Reconstructing phase transitions from future LISA data

Deanna C. Hooper

(they/them)

Mostly based on 2209.13551

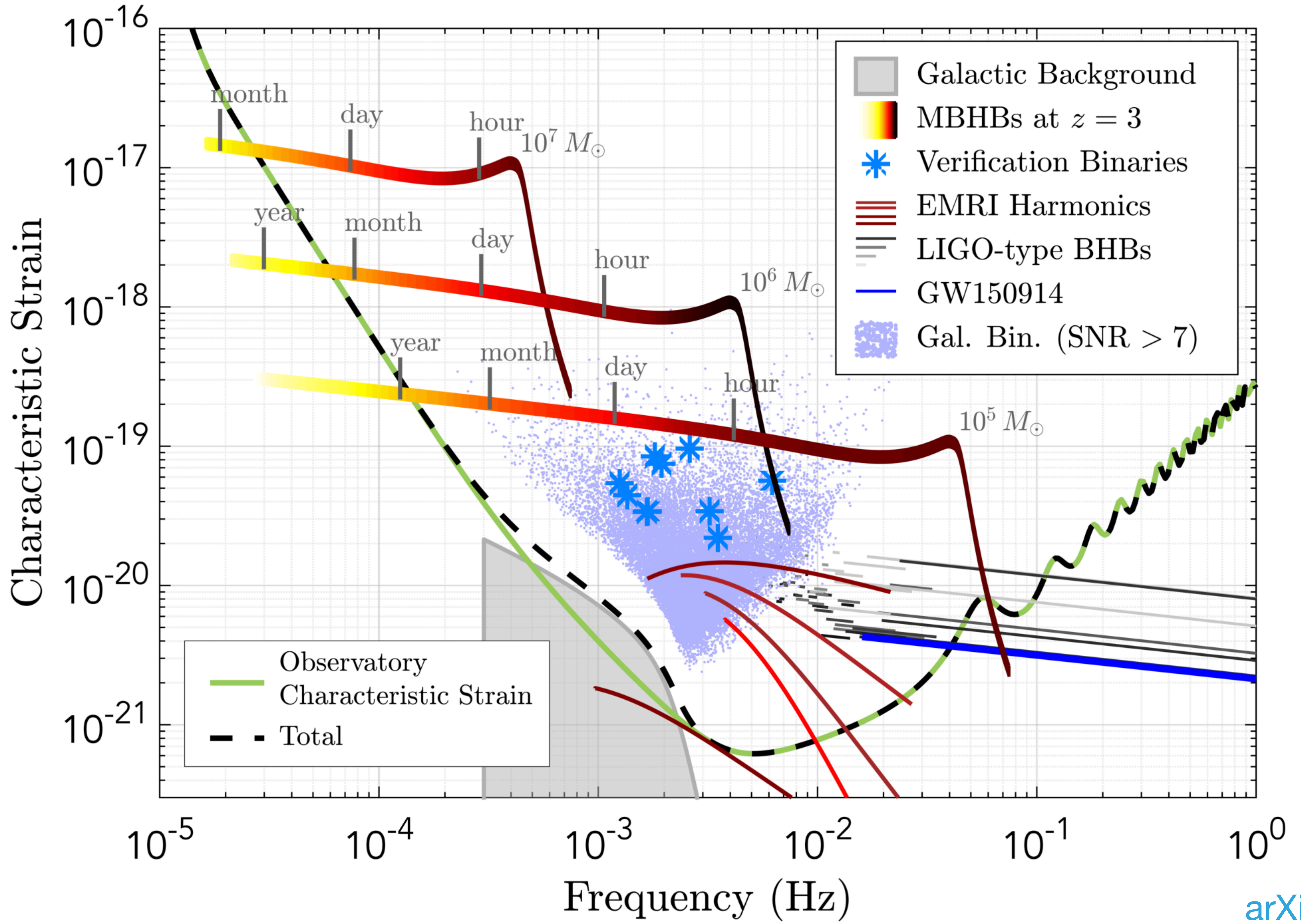
LISA CosWG Workshop

7th June 2023

HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

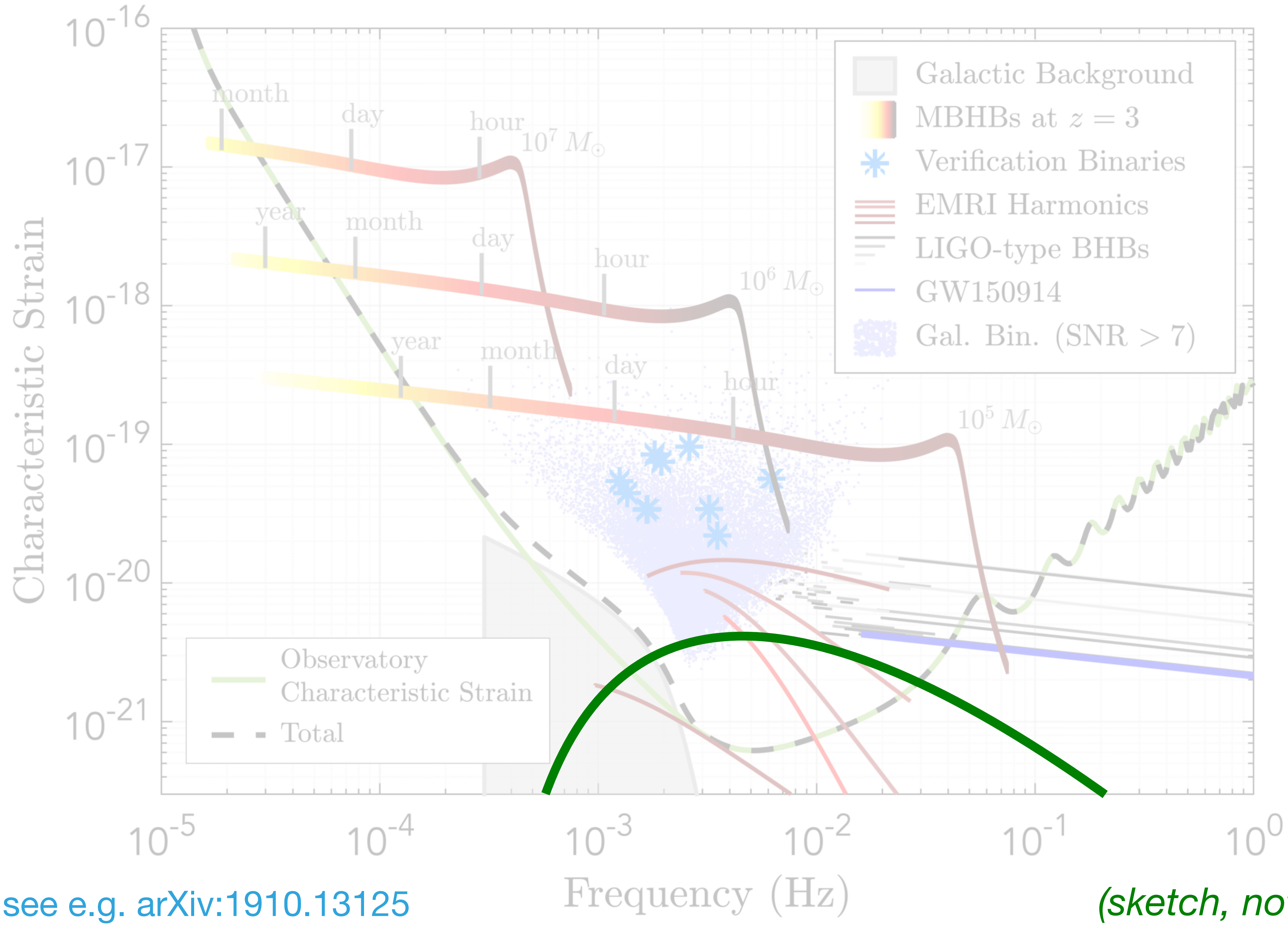
HELSINKI INSTITUTE OF PHYSICS

LISA will measure a lot of astrophysical sources of GW



arXiv:1702.00786

A stochastic GW background from a phase transition would be behind everything else



For a review, see e.g. arXiv:1910.13125

(sketch, not a real model)

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

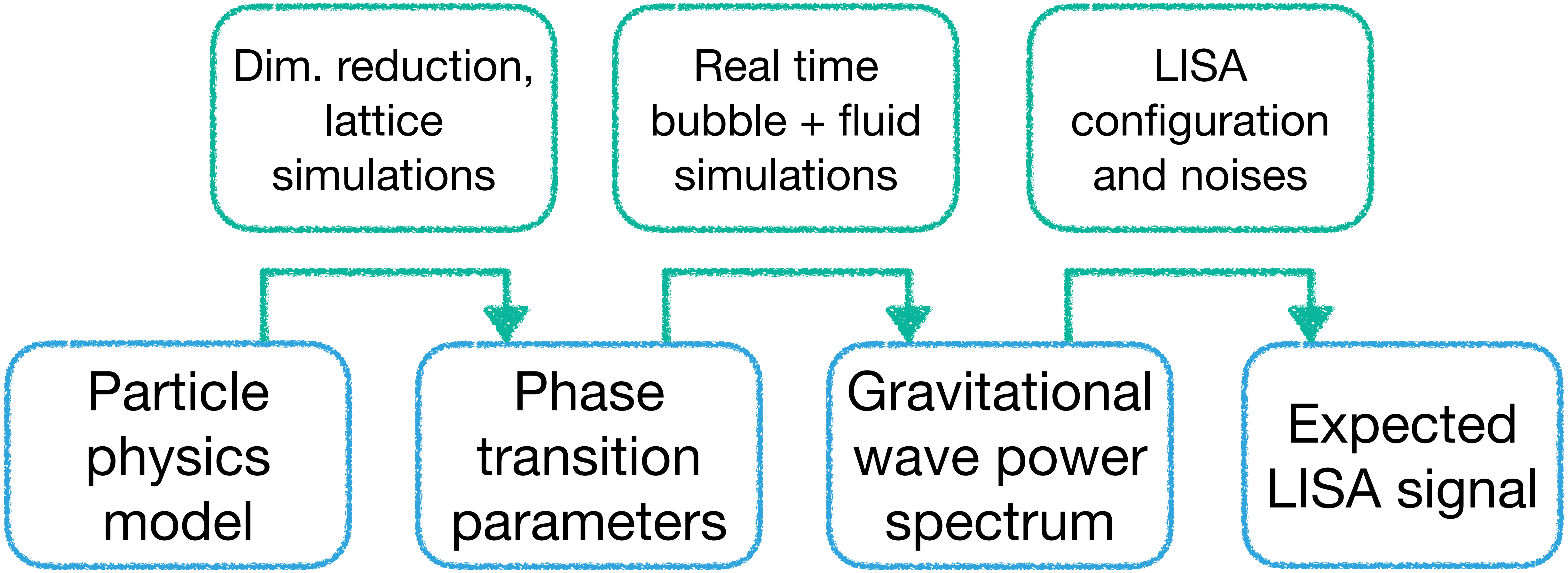
Particle physics model

Phase transition parameters

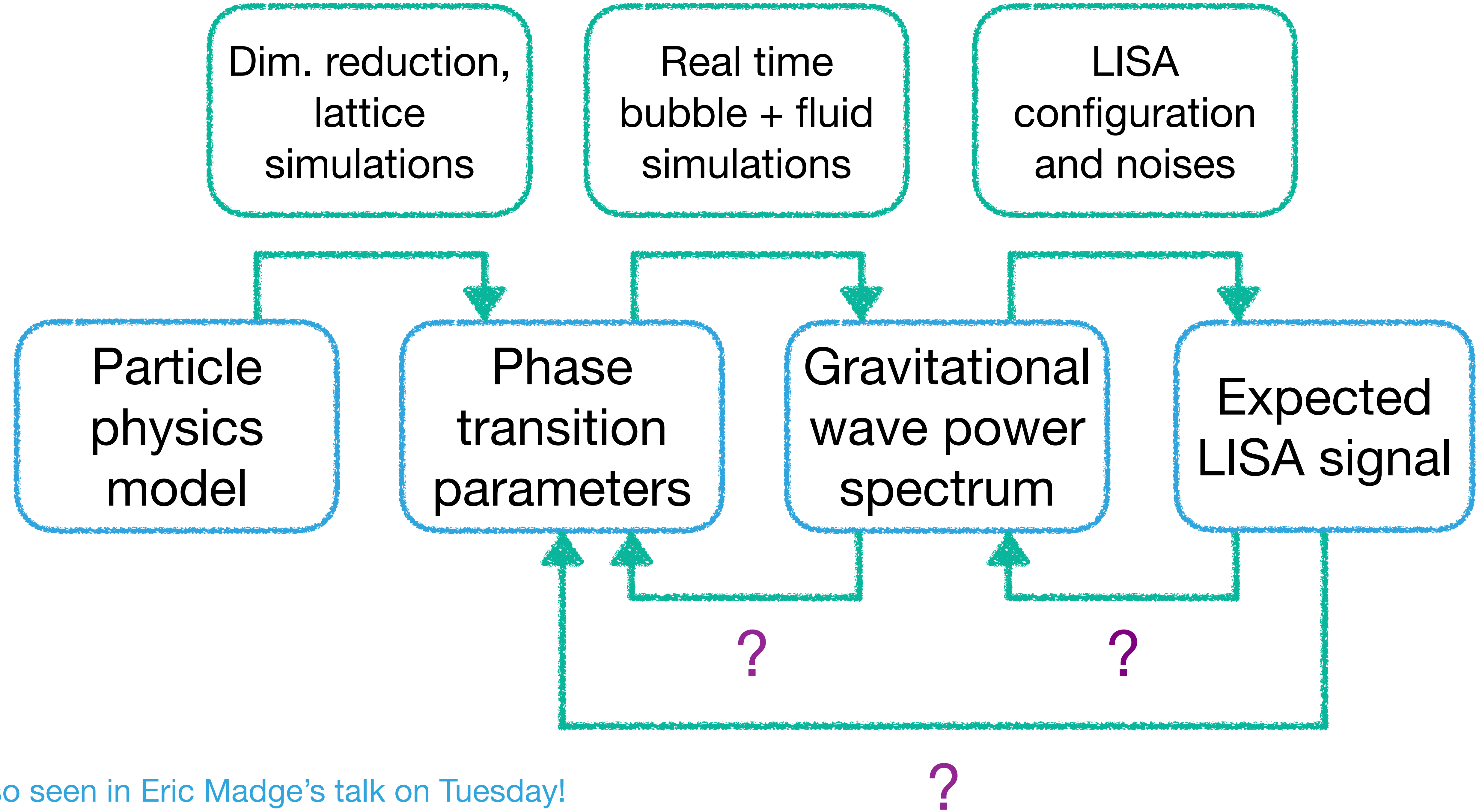
Gravitational wave power spectrum

Expected LISA signal

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



Also seen in Eric Madge's talk on Tuesday!

You can directly sample on the PT parameters… if you are patient

1. Choose a set of PT parameters

   α : Phase transition strength

   r_* : Hubble-scaled mean bubble spacing

   T_n : Bubble nucleation temperature

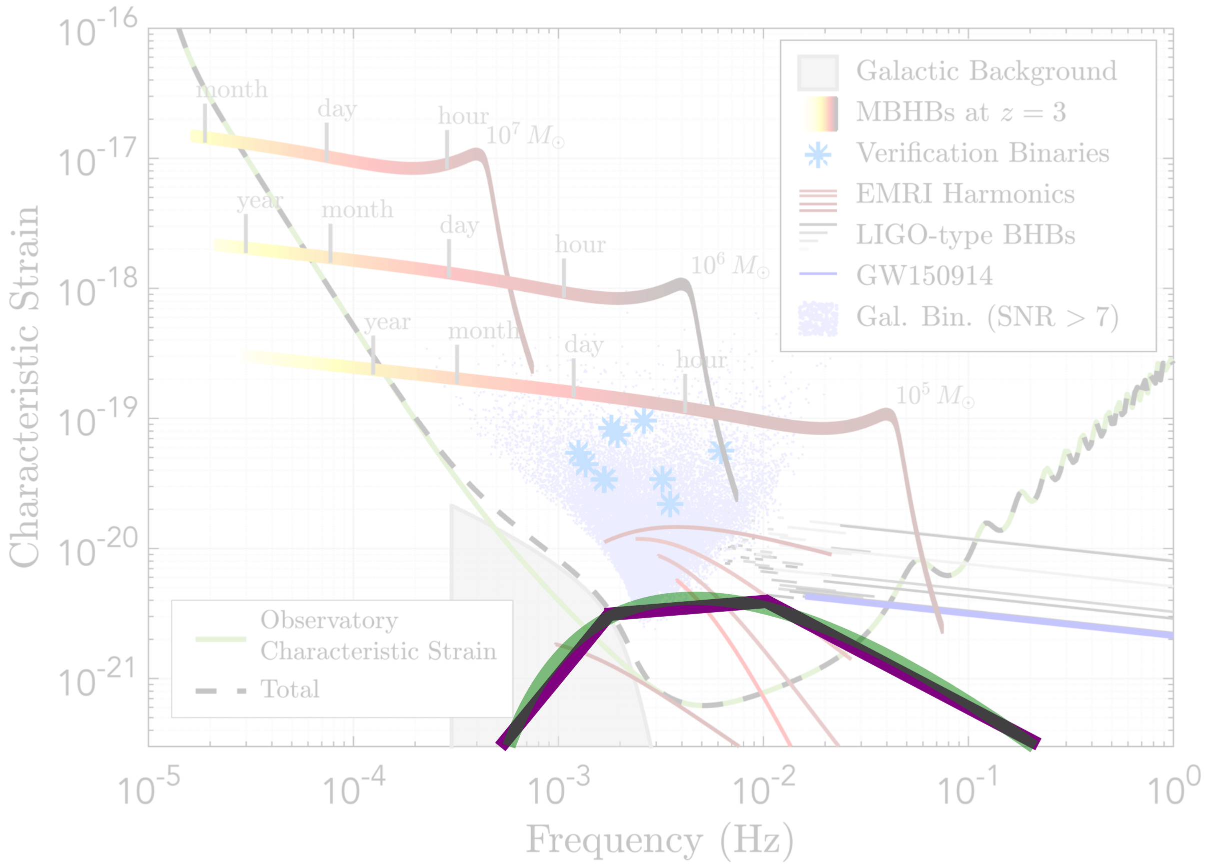
   v_w : Wall velocity

2. Run simulations or use existing approximations (like Sound Shell Model*) to get GW power spectrum. We use `PTtools` for the power spectra

3. Compare to (mock) LISA data with an MCMC analysis

* arXiv:1608.04735, 1909.10040

We propose to use template spectra with a remapping to PT parameters



1. Use a template for the GW signal: we choose a double broken power law*

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

3. Run MCMC on spectral parameters, use mapping to reconstruct PT parameters (we include instrument noise)

Careful with priors - choose spectral priors based on mapping

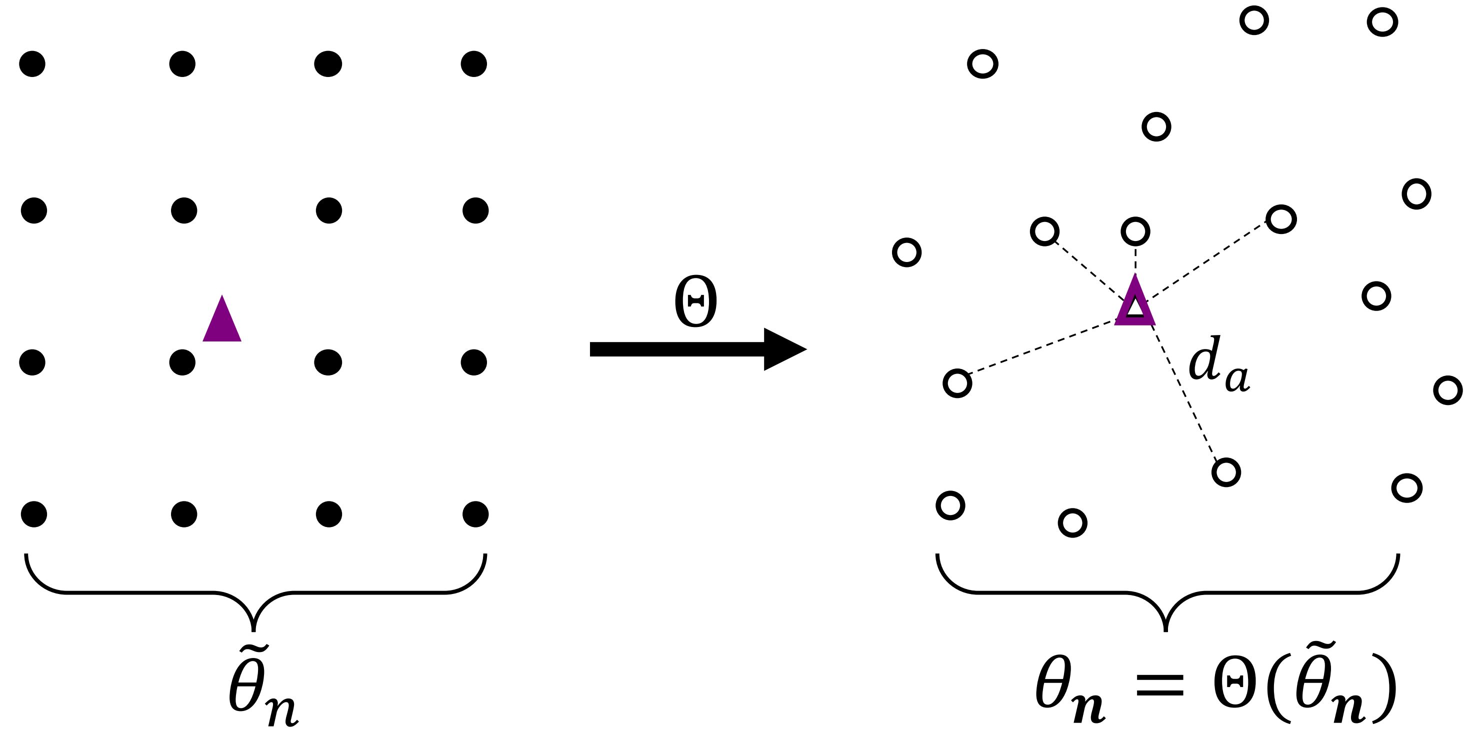
* arXiv:1608.04735

Mapping done by building a grid and interpolating with nearest neighbours

arXiv:2209.13551

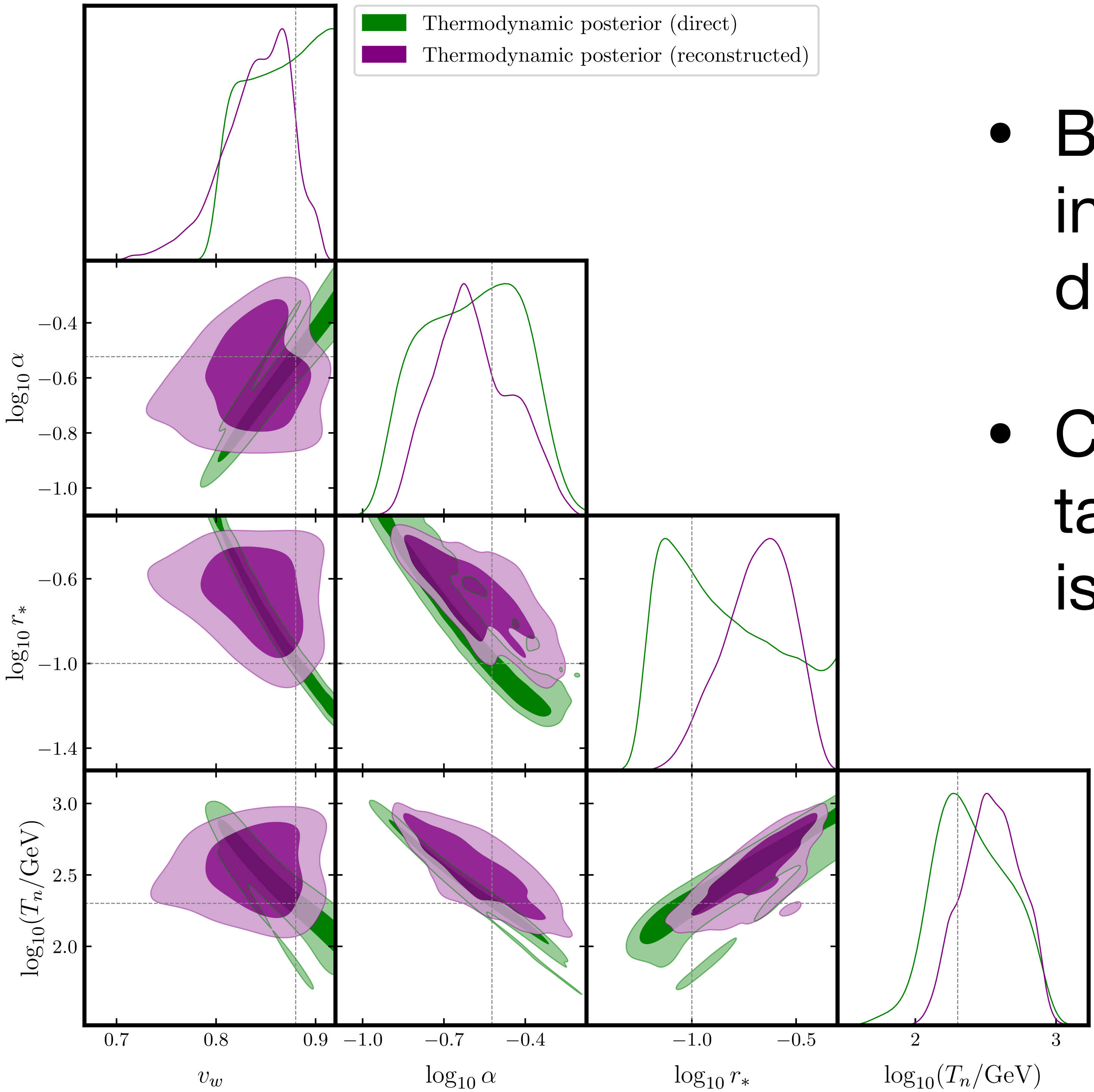
1. Build grid of PT parameters

2. Find corresponding spectral parameters



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

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



MCMCs done with Cobaya, arXiv:2005.05290

- Both approaches recover injected signal (dashed lines), direct is more precise
- Creating the first mapping takes time, but reconstruction is much faster

α : Phase transition strength

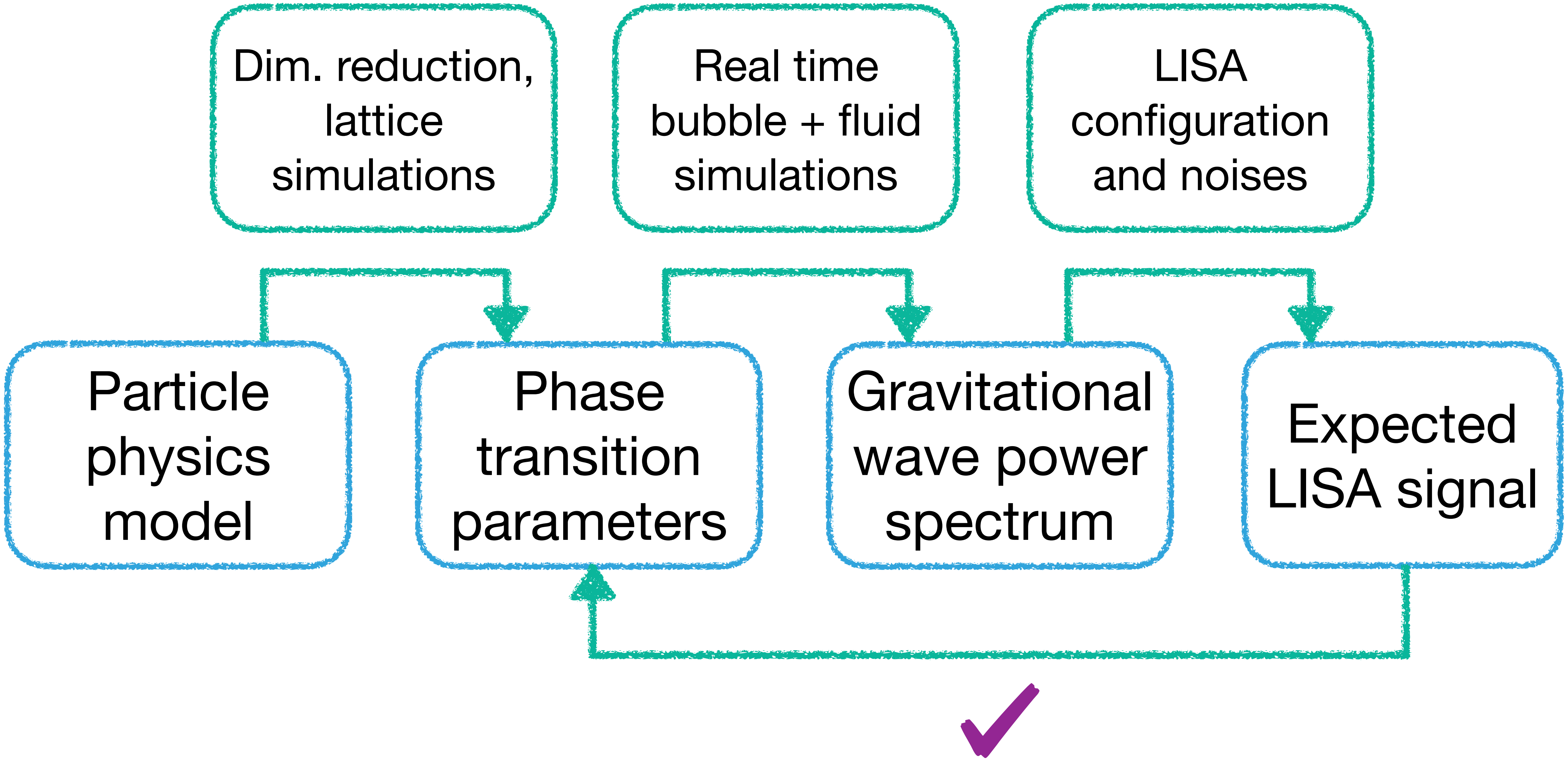
r_* : Hubble-scaled mean bubble spacing

T_n : Bubble nucleation temperature

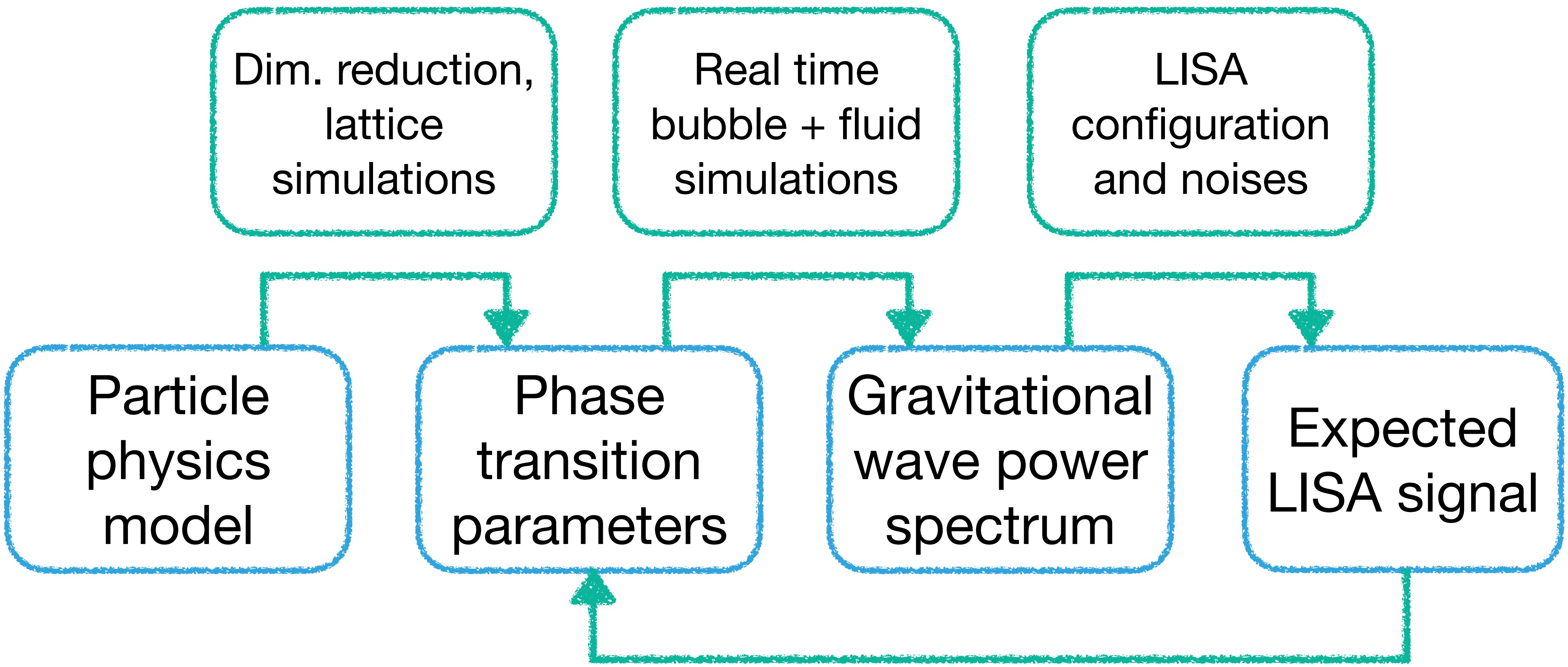
v_w : Wall velocity

arXiv:2209.13551

We can get PT parameters from GW spectrum. Can we get a SGWB spectrum from LISA?



We can get PT parameters from GW spectrum. Can we get a SGWB spectrum from LISA?



What if we add more realistic noise?

We are making more realistic mock LISA data with more noise sources

Ongoing project with M. Hindmarsh, T. Minkkinen, D. J. Weir

1. Create mock LISA data using LISA simulation pipeline* with:

   i. Instrument noise

   ii. Broken power law PT signal

   iii. Confusion noise from galactic white dwarf binaries

2. Run MCMC to see if we recover injected signals†

LISA Orbits[1] LISA GW Response[2]

LISA Instrument[3] pyTDI[4]

* Developed by the LISA data-processing group

1 zenodo.org/record/7700361

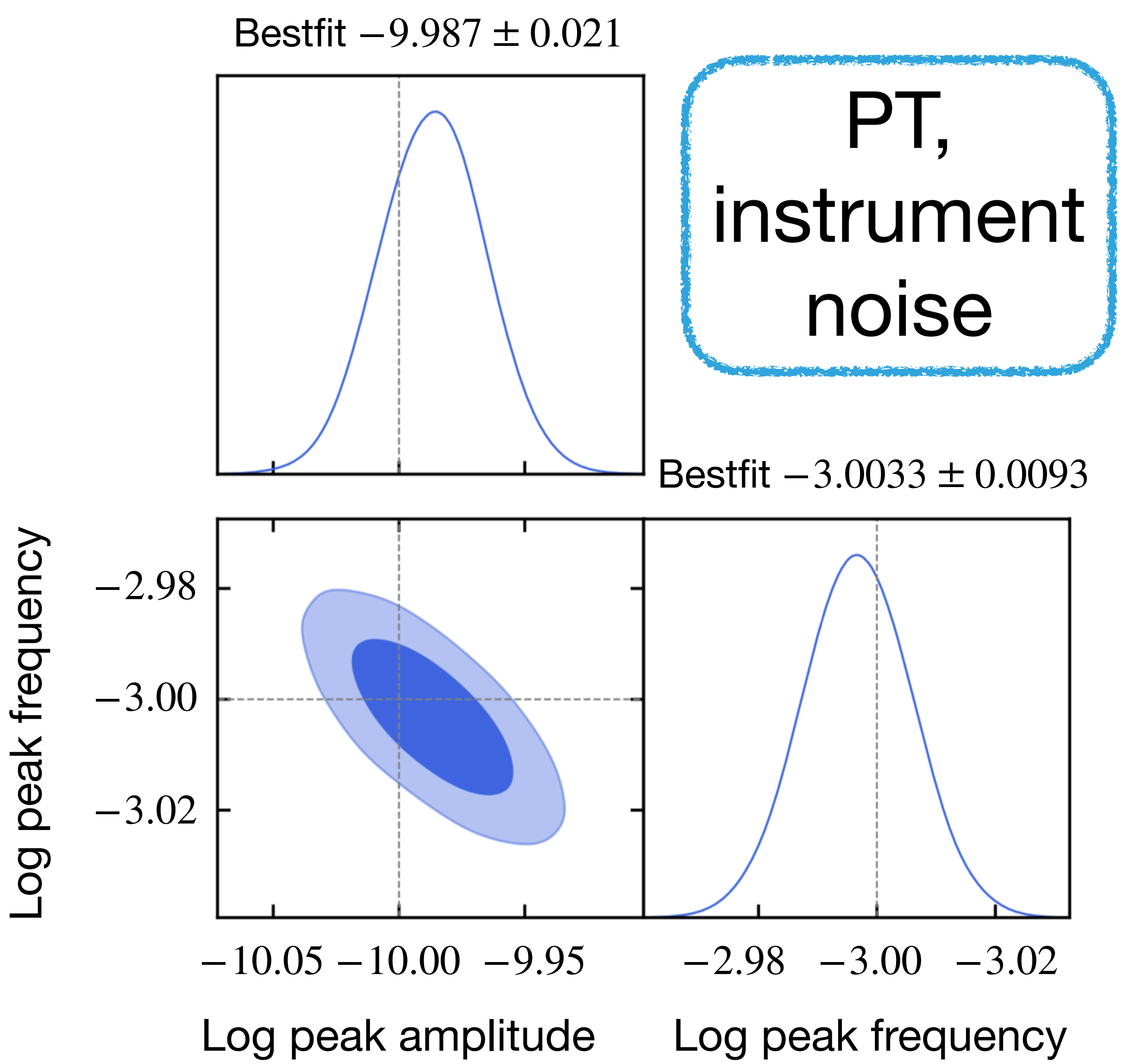
2 zenodo.org/record/6798946

3 arXiv: 2212.05351

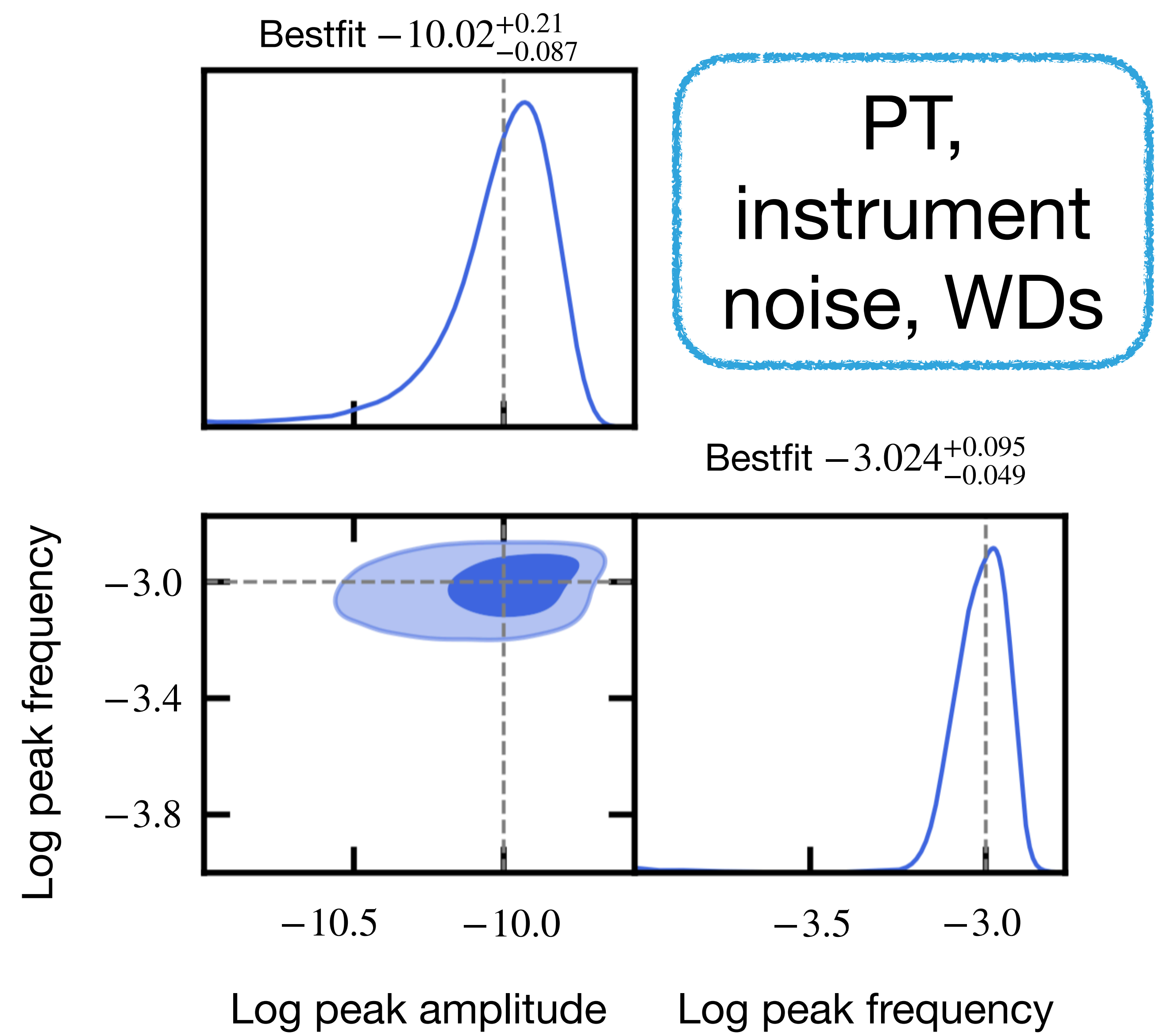
4 zenodo.org/record/7704609

† Related work in e.g.: arXiv:2011.05055, 2105.04283 2107.06275, 2209.13277

We can recover the PT parameters quite accurately, even with added noises



+2 parameters for instrument noise



+2 parameters for instrument noise,
+4 parameters for white dwarf binaries

Preliminary figures by T. Minkkinen

If we can detect a SGWB with LISA, we can hopefully recover the PT parameters

Summary

- We can reconstruct (strong) PT signals using spectral templates
- The LISA Simulation codes provide a consistent framework for realistic mock data production

Next steps

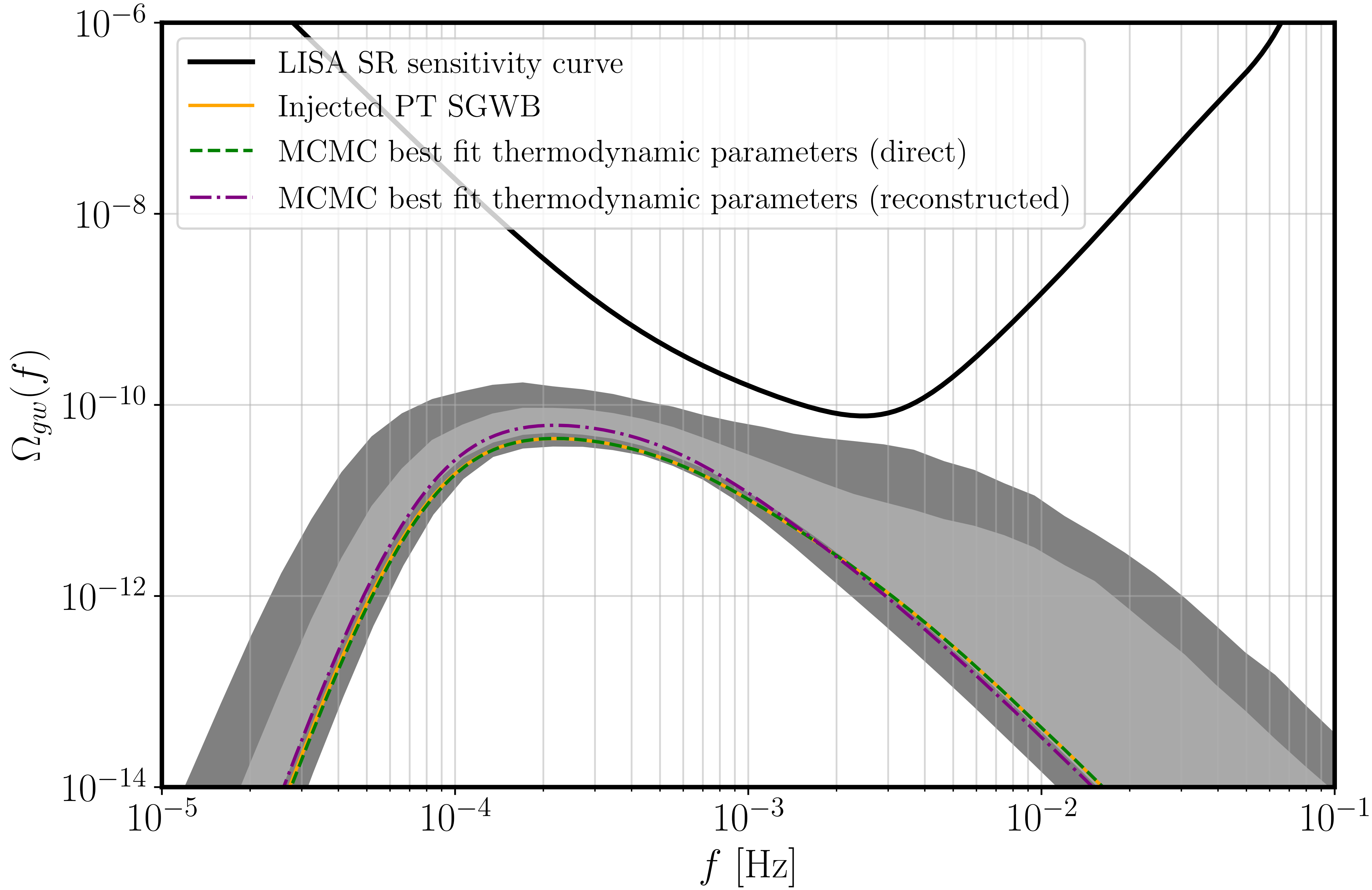
- We want to add annual modulation of binaries (angular information), change to double broken power law
- How small can we make the injected signal and how well do we need to know the astrophysical noises?

Thanks for listening!

Get in touch!

Email: deanna.hooper@helsinki.fi

GW spectra from the MCMC



arXiv:2209.13551

Our fiducial model(s)

- Detonation fiducial

$$v_w = 0.88,\ \alpha = 0.2,\ r_* = 0.1,\ T_n = 200GeV$$

- Deflagration fiducial

$$v_w = 0.4,\ \alpha = 0.55,\ r_* = 0.1,\ T_n = 120GeV$$

arXiv:2209.13551