Status of the Cosmic Explorer Project

Lisa Barsotti
(on behalf of the CE Management Team)

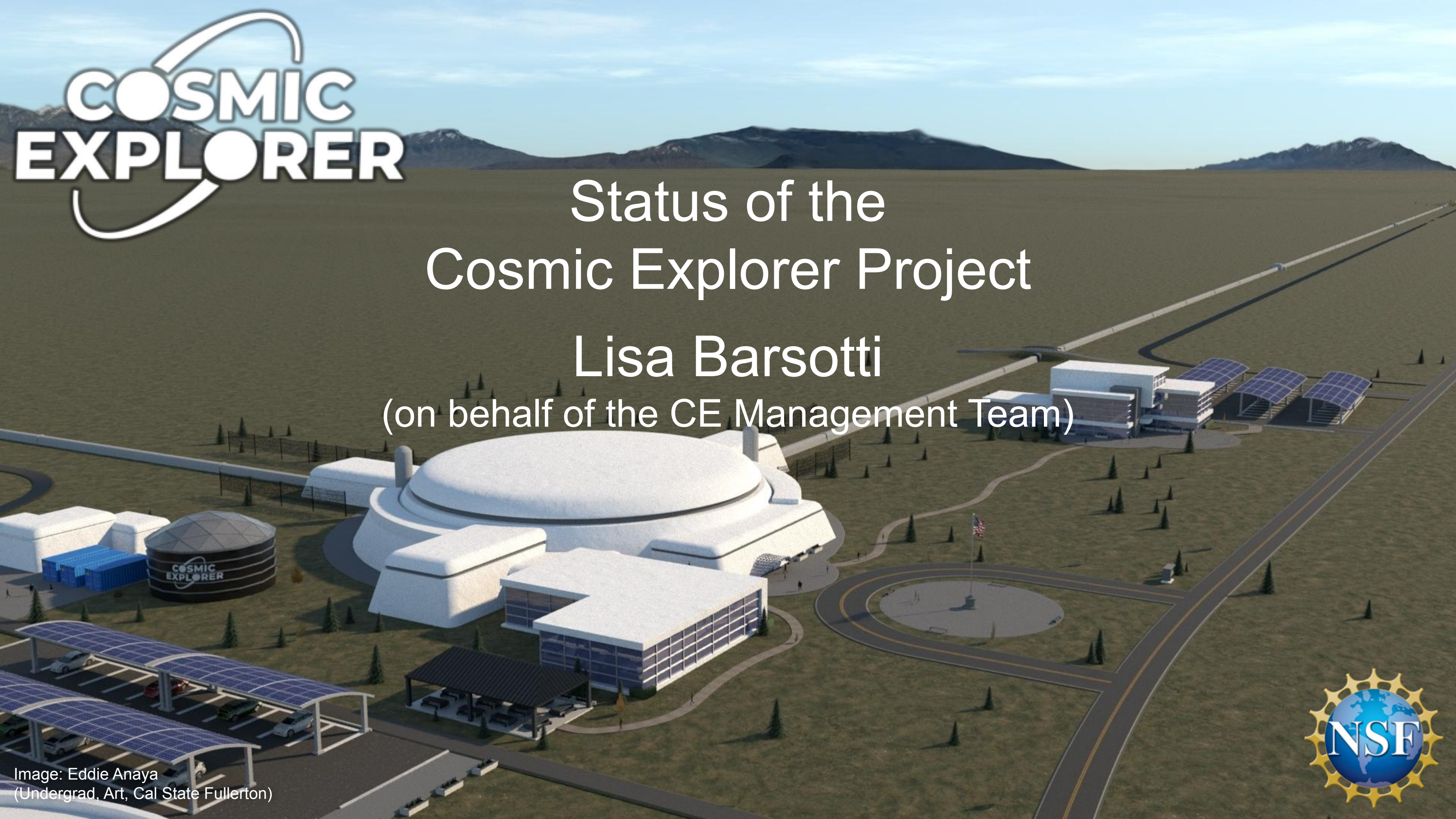
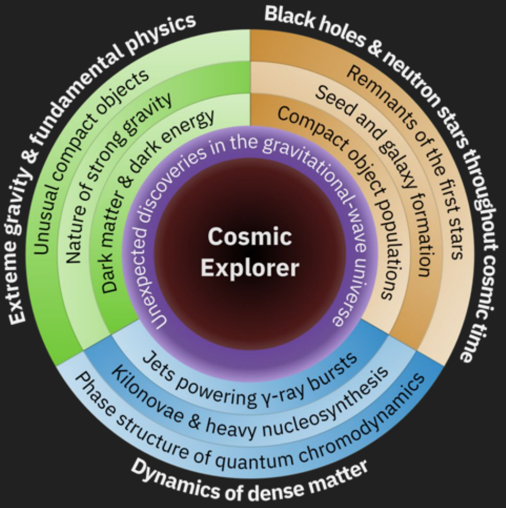


Image: Eddie Anaya
(Undergrad, Art, Cal State Fullerton)

Cosmic Explorer

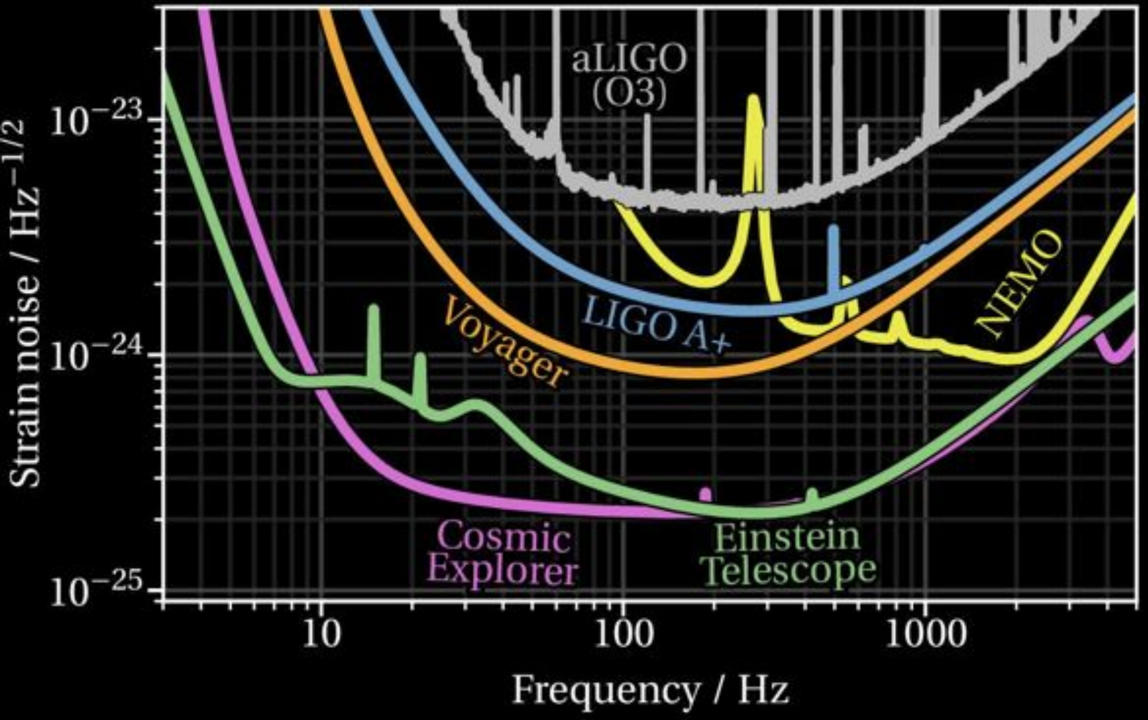
- Next Generation gravitational-wave observatories, US led
- Based on current LIGO concept: 10x longer, 10x more sensitive
- Two L-shaped sites, above ground, one 40km, other 20km arms
- Observatories with ~50-year lifetime, progression of detectors
- $1.6B (2021 $), operational in ~2035
- Community endorsement
    - Dawn meeting 2021
    - Astro2020 Decadal

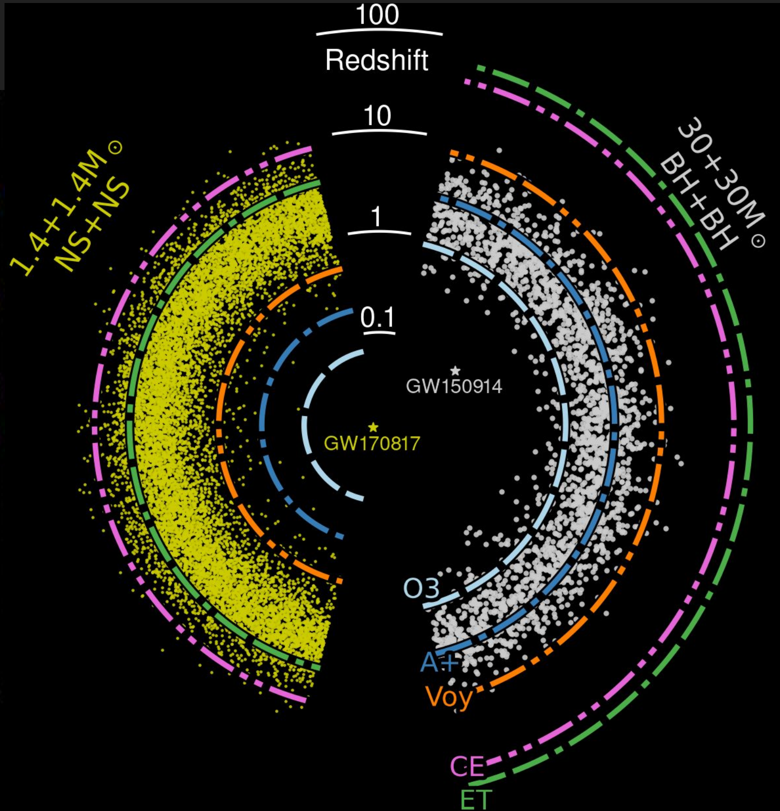


Collaborative study (MIT, Fullerton, Syracuse, Penn State, Caltech)
NSF funded 2018-2021, $2.2M

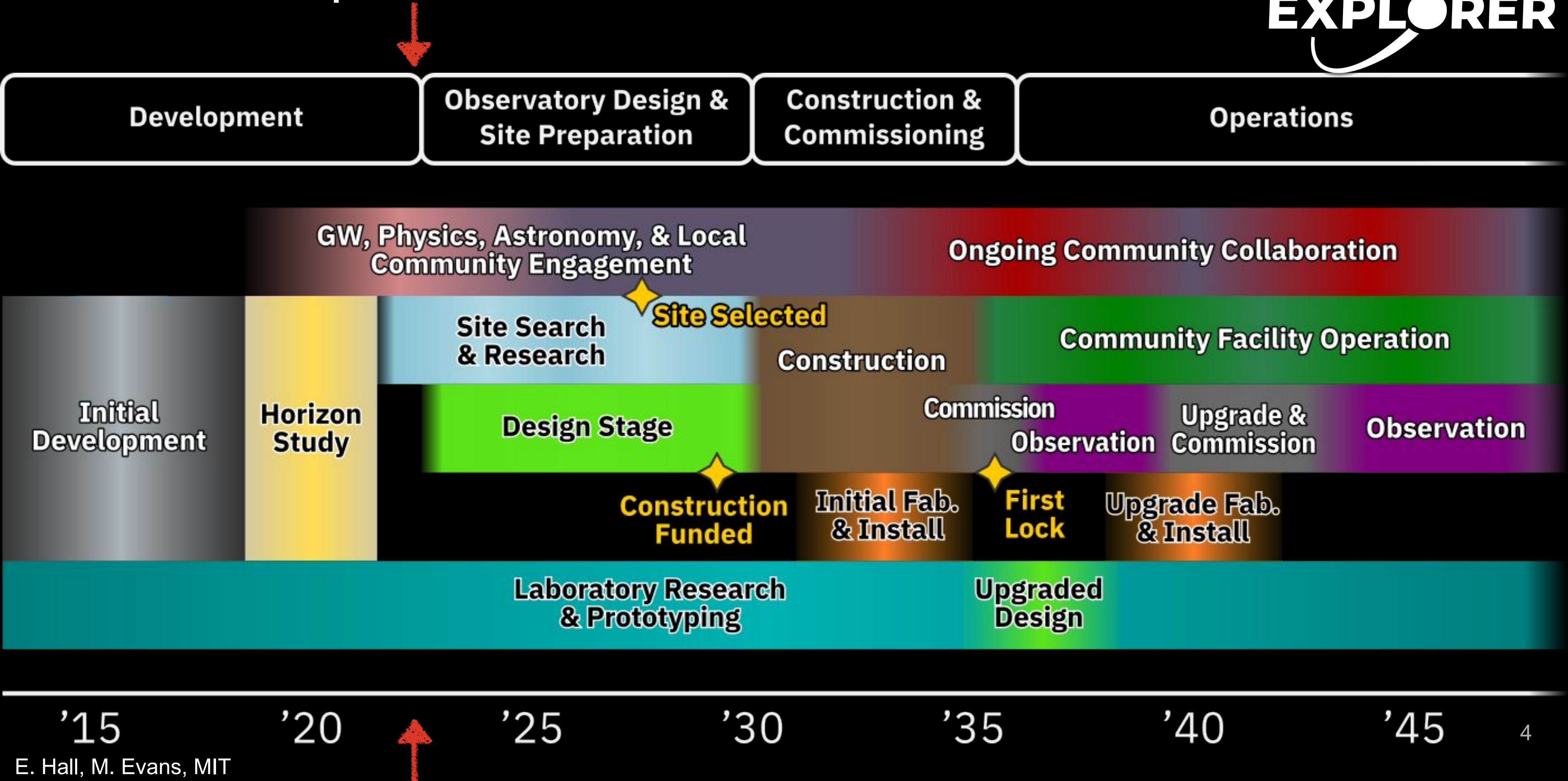
http://cosmicexplorer.org

Cosmic Explorer in context





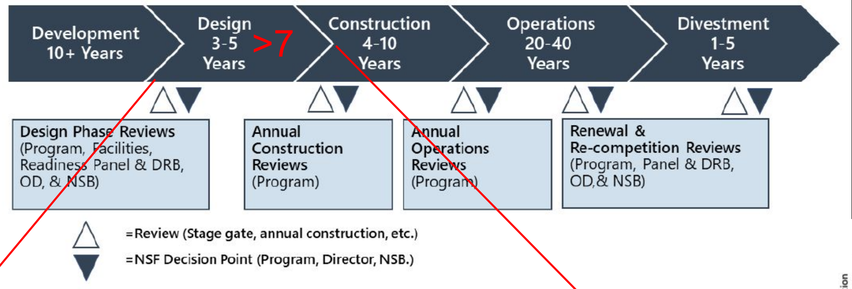
Cosmic Explorer Notional Timeline



E. Hall, M. Evans, MIT

From Development to Design Phase

Figure 2.1.3-1 Progressive steps in the facility life cycle, showing the high-level review and decision points for exit and entry into each stage. The Design Stage is further broken down into phases.



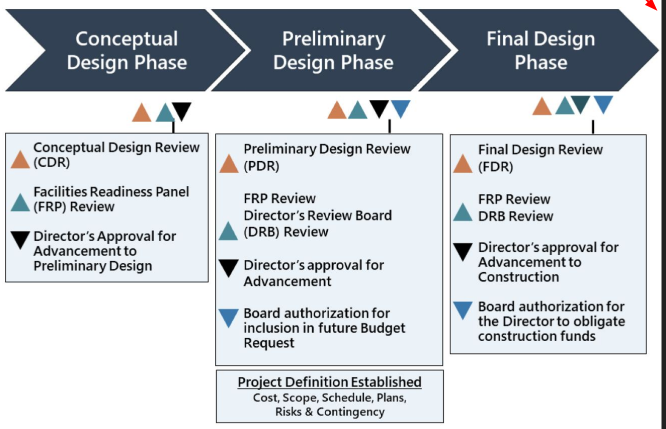


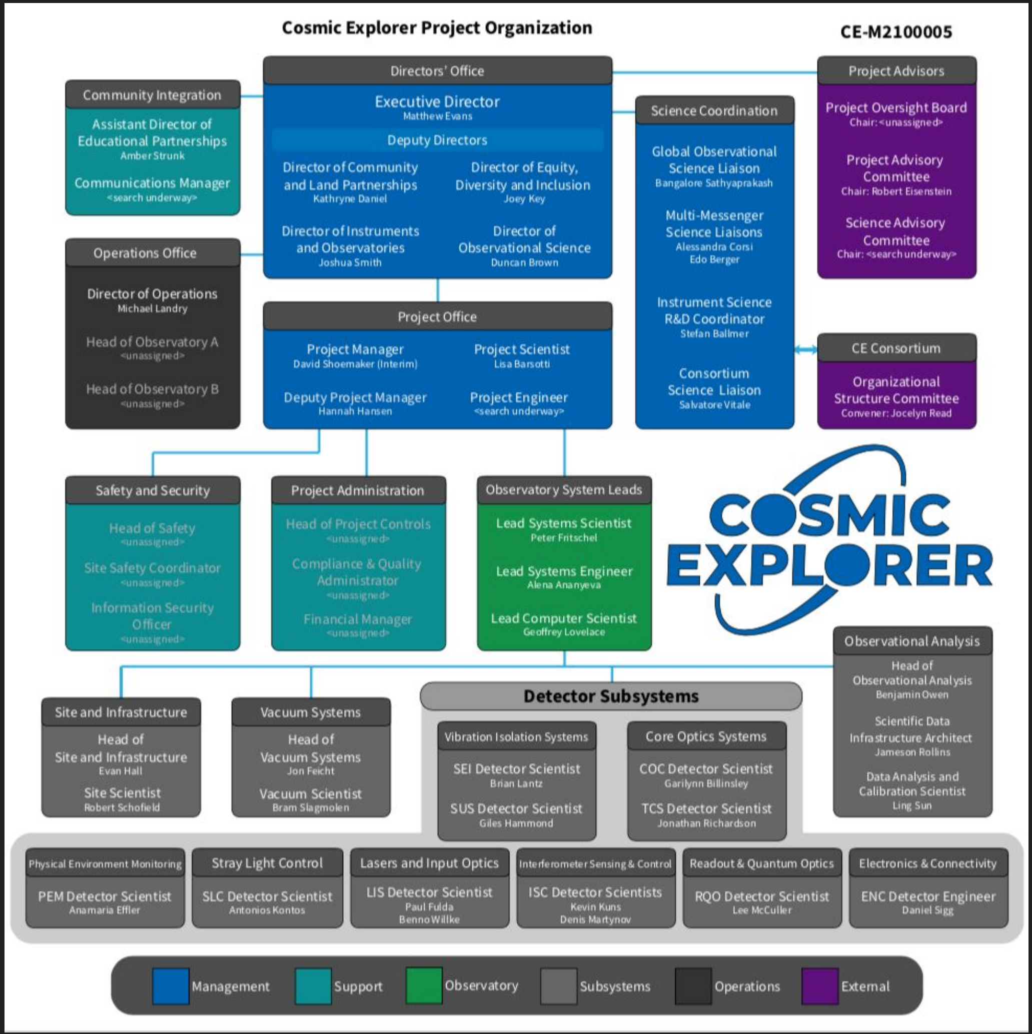
Figure 2.1.4-1 Summary Timeline for Major Facility Projects (Development and Design)

	Development	Conceptual Design Phase	Preliminary Design Phase	Final Design Phase
	Preconstruction Planning Funded via R&RA and EHR funds			
Budget evolution		Develop construction budget based on conceptual design Develop budget requirements for advanced planning Estimate operations costs	**Expend ~5-25% of construction cost on planning & design activities** Construction estimate based on preliminary design Update operations cost estimate	Final design over approximately 2 years Construction-ready budget & contingency estimates Update operations cost estimate
Program evolution	Initial ideas emerge Broad science community consensus built for potential long-term needs, priorities, and general requirements High level concept developed	Formulate science goals: define requirements, prioritize, review Develop conceptual design, identify critical technologies, high risk items Formulate initial risk assessment Develop top-down parametric cost and contingency estimates Initial proposal submission to NSF Initial Project Execution Plan (PEP)	**Proponents development strategy defined in Project Development Plan** Develop site-specific preliminary design, environmental assessments/ impacts (NEPA) Develop enabling technologies Bottom-up cost and contingency estimates, updated risk analysis Develop Project Management Control System Develop preliminary operations cost estimate Update PEP	Develop final construction-ready design & PEP Verify key technologies are ready for production or detailed production design Refine bottom-up cost and contingency estimates Finalize Risk Assessment & Mitigation, Management Plans Complete key staff recruitment
	NSF oversight defined in Internal Management Plan (IMP) updated at each development phase.			
			NSF Director approves PD phase	NSF approves submission to NSB
Project oversight	Interface with the research community to nurture concepts for development Recommends to the NSF Director that a project advance to Conceptual Design	Integrated Project Team (IPT) organized Develop Internal Management Plan (IMP), estimate PD costs, timeline Establish interim review plan and competition milestones Forecast international and interagency participation, issues Initial analysis of NSF opportunities, risks Conceptual Design Review (CDR) – external panel review and internal review CDR Cost Analysis Merit review, apply 1st ranking criteria	Approve Project Development Plan (PDP) & budget Forecast external partner decision milestones Preliminary Design Review (PDR) – external panel review and internal review Establish target total project cost (TPC) PDR Cost Analysis Project Definition established – cost, scope, schedule, plans, risks, & contingency	OMB/Congress negotiations on proposed project and budget profile Evaluate design costs, schedules; and operations cost estimate. Semi-annual assessment of baseline and projected operations budget for projects not in construction Finalization of interagency and international requirements, agreements Final Design Review (FDR) - external panel review and internal review FDR Cost Analysis - informed by an Independent Cost Estimate (ICE) if not done earlier EVMS Acceptance Establish project construction baseline
FRP, DRB, OD & NSB	Internal review regarding advancement to design stage NSF Director approval to start Conceptual Design	Facilities Readiness Panel Review NSF Director approval for advancement to Preliminary Design	Apply 2nd and 3rd ranking criteria Facilities Readiness Panel Review DRB Review NSF Director requests NSB approval for MREFC request & approves advancement to Final Design NSB authorization for inclusion in MREFC Budget Request & to proceed with final design	Facilities Readiness Panel Review DRB Review NSF Director approves advancement to construction stage NSB authorizes NSF Director to make a construction award

The Cosmic Explorer Project Organization today

To the original set of 5 institutions (MIT, Fullerton, Syracuse, PennState, Caltech), we have added members from:

- University of Washington Bothell
- University of Oregon
- University of Florida
- Texas Tech University
- Bryn Mawr College
- Bard College
- Stanford
- Harvard
- UC Riverside
- The Australian National University
- Albert Einstein Institute
- University Birmingham
- University of Glasgow



Funding Landscape

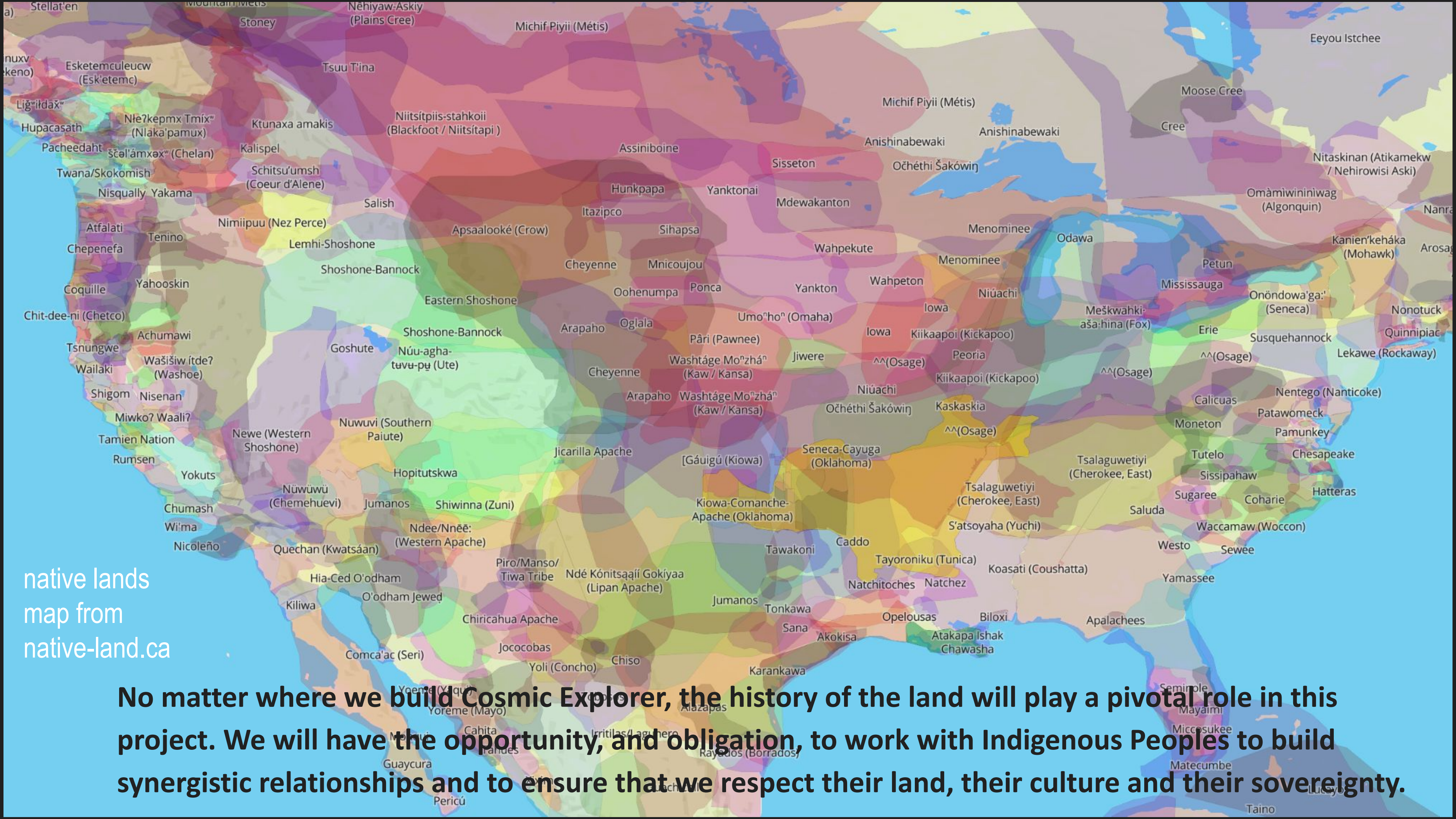
- Some CE activities funded starting this year
  - single PI grants, most notably R&D for vacuum research (with LIGO Lab engineers)
  - agreement with the NSF and LIGO management for up to 10% of time donated from some LIGO staff personnel
  - working to grow our institutional connections and support network for conceptual design activities
- Currently preparing proposals for the NSF to fund the Conceptual Design activities
  - Likely multiple coordinated proposals
- Recent news from NSF:
  - Mathematical and Physical Science Advisory Committee (MPSAC) being formed to study NSF direction on next-generation GW observatories

Currently seeking support for Conceptual Design

- Conceptual Design scale: $25M, 3-5 years

- Urgent activities include:
  - Site search and evaluation, in concert with Indigenous Partnership Program
  - Research for topics that directly impact facility design and cost
    (vacuum system materials, local gravitational noise, scattered light mitigation)
  - Assembly of professional core project team (project management, communications, etc.)

- Preliminary and Final Design scale: $100M, 4 years



native lands
map from
native-land.ca

No matter where we build Cosmic Explorer, the history of the land will play a pivotal role in this project. We will have the opportunity, and obligation, to work with Indigenous Peoples to build synergistic relationships and to ensure that we respect their land, their culture and their sovereignty.

Directors' Office

Executive Director
Matthew Evans

Deputy Directors

Director of Community and Land Partnerships
Kathryne Daniel

Director of Equity, Diversity and Inclusion
Joey Key

Director of Instruments and Observatories
Joshua Smith

Director of Observational Science
Duncan Brown

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The Cosmic Explorer Consortium

The Cosmic Explorer Consortium

Cosmic Explorer is a plan for a U.S. next-generation gravitational-wave observatory that aims to be an order of magnitude more sensitive than Advanced LIGO. At this sensitivity, Cosmic Explorer will be able to answer questions from the smallest scales of fundamental physics to the largest scales of cosmology.

The purpose of the Cosmic Explorer Consortium is to provide an open and efficient way for members of the international physics and astronomy communities to contribute to the conceptualization of Cosmic Explorer, its design, and its future use. Participation in the Cosmic Explorer Consortium provides access to a mailing list that can be used to communicate with other consortium members and access to a Document Control Center if members wish to share documents related to Cosmic Explorer with each other. Membership in the Cosmic Explorer Consortium is open to all interested scientists. Membership in the Cosmic Explorer Consortium does not carry any obligations and may overlap with membership in other collaborations (e.g., the LIGO Scientific Collaboration, Virgo, KAGRA, or OzGrav). Members are encouraged to collaborate with each other, as well as scientists outside the Cosmic Explorer Consortium, on projects related to Cosmic Explorer.

If you have questions about Cosmic Explorer, please send an email to ce-questions@cosmicexplorer.org

To join the Cosmic Explorer Consortium visit the CE Consortium registration page.

Everyone is welcomed to join (no FTE commitment): https://cosmicexplorer.org/consortium.html

The Cosmic Explorer Consortium

- Nearly 400 members at the moment
- Observational Science calls led by Salvatore Vitale:
    - http://cosmicexplorer.org/sciencecalls.html
- Jocelyn Read is leading the evolution of the CE Consortium into a more structured entity to:
    - organize topical Groups to coordinate research activities. In particular, Groups may write and contribute white papers for an anticipated NSF-initiated Cosmic Explorer assessment process.
    - support critical technology development outlined in the Cosmic Explorer Design Stage Research and Development Document https://dcc.cosmicexplorer.org/CE-P2100005
        - Instrument Science R&D coordinator: Stefan Ballmer
- Discussions within the Consortium started

Collaborations

- Cosmic Explorer and NSF welcome international collaborations
  - Recent Gravitational Wave Agencies Correspondents (GWAC) meeting where this point has been highlighted
  - Active collaborations on-going with UK, Australia, Germany - we hope to grow the list
- Cosmic Explorer represented in the Particle Physics Community Planning Exercise (SnowMass)
  - Potential for participation by scientists and possibly funding from the Department of Energy
- Einstein Telescope is a critical partner in the XG (neXt Generation) Network
  - Wish to see collaboration in all aspects

Cosmic Explorer and ET

https://dcc.cosmicexplorer.org/CE-P2100005

- Fundamental facility and technology differences between CE and ET, but some areas of overlap do exist:
    - vacuum technology
    - suspension/seismic isolation
    - Newtonian noise mitigation
    - 1 um technology for ET-HF
    - facility design to support 2um, cryogenics

- Strong overlap for everything related to astrophysics and data analysis, calibration, computing
- We all have a lot to learn about participating in a 2Bn project
    - Must strive to learn lessons *once*

		Initial CE	CE
Core Optics	Substrates (§3.2)	Production of 70 cm ⌀ fused silica optics, 320 kg Polishing at spatial scales $\gtrsim$ 20 cm	
Core Optics	Coatings (§3.2)	A+ coatings at 70 cm scale	Best effort for improved coatings
Test mass isolation	Suspensions (§3.3)	2 m fibers 1.2 GPa fiber stress	2 m fibers 1.6 GPa fiber stress
Test mass isolation	Active vibration isolation (§3.4)	$0.1\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 10 Hz $1\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 1 Hz	$0.03\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 10 Hz $0.1\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 1 Hz
Test mass isolation	Newtonian noise mitigation (§3.5)	6 dB Rayleigh-wave suppression No body-wave suppression No infrasound suppression	20 dB Rayleigh-wave suppression 10 dB body-wave suppression No infrasound suppression
Lasers & squeezing	Lasers (§3.6)	140 W into interferometer Frequency noise $< 0.7\,\mu\mathrm{Hz}/\sqrt{\mathrm{Hz}}$ at 10 Hz	
Lasers & squeezing	Squeezing (§3.7)	6 dB frequency-dependent squeezing	10 dB frequency-dependent squeezing
Controls & data	Control systems (§3.8)	Fully deterministic lock acquisition Environmental robustness	
Controls & data	Calibration (§3.9)	$< 0.1\%$ absolute calibration Investigation into • photon calibration, • Newtonian calibration, • frequency calibration, • astrophysical calibration	
Controls & data	Computing (§3.10)	2 TB/day	

Table 3.1: Summary of Cosmic Explorer detector R&D activities.

Cosmic Explorer and synergy with *post-O5* detectors

- Main upgrades envisioned in LIGO facilities post-O5:
  - larger test mass, suspension and seismic isolation improvements, higher power, more squeezing, 1um technology
- Very significant overlap with Cosmic Explorer
  - Same technology
  - R&D towards CE feeds into post-O5
  - post-O5 detectors will be the best possible CE prototype
- Strong support from LIGO leadership for Cosmic Explorer
- LIGO success is a top priority for Cosmic Explorer
  - careful balance of resources

The Message

- Cosmic Explorer is receiving strong support by LIGO, NSF, Astro community
- Progress is happening thanks to the (volunteered) effort of many people
  - Some funds available to start critical activities
  - Main near term goal: fund the conceptual design phase
- Collaborations are welcomed


Thank You!
COSMIC
EXPLORER

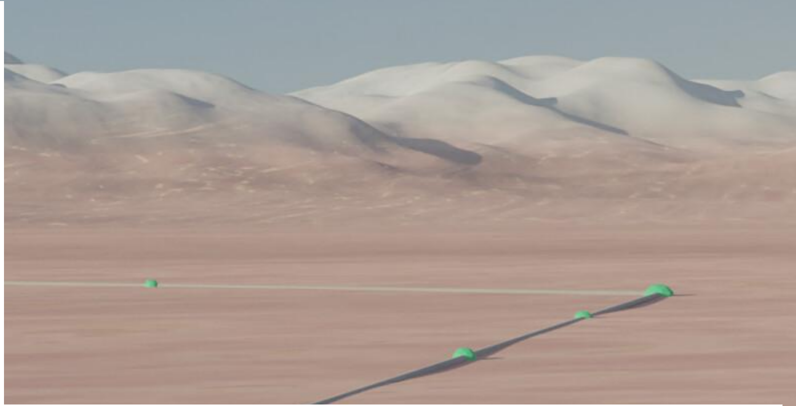
Reference concept budget

The Cosmic Explorer concept consists of two widely-separated L-shaped observatories in the US, one with 40 km arms and another with 20 km arms.

The following cost tables represent the same content as the ones presented in §11.1 and §11.3. The only difference is that they are presented in 2021 USD, i.e. without any attempt to estimate future inflation rates.

Top-Level Costs	$(M) 2021 USD	Percent
Civil Engineering	422	26
Vacuum System	569	34
Detector	432	26
Management, Design, Project	227	14
Grand Total (2 Observatories)	**1650**	100

Table 1: Top-level cost breakdown for Cosmic Explorer including 20 % contingency, but excluding operating costs, in millions of 2021 US dollars. The content of this table is the same as Table 11.2, but with no attempt to estimate future inflation.



Yearly Operations Cost Estimates	$(M) 2021 USD	Percent
Facilities	18	30
Vacuum Systems	7.7	13
Detector	16.9	28
Analysis, Data, and Computing	7.2	12
Management	5.7	9
Community Engagement	4.7	8
Grand Total (2 Observatories)	**60.2**	100

Table 2: Estimated yearly operations costs for Cosmic Explorer with two observatories, based on Advanced LIGO and scaled for CE facility sizes, in millions of 2021 US dollars. The content of this table is the same as Table 11.3, but with no attempt to estimate future inflation.

Top-Level Costs	$(M) 2030 USD	Percent
Civil Engineering	528	26
Vacuum System	712	34
Detector	540	26
Management, Design, Project	283	14
Grand Total (2 Observatories)	**2062**	100

Artist: Evan Hall (MIT)

We live and work on the unceded ancestral lands of Indigenous peoples.

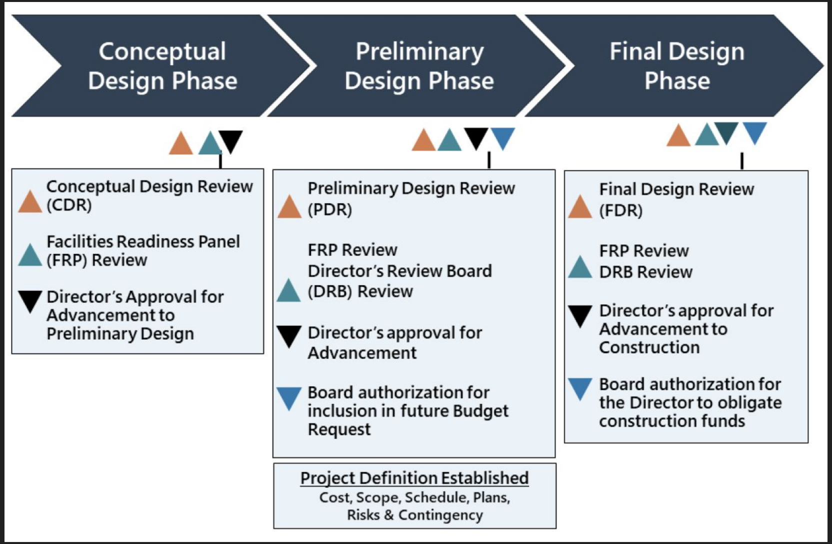
I, together with the Cosmic Explorer team, acknowledge these Indigenous communities and their stewardship of the land, past, present and future.

The Cosmic Explorer team is committed to building long-lasting synergistic relationships with Indigenous communities in order to align our goals while building trust and mutual respect.

native lands map from native-land.ca

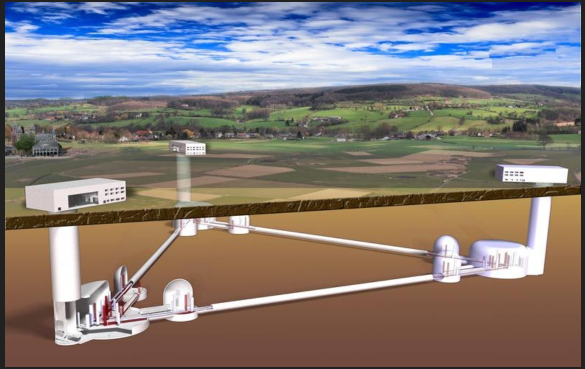
CE Milestones past and planned future

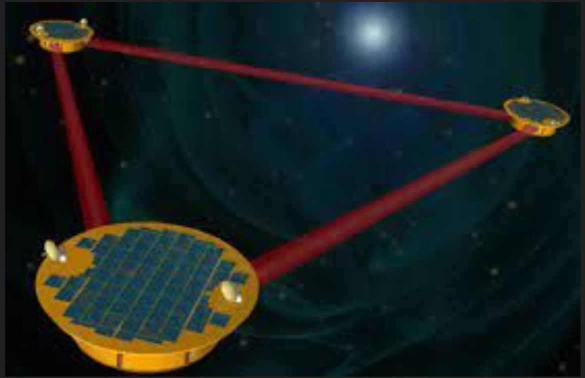
- 2010-2015 LIGO Scientific Collaboration R&D musing
- 2015 Solidification of
  - Scientific Motivation for a future observatory
  - Focus on a low-risk approach of a longer instrument
- 2018-2021 Horizon Study
  - 3-year NSF funded Collaborative proposal, $2.2M
  - Produced the Cosmic Explorer Horizon Study
  - Decadal White papers; NSF physics request to consider but not ranked in Decadal
  - Dawn Community Report (GW Roadmapping)
- 2022-2025 Conceptual Design
  - Currently Writing proposal to NSF for support to undertake CD; $25M, 3-5 years
  - Placement by Chief Officer for Research Facilities (CORF, Linnea Avallone) on the list of NSF research projects
- 2025-2028 Preliminary Design, ending with NSB authorization (cost, plans, …)



CE in the International Context

- Einstein Telescope is a similar project underway in Europe
  - Coordination in discussion; data *must* be combined
  - ET is on the European Strategy for Research Infrastructures (ESFRI) Roadmap
  - Technically challenging (underground cryogenic multiple interferometers)
- Laser Interferometer Space Antenna (LISA)
  - An ESA-led space observatory with a small NASA contribution
  - Expected to be launched in 2034 and take data concurrently with CE and ET
  - Similar efforts also in China (two space observatories)
- Neutron-star Extreme Matter Observatory (NEMO)
  - An Australian observatory but a smaller observatory focussed on specific science
  - Aspire to build a 20km CE-like detector in the future





Another ``POST-O5" upgrade (~2028) being planned

Current idea is an upgrade in 2028, with:

- Larger/heavier test masses, improved suspensions and seismic isolation
- Further increase of laser power, higher levels of squeezing
- Technology development for POST-O5 will define the path for the next generation detectors in US, Cosmic Explorer