FUTURE TERRESTRIAL GRAVITATIONAL-WAVE OBSERVATORIES

LIGO SCIENCE WORKSHOP, OCTOBER 27, 28, ICTS, BANGALORE, INDIA

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Penn State and Cardiff University

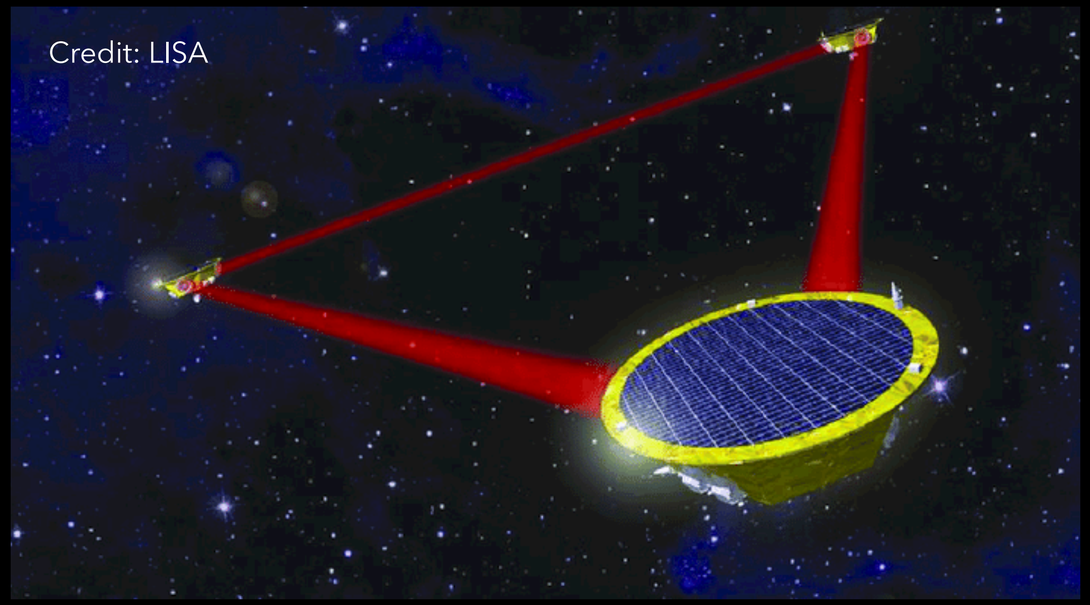
COSMIC EXPLORER

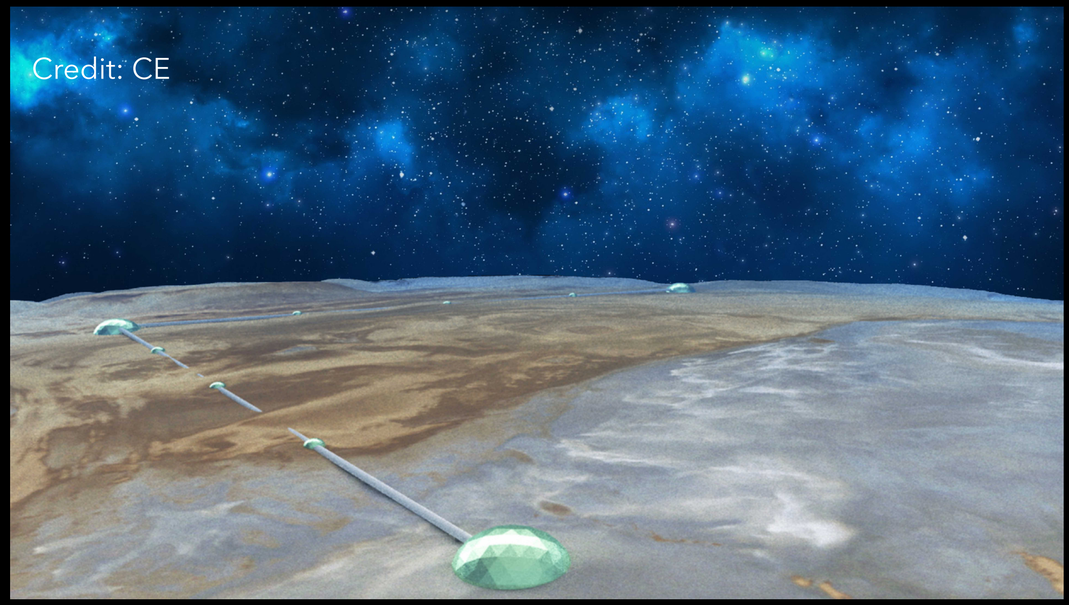
NSF

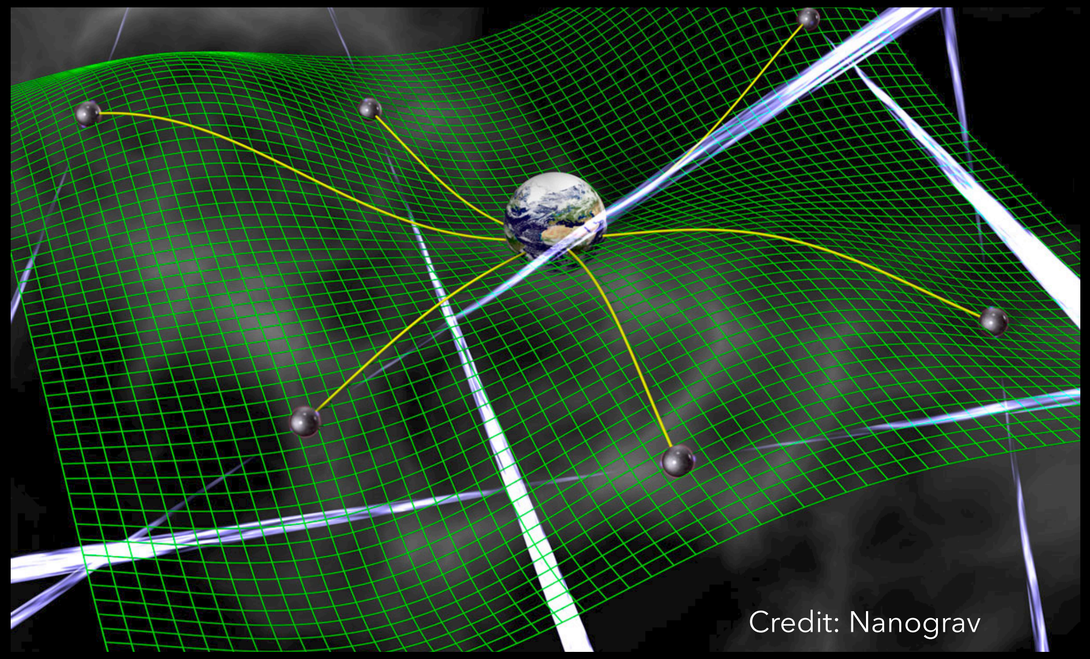
CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

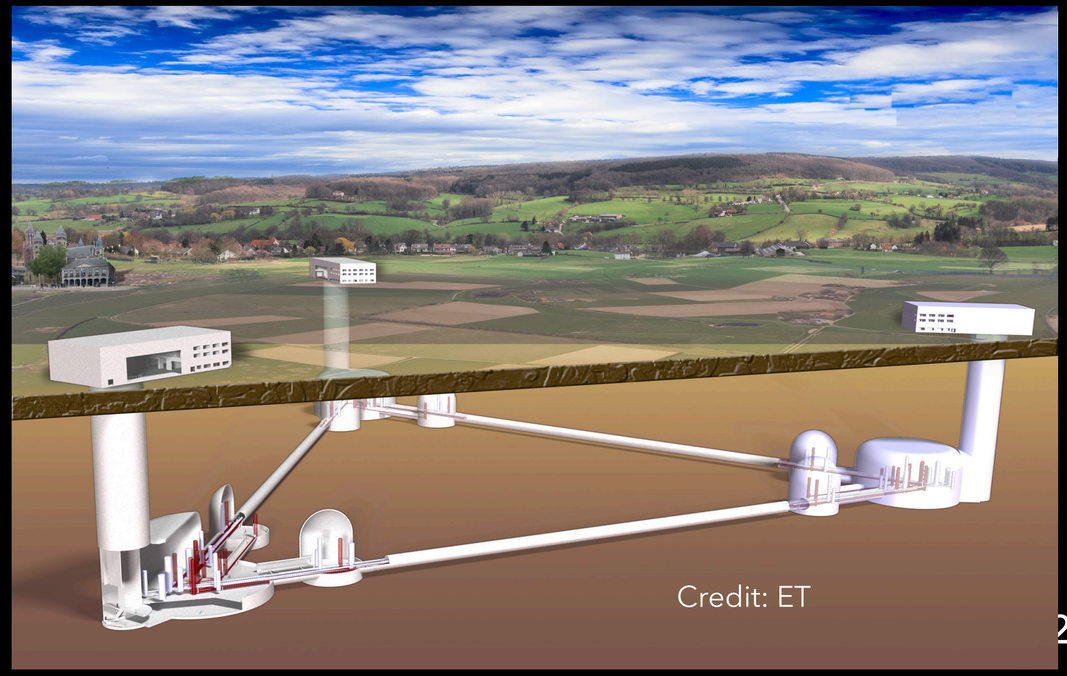
LIGO VIRGO KAGRA

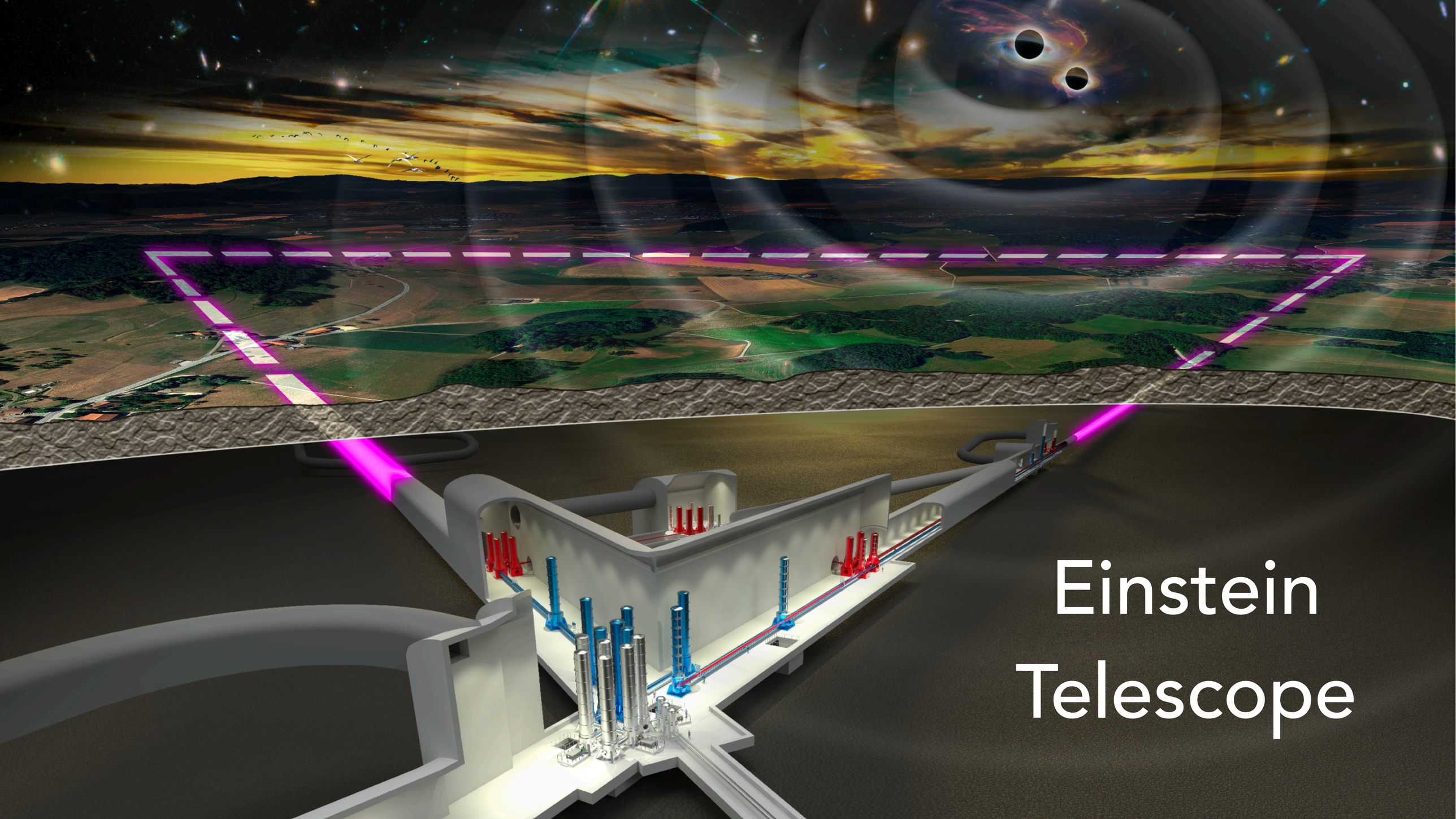
FUTURE GRAVITATIONAL-WAVE OBSERVATORIES










Einstein
Telescope

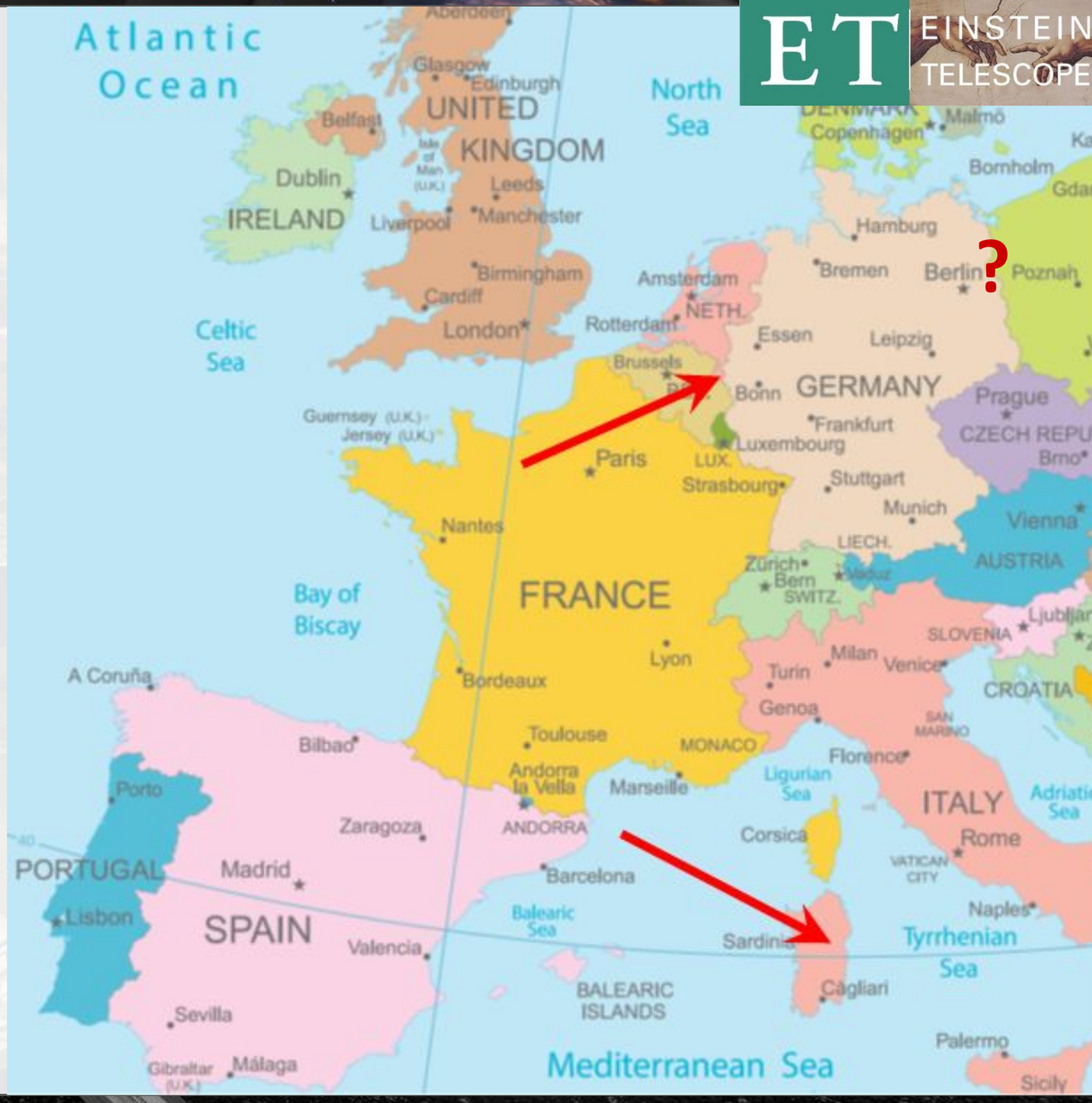
Site Selection

Currently two site candidates:

- Sardinia
  - 50Mio€ ETIC
    + 350Mio€ for construction by local Sardinian government
    + financial support by Italian government for the construction

- EU Regio Meuse-Rhine/Limburg
  - 42Mio€ preparation
    + 870MEUR construction

Geologial properties and underground seismic being investigated.



Triangle vs. two L

Best configuration for ET is being evaluated:

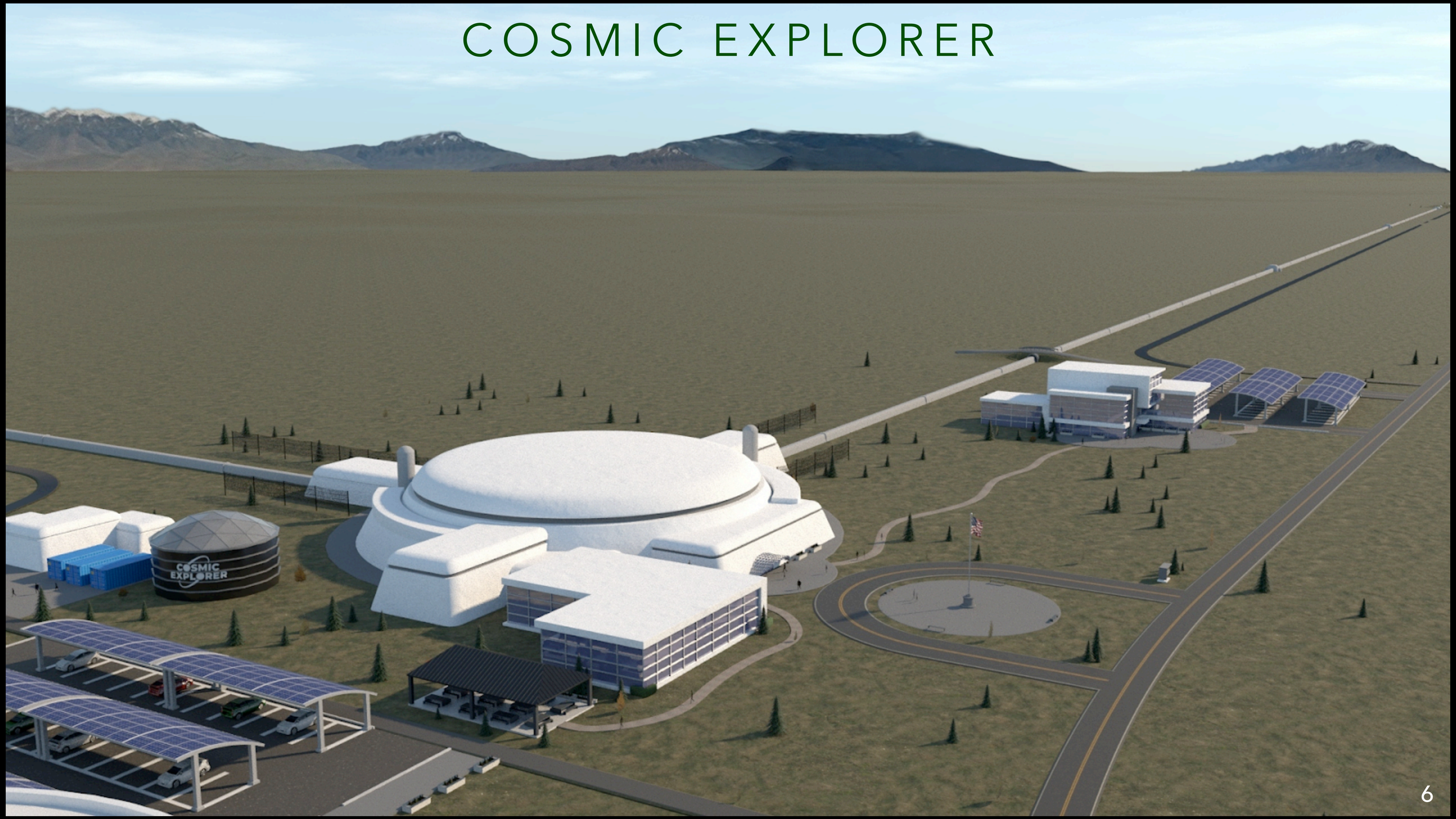
- two L configuration (as LIGO, Cosmic Explorer)
- or triangle in one location

→ maximize the science return and reduce risks

Since 2011 (CDS, triangle configuration) the situation drastically changed:

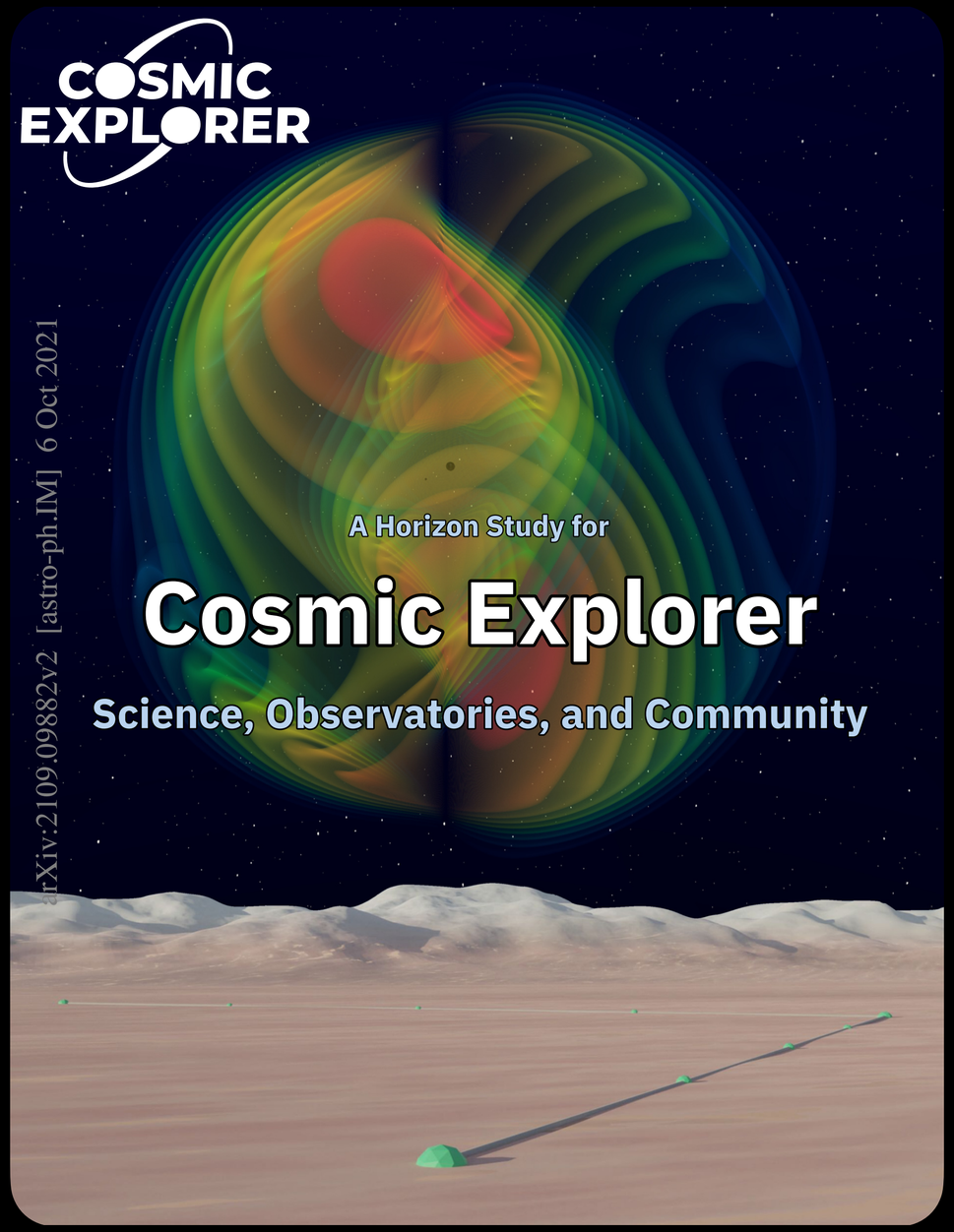
- first detections, GTWC-3 catalog → BH population → new SF and evolution models;
- science case developed;
- know-how with advanced (L) detectors;
- international scenario (+ Cosmic Explorer in US);
- two candidate sites strongly supported (and a potential third site…).

COSMIC EXPLORER



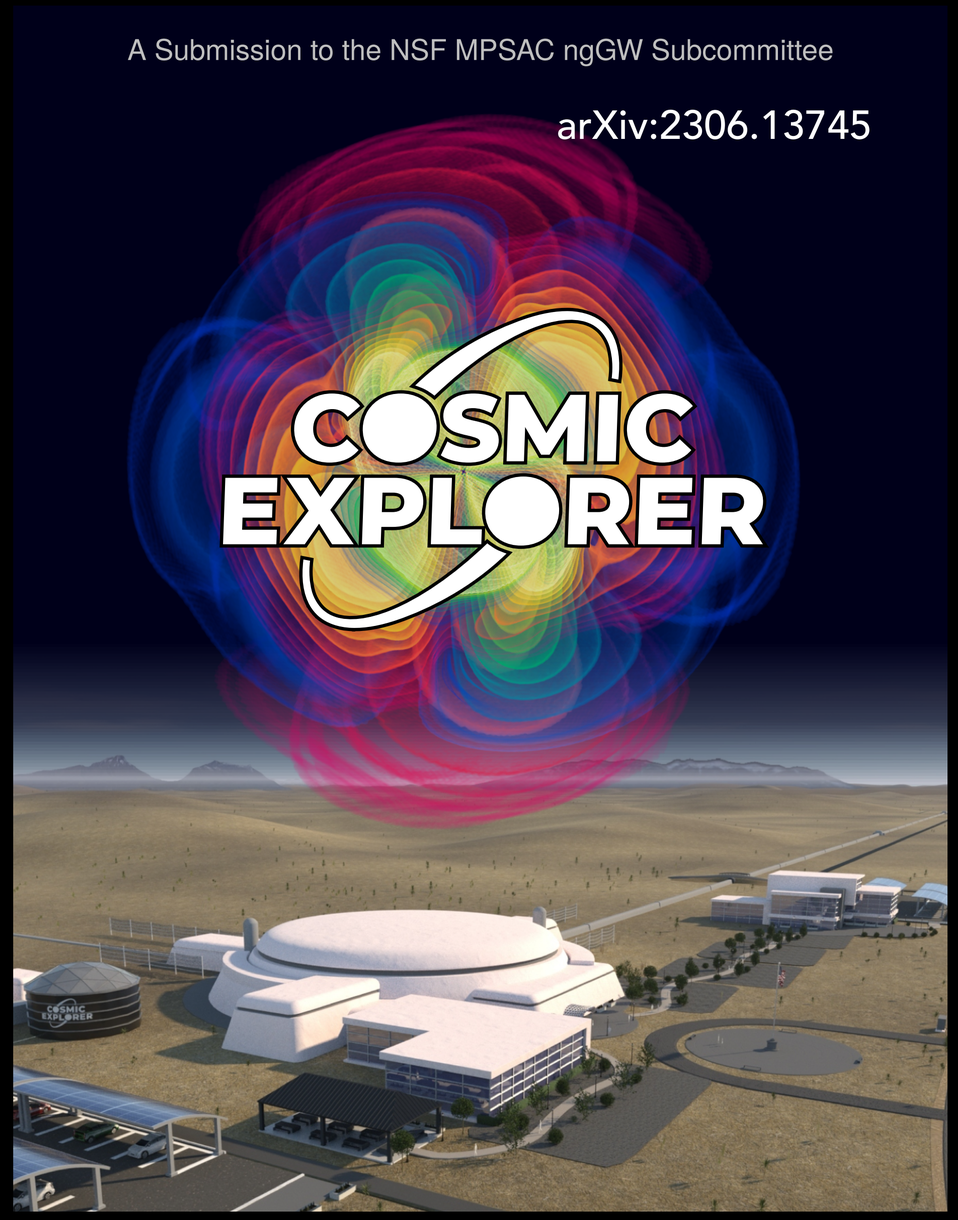
WHAT'S COSMIC EXPLORER

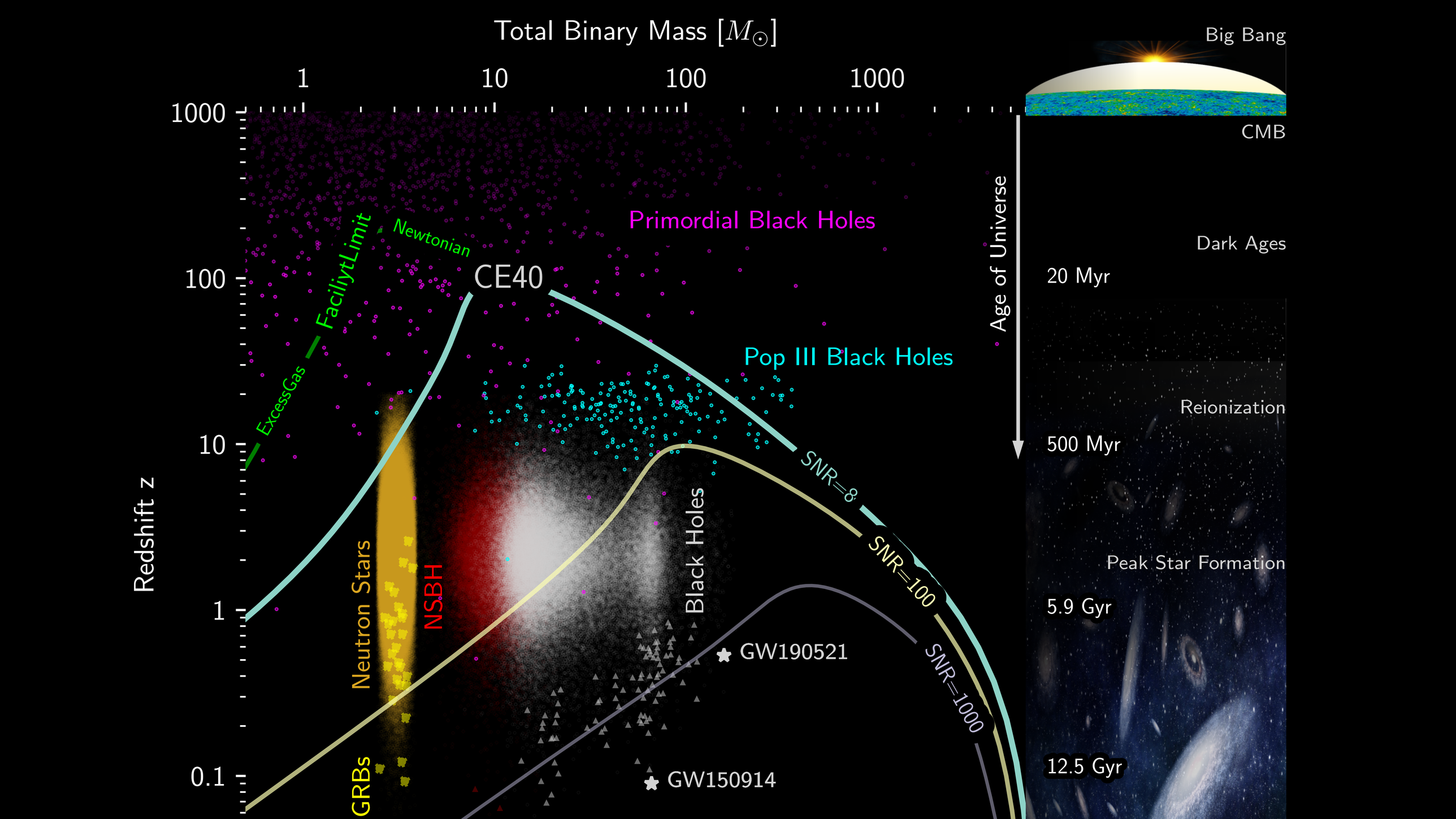
- Cosmic Explorer is the US concept for a next-gen gravitational-wave observatory
  - 40 km and 20 km L-shaped surface observatories
  - roughly 10x sensitivity of today's observatories
- CE is as envisioned an NSF-funded Project
  - Horizon Study completed in 2021, arXiv:2109.09882
- Currently in Conceptual Design Study:
  - "Launching the Cosmic Explorer Conceptual Design"
  - "Collaborative Research: Identifying and Evaluating Sites for CE"
  - "Cosmic Explorer Optical Design"
  - "Enabling Megawatt Optical Power in Cosmic Explorer"
  - XG Mock Data Challenge
  - "Local Gravity Disturbances and Next-GenerationGW Astrophysics."
  - "CE: Research and Conceptual Designs for Scattered-Light Mitigation."

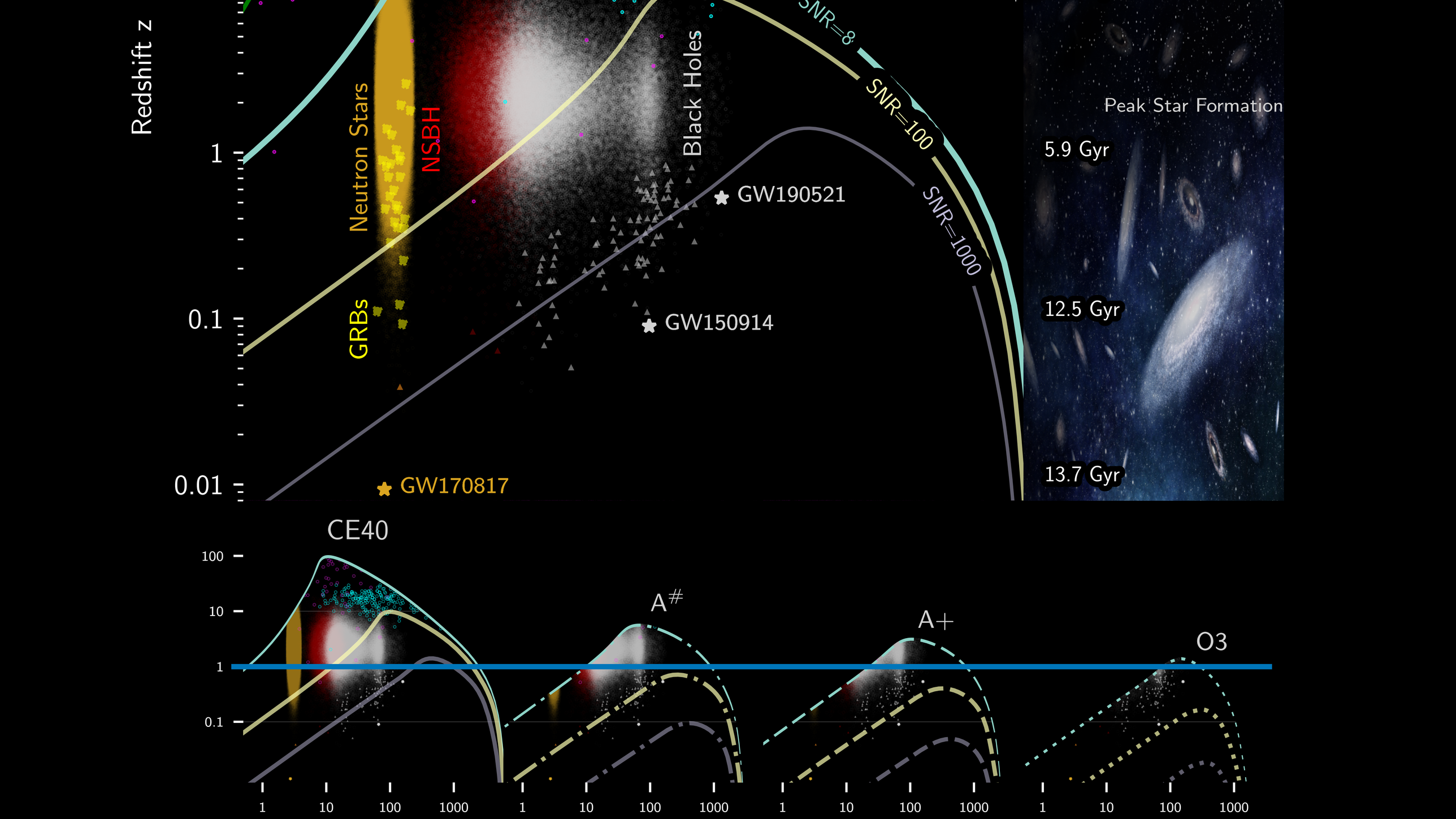


NEXT-GENERATION GRAVITATIONAL-WAVE SUBCOMMITTEE

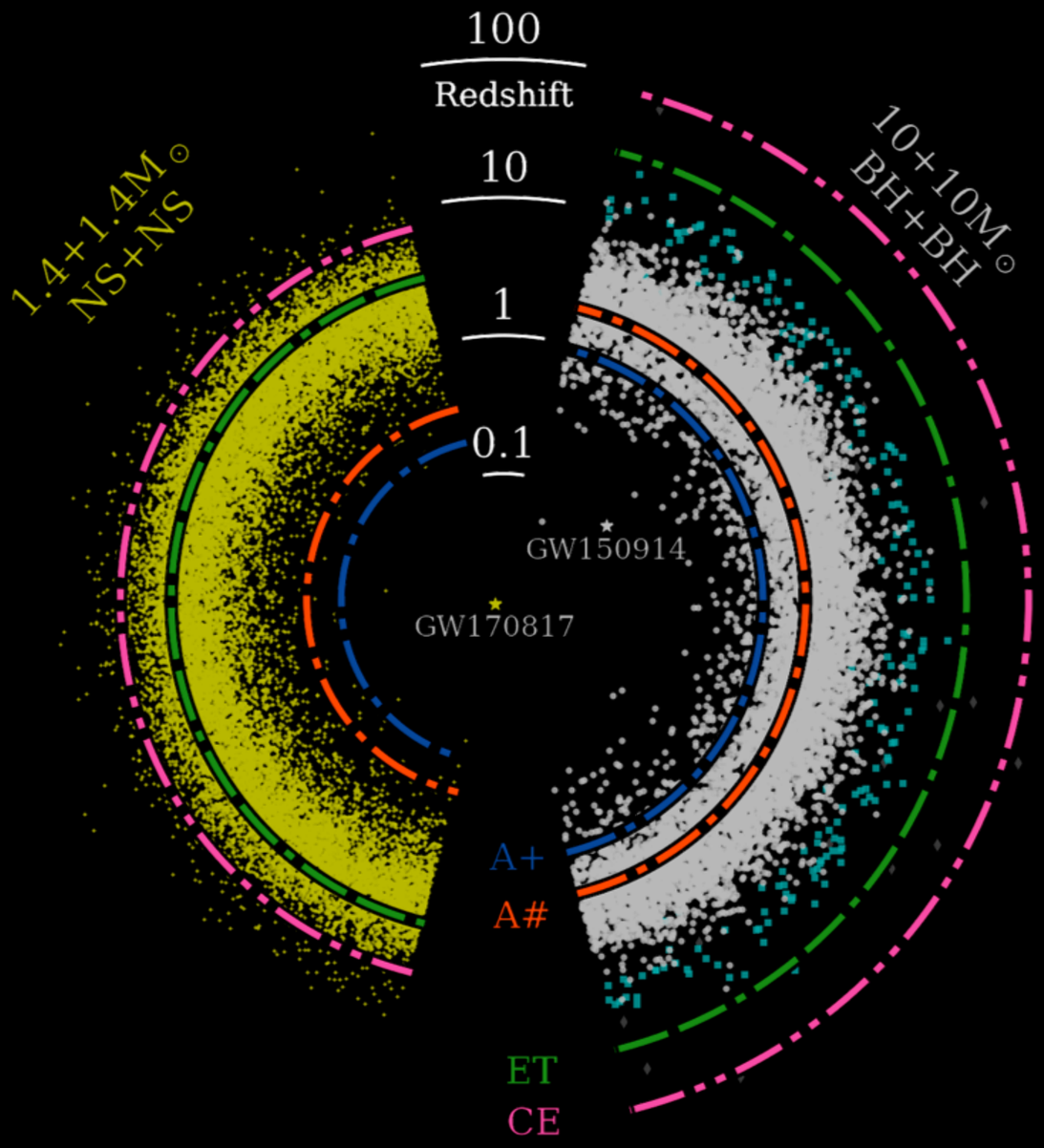
- ngGW was established by the NSF
  - Committee home page with membership: https://www.nsf.gov/mps/phy/nggw.jsp
- Charge:
  - "… Based on this survey, a recommended list of GW detection network configurations that will deliver a detector with sensitivity an order of magnitude greater than the LIGO A+ design…."
  - https://www.nsf.gov/mps/advisory/subcommittee_charges/mpsac-nggw-charge_signed.pdf
  - Preliminary Report: Oct 2024 / Final Report: Jan 2024

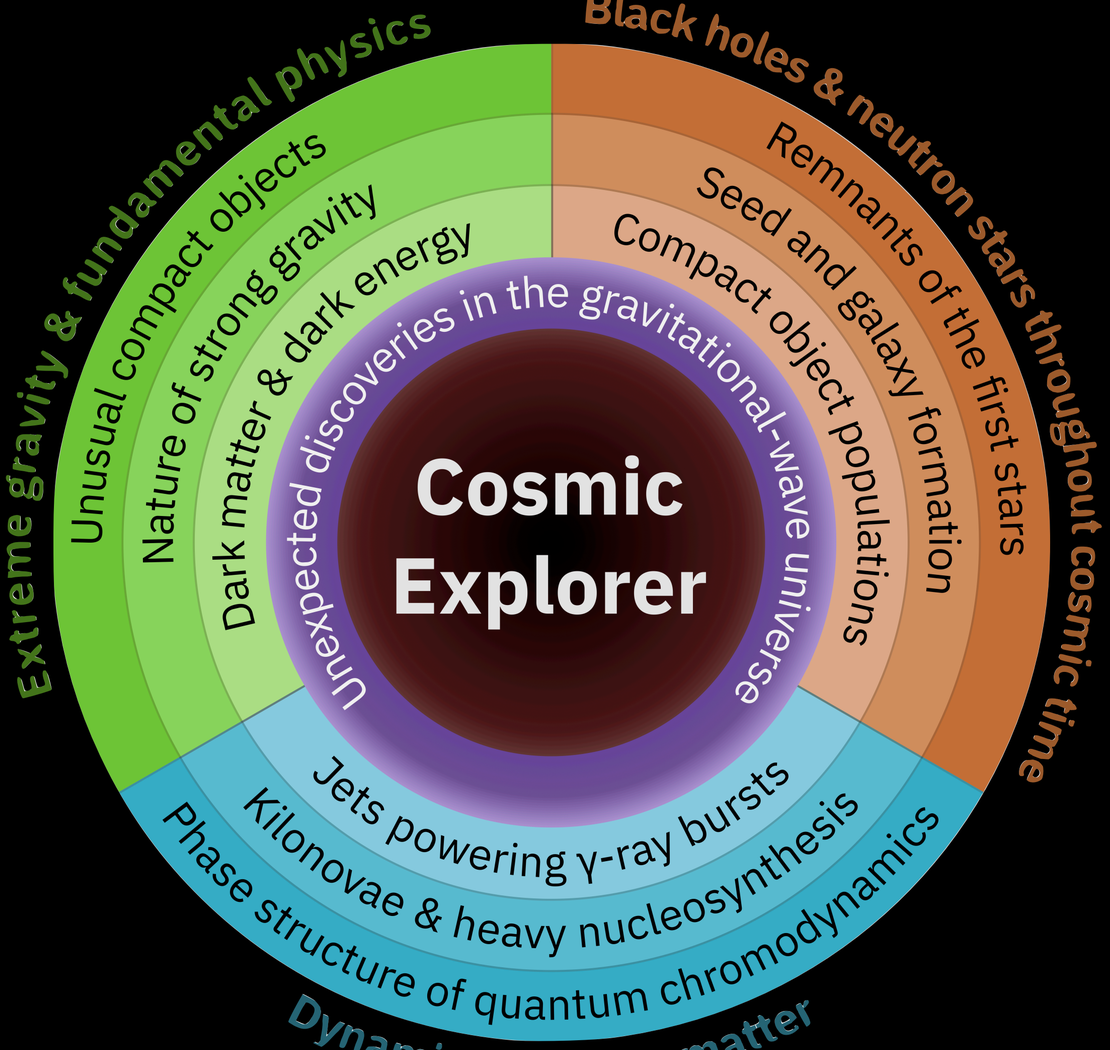



Total Binary Mass [$M_\odot$]
1
10
100
1000
Redshift z
1000
100
10
1
0.1
Primordial Black Holes
Pop III Black Holes
CE40
FacilityLimit
Newtonian
ExcessGas
Neutron Stars
NSBH
Black Holes
GRBs
GW190521
GW150914
SNR=8
SNR=100
SNR=1000
Age of Universe
Big Bang
CMB
Dark Ages
20 Myr
Reionization
500 Myr
Peak Star Formation
5.9 Gyr
12.5 Gyr


Redshift z
1
0.1
0.01
Neutron Stars
NSBH
Black Holes
GRBs
SNR=8
SNR=100
SNR=1000
GW190521
GW150914
GW170817
Peak Star Formation
5.9 Gyr
12.5 Gyr
13.7 Gyr
CE40
A#
A+
O3
100
10
1
0.1
1
10
100
1000

SCIENCE CAPABILITIES OF FUTURE OBSERVATORY



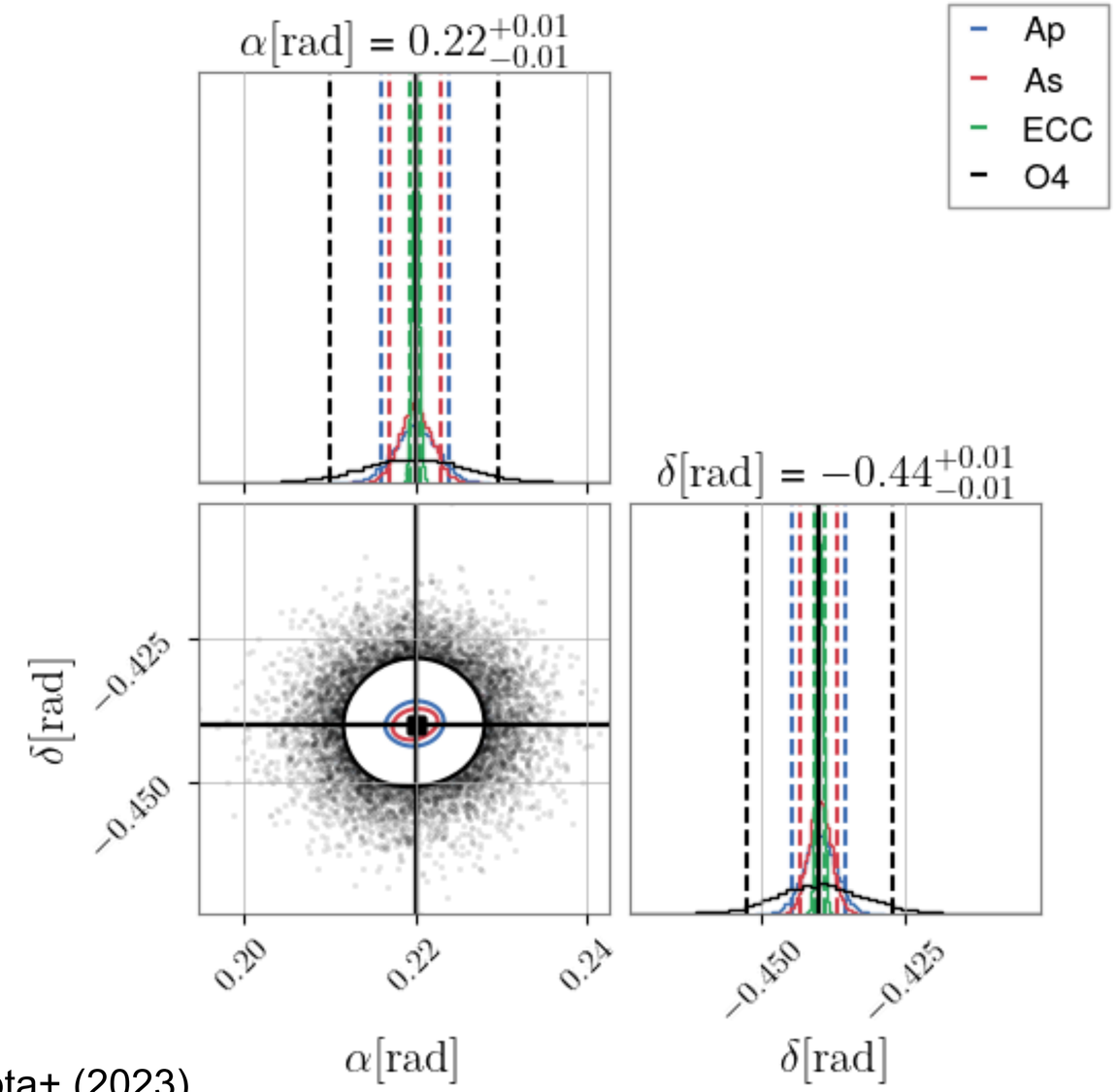


RESOLVE THE HUBBLE TENSION

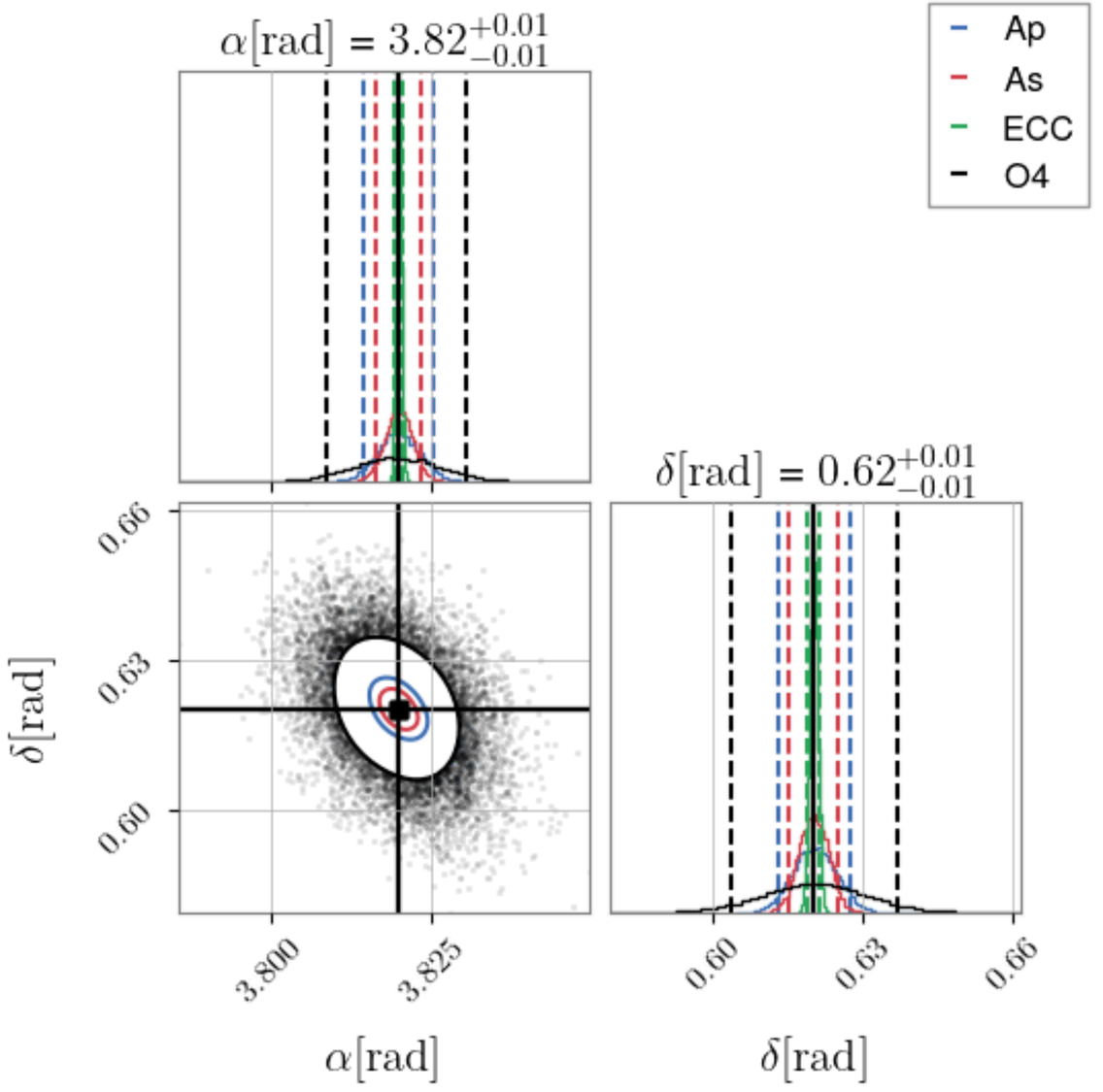
Key Idea: Black hole binaries with higher modes break the distance-inclination degeneracy

LOCALIZATION WITH FUTURE OBSERVATORIES

GW190814-like event

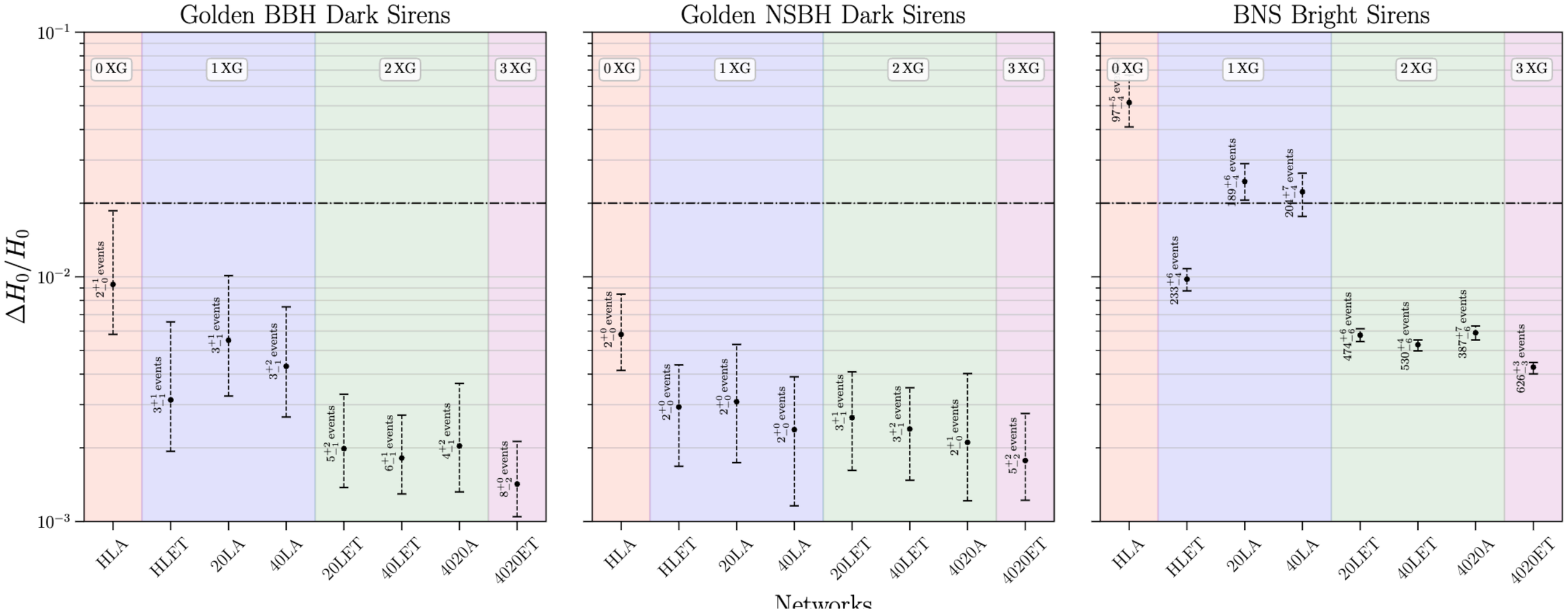


GW190412-like event



Gupta+ (2023)

PROSPECT FOR MEASURING H_0 WITH FUTURE OBSERVATORIES

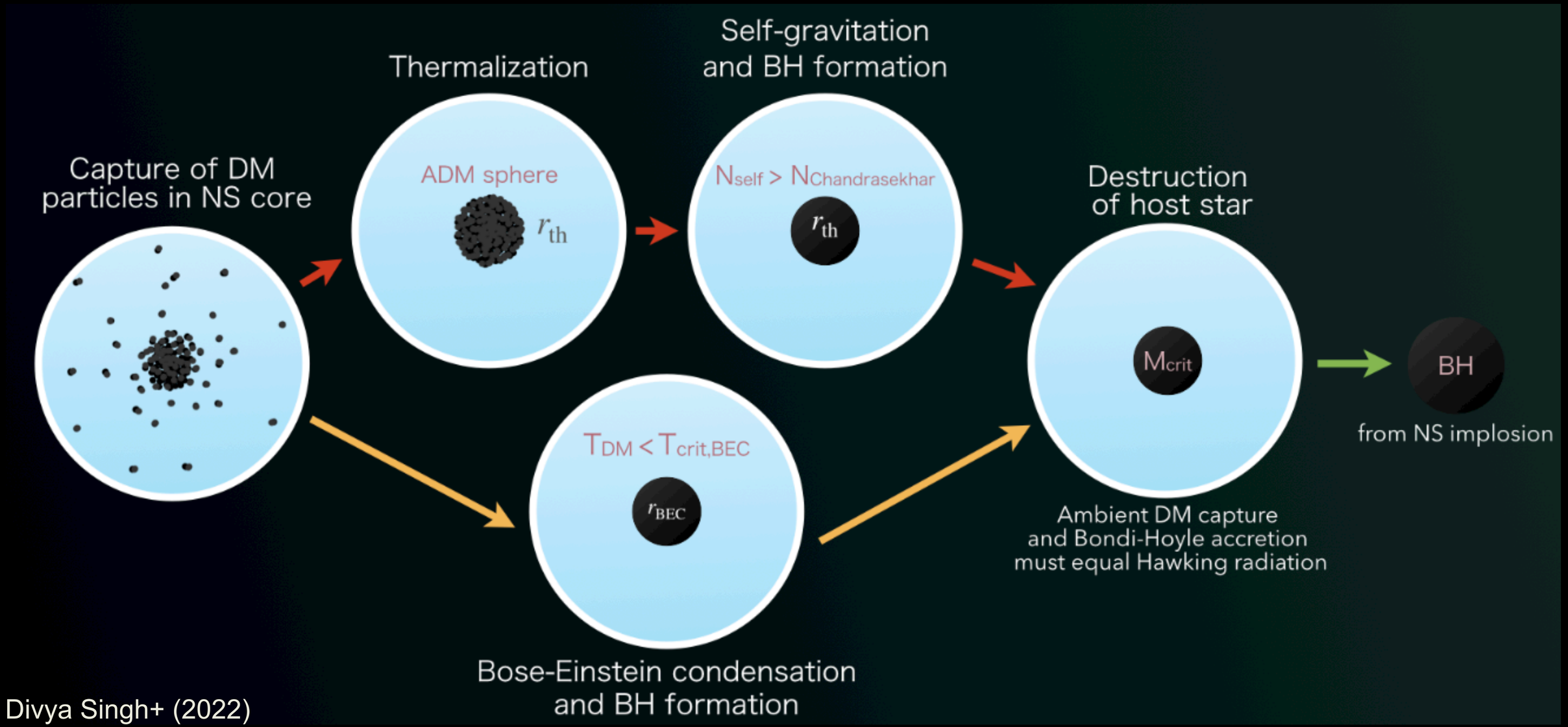


Gupta+ (2023), arXiv: 2307.10421

CONSTRAIN WIMP DARK MATTER FROM GRAVITATIONAL WAVE OBSERVATIONS

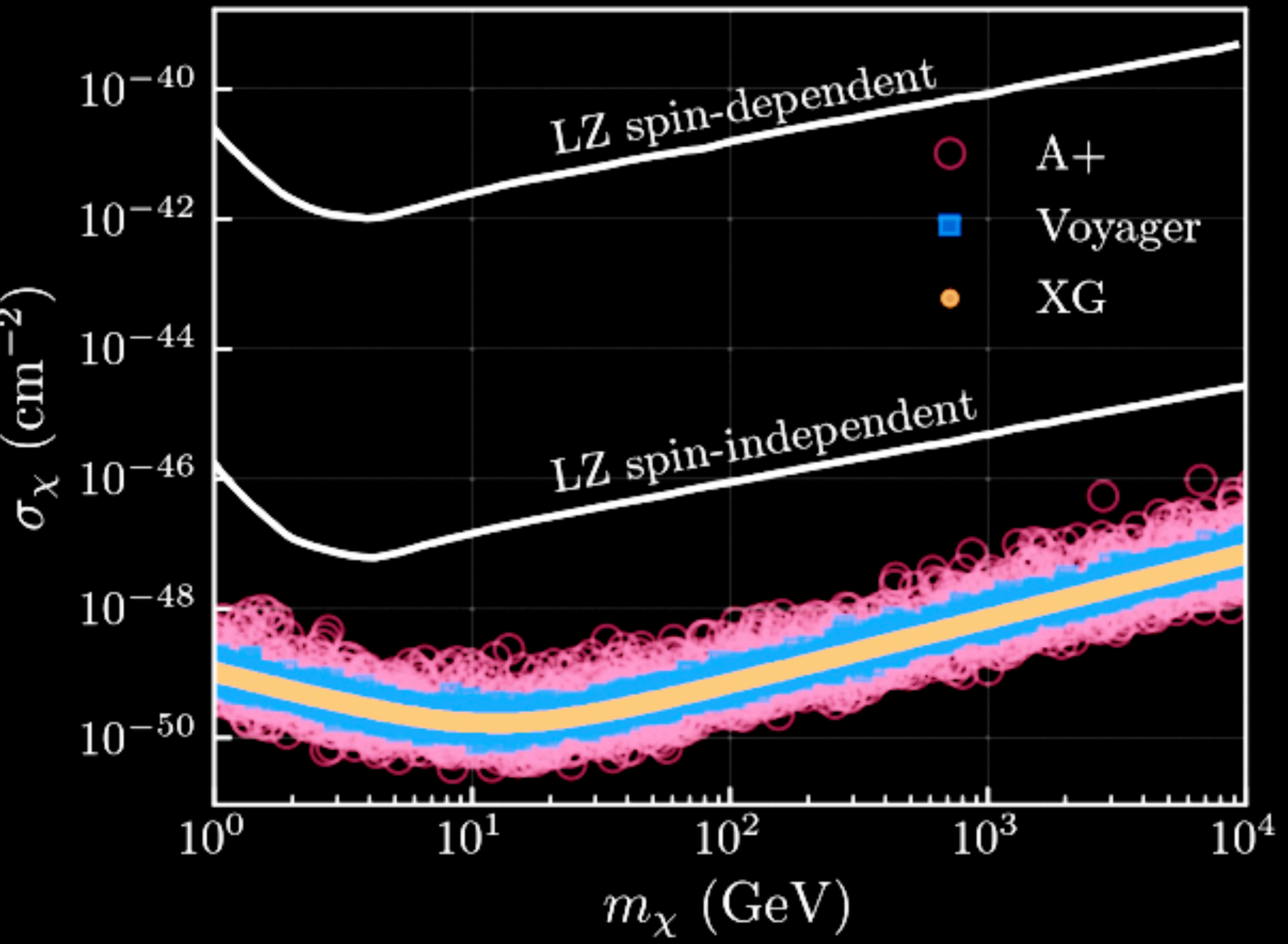
Key Idea: Black holes have zero tidal deformability

DARK MATTER INDUCED IMPLOSION OF NEUTRON STARS



Divya Singh+ (2022)

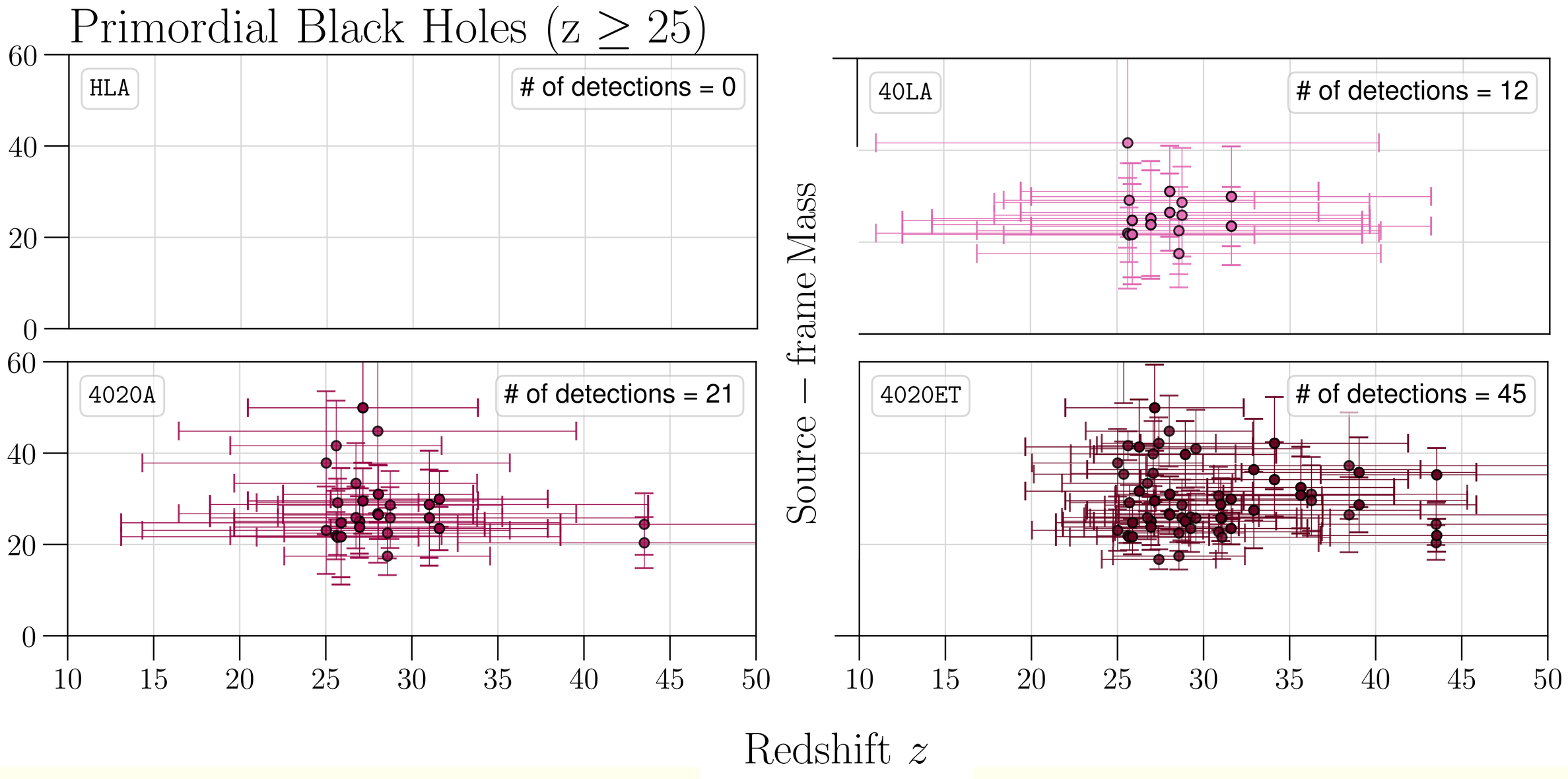
MEASURING WIMPS IN NEUTRON STARS



OBSERVE PRIMORDIAL AND POP-III BLACK HOLES

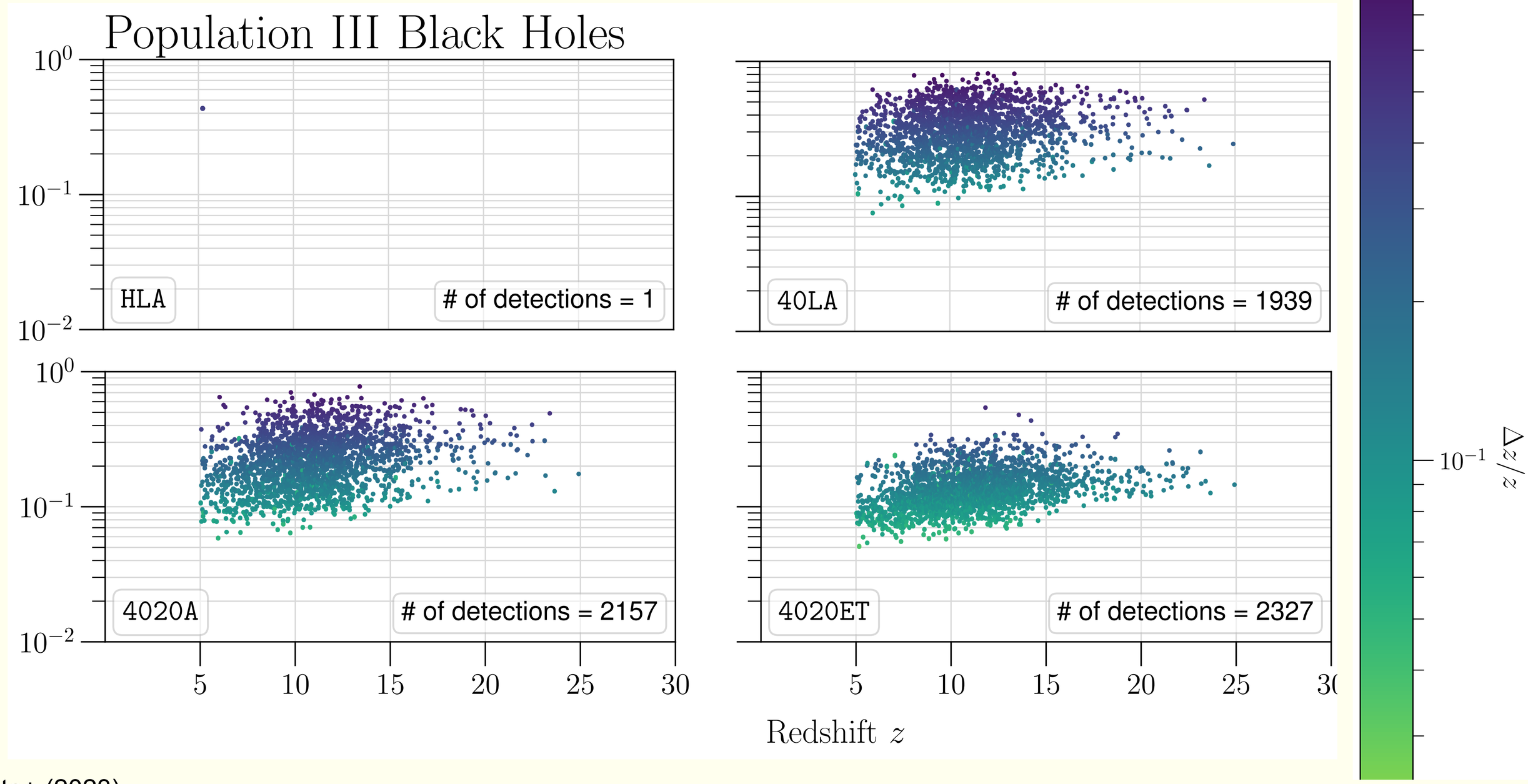
Key Idea: Observe black hole binary mergers at z>20 by decisively measuring their redshift

PINNING DOWN PRIMORDIAL BLACK HOLES



Gupta+ (2023)

OBSERVING POP-III BLACK HOLES



Gupta+ (2023)

PHYSICS BEYOND THE STANDARD MODEL

- Black hole horizons, quantum gravity, information paradox
  - black hole spectroscopy, multipolar structure, quantum modifications at horizon scales
- Corrections to general relativity
  - additional fields, modifications of inspiral radiation
  - black hole uniqueness theorems and exotic compact objects
- Probing dark matter
  - primordial black holes, dark matter, ultralight boson clouds
- Gravitational-wave propagation and graviton mass
  - constraints on Lorentz violation in the gravitational sector, graviton mass, extra dimensions, parity violation