An Interdisciplinary Site Suitability Analysis for Cosmic Explorer

Warren Bristol[1], Chris Lukinbeal[1], Joseph Hoover[1], Kate Daniel[1], Piper Sledge[1], Joshua Russell[2], and Matthew Evans[3] on behalf of the Cosmic Explorer Project

[1]University of Arizona, Tucson, AZ, USA, [2]Syracuse University, Syracuse, NY, USA, [3]Massachusetts Institute of Technology, Cambridge, MA, USA

E-mail: wbristol@arizona.edu

Abstract. Cosmic Explorer (CE) is the proposed next-generation ground-based gravitational wave observatory in the US. Its concept is based on the Laser Interferometer Gravitational Wave Observatory (LIGO), but the footprint will be scaled up by an order of magnitude thus posing a unique challenge for site identification and evaluation. This investigation focused on a National Suitability Analysis (NSA) conducted by the CE geographic information systems (GIS) team at the University of Arizona. GIS is a platform that integrates geospatial data for analysis and management and is extremely well suited for site suitability studies. This analysis sets acceptable thresholds across 91 interdisciplinary factors to search for promising locations for the CE observatories in the contiguous United States.

1 Introduction

The CE reference concept [1, 2] has two widely separated observatories. The physical scale of CE is significantly larger than its LIGO predecessors since it pairs one observatory with 40 km arms with another that has 20 km arms. The CE Project team is currently searching for promising locations for these facilities. We briefly describe our approach to finding a set of promising locations on the national scale using a GIS suitability analysis. This method allowed us to evaluate locations across the lower 48 states that could physically fit an observatory, provide an environment that does not compromise the scientific performance of the instruments, and which could attract and retain a robust workforce.

2 Site Search Overview

The site suitability analysis used a land-and-people approach to find promising sites in order to support CE's scientific goals while also retaining a talented workforce [3]. Our NSA integrates 91 different social, cultural, physical, and scientific considerations. It works in concert with information gathered from location visits, relationship building with the relevant communities, and software produced to characterize costs, known as Cosmic Explorer Location Search (CELS) [4]. CELS is a Python package designed to score potential detector configurations based on United States Dollars (USD) and science costs incurred by the topography, geology and geography of the land.

The NSA uses a threshold analysis to identify locations that meet instrument requirements and acceptable living conditions for observatory staff based on data from sociological, geographical, and geological studies [4, 5, 6]. The NSA integrates all considerations simultaneously inside a geometric algorithm to find sites where CE could physically fit. Figure 1 illustrates this integrated land-and-people approach. The 91 datasets include quantitative indicators for whether or not an area could be a desirable home for observatory staff, local community sentiments, high potential that the land can support the scientific needs of CE, and likelihood that staff will feel safe and welcome in the community from which they would most likely commute.

3 Crafting An Interdisciplinary Approach

The NSA integrates three key indices: science, quality-of-life, and social landscape; each index is equally weighted (see Figure 1). The Science Index (SI) includes a Topographic Position Index, Anselin's Local Moran's I statistic on elevation data, earthquake risk, 5 second seismic noise, 1 second seismic noise, land use, wind speed estimations, and wilderness preserves. Wilderness preserves also include a series of no-go areas such as national monuments, national parks, specific land use categories, and wilderness areas. The Quality-of-Life Index (QoLI) examines amenities for staff that are living in a proximate community but commuting to the observatory. The QoLI considers factors such as food access, educational opportunities, and environmental burden. The Social Landscape Index (SLI) broadly addresses matters of inclusion. The SLI considers LGBTQ inclusion, segregation, ethno-racial inclusion, and women inclusion. These factors come from census-derived geometries, such as census tracts and public use microdata areas, and each area receives an inclusivity score based on these variables. The SLI comes from work done in concert with the National Opinion Research Center (NORC). The NSA excludes potential observatory regions that are farther than a 2.5 hour drive time from the top 75th percentile of the QoLI and SLI. The aim is to identify physically promising sites that are within a reasonable commute from a locale offering a high quality-of-life.

From each spatial dataset within the NSA, a Boolean mask, in the form of a binary raster data set, is created. A raster data set is an image of pixels that is georectified to the Earth. Thresholds are established by considering what is not acceptable for the CE observatory or staff, and these data are reclassified into a binary (acceptable/not acceptable) in geographic space. For instance, in Figure 2 areas in red are considered less promising since we don't want any portion of an observatory to spatially intersect with a region where the earthquake hazard is high. A threshold is set on that dataset based on whether an area will produce excessive amounts of downtime or damage to the instruments. Using thresholds in this manner, it is possible to set Boolean masks for all 91 factors that can then be aggregated based on spatial coincidence, where all factors occupy the same space. From this Boolean mask, for the science considerations in particular, CE is modeled to take the form of an 'L' shape with 40 km arms. Opening angles between 75°-110° and all rotation orientations, in increments of 5°, are considered. This defines possible observatory 'footprint's. This binary surface then undergoes a moving window operation to produce a robust and satisfactorily complete set of promising observatory locations in the contiguous U.S.

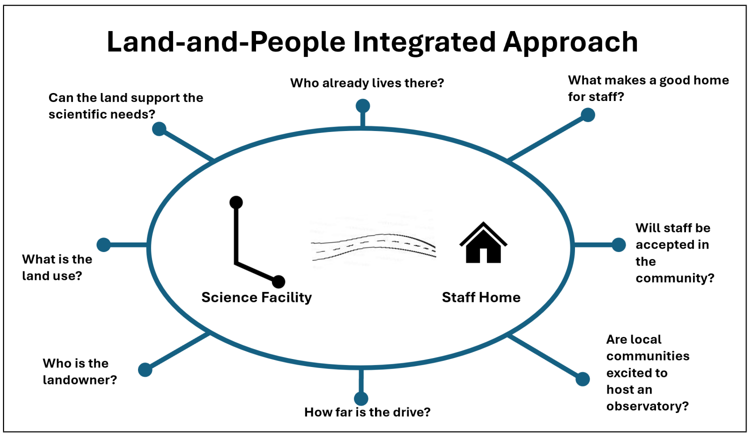

Figure 1: Motivating questions for NSA.

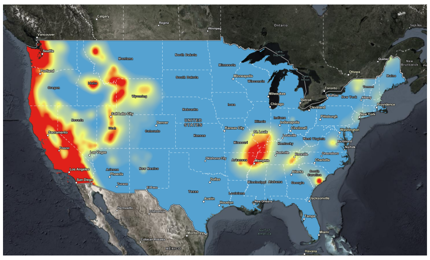

Figure 2: Earthquake hazard estimation for the contiguous U.S.

4 National Level Data Limitations and Future Work

Results from the NSA produce clusters of observatories where it is possible to define promising areas (Figure 3) that need to be further studied through regional and site level analysis. There are some limitations to a national scale suitability analysis since it is not possible to aggregate all types of data together and there is a non-negligible margin of error in national data. For instance, only local and regional scale data offer the precision necessary to determine local land ownership and infrastructure. For example, Figure 4 shows Midland, Texas, which looks very promising from a scientific perspective on the national scale, but local data reveals that Texas is ∼95% privatized land. More landowners equates to more negotiation. Further, Midland has a high density of oil wells, pipelines, and railroads that render construction of an observatory intractable. Regional and site level analysis is the next step toward a finalized recommended site list.

Suitability analysis is a common form of GIS analysis and well suited to determine the best locations for CE. The CE GIS analysis includes social, cultural, and scientific factors. The results of the NSA are areas of interest for further analysis. CE is considering further technical documentation and metadata for the GIS analysis, creating a data architecture and repository and then following up with regional and site-level analysis on the areas of interest.

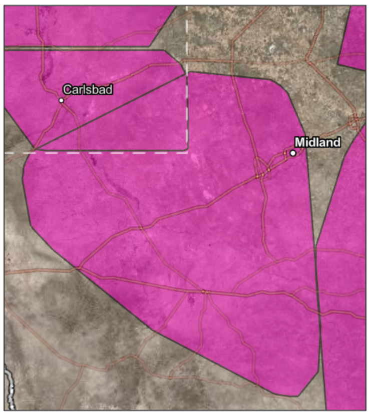

Figure 3: An area of interest in West Texas.

Figure 4: Oil wells and infrastructure in West Texas (Product name is a trademark of Google Maps).

References

[1] Evans M, Corsi A, Afle C, Ananyeva A, Arun K G, Ballmer S, Bandopadhyay A, Barsotti L, Baryakhtar M, Berger E, Berti E, Biscoveanu S, Borhanian S, Broekgaarden F, Brown D A, Cahillane C, Campbell L, Chen H Y, Daniel K J, Dhani A, Driggers J C, Effler A, Eisenstein R, Fairhurst S, Feicht J, Fritschel P, Fulda P, Gupta I, Hall E D, Hammond G, Hannuksela O A, Hansen H, Haster C J, Kacanja K, Kamai B, Kashyap R, Key J S, Khadkikar S, Kontos A, Kuns K, Landry M, Landry P, Lantz B, Li T G F, Lovelace G, Mandic V, Mansell G L, Martynov D, McCuller L, Miller A L, Nitz A H, Owen B J, Palomba C, Read J, Phurailatpam H, Reddy S, Richardson J, Rollins J, Romano J D, Sathyaprakash B S, Schofield R, Shoemaker D H, Sigg D, Singh D, Slagmolen B, Sledge P, Smith J, Soares-Santos M, Strunk A, Sun L, Tanner D, van Son L A C, Vitale S, Willke B, Yamamoto H and Zucker M 2023 Cosmic explorer: A submission to the nsf mpsac nggw subcommittee (*Preprint* `2306.13745`) URL `https://arxiv.org/abs/2306.13745`

[2] Evans M, Adhikari R X, Afle C, Ballmer S W, Biscoveanu S, Borhanian S, Brown D A, Chen Y, Eisenstein R, Gruson A, Gupta A, Hall E D, Huxford R, Kamai B, Kashyap R, Kissel J S, Kuns K, Landry P, Lenon A, Lovelace G, McCuller L, Ng K K Y, Nitz A H, Read J, Sathyaprakash B S, Shoemaker D H, Slagmolen B J J, Smith J R, Srivastava V, Sun L, Vitale S and Weiss R 2021 A horizon study for Cosmic Explorer: Science, observatories, and community (*Preprint* `2109.09882`)

[3] Daniel K J, Smith J R, Ballmer S, Bristol W, Driggers J C, Effler A, Evans M, Hoover J, Kuns K, Landry M, Lovelace G, Lukinbeal C, Mandic V, Pham K, Read J, Russell J B, Schiettekatte F, Schofield R M S, Scholz C A, Shoemaker D H, Sledge P and Strunk A 2025 *Review of Scientific Instruments* **96** 014502 (*Preprint* `2410.00293`)

[4] Datrier L 2025 *J. Phys.: Conf. Series* Submitted URL `https://dcc.cosmicexplorer.org/CE-P2500002/public`

[5] Key J 2025 *J. Phys.: Conf. Series* Submitted URL `https://dcc.cosmicexplorer.org/P2500003/public`

[6] Shoemaker D 2025 *Phys.: Conf. Series* Submitted URL `https://dcc.cosmicexplorer.org/CE-P2500001/public`