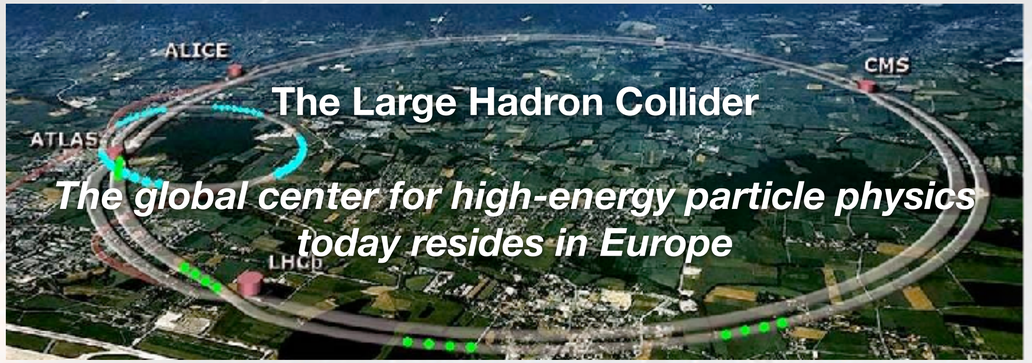
The scientific landscape has changed since NSF's inception in 1950



ALMA required a partnership of North America, Europe and Japan to raise $1.4B

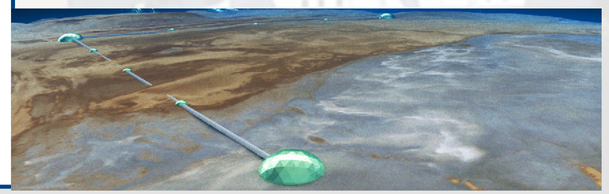
DKIST $0.4B

Rubin Observatory $0.8B

To remain globally competitive in 2030 - 2040, the expected scale of NSF investment in the next generation of large astrophysics facilities

USELT Program	$2B to $3 billion
ngVLA	>$2.5 billion
Cosmic Explorer	>$2 billion

$2B - $3B per project



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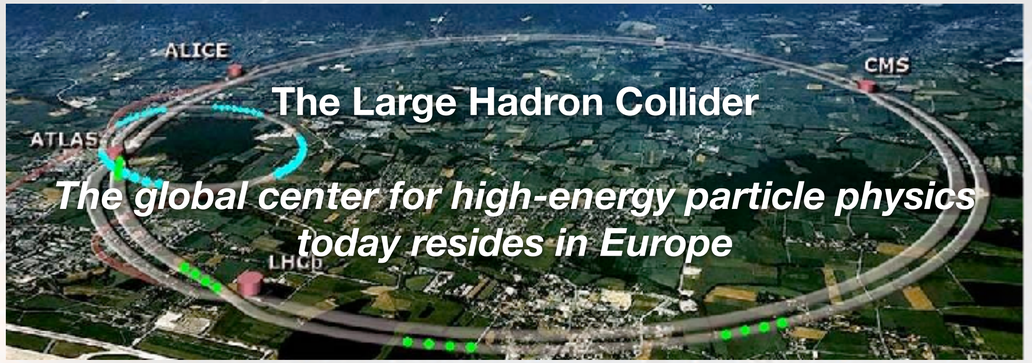

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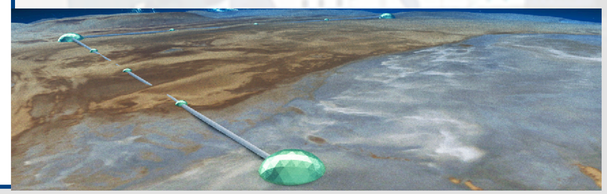
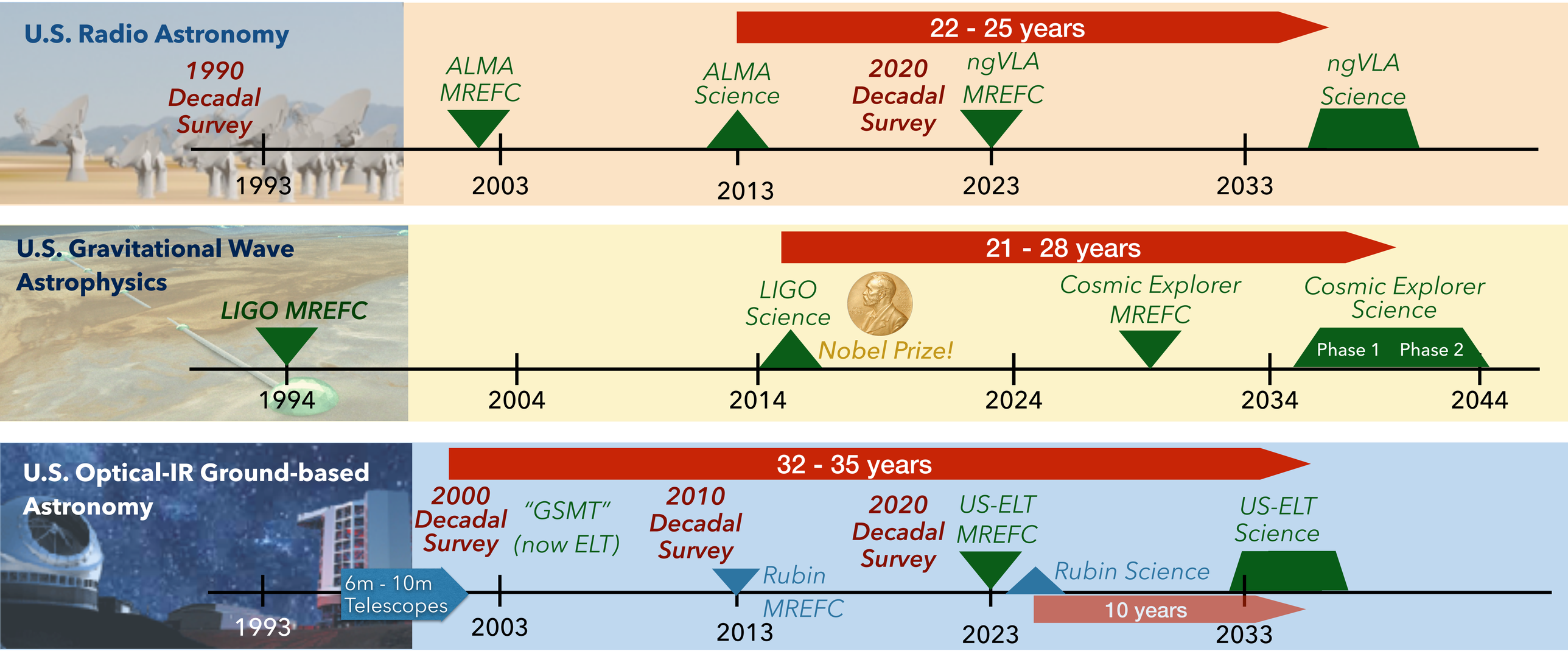


The NSF is now the indispensable Agency required to maintain U.S. ground-based astrophysics at globally competitive levels

"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"

– The National Science Board's Vision 2030



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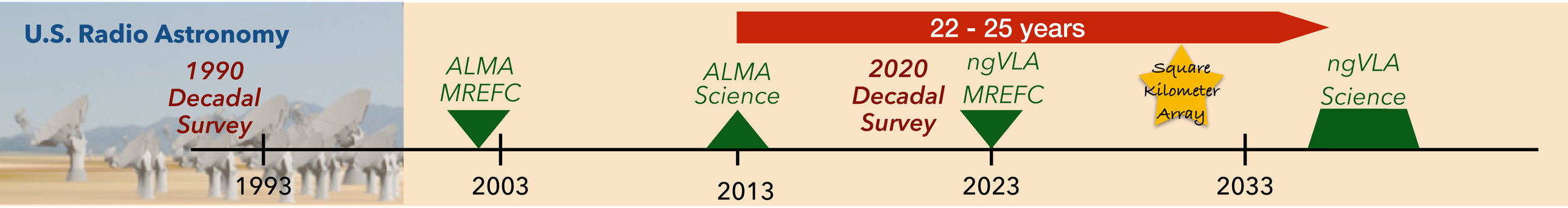
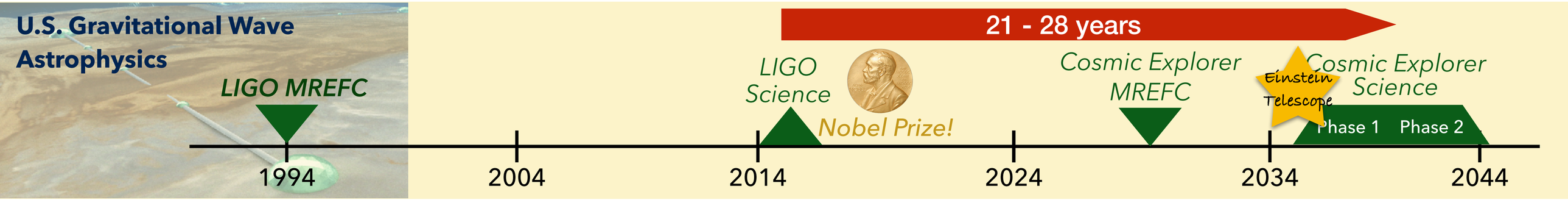
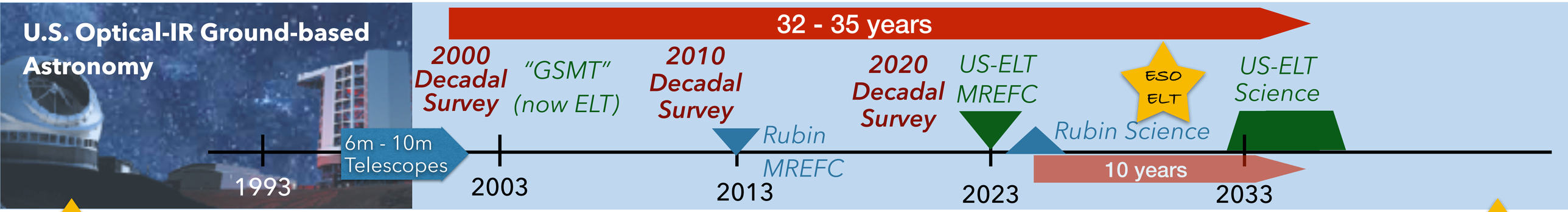






Competing capabilities

NSF's MREFC process is now potentially lagging global investments in areas of basic discovery science previously led by the US

Competing capabilities

Lessons learned from the National Science Foundations MREFC projects and how these would apply to US-ELT

Matt Mountain
with help from: Mark Warner, Victor Krabbendam, Bob Kirshner, Robert Shelton, Pat McCarthy
Jean Toal Eisen, Phil Puxley

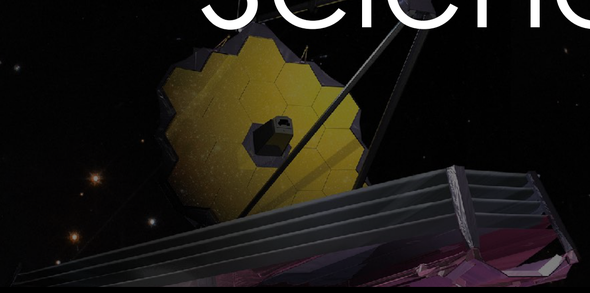
Setting the stage: the NSF, US-ELT Program and why it's challenging

What lessons has AURA learned building telescopes with NSF's Major Research Equipment and Facilities Construction (MREFC) account

Hurdles to overcome to enable multi-billion dollar facilities within NSF's culture

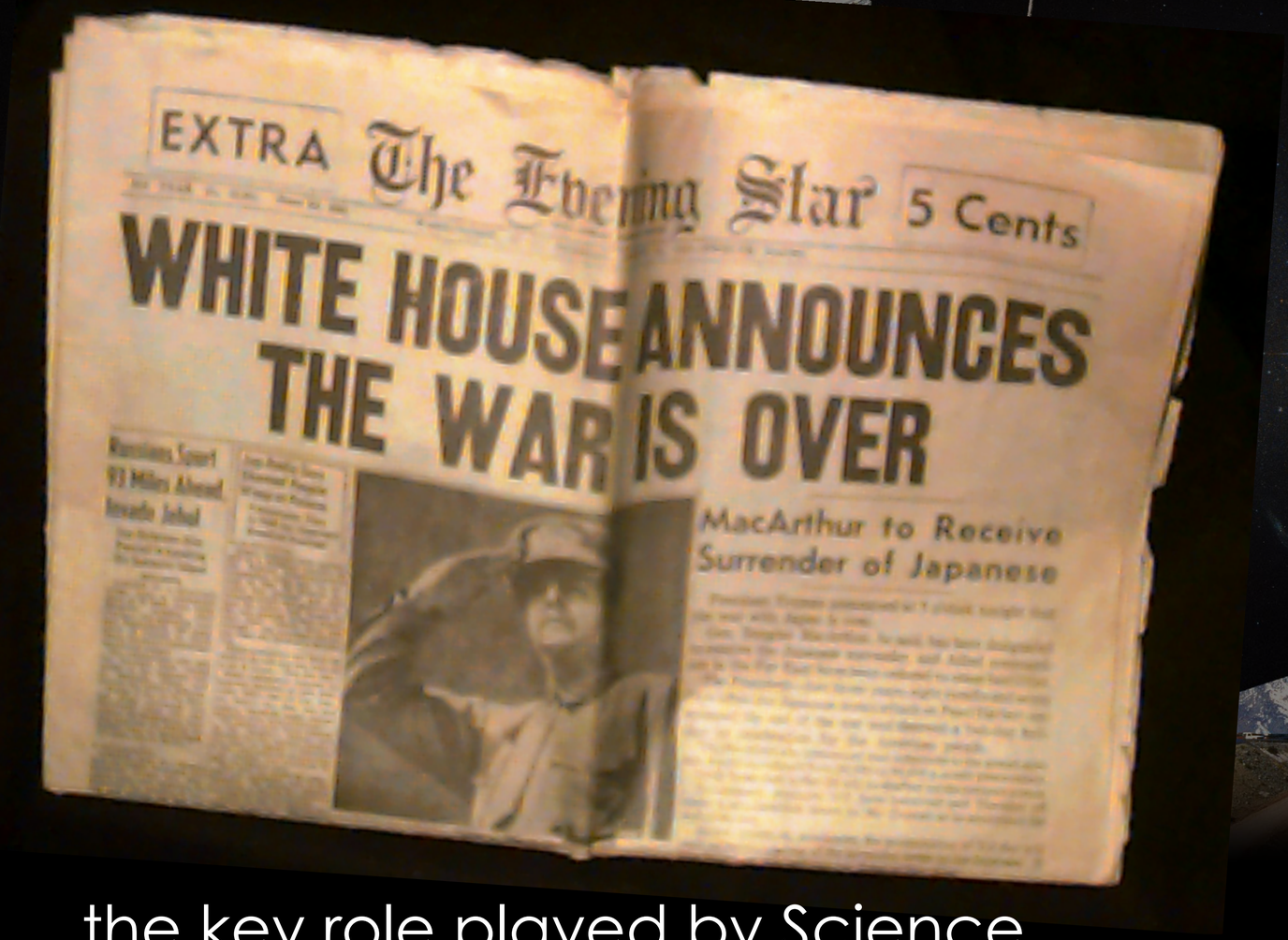
Concluding thoughts

Science: The Endless Frontier



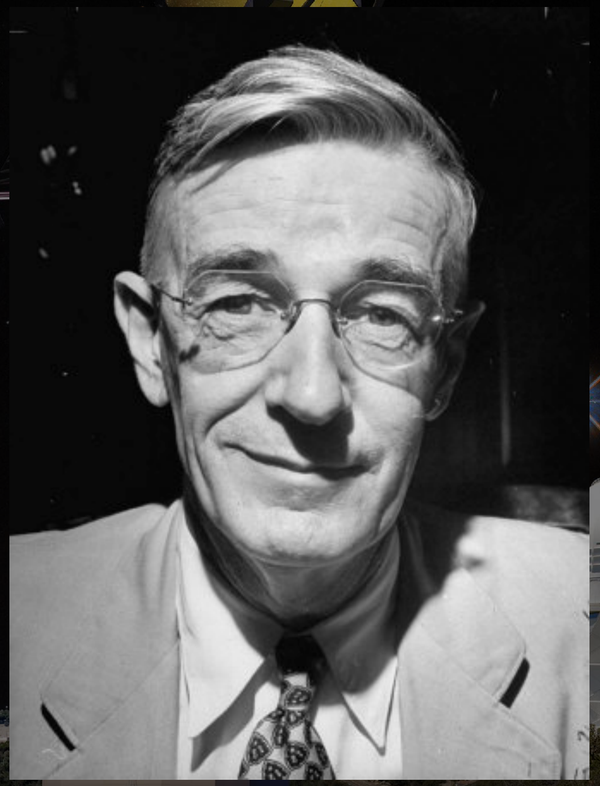
With the coming of peace, the challenge facing politicians and researchers alike was how to ensure that **science and engineering** would continue both to **expand the frontiers of knowledge** and **serve the American people**.

(http://www.nsf.gov/about/history/)



the key role played by Science

Science: The Endless Frontier

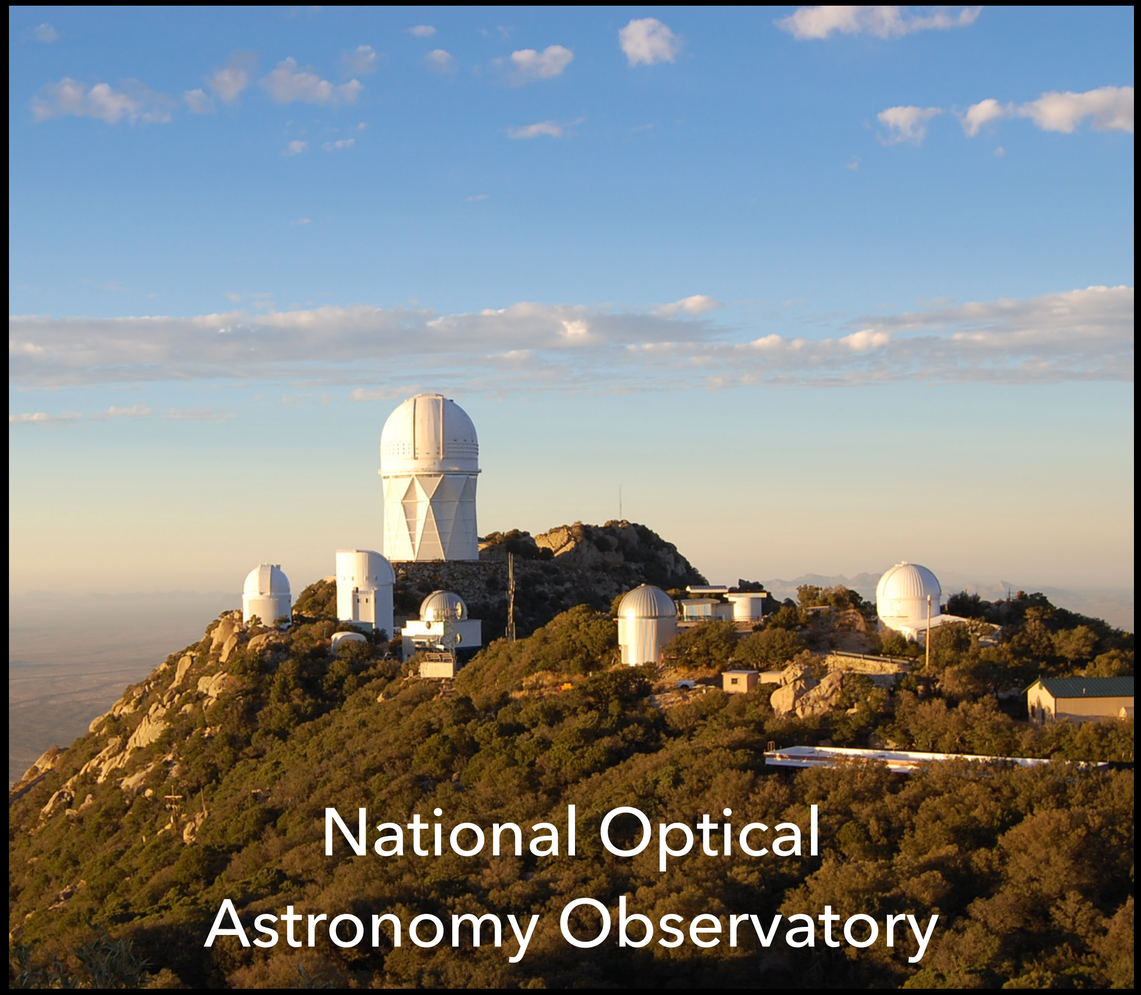


A Report to the President by
Vannevar Bush,
Director of the Office of Scientific
Research and Development,
July 1945

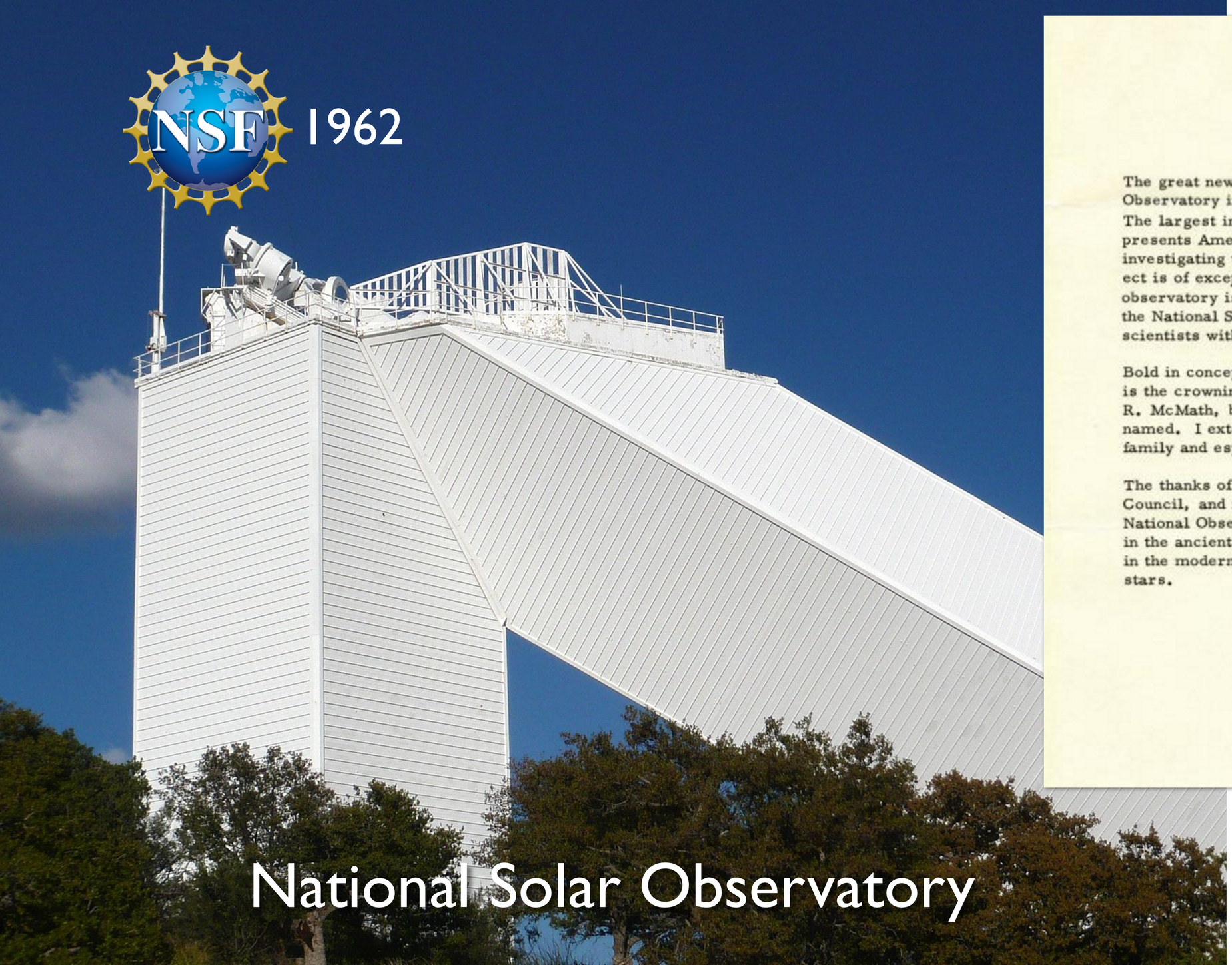
1950 The National Science Foundation

1956 -1957 the creation of the National Observatories

National Radio
Astronomy Observatory



National Optical
Astronomy Observatory



NSF 1962

National Solar Observatory

THE WHITE HOUSE

WASHINGTON

October 22, 1962

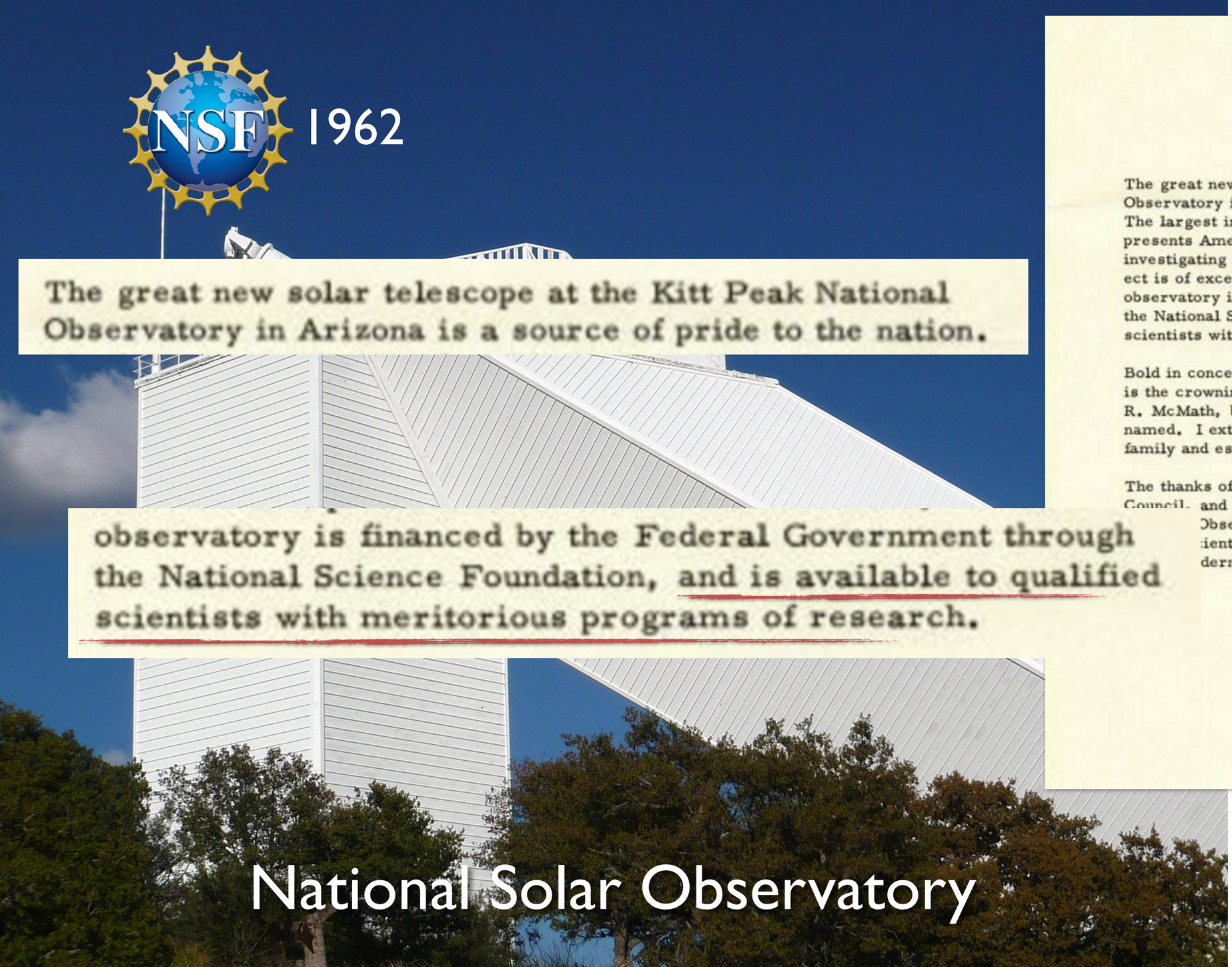
The great new solar telescope at the Kitt Peak National Observatory in Arizona is a source of pride to the nation. The largest instrument for solar research in the world, it presents American astronomers with a unique tool for investigating the nearest of the stars, our sun. This project is of exceptional interest to all our citizens, for the observatory is financed by the Federal Government through the National Science Foundation, and is available to qualified scientists with meritorious programs of research.

Bold in concept and magnificent in execution, the instrument is the crowning achievement of the career of the late Robert R. McMath, builder of solar telescopes, for whom it is named. I extend the gratitude of the nation to Dr. McMath's family and especially to his wife, Mary Ridgely McMath.

The thanks of the nation go also to the Papago Indian Tribal Council, and members of the tribe, for welcoming the National Observatory to Kitt Peak. This mountain, notable in the ancient lore of the tribe, will now have a salient role in the modern exploration of the sun and the universe of stars.

John F. Kennedy

National pride and ownership of NSF's National Observatories



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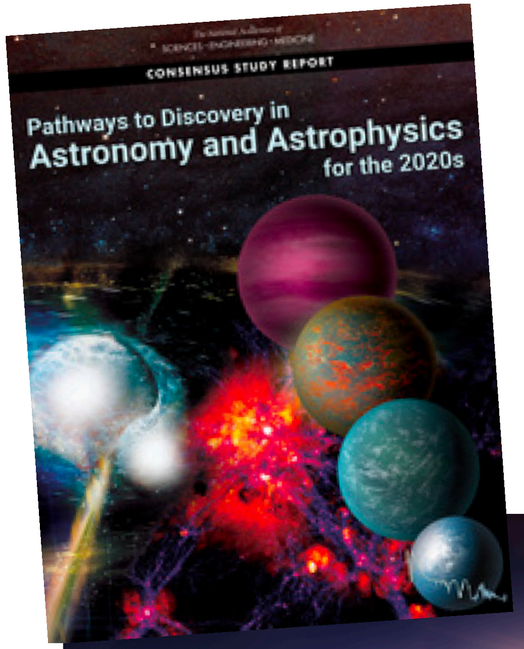
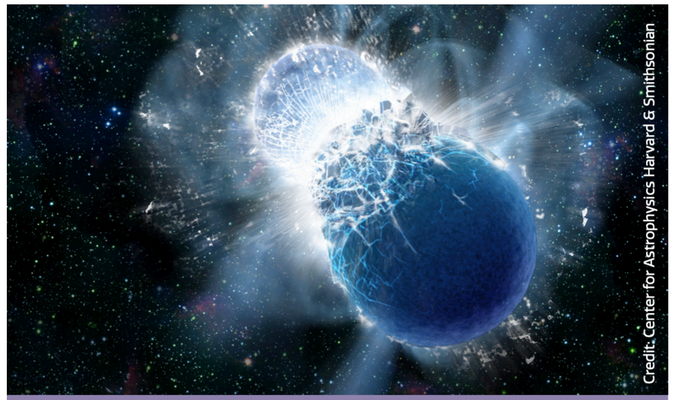
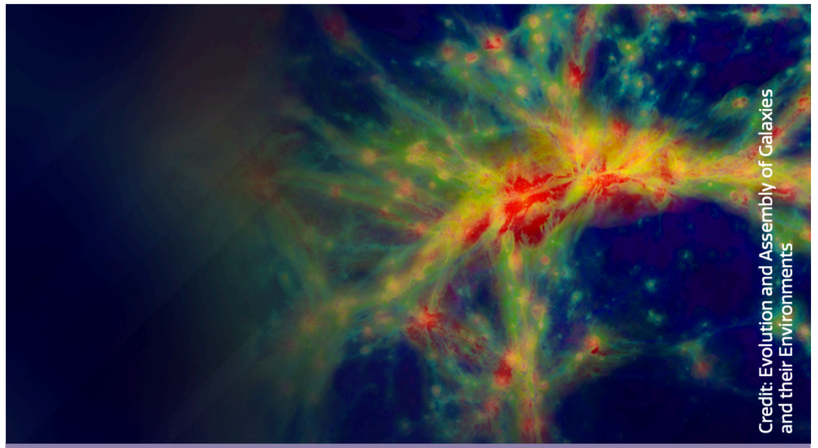


Because of the powerful potential that large (20–40 m) telescopes with diffraction-limited adaptive optics have for astronomy, and because of the readiness of the projects, the survey's priority for a frontier ground-based observatory is a significant U.S. investment in the Giant Magellan Telescope (GMT) and Thirty Meter Telescope (TMT) projects, ideally as components of a coordinated U.S. Extremely Large Telescope Program (ELT) program.

Is there life outside our Solar System?
The US-ELTP will study planets in the habitable zones around nearby stars in any part of the sky and measure atmospheric biomarkers that can indicate whether a planet harbors life.



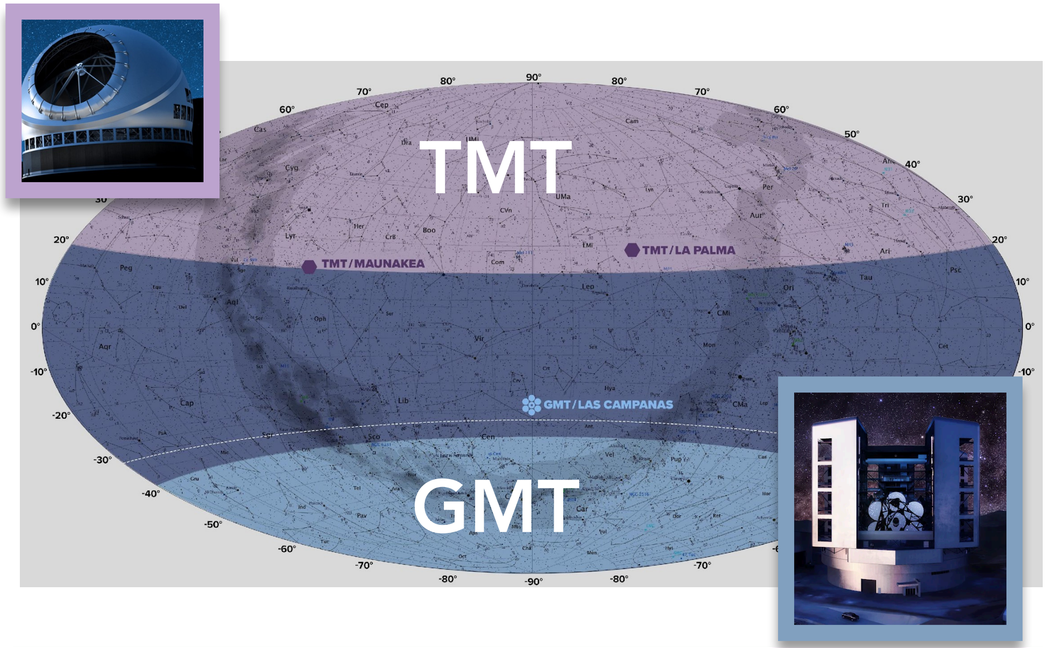
What can gravitational waves teach us about the basic properties of matter?
The detection of gravitational waves in 2015 opened up a new vista of astronomical discovery and won a Nobel Prize. Observing transient events resulting from merging neutron stars and black holes with the US-ELTP will answer fundamental questions about gravitation and the age of the Universe.



How did galaxies form and grow in the early Universe?
The US-ELTP will resolve the detailed inner structure of galaxies 13 billion years ago and measure the dynamics of intergalactic matter, improving our understanding of the early Universe and the galaxy formation occurring then.

Since 1956, it has been the National Science Foundation that has provided broad, **peer-reviewed access to state-of-the-art ground-based Astrophysics facilities**

The science vision is deeply compelling to the American people - for the first time in human history, the NSF could enable the capabilities to answer the question "are we alone?"



"The most common stars in the Milky Way Galaxy are dim, red "M dwarfs." Their habitable zone will be very close to the star….

"To expand that sample will require the spectroscopic sensitivity of ground-based 25-40 m extremely large telescopes (ELTs)."

ASTRO2020 1-4

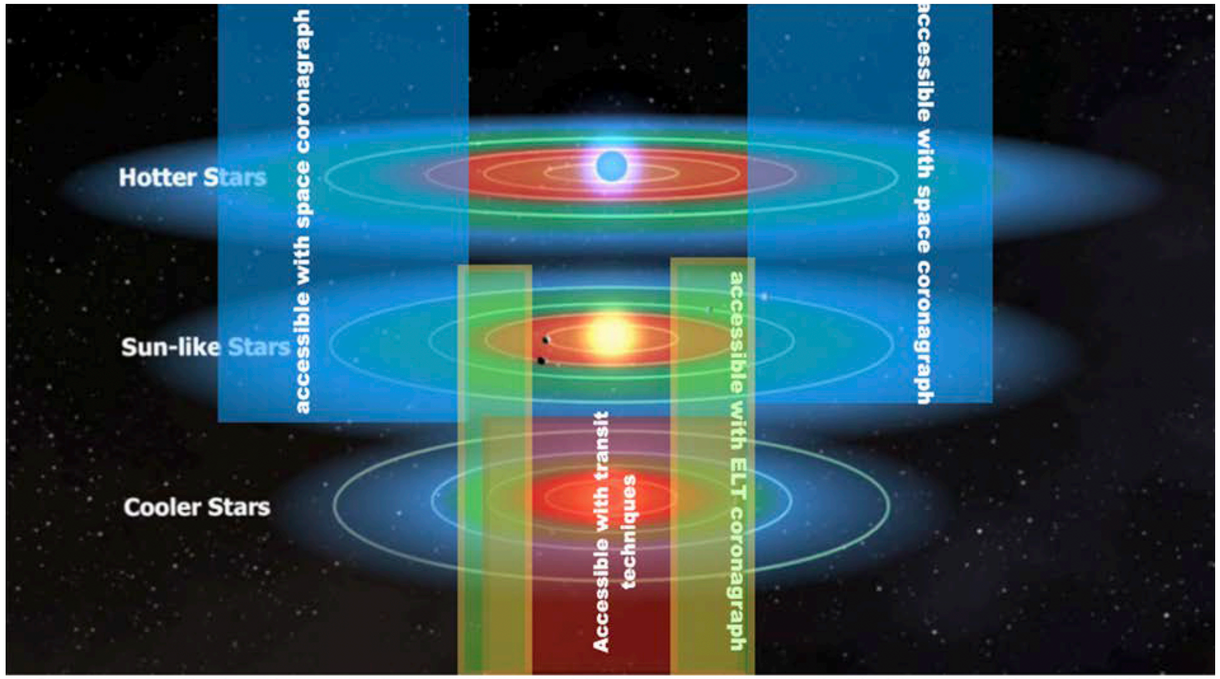
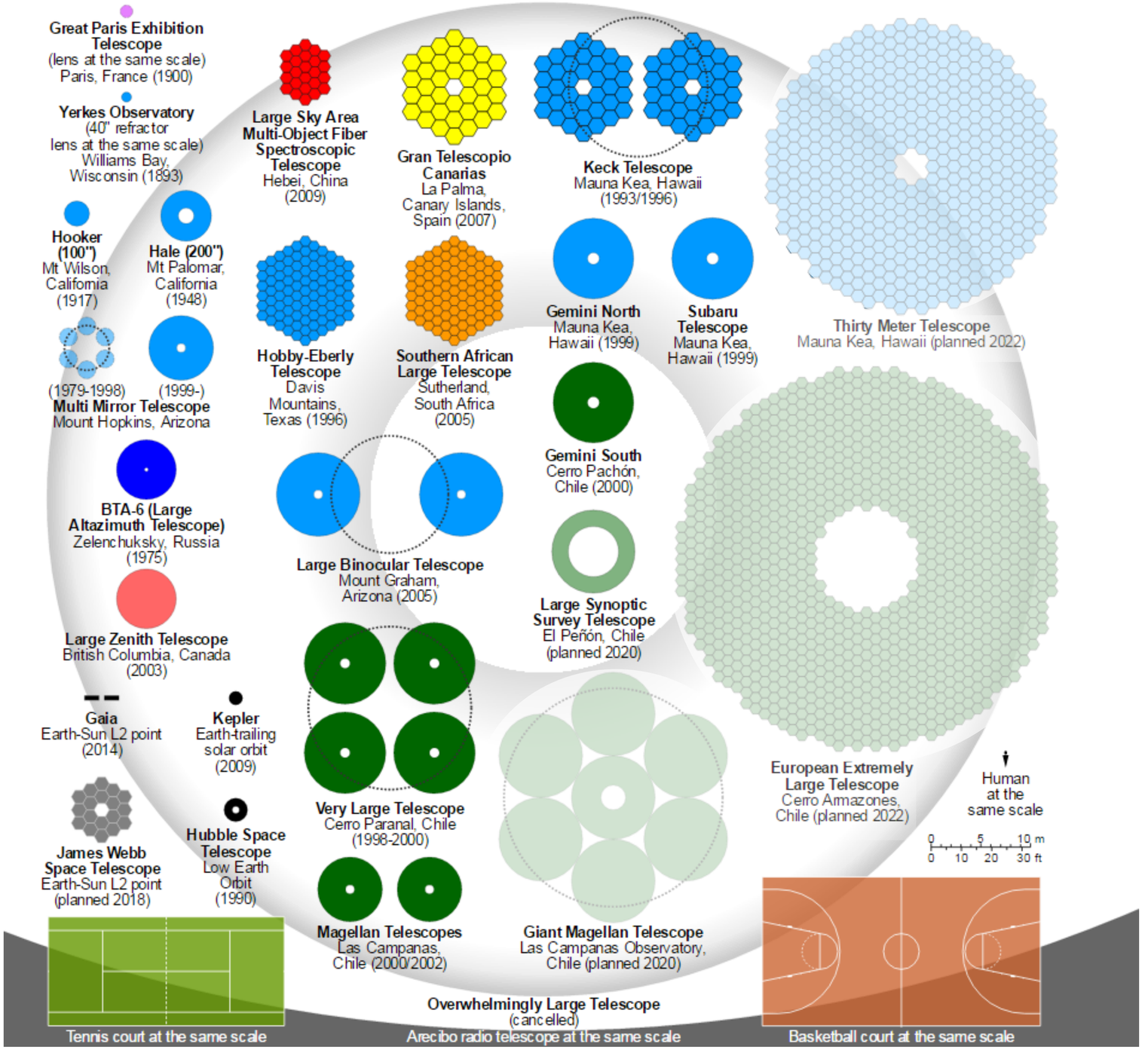


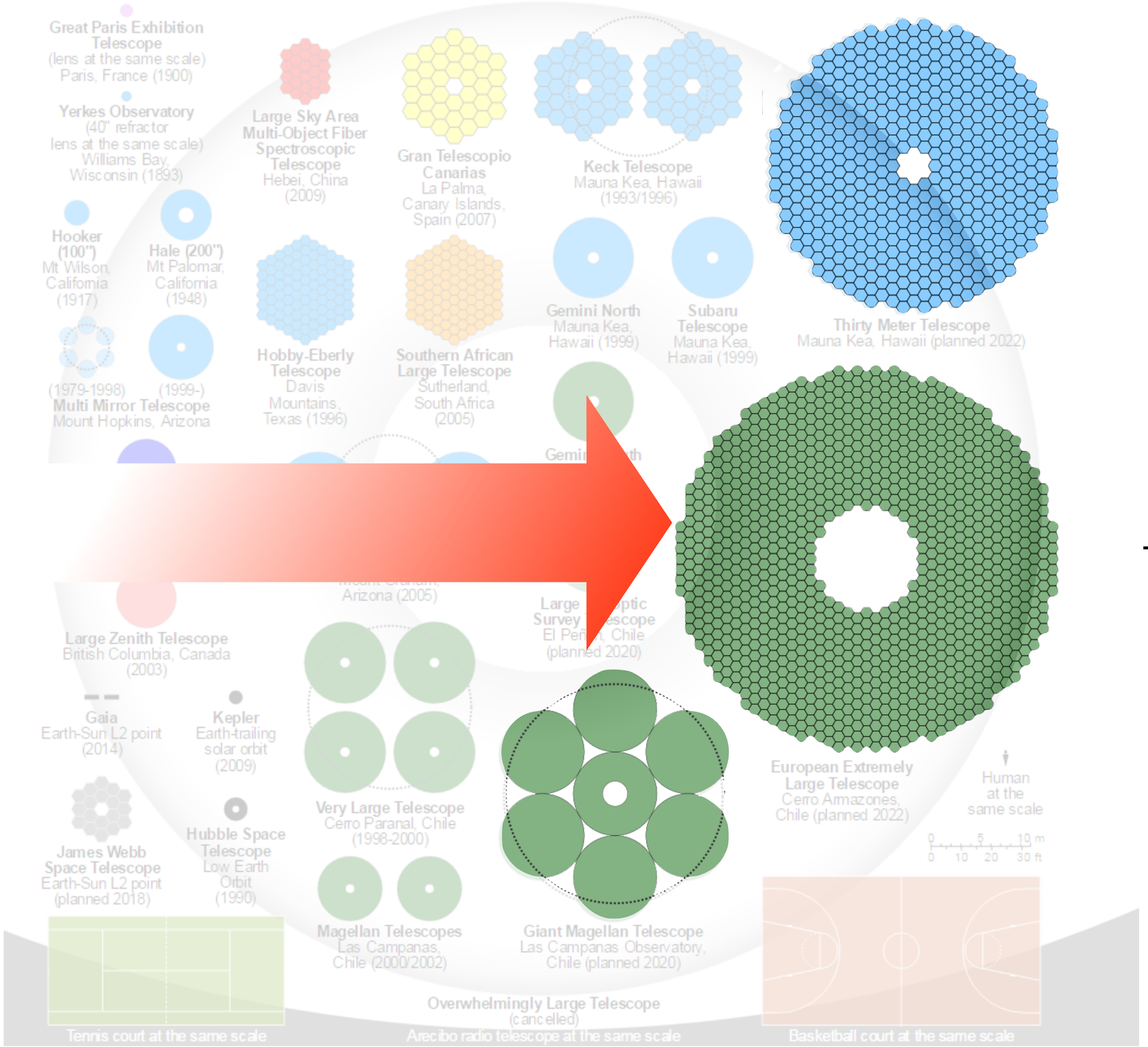
FIGURE 2.1.1 The location around a star where liquid water can exist—the habitable zone—changes with stellar temperature. Different types of telescopes are needed to probe these locations, from space- and ground-based coronagraphs which can return imaging observations of planets, to close-in planets only accessible through transit measurements. SOURCE: NASA/Kepler Mission/Dana Berry, adapted from https://www.nasa.gov/ames/kepler/habitable-zones-of-different-stars.

As JWST is demonstrating, it would be public money well spent

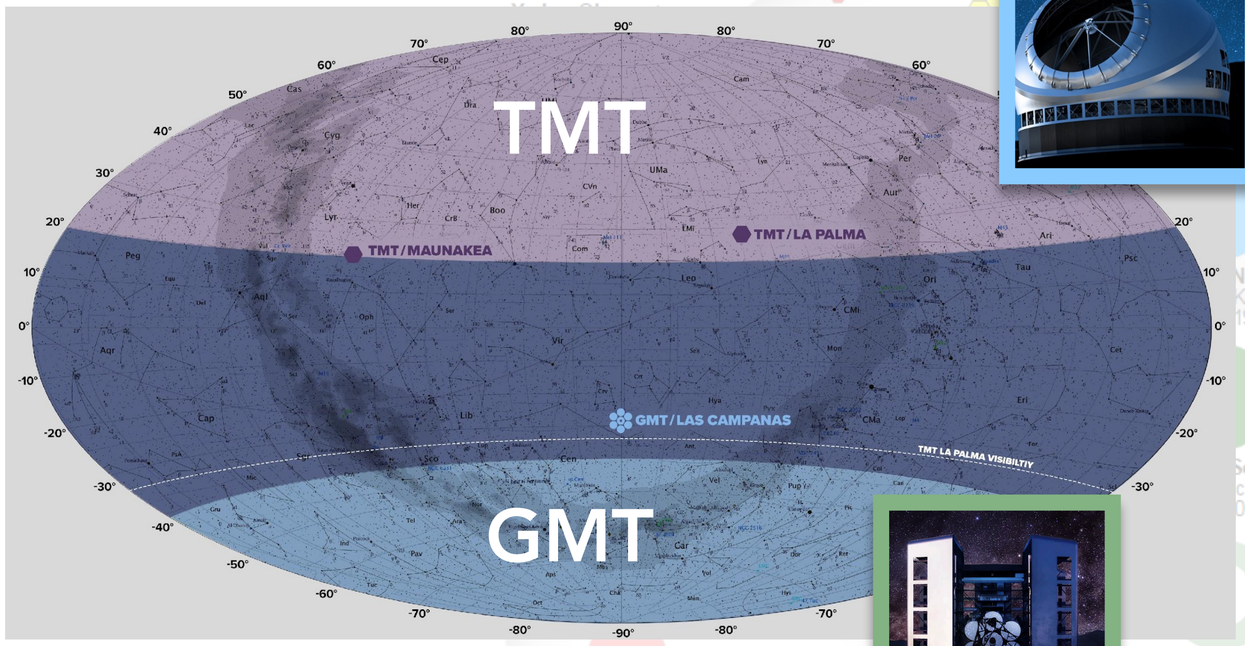
$100M Telescopes

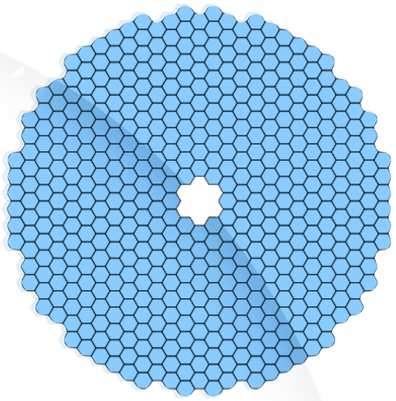


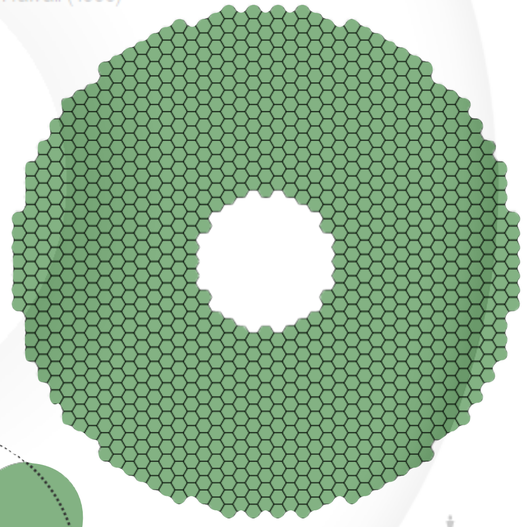
$100M
Telescopes

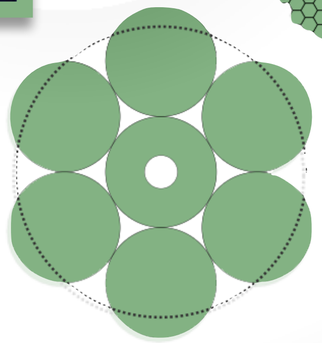


$2B - $3B
Telescopes
(2023 $'s)





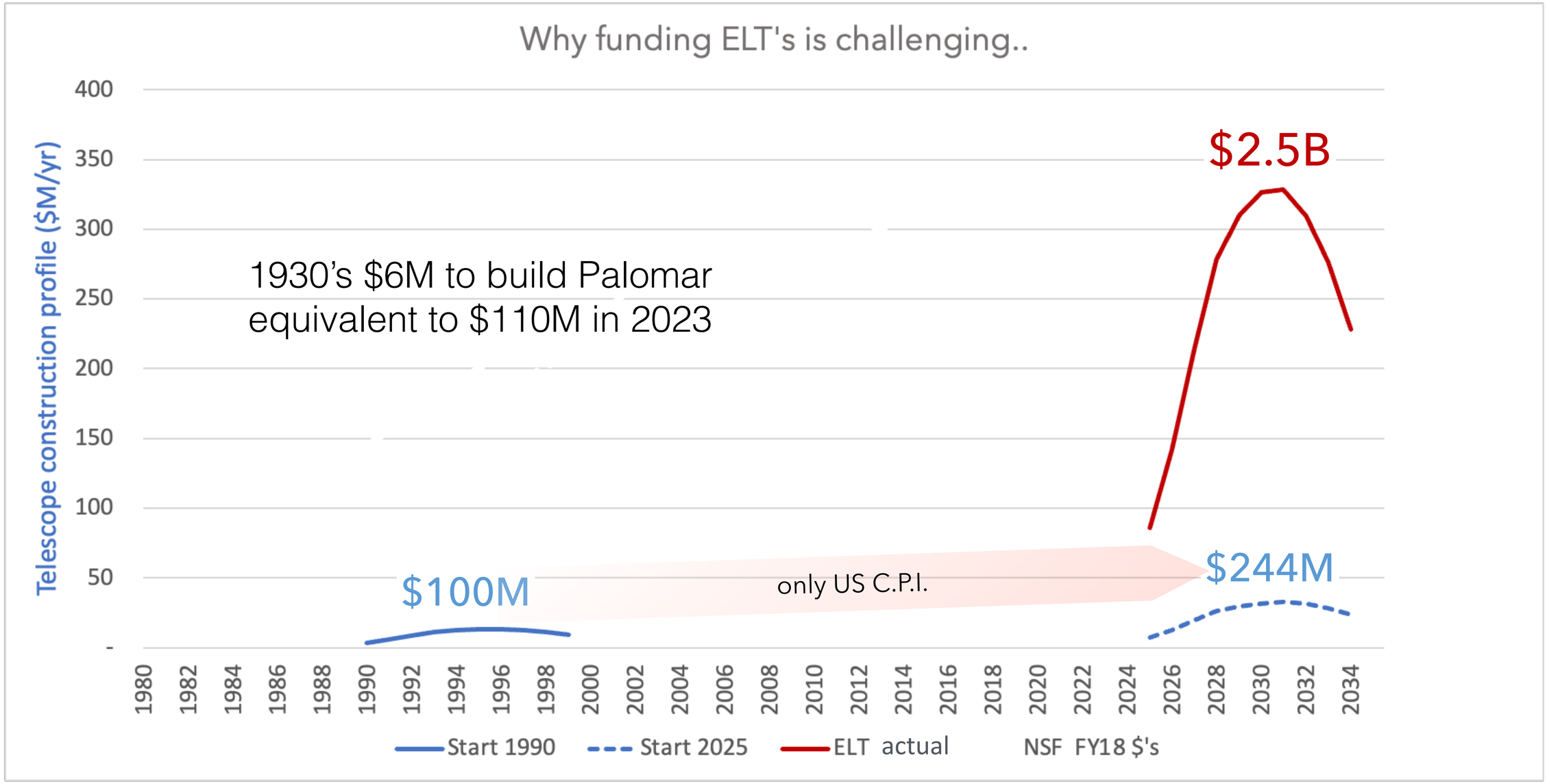




THIS IS A COMPETITIVE SYSTEM

BI-HEMISPHERIC ~ 6,800 on-sky hrs/yr

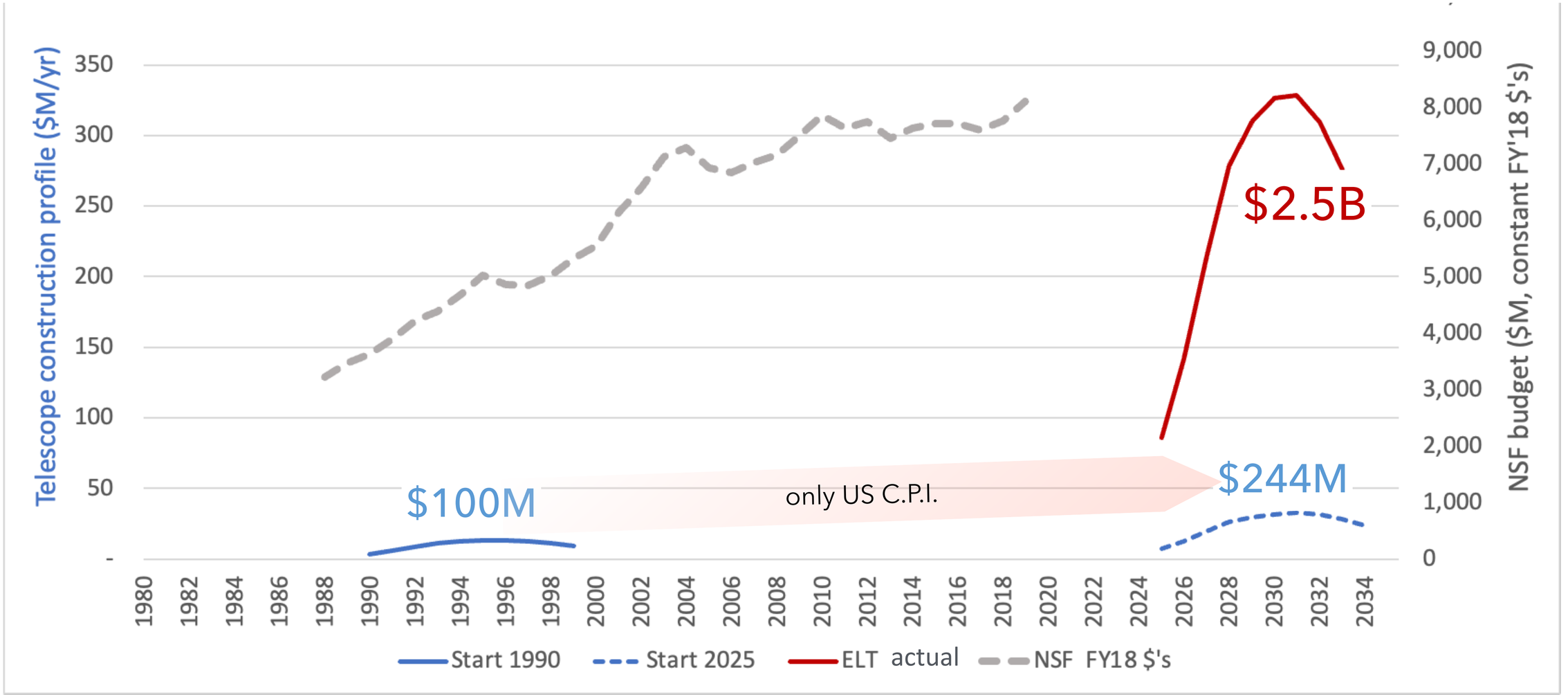
The ELT's are a new paradigm in terms of scale, complexity and cost



8m-10m era

20m-30m era

Since 1955 the National Science Foundation has the mandate to support the U.S. ground-based observational astrophysics that is beyond the scope of individual Universities



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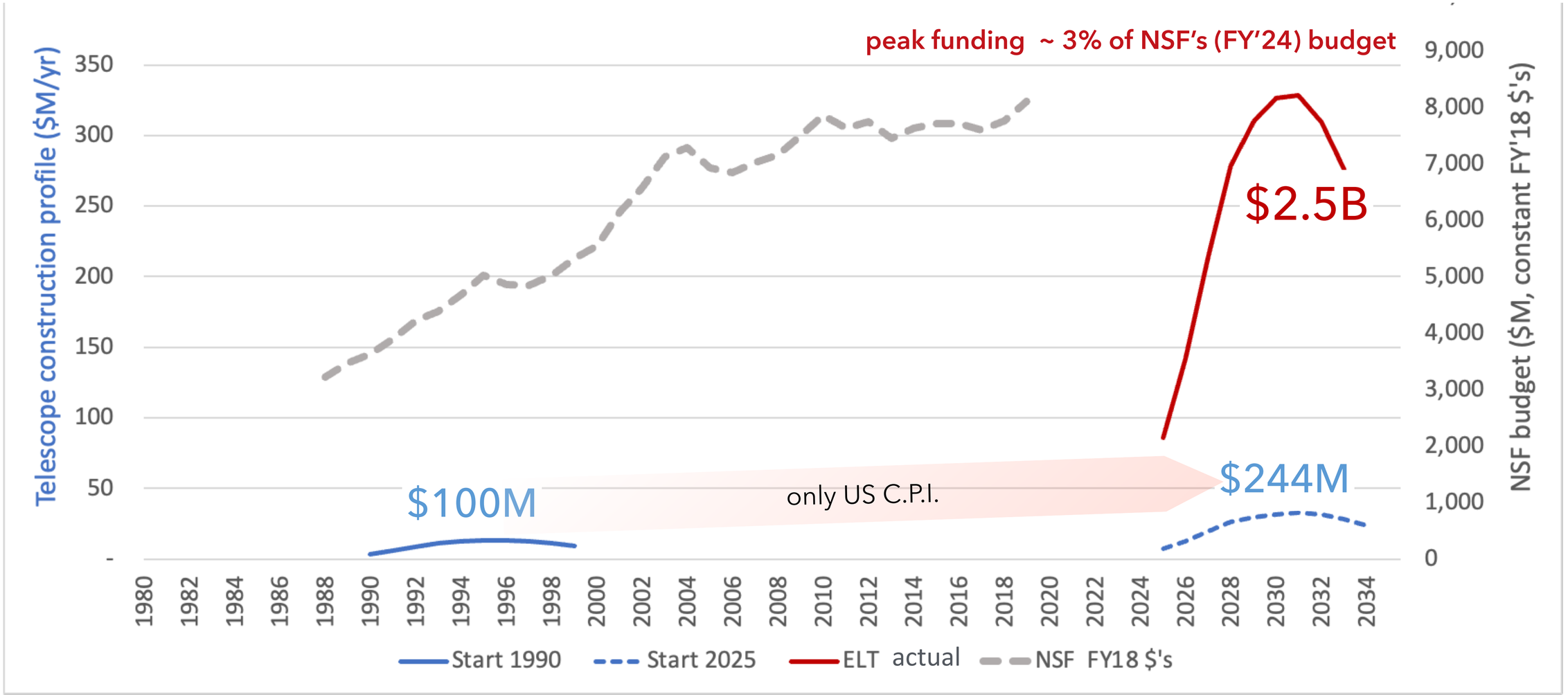
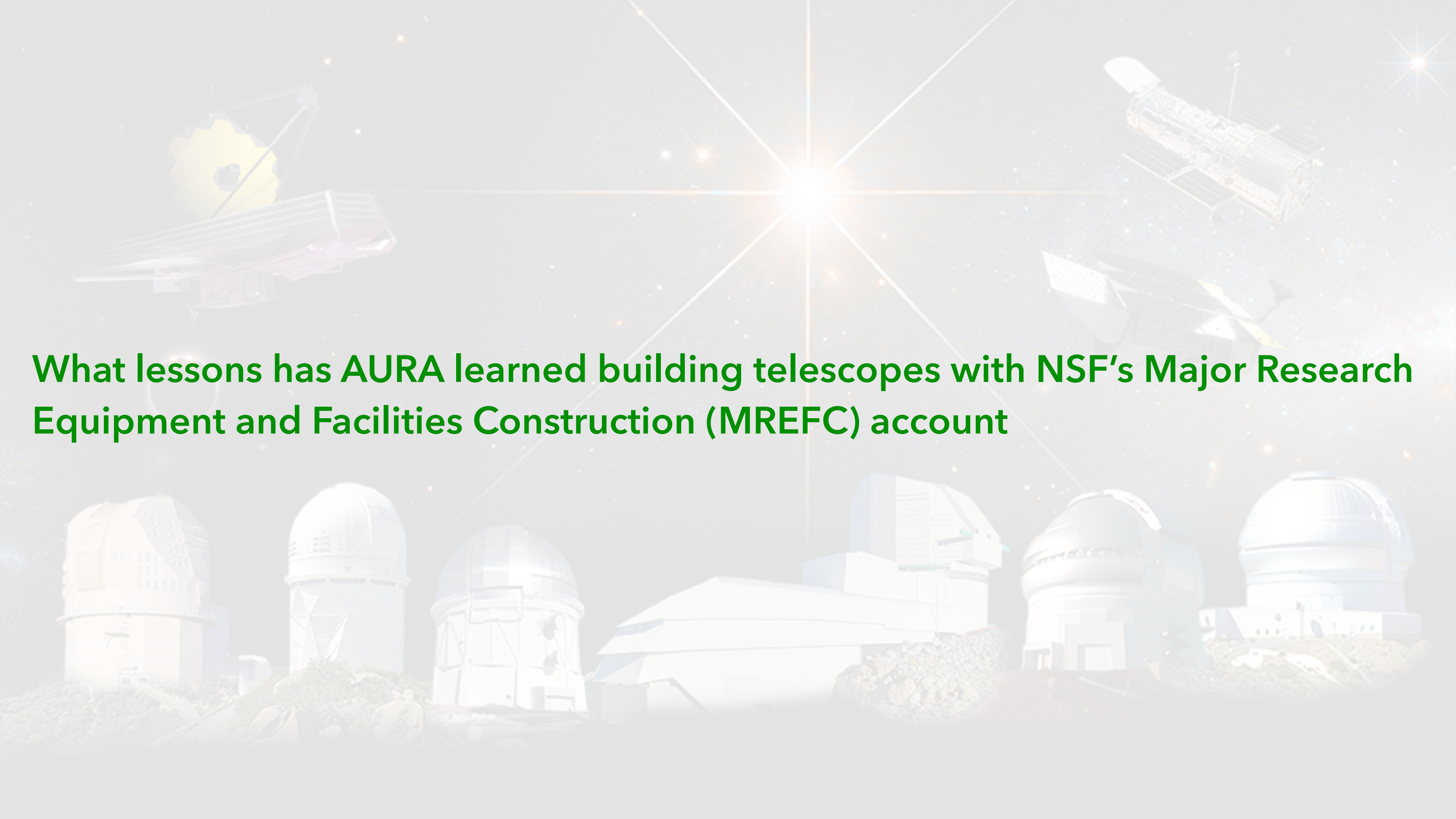




What lessons has AURA learned building telescopes with NSF’s Major Research Equipment and Facilities Construction (MREFC) account

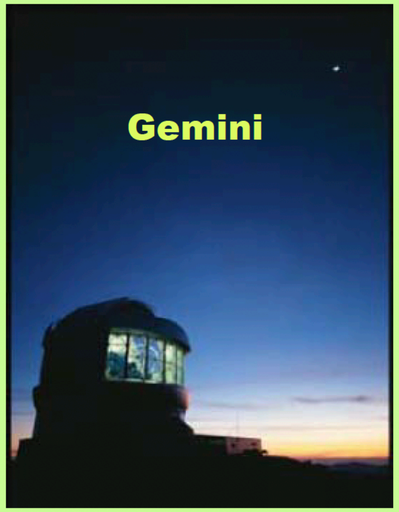
NSF's Major Research Equipment and Facilities Construction (MREFC) account

NSF MREFC Program

early history

The MREFC program was initiated in the mid-90s for large scale science projects

The LIGO Gravitational-wave Observtory in Livingston, LA



The Gemini South telescope on Cerro Pachon in Chile

Barry C. Barish
NSB Consultant (former member)
15 Dec 10

4

NSF- supported construction projects are funded from the Major Research Equipment and Facilities Construction (MREFC) account.

This is distinct from NSF's grant funding within Research and Related Activities which funds facility operations, as well as design & development investments for new facilities.

The U.S. Congress directed NSF to create the MREFC account, **to fund LIGO and Gemini**, to provide greater transparency, and to enable projects to be funded with "no-year" dollars with the expectation of multi-year budgets, with low outlay rates.

"Astronomy has always been the bow wave for change at the NSF"

former Staff Director of the Senate CJS Appropriations Subcommittee

Example 1: Rubin Observatory Construction

NSF MREFC: $ 557.2 M**

DOE MIE: $ 165.3 M

LSSTCam CD-4 completed Sept 2021

DOE Commissioning: $ 47.9 M**

Private Funding: $ 34.0 M

Early contribution for delivered M1M3. M2, site prep

** EAC plus contingency Values based on current requests and includes amounts still pending approval

.

NSF Supplemental Funding Request Status:
Includes COVID and Data Security increases

	Amount
SFR1 COVID-19 Pandemic Direct Costs	$ 1,533,913
SFR2 * COVID-19 Project Rebaseline FY22	$ 28,145,870
SFR2a * COVID-19 Project Rebaseline FY23-FY24	$ 37,124,846
SFR3 COVID-19 Schedule Impact and Expenses	$ 907,816
SFR4 COVID-19 Impacts and Unplanned Expenses	$ 967,656
SFR5 Data Security and Huawei Avoidance	$ 7,466,509
SFR5 Contingency (pending approval)	$ 1,069,855
SFR6 Covid Mini-rebaseline (pending submittal)	$ 7,582,500
Total	**$ 84,798,965**

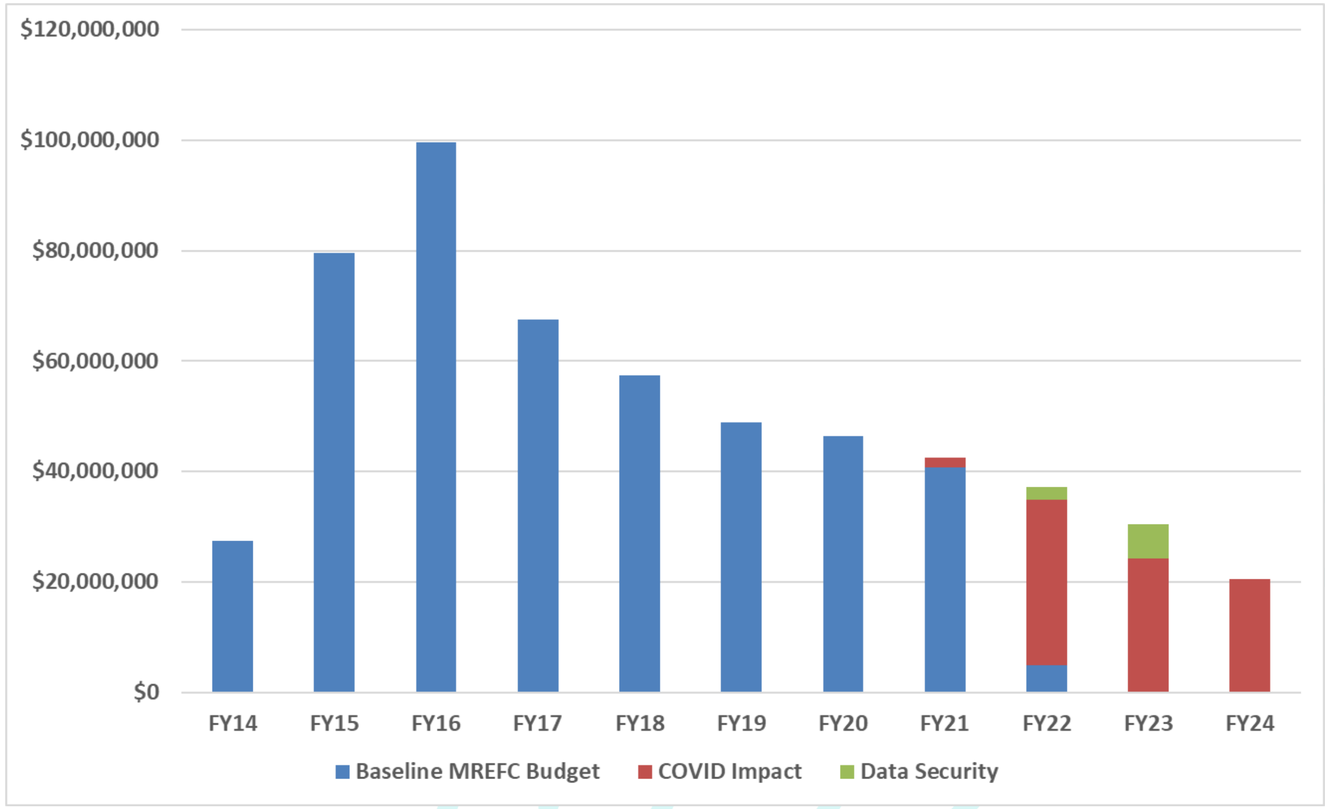
Early private funding was crucial for long lead / high risk mirror development

However, NSF's commitment to cover "unknown - unknowns" once project was in MREFC has been equally crucial

NSF Construction through MREFC account

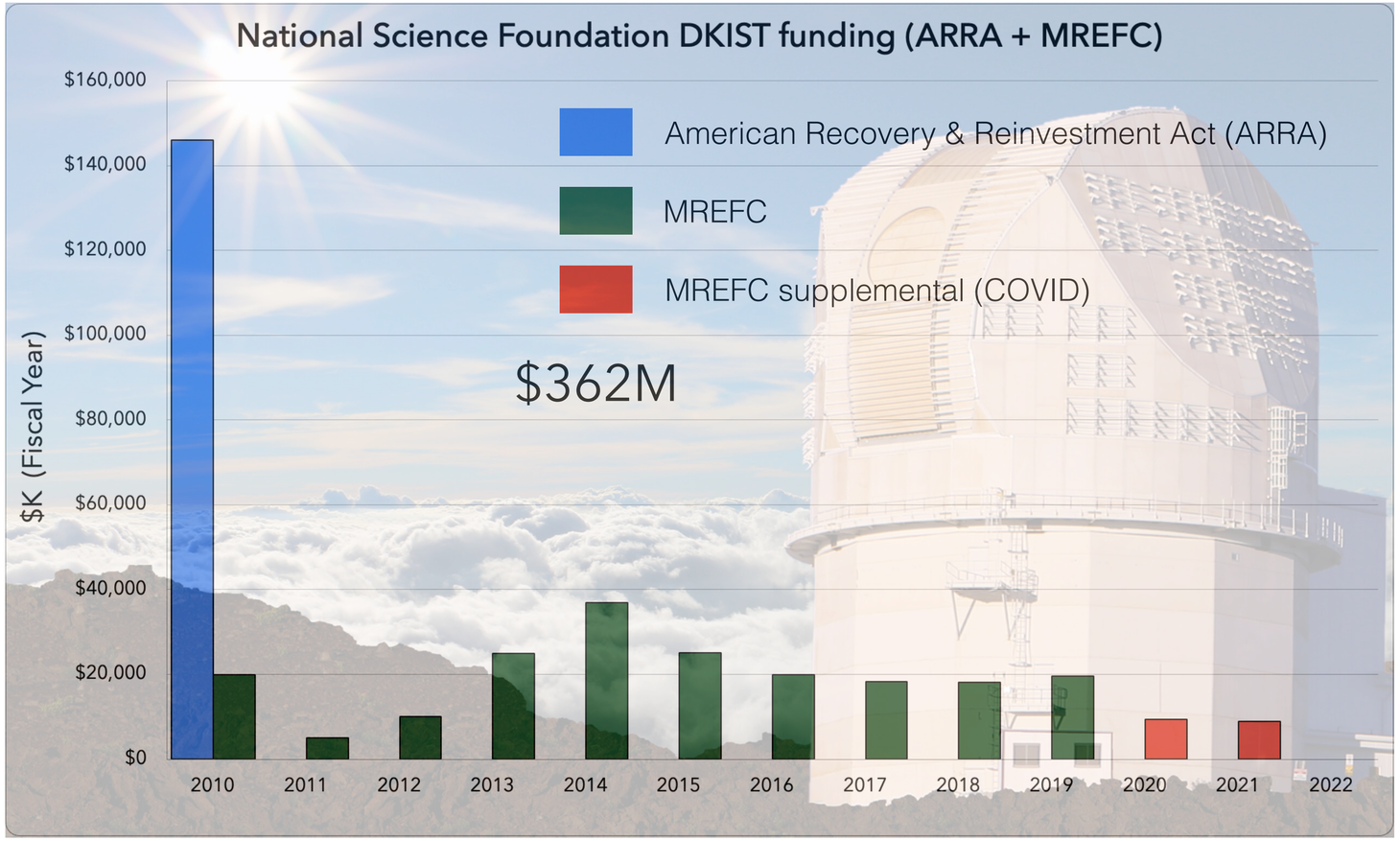
- Construction began August 2014
- Original NSF Budget was $473 M for a planned 8 year 3 month Project
- Added $76.1M for COVID impacts and schedule delays
- Added $8.5 M for new Data Security scope

Funding remained predictable and consistent with plan (COVID Rebaseline was a bit rough)



NSF Budget for Construction	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
Baseline MREFC Budget	$27,500,000	$79,640,050	$99,682,764	$67,497,557	$57,314,797	$48,831,889	$46,349,626	$40,785,623	$4,891,803	$0	$0	$472,494,109
COVID Impact								$1,671,766	$29,883,489	$24,200,474	$20,409,077	$76,164,806
Data Security									$2,320,020	$6,216,344		$8,536,364
												$557,195,279

Example 2: Daniel K Inouye Solar Telescope



Once accepted into the MREFC account, it is an incredibly effective and powerful way to build BIG science facilities.

- ➡ risks have been reduced/quantified through extensive D&D
- ➡ resources are in the right years, allowing optimal schedules
- ➡ rational and collegial on-going risk management

"Think slow, act fast"

Big Projects don't go wrong, they start wrong

Independent review by GAO confirms MREFC Projects have reasonable cost and schedule performance

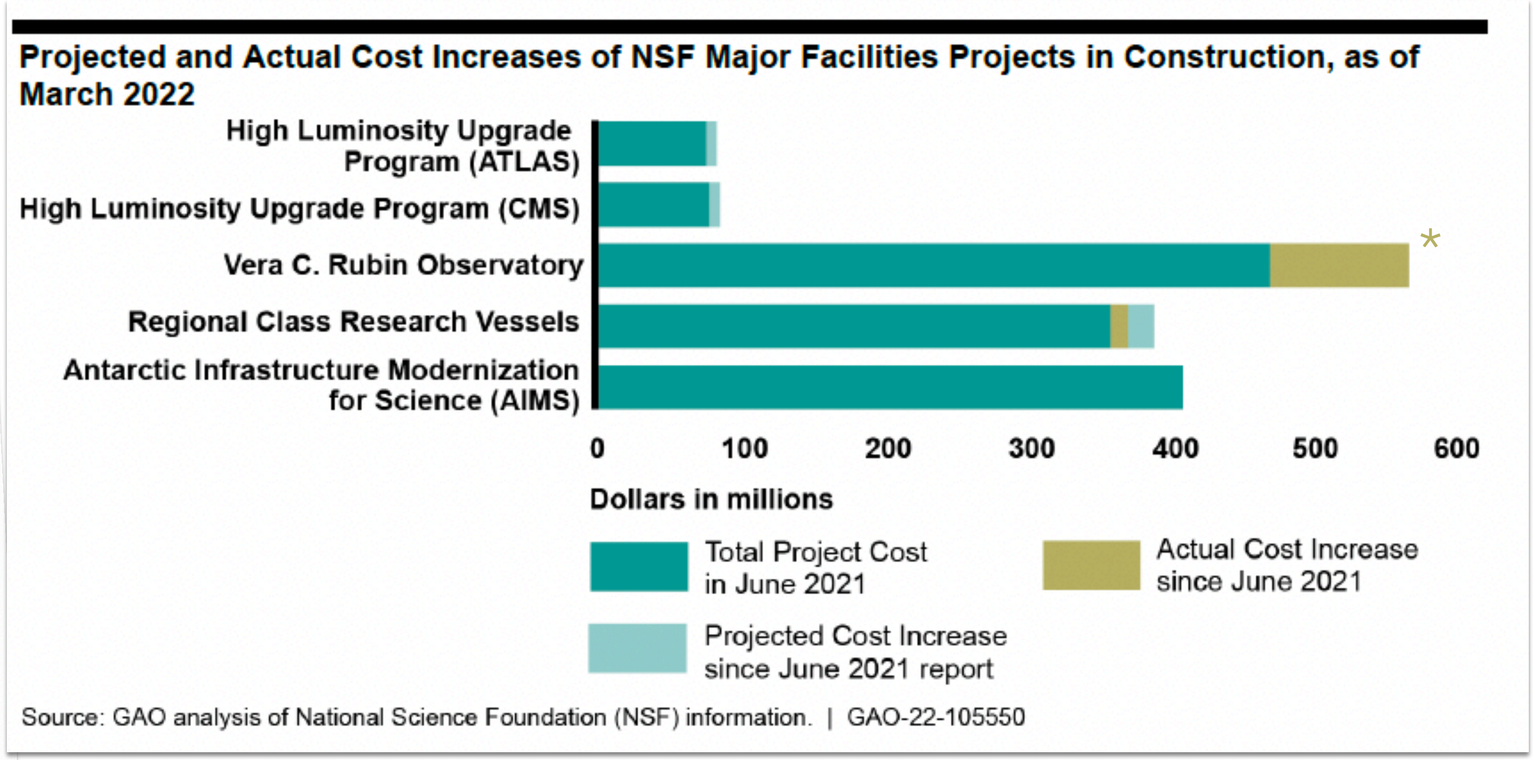
United States Government Accountability Office

Report to Congressional Committees

July 2022

NATIONAL SCIENCE FOUNDATION

Continued Cost and Schedule Increases for Major Facilities Projects in Construction



* COVID and security upgrades

"Specifically, the guidance instructs award recipients to refrain from using contingency funds reserved for foreseen risks identified during the design of a project or de-scoping a project to respond to pandemic-related risks. **Instead, award recipients should request NSF-held management reserve, re-plan (adjust cost, schedule, or scope without impacting award amounts), or re-baseline their projects.** NSF followed its guidance to respond to the pandemic, such as by using management reserves for the three projects that are farthest along. "

MREFC, a multi-step process – examples from AURA

NSF (MREFC) $362M

Major reviews and dates for the Daniel K. Inouye Solar Telescope (originally ATST), Maui

- CoDR – Aug 2003
- PDR – Nov 2006
- FDR – May 2009
- Funding Award – Jan 2010
- Construction completed - Fall 2021

NSF (MREFC) $557M
DOE (Science) $213M
Private $ 34M

Major reviews and dates for Rubin Observatory (originally LSST), Chile

- CoDR - Sep 2007
- PDR - Aug 2011 (delayed to wait for decadal survey)
- FDR - Dec 2013
- Funding Award - July 2014
- Expected construction completion* - now late 2024

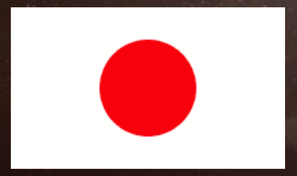
**Covid 19 outbreak and rebaseline*

However, it can take a long time, patience and persistence to get NSF to approve MREFC projects

Hurdles to overcome to enable multi-billion dollar facilities within NSF’s culture

The US-led Extremely Large Telescope Project






Formed to build a
dual-hemisphere system of
state-of-the-art
optical-infrared telescopes
with key international partners





30m telescope,
Maunakea, Hawaii

24m telescope,
Las Campanas, Chile

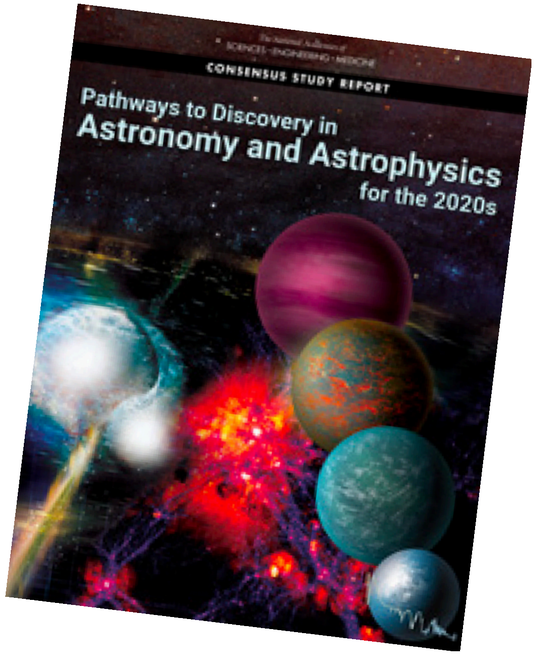
There are no other big partners out there, who are not already part of GMT, TMT or ESO

TMT
THIRTY METER TELESCOPE

NOIR Lab

GIANT MAGELLAN TELESCOPE

November 2021



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December 2022 - January 2023

NSF convenes two phase PDR, with national & international experts

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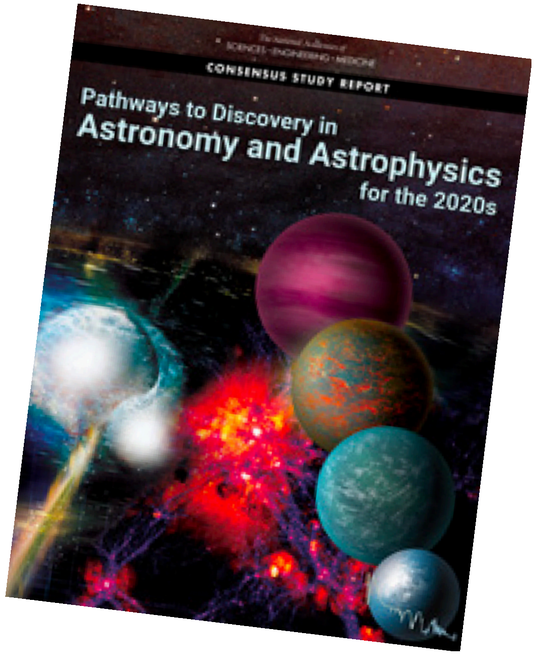

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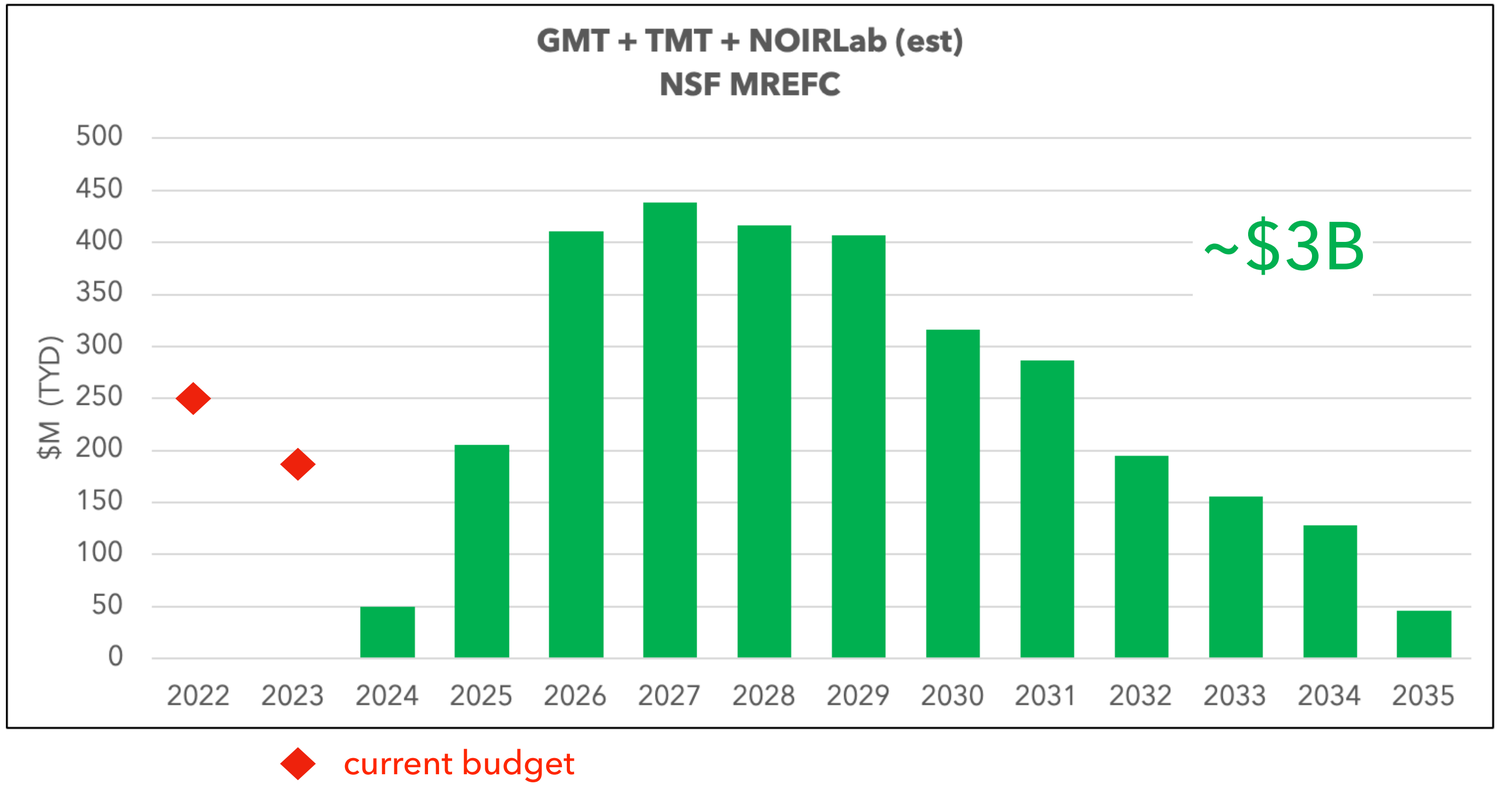
The US ELT Program and the NSF

The amount and phasing of MREFC funds required to get both GMT and TMT on-line by the early 2030's, **and** put in place the science support system through NOIRLab, essential to enabling the broad US community to be able to exploit the US-ELT system is shown below:



$3B to enable a fully supported & instrumented bi-hemispheric system of diffraction-limited 24m - 30m telescopes, operating from the infrared down into the visible, **that can be easily, and cost-effectively** re-instrumented and upgraded over the course of the next 10, 20, 30 years.

Including eventually adaptive optics operating in the visible

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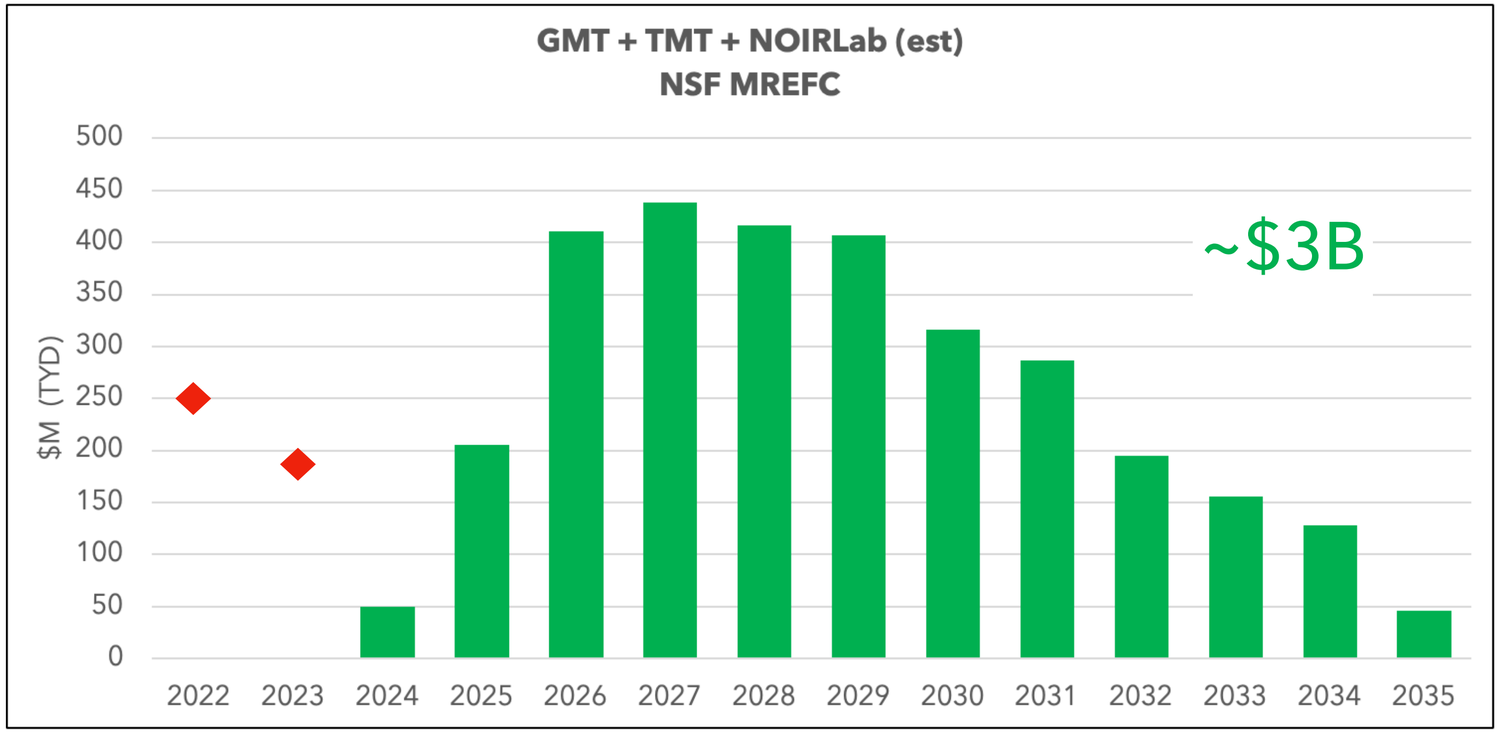

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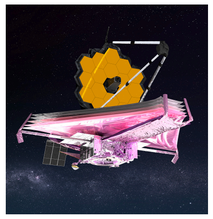

"Frankly, it's a bargain"

Matt Mountain, JWST Telescope Scientist

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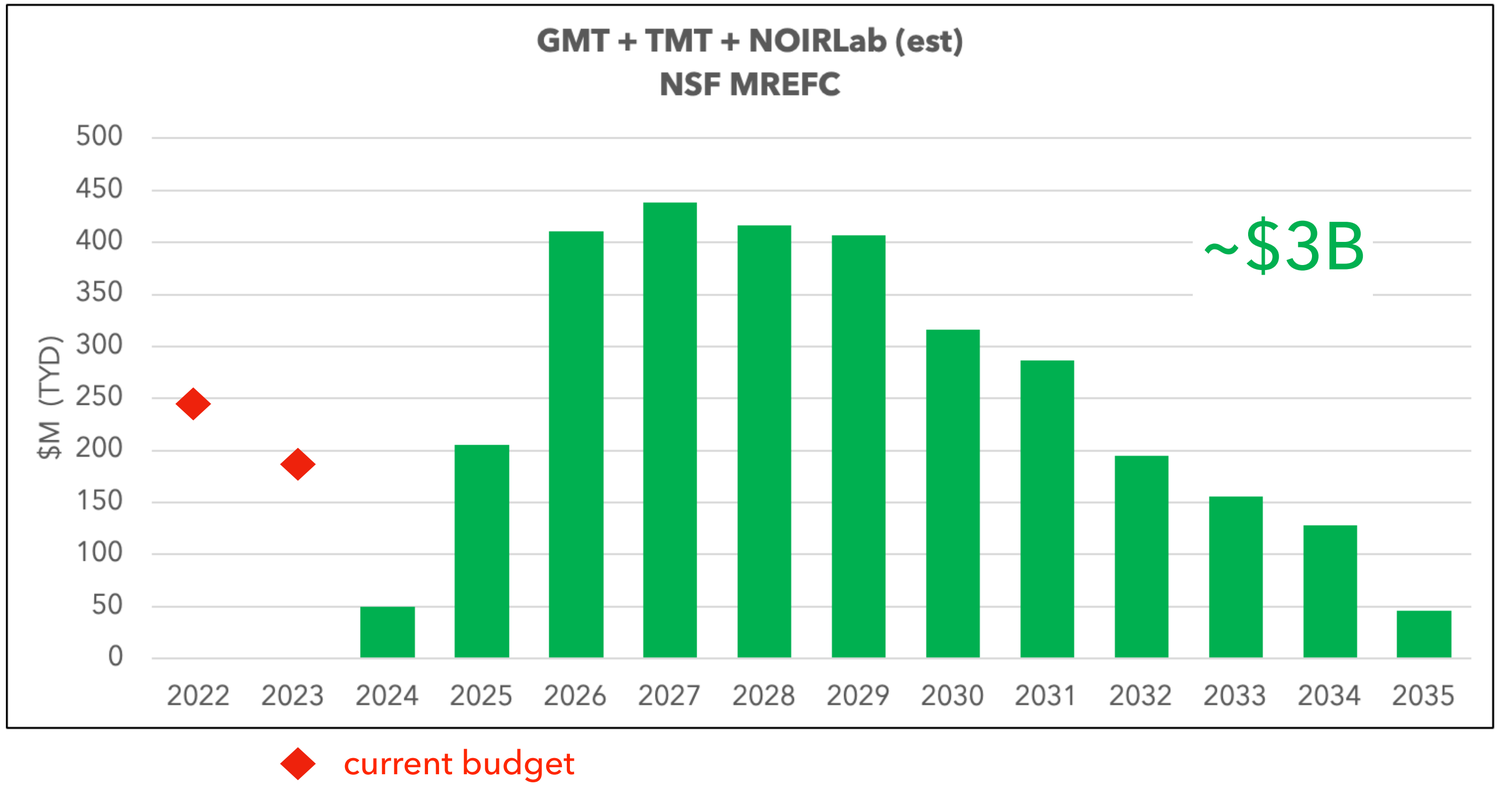


The required annual MREFC funding is approximately x 3-4 what has been traditionally allocated to NSF construction projects - but neither has the MREFC account been **consistently grown since 1995…….**

This is the scale of investments **now required** for future major projects beyond the US-ELT

- ngVLA
- Cosmic Explorer

Noting:

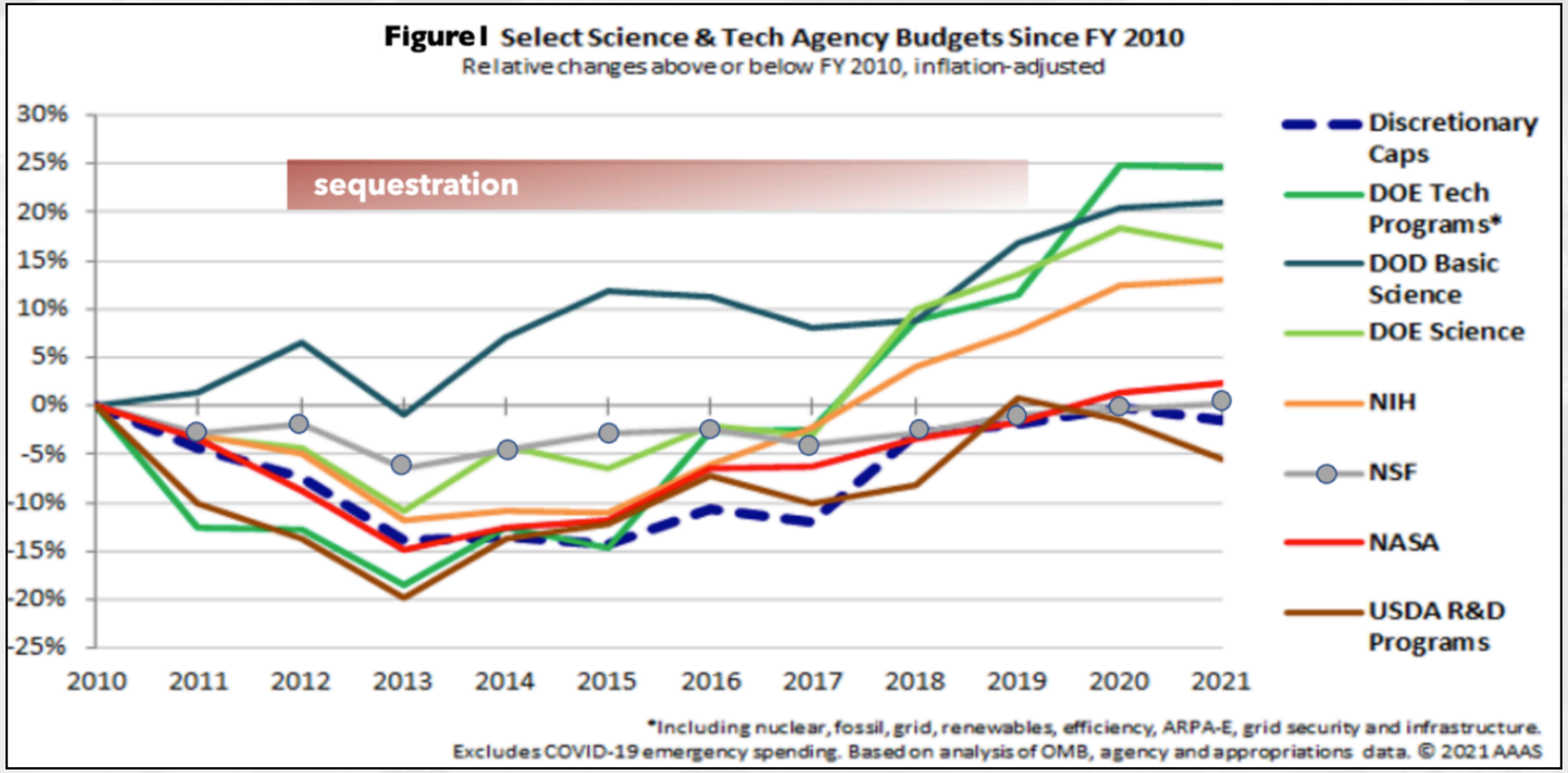
- ESO's ELT ~ $2B
- Square Kilometer Array $2B ~ $3B
- Einstein Telescope $2B ~ $3B

How does the NSF enter into this scale of Major Projects?

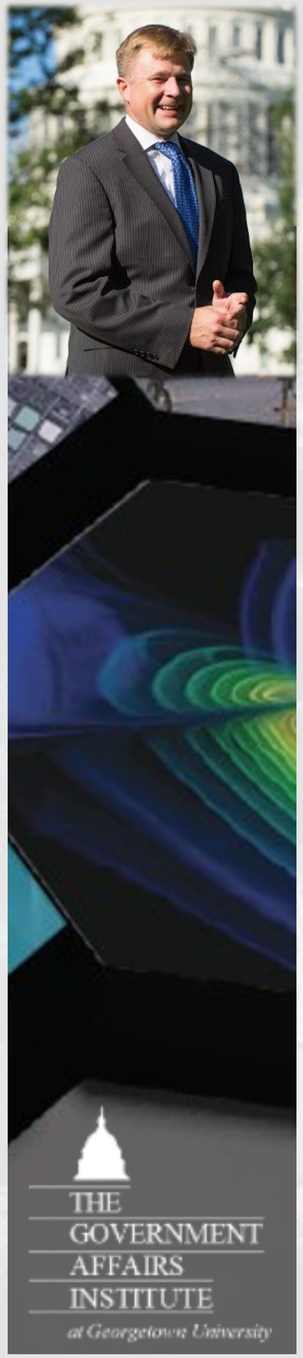
- by committing (and asking) to invest in 21st Century science infrastructure

What is going on here?

- courtesy Joel Parriot



Despite sequestration, the science budgets at DOD, DOE, NIH and NASA all grew from “lows” in FY’12 - FY’13 - the exception was the NSF (—●—)



Science Funding – Two Categories

"Grants by the Pound"

- **Means:** The total spending for the agency/account drives the metrics for what can be accomplished
- **Examples:** NSF Research and Related Activities (R&RA) grants, NSF Mid-Scale Research Projects
- **Point:** Backbone of science funding, but faceless, scalable accounts are difficult to grow

"Rack and Stack"

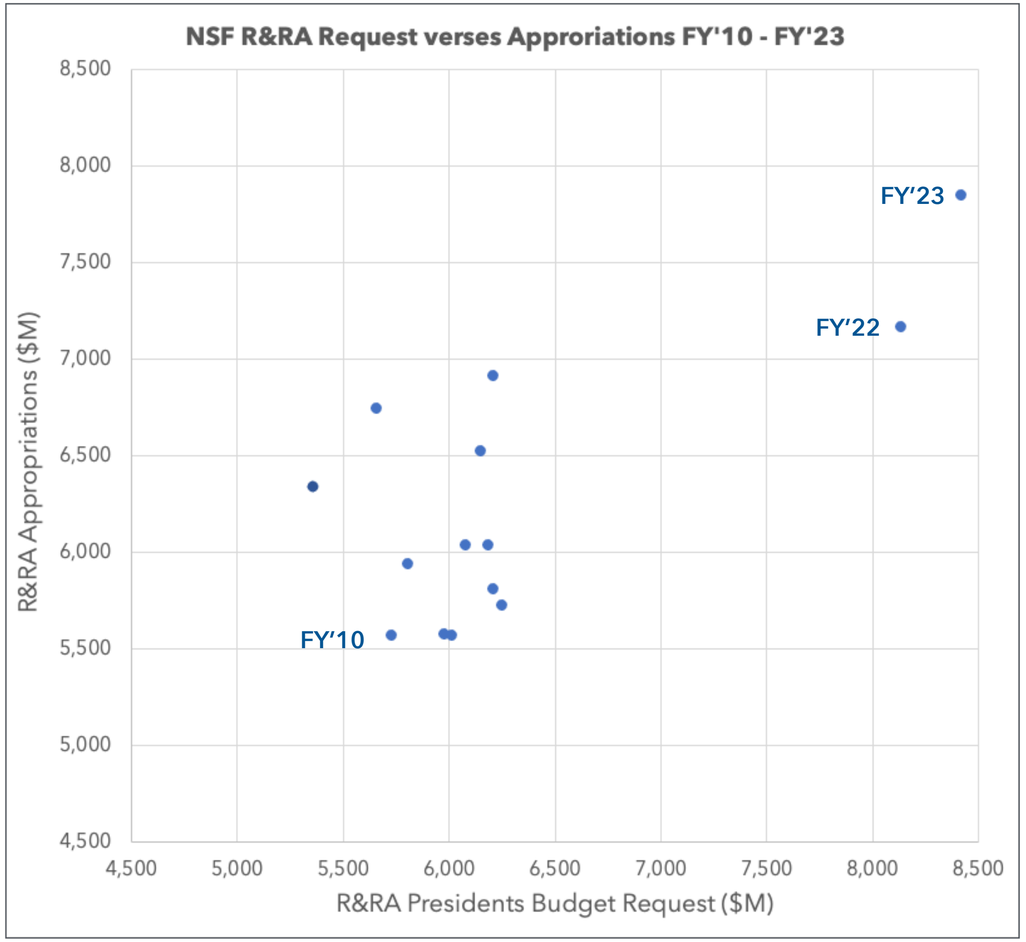
- **Means:** The sum of each project's funding drives the overall agency/account funding level
- **Examples**: NASA Science directorate funding (i.e., Planetary, Astro); NSF Major Construction (MREFC)
- **Point:** Procurement-dependent and fluctuates, but **Big projects drive big budgets**, ***not the other way around***

Presentation on "*Science & Appropriations*", at Georgetown University, 2021

Jeremy Weirich, former AURA VP for Corporate Strategy, former Senate Majority Clerk for the Commerce, Justice, Science, and Related Agencies Subcommittee

Where does NSF's support, and budget come from?
(FY'10 - FY'23)

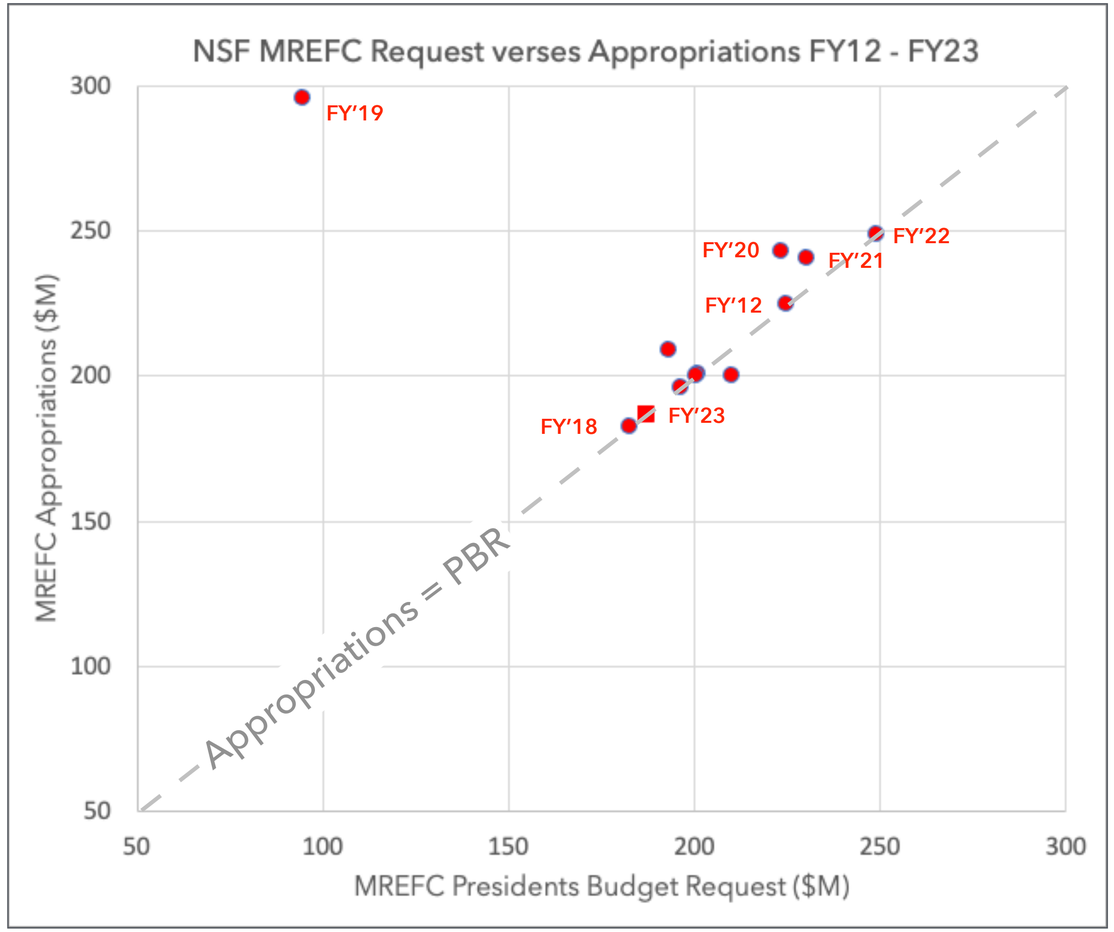
Grants



Appropriation

Request

Projects

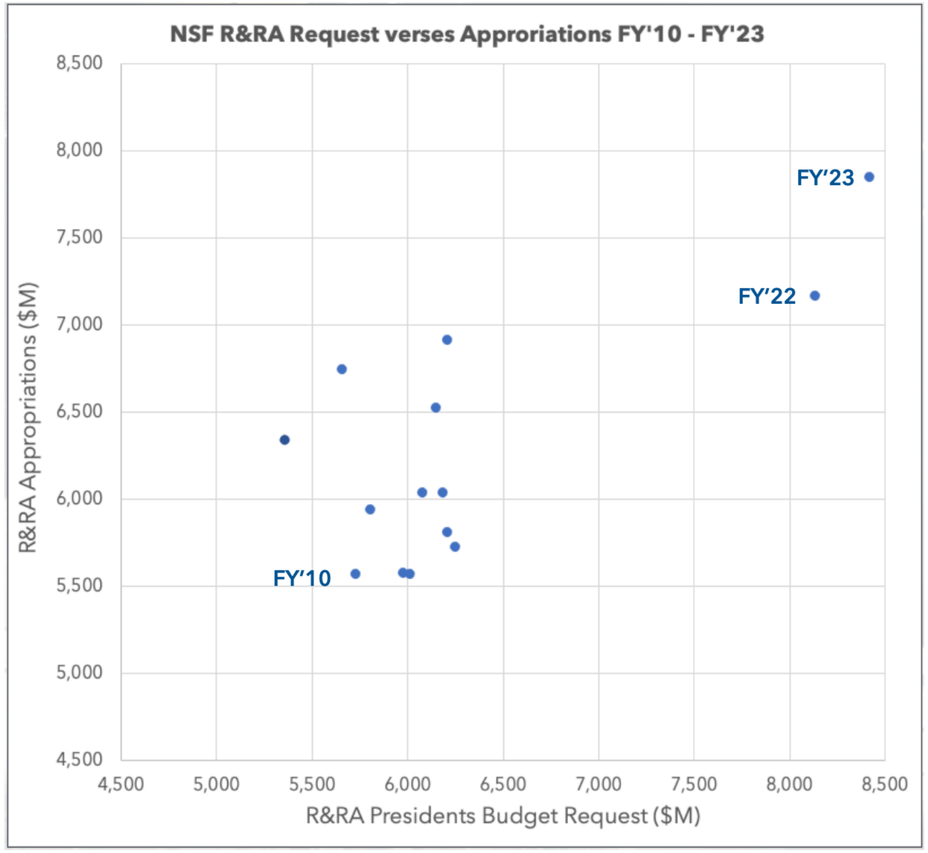


Appropriation

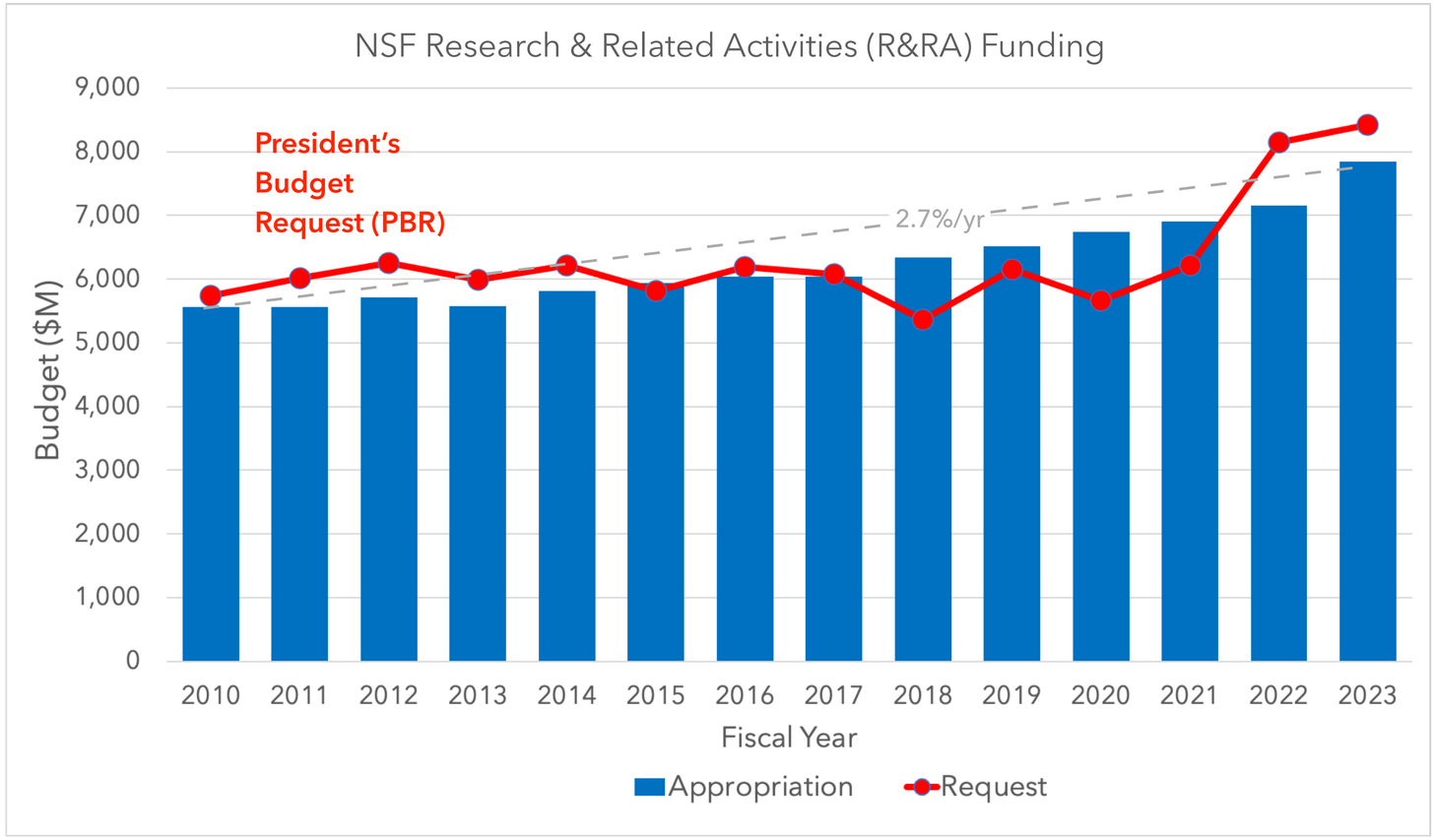
Request

Who supports NSF's grant (R&RA) programs?

Congressional appropriations FY'10-FY'23 largely independent of Administration requests



Correlation of annual outcome - Congressional Appropriations versus Presidents Budget Request for NSF's grants line (Research & Related Activities)

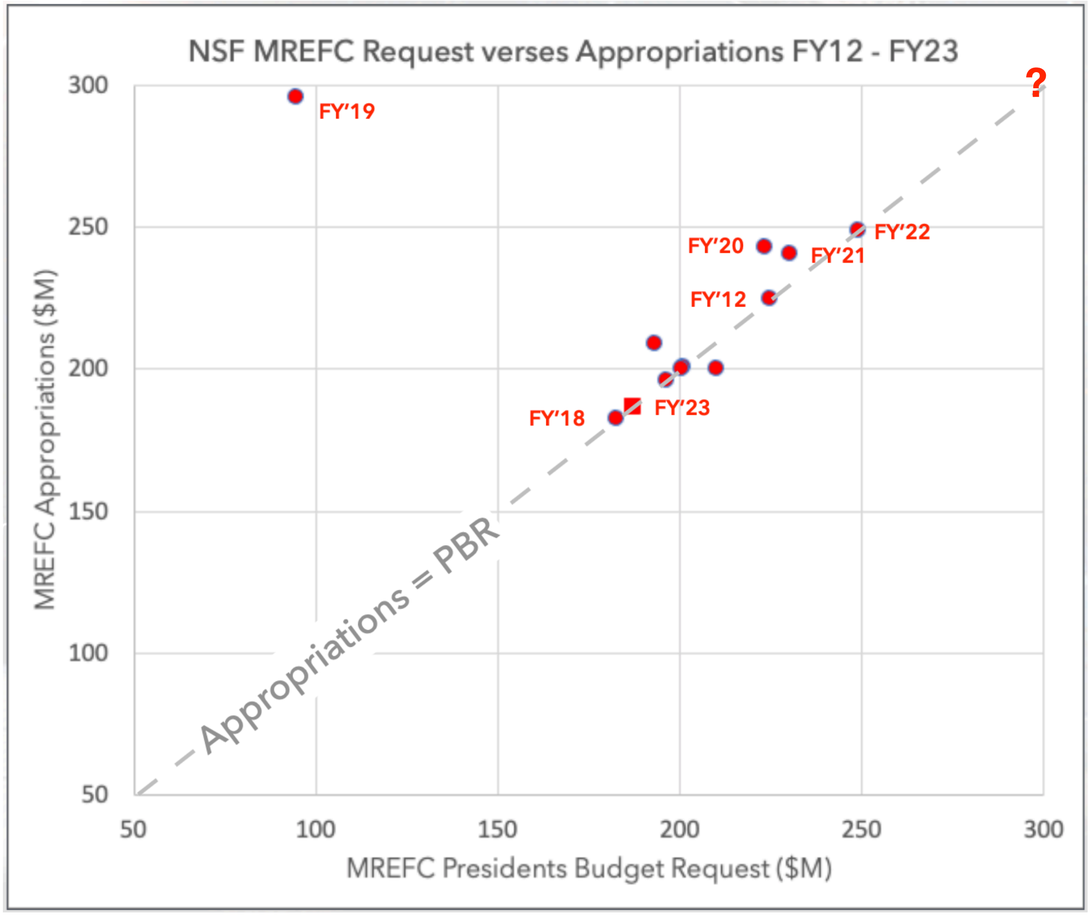


Annual Congressional funding levels for NSF's grants line (Research & Related Activities)

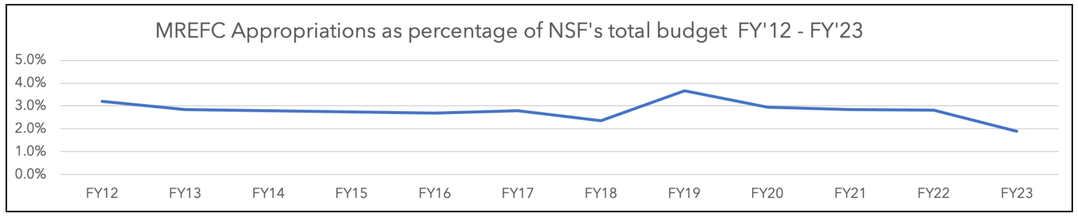
Who supports the NSF's Major Research Equipment and Facilities Construction (MREFC) budget?

In contrast:

For the last Decade, Congress has consistently supported, or increased upon the President's Budget Requests (PBR) for MREFC Projects



The MREFC budget, in any one year, is a small fraction of the total NSF budget



And in FY'23 for the first time since FY'12, investments in Major Facilities dips below 2% of the NSF budget

Concluding thoughts

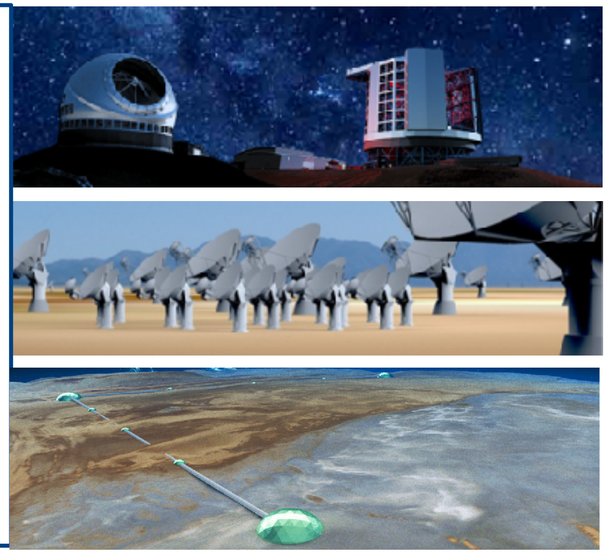
1. **Once construction has started within the MREFC account, the NSF has a great track record of delivering BIG state-of-the-art facilities.**

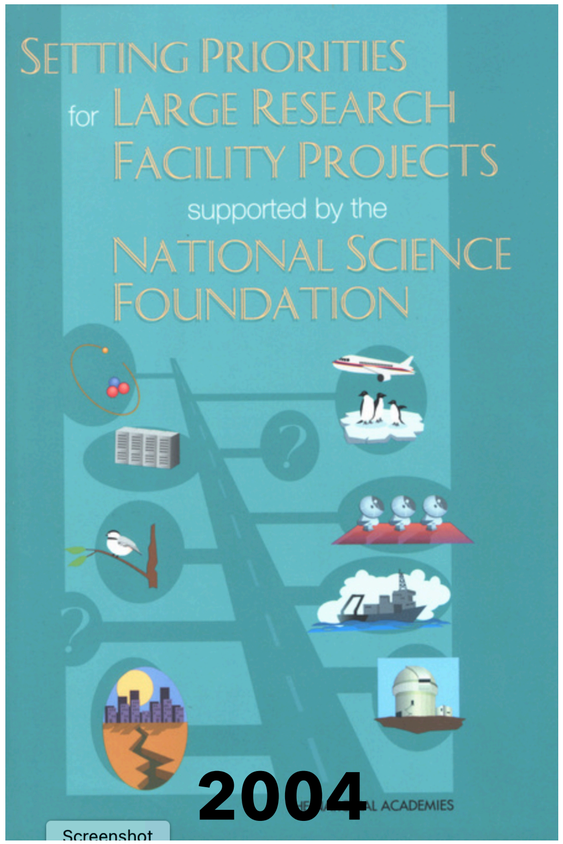
Through the MREFC account, the NSF can enable the scientific infrastructure the U.S. will need in the 21st Century.

To remain globally competitive in 2030 - 2040, the expected scale of NSF investment in the next generation of large astrophysics facilities

USELT Program	$2B to $3 billion
ngVLA	>$2.5 billion
Cosmic Explorer	>$2 billion

$2B - $3B per project





The National Science Board should oversee a process whereby the National Science Foundation produces a roadmap for large research facility projects that it is considering for construction over the next 10- 20 years.

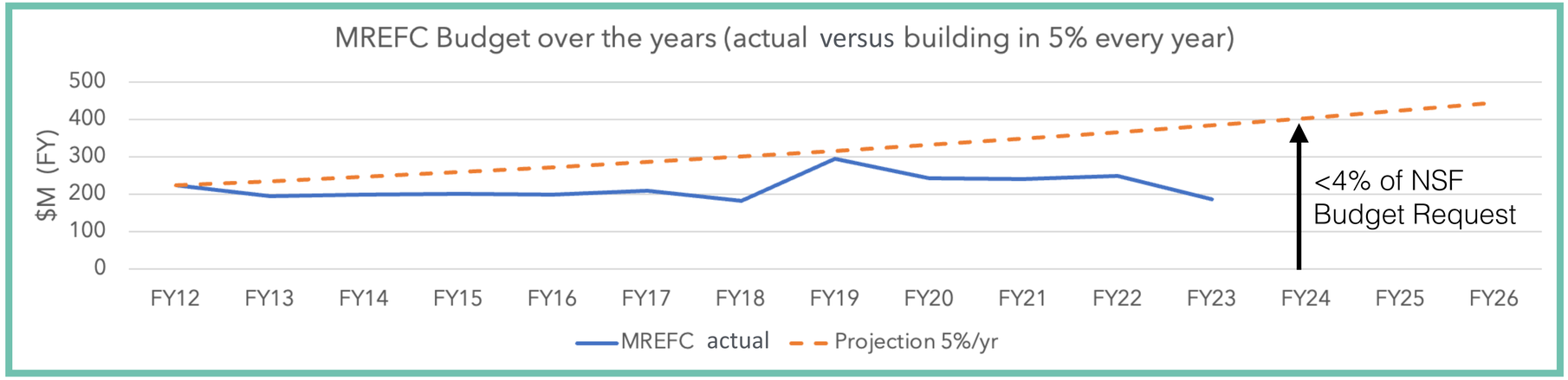
2. However, to remain globally competitive, billion-dollar science infrastructure must be planned strategically:

Appropriate levels of design & development funds to reduce risk

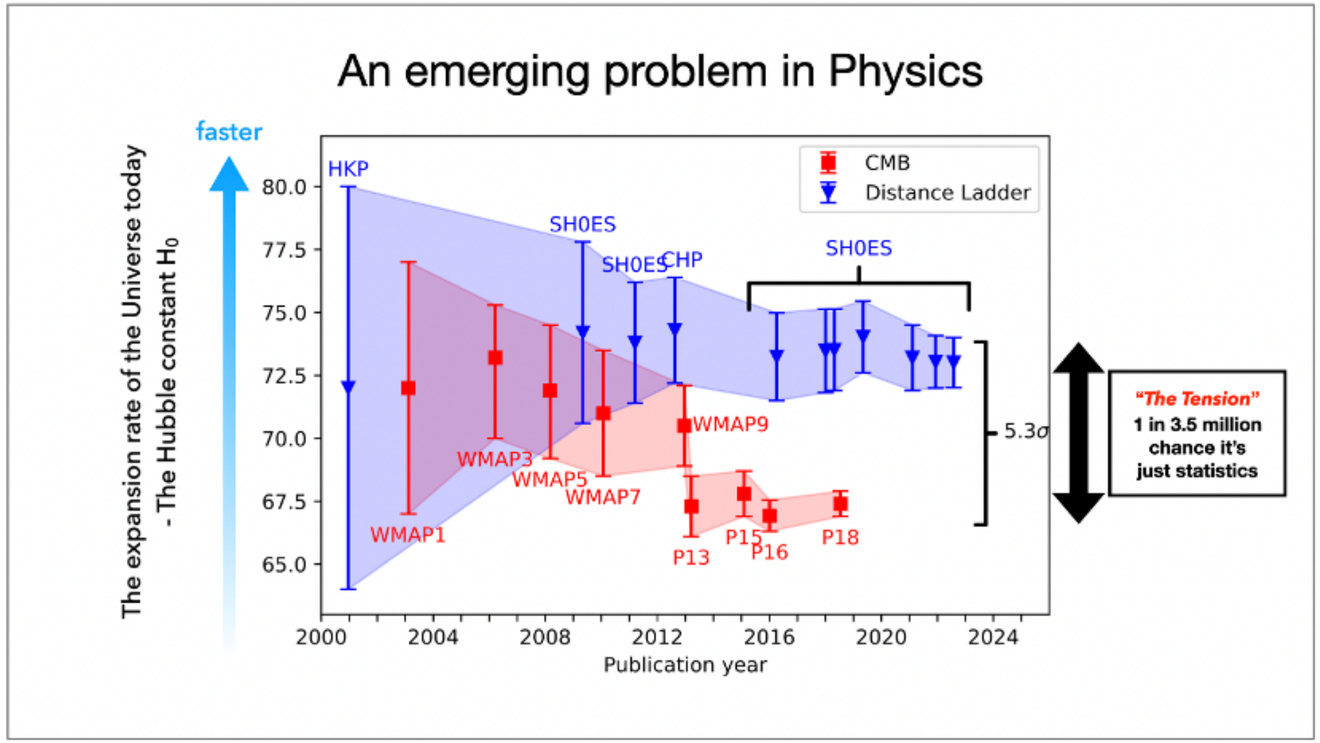
Billion-dollar projects cannot be "reacted to"; they have to be anticipated. 6, 7, 8 years is too long "to get into the MREFC queue."

Projects must be "racked and stacked" to ensure the U.S. Congress gets a framework for the scale of the forward investments that will be required, **prior to approval**

- the U.S. Congress has consistently funded NSF's MREFC requests

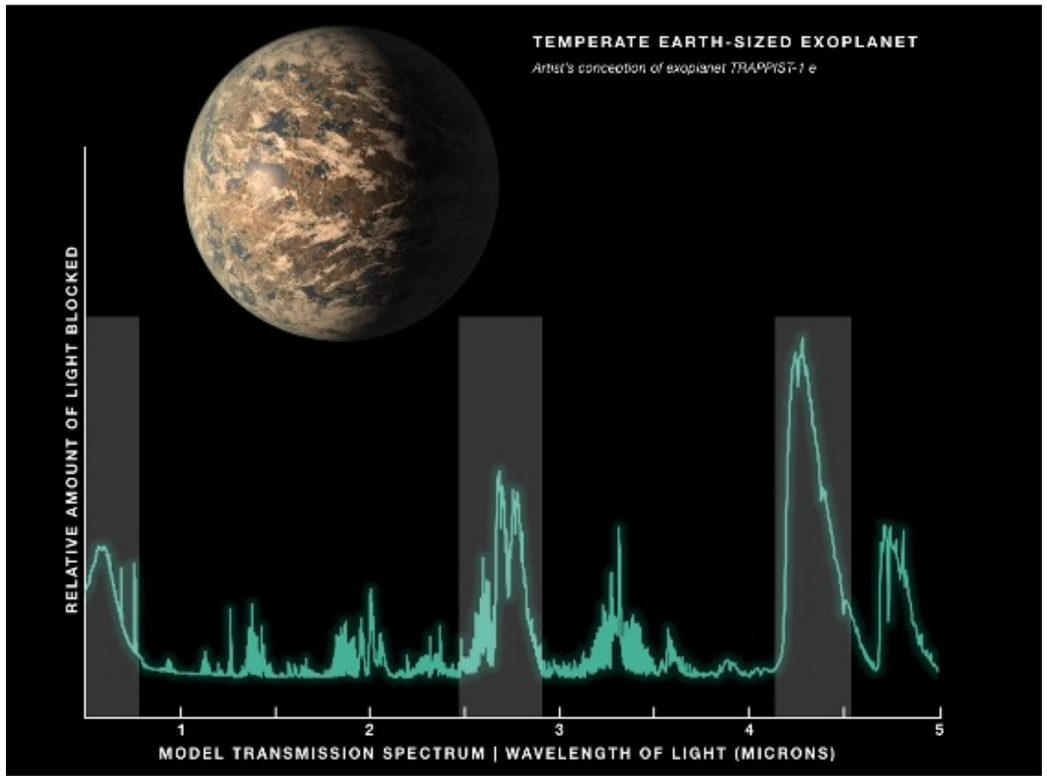


3. The science and questions ahead of us in astrophysics are extraordinarily compelling



Evolution of the Hubble tension (determinations of the Hubble constant) in the last 23 years using direct measurements from the distance ladder in the local universe (in blue) and models based on the early universe cosmic microwave background (CMB) (in red). The tension is the gap between the two measurements which is growing and is now statistically significant. Image Credit: D'arcy Kenworthy

Our picture of our evolving Universe may be incomplete
- can we resolve the emerging "crisis" in Lambda-CDM cosmology?



And perhaps, within the 2030s, we will become that privileged generation that discovers life has arisen and biological evolution has occurred elsewhere in the Universe?

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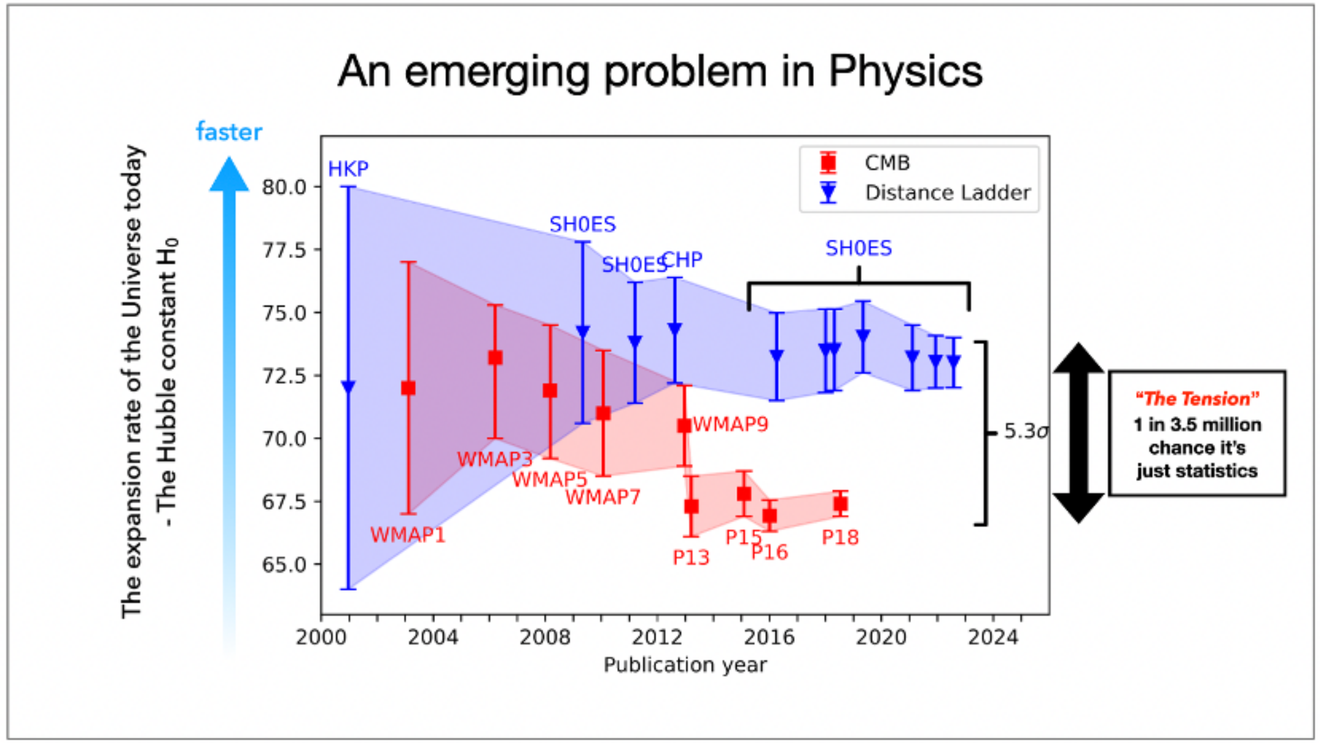

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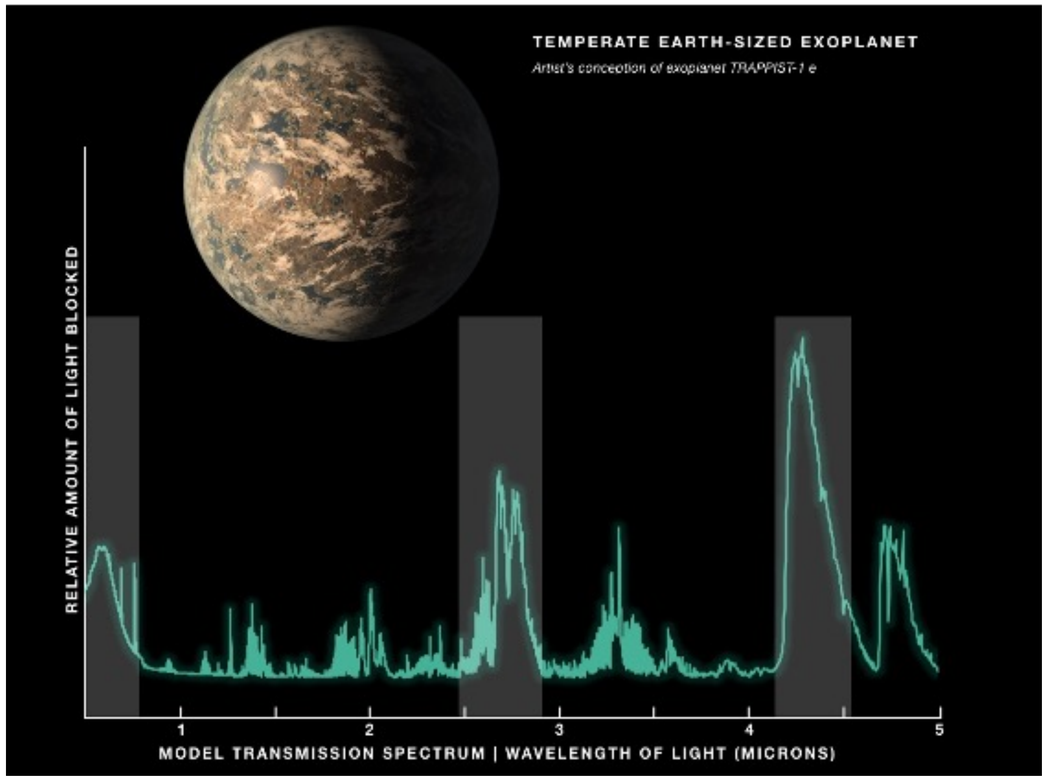
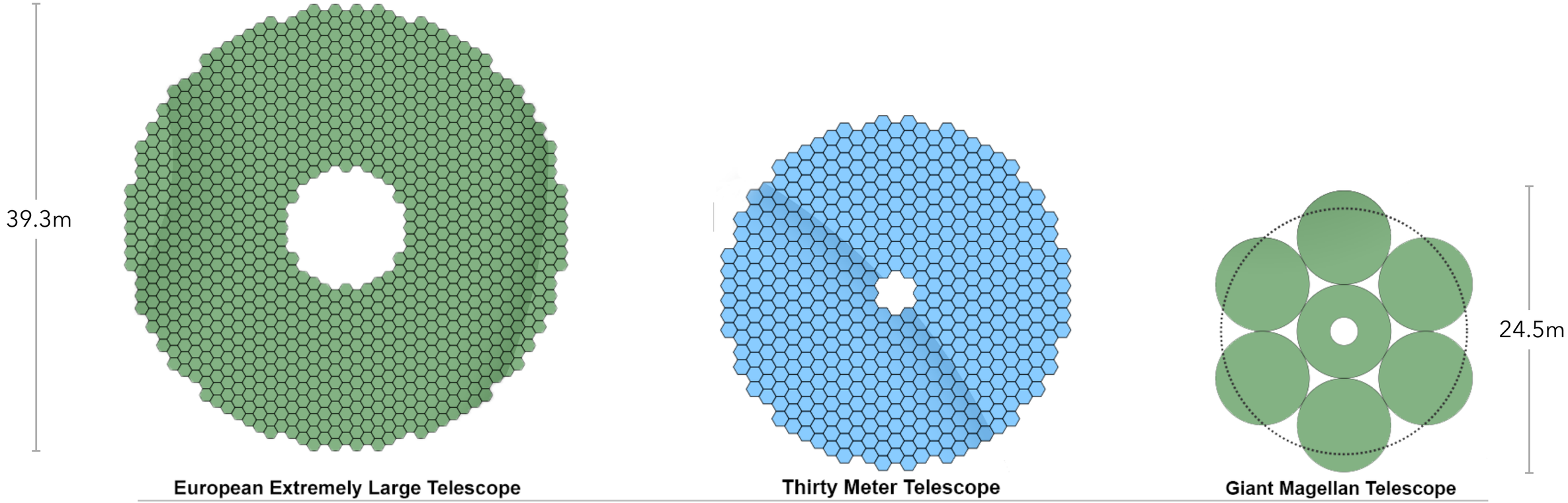


And perhaps, within the 2030s, we will become that privileged generation that discovers life has arisen and biological evolution has occurred elsewhere in the Universe?

The NSF is now the indispensable Agency to ensure the U.S. astrophysics community and the American people have the possibility to lead the quest to answer such profound questions

Back Up

Extremely Large Telescope (ELT) global landscape



ACCESS ~ 3,400 on-sky hrs/yr

"If an ESO member state proposal and a non-member state proposal are rated equally, preference will be given to the ESO member state proposal" Page 29 of http://www.eso.org/sci/observing/phase1/p101/CfP101.pdf

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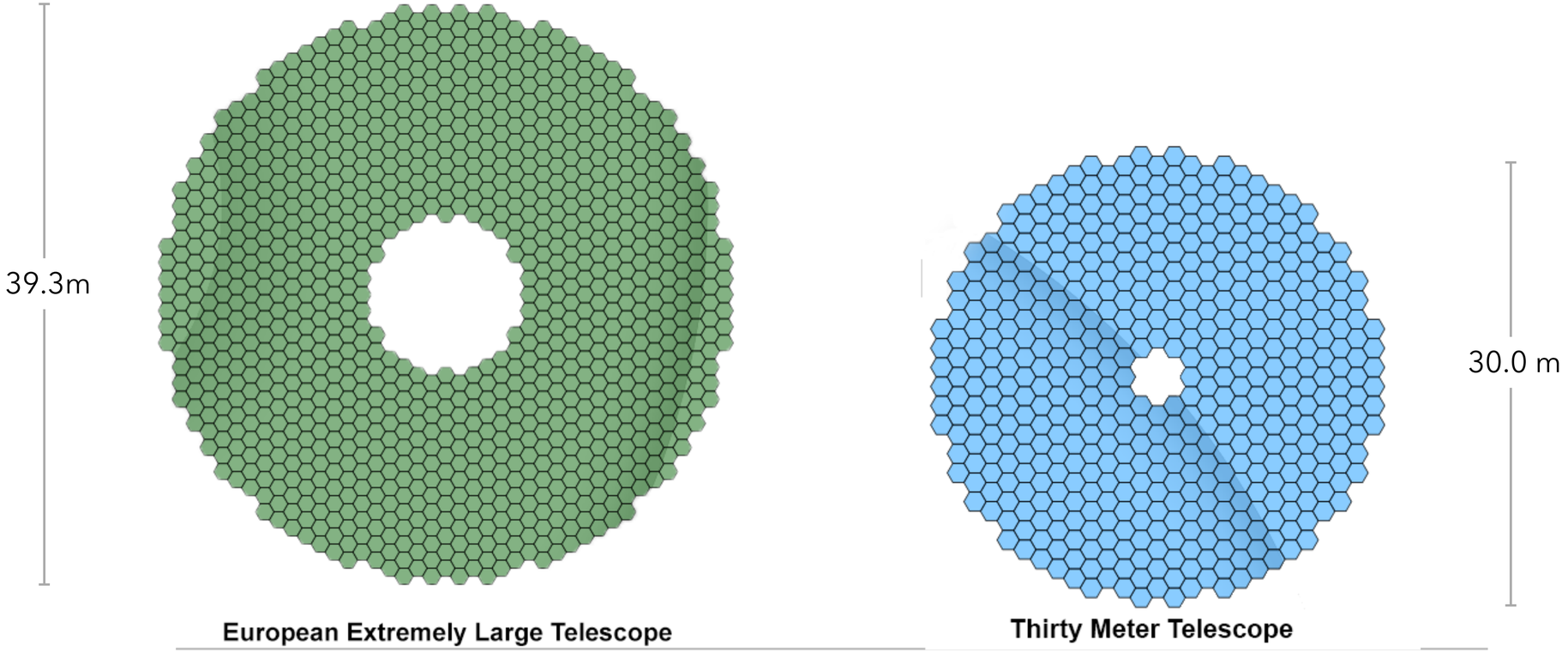

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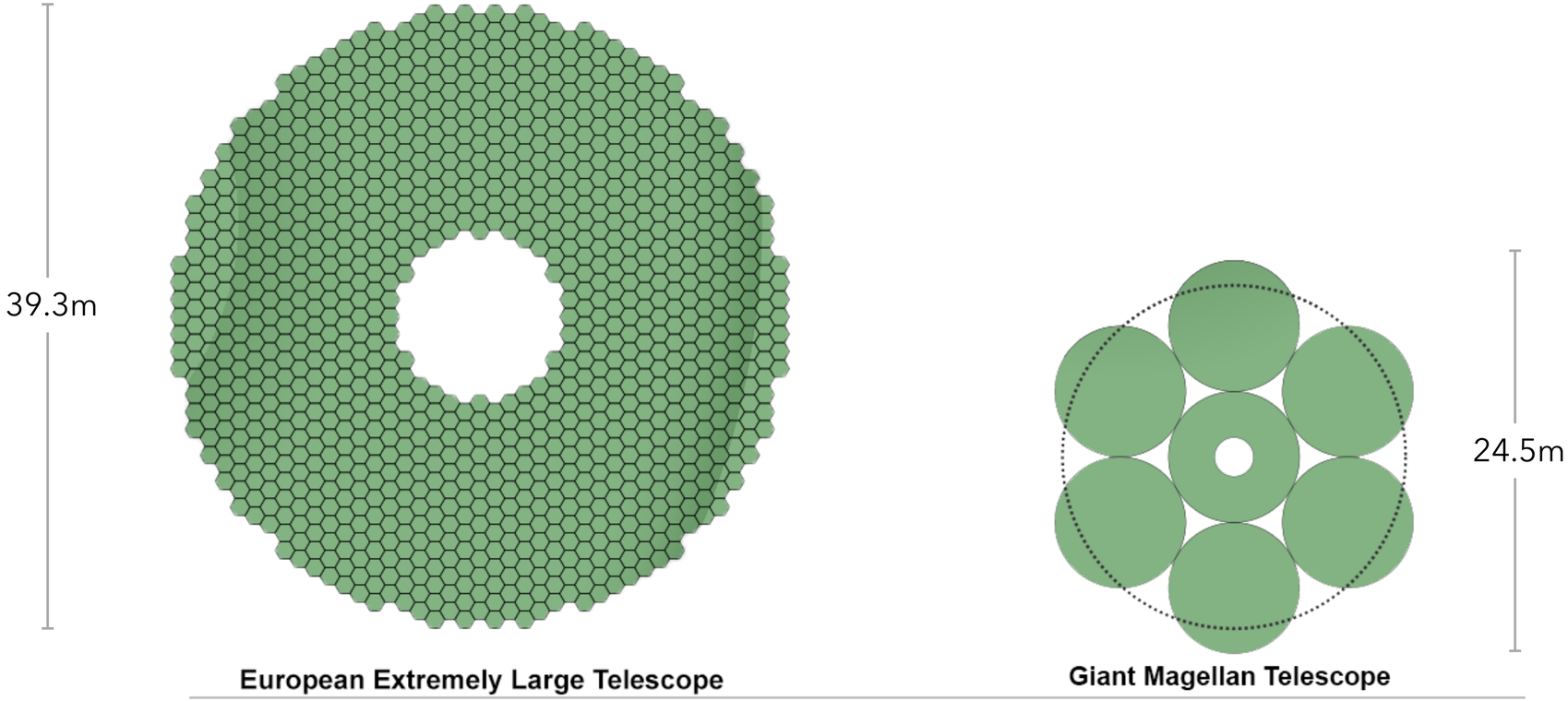

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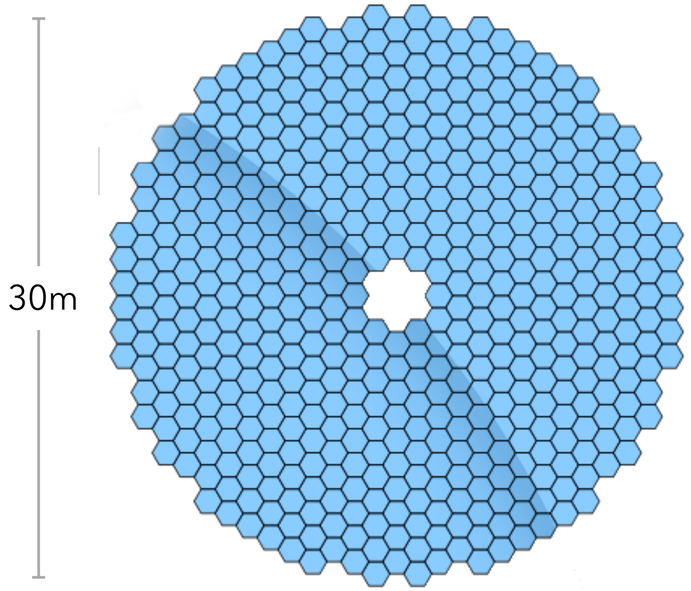
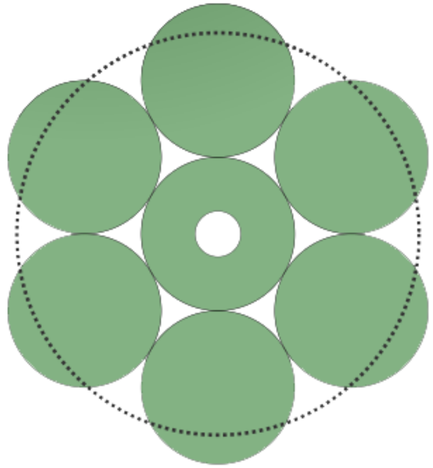
The US Extremely Large Telescope Program



Thirty Meter Telescope



Giant Magellan Telescope

THIS IS A COMPETITIVE SYSTEM

BI-HEMISPHERIC ~ 6,800 on-sky hrs/yr

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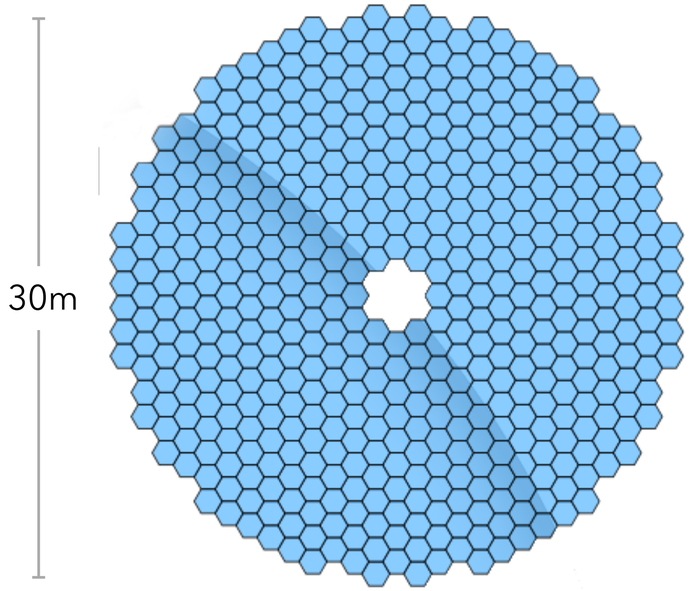

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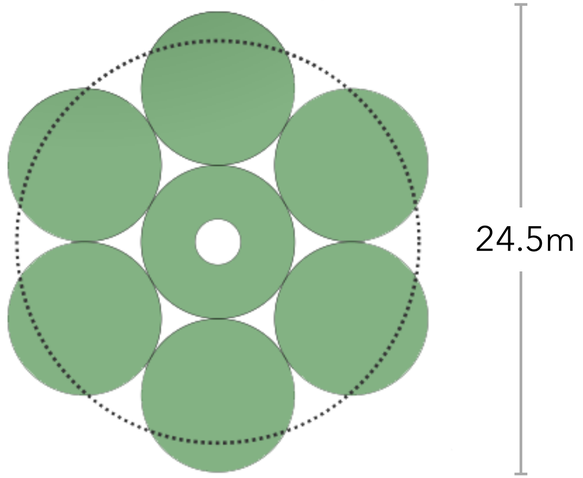

Giant Magellan Telescope

THIS IS A COMPETITIVE SYSTEM

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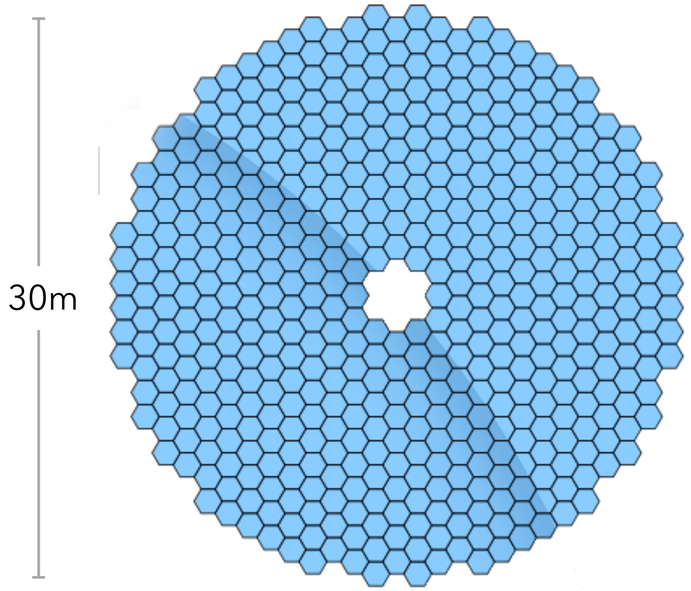
AURA has agreed to work with ***both*** Projects to bring a single, coherent multi-hemisphere US-ELT Proposal forward to the US Decadal Survey

The US Extremely Large Telescope Program



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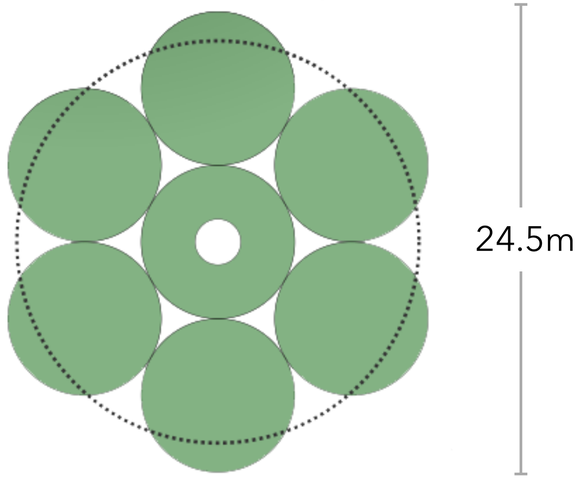


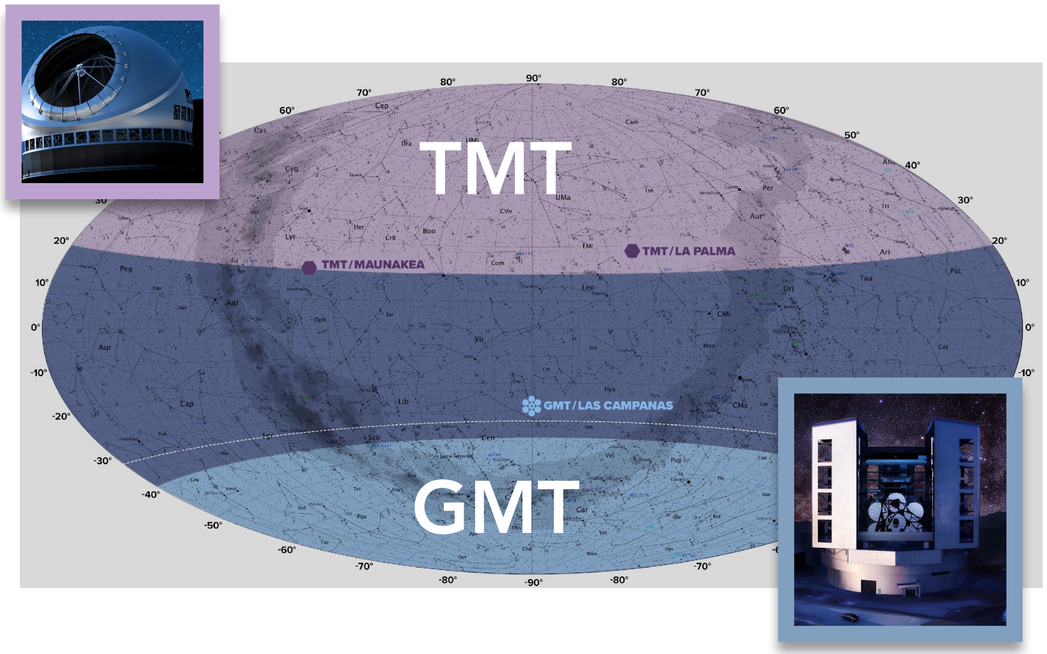
Giant Magellan Telescope

THIS IS A COMPETITIVE SYSTEM

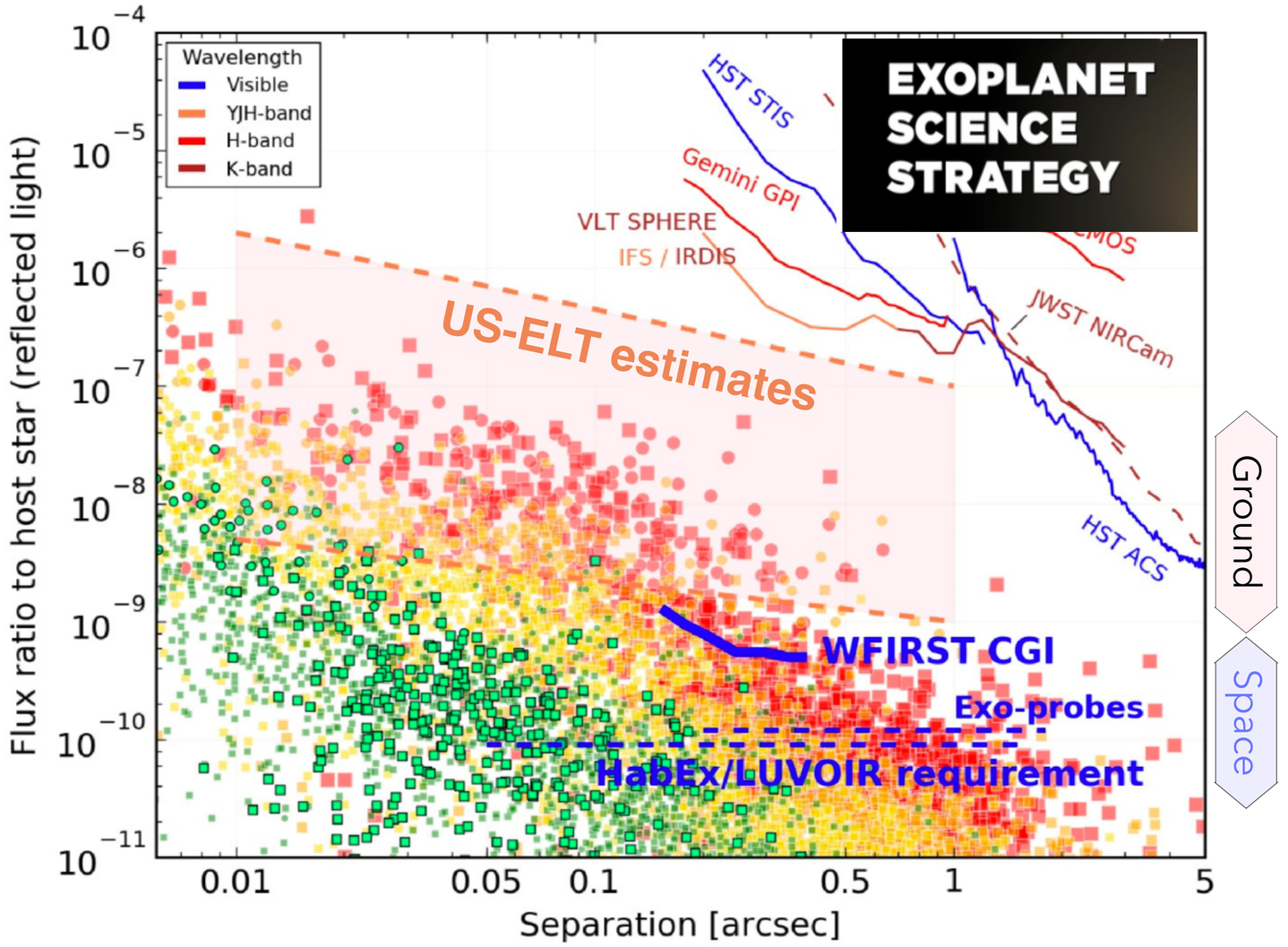
BI-HEMISPHERIC ~ 6,800 on-sky hrs/yr

AURA believes this is the *most scientifically effective, and timely* investment available to the National Science Foundation, leveraging considerable non-U.S. Federal contributions to ensure a globally competitive future for the broad U.S. astronomical community

The emerging global consensus: 20m - 40m Extremely Large Telescopes are the future of optical/IR ground-based observational astrophysics



"To expand that sample will require the spectroscopic sensitivity of ground-based 25-40 m extremely large telescopes (ELTs)." ASTRO2020 1-4



Earth-like planets around warm Solar-type stars (T_{eff} > 4,000K)

Earth-like planets around cool M-type stars (T_{eff} < 4,000K)

Warm Earth-like planets