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# Cosmic Frontier Strategic Plan Briefing

Josh Frieman, Brenna Flaugher, Andrew Sonnenschein

Dec. 19, 2018

# FNAL Cosmic Planning Process

- We have undertaken a 3-phase strategic planning process for our Cosmic Frontier (CF) program this year:
  - **Phase 1**: identify core capabilities that the laboratory provides to the OHEP Cosmic Frontier program;
  - **Phase 2**: identify the major CF activities the lab should pursue over the next 5-10 years, that exploit these capabilities, align with OHEP/P5 priorities, deliver on our commitments, and maximize scientific impact;
  - **Phase 3**: implement *focused* plan by sensibly directing effort from activities not deemed essential in the first two phases, to build our future program.
- Focus of this briefing is to present & get feedback on the plan elements. Written plan will follow in early CY19 to fulfill FNAL PEMP Notable for FY19:
  - "Working with OHEP, and taking into account Laboratory Optimization guidance, deliver and begin to implement a Cosmic Frontier Strategic Plan by March 2019 that builds on the laboratory's core capabilities in this area."

# FNAL Cosmic Planning Steering Group

- **CMB:** Brad Benson, Brenna Flaugher
- **Dark Matter:** Juan Estrada, Lauren Hsu, Hugh Lippincott, Andrew Sonnenschein, with input from Gordan Krnjaic
- **Cosmic Surveys:** Alex Drlica-Wagner, Josh Frieman
- **Astro Theory:** Dan Hooper
- This group has been meeting weekly since mid-summer to discuss thrusts and scenarios and draft the plan. Feedback received from FNAL astro colleagues 3 weeks ago.
- **Goal**: review the current cosmic portfolio and lay out a *focused,* compelling, world-class program of R&D, project construction, operations, science analysis, and theory that optimally exploits the lab's capabilities and builds on its strengths, and *set relative priorities in different funding scenarios*
- We expect the plan to continually evolve and be flexible in response to changing priorities & opportunities.

# FNAL Current Cosmic Activities

- Plan is based on addressing P5 science drivers: 
  - Understand cosmic acceleration (inflation and dark energy)
  - Pursue physics of neutrinos
  - Pursue new physics of dark matter
- Partnering with labs & universities on near-future program:
  - Dark Energy/Surveys: DES operations, DESI construction, LSST operations
  - Dark Matter: G2 experiments SuperCDMS, LZ, ADMX
  - Inflation, neutrinos, dark sector: SPT-3G, CMB-S4
  - Innovative R&D program that seeds future projects
- Astro theory program supports and stimulates these efforts
- Cosmic program (not just Cosmic Research) is ~3.5% of the lab budget.
  - Supported ~24 FTEs (Sci+PD) on Cosmic Research in FY18
  - Additional support (9.6 FTE) from Detector R&D, experiment operations, LDRD, Early Career Awards, Quantum, Theory, and private & international sources: **the program is highly leveraged and serves a large user community**

# FNAL Core Capabilities for the Cosmic Frontier

## *leverage investments in Energy and Intensity Frontiers*

- Precision assembly, integration, and test facilities at SiDET → IERC
- Underground facilities (on- and off-site, e.g., NEXUS, plus experience at SNOLAB, Homestake, Soudan, LNGS, SURF)
- Cryogenic engineering & operations (K and sub-K)
- Detector R&D and integration expertise
- Liquid noble gas detectors
- Front-end electronics and RF engineering
- Low-background test facilities & materials expertise
- Superconducting magnets & detectors
- Quantum sensors, Quantum computing, and AI/Machine Learning
- Large-scale computing for HEP experiments
- Design, construction, and operation of cosmic surveys
  - including advanced data processing and handling
- Project management for construction & operations
- Theoretical Astrophysics and Cosmology theory
  - Dark sector phenomenology, cosmic surveys, CMB, numerical cosmology




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# Current Cosmic Frontier @ FNAL

Dark Energy | Dark Matter | CMB

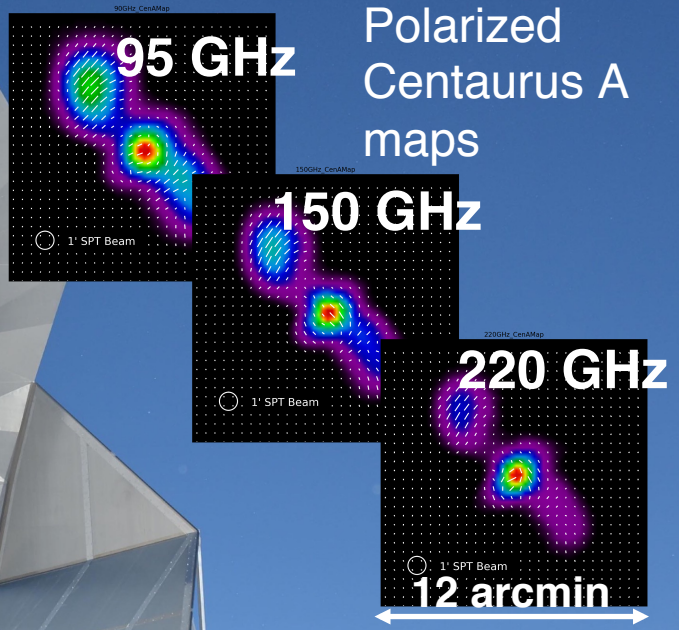
| Dark Energy | FNAL roles | FNAL capabilities |
|---|---|---|
| DES | Project management, detector test & integration, ops management, calibration, science, collaboration leadership, computing, data management & database | Detector testing, assembly & integration at SiDet; survey design & ops; data mgmt; project mgmt |
| DESI | Detectors, corrector support, science, online database, fiber to target translation | Detector packaging, testing, assembly at SiDet; survey design & operations, active optics software, commissioning |
| LSST | Dark Energy Science framework, survey operations & strategy, data management | Survey operations, computing infrastructure, computing operations |
| **Dark Matter** | **FNAL roles** | **FNAL capabilities** |
| SuperCDMS | cryogenics, electronics, operations, calibration, data analysis/science, project management | Precision assembly, testing; underground facility (NEXUS); cryo engineering; project management |
| LZ | TPC engineering, process control, science | Cryo and process control engineering |
| ADMX | RF cavity development, operations management, science, Quantum sensors | RF engineering; test & assembly at SiDet; Quantum sensors; magnets; ops management |
| Skipper CCD R&D | dark matter search (SENSEI), R&D for applications to dark matter/neutrino expt's & large scale surveys | Detector R&D expertise; SiDet facility |
| **CMB** | **FNAL roles** | **FNAL capabilities** |
| SPT 3G | Cryostat, detector packaging and FP design, testing, integration, camera installation, operations lead | Detector test, assembly, integration at SiDet; operations management; detector electronics; project management |
| CMB S4 | R&D, design, electronics, integration, management | |

# Elements of the Plan

- Cosmic Microwave Background (inflation, neutrinos)
  - SPT 3G lead operations → CMB Stage 4 leading/major roles
- Dark Matter Detection
  - Axions: lead ADMX operations and upgrades, develop Quantum sensors to cover broader mass range in next-generation experiment
  - Light Dark Sector Particles (sub-GeV DM)
    - SuperCDMS construction, operations, R&D
    - Skipper CCD R&D and deployment/scale-up
  - Ramp down LZ effort when deliverables completed
  - Concept & motivation for accelerator-based experiments & engineering support for DarkSide/LAr (neither supported by Cosmic Research)
- Cosmic Surveys (cosmic acceleration, dark matter)
  - DES → LSST operations (w/ small but critical role in DESI operations)
  - R&D toward future southern spectroscopic survey (LDRD)
- Astro Theory program w/ growing focus on cosmic neutrinos
- Cosmic Physics Center
- *These activities flow from P5 themes and from our core capabilities.*

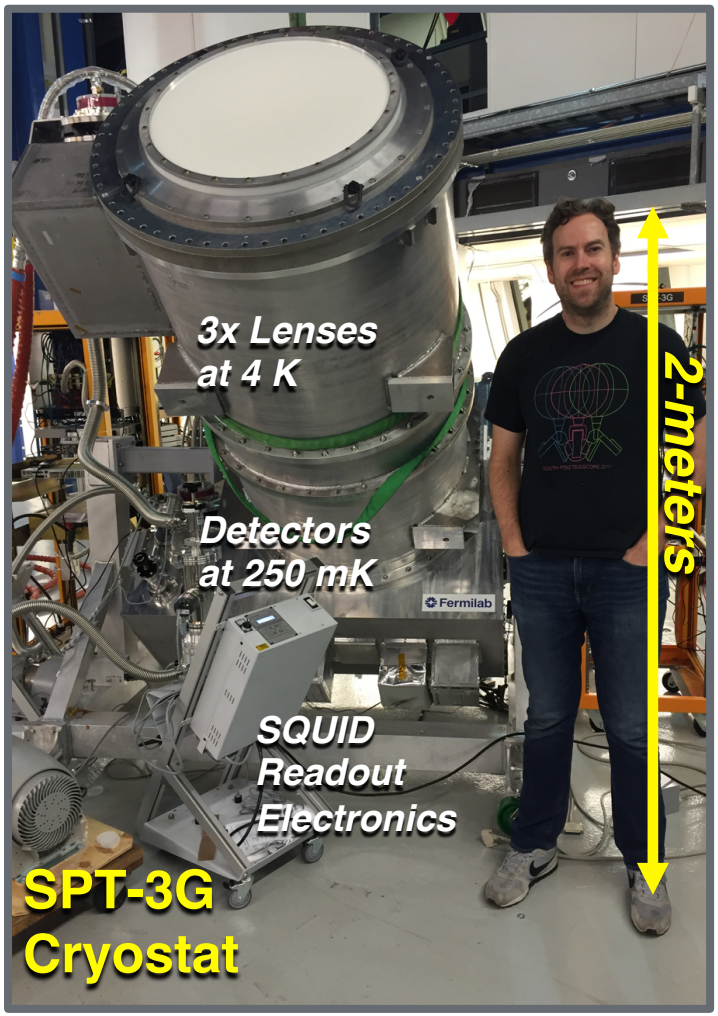
# The 10-m South Pole Telescope: SPT-3G

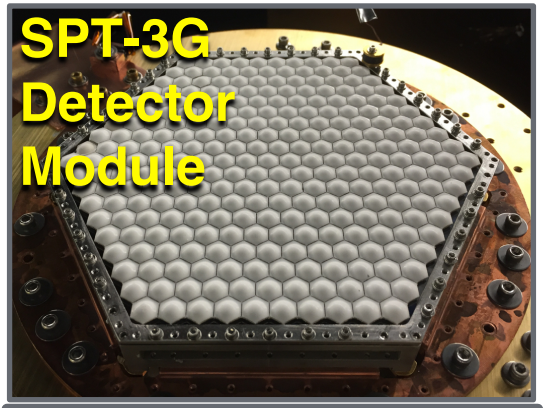
- *SPT-3G camera 16,000 detectors*
  - *3 frequencies: 95, 150, 220 GHz*
- *SPT-3G 5-year 1500 deg$^2$ survey in progress*




Polarized Centaurus A maps

# SPT-3G: FNAL Project Roles





- Camera cryostat design and integration
- Detector & readout development
- Detector & readout test & packaging
  - >100 detector wafers from R&D through production
  - S4 will need to process 40x more
- Focal plane integration



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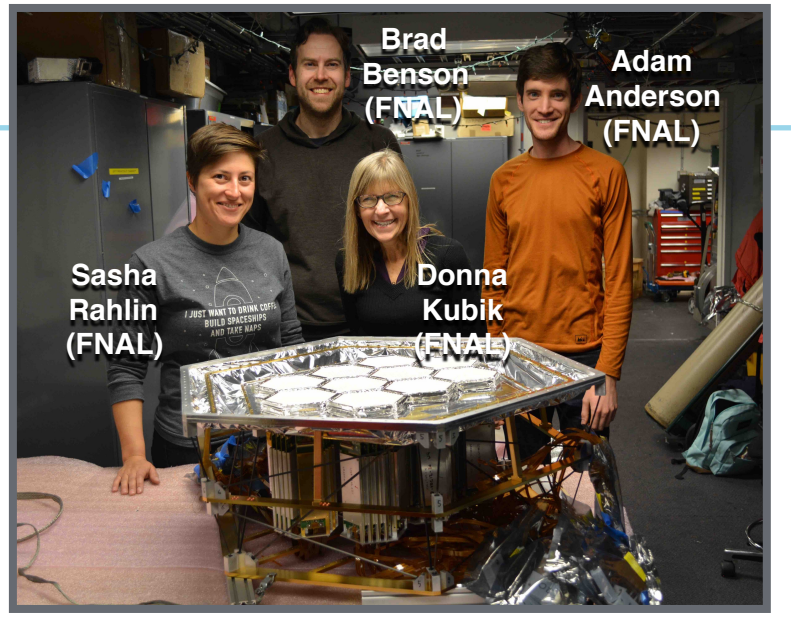
# SPT-3G: Operations Roles

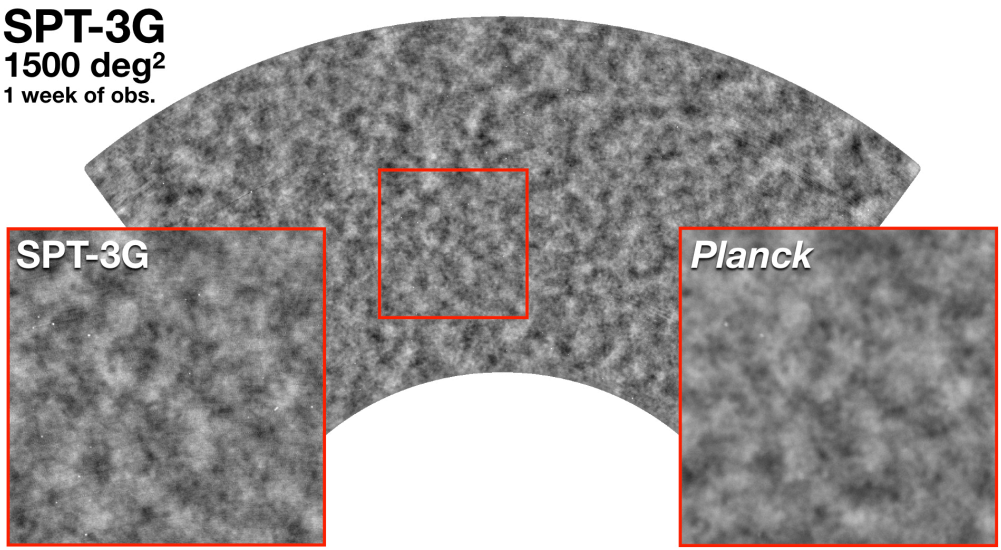



## Operations:

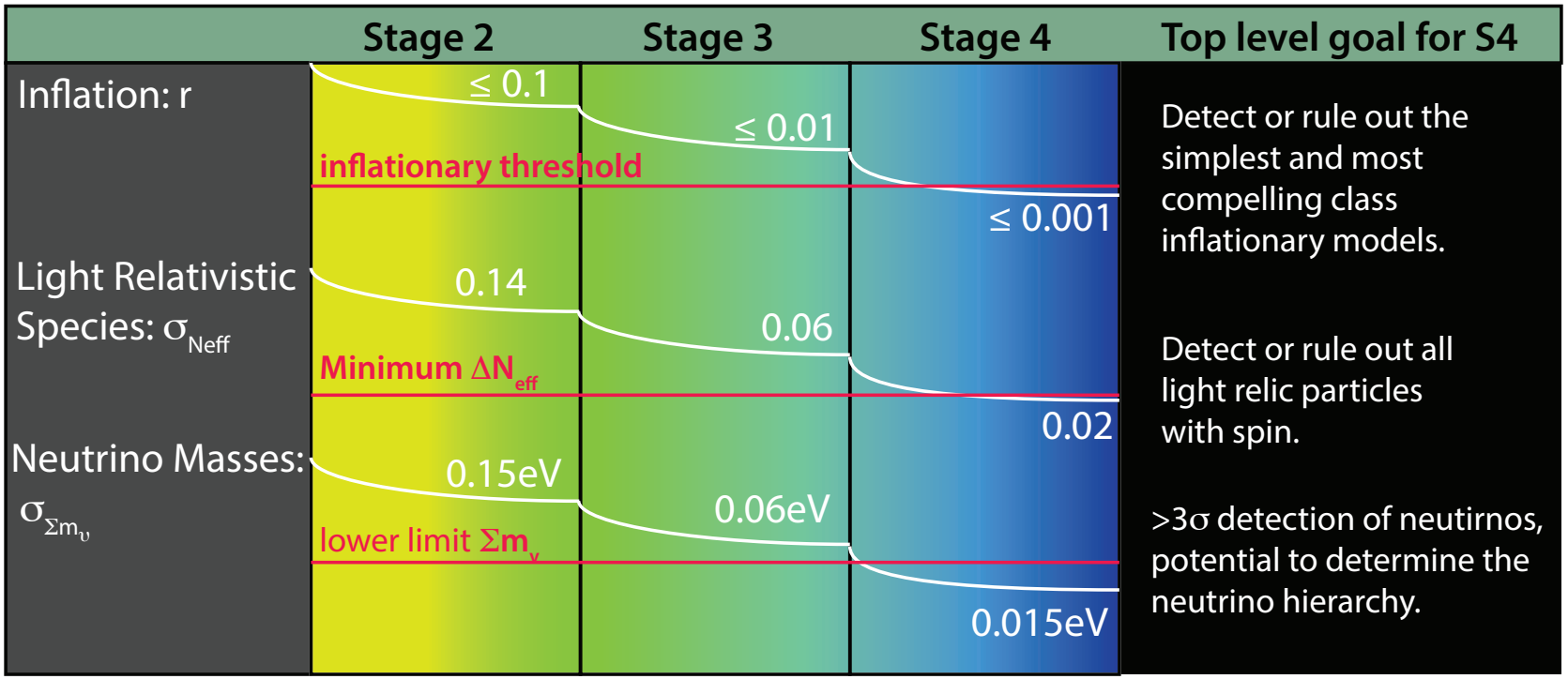
- Benson leading site operations:
  - Instrument and telescope maintenance
  - Site scheduling and staffing
  - Survey planning

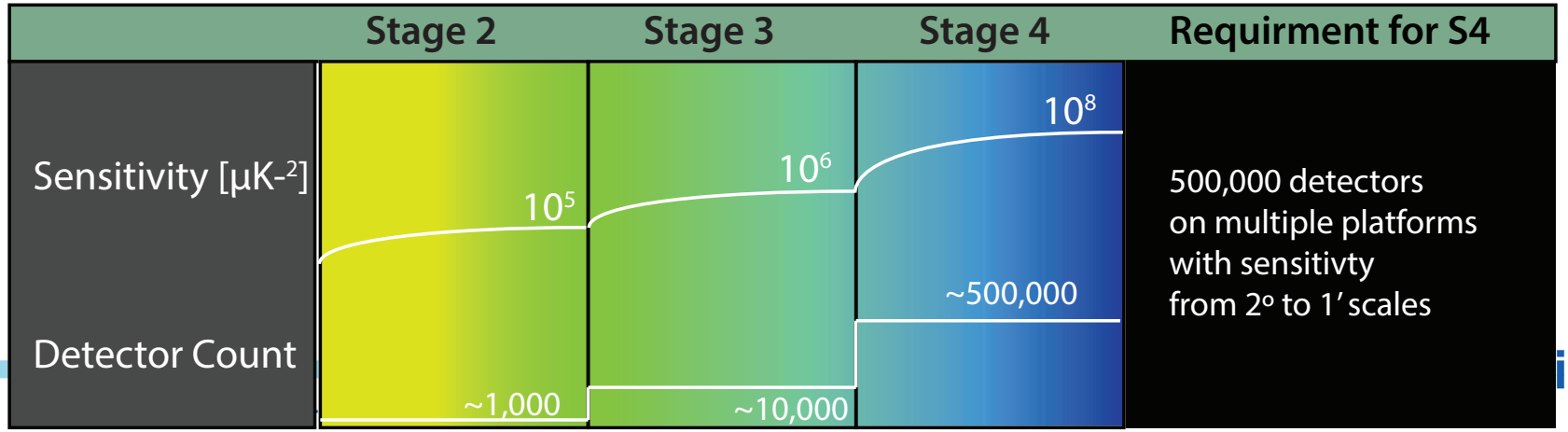
## Science:

- 5-year, 1500 sq. deg. survey
- First year completed; sufficient sensitivity to reach Planck S/N in less than 1 week
- FNAL leads:
  - Camera optimization, sensitivity estimates, data quality checks (PD Anderson)
  - CMB power spectrum pipeline (PD Rahlin)



# CMB-S4: Science Goals



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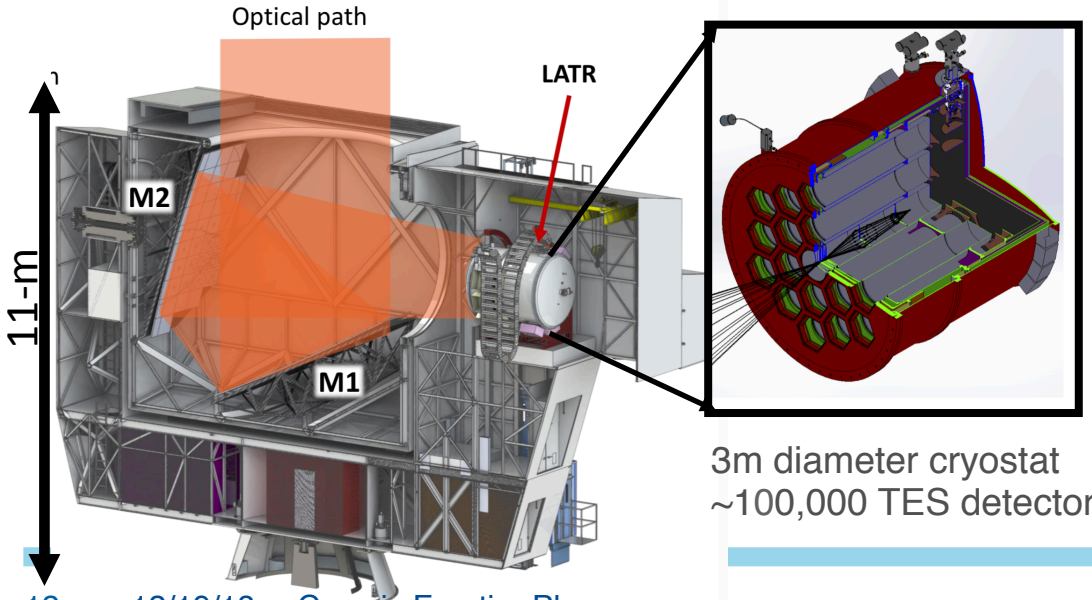
# The CMB-S4 Experiment

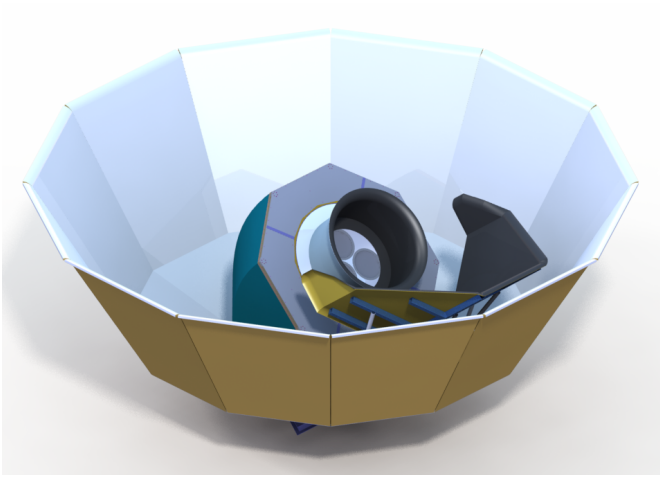
- Endorsed by P5, NRC (NSF) Antarctic Science report; Concept Definition Taskforce (CDT) report accepted by AAAC panel Oct. 2017
- Reference Design developed by CMB-S4 Collaboration 2017- 2018, reviewed Dec. 11-13, 2018
- CMB-S4 concept:
  - **~500,000 detectors** split between 3x 6m aperture (LAT), 6x3x 0.5m aperture telescopes (SAT)
  - **Two sites:** South Pole – 1 LAT + 4x3 SAT; Chile – 2 LAT + 2x3 SAT
  - **Two surveys:** Inflation survey ($r$) ~3% sky; Legacy survey ($N_{eff}$, $m_\nu$, DE) ~40% sky.

High-resolution Science + De-lensing:
~300,000 detectors on 3x 6-m LATs




3m diameter cryostat
~100,000 TES detectors

Low-resolution Inflation Science:
~200,000 detectors on 6x3x 0.5-m SATs





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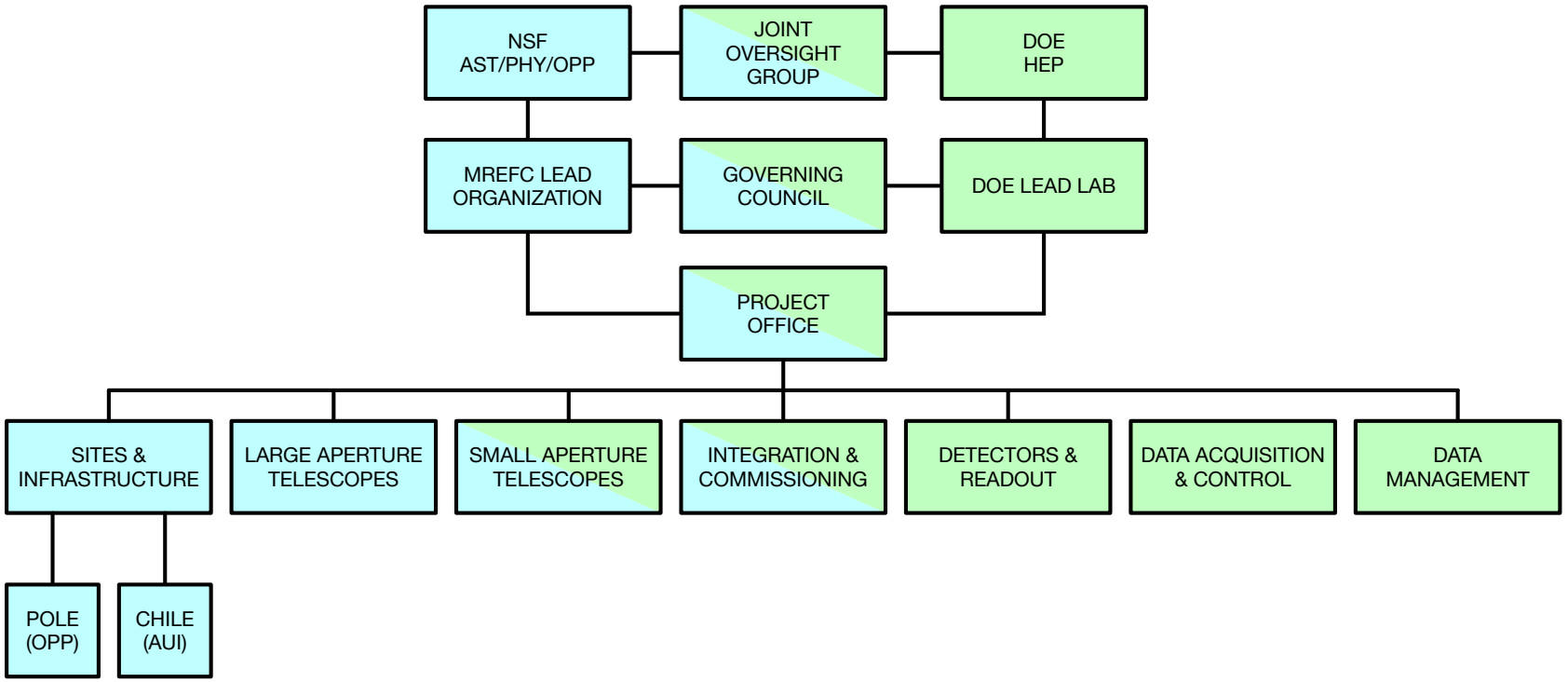
# Determination of DOE/NSF Scope is in progress




- Key Features:
  - A single Integrated Project Office established by the lead institutions and their oversight council with clear reporting lines to NSF and DOE
  - Expect roughly 50-50 split between NSF and DOE



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# FNAL well positioned to play major roles in CMB-S4

- Core Capabilities & Experience
  - Expertise/leadership of SPT–3G detector testing, integration, cryostat design, ops
  - Project management expertise and infrastructure
  - Cryogenic Engineering
  - Technical facilities:
    - SiDet – wirebonding, precision assembly, integration and testing
    - IERC cryogenic lab will house multiple dilution fridges for CMB S4
- Strong connections with ANL and UChicago/KICP
  - History of close collaboration on SPT-3G and CMB-S4
  - Chicagoland institutions already working closely, providing local integrated effort to move CMB-S4 project forward
  - Combined expertise in project leadership, science, engineering and operations well matched to needs of CMB-S4
- Strong working relationships with other labs and universities:
  - Complementary strengths, e.g., detector fab at other labs will feed FNAL testing
  - On DES/DECam, FNAL distributed significant scope to multiple labs to achieve project success

# Potential FNAL Roles in CMB-S4 Project

- **Project management**: experience managing large HEP projects, coordinating multi-lab, multi-university efforts. ~4 FTE scientists will have L1, L2 or L3 roles
- **Detector module packaging**: FNAL core capability, experience from CDF, D0, CMS, DES, DESI, SPT-3G. ~0.5 FTE scientist and 0.5 postdoc
- **Detector testing and characterization**: Experience from DES, SPT-3G, DESI. Leverage FNAL infrastructure: two sub-Kelvin test-beds built for SPT-3G detector & readout development; cryo facilities in IERC; synergy with Quantum initiative (new core capability), which shares similar technology and infrastructure. ~ 0.5 FTE scientist and 2-3 postdocs
- **Cryostat Integration:** Experience with integration of DES, SuperCDMS, SPT-3G. In IERC, will use new 2500 sq. ft. project lab for integration of largest CMB-S4 cryostats. ~ 2 FTE scientists and 2 postdocs plus others as they complete other roles.
- **Deployment, Integration and Commissioning on-site:** Builds on expertise developed during project, and experience with SPT-3G, DES and DESI

# Potential FNAL Roles in CMB-S4 Project

- Core Expertise and Capabilities in these areas will be critical for oversight of work at other labs and universities:
  - **Cryostat design**: Cryo Engineering core capability. FNAL designed sub-Kelvin SuperCDMS and SPT-3G cryostats.
  - **Readout electronics**: RF electronics core capability. FNAL scientists at forefront of development of fMESSI electronics, an FPGA-based GHz-bias readout for kinetic inductance detectors. FNAL collaborating with SLAC to co-develop a similar GHz-bias system for CMB TES detectors.

- FNAL scientist roles will be determined in coordination with Project Office, with sensible match to scope of engineering and technician roles.

- To carry out S4 roles, FNAL CMB Research effort would grow from 3.5 FTE (including PDs) to 8 FTE by FY25, plus technical/engineering support for the project (benefit from Mu2e roll-off in 2020). ANL and Chicago also exploring staff & faculty growth; joint positions under discussion.

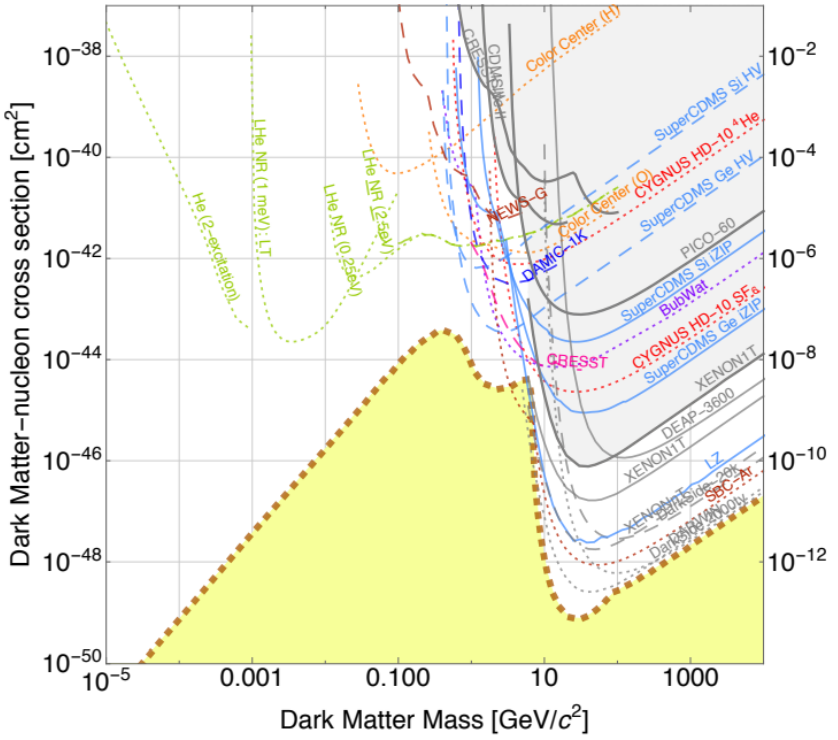
# CMB-S4 Interim Project Organization Planned for 2019

- Lead MREFC and MIE institutions will be identified no earlier than the end of 2019

- Developing plans for an Interim Project Office in 2019
  - pPDG Chair – J. Yeck
  - Spokespersons – J. Borrill and J. Carlstrom
  - Technical Coordinator(s) – 3J Appointed
  - PM for Integrated Schedule and R&D – **B. Flaugher (FNAL)**
  - Systems Engineering/Risk Coordination – Z. Ahmed/N. Kurita (SLAC)
  - Project Controls Coordination – K. Bailey (ANL)
  - Planned Detector R&D Task Force – **B. Benson (FNAL)**
  - Working on an approach to mature L2/L3 coordination:
    - Chilean Site – A. Cohen (AUI), South Pole Site
    - Detectors & Readout Coordination (possibly split)
    - LATs Chile Coordination, LAT Pole Coordination
    - SATs Chile Coordination, SATs Pole Coordination
    - DAQ, DM, I&C

# Changing Priorities in Dark Matter Detection

- Historically, most effort spent searching for WIMPs:
  - Motivated by “WIMP miracle”
  - Lightest neutralino from SUSY considered most natural candidate
- Dramatic progress over the years in excluding WIMPs above ~1 GeV
- Emerging opportunities offer exciting alternatives to the pursuit of ever-smaller WIMP cross sections:
  - Axions or other “wave-like” dark matter
  - Sub-GeV dark sector particles interacting with nucleons and electrons
  - Accelerator-based experiments to probe dark sector particles
- *These opportunities highlighted in recent Cosmic Visions and Basic Research Needs reports.*



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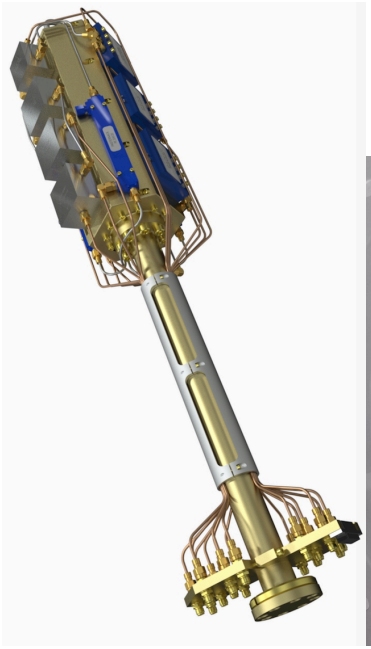
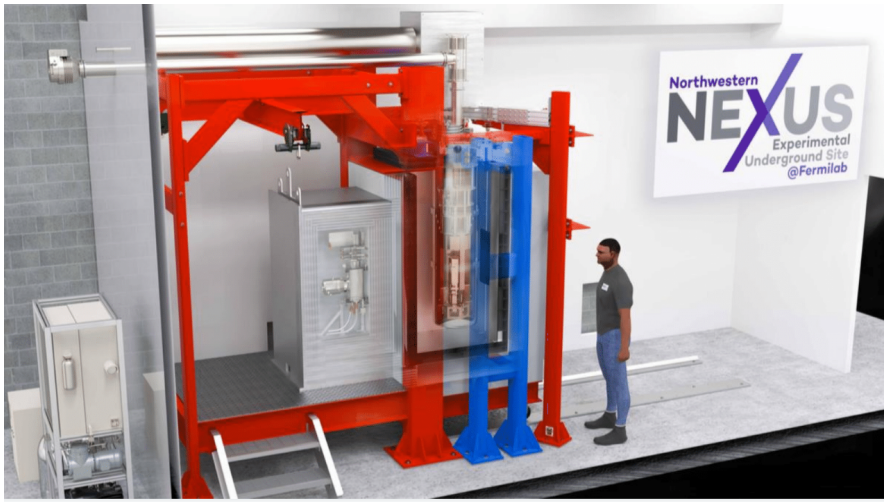
# FNAL Core Capabilities for Dark Matter Research

- Sophisticated set of capabilities built up over time -- wide range of projects over >20 years
- Low background detectors:
  - Design, operation at underground labs
  - On-site underground facility at NuMI tunnel for R&D and prototyping (SuperCDMS, SENSEI)
- Cryogenic engineering at milliKelvin temperatures (ADMX, LZ, SuperCDMS, CMB)
- Superconducting and quantum sensors (ADMX, LZ, SuperCDMS, CMB)
- Liquid argon and xenon detectors
- RF and magnet engineering (ADMX & future axion searches)
- Others …

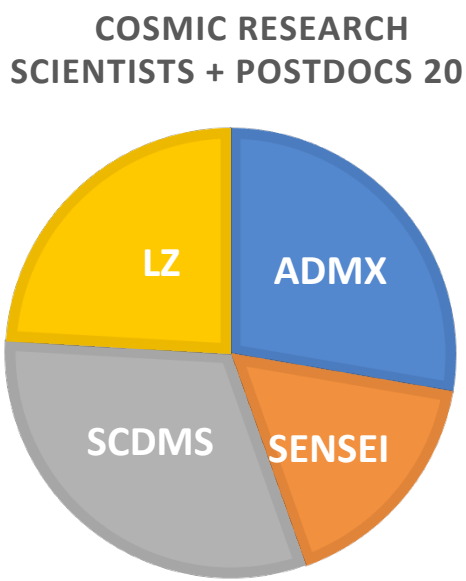




# Current Dark Matter Detection Program at FNAL

- **ADMX**
  - Operations management, analysis coordinator, cryogenics, data management, resonator test, R&D for next-generation experiment (ECA, Quantum awards)
- **LZ**
  - Control system, Cryo engineering, Skin veto, instrument scientist, physics & simulations coordinators
- **SuperCDMS**
  - Cryogenics, electronics, operations, calibration, spokesperson, pub chair, deputy project manager, R&D
- **Skipper CCD development**
  - SENSEI management, engineering, spokesperson
  - Skipper CCD R&D (ECA, LDRD)

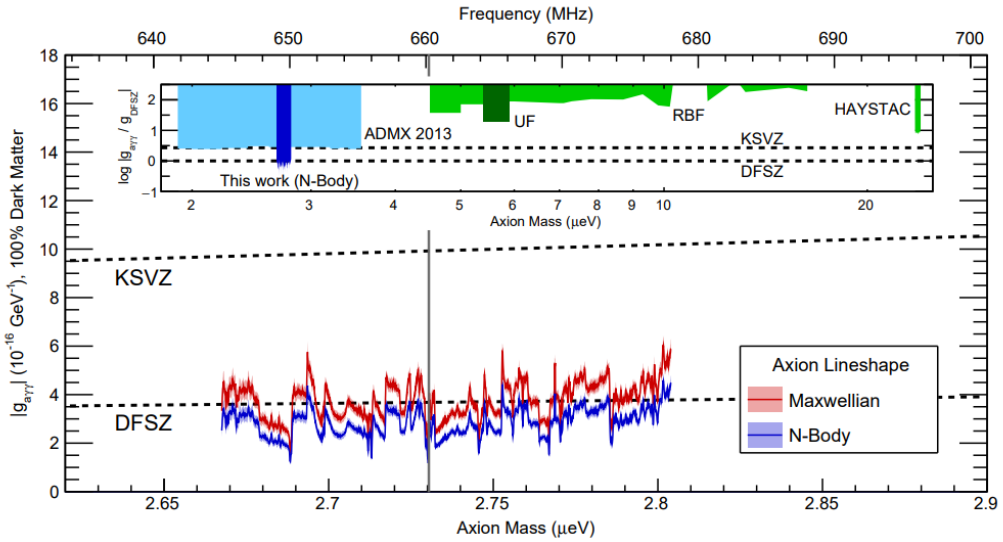
6.8 FTE dark matter scientists + 3 postdocs supported on Cosmic Research budget. 2.5 FTE from other funding

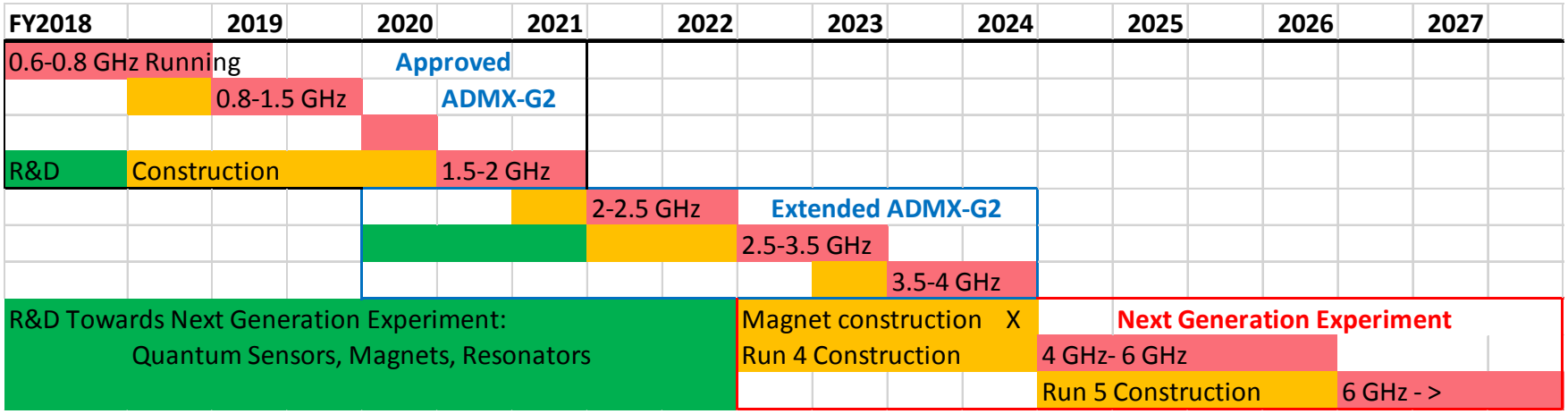


# Searching for Axions: ADMX-G2

- ADMX-G2 approved for operation through 2021 at U. Washington (0.6-2 GHz).
- FNAL is lead lab.
- We aim to extend running to 2024, covering up to 4 GHz.
- Next generation experiment could be located at FNAL, with construction starting 2022.

## ADMX 2018 Results



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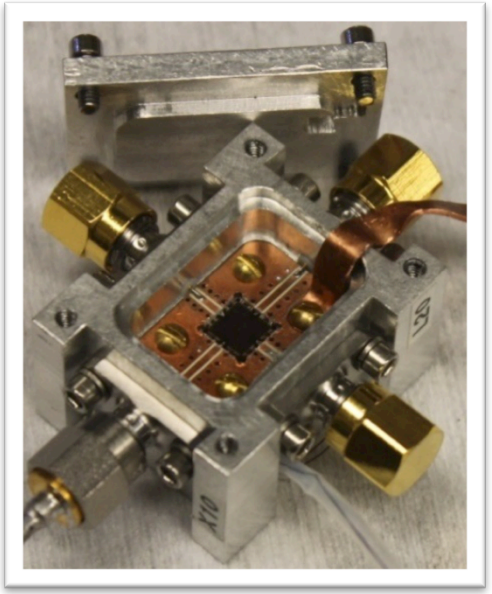
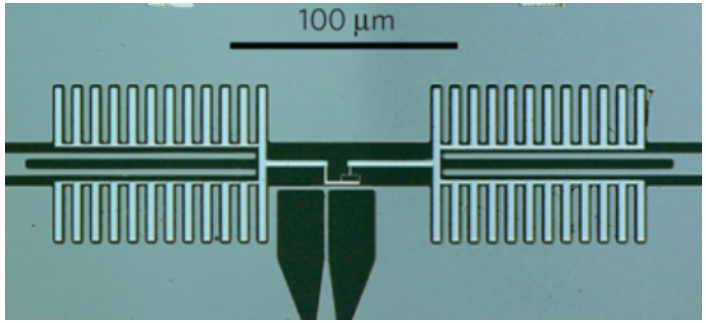
# Quantum Sensor R&D for Axion Detection

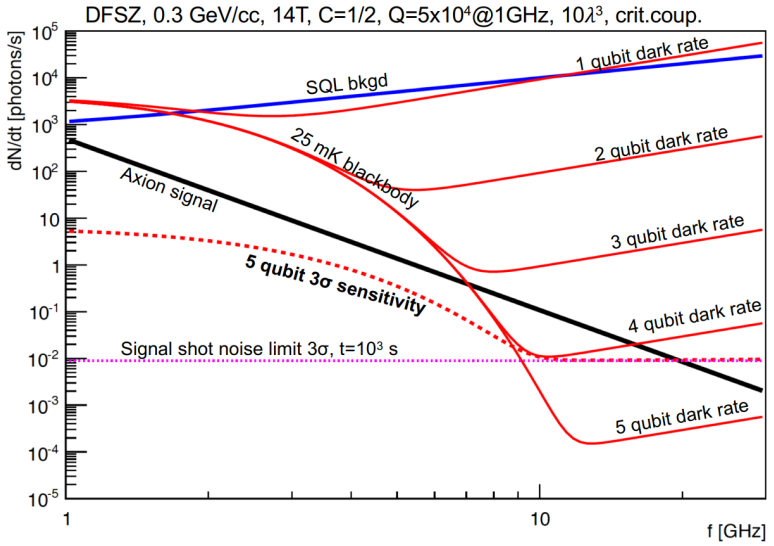
- Axion detection is natural application for quantum sensors.
  - Today: Josephson Parametric Amplifiers (JPAs) with noise close to standard quantum limit
  - Future: Qubits with noise below standard quantum limit
- FNAL is developing qubit-based detectors for axions.



JPAs used for ADMX-G2
I. Siddiqi, UC Berkeley




Qubit work in collaboration with UChicago, funded by DOE Early Career, Heising-Simons QuantiSED, and LDRD.



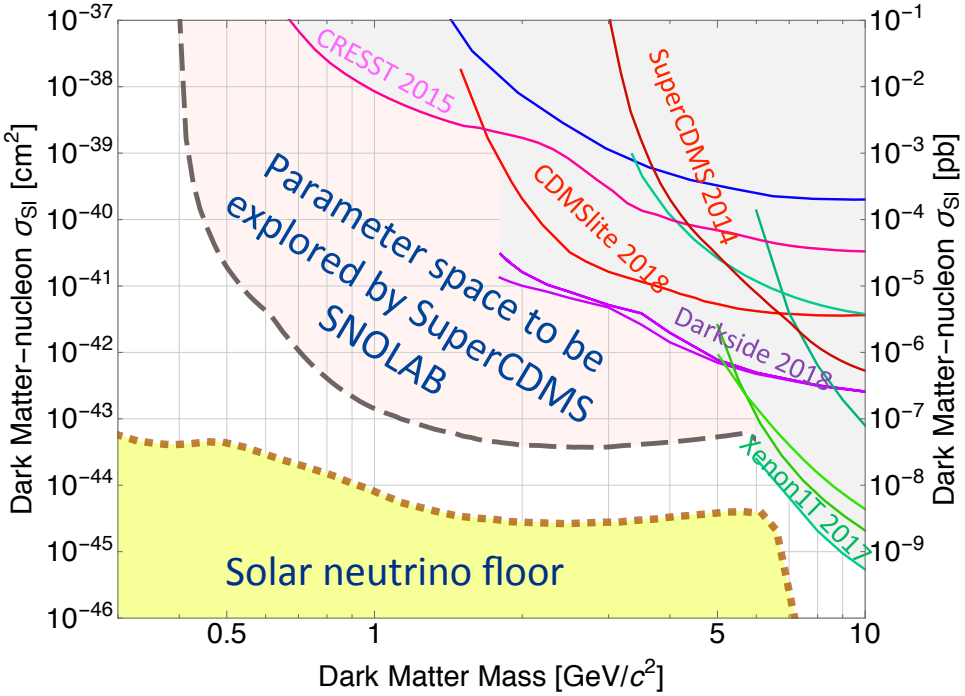

Qubit sensitivity to Axions (A. Chou, FNAL)

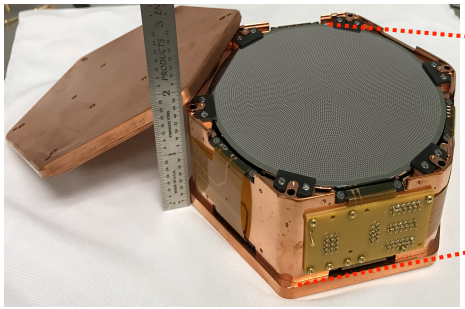
# SuperCDMS SNOLAB

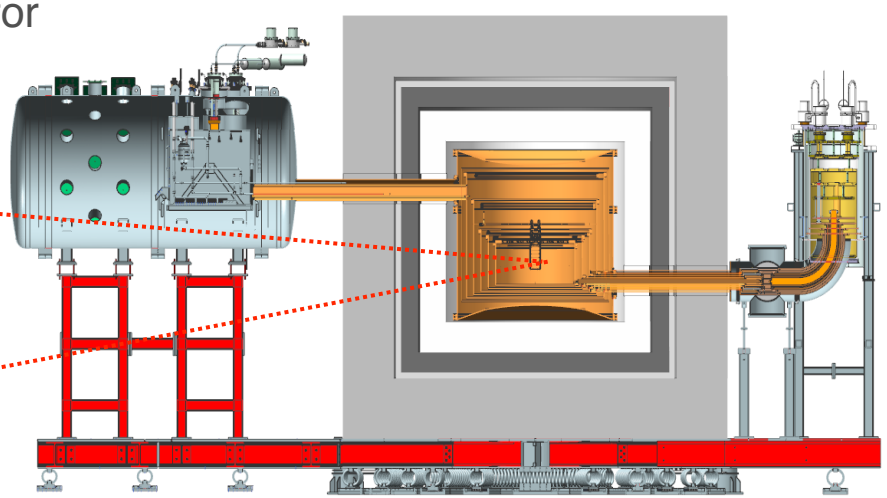
- Search for low-mass dark matter with solid state Ge and Si detectors
- FNAL roles: cryogenics, shielding, warm electronics, calibration, R&D with NEXUS
- Plan to run prototype detectors with sub-GeV sensitivity at NEXUS

Timeline:

- Construction at FNAL-> 2019
- Commission at SNOLAB in 2020
- SNOLAB Physics running 2021-2025
- NEXUS commissioning 2019, calibration for ops starting in 2020





SNOLAB installation



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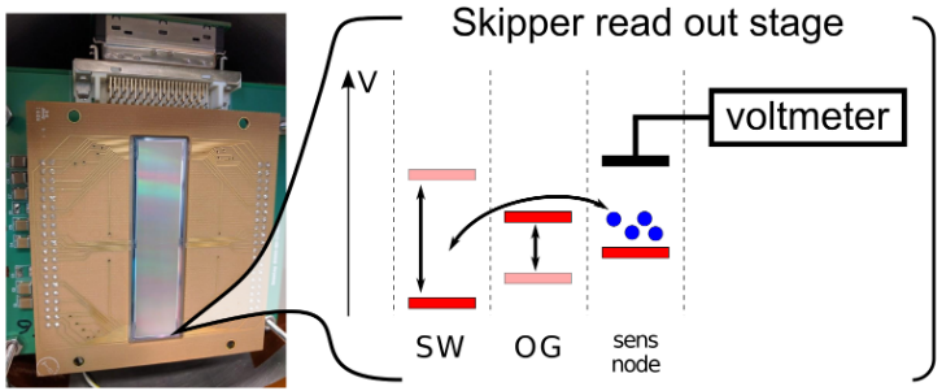
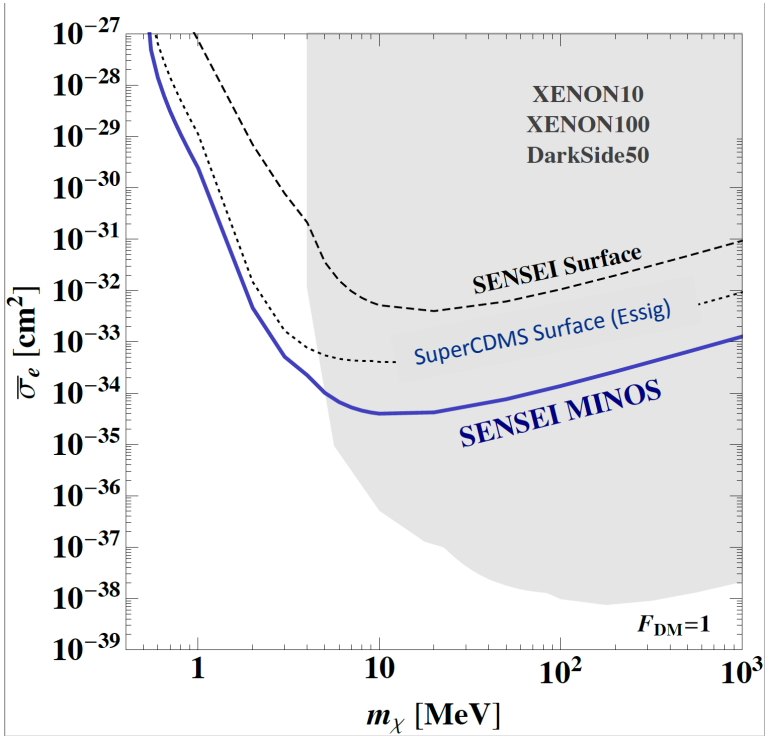
# Light Dark Matter: Skipper CCDs

- SENSEI: 1st demonstration of Skipper CCD technology (pioneered by FNAL and LBL) for DM detection, supported by Heising-Simons.
- Work on Skipper CCDs for neutrinos supported by Tiffenberg 2018 Early Career Award, LDRD, QuantiSED; program is highly leveraged (Skipper+MKiDS 14 FTE visitors in last year).
- Skipper and SuperCDMS have potential for factor of ~$10^7$ sensitivity improvement at SNOLAB with 1 kg-year background-free exposure.

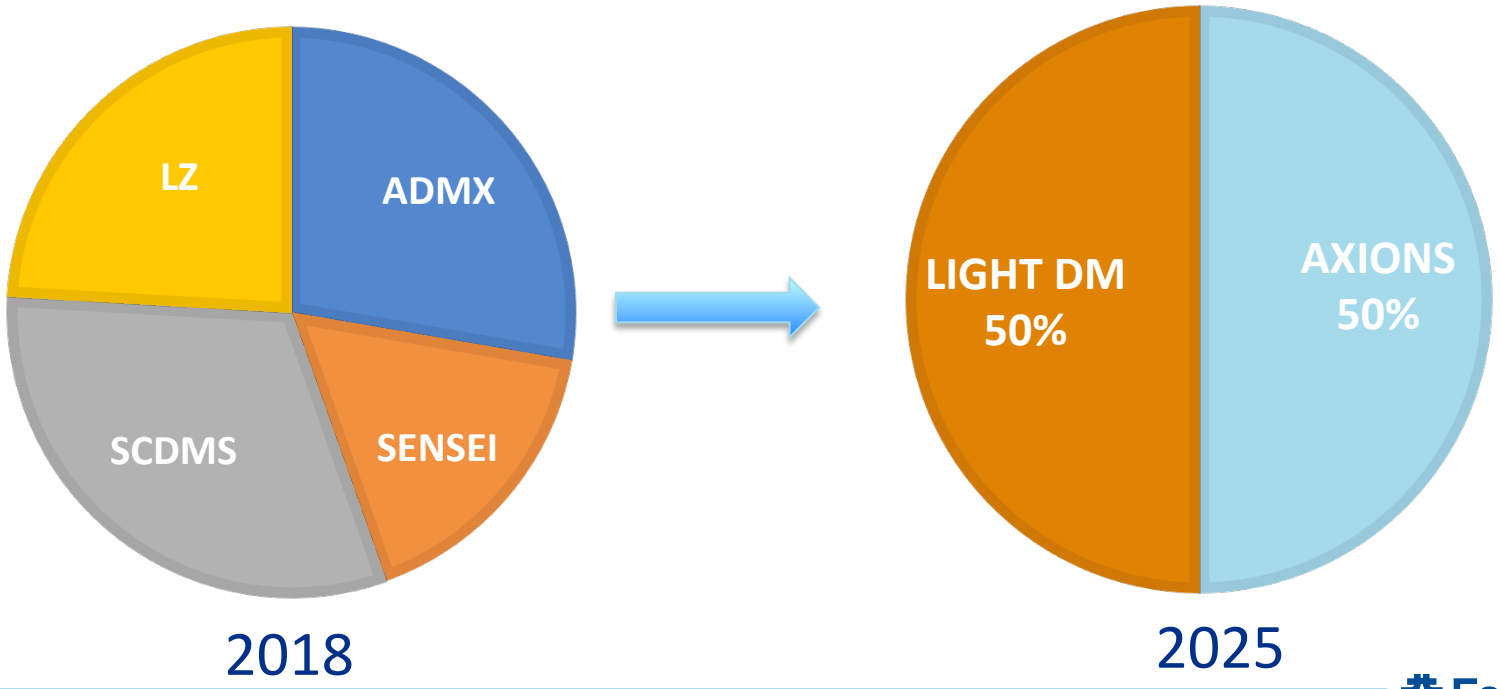



**New SENSEI result to be released this week-** world's best limit for dark matter scattering on electrons. These experiments making rapid progress.

# Dark Matter Future at FNAL

- Deliver on commitments to G2 experiments.
- Upgrade ADMX and build toward next-generation axion experiment at FNAL, ideally with quantum sensors
- Develop technology for next-generation sub-GeV DM search (based on SCDMS or Skipper)

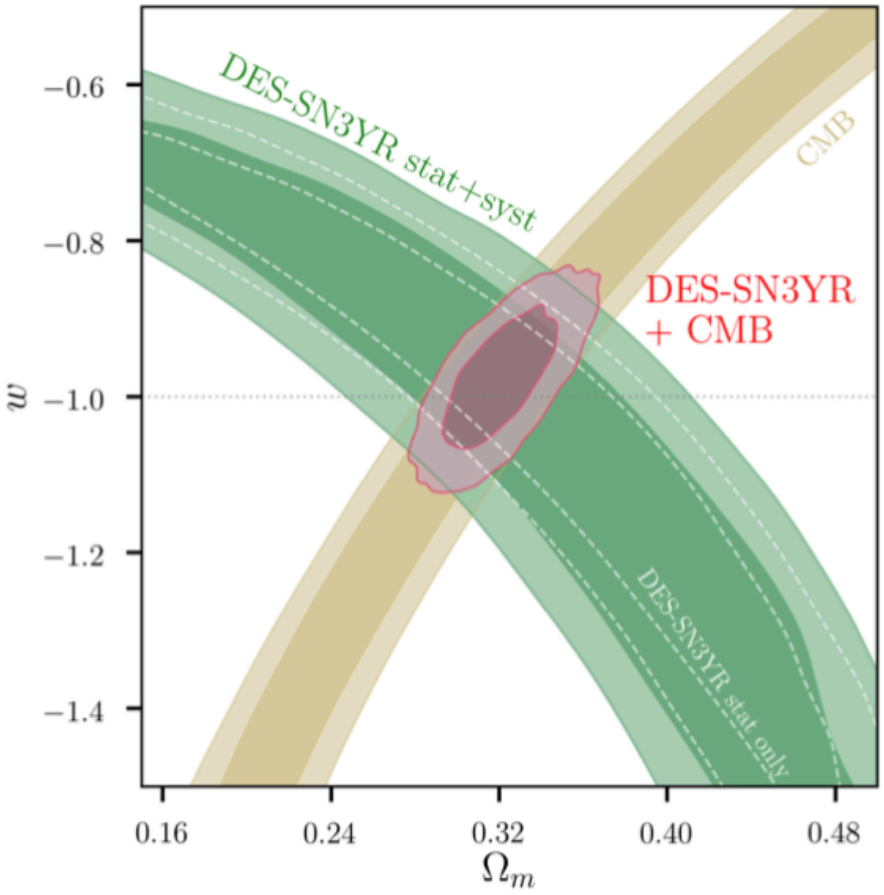


# Cosmic Surveys: Dark Energy Survey (DES)

- DES is the world-leading dark energy experiment.
- FNAL continues to lead the DES Collaboration (director, deputy director, operations scientist, data management project scientist, photo-z, milky way, strong lensing working group leads, cluster cosmology lead)
- Over next 3 years, DES will produce the most precise measurements of dark energy by a single experiment, using 3-year and 6-year data sets.
- Mountaintop operations finish in 2019; science operations continue through 2021.
- Transfer expertise & data analysis pipelines to the next generation of experiments

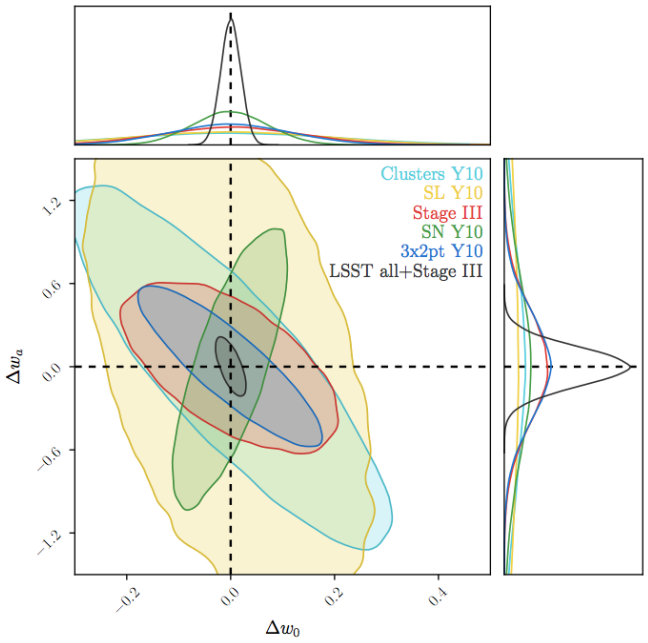
DES Supernova Y3 Cosmology Results

*arXiv: 1811.02374*



# Large Synoptic Survey Telescope (LSST)

- Next-generation large photometric survey now under construction
- FNAL roles in the LSST Dark Energy Science Collaboration: science pipeline architect, survey simulation working group co-convener, dark matter task force lead
- Build on critical science expertise: galaxy clusters, strong lensing, dark matter, gravitational wave cosmology, supernovae
- FNAL slated for and committed to major roles in DOE-funded operations (technical and scientific support): ~10 FTEs in 2023, exploiting computing and survey operations core capabilities
- Effectively transfer all effort from DES to LSST by 2023

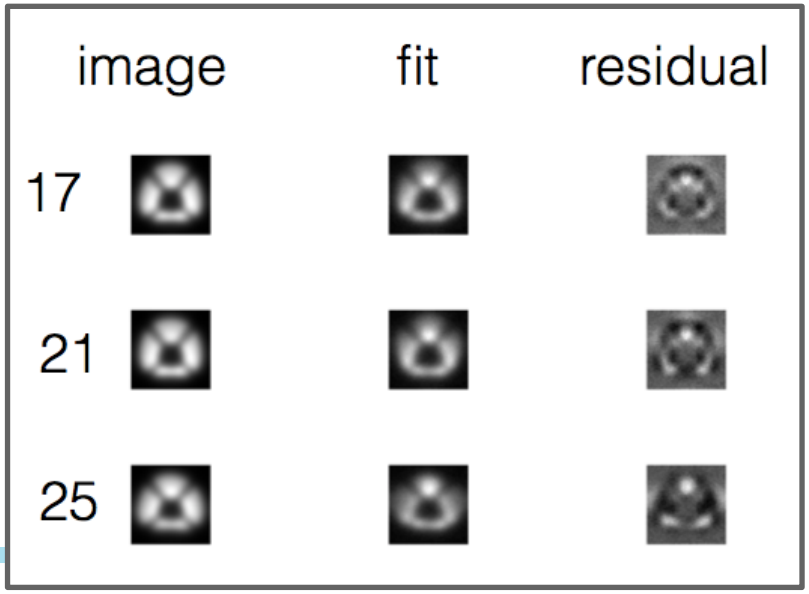



arXiv:1809.01669 DESC SRD

# Dark Energy Spectroscopic Instrument (DESI)

- FNAL played critical roles in DESI construction, based on core capabilities:
  - Outer ring, barrel, cage, hexapod, and ADC rotator
  - Testing and packaging of DESI CCDs
  - Software for fiber positioning, instrument control, and telemetry
  - Commissioning and observing support
- DESI effort ramping down to level requested by the experiment to support critical operations
- Continued scientific involvement will focus on cross-correlation of DES, DESI, LSST, SPT-3G and CMB-S4: powerful probe of neutrino mass

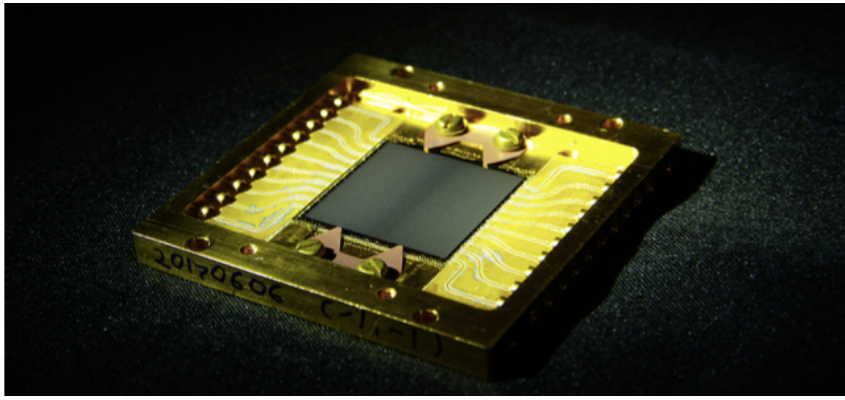
DESI Barrel, Cage, Hexapod

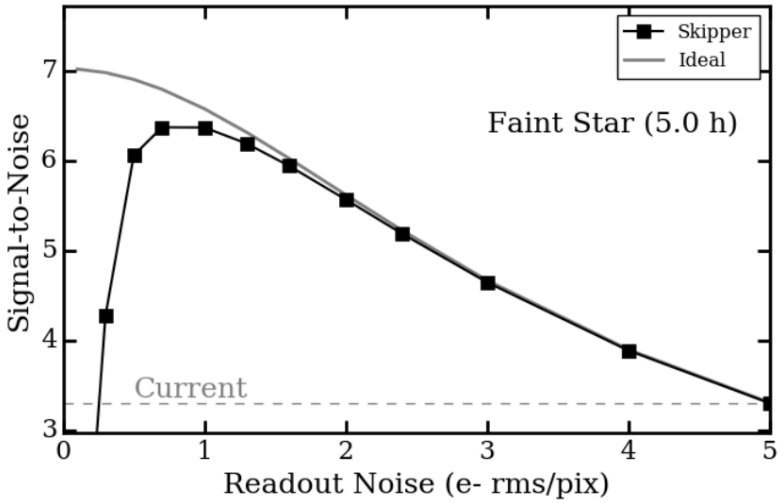



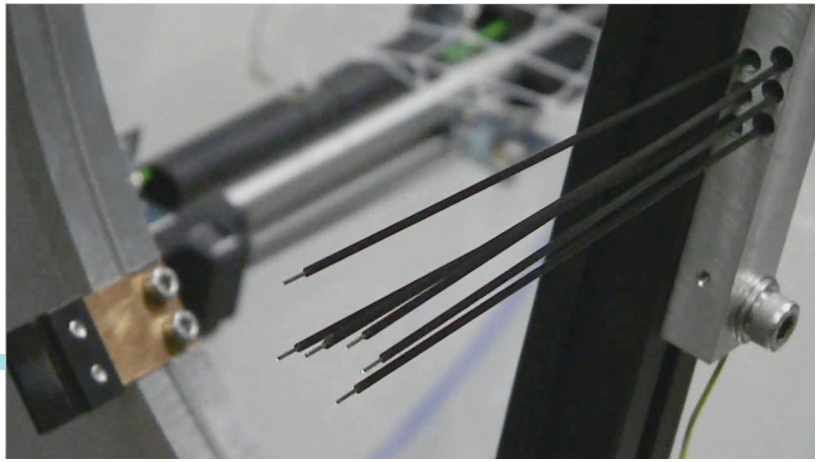

DESI donut analysis (T. Li)

# Cosmic Survey R&D

- R&D targeting next-generation, wide-area spectroscopic survey to enhance dark energy science reach of LSST (LDRD)
  - MKIDs – Low-resolution, time-resolved spectroscopy over the entire sky
  - Skipper CCDs – Low readout noise to increase sensitivity to faint systems
  - Fiber positioners – Decrease fiber separation (~5mm) to achieve dense packing & large multiplexing
- Lay groundwork for DOE involvement in possible future spectroscopic missions: DESI-II, Maunakea Spectroscopic Explorer (MSE), Southern Spectroscopic Survey Instrument (SSSI)
- Specific interest in southern hemisphere instruments to overlap with LSST
- P5 and Cosmic Visions - Dark Energy reports called out need for such R&D





# The Roles of Theoretical Astrophysics at FNAL

- Theoretical astrophysics group is integrated within FNAL Astrophysics Department, interacts closely with Theoretical Physics, seeds, analyzes, and interprets Cosmic Frontier experiments, and connects CF efforts to Intensity and Energy Frontier activities.
- Current activities of the group include:
  - Dark matter model building (informed by direct, indirect, collider and fixed target expts)
  - Neutrino cosmology (neutrino mass, structure formation, interactions with dark matter)
  - Numerical cosmology (probe of dark matter, analysis of surveys)
  - Neutrino astronomy (sources of high-energy neutrino flux)
  - Early universe (inflation, baryogenesis, neutrino decoupling, dark matter production)
- Anticipated areas for future investigation also include:
  - Dark matter searches in accelerator experiments
  - Using DES/LSST/DESI/CMB to constrain dark matter, dark energy, neutrinos
  - Impact of dark matter interactions on the early universe, recombination, dark ages

# Cosmic Physics Center

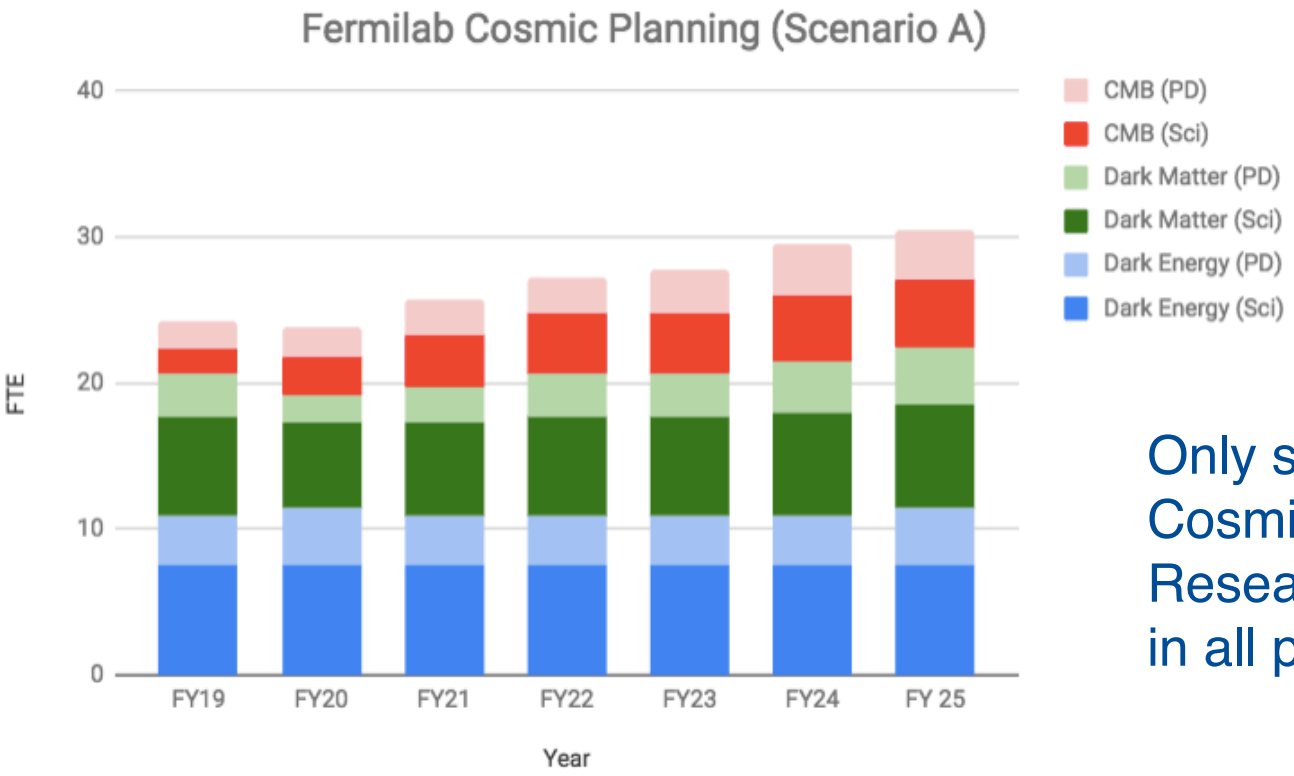
- **Goal:** energize connective *community* cosmic activities at the lab
- Learn from FNAL LHC & Neutrino Physics Centers
  - Host/support visiting scientists, grad students, workshops: make the lab an attractive, intellectually vibrant hub of cosmic activity that serves the growing cosmic user community (~100 annual on-site users, 700+ using computing facilities)
  - Enable analysis of Cosmic experiments, exploiting synergies between them, e.g.:
    - Combine SPT/S4 with DES/LSST/DESI
    - Combine multiple probes of DM: collider/direct/indirect/astrophysical
    - Combine cosmic w/ accelerator-based neutrino constraints: cosmic neutrino initiative (theory)
    - Exploit FNAL core capability in computing for user community
  - Enable user community training in hardware & detector development
  - Develop/strengthen synergies and connections with KICP/UChicago, Argonne, and Northwestern, to realize potential of the Chicagoland Cosmology community

# Planning Scenarios

- Scenario A: grow ~1 FTE/yr
  - Substantial growth in CMB for major roles in S4
  - Growth in axion to lead ADMX into next generation
  - Maintain constant low-mass DM, cosmic survey efforts, positioned for next-generation sub-GeV DM & future spectroscopic survey
- Scenario B: flat FTE from FY18 level
  - Substantial growth in CMB for major roles in S4
  - Growth in axion to lead ADMX into next generation
  - Modest reduction in low-mass DM effort over time
  - Significant reduction in cosmic surveys (fewer LSST scientists)
- Scenario C: decline by ~0.5 FTE/yr
  - Substantial growth in CMB for major roles in S4
  - More modest growth in axion to lead ADMX
  - Reduce low-mass DM effort (ramp down SCDMS operations support)
  - Substantial reduction in cosmic surveys (fewer LSST scientists, ramp down DESI support)
- In all scenarios, we plan to grow postdocs relative to scientists.

# Planning Scenarios

- Scenario A: grow ~1 FTE/yr
  - Grow CMB for major roles in S4
  - Grow axion to lead ADMX into next generation
  - Maintain cosmic survey and low-mass DM efforts



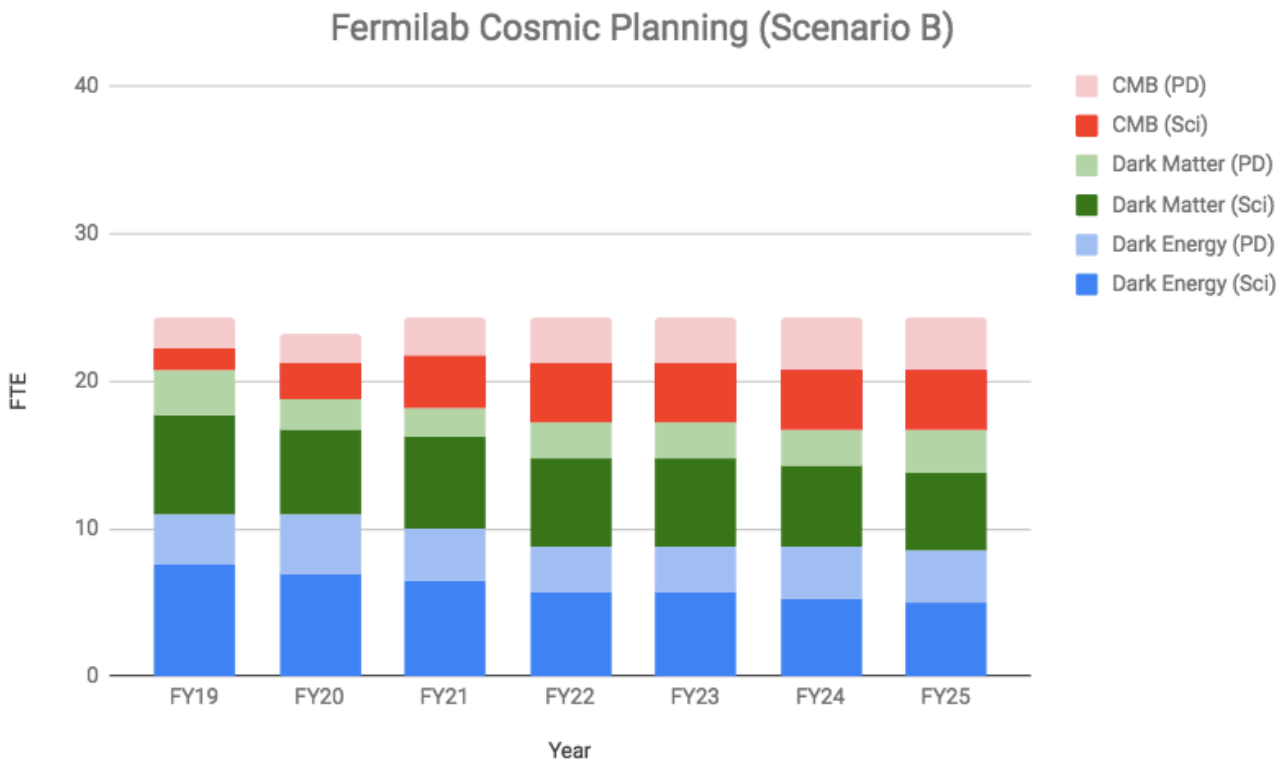

Only showing Cosmic Research FTEs in all plots



Fermilab

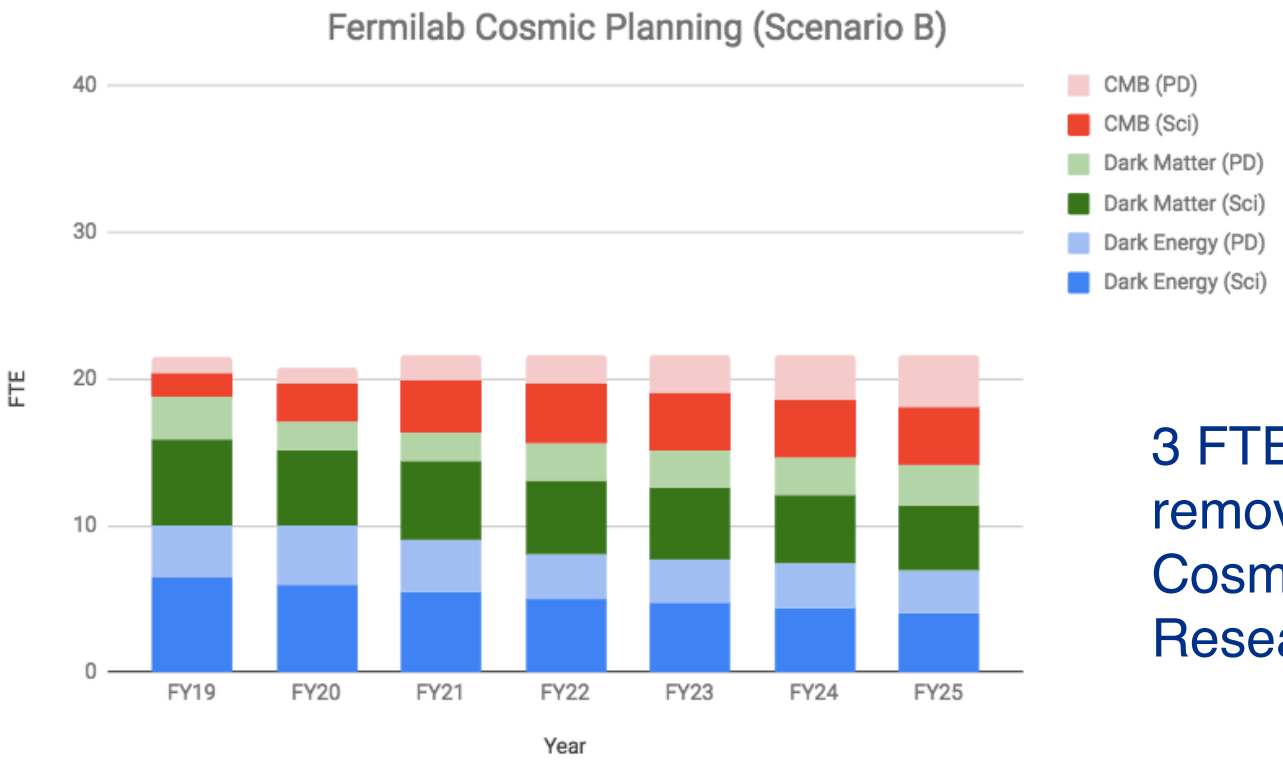
# Planning Scenarios

- Scenario B: flat FTE
  - Grow CMB for major roles in S4
  - Grow axion to lead ADMX into next generation
  - Reduce cosmic survey and low-mass DM efforts



# Planning Scenarios

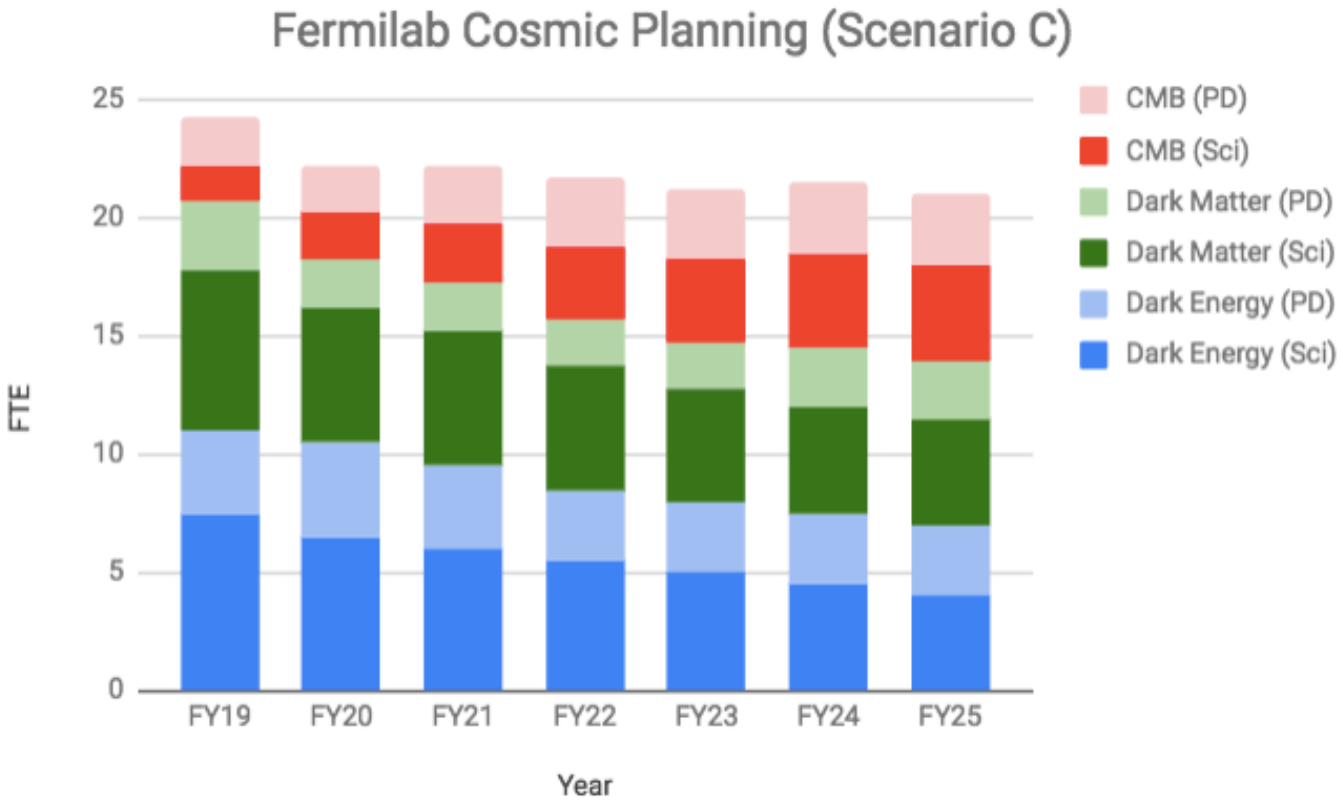
- Scenario B: flat FTE starting from 6.4M in FY19
  - Grow CMB for major roles in S4
  - Grow axion to lead ADMX into next generation
  - Reduce cosmic survey and low-mass DM efforts substantially



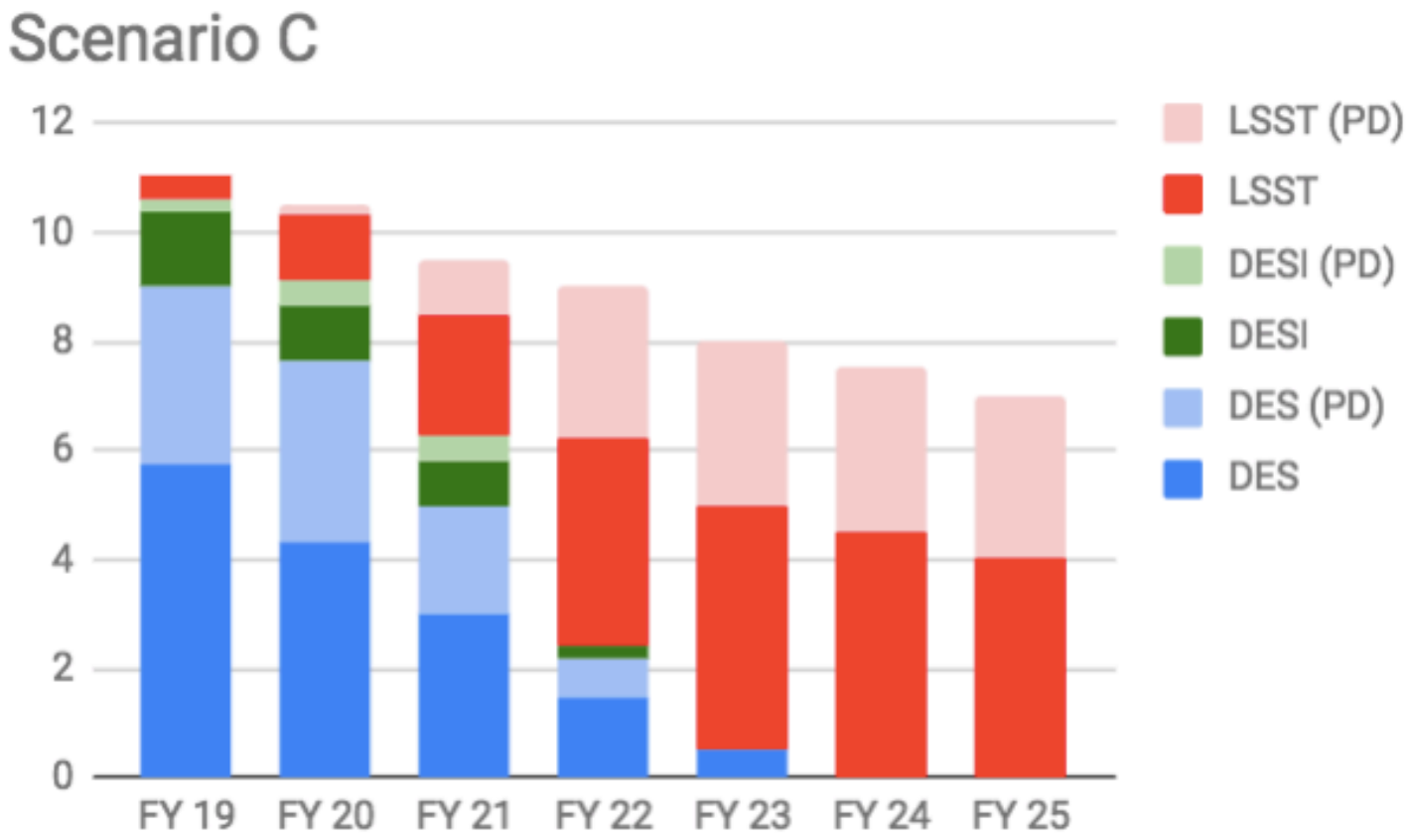

3 FTEs removed from Cosmic Research

# Planning Scenarios

- Scenario C: declining FTE
  - Grow CMB for major roles in S4
  - Modestly grow axion to lead ADMX into next generation
  - Substantially reduce cosmic survey and low-mass DM efforts



# Cosmic Survey Effort Plan in Scenario C




Imperils cosmic surveys hardware, project management, and Stage V R&D programs, puts at significant risk scientist support for LSST (and DESC) and DESI operations. Ramp down of SCDMS also puts SCDMS ops at risk.

# Conclusion

- The plan aims at major/leadership roles in CMB and axions.
  - includes SuperCDMS operations support, R&D toward sub-GeV DM, LSST operations support, R&D toward Stage V DE survey
- The plan builds on FNAL core capabilities, delivers on commitments to on-going experiments, aligns with OHEP and community (P5) science priorities, while serving a growing cosmic user community.
- The plan is *focused* (no longer in DAMIC, PICO, DarkSide, Holometer; ramping down LZ, DESI; not pursuing 21cm, etc).
- In scenarios B and C, the plan requires difficult choices and redirection of effort toward the highest-priority activities. Scenarios C and B-6.4M put cosmic survey R&D and operations, SuperCDMS operations, and future sub-GeV DM program at risk.

# Backup Slides

# Cosmic Science FNAL Strategic Plan (1 of 2)

## Cosmic Science

**Fermilab in alliance with U.S. universities and laboratories will lead the world in CMB science. If dark matter direct detection is confirmed, Fermilab will have played a leading and/or critical role while maintaining intellectual leadership in dark energy.**

| Lab Goals | Lab Objectives | Finish in |
|---|---|---|
| 1. Develop new ways to probe the cosmos | | |
| | 1.1 Advance R&D of detector technologies for next-generation dark matter experiments | FY20 |
| | 1.2 Advance detector and readout technical development for CMB-S4 | FY20 |
| | 1.3 Advance R&D on new technologies for future large surveys and CMB experiments | FY22 |
| | 1.4 Design new RF structures and magnets to explore the full axion DM parameter space | FY22 |
| 2. Drive towards discovery and study of particle dark matter | | |
| | 2.1 Build and commission SuperCDMS at SNOLAB by 2019 | FY19 |
| | 2.2 Provide process control, cryogenic and scientific expertise to enable LZ to take data by 2020 | FY20 |
| | 2.3 Analysis of Dark Matter data sets to discover, or constrain, the nature of Dark Matter | FY25 |
| 3. Use the cosmos to understand cosmic acceleration and physics of neutrinos | | |
| | 3.1 Complete operations of DES by the end of 2018 | FY19 |
| | 3.2 Lead DOE lab coordination of CMB-S4 | FY19 |
| | 3.3 Support DESI project and science planning through instrument commissioning | FY20 |
| | 3.4 Advance computing and software resources for LSST to enable science at first light | FY22 |
| | 3.5 Complete operations and science planning of SPT-3G survey | FY22 |
| | 3.6 Extract cosmological constraints on dark energy and neutrinos from cosmic science experiments | FY25 |
| 4. Serve as a hub for cosmological data and data analyses | | |
| | 4.1 Establish infrastructure to capitalize on multi-wavelength observations of the universe | FY20 |
| | 4.2 Host workshops, establish visitor program, and enable cross-collaboration communication | FY20 |

# Cosmic Science FNAL Strategic Plan (2 of 2)

## Cosmic Science – FY19 Lab Activities

| Lab Activities (Research) | Primary Lab Objective |
|---|---|
| Astrophysical Dark Matter Research | 2.3 Analysis of Dark Matter data sets to discover, or constrain, the nature of Dark Matter |
| CMB R&D | 1.2 Advance detector and readout technical development for CMB-S4 |
| CMB Research | 3.6 Extract cosmological constraints on dark energy and neutrinos from cosmic science experiments |
| CMB-S4 Research | UNASSIGNED |
| Dark Energy R&D | 1.3 Advance R&D on new technologies for future large surveys and CMB experiments |
| Dark Energy Research | 3.6 Extract cosmological constraints on dark energy and neutrinos from cosmic science experiments |
| Dark Matter R&D | 1.1 Advance R&D of detector technologies for next-generation dark matter experiments |
| Dark Matter Research | 1.1 Advance R&D of detector technologies for next-generation dark matter experiments |
| DOE HEP Planning for Next-Generation Experiments | 4.2 Host workshops, establish visitor program, and enable cross-collaboration communication |
| Particle Astrophysics and Cosmology | 4.1 Establish infrastructure to capitalize on multi-wavelength observations of the universe |
| Phenomenology Dark Matter | 4.1 Establish infrastructure to capitalize on multi-wavelength observations of the universe |

| Lab Activities (Operations, Overhead, Project) | Activity Type |
|---|---|
| ADMX Operations | Operations |
| CMB SPT-3G Operations | Operations |
| Dark Energy Operations | Operations |
| Dark Matter Operations | Operations |
| Optical MKIDs for Cosmic Surveys (LDRD-2017-003) | Overhead |
| Tuning Axion Detectors (LDRD-2016-007) | Overhead |
| CMB-S4 Project Participation | Project |
| DESI Project Participation | Project |
| LSST Project Participation | Project |
| LZ Project Participation | Project |
| SuperCDMS(G2) Project Participation | Project |