U.S. National Science Foundation

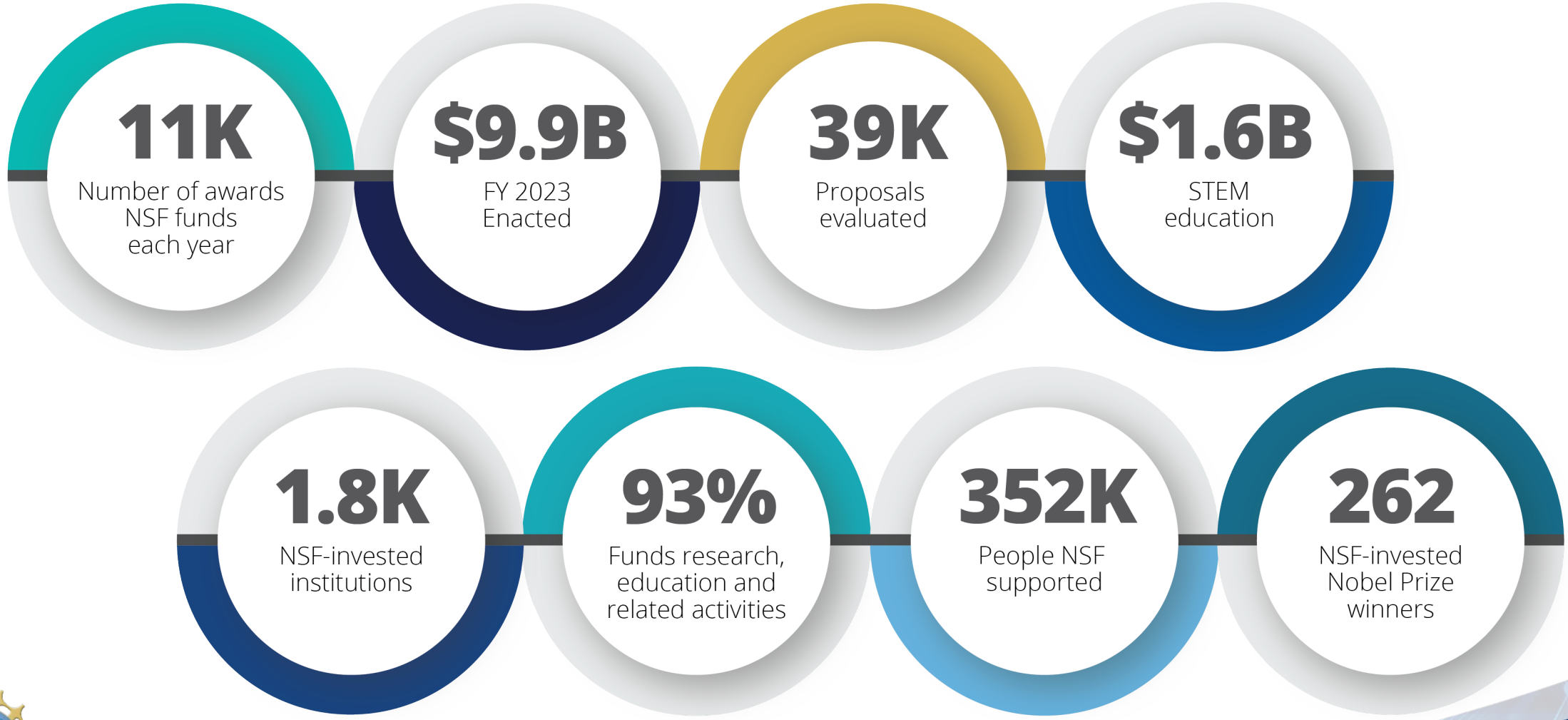
Space Science Week

Saul Gonzalez, Physics Division Director
Directorate for Mathematical and Physical Sciences
March 19, 2024

NSF Mission


Promote the progress of science
Advance the national health, prosperity and welfare
Secure the national defense
NSF

NSF By the Numbers



NSF's Strategic Priorities

STRENGTHENING ESTABLISHED NSF

With investments that expand the frontiers of knowledge and technology.

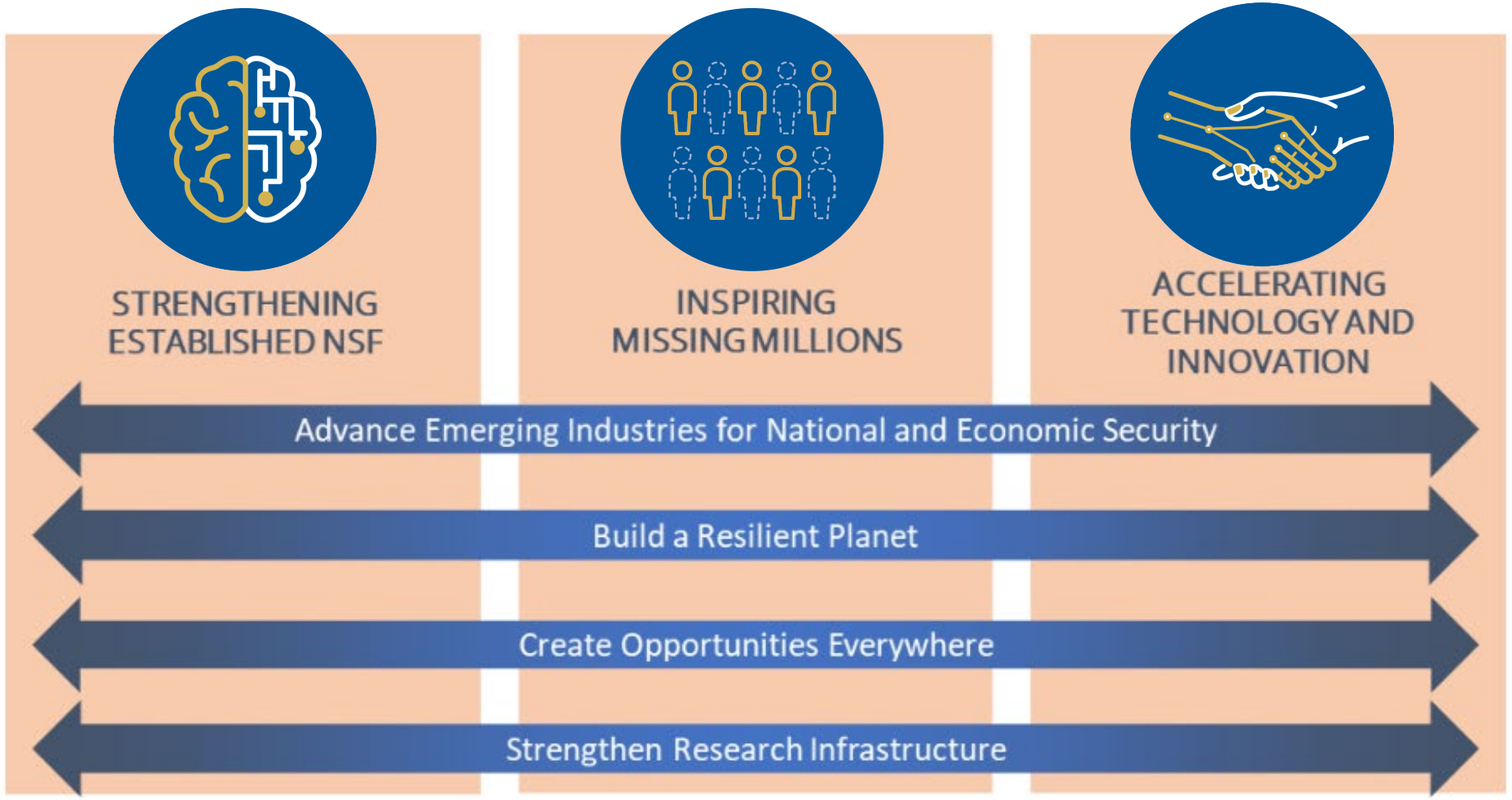
INSPIRING THE MISSING MILLIONS

Using interventions and capacity building that enhance and broaden participation.

ACCELERATING TECHNOLOGY AND INNOVATION

Through innovative, cross-cutting partnerships and programs.

Strategic Priorities and Themes



FY2024 Enacted

$9.06 Billion

+$221 million

+2.5% above

FY2023 Base[1]

Signed by the President March 9, 2024
(Current Plan in progress)

Provides NSF with a total $9.060 billion

Note: FY2023 Total ($9.877 billion) included additional $1.03 billion Disaster Relief Supplements

[1]See https://new.nsf.gov/about/budget/fy2025 for details

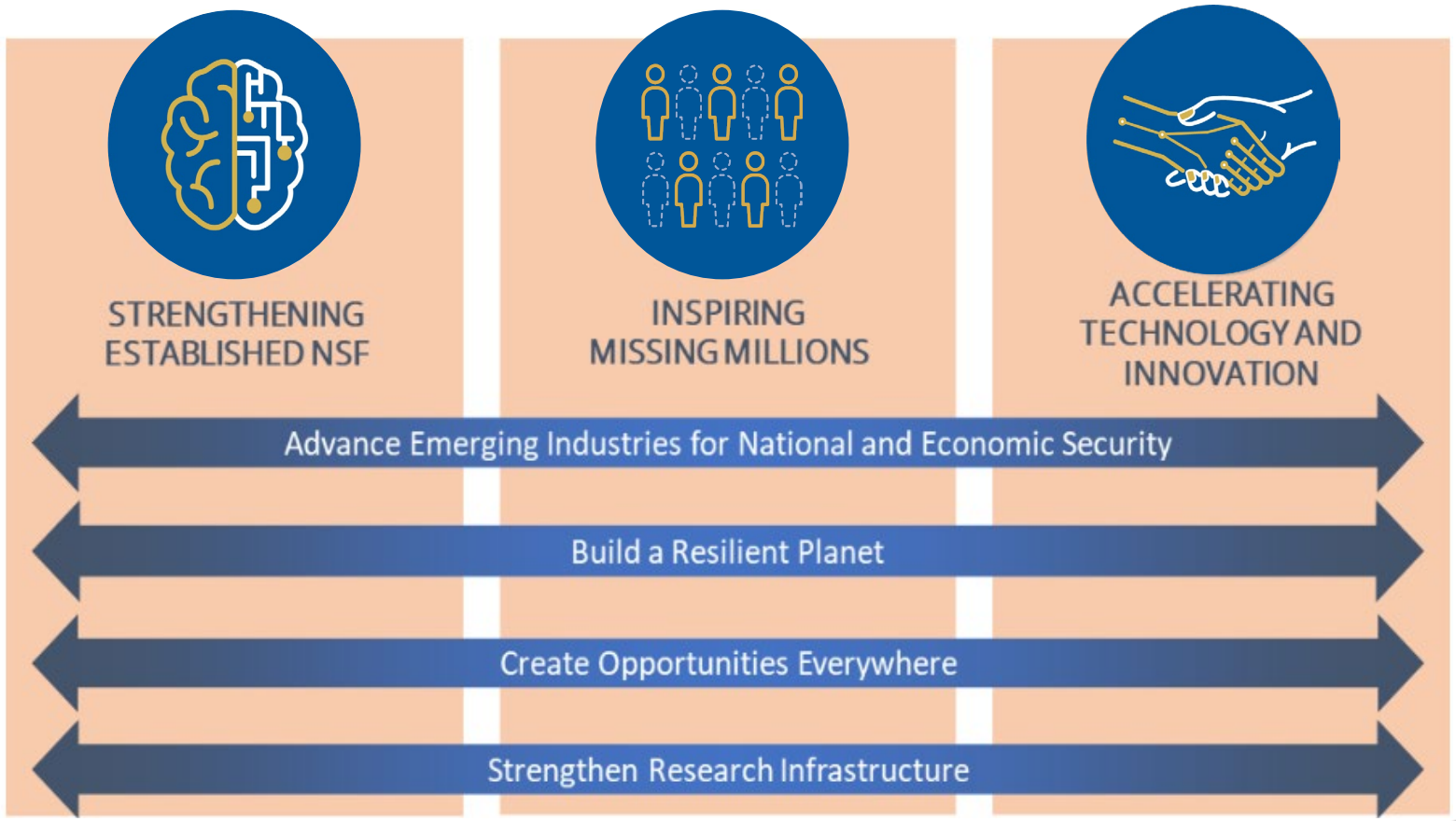
FY2025 President's Request to Congress

$10.183 Billion

+$306 million

+3% above

FY2023 Enacted



FY2025 President's Budget Request (Example): Strengthen Research Infrastructure

Research Infrastructure Total, $2.34B, or +$277 million above FY2023 Base Plan

Operations and Maintenance of Major Facilities:

- $1.12B, +$124 million from FY 2023 Base Plan

Major Research Facilities Construction:

- $300 million, +$113 million from FY 2023 Base Plan for **Construction** (MREFC), including Antarctic Infrastructure Recapitalization, Leadership Class Computing Facility, and Mid-scale Infrastructure
- $46 million, +$16 million from FY 2023 Base Plan for **Design** Activities, including Antarctic Research Vessel and Astro2020 (ngVLA, and the ELT)

"FY2025 Request supports the continued design of a single telescope within the U.S. Extremely Large Telescope program."

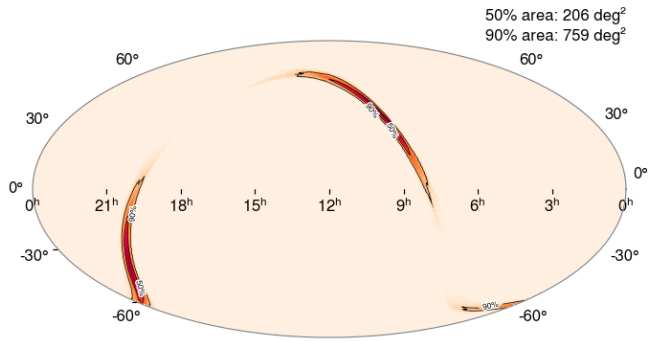
Science directorates and offices supporting the NSF Mission

Primary Touchpoints with Space Science

Laser Interferometer Gravitational Wave Observatory

- Premier Gravitational Wave Observatory located at two sites in the U.S.
- 4th Observing Run started on May 24, 2023, and will last 20 months, including a ~two-month break that started mid-January 2024
- With a partially completed upgrade, LIGO is performing at a sensitivity of 160 Mpc, an increase of 30% over previous run
- Virgo (Italy) and KAGRA (Japan) will resume observations after LIGO's commissioning break

Community currently considering options for Next-Generation GW Observatory in the U.S.



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81 significant detections have been announced during current run so far

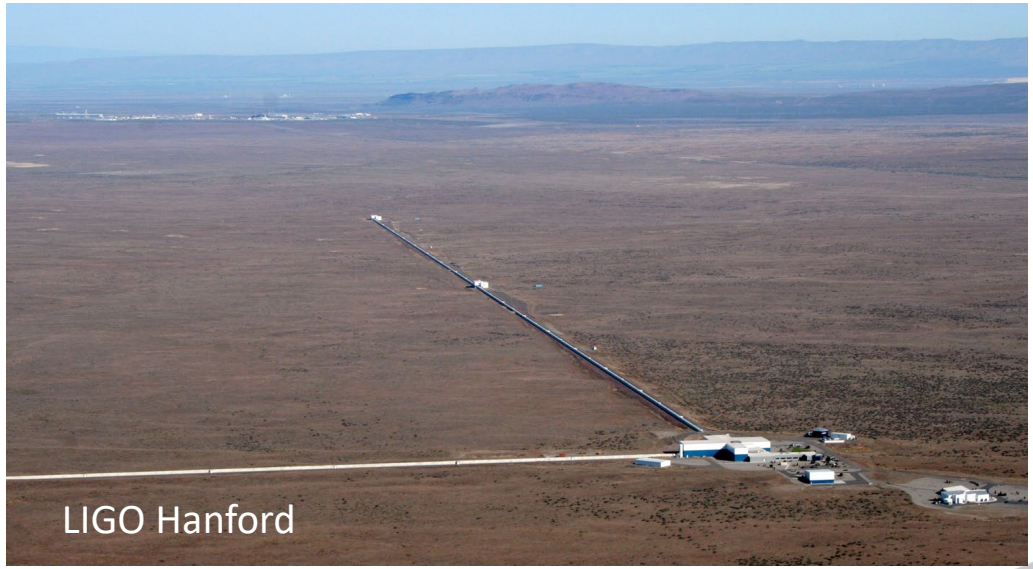


Image Credits: LIGO.org

NANOGrav Detects GW Background

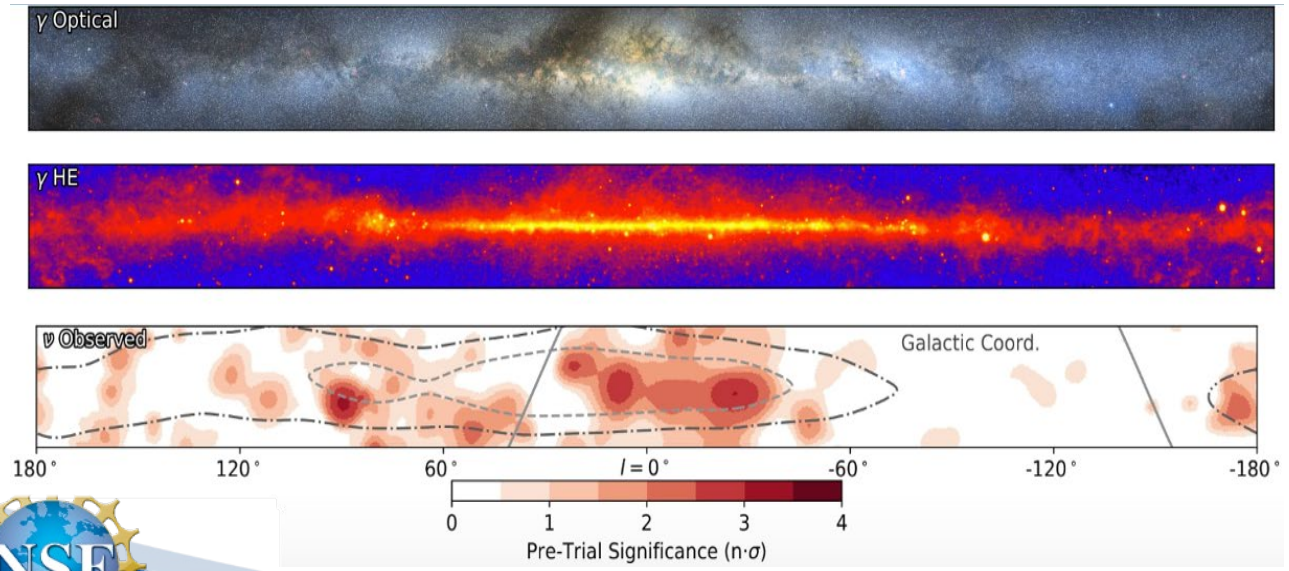
North American Nanohertz Observatory for Gravitational Waves (NANOGrav) – A Physics Frontier Center

Image Credits: NANOGrav

- On June 28, 2023, NANOGrav announced the detection of the stochastic gravitational wave background
- Data set included 15-years of timing observations of 68 millisecond pulsars using the NSF facilities Arecibo, Green Bank, and the Very Large Array
- NANOGrav and IPTA observations give powerful insights into galaxy formation, large scale structure of the Universe, and cosmology
- A Galactic-scale Observatory

IceCube Neutrino Observatory

- 1 cubic kilometer of instrumented clear ice beneath the South Pole to capture the highest energy cosmic neutrino interactions
- IceCube unveiled the first image of the Milky Way in neutrinos (June 28, 2023)
- Opening new vistas to our galaxy, nearby sources of neutrinos, the diffuse neutrino background, and ν "quietness" from the central black hole



Status:

- Currently upgrading IceCube to add 7 additional strings of closely spaced and improved sensors
- Staff deployed for 2024 season in addition to 2 "winter-overs."
- Lost 3 seasons to COVID

Image Credits: IceCube Neutrino Observatory

NSF's Daniel K. Inouye Solar Telescope: The Worlds Largest Solar Telescope

- 4 meter mirror
  - Focuses about 14kW of solar power
  - Observes all day, make ice during the night
- Resolves small scale vector magnetic fields, providing insights into the underlying mechanisms for solar eruptions and space weather
- Now observing

First movie from Inouye showing granulation cells, which are approximately the size of North America (DKIST)

- 8.4 m telescope, 3.2 Gigapixel camera
- Survey Southern sky twice a week for 10 years.
- Primary science themes:
  - Probing dark energy and dark matter
  - Taking an inventory of moving objects in the Solar System
  - Exploring the transient optical sky
  - Mapping the Milky Way Galaxy
- NSF and DOE partnership.
- Status:
  - Telescope optics integration this spring and summer.
  - DOE's LSST Camera to ship in May.
  - Aiming for on-sky images with Commissioning Camera this summer
  - Operations forecast to begin late 2025.

Windows on the Universe: Multi-Messenger Astrophysics (WoU-MMA)

NSF/NASA Windows on the Universe Workshop (2023)

Three categories of messengers - electromagnetic waves, high-energy particles including neutrinos and cosmic rays, and gravitational waves.

WoU-MMA builds the capabilities and integrates observations and theory to realize multi-messenger astrophysical explorations of the Universe.

New solicitation NSF 24-542: Multi-Messenger Coordination for Windows on the Universe

- Collaborative awards to develop a robust and inclusive environment for MMA discovery and follow-up;
- Reduce barriers to entry into the field and between software and other tools;
- Increase interoperability, reduce redundancy; and
- Ensure equitable and appropriate credit for discovery shared within the community.

Satellite Constellations and Space Science

Proliferation of satellite constellations in low-Earth orbit pose a potential impact to scientific productivity of NSF ground-based

- Optical/infrared telescopes; and
- Radio astronomy observatories, especially those in remote locations and the National Radio Quiet Zone

NSF has signed coordination agreements with SpaceX and Amazon Kuiper, and is working towards several more

- These agreements encourage best practice guidance as published by an international center (IAU CPS), co-founded by NSF's NOIRlab

R&D is ongoing; including field testing and observations

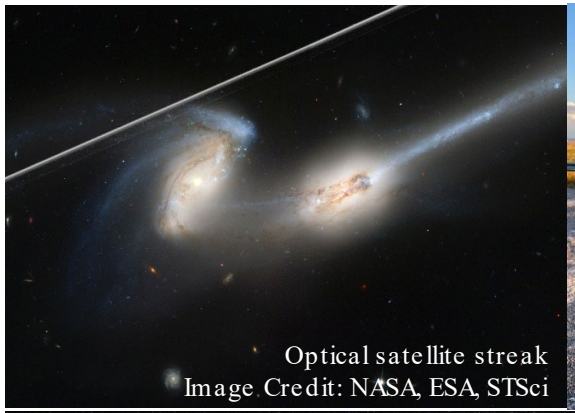
- NSF Spectrum Innovation Initiative funding program (e.g., SWIFT-SAT)

FCC authorizations now include conditions in several satellite constellation licenses to address the impact

- Annual report to the Commission including any steps taken to reduce the impact of its satellites on optical astronomy

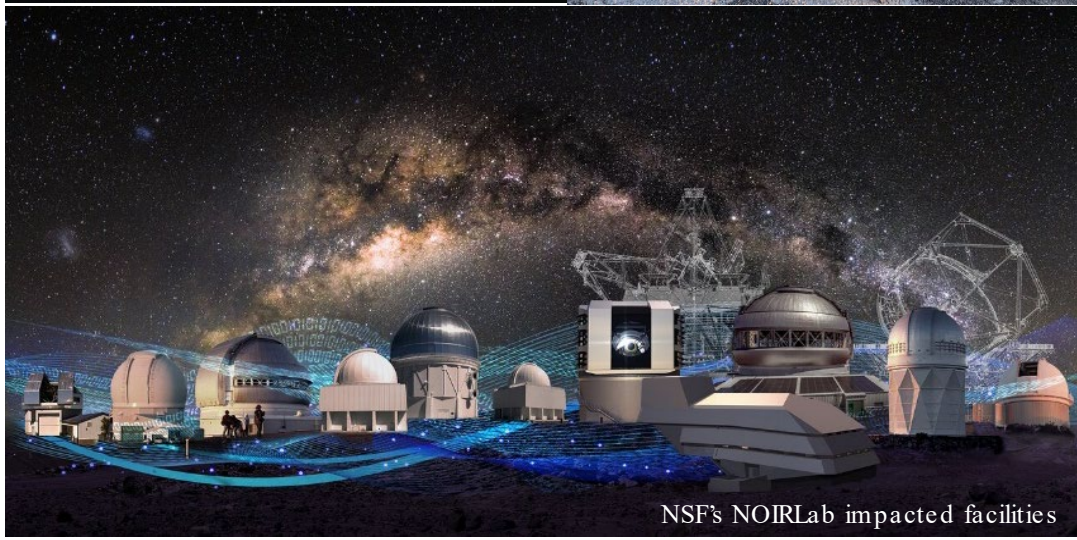
International attention:

- 5-yr agenda item on optical portion of Dark and Quiet Skies recommended for Committee on Peaceful Uses of Outer Space and a future agenda item on radio quiet zones for the 2027 World Radiocommunication Conference



Optical satellite streak
Image Credit: NASA, ESA, STSci

Coordinated testing at VLA;
Image Credit: NRAO

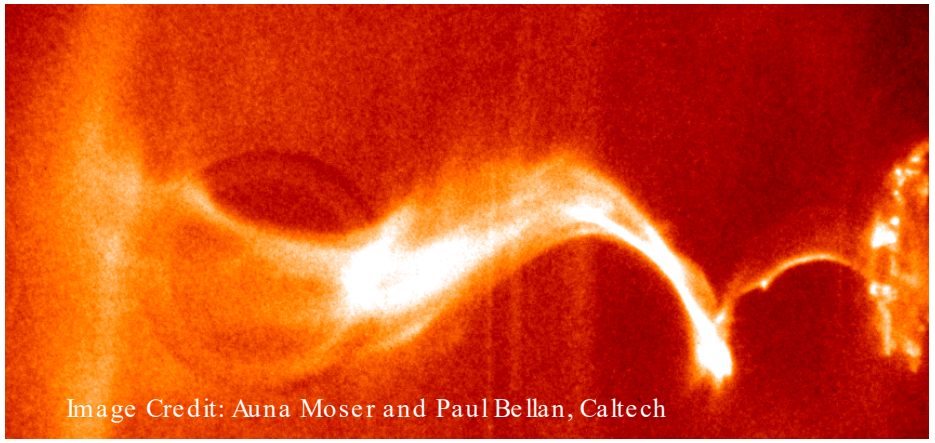


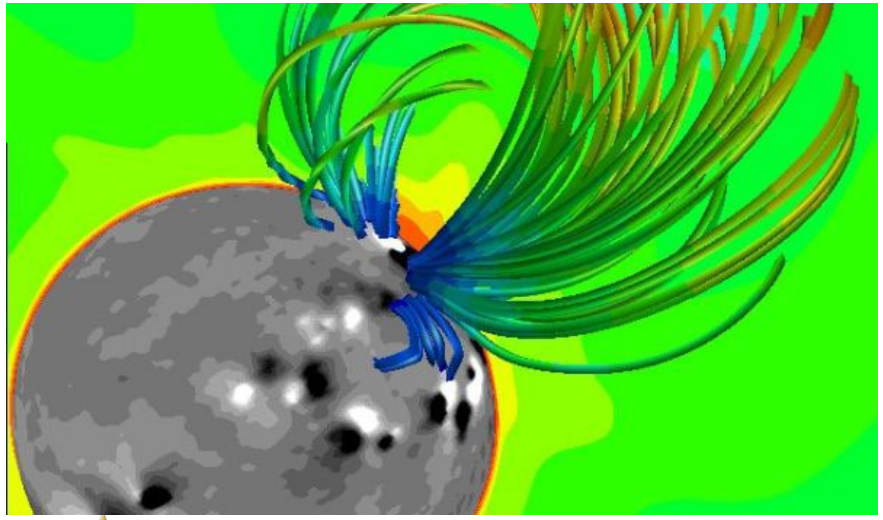
NSF's NOIRLab impacted facilities

Space as a Plasma Physics Laboratory

Research in plasma physics advances our understanding of space from compact astrophysical objects and their environments to space weather prediction. Example:

- Laboratory solar flares reveal clues to bursts of high-energy particles from space: "Simulating solar flares on a scale the size of a banana, researchers have parsed out how these massive explosions blast potentially harmful energetic particles and X-rays into the cosmos" (Caltech)





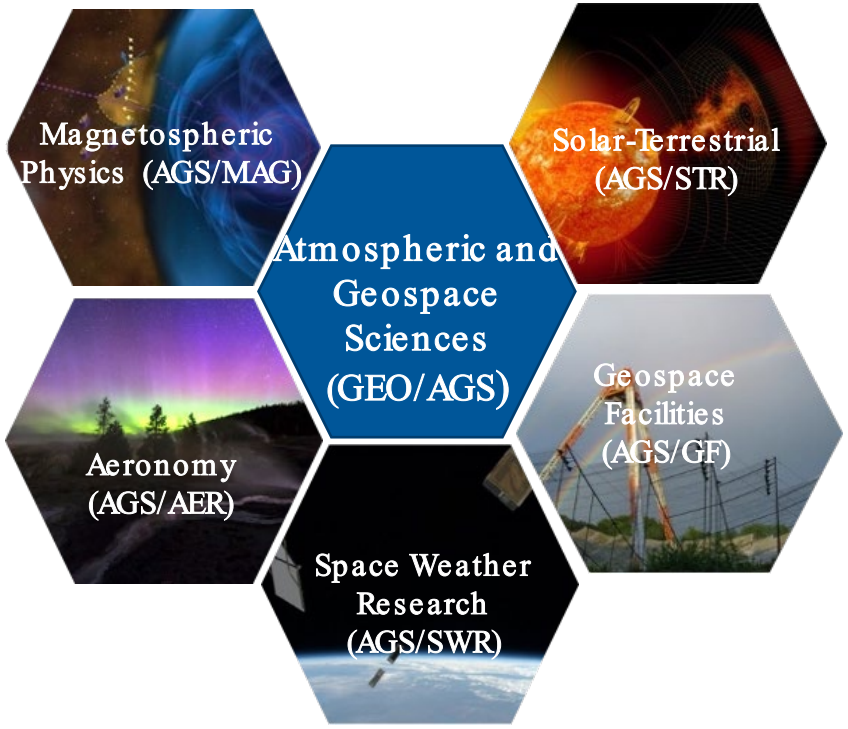
Space weather modeling framework simulation of the 9/10/2014 coronal mass ejection. Credit: Gabor Toth.

Ecosystem for Leading Innovation in Plasma Science and Engineering (ECLIPSE)
NSF program to bring fundamental plasma science to bear on problems of societal and technological need. Examples:

- Studies of complex plasmas under microgravity for novel materials design
- Development of new computational methods and tools for space weather prediction
- Sensor development for cubesat-based geospace measurements

Geospace Science at NSF

Programs



- NSF 22-575: Coupling, Energetics, and Dynamics of Atmospheric Regions (AER)
- NSF 22-537: Geospace Environment Modeling (MAG)
- NSF 22-570: Solar, Heliospheric, and Interplanetary Environment (STR)

Research Infrastructure

- Ground-based Radars, Lidars, Aurora and airglow monitors, Magnetometers, Solar observatories, Neutron monitors
- CubeSats and airborne instruments
- Modeling centers, HPC resources, and data repositories

Geospace Science at NSF

Workforce

NSF 23-577: Faculty Development in geospace Science (FDSS)

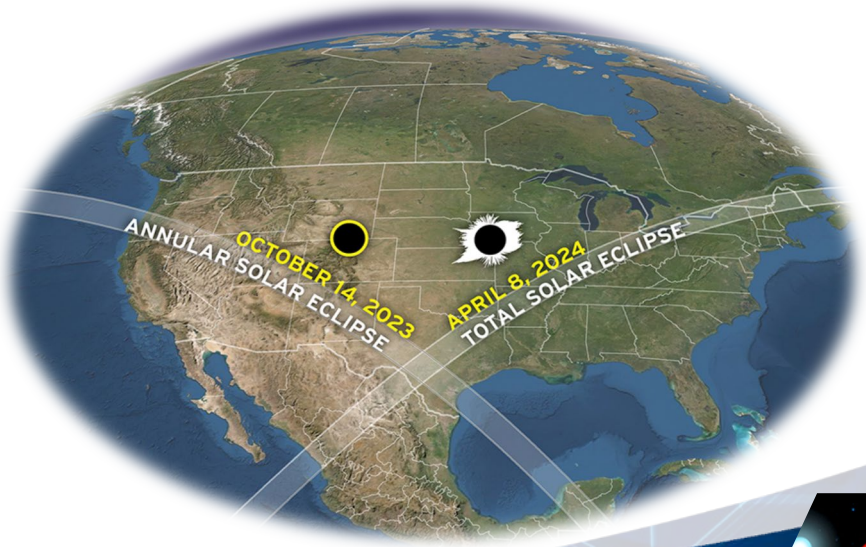
Goal: Integrate topics in geospace science into natural sciences or engineering or related departments at U.S. institutions

- Newly recruited tenure-track faculty--up to five years and $1,500,000 total
- Track to support minority-serving institutions and emerging research institutions

Outreach

NSF 23-014 DCL: Great American Solar Eclipses of 2023 and 2024

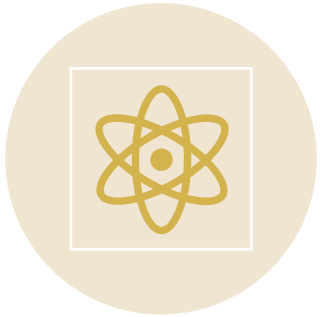
- Awards and supplemental funding from NSF's Division of Atmospheric and Geospace Sciences and Division of Astronomical Sciences for science and outreach



NSF Engineering Research at the ISS

Long-standing (2016--) collaboration between NSF and CASIS on science that can only be done in a microgravity environment

So far, 37 projects in transport phenomena (fluids, particulates, combustion, nano, thermal) and 20 in tissue/bioengineering



NSF 24-502: NSF/CASIS Collaboration on Tissue Engineering and Mechanobiology on the International Space Station (ISS) to Benefit Life on Earth

NSF 24-501: NSF/CASIS Collaboration on Transport Phenomena Research on the International Space Station (ISS) to Benefit Life on Earth

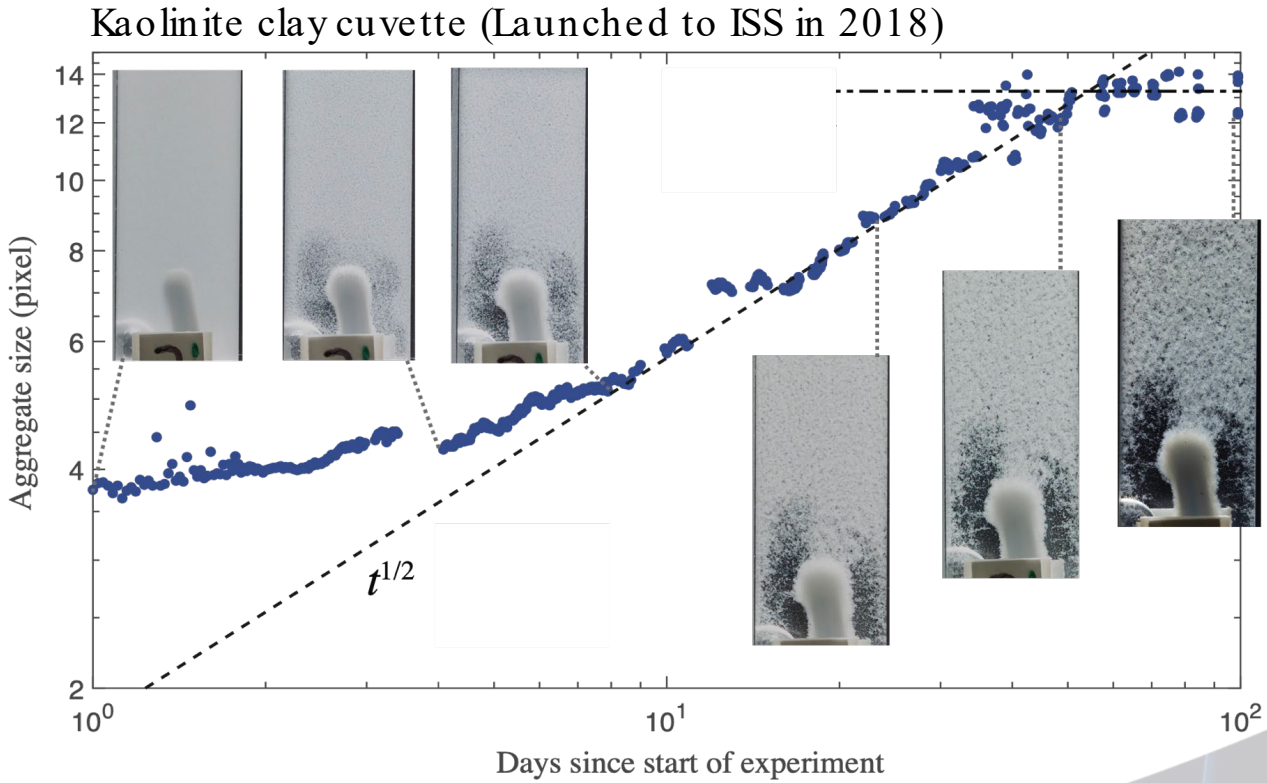
Example: Sediment Dynamics in Microgravity

Findings from ISS experiment

- Aggregation rates successfully measured as a function of sediment composition;
- Aggregation measured even for very weakly cohesive sediment;
- Long-term experiments also uncovered:
  - Ongoing aggregation far beyond initially expected (~100 days);
  - Unexpected power law for aggregate growth (~$t^{1/2}$);
  - Aggregation faster than supported by Brownian motion (~$t^{1/3}$) and affecting larger particles.

ISS-CASIS: Quantifying Cohesive Sediment Dynamics for Advanced Environmental Modeling

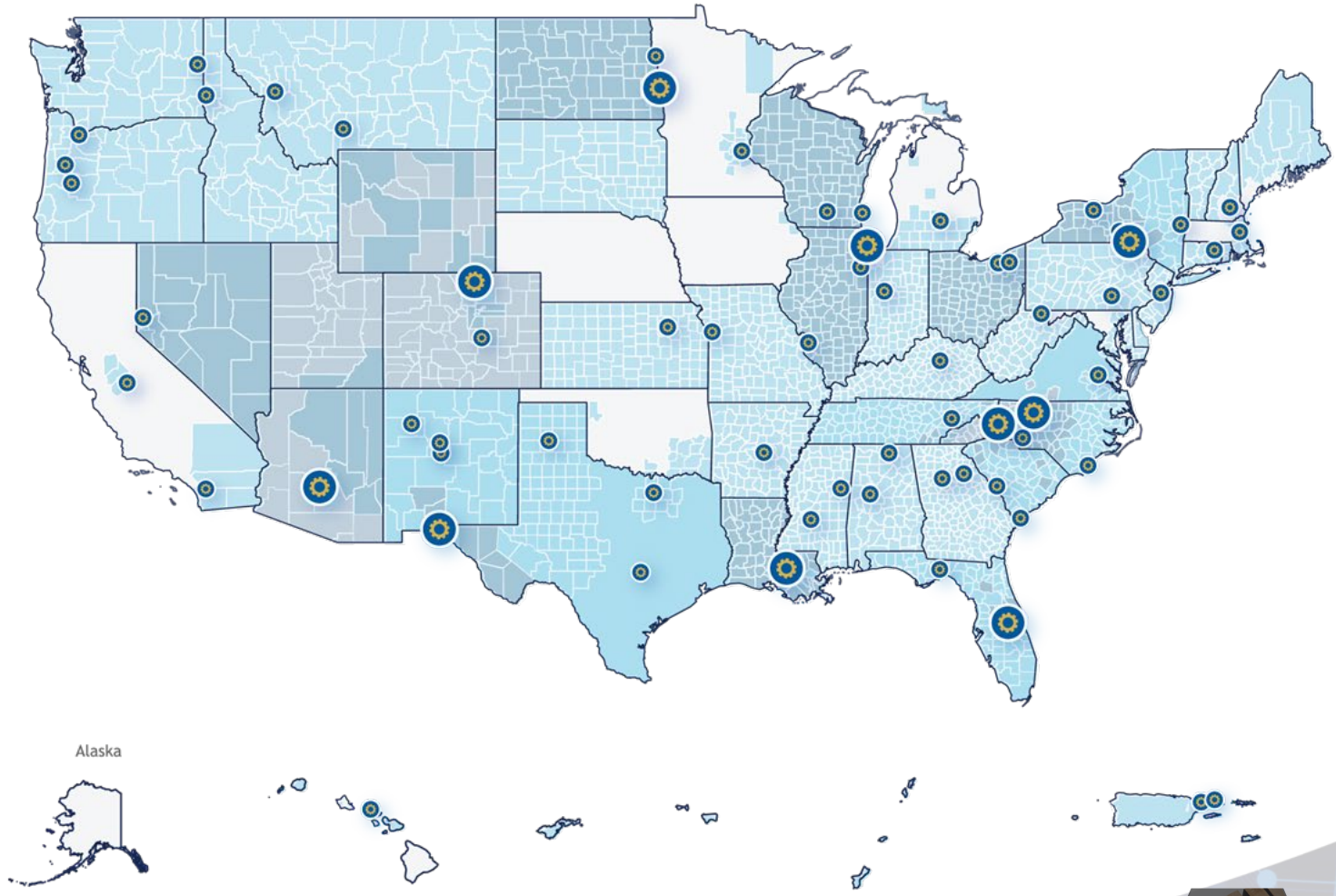
P. Luzzatto-Fegiz & E. Meiburg, UC Santa Barbara



NSF Regional Innovation Engines

NSF Engines program envisions supporting multiple regional innovation ecosystems across the U.S., spurring economic growth in regions that have not fully participated in the technology boom of the past few decades.

- Boost Innovation Capacity
- Create sustainable innovation ecosystems
- Demonstrate inclusive economic growth

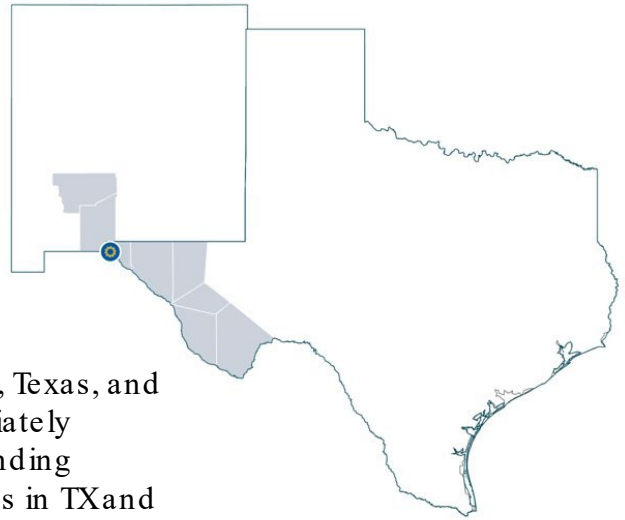


Space Technology Innovation Engines

Paso del Norte Defense and Aerospace Innovation Engine

(University of Texas-El Paso (UTEP)) $15 million / 2 years

To fuel the growth of dynamic aerospace and defense manufacturing in Paso del Norte by creating a platform that combines an emerging digital engineering paradigm and skilled workforce development.



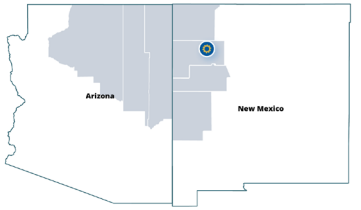
El Paso, Texas, and immediately surrounding counties in TXand NM

Development Award: Advanced Manufacturing for Tribal Communities

(Navajo Technical University) $1 million / 2 years

Develop distributed manufacturing micro-factories and technology centers in the Navajo Nation enabling remote rural tribal communities to participate in emerging supply chain operations in the space industry.

Tribal nations and rural communities in Arizona and New Mexico

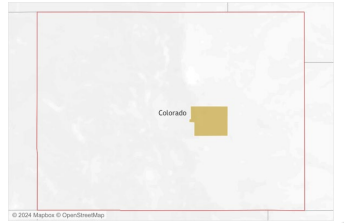


Development Award: Advancing Space Technologies

(Catalyst Campus for Technology and Innovation, Inc.) $1 million / 2 years

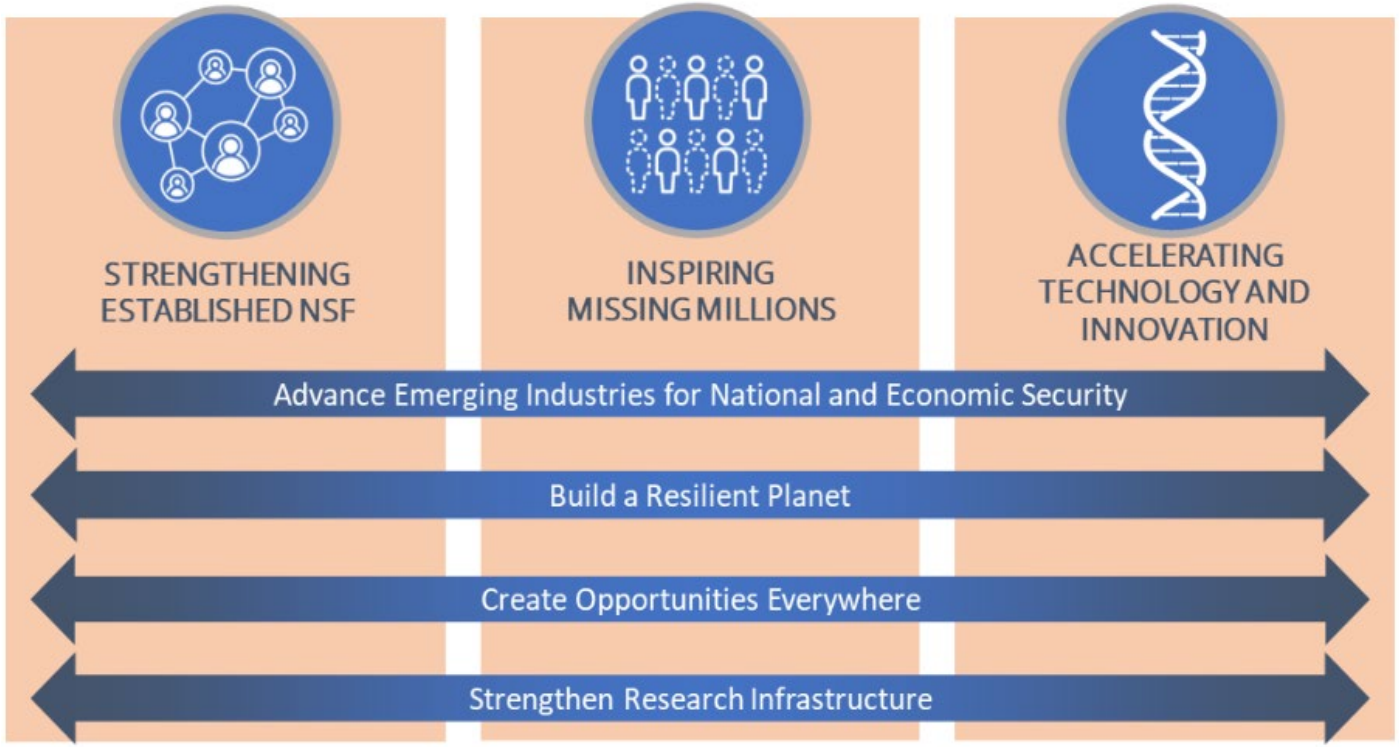
Ignite technological innovation and workforce development to foster technology commercialization and technology transfer in space systems, space infrastructure, and space cybersecurity for the space economy.

Pikes Peak region into Southern Colorado



Conclusion

- NSF investments in space-related sciences and technologies span:
  - Individual investigators, Research Infrastructure, Centers, and Partnerships
  - Multiple science and engineering domains
- From ground-based observations of the Universe to experiments at the ISS, space science at NSF is focused on fostering discovery and delivering societal impacts.




NSF

NSF TIP Space portfolio across CHIPs tech

Communications
Swarm
Unspace
US Air Tech
Uninet
Care Weather
TF Wireless
Chascii
Xona Space Systems
StarNav

Advanced Materials
Interlune
Ascend Elements*
Astroforge
Off-World
TPL
Off Planet Research
Lunar Resources
Outward Tech.

Adv. Manufacturing
Stoke Space
Vortex Space Systems
Raven Space Systems
Fenix
Rocket Propulsion Systems
Magma Space
Space Kinetic
AnyGLabs
Radiant Space Labs
Lunexus Space

Disaster Risk Resilience, Comms, Sensing
Urban Sky
ARSI
Guardiansat
Spake Rake

Artificial Intelligence
Epirus
AI Acuity

Semiconductors & Advanced Computing:
United Semiconductors
Direct Kinetic Solutions

Cybersecurity:
Forward Edge AI
NDF (National DigiFoundry)

Bio:
Space Tango
Rhodium Scientific
Zaiput Flow Tech.
Nu Planet
Meati*

Energy[1]:

Fusion:
Avalanche
NearStar
Tibbar Plasma

Energy & efficiency:
Orbital Services Corp.
Magma Space
Nu Planet
Torre Space & Power Systems
Innotech

Propulsion:
Howe Industries
Morningbird Corp.
Viridina Space Corp
Hoverr

Conversions (H, CO_2)
Air Company*
Syzygy Plasmonics*
FC Renew

* Terrestrial focus with applicability to space, Energy examples; NSF has funded several hundred energy start-ups; many with capabilities applicable to space; these are just a few examples. Contact PD Anna Brady-Estevez

NSF TIP Space Portfolio Examples

Communications & satellites:
Swarm
Unspace
US Air Tech
Uninet
Care Weather
TF Wireless

PNT:
Chascii
Xona Space Systems
StarNav

Sensing
Urban Sky
ARSI
Astrabeam

Space debris:
Guardiansat
Spake Rake

Transport:
Stoke Space
Vortex Space Systems
Raven Space Systems
Fenix

Engines:
Rocket Propulsion Systems

Fusion:
Avalanche
NearStar
Tibbar Plasma

Energy & efficiency:
Magma Space
Nu Planet
Torre Space & Power Systems

Resources:
Interlune
Astroforge
Off-World
TPL
Off Planet Research
Lunar Resources
Outward Tech.

CO2 Conversion
Air Company

Recycling
Ascend Elements*
Lunexus Space

Directed Energy
Epirus

Propulsion:
Howe Industries
Morningbird Corp.
Viridina Space Corp
Hoverr

In Space Manufacturing:
NDF

Semiconductors:
United Semiconductors
Direct Kinetic Solutions

Bio:
Space Tango
Rhodium Scientific
Zaiput Flow Tech.
Nu Planet
Meati*

Data/AI:
AI Acuity

Docking
Orbital Services Corp.
Innotech Systems

Equipment
Magma Space
Space Kinetic

Space Internet & Cyber:
Forward Edge AI

Gravity
Radiant Space Systems
AnyGLabs

* Terrestrial focus with applicability to space

Accelerating Space Economy: "More Shots on Goal"

NSF, NASA, ISS and other agencies (e.g. DARPA, Air Force) have funded higher throughput approaches

Innovating a national level acceleration model in space:

- Exceptional opportunities for advantage and benefits across CHIPs and science technology (biotechnology, semiconductors, energy, communications…).
- Opportunity to prioritize highest potential impact commercially focused R&D
- Potential for more wins and impacts faster, by developing more in parallel, data sharing and information
  - Hundreds of entities interested in space commercialization and R&D
  - Need to incorporate diverse and rich skills from other terrestrial areas of expertise (AI, robotics, advanced materials, bio, energy…). Building "plug and play" ramps into space R&D (without in-depth space expertise)
- Ability to amplify through AI, data sharing and fast iteration
- Make the most of limited assets (space and time constrained)
  - LEO platforms (such as ISS) are constrained (container sized modules), so enhanced prioritization and speed of throughput enable us to make the most of the valuable microgravity environment
  - Expansion of what is possible in a given space/time expected to be even more important on Mars (&Moon potentially)
- Opportunity for enhanced capital formation and tools to facilitate build out

Launch Cadence: Stoke Space

Building towards rocket reusability and daily access

Rocket Propulsion Systems

Lower cost engines and capsule cost that are customizable and rapidly scalable for manufacturing

Communications: Swarm (SpaceXacquired)

Cube satellite swarms enabling higher connectivity, expanding global internet access

Flawless Photonics*

Higher throughput production of ZBLAN fiber in-space (kms), potential for repeaterless undersea cables

Biotechnology: Rhodium Scientific

Building an in-space biobank to increase access and usability

Space Tango

Expansion of cryovial biology throughput to many hundreds per unit

Semiconductors: United Semiconductors

Building microgravity equipment to accelerate many semiconductors in parallel

Miniaturization: Matiq

Ability to screen orders of magnitude higher materials

AI/Data &Cyber NDF

Consortium working group focused on high throughput in-space manufacturing

ForwardEdge AI

Cybersecurity for data sharing across in-space assets, enabling higher levels of exchange