Status of the Fermilab Cosmic Physics Center

Brenna Flaugher

Fermilab PAC Meeting

June 6, 2023

Charge & Recommendations

•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.

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.”

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

Early Years

Diverse program: Cosmic Rays, Direct Dark Matter, Dark Energy, Theory

Astro Theory Dept. moved up to the remodeled 6th floor west side, mixed in with Experimental Astro office space on 6 and 7 West.

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

Established named Fellowships (Schramm, Brinson) and a strong visitor program

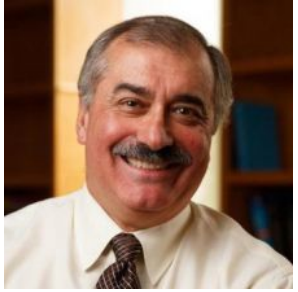
Established two houses in the Village for Astro visitors. Usually fully booked.

Postdocs were organizationally in the Center and organized Center activities (seminars, journal club, chalk-talks, BBQs). Center provided mentorship structure.

Funding of visitors through research budget plus leveraging other sources, e.g. URA visiting scholars, Summer Student programs, project and operations funds etc.

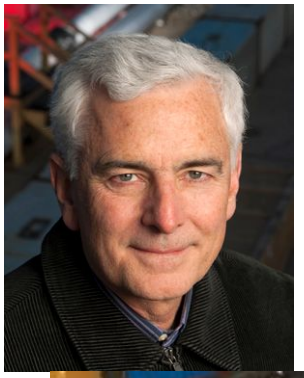
Held retreats for strategic planning 2007, 2009, 2010, 2012

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

Cosmic program and Center evolution in 2010's

Dark Energy Survey Camera project finished in 2012! DES observing continued until Jan. 2019. Full cosmology constraints expected in 2024/25. Operations expertise transitioned to LSST/DESC, Rubin Operations and DESI.

2014 P5 Report Impact: Focus on G2 Dark Matter experiments (SuperCDMS, LZ, ADMX) support for DESI, LSST and CMB-S4

HEP was NOT enthusiastic about Cosmic Centers (every Lab wants a Cosmic Center, University groups would rather have the funding directly). Nigel preferred line management organization.

Funding specifically for Center activities and management was gradually reduced to ~zero from ~2012-2018 as overall pressure on research budget increased. Two houses in the village still provide housing for visitors: one funded by Research, one funded by projects.

The Center concept has value: provides cohesive organization of a diverse program of small projects, encourages connections between experiments and with astro theory, rest of Fermilab program, University of Chicago, US universities and international groups

Center was part of the Cosmic Strategic plan developed in 2018-2019

COVID:

Seminars and journal club continued on Zoom

Provided personal connection in very strange period

Had many requests from new people to tune-in

When people were allowed back to Fermilab, hands on efforts continued at Sidet. People in offices in Wilson Hall were slower to come back.

When visitors were allowed again, they came!

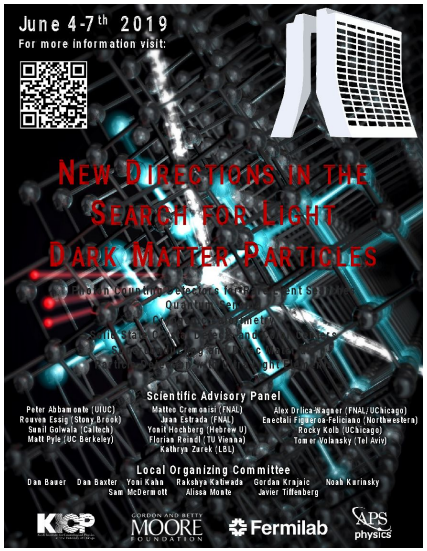
Fermilab Cosmic Strategic Plan 2019, updated 2021

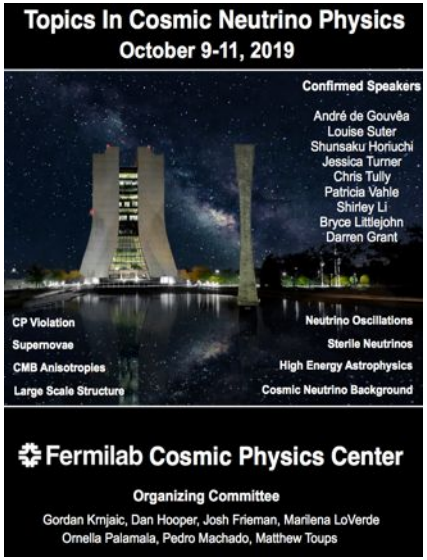
- **Cosmic Microwave Background** (inflation, neutrinos) — Grow
  - **SPT 3G lead operations, CMB Stage 4** major roles
- **Dark Matter Detection** — Consolidate
  - **Axions**: lead lab ADMX*, develop Quantum sensors for next-gen expt
  - **Sub-GeV DM**:
    - SuperCDMS construction, operations; R&D 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...)*

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
  - Hosted 2 in 2019. **COVID and Site Access issues have made recent workshops difficult.**
- 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





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

CPC at P5 Cosmic Town Hall at LBNL

Some CPC Highlights

Highlights

Edgar Marrufo Villalpando Wins Graduate Instrumentation Research Award

December 16, 2022

University of Chicago graduate student Edgar Marrufo Villalpando was recently awarded the Graduate Instrumentation Research Award from the APS Division of Particles and Fields. Edgar works at SiDet with CPC Scientists on the developing "Skipper CCDs for Dark Matter Measurements with Cosmic Surveys". Congratulations Edgar! Read more about the DPF Instrumentation Awards here.

Dark Matter Day 2022

October 17, 2022

The Fermilab CPC is partnering with Dark Matter Coffee to host Fermilab's 4th annual Dark Matter Day event. This year Dark Matter Day will be held at Dark Matter Coffee's Star Lounge Coffee Bar in Chicago on Sunday November 6th starting at 1PM (don't worry, the event will be recorded if you can't make it... More »

Brian Nord Wins DOE Early Career Research Award

May 27, 2021

Fermilab Cosmic Physics Center scientist Brian Nord was awarded a DOE Early Career Research Award from the Office of High Energy Physics for "for simulation-based inference for cosmological parameter estimation and discovery". Congratulations Brian! To read more about the award see the Fermilab announcement here or the DOE Early Career Award webpage. T

Tagged: AI/ML, award

Dark Energy Survey 3-Year Results

May 27, 2021

The Dark Energy Survey (DES) released new results today using the largest ever sample of galaxies observed over an enormous piece of the sky to produce the most precise measurements of the universe's composition and growth to date. DES scientists (include many scientists at Fermilab) measured that the way matter is distributed throughout the universe... More »

Tagged: dark energy, dark matter, DES

Fermilab

CPC Activities 2022/2023

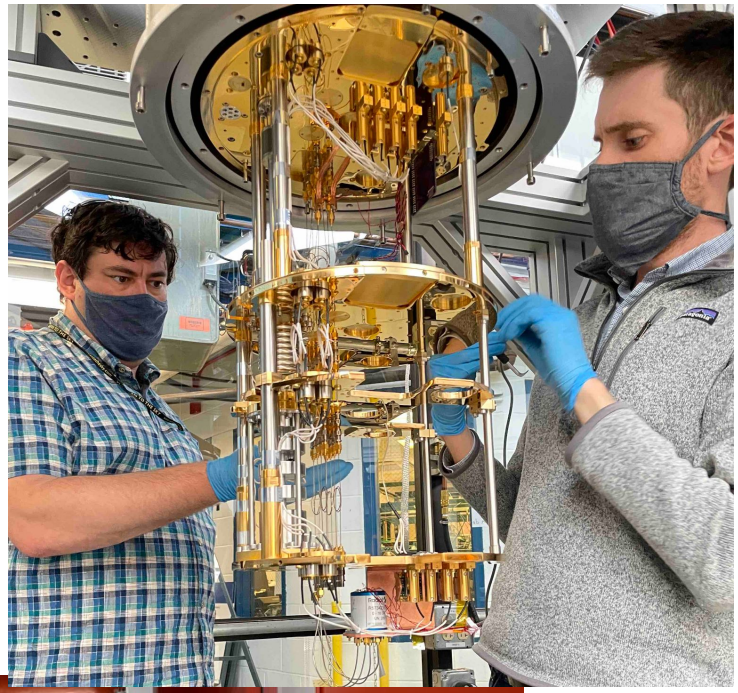
- Updating Cosmic Strategic Plan (in progress)
- Annual Meeting in ~ Oct. when new postdocs arrive to welcome new arrivals, make connections, shift new people into active roles.
- Postdocs organize many activities
  - Astro Seminars Monday 2pm
  - Munch Journal Club – Monday 1pm
  - Astro-ML Journal Club Wednesday 12pm
  - Astro-ML Educational Club - Monday 3pm
  - Pre-Covid: Chalk talks – informal/no slides 20 min presentation and discussion, has not restarted
- Seminars and Munch now in-person only to encourage people to come into the lab
  - Activities are pretty well attended
  - Monday's have good occupancy, rest of the week is a bit thin in WH but Sidet is very active
- CCD lab and CMB-S4 are moving into IERC, consolidating effort in Wilson Hall

CCD Lab in IERC - lots of beautiful space

Postdoc Brenda Cervantes setting up CCD Lab in IERC

CMB Lab in IERC

Dilution refrigerator for CMB-S4 testing currently in Sidet, will move to IERC. CMB-S4 will have 6 high throughput cryostats/DRs in this area for module testing



CPC Visitor Programs

- 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 planned so far

Site access issues have made visiting increasingly difficult, and are eroding enthusiasm for future visits. Visitors strengthen our program and enable world leading science.

Visitors strengthen our program!

Aleksandra Ciprijanovic

AI/ML, DES and LSST

Came as visitor for a month in 2019 funded by Brian Nord's LDRD

Joined Fermilab as a postdoc in 2020

2022 Wilson Fellow!

Brenda Cervantes-Vergara

Came as visitor in 2022 funded by Skipper CCD/OSCURA

Joined Fermilab as Schramm Fellow/Postdoc in 2023!

CPC Fellowship program

Launched a CPC Fellowship program in 2021

Fellowship Program:

- 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, project, ECA funds (total ~ $50k)
- FY22 fellowships supported by Josh, LDRD funds (total ~ $20k)
- FY23 call for fellowships supported by Josh (~ $25k) . Call for applications just opened, will close July 28. Additional support may be possible depending on applicants

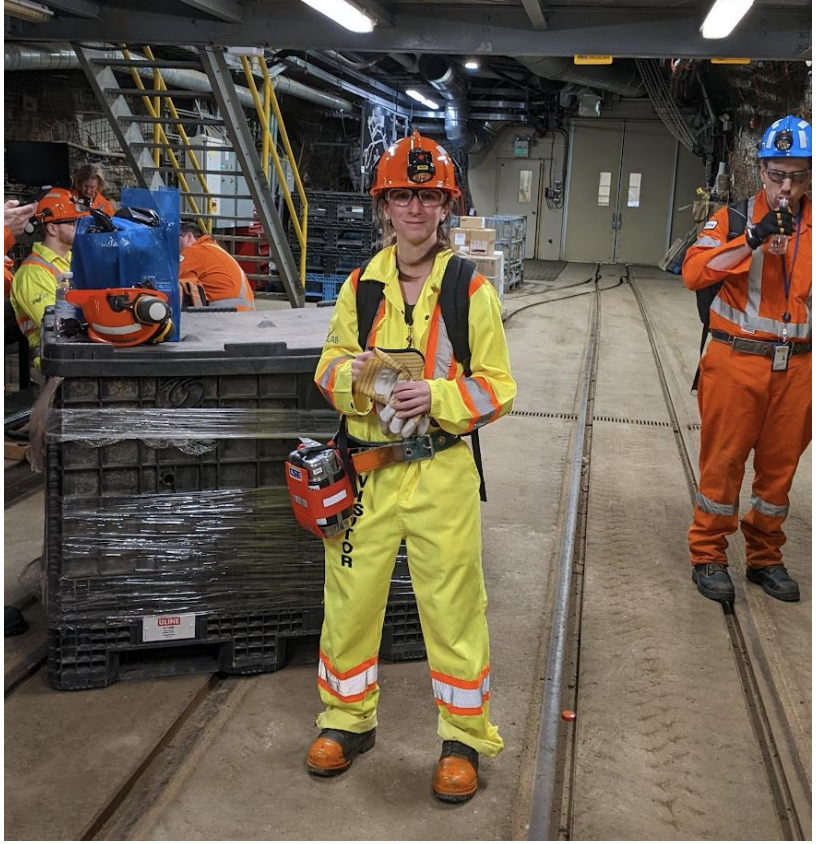
Would like to expand program:

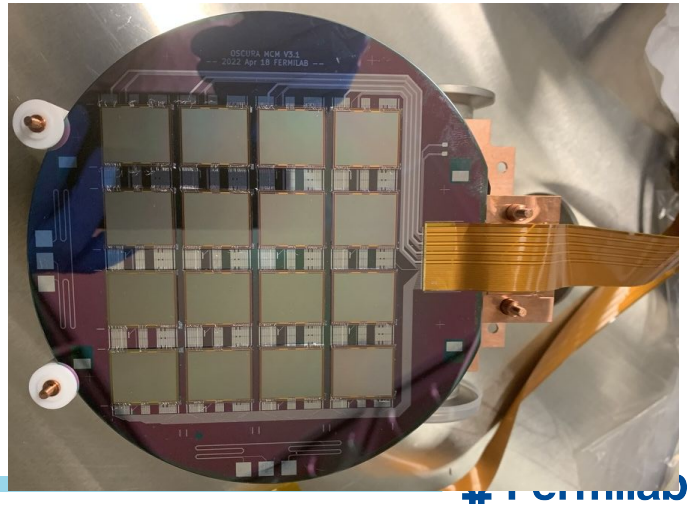
- secure funding of ~ $50k/year would allow broader program and more fellowships
- expand committee to include university representatives
- organize workshops with support for ECA to attend
- explore options for supporting sabbaticals

2021 CPC Fellow Ana Botti

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

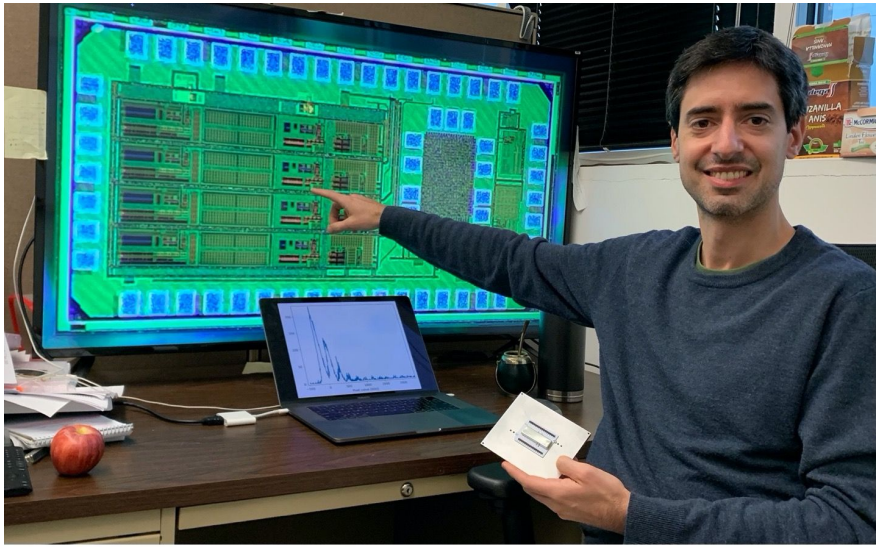
- Came to Fermilab as a Fellow in 2021 working on skipper-CCDs for dark matter
- 1 year visit funded by Javier Tiffenberg's ECA
- Accepted a FNAL postdoc in 2022
- Leading the effort to upgrade SENSEI in 2023.
- Leading the effort to fabricate low background circuits for OSCURA at ANL





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

CPC GIRA (Graduate Instrumentation Research Award) winners

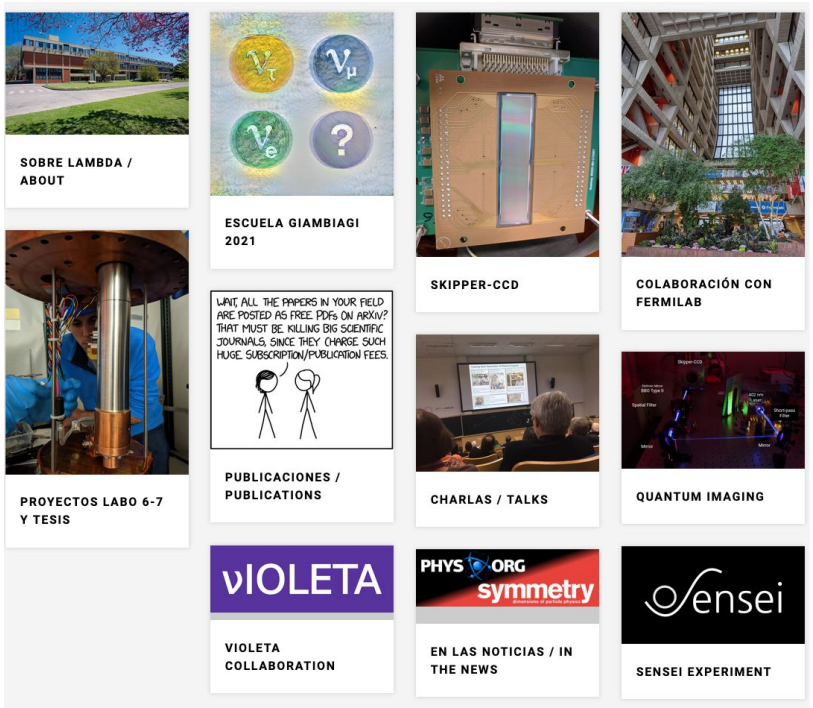
- Edgar Marrufo (CCDs, Dark Matter 2022)
- Karia Dibert (CMB, 2021)

Strong connection with University of Buenos Aires produced the Lambda Lab

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

CPC Scientists advise Students

- 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 is defending his Thesis next week and was the leading person and corresponding author in https://arxiv.org/abs/2106.08347 (published in PRApp)
- Manu Gaido an Undergrad currently at FNAL working with Alex Drlica-Wagner
- First paper FNAL-LAMBDA published with data fully acquired at LAMBDA. https://arxiv.org/abs/2301.10891 (PRApp 2023)



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

CPC connections to Non-Cosmic Research Activities

Cosmic Center also provides organizational connection to efforts not funded by Cosmic research 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}

LDMX FNAL Activity

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

LDRD: Accelerator-based Dark Matter Initiatives at Fermilab feasibility studies for various experimental possibilities (Blinov, Kelly, Krnjaic, Toups, 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)

NASA: "Development of Skipper CCDs for Robust Single-Photon Measurements in Future NASA Missions"

Gaseous Radioisotope Analysis In Situ Laboratory (GRAIL) Program (IARPA): Skipper CCD application

Conclusions

The Fermilab Cosmic Physics Center is almost 20 years old

We are updating the Cosmic Strategic plan

Cosmic program and CPC have evolved with changing funding environment

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 but is not sustainable in its current form

We would like to grow the fellowship program, provide support for visitors who strengthen our program, give the community access to the unique facilities and vibrant cosmic program at Fermilab

Secure funding is needed, $50k annually would enable a strong, impactful program