LISA SCIENCE AND MULTI-MESSENGER ASTRONOMY

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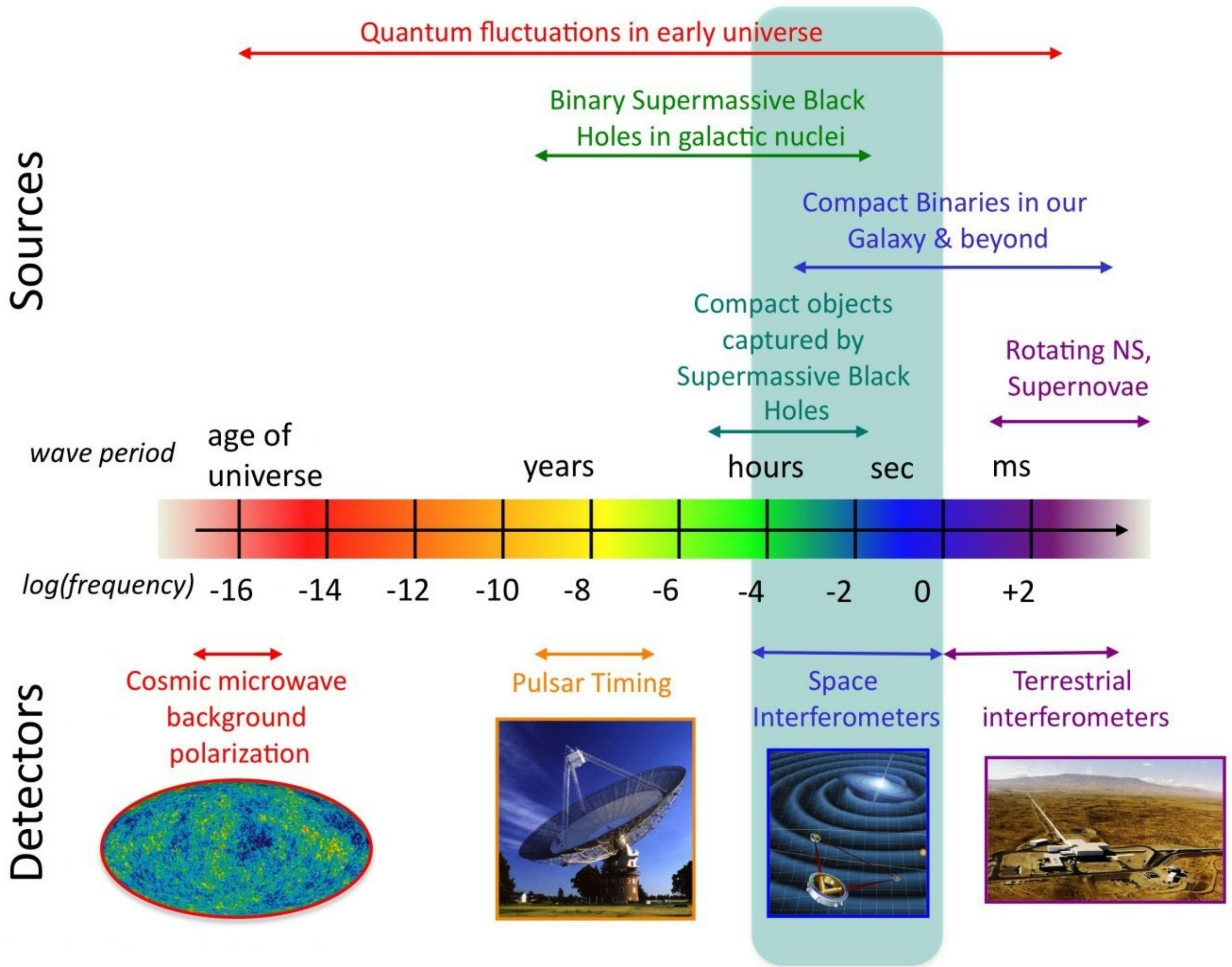
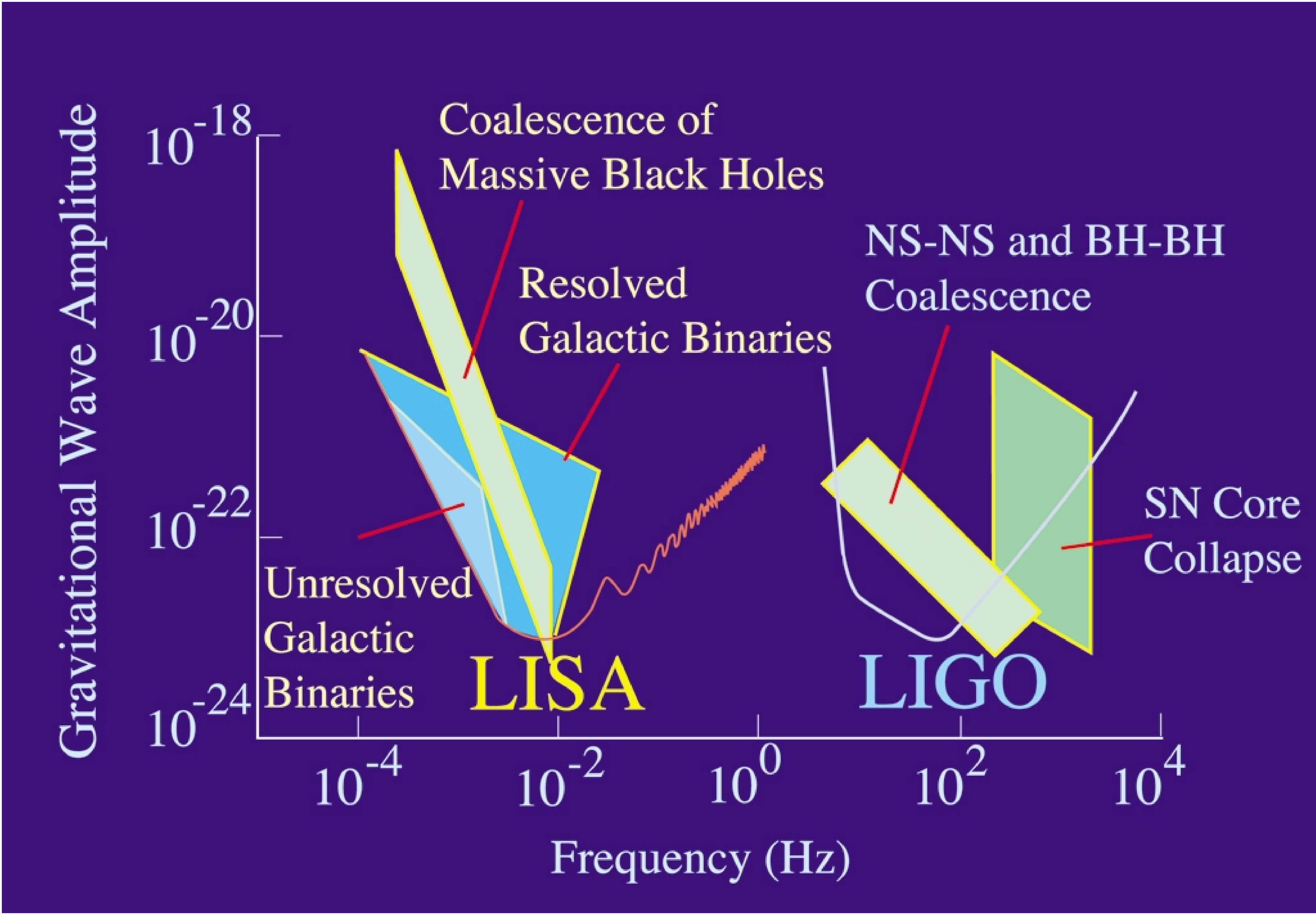
12th INTEGRAL Conference, 1st AHEAD Gamma-ray Workshop

11 February 2019

The Gravitational Wave Spectrum




Gravitational Wave Amplitude
10^{-18}
10^{-20}
10^{-22}
10^{-24}
Coalescence of
Massive Black Holes
Resolved
Galactic Binaries
NS-NS and BH-BH
Coalescence
Unresolved
Galactic
Binaries
SN Core
Collapse
LISA
LIGO
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Frequency (Hz)

Observational facts

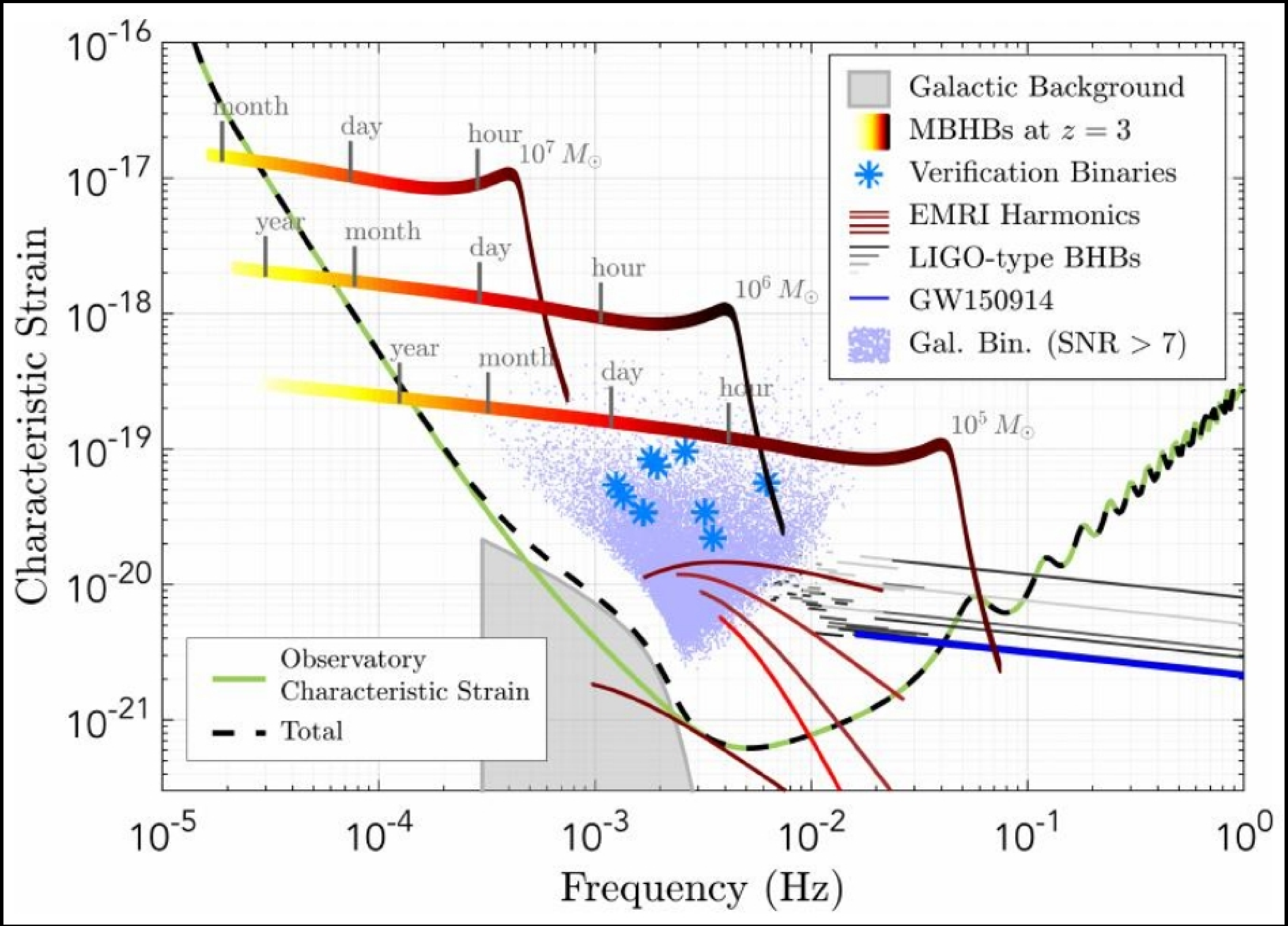
1- In all the cases where the inner core of a galaxy has been resolved (i.e. In nearby galaxies), a massive compact object (which I'll call Massive Black Hole, MBH for convenience) has been found in the centre.

2- MBHs must be the central engines of Quasars: the only viable model to explain this cosmological objects is by means of gas accretion onto a MBH.

3- Quasars have been discovered at z~7, their inferred masses are ~10^9 solar masses!

THERE WERE 10^9 SOLAR MASS BHs WHEN THE UNIVERSE WAS <1Gyr OLD!!!

MBH formation and evolution have profound consequences for GW astronomy



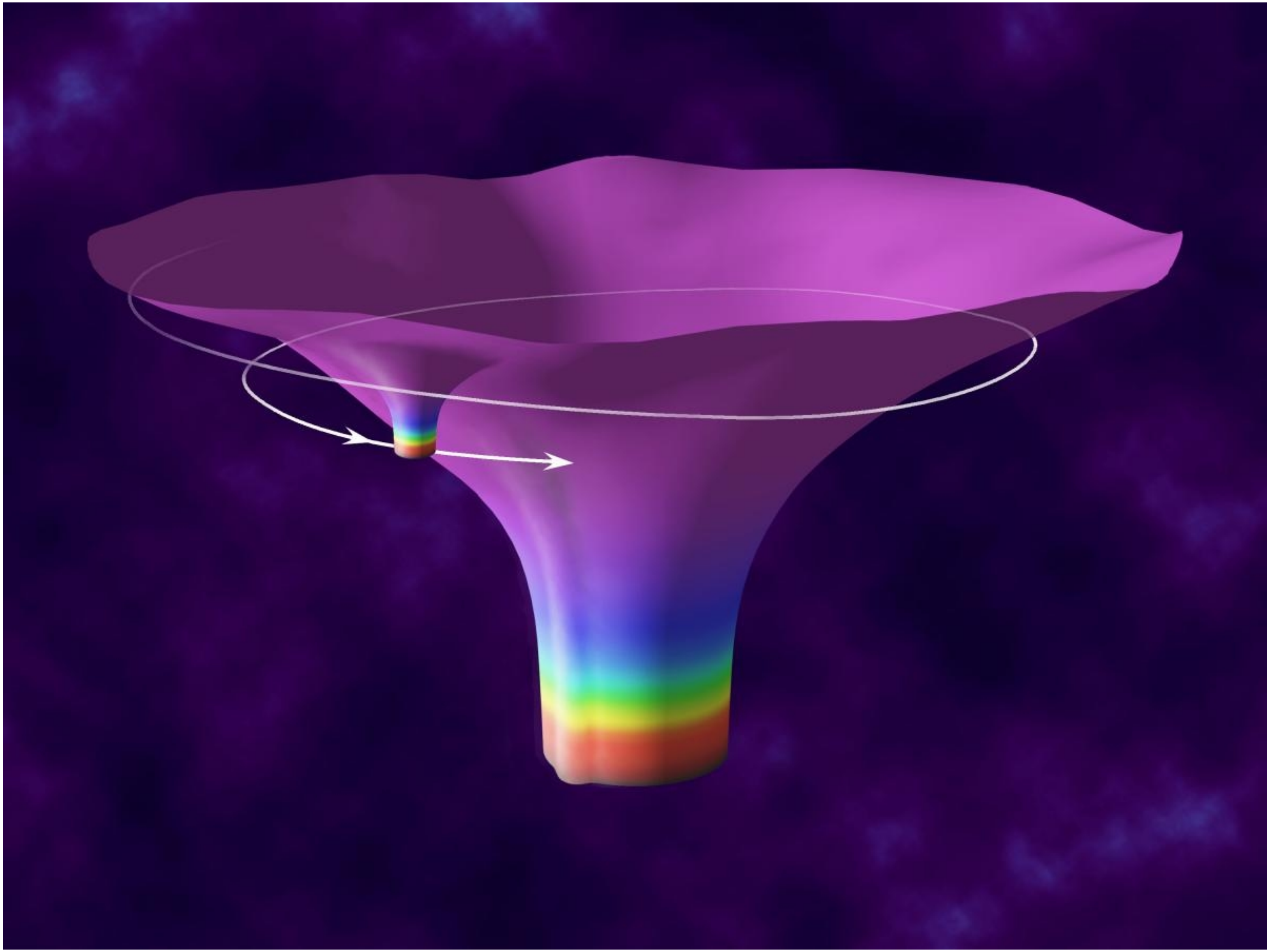
Possible other sources (not shown): cosmic strings (kink, cusps) cosmological backgrounds (non-standard inflation, phase transitions)

Astrophysical black holes

LISA observations will probe massive black holes over a wide range of red-shifts and will thus be able to address a number of unanswered questions:

- When did the first black holes form in pre-galactic haloes?
- What is their initial mass and spin?
- What is the mechanism of black hole formation in galactic nuclei?
- How do black holes evolve over cosmic time due to accretion and merger?
- What can we learn about galaxy hierarchical assembly?

Extreme Mass Ratio Inspirals (EMRIs)



A smaller black hole orbits around a supermassive black hole

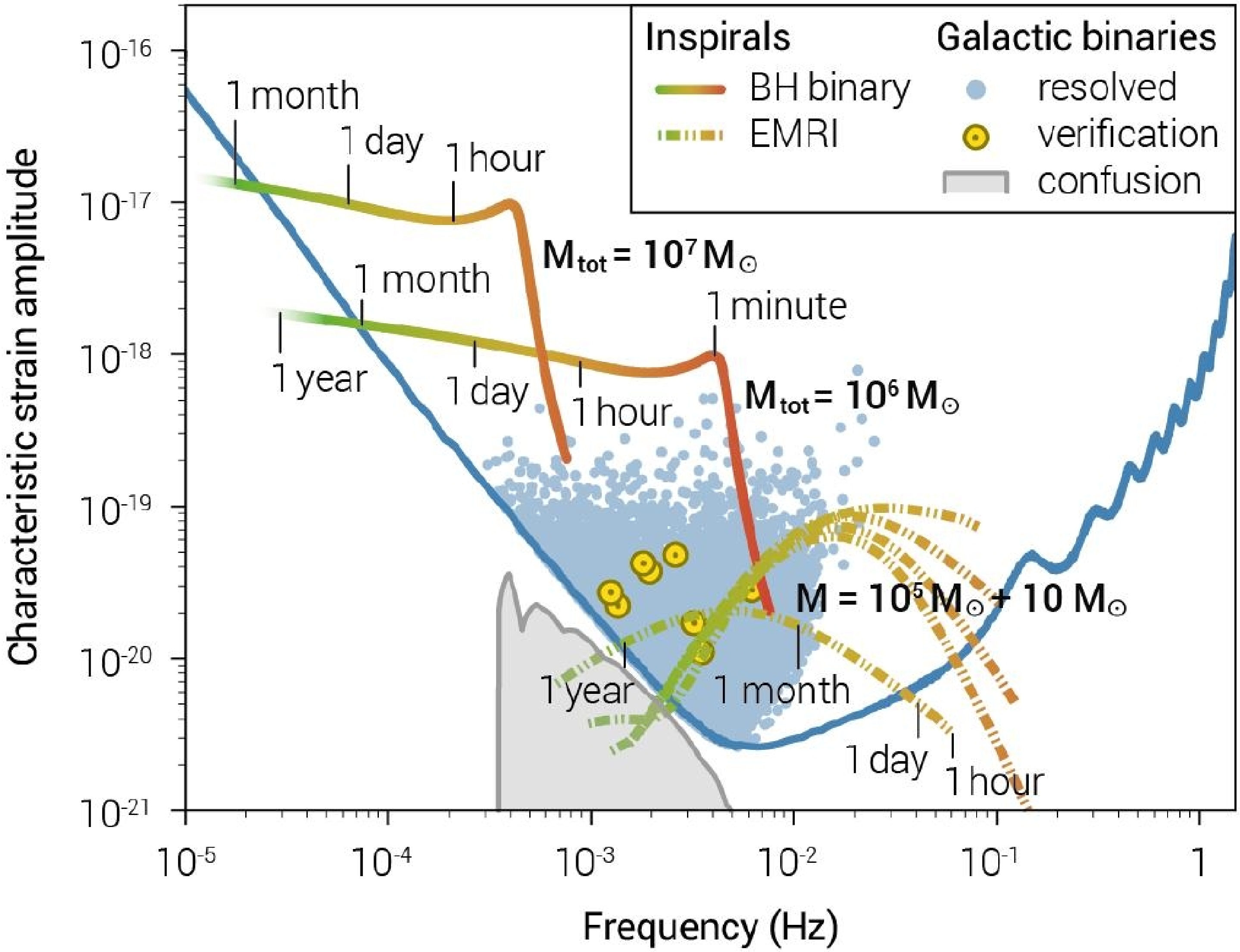
Extreme Mass Ratio Inspirals (EMRIs)

Are compact stars (either a neutron star or a stellar-mass black hole) captured into a highly relativistic orbit around a massive black hole and spiralling into the massive black hole.
As the compact star weighs much less than the massive black hole, the mass ratio is extreme, and the inspiral phase is governed by the emission of gravitational waves.

- What is the distribution of stellar remnants at the galactic centres?
- What is the mass distribution of stellar relics?
- Are stellar-mass black holes of 100 solar masses or/and medium sized black holes of 1000 solar masses present in galactic centres?

LISA will see EMRIs out to red-shifts of about $z \sim 0.7$

LISA sensitivity and EMRIs



Ultra-compact double white dwarf (DWD) binaries in the Milky Way

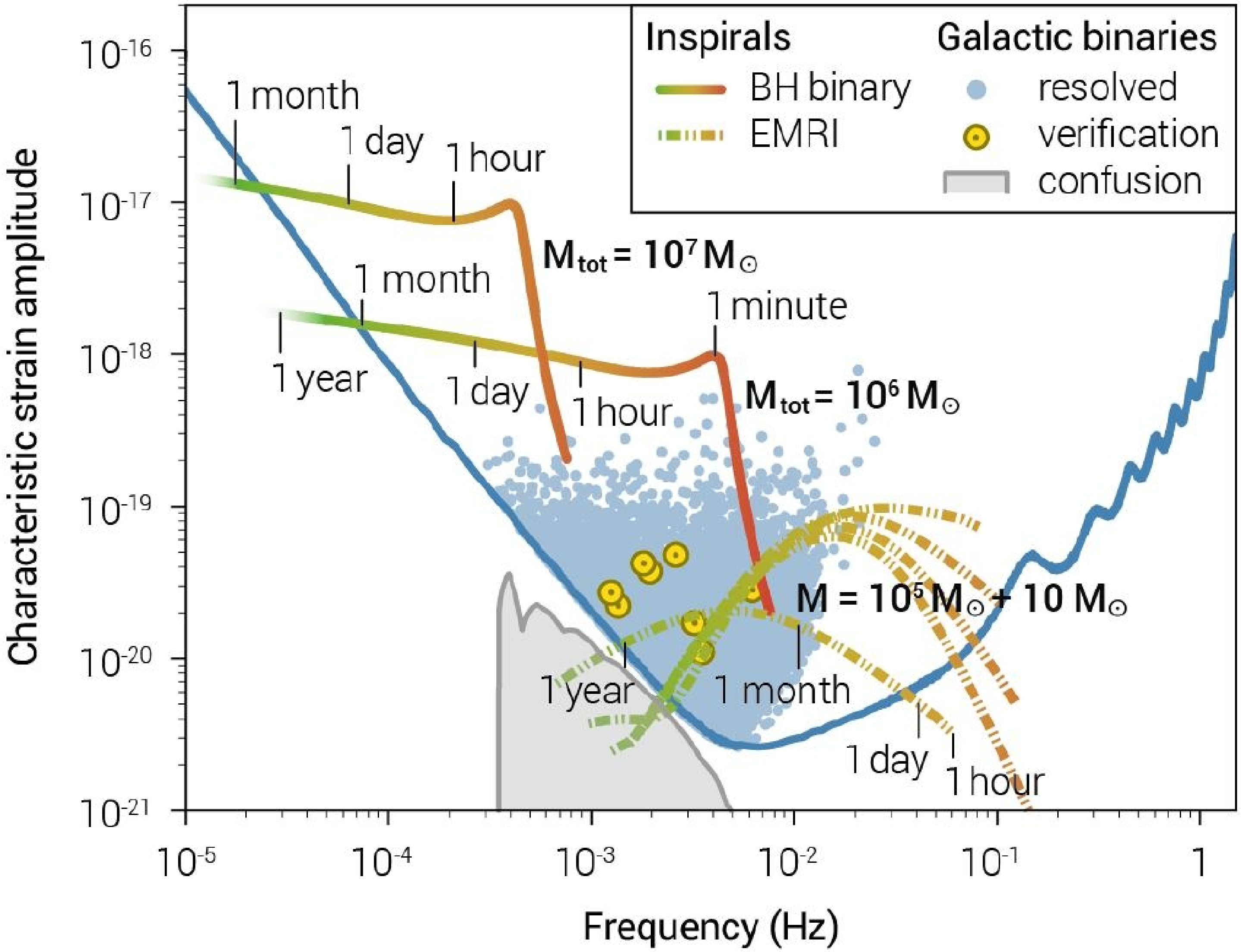
At present less than 50 ultra-compact binaries (mainly binary white dwarfs) are known, of which only two have periods less than 10 minutes.

The shortest period systems, known as ultra-compact binaries, are important sources of gravitational waves in the millihertz frequency range and thus will be detected by LISA.

- How many ultra-compact binaries exist in the Milky Way?
- What is their merger rate?
- What is the spatial distribution of ultra-compact binaries and what can we learn about the Milky Way structure as a whole?

LISA will detect several thousands or more of such objects in our Galaxy.

LISA sensitivity and ultra-compact binaries in the Milky Way



Multi-messenger: double white dwarfs (DWDs) in the Milky Way with LISA, Gaia and LSST (Large Synoptic Survey Telescope).

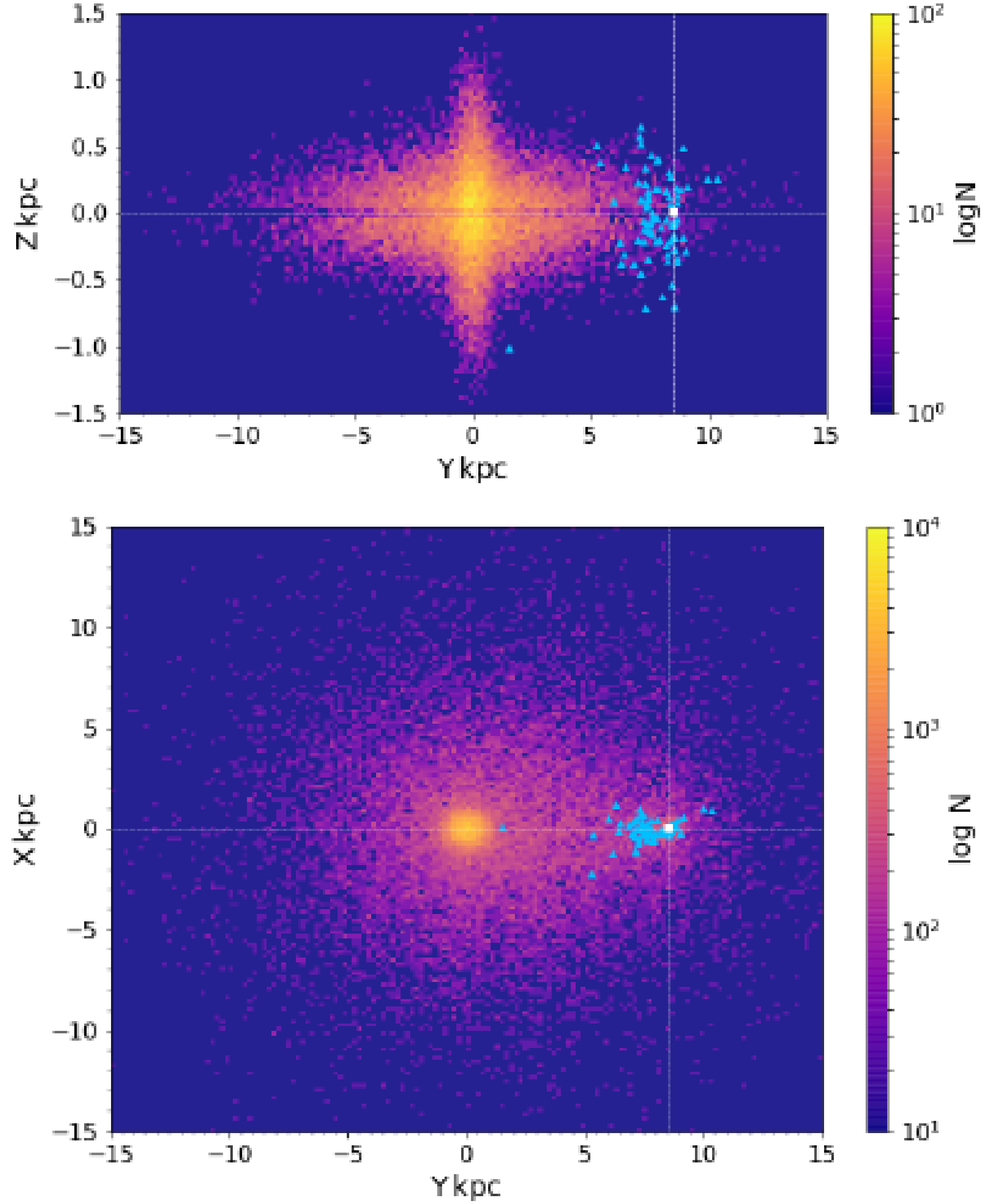


Figure 3. Source-count maps of DWDs detected by LISA (SNR>7) in the Galactocentric Cartesian coordinate system defined by eq. (24): in the $Y - Z$ plane (top panel) and in the $Y - X$ plane (bottom panel). The white square identifies the position of the Sun in the Galaxy, $(0, 8.5\text{kpc}, 0)$. Blue triangles represent the position of EM counterparts detected with *Gaia* and/or LSST.

Multi-messenger: DWDs in the Milky Way with LISA, Gaia and LSST.

- LISA will resolve some 10^5 ultra-compact DWDs
- Some 80 DWDs might be detected via electromagnetic observations (e.g. Gaia, LSST)

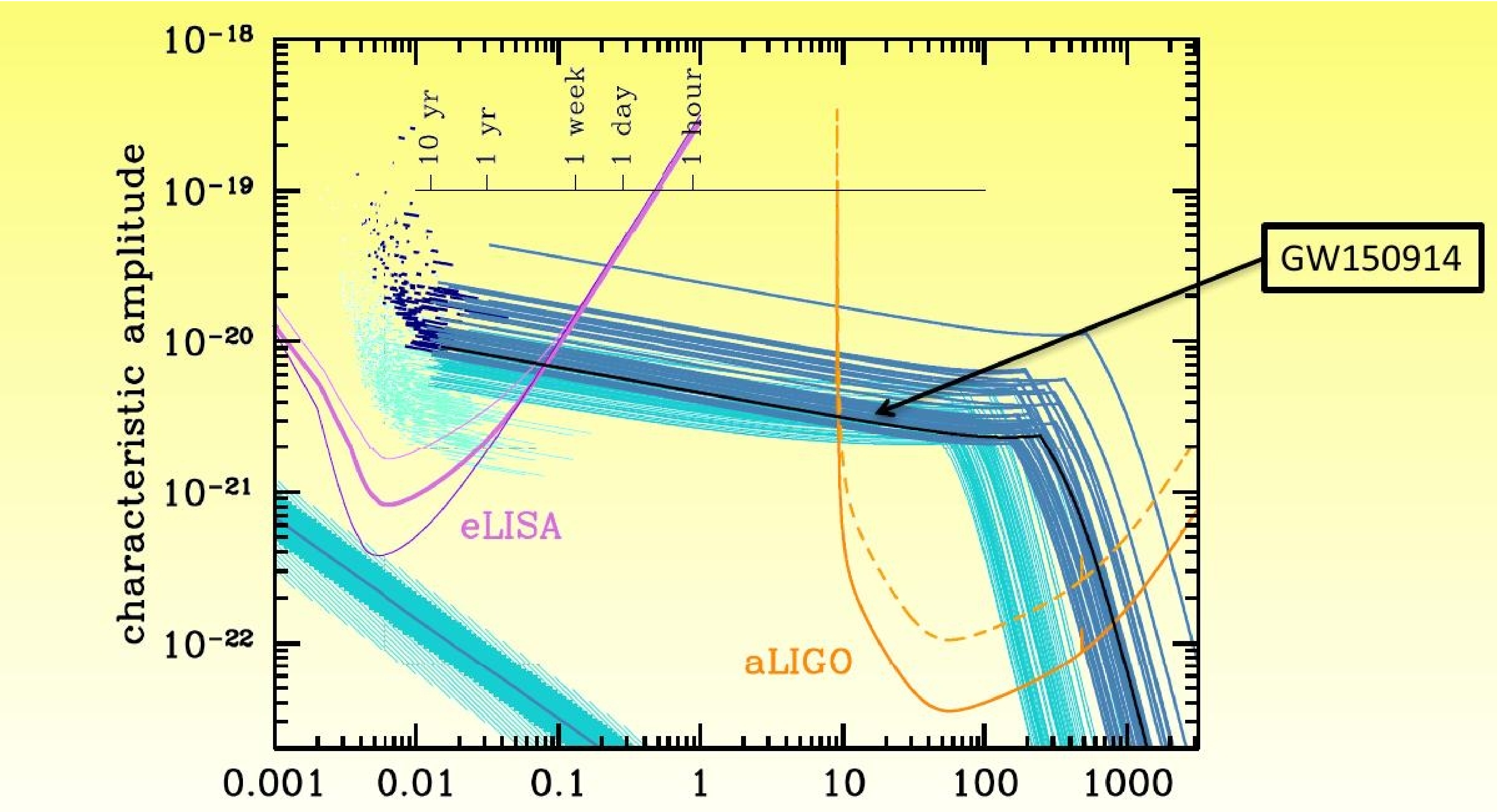
- These DWDs will be the closer one, within a distance of 2 to 10 kpc

- Information on the local properties of Milky Way (e.g. dark matter content)

(see Korol et al. Astro-ph:1806.03306)

Multiband GW observations with LISA and LIGO/VIRGO/ET

LISA: 1st LIGO event "predicted" 10 years in advance



Frequency

Sesana, PRL 116, 231102 (2016), Gerosa et al astroph:1902.00021

ATHENA – LISA SYNERGIES

Studies under way, in particular the merger of Supermassive Black Holes closer than about $z = 2$ could be detected also with Athena provided there is emission of X-ray during the merging.

GRAVITATIONAL WAVE POLARIZATION:

for its measurement combination of Earth and Space based observations might be crucial

(see e.g. Philippoz, Boitier, PJ, PRD98 (2018) 044025)

There might synergies also with SKA ….

The Laws of Nature

Confronting general relativity with high-precision measurements of strong gravity:

- Does gravity travel at the speed of light?
- Does the graviton have mass?
- Are there more than two transverse modes of propagation?
- Does gravity couple to other dynamical fields, e.g., massless or massive scalars?
- What is the structure of spacetime just outside astrophysical black holes?
- Do black holes have an horizon?
- Are astrophysical black holes described by the Kerr metric, As predicted by GR?