Fermilab Cosmic Physics Center

Brenna Flaugher,

Cosmic Day Oct. 30, 2023

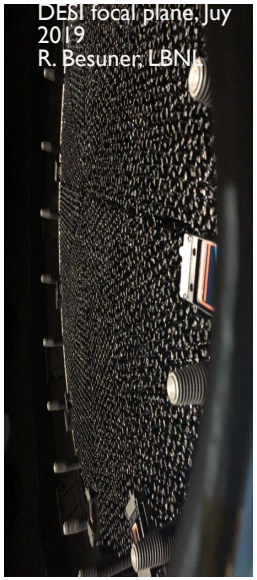
Derived from Fermilab PAC Meeting June 6, 2023

Fermilab has a long-term commitment to the Cosmic Frontier Program

Conf. at FNAL in 1984

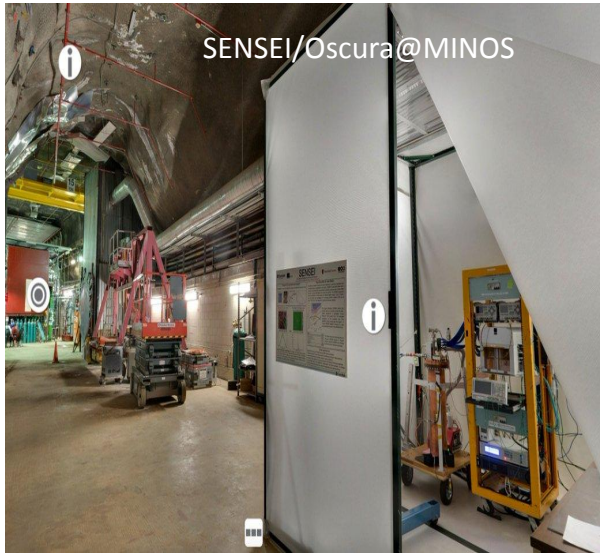

SDSS


DES/DECAM


DESI focal plane, Juy 2019
R. Besuner, LBNL


CDMS


ADMX


SENSEI/Oscura@MINOS

SPT-3G

Fermilab Center for Particle Astrophysics Origins

Established Nov. 1, 2004 with Rocky Kolb as the Director. Full Article

"Astrophysics efforts began at our lab with the very successful Theoretical Astrophysics Group, and Rocky Kolb was a big part of establishing that tradition here," Witherell said.

"The Center will function as an intellectual focus for particle astrophysics efforts at the world's highest-energy particle physics lab, bringing together the Theoretical and Experimental Astrophysics Groups." - Recognition that together, in a Center, the Fermilab Cosmic program had more visibility and viability

Existing projects: Sloan Digital Sky Survey, the Pierre Auger Cosmic Ray Observatory, and the Cryogenic Dark Matter Search

Proposed projects: SuperNova Acceleration Probe/Joint Dark Energy Mission and the Dark Energy Survey (Fermilab-led project to build a camera for the Cerro Tololo Interamerican Observatory (CTIO) in Chile)

Fermilab Center for Particle Astrophysics Origins

Grand Opening Dec. 8, 2004 write-up in Fermilab Today Dec. 10

The cake makes it official!

Peter Limon and William Wester showing Mont and Mike the model of the DES Camera

20 Years of the Cosmic Center

Astro Theory Dept. moved to 6th floor west, mixed with Experimental Astro office space on 6 and 7.

Engaged people and resources from multiple divisions (PPD, SCD, AD, TD)

Established Schramm Theory and Experimental Fellowships and a strong visitor program

Established two houses in the Village for Astro visitors. Usually fully booked.

Postdocs always key to Center activities: organized seminars, journal clubs, etc

Funding specifically for Center activities gradually reduced as overall pressure on research budget increased. **Two Cosmic houses in the village still provide housing for visitors: one funded by Research, one funded by projects.**

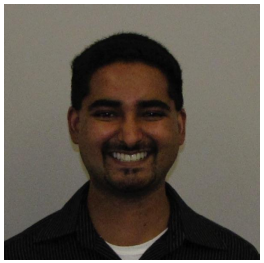
The Center concept has value. It provides cohesive organization of a diverse program of small projects, encourages connections between theory and experiment, and builds connections across Fermilab divisions, University of Chicago, US universities, and international groups

Center was part of the Cosmic Strategic plan developed in 2018-2019, and update in 2021

CPC activities depend on Postdocs!

Gabriela Marques
(Dark Energy)

Lauren Saunders
(CMB)

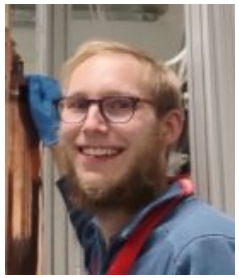


Joshua Sobrin
Lederman Fellow
(CMB)

Matt Young (CMB)

Jessica Zebrowski
Lederman/KICP
Fellow (CMB)

Sam McDermott
(Deep Skies AI/ML)



Stefan Knirck
(DM, Axions)

Anna Botti
(DM, CCDs)

Nate Saffold
Lederman Fellow
DM CCDs

Rebecca Nevin
(Deep Skies, AI/ML)

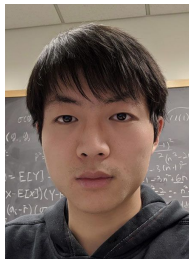
Sreevani Jarugula
(Deep Skies AI/ML)

Omari Paul
(Deep Skies AI/ML)

Brandon Roach
(CCDs, KICP)

Dylan Temples
Lederman Fellow,
MAGIS (Quantum)

Brenda Cervantes
Schramm Fellow
(DM, CCDs)



Huangyu Xiao
(Theory, KICP)

Hongwan Liu
(Theory, KICP)

Anastasia Sokolenko
(Theory, KICP)

Elena Pinetti
(Theory, KICP)

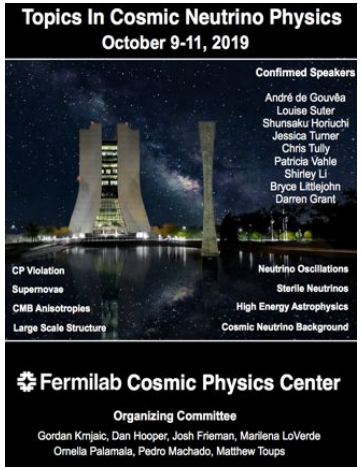
Ryan Linehan
(QIS)

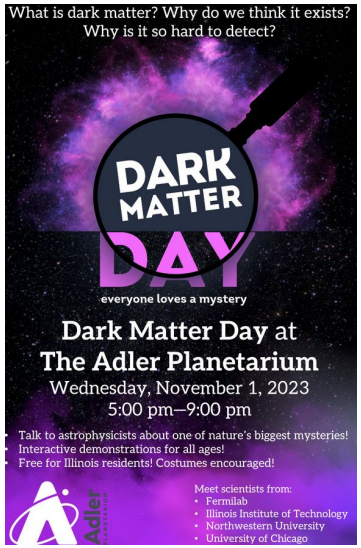
Cosmic Physics Center (CPC) 2021 reboot

Cosmic Science

- The CPC aims to serve the growing cosmic user community, following the successful Fermilab models of the LHC Physics Center and the Neutrino Physics Center:
  - roughly 100 annual on-site Cosmic users
  - over 700 Cosmic users of Fermilab computing facilities
- Fermilab provides a unique opportunity to connect to the rest of the HEP program and other emerging areas (e.g Quantum, AIML…)
- **Host and modestly support visiting scientists and students** to
  - formalize and expand hands-on training opportunities in hardware and detector development
  - enable joint analysis and cross-correlation of cosmic experiments
- **Host targeted workshops** to accelerate the pace of research
- **Develop and strengthen the cosmic synergies between Fermilab and local institutions** to realize the tremendous potential of the Chicagoland cosmic community
- **Organization for Snowmass/P5 Town Hall participation**
- Now Not funded as explicit task under Cosmic Research: rebranding visitor, seminar funds, LDRD, ECA

CPC Web pages: https://astro.fnal.gov/





CPC partnering with Adler Planetarium

Dark Matter Day Nov. 1, 2023 link

Fermilab Cosmic Strategic Plan 2019, updated 2021

- **Cosmic Microwave Background** (inflation, neutrinos) — Grow
  - **SPT 3G lead operations, CMB Stage 4** major roles
- **Dark Matter Detection** — Consolidate
  - **Axions**: lead lab ADMX*, develop Quantum sensors for next-gen expt
  - **Sub-GeV DM**:
    - SuperCDMS construction, operations; R&D at NEXUS
    - Skipper-CCD R&D and deployment: SENSEI /Oscura*
  - Completed deliverables for LZ project
  - Concept & trigger/DAQ for LDMX* (accelerator-based expt)
  - ***Dark Matter New Initiatives** (2 led by Fermilab)
- **Cosmic Surveys** (dark energy, dark matter, neutrinos) — Transition
  - **DES, LSST operations** (small but critical role in DESI ops)
  - **R&D toward next-gen spectroscopic survey** (LDRD)
- **Astro Theory program**
- **Cosmic Physics Center to provide connectivity and serve users**
- ***Cosmic activities flow from P5 drivers and from our core capabilities and synergize with other lab activities (Quantum, Neutrino, Energy...)***

CPC at P5 Cosmic Town Hall at LBNL Feb. 2023

CPC Visitor Program

- Foster collaboration between Fermilab and the community of cosmic frontier scientists.
- Participate in on-going experiments (DES, DESI, LSST/RUBIN, SCDMS, SENSEI/OSCURA, ADMX/ADMX-EFR, SPT-3G/CMB-S4)
- Investigate new technology development and experimental initiatives, such as quantum detector development for axion searches, detector fabrication and testing for cosmic microwave background experiments, innovative low-noise detector R&D, and advanced artificial intelligence and machine learning algorithm development.

Visitor program
- Visiting Scientists: Short and long term
- Visiting Students and teachers
- Fermilab scientists work with visitors to prepare applications for funding (e.g. URA visiting Scholar, QuarkNet, etc)

Village Housing Critical for Visitors program:

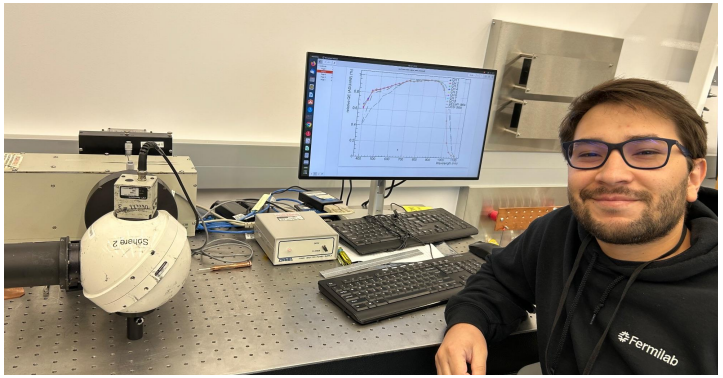
2021: 5 Visitors
2022: 11 Visitors
2023: 14 Visitors

Visitors strengthen our program and enable world leading science.

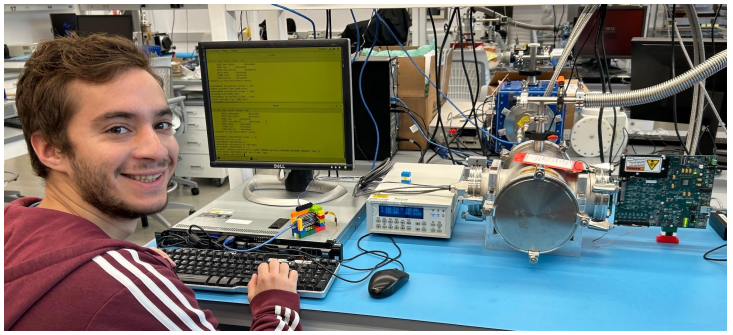
Current Visitors

Fabricio Alcalde (Scientist, Instituto Balseiro, Argentina)

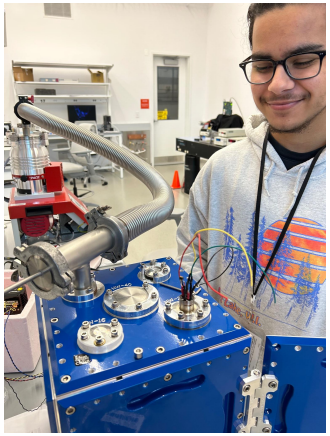
Terri Kim - (Rutgers)



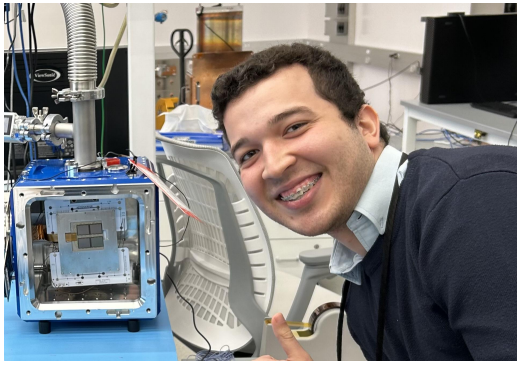
Blas Irigoyen (PhD student, UNS Argentina)



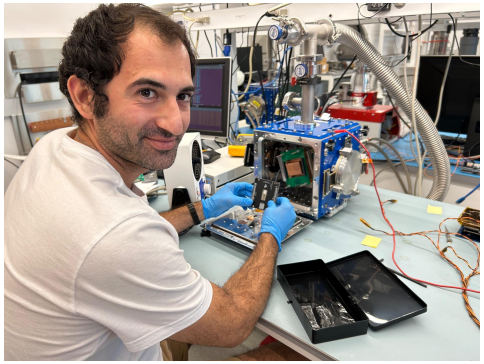
Santiago Perez (PhD student, UBA, Argentina)



Matthew Arteaga - (Geneva HS)

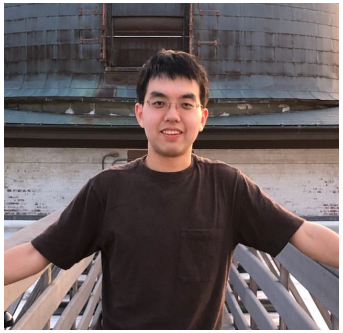


Giovanni Batista (Engineer, UNA Paraguay)

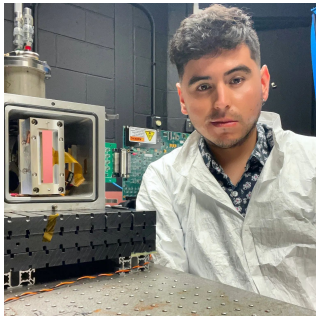


Augustin Lapi (Ph.D. student, UNS Argentina)

DOE Funded Student Visitors (incomplete list)



Kenneth Lin (CCDs; UC Berkeley)



Edgar Marrufo Villalpando (CCDs; UChicago)

Karia Dibert (CMB, UChicago)

Shreya Sutariya (CMB, UChicago)

DOE SCGSR/CGSR Students:

- Kennith Lin (Cosmology CCDs, 2023)
- Grace Cheshire (CMB 2022)
- Shreya Sutariya (CMB 2022)
- Alexander Hrycuik (CMB 2021)
- Edgar Marrufo (Cosmology CCDs, 2021)
- Nora Shipp (Dark Matter, DES 2017)

CPC GIRA (Graduate Instrumentation Research Award) winners

- Edgar Marrufo (Cosmology CCDs, 2022)
- Karia Dibert (CMB, 2021)

CPC Fellowship Program

Launched Fermilab CPC Fellowship Program in 2021

- Fellows will pursue novel concepts that enhance the current program at Fermilab and participate in current and future Fermilab experimental and theory efforts. Fellows are expected to spend significant time at Fermilab (2 weeks to 6 months), with the goal of expanding and sustaining an intellectual center of excellence within the laboratory. Fellows may receive support for travel and accommodations at Fermilab.

- There are three tracks for the fellowship:
  - **Track 1**: Support for experimental or theoretical researchers wishing to pursue novel concepts with Fermilab scientific staff to enhance or strengthen the current program at Fermilab.
  - **Track 2**: Support for researchers transitioning to the Cosmic Frontier from other fields, e.g., from the Energy Frontier, Intensity Frontier, Nuclear Physics, etc.
  - **Track 3**: Support for researchers seeking hands-on experience with instrumentation or who play a critical role in R&D, projects, or operations.

CPC Fellowship Program

Call for Fellowship Applications yearly if funding is available (sources vary)

2019 Josh Frieman awarded Distinguished Scientist Fellowship

“The Distinguished Scientist Fellowship was established to develop, sustain and promote excellence in Office of Science research through collaborations between institutions of higher education and national laboratories”

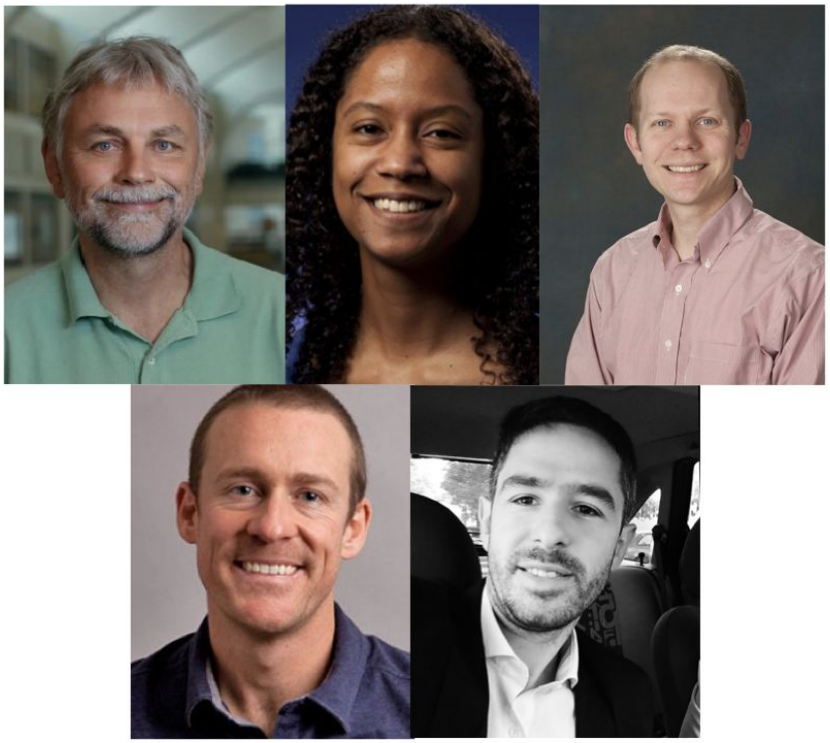
Josh has generously provided partial support for the fellowships each year.

- FY21 fellowships supported by Josh, ECA, project funds (total ~$50k)
- FY22 fellowships supported by Josh, LDRD funds (total ~$20k)
- FY23 fellowships supported by Josh, ECA funds (total ~$30k)

At June PAC I requested funding to continue and expand program:

- **secure funding of ~ $50k/year would allow broader program and more fellowships**
- organize workshops with support for Early Career scientists to attend
- explore options for supporting sabbaticals

2023 CPC Fellows



- **Klaus Honscheid (OSU), Marcelle Soares-Santos (UMich), Paul Martini (OSU), Kyle Dawson (Utah)**
  - Coordinated R&D for a Stage-5 Spectroscopic Facility
  - 4 x 2 week visits
  - Organizing Spec-5 instrument R&D workshop

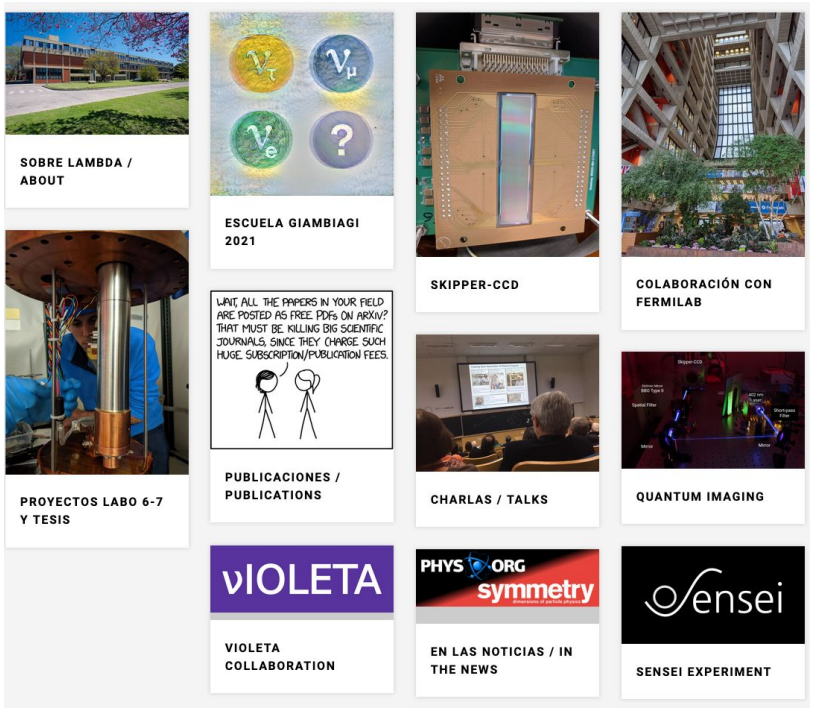
- **Fernando Chierchie (CONICET)**
  - Readout electronics for a Stage-5 Spectroscopic Instrument
  - 4-month visit for development of electronics

CPC helped develop strong connection with University of Buenos Aires and produced the Lambda Lab

http://lambda.df.uba.ar/portfolio/about/

CPC Scientists advise Students from Argentina

- Santiago Perez (Juan is his PhD Director). Santiago was the submitting author of World-Leading constraint on Milli-Charged Particles from the beam produced by SENSEI (https://arxiv.org/abs/2305.04964).
- Mariano Cababié (Javier is his PhD Director). Mariano completed his PhD Thesis and was the leading person and corresponding author in https://arxiv.org/abs/2106.08347 (published in PRApp)
- Manu Gaido (undergrad from Buenos Aires) came to FNAL to work with Alex Drlica-Wagner for 6 months on Skipper CCDs for cosmology and astronomy.
- First paper FNAL-LAMBDA published with data fully acquired at LAMBDA. https://arxiv.org/abs/2301.10891 (PRApp 2023)



Fermilab

Connections to Other Research Activities

Fermilab Cosmic Physics Center also provides organizational connection to efforts not funded by the DOE Cosmic Frontier program including:

Quantum: Aaron Chou gave talk at the Jan. '23 PAC

- Strong overlap in people and expertise with low mass DM experiments
- Qubits could reduce threshold for detection of DM by 10^{-4}

Fermilab LDMX Activities

- BSM model discrimination studies (Blinov, Krnjaic)
- HCAL development (Tran)

Broad FNAL/CPC Accelerator Based Dark Sector Efforts:

- Dark/Long Quest, DUNE DM, FerMINI (Blinov, Kelly, Tsai, Toups, Tran)
- Physics Opportunities at Beam Dump Facility with PIP-II Workshop (Estrada, Zettlemoyer, Toups, Yu)

CCD Development:

- IARPA: Gaseous Radioisotope Analysis In Situ Laboratory (Fernandez-Moroni, Estrada)
- NASA: "Development of Skipper CCDs for Robust Single-Photon Measurements in Future NASA Missions" (Drlica-Wagner, Estrada)
- Heising-Simons "Large-Format Multi-Amplifier Sensing CCDs for Astronomy and Cosmology" (Drlica-Wagner, Fernandez-Moroni)
- Heising-Simons "DarkNESS CubeSat : development of Skipper CCDs for X-ray astronomy" (Estrada)

… and many more!

Charge & Recommendations for June PAC meeting

- Charge: The PAC is asked to review the status of the Cosmic Physics Center (CPC), its role and impact within the domestic and international community. The PAC is also asked to review the CPC's strategic plan for the center operations in the post-pandemic era.

Recommendations from Jan. 2023

- Fermilab develop a comprehensive strategic approach (that includes prioritization) to light dark matter searches that leverages laboratory capabilities
- In concert with this Lab planning, the Fermilab Cosmic Frontier group should update their strategic plan, **including the vision and purpose of the Cosmic Physics Center.**
- The Laboratory works with DOE to secure adequate funding to support its Cosmic Frontier program and strategy.

Response from June ‘23 PAC (next presentation June ‘ 24)

Charge: The PAC is asked to review the status of the Cosmic Physics Center (CPC), its role and impact within the domestic and international community.

Executive Session: [...] the current rationale relies heavily on historical context and funding that is in danger of running out. Thus the justification and strategy for the Center would benefit from being updated to match the Lab’s evolving activities and strategy.

Findings

- The Cosmic Physics Center at Fermilab was founded around the same time as the LPC and has a history of promoting and defining the cosmic program at the Lab and beyond.
- The Center was part of the Cosmic Strategic Plan developed in 2018-19. That plan included: growing in CMB, consolidating in direct dark matter experiments, and refocusing in dark energy survey science.
- The Lab has between 15-20 FTE’s working on Cosmic Science. Several of them have won prestigious awards. They are in the process of updating the cosmic strategic plan.
- Funding for the cosmic frontier effort has decreased by 30% over the past years, and the Cosmic Center no longer enjoys its own funding.

Comments

1. **The effort to update the cosmic strategic plan is timely, especially given the opportunities due to progress in quantum sensing and accelerator-based searches for dark matter.**
2. **A vibrant visitors program would stimulate the intellectual environment.**
3. The current rationale for the Center relies heavily on historical context and funding that is in danger of running out. The justification and strategy for the Center would benefit from being updated to match the lab’s evolving activities and strategy

Recommendations

1. **Lab and Cosmic leaders should refine the overall strategy for the cosmic frontier and in the context of this strategy, reassess the vision for the CPC**

Summary

The Fermilab Cosmic Physics Center is almost 20 years old. The Cosmic program and the role of the Center have both evolved.

The strength of FNAL Cosmic program is derived from core Lab capabilities, spanning multiple Divisions/Directorates. The Center was designed to increase communication and collaboration between cosmic projects, with the rest of the FNAL program, and with the community

Recent developments in Quantum have many synergies with the Cosmic program - but we aren't very organized in this yet… Is there a "FNAL Cosmic Quantum strategic plan?"

People want to come to Fermilab for in-person hands on experience, to work with our scientists, make connections with theory and efforts in other areas of the HEP program

The CPC Fellowship program had a great start with minimal funding. We asked the Fermilab Director for $50k annual support to enable a strong, impactful program, no feedback yet.

What should the Role of the CPC be in the future?

- Fermilab provides a unique opportunity to connect to the rest of the HEP program and other emerging areas (e.g Quantum, AIML…)
- Cosmic Efforts are getting very diffuse, multiple funding sources, recent PAC criticism on lack of Cosmic Quantum organization/plan

Possible future CPC activities:

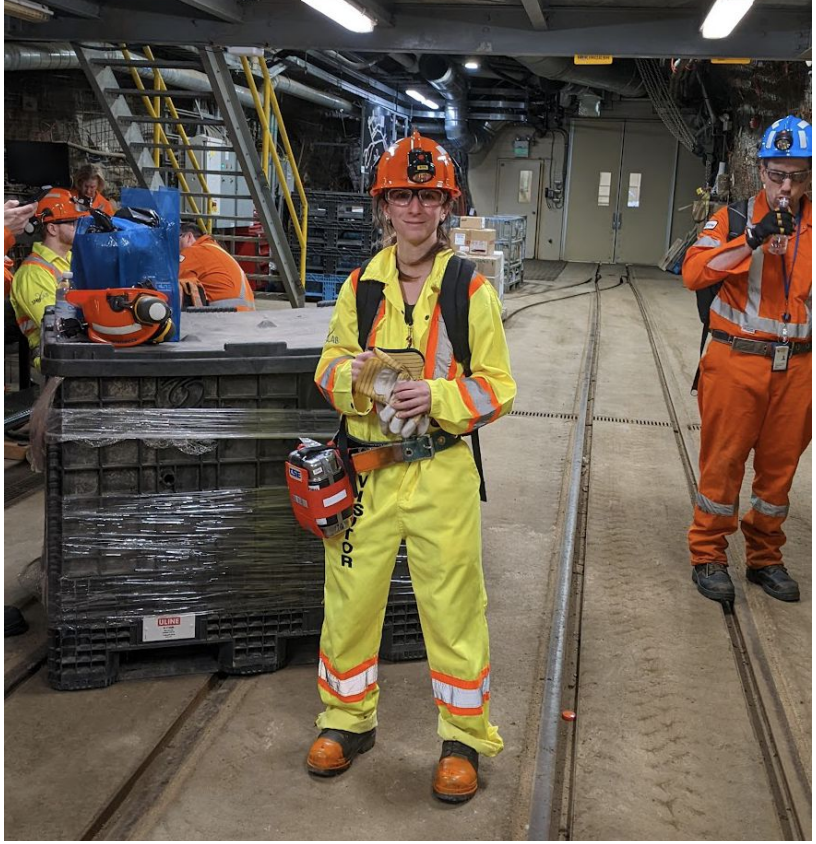
- Continue/expand to organize Seminars, journal clubs, workshops, outreach?
- Update/expanded email lists, encourage broader participation across the lab
- Continue and expand Fellows program
- Continue support for Visitors housing
- Strengthen connections to cosmic efforts across the lab - e.g. quantum, SQMS, Emergent Technology Division (ETD)...
- Connections to surrounding Universities, Chicago/KICP, Northwestern, UIUC…
- P5 report will set directions for next decade(s), comes out Dec. 7. Town Hall at FNAL Dec. 11. What role should CPC could have role in crafting response to P5 and in updating the Cosmic Strategic plan?
- Improved connections to Quantum, SQMS, develop Cosmic-Quantum Strategic plan
- Other areas - Accelerator DM, LDMX, PIP-II Beam Dump…

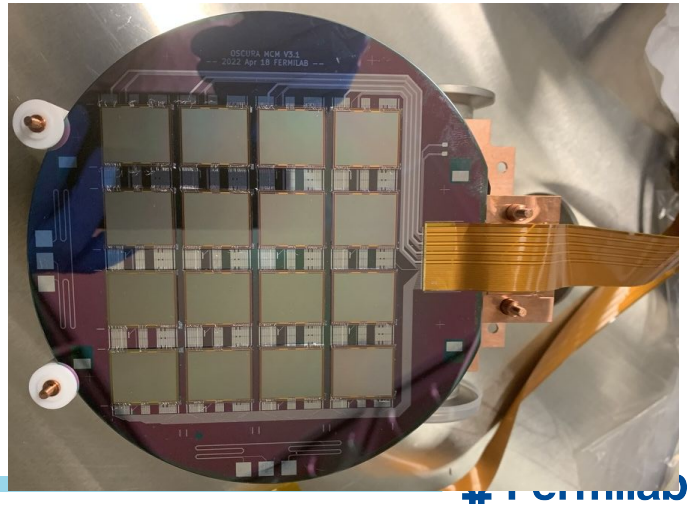
Extras

2021 CPC Fellow Ana Botti

Dr. Ana Botti (Universidad de Buenos Aires, Argentina)

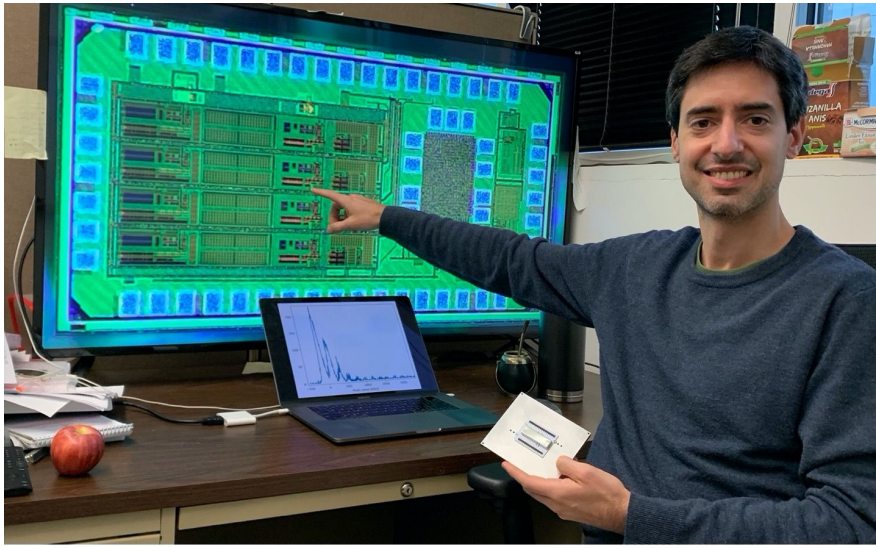
- Came to Fermilab as a Fellow in 2021 working on skipper-CCDs for dark matter
- 1 year visit funded by Javier Tiffenberg's ECA
- Accepted a FNAL postdoc in 2022
- Leading the effort to upgrade SENSEI in 2023.
- Leading the effort to fabricate low background circuits for OSCURA at ANL





2021 CPC Fellow Fabricio Alcalde

Dr. Fabricio Alcalde (Instituto Balseiro, Argentina)
•https://news.fnal.gov/2021/11/successful-demo-of-the-new-midna-asic/



- ASIC researcher (PhD in EE).
- Came to visit FNAL to work on the design and characterization of the MIDNA asic for skipper-CCDs.
- 6 m visit funded by OSCURA funds
- Big success! MIDNA works and meets the requirements for OSCURA.
- New versions of MIDNA could be used by other skipper-CCD experiments and also for more general imaging applications with skipper-CCD.

Since his visit he got a position as a researcher in the scientific system in Argentina (CONICET), Juan Estrada is his co-supervisor and his research is focused on the OSCURA program.

2022 Fellowships

Fermilab CPC Fellowships Awarded
February 22, 2022

- Dr. Julia Campa (Instituto de Física de Cantabria; IFCA CSIC-UC)
  - Came to FNAL to work on CCD characterization for imaging experiments.
  - 4 month visit funded by LDRD and OSCURA
  - After her visit she moved to a position as professor at Universidad de Cordoba (Spain).

- Dr. Peter Nugent (LBNL, Berkeley)
  - Came to FNAL to work on the Development of the La Silla Schmidt Southern Survey (LS4). All the sensors for this instrument have now been tested and are ready for installation
  - 3 months visit funded by Josh and LDRD

CPC Hosted DOE SCGSR/CGSR Students:

- Nora Shipp (Dark Matter, DES 2017)
- Edgar Marrufo (CCDs, Cosmology 2021)
- Kenneth Lin (CCDs Cosmology 2023)
- Alexander Hrycuik (CMB 2021)
- Grace Cheshire (CMB 2022)
- Shreya Sutariya (CMB 2022)

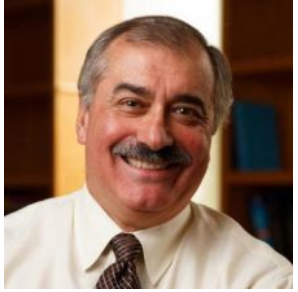
CPC GIRA (Graduate Instrumentation Research Award) winners

- Edgar Marrufo (CCDs, Cosmology 2022)
- Karia Dibert (CMB, 2021)

Cosmic LDRD & Other Related Grants (plus private)

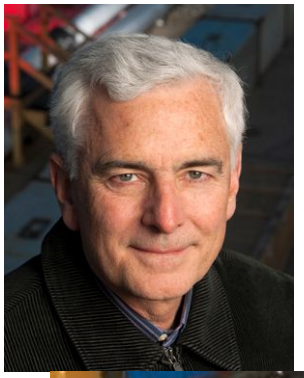
- **Fermilab supported LDRD Efforts:**
  - Scintillating Bubble Chambers: superheated argon for low-mass WIMP and CEvNS detection
  - Pixel-configurable CCD's for cosmological applications
  - Development of Microwave Readout Electronics for Massively Multiplexed Arrays of TES
  - Cryogenic photon sensors for the low mass frontier
  - 10 kg skipper-CCD development for next gen dark matter/neutrino experiments
  - MKIDs sensors for optical and near-IR
  - Dark Matter as Sterile Neutrino Search Satellite: Cubesat to look for the 3.5 keV line
  - Deep Learning Algorithms
- **QuantiSED/Dark Matter New Initiatives:**
  - Qubit single photon detection for axion searches (QuantiSED)
  - Skipper CCD's for quantum imaging (QuantiSED)
  - Design of next phase of ADMX to search for axions in 2-4 GHz range (DM New Initiatives)
  - Design of OSCURA, a 10-kg Skipper CCD dark matter experiment (DM New Initiatives)
  - Trigger/DAQ for ADMX (DM New Initiatives)
- **DOE R&D Grant** for CMB-S4 detectors and readout development
- **DOE Early Career:**
  - 2021 Nord: Simulation-based inference for cosmological parameter estimation and discovery
  - 2018 Bowring: Microwave Single-Photon Sensors for DM Searches and Precision Neutrino Measurements
  - 2018 Tiffenberg: Towards table-top neutrino detectors: A 10 kg Skipper-CCD experiment (2018)
- **DOE Late Career:** Office of Science Distinguished Scientist Fellow Award

Directors



Rocky Kolb Director 2004-2006

Scott Dodelson Director 2006-2008



Craig Hogan Director 2008-2018

Brenna Flaugher Interim/acting Director 2019-2021

Josh Frieman Director 2021-present