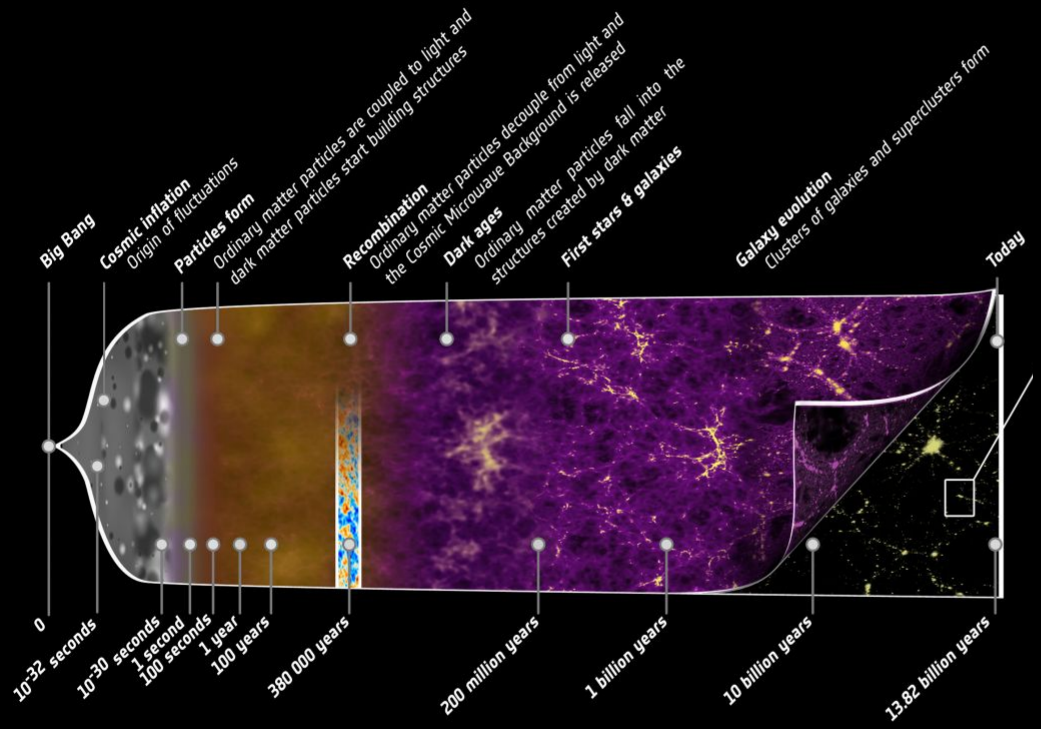
A BOLD FUTURE FOR ASTROPHYSICS

INTRODUCTION

240th Meeting of the AAS
Patrick McCarthy, Director, NSF's NOIRLab

Pasadena, CA June 2022



COSMIC TIMELINE & THE BIG QUESTIONS

Why is there structure in the Universe?

What are dark matter and dark energy and how do they shape the universe and its evolution?

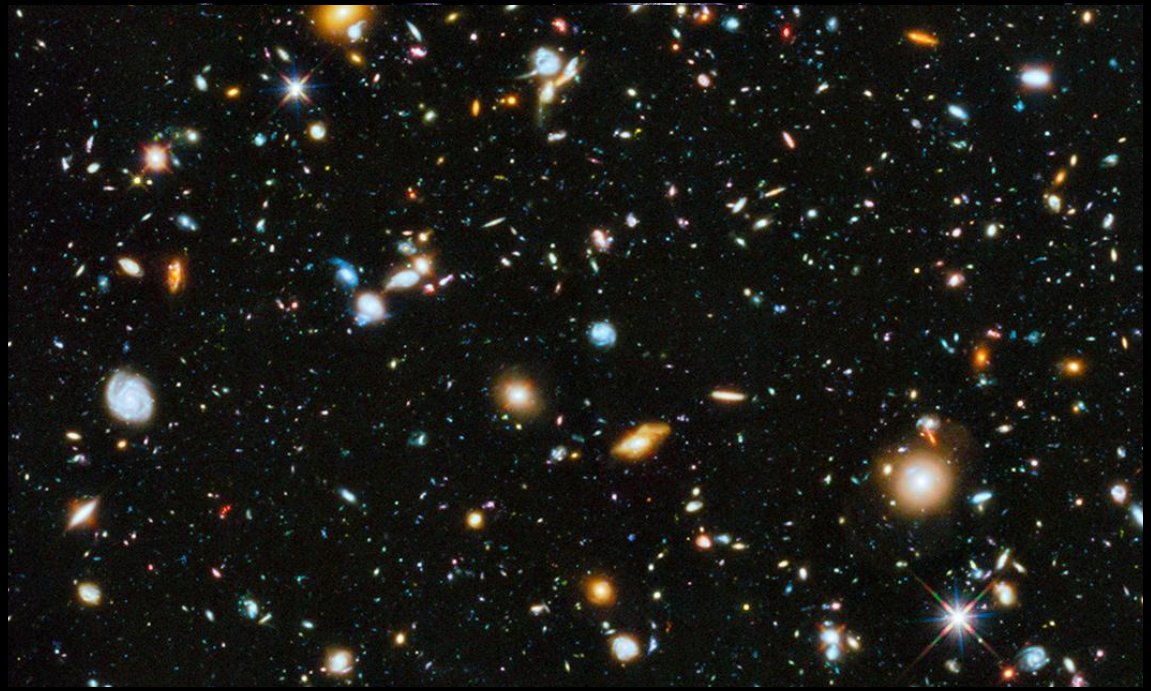
How did dark matter, gas and black holes co-evolve into today's galaxies?

When, where and how did biology emerge in planetary systems?

The Dark Ages and Cosmic Dawn

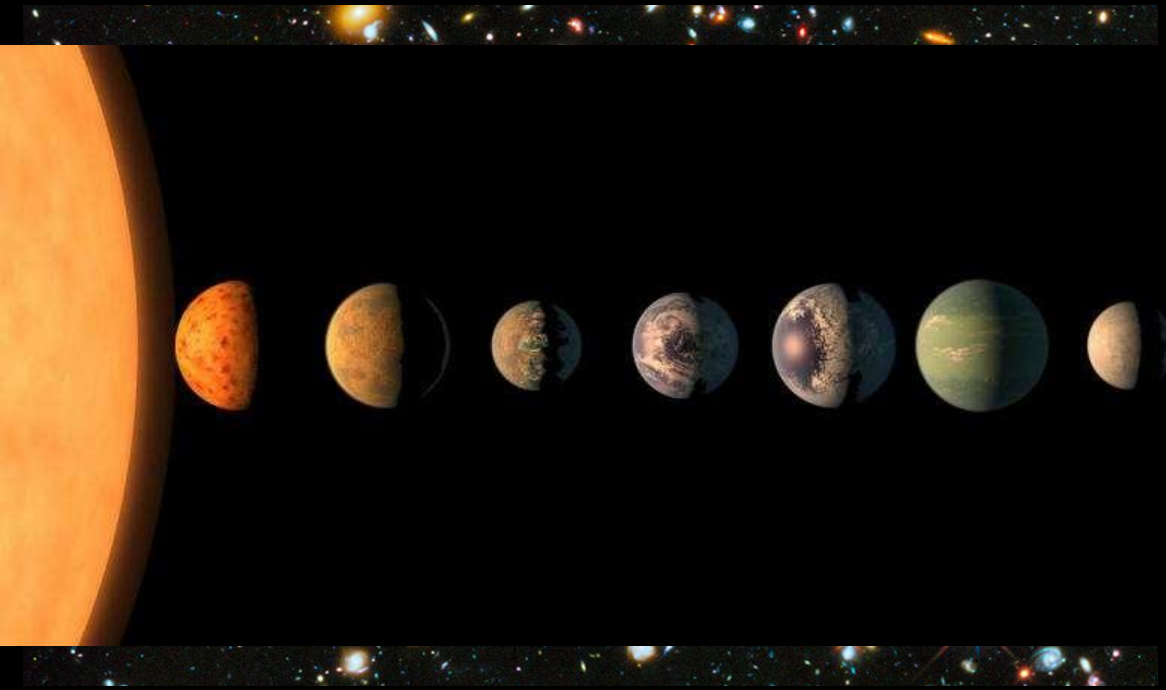
How were the seeds of today's universe laid down?

What lit up the Universe, and when?



From Cosmic Dawn to Cosmic Noon

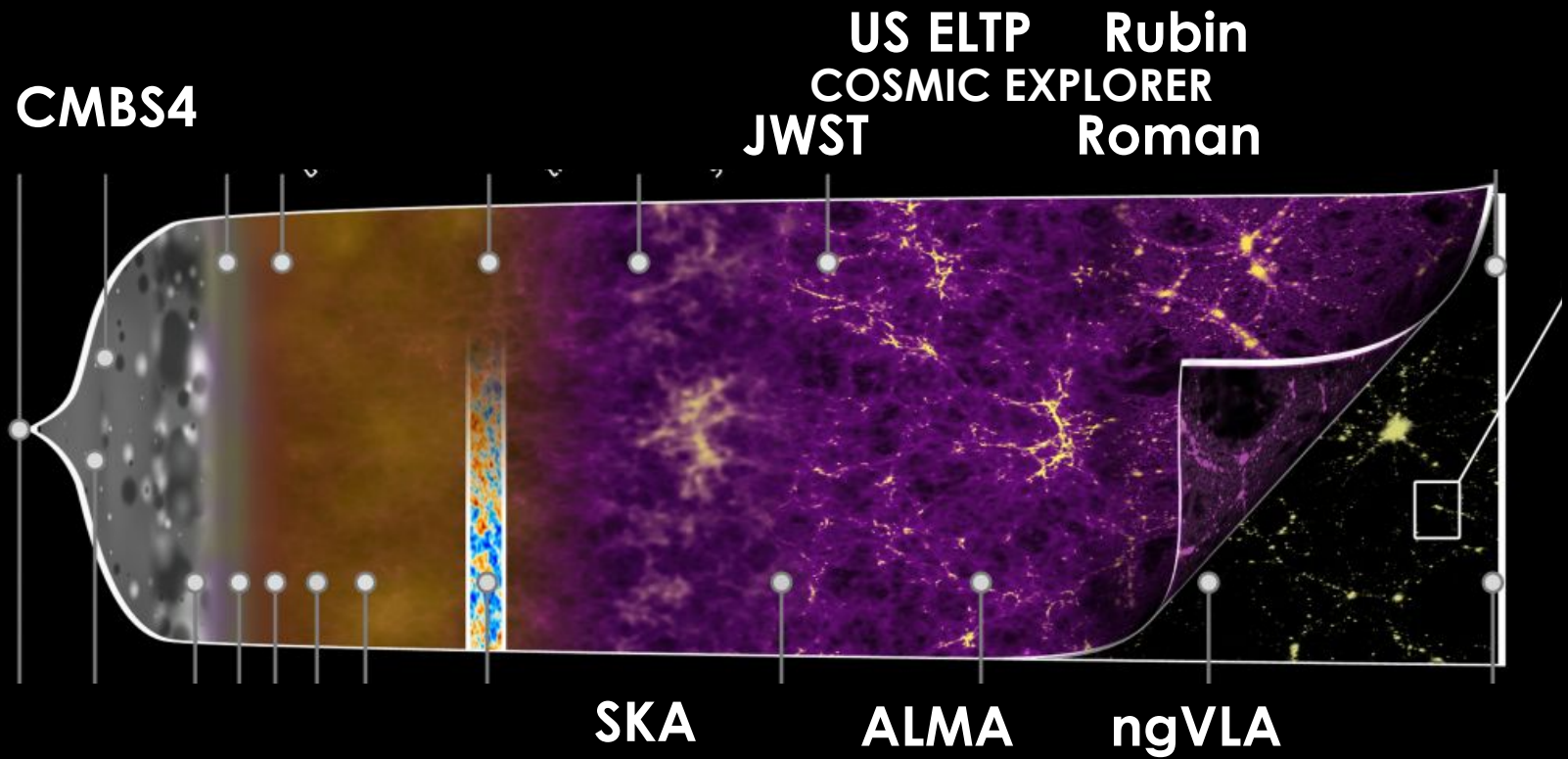
How do black holes, star formation and supernovae regulate galaxy growth?



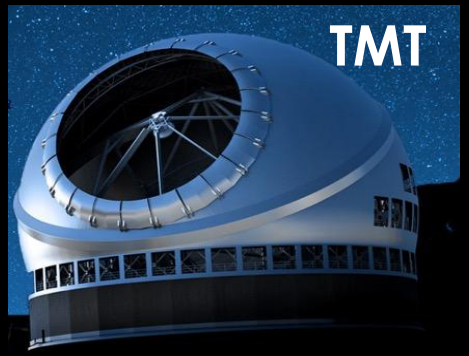
Exoplanets and the Search for Life Elsewhere

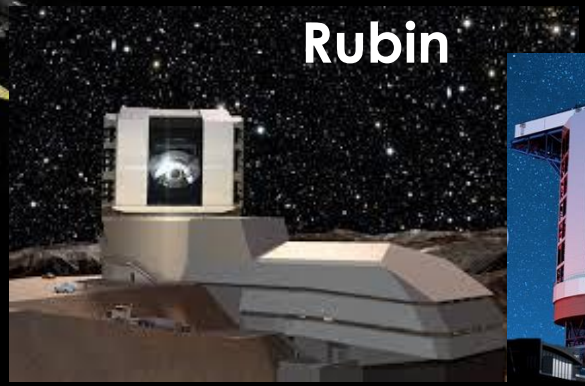
What drives the diversity of planetary systems?

What conditions are necessary and sufficient for life?

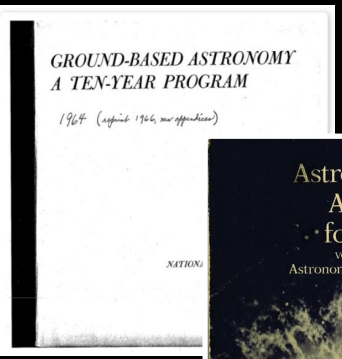

US ELTP
Rubin
COSMIC EXPLORER
CMBS4
JWST
Roman
SKA
ALMA
ngVLA
CHANDRA
SWIFT
DESI
MSE
MegaMapper

Tools for Discovery

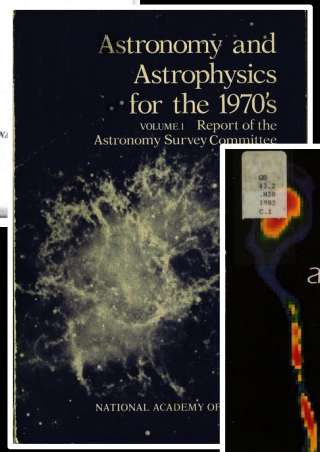




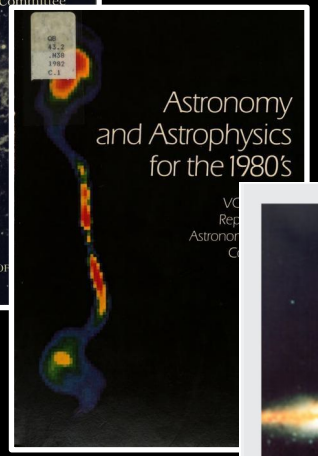
How to Prioritize?



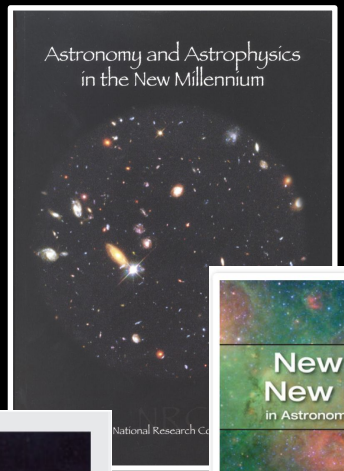
KPNO



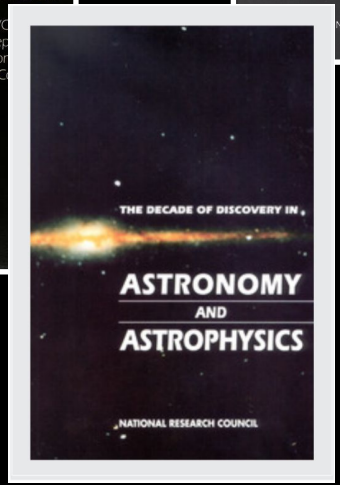
CTIO
VLA



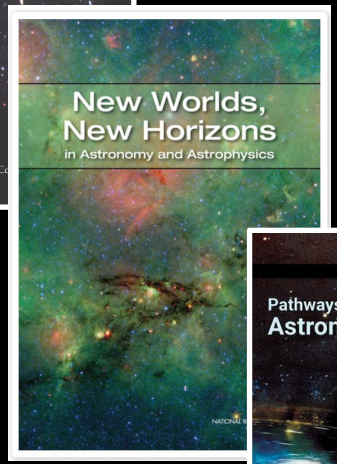
VLBA
Chandra



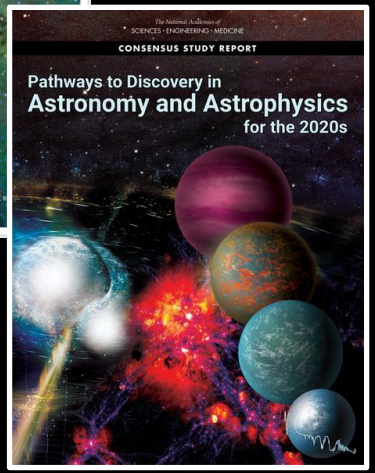
GSMT
JWST



ALMA
Gemini
Spitzer



Rubin
Roman



US ELT
CMBS4
ngVLA

WHAT DO WE NEED FOR SUCCESS?

Coordination, Cooperation, Collaboration

Time domain systems, software, networks
Cross-referenced survey data sets
Connected data archives

Technology

Focal plane instruments
Controls, signal processing, algorithms, real-time computing

Support for Science Users

End-to-end planning tools
Pipelines that produce science-ready data

Prepared Diverse Professional Workforce

Engineering disciplines
Scientists, Systems Engineers, Project Managers

A *strategy* for Supporting All of the Above!

HOW CAN WE HELP NSF?

- Advocate for science!
  - *Within your community*
  - *Within your university*
  - *With your local congressional delegation*
- Advocate for growing NSF's top-line budget
  - *A healthy NSF is good for the nation*
- Advocate for continued US leadership in science and technology
- Share the excitement of astronomy widely!

TODAY'S PROGRAM

US ELT Program	Rebecca Bernstein
CMB S4	Abigail Crites
ngVLA	Tony Beasley
Cosmic Explorer	Matthew Evans
Panel Q&A	Bob Kirshner et al.

US-ELTP

Rebecca Bernstein

Member of the Scientific Staff
at Observatories of the Carnegie Institution for Science
and Chief Scientist
at the Giant Magellan Telescope Organization

Leadership in O/IR Capabilities for the Next Generation of Scientists

Rebecca Bernstein for the US-ELT Program
Chief Scientist, GMTO

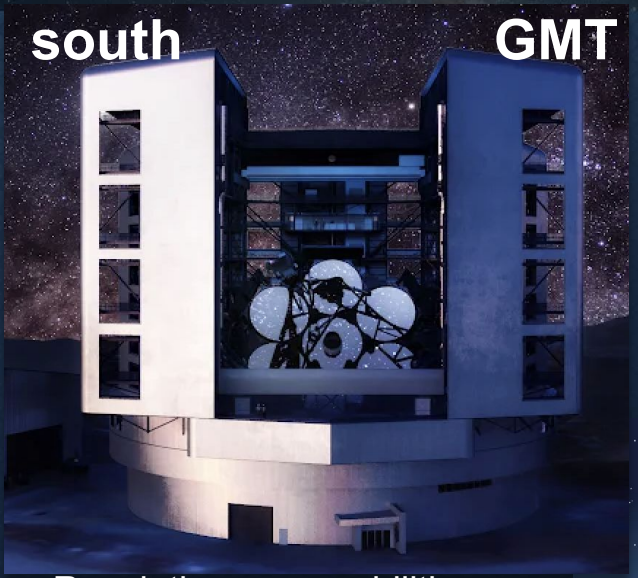
TMT THIRTY METER TELESCOPE

NOIR Lab

GIANT MAGELLAN TELESCOPE

The next generation of O/IR telescopes: an world-leading system for US astronomers

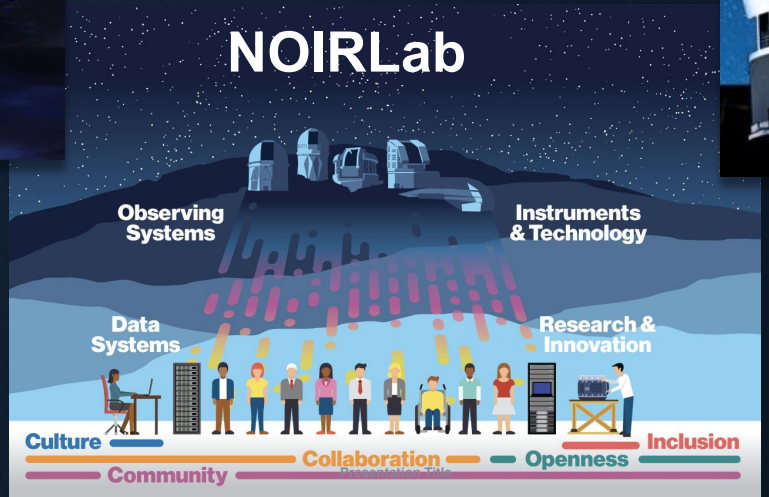
USELTP

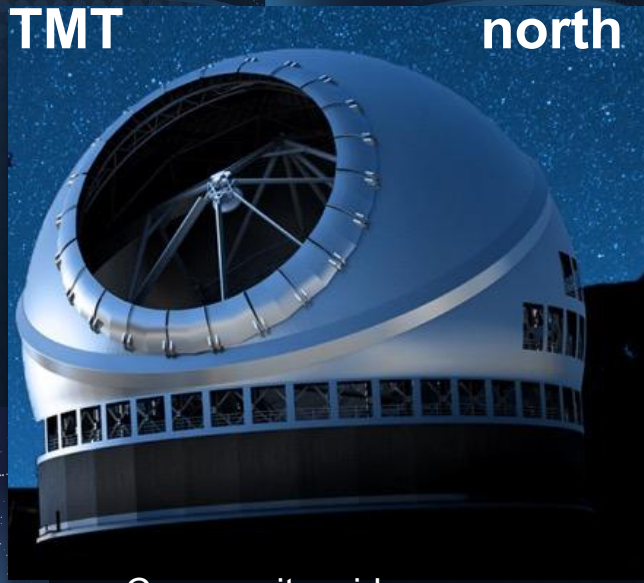


Revolutionary capabilities:
- Sensitivity
- Resolution
- State-of-the-art instruments

Data archives

Full sky coverage





Community-wide access
- >25% of both facilities
- Key Science Programs
- Individual PI Programs

User support

Data products & platforms

Greatest leap in discovery potential since Galileo:

Angular Resolution (~λ/D)

$\theta_J \approx 0.01$ asec

K-band Strehl ~80%

Astrometric stability ~0.01 mas (rms in 1 hr)

10x better than HST

4x better than JWST (1-10μm)

Sensitivity (~D2/Θ2)

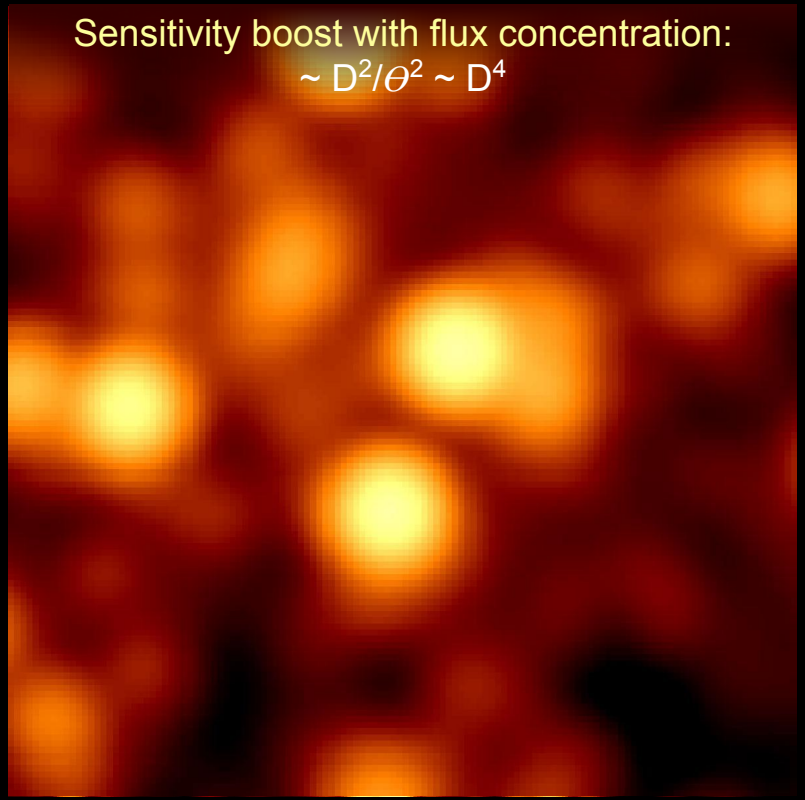
14-200x better than 8m telescopes

Powerful instruments:

Wide field (20 arcmin), Wide band (0.3-10μm),

State-of-the-art technology & techniques

Multiple generations



Capabilities to transform our understanding of the universe

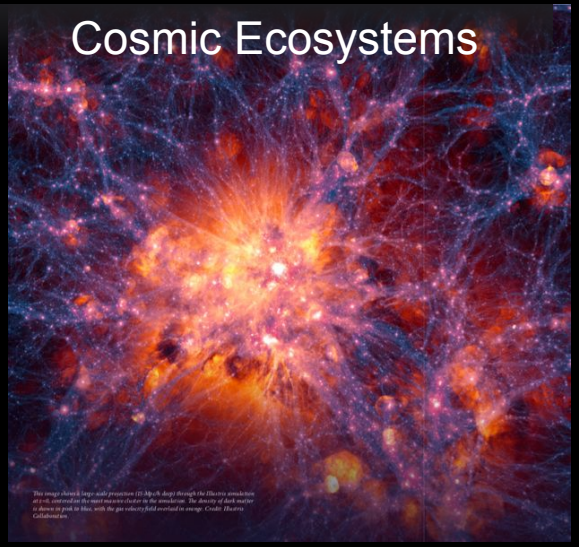
Worlds and Suns

- Exoplanet formation and the statistics of habitable worlds.
- Search for life beyond the solar system

New Messengers, New Physics

- Gravitational wave events & relics
- The composition (dark matter) and physics (dark energy) of the Universe

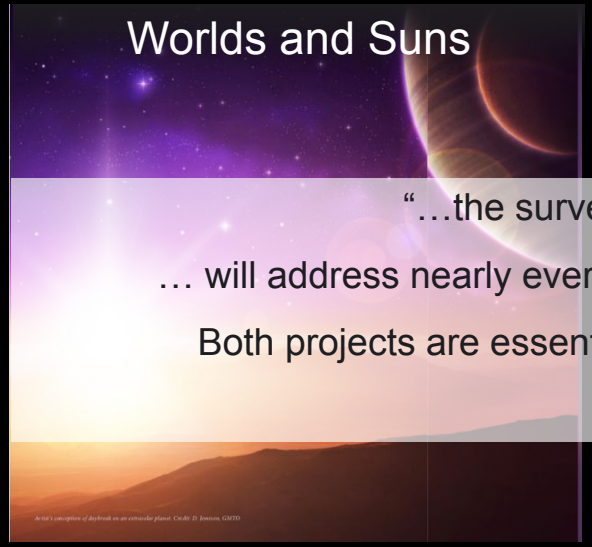
Cosmic Ecosystems



- The physics and chemistry of the first galaxies
- Black holes and galaxy evolution

Capabilities to transform our understanding of the universe

Worlds and Suns



- Exoplanet formation and the statistics of habitable worlds.
- Search for life beyond the solar system

New Messengers, New Physics

- Gravitational wave events & relics
- The composition (dark matter) and physics (dark energy) of the Universe

Cosmic Ecosystems

- The physics and chemistry of the first galaxies
- Black holes and galaxy evolution

"…the survey's priority for a frontier ground-based observatory…

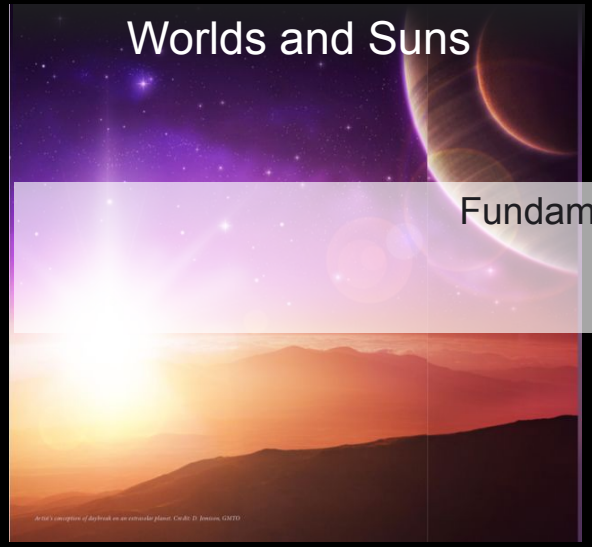
… will address nearly every important science question across all three priority science areas.

Both projects are essential for keeping the U.S. community's global scientific leadership."

— Astro2020

Capabilities to transform our understanding of the universe

Worlds and Suns

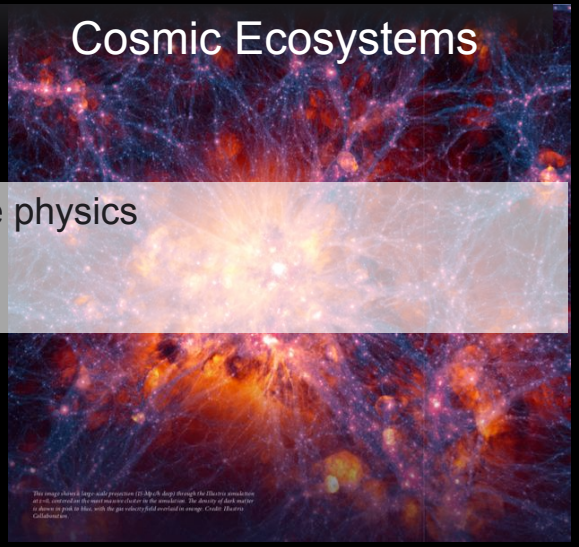


- Exoplanet formation and the statistics of habitable worlds.
- Search for life beyond the solar system

New Messengers, New Physics

- Gravitational wave events & relics
- The composition (dark matter) and physics (dark energy) of the Universe

Cosmic Ecosystems

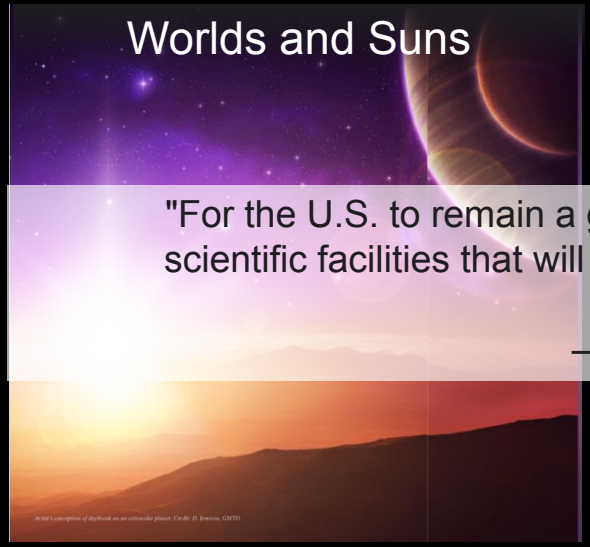


- The physics and chemistry of the first galaxies
- Black holes and galaxy evolution

Fundamental physics, solid state physics, particle physics
chemistry, geology, astrobiology,
our place in the universe

Capabilities to transform our understanding of the universe

Worlds and Suns

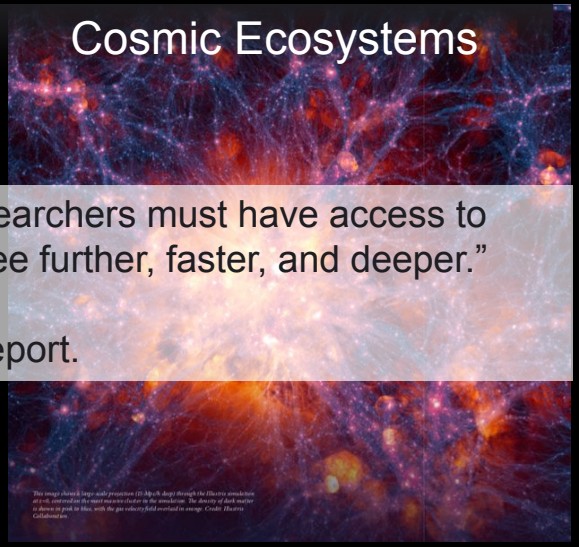


- Exoplanet formation and the statistics of habitable worlds.
- Search for life beyond the solar system

New Messengers, New Physics

- Gravitational wave events & relics
- The composition (dark matter) and physics (dark energy) of the Universe

Cosmic Ecosystems



- The physics and chemistry of the first galaxies
- Black holes and galaxy evolution

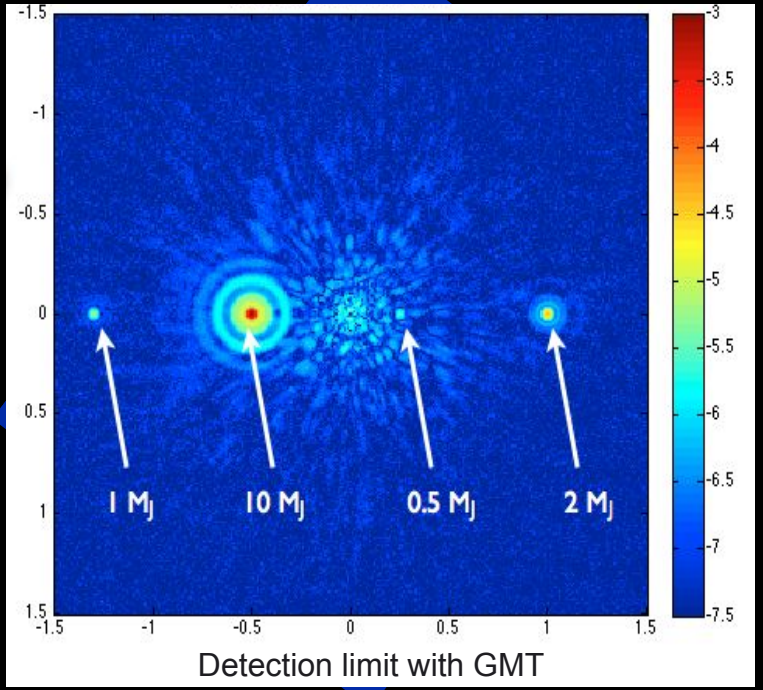
"For the U.S. to remain a global leader in innovation, America's researchers must have access to scientific facilities that will astonish the world – tools that let them see further, faster, and deeper."

— National Science Board, Vision 2030 report.

Capabilities to transform our understanding of the universe

Solar system: 30 km at Jupiter (5 AU)

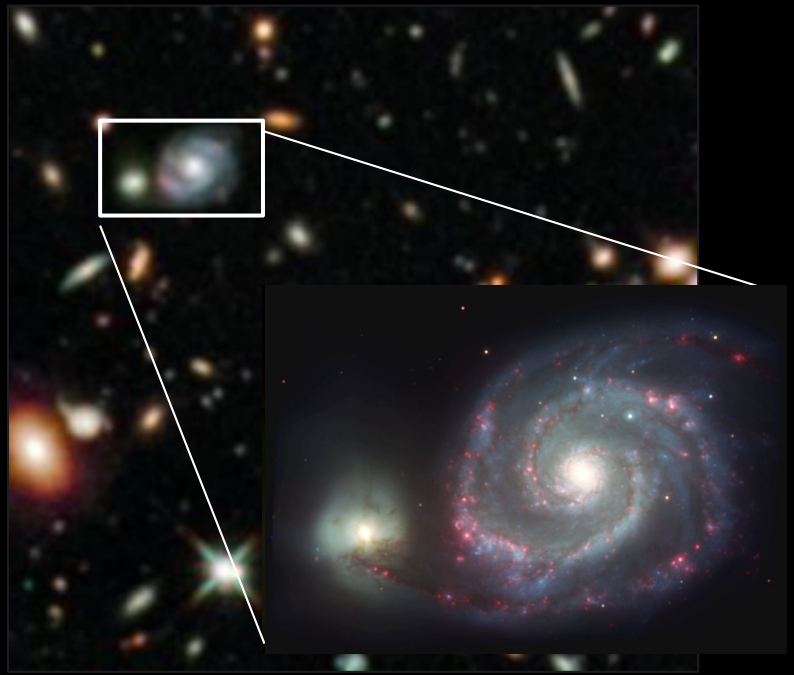
Habitable zones: 1 AU at 100 pc



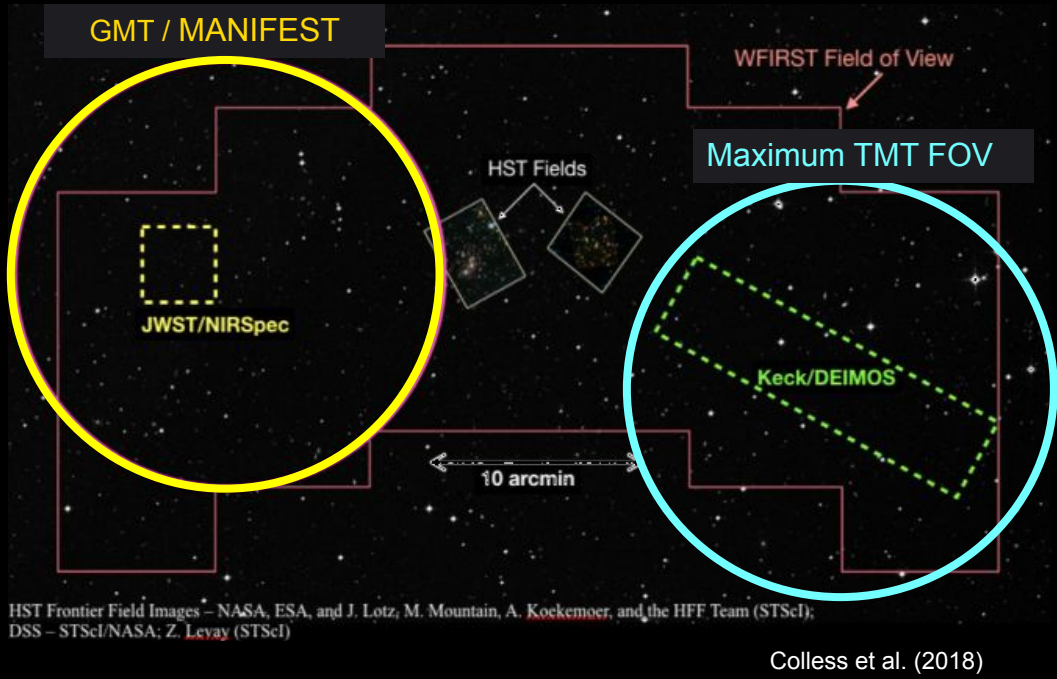
Detection limit with GMT

Capabilities to transform our understanding of the universe

Star forming regions: 60 pc at z=2.5



Multiplexing for ~100's of ultrafaint sources

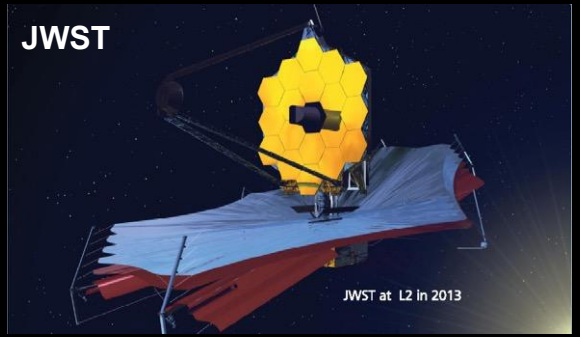


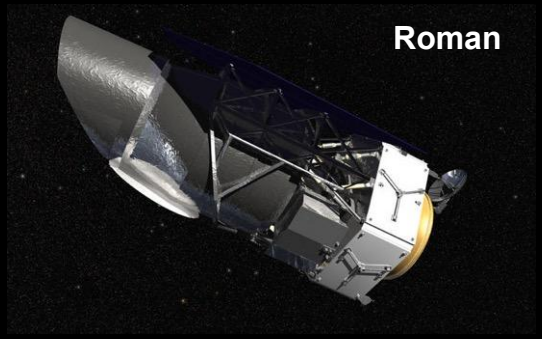
Colless et al. (2018)

Amplifying the impact of current and future investments:

High-resolution spectroscopy (0.3-10μm) for physics, chemistry, and astrobiology.

Wide-field, high sensitivity spectroscopy for efficient survey science.





Amplifying the impact of current and future investments:

chemistry and *dynamical* data =

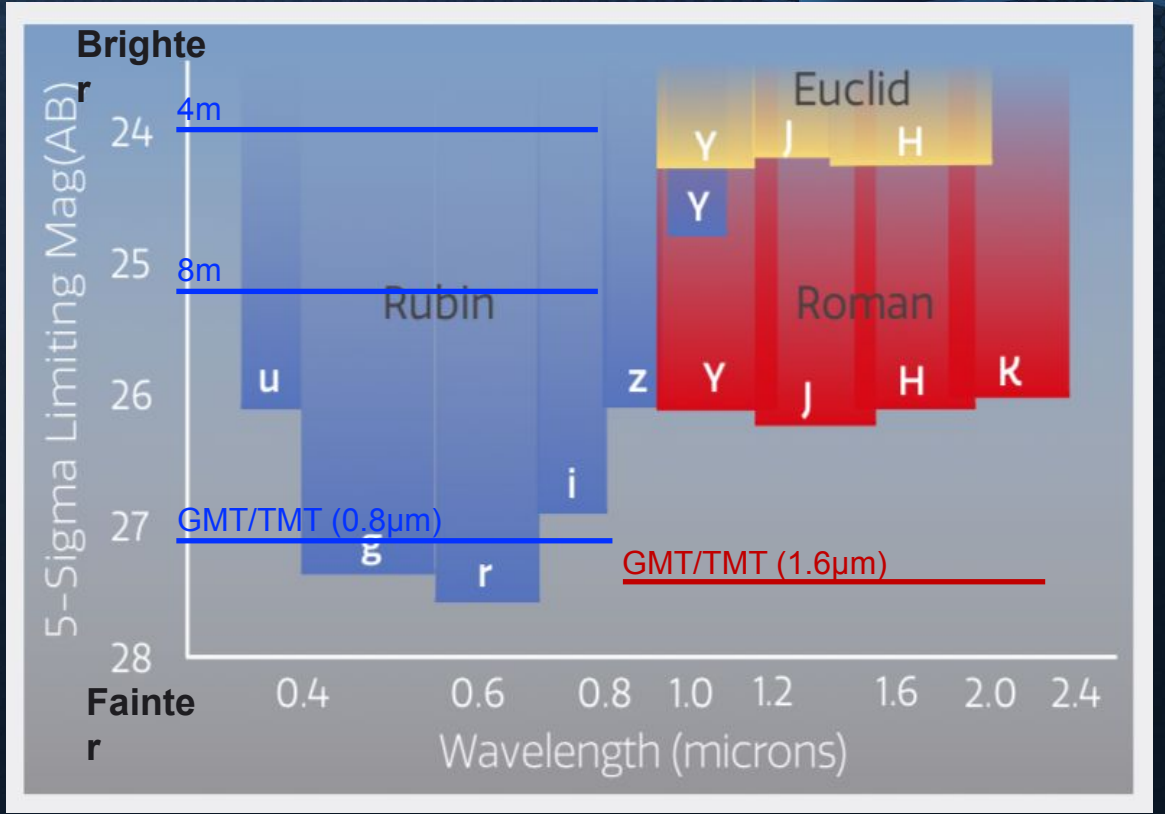
The assembly history of galaxies over cosmic time.

The conversion of gas (Hydrogen) into stars the elements around us.

Constraints on dark matter and dark energy

The physics of black holes and their co-evolution with galaxies

…And answer to questions we haven't yet begun to ask!



Lines=5-sigma detection limits (20 hr). 8 hr integration limits are 1 mag brighter.

The unique power of a bi-hemispheric system:

Full sky access

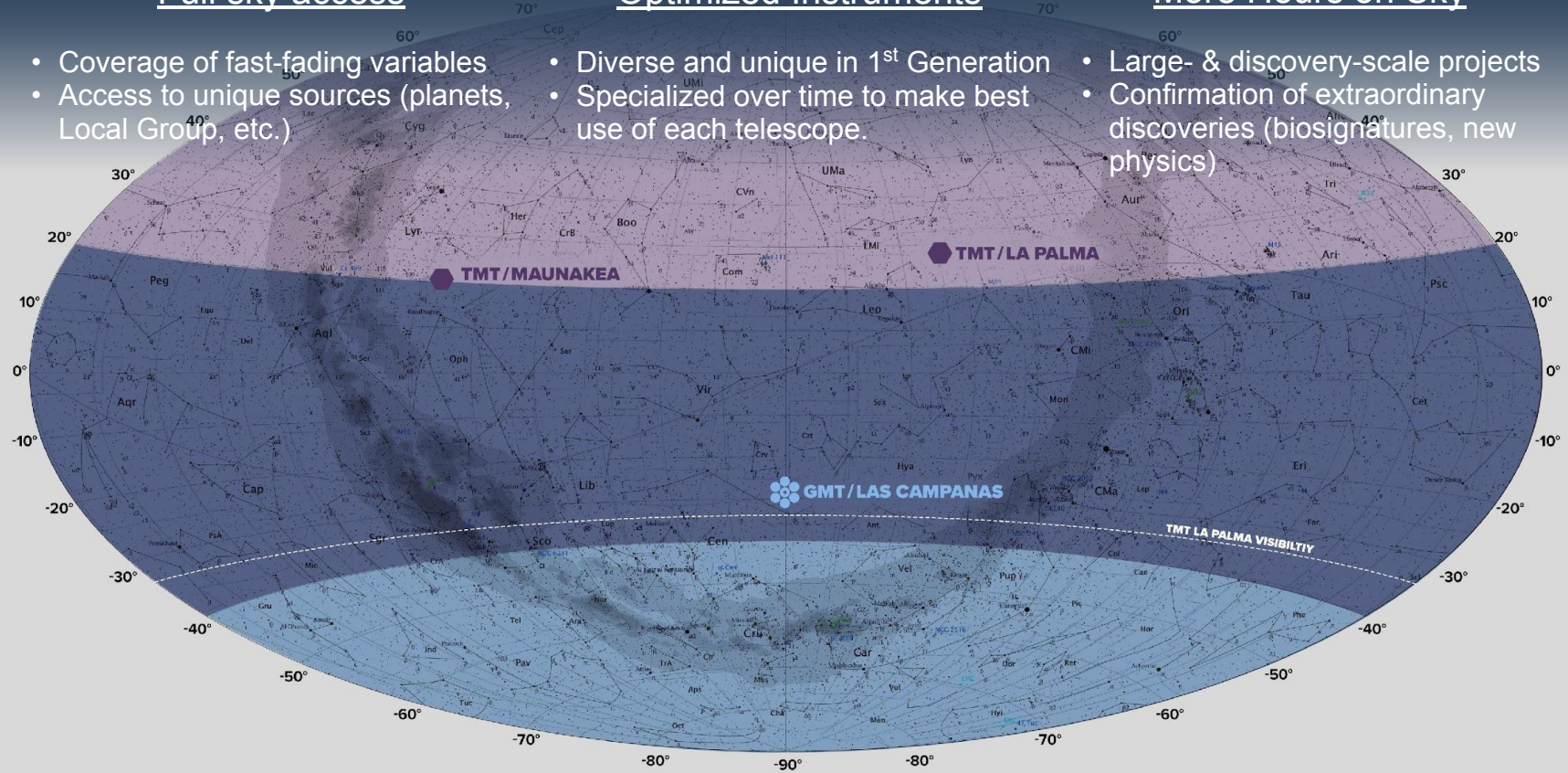
- Coverage of fast-fading variables
- Access to unique sources (planets, Local Group, etc.)

Optimized Instruments

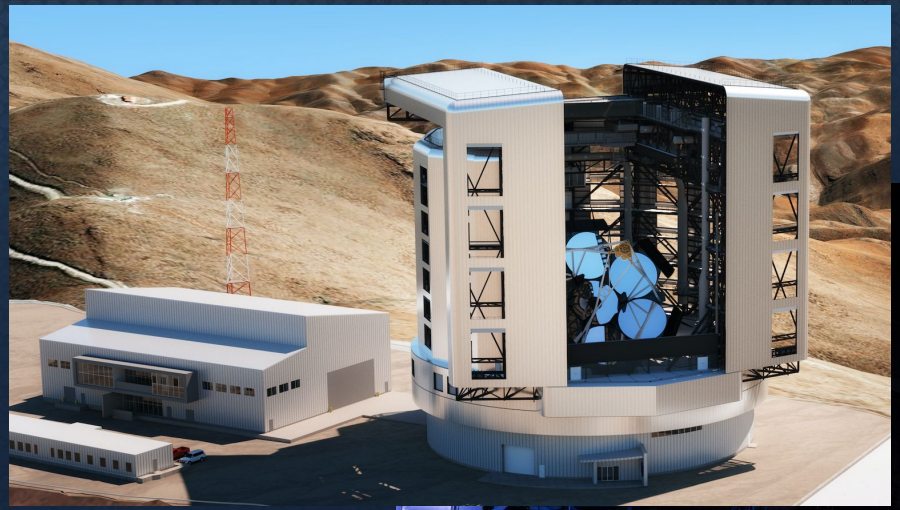
- Diverse and unique in 1st Generation
- Specialized over time to make best use of each telescope.

More Hours on Sky

- Large- & discovery-scale projects
- Confirmation of extraordinary discoveries (biosignatures, new physics)



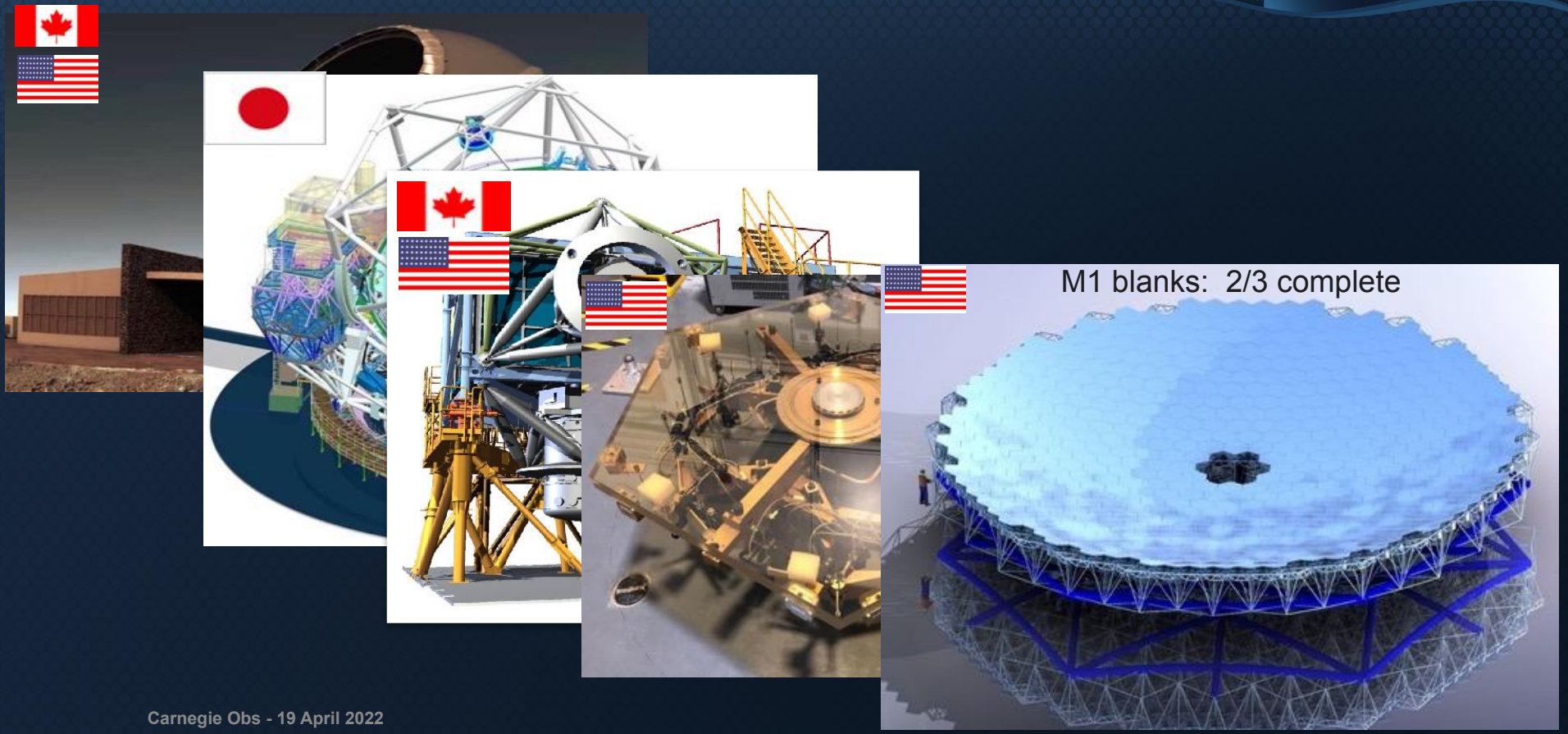
GMT status –
Majority in final design or construction



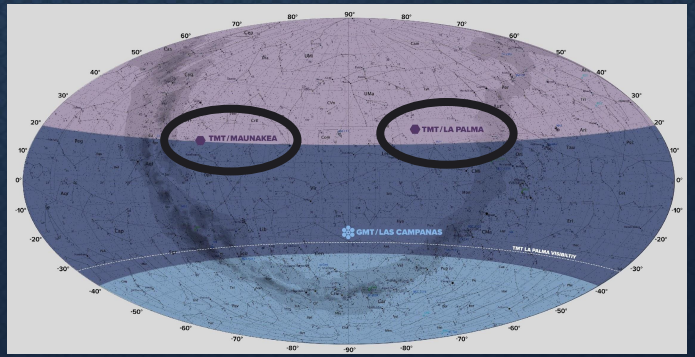
M1 segments:
2 completed, 4 in processing, 2 remain to cast

GMT status –
Hard rock excavation and infrastructure completed.

GMT status –
Majority in final design or fabrication



TMT Status —
Working to build trust and relationships in Hawaii. ORM as alternative.



Tutors Needed at Hilo High!

Summer Credit Recovery Program (June 6 - July 14)

The school is requesting help from all staff & students of the Maunakea Observatories, the University of Hawai'i & the Institute for Astronomy!

Our Community needs our help!
(~100 students are struggling to graduate)

Date & Time: 06/06 - 07/14 2022, daily (M-F), 8am-12pm

Location: Hilo High School (HHS)

Target: 20 students each day

Request: 4-5 tutors for each hour every day

Subject: Primarily **Math & Science** HHS will provide access to class notes & curriculums.

Learn more and Sign up HERE today!

HHS teachers will hold a tutorial on June 3 for all volunteers

Supporting local students in their education journey is the most effective & appreciated way to build Community Astronomy!

'A'ohe hana nui ke alu 'ia!
No work is too big when done by all!

A public-private partnership for a world-leading, inclusive system of O/IR telescopes for the future of US scientist

TMT
THIRTY METER TELESCOPE

NOIR Lab

GIANT MAGELLAN TELESCOPE

CMB-S4

Abigail Crites

Assistant Professor at Cornell University
and Member of the Executive Team, CMB-S4

CMB-S4

Abigail Crites
For the CMB-S4 Collaboration
Assistant Professor at Cornell University
and Member of the Executive Team, CMB-S4

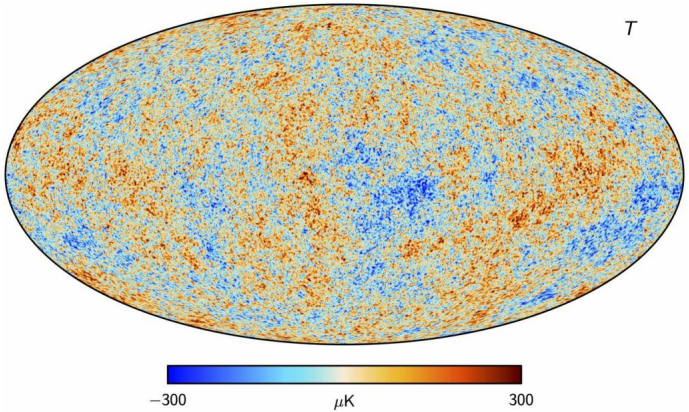
CMB-S4

What is CMB-S4?

CMB-S4 is the next-generation ground-based cosmic microwave background experiment.

CMB-S4 consists of 21 telescopes at the South Pole and in the Chilean Atacama desert

It will survey the sky with over 500,000 cryogenically-cooled superconducting detectors for 7 years, CMB-S4 will deliver transformative discoveries in fundamental physics, cosmology, astrophysics, and astronomy.



CMB-S4 is supported by the Department of Energy Office of Science and the National Science Foundation.

Where can I get more information?

Snowmass 2021 CMB-S4 White Paper:
https://arxiv.org/pdf/2203.08024.pdf

CMB-S4: Forecasting Constraints on Primordial Gravitational Waves:

https://arxiv.org/pdf/2008.12619.pdf

CMB-S4 Science Case, Reference Design, and Project Plan:

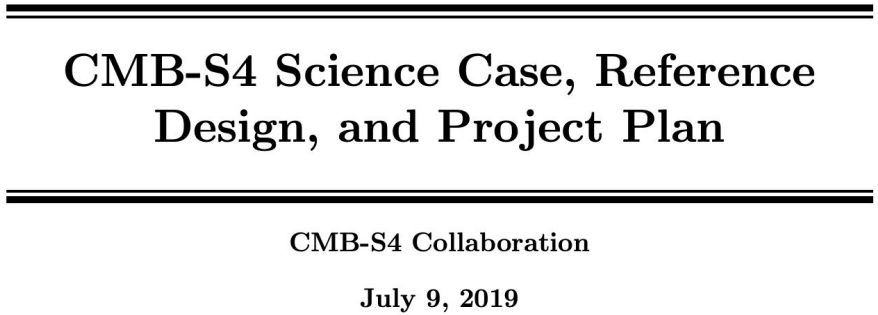
https://arxiv.org/pdf/1907.04473.pdf

CMB-S4 Technology Book, First Edition:

https://arxiv.org/pdf/1706.02464.pdf

CMB-S4 Science Book, First Edition:

https://arxiv.org/pdf/1610.02743.pdf


CMB-S4 Science Case, Reference Design, and Project Plan

CMB-S4 Collaboration

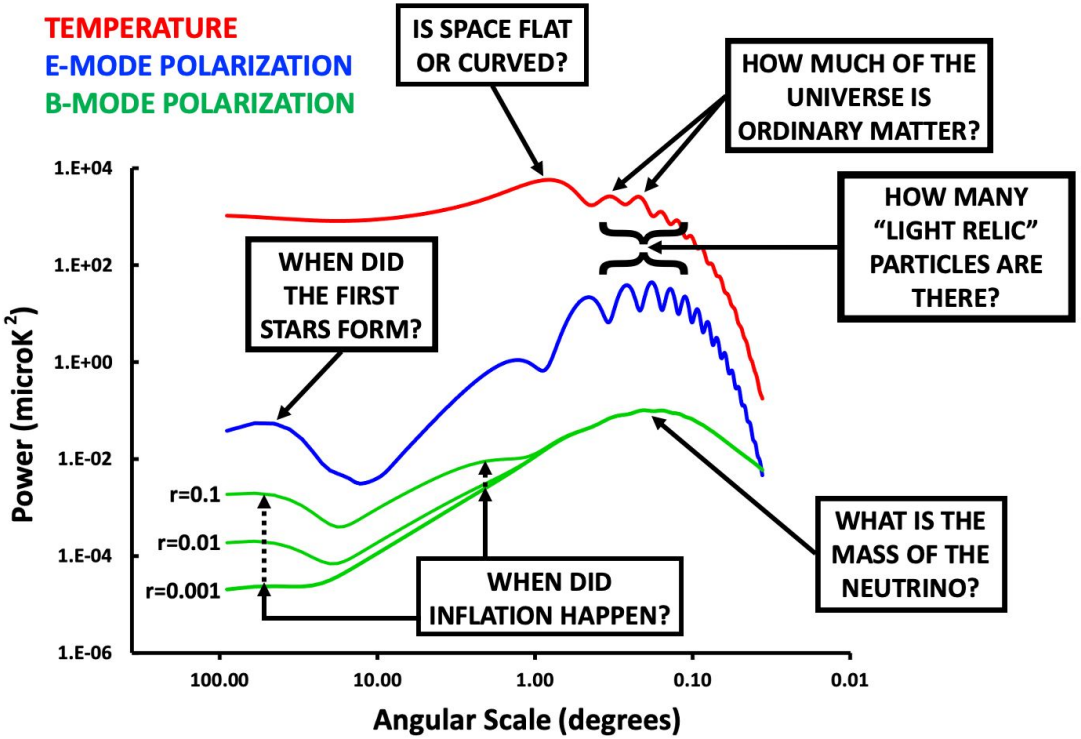
July 9, 2019

cmb-s4.org

Science From the CMB

Encoded in the weak anisotropy of the CMB intensity and polarization is the story of the origin, evolution, and make up of the Universe.

To extract it we need to measure the anisotropy from angular scales of degrees to arcminutes with exquisite sensitivity and fidelity.



Why CMB-S4?

CMB-S4 will cross critical thresholds in key cosmological parameters in the search for primordial gravitational waves and relic particles.

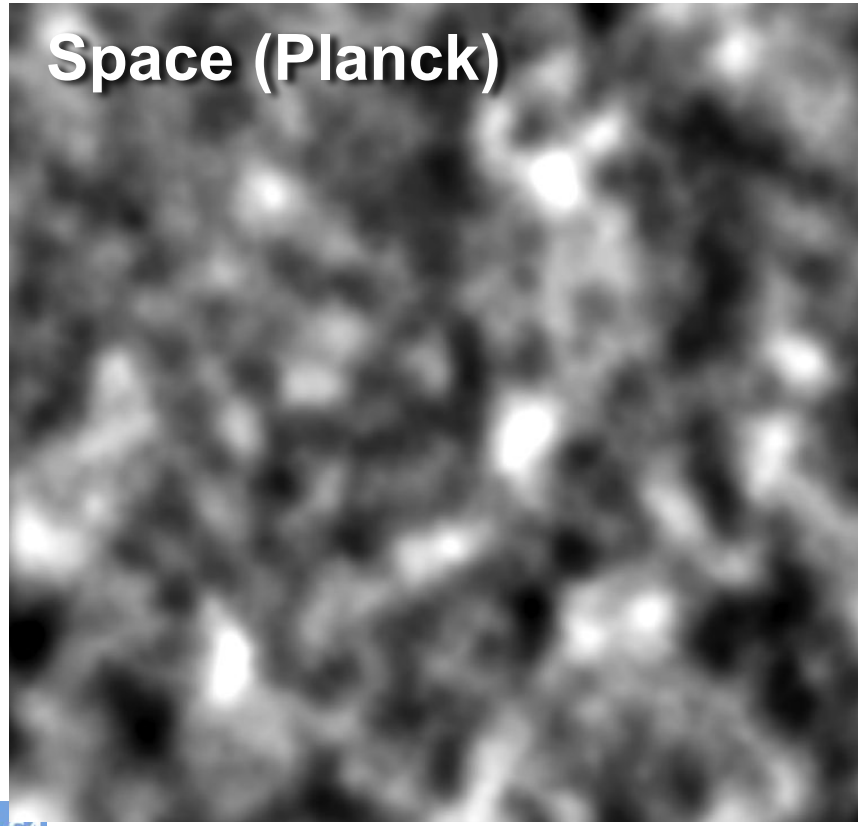
CMB-S4 will provide unique astrophysical information, from the reionization of the Universe to the role of baryonic feedback in structure and galaxy formation. It will provide a powerful and unprecedented catalog of high-redshift clusters and galaxies, and open up the mm-wave transient universe for Multi-Messenger Astrophysics.

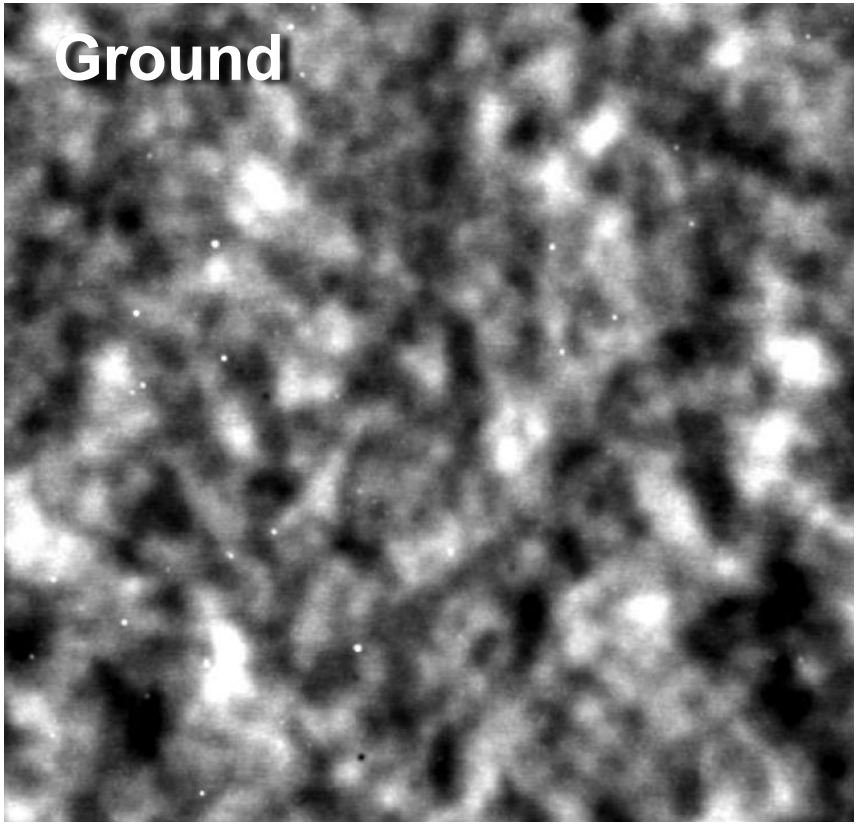
These goals drive the experimental design and cannot be met with any precursor experiments.

CMB-S4 instrument and survey strategy are designed to be an extremely powerful complement to other astronomical surveys— breaking degeneracies and increasing sensitivity —to investigate neutrino properties, dark energy, and dark matter.

Why CMB-S4?

Transformational discoveries will come from ground-based telescopes.



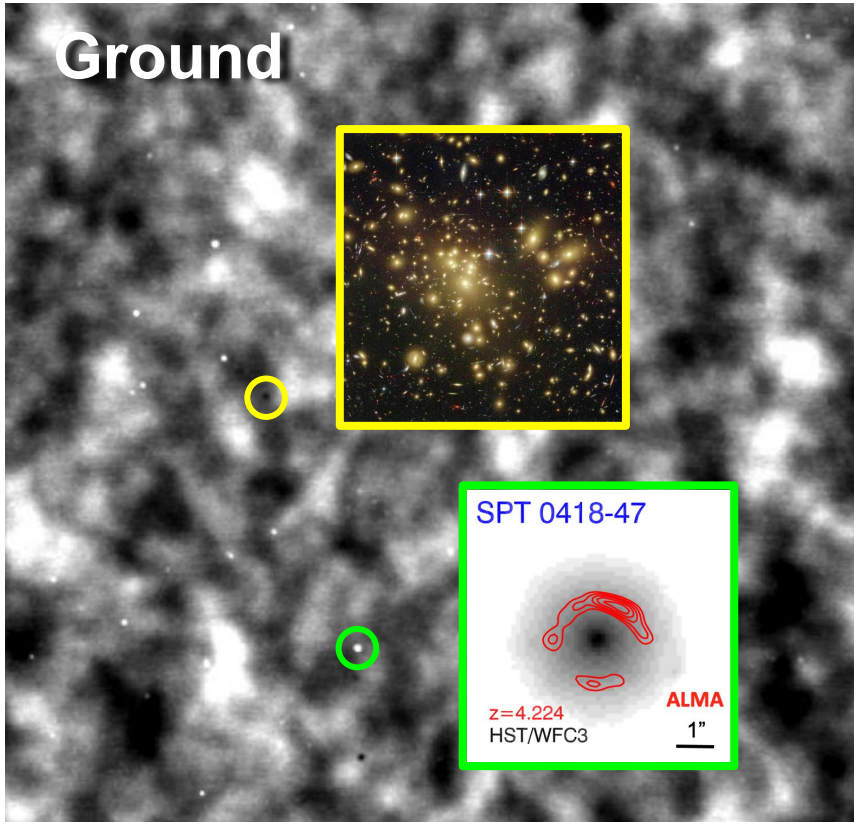


Why CMB-S4?

Transformational discoveries will come from ground-based telescopes.

CMB-S4 measurements will lead to a wide range of additional science, from CMB lensing mass maps and sources appearing either backlit by the CMB or as mm-wave foregrounds.

- Extragalactic: large scale structure, galaxies, galaxy clusters, GRBs, ...
- Galactic: star forming clouds, dust & synchrotron emission, …
- Solar system: planet 9, …
- mm sky surveys provides objects for ALMA, VLA, Gemini, and others to follow up at all λ's



CMB-S4 is a Community Effort

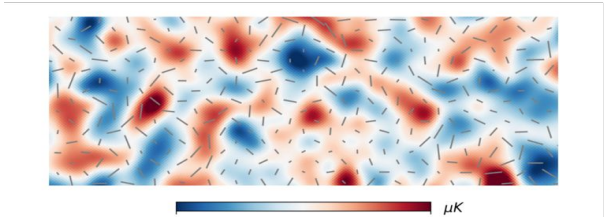
CMB-S4 will be enabled with broad participation of the CMB community, including those in the existing CMB experiments (e.g., ACT, BICEP/Keck, CLASS, POLARBEAR/Simons Array, Simons Observatory & SPT), the National Labs and the Astronomical and Particle Physics communities.

The CMB-S4 Science Collaboration is highly active and engaged with the project

- >350 members
- >110 institutions
- 16 countries
- 22 U.S. States
- 2 major collaboration meetings per year

10th CMB-S4 Workshop, UCSD October 2019
Next in-person meeting will be August 2022!

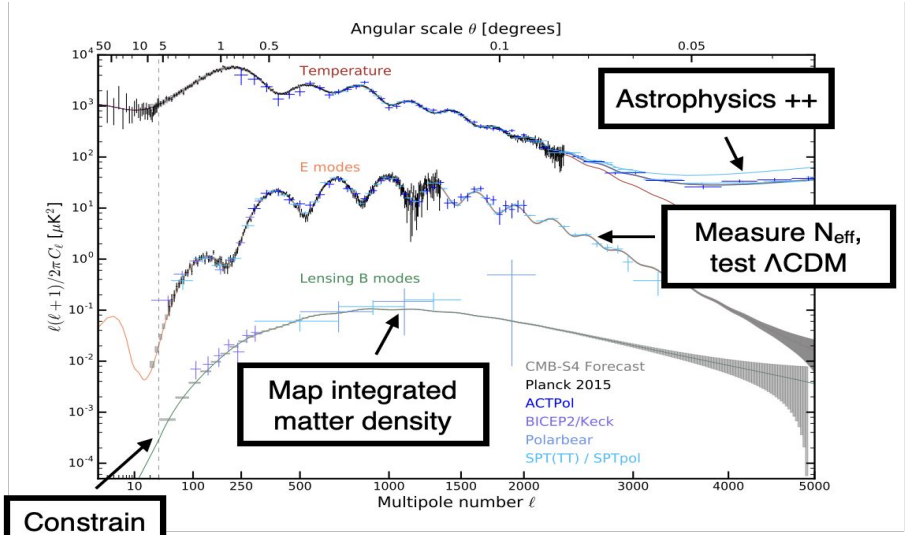
Science Goals

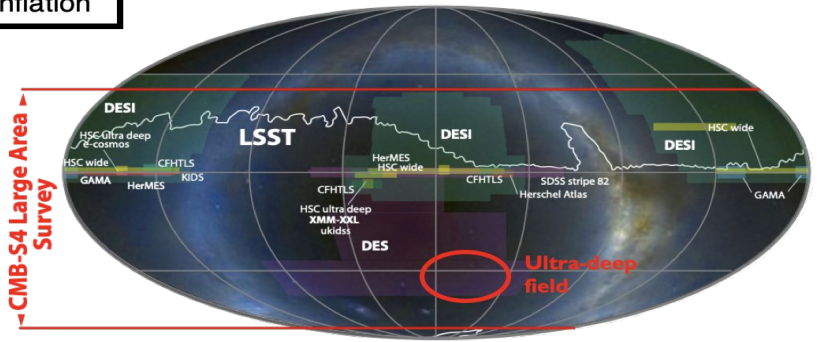


Simulated B-mode polarization in the CMB (cmb-s4.org)

Four Broad Science Themes

1. Primordial Gravitational Waves and Inflation
2. The Dark Universe
3. Mapping Matter in the Cosmos
4. The Time-Variable Millimeter-Wave Sky





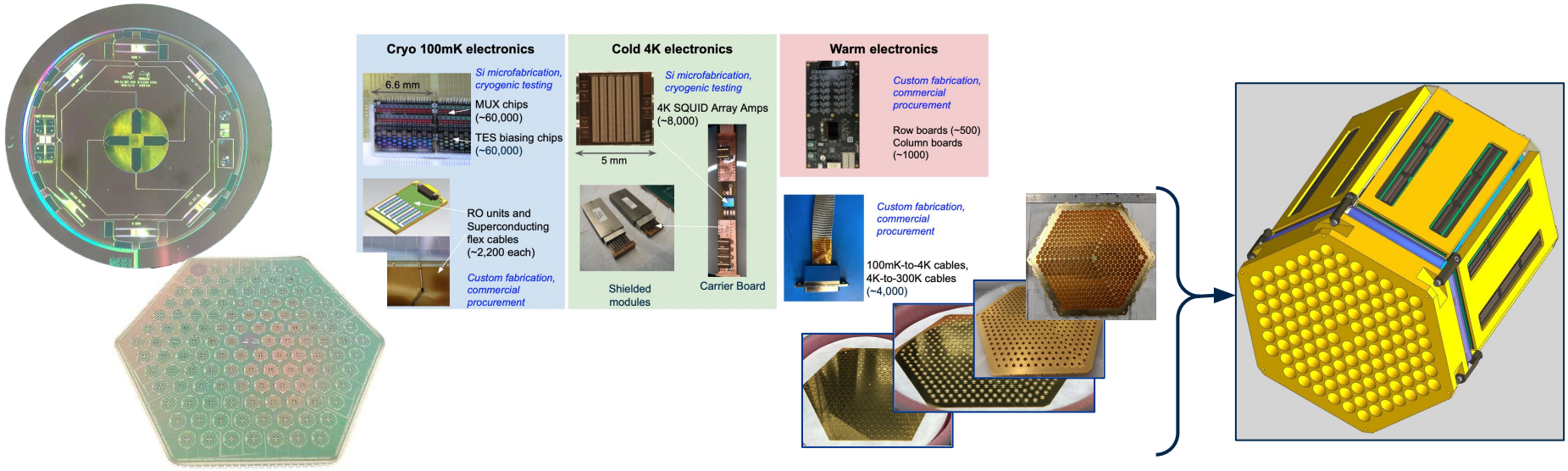
CMB-S4 science book: https://arxiv.org/abs/1610.02743

Observing Sites

CMB-S4 will conduct **ultra-deep measurements focused on small sky area**, and will use **large apertures for high angular resolution over ultra-deep and deep-wide fields.**

Instrument Design

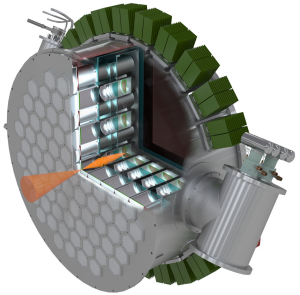
Transition Edge Sensors and Readout



O(500,000) detectors spanning 20 - 300 GHz using multiple telescopes, large and small, at South Pole and Chile, to map deep targeted fields, as well as a large fraction of the sky.

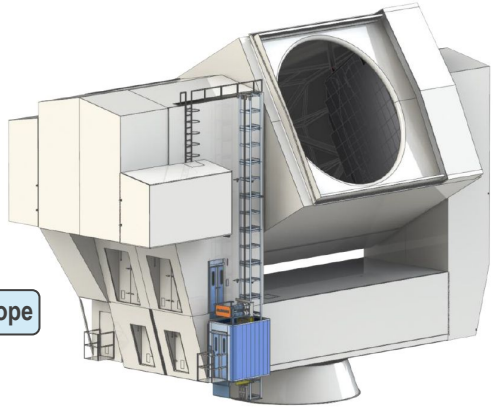
Tenfold increase in sensitivity over Stage 3 experiments, to cross critical science thresholds.

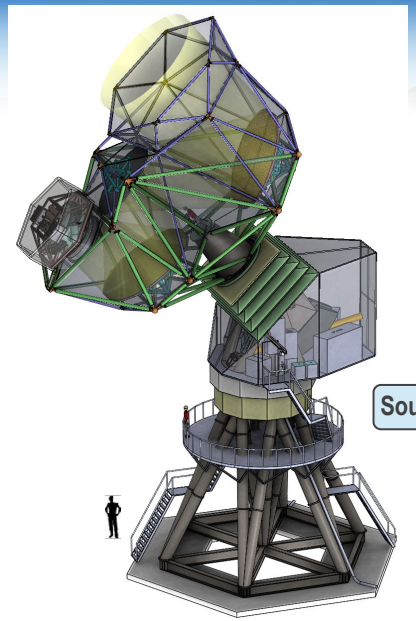
Instrument Design



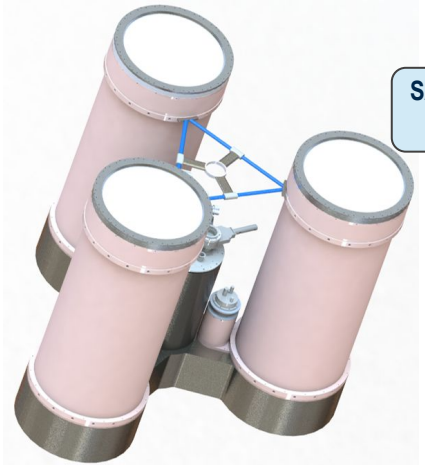
85-Tube LAT Receiver Cryostat

Chile Large Telescope

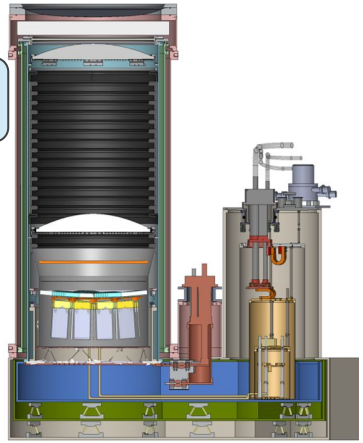


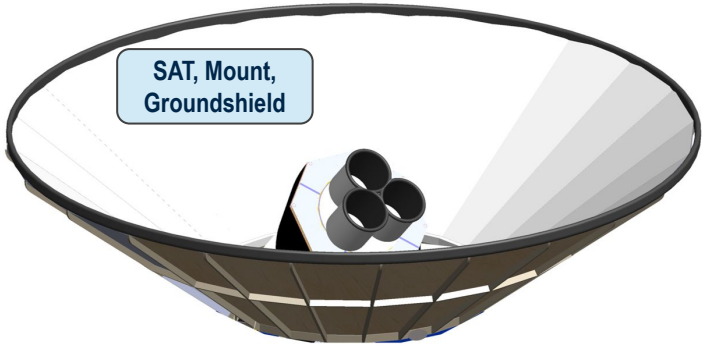


South Pole Large Telescope



SAT Cryostat System, Optics Tubes





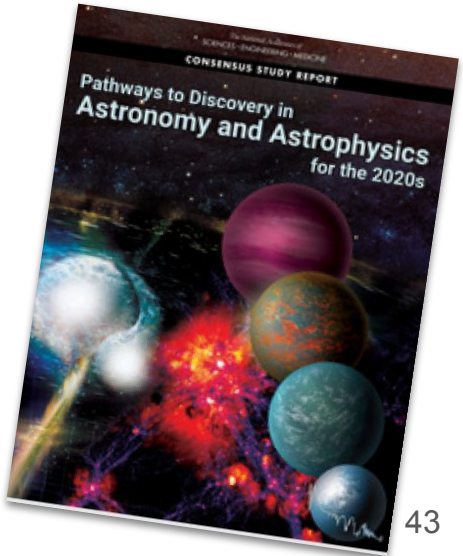
SAT, Mount, Groundshield

Summary

- CMB-S4 will do transformational science and no doubt make new discoveries. It is designed to cross critical thresholds in physics and astrophysics at the frontier of our knowledge, while serving the entire astronomical community.
- No current or planned CMB experiment will cross these critical thresholds, even if they continued for 50 years.
- Builds on NSF's decades of investment and leadership in ground-based CMB experiments.

And is well aligned with decadal survey recommendations:

"An important requirement for our strong endorsement is that the project broadly engage astronomers beyond the traditional CMB community. **CMB-S4 will produce data sets of unprecedented sensitivity, cadence and spectral coverage that will advance general astrophysics** and open discovery space opportunities for diverse scientific communities."

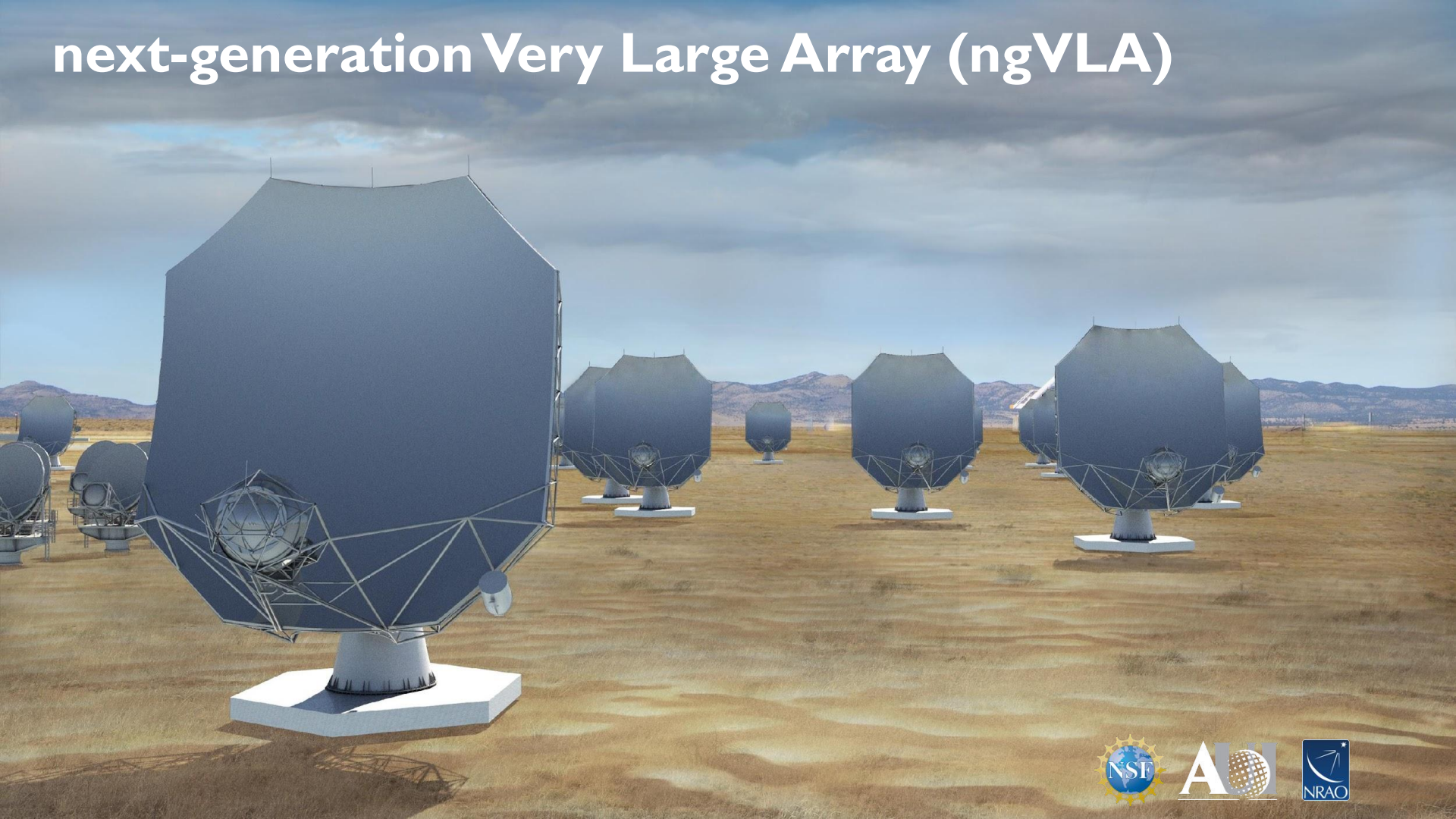


ngVLA

Tony Beasley

Project Director of ngVLA

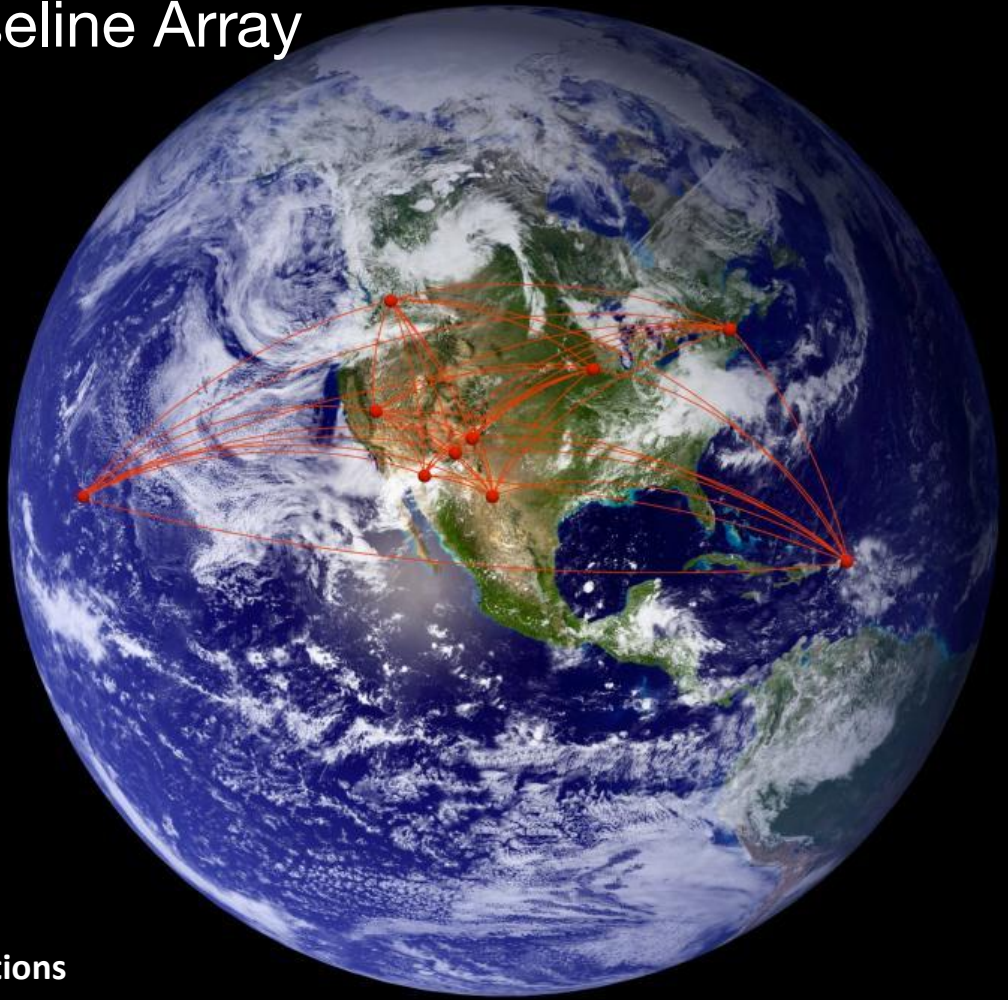
next-generation Very Large Array (ngVLA)



Jansky Very Large Array

1980 – Full science operations

Very Long Baseline Array



1993 – Full science operations

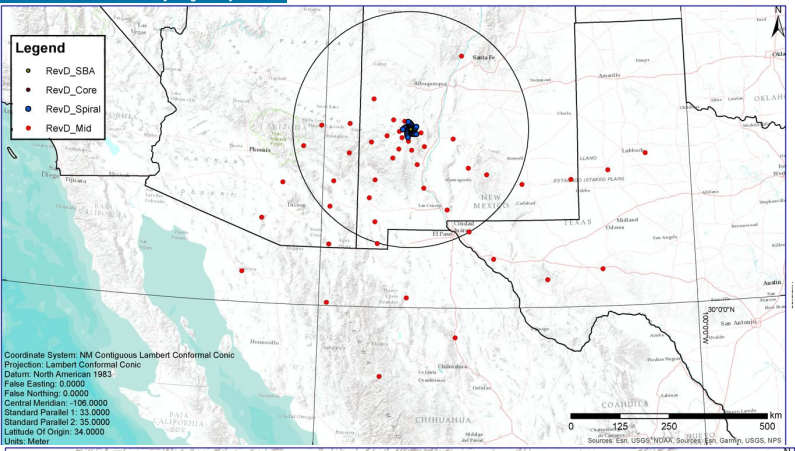
ngVLA – next step in cm astronomy

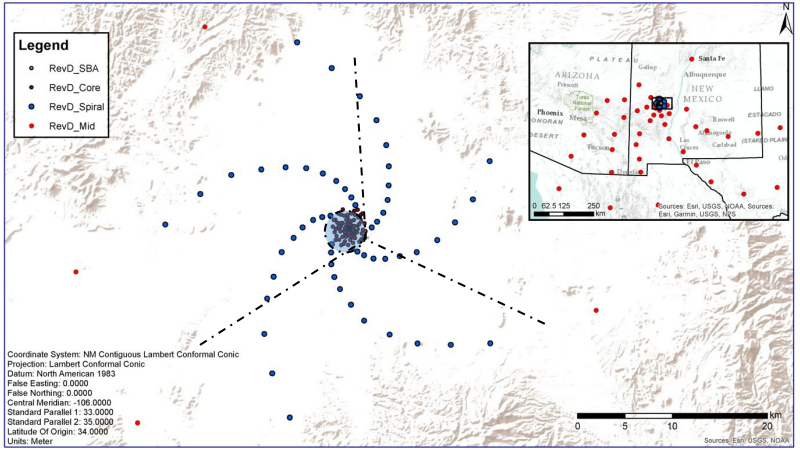
- **1.2 - 116 GHz** Frequency Coverage
- **Main Array**: 214 x 18m offset Gregorian Antennas
  - Fixed antenna locations across NM, TX, AZ, MX
- **Short Baseline Array**: 19 x 6m offset Greg. Antennas
  - Use 4 x 18m in TP mode to fill in (*u, v*) hole.
- **Long Baseline Array**: 30 x 18m antennas located across continent for baselines up to 8860km

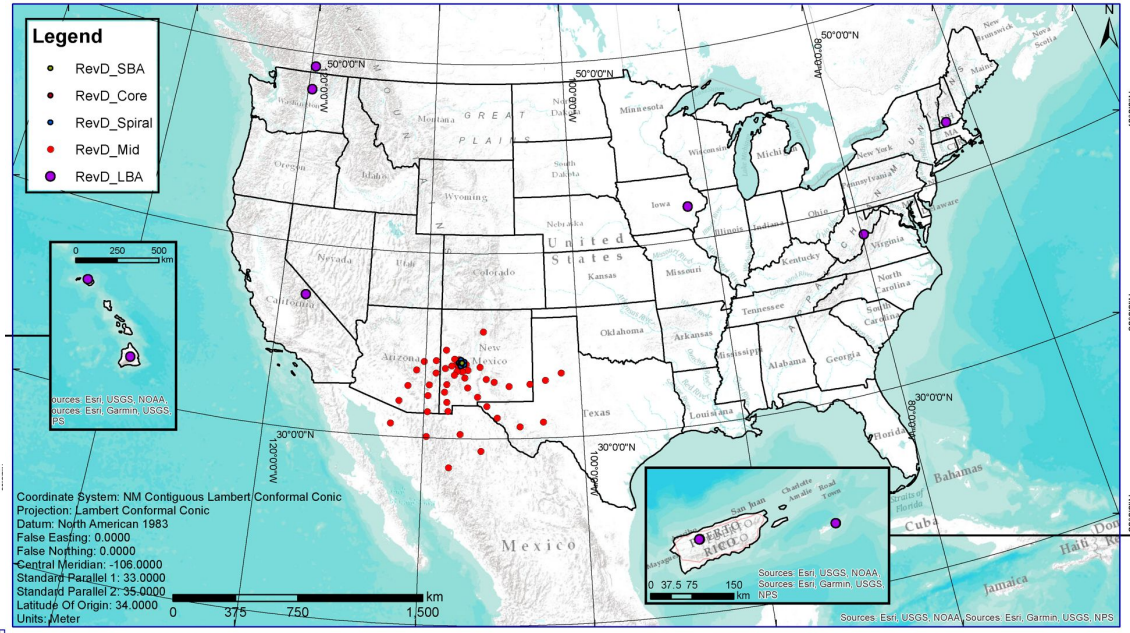
Band #	Dewar	f_L GHz	f_M GHz	f_H GHz	$f_H : f_L$	BW GHz
1	A	1.2	2.35	3.5	2.91	2.3
2	B	3.5	7.90	12.3	3.51	8.8
3	B	12.3	16.4	20.5	1.67	8.2
4	B	20.5	27.3	34.0	1.66	13.5
5	B	30.5	40.5	50.5	1.66	20.0
6	B	70.0	93.0	116	1.66	46.0

Configuration

SBA/Core/Spiral/Mid/Long







Long Baseline Antenna Locations

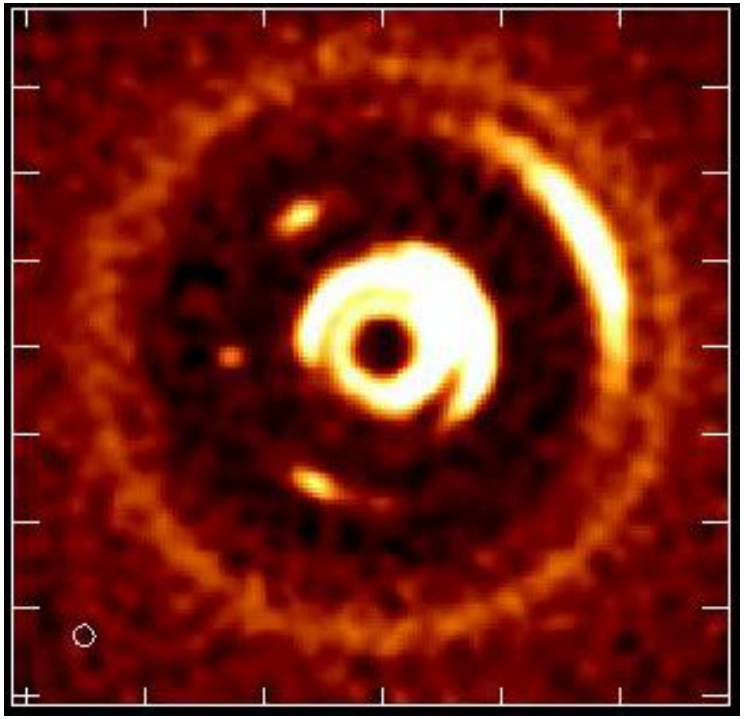
Qty	Location	Notes	Qty	Location	Notes
3	Puerto Rico	Arecibo Site	3	Green Bank, WV	GBO
3	St. Croix	VLBA Site	3	Brewster, WA	VLBA Site
3	Kauai, HI	Kokee Park Obs.	3	Penticton, BC	DRAO
3	Hawaii, HI	Not MK Site	3	North Liberty, IA	VLBA site
3	Hancock, NH	VLBA Site	3	Owens Valley, CA	VLBA site

ngVLA Key Science Goals (ngVLA memo #19/ Science Book)

1. *Unveiling the Formation of Solar System Analogues on Terrestrial Scales*
2. *Probing the Initial Conditions for Planetary Systems and Life - Astrochemistry*
3. *Charting the Assembly, Structure, and Evolution of Galaxies Over Cosmic Time*
4. *Using Pulsars in the Galactic Center as Fundamental Tests of Gravity*
5. *Understanding the Formation and Evolution of Stellar and Supermassive BH's in the Era of Multi-Messenger Astronomy*

KSG1: Unveiling the Formation of Solar System Analogues

The ngVLA will measure the orbital motion of planets and related features on monthly timescales.



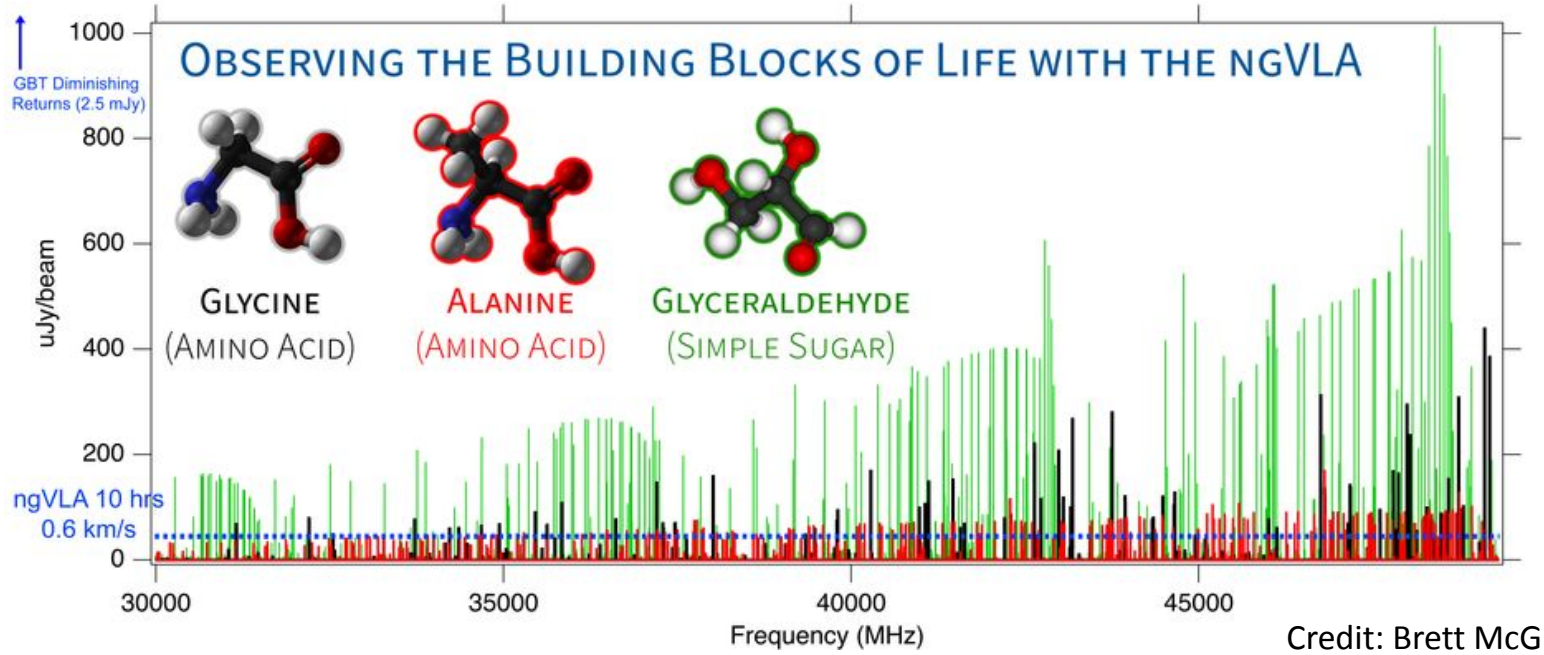
The ngVLA will measure the planet IMF down to ~5-10 Earth masses and unveil the formation of planetary systems similar to our own Solar System.

Simulated 100 GHz ngVLA observations of a newborn planetary system comprising a Jupiter analogue orbiting at 5 AU from a Solar type star.

Ricci et al. (2018)

KSG2: Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

The ngVLA can detect complex pre-biotic molecules and provide the chemical initial conditions in forming solar systems and individual planets

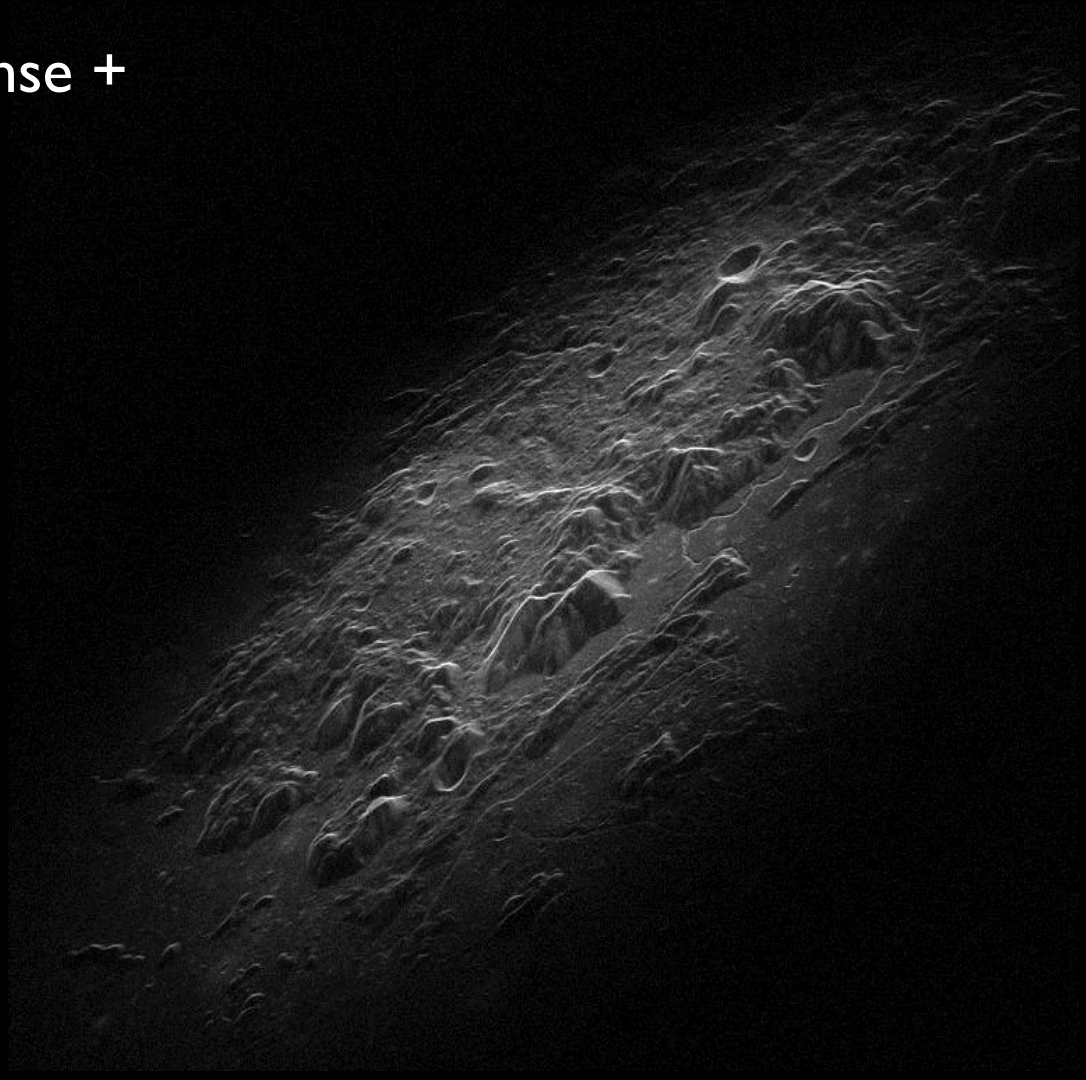


Credit: Brett McGuire (NRAO)

In its first 10 years, the ngVLA will:

- ***Movies of planets***: Map hundreds of PP disks within 500pc on scales as small as 0.1 au with enough sensitivity to constrain the orbital motions of Earth-mass planets (KSG1).
- ***Origins of Life***: Measure the spatial and temporal evolution of the complex organic chemistry in the mid-planes of 100's of PP disks (KSG2).
- ***Origins of Galaxies***: Image the cold molecular gas (fuel for star formation) down to GMC scales in galaxies back to cosmic reionization and the first galaxies, by detecting their fundamental low-*J* CO emission (KSG3).
- ***GR beyond Einstein***: Detect hundreds of millisecond pulsars near the Galactic Center (if they exist) to test GR with unprecedented precision (KSG4).
- ***Precision GW physics/Multi-messenger science***: Detect nearly all EM counterparts from next-generation GW facilities, enabling time-series imaging of astrophysical jets on sub-mas scales (KSG5). Explore BH jet-launching regions at high resolution.

ngVLA - Planetary Defense + Solar System Studies

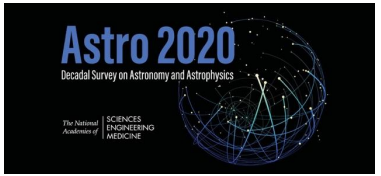


Radar Pilot – 750W
Green Bank Transmit – VLBA Receive
1.25m resolution
6000s integration

NRAO/GBO/Raytheon Technologies, Inc.

ngVLA - Space Domain Awareness

ngVLA Concept Development



2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021

Inaugural ngVLA Technical Workshop

ngVLA Science White Papers Published

1st Radio Futures Kavli Meeting (Chicago)

ngVLA Project Office Established

ngVLA SAC Established

2nd Radio Futures Kavli Meeting

ngVLA TAC Established

Science & Tech Meeting (Socorro)

Reference Design Memo Posted

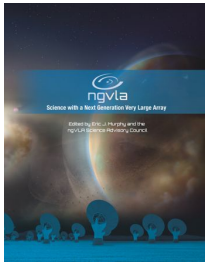
Key Science Goals Memo Posted

ngVLA Development Funding ($11M)

3rd Kavli Meeting (Berkeley)

2nd Science Meeting (Portland)

ngVLA Science Book Published



3rd ngVLA Science Meeting (Cville)

APC White Paper Submitted to Astro2020

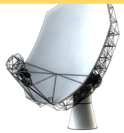
Reference Design published

ngVLA CSA Created

Presentation to Astro2020 RMS Panel

ngVLA Summer Talk Series

4th ngVLA Science Meeting (virtual)



ngVLA Endorsed by Canadian LRP

ngVLA- Japan Website Launched

NRAO Contracts mtex for Antenna Dev.

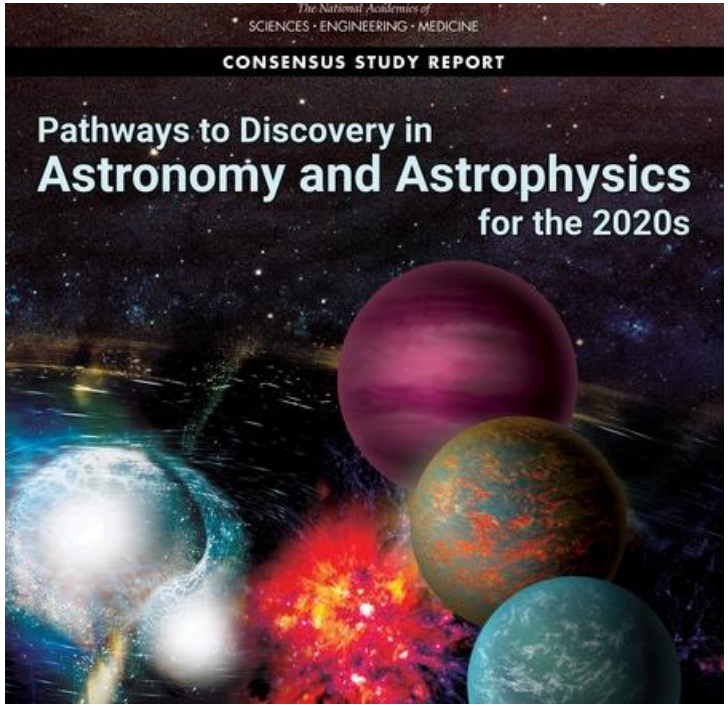
NSF awards prototype funding ($23M)

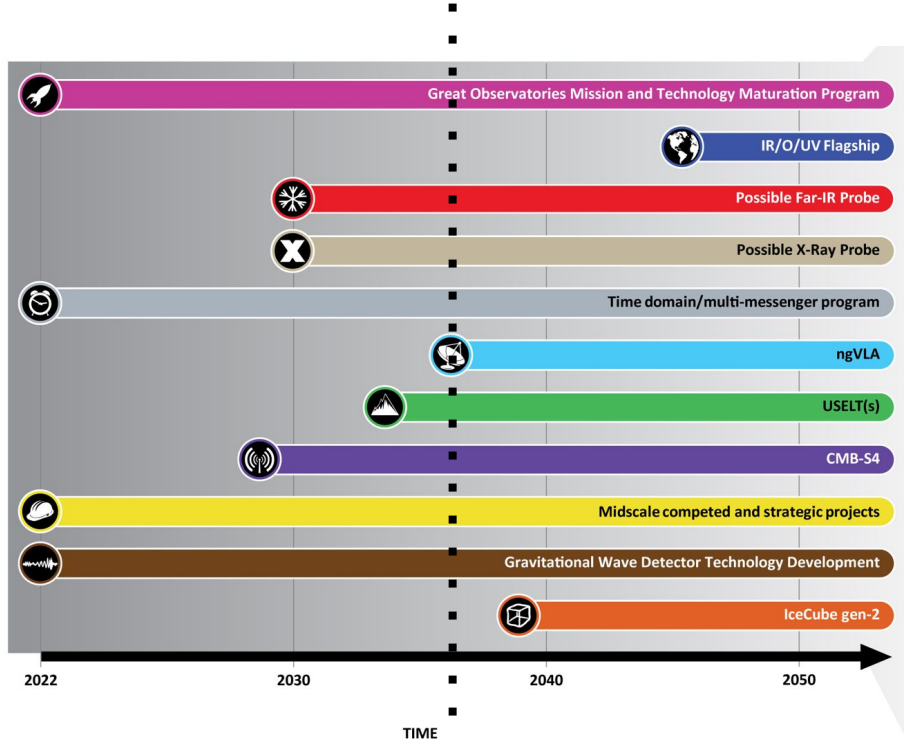
Astro2020 Report Published – **ngVLA Strongly Endorsed**

ngVLA Academic/International/Industrial Participation

NSF AUI NRAO

Astro2020 identified the ngVLA as a high-priority large, ground-based facility whose construction should start this decade.

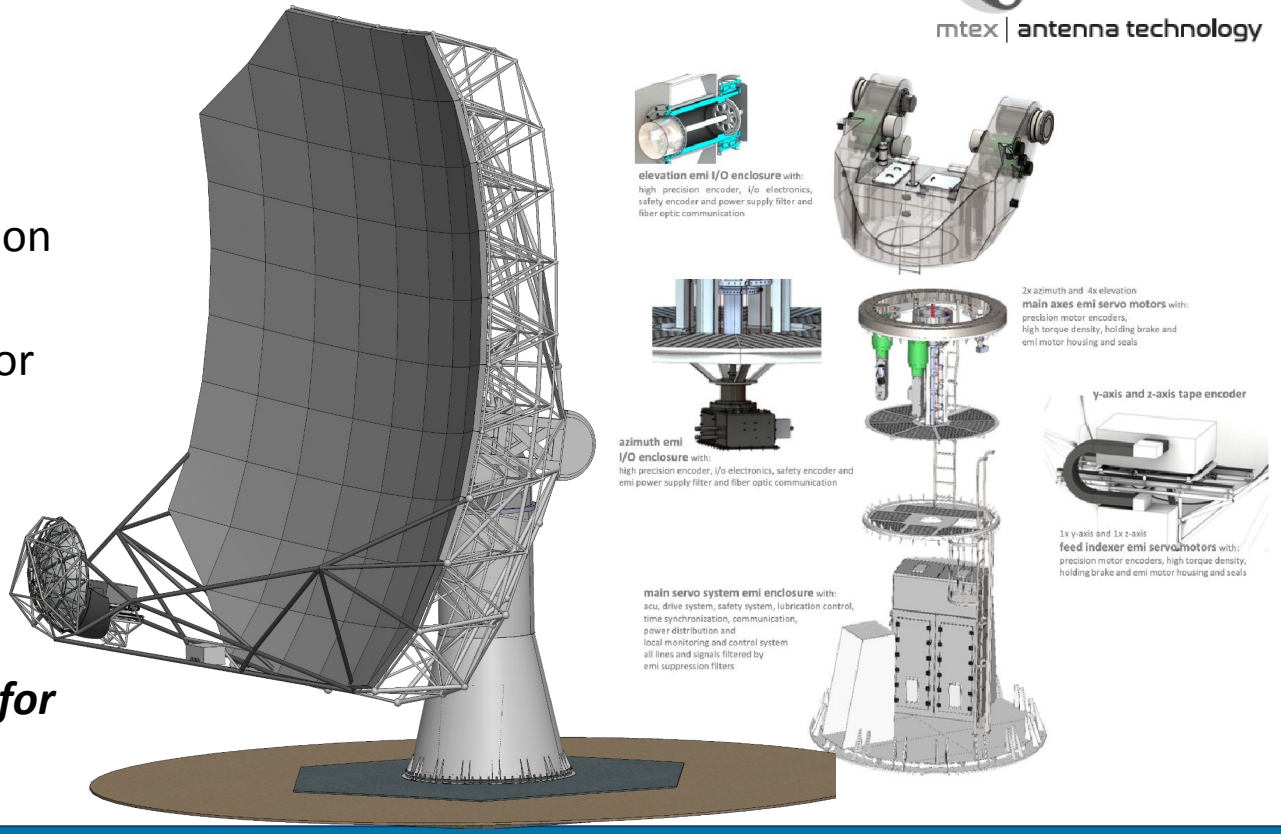




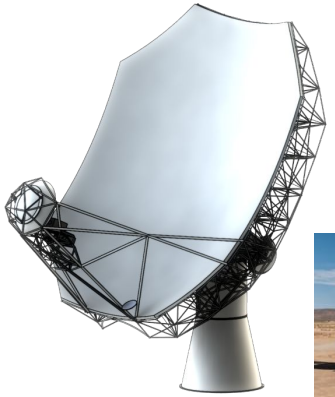
mtex ngVLA 18m Antenna

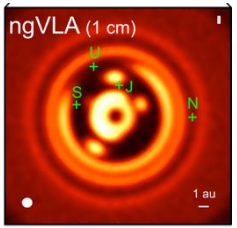
- Design – PDR in December
- Prototype antenna construction - 2023
- Less than 160 µm surface error
- Absolute Pointing: 18” rms
- Referenced Pointing: 3” rms

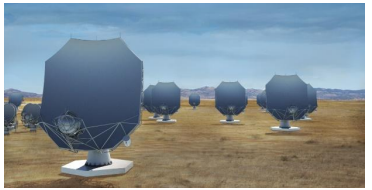
Key enabling technology for ngVLA and a flexible platform for other future arrays.

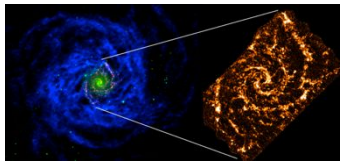


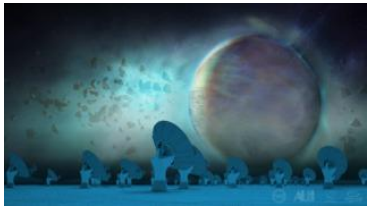
Project Timeline











2019 — ngVLA Submission to Astro2020

2021 — Astro2020 Recommendation Published

2023 — Prototype Delivered to VLA Site; Enter MREFC

2026 — Complete NSF/MREFC FDR; **ngVLA Construction**

2029 — Initiate ngVLA Early Science (> VLA capabilities)

2035 — Full Science Operations

Why build National Observatories?

ngvla
Next Generation Very Large Array

National Science

48 states
3750+ proposers

NRAO – 10 years

Science Impacts: NSF Facilities are key tools in democratizing science in US

ngvla
Next Generation Very Large Array

International Science

64 countries
4800+ proposers

NRAO – 10 years

“Open Skies” approach drives international science collaborations

Summary

- ngVLA is designed to tap into the astronomy community's intellectual curiosity, enable a broad range of scientific discovery and new capabilities, and broaden participation and diversity in the scientific endeavor.
- Project technical Conceptual Design Review – July 2022. Antenna prototype – 2023/2024. **Goal: construction ready 2025/2026.**
- Project technical definition/cost – minimal changes since ASTRO2020.
- Major Challenges: Funding. No major technical blockers are seen. Challenges in cost-performance optimizations, manufacturability and reliability are being addressed. Permitting efforts underway.


ngvla
Next Generation Very Large Array

Cosmic Explorer

Matthew Evans

Associate Professor of Physics at MIT
and Principal Investigator of Cosmic Explorer


COSMIC
EXPLORER
COSMIC
EXPLORER
NSF

What is Cosmic Explorer?

- LIGO has been very successful, but the next big step in gravitational-wave science will require new facilities
- Cosmic Explorer is a larger, and more technically advanced version of the current LIGO observatories
  - Two observatories: one 40km (25 miles) and the other 20km on a side

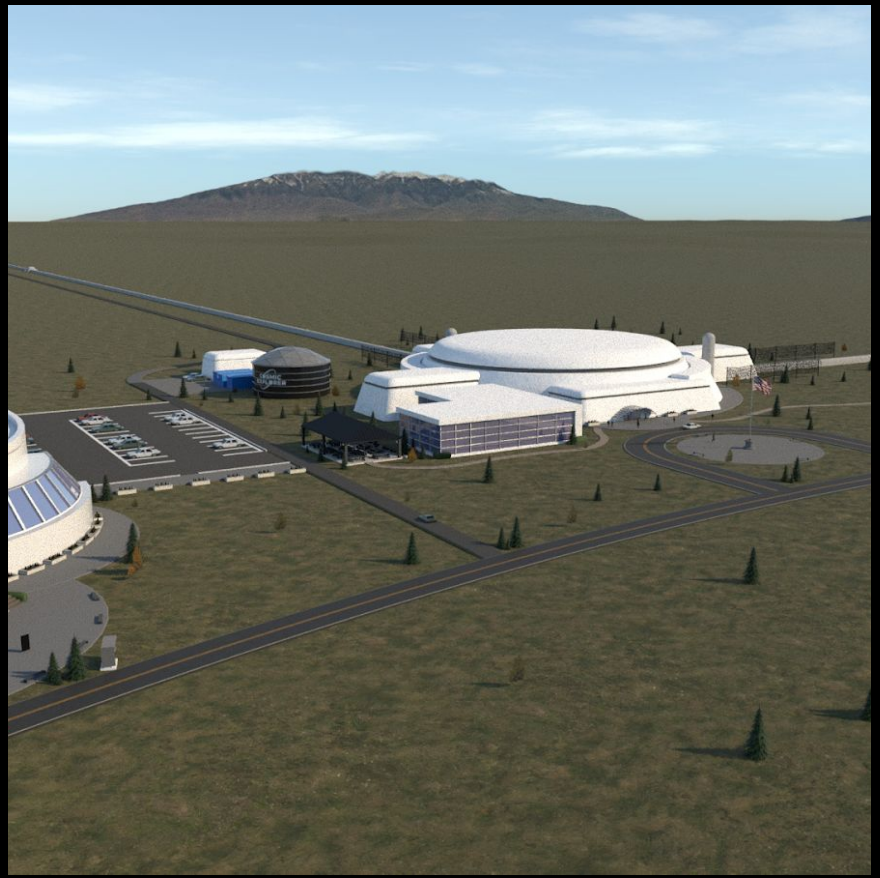
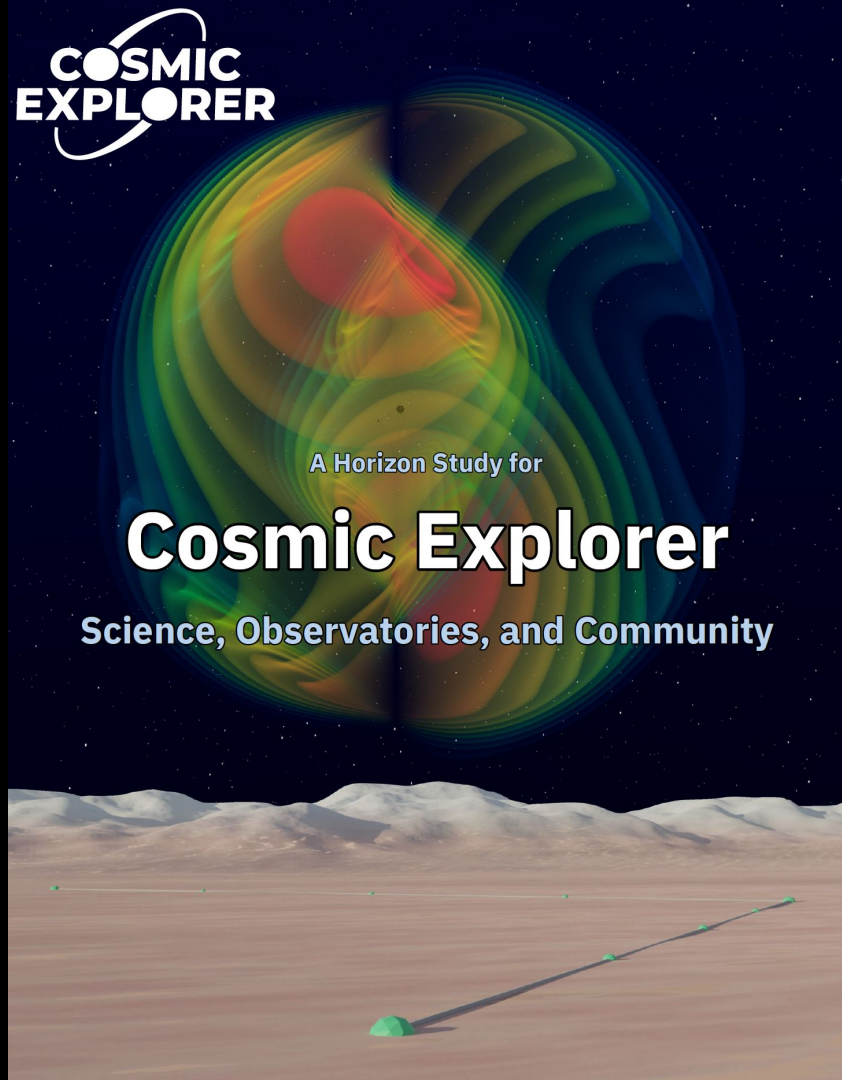


Image: Eddie Anaya (Cal State Fullerton)

Where can I get more information?

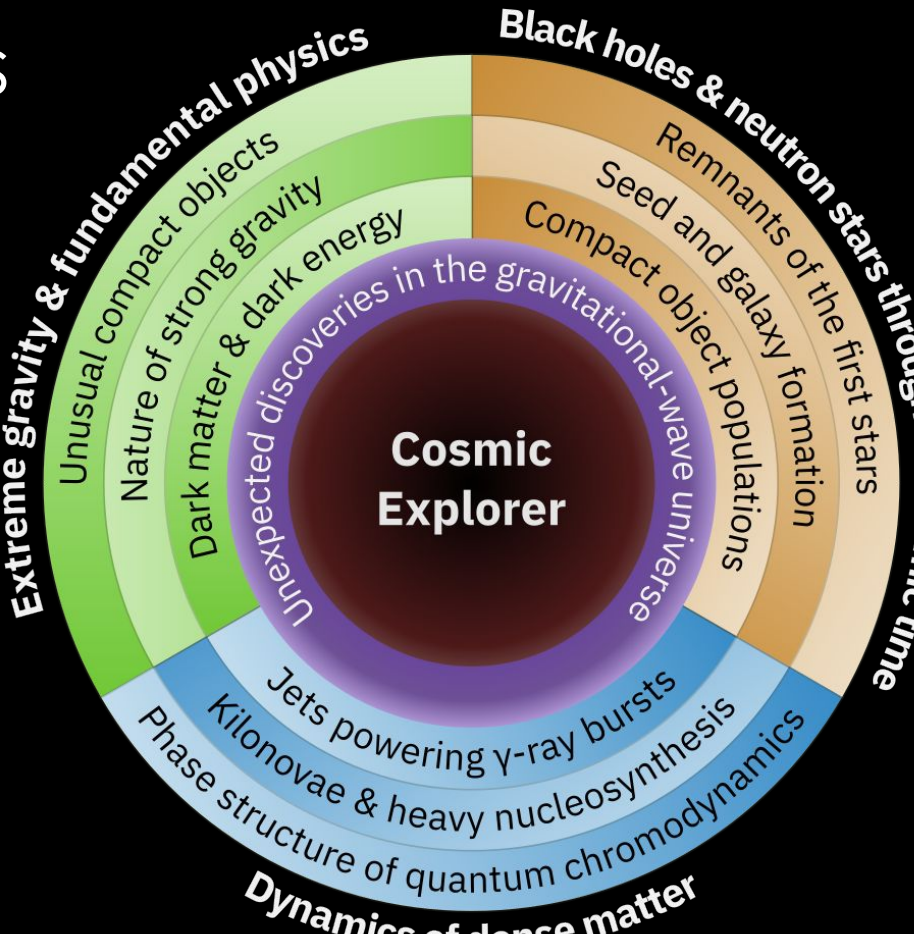
- The Cosmic Explorer Horizon Study contains information about CE science targets, technical design, and social awareness.
- More information can also be found on the Cosmic Explorer website, and all are welcome to join the CE Consortium.

cosmicexplorer.org



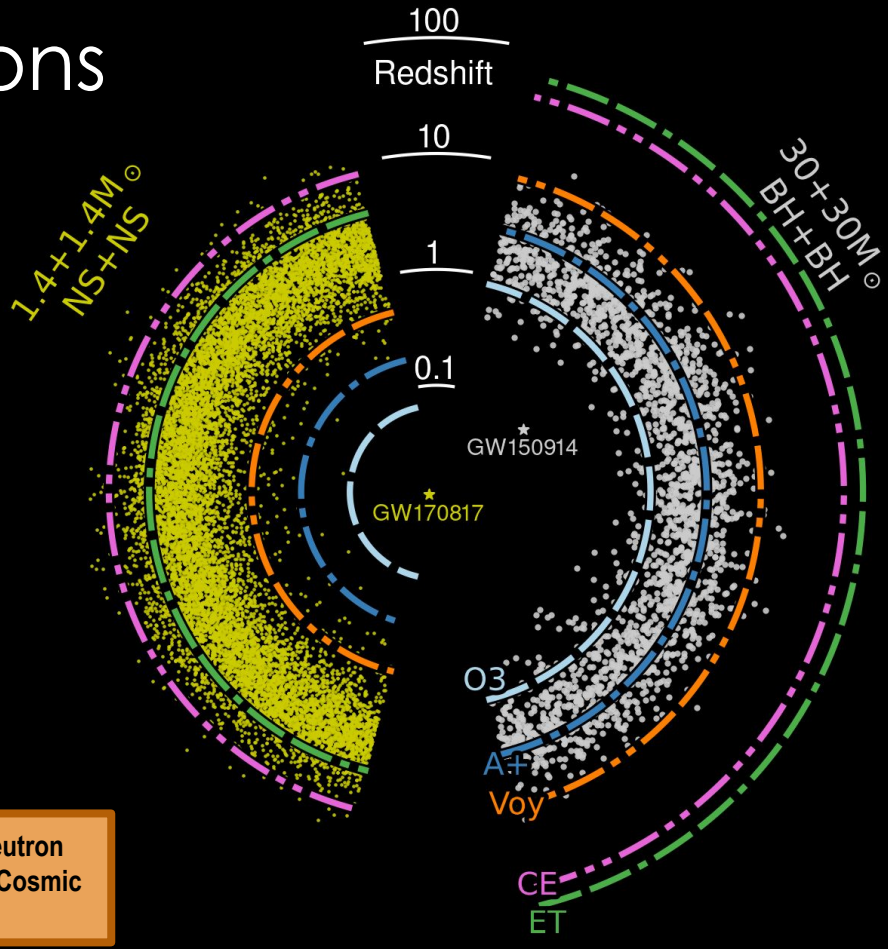
Science Targets

- The Cosmic Explorer science targets/goals are separated into 3 broad categories, shown in the "science wheel" at right.



Source Populations

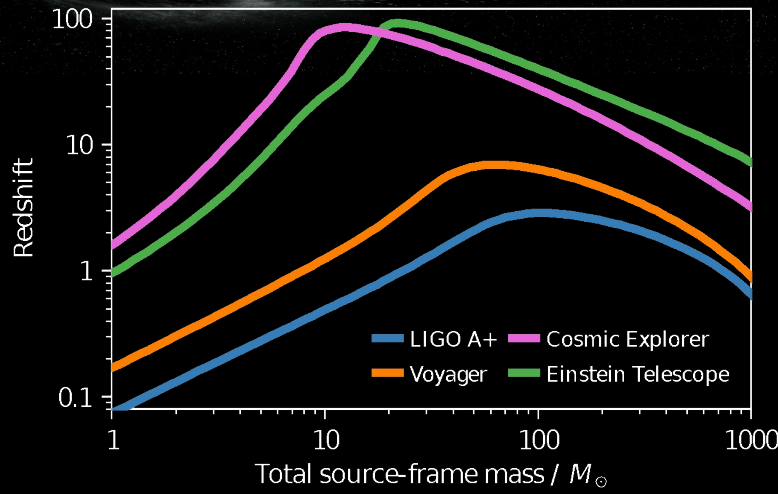
- The best understood source of gravitational wave emissions for Cosmic Explorer are compact binary systems.
- CE will be able to detect individual stellar-mass systems out to high red-shift.



Black Holes & Neutron Stars Throughout Cosmic Time

Fundamental Physics

- Precision tests will be enabled by black hole mergers like those seen now (~30 solar mass, at z ~ 0.3), which will have an SNR ~ 1000 in CE.
- With thousands of BBH events per day, we will be able to cherry pick the most telling events (high spins, large kicks, edge-on, high ellipticity, etc.).

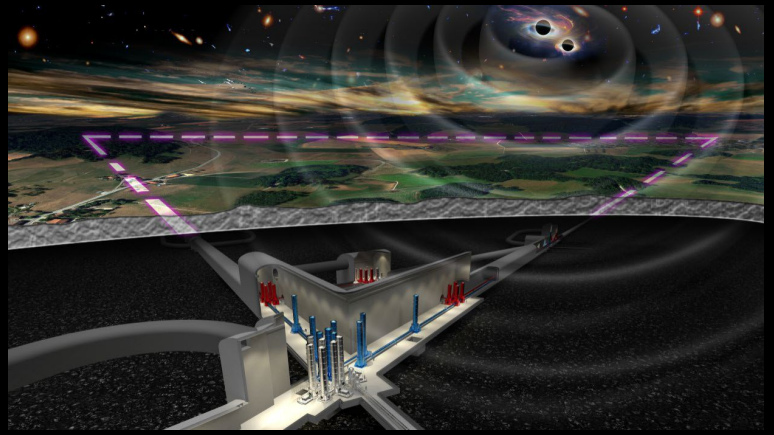


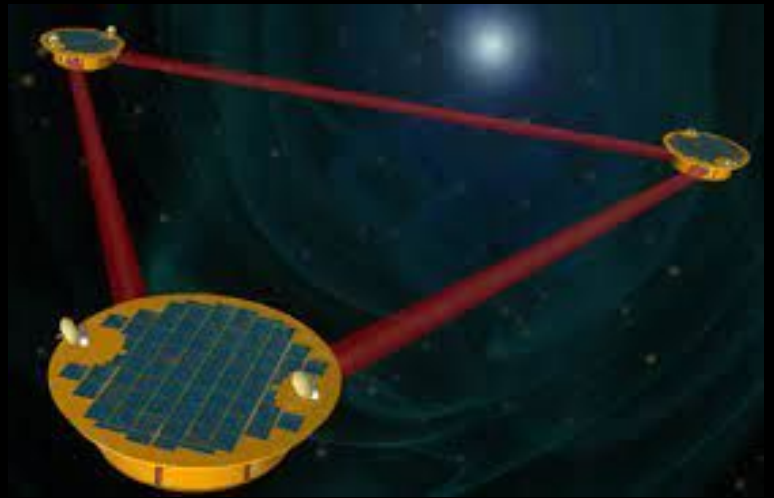
COSMIC EXPLORER

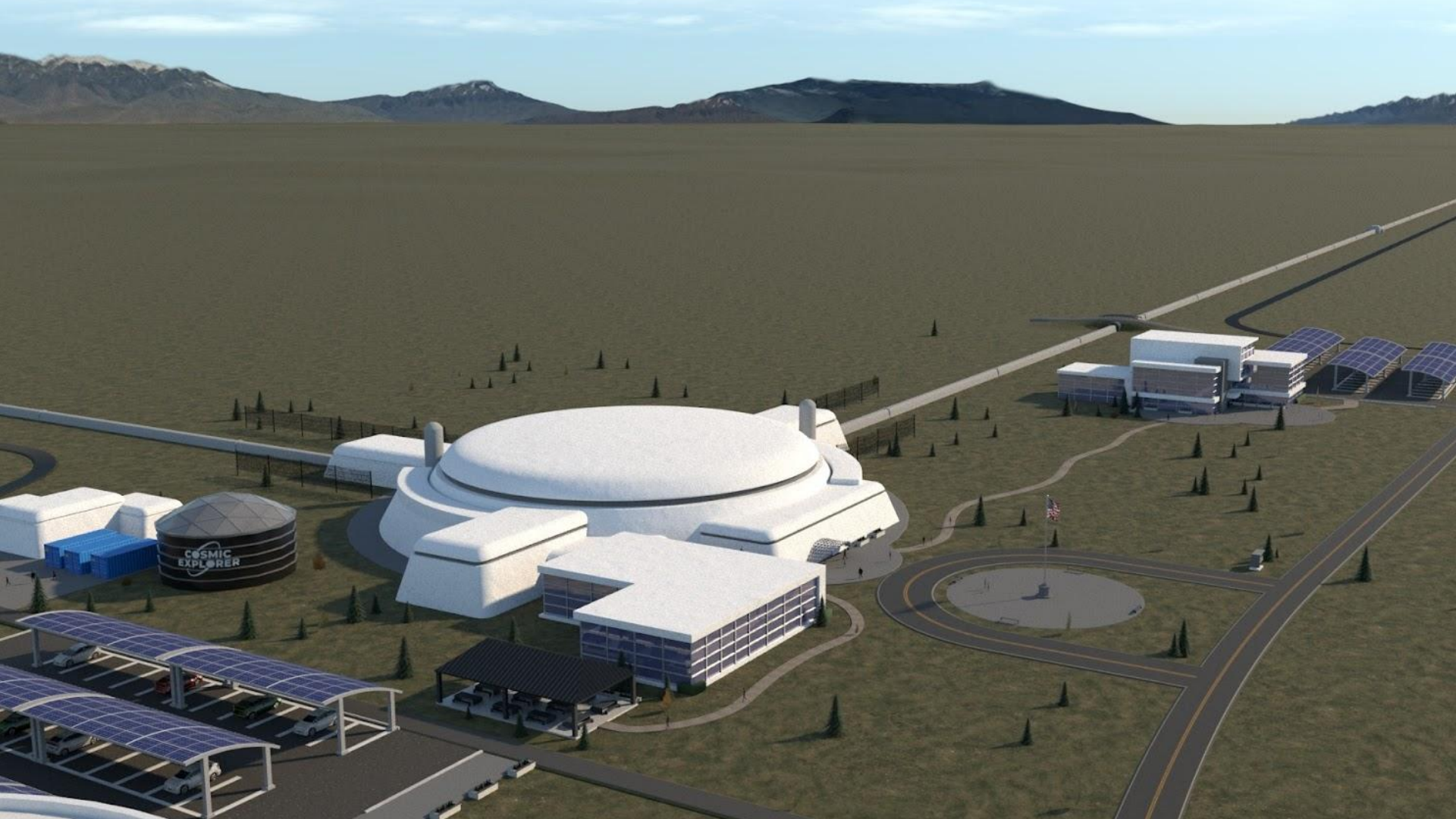
Extreme Gravity & Fundamental Physics

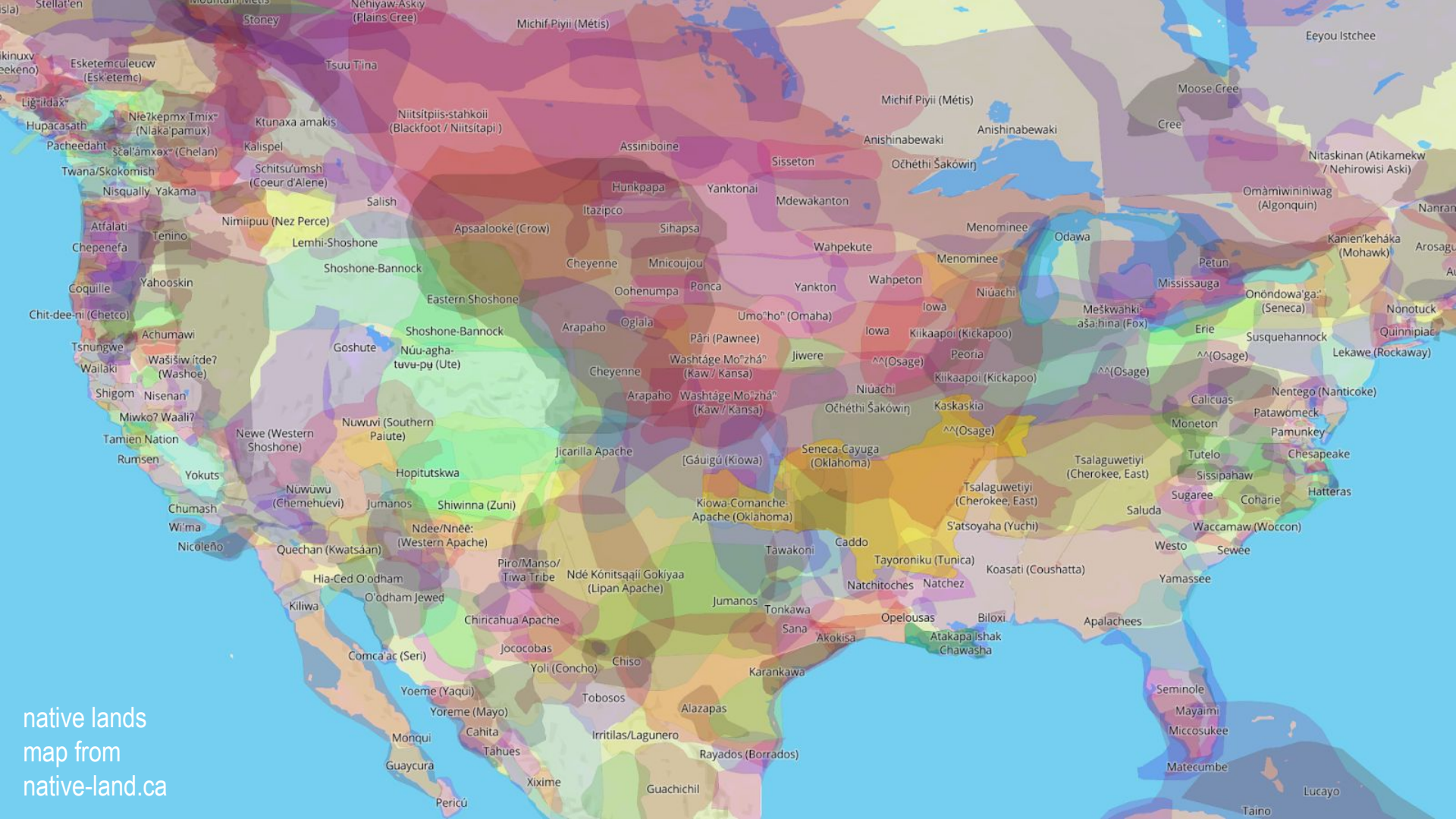
The Next-Gen GW Network

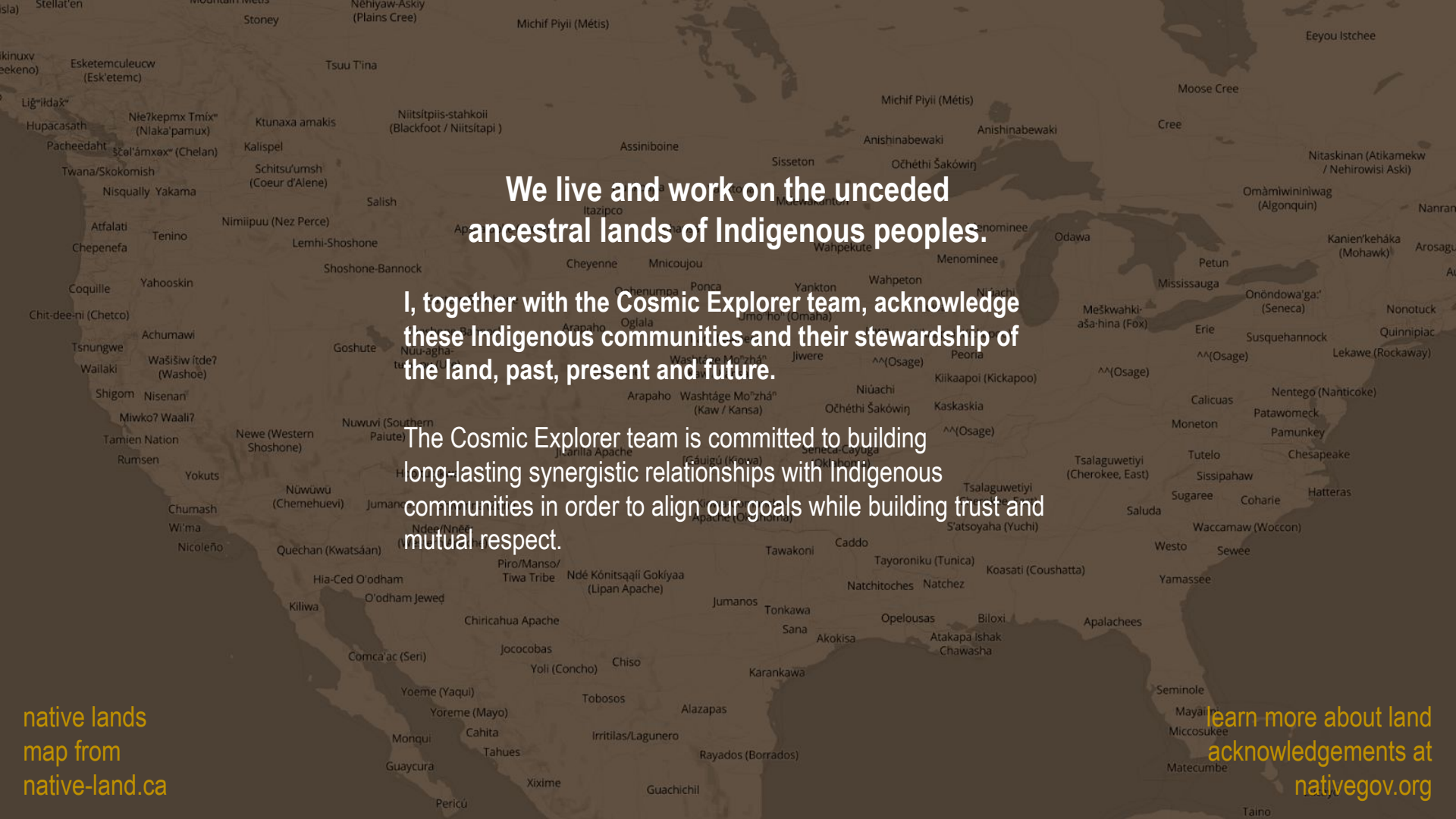
- Einstein Telescope (ET) is a similar project underway in Europe
  - We are planning to operate together
  - Different design (underground triangle, 6 interferometers, 3 of them cryogenic)
- Laser Interferometer Space Antenna (LISA)
  - An ESA-led space observatory with a NASA contribution
  - Expected to be launched in 2034 and take data concurrently with CE and ET

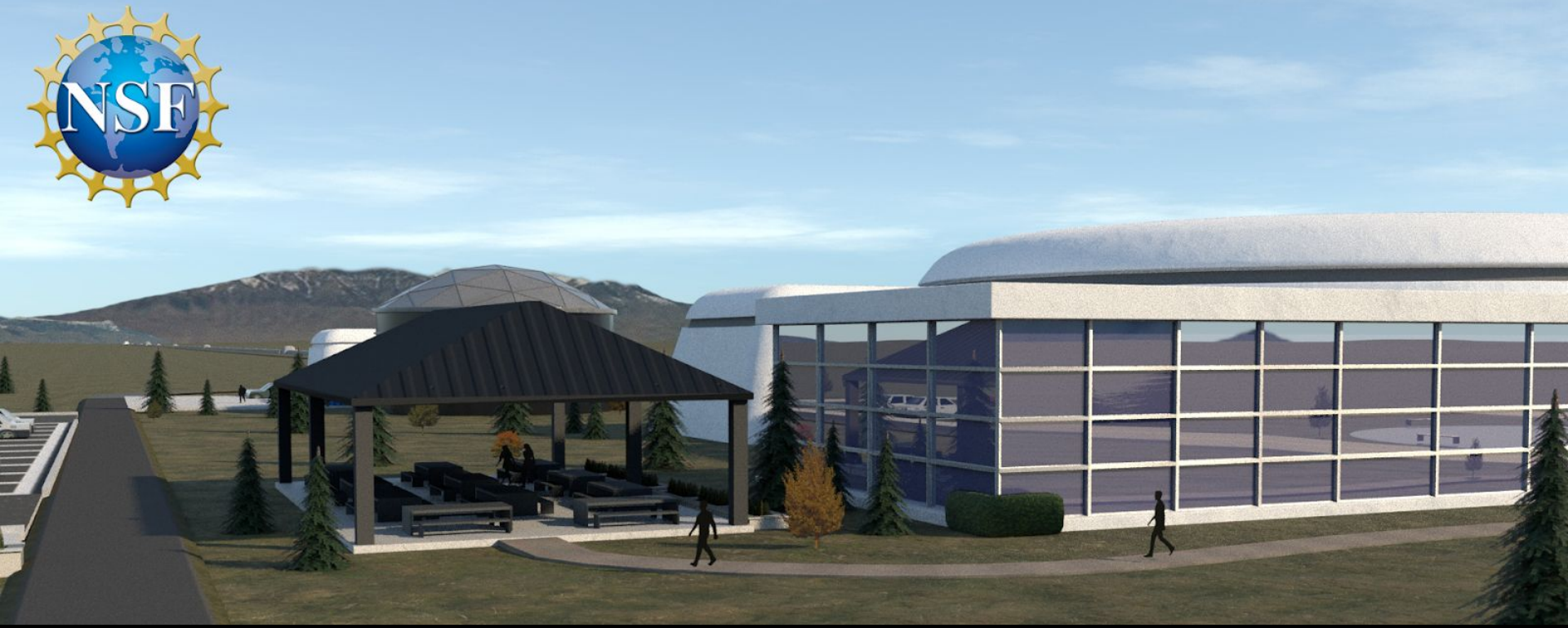





COSMIC
EXPLORER


native lands
map from
native-land.ca


We live and work on the unceded ancestral lands of Indigenous peoples.
I, together with the Cosmic Explorer team, acknowledge these Indigenous communities and their stewardship of the land, past, present and future.
The Cosmic Explorer team is committed to building long-lasting synergistic relationships with Indigenous communities in order to align our goals while building trust and mutual respect.
native lands map from native-land.ca
learn more about land acknowledgements at nativegov.org



COSMIC EXPLORER

- Cosmic Explorer is the US concept for a next-generation gravitational-wave detector
- There is a lot of great science to do!
- And some complicated issues to address…

A BOLD FUTURE FOR ASTROPHYSICS

Q & A

MODERATED BY BOB KIRSHNER

EXECUTIVE DIRECTOR OF TMT INTERNATIONAL OBSERVATORY