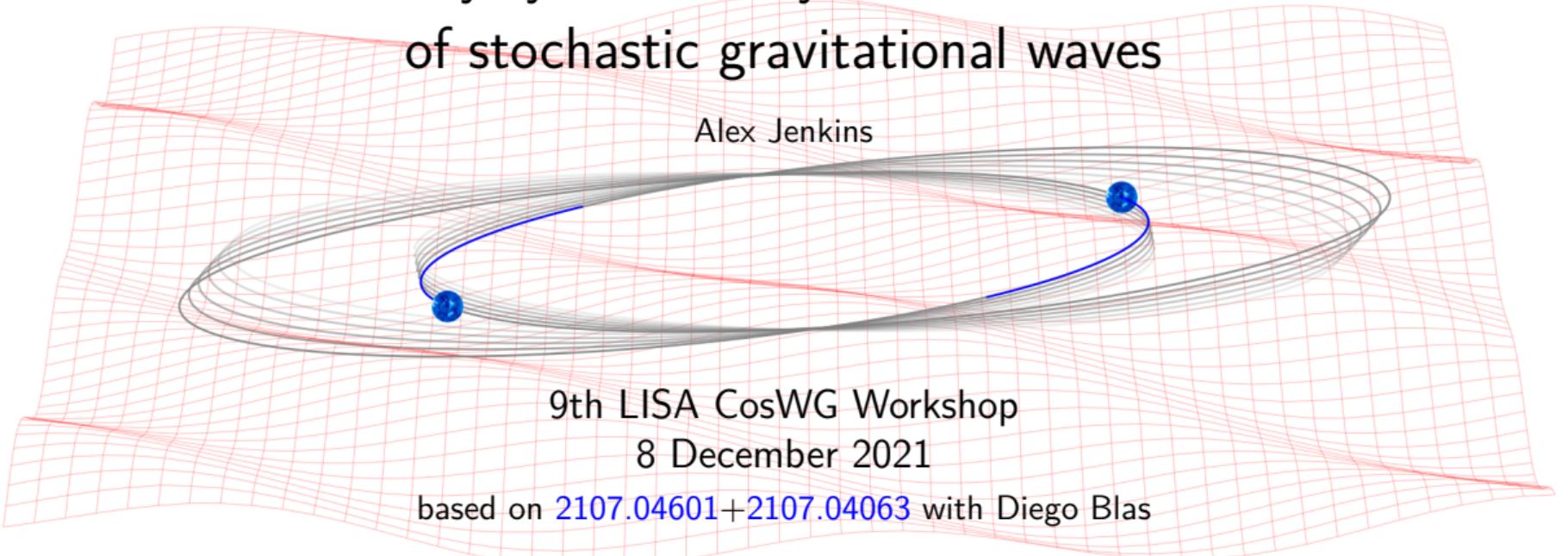


# Binary systems as dynamical detectors of stochastic gravitational waves

Alex Jenkins



9th LISA CosWG Workshop  
8 December 2021

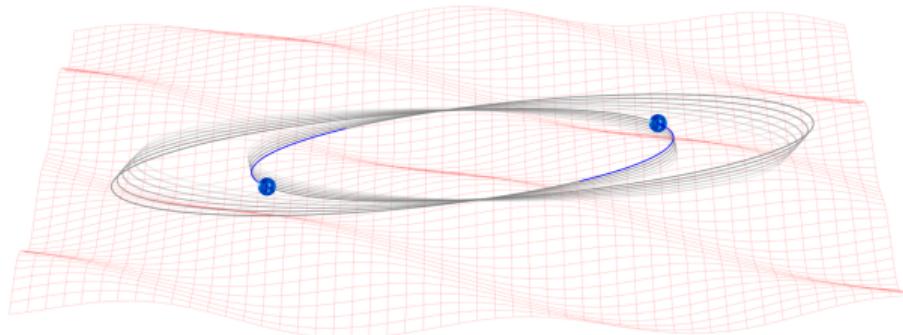
based on [2107.04601](#)+[2107.04063](#) with Diego Blas



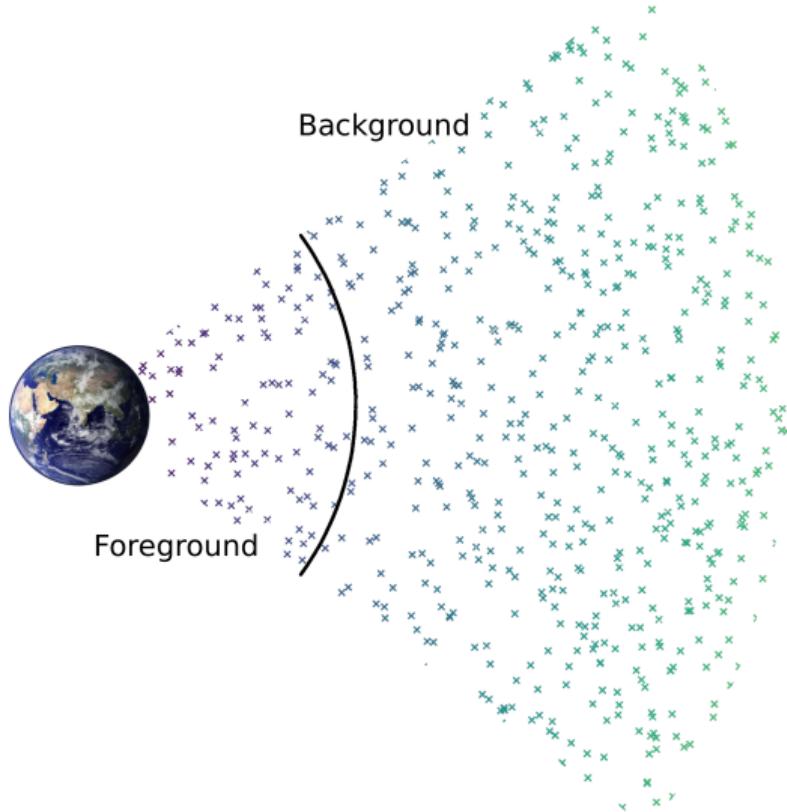
## 1 The stochastic GW background

## 2 The binary resonance mechanism

## 3 Our results



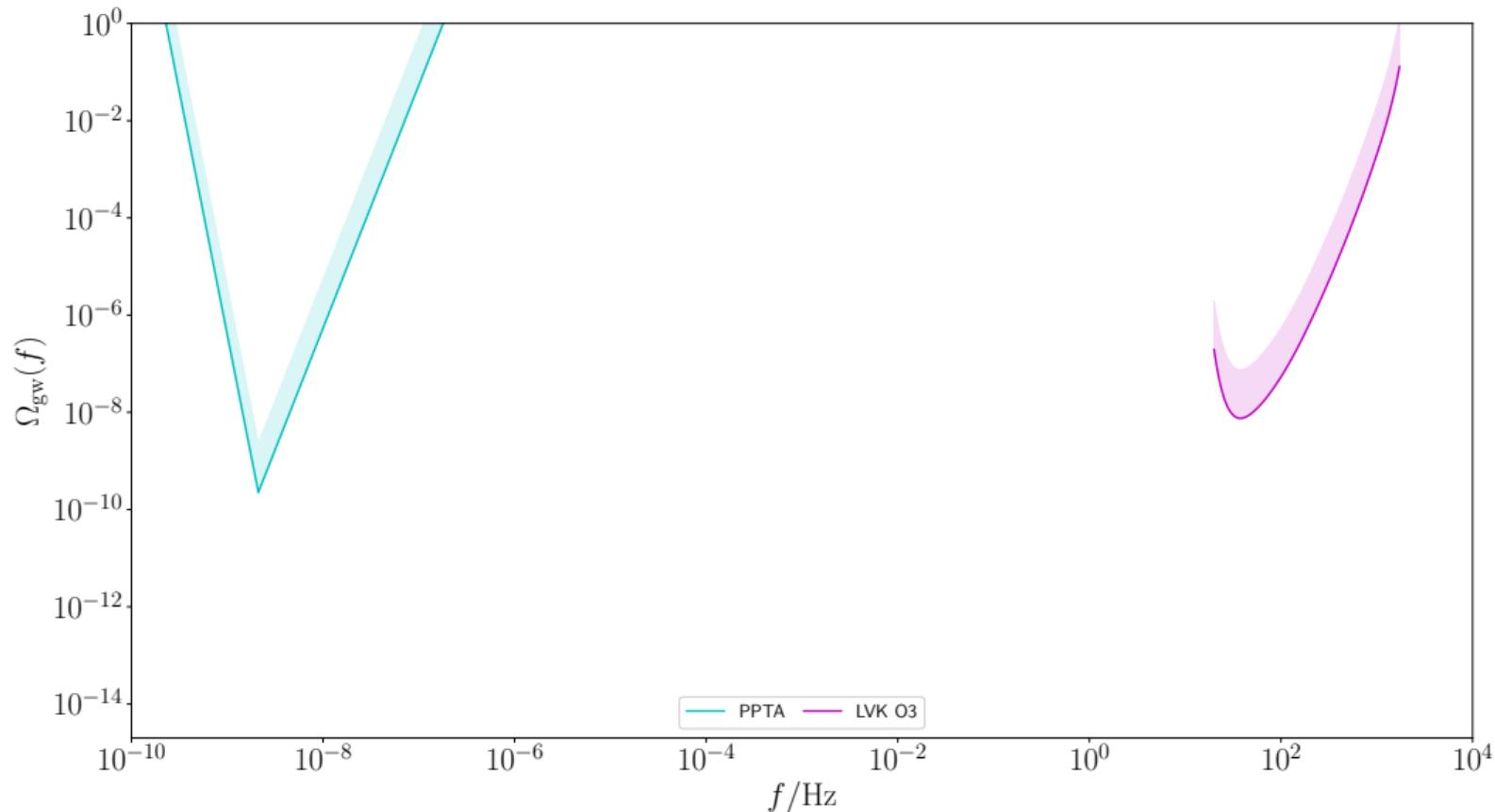
# Stochastic gravitational-wave background (SGWB)



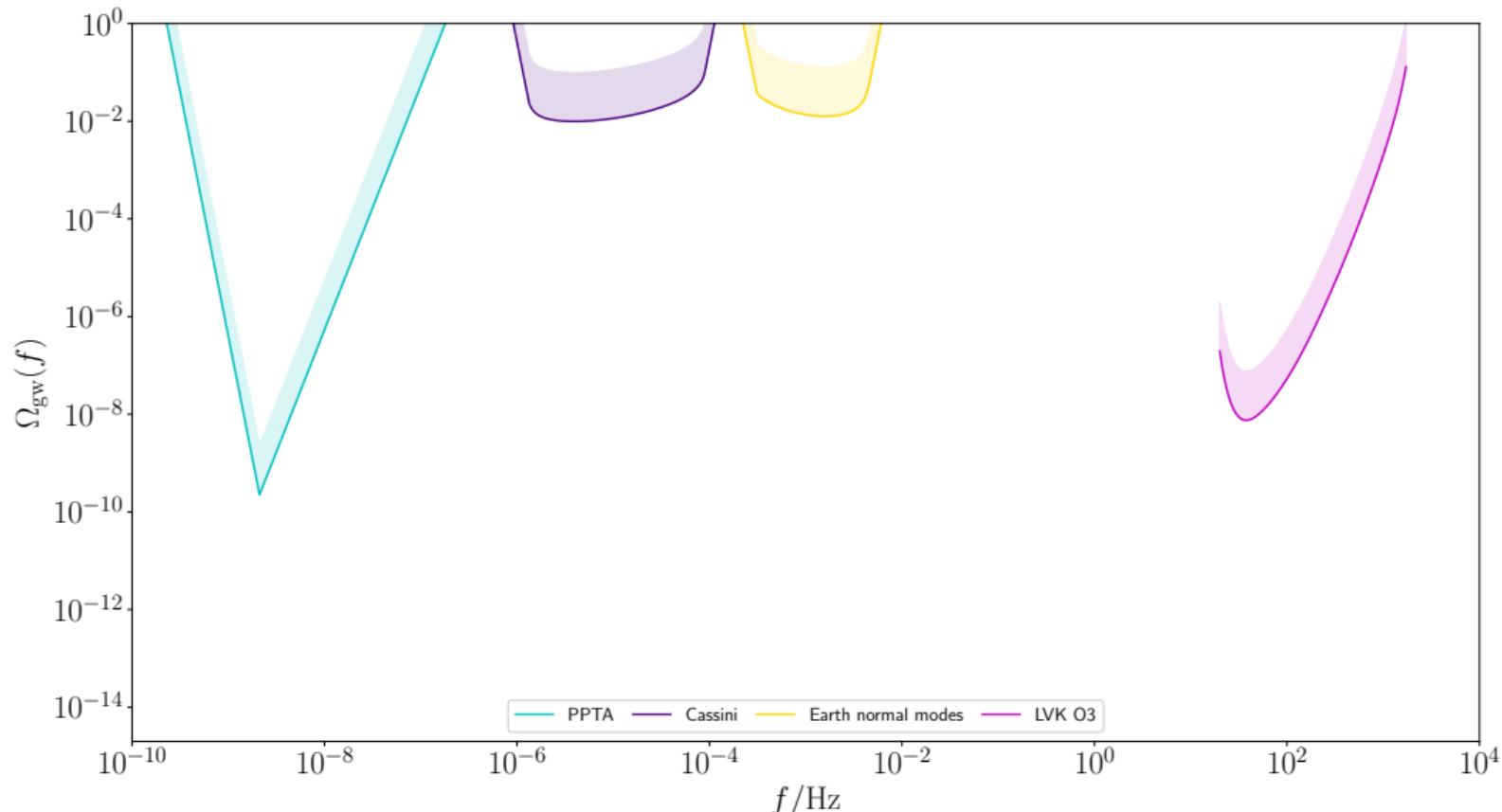
- incoherent, persistent GW signal
- faint/numerous sources
- astrophysical (compact binaries) and cosmological (inflation, cosmic strings, . . . )
- GW density parameter:

$$\Omega_{\text{GW}}(f) = \frac{1}{\rho_{\text{crit}}} \frac{d\rho_{\text{GW}}}{d(\ln f)}$$

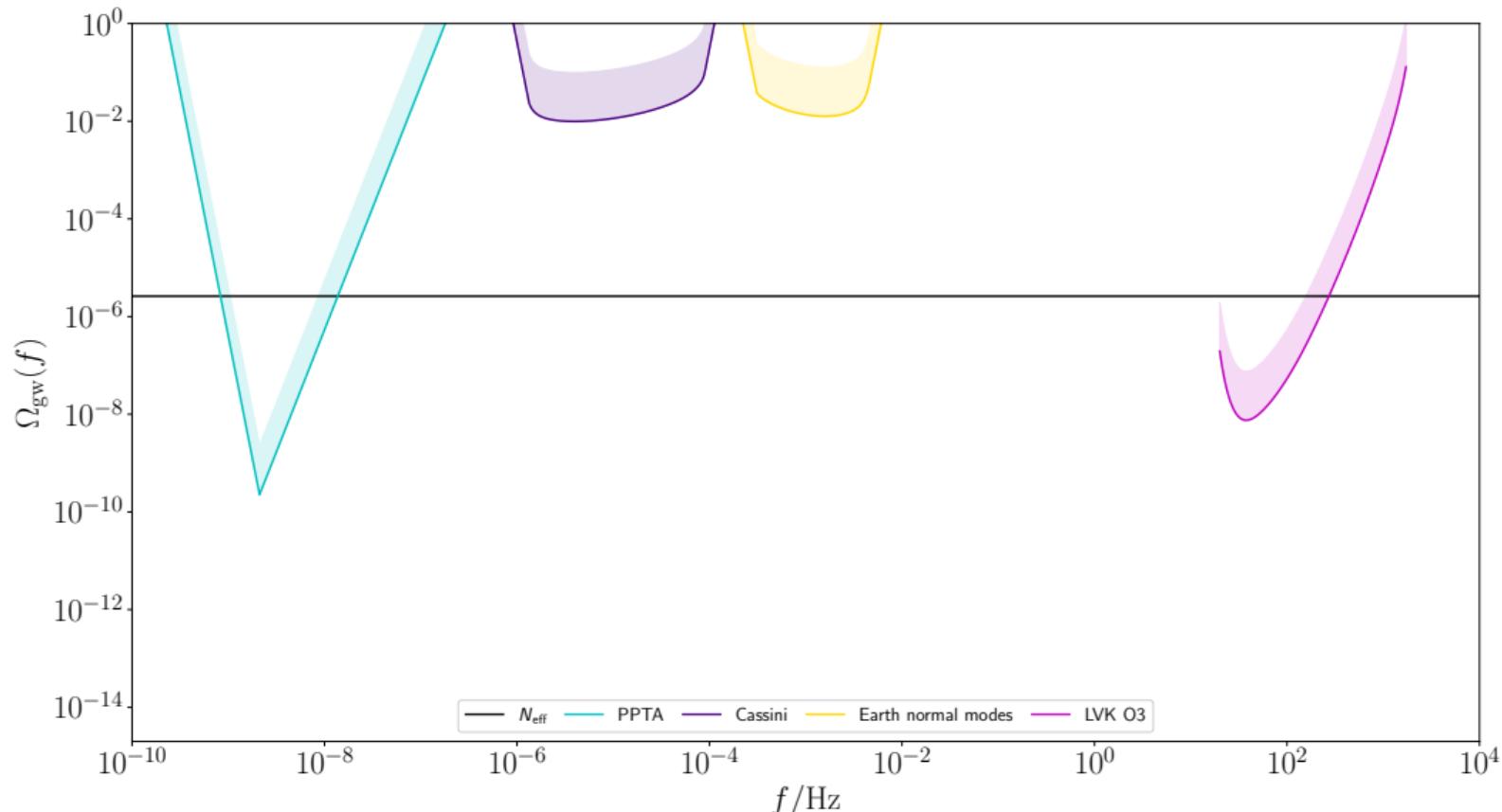
# Current SGWB constraints



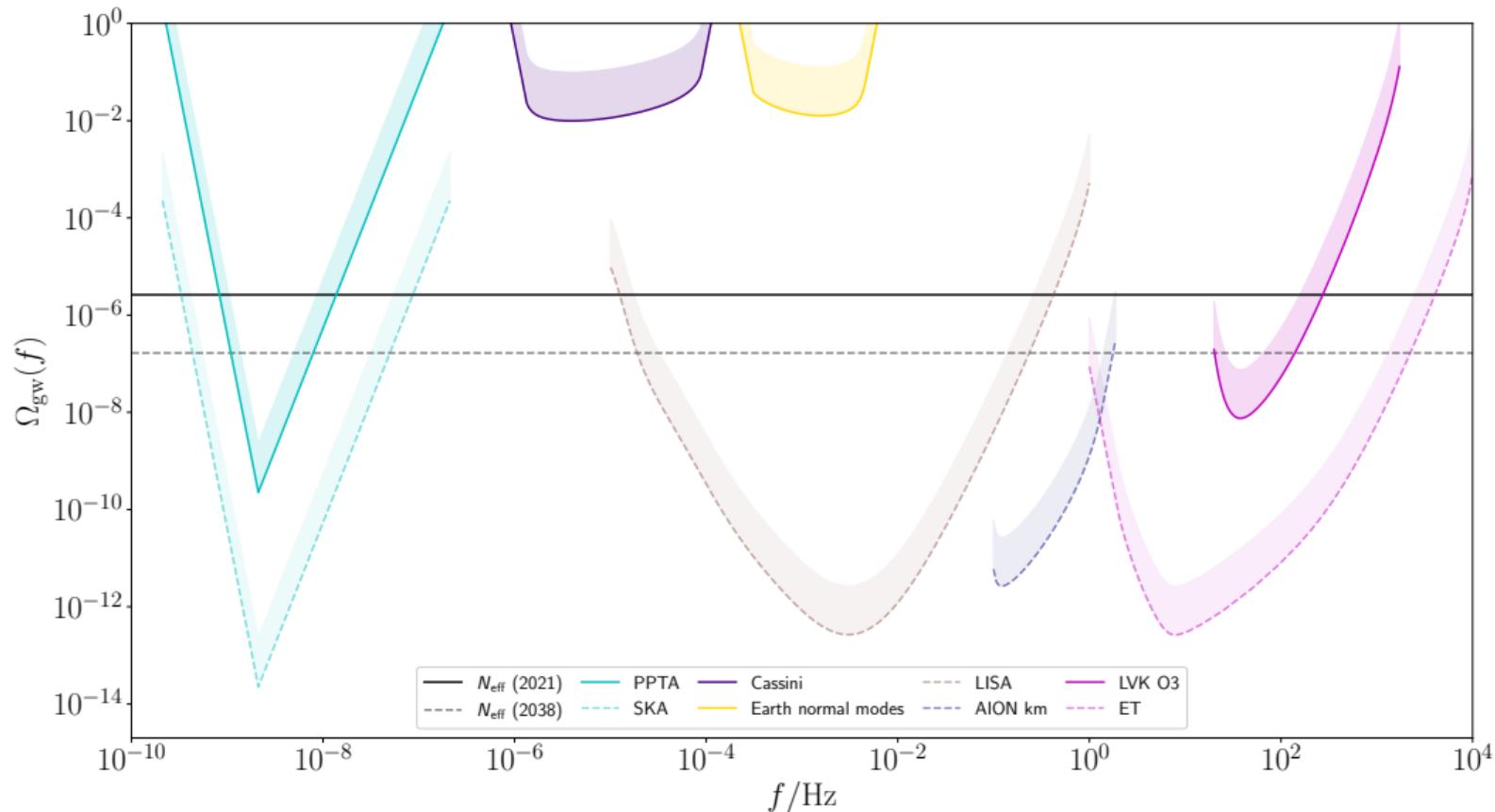
# Current SGWB constraints



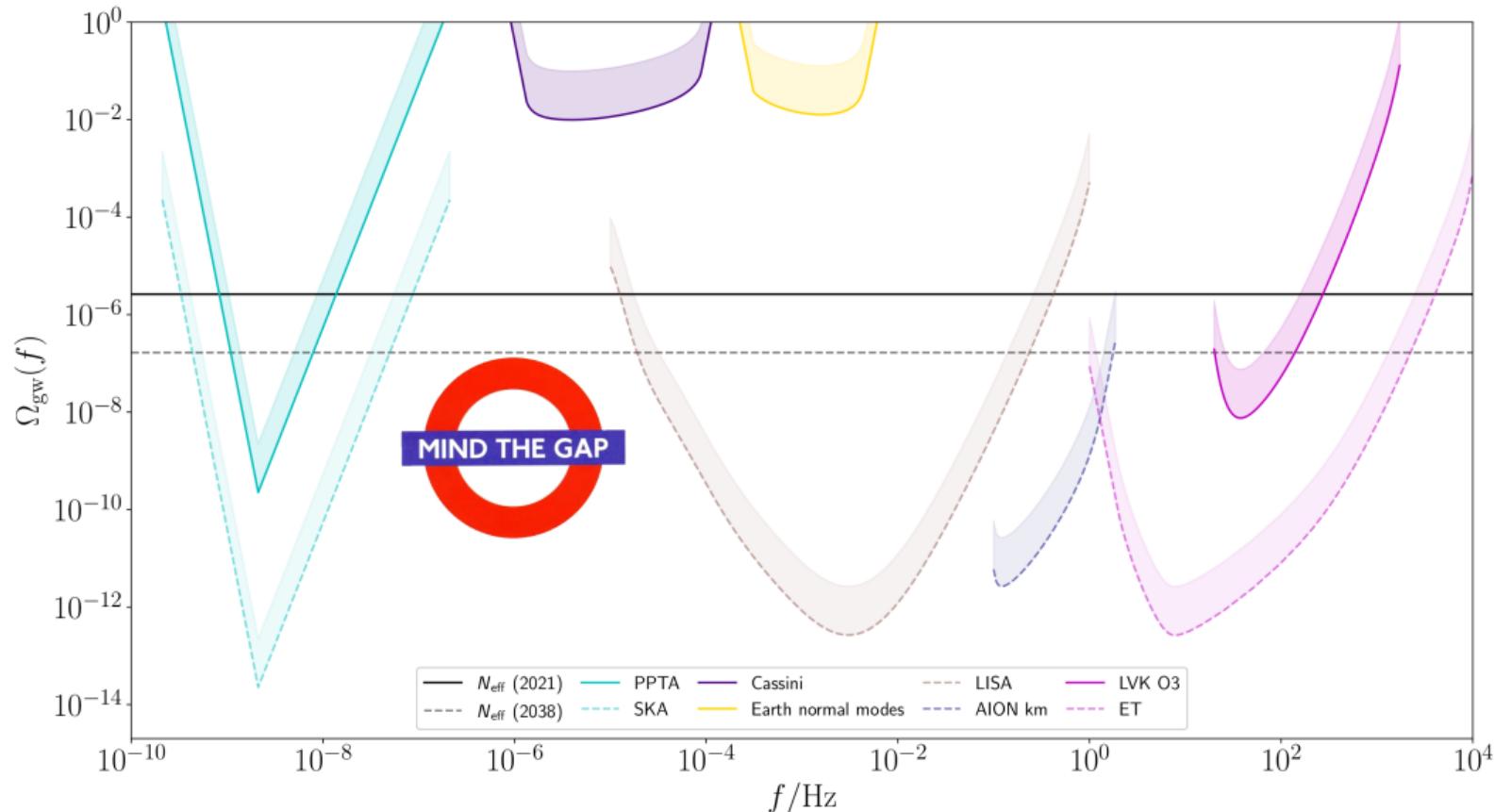
# Current SGWB constraints



# Future SGWB constraints



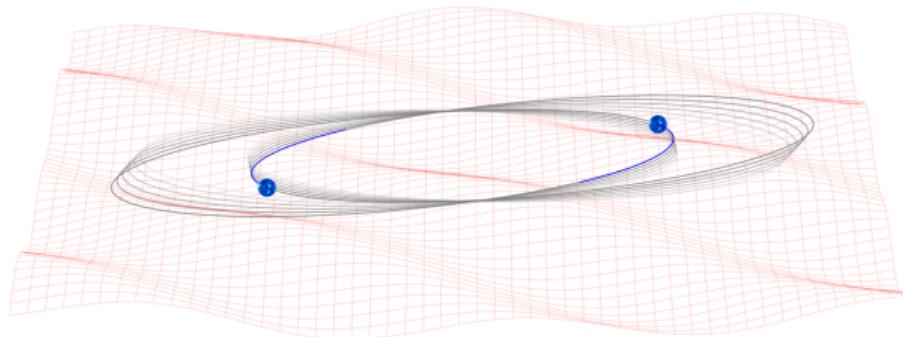
# Future SGWB constraints



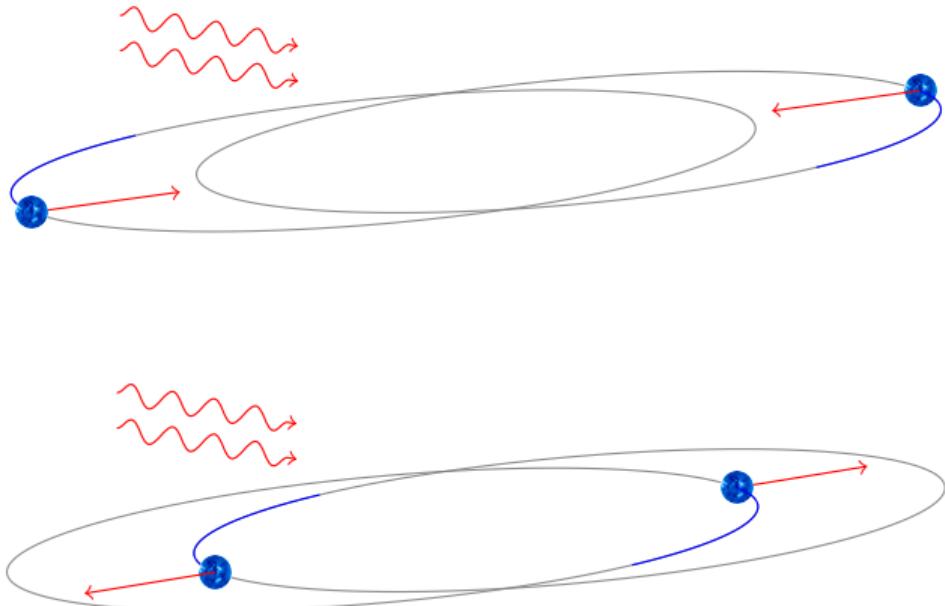
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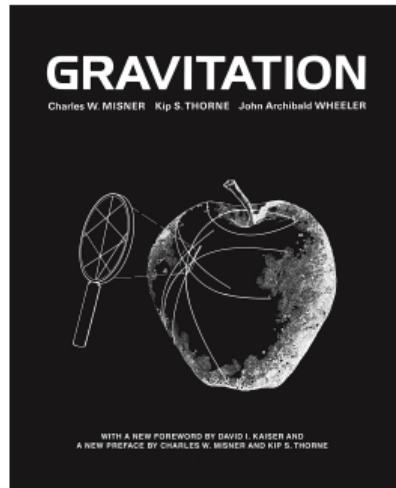
## A way forward: binary resonance



- GWs cause oscillations between orbiting bodies
- resonant for frequencies  $f = n/P$ , where  $P$  is the period
- imprints on the orbit accumulate over time

# Binary resonance: a brief history

discussed by Misner, Thorne, and Wheeler...



## 1. The Relative Motions of Two Freely Falling Bodies

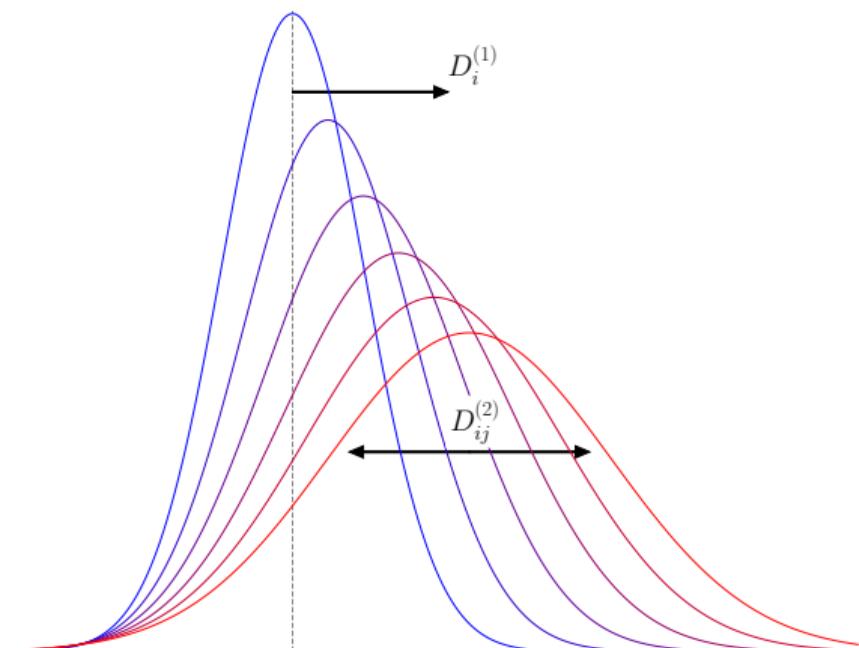
As a gravitational wave passes two freely falling bodies, their proper separation oscillates (Figure 37.3). This produces corresponding oscillations in the redshift and round-trip travel times for electromagnetic signals propagating back and forth between the two bodies. Either effect, oscillating redshift or oscillating travel time, could be used in principle to detect the passage of the waves. Examples of such detectors are the Earth-Moon separation, as monitored by laser ranging [Fig. 37.2(a)]; Earth-spacecraft separations as monitored by radio ranging; and the separation between two test masses in an Earth-orbiting laboratory, as monitored by redshift measurements or by laser interferometry. Several features of such detectors are explored in exercises 37.6 and 37.7. As shown in exercise 37.7, such detectors have so low a sensitivity that they are of little experimental interest.

...but that was *50 years ago!*

investigated more recently by Hui+ ([1212.2623](#)),  
similar ideas used to search for dark matter by Blas+ ([1612.06789](#))

**time for a closer look?**

## Our new approach



- track distribution function  $W(\mathbf{X}, t)$  of orbital elements  $\mathbf{X} = (P, e, I, \Omega, \omega, \varepsilon)$
- evolves through *Fokker-Planck eqn.*

$$\frac{\partial W}{\partial t} = -\frac{\partial}{\partial \mathbf{X}_i} (D_i^{(1)} W) + \frac{\partial}{\partial \mathbf{X}_i} \frac{\partial}{\partial \mathbf{X}_j} (D_{ij}^{(2)} W)$$

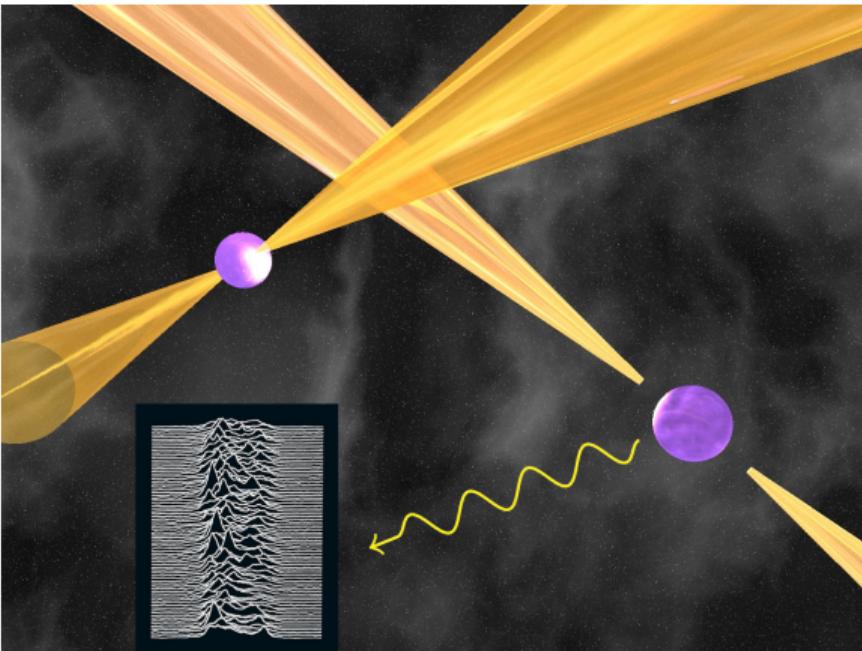
- *drift* and *diffusion* coefficients

$$D_i^{(1)}(\mathbf{X}) = V_i(\mathbf{X}) + \sum_{n=1}^{\infty} \mathcal{A}_{n,i}(\mathbf{X}) \Omega_{\text{gw}}(n/P)$$

$$D_{ij}^{(2)}(\mathbf{X}) = \sum_{n=1}^{\infty} \mathcal{B}_{n,ij}(\mathbf{X}) \Omega_{\text{gw}}(n/P)$$

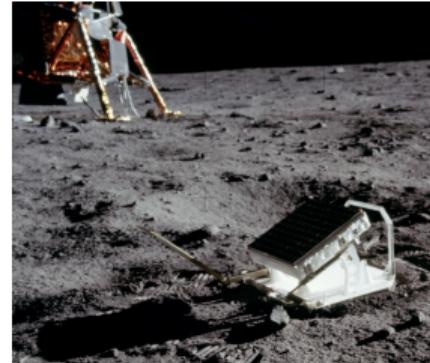
## Two binary probes

timing of binary pulsars



(pulsar animation credit: Michael Kramer)

lunar and satellite laser ranging



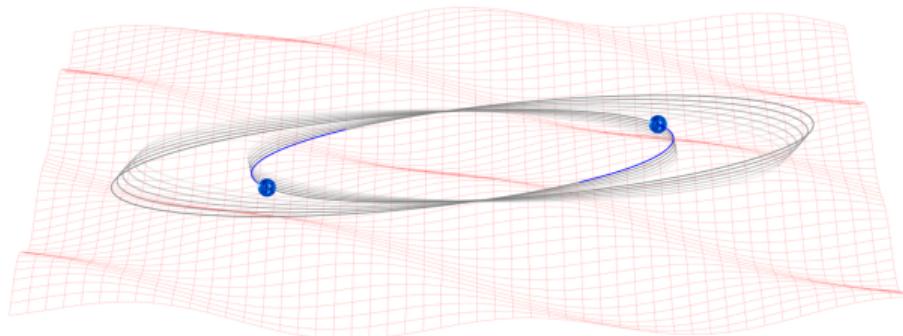
(image credit: NASA)

these data will be taken anyway—we get GW constraints “for free”!

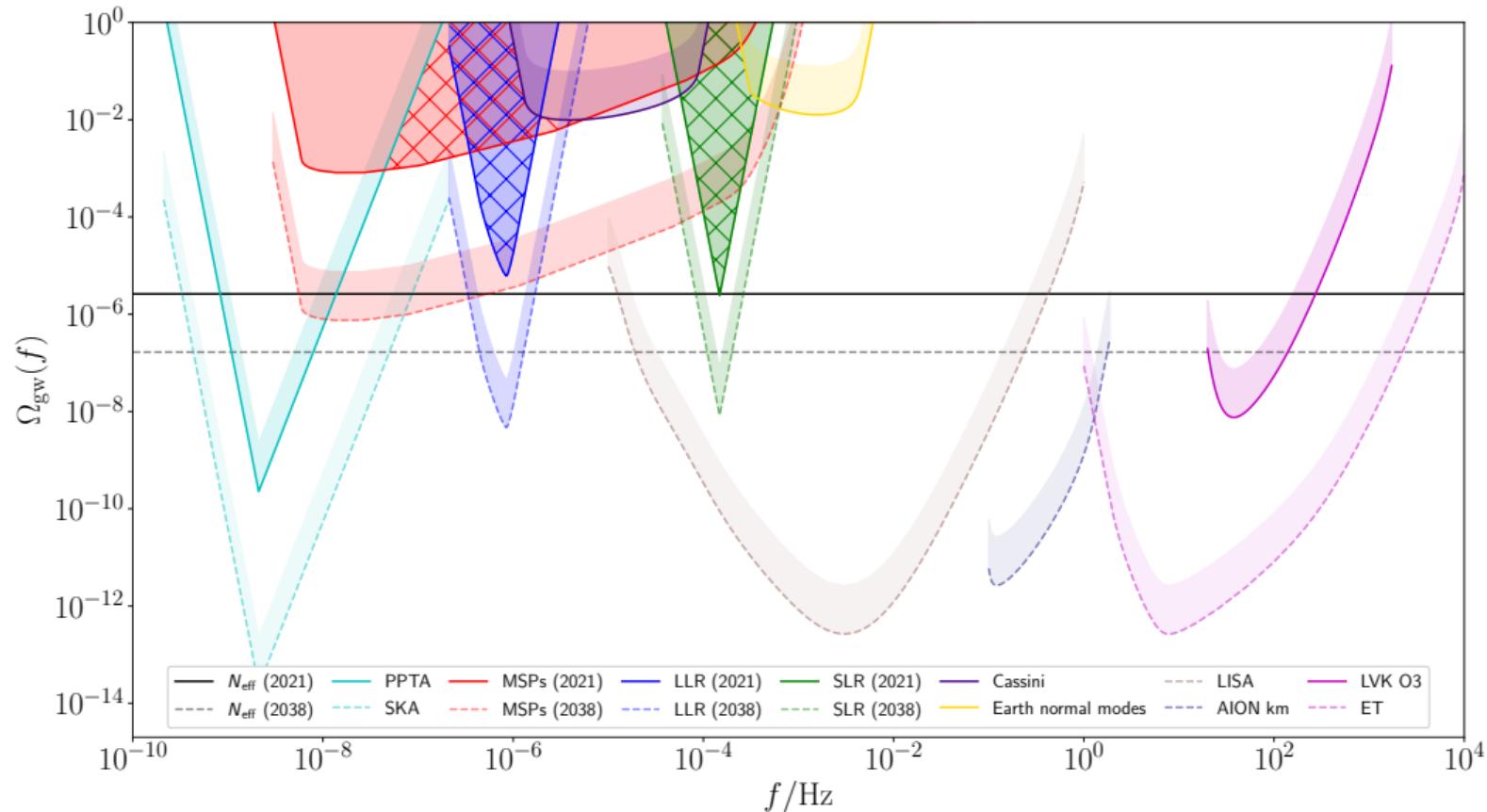
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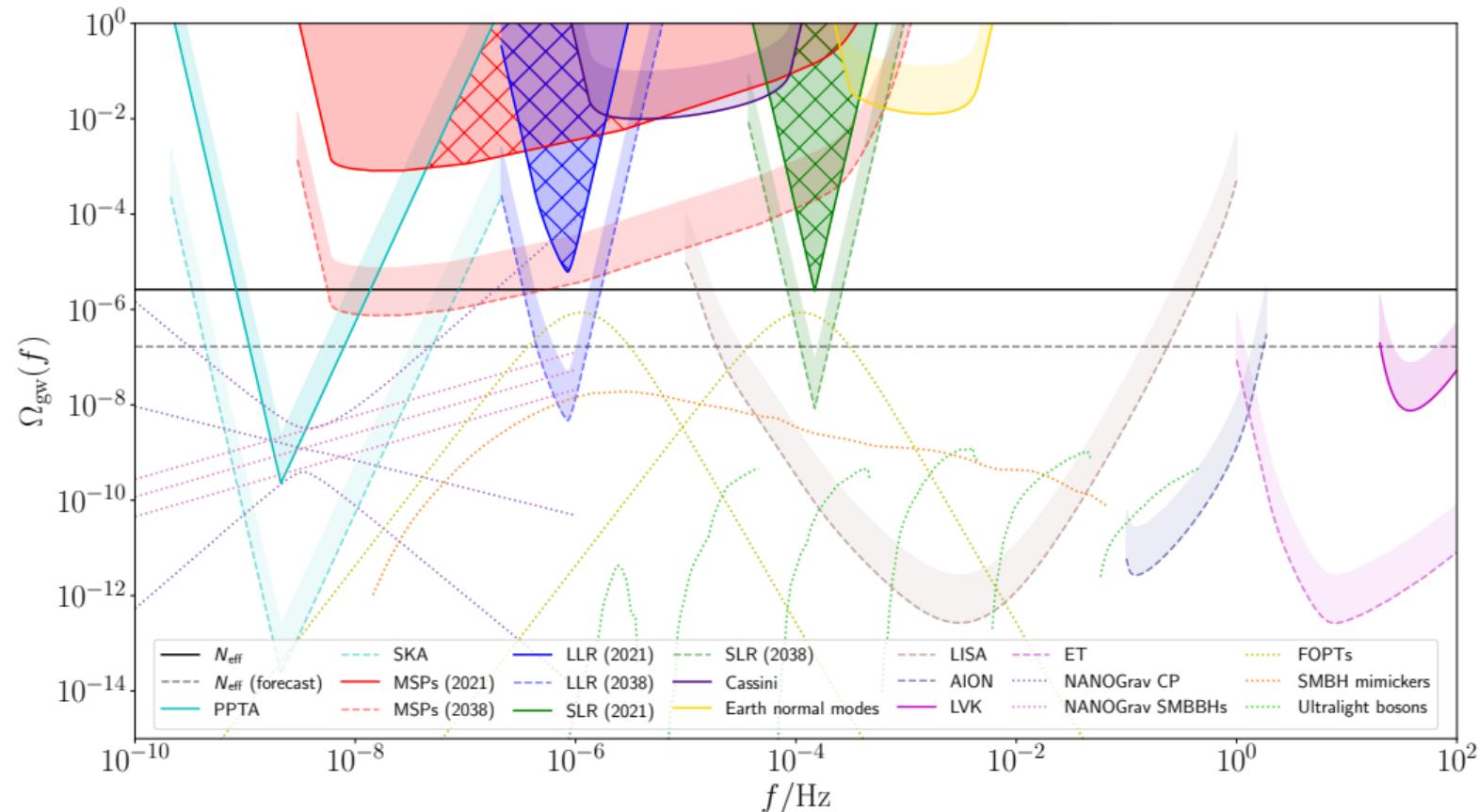
3 Our results



# Our forecast constraints

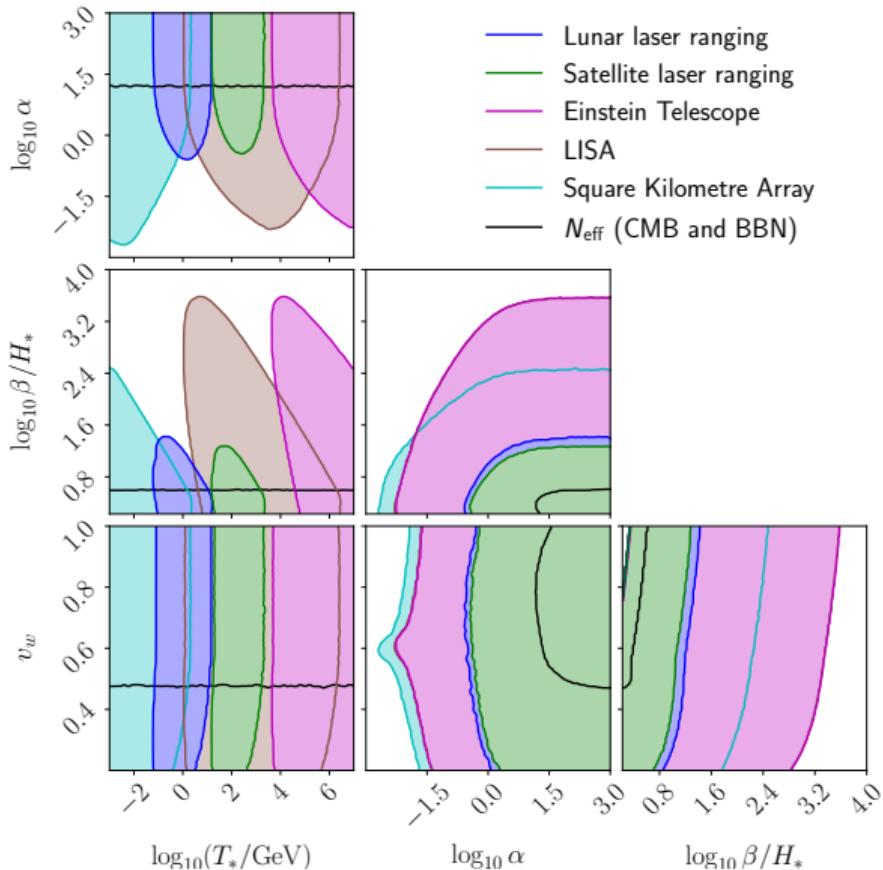


# Signals in the $\mu\text{Hz}$ band



# Phase transition constraints

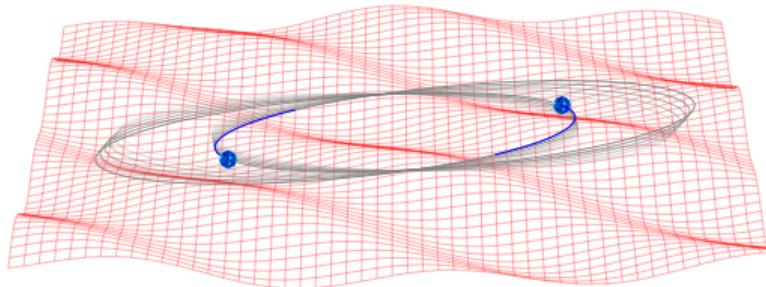
- LLR can access a unique region of parameter space!
- SLR might provide an independent confirmation of a LISA detection



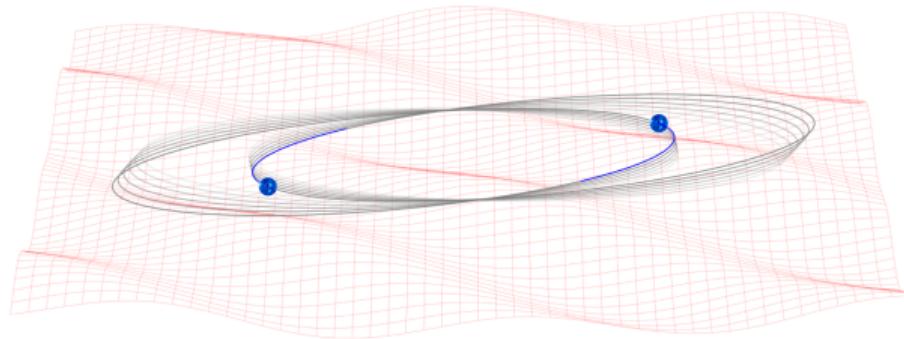
## Summary and outlook

- binary resonance can probe a unique GW frequency band
- we have developed a powerful new formalism
- unique constraints on phase transitions (and more)
- great synergies with LISA
- plenty more work to do! more signals, more systems, plus running on real data

*thanks for listening!*

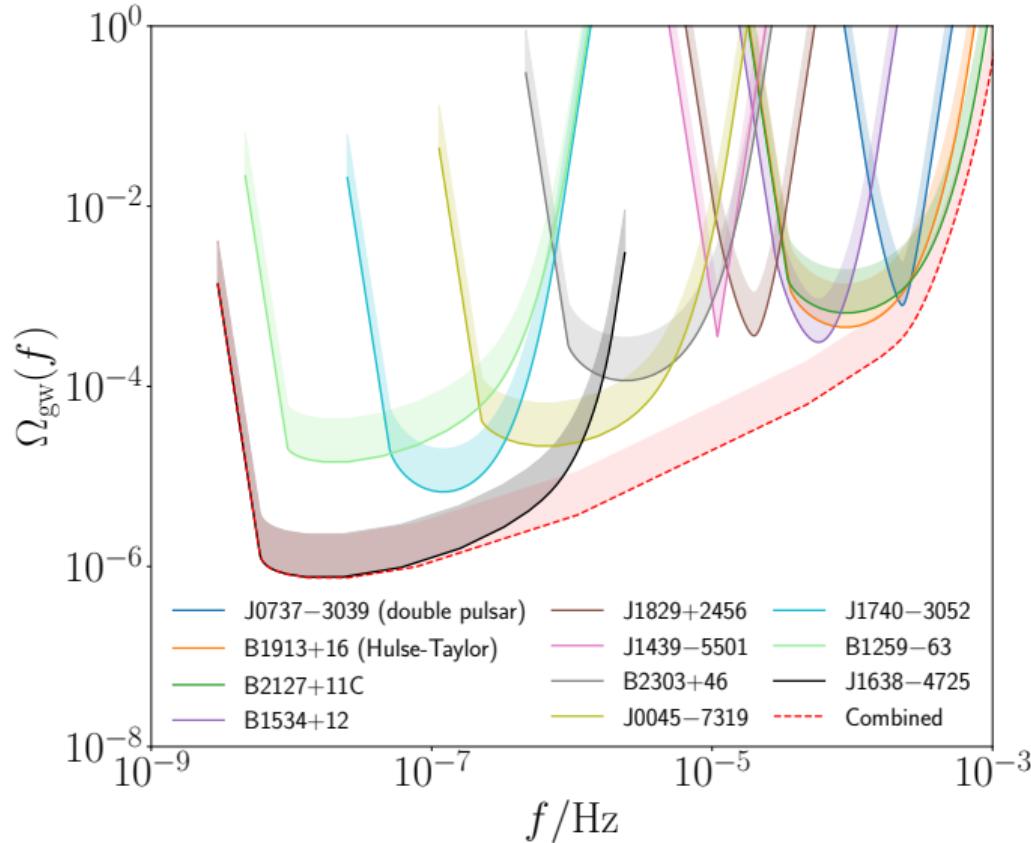


## Backup Slides



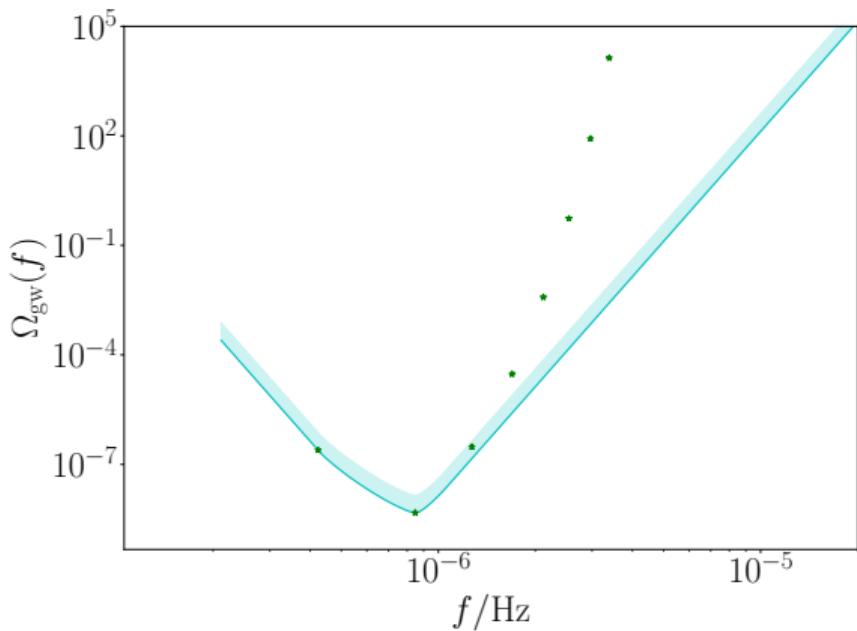
# Combining binary pulsar bounds

- red curve (same as previous slide) uses 215 binaries from the ATNF pulsar catalogue
- constraint driven by just a handful of systems

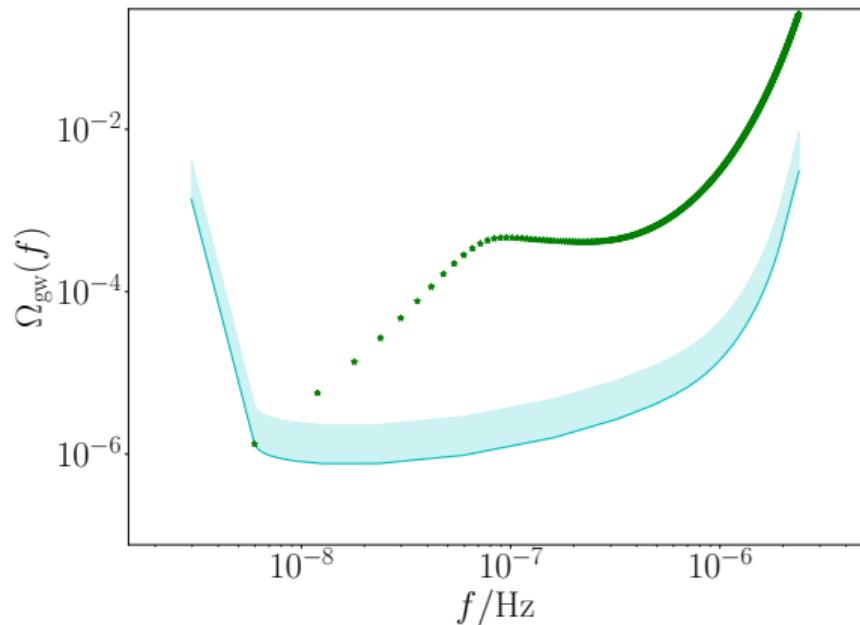


# Power-law sensitivity vs. monochromatic sensitivity

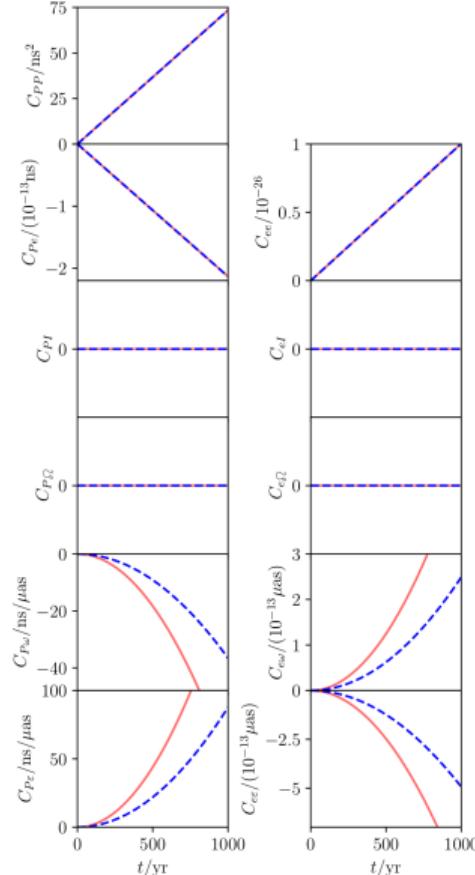
lunar laser ranging,  $e \approx 0.055$



pulsar timing (J1638-4725),  $e \approx 0.955$



# Example: the Hulse-Taylor binary



each box shows one element of the covariance matrix evolving over time

