LISA and the Global Fit Problem

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25th Anniversary

Excelencia María de Maeztu

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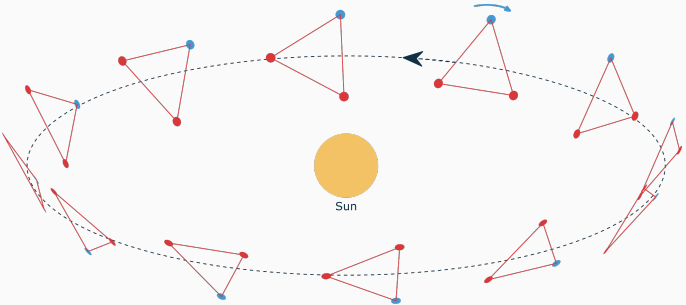
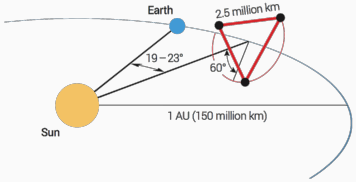
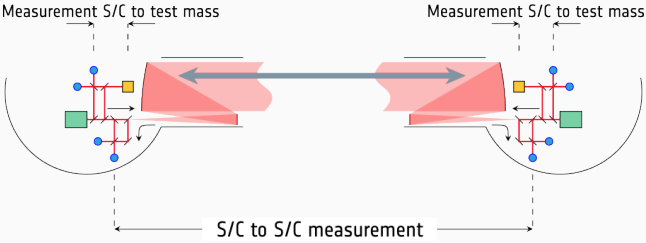
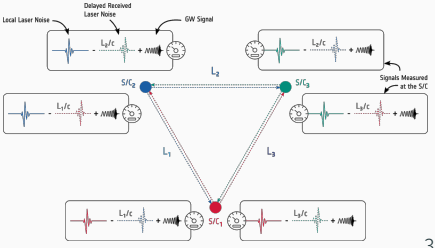
The LISA Ground Segment

LISA Measurement Principle

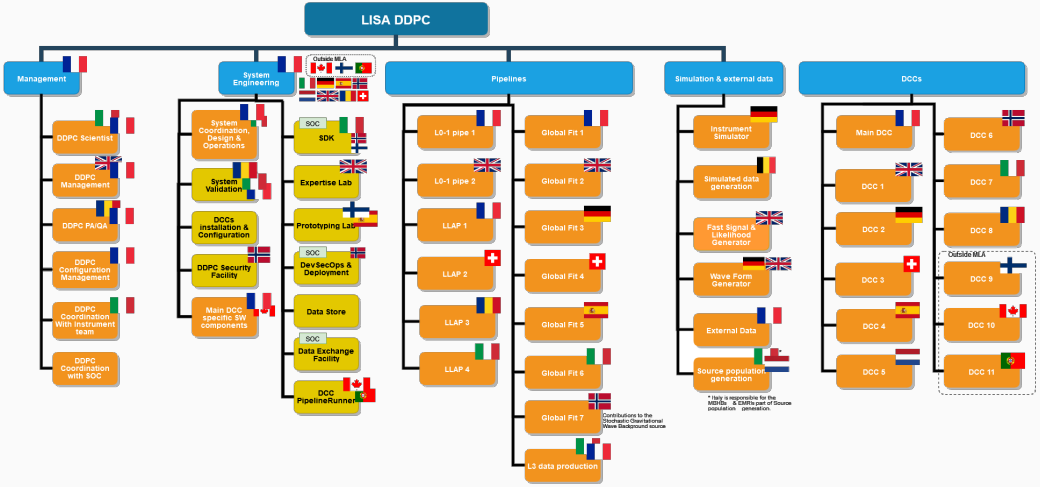








The Distributed Data Processing Centre (DDPC)



DDPC Coordination Units

Aside from the higher-level management (Project Office, Science Experts and System Team), there are 6 Coordination Units in the DDPC:

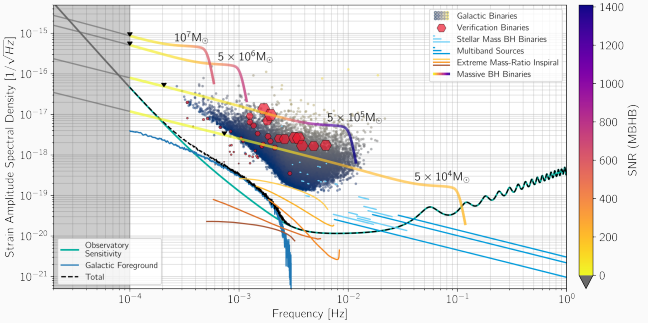
- **L0L1**: Processing from measurements to TDI observables.
- **L2A**: Low-latency alerts.
- **L2D**: Deep analysis: global fit and deep alerts.
- **L3C**: Consolidation and cataloguing of L2D outputs.
- **SIM**: Realistic instrument simulator and L1/L2 data.
- **WAV**: Waveform modelling.

The Global Fit Problem

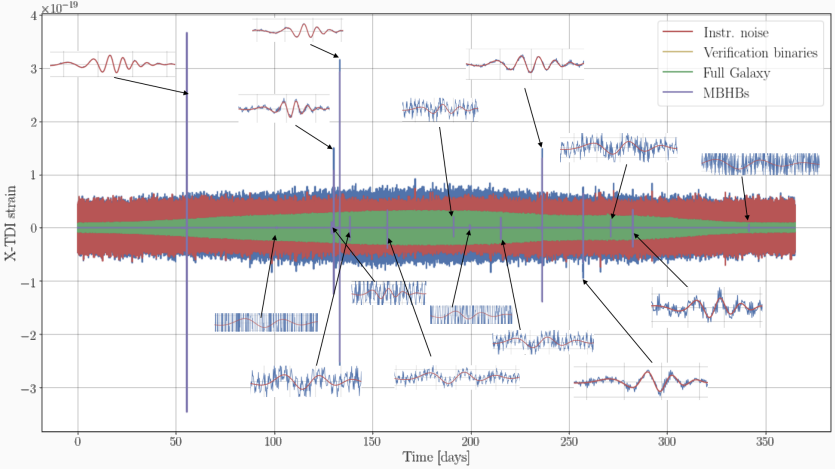
Sources in the LISA band

In LISA, we expect to find:

- ~10 Massive Black Hole Binaries (MBHBs)/yr.
- ~10^7 Galactic Binaries all the time (!!!)
  - Of these, ~10^4 are individually resolvable.
  - 37 are already known ⇒ guaranteed science!
  - The rest form a stochastic foreground.
- ~1-1000 Extreme Mass Ratio Inspirals (EMRIs)/year.
- ~10^4 stellar-mass Black Hole Binaries
- Stochastic backgrounds
- Unknown signals...?

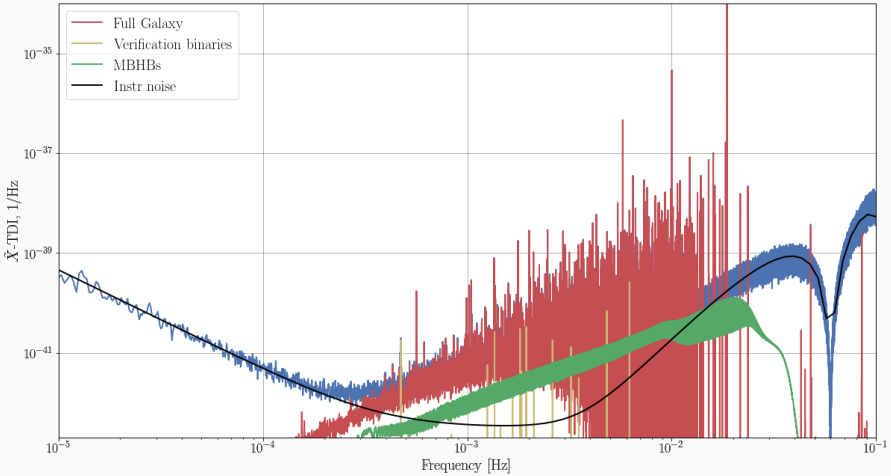


LISA Data Challenges



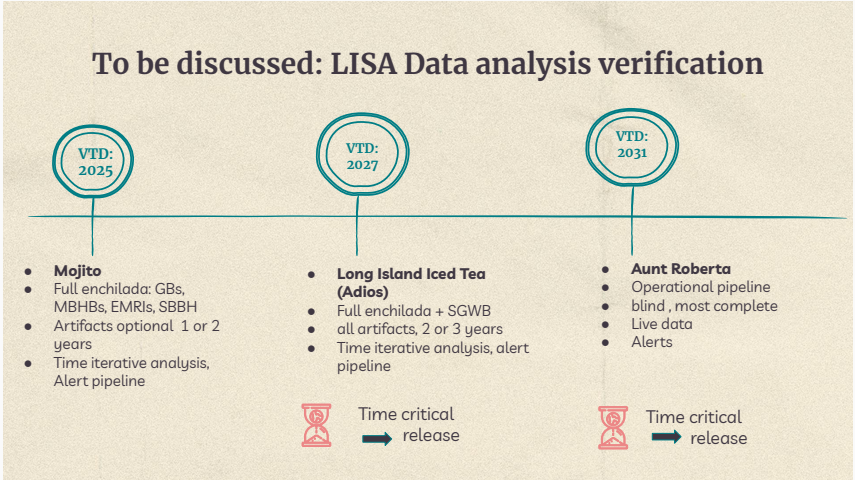
- Test on simulated data before LISA launches.
- Public data to be analyzed by participants, as a common benchmark.

LISA Data Challenges



- Test on simulated data before LISA launches.
- Public data to be analyzed by participants, as a common benchmark.

DDPC Common Datasets

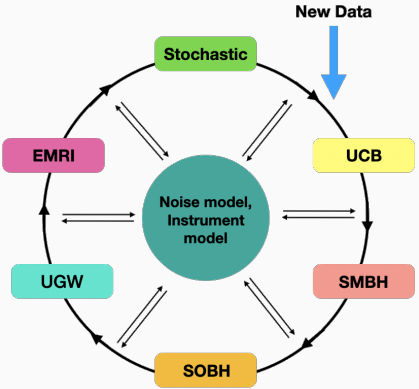


Credit: S. Babak (2023)

The Global Fit Solution

The Wheel of Fortune

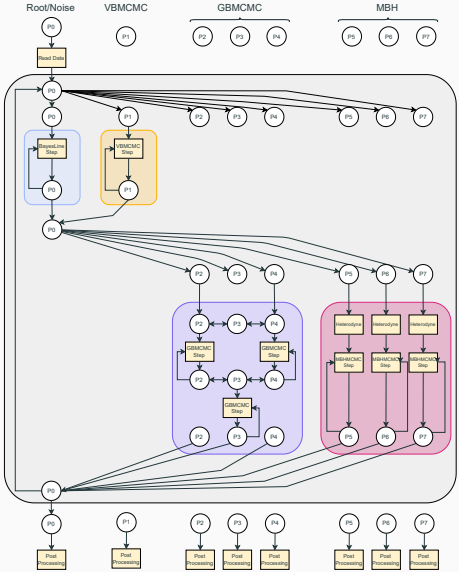
- Assumption: each source type is independent from the others.
- This allows for Blocked Gibbs sampling
- In practice:
  - Package source types as modules
  - Use residuals as input
- There are currently 4 global fit prototypes in the literature.



Credit: Littenberg+20, arXiv:2004.08464

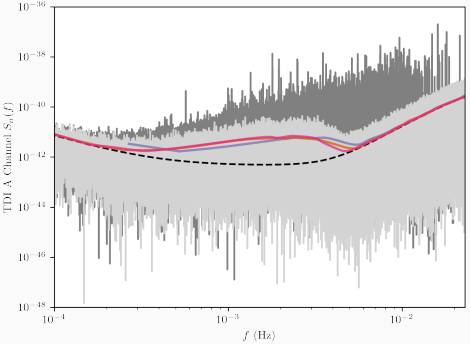
Global LISA Analysis Software Suite (GLASS)

- First pipeline, from NASA. (Littenberg+23, arXiv:2301.03673)
- Orchestrate and coordinate the launch of legacy source-specific codes with many years of development.
- Parallel-tempered MCMC with reversible jump capabilities.

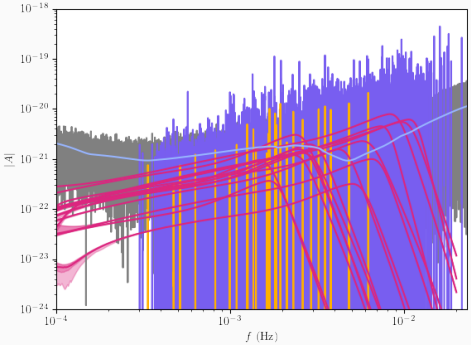


Global LISA Analysis Software Suite (GLASS)

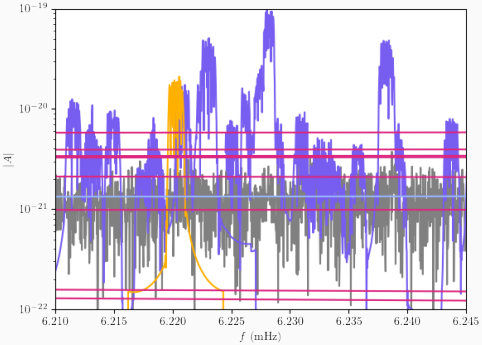
- Time evolving analysis: spans of 1.5, 3, 6, 12 months.
- PSD (including instrumental noise and unresolved GBs) fit with a spline model.
- The number of spline components is left to trans-dimensional MCMC.



Global LISA Analysis Software Suite (GLASS)

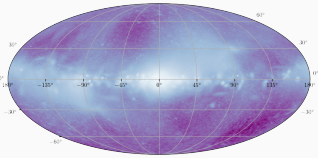


Reconstructed sources.

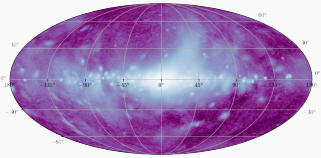


Close-up on a GB analysis band.

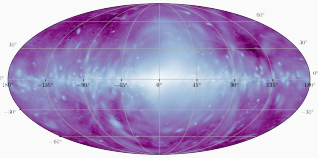
Global LISA Analysis Software Suite (GLASS)



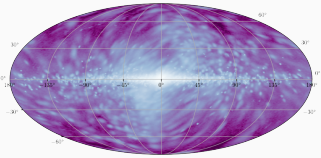
1.5 months.



3 months.

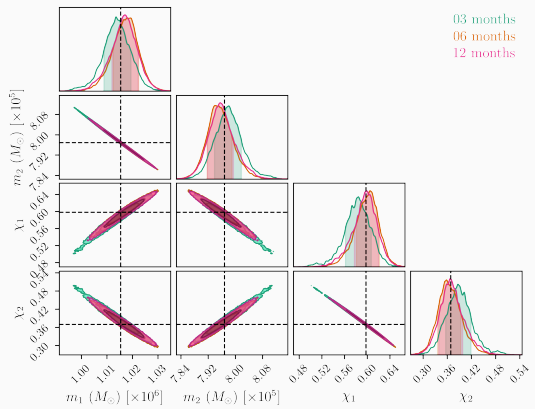


6 months.

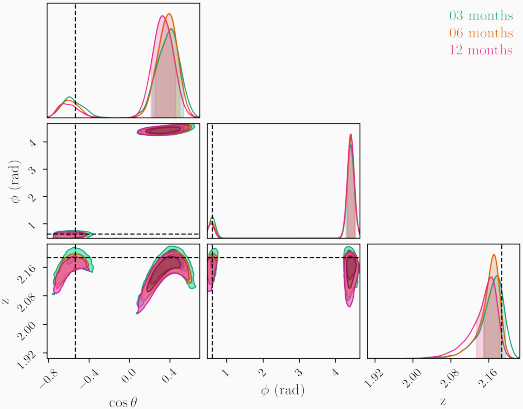


12 months.

Global LISA Analysis Software Suite (GLASS)



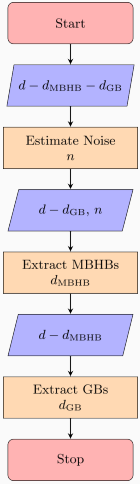
Intrinsic MBHB parameters.



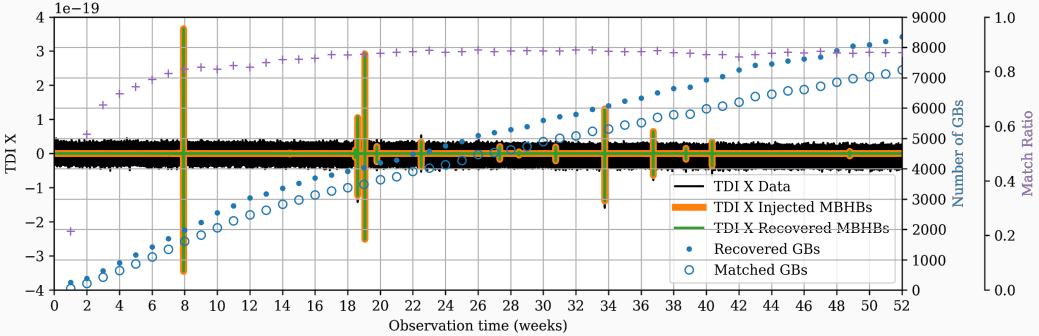
Extrinsic MBHB parameters.

The Swiss Global Fit Pipeline

- Developed at ETH-Zurich (Strub+24, arXiv:2403.15318).
- Catalog of found sources: not full posteriors.
- Differential evolution to maximize $p\left(\vec{x} \mid \theta\right)$.

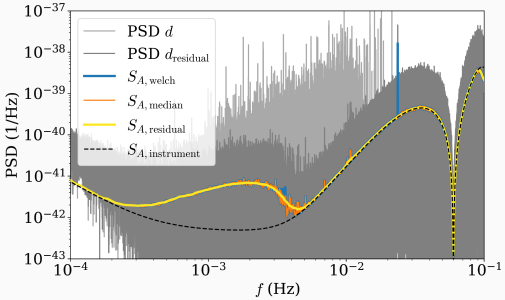


The Swiss Global Fit Pipeline

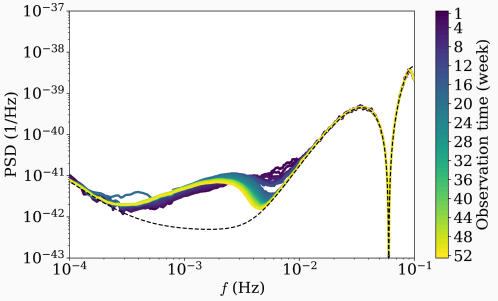


Time-evolving global fit: week-by-week analysis.

The Swiss Global Fit Pipeline

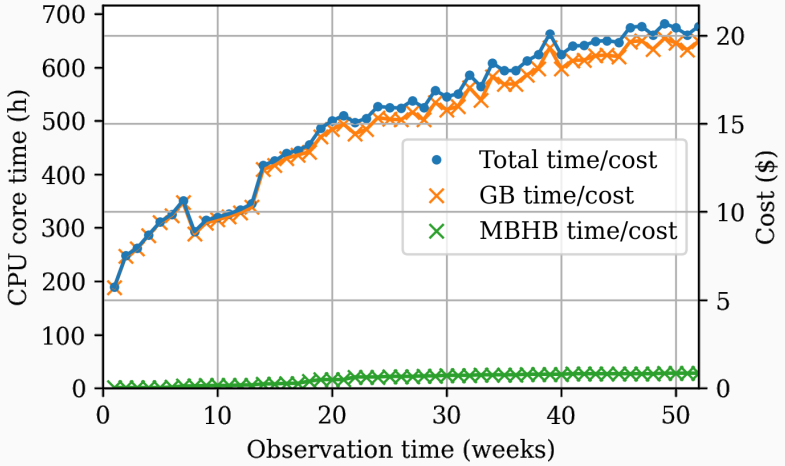


PSD estimate by smoothing and fitting to a spline model.



Weekly evolution.

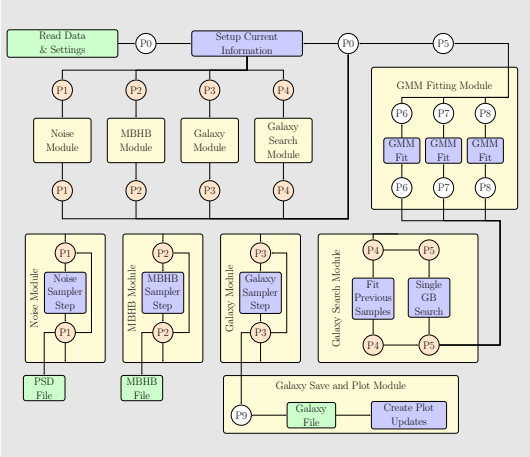
The Swiss Global Fit Pipeline



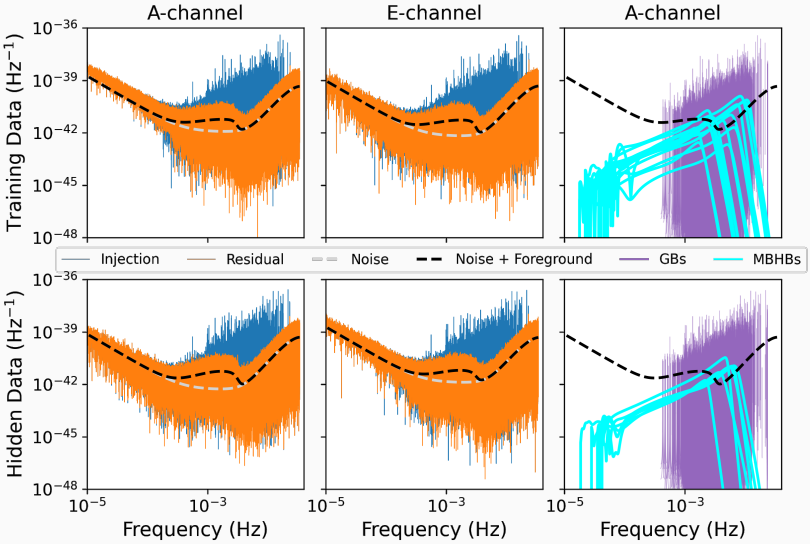
Very cheap!

Erebor

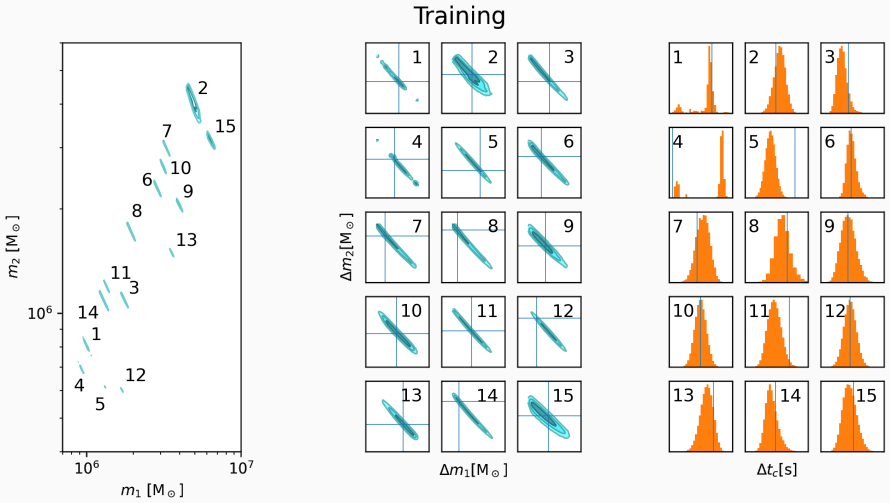
- International collaboration (Katz+25, arXiv:2405.04690).
- Open-source, community-developed tooling.
- Move compute to GPU whenever possible.
- Entire year of data analyzed at once (no time evolution).



Erebor

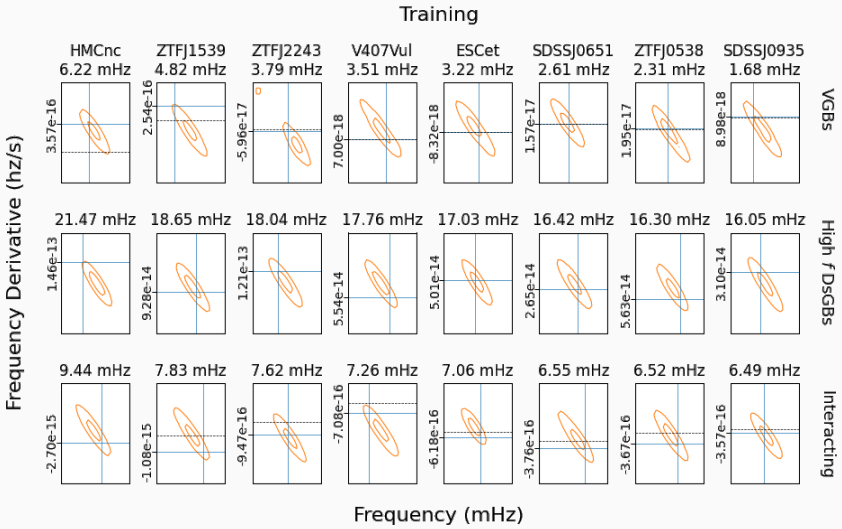

A-channel
E-channel
A-channel
Training Data (Hz^{-1})
Hidden Data (Hz^{-1})
10^{-36}
10^{-39}
10^{-42}
10^{-45}
10^{-48}
Injection
Residual
Noise
Noise + Foreground
GBs
MBHBs
10^{-5}
10^{-3}
Frequency (Hz)

Erebor



MBHB posteriors: masses and coalescence times.

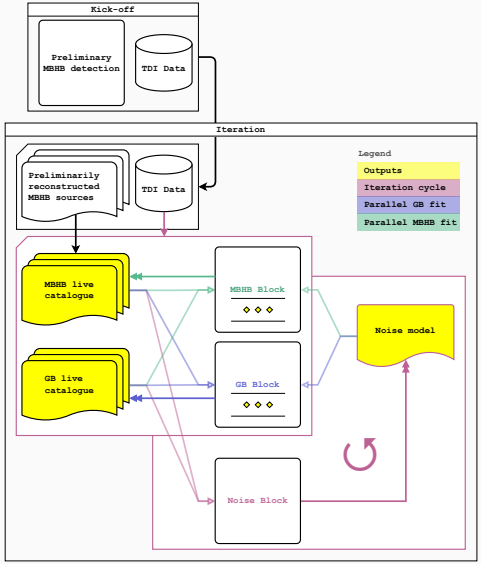
Erebor



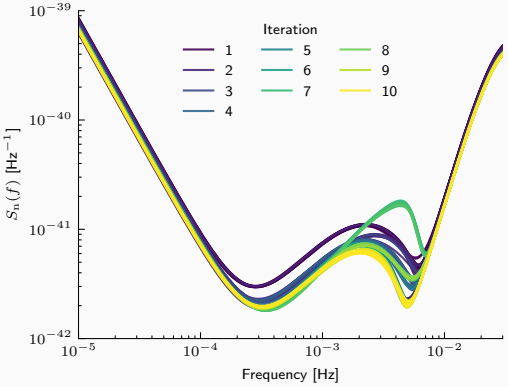
Some GB posteriors: frequency and derivative.

Gee-Moo

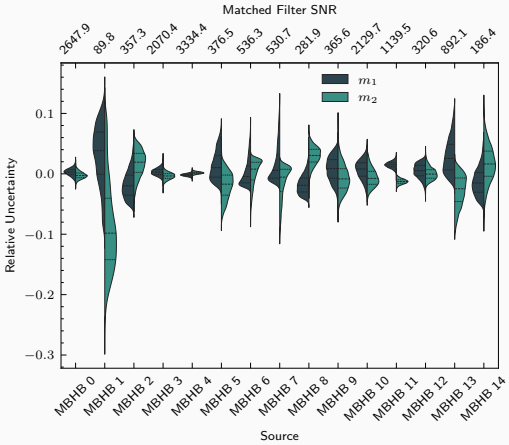
- French collaboration, APC-L2IT (Deng+25, arxiv:2501.10277).
- Use many domain-specific tricks to accelerate computation and improve efficiency.
- Entire year of data analyzed at once (no time evolution).



Gee-Moo

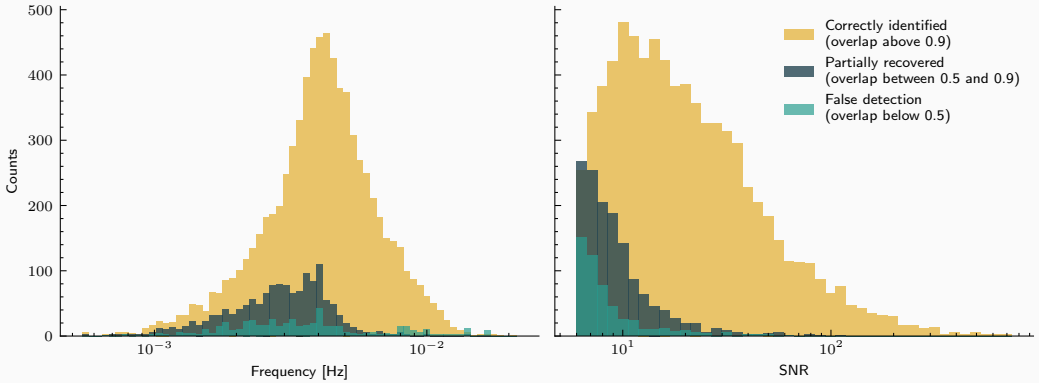


PSD estimate as global fit rounds pass.



Uncertainty in MBHB masses.

Gee-Moo

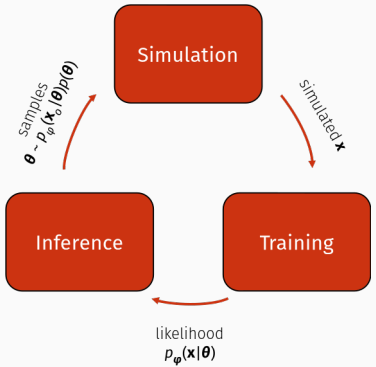


Some GB detection statistics.

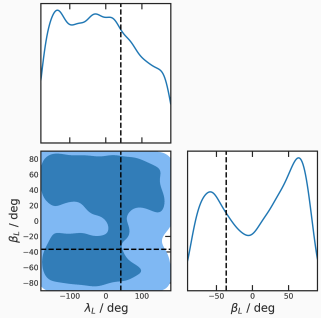
Our activities

Sequential Simulation-Based Inference for LISA

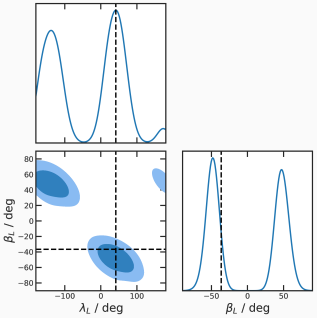
- Using Machine Learning to approximate the likelihood function.
- Adapt to observed data, minimize the number of simulations required.
- Critical step: find information-preserving low-dimensional representations of GW data.
- Check it out: Martín-Vílchez+25, arXiv:2406.00565.



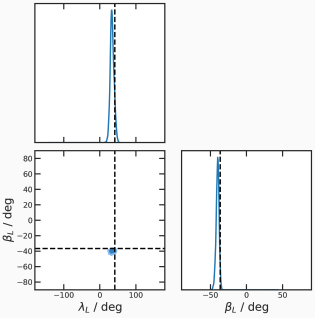
Sequential Simulation-Based Inference for LISA



Round 1



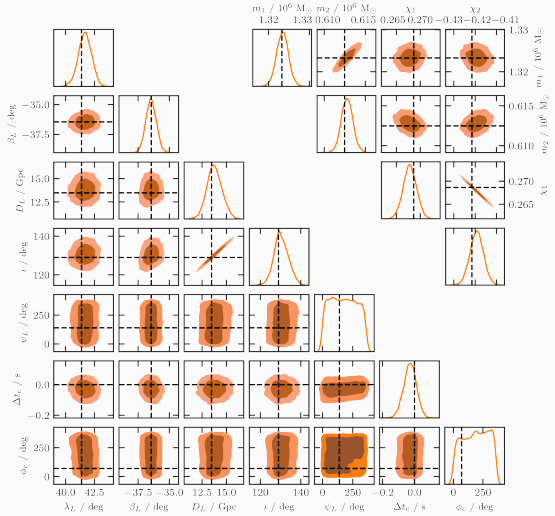
Round 15



Round 90

Example: evolution of sky location.

Sequential Simulation-Based Inference for LISA



SNL-PCA: all parameters.

Towards a more experimental global fit

- We want to build and test global fit modules that use more sophisticated algorithms.
- Example: making use of automatically differentiable templates to use techniques that require the likelihood gradient.
- Interested? Join us!

Thank you very much!

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