

Directional dark matter searches

CNP Research Day 2024

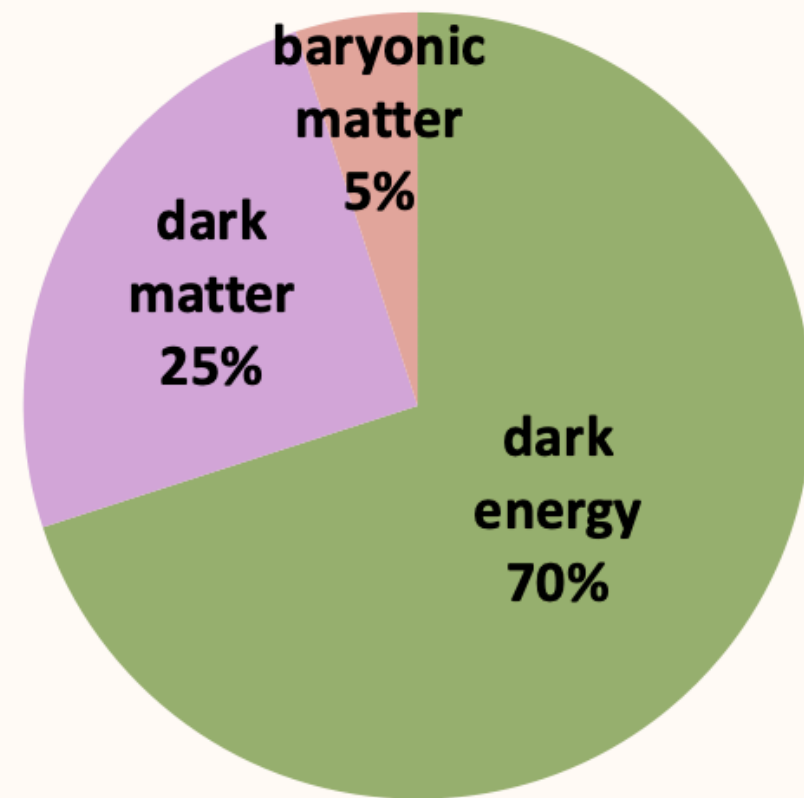
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The Center for
Neutrino Physics

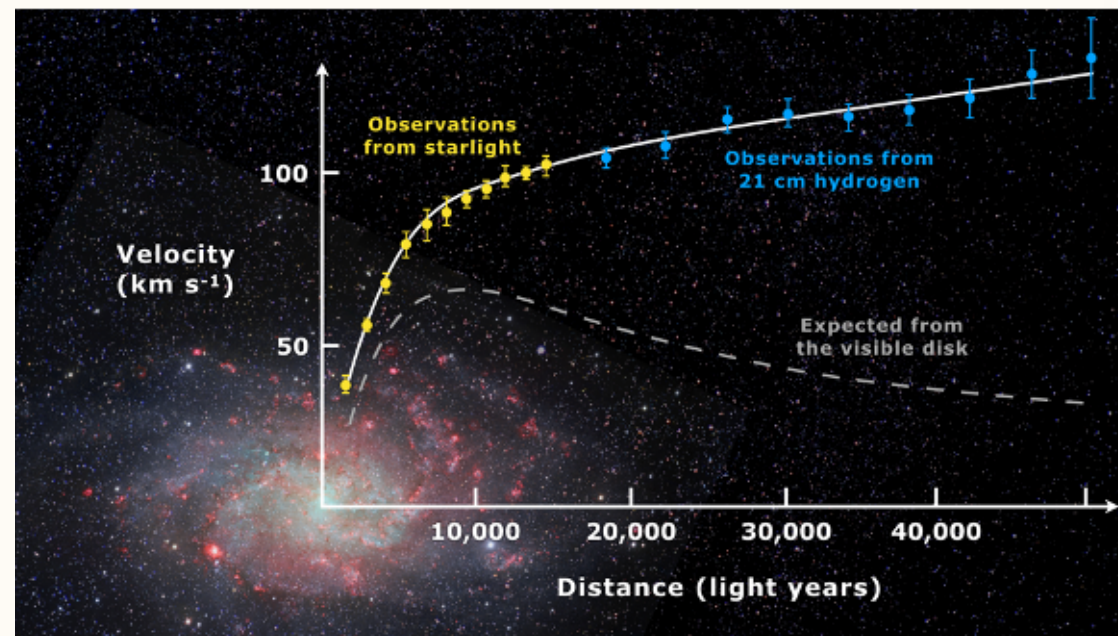


Dark matter context



- Almost a century since it was proposed, and it has not yet been detected.
- The particle nature of DM remains unknown

EVIDENCE



Flattening of galaxy rotation curves



Small gravitational lensing effects

The leading experiments looking for DM use liquid noble gas detectors or milli-Kelvin crystal bolometers.



XENON



PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

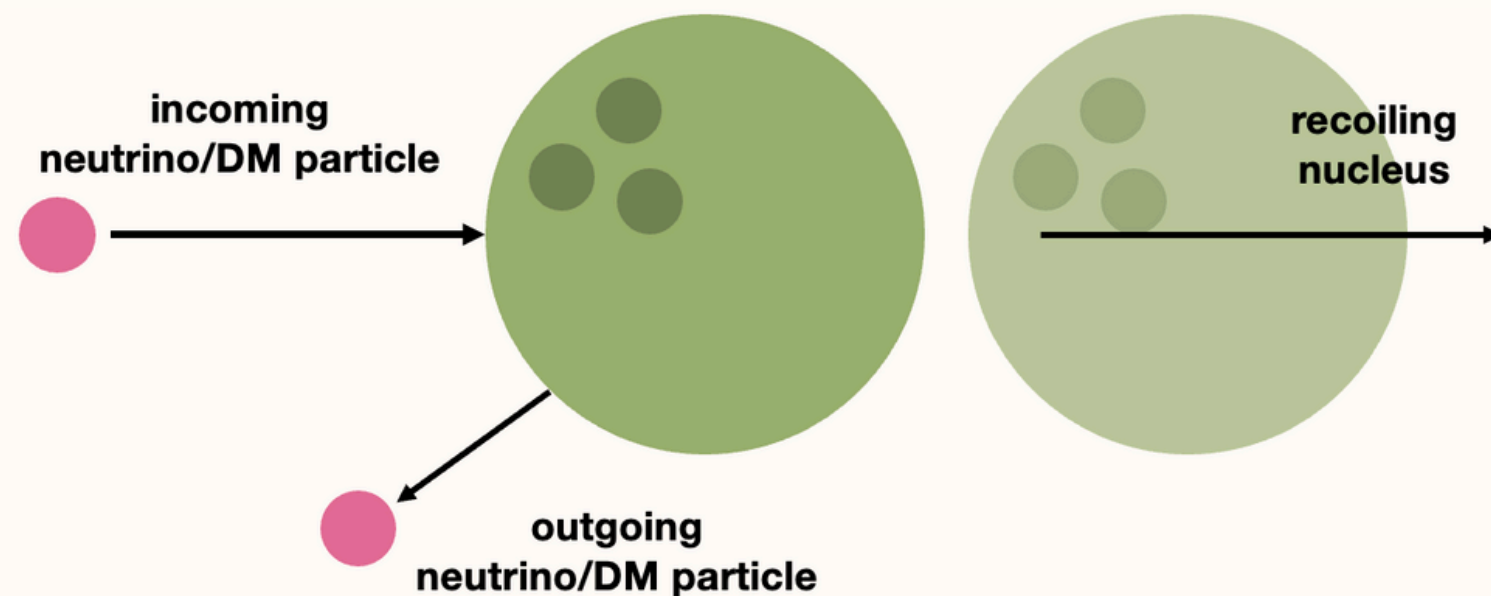
What we know about DM

- It's abundant
- It weakly interacts with matter
- It's elusive
- It's neutral

DM behaves a lot like neutrinos

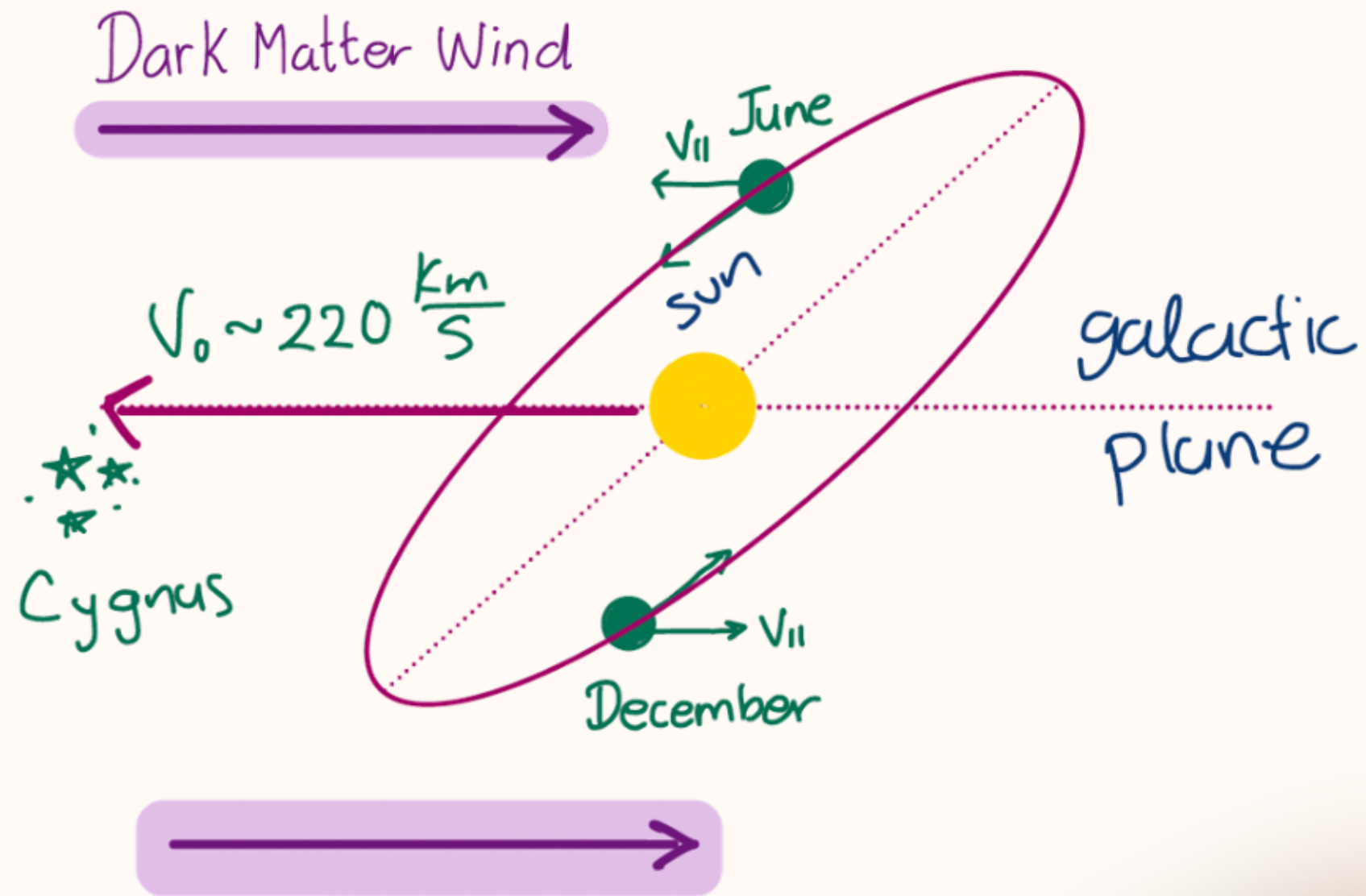
Coherent Elastic Neutrino Nucleus Scattering (CE ν NS) provides a blue print for an analogous Coherent Elastic DM–Nucleus Scattering (CE χ NS)

$$\frac{d\sigma}{dE_r} = \begin{cases} \frac{G_F^2}{8\pi} m_N N^2 \left[1 - \frac{m_a E_r}{2E_\nu^2} \right] & \text{CE}\nu\text{NS} \\ 4\pi\epsilon^2 Z^2 \alpha\alpha_D \frac{2m_N E_\chi}{p_\chi^2 (m_V^2 + 2m_N E_r)^2} & \text{CE}\chi\text{NS} \end{cases}$$

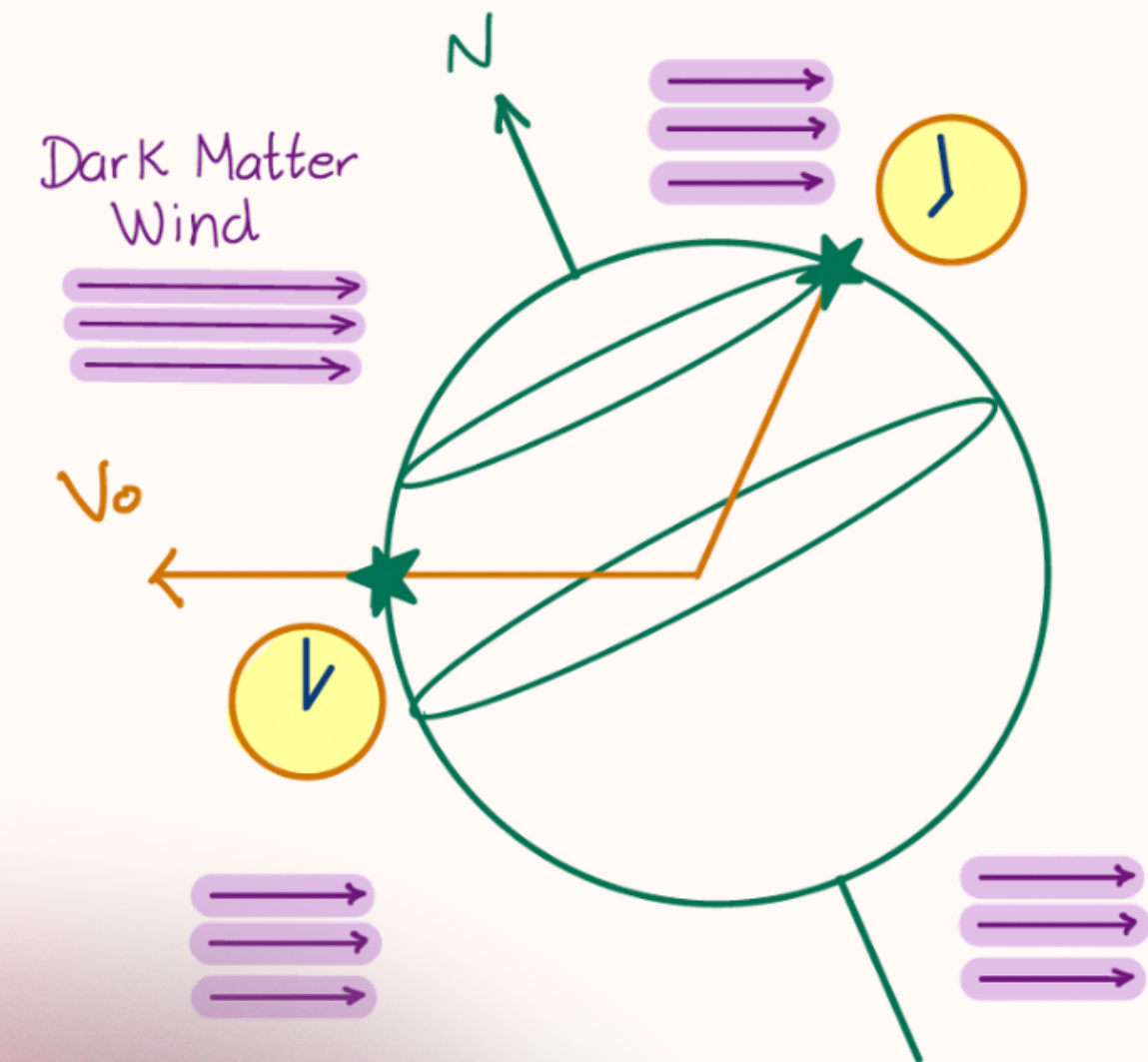


The sensitivity of an experiment will be proportional to the product of target mass and exposure time

Where do we look for DM?



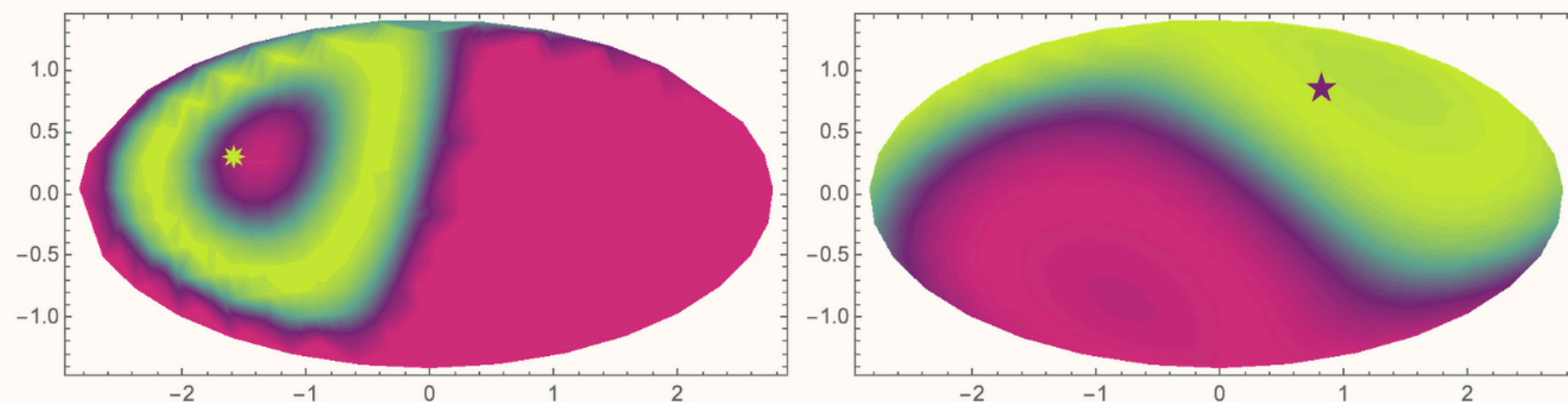
The relative motion of the Solar System with respect to the DM Galactic Halo, and the Earth's axis of orientation establish a difference in the direction of incoming DM particles.



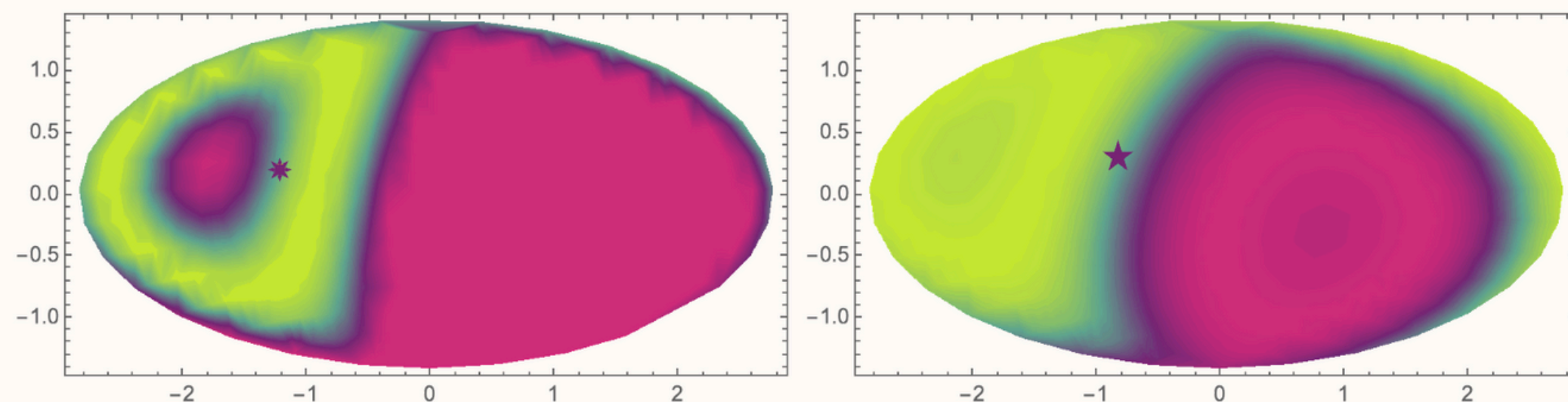
- Producing an **annual** and **daily modulation**
- While the Lab position changes during the day, the **DM wind direction is fixed**.

Where do we look for DM?

September 6, 2023, at 6:00 at Blacksburg, VA

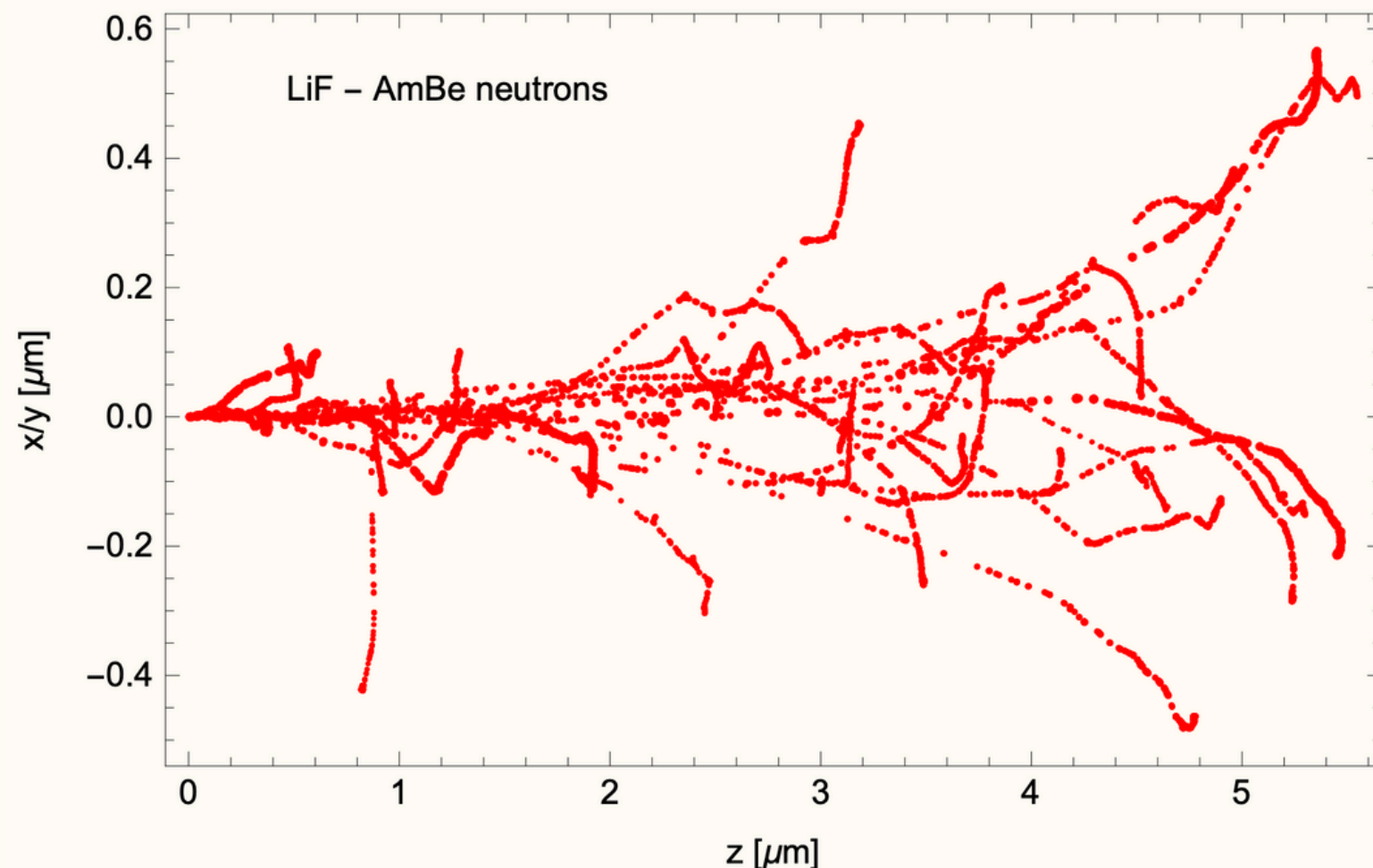
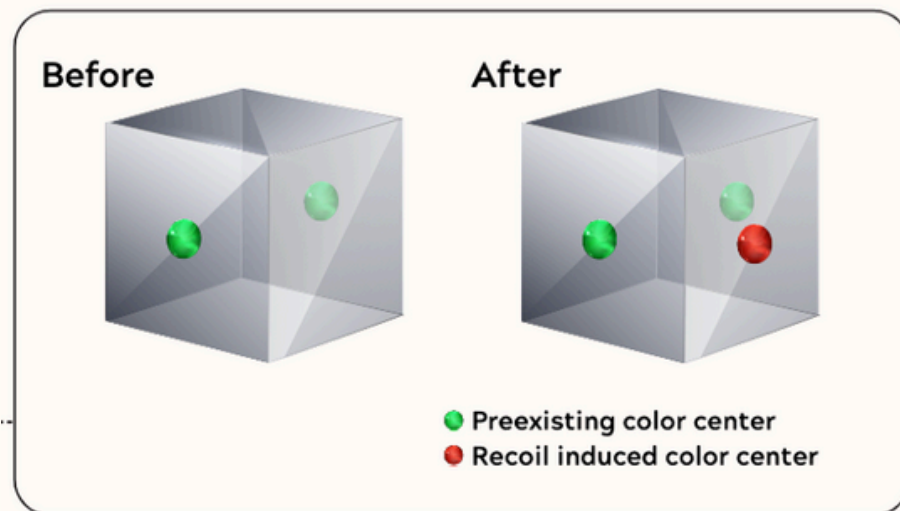


February 6, 2023, at 6:00 at Blacksburg, VA



Hammer Projection of the Solar 8B neutrino (left) and the WIMP (right) angular differential event rate for recoil energy $E_r = 1.66$ to 5 keV, a Xenon target and a WIMP mass $m_\chi = 100$ GeV.

PALEOCCeNe (PAssive Low Energy Optical Color CEnter Nuclear rEcoil) [💡]

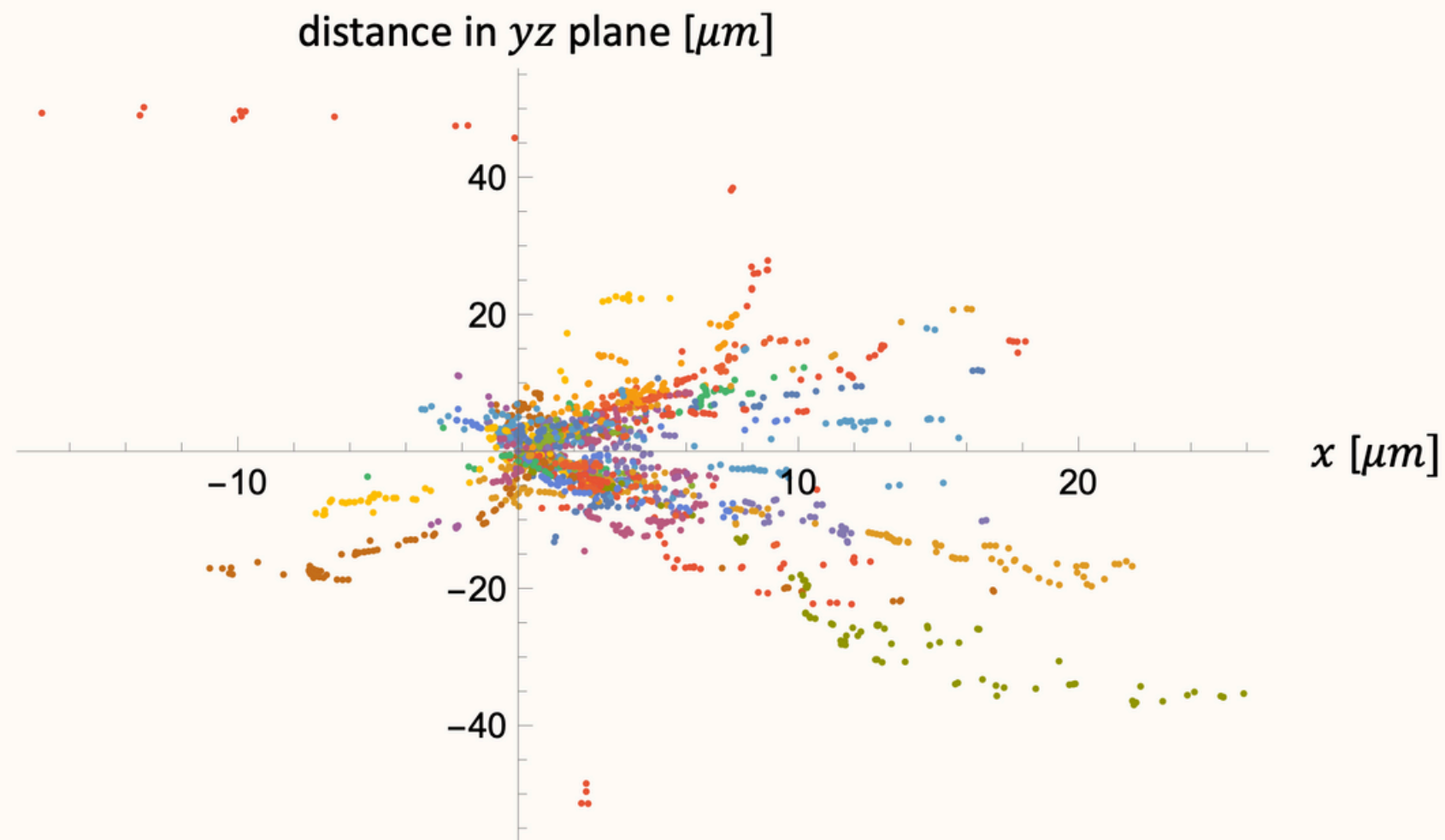


- When an event occurs, the **recoiling nucleus** will lose its **kinetic energy to the crystal atoms**.
- If $E_{\text{transfer}} > E_{\text{binding}}$, it will create a **vacancy** that traps an electron: a **color center**.
- The energy levels of it can be excited by light and de-excited by photon emission.
- Individual color centers can be detected using **Fluorescence Microscopy**.
- **The threshold damage energy has a dependence on the crystal direction** that allows to provide directional information of the interaction.

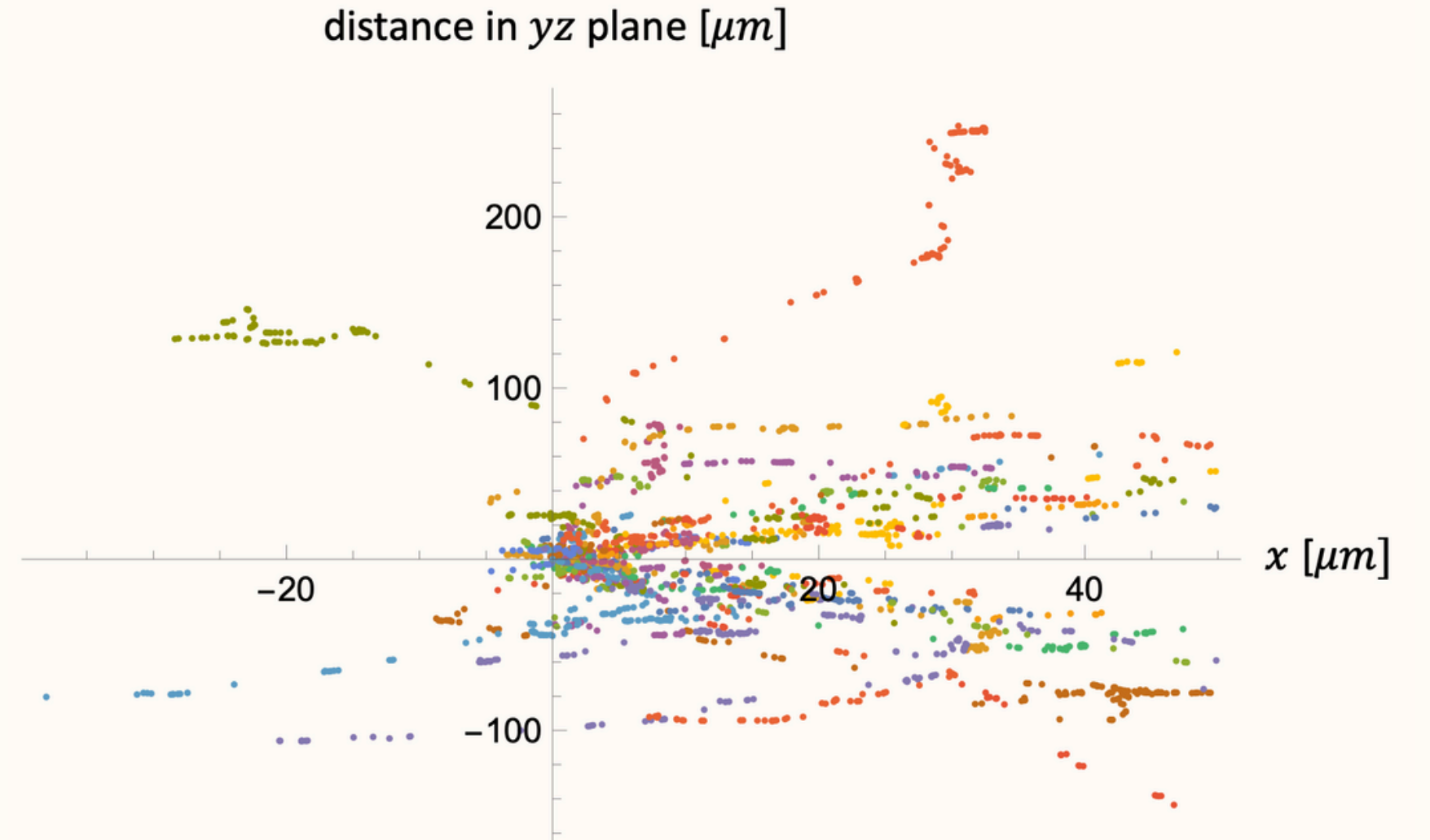
[💡] Bernadette K. Cogswell et al.,
Phys. Rev. Applied 16, 064060
(2021), 2104.13926.

The Range of Ions in Matter (TRIM) simulations of solar neutrinos

CE ν NS in Lithium



CE ν NS in Fluorine



Summary

Research Focus

- How to infer the direction of incoming particles like dark matter or neutrinos.
- Directionality is linked to the relative motion of the Solar System and the Earth's orientation, creating daily and annual modulations.

Current Work

- Using TRIM software to simulate recoil events from $CE\nu NS$ and $CE\chi NS$.
- Analyzing defect locations in crystals, specifically for lithium (Li) and fluorine (F).

Hopefully

Our work on directional reconstruction could help distinguish signal from noise and provide new insights into experimental development



Thank you