Introduction to “Cosmic Day”

Andrew Sonnenschein

Cosmic Day

30 October 2023

Why are we here?

- Have not had a general meeting of Cosmic Physics Center in several years.
- During this time:
  - Many new people– including some people who are new at the lab an others who have moved into cosmic research from other areas.
  - New funding sources (especially Quantum & AI/ML) broadening the scope of the program.
  - Reorganization of the lab with creation of more Directorates and Departments involved in Cosmic research & more physical locations.
- *Risk of fragmentation*: Appears to be increasingly common that people working on related things at Fermilab have never met each other. Let's try to fix that.
- Helpful to have meetings where everyone can hear about status of related research across the whole lab. Opportunity to identify new collaborators.
- An opportunity to collect input for our strategic planning process and other lab presentations of the cosmic program E.g. to the PAC and DOE program managers.
- We may repeat this meeting annually if it's successful.

Today's Schedule

9:00 AM → 9:20 AM **Introduction**
Speaker: Andrew Sonnenschein (Fermilab)

9:20 AM → 9:40 AM **Cosmic Physics Center**
Speakers: Alex Drlica-Wagner (Fermilab), Brenna Flaugher (Fermilab), Joshua Frieman (Fermilab)
Cosmic-Physics-Ce...

9:40 AM → 10:10 AM **Cosmic Physics Center Discussion**

10:10 AM → 10:30 AM **Overview of Astrophysics Theory at Fermilab**
Speaker: Dan Hooper (Fermilab)

10:30 AM → 10:45 AM **SPT-3G**
Speaker: Bradford Benson (Fermilab)
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10:45 AM → 11:05 AM **Coffee 1**

11:05 AM → 11:20 AM **CMB-S4**
Speaker: Sara Simon (Fermi National Accelerator Laboratory)
Slides

11:20 AM → 11:30 AM **Cosmic MKIDS**
Speaker: Adam Anderson (Fermilab)

11:30 AM → 11:45 AM **Dark Energy Survey (DES)**
Speaker: Thomas Diehl (fnal)

11:45 AM → 12:00 PM **DESC & LSST**
Speakers: Alex Drlica-Wagner (Fermilab), James Annis (Fermilab)

12:00 PM → 12:20 PM **Cosmic AI/ML**
Speaker: Brian Nord (Fermilab)

12:20 PM → 1:00 PM **Lunch**

1:00 PM → 2:10 PM **Directorate All Hands Meeting**

2:10 PM → 2:30 PM **OSCURA**
Speaker: Juan Estrada Vigil (FNAL)

2:30 PM → 2:50 PM **Spec-S5 R&D**
Speakers: Guillermo Fernandez Moroni, Guillermo Fernandez Moroni (Fermilab)

2:50 PM → 3:10 PM **SuperCDMS**
Speaker: Lauren Hsu (Fermilab)

3:10 PM → 3:30 PM **ADMX and Dark Wave Lab**
Speaker: Andrew Sonnenschein (Fermilab)

3:30 PM → 3:50 PM **Coffee 2**

3:50 PM → 4:10 PM **Overview of Fermilab's Cosmic/ Quantum Program**
Speaker: Aaron Chou (Fermilab)

4:10 PM → 4:30 PM **SQMS Dark Matter Searches**
Speaker: Roni Harnik (FNAL)

4:30 PM → 4:50 PM **MAGIS-100**
Speaker: Robert Plunkett (Fermilab)
FNAL Cosmic Day 2...

4:50 PM → 5:10 PM **Quantum Science Center and NEXUS**
Speaker: Daniel Baxter (Northwestern University)

5:10 PM → 5:30 PM **GQUEST**
Speaker: Chris Stoughton (Fermilab)
Stoughton-GQuEST-...

Fermilab's 2019 Cosmic Strategic Plan

- Strategic planning exercise completed in 2018-2019 at request of DOE.
- Working group of 10 Fermilab scientists led by Josh Frieman.
- Three phase plan:
  - **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. Conclusions of planning exercise summarized in a report available at https://astro.fnal.gov/wp-content/uploads/2019/05/Cosmic-Steering-Report-public.pdf.
  - **Phase 3**: implement *focused* plan by sensibly directing effort from activities not deemed essential in the first two phases, to build our future program

  We are now (October 2023) ~5 years into this implementation phase.

Our Unique Capabilities

- Many capabilities created for accelerator-based program also apply to non-accelerator program.
- Largest HEP investment in detector development capabilities- a national resource available to our partners.
- Large pool of talented engineers and technician.
- Facilities and expertise are being continuously renewed.

Capabilities:

Cryogenics *& vacuum technology*
Electronics*, including RF, ASICs, FPGAs,*
Superconducting detectors*, amplifiers and circuits*
Photosensors: *CCDs, SIPMs, PMTs…*
Advanced ***computing****, including management of* ***petabyte-scale*** *data sets,* ***AI/ML***
Mechanical design *and assembly, cleanrooms*
Quantum sensors*, Qubits, Superconducting resonators*
Large-scale ***optical and sub-mm focal planes***
Wire bonding and ***sensor packaging***
Magnet *engineering and operations*
Noble liquid *detectors*
Underground, ***low-background facilities***
Project and operations ***management*** *to DOE standards*

Award Winning Scientific Staff

- Expertise of unique scientists also creates unique lab capabilities.
- Continuous investment in hiring top scientific talent over decades.
- Recent hiring at Associate Scientist level (Junior faculty equivalent) focuses on building expertise in quantum sensing and artificial intelligence.
- A distinguished group– many DOE Early Career Awards, Wilson Fellowships.
- Breakthrough Prizes in 2020 (Benson and Rahlin) & 2021(Tiffenberg)
- Joint appointments with local universities: Chicago, IIT.

Associate Scientist Hires Since 2017

Adam Anderson
Wilson Fellow
Cosmic Microwave Background

Javier Tiffenberg
DOE Early Career Award
Dark Matter

Guillermo Fernandez Moroni
Dark Matter/ Dark Energy
DOE Early Career Award

Aleksandra Ciprijanovic
Wilson Fellow
Dark Energy/ AI

Dan Baxter
Dark Matter/
Quantum Sensing

Sara Simon
Wilson Fellow
Cosmic Microwave Background

Brian Nord
DOE Early Career Award
Dark Energy/AI

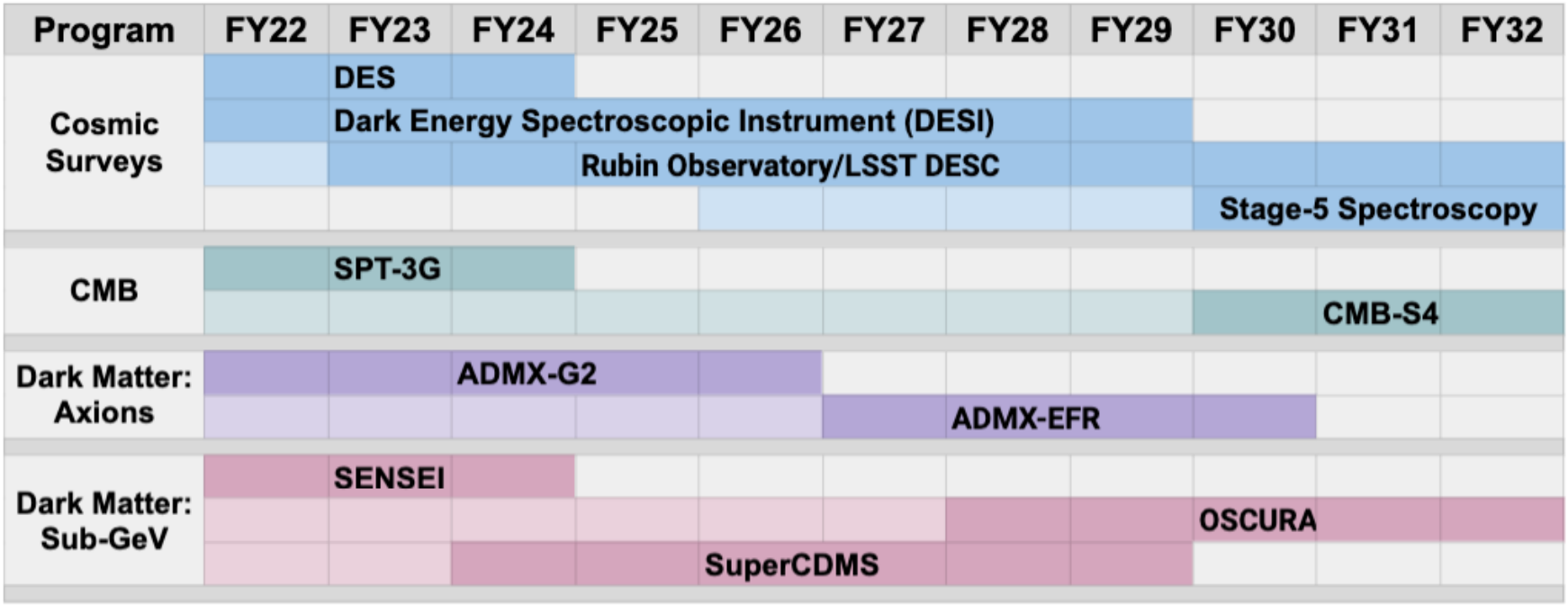
Alex Drlica-Wagner
Wilson Fellow
Dark Energy

Rakshya Khatiwada
Joint with Illinois Institute of Technology
Dark Matter/ Quantum Sensing

Elements of the 2019 Strategic Plan

- Cosmic Microwave Background (inflation, neutrinos)
  - Strong Fermilab contribution to CMB-S4 identified as top priority for next decade. CMB group planned to grow in size while transitioning from SPT-3G operations.
- Dark Matter Detection
  - Increase efforts to search for axion dark matter. *Exploit emergence of new techniques closely related to Fermilab's critical capabilities.* ***Develop a plan to host next generation axion search at Fermilab.***
  - Light Dark Sector Particles (sub-GeV DM). *Increasing scientific importance as heavier WIMP searches become background limited.* Deliver on SuperCDMS operations roles and develop Skipper CCD experiment (OSCURA).
- Cosmic Surveys (cosmic acceleration, dark matter)
  - Transition from DES to LSST Operations while maintaining small but critical role in DESI.
  - R&D toward future southern spectroscopic survey (LDRD)
- The 2019 plan writeup is available on the Astro department Sharepoint https://fermipoint.fnal.gov/org/ocro/ppd/astro/SitePages/Home.aspx

Summary Timeline for Fermilab's Cosmic Projects



Fermilab

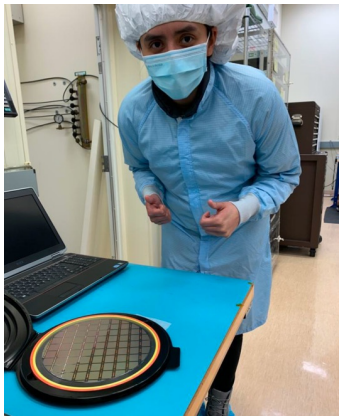
Three Opportunities Highlighted by Snowmass

- Stage 5 spectroscopic galaxy survey in 2030s.
  - Broad community interest in a spectroscopic survey with order of magnitude larger throughput than DESI. Fermilab is participating in NSF proposal with Noirlab, LBNL, Carnegie, Berkeley Space Sciences for development of MegaMapper. Pursuing R&D on spectrometer technologies through LDRD.
- Wider ranging direct searches for wave-like and particle-like dark matter.
  - Fermilab aims to be at the forefront in exploration of new quantum technologies for dark matter searches, including searches for the QCD axion over a wide mass range. Dark Wave Lab would be a new center for this work at Fermilab.
- WIMP search to neutrino floor. Should we re-engage?
  - Fermilab has unique expertise and testing facilities for liquid noble TPCs and bubble chambers. Participation in current generation LZ and DarkSide experiments and in PICO was curtailed due to Research budget shortfalls and loss of key personnel. We would consider rejoining if next generation search is prioritized by P5.

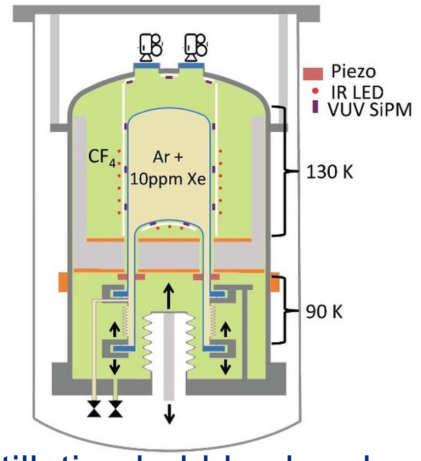
Cosmic R&D

- Cosmic sensor & experiment R&D at Fermilab is a strength.
- Very diverse, innovative and complementary to other lab programs.
- Financial support for R&D comes largely from outside “Cosmic Research” (KA23):
  - DOE QuantiSED program
  - Quantum Centers (SQMS, QSC)
  - DOE Dark Matter New Initiatives grants
  - DOE Microelectronics
  - DOE Generic detector R&D (KA-25)
  - Laboratory Directed R&D (LDRD)
  - Other agencies (NASA, IARPA)
  - Heising-Simons foundation

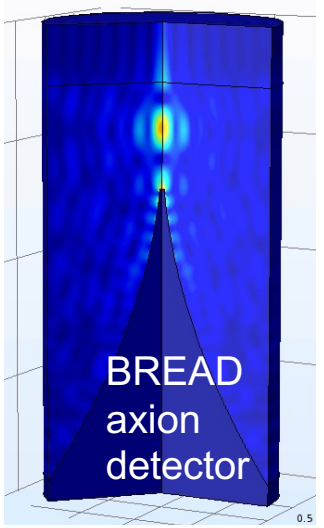
Skipper group “lowest noise” prize @ SDW2022



Skipper CCDs



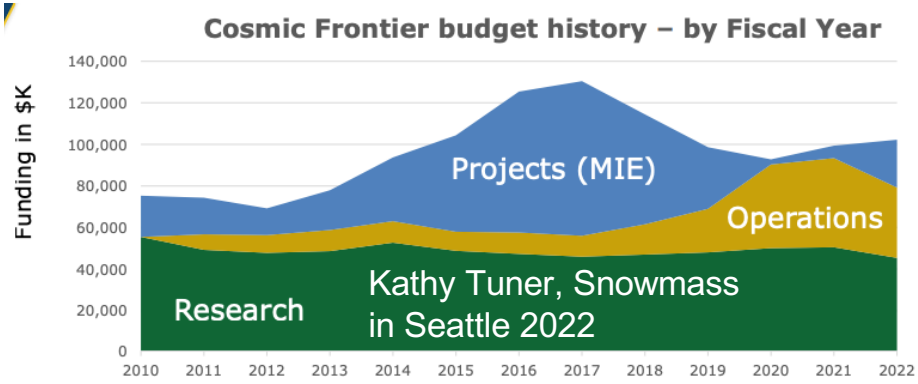
Scintillating bubble chamber



Fermilab

Crisis in Cosmic Frontier Funding

- Declining Cosmic Frontier research budgets are a challenge for delivery of 2019 plan or anything new we want to add. Program supports only 15 FTEs in FY24, down 40% since 2019.
- Reflects DOE-wide trend towards lower research budgets to accommodate growth in projects and operations.
- Situation at Fermilab worse than at other labs because we receive a tiny fraction of Cosmic Project and Operations funds.
- Research program funding steered by Project and Operations needs.
- **<u>Offsetting positive trend: growth in Quantum and AI/ML funding.</u>**



Fermilab Cosmic Research Funded FTEs

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Feedback on Cosmic Program from PAC

- Presentations were made to PAC in January 2023 (Sonnenschein, “Fermilab Cosmic Frontier Strategy”) and in June (Flaugher, “Status of the Fermilab Cosmic Physics Center”).’
- Selected comments:
  - *Program is well-aligned with the DOE mission and the vision for the future articulated by the broader community at Snowmass 2021.*
  - *Armed with two powerful capabilities – the accelerator and quantum sensing expertise – the Lab has an opportunity to play a major role in the search for light dark matter including axions.*
  - *Dark matter detection efforts across the lab do not appear to be coordinated in a strategic way.*
  - *The current rationale for the Center relies heavily on historical context and funding that is in danger of running out.*
- *Recommendations:*
  - ***Fermilab should develop a comprehensive strategic approach (that includes prioritization) to light dark matter searches that leverages laboratory capabilities.***
  - ***The Fermilab Cosmic Frontier group should update their strategic plan, including the vision and purpose of the Cosmic Physics Center.***

2024 Cosmic Strategic Plan Update

- Astro dept group leaders have begun a draft text for an update to the 2019 plan.
- Upcoming P5 report expected in December will be crucial input. In particular, we are hoping for language that supports:
  - Next generation axion and light dark matter searches, including the ADMX and OSCURA Dark Matter New Initiatives.
  - Spec-S5
  - Reinforcement of our commitment to CMB-S4
- Given recent funding trends and recommendation from PAC, I believe we should be enlarging the scope of strategic plan to include inputs from a wider group of people and projects– not just those funded by “Cosmic Frontier”. Include Quantum efforts in SQMS and ETD? Need input from directorate and program managers on this.
- Presentations at this meeting will be useful input to planning process.
- Should engage wider group of people in writing the report.

Summary

- Welcome to “Cosmic Day”. Looking forward to some great presentations.
- Discussions (including coffee breaks, lunch…) are important.
- Let’s try to stay on time with presentations and save time for discussion.
- Important input to our strategic plans for Cosmic Frontier.