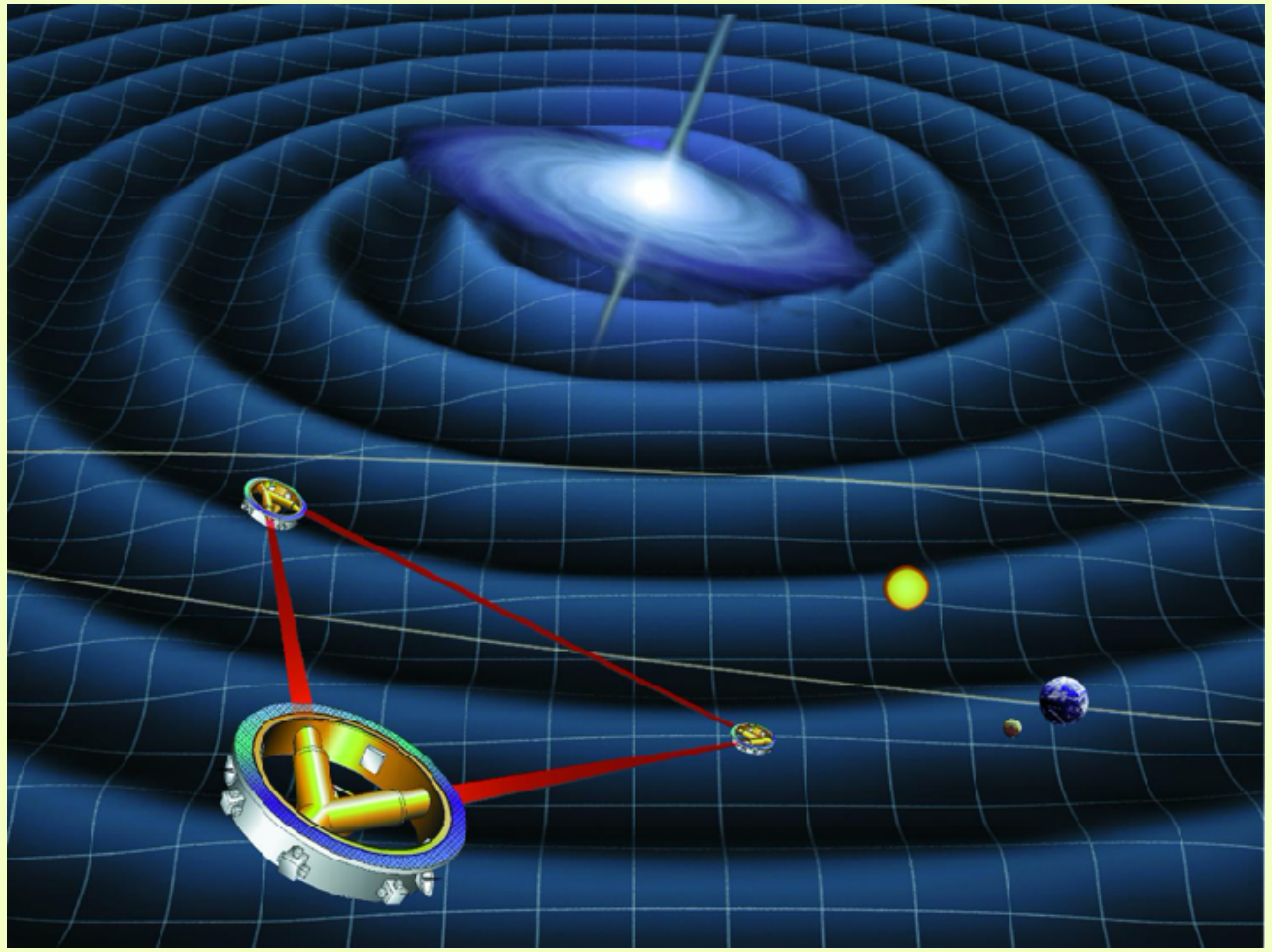
Finding sound shells in LISA mock data using likelihood sampling

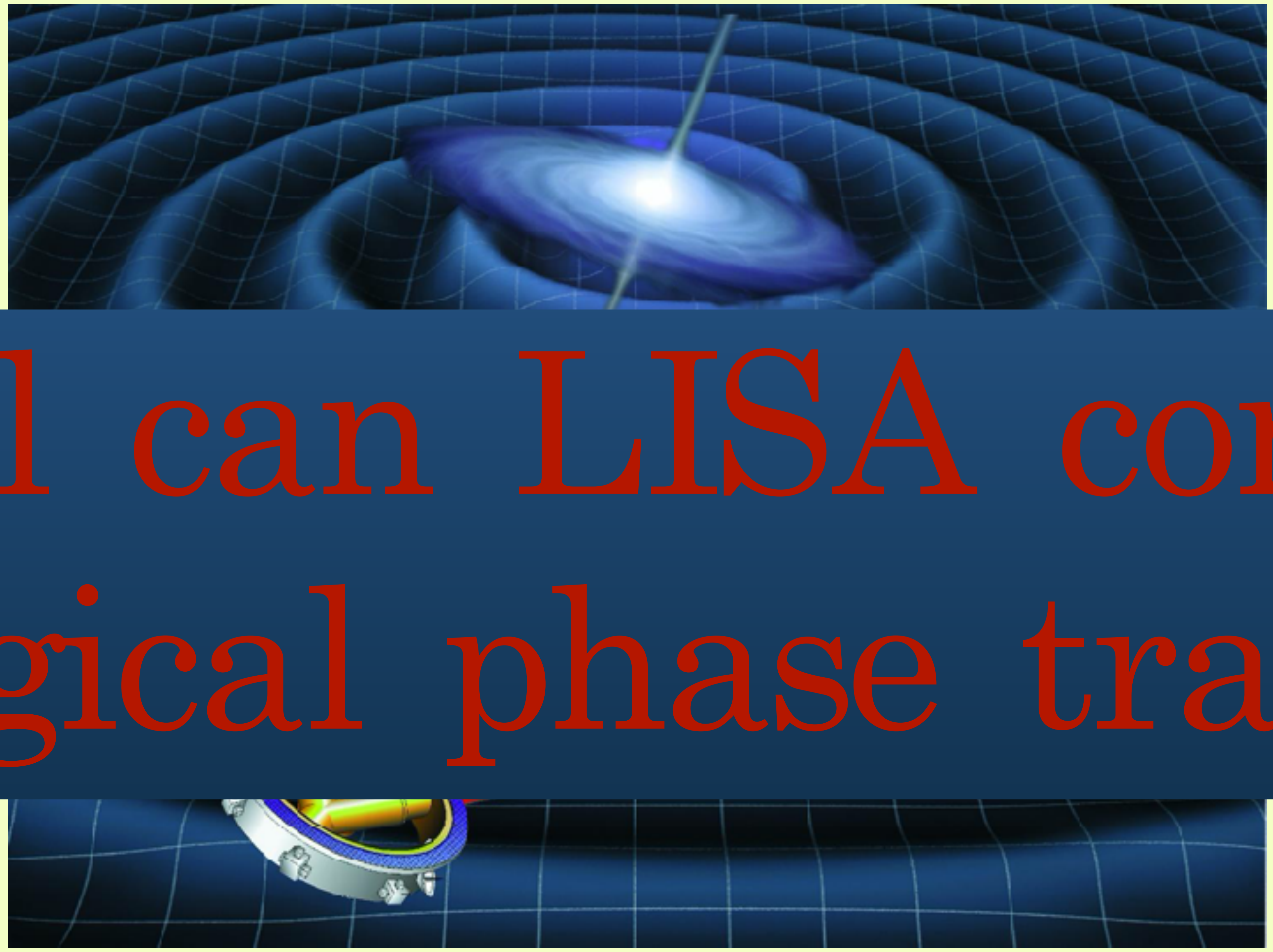
Jorinde van de Vis - DESY

DESY Theory Workshop 2021

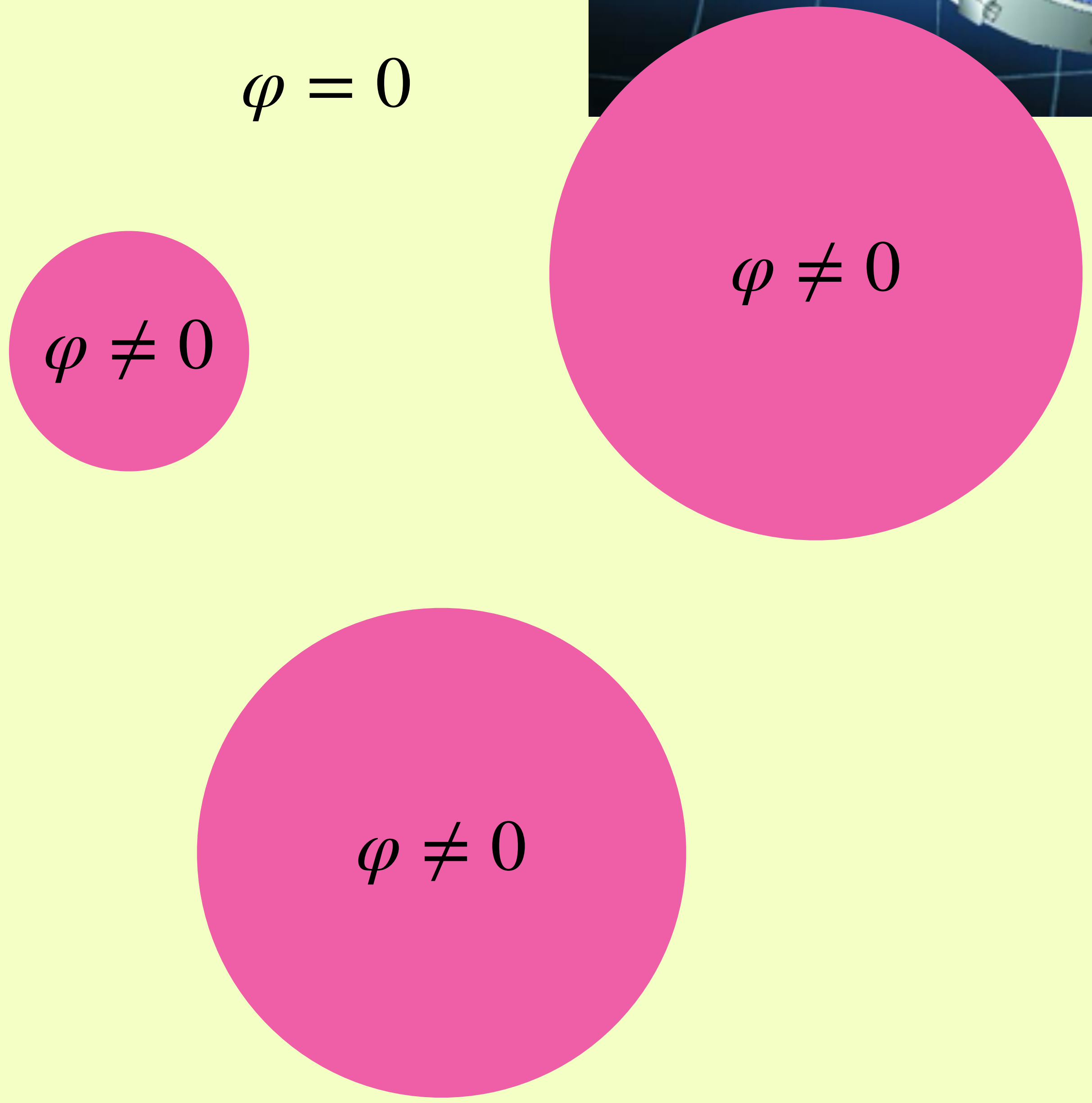
Based on F. Giese, T. Konstandin, JvdV: 2107.06275



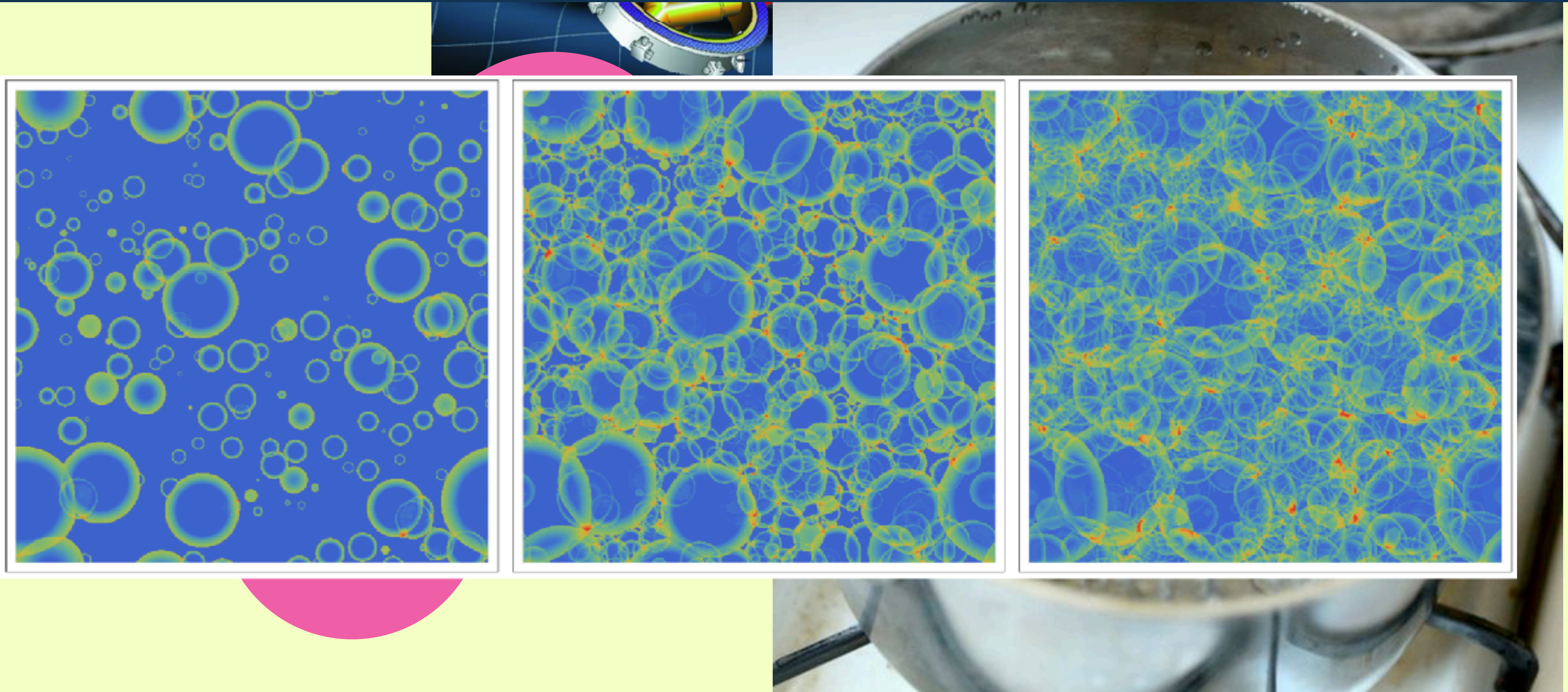
How well can LISA constrain a cosmological phase transition?



How well can LISA constrain a cosmological phase transition?



How well can LISA constrain a cosmological phase transition?



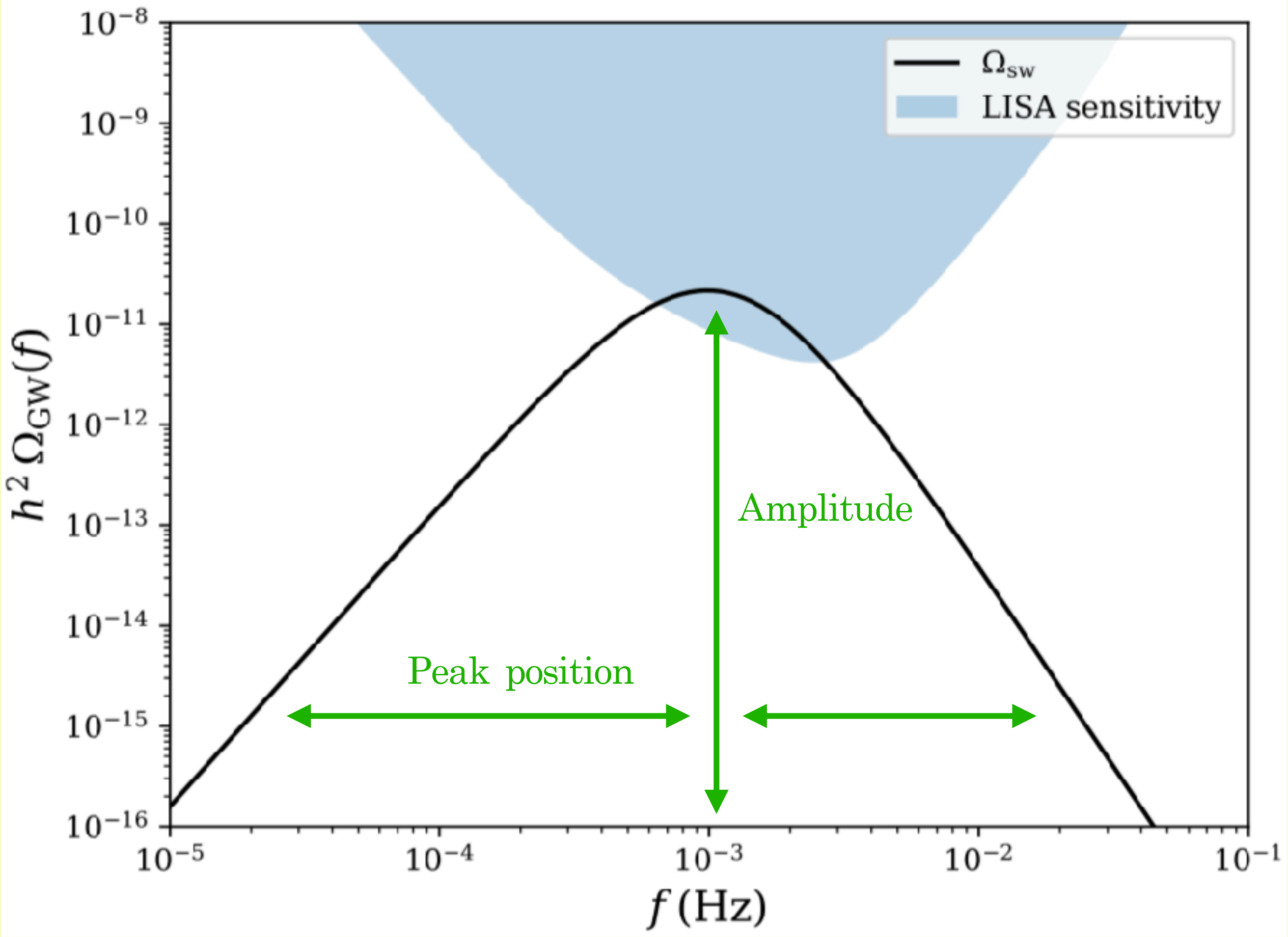
Jinno, Konstandin, Rubira, 2020

Phase transition parameters

- Phase transition temperature T_*
- Phase transition strength α
- Bubble wall velocity v_w
- Phase transition duration β^{-1}
- Sound speed c_s Giese, Konstandin, JvdV, 2020 & Giese, Konstandin, Schmitz, JvdV, 2020

Fit from hydrodynamic simulations

Hindmarsh, Huber, Rummukainen, Weir 2015 & 2017

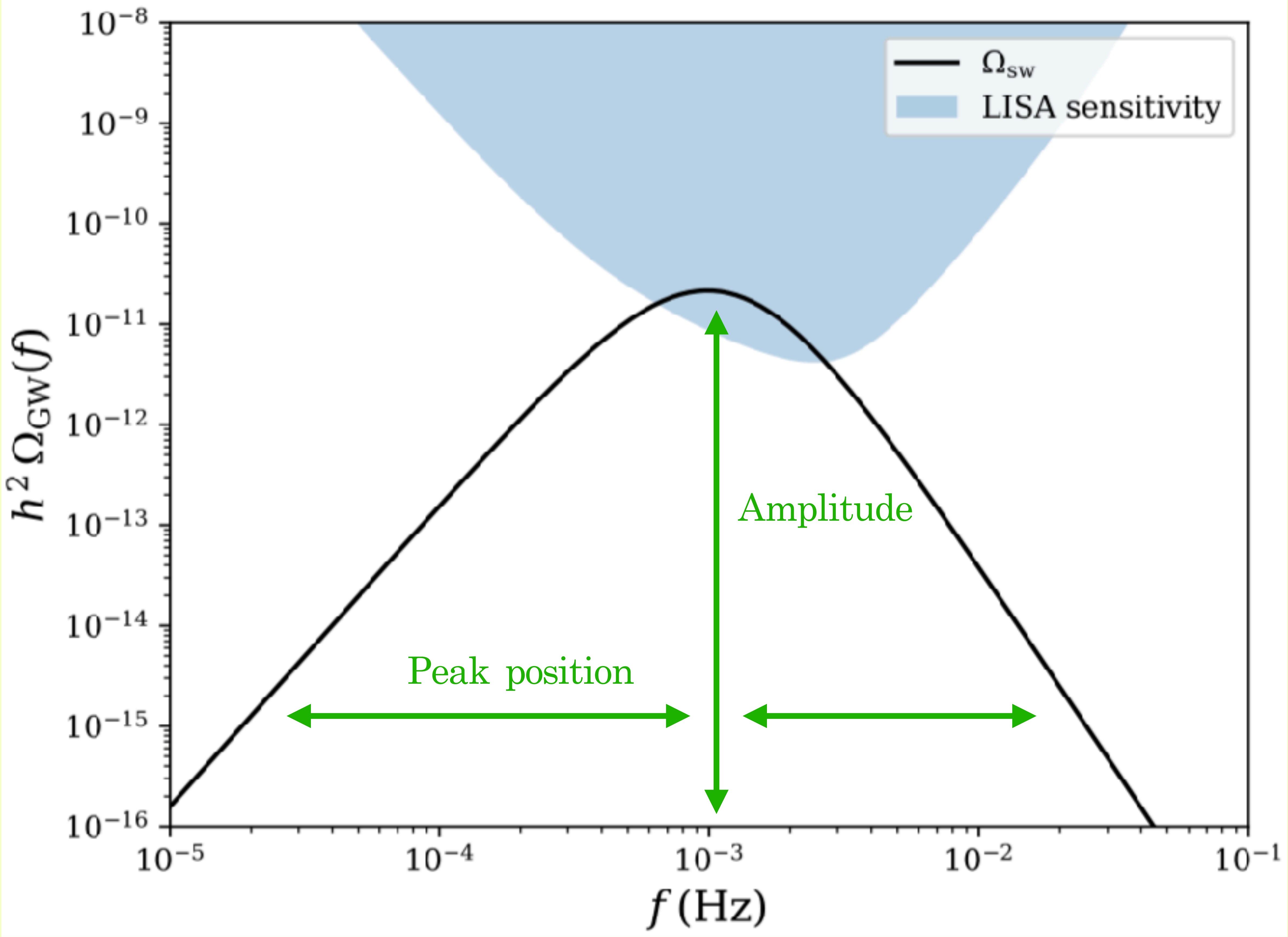


LISA Cosmology Working Group 2019

Fit from hydrodynamic simulations

Hindmarsh, Huber, Rummukainen, Weir 2015 & 2017

Possibly detectable by LISA

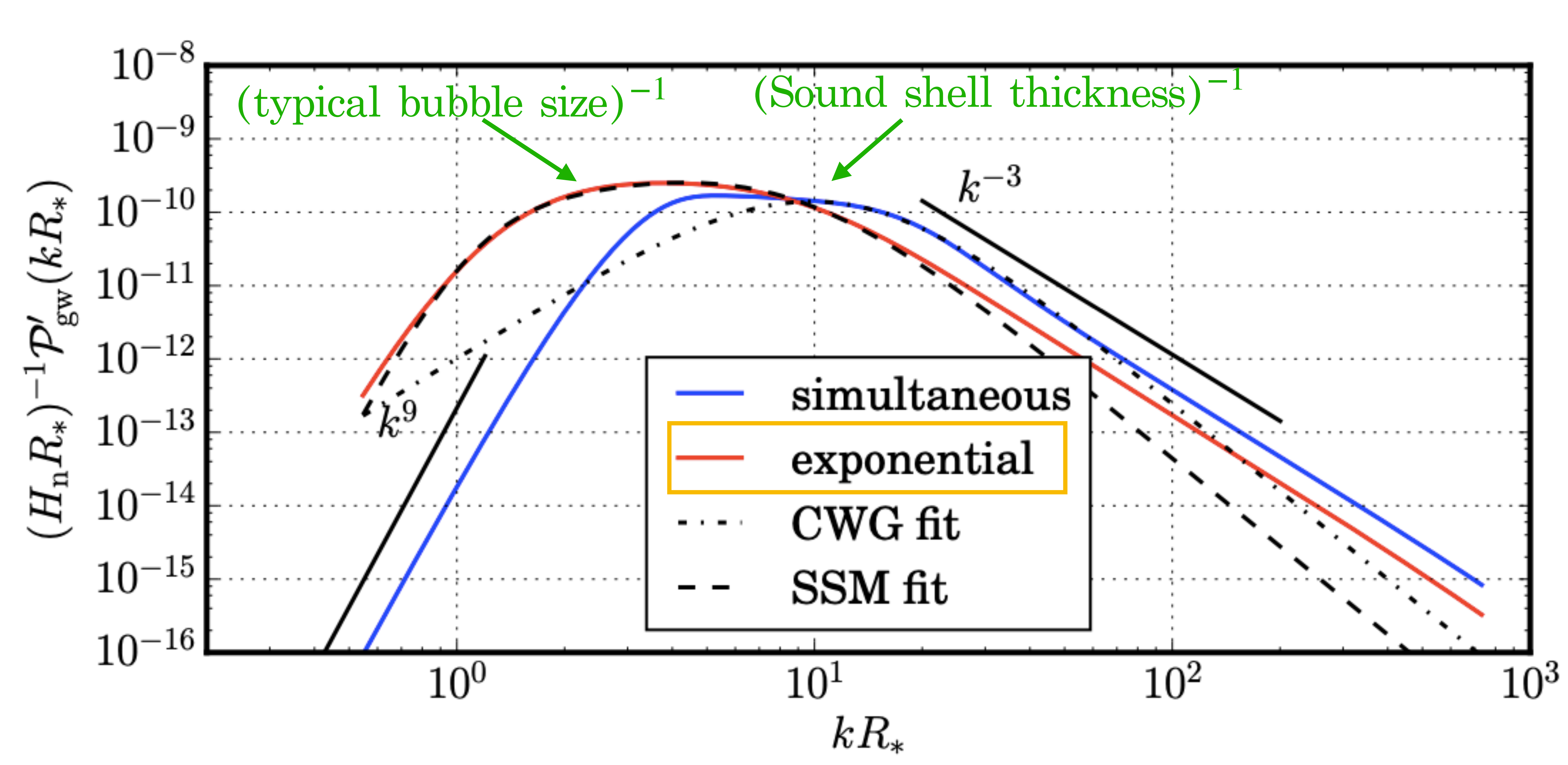


LISA Cosmology Working Group 2019

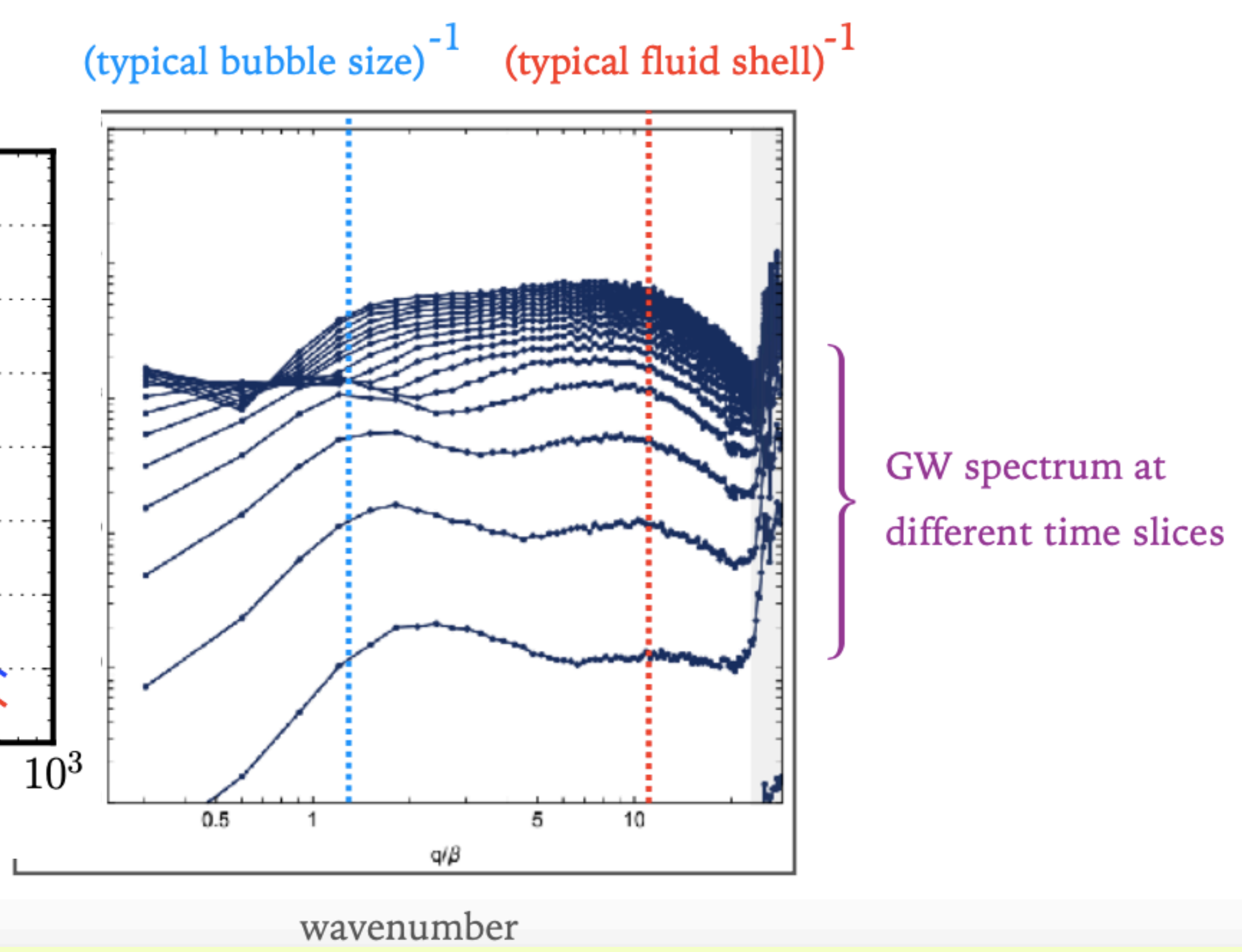
Just two constraints

Two relevant length scales

- Sound shell model: Hindmarsh 2016, Hindmarsh, Hijazi 2019
  Hybrid simulations: Jinno, Konstandin, Rubira, 2020



$\alpha = 0.0046,\ v_{wall} = 0.52$



Picture from R. Jinno

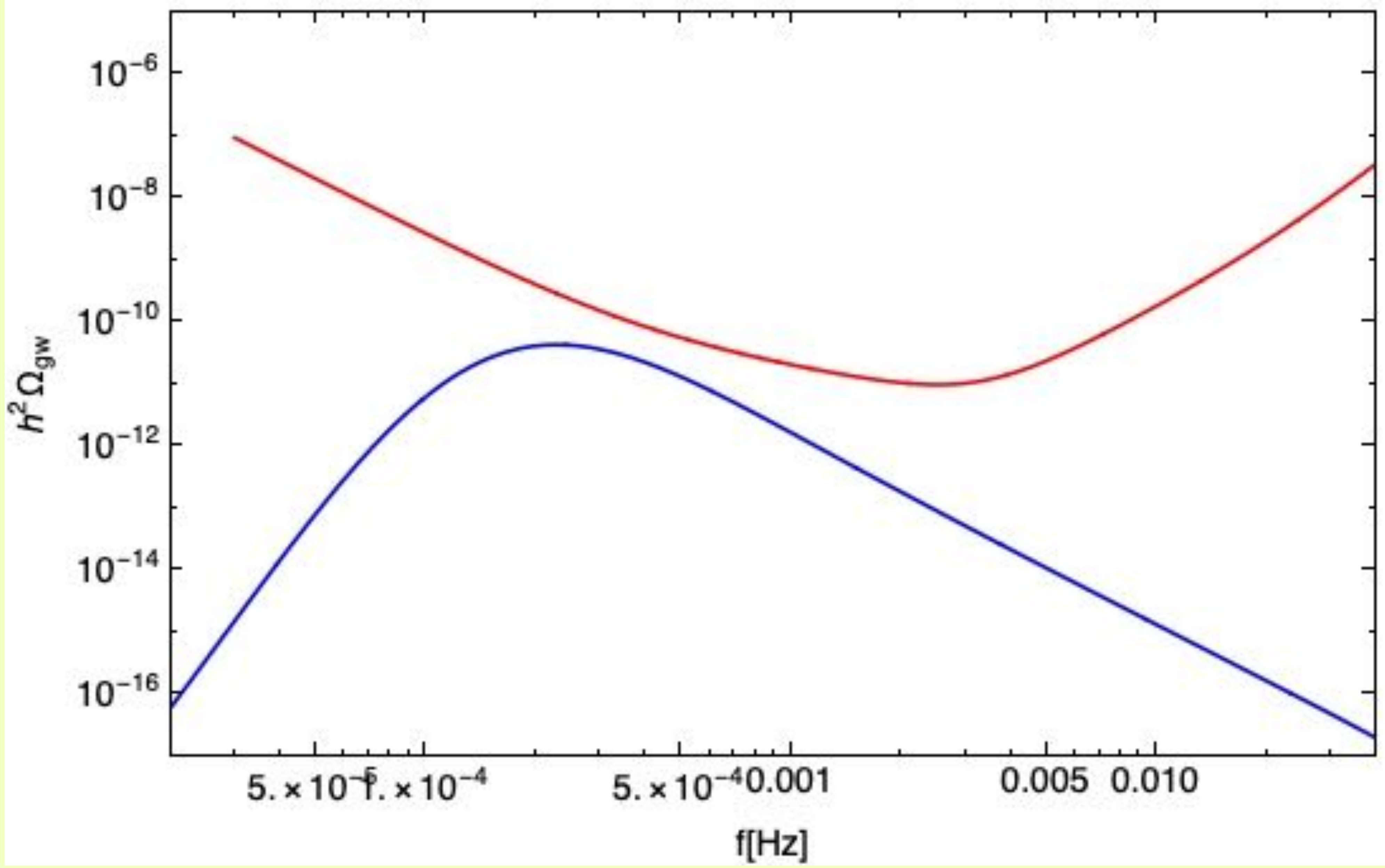
Can LISA detect two breaks?

- 3 observables: position of two breaks and overall amplitude.
- Can LISA reconstruct the doubly-broken power law?
- Approach: generate mock data and determine best fit.

Step 1:
Generate LISA mock signal

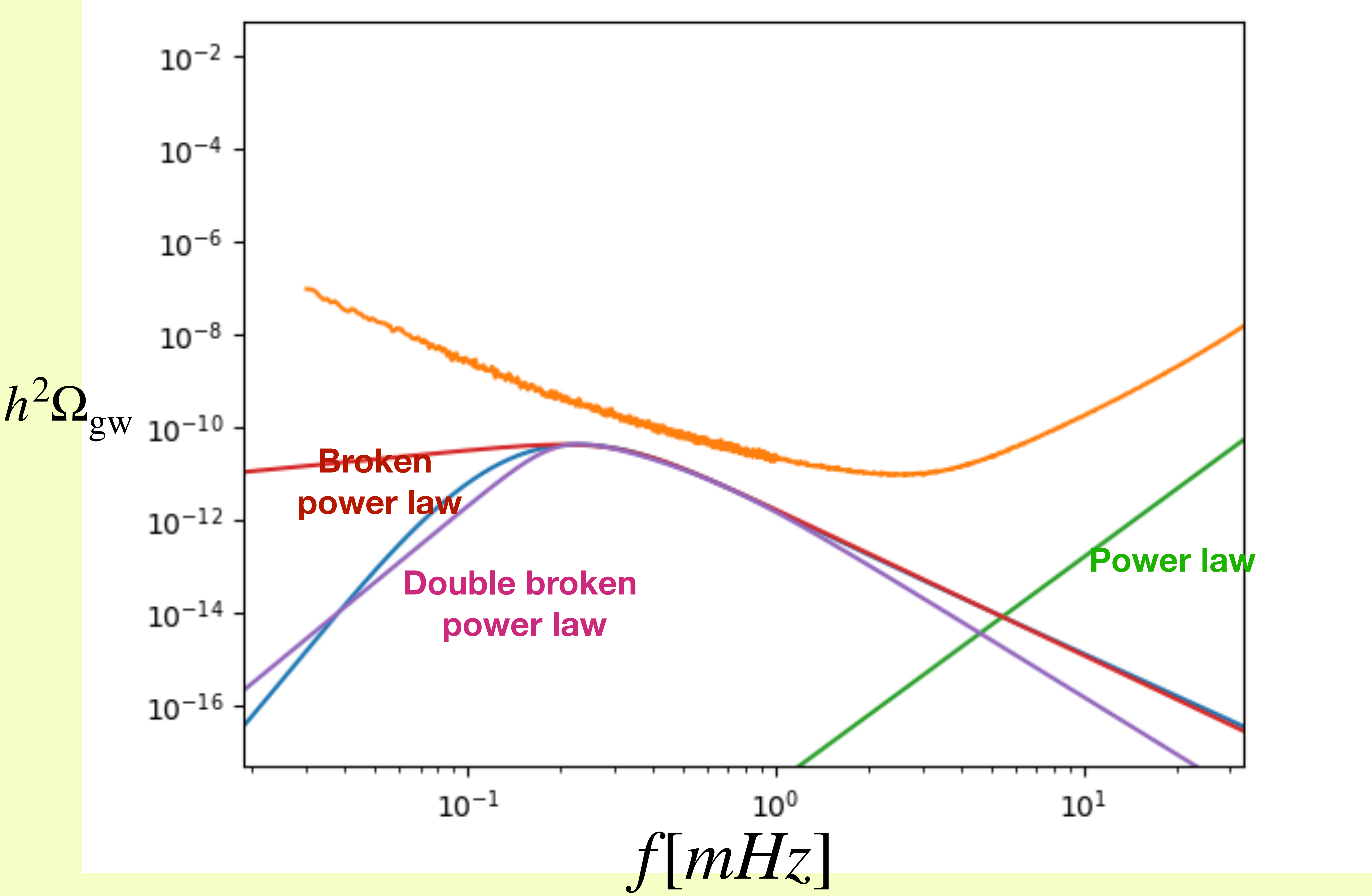
- Mock data from LISA noise curve and fit from hybrid simulation.*
  Vary α and v_w

- Relation between α, β and T_* from 2HDM
  G. Dorsch, J.M. No via PTPlot.org



*Data generation:
Caprini, Figueroa, Flauger, Nardini, Peloso, Pieroni, Ricciardone, Tasinato 2019,
Flauger, Karnesis, Nardini, Pieroni, Ricciardone, Torrado 2021

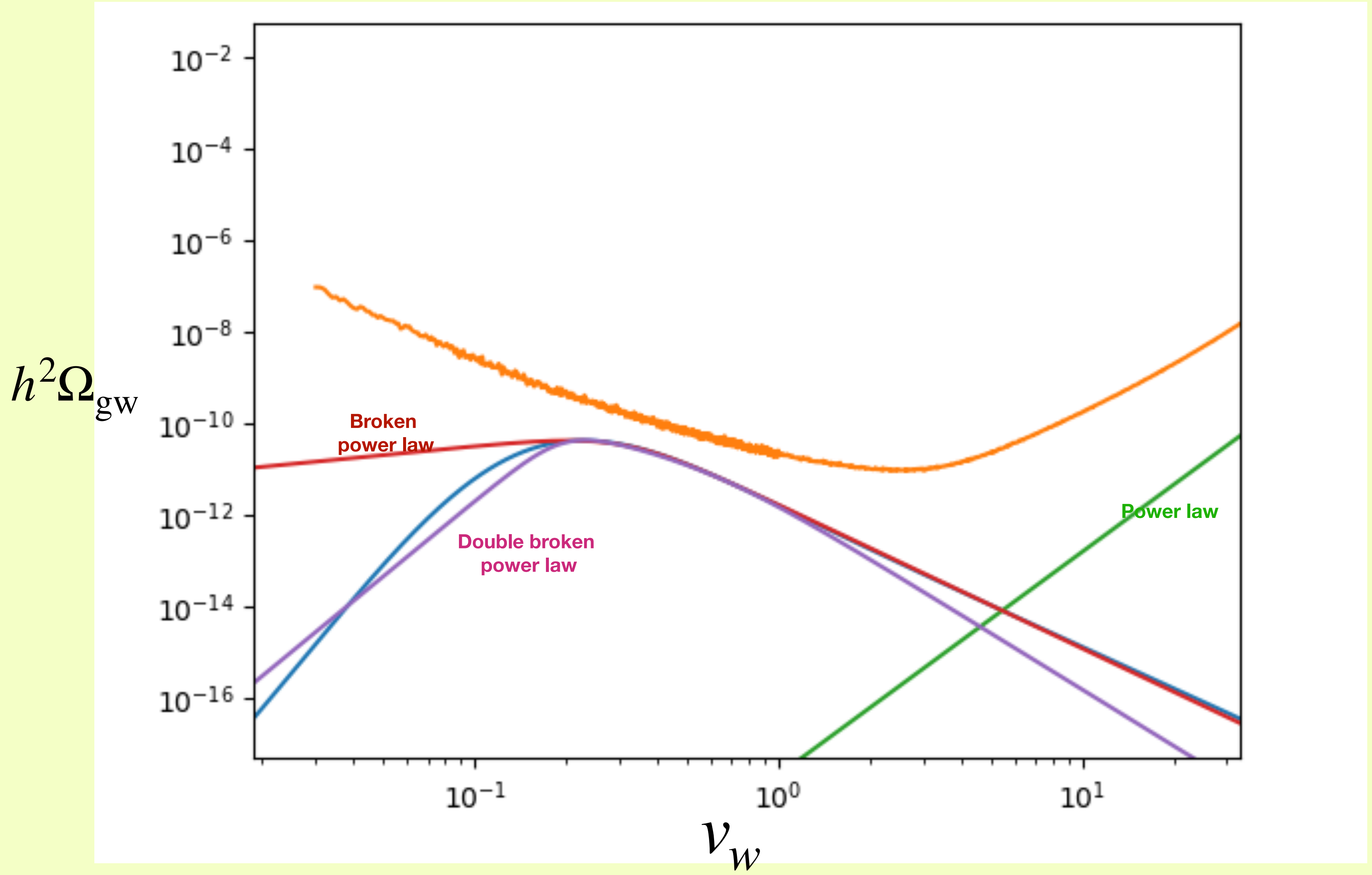
Step 2:
Fit the signal



Step 2:
Fit the signal

- Minimize χ^2

$$\chi^2 \propto \sum_i \left(\frac{\bar{D}_i - h^2\Omega_{\rm gw}(f_i, \vec{\theta}_s) - h^2\Omega_{\rm noise}(f_i, \vec{\theta}_n)}{\sigma_i} \right)^2$$



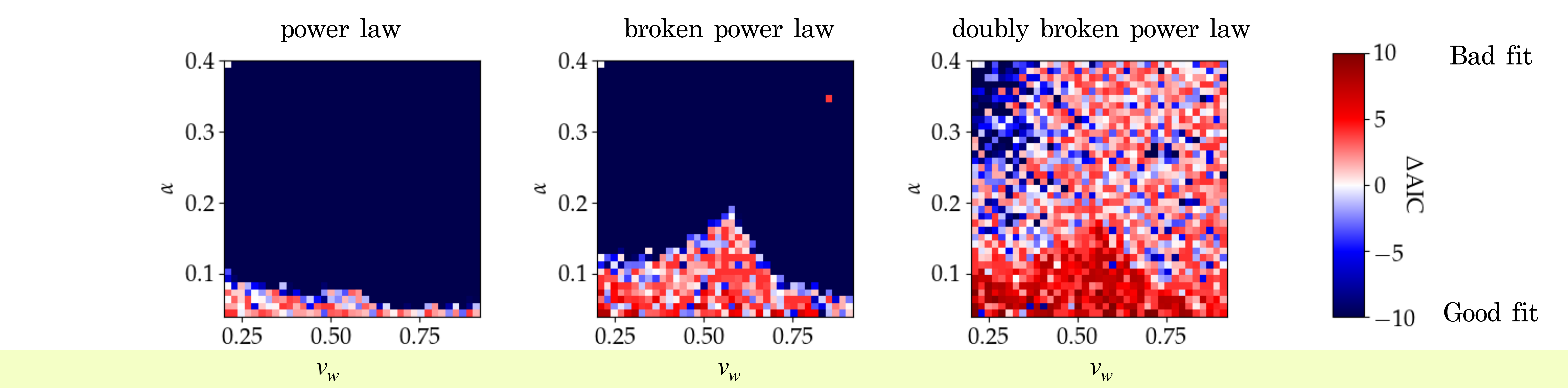
Step 3:
Determine the best fit

- Avoid overfitting: minimize Akaike information criterion Akaike 1974

$$AIC = \chi^2_{\text{best fit}} + 2k$$

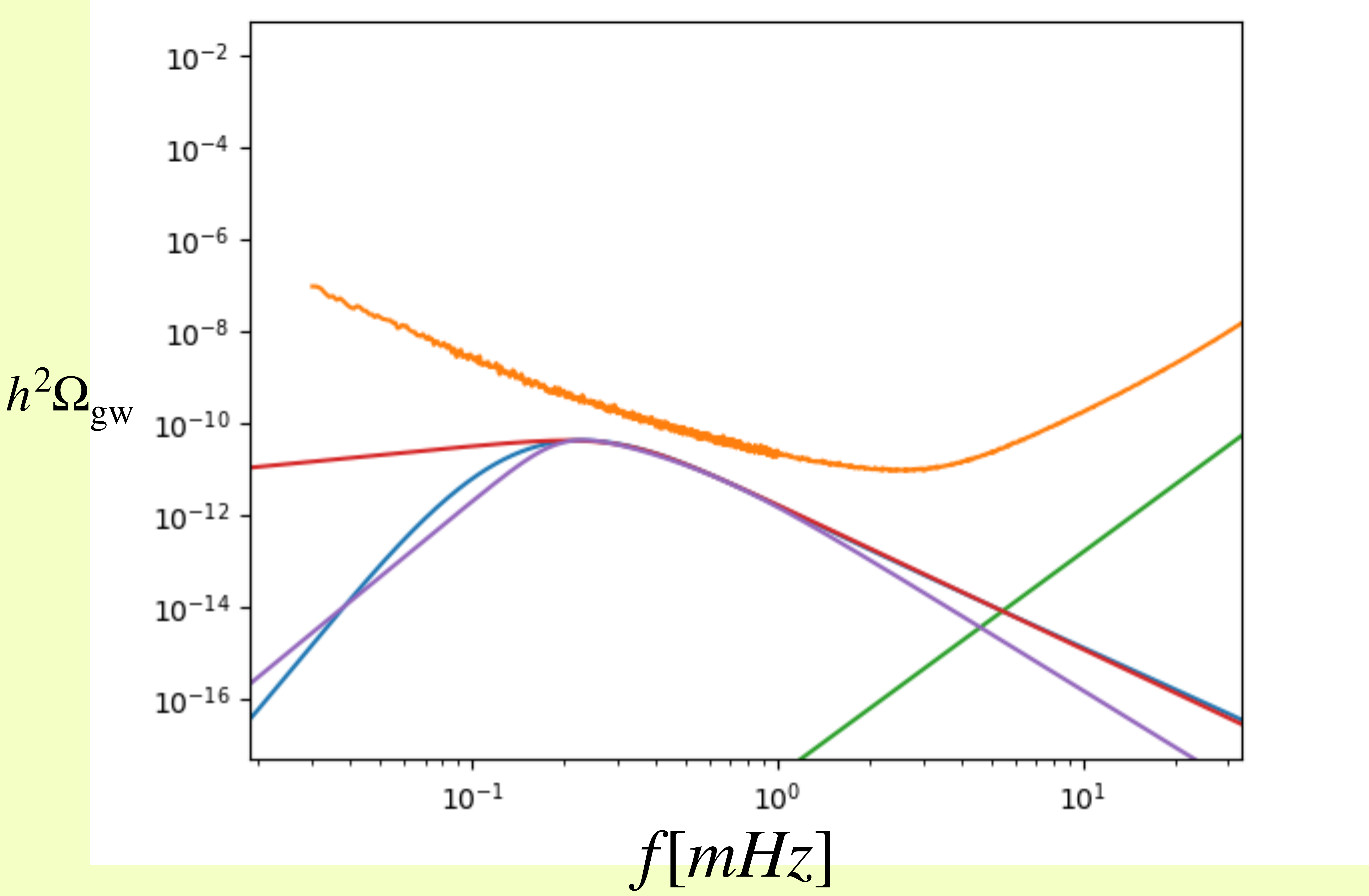
Number of fitting parameters (k)

Results

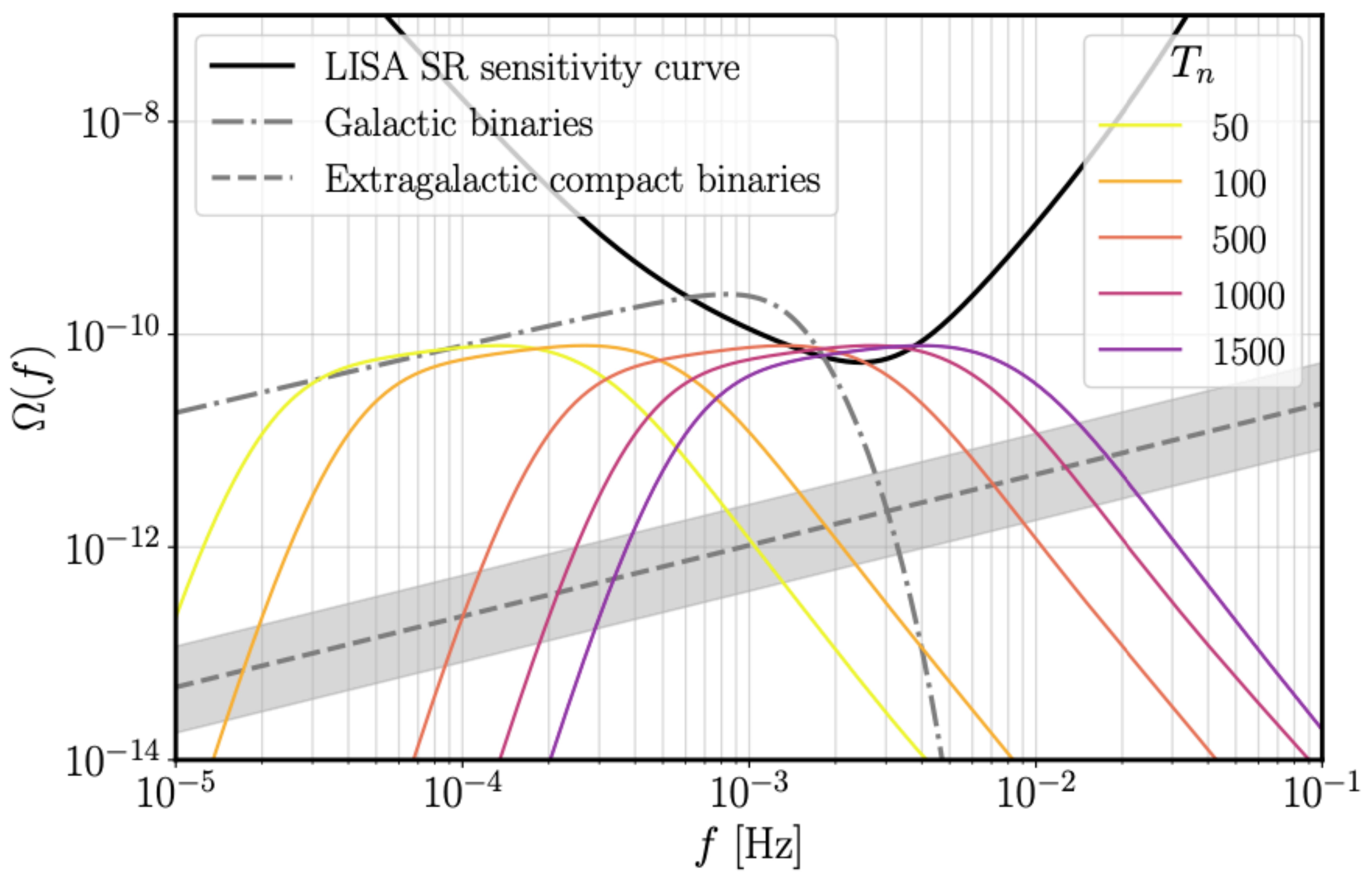


Comparison of AIC with fits with fewer parameters

Spectrum peaks at small frequency



Increasing T_* increases the peak frequency

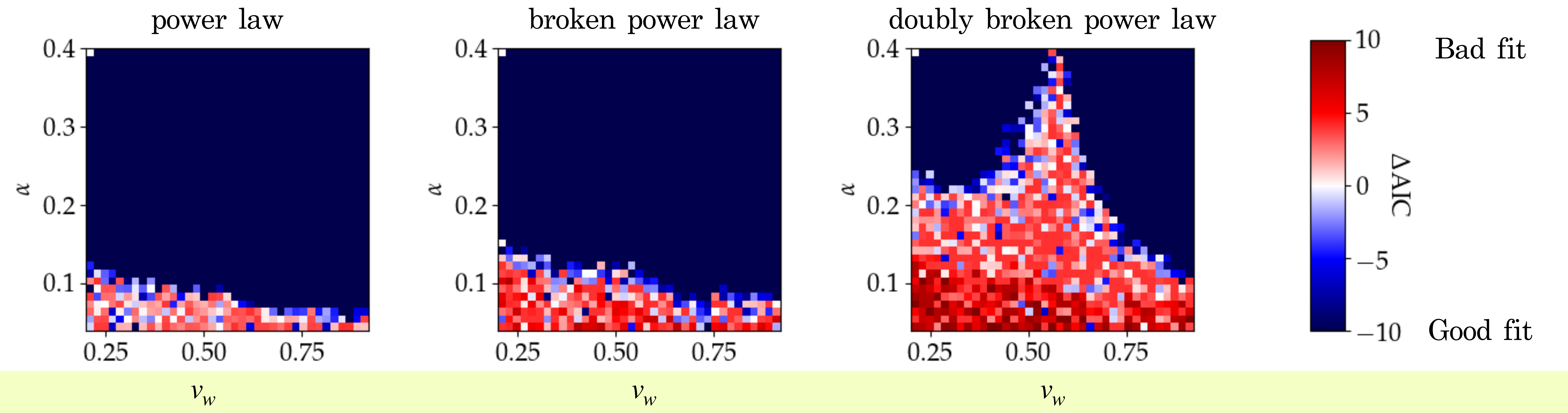


(d) Fixed: $v_{\mathrm{w}} = 0.6, \quad \alpha = 0.2, \quad r_* = 0.1.$

Gowling , Hindmarsh 2021

Results

$T_* \to 10T_*$ (composite Higgs, gauged lepton models)



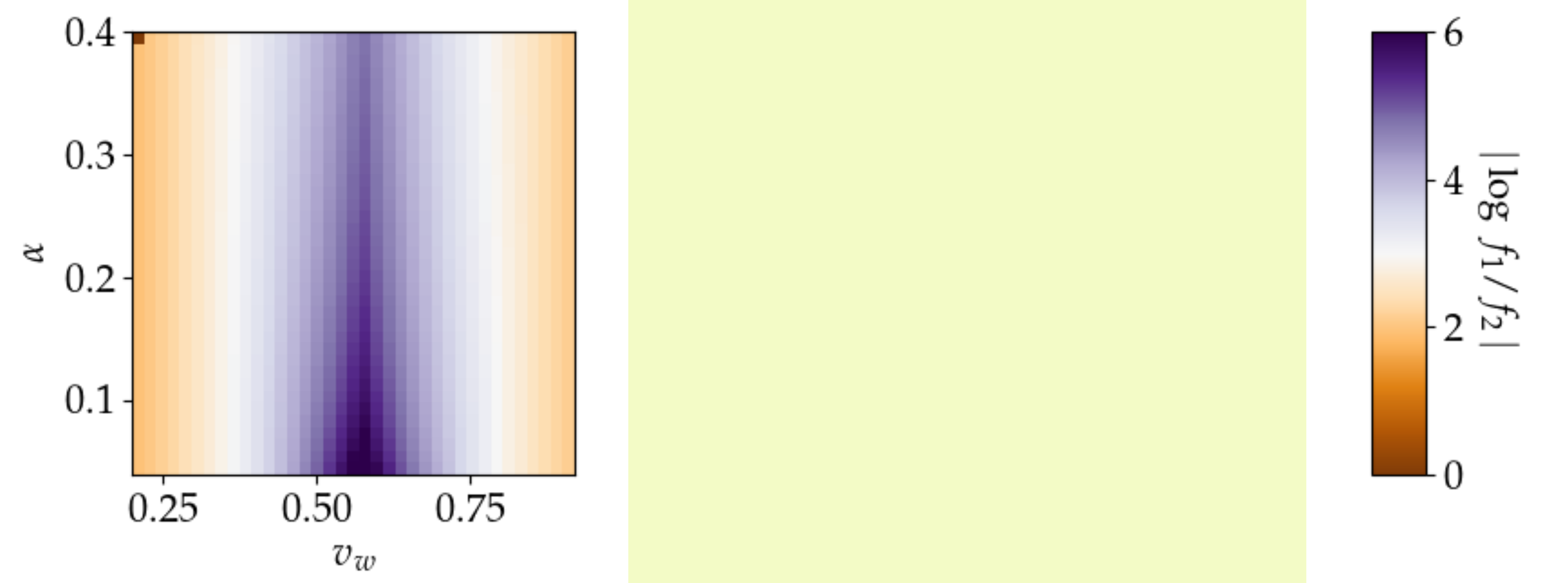
Comparison of AIC with fits with fewer parameters

Markov chain Monte Carlo

- Qualitatively the same results
- χ^2-minimization does not account for non-Gaussianities, small effect in reconstructed parameters

Break ratio (large T_*)

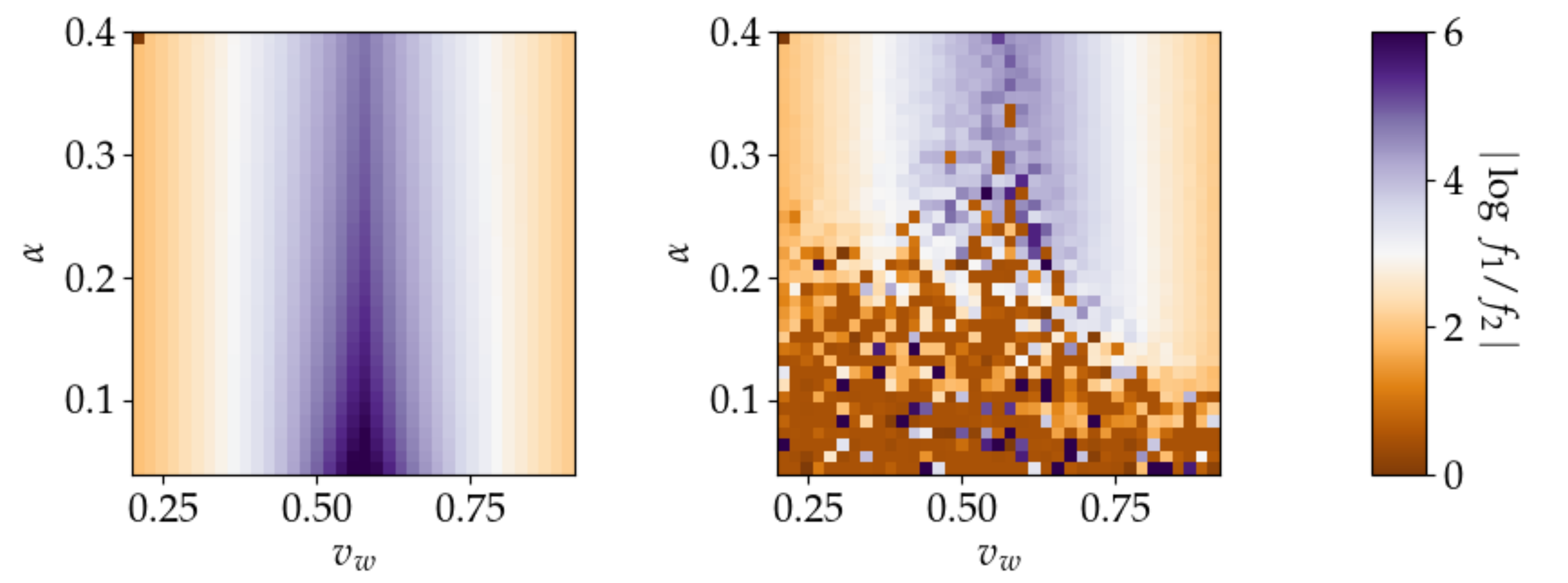
Fit to input signal

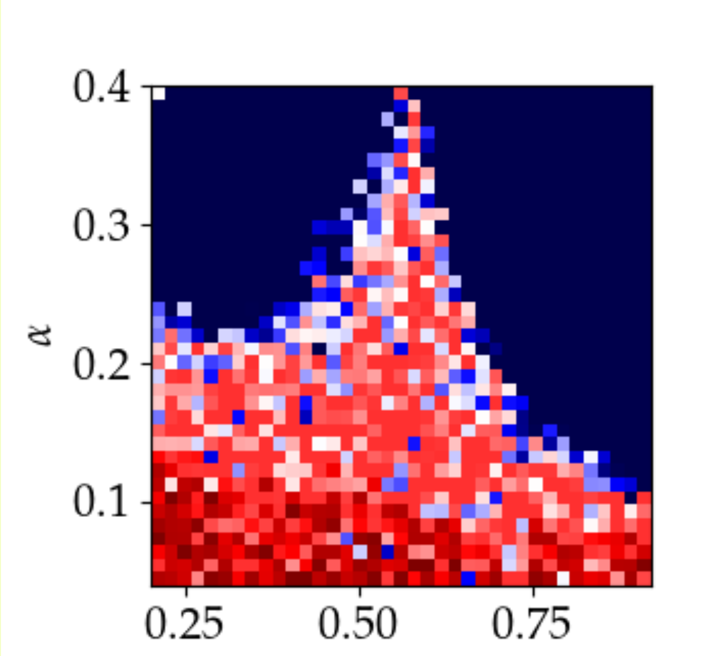


Break ratio (large T_*)

Fit to input signal

Fit to reconstructed signal





Break ratio

See talk by M. Hindmarsh
and Gowling, Hindmarsh 2021

- MCMC: $|\log f_1/f_2|$ can be measured with ~10% accuracy

Conclusion

- Sound shell model and hybrid simulations suggest GW spectrum described by doubly broken power law.
- Depending on the model of new physics the doubly-broken power law can be reconstructed, leading to 3 constraints on PT parameters.
- Reconstruction is more successful for large T_*.
- Break ratio informs about the wall velocity.

Break ratio (small T_*)