



Funded by
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gwg Hands-on session

ACME

Astrophysics Centre for
Multimessenger studies in Europe

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Introduction

The **gwg** is an algorithm that simulates the LISA Global Fit scheme. It essentially allows us to predict the resolvable Gravitational Wave signals from Double White Dwarf systems, and the resulting confusion GW signal.

The version presented here is based on [\[2103.14598\]](#).

A series of works have been based on this algorithm. See for example:

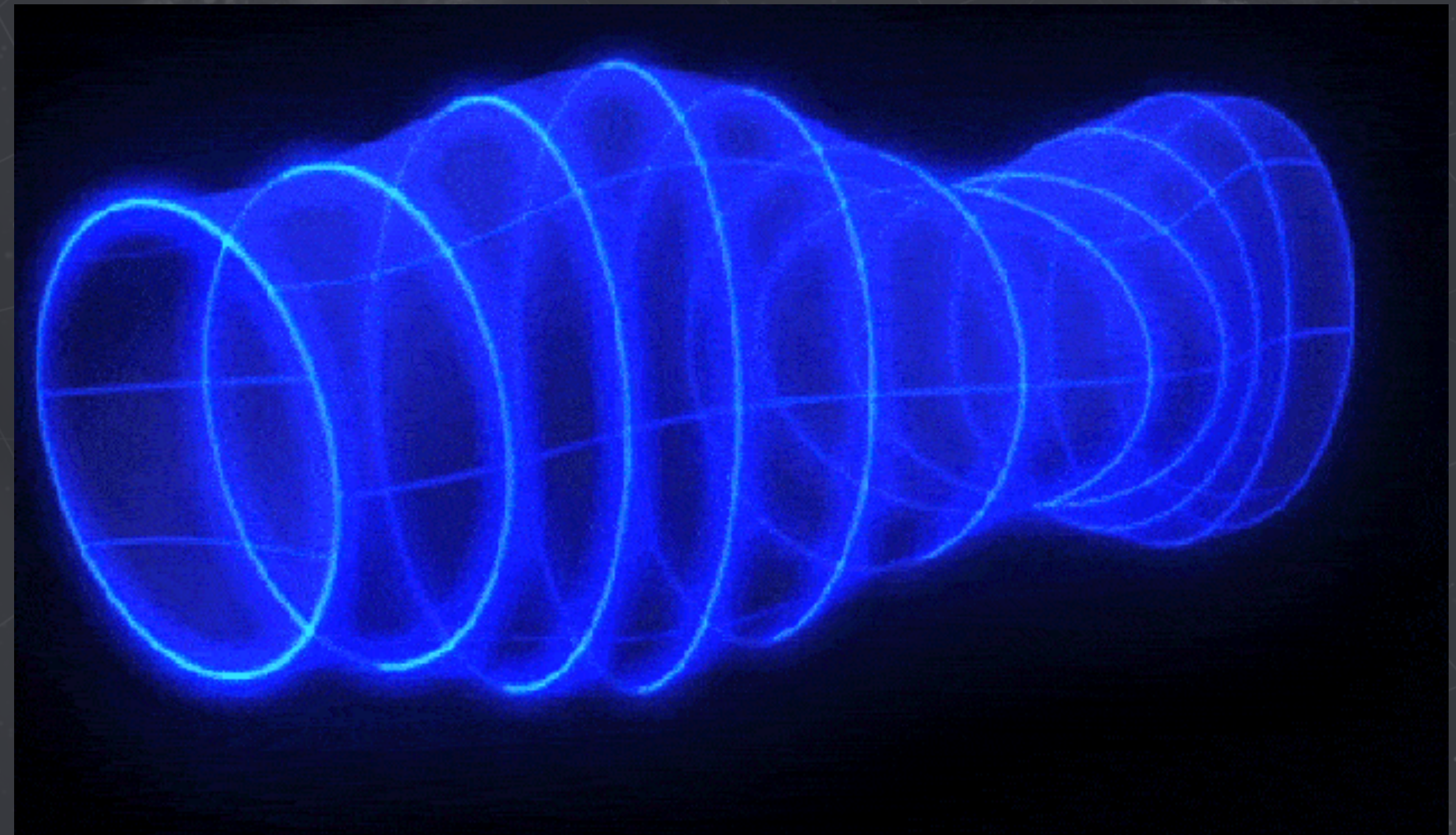
- The Effect of Mission Duration on LISA Science Objectives [\[2107.09665\]](#).
- Observationally driven Galactic double white dwarf population for LISA [\[2109.10972\]](#).
- Gravitational Waves from Double White Dwarfs as probes of the Milky Way [\[2204.07349\]](#).
- Computation of stochastic background from extreme mass ratio inspiral populations for LISA [\[2302.07043\]](#).
- Stochastic gravitational wave background from stellar origin binary black holes in LISA [\[2304.06368\]](#).
- The interacting double white dwarf population with LISA; stochastic foreground and resolved sources [\[2403.16867\]](#).
- [...]
- Inferring the population properties of galactic binaries from LISA's stochastic foreground [\[2602.18560\]](#).

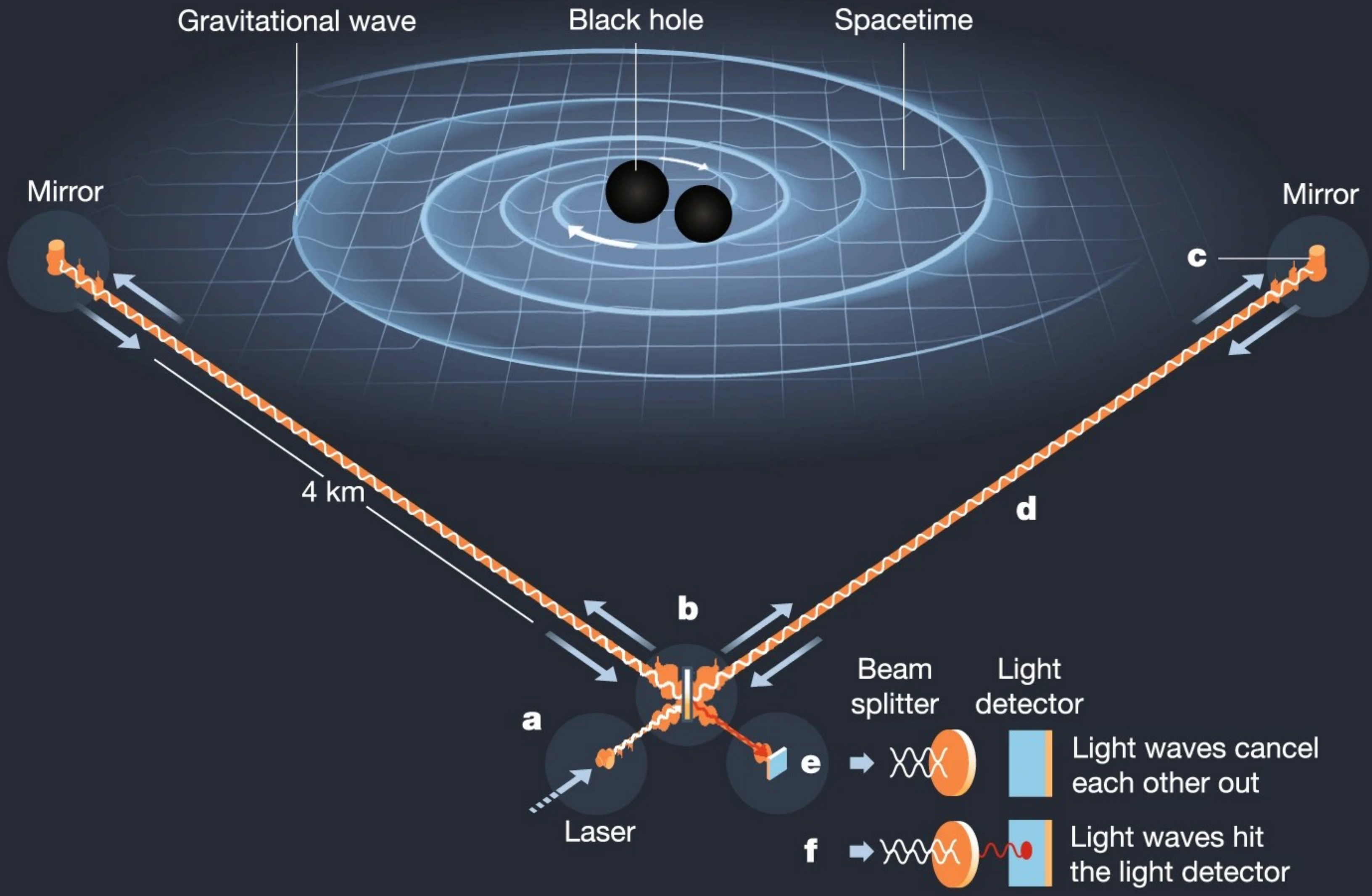
Gravitation Wave Astronomy

Gravitational Wave Astronomy

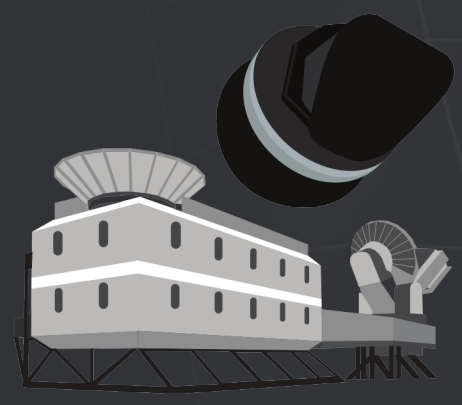
A new way to observing the Universe

- Predicted by General Relativity.
- Travelling fluctuations on the space-time itself.
- Caused by rapid violent changes in mass distribution.
- For example inspiraling Black Hole binaries, rotating Neutron Stars, super novae, [...]
- Propagating GWs has two polarisations, the \times and $+$.
- Laser interferometry to actually measure GWs.





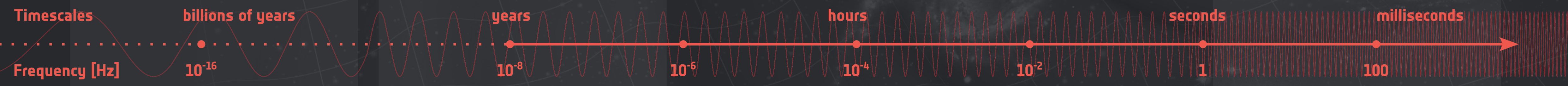
Cosmic microwave background polarisation



Pulsar timing array



Ground-based experiments



Cosmic fluctuations in the early Universe

Merging supermassive black holes

Compact object and supermassive black hole systems

Pulsar

Supernova

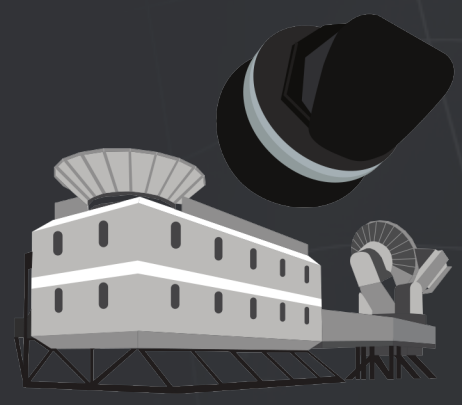
Galactic Binaries

Merging stellar-mass black holes

Merging neutron stars



Cosmic microwave background polarisation



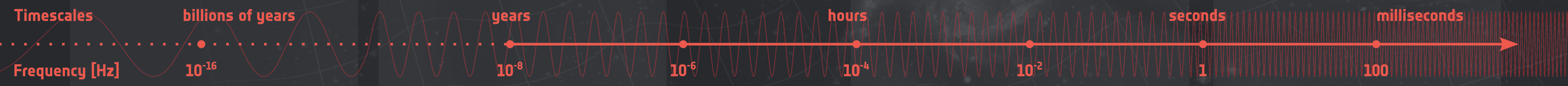
Pulsar timing array



Space-based observatory



Ground-based experiments



Cosmic fluctuations in the early Universe

<p>Merging supermassive black holes</p>	<p>Compact object and supermassive black hole systems</p>		

Galactic Binaries Merging stellar-mass black holes Merging neutron stars



The Science of LISA

LISA SCIENCE OBJECTIVES

Summary

1. Galactic Binaries

2. Massive Black Holes

3. Extreme and Intermediate mass-ratio Inspirals

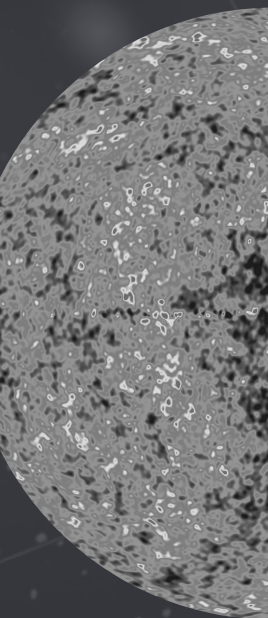
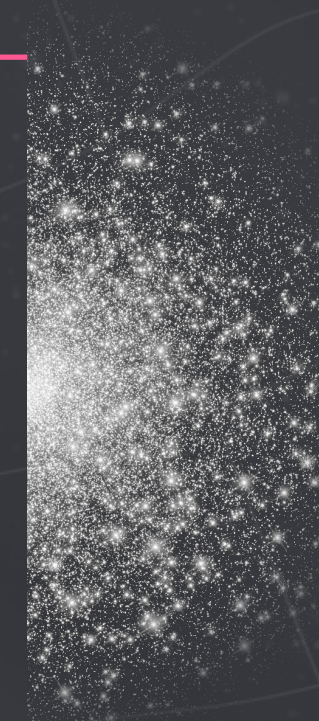
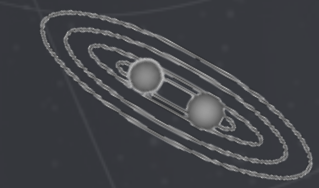
4. Stellar Mass Black Holes

5. Fundamental nature of gravity

6. Expansion of the Universe

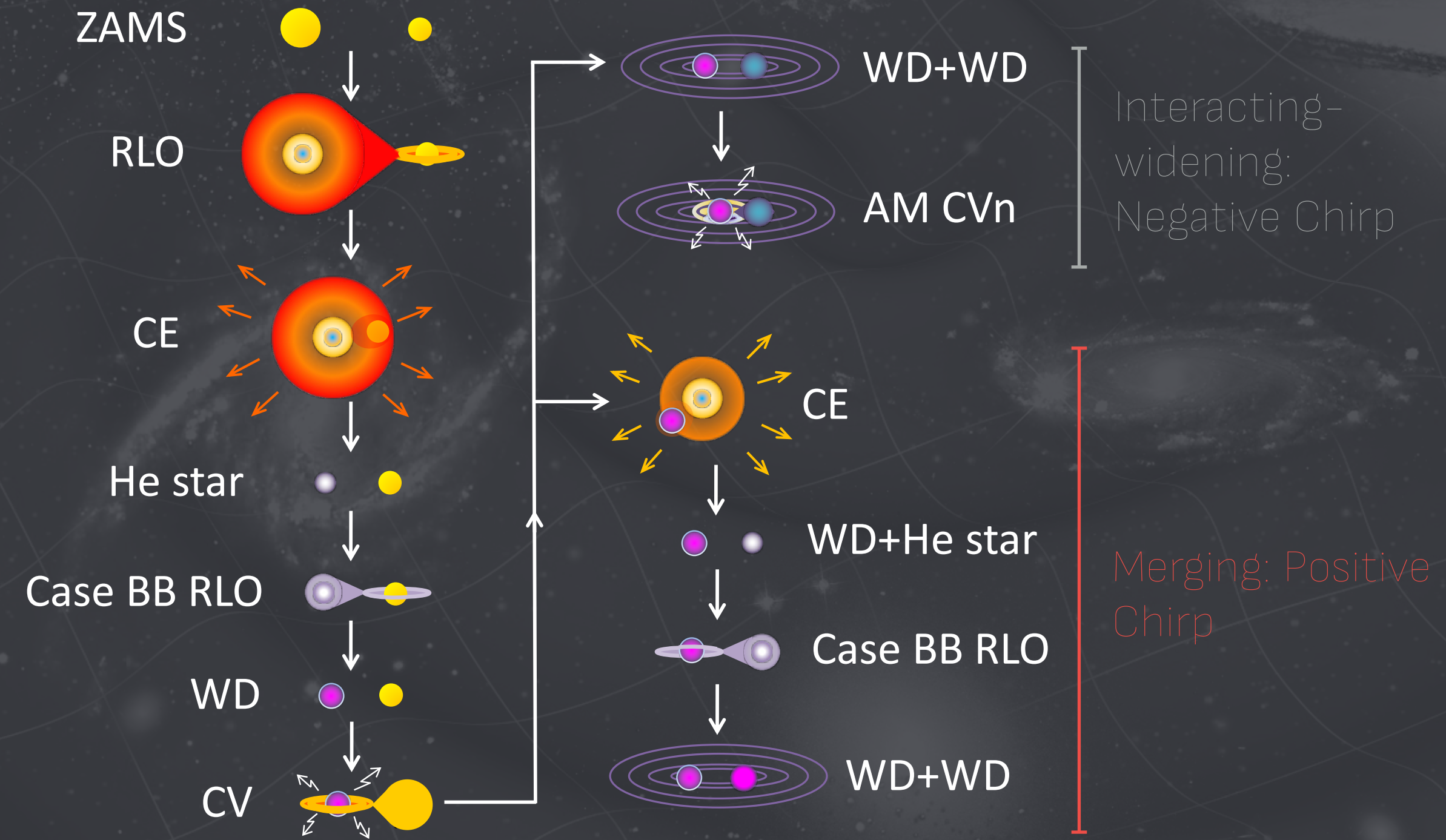
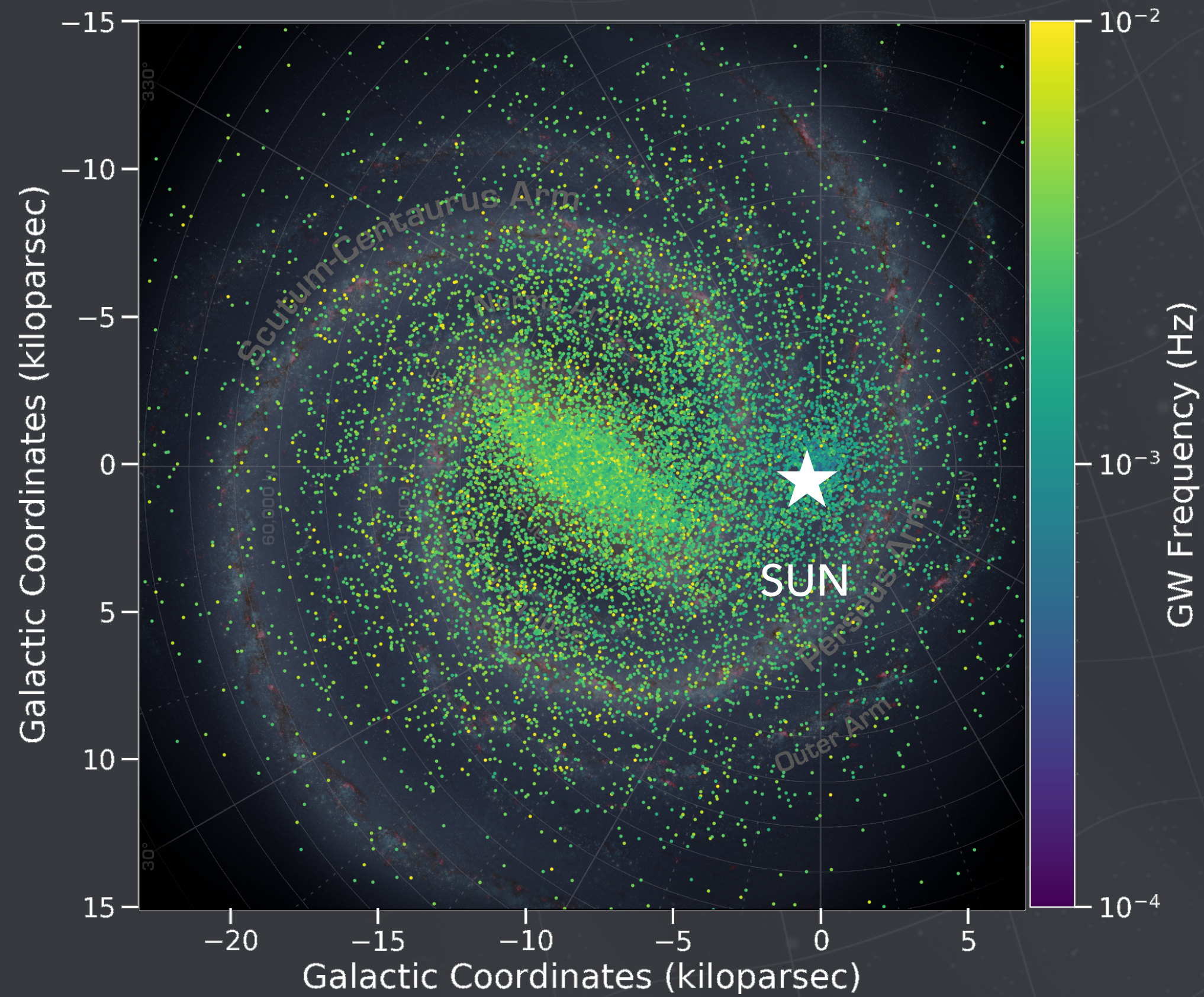
7. Stochastic gravitational wave backgrounds

8. Unforeseen sources

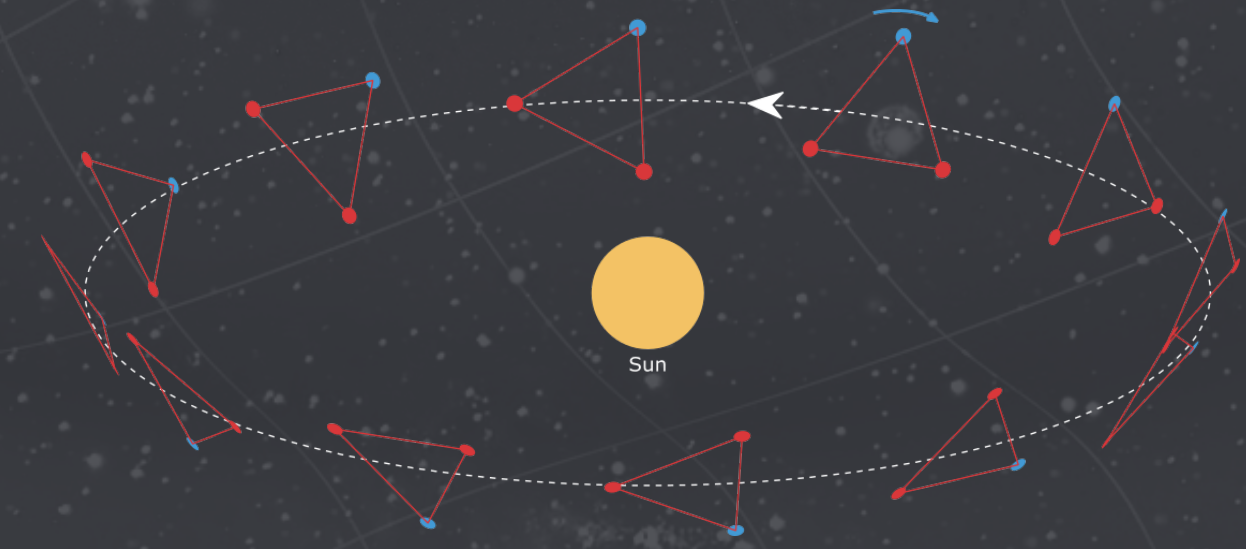


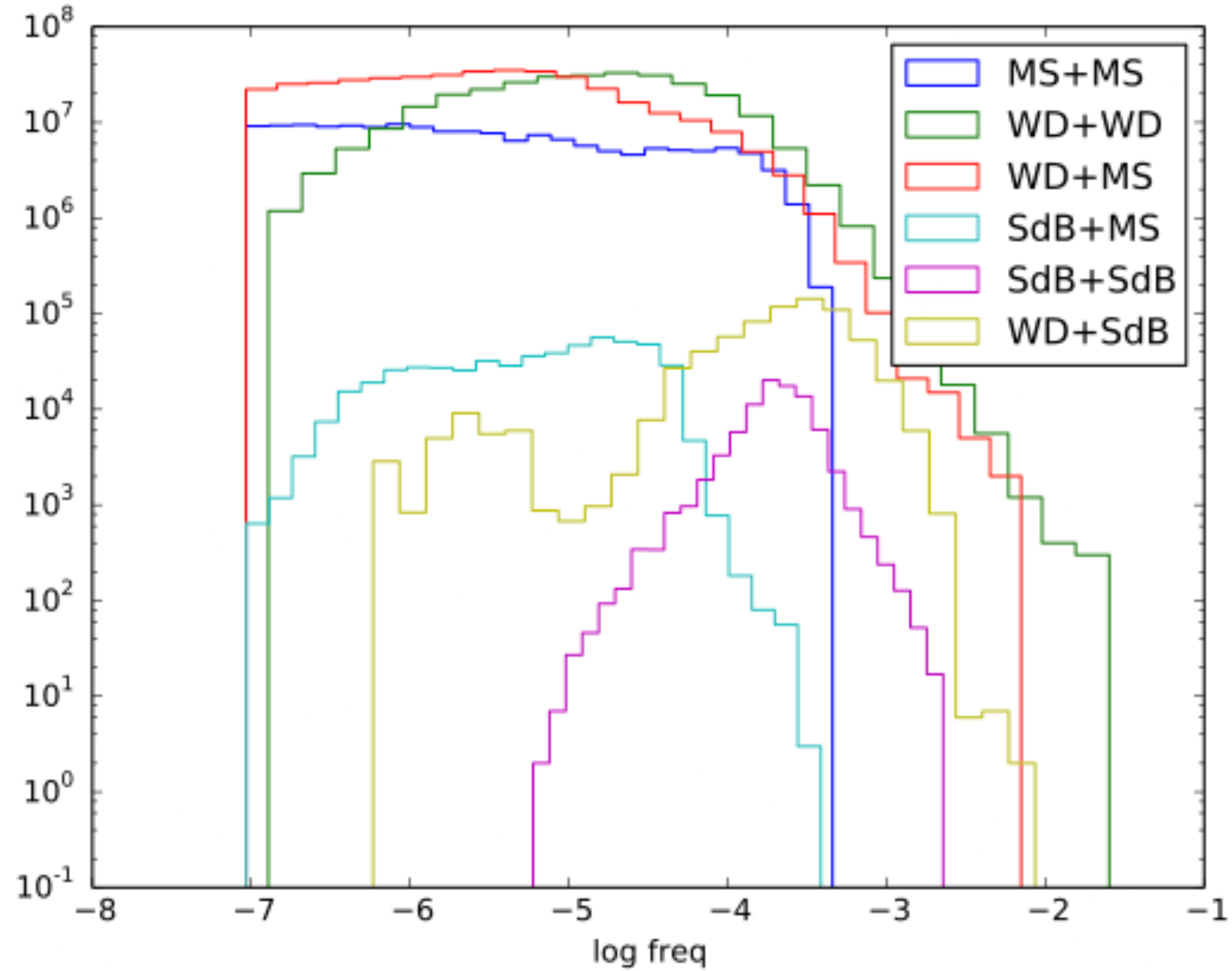
1. GALACTIC BINARIES

- ▶ Will observe > 10 000 galactic binaries
- ▶ How did they form?
- ▶ What is the spatial distribution of compact binaries invisible to telescopes?

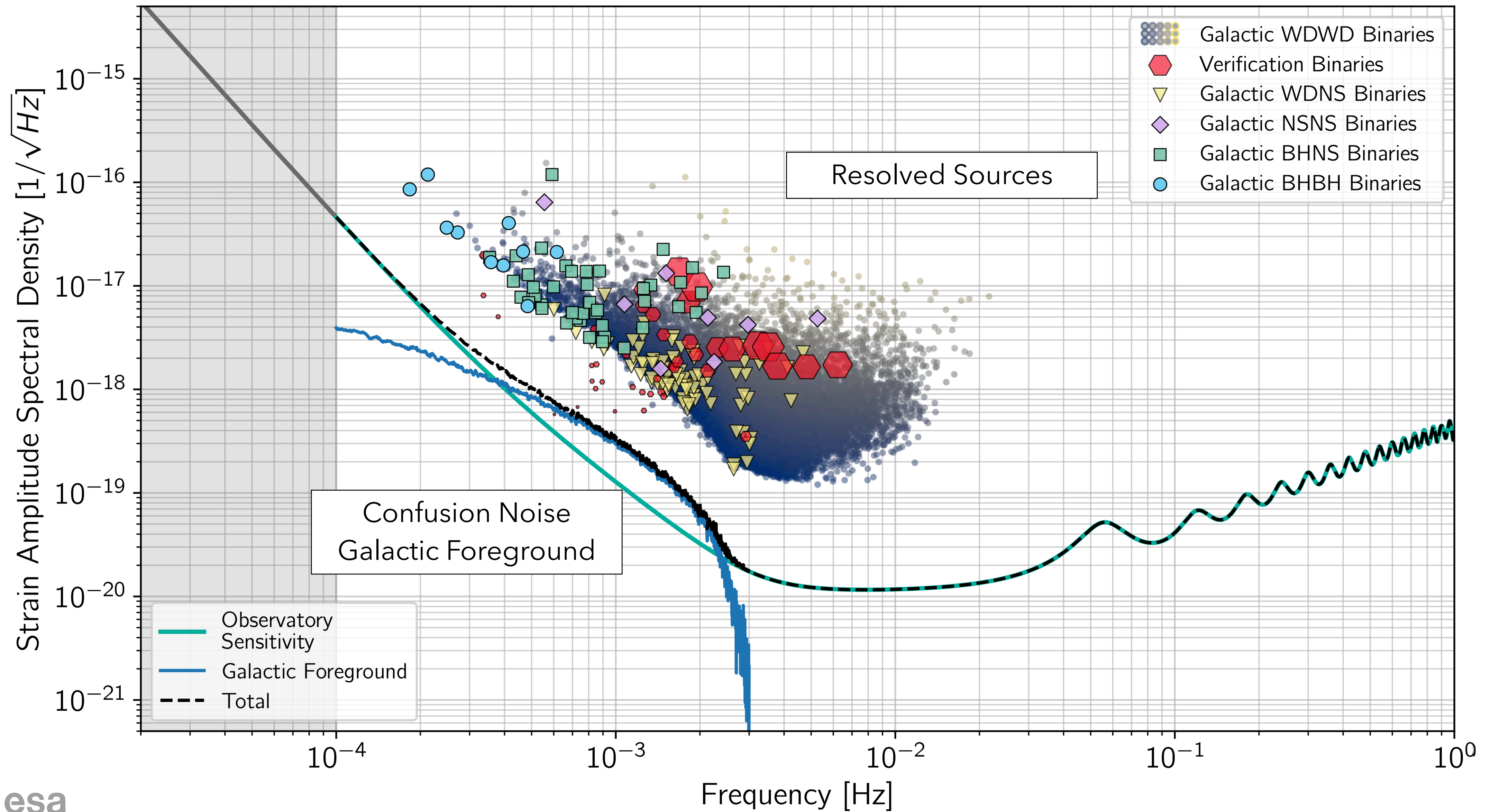


- ▶ Sky localisation of a few to fractions of a deg²
- ▶ Beyond the Galactic Center

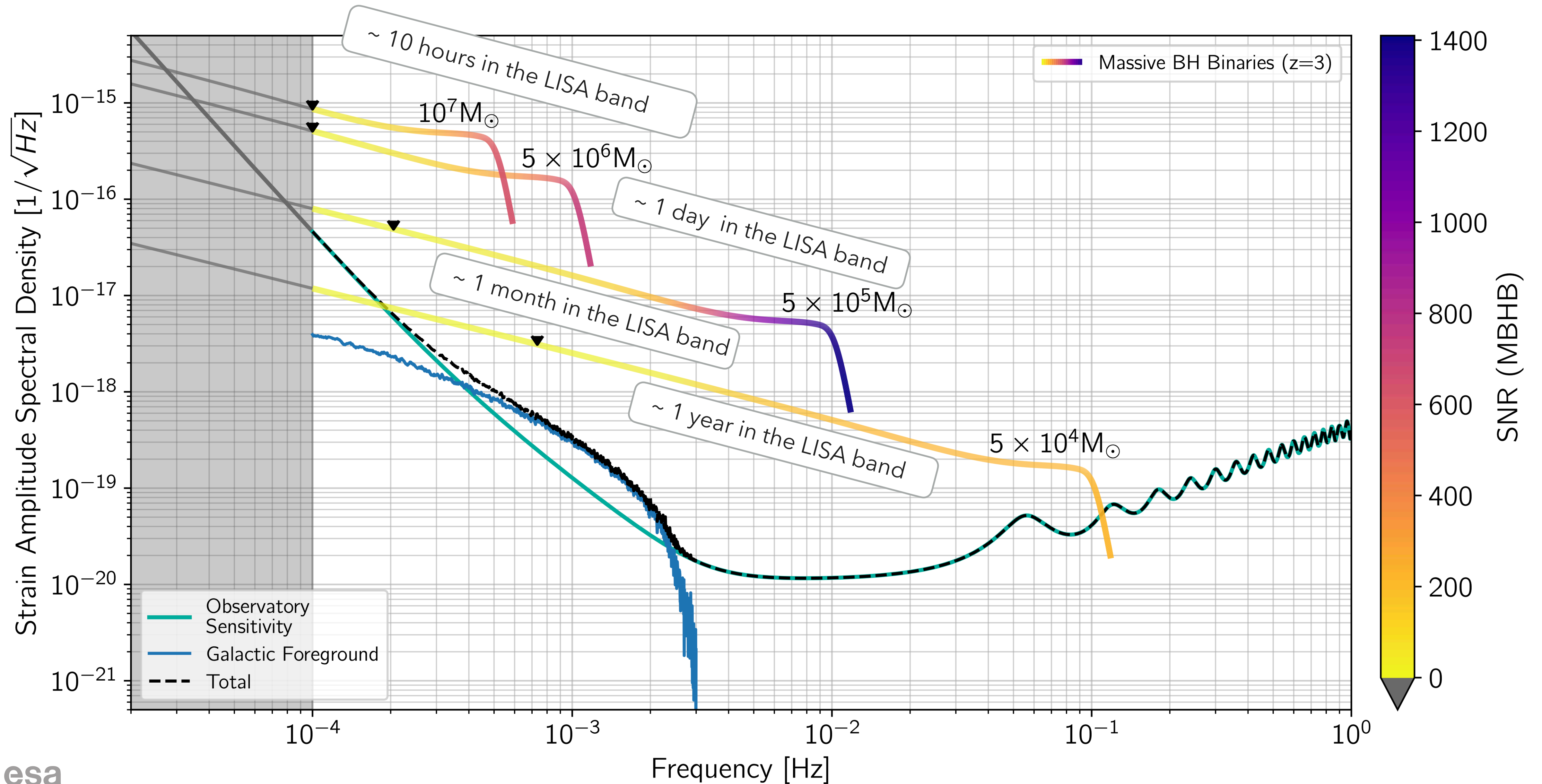




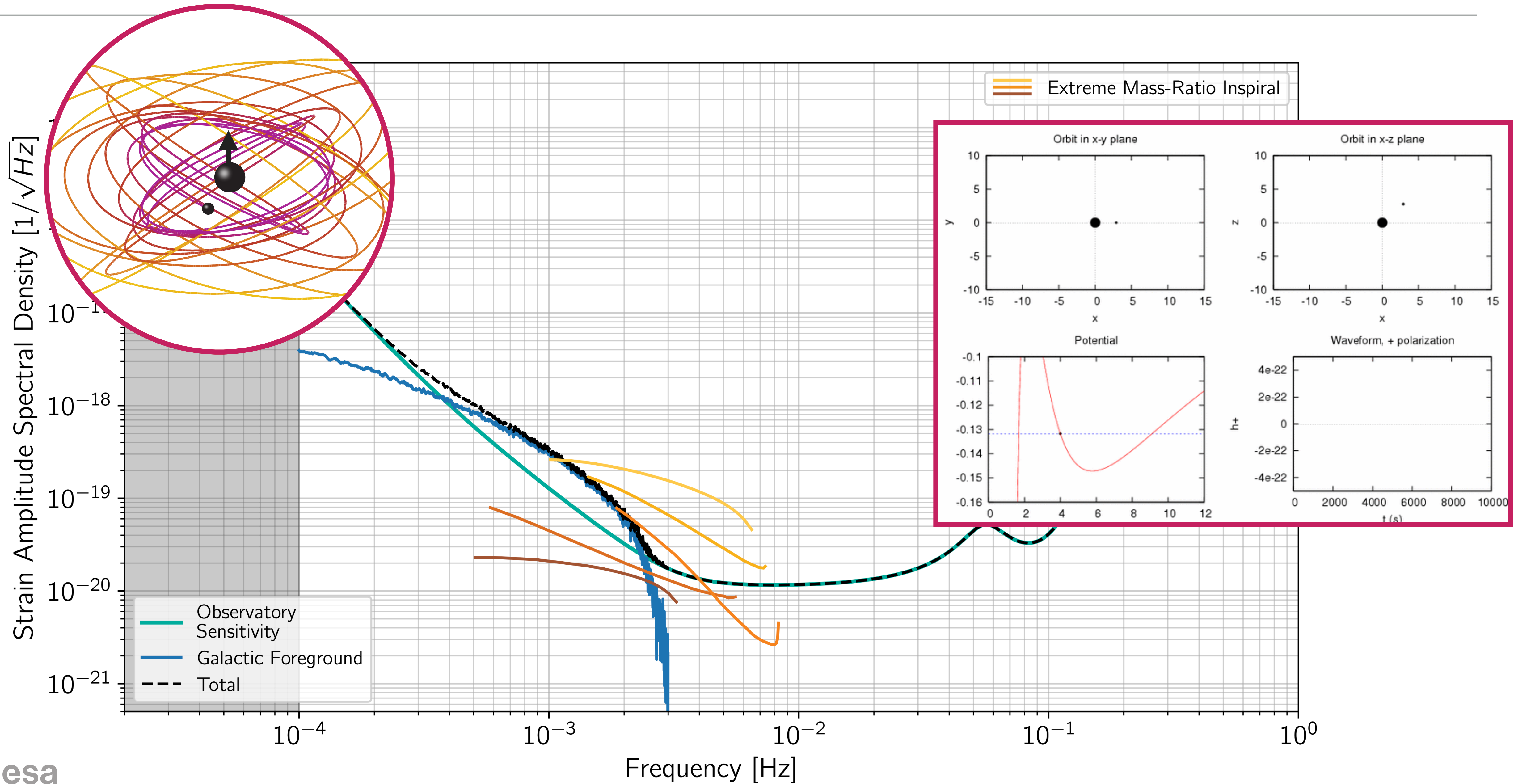
1. GALACTIC BINARIES



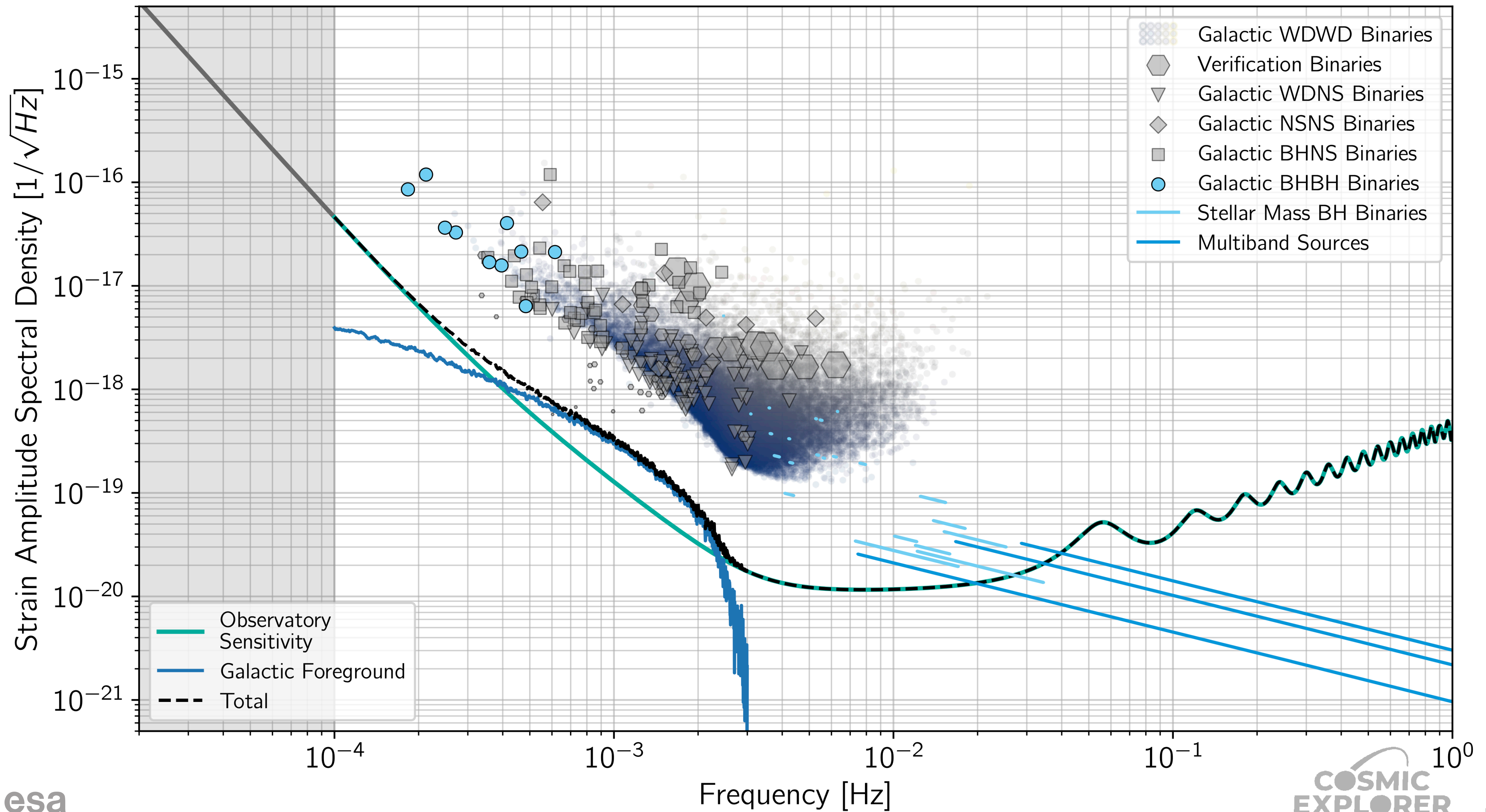
2. MASSIVE BLACK HOLES



3. EXTREME AND INTERMEDIATE MASS RATIO INSPIRALS



4. STELLAR MASS BLACK HOLES



The data

Massive BH Binary Merger



Extreme Mass-Ratio Inspiral



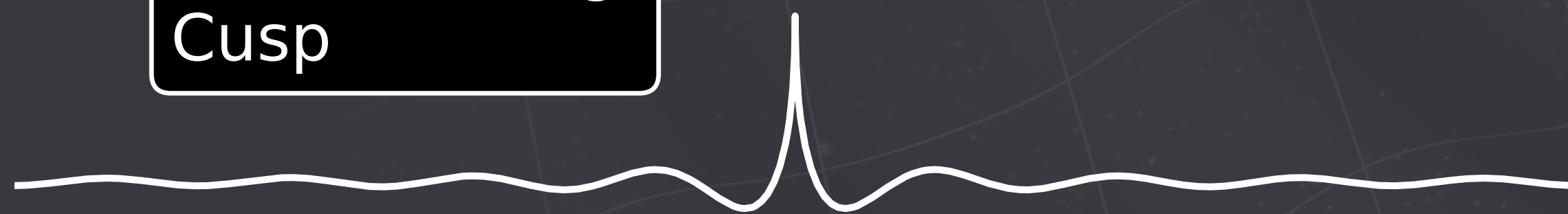
Galactic Binary



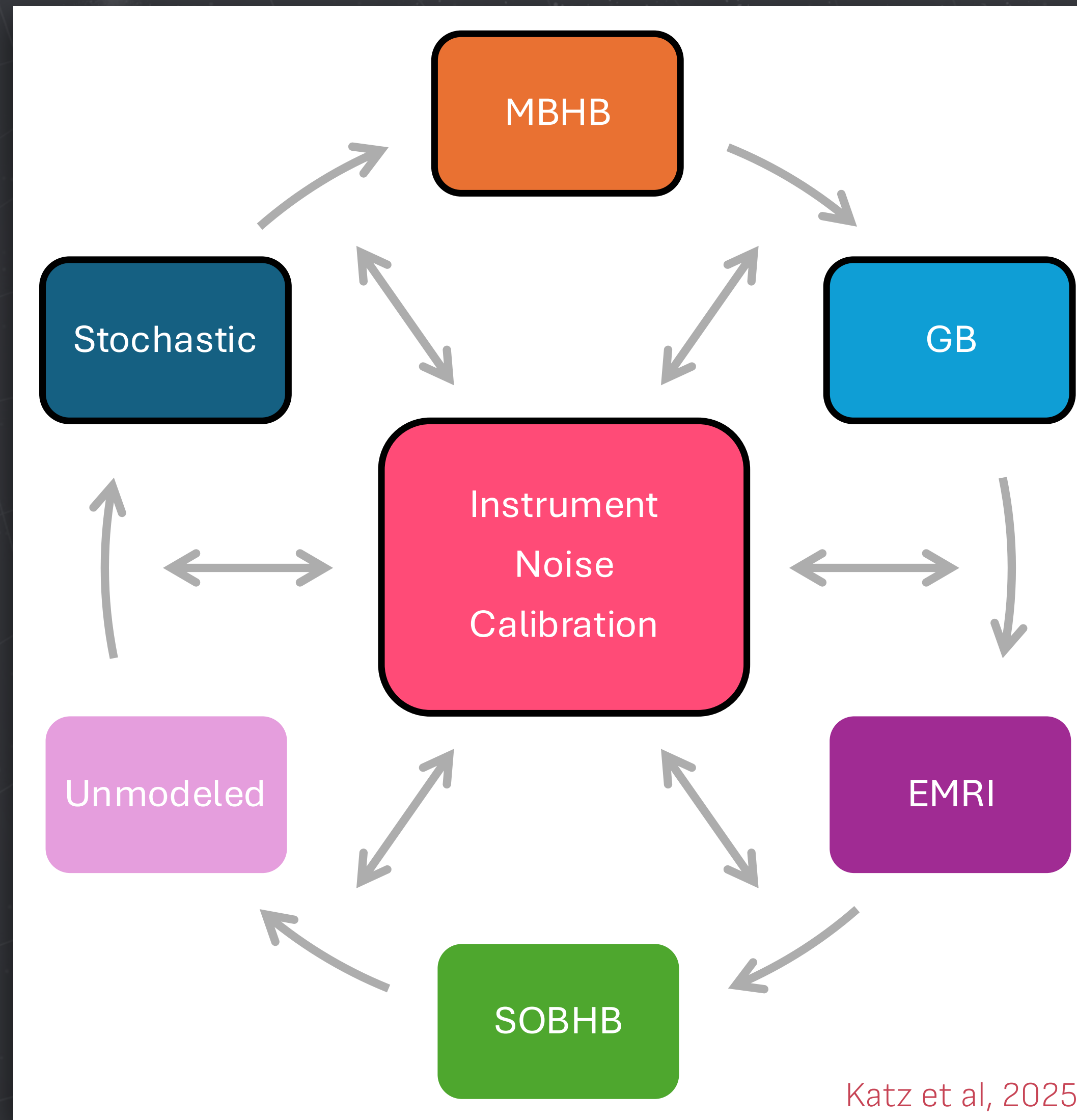
Stochastic GW Background

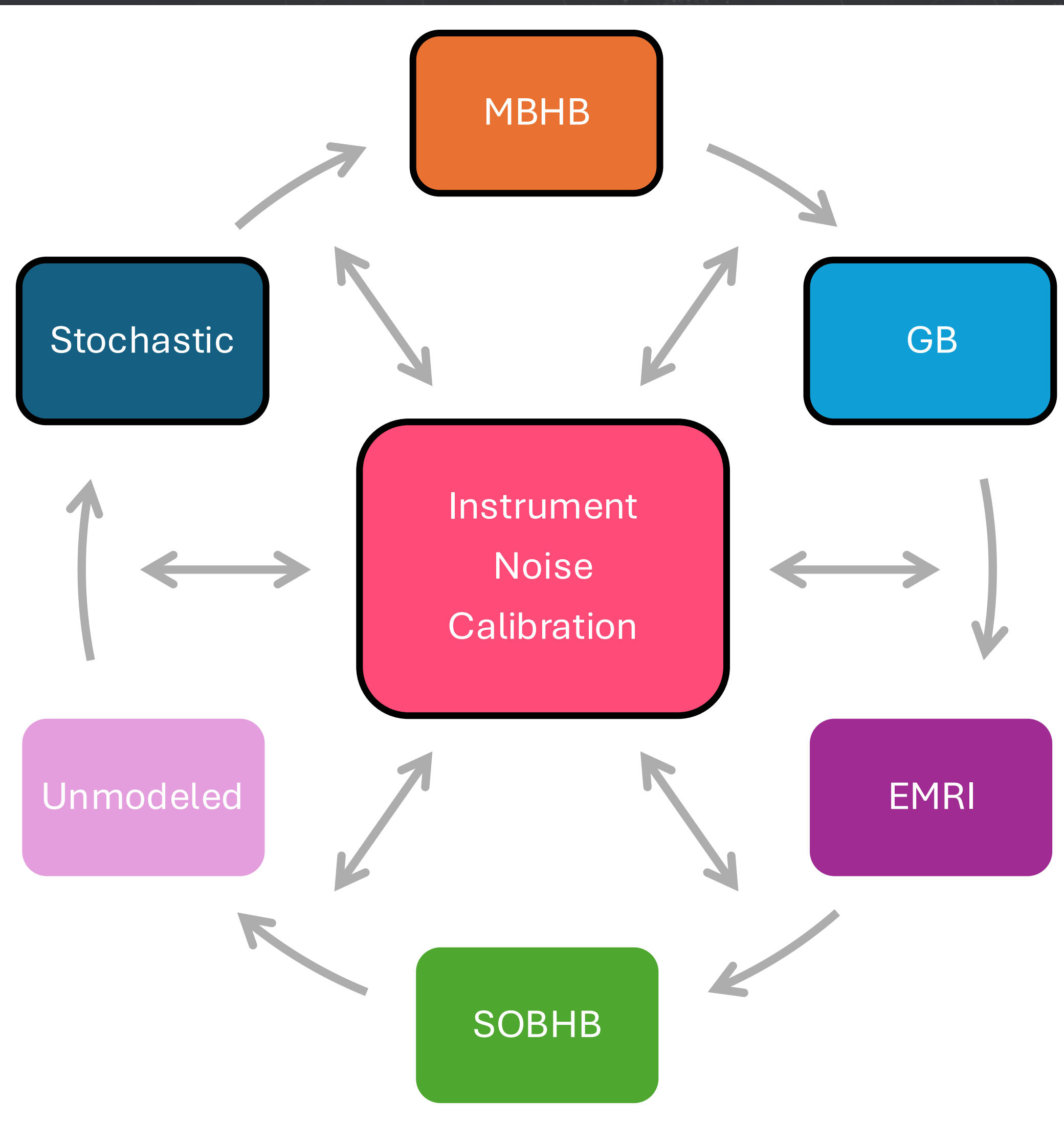


Cosmic String Cusp



- ▶ Different types of waveforms
- ▶ Long-lived sources
- ▶ $\mathcal{O}(10^5)$ parameters to estimate
- ▶ Overlap of signals in time *and* in frequency
- ▶ Instrumental noise will not be completely known.
- ▶ Correlations!
- ▶ Everything is connected through the residuals!





- ▶ Ideally: Just update everything all at once. However the curse of dimensionality is ... well ... cursing us. Rejection rates are too high.
- ▶ Blocked Gibbs type of sampling should alleviate the problem.

```

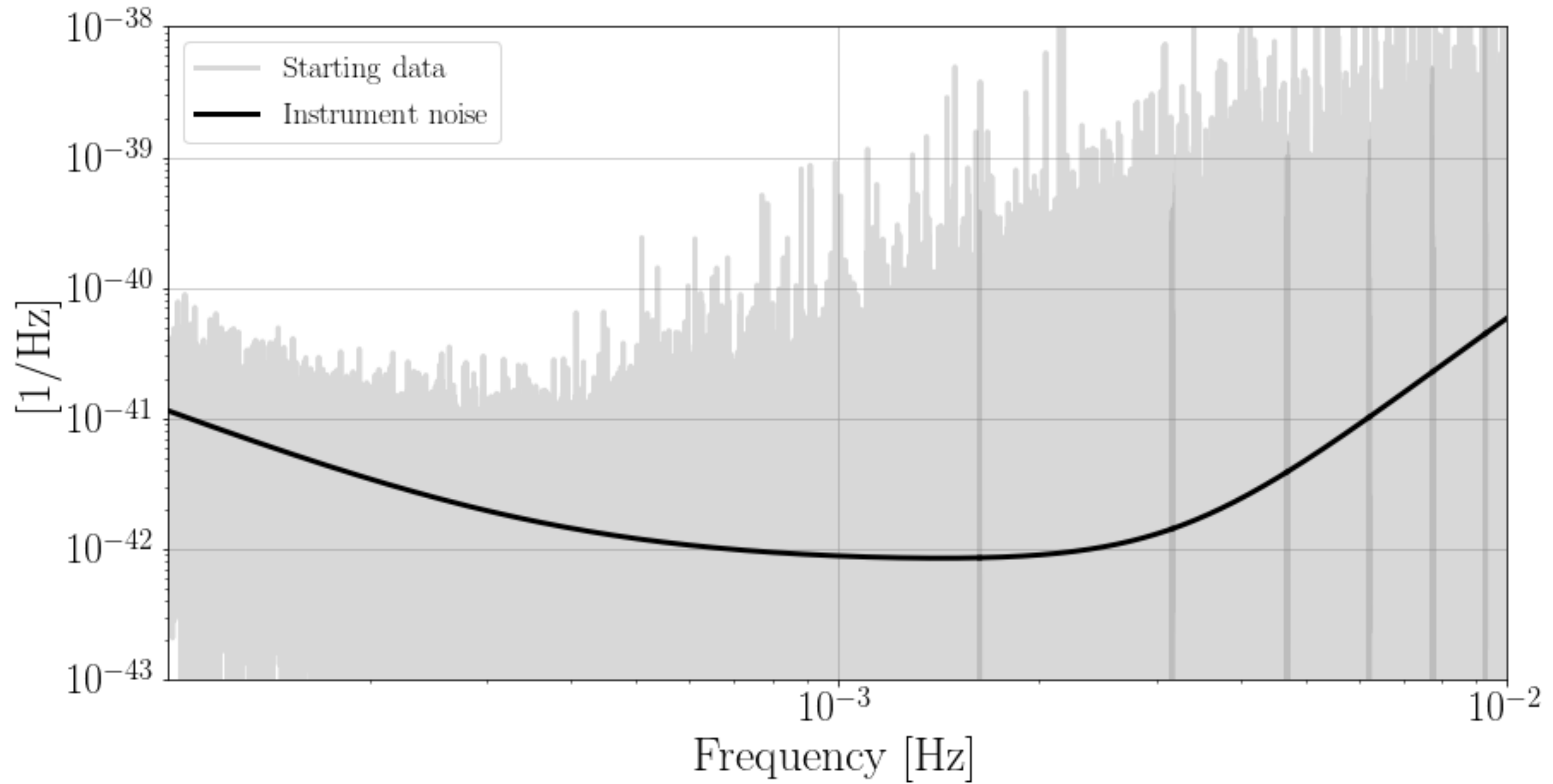
initialize  $Y^0, X^0$ 
for  $j = 1, 2, 3, \dots$  do
  sample  $X^j \sim p(X|Y^{j-1})$ 
  sample  $Y^j \sim p(Y|X^j)$ 
end for
  
```

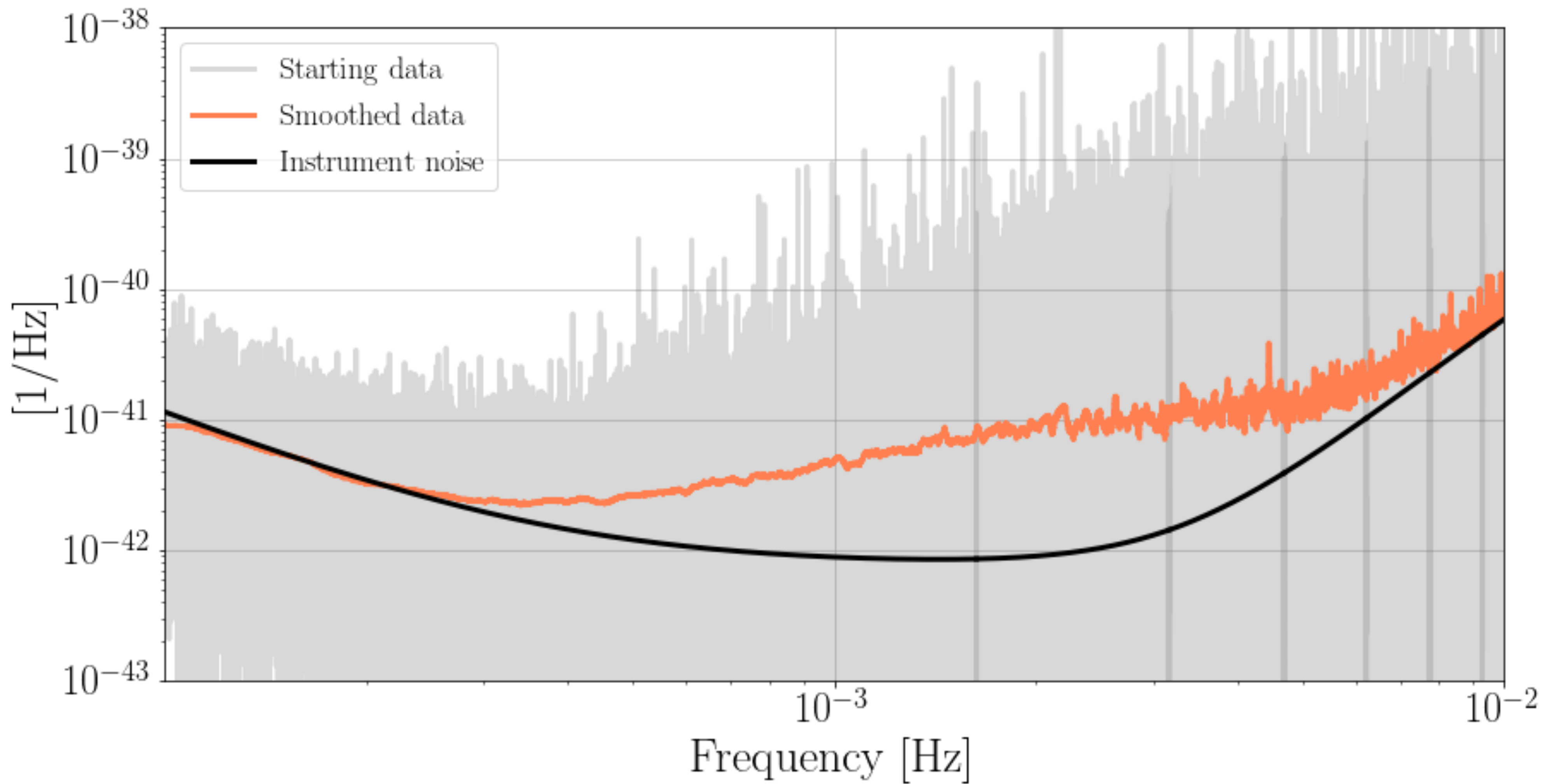
Global Fit Summary

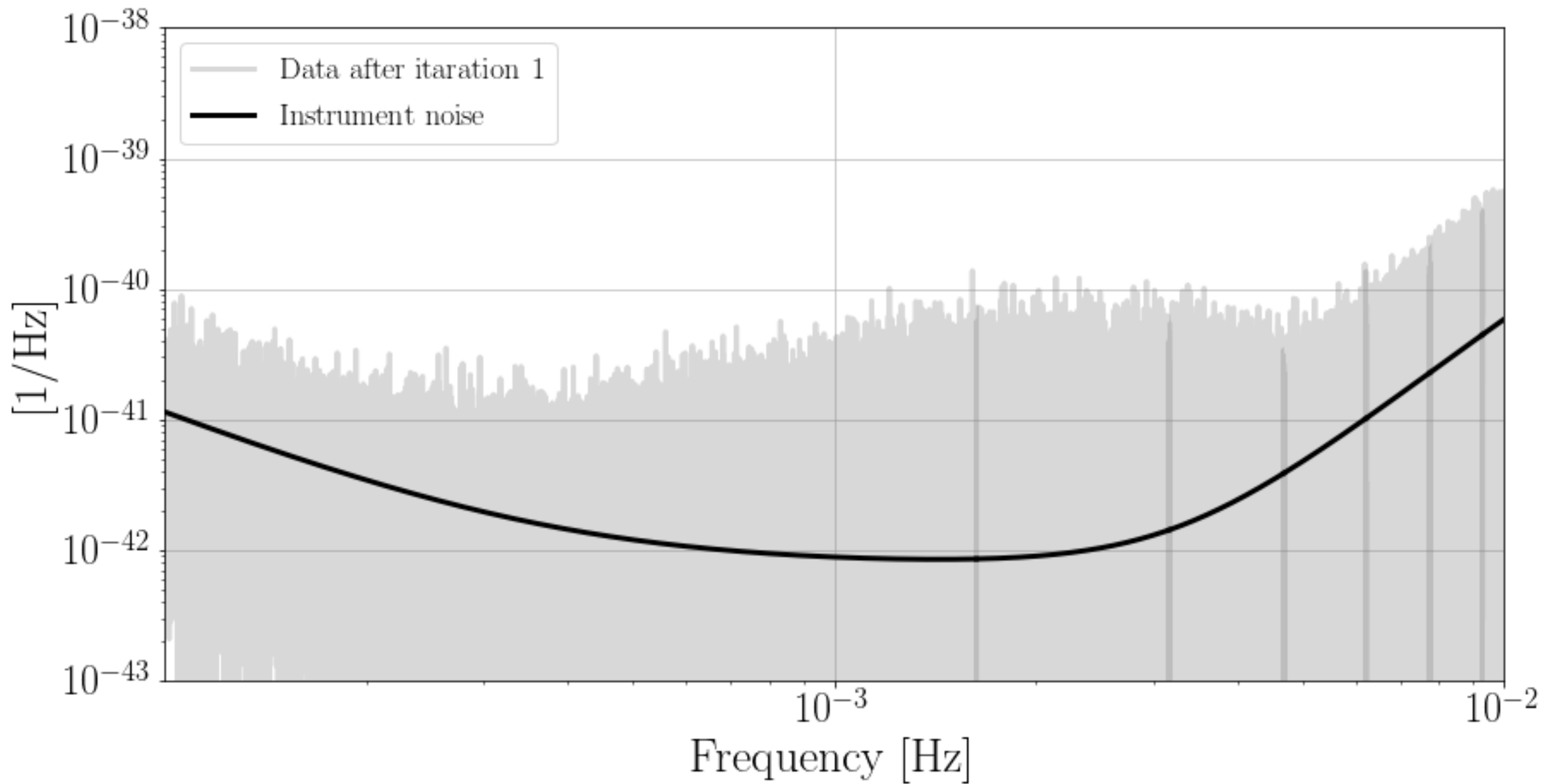
- Blocked-Gibbs sampler over the types of sources.
- Updating 10^5 parameters at each iteration.
- Expensive!
- Takes time!
- Interpretation of the results takes time as well.

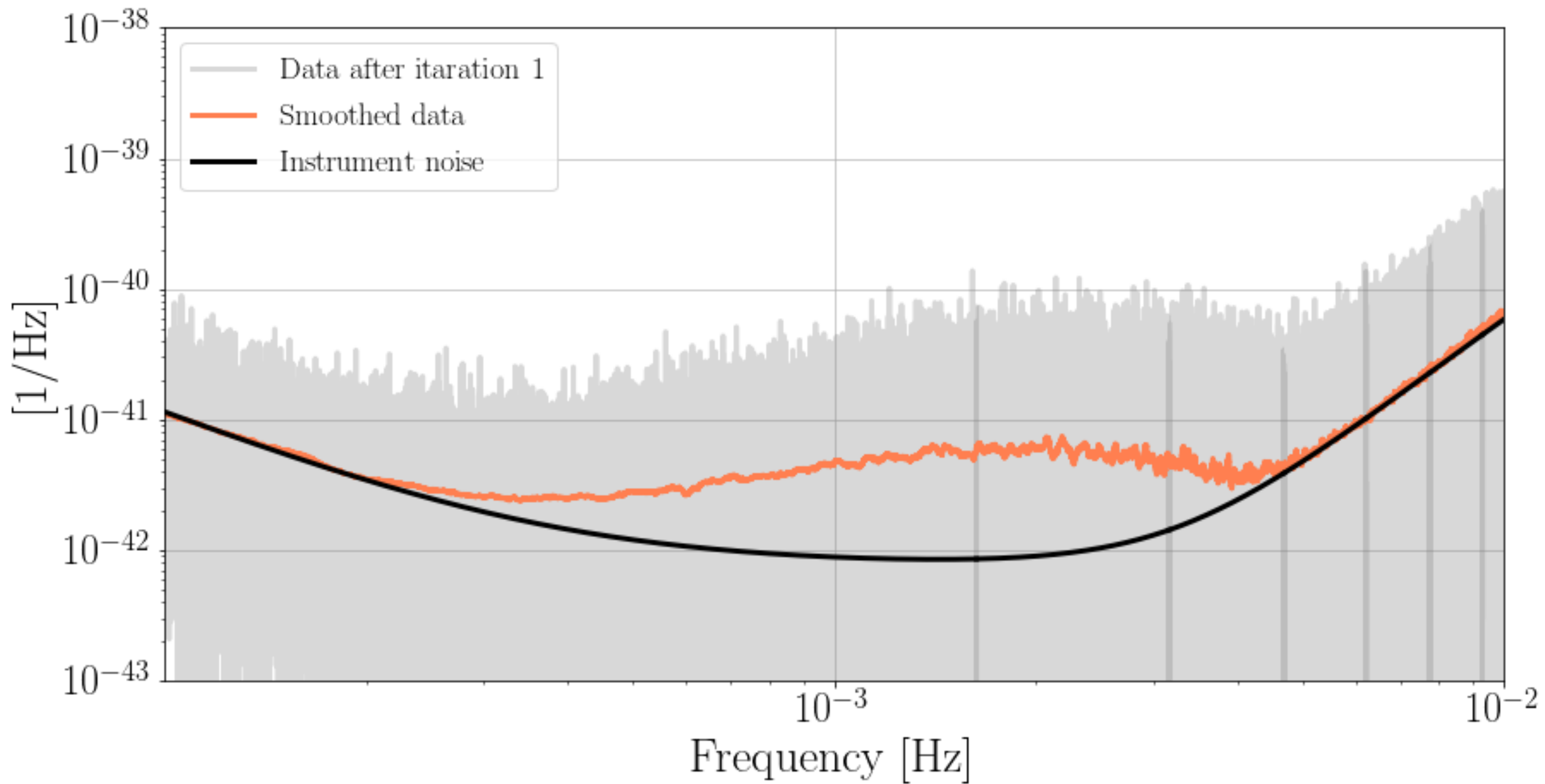
We can try another approach!

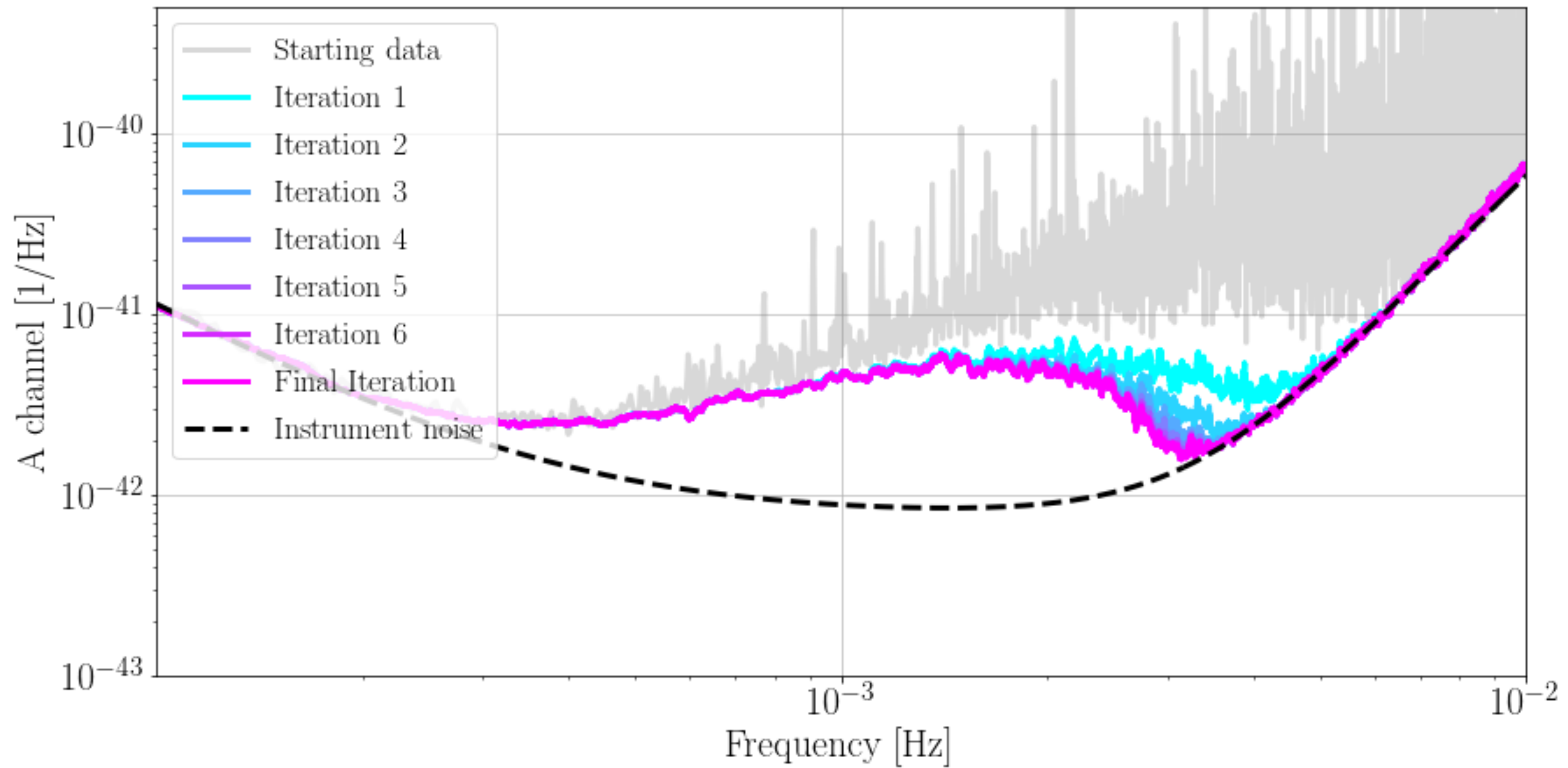
- ❖ Iterative process, based on more “loose” criteria about the detection of each source, i.e. a SNR limit.
- ❖ For example, we define a SNR_0 , for which if a given source surpasses it, then we subtract it. Basically loop over the known catalogue.
 - ▶ Fast
 - ▶ Generic
 - ▶ Idealized: no source overlap problem.
 - ▶ Idealized: perfect subtraction == perfect residuals.
 - ▶ Idealized: Noise.
 - ▶ Ignore non-stationarities.











In more details

1. We generate waveforms for TDI variables AET for a given catalogue.
 - Assume **equal-arms constellation**, uninterrupted measurement for the given observational time.
 - This means we get **uncorrelated data channels**!
 - Compute the **optimal SNR ρ_0** , which is w.r.t. instrumental noise only. It will be used for making the process faster.
2. We begin the process of the iterative subtraction ($n=0$). We choose an **SNR threshold ρ_{thres}** where sources can be assumed resolvable ($\rho_{\text{thres}} \sim 10$).
 - i) From the accompanied catalogue (remember, we now have ρ_0), we choose a subset of potentially resolvable sources, for which $\rho_0 > \kappa \rho_{\text{thres}}$ and κ a safety margin constant < 1 .
 - ii) We do a first estimate of the **overall confusion $S_{n=0}$** by smoothening the data.
 - iii) We iterate the reduced catalogue and check if $\rho_i > \rho_{\text{thres}}$, for each source i . If true we subtract source i from the data and from the reduced catalogue, and mark source i as resolvable.
 - iv) After finishing running over the catalogue, we estimate the **overall confusion $S_{n=1}$ anew** from the residuals.
 - v) Go to (iii). **Repeat until convergence: $S_{n-1} \sim S_n$.**

Why do we need it

- ❖ Study populations!
- ❖ It's fast!
- ❖ Study residuals and impact on the recovery of other sources.
- ❖ Study non-stationarity.
 - See for example [[2206.14813](#)].

Installation

```
$ conda create -n gwg_env -c conda-forge gsl numpy scipy jupyter pandas  
matplotlib xarray h5py tqdm pytables astropy python=3.12
```

```
$ conda activate gwg_env
```

```
$ git clone https://github.com/mikekatz04/LISAanalysistools.git
```

```
$ cd LISAanalysistools
```

```
$ pip install .
```

```
$ pip install gbgpu
```

```
$ git clone https://gitlab.in2p3.fr/Nikos/gwg.git
```

```
$ cd gwg/
```

```
$ pip install .
```