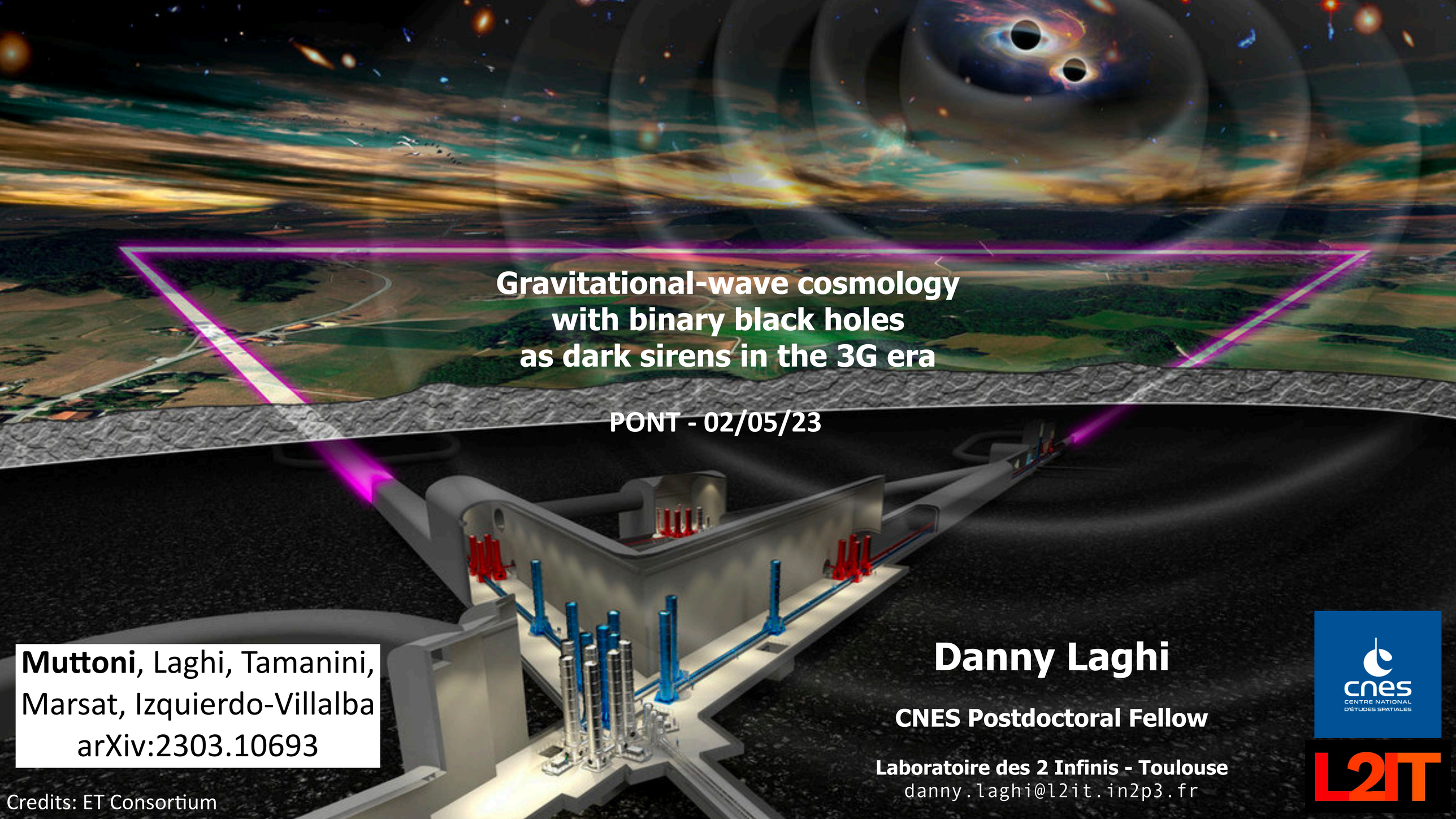
Gravitational-wave cosmology with binary black holes as dark sirens in the 3G era

PONT - 02/05/23



Muttoni, Laghi, Tamanini, Marsat, Izquierdo-Villalba
arXiv:2303.10693

Credits: ET Consortium

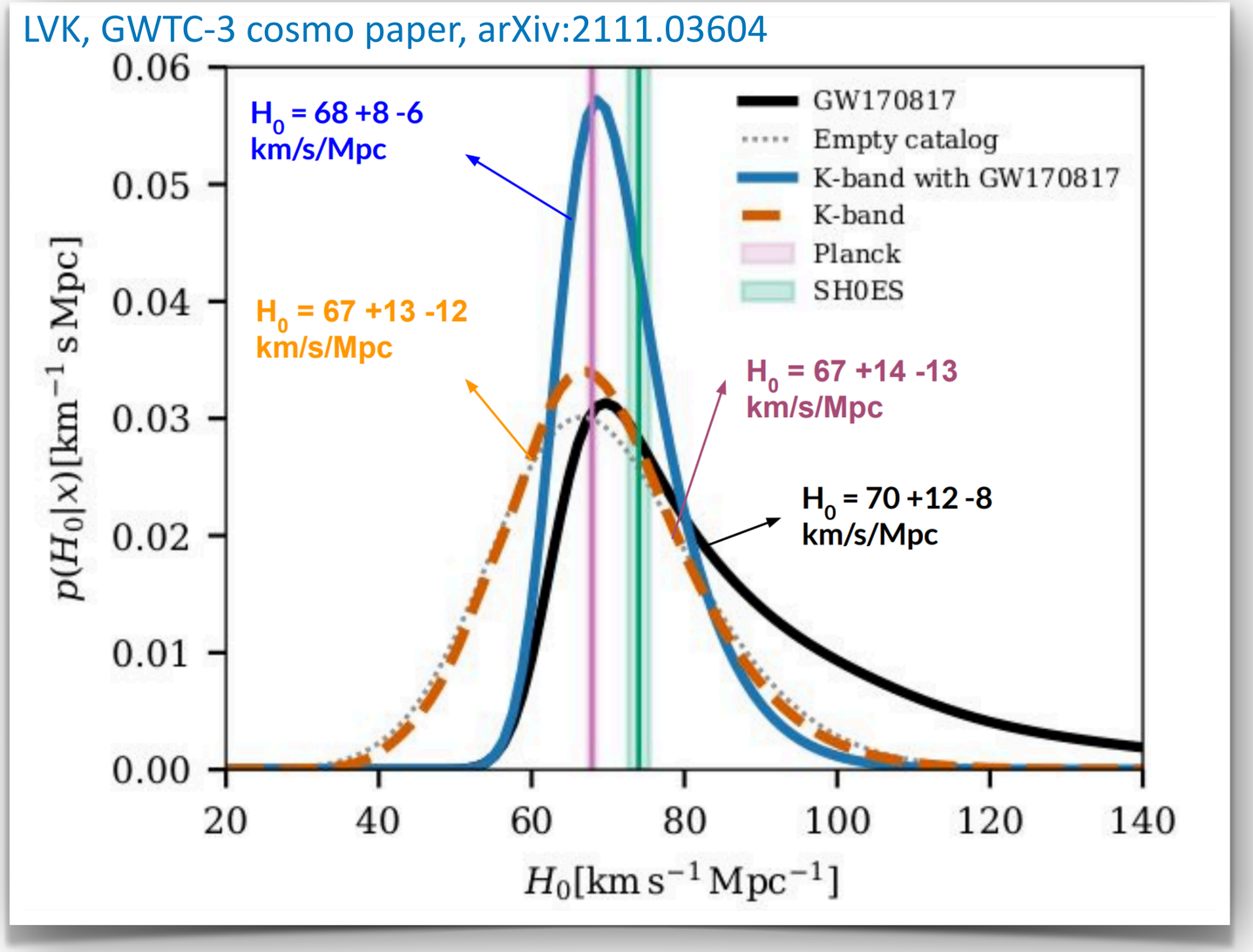
Danny Laghi

CNES Postdoctoral Fellow

Laboratoire des 2 Infinis - Toulouse
danny.laghi@l2it.in2p3.fr

LATEST H0 MEASUREMENTS WITH STANDARD SIRENS

LVK, GWTC-3 cosmo paper, arXiv:2111.03604



LIGO-VIRGO detectors

Other recent standard siren studies:

- $H_0 = 72.2^{+13.9}_{-7.5}$ km/s/Mpc
  [Finke et al., JCAP (2021) with GWTC-2 catalog]
- $H_0 = 72.8^{+11.0}_{-7.55}$ km/s/Mpc
  [Palmese et al., ApJ (2023) with GWTC-3 catalog]

HEADING TOWARDS THE 3G ERA

2G GW detectors

LIGO-Virgo-KAGRA (LVK)

$10 - 10^2$ detections per year

$z < 2$

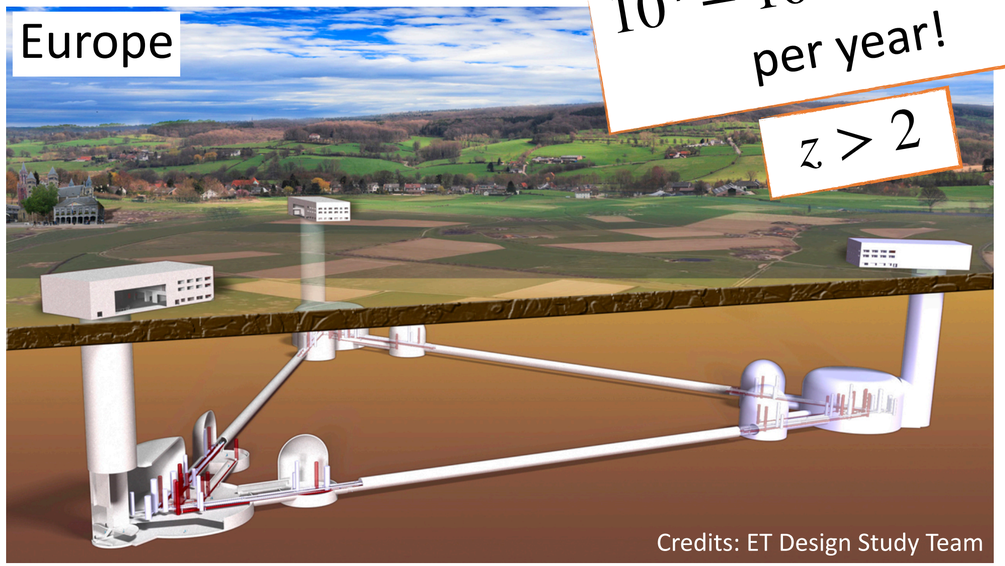
Credits: EGO/VIRGO/LIGO/KAGRA

3G GW detectors

Einstein Telescope (ET)

$10^4 - 10^5$ detections per year!

$z > 2$



Credits: ET Design Study Team

2023 → towards "**Precision GW Astronomy**" → **2030+**

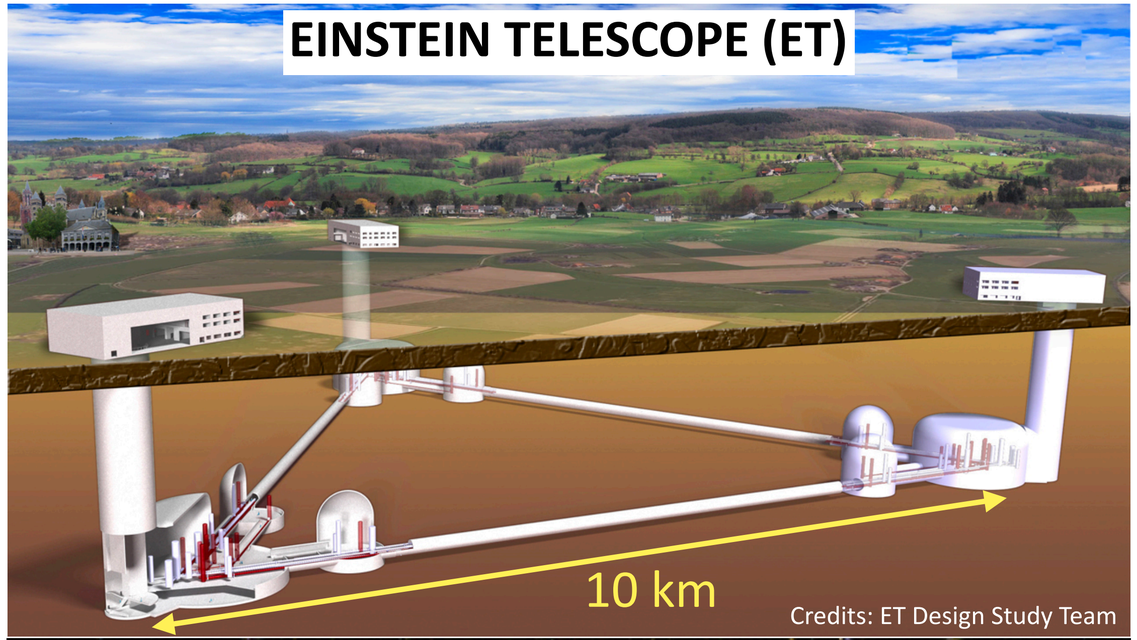
H0 WITH BINARY BLACK HOLES: OUR 3G STUDY

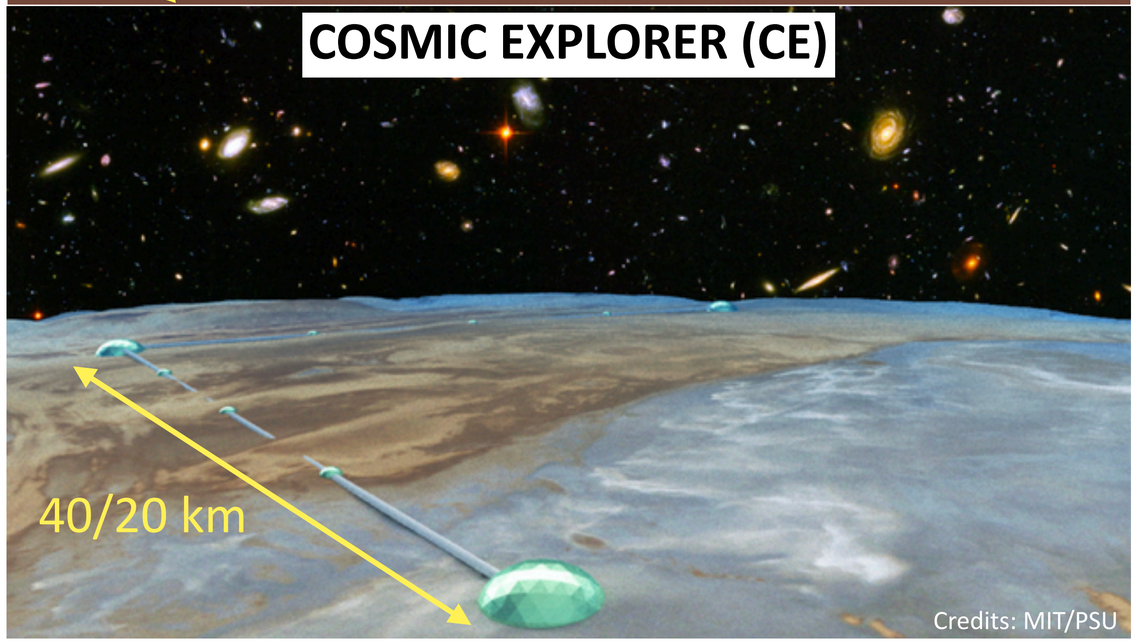
We consider three 3G detectors:

- **ET** (Italy) — 10 km ET-D (Hild+ 2011)
- **CE1** (USA) — 40-20 km arms (Evans+ 2021)
- **CE2** (Australia)

We consider three 3G networks:

- **ET**
- **ET+CE1**
- **ET+CE1+CE2** This talk

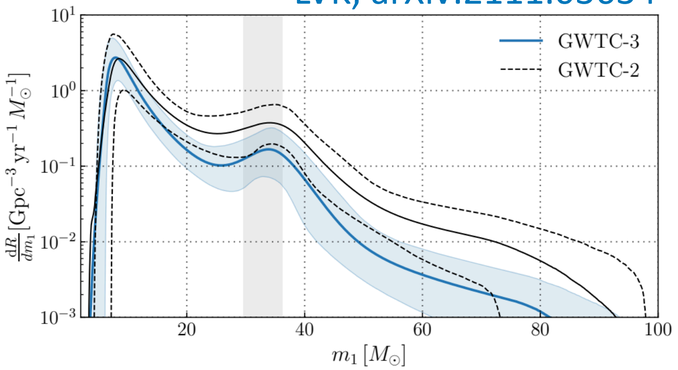


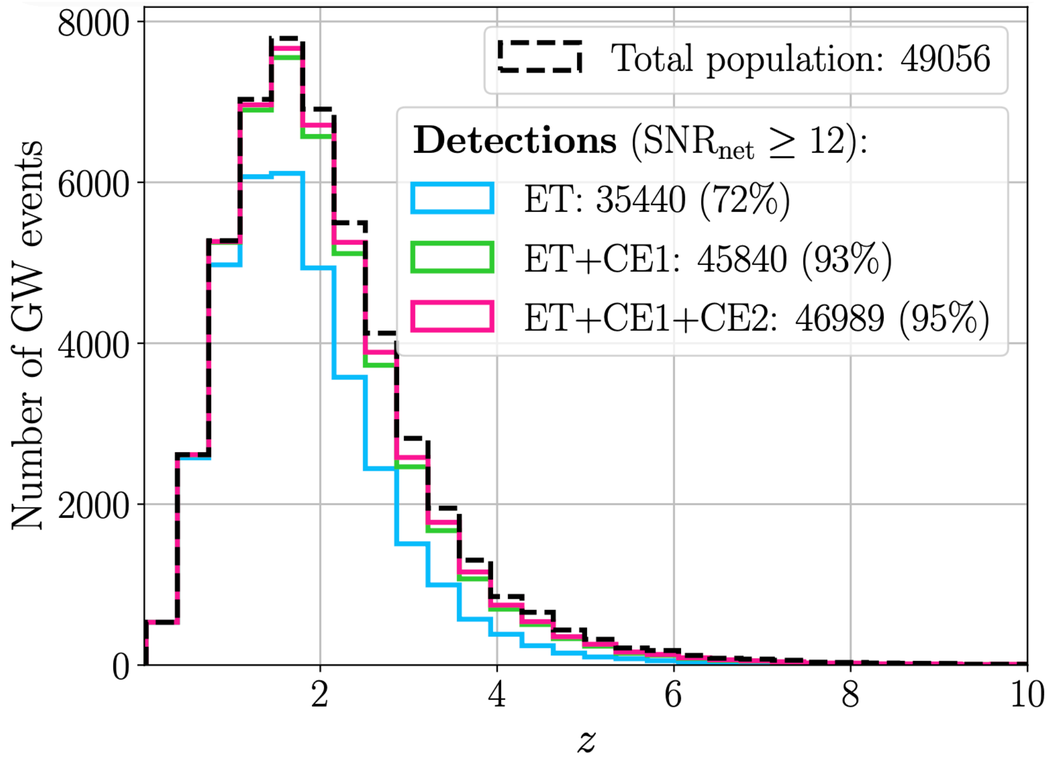


BINARY BLACK HOLES DETECTED

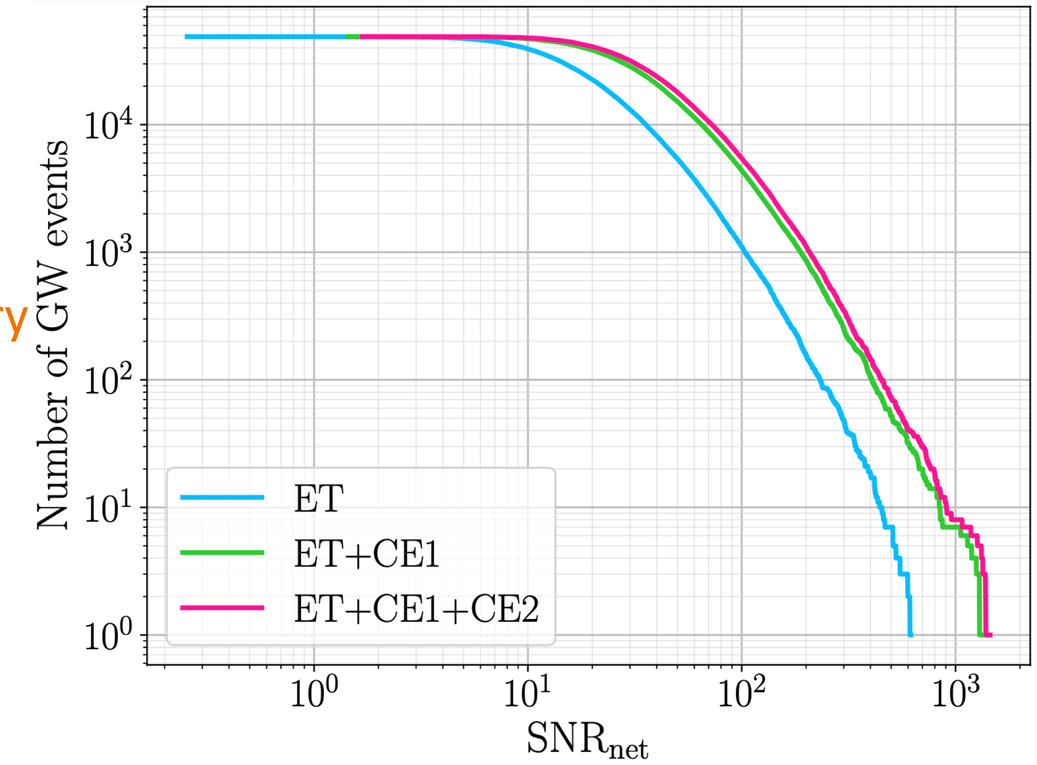
- **Primary mass distribution**: POWER LAW + PEAK (from LVK GWTC-3)
- **Redshift**: Madau-Fragos (2017) + delay $t_d \in [10\,\mathrm{Myr}, 10\,\mathrm{Gyr}]$
- **Waveform model**: IMRPhenomXHM

LVK, arXiv:2111.03634





Preliminary



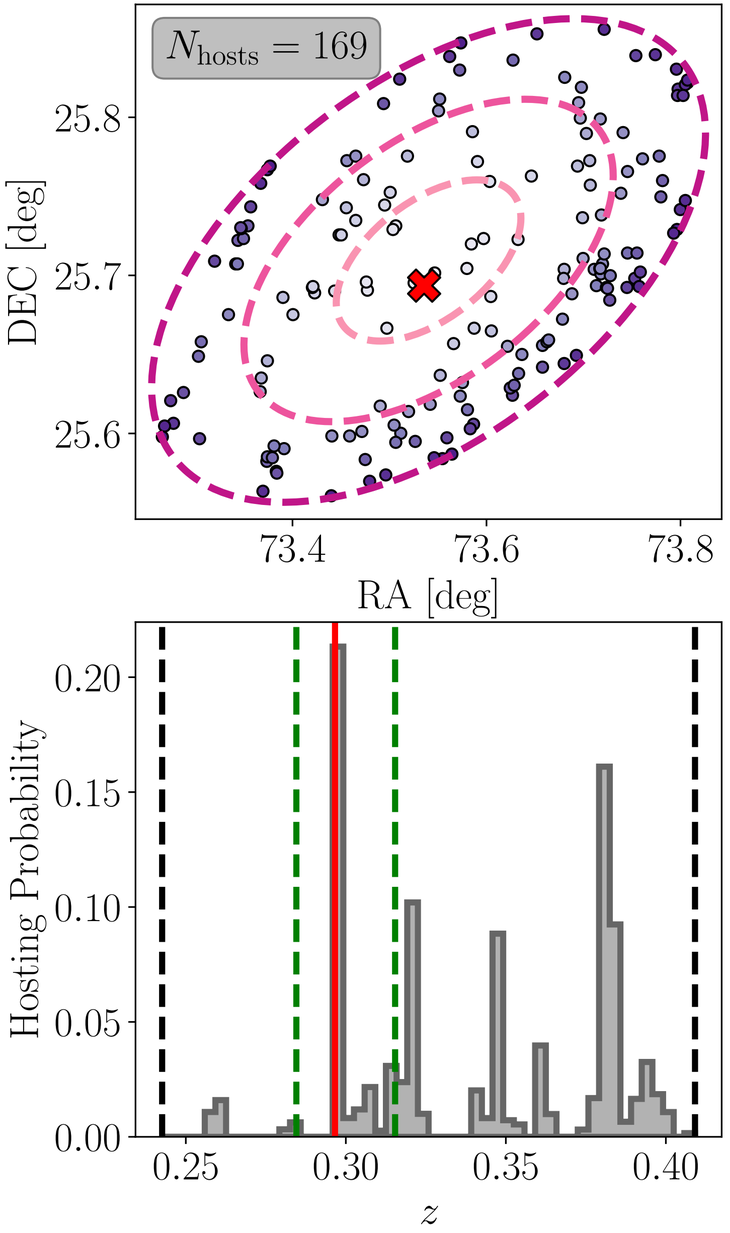
GALAXY CATALOG & LOCALISATION ERROR VOLUMES

- Run **11x11 Fisher Information Matrix** for all **detected** events
  - **ET+CE1+CE2**: $10^{-3} < \sigma_{d_L}/d_L < 10^{0}$, $\Delta\Omega_{90\%}[\mathrm{deg}^2] > 10^{-3}$

- Simulated **complete** light cone ($M_* > 10^{10} M_\odot$) up to $z < 1$

  Henriques+, MNRAS (2015)
  Izquierdo-Villalba+, A&A (2019)

- **Cross-match** BBH sky location with $SNR_{\mathrm{net}} > 300$ with galaxy catalog
  - **ET+CE1+CE2**: $10^2 - 10^3$ potential hosts for most dark sirens



COSMOLOGICAL INFERENCE SCHEME

$$d(z,\Omega) = \frac{c(1+z)}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + 1 - \Omega_m}}$$

Flat-LCDM model

$$\Omega = \{h, \Omega_m\}$$

sky-position-dependent w_j

3G detector likelihood

GW redshift prior

$$p(\Omega \mid D, \mathscr{H}) \propto p(\Omega \mid \mathscr{H}) \prod_{i=1}^{N} \int dz_{\rm GW}\, \mathcal{N}(d(z_{\rm GW},\Omega) - \bar{d}_L, \sigma^2_{d_L}) \sum_{j=1}^{N_{\rm hosts}} w_j\, \mathcal{N}(z_j - z_{\rm GW}, \sigma^2_{v_p})$$

Posterior ← Nested sampling **[CPNest]** (Parallelised) ← **Prior**, **Quasi-likelihood**

Del Pozzo, Laghi [github.com/wdpozzo/cosmolisa] **cosmoLISA**

FORECASTS: H_0 and Ω_m

1 year of full observation

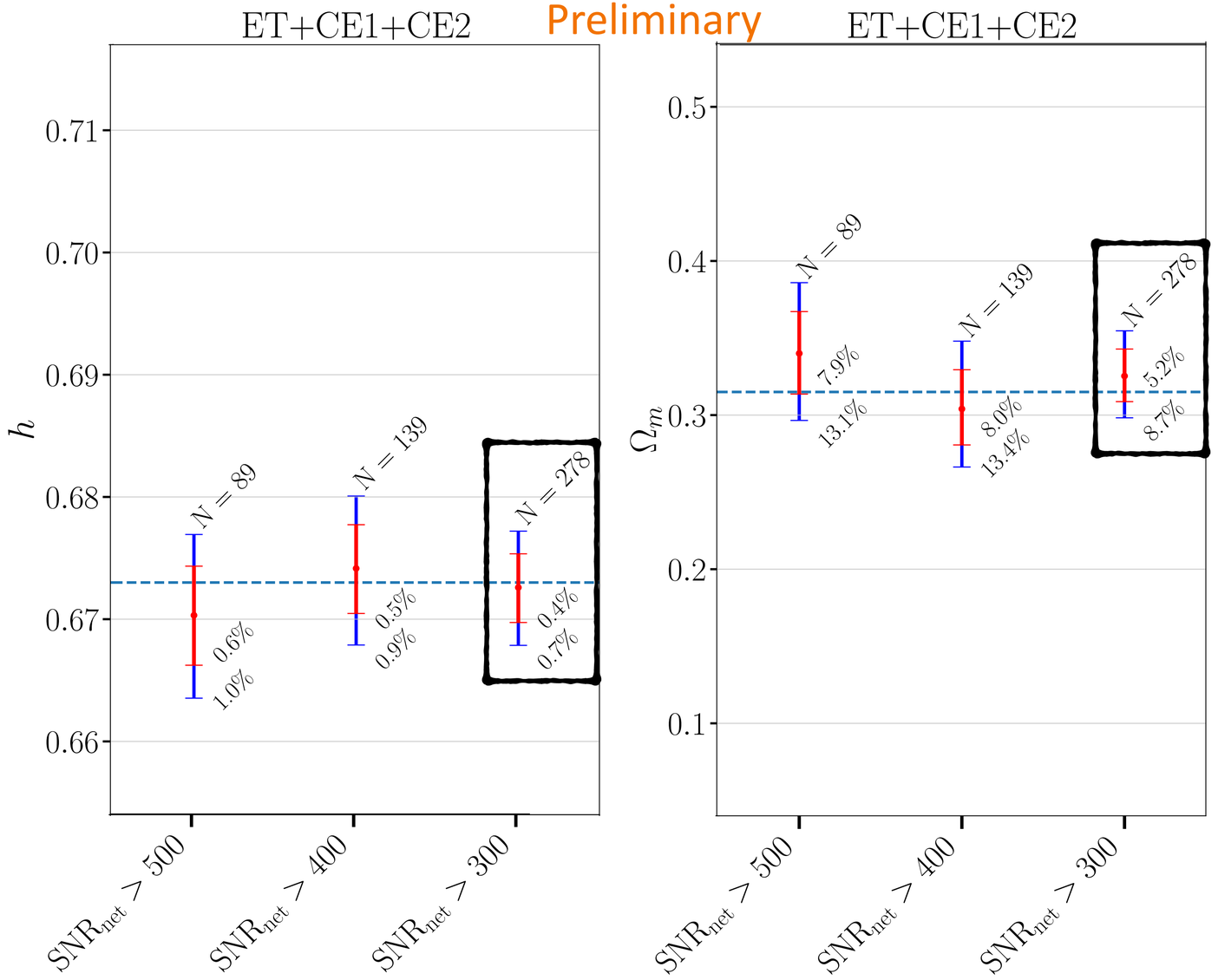
h at $\sim 1\,\%$ (90%CI) with **ET+CE1+CE2**

Preliminary

Ω_m at $\sim 10\,\%$ (90%CI) with **ET+CE1+CE2**

Assuming Ω_m known:

h at $\sim 0.5\,\%$ with **ET+CE1+CE2**



$h = H_0/100\,\mathrm{km^{-1}s\ Mpc}$

CONCLUSIONS

Preliminary results:

Binary black holes + **3G** detectors can open to a **sub-% measure** of H_0

FUTURE PROSPECTS

Ongoing analysis:

- **ET** and **ET+CE1** networks: currently **double-checking** our **results** due to some code issues with the GW parameter estimation
- Inclusion of **GW selection effects** (analysis of **lower** SNR_{net} events), **optimisation** of the code (large data sets are **computationally costly**)

Thank you for your attention!