Multimessenger prospects for massive black hole binaries in LISA

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Based on ArXiv:2207.10678

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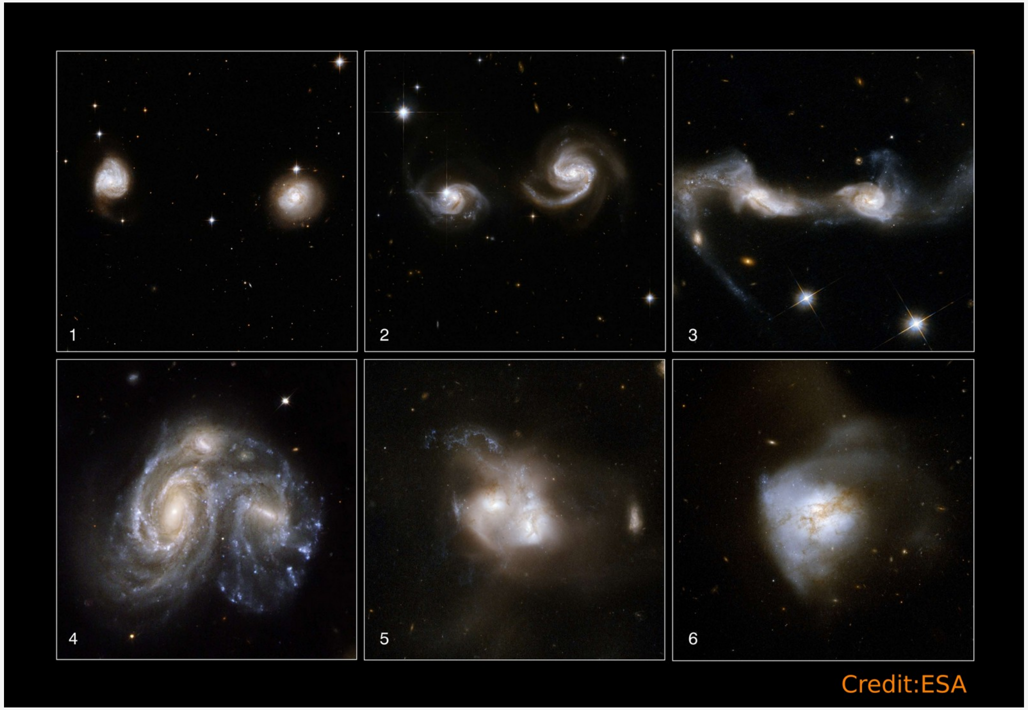
From single MBH to binaries

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



At the center of galaxies, there might be enough gas to produce an EM counterpart

Multimessenger with MBHBs (ArXiv:2207.10678)

Estimate the number of counterparts over LISA time mission and constrains on the expansion of the Universe

Key improvements respect to previous works (Tamanini+16)

- Improve the modeling of the EM counterpart
- Bayesian analysis for GW signal : *lisabeta* (Marsat+20)

Starting point

- Semi-analytical models: tools to construct MBHBs catalogs (Barausse+12)

Three astrophysical models

Light	Heavy	Heavy-no-delays
From PopIII stars BHs ~ $10^3\ M_\odot$	From the collapse of hydrogen cloud BHs ~ $10^{4\text{-}6}\ M_\odot$	Same as 'heavy' but without delay times

Constructing the population of MBHBs with EM counterpart

Observing strategies

Optical

LSST, Rubin Obs.

X-Ray

Athena

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

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

(Shen+20)

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

- $\Delta\Omega <$ 10 deg^2
- $m_{\rm lim,\,opt} \sim 27.5$

- $\Delta\Omega <$ 0.4 deg^2
- $F_{\rm lim,\,X} \sim 3 \times 10^{-17}$ erg/s/cm^2

Radio

SKA

(Meier01)

$$L_{\rm radio} = L_{\rm flare} + L_{\rm jet}$$

- $\Delta\Omega <$ 10 deg^2
- $F_{\rm lim,\,radio} \sim 1\,\mu$Jy

AGN obscuration (Ueda+14, Gnedin+07)

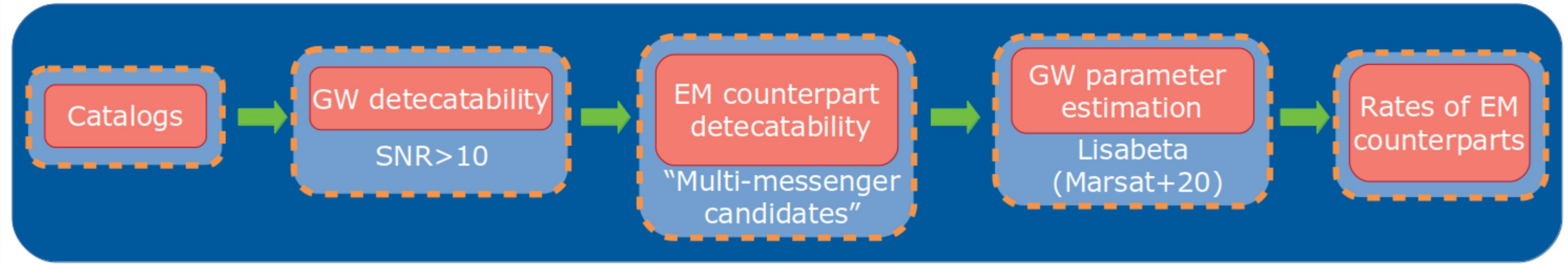
- No obscuration
- Typical hydrogen column density

Radio Jet (Cohen+06)

- Isotropic radio emission
- Collimated radio emission $\theta \sim 30^{\rm o}$

Two main scenarios

General procedure



We focus on two scenarios

Maximising

- No AGN obscuration
- Isotropic radio emission

Minimising

- AGN obscuration
- Collimated radio emission

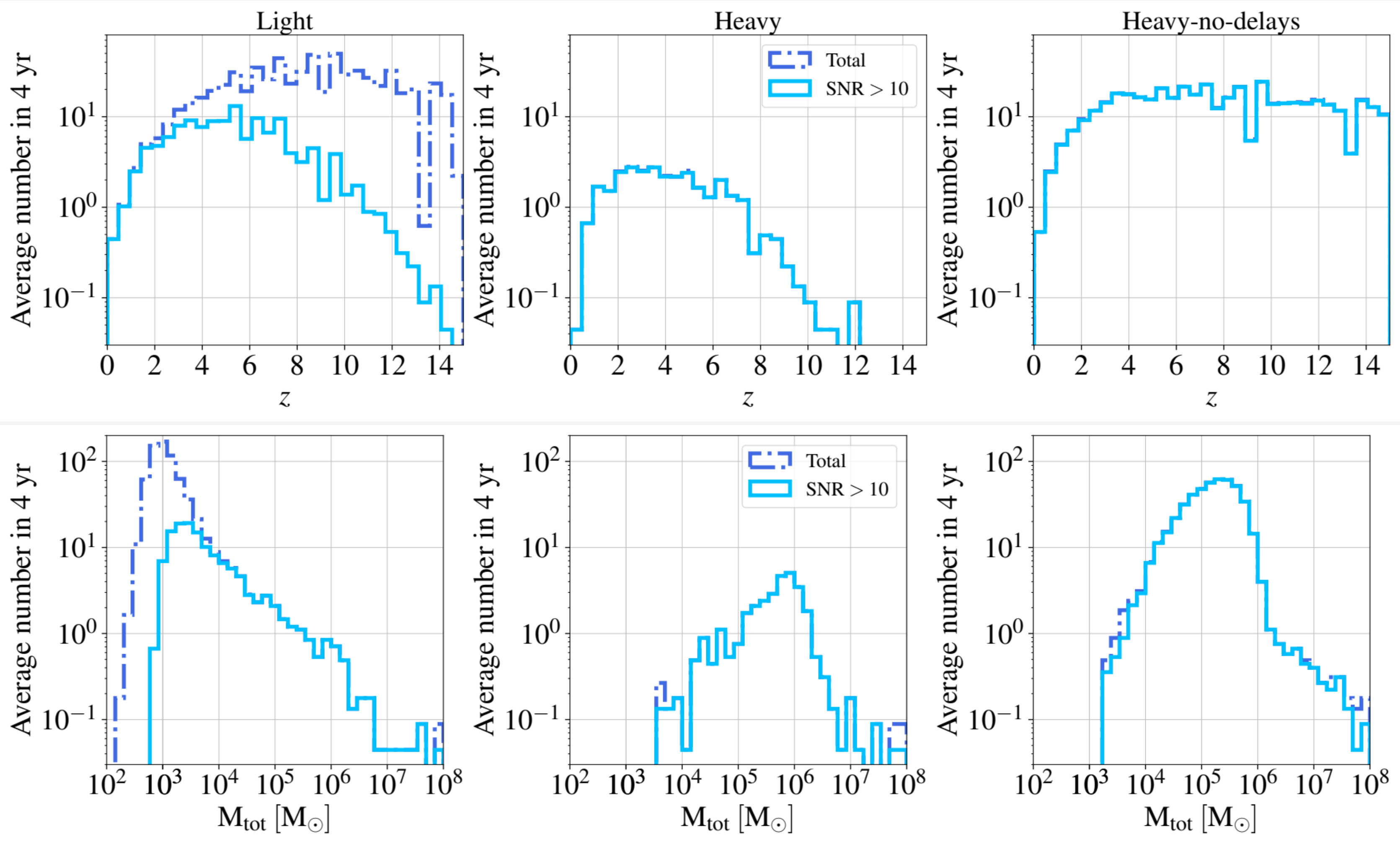
Some caveats

- Detection is claimed when F> F_{lim}

(Lops+22) Detection ≠ Identification

- Analysis valid only for post-merger emission
- No tiling of LISA area

Redshift and total mass distributions



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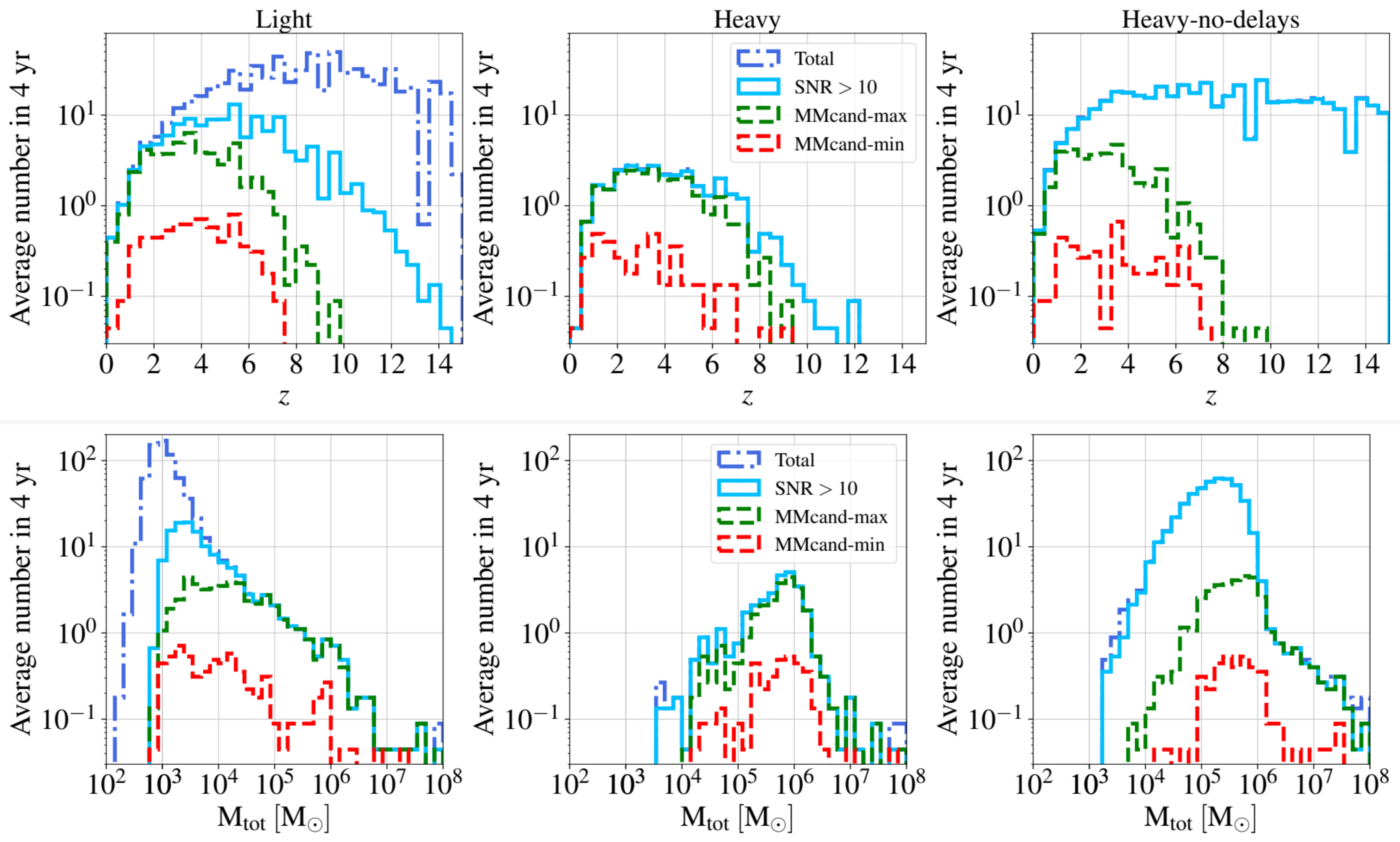

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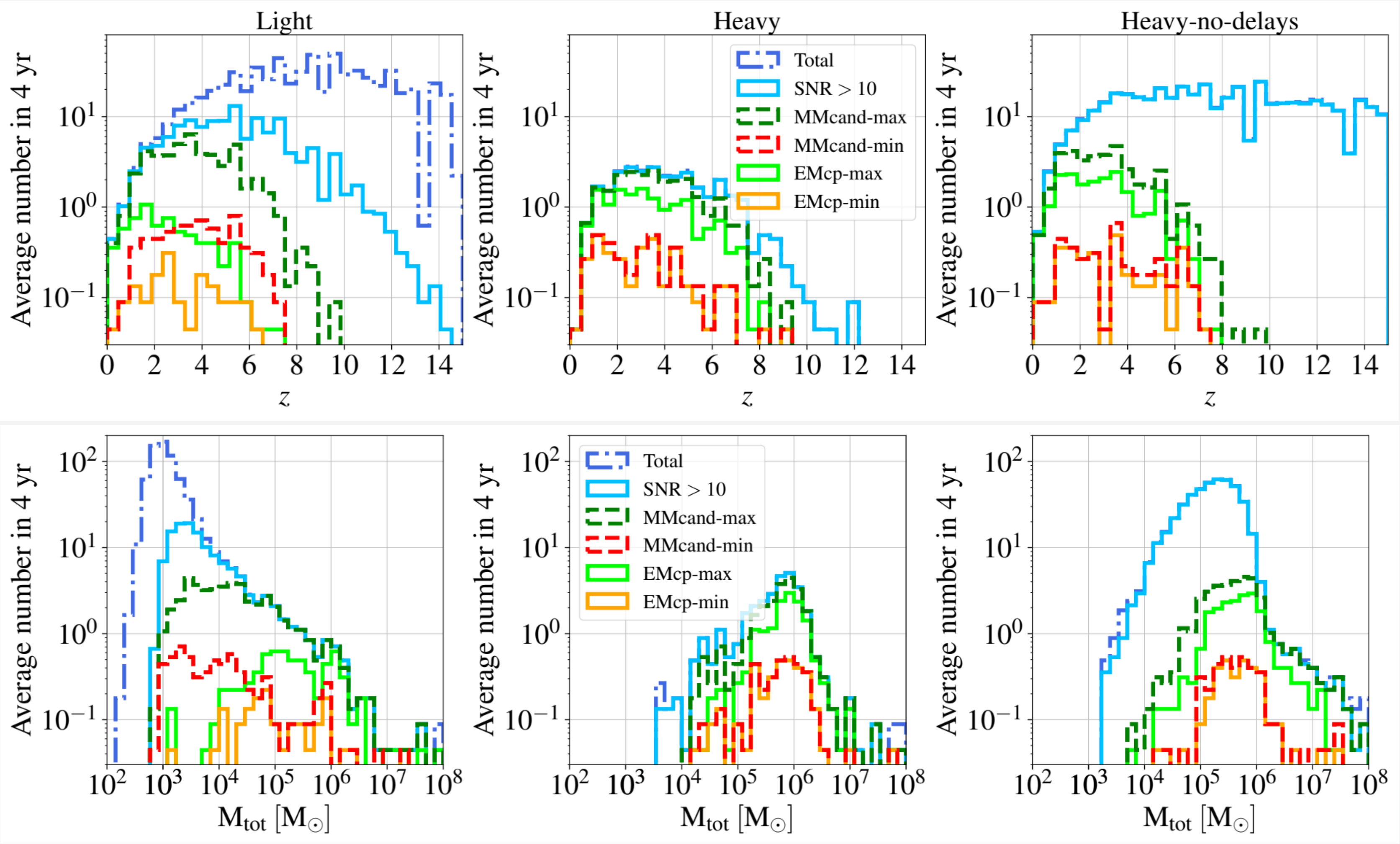
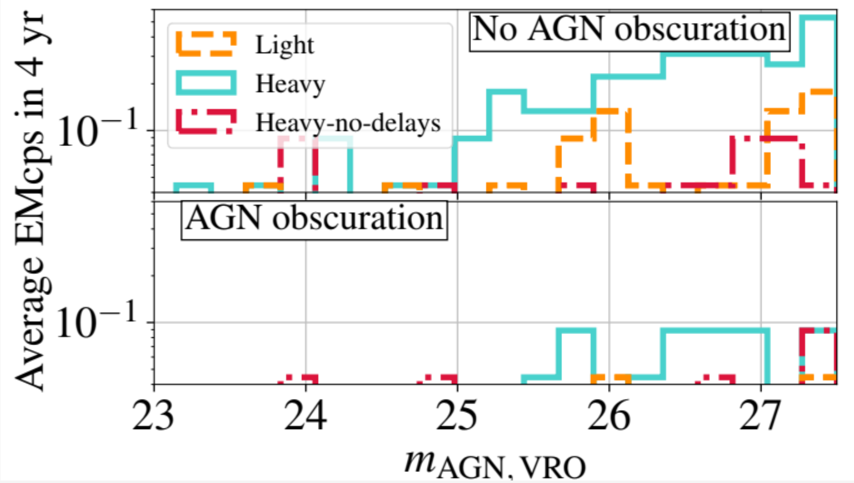
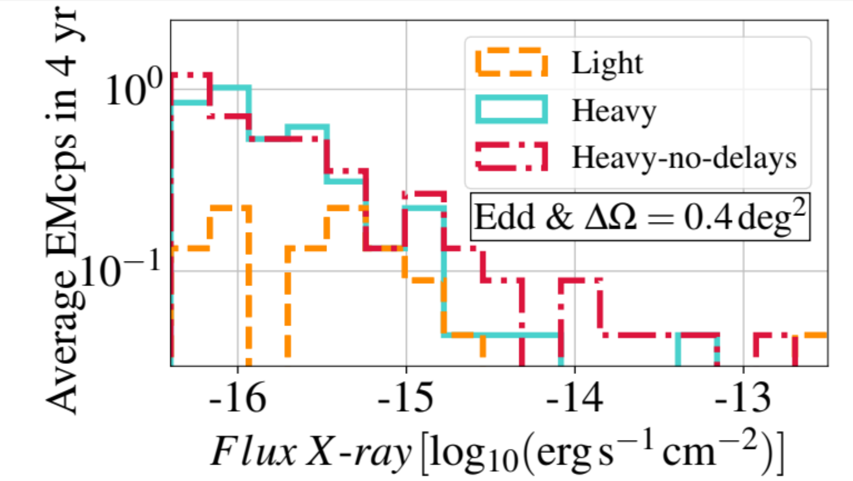
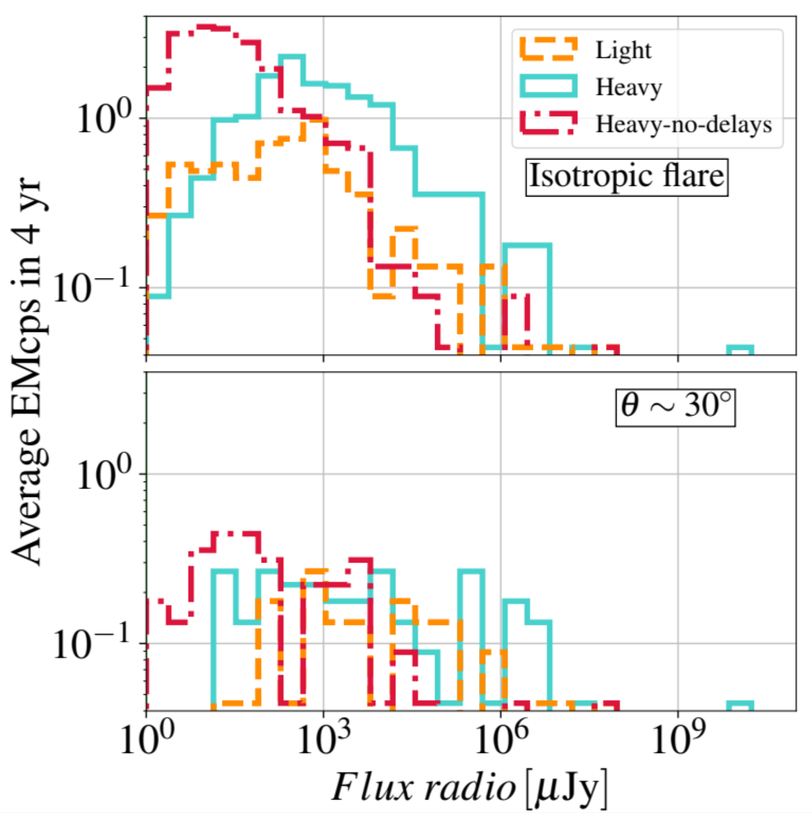


EMcps in optical, X-ray and radio







LISA sources might be intrinsically faint

EMcps in 4 yr

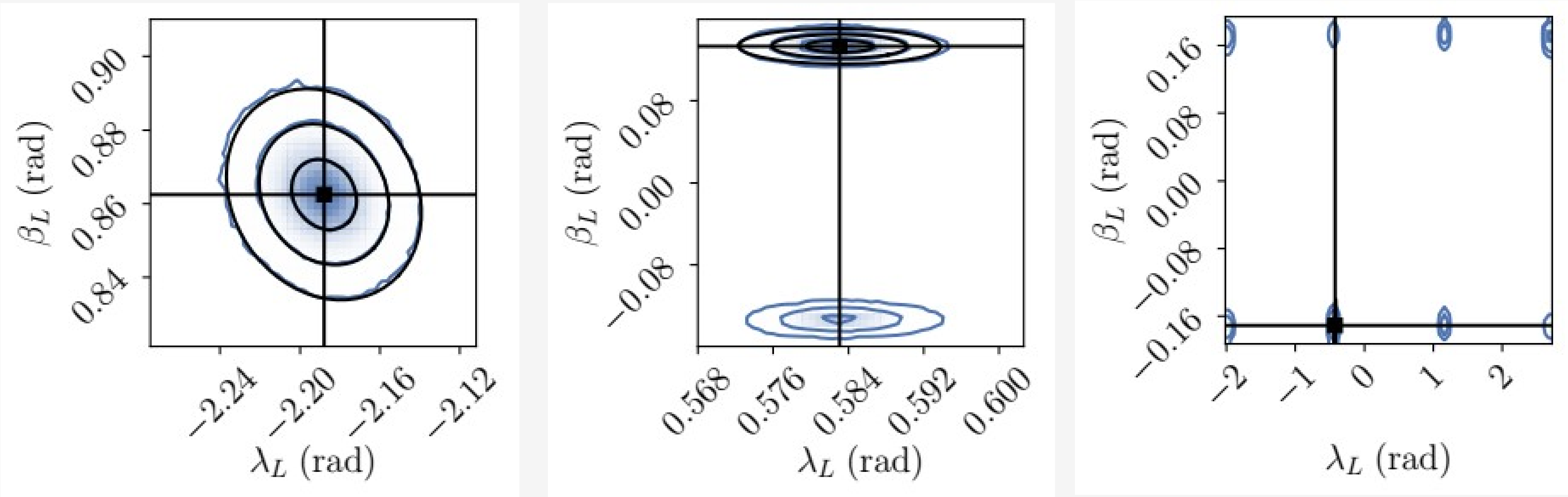
(In 4 yr)	LSST, VRO	SKA+ELT			Athena+ELT		
		Isotropic	$\theta \sim 30°$	$\theta \sim 6°$	Catalog $F_{\mathrm{X,\,lim}}$ = 4e-17	Eddington $F_{\mathrm{X,\,lim}}$ = 4e-17	
	$\Delta\Omega = 10\,\mathrm{deg}^2$				$\Delta\Omega = 0.4\,\mathrm{deg}^2$	$\Delta\Omega = 0.4\,\mathrm{deg}^2$	
No-obsc.	0.84	6.4	1.51	0.04	0.49	1.02	Light
	3.07	14.8	2.71	0.04	2.67	3.87	Heavy
	0.53	20.3	3.2	0.04	0.58	4.4	Heavy-no-delays
Obsc.	0.13	6.4	1.51	0.04	0.04	0.13	Light
	0.75	14.8	2.71	0.04	0.22	0.18	Heavy
	0.35	20.3	3.2	0.04	0.18	0.27	Heavy-no-delays

- Dramatic decrease with obscuaration and radio jet
- Parameter estimation selects preferentially heavy

(In 4 yr)	Maximising	Minimising
Light	6.4	1.6
Heavy	14.8	3.3
Heavy-no-delays	20.7	3.5

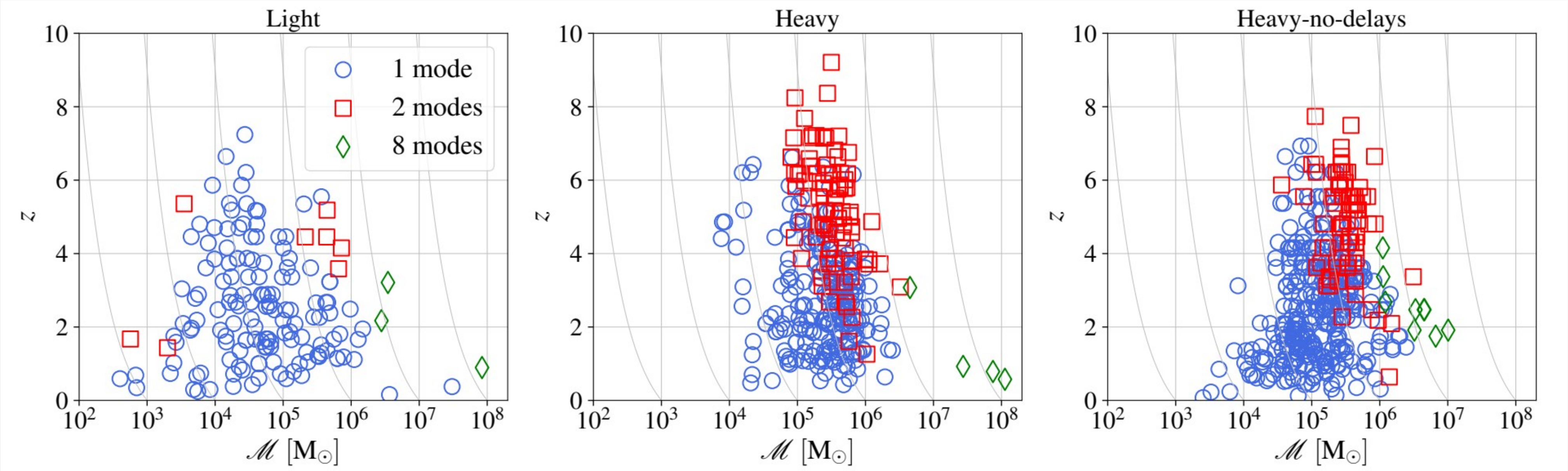
“Multimodal” LISA events

Systems with multimodal sky posterior distribution from LISA data analysis



- Arise from LISA degeneracy pattern function
- Degeneracies can be broken with :
  - Orbital motion of the detector for f~10^{-4} Hz
  - High frequency response of the detector for f~10^{-3} -10^{-2} Hz

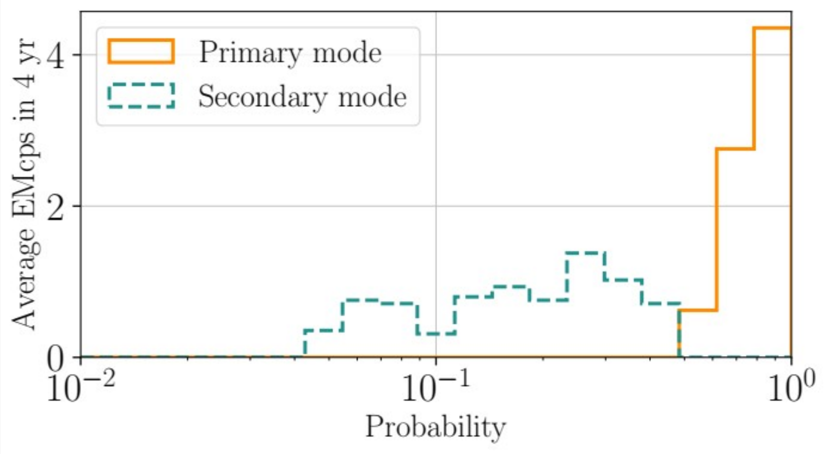
Multimodality in the parameter space

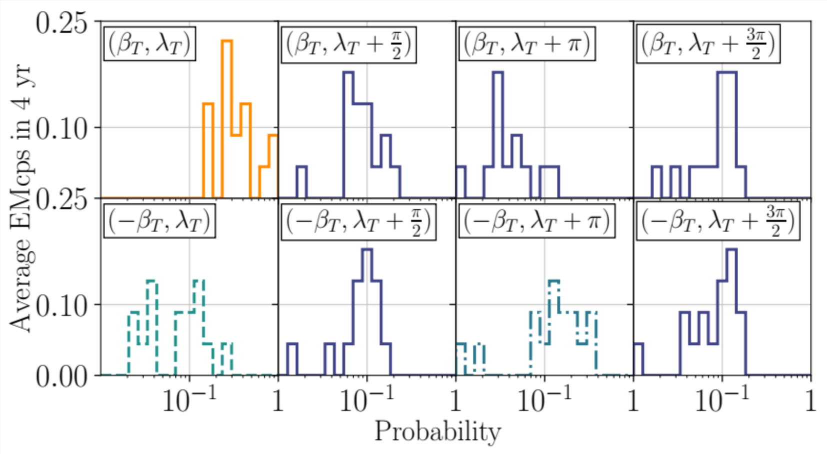


- 1mode systems are the vast majority
- 2mode systems appear at high mass and high redshift
- Still large spread across sub-populations

Contribution of multimodal events

Modes probability





Contribution to the expected rate in 4 yr

	1mode	2modes	8modes
Light	6.0	0.31	0.13
Heavy	10.7	3.9	0.18
Heavy-nd	16.8	3.5	0.4

- 2modes have always one mode more probable than the other
- 8modes provide <1 counterparts in the entire mission

Multimodal events do not contribute (significantly) to the number of EMcps

Conclusion

Multimessenger with MBHBs will be challenging

EMcps to MBHB mergers in LISA

- Most sources are faint (see also Villalba+23)
- Obscuration and collimated radio emission decrease the counterpart rates by $\sim 75\%$
- Few events $\Rightarrow$ we need accurately planned follow-up strategy

Sky localization of MBHB mergers in LISA

- Multimodality affect high-redshift sources
- Multimodal events do to not contribute significantly to the number of EMcps
- Stay tuned for new results (Marsat,..., AM+ *in prep.*)

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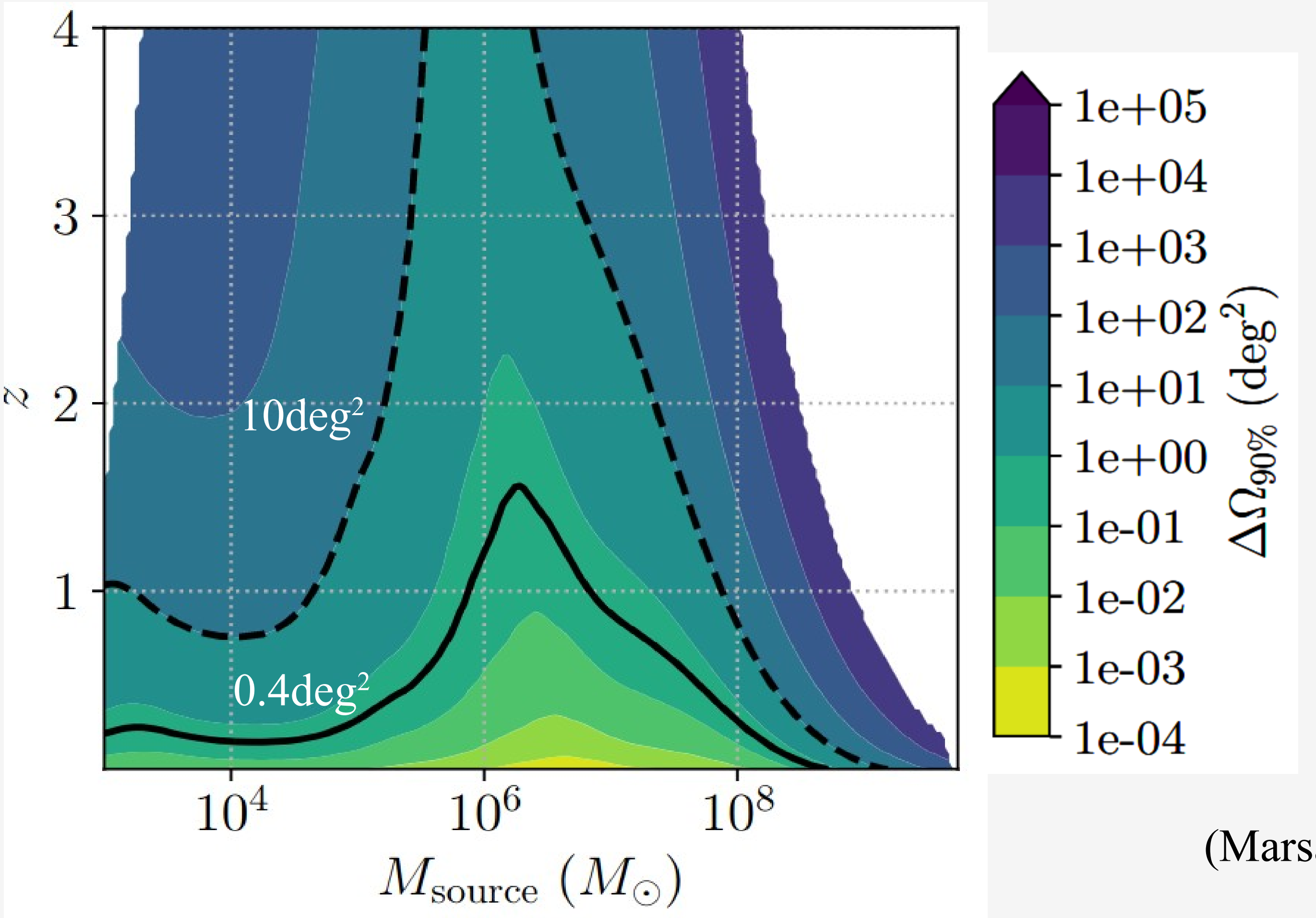
Thanks! Any question ?

Backup slides

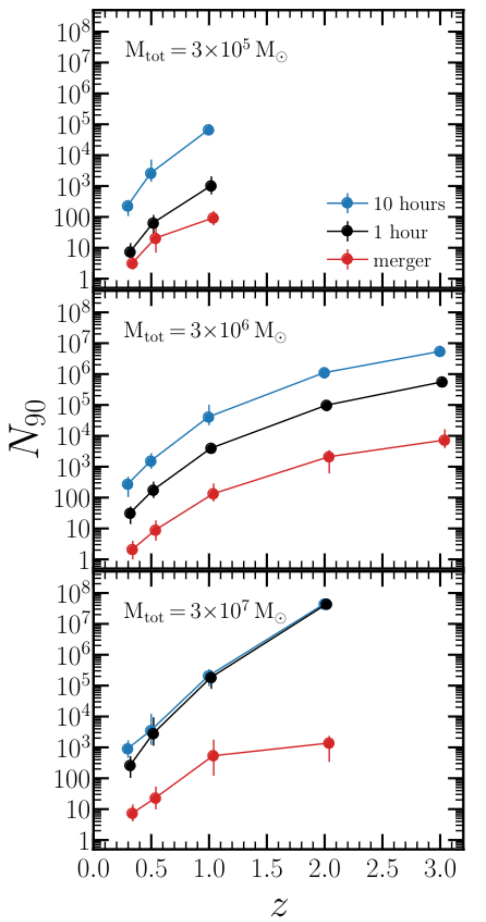
Reconstructing the binary sky position with LISA

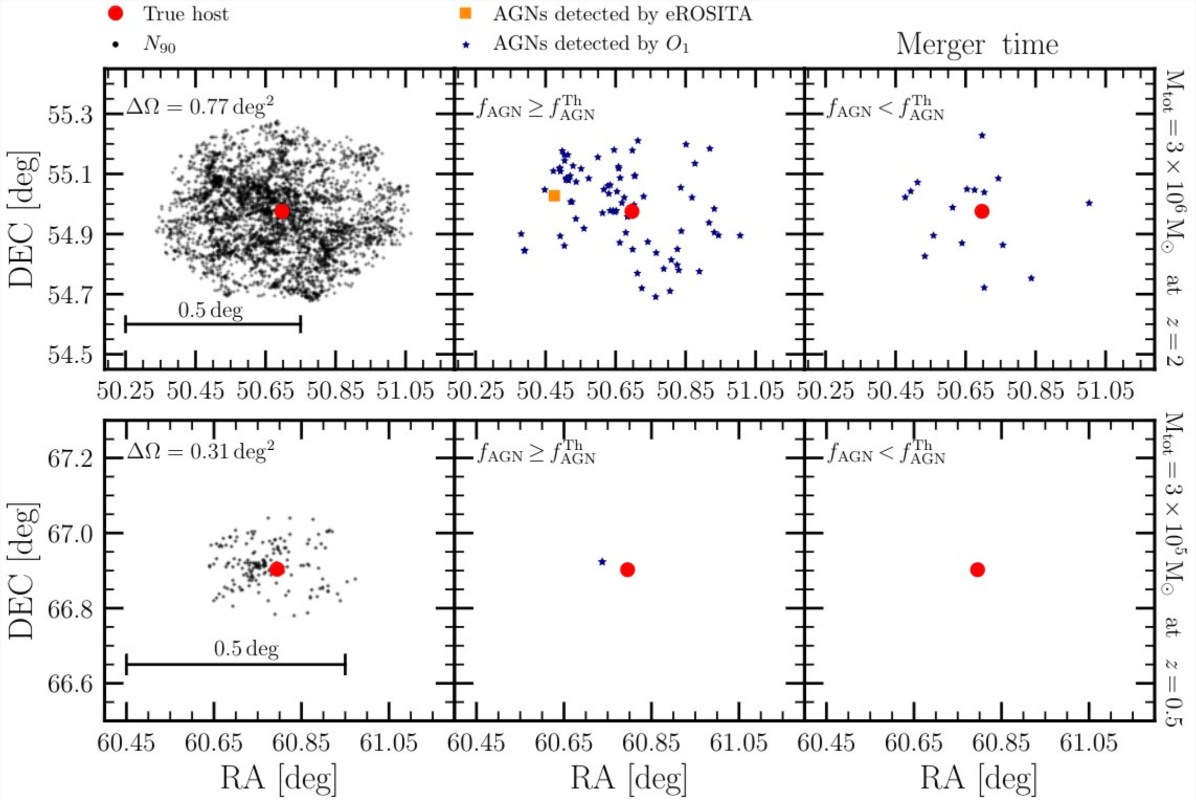


(Marsat,..., AM+ *in prep.*)

Identifying the real host galaxy

How many galaxies there will be in LISA error volume ?





Detection ≠ Identification

(Lops+22 Villalba+23)