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# **Strategic Overview of Fermilab Particle Astrophysics Program**

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# Particle Astrophysics at Fermilab

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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 require capabilities of national laboratories: technologies, development, engineering, scale, management

*DOE labs share effort on most cosmic experiments*

*Program is planned with University community*

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

# Fermilab Center for Particle Astrophysics Strategic Plan - January 2015

<b>P5 Driver</b>	<b>Experiments</b>
Dark Matter	G1: SuperCDMS Soudan, COUPP/PICO, Darkside, DAMIC G2: SuperCDMS SNOLAB, LZ, ADMX G3: R&D towards advanced WIMP and Axion experiments
Dark Energy	DES, DESI, LSST
CMB	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

# Dark Matter

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Astrophysical evidence suggests that most of our Galaxy is made of a new form of matter

Theory suggests that it may be detectable in this decade

- Weakly Interacting Massive Particles (WIMPs)

- Axions (solution to CP problem of strong interactions)

P5: diverse program for direct detection of WIMPs and axions

- We only know about these particles from their gravity

Generation 2 experiments will provide greatest parameter reach

- SuperCDMS, LZ (WIMPs)

- ADMX (axions)

- Fermilab effort will migrate from G1 experiments

Other technologies allow broader exploration and followup

- DAMIC, Darkside, PICO

# Dark Matter Experiments

Experiment	Location	Status	Technique	Physics Focus
<b>G1 experiments (2012-2017)</b>				
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 $> 1 \text{ TeV}/c^2$
DAMIC	SNOLAB	Operating	CCDs	WIMPS $< 1 \text{ GeV}/c^2$
<b>G2 experiments (2018-2023)</b>				
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

# Dark Energy

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Astrophysical evidence suggests that the expansion of the universe is accelerating

Signals a new deep form of energy and/or space-time

P5: Precision studies of cosmic structure and evolution

Order of magnitude improvement is possible with new experiments

Wide, deep imaging probes evolution of expansion and structure via supernovae and galaxies (DES, LSST)

Wide, deep spectroscopic surveys increase precision of redshift measurements (DESI)

Fermilab effort will migrate from DES to new surveys and CMB

# Dark Energy Experiments

Experiment	Location	Status	Operations	Physics Focus
Dark Energy Survey (DES)	CTIO, Chile	Operating	2013-2018	Deep imaging survey (supernova, BAO, Weak Lensing, Clusters)
DESI	Kitt Peak	Design	2019-2023	Deep spectroscopic survey (BAO to redshift $\sim 3$ )
LSST	Chile	Fabrication	2021-2030	Very deep, all-sky imaging survey (Broad science program)

# Cosmic Microwave Background

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Anisotropy of CMB temperature and polarization depends on new physics: dark energy, neutrino mass, dark radiation, cosmic inflation

New opportunity: map of polarization at high angular resolution over most of the sky will measure sum of neutrino masses

P5: High priority for Stage 4 CMB experiment, supported by NSF, DOE and national labs, in the next decade

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

- DES was strategically planned with SPT

- Collaboration with ANL and U Chicago

- Camera, cryostat to be built at SiDet; deploys this year

Fermilab working to help shape collaboration, consortium for S4



# CMB & Exploring the Unknown

Experiment	Location	Status	Operations	Physics Focus
SPT-3G	South Pole	Fabrication	2016-2020	CMB polarization
CMB-S4	South Pole +	Design	2020-2025	Wide-area CMB polarization, neutrino masses
Pierre Auger	Argentina	Operating	2008-2015	Very high energy cosmic ray flux, composition
Holometer	Meson Lab	Operating	2014-2016	Structure of spacetime

# New Initiatives, Research and Development, Exploration

Fermilab can uniquely empower new directions in research

Early Career awards and Wilson Fellowships have enabled development of new technologies building on old ones

DAMIC, Holometer, PICO

Individual R&D effort naturally migrates to an experiment

Experiment portfolio allows new synergies, capabilities

Sub-Kelvin cryogenics: CDMS, CMB, MKIDs, ADMX

RF cavities: ADMX and accelerators

P5: sustained commitment to technical innovation

# Theoretical Astrophysics

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Astrophysical theory encompasses broad synthesis

- Required to extract fundamental physics from cosmic data

- Needs versatility in modeling, phenomenology, statistics

- Simulation, model building, projection, analysis, tool development

- Gravity, particle phenomenology, complex astrophysical systems

Fermilab theory group is critical to lead and shape the experimental program

- Many experiments conceived in the theory group (eg, B modes)

- Hands-on involvement extends to important leadership positions in experimental collaborations

High praise for Fermilab group in 2014 3-year program review

- Clear endorsement for strong support

# Summary of ten year plan

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Long term commitment to dark matter direct detection

- Increase sensitivity by orders of magnitude

- Take WIMP search to the solar limit across large mass range

- Explore axion parameters across the QCD window

Long term commitment to dark energy surveys

- Dominant effort on DES will migrate to DESI and LSST

Long term theory, development, initiatives, exploration

- Sow seeds for future

Growing effort on CMB

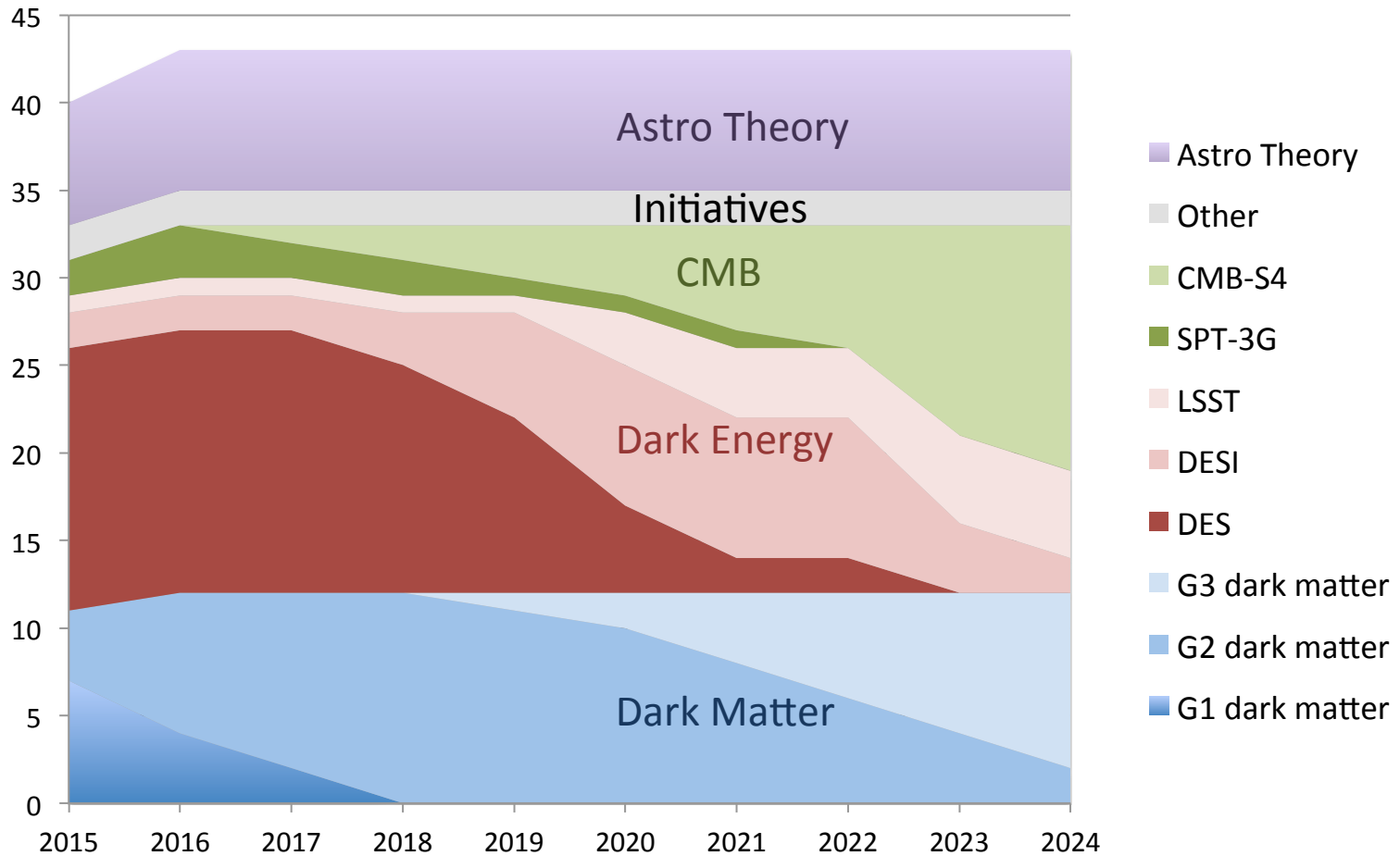
- Effort will migrate from other areas

- CMB S4 will become the largest effort in the next decade

Program will adapt to discoveries and opportunities

# Projected FCPA Scientist Effort

(includes ~12 postdocs)



# FCPA Experimental 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 ( <b>Sonnenschein</b> )
Darkside 50	LAr expertise, data acquisition	1/1 (Pordes)
DAMIC	CCDs, management,	1/1 ( <b>Estrada</b> )
LZ	TPC, process control, science	1/1 ( <b>Lippincott, Dahl</b> )
ADMX	Project management, R&D	1/0 ( <b>Chou</b> )
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	Cryostat assembly, testing, design for S4	2/1 ( <b>Benson</b> )
Holometer	Project/operations management, science	2/0 ( <b>Chou</b> )