Cosmic Explorer, the Next-Generation of US Gravitational-Wave Observatories

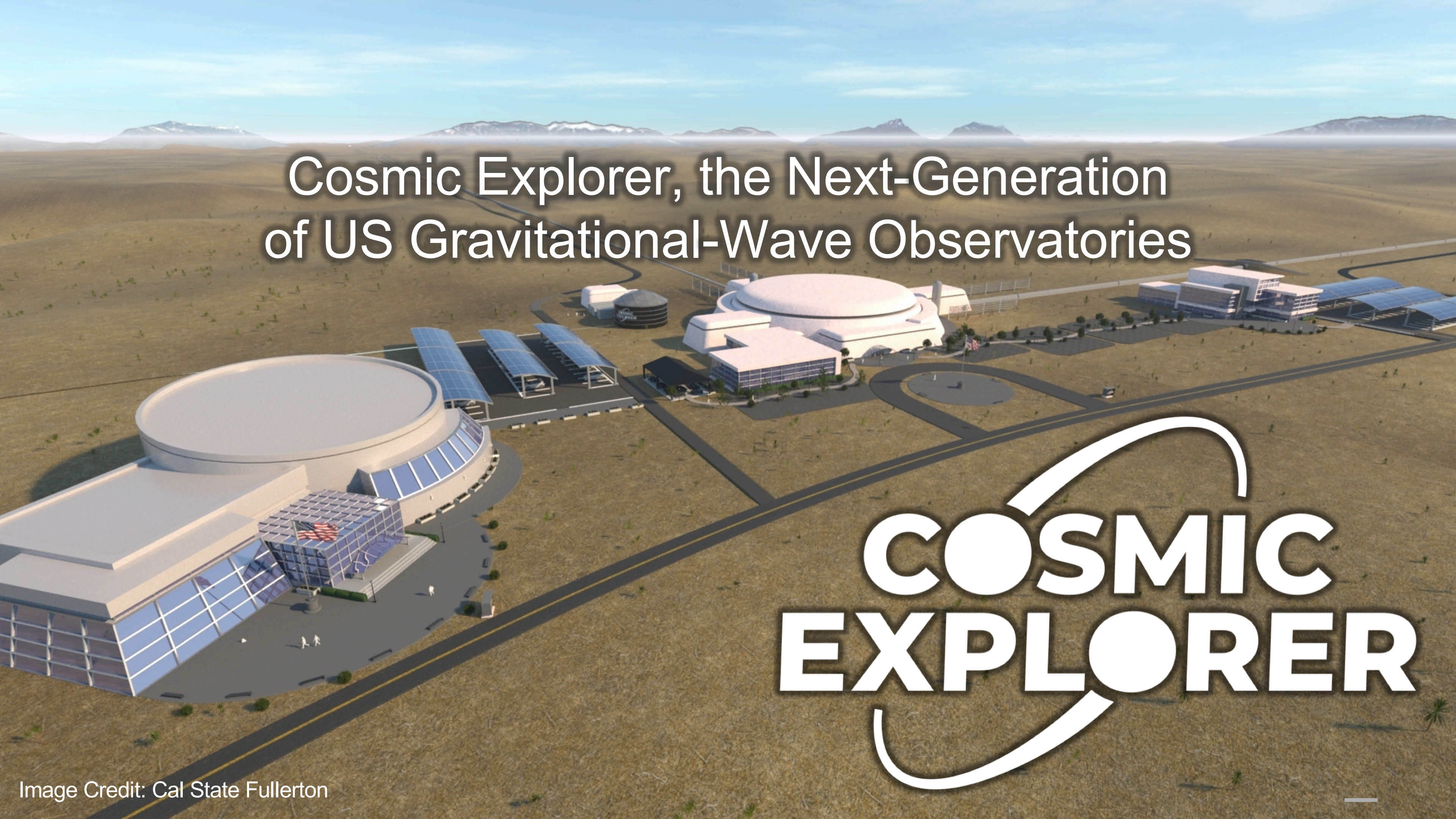
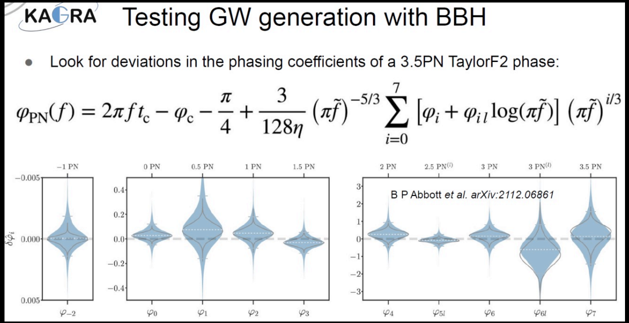
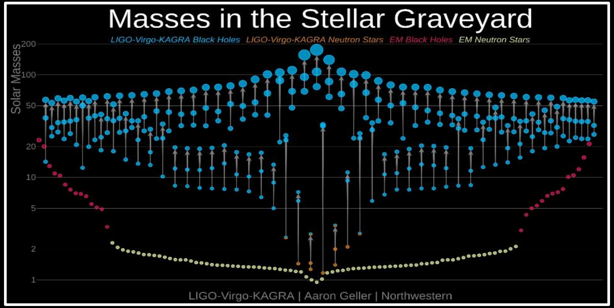


Image Credit: Cal State Fullerton

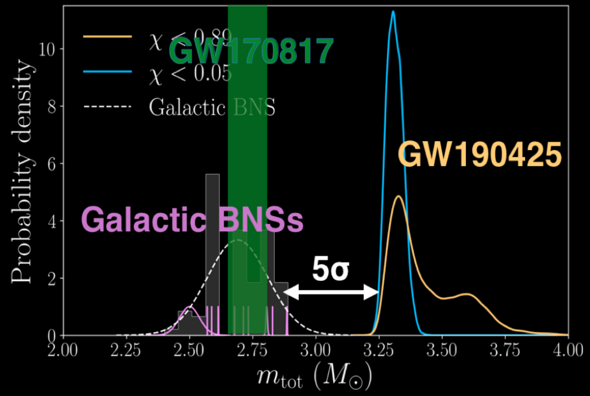
The GW Field Is Rapidly Advancing Since Discovery



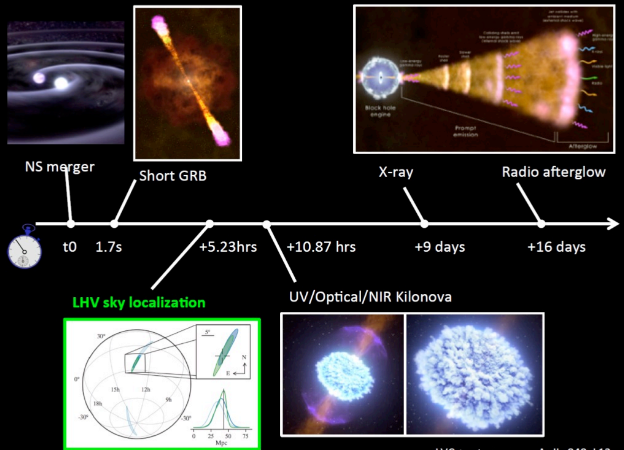
Limit on Graviton Mass $M_g \leq 7.7 \times 10^{-23}$ eV/c^2



Nearly 100 detected mergers BH-BH, NS-BH, NS-NS



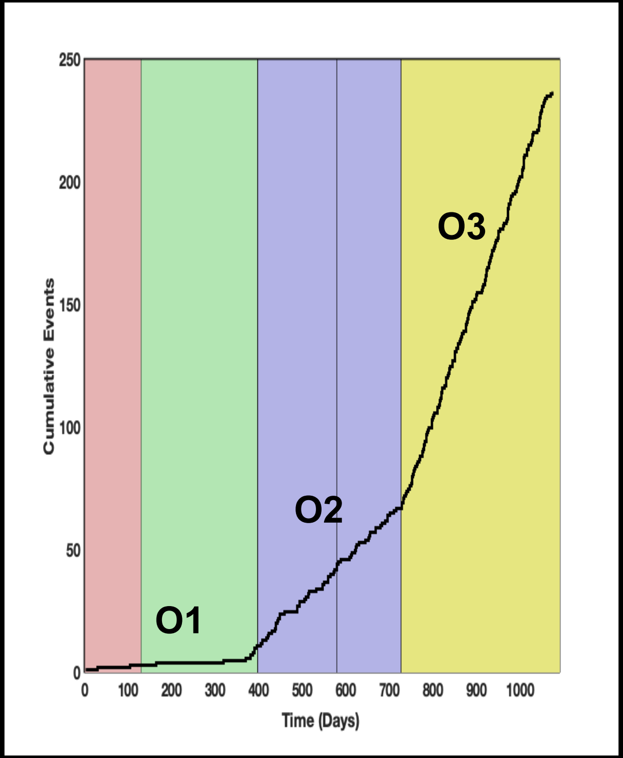
A few Intriguing Exotic Events



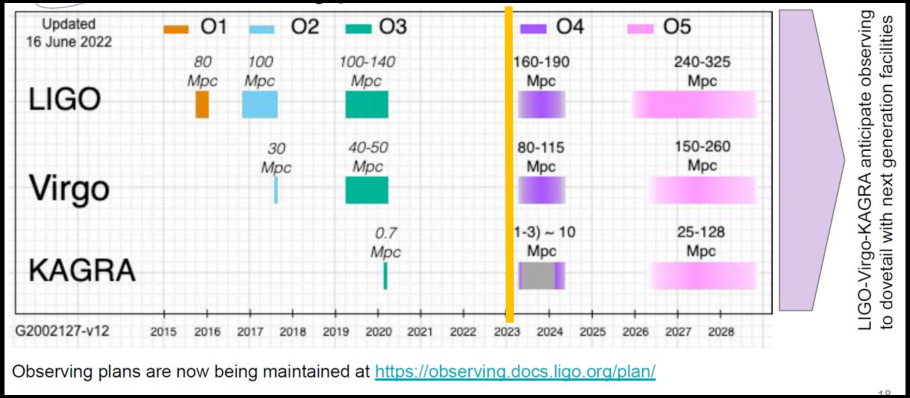
LVC + astronomers, ApJL, 848, L12

NS-NS Merger – Birth of Multimessenger Astronomy

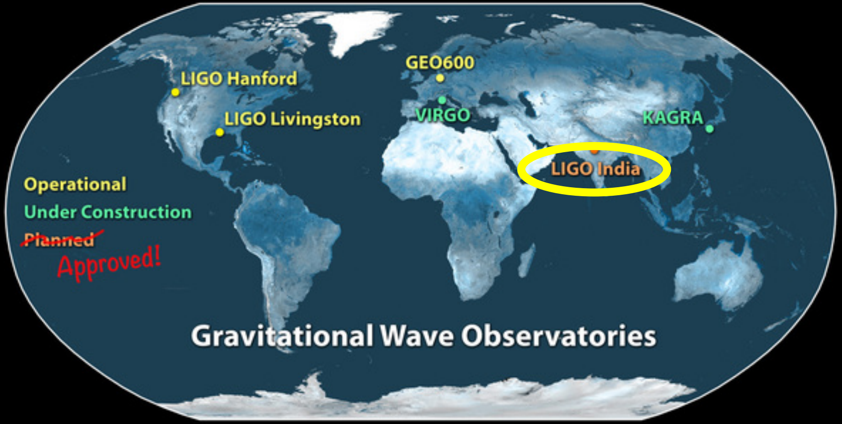
Technical/Sensitivity Advances over the Coming Decade



Incremental Increases in Sensitivity/Rate

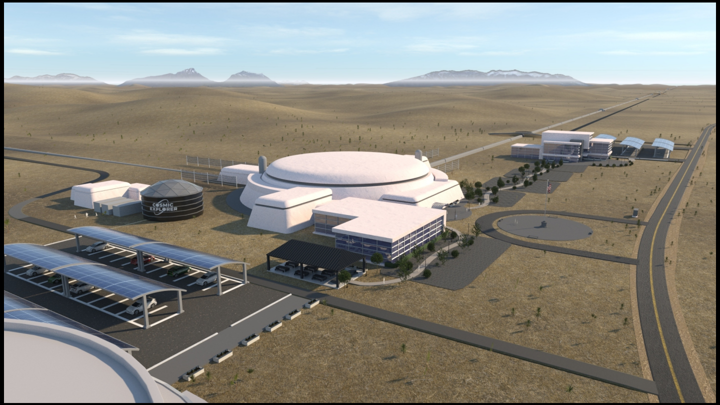


Run Plan Over Next 5-10 Years



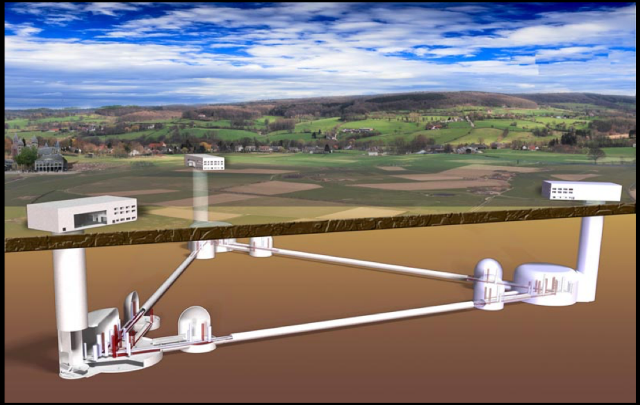
LIGO India Funded Last Week - $320M India + $80M U.S.

Next Generation Detectors (2030s) ~x10 aLIGO



Cosmic Explorer → x10 Advanced LIGO

Earths surface;
40 km arms + 20 km arms
Low frequency configuration
high frequency configuration

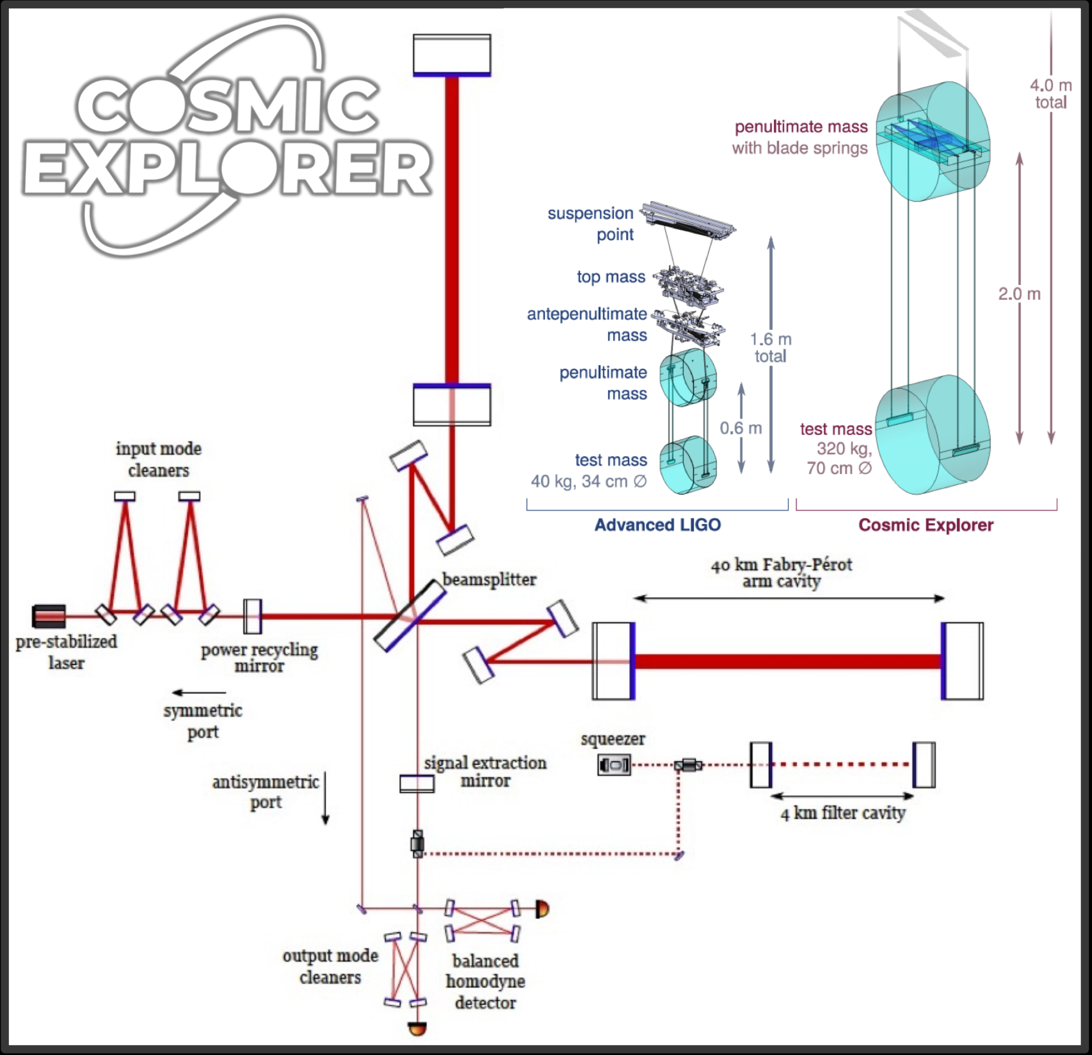


The Einstein Telescope

Deep Underground
Site Proposals: Sardinia; Holland
10 km arms
Triangle (polarization)

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

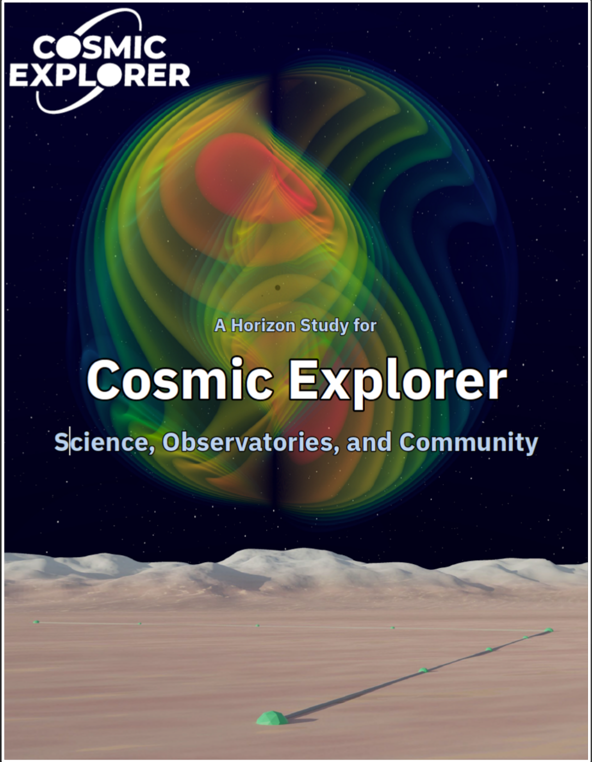


Horizon Study Document

- High-impact science in context of 2030-era astronomical observatories (Athena, Lynx, LISA, etc.)

- Connects science goals to design choices
  - Number of detectors and location
  - Detector length and configuration

- Delivered to the NSF Fall 2021:
  - https://arxiv.org/abs/2109.09882
  - https://cosmicexplorer.org

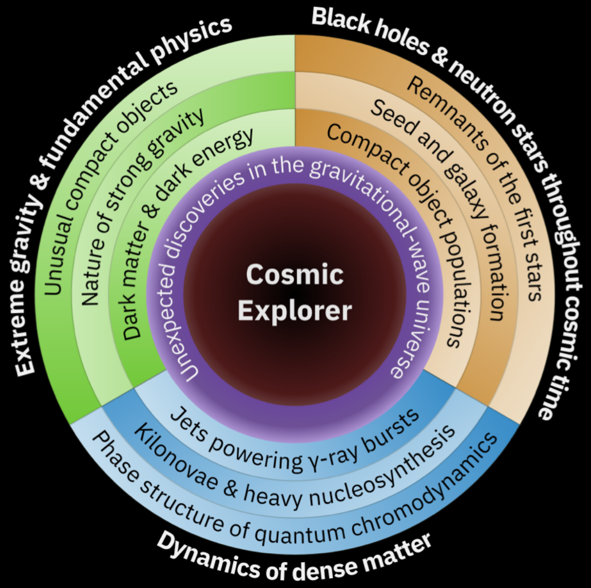


Cosmic Explorer

The 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 (Advanced LIGO)
  - Global network together with European Einstein Telescope

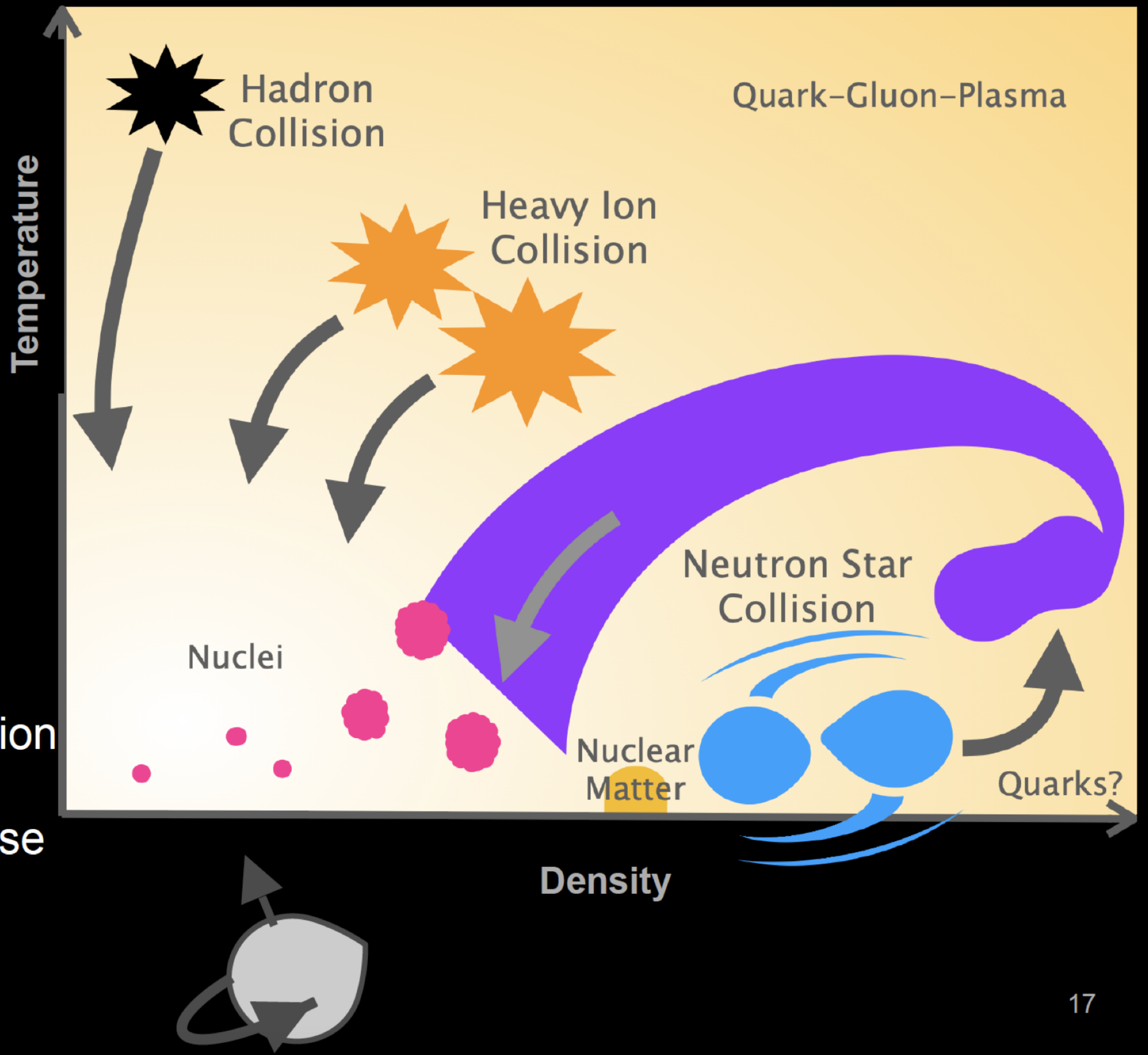
- Enables access to
  - Stellar to intermediate mass mergers throughout Cosmic Time
  - Dynamics of Dense Matter
  - Extreme Gravity



Dynamics of dense matter

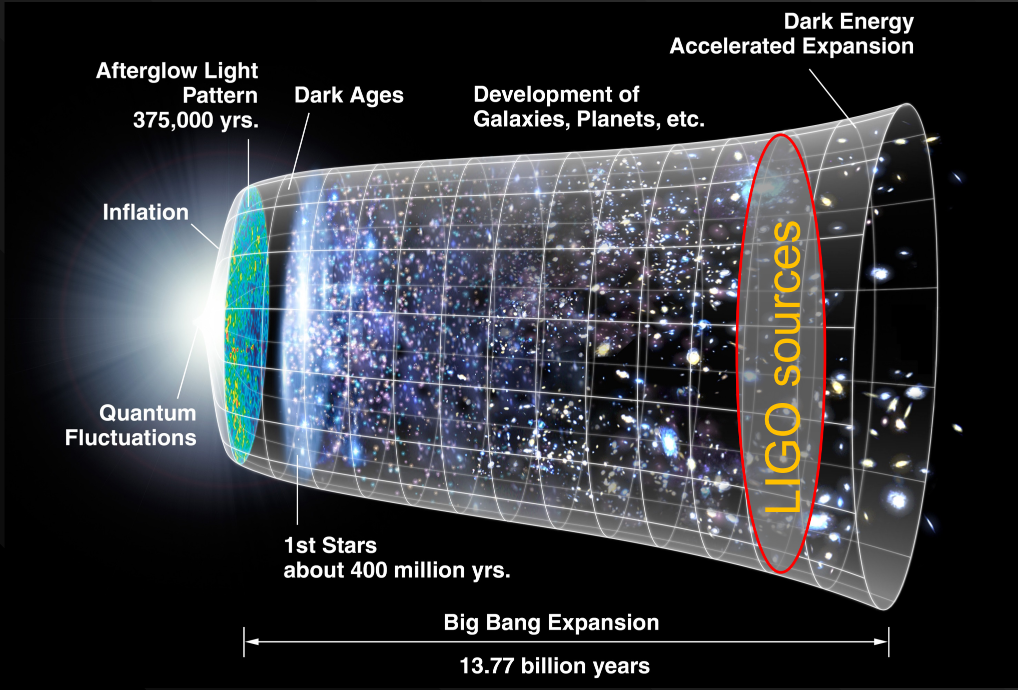
How does matter behave under the most extreme conditions in the universe?

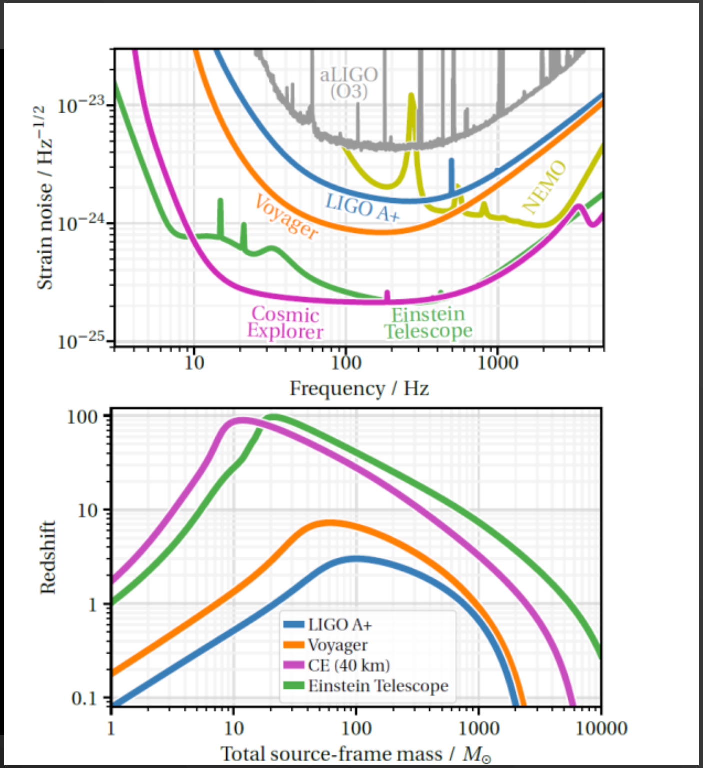
- Neutron star structure, composition
- New phases of dense matter
- Chemical evolution of the universe
- Gamma-ray bursts and jets



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

Probing the Early Universe

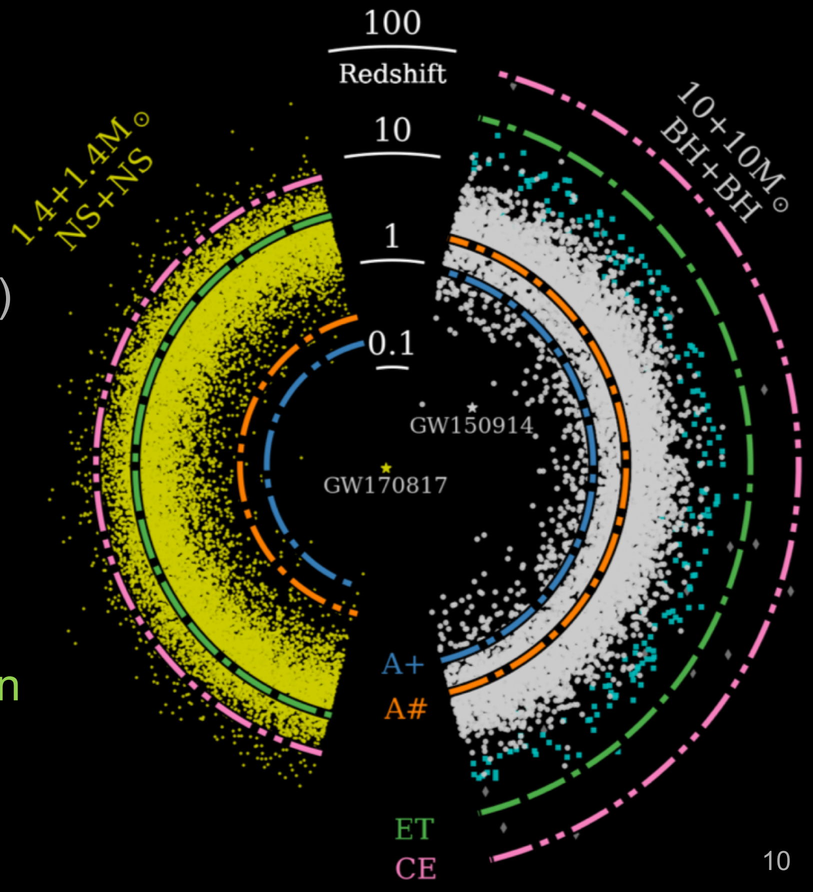




Credit: NASA

Cosmology and Precision Science with Cosmic Explorer

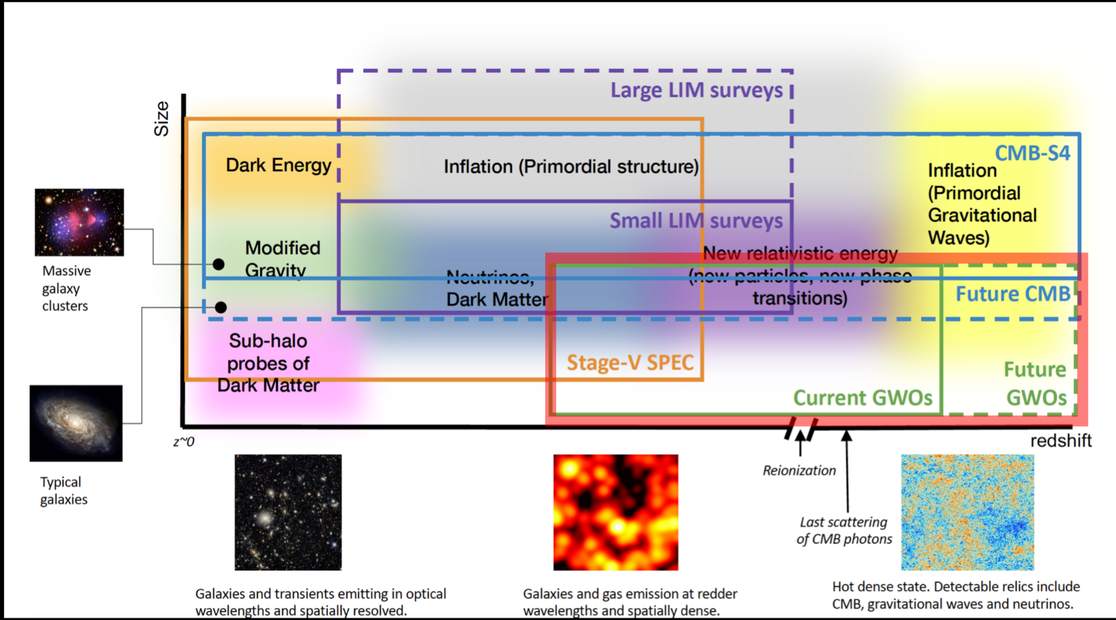
- Expected event rate
  - O(1e5) BHBH merger annually
  - O(1e6) NSNS mergers annually
- SNR NS-NS up to ~300 (post merger physics)
- SNR BH-BH up to ~3000 precision tests of Einstein GR.
- Across redshifts up to z ~ 30
  - Sky localization from detector network
- The full Cosmic Explorer data set will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



Primordial GW

Early-universe GW fingerprints:

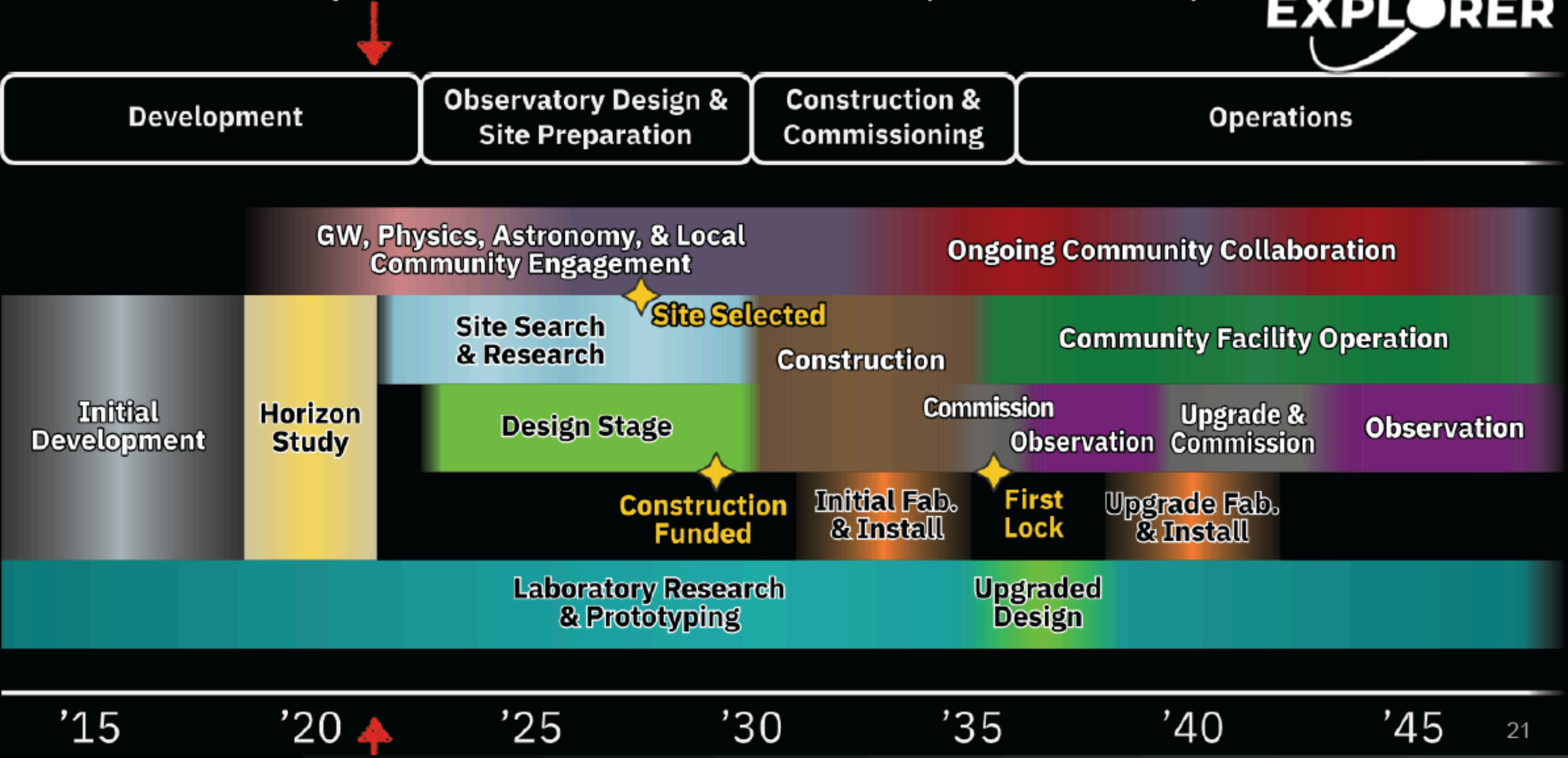
- Primordial BHs & GWs
- Dark Matter signatures
  - Gravity is only confirmed DM coupling (galactic scale)
  - GW are only way to probe gravitational coupling on smaller scale (stellar-size)



From Snowmass CF7 report

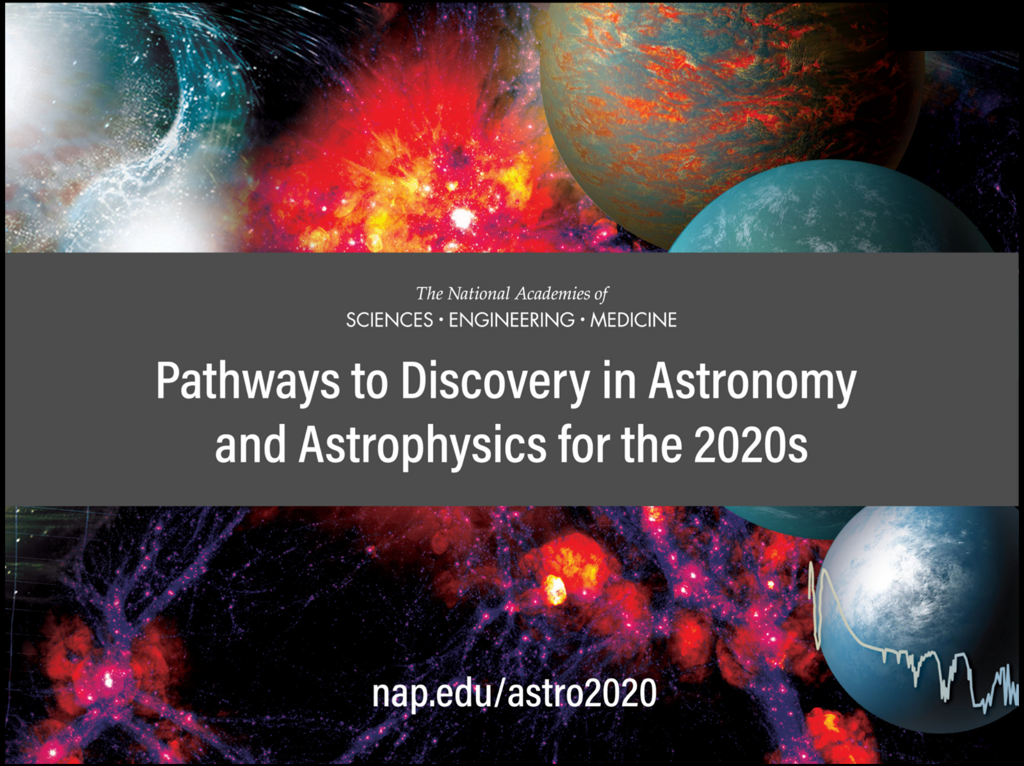
- Terrestrial GW Observatories can provide access to the smallest individual objects out to redshifts of z=O(10)

Cosmic Explorer Notional Timeline (see CEHS)



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."



Snowmass Cosmic Frontier Report

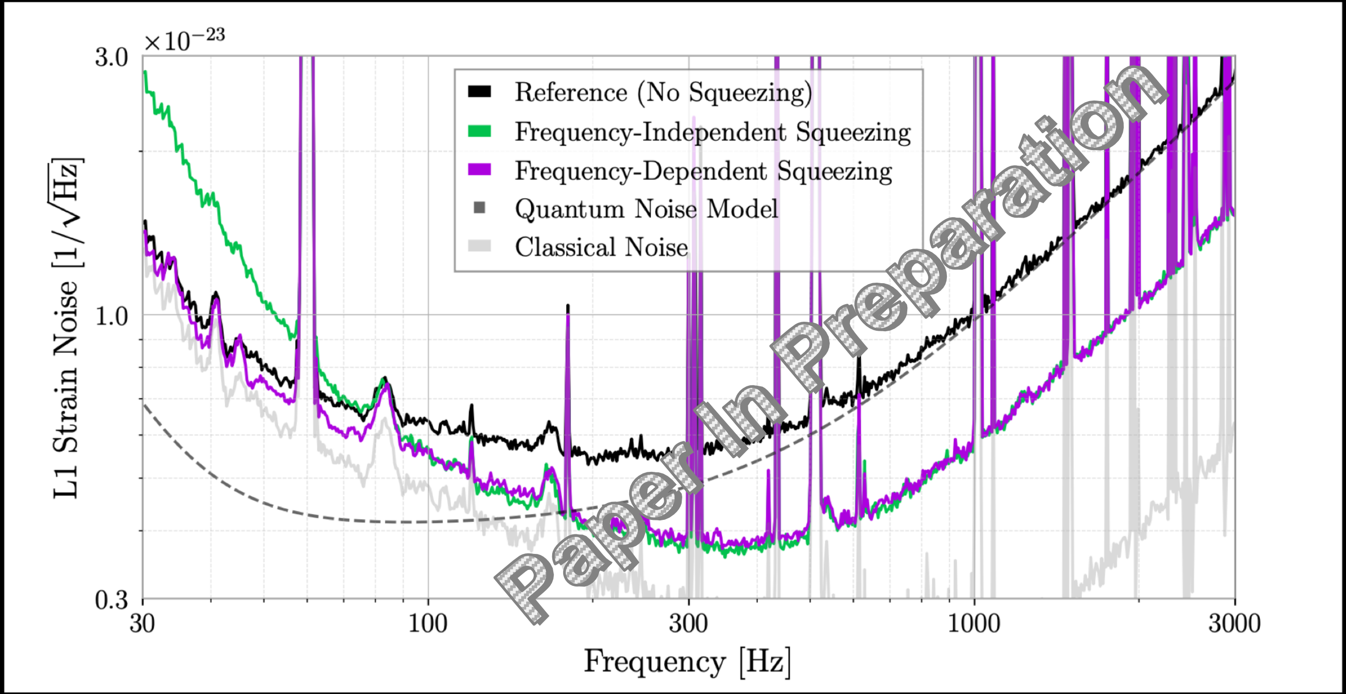
- 5.3.3 New Opportunity: Gravitational Waves

- 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.

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…)



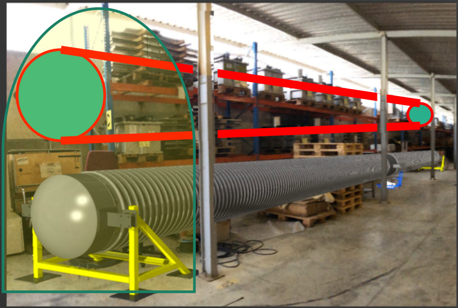
Preliminary Cost and Schedule

- Cosmic Explorer for the next decade
  - Conceptual Design, next 5 years ~$25M
    - vacuum system R&D + design, site identification, civil engineering concepts and cost estimates, scaling up LIGO technology, etc.
    - Improved cost estimates are a major output of the CD phase
  - Preliminary Design, 3 years ~$50M
    - site selection, detailed civil and vacuum designs, etc.
    - Final budget submitted at time of Preliminary Design Review
  - Final Design, 2 years ~$80M
    - refinement and preparation for construction
- Construction, starting early 2030s: ~$2B for 2 observatories
  - Operations: ~$60M/year in 2021 USD, based on LIGO experience

European Einstein Telescope Collaboration with CERN

- Europe / Einstein Telescope is ahead of US:
  - ET is on 2021 ESFRI road map (https://www.esfri.eu/esfri-roadmap)
  - Financial pledges by Netherlands, Italy,…

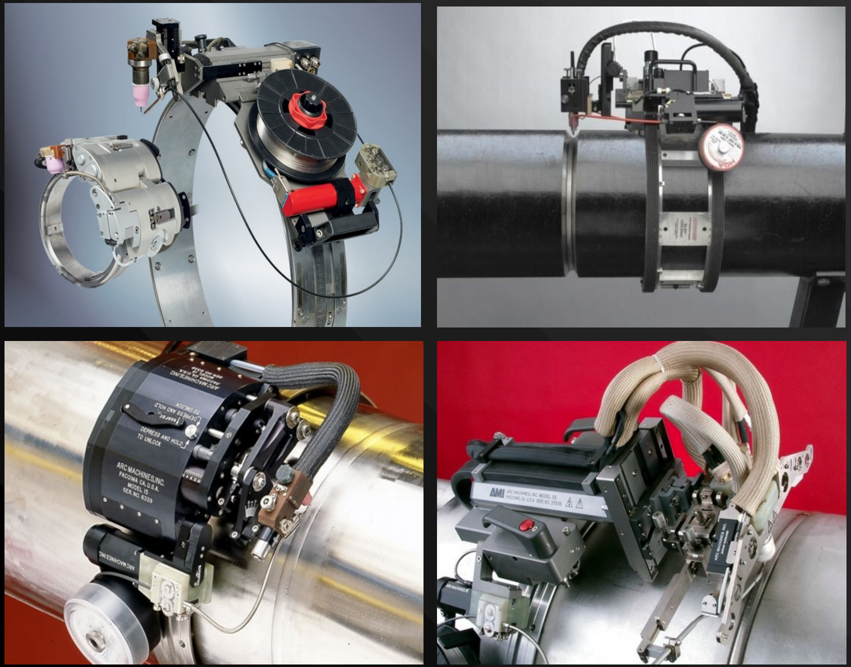
  - ET has an MOU with CERN for support on technical topics.
    - Covers the work for the ET beampipe
      (coordinate efforts, link to CE, less expensive technical solutions)
    - Leading to a beampipe **pilot sector** and a **TDR** by end of **2025**.



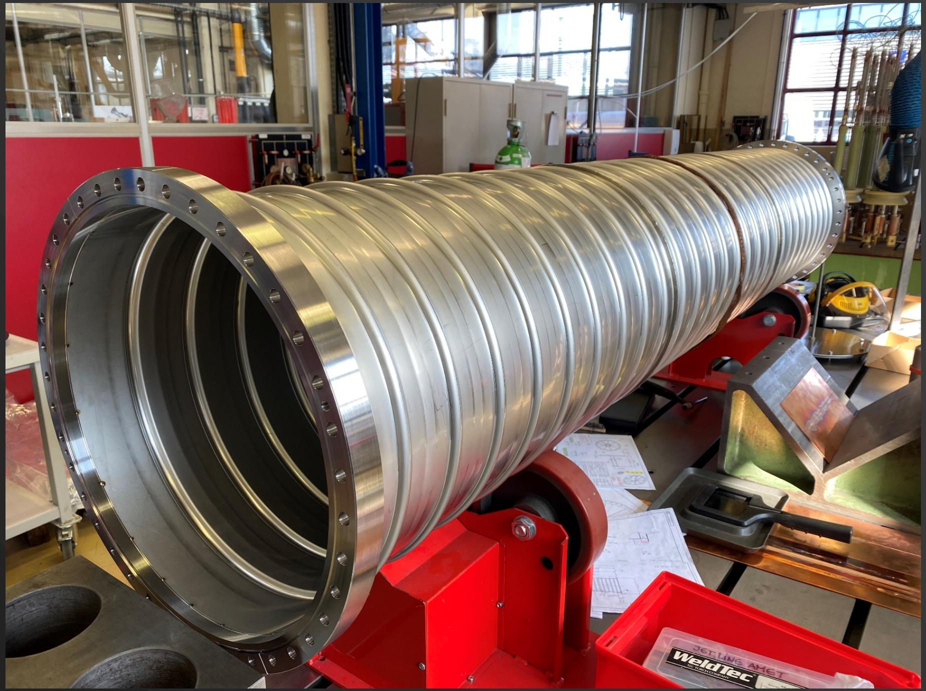
ET beampipe pilot sector conceptual model

  - 2nd MOU agreed on: CERN will provide support for the technical design for the underground structure (civil engineering)
  - Discussion with CERN on other topics: safety, document management, coordination and engineering, and cooling and ventilation.

ET vacuum hardware at CERN



Examples of mechanized welding machines



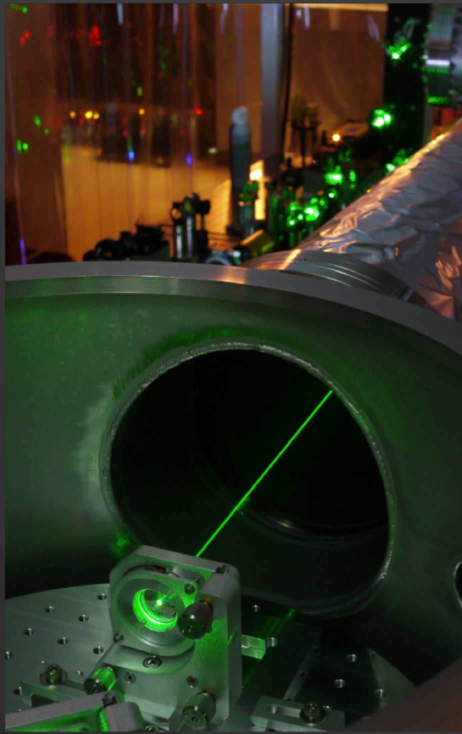
304L Pre-prototype available for UHV tests

Key Points (1/2)

- Gravitational-wave Observatories are a “once-in-a-century opportunity“ for the HEP community (Snowmass CF report)
  - Essential for NSF/DOE science priorities in the 2030s
  - Broad overlaps with National Laboratory / DOE technological expertise
- Funding priorities
  - CE’s intention is to seek NSF funding through the MREFC program.
  - Support/prioritization of exploratory work for GW science, and instrument R&D for GW observatories, from DOE/National Laboratories can facilitate the design phase.
  - At the time of construction (2030s) a larger DOE project role may be beneficial for US community.

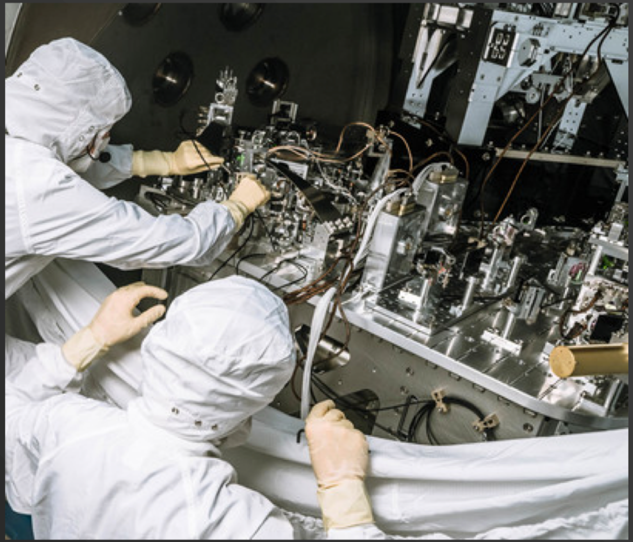
Key Points (2/2)

- National labs/DOE-HEP key areas of expertise:
  - Construction and Management of large scientific facilities
  - Quantum Sensing (GW readout, atom-interferometric gravimeters, …)
  - Vacuum system design
  - Control systems for interferometers/accelerators/readout (e.g. ACORN, FPGA-based QICK boards,..)
  - Seismic field modeling for Newtonian noise suppression
  - Extreme/precision manufacturing expertise (optics, coatings, suspensions, etc)
  - Civil Engineering expertise
  - Large project management expertise



Our Message to P5

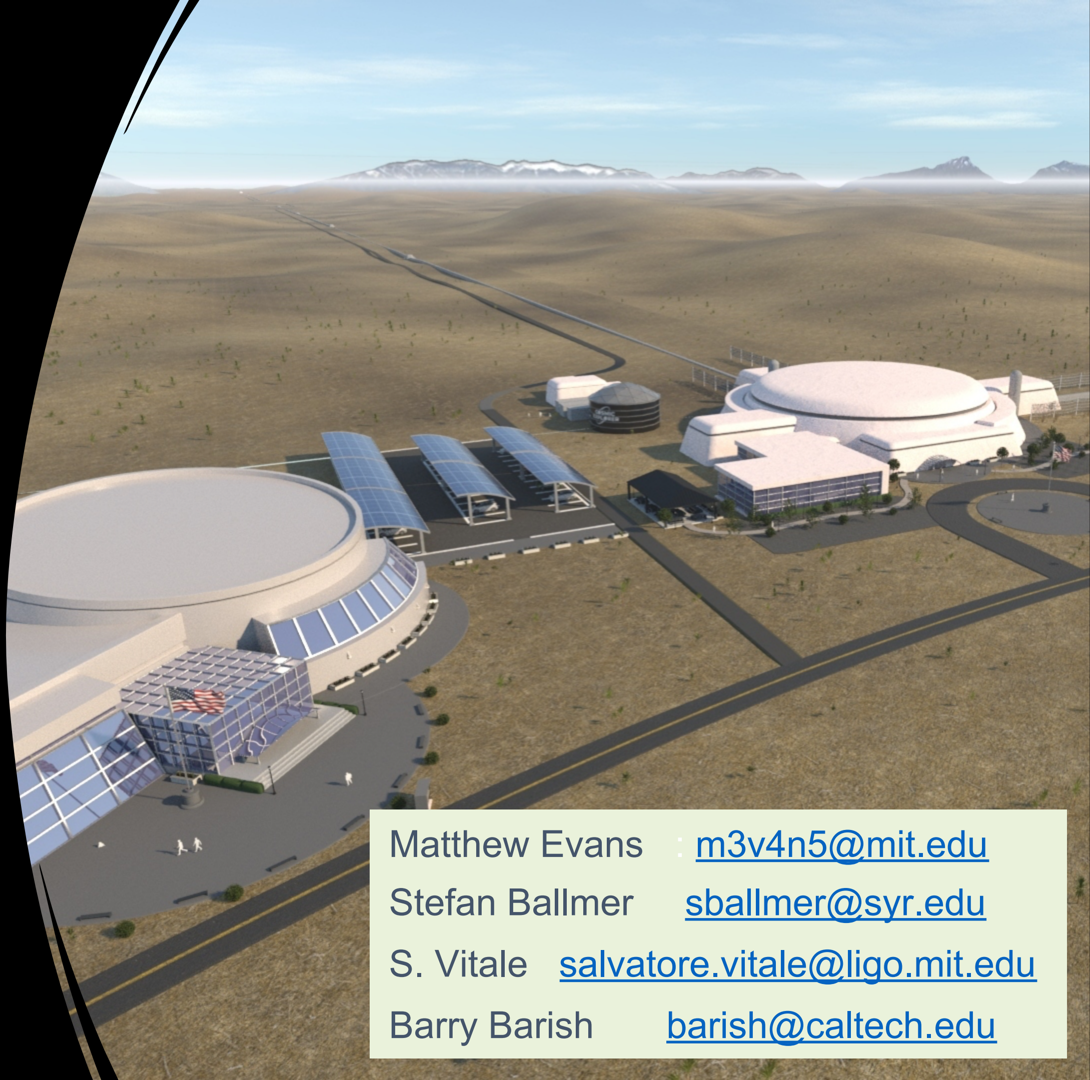
- Cosmic Explorer represents
  - A compelling science case for a new facility.
  - It will require funding for R&D that develops new technologies over the next decade (Quantum Sensing, Vacuum technology, etc.)
  - This will take the form of focused investments in small-scale projects that advance national initiatives in quantum information science, advanced electronics and instrumentation.
  - Requesting support for/prioritization of exploratory work during the CE design stage as we move toward a construction proposal near the end of this decade



Example small-scale project: Advanced LIGO squeezed light source. The technology is now redefining the LIGO's observational range and has applications in quantum networks.

Thanks!

COSMIC EXPLORER



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