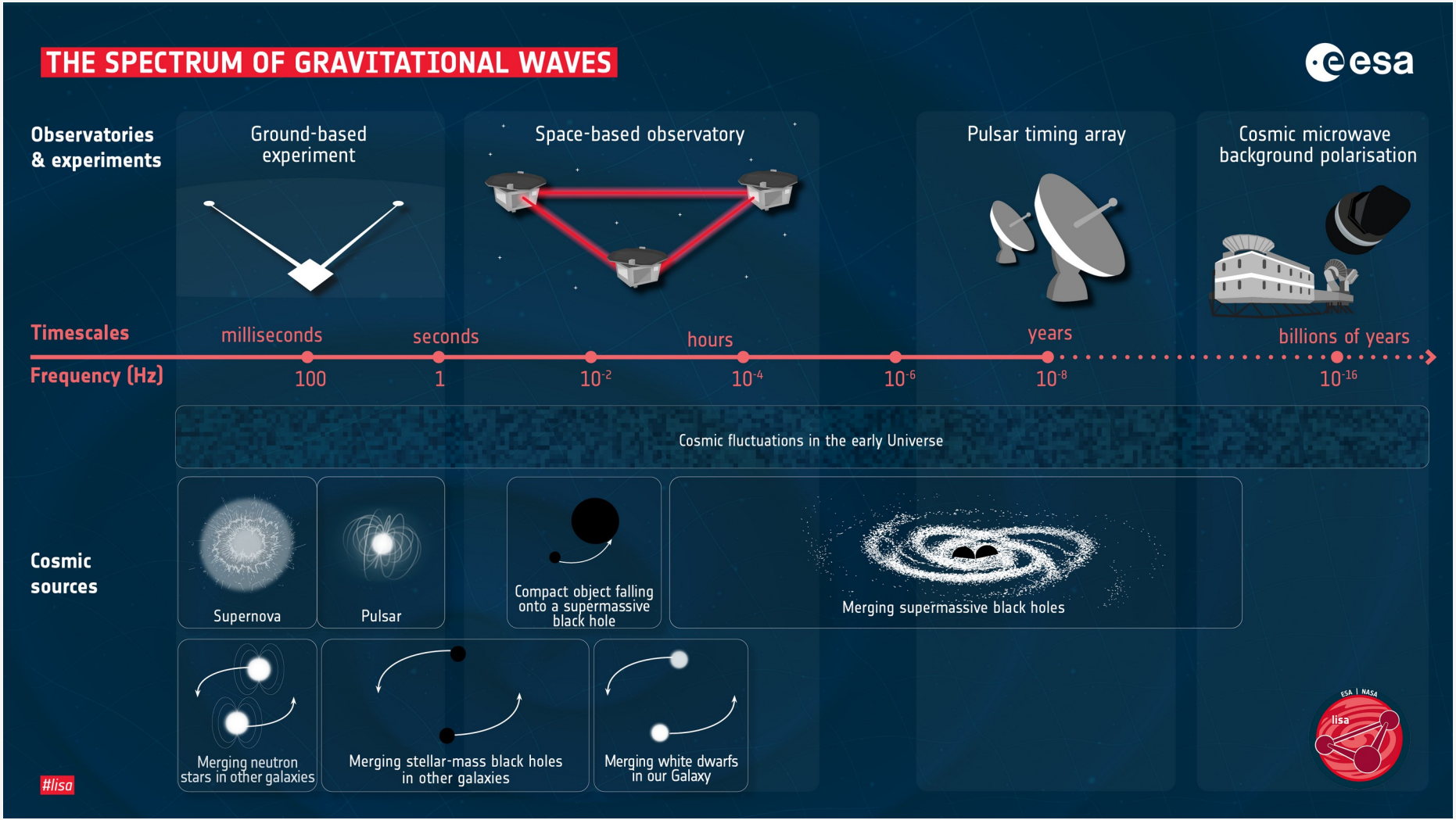
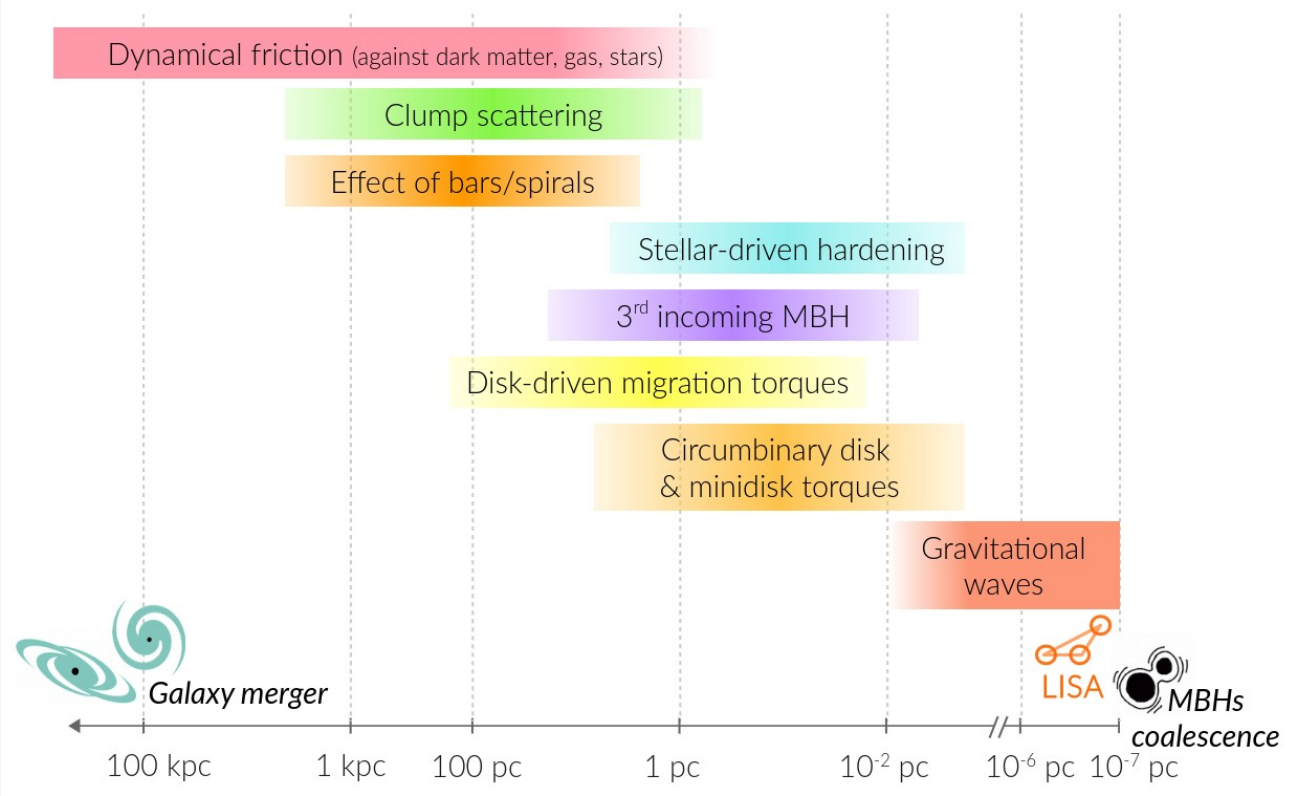
# Multi-messenger prospects for massive black hole binaries in LISA

Alberto Mangiagli

Multi-Messenger Astrophysics in the Dynamic Universe
25th February 2026, YITP


THE SPECTRUM OF GRAVITATIONAL WAVES
esa
Observatories & experiments
Ground-based experiment
Space-based observatory
Pulsar timing array
Cosmic microwave background polarisation
Timescales
milliseconds
seconds
hours
years
billions of years
Frequency (Hz)
100
1
10-2
10-4
10-6
10-8
10-16
Cosmic fluctuations in the early Universe
Cosmic sources
Supernova
Pulsar
Compact object falling onto a supermassive black hole
Merging supermassive black holes
Merging neutron stars in other galaxies
Merging stellar-mass black holes in other galaxies
Merging white dwarfs in our Galaxy
#lisa
ESA | NASA
lisa

When two galaxies merge, the MBHs in their centre form a binary and merge emitting gravitational waves (GWs) and electromagnetic (EM)/particles radiation




Courtesy of Elisa Bortolas

Large uncertainties in the formation and evolution processes :

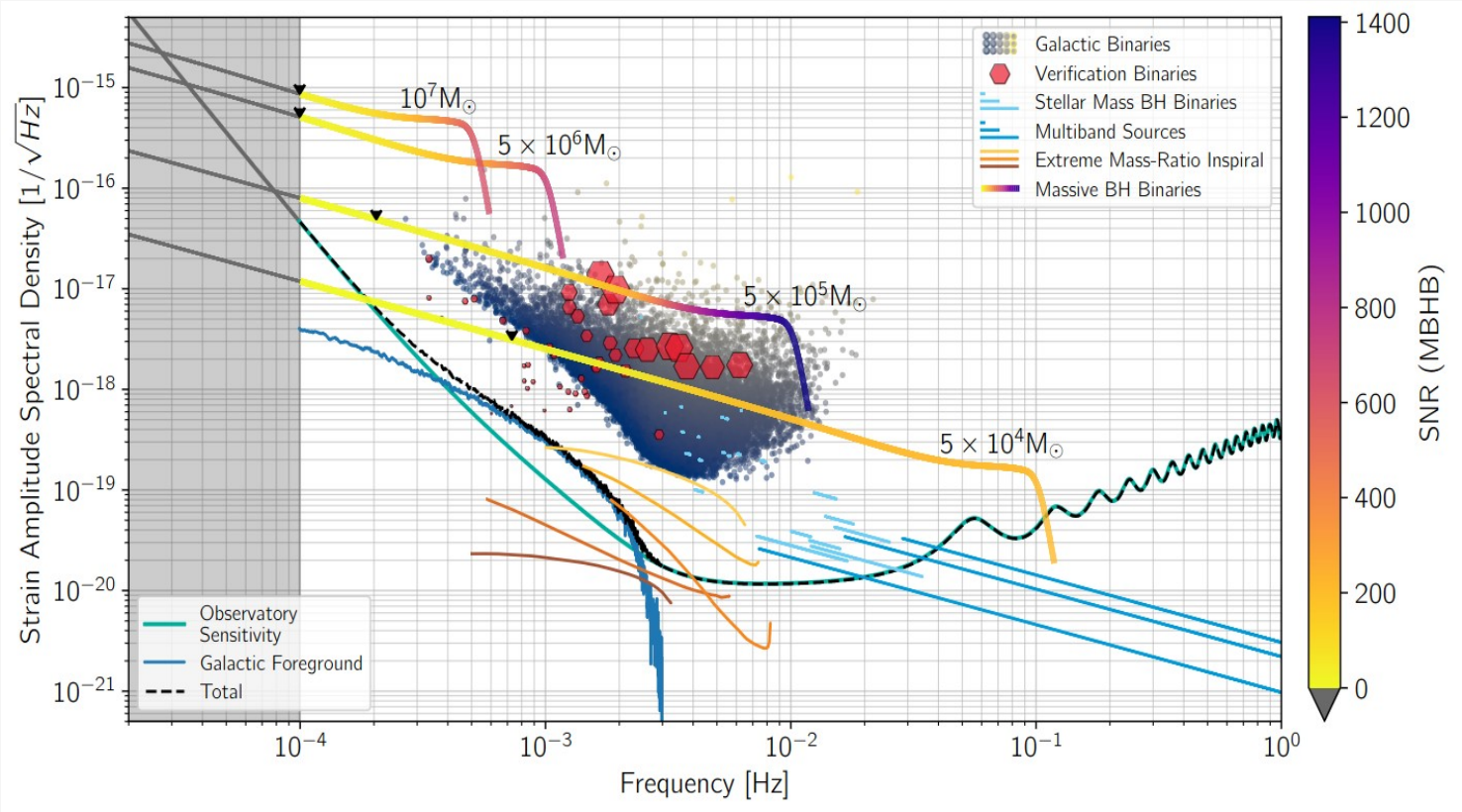
- Seed mechanisms ?
- Accretion ?
- Time delays ?

(For reviews : Volonteri+10, Mayer+13, De Rosa+19, arXiv:2203.06016)

# Massive Black Hole Binaries (MBHBs) represent one of the key target for LISA

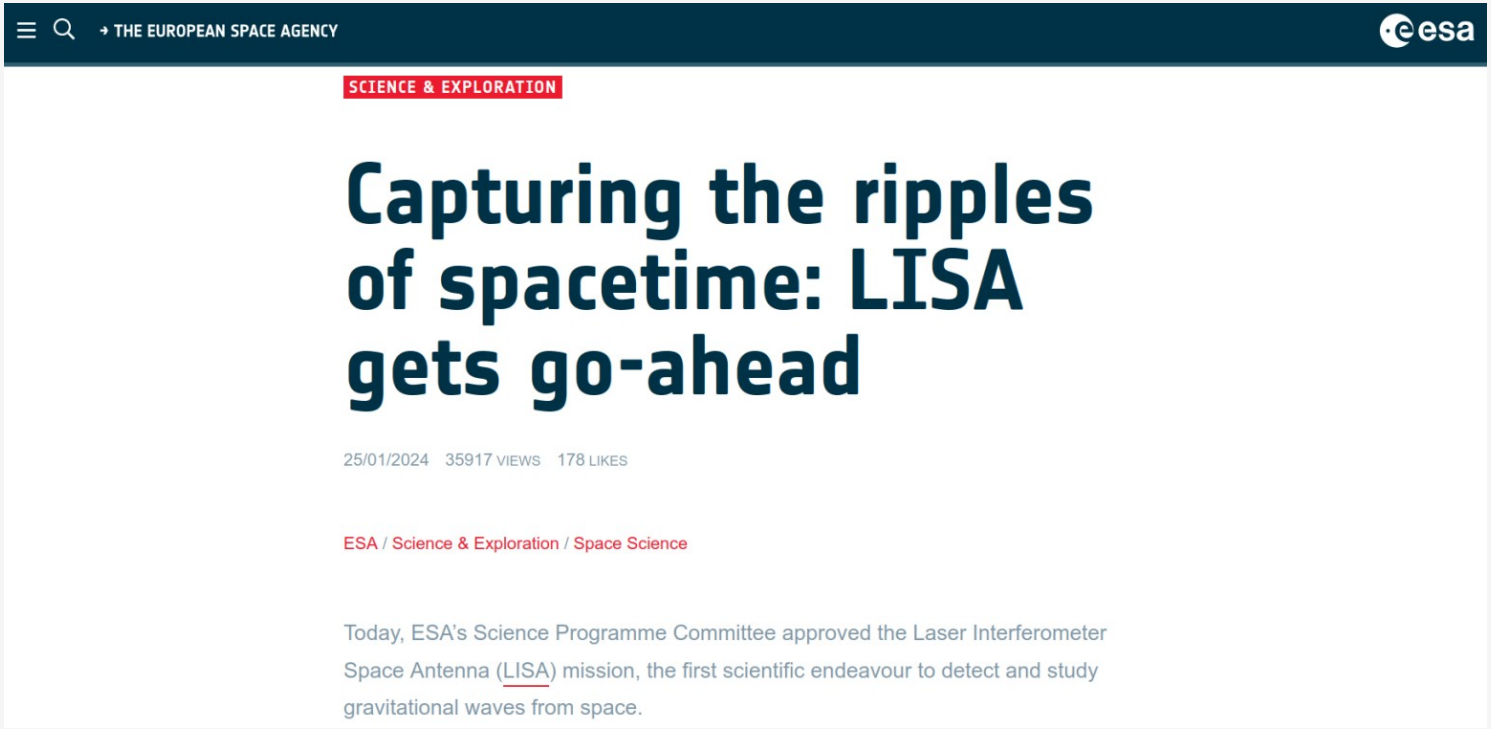
- Coalescence f~$10^{-3}$Hz Inaccessible to ground-based detectors
- Observation at sub-pc Inaccessible to EM telescopes
- Large Signal-to-Noise Ratios

Promise to reconstruct the merging history and shed light on the formation mechanisms




2402.07571

ESA adopted LISA on January 25th 2024 with a budget of €1.7 billion



→ THE EUROPEAN SPACE AGENCY

esa

SCIENCE & EXPLORATION

# Capturing the ripples of spacetime: LISA gets go-ahead

25/01/2024 35917 VIEWS 178 LIKES

ESA / Science & Exploration / Space Science

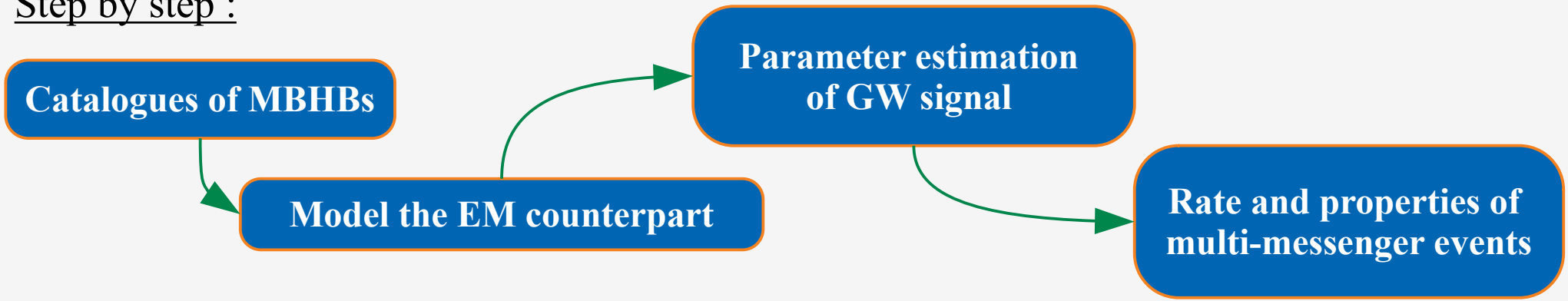
Today, ESA's Science Programme Committee approved the Laser Interferometer Space Antenna (LISA) mission, the first scientific endeavour to detect and study gravitational waves from space.

LISA is under construction and will soon be a fundamental asset for GW physics

How many multi-messenger (GW+EM) MBHB events do we expect ?

AM+2207.10678

Step by step :



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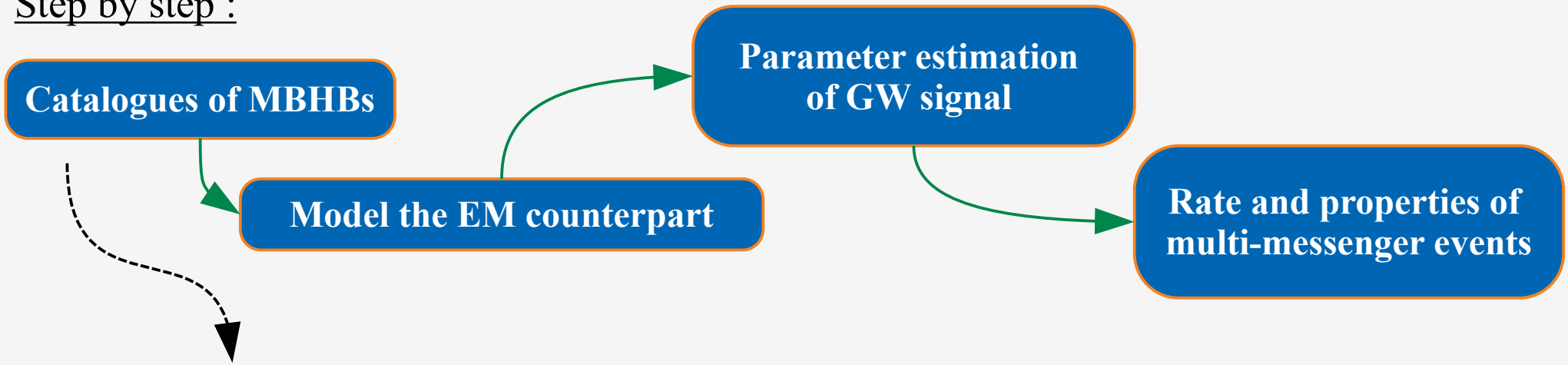


- How many events do we expect?
- What are the typical masses and redshifts?

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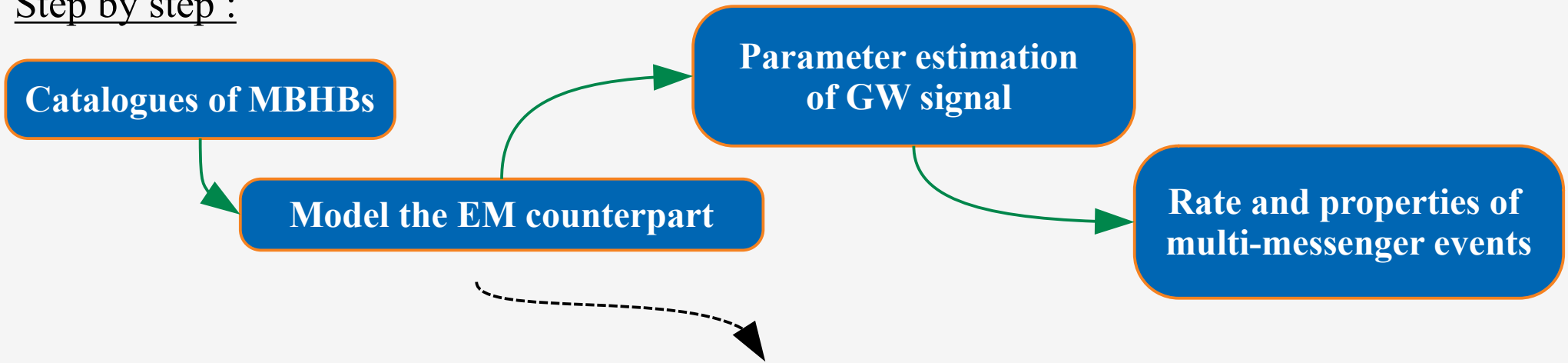


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- What type of EM counterparts should we consider?
- What are the uncertainties related to our counterparts? How solid are our EM models?

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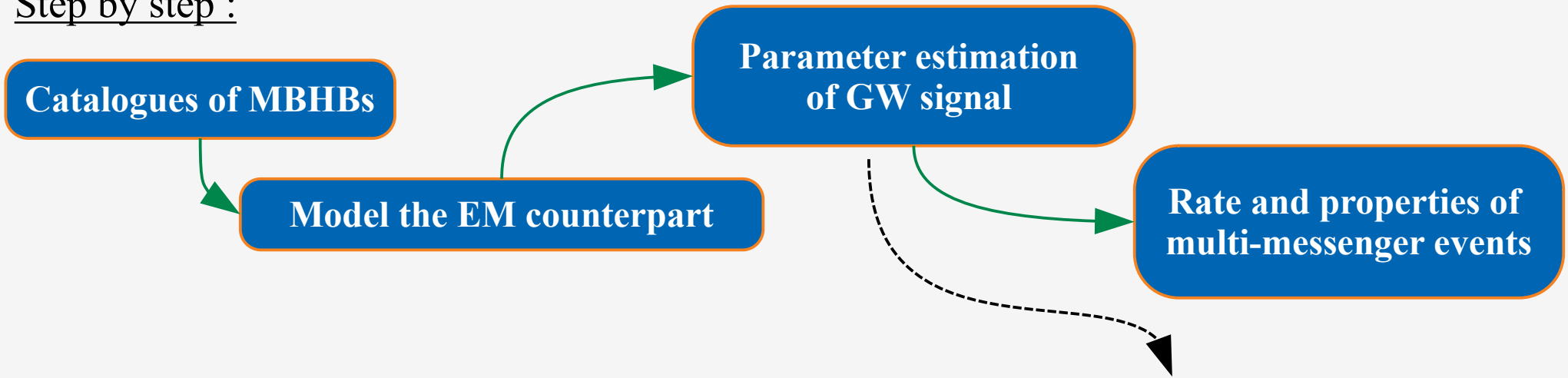


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- What is the typical sky localisation uncertainty?

# Massive Black Hole Binaries

## Three astrophysical models

(Barausse+12 and updates)

**Light**

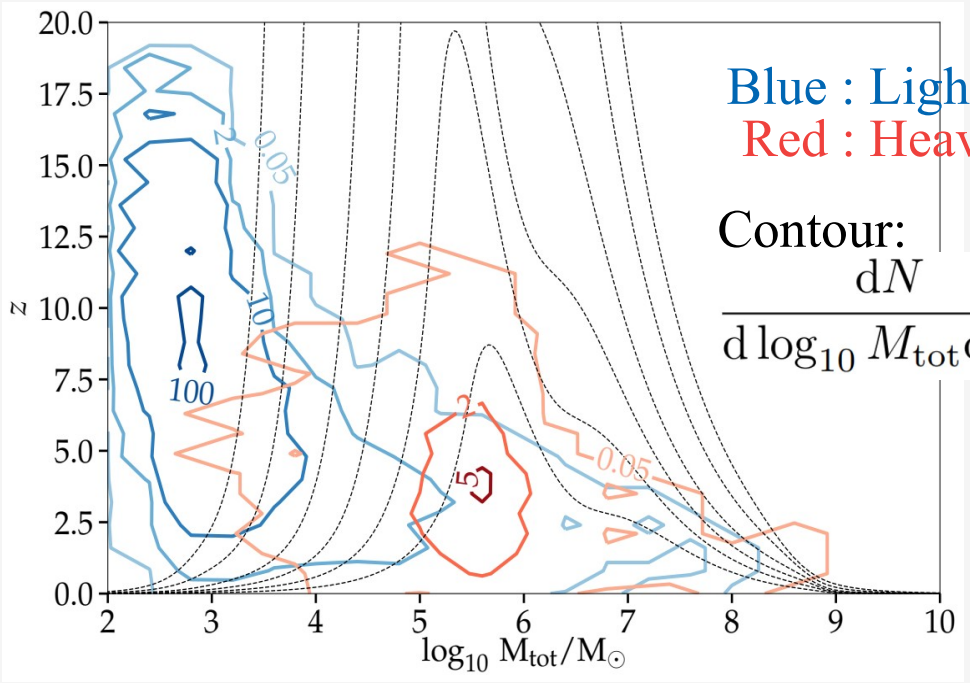
**Remnants of PopIII stars**
**BHs ~ $10^3$ $M_\odot$**

**Heavy**

**Collapse of hydrogen clouds**
**BHs ~ $10^{4\text{-}6}$ $M_\odot$**

**Heavy-no-delays**

**Same as heavy but without delay times**




| (in 4 yr) | Total catalogue | SNR > 10 |
|---|---|---|
| Light | 690.9 | 129.3 |
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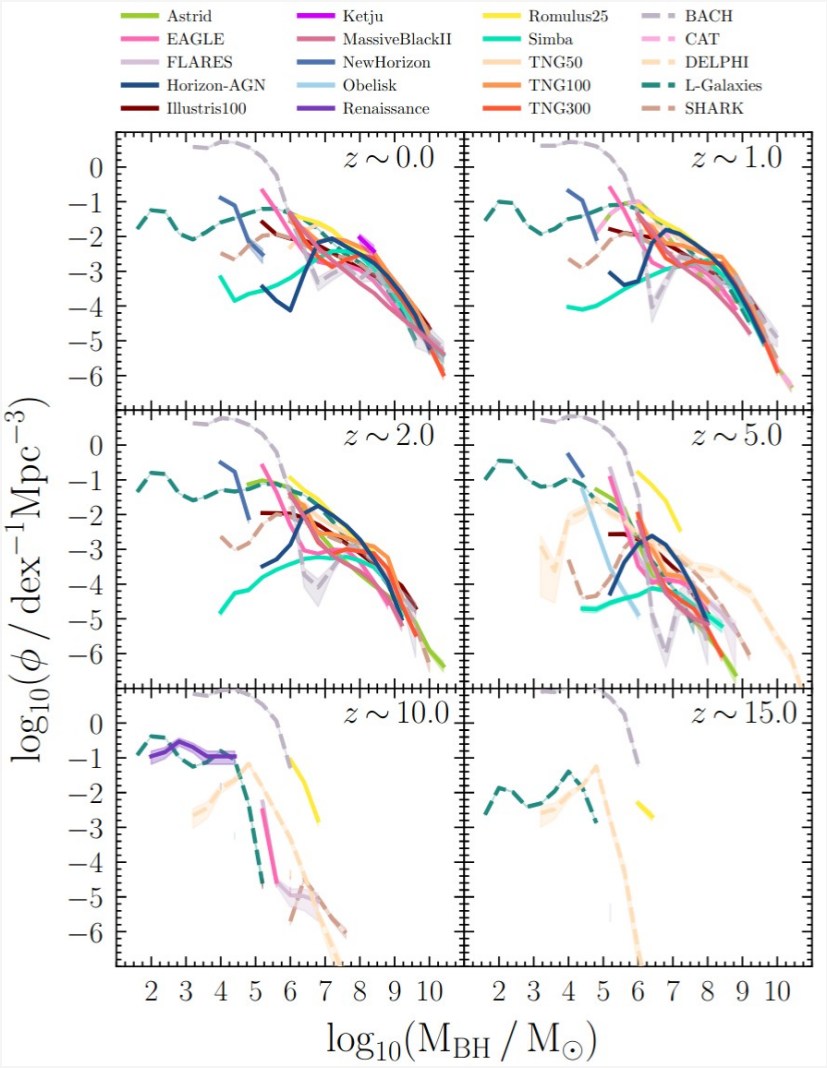
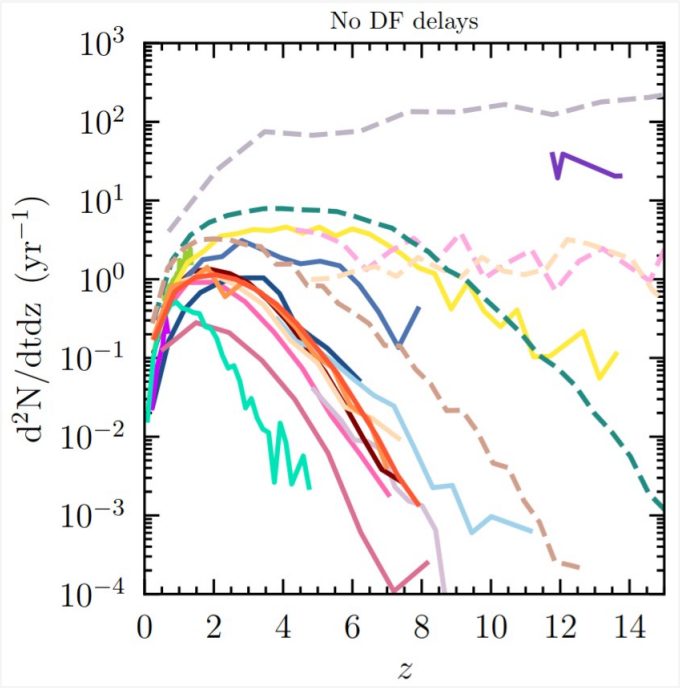



(From MBHCatalog project, preliminary)




These uncertainties are ‘natural’ for a population that has never been observed
(compare with LVK predictions before GW150914)

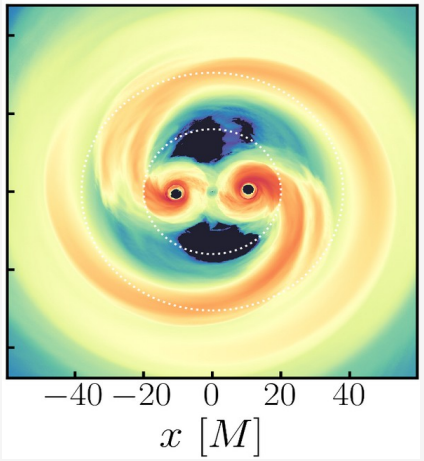
# EM counterpart to MBHB mergers

- No transient AGN-like emission has been associated unambiguously to a MBHB merger

  Dual AGN : ~ 1pc-100 kpc  Binary AGN : ≲ 1pc  (Titarchuck+23, Rodriguez+06, Kharb+17)

- Uncertainties on BH of $10^4$–$10^7$ $M_\odot$ concerning bolometric correction, obscuration, spectra ...

Before the merger




( Bowen+18, Haiman+17, Tang+18, Nobel+21,Combi+22, Cattorini+22, Gutiérrez+22 … )

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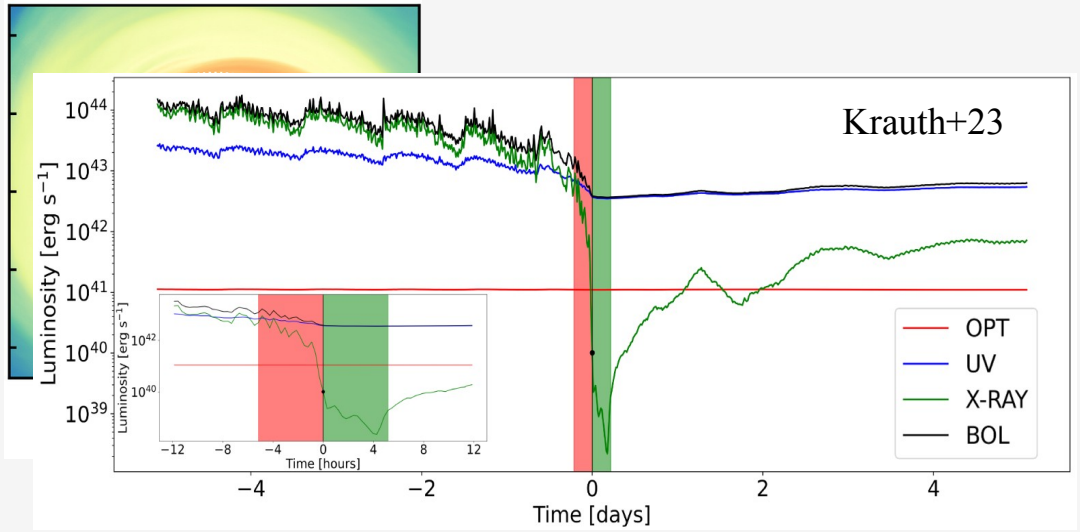


Modulation and drop are unique features of the presence of an underlying MBHB
(Dal Canton, AM+19)

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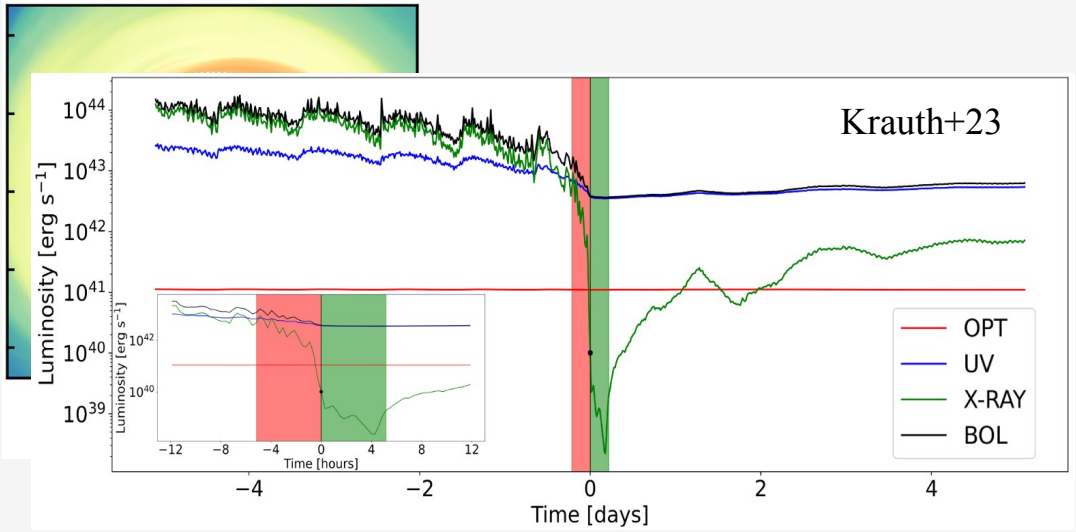


Modulation and drop are unique features of the presence of an underlying MBHB
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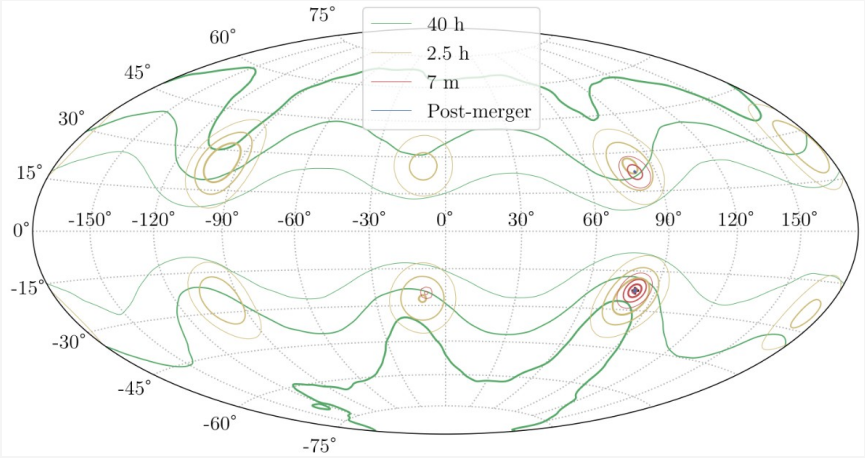
Main caveats:

- Sky localization is strongly multimodal during the inspiral




- Periodicity requires long exposure time

- No transient AGN-like emission has been associated unambiguously to a MBHB merger

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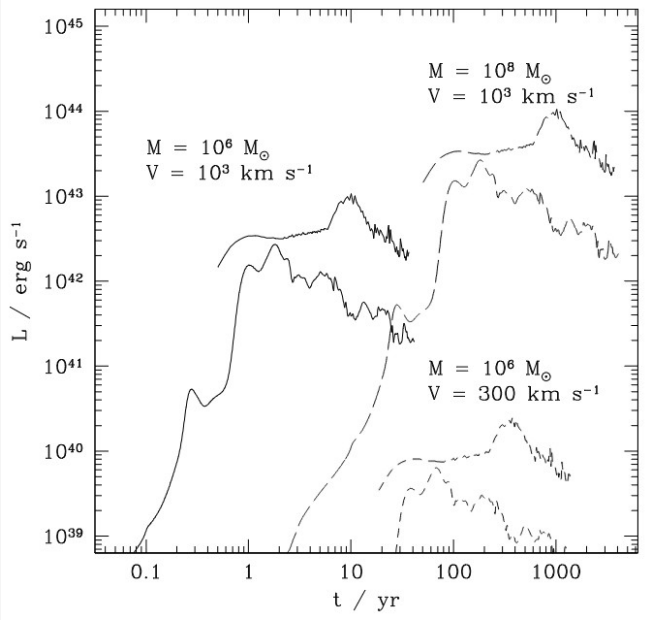
<u>After the merger</u>

BH kick in the circumbinary disk




Rossi+10

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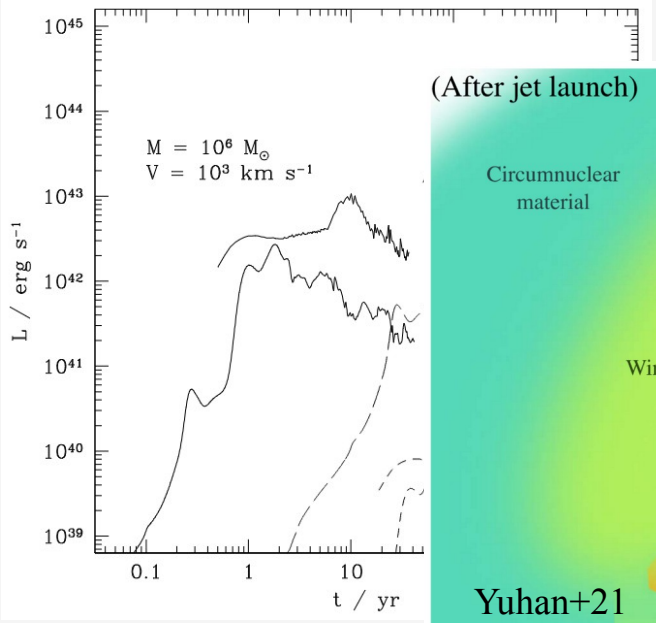
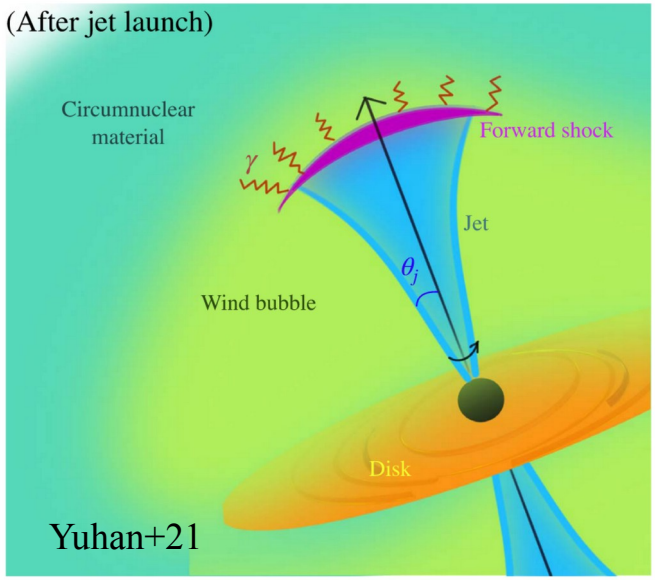



Afterglow emission




Main caveats:

- EM counterpart emerges weeks/months after the merger

**Optical :** *Rubin Observatory*

$$L_{\rm bol} = \min\left(\epsilon_{\rm rad}\dot{M}_{\rm acc}c^2, L_{\rm Edd}\right)$$

$$L_{\rm opt} = 0.1 L_{\rm bol}$$

- FOV < 10 deg$^2$
- $m_{\rm lim}$ ~ 27.5

**X-Ray :** *Athena*

$$L_{\rm X} = \frac{L_{\rm bol}}{c_1\left(\frac{L_{\rm bol}}{10^{10}L_\odot}\right)^{k_1} + c_2\left(\frac{L_{\rm bol}}{10^{10}L_\odot}\right)^{k_2}}$$ (Shen+20)

- FOV < 0.4 deg$^2$
- $F_{\rm lim}$ ~ 3x10$^{-17}$ erg/s/cm$^2$

**Radio :** *SKA*

$$L_{\rm radio} = L_{\rm flare} + L_{\rm jet}$$ (Meier01)

- FOV < 10 deg$^2$
- $F_{\rm lim,\ radio}$ ~ 1μJy
- Flare is isotropic

We also explored the possibility of AGN obscuration and collimated radio emission

**'MM candidate' : SNR>10 + detectable EM counterpart**

| | Total catalogue | SNR > 10 |
|---|---|---|
| Light | 690.9 | 129.3 |
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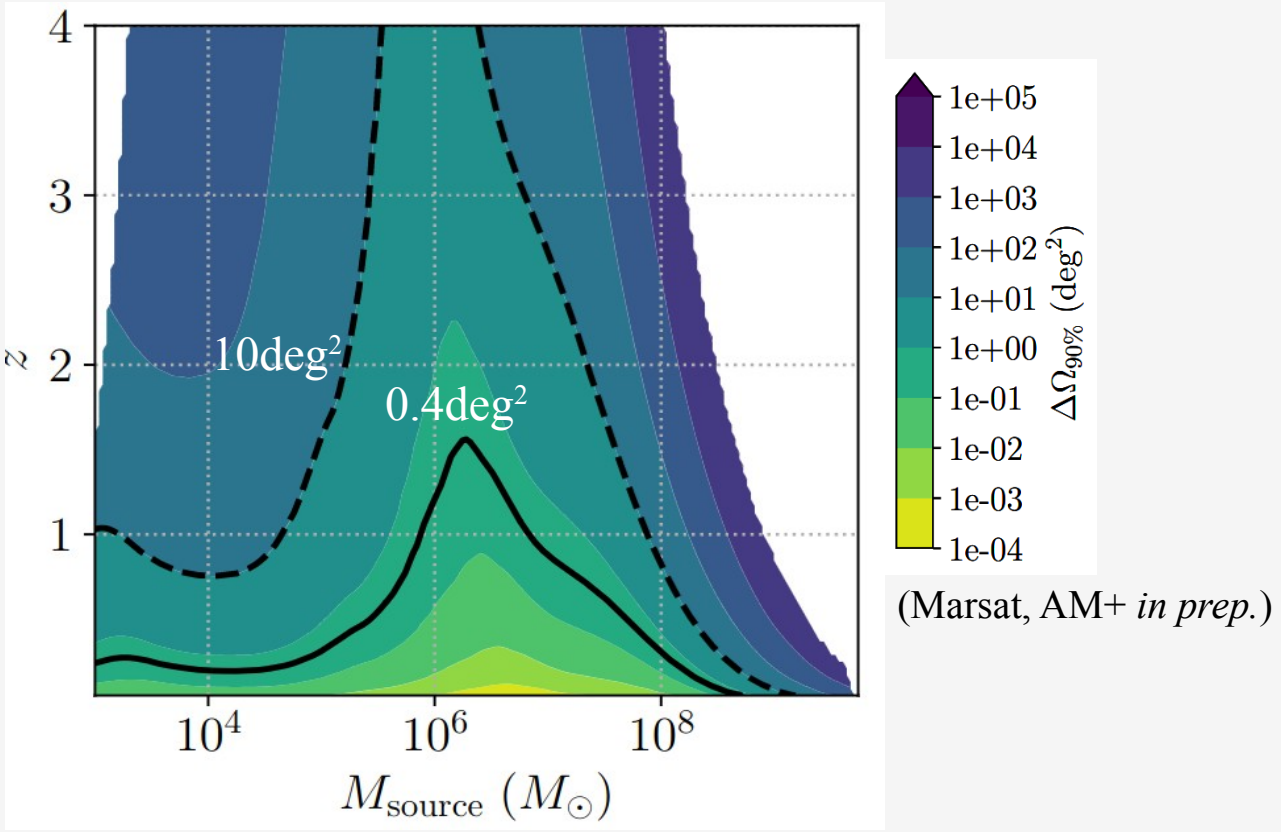
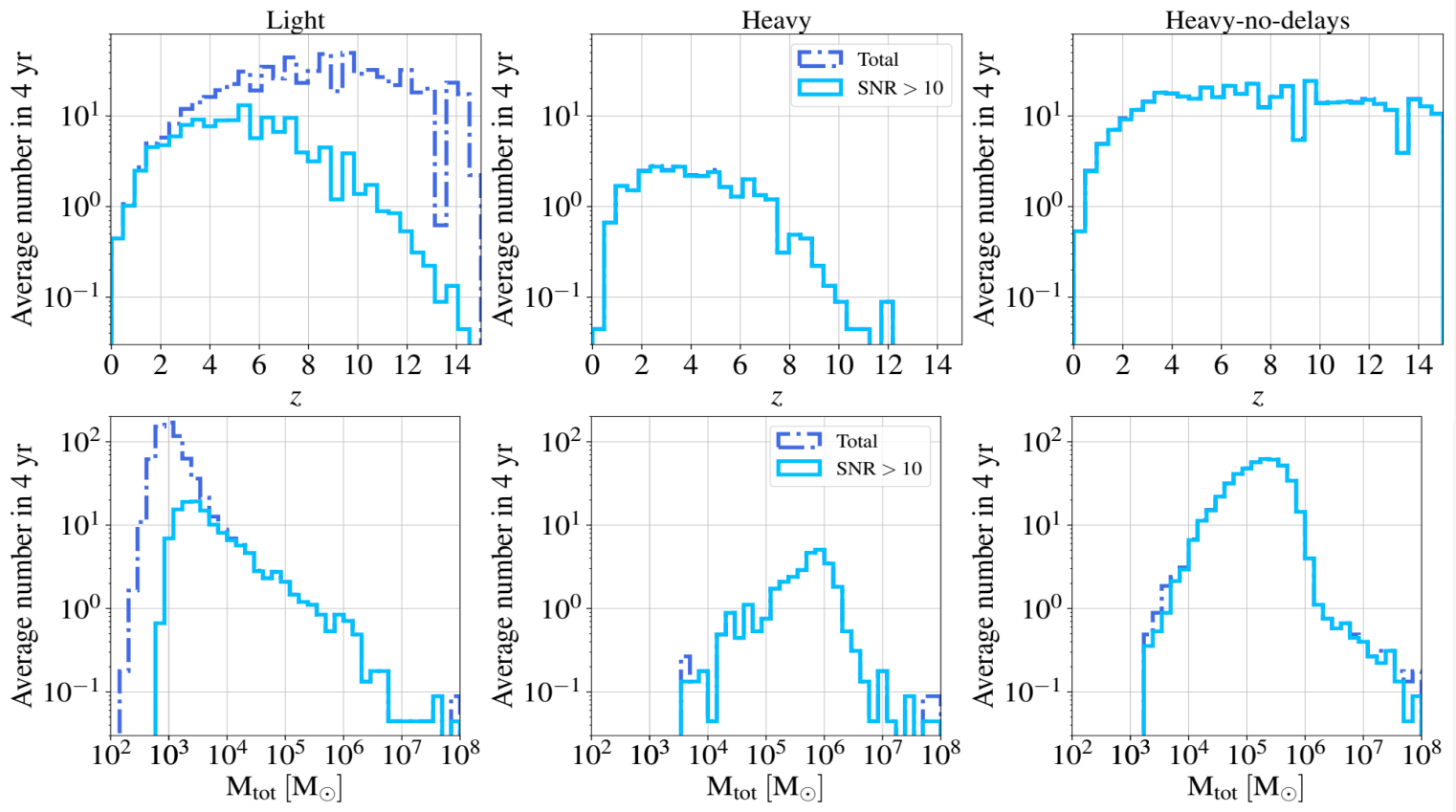
| (in 4 yr) | Standard | w Obsc./Colli. radio |
|---|---|---|
| Light | 35.0 | 6.62 |
| Heavy | 24.0 | 3.55 |
| Heavy-no-delays | 37.5 | 4.22 |

# Sky localisation of MBHBs




(Marsat, AM+ *in prep.*)

Now we can combine all the info together :
'EM counterpart' = SNR>10 + detectable EM counterpart + $\Delta\Omega <$ FOV of EM telescopes

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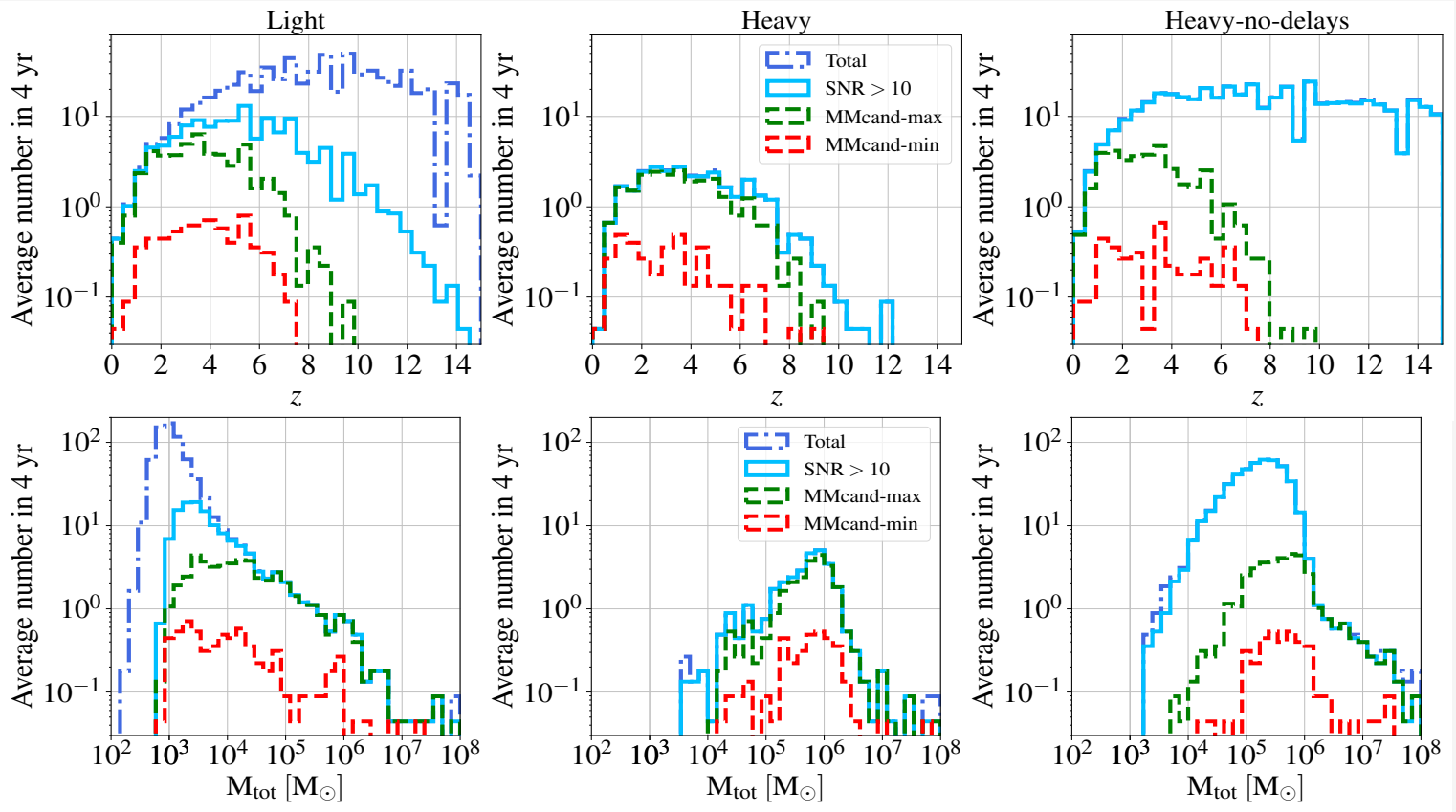


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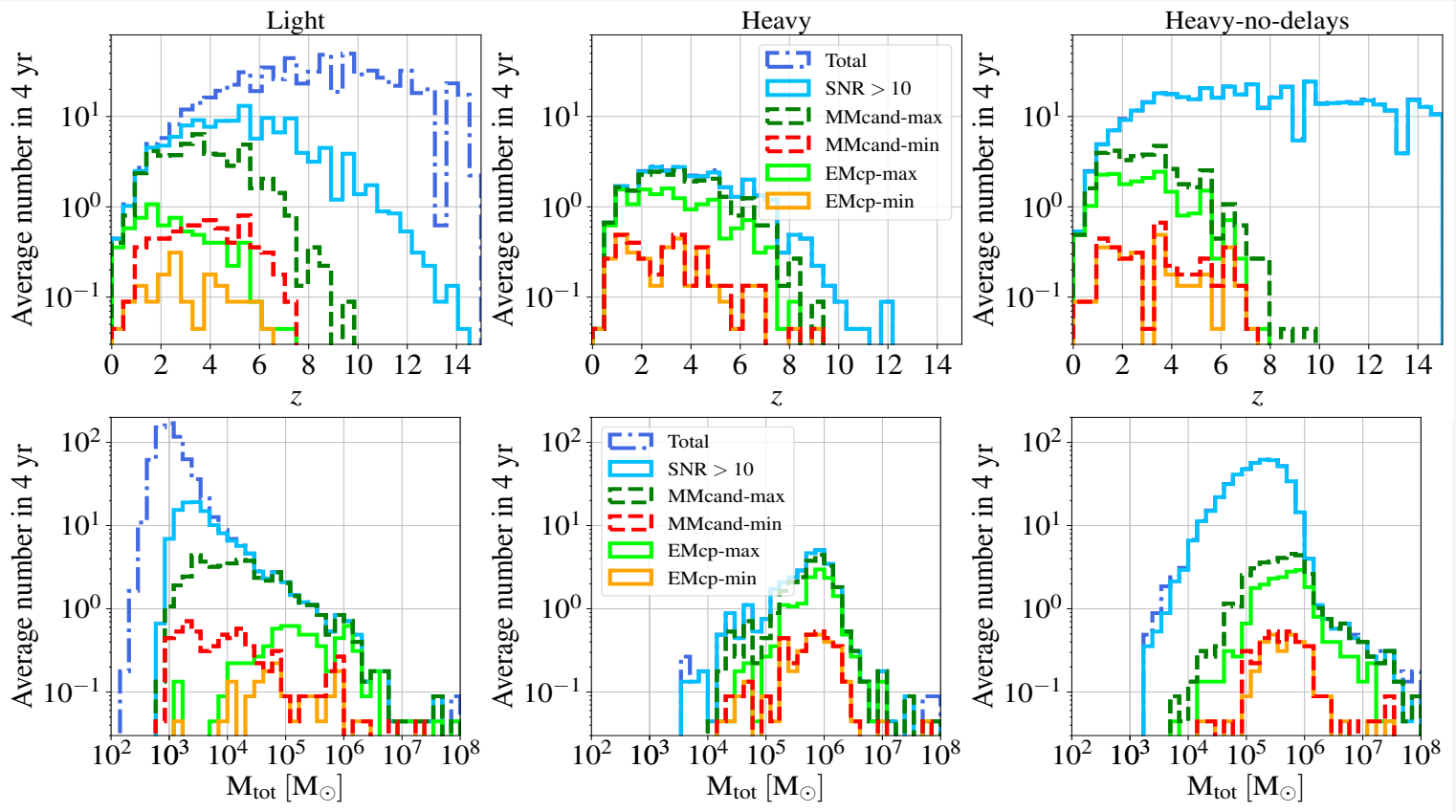


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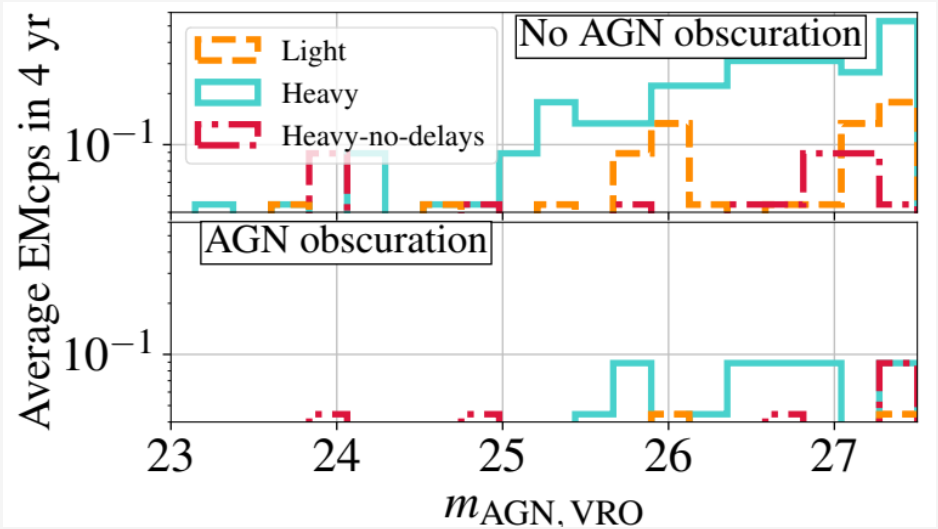
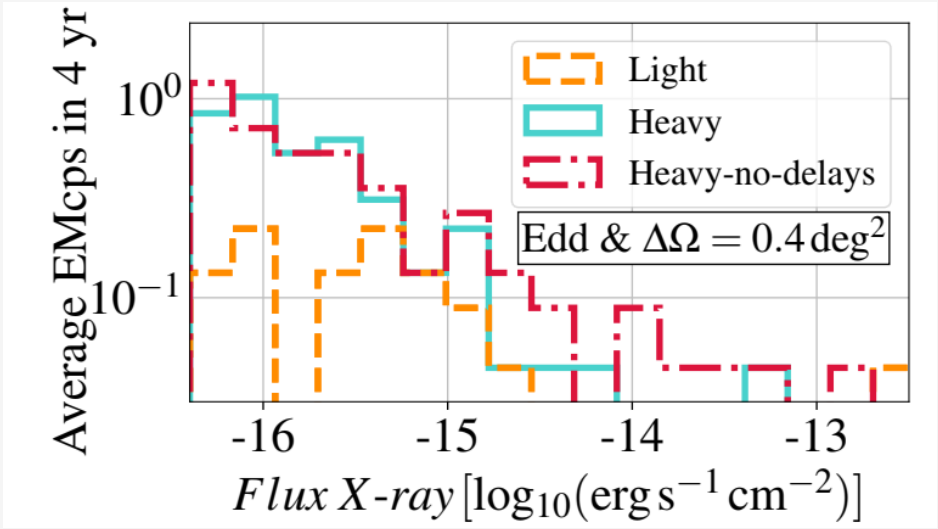
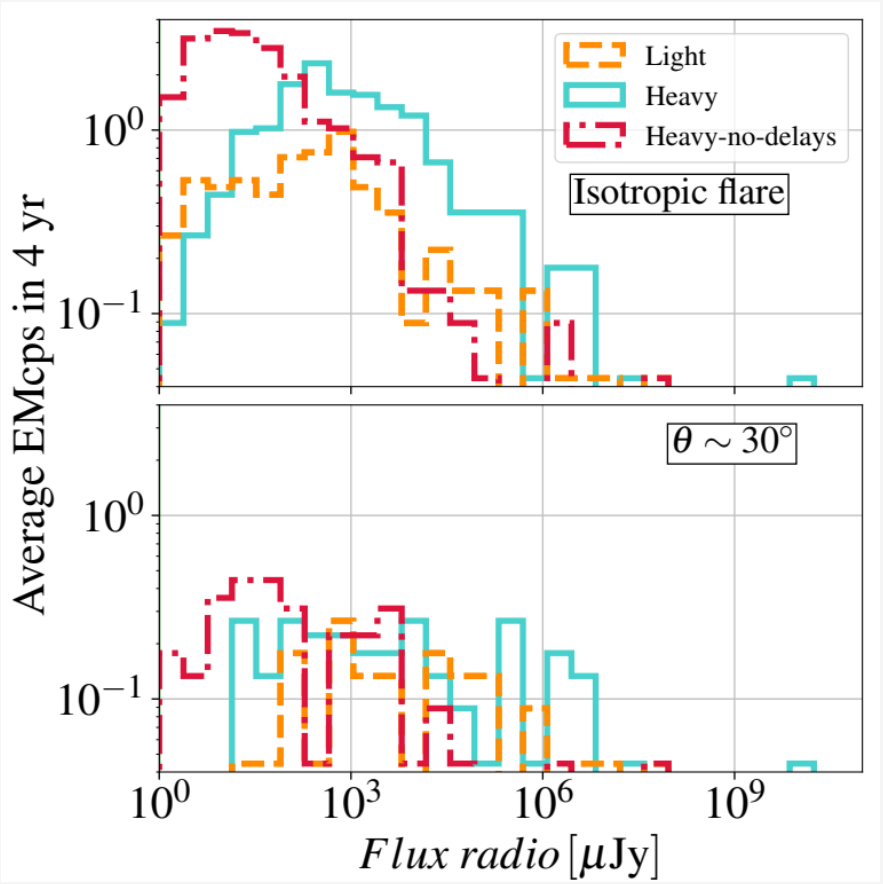
| (In 4 yr) | Standard | w Obsc./Colli. radio |
|---|---|---|
| Light | 6.4 | 1.6 |
| Heavy | 14.8 | 3.3 |
| Heavy-no-delays | 20.7 | 3.5 |




LISA sources are intrinsically faint

# Conclusion

Multi-messenger with MBHBs will be a challenging science

**From the current results**

- GW signal detectable up to high redshift
- Good sky localisation up to z~3
- The rates strongly depend on the population and the EM counterpart modeling

**Prospects for the future**

- Need better modelling for the EM counterpart
- Can we identify the host galaxy?
- Few events → We need specific follow-up strategies

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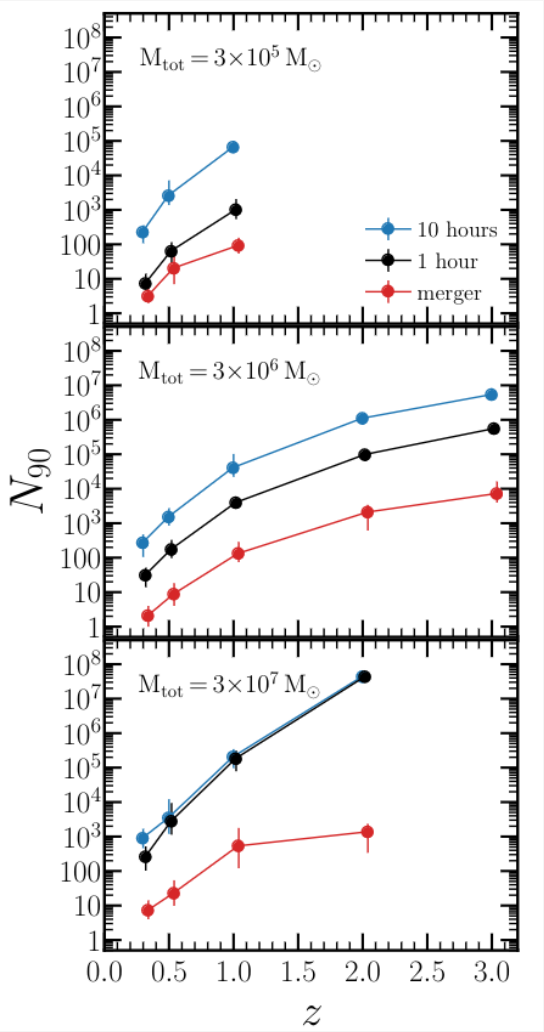
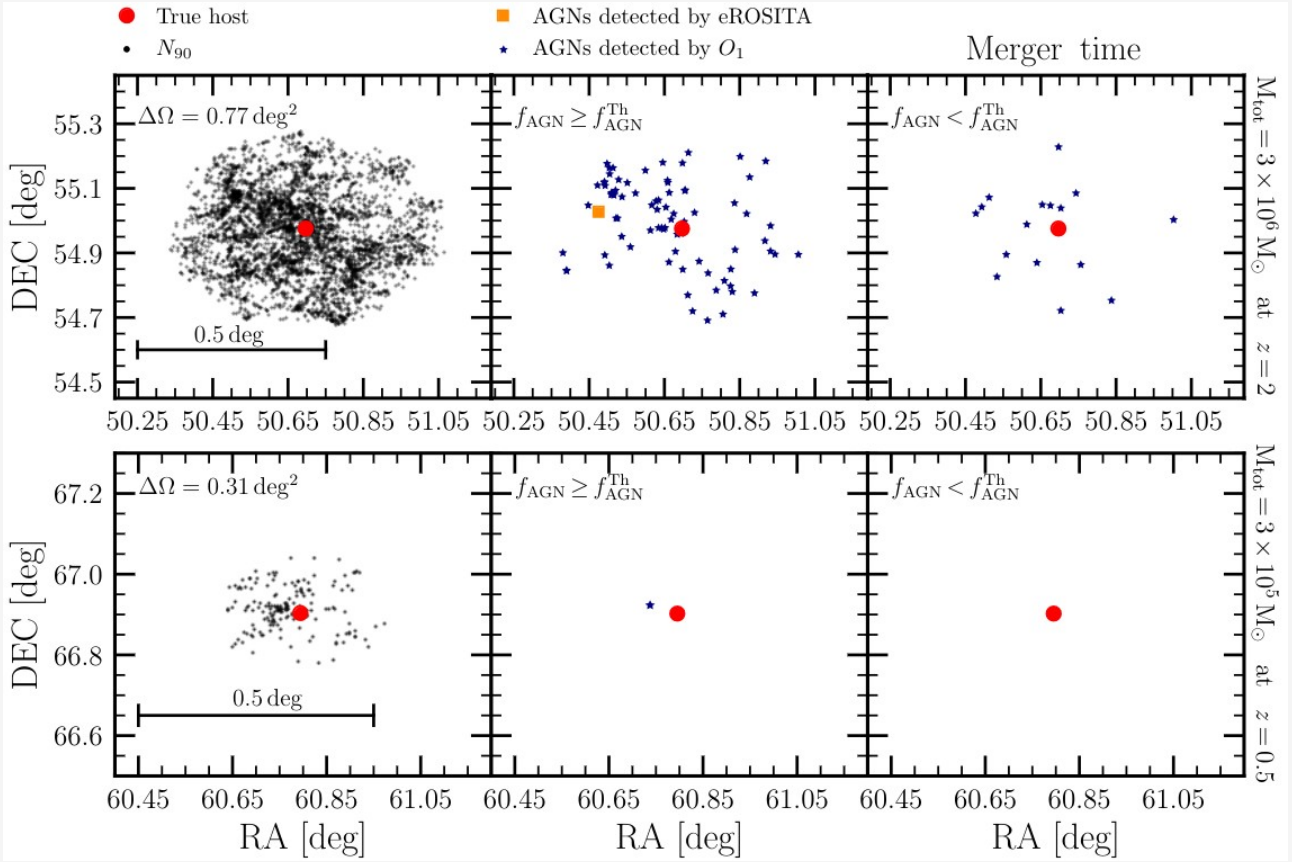
Any questions ?

Backup slides

# How many galaxies there will be in LISA error volume ?

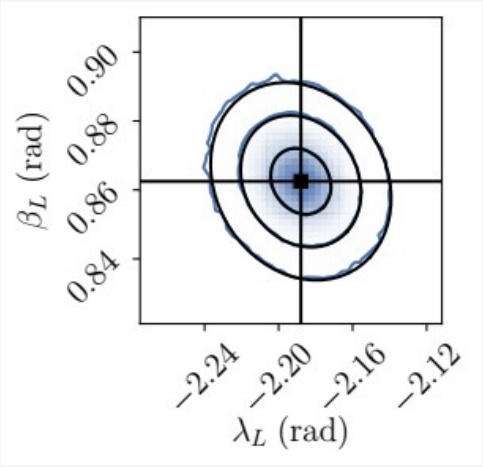


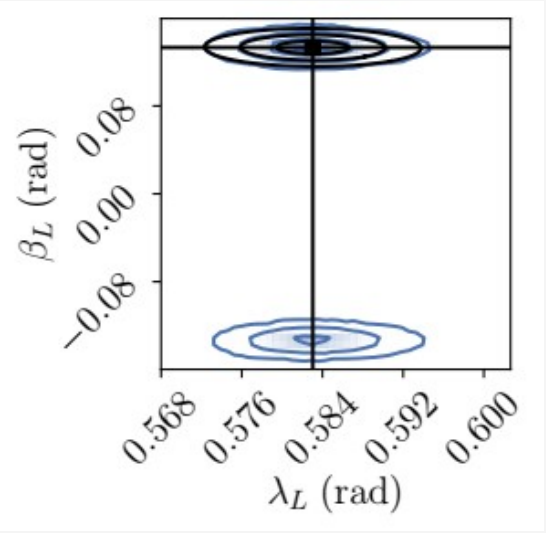

Detection ≠ Identification

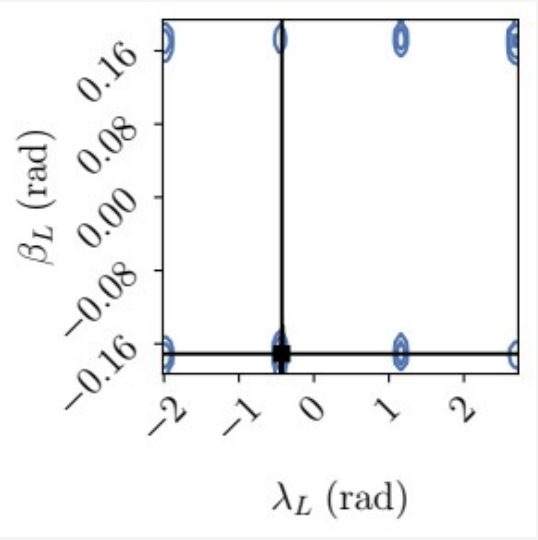
(Lops+22
Villalba+23)

We simulate 90 yr of data for each astrophysical model and perform the parameter estimation with a Bayesian code (*lisabeta*, Marsat+20)




Multimodal events




Marsat+20
Baibhav+20

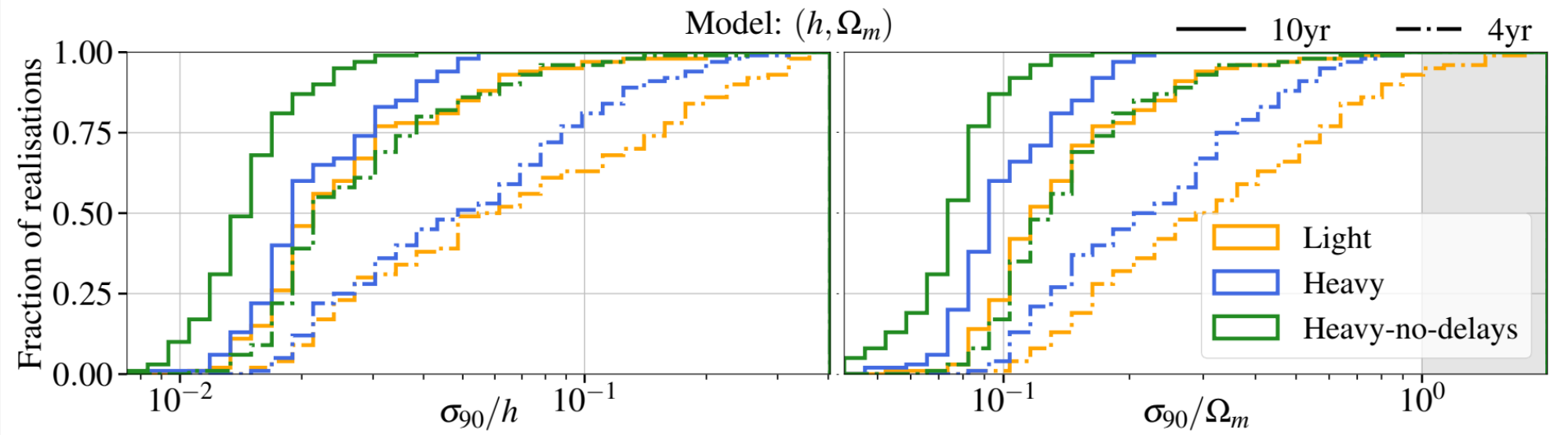
Degeneracies can be broken with :

- Orbital motion of the detector for f~$10^{-4}$ Hz
- High frequency response of the detector for f $\gtrsim$0.05 Hz

Fit: $H(z) = H_0\sqrt{\Omega_m(1+z)^3 + (1-\Omega_m)}$

(in 4 yr)

| Light | Heavy | Heavy-no-delays |
|---|---|---|
| 6.4 | 14.8 | 20.7 |




$H_0$ can be constrained to few percent

Larger uncertainties on $\Omega_m$

For CPL parametrization → Poor constrains on $\omega_0$ and no constrain on $\omega_a$