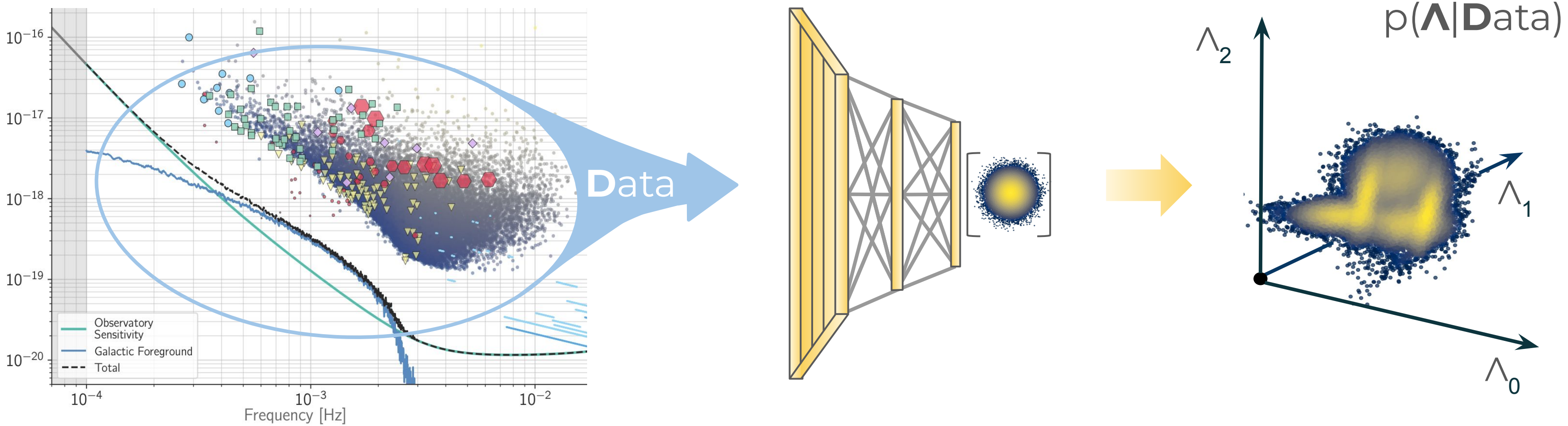
SISSA DATASCIENCE
Machine Learning for the Natural Sciences

SISSA
Scuola Internazionale Superiore di Studi Avanzati

Simulation Based Population Inference

Galactic Binaries in LISA



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In collaboration with Enrico **Barausse,** Natalia **Korsakova**, Roberto **Trotta**

EuCAIF

The Galactic Double White Dwarf Population

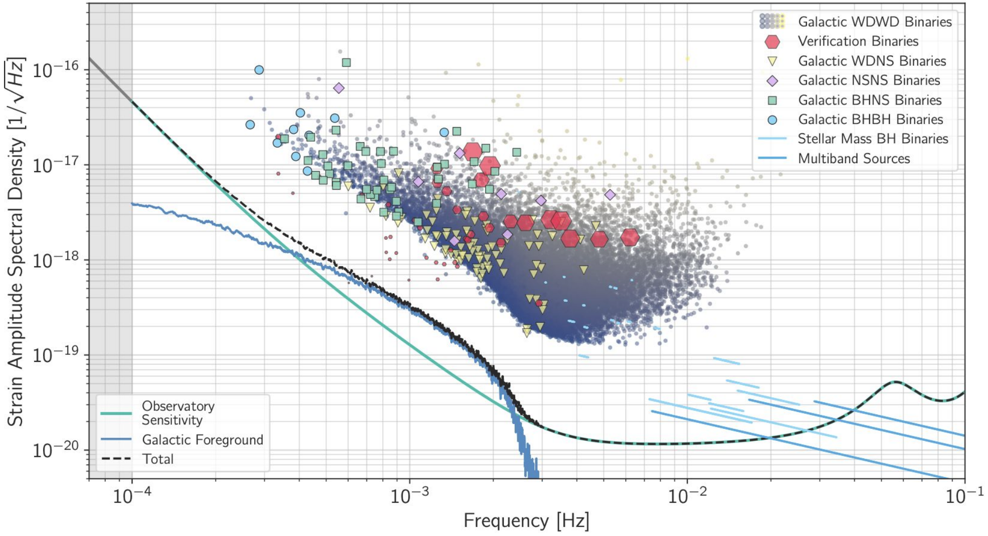
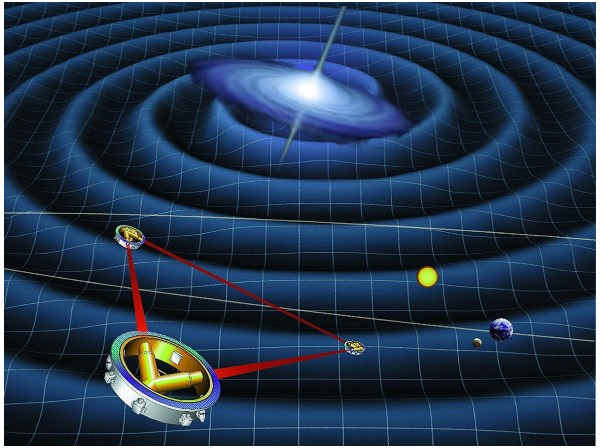


Figure from the LISA red book

LISA



The Galactic Double White Dwarf Population

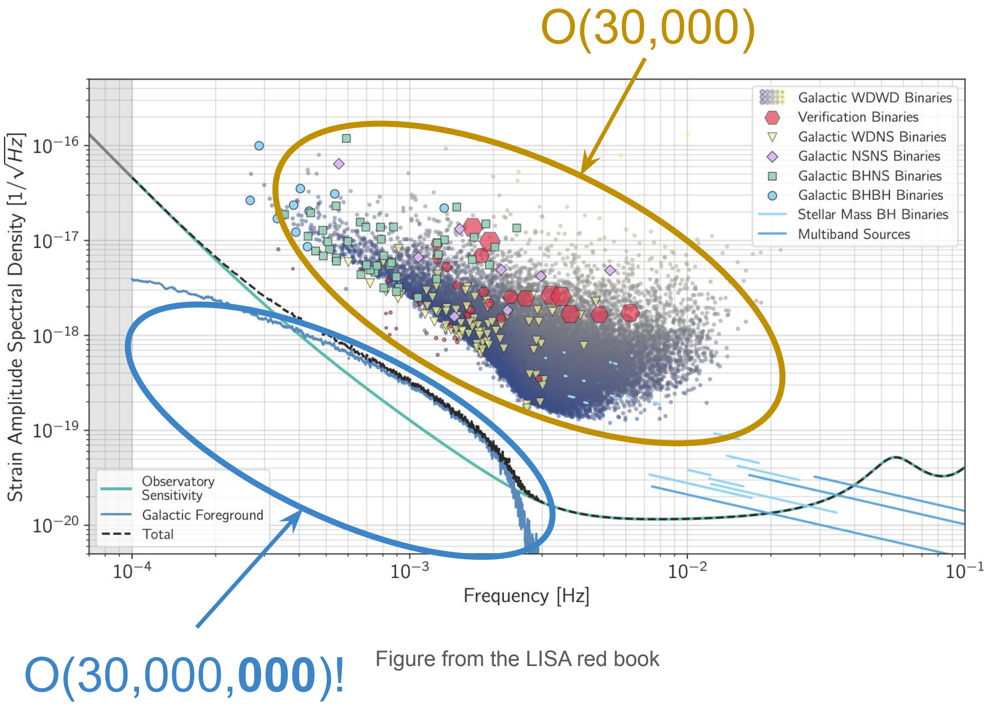
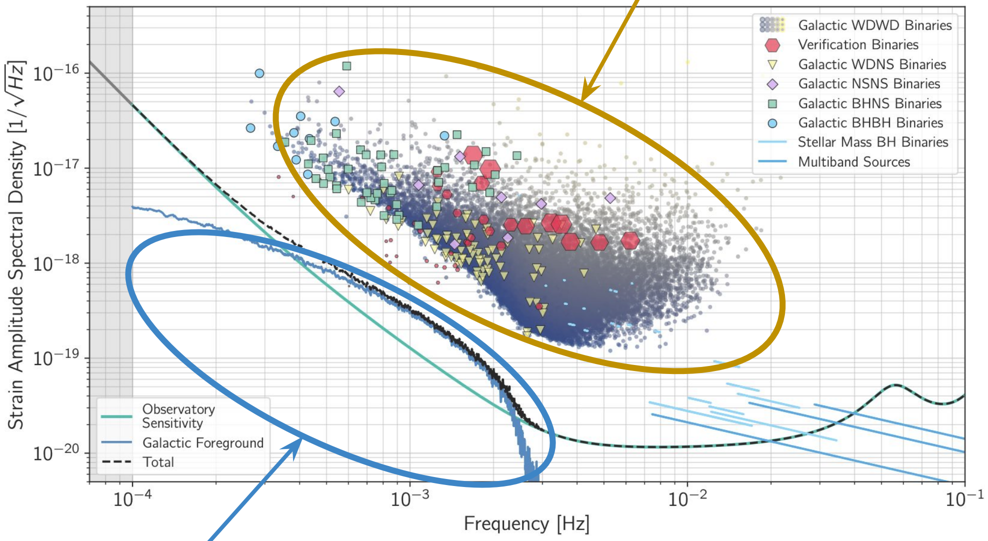


Figure from the LISA red book

A cocktail party of a few, loud, resolvable sources, and an overlapping, cacophonous, incoherent foreground.

The Galactic Double White Dwarf Population

O(30,000)



O(30,000,**000**)!

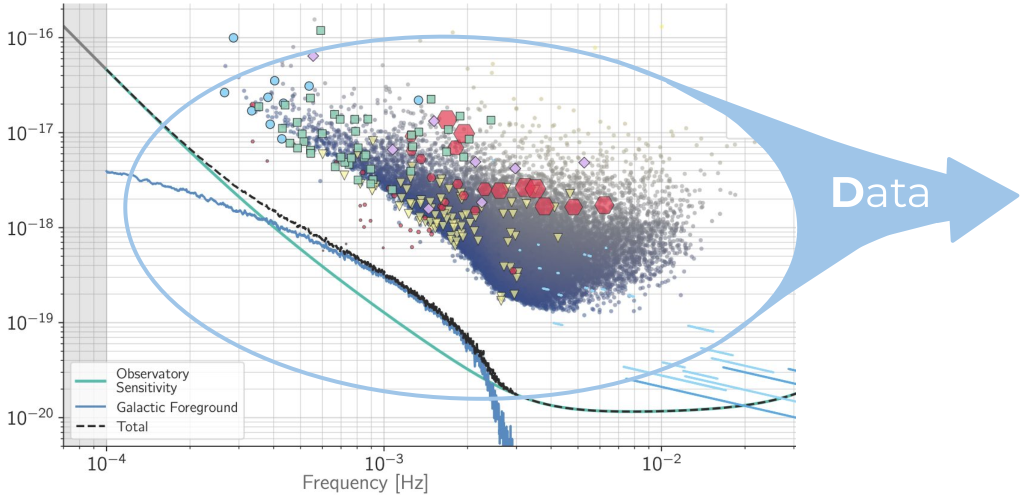
Figure from the LISA red book

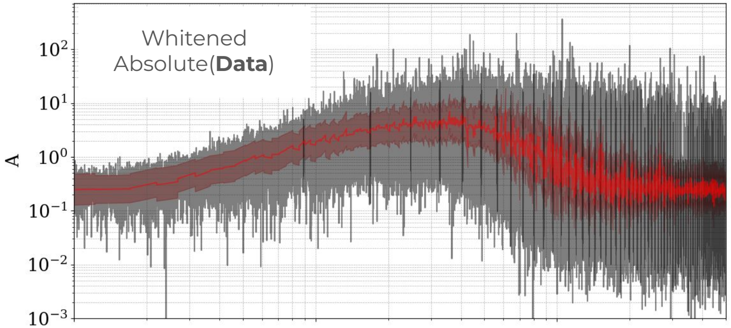
Where lies the population signature:
the few resolvable sources[1] or
the many unresolvable sources[2]?

[1] Korol, Rossi, Barausse, MNRAS 483 no. 4 5518–5533
[2] Smith et al 2020; 2004.09700

The Data

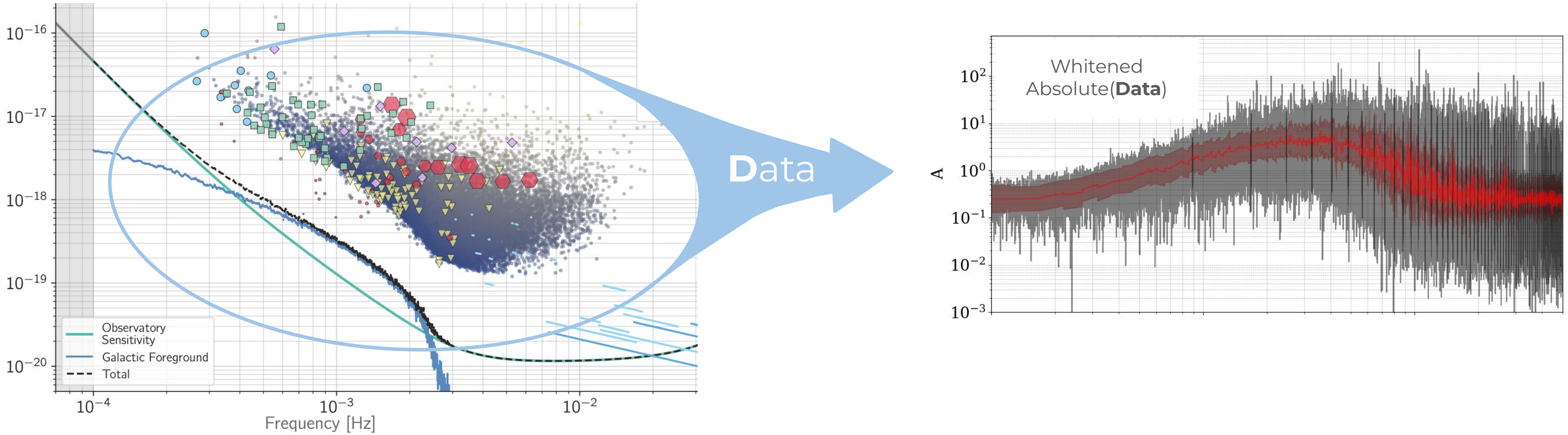
GPU-leveraged forward simulator





The Data

O(10^6) frequency bins!
Computational *prohibitive* likelihood evaluation.
Major bottleneck for Bayesian samplers.



SBI might be a *necessity*.

Simulation-based Inference

Population $\boldsymbol{\Lambda}$: = $\rho_{\text{Distribution}}$(Mass, Separation), N_{Sources}, Milky $\text{Way}_{\text{Scale}}$

Simulation-based Inference

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$\downarrow$ **Simulator**

Source $\boldsymbol{\theta}$: = Mass, Separation, Sky-position, Distance

Simulation-based Inference

Population $\boldsymbol{\Lambda}$: = $\rho_{Distribution}$(Mass, Separation), $N_{Sources}$, Milky Way_{Scale}

Source $\boldsymbol{\Theta}$: = Mass, Separation, Sky-position, Distance

Simulator

Data $\mathbf{D}$: = $\sum_i GW_i + n_{LSIA}$

Simulation-based Inference

SBI

Population $\mathbf{\Lambda}$: = $\rho_{\text{Distribution}}$(Mass, Separation), N_{Sources}, Milky $\text{Way}_{\text{Scale}}$

Source $\mathbf{\Theta}$: = Mass, Separation, Sky-position, Distance

Simulator

Data $\mathbf{D}$: = $\sum_i GW_i + n_{LSIA}$

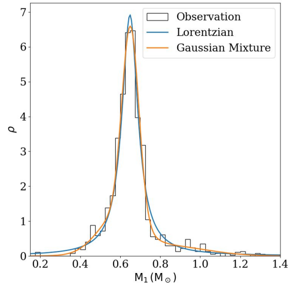
Given examples of $\mathbf{\Lambda} \rightarrow \mathbf{D}$,

SBI solves the *inverse problem* $\mathbf{D} \rightarrow \mathbf{\Lambda}$, i.e., $p(\mathbf{\Lambda}|\mathbf{D}, \mathbf{M}_{\text{Simulator}})$

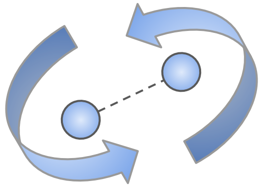
Λ : Parameterizing the Population

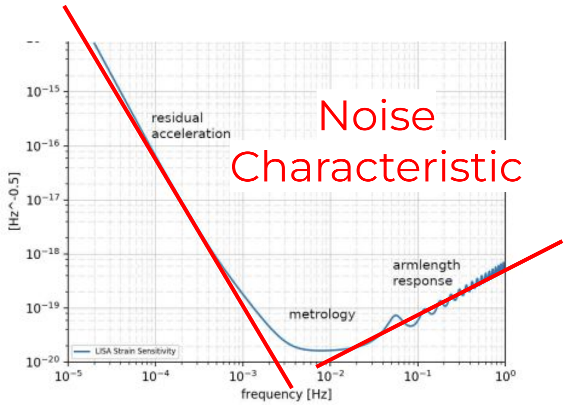
Total DWD Number	: 1
Primary DWD Mass Dist.	: 2
Separation Dist.	: 1
MW Disc	: 2
MW Bulge	: 2
LISA Noise Parameters	: 2
Total	: 10d

M_1 distribution

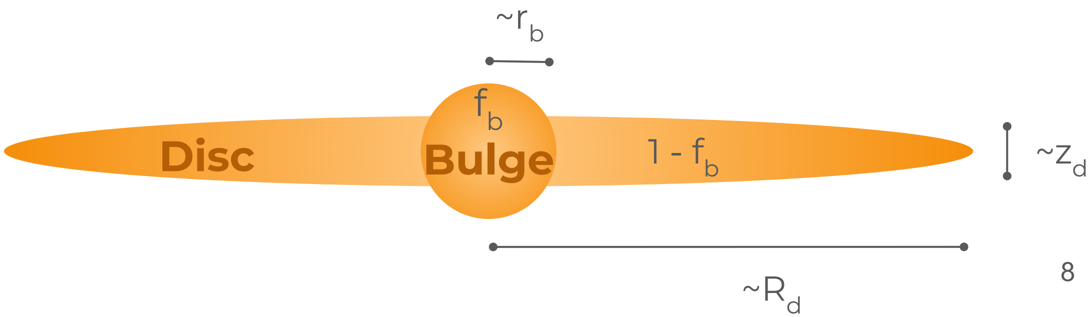


Separation Index

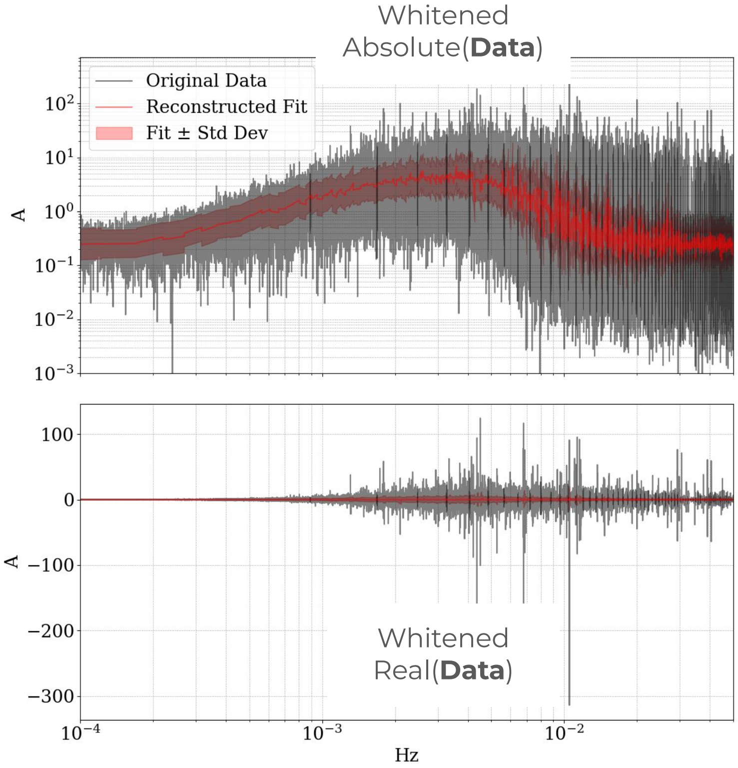




Milky Way Scale



Data summary



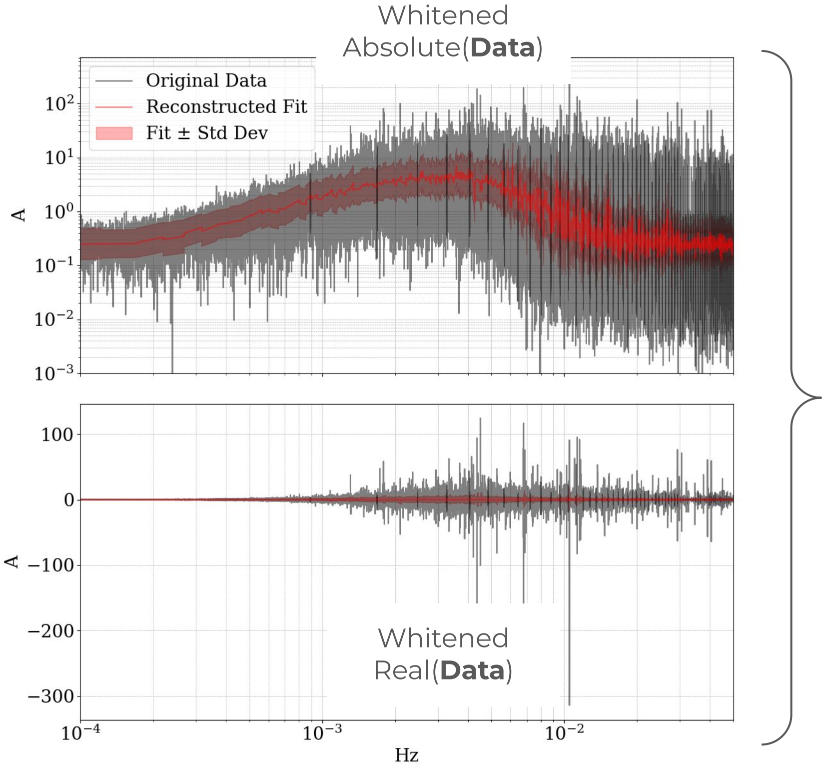
A network with O(10^6) input neurons is very memory intensive and data hungry.
Need to summarize the data.

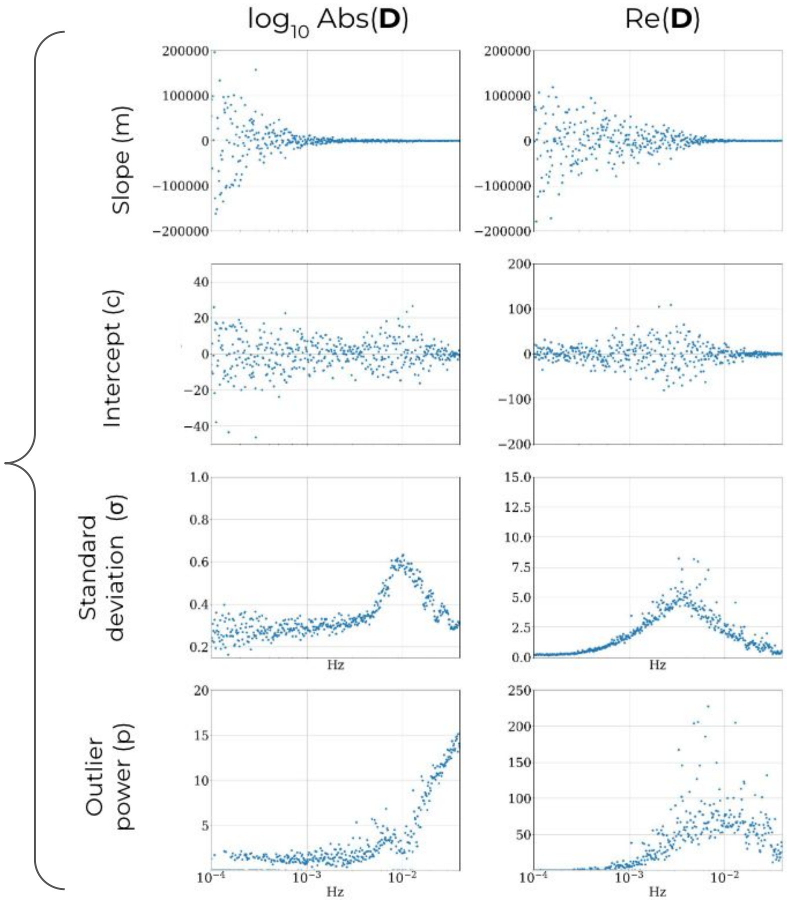
Our *current* prescription:

Linear fit of data within frequency batches
Summary: fit and residual parameters.

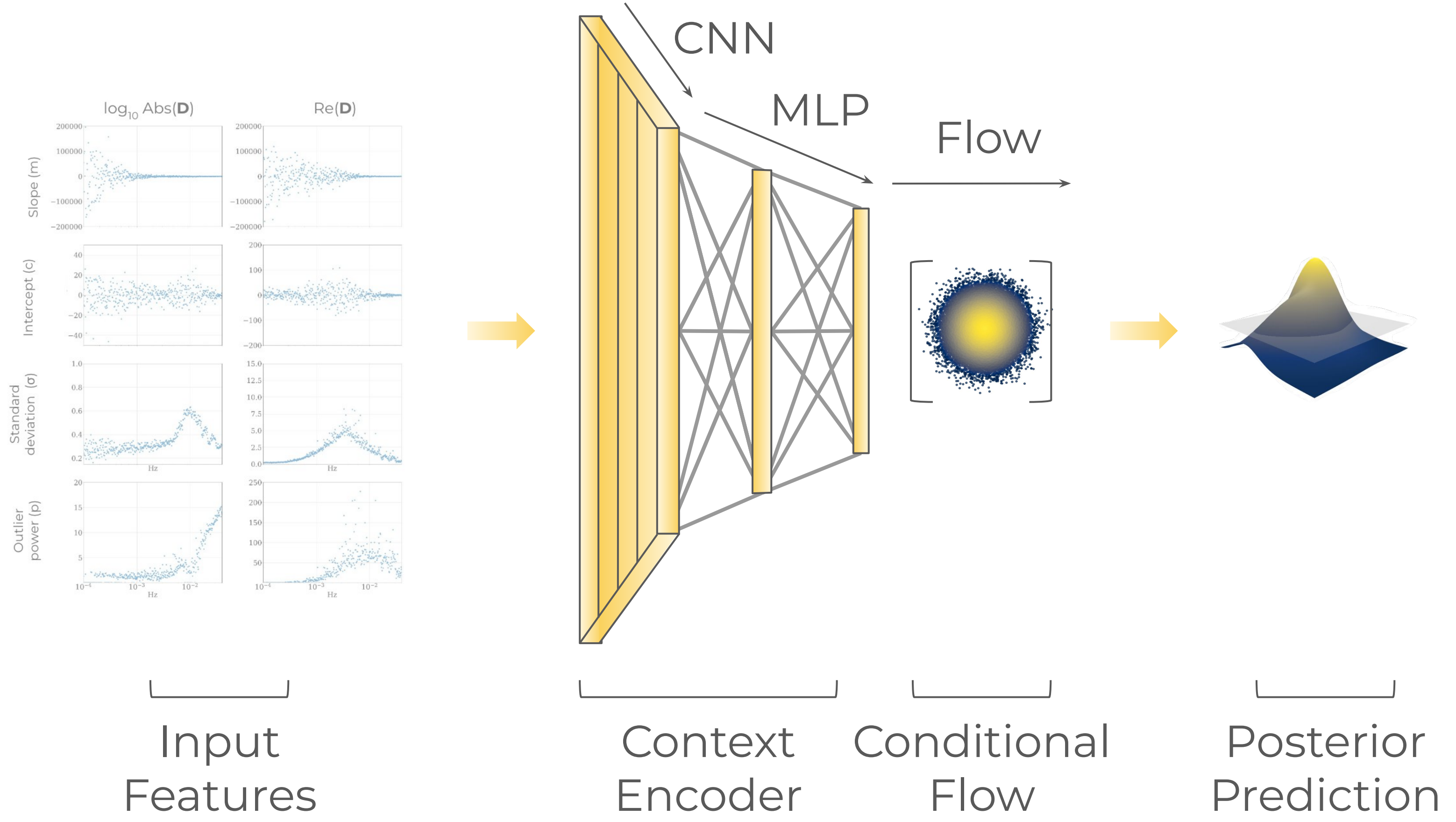
Data reduction: O(10^6) → O(10^3)

Data summary

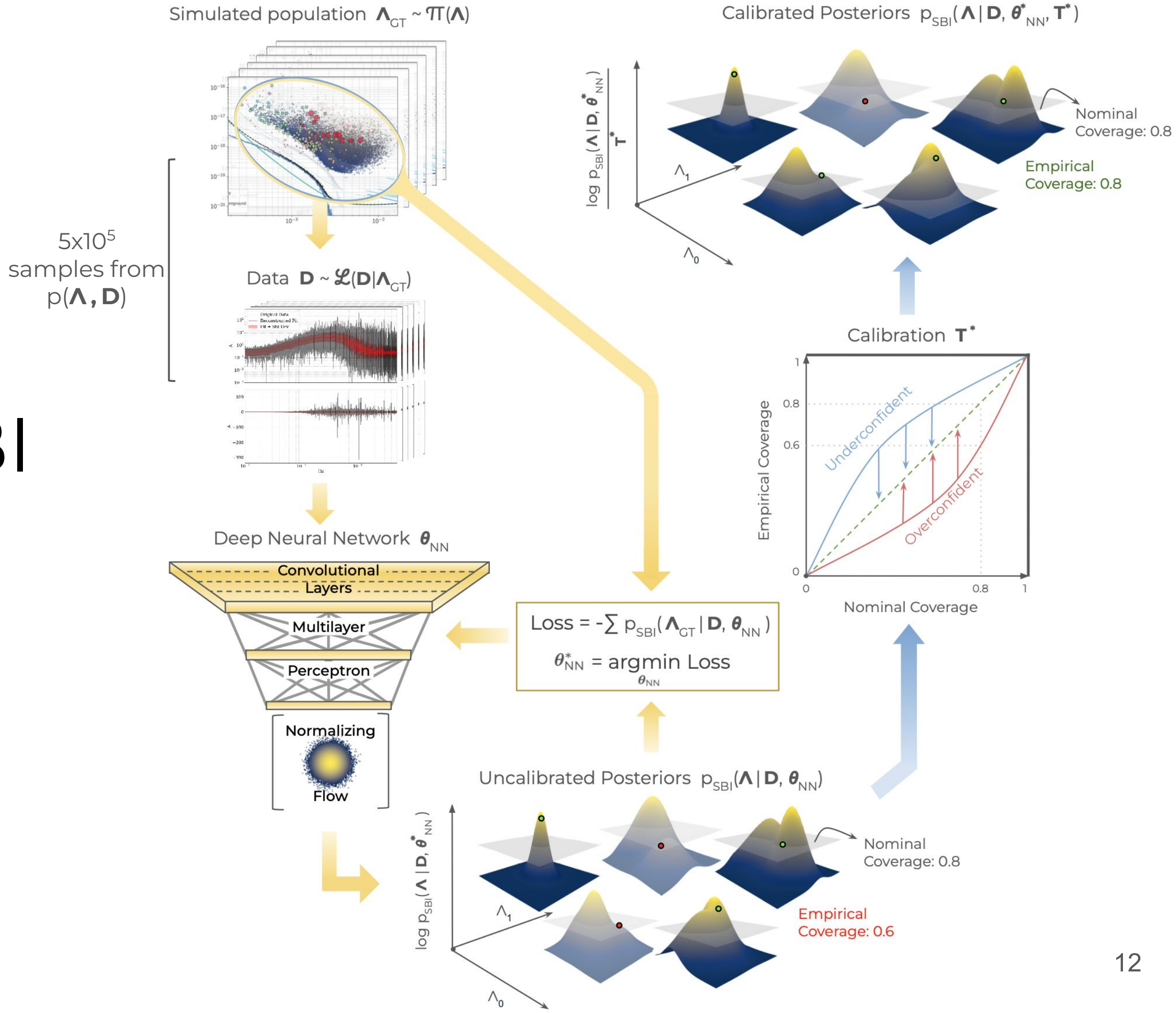


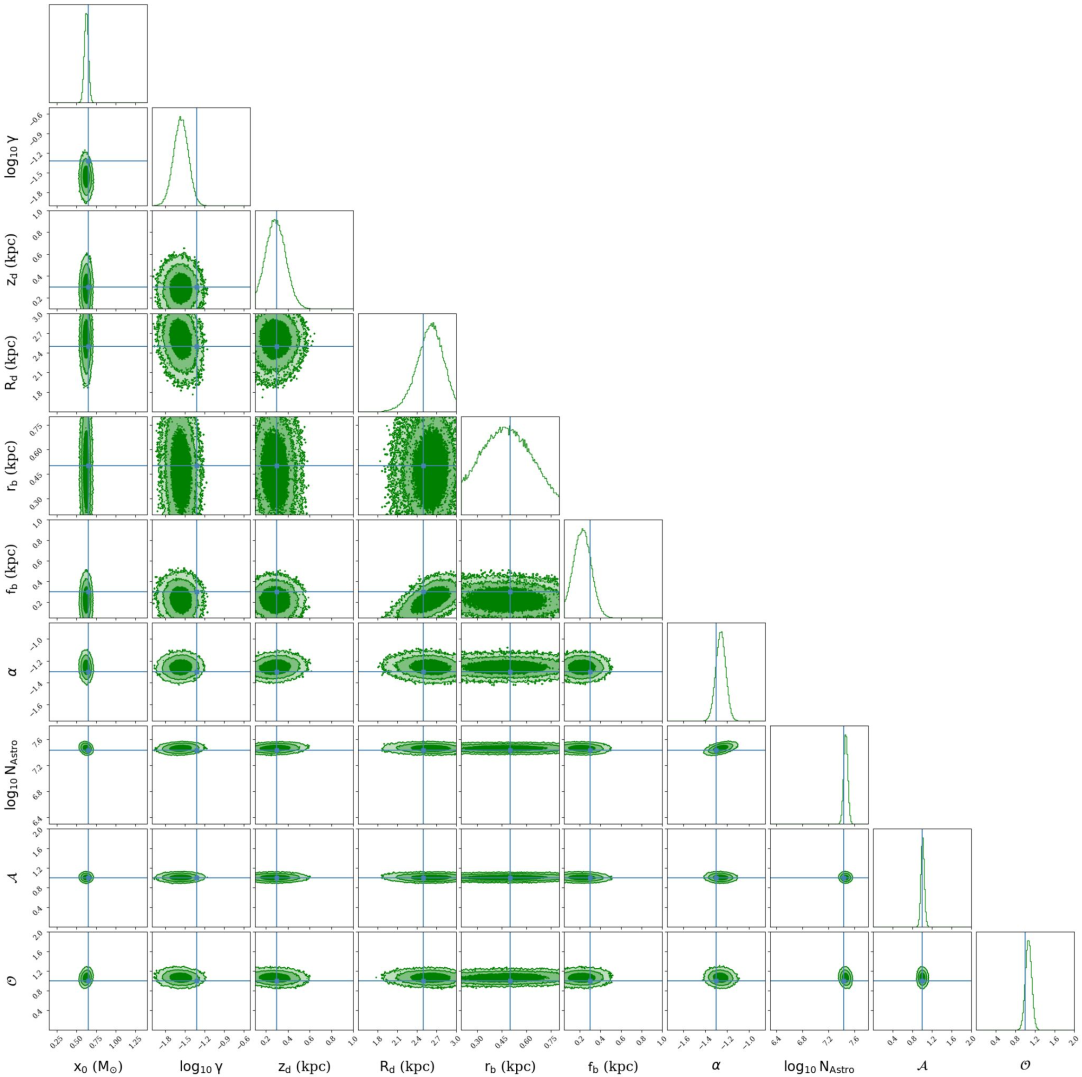


Network Architecture

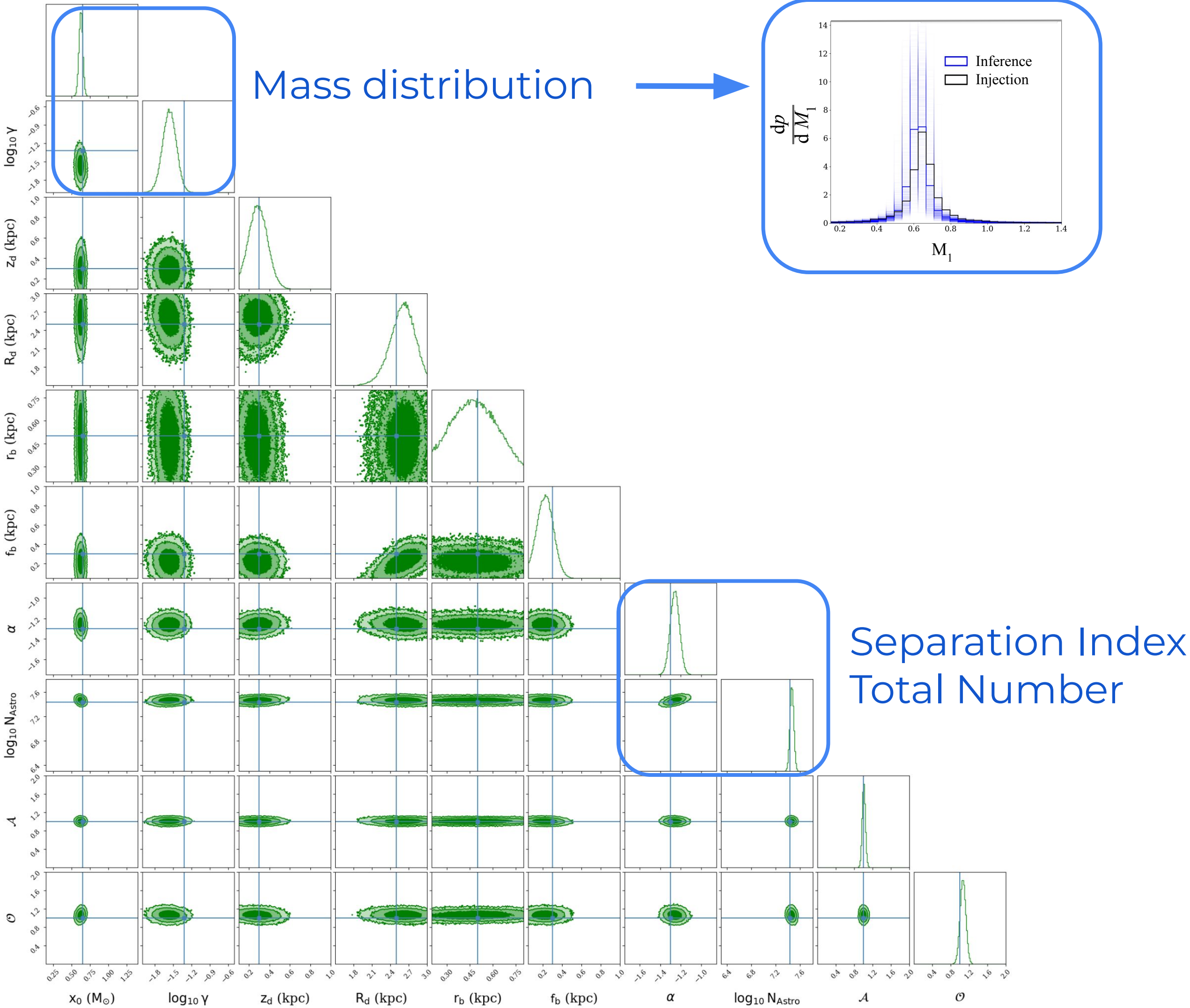


Training the SBI





Galactic Double White Dwarf Population Inference



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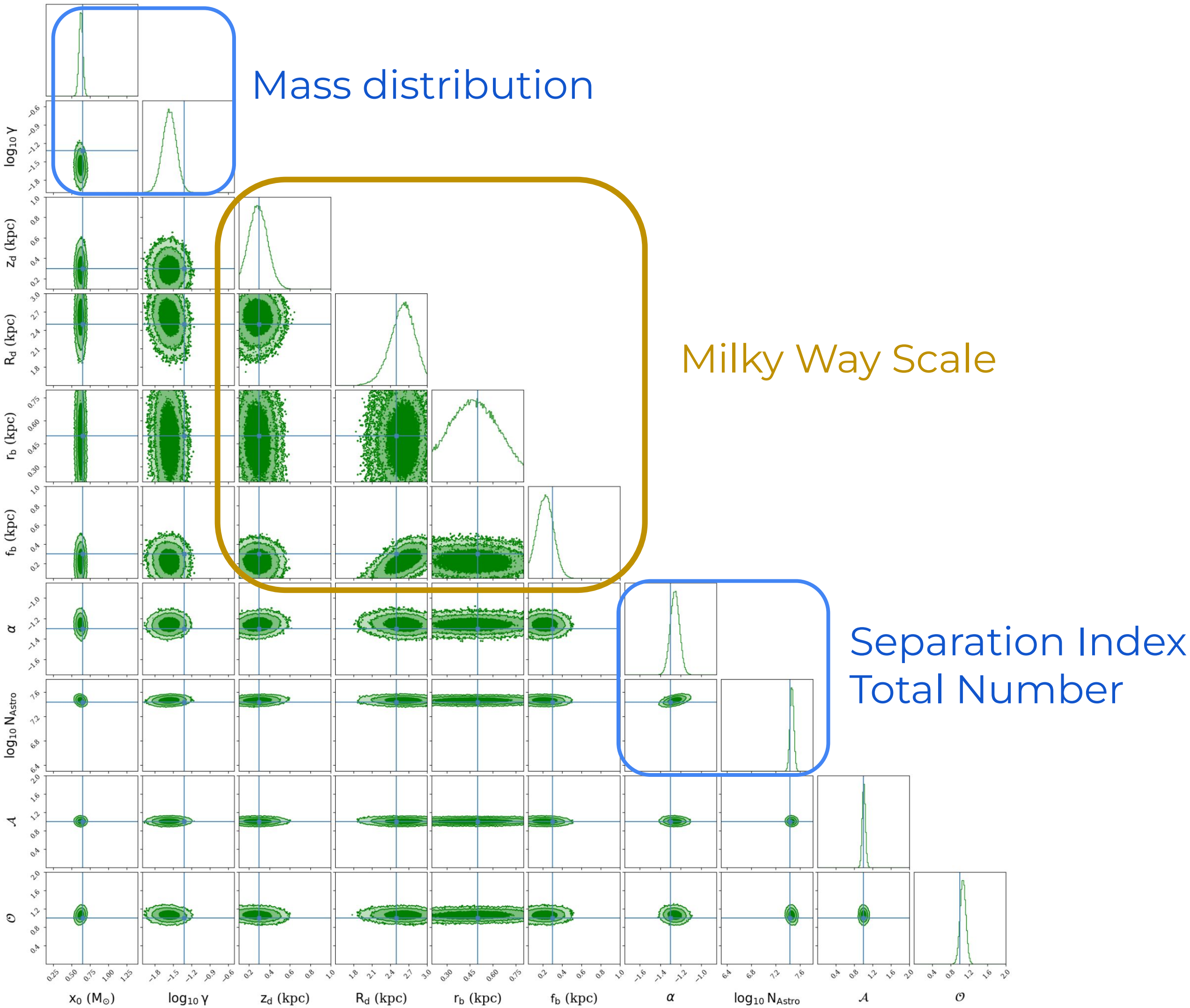

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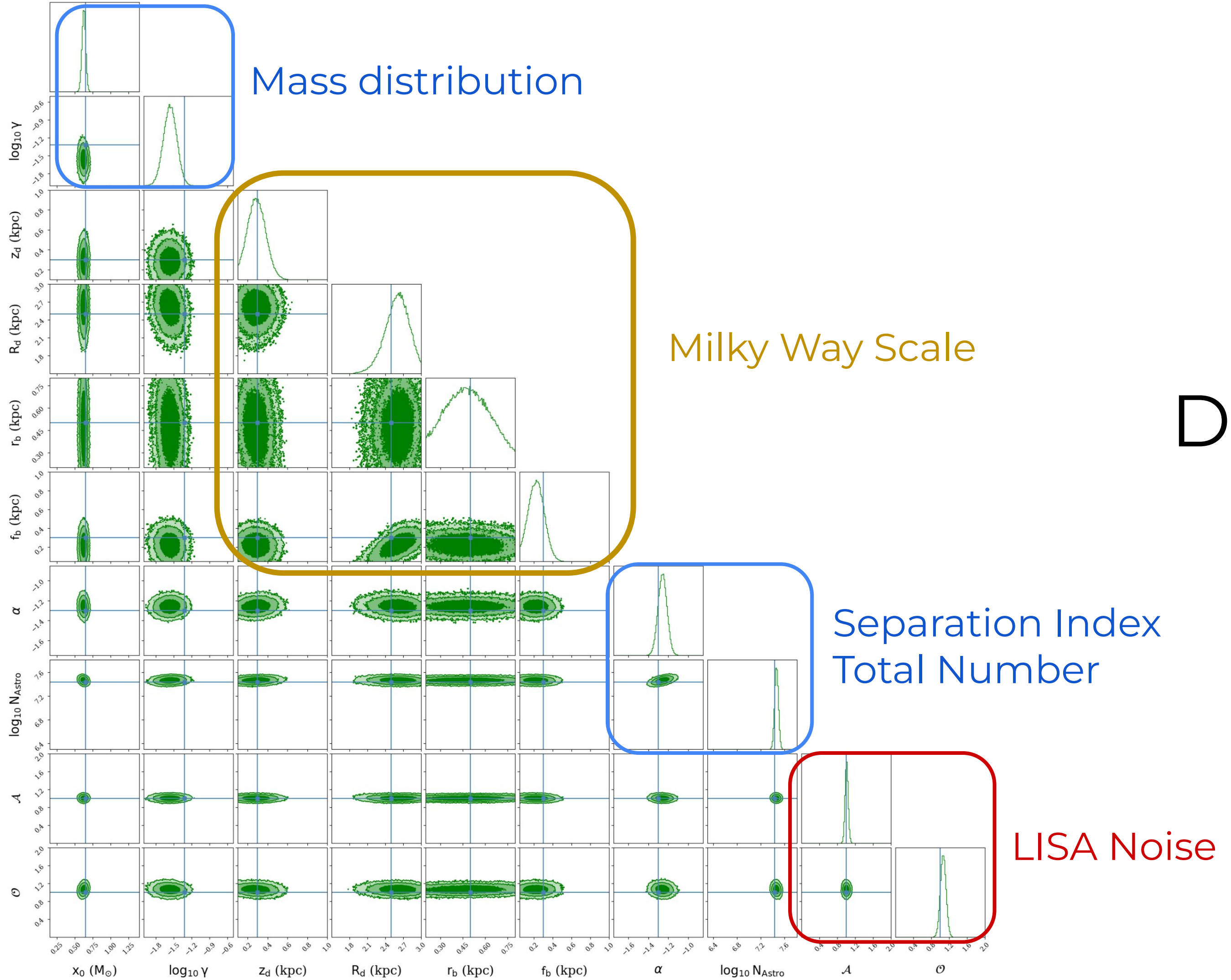
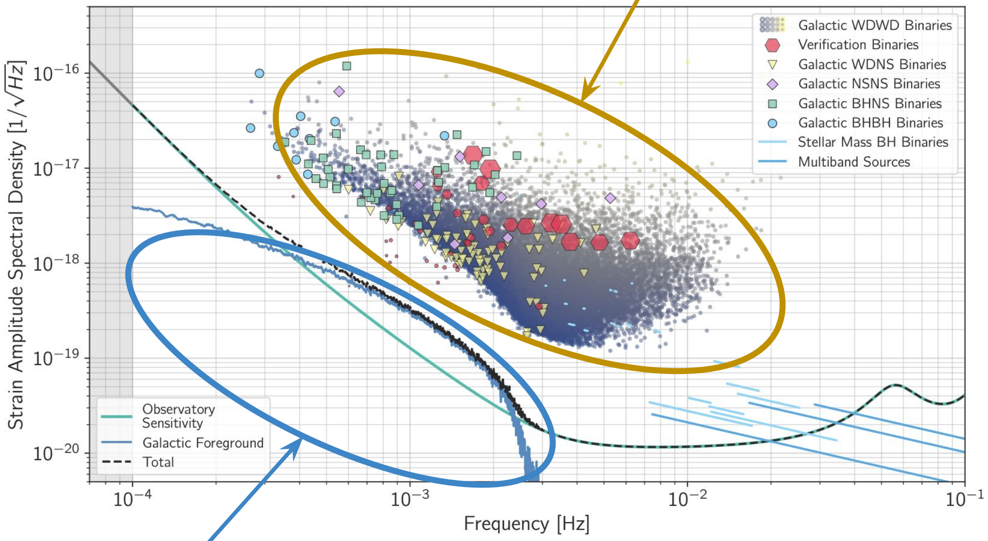


But, where lies the information?

O(30,000)



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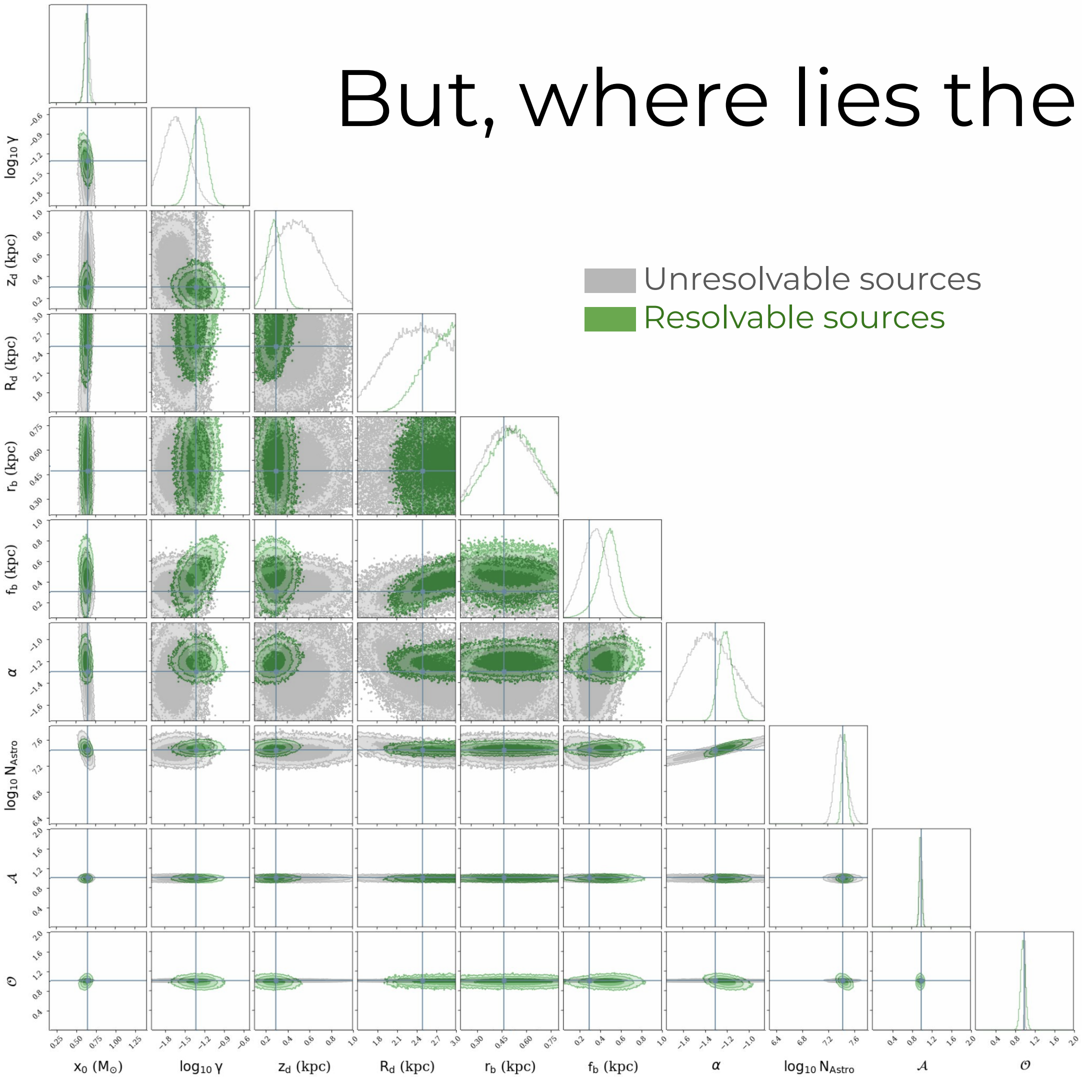

Probably the resolvable !

(at least for this particular data summary)

Paper & codes soon to be made public!

Caveats, caveats, caveats

* The inference can only be as good as the simulator/model $p(\mathbf{\Lambda}|\mathbf{D}, \mathbf{M}_{\text{Simulator}})$.

* The inference can only be as good as the data summary.

* The intractable (or at least hard-to-pose) likelihood prevents testing SBI for convergence to an "optimal" posterior.

* The SBI can often be underconfident: Calibration <u>required</u>.