

Discussion:

ML methods in forward models
and data analysis

EMRI Global Fit II

ML methods in forward models: background

- Why do we need ML in forward models? Cost, accuracy (often complementary)
- How is ML used in forward models?
 - Waveform surrogates (substitutes for linear representations, generative modeling, ROMAN),
 - integration in existing pipelines (FEW interpolation? Trajectory generation?), etc.
- Some example papers?

ML methods in forward models: open questions

- TDI response calculations are time-consuming. ML for TDI computation?
- Non-linear transformation of TDI channels to uncorrelated basis (double check for 2nd-gen TDI, especially at high frequencies -> is this sufficient in a “realistic” setup)
- Surrogate models/ROMs in vacuum-GR only? What about beyond-vacuum-GR effects?
- ML-based forward models in search or inference only, or both?
- Which representation (time, frequency, or time-frequency, or something else) of the signal and the templates is the most useful for ML applications? What are some major pros and cons in each case?

ML in data analysis: EMRI data analysis challenges [review]

- **Waveform computational cost:** expensive waveform / TDI response generation + large number of templates
- **High dimensional parameter space:** ≥ 14 -D (more for beyond-GR or non-vacuum case)
- **Complex likelihood surface:** Multimodality (or “non-local degeneracy”), Needle-in-haystack morphology
- **Source confusion:** the global fit context, e.g. cross-talk between EMRIs and GBs
- **Impacts of data anomaly:** glitches, gaps, non-stationarity

ML in data analysis: existing explorations [review]

Non-AI methods:

[1] Gair J R+. [\[arXiv:gr-qc/0610046\]](#)

"Detecting EMRI events in LISA data using the Hierarchical Algorithm for Clusters and Ridges (HACR)"

→ Point estimation via HACR time-frequency search, template-free, semi-coherent.

[2] Gair J R+. [\[arXiv:0710.5250\]](#)

"Time-frequency analysis of EMRI signals in mock LISA data"

→ HACR applied to mock LISA data.

[3] Strub S H+. [\[arXiv:2505.17814\]](#)

"Searching for extreme mass ratio inspirals in LISA: from identification to parameter estimation"

→ Posterior estimation via semi-coherent time-frequency statistic + differential evolution + MCMC.

[4] Zou X B+. [\[arXiv:2506.21955\]](#)

"Constraining the Deviation of Kerr Metric via Bumpy Parameterization and Particle Swarm Optimization in EMRIs"

→ Point estimation for Kerr-deviation EMRI via PSO + reduced-dimensionality likelihood + averaging over peaks.

ML in data analysis: existing explorations [review]

Non-AI methods:

[5] Ye C Q+. [\[arXiv:2310.03520\]](#)

"Identification of gravitational waves from extreme-mass-ratio inspirals"

→ Point estimation via hierarchical search combining harmonic mode search, semi-coherent phenomenological waveform search, and grid-based parameter mapping.

[6] Wang T X+. [\[arXiv:2601.22464\]](#)

"Constructing a gravitational wave analysis pipeline for extremely large mass ratio inspirals"

→ Point estimation for XMRI via hierarchical semi-coherent F-statistic + PSO + harmonic-power eccentricity estimation.

[7] Ji L+. [\[arXiv:2506.17380\]](#)

"Time-frequency Imprints of Extreme Mass-Ratio Inspirals in Confusion Gravitational Wave Background"

→ Posterior estimation of EMRI population parameters via time-frequency covariance analysis and Fisher.

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ML in data analysis: existing explorations [review]

AI (or AI-assisted) methods:

[1] Yun Q+. [arXiv:2311.18640]

"The detection, extraction and parameter estimation of extreme-mass-ratio inspirals with deep learning"

→ Point estimation via CNN detection, UNet extraction, and VGG regression for key intrinsic parameters.

[2] Liang B+. [Chin. Phys. Lett. 42, 081101 (2025)]

"Unlocking New Paths for Efficient Analysis of Gravitational Waves from Extreme-Mass-Ratio Inspirals with Machine Learning"

→ Posterior estimation via flow-matching posterior estimation (FMPE).

[3] Liang B+. [Research 9:1055 (2026)]

"Toward Efficient and Accurate EMRI Parameter Estimation: A Machine Learning-Enhanced MCMC Framework"

→ Posterior estimation via FMPE + PTMCMC refinement.

ML in data analysis: existing explorations [review]

AI (or AI-assisted) methods:

[4] Cole P S+. [arXiv:2505.16795]

"Sequential simulation-based inference for extreme mass ratio inspirals"

→ Posterior estimation via Truncated Marginal Neural Ratio Estimation (TMNRE).

[5] Speri L+. [arXiv:2510.20891]

"Ab uno disce omnes: Single-harmonic search for extreme mass-ratio inspirals"

→ Posterior estimation via SVD-based EMRI frequency evolution model, time-frequency-domain semi-coherent statistic, DE+Adam optimization, SBI proposal, and MCMC refinement.

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ML in data analysis: updates / comments on the above [discussion]

- **EMRI data analysis challenges**
- **Existing explorations towards solving these problems**

ML in data analysis: updates / comments on the above [discussion]

- **EMRI data analysis challenges**

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- **Existing explorations towards solving these problems**

- non-AI
- AI
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