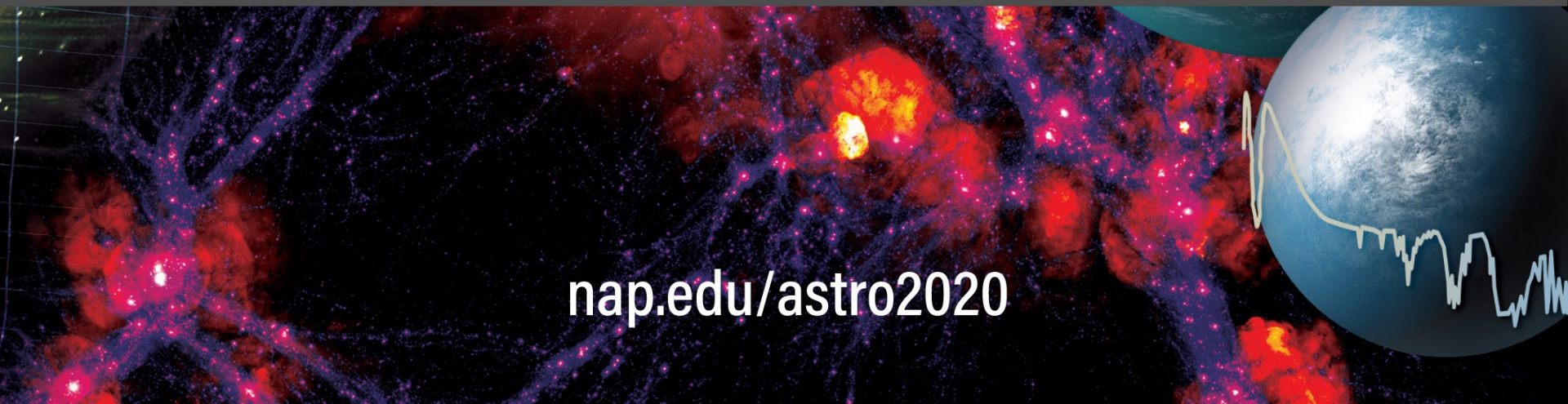
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Pathways to Discovery in Astronomy and Astrophysics for the 2020s



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Approach

NASA, NSF, and DOE provided budget guidance, bounded by ambitious and conservative scenarios

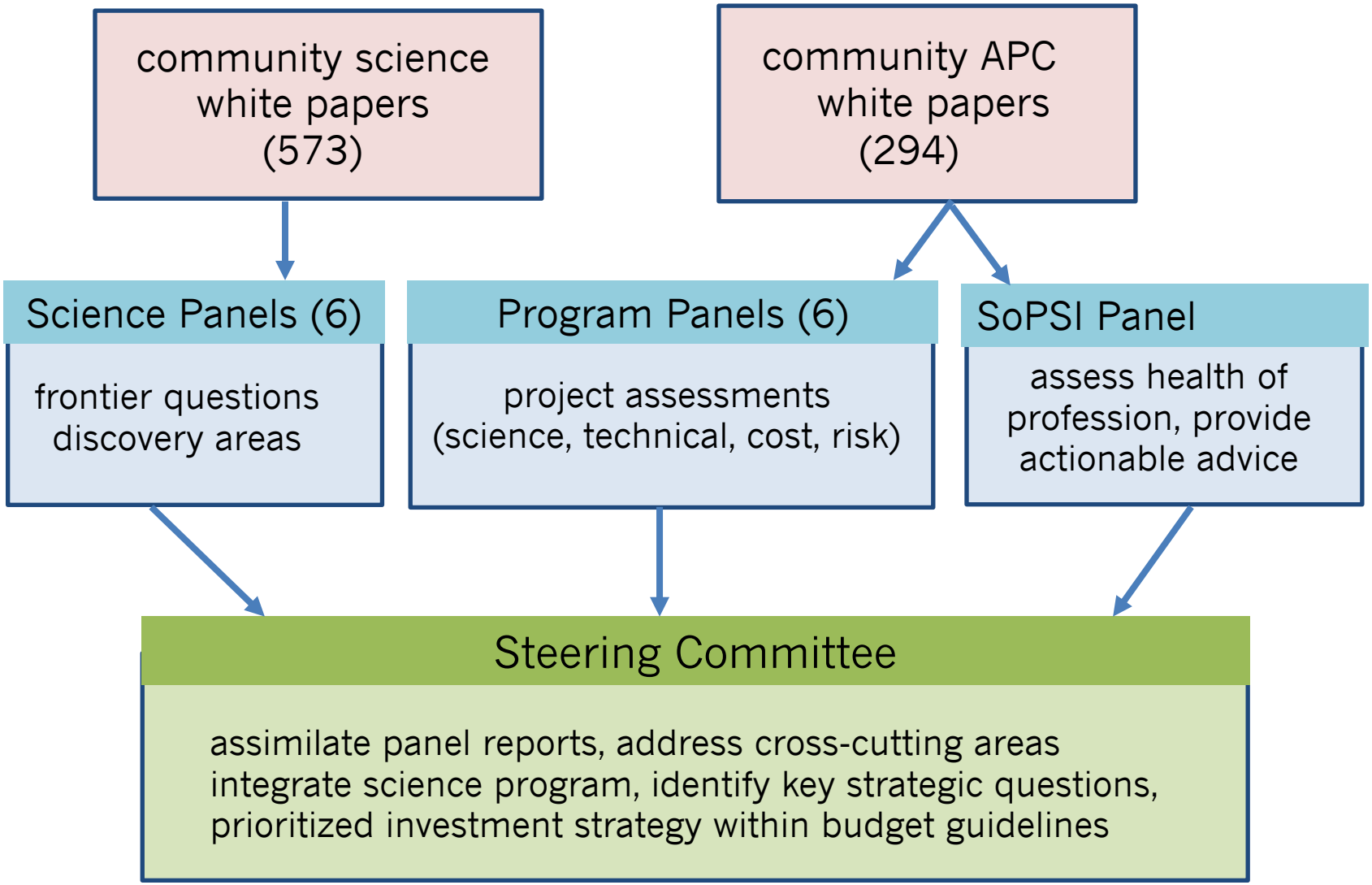
The agencies urged the survey to develop an “ambitious”, “aspirational”, and “inspirational” plan

But a plan also needs to be realistic, responsible, achievable, sustainable

The Survey’s Approach:

- Propose an ambitious program, but with decision rules, decision points, and contingencies
- Emphasize phased development of many projects to lower risks and provide flexibility to agencies
- Present a strategy, with details of implementation resting with agencies and their advisory committees

Astro2020 Process



Realizing the Astro2020 Program: Pathways From Foundations to Frontiers

Explore the Cosmos

Worlds and Suns in Context

- New Messengers and New Physics
- Cosmic Ecosystems
- Pathways to Habitable Worlds
- New Windows on the Dynamic Universe
- Unveiling the Drivers of Galaxy Growth

Forge the Frontiers

- Enable U.S. community participation in ELT program
- Develop and Implement Cosmic microwave Background S4 (joint DOE)
- Begin ngVLA design, technical demonstration, construction
- Upgrade IceCube to Gen2 (NSF/PHY)
- Begin implementation of an Infrared/Optical/Ultraviolet large strategic mission for exoplanet exploration and general astrophysics after a successful maturation program

Enable Future Visions

- Develop technology for future gravitational wave upgrades and observatories (NSF/PHY)
- Commence Great Observatories Missions and Technology Maturation Program

  First entrant: IR/O/UV missions

  Second entrants: Far-IR and X-ray missions

Sustain and Balance the Science

- Augment mid-scale programs, add strategic competitions
- Implement time domain & multi-messenger program
- Compete probe missions in strategic areas of Far-IR and X-ray Astrophysics

Build the Foundations

- Expand grants to bring science and ideas to fruition
- Develop and diversify the scientific workforce
- Support data archives and curation
- Bolster theory underpinnings
- Advance crucial laboratory measurements
- Expand support for early-stage and basic technology development
- Promote scientific literacy and engage the public

Guiding Principles

- Balance the portfolio
- Broaden and optimize the science
- Advance diversity and equity
- Nurture sustainability

Ground-Based

Space-Based

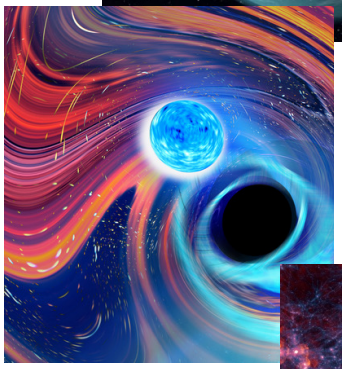
Science Themes and Priority Areas

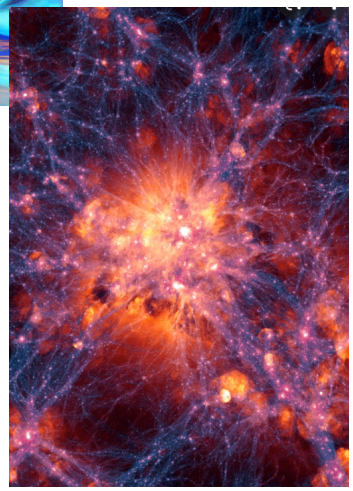
Science Themes

- Worlds and suns in context
- New messengers and new physics
- Cosmic ecosystems

Priority Areas

- Pathways to habitable worlds
- New windows on the dynamic universe
- Unveiling the drivers of galaxy growth





Ground Medium/Large Program Overview

Enabling and Realizing Major Observatories

MREFC Observatories

Federal Investment in U.S. ELTs for community access

CMB-S4 (~equal share NSF/DOE)

ngVLA Studies and Prototyping

Review

ngVLA Construction

2022

2032

Sustaining Programs

Enhancements to Astronomy Mid-scale Programs

Endorsements for Programs in NSF/PHYS

Technology Development for Future Gravitational Wave Observatories

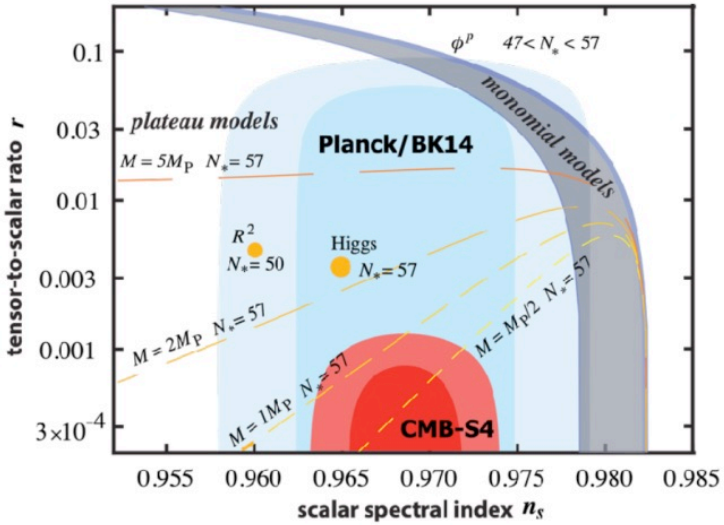
The IceCube-Generation 2 High Energy Neutrino Observatory

The Cosmic Microwave Background Stage 4 Observatory

CMB-S4 builds on the foundation of decades of CMB measurements to take a major leap, pushing CMB science to the next level

Scientific goals

- B-mode CMB polarization signatures of primordial gravitational waves and inflation
- Maps 50% sky, every other day from 0.1- 1 cm with unprecedented sensitivity
- Broad science including systematic time domain science



CMB-S4 consists of a systematically planned suite of facilities in Antarctica and Chile designed to sample a wide range of independent frequencies, and probe a combination of large and small angular scales

The Cosmic Microwave Background Stage 4 Observatory

Key Attributes

- Balanced program between DOE (60%) and NSF (40%) for all phases

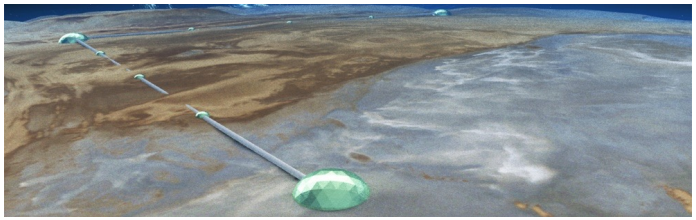
  Brings wide range of technical and scientific expertise to bear from community and national labs

- Total design, development and construction cost: $660M
- First observations could begin by 2030

Recommendation: The NSF and DOE should jointly pursue the design and implementation of the next generation ground-based cosmic microwave background experiment (CMB-S4).

Because of its great potential to advance general astrophysics and open discovery space, it is essential that CMB-S4 produce transient alerts, as well as calibrated maps in all bands and on all angular scales that are openly usable and accessible on as rapid a cadence as practical

Technology Development for Future Ground-based Gravitational Wave Observatories



Gravitational wave detection is one of the most exciting and expanding scientific frontiers impacting central questions in astronomy

- Directly relevant to two Astro2020 priority areas: New Windows on the Dynamic Universe, Hidden Drivers of Galaxy Formation

More advanced detectors in the current LIGO facility (beyond A+) and planning for future generation facilities such as Cosmic Explorer are essential

Conclusion: … Continuous technology development will be needed this decade for next generation detectors like Cosmic Explorer. These developments will also be of benefit to the astrophysical reach of current facilities.

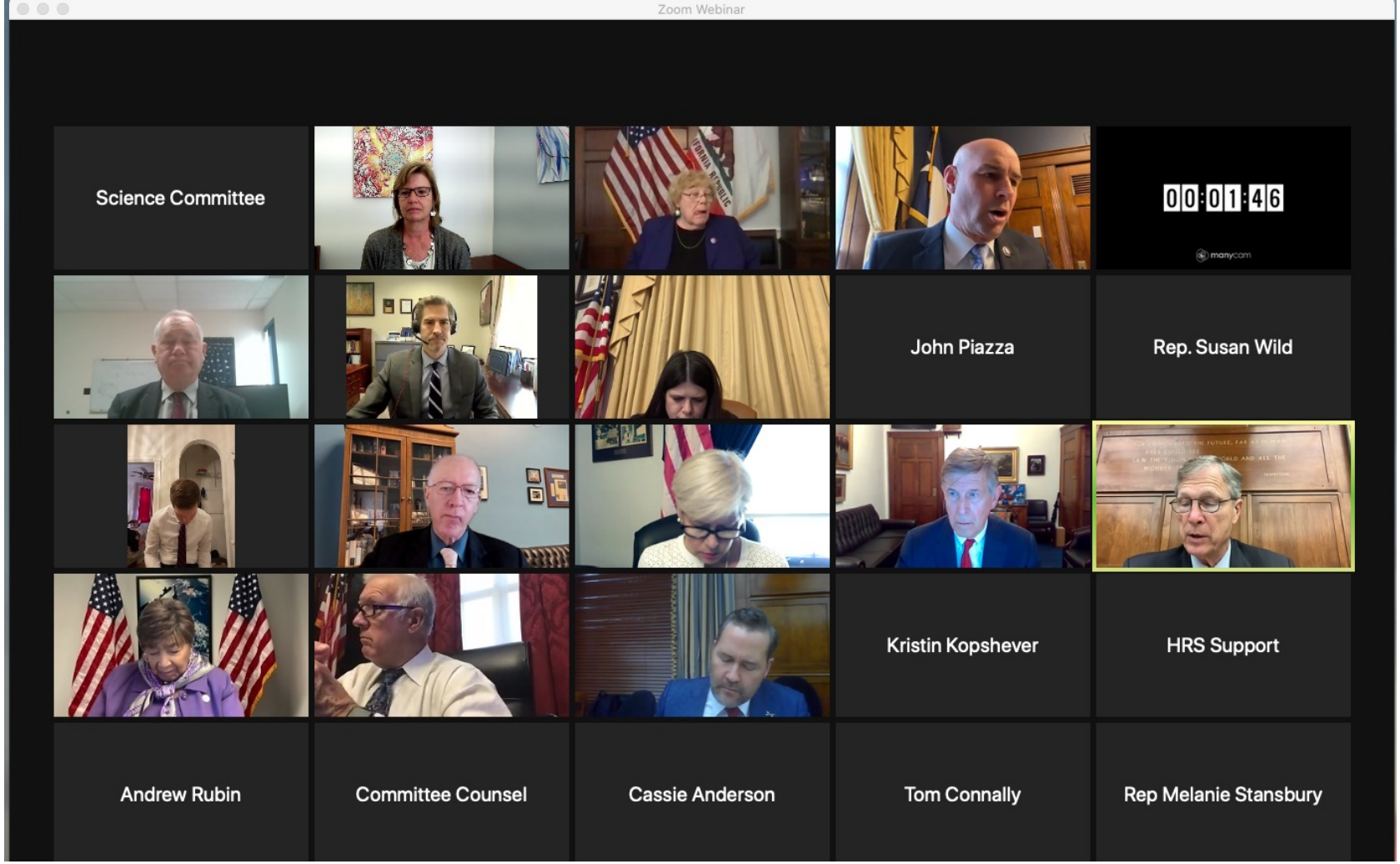
IceCube-Generation 2 Neutrino Observatory

IceCube at South Pole detects 100 TeV – 10 PeV cosmic neutrinos

Upgrade to Generation-2 observatory will add detector elements and a radio array to increase sensitivity (5x), detection rate (10x), and energy range (to 1000 PeV)

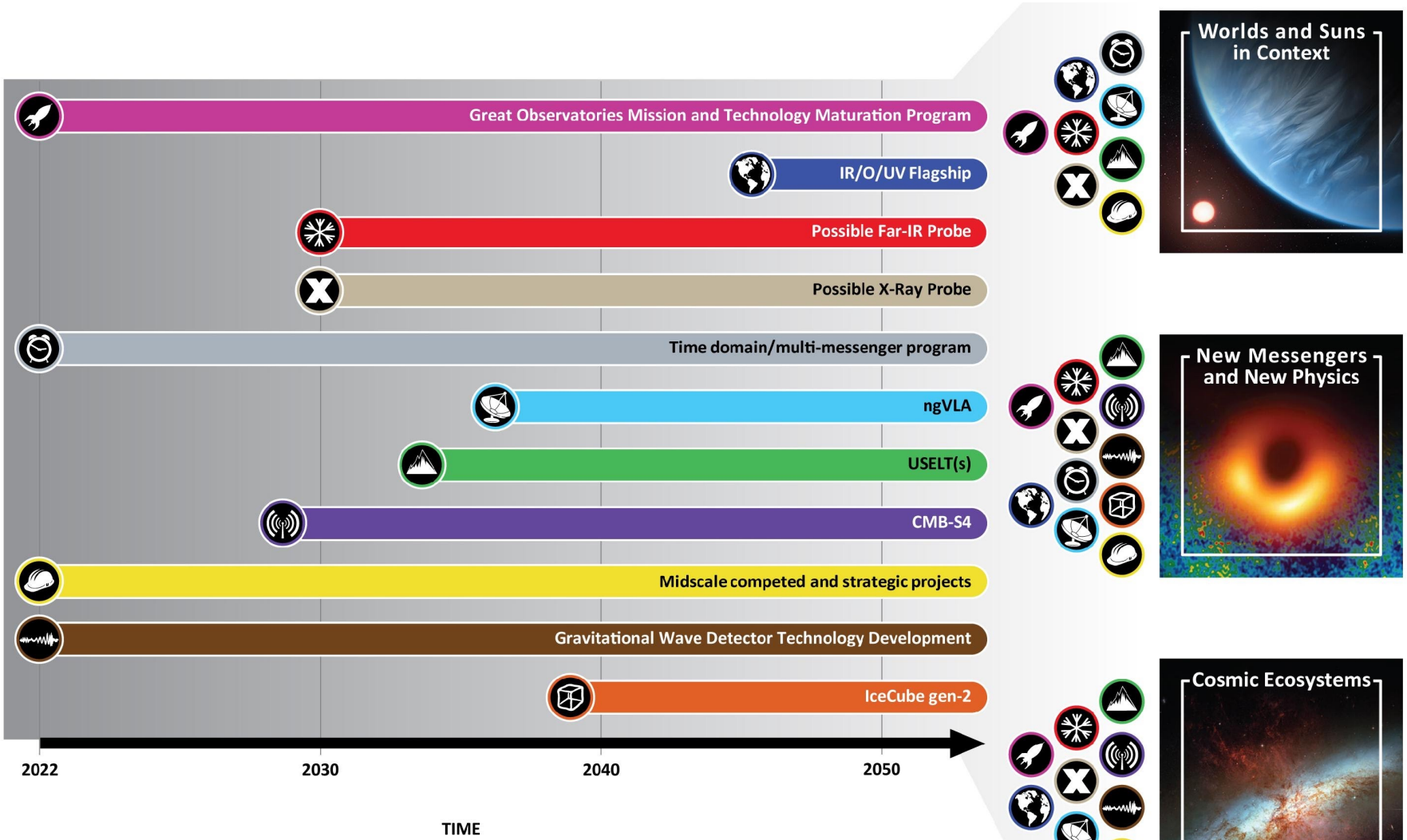
- resolve diffuse (currently) cosmic neutrino background
- localize, identify individual astrophysical sources
- coordinated multi-messenger observations

Conclusion: The IceCube-Generation 2 neutrino observatory would provide significantly enhanced capabilities for detecting high-energy neutrinos, including the ability to resolve the bright, hard-spectrum TeV-PeV neutrino background into discrete sources. Its capabilities are important for achieving key scientific objectives of this survey



House Science, Space and Technology Committee Dec 1, 2021

Subcommittee on Space and Aeronautics
Subcommittee on Research and Technology



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Backup Slides

The Profession and its Societal Impacts

"The pursuit of science, and scientific excellence, is inseparable from the humans who animate it."
-- Panel on the State of the Profession and Societal Impacts

Guiding principles: diversity, equitable access, benefits to the nation and the world, sustainability and accountability

Astro2020 report includes 10 recommendations in this area

Here we provide a brief synopsis: see the full report for additional discussions of education, career paths and pipelines, public outreach and engagement, climate change, and benefits to the nation

The Profession and its Societal Impacts

Areas of key recommendations for the state of the profession

- Collecting demographic data to understand equity in funding
- Diversity of the profession
  - Improving diversity of project and mission teams
  - Investing in and sustaining workforce diversity ”bridge” programs
  - Undergraduate and graduate traineeship programs
- Professional policies related to harassment and discrimination
- Community relations
- Dark skies and protecting the radio frequency spectrum