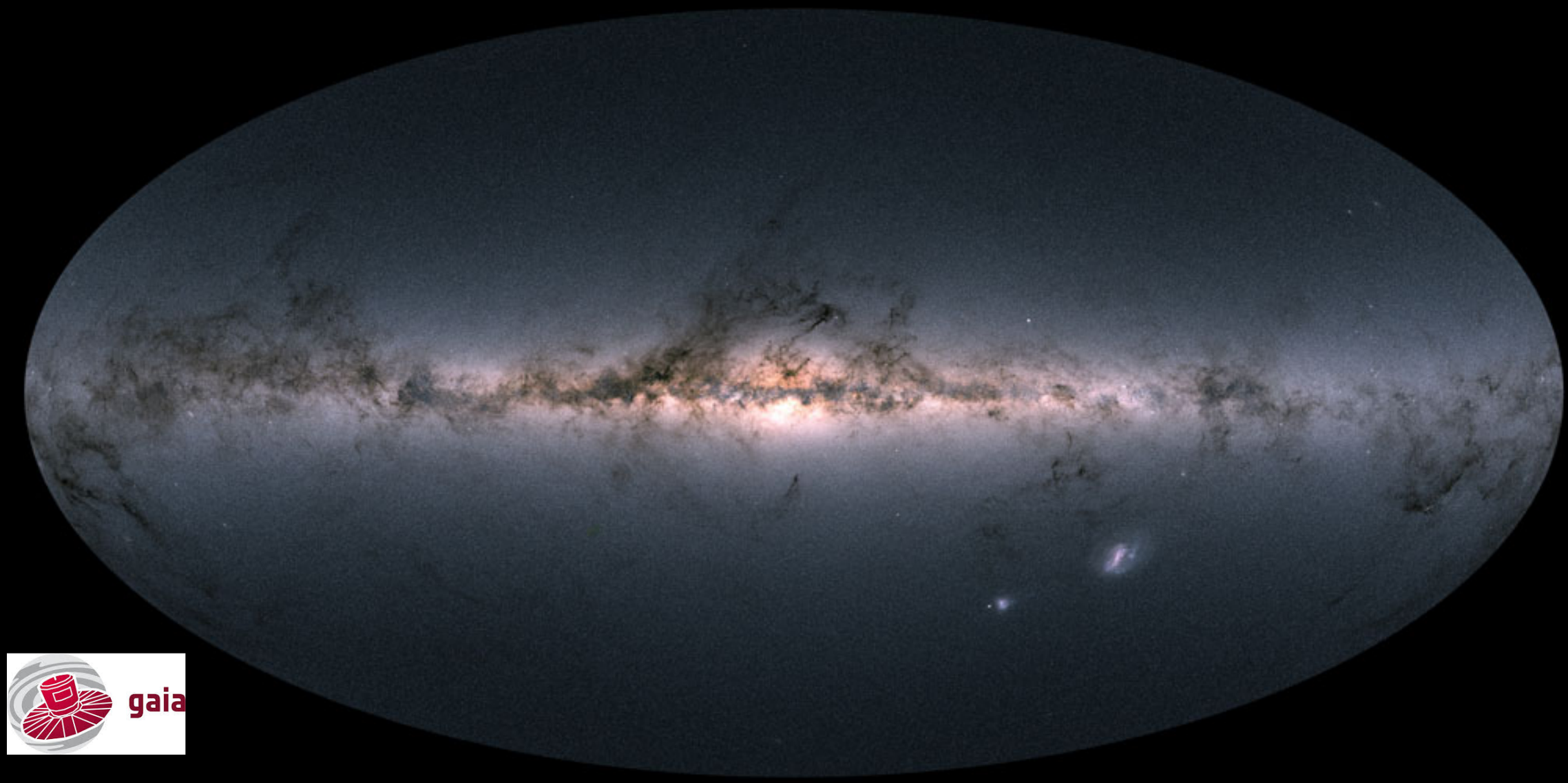
Bringing Gravity to Light with LISA

Kelly Holley-Bockelmann (she/her)
Vanderbilt University and Fisk University
k.holley@vanderbilt.edu

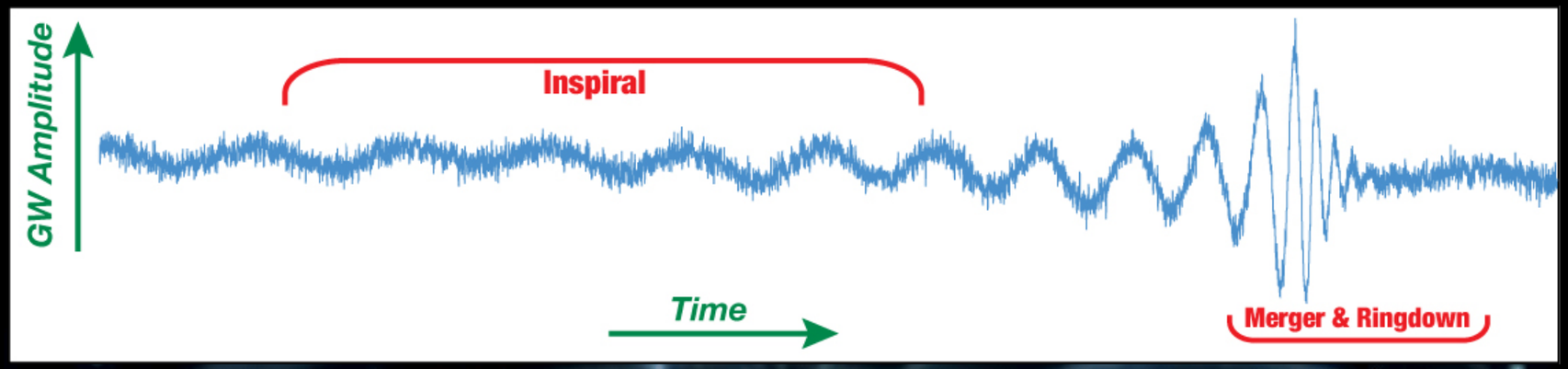
Photons encode temperature, density, kinematics, composition of matter

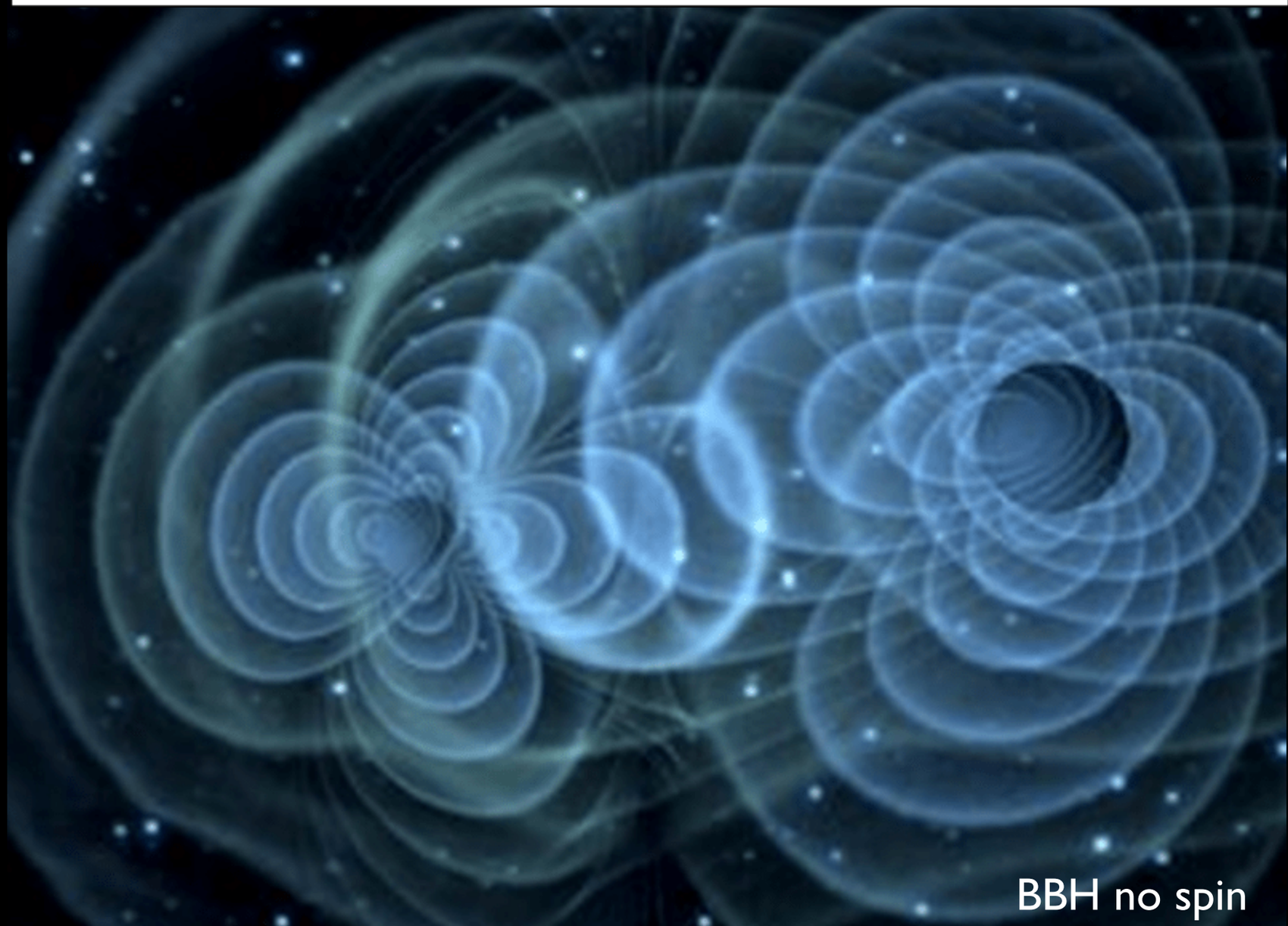


gaia

...but are easily distracted by other matter, magnetic fields, other photons

Gravitational waves encode mass, spin, orbit and distance





BBH no spin

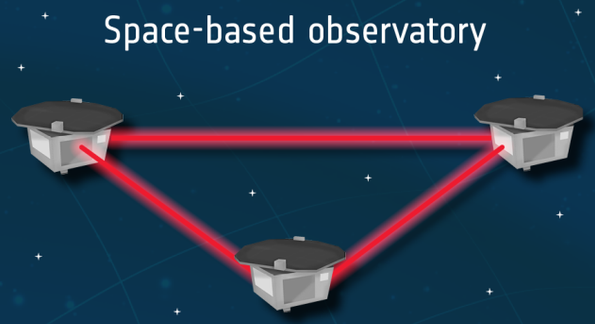
THE SPECTRUM OF GRAVITATIONAL WAVES

esa

Observatories & experiments

Ground-based experiment

Space-based observatory



Pulsar timing array

Cosmic microwave background polarisation

Timescales

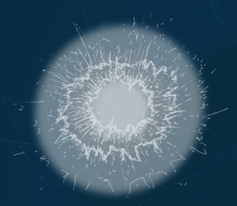
milliseconds — seconds — hours — years — billions of years

Frequency (Hz)

100 — 1 — 10^{-2} — 10^{-4} — 10^{-6} — 10^{-8} — 10^{-16}

Cosmic fluctuations in the early Universe

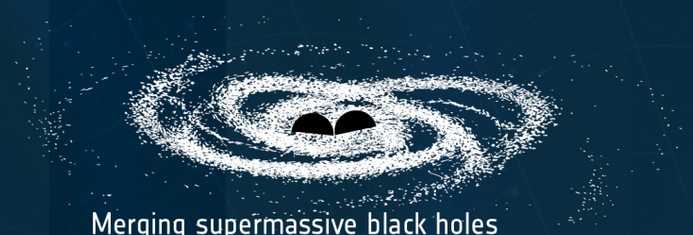
Cosmic sources



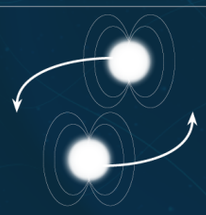
Supernova

Pulsar

Compact object falling onto a supermassive black hole



Merging supermassive black holes



Merging neutron stars in other galaxies

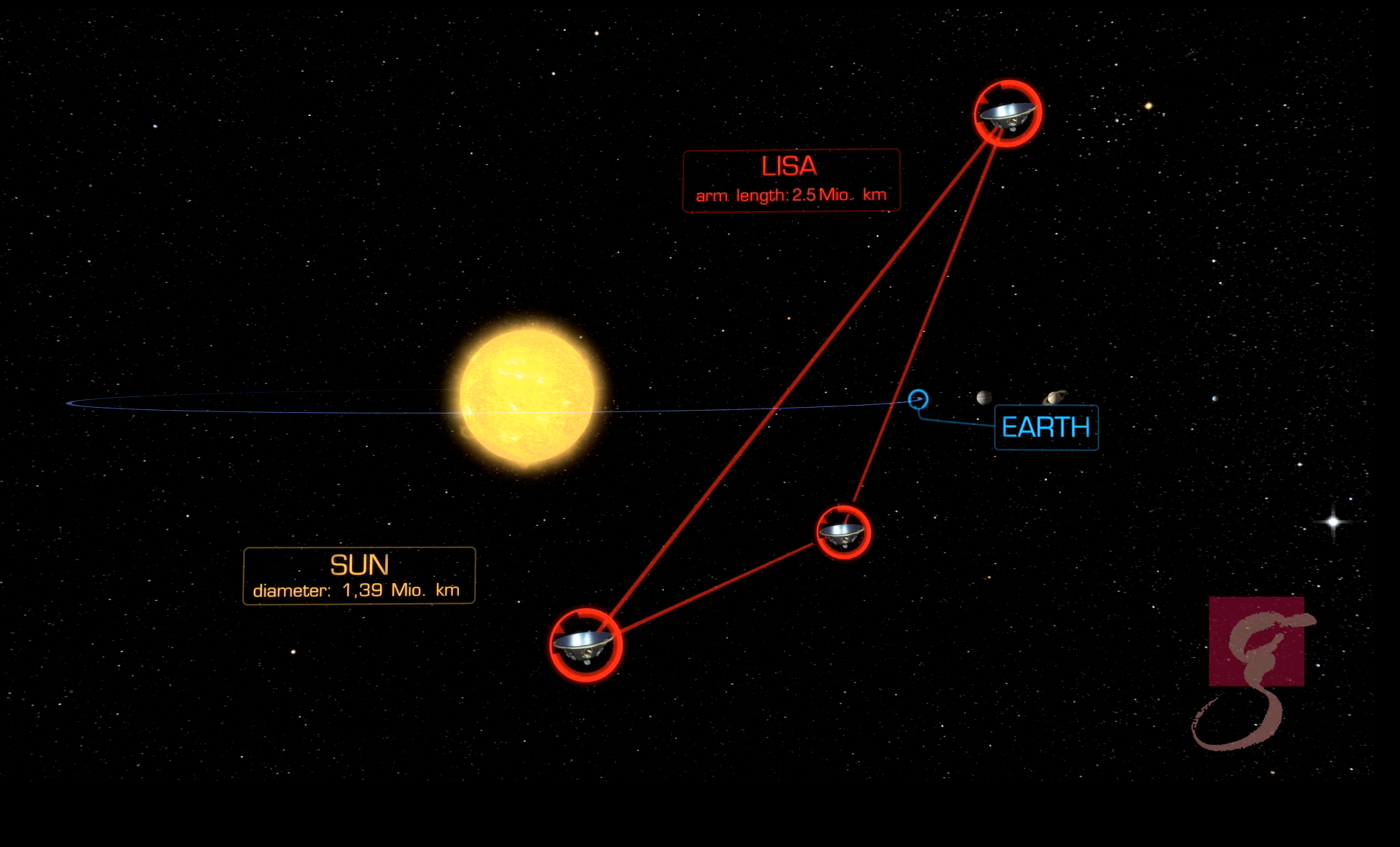
Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

#lisa

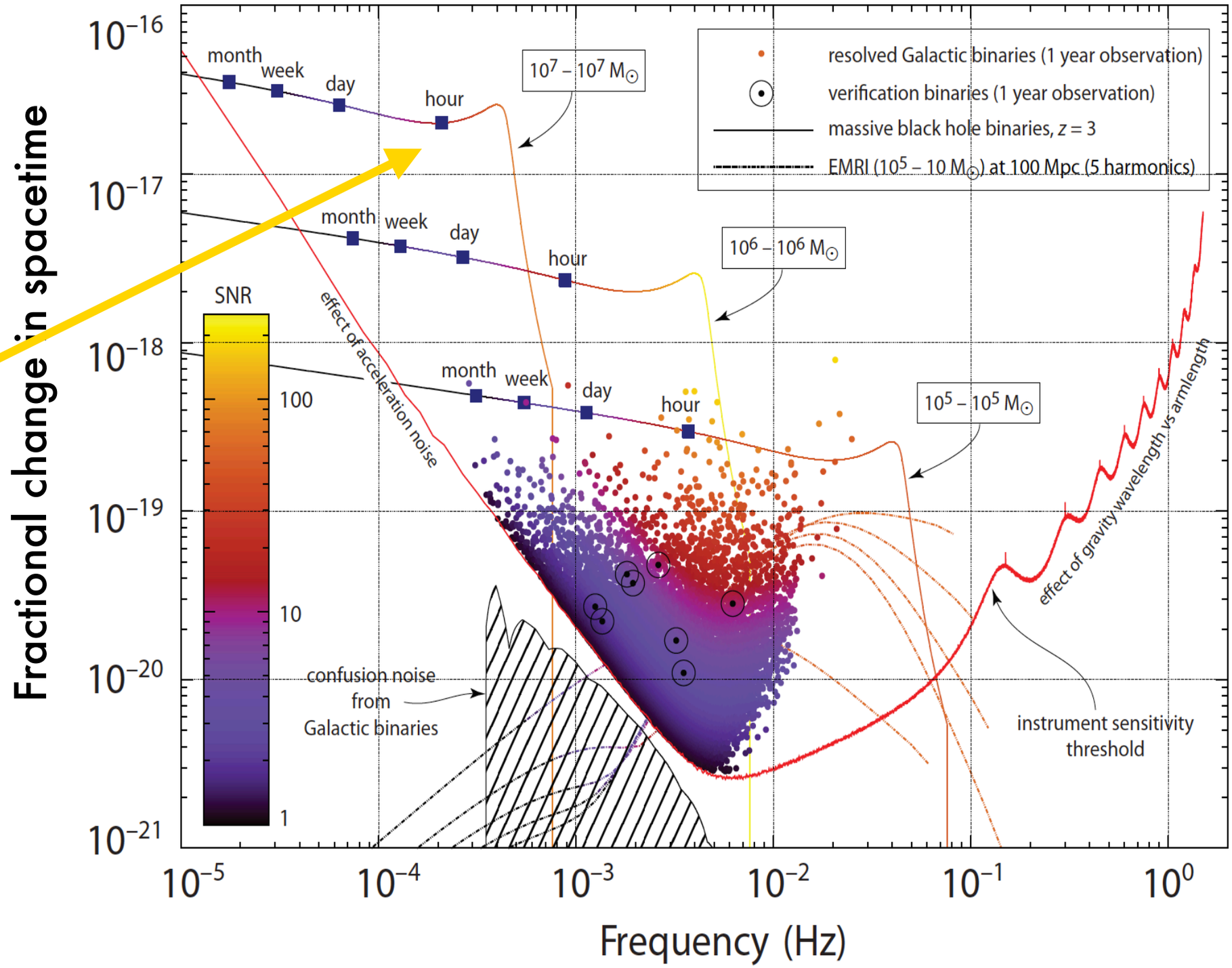
ESA | NASA lisa

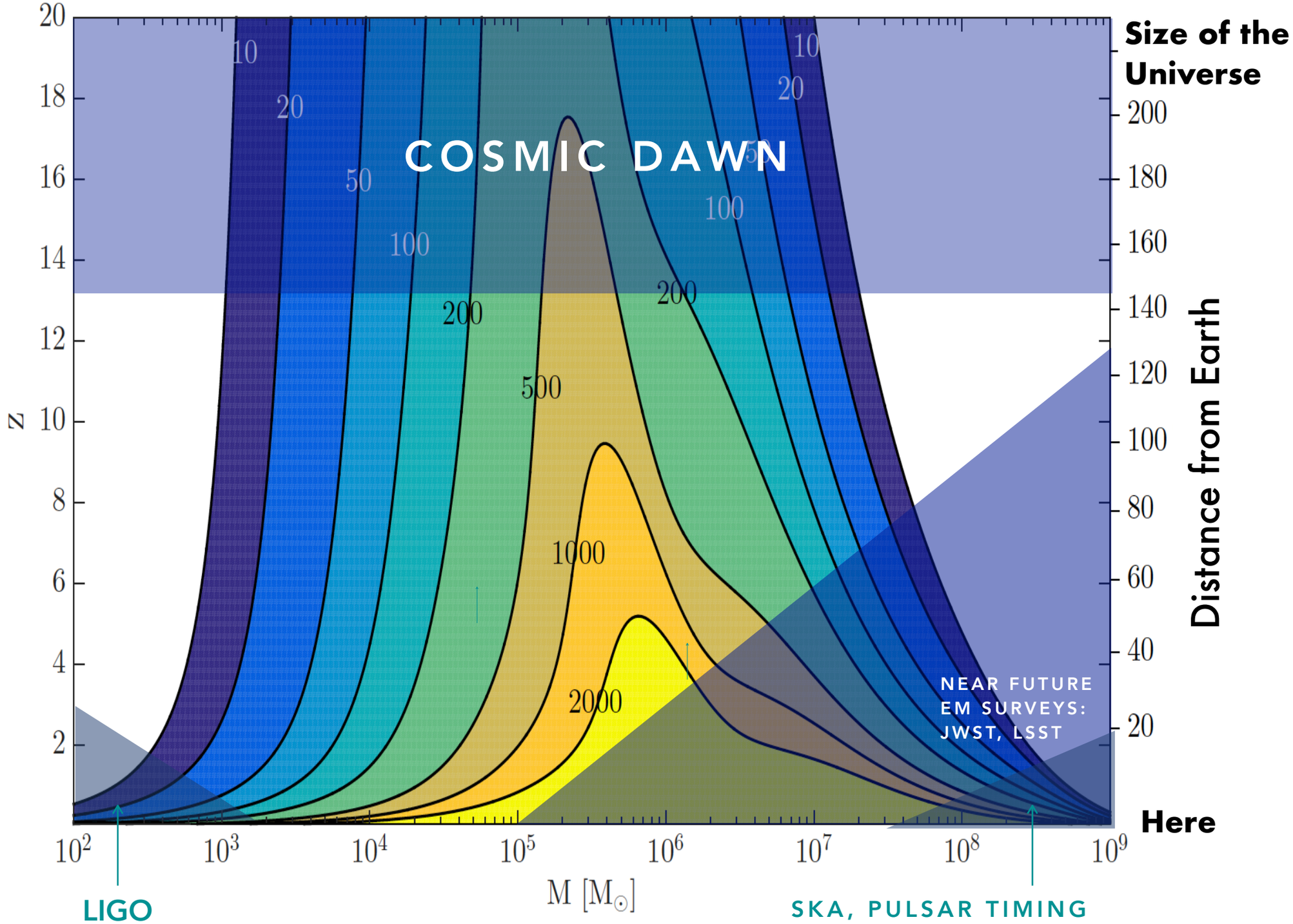
Behold! LISA, an ESA/NASA space-based gravitational wave mission (launch in 2030s)



lisa discovery space

Massive Black Hole Mergers





LISA detects the inspiral and merger of intermediate and massive Milky Way-class black holes with huge SNR throughout the observable universe and into the Cosmic Dawn.

What We Hope to Learn With lisa

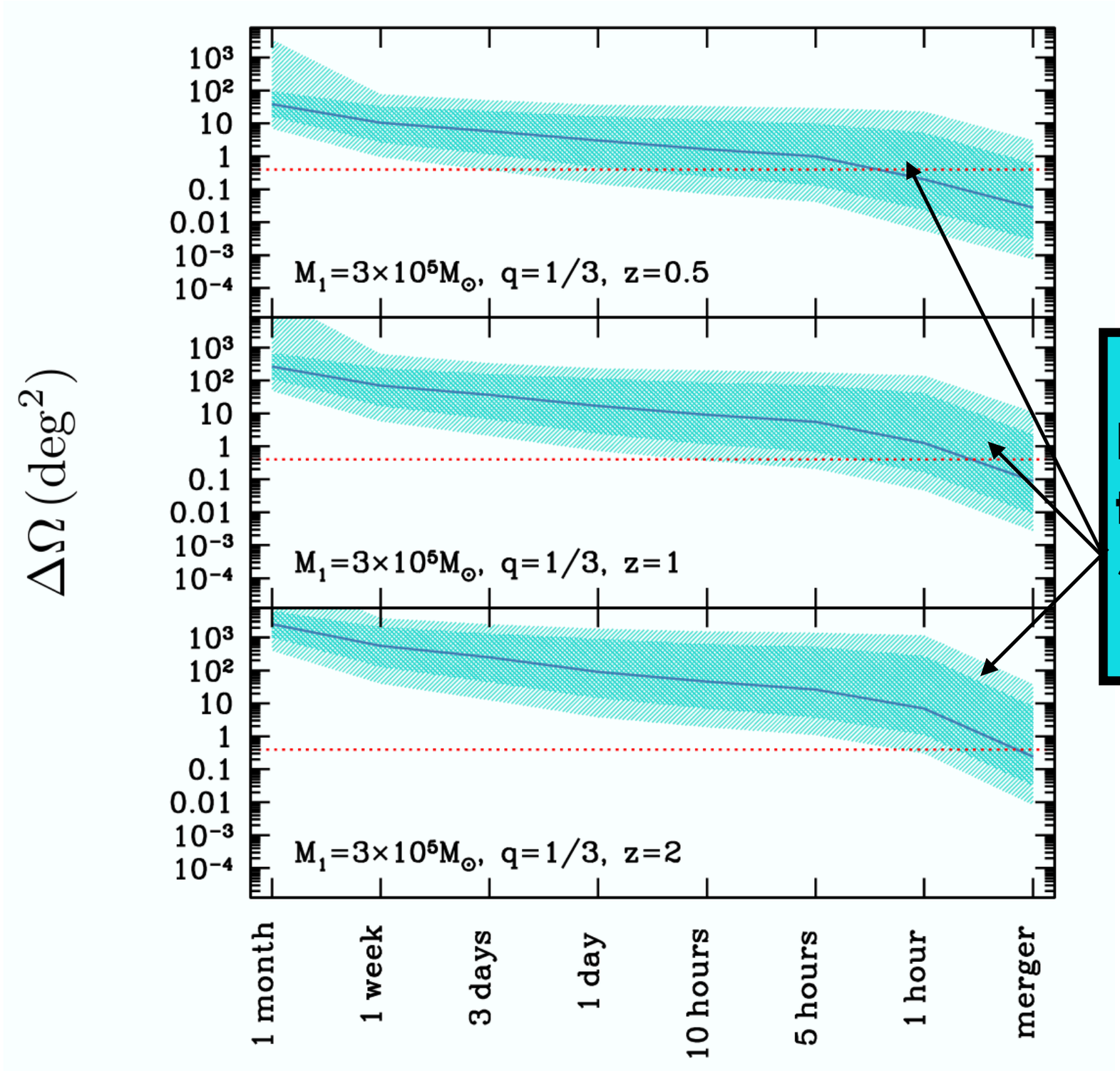
10^3-10^7 $M_\odot$ Black Hole Mergers — a new regime

BH seeds at high redshifts, IMBHs in dwarf galaxies, Milky Way mass black holes

Complement Multimessenger and Multiband data to trace black hole formation, evolution, and connection to host galaxies

Come Tuesday @10am to session 218 to hear more!

Challenges of prompt detection of GW+EM black hole mergers with LISA



LISA sky location shrinks to less than 1 deg² only ~1 hour before merger

Colpi et al. 2019

Challenges of prompt detection of GW+EM black hole mergers with LISA

An hour before merger, error volume contains $>10^4$ hosts

(L-star galaxies, dwarf galaxies, low surface brightness galaxies, globular clusters)

Challenges of prompt detection of GW+EM black hole mergers with LISA

It's not clear which EM band is best!

(e.g. SED peak can vary from X-ray to sub-mm, depending on accretion rate for ADAF)

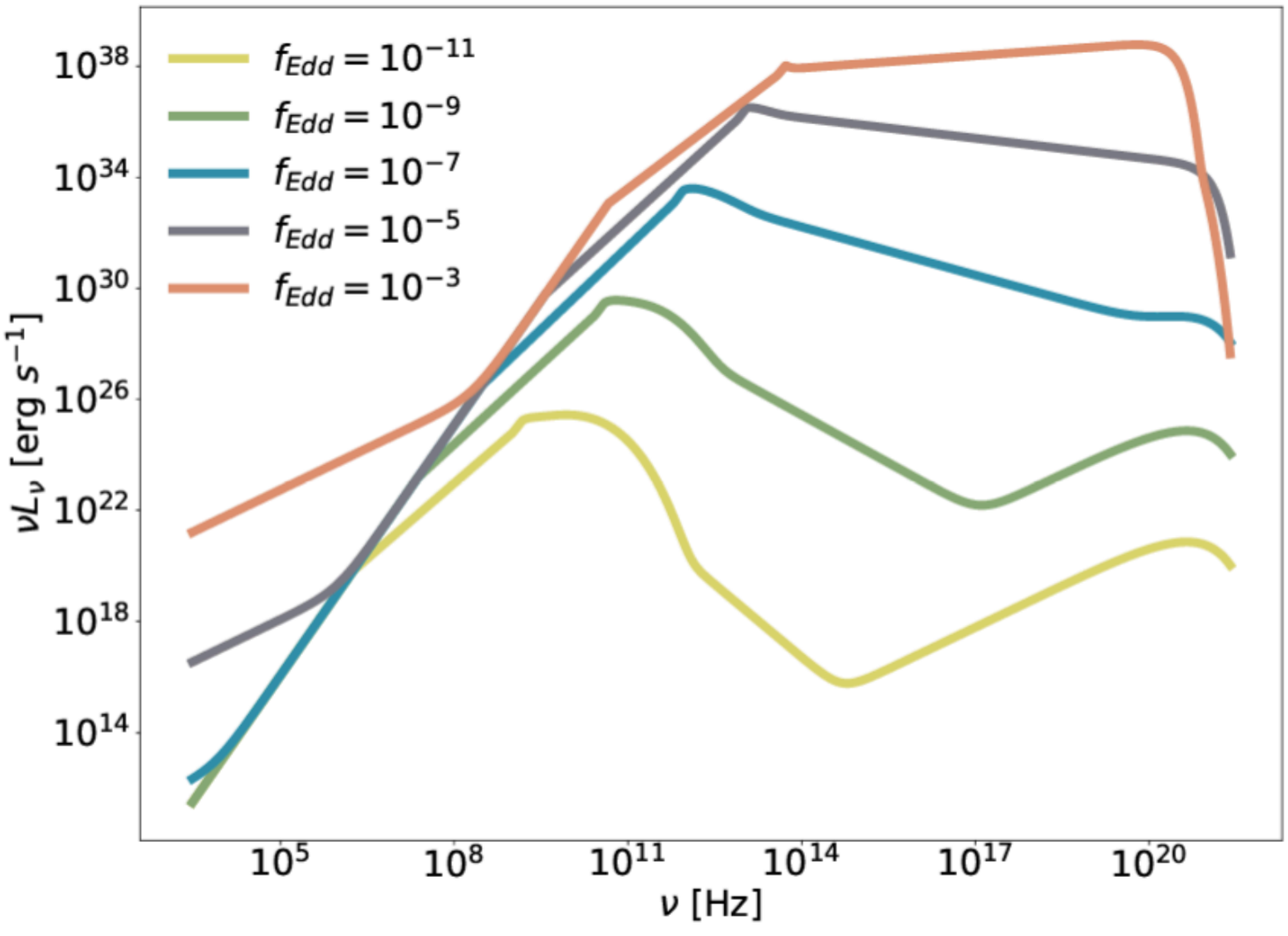


Figure 2. Display of SEDs for a 10^5 $M_\odot$ IMBH with five Eddington ratios in the range 10^{-11} to 10^{-3}.

Seepaul et al. 2022

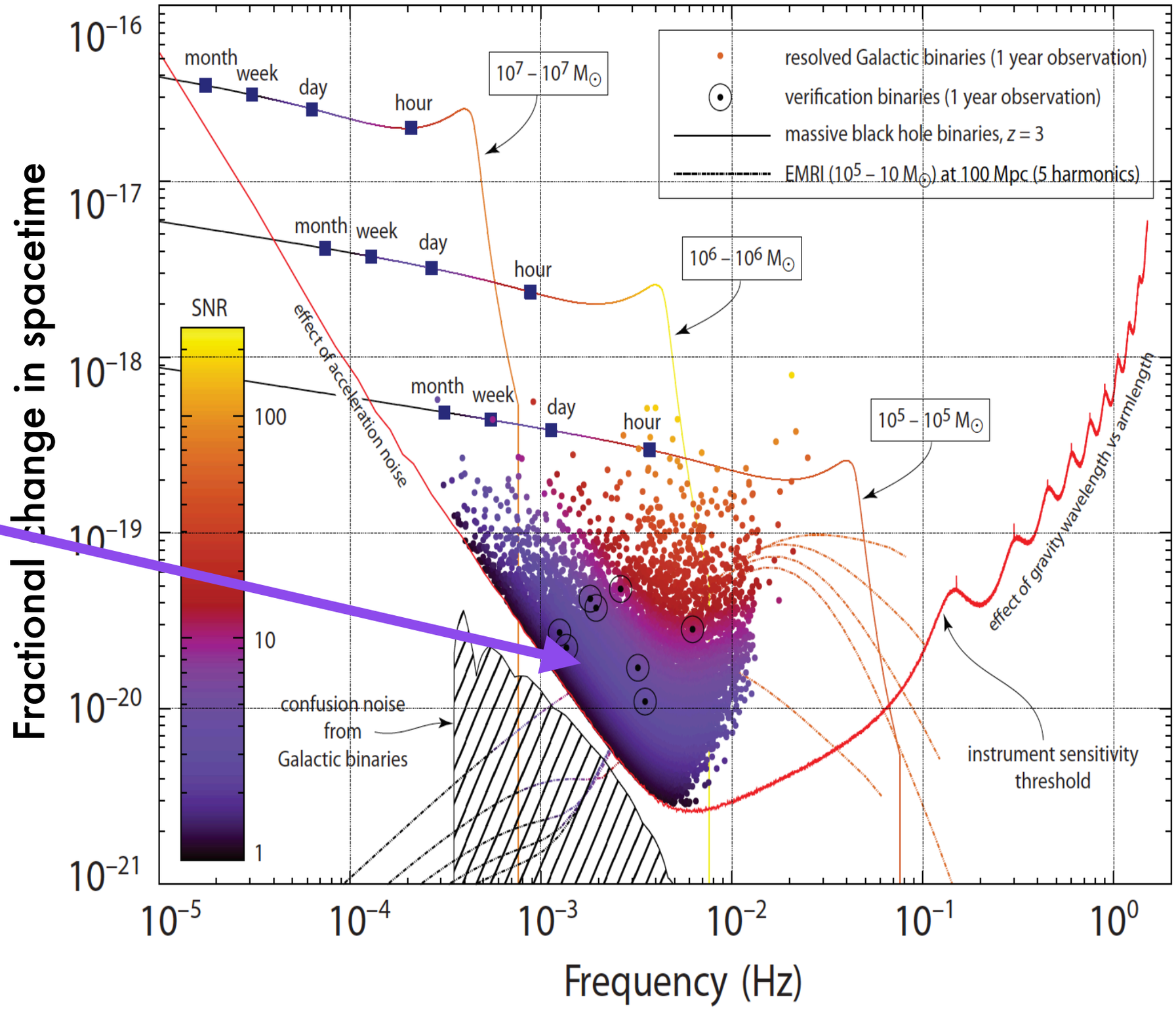
LISA black holes need open archival time-domain EM/particle/GW survey data

Counterpart hunts

Demographics

Galaxy co-evolution

Millions of close compact object binaries



What we hope to measure with  lisa

- Binary Star Evolution
  - Compact binary census, especially WD+WD
  - Binary parameter determination
- Mapping old Milky Way stellar population
- Accretion Physics
  - Obtain system parameters — masses+mass transfer rates
  - Add distance/luminosity to constrain accretion flow models
- Preview LIGO sources (out to z~2)

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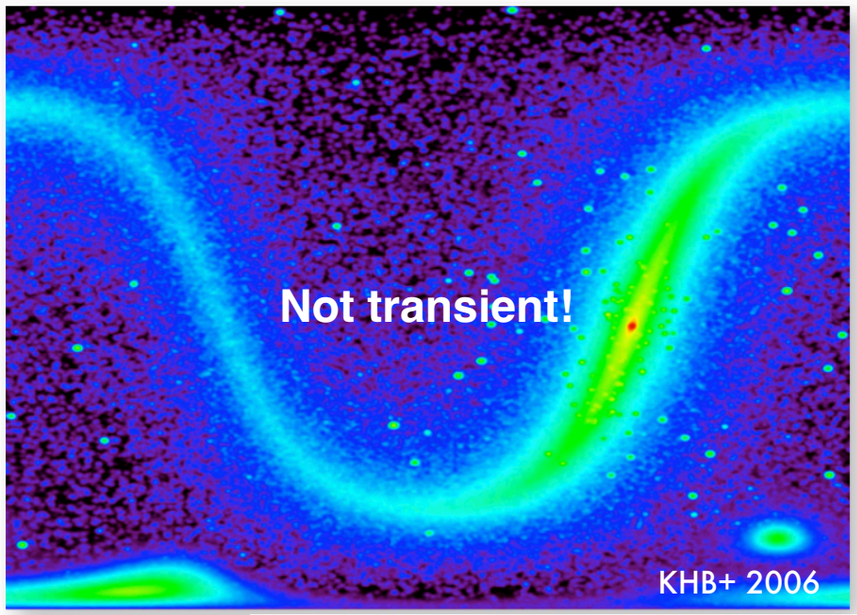
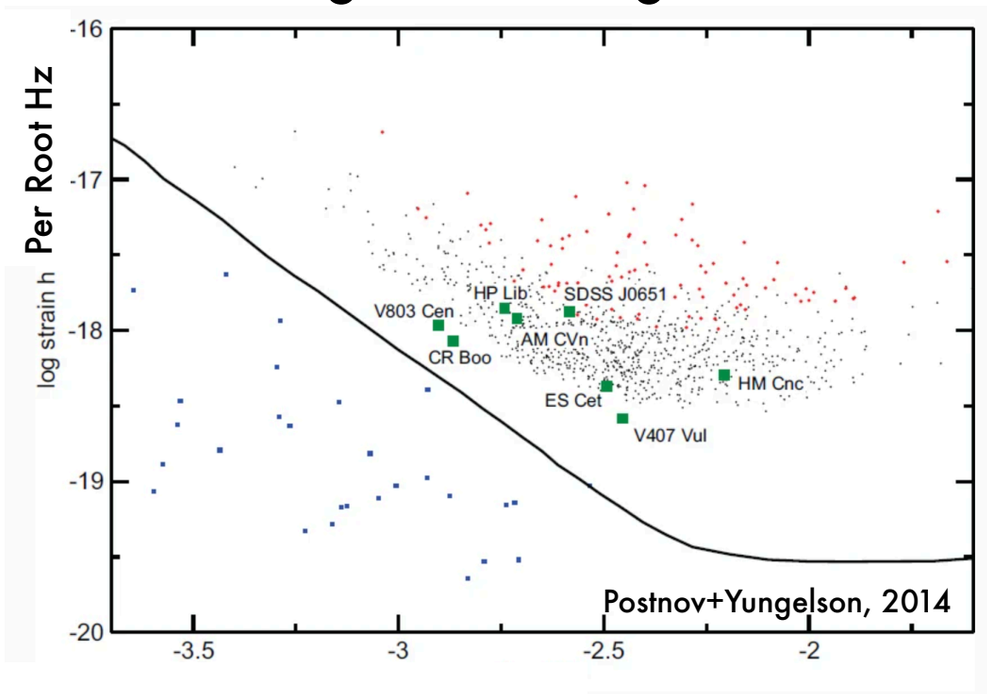
All the close white dwarf binaries in the galaxy++ are gravitationally-loud!



A smattering of EM-bright close binaries



	Gravitational-Wave	Electromagnetic	Combined
ι [deg]	$31.6^{+14.7}_{-21.8}$	$25.6^{+6.7}_{-5.4}$	$26.8^{+6.0}_{-4.8}$
P_0 [s]	$243.9849437^{+0.0000062}_{-0.0000062}$	$243.9849^{+0.0048}_{-0.0049}$	$243.9849439^{+0.0000066}_{-0.0000068}$
$\dot{P}$ [s s^{-1}]	$3.1474^{+0.0048}_{-0.0048} \times 10^{-11}$	$3.15100^{+0.00059}_{-0.00052} \times 10^{-11}$	$3.15098^{+0.00036}_{-0.00036} \times 10^{-11}$
$\mathcal{M}$ [$M_\odot$]	$0.22208^{+0.00020}_{-0.00021}$	$0.222236^{+0.000025}_{-0.000022}$	$0.222235^{+0.000015}_{-0.000015}$
q		$0.775^{+0.210}_{-0.237}$	$0.797^{+0.182}_{-0.239}$
R_1 [$R_\odot$]		$2.1^{+1.3}_{-1.1} \times 10^{-2}$	$1.96^{+1.38}_{-0.91} \times 10^{-2}$
R_2 [$R_\odot$]		$1.88^{+0.36}_{-0.28} \times 10^{-2}$	$1.84^{+0.33}_{-0.24} \times 10^{-2}$

Johnson et al. 2021

Combined GW + high-cadence EM data (e.g. ZTF, CHIMERA) improve orbital solution by orders of magnitude

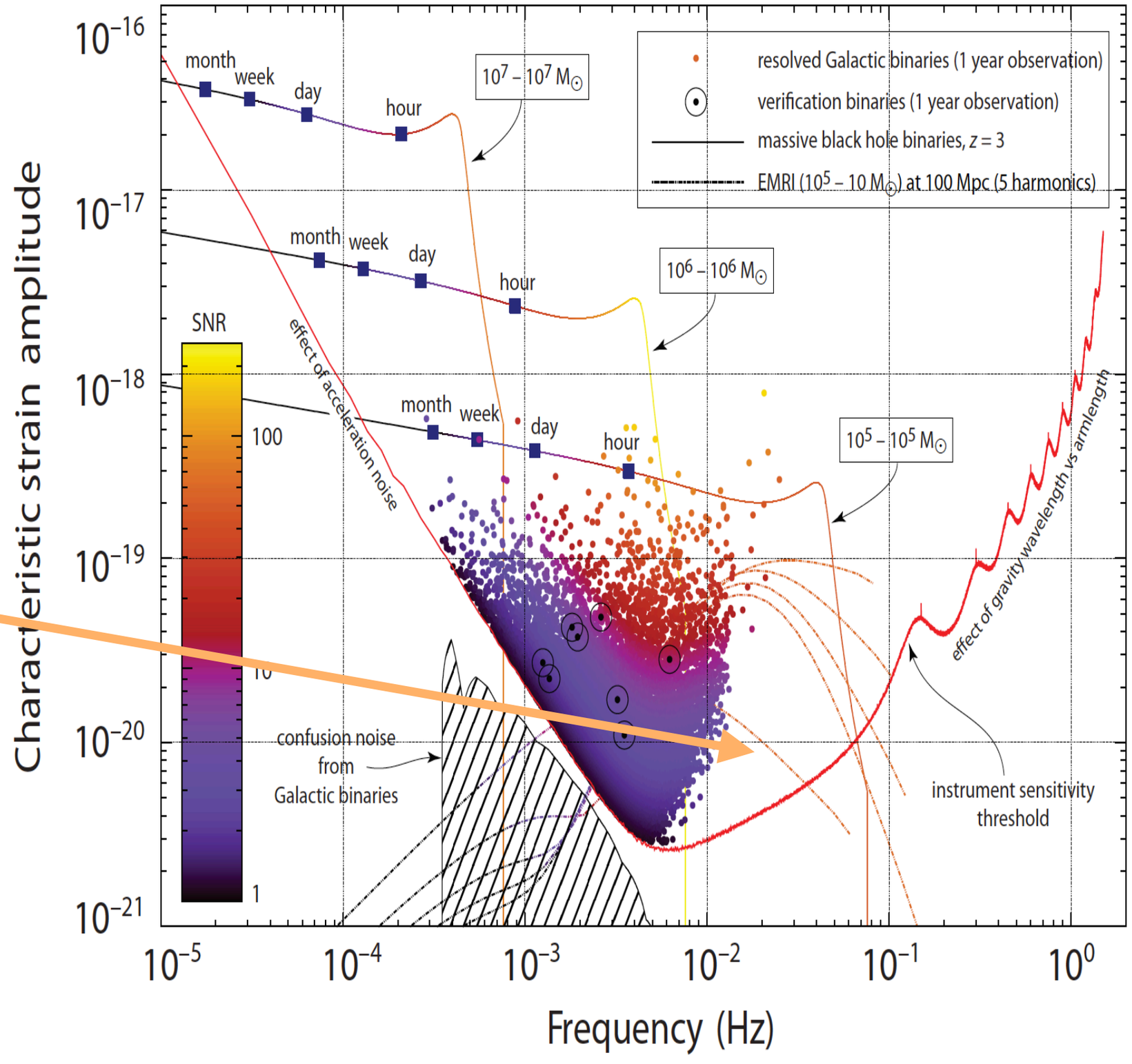
LISA ‘galactic’ binaries need open archival time-domain EM/particle/GW survey data

Galactic Archeology

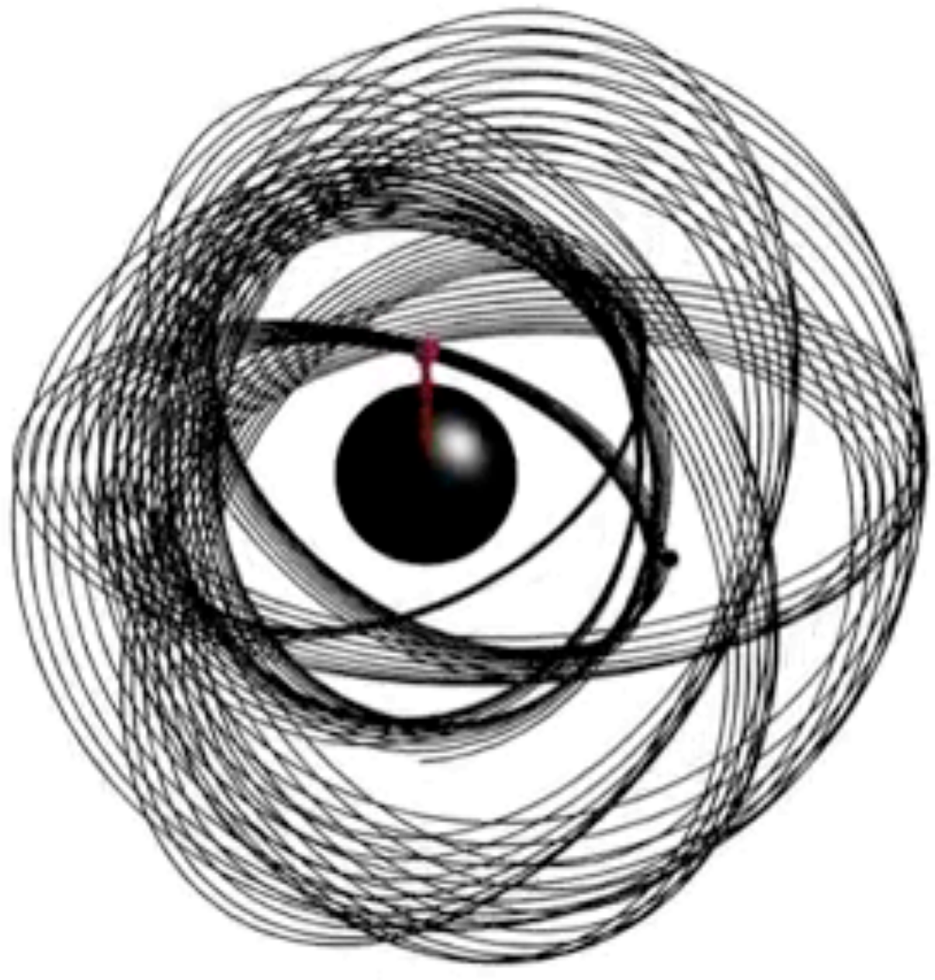
Demographics

Binary astrophysics

STELLAR REMNANTS ORBITING SMBHS



59 days before merger, 39% of light speed

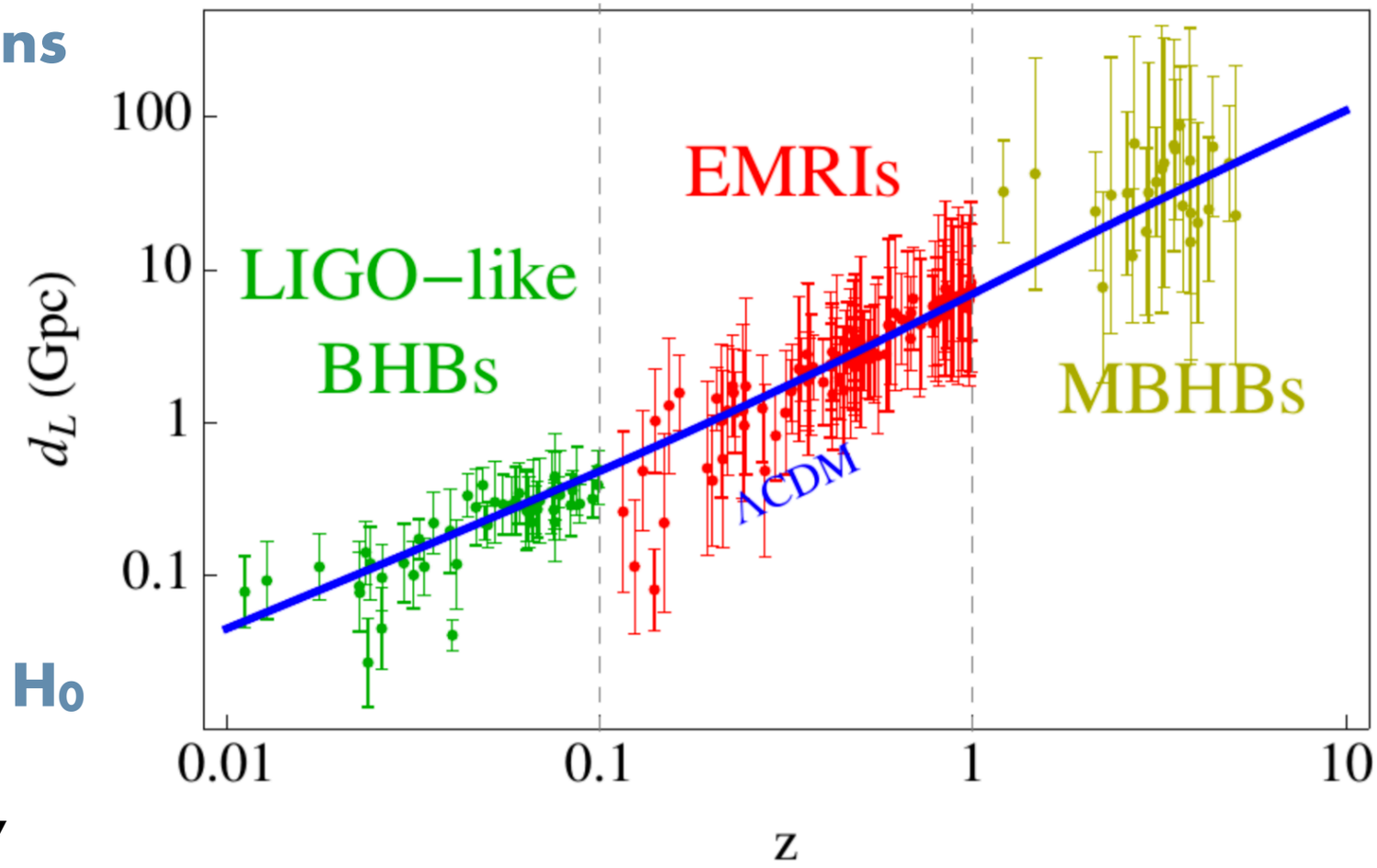


Exquisite tracers of black hole spacetime!

Credit: Steve Drasco, who is awesome

Black hole cosmology with lisa

- **BH mergers as standard sirens**
  - chirp rate gives mass
  - mass gives intrinsic amplitude
  - measured amplitude gives distance
- **combine with redshift to get H_0**
  - Need EM follow-up to identify (or constrain) hosts



Luminosity distances for simulated catalog of LISA BH binaries (N. Tamanini)

Cosmology with stochastic backgrounds

Merger rate

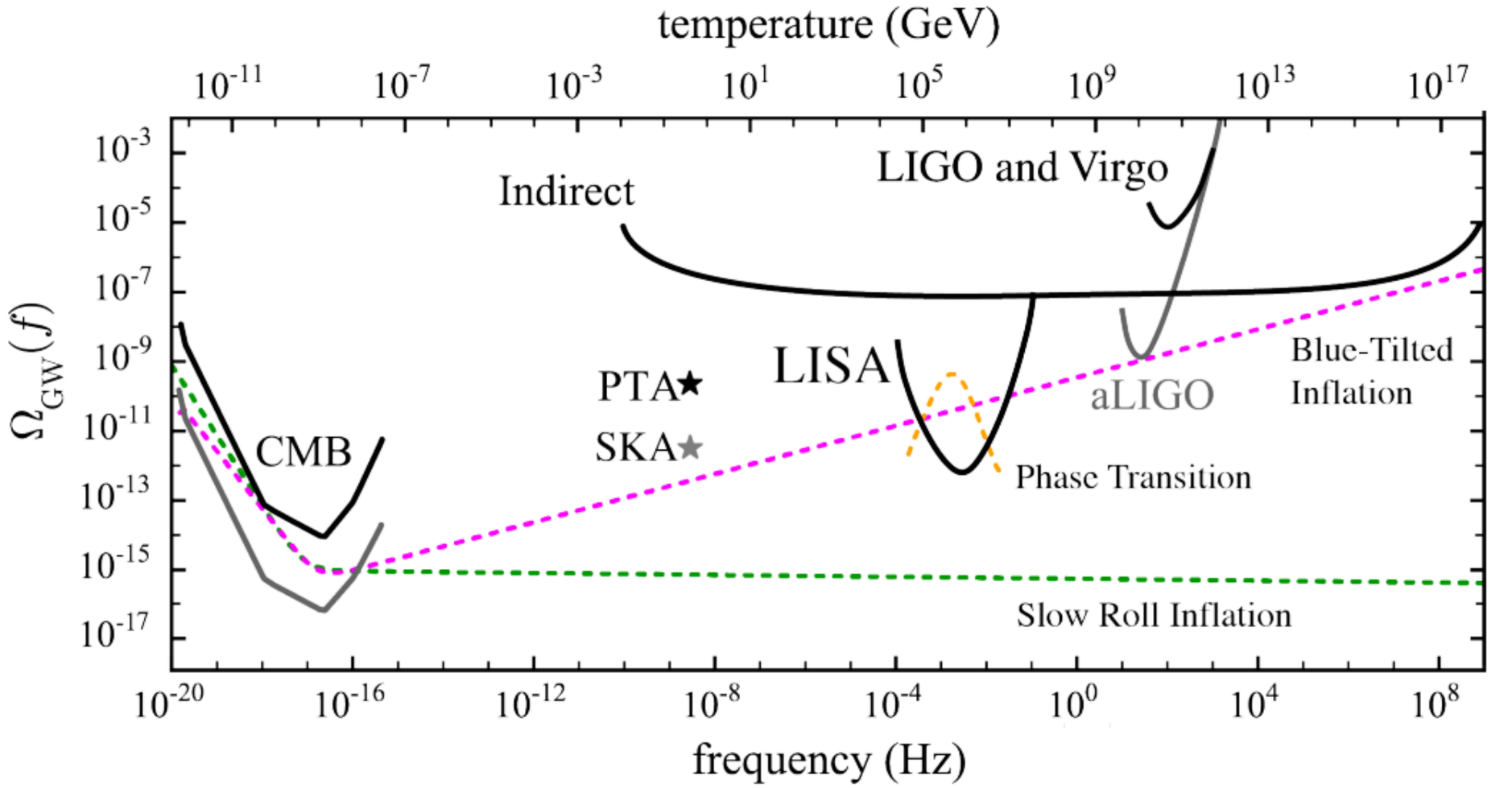
Energy emitted as a function of frequency

$$\Omega_{GW}(f;\theta_k) = \frac{f}{\rho_c H_0}\int_0^{z_{max}} dz \frac{R_m(z,\theta_k)\frac{dE_{GW}}{df_s}(f_s,\theta_k)}{(1+z)E(\Omega_M,\Omega_\Lambda,z)} \,.$$

Volume of the Universe as a function of z

lisa

Cosmology with stochastic backgrounds



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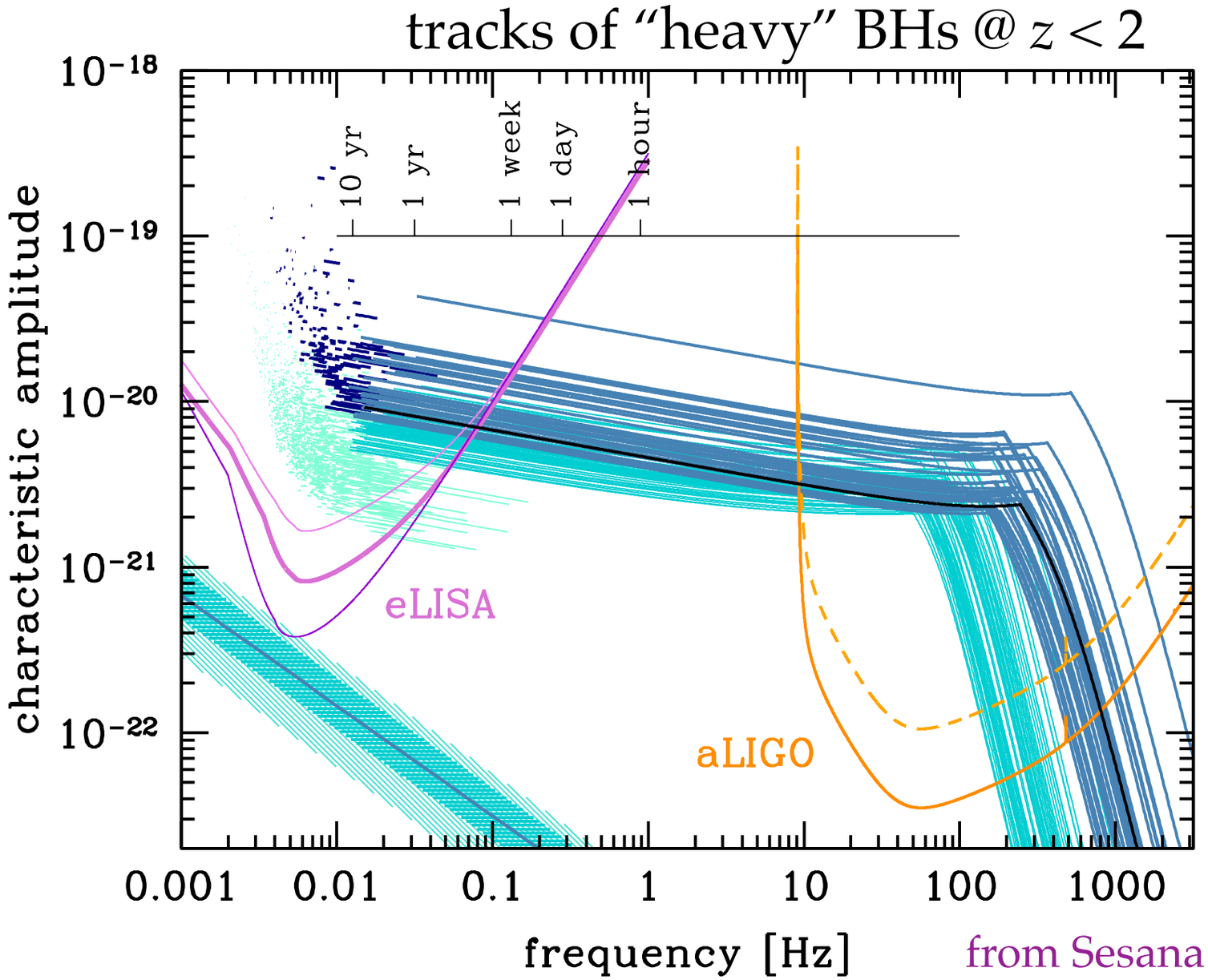
It’s a wonderful time to be an astronomer!

LISA is happening! It’s time to think about how how to get the most science out of LISA data. We need to build capacity in the brand new field of gravitational wave astronomy, and we’d love to work with you.

Thanks!

Extra things I didn’t get to talk about. Please ignore and/or ask me about them!

Extending and complementing LIGO



from Sesana 2016, *Phys. Rev. Lett.*, **116**,

Imagine what you could do with:

Component masses — 1%
Distances — 3%
Spins — 1-10%
Spin directions — 10 degrees
Sky localization — few arcmin — 10 deg^2
Eccentricity — 1%

Astrophysical messengers, pre-2015:
photons,
neutrinos,
cosmic rays
(and rocks)

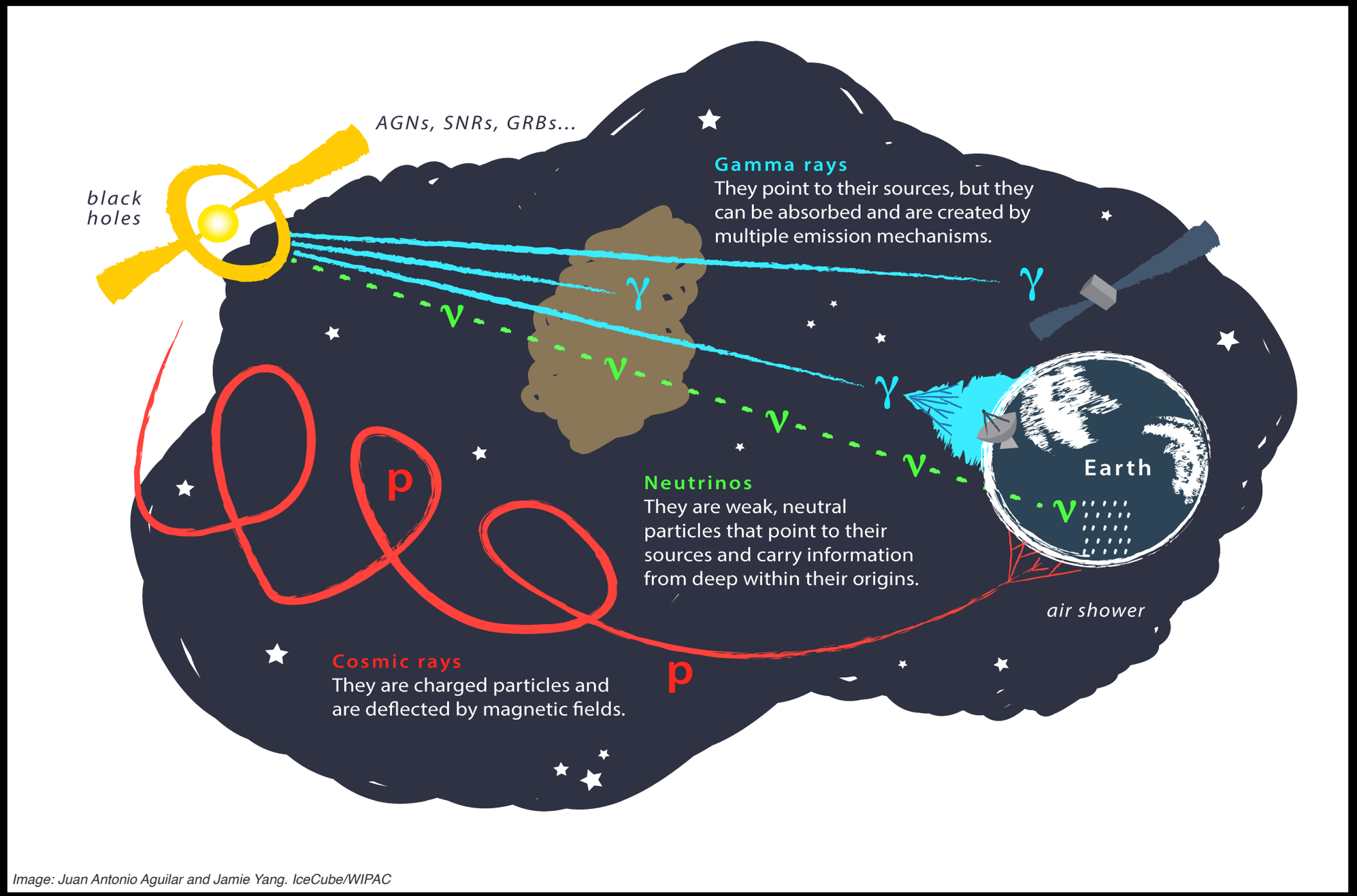
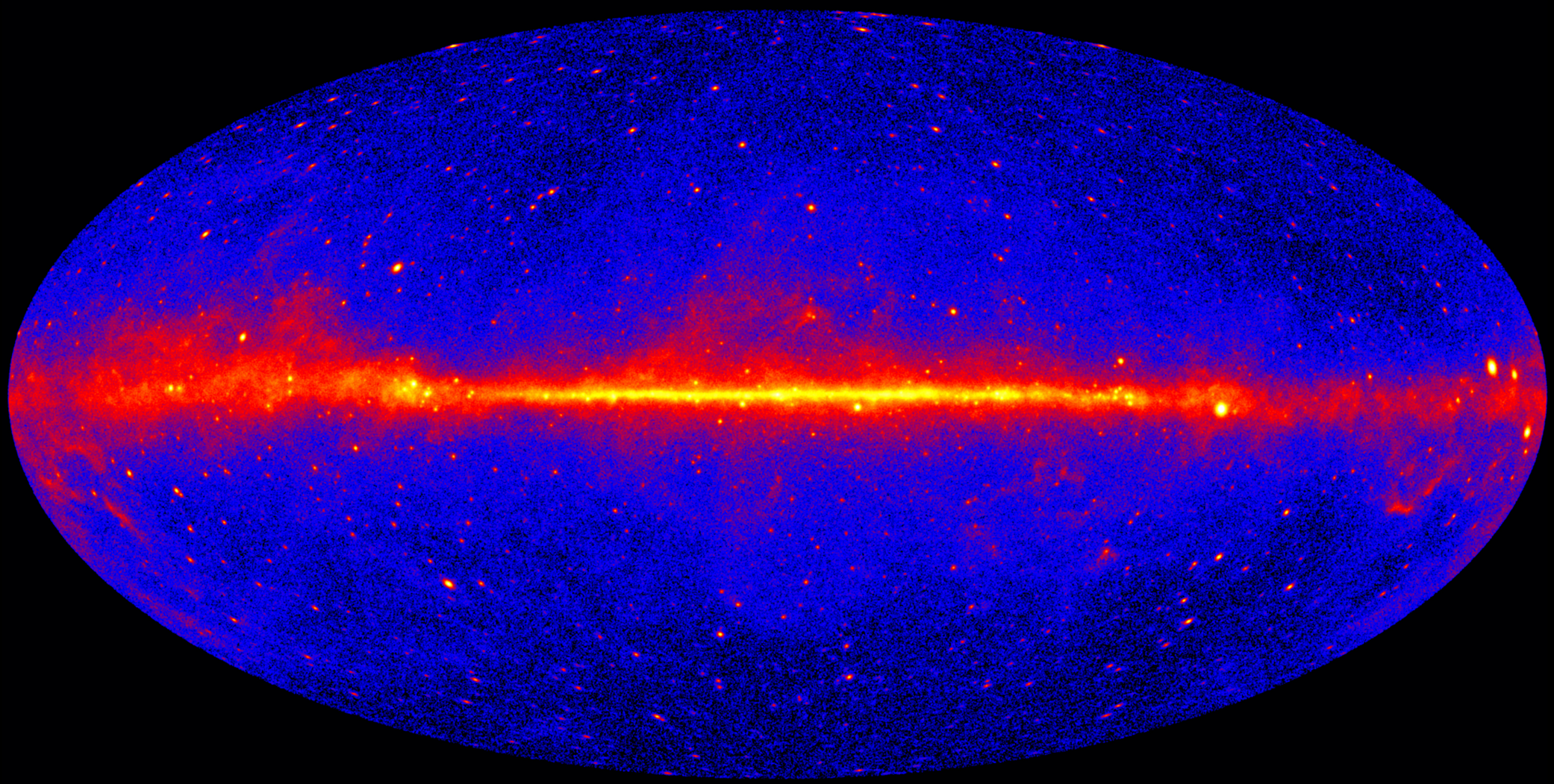


Image: Juan Antonio Aguilar and Jamie Yang. IceCube/WIPAC

Photons encode temperature, density, kinematics, composition of matter



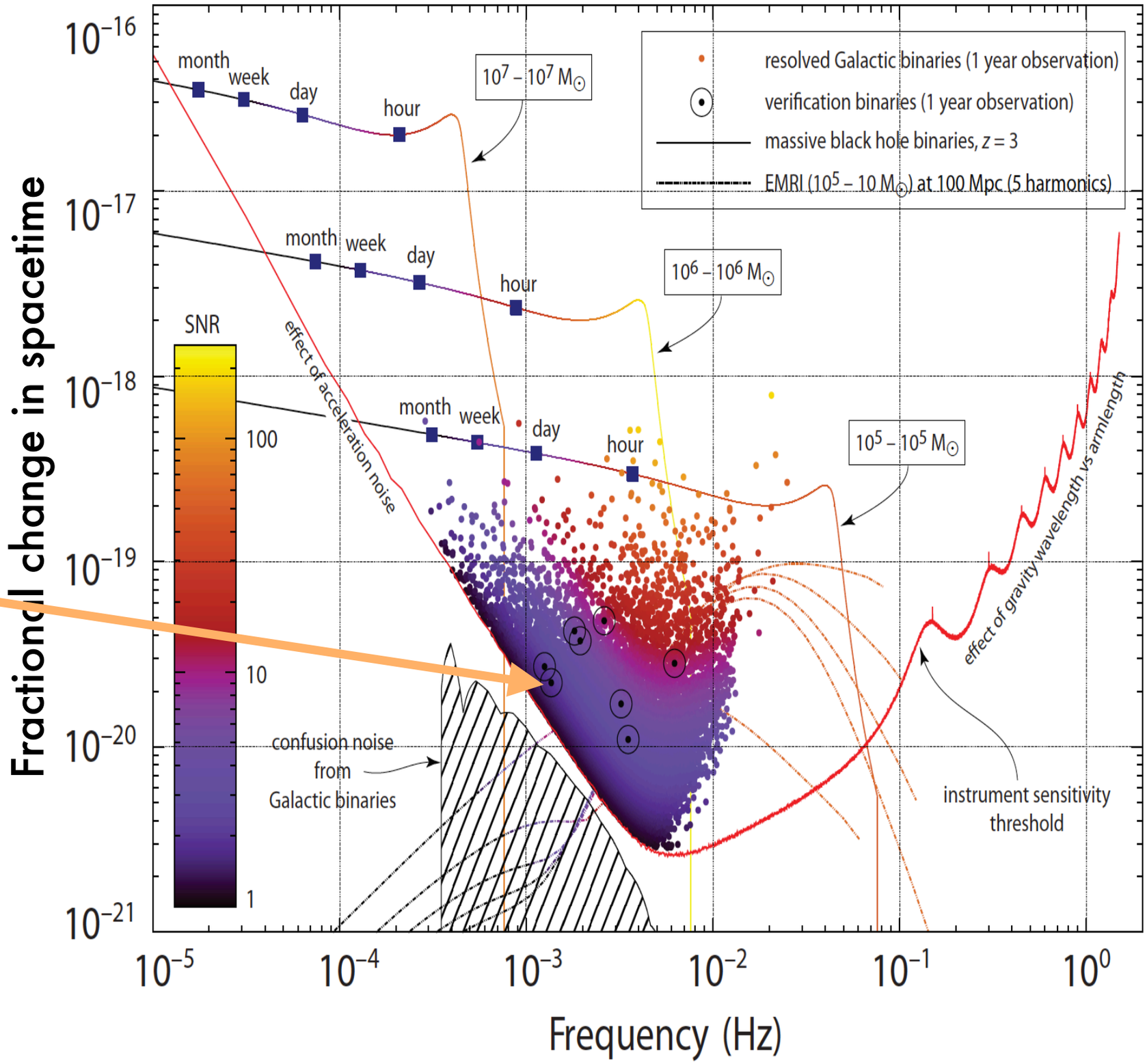
Fermi Gamma-ray Space Telescope

...but are easily distracted by other matter, magnetic fields, other photons

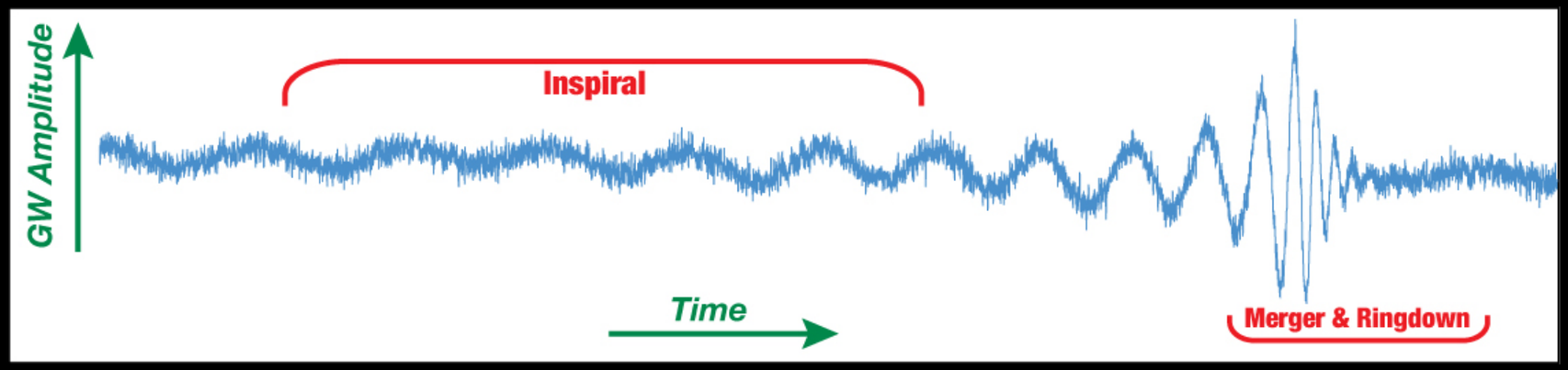
...and ultra-high energy photons annihilate each other, limiting our view of the ultra-high energy universe to the solar neighborhood

100 TeV photons travel ~ few kpc

Gravitational waves are unaffected by dust!



Gravitational waves encode mass, spin, orbit and distance



BBH no spin

BBH with spin