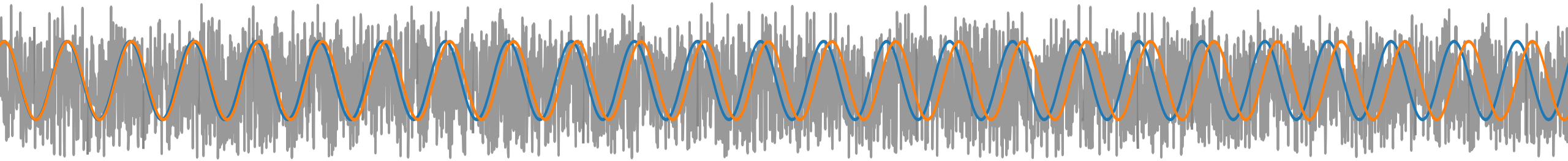
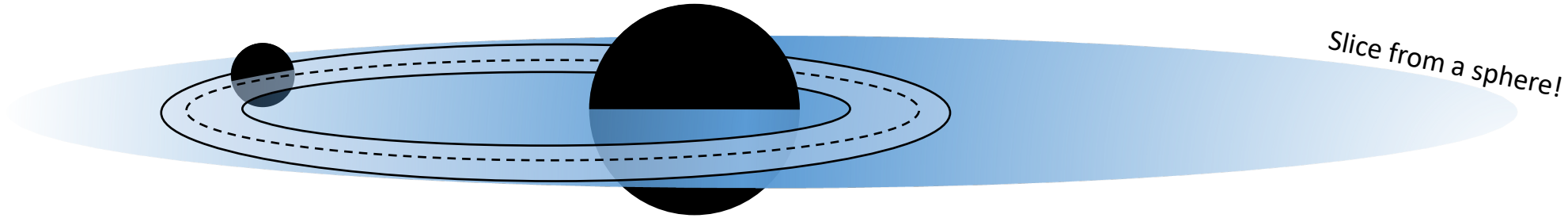


A surrogate model for IMRIs in presence of a dark matter spike

By: Karydas K. Theophanes as MSc at GRAPPA, UvA



Acknowledgements:

Prof. Gianfranco Bertone
Dr. Bradley J. Kavanagh
Dr. Philippa Cole

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GRavitation AstroParticle Physics Amsterdam

University of Amsterdam

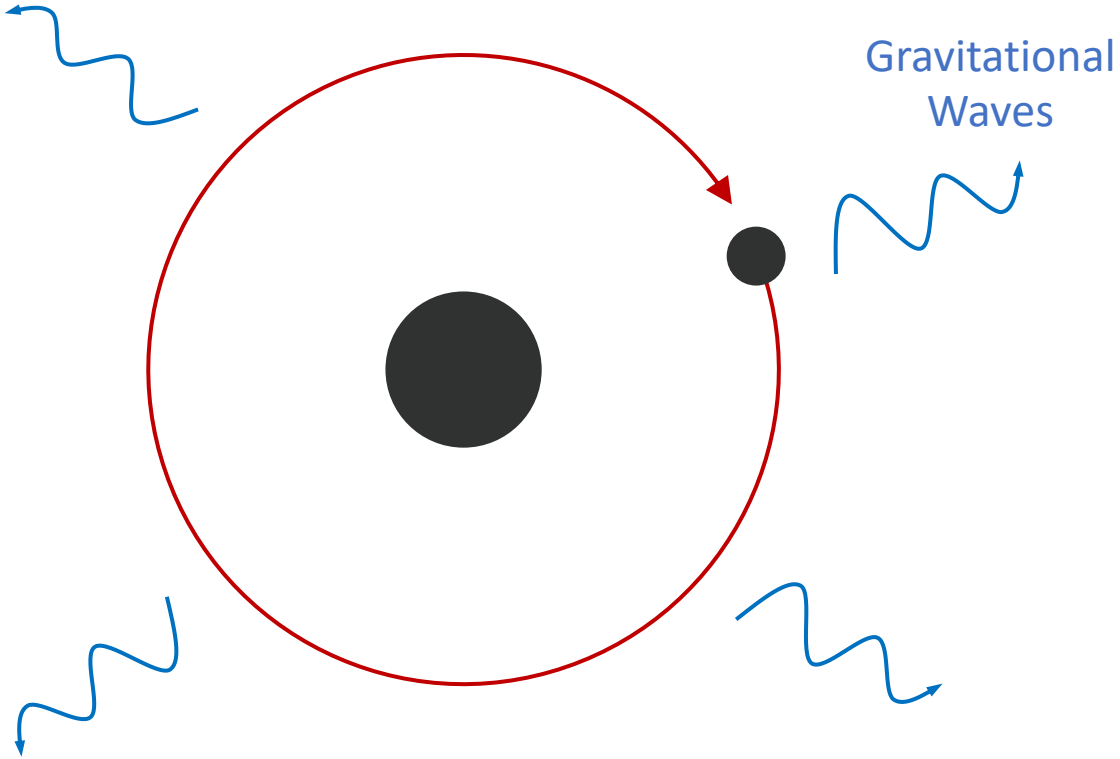
A surrogate model fo IMRIs in presence of a dark matter spike

Outline:

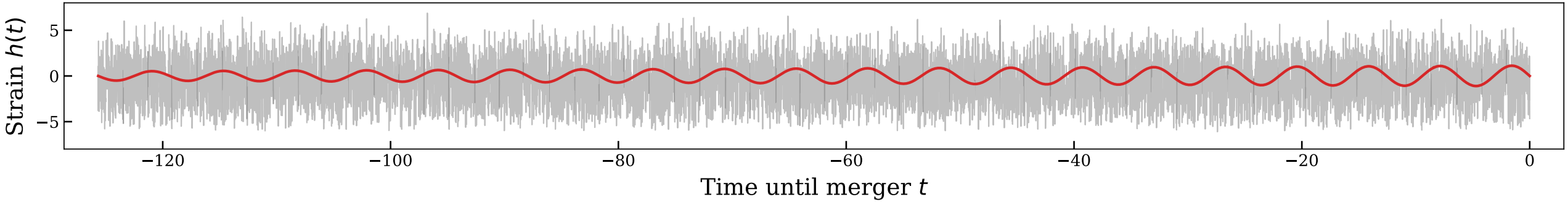
- Exotic waveforms & dark matter spikes
- Environment’s impact & costly simulators
- Creation of the surrogate model
- Comparison to analytical fits.
- Application in mock parameter estimation for LISA.

Binary Black Hole Mergers in Vacuum Space

Gravitational waves track the companion's path

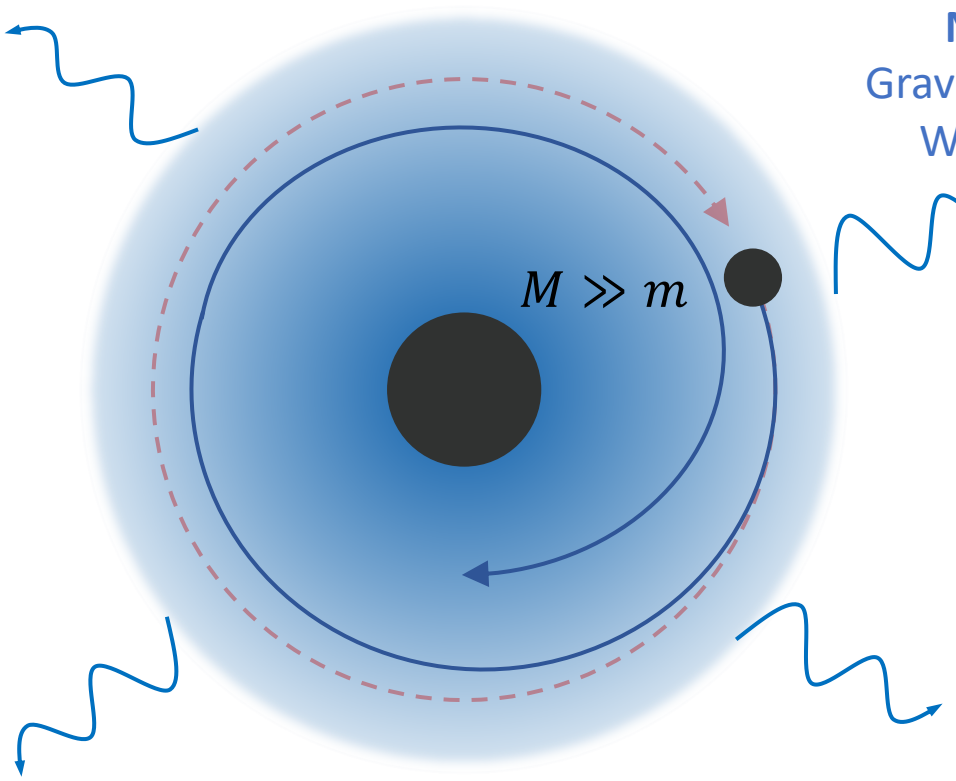


$$GWs \rightarrow Orbit\ Decay$$



Binary Black Hole Mergers in environments

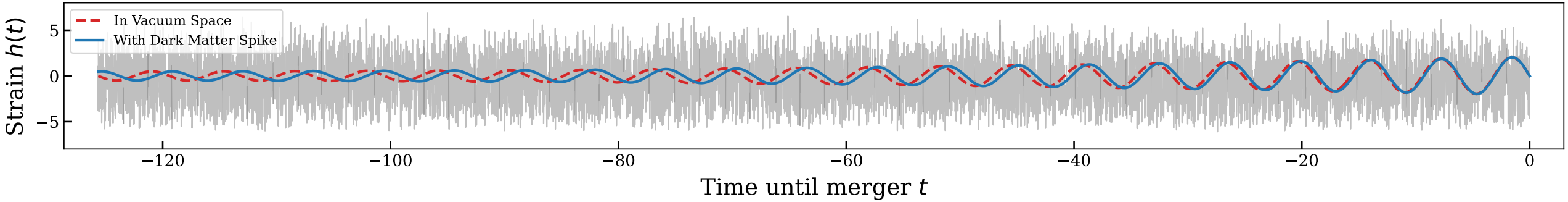
Gravitational waves are out of sync with respect to vacuum case



New Gravitational Waves!

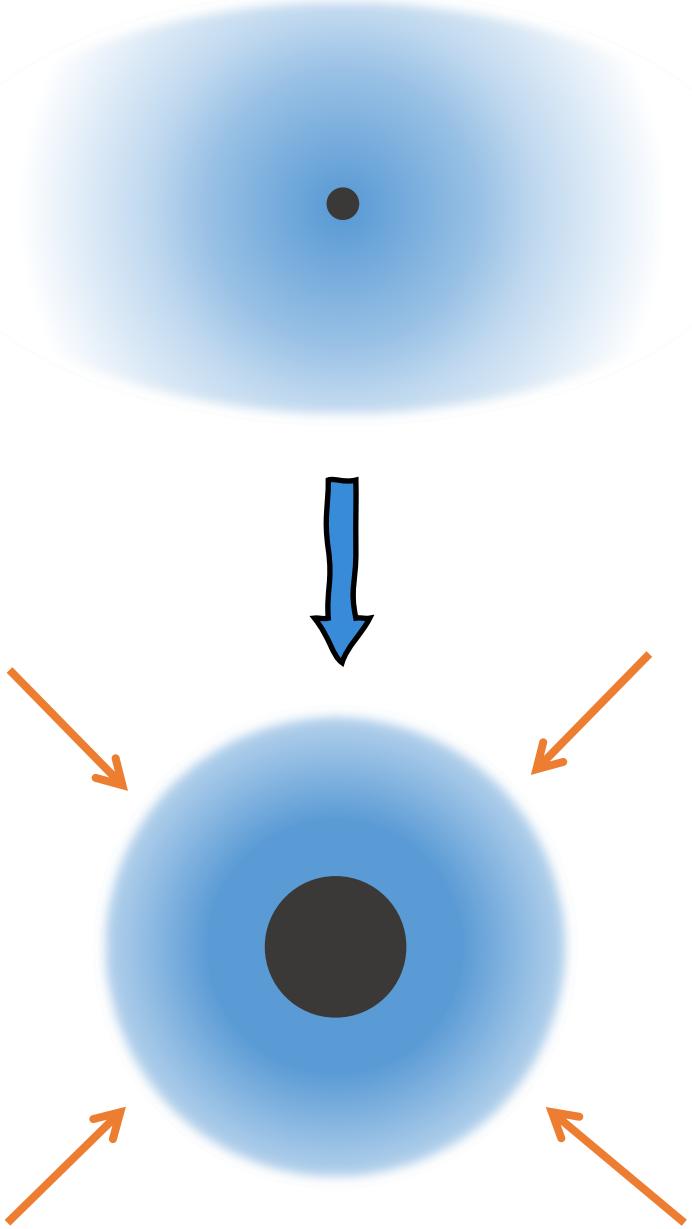
$$GWs + \boldsymbol{Environment} \rightarrow (\boldsymbol{Larger})\ Orbit\ Decay \quad \propto \rho(r)$$

Dephasing: The difference in cycles in dressed vs vacuum



Dark Matter Spikes

A natural laboratory in the search of dark matter



`Spikes' or `Dresses'

From `heavy' particle-like dark matter

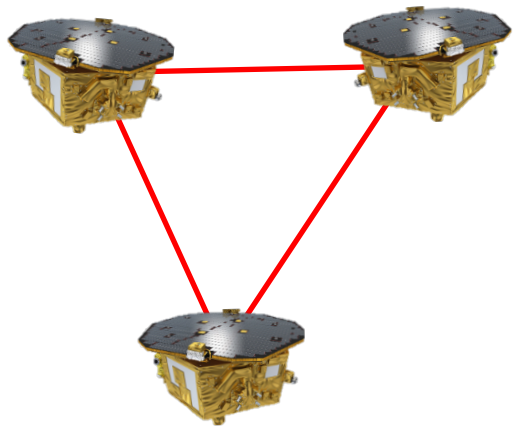
Astrophysical Formation

From the slow growth of a BH at the center of a DM halo

Primordial Formation

From density fluctuations In the early universe

LISA



Interactions between DM particles and the companion

Particles deflect and cause dynamical friction

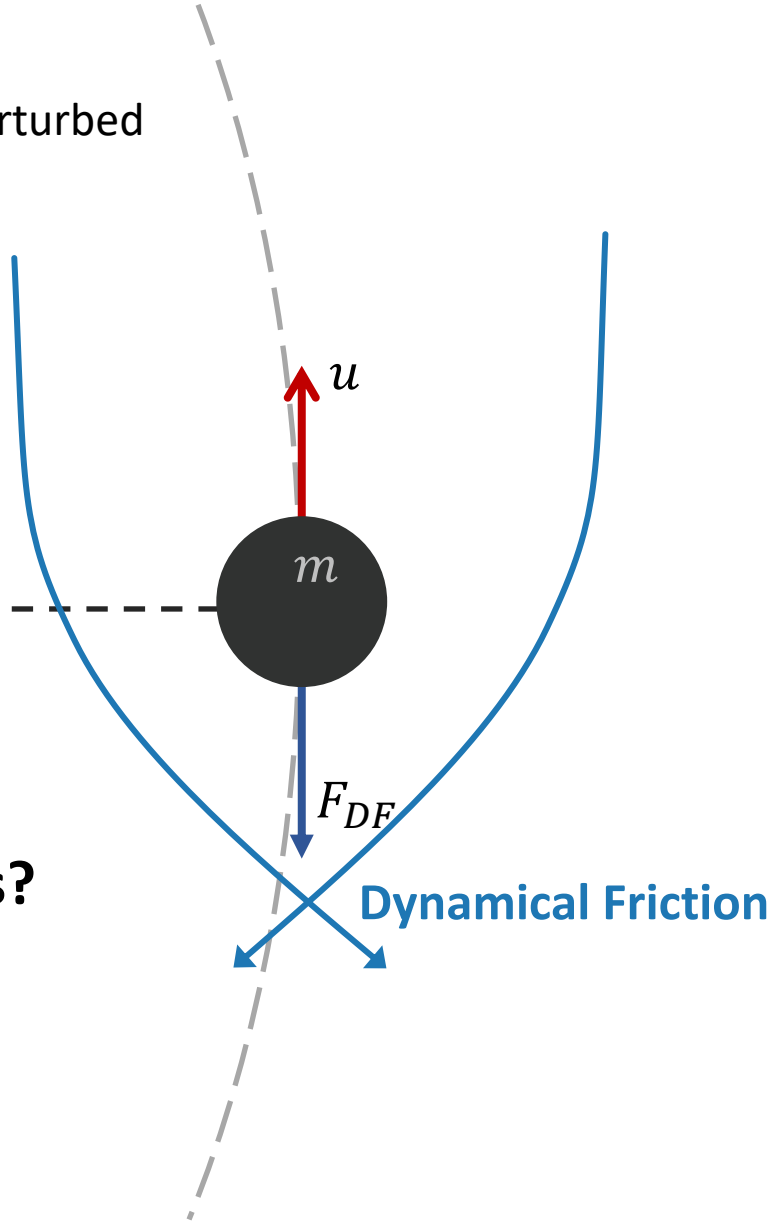
Particles scatter and induce additional drag

Particle orbits perturbed

Quite Costly

Order 1 day/waveform

$M \gg m$



Surrogate model instead of endless simulations?

B. J. Kavanagh et al. Phys. Rev. D 102, 083006 (2020)

The model's design

Waveform generation

Waveforms

Frequency domain

$A(f)$ $\phi(f)$

Roughly 1k
waveforms following
10 years before merger

Intrinsic Parameters

$\boldsymbol{\theta} = (binary, spike)$

The model's design

Decomposition

Waveforms

Frequency domain

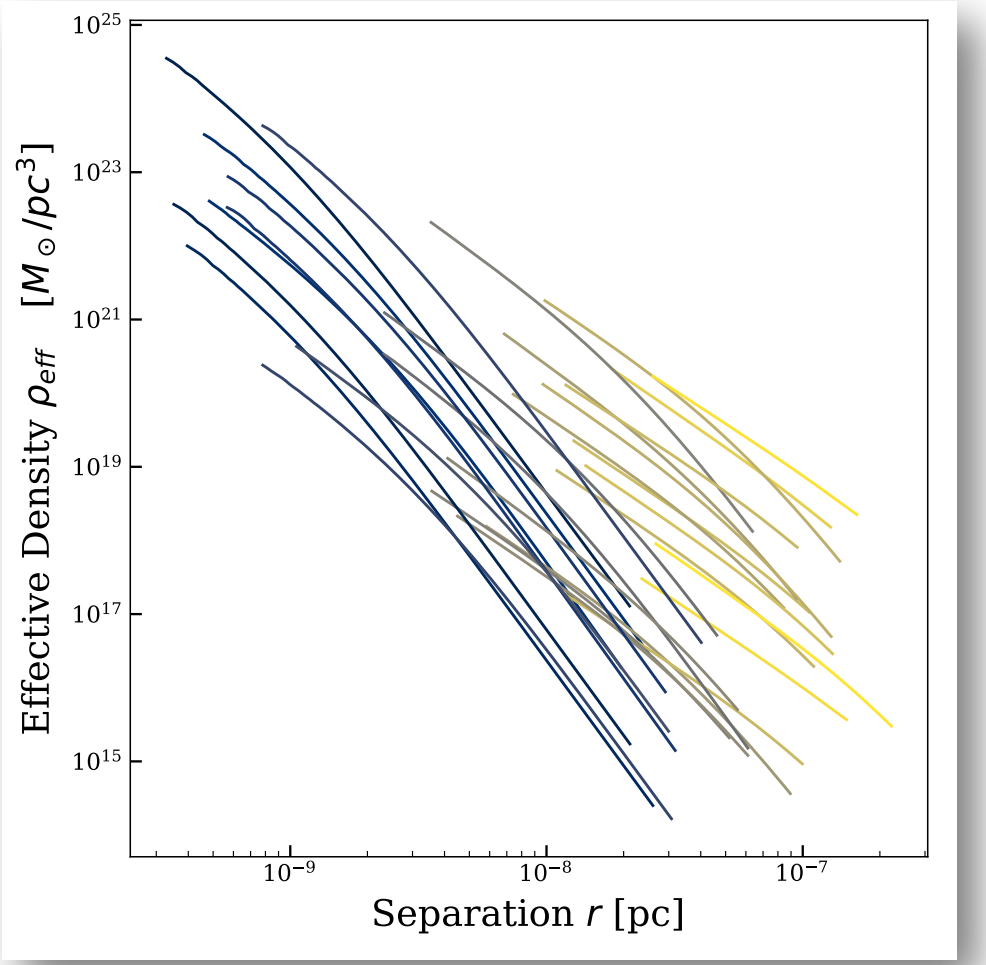
$A(f)$ $\Phi(f)$

Decompose

Energy emitted due to spike

Intrinsic Parameters

$\boldsymbol{\theta} = (binary, spike)$



The model's design

Exploit approximate boundary conditions

Waveforms

Frequency domain

$A(f)$ $\Phi(f)$

Decompose

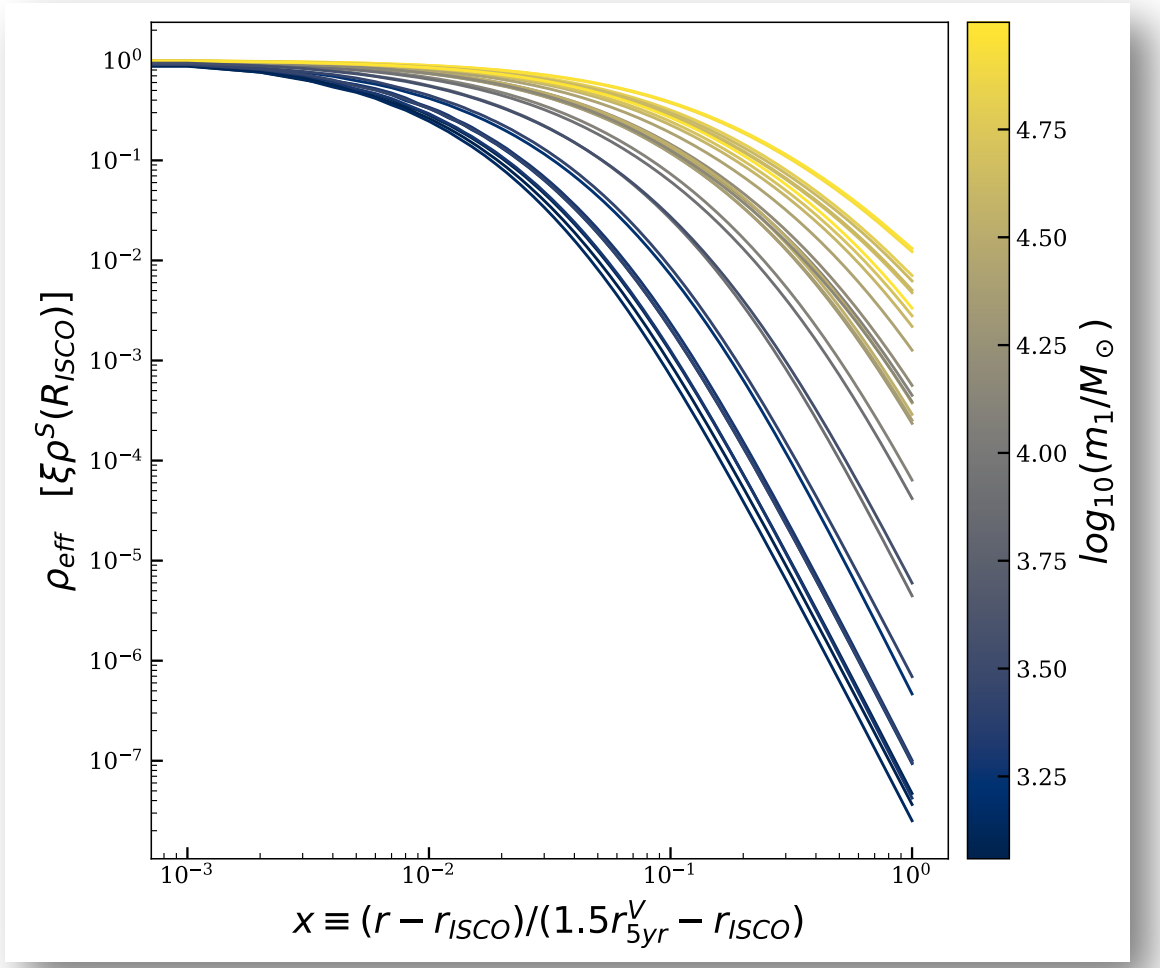
Energy emitted due to spike

+

Approximate Boundary conditions

Intrinsic Parameters

$\boldsymbol{\theta} = (binary, spike)$



The model's design

Avoiding slow training and deployment

Waveforms

Frequency domain

$A(f)$ $\phi(f)$

Decompose

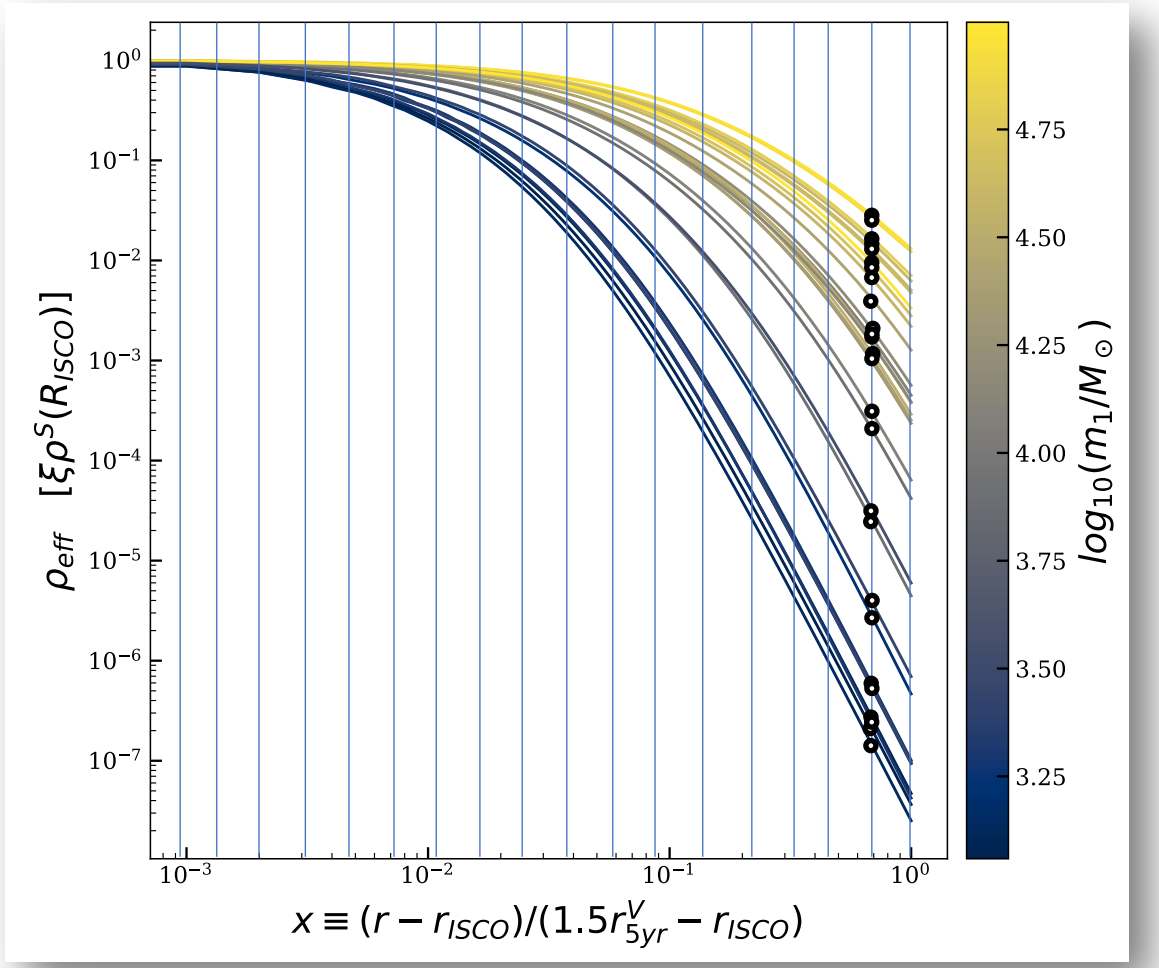
Energy emitted due to spike

+

Approximate Boundary conditions

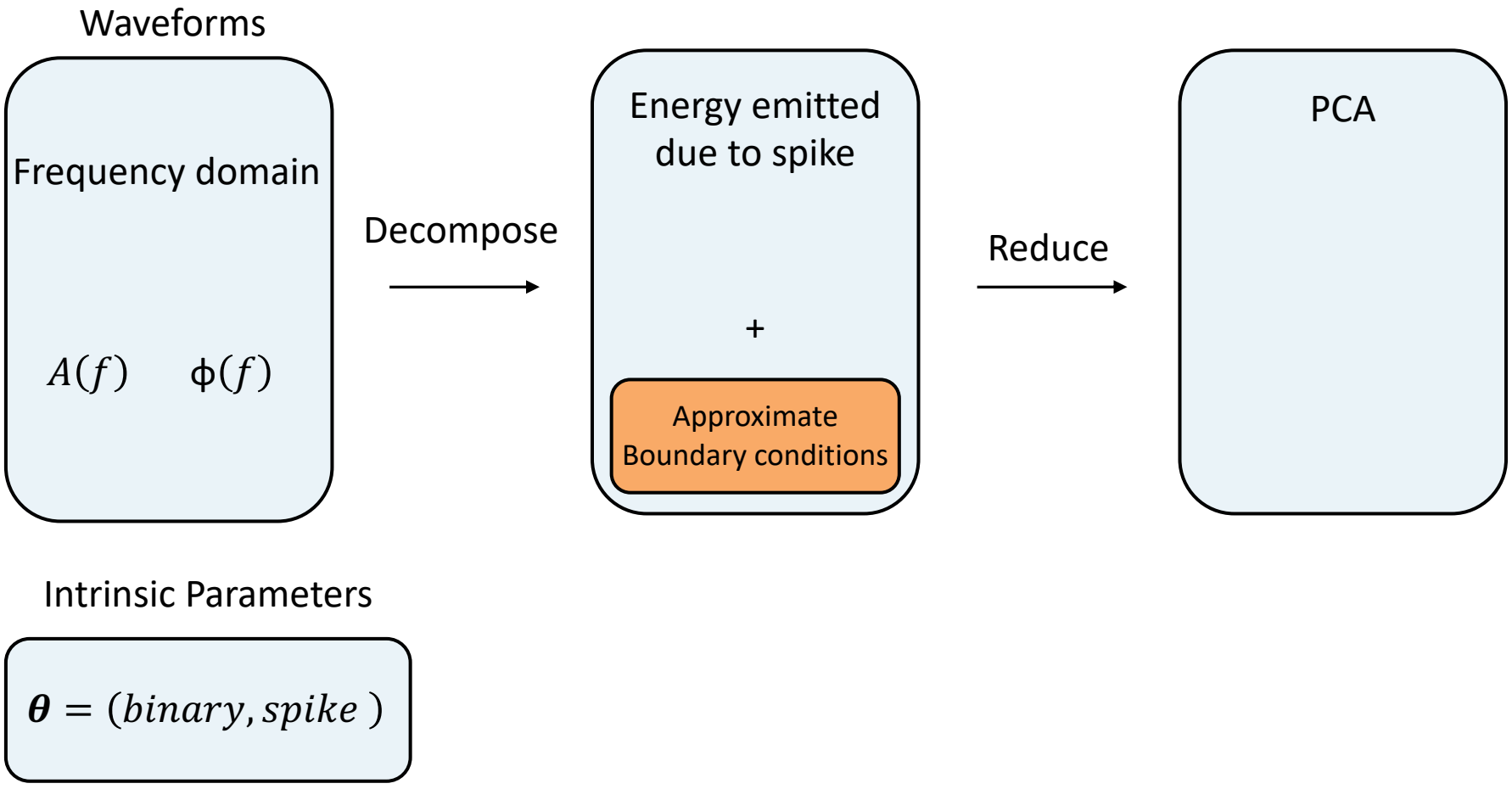
Intrinsic Parameters

$\boldsymbol{\theta} = (binary, spike)$



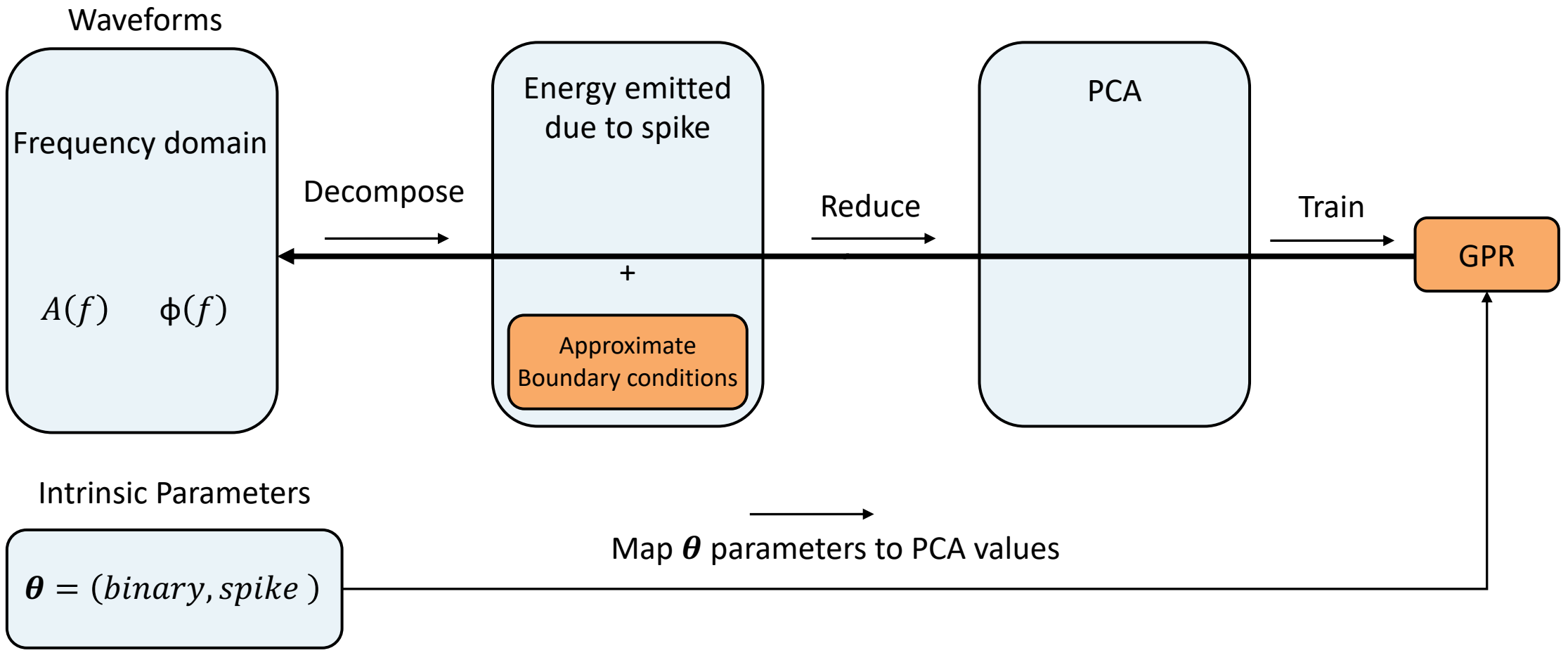
The model's design

Dimesionality reduction



The model's design

Saving training and evaluation time.



Putting the surrogate model to the test

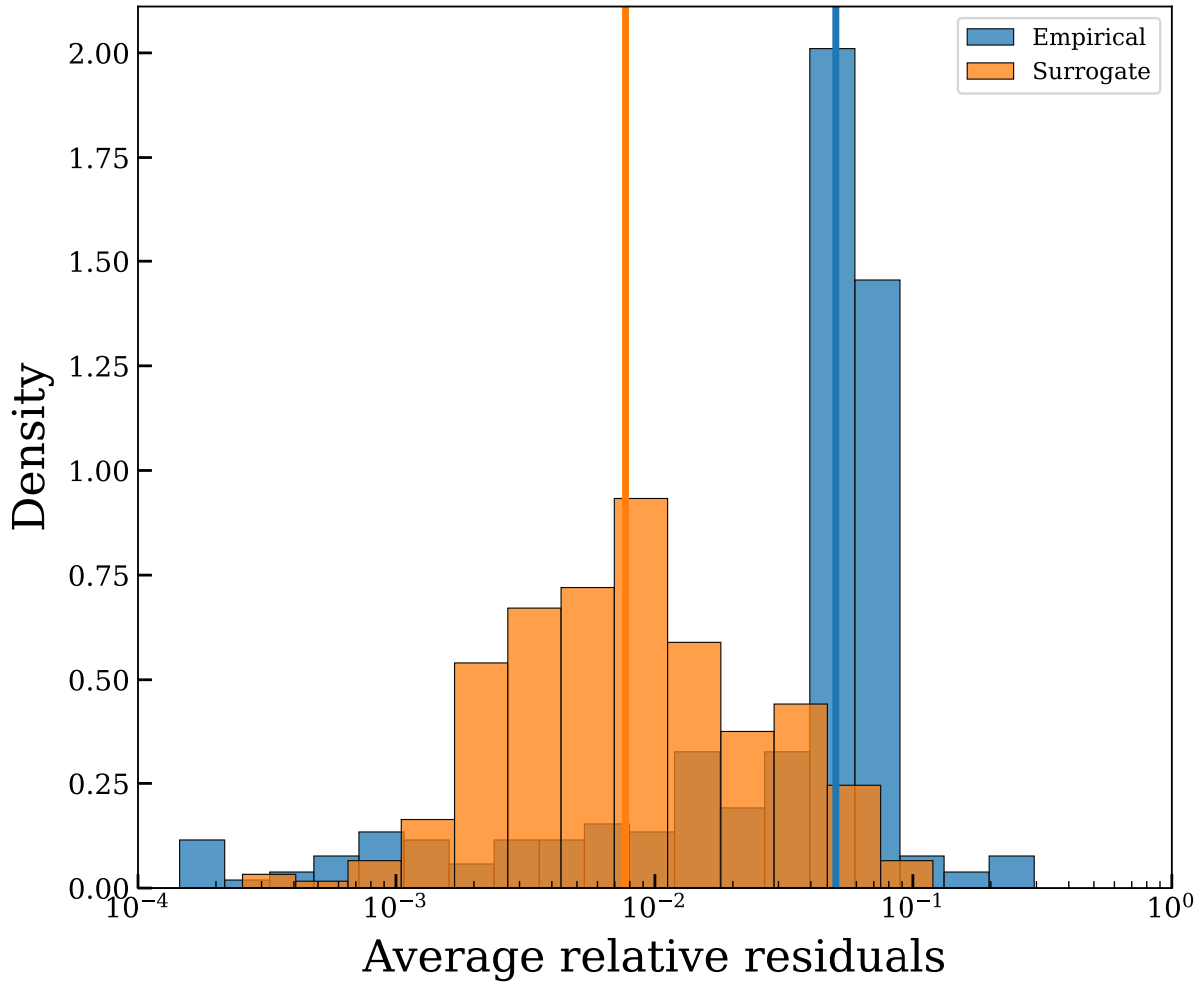
Interestingly:

Analytical fit = analytical solution

= better when $q = \frac{m_2}{m_1} < 10^{-5}$.

↓

Hybridize with that solution



Analytical fit: broken power-law

A. Coogan et al. (Phys. Rev. D 105, 043009 (2022))

Putting the model to the test vol. 2

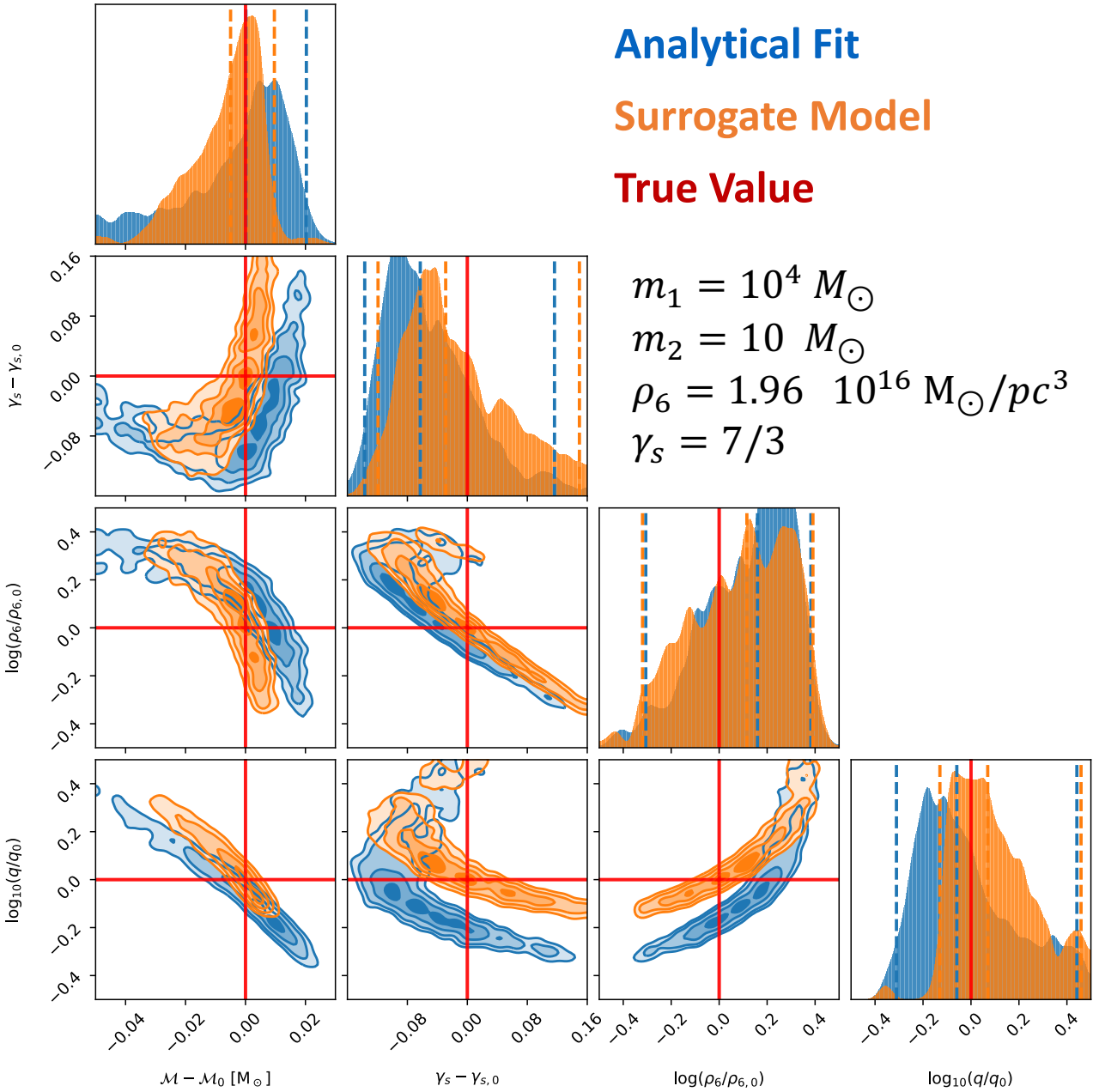
Mock data analysis for a LISA signal

Nested Sampling

Mock parameter estimation for LISA

1 year

$SNR = 15$



Parameter estimation using **pydd** and dynesty

A. Coogan et al. (Phys. Rev. D 105, 043009 (2022))

Take home messages

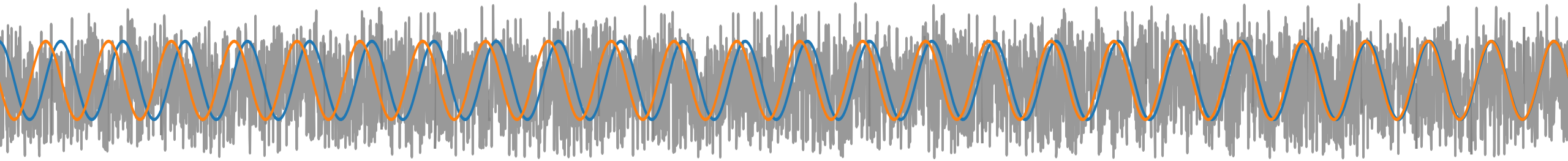
What have we learned?

Remarks:

- Surogate modeling indeed a powerful tool in the search of exotic waveforms contaminated by BH environments.
- (For the physicists) Signs that LISA could be used to recover properties of dark matter.

Outlook:

- Increase complexity of our physical model & reiterate.
- Apply in the search and discrimination between other black hole environments (disks, clouds) led by Pippa Cole (later this fall)



Thank you for your attention!

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