OFFICE OF SCIENCE OVERVIEW

Board on Physics and Astronomy 2023 Spring Meeting

Harriet Kung, Linda Horton, John Mandrekas,
Glen Crawford, Sharon Stephenson, Ceren Susut

April 26, 2023

U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. DEPARTMENT OF ENERGY | Office of Science

Driving Discovery Science for the Nation

Discovery science supported by the Office of Science builds the foundation for ensuring America's future prosperity and competitiveness by addressing its energy, environment, and national security challenges.

Fostering Great Minds and Great Ideas

The Office of Science addresses the world's most challenging scientific problems, supporting innovation from America's brightest minds, across multiple disciplines, and at universities, DOE's national laboratories, and other research institutions.

Providing Unique, World-Class Facilities

The Office of Science stewards a suite of scientific user facilities that provide the broad scientific community with world-leading capabilities for research - from physics, materials science, and chemistry to genomics and medicine.

SC ORGANIZATION CHART
(as of 4/9/23)

Director
Asmeret Asefaw Berhe

Deputy Director for Science Programs (DDSP)
Harriet Kung

- Advanced Scientific Computing Research (ASCR)
- Basic Energy Sciences (BES)
- Biological & Environmental Research (BER)
- Fusion Energy Sciences (FES)
- High Energy Physics (HEP)
- Nuclear Physics (NP)
- Accelerator R&D and Production (ARDAP)
- Office of Equity and Workforce Development (EWD)
  - Office of Workforce Development for Teachers & Scientists (WDTS)
  - Office of Scientific Workforce Diversity, Equity & Inclusion (SW-DEI)
- Office of International Activities, Research Security, and Interagency Coordination (IRIC)
- Office of Communications & Public Affairs (OCPA)
- Office of Scientific & Technical Information (OSTI)
- Office of Sponsored Activities (OSA)
- Office of SBIR/STTR Programs (SBIR/STTR)

Deputy Director for Operations (DDO)
Juston Fontaine

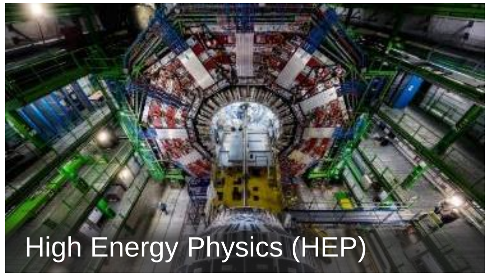
- Ames Site Office (AMSO)
- Argonne Site Office (ASO)
- Berkeley Site Office (BSO)
- Brookhaven Site Office (BHSO)
- Fermi Site Office (FSO)
- ORNL Site Office (OSO)
- Pacific Northwest Site Office (PNSO)
- Princeton Site Office (PSO)
- SLAC Site Office (SSO)
- Thomas Jefferson Site Office (TJSO)
- Science Laboratories Infrastructure (SLI)
- Office of Isotope R&D and Production (IRP)
- Office of Safety & Security (OSS)
- Office of Acquisition Management (OAM)
- Office of Laboratory Policy (OLP)
- Consolidated Service Center (CSC)
- Office of Corporate Business Operations (OCBO)
  - Office of Information Management (OIM)
  - Office of Budget (OB)
  - Office of Resource Management (ORM)
  - Office of Project Assessment (OPA)

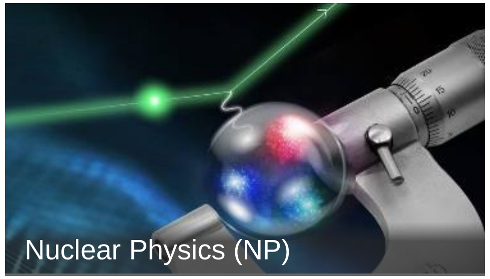
U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Science Guiding Principles for Budget Formulation

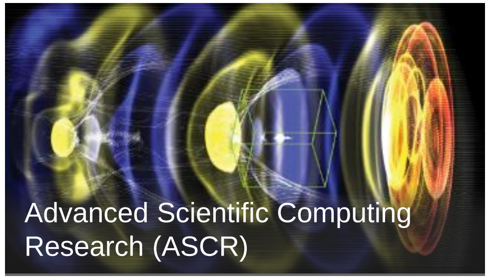
FY 2022 Enacted: $7.5B
FY 2023 Enacted: $8.1B
FY 2024 President's Request: $8.8B

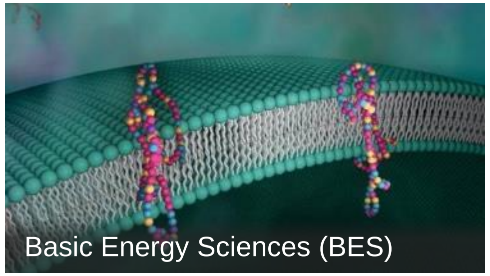
- FY 2024 request supports a balanced research portfolio focused on cutting edge, early-stage R&D that probes some of the most fundamental questions in science
- The future of the Office of Science includes:
  - Research investments
  - Moving towards optimal operations and upgrades to scientific user facilities
  - Upgrades/improvements to national laboratories infrastructure/utilities and reduce deferred maintenance


High Energy Physics (HEP)

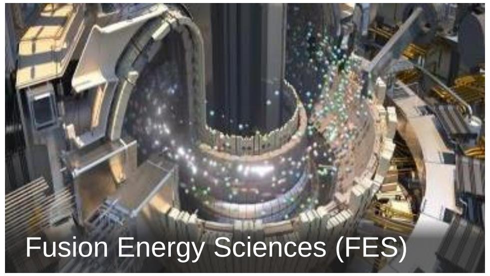

Nuclear Physics (NP)


Isotope R&D and Production (DOE IP)


Advanced Scientific Computing Research (ASCR)


Basic Energy Sciences (BES)


Biological & Environmental Research (BER)


Fusion Energy Sciences (FES)


Accelerator R&D and Production (ARDAP)

OFFICE OF SCIENCE GUIDING PRINCIPLES

- Sustain the critical enabling infrastructure for U.S. global leadership in innovation that is unique to SC
  - Advance critical and emerging technologies crucial to U.S. leadership in innovation and the growth of our inclusive 21st-century economy
    - Recruit and retain the next generation innovation workforce that looks like all of America and deliver on Justice40
      - Bring all of SC's capabilities to bear on addressing the climate crisis
        - Meet the challenges of our present moment by addressing the impact of inflation, supply-chain challenges, and rapidly changing threat landscape

OFFICE OF SCIENCE HIGHLIGHTS RESEARCH

Increases investments in Administration priorities to include:

- **U.S. Fusion Program Acceleration** supporting public/private partnerships ($275.7M)
- **Microelectronic Science Research Centers** ($60M)
- **Reaching a New Energy Sciences Workforce (RENEW)** for targeted efforts to increase participation and retention of underrepresented groups in SC research activities to include non-R1 MSIs ($47M)
- **Funding for Accelerated, Inclusive Research (FAIR)** ($13.5M)
- **Earthshots** to include Geothermal, Offshore Wind, Building Sector, Processed Heat, and Transportation Sector ($75M)
- DOE **Isotope Initiative** ($14.5M)
- **Climate Resilience Centers** and **Urban Integrated Field Laboratories** ($6M)

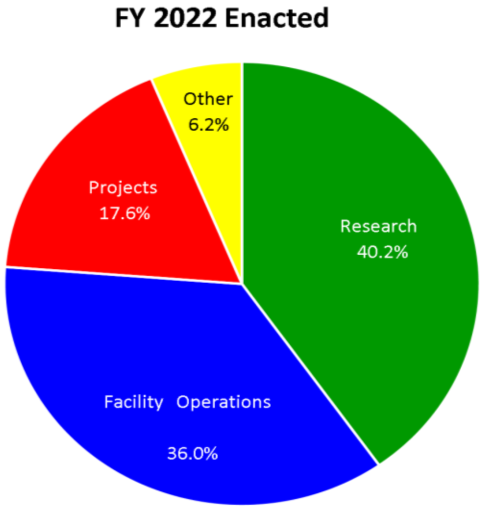
OFFICE OF SCIENCE HIGHLIGHTS
LABS, FACILITY OPERATIONS, AND PROJECTS

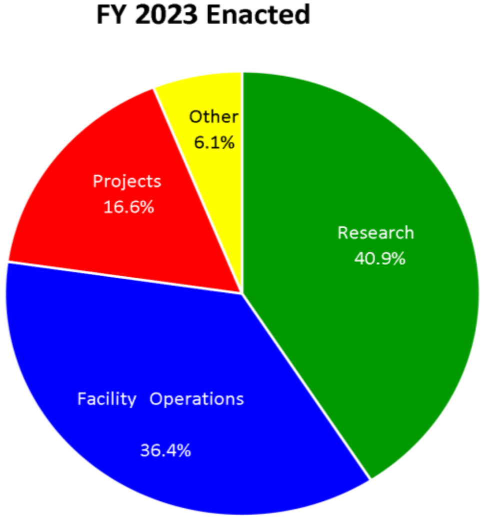
- **Operations of the SC-stewarded national laboratories**
  - Upgrade core laboratory infrastructure, i.e. utilities and laboratory workspace through ongoing SLI infrastructure projects and General Plant Projects
  - Reduce backlog of deferred maintenance and improve obsolete infrastructure at SC National Laboratories
  - Initiate a new Laboratory Operations Apprentice Program
  - SC fully funds Oak Ridge Nuclear Operations

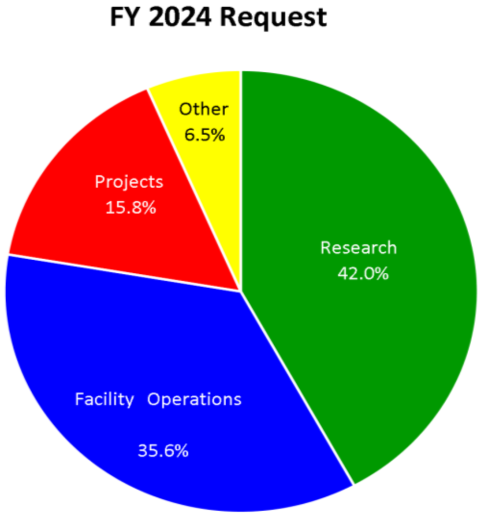
- **Facility operations supported at ~90% optimal funding levels**
  - SC Facilities "rebaselined" to show full costs of operations to include impacts of inflation, staffing costs, telework/remote capabilities, enhanced maintenance activities, etc.

- **Support line-item construction and MIE projects**
  - Initiates six new construction projects
  - Continue to support ongoing infrastructure projects

FY 2024 PRESIDENT'S REQUEST BY BUDGET ELEMENT







	FY 2022		FY 2023		FY 2024					
	Enacted	% of Total	Enacted	% of Total	President's Request	% of Total	vs. FY 2023 Enacted		vs. FY 2022 Enacted	
							$ Change	% Change	$ Change	% Change
Research	3,004,900	40.2%	3,312,207	40.9%	3,700,413	42.0%	388,206	11.7%	695,513	18.8%
Facility Operations	2,690,678	36.0%	2,947,128	36.4%	3,136,443	35.6%	189,315	6.4%	445,765	14.2%
Projects	1,314,413	17.6%	1,344,943	16.6%	1,392,465	15.8%	47,522	3.5%	78,052	5.6%
Other	465,009	6.2%	495,722	6.1%	571,079	6.5%	75,357	15.2%	106,070	18.6%
Total	**7,475,000**	**100.0%**	**8,100,000**	**100.0%**	**8,800,400**	**100.0%**	**700,400**	**8.6%**	**1,325,400**	**15.1%**

SC'S FY 2024 PRESIDENT'S REQUEST

(dollars in thousands)

	FY 2022 Enacted	FY 2023 Enacted	FY 2024 Request	FY 2024 Request vs FY 2023 Enacted		FY 2024 Request vs FY 2022 Enacted	
Office of Science							
Advanced Scientific Computing Research	1,035,000	1,068,000	1,125,973	+57,973	+5.43%	+90,973	+8.79%
Basic Energy Sciences	2,308,000	2,534,000	2,692,858	+158,858	+6.27%	+384,858	+16.67%
Biological and Environmental Research	815,000	908,685	931,700	+23,015	+2.53%	+116,700	+14.32%
Fusion Energy Sciences	713,000	763,222	1,010,496	+247,274	+32.40%	+297,496	+41.72%
High Energy Physics	1,078,000	1,166,000	1,226,334	+60,334	+5.17%	+148,334	+13.76%
Nuclear Physics	728,000	805,196	811,418	+6,222	+0.77%	+83,418	+11.46%
Isotope R&D and Production	82,000	109,451	173,051	+63,600	+58.11%	+91,051	+111.04%
Accelerator R&D and Production	18,000	27,436	34,270	+6,834	+24.91%	+16,270	+90.39%
Workforce Development for Teachers and Scientists	35,000	42,000	46,100	+4,100	+9.76%	+11,100	+31.71%
Science Laboratories Infrastructure	291,000	280,700	322,000	+41,300	+14.71%	+31,000	+10.65%
Safeguards and Security	170,000	184,099	200,000	+15,901	+8.64%	+30,000	+17.65%
Program Direction	202,000	211,211	226,200	+14,989	+7.10%	+24,200	+11.98%
Total, Office of Science	**7,475,000**	**8,100,000**	**8,800,400**	**+700,400**	**+8.65%**	**+1,325,400**	**+17.73%**

Basic Energy Sciences

Linda Horton, Associate Director

U.S. DEPARTMENT OF ENERGY | Office of Science

FY 2024 BES Request $2,693M (+6.3% over FY 2023 Enacted)

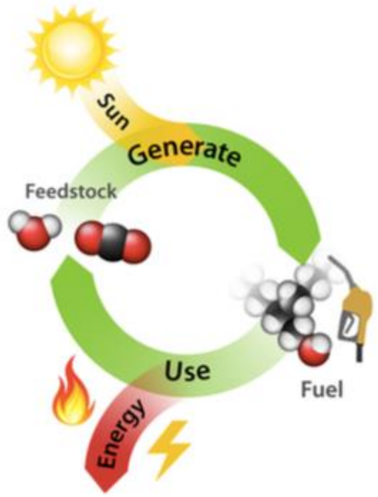
- Balances support for critical science foundations and national user facilities for the Nation (operations and construction/upgrade of facilities). Increased investment areas include:
  - SC Energy Earthshots Initiative (+$35M): Focus on DOE Energy Earthshots topics that have under-investment in the SC portfolio and accelerate innovation for underpinning science challenges for clean energy technologies.
  - Microelectronics (+$25M): New Microelectronics Science Research Centers are established as authorized under the CHIPS and Science Act (Section 10731, Micro Act).
  - Research Opportunities for Underrepresented Communities: RENEW (+$12M) expands targeted efforts, including a RENEW graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research. Continued SC support for DOE EPSCoR.
- Increased support for user facilities would provide 90% of the operational budget as determined by the facilities and will balance safe operations with user access.

Climate and Clean Energy

FY 2024 $3.5B, Δ=+$440.5M

SC will provide scientific understanding for innovations for goals of DOE Energy Earthshots and beyond

- **renewable energy**, including wind, geothermal, and solar energy
- **energy storage** for both vehicles and the grid
- harnessing **biology in clean energy** technologies
- **carbon dioxide removal, capture, and durable storage/sequestration**
- **carbon-neutral hydrogen generation, storage, and use**
- **future nuclear fusion and fission energy**
- low-carbon, efficient, sustainable, **circular manufacturing**
- stable and diverse supplies of **critical materials**
- transformative technology development to **enrich isotopes** that can yield **fuel cycle** cost savings and reduced **nuclear waste**
- cross-cutting efforts in **high-end computing, AI/ML and data** to support **predictive models** for new clean energy solutions



ENERGY earthshots U.S. DEPARTMENT OF ENERGY

Hydrogen Shot

Long Duration Storage Shot

Carbon Negative Shot

Enhanced Geothermal Shot

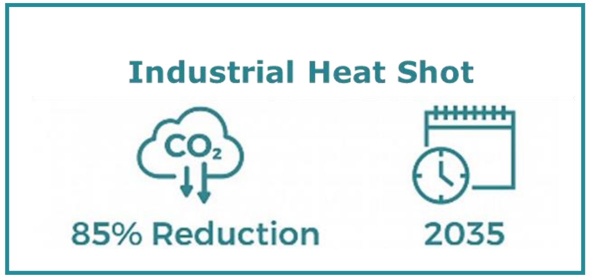
Industrial Heat Shot

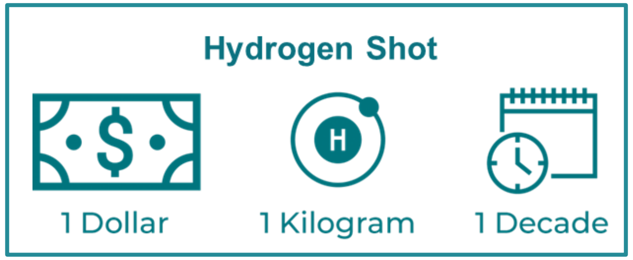
Floating Offshore Wind Shot

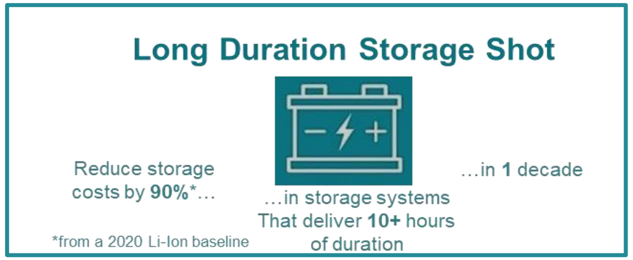
SC Energy Earthshots

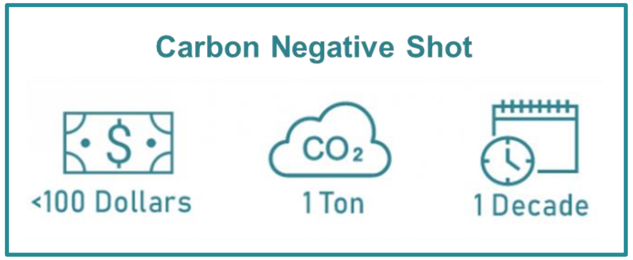
FY 2024 $175.0M, Δ=+$75.0M

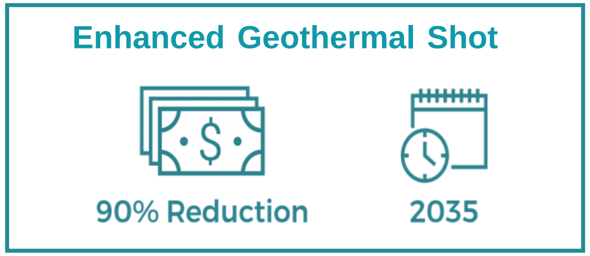
- **Investments to accelerate breakthroughs required for abundant, affordable, and reliable clean energy solutions**
  - **EERCs: multi-investigator, multi-disciplinary teams focused on advancing a single Earthshot**
  - **Team-based academic awards focus on the scientific foundations for Earthshot goals**
- **All-hands-on-deck approach to provide S&T innovations to address tough challenges required to achieve climate and economic goals**
  - **Six Energy Earthshots have been announced:**
    Hydrogen, Long Duration Storage, Carbon Negative, Floating Offshore Wind, Enhanced Geothermal, and Industrial Heat
  - **New topics are in planning stages**





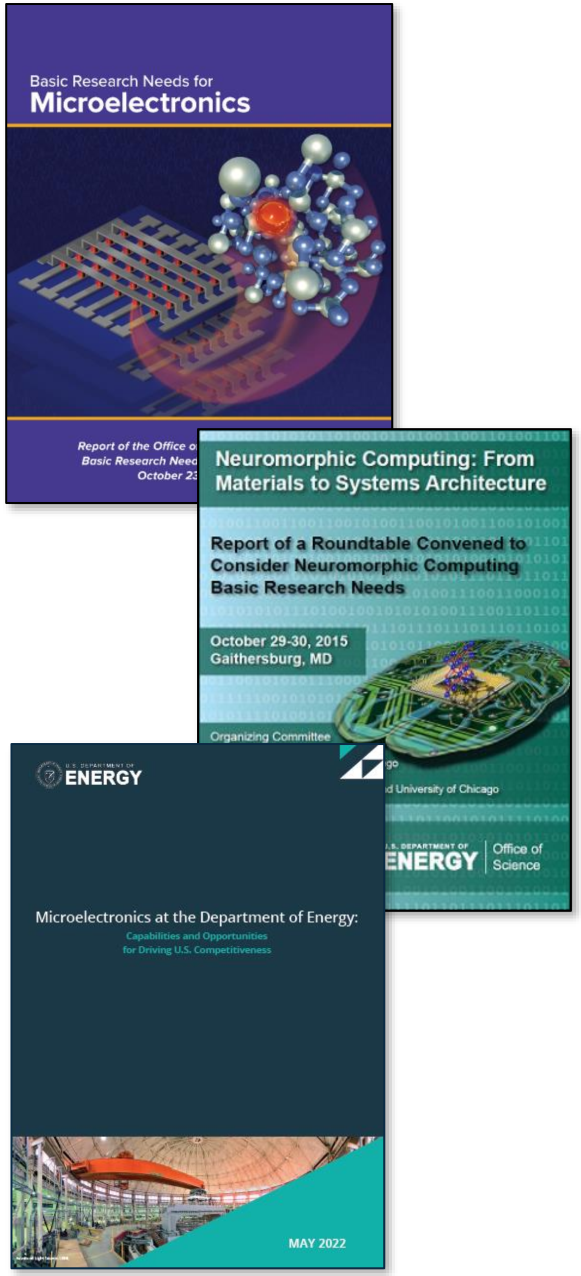




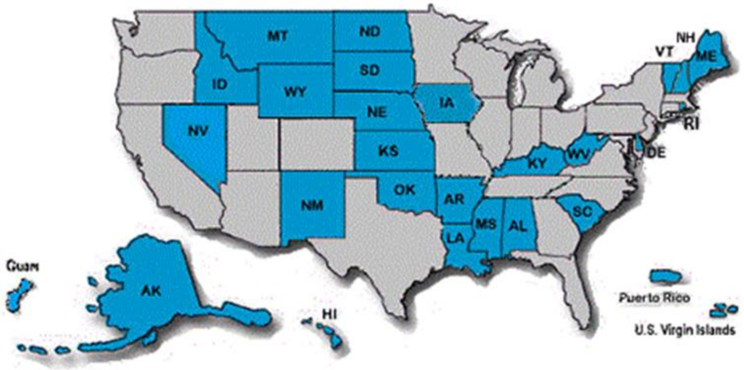


Advanced Microelectronics
FY 2024 $109.7M, Δ=+$62.0M

- Continues coordinated support for multi-disciplinary research to accelerate the innovation and advancement of microelectronic technologies in a co-design innovation ecosystem
- Establishes up to four new Microelectronics Science Research Centers, as authorized by the CHIPS and Science Act (Section 10731, Micro Act)
  - Perform mission-driven research to address foundational challenges in the design, development, characterization, prototyping, demonstration, and fabrication of microelectronics
  - Facilitate the translation of basic research results to technology development and commercialization
  - Interface with other CHIPS Act activities, including those supported by DOC, DOD, and NSF



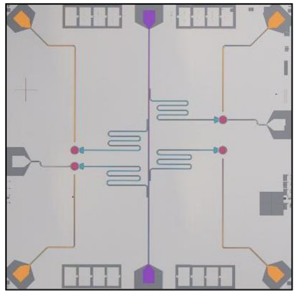
DOE EPSCoR Program – FY 2024 Request



- EPSCoR program funding continues to be distributed among the six major research programs within the Office of Science (ASCR, BER, BES, FES, HEP, NP)
- FY 2024 program will focus on EPSCoR State-National Laboratory Partnership awards promoting single-investigator and small-group interactions with the unique capabilities of the DOE national laboratory system
  - EPSCoR program will continue to support Early Career Research Program awards as well as complementary support for grants to eligible institutions under the SC-wide RENEW and FAIR initiatives
  - As called for in the CHIPS and Science Act of 2022, in addition to the EPSCoR Program funds, the Office of Science will strive to annually invest 10% of academic research funds at institutions in EPSCoR jurisdictions.

FY 2024 Continues Focus on Science for Critical & Emerging Technologies

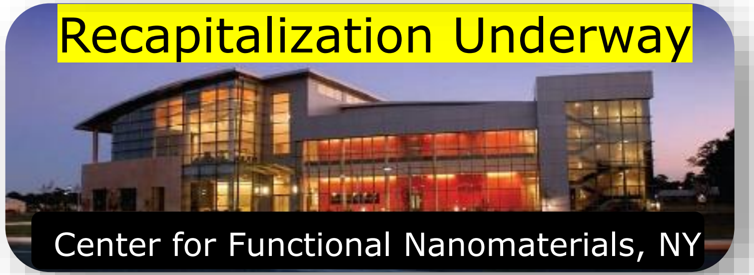
- **Accelerate Innovations in Emerging Technologies (ACCELERATE)**: BES, with other SC Offices, will continue research to accelerate the transition of science advances to clean energy technologies, including future-generation microelectronics, low-carbon manufacturing, and emerging technologies to move from laboratory to industrial prototypes.
- **Manufacturing**: BES will continue to support multi-disciplinary basic research to advance new materials, chemistry, synthesis, fabrication, and processing research that accelerates the decarbonization of manufacturing, including a focus on alternatives for thermal processing and promotion of a co-design innovation ecosystem.
- **Quantum Information Science (QIS)**: BES will continue research to understand and control quantum coherence and entanglement in atomic, molecular, and materials systems; develop systems with properties needed for quantum computing and sensing; and advance approaches and algorithms to harness quantum computers for BES research.
- **Artificial Intelligence and Machine Learning (AI/ML)**: BES will continue support of data science to accelerate BES discovery science, and to aid in effective user facility operations and interpretation of massive data sets.

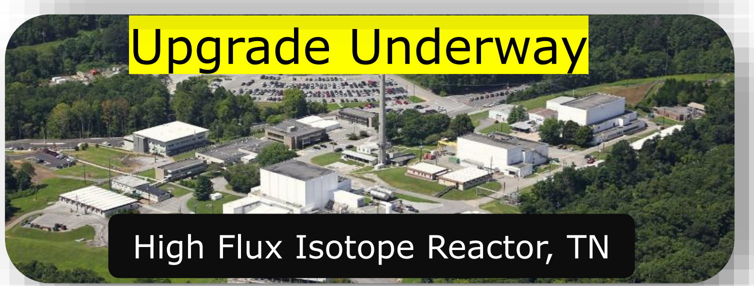

Superconducting multiqubit chip

FY 2024 Team Science Continues

- In FY 2024, BES will continue to support major team science research centers/awards that leverage advances in the core research programs and are critical to clean energy and QIS innovation.
  - Energy Frontier Research Centers – Continued support for 4-year awards made in FY 2022; biennial recompetition for ~$25M ($100M for all years) for science for environmental management, sustainable manufacturing, and other national priorities.
  - Fuels from Sunlight Energy Innovation Hub Program – Continued support for two Hub projects initiated in FY 2020.
  - Batteries and Energy Storage Energy Innovation Hub Program – Continued support of awards based on FY 2023 program recompetition.
  - National QIS Research Centers – Continued support for SC QIS Centers started in FY 2020.
  - Computational Materials and Chemical Sciences – Continued support focusing on software that takes advantage of SC leadership class computers (FY 2024 recompetes ~$5M). As the Exascale Computing Project concludes, this recompetition will place a priority on transitioning researchers, software, and technologies.

Continued Support for BES User Facilities: X-ray, Neutrons, and Nanoscale Science





Fusion Energy Sciences

John Mandrekas, Acting Associate Director

U.S. DEPARTMENT OF ENERGY | Office of Science

FES Mission and Strategic Priorities

MISSION

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundations needed to develop a fusion energy source. This is accomplished by the study of the plasma state and its interactions with its surroundings.

The Energy Act of 2020 expanded the scientific mission of FES to support “the development of a competitive fusion power industry in the U.S.”

FES PROGRAM PRIORITIES

1. Accelerate fusion development as a carbon-free energy source via public-private partnerships (“bold decadal vision”)
2. Continue U.S. participation in ITER to study burning plasma science and technology at power plant scale
3. Strengthen the U.S. program to aim at a Fusion Pilot Plant (FPP)
4. Support discovery plasma science
5. Enhance broadening participation and DEIA activities to enable the program

U.S. Fusion Program Acceleration
FY 2024 $275.7M *(new initiative)*

Fusion Development Milestone Program

- Resolve scientific and technological challenges toward commercializing fusion energy through partnerships with the private sector
- Key goal is the achievement of preliminary designs and technology roadmaps for a Fusion Pilot Plant (FPP)

Initiate four multi-institutional, multi-disciplinary fusion energy R&D centers

- Includes enabling technologies, advanced simulations, blanket/fuel cycle and materials:
- Focus on S&T basis for fusion energy and support both public and private FPP efforts

INFUSE

- Provide private-sector companies with access to world-class expertise and capabilities available at DOE's national laboratories and U.S. universities

Inertial Fusion Energy (IFE)

- Implement priority research opportunities identified in the IFE Basic Research Needs Workshop

Future Facilities Studies

- Support design studies/R&D for a fusion neutron source

Milestone-Based Fusion Development Program

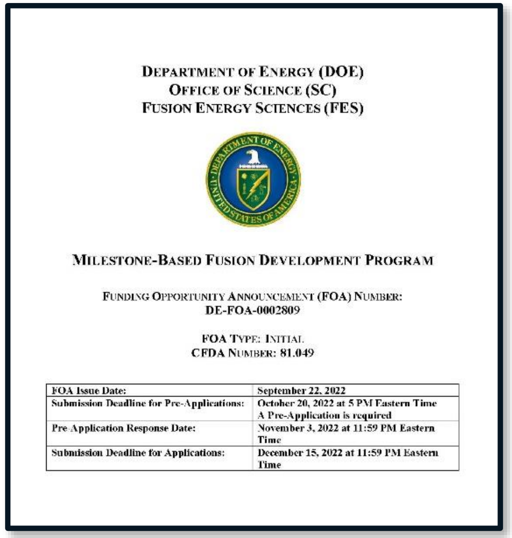
- **Purpose**: Facilitate the successful design of a Fusion Pilot Plant (FPP) through partnerships with the private sector
- First step toward the implementation of the Administration's Bold Decadal Vision (BDV) for commercial fusion energy
- Following the March 2022 White House Fusion Summit and an SC-sponsored workshop on "Fusion Energy Development via Public-Private Partnerships", FES issued a Funding Opportunity Announcement (FOA) for a Fusion Milestone Development Program
- FES is in the process of selecting the first awards under this FOA

March 2022 White House Summit on the BDV

Milestone-Based Development Program

Year	1	2	3	4	5
FOA Scope	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

$50M over 18 months → *Additional funding has been authorized (not yet appropriated)*



DEPARTMENT OF ENERGY (DOE)
OFFICE OF SCIENCE (SC)
FUSION ENERGY SCIENCES (FES)

MILESTONE-BASED FUSION DEVELOPMENT PROGRAM

FUNDING OPPORTUNITY ANNOUNCEMENT (FOA) NUMBER:
DE-FOA-0002809

FOA TYPE: INITIAL
CFDA NUMBER: 81.049

FOA Issue Date:	September 22, 2022
Submission Deadline for Pre-Applications:	October 20, 2022 at 5 PM Eastern Time A Pre-Application is required
Pre-Application Response Date:	November 3, 2022 at 11:59 PM Eastern Time
Submission Deadline for Applications:	December 15, 2022 at 11:59 PM Eastern Time

Milestone Program FOA

Fusion Energy R&D Centers

- The centers build upon and leverage core program efforts in materials science, fusion nuclear science, enabling technologies, and SciDAC and conduct necessary R&D to resolve science and technology challenges.
- Aligned with recommendations in the LRP, the NASEM report on Bringing Fusion to the U.S. Grid, and the objectives of the Bold Decadal Vision.
- Envisioned as multi-institutional multidisciplinary activities.
- Their focus will be informed by recent and upcoming community workshops and the needs of the milestone program teams that will be selected in FY 2023.
- Will be selected competitively through FOAs.
- Will contribute to the development of a diverse and inclusive workforce.

Fusion Energy R&D Centers (cont.)

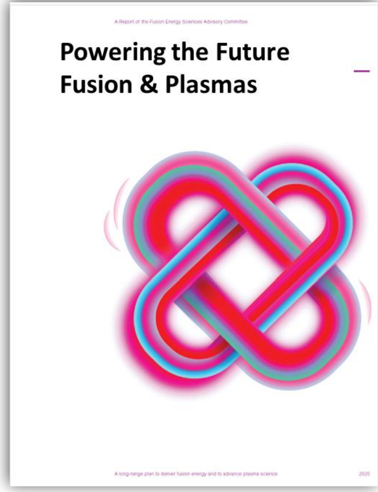
- **Structural/Plasma-Facing Materials Center**
  - Develop and qualify new materials that can withstand the harsh fusion environment for long periods of time and be safely disposed under current regulations in existing disposal sites.
- **Blanket/Fuel Cycle Center**
  - Develop the fusion fuel cycle which includes blankets to breed and safely process, as quickly and efficiently as possible, the necessary fuel elements (i.e., tritium) required to make fusion a near inexhaustible future energy resource.
- **Enabling Technologies Center**
  - Develop the required heating, fueling, magnets and other enabling technologies that are necessary to make fusion a carbon-free energy source.
- **Advanced Simulations Center**
  - Leverage research performed by the SciDAC partnerships to develop and apply predictive simulation tools to optimize the design and assess the performance of multiple FPP concepts.

Innovation Network for Fusion Energy (INFUSE)

- **INFUSE** is now in its fifth year
- Provides private fusion companies with access to the leading expertise and capabilities available at DOE National Laboratories and universities (since FY22) to address critical scientific and technological challenges in fusion energy.
- To date, **72 awards** totaling **$14.8M** have been made, enabling **10 DOE national labs** and **8 universities** to collaborate with **21 private fusion companies**
- The FY 2023 RFA has been posted– applications were due 3/31/2023.

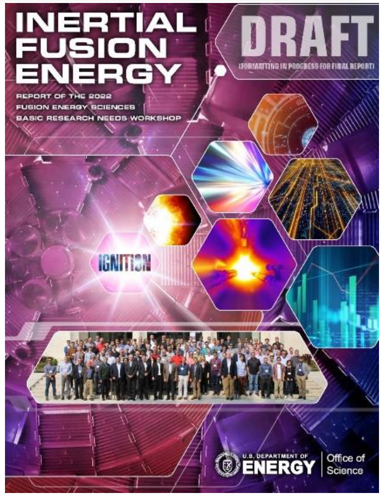
https://infuse.ornl.gov/

Inertial Fusion Energy (IFE)



LRP:

"An IFE program that leverages US leadership and current investments should be targeted."



IFE Basic Research Needs Workshop Report:

"The recent demonstration of thermonuclear ignition on the National Ignition Facility constitutes a pivotal point in the development of inertial fusion energy."

Background

- In December 2022, the National Ignition Facility achieved ignition and scientific (target) gain of 1.5.

IFE Research Activities

- A FOA will be issued in FY 2023 to address the Priority Research Opportunities (PROs) outlined in the IFE BRN.
- The PROs include S&T in Target Physics & Ignition, Driver & Target Technologies, IFE Workforce Development, and Public-Private Partnerships.

Future Facilities Studies – Fusion Neutron Source

- Gaining an improved understanding of the science of materials degradation due to fusion neutron bombardment is a critical need for the program as it moves toward the design of an FPP.
- A fusion prototypic neutron source was among the highest priorities identified in the FESAC LRP, the NASEM report, and addresses needs of both the public and private sectors.
- The desired parameters of such a source were identified in a series of community workshops, the most recent one in September 2022.

Table 1. *FPNS performance requirements desired by 2028 or earlier, and 2032 or earlier, as indicated in Columns 2 and 3, respectively.*

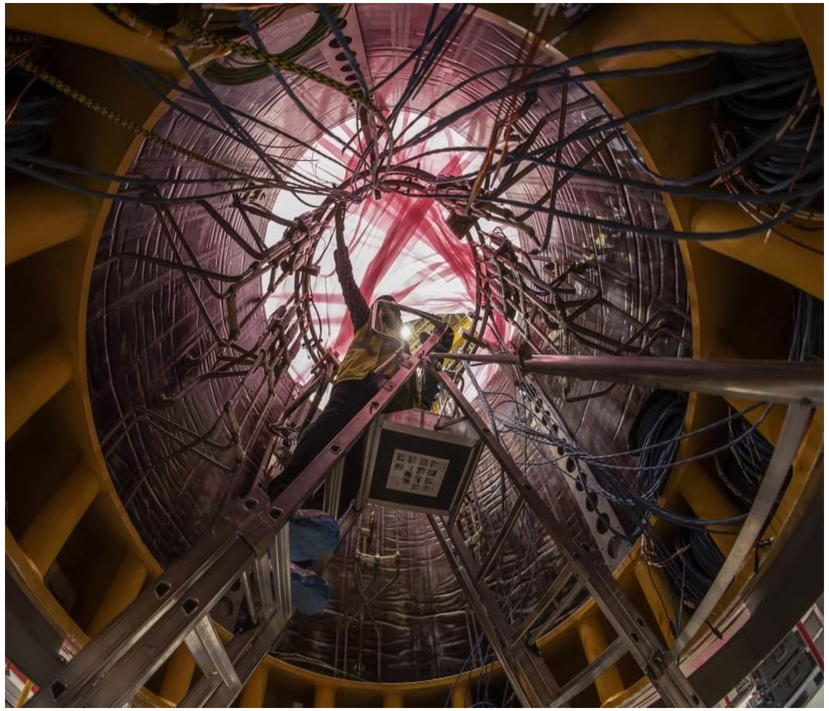
Parameter	Capability Requirement by 2028 or earlier	Capability Requirement by 2032 or earlier
Damage rate	5 to 11 dpa/calendar year (Fe equivalent)	15 dpa/calendar year (Fe equivalent)
Spectrum	Gaseous and solid transmutant generation rates consistent with 14 MeV fusion neutron	Gaseous and solid transmutant generation rates consistent with 14 MeV fusion neutron
Sample volume in high flux zone	≥ 50 cm^3	≥ 300 cm^3
Temperature range	~300 to 1200°C	~300 to 1200°C
Temperature control	3 independently monitored and controlled regions	4 independently monitored and controlled regions
Flux gradient	≤ 20%/cm in the plane of the sample	≤ 20%/cm in the plane of the sample

- An RFI has been issued* on potential technological approaches to meet the needs listed in Table 1, and on potential ways to accelerate the construction of a cost-effective fusion neutron source, including public-private partnerships.
  - *Responses due by **May 11***
- The FY 2024 Request will support studies and research for a future fusion neutron source facility.

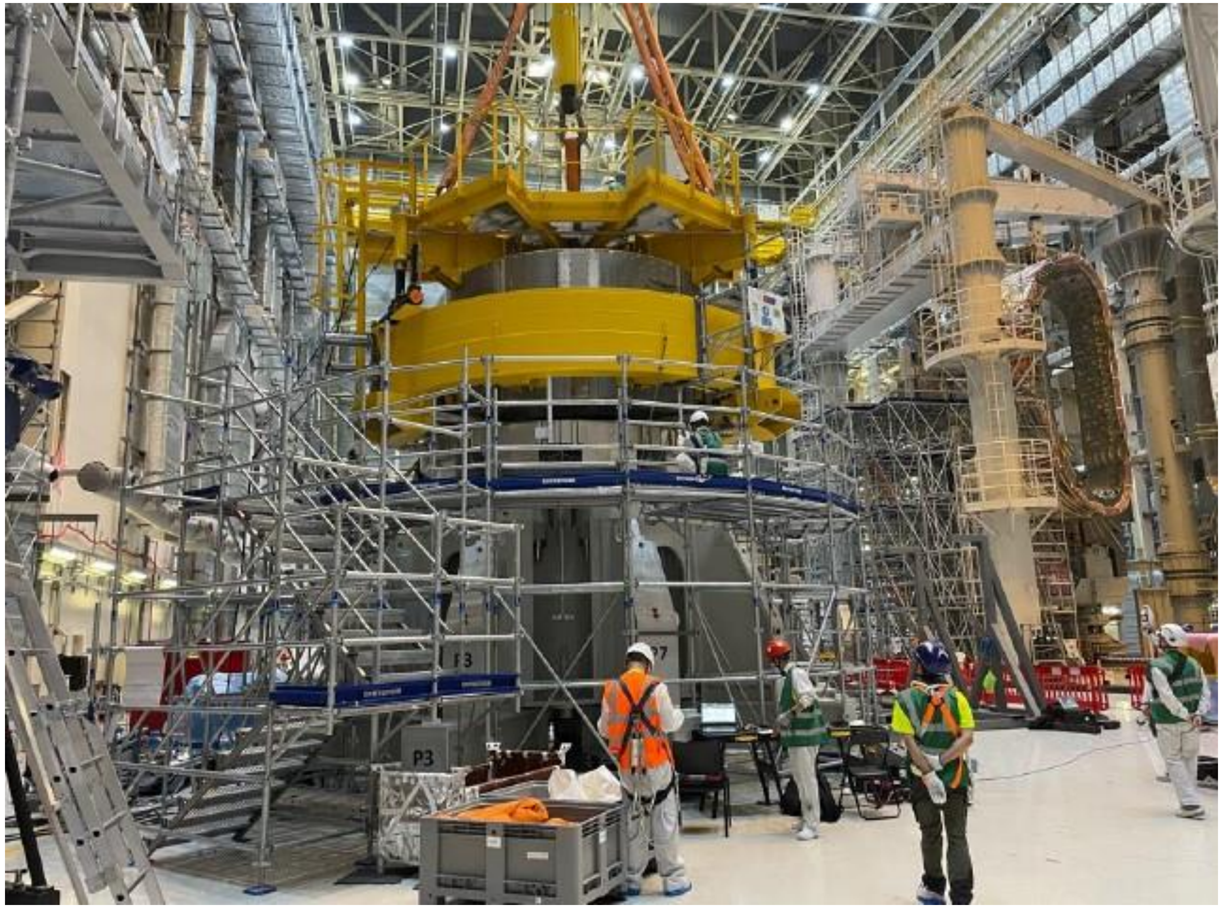
*https://www.regulations.gov/document/DOE_FRDOC_0001-4610

Continue U.S. Participation in ITER

Study burning plasma science and technology at reactor scale



A look inside the first central solenoid module. Five more will stack on top to complete the 18-meter-tall system

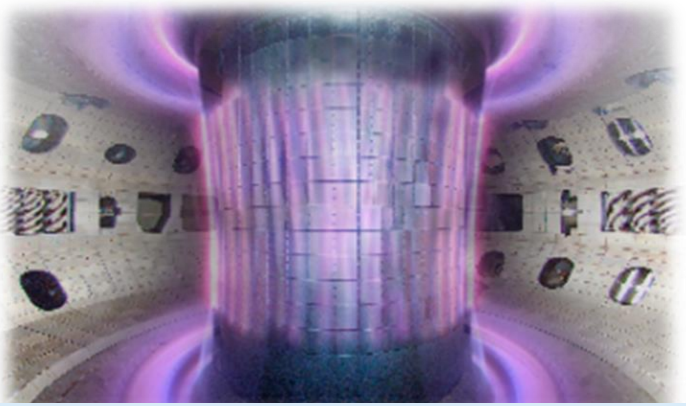


Central solenoid module assembly progressing at the ITER site

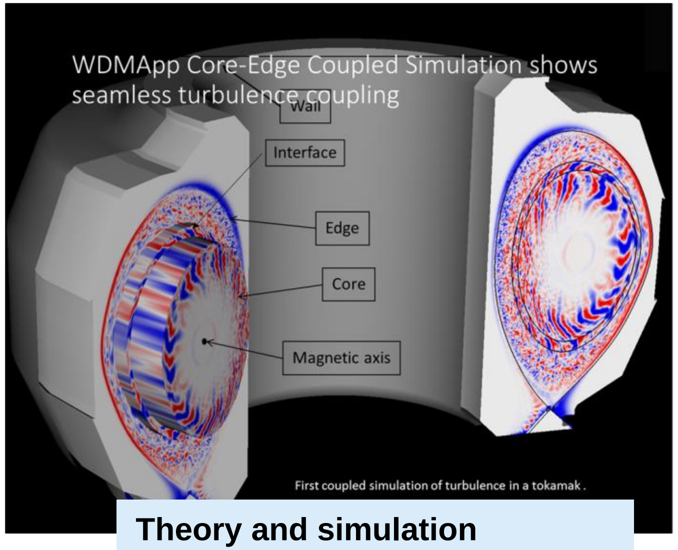
Maintain Robust Support for Core Research, Facilities, and Projects

Funding at 64 universities, 15 national laboratories, and 14 private companies

SC user facilities

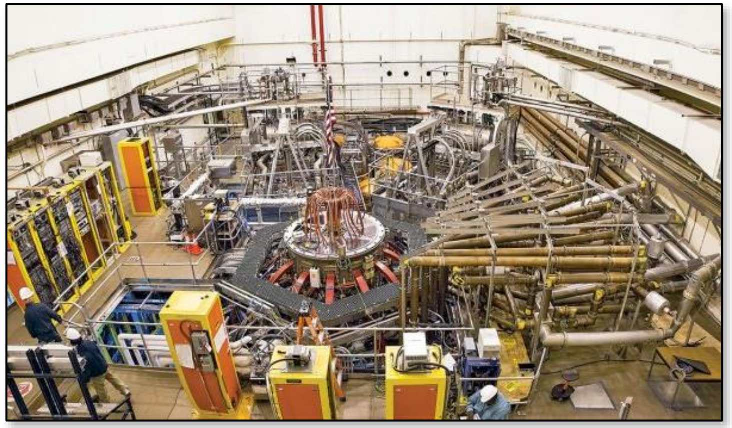


DIII-D National Fusion Facility

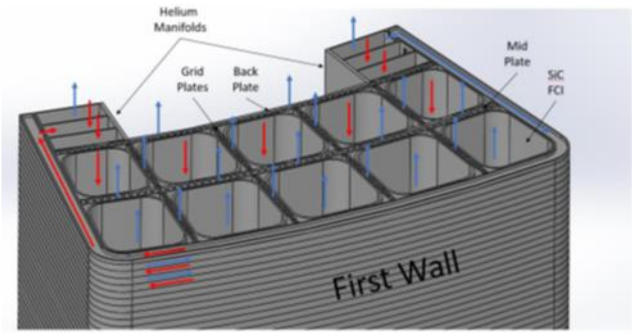


Theory and simulation

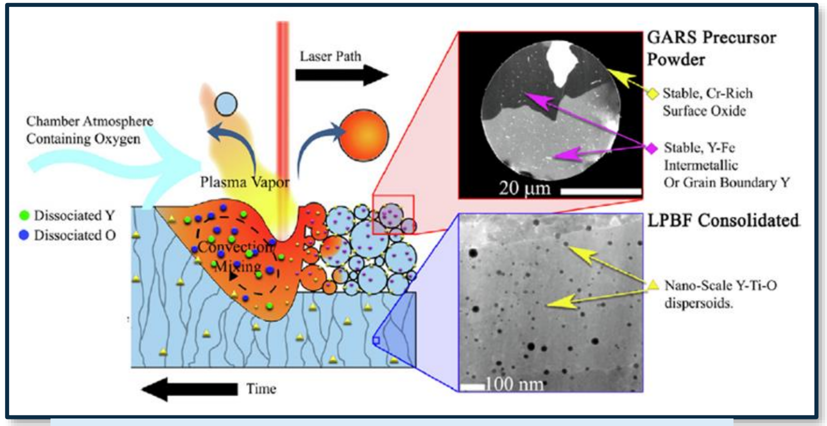
International Collaborations



National Spherical Torus Experiment-Upgrade

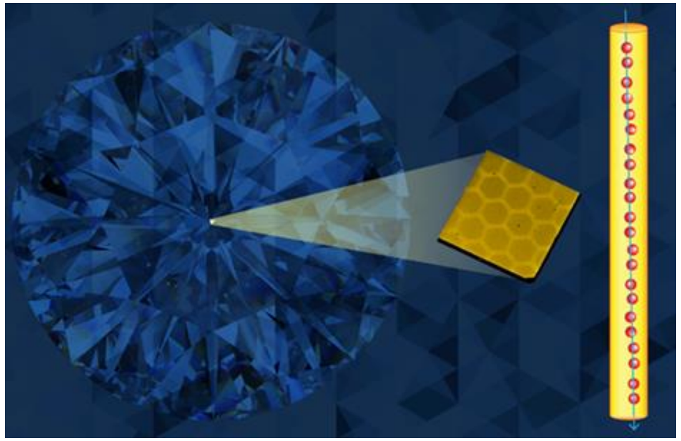


Fusion Nuclear Science

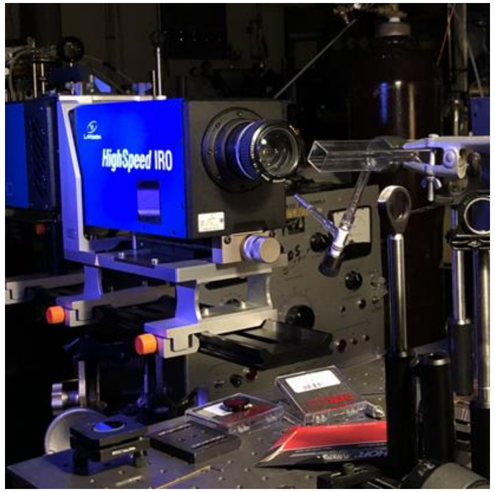


Materials Science / AM

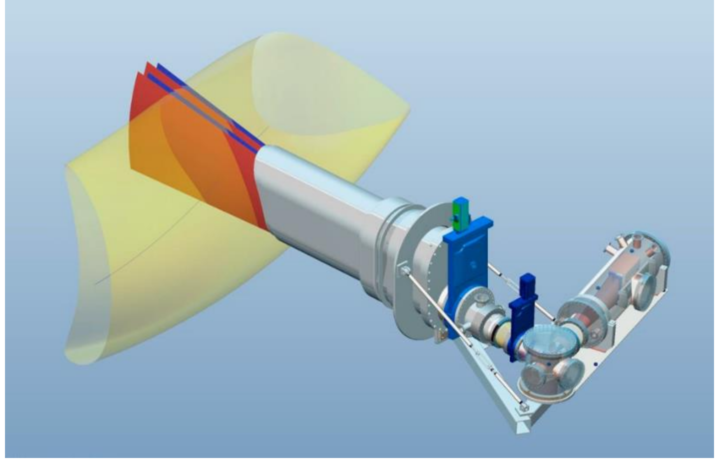
Maintain Robust Support for Core Research, Facilities, and Projects (cont.)



Quantum Information Science

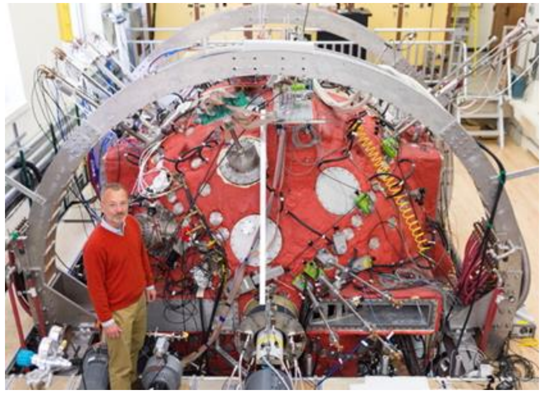


Low Temperature Plasmas



Plasma Diagnostics

AI/ML



General Plasma Science

LaserNetUS / HEDLP

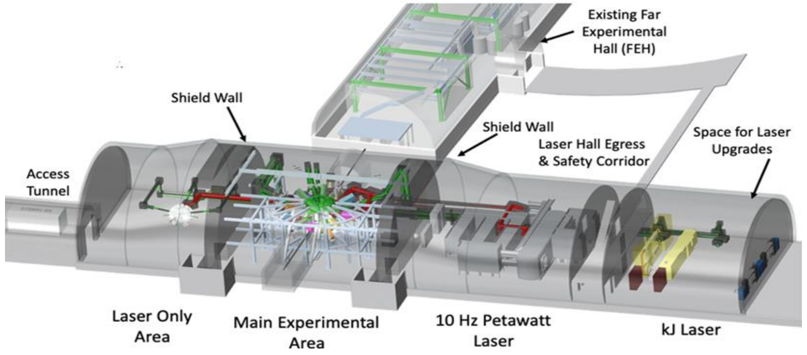
Projects

Material Plasma Exposure Experiment (MPEX)

MPEX will deliver world-leading experimental capability for evaluating the performance of plasma-facing materials under fusion energy-relevant conditions

- Steady-state, high-heat-flux plasma exposure for accelerated materials life-time testing under a large range of plasma parameters
- Ability to test neutron-irradiated materials
- Ability to test material samples in unique target geometries
- Under construction (MIE) at **ORNL**
-

Matter in Extreme Conditions Petawatt Laser Upgrade



- World-leading laser performance; unique capabilities when combined with LCLS XFEL
  - 10x higher power @ 10 Hz (Petawatt); 10x higher energy laser (kilojoule)
- High energy Density Science
  - Relativistic HED plasma, Nonlinear optics of plasmas, HED hydrodynamics, Warm Dense Matter
- Focused fusion-relevant capabilities
  - Rep-rate and hardened diagnostics, capsule ablator material

High Energy Physics

Glen Crawford, Research and Technology Division Director

U.S. DEPARTMENT OF ENERGY | Office of Science

HEP’s Competitive Advantage

HEP is a global science enterprise that enables and leverages multiple international connections and resources:

- Fermilab and CERN are the premier international accelerator research facilities that attract thousands of users and significant partnerships
- The strength of these science and technology programs has resulted in over $300M in-kind investment in Fermilab facilities by CERN and EU partners, UK, India and others.
- US researchers working at CERN in pre-COVID times numbered well over 1000; non-US researchers working at Fermilab ~several hundred and growing
- Plus hundreds of researchers contributing to US-led particle astrophysics and cosmology observatories (Rubin/LSST [Chile]; DESI [Kitt Peak]; AMS [on ISS])

HEP students learn to problem-solve with international teams on large, complex technologies that have real-world applications.

DOE Particle Physics Agency Partnerships

DOE is the central player in US particle physics, providing ~85% of annual resources & leveraging interagency partnerships

CERN

European Organization for Nuclear Research, known as CERN, is a European research organization that operates the largest particle physics laboratory in the world.

NSF

- **Proposal driven program**
- **Funds facilities and equipment, such as telescopes, through cooperative agreements with research consortia**

DOE

Mission driven program

National Laboratory enterprise and National User Facilities provide important capabilities & expertise

NASA

- **Mission driven program**
- **Expertise in human spaceflight, aeronautics, space science, and space applications**
- **Partnership enables unique science opportunities**

HEPAP Coordination (NSF ↔ DOE)

AAAC Coordination (NSF ↔ DOE ↔ NASA)

Strong connections	Large Hadron Collider at CERN
Modest ties	Neutrino Experiments
Strong connections	Dark Matter and Dark Energy — ***Space-based experiments***
Strong connections	Theoretical Physics
Modest ties	Technology R&D (Department of Defense, NIST, Homeland Security, NIH)

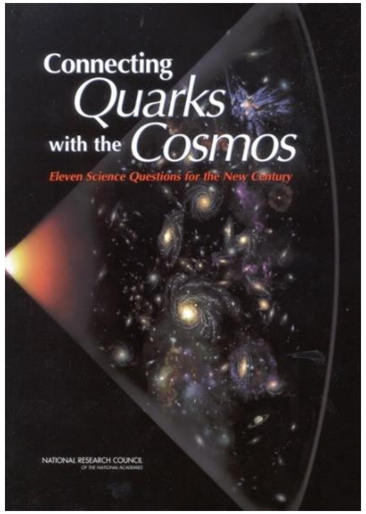
NIST National Institute of Standards and Technology U.S. Department of Commerce

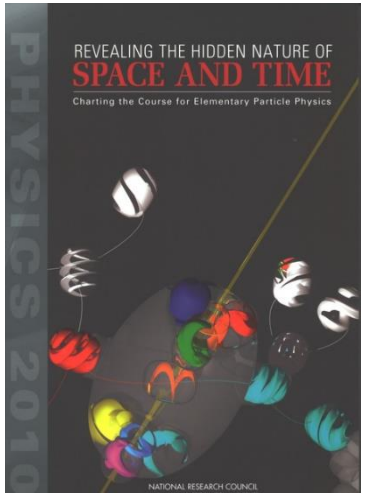
National Institutes of Health

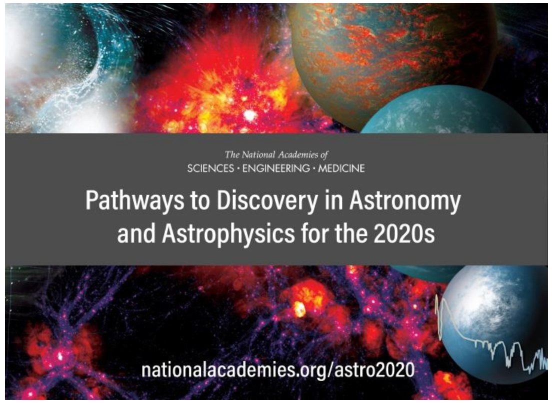
Roadmaps for and from the HEP community

- In collaboration with the National Science Foundation we sponsor community-led and externally vetted **strategic planning activities for HEP looking forward 2-3 decades**
- **Snowmass** is largely HEP community view, and provides updated input to P5
- **Particle Physics Project Prioritization Panel** (P5) will look at specific projects within specific budget guidance, and related topics
- We look to a **National Academy Panel** (EPP2024) to bring in other viewpoints, other fields of science, "outside the box" thinking

  Past successful examples of these type studies would include *Quantum Universe* and *Quarks to Cosmos* studies







Progress on the 2014 P5 plan

- 2019 Evaluation of progress on the plan was very positive
- March 2020 was a game changer
  - COVID impact was huge ….
- We (across the board) are slowly adjusting to a new normal
- A number of important events are influencing the way we move forward
- We note that the Inflation Recovery Act (IRA) has benefitted our ability to get back on track with projects on the 2014 roadmap
- **A major focus in 2023 is to update this plan**

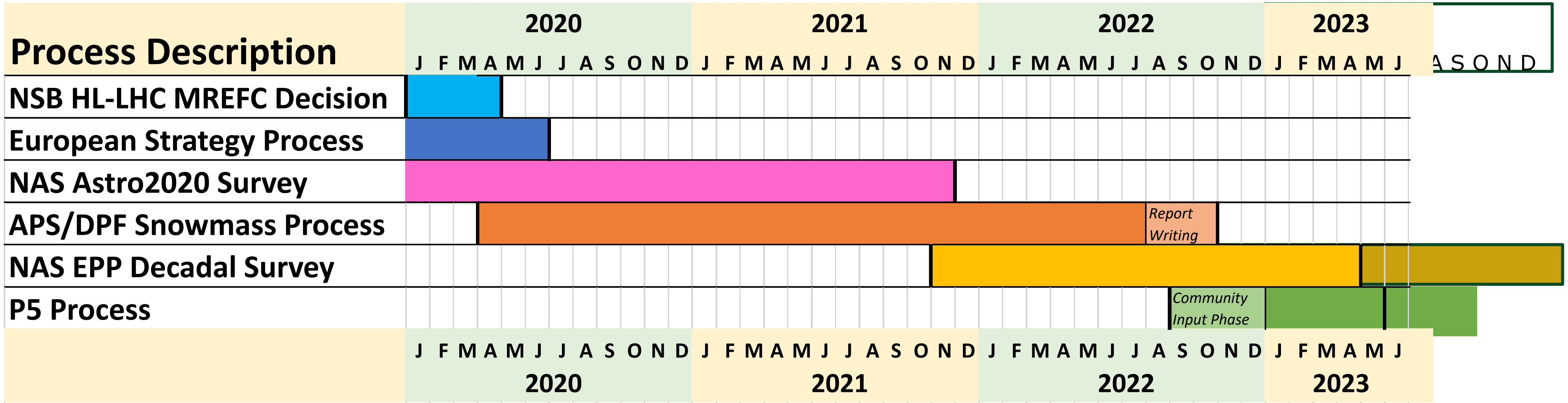
Roadmap Timelines

HEP community-wide "Snowmass" study process organized by the American Physical Society (APS) Division of Particles and Fields (DPF) & Division of Particles and Beams held July 2022. https://snowmass21.org/start

- Identify science questions & directions & options to address these for the coming decade.

National Academy of Sciences (NAS) Elementary Particle Physics (EPP) Decadal Survey will complement the P5 process.

Snowmass 2021



Office of High Energy Physics at a Glance

FY 2023 Enacted: $1.166B

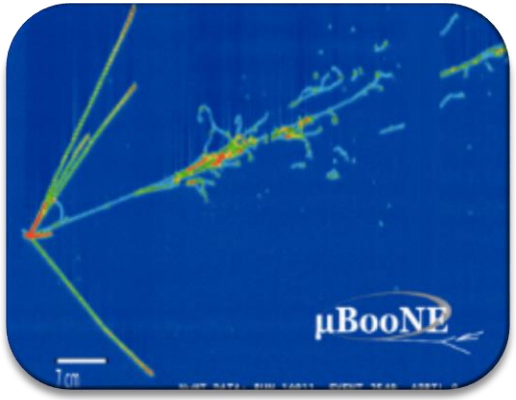
Largest Supporter (**~85%**) of Particle Physics in the U.S.

Funding at **>160** Institutions, including **12** DOE Labs

Over **1,175** Ph.D. Scientists and **525** Grad Students Supported

Over **2,325** Users at **2** SC Scientific Facilities

~30% of Research to Universities



Research:

39.8%, $464.4M

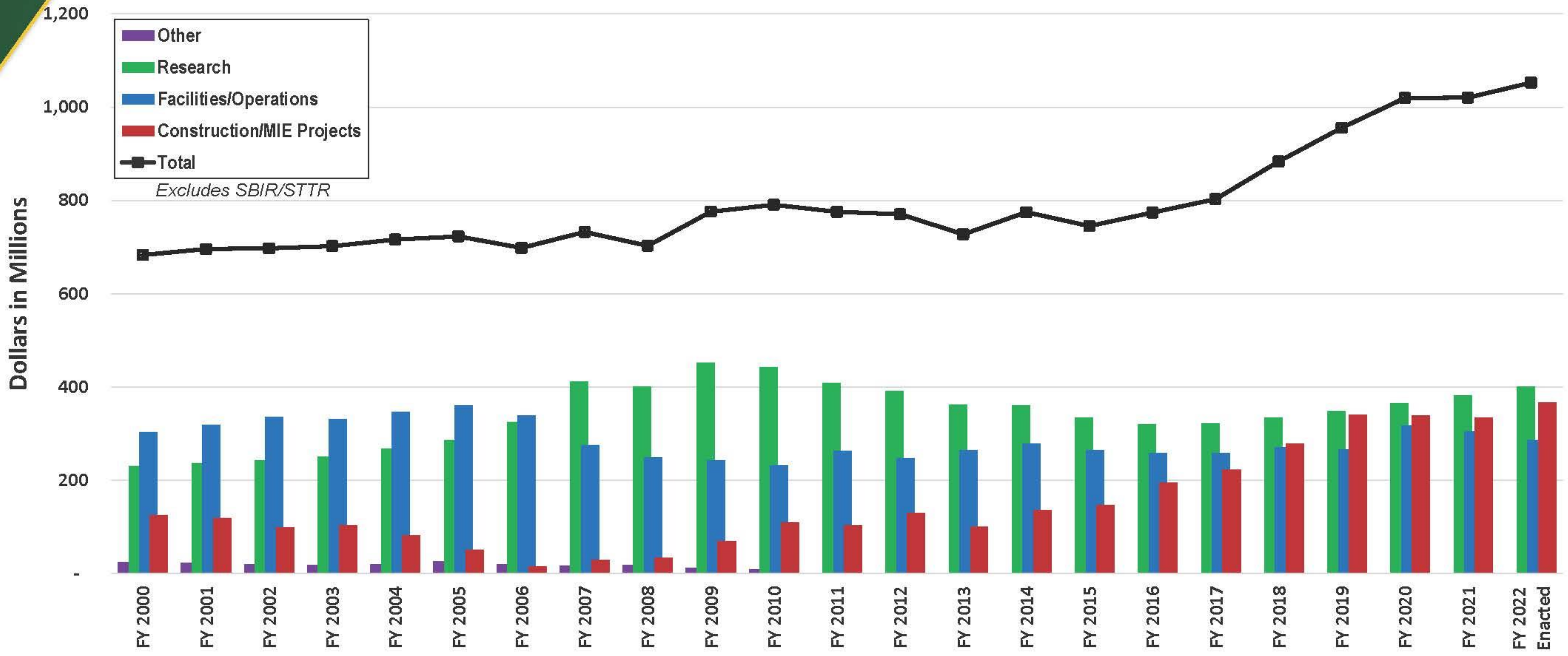
Facility Operations:

29.7%, $346.6M

Projects:

30.4%, $355M

HEP Budget by Component FY 2000-2022

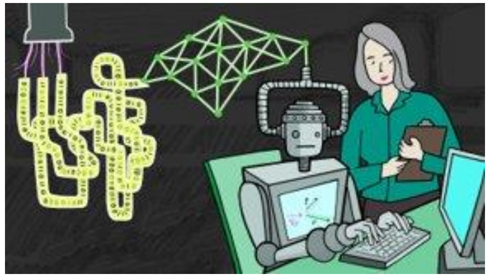


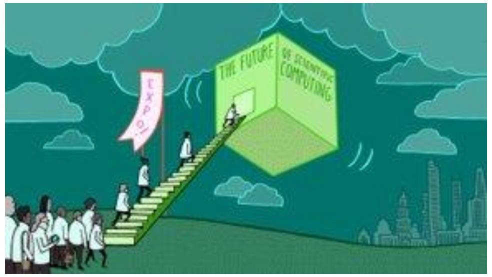
Inflation Recovery Act (IRA) and HEP

- Inflation recovery act passed just before end of FY2022
- OHEP received significant funding to aid projects to get back on track from effects of Covid, inflation etc.
- Total of $303.7M
  - HL LHC
  - PIP-II
  - LBNF/DUNE
  - CMB-S4
  - ACORN
  - Mu2e project

HEP Research Initiatives

- QIS, AI/ML, Microelectronics, Advanced Computing, Accelerator Science and Technology, and ACCELERATE
- Quantum Information Science co-develops quantum information, theory, and technology with core research activities.
  - to more strongly focus and integrate efforts that align with HEP strengths in quantum sensors and theory
- AI/ML effort is highly embedded in core HEP research and accelerator technology, with a new thrust in proposal-driven, cross-cutting R&D. The balance between leveraging AI/ML tools for HEP science and using HEP data to drive AI/ML development will be reassessed.





Nuclear Physics

Sharon Stephenson, Program Manager, Low Energy Physics and Nuclear Astrophysics

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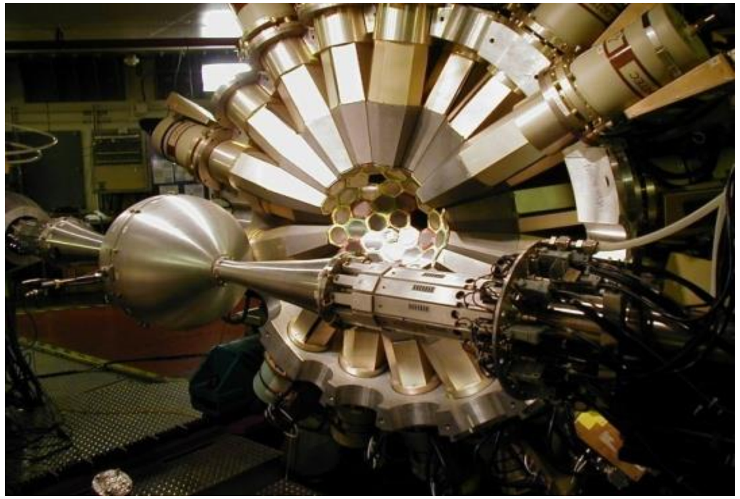
Support for NP Facilities is Strong: > 96% of Optimal Funding in FY 2023

Relativistic Heavy Ion Collider

Continuous Electron Beam Accelerator Facility



Argonne Tandem Linac System

Facility for Rare Isotope Beams

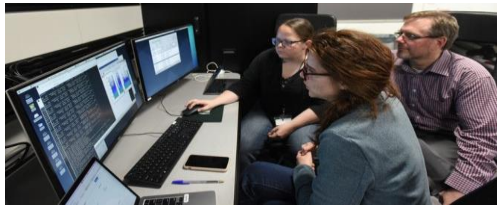
Are “Microscopes” with Complementary Resolving Power

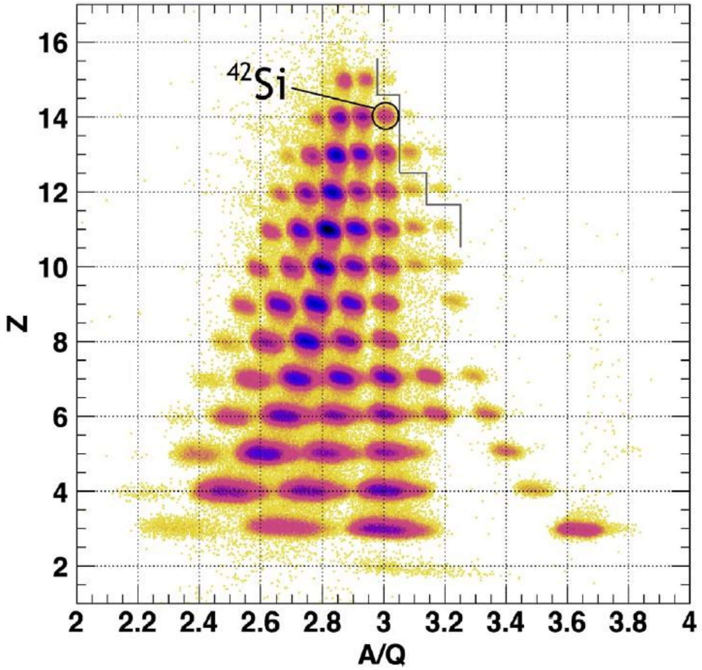
The Newest SC User Facility: the Facility for Rare Isotope Beams

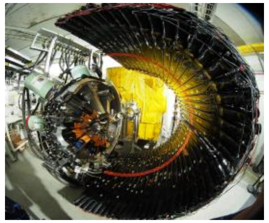
Secretary Granholm at the FRIB Ribbon Cutting

May 2, 2022

FRIB Experiment E21062
Spokespersons: J. Allmond (ORNL), H. Crawford (LBNL), B. Crider (Mississippi State University), R. Grzywacz (University of Tennessee Knoxville) and V. Tripathi (Florida State University)







Multiple papers with first FRIB science now published

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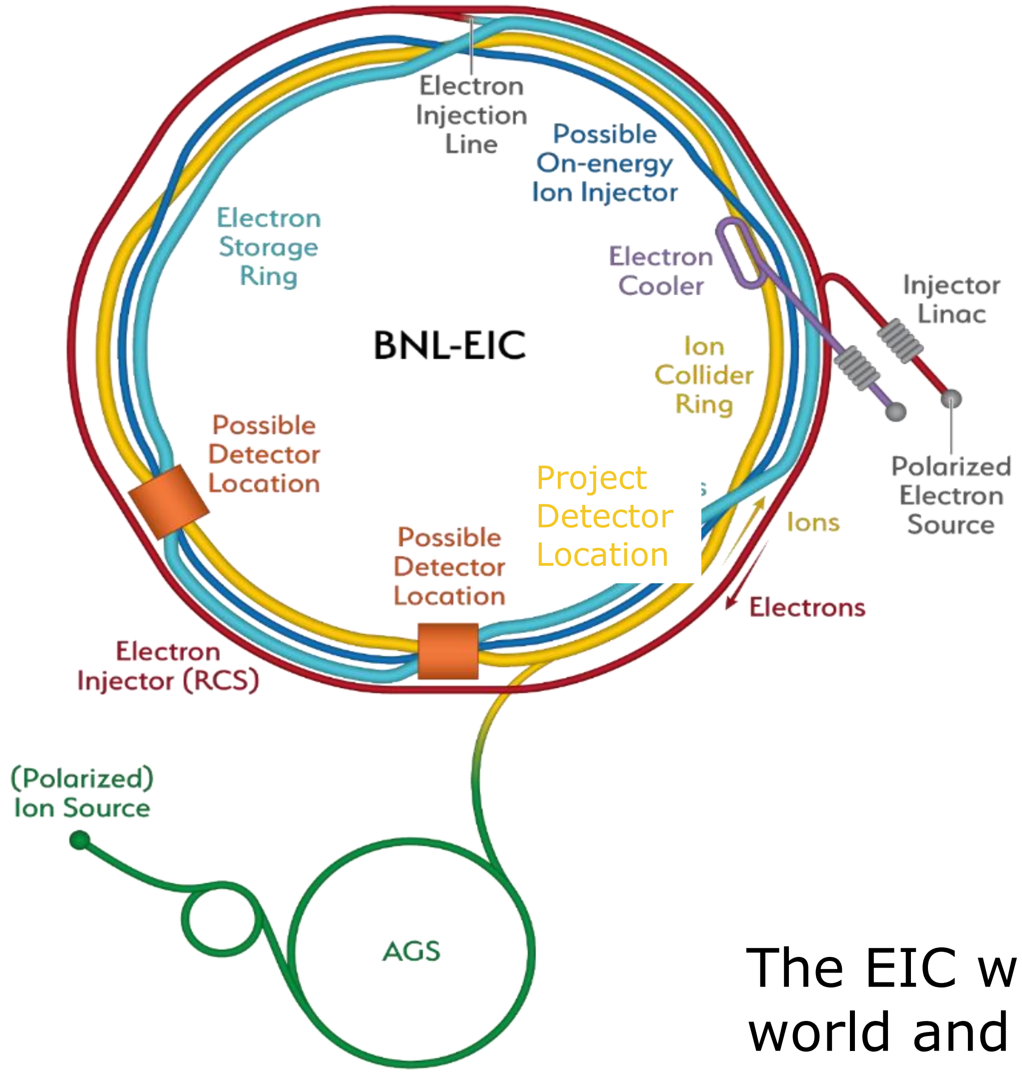
NP is Also Constructing Future Tools to Maintain World Leadership Throughout The Century: the Electron-Ion Collider

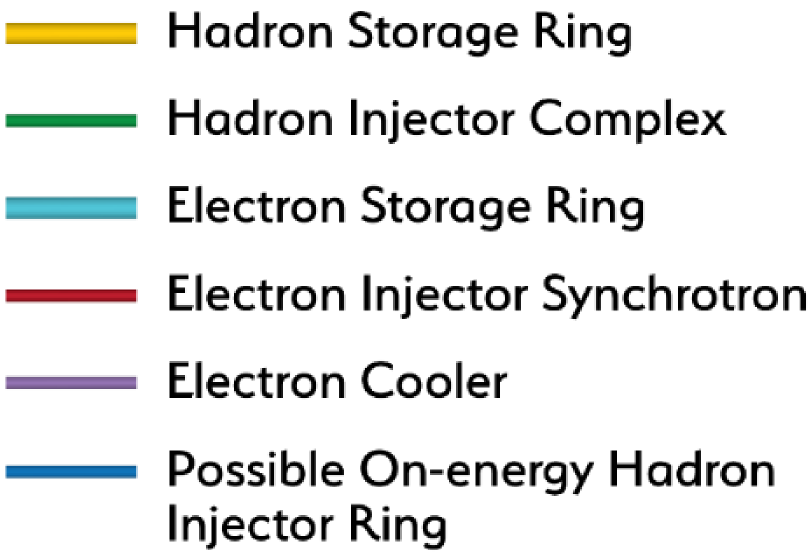


Recent Progress

Successful OPA Progress Review 1/ 2023

Significant Project staffing increases via IRA

Pursuing Long Lead (CD3a) followed by CD-2



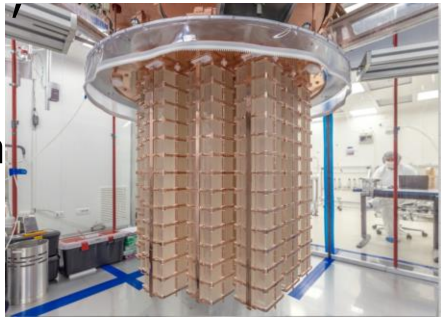
The EIC will be the most advanced accelerator in the world and the only new collider built for decades. It will keep US capability in accelerators physics number one.

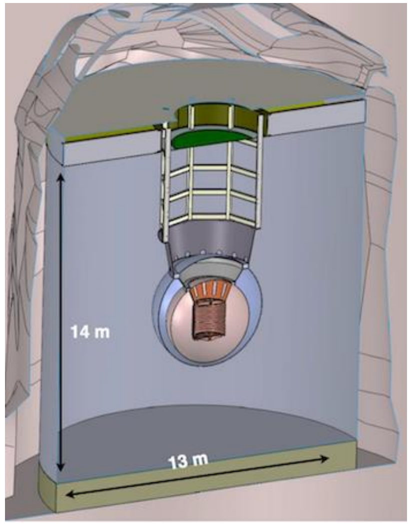
Status of The Other Priority of the 2015 Long Range Plan for Nuclear Science: Neutrinoless Double Beta Decay

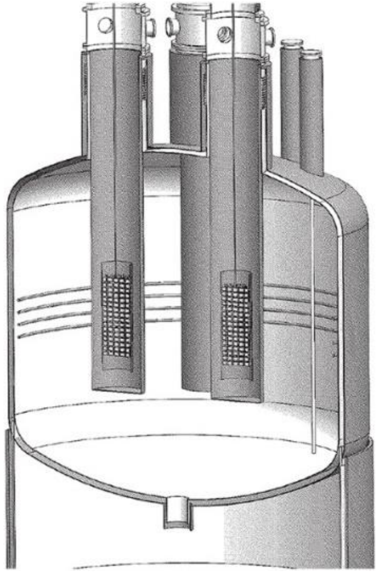
- Between IRA funding and NP Program Funding, approximately $12.8 M allocated to the three technologies being explored LEGEND 1000, nEXO, and CUPID since FY 2020.
- Additional resources provided by international partners
- Inability to procure isotopes from Russia is having a severe, existential impact
- The next DBD international summit is April 27, 2023 at SNOLab in Canada.
- NP is thinking about options to demonstrate a proof-of-principle isotope procurement test

Three Proposed Technologies

- Scintillating bolometry (**CUPID**, ^{100}Mo enriched Li_2Mo_4 crystals)
- Enriched ^{76}Ge crystals (**LEGEND-1000**, drifted charge, point contact detectors)
- Liquid Xenon TPC (**nEXO**, light via SiPM, drifted ionization)







Potential Partners:
Italy, Canada, and Germany, ??

Overall, NP Projects Are Progressing Well

Project	Location	Status	Cost	CPI	SPI	CD-4	Operation cost plan
Construction Projects							
Facility for Rare Isotope Beams (FRIB) *	MSU	CD-4	$730M	1.00	1.00	6/2022	Included in NP budget formulation
Electron-Ion Collider (EIC)	BNL	CD-1	$1.7B to $2.8B			Q4 FY33	RHIC operations funds redirected to EIC project recovered for EIC operations
Major Items of Equipment							
Gamma Ray Energy Tracking Array (GRETA) FF	LBNL	CD-2/3	$58.3M	1.00	1.01	4/2028	Mostly covered by host laboratory operations experimental support
Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX) *	BNL	PD-4	$26.5M	1.00	1.00	12/2022	Covered by RHIC operations experimental support
Measurement of Lepton-Lepton Electroweak Reactions (MOLLER) FF	TJNAF	CD-1	$45.8M to $56.6M			Q4 FY27	Covered by TJNAF operations experimental support
High Rigidity Spectrometer (HRS)	*MSU*	*CD-1*	*$85.0M to $111.4M*			*Q2 FY29*	*Covered by FRIB operations experimental support*
Ton Scale Neutrinoless Double Beta Decay (TS-NLDBD)	TBD	CD-0	$215M to $250M			TBD	TBD

Blue (*) indicates "Completed", green (FF) "Fully Funded", *and purple italic "Substantially Funded"*

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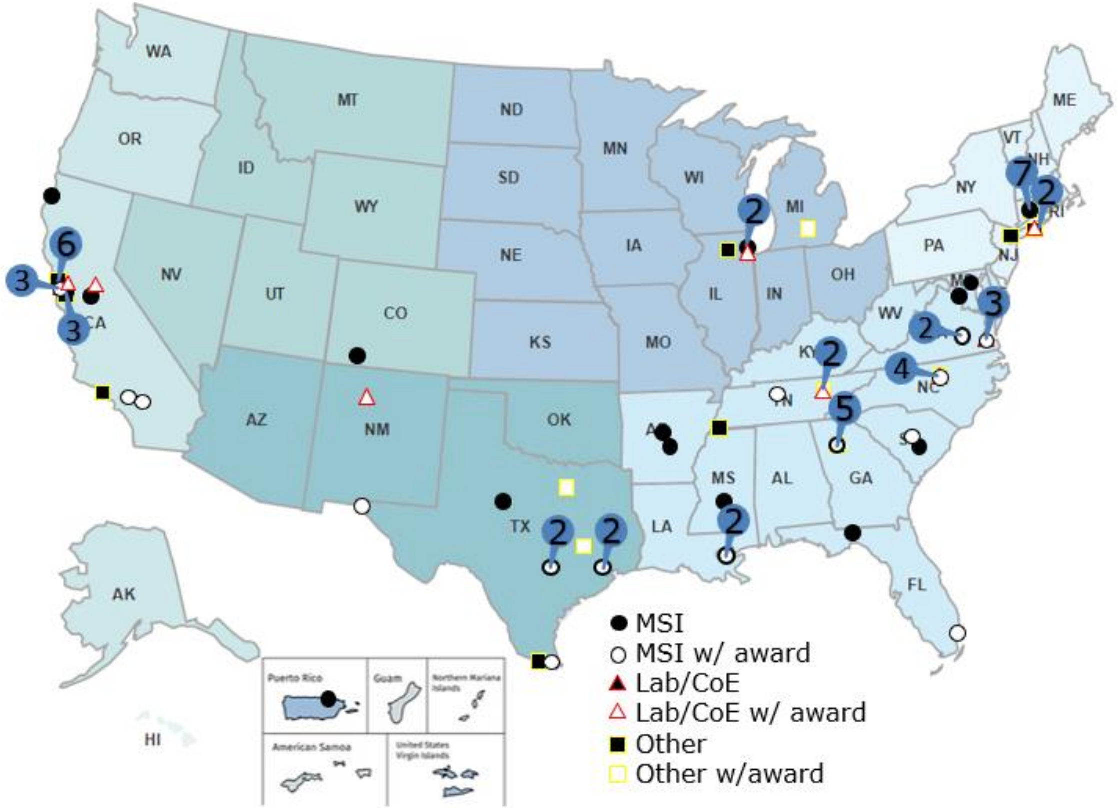
Smaller NP Projects are being "cleared off the books"

NP Is Also Making Significant In-Roads on SC Initiatives such as RENEW

- 110 NP traineeship award recipients include:
  - 18 MSIs,
  - 10 other colleges/universities,
  - 5 DOE laboratories
- MSI award recipients include:
  - 9 Hispanic Serving Institutions (HSIs),
  - 8 HBCUs,
  - 5 Asian/Native American, and Pacific Islander Serving Institutions (AANAPISI),
  - 1 Predominantly Black Institution (PBI)



Other institutions on the map are involved in the traineeship program as recruitment sites (38), Co-Is (9), and/or hosts (7).

Of the funds awarded, ~ 70% went to MSIs, MSI faculty, or MSI students. About 50% of trainees awarded continued on to Graduate Programs in Science or Engineering

The Main Challenge is Constrained Funding for Basic Research and Realizing the Exciting Future Vision For the Field:

- New physics discovered at FRIB/ANL via anomalous atomic electric-dipole moments using laser trapped isotopes
- New quantum loop(s) discovered via anomalous parity violation in electron scattering via MOLLER
- Discovery of A = 120 at the LBNL 88 inch cyclotron
- Discovery of the origin of jet-quenching and the EOS of the quark-gluon plasma using sPHENIX
- Mapping out how many is too many when you try to add neutrons to an isotope at FRIB
- Discovering a way to suppress the effects of natural radiation on quantum coherence times
- Discovering (or not) neutrino-less double beta decay at the level of $m_{\beta\beta} \approx < 10$ meV
- Reduction of the limit on the neutrino mass to $\approx < 40$ meV
- Discovering once and for all whether something is going on with the neutron lifetime
- Discovering the pdfs and orbital dynamics of quarks/gluons in the proton and how they generate its properties
- An EIC that can be operated by 2 people via AI/ML

NP Outlook

- In FY 2024, NP continues stewardship of a world-leading program in nuclear physics that delivers new science, operates unique leadership user facilities, supports and enhances a diverse workforce, and delivers impactful applications

- The EIC Project is making steady progress, towards CD3a (Long Lead Procurement), and the next DOE gateway CD-2 (Approve Performance Baseline). Although not yet baselined, increased support from annual appropriations is essential to enable timely progress and a smooth transition of workforce from the Relativistic Heavy Ion Collider in FY 2025.

- The FY 2024 Request is greatly appreciated, allowing NP National User Facilities to operate at or above 90% of optimal funding

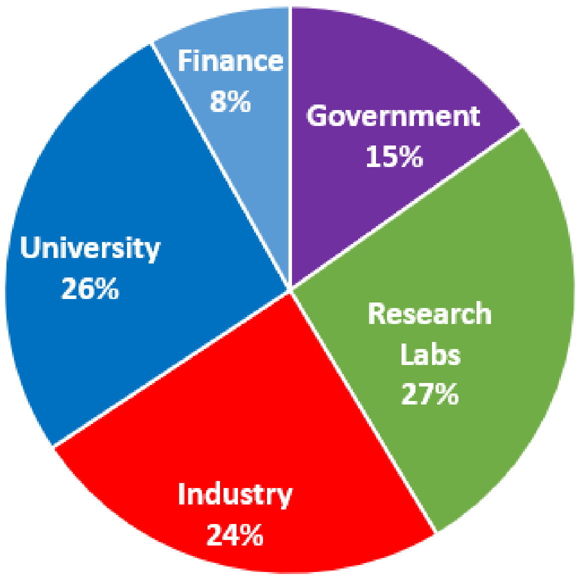
- NP Research funding allows for a compelling program of science but continues to be constrained

Constrained Research May also Impact Benefits to the Nation of Training in Nuclear Science

- Highly Specialized Technical skills
- Creative problem analysis/solving ability
- Scientific communication skills
- Resilience/perseverance despite set-backs
- Self confidence
- Time management ability
- Project planning skills
- Ability to work within a large collaboration
- Leadership development

The result is an essential national core competency useful not only for "things nuclear", but for a variety of other challenging pursuits as

Where NP PhDs go



U.S. science, commerce, medicine, defense —all benefit, in part, from a stable level of sustained competence, capability, capacity, and leadership in nuclear physics;

Advanced Scientific Computing Research

Ceren Susut, Acting Associate Director

U.S. DEPARTMENT OF ENERGY | Office of Science

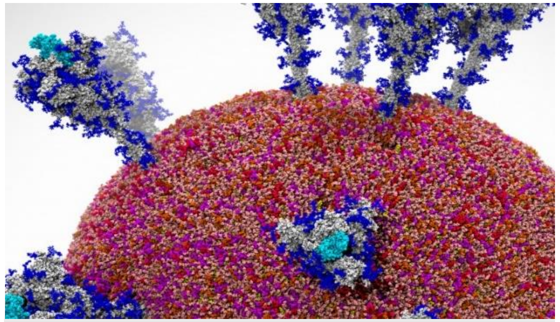
Advanced Scientific Computing Research (ASCR)

FY 2022 Enacted	FY 2023 Enacted	FY 2024 President's Request
$1,035M	$1,068M	$1,126M

- ASCR research lays the groundwork for scientific discoveries
  - **Applied Mathematics and Computer Science foundations** to advance the understanding of natural and engineered systems and to reveal scientific insight from massive data.
  - **Advanced Computing** to prepare for the future of science based on emerging computing technologies and microelectronics.
- ASCR facilities drive the American global leadership in computing, data and networking
  - As we deploy the world's first **exascale supercomputers**, we continue to build an open national research infrastructure for all.
  - Advanced network capabilities connect **DOE science** to global partners.
- ASCR's strategic partnerships enable scientific breakthroughs and advance America's economic competitiveness
  - ASCR's world-leading programs in **interdisciplinary research** enable scientific applications take full advantage of computing and networking capabilities that push the frontiers.
  - Unique models of partnerships advance **American vendor computing technologies.**
- ASCR invests in people
  - **Computational Science Graduate Fellowship** continues to train leaders since 1991.

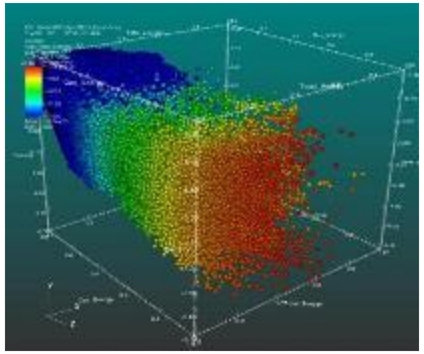
Leadership Computing


Quantum Testbeds

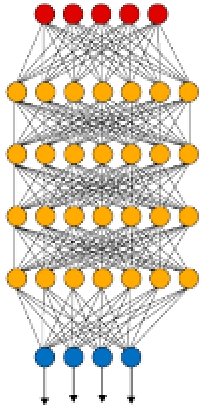

Gordon Bell Prize researchers leverage modeling and AI to understand COVID mutations

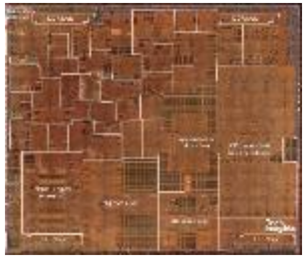
Critical Technology Trends Motivating ASCR Today

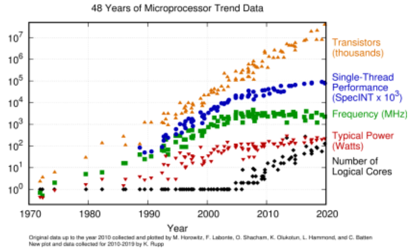
Data, Privacy, and Scientific Integrity



Artificial Intelligence and Deep Learning

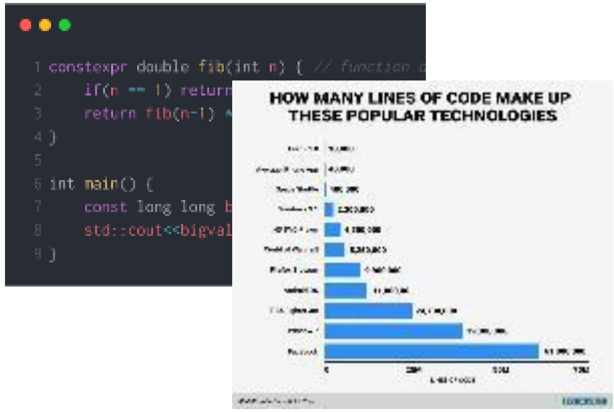


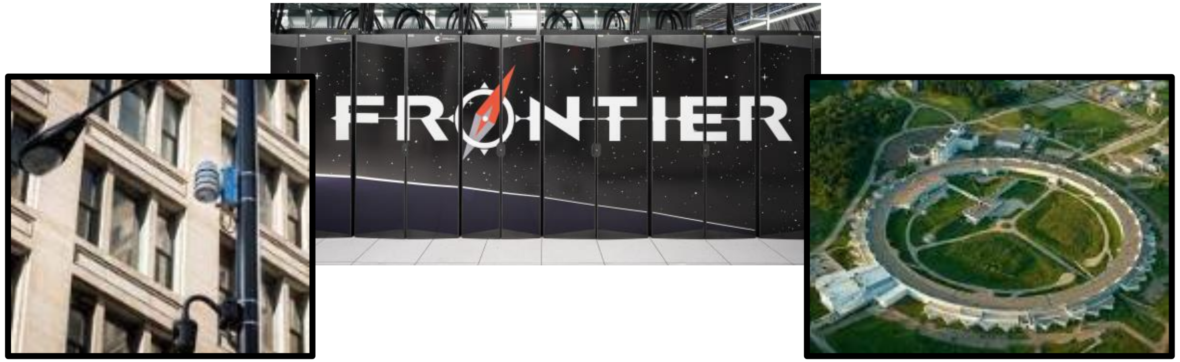




Heterogeneous, Distributed, Special-Purpose, Energy-Efficient Computing

Exploding Software Complexity

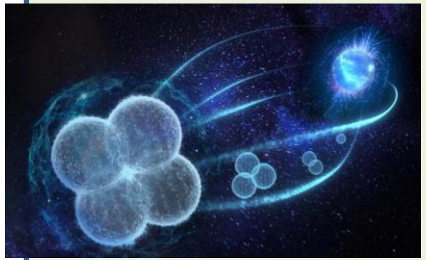




Scientific Computing and Networking: from HPC to the Edge

ASCR Research: Key To Enabling DOE and SC Scientific Enterprise

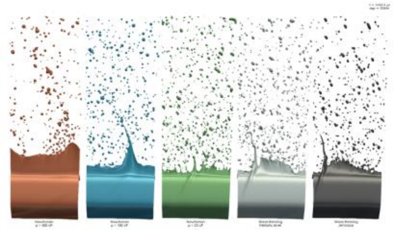
Simulation, modeling and data-driven discovery combined with testbeds and prototypes equip the ASCR community, big and small, to tackle scientific and societal crises.



Discovery Science

ASCR's 20-year SciDAC partnership with NP confirmed the prediction of the existence of tetraneutrons.

Lowering Energy Costs



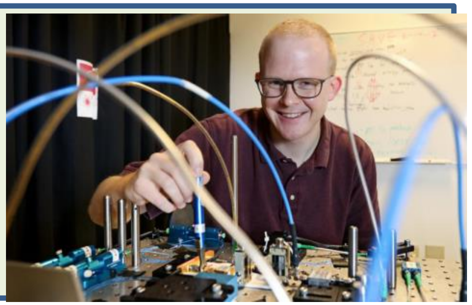
Multi-scale mathematics algorithms and models led to insights to reduce cost in applications from electric grid to automotive industry.

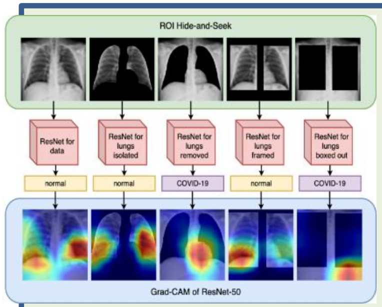
Optimizing Experiments

Optimization and machine learning methods provided real-time experiment steering at beamlines.

Foundations For the Future

Design and demonstration of the first ever Bell state analyzer enabled new quantum communication protocols.





Emergency Response

ASCR CS community's expertise propelled the application of deep learning methods for pandemic response.

Decision Support

5G drone data combined with citizen images and videos lead to better predictions of smoke and fire spread.

ASCR Research Is Inspired by Daring Ideas

ASCR EXPRESS: Single-investigator to small teams to explore high-risk high reward basic research approaches in scientific computing and extreme-scale science.

Science on "complex" architectures

2014

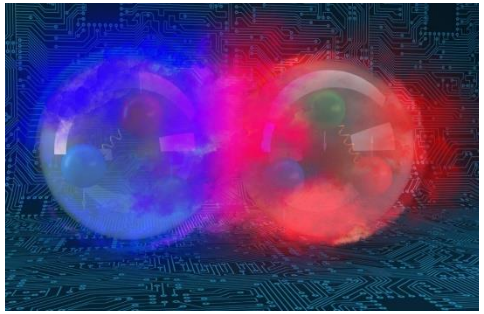
World's Fastest Supercomputer featuring GPUs

Seeds for an integrated research infrastructure

2015

Launch of SC's QIS investments

2017 & 2018



The First Simulation of an Atomic Nucleus on Quantum Cloud

Rise of AI

2019

"Responsible" AI

2021

Quantum Edge Computing

2022

Quantum Algorithms

Programming Techniques

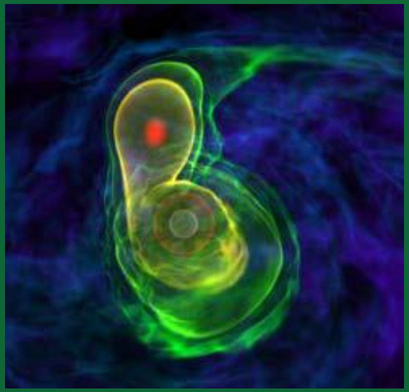
Modeling Future Computing Systems

2023

ASCR Research Advances Interdisciplinary Centers

In FY24, ASCR will maximize its contributions to Energy Earthshot Research Centers and to new Microelectronics Research Centers by building on our decades-long experience enabling co-design through partnerships.

SciDAC & ECP



SciDAC and ECP capabilities are widely used across science domains and have been integrated into Intel's, NVIDIA's, and AMD's tools.

National QIS Research Centers

SQMS

QUANTUM SCIENCE CENTER

C²QA Co-design Center for Quantum Advantage

Q-NEXT NEXT GENERATION QUANTUM SCIENCE AND ENGINEERING

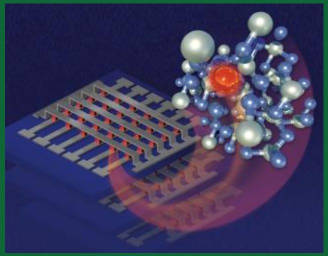
The Centers include 1200 experts and 600 students from 80 institutions from 24 states and international partners.

Energy Earthshot Research Centers

ENERGY earthshots U.S. DEPARTMENT OF ENERGY

The Centers will bring together large, multi-investigator, multi-disciplinary teams to advance foundational knowledge and state-of-the-art capabilities in experimental, theoretical, and computational sciences needed to realize new approaches and solutions.

Microelectronics Science Research Centers



The Centers will bring together large, multi-investigator, multi-disciplinary teams to foundational challenges in the design, development, characterization, prototyping, demonstration, and fabrication of microelectronics.

Continue our investments

Initiate new investments

ASCR Facilities provide world-leading computing, data, and networking infrastructure for extreme-scale science, and advance U.S. competitiveness

High Performance Computing Facilities: ALCF, OLCF, NERSC

NERSC at LBNL

Argonne Leadership Computing Facility

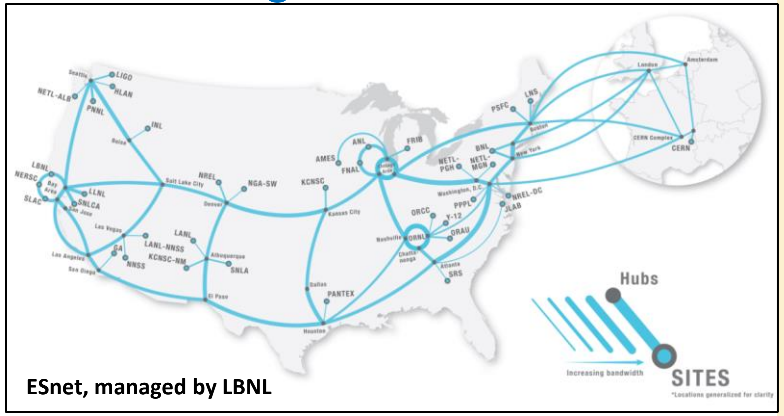
Oak Ridge Leadership Computing Facility

ASCR HPC focuses on advancing U.S. competitiveness -- *To* ***accelerate discovery*** *and translate scientific insight into* ***real-world solutions; provide open national research infrastructure; and*** *advance* ***U.S. vendor*** *computing technologies*

High Performance Production Computing Facility (NERSC): Dedicated HPC resource for the Office of Science research community, serving many thousands of users

Leadership Computing Facilities (ALCF, OLCF): Unique national HPC resources for extreme-scale applications, the start of the exascale (10^{18}) era

High Performance Network Facility: ESnet



ESnet, managed by LBNL

Connects all DOE national labs and dozens of other DOE sites to 150+ global research networks, commercial cloud providers, and the internet

Engineered for lossless transmission of huge data flows

FRONTIER

CONGRATS TO OUR COLLEAGUES AT THE OLCF AND VENDOR PARTNERS AT HPE & AMD

- **74 HPE Cray EX cabinets**
- **9,408 AMD EPYC CPUs, 37,632 AMD GPUs**
- **700 petabytes of storage capacity, peak write speeds of 5 terabytes per second using Cray Clusterstor Storage System**
- **90 miles of HPE Slingshot networking cables**

TOP500

#1*

1.1 exaflops of performance on the TOP500 List.

*May and November 2022

GREEN500

#2*

62.04 gigaflops/watt power efficiency on a single cabinet.

*November 2022

HPL-MxP

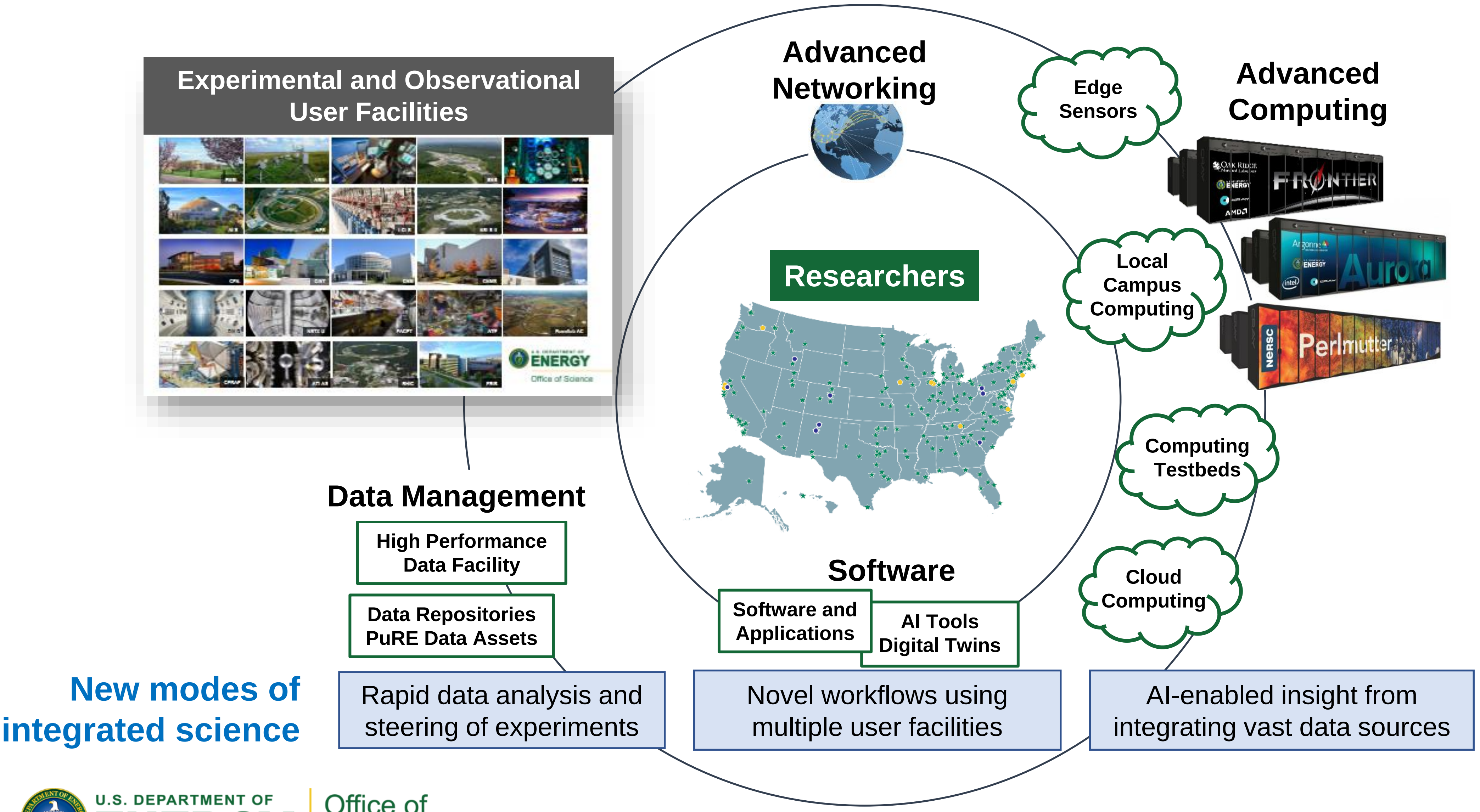
#1*

7.9 exaflops on the HPL-MxP (formerly HPL-AI) benchmark.

*November 2022

Sources: May 30, 2022, and November 14, 2022, Top500 releases

DOE's Integrated Research Infrastructure (IRI) is a new effort to provide researchers with seamless interoperability of DOE's unique data, user facilities, & computing resources.



ASCR Continues to Invest in People

ECP's Broadening Participation Initiative

- **Computational Science Graduate Fellowship (CSGF)**
  - Increase support for increased tuition costs and increased stipend and to increase the number of fellows focused on emerging technologies and from underrepresented groups.
- **Reaching a New Energy Sciences Workforce (RENEW)**
  - Expand targeted efforts, including a graduate fellowship, to broaden participation and advance belonging, accessibility, justice, equity, diversity, and inclusion in SC-sponsored research.
- **Funding for Accelerated, Inclusive Research (FAIR)**
  - Provide focused investment for enhancing research on clean energy, climate, and related topics at minority-serving institutions (MSIs), including attention to underserved and environmental justice regions.
- **Accelerate Innovations in Emerging Technologies**
  - Support scientific research to accelerate the transition of scientific advances to energy technologies.
- **EPSCoR**
  - Support EPSCoR State-National Laboratory Partnership awards and early career awards.

THANK YOU!

www.Energy.gov/Science

U.S. DEPARTMENT OF ENERGY | Office of Science

Achieving Fusion Ignition on the National Ignition Facility

National Academy of Sciences

Board of Physics and Astronomy 2023 Spring Meeting

April 26, 2023

Dr. Mark Herrmann for the LLNL ICF team
Program Director for Weapon Physics and Design
Lawrence Livermore National Laboratory

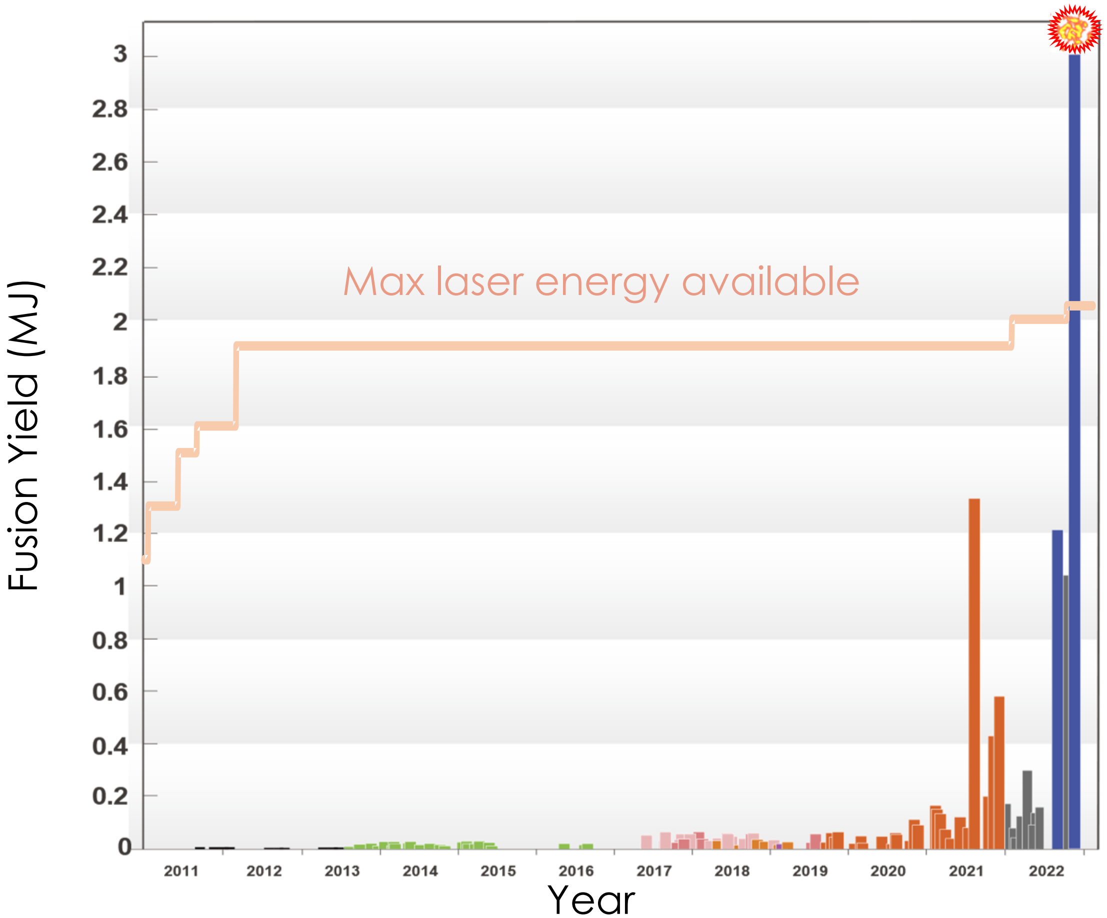
Sandia National Laboratories | Los Alamos NATIONAL LABORATORY | UR LLE | GENERAL ATOMICS | Diamond Materials Advanced Diamond Technologies | NNSA National Nuclear Security Administration

LLNL-PRES-846694
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

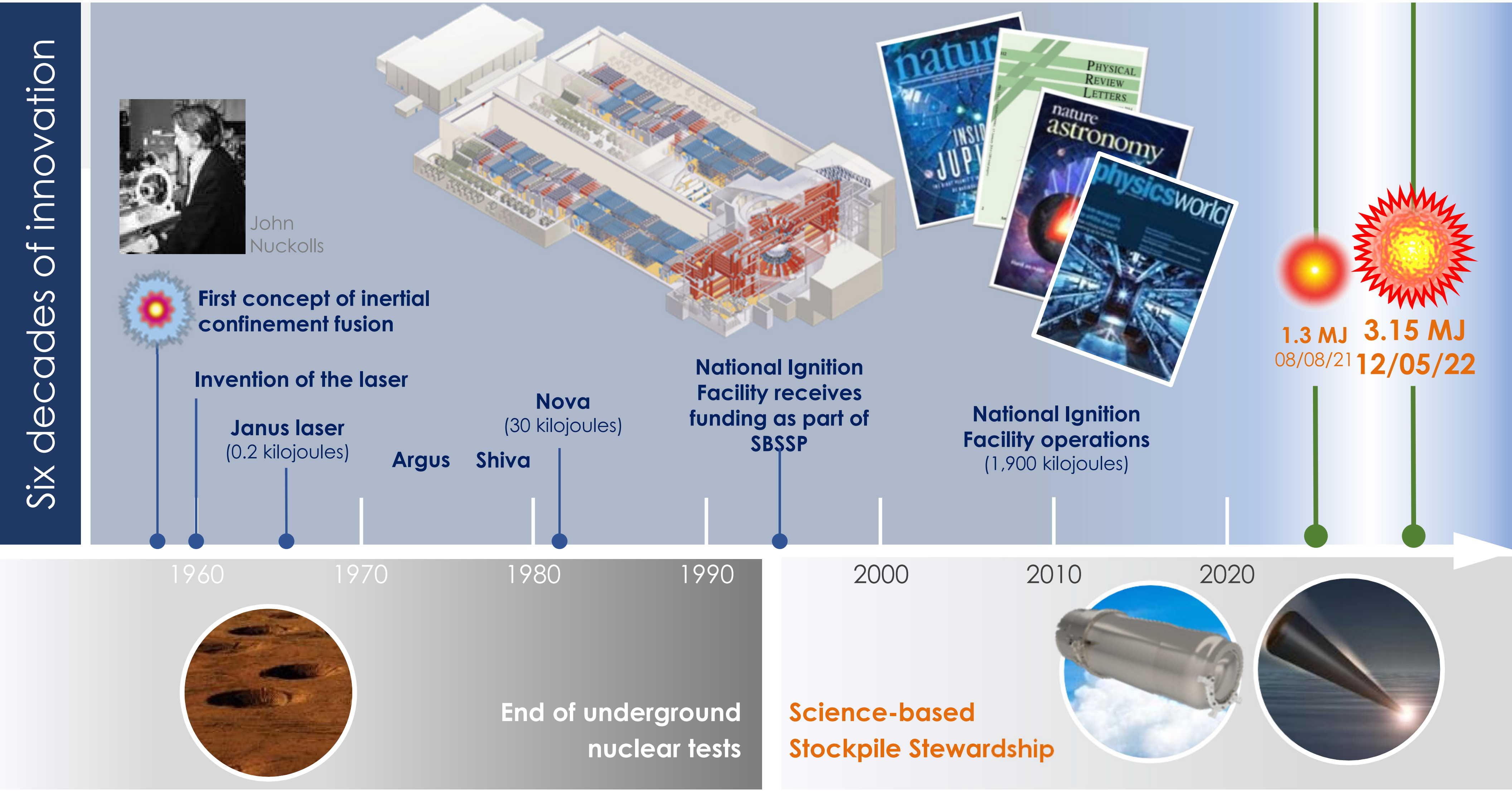
Lawrence Livermore National Laboratory

In an experiment on 12/5/2022, **NIF exceeded the threshold* for fusion ignition**

… reaching a goal that had been laid out at the beginning of the stockpile stewardship program, enabling access to a new experimental regime to help sustain our nuclear deterrent, and reenergizing the effort to explore inertial fusion as a path to carbon free energy



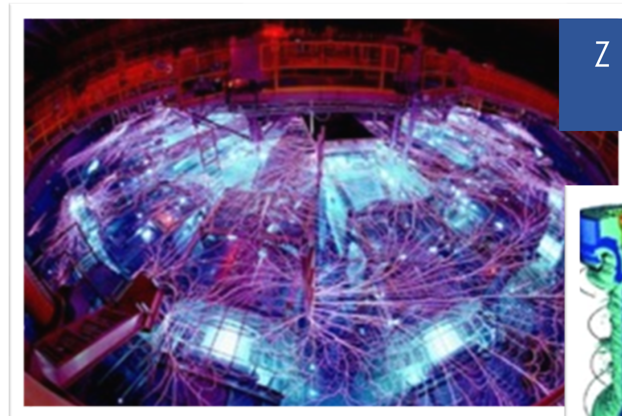
*National Academy of Sciences 1997 definition for ignition

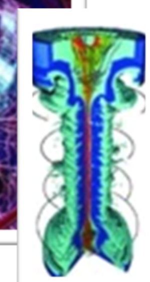

Six decades of innovation
John Nuckolls
First concept of inertial confinement fusion
Invention of the laser
Janus laser
(0.2 kilojoules)
Argus
Shiva
Nova
(30 kilojoules)
National Ignition Facility receives funding as part of SBSSP
National Ignition Facility operations
(1,900 kilojoules)
nature
Physical Review Letters
nature astronomy
physicsworld
1.3 MJ
08/08/21
3.15 MJ
12/05/22
1960
1970
1980
1990
2000
2010
2020
End of underground nuclear tests
Science-based Stockpile Stewardship

NNSA's Inertial Confinement Fusion Program is a national effort to study HED matter in support of the Stockpile Stewardship Program

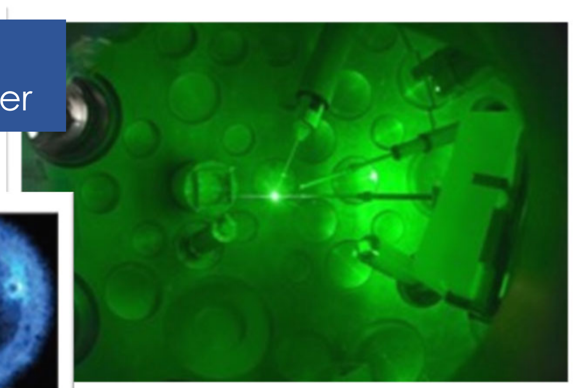
National Ignition Facility at LLNL

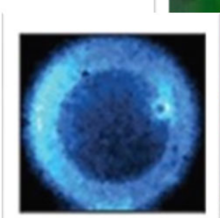
Z Pulsed Power Facility at SNL





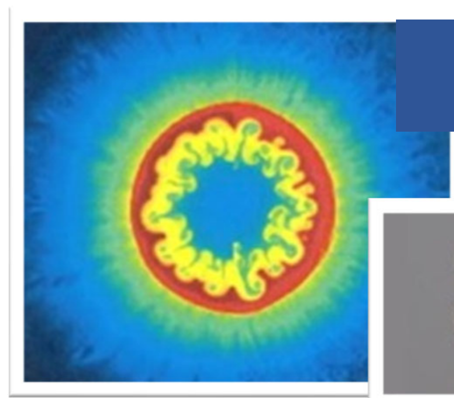
Omega Laser at University of Rochester





These facilities came online in 2007-2009

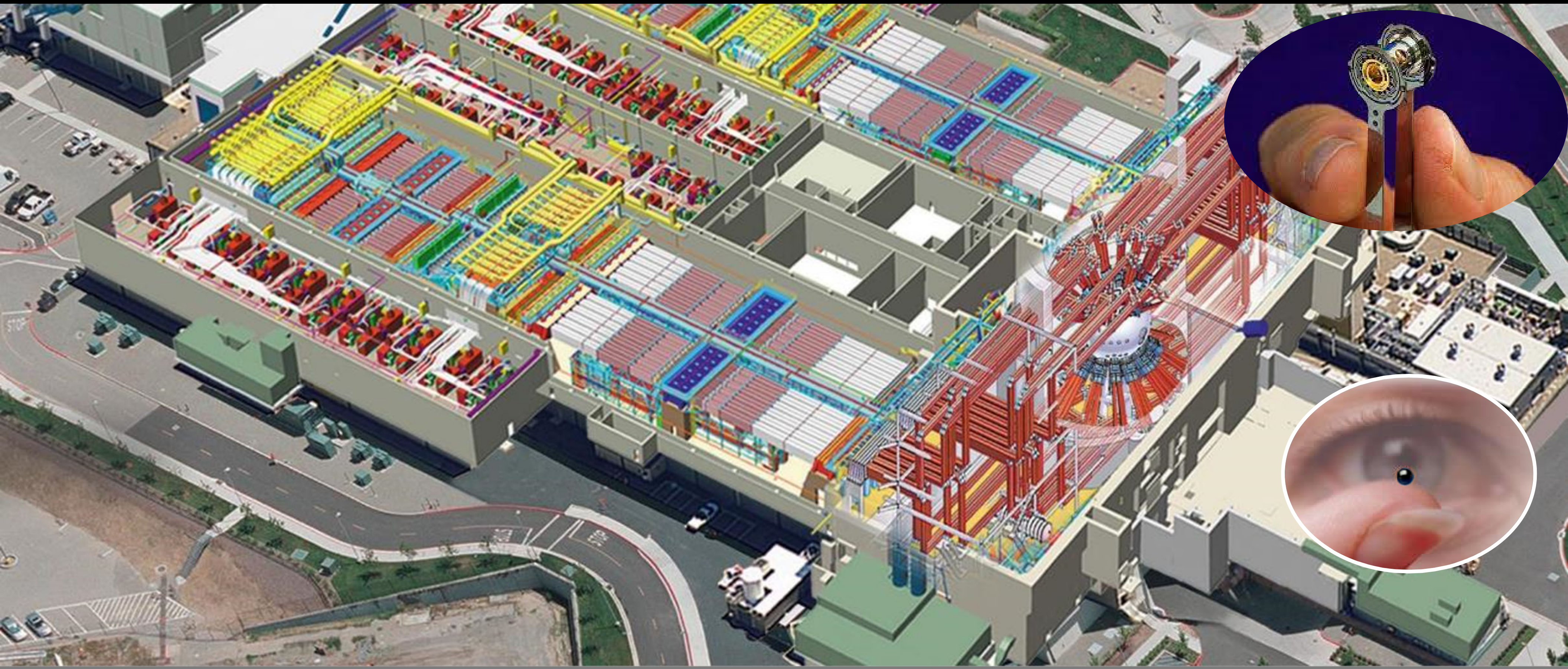
HED Physics at LANL

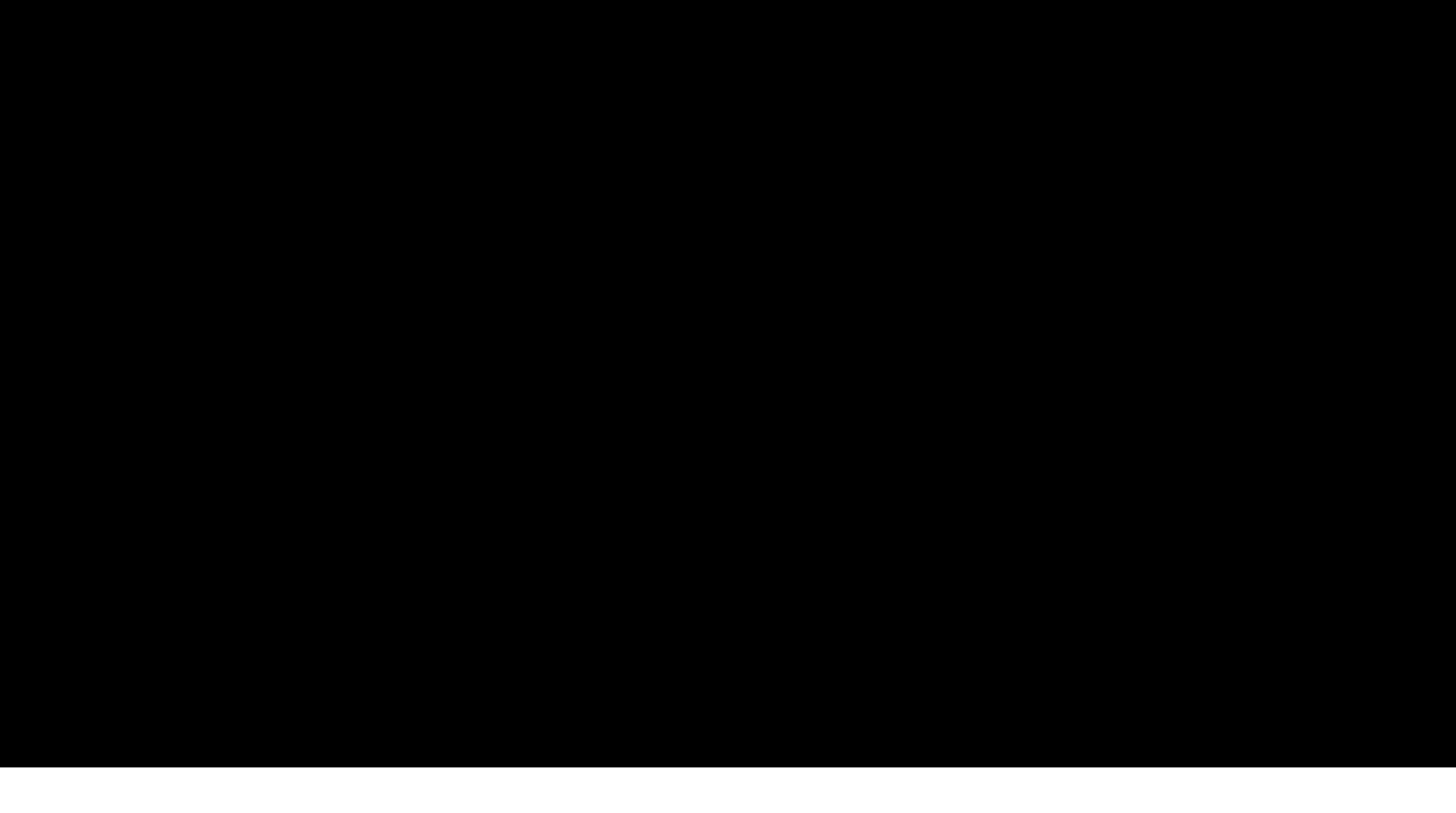


Target fabrication at General Atomics

LLNL-PRES-844338

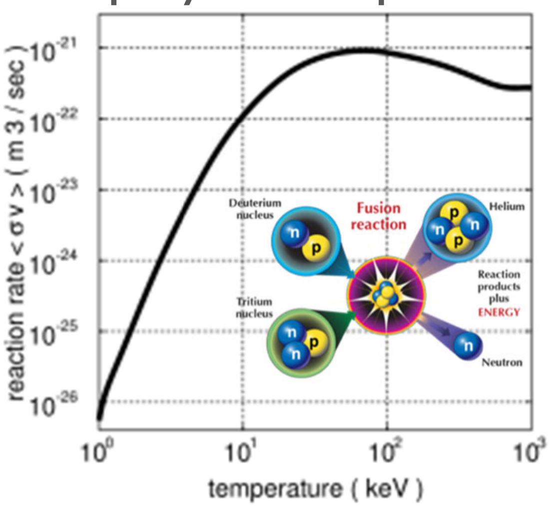
NIF, the world's most energetic laser, concentrates 192 laser beams into ½" scale targets to recreate the conditions in nuclear weapons

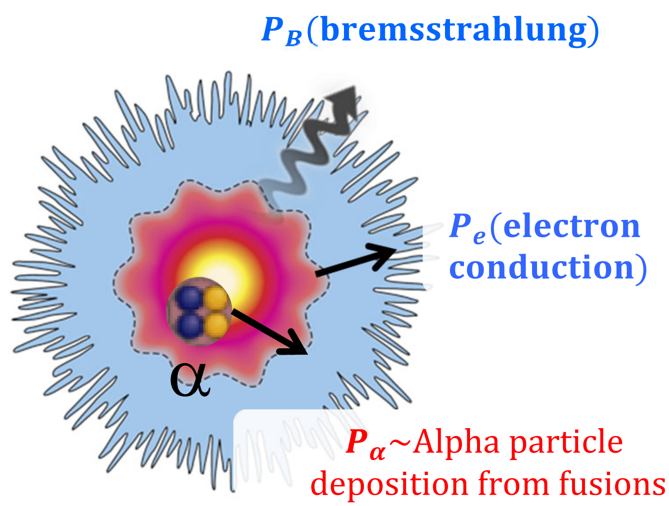




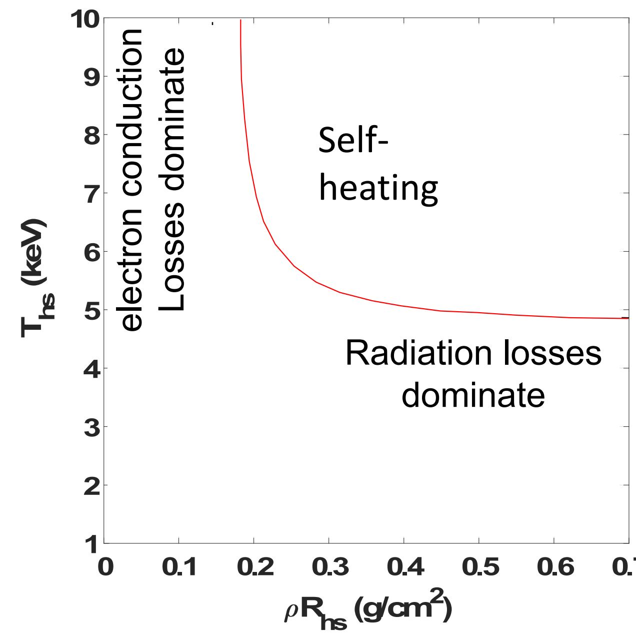
One of NIF's goals is to study fusion ignition of deuterium and tritium fuel, a key process in our thermonuclear weapons. The conditions required are extreme!

DT Fusion rate increases rapidly with temperature





$$c_{DT}\frac{dT}{dt} = f_\alpha P_\alpha - f_B P_B - P_e - \frac{1}{m} p \frac{dV}{dt}$$



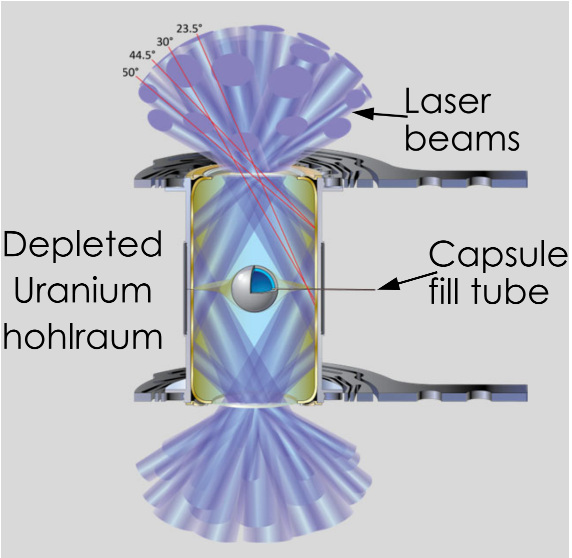
For self heating $\rho R \gtrsim 0.3$ gm/cm^2, $T \gtrsim 5$ keV

$$E_{HS} P_{HS}^2 \propto (\varrho_{HS} R_{HS})^3 T_{HS}^3$$

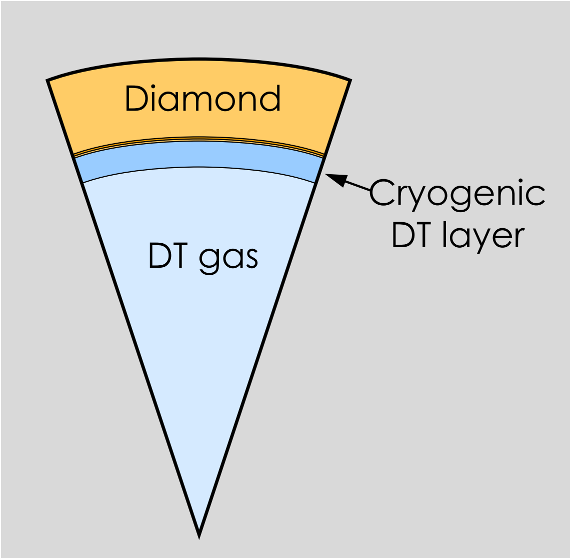
E_{HS}~25 kJ
P_{HS}~ 300 Gigabars!!

The ignition experiments were done using laser indirect drive

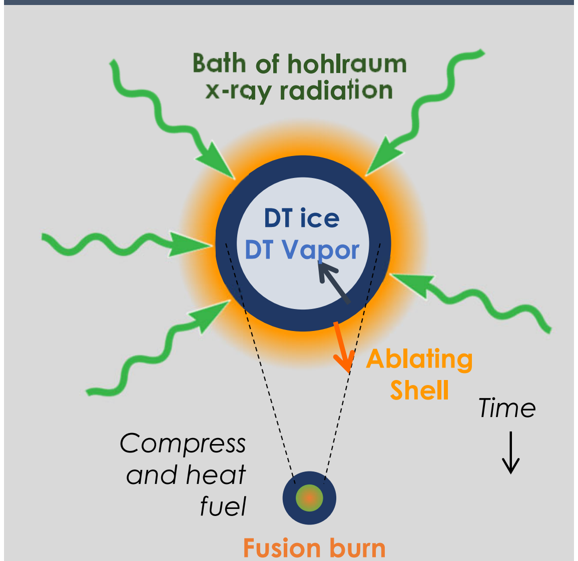
The Hohlraum is a Cylindrical Cavity that Serves as an X-ray Oven



The Fuel Capsule Consists of an Ablator Surrounding DT Ice and Gas

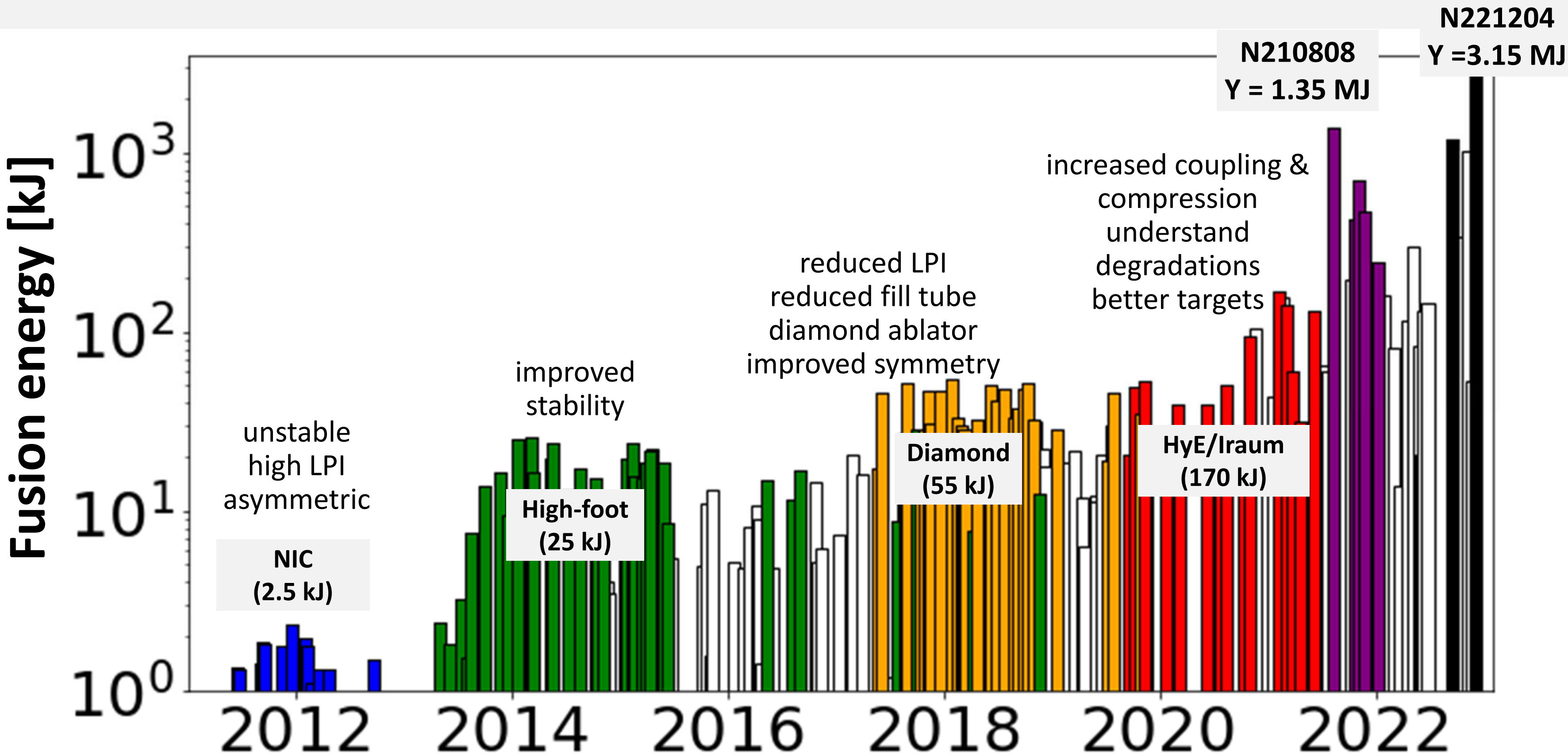


Turn 100 Million Atmospheres of Pressure into 300 Billion

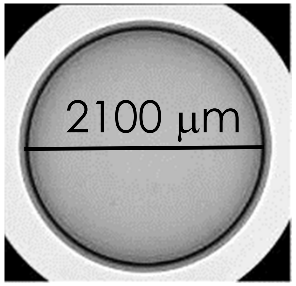


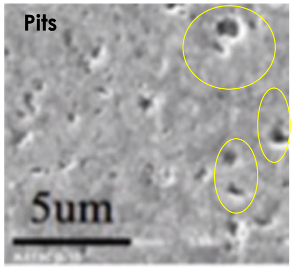
Achieving the conditions for ignition demands precise control of laser and target parameters for a high convergence implosion with low ablator fuel mix

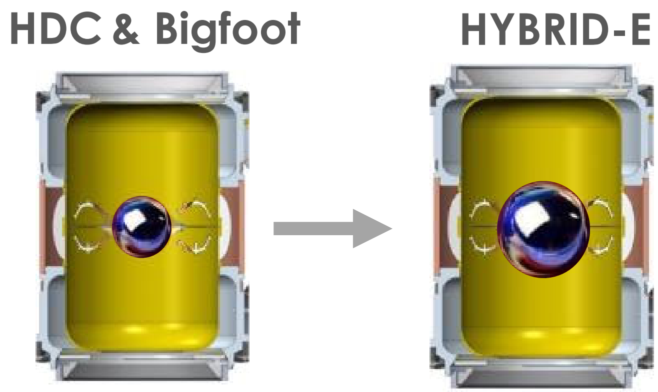
These tools enabled steady advances in physics understanding and understanding, culminating in ignition (target gain >1) on Dec. 5th, 2022



Spurred on by advances in diagnostics, targets, the NIF laser, and target designs progress accelerated in 2021



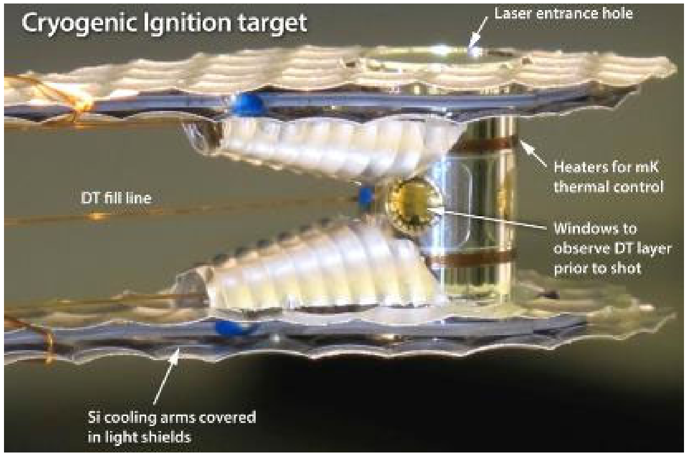




- Target Fabrication
- Laser
- Diagnostics
- Improved Simulations
- Design Changes

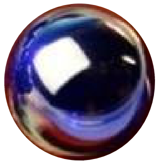
Targets require state-of-the-art microfabrication precision

Gold-lined uranium hohlraum



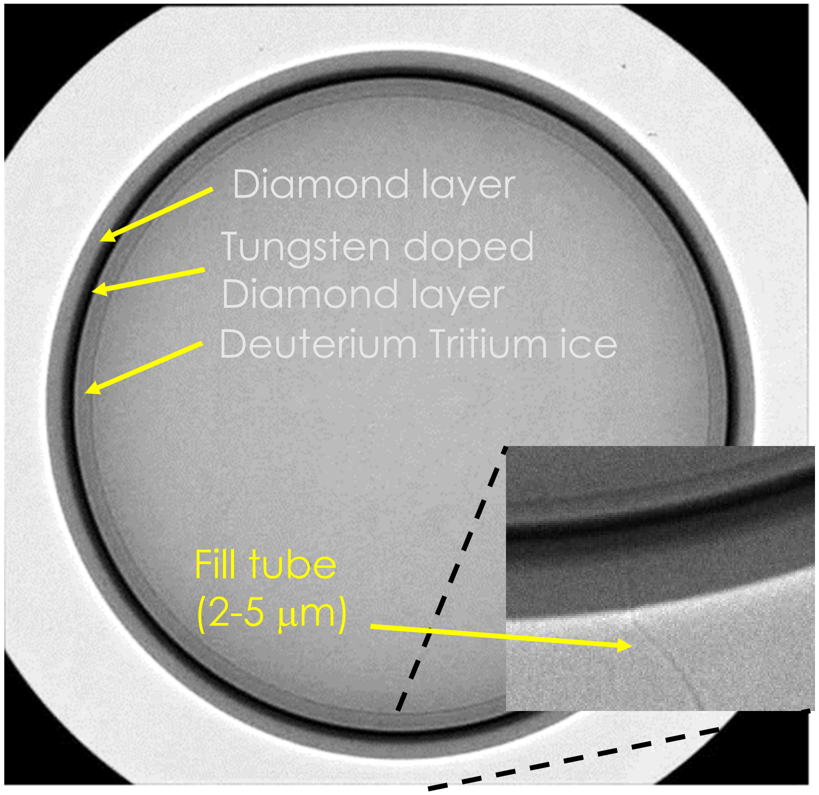
~ 1 cm long
Cryogenically cooled
w/ dozens of components

Diamond Nanocrystalline Capsule
(High Density Carbon – HDC)

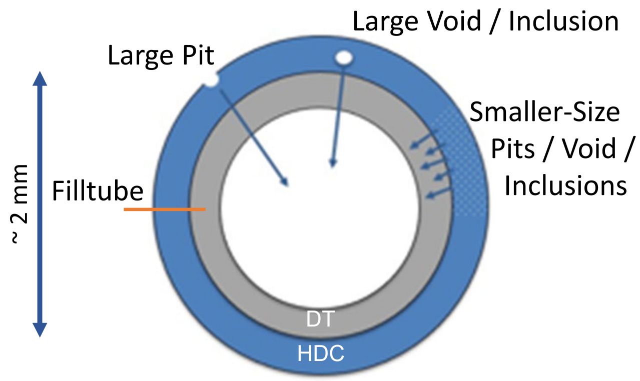


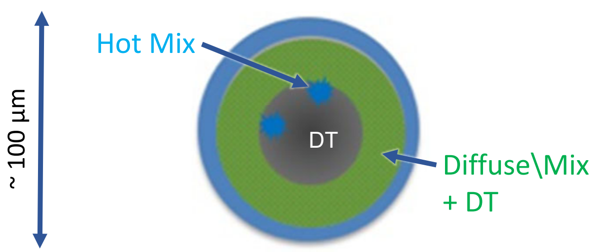
≈ 2 mm diameter,
smooth to 10 nm

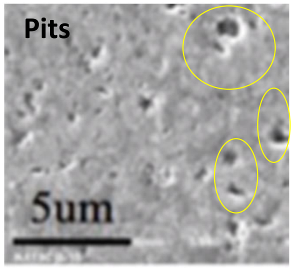
Capsule with DT layer @ 19 K

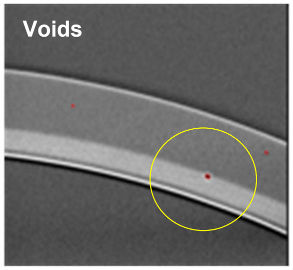


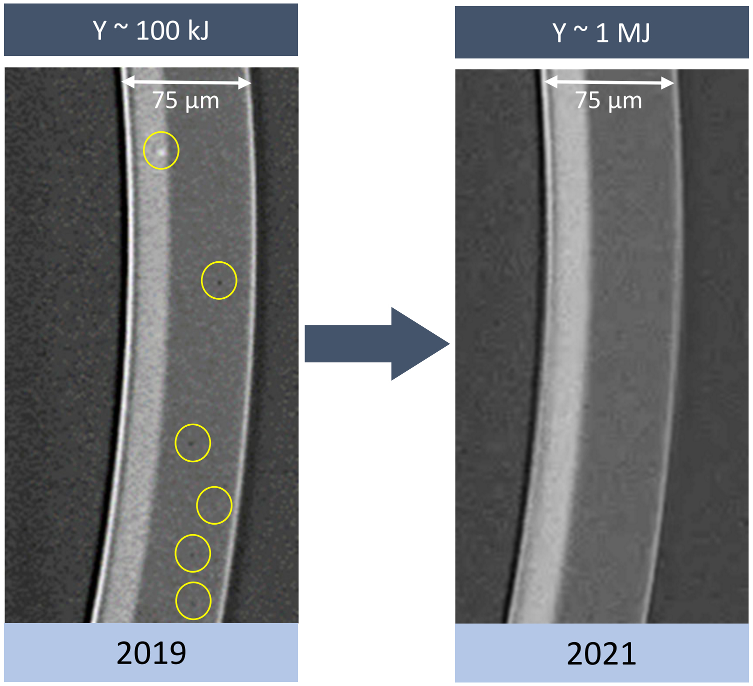
Substantial improvements in target quality and metrology in the past three years are a key component of recent advances





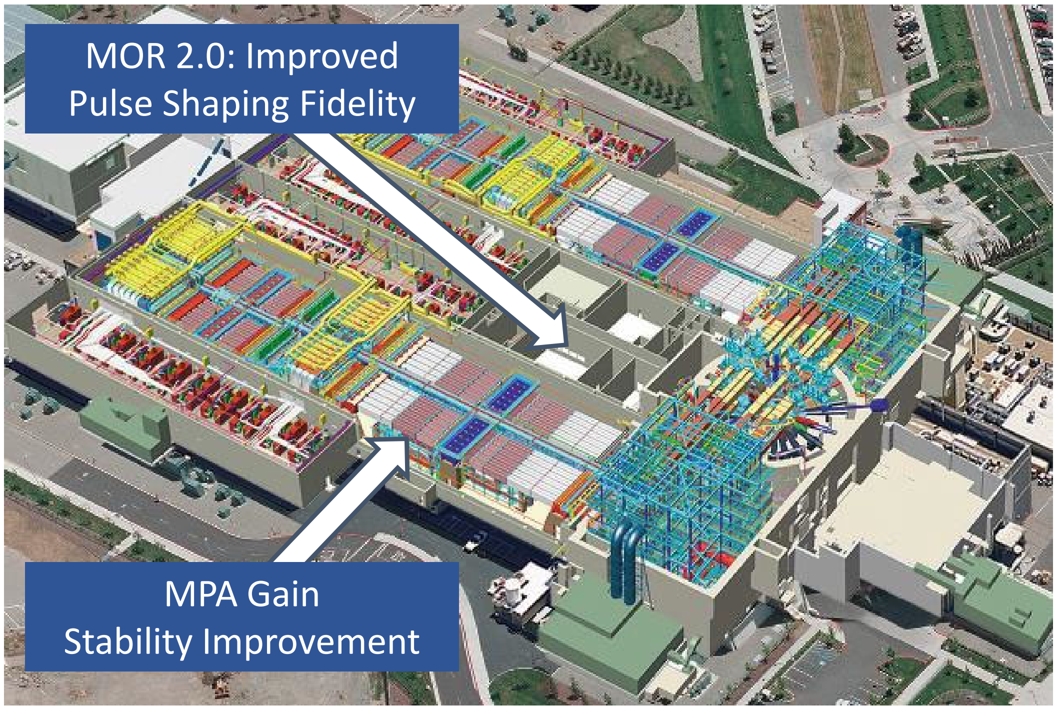




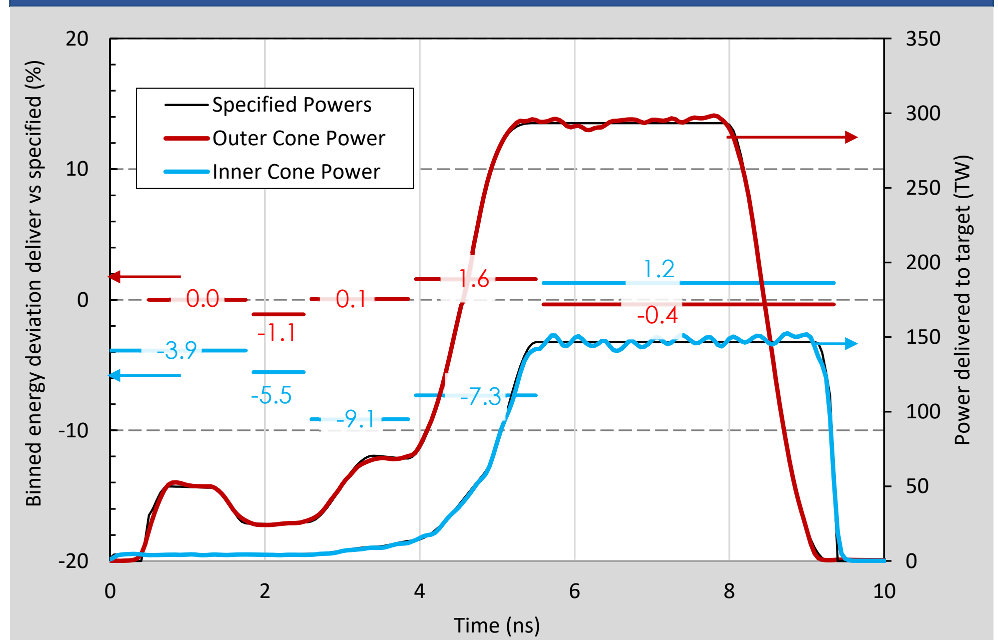


Current capsule quality has 100x reduction in pits and voids compared with pre- 8/2021 but the processes are not robust

Significant improvements were made to the NIF laser to improve precision pulse shaping, power balance, and the total laser energy

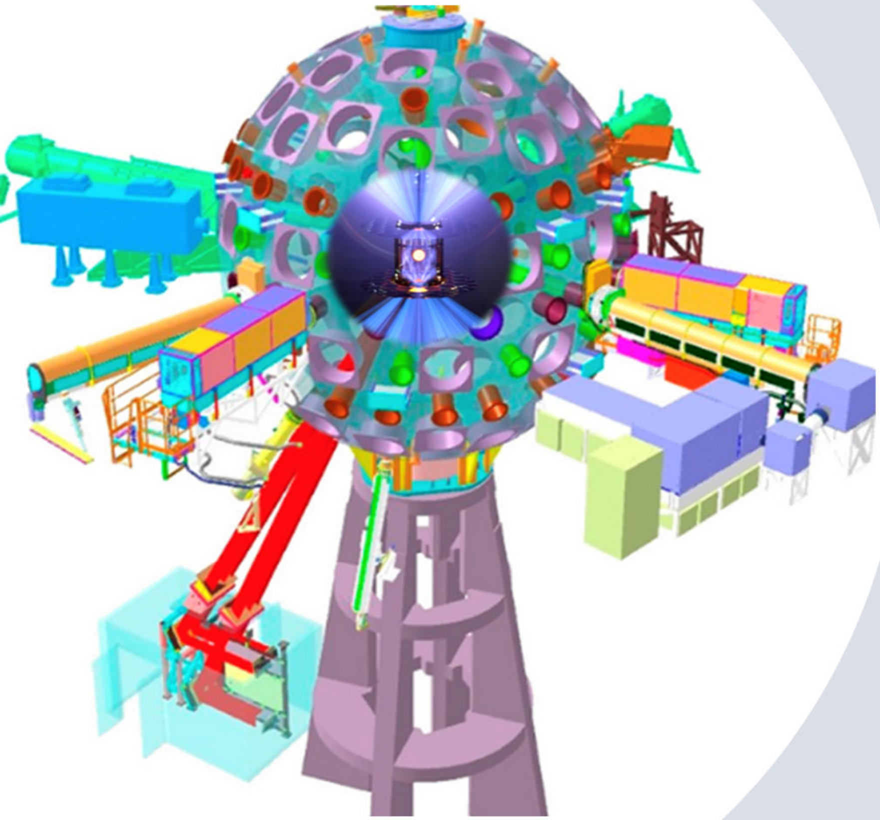


Dec. 5th: Laser Delivery on Dec. 5th Met All Requirements

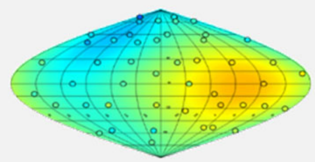


The NIF laser delivers requested energy within a 50 µm pointing, 30 ps timing, and a few % of power accuracy to provide the required conditions for ignition

Diagnostics provided key insights into fusion degradation mechanisms

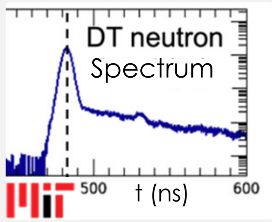


Yield / Fuel Uniformity

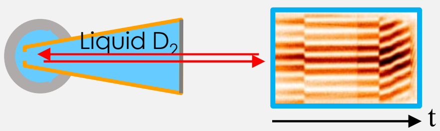


Hot Spot Electron Temperature and Impurities

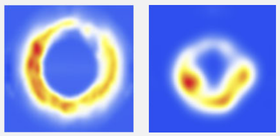
Ion Temperature, Hot Spot Velocity, Fuel Areal Density, Yield



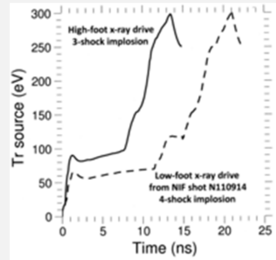
Shock Speeds, Timing



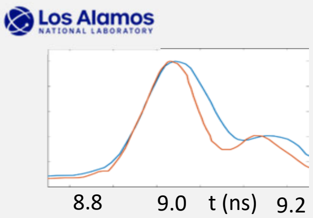
DT* Fuel Uniformity



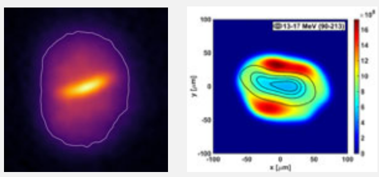
Hohlraum Radiation Flux



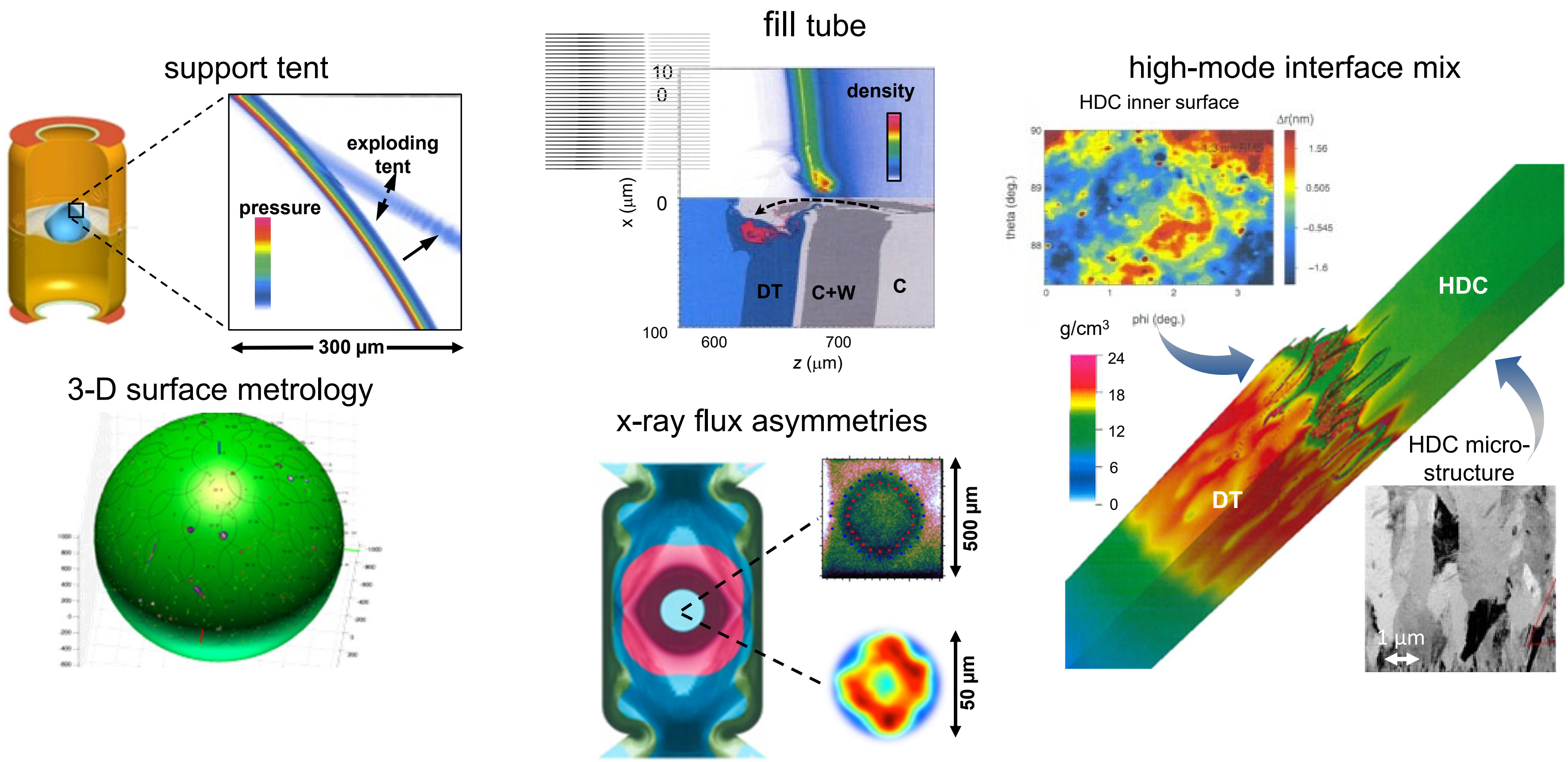
Burn Width, Bang Time



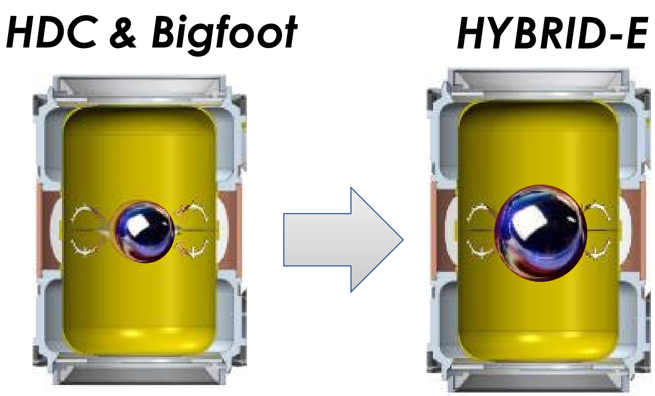
Hot Spot and Fuel Shape

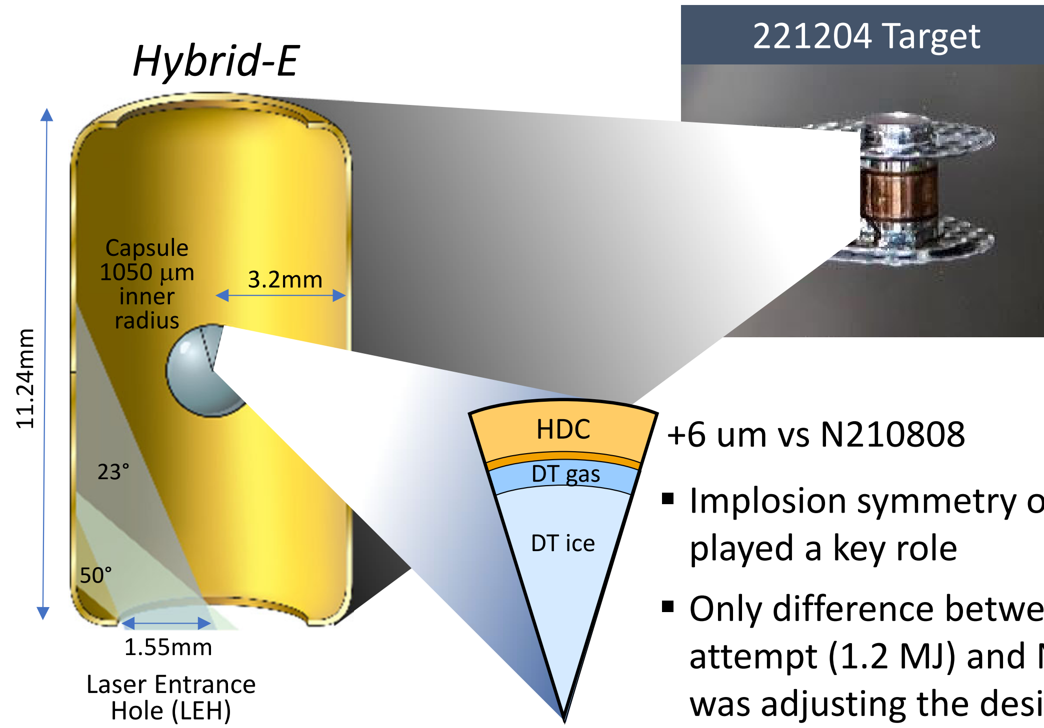


High fidelity simulations are an essential tool for navigating the vast parameter space and understanding potential degradations



Design changes were made for improved coupling and robustness

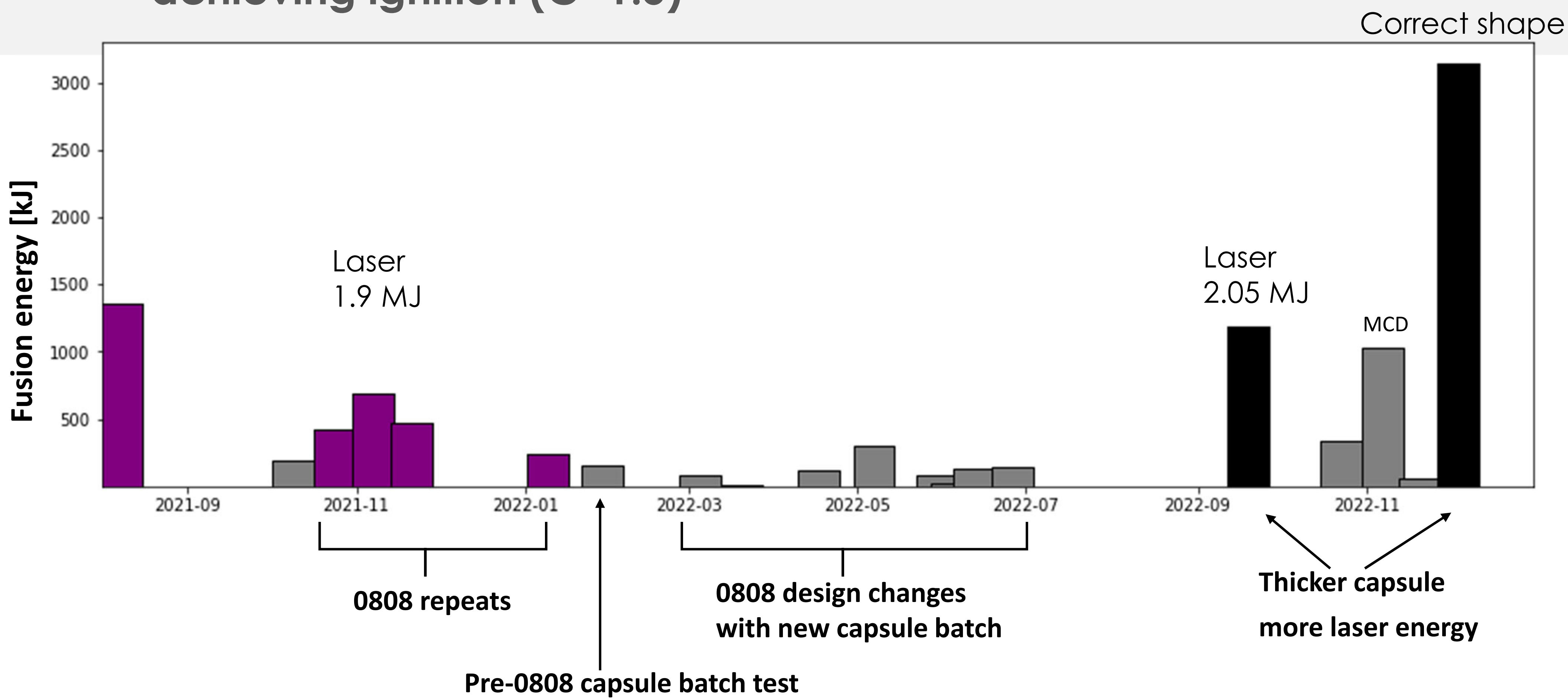




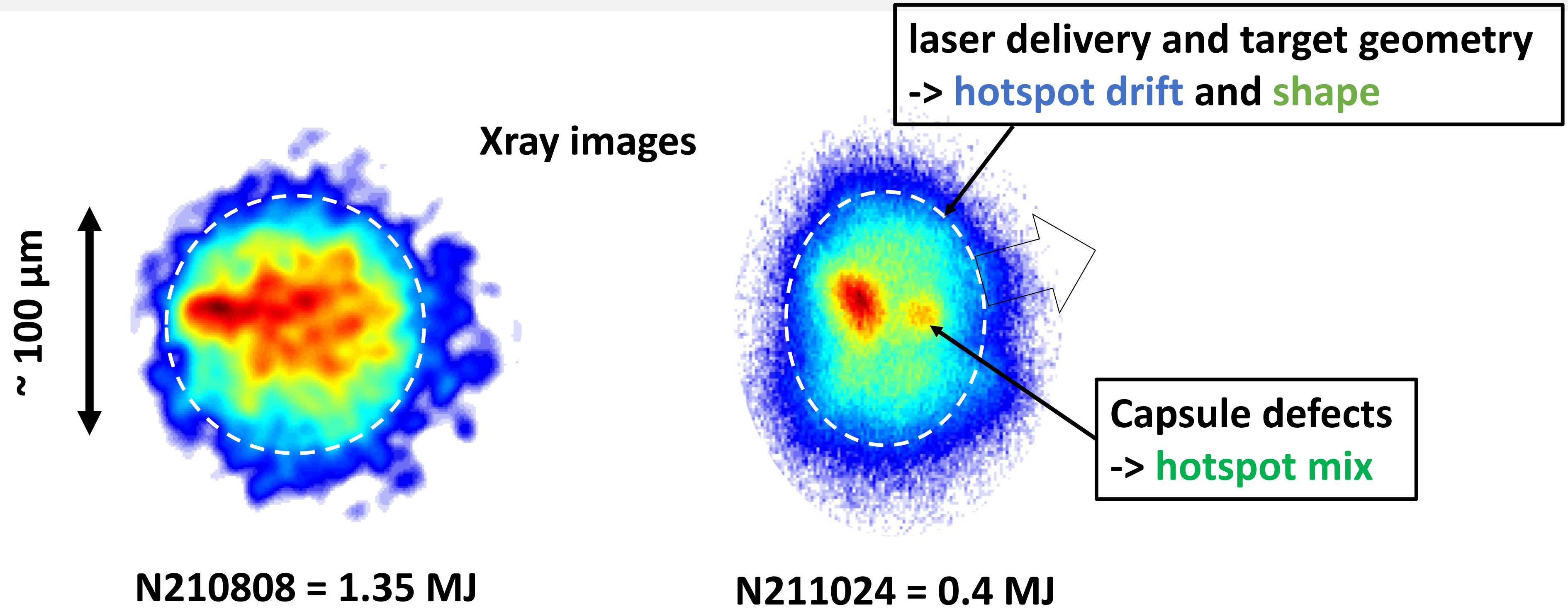
- Implosion symmetry optimization played a key role
- Only difference between first attempt (1.2 MJ) and N221204 was adjusting the design symmetry

210808 repeat attempts identified mix from target imperfections as main yield degradation mechanism; design refinements used new 2.05MJ laser capability to drive thicker, more stable capsule for ignition on 221204

The last 18 months: from trying to repeat N210808 (G=0.7) to achieving ignition (G=1.5)

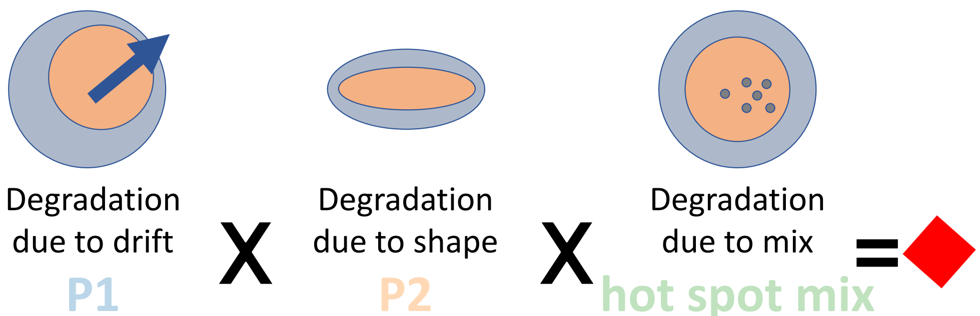


The N210808 repeat series identified 3 main sources of variability



The key impact of the perturbations is to lower the internal energy of the hotspot at stagnation (minimum volume), impairing hotspot ignition and subsequent burn (either by radiative loss or reduced conversion of the pusher kinetic energy into hotpot internal energy)

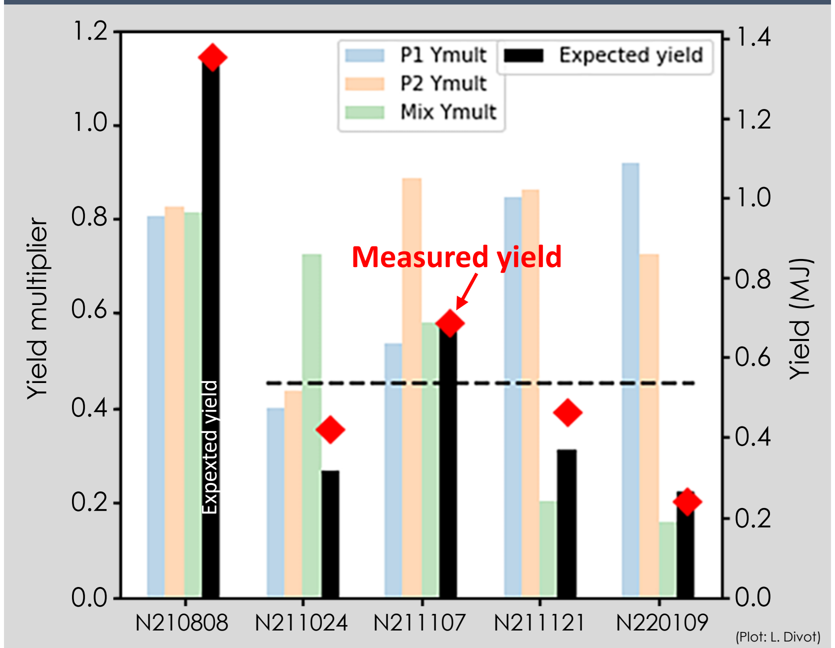
Three main sources of degradations that affect the fusion yield were quantified



With N210808 capsule quality: <1.1MJ> ± 0.3

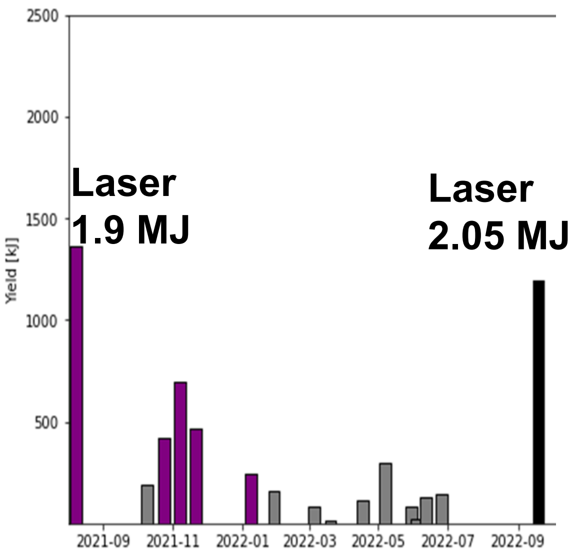
With current capsule quality: <0.5 MJ> ± 0.2

Yield variation for repeat experiments



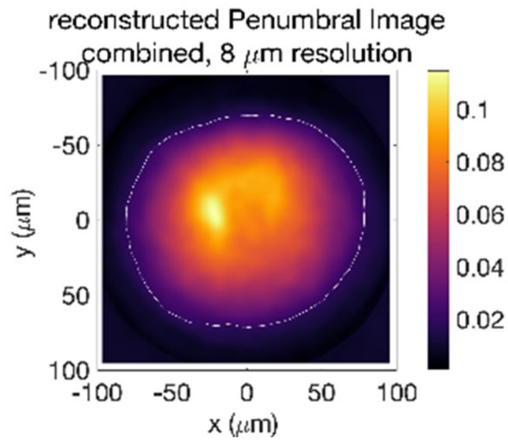
Mix was the dominant nuclear yield degradation mechanisms in the 1.35MJ repeats

N220919 was the first NIF shot using 2.05 MJ of laser energy to drive a thicker diamond capsule (i.e. a bigger rocket)

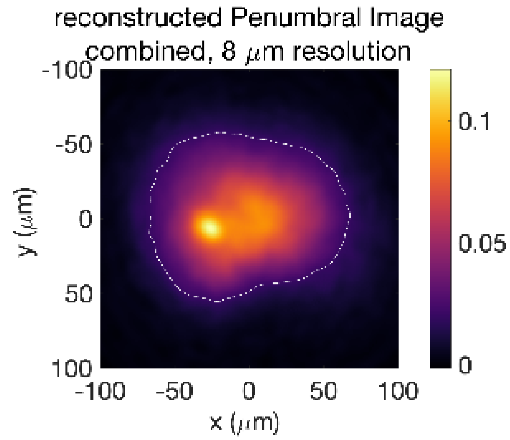


N210808   N220919

N210808 : Y=1.35 MJ



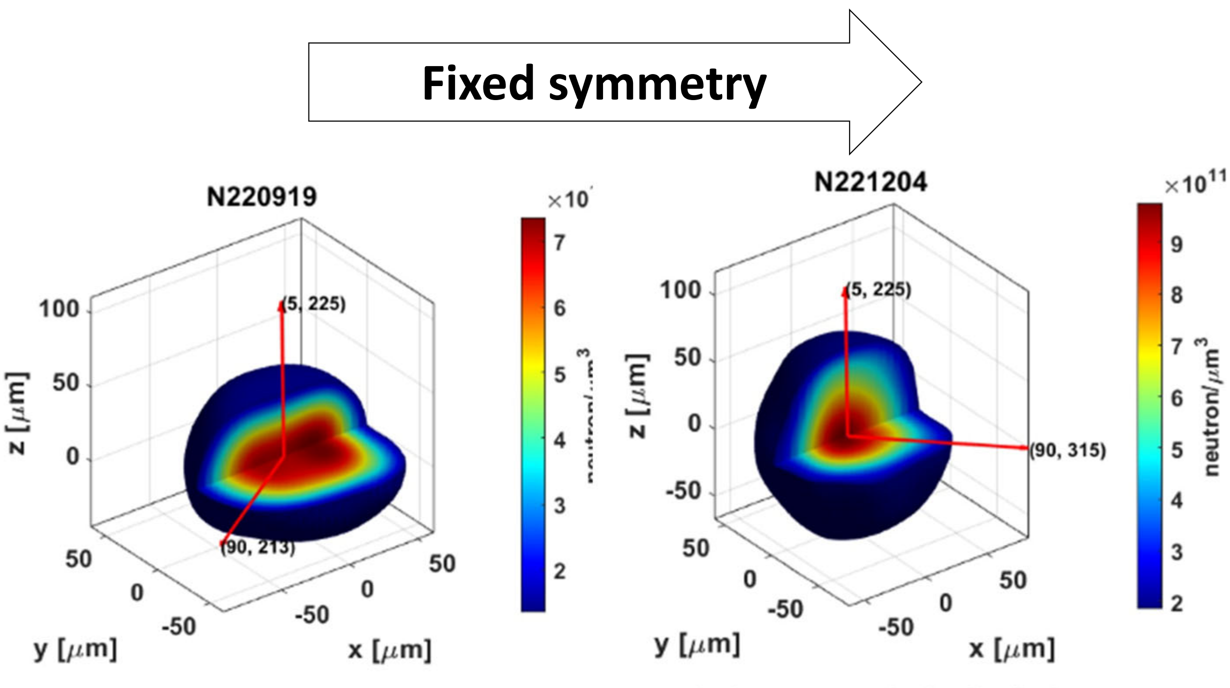
N220919 : Y=1.2 MJ

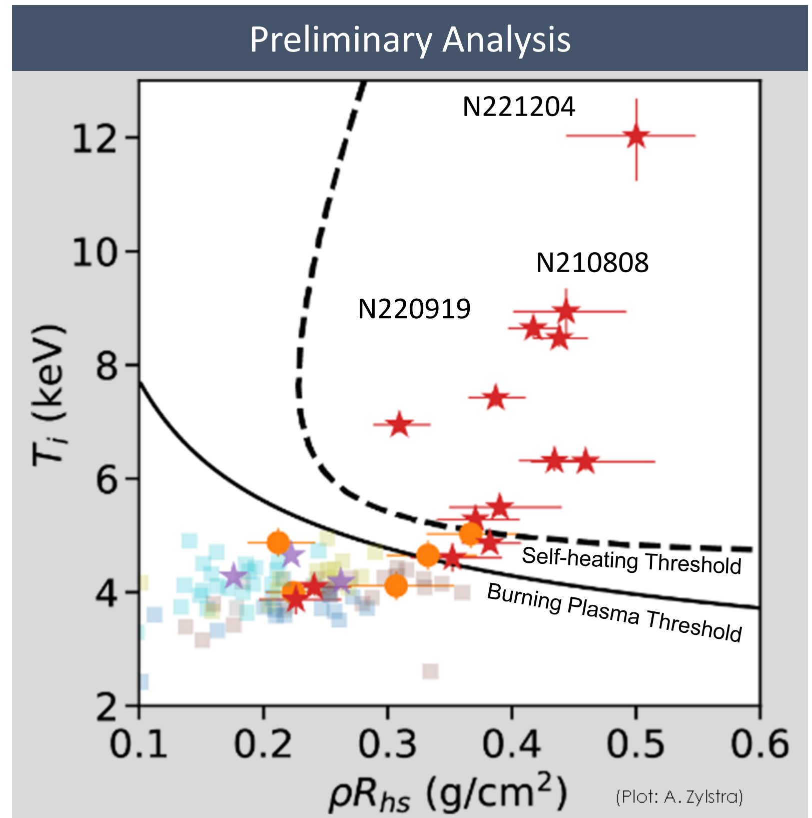


	N210808	N220919
Hotspot drift [km/s] :	**68**	**51**
P2 [µm]:	**2.2 µm (-4%)**	**-11 µm (-20%)**
Mix mass [ng] :	**60 +/- 20**	**60 +/- 40**

First shot with higher laser energy, looked promising but was not symmetric

Improving the symmetry from N220919 more than doubled the yield on N221204: Y=3.15 MJ (G=1.5)



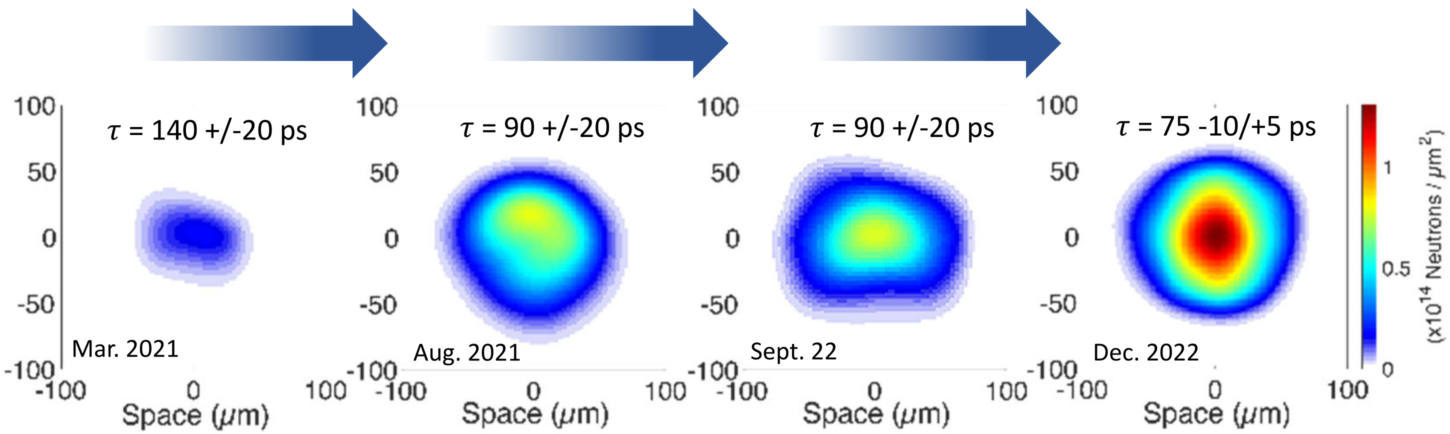


Over last two years, we increased hotspot reactivity and mass to achieve ~20x yield via improved targets and designs, laser energy, and systematic tuning

1.07X increase in hohlraum efficiency + improved target quality

1.08X increase in laser energy

Symmetry adjustment



Y = 150 kJ

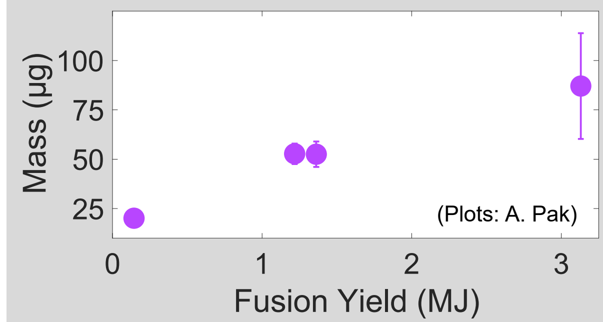
Y ~ 1.3 MJ

Y = 3.15 MJ

Preliminary analysis (A. Pak)

Temp. increases 2.2X

Mass increases 4.3X

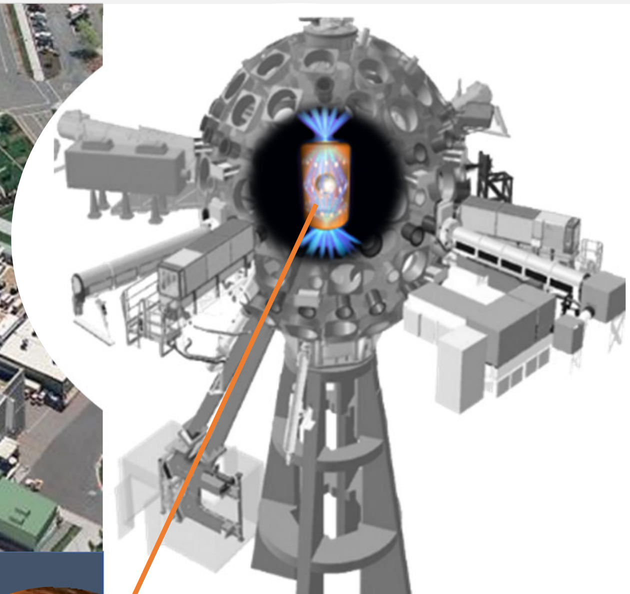


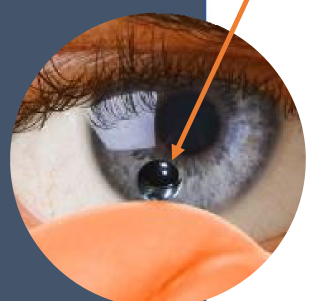
Upcoming shots in 2023 will continue efforts to make best use of higher quality targets and increasing laser energy

A burning inertial confinement fusion capsule releases fusion energy at very high power from a very tiny volume

NIF lasers

500 trillion watts for
> 4 nanoseconds (ns)
> 1.9 million joules (MJ)

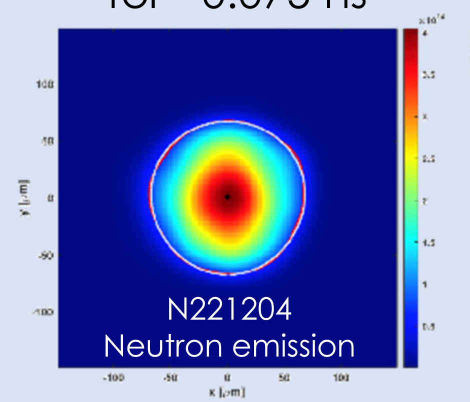




Target
~ 1 cm
Temperature
~3,000,000 K

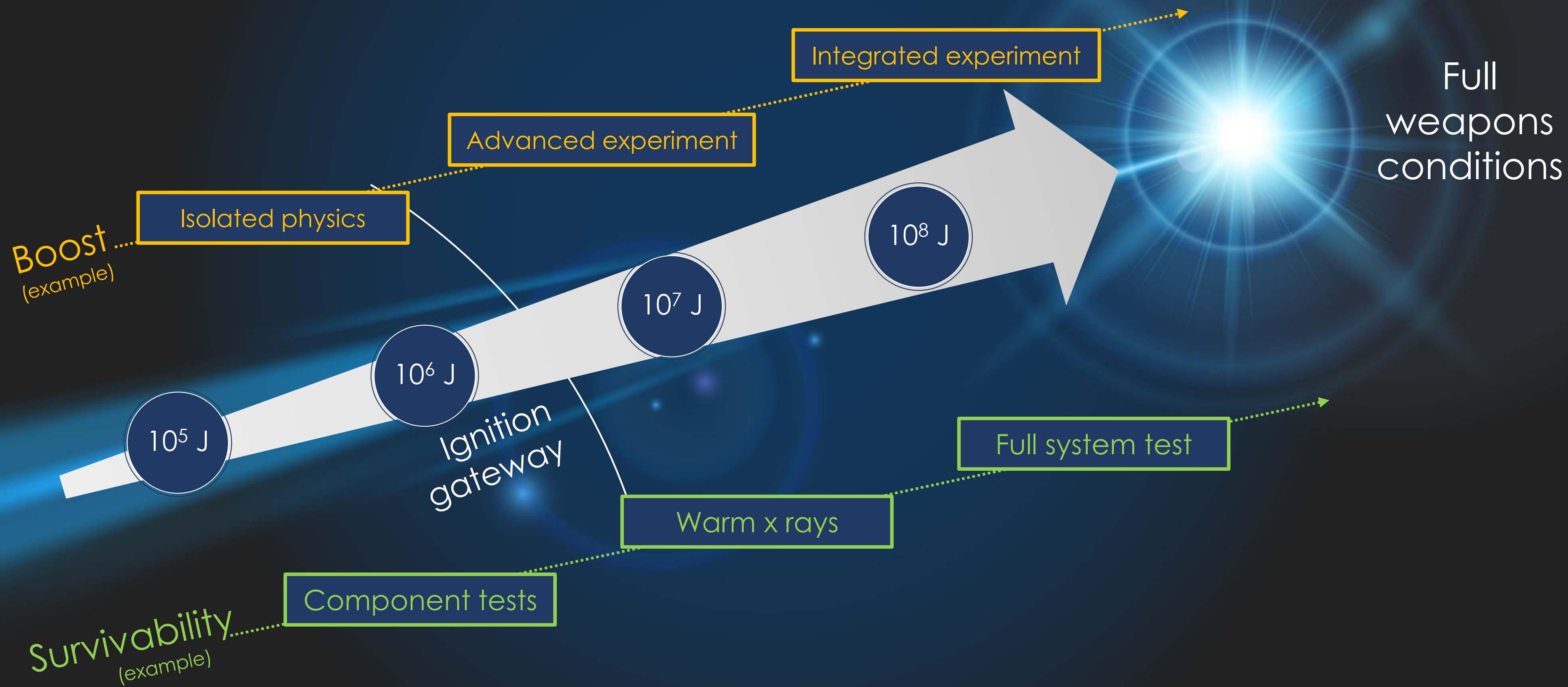
Energy output
from 12/5/2022 experiment

>40,000 trillion watts
~3.15 MJ
for ~0.075 ns

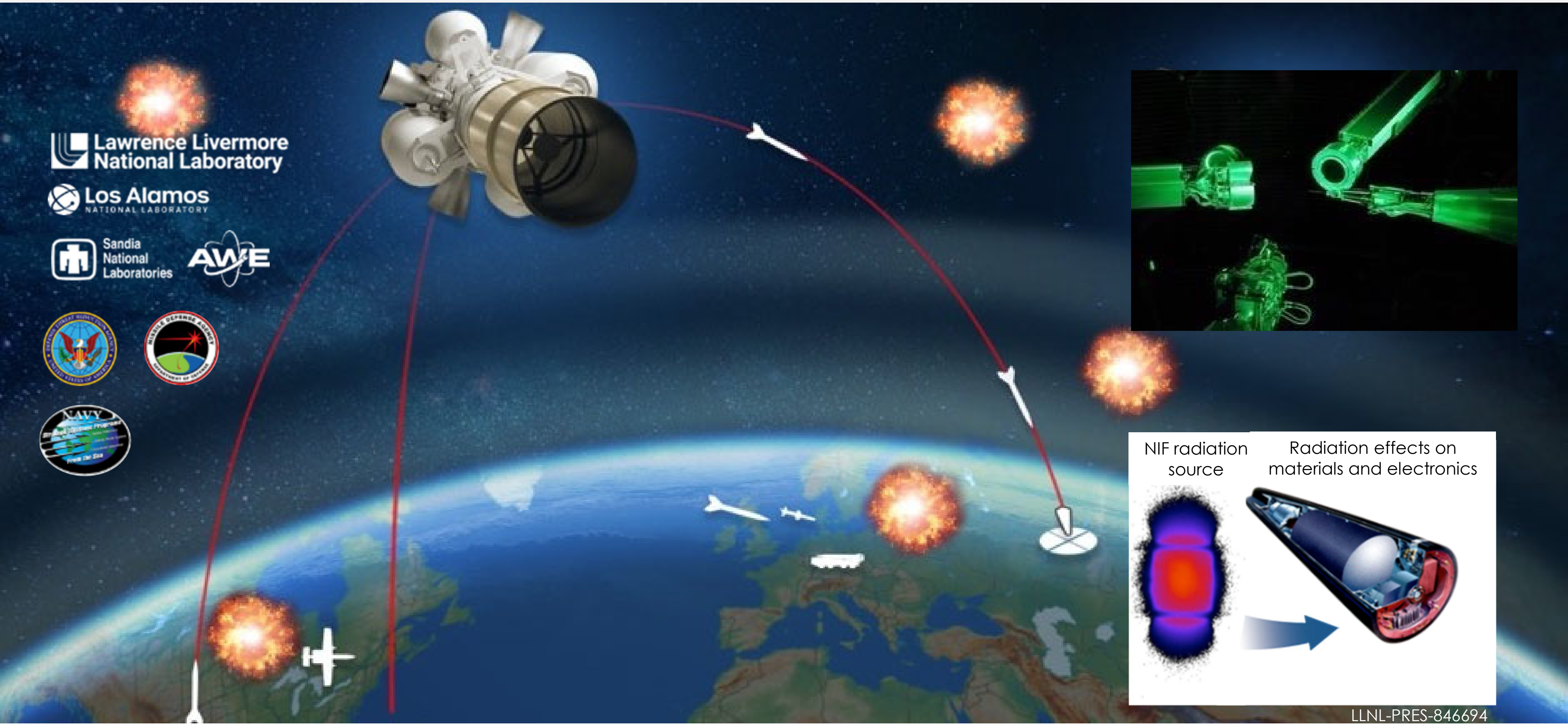


Fusion plasma
~0.01 cm
Temperature
~130,000,000 K

The output of an igniting capsule is the most powerful and energetic source we can envision in the lab, opening new capabilities for stewardship



In fact, on the December 5th experiment we fielded a new platform to ensure our strategic systems can survive hostile encounters



NEXT STEP: achieve ignition routinely and exploit it for stewardship while speeding up path to 10s of MJ yields and high gain

NIF has not yet reached its full potential

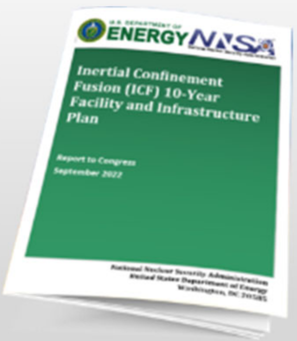
Few MJ → 10s of MJ → 100+ MJ??

2023

Routine MJ-yield operations and ignition

2023–2033

Long-term sustainment



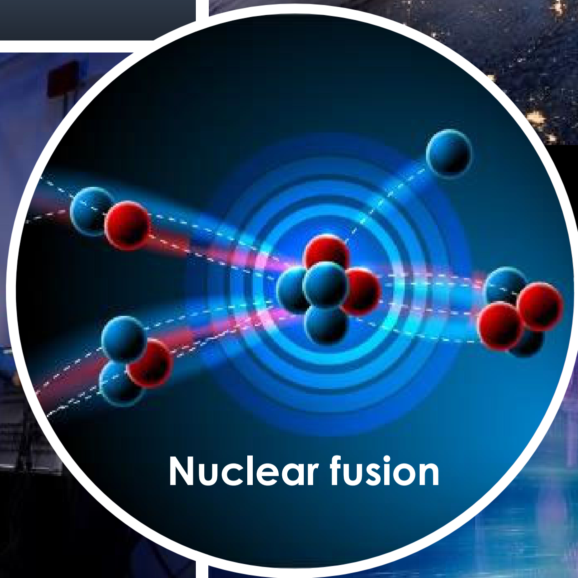
Increase energy and power

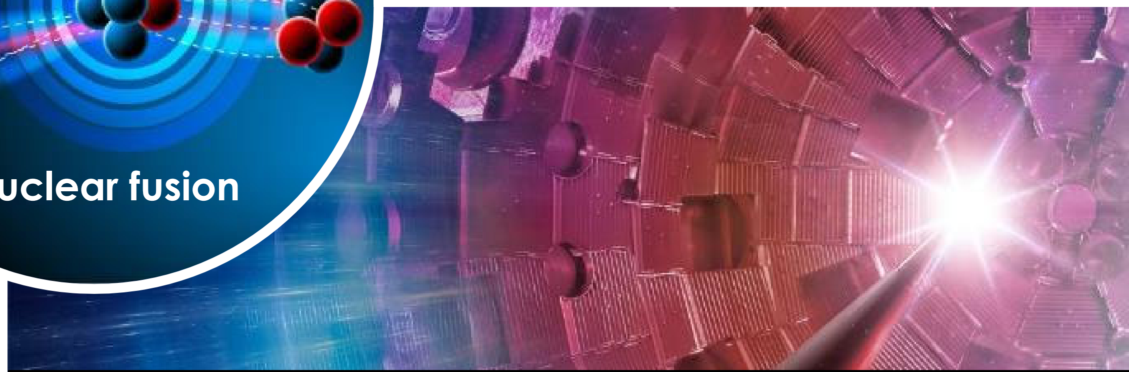
2033–

Explore high-yield, high-gain regime

Advancing science and technology to support our national security

Energy security

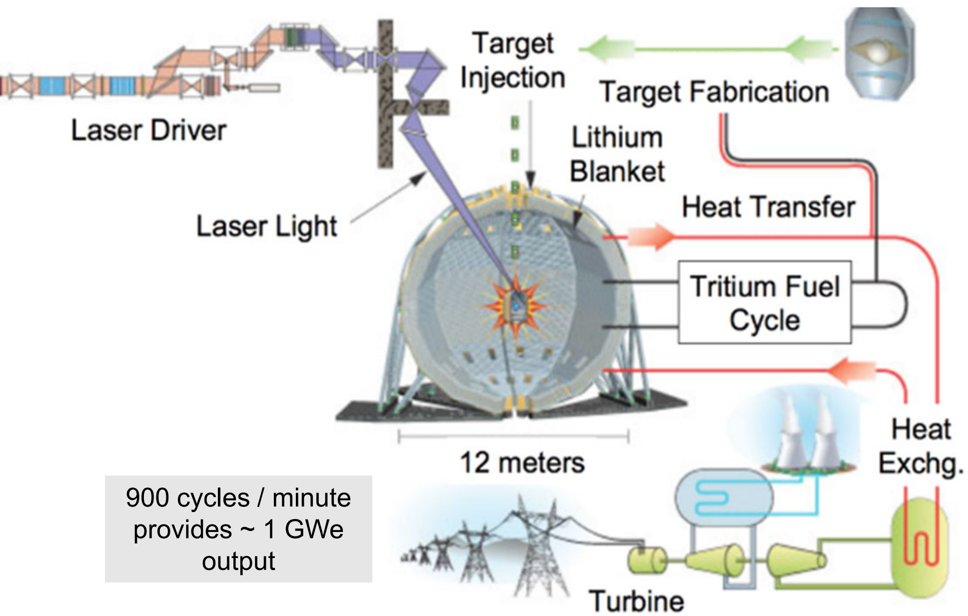




Nuclear deterrence

Scientific advances

Ignition on the NIF has spurred interest in the feasibility of laser-driven Inertial Fusion Energy (IFE)



900 cycles / minute provides ~ 1 GWe output

The path forward for inertial fusion energy will require technologies different from the Stockpile Stewardship Program

The challenges are many:	**But the benefits may outweigh the challenges:**
• Ignition and then high gain • High efficiency, high rep-rate laser • Target production and cost • Lifetime of the fusion chamber and optics • Safety and licensing • Plant operations	• Diversified risk from magnetic fusion (tokomaks) • Separation between driver and fusion source • Attractive economic development path (spin-out technologies) Energy security & US scientific competitiveness

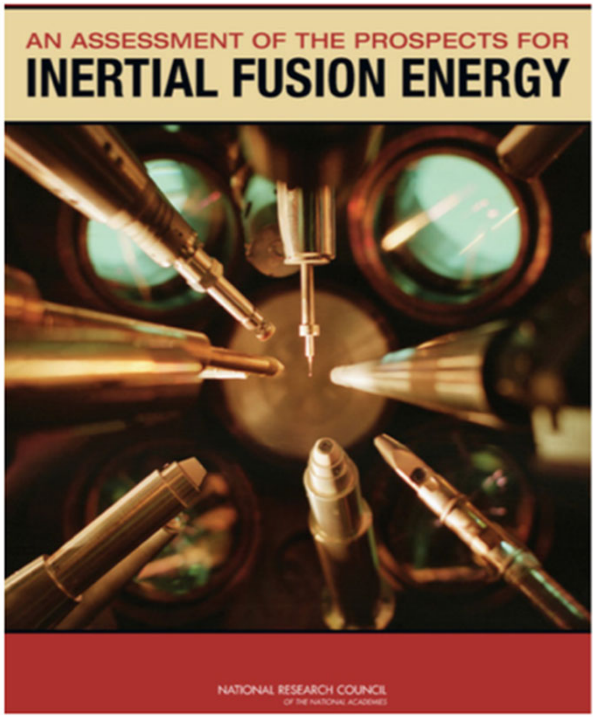
The scale of investment needed will be at least comparable to the investment required to obtain ignition

The 2013 NAS Assessment on Inertial Fusion Energy provides a starting point for the next steps

NAS 2013 Study "An Assessment of the Prospects for Inertial Fusion Energy"* had a number of conclusions and recommendations including:

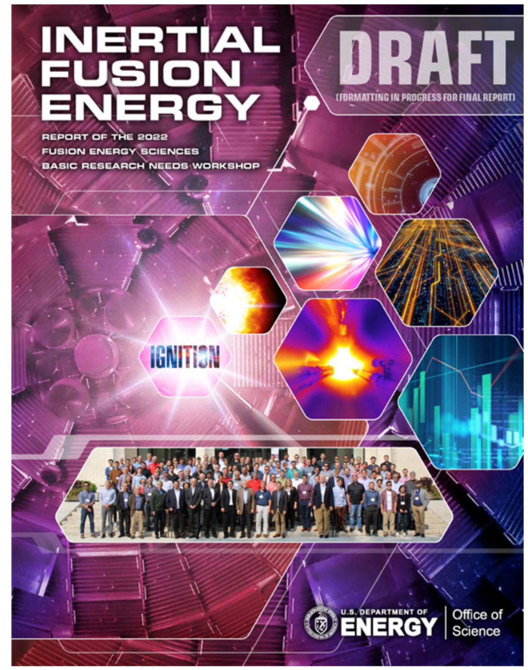
- "The appropriate time for the establishment of a national, coordinated, broad-based inertial fusion energy program within DOE would be when ignition is achieved."
- "The potential benefits of energy from inertial confinement fusion … also provide a compelling rationale for including inertial fusion energy R&D as part of the long-term R&D portfolio for U.S. energy."

**An Assessment of the Prospects for Inertial Fusion Energy*, Committee on the Prospects for Inertial Confinement Fusion Energy Systems, NRC (National Academies Press, Washington, D.C., 2013)



The U.S. DOE recently held a Basic Research Needs in IFE to define a new national IFE program

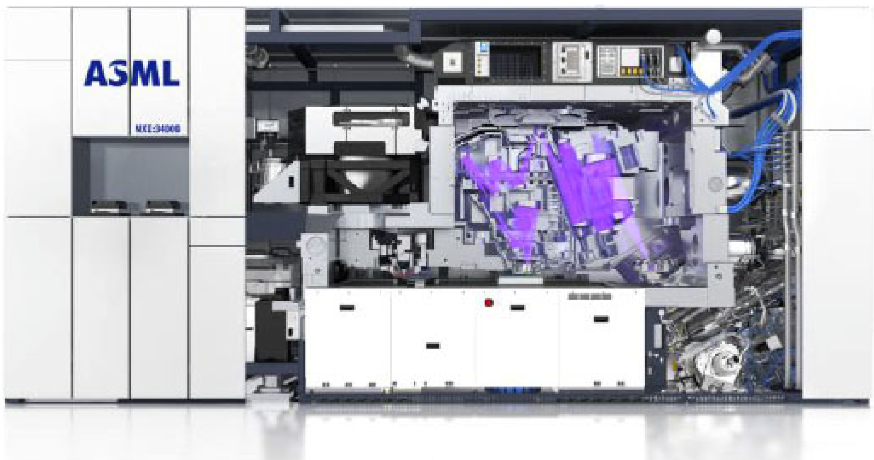
U.S. DEPARTMENT OF ENERGY | Office of Science



https://events.bizzabo.com/IFEBRN2022/home

Report provides a set of priority research opportunities to inform future research efforts in IFE and build a community of next-generation researchers in this area.

EUV lithography commercial systems demonstrate many of the elements of an eventual inertial fusion energy (IFE) powerplant, although decadal challenges remain



EUVL research was an outgrowth of a multi-lab CRADA in the 1990's (including ICF technologies)

25 years and $6B+ of investment

Advances in:
Laser, targets, x-ray optics, debris mitigation, precision alignment, …….

	EUVL	IFE
High Average Power laser	40 kW 10.6 μm	10,000-30,000 kW 200-500 nm
High Rep Rate Targets	30 μm tin droplet 50 kHz	Ignition target 10 Hz
Harsh Environment (X-rays and Debris)	250W x-ray, 5 mg/sec, vacuum/gas	200 MW x-ray, 800 MW neutron, 10 g/sec
Long Lifetime Optics	Gigashot	Gigashot+

EUV = extreme ultraviolet

Lawrence Livermore National Laboratory

WCI WEAPONS AND COMPLEX INTEGRATION

NIF&PS

GENERAL ATOMICS

Sandia National Laboratories

cea

Los Alamos NATIONAL LABORATORY

Diamond Materials Advanced Diamond Technologies

UR LLE

AWE

MIT PSFC Plasma Science and Fusion Center

NNSA National Nuclear Security Administration

...and many more

The National Academies of SCIENCES ENGINEERING MEDICINE

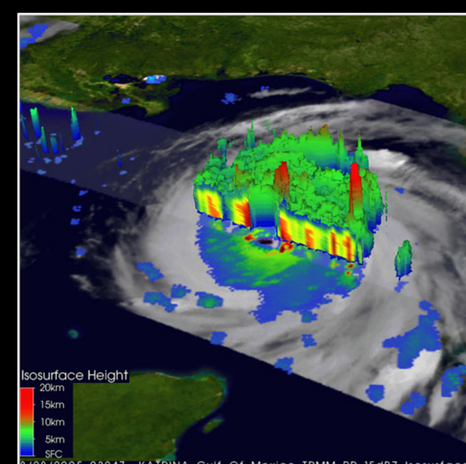
BOARD ON PHYSICS AND ASTRONOMY
Division on Engineering and Physical Sciences

Committee on Radio Frequencies Recent Activities

Meeting of the Board on Physics and Astronomy

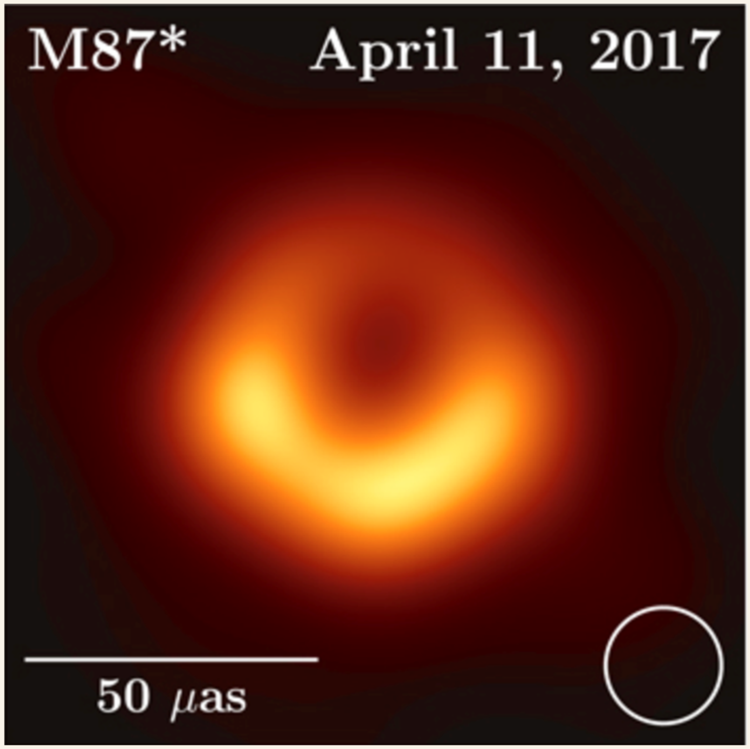
April 27, 2023

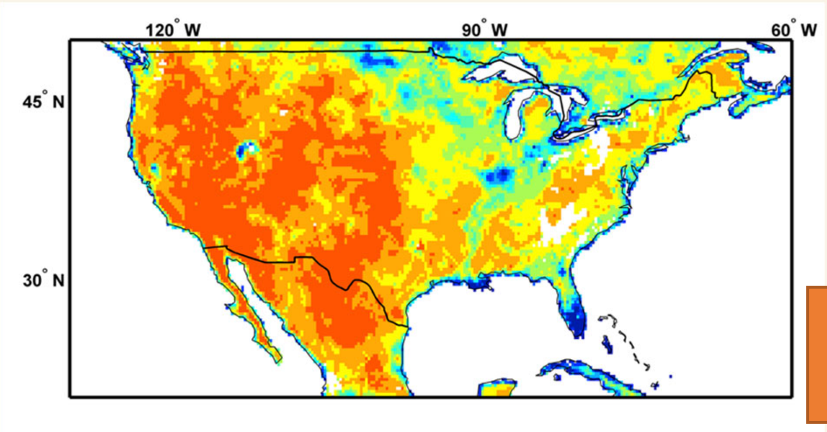
Nathaniel Livesey, Chair of CORF
with input from Scott Paine, Vice Chair of CORF
and reflecting the work of the entire CORF membership



THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Scientific Use of the Radio Spectrum





- Radio frequencies have played a vital role in scientific discovery, as witnessed by Nobel Prizes awarded to Radio Astronomers, and to the IPCC, whose efforts were informed by passive microwave observations
- "Radio Astronomy Service" (RAS): origins and evolution of the Universe; chemistry and formation of stars and solar systems; matter in extreme environments; gravitational radiation; solar activity
- "Earth Exploration Satellite Service" (EESS): a critical tool for predicting weather and investigating climate change. Satellites provide data on issues including food, transportation, energy, and national security
- Together, these activities represents billions of dollars in federal investment

Upper: EHT image of M87 black hole at 230 GHz.
Lower: Soil moisture (1–10 July 2013) at 1.41 GHz.

Spectrum Management and Policy

- The radio spectrum is shared between commercial, governmental, and scientific users (the latter both "passive" and "active")
- Radio regulations are codified both internationally (by the International Telecommunication Union, ITU) and domestically (by the Federal Communications Commission, FCC, and the National Telecommunications and Information Administration, NTIA)
  - Much of the ITU work is focused on "World Radiocommunication Conferences" WRCs, held roughly every four years (next is WRC-23)
- There is an ever-increasing commercial demand for and usage of radio frequencies, driven in part by recent advances in telecommunications technologies
  - The 2021 FCC auction of 3.70–3.98 GHz raised $81.1 billion!
  - (By contrast, NOAA estimates $3 trillion of the US economy is weather-sensitive, and $35 billion in annual economic benefit derives from weather forecasting*)
- This increases the need for spectrum sharing and coordination
  - The passive use of the spectrum is under an ever-growing threat
  - It is difficult to reverse regulations and recover spectrum when passive services are negatively impacted

* https://www.noaa.gov/weather and https://www.performance.noaa.gov/economics/

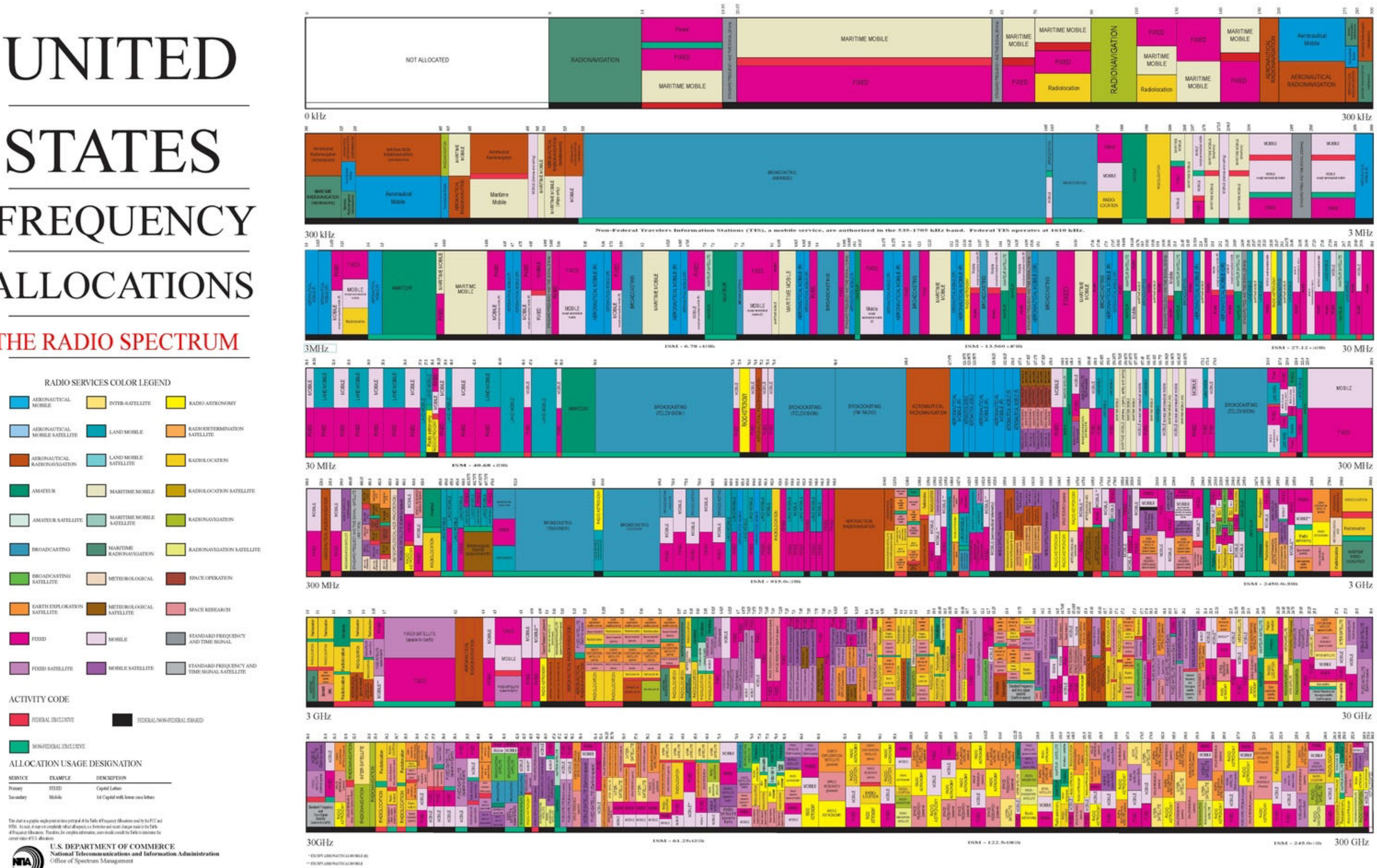
The National Academies of SCIENCES ENGINEERING MEDICINE

BOARD ON PHYSICS AND ASTRONOMY

Division on Engineering and Physical Sciences

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
JANUARY 2016

Roles of CORF

- CORF represents the interests of U.S. users of the radio spectrum for astronomy and Earth science, both basic and applied
- CORF coordinates the views of U.S. scientists and acts as a channel to represent their interests
- We recommend requirements and limits necessary to protect scientific use of the radio spectrum from interference
  - This is largely through filing comments in public proceedings of Federal Communications Commission (FCC)
  - Comments are drafted by CORF and its legal counsel, then reviewed per standard NAS protocols and approved and signed by the NAS President
- CORF also performs specific studies, maintains a Handbook, and conducts various forms of outreach to scientists and industry
- CORF is funded by NSF and NASA

Membership of CORF

Committee Members

Nathaniel Livesey, JPL (Chair) – EESS

Scott Paine, CfA (Vice Chair) – RAS

Nancy Baker, NRL – EESS

Laura Chomiuk, Michigan State – RAS

Dara Entekhabi (NAE), MIT – EESS

Phil Erickson, Haystack Observatory – EESS

Kelsey Johnson, U Virginia – RAS

Christopher Kidd, GSFC/UMD – EESS

Karen Masters, Haverford – RAS

Mahta Moghaddam (NAE), USC – EESS

Frank Schinzel, NRAO – RAS

Consultants

Darrel Emerson, Ariz., retd. – RAS

Tomas Gergely, NSF, retd. – RAS

Paul Feldman, Esq., Fletcher, Heald and Hildreth – Legal counsel

Staff

Colleen Hartman, Director, Space, Physics, and Aeronautics

Neeraj Gorkhaly, Linda Walker

Recent CORF FCC Filings

- One filing in 2022:
  - June 2022: Responding to FCC request for views on adoption of standards for receivers (currently, only transmitters regulated)
- Four filings already in 2023:
  - March 2023: On FCC proposals to streamline new satellite licenses, including potentially authorizing transmission in bands not allocated to spaceborne use in the international radio regulations
  - March 2023: On FCC proposals for use of the 5 GHz band for "Unmanned Aircraft Systems" (i.e., drones)
  - April 2023: On FCC proposals seeking more efficient usage of the 4.9 GHz band allocated to public safety services
  - Due May 12, 2023: On FCC plans to allow direct-to-satellite cellphone service

CORF filing on potential “receiver standards”

- Different sensitivity to out-of-band signals among different classes of receivers has been a factor in some recent high-profile contentious spectrum issues in the US, including:
  - The controversial FCC L-band license to Ligado Networks, whose proposed usage could interfere with certain GPS receivers and other users
  - A more recent issue with 5G base stations potentially interfering with some, but not all, commercial aircraft landing radars
- In 2022 the FCC (not for the first time) solicited inputs on enacting “standards” for receivers

CORF response on "receiver standards" (filed June 2022)

- Receivers used in the passive services have exceptionally high sensitivity and the highest possible spectral selectivity, driven by the need to observe very weak natural radio emissions and small changes therein (e.g., for CMB, climate)
- Such measurements must be accurate and repeatable, and thus as immune as possible from interference
- As such, receivers used in the passive services already possess levels of selectivity the FCC is seeking to encourage and would be difficult to improve upon
- Accordingly, any general receiver standards designed to improve interference immunity performance in active services would likely be inappropriate and/or inapplicable to passive receivers

Accelerated licensing for new satellites (March 2023)

- The FCC sought comment on approaches to accelerating new authorizations for spaceborne transmitters
- Worryingly, this was expected to include authorizing spaceborne transmission in international terrestrial-only bands
- CORF argued that the international nature of both EESS and RAS argues for continuing to view the ITU as:
  "the natural forum for work to identify and manage potential incompatibilities between new spaceborne applications of the radio spectrum and existing services, including RAS and EESS"
- CORF also recommended that:
  "…an investment undertaken under grant of waiver must be understood as necessarily being at risk, rather than as a fait accompli *that serves to coercively influence the ITU process"*

CORF recommendations on accelerated satellite licensing

1. No waivers should be granted for space-to-Earth transmissions in RAS primary/secondary bands, or those listed in footnotes 5.149 or US342
2. No waivers should be granted for space-to-Earth, Earth-to-space, or space-to- space transmissions at frequencies where EESS (passive) has a primary or secondary allocation.
3. Licensed systems should be engineered with spatial, spectral, and temporal geofencing capability to protect radio quiet zones and RAS observatories with geographic footnote protection
4. Licensed systems should be engineered with guard bands, OOBE masks, and spurious emission limits sufficient to ensure that the interference levels in ITU-R RS.2017 are not exceeded in aggregate for either direct or Earth-reflected coupling into EESS (passive) systems
5. The FCC should indeed require waiver applicants to "provide a sufficient electromagnetic compatibility analysis … [that they] … will not cause harmful interference to other stations operating in conformance with the ITU Radio Regulations"

5 GHz band for UAS control

- Unmanned Aerial Systems (UAS, aka drones) are expected to assume increasing economic and public safety importance
- No US spectrum allocation for exclusively for UAS remote operation
- FCC proposed 5030 – 5091 MHz
- FCC did note the need for coordination with RAS observatories in the National Radio Quiet Zone, but other observatories also operate at 5 GHz

5 GHz band for UAS control – CORF response

- CORF cited recent leading-edge science in the 5 GHz band, including studies of transient phenomena including a neutron star merger and the first localization of a fast radio burst source
- Pointed out the need for strict protection of the RAS primary band at 4990 – 5000 MHz from OOBE
- CORF also noted that UASs should be subject to footnote US 211 to the US table of frequency allocations, which urges air- and spaceborne operators to take ”all practicable steps” to protect RAS in certain bands, including 5000 – 5250 MHz

4.9 GHz public safety land mobile radio band

- The FCC has long been concerned that the 4940 – 4990 MHz public safety LMR band is under-utilized
- FCC proposes to increase use by allowing state and local entities to lease out usage subject to coordination by a national band manager
- Once again, a concern for 5 GHz RAS science

4.9 GHz public safety band – CORF response

- CORF noted that in the band 4950 – 4990 MHz, footnote US 342 calls for "all practicable steps" to protect RAS, and US 385 states that "every practicable effort" be made to avoid use near certain RAS observatories.

- CORF emphasized the importance of these footnote protections, and further recommended against changing FCC rules to allow airborne use

- If airborne use were to be allowed, CORF recommended FCC rules setting height limits as well as exclusion zones protecting RAS observatories listed in footnotes US 385 and US161

Direct satellite to cell phone transmissions

- Following proposals from multiple satellite operators, the FCC is proposing a new regulatory framework for “Supplemental Coverage from Space” (SCS) – i.e., direct-satellite-to-cell communications
- Among many considerations the FCC acknowledges the potential for such usage to negatively impact RAS
- Hitherto, the placement of radio astronomy facilities in remote locations, some with associated radio quiet zones, has enabled significant protection from interference
- The proposed new capability would completely undermine that approach
- A CORF response to this FCC plan has been drafted and reviewed and is headed through the signature process

Upcoming CORF spring meeting

- We have finalized the agenda for our (virtual) Spring meeting May 10–11, 2023
- Our Spring meeting focuses on reports from and discussions with the various government entities CORF engages with (FCC, NTIA, NSF, NASA, NOAA)
- We will also have two science talks:
  - One on the planned DSA-2000 Radio Astronomy observatory
  - One on the new Compact Ocean Vector Wind Vector Radiometer (COWVR) mission measuring sea-surface winds and other properties
- As ever, this is mostly a public meeting, and all are welcome

Plans for CORF Fall meeting

- The CORF Fall meeting typically focuses more on higher level science and strategy and is held at a site of interest to RAS and/or EESS
- This year, we plan to hold it in Boulder, Colorado, home to:
  - Silicon Flatirons Institute – part of UC Boulder Law Department focused on technology and spectrum regulation
  - Several members of the NSF Spectrum X team
  - NIST and NTIA facilities focused on spectrum regulation and technology
- We plan panel discussions on “Preserving and enhancing passive use of the radio spectrum”

Colliding trends – active and passive

- Telecommunications
  - Ubiquitous access becoming an economic and public safety essential
  - Supported by dense terrestrial networks and large satellite constellations
- Radio Astronomy
  - Opportunistic broadband observations from remote locations
  - Deep surveys and discovery of new transient phenomena, enabled by wide fields of view and thousands of detectors
- Earth Remote Sensing
  - New observables such as ice clouds and soil moisture
  - Higher-cadence observations enabled by low-cost space access
- Passive use does not interfere but must not be neglected
  - In addition to protected bands, spatial and temporal modes of protection will be increasingly important, and must be part of system designs

CORF at the International Level

- ITU-R Study Groups (and Working Parties) are well into the study cycle for WRC-23
- SG 1: Spectrum Management
  - WP 1A: Spectrum Engineering Techniques
- SG 3: Radiowave Propagation
  - Multiple working groups, but usually meeting in plenary
- SG 4: Satellite Services
- SG 5: Terrestrial Services
- SG 6: Broadcasting Services
- SG 7: Science Services
  - WP 7C: Earth Remote Sensing Systems
  - WP 7D: Radio Astronomy

CORF at the International Level (cont.)

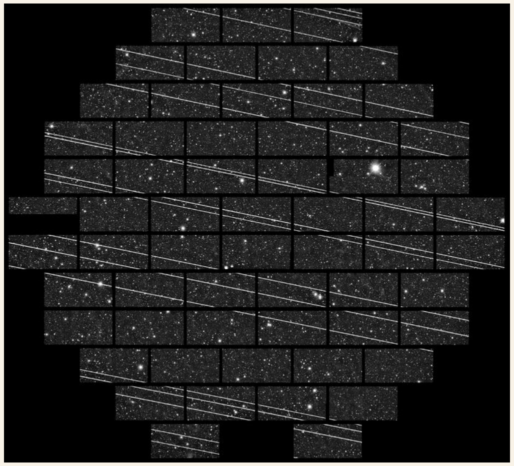
- WP 7C – Earth Remote Sensing
  - CORF members are participating in US WP 7C
  - Numerous NASA/NOAA representatives on US Delegation
- WP 7D – Radio Astronomy
  - CORF members are participating in US WP 7D and in ITU WP 7D
  - CORF has sent one of its consultants to ITU WP 7D for many decades; more recently, sending its former Chair as well
  - Prof. Liese van Zee (prior CORF chair) continues to champion more participation by RAS scientists. This has worked very well
    - Multiple US delegates (CORF members and others)
    - Valuable US-originated reports being developed and slowly being approved (documentation of the EHT, low-frequency arrays, bolometers, and threats posed by harmonics)
  - Most recently, Prof. van Zee was part of the US delegation to the “Conference Preparatory Meeting”

CORF Activities: Outreach

- Participation with other groups around the world.
  - ITU-SG7; Working Parties – 7C (EESS), 7D (RAS), WP 1A, SG 3
  - IUCAF, CRAF, etc. – primarily RAS
  - IEEE-GRSS – Frequency Allocation Technical Committee
  - AMS – Radio Frequency Allocations Committee
- Presentations at and/or participation in other events.
  - Presentation at NSF "Spectrum Week" (Scott Paine, this week)
  - Participation in "Aspen Institute" workshop "Towards A National Spectrum Strategy" (Nathaniel Livesey, May 2023)

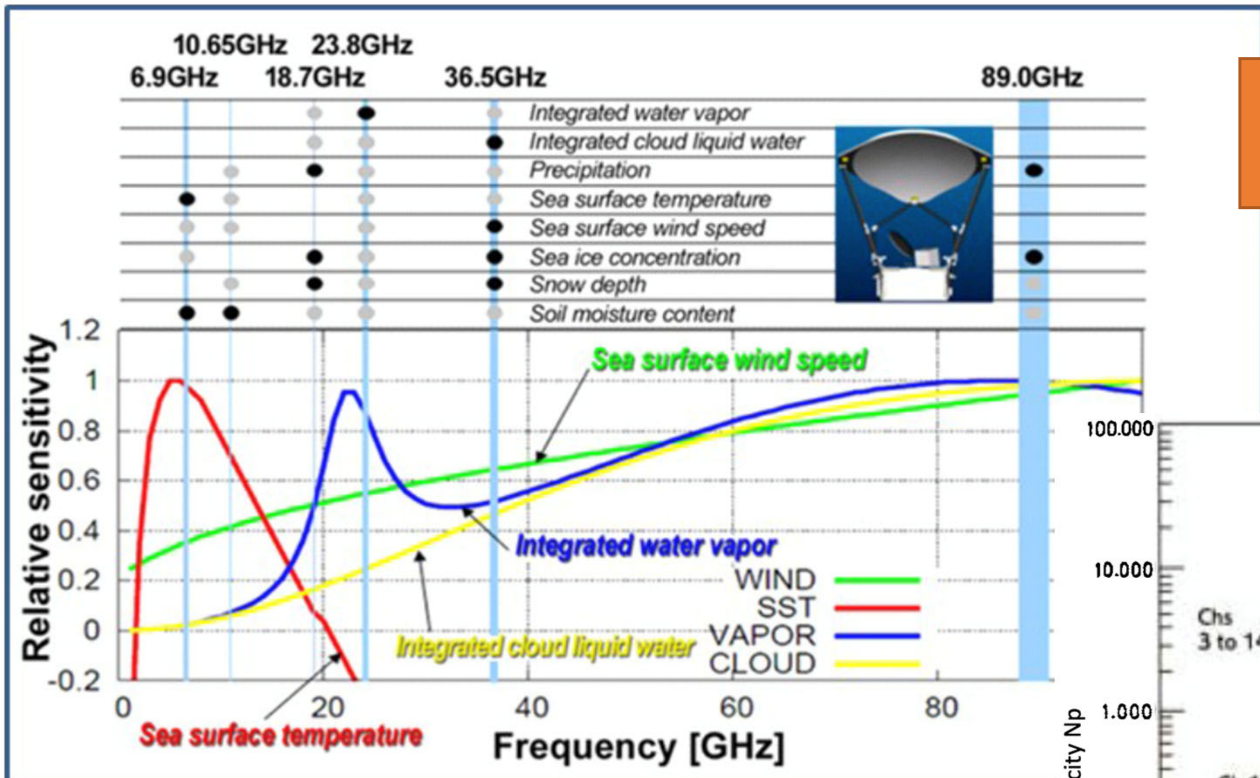
Backup material

Other "Hot Button" Issues

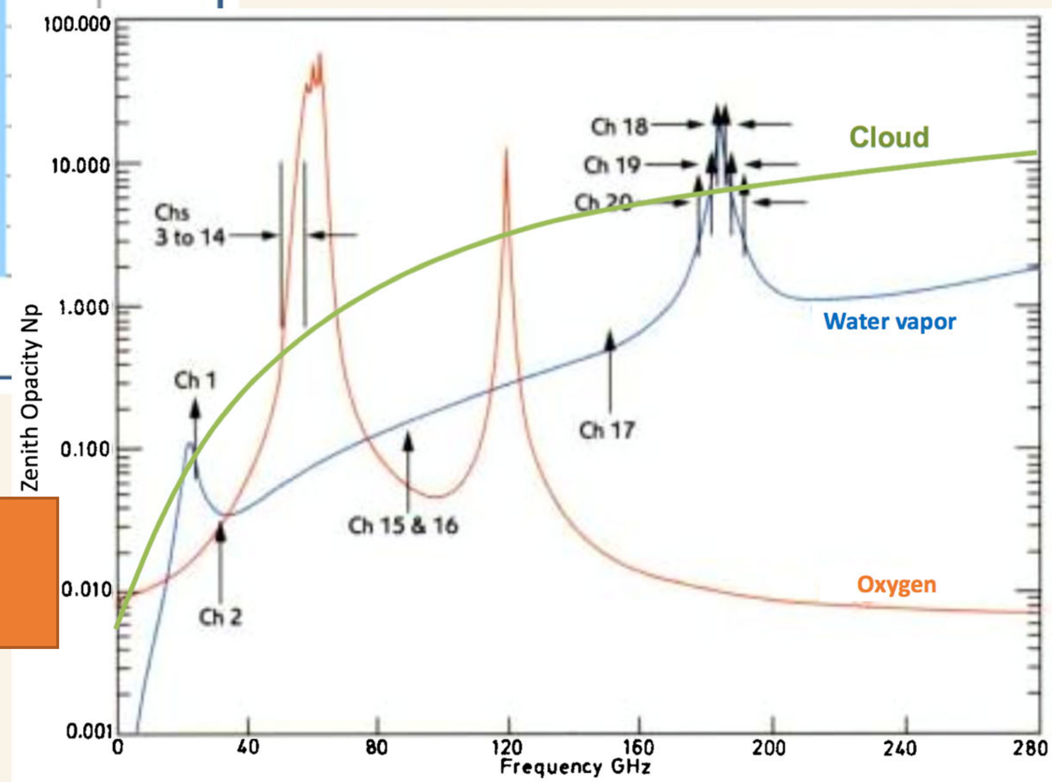


- Constellations with thousands of satellites
  - We are monitoring discussions related to dark skies triggered by the dramatic rise in number of Low-Earth Orbiting satellites
- NSF Spectrum Innovation Initiative program
  - The "Spectrum X" consortium funded under this program includes participation by current and previous CORF members
- RAS observations outside protected bands
  - An increasing number of RAS observations are made outside of the protected bands. This is starting to to be acknowledged in CORF discussions and in some FCC documents (likely initiated by NSF). The associated risk is that it implies we no longer "need" the protection
- Threats to "all emissions prohibited" restrictions > 95 GHz
  - We join with others in resisting efforts from industry to undermine/revise the "All emissions prohibited" status of all the passive bands above 95 GHz currently having that protection

EESS (passive) as a System

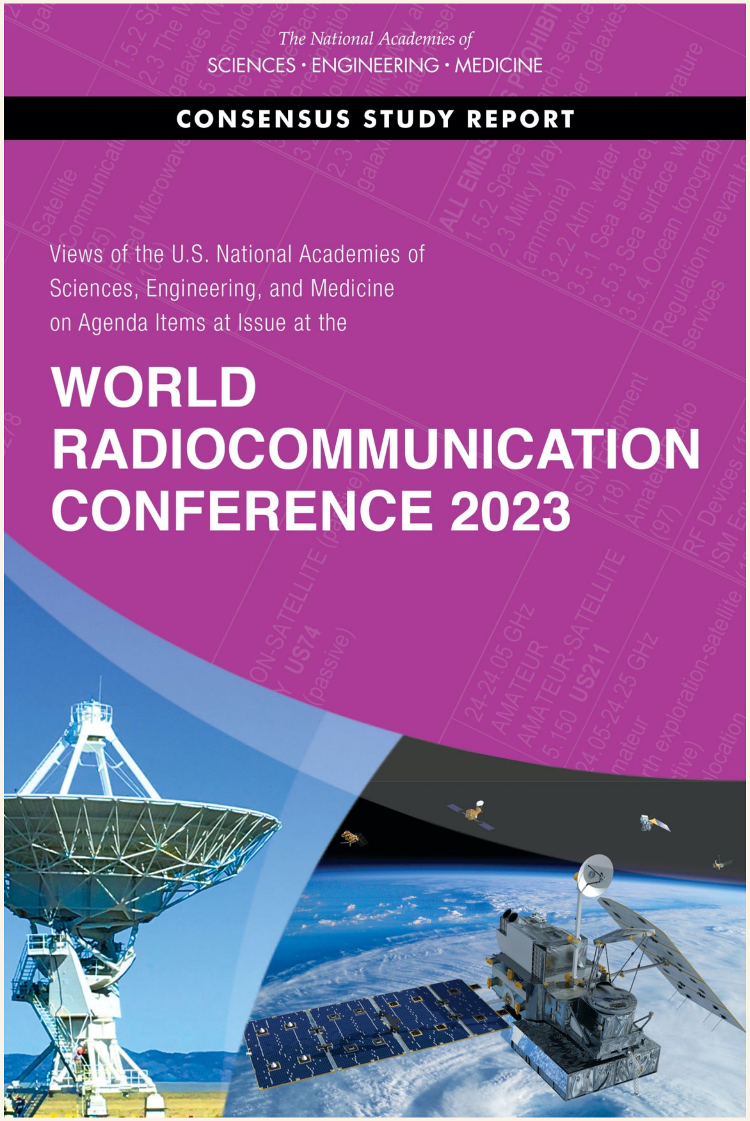


Advanced Scanning Radiometer 2 (AMSR2) onboard GCOM-W1



Advanced Microwave Sounding Unit (AMSU) on NOAA-15, NOAA-16, and NOAA-17.

CORF Activities: WRC-23 Views Report



- Separate consensus committee
- Represents input from US scientists regarding agenda items at the World Radiocommunication Conference 2023 (WRC-23), and preliminary items for the WRC-27 agenda
- Decisions at the WRCs lead to international regulations under the ITU
- Multiple agenda items with potentially significant impact to RAS/EESS
  - NASA and NSF (and FCC) heavily involved
- More than 250 downloads from the National Academies Press since its June 2021 release
- Report briefed to NSF, NASA, and staffers from House Science Committee

Views on WRC-23 Agenda Items

1.2 International Mobile Telecommunication (IMT, cell phones) at 3.3–3.4, 3.6–3.8, 6.425–7.125, and 10.0–10.5 GHz

1.4 High Altitude Platforms (HAPS) as IMT (cell phone) Base Stations (HIBS) below 2.7 GHz

1.5 Review 470–960 MHz in Region 1

1.8 Fixed Satellite Services (FSS) and unmanned aircraft (10–15 GHz, 19.7–20.2 GHz, 29.5–30 GHz)

1.9 Aeronautical mobile in HF bands (adjacent to RAS at 13.36–13.41 MHz)

1.10 Aeronautical mobile at 15.4–15.7 and 22–22.1 GHz

1.11 Maritime distress services (1610–1626.5 MHz and 2483.5–2500 MHz)

1.12 EESS (active) radar sounders at 45 MHz

1.13 Space Research Services at 14.8–15.35 GHz

1.14 EESS (passive) at 231.5–252 GHz

1.15 Geostationary Earth Stations in Motion (GSO-ESMIS) at 12.75–13.25 GHz

And more. See the next slide

WRC-23 Agenda Items (cont.) and WRC-27 Items

1.16 nGSO-ESIMs at 17.7–18.6, 18.8–19.3, and 19.7–20.2 GHz, and others

1.17 Inter-satellite links at 18.1–18.6 GHz, 18.8–20.2 GHz, and others

1.19 Fixed Satellite Services (FSS, space-to-Earth) at 17.3–17.7 GHz in Region 2

9.1 Topic A: Space Weather

9.1 Topic B: Amateur Service at 1240–1300 MHz

9.1 Topic C: Mobile use (IMT, cell phones) in bands allocated to Fixed services

9.1 Topic D: Protection of EESS (passive) at 36–37 GHz

WRC-27 Preliminary Agenda Items:

- WRC-27 2.8 and 2.9 (1330–1350 MHz; 1610.6–1613.8 MHz; 1660–1670 MHz)
- WRC-27 2.2 and 2.3 (37.5–51.4 GHz)
- WRC-27 2.4, 2.5, and 2.7 (71–76 and 81–86 GHz)
- WRC-27 2.1 (231.5–275 GHz; 275–700 GHz)

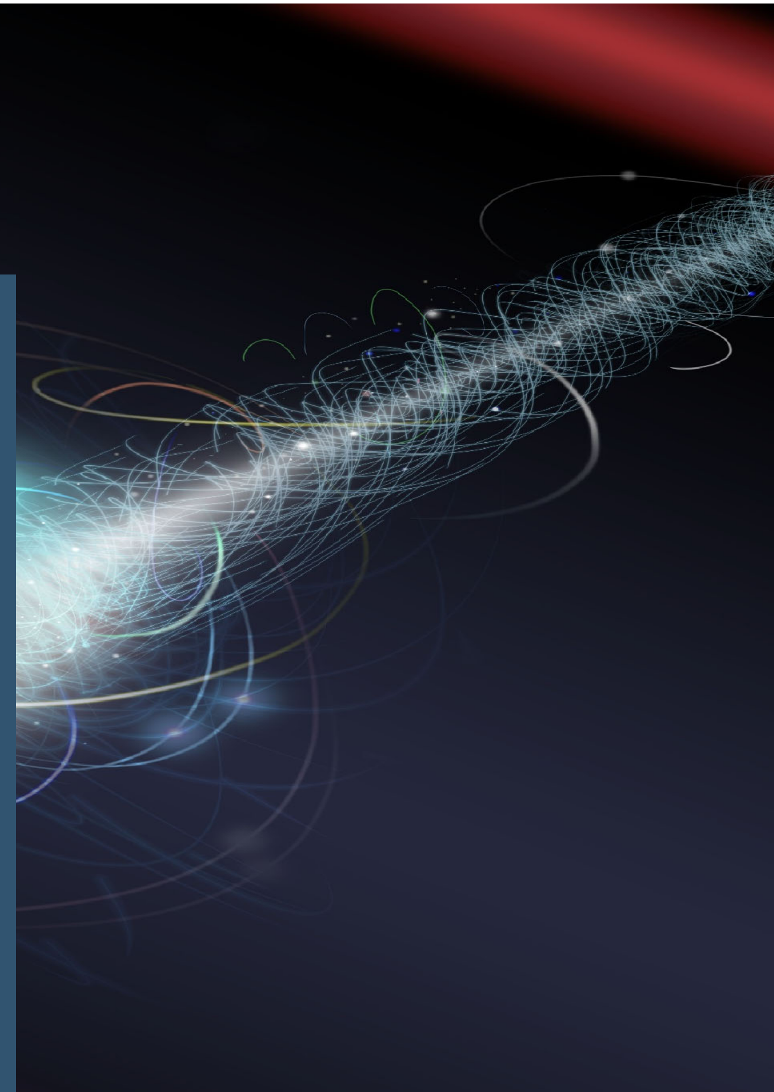
NATIONAL ACADEMIES *Sciences Engineering Medicine*

Elementary Particle Physics 2024: Progress and Plans

Committee of Elementary Particle Physics

Board on Physics and Astronomy

Dr. Maria Spiropulu and Dr. Michael Turner, EPP2024 Co-Chairs



BOARD ON PHYSICS AND ASTRONOMY, SPRING MEETING
WASHINGTON, DC | 26 APRIL 2023

EPP2024: Project timeline

I. Information gathering

II. Formulate findings, conclusions & recommendations Writing & review

III. Roll out and dissemination activities

V5: 27 February 2023

- June 2022: Kick off meeting -- Bias and conflict, organization, SOT discussion
- July 2022 (Seattle): Agencies, organization, SM2021, progress since 2011, Europe strategy
    - October 2022: Timeline, WGs, and EPP 2024 organization
    - October 2022: EC Town Hall
    - November 2022: Academic Leadership Panels (ALP)
- November 2022 (Irvine): Cosmic, Neutrino and Theory Frontiers, EC WG and ALP summary
    - December 2022: LA speakers and P5 discussion
    - January 2023: LA WG report out and DOE HEP Directors Panel
    - February 2023: CERN visit including Directorate meeting and Town Hall
    - March 2023: Computation WG report out
    - March 2023: Fermilab visit and Fermilab Town Hall
- April 2023 (DC): Final information gathering (Rare/precision processes and instrumentation)
    - May 2023: Japan EPP panel moderated by Barish
    - May 2023: Finish WG report outs
- June 2023 (Irvine): Formulate findings and conclusions
    - July 2023: Further prep for September meeting
    - August 2023: Further prep for September meeting
- September 2023 (DC): Formulate recommendations and make writing assignments
    - October 2023: P5 report released
    - October/November 2023: writing continues, discussion of P5 report
- December 2023 (Irvine): Review draft report in light of P5 report
- Early 2024: Report goes to review
- Winter/spring 2024: response to review and planning for dissemination
- June 2024: Report released and <u>sustained</u> dissemination phase begins
    - Out briefings: Agencies, OSTP, Congress, intl partners, thought leaders, science societies, university leadership, media, …
    - In briefings: HEPAP, DPF, EPP communities (US and global), HEP Labs, …

Notes: indented meetings are virtual and 4 hours; WGs and P5 activities not shown

Information gathering: EPP2024 has been busy!

Contextualizing the Study

- Met with federal science leadership to contextualize our task (beyond the words of the charge)
  - Denise Caldwell (NSF)
  - Sean Jones (NSF)
  - Harriet Kung (DOE)
  - Gina Rameika (DOE)
  - Joel Parriott (OSTP)

Input from Snowmass 2021

- Attended Final Plenary of Snowmass 21
- Progress in Particle Physics since 2010 (Lykken)
- Snowmass Process (Butler)
- Frontier Presentations:
  - Theory (Craig)
  - Neutrinos (Beacom and de Gouvea)
  - Cosmic (Tait)
  - Rare Processes and Precision Measurements (Artuso, Kaplan, Arkani-Hamed and Gratta)

Listening to Thought Leaders

- Two Academic Leadership Panels (Bean, Ero-Tolliver, Hellman, Incera, May, Moler, Olinto, Schnell, Seo)
- Future of Particle Physics panel (Colglazier, Crim, Dehmer, Randall and Witherell)
- DOE Lab HEP Divisions Directors panel (ANL, BNL, FNAL, LBNL and SLAC)
- Two Panels on Large Accelerators (Cousineau, Palmer, Rivkin, Roser, Schulte, Shiltsev)
- International Collaboration Panel (Donovan, Rabinovici and Rameika)
- Japan HEP Panel (Asai, Kajita, Yamauchi)
- China HEP Plans (Yifang Wang)

Listening to the EPP Community (Town Halls)

- EPP2024 EC Town Hall (virtual)
- Two EPP2024 CERN Town Halls
- EPP2024 Fermilab Town Hall

Listening to the EPP Community (Snowmass and P5 Town Halls)

- Final Snowmass 2021 Final Plenary Session
- P5 Town Halls (LBNL, Fermilab, ANL, BNL)

EPP 2024 Committee Activities

- 6 Face-to-face meetings
  - Three to date: July 2022, November 2022, April 2023 (links to each)
  - Three to come
- 15 monthly 4-hour zoom meetings
  - Seven to date: June 2022, October 2022, November 2022, December 2022, January 2023, February 2023 and March 2023
  - More to come

Other EPP 2024 Activities

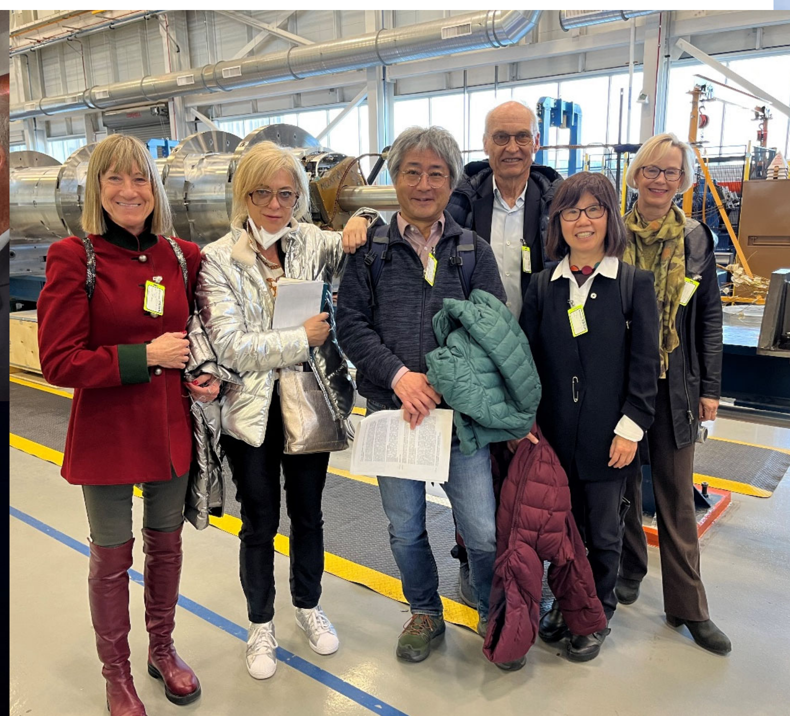
- CERN (February 2023) and Fermilab (March 2023) two-day visits each
- Presentations (Snowmass 2021, HEPAP, P5, LBNL, DPF)
- Attended workshops (e.g., KITP Muon Collider Workshop, Feb/Mar 2023)
- Spoke individually with countless colleagues, attended seminars and colloquia, etc (my calendar records more than 40 such activities)
- Attended P5 activities (virtually and in person)
- Committee members read, listened, and thought

We now go into the quieter and more intense formulation phase

EPP-2024 Visit to CERN – February 14-15, 2023

Credit: CERN, C. Hartman

EPP-2024 Visit to Fermilab – March 20-21, 2023



Credit: D. Nagasawa, M. Turner

VERA C. RUBIN OBSERVATORY

Rubin Observatory

Victor Krabbendam, Leanne Guy, Tony Tyson

Presentation to the National Academies Board on Physics and Astronomy

26 April 2023

NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION


Rubin Observatory's mission is to build a well-understood system that will produce an unprecedented astronomical data set for studies of the deep and dynamic universe, make the data widely accessible to a diverse community of scientists, and engage the public to explore the Universe with us.
Wide-Fast-Deep image survey of the full visible southern sky every 3-4 nights for 10 years
Credit: Y. AlSayyad/Rubin Obs/NSF/Princeton
NSF
AURA
U.S. DEPARTMENT OF ENERGY
SLAC
CHARLES AND LISA SIMONYI FUND
LSST CORPORATION

VERA C. RUBIN OBSERVATORY

- Project Status
- Data to Science
- Science Opportunities & LEOsats

NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION

VERA C. RUBIN
OBSERVATORY

- Project Status
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NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION

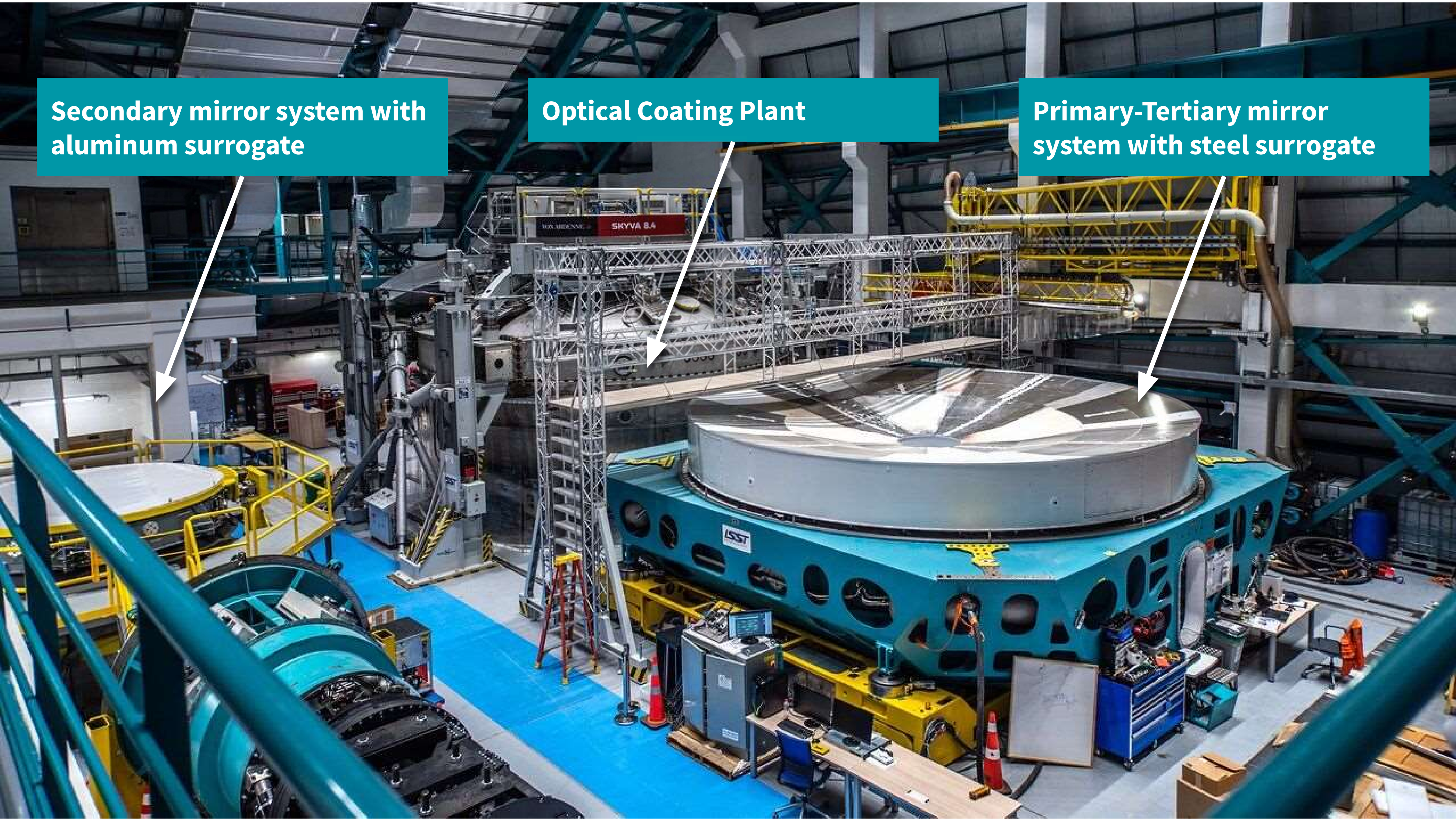
Rubin is a Public-Private partnership led by NSF

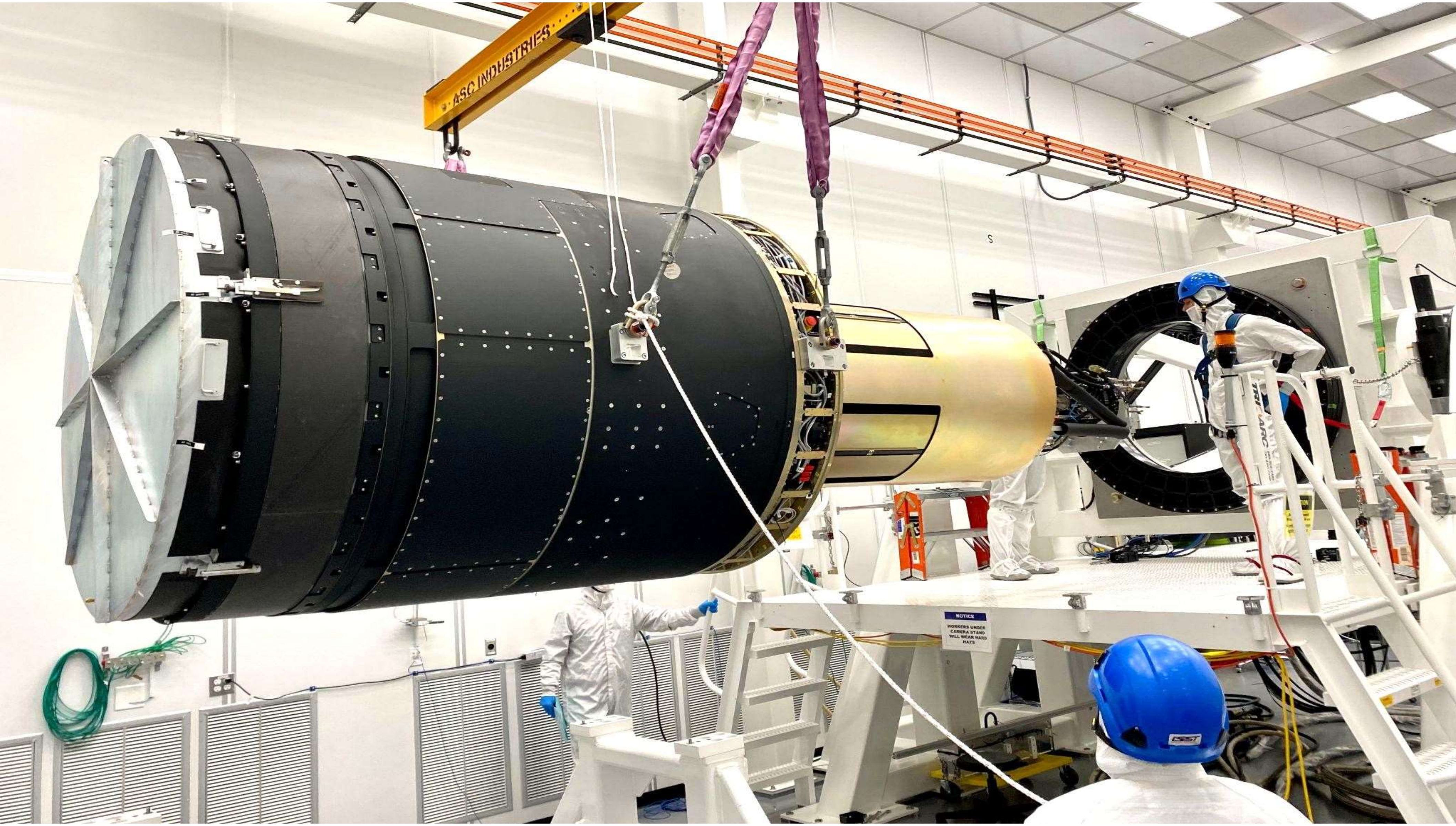
NSF MREFC:	**$ 473.0 M**	Formal Construction Start was August 2014
NSF COVID and Data Security	$ 85.0 M*	
DOE MIE:	**$ 165.3 M**	Camera MIE finished with CD-4 in Sept 2021
DOE Commissioning:	$ 47.9 M*	
Private Funding:	**$ 34.0 M**	Early contribution for delivered M1M3. M2, site prep

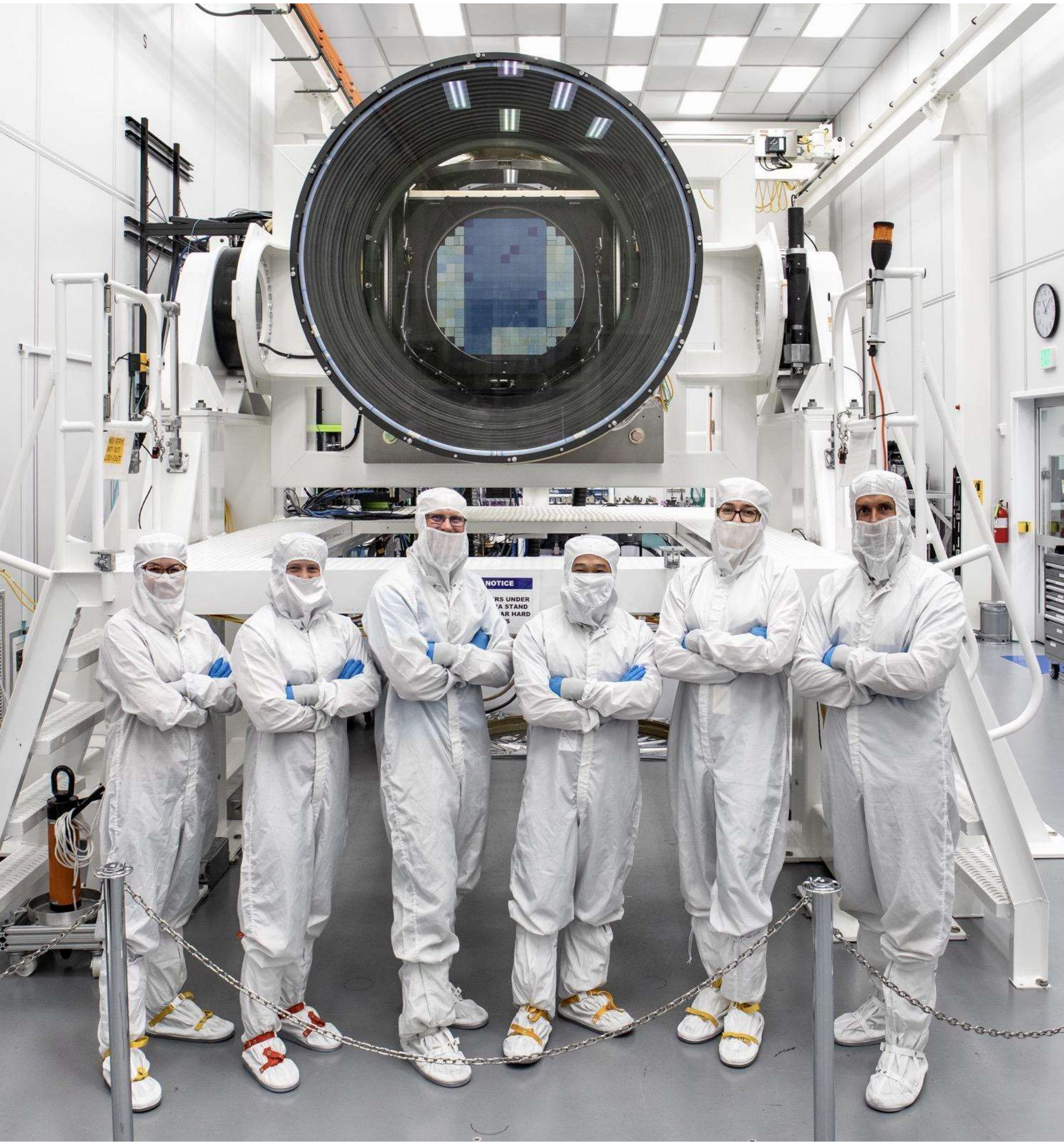
* impacts are still subject to forecasts and approval

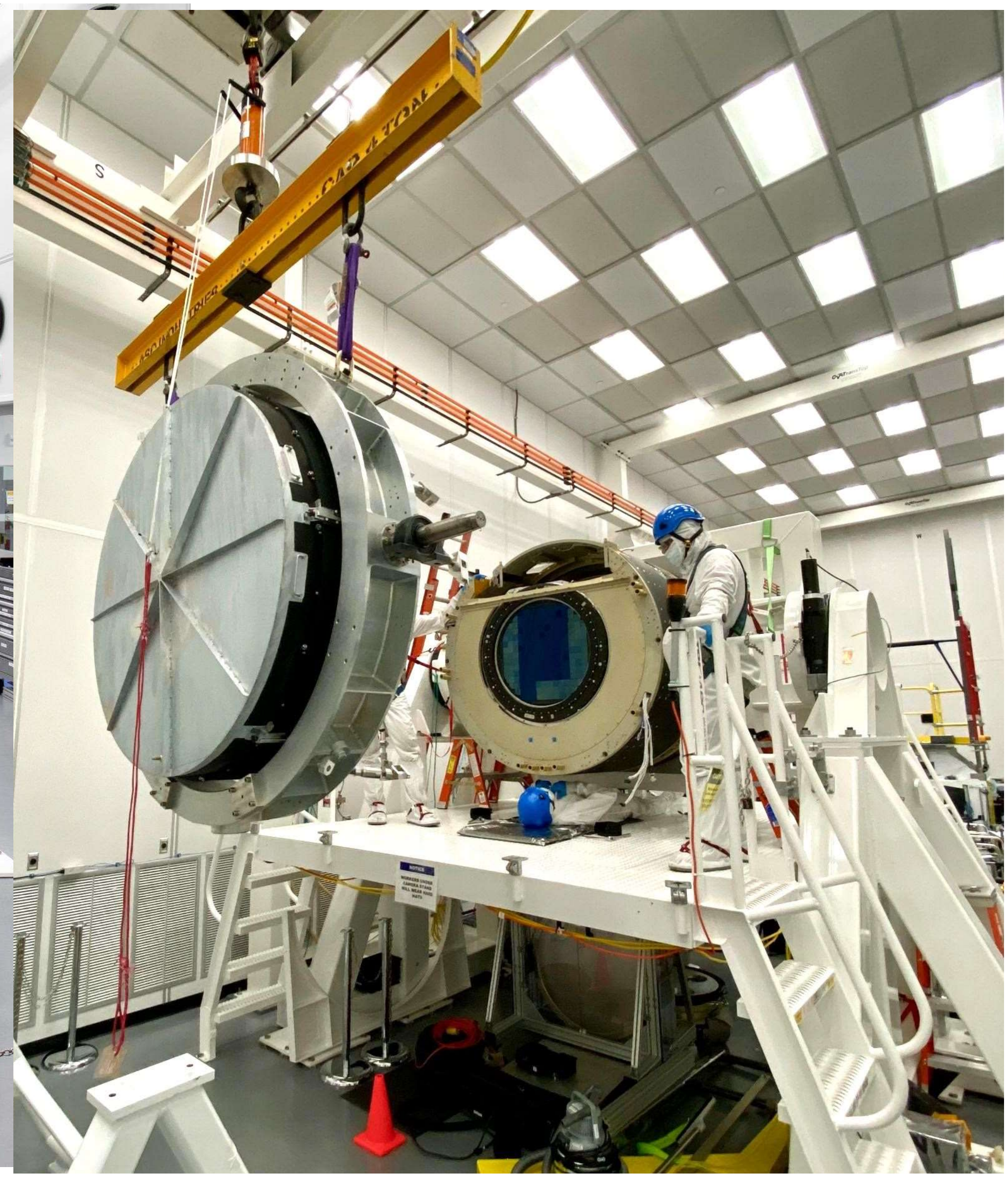
Construction and Commissioning of Rubin Observatory currently projected to be $810 M and roughly 11 years

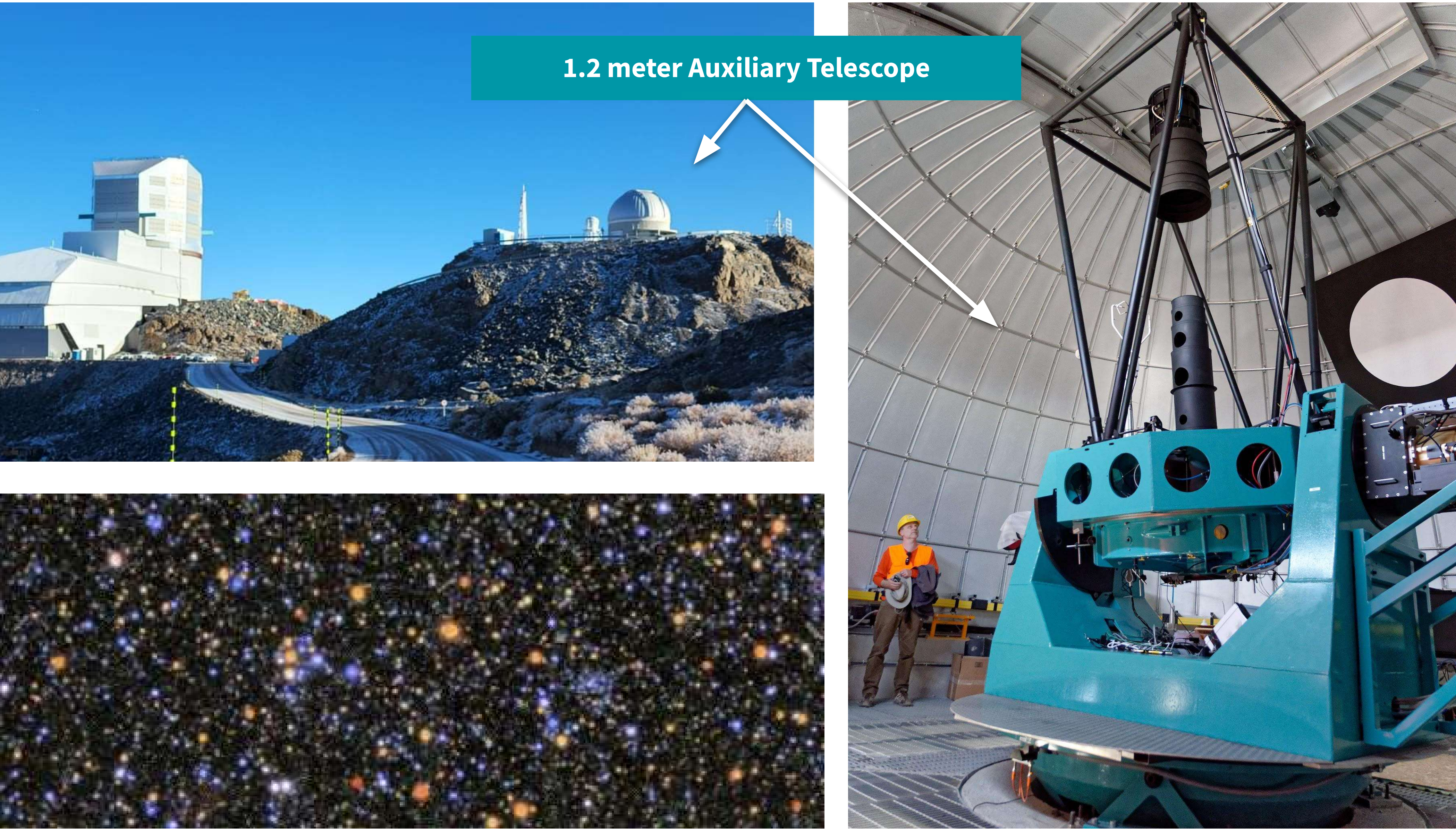

Satellite Imagery: GOES16 Advanc
Sequence 179
Sequence 576
-3.877mm
2.249mm
-1.24mm
LSST Camera Image Viewer
Recent Auxtel Images
Ridgeline plot
Cerro Pachon current sky


Secondary mirror system with aluminum surrogate
Optical Coating Plant
Primary-Tertiary mirror system with steel surrogate
SKYVA 8.4
LSST

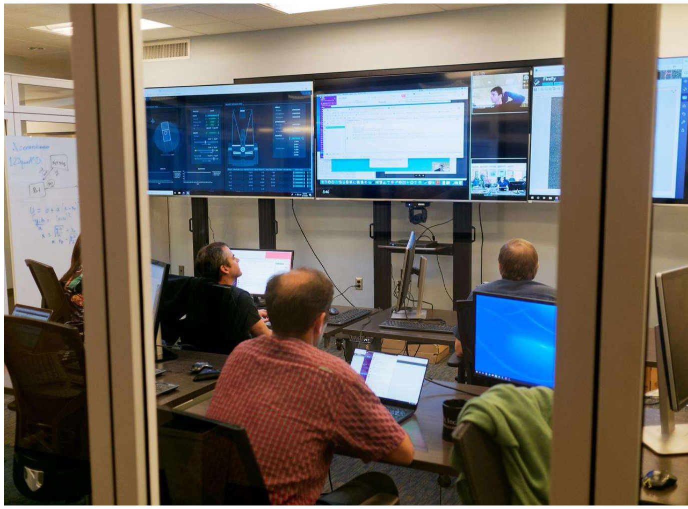

ASC INDUSTRIES
NOTICE
WORKERS UNDER CAMERA STAND WILL WEAR HARD HATS


NOTICE



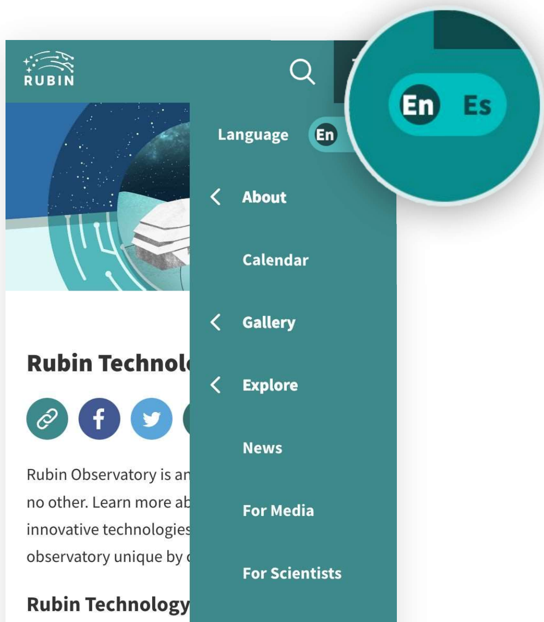

1.2 meter Auxiliary Telescope

Data getting to USDF through DM pipelines and quickviews...



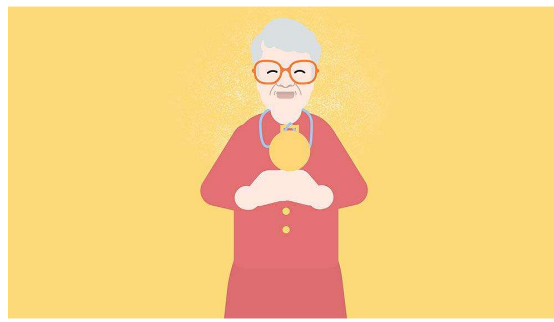
Rubin's Education and Public Outreach System is complete and ready to engage the public to explore the Universe with us!

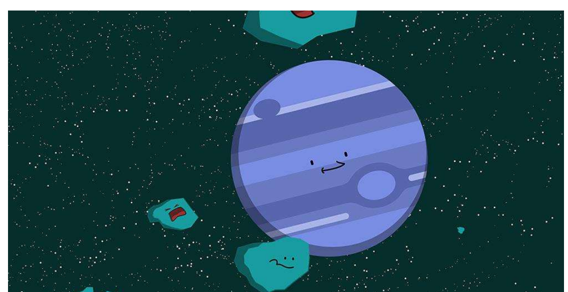
A new mobile-first, accessible website with engaging, conversational content in English and Spanish



rubinobs.org
(soon to be rubinobservatory.org)

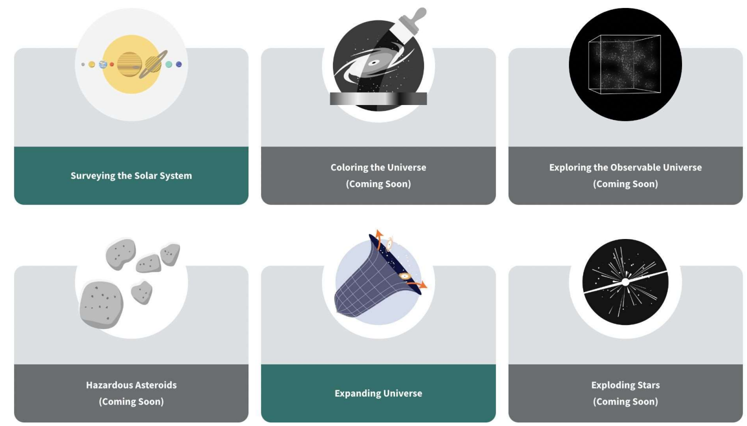
Animated videos about Rubin and its science, on Youtube in English and Spanish



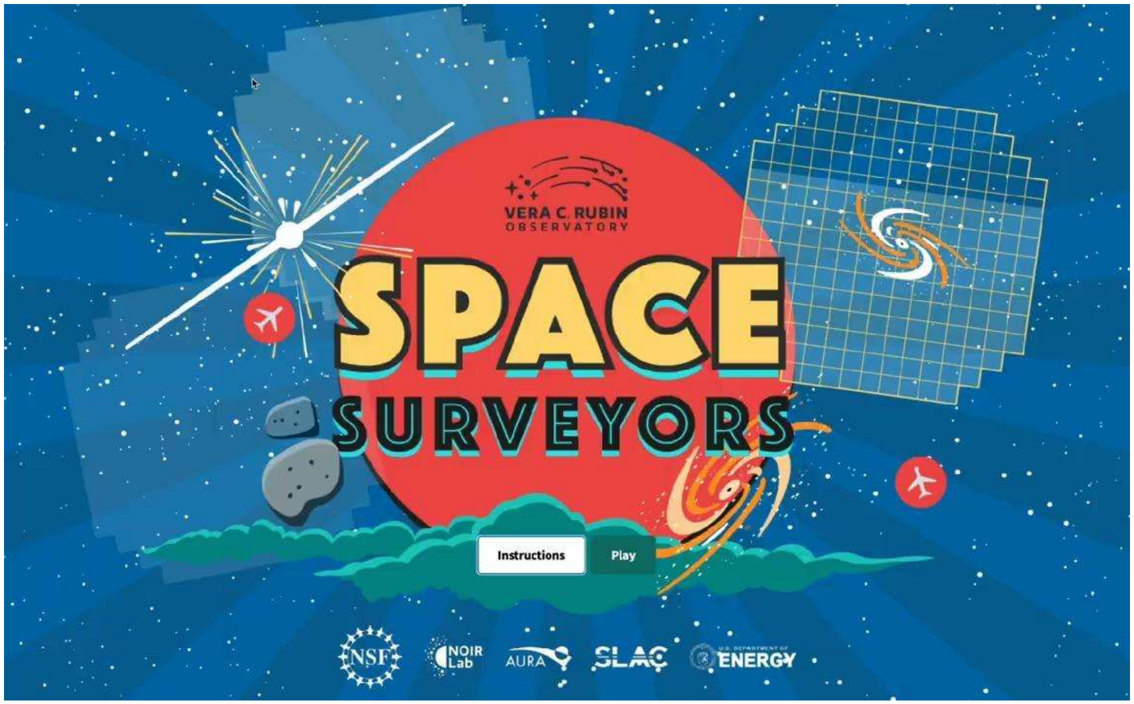


youtube.com/RubinObservatory

Formal education investigations with resources for teachers



Space Surveyors



spacesurveyors.app

What else we have in store

Engage with us on social media!

/VRubinObs

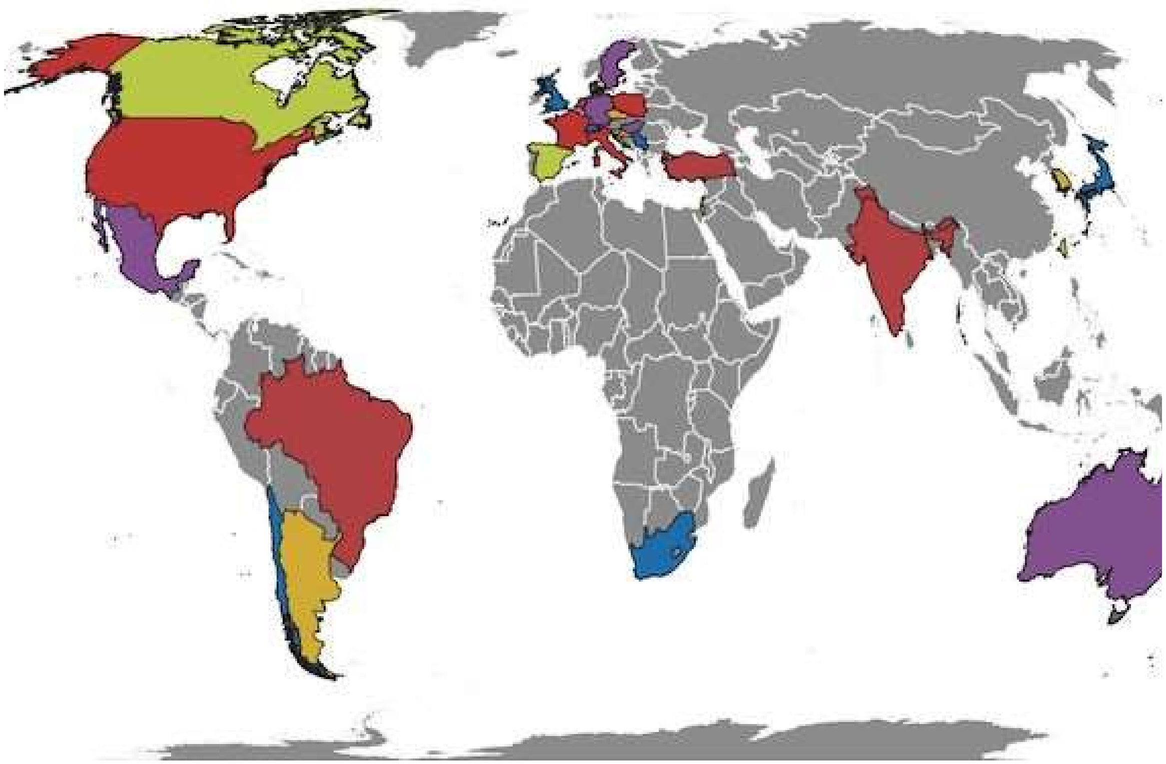
/VRubinObs

/rubin_observatory

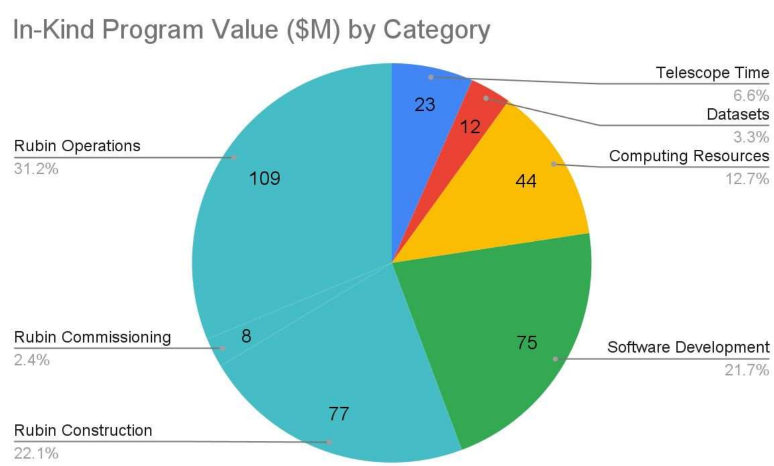
/RubinObservatory

/company/rubinobservatory

Rubin In-kind Program managed by Operations team



There are **43** individual international teams (**30** countries) who are providing **153** in-kind contributions to Rubin and the LSST science community in return for LSST data rights.



In Summary: Rubin Timeline

Starting a key year for full system integration and commissioning!

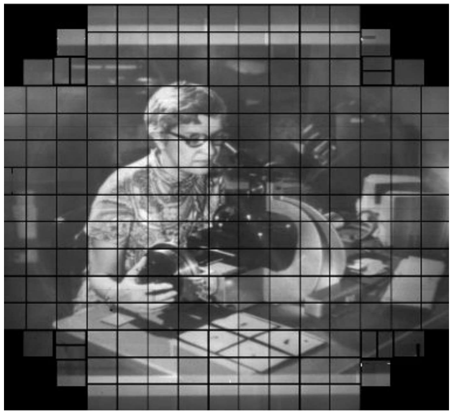
2023 **2024** **2025**

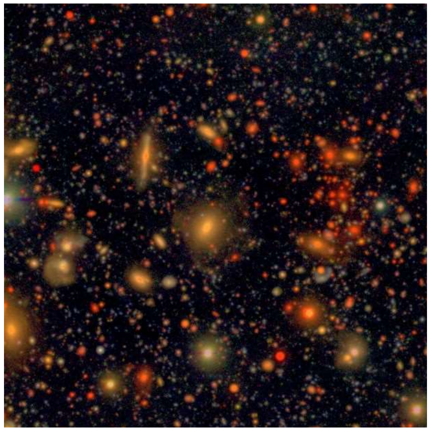
Analysis software ready for commissioning

Oct 2023 : Arrival of LSSTCam on the summit

System First Light ~ **October 2024**.

Legacy Survey of Space and Time (LSST) starts 2025





The COSMOS field seen by Hyper Suprime-Cam, courtesy of the HSC Collaboration, R. Lupton, and N. Lust.

VERA C. RUBIN OBSERVATORY

- Project Status
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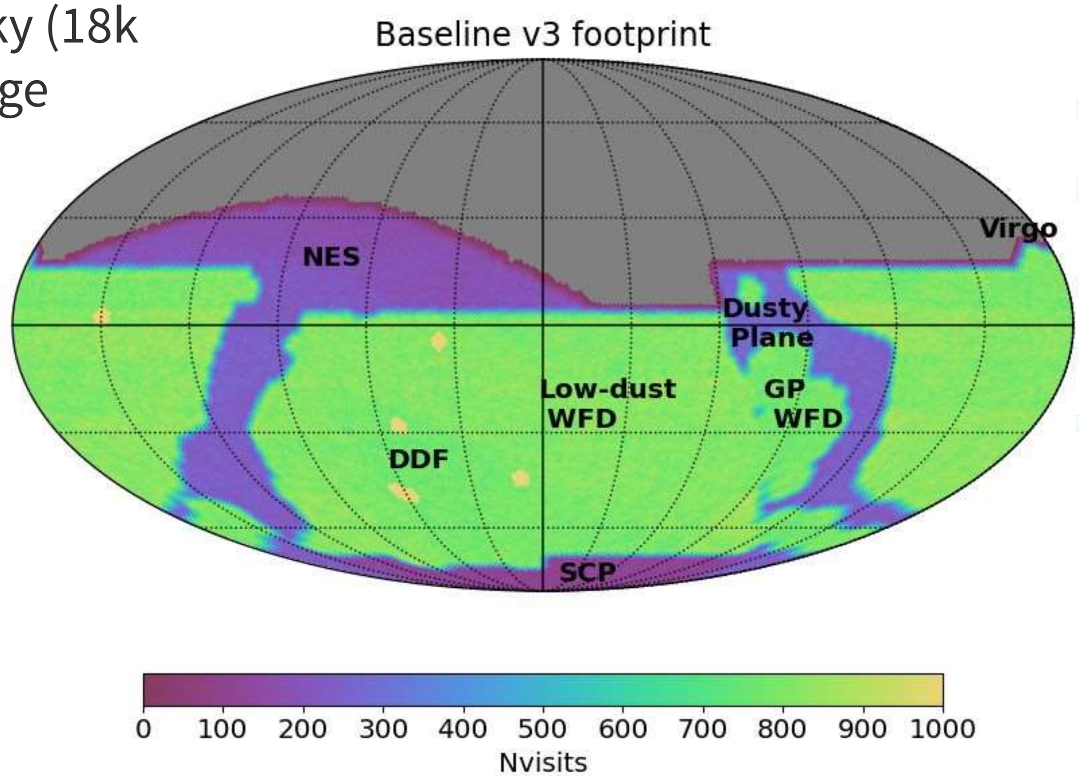
NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION

Baseline Survey Observing Strategy V3.0

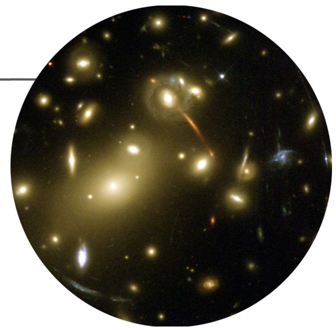
- Rubin will image the entire Southern sky (18k sq deg) every few nights, taking an image every ~40 seconds for 10 years.
- Survey Cadence Optimization Committee (SCOC) Phase 1 & Phase 2 recommendations provide the initial implementation of the LSST
- SCOC will continue to work through commissioning & operations to review and refine the survey strategy to produce the best science with Rubin

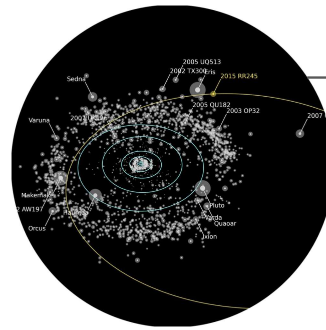


LSST Key Science Drivers

Probing Dark Matter & Dark Energy

- Strong & Weak Lensing
- Large Scale Structure
- Galaxy Clusters, Supernovae



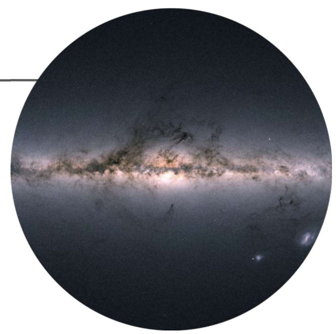


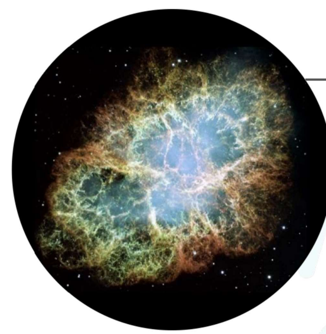
Inventory of the Solar System

- Comprehensive small body census
- Comets & ISOs
- Planetary defence

Mapping the Milky Way

- Structure and evolutionary history
- Spatial maps of stellar characteristics
- Reach well into the halo





Exploring the Transient Optical Sky

- Variable stars, Supernovae
- Fill in the variability phase-space
- Discovery of new classes of transients

"From Science Drivers to Reference Design", Ivezić et al. (APJ, 2019), arXiv:0805.2366

Data Management System Vision

Raw Data: 20TB/night

Sequential 30s images covering the entire visible sky every few days

Prompt Data Products

Alerts: up to 10 million per night — 60s via nightly alert streams → Community Brokers

Raw & Processed Visit Images, Difference Images, Templates

Transient and variable sources from Difference Image Analysis

Solar System Objects: ~ 6 million

24h via Prompt Products DB

Data Release Data Products

Final 10yr Data Release:

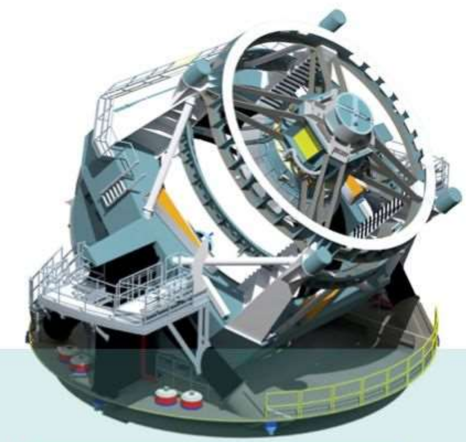
- Images: 5.5 million x 3.2 Gpixels
- Catalog: 15PB, 37 billion objects

via Data Releases

Rubin Data Access Centres (DACs)

USA (USDF)
Chile (CLDF)
France (FRDF)
United Kingdom (UKDF)

Independent Data Access Centers (IDACs)

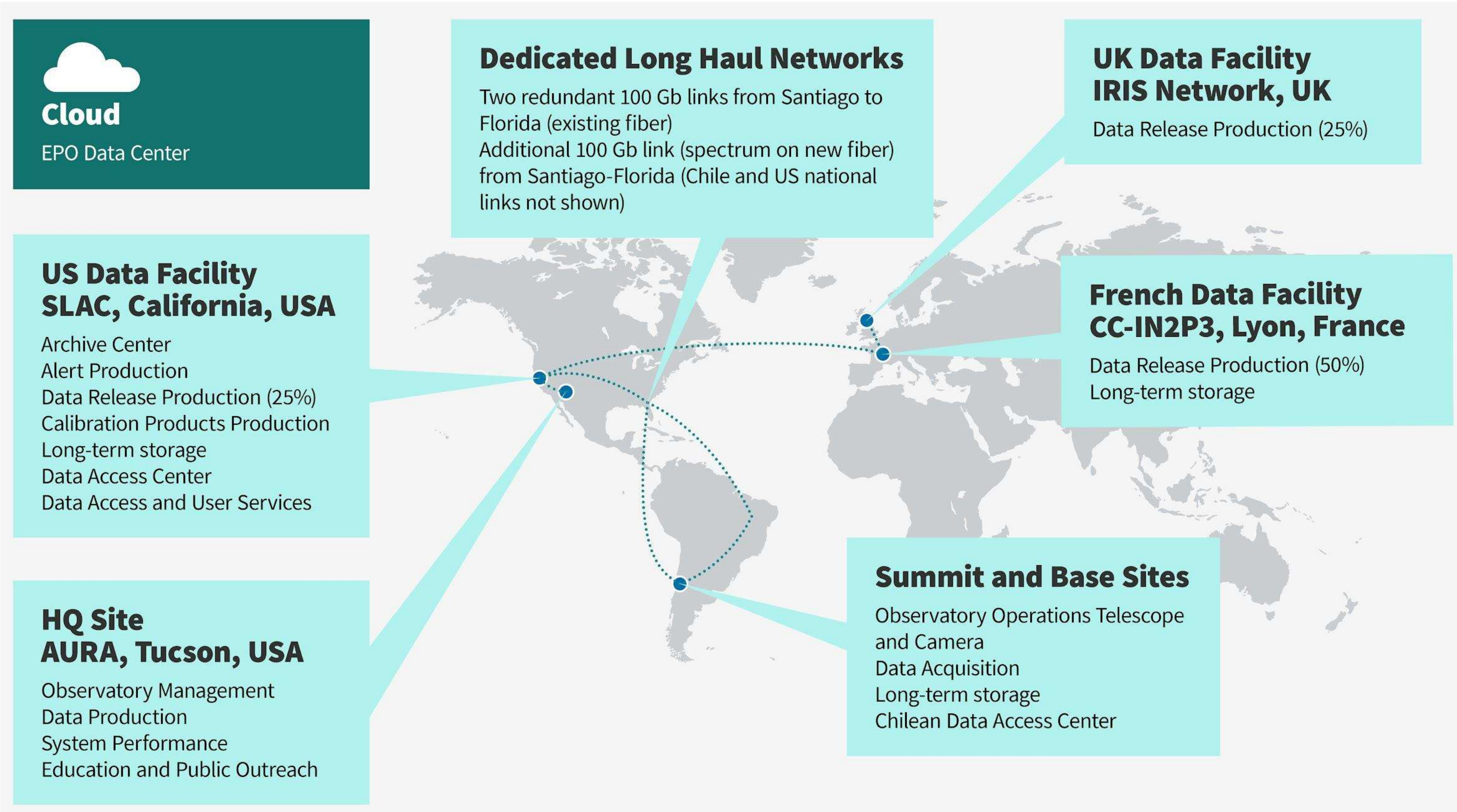


Access to proprietary data and the Science Platform require Rubin data rights

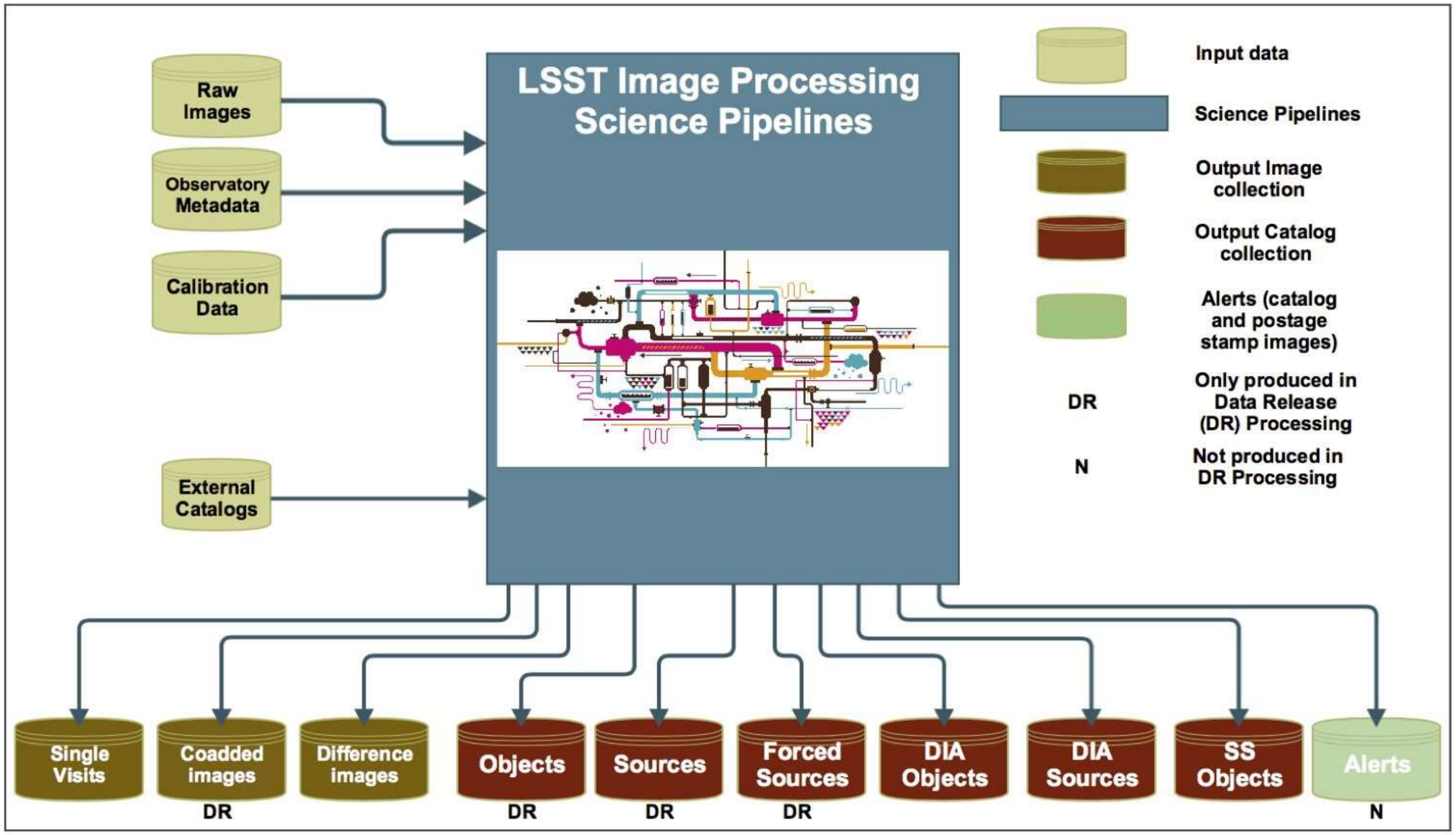
Rubin Science Platform

Provides access to LSST Data Products and services for all science users and project staff.

Credit: Leanne Guy


Cloud
EPO Data Center
Dedicated Long Haul Networks
Two redundant 100 Gb links from Santiago to Florida (existing fiber)
Additional 100 Gb link (spectrum on new fiber) from Santiago-Florida (Chile and US national links not shown)
UK Data Facility
IRIS Network, UK
Data Release Production (25%)
US Data Facility
SLAC, California, USA
Archive Center
Alert Production
Data Release Production (25%)
Calibration Products Production
Long-term storage
Data Access Center
Data Access and User Services
French Data Facility
CC-IN2P3, Lyon, France
Data Release Production (50%)
Long-term storage
HQ Site
AURA, Tucson, USA
Observatory Management
Data Production
System Performance
Education and Public Outreach
Summit and Base Sites
Observatory Operations Telescope and Camera
Data Acquisition
Long-term storage
Chilean Data Access Center

LSST Science Pipelines



Three major types of data products produced by the LSST science pipelines: Images, Catalogs and Alerts

Rubin LSST Data Products

Prompt Data Products

Real Time Difference Image Analysis (DIA)

- Stream of ~10 million time-domain events per night (Alerts), transmitted to event distribution networks within 60s of camera readout.
- Images, Object and Source catalogs derived from DIA, and an orbit catalog for ~6 million Solar System bodies within 24h.
- Enables discovery and rapid follow-up of time domain events.

Data Release Data Products

Reduced single-epoch & deep co-added images, catalogs, reprocessed DIA products

- Catalogs of ~37 billion objects (20 billion galaxies, 17 billion stars), ~7 trillion sources and ~30 trillion forced source measurements.
- 11 Data Releases, produced ~annually over 10 years of operation.
- Accessible via the Rubin Science Platform (RSP) & Rubin Data Access Centers (DACs).

User Generated Data Products

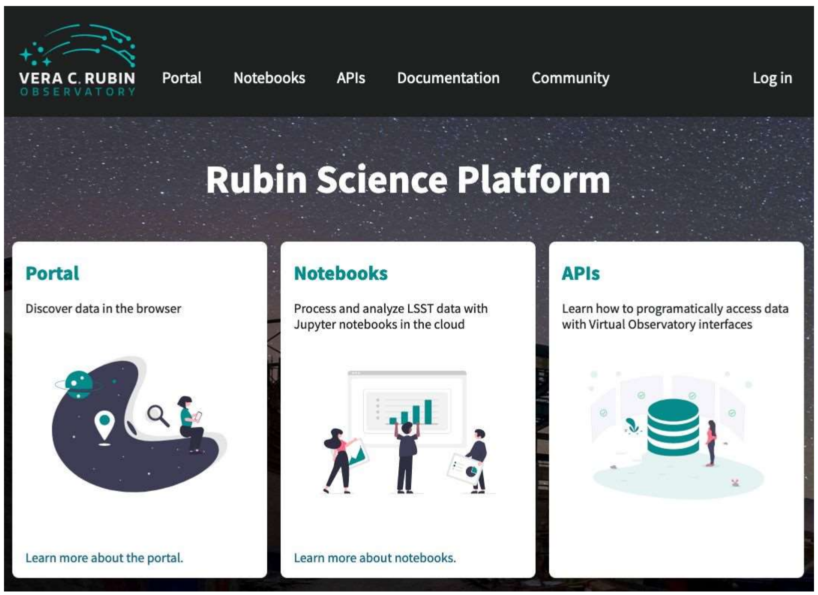
User-produced derived, added-value data products

- Deep KBO/NEO, variable star classifications, shear maps, etc …
- Enabled by services & computing resources at Rubin DACs and via the Rubin Science Platform (RSP).
- 10% of computing resources at the US Data Facility (USDF) will be allocated for User Generated data product storage & processing.

Rubin Science Platform (RSP)

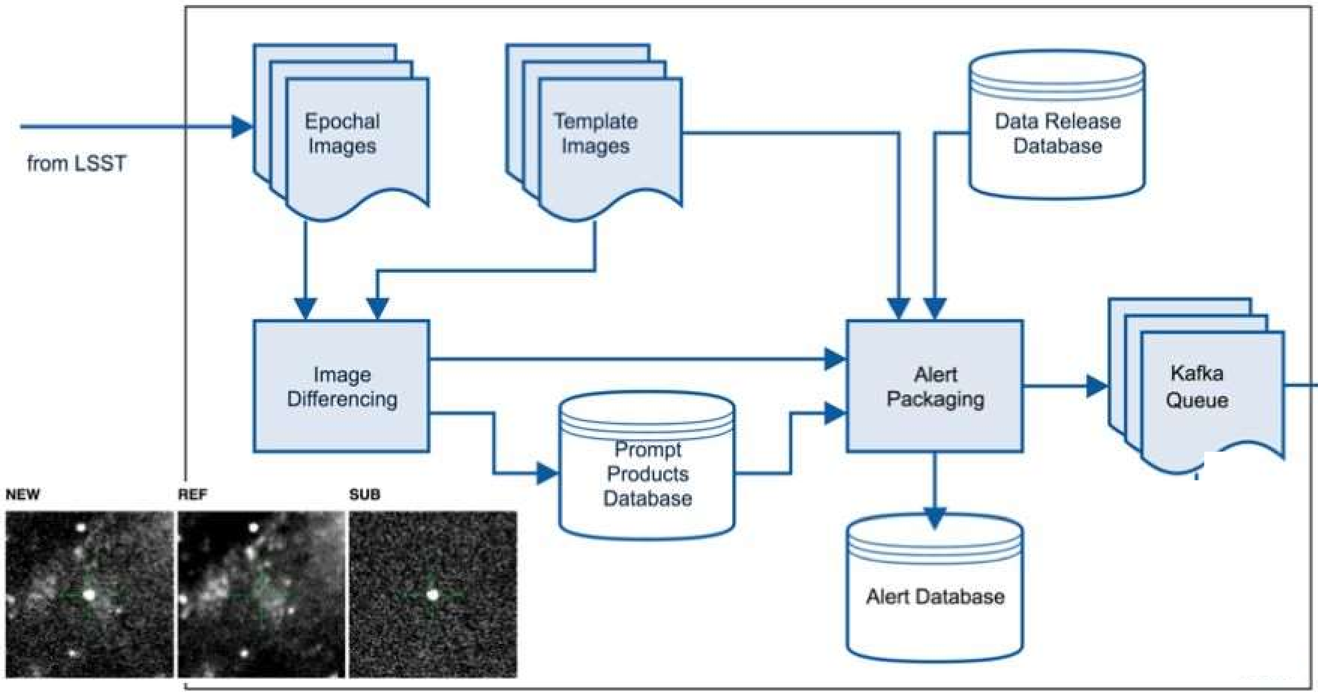
LSE-319: LSST Science Platform Vision Document

A set of integrated web applications & services deployed at Data Access Centers through which the scientific community will access, visualize, subset and perform next-to-the-data analysis of Rubin Data products.



- Enable peta-scale analysis of LSST data
- Exploratory analysis via browsing & visualisation
- Enable discovery –'bring the analysis to the data'
- Supports User-Generated product creation
- Integration with extant archives via IVOA protocols
- Collaborative working environment
- Provision of backend computation and analysis resources, ~1TB storage and 2 cores per user

Alert Distribution



Alerts are distributed to 7 full stream and 2 downstream third party community brokers

LASAIR ANTARES BABA·MUL Pitt FINK NAU

Discovery is only the start

The planned AEON network is a follow-up system that dynamically turns alerts into requested data

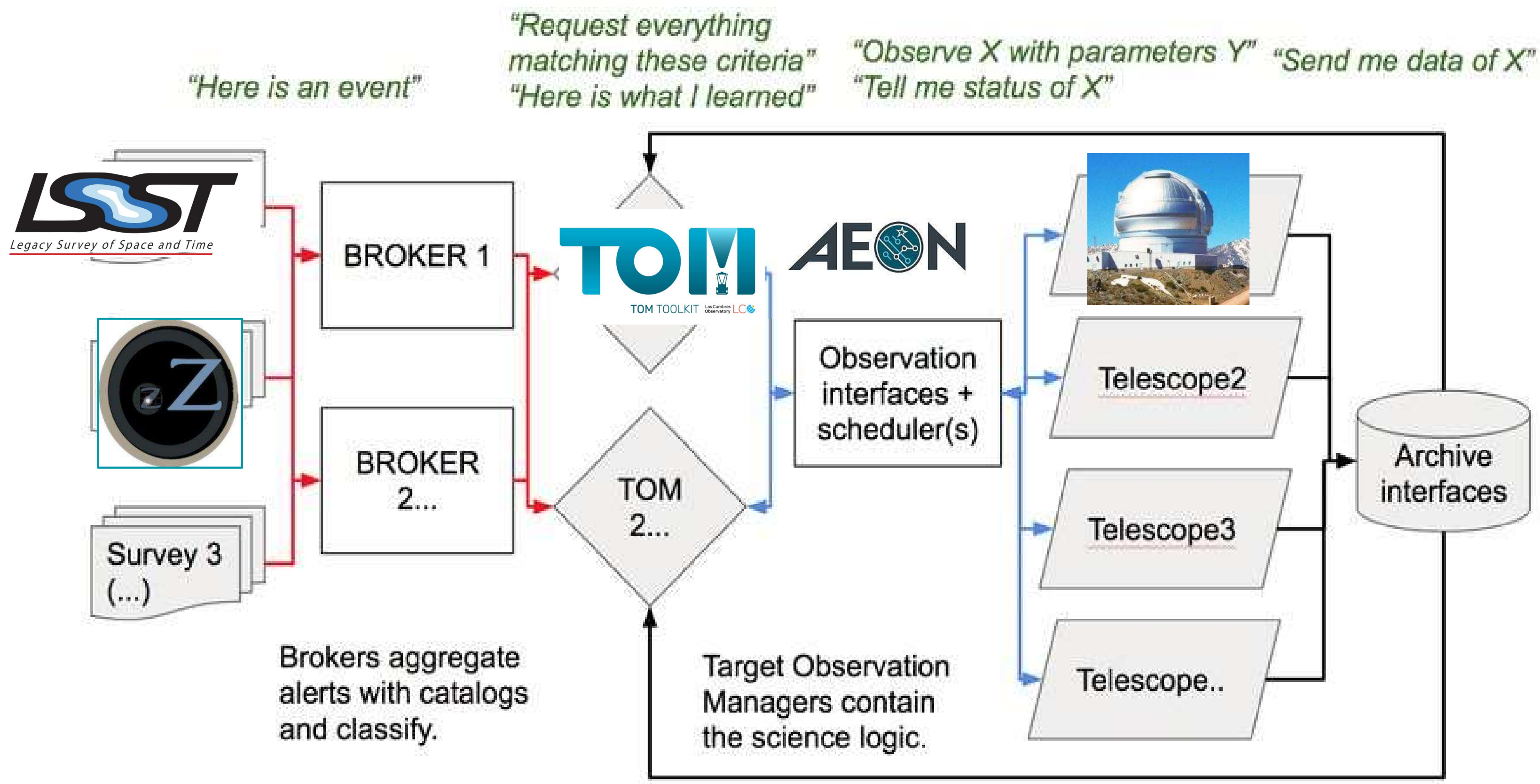
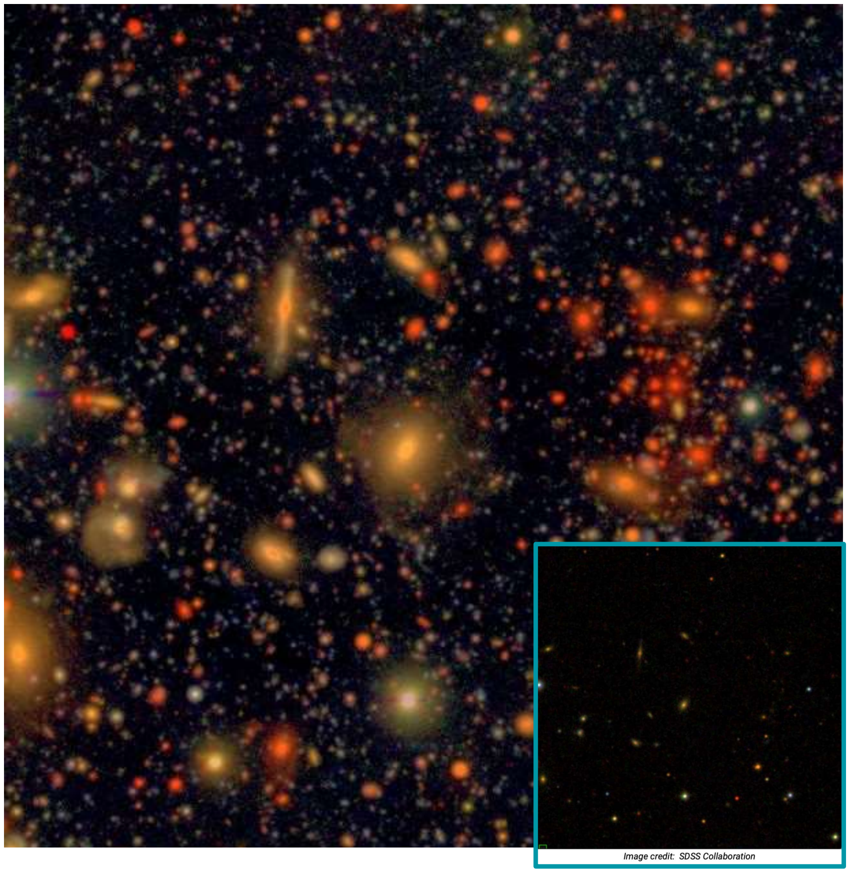


Figure Credit: Infrastructure and Strategies for Time Domain and MMA and Follow-Up, Miller, et al. (2019)

Everything is blended



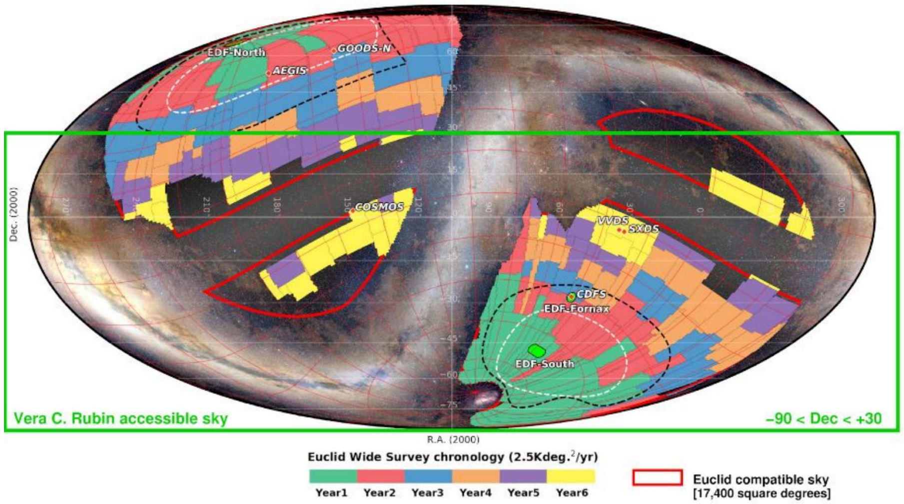
The COSMOS field seen by Hyper Suprime-Cam, courtesy of the HSC Collaboration, R. Lupton, and N. Lust.

- Everything is blended at LSST depths
- The combination of depth, area and throughput make processing uniquely challenging
- Hyper Suprime-Cam Subaru Strategic Survey Program uses an early version of the LSST Science Pipelines.
- Regular testing of algorithms on precursor datasets is crucial.

External Synergies

Combining densely sampled deep multiband optical imaging Rubin data with high spatial resolution near infrared space-based data from Euclid and the Nancy Grace Roman Space Telescope can enhance the scientific yield of all surveys

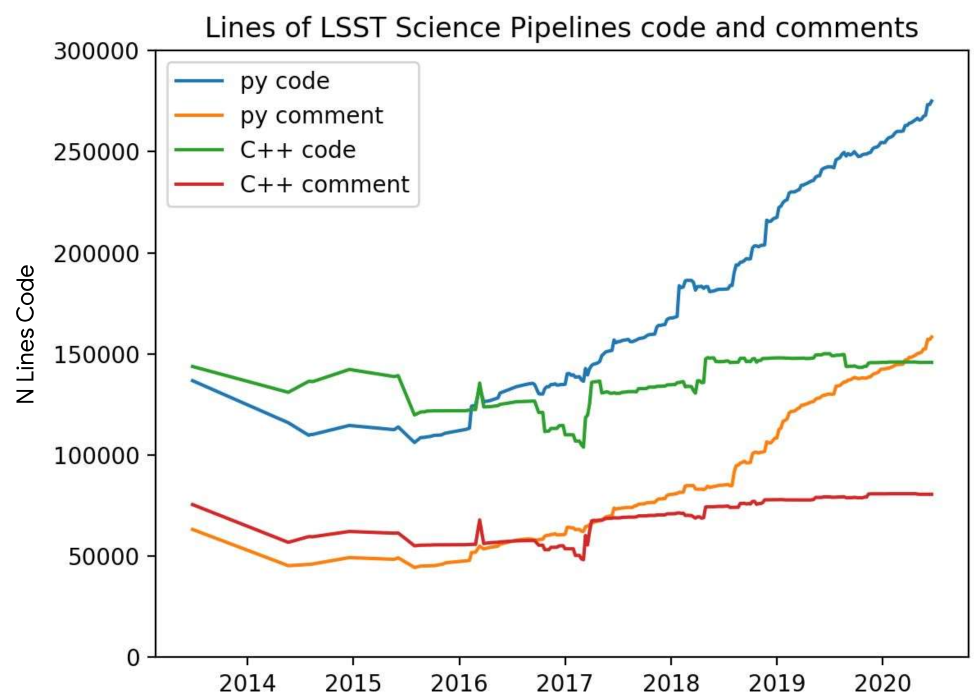
- Improved deblending at the faint end, leading to more accurate estimates for photo-z & galaxy count;
- Improved estimation of photometric redshifts through the generation of precise multi-wavelength catalogs;
- Reduced systematics such as source confusion and astrometric mismatch;
- Better star-galaxy separation;
- Improved supernova/host galaxy identification.
- Improved SSO discovery rates, orbit determinations, colorimetry, and light curves



Rubin-Euclid: overlap of ~9000 sq. deg. at high galactic latitudes

A big open source software project

- At the petabyte scale, software is a critical component of scientific discovery
- Software is critical for driving control systems, driving the scheduler, the processing of raw data products, etc
- Documentation & guidelines are essential
  - LSST developer guide,
  - Release notes
- All LSST software is free and open source (GPLv3) and available on github:https://github.com/lsst

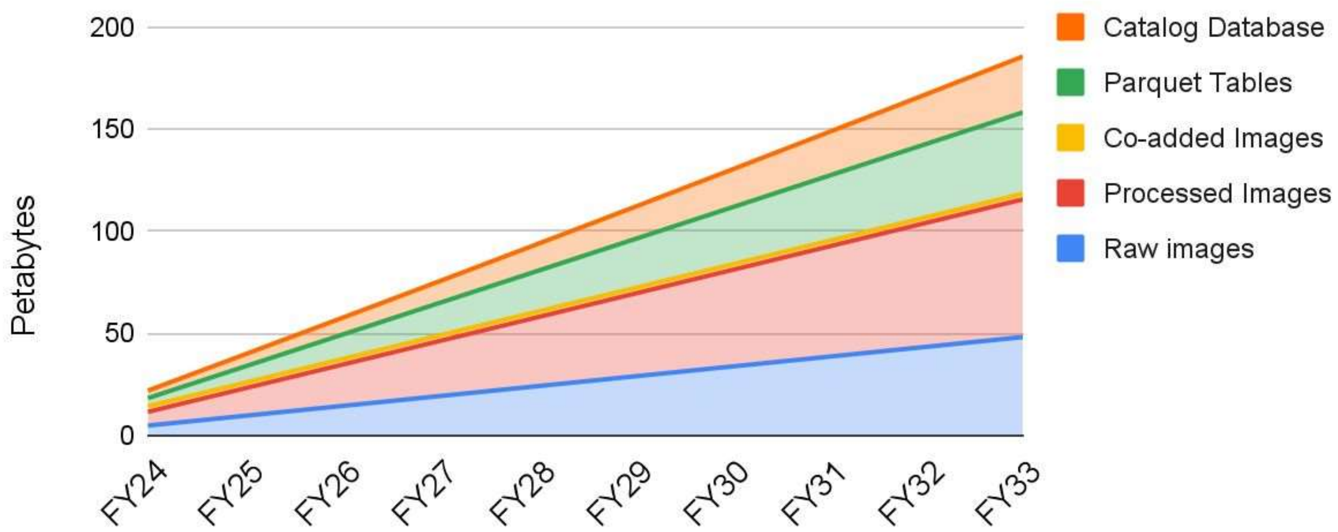


LSST Science Pipelines codebase
Figure Credit: Tim Jenness.

Slide credit: *W. O'Mullane*

20TB/night – growth in storage needs

Astronomy Data Reduction tends to increase data volume



300-500 PB data products

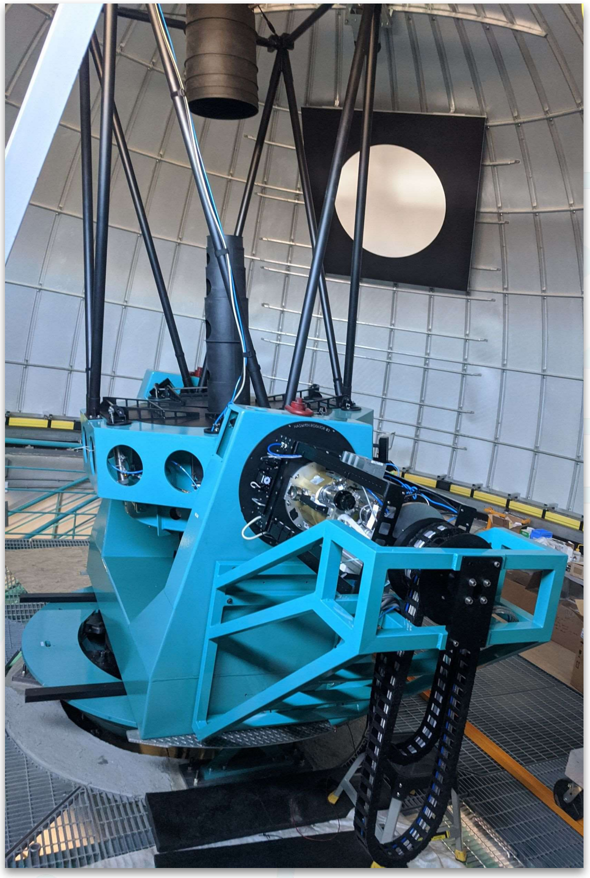
50-60 PB raw data

Details in DMTN-135

Commissioning Data Management

- AuxTel imaging surveys runs twice per month, ~3 nights
- DM routinely uses precursor data (Hyper Suprime Camera (HSC) and DESC Data Challenge 2 (DC2)), AuxTel imaging data and ComCam calibration data to develop and exercise the infrastructure needed to conduct on-sky observing campaigns, transfer data from summit, reduce data, and evaluate technical and science performance.
- All data processed by the LSST science pipelines and served at the USDF and used for verifying and validating science level requirements

AuxTel is great pathfinder for the Simonyi Survey Telescope commissioning and transition to operations



Night-time Ops Team Observing with AuxTel

Summit Control Room displays during an AuxTel run

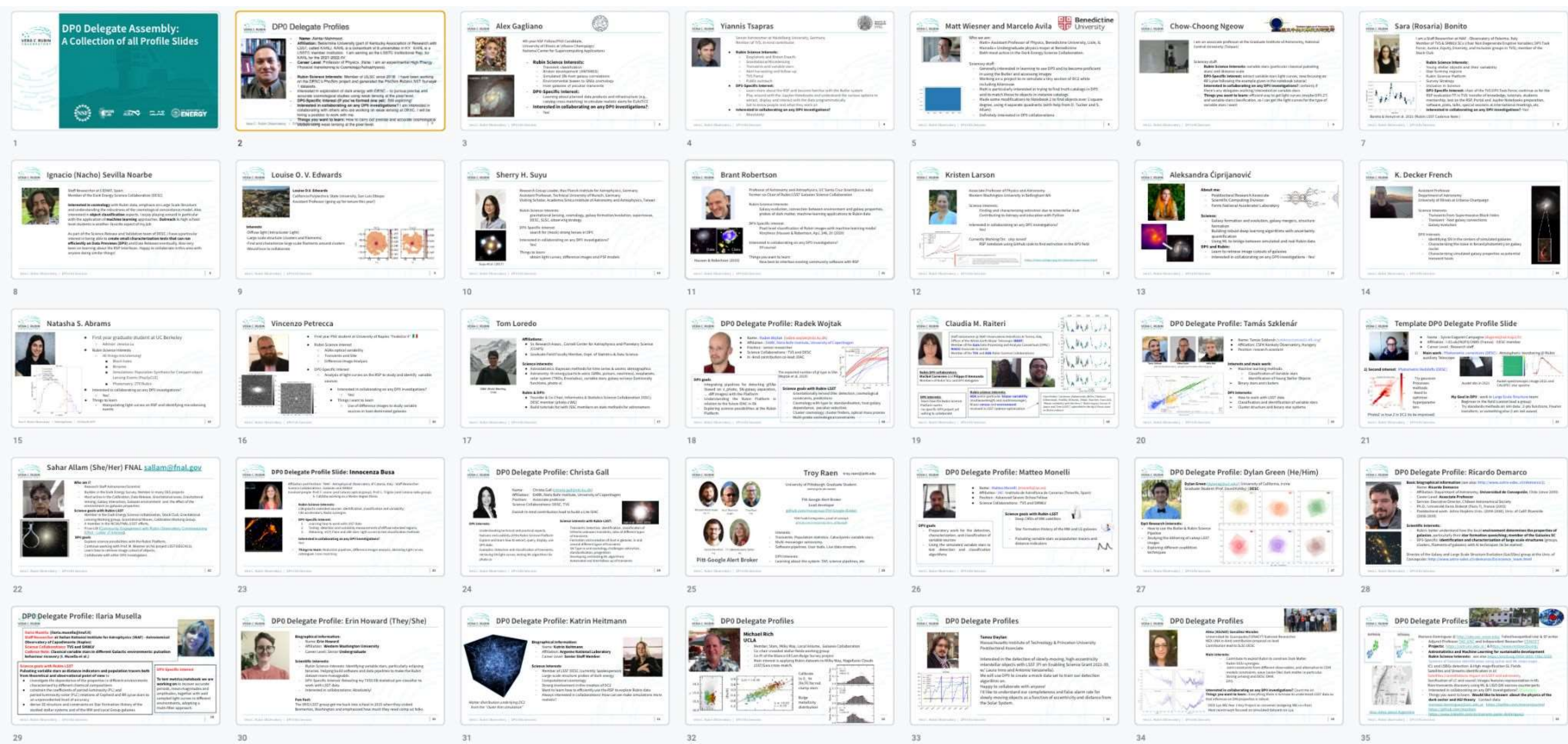
Rubin Data Previews

Rubin Observatory Operations will prepare both the community and itself by providing early data for science through a series of Data Previews (DPs)

Data Previews lead deliberately to Operations readiness through the systematic addition of data products and users at each stage.

- 3 planned Data Previews (DP):
  - DP0: Simulated data – Active since June 2021
  - DP1: A few nights of early LSSTCam data – late 2024
  - DP2: All science-grade LSSTCam commissioning data – late 2025
- Data Preview 0 split into three parts:
  - DP0.1: DESC DC2 -produced data products (June 2021)
  - DP0.2: Rubin reprocessed DESC DC2 data (June 2022)
  - DP0.3: Solar System simulated data (July -Sep 2023)
- 300 Delegates (users) gained access in June 2021 to DP0.1, a further ~300 in June 2022 for DP0.2

DP0.2: Community Science Contributions

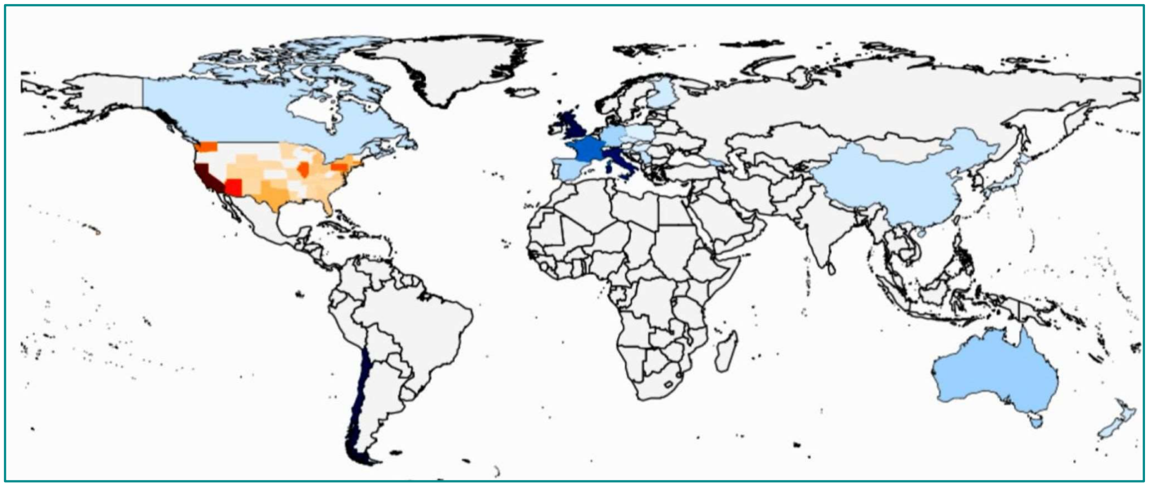


Over 50 delegates did flash talks for DP0.1 or DP0.2; these are just a few of their slides.

Slide credit: M. Graham

Rubin Community & Science Collaborations

Rubin/LSST presents a new regime not only in terms of its data volume and complexity, but also the **size and variety of its science community**.



>7500 people, 2500 affiliations, 6 continents, 33 countries

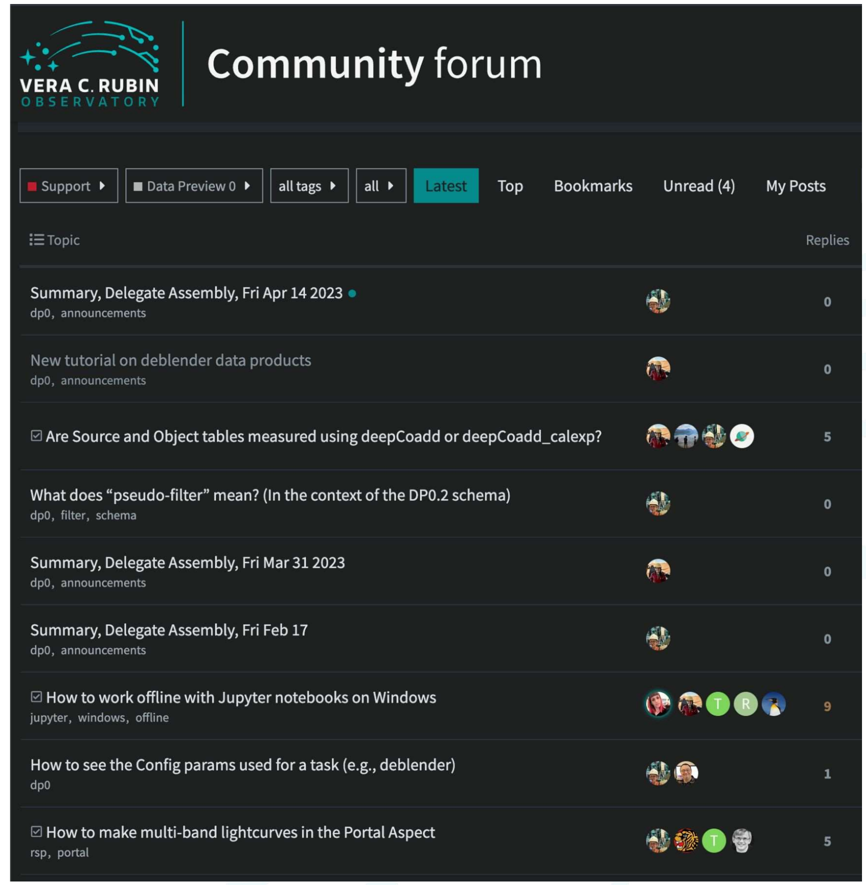
- AGN
- Dark Energy
- Galaxies
- Informatics & Statistics
- Strong Lensing
- Stars, Milky Way & Local Volume
- Solar System
- Transients & Variable Stars

Formed in 2008, Rubin Science Collaborations are 8 independent, worldwide communities of scientists, self-organized into collaborations based on their research interests and expertise.

Novel Community Science Model

Traditional models of user support will not scale to the size and variety of the Rubin science community.

Rubin's novel model for community science focuses on building and fostering a **vibrant diverse and inclusive community,** supported by infrastructure (Discource), that is able to help itself and to crowd-source solutions and build a deep reservoir of expertise.



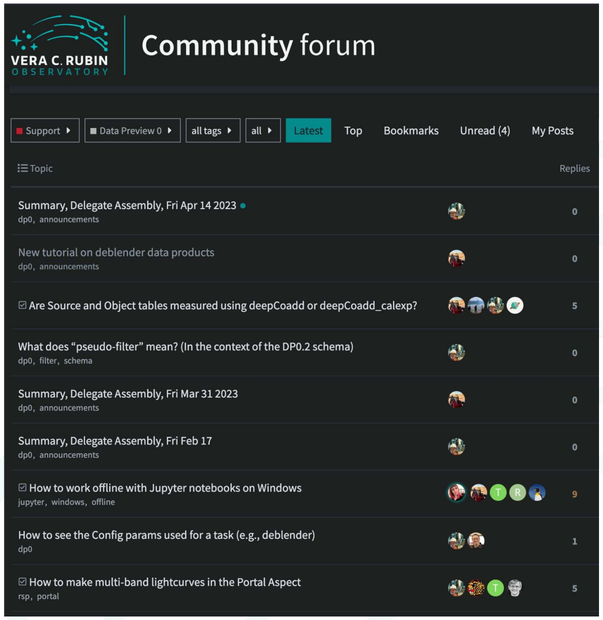
Community Interactions

Users Committee is charged with soliciting feedback from the community and recommending science driven improvements to the LSST data products and Rubin Science Platform (RSP). The committee reports to the Lead Community Scientist and Rubin Director. Charge: rdo-051.lsst.io

Liaisons with the Science Collaborations

TVS SSSC GalaxiesSC SMWLV DESC ISSC SLSC AGN

VERA C. RUBIN OBSERVATORY



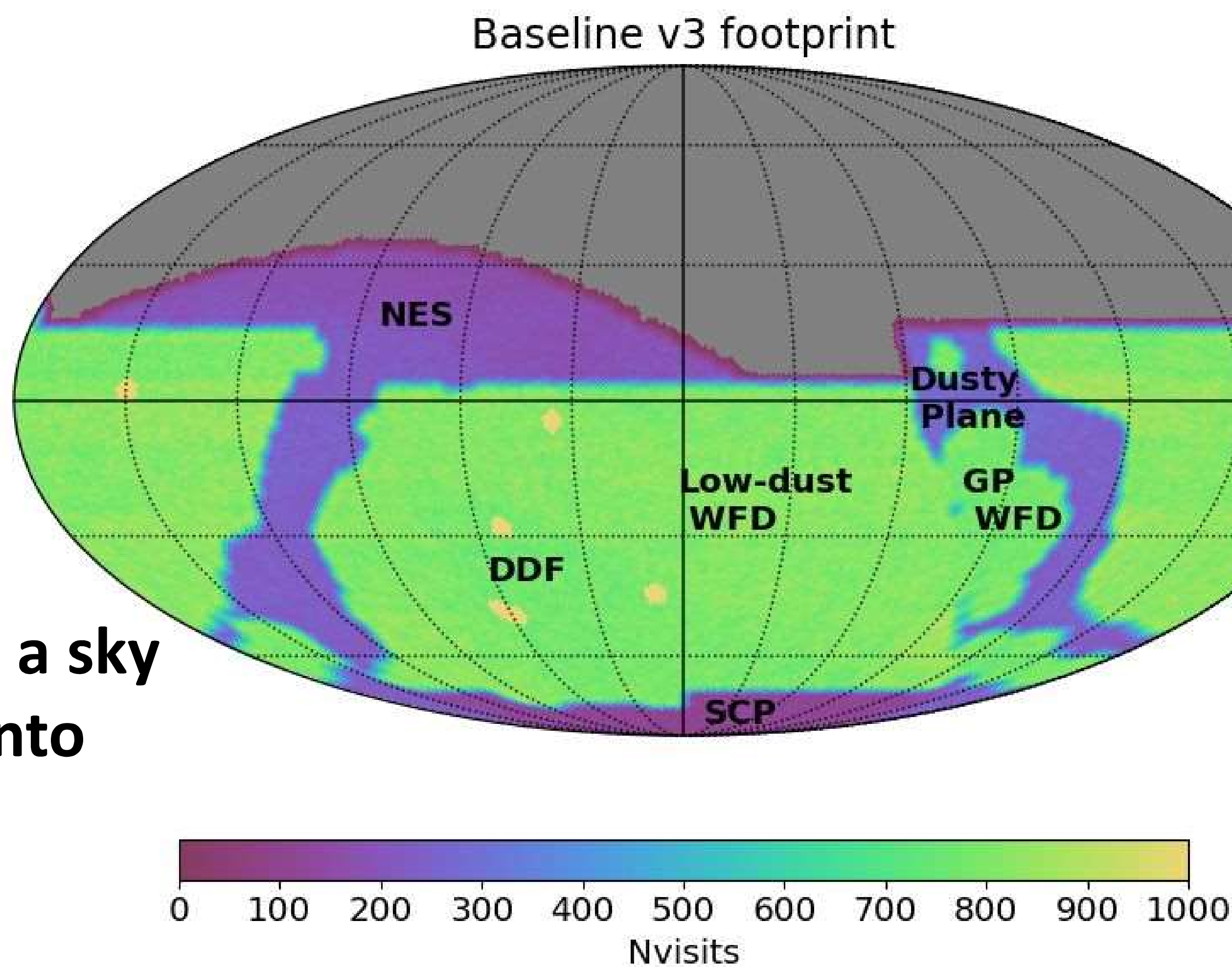
Survey Cadence Optimization Committee (SCOC) – advises on survey strategy to the Lead Survey Scientist and Rubin Director

Sustainable & scalable community science model aims to build a deep reservoir of knowledge by crowd sourcing solutions from thousands of LSST scientists

VERA C. RUBIN OBSERVATORY

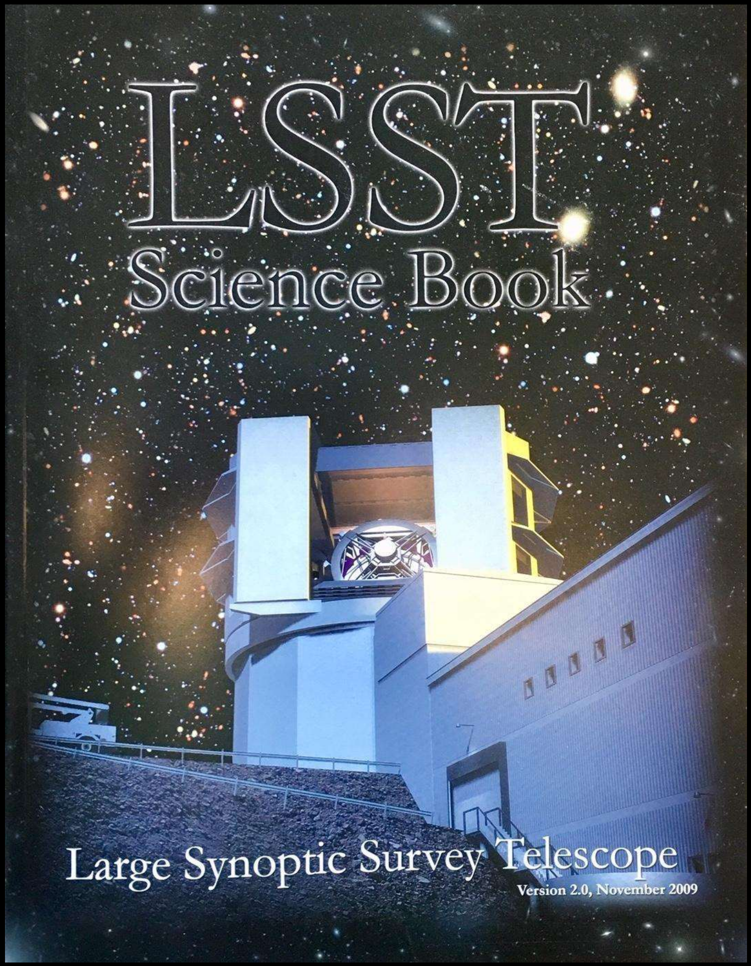
- Project Status
- Data to Science
- Science Opportunities & LEO Satellites

NSF AURA U.S. DEPARTMENT OF ENERGY SLAC CHARLES AND LISA SIMONYI FUND FOR ARTS AND SCIENCES LSST CORPORATION



30 sec visits to a sky location split into two 15 sec exposures

Many exciting science programs



Unprecedented sample sizes:
Tens of billions of objects in space and time

Ability to search for rare objects.

New paradigm:
Systematics limited science

- LSST will probe the sky in new ways for dynamic events, to unprecedented faintness.

- Not limited by statistics! Discovery frontier is at the tail of this distribution: *rare objects and rare faint events*

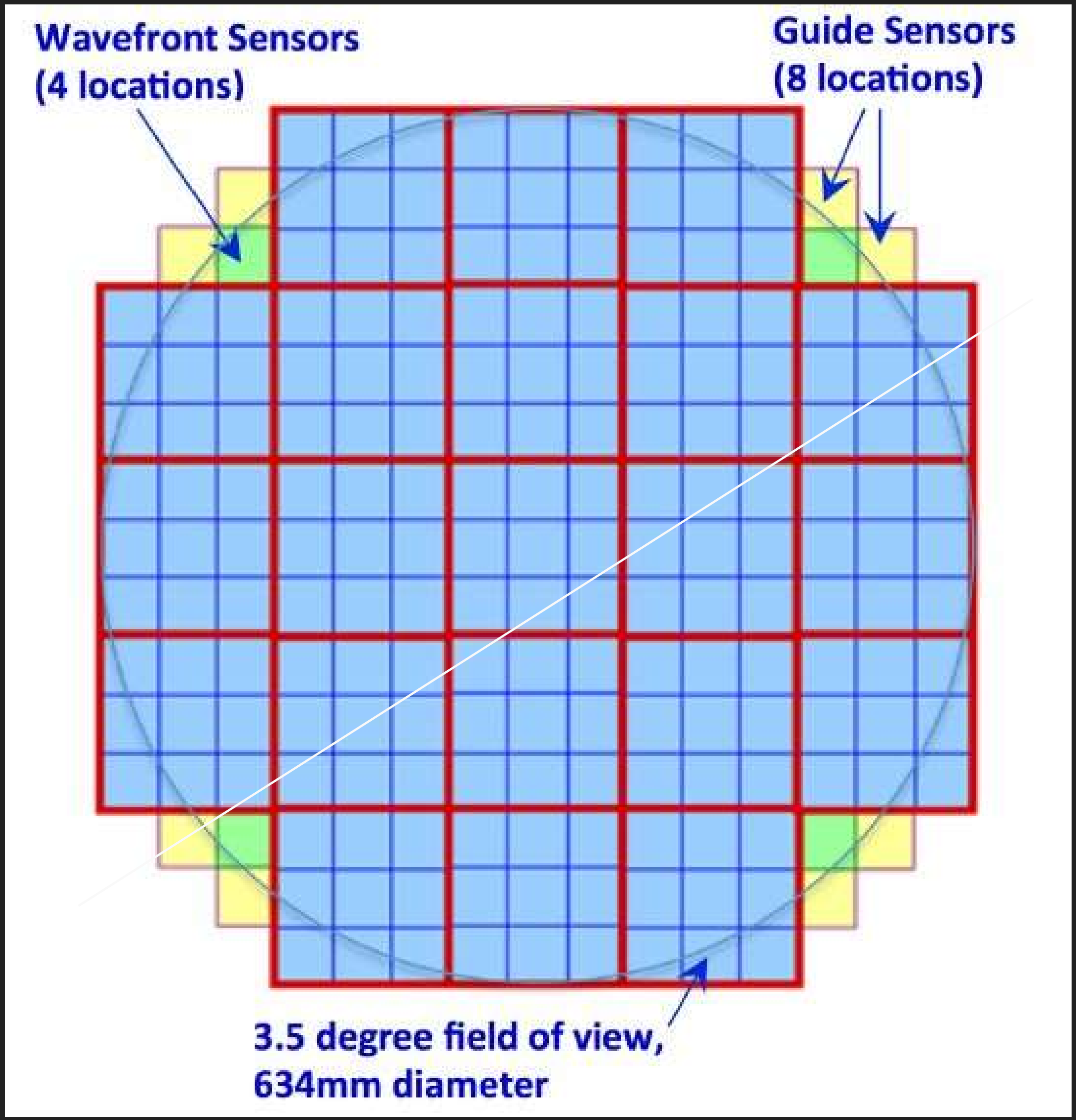
Automated discovery and data exploration

DISCOVERING
THE
UNEXPECTED

Rubin's potential for discovery is also its vulnerability to Low Earth Orbiting satellites

LEOsat Mitigation Challenges

- Streaks
    - CCD non-linear crosstalk
    - Streak masking residuals
- Variability & Glints
- Bogus events
- Brightness mitigations by industry



189 CCDs

Each CCD is split into 16 segments, each with its own output amplifier

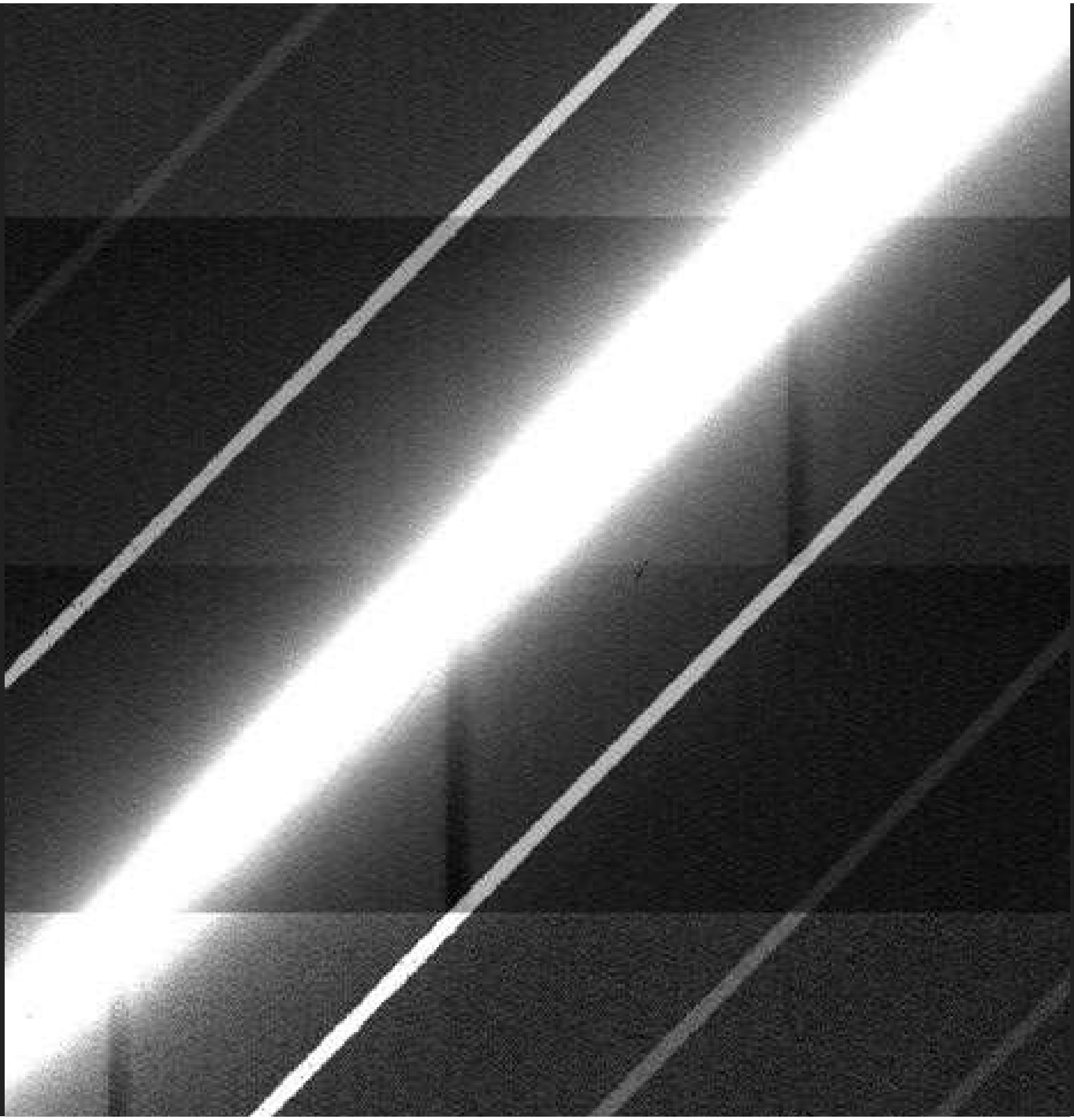
3024 channels

Individually tuned and calibrated

Bright satellite trail in the Rubin Observatory camera induces image artifacts

Electronic crosstalk between output amplifiers on 16 segments

Non-linear with intensity!

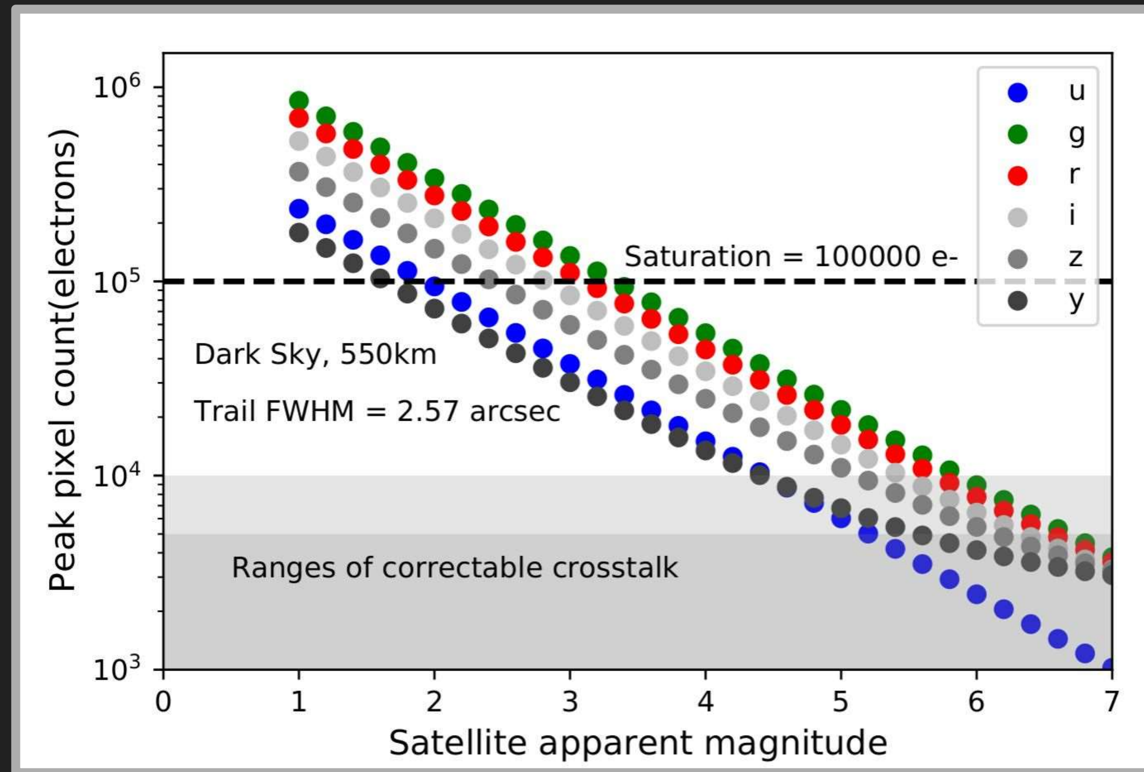


Correctability vs Flux

A non-linear crosstalk algorithm must correct to several electrons precision in 100 frame co-add.

At 6.5 *g* mag, a 10% error on any crosstalk coefficient could create a false faint galaxy image in a co-add.

Clearly, fainter satellites are needed



Crosstalk nonlinear in intensity -> million parameters to calibrate!

- SpaceX is working with the astronomical community to reduce the light pollution effects on optical astronomy
- Making the spacecraft 10 times darker enables removal of most satellite trail crosstalk residuals in the LSSTCam
- However, *even if that works*, evidence of the main satellite trails will clearly be in the data – complicating data analysis, and limiting discoveries

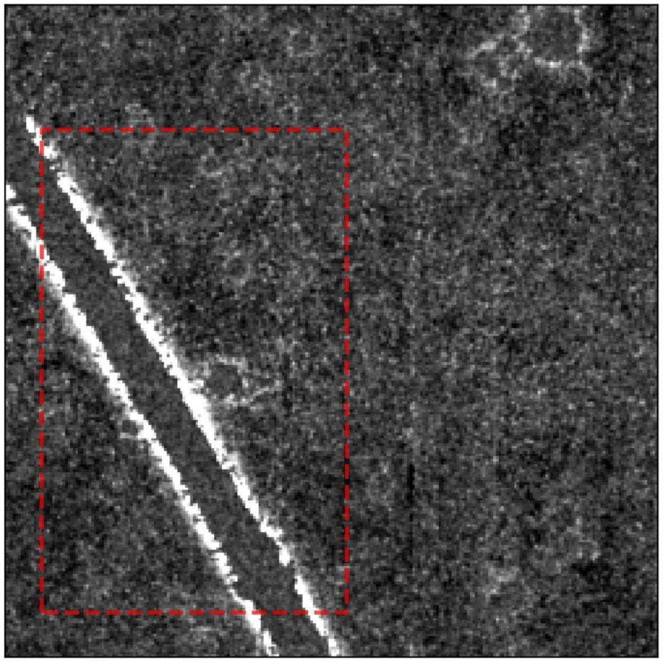
http://ls.st/satcon

Masking Satellite Trails

Incomplete masking of satellite trails can cause systematic effects in static sky and time-domain science:

- Residual spill-over light.
- Lines of “bogus galaxy detections”.
- Bogus alerts.

- Challenges: LEOsat trail brightness varies with time, and trail detection is not 100% complete. *Tail of distribution!*



Satellite trail in a Blanco DECam coadd image masked using a 40-arcsecond wide mask.
Hasan et al (2022)

Direct-to-cell

AST-SpaceMobile

Bluewalker3
small scale
prototype.

Direct-to-cell

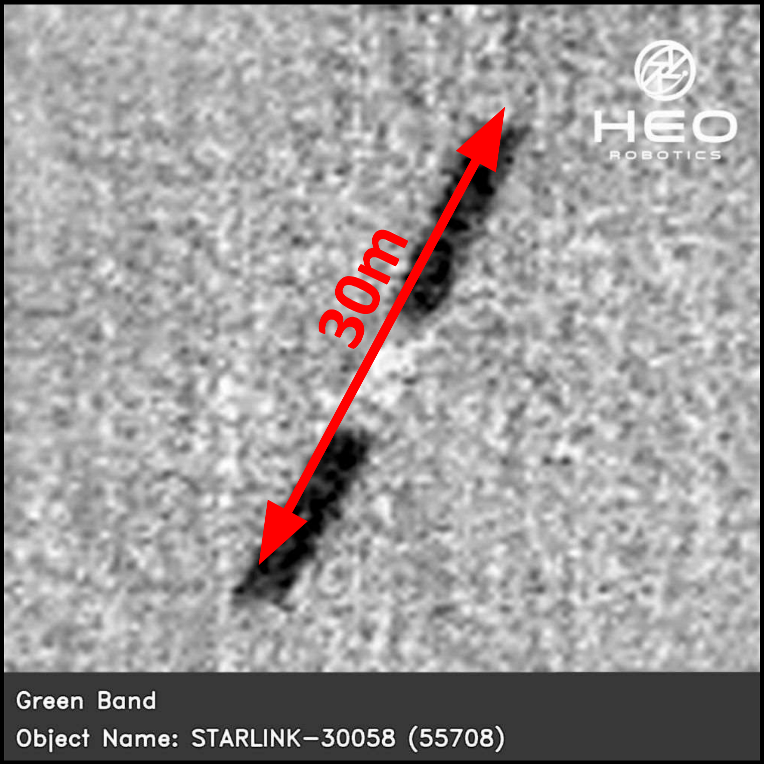
AST-SpaceMobile

Direct-to-cell is now attracting billions $ investment and strong telco support

Bluewalker3 small scale prototype.

Direct-to-cell

Starlink V2-mini



Starlink V2 is 50m long.

Summary

- Possibly 10% lost etendue if we avoid exposing on bright satellites.

- However: Science impact at tails of distributions.
  Rare detections.   Rare alerts.
- Impact on Rubin science depends on science goal.
- Undertake full science simulations with systematics.
- Working with SpaceX on brightness: ConOps + scattered light simulations.

Rubin Observatory's mission is to build a *well-understood* system that will produce an unprecedented astronomical data set for studies of the deep and dynamic universe, make the data widely accessible to a diverse community of scientists, and engage the public to explore the Universe with us.

NATIONAL ACADEMIES *Sciences Engineering Medicine*

Condensed Matter and Materials Research Committee

2023 Status Update

Tom Witten (University of Chicago), Committee Chair

1

Committee charge, Core elements

"…The CMMRC plans and develops prospectuses for studies and other activities (e.g., workshops), which are to be carried out by separately appointed ad hoc committees/panels and can result in NRC reports. Such reports may contain assessments of research areas with recommendations aimed at facilitating scientific progress in the forefront areas of research in these fields [i.e., condensed matter science and materials research]…"

Slide 2

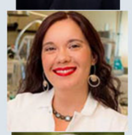
1 We serve the National Research Council in its mandate to maintain active, impartial awareness across condensed matter and materials research, to guide decision making and also to promote the dynamism of this research community.
To this end we sponsor a series of workshops, each highlighting a promising and under-appreciated topic of its choosing.
We also consider other ways in which our expertise can serve the committee's charge. One way is to alert the NRC about issues impacting condensed matter science. Another way is to devise visible ways to listen to the community.
Thomas Witten, 4/26/2023

Membership

Tom Witten
University of Chicago

Raymundo Arroyave
Texas A&M University

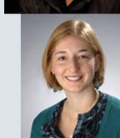
Olivia A. Graeve
University of California, San Diego



Samson A. Jenekhe
University of Washington

Anthony Ku
Independent

Lisa Manning
Syracuse University



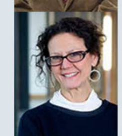
Charles Marcus
University of Washington

Nadya Mason
University of Illinois at Urbana-Champaign

Leslie Momoda *Incoming chair 7/1/23*
HRL Laboratories

Jagdish Narayan
North Carolina State University

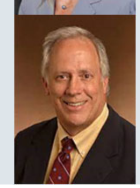
Monica Olvera de la Cruz
Northwestern University



Ana Maria Rey
University of Colorado

Jill E. Seebergh
The Boeing Company

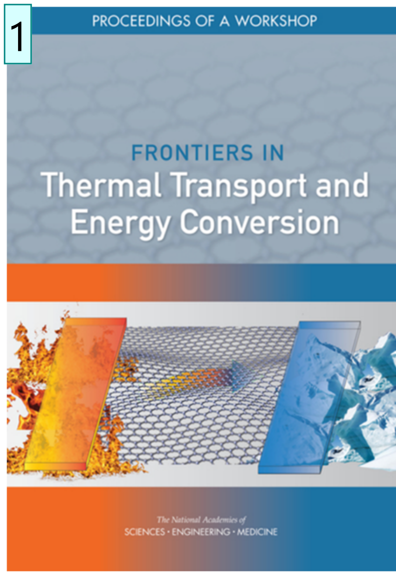
Steven J. Zinkle
The University of Tennessee, Knoxville



Activities and Products: workshops

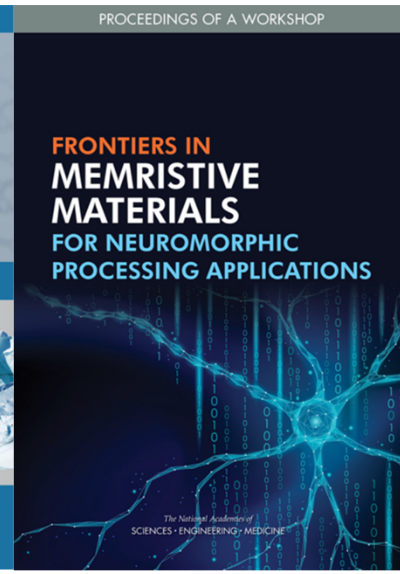
The primary activity of the CMMRC is to choose and host annual topical workshops that merit increased awareness

- Sponsors: DOE, NSF
- Topics are proposed by committee members, then chosen with sponsor input
- an ad-hoc committee organizes it
- Successful online and in-person engagement for four years



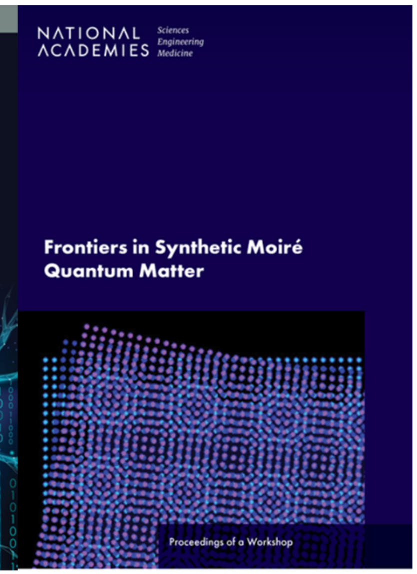
April 2019

69 reg. participants



February 2020

163 reg. participants



May 2021

405 reg. participants

NATIONAL ACADEMIES *Sciences Engineering Medicine*

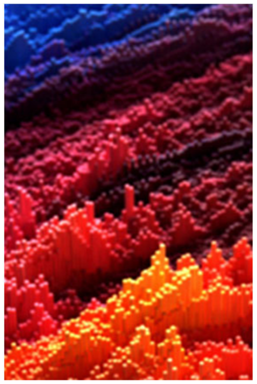
Slide 4

1 Dig up participation or registration for these, if possible
Chris Jones, 4/26/2023

Activities and Products: workshops

The primary activity of the CMMRC is the review and selection of exciting annual topical workshops with growing scientific merit.

- Sponsors: DOE, NSF
- Topics are proposed by committee members, then chosen with sponsor input
- Successful online and in-person engagement for four years

Oct 2022	2023	2024
 Publication soon*	Topic chosen, formal proposal in progress	Initial suggestions gathered

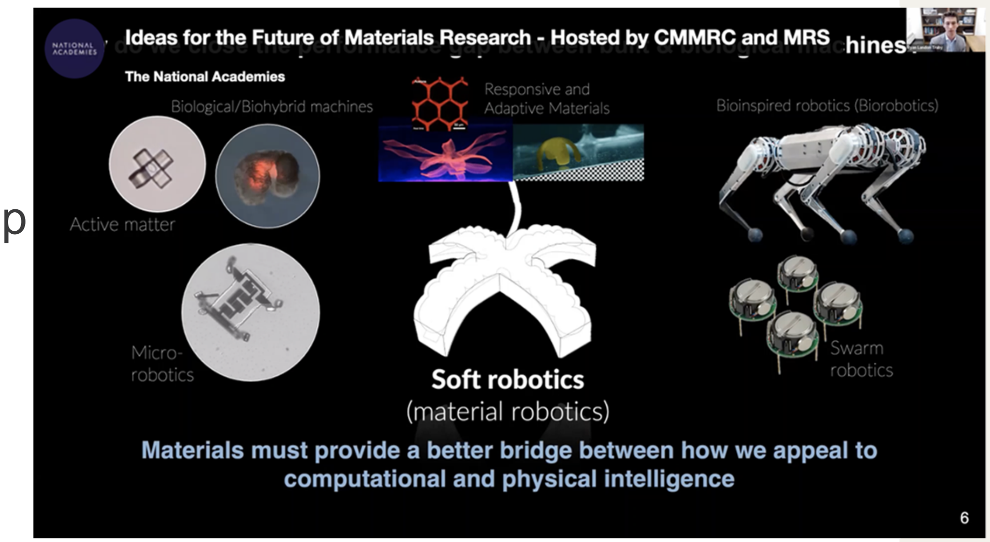
400 participants

*"Frontiers in Data Analytics and Monitoring Tools for Extreme Materials"

Community engagement: listening events

Events to hear and recognize novel research ideas by early-career scientists

- We jointly host a ~90-minute session with eg Materials Research Society
  - Early-career members propose a talk pitching a new research direction.
  - Committee evaluates and selects talks for the session, hosts session and questions
- Initial event held by Zoom April, 2022
  - 300+ webinar registrants, 5 intriguing pitches
  - One pitch was a finalist for the 2023 workshop
- MRS Executive Director is keen to continue this year



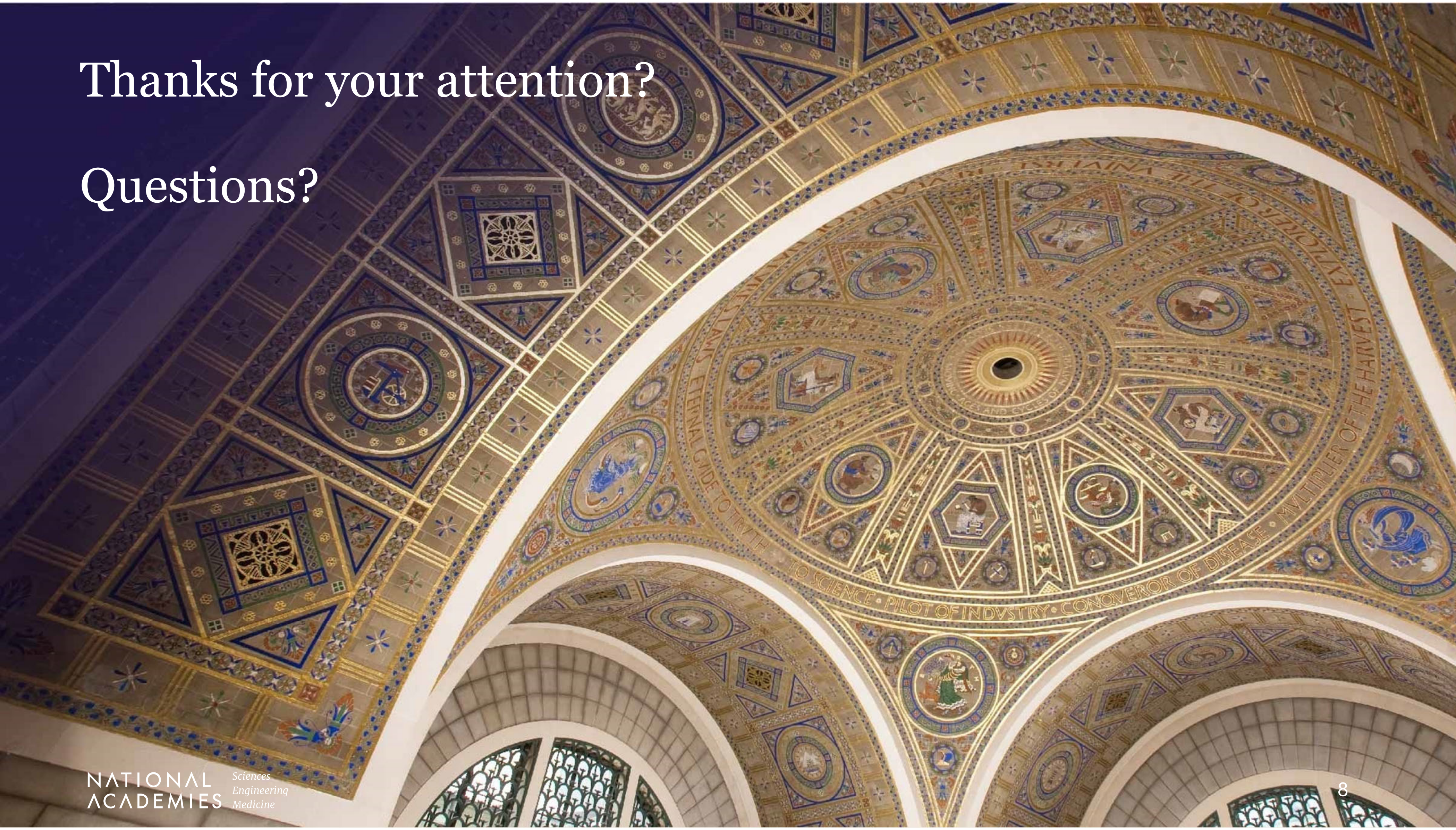
Potential study topics

We considered societal topics that may warrant a NASEM study

1. **National Quantum Initiative (NQI) assessment:**
   - Is the National Quantum Initiative fulfilling its goals optimally?
   - An impartial review by involved scientists, policy makers, stakeholders
2. **Big Data Infrastructure for Condensed Matter and Materials Research**
   - Plans to unify materials data have made limited progress
   - What should be our expectations in light of analogous efforts elsewhere?
3. **CHIPs Act items, Semiconductors**
   - Survey of basic-science routes to enhance our competitiveness
4. **Helium Scarcity and Cryogenics** *(He3 but also He4)*
   - What are our prospects for low-temperature science in a world of scarce He?

Thanks for your attention?

Questions?



1. National Quantum Initiative (NQI) assessment

- NASEM adds value:
  - keeps NQI relevant, brings attention to NQI, also, better to commission us than have congress do it

- Similar to Academies National Nanotechnology Initiative (NNI) review

- Review to add insight about how well the initiative has gone.

- Lessons learned can be used for the chips-in-science initiative.

NATIONAL ACADEMIES Sciences Engineering Medicine

2. Big Data Infrastructure for Condensed Matter and Materials Research

- Some on committee believe becoming more important than ever.
- Exchange of data is not a trivial effort.
- Not only a materials science-related issue.

3. CHIPs Act items

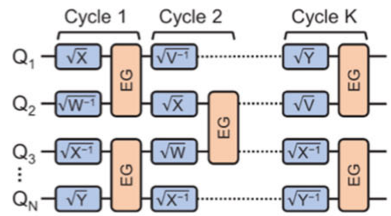
- Looking at how new physics might help overcome traditional semiconductor issues.

- New physics and material can be helpful in advancing chip capabilities.

4.Helium Scarcity and Cryogenics

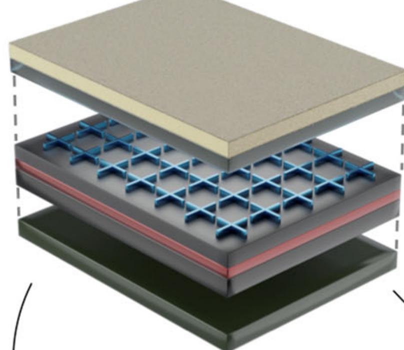
(He-3 but also He-4)

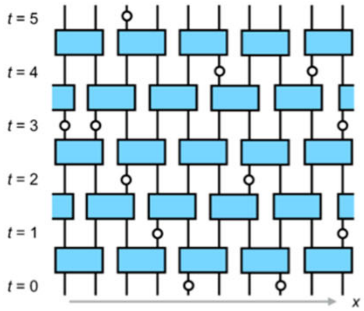
- Persistent issue adversely affecting users of helium.
- No one federal agency has sole jurisdiction or controls the usage of the helium supply.
- Academies is well-suited to convene a variety of agency representatives experts to follow-up, hear opinions, and weigh in on the issue



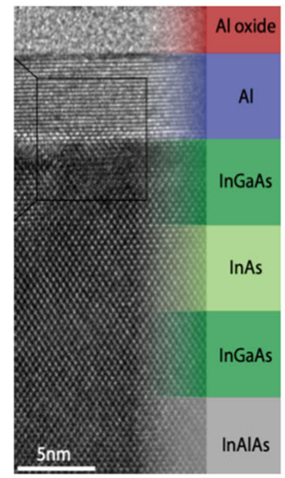
X. Mi (Google Team), *Information Scrambling in Quantum Circuits*, Science **374**, 1479 (2021). K. J. Satzinger (Google Team), Realizing topologically ordered states on a quantum processor. Science 374, 1237–1241 (2021).

Coherent Networks

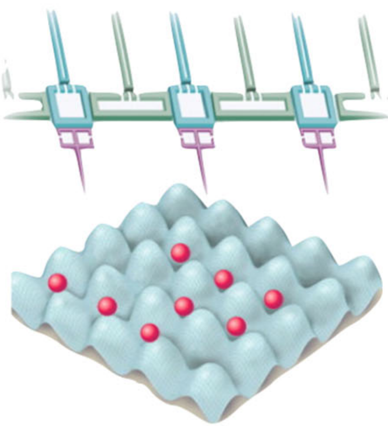




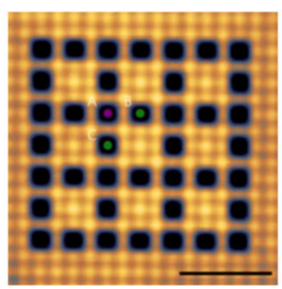
Y. Li, X. Chen, and M. P. A. Fisher, *Measurement-Driven Entanglement Transition in Hybrid Quantum Circuits*, Phys Rev B **100**, 134306 (2019).



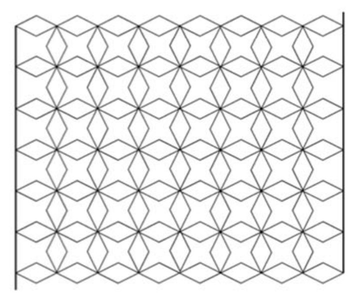
J. Shabani, *et al. Two-Dimensional Epitaxial Superconductor-Semiconductor Heterostructures: A Platform for Topological Superconducting Networks*, Phys Rev B **93**, 155402 (2016).



I. Buluta and F. Nori, Quantum Simulators, Science 326, 108 (2009); E. Altman, *Quantum Simulators: Architectures and Opportunities*, PRX Quantum **2**, (2021).



R. Drost, *et al. Topological States in Engineered Atomic Lattices*, Nat Phys **13**, 668 (2017).



B. Douçot, L. B. Ioffe, Physical implementation of protected qubits. *Rep Prog Phys* 75, 072001 (2012).