# Gravitational waves from supermassive black hole binaries

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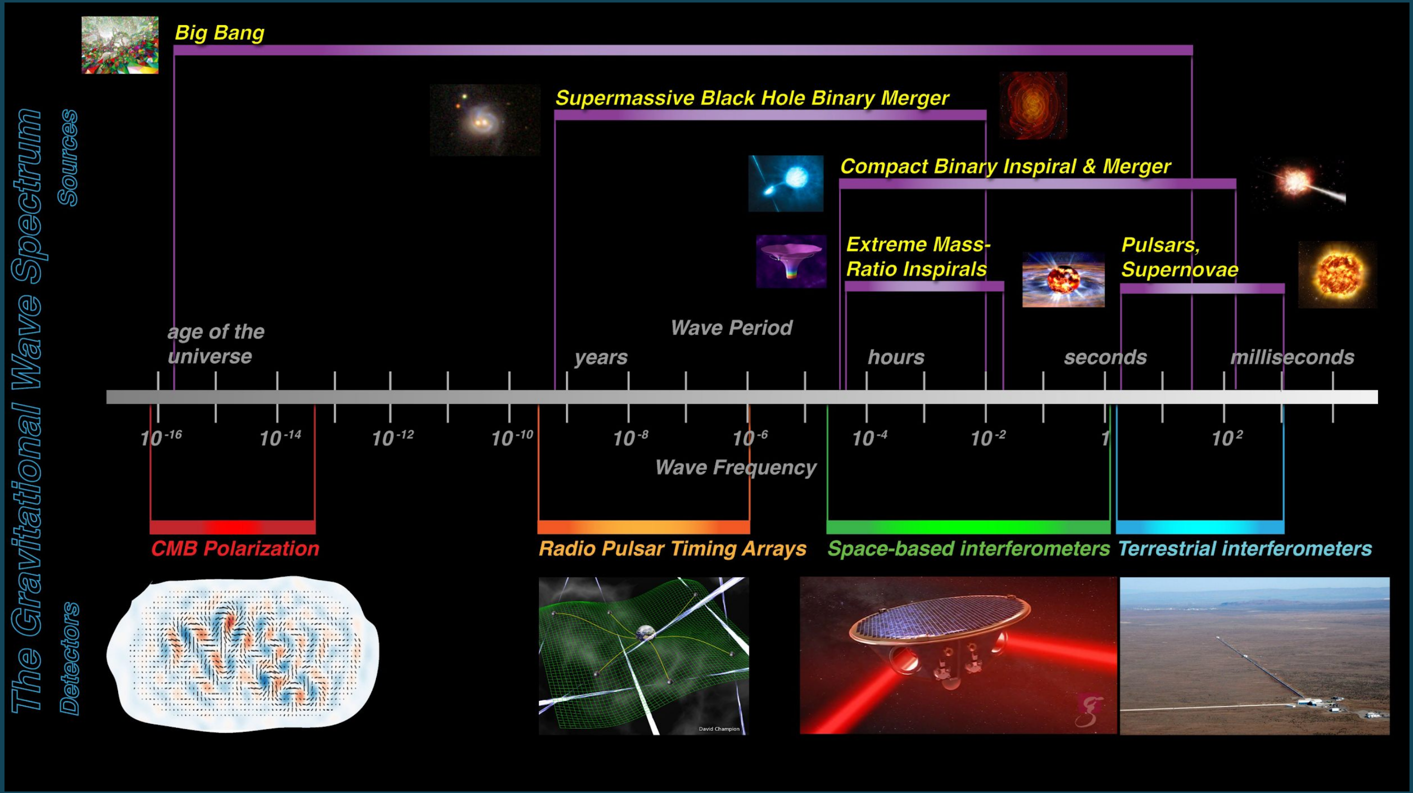
# Overview

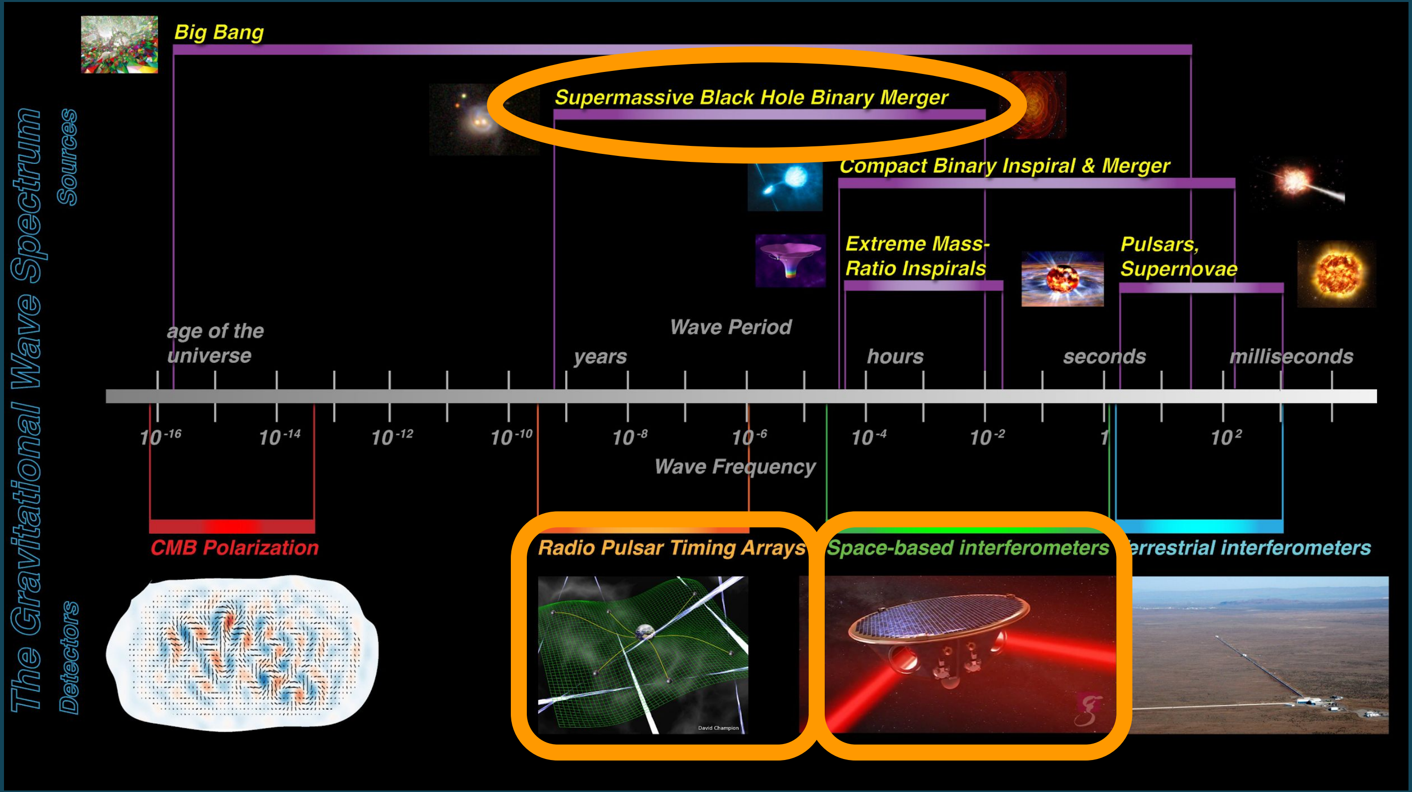
- Gravitational wave spectrum
- Pulsar timing arrays & massive black hole binaries
- LISA & massive black hole binaries
- The future is multi-band!

# Gravitational wave spectrum




[Image: NASA/J. I.Thorpe]

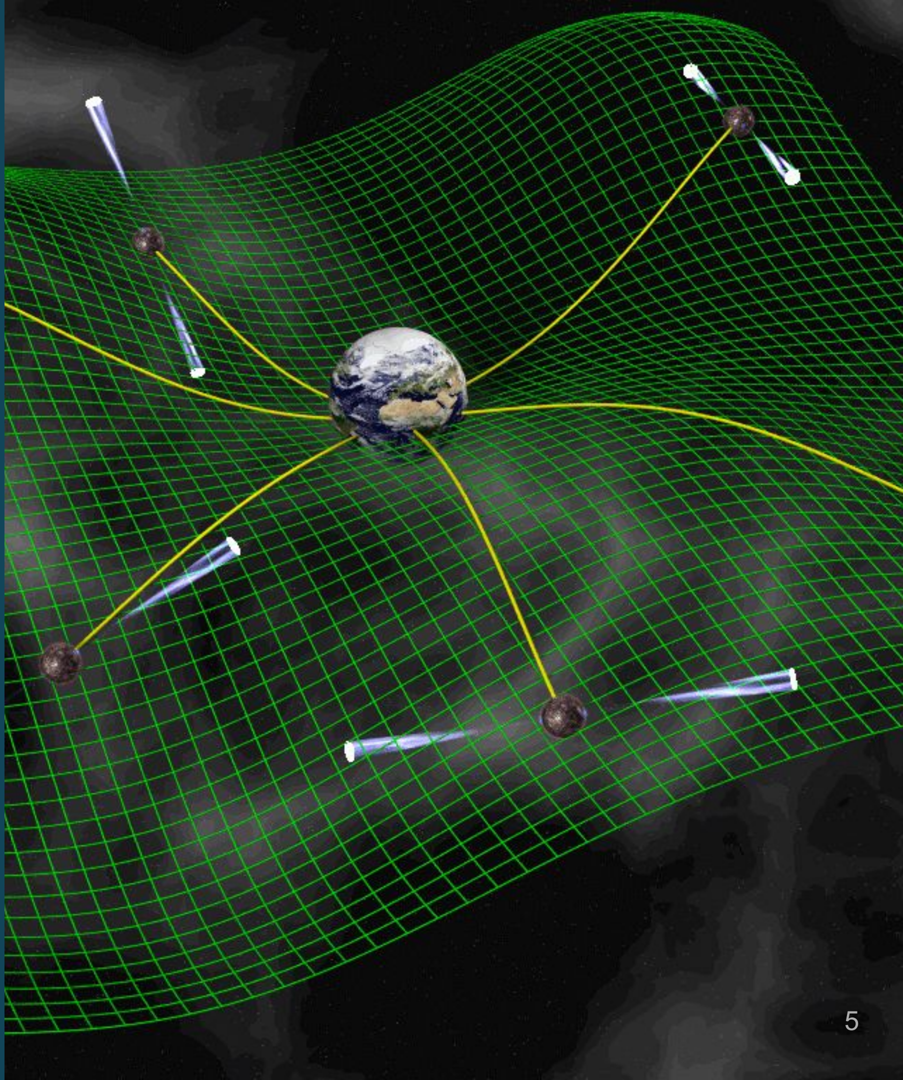
# Gravitational wave spectrum




[Image: NASA/J. I.Thorpe]

# Low frequency

*Pulsar timing arrays*



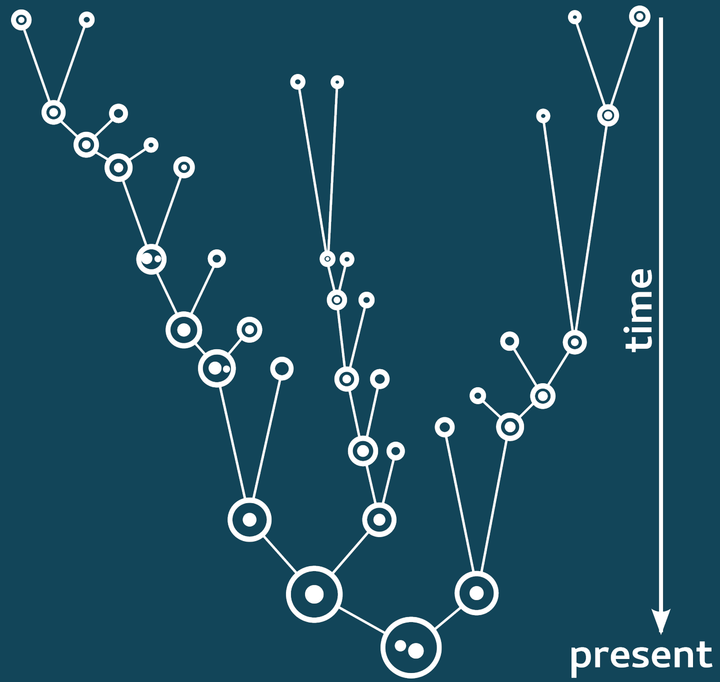
[Image: D. Champion]

# Massive black hole binaries

Expect there to be massive black hole binary mergers throughout cosmic history.

-> A population of merging systems.

-> Gravitational wave background.

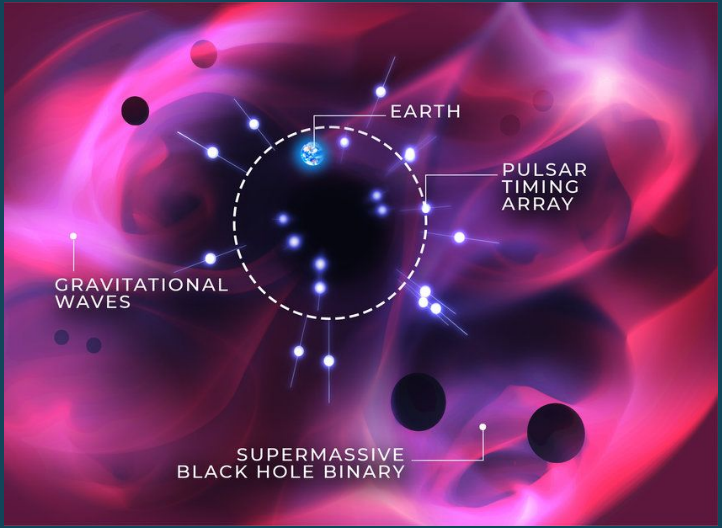


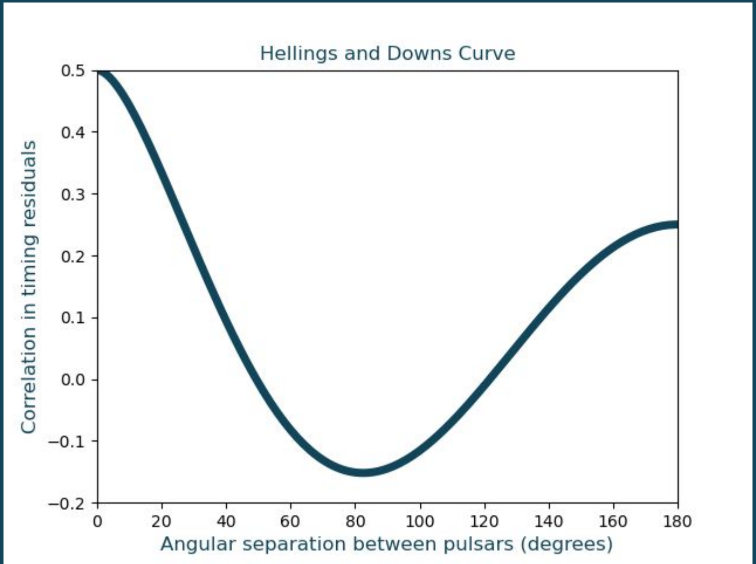

[Images: Galaxies: NASA. Merger tree: M. Volonteri (adapted).]

# Pulsar timing arrays

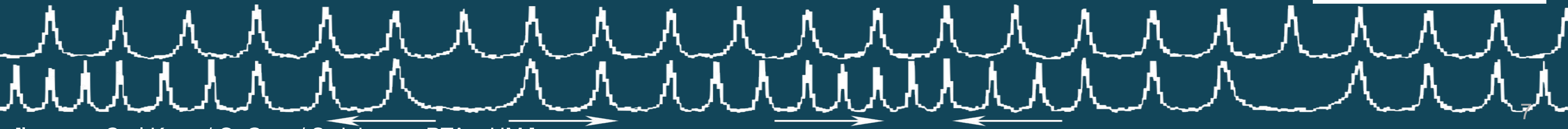
Search for changes in pulse time of arrivals from array of pulsars.

**PTA GW search papers**
Antoniadis+2021 (IPTA)
Arzoumanian+2020 (NANOGrav)
Chen+2021 (EPTA)
Goncharov+2021 (PPTA)




IPTA EPTA PPTA NANOGrav InPTA MEERTIME CPTA



[Images: Carl Knox / OzGrav / Swinburne. PTAs. HM.]

# Current pulsar timing array results

Common red noise process.

Seen by IPTA, PPTA, NANOGrav & EPTA.

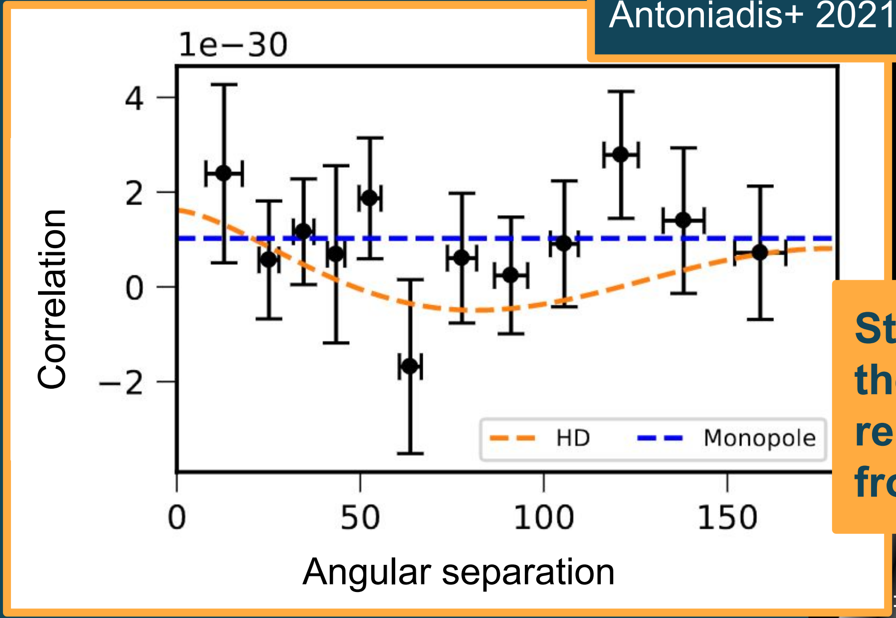
**IPTA Results:**

Assuming a spectral index:

$$\alpha = -2/3$$

consistent with a population of inspiraling massive black hole binaries, the amplitude is:

$$A = 2.8^{+1.2}_{-0.8} \times 10^{-15}$$




Results from IPTA second data release Antoniadis+ 2021

**Stay tuned for the next data release results from the PTAs**

: HM]

# A hint of gravitational waves?

*If we assume that the observed common noise process is a real gravitational wave signal, what could we learn from it?*

**Two parameterised models:**

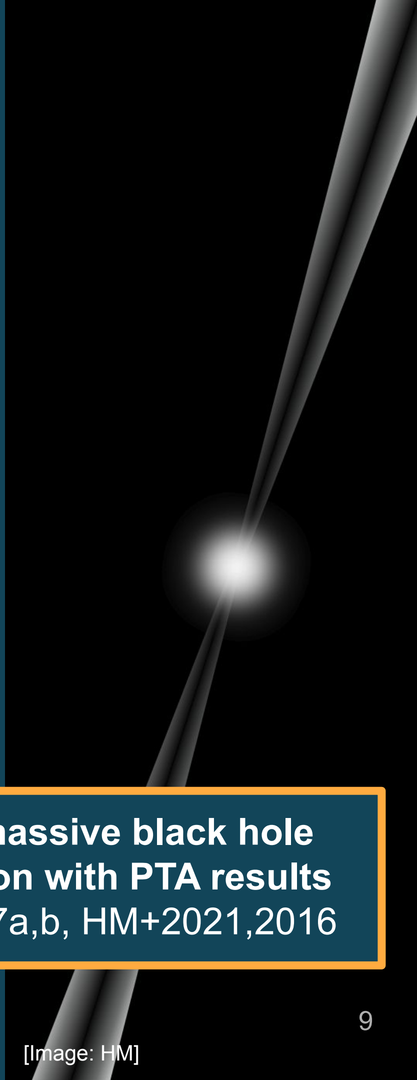
1. **Minimal assumptions (agnostic)**
2. **Astrophysically informed**

**Results from pulsar timing arrays**

**Bayesian analysis**

**Place constraints on population model parameters**

**Inferences on massive black hole binary population with PTA results**
Chen+2019,2017a,b, HM+2021,2016



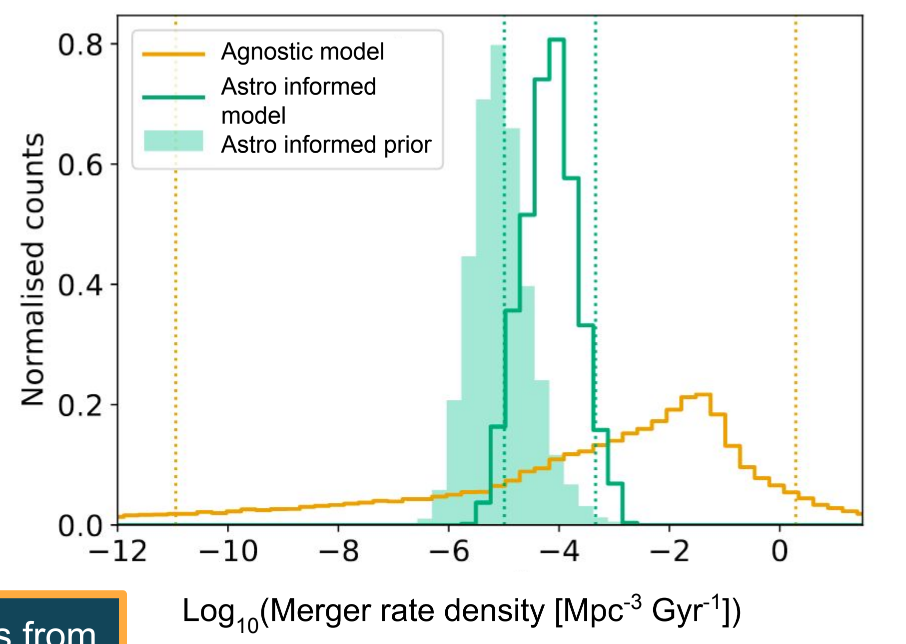
[Image: HM]

# Learning about massive black hole binaries with PTAs

The merger rate density is at the higher end of that allowed by the astro-informed model.

Other constraints from astro-informed model:

- Prefer higher masses
- Prefer shorter merger timescales




Results from HM+2021

# Mid frequency

*Space-based detector*

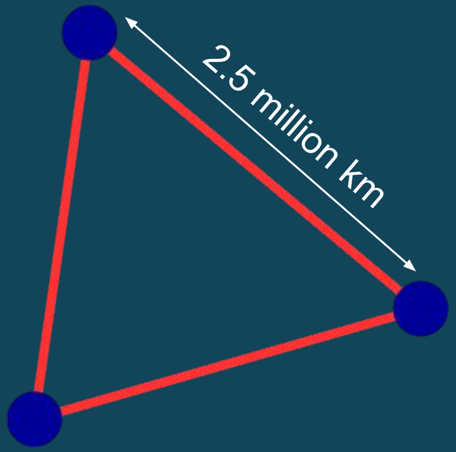
*LISA:*
*Laser Interferometer Space Antenna*

[Image: AEI/MM/exozet]

# LISA

Large-scale space mission led by European Space Agency (ESA).

Launch in ~ mid 2030’s.




**Aiming for ESA adoption later this year / early next year**

## What will LISA observe?

Living Review: Amaro-Seoane+ 2023
***Astrophysics the Laser Interferometer Space Antenna***

**Galactic binaries**
e.g. Kupfer+2023, Finch+2022

**Stellar mass black hole binaries**
e.g. Klein+2022, Sesana 2016

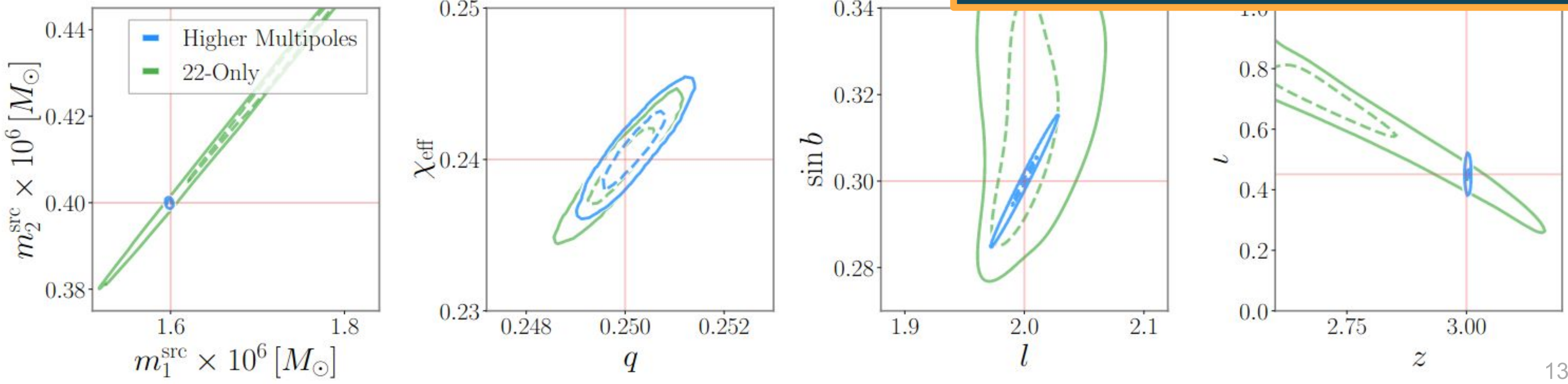
**Massive black hole binaries**
e.g. Steinle+2023 (in prep), Pratten+2022, Mangiagli+2020

**Extreme mass ratio inspirals (EMRIs)**
e.g. Amaro-Seoane 2021, Berry+2019

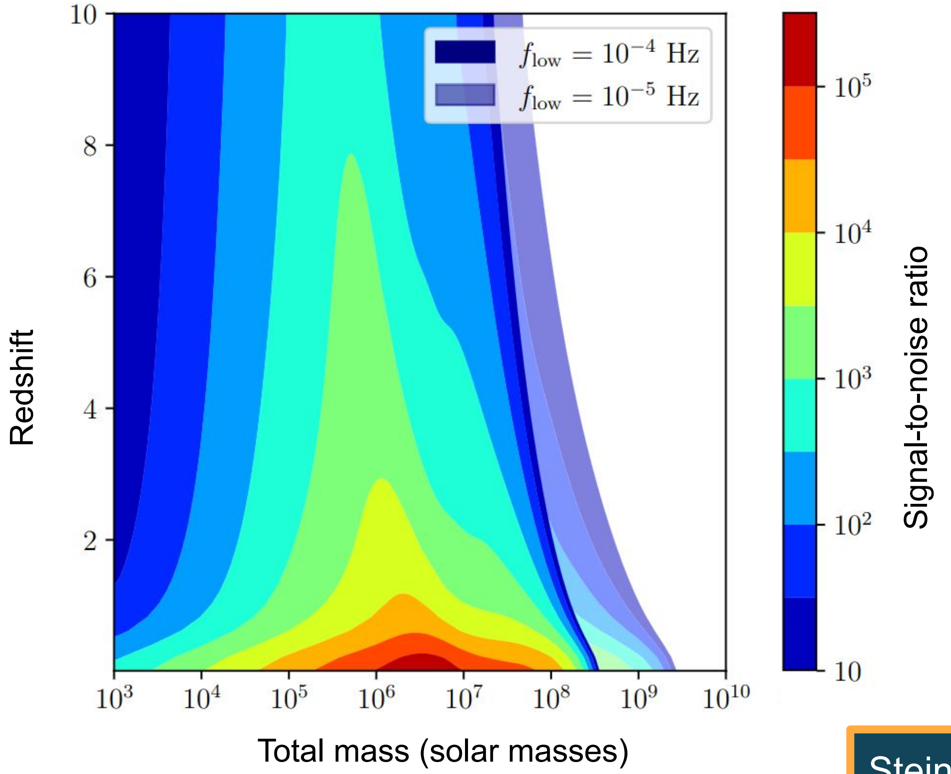
# Observing black hole binaries with LISA

Testing parameter estimation with black hole binaries in LISA.

**Results from Pratten+2022.**
Using `Balrog`, a software package for LISA data analysis being developed in Birmingham.
See e.g. Roebber+2020, Buscicchio+2021



# Observing black hole binaries with LISA

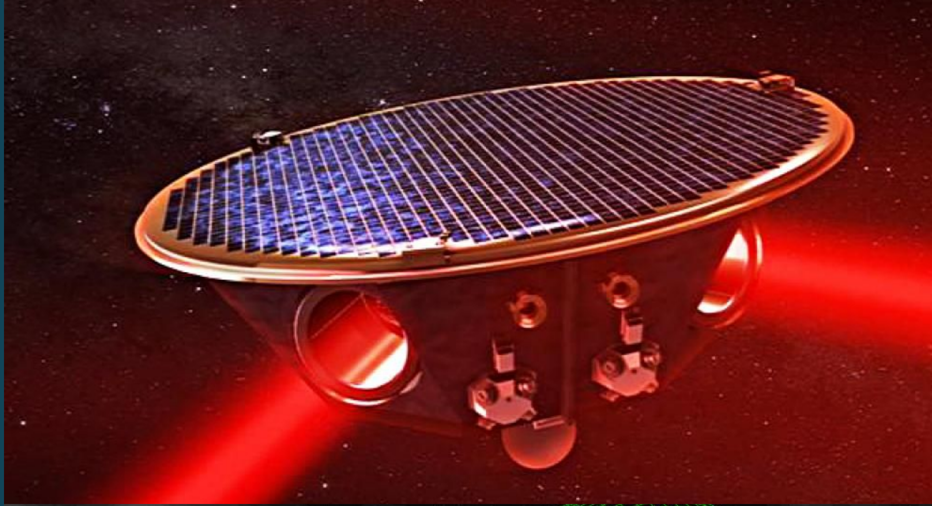


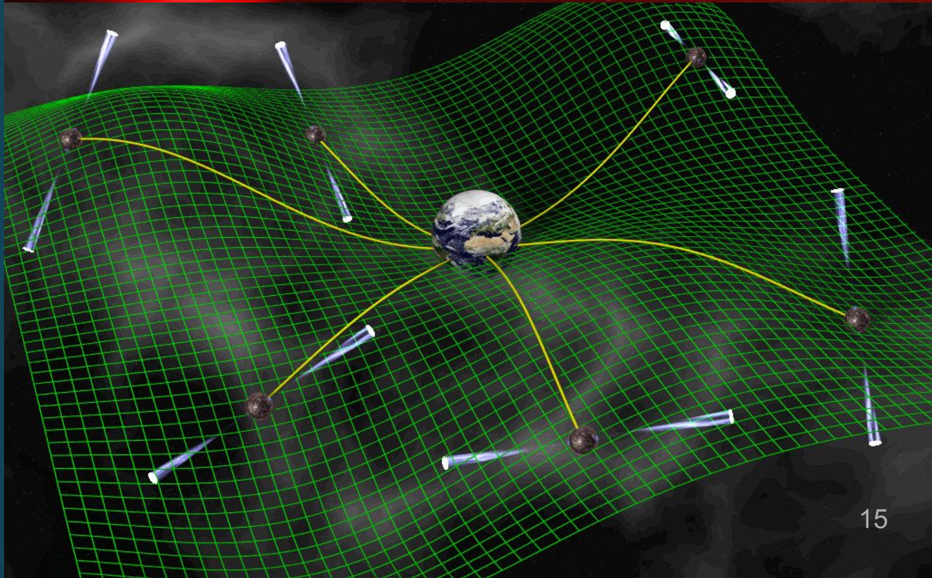

LISA sensitivity to massive black hole binaries.

Higher mass overlap with possible PTA sources.

Steinle,HM+2023 (in prep).

# Multiband with LISA and PTAs





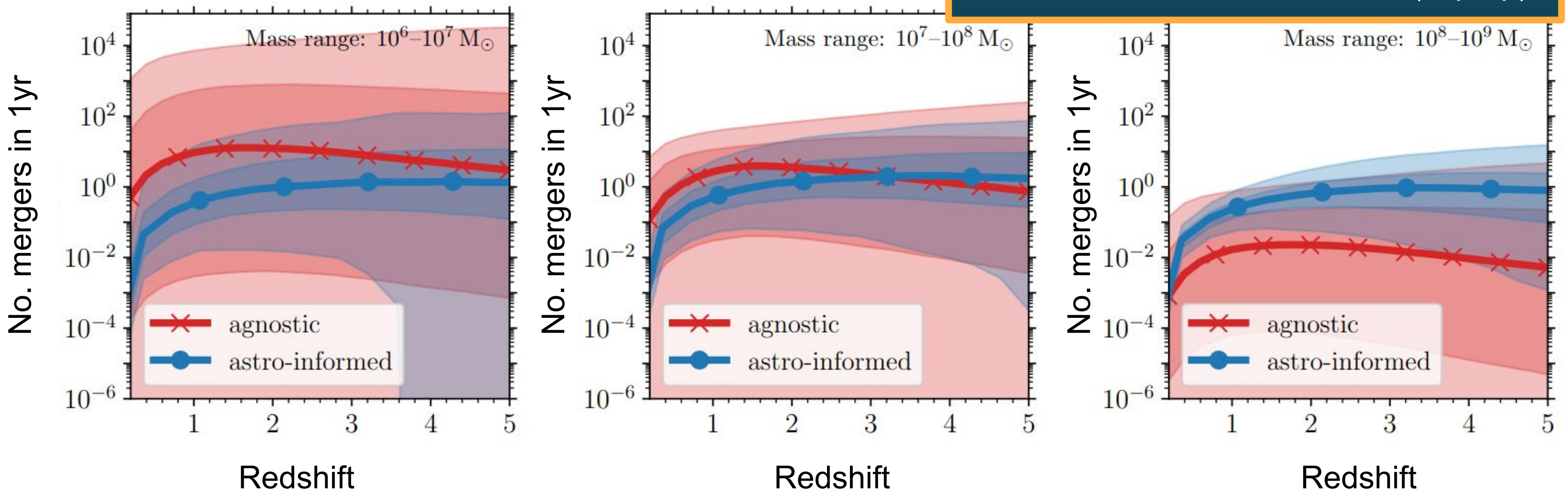
[Image: LISA: AEI/MM/exozet. PTA: D. Champion.]

# Combining LISA & PTA results

Using the two population models & PTA results, how many mergers in 1 year?

**Again, we make the assumption that the speculative PTA signal is a detection.**

Results from Steinle, HM+2023 (in prep).



# What does this mean for LISA?

- Compute number of mergers in 1 year
- What fraction are detectable?
  - Using Balrog data analysis software
- Estimate ranges for number of mergers LISA might see in 1 year:

| Total mass range: | $10^6$–$10^7 M_\odot$ 5–95% credible range (median) | $10^7$–$10^8 M_\odot$ 5–95% credible range (median) | $10^8$–$10^9 M_\odot$ 5–95% credible range (median) |
|---|---|---|---|
| Agnostic model | 0–82700 (median: 75) | 0–434 (median: 15) | 0–2 (median: ~0.2) |
| Astro-informed model | 0–391 (median: 5) | 0–134 (median: 6) | 0–1 (median: ~0) |

Results from Steinle, HM+2023 (in prep).

# Summary

- Pulsar timing arrays will provide insights to the massive black hole binary population.
- LISA will observe the merger of individual signals.
- The future is multi-band!

***Thank you!***


**A few references**

Amaro-Seoane+2023,Living Rev. Relativ. 26 <10.1007/s41114-022-00041-y>
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Steinle, HM+2023, *in prep.*