRI plugin (FEW) and two stBBH plugins (lisabeta/ripplegw) available.**

02

SECTION

Parameter Estimation Results for Mojito sources

Time-frequency map (EMRI #3 from Mojito Catalogue)

Exact STFT of

Time - domain
plugin Waveform

+

Time - Domain
response

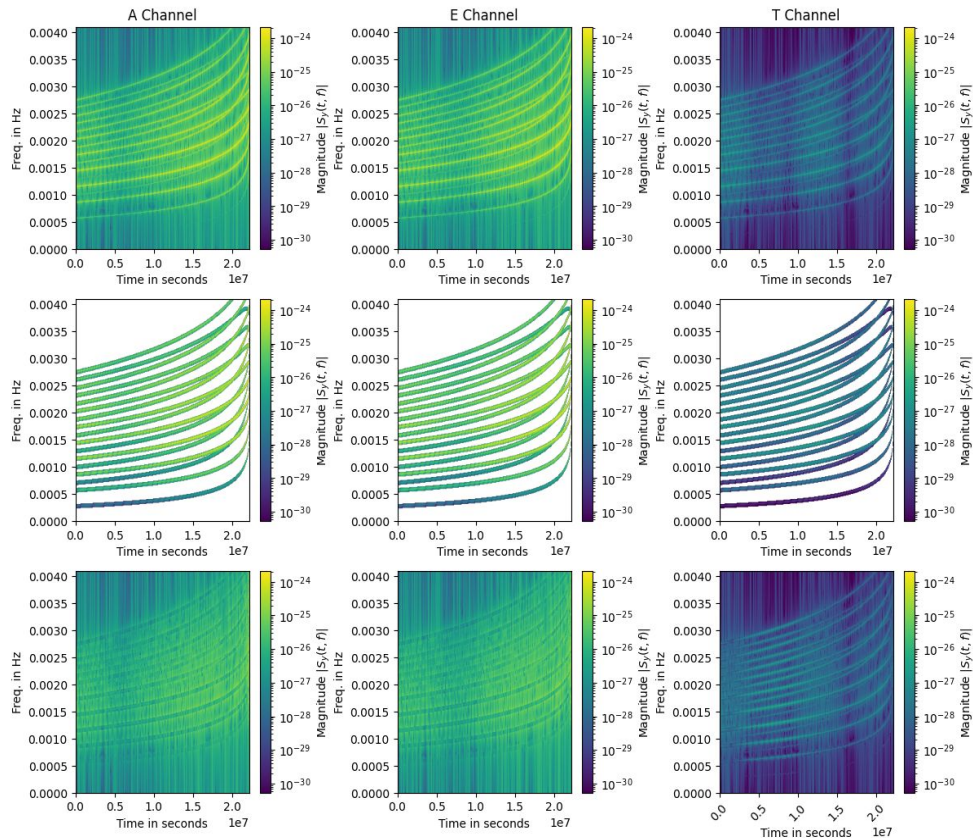
Approximate STFT of

TF waveform

+

TF response

**Difference
between STFTs**



Overlap for A Channel: 0.9755

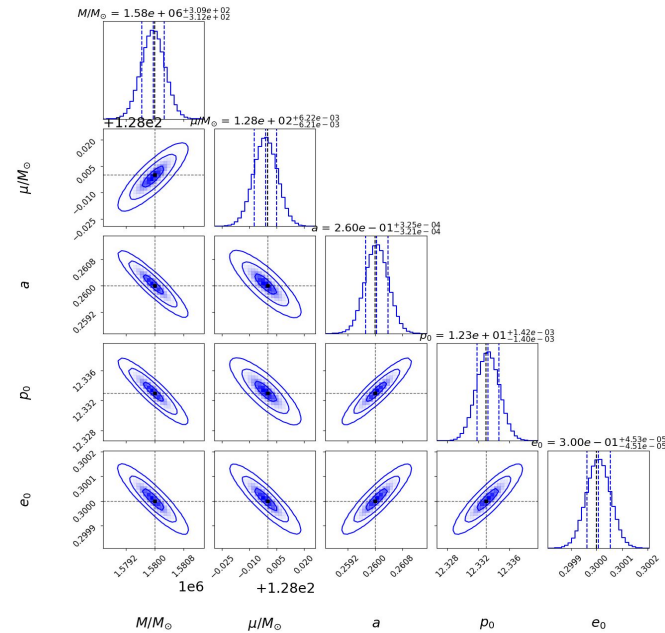
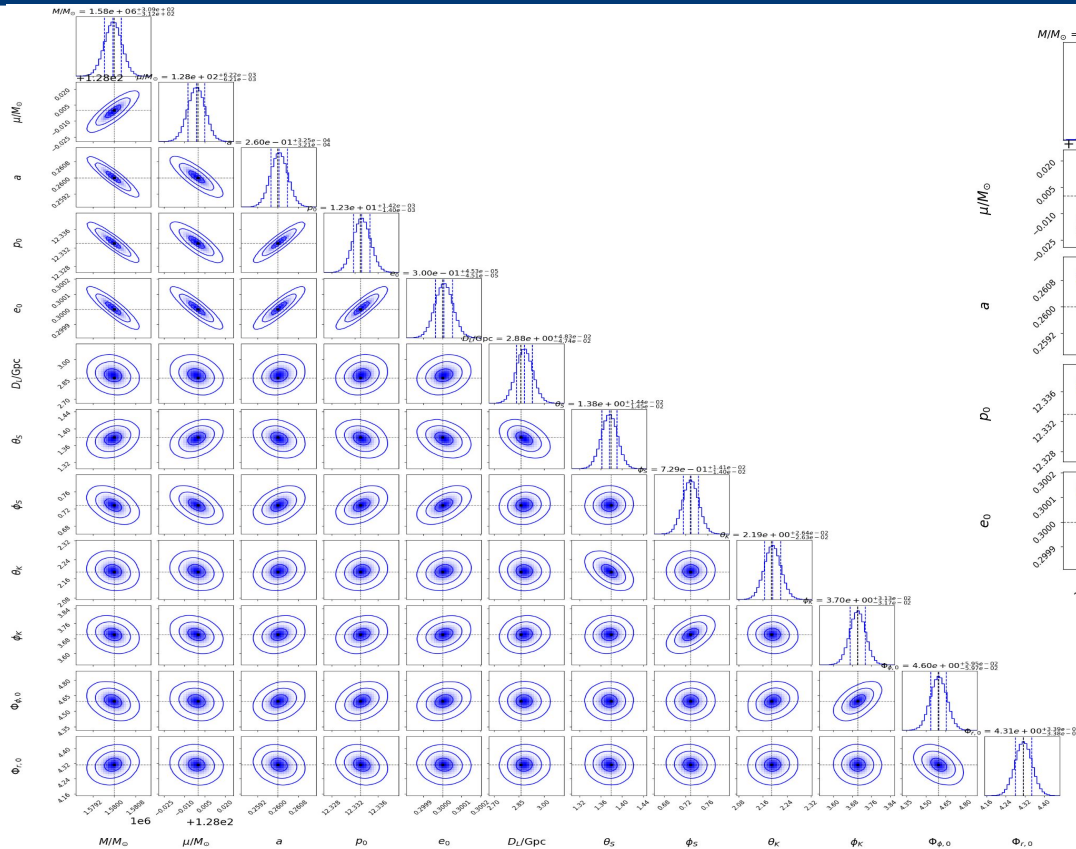
Overlap for E Channel: 0.9787

Overlap for T Channel: 0.6570

Summary of overlaps

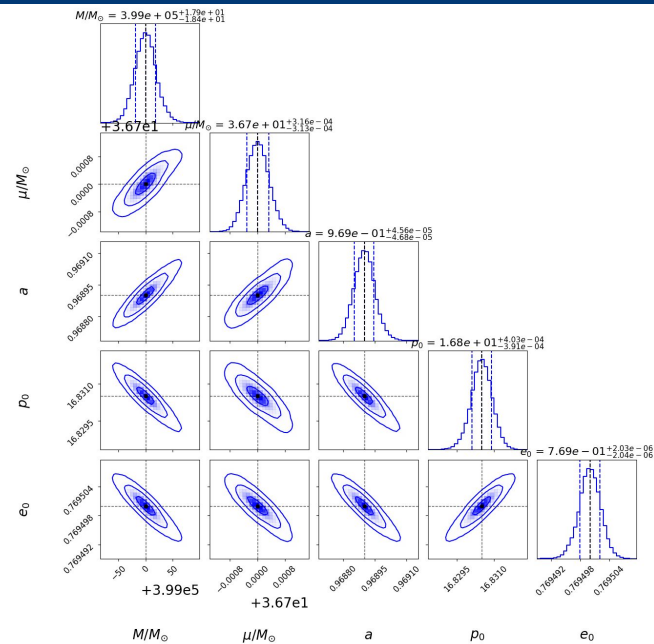
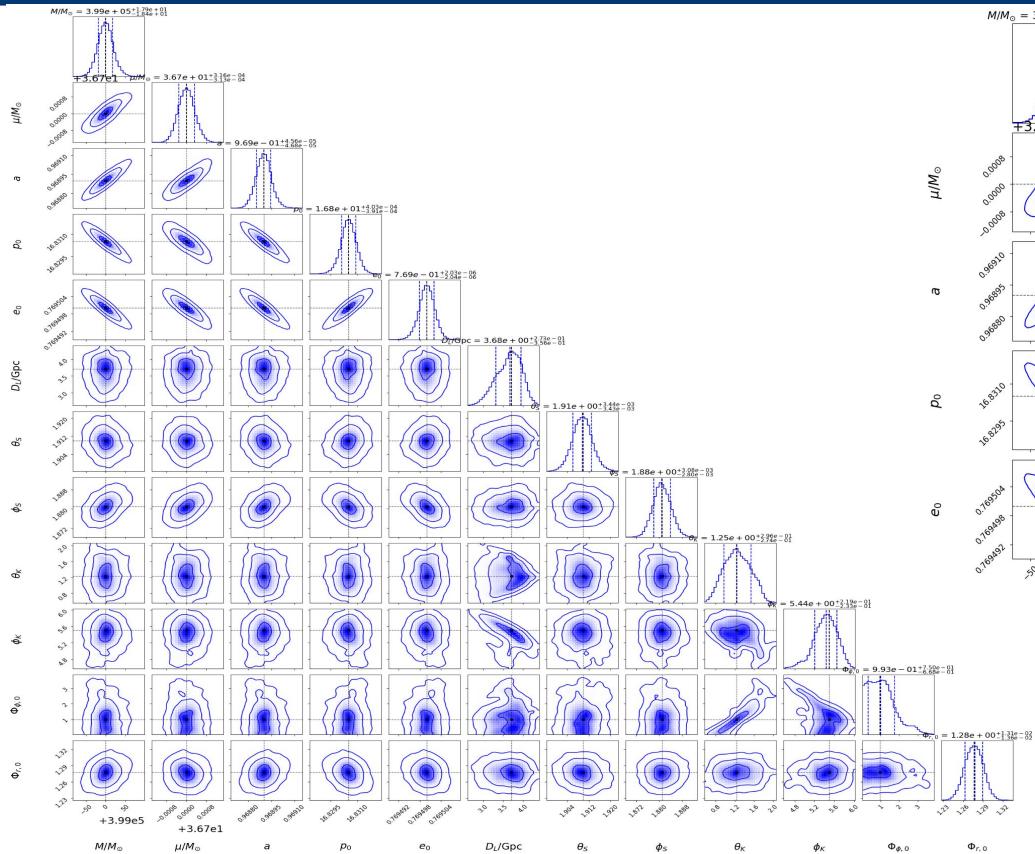
Source	Overlap A	Overlap E	Mismatch A	Mismatch E
0	0.9813	0.9787	1.86e-02	2.13e-02
1	0.9674	0.9676	3.26e-02	3.24e-02
2	0.9587	0.9720	4.12e-02	2.79e-02
3	0.9758	0.9798	2.41e-02	2.01e-02
4	0.9561	0.9534	4.39e-02	4.65e-02
5	0.9719	0.9734	2.80e-02	2.65e-02
6	0.9502	0.9553	4.98e-02	4.46e-02
7	0.8887	0.8937	1.11e-01	1.06e-01

Noiseless Parameter Estimation (EMRI #3)



Single likelihood evaluation average
timing = 53.9 ms (for 5 significant
modes)

Noiseless Parameter Estimation (EMRI #7)



Single likelihood evaluation average
timing = 188 ms (for 12 significant
modes)

Conclusions

- Mojito Lite EMRI validation going well (on CPUs).
- Has also been used to analyse Mojito Lite stBBH sources (using JAX/GPUs, reaching sub-ms likelihood evaluation) (see backup).
- Reduce leakage with Tukey window.
- To be incorporated in globalfit pipeline Gee-Moo (APC): stay tuned!
- <https://gitlab.in2p3.fr/lisa-apc/tfwaves>,
<https://gitlab.in2p3.fr/servignat/jaxtfwaves>, both public.

Thanks for your attention



Questions & Discussion

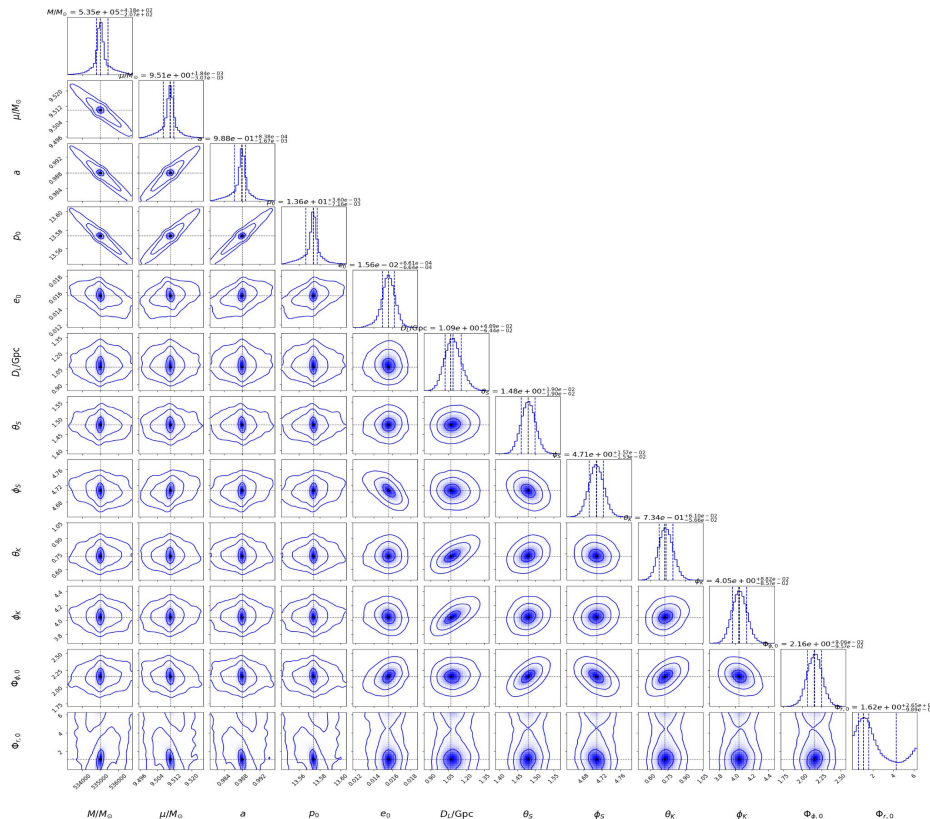
saptarshi.ghosh@apc.in2p3.fr

baghi@apc.in2p3.fr

servignat@apc.in2p3.fr

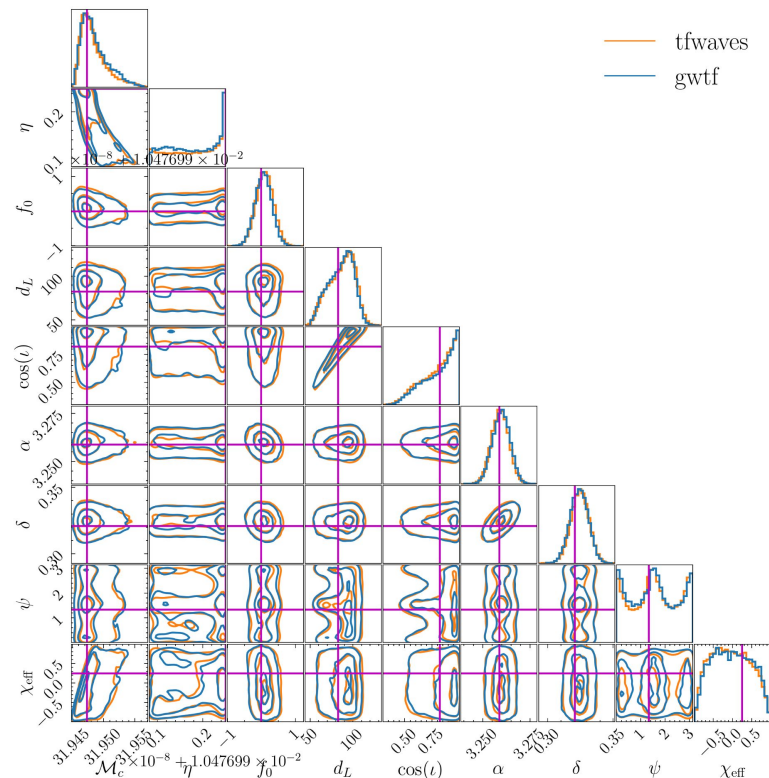


Noiseless Parameter Estimation (EMRI #0) [Backup]



Noisful Parameter Estimation (stBBH #1 and #2) [Backup]

Source 1



Source 2

