ET Symposium 2024

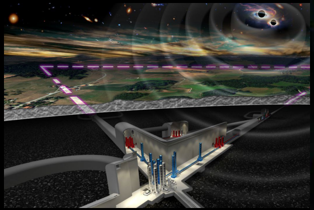
Cosmic Explorer: Status and Plans

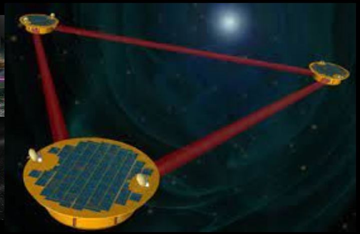
Lisa Barsotti (MIT)
for the Cosmic Explorer Project

Brief Recap

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
- will operate as part of a global network with ET, LISA, and others

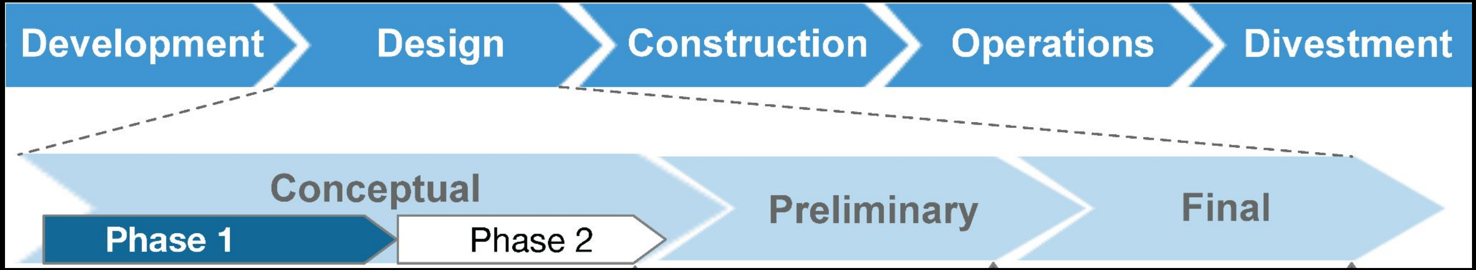




CE is envisioned as an NSF-led Project

- 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 core

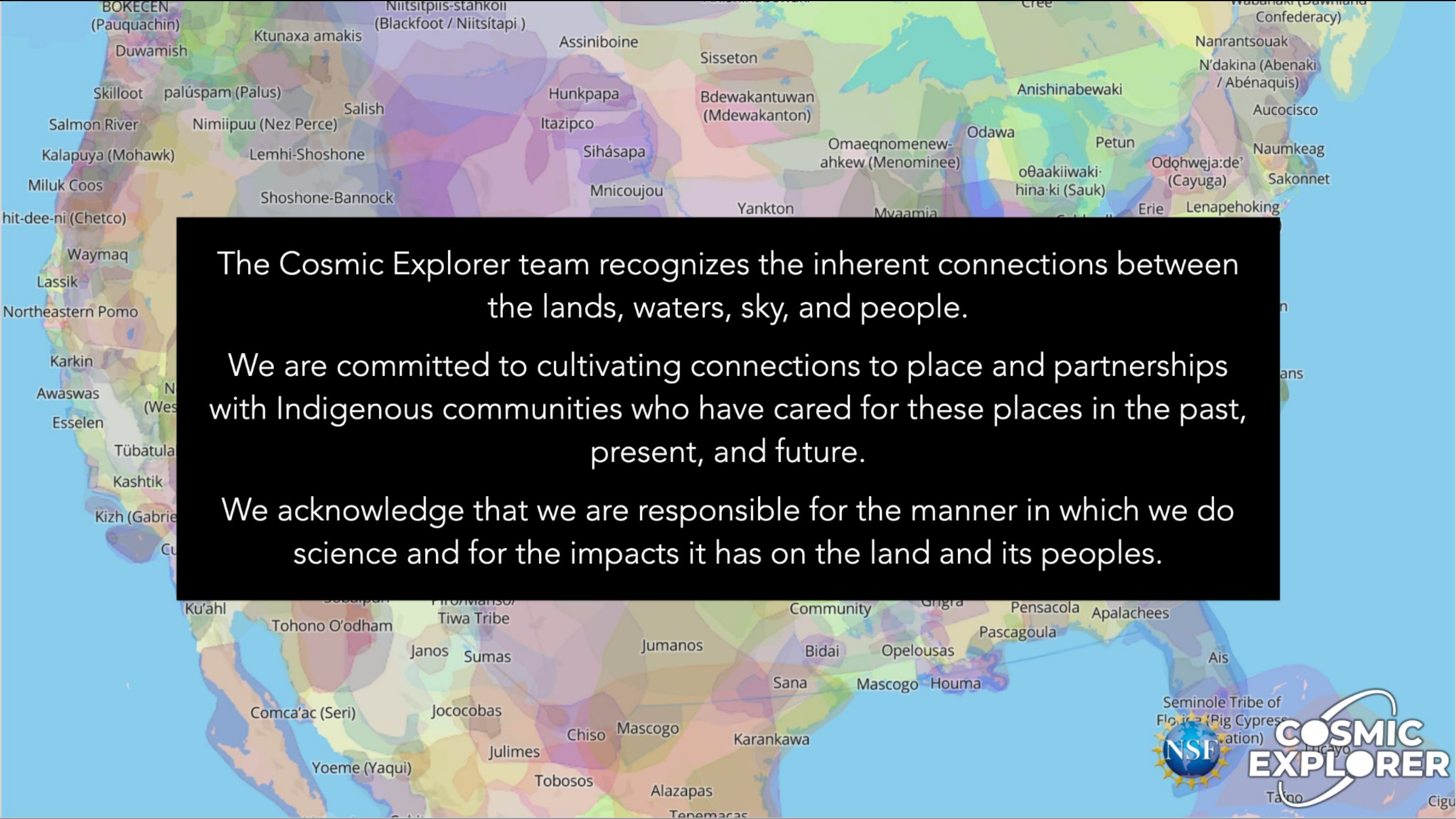
NSF processes define the possible CE funding path and project timeline



The Cosmic Explorer team recognizes the inherent connections between the lands, waters, sky, and people.

We are committed to cultivating connections to place and partnerships with Indigenous communities who have cared for these places in the past, present, and future.

We acknowledge that we are responsible for the manner in which we do science and for the impacts it has on the land and its peoples.



Breaking news:
Cosmic Explorer recommended to the NSF!

Next-Generation Gravitational Wave Observatory Subcommittee (NextGenGW SC)

https://www.nsf.gov/mps/phy/nggw.jsp

The Assistant Director of the Mathematical and Physical Sciences Directorate requests that the Mathematical and Physical Sciences Advisory Committee (MPSAC) establish a Next Generation Gravitational Wave (GW) Detector Concept Subcommittee (NextGenGW SC) to assess and recommend a set of concepts for new GW observatories in the U.S.

- aLIGO facilities to be phased out by the time the CE wide-band sensitivity (of one or two detectors) is better than that of the aLIGO detectors.
- The availability of the LIGO-India detector in the network is important for MMA and, in fact, critically important in the absence of ET. The absence of LIGO-India cannot be balanced by keeping the aLIGO detectors operational.

ngGW Subcommittee Report to MPSAC, March 2024

CE40, ET, LIGO-India (Network #1)

CE40, ET (Network #2)

CE40, CE20, LIGO-India (Network #3)

CE40, CE20 (Network #4)

credit: Vicky Kalogera, Harald Lueck, Marica Branchesi and others

What does it mean for CE?

- Design study will continue as planned for CE 40km + 20km
- Encouragement to continue exploring multiple options from the scientific side
  - E.g., Collin Capano: should we stop using 40km+40km for simulations and papers?
  - Vicky Kalogera: No, we will want to keep exploring science that can be done in the best case scenario, scientifically. Also the landscape might change in the next few years.
- We will continue the design work with parallel coordinated efforts
- The expectation is that the NSF Physics Division, via the Assistant Director for Mathematical and Physical Sciences, will request the NSF to consider adding CE to the list of “mega-projects”

Cosmic Explorer Timeline

What are the steps for Cosmic Explorer? (Dawn V 2019)

Horizon planning (3G Design NSF award in 2018)	3 years (2021)	CEHS (2021)
Cosmic Explorer White Paper (3G Design award product)		
Community endorses the WP (through Dawn meeting?)	½ year (2021)	Dawn VI (2021)
NRC report based on CE WP and GWIC reports	1 ½ years? (2023)	Bypassed
MPSAC subcommittee reviews NRC report	½ year (2024)	ngGW (2024)
Physics Division develops a written plan for MPS approval		In the works
NSF Director decides to authorize CD funding		In the works
Conceptual Design period	2-3 years (2027)	Support started in 2023 ($8M)
Preliminary Design period award	2-3 years (2030)	
NSF approves submission to NSB	½ year (2030)	
Final Design period	2-3 years (2032)	
NSB prioritization		
OMB/Congress budget negotiations		
Congress appropriates MREFC funding (2032-37)	**14 years (2032)**	

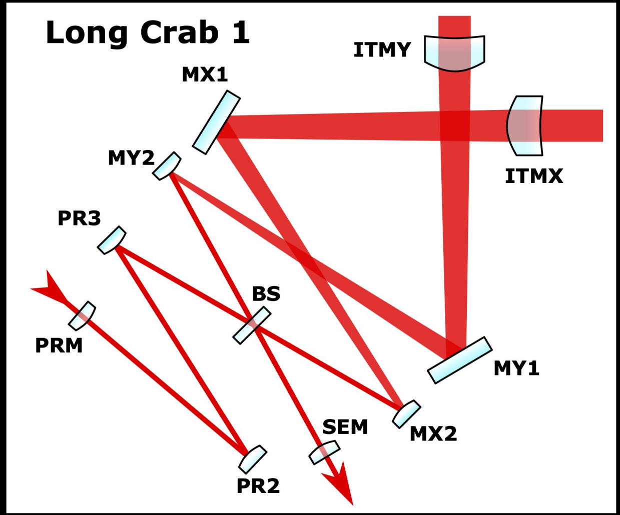
credit: Pedro Marronetti (NSF gravity program director)

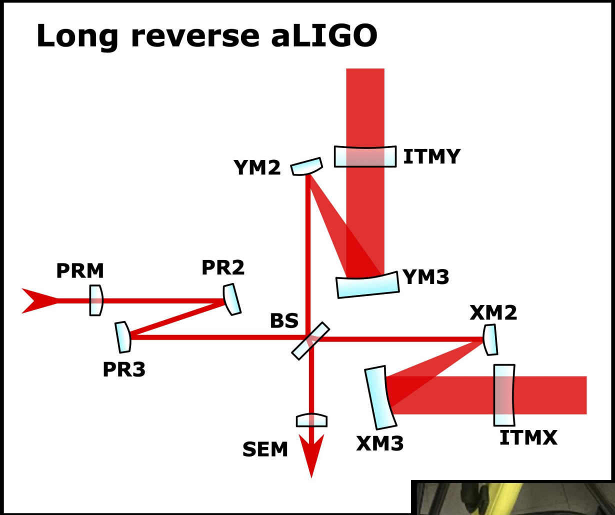
Several design activities ongoing

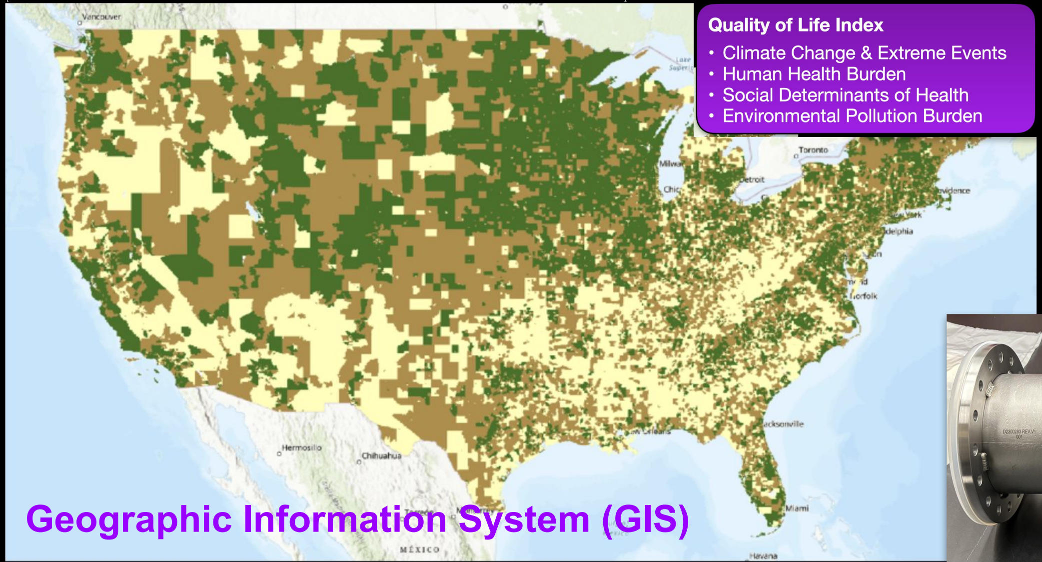
- Vacuum work
- Site evaluation and indigenous and place-based partnership
- Optical design and Mode Sensing and Control
- Project “core” (coordination, management, project structure)
- Straylight mitigation (in part)

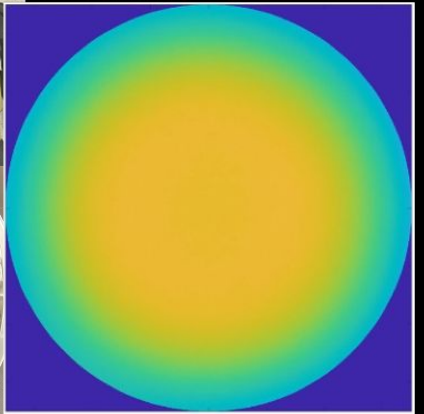
<u>Hot topics these days:</u>

- Robust design to achieve 1.5 MW arm power and 10 dB squeezing
- Beam tube baffle design
- Process and community engagement for site evaluation


Long Crab 1
ITMY
MX1
MY2
ITMX
PR3
BS
PRM
MY1
SEM
MX2
PR2


Long reverse aLIGO
ITMY
YM2
PRM
PR2
YM3
BS
XM2
PR3
SEM
XM3
ITMX


Quality of Life Index
• Climate Change & Extreme Events
• Human Health Burden
• Social Determinants of Health
• Environmental Pollution Burden
Vancouver
Toronto
Detroit
Hermosillo
Chihuahua
Miami
Havana
Geographic Information System (GIS)



neXt-Generation Collaborative Design (XGCD)

https://indico.gssi.it/e/xgcd

- ET-CE technical discussion on topics of common interest
- Optical Design and Straylight mitigation discussed so far
  - Inputs to me and Jan on topics of interest and volunteers to lead discussions are very welcomed!

NeXt Generation Collaborative Design

Monday Apr 22, 2024, 11:00 AM → 12:40 PM US/Eastern

Jan Harms (Gran Sasso Science Institute), Lisa Barsotti (MIT)

Description The goal of this series of online meetings is to provide a forum for regular discussions between the teams that work on common design aspects of next-generation gravitational-wave detectors Einstein Telescope and Cosmic Explorer.

The plan is to have a meeting each 2-3 months and start with topics that are more urgent, i.e., that have a strong impact on the detector infrastructure including optical layout, stray-light noise, Newtonian noise, ...

More activities ramping up this year

- Major vacuum proposal led by Mike Zucker submitted to the NSF in February to build a “sector test” prototype of the CE vacuum tube at Hanford
  - Proposed work tightly coordinated with ET-CERN vacuum team
- Straylight mitigation, newtonian noise studies, suspension design, science data processing
- Activities in UK in support of “next-gen GW” started

“Next-gen GW” - The next-generation gravitational-wave observatory infrastructure

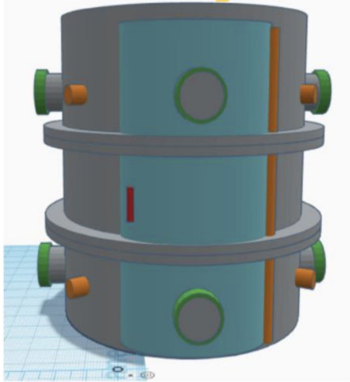
Sheila Rowan

An award by the UK Science and Technology Facilities Council (2023 – 2026)

University of Birmingham, Cardiff University, University of Glasgow, University of Portsmouth, University of Southampton, University of Strathclyde, University of the West of Scotland.

- Collaborations with Germany, Australia, Canada

Sheila Rowan



WP 1.2.3. Vacuum tank (3.5m tall) currently under tender. Delivery late 2024.

An energizing Cosmic Explorer Symposium April 23-25!

Second Cosmic Explorer Symposium

Apr 23 – 25, 2024
Zoom
America/New_York timezone

https://indico.mit.edu/e/CES2024

Thanks to several ET members for contributing to the CE Symposium: Jan Harms, Stefan Hild, Dan Brown, Piero Rapagnani, Jerome Degallaix, Andreas Freise, Michela Mapelli

CE Symposium - Observational Science Highlights

- Several members of the broader community gave an overview of the scientific potential of XG gravitational-wave detectors
  - One area of particular interest is exploring the connection with high energy physics science, following recommendation of the P5 report

> Gravitational waves are a powerful new tool for exploring a range of astronomical and particle physics topics, including probing the expansion history of the universe using standard sirens. NSF has been an excellent steward of this program and should support the development of new capabilities and a next-generation project. The particle physics case for studying gravitational waves at all frequencies should be explored by expanded theory support.

  - Discussion on going about starting a “topical group” in the CE Consortium to understand the science implications of NOT having a CE 20 km detector

CE Symposium - Instrument Science Highlights

- Optical design: we move ahead with two corner layouts, several suggestions for additional studies; need to identify areas that require dedicated experimental effort in addition to ongoing efforts (if any)
- Coatings: we will write down a “coating manifesto” for CE - very much interconnected with path forward for A#
- Facility compatibility with cryogenics: several requirements to make the CE facility compatible with cryogenics identified (as potential future upgrade), they need to be written down and additional calculations need to be done
- R&D for CE and connection with A#: first draft of a table that goes in some of the details of the needed research; need to add prioritization

Future

- GW Detector construction will transition from a MREFC level (2G) to a supra-MREFC level (3G), similar to those of the largest scientific installations in the world (CERN, Fermilab, etc.)

- What worked for LIGO/Virgo in the past may be inadequate for projects like Einstein Telescope/Cosmic Explorer. More human resources need to be dedicated to the social/collaborative/organizational/political efforts

- The scientific and political paths ahead are not clear and they will possibly not be for a while
  - A management organization (awardee) must be identified
  - R&D and design concepts might need to be developed and re-developed
  - International collaborations must be formalized
  - Scientists and funding agencies need to work on a viable plan to support the construction and, also critically important, the operations of these installations

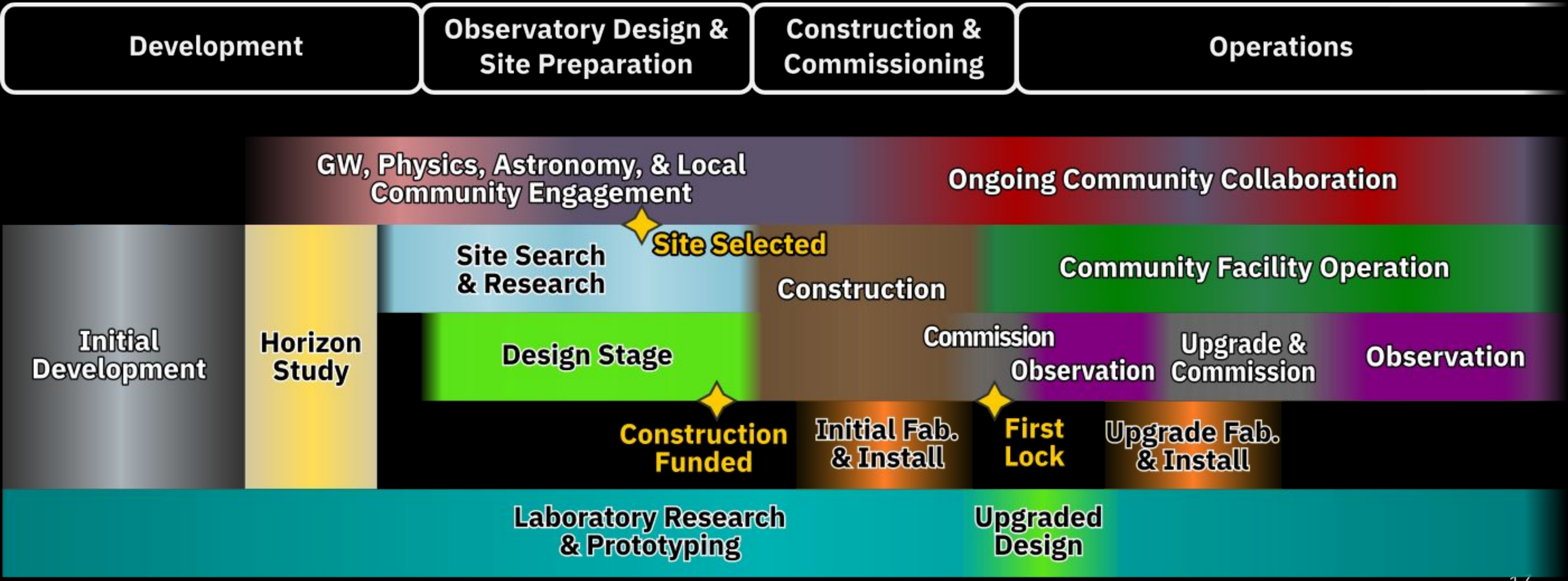
credit: Pedro Marronetti (NSF gravity program director)

The Message

- Work will continue with the current CE “distributed” structure for a while
- NSF Physics division working to propose CE for the NSF large facility process
  - This would allow CE to enter the “design stage” for NSF major facilities
- We received several recommendations, including:
  - continue the design as planned for CE 40km + 20km, keep studying scientific benefits of multiple network configurations
  - strengthen international collaborations
  - think about a management structure
  - keep in mind that what worked in the past might not worked in the future
- Important to establish close collaboration with ET on topics of common interests:
  - It is already happening on the technical side (Vacuum, XGCD, …)
  - It will be great to find a venue to discuss other aspects (like IGWN, …)

Backup Slides

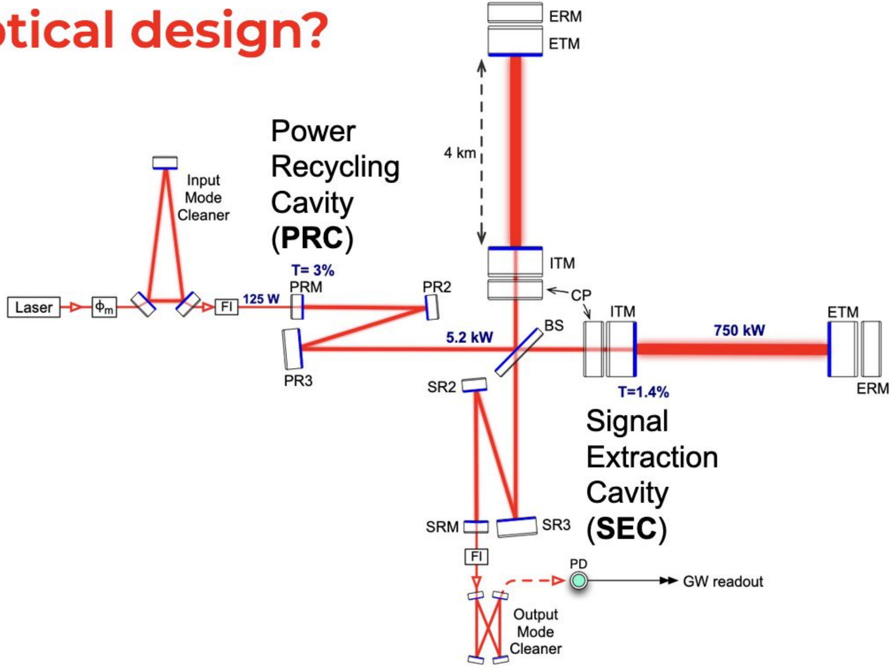
Cosmic Explorer Timeline



Upgrade Path for Fused-Silica Interferometers

Why not just scale up LIGO optical design?

Quantity	A+ (O5)	A# (O6)	CE
Arm length (km)	4	4 →	40
Wavelength (nm)	1064	1064	1064
Mirror mass (kg)	40 →	100 →	320
Mirror diameter (cm)	34 →	46 →	70
Arm power (MW)	0.8	1.5	1.5
Squeezing (dB)	6	10	10



Credit: Paul Fulda and Jon Richardson for the Optical Design team

Cosmic Explorer: Why Not Just Scale up LIGO Design?

1) Unique challenges arise from a 10x longer arm length (CE-G2300033)

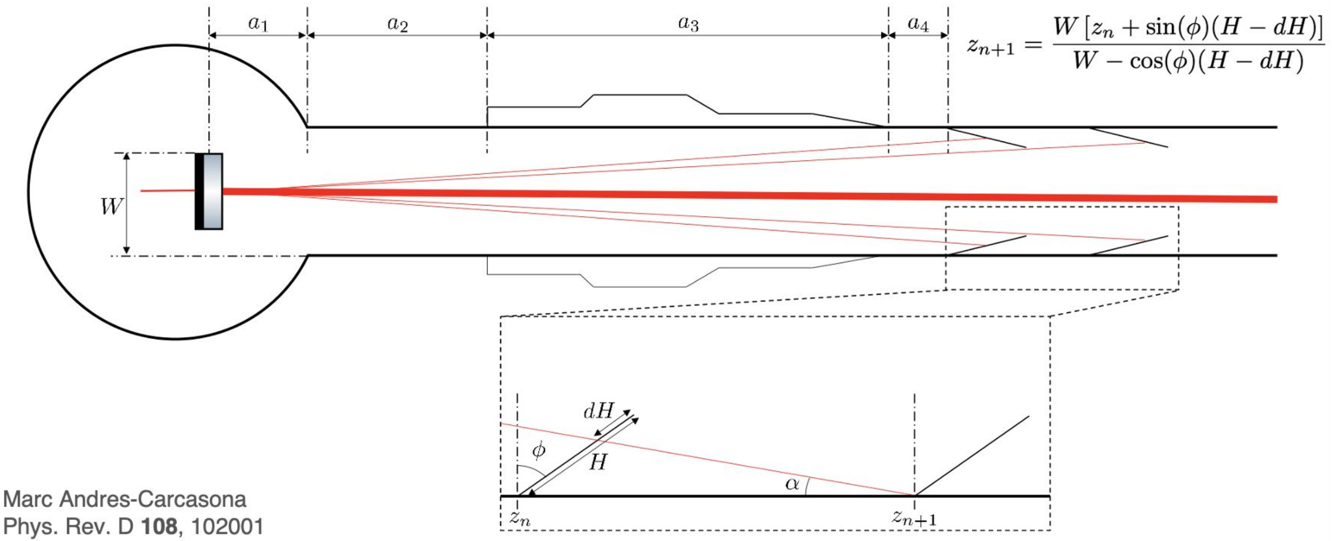
- Minimum beam size for 40 km arms is ~12 cm. For < 1 ppm clipping loss on ITMs, require **~70 cm ITMs**. Beamsplitter should be **√2 bigger*** (at 45° AOI). *1 m diameter unfeasible*?
  - ➥ Consider alternate layouts with a **different beamsplitter location**
- SEC resonance **approaches detection band** with 40 km or 20 km arms ($f_s \propto 1/\sqrt{L_s}$)
  - ➥ SEC length must be kept to **< 200 m** (40 km arms) or **< 90 m** (20 km arms)
- FSR of 40 km arms is 3.75 kHz. With same arm finesse, **DARM pole is 10x lower** ($f_p \propto 1/L_a$)
  - ➥ Need **10x higher SEC finesse** to recover same bandwidth
- With a 10x lower arm cavity FSR, **nearly all higher-order mode (HOM) resonances will lie in the observation band**
  - ➥ **Precision mode-matching** is critical to suppress noise couplings, squeezing loss, and squeezing angle mis-rotation around the frequencies of these resonances

Credit: Paul Fulda and Jon Richardson for the Optical Design team

Baffle Locations: Going beyond ray optics

- Traditional approach to the placement of baffles is to use ray optics and try to shadow the entire beam tube.
- Another approach is to use SIS to calculate the wave propagation and calculate the power on the beam tube between baffles, and try to keep it below a given threshold

Ray Optics



Marc Andres-Carcasona
Phys. Rev. D **108**, 102001

Credit: Antonios Kontos for the straylight team

Integrated Approach to Location Identification and Evaluation

Suitability analysis uses weighting of mapped variables

Cost

- Flatness
- Tilt
- Landcover

Positioning

- Opening Angle
- Orientation

Science Suitability

- Flatness
- Seismic Noise
- Seismic Risk

Quality of Life

- Climate Change & Extreme Events
- Human Health Burden
- Social Determinants of Health
- Environmental Pollution Burden

Social Landscape

- Creative Capital
- Workforce Sustainability
- Social Climate
- Attitudes toward science

Masking / Toggle Layers

- Wilderness / BLM Land
- Federal American Indian Reservation
- Military Installations
- Bodies of Water
- Roads
- Railroads
- High Population Density

NSF

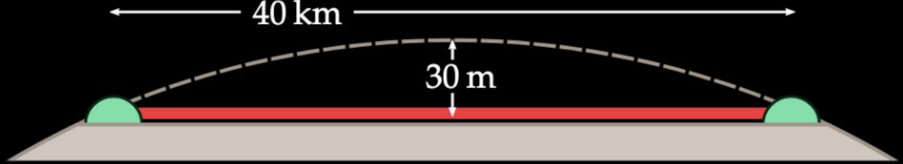
COSMIC EXPLORER

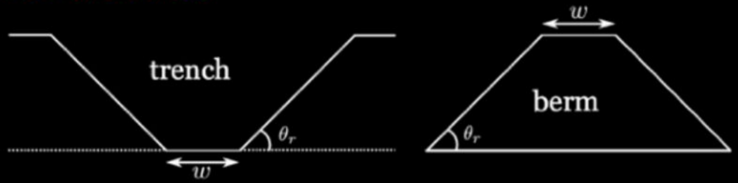
Credit: Josh Smith and Kate Daniel for site eval and IPP-RS teams

Position Optimization and Costing

1) Euclidean flat (basins, bowl elevation) minimize cost and changes to the land.

$$H = \frac{L^2}{8R_{\text{Earth}}} \simeq \frac{(40000\text{ m})^2}{8 \times 6400000\text{ m}} \simeq 30\text{ m}$$

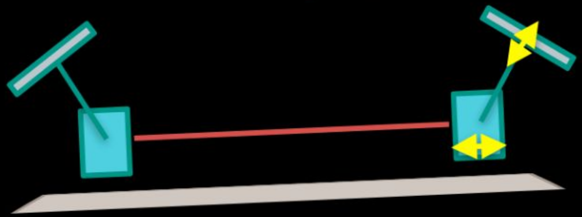




$$\text{elevation score} = \frac{V_{\text{cut}} + V_{\text{fill}} + |V_{\text{cut}} - V_{\text{fill}}|}{10^5\ \text{m}^3}$$

2) Tilted arms couple vertical motions into the gravitational-wave readout.

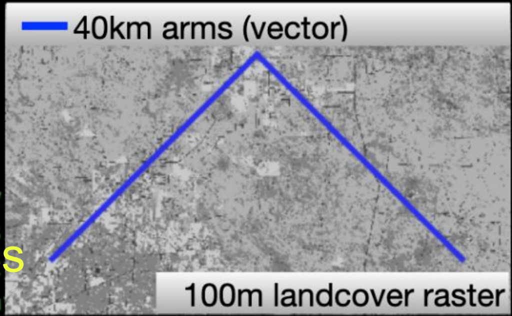
$$\text{tilt score} = 10\left[(\theta_x/\theta_0)^2 + (\theta_y/\theta_0)^2\right]$$



3) Cost, complexity, and changes to land will increase for certain landcover types

$$\text{landcover score} = \sum_{\text{arm points}} (\text{land use score}) \times (\text{length between arm points})$$

```
landcover_score_by_type = {
    0: 1e4,  # ocean
    11: 1e4,  # open water
    12: 1e4,  # perennial ice/snow
    21: 100,  # developed, open space
    22: 300,  # developed, low intensity
    23: 1e4,  # developed, medium intens
    24: 1e4,  # developed, high intensit
    31: 0,  # barren land (rock/sand/cla
```



Credit: Josh Smith and Kate Daniel for site eval and IPP-RS teams

Some figures courtesy T2000016-v2