First level characterization the stochastic foreground signal of the LISA mission

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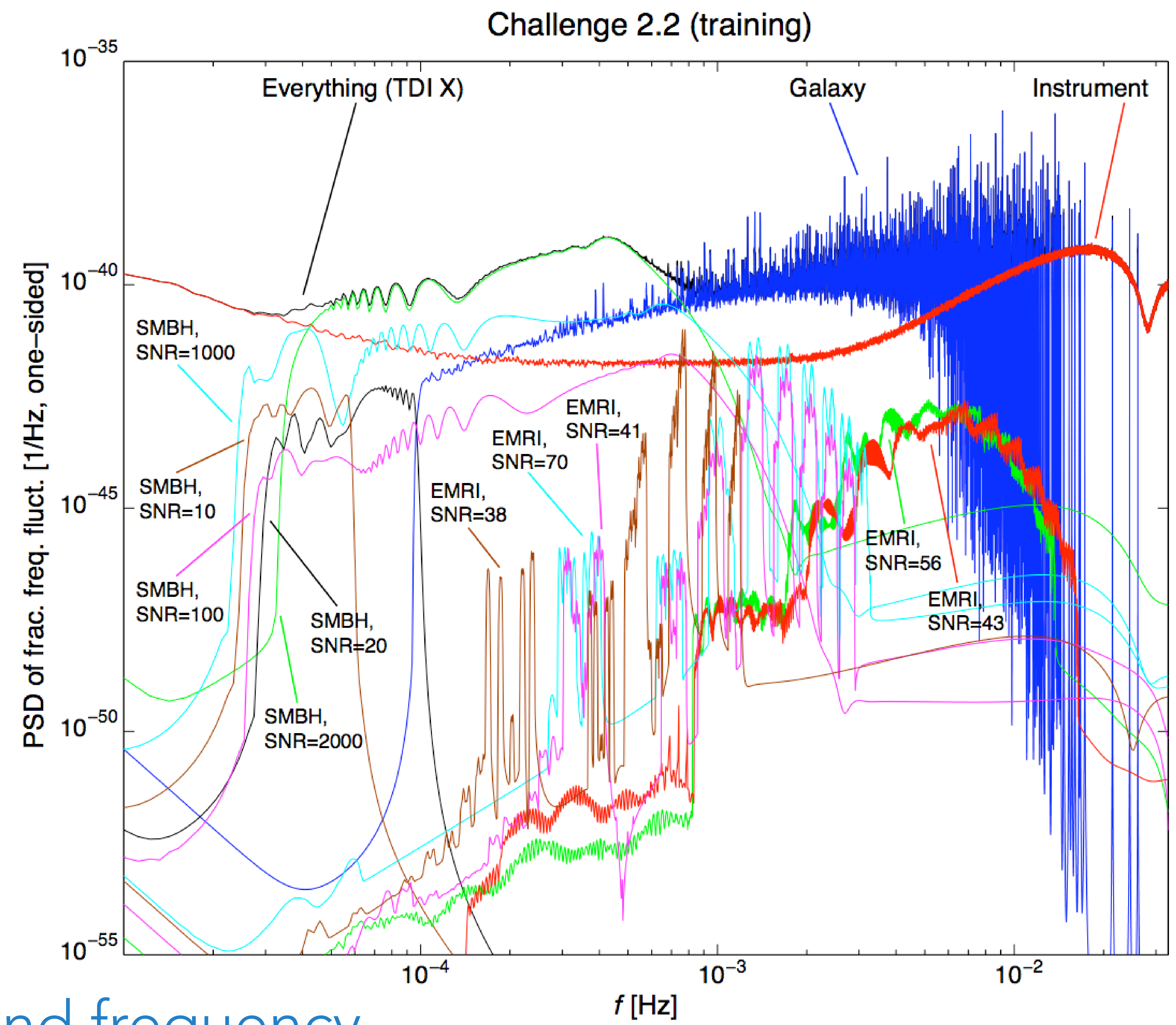
Ondes gravitationnelles

- In this talk we will present a methodology to make a first level characterization of the stochastic foreground signals in LISA.
- This method is based in previous work, and assumes that given Gravitational-Wave sources can be detected if their SNR is high enough.
- With an iterative process, we estimate both the confusion foreground and the resolvable sources.

- The problem:
  - LISA will be a signal dominated observatory
    - SuperMassive Black Hole Binaries (SMBHBs)
    - Compact Galactic Binaries (GBs)
    - Stellar Origin Black Hole Binaries (SOBBHs)
    - Extreme Mass Ratio Inspirals (EMRIs)
    - Stochastic signals from Cosmological sources
    - [...]



  - This means that there is going to be signals overlapping in time and frequency.
  - At the same time, given different population synthesis models, we expect contributions that would yield a confusion signal in certain frequency bands (.i.e the GBs case).

  - Two questions:
    - Can a given population of GW sources create detectable GW confusion (foreground)?
    - How this prediction varies within current astrophysical uncertainties?
      - How to deal with them (analyze them) is probably another but related topic.

- The hard way:
  - We need to run the search algorithm to evaluate number of sources and where in the parameter space they “live”
  - Do parameter estimation & subtract them.

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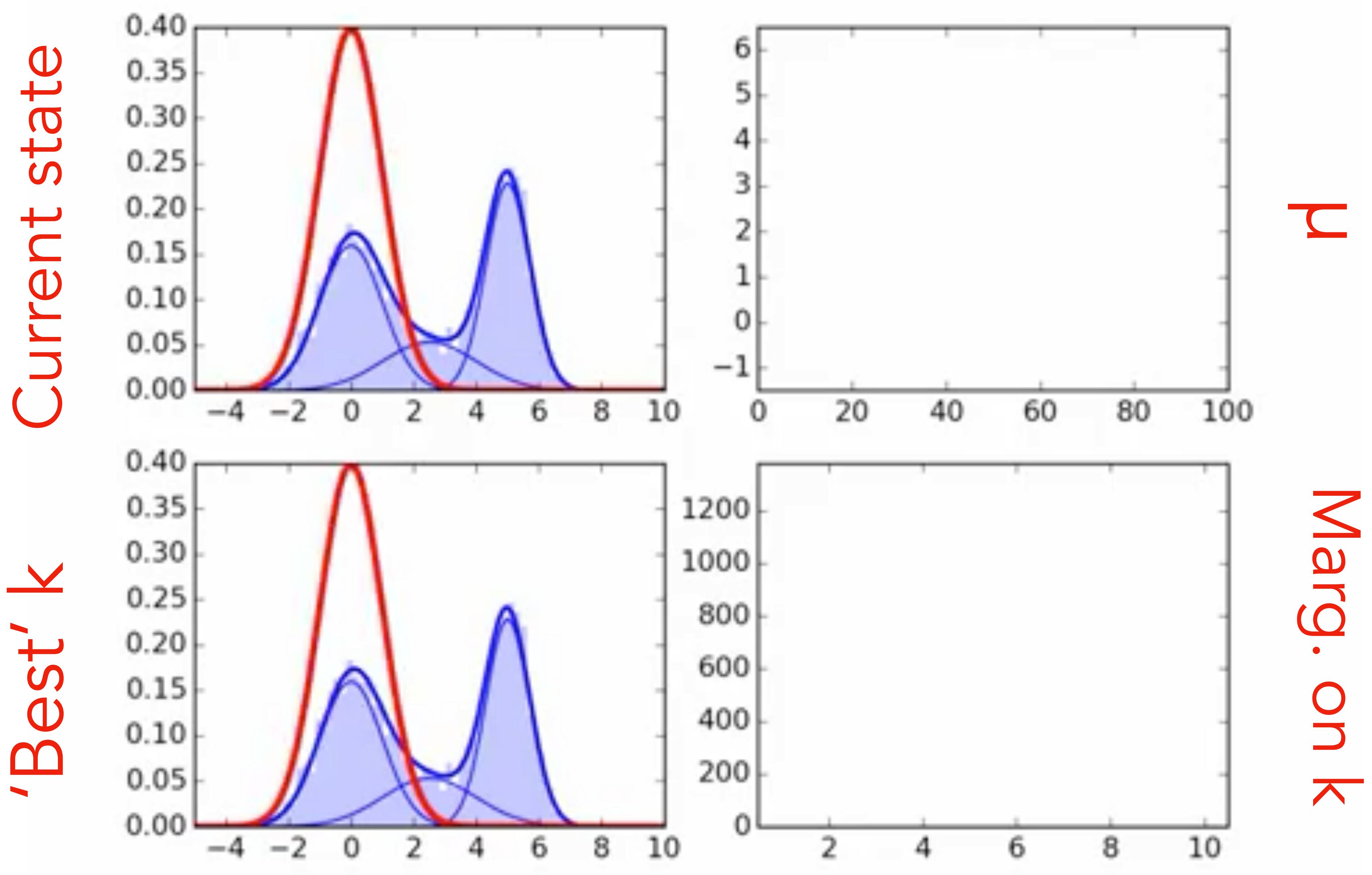
  - We need to run the search algorithm to evaluate number of sources and where in the parameter space they "live"
  - Do parameter estimation & subtract them.
- Get the data, start MCMC chains capable of inter dimensional jumps (propose birth & death of sources):



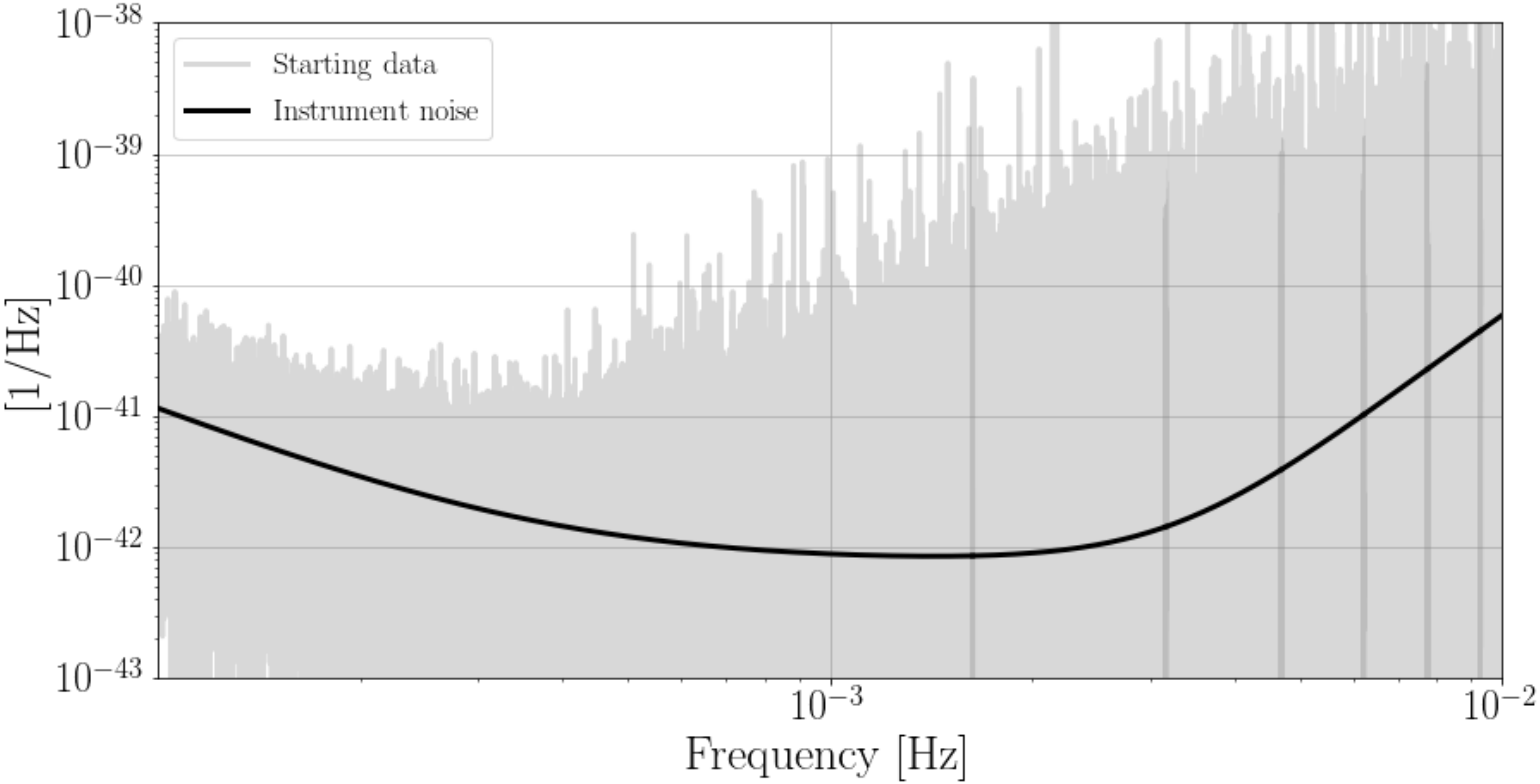
- This will return the *statistically* most probable solution: Littenberg+ 2020 - *PRD 101, 123021*
  - Slow, needs configuration & tuning, and computational resources, has been demonstrated only on a narrow band of LISA, […].

Video source: https://www.youtube.com/watch?v=wBTGoA_dIIo

- Another, more practical 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.

*There is previous work on this method, for example: S Nissanke+, *Astrophys.J.* 758 (2012) 131

- In more details:



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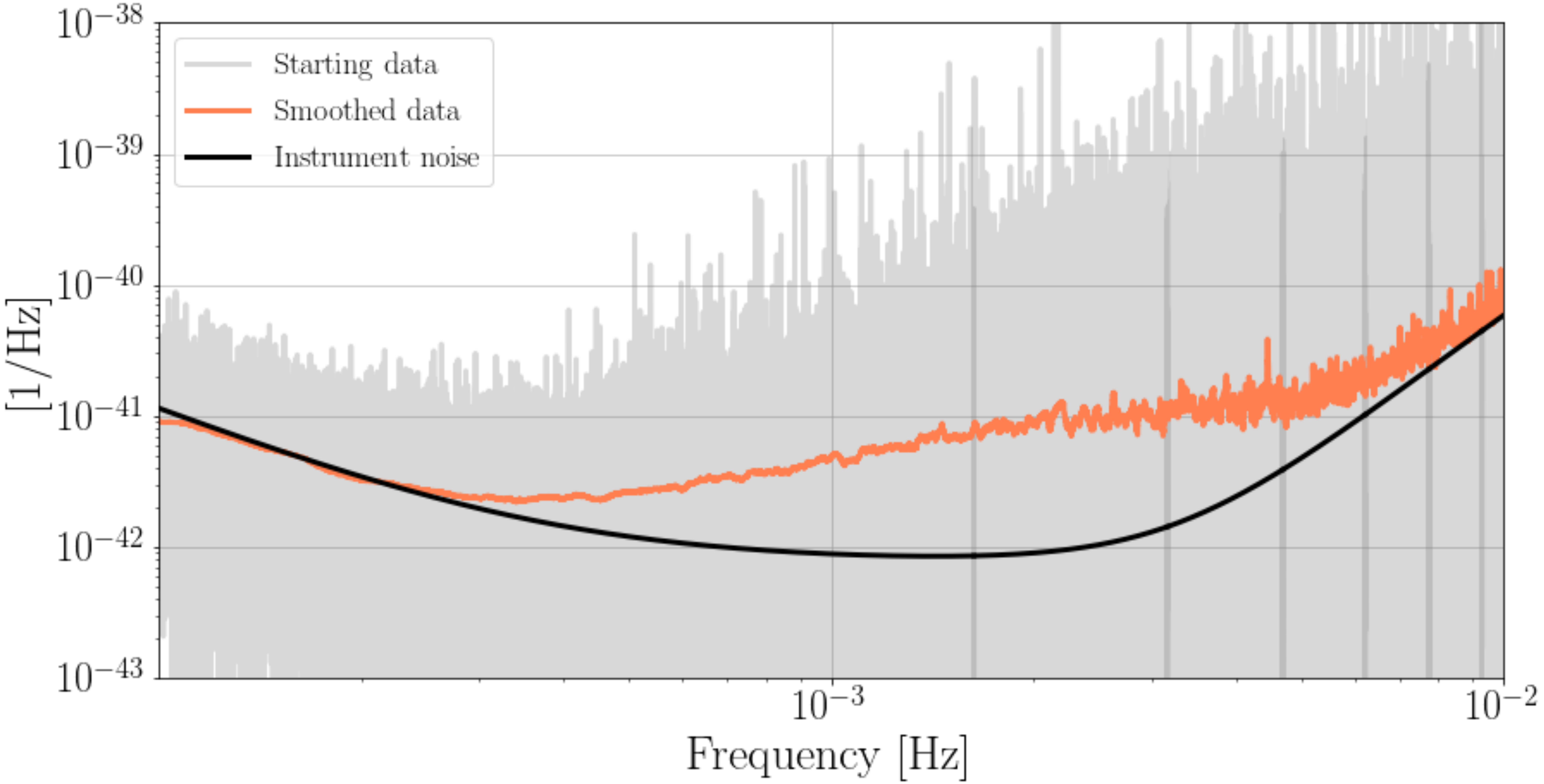

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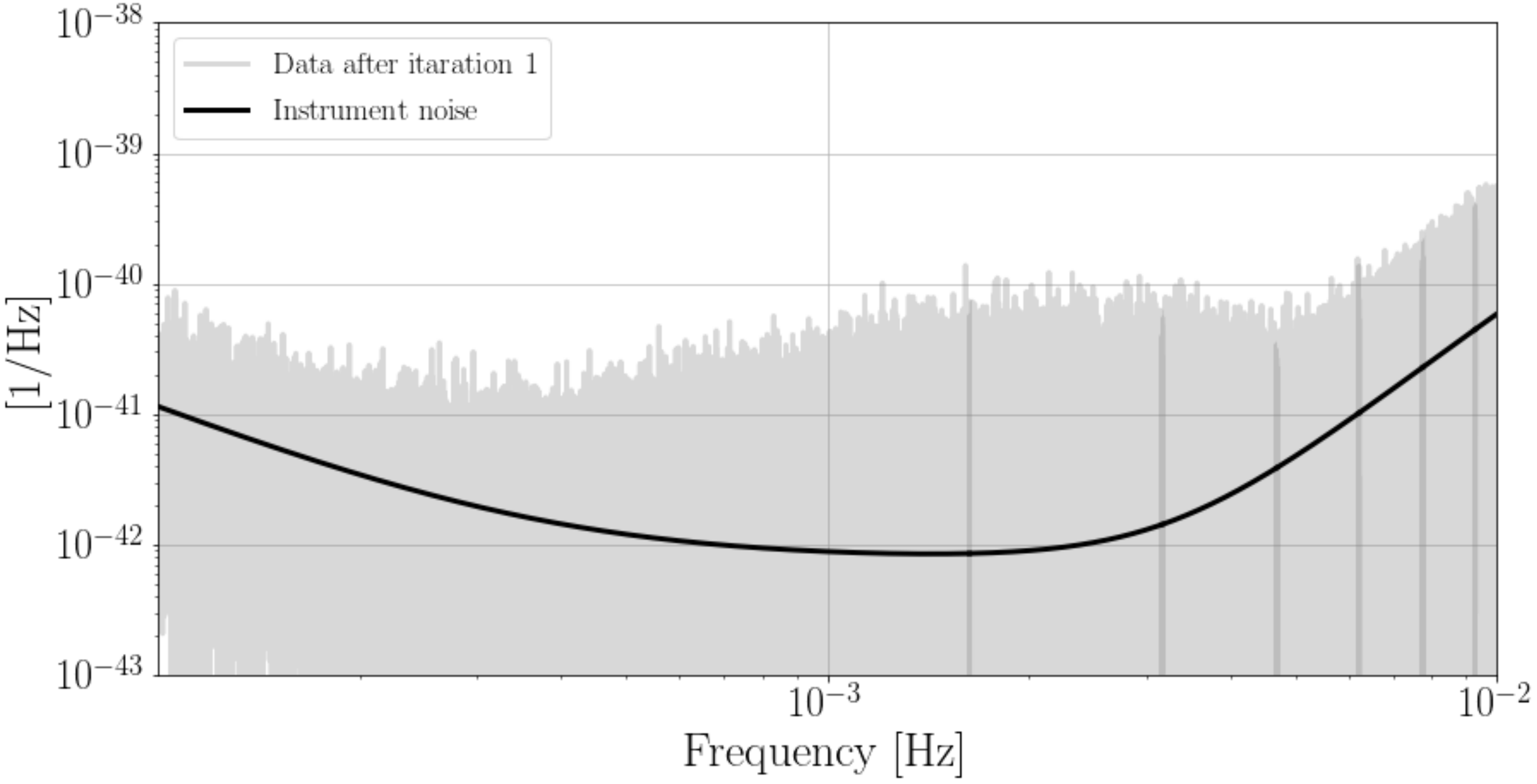

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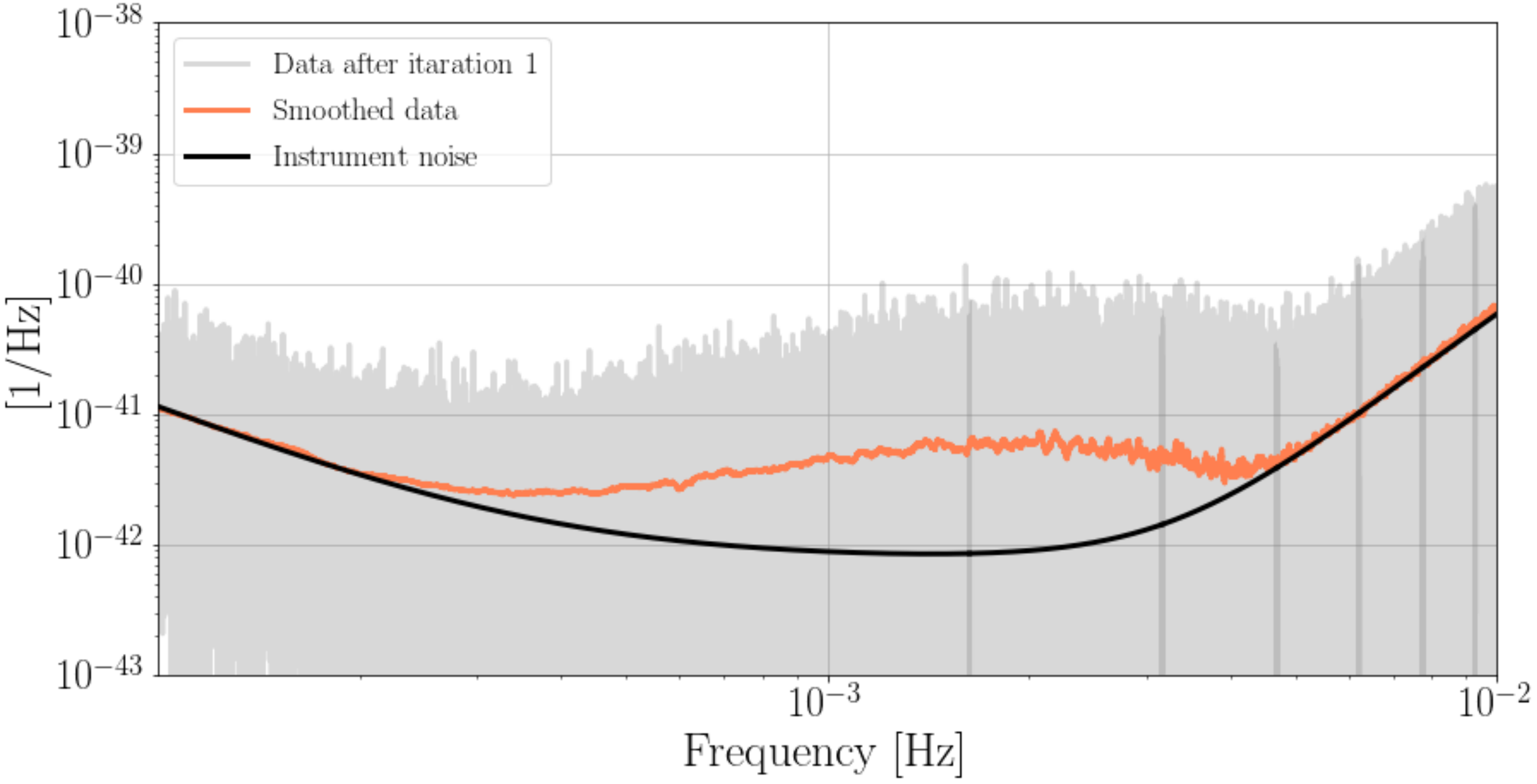

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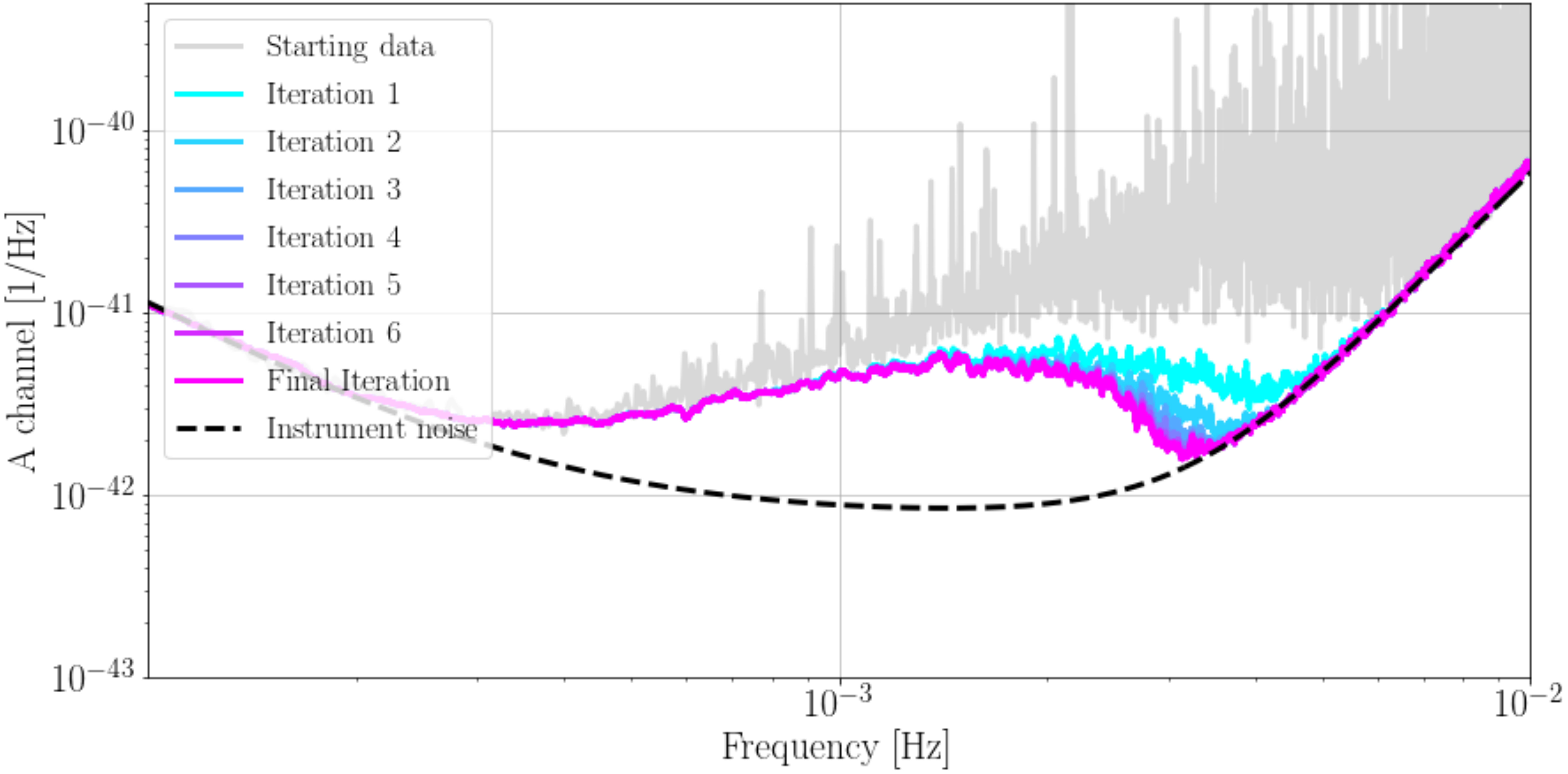

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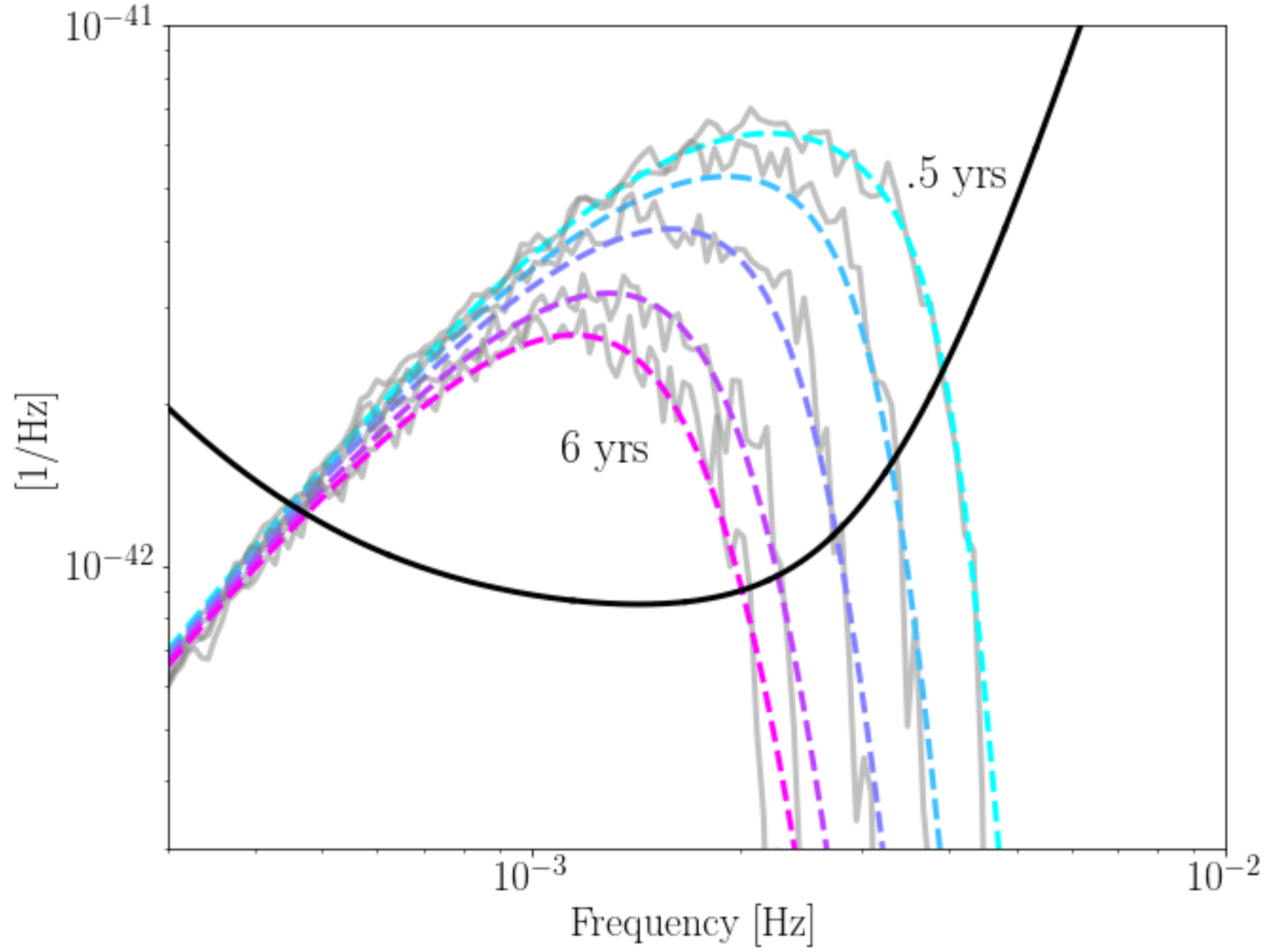
- These sources are long-lived, which means that we will measure them for the duration of the mission.
    - Therefore, the generated confusion signal will shrink as we gather more data.
- We can model this behavior: Do this analysis for different observation durations of the mission
    - This will give us the level of stochastic signal as measured by LISA given the amount of information we get as more data gets to the ground.
- Then we can define a model of the signal from the galaxy, depending on T_{obs}.
- We simulated data for different T_{obs} and fitted this model:

$$S_{gal} = \frac{A}{2} e^{-(f/f_1)^\alpha} f^{-7/3} \left(1 + \tanh\left(\left(f_{knee} - f\right)/f_2\right)\right)$$

$$\begin{aligned} \log_{10}(f_1) &= a_1 \log_{10}(T_{obs}) + b_1, \text{ and,} \\ \log_{10}(f_{knee}) &= a_k \log_{10}(T_{obs}) + b_k, \end{aligned}$$



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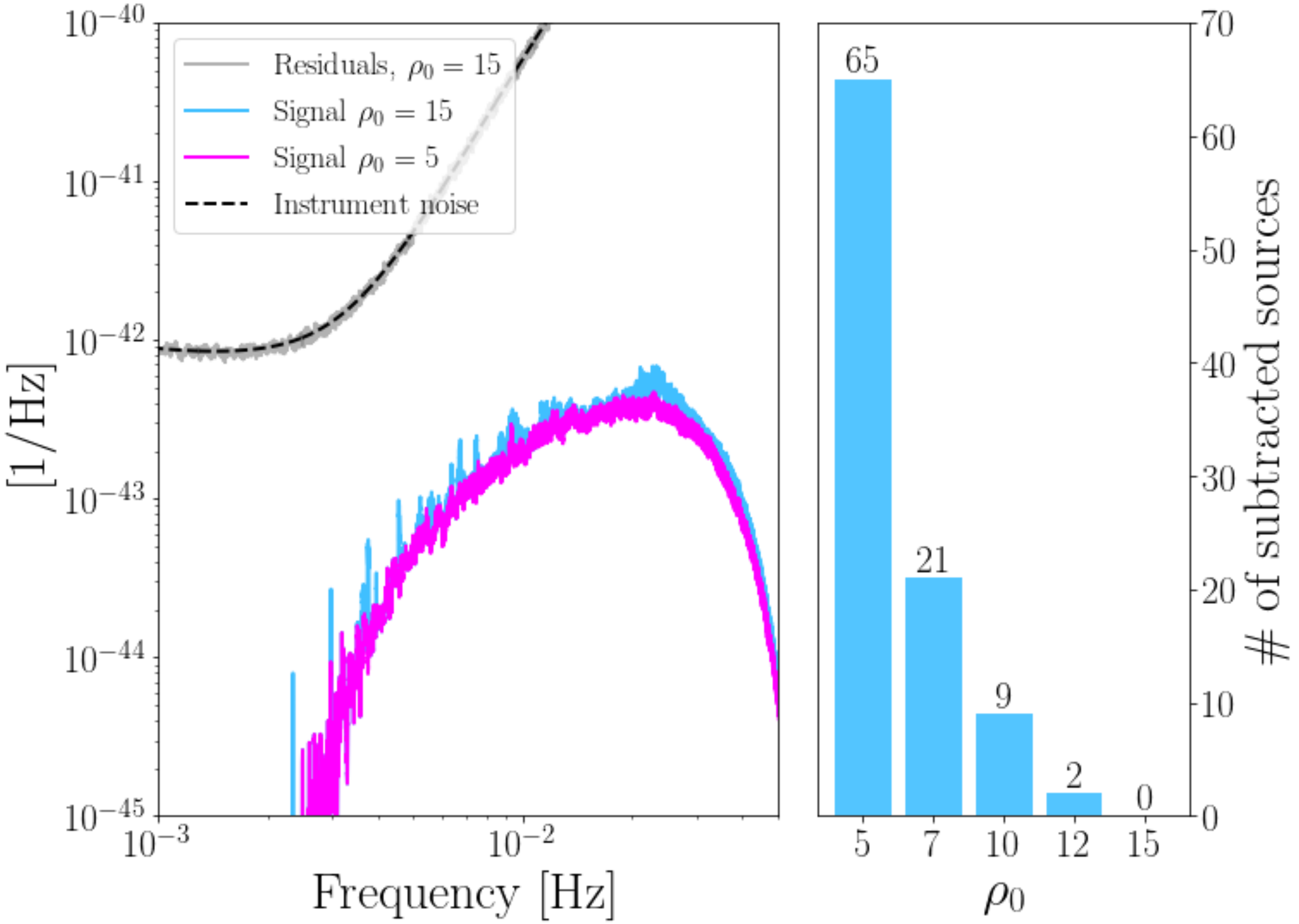
- This is already very useful for the compact galactic binaries.
- But what about other types of sources?
  - Why not?
- For example we have used it as proof-of-principle to a Stellar Origin Black Hole Binary population (SOBBH)*.
- With this method, we investigated the number of resolvable sources for different SNR thresholds.
- In contrast to the GBs case, here we are not able to recover sources with SNR>15.

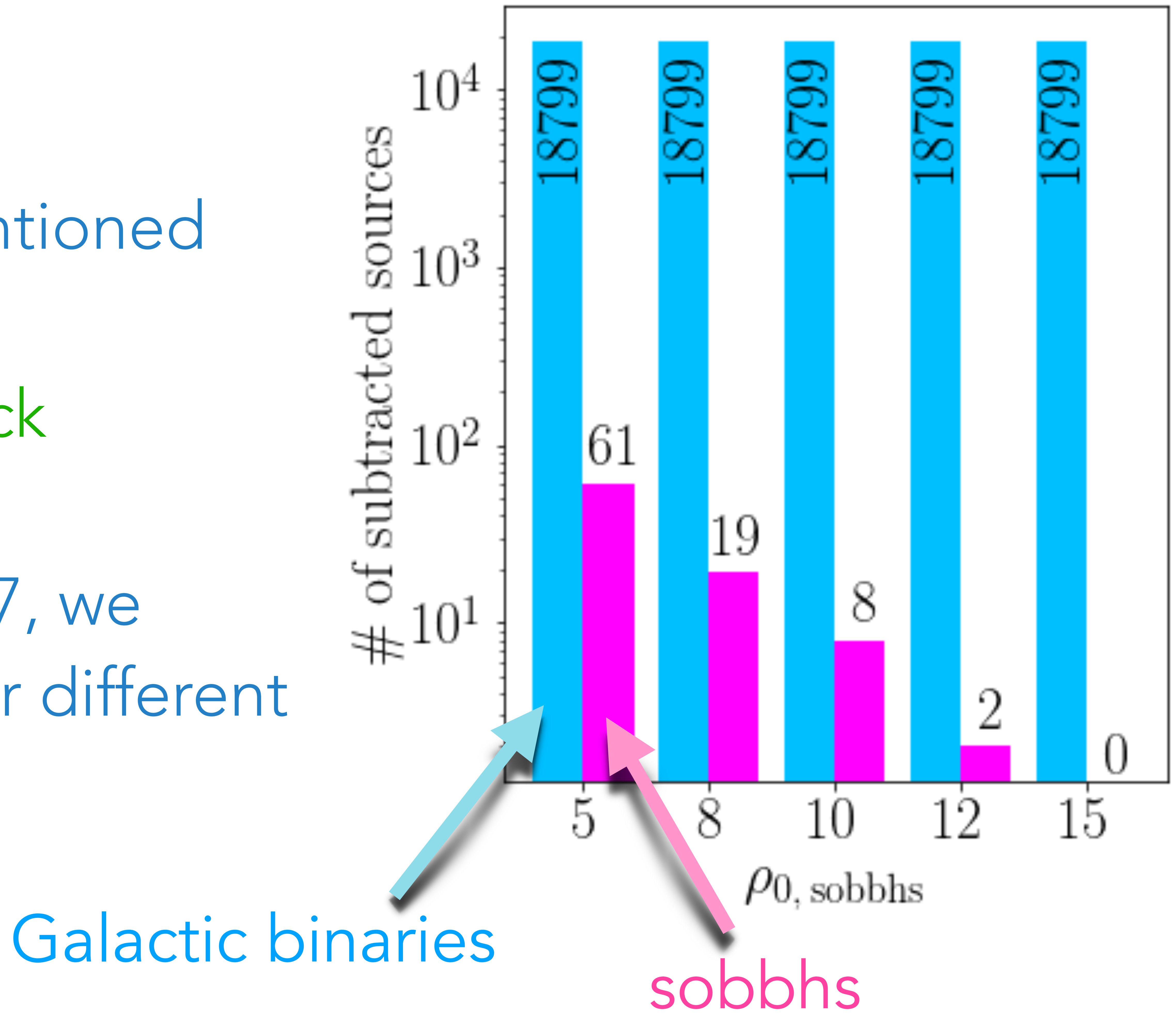


* This is taken from [Sesana, 2016*], which is maybe outdated.

- As described in [CJ Moore+ 2019*], for the given population, it we might need SNR higher than 15 to allow for detection.

* MNRAS, *Letters*, 488, Issue 1, 2019, Pages L94–L98
* PRL116.231102

- Combining the two! (or more):
  - This method is generic enough to allow us to combine any given population of sources, of any type.
  - We only need simulated catalogues to iterate upon.
  - We have applied it in the two aforementioned cases, for a given mission duration:
    - Compact galactic & stellar origin black hole binaries.
  - Keeping the SNR threshold for GBs to 7, we tested the resulting stochastic signal for different thresholds for the SOBBHs.



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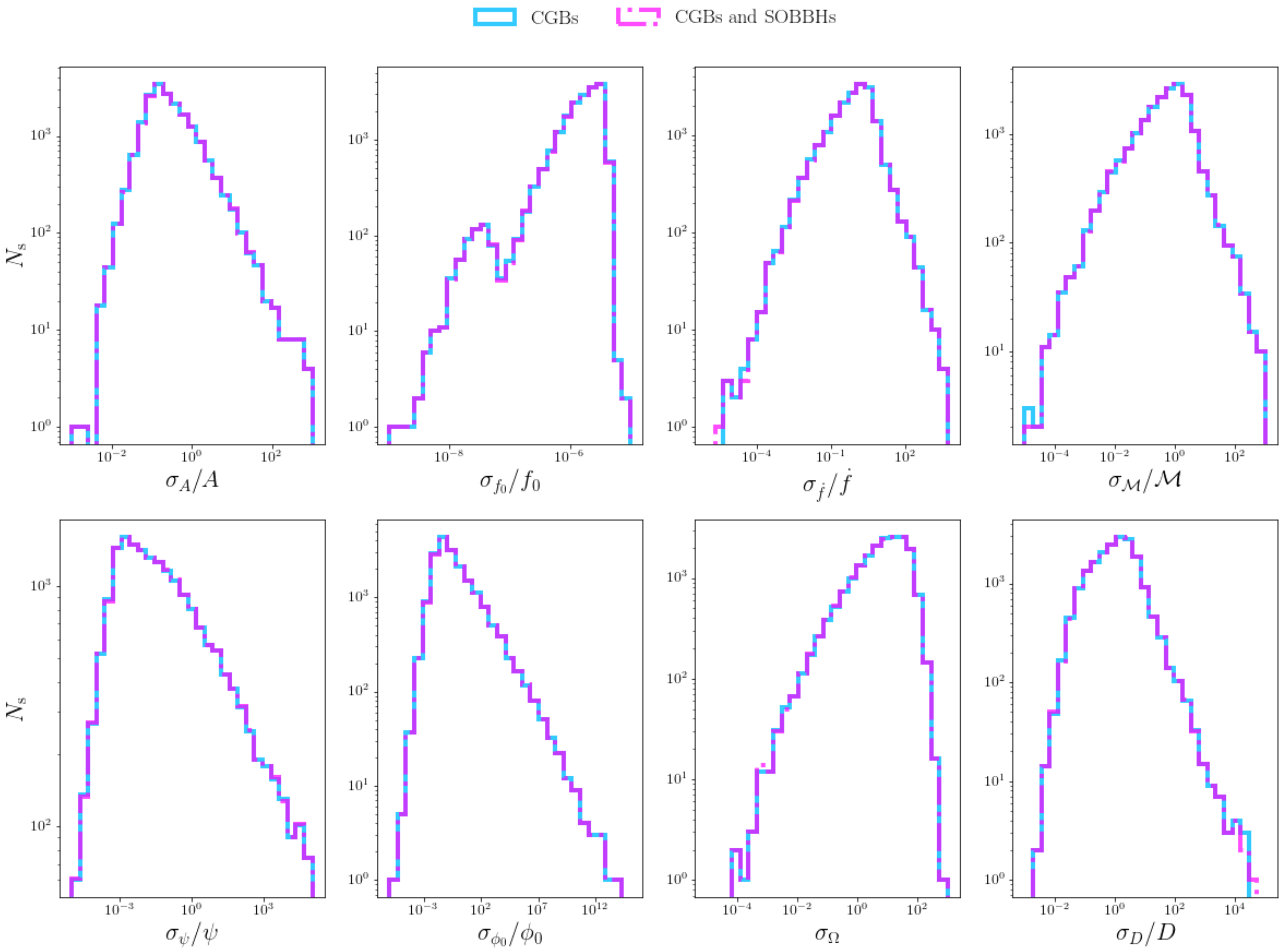
- We can evaluate the impact of different foregrounds by looking at the errors of the parameters of the recovered sources.
- We use a Fisher Information Matrix approach to get the errors w.r.t. final estimated confusion noise.
- It is quite evident that the inclusion of the SOBBH population did not affect the recovery accuracy of the GBs.
- It is simply too low *AND*, for long mission durations, the galactic foreground is reduced enough, that there is not significant overlap between the two contributions.



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- We have developed a generic method to test the characteristics of the expected stochastic signals for LISA.
- Works for any given type of binaries, provided a sensible SNR limit for detection threshold.
- It is rather idealistic -assume perfect data analysis- , but a very good starting point concerning the study of the stochastic signals and different population models.
- The Galactic Binaries code is public:

https://gitlab.in2p3.fr/Nikos/gwg.git