Cosmic Explorer Update

Stefan Ballmer on behalf of CE Project

XIII ET Symposium May 11, 2023

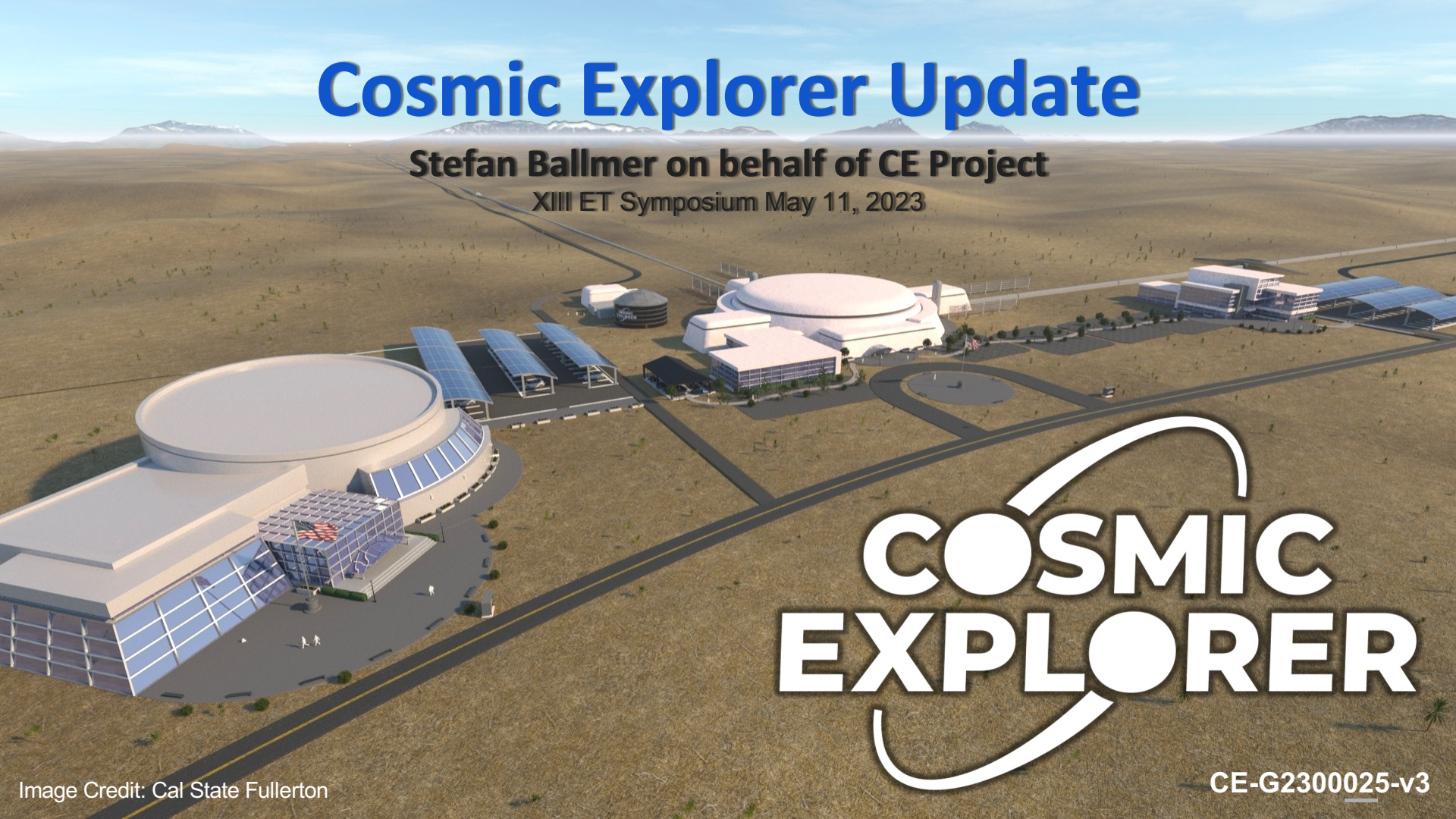

Image Credit: Cal State Fullerton

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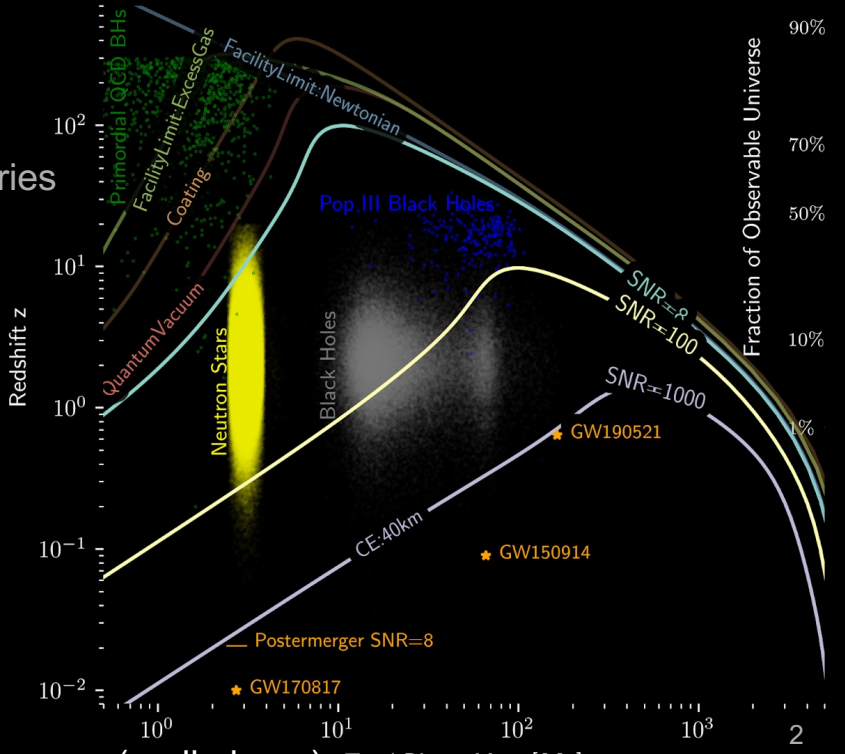
Cosmic Explorer

The US Vision for Gravitational-Wave Astrophysics

- Next-Generation Gravitational-Wave Observatory
  - 40 km and 20 km L-shaped surface observatories
  - 10x sensitivity of today's observatories
  - Global network together with European Einstein Telescope
- Enables access to
  - Stellar to intermediate mass mergers throughout Cosmic Time
  - Dynamics of Dense Matter
  - Extreme Gravity

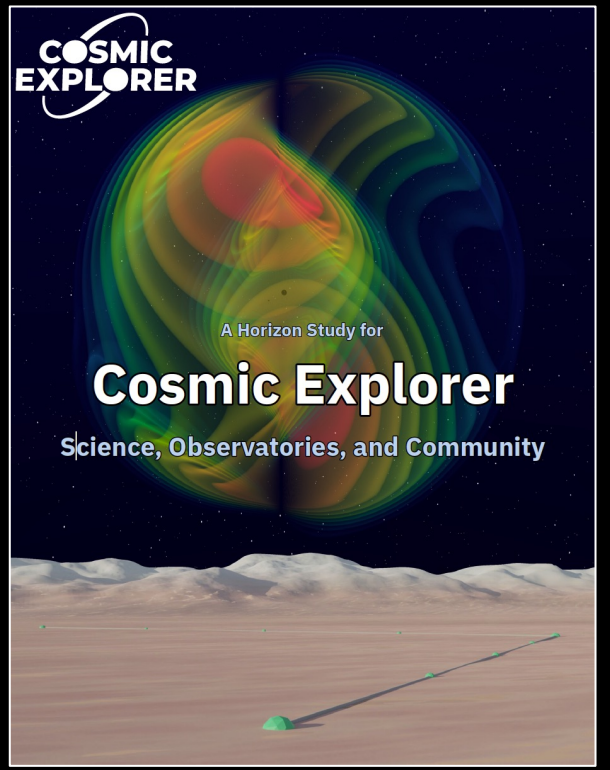


Cosmic Explorer Updates

- Horizon Study for more information available at:
  - https://arxiv.org/abs/2109.09882
  - https://cosmicexplorer.org

- CE is as envisioned an NSF-funded Project
  - 7 proposals submitted to start CE conceptual design

- NSF formed MPSAC (Mathematical and Physical Sciences Advisory Committee) sub-committee…



Next-Generation Gravitational Wave Observatory Subcommittee (NextGenGW SC)

- Established by the NSF
- Committee home page with membership: https://www.nsf.gov/mps/phy/nggw.jsp
- Charge:
  - "… Based on this survey, a recommended list of GW detection network configurations that will deliver a detector with sensitivity an order of magnitude greater than the LIGO A+ design…."
  - https://www.nsf.gov/mps/advisory/subcommittee_charges/mpsac-nggw-charge_signed.pdf
  - Preliminary Report: Oct 2024 / Final Report: Jan 2024
- Call for White Papers:
  - Addressing"… science motivation and key science objectives, technical description of the proposed concept(s) and how different aspects are associated with key science, current and new technologies needed, risks, timelines, and approximate cost assessment, any synergies or dependencies on other multi-messenger facilities. …"
  - Submission deadline: June 12, 2023
  - https://www.nsf.gov/mps/phy/nggw/WhitePaperCall2.pdf
- CE White Paper in preparation…

P5 Town Hall Meeting
on the Future of High Energy Physics

Hosted by Brookhaven National Laboratory
April 12–14, 2023

Mar 2023

- Comic Explorer invited presentation at P5 Town Hall

COSMIC EXPLORER

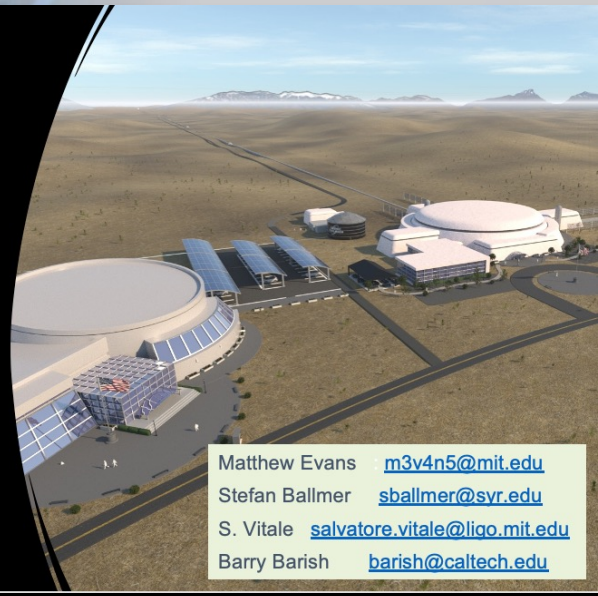
P5: Take-away Points (1/2)

- Cosmic Explorer represents
  - A compelling science case for a new facility.
  - It will require funding for R&D that develops new technologies over the next decade (Quantum Sensing, Vacuum technology, etc.)
  - This will take the form of focused investments in small-scale projects that advance national initiatives in quantum information science, advanced electronics and instrumentation.

Example small-scale project: Advanced LIGO squeezed light source. The technology is now redefining the LIGO's observational rage.

P5: Take-away Points (2/2)

- The GW Field is rapidly advancing.
- Next-generation observatories are based on proven technologies, but some critical R&D related to scaling is needed (vacuum, optics, etc.)
- GW science has significant overlap with DOE/HEP mission, though synergies remain largely unexplored (Dark Matter, Dark Energy, Quantum, …)
- GW observatories are an opportunity for National Labs, bringing in key expertise



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Snowmass Cosmic Frontier Report

Nov 2022

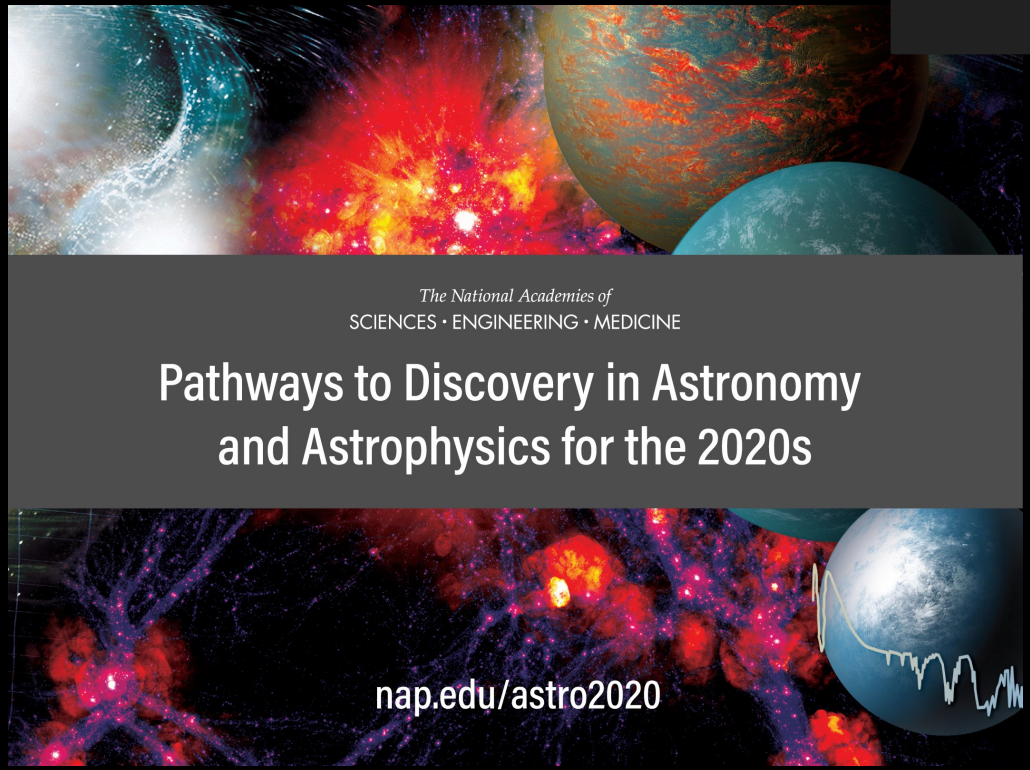
- 5.3.3 New Opportunity: Gravitational Waves

- The Cosmic Frontier community plans to incorporate Gravitational Wave Observatories in its portfolio of tools for discovery with a long term strategic vision. We will pursue EM counterparts of events detected by the growing Gravitational Wave Observatory network while launching new pathfinder (R&D) efforts to enable the HEP community to participate in the next-generation GWO project in a leading role. The new detector's sensitivity, roughly 10 times better than the planned LIGO upgrade, requires significantly larger facilities and a number of technological upgrades. Both are challenging requirements that the HEP community is well-equipped to meet, given our experience.
- This is likely a once-in-a-century opportunity for the HEP community to make new breakthroughs in an entirely new class of experiments and utilize this new opportunity to advance on our scientific drivers at a much faster pace than previously anticipated.

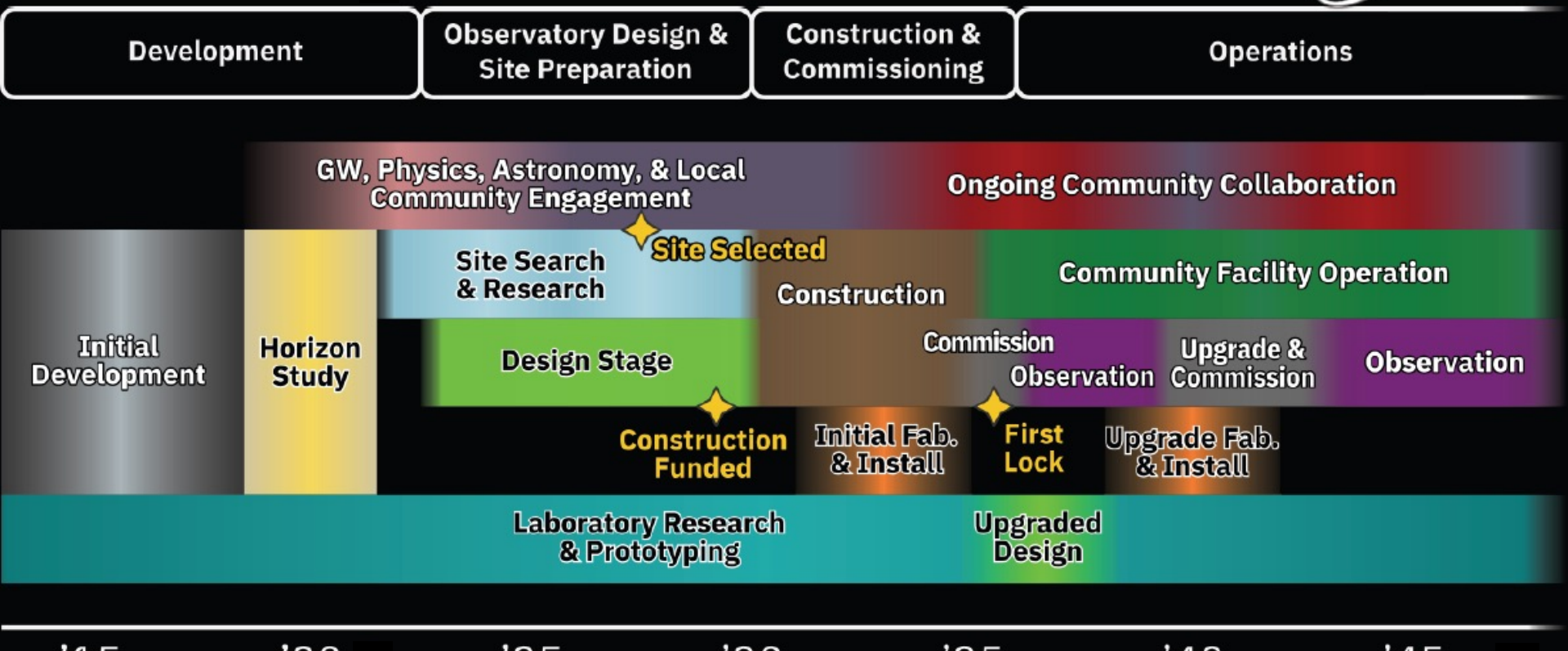
https://arxiv.org/abs/2211.09978

Astro2020 Decadal Survey: A Resounding Endorsement

- Released in Nov 2021
- Next-generation gravitational-wave observatory in the United States is "central to achieving the science vision laid out in the survey's roadmap."



Cosmic Explorer Notional Timeline (see CEHS)



Overview of CE Research Activities

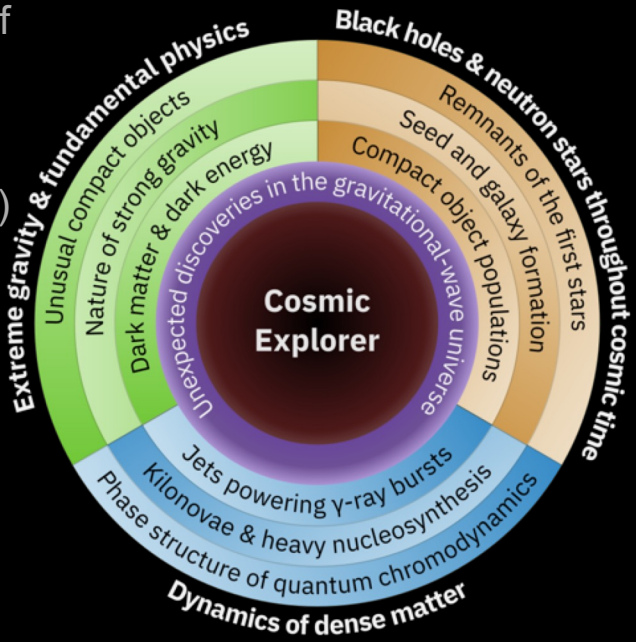
- Observational Science (consortium driven) ♀
- Site evaluation and Indigenous Partnership Program *
- Vacuum system ♀
- Stray-light control *
- Newtonian Noise reduction *
- Optical design *
- Mode sensing and control *
- Suspension design (A#) ♀

♀: (Partially) funded activities
*: Design funding pending

Observational Science

Our observational science goals drive the CE design!

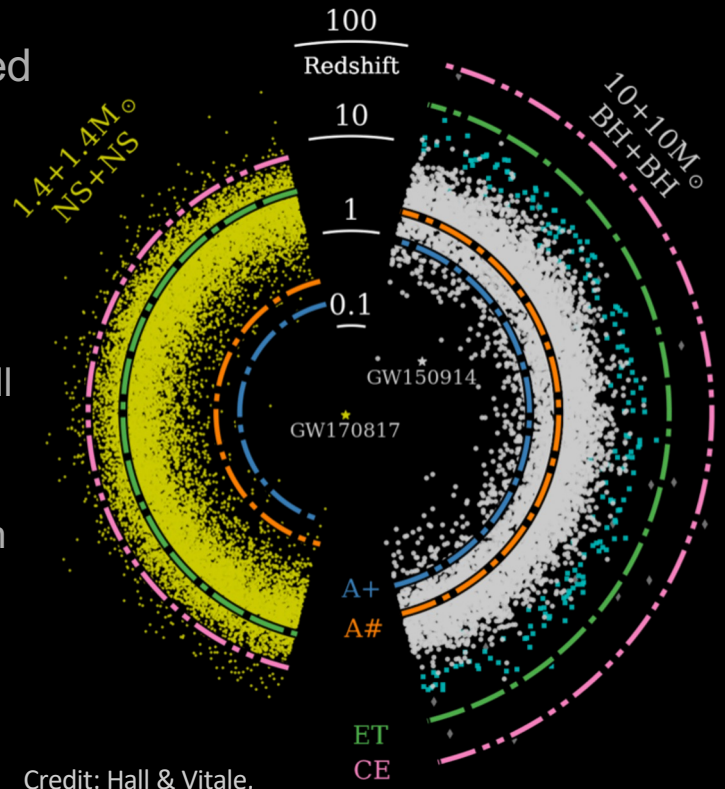
- Development of our understanding of CE science happens in the CE Consortium
- Salvo Vitale (CE Consortium Liaison) is our primary point of contact, and he holds regular CE Science Calls
- Alessandra Corsi and Edo Berger (CE Multi-Messenger Science Liaisons) are our primary contact points with other observers. They bring input from the broader astro community into the CE Project.



Observational Science

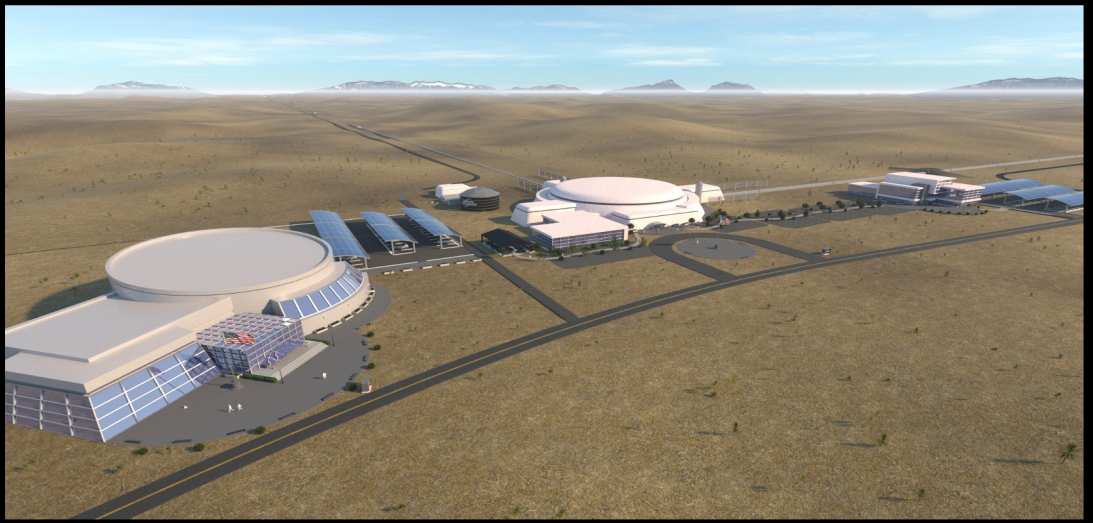
Sathya, Brown and Vitale awarded an NSF grant to prepare a **Mock Data Challenge** for CE

- Focus on challenges and opportunities for next-gen observatories
- Presented at the CE Science call on Sep 29 2022, CE DCC G2300010
- Welcome input and collaboration from the community
- Please contact them if you are interested, or want to contribute!



Credit: Hall & Vitale, data from Ng et al 2021, 2022

Site evaluation and Indigenous partnership program



Preliminary studies suggest there are many physically promising locations in the US that could accommodate 20km or 40km detectors

Now assembling a team of physicists, geologists, geographers, and sociologists to carry out a deeper study of potential locations, including building local contacts with interest groups

Locations will be evaluated for how they support CE's science goals and for relevance and potential synergies with Indigenous and other local communities

Work led by Josh Smith (CSUF) and Kate Daniel (UA)

Research Highlights: Vacuum Research

The LIGO vacuum system could be scaled up, but it would be expensive

On-going R&D funded by NSF to explore alternative approaches (PI: Lazzarini, co-PI: Weiss)

- Mild steel for beam tubes
- Looking into cheaper tube bake-out

Active collaboration with CERN

- ET vacuum system design
- Coordinated R&D
- Workshop in March 2023 at CERN
  - Mild steel works (100x lower H2 outgassing)

Research Highlights: Stray-Light Mitigation

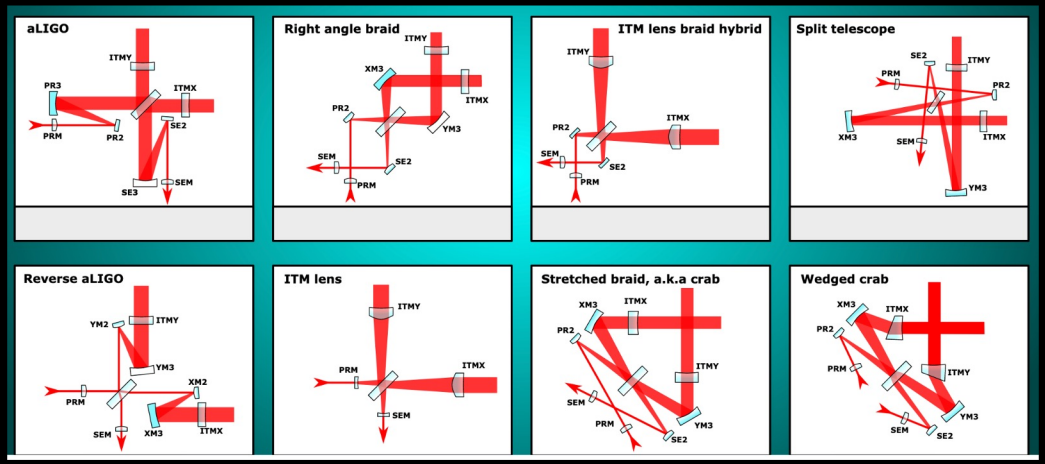
- One of the proposed activities to NSF last fall (PI: Kontos, co-PI: McCuller)
  - Most pressing aspect: conceptual design of vacuum tube baffles
- Baffle modeling now possible in Hiro Yamamoto's Static Interferometer Simulation tool (SIS)
- Need to define:
  - Optimal baffle location and spacing
  - Baffle material

(Alena Ananyeva, collab. with ET)

Research Highlights: Optical Design

- One of the proposed activities to NSF last fall
  (PI: Fulda, co-PI: Mansell, McCuller, Barsotti)
- First open question: what is the best corner layout?

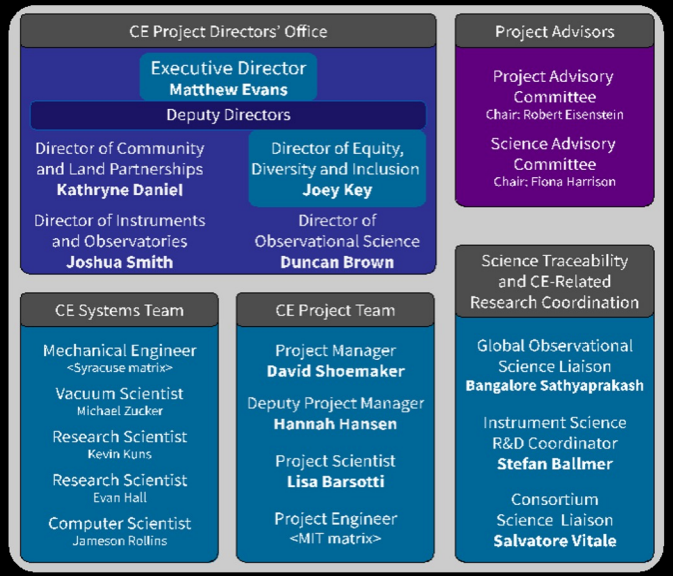
See Paul Fulda's poster

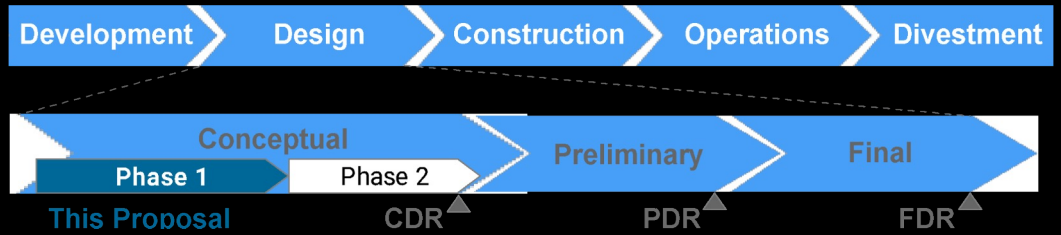


And a lot more…
Central Project and EDI Efforts

In addition to the R&D efforts…

Proposed activity also includes project management, and planning efforts, as well as centralized R&D and EDI coordination.





The Message

The conceptual design phase of CE is starting.

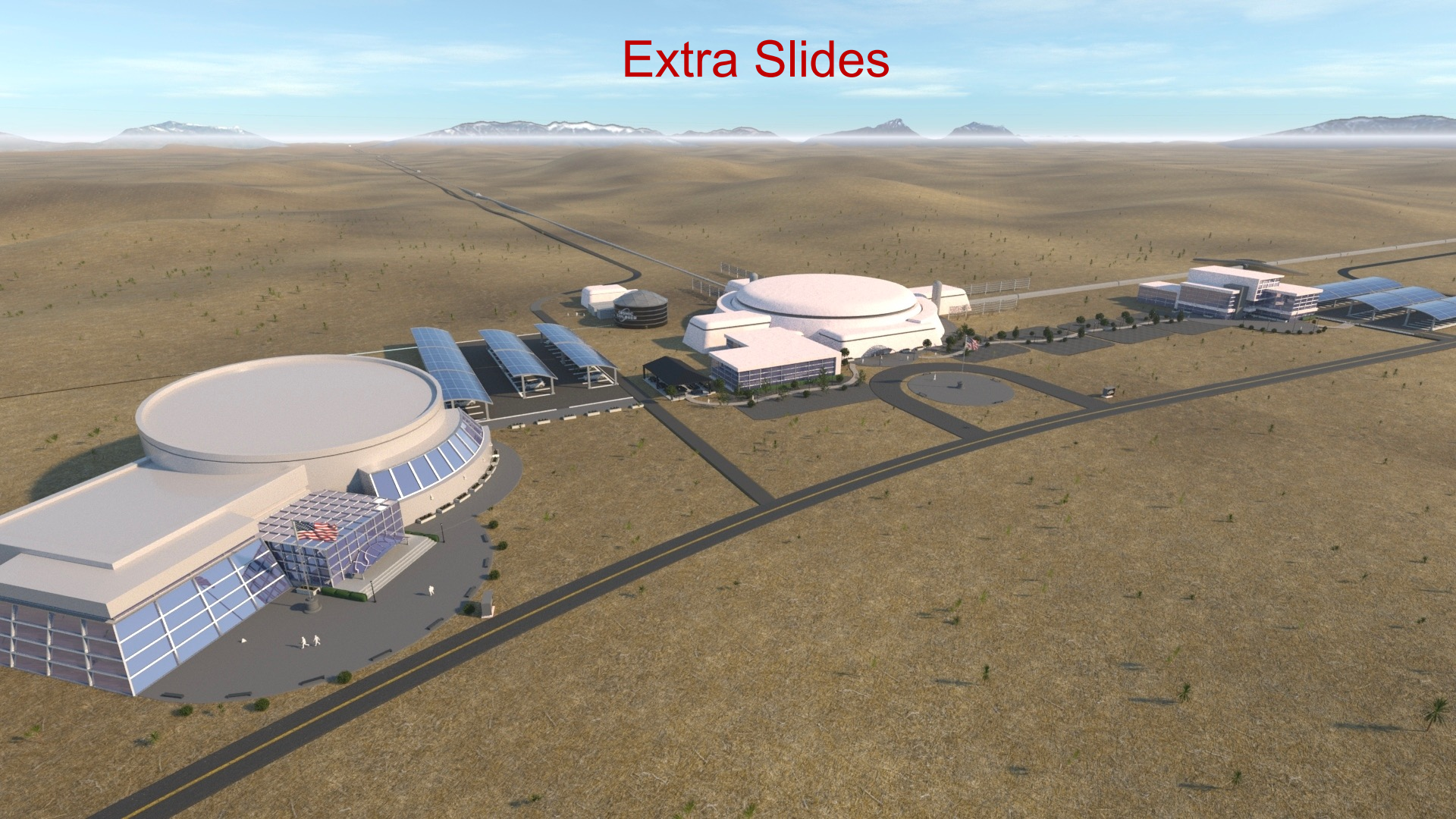
We are anticipating good news from the NSF later this year.

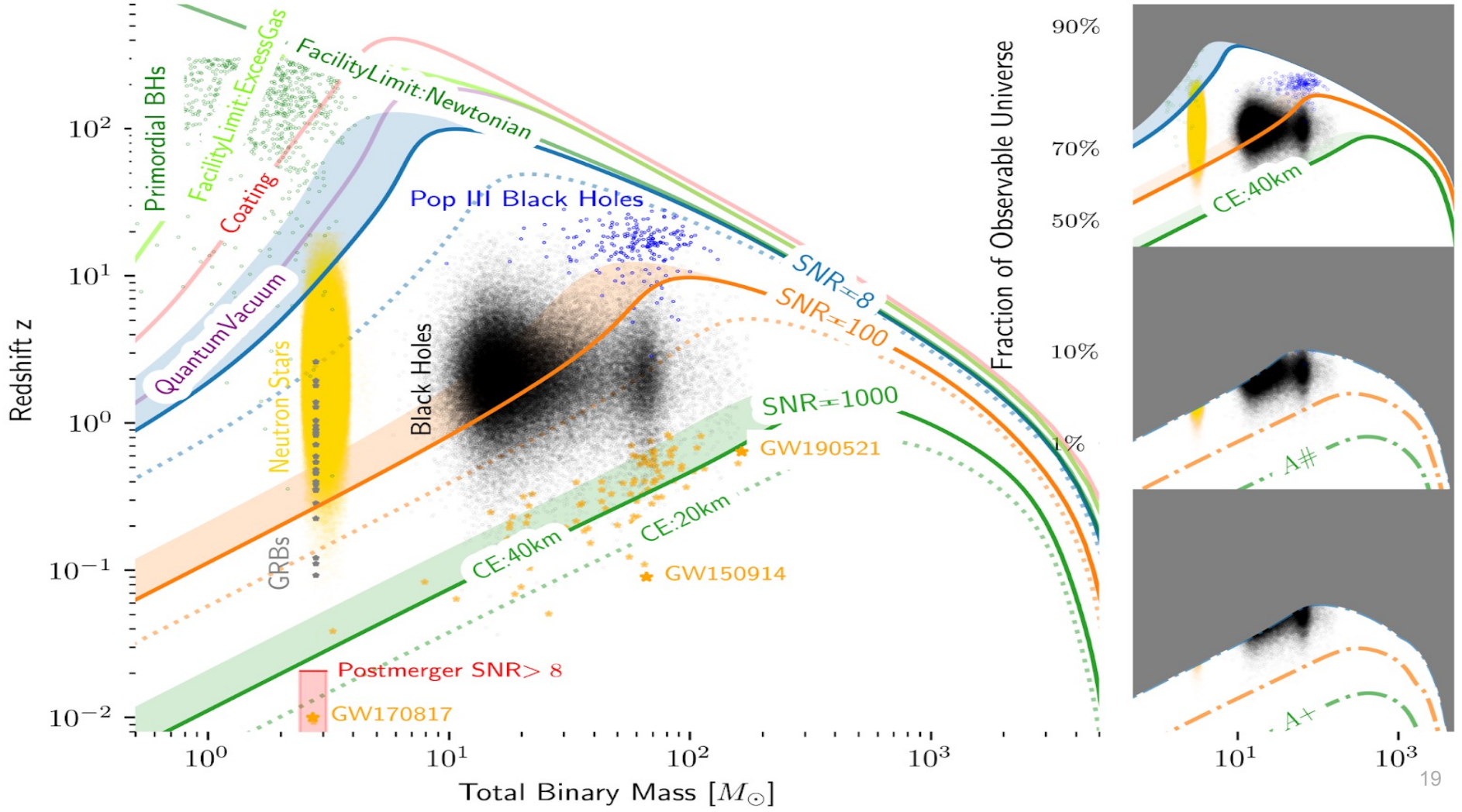
If you want to be involved, please join the consortium!

Thanks!

cosmicexplorer.org

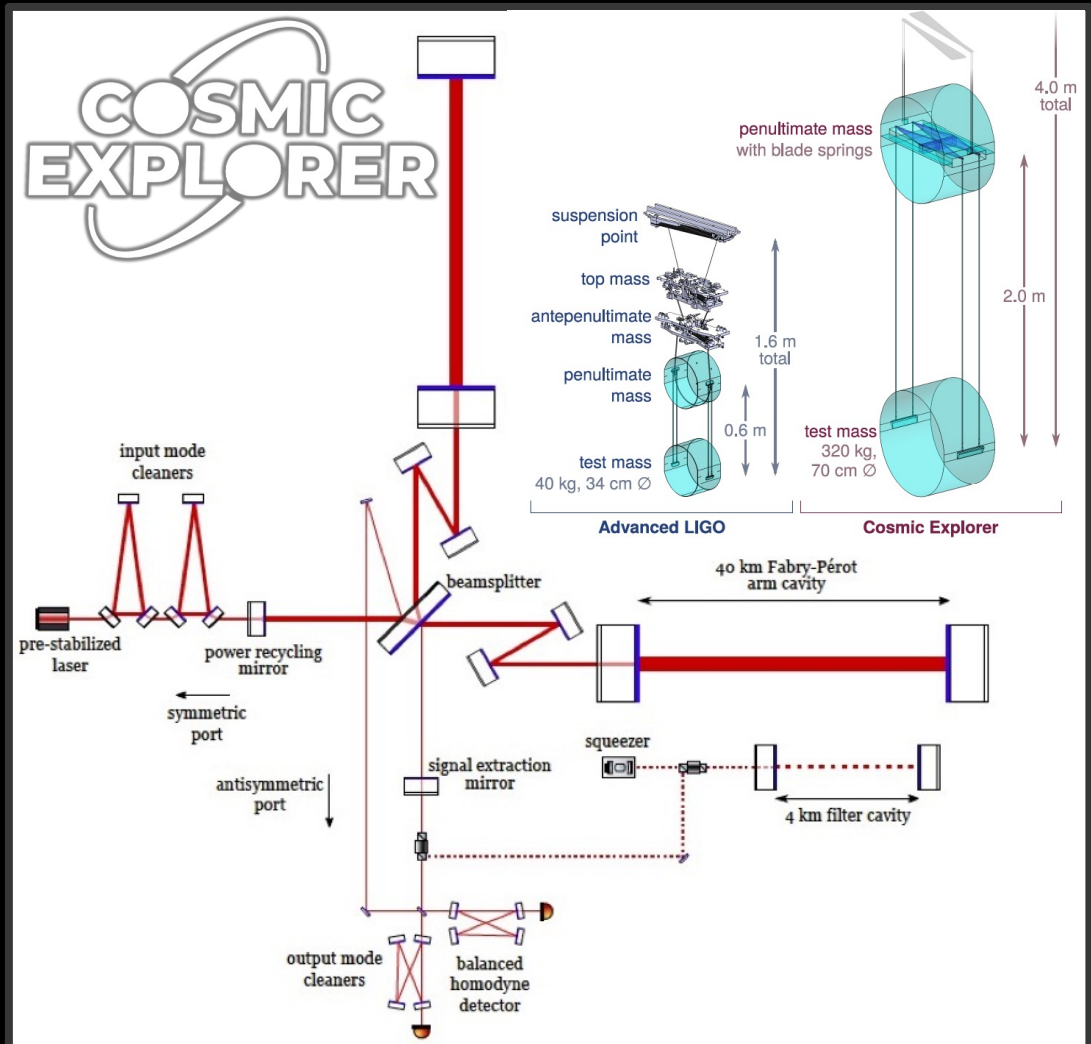
Extra Slides




Primordial BHs
FacilityLimit:ExcessGas
FacilityLimit:Newtonian
Coating
Pop III Black Holes
QuantumVacuum
Neutron Stars
Black Holes
GRBs
SNR=8
SNR=100
SNR=1000
GW190521
CE:20km
CE:40km
GW150914
Postmerger SNR> 8
GW170817
Redshift z
Total Binary Mass [$M_\odot$]
Fraction of Observable Universe
90%
70%
50%
10%
1%
CE:40km
A#
A+

CE Detector Concept

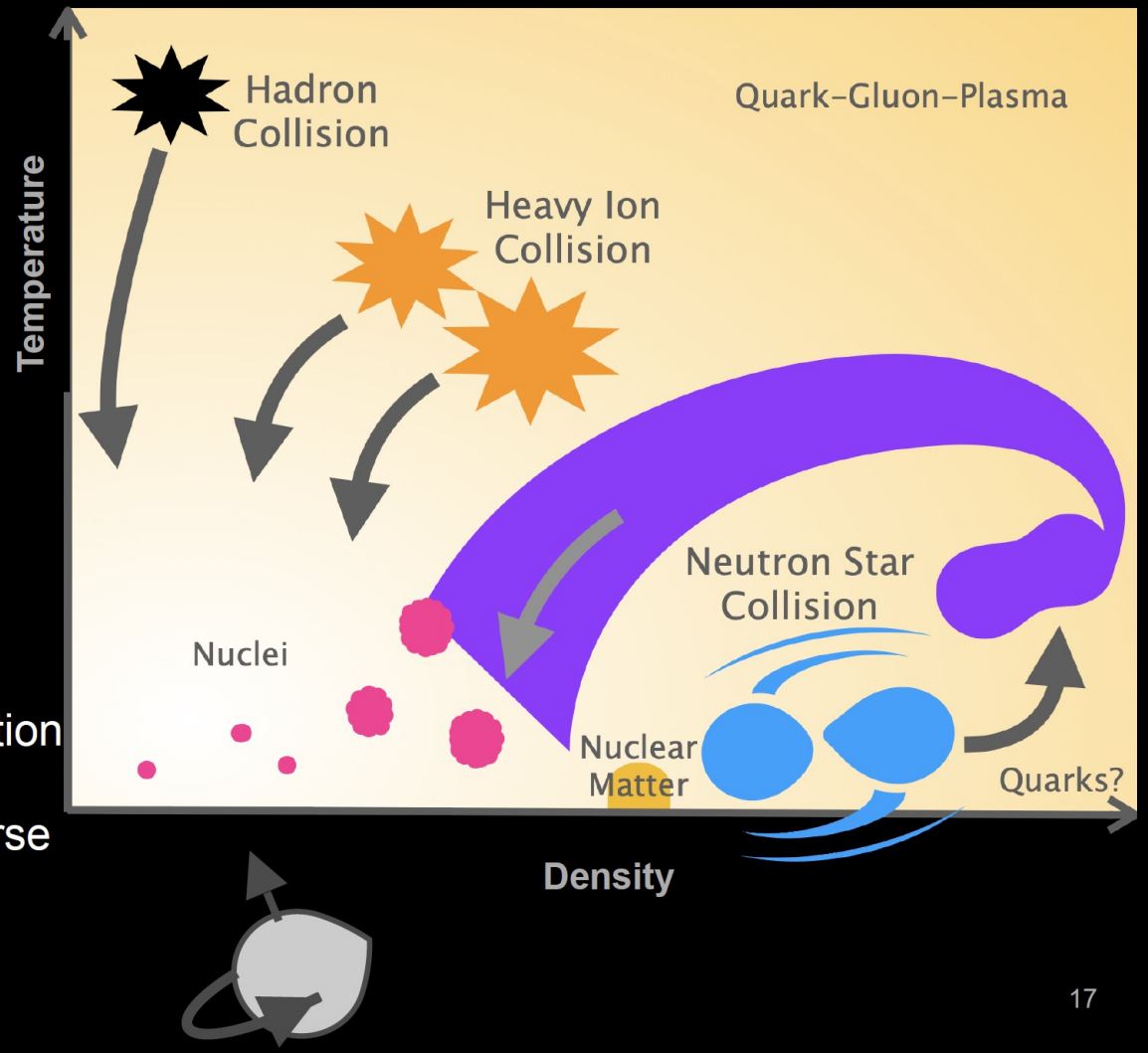
- The Cosmic Explorer instrument design is based on proven LIGO technology
- Development will be required to scale-up some technologies (e.g., larger mirrors, longer suspensions, …)
- Vacuum system is major cost driver, so R&D ongoing to find better and cheaper solutions



Dynamics of dense matter

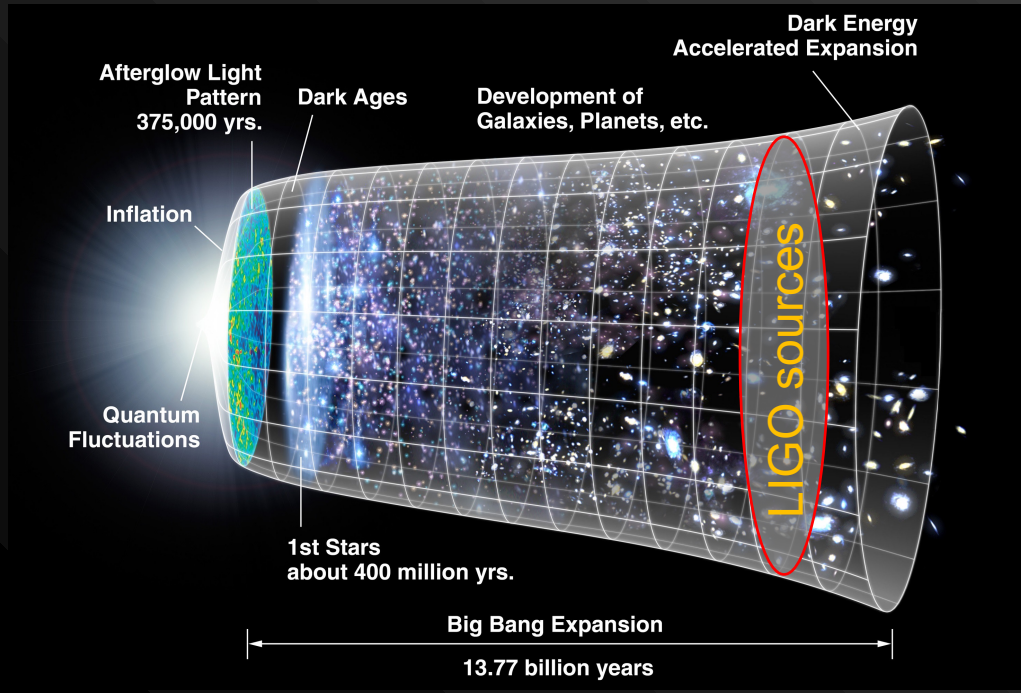
How does matter behave under the most extreme conditions in the universe?

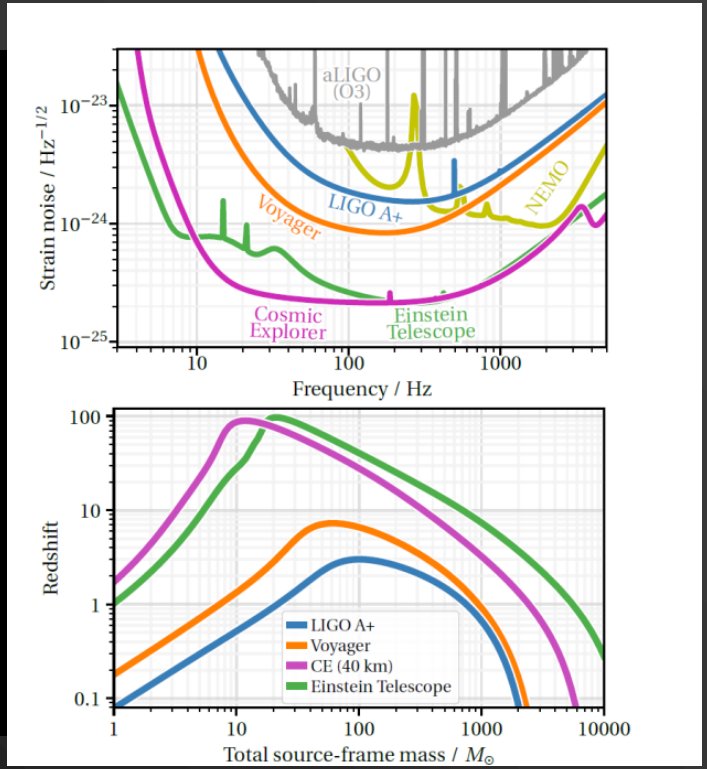
- Neutron star structure, composition
- New phases of dense matter
- Chemical evolution of the universe
- Gamma-ray bursts and jets



Slide: P Landry, Figure: P Landry, J Read

Probing the Early Universe

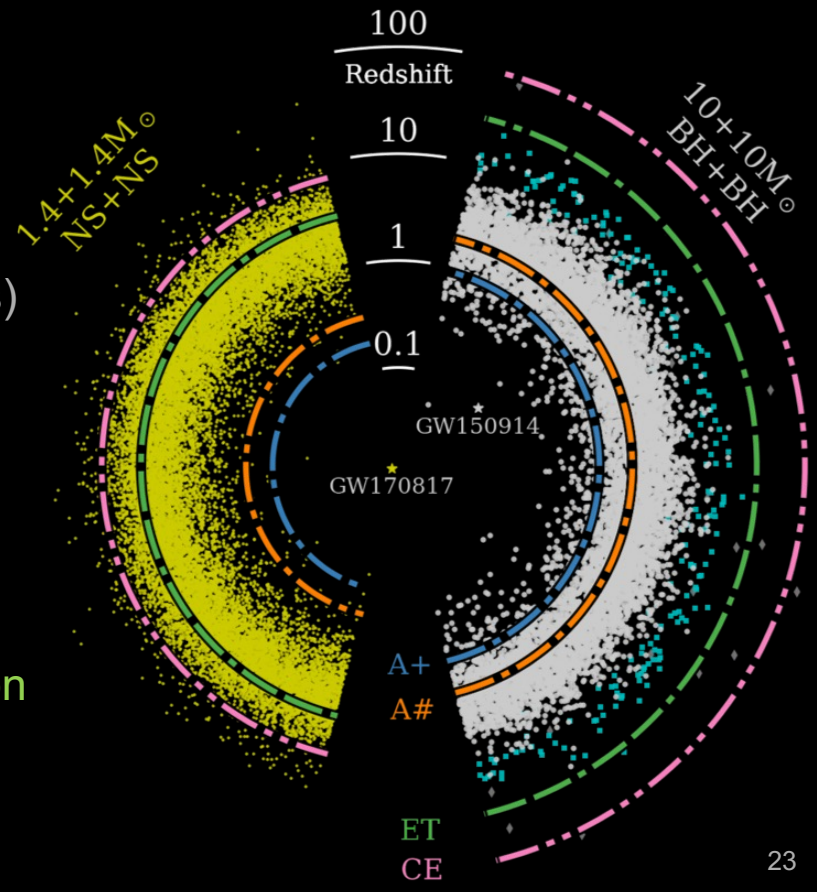




Credit: NASA

Cosmology and Precision Science with Cosmic Explorer

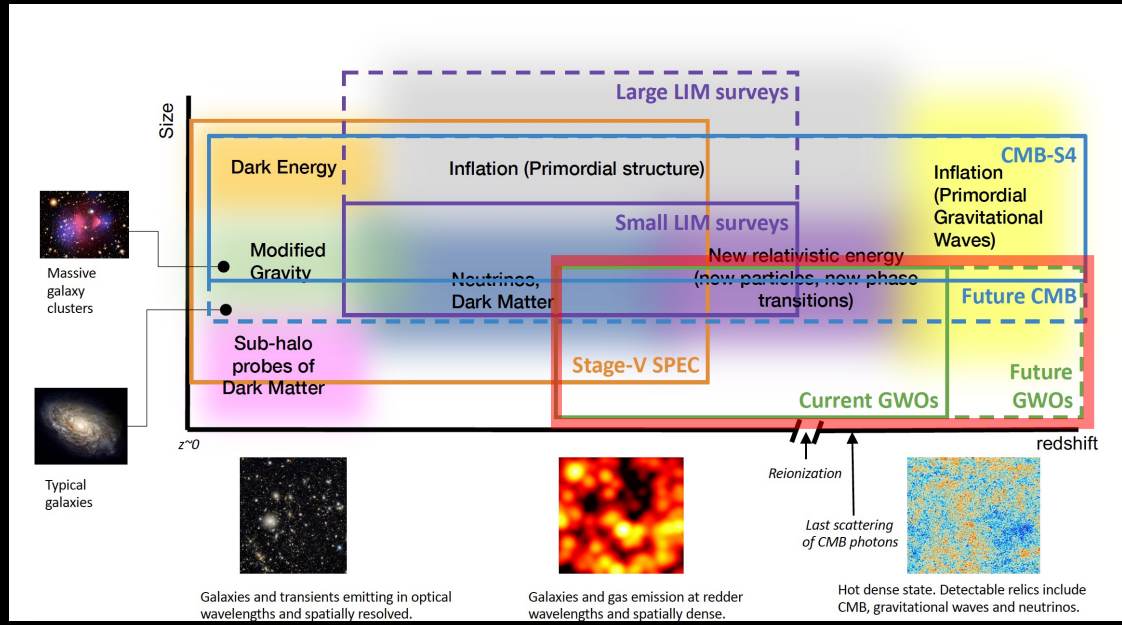
- Expected event rate
  - O(1e5) BHBH merger annually
  - O(1e6) NSNS mergers annually
- SNR NS-NS up to ~300 (post merger physics)
- SNR BH-BH up to ~3000 precision tests of Einstein GR.
- Across redshifts up to z ~ 30
  - Sky localization from detector network
- The full Cosmic Explorer data set will be a treasure trove for structure formation correlation studies, dark matter, dark energy signatures



Primordial GW

Early-universe GW fingerprints:

- Primordial BHs & GWs
- Dark Matter signatures
  - Gravity is only confirmed DM coupling (galactic scale)
  - GW are only way to probe gravitational coupling on smaller scale (stellar-size)



From Snowmass CF7 report

- Terrestrial GW Observatories can provide access to the smallest individual objects out to redshifts of z=O(10)

Quantum Sensors beyond the standard quantum limit

Happening right now in Advanced LIGO. Squeezers are working at both LIGO observatories!

Latest results show quantum noise reduction across the band (publication in the works…)