Cosmic Explorer
The US Next-Generation GW Observatory


CE concept by SmithGroup

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Thanks to Mike Landry and the entire CE Team

Cosmic Explorer

LIGO

- LIGO has been a great success…
- **In conception** (4km, surface observatories, continental baseline separation, sites under firm central management, prototype-tested detector designs)
- **In practice** (Dave's talk)

Cosmic Explorer

- Use all the lessons from LIGO
- Evolve staffing from LIGO to CE
- Design an evolution from the LIGO design
- Ensure deep connections to the host community
- Enable a long lifetime for CE through a flexible observatory environment

Cosmic Explorer

Cosmic Explorer is the US concept for a next-gen gravitational-wave observatory

- 40 km and 20 km L-shaped surface observatories
- 1064 nm @ room temperature
- Roughly 10x sensitivity of today's observatories
- **Planned to operate as part of a global network with ET**, LISA, LIGO India, others

CE is envisioned as an NSF-led Project

- Several coordinated grants by the NSF to work on aspects of CE conceptual design, including: vacuum technology research, site evaluation and responsible siting, detector optical design, mode sensing and control, project management and systems
- NSF looking at models for the path forward – a Very Large Project for NSF

Blue-Ribbon Panel recommendation for CE
NSF ‘ngGW’ Advisory Committee 2024

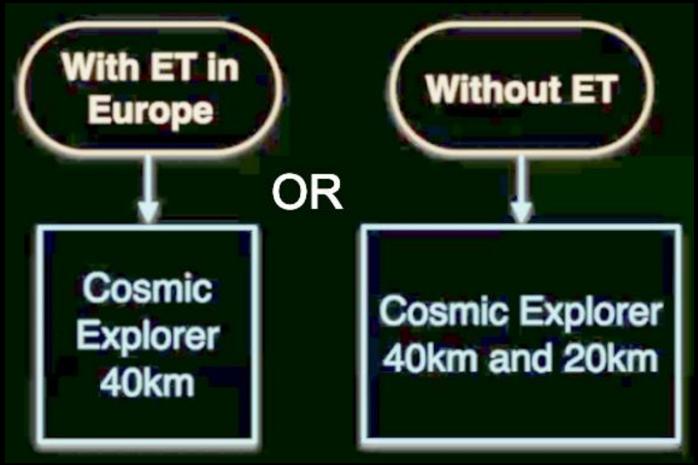
Two scenarios:

- With ET in Europe → CE40 only recommended
- Without ET in Europe → CE40+CE20 recommended
- **LIGO India an important element of the Network**

- **All recommendations include CE**

What does this mean for CE?

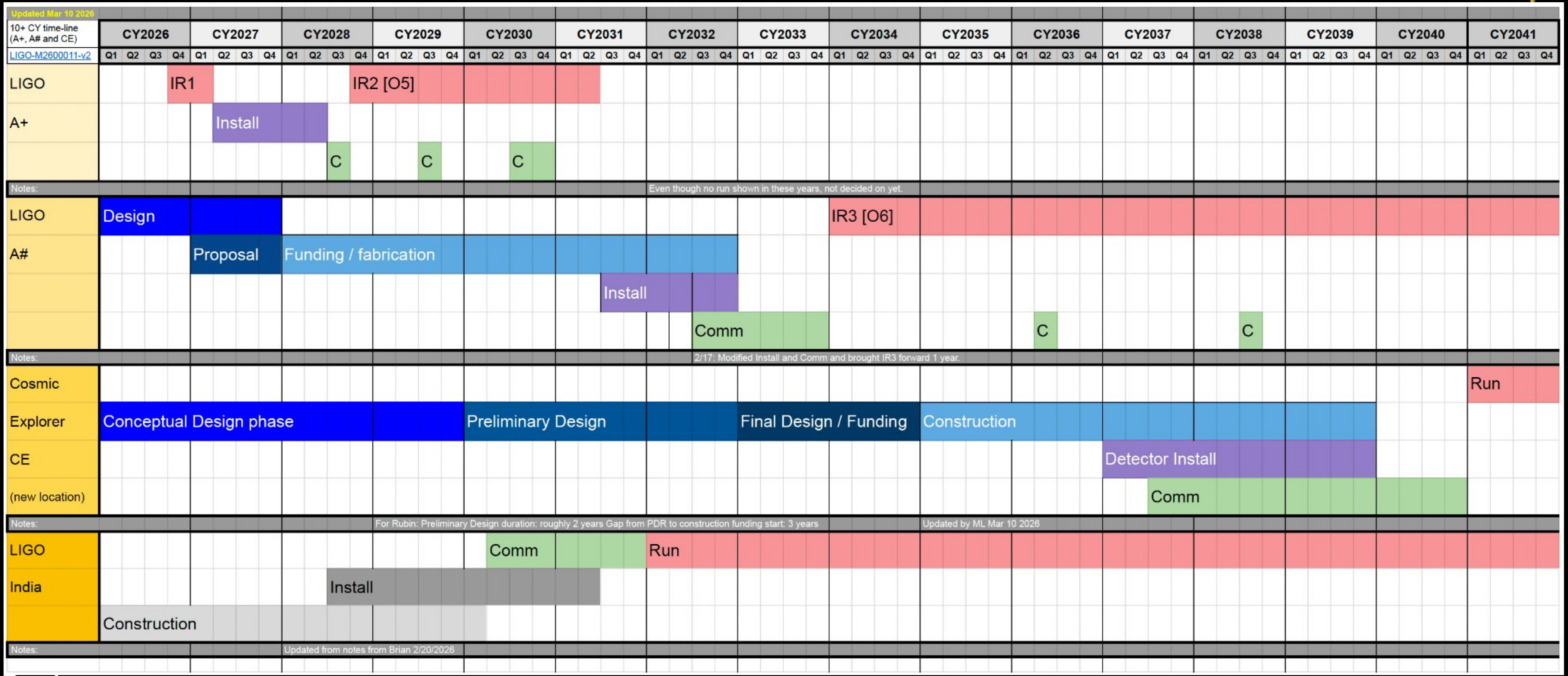
- Continued support and planning by the NSF
- Design work will continue for CE 40km + 20km
- We are working with NSF in anticipation of a solicitation for support to complete the design



credit : Kalogera et al.

[NSF MPSAC ngGW report]

LIGO and CE Project timelines

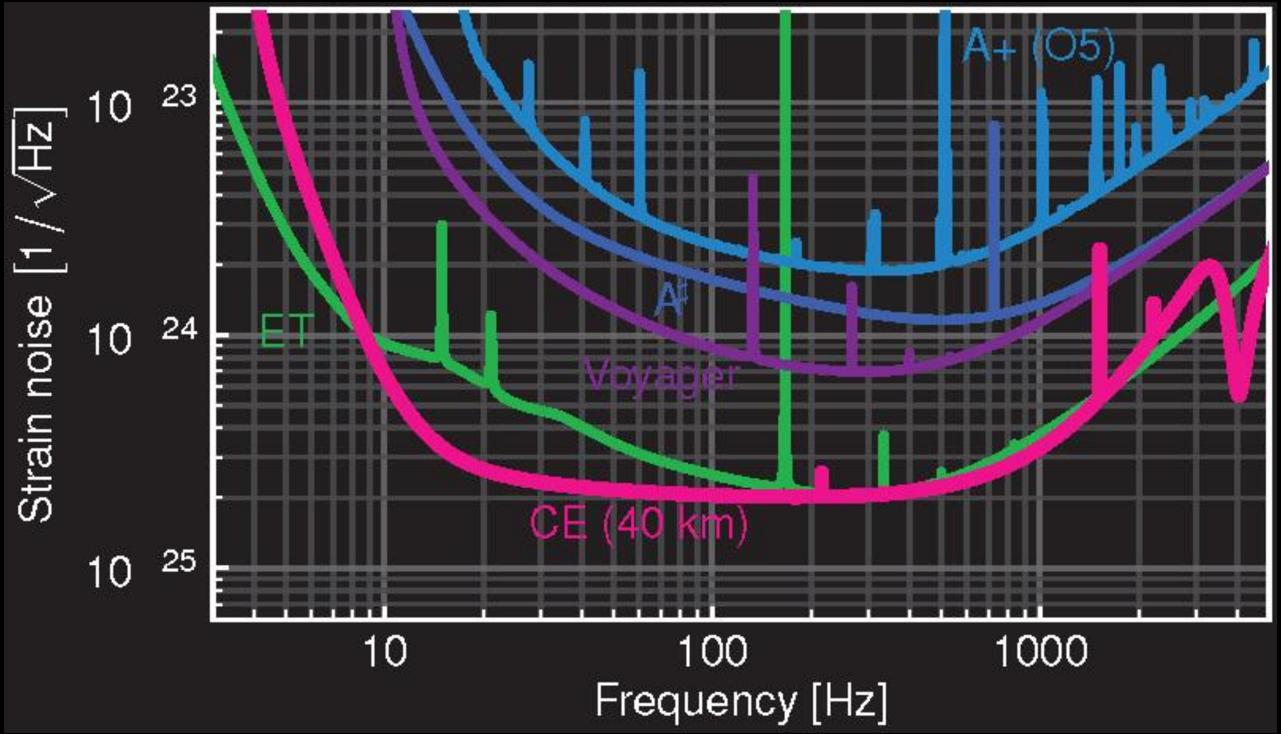


What Changes With Cosmic Explorer?

- Today
  - Observing only binary inspirals to date; too few BNS for Mult-Messenger Astro
  - Detect only loud events from the nearby Universe
    - (~400 confirmed detections to date, see https://arxiv.org/abs/2605.27225)
  - Population studies are limited by selection effects.
- With Cosmic Explorer
  - Observe binary black holes to the epoch of first star formation.
    - …and maybe see primordial black holes
  - Observe neutron star mergers throughout much of cosmic history.
  - Measure compact object evolution across cosmic time.
  - Enable precision tests of gravity with thousands of high-SNR events.

Together with Einstein Telescope, Cosmic Explorer transforms gravitational-wave astronomy from an event-driven science into a population-driven science

Sensitivity evolution from LIGO to Cosmic Explorer

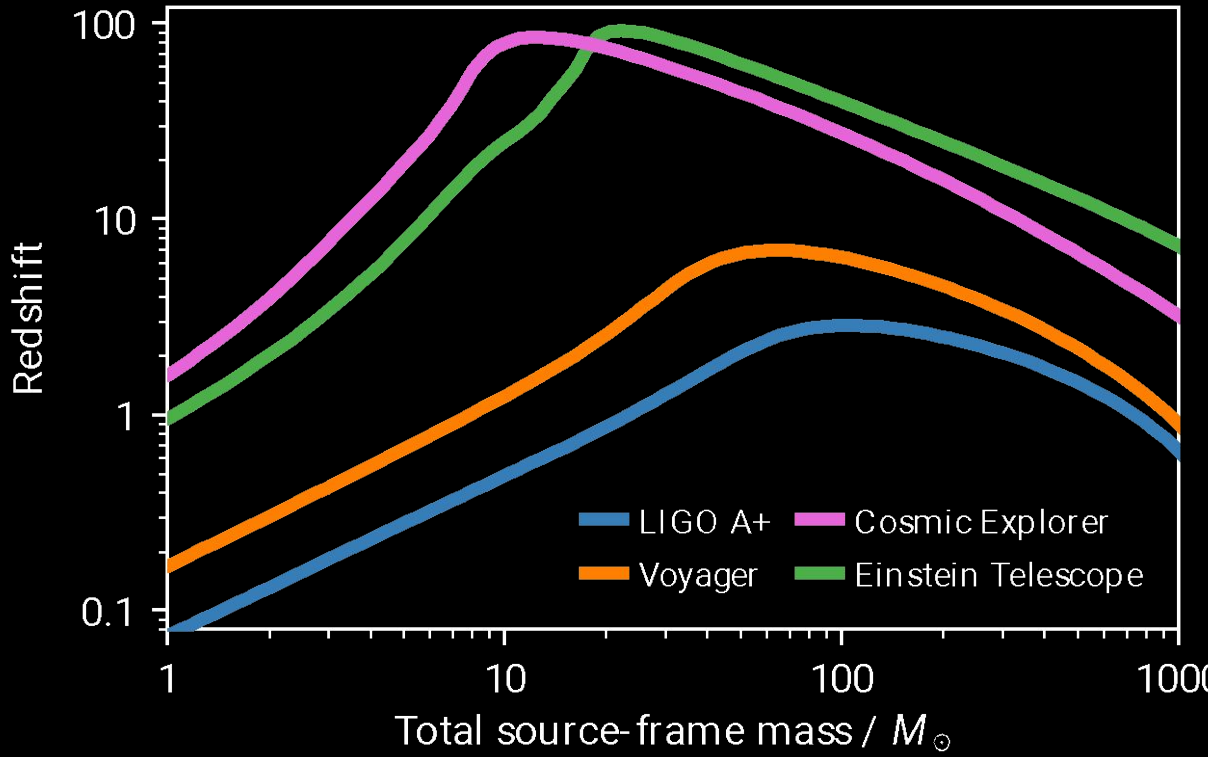


K Kuns 2026-06

Cosmic Explorer Horizon document: https://arxiv.org/abs/2109.09882

CE/ET Science

- Trace the formation and evolution of black holes and neutron stars across cosmic history
- Probe matter, gravity, and fundamental physics
  Open a new observational window on the Dark Universe and the earliest epochs of cosmic evolution.
- Push quantum measurement technology even further
- ET/CE: A great deal of common ground in Observational Science goals

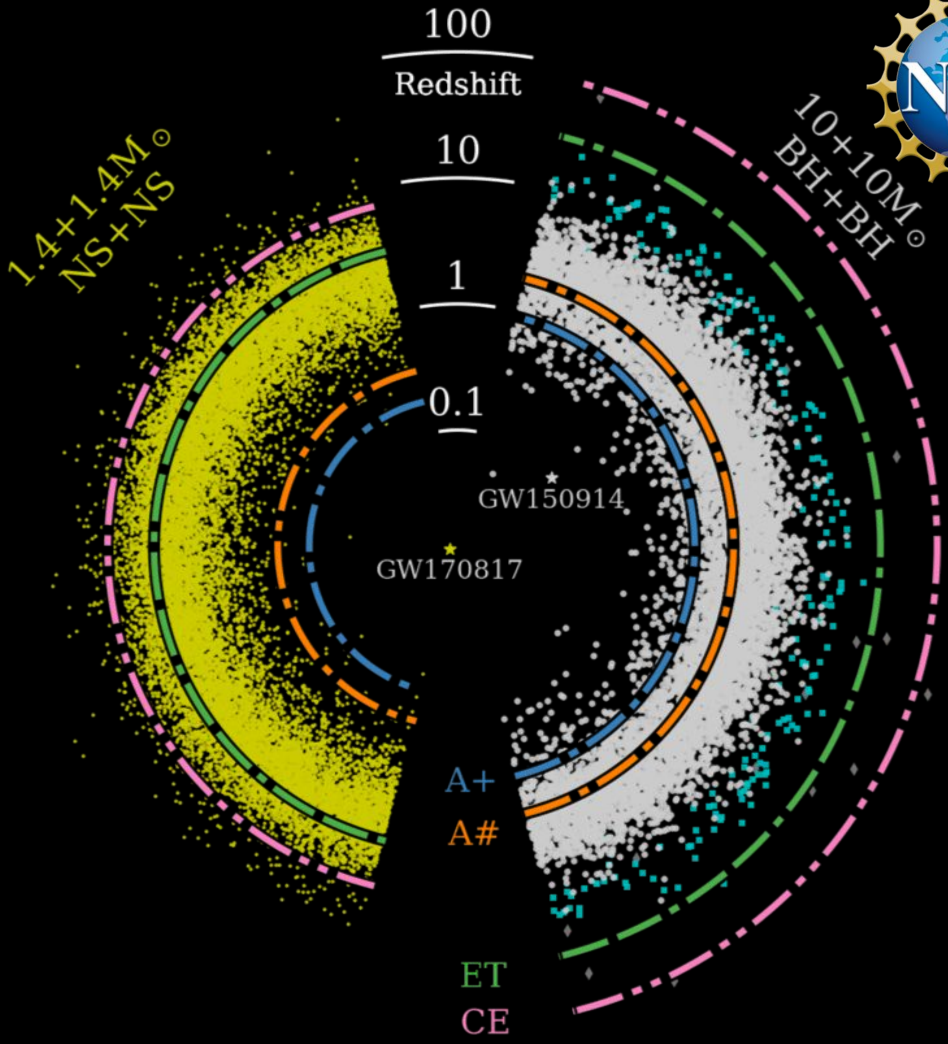


https://arxiv.org/abs/2306.13745

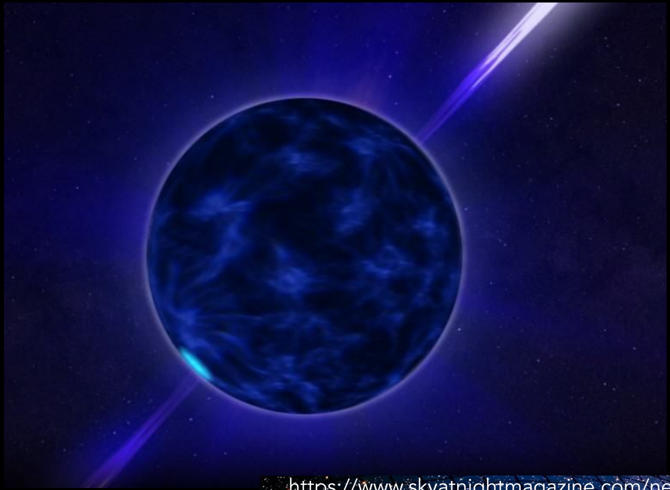
Science: Binaries

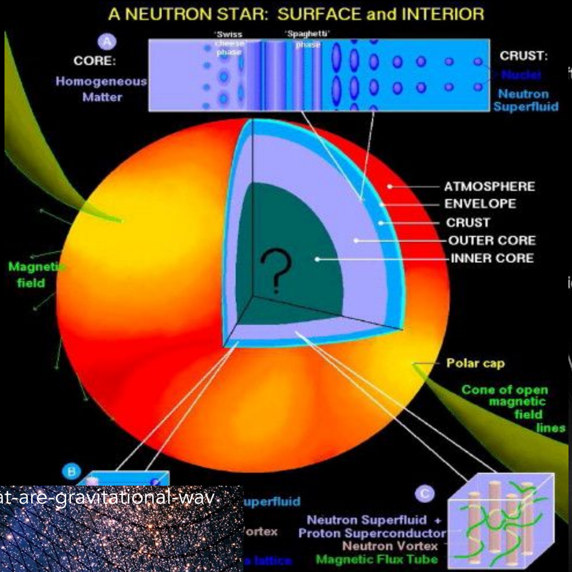
- The best understood source of gravitational wave emissions for CE/ET are compact stellar-mass binary systems.

- ET/CE will be able to detect effectively *all* stellar-mass systems in coalescence

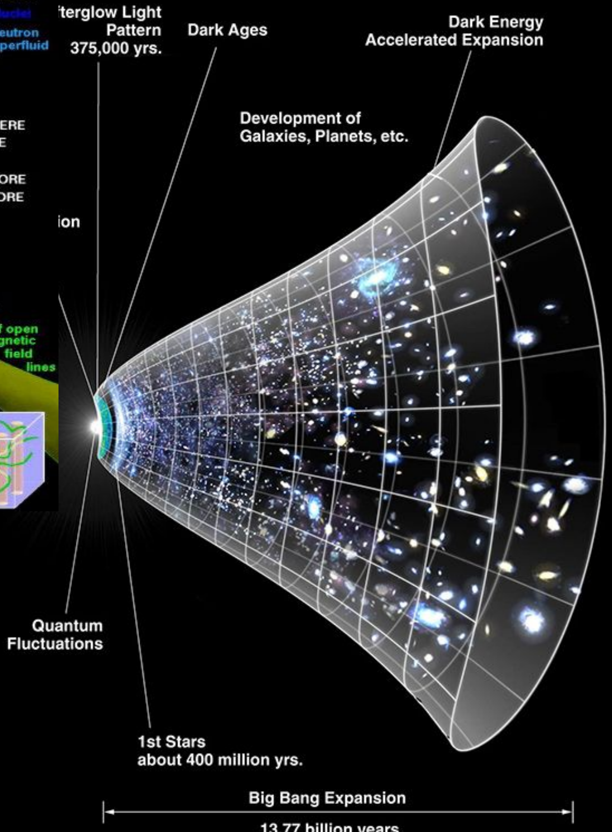


ET/CE Science Objectives





https://www.skyatnightmagazine.com/news/what-are-gravitational-waves



https://astronomynow.com/2025/06/09/is-the-hubble-tension

ET/CE Science Objectives

- Compact Objects Across Cosmic History
  - When did the first black holes form?
- Matter at Extreme Density
  - What is the equation of state of supranuclear matter?
- Strong-Field Gravity
  - Does gravity behave exactly as predicted by GR?
- The Dark Universe
  - Shed light on dark matter and its interactions?
- Cosmology
  - How accurately can gravitational waves measure H0?
  - Can GW observations constrain dark energy?
  - What can compact binary populations reveal about cosmic structures?
- Multimessenger observations
  - What fraction of the cosmic abundance of heavy elements originate in compact binary mergers?
  - Are binary neutron stars also responsible for high energy neutrinos in the Universe?
- Surprises
  - 1/100 year local Supernova
  - Initially unexplained unambiguous network-detected signals

Cosmic Explorer Design Philosophy

LIGO – Initial, and then Advanced – established an excellent paradigm for Observatory and Instrument design. CE is an evolutionary step forward:

- Design of Observatory and Detector motivated by astrophysics
  - Initial/Advanced LIGO were designed at the limit of technology
  - CE has some degrees of freedom to focus on Astrophysics Goals
  - Enables a true "Science flowdown"

- Low risk for observatory configuration
  - Huge capital investment required for the Observatory
    - → Scale up LIGO
- Low risk for the initial detector
  - Must have high confidence in quick success with Initial detector
    - → Scale up LIGO
  - 50 year lifetime, flexible buildings will allow new ideas for later detectors – Coatings/NewtonianNoise/Topologies/Quantum/AI/Cryogenics/etc.

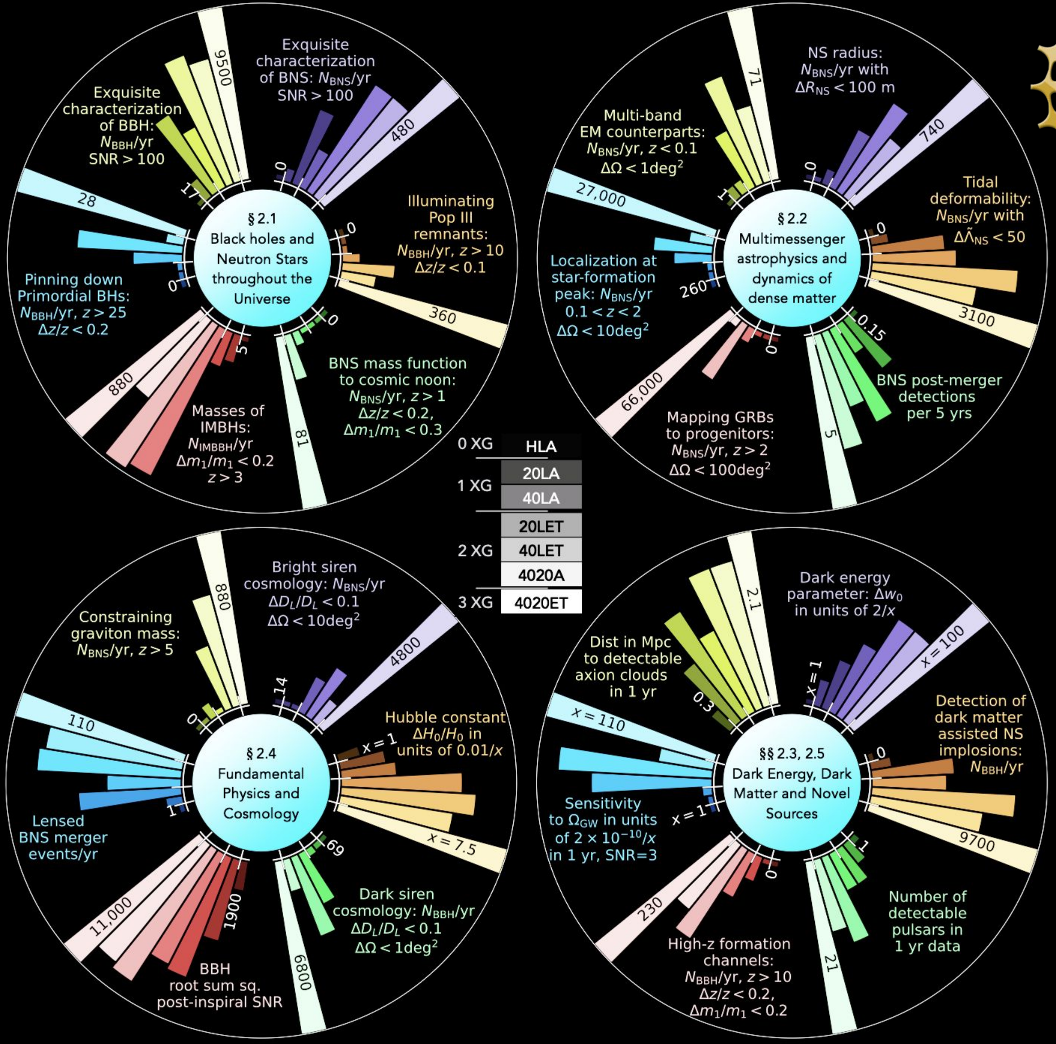
Science Traceability Matrix

Objective: Justify funding via with strategic, clearly stated/credible, science goals

- **Science Goals**: From high-level strategy/vision documents.
- **Science Objectives**: The specific science questions we need to answer.
- **Measurement Objectives**: The specific measurements required.
- **Measurement Requirements**: What a measurement must include in terms of content, precision and quality in order to accomplish the measurement objectives.
- **Instrument Technology Requirements**: Identify technology critical for accomplishing the measurement requirements (including detector networks).
- **Data Products**: Define the output of each measurement, including likelihood, Bayesian evidence, Bayes factor, etc.

Science Traceability Matrix

Assessing the Science Objectives



Observatory Design

- 10x longer than LIGO
    - 40km baseline (+20km for BNS)
    - Boosts sensitivity x10
- Surface construction
    - Sacrifice some low-frequency sensitivity (Newtonian Noise)
    - Gain length, moderate the cost, maximize future flexibility
    - **Completed architectural study** ⟶
- Vacuum system study underway
    - Significant NSF funding
    - Collaboration with CERN, ET

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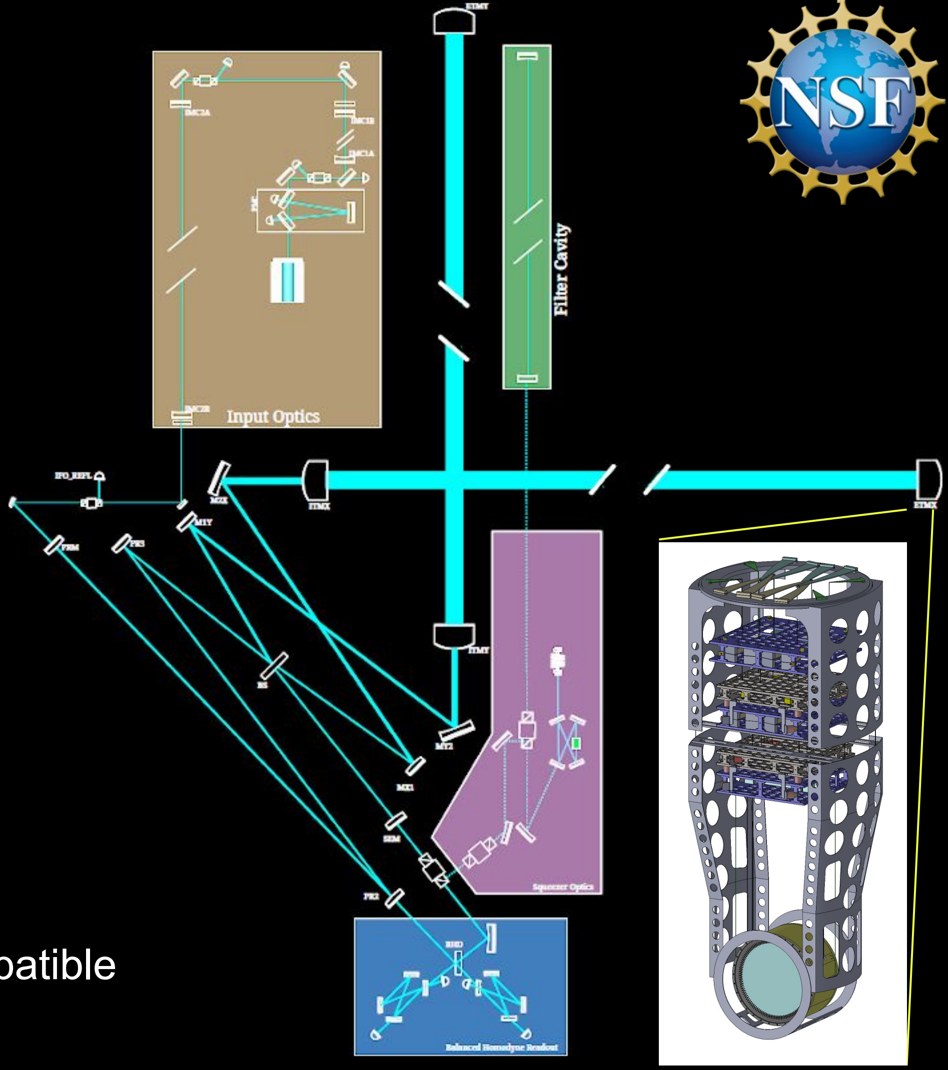
Path to Cosmic Explorer:
LIGO A# upgrade

	LIGO A+ (O5)	LIGO A# (O6)	CE
Arm Length (km)	4	4	40
Wavelength (nm)	1064	1064	1064
Mirror mass (kg)	40	100	440
Mirror diameter (cm)	34	46	80
Coating noise	1	0.5/0.1	1 (!)
Arm Power (MW)	0.75	1.5	1.5
Squeezing (dB)	6	10	10



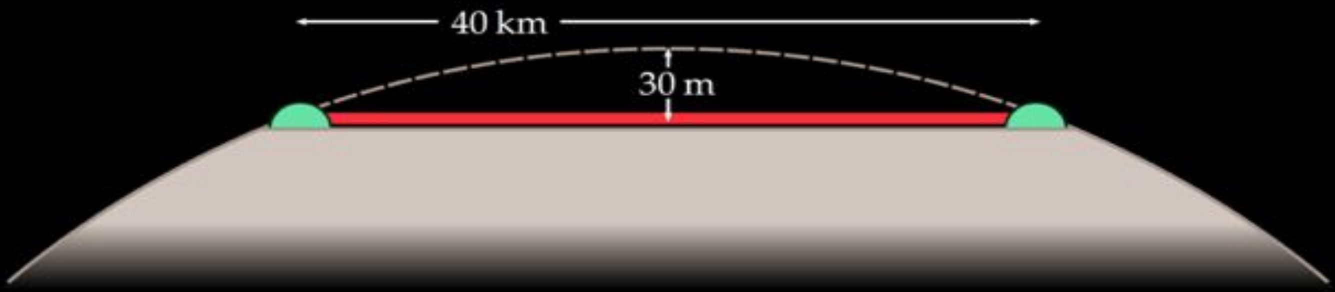
Facility designed to be compatible
with future upgrades

COSMIC EXPLORER

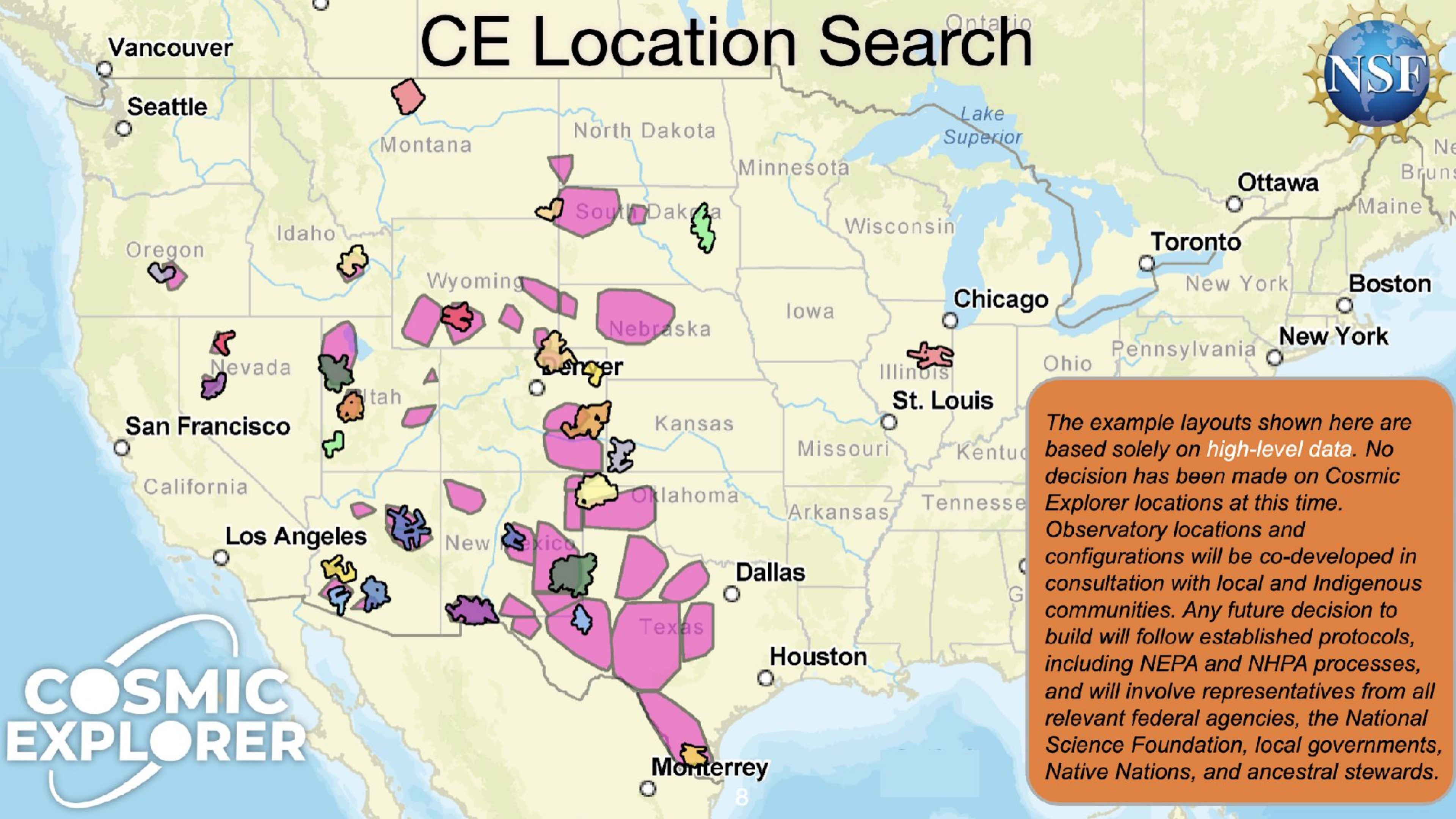
Cosmic Explorer Location Search

- Main Criteria: Observatory footprint, Global separation and orientation, Environment and geology, Environmental limits to sensitivity and up-time, Cost boundaries and access, Land rights and permitting, interests and context, Quality of life, Indigenous Peoples protections

- **Observatory Footprint:**
  - A sample site that follows Earth curvature would require order of **20 million cubic meters** of earth to be moved
  - A sample site that has a ‘bowl’ in elevation would only require order of **4 million cubic meters** earthmoving



CE Location Search



The example layouts shown here are based solely on high-level data. No decision has been made on Cosmic Explorer locations at this time. Observatory locations and configurations will be co-developed in consultation with local and Indigenous communities. Any future decision to build will follow established protocols, including NEPA and NHPA processes, and will involve representatives from all relevant federal agencies, the National Science Foundation, local governments, Native Nations, and ancestral stewards.

COSMIC EXPLORER

Figures from Preliminary Site Selection Report

Delivered to NSF

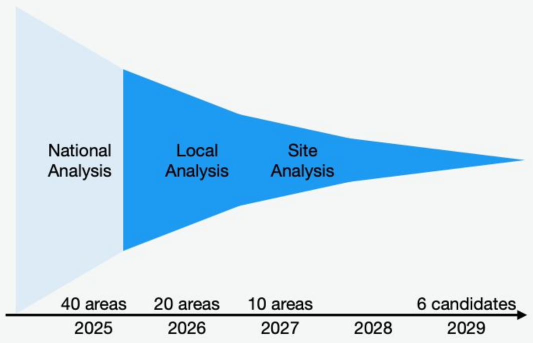


Figure 2: Timeline showing the progression from national, to local, and site-level GIS analysis along with the reduction in number of areas being considered, finally reaching 6 candidate sites.

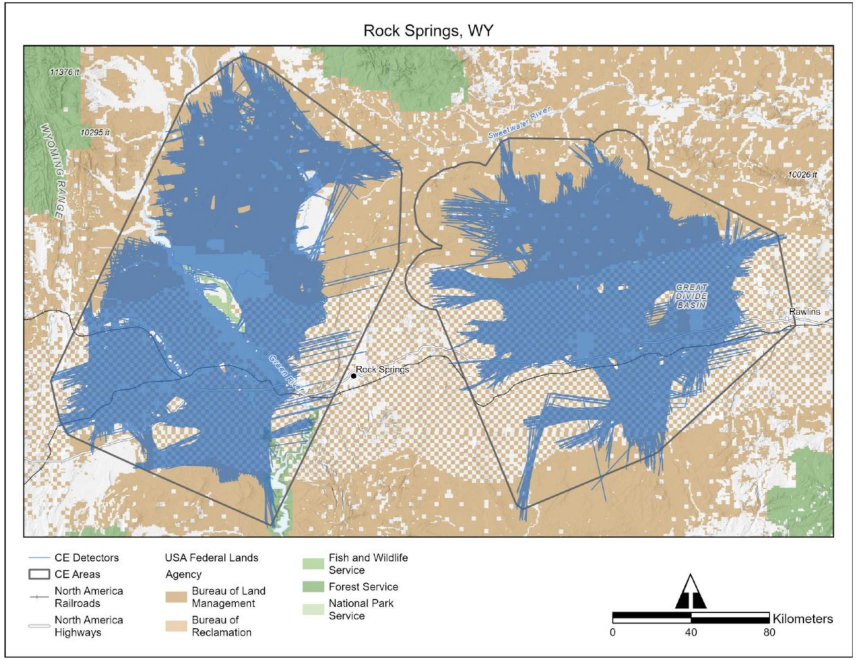
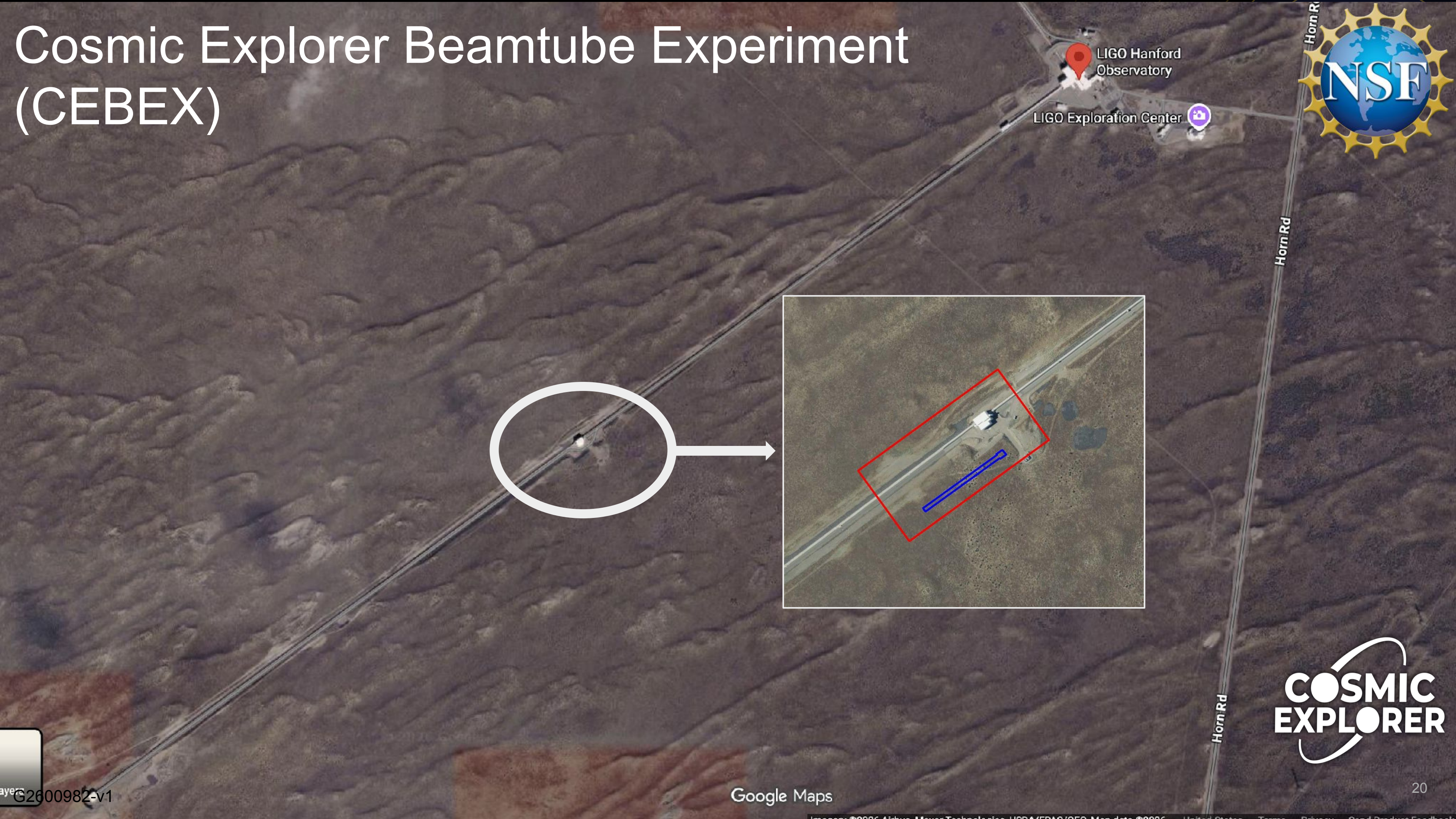


Figure 39: Map showing 40 km potential detector layouts (NSA suitable alignments and CELS low-cost placements) and zones (NSA areas of interest and CELS low-cost zones), overlaid on surface management, highways, and railroads for this location.

COSMIC EXPLORER

Cosmic Explorer Beamtube Experiment (CEBEX)



CEBEX Goals

- CEBEX program goals
  - Cosmic Explorer Beamtube Experiment-goal reduce BT cost, speed build rate
  - What we learn on CEBEX will flow into the CE design.
  - The program: 4-year 17.5M funding.
- Evaluate methodologies to *economically* build a 40km beamtube.
  - CE is a 10x scale LIGO but we don't want to take 10x longer to build it (20+ years)
  - Reduce costs: Leverage materials, methods and tech from large scale projects- oil pipelines, pipe mills, alt SSTs, modern technologies.
  - Reduce touch labor : combine functionality, novel designs, LIGO lessons learned
  - Increase assembly rate : automated equipment, design self-fixturing components
- **Partnering with CERN and ET to share ideas and lessons learned - ET and CE have the same challenges.**

CEBEX Status

- Facility structure construction well underway; completion Jan ‘27
- Installation of beam tube complete Jan ‘28
- CE Concept established Sept ‘28

Funded areas of conceptual design work

NSF funded several proposals in Fall 2023; 3 year proposals

- Core Project – Management, Requirements, Engineering, Central Services
- Site Search and Indigenous Place-based Partnerships
- Interferometer Optical Design
- Mode Sensing and Control
- Stray Light Control

And there are some important efforts that have been funded since:

- Vacuum R&D, prototyping and design (CEBEX)
- Digital Architecture
- Newtonian Noise
- UK STFC funding (supporting CE and ET) – Instrument and Observational Science

Fall 2025 Renewal proposals for Site Search, and Core Project received partial funding; no funding for Optical Design

Areas of CE-ET collaboration

Currently:

- Vacuum beam tube material and process (with CERN)
- Periodic ‘XGCD’ technical deep dive online meetings
- Science case development – Science Traceability Matrix
- Mutual review of internal documentation
- Panels and Advisory Committee cross-pollination
- Participation in GWIC – Gravitational-Wave International Committee
- NSF-initiated GWAC – Gravitational-Wave Agencies Correspondents

Goals for coming years:

- Leadership regular contact; joint Working Group/Collaboration meetings
- Network optimization; coordination of large-scale planning

Concluding Remarks

- There has been great progress in the last three years of design-phase funded activity
- The Cosmic Explorer project is evolving into a more formal project structure that will enable the pace of progress to increase/accelerate, assuming appropriate funding levels
- Driving towards the formal design processes including conceptual, preliminary, and final design phases
- ET and CE will form a formidable network!

CE vertex concept by SmithGroup