
# CAA – Dec 1, 2022

Debra Fischer

NSF MPS/AST DD

1. Astro2020 Major facility update
2. NSF existing facility news
3. Updates on Grants program
4. New opportunities – national security
5. Astro2020 progress
6. AST Budget update
7. Closing thoughts on Communication

# Astro2020 major facility recommendations

1. *"NSF should invest in at least one and ideally two Extremely Large Telescopes (GMT and TMT) with a target level of at least 25% of the time on each telescope. If only one project proves to be viable, NSF should invest in a 50% timeshare."*

2. *"The NSF and DOE should pursue design and implementation of the next generation ground-based Cosmic Microwave Background experiment (CMB-S4)."*

   *"The NSF should proceed with a program to support science design, development, cost studies and antenna prototyping for the next generation very large array."*

# Are these investments that we should consider?

## Is there a role for the Nation in these facility recommendations?

- Ensure US leadership and scientific competitiveness
- National Service (GPS, Near Earth Asteroids, space weather)
- Develop workforce – not just for astronomy, but for the nation.

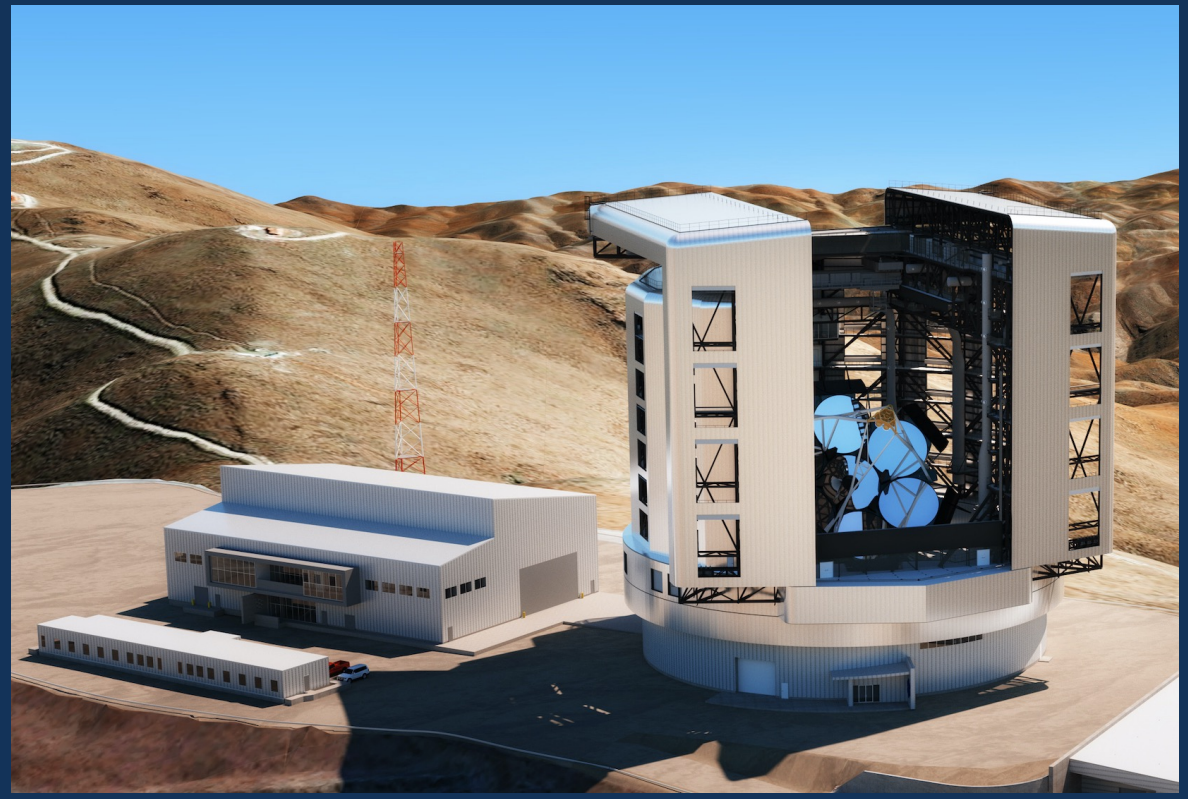
## A role for the federal government?

- Too big for states or universities
- Partnerships with other countries, agencies, national defense

## A role for the NSF?

"To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense…."

- Leader in ground-based astronomy
- Broaden participation – STEM for the missing millions.
- Access to facilities for all astronomers



The existing suite of ground and space-based astronomical telescopes have allowed scientists to glimpse amazing phenomena in the universe, but our data are biased by small number statistics of the nearest and brightest objects. The next generation of ELTs will see further and with greater resolution.

# ELTs

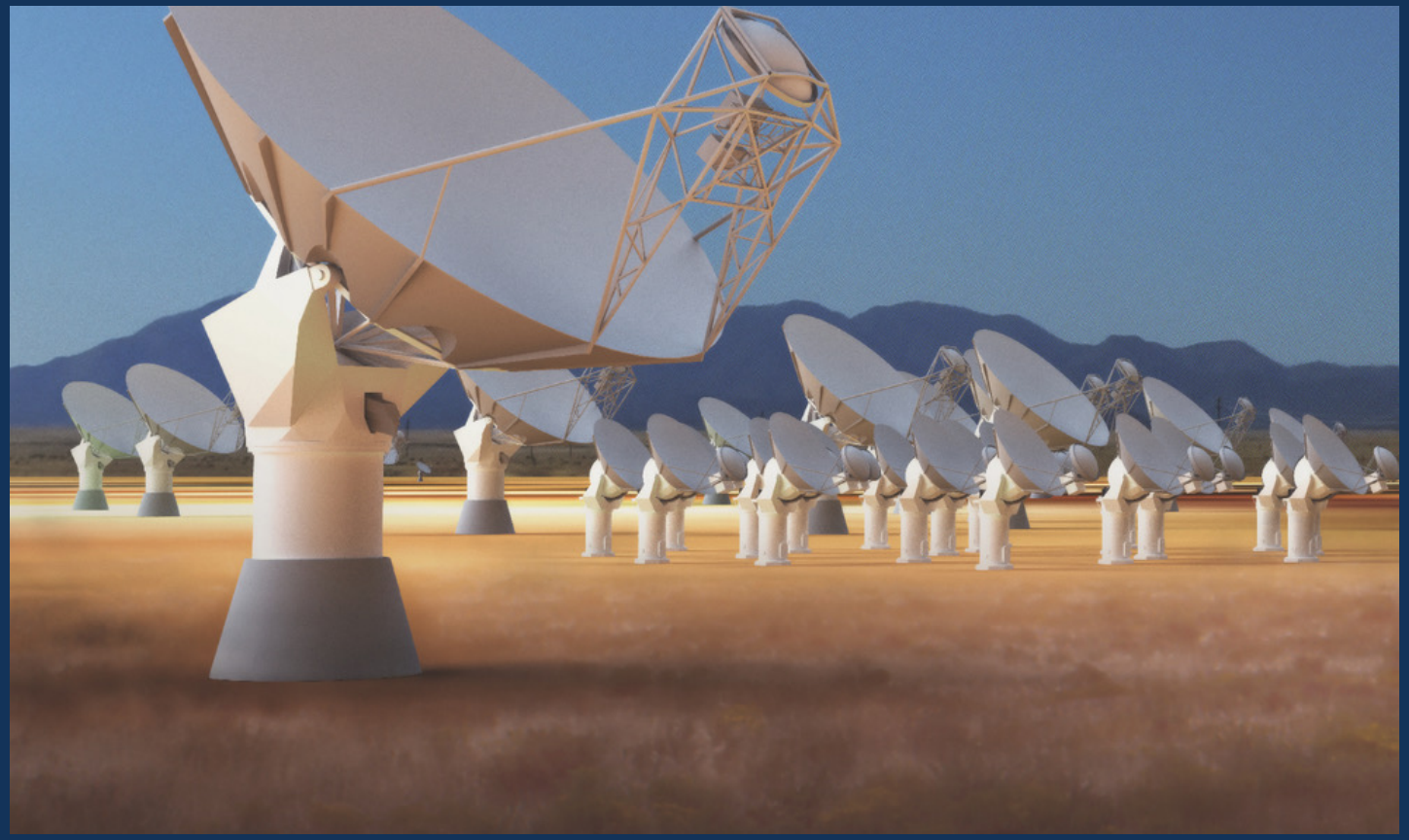
- A decision has not yet been made regarding a potential partnership.
- Regular (weekly+) engagement between NSF and the GMT and TMT teams; both projects are technically advanced
- Working with NOIRLab to define their role in data management for a US-ELT program.

# Status of Maunakea and TMT

We have been engaged - in discussions within NSF, with other Maunakea Observatories, with members of the Native Hawaiian community, and with the Institute for Astrophysics at the University of Hawaii about astronomy on Maunakea.

State of Hawaii is moving the management of Maunakea to a new Oversight Authority: 11 members representing a broad range of interests and expertise including the traditions and culture of Native Hawaiians. NSF issued a notice of intent to prepare an Environmental Impact Statement and initiated Section 106 Consultation with public scoping meetings and comment period. This is now paused as we wait to have meaningful engagement with the new Authority.

NSF is committed to building a stronger relationship with the Hawaiian community.



Cosmic Microwave Background – Stage 4 (CMB-S4) probe the earliest moments of the universe, trace seeds of galaxy formation. (50% split w/DOE)

Next-Gen Very Large Array (ngVLA) formation and orbital motion of planets and complex pre-biotic molecules, chart assembly, structure and evolution of the earliest galaxies, formation and evolution of black holes, Earth orientation (GPS and global navigation satellites).

# CMB-S4

- A decision has not yet been made regarding a potential partnership.
- Team has been funded to develop alternative designs with different infrastructure footprints at South Pole.
- Regular engagement between NSF / DOE / OPP

# ngVLA

- A decision has not yet been made regarding a potential partnership.
- Prototype ngVLA antenna nearly complete.
- Internal NRAO preliminary design review for ngVLA antenna in Dec 2022
- NRAO design and development program office funded for FY23.
- MOU between NRAO and UNAM for ngVLA activities signed Nov 2022.
- Regular engagement with ngVLA team and NSF to develop

# AST Facility Updates
# Radio, OIR, Solar

# The Arecibo Observatory

| | | |
|---|---|---|
| November | 2020 | Plan to decommission the 305-meter due to safety concerns |
| December | 2020 | The 305-m telescope platform collapsed |
| January | 2022 | National Academies committee begins study regarding Causes of Failure and Collapse |
| March | 2022 | Emergency Cleanup complete; Science and Visitor's Center reopened ~2 years of shutdown |
| August | 2022 | Thornton Tomasetti Forensic Investigation complete |
| October | 2022 | The Arecibo Center for STEM Education and Research (ACSER) solicitation released: NSF 23-505 |

*The proposed re-imagined Center would have a significant role in modeling and advancing equitable and inclusive STEM education and research, especially in Puerto Rico and for individuals and communities underrepresented in STEM*

- NSF is conducting a search for a third-party site contractor – 8(a) Business Development Program
- NSF is closing out the current cooperative agreement with UCF (ends on March 31, 2023) and plans to extend award period through 30 September 2023 to support a smooth transition
- Current scientific activities at AO use archival data and ancillary instrumentation

*https://www.nsf.gov/news/special_reports/arecibo/*

# NSF Center for Advanced Radio Sciences and Engineering

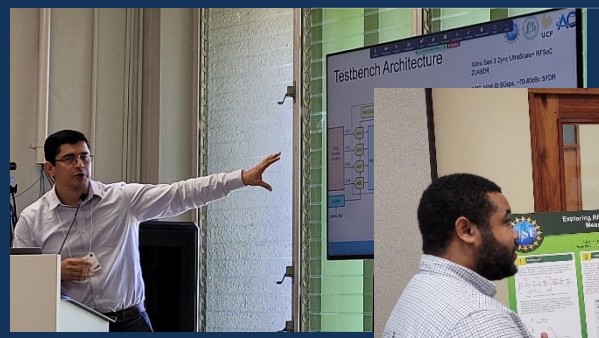
- Director: Rafael A. Rodríguez Solís

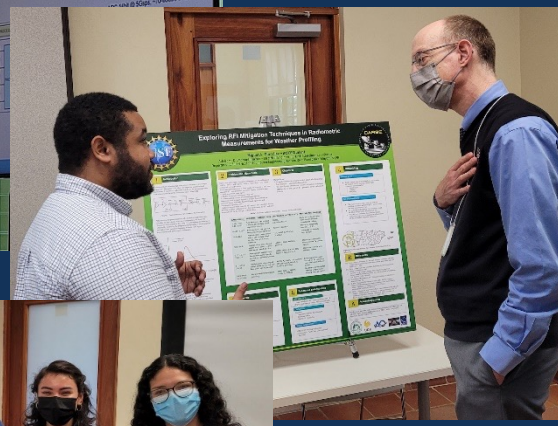
The University of Puerto Rico at Mayagüez (UPRM), partnering with Arecibo Observatory via the University of Central Florida (UCF), Resonant Science, LLC, and the National Radio Astronomy Observatory (NRAO)

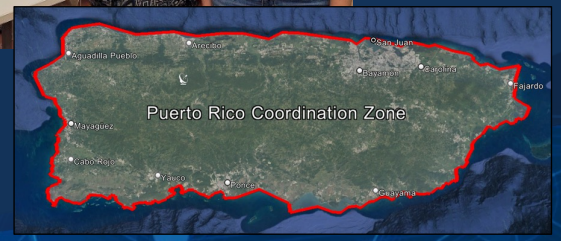
- **Science:** Develop integrated tools to resolve spectrum sharing and coexistence issues, and improve performance on radio science observations

- **Education, Outreach and Workforce Development activities**: partnership with the UPRM Centro Universitario para el Acceso (CUA) and the NRAO Radio Astronomy Data Imaging and Analysis Lab (RADIAL) Project.

**Environment**: Situated in the Puerto Rico Coordination Zone, CARSE could leverage a unique spectrum environment toward research and educational advantage.





ALMA suffered a cyberattack on 29 October, forcing the suspension of astronomical observations.

- The attack was contained and no science data or antennas were compromised.

- ALMA staff continue to restore their systems, with science operations returning to normal as soon as possible.

# Rubin Observatory

- EPO construction essentially complete (EPO closeout review taking place now).
- Telescope mount assembly is nearly complete.
- LSSTCam is fully assembled at SLAC, with final pre-ship testing set to occur in early 2023 using the new pumped coolant system.
- Still aiming for completion in 2024.

# NSF-Simonyi Scholars

New partnership with Charles Simonyi, supporting early career astronomers with research that supports Rubin science.

- Proposals (e.g. CAREER, AAG) are evaluated through regular merit review process.
- Research connected to Rubin Observatory (theory or observation) will be identified as eligible by program officers and will receive 50:50 support by NSF and Simonyi award.
- Up to $2M awards / year for up to 10 years, doubling the impact of AST in supporting research related to Rubin science.

# Gemini-N Primary Mirror Incident

- Oct 20, 2022, the Gemini-North primary mirror suffered damage during recoating activities.
- No-one was injured during this accident.
- The damaged area of the mirror is outside the clear aperture used for observations.
- Operations are suspended; NOIRLab staff performing an investigation into how this event occurred, what can be done to prevent similar events in the future, and what steps are necessary to return Gemini-North to normal science operations. The process will proceed at a deliberate and careful pace; the primary concern is staff safety.
- NOIRLab convened an Independent Review Board to review root cause and to advise Gemini on the best approach to repair the mirror.
- The timescale for Gemini-North's return to operations will be determined by the findings of the investigation and the repair plans, but semester 2023A (Feb-Jul) proposals are being reviewed earnestly. High-priority 2022B programs will be transferred to Gemini-South where possible or retained for future completion.


# Kitt Peak Contreras Fire

- **Power**: Main power reinstated
- **Internet**: fiber installed this week
- **Operations**: Mayall 4.0-m and WIYN 3.5-m telescopes have been operating, with some time lost periodically because of power issues.
- **Summit Access**: the road is open to observatory staff, but will remain closed to the public through the winter.

# Maunaloa volcanic eruption

- NSO GONG station closed, not impacting Maunakea telescopes at this time.

# AST Grants Program Updates: faster turn around and more inclusive

# Conflicts of interest can be program-wide, panel-level or proposal-level. Negotiated more flexibility on “conflict of interest” with OGC to increase pool of expert panelists.

| OLD | NEW |
|---|---|
| Proposers to AAG program had **program-wide** CoI and could not serve on any panels in the AAG program. | Proposers to AAG program now have **panel-level** CoI and can serve on panels that are not reviewing their proposal. |
| Institutional CoI had **panel-level** CoIs. | Institutional CoI are now just **proposal-level** and step out of room for proposals from their institutions. |
| Top 3 co-authors had **panel-level** CoI | Co-authors no longer have assumed CoI and are asked to self-identify any CoI. |

Modified “NASA-centric” exclusions in solicitation.

- “NSF strives to allocate federal funding to maximize scientific discovery in coordination with other funding agencies, but do not want to penalize proposers for using the best data sets for their science.”
- Removed ”return without review” for proposals using NASA data.
- Ask proposers using significant NASA data to include section explaining why this is required to advance goals of an NSF proposal.
- Eliminated prohibition of AAG proposal submission from researchers at NASA centers or FFRDCs.

## Shorten timeline to decision and notification.

1. Calendar benchmarks for programs.
2. Shorter timeline to setting up panels with relaxed CoI.
3. Reduce some non-essential documentation.
4. Encourage triaging of proposals – spend less time with bottom third (non-competitive) after reviewer ranking. Panelists can always request full consideration of any of these proposals.

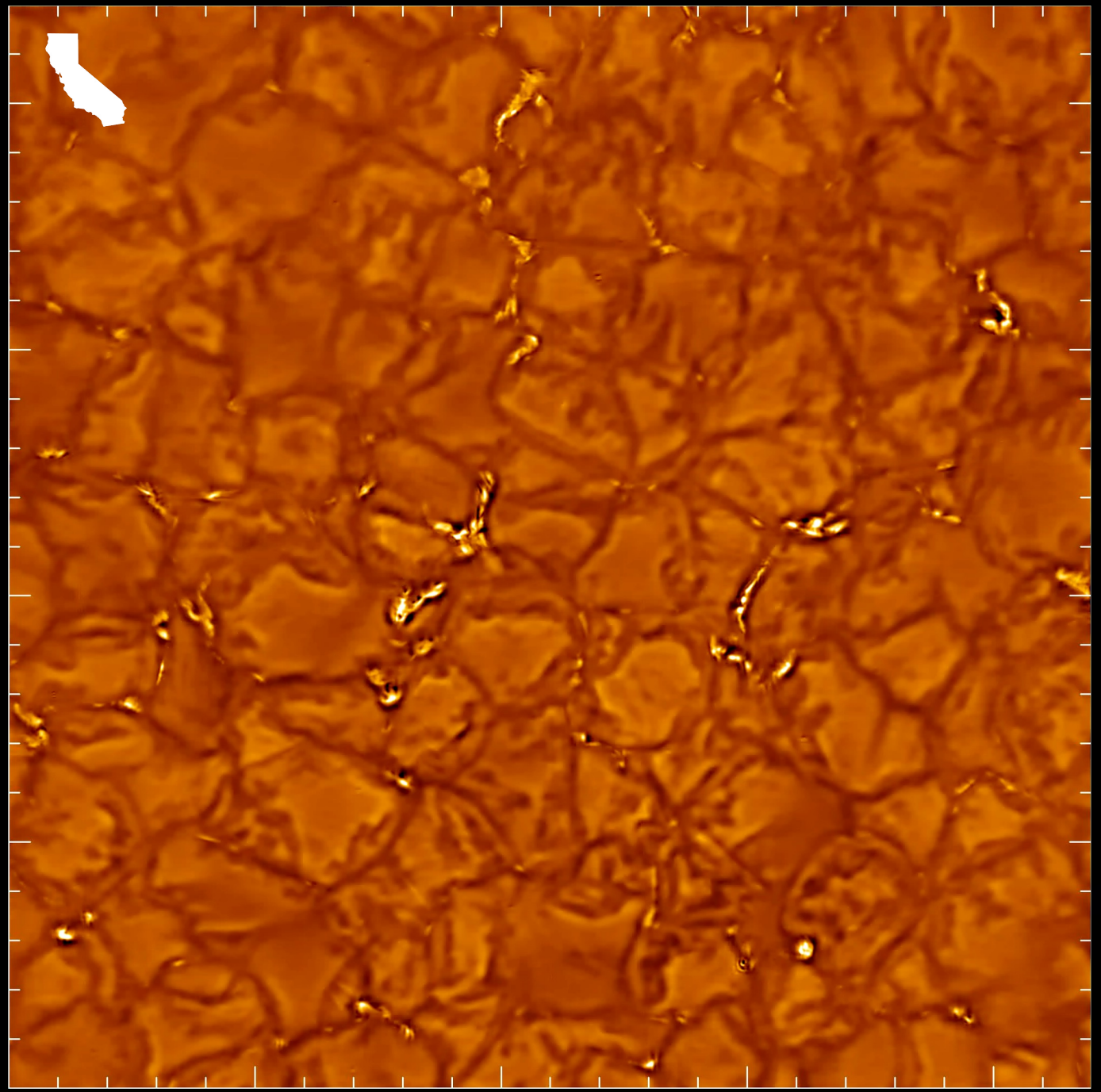
# AST New Opportunities

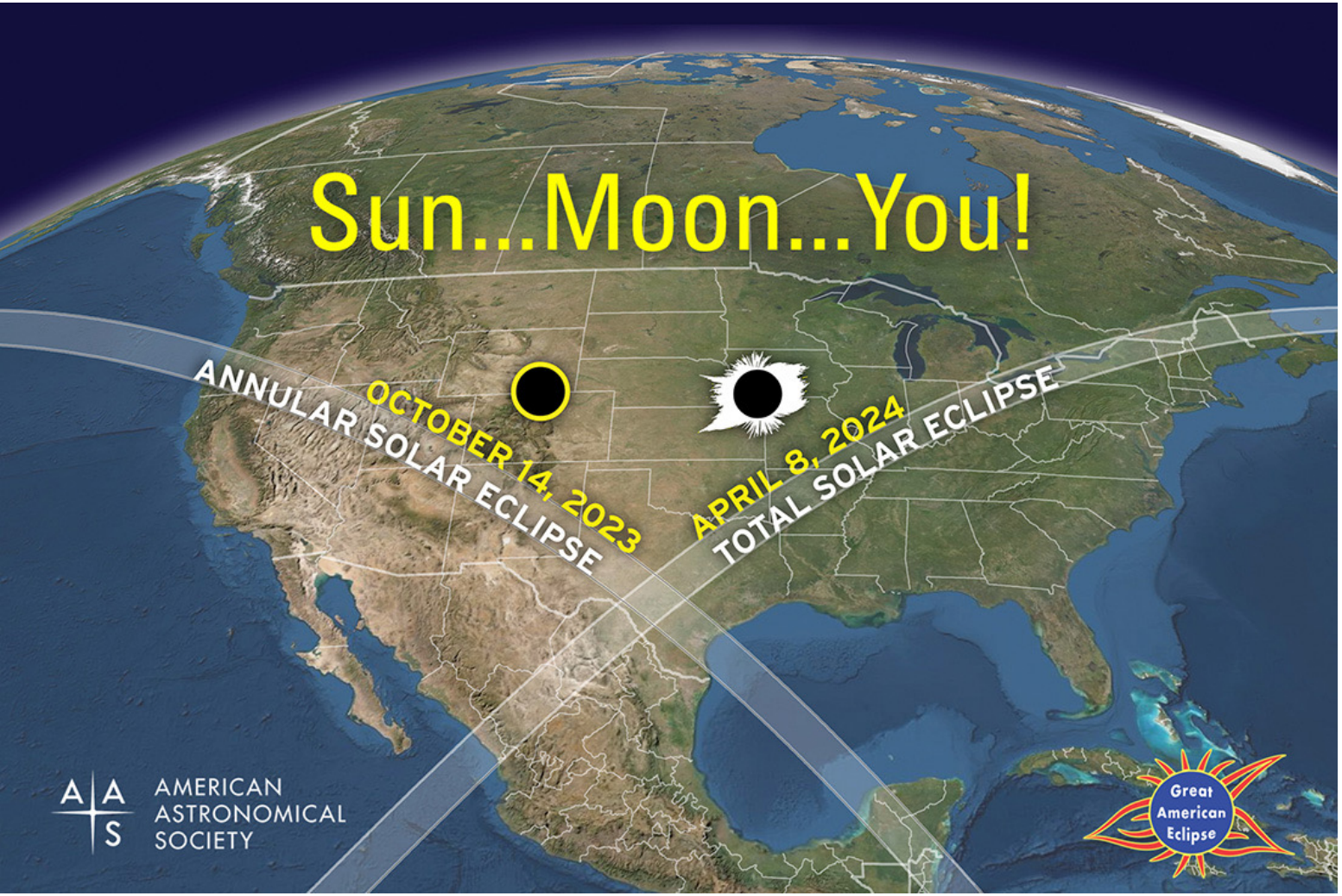
# Making solar astronomy “whole”.

| | |
|---|---|
| Daniel K. Inouye Solar Telescope | The largest, most powerful solar observatory on planet Earth, but high spatial resolution and small FOV |
| GONG network | Full disk imaging to track solar activity and space weather. Critical information for protecting electric grid. We need to start planning for ngGONG now (potential partnership with NSF GEO, NOAA) as a matter of national / global security. |

# DKIST

- Short video clip from observations – May 27, 2022
  - VBI Blue – 430 nm
  - 4.5 sec = 8.3 min on Sun
- Bright points are concentrations of high magnetic flux






# Solar eclipse 2024:

An opportunity to excite interest in STEM. Developing educational packets with protective filters and gratings.

NSF, NSO, NOAA, NCAR, AAS, ASP, coordinating with philanthropic groups (Simons Foundation and others).


Credit: DOE/FNAL/DECAM/CTIO/NOIRLAB/NSF/AURA/J. DA SILVA/SPACEENGINE

# Planetary Defense

Aerospace study supported by AST and NASA PSD (assess ground and space-based capability). USSF is potential partner.  Potential matter of national / global security.

A team using DOE-built DECam on Blanco discovered three new near-Earth objects (NEOs) hiding in the inner Solar System, the region interior to the orbits of Earth and Venus. Only a few dozen of these near-sun NEOs are known. One of the newly discovered objects is a 1.5-kilometer-wide asteroid called 2022 AP7, which has an orbit that may someday place it in Earth's path.

# Astro2020 updates

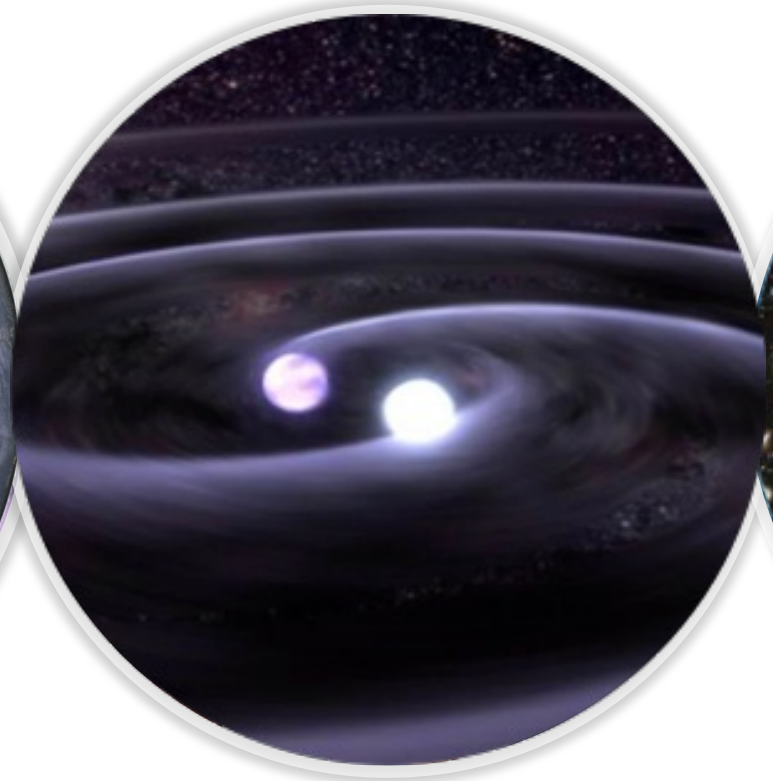
# Astro-2020 Science-centered

Astro2020 describes a pathway to major scientific breakthroughs that will impact the lives of our citizens and other scientific disciplines.

# Astro 2020 Science:

## Three science themes addressing fundamental and profound questions for humanity and for understanding our place in the space and time of the Cosmos.

A step-by-step path to discovering habitable worlds and life elsewhere.



Time-domain multi-messenger astrophysics to trace the earliest stages of the observable universe

Formation and evolution of stars and galaxies from the Big Bang to today

# Recommendations: Develop the Workforce

*Increase funding incentives for improving diversity among college/university astronomy faculty (e.g. number of awards for development and retention of early-career faculty).*

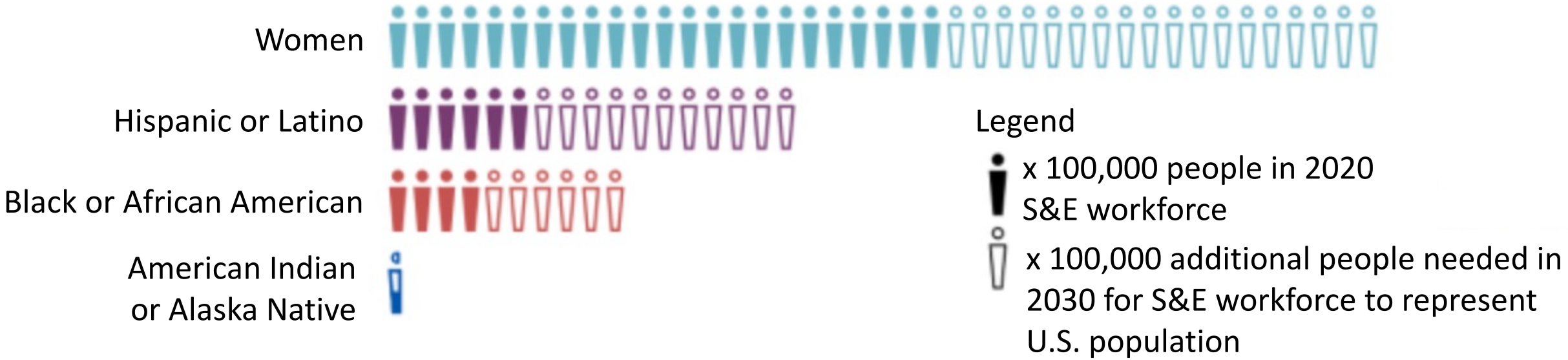
*Pipeline transitions are loss points: support creation and continued operation of "bridge" type programs.*

*Provide undergrad and graduate "traineeship" funding for professional workforce development.*

*Support postdoctoral fellowships that provide independence and encourage development of scientific leaders.*

*Include diversity of project teams and participants in evaluation of funding awards to PIs, projects, teams, and organizations that manage facilities.*

# NSB: Faster progress increasing diversity is needed to reduce significant talent gap.




The qualities that make great scientists are not linked to gender, race, ethnicity, country of origin. They are linked to opportunities and inclusion.

NSF must partner with universities to support research and training.

# Examples: MPS-ASCEND

*Natalie Nicole Sanchez*

*Aaron Stemo*

*Raquel Martinez*


*Erin Cox giving her firs conference (June 2022)*

| | Description | FY22 |
|---|---|---|
| PAARE | Partnerships in Astronomy & Astrophysics Research and Education | 10 |
| REU | Research Experience for Undergraduates | 7+3 |
| GRFP | Graduate Student Research Fellowships Program | 51 |
| *ASCEND* | MPS: postdocs with potential to broaden participation | 4 |
| *LEAPS* | MPS: early career faculty at institutions with little NSF STEM funding | 3 |

# Examples: Partnerships in Astronomy & Astrophysics Research and Education (PAARE)

| | Description | FY22 |
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*University of Texas Rio Grande*

*City University of New York*

AstroCom NYC program

We support CUNY students up to the challenge to join this exciting community of New York City astronomers.

Eligible students may apply now at https://bit.ly/2QIYblo.

*Deadline: Fri, Oct 14, 2022*

*California State University Fullerton*

The PAARE program provided $5.4 million in grants to support 10 programs in 7 states and Puerto Rico. Supports students in undergraduate and graduate programs and on the path between. Enhance and develop research capability at minority-serving institutions, provide student traineeships and diversify the astronomy workforce.

# Recommendations: Collect and Report Demographic Data

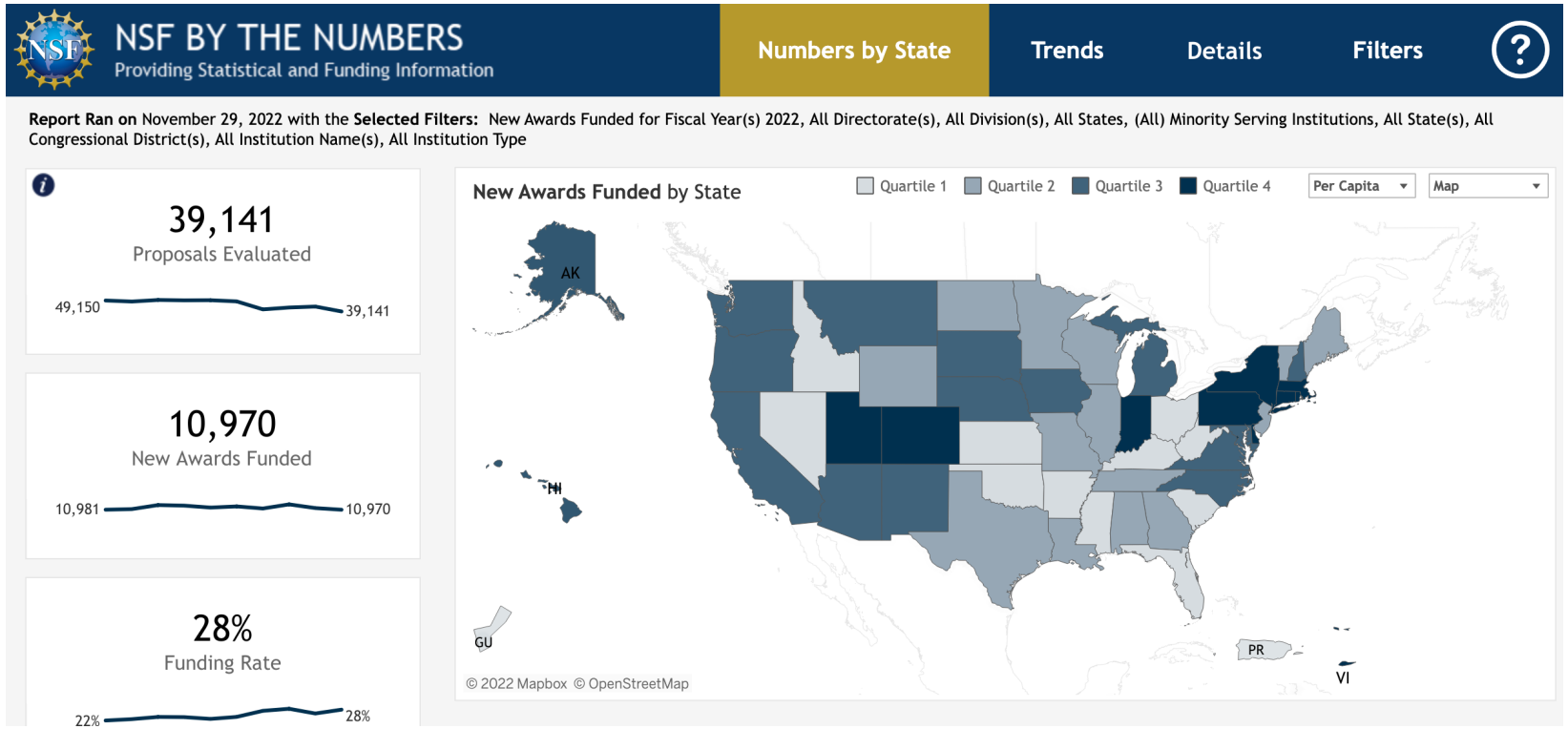
*Ensure that scientific integrity policies address harassment and discrimination as forms of research/scientific misconduct.*

*Establish a cross-agency committee or working group for collecting, evaluating and publicly reporting demographic data pertaining to proposal competitions.*

*NSF (and NASA and DOE) should release data on proposal success rates on annual basis and track metrics that allow statistical analysis of what is being supported.*

# NSF By the Numbers: web interface to Tableau data visualizations.

- Information is aggregated for all of NSF, and can be resolved by Directorate (e.g., MPS)
- Working on how far down this can be divided before identifiable information released.
- There is missing context and some nuance that is important for small number statistics (e.g. no “Return Without Review” or holds on declines)



# Recommendations: Protect the Skies

*Work with federal regulatory agencies to develop a regulatory framework to control impacts of satellite constellations on astronomy and the night sky. International issues.*

*Avoidance and mitigation of radio-frequency interference. Seek spectrum allocations to radio astronomy in bands above 95 GHz with international coordination.*


# Radio Spectrum Management and Addressing the Impact of Satellite Constellations (existential threat for astronomy):

- NSF led U.S. astronomy community input for four new ITU-R reports (three address >95 GHz)
- Updated Coordination agreement with SpaceX (details forthcoming at January AAS meeting)
- Continued support:
  - National Academies Committee on Radio Frequencies (CORF); WRC-23 views report and FCC filings
  - U.S. delegations to U.N. COPUOS and ITU-R
  - Support of SpectrumX (Spectrum Innovation Initiative, including passive services)
  - IAU SKAO / NOIRLab leadership: Center for Protection of Dark and Quiet Skies

# Electromagnetic Spectrum Management

In the future, observatories like ngVLA will have to work around radio frequency (RF) interference from other users that knocks out access to certain frequencies at certain times.  NSF working on dynamic scheduling plan to enhance spectrum management.

The expected lack of flexibility associated with pre-assigned radio frequencies and times will be a challenge for time domain astronomy (TDA).

*NSF's NRAO and NSF's NOIRLab working on technical collaboration with SpaceX and other satellite operators.*

# Recommendations: More funding for individual investigator research

*NSF should increase funding for AAG by 30% in real dollars b/t 2023 – 2028 to restore success rates to a healthy competitive level.*

*NSF should create three tracks withing the AST Mid-Scale Innovations Program (MSIP)*

1. *Open calls*
2. *Strategic proposals*
3. *new instruments on existing facilities*

*NSF should increase midscale funding with a target of reaching $50M / yr for MSIP*

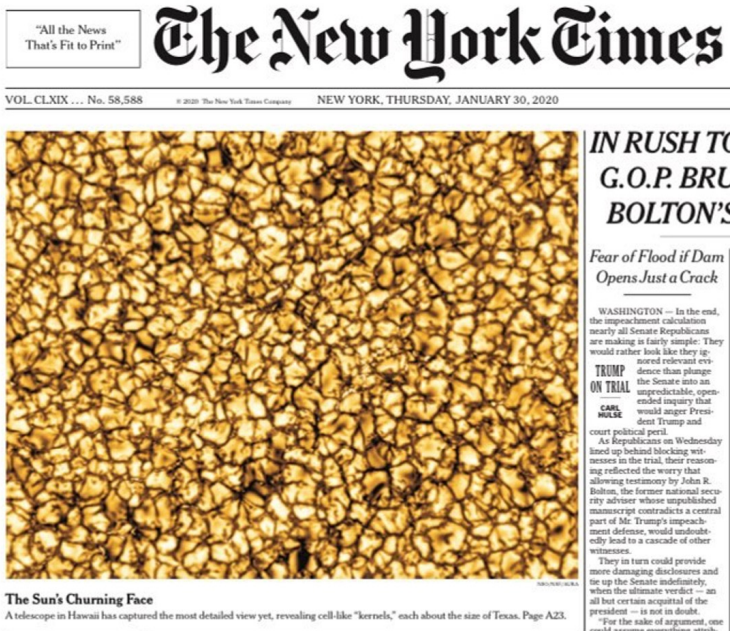
*NASA Astrophysics Theory Program should resume annual cadence and be augmented*. Here, NSF is partnering to expand the impact of ATP.

The New York Times

58,294 © 2019 The New York Times Company THURSDAY, APRIL 11, 2019

Scientists captured a view of a black hole at the heart of a galaxy known as Messier 87, some 55 million light-years away from Earth.

Peering Into Light's Graveyard: The First Image of a Black Hole



"All the News That's Fit to Print"

The New York Times

VOL. CLXIX .... No. 58,588 © 2020 The New York Times Company NEW YORK, THURSDAY, JANUARY 30, 2020

The Sun's Churning Face

A telescope in Hawaii has captured the most detailed view yet, revealing cell-like "kernels," each about the size of Texas. Page A23.

IN RUSH TO G.O.P. BRU... BOLTON'S

Fear of Flood if Dam Opens Just a Crack

TRUMP ON TRIAL

CARL HULSE

WASHINGTON — In the end, the impeachment calculation nearly all Senate Republicans are making is fairly simple: They would rather look like they ignored relevant evidence than plunge the Senate into an unpredictable, open-ended inquiry that would anger President Trump and court political peril.

As Republicans on Wednesday lined up behind blocking witnesses in the trial, their reasoning reflected the worry that allowing testimony by John R. Bolton, the former national security adviser whose unpublished manuscript contradicts a central part of Mr. Trump's impeachment defense, would undoubtedly lead to a cascade of other witnesses.

They in turn could provide more damaging disclosures and tie up the Senate indefinitely, when the ultimate verdict — an all but certain acquittal of the president — is not in doubt.

"For the sake of argument, one

"All the News That's Fit to Print"

The New York Times

VOL. CLXXI .... No. 59,483 © 2022 The New York Times Company NEW YORK, WEDNESDAY, JULY 13, 2022

WHERE STARS ARE BORN The cliffs of the Carina nebula, captured by the James Webb Space Telescope. Its images revealed the earliest periods of star formation.

Midscale and new major facilities are critical to innovation.

Astronomical discoveries are very high profile and a source of national pride. Workforce development is a key pillar for the NSF.

"The world's best talent – including American talent – will go where the opportunities are greatest and research infrastructure is increasingly an essential part of the equation" – NSB "Vision 2030".

# NSF Response:

## Workshop on Centers of Excellence for Instrumentation and technology

Thinktank: building an integrated system of centers in universities (astronomy, physics, engineering, business), each with specialized technical expertise to retain scientist-engineers and seed innovation

- Workforce development, translation of innovation into commercial ventures
- Potential partnerships with TIP, federal facilities, community, private organizations. Coordinate and collaborate with other agencies, potentially NASA, DOE.

Workshop planned: Spring / Summer 2023

# Recommendations: Reduce greenhouse gas emissions associated with research

*Increase remote observing, hybrid conferences to reduce travel impact on carbon emissions*

Astronomy is **contributing** to climate change

# *Nature Astronomy* 2022

**Jürgen Knödlseder ✉, Sylvie Brau-Nogué, Mickael Coriat, Philippe Garnier, Annie Hughes, Pierrick Martin and Luigi Tibaldo**

Astronomy facilities / missions contribute 2 million metric tons of carbon emissions per year, 36 tons per year for each astronomer.

Astronomy is **affected** by climate change

Wildfires are threatening Observatories. Domes need to remain closed to protect mirrors from smoke damage.

# Astronomers can **help solve** climate change

Our view of Earth from space changes how **we see ourselves**. The images we see instill awe. Awe triggers empathy and a recognition of the interconnectedness of all creatures.

Astronomers can **help inspire activism on** climate change

"If somebody had said before the flight, 'Are you going to get carried away looking at the Earth from the moon?' I would have said, 'No, no way.' But yet when I first looked back at the Earth, standing on the moon, I cried."

- Alan Shepard (Apollo 14)

ASTRONOMERS FOR PLANET EARTH

Share this incredible perspective! More than 300,000 students in Astro101 classes each year.

Astronomers can help solve climate change and we are stepping up!

Big thanks to Inger Jorgenson and the NOIRLab team!

Gemini-S Observatory: NSF funding to make G-S carbon neutral with PV arrays and battery backup in the next few years.

Working to reduce the GHG emissions of all NOIRLab facilities by ~50% in the next few years (infrastructure upgrades).

Requiring new section on climate impact for major facility proposals.

Working with all facility directors to get estimates of energy use, carbon emissions, and possible renewable power.

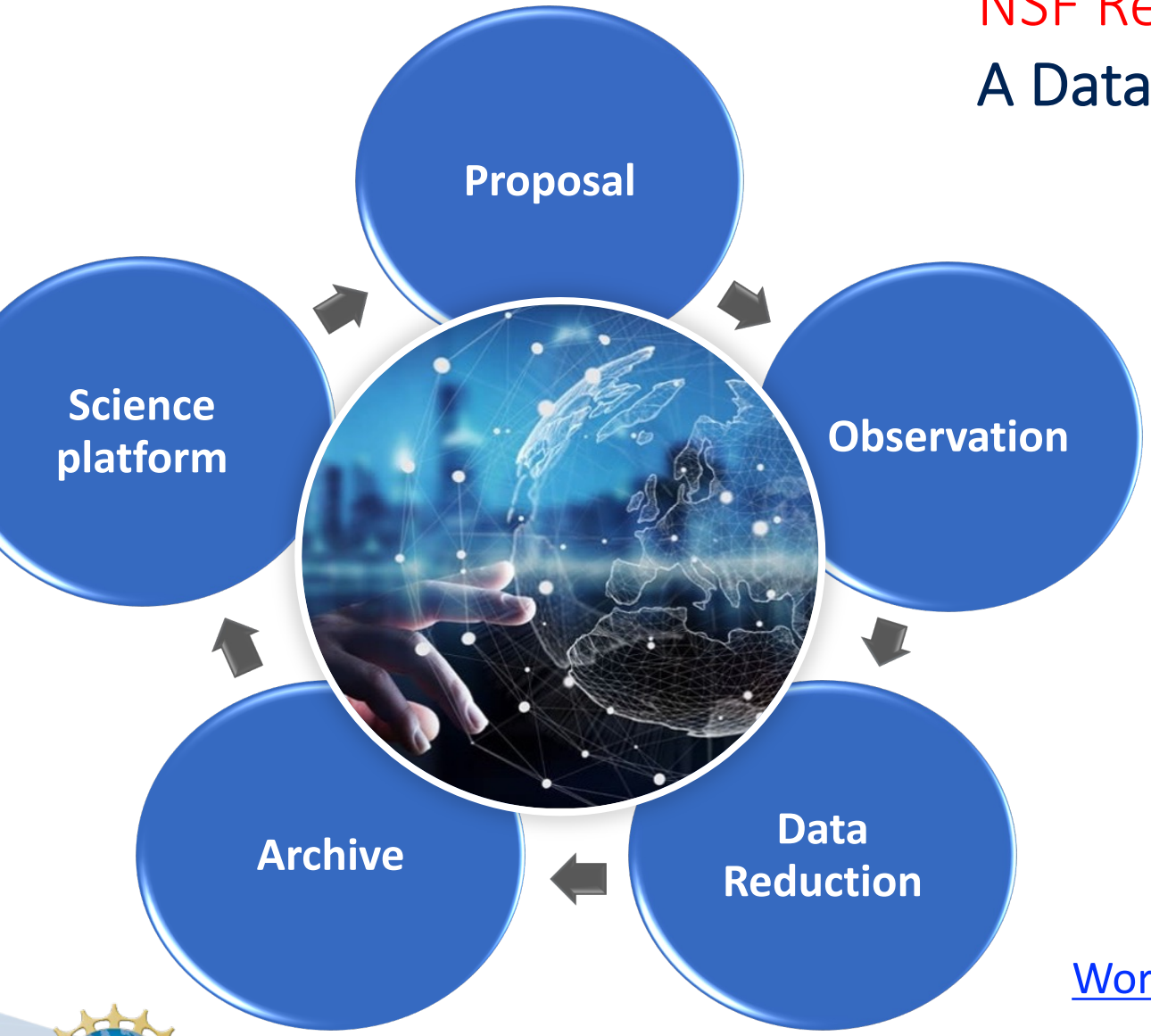
# Recommendations: Improve data management across agencies

*Fund data analysis and production of high-level data products for large PI-led programs on MREFC-scale astronomical facilities.*

*NASA and NSF should explore mechanisms to improve coordination among U.S. archive centers and create a centralized nexus for interacting with international archive communities.*

*Plan how to design, build, and sustain pipelines for producing science-ready data across all ground-based observatories, providing funding in exchange for ensuring that all pipelined observations are archived in a standard format for eventual public use.*

# NSF Response:
## A Data-oriented Integrated OIR System




**Thinktank**: build an integrated system focused on delivering high quality, science ready data for all instruments:

- Unified archive and science platform
- Unified data reduction framework
- General data acquisition framework and standardized metadata
- coordinate private and federal facilities, collaborate with NASA and DOE, and leverage the expertise of our data centers and of the community

Workshop scheduled: February 2023 @Flatiron Inst


Solicitation for AI institutes will be announced in the next few months. Encourage the community to watch for this opportunity and apply for possible AI institutes for Astronomy.

# Recommendations: Support laboratory astrophysics

*Convene a broad panel of experts to identify needs for supporting laboratory data to interpret results from new generation of astronomical observatories, Identify national resources that can be brought to bear to satisfy those needs. Consider new approaches or program for building the requisite databases.*

- Program officers from NSF and NASA working together.
- They have chartered a task force through the AAAC; invitation to TF members will go out in ~ the next week.
- Planning for a first meeting of the TF during the January 2023 AAAC meeting.

# Recommendations: Sustainable plan for operations and management of facilities

*The addition of new MREFC facilities should be contingent on implementation of a sustainable plan for O&M.*

- This is an important and recurring recommendation (NSB 2018 report recommended developing a plan for operations and management).
- This would apply to facilities NSF-wide (much bigger than just AST).
- Do not yet have a silver bullet, but this is on the radar for the CORF, who has been working on this.

# Recommendations: Community Portfolio reviews

*NSF should establish a regular cadence of reviews of the AST portfolio at frequency that is sufficient to respond to changes in scientific and strategic priorities in the field (2 portfolio reviews per decade).*

- We agree.  Schedule for the next 6 months is quite intense, but we are planning a “committee of visitors” meeting in Fall 2023 and we would like to combine this with a portfolio review that considers facilities.

# AST Budget Updates

# AST Budget – Four "buckets"

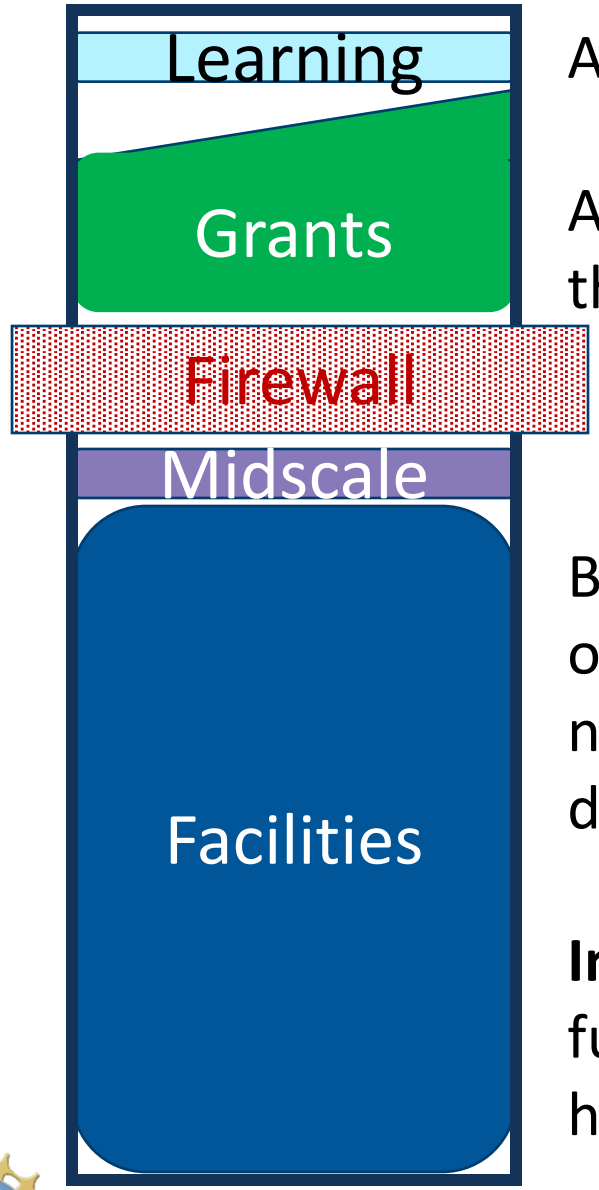
Learning: AAPF, CAREER, REU, PAARE, etc

Grants: AAG ~$50M

Midscale: ATI, MSIP

Facility operations: NRAO, NOIRLab, NSO ~200M
Built in 3% annual increases
Supplementary requests

Grants historically provides needed funds when AST budget falls short of providing everything needed.




AAPF, CAREER, REU, PAARE, etc: grow as possible with budget

AAG ~$50M FY23; **grow** $3M / year to reach $65M/yr FY28, then grow at 3% / yr

Balancing funding for Facilities and Midscale (ATI, MSIP) will occur in trade spaces with each other. No budget bucket for new major facilities; Midscale likely needed to help support design funding.

**Impact**: Astronomers will need to compete for midscale funding through NSF-wide MRI, MSRI-1, MSRI-2. There is hope that these may grow - prioritized by NSF and the NSB.

# $280-billion CHIPS and Science Act of 2022

- In addition to support for semiconductor technology, significant increase for NSF – proposed $81B through 2027.
- Passed authorization but will need to see if appropriation is made.

- Federal budget is currently in a Continuing Resolution and this requires us to plan for flat funding (w.r.t. FY22) in FY23.
  - Facility directors advised in March 2022 to plan for flat funding in FY23
  - No ability to increase AAG or start new initiatives.

# AST Importance of Communication

# Hosted a “Communication Workshop” at the Large Facilities Meeting

## Branding and communication – a tool for science.

NSF does “science by the pound” – equivalent to a pile of Legos. Congress hopes that scientists will do something with this, but it is an amorphous pot of $$ and therefore hard to motivate funding. Our message:

- Science contributes to job and high tech workforce in local districts.
- International leadership: competition vs collaboration.
- Urgency: we are solving problems today

Because of conflict of interest laws, these messages must come from the community. Helpful to let representatives know when constituents receive funding (and for what), invite them on tours of facilities or open houses, profile young people in STEM.

Astronomical observatories advance physics, chemistry, atmospheric science, and potentially biology and support national security.

- The standard model of particle physics fails to explain 95% of the universe; an uncertainty of $10^{-23}$ in vacuum energy results in dramatically different models: constant *vs* accelerating expansion of universe. Unmeasurable in labs, but ELTs provide multiple ways to explore DM / DE: lensing, dwarf galaxies, SN on astronomical scales.

- Extreme temperature and extreme density laboratories for chemistry and formation of biomolecules.

- Spectroscopy of exoplanet atmospheres may help advance understanding origin of life, erased on Earth.

- Earth orientation (ngVLA) supports high fidelity GPS and technology transfer (detectors, lasers, photonics) enriches lives.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