Status of Cosmic Explorer Location Evaluation

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Steward Observatory

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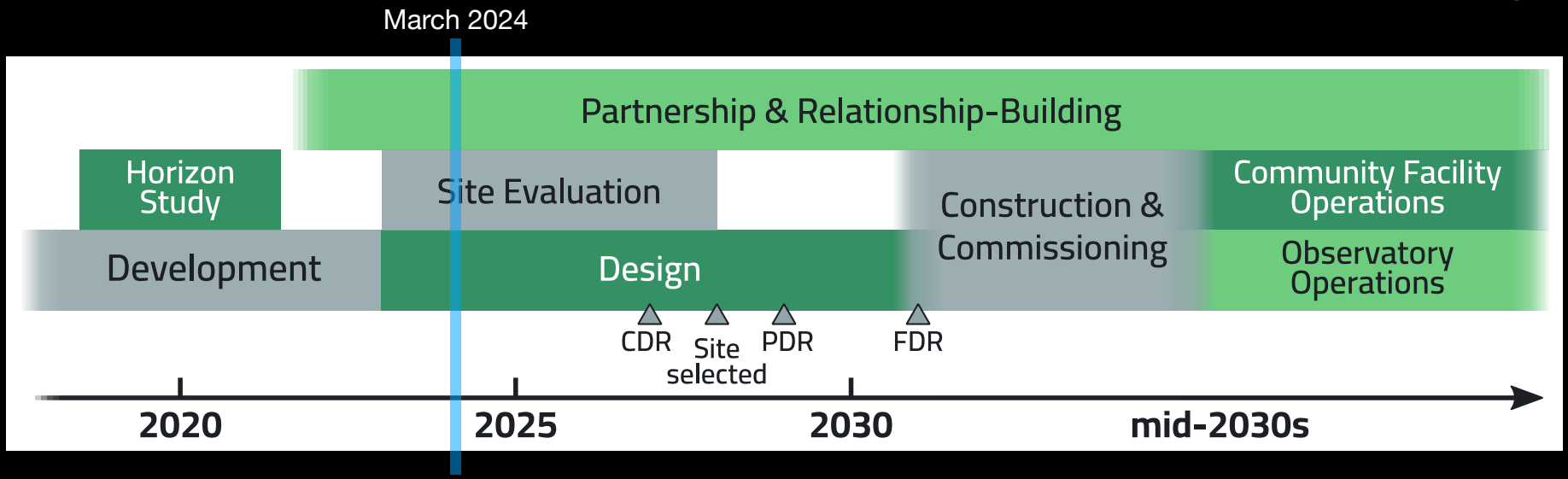
CE-G2400024

Cosmic Explorer Timeline



White Paper for NSF MSCAC ngGW

Site evaluation and design funded by NSF starting 2023

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Astro2020 Decadal

"Gravitational wave astrophysics is one of the most exciting frontiers in science."

"…strongly endorses gravitational wave observations as central to many crucial science questions."

Cosmic Explorer named 24 times.

Recommendation:
The astronomy community… with experts from other experienced disciplines… and representatives from local communities define a Community Astronomy Model of engagement …

COSMIC EXPLORER

Location Identification and Responsible Siting

- Activities required to **facilitate a successful site selection by the NSF**
  - Complete by ca. 2028, ahead of Preliminary Design Review
- Identify several locations where Cosmic Explorer can:
  - achieve its **science goals**
  - be built within appropriate **cost boundaries**
  - **attract, support and retain a diverse workforce**
  - **community based model** that integrates observatory activities (design to divestment) with local and Indigenous community values and interests

SiteEval Team

Supported by NSF-PHY Collaborative Award

- **Fullerton**: Joshua Smith, Geoffrey Lovelace, PDA offer, Maya Bakijan, Andrew Saenz
- **Arizona**: Kathryne Daniel, Piper Sledge, Warren Bristol, Chris Lukinbeal, Joe Hoover, Robert Hershey, TBA researcher
- **Caltech**: Amber Strunk, Michael Landry, SURF+Fellow students
- **Minnesota**: Vuk Mandic, Kiet Pham
- **Syracuse**: Joshua Russell, Stefan Ballmer, Christopher Scholz, Isaac Babatunde, Sarmad Rameez, Douglas Wood
- **Oregon**: Robert Schofield, TBA student
- **Collaborators:** François Schiettekatte (Canada), Bram Slagmolen (Australia), Jenne Driggers, Matthew Evans, David Shoemaker, CE Project

Multidisciplinary:

- Gravitational-wave science
- Sociology
- Geology/Seismology
- Geography/GIS
- Law
- Native American Studies
- Education
- Astronomy

Bi-weekly project meetings, bi-weekly management meetings

siteeval@cosmicexplorer.org

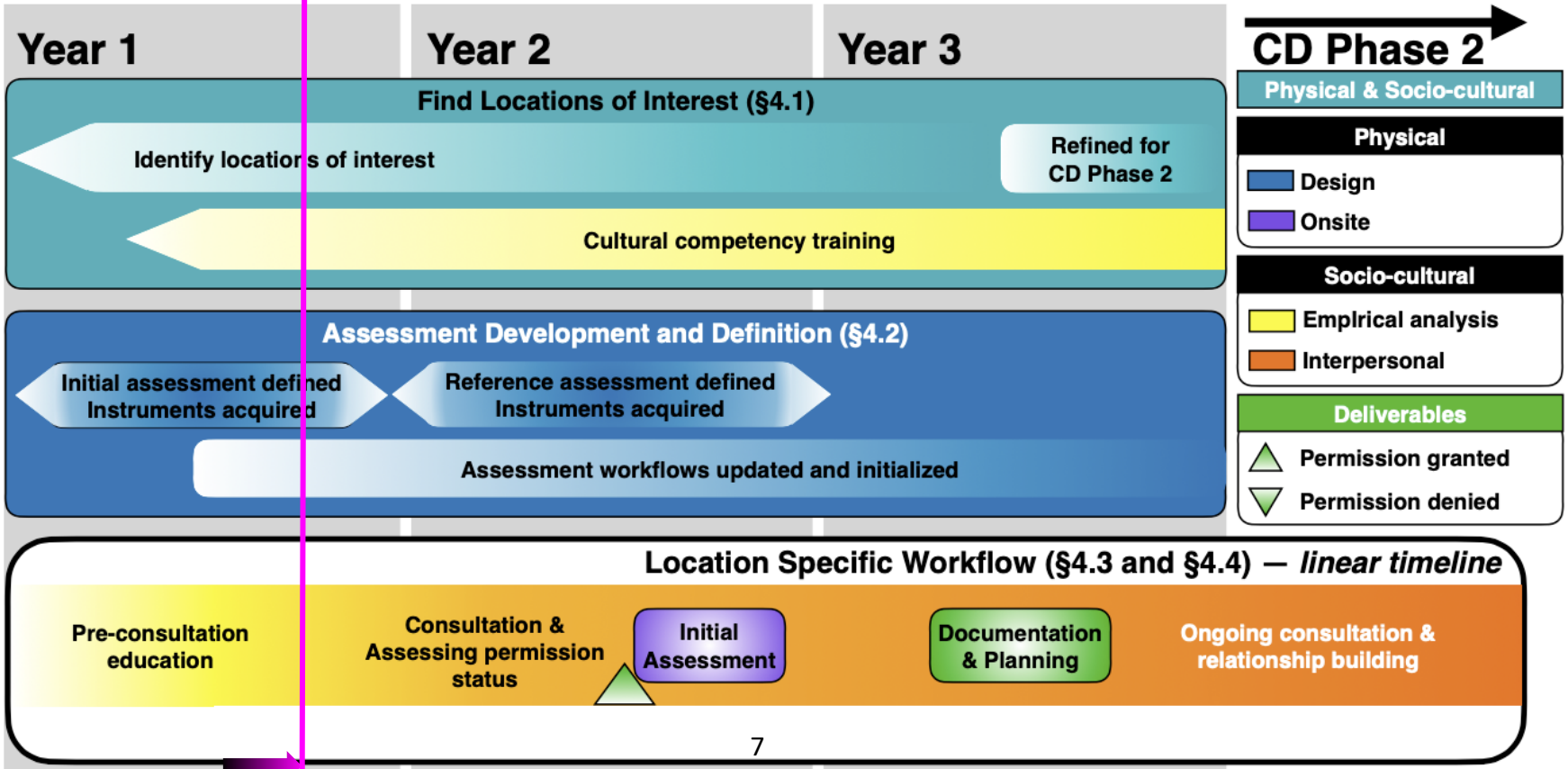
Cosmic Explorer Location Identification

We are considering many factors,

- Wide separation for 20km and 40km locations
  - Continental US focus, collaborate with Canadian effort
- Topography and geology
- Environmental noise (seismic, wind, etc.)
- Environmental impact (NEPA, carbon footprint)
- Local and Indigenous community interest and expertise (e.g. nearby university)
- Social landscape (quality of life factors, community relationship to science, etc.)
- Land acquisition

Early and ongoing engagement with communities connected with Cosmic Explorer (local, scientific and global) is crucial to the project's success.

SiteEval Project Timeline

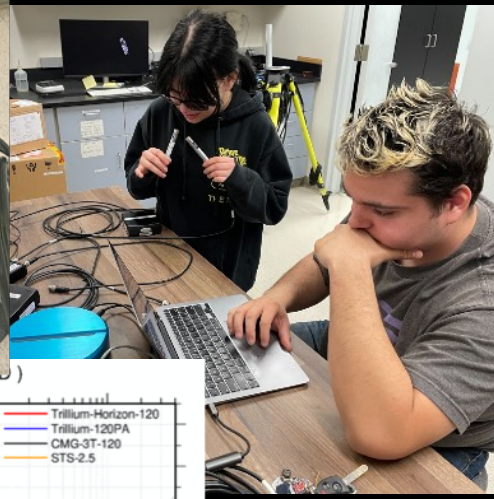


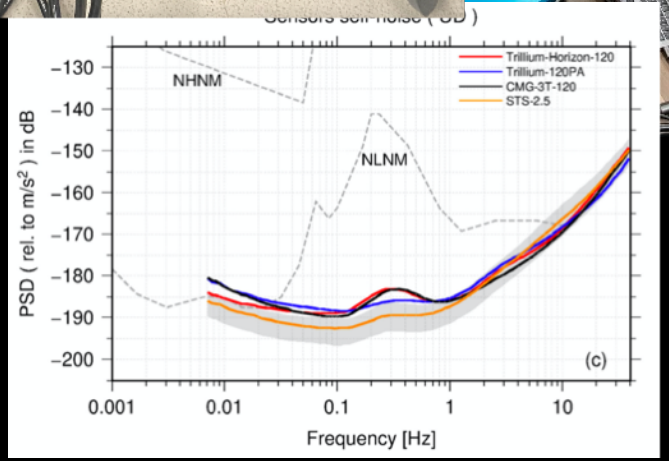
CE economic impact study with Economic & Planning Systems (EPS)

- EPS working with CE team to learn about
  - Comparable scientific projects
  - Site location considerations
  - Construction and operation costs
  - Interested/impacted communities
- EPS will construct a model to estimate:
  - Economic Impacts (regional, national, global) of construction and operations, and the effects of uncertain siting
  - Scientific/Technical/Community Impacts: with more qualitative info
- First draft in few months, more clarity in report as siting efforts progress
- Project request modeled after Einstein Telescope economic impact assessment

Initial Assessment: Equipment and Workshopping

- 4 stations [staging, to be ordered]
  - Seismometers: Guralp 3T-120s
  - Magnetometers: Bartington Mag-03s
  - Microphones: Bruel&Kjaer 4188
  - Anemometers (wind)
  - Digitizers, tripods, batteries, shovels, toilet, bivouac, chairs
- NSF-compliant safe, inclusive field plans in place
- Workshop procedures with equipment at LIGO Hanford September 2024
- Then ready (when permitted) to assess candidate locations



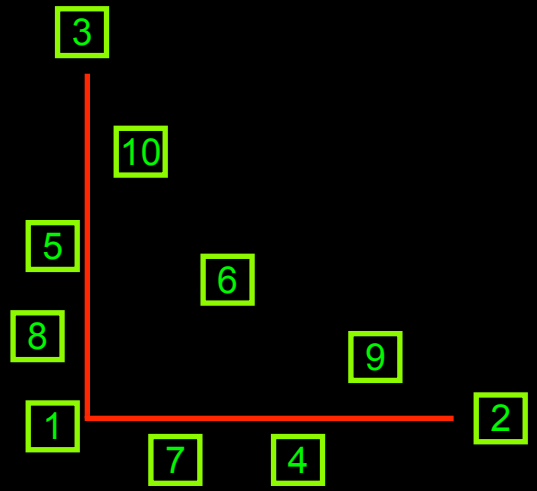


Initial assessment defined
Instruments acquired

Reference Assessment: Equipment and Workshopping

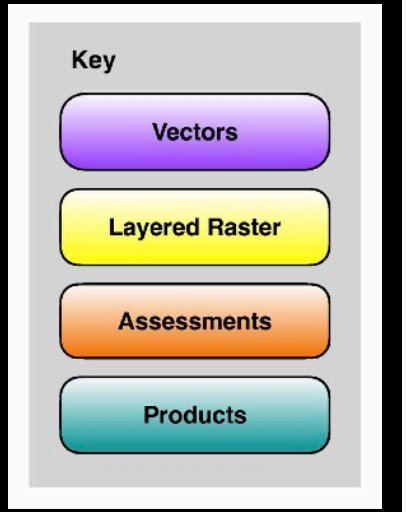
- Seismometer and field training at Earthscope Primary Instrument Center, Socorro, NM, July 2024
- Seismic Array (10+ instruments) from Earthscope in 2025
- Then ready (when permitted) to deploy at a candidate location for 12 months

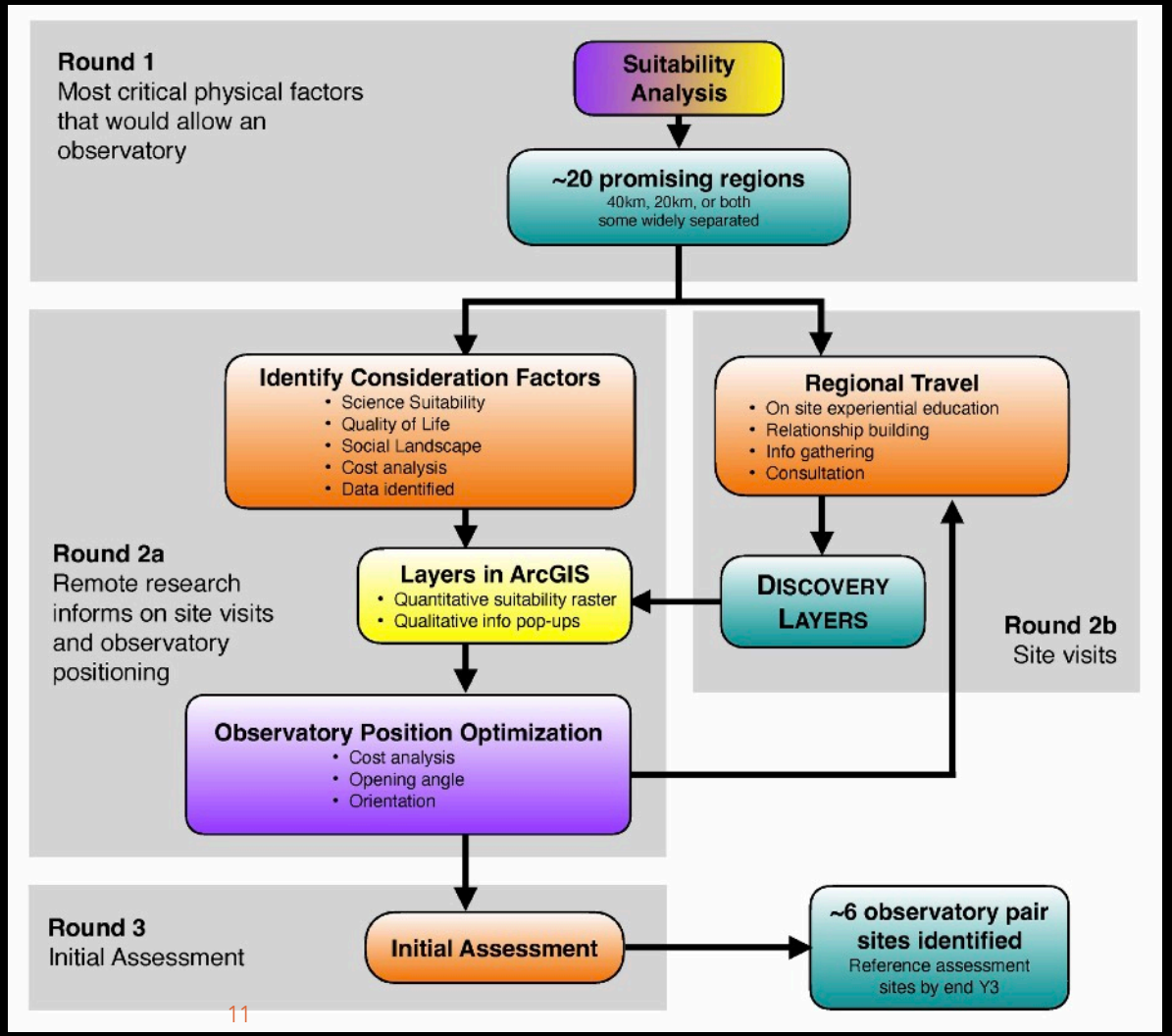
EarthScope Primary Instrument Center



Reference assessment defined
Instruments acquired

Site Evaluation Workflow
Iterative Updates

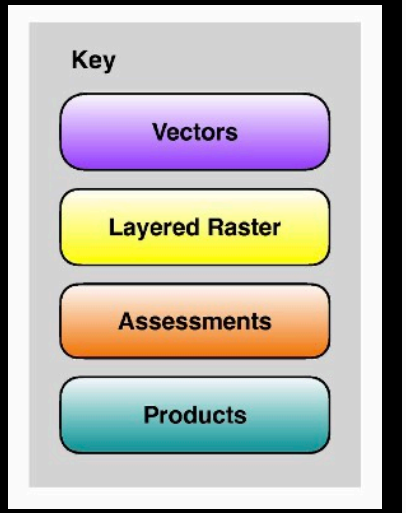


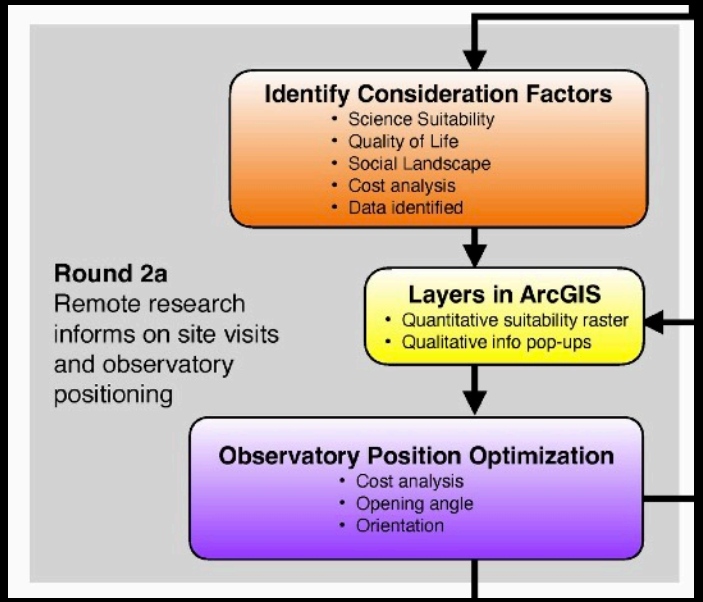


CE DCC #D2300002

Integrated Approach to Location Identification and Evaluation

Remote Research and Observatory Positioning





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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

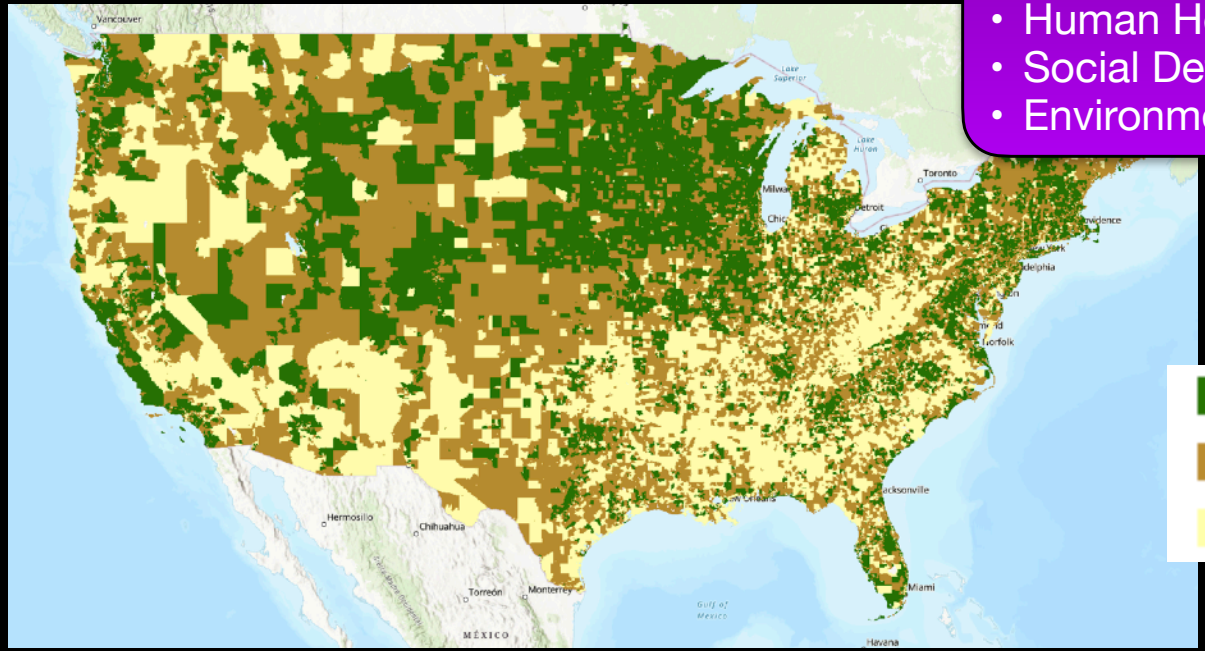
- Wilderness / BLM Land
- Federal American Indian Reservation
- Military Installations
- Bodies of Water
- Roads
- Railroads
- High Population Density

Quality of Life

- Variables & Data - Identified and included
- Weightings - Not Finalized

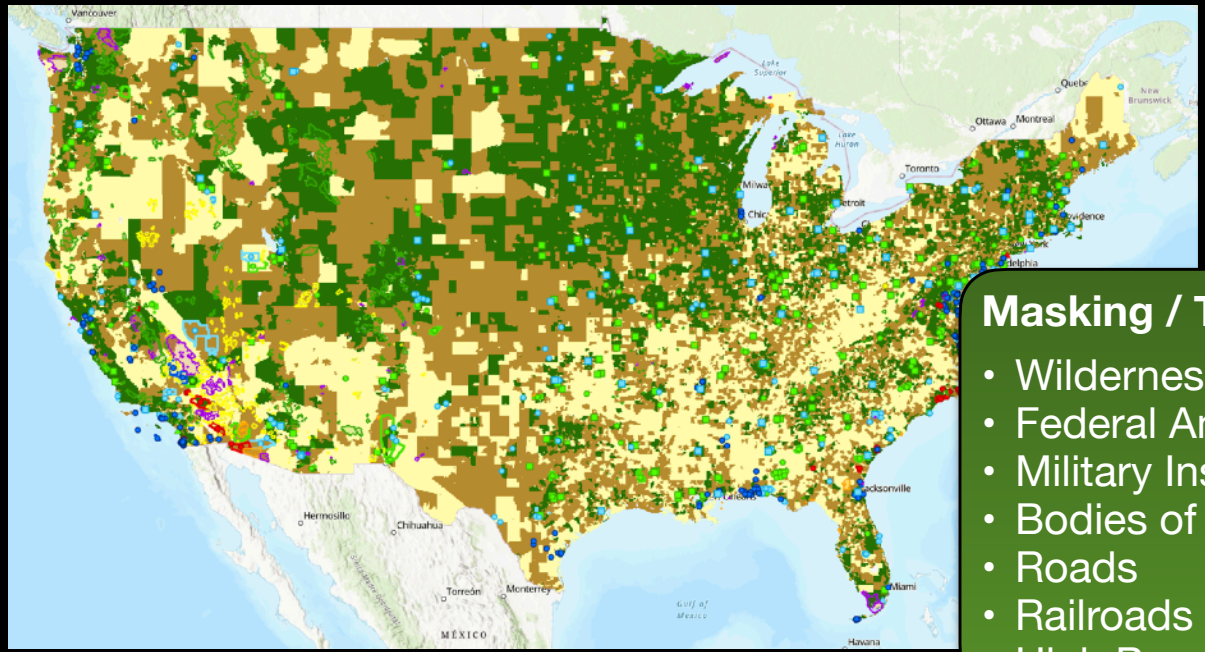
Quality of Life Index

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



Masking / Toggle Layers

- Overlay masks, boundaries, or other layers on maps
- Can be used for Positioning (eg distance of an end station to a major highway)



Showing:

Quality of Life Index

Wilderness Areas

Military Installations

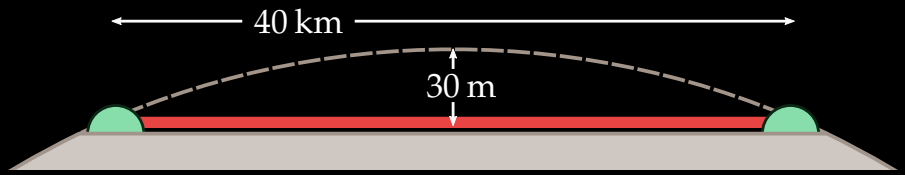
Masking / Toggle Layers

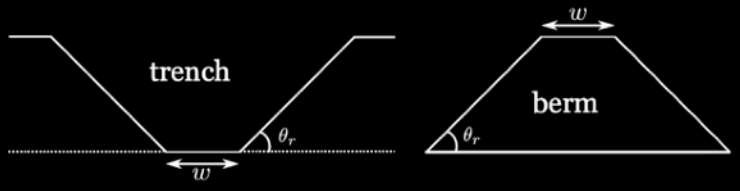
- Wilderness / BLM Land
- Federal American Indian Reservation
- Military Installations
- Bodies of Water
- Roads
- Railroads
- High Population Density

Position Optimization and Costing

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

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

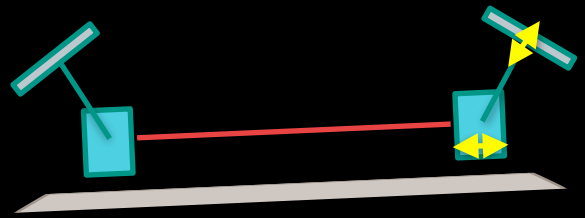




$$\text{elevation score} = \frac{V_{\text{cut}} + V_{\text{fill}} + |V_{\text{cut}} - V_{\text{fill}}|}{10^5\ \text{m}^3}$$

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

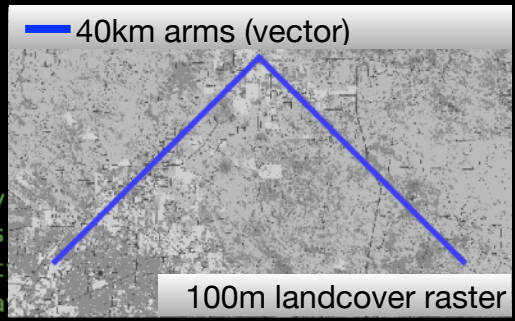
$$\text{tilt score} = 10\left[(\theta_x/\theta_0)^2 + (\theta_y/\theta_0)^2\right]$$



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
```



Some figures courtesy T2000016-v2

Position Optimization and Costing

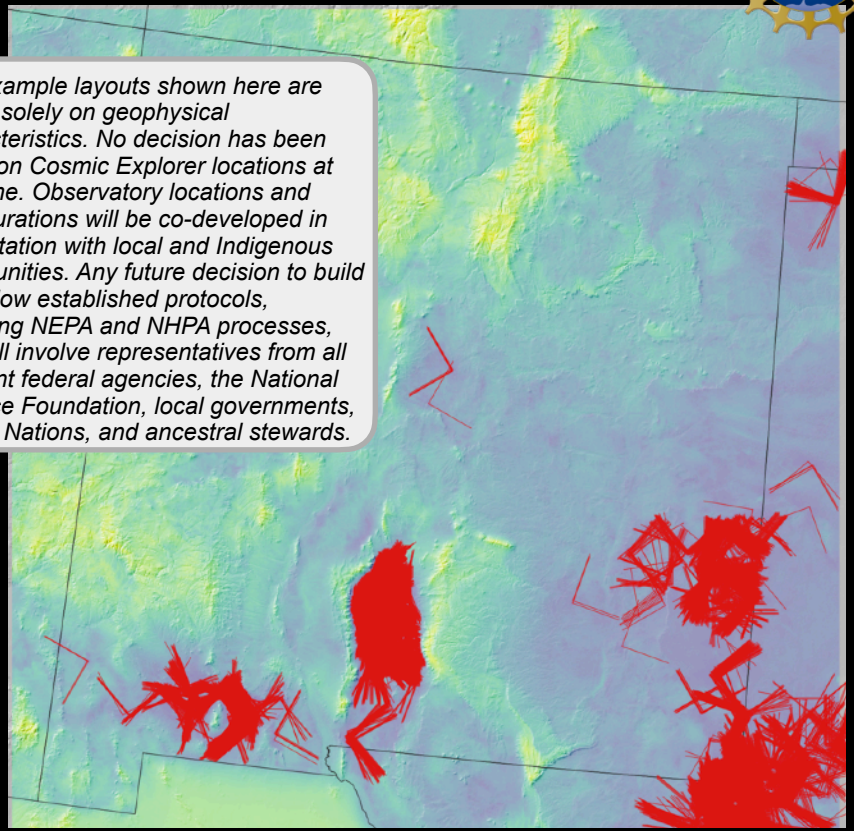
Process

- Loop over detector configurations (vertex location, rotation angle, opening angle)
- Output
  - Score based on flatness, landcover, and tilt, to geotiffs
  - Detector configurations to shapefiles

Next steps

- Ensure vertex and ends close to grade
- Combine with suitability analysis and newest maps

The example layouts shown here are based solely on geophysical characteristics. 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.



100m resolution landcover and elevation.
Color=log(total score), relief shading = elevation

https://gitlab.com/cosmic-explorer/cess

Combining Outputs

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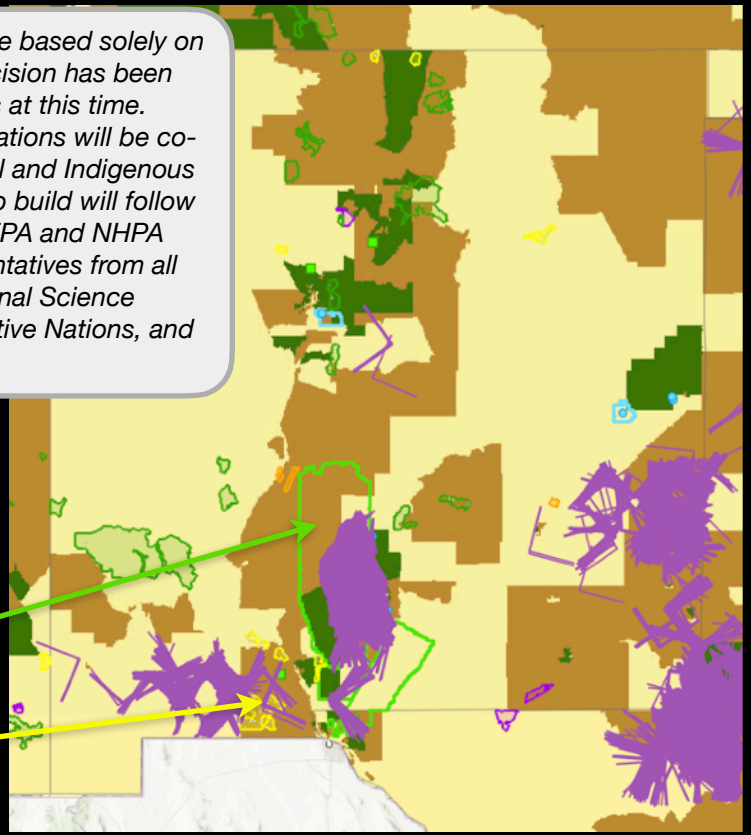


Cost

- Flatness
- Tilt
- Landcover

Positioning

- Opening Angle
- Orientation

Showing:

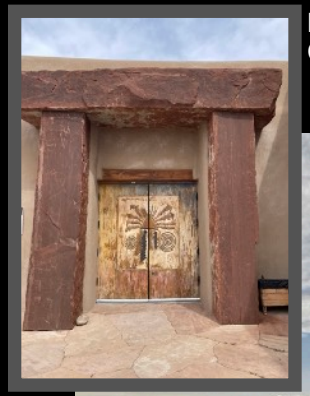
Quality of Life Index

Wilderness Areas

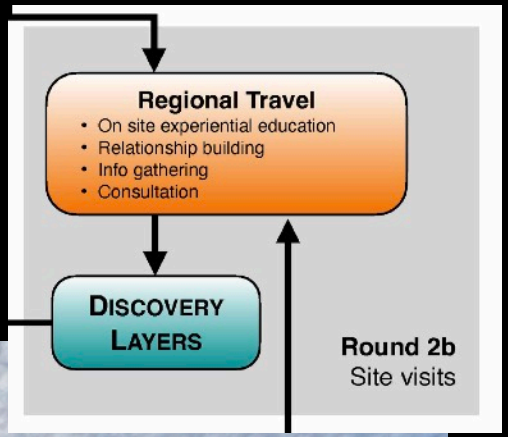
Military Installations

Lowest cost positions

Pilot Trip to New Mexico



Poeh Cultural Center



South Central NM

Visited

- University of New Mexico
- Los Alamos National Labs
- Mescalero Apache, Indian Pueblo & Poeh Cultural Centers
- Earthscope

Purpose

- On the ground understanding of the scientific and cultural landscape
- Introduce ourselves and CE
- Relationship building

Method

- Based on ethnographic field methodology (eg morning debrief, field notes)

Deliverables

- Curated field notes and summary
- Discovery layer information
- Story map

Story Maps Compliment Quantitative Measures

- Interactive, comprehensive & low bar for entry
- Deconstruct complicated information
- Combine informational data and suitability data
- Communication tool: communities, within CE, government relations, public relations, etc
- Accepted within tribal communities → good for consultation
- Can be used to palpably understand a place before travel / "training"

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.

native-land.ca

Kathryne J Daniel

Summary

- There are many promising locations for CE in the US and we're learning more about them
- Our multidisciplinary team scaling up and combining methods
- Integrating physical+sociocultural info to iteratively learn about locations, add new ones, inform travel
- Pilot introduction trip in NM a big success
  - Underscored importance of early, maintained work with community
  - Introductory trips to additional regions to follow
  - Followup trips to NM in planning stages
- Assessment equipment in; field workshopping planned; assessment will be ready to start once permitted

Cosmic Explorer

NEXT GENERATION GRAVITATIONAL WAVE OBSERVATORY

Join the consortium!
cosmicexplorer.org

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