The Einstein Telescope: opportunities and challenges of a next-generation detector

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Talk on behalf of the ET collaboration

ÖPG-CMD Joint Meeting 2026
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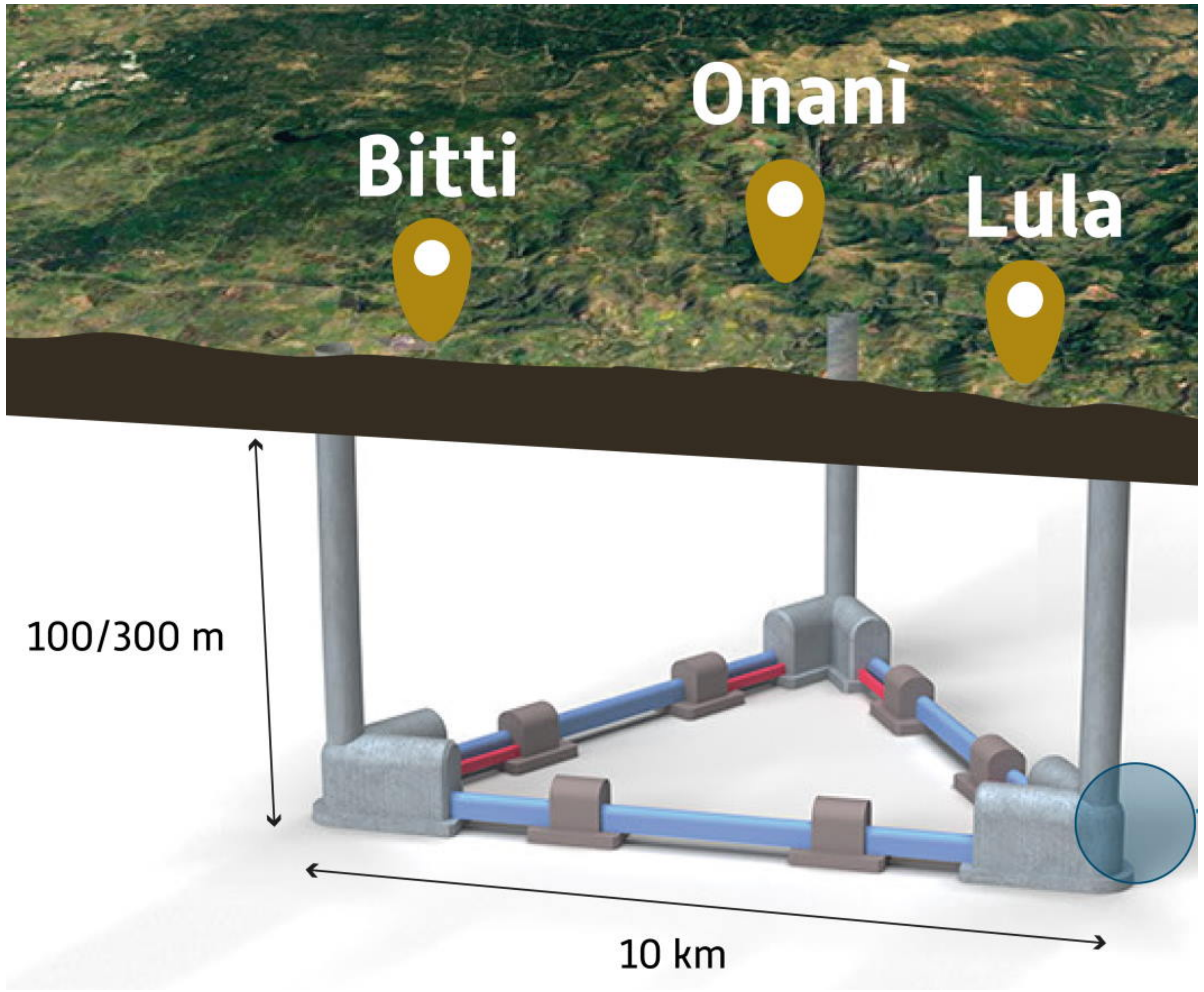
Where we stand

- Operations by 2040
- Estimated budget ~2 billion euros
- Geometry and site selection expected by 2027
- Three candidate sites and two geometries

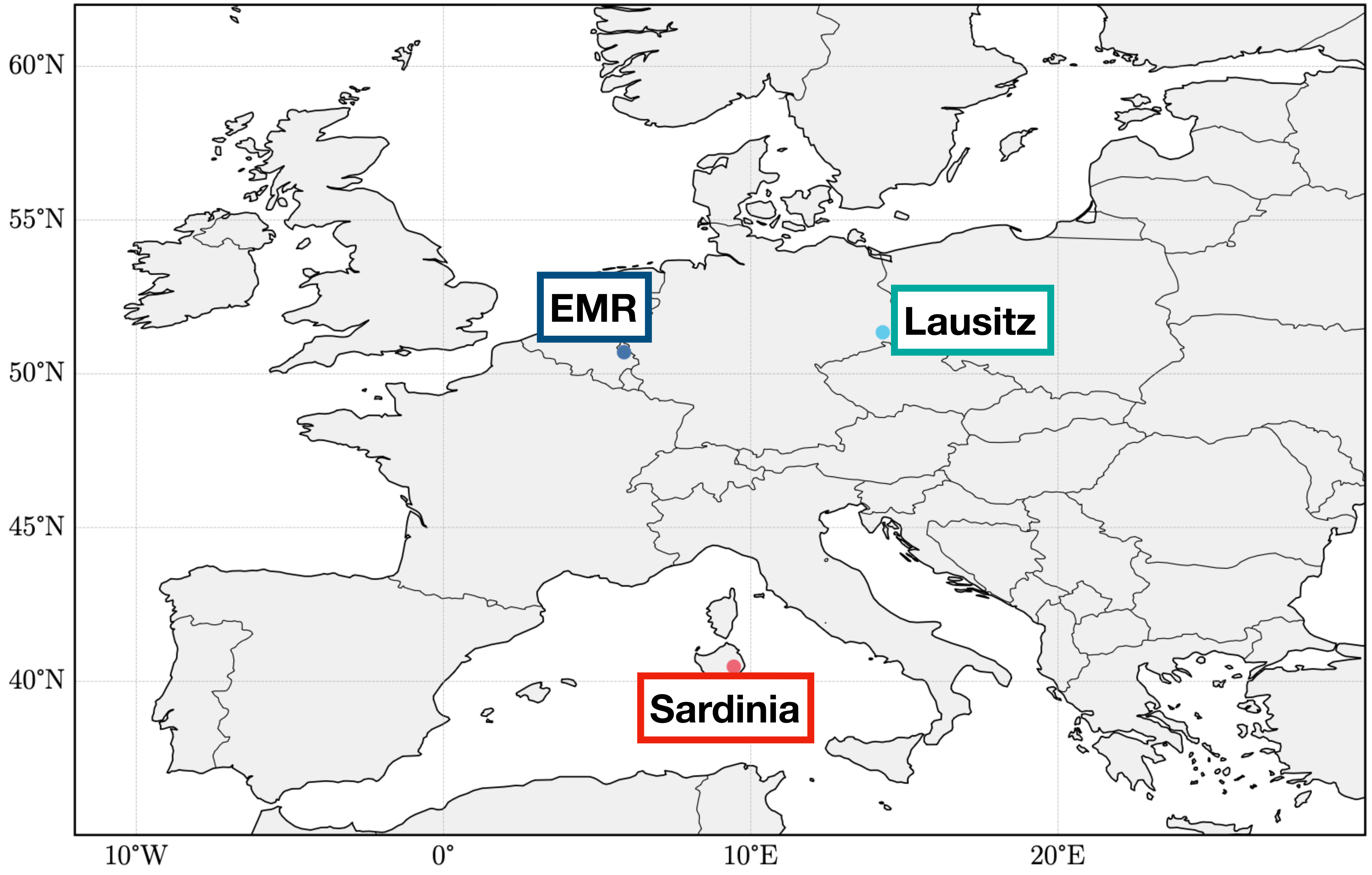


Credits and adapted from INFN

Candidate sites

- Italy and the Netherlands-Belgium have pledged to cover nearly half of the cost if their proposed site is selected

- Sardinia and Saxony have signed a declaration of intent to strengthen scientific collaboration for the 2L design

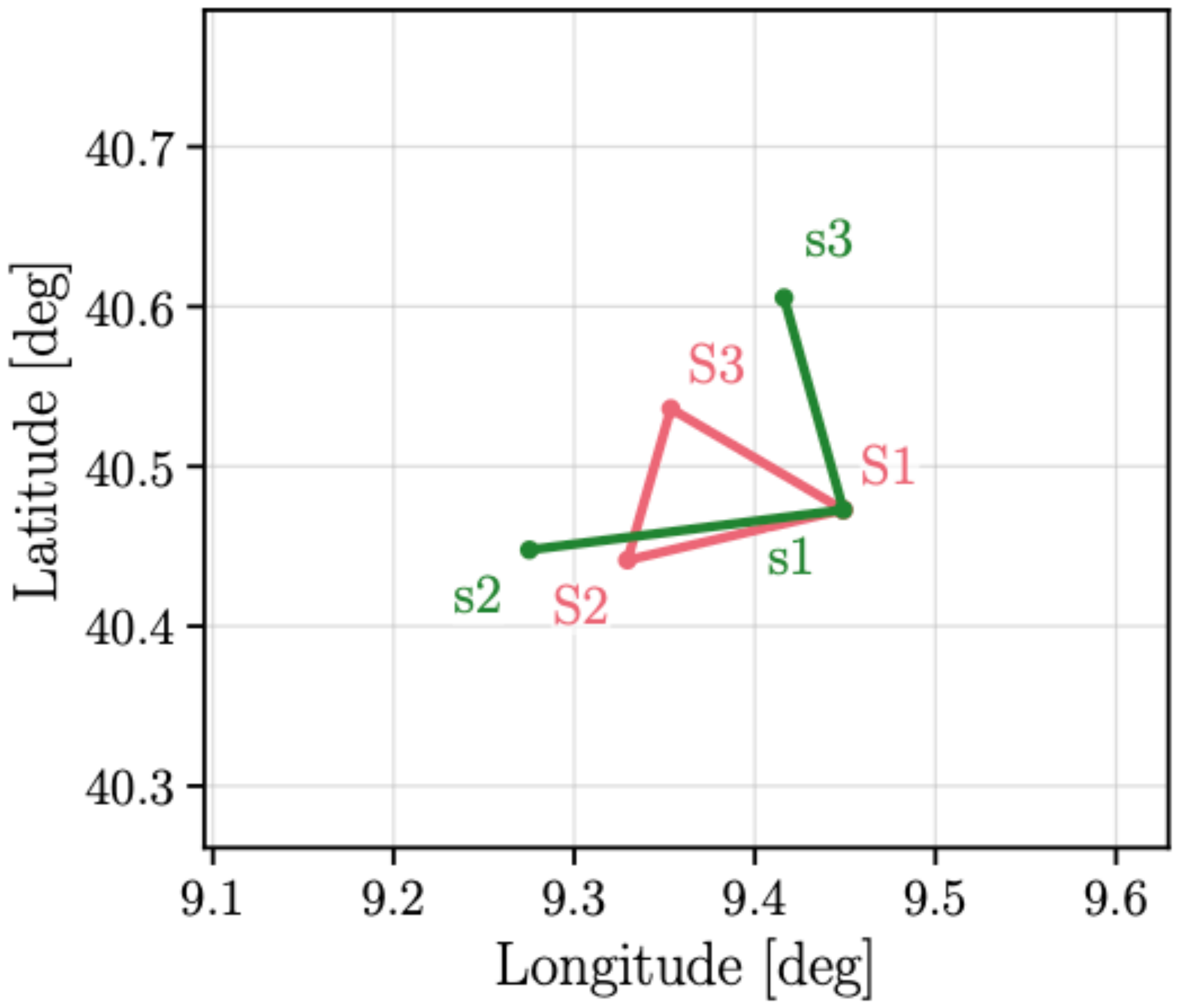


Credits: **Crescimbeni et al. 2026**

Geometries

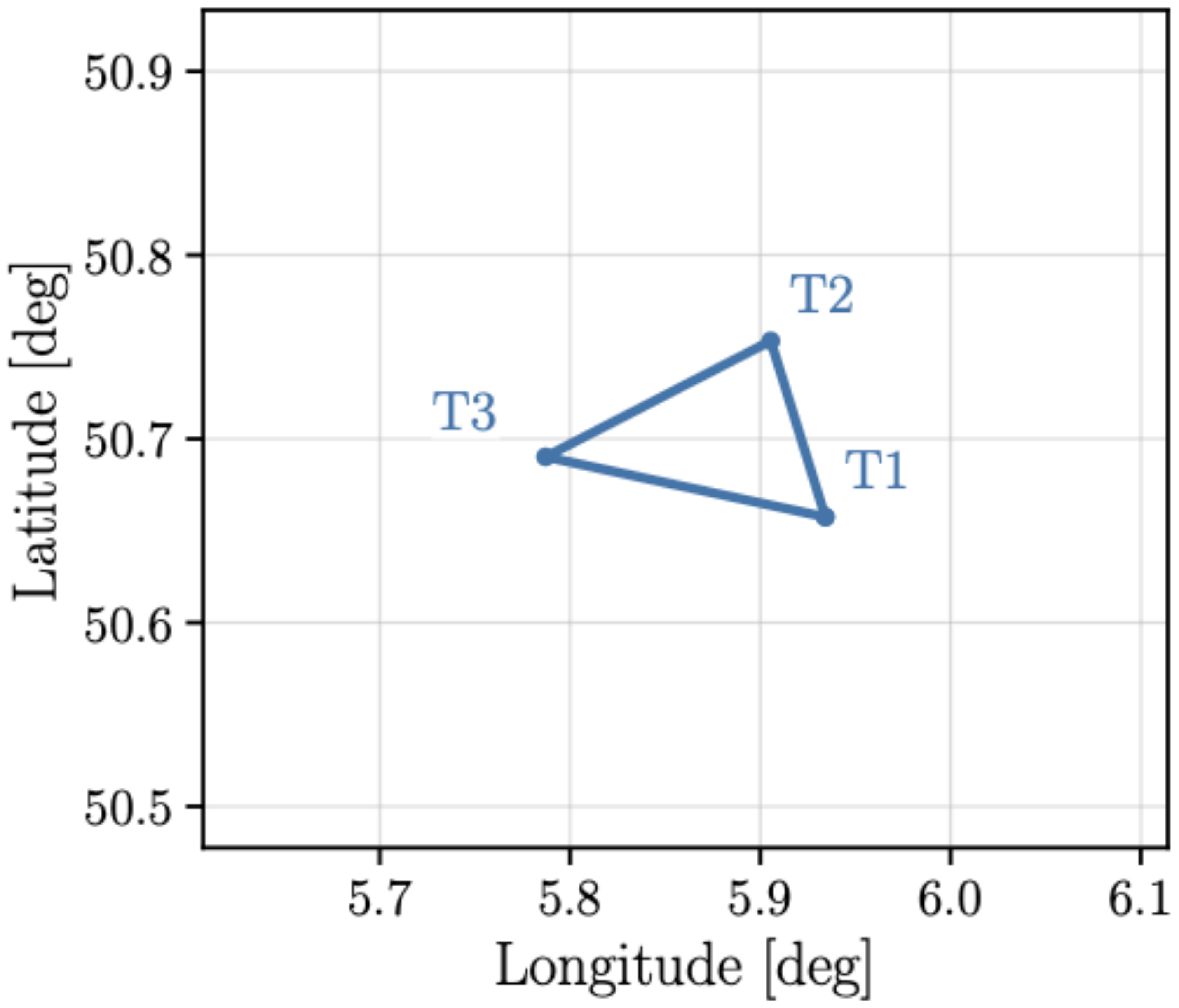
Triangular (10-km arms) vs. 2L misaligned (15-km arms)

Sardinia



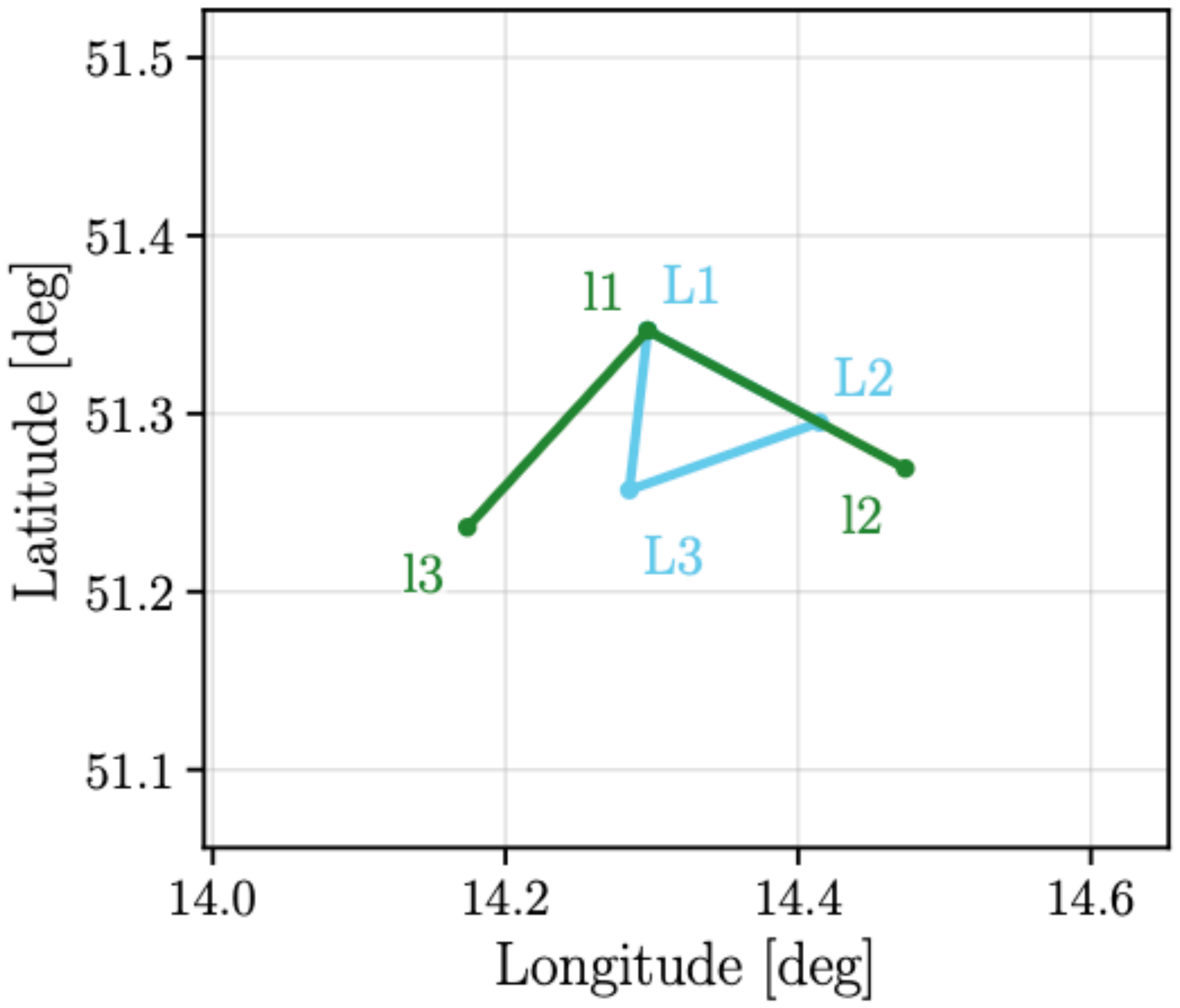
https://www.einstein-telescope.it/

EMR



https://www.einsteintelescope-emr.eu/en/

Lausitz



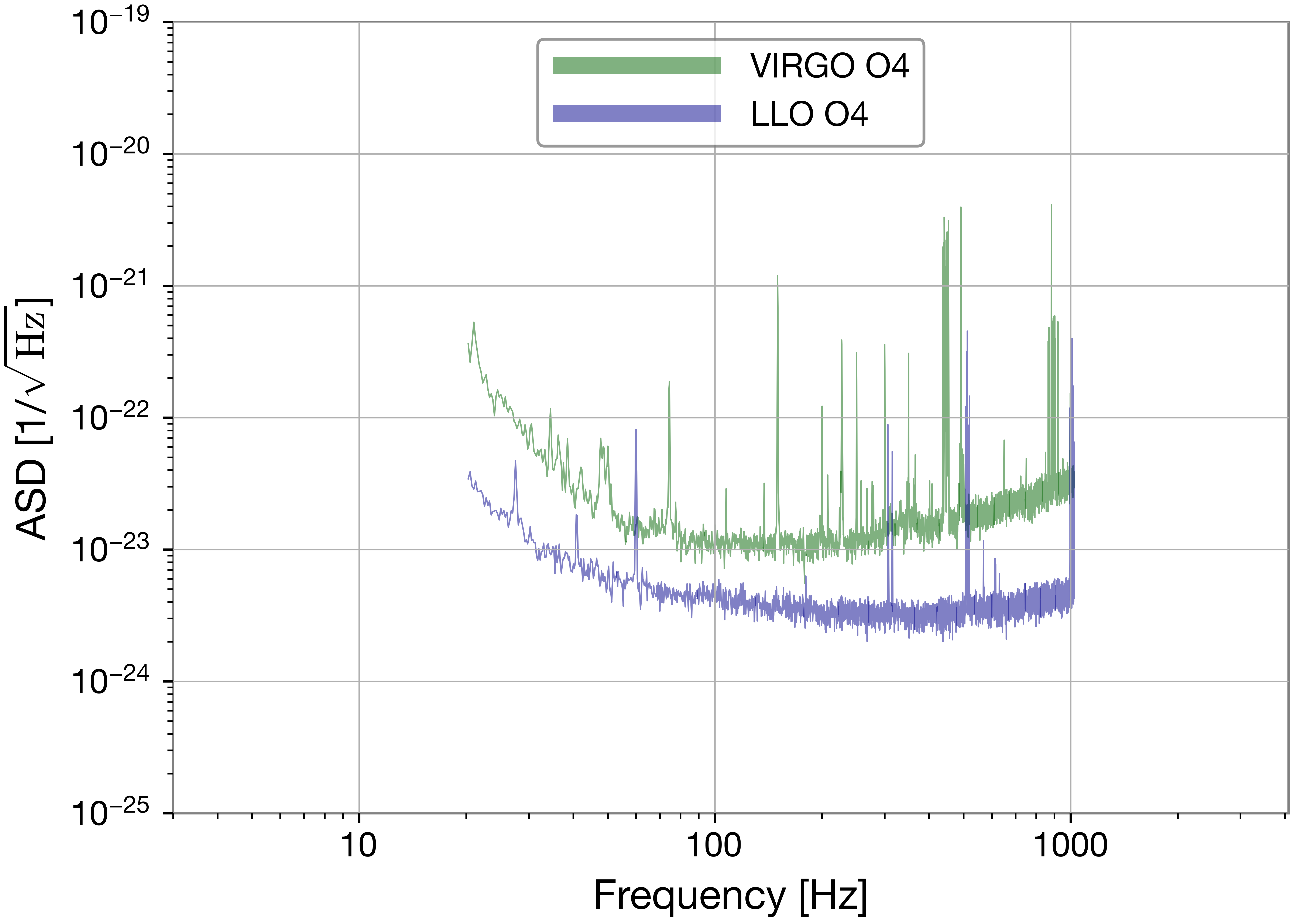
https://einsteintelescope-lausitz.de/

Credits: **Crescimbeni et al. 2026**

Opportunities

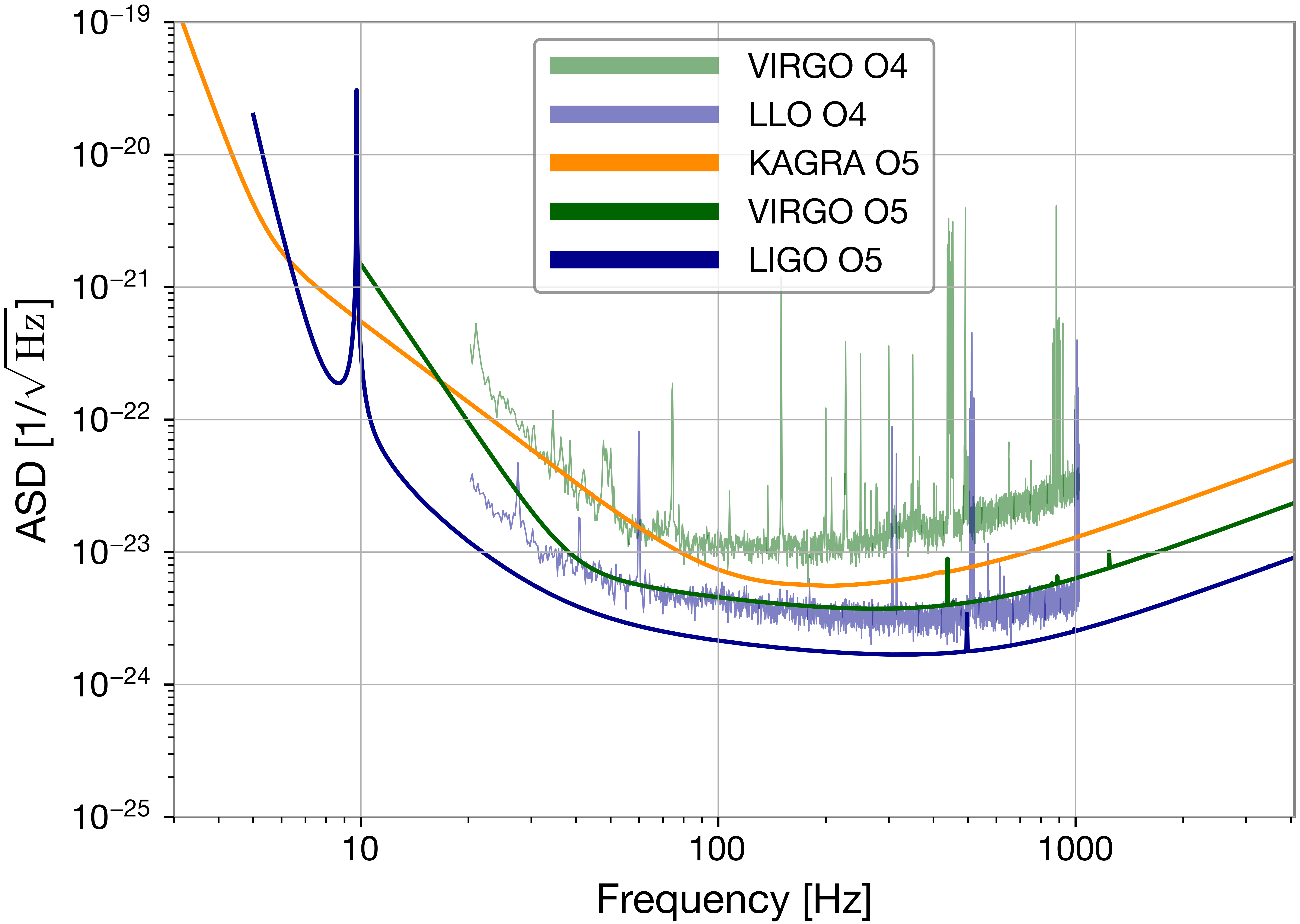
Science goals

Sensitivity



Ref: ET **Dupletsa et al. 2026**, LVK **2200043-v3**

Sensitivity



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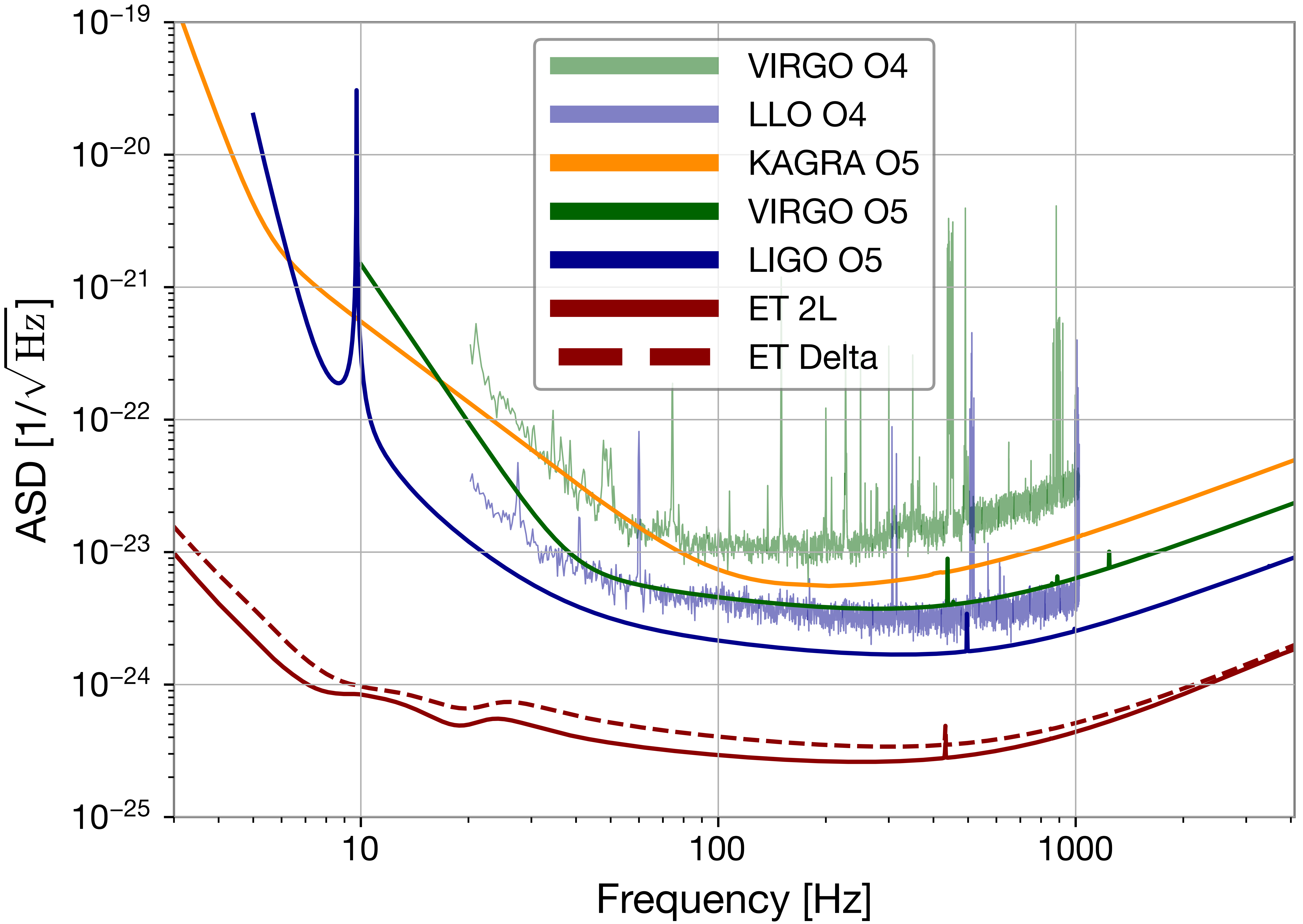

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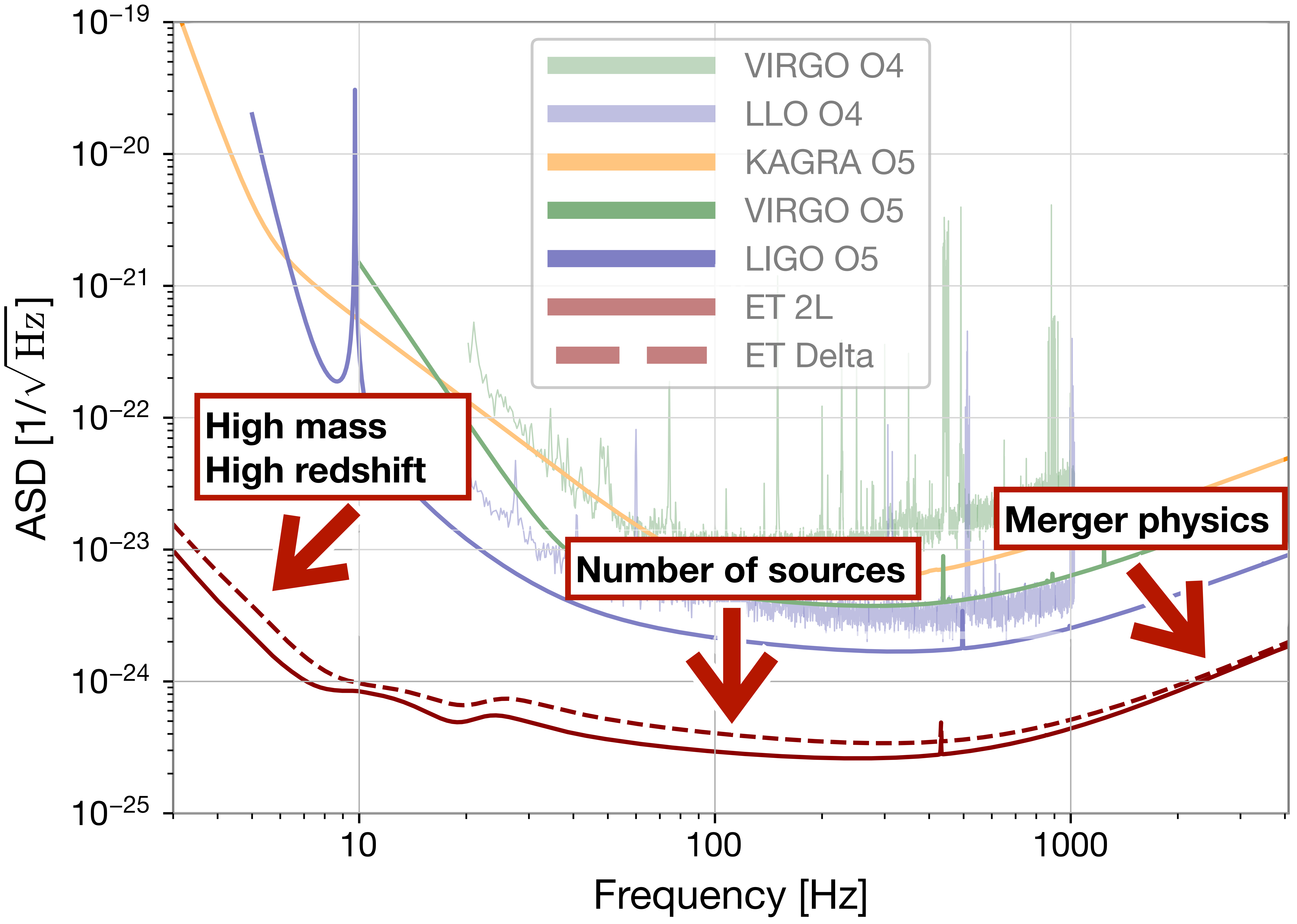
Sensitivity



ET science case in one book

- First collaboration paper
- Coordinated by the Observational Science Board
- > 300 contributors, > 800 pages
- All the science objectives of the Einstein Telescope in detail

Journal of Cosmology and Astroparticle Physics
An IOP and SISSA journal

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The Science of the Einstein Telescope

The Einstein Telescope collaboration

Full author list at the end of the paper

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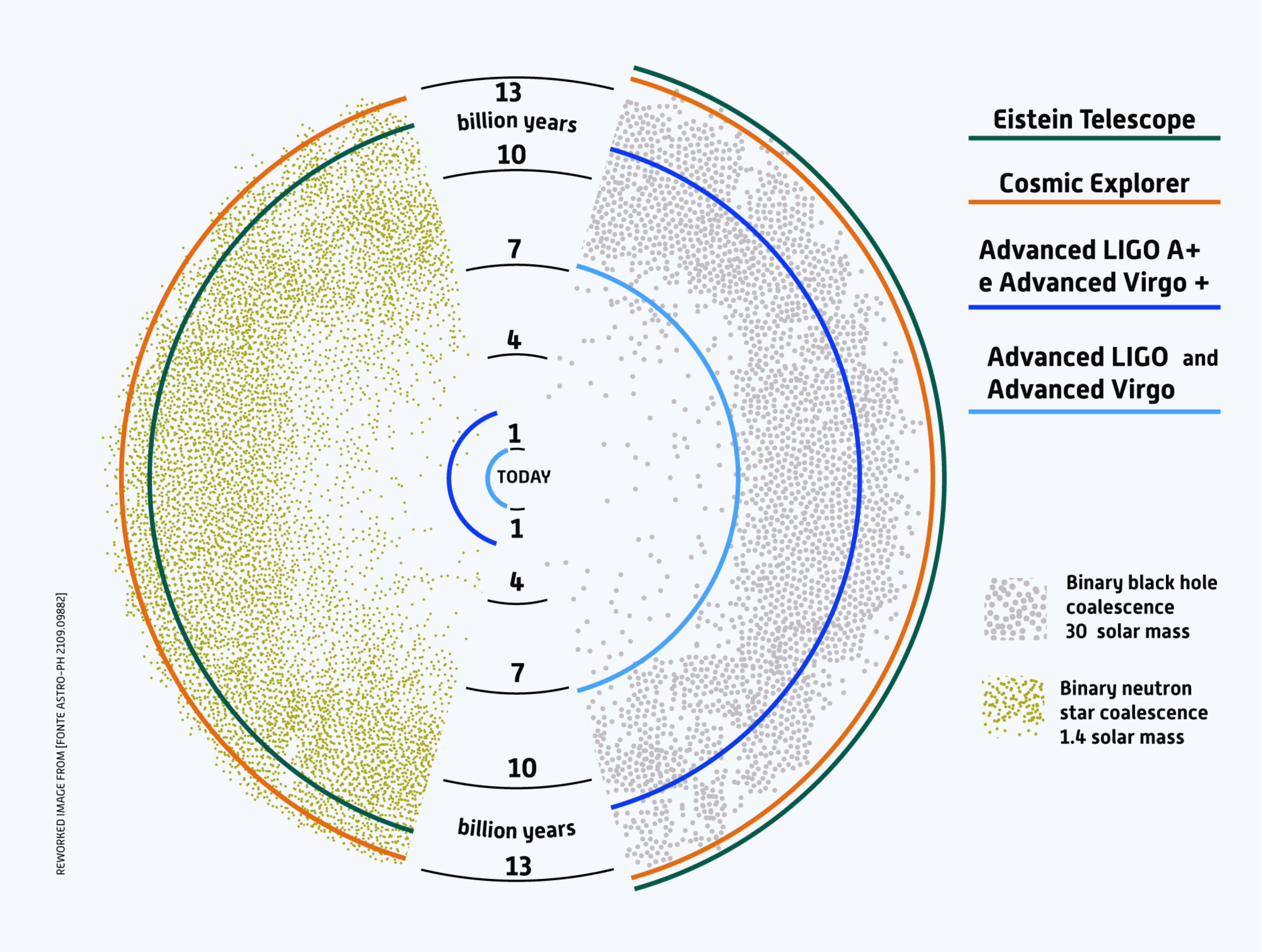
Ref: [Abac et al. 2026]

ET science case

- Combination of:
  - Larger distances
    ➡️ explore the early Universe
  - Increased number of detections
    ➡️ advanced population studies
  - Detections with very high-SNR
    ➡️ precise GW astronomy



ET science case

Astrophysics:

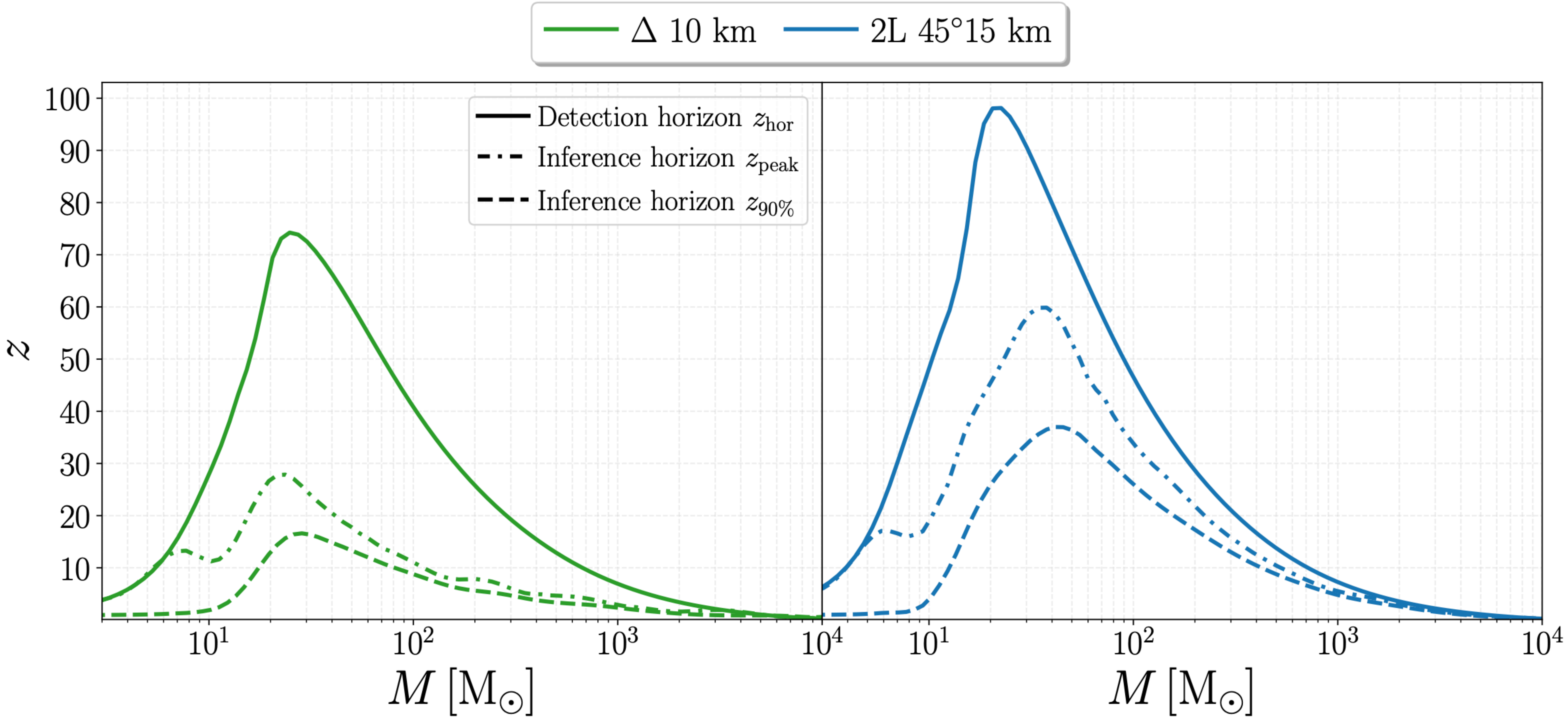
- **Black hole properties**
  - Origin (stellar vs. primordial)
  - Formation and demography
- **Neutron star properties**
  - Interior structure (QCD at ultra-high densities, exotic states of matter)
  - Demography
- **Multimessenger astronomy**
  - Joint GW/EM observations (GRBs, kilonovae)
  - Multiband GW astronomy (LISA)
  - Neutrinos
- **New GW sources:**
  - CC supernovae
  - Isolated neutron stars
  - Stochastic background of astrophysical origin

Fundamental physics and cosmology:

- **Nature of compact objects**
  - Near-horizon physics
  - Test of no-hair theorem
  - Exotic compact objects
- **Test of General Relativity**
  - post-Newtonian expansion
  - Strong-field regime
- **Dark matter**
  - Primordial BHs
  - Axion clouds, dark matter accreting on compact objects
- **Dark energy and modified gravity:**
  - Equation of state
  - Modified GW propagation
- **Stochastic background of cosmological origin**
  - Inflation, cosmic strings

Ref: Abac et al. 2026

Horizon distance



- The first generation of black holes in the early Universe

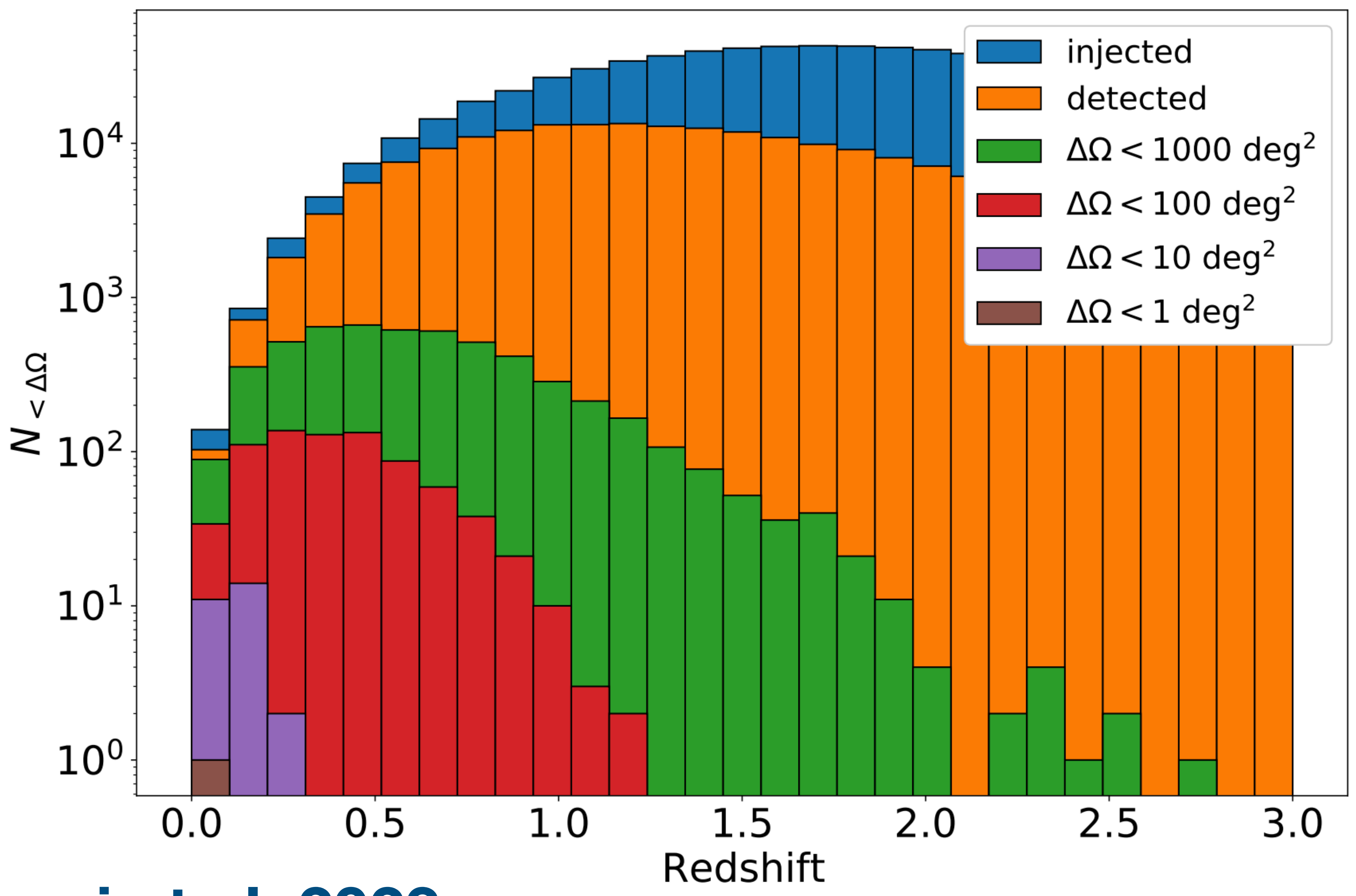
- Intermediate-mass black holes (IMBHs) with masses between 100-10^4 solar masses ➡️ progenitors of supermassive black holes

Credits: **Abac et al. 2026**

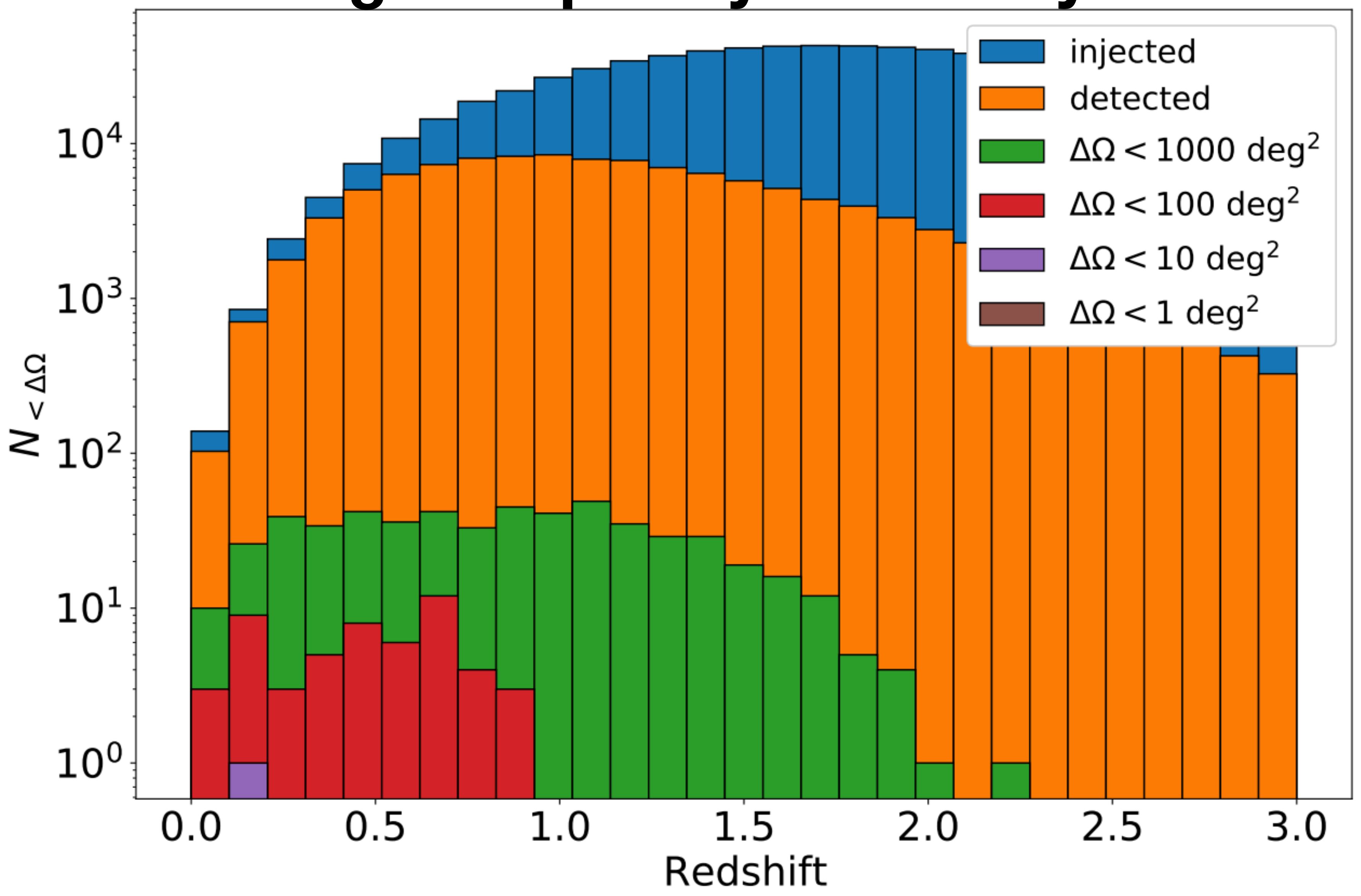
Sky localization

- $>$ 100 sources per year with sky localization error $<$ 100 deg^2
- Sky localization and pre-merger alerts ➡️ sensitivity at low frequency is paramount

Enhanced low-frequency sensitivity



High-frequency sensitivity



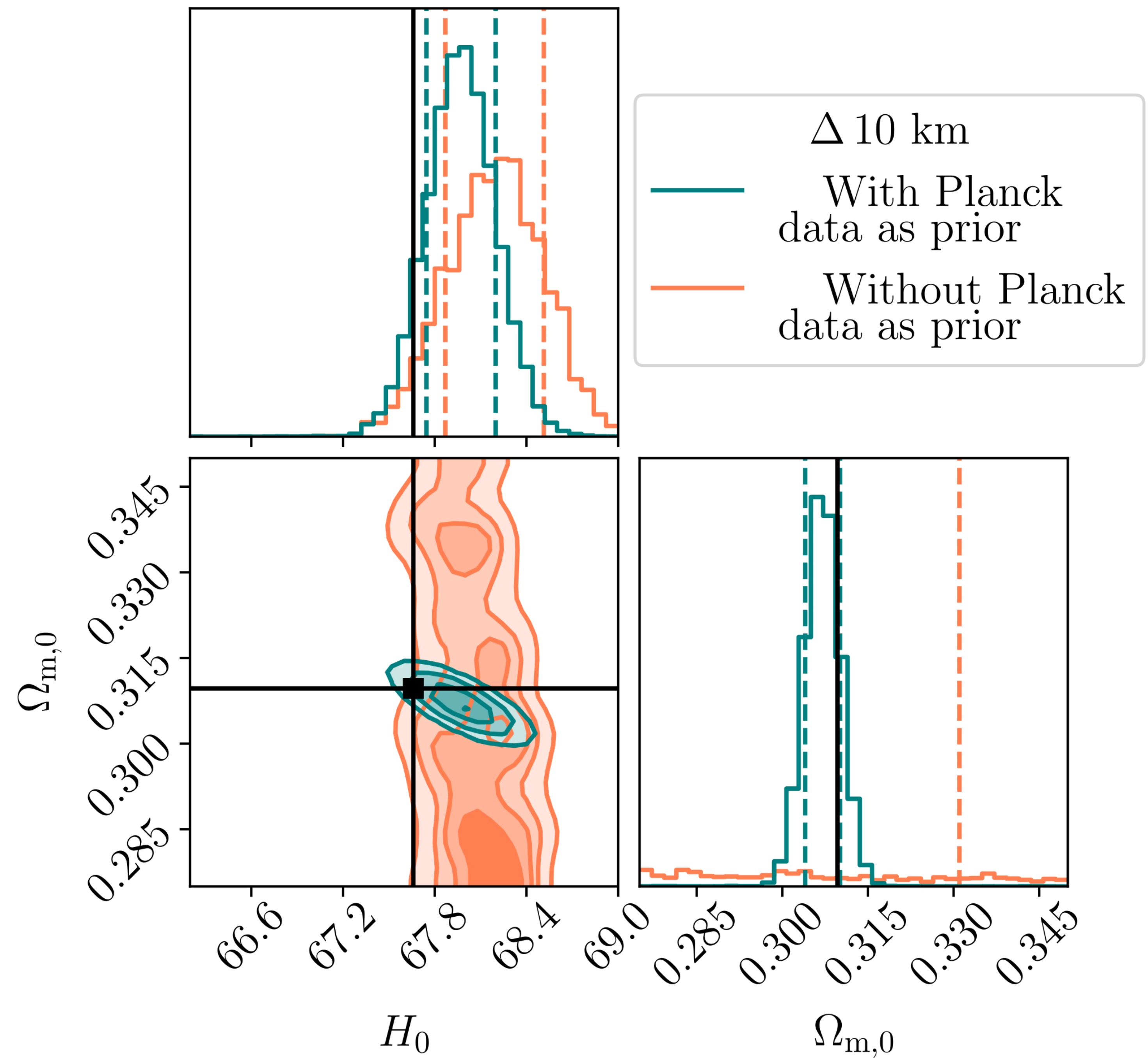
Credits: **Branchesi et al. 2023**

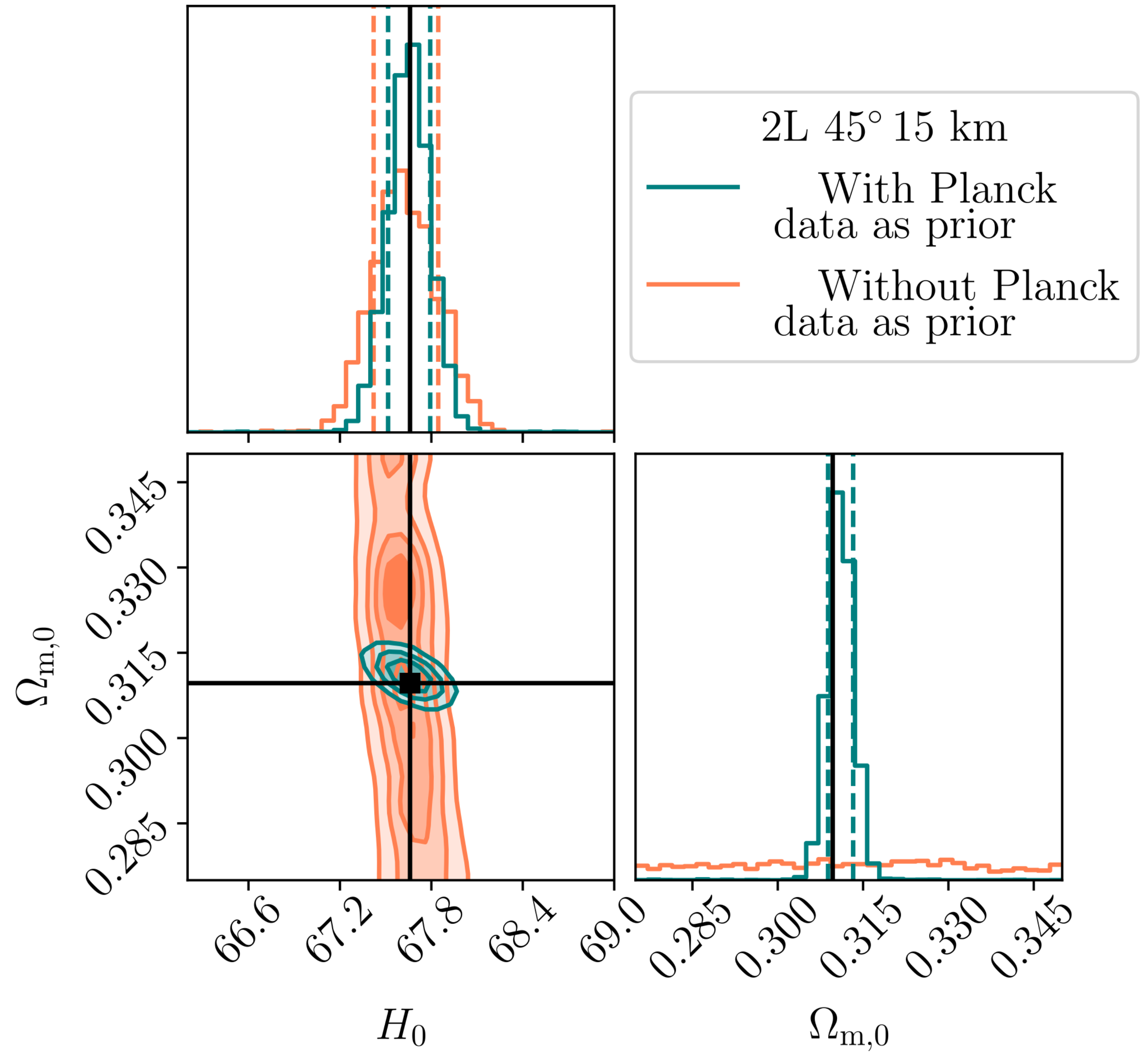
Cosmology

- Independent measurement of cosmological parameters

- $$D_L(z) = (1+z)\frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_{m,0}(1+z')^3 + (1-\Omega_{m,0})}}$$

- In the example: $H_0, \Omega_{m,0}$ from GW + Kilonova events in one year with Vera Rubin Observatory





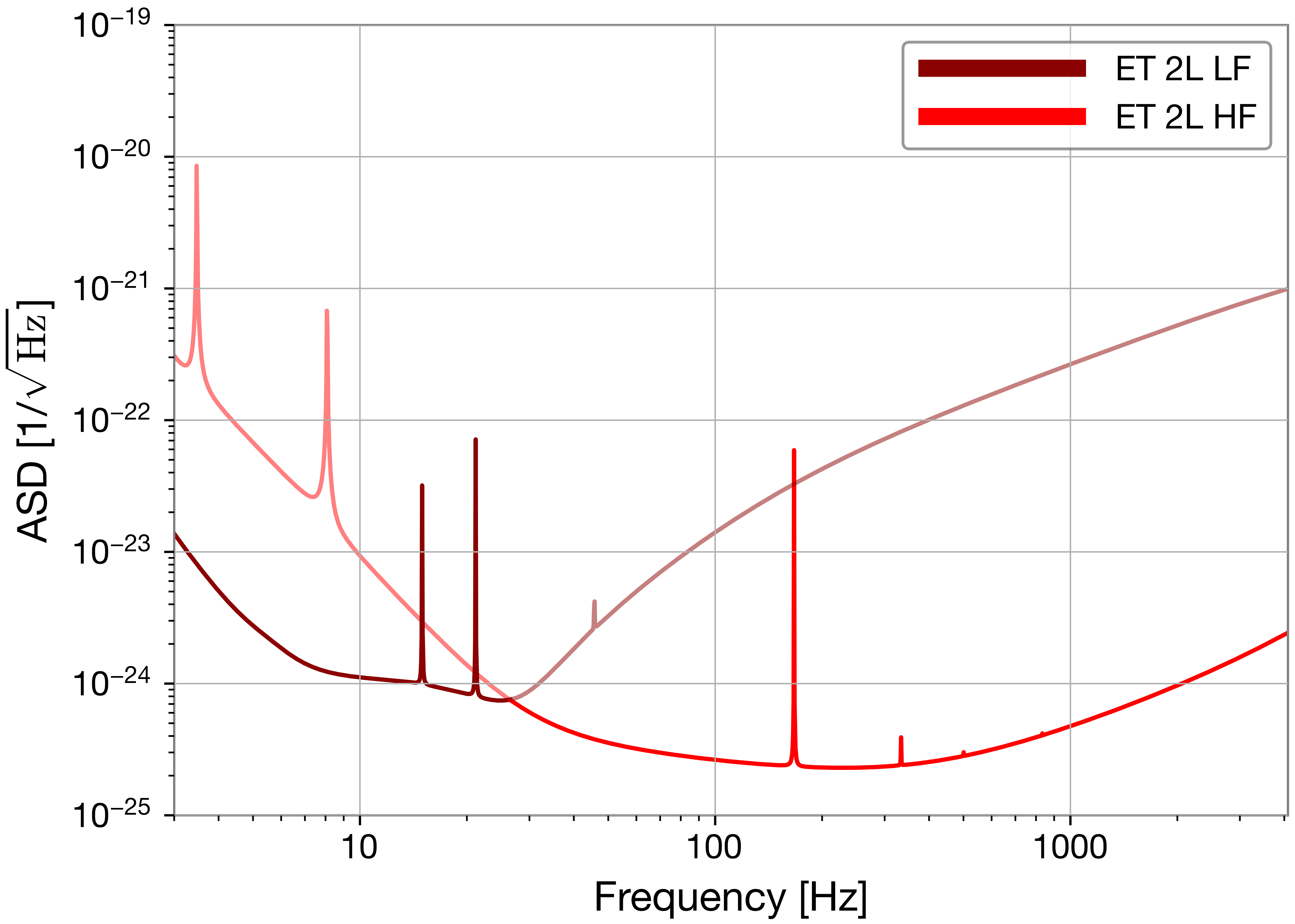
Credits: **Abac et al. 2026**

Challenges

Technological development

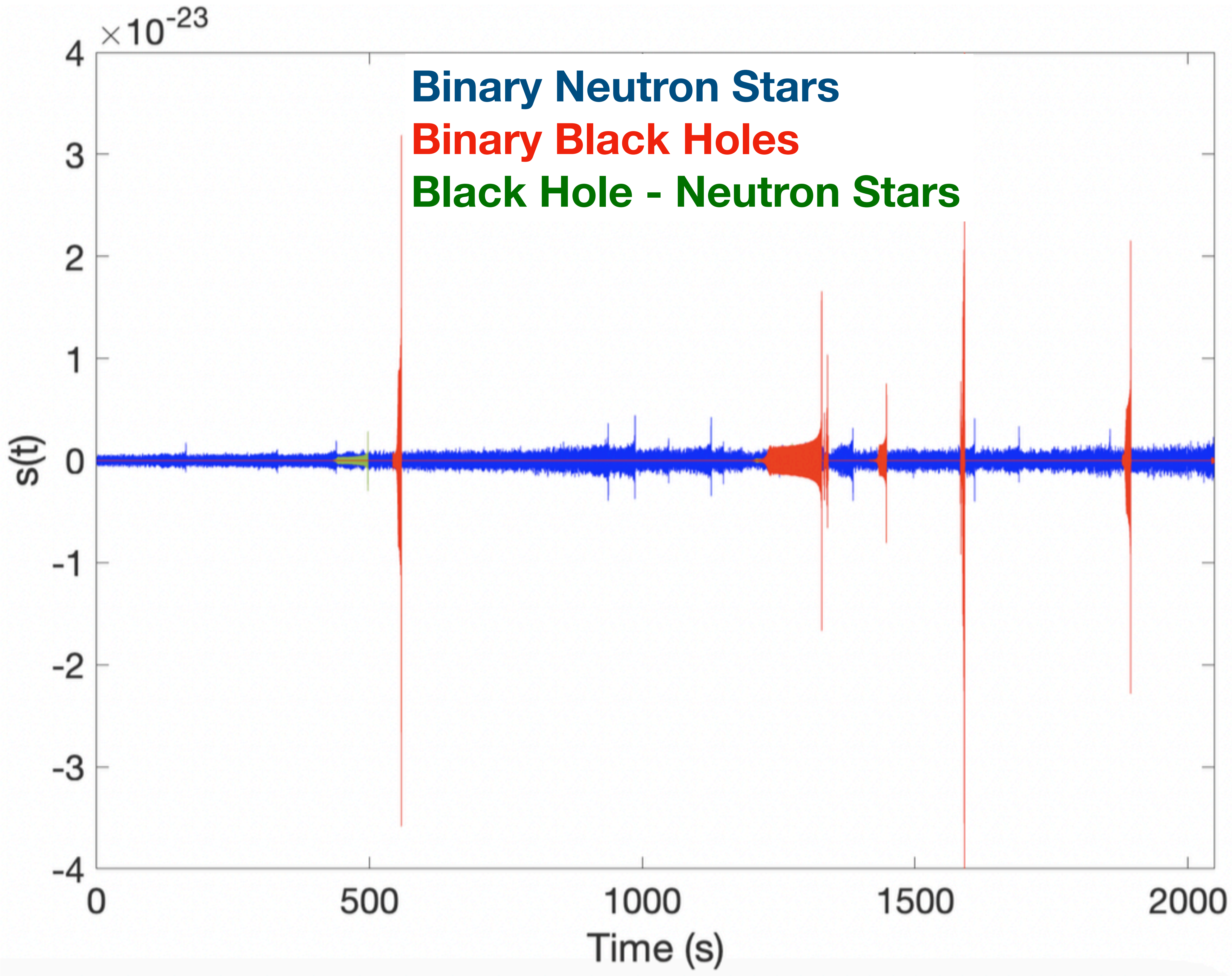
Low frequency sensitivity

- The great potential of ET lies in its ability to access the 3-30 Hz regime
- Many sources of noise: seismic, thermal, Newtonian, electromagnetic
- Underground + cryogenics (10-20 K)
- **Xylophone configuration**: one instrument tuned to low frequency (LF) and one for high frequency (HF)



Ref: **ET-0304B-22**

Data analysis challenge

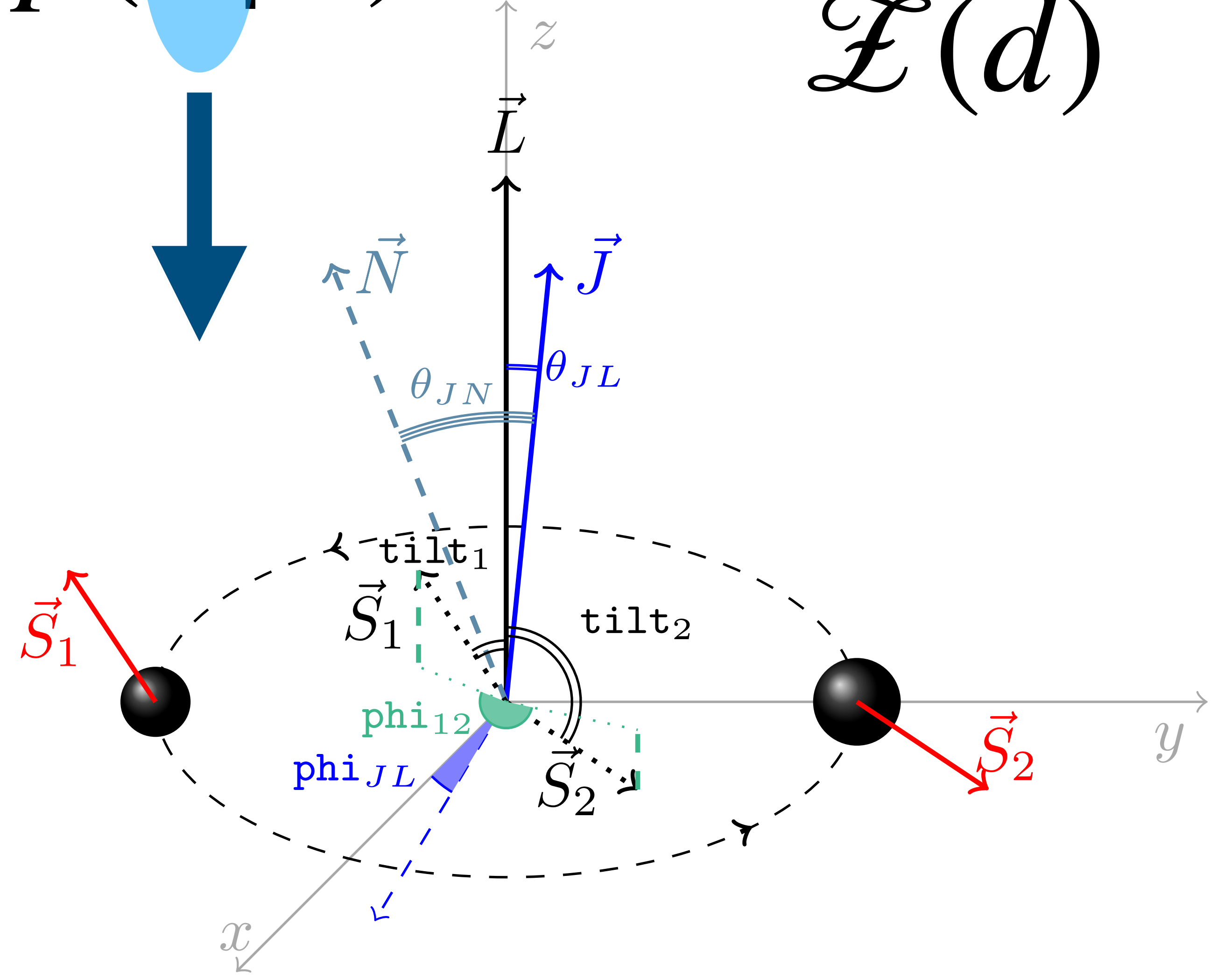


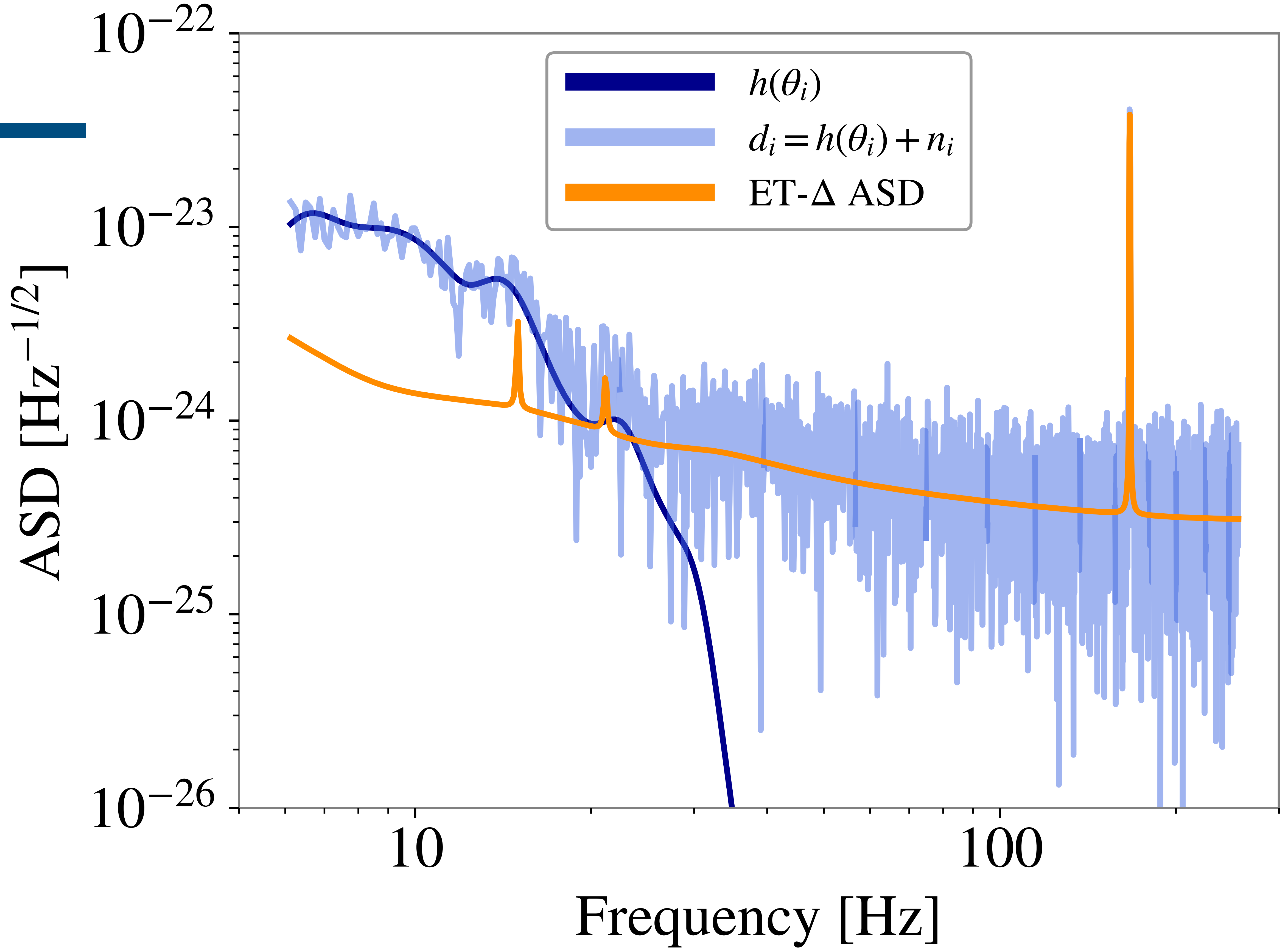
- 10^5 signals per year
- Long signals
- Non-stationary noise
- Overlapping signals

Credits: [ET Mock Data Challenge]

Bayesian inference

$$p(\theta \mid d) = \frac{\mathcal{L}(d \mid \theta)\pi(\theta)}{\mathcal{Z}(d)}$$





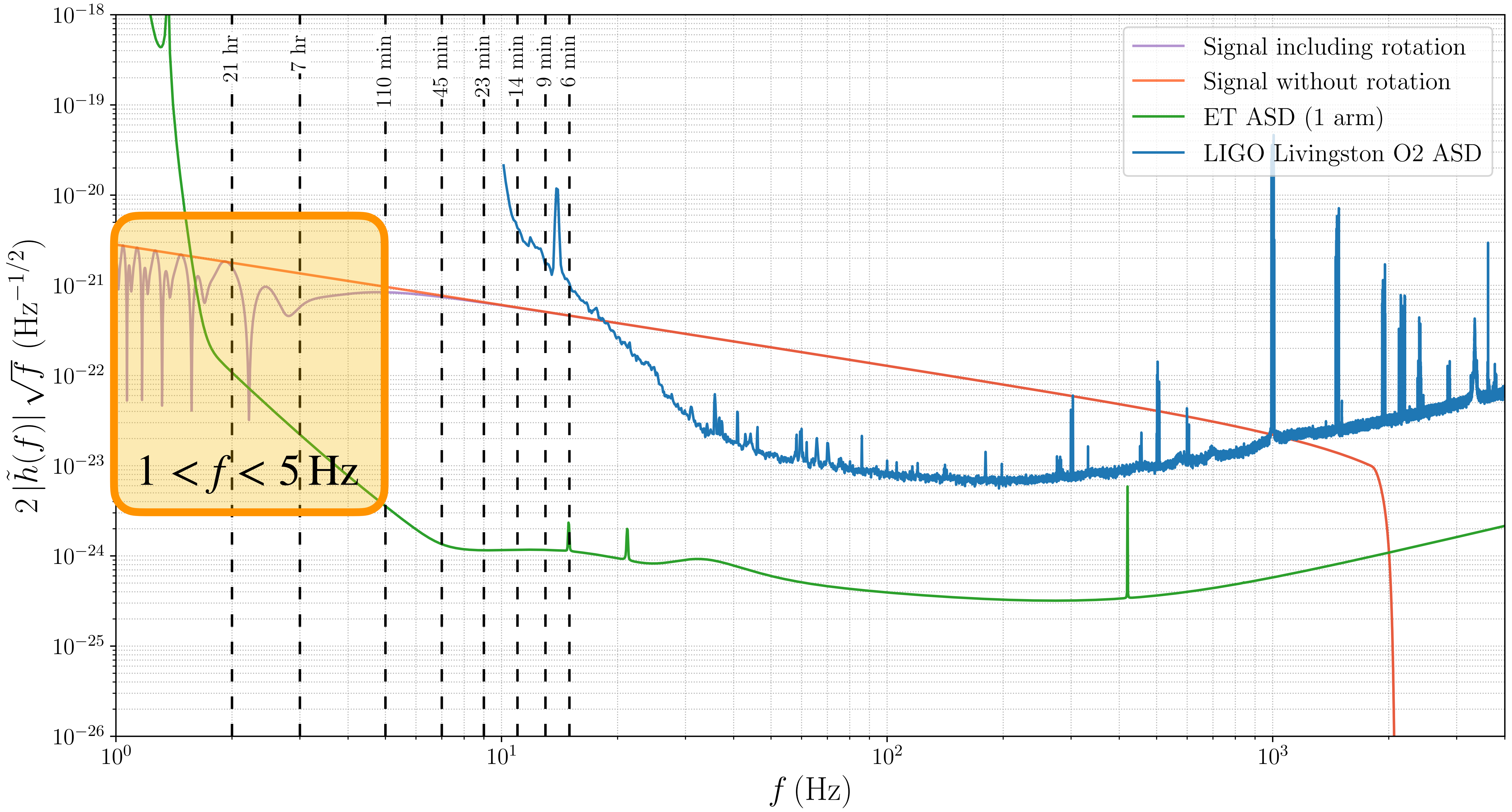
$$\theta = \{\mathcal{M}_{\rm d},\, q,\, d_{\rm L},\, \mathrm{ra},\, \mathrm{dec},\, \theta_{\rm JN},\, \psi,\, \phi,\, t_{\rm geocent},\, \chi_1,\, \chi_2\}$$

Credits: **Dupletsa et al. 2025**

Credits: **Santoliquido et al. 2025**

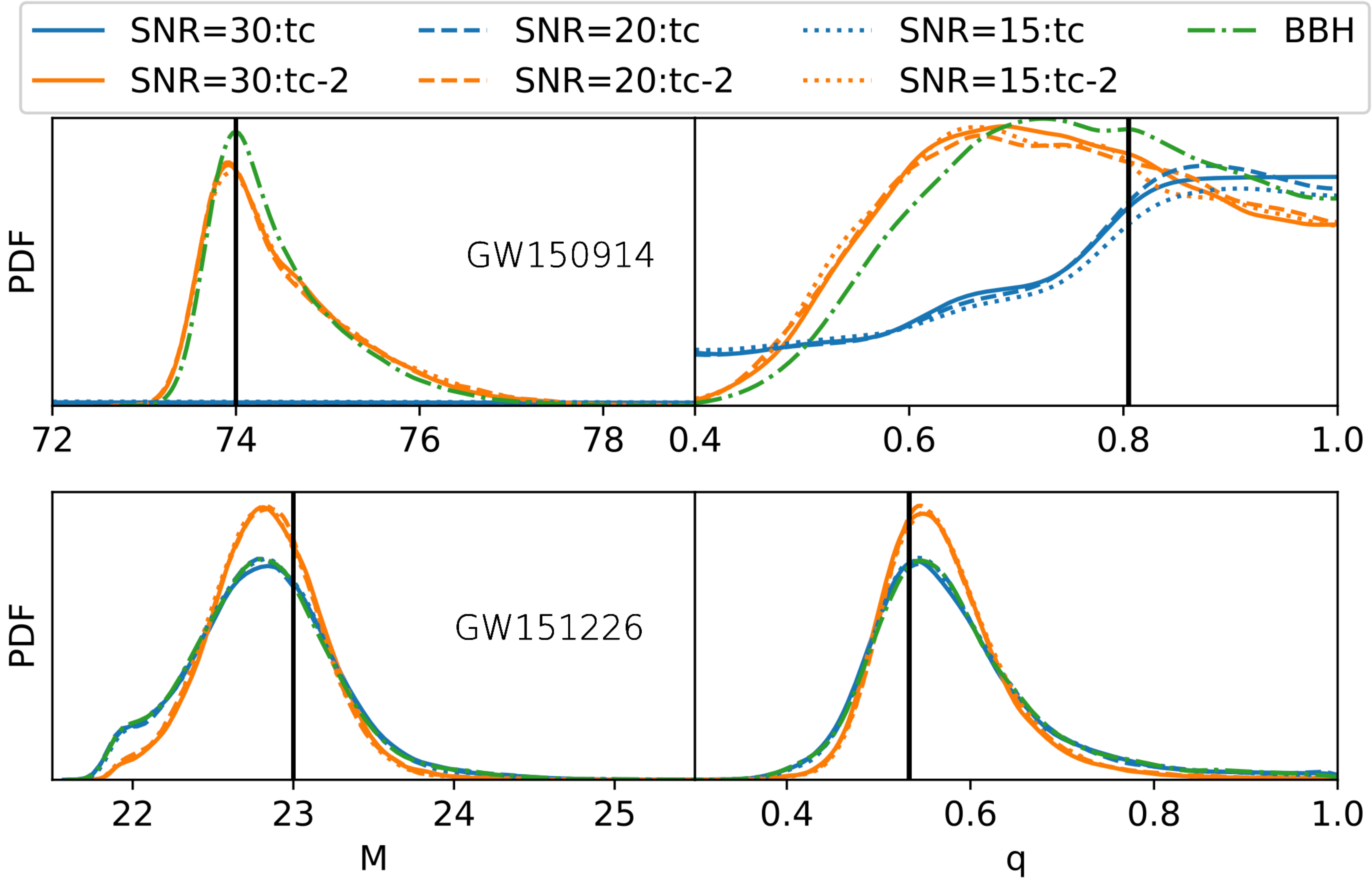
Long signals

- GW170817-like signal lasts ~ 7 hours starting from $f_{\min} = 3$ Hz. Challenges:
  - Linear increase with signal duration in the evaluation cost of the likelihood
  - Measured signal is modulated in amplitude and phase due to Earth's rotation
  - Detector noise could change over time and signals could overlap



Credits: **Iacovelli et al. 2022**

Overlapping signals



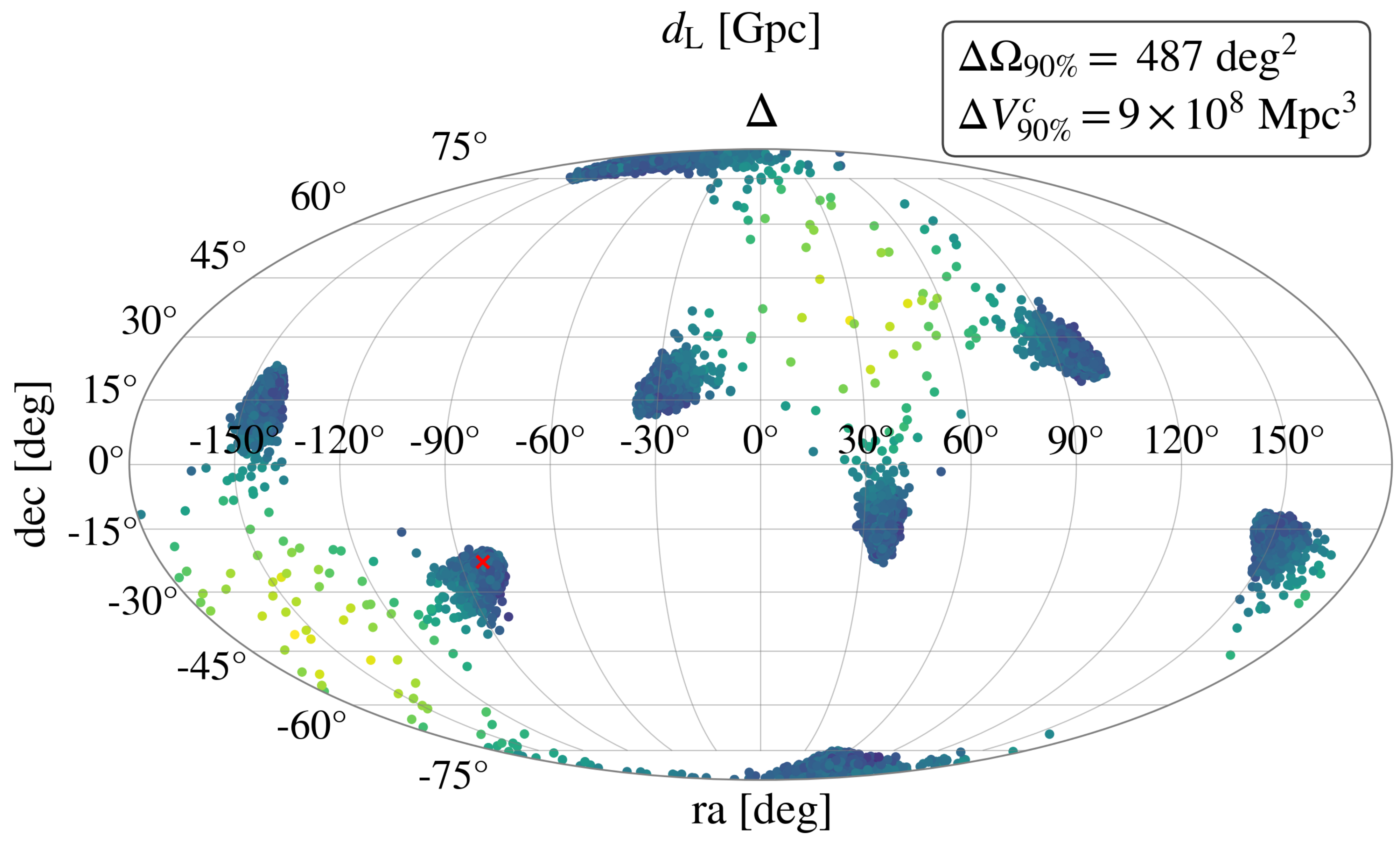
In the example: BBH signal overlapped with a BNS signal at **different SNRs** (line styles) and at **different coalescing times** (colors). Green-dotted lines are posterior of single BBH

- Traditional single-signal models may introduce biases, particularly for closely timed or comparable signal amplitudes.
- New methods to separate and analyze overlapping signals simultaneously are crucial.

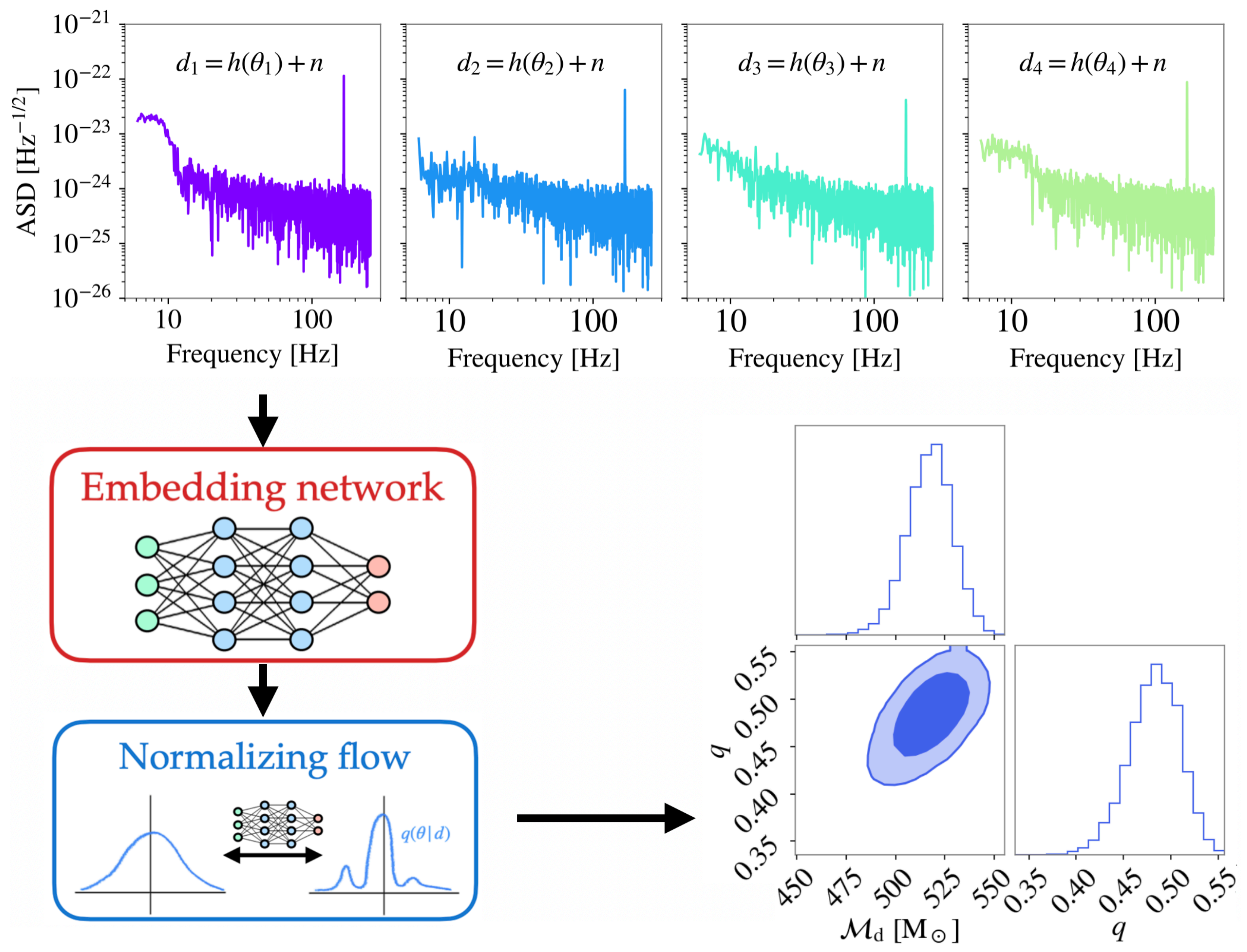
Credits: [Samajdar et al. 2021]

Scaling inference

Large and disconnected parameter space requires **long computational times with standard methods**



Necessary to develop new methods based on deep learning (simulation based inference)



Credits: [Santoliquido et al. 2026]

Mock data challenges

The Data Analysis division stimulates, guides and validates the methods that will handle ET data

Why

- Benchmark algorithms, evaluate computational cost
- Predict ET performance in realistic scenarios

How

- `gwmock`: Python package for generating simulated datasets
- Complexity of the data increases with each challenge

"The Einstein Telescope will open new frontiers in GW astronomy, but it demands a paradigm shift in data analysis methodologies"

The Science of the Einstein Telescope, **Abac et al. 2026**

Conclusions

- Unprecedented scientific reach ➡️ Europe’s science flagship of the next decades
- Precision GW astronomy, multimessenger astronomy, high-redshift sources ➡️ potential for new discoveries
- Einstein Telescope is one of the greatest challenges ever, both in infrastructure and in data analysis