Multi-messenger perspectives with LISA

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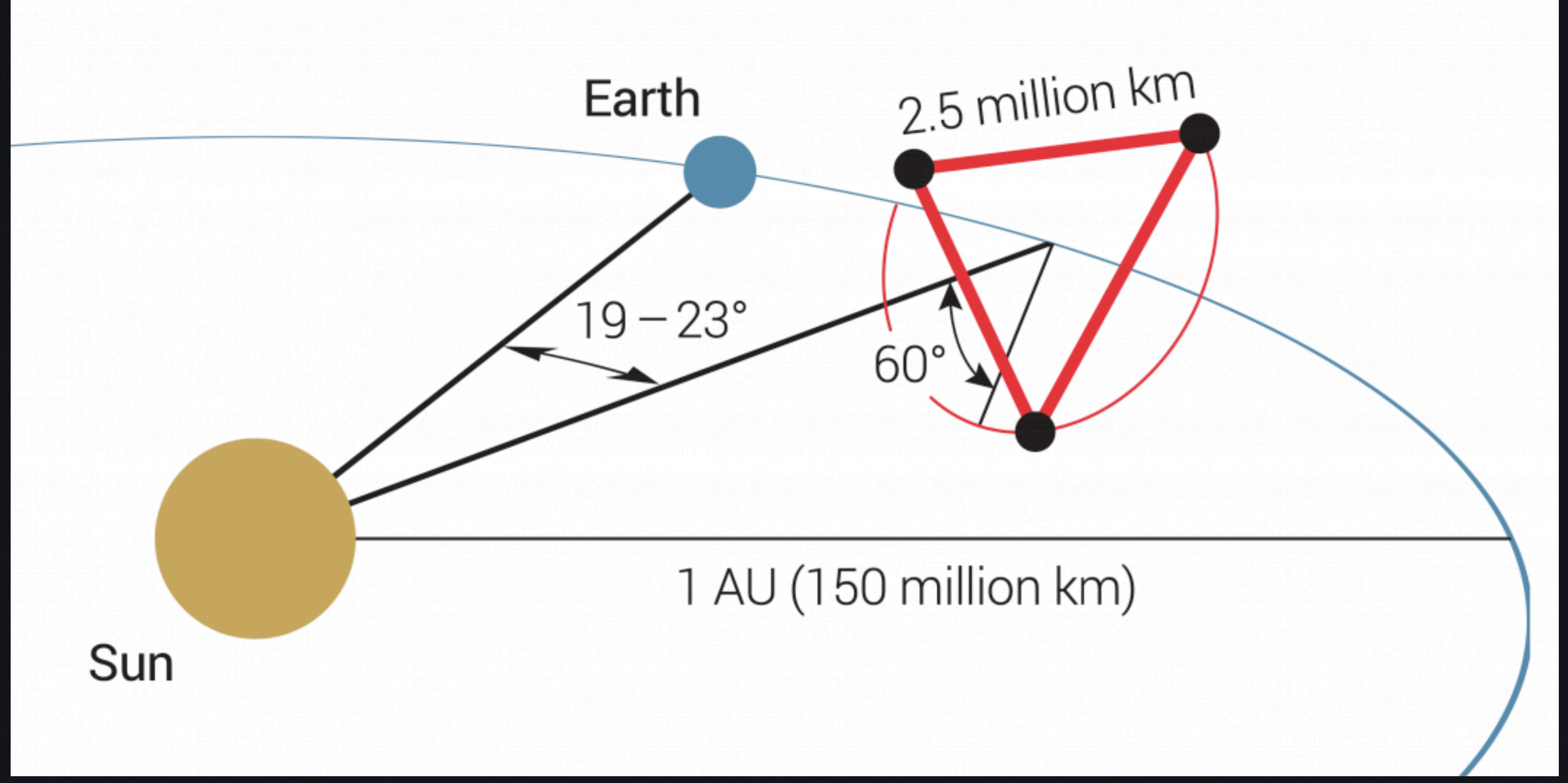
IAPS Istituto di Astrofisica e Planetologia Spaziali

Multimessenger astronomy in the Einstein Telescope Era. Padova, February 2026

LISA

project status



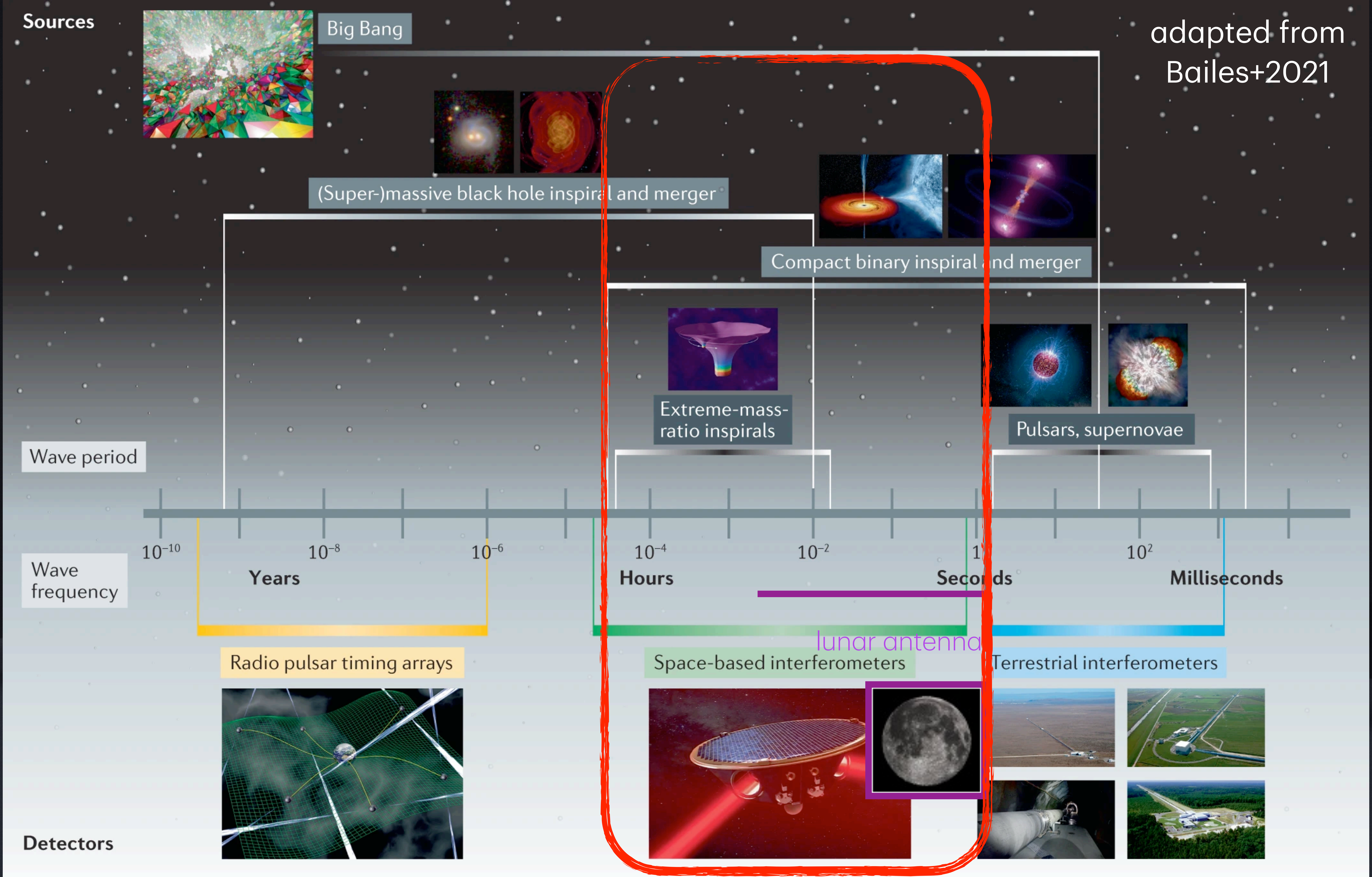
LISA is a large-scale space mission designed to detect gravitational waves in the mHz domain (0.1 mHz-0.1 Hz). It will be the first space-based gravitational wave observatory.

LISA will consist of three spacecraft separated by 2.5 million km in a triangular formation, following Earth about 50 million km in its orbit around the Sun.

The LISA launch is expected in 2035

The LISA Consortium is a large international collaboration that combines the resources and expertise from scientists in many countries all over the world. Together with ESA, its member states, and NASA, the LISA Consortium is working to bring the LISA Mission to fruition.

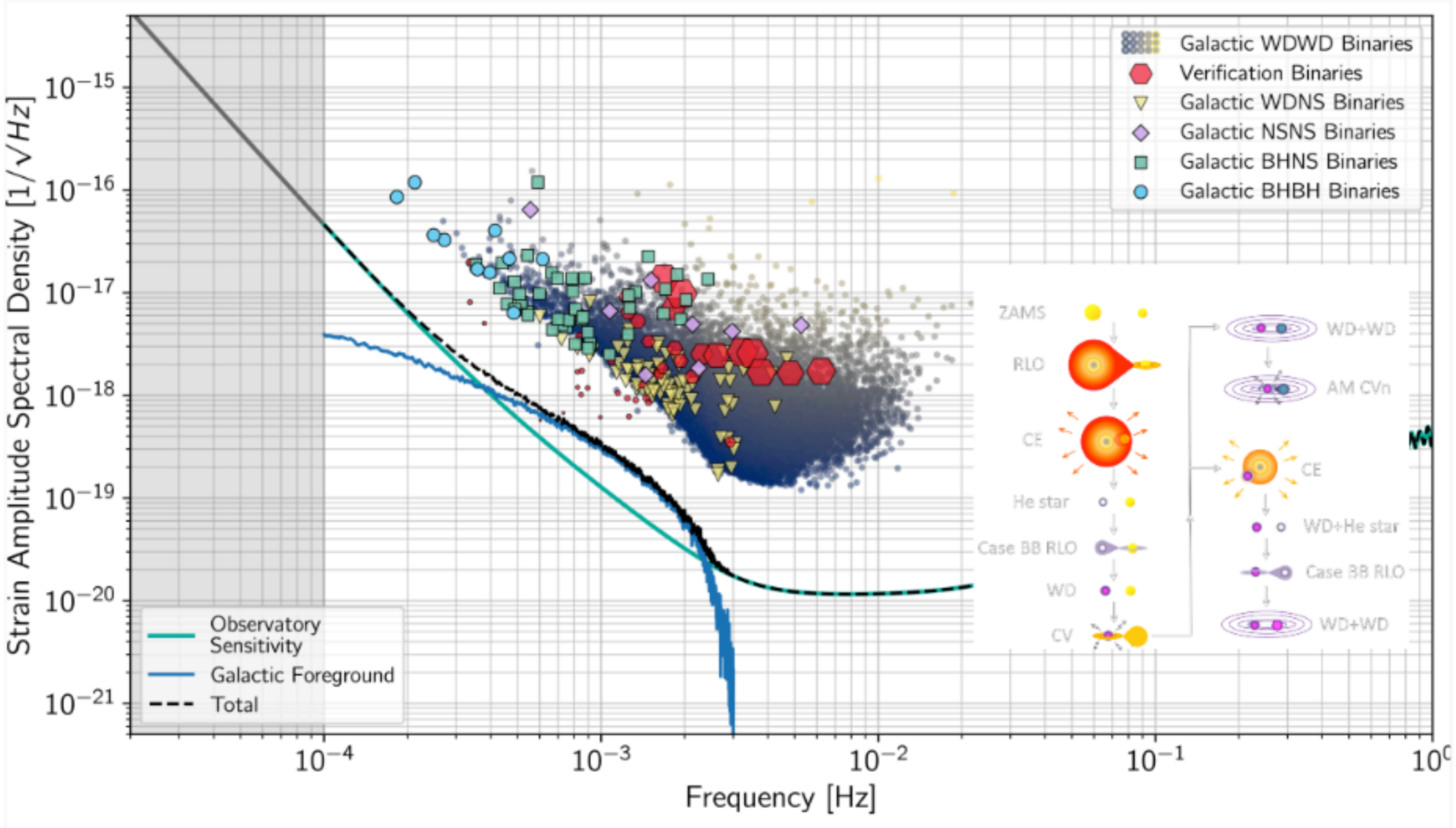
INAF contribution to LISA



adapted from Bailes+2021
Sources
Big Bang
(Super-)massive black hole inspiral and merger
Compact binary inspiral and merger
Extreme-mass-ratio inspirals
Pulsars, supernovae
Wave period
Wave frequency
10^-10
10^-8
10^-6
10^-4
10^-2
1
10^2
Years
Hours
Seconds
Milliseconds
lunar antenna
Radio pulsar timing arrays
Space-based interferometers
Terrestrial interferometers
Detectors

LISA science I - Compact binaries

GW Astrophysics



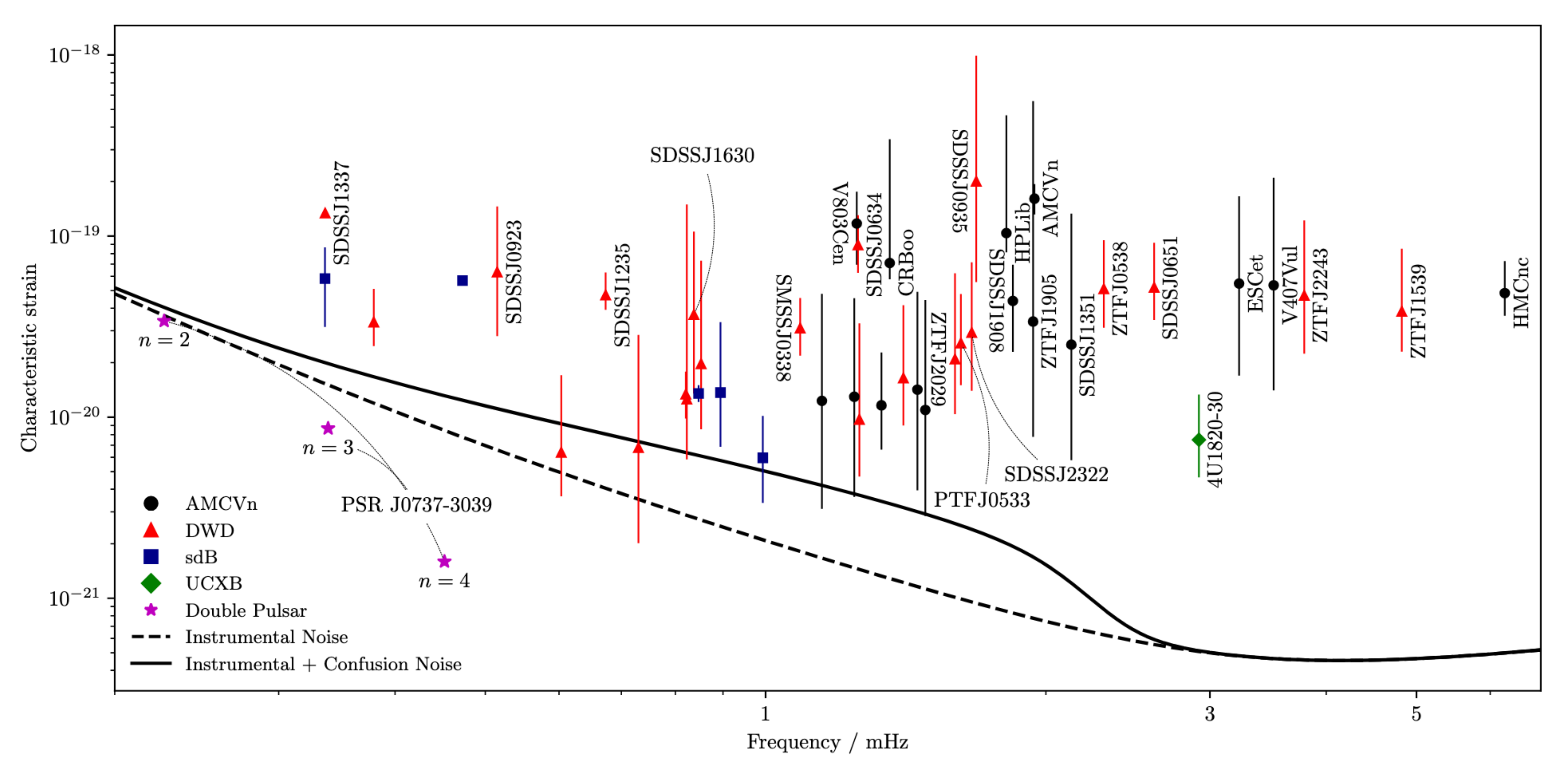
Source	N	N^{detected}
WD+WD	$\sim 10^8$	6,000–10,000
NS+WD	$\sim 10^7$	100–300
BH+WD	$\sim 10^6$	0–3
NS+NS	$\sim 10^5$	2–100
BH+NS	$\sim 10^4 - 10^5$	0–20
BH+BH	$\sim 10^6$	0–70

Stellar compact binaries will be the most numerous GW sources in the LISA band; many are invisible in EM while some will be multi-messenger sources.

LISA Definition Study Report

LISA science I - Compact binaries

EM+GW Astrophysics



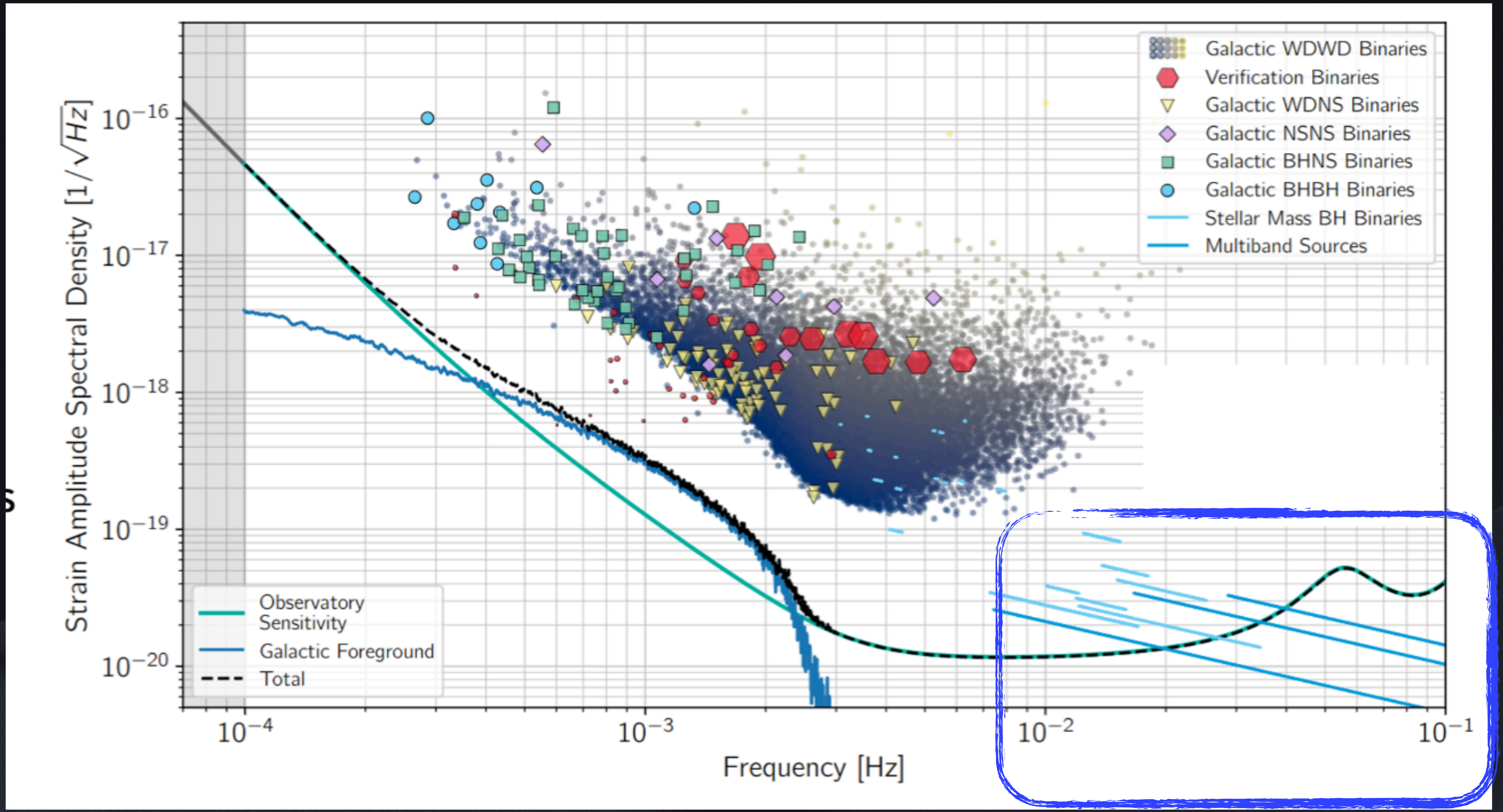
Finch+2023

Coordinated EM observations help distinguish detached from interacting systems and reveal their accretion states, complementing LISA's precise GW-derived orbital parameters.

Together, EM and GW data provide a complete and unbiased census of Galactic compact binaries, essential for understanding their formation and evolution.

LISA science II - stellar mass BH binaries

multi-band sources

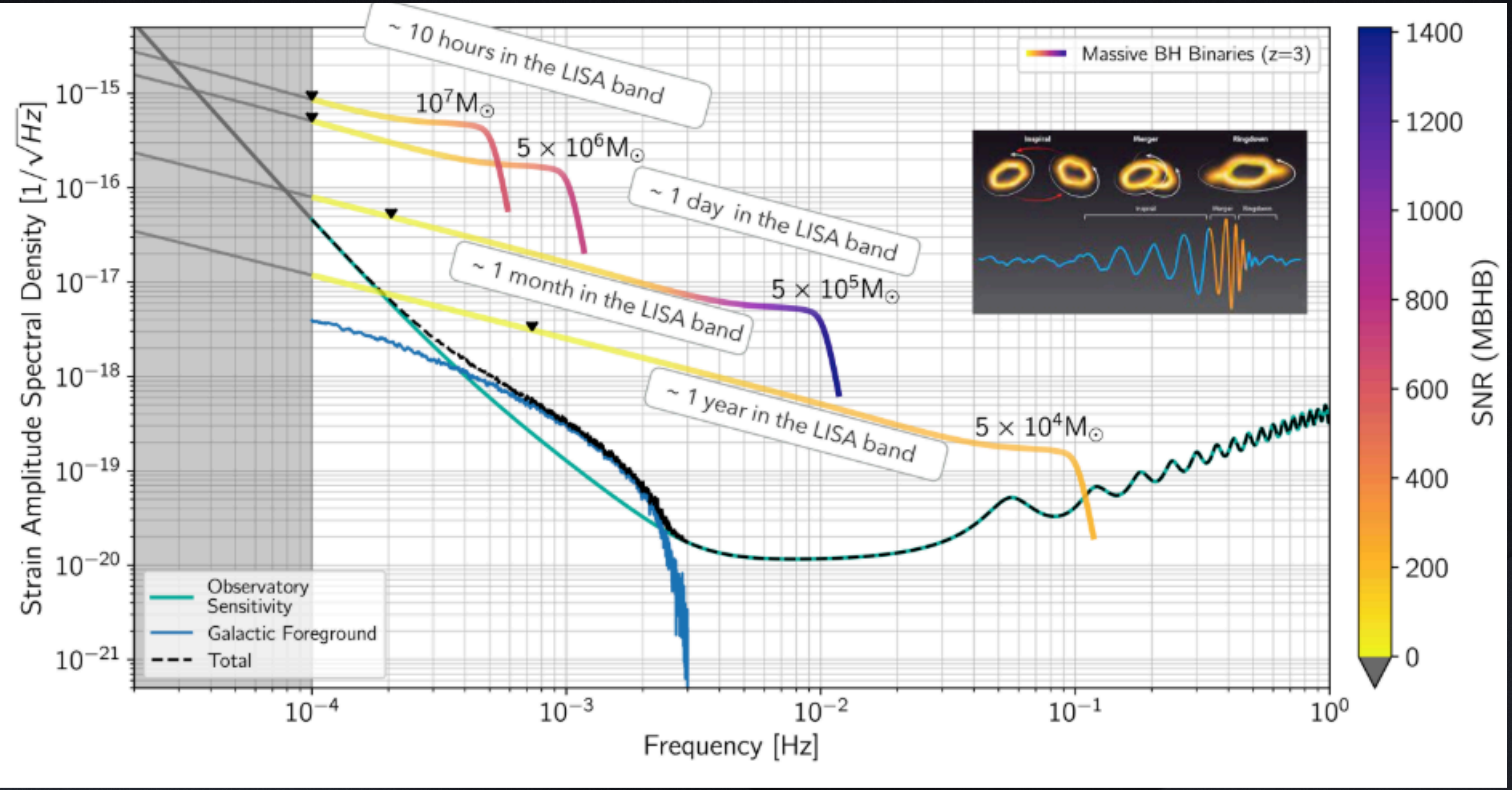


GW150914-like binaries a few years prior to their coalescence. The inferred sky position and time to coalescence will inform ground-based GW detectors and EM observatories to enable GW multi-band and multi-messenger observations

LISA Definition Study Report

LISA: Science III - Growth and merger of MBH

GW domain



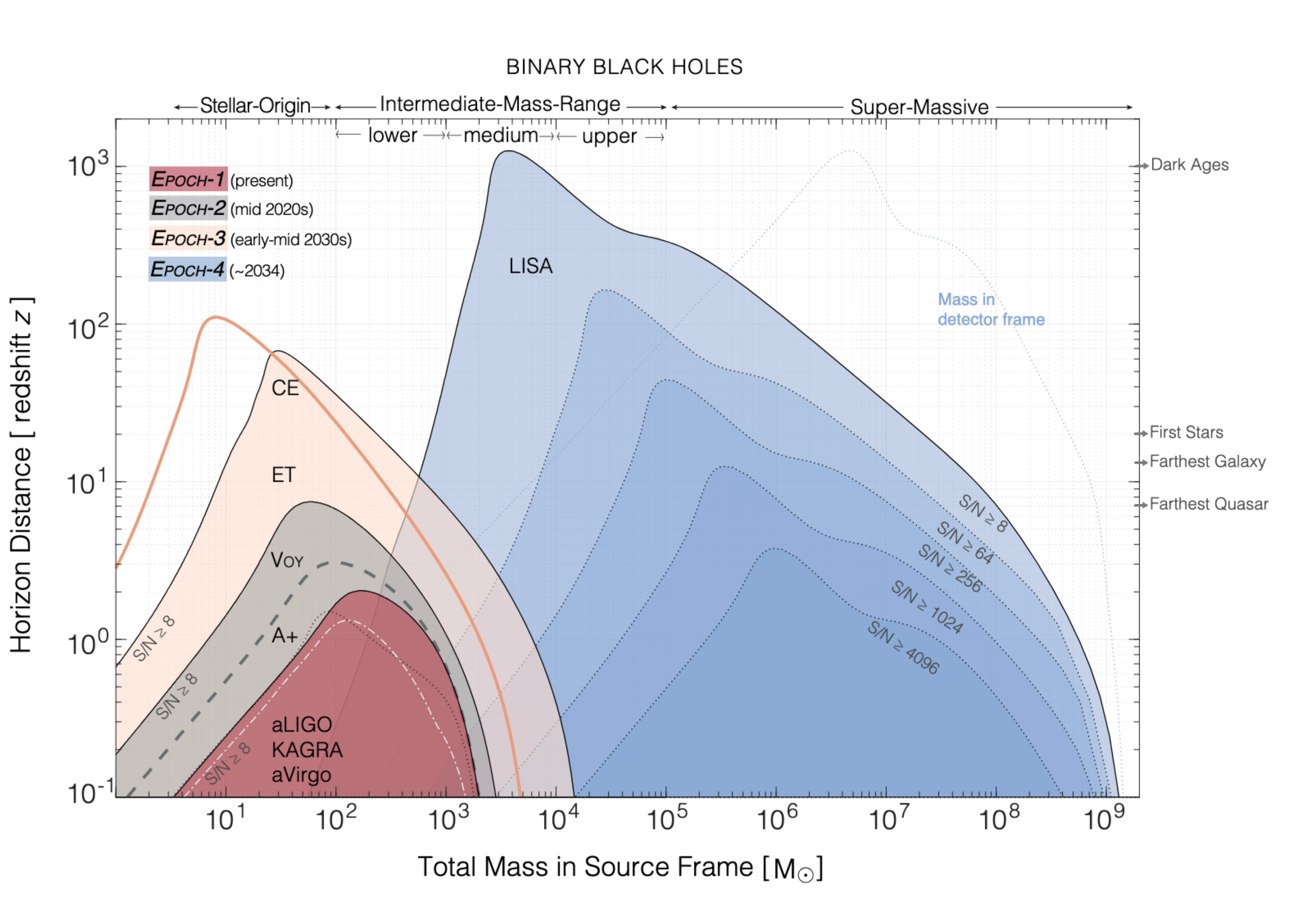
MBH binaries become detectable by LISA weeks/days/hours before the merger, depending on BHM and redshift, and become quiescence shortly after coalescence, forming a class of transient sources

(in contrast to the continuous sources such as Galactic binaries)

LISA Definition Study Report

BH population in the GW domain

LISA & ET



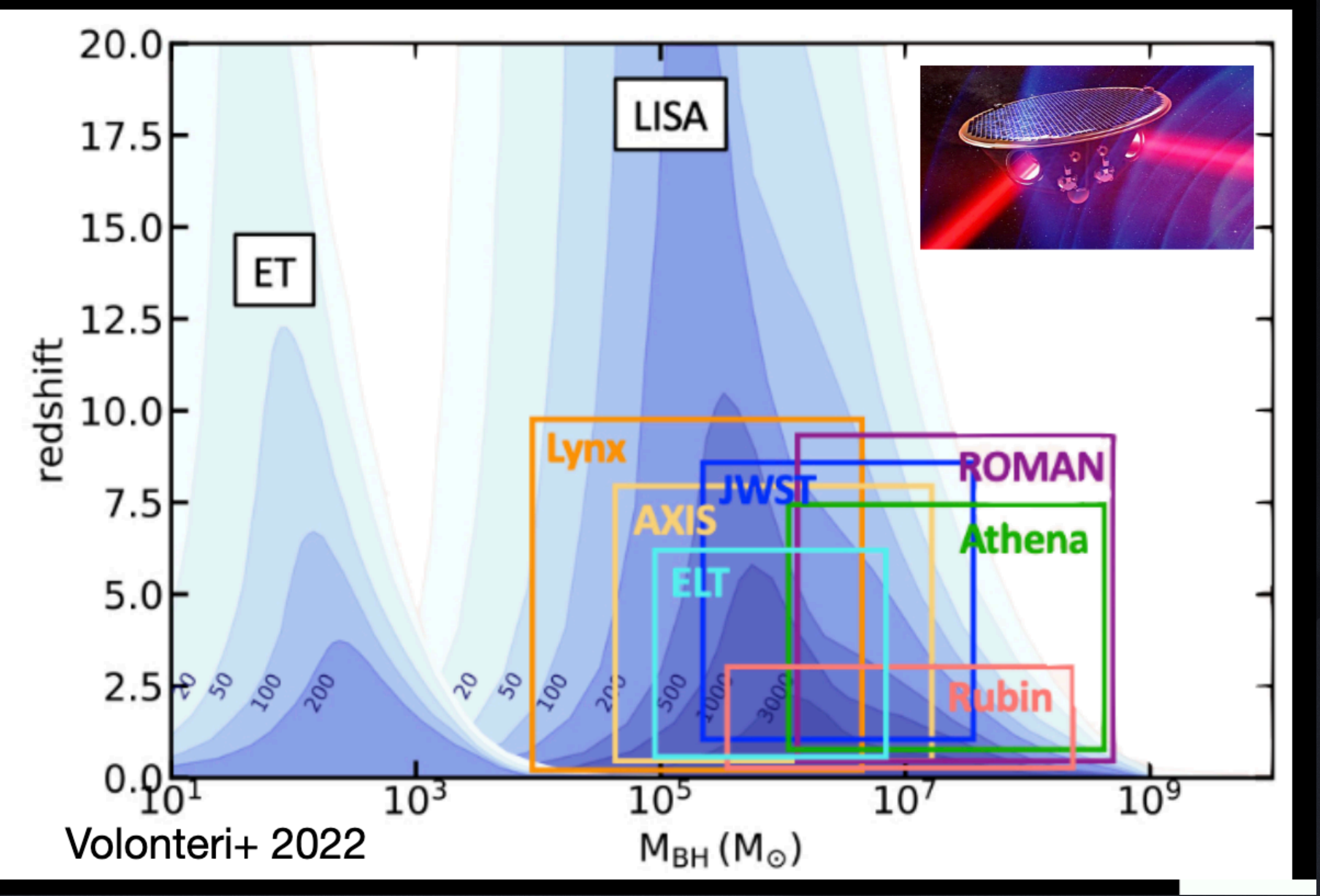
Mass range coordinated multi-band GW observations (ET, CE in LISA's mission lifetime) are possible, with LISA having the capability to first follow the early inspiral of IMBHs, and tracking the merger phase. This unique combination will allow precise measurements out to z ~ 5

multiband observations LIGO+LISA would detect the inspiral, merger and ringdown of IMBH binaries out to redshift z ~ 2.

Valiante+21, Jani+19

BH population in the GW domain

LISA & ET



Valiante+21, Jani+19

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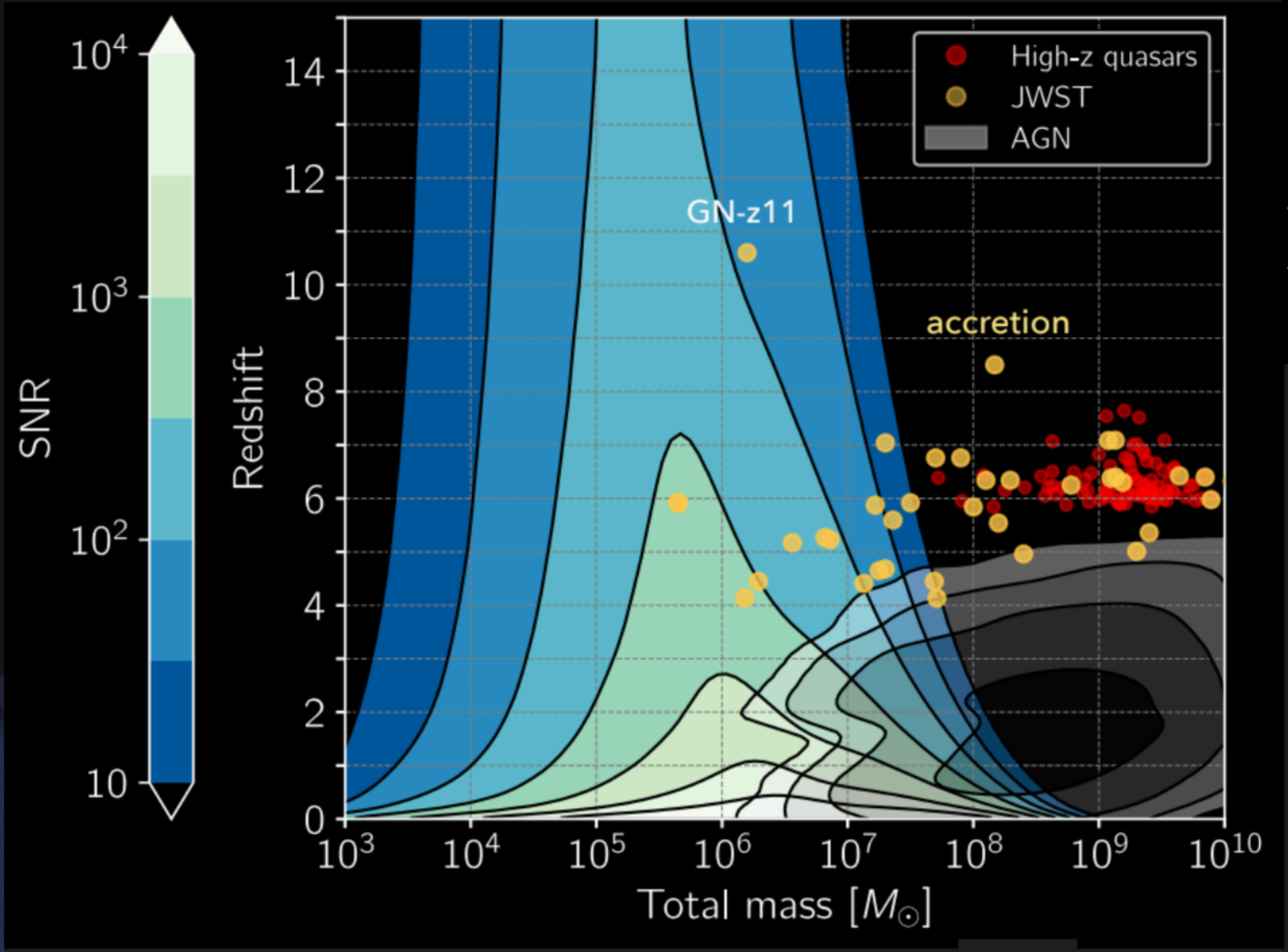
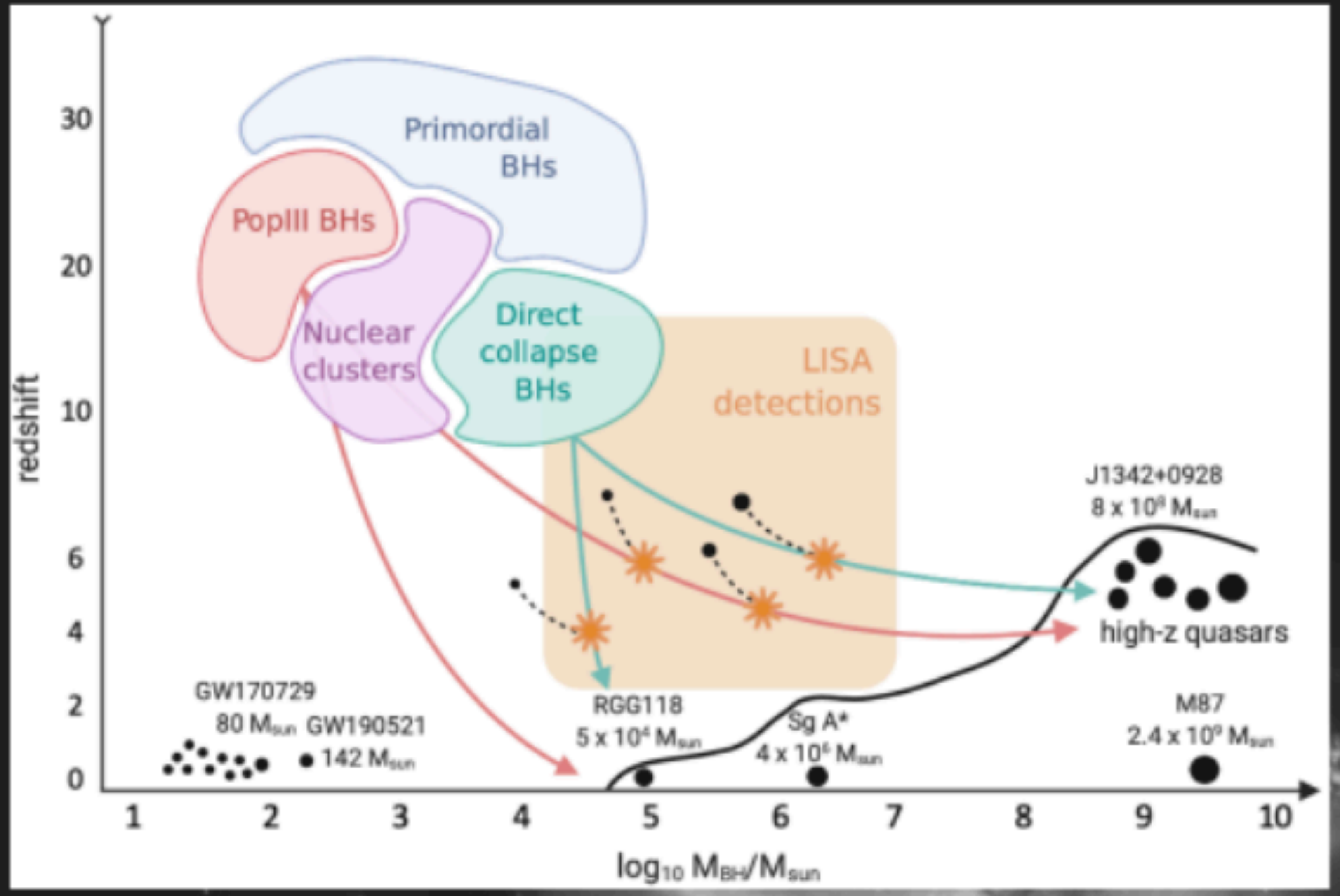
massive BH population in the MM domain



LISA will explore the low-mass tail of the MBH mass function.

GW+EM view of MBH will allow us to understand how AGN are triggered, how MBH grow and evolve



Astrophysics with LISA Amaro-Seoane+23 /w De Rosa

Chap. 2.6 *Multimessenger view of MBH populations*

Table 2.1: Landscape of the upcoming and concept missions that will be complementary to LISA, and will provide us with crucial constraints on the population of MBHs and their host galaxies. See the text for references.

Missions	Wavelength	Types	Sky coverage	Launch	Goals
LISA	GW mHz	laser interferometery	all sky	mid 2030s	MBH mergers with $M_{\rm BH}$ = up to $z = 20$, constraints on BH mass, redshift, spin.
PTAs	GW nHz	pulsed radio emission	all sky	current	GW background powered by low-redshift MBHs of $M_{\rm BH} \sim 10^{7-9}$ $M_\odot$.
eROSITA	X-ray (0.3–10 keV)	spectroscopy imaging	all sky	2019	3 million AGN, of which several tens of thousands at z≥ 3
Athena	X-ray (0.3–10 keV)	spectroscopy imaging	2.4/30 deg^2 WFI deep/shallow	2030s	AGN with $L_{2-10\,\rm keV} \geqslant 10^{41-43}$ erg/s depending on redshift.
AXIS	X-ray (0.3–10 keV)	spectroscopy imaging	2.5/50 deg^2 Medium/Wide	concept mission	AGN with $L_{2-10\,\rm keV} \geqslant 10^{40-43}$ erg/s depending on redshift.
Lynx	X-ray (0.3–10 keV)	spectroscopy imaging	2 deg^2	concept mission	AGN with $L_{2-10\,\rm keV} \geqslant 10^{39-41}$ erg/s depending on redshift, potentially reaching MBHs of $M_{\rm BH} \sim 2 \times 10^4 M_\odot$ at z = 7-10.
IXPE/ XL-Calibur/eXTP	X-ray (2-8 keV)	polarimetry	pointed observations, limited survey capability	2022	MBH accretion in star forming galaxies MBH spin and mass, astrophysical environments of the MBHs, AGN outflows
JWST	NIR-midIR ($0.6 - 28\mu m$)	spectroscopy imaging	46/190 arcmin^2 Deep/Medium	2021	High-redshift galaxies up to $z \sim 10$, high-redshift quasars, spectrum of young MBHs, constraints on MBH formation mechanisms.
Roman	optical/NIR ($0.5 - 2\mu$m)	imaging	2000 deg^2 WFI HLS	~ 2025	Mapping high-redshift galaxies, detection of massive quasars of $\sim 10^9$ $M_\odot$ up to $z \sim 10$
Euclid	optical/NIR ($550 - 2000nm$)	spectroscopy imaging	40/15000 deg^2 Deep/Wide	~ 2022	Mapping high-redshift galaxies, detection of massive quasars of $\sim 10^9$ $M_\odot$ up to $z \sim 10$
DESI	360-980 nm	spectroscopy	14000 deg^2	2021	Mapping high-redshift galaxies and quasars
E-ELT	$0.35 - 14\mu m$	imaging spectroscopy		2025	confirmation of high-redshift quasar candidates
SKA	$0.01 - 4m$	radio interferometry	10-20 deg^2 SKA1-MID deep	2027	duty cycle of jet launching in AGN provide detailed insights on feedback/feeding loop in AGN
Rubin LSST	320–1050 nm	photometry	18000 deg^2	2023	detection of sub-pc MBHBs through photometry variability study on 10^{4-5} AGN
SDSS-V	$380 - 920nm$	spectroscopy	all sky	2020	detection of sub-pc MBHBs through spectroscopy spectroscopic identification and redshift of quasar/AGN MBH mass at $z = 0.1$–4.5

future/current EM facilities for MBH

a not complete overview

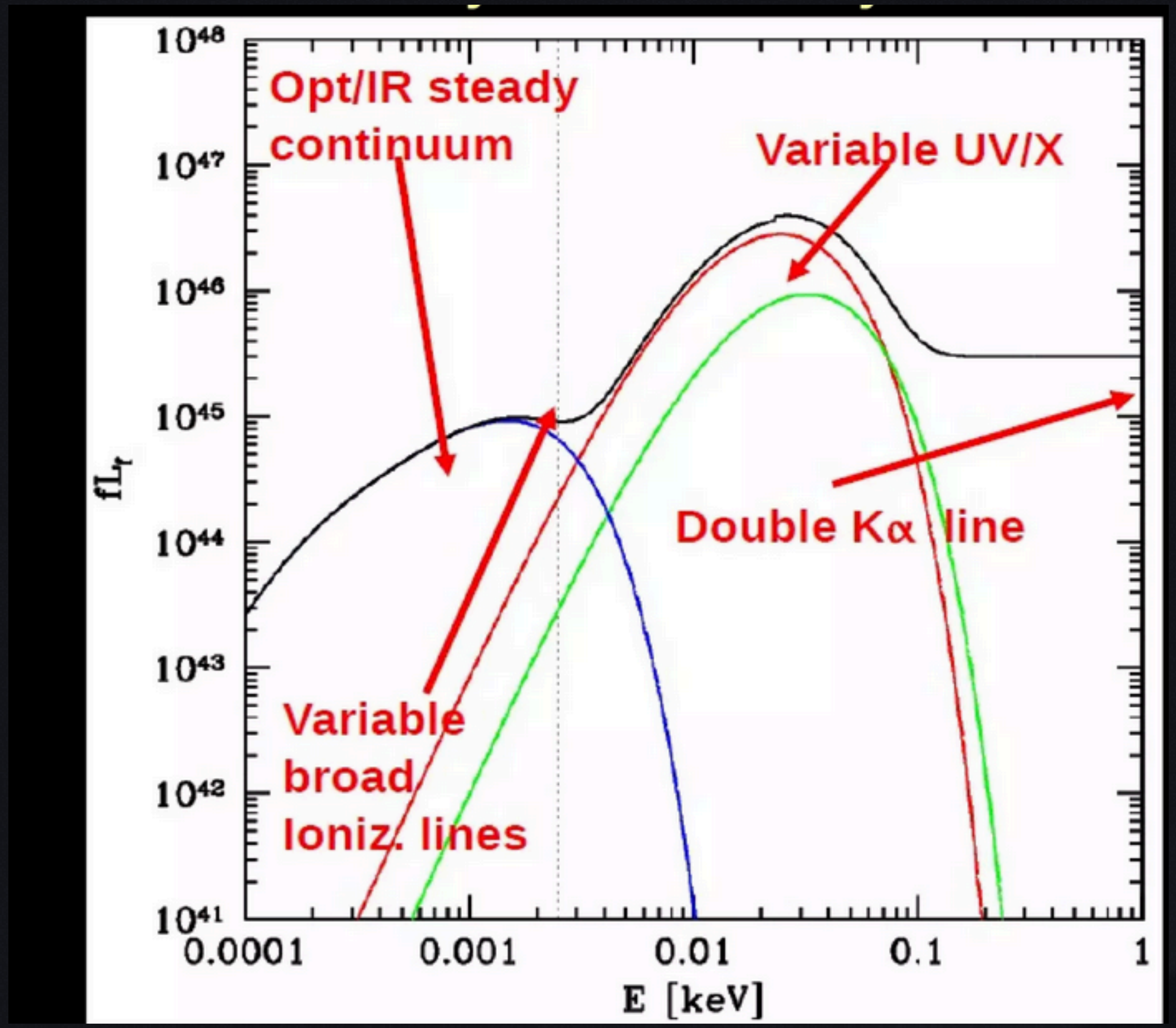
	Description	Observatories/Missions
BH population	Measure SMBH masses in distant and nearby galaxies using high-resolution (image/spec) infrared and optical data.	JWST, E-ELT, SDSS-V
BH Growth	Study SMBH growth through X-ray emission, accretion processes, and transient events. High-z QSO	Athena, AXIS, XRISM, Euclid, LSST, ROMAN
Host Properties and Coevolution	Understand the relationship between SMBHs and their host galaxies, including dark matter distribution.	DESI, Euclid, ROMAN, JWST, SKA

multi-messenger on a single event

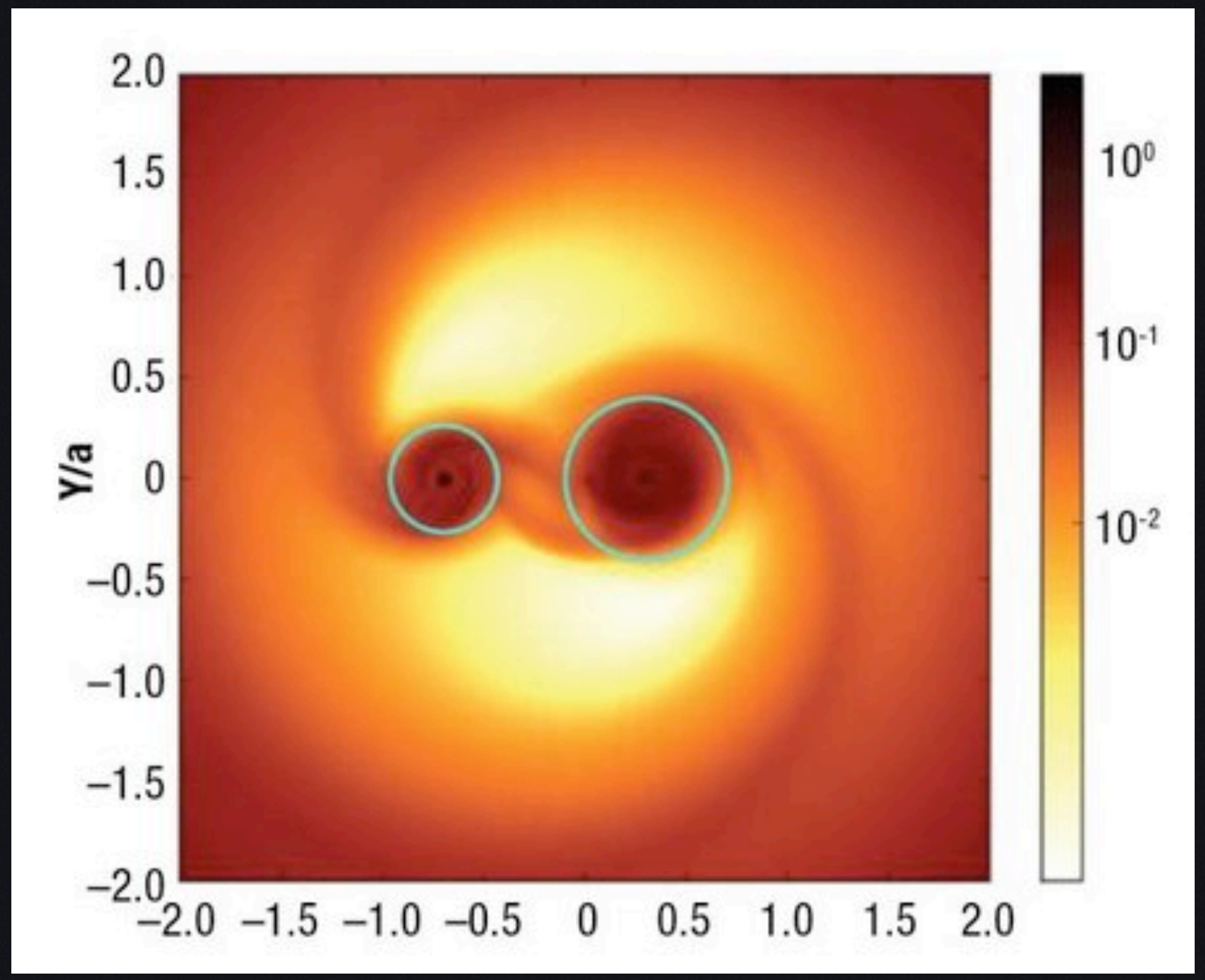
electromagnetic and gravitational events of binary and merging MBHs

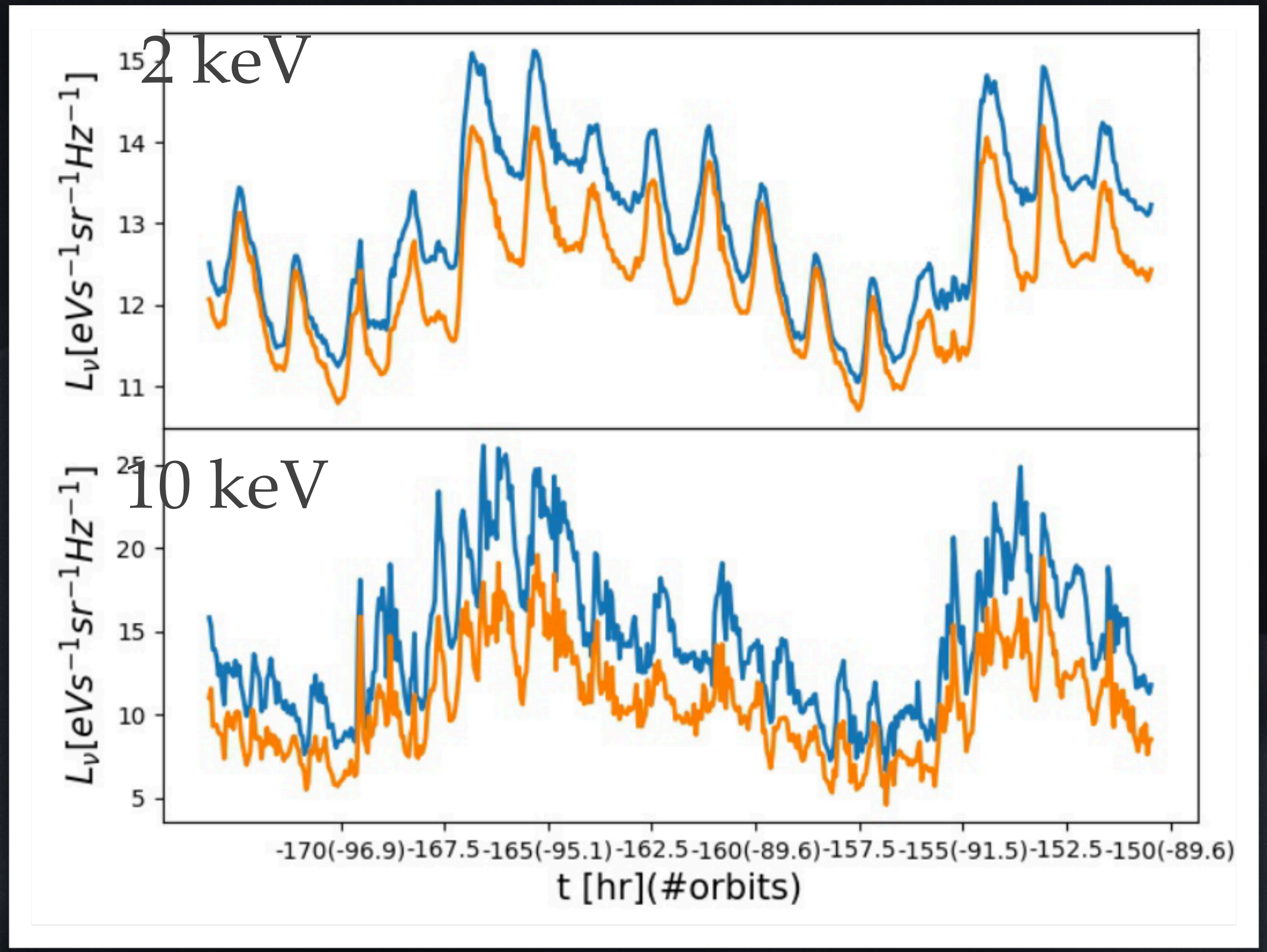
Aurore Simonnet for the NANOGrav Collaboration

Multi-messenger of MBH: final stage of the mergers



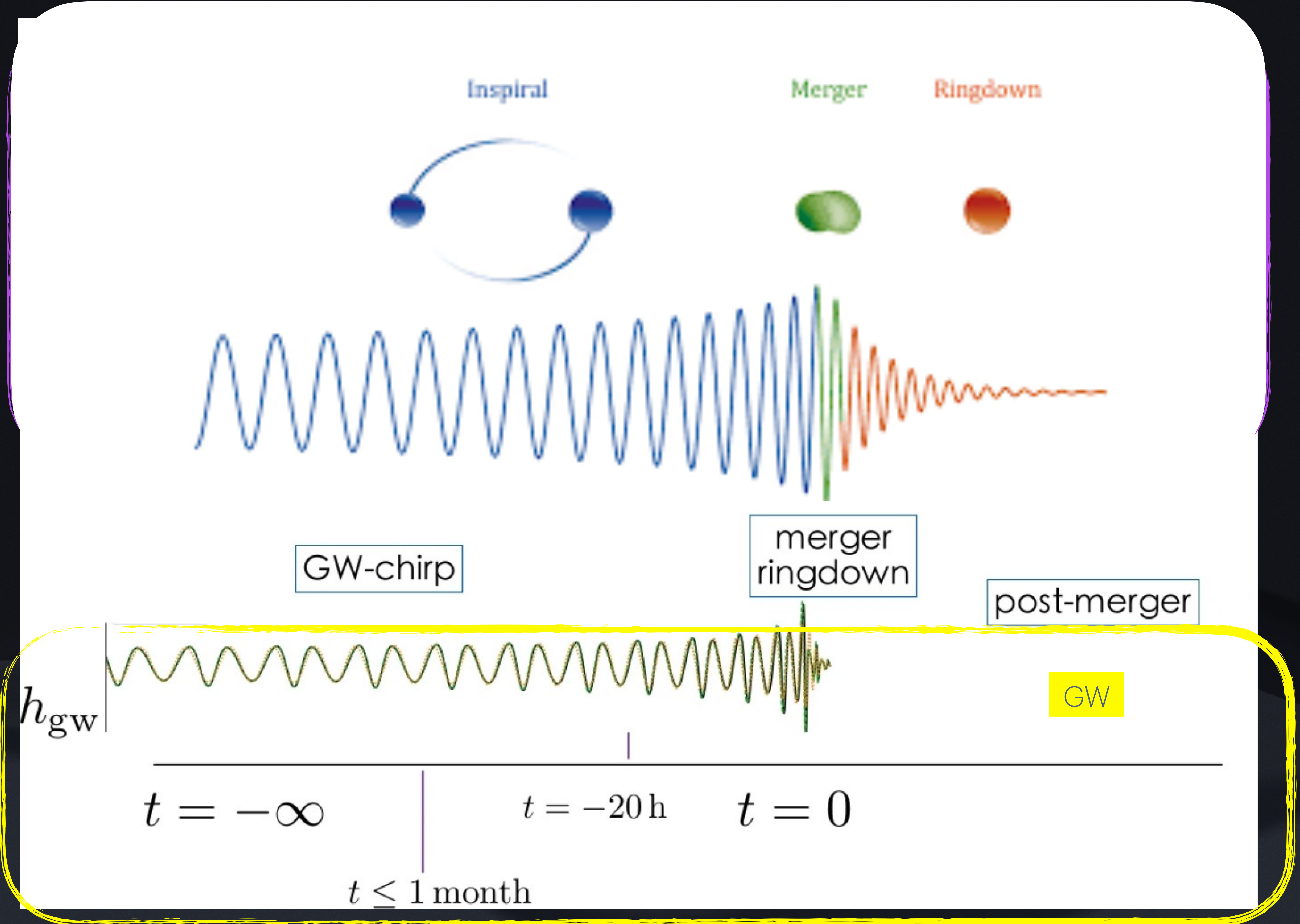
Is there any gas around MBHs before the coalescence?
Sub-pc to milli-pc separations in a gas-rich environment: formation of a circumbinary disc and mini-discs

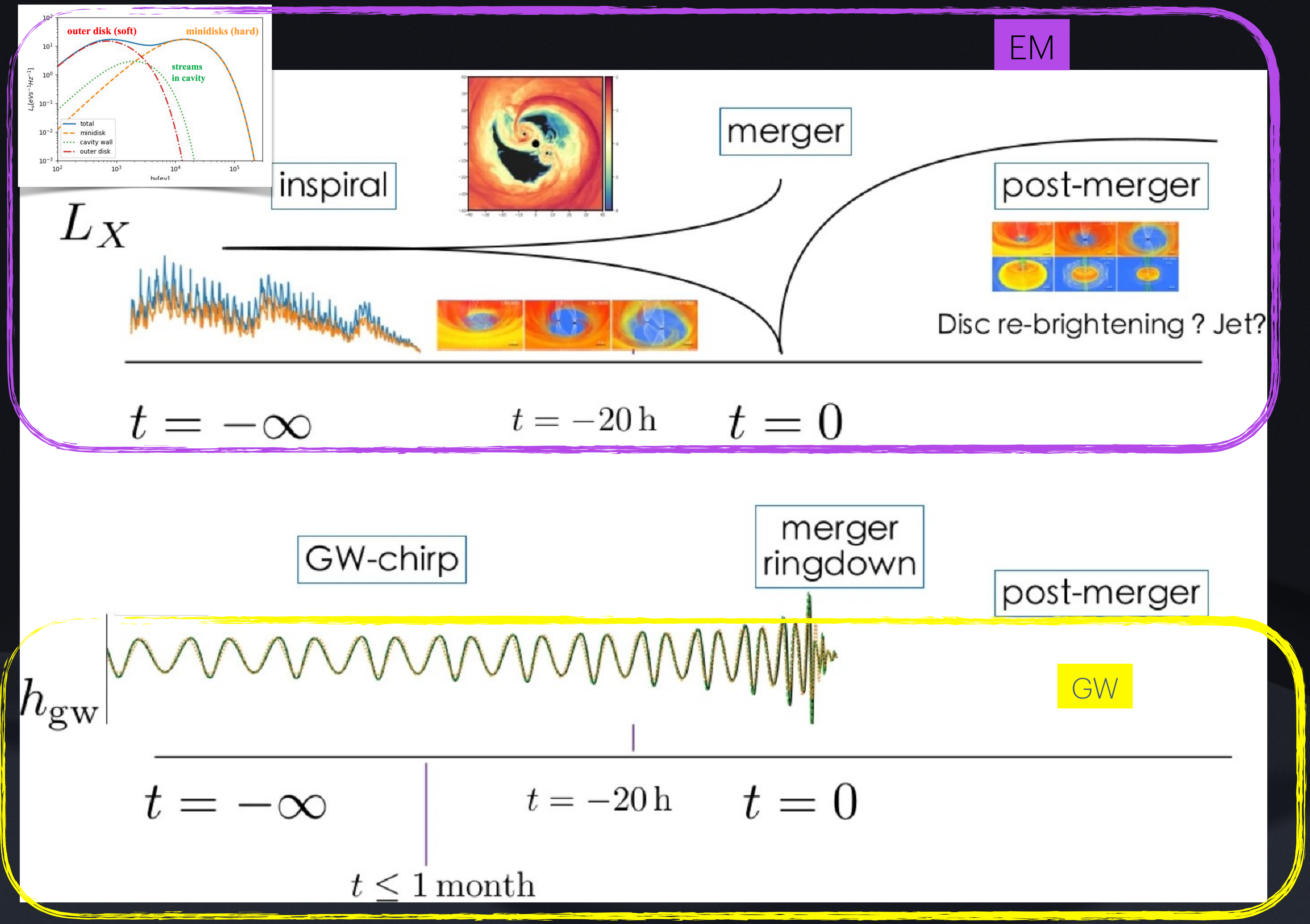




- Richness of states: the flow pattern depends on BH mass, q, BH spin.
- Three general statements: periodicity, enhanced brightness (shocks) and unusual spectral shapes (X-optical)

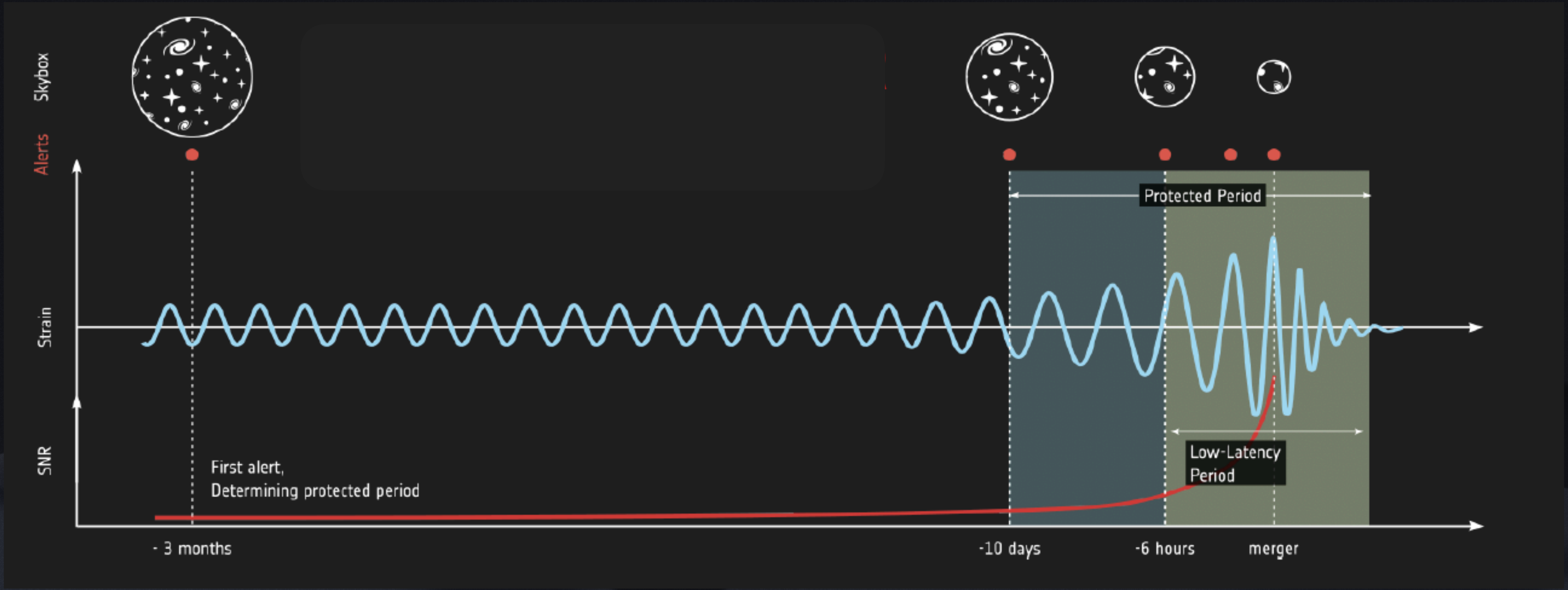
Farris+15,17; Tang+18; D'Orazio+18,D'Ascoli+18, Bowen+18, Roeding+11, Sesana+12, Franchini+24, ..


Inspiral
Merger
Ringdown
GW-chirp
merger
ringdown
post-merger
GW
h_{gw}
$t = -\infty$
$t = -20\,\mathrm{h}$
$t = 0$
$t \leq 1\,\mathrm{month}$


EM
outer disk (soft)
minidisks (hard)
streams
in cavity
total
minidisk
cavity wall
outer disk
inspiral
merger
post-merger
Disc re-brightening ? Jet?
L_X
$t = -\infty$
$t = -20\,\mathrm{h}$
$t = 0$
GW-chirp
merger
ringdown
post-merger
GW
h_{gw}
$t = -\infty$
$t = -20\,\mathrm{h}$
$t = 0$
$t \leq 1\,\mathrm{month}$

LISA alerts and multi messenger

Low-Latency pipeline

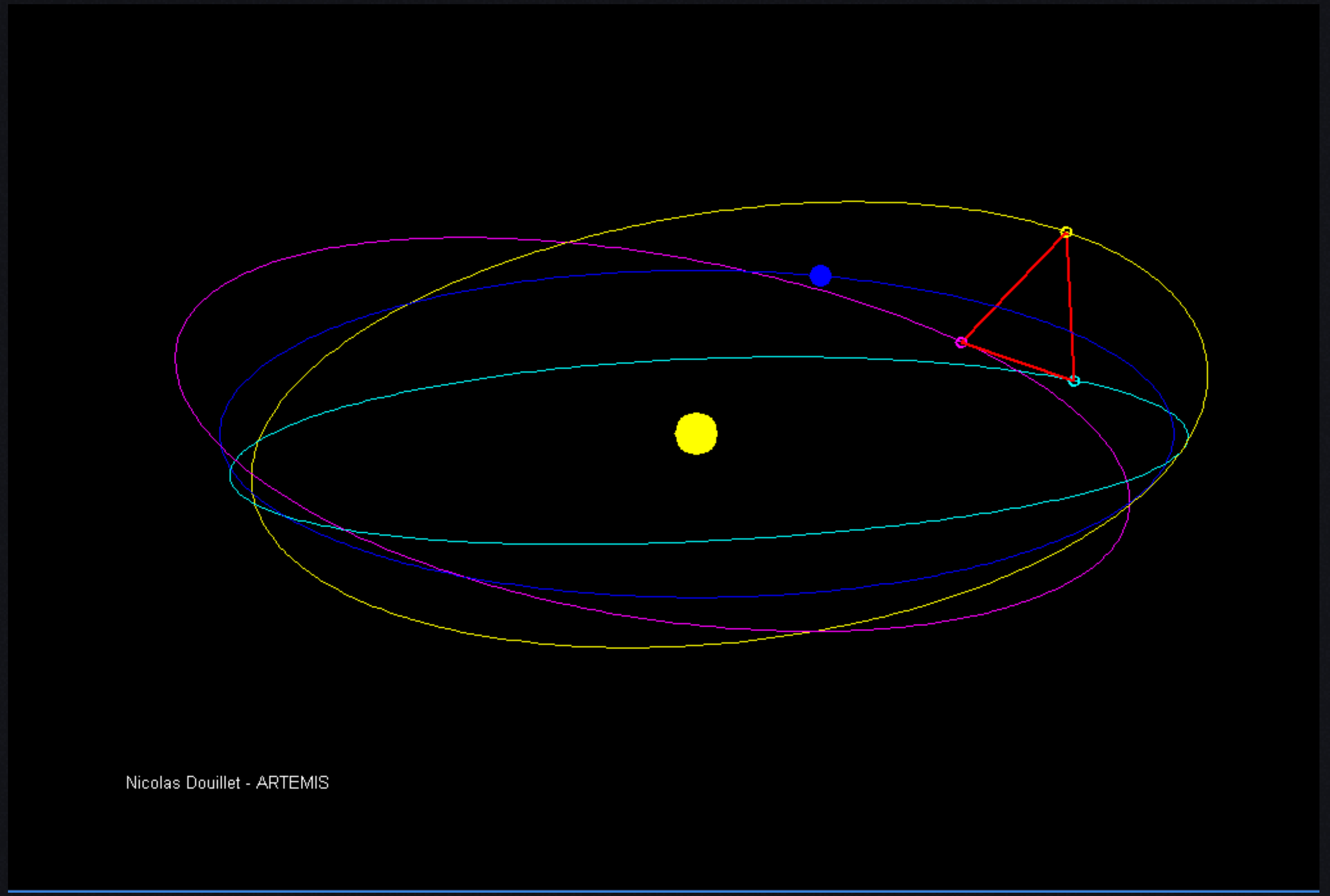


protected period of quasi-realtime data (outside the nominal 8 hr)

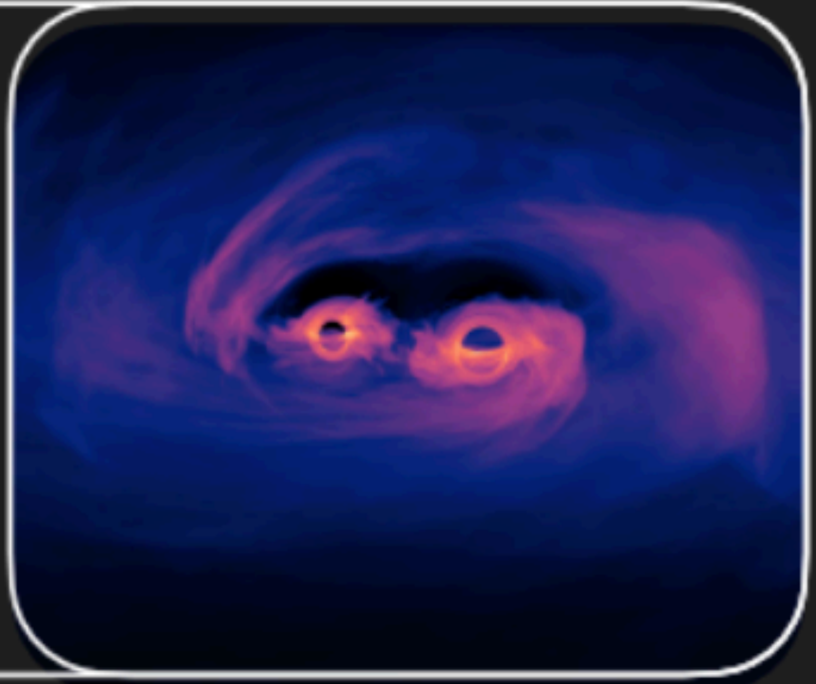
LISA Definition Study Report

GW localization with LISA

following GW events from MBH mergers with EM observatories

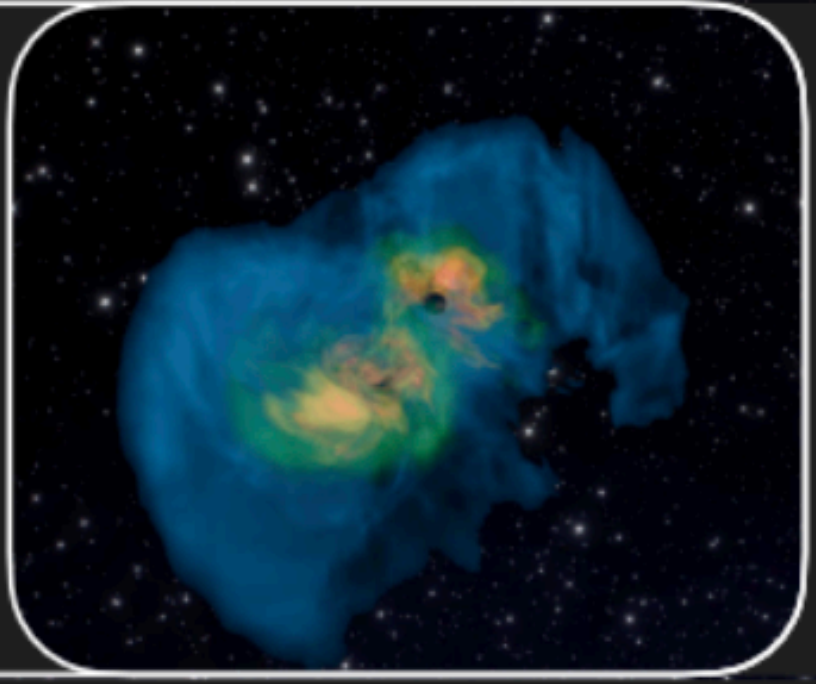


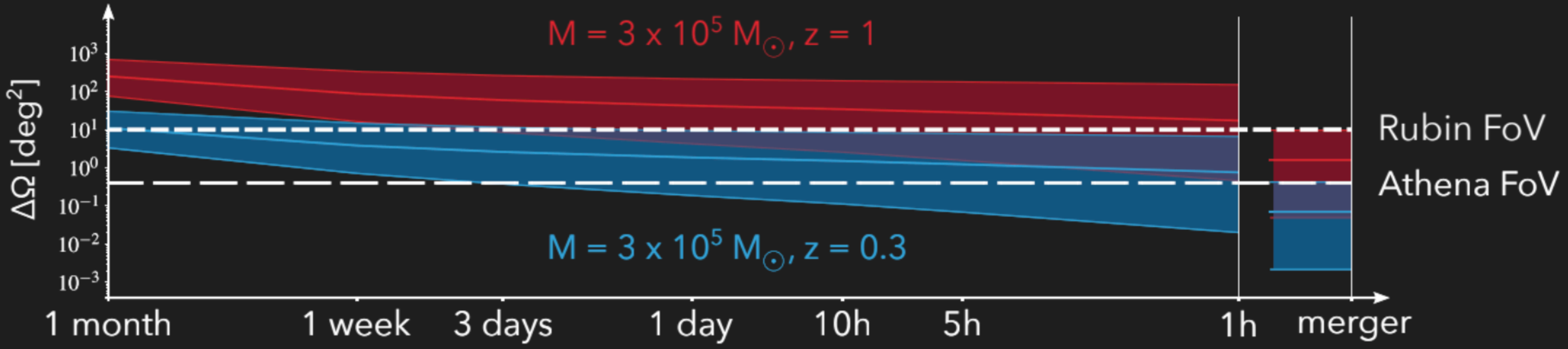
Current simulations a 4 hours (Athena) response time and 5″ Angular resolution (HEW) instead of 12 hours and 9″



Afterglow emission

- At merger localisation within ~0.1 deg^2 or better is possible for the LISA binaries out to z~3

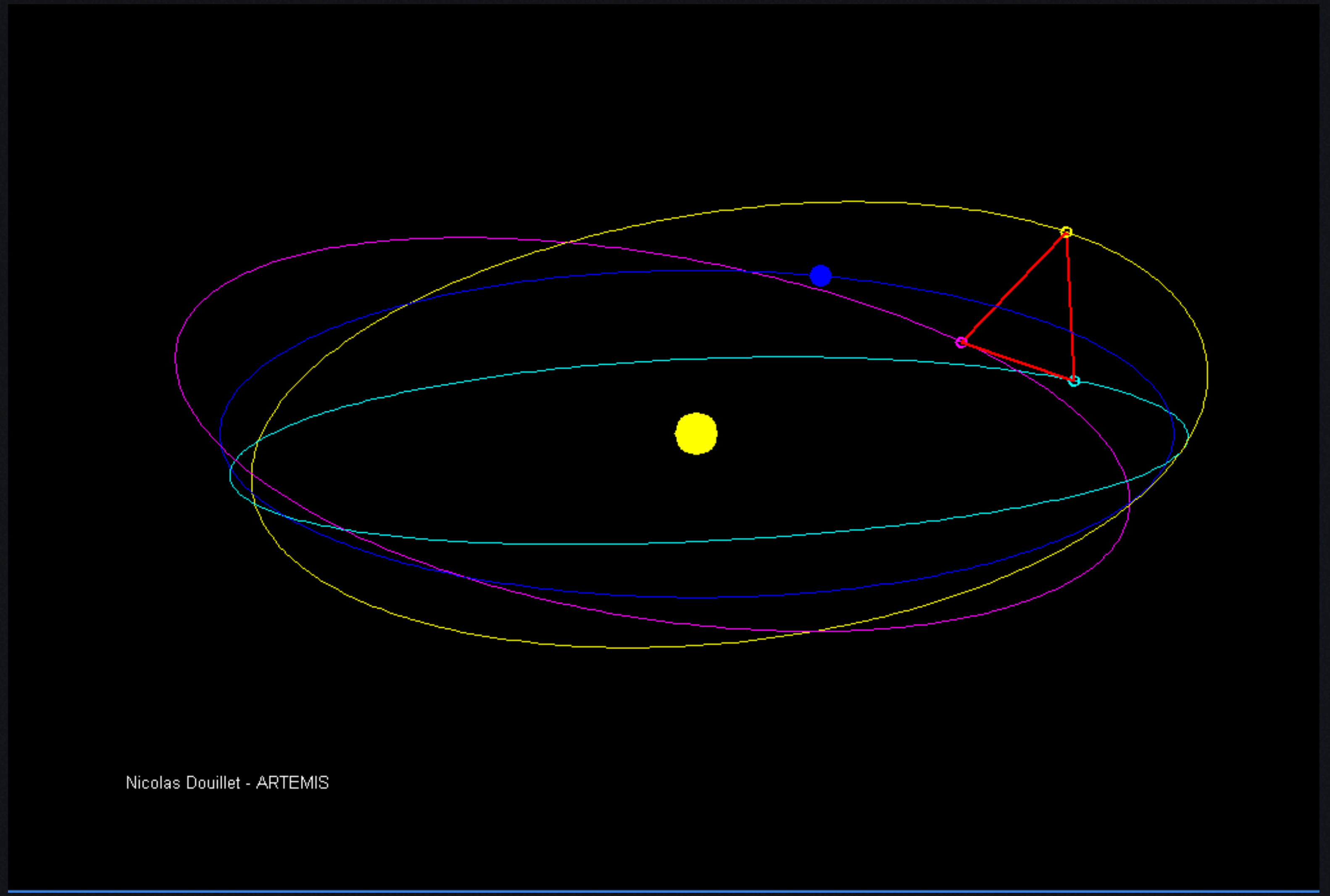




Mangiali et al. 2021, Piro et al. 2023, Lops et al. 2023

GW localization with LISA

following GW events from MBH mergers with EM observatories



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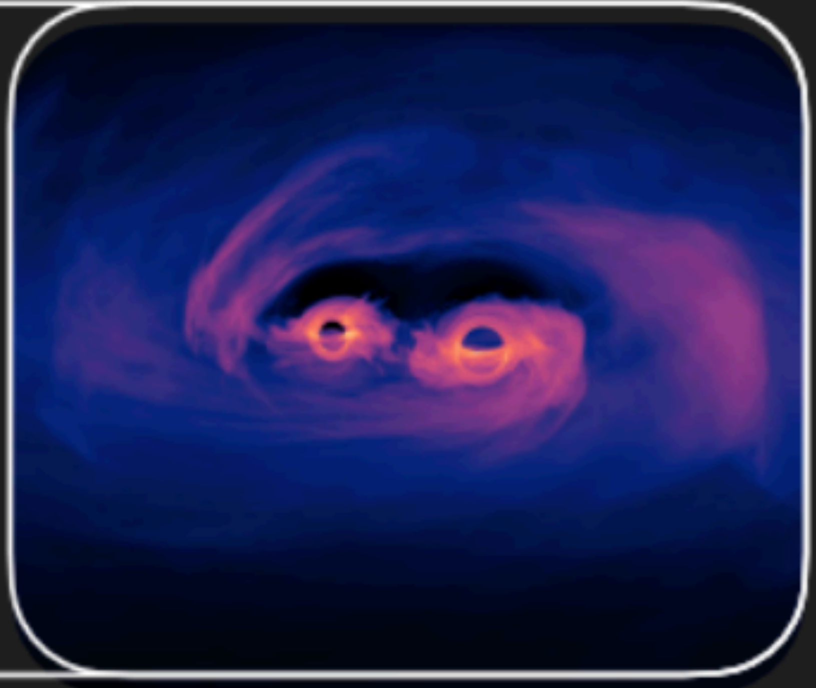

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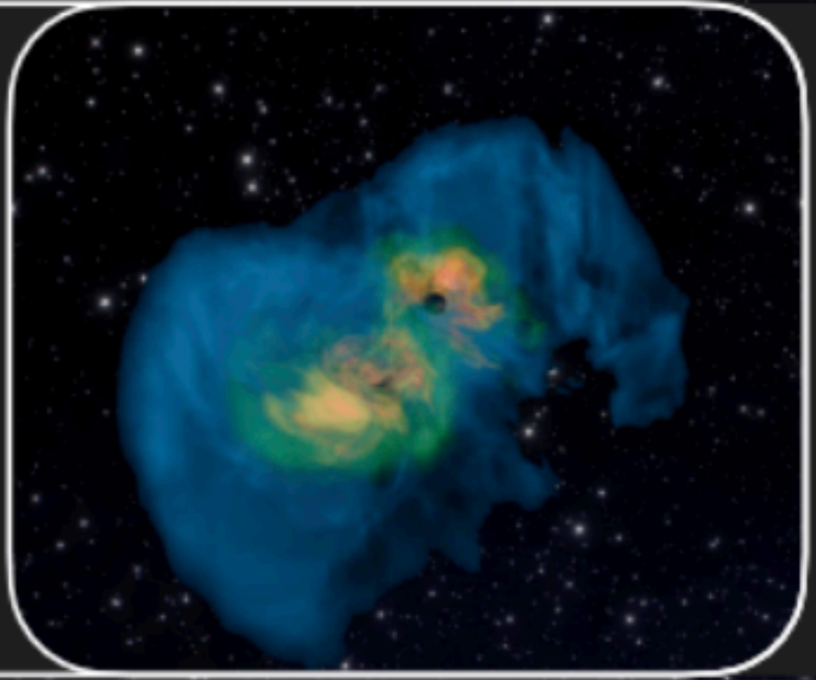

Mangiali et al. 2021,
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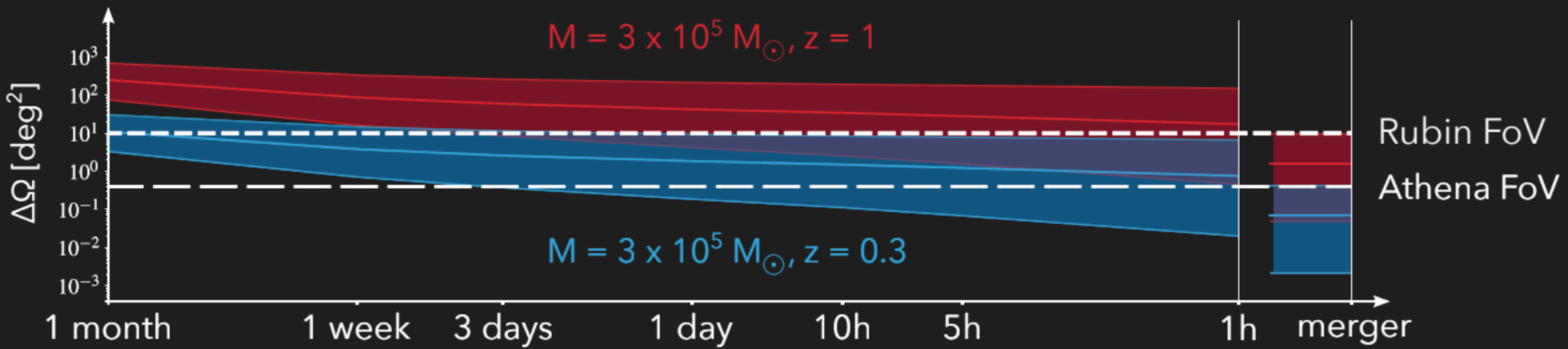
Lops et al. 2023

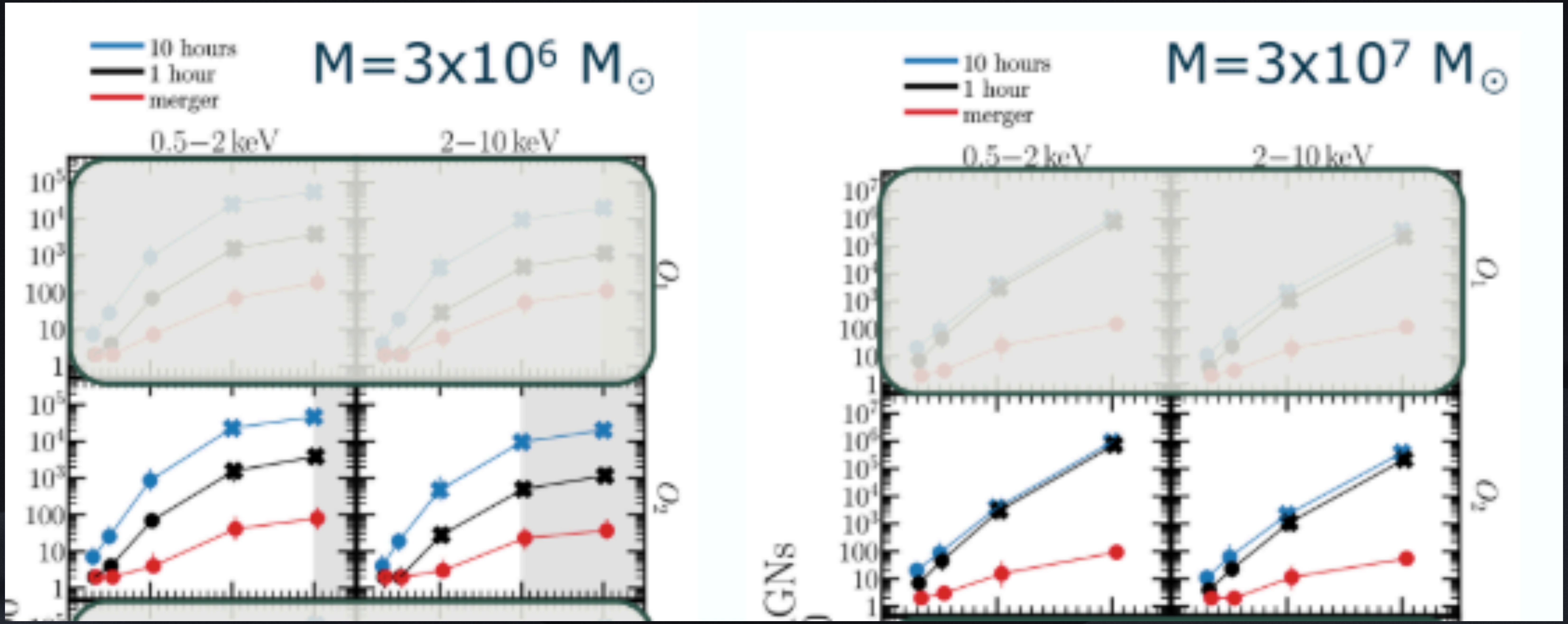


GW localization with LISA

following GW events from MBH mergers with X-ray EM observatories

MBH accrete at Eddington limit with neutral absorption log(NH/cm-2)=21.5

AGN Host



1 2 3

redshift

1 2 3

redshift

inspira phase > 100 potential hosts especially at high-z

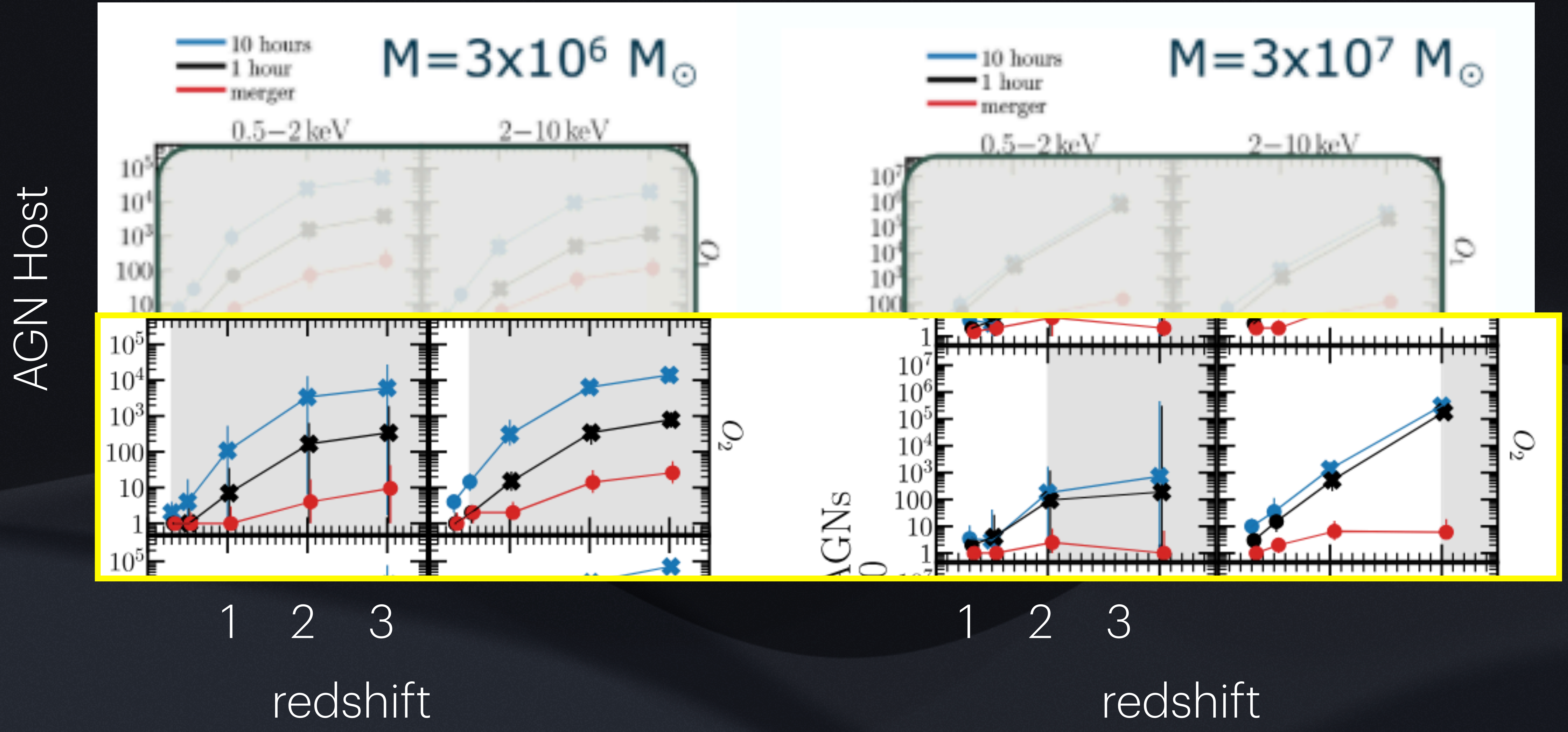
at merger X-ray AGNs in the LISA error-box is < 10 at z < 1

M. Guainazzi. Lops+2023

GW localization with LISA

following GW events from MBH mergers with X-ray EM observatories

MBH accrete at Eddington limit with neutral absorption log(NH/cm-2)=21.5



inspira phase > 100 potential hosts especially at high-z

at merger X-ray AGNs in the LISA error-box is < 10 at z < 1

If log(NH/cm-2)=23, more sources with X-ray fluxes falling below the detection limit

M. Guainazzi. Lops+2023

Astrophysics LISA Science Projects

- *Dual and binary AGN* - Alessandra De Rosa, Leonid Gurvits, David Izquierdo-Villalba, Kunyang Li
- *Environment of MBH mergers* - Nianyi, Chen, John Regan, Sean McGee
- *EMRI catalogs* - Elisa Bortolas, Matteo Bonetti, Luca Broggi, Alessandro Trinca
- *Waveform parameter space (with wavWG)* - Luca Broggi, Lucio Mayer, Sean McWilliams, Marta Volonteri
- *Data standard and DDPC-friendly catalogs* - Laurentiu Caramete, Golam Shaifullah, Tristan Bruel, David Izquierdo-Villalba
- *Comparing UCB catalogues for LISA with existing observations* - Alexey Bobrick, Simone Scaringi, Silvia Toonen
- *Extending UCB catalogs to include mass-transferring systems (e.g. AM CVns, CVs, UCXBs, etc.)* - Thomas Kupfer, Simone Scaringi, Nathan Steinle
- *Dynamical binaries in the Galaxy and Local Volume* - Sara Rastello, Manuel Arca Sedda, Tristan Bruel, Cristiano Ugolini
- *Extragalactic DWD foreground* - Valeriya Korol, Mauro Pieroni, Gijs Nelemans
- *LISA triples and CBPs* - Camilla Danielski, Nicola Tamanini, Silvia Toonen
- *Updatable predictions for stBBH in LISA* - Riccardo Buscicchio, Alexandre Toubiana
- *Updating the astroWG LRR (2025)*: Compact binaries - Thomas Kupfer, Thomas Tauris, Tassos Fragos
- *Updating the astroWG LRR (2025)*: Massive black holes - Elisa Bortolas, Melanie Habouzit, Pedro Capelo Alessandra De Rosa coordinates MM chapter
- *Updating the astroWG LRR (2025): EMRIs* - Pau Amaro-Seoane, Lorenz Zwick, Saavik Ford, Alejandro Torres Orjuela, Verónica Vázquez-Aceves

LISA consortium

The LISA Consortium is a scientific collaboration working together to maximize the scientific return of LISA, in particular using the LISA data. The Consortium will support all aspects of the LISA mission throughout the mission lifecycle.

The LISA Consortium is committed to promoting the long-term growth and development of the LISA scientific Community, by providing a supportive and inclusive environment that offers training, mentoring and opportunities for scientists at all stages of their careers, in particular, early career scientists. The Consortium will also engage with the wider scientific community to foster interest in and support applications of the LISA data.

Two types of members

- **Core members** [commit to deliverables]
- **Community members** [involved and informed

LISA Consortium Members

- Involved and informed
- Directory and email lists
- Workshops and meetings
- Announcements and LISA communications
- No proprietary access to LISA data

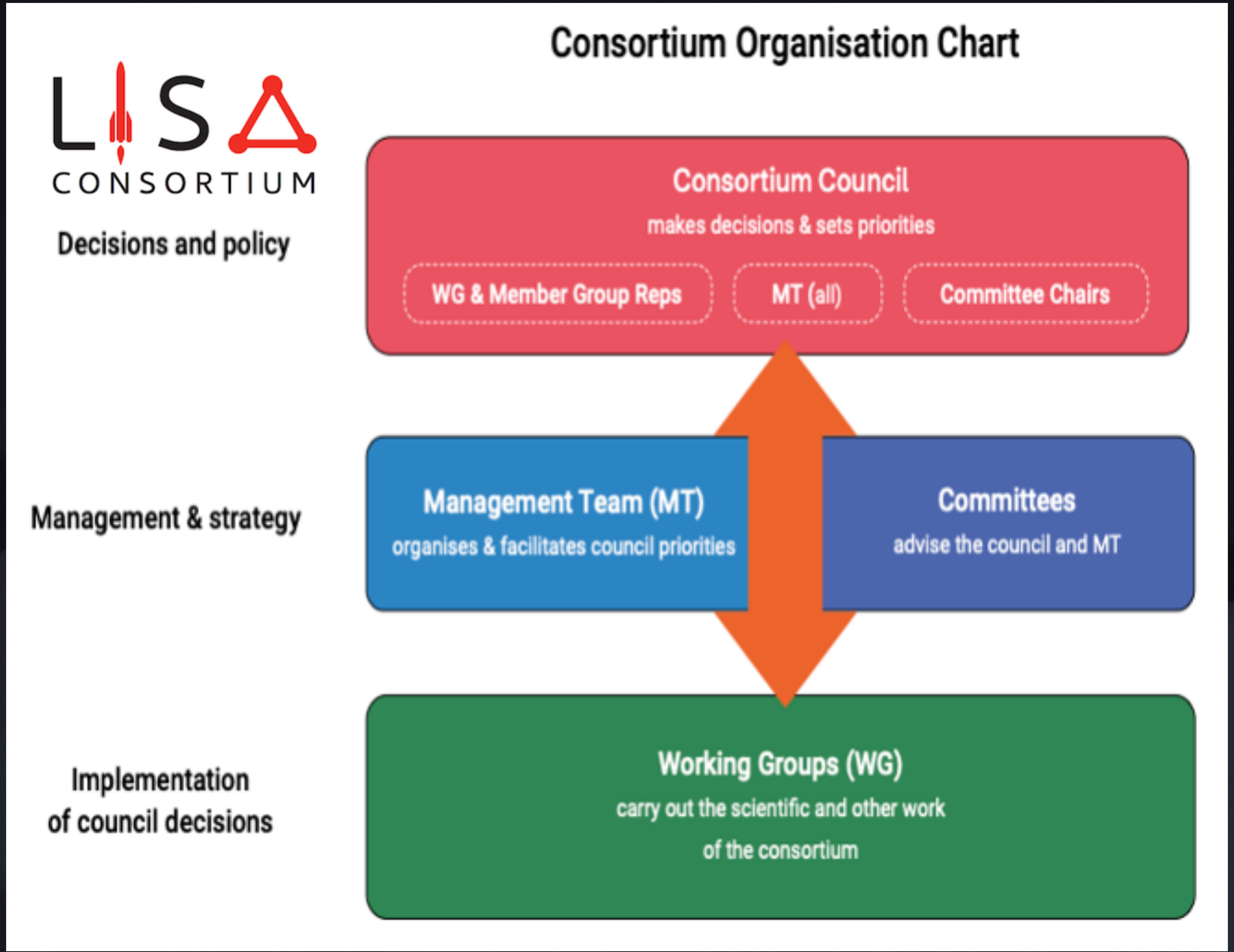
Community members	Core members
•No deliverables required •No membership contribution reviews •No automatic right to opt-in to author list of consortium papers •Cannot be attached to member groups	•Deliverables required •Membership contribution reviews •Opt-in to author list of consortium papers •Can self-organise into member groups

LISA Consortium organization and structure

- Council + Management Team (MT)
- Committees
  - Permanent (e.g. DEI, communication, membership etc)
  - Temporary (e.g. conference team etc)
- Working Groups (WGs)
  - Science WGs (Astrophysics, Cosmology, Data analysis, Fundamental physics, Instrument, Waveform)
  - Other Core WGs (LECS, communications, etc.)
- Member groups (self-organised groups of core members from institution/country/other)

A. De Rosa (3 years), F. Mannucci (2 years) rappresentative at the Council

A. De Rosa as member groups chair



INAF contribution to LISA

LISA-Science@INAF member groups

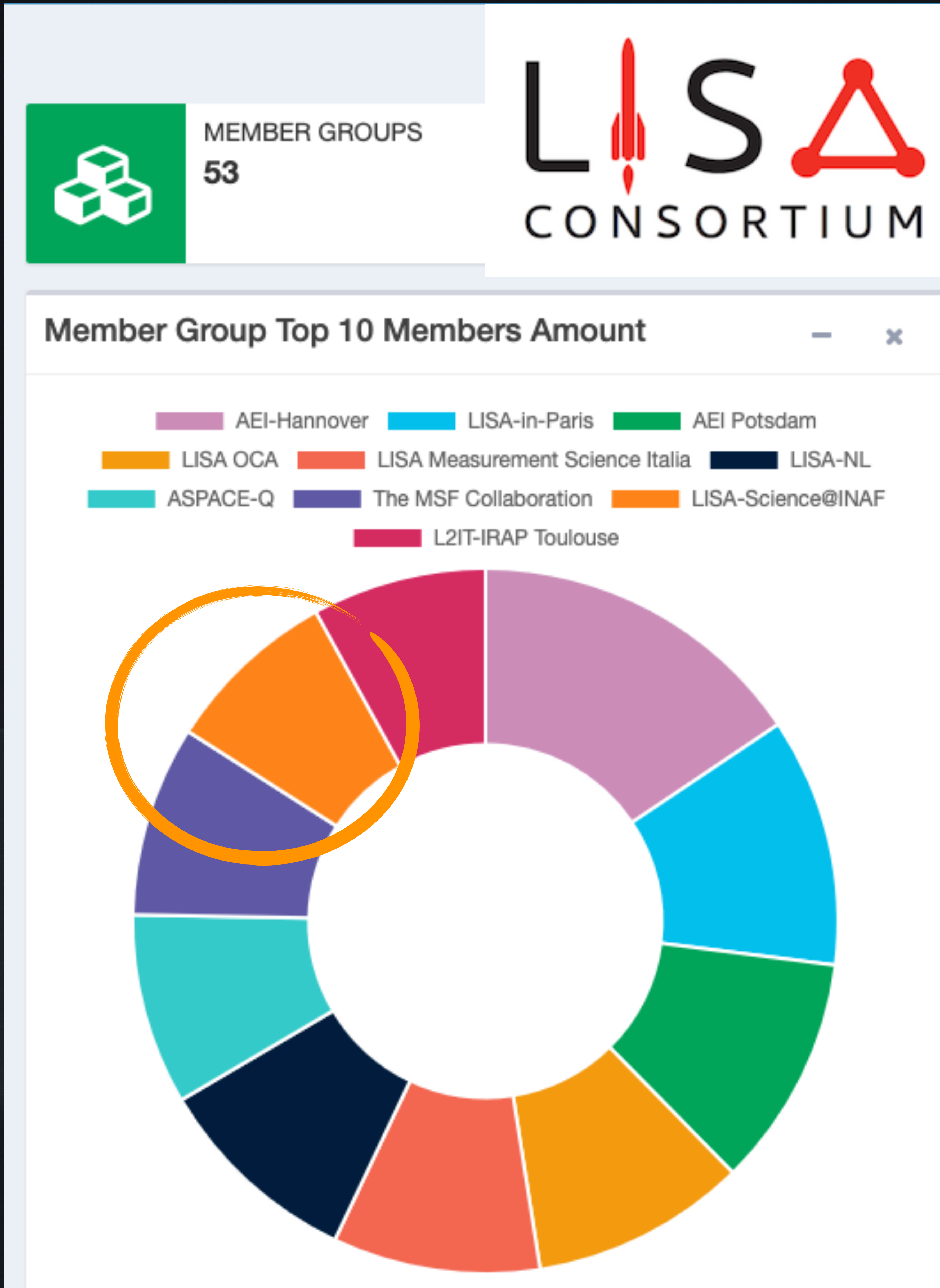
Chair A. De Rosa (IAPS)

Group Comment: The group will coordinate the scientific activities conducted at INAF. The proposed activities encompass a broad range of LISA-related science, including astrophysics (such as the study of massive black hole catalogs and simulations, compact objects, and multi-messenger astronomy) and cosmology. The group will also oversee data analysis efforts, including INAF's contributions to the DDPC.

It is among the largest Member groups in LISA (24)

Italy LISA Data Analysis: E. Barausse (SISSA) 2 INAF + 2 INAF Ass

Italy LISA Astrophysics: A. Lupi (U Bicocca, INAF Ass), 6 INAF Ass



LISA ASI Contribution: INAF addendum

ASI-INAF addendum

Low latency pipeline, SMBH simulations and catalogues, Italian DCC (Data Computing Center)

Definition and development of the IT infrastructure (in collaboration with SSDC) necessary for simulations and data analysis.

The program is part of the following LISA DDPC (Distributed data processing center) branches: Simulations and external data (Source population generation); Low Latency alert (LA2); Catalogues (L3C); System Engineering and DCC

OA Trieste (PI. D. Tavagnacco)
IAPS (A. De Rosa)
OA Arcetri (F. Mannucci)
OA Brera (P. Severgnini)
OA Roma (R. Valiante)

Future gravitational-wave observatories such as LISA, ET, and CE will revolutionize our understanding of the Universe.

In this context, multi-messenger astronomy is not simply about searching for counterparts, but about leveraging the complementary strengths of different messengers to study the complex physical processes from distinct and synergistic perspectives

Thank you!