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Recap of the Cosmic Program

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Fermilab Institutional Review

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Particle Astrophysics at Fermilab

Fermilab (and HEP) mission: study the fundamental nature of matter, energy, space and time

Cosmic studies uniquely probe deep mysteries: dark matter, cosmic acceleration, neutrino mass, gravity

Challenging experiments benefit greatly from unique capabilities of national laboratories: technologies, development, engineering, scale, management

DOE labs and University community share many cosmic experiments

Fermilab's plan is based on the scientific drivers in the HEPAP P5 report, as shaped by community needs, agency funding opportunities, and unique laboratory capabilities

Charge question: Scientific and Technical Accomplishments

- Successful leadership of DES to first science results
- World leading low mass and spin-dependent dark matter results
- Successful launch of SPT-3G group
  - Grant awarded in new competitive LDRD program
- High impact results from astro theory in dark matter and CMB
- Holometer achieves Planck sensitivity operations
- Capstone Auger result on composition of cosmic rays
- Commissioning sub-Kelvin cryogenics for dark matter, CMB, MKIDs

Charge question: alignment with P5

P5 Driver	Experiments
Dark Matter	G1: SuperCDMS Soudan, COUPP/PICO, Darkside, DAMIC G2: SuperCDMS SNOLAB, LZ, ADMX G3: R&D towards advanced WIMP and Axion experiments
Cosmic acceleration and neutrinos	DES, DESI, LSST
Cosmic acceleration and neutrinos	SPT-3G, CMB-S4
Exploring the Unknown	Holometer, Pierre Auger
Detector R&D	R&D on new techniques for particle astrophysics experiments
Astrophysics Theory	Strong coupling with particle astrophysics experiments

Charge question: Facilities, Operations

- Leading operations for many experiments
  - DES
  - CDMS
  - COUPP
  - DAMIC
  - Holometer
- Restructuring laboratory facilities (SiDet) for future programs
  - DESI CCDs
  - MKIDs
  - SuperCDMS
  - SPT-3G

Charge question: Strategic planning and management

- Rapid pivot of program to P5 priorities and G2 dark matter selection
- New strategic plan presented to PAC
  - Dark energy: maintain scientific leadership
  - Expand scope of dark energy group to CMB
  - Dark matter: continue world leading direct detection program
    - manage transition from G1 to G2
  - Robust detector R&D program
  - Grow astro theory group

Charge Questions: Interactions with Community

- Leadership and support of collaborations
  - Depend on and enable university groups in projects and operations
  - Provide opportunities for students in unique hands-on laboratory situations
  - Enhance science by hosting workshops
- Host cross-cutting symposia
  - “Experiments on the Cosmic Frontier”
  - “Joint DES-LSST Workshop”
  - “Midwest Dark Matter Workshop”
  - Co-host and participate in conferences with KICP
- Guest and visitors
  - Housing support
  - Students (summer, high school, college, grad, foreign), postdocs, senior scientists
  - URA visiting scholars

Charge question: Scientific Leadership
(highlighting Wilson Fellows, Early Career awardees)

Experiment	Fermilab roles	Fermilab scientists/ postdocs (Leader)
SuperCDMS	Project/Operations management, Cryogenics/ shielding/electronics, Data analysis/Science	3/1 (Bauer)
COUPP/ PICO	Project/Operations management, Fabrication Data Analysis/Science	3/1 (***Sonnenschein***)
Darkside 50	LAr expertise, data acquisition	1/1 (Pordes)
DAMIC	CCDs, management	1/1 (***Estrada***)
LZ	TPC, process control, science	1/1 (***Lippincott, Dahl***)
ADMX	RF cavity R&D, analysis, science	1/0 (***Chou***)
DES	Project/operations management, DECAM, Calibration/Science	13/2 (Frieman, Flaugher, Diehl)
DESI	CCD packaging, optics, science	2/0 (Flaugher)
LSST	Dark Energy Science	1/0 (Dodelson)
SPT/CMB	Camera assembly, testing, design	2/1 (***Benson***)
Holometer	Project/operations management, science	2/0 (***Chou***)

Charge Question: Scientific Leadership (Theory)

Fermilab's Theoretical Astrophysics Group
- Ties many threads together
- Connects to particle theory (and Particle Theory Department)
- Works to extract fundamental physics from cosmic data
- Brings versatility in modeling, phenomenology, statistics
- Simulation, model building, projection, analysis, tool development
- Gravity, particle phenomenology, complex astrophysical systems

Shapes and leads the experimental program
- Leadership in Fermilab and national program for >30 years
- Many experiments conceived in the theory group (eg, B modes)
- Hands-on involvement includes important leadership positions in experimental collaborations

High praise for Fermilab group in 2014 3-year program review
- Clear endorsement for strong support

A request from the reviewers

Please describe the specific contributions Fermilab brings to the various dark matter direct detection experiments in which laboratory staff currently participate, the likely evolution of staffing across direct detection projects, and the basis for this management plan.

Fermilab Dark Matter Experiments

Experiment	Location	Status	Technique	Physics Focus
G1 experiments (2012-2017)				
SuperCDMS	Soudan	Operating	Cryogenic Solid-State	Background-free WIMP search
COUPP/PICO	SNOLAB	Operating	Bubble Chamber	Spin-dependent dark matter
Darkside 50	LNGS	Operating	Liquid Argon TPC	WIMPS > 1 TeV/c^2
DAMIC	SNOLAB	Operating	CCDs	WIMPS < 1 GeV/c^2
G2 experiments (2018-2023)				
SuperCDMS	SNOLAB	Design	Cryogenic Ge/Si target	Low-mass WIMPs to neutrino floor
LZ	SURF	Design	Liquid Xenon TPC	High-mass WIMPs
ADMX	U. Wash	Fabrication	Cryogenic resonant cavity	Axion dark matter

Fermilab Roles in Dark Matter Experiments
(highlighting Wilson Fellows, Early Career awardees)

Experiment	Fermilab roles	Fermilab scientist/ postdocs FTEs (Leader)
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Specific Fermilab Contributions

- CDMS/SuperCDMS – Experienced leadership, project management, cryogenics expertise, shielding, electronics
  - Staffing: 3 scientists, 1 postdoc. Plan to add another scientist.
- COUPP/PICO –Fermilab scientists led development of large scale systems, and fill critical roles in operations.
  - Collaboration now has strong Canadian presence.
  - Potential as a G3 detector depends on outcome of G1 operations.
  - Staffing: 3 scientists now, two transitioning now to LZ and ADMX.
- LZ – Fermilab recently joined. Invited to take a leading role on process controls and simulations.
  - Small effort now (2 x 0.5 scientists, 1 postdoc), will grow
- ADMX – Small collaboration currently. Fermilab is invited to provide expertise in RF cavity design, axion science, and analysis
  - A small fraction of 3 scientists now, will grow those fractions as other efforts wind down.

Specific Fermilab Contributions (continued)

- Darkside – Fermilab designed and built the distillation column for LAr purification, and the DAQ system.
  - Will provide technical support for the current run as needed.
  - Potential for G3 will depend on outcome of G1 operations
  - Staffing: <1 scientist, 1 postdoc; will transition to other projects
  - Bulk of funding is from NSF and from overseas
- DAMIC - Leadership and CCD packaging, testing and operational experience grew from Fermilab role in DECam
  - Growing collaboration with Chicago/KICP and others
  - <1 scientist and 1 postdoc, expect to stay roughly this level through DAMIC 100 deployment and operations, next year.
  - Supported by Presidential Early Career Award

Likely Evolution of Fermilab Dark Matter program

- We are in a unique period of transition from G1 to G2
  - Driven at a high level by the timing of P5 and the G2 selection
  - Plan shaped by community, collaborations, lab capabilties, science opportunities
- Fermilab G1 operating experiments are still doing world-leading science and capitalizing on early investments.
  - SuperCDMS Soudan, DAMIC for low-mass WIMPs
  - PICO for spin-dependent interactions
  - Darkside-50 is demonstrating a possible path towards a very large G3 experiment to explore high-mass WIMPs
- G1 efforts will wind down as G2 experiments ramp up over the next 1-2 years
- G2 dark matter program focuses on selected technologies that have proven capable of probing the whole parameter space and cross checking each other
  - SuperCDMS SNOLAB for low-mass WIMPS
  - LZ for high-mass WIMPS
  - ADMX for axions
- Need for R&D towards G3 experiment(s) to reach neutrino floor

Some things we heard during the sessions

We were asked about the coherence between our detector R&D program on astrophysics with the national program

Response

- There is a close alignment of the R&D program and the national astrophysics program
  - CCD packaging and testing facility developed for DECam and expanded for other CCD types (DAMIC, DESI, test devices)
  - MKIDS effort led to development of a sub-K refrigeration system that is useful for MKIDs and for CMB initial testing.
  - Unique MKIDs effort aimed at development of demonstration with an optical camera for SOAR
  - CMB effort in progress to gain experience for SPT S4
- Groups know each other and communicate frequently, could investigate more formal/regular meetings
- Program is reviewed every three years by DOE
- Perhaps the APS/DPF group CPAD can play a larger role

Some things we heard during the sessions

We need to demonstrate a major role for Fermilab in CMB through SPT-3G and show how that translates to a major role in CMB-S4

CMB experiments

Experiment	Location	Status	Operations	Physics Focus
SPT-3G	South Pole	Fabrication	2016-2020	CMB polarization
CMB-S4	South Pole + Chile + ??	Design	2020-2025	Wide-area CMB polarization, neutrino masses

Fermilab is currently a partner in Stage 3 experiment at the South Pole Telescope (SPT-3G)

- DES was strategically planned to overlap SPT to maximize the science
- Collaboration with ANL and U Chicago
- Camera being built and tested at Fermilab; deploys this year

Fermilab helping to shape S4 design, collaboration, consortium

- Order of magnitude more detectors than 3G

Fermilab Roles in CMB experiments

Experiment	Fermilab roles	Fermilab scientists/ postdocs (Leader)
SPT 3G	Cryostat and focal plane design and fabrication, integration, detector testing	2/1 (***Benson***)
CMB S4	R&D, design, collaboration development	2/1 (***Benson***)

Builds on Fermilab technical experience with CMS, QUIET, DECam

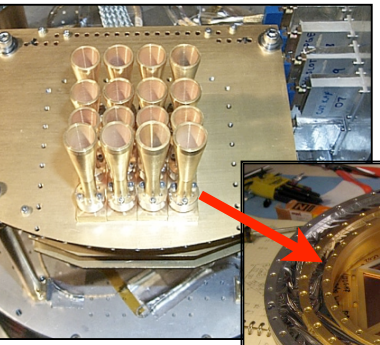
Scientific ties with DES, U Chicago, ANL

SiDet capabilities are now being extended to sub-Kelvin cryogenics

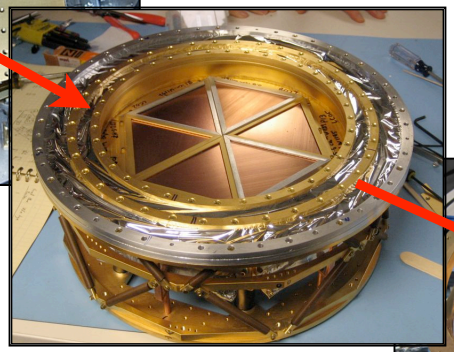
Many applications of advanced superconducting detectors tie different experiments together (CMB, Dark Matter, MKIDs)

CMB-S4: A coordinated community wide program to put 200,000 to 500,000 detectors spanning 40 - 240 GHz on multiple telescopes and map over 20,000 deg^2 of sky

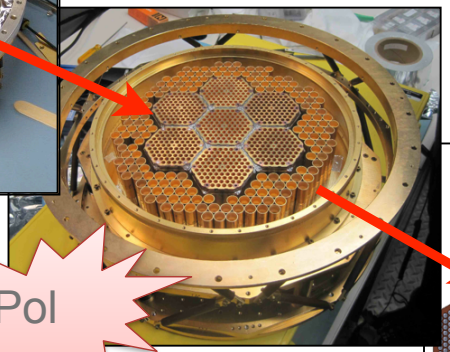
2001: ACBAR
16 detectors



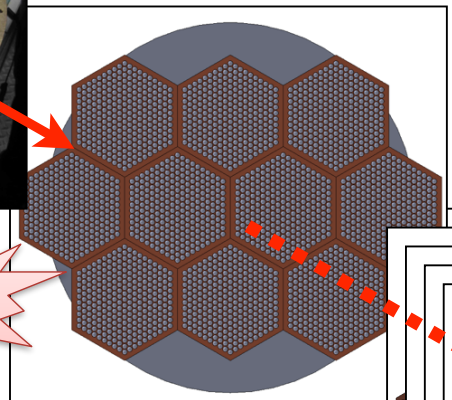
2007: SPT
960 detectors



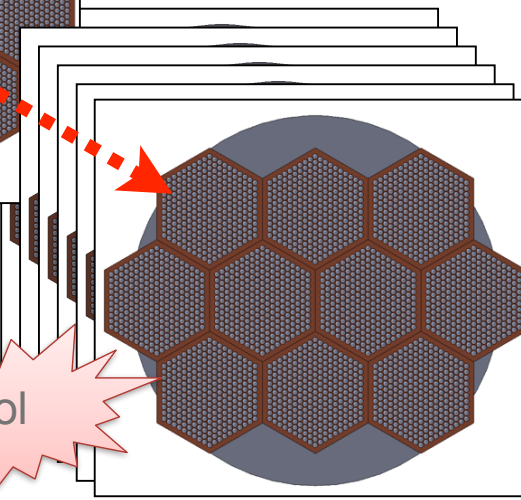
Stage-2
2012: SPTpol
~1600 detectors



Stage-3
2016: SPT-3G
~16,000 detectors



Stage-4
2020?: CMB-S4
200,000+ detectors



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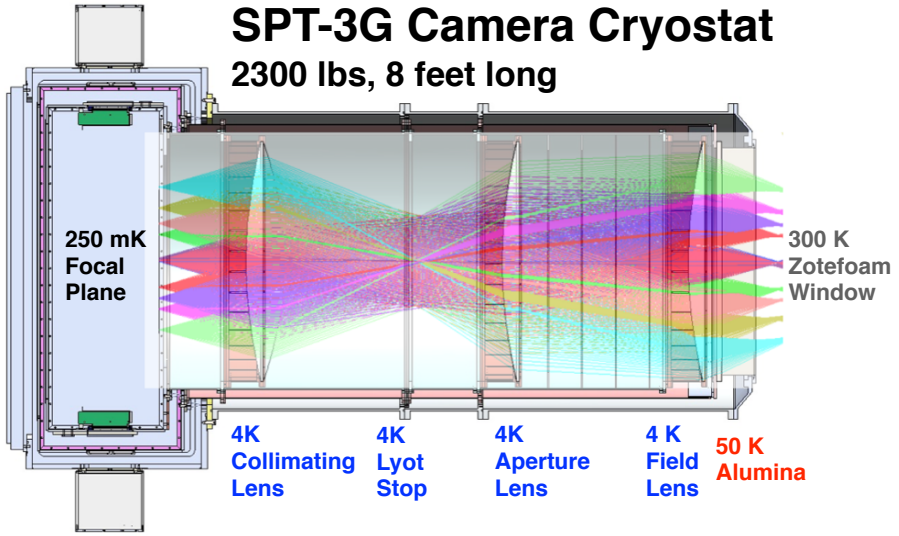
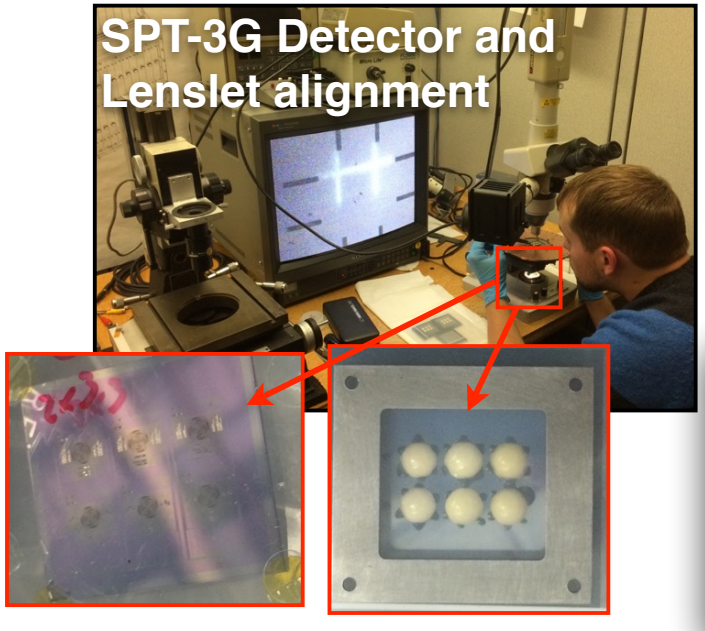
ACT and Polarbear planning similar detector upgrades

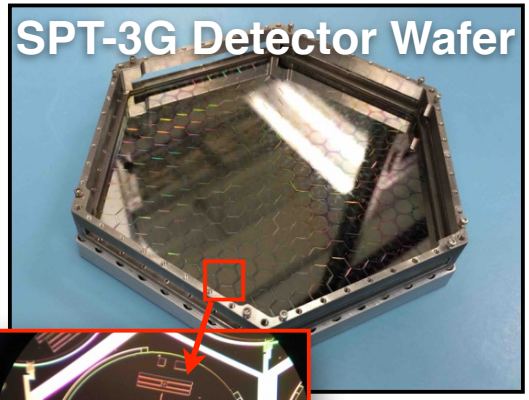
CMB Stage-4 Experiment
Described in Snowmass CF5:
Neutrinos: arxiv:1309.5383
Inflation: arxiv:1309.5381

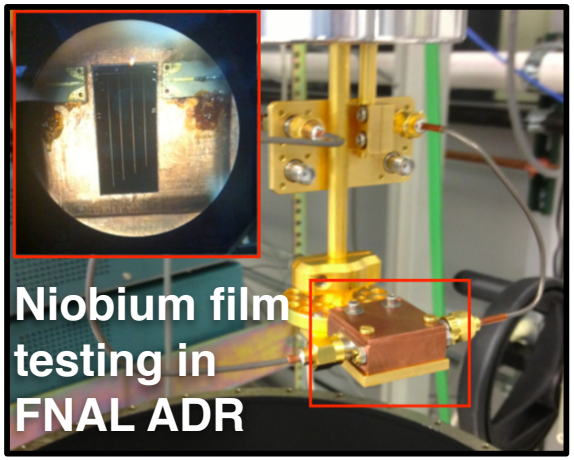
FNAL Leadership Roles for SPT-3G

- **SPT-3G Camera:** Design and fabrication of cryostat, integration with focal plane.
- **Detector Module Assembly:** Packaging detector wafers for SPT-3G (wire-bonding, wafer alignment)
- **Detector Testing:** Adiabatic de-magnetization and He3 cryostats to characterize TES detectors and superconducting films.









Argonne NATIONAL LABORATORY

- Investment in robust, large scale detector fabrication.
- Provided 90 GHz detectors for SPTpol.
- Leadership roles in SPT Stage II and Stage III, providing detectors.
- Large scale cosmological simulation

Fermilab

- Investment in detector testing.
- SiDet facility for module assembly.
- Camera design and fabrication, testing and integration.
- Experience with QUIET detector module testing and assembly.
- Leadership roles in SPT-3G.

CMB-S4

BERKELEY LAB

- CMB heritage and connections with UCB detector development.
- Investment in multiplexer readout.
- High performance computing/massively parallel data analysis.
- Involvement in Polarbear and SPT all stages.

SLAC NATIONAL ACCELERATOR LABORATORY

- Investment in developing large aperture cryogenic optics, providing optics for SPT-3G
- Investing in robust, large scale detector and SQUID design and fabrication, migrating from NIST.
- Leadership roles in BICEP / KECK.

Summary of long term plan and vision

- Long term commitment to dark matter direct detection
  - Increase sensitivity by orders of magnitude
  - Take WIMP search to the astrophysical limit across large mass range
  - Explore axion parameters across the QCD axion mass window
- Long term commitment to dark energy surveys
  - Dominant effort on DES will migrate to DESI and LSST
  - Beyond LSST: a next generation spectroscopic survey?
- Long term theory, development, initiatives, exploration
  - Sow seeds for future
- Growing effort on CMB
  - Effort will migrate from other areas
  - CMB S4 will become the largest effort in the next decade
  - Important contributor to the neutrino program
- Program will adapt to discoveries and opportunities