Cosmic Explorer

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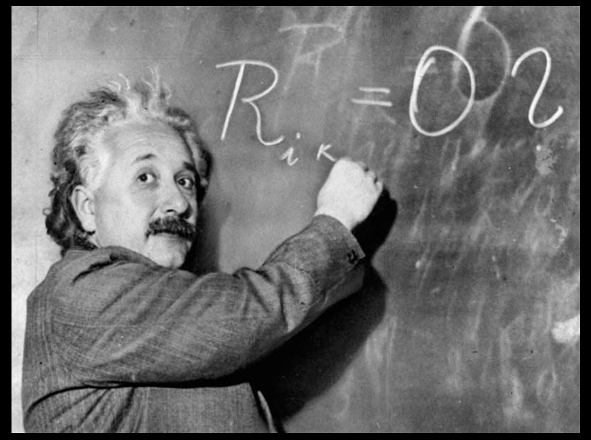
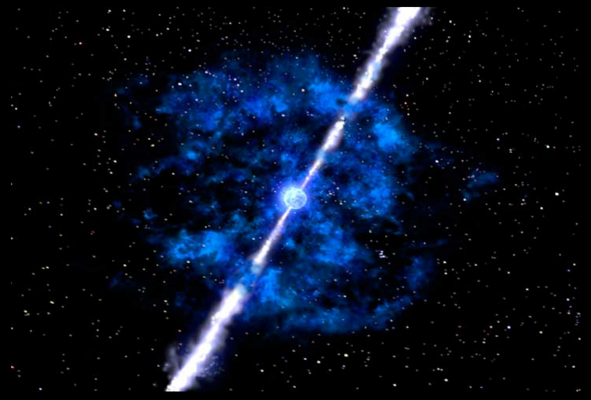
On behalf of the CE Project Team
(MIT, Caltech, Penn State, Cal State Fullerton, Syracuse)

https://cosmicexplorer.org/

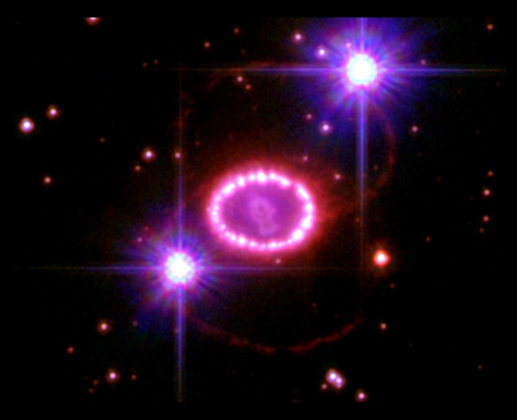


Is general relativity the correct theory of gravity?
What is the nature of one of the four fundamental forces?

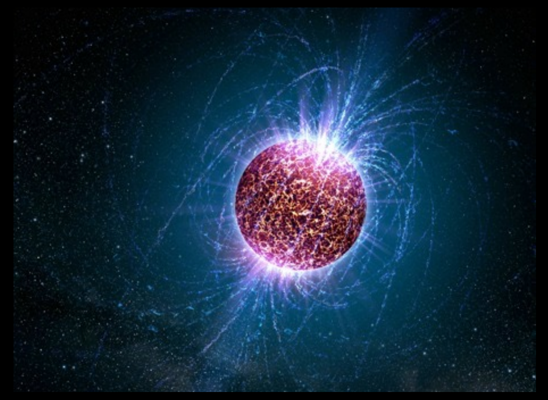
What happens when two black holes collide?
Do black holes really have no hair?



What are the progenitors of short gamma ray bursts?
What is the engine that powers them?

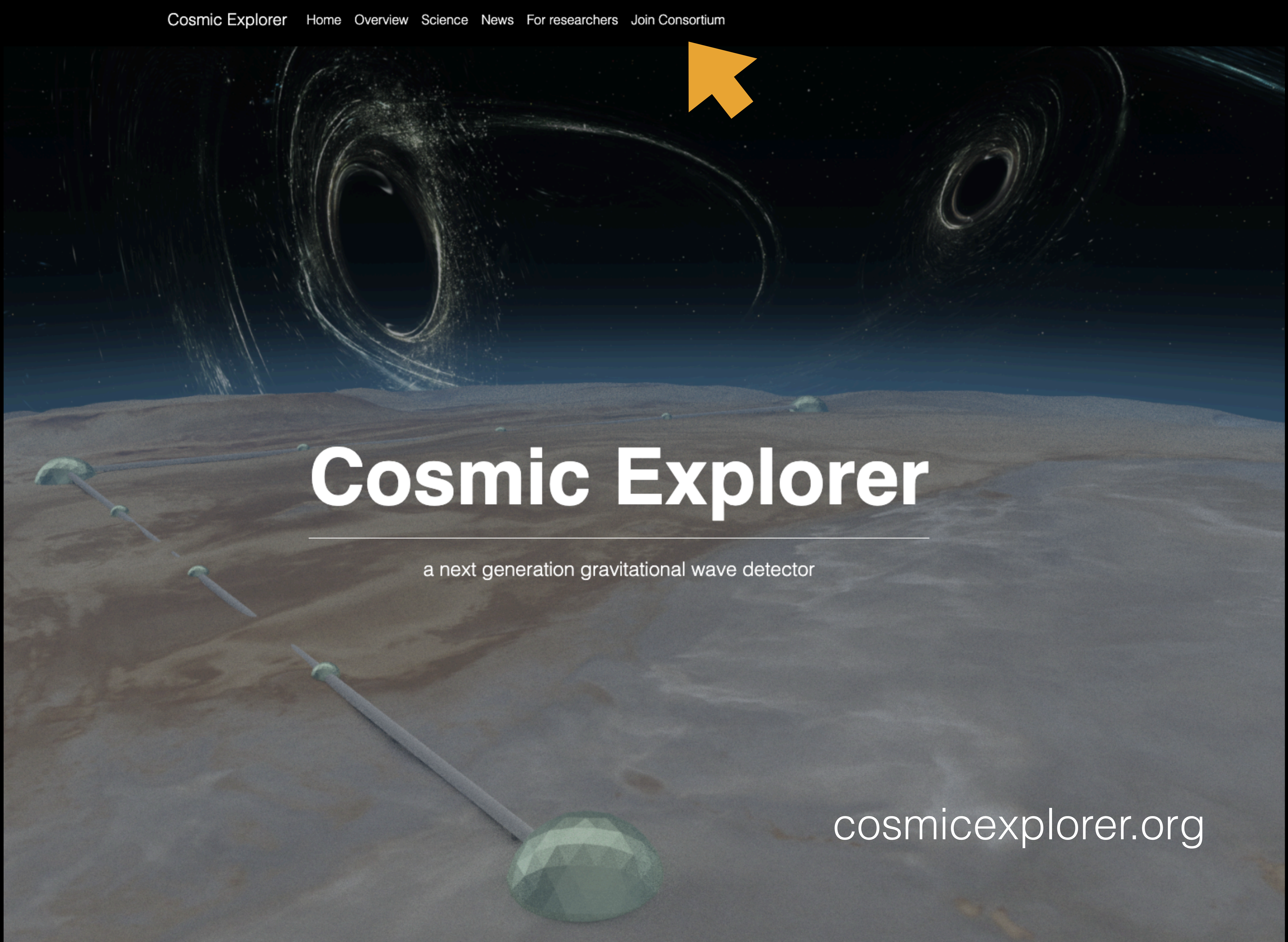


How does core collapse power a supernova?
Is there a mass gap between neutron stars and black holes?



What is the maximum mass of a neutron star?
What is the nuclear equation of state at very high densities?

What is the future of gravitational-wave astronomy beyond LIGO?


Cosmic Explorer
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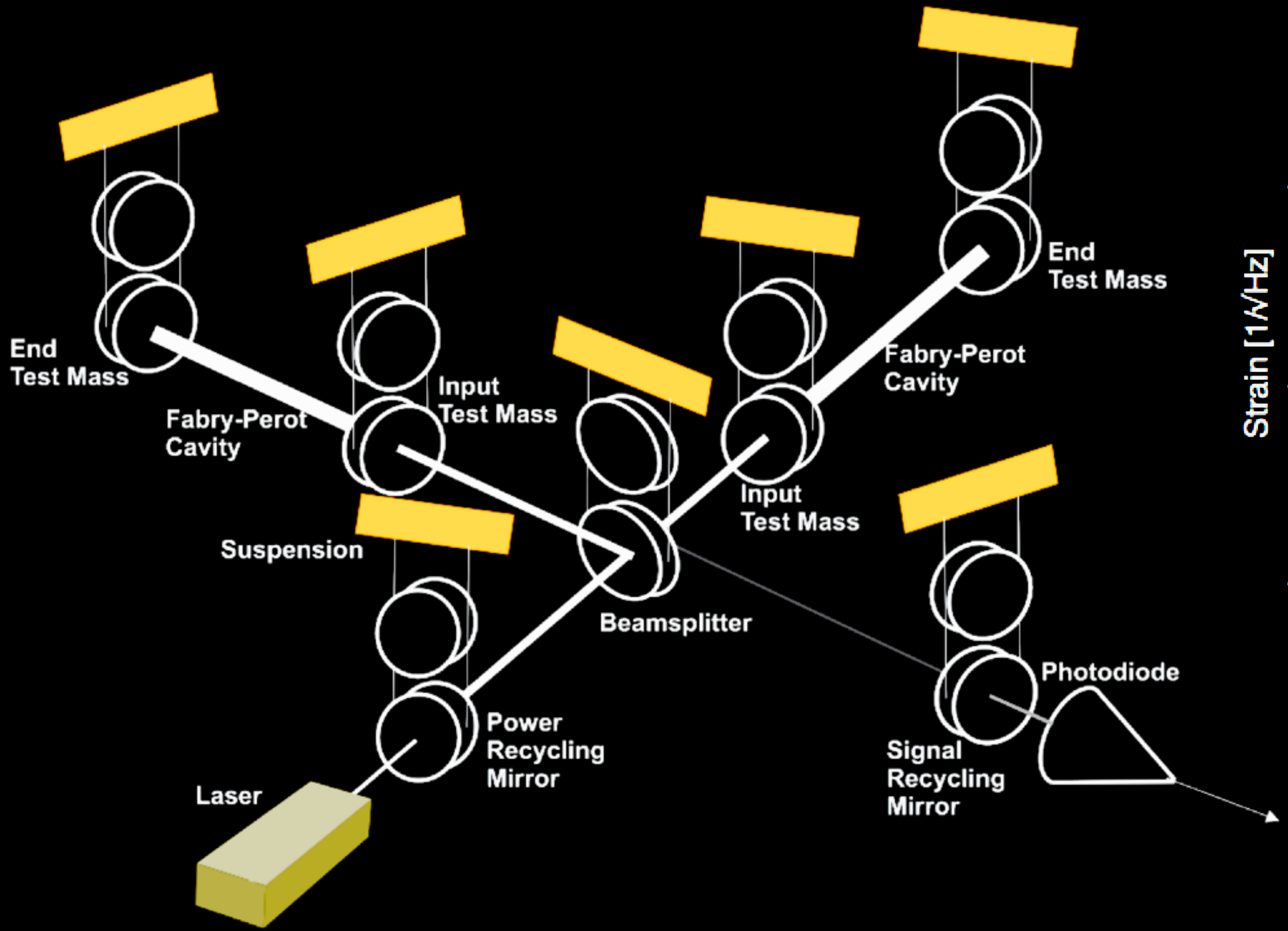
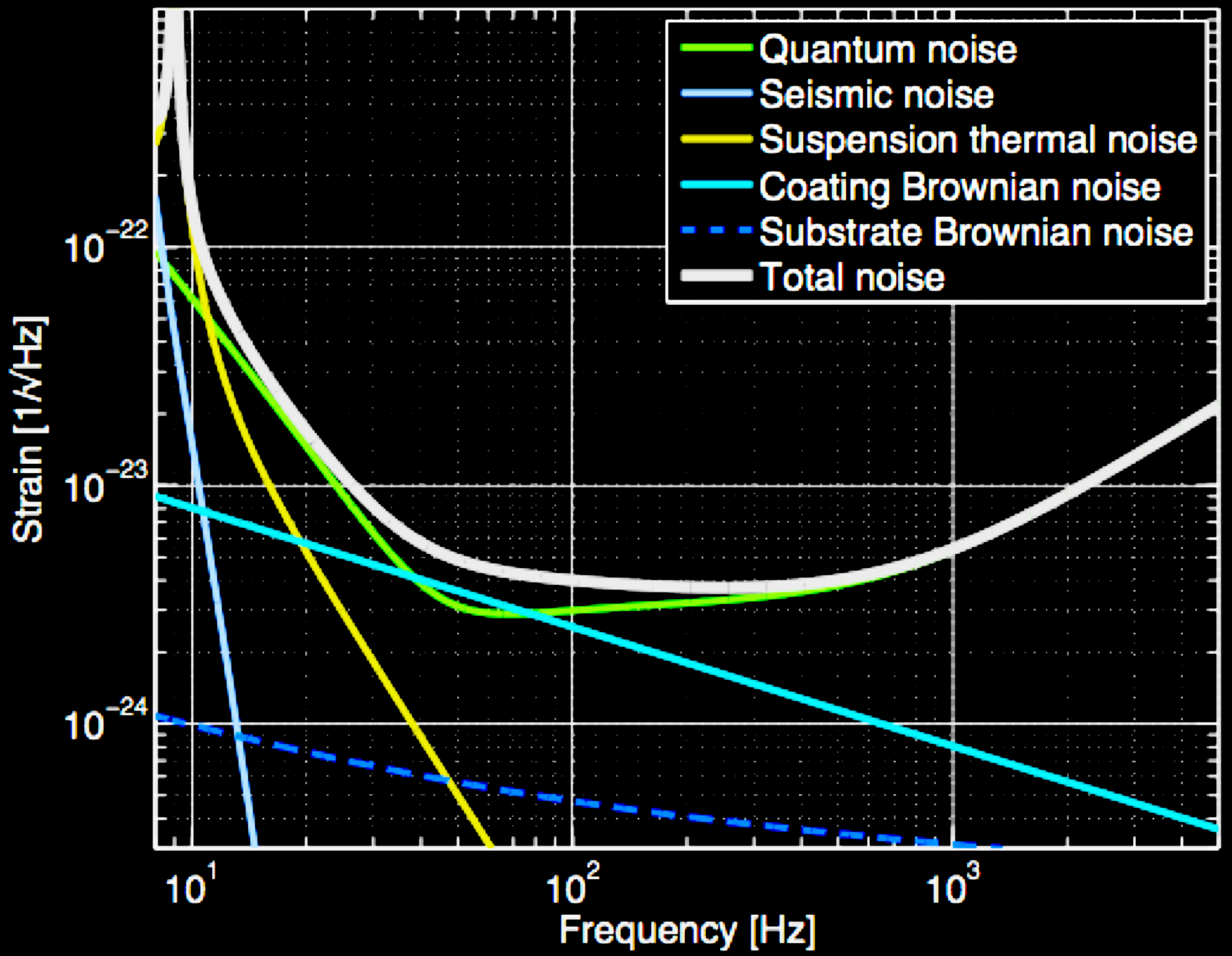
Cosmic Explorer
a next generation gravitational wave detector
cosmicexplorer.org

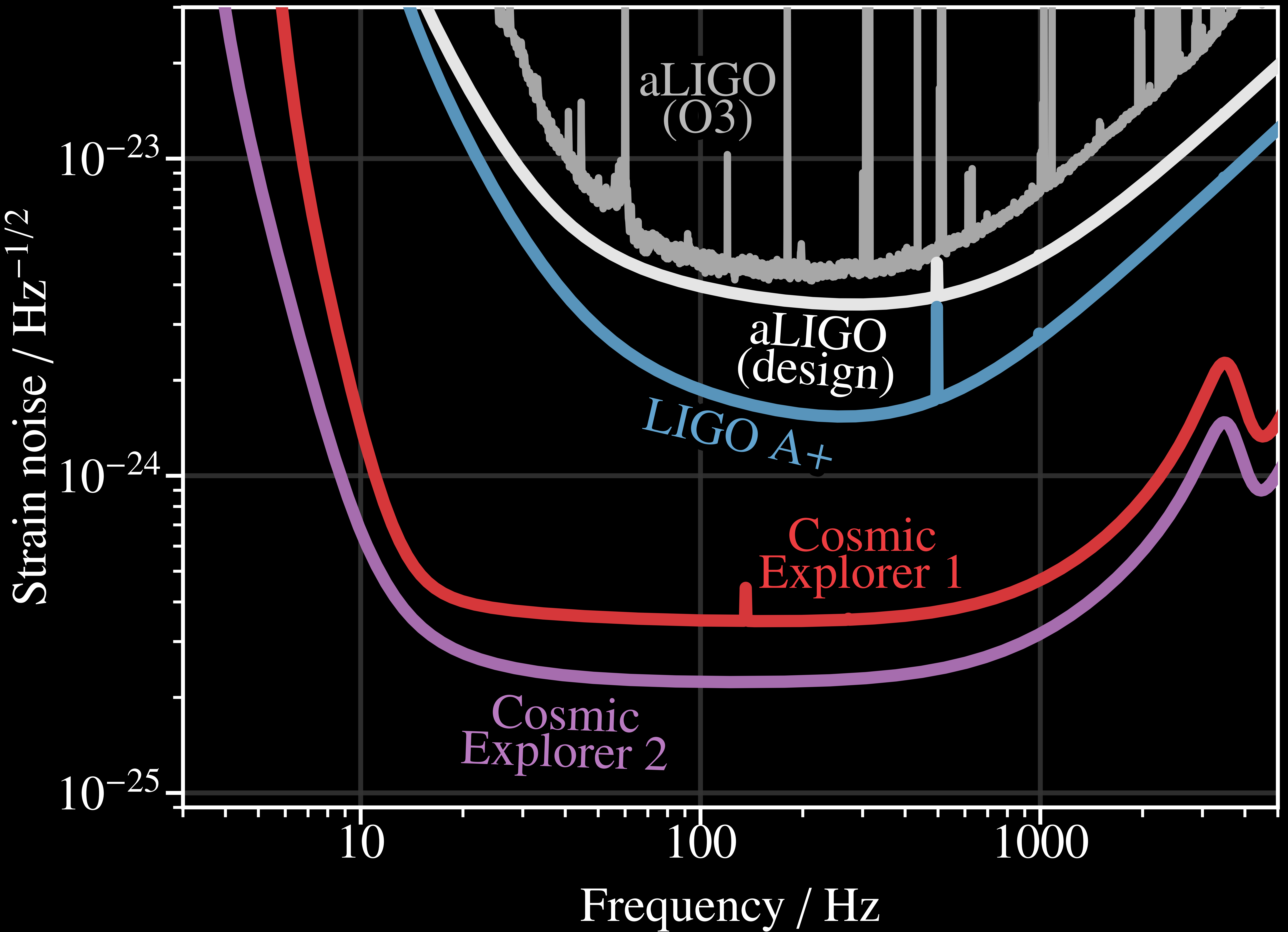
Anatomy of a Gravitational-Wave Detector





What sets the detector sensitivity?

- Gravitational-wave detectors are essentially antennas
- The highest frequency of interest sets the ideal scale of the antenna
- For neutron star mergers, this is ~ few kHz
- Detector length should be ~ few x 10 km
- About ten times the size of Advanced LIGO
- Scaling up length gains sensitivity with only modest technology improvements



aLIGO (O3)
aLIGO (design)
LIGO A+
Cosmic Explorer 1
Cosmic Explorer 2
10^{-23}
10^{-24}
10^{-25}
10
100
1000
Strain noise / $Hz^{-1/2}$
Frequency / Hz

Science Drivers for the Next Generation

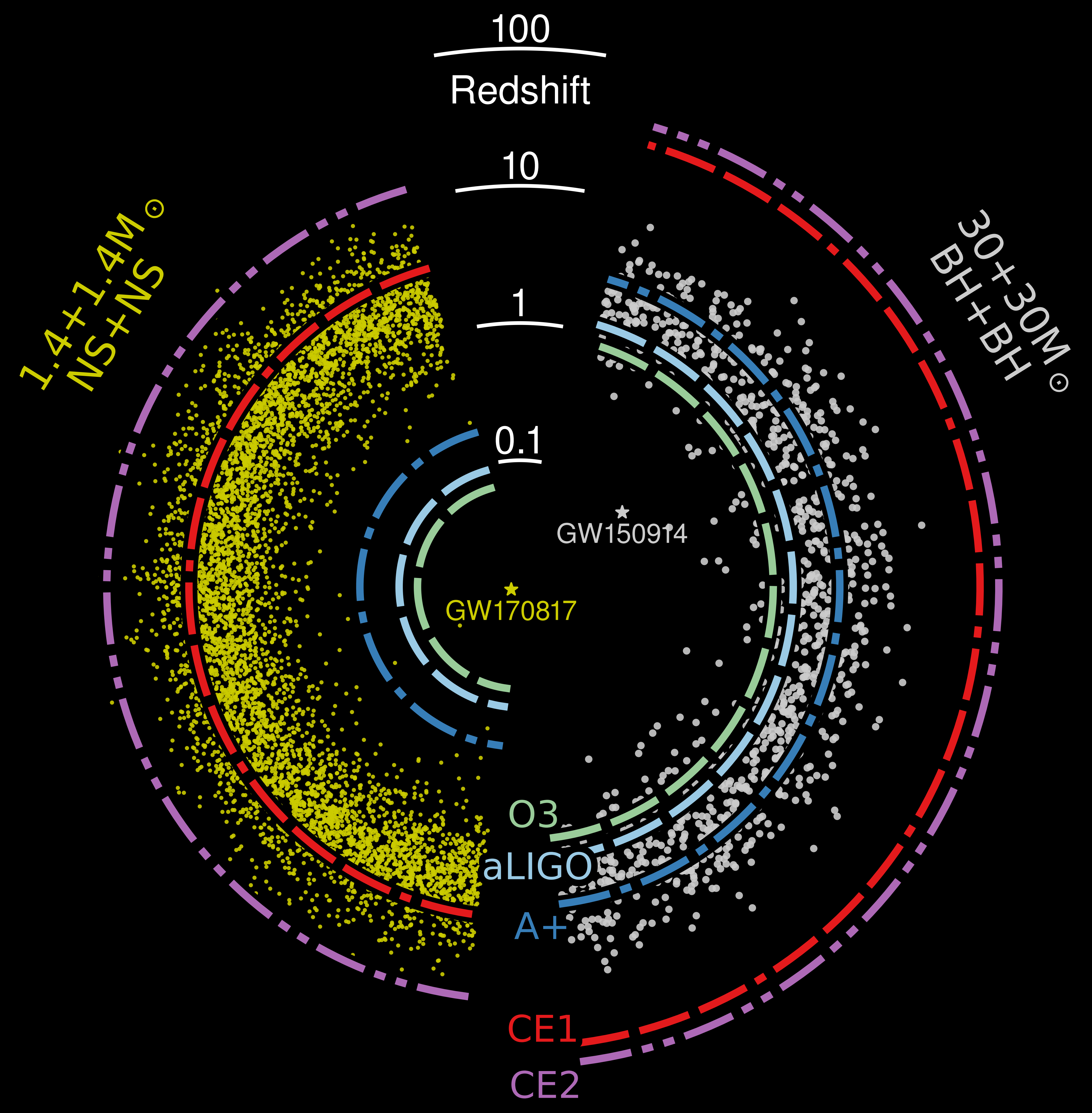
Compact Objects Throughout Cosmic Time

Cosmic Explorer will detect gravitational waves from black holes and neutron stars in binaries all the way to redshifts of ~ 10 and above, allowing us to:

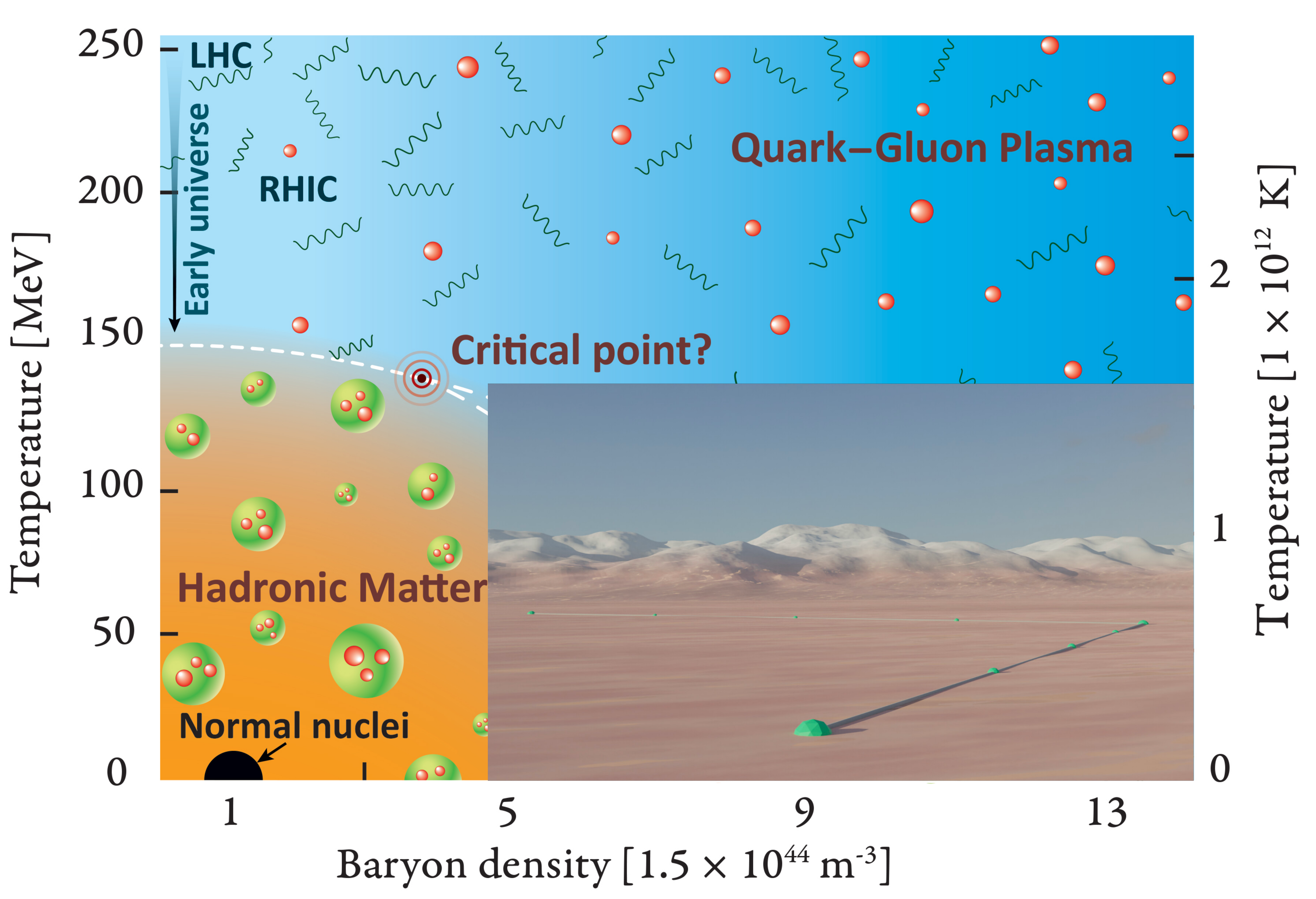
Explore Population III stars through the black holes they might have left behind

Measure the properties of the first black holes and their role in galaxy formation

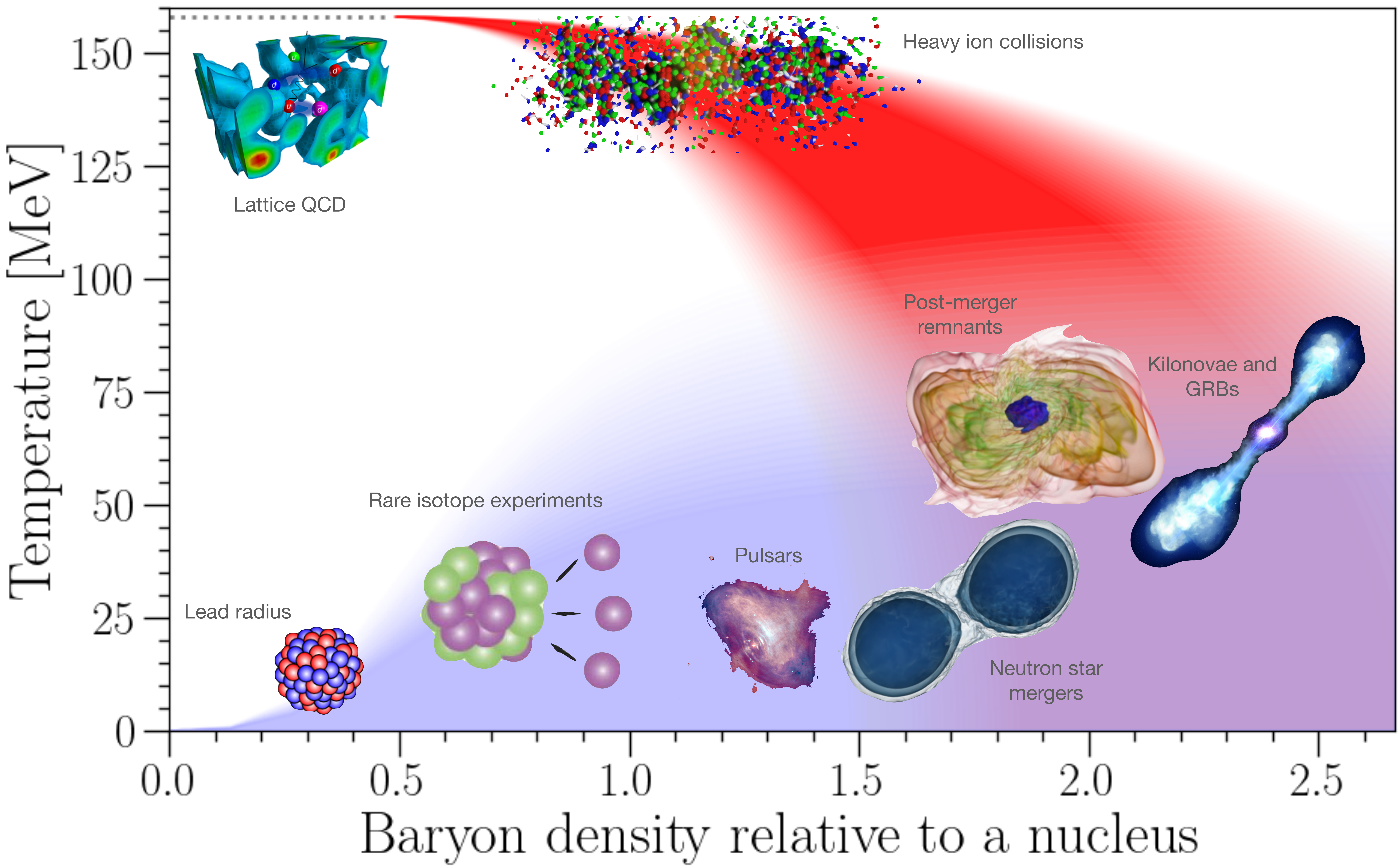
Characterize the populations of compact objects and their evolution

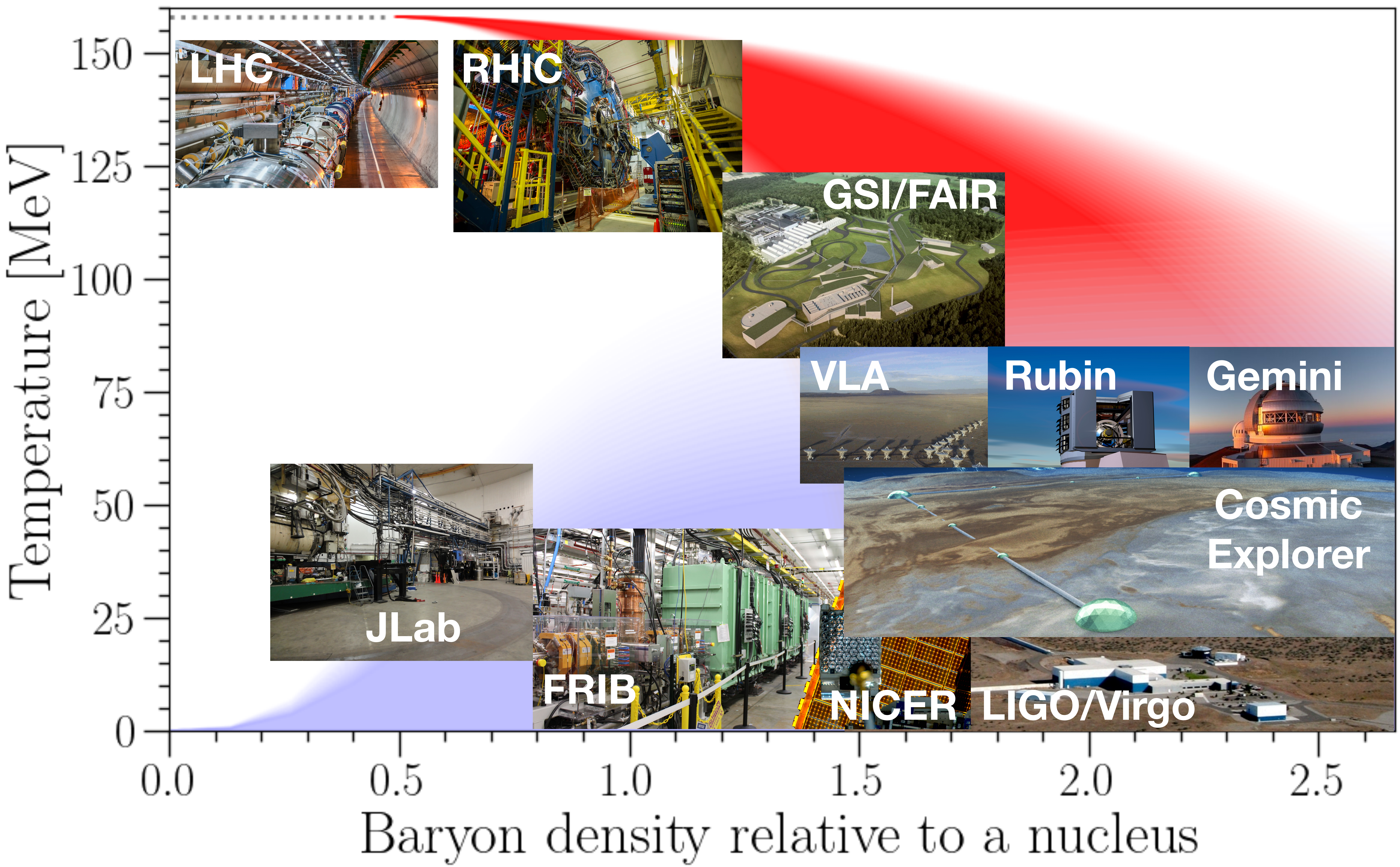


dcc.cosmicexplorer.org CE-G2000037 - Evan Hall



250
200
150
100
50
0
LHC
Early universe
RHIC
Quark–Gluon Plasma
Critical point?
Hadronic Matter
Normal nuclei
Temperature [MeV]
Temperature [1 × 10^12 K]
2
1
0
1
5
9
13
Baryon density [1.5 × 10^44 m^-3]


Heavy ion collisions
Lattice QCD
Post-merger remnants
Kilonovae and GRBs
Rare isotope experiments
Pulsars
Lead radius
Neutron star mergers
Temperature [MeV]
150
125
100
75
50
25
0
0.0
0.5
1.0
1.5
2.0
2.5
Baryon density relative to a nucleus



Temperature [MeV]
150
125
100
75
50
25
0
0.0
0.5
1.0
1.5
2.0
2.5
Baryon density relative to a nucleus
LHC
RHIC
GSI/FAIR
VLA
Rubin
Gemini
Cosmic Explorer
JLab
FRIB
NICER
LIGO/Virgo

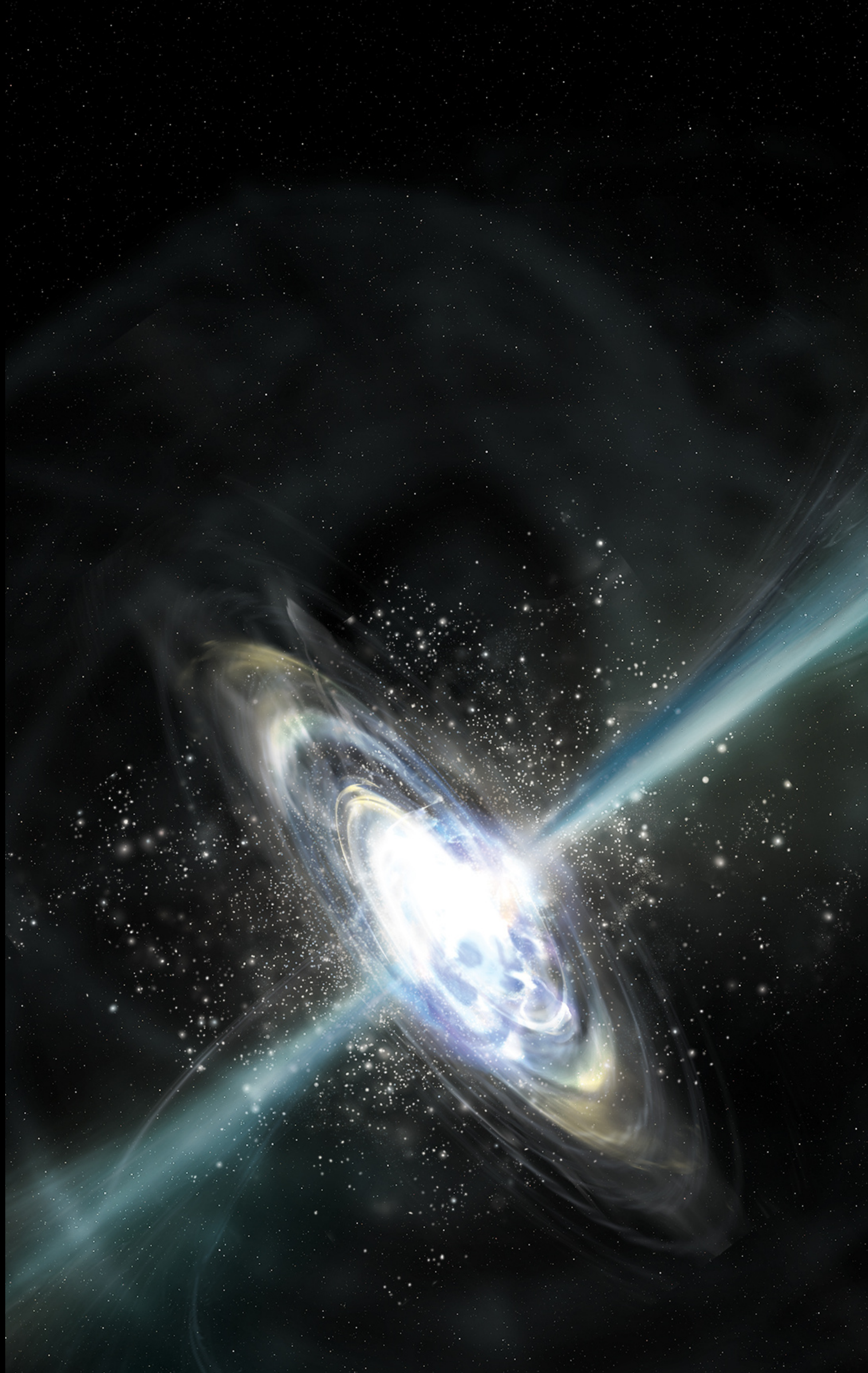
Dynamics of Dense Matter

Cosmic Explorer will make precision measurements of neutron star inspiral and measure post-merger gravitational radiation from binary neutron star coalescences and provide the precise source localizations required for multi-messenger astronomy, allowing us to:

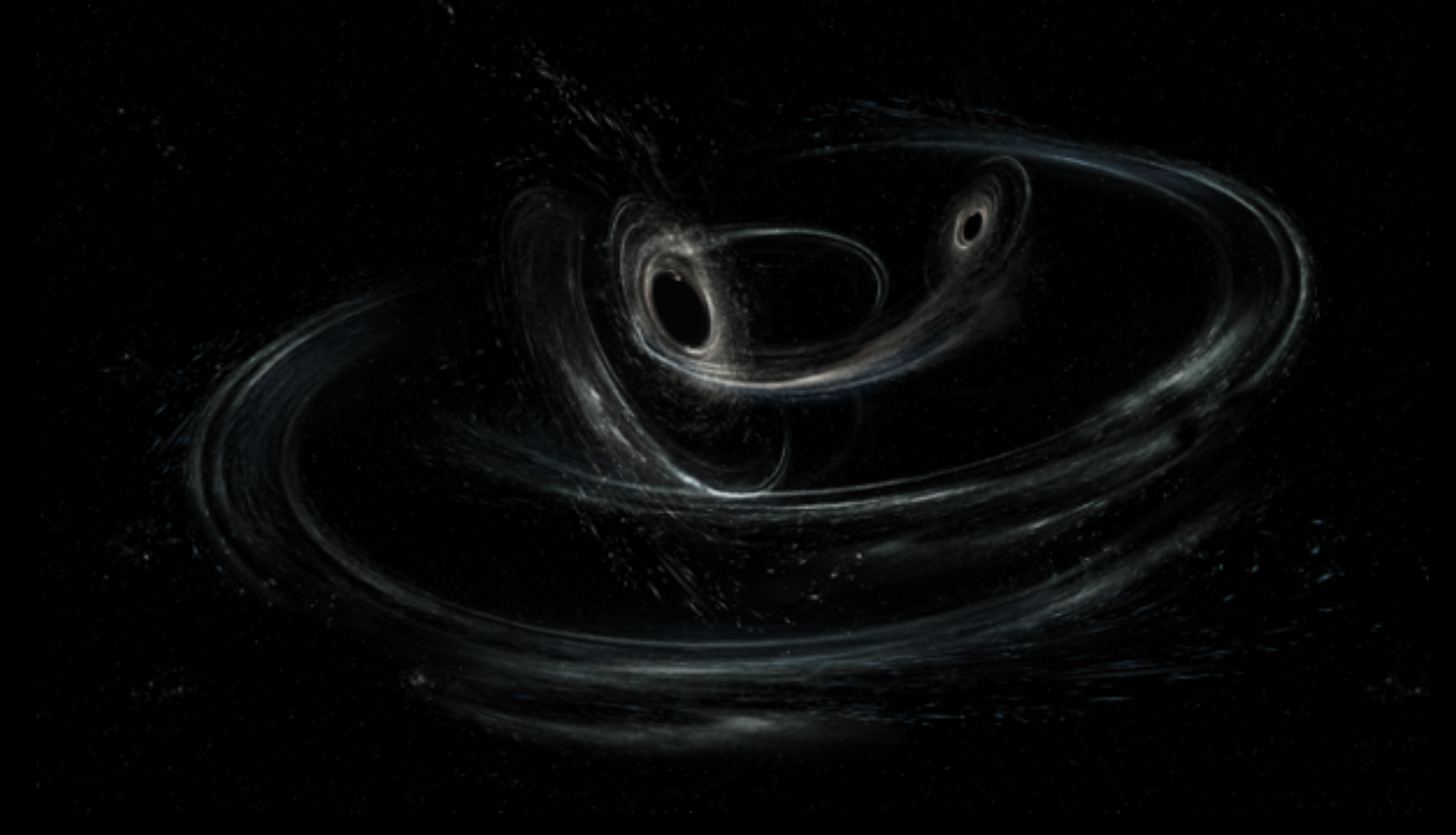
Explore the QCD phase transition from confined to unconfined quark matter

Map heavy element nucleosynthesis throughout the universe

Reveal the central engine of gamma-ray burst jets

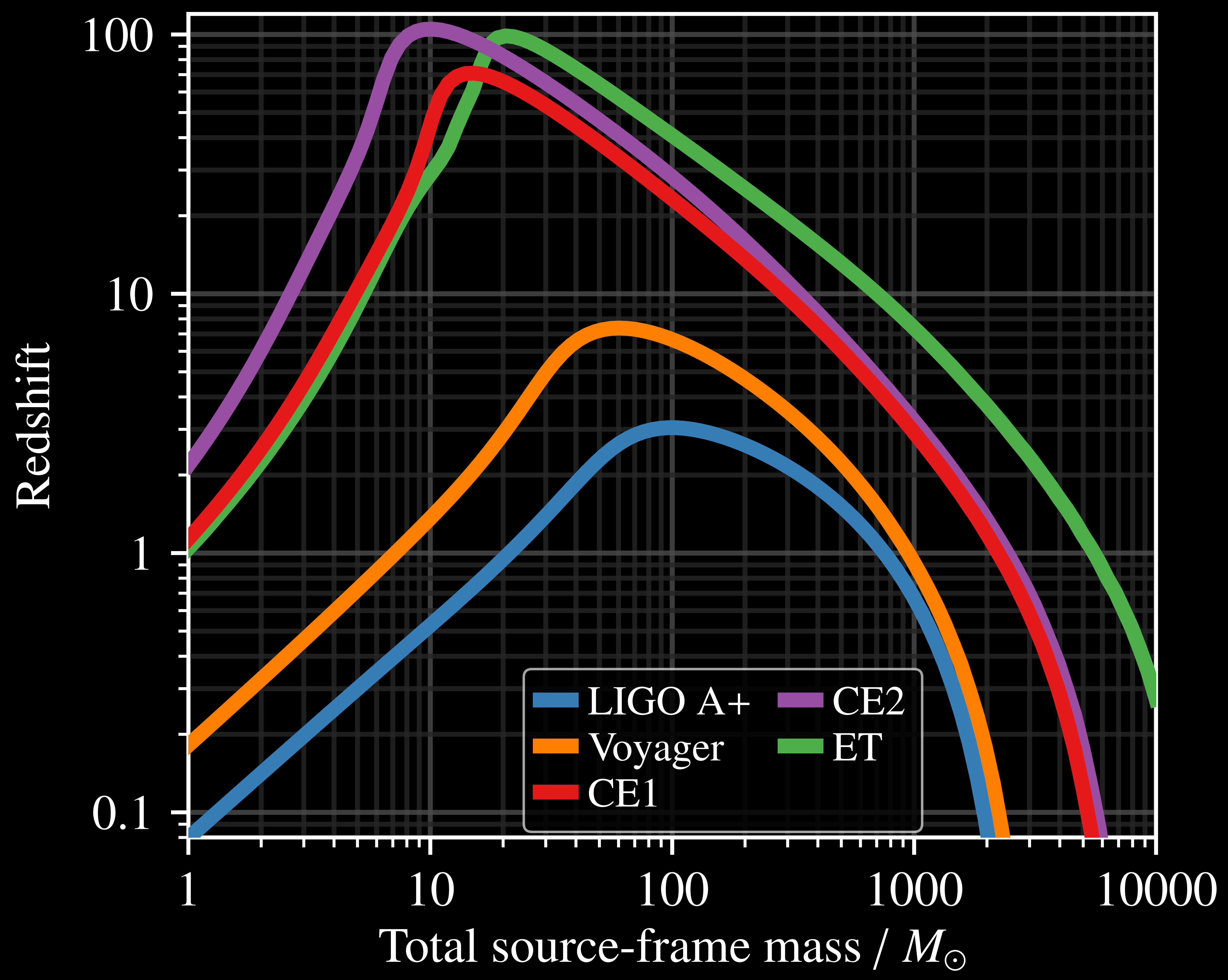


Extreme Gravity and Fundamental Physics

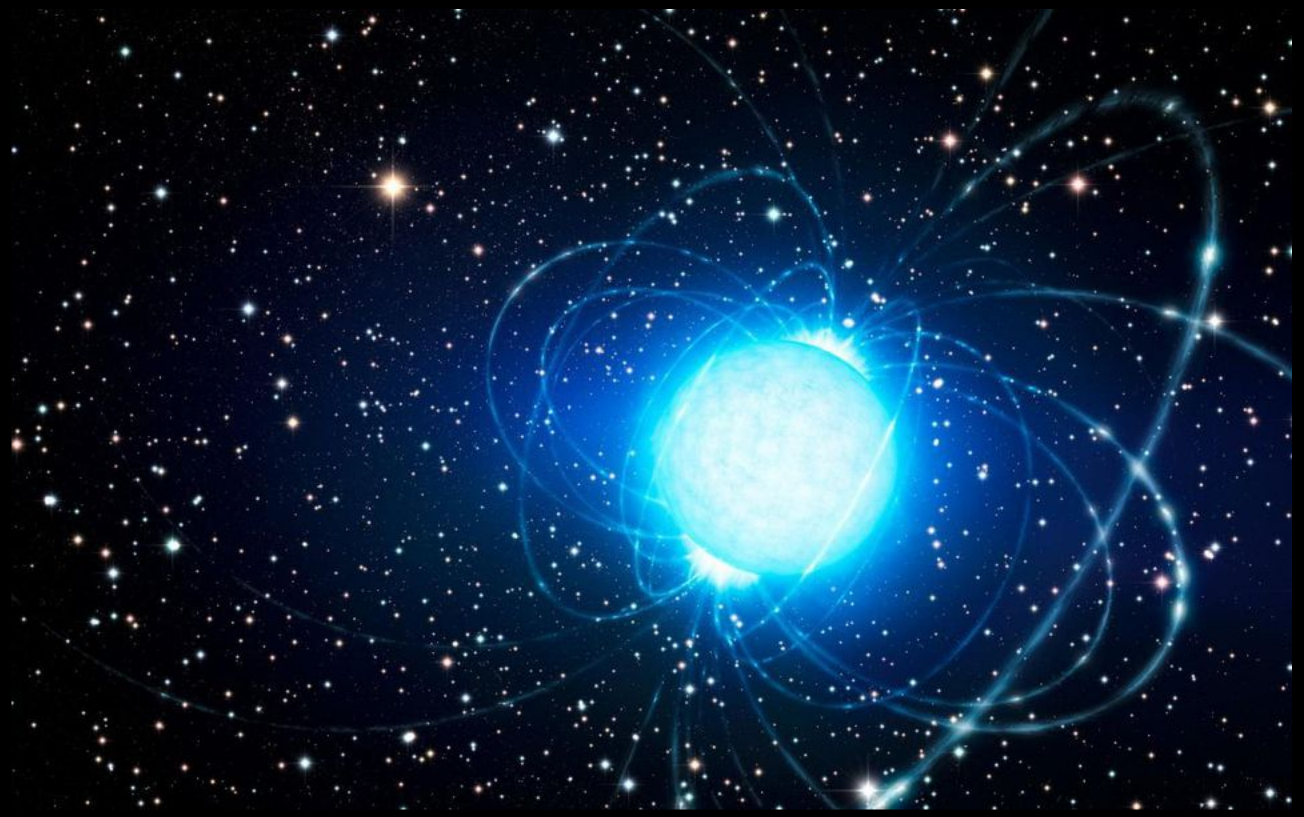


With thousands of BBH events per day, we will see the rare and very interesting events (high spins, large kicks, edge-on, high ellipticity, etc.).

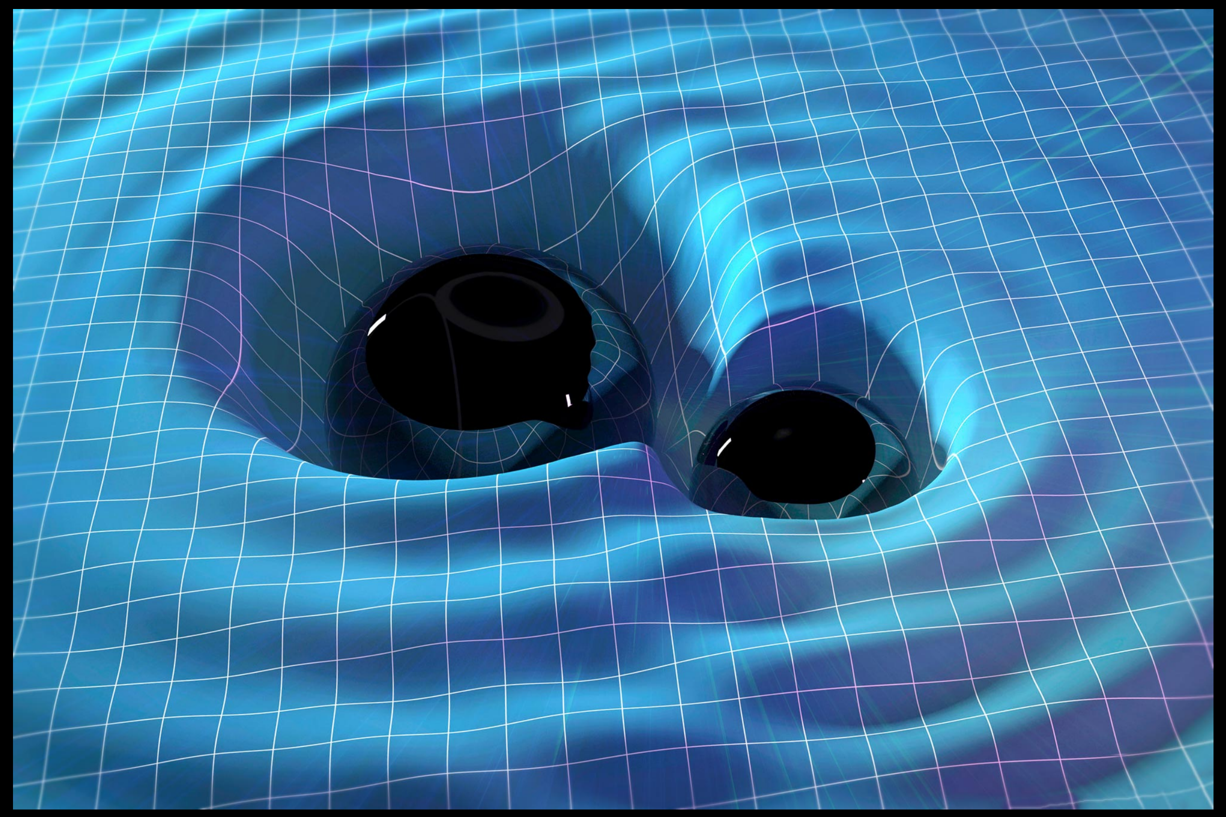
Precision tests will be enabled by black hole mergers like those seen now (~30 solar mass, at z ~ 0.3), will have an signal-to-noise ratio ~ 1000 in CE



Extreme Gravity and Fundamental Physics



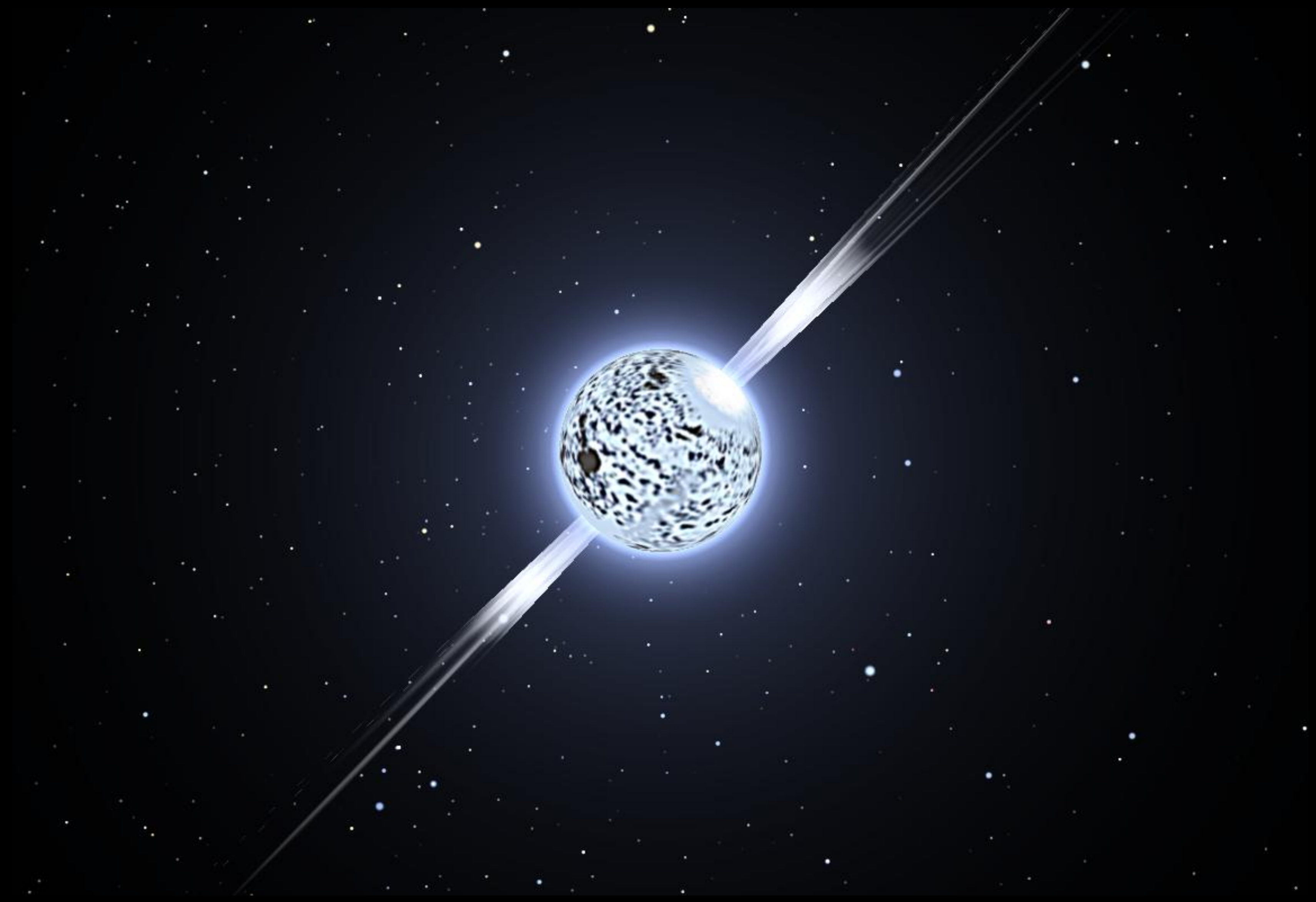
Is dark matter hiding in the cores of neutron stars?



Could black hole echoes tell us about quantum gravity?

Potential for New Discoveries

Core collapse supernovae



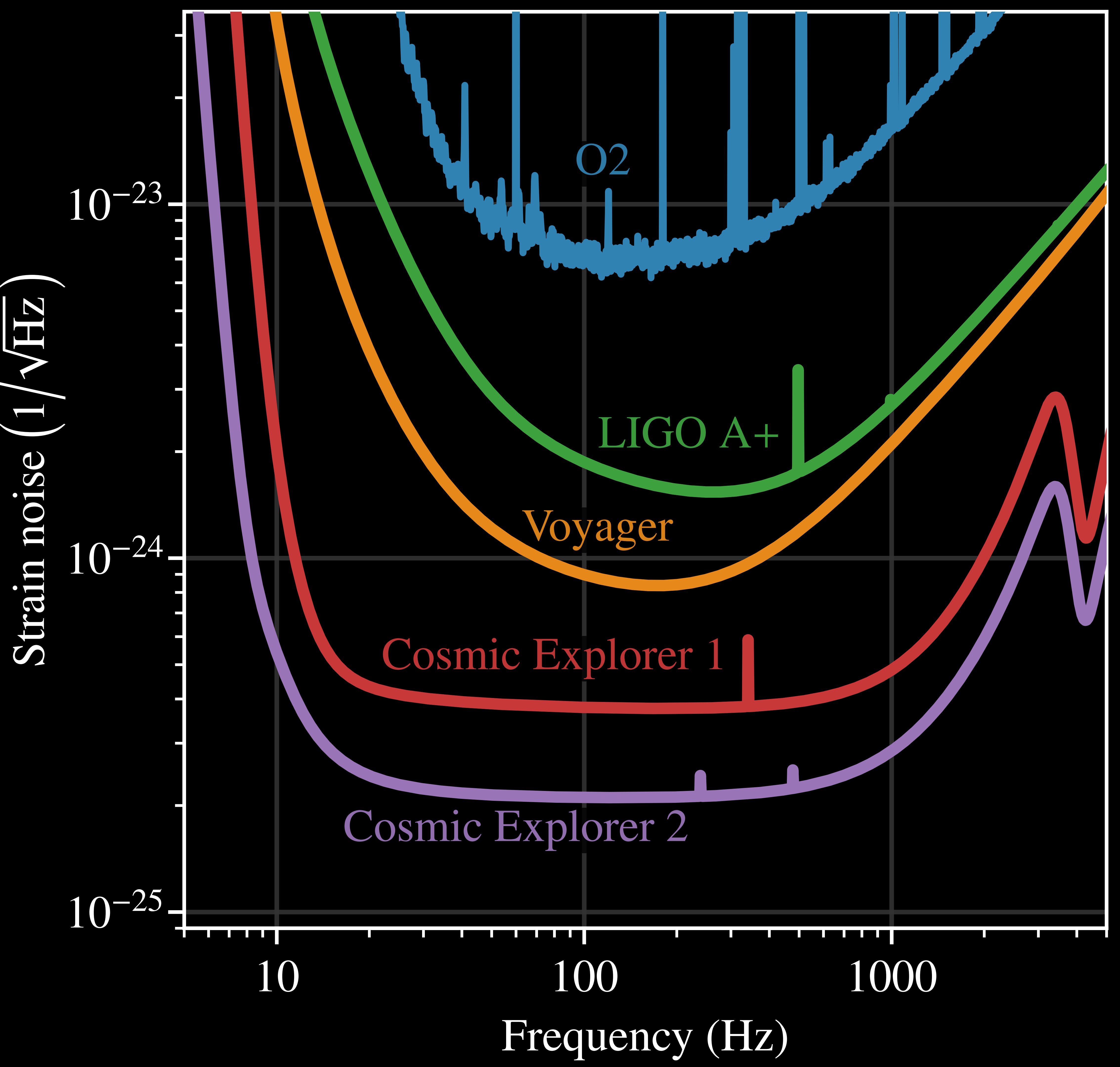
Gravitational Waves from Pulsars

Realizing Cosmic Explorer

CE1 and CE2: two-stage approach

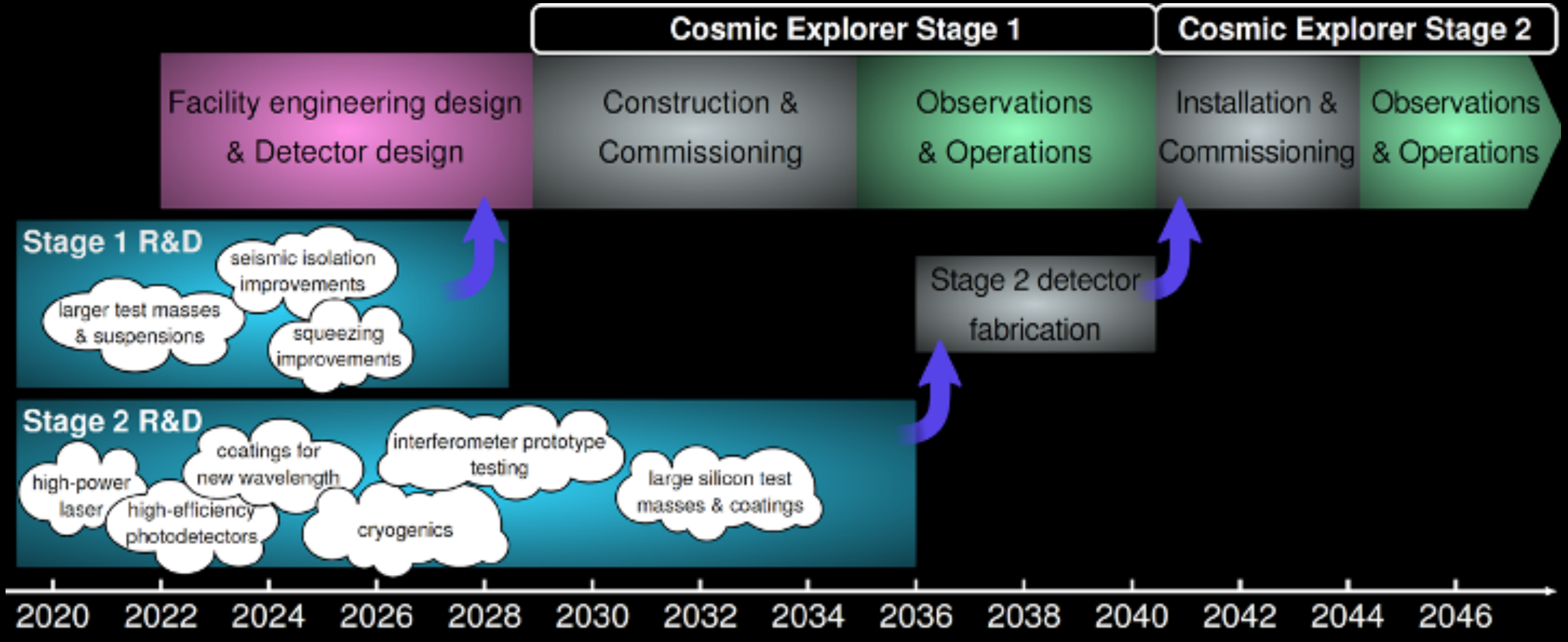
	CE1 2030s, à la aLIGO	CE2 2040s, à la Voyager
Wavelength	1.0 μm	1.5 to 2.0 μm
Temp.	293 K	123 K
Material	glass	silicon
Mass	320 kg	
Coating	silica/tantala	silica/aSi
Spot size	12 cm	14 to 16 cm
Suspension	1.2 m fibers	1.2 m ribbons
Arm power	1.4 MW	2.0 to 2.3 MW
Squeezing	6 dB	10 dB

Reitze, ..., DAB, et al. arXiv:1907.04833



Cosmic Explorer Timeline

Depending on funding situation…

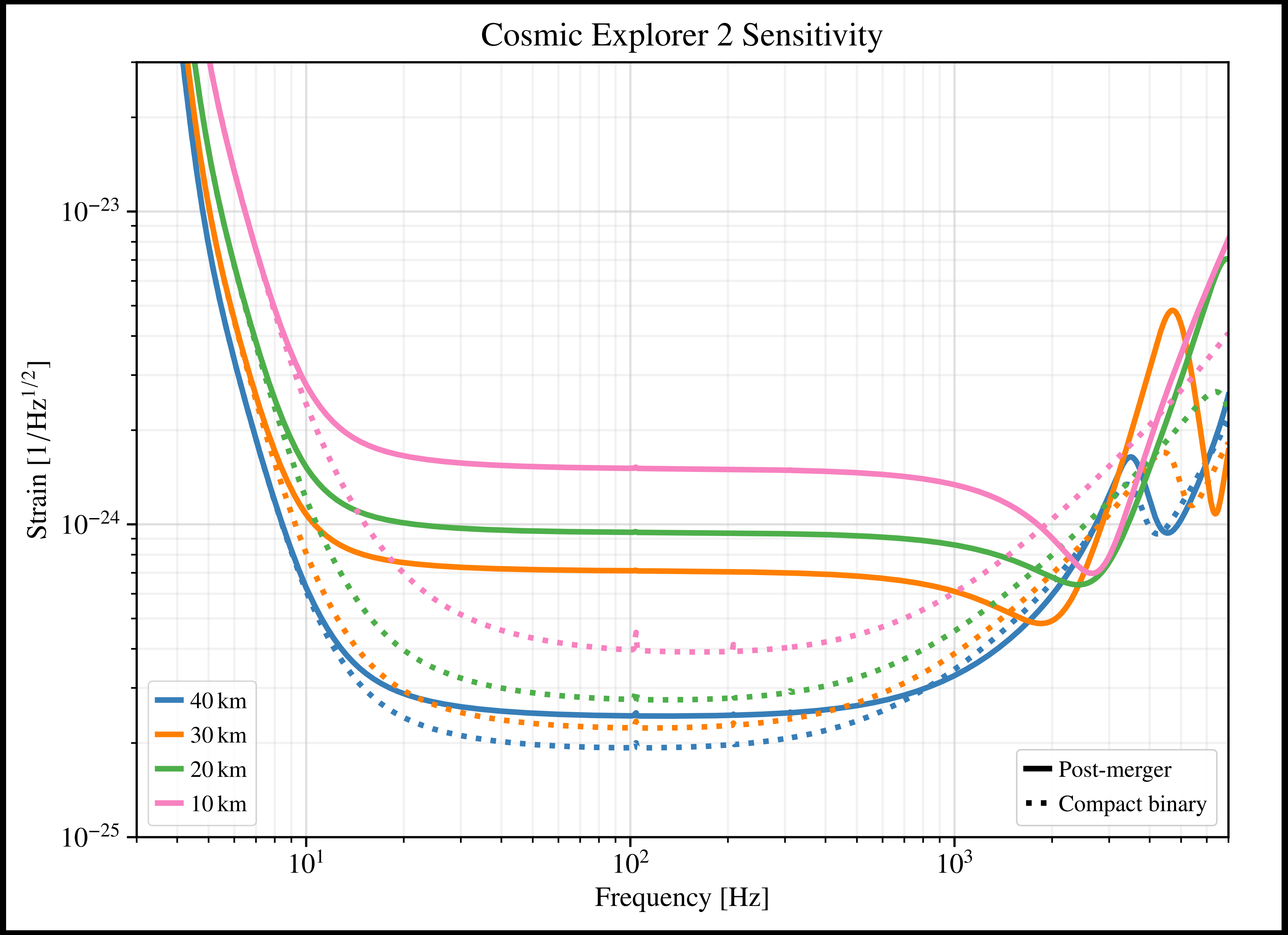


Current Work in Data Analysis

Trade Study to Determine Best Configuration

Optimize Design, Locations, Number of Detectors

- We can improve access to post-merger binary neutron star physics by designing the interferometer to allow for flexible quantum noise tuning
- Post-merger and compact-binary tunings are both possible with the same infrastructure (change signal recycling mirror)
- 40 km and 20 km designs both have their advantages, and that the ideal network would have at least one of each (and farther apart is generally better)



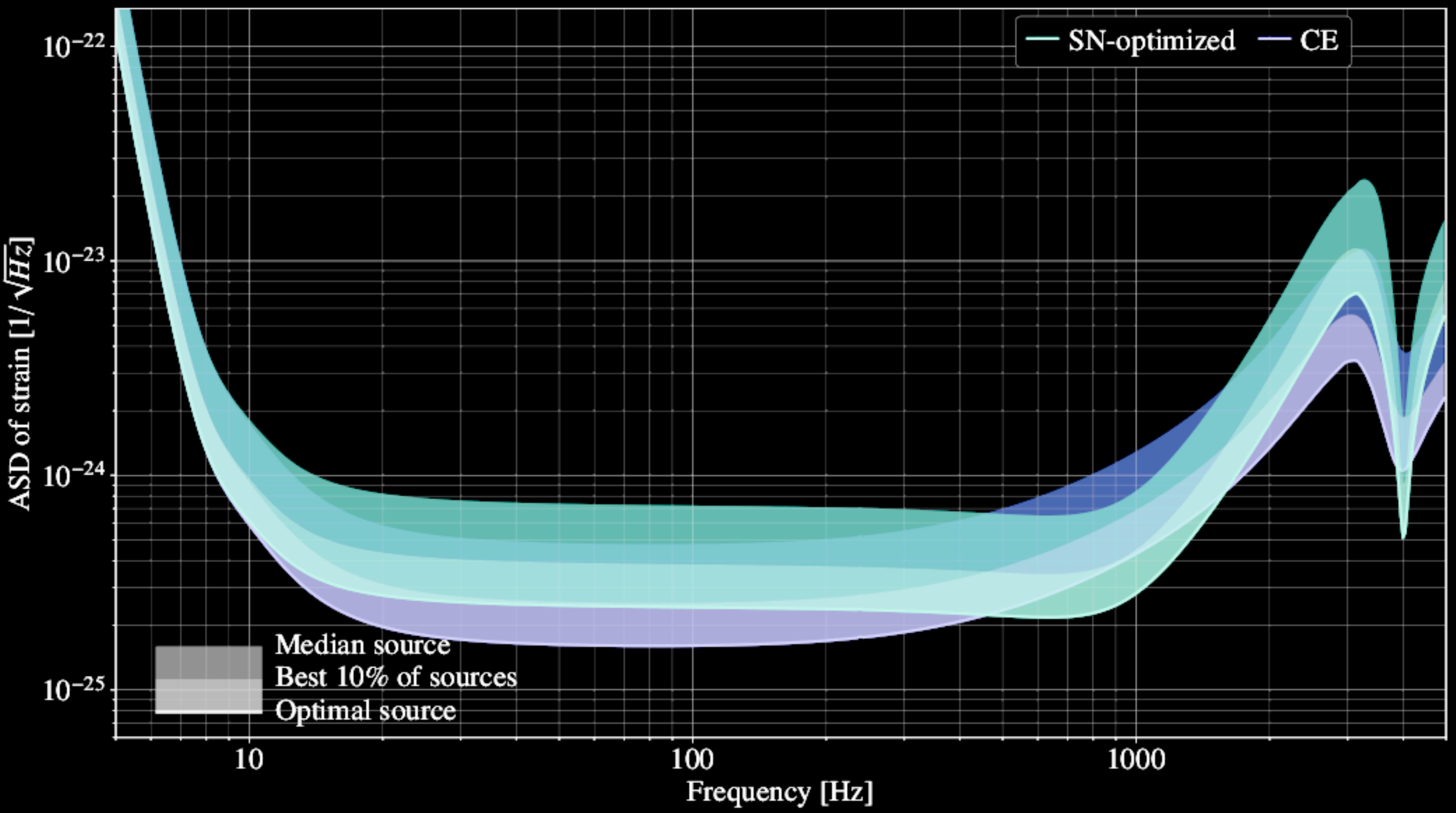
Srivastava and Kuns dcc.cosmicexplorer.org CE-T2000007

Exploring Detector and Network Configurations

- Developed GWBENCH – Python-based infrastructure to assess detector networks
- Performed a large computational study that allows us to maximize the science produced by Cosmic Explorer
- OzGrav has been directly involved to help in our exploration of networks including a possible “CE South”
- We have used preliminary outputs of the CE trade study to iterate on the CE design, and to refine our understanding of which aspects of our science goals are achievable

Ssohrab Borhanian arxiv.org/abs/2010.15202

Supernovae in Cosmic Explorer

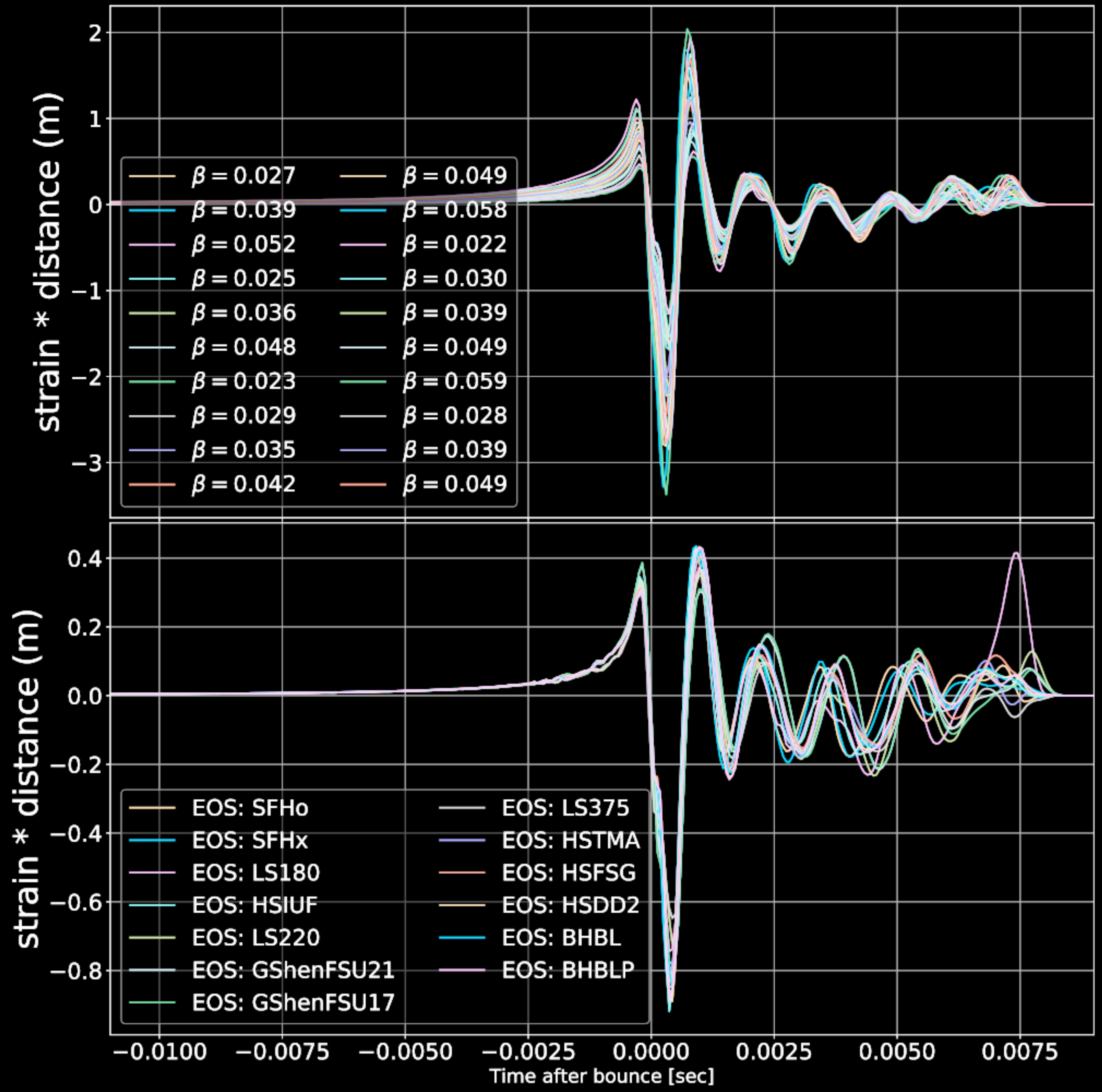


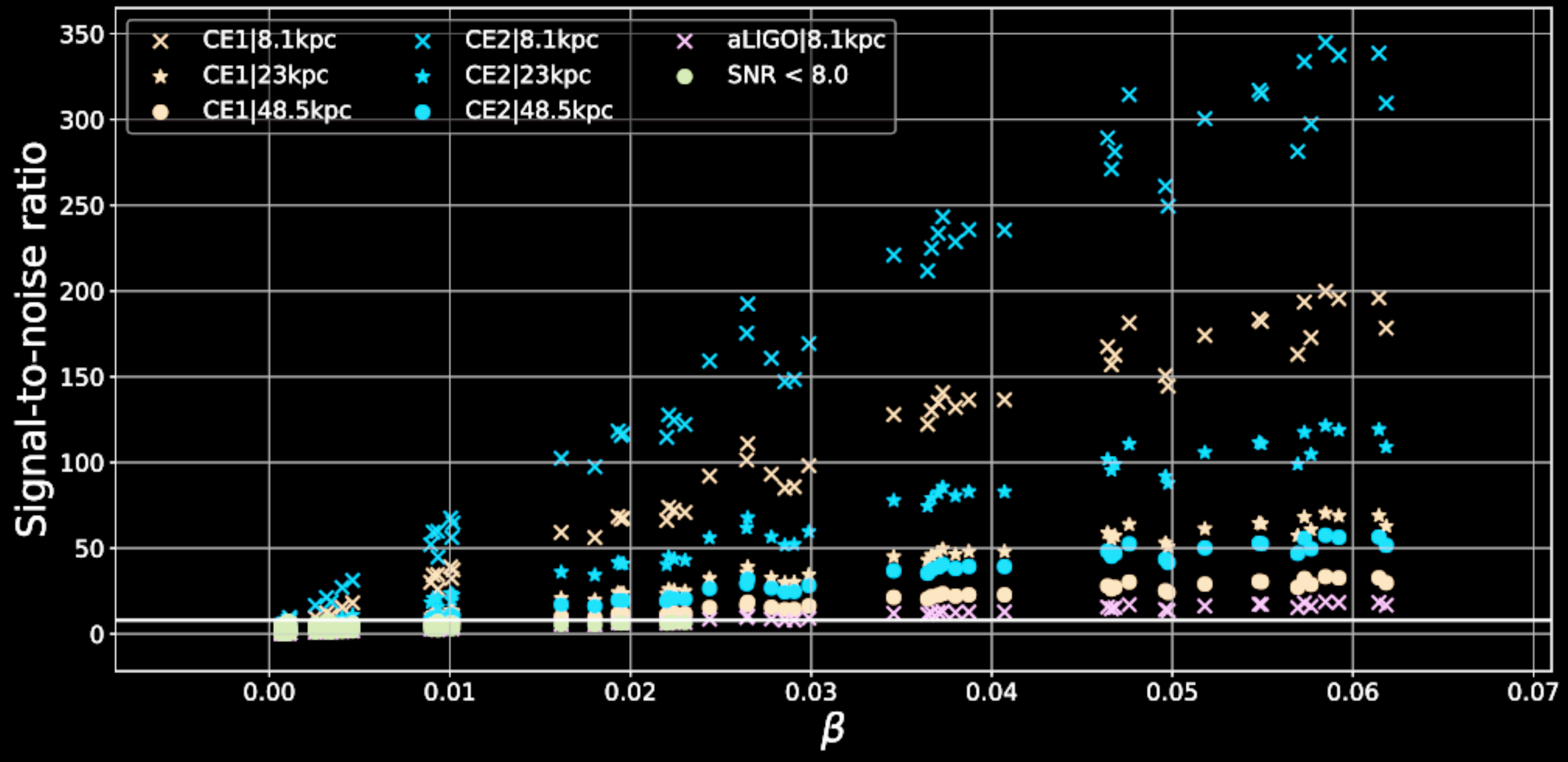
70 kpc at SNR 8

95 kpc at SNR 8

c.f. DUNE

Srivastava, Ballmer, DAB, Afle, Burrows, Radice, Vartanyan PRD **100**, 043026 (2019)

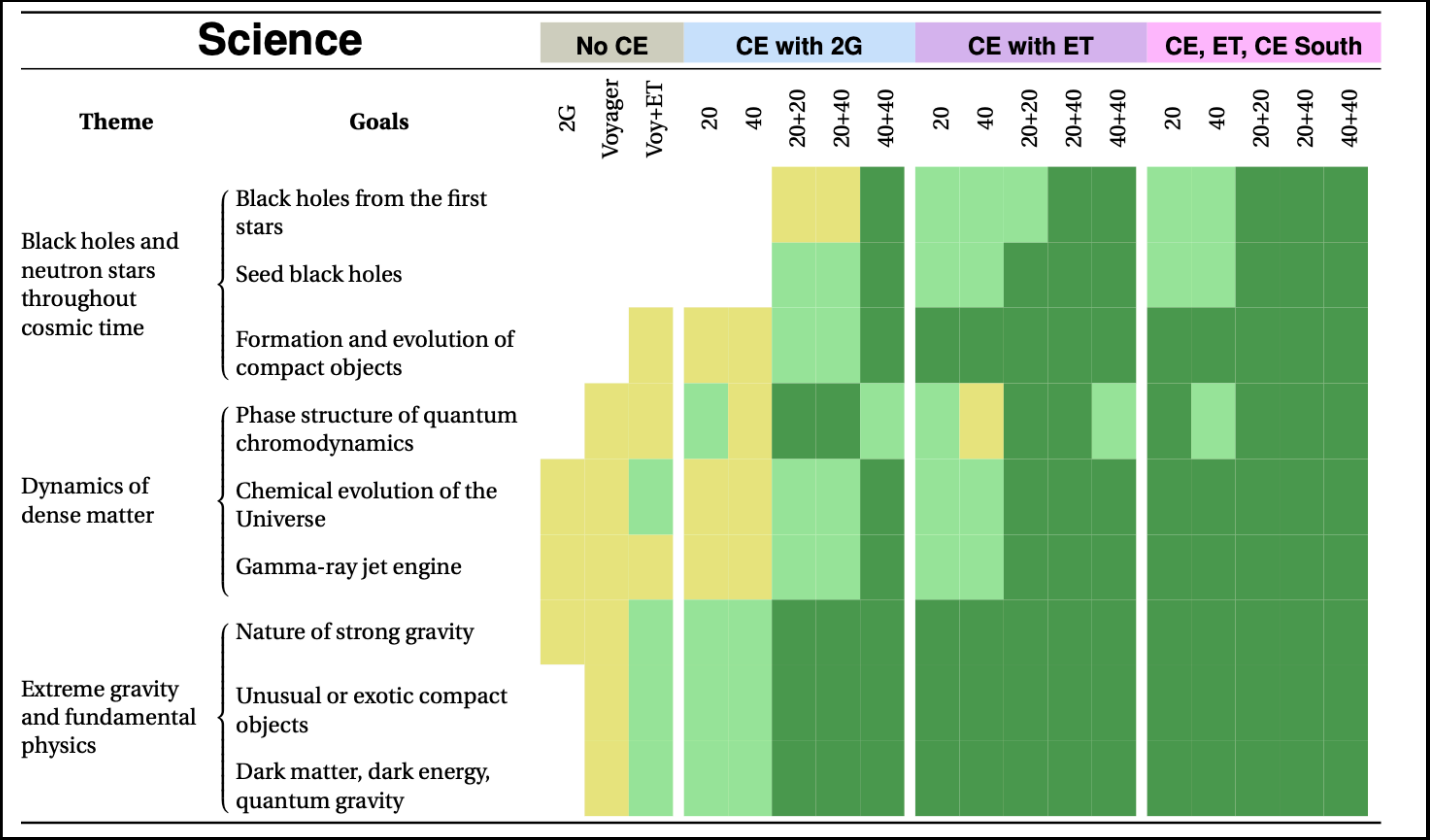




For a galactic progenitor with β = 0.02, 90 % credible interval is 0.02 (aLIGO), 0.002 (CE)

A galactic supernova observed by Cosmic Explorer could constrain f_{peak} to within 10 Hz

Afle and DAB Phys. Rev. D **103**, 023005 (2021)


Science
No CE
CE with 2G
CE with ET
CE, ET, CE South
Theme
Goals
2G
Voyager
Voy+ET
20
40
20+20
20+40
40+40
20
40
20+20
20+40
40+40
20
40
20+20
20+40
40+40
Black holes and neutron stars throughout cosmic time
Black holes from the first stars
Seed black holes
Formation and evolution of compact objects
Dynamics of dense matter
Phase structure of quantum chromodynamics
Chemical evolution of the Universe
Gamma-ray jet engine
Extreme gravity and fundamental physics
Nature of strong gravity
Unusual or exotic compact objects
Dark matter, dark energy, quantum gravity

Getting Involved in Cosmic Explorer

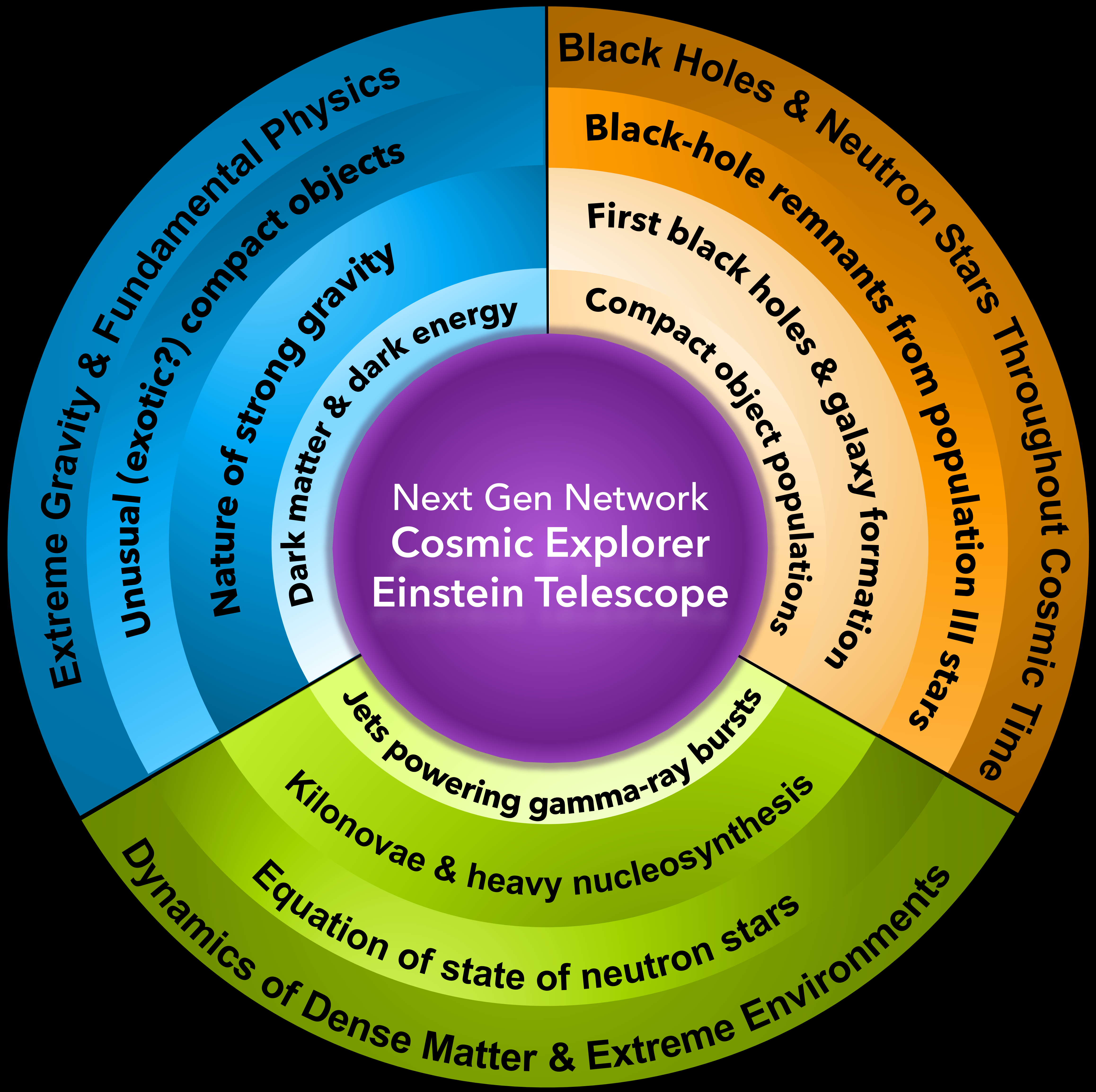
If you want to be ahead of the curve…

- Join the CE Consortium
- Cut your teeth on Open LIGO/Virgo data
  - Check out gw-openscience.org
- Tutorials at pycbc.org and https://gitlab.com/sborhanian/gwbench
- Planning a series of community “data challenges” for Cosmic Explorer
- Plan is for Cosmic Explorer data to be fully open!

Cosmic Explorer Horizon Study

Summarizes the roadmap for US third-generation detectors

- Completed by end of 2021… looking for community input!
- For the next few years, we (including you!) will be
  - Deepening our understanding of the next-generation science case,
  - Developing instrument science to pave the wave for new detectors
  - Creating theoretical frameworks and data analysis algorithms for CE science
- Join the consortium!
- https://cosmicexplorer.org/consortium.html



Next Gen Network
Cosmic Explorer
Einstein Telescope
Extreme Gravity & Fundamental Physics
Unusual (exotic?) compact objects
Nature of strong gravity
Dark matter & dark energy
Black Holes & Neutron Stars Throughout Cosmic Time
Black-hole remnants from population III stars
First black holes & galaxy formation
Compact object populations
Dynamics of Dense Matter & Extreme Environments
Equation of state of neutron stars
Kilonovae & heavy nucleosynthesis
Jets powering gamma-ray bursts