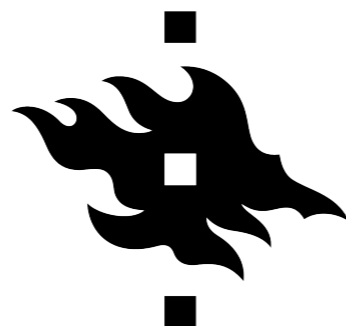


# Reconstructing early universe physics from future LISA data

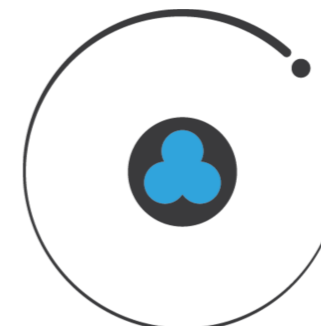
Deanna C. Hooper

*Based on C. Gowling, M. Hindmarsh, **DCH**, J. Torrado (2209.13551)  
and M. Hindmarsh, **DCH**, T. Minkkinen, D. J. Weir (2406.04894)*

**HECA Seminar**  
**27<sup>th</sup> January 2026**



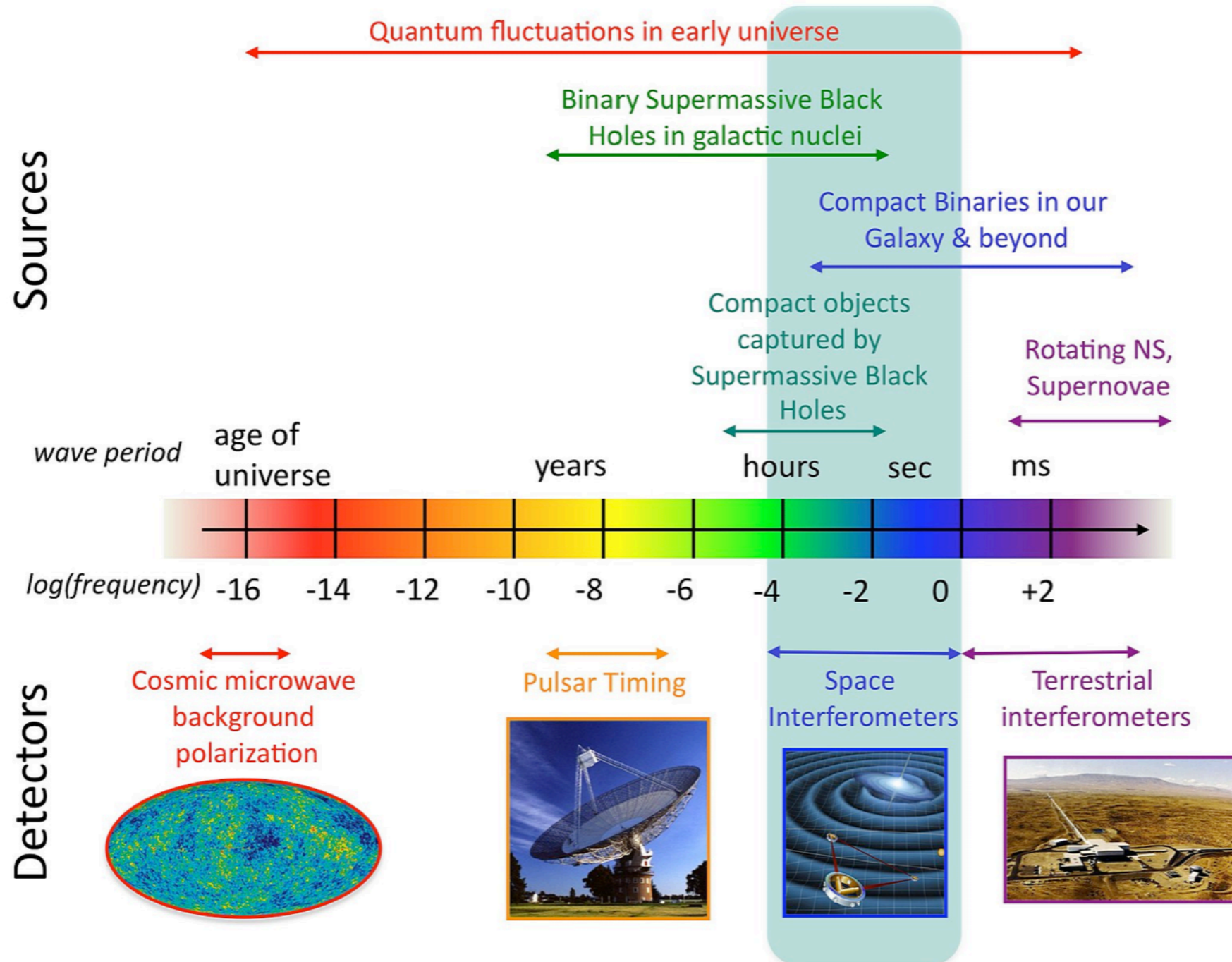
HELSINGIN YLIOPISTO  
HELSINGFORS UNIVERSITET  
UNIVERSITY OF HELSINKI



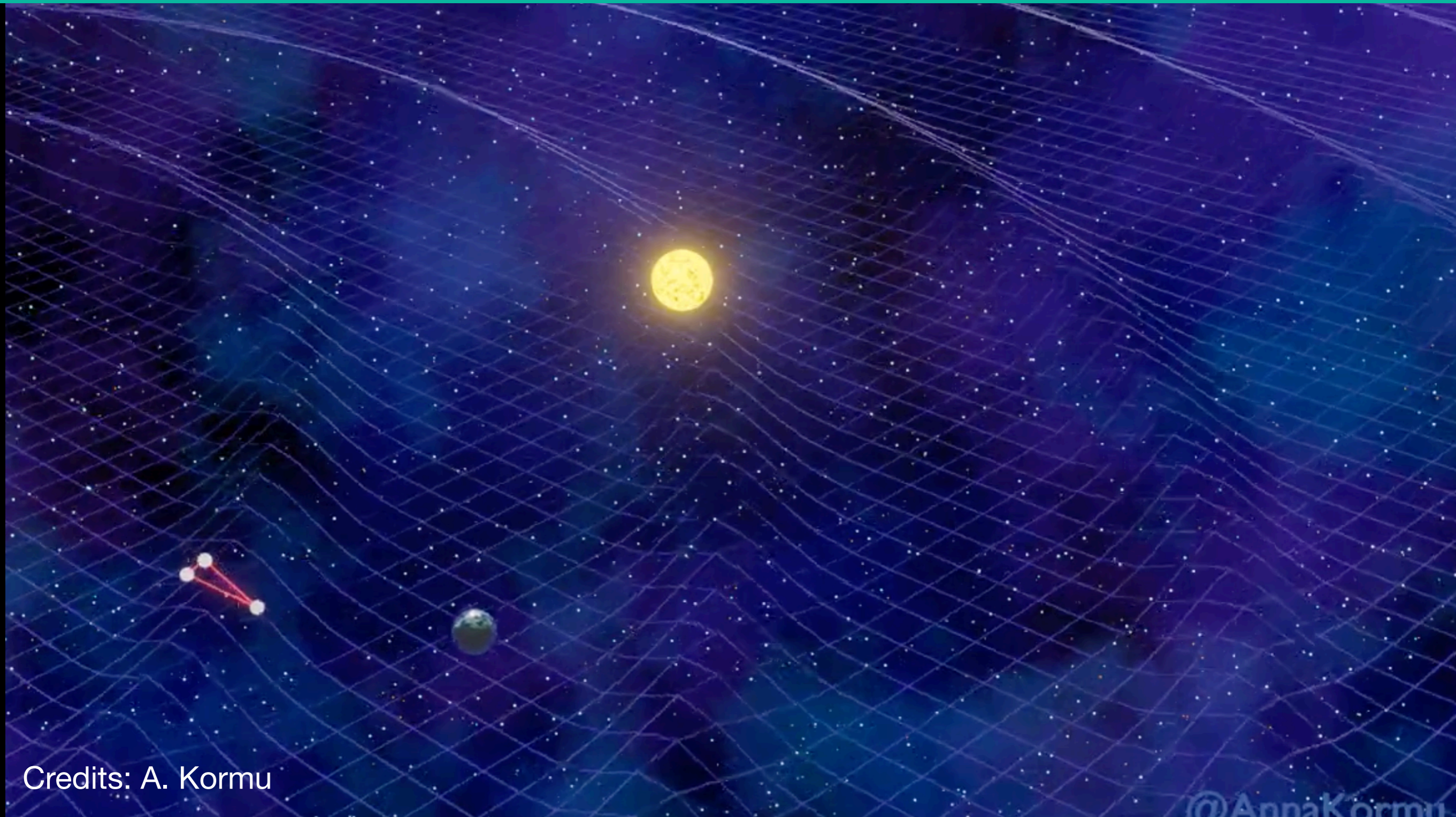
HELSINKI  
INSTITUTE OF  
PHYSICS

# Gravitational waves can probe vastly different cosmological epochs

## The Gravitational Wave Spectrum



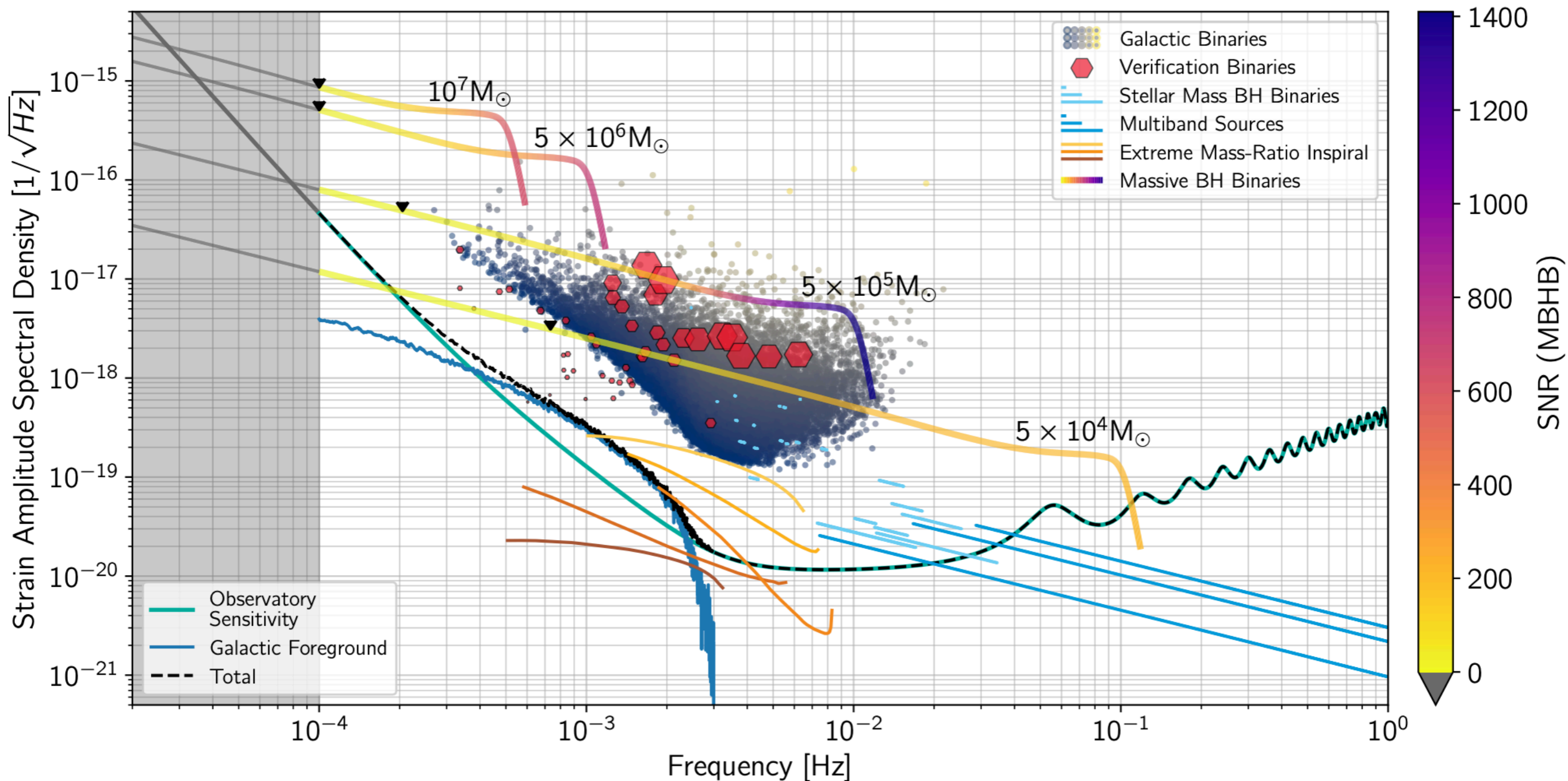
# LISA is a future space-based gravitational wave mission set to launch in 2036



Credits: A. Kormu

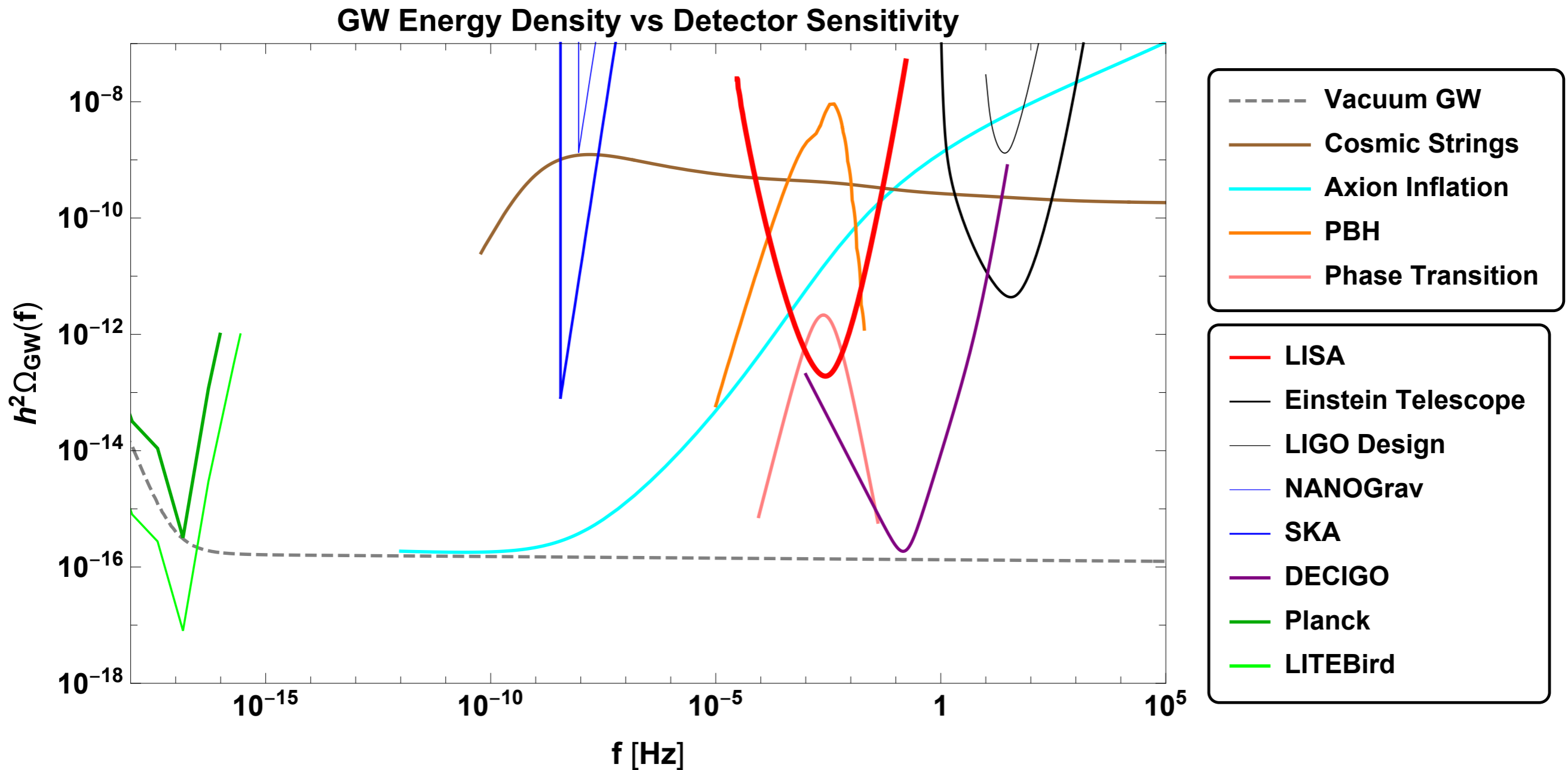
@AnnaKormu

# LISA will be sensitive to millihertz frequency GW, including galactic binaries



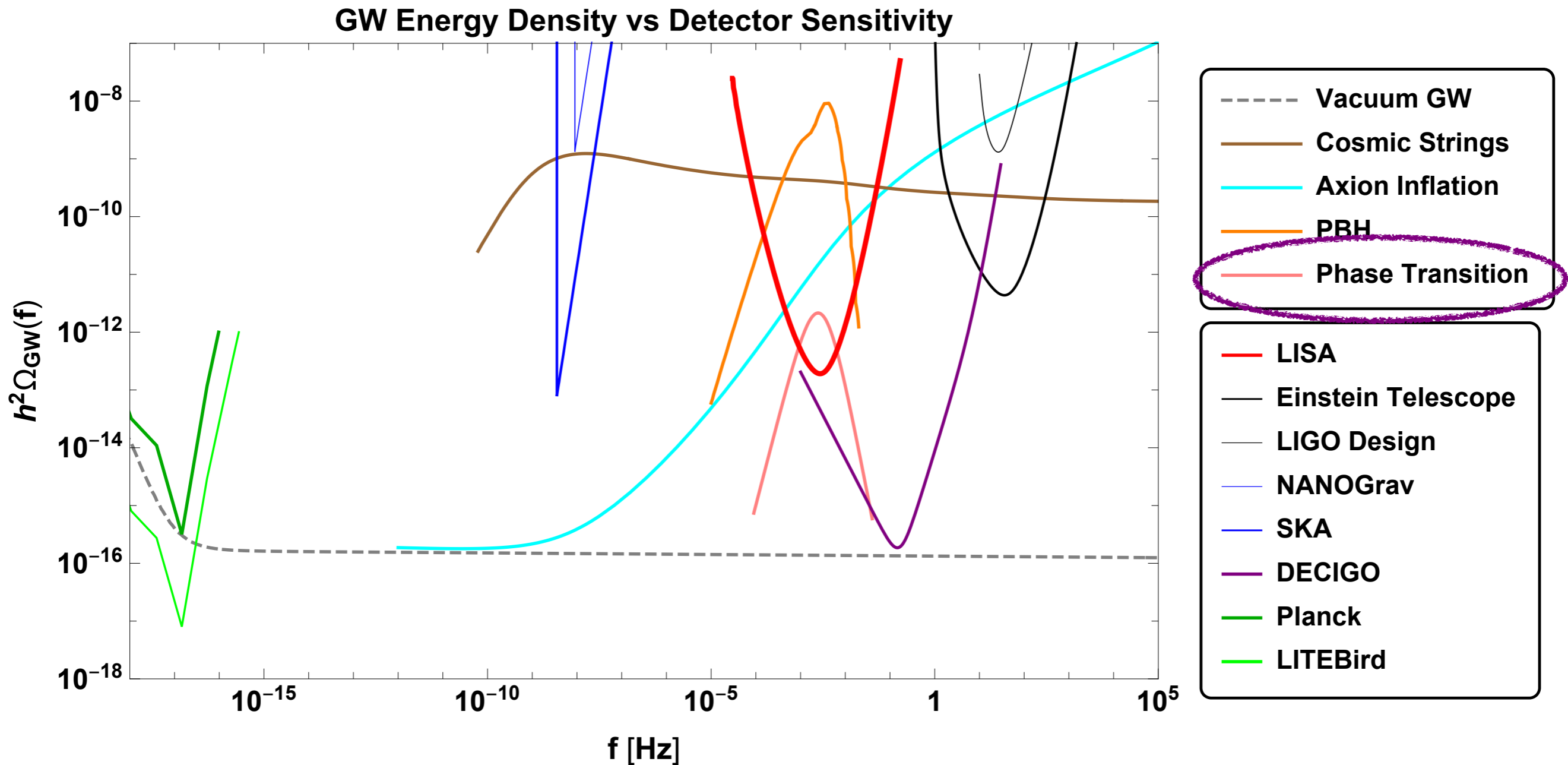
[arXiv: 2402.07571](https://arxiv.org/abs/2402.07571)

# LISA is also looking for a stochastic gravitational wave background



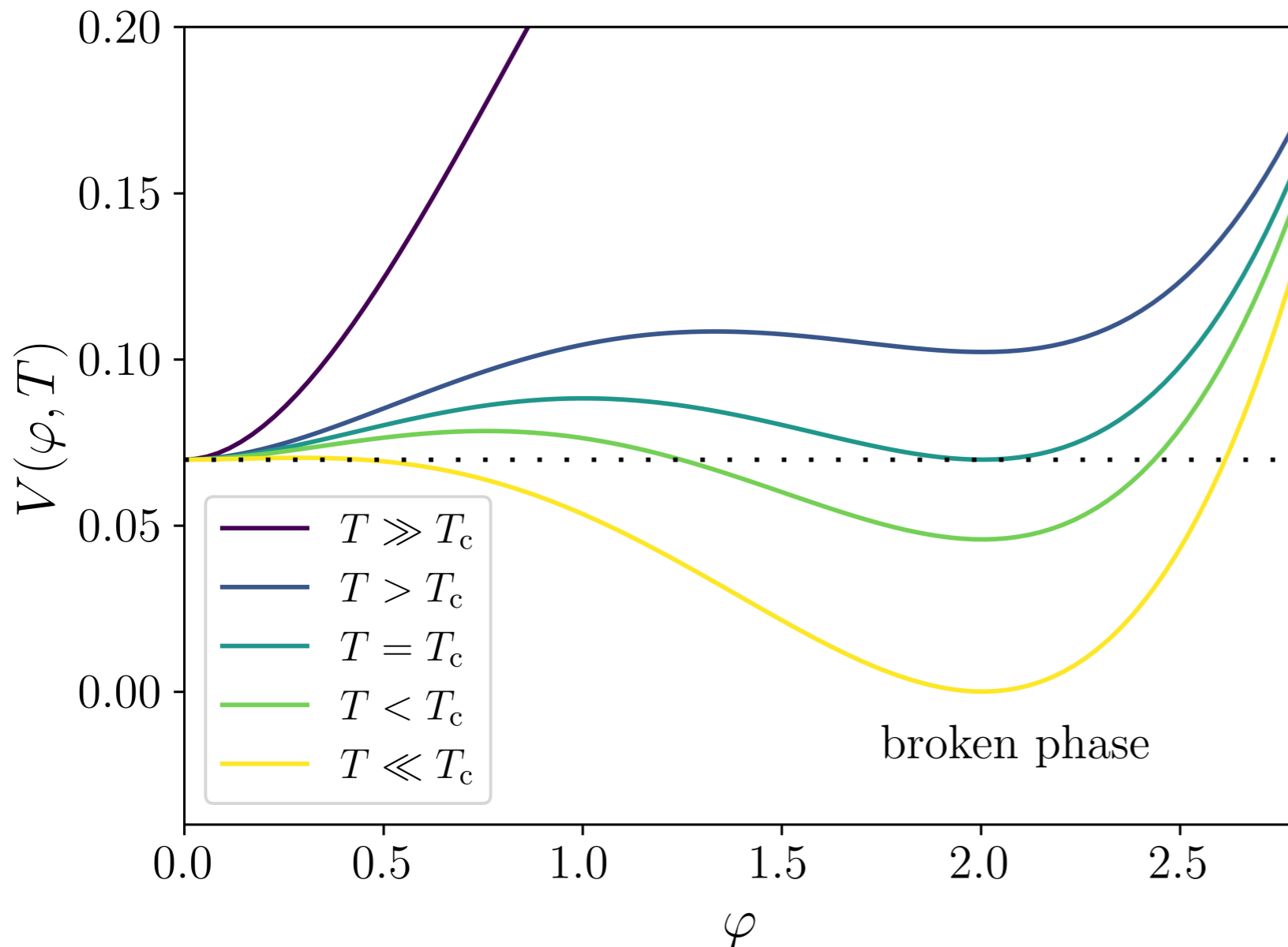
[arXiv: 2204.05434](https://arxiv.org/abs/2204.05434)

# LISA is also looking for a stochastic gravitational wave background



arXiv: 2204.05434

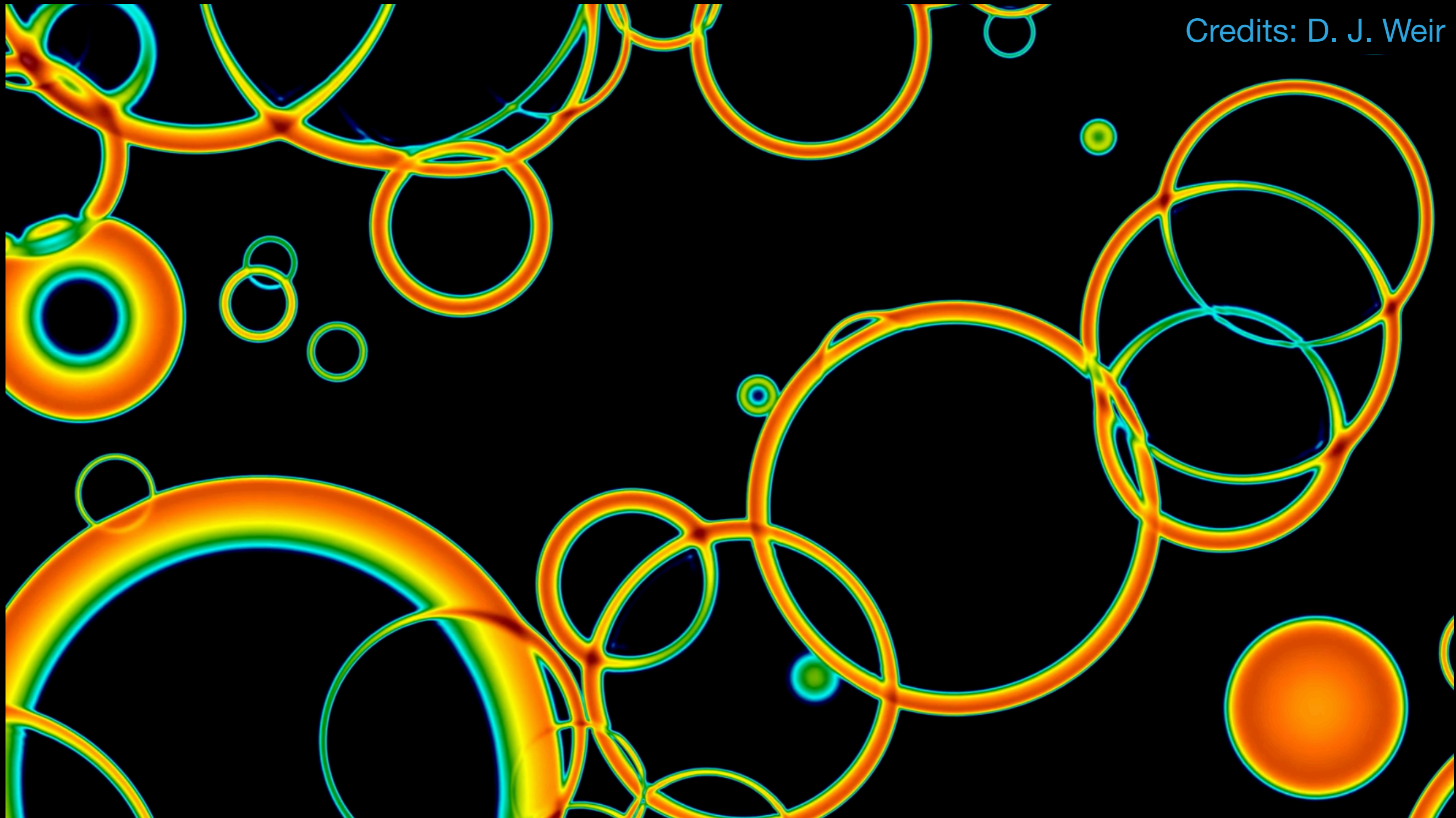
# The universe can have phase transitions if a field tunnels to a lower energy state



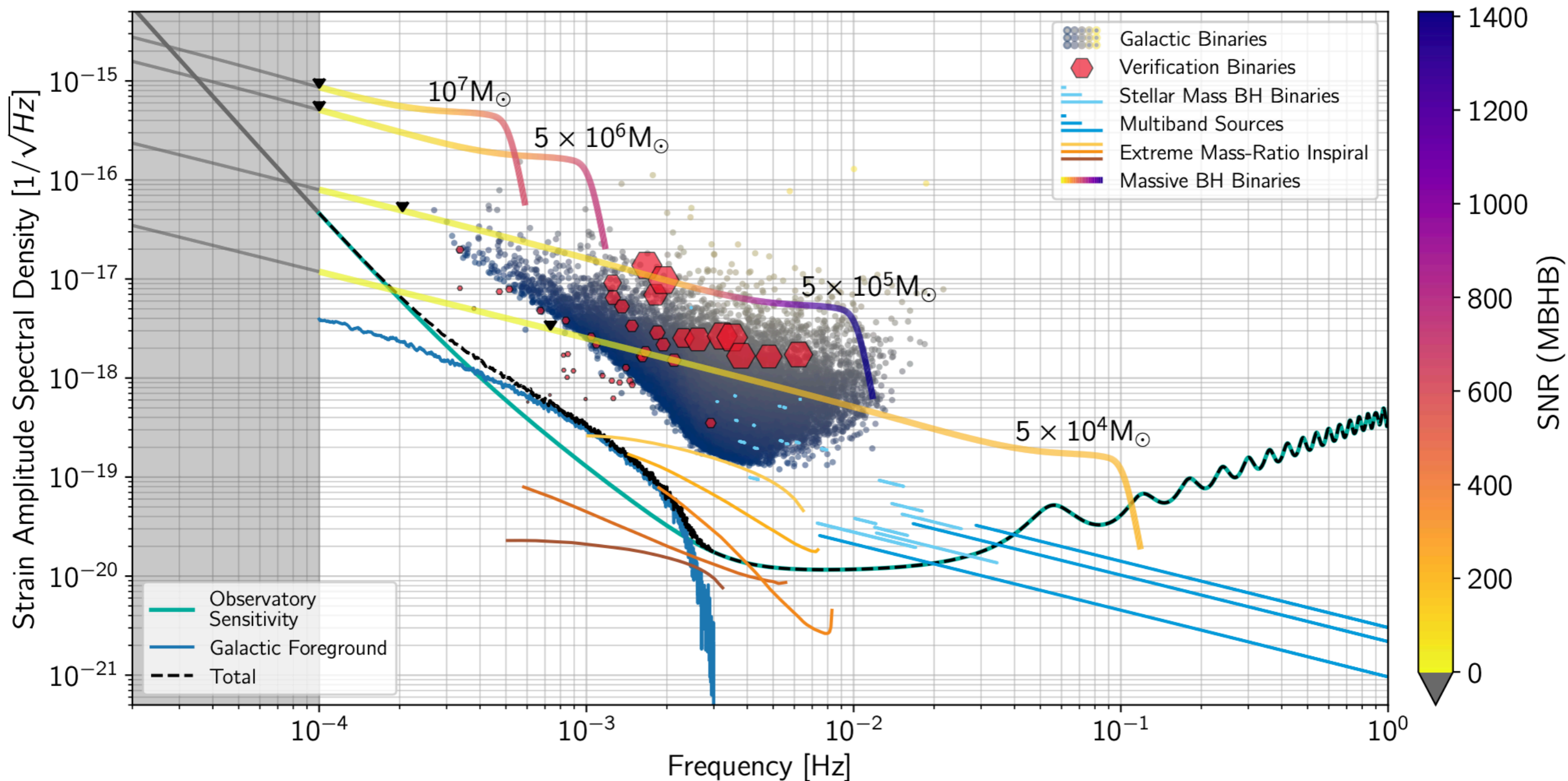
- Clearest example: electroweak symmetry breaking
- Does not produce gravitational waves in Standard Model

# FOPT: bubbles of the new phase expand and collide, producing GW

Credits: D. J. Weir

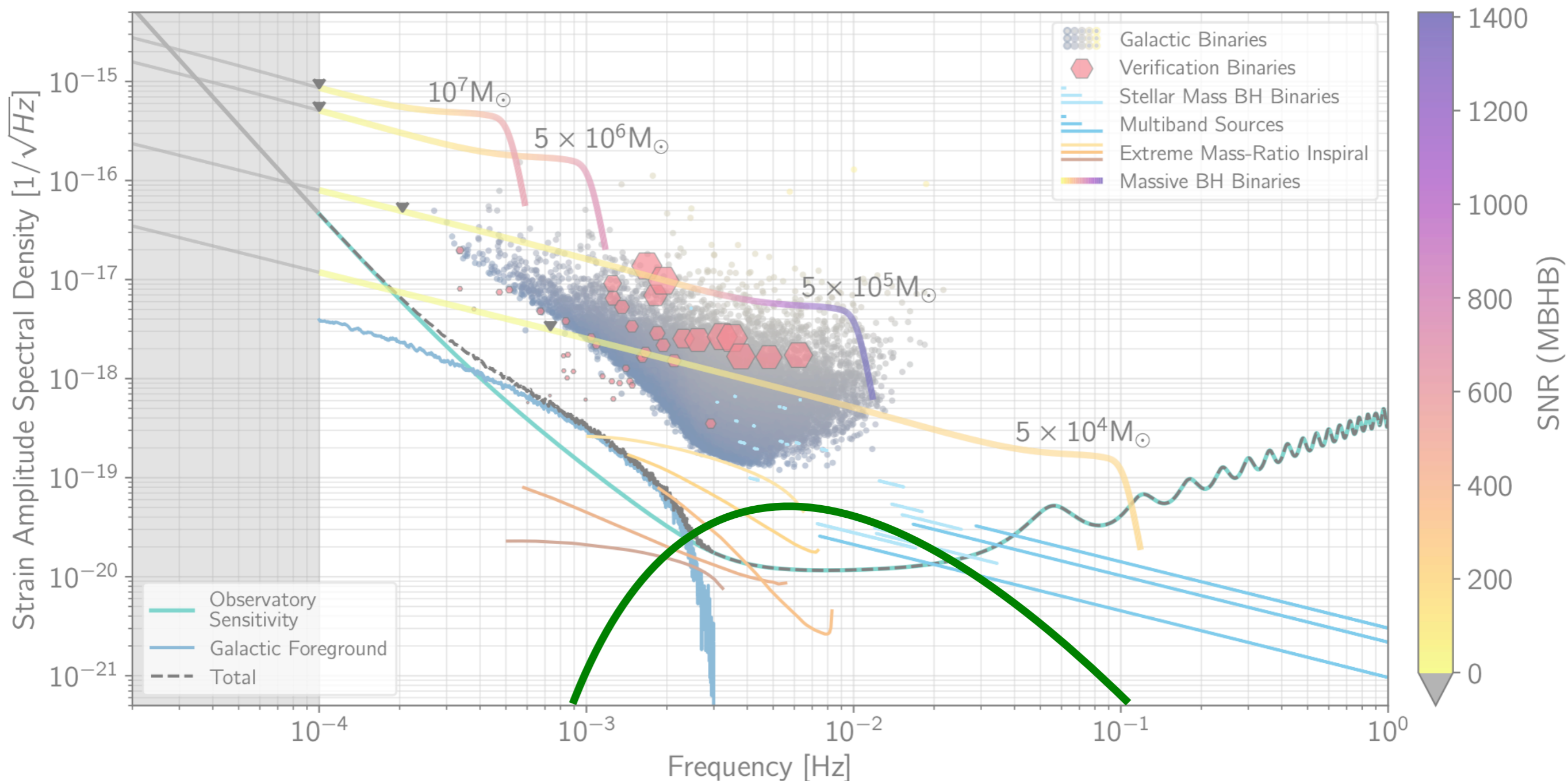


# Measuring a SGWB coming from a phase transition will be difficult



arXiv: 2402.07571

# Measuring a SGWB coming from a phase transition will be difficult



arXiv: 2402.07571

*(sketch, not a real model)*

# Going from a particle physics model to a LISA sensitivity prediction is difficult

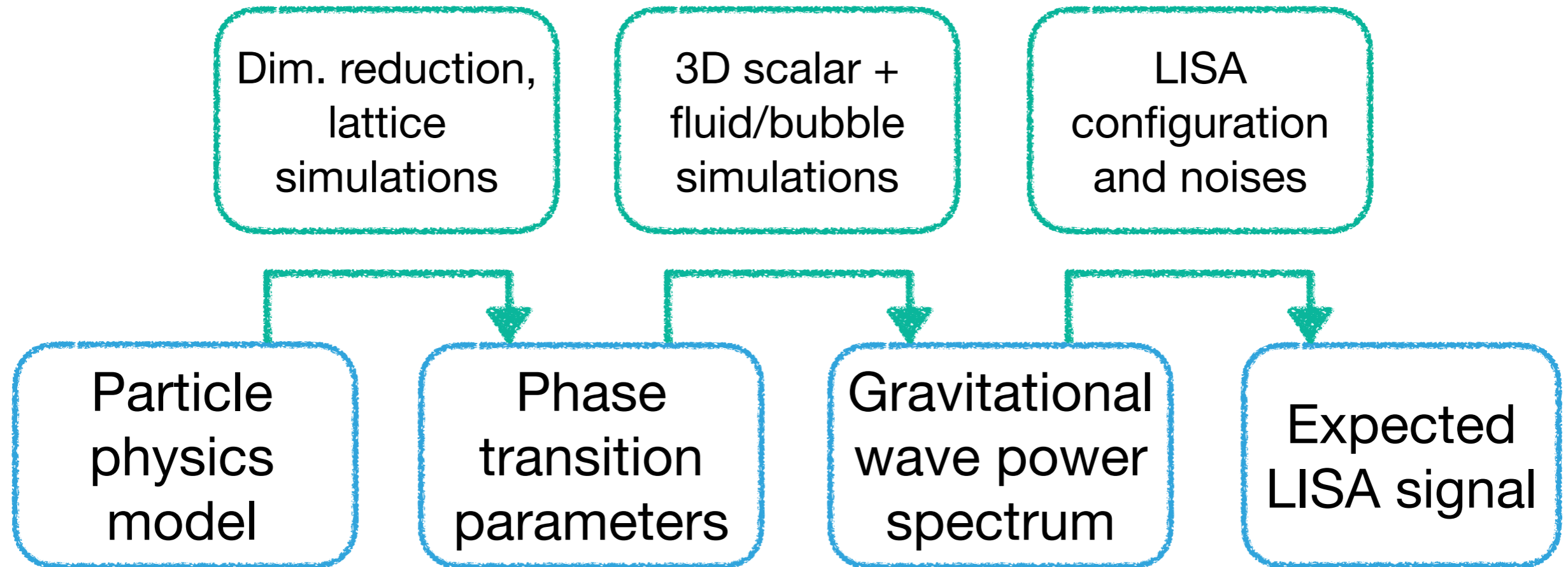
Particle  
physics  
model

Phase  
transition  
parameters

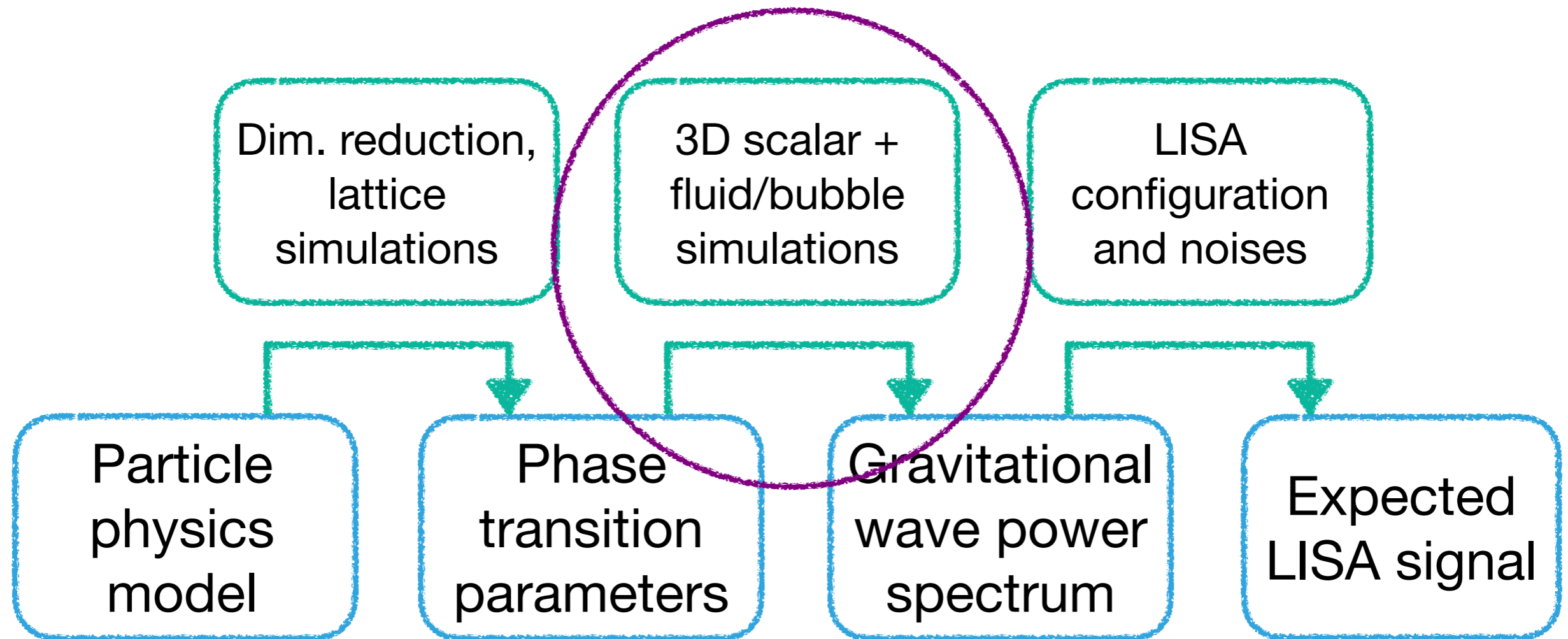
Gravitational  
wave power  
spectrum

Expected  
LISA signal

# Going from a particle physics model to a LISA sensitivity prediction is difficult



# Going from a particle physics model to a LISA sensitivity prediction is difficult



# Different levels of approximation: trade-off in precision and computational time

Run full fluid simulations

Use theoretical framework for acoustic waves: Sound Shell Model\* (PTtools)

Use analytical fits based on bubble simulations (PTPlot)

Describe GW spectra as a broken or double broken power law

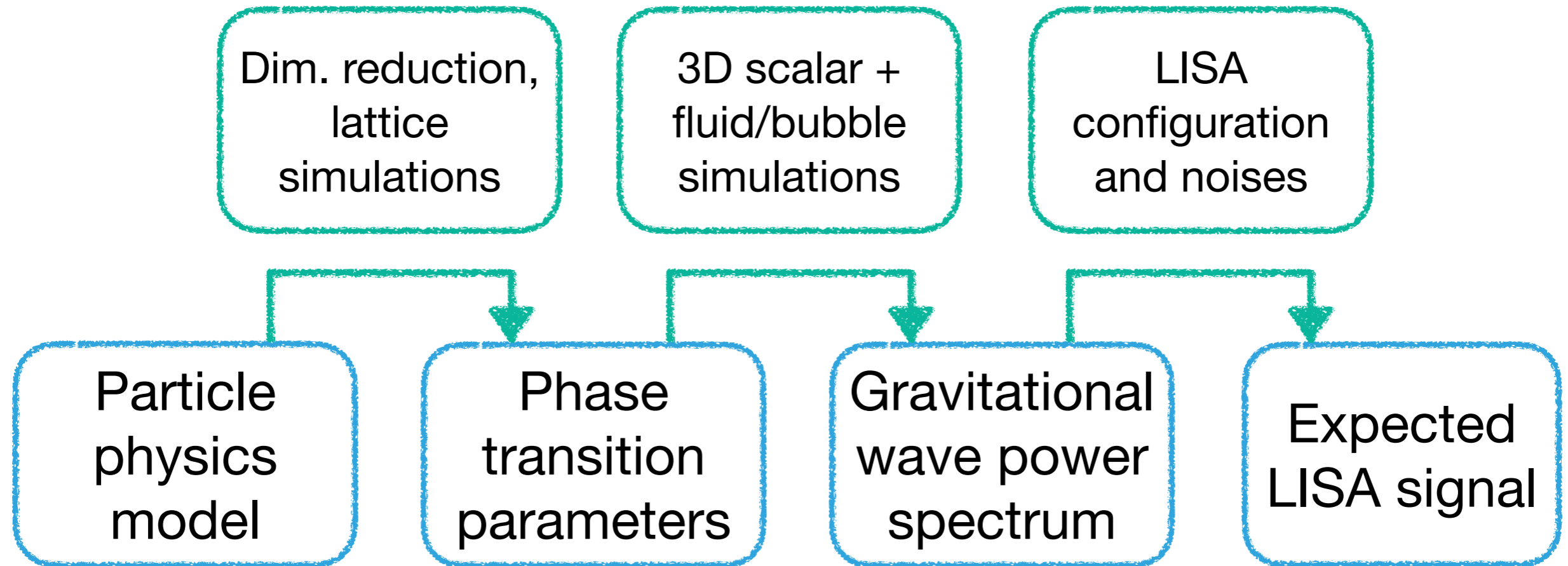
More  
precise



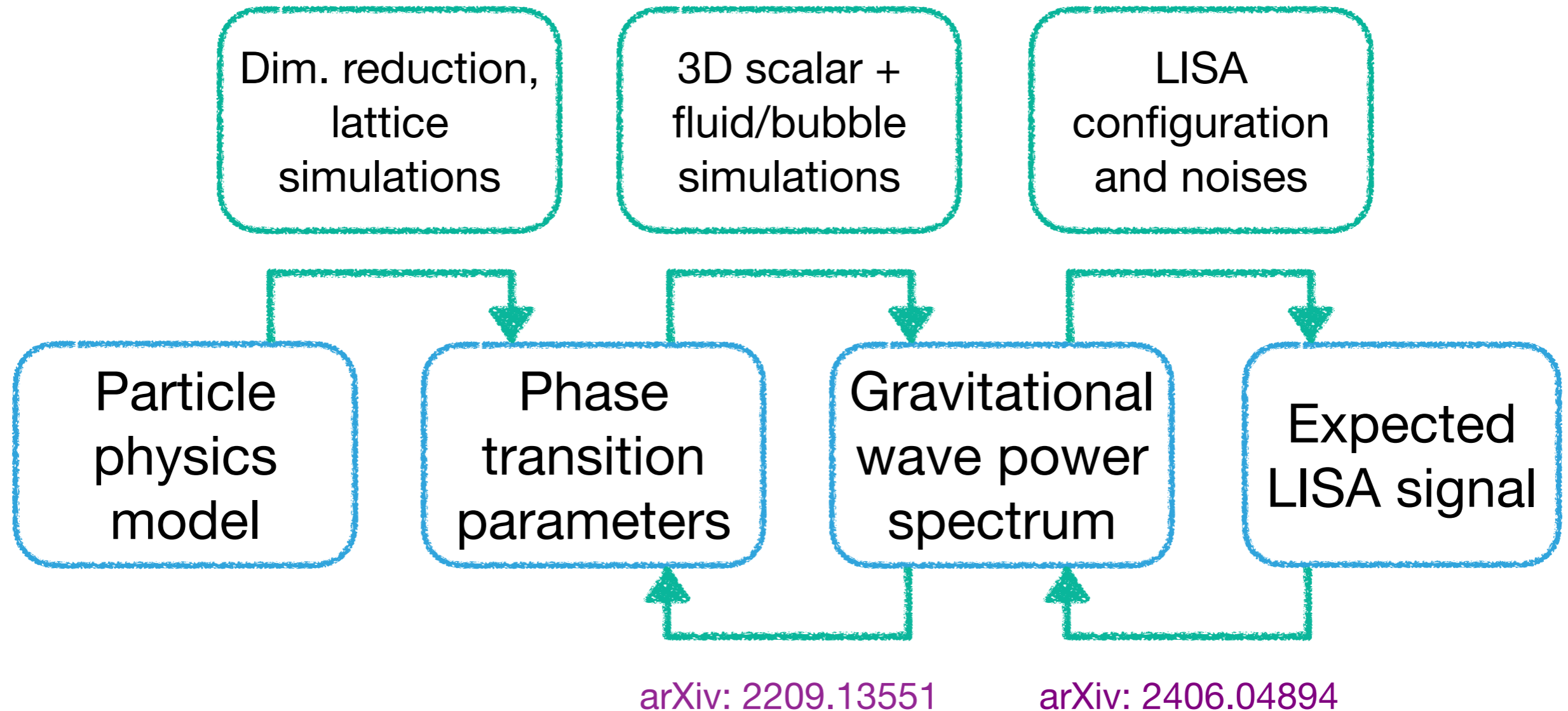
Quicker

\*arXiv: 1608.04735, 1909.10040

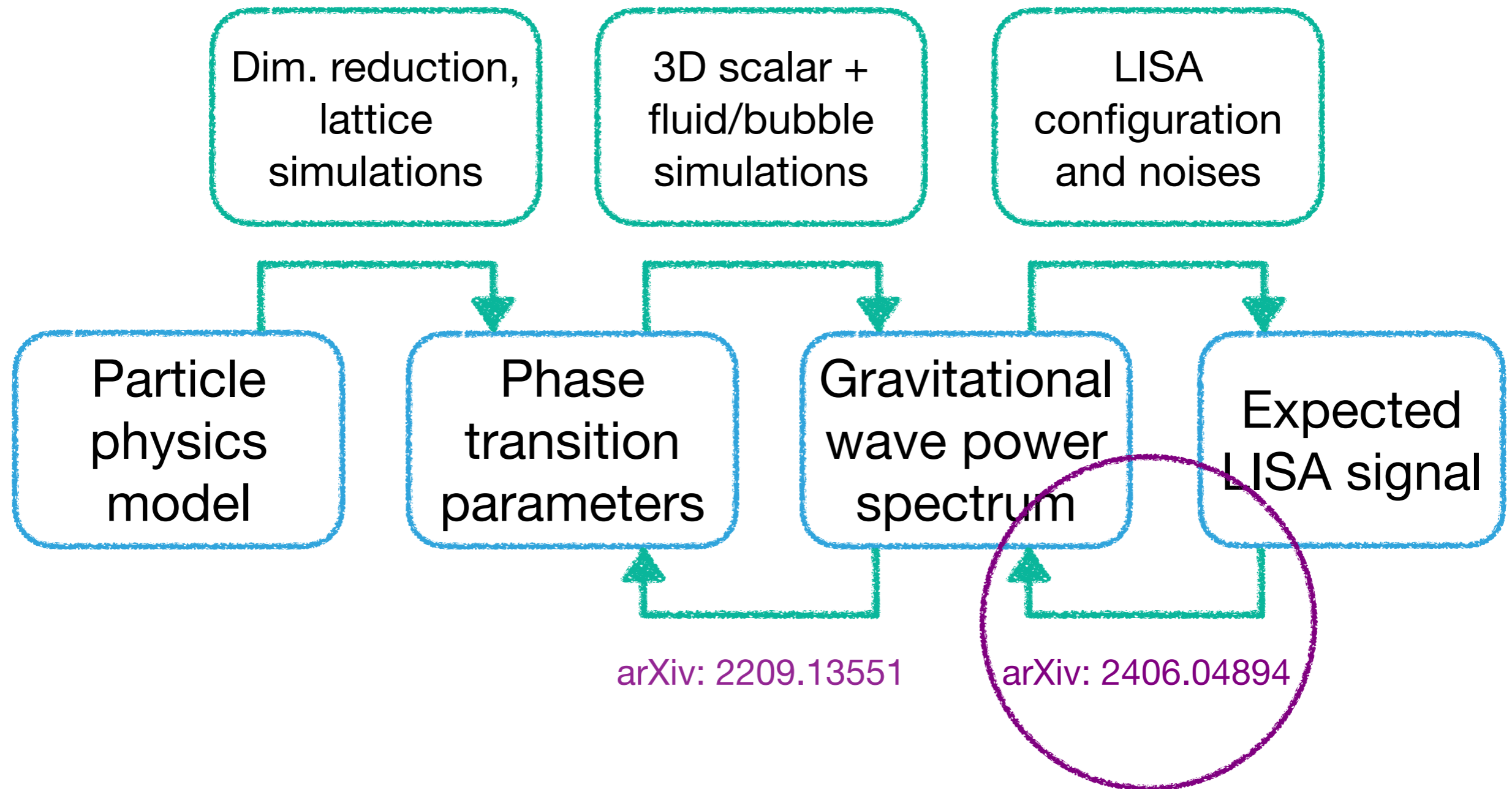
# We can go from a particle physics model to an SNR; we want to invert the process



# We can go from a particle physics model to an SNR; we want to invert the process



# We can go from a particle physics model to an SNR; we want to invert the process



# From LISA to GW spectra: make data with injected signals, analyse data, recover signals

1. Produce mock LISA data using the LISA Simulation suite



# From LISA to GW spectra: make data with injected signals, analyse data, recover signals

1. Produce mock LISA data using the LISA Simulation suite



2. Process the data: converting from time domain to frequency space, welching and windowing, ...

# From LISA to GW spectra: make data with injected signals, analyse data, recover signals

1. Produce mock LISA data using the LISA Simulation suite



2. Process the data: converting from time domain to frequency space, welching and windowing, ...

3. Run Markov Chain Monte Carlo analyses on the data to recover the injected signals

COBAYA

# From LISA to GW spectra: make data with injected signals, analyse data, recover signals

1. Produce mock LISA data using the LISA Simulation suite



2. Process the data: converting from time domain to frequency space, welching and windowing, ...

3. Run Markov Chain Monte Carlo analyses on the data to recover the injected signals

COBAYA

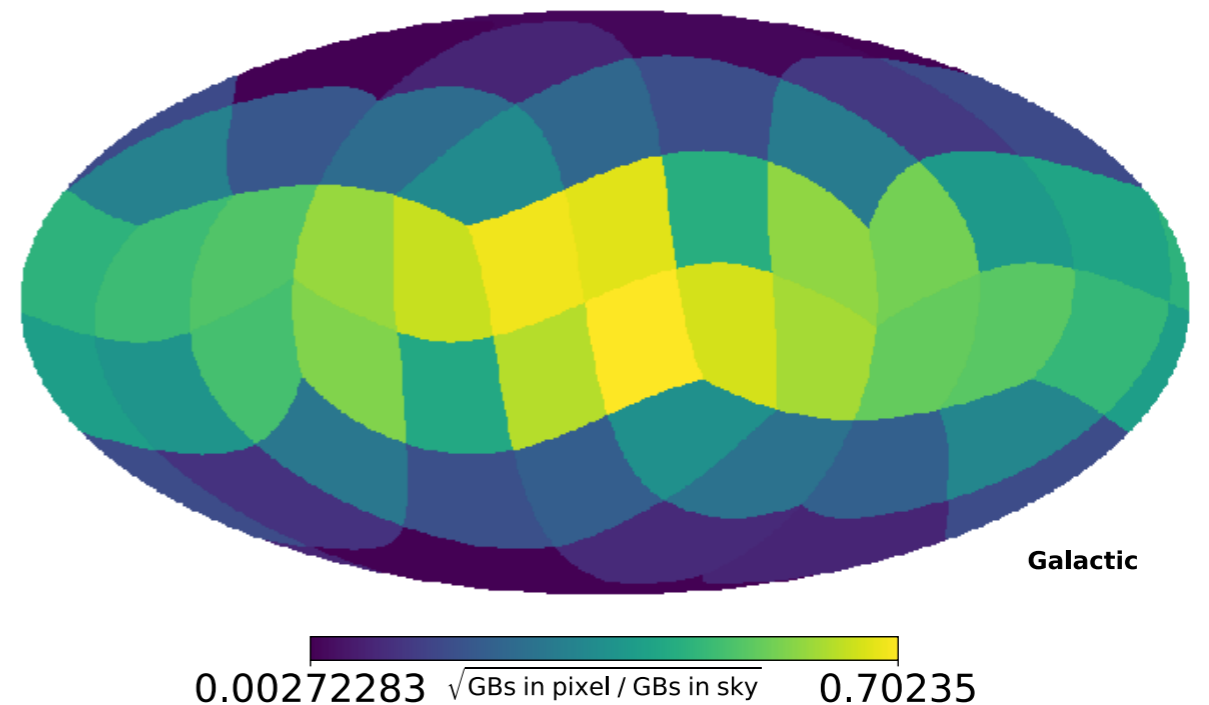
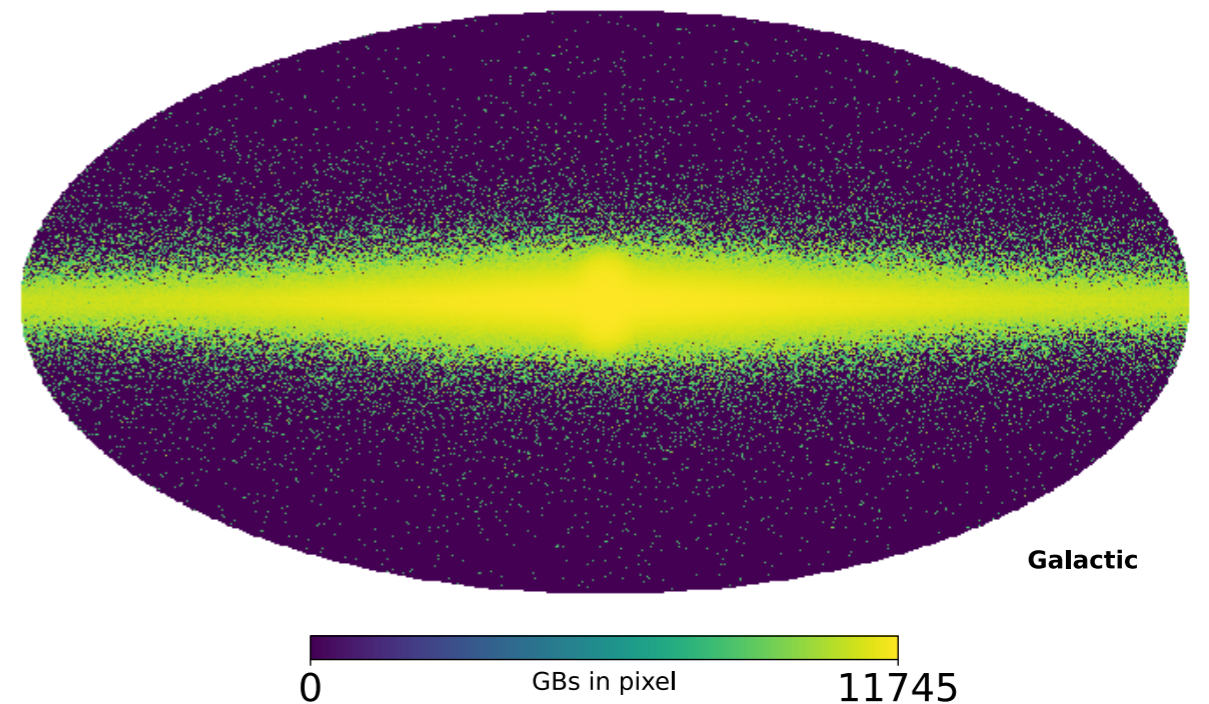
4. What PTs can we recover? What can we do to improve this? Statistical analyses

$\Delta$ DIC

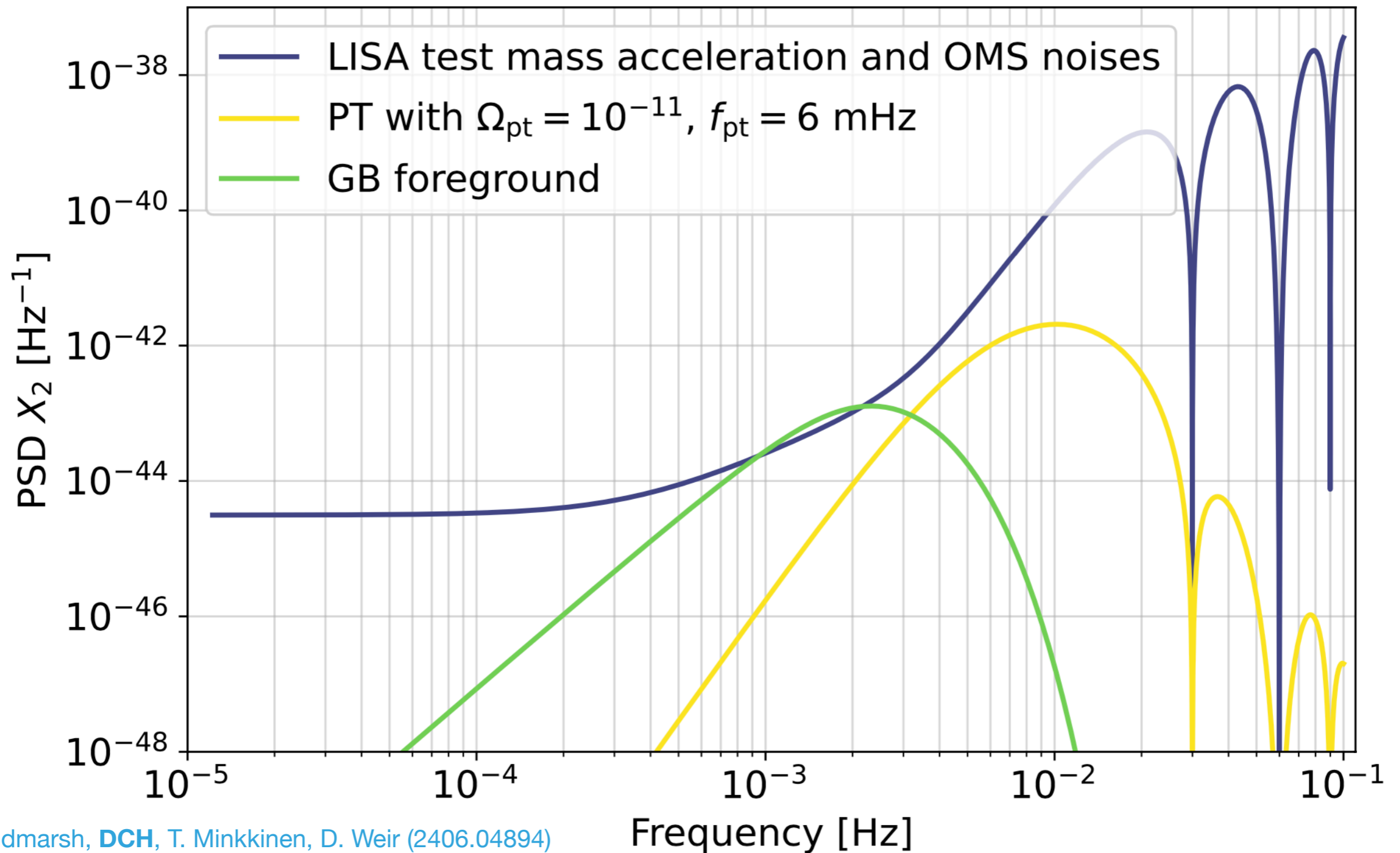
# Our mock data includes instrument noise, galactic binaries and PT signal

Our data includes:

- Instrument noise
- PT signal (modelled as a broken power law)
- Confusion noise from galactic white dwarf binaries (via a sky map)



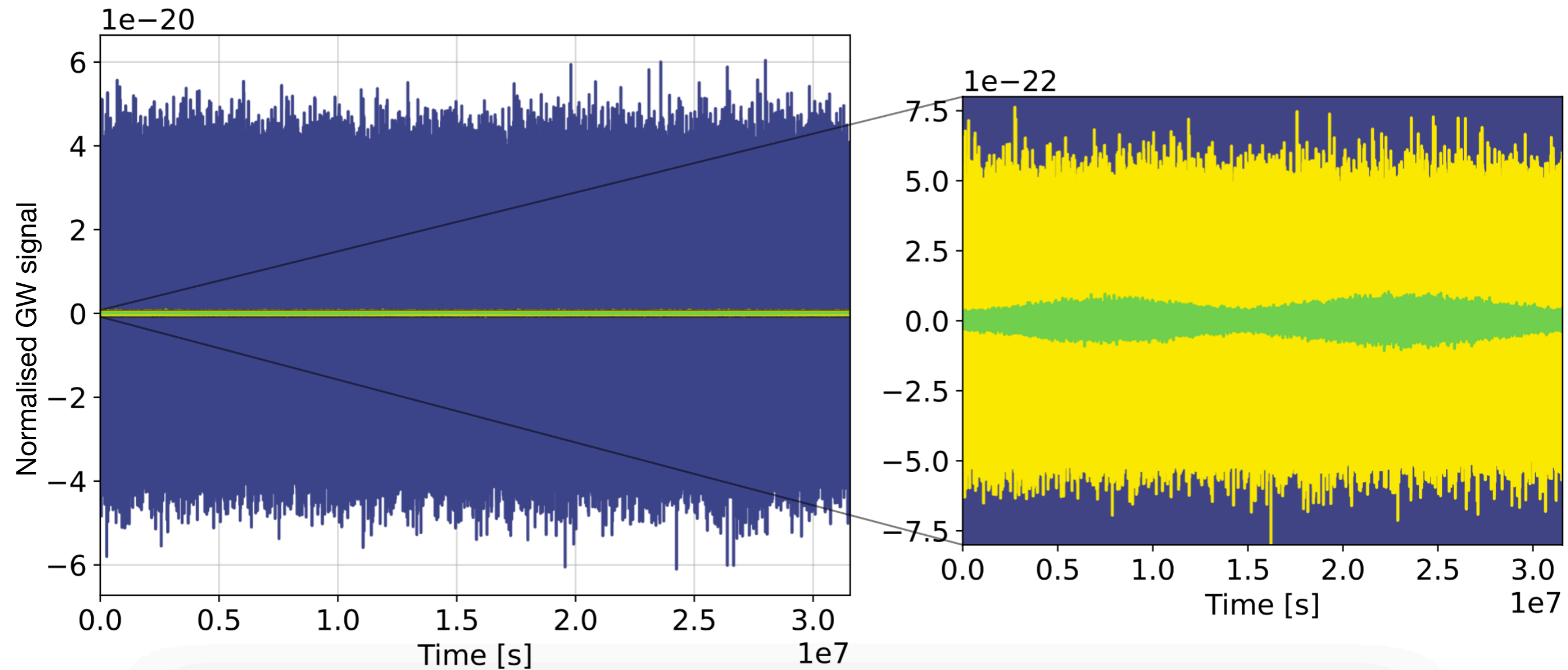
# Depending on amplitude and frequency, the PT signal might be detectable



M. Hindmarsh, DCH, T. Minkinen, D. Weir (2406.04894)

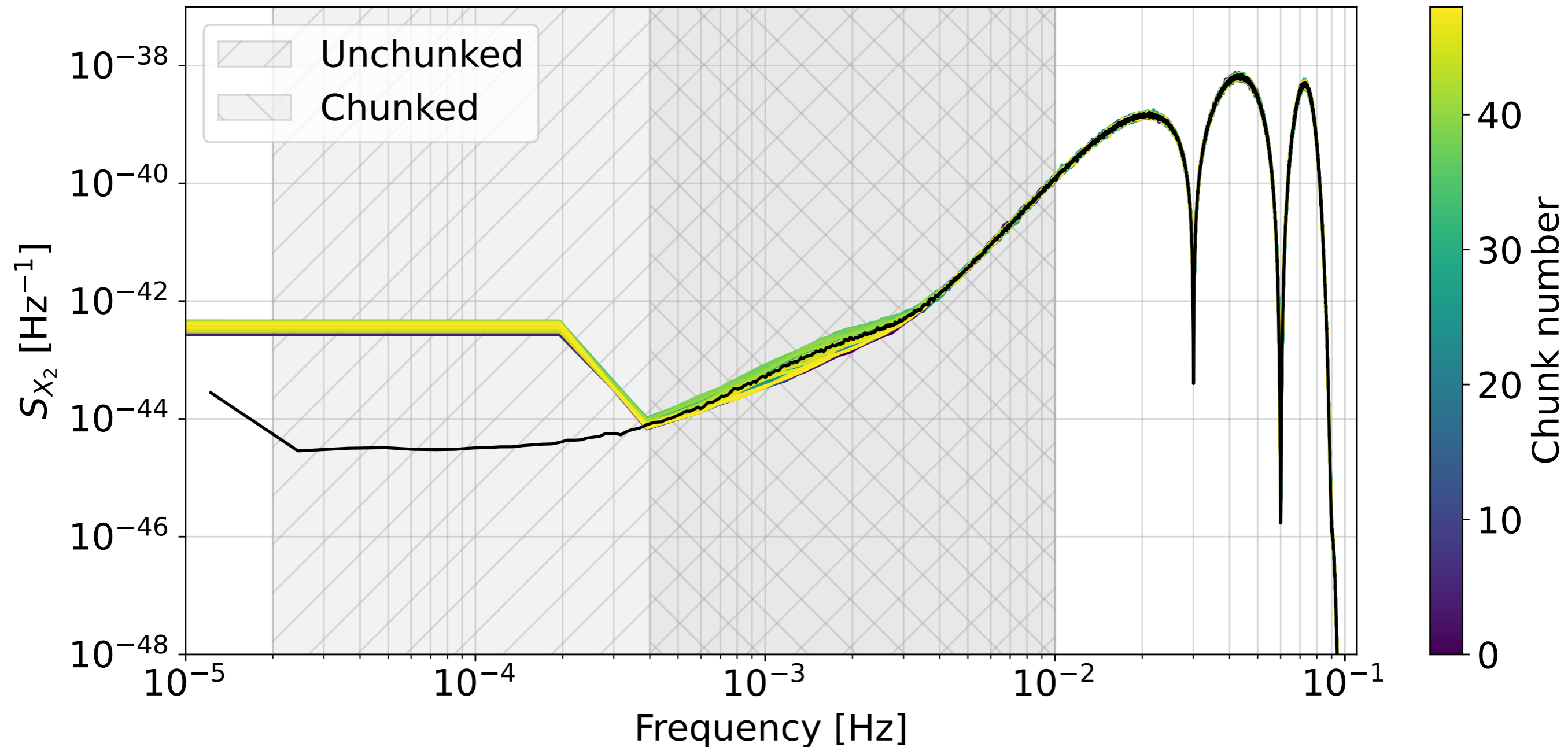
Frequency [Hz]

# Some of the astrophysical signals will be modulated, we can exploit this



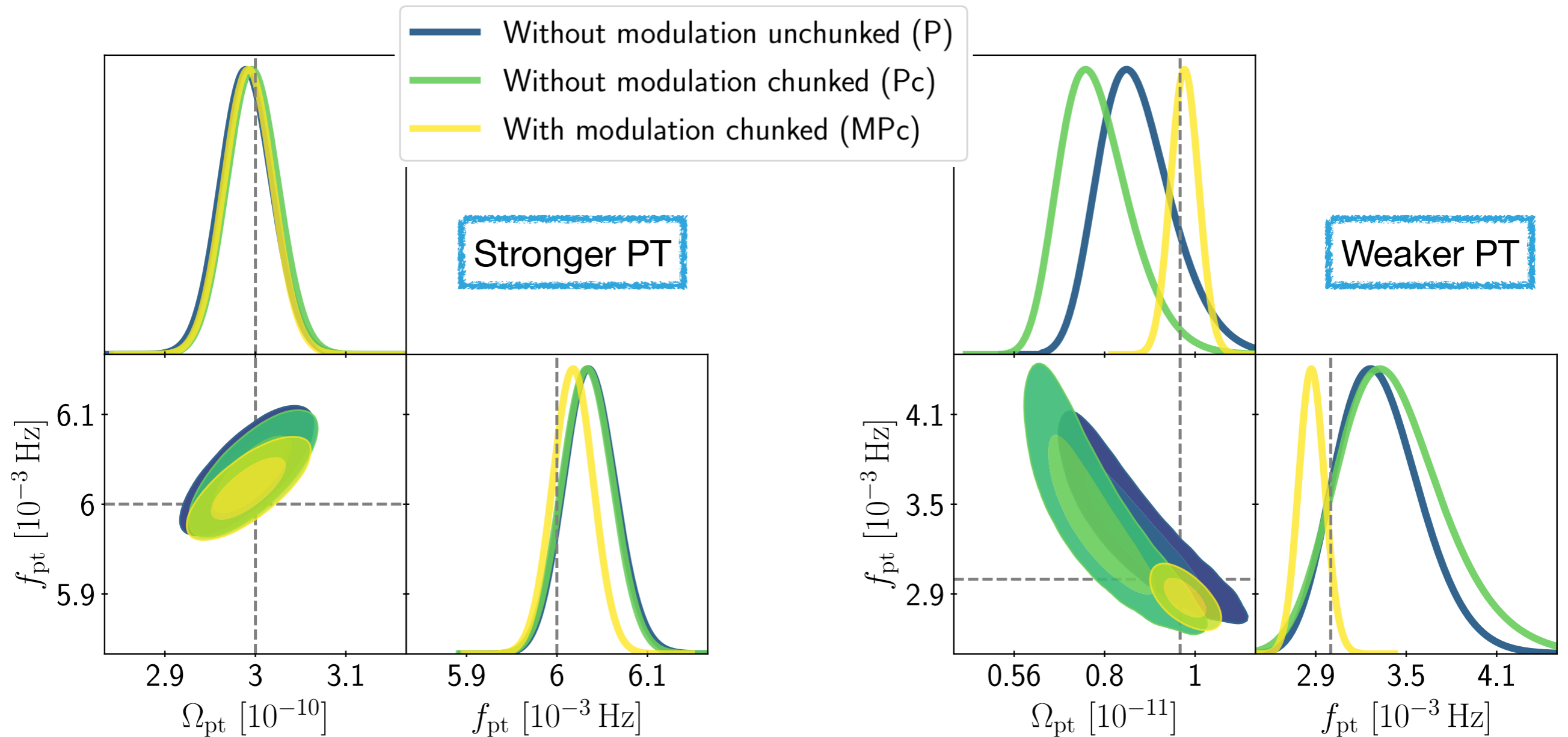
M. Hindmarsh, [DCH](#), T. Minkkinen, D. Weir (2406.04894)

# To account for the annual modulation, we divide our simulated data into chunks



M. Hindmarsh, [DCH](#), T. Minkkinen, D. Weir (2406.04894)

# We run MCMCs to see if we can recover the injected PT parameters

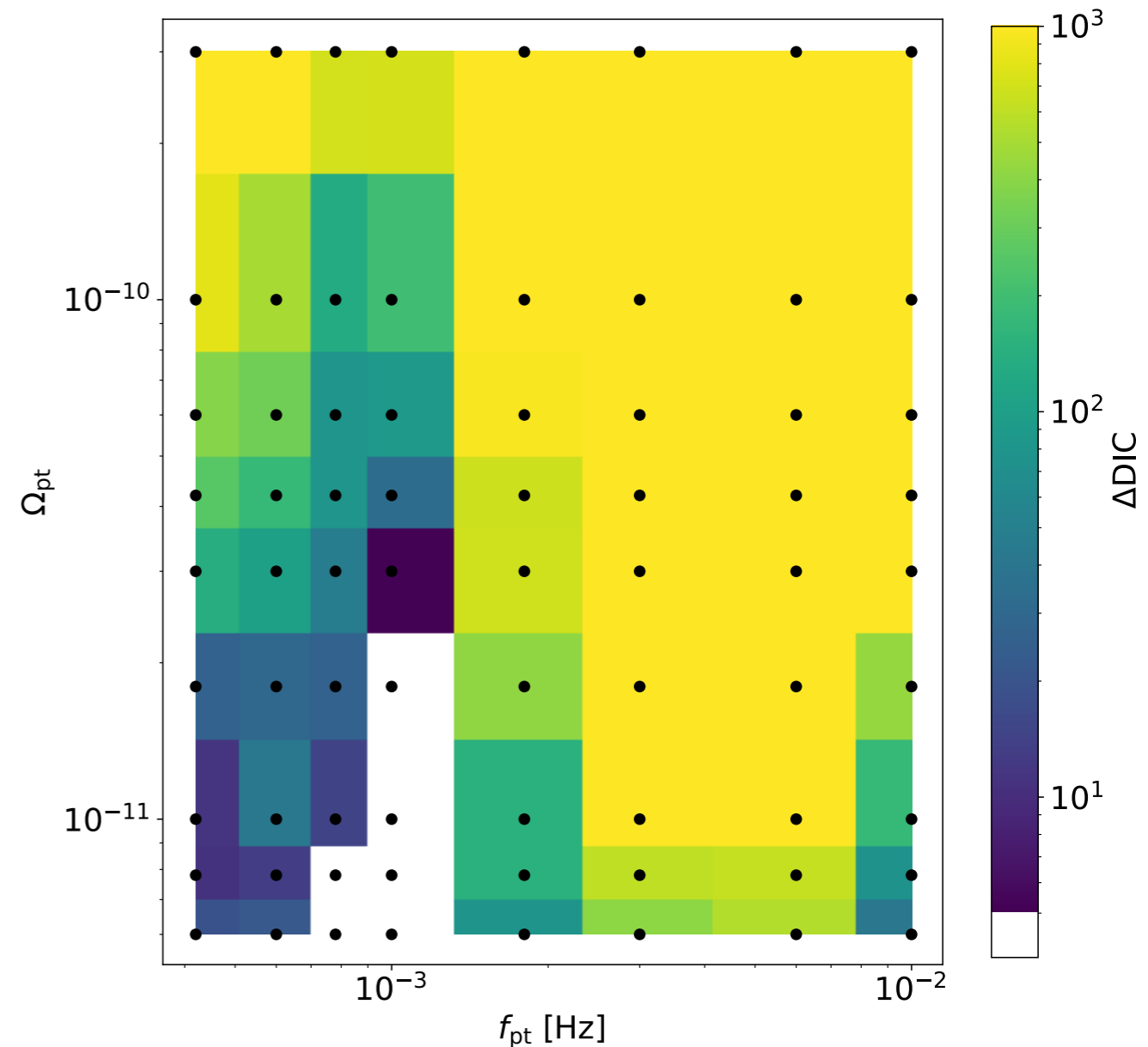
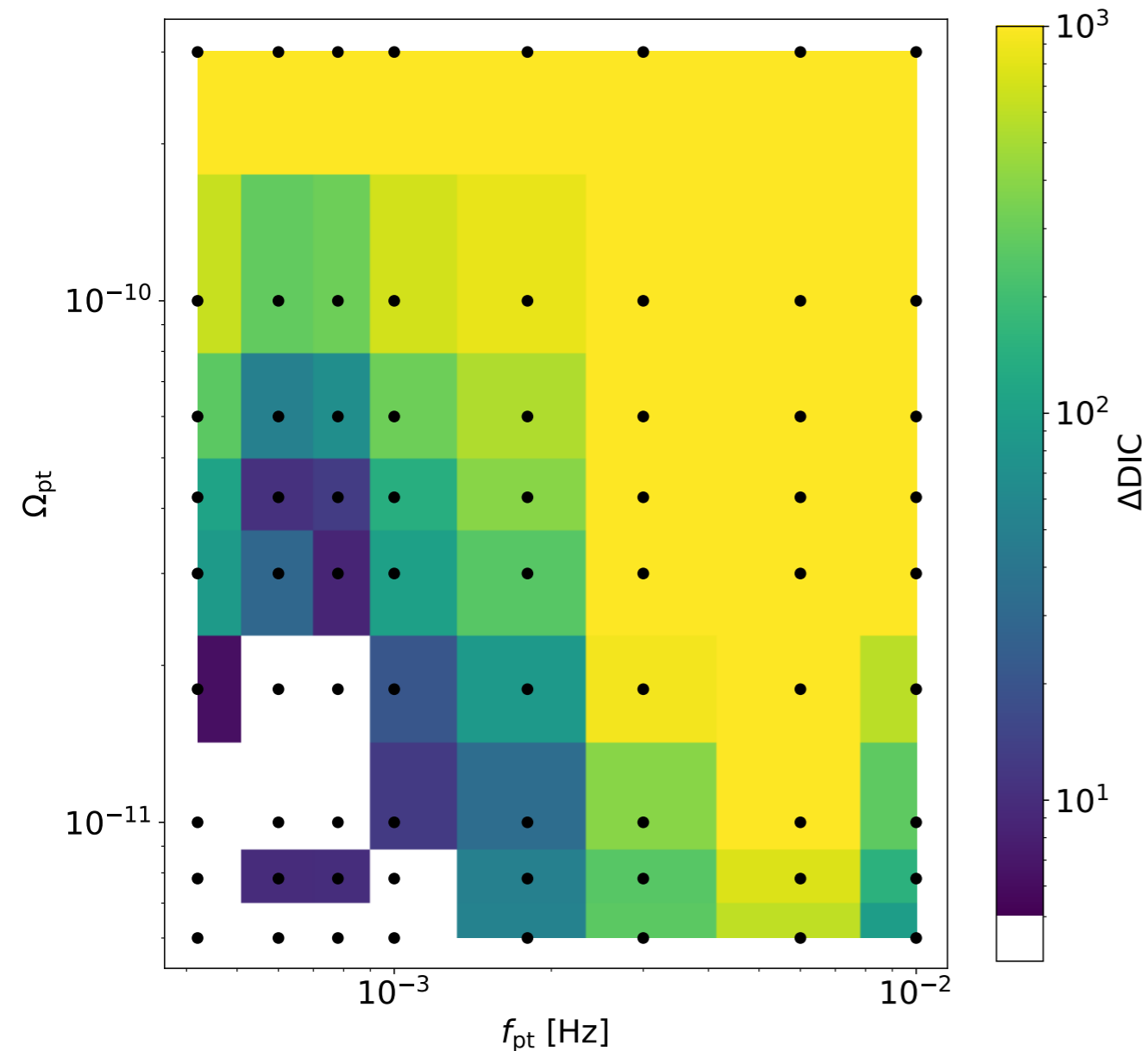


+2 *params* for instrument noise, +3 *params* for white dwarf binaries, +4 *parameters* for annual modulation

# How strong does a PT signal need to be in LISA so that we can recover it?

Without annual modulation

With annual modulation

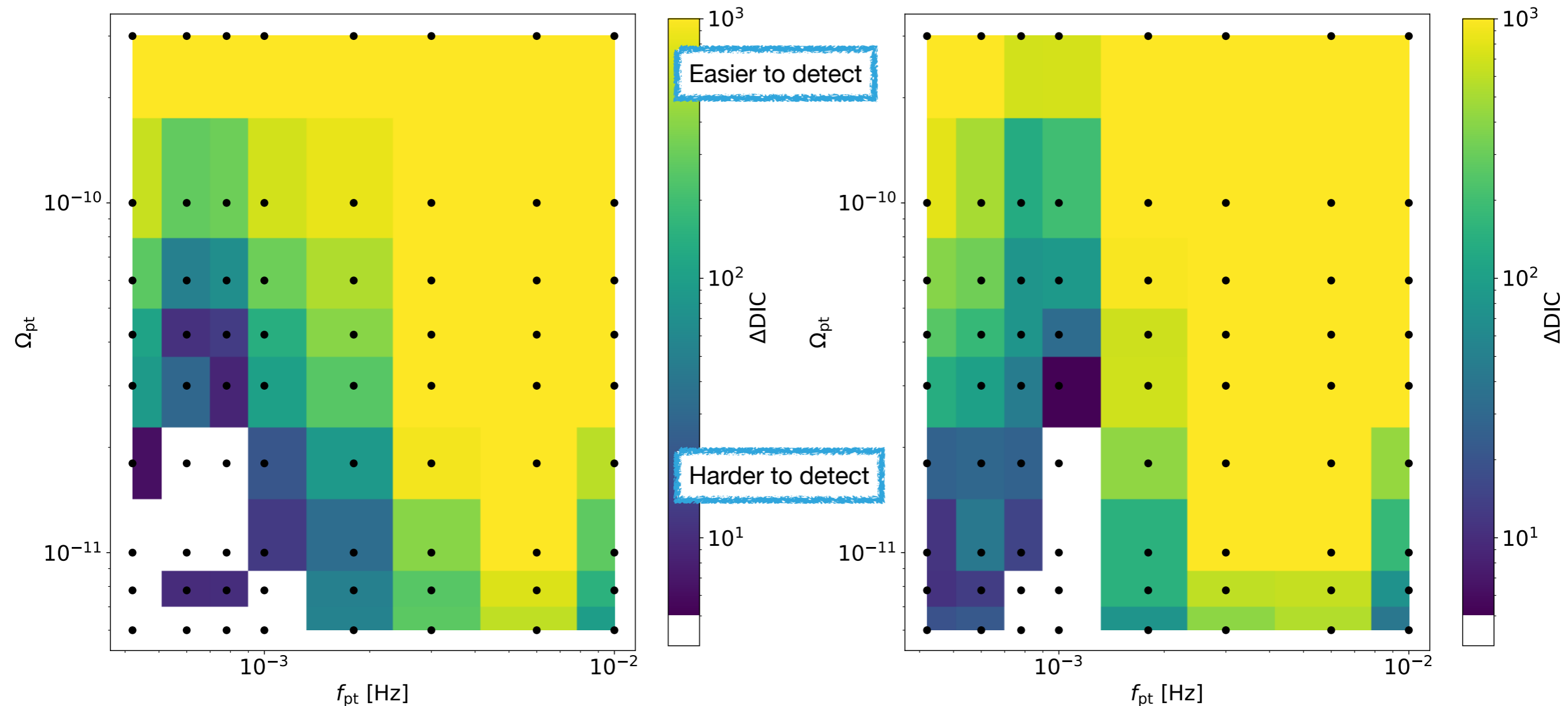


M. Hindmarsh, DCH, T. Minkinen, D. Weir (2406.04894)

# How strong does a PT signal need to be in LISA so that we can recover it?

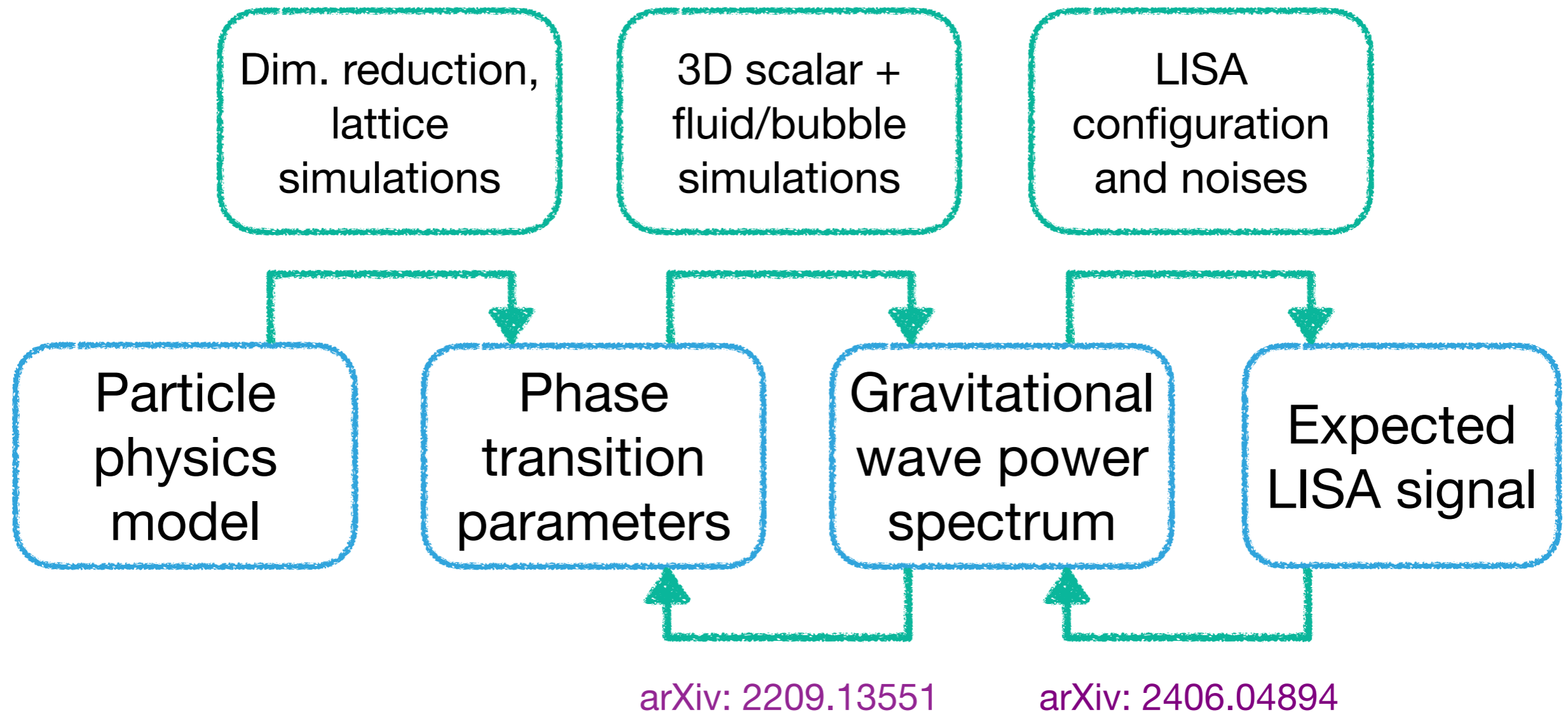
Without annual modulation

With annual modulation

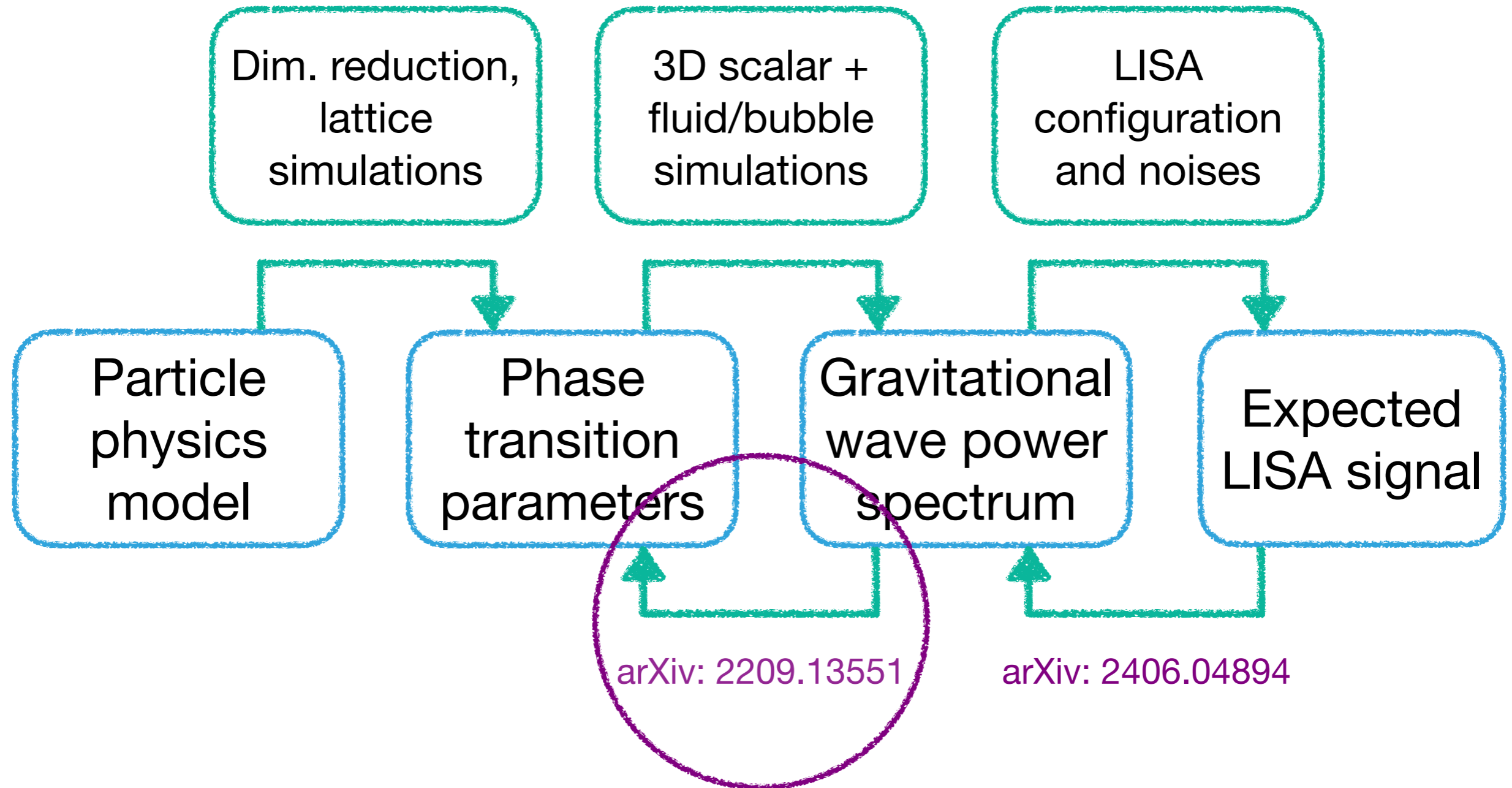


M. Hindmarsh, DCH, T. Minkinen, D. Weir (2406.04894)

# We can get GW parameters from LISA. Can we get PT parameters from GW?



# We can get GW parameters from LISA. Can we get PT parameters from GW?



# From GW spectra to PT: make a spectral template, create mapping, compare methods

1. Approximate the GW power spectrum as a double broken power law (spectral parameters)

# From GW spectra to PT: make a spectral template, create mapping, compare methods

1. Approximate the GW power spectrum as a double broken power law (spectral parameters)

2. Create a mapping between the PT parameters and the spectral parameters

# From GW spectra to PT: make a spectral template, create mapping, compare methods

1. Approximate the GW power spectrum as a double broken power law (spectral parameters)

2. Create a mapping between the PT parameters and the spectral parameters

3. Run Markov Chain Monte Carlo on both sets of input parameters

COBAYA

# From GW spectra to PT: make a spectral template, create mapping, compare methods

1. Approximate the GW power spectrum as a double broken power law (spectral parameters)

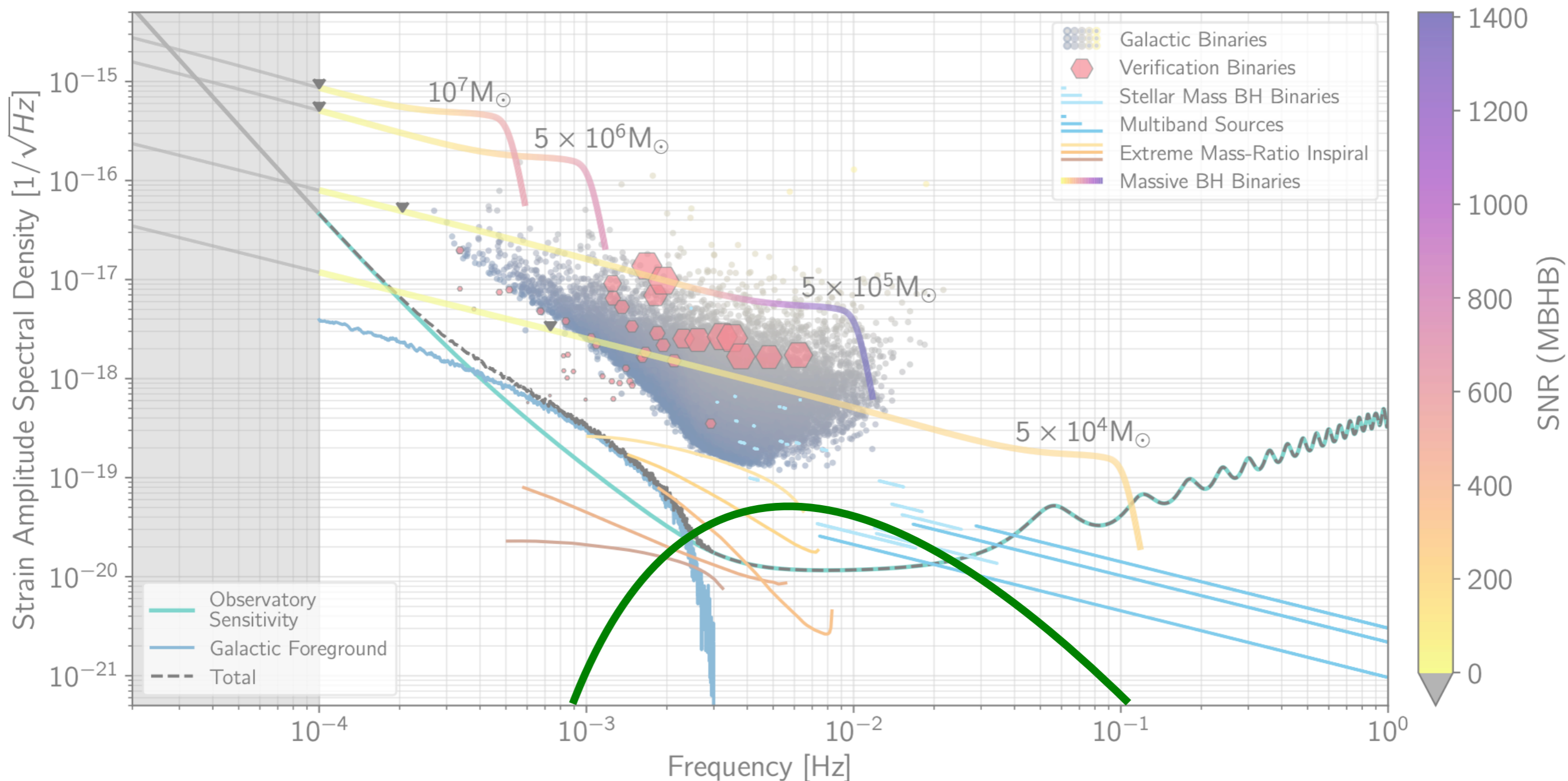
2. Create a mapping between the PT parameters and the spectral parameters

3. Run Markov Chain Monte Carlo on both sets of input parameters

COBAYA

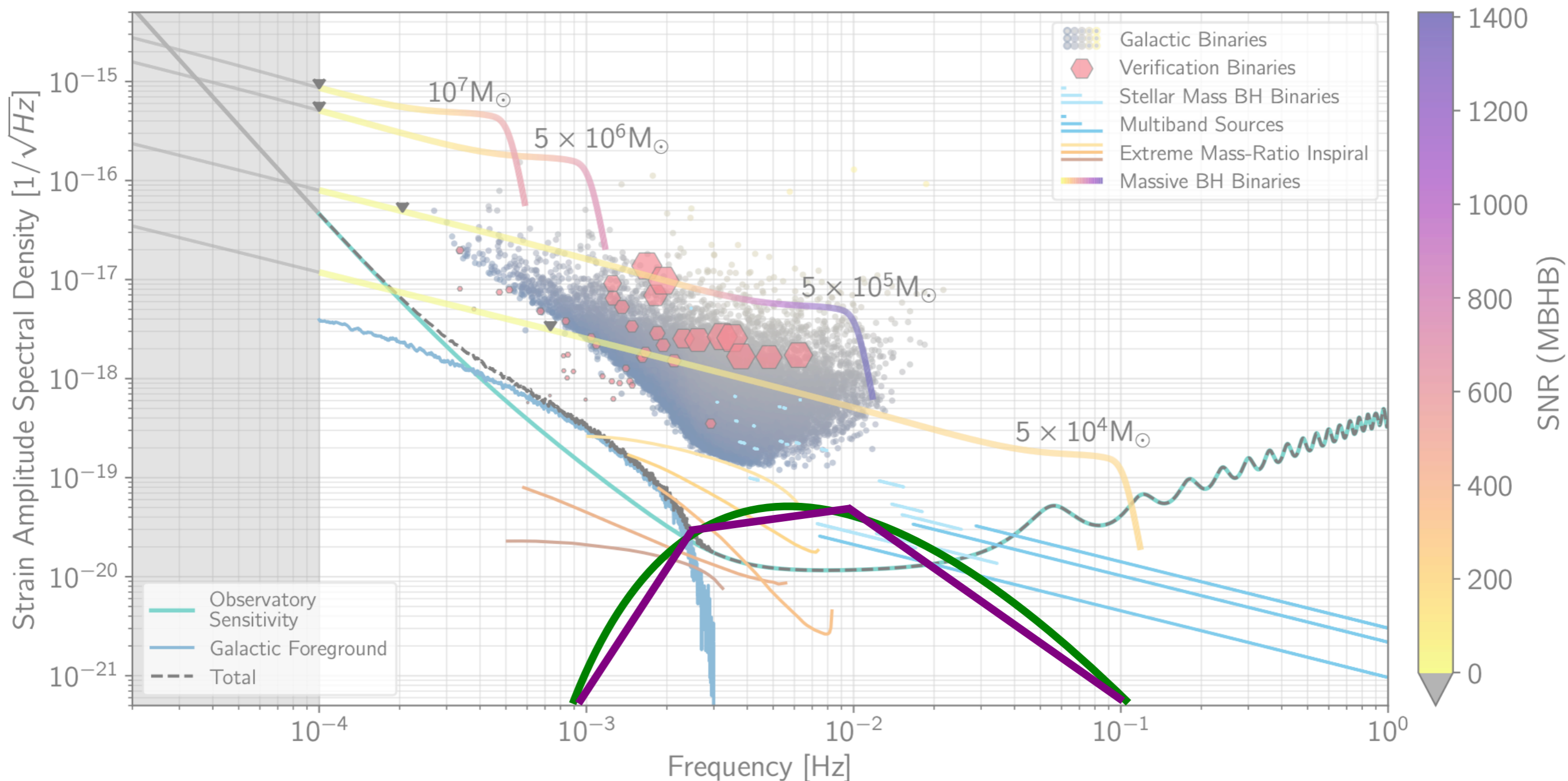
4. How do the two methods compare? Is the mapping precise enough?

# We want to recover the PT parameters from a double broken power law



arXiv: 2402.07571

# We want to recover the PT parameters from a double broken power law

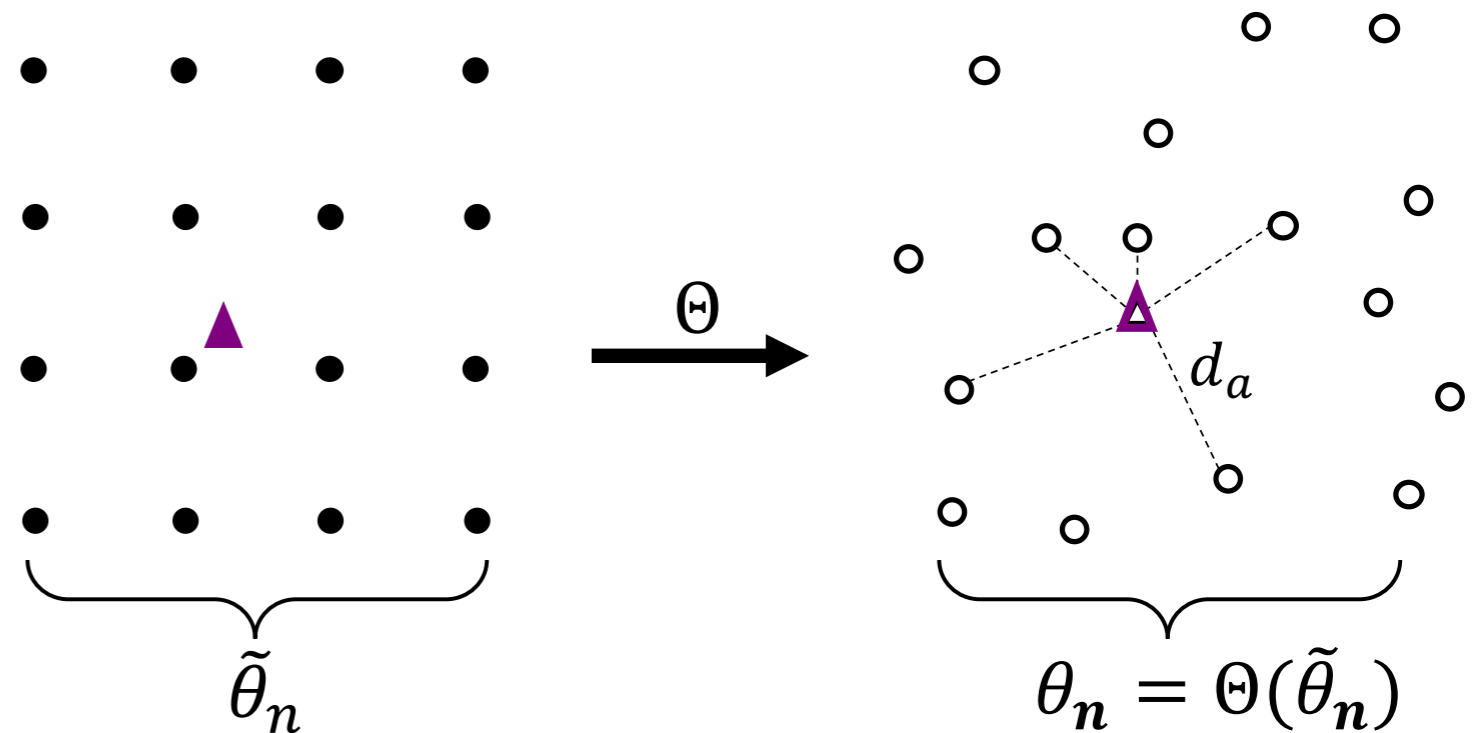


[arXiv: 2402.07571](https://arxiv.org/abs/2402.07571)

# Create a mapping between PT and spectral parameters - only needs to be done once!

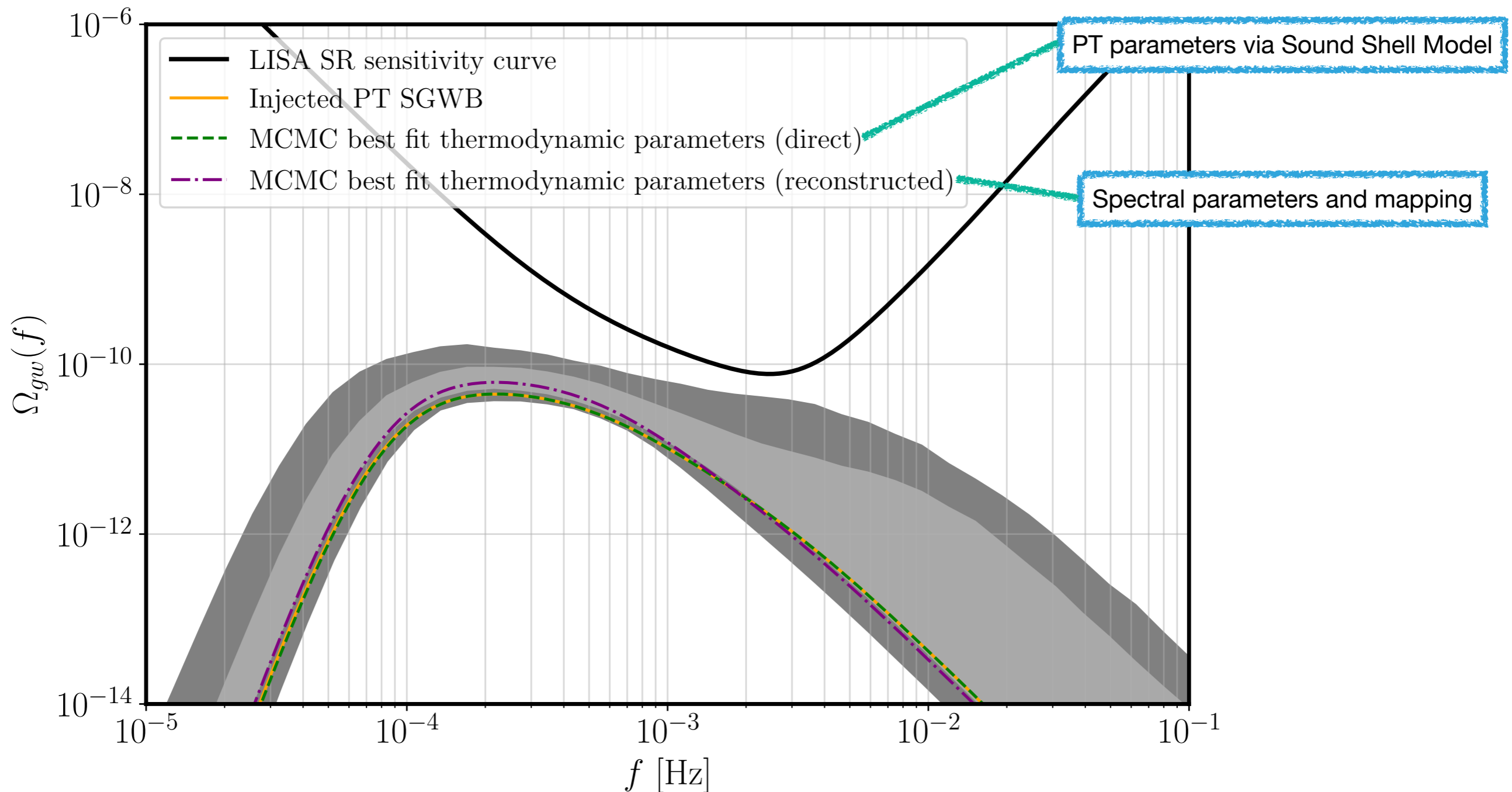
1. Build grid of PT parameters

2. Find corresponding spectral parameters



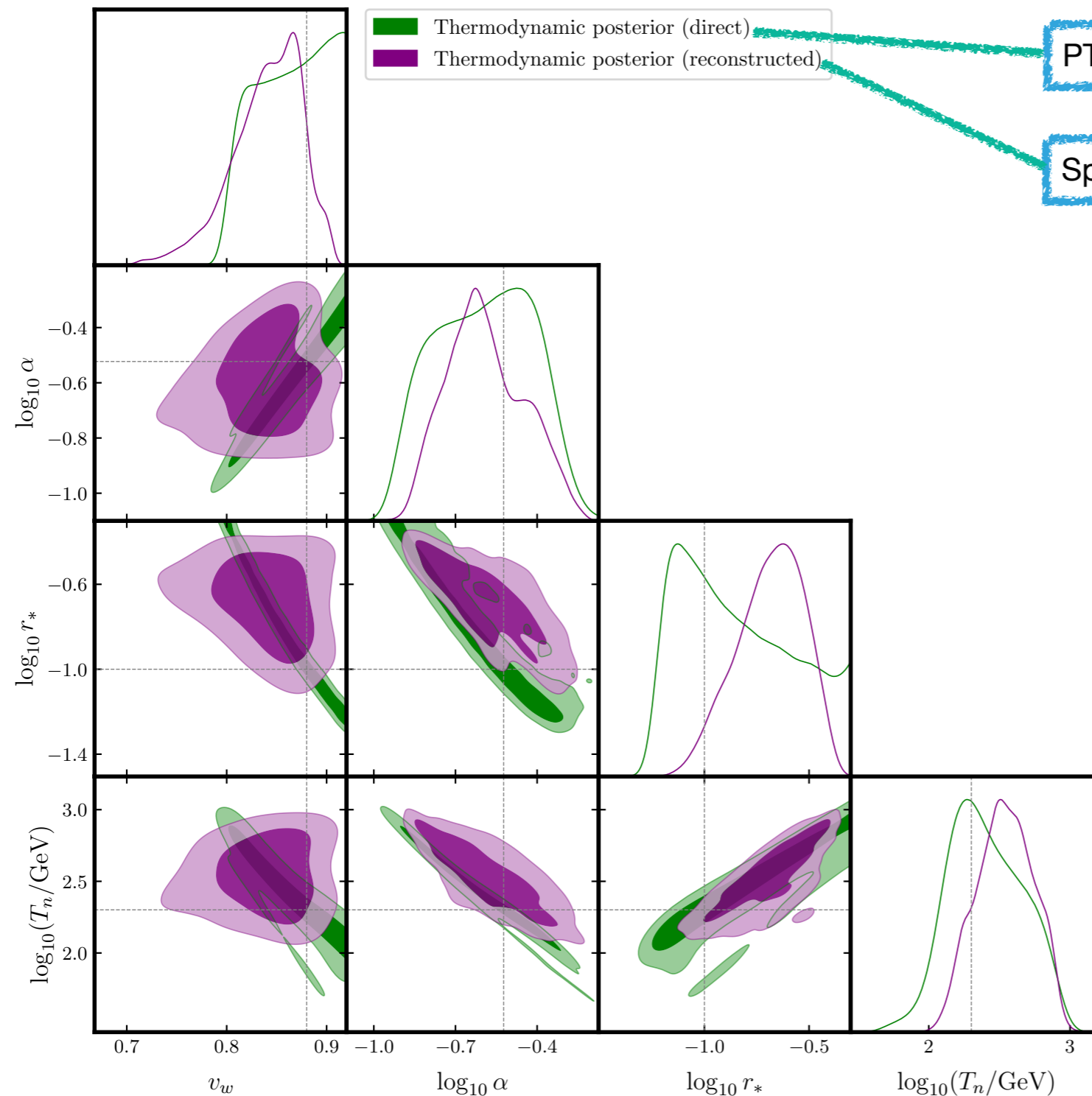
3. For a point in spectral parameter space, use nearest neighbours interpolation in spectral grid to reconstruct PT parameters

# Two approaches to MCMC: sample on PT or spectral parameters



C. Gowling, M. Hindmarsh, **DCH**, J. Torrado (2209.13551)

# Direct sampling and reconstruction give similar results, latter is $\mathcal{O}(10^3)$ faster



PT parameters via Sound Shell Model

Spectral parameters and mapping

$\alpha$  : Phase transition strength  
 $r_*$  : Hubble-scaled mean bubble spacing  
 $T_n$  : Bubble nucleation temperature  
 $v_w$  : Wall velocity

C. Gowling, M. Hindmarsh, DCH, J. Torrado (2209.13551)

# LISA will shed light on early universe phase transitions

## Summary

- We are looking for PT signals in mock LISA data
- By using the annual modulation of galactic binaries, we can recover weaker PT signals
- We can reconstruct PT parameters in strong signals using spectral templates
- Still a lot of assumptions in our modelling
- How can we make our predictions more realistic?

# Thanks for listening!

*Get in touch!*

*Email: [deanna.hooper@helsinki.fi](mailto:deanna.hooper@helsinki.fi)*