# **ACDM Forecasts with LISA**

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# Standard sirens with LISA

### Laser Interferometer Space Antenna



#### LISA standard siren sources:

- Stellar-mass BBHs ( $10 100 M_{\odot}$ )
- Extreme mass ratio inspirals (EMRIs)
- MBHBs  $(10^4 10^7 M_{\odot})$
- Intermediate-mass BBHs? (  $\gtrsim 100\,M_{\odot}$ )
- Strongly-lensed events

#### \*EM counterparts expected

#### [LISA, ArXiv (2017)]

# **Stellar-mass BHBs**



- Redshift range:  $z \leq 0.5$
- No EM counterparts expected
- LISA detections: ~50/yr (optimistic)
- Useful as standard sirens:
  - $z \lesssim 0.1$
  - If  $\Delta d_L/d_L < 0.2$
  - If  $\Delta \Omega \sim 1 \ \mathrm{deg}^2$
  - $\Rightarrow$  ~ 5 standard sirens / yr

#### Expected results:

•  $H_0$  to few % (very optimistic - depend on LISA high-f sensitivity)

[Kyutoku & Seto, *PRD* (2017)] [Del Pozzo+, *MNRAS* (2018)]

# **Stellar-mass BHBs**



- Redshift range:  $z \lesssim 0.5$
- No EM counterparts expected
- LISA detections: ~50/yr (optimistic) ~1/yr
- Useful as standard sirens:
  - $z \lesssim 0.1$
  - If  $\Delta d_L/d_L < 0.2$
  - If  $\Delta \Omega \sim 1 \ \mathrm{deg}^2$
  - $\Rightarrow \sim 5 \text{ standard sirens / yr}$ ~0.1 standard sirens / yr
- Expected results:
  - $H_0$  to few %  $H_0$  not measured

\*with O3 LVK rates and latest LISA noise curve

### **Stellar-mass BHBs**



Stellar-mass BHs (and IMBHs) can also be used in **multi-band analyses** since their merger can be observed by groundbased detectors

- Expected results:
  - *H*<sub>0</sub> to few % (if enough IMBHs "above the gap" are detected)



[Muttoni+, PRD (2022)]

# EMRIs



- Redshift range:  $0.1 \leq z \leq 4$
- No EM counterparts expected
- LISA detections: from 1 to 1000/yr
- Useful as standard sirens:
  - $0.1 \leq z \leq 1$
  - If  $\Delta d_L/d_L < 0.1$
  - If  $\Delta \Omega < 2 \ \text{deg}^2$
  - $\Rightarrow$  ~ 1 to 100 standard sirens / yr

### • Expected results:

- $H_0$  between 1 and 10 %
- $w_0$  between 5 and 10 %

[MacLeod & Hogan, *PRD* (2008)] [Babak+, *PRD* (2017)] [Laghi+, *MNRAS* (2021)]

# EMRIs



- Redshift range:  $0.1 \leq z \leq 4$
- No EM counterparts expected
- LISA detections: from 1 to 1000/yr
- Useful as standard sirens:
  - $0.1 \leq z \leq 1$
  - If  $\Delta d_L/d_L < 0.1$
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### Expected results:

- $H_0$  between 1 and 10 %
- $w_0$  between 5 and 10 %

# Strongly-lensed EMRIs

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- Redshift range source:  $0.5 \leq z \leq 2$
- Lensed host galaxy may be identified
- LISA detections:  $\lesssim 10/yr$
- Expected results with one LEMRI:
  - $H_0$  at 1% or better (assuming  $\Omega_m$ )





- Redshift range:  $z \lesssim 20$
- EM counterparts expected
- LISA detections: 1 to 100/yr
- Useful as standard sirens:
  - $z \lesssim 7$
  - If  $\Delta d_L/d_L \lesssim 0.1$  (include lensing)
  - If  $\Delta \Omega < 10 \text{ deg}^2$
  - ⇒ ~ 3 standard sirens / yr (with EM counterpart)
- Expected results:
  - $H_0$  to few %
  - "Precise" high-z cosmography

[Tamanini+, *JCAP* (2016)] [Mangiagli+, *in prep*]

(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	



- Redshift range:  $z \lesssim 20$
- EM counterparts expected
- LISA detections: 1 to 100/yr
- Useful as standard sirens:
  - $z \lesssim 7$
  - If  $\Delta d_L/d_L \lesssim 0.1$  (include lensing)
  - If  $\Delta \Omega < 10 \text{ deg}^2$
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  - $H_0$  to few %
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[Tamanini+, *JCAP* (2016)] [Mangiagli+, *in prep*]





**Preliminary!** 

(10 yr of LISA observation)

- Expected results:
  - $H_0$  to few %
  - "Precise" high-z cosmography

[Mangiagli+, in prep]

LISA MBHB data will be very useful to probe  $\underline{\Lambda \text{CDM}}$  at high-redshift



# Strongly-lensed MBHBs

- Redshift range source:  $1 \leq z \leq 20$
- Lensed host galaxy may be identified (for low-z sources)
- LISA detections:  $\leq 1/yr$
- **Expected results with one LMBHB:**  $H_0$  at few % (assuming  $\Omega_m$ )



# Standard sirens with LISA

The combination of different standard sirens will allow LISA to measure the expansion of the universe from  $z \sim 0.01$  to  $z \sim 10$ 



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[Tamanini, *J. Phys. Conf. Ser.* (2017)] [Laghi+, *in prep.* (2023)]

# Summary

LISA Source	Redshift Range	Detection Rates	Redshift Measure (Bright Sirens)	Well Localised (Dark Sirens)	$\frac{\Delta H_0}{H_0}$	More
SOBHBs	$\lesssim 0.1$	$\lesssim 1/{ m yr}$	None	$\lesssim 0.1/{ m yr}$	None	
EMRIs	$\lesssim 4$	$\lesssim 1000/{ m yr}$	None	$\lesssim 100/yr$ @ $z \lesssim 1$	1-10%	$\Delta w_0 \lesssim 0.1$
LEMRIs	$\lesssim 4$	$\lesssim 10/{ m yr}$	$\lesssim 1/yr$ @ $z \lesssim 2$	$\lesssim 10/yr$ (?) @ $z \lesssim 1$	~1%	
MBHBs	$\lesssim 20$	$\lesssim 100/{ m yr}$	$\lesssim 3/yr$ @ $z \lesssim 7$	$\lesssim 10/yr$ (?) @ $z \lesssim 2$	~10%	High-z Analyses
LMBHBs	$\lesssim 20$	$\lesssim 1/{ m yr}$	$\lesssim 0.1/yr$ (?) @ $z \lesssim 2$	$\lesssim 0.1/yr$ (?) @ $z \lesssim 2$	~10%	High-z Analyses
Combined			$\lesssim 3/\mathrm{yr}$	$\lesssim 100/{ m yr}$	≲1%	High-z and dark energy Analyses