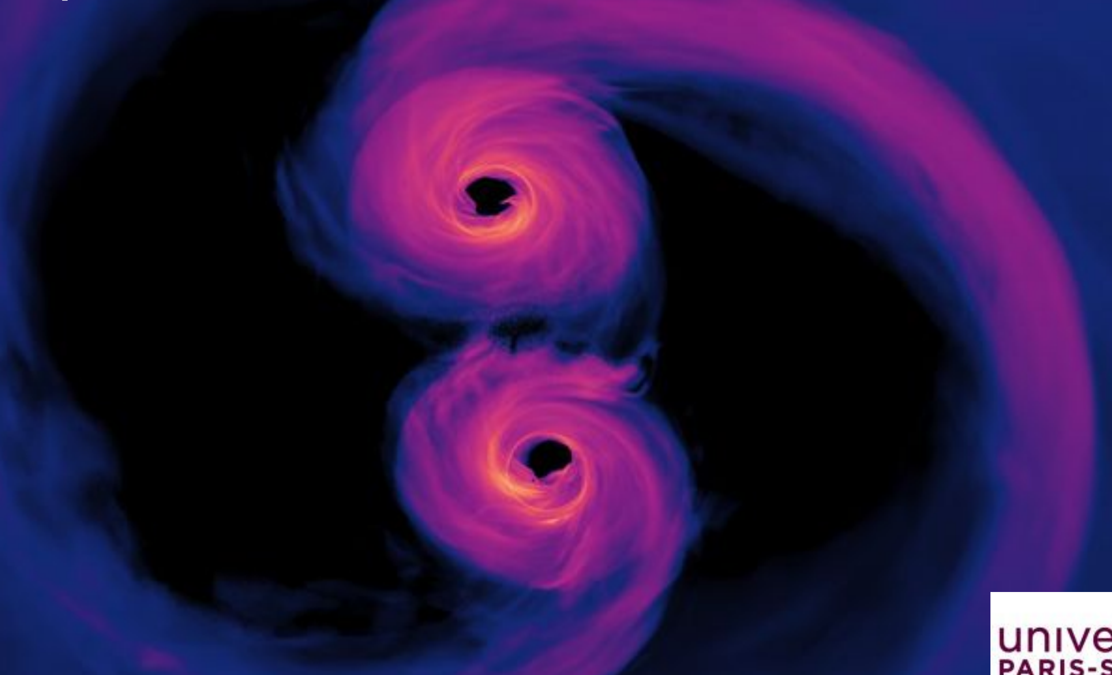
# Gravitational-wave observations in the 2030s: Einstein Telescope and LISA



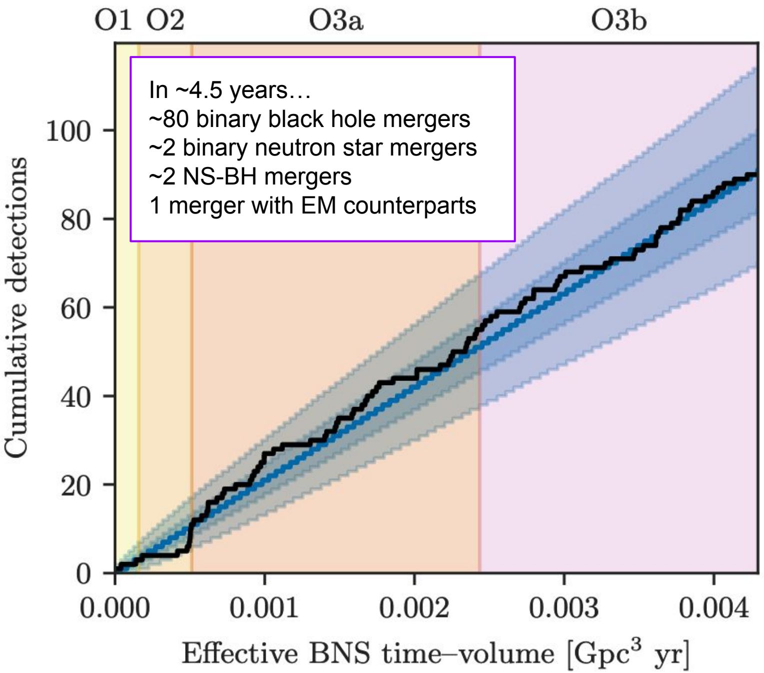
Tito Dal Canton and colleagues - IJCLab

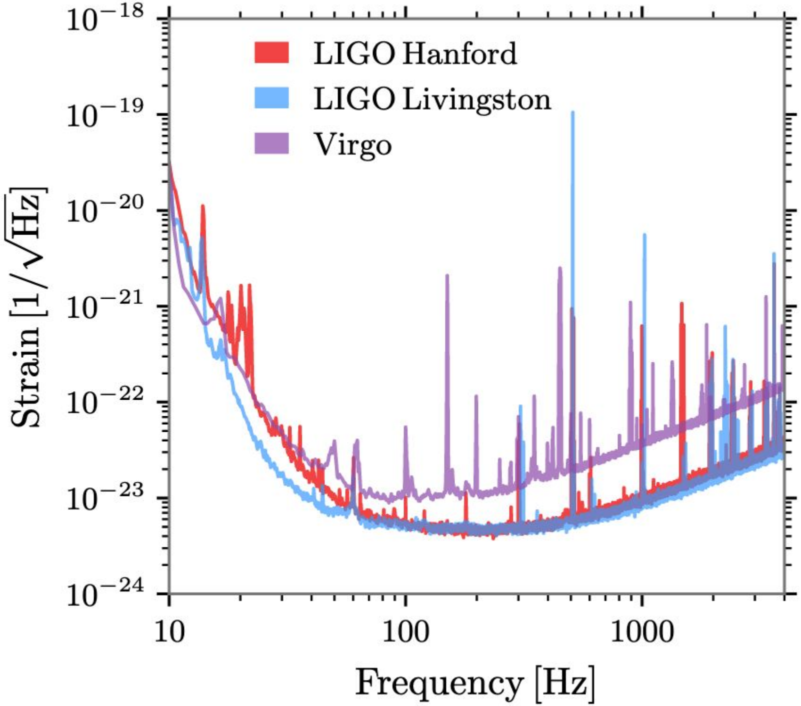
2 Dec 2021

université PARIS-SACLAY
GRADUATE SCHOOL
Physique
P2I
Physique des deux Infinis

# Present gravitational-wave observations

LIGO, Virgo & KAGRA 2021 (arXiv:2111.03606)

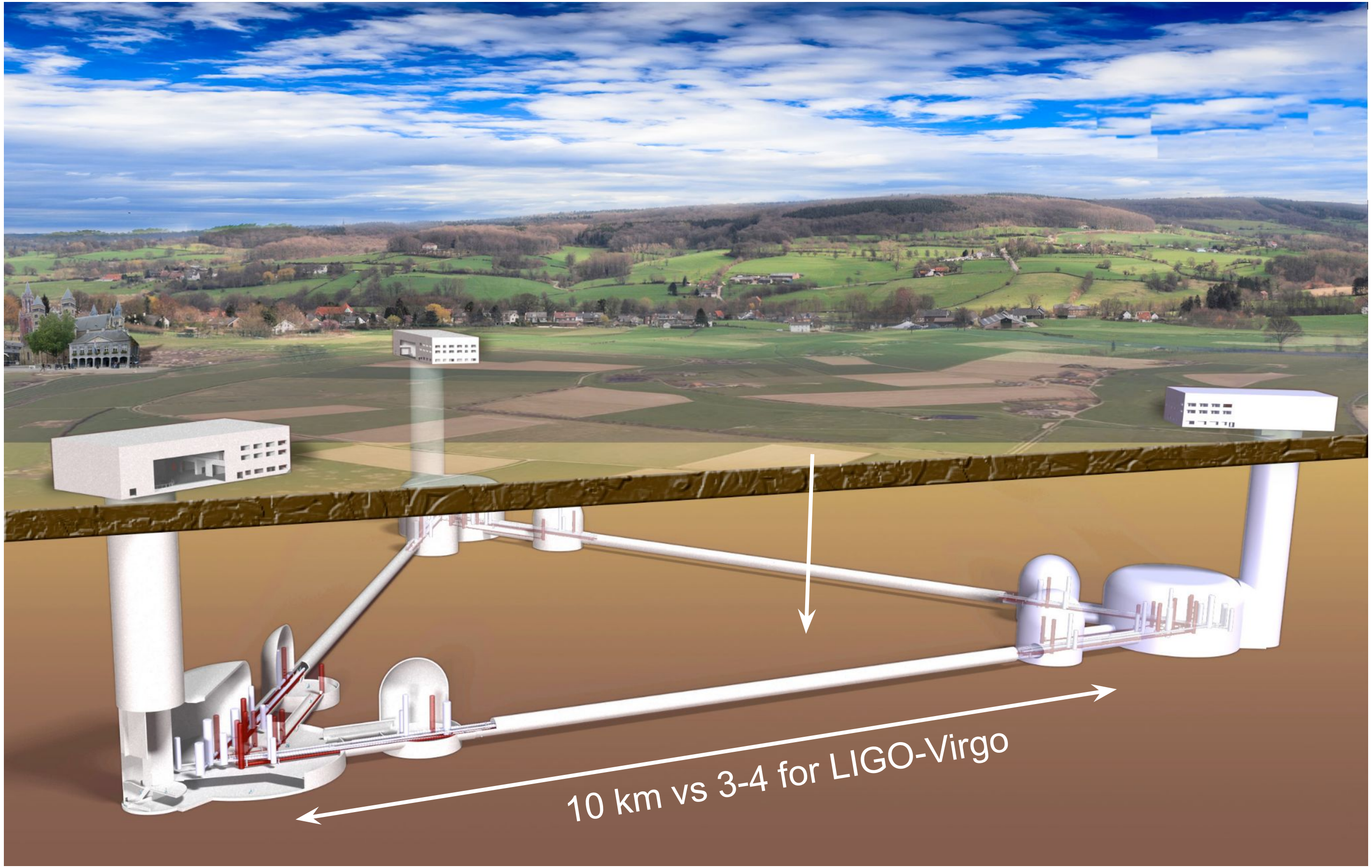



Can we improve this by orders of magnitude?

# Einstein Telescope: hardware changes

http://www.et-gw.eu




**Underground**:
improve gravity gradient and seismic noise (low frequency)

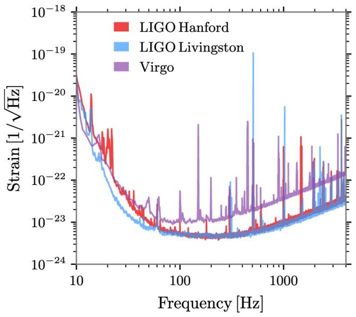
**Longer arms**:
improve displacement noise as ~1/L (broadband)

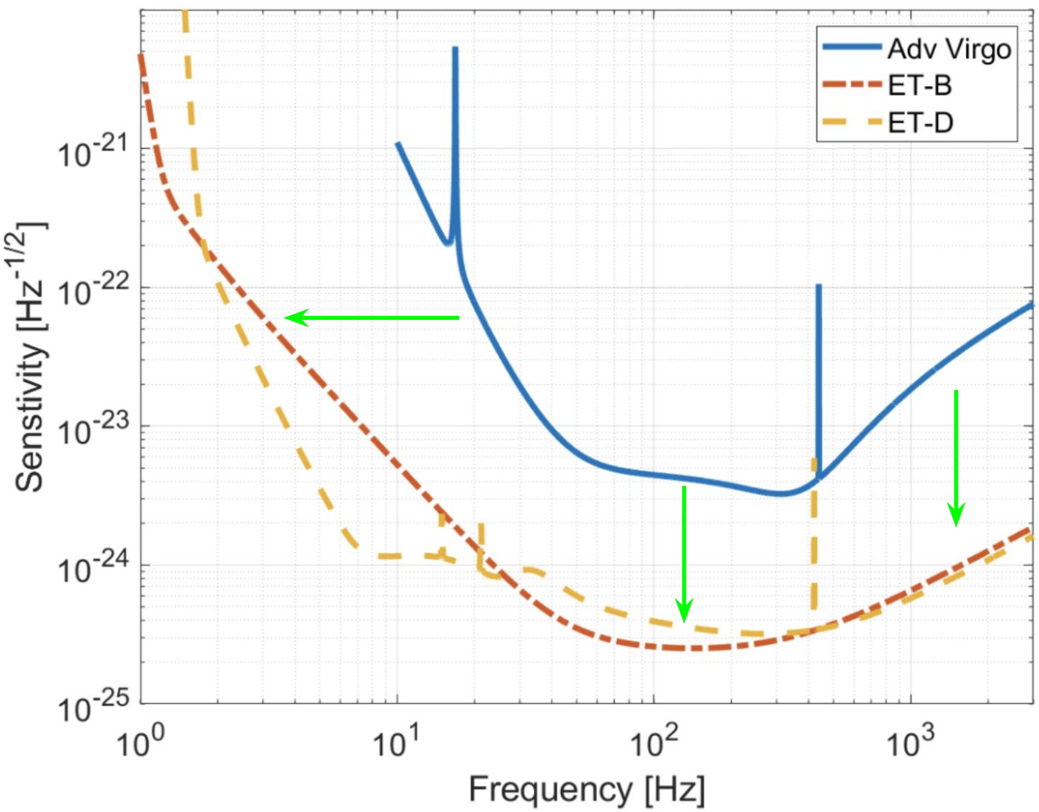
**Three interferometers**:
more isotropic sensitivity, redundancy

**Cryogenic mirrors *or* higher laser power**:
improve thermal *or* shot noise; “xylophone” configuration?

# Einstein Telescope: sensitivity

Maggiore et al 2020 (arXiv:1912.02622)

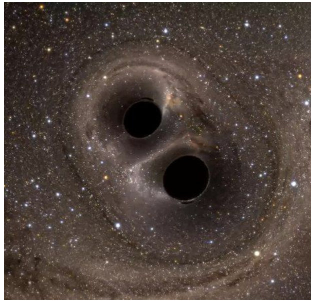


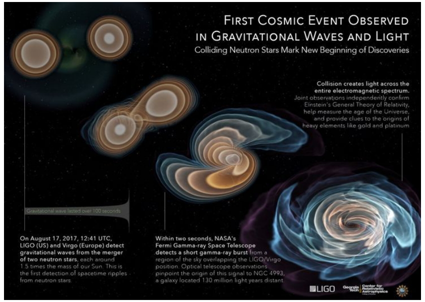




More noise, less sensitive

Less noise, more sensitive

# Einstein Telescope: stellar-mass compact binary mergers






**Higher event rates**

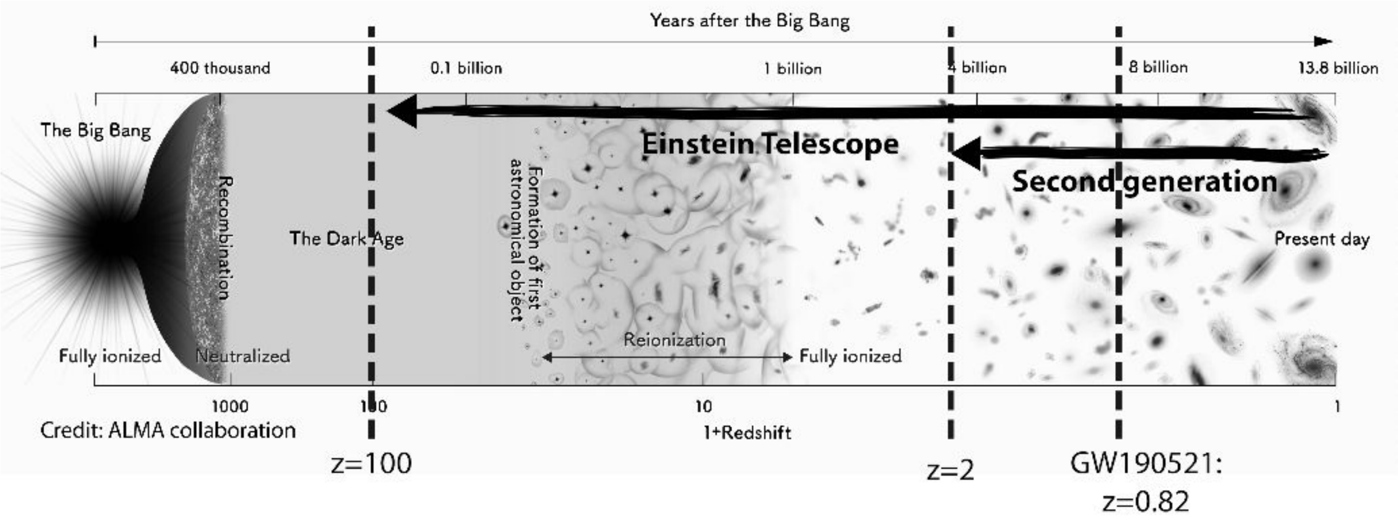
Noise curve lowers by factor *x*
→ Observed volume increases as ~$x^3$

Extrapolate today's event rates:
$10^5$-$10^6$/yr binary black hole mergers
$10^4$/yr binary neutron star mergers

**Longer signals**

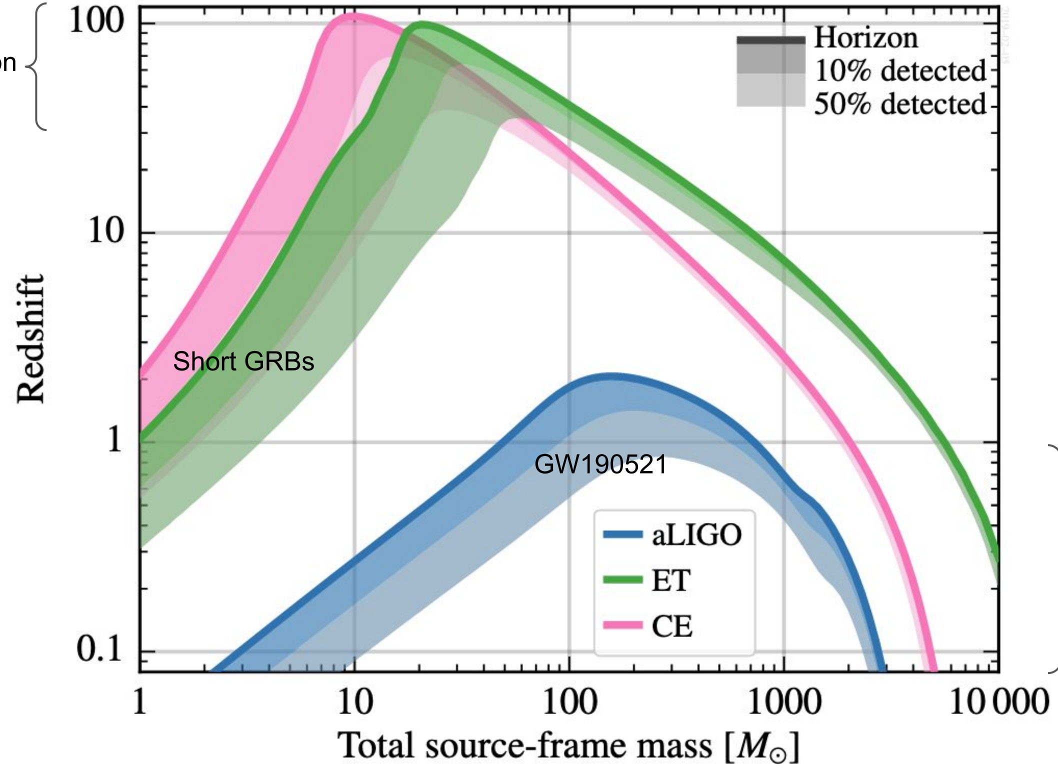
Minimum frequency lowers by *x*
→ Signal length increases as ~$x^{8/3}$

Inspiral signals observable for hours instead of minutes



# Einstein Telescope: stellar-mass compact binary mergers

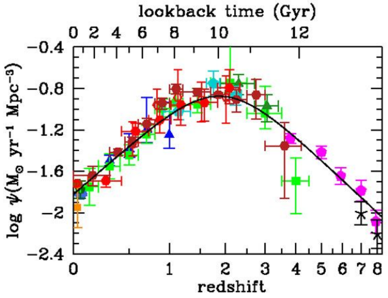
Before star formation




Signals with
S/N ~ 200
(~10x present)

Binary neutron stars

Binary black holes

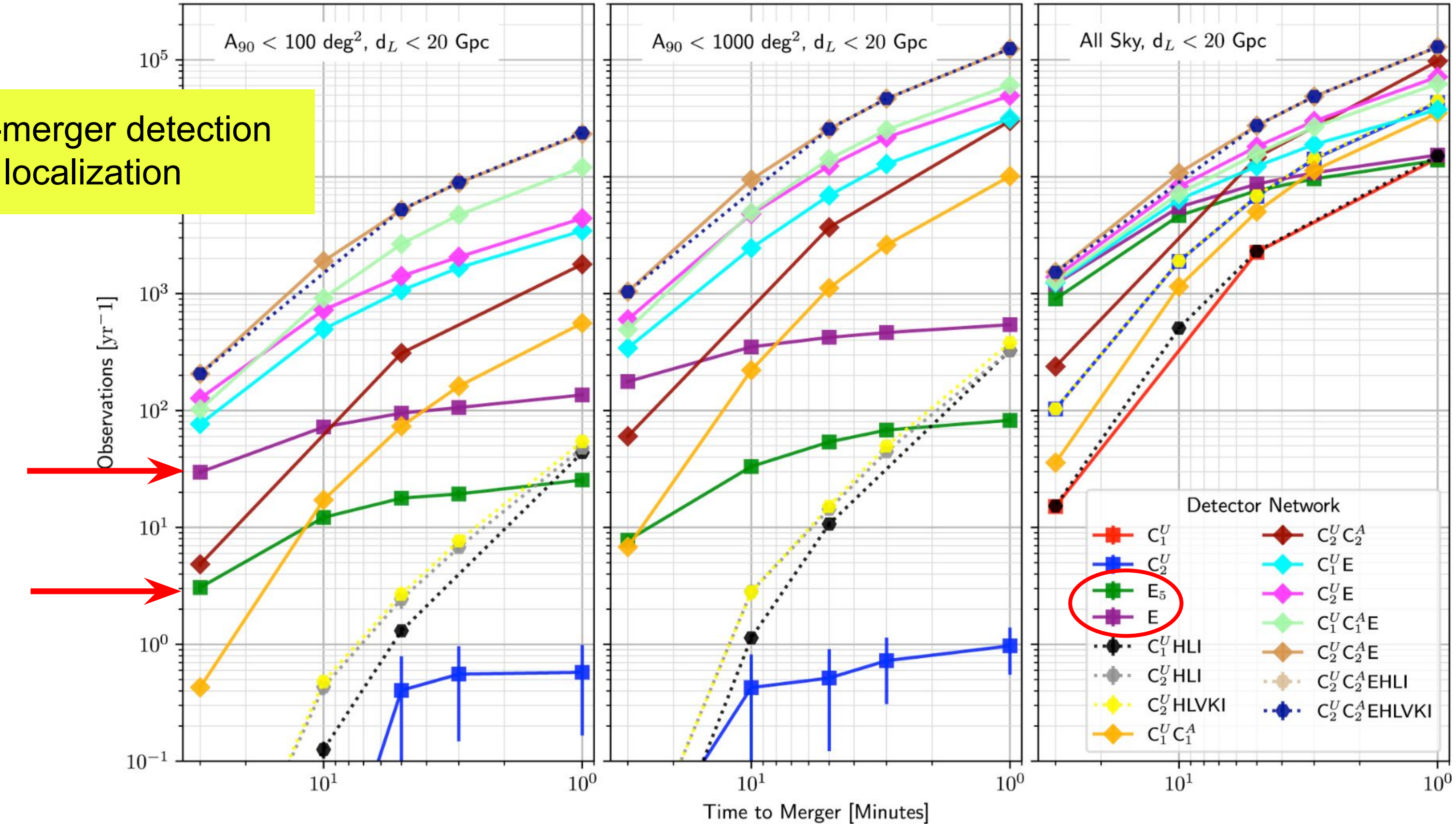



Star formation rate

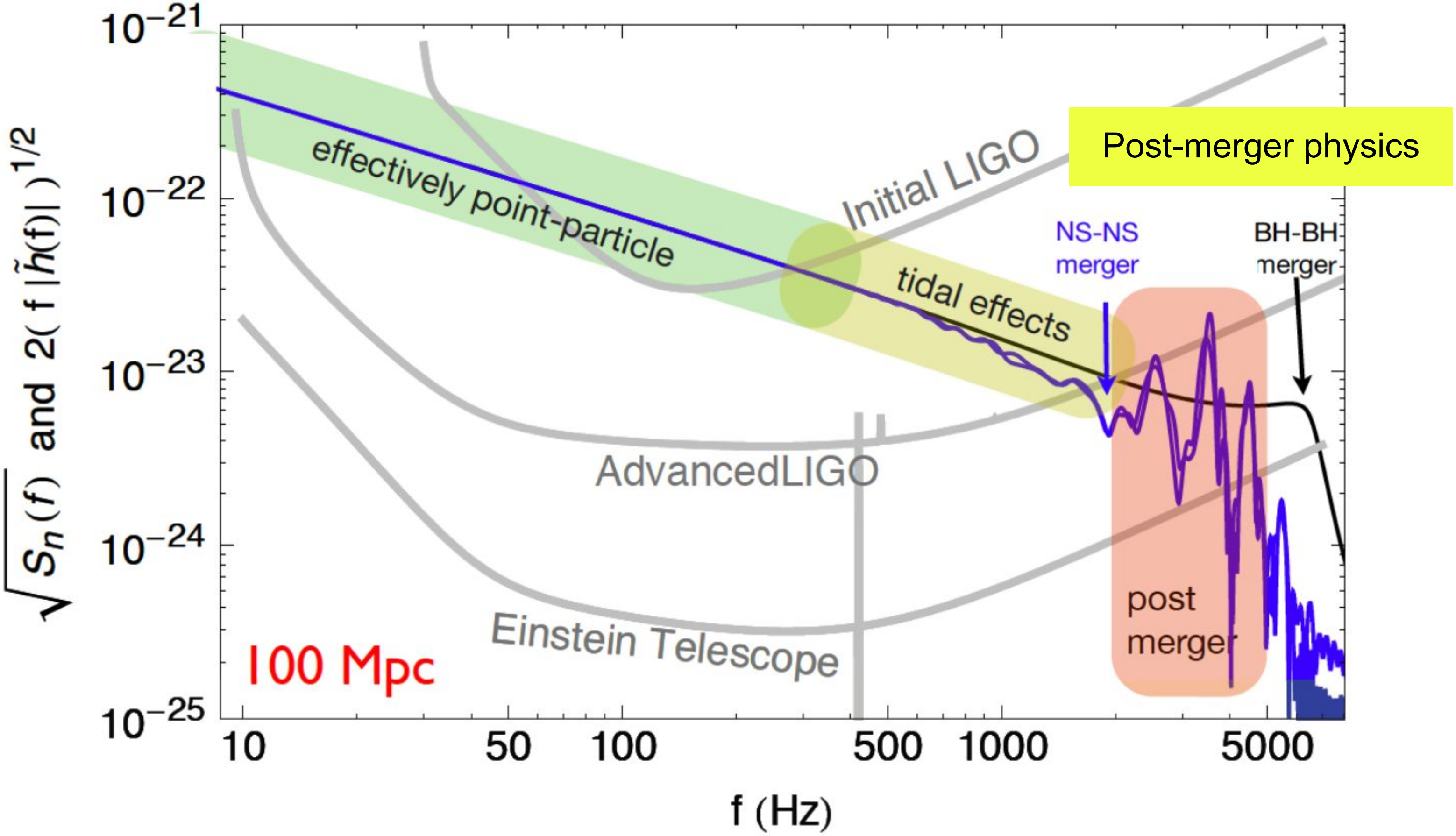
# Einstein Telescope: binary neutron star mergers

Nitz & Dal Canton 2021

Pre-merger detection and localization

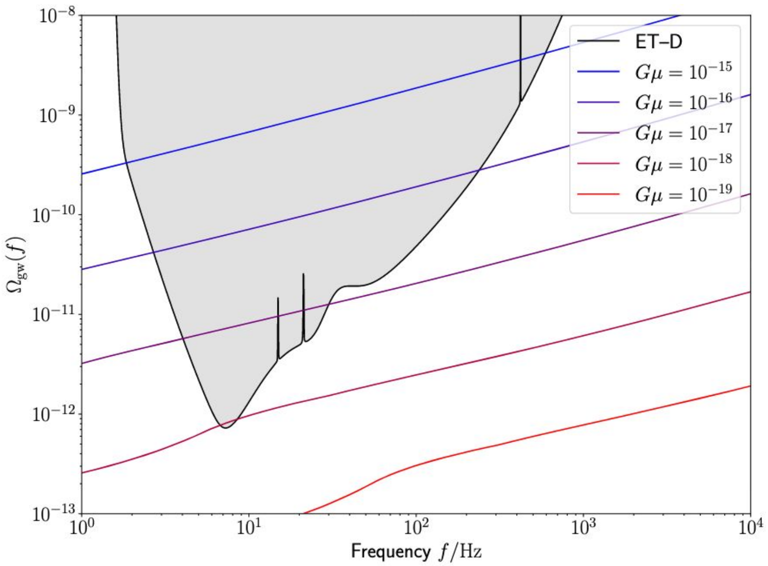


# Einstein Telescope: binary neutron star mergers

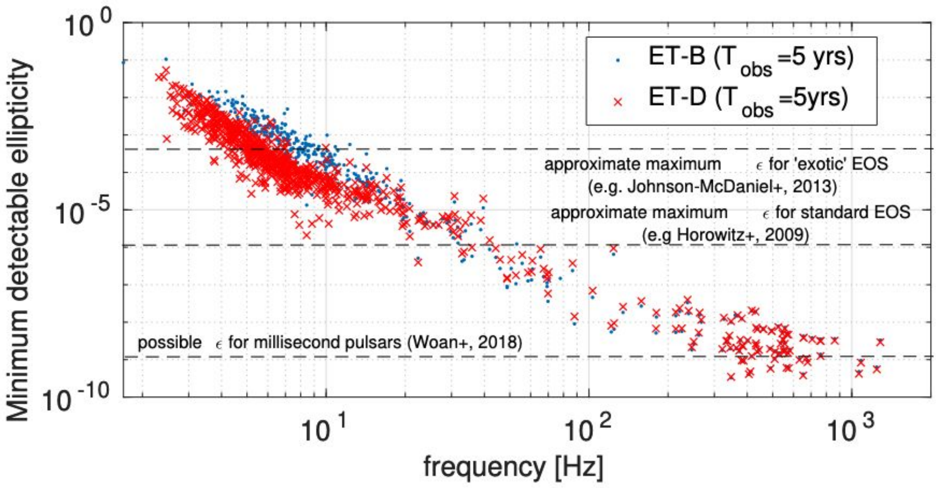


# Einstein Telescope: persistent sources?

Cosmological stochastic backgrounds




Isolated rotating neutron stars



# Einstein Telescope: status

https://www.esfri.eu/latest-esfri-news/new-ris-roadmap-2021


"ESFRI announces the 11 new Research Infrastructures to be included in its Roadmap 2021

€4.1 billion investment in excellent science contributing to address European challenges

After two years of hard work, following a thorough evaluation and selection procedure, ESFRI proudly announces the 11 proposals that have been scored high for their science case and maturity for implementation and will be included as new Projects in the ESFRI 2021 Roadmap Update.

The new ESFRI Projects are:

- *[…]*
- ET - Einstein Telescope, the first and most advanced third-generation gravitational-wave observatory, with unprecedented sensitivity that will put Europe at the forefront of the Gravitation Waves *[sic]* research."

# Paris-Saclay activities related to Einstein Telescope

**Gravitational-wave group, IJCLab (N. Leroy)**

ET detector hardware development

Computing infrastructure, data model

Detector characterization

- Data quality assessment
- Understanding and improving noise sources

Compact binary mergers

- Searches for GW/GRB/optical signals
- Interpretation of GW data
- Generation of rapid alerts for other telescopes

Cosmic strings

- Searches for GW signals
- Interpretation of GW data

Core-collapse supernovae

- Searches for GW/GRB/optical signals

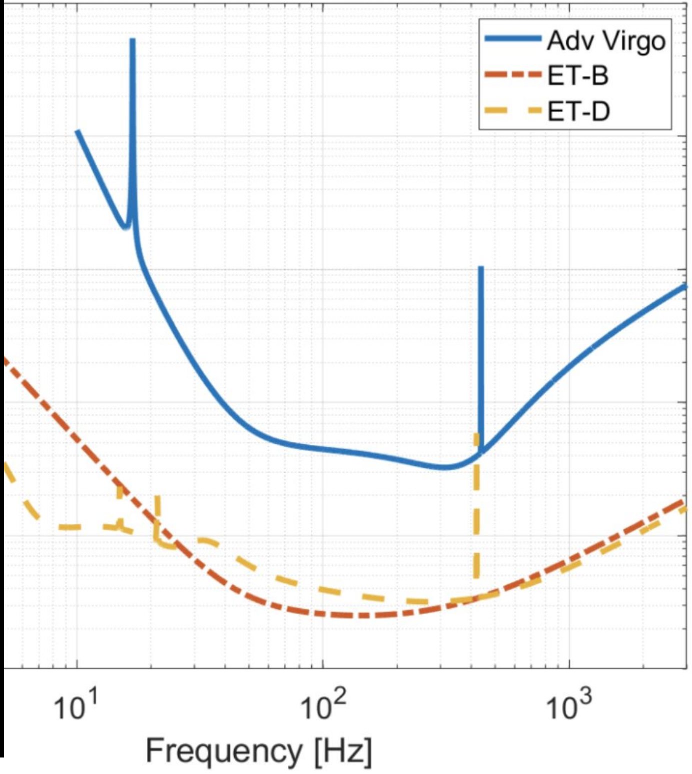
**Nuclear physics group, IJCLab (E. Khan)**

Constraints on the neutron star equation of state using ET observations

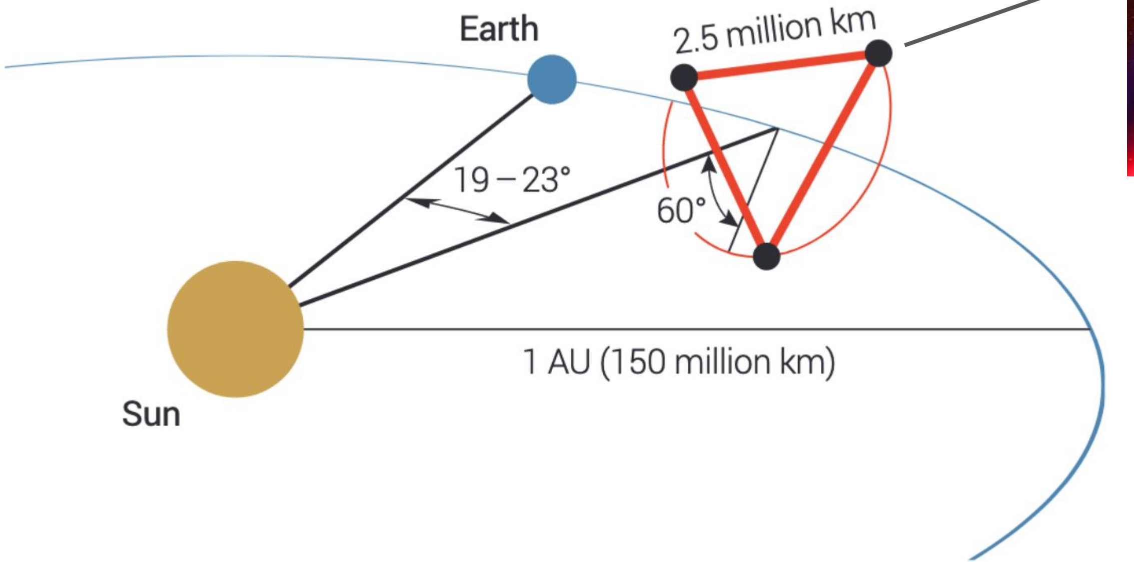
*R*-process nucleosynthesis (kilonovae)

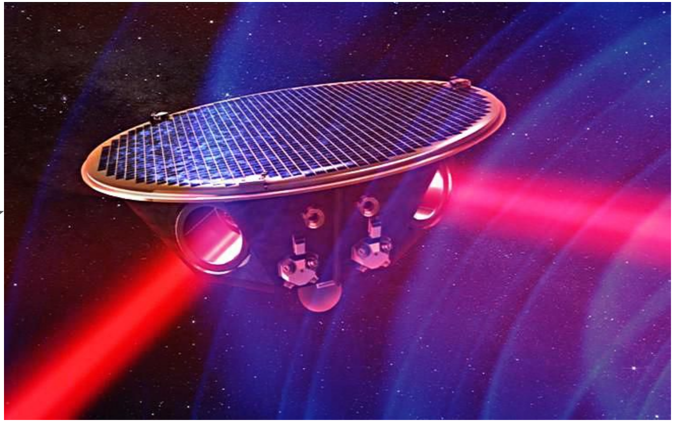
Electron capture in supernovae

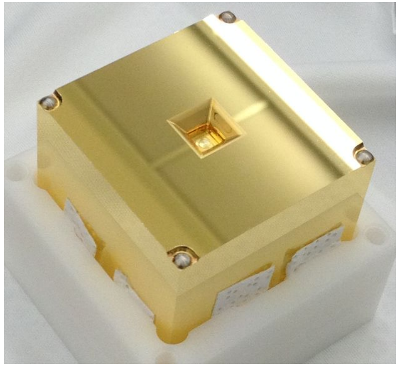
# Einstein Telescope: the ultimate detector?



# LISA: the Laser Interferometer Space Antenna

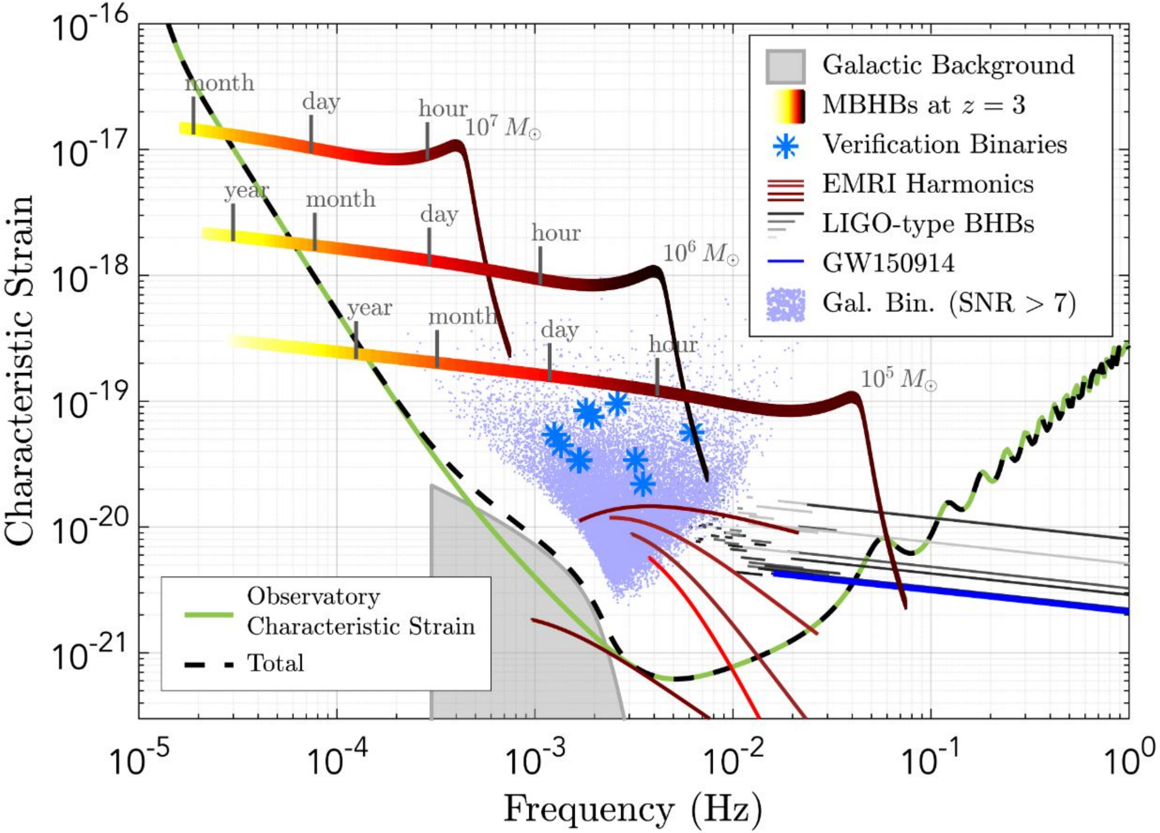




# LISA: sensitivity, overview of expected signals

Amaro-Seoane et al 2020 (arXiv:1702.00786)



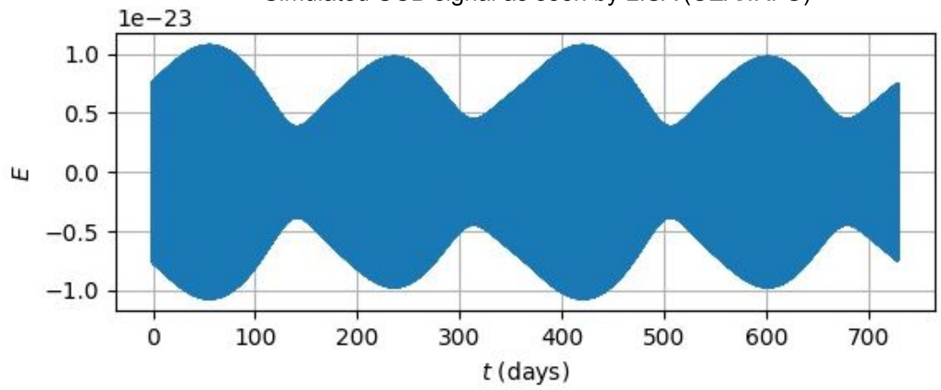
# LISA: ultracompact galactic binaries

White-dwarf binaries (non-merging)
with orbital period under ~1 hour.

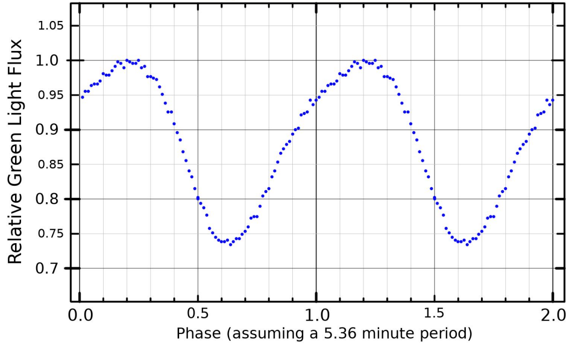
~$10^4$ individually resolvable signals;
confusion noise from superposition of weaker signals.

Multimessenger sources: many observable optically
(e.g. HM Cancri), could enable the study of mass transfer.

Simulated UCB signal as seen by LISA (CEA/IRFU)

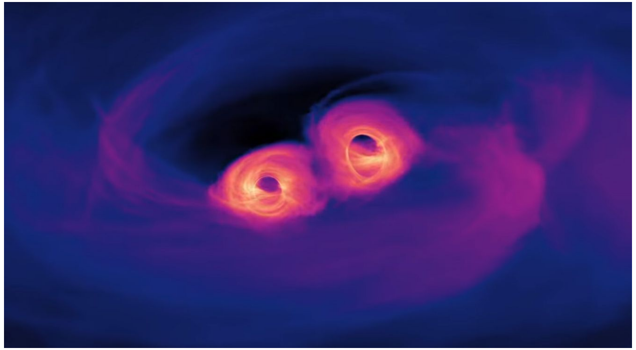



A Light Curve for HM Cancri



# LISA: massive black hole mergers

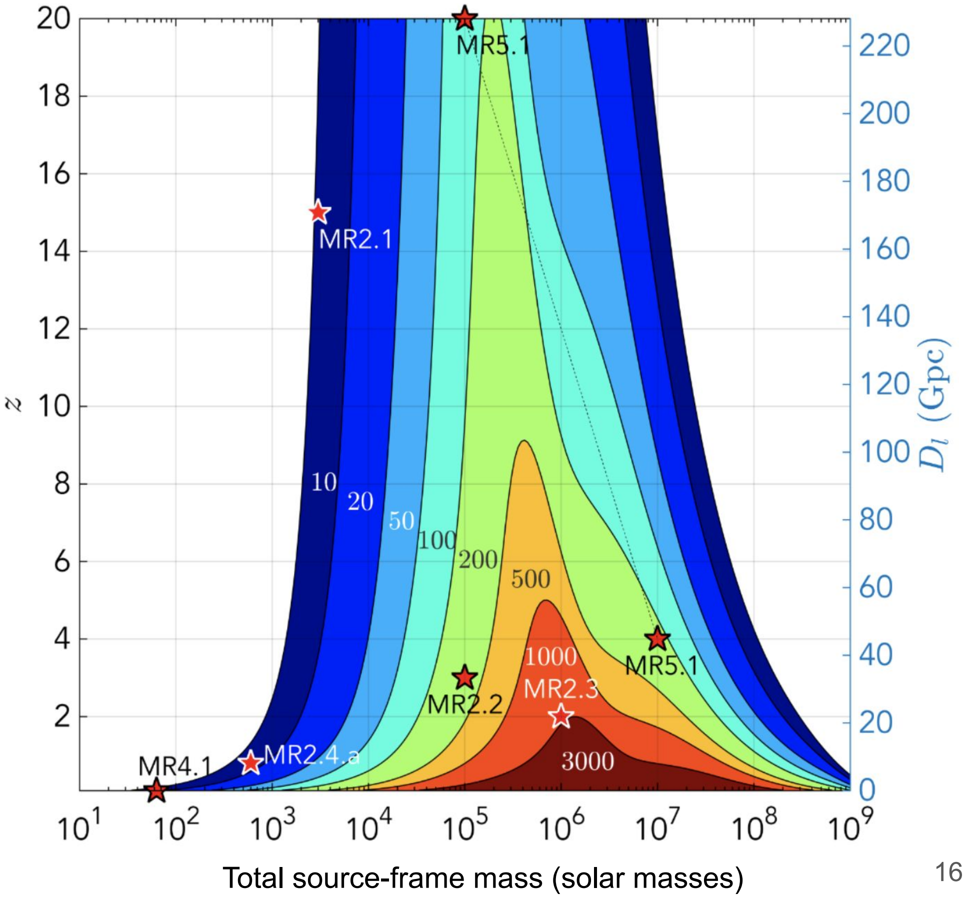
Merging binary systems containing black holes of $10^5$-$10^6$ solar masses



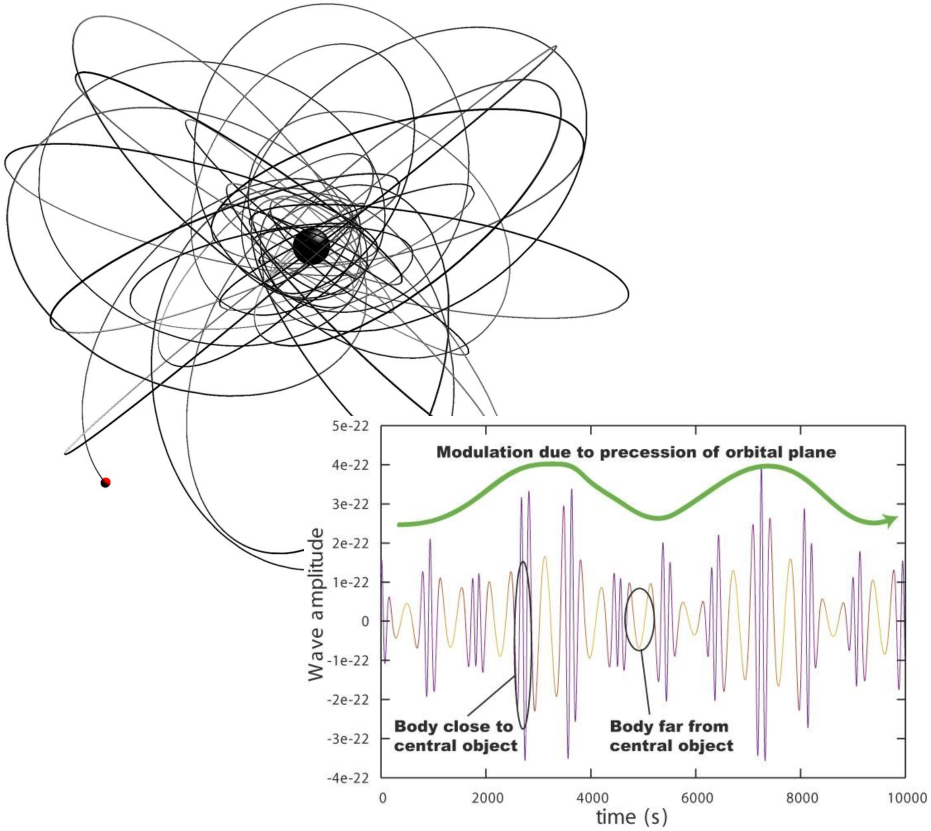
In LISA band for hours to months; some ~100x louder than current GW signals.

Detection rate highly uncertain, at least few per year expected.

Multimessenger sources? Possible connections with AGNs, physics of accretion, cosmology…



# LISA: extreme mass ratio inspirals



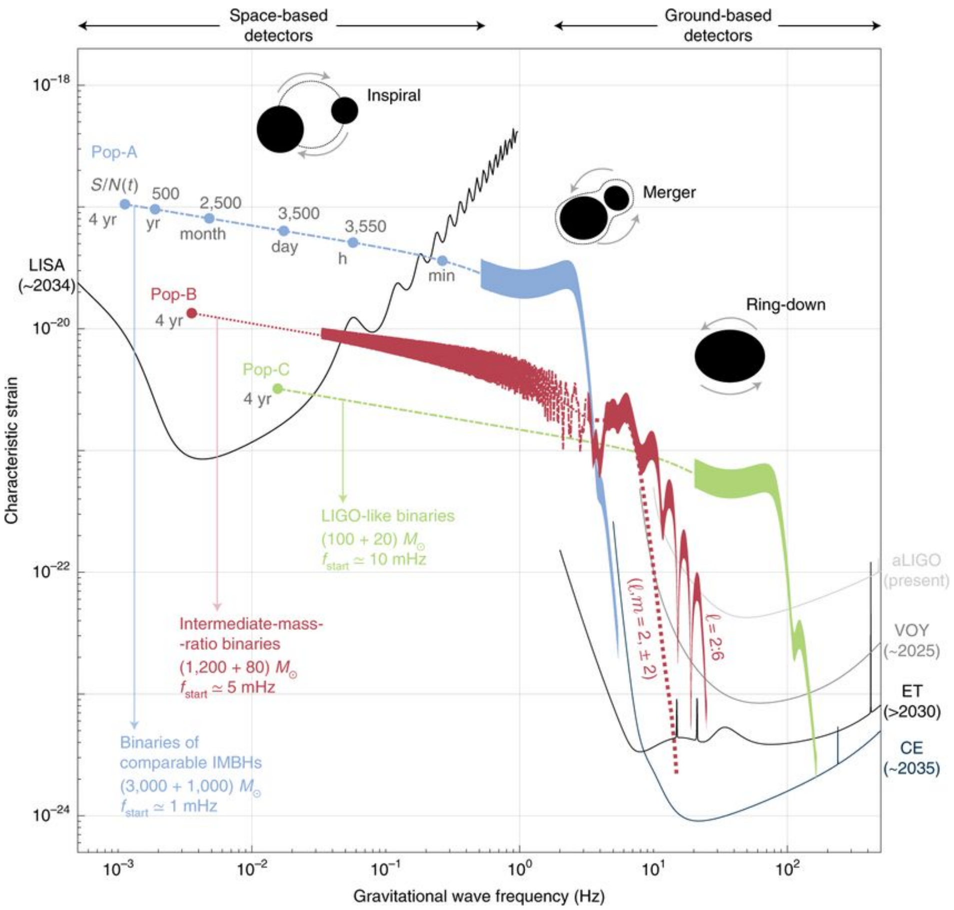

Stellar-mass black holes merging with massive black holes at the center of galaxies.

Extremely rich signals due to the long-lasting orbit and large number of precession cycles.

Excellent laboratories for detailed measurements of black hole population, and for testing general relativity.

Detection rate highly uncertain, likely 100-1000 per year.

# ET *and* LISA: intermediate-mass black hole mergers




"Multiband" gravitational-wave astronomy

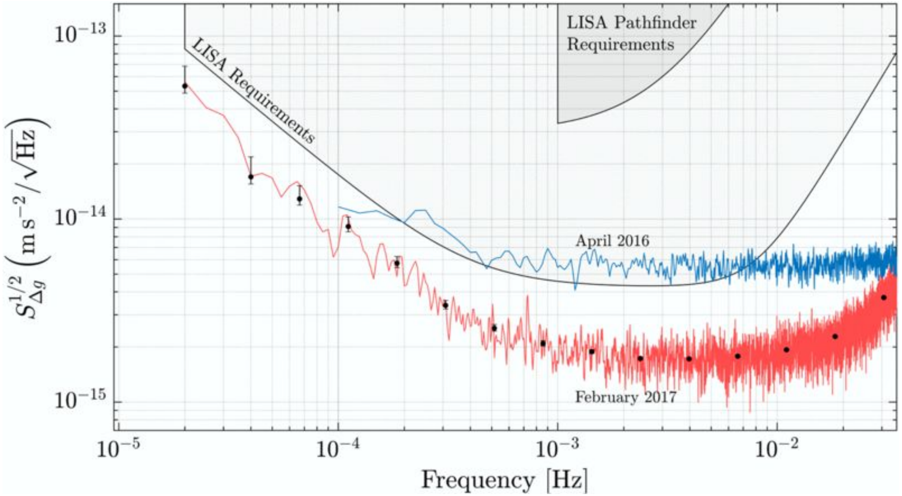
# LISA: status

Part of the technology demonstrated with the LISA Pathfinder mission in 2016.

LISA approved as one of the main ESA missions (third large-class mission, under the “gravitational universe” theme) in 2017.

Formal adoption expected in the next few years.

Nominal launch in 2034.



# Paris-Saclay activities involving LISA

### CEA/IRFU

Methods for analysis of realistic data with artifacts and interruptions.

Galactic binaries.

Baghi et al 2021 (arXiv:2110.06024)
Blelly et al 2021 (arXiv:2104.05250)
Blelly et al 2020 (arXiv:2005.03696)

### IJCLab

Methods for parameter estimation of compact binary mergers.

Methods for multimessenger observations of massive black hole mergers.

Toubiana et al 2020 (arXiv:2007.08544)
Dal Canton et al 2019 (arXiv:1902.01538)

# Conclusion

Interesting discoveries definitely expected in the next ~10 years with the existing LIGO-Virgo-KAGRA network.

Dramatic transformation of the field expected with next-generation detectors like ET and LISA.

Many challenges ahead:

- Hardware development and infrastructure
- Theory (accurate models of astrophysical signals)
- Data analysis methods and computational cost
- Organization of the results

Many of us are interested!