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The Dark Side of the Universe:

Hunting Dark Matter with Liquid Noble Gas Detectors

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PH.D. Seminars, Season 10 Episode 4
05/06/2024

DARKSIDE

Outline

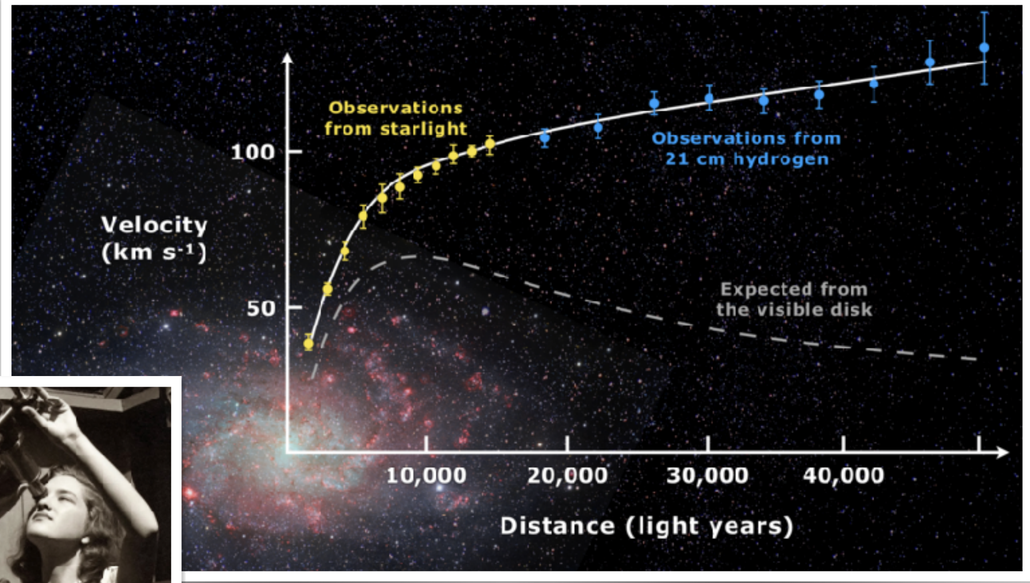
- Introduction to Dark Matter
- Direct Detection
- Liquid Noble Gas Detectors
- The DarkSide-20k Experiment

Artwork by Sandbox Studio, Chicago with Corinne Mucha

Who turned off the light?

- **1933**: F. Zwicky predicted the existance of additional (invisible) mass from the motion of galaxies in the **Coma Cluster**:
  - Virial Theorem application requires more mass respect to the luminous one!
- **1970**: V. Rubin found the first ever indirect evidence of DM by observing **Galaxies rotation's curves:**
  - Flat distribution instead of exponentially decreasing one imply the presence of additional invisible matter!

Coma Cluster and F. Zwiky

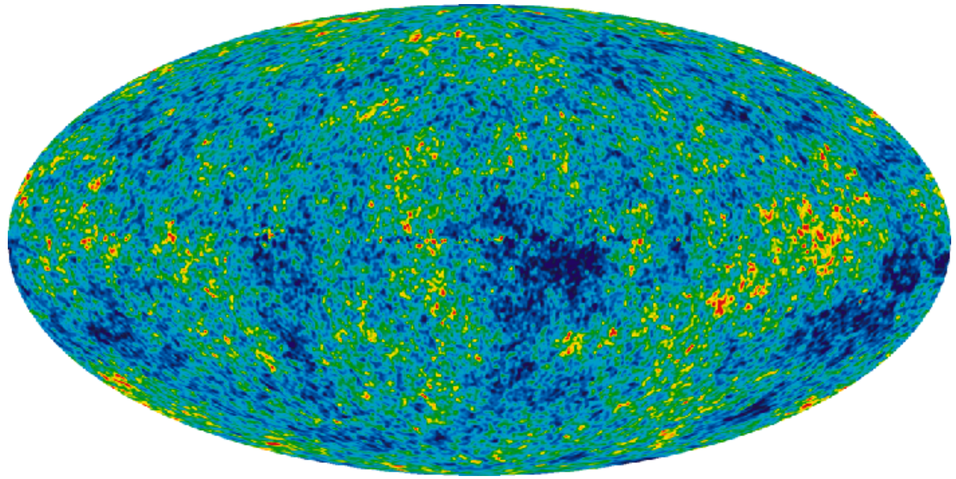


V. Rubin and Galaxy rotation curve example

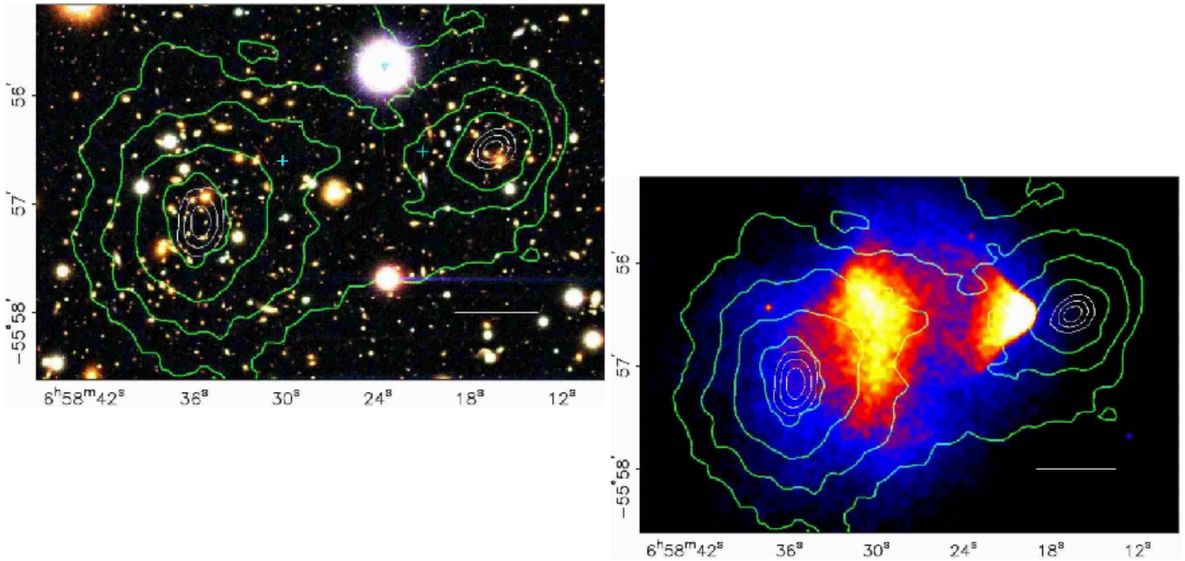
Who turned off the light?

Other **Cosmological evidences**:

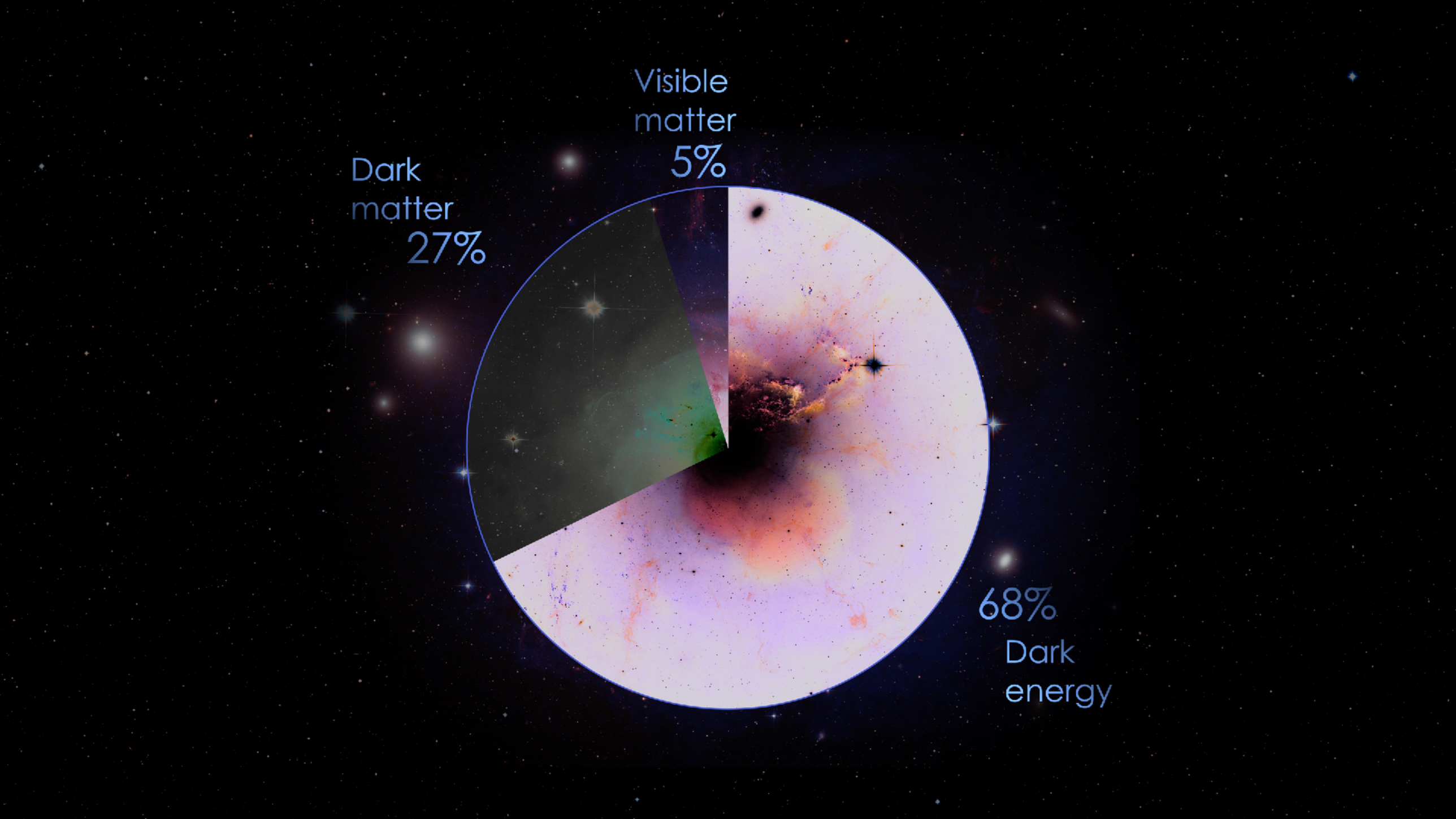
- Since 1980 evidence of Dark Matter were found in the pattern of anisotropies of the **cosmic microwave background** (CMB).
    - Necessary to explain current Universe Structure under the ΛCDM paradigm.
- Gravitational **Lensing** effects.
    - Bullet Cluster: mass of the system (x-ray map) does not trace the reconstructed lensing signal.



CMB Temperature anisotropy data from WMAP (2010)



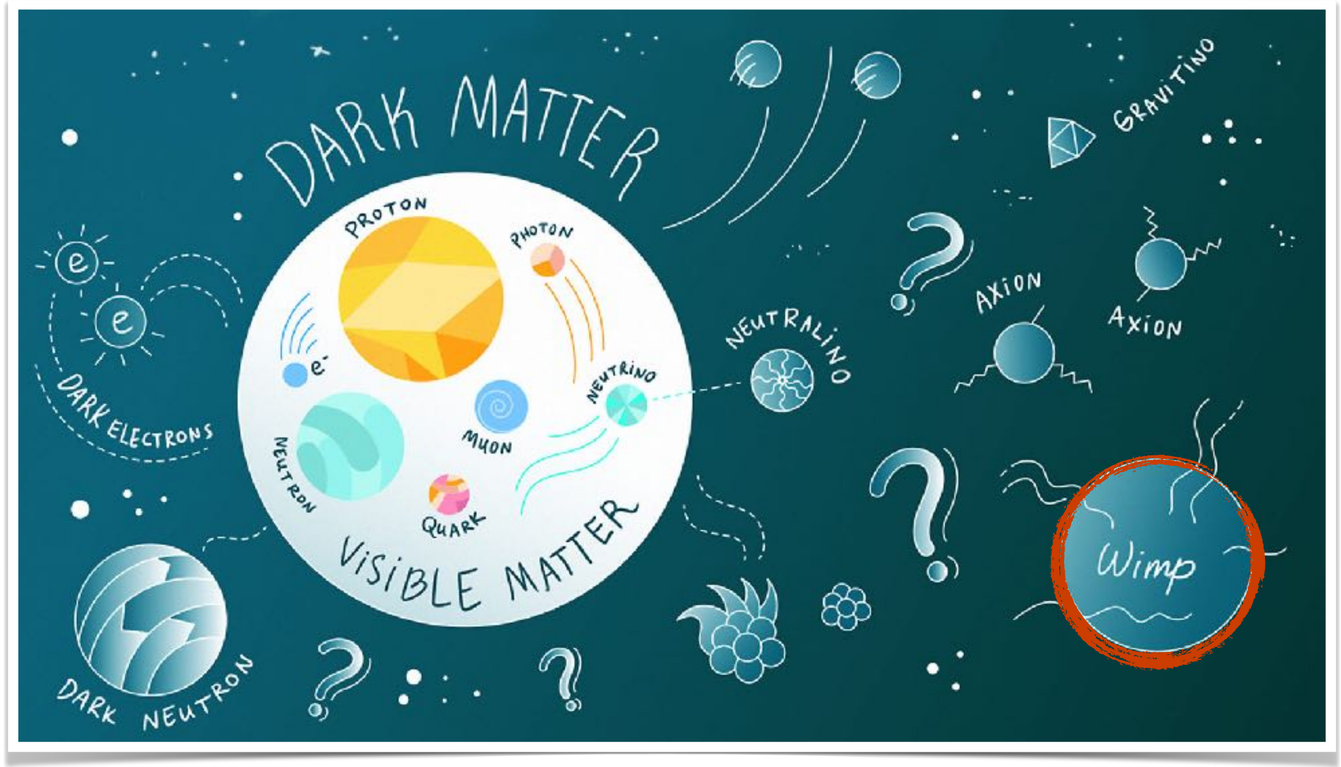
Magellan and Chandra images of the Bullet Cluster

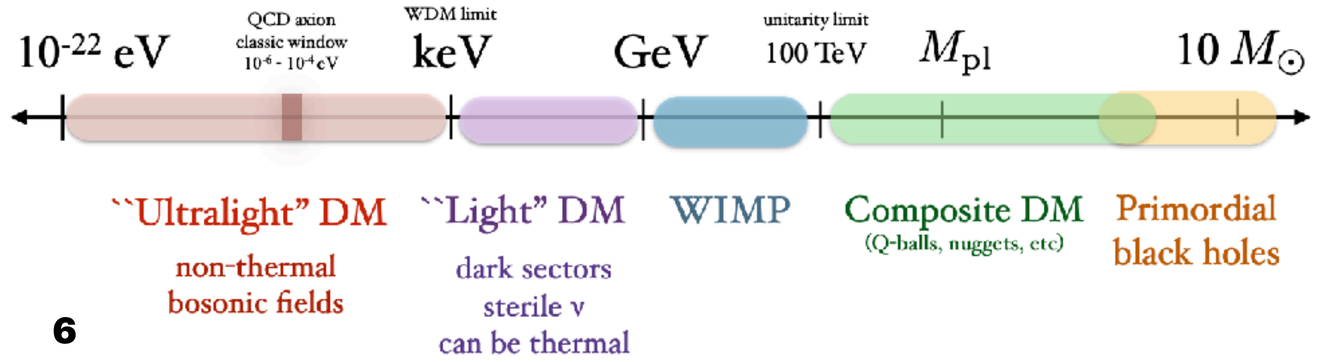

Visible
matter
5%
Dark
matter
27%
68%
Dark
energy

WIMP as Dark Matter Candidate

- **W**eakly **I**nteractiv **M**assive **P**articles
  - new particles with masses and cross sections characteristic of the electroweak scale.
  - Cold (non relativistic).
- In thermal equilibrium in the hot early universe with SM particles.
- Detection rates are within reach of current or planned detectors, making them **testable**!

Artwork by Symmetry Magazine



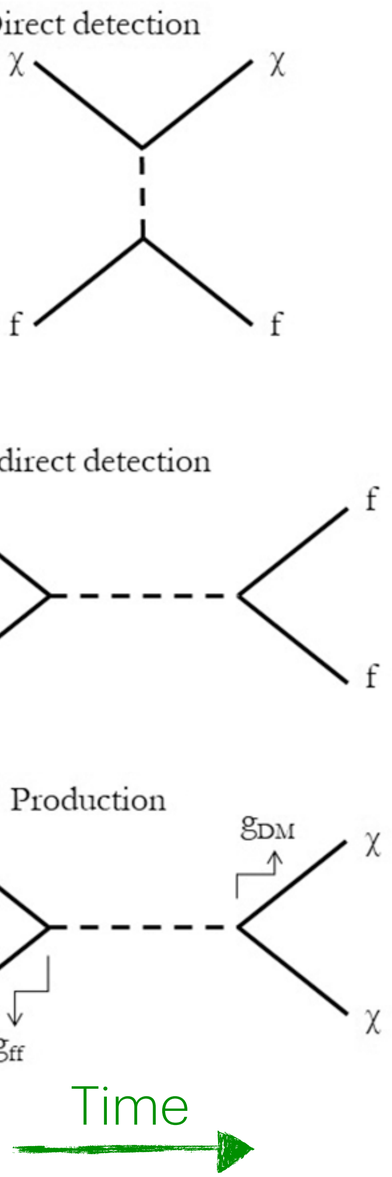


The Hunt for Dark Matter

- **Direct**: Detect the recoil of a nucleus after scattering with WIMP dark matter.

- **Indirect**: Detect product of DM particles annihilation in presence of clump of gravitational matter.

- **Production**: Collider Search for new production chain leading to missing transverse momentum.



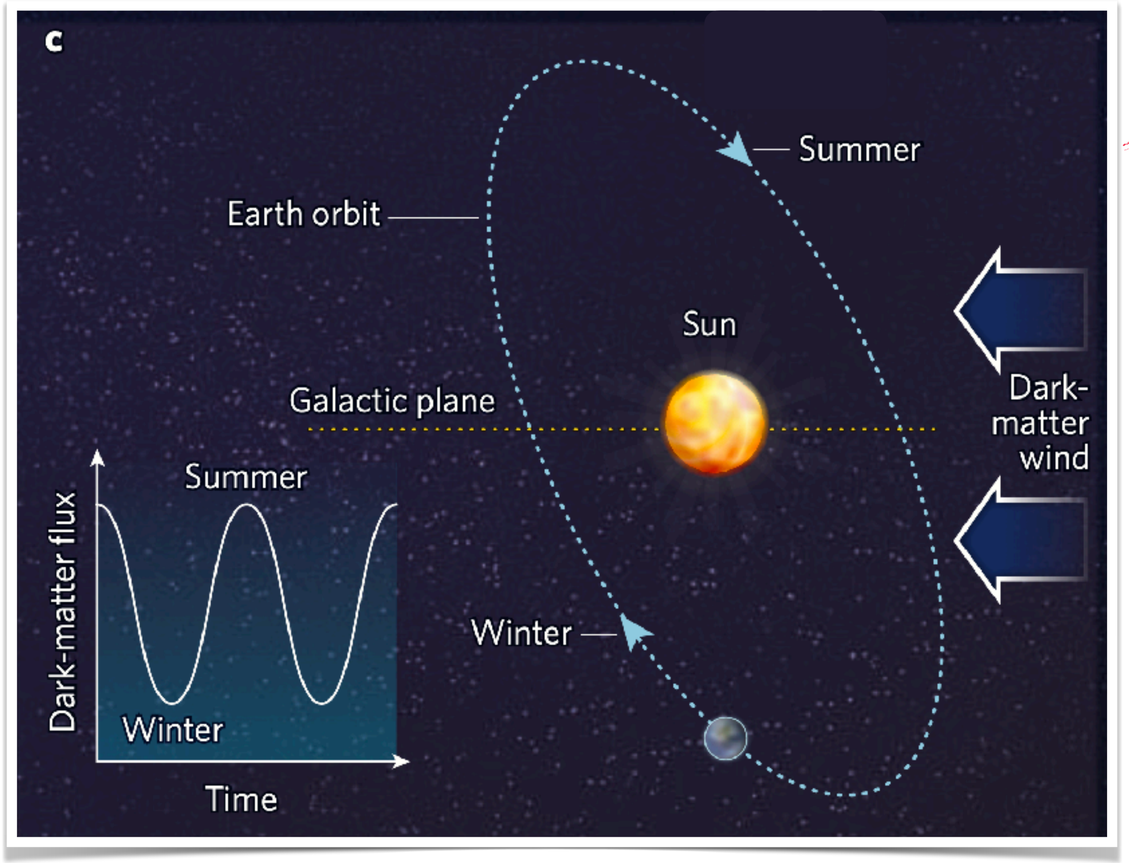
XENONnT at LNGS

AMS on the ISS

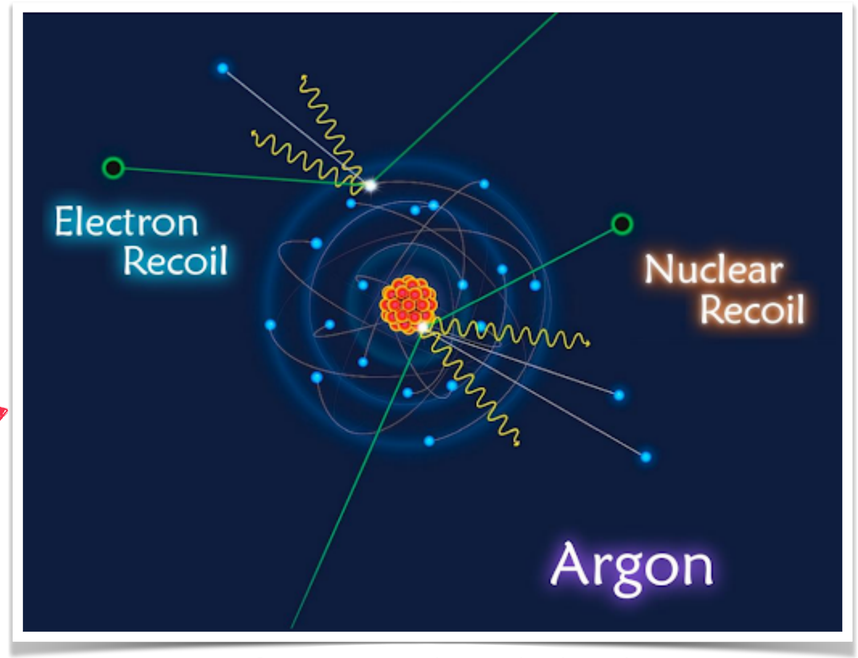
LHC at CERN

Direct Detection

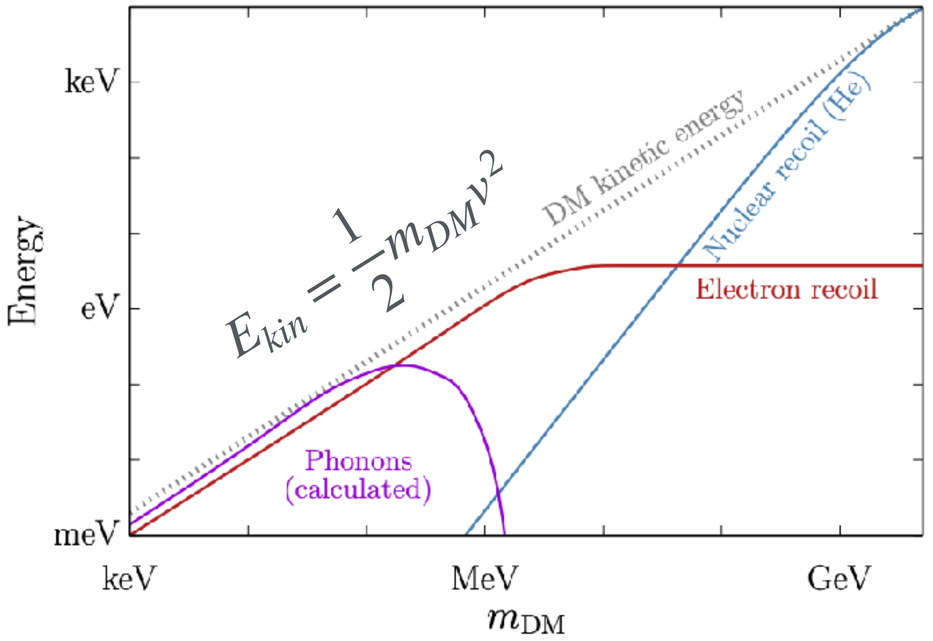
Intro



Sun and Earth motion in the Galactic Dark Matter Halo



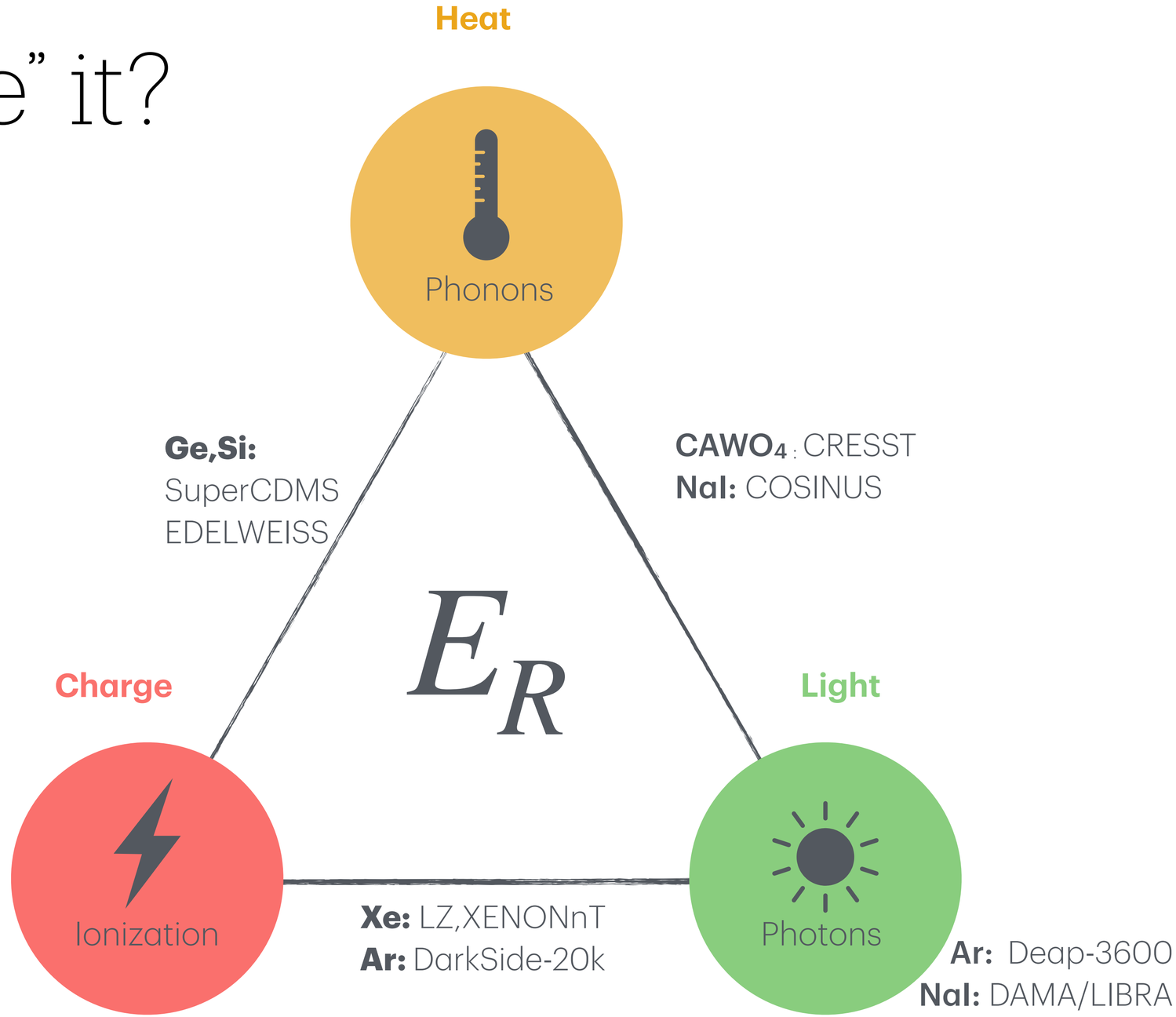
Elastic Scattering of DM particle with the detector constituents



How can we “see” it?

Direct Detection

- **Recoil Energy** of the detector constituents is the key and depends from the DM kinetic one!
- Different experiments focus on one or two **techniques** to access different energy scales and DM mass ranges



Energy Spectra

Direct Detection

XSection

Target Atomic Mass

Local DM Density

$$\frac{dR}{dE_R} \propto M_T \frac{\sigma_{SI}}{M_\chi} \times A^2 \,|\, F(E_R) \,|^2 \times \rho_0 \int_{v_{min}}^{v_{max}} \frac{f(v)}{v} dv$$

Wimp mass

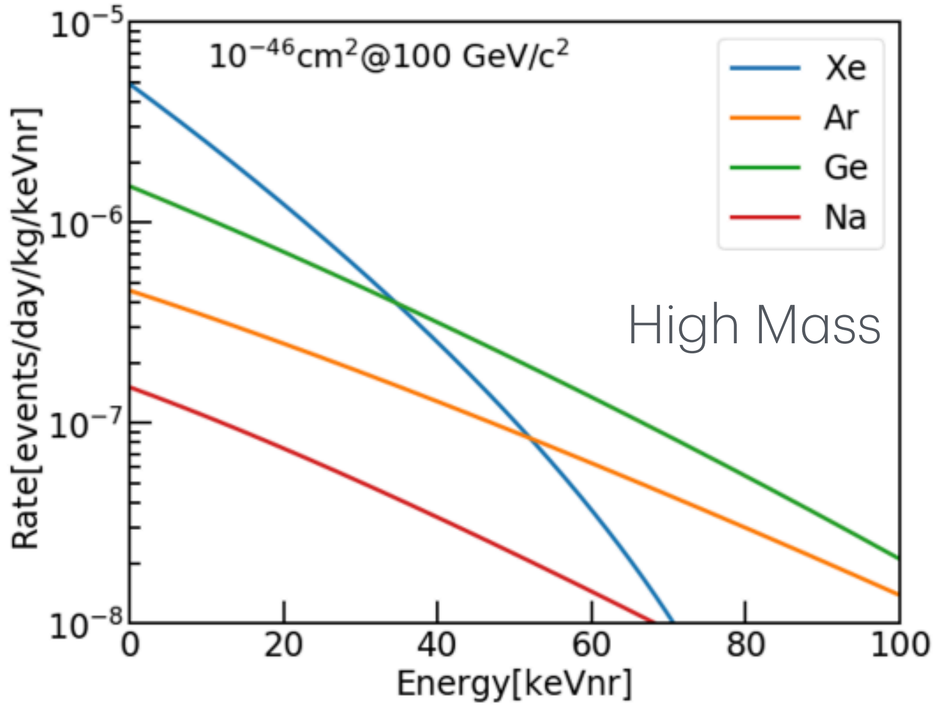
Form Factor

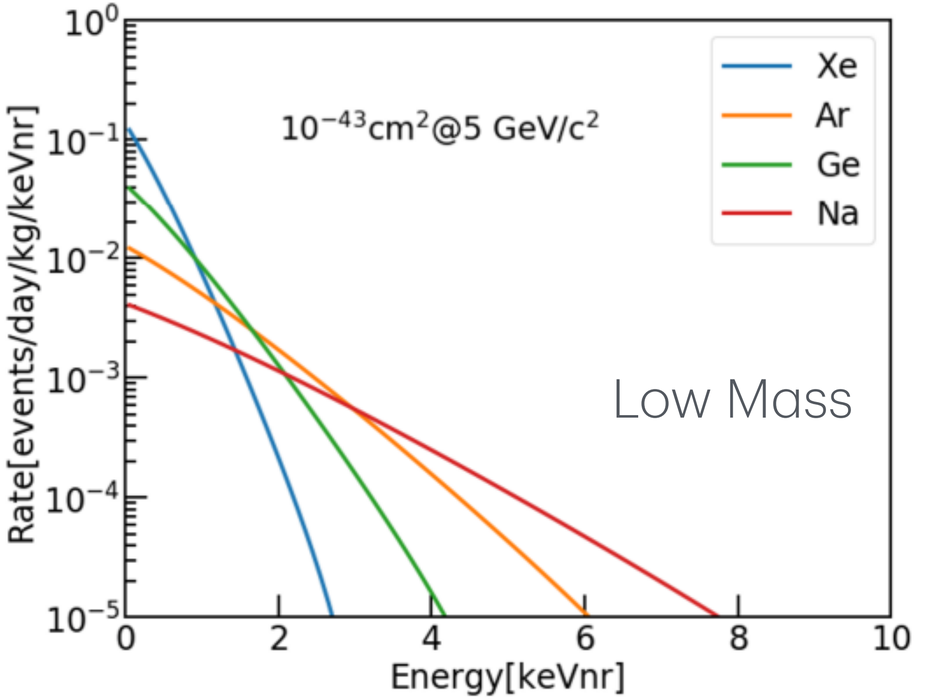
Velocity Distribution

Particle Physics **Nuclear Physics** **Astrophysics**

$$E_R^{max} \simeq 20 - 200\, keV$$

$$\mu_{\chi N} \simeq 10 - 100 \text{ GeV} \qquad |\mathbf{q}|_{\max} \simeq 20 - 200\,\text{MeV}$$

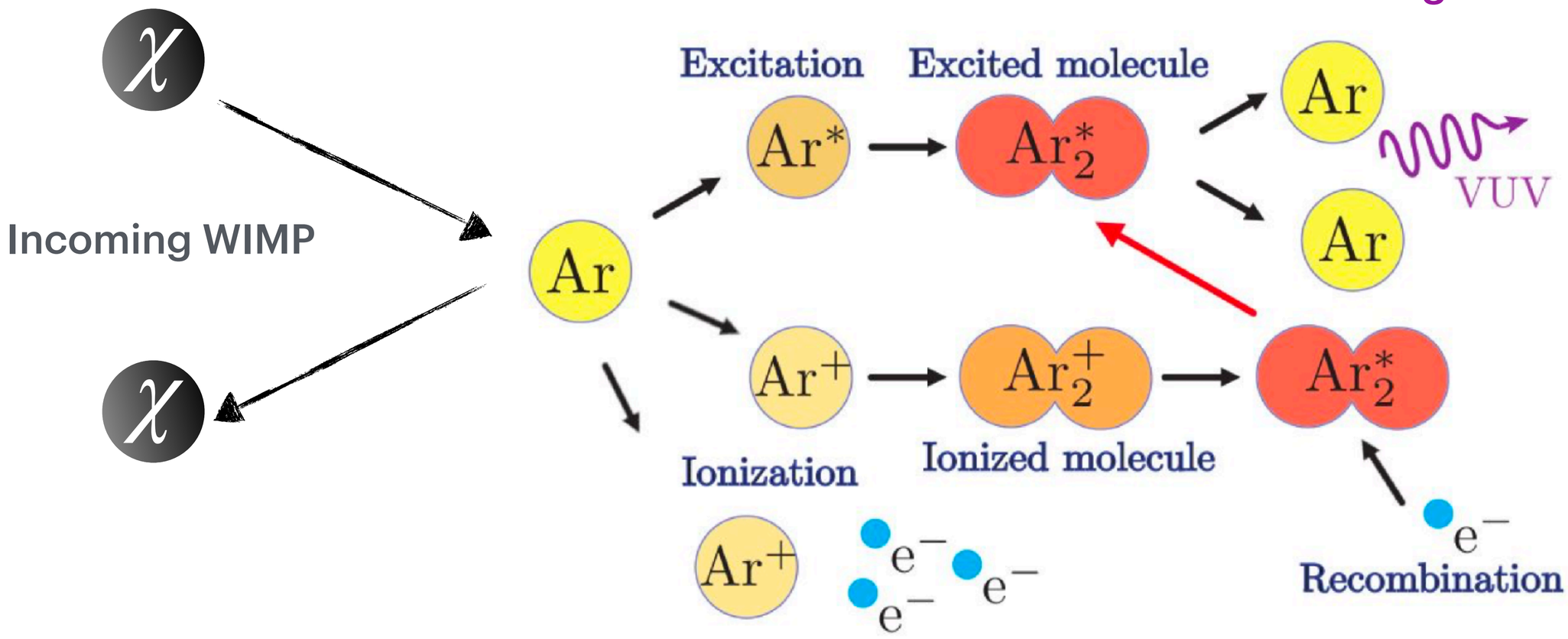




Liquid Noble Gas Detectors

Argon - Xenon

Light Emission!



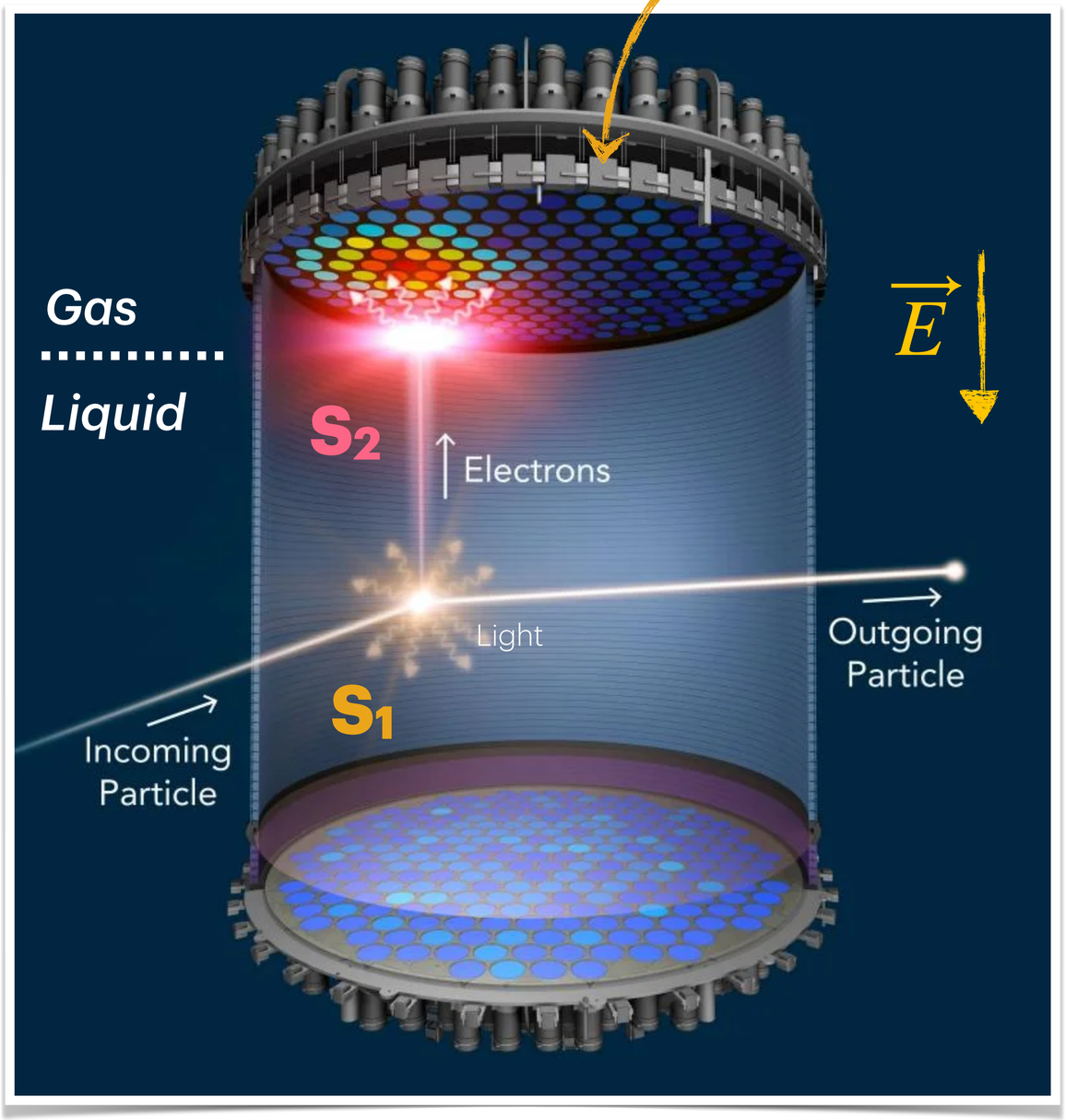
Electron Emission!

Liquid Noble Gas Detectors

Dual Phase detectors

Time Projection Chamber

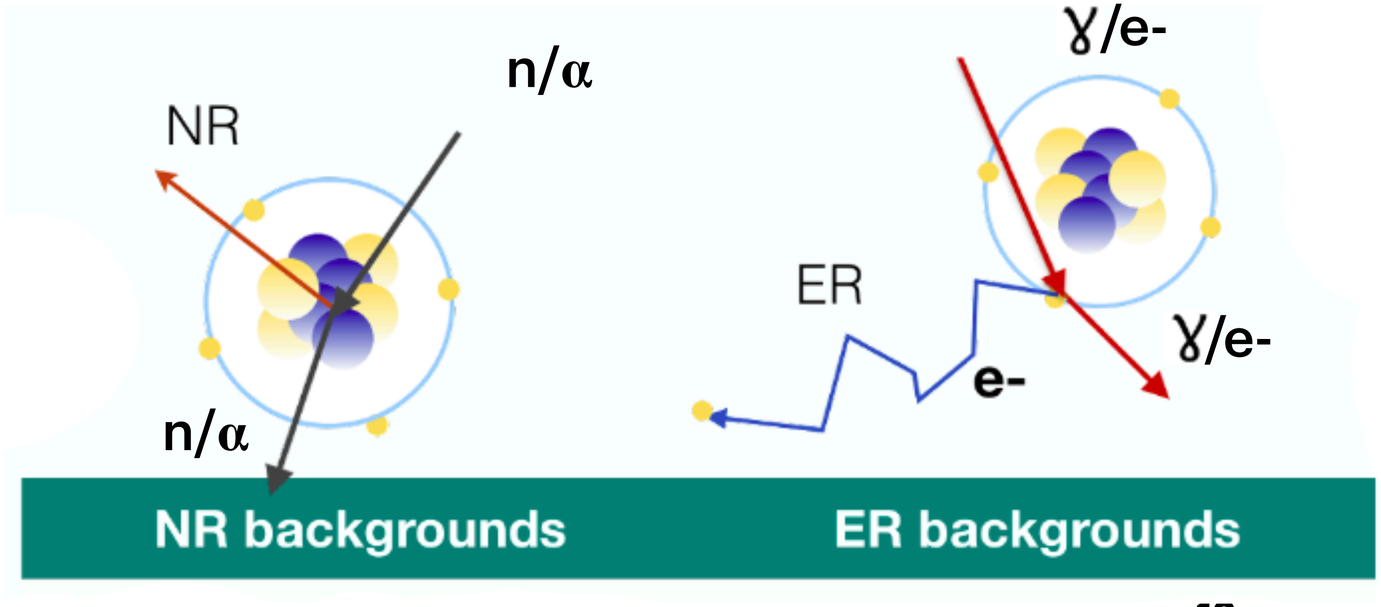
- Electrons (from ionization) drift up to the gas phase under **E field** action.
- **Photosensors** (PMT or SiPMs) collect light signals:
  - S_1 Primary signal (Scintillation) in liquid.
  - S_2 Secondary signal (Electroluminescence) in gas.
- Event **position reconstruction**.

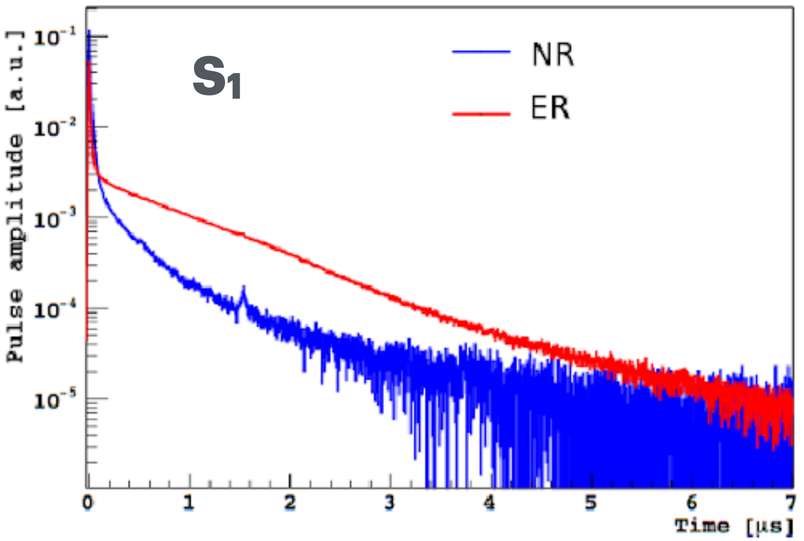


Liquid Noble Gas Detectors

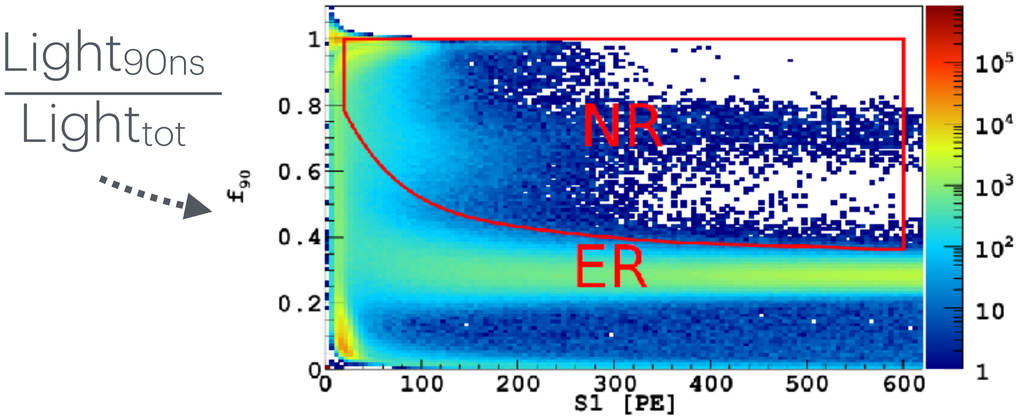
Background

- Other particles can replicate DM signals either producing **Nuclear** or **Electron Recoil** (NR - ER)
- Solution: Material Selection - Tagging - PSD* and Underground Labs!



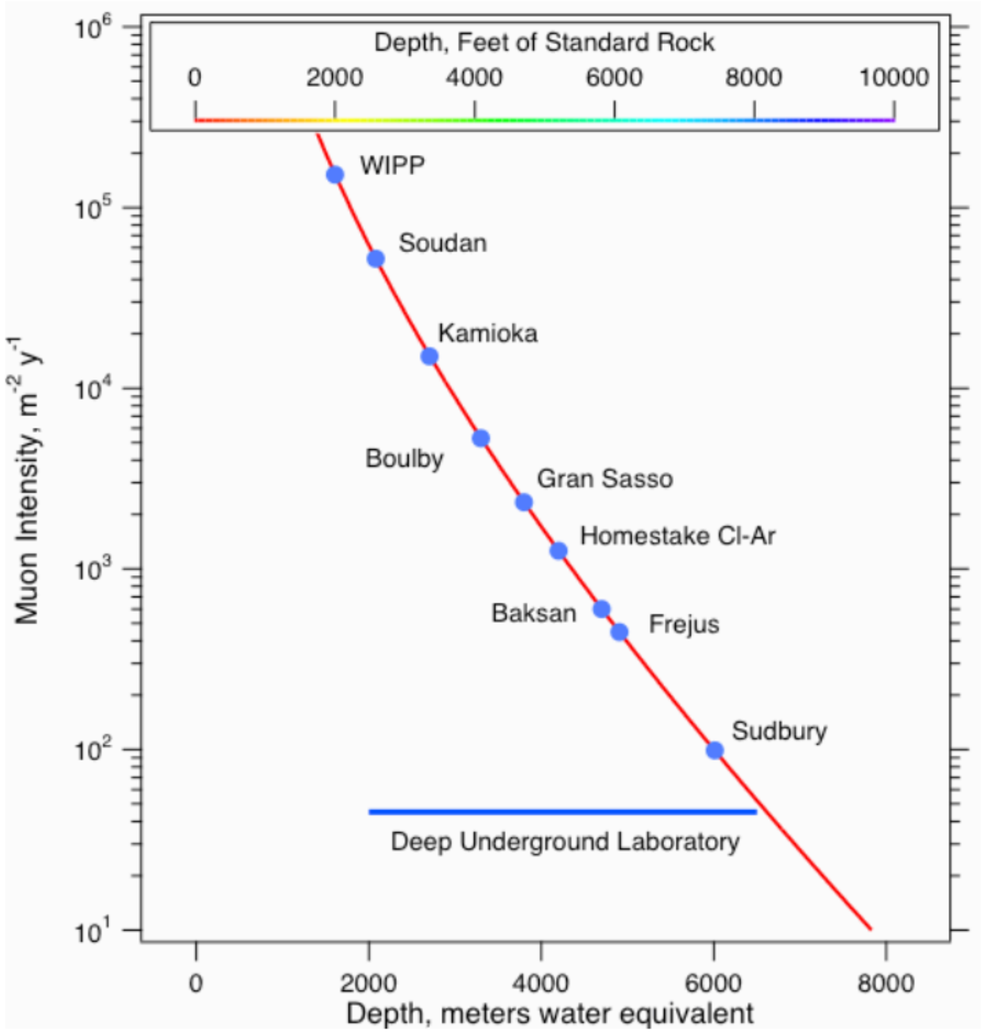


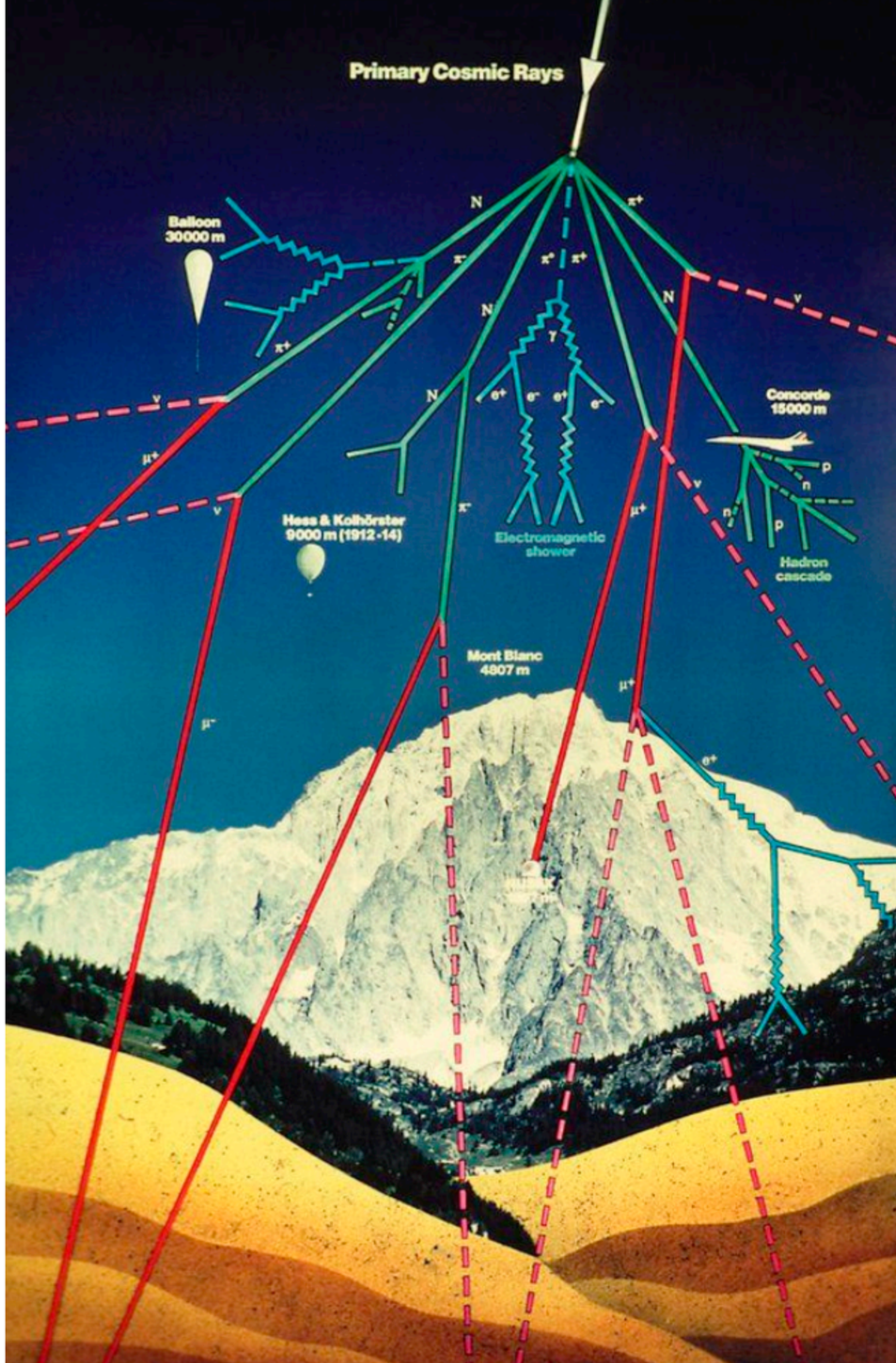
DS50 Data



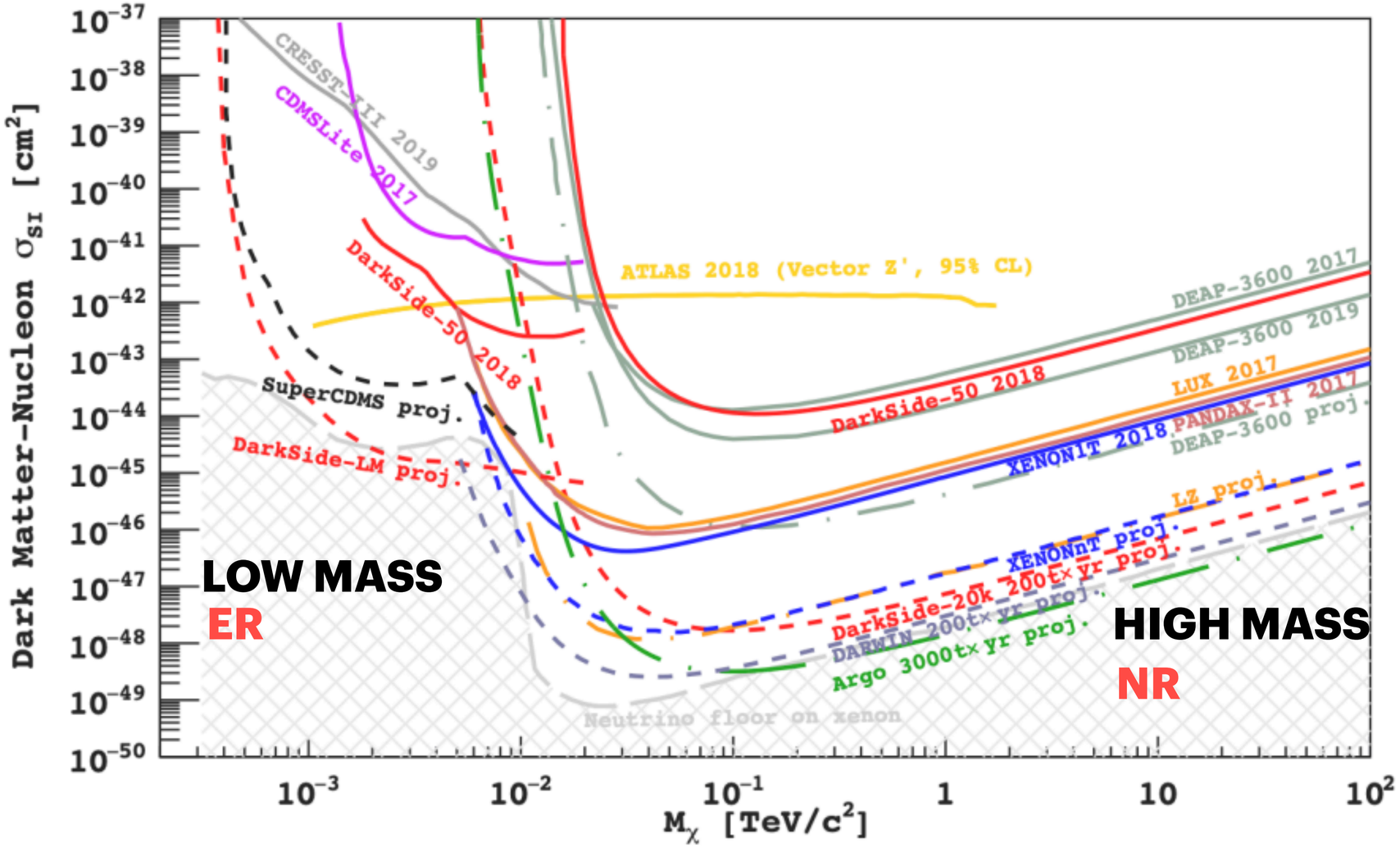
*Pulse Shape Discrimination technique to discriminate NR - ER from light signalnal shape analysis. (Argon)

Under the mountain





Experiment results: Sensitivity Plot

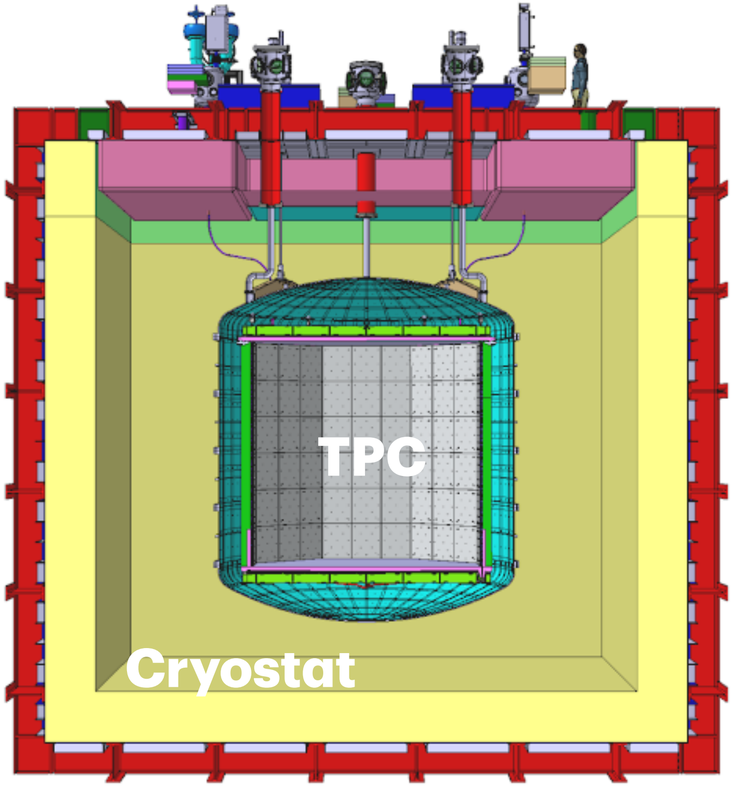


DarkSide-20k

Dual Phase **Argon TPC Detector** under construction at LNGS (Hall C).

- Nominal Exposure of **200 t yr**
- **TPC**: *50t of Liquid Argon (20t active)*
- **Membrane Cryostat**: *700t LAr as thermal bath and Veto.*
- Instrumental Background: **0.1 events from neutrons.**

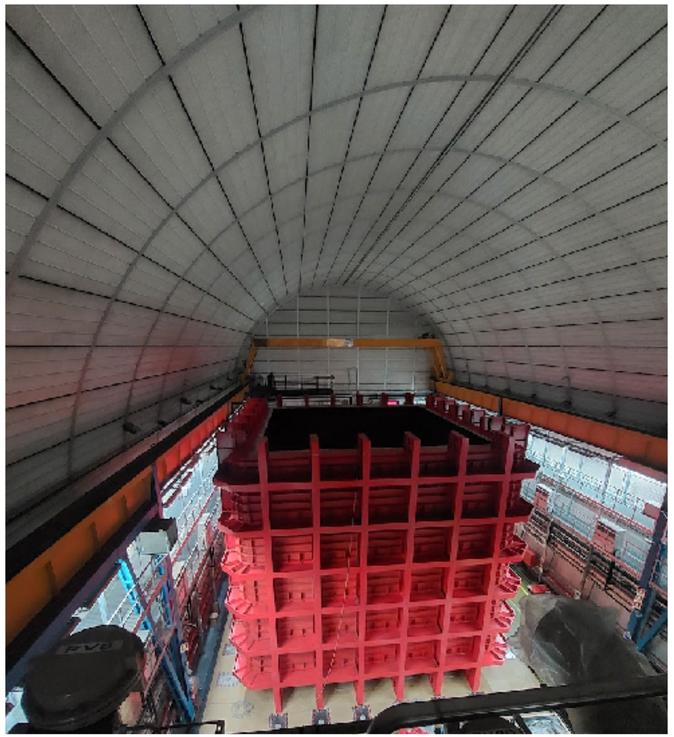
Detector Semplified Scheme



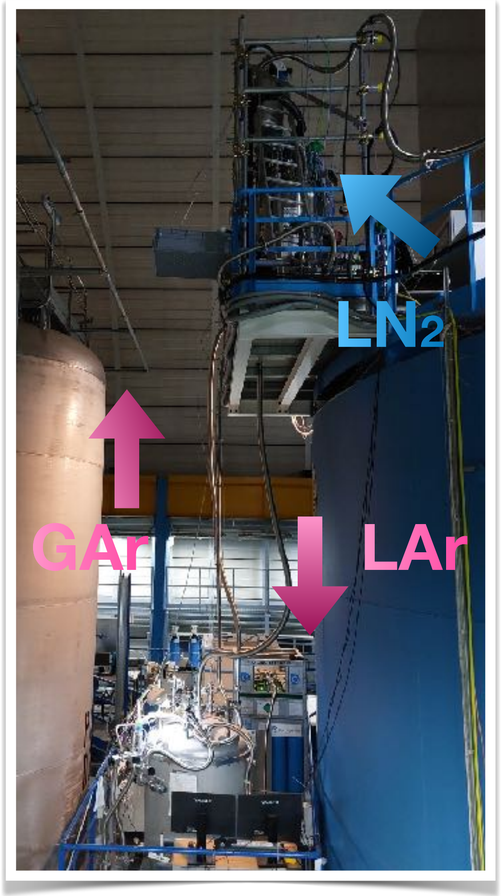
Operations expected to start in late 2026

Laboratori Nazionali del Gran Sasso

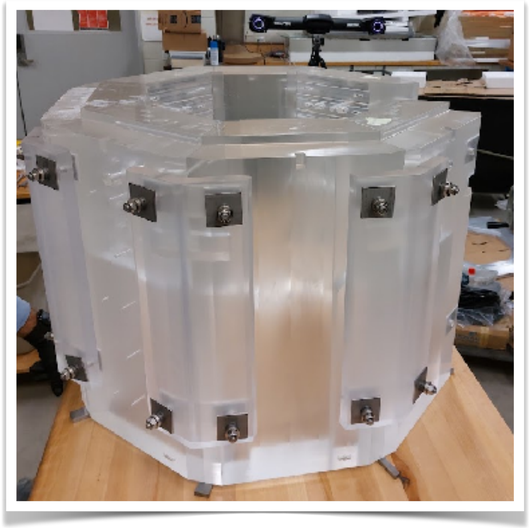
Hall C - Jenuary 2024



Ongoing Research Activity

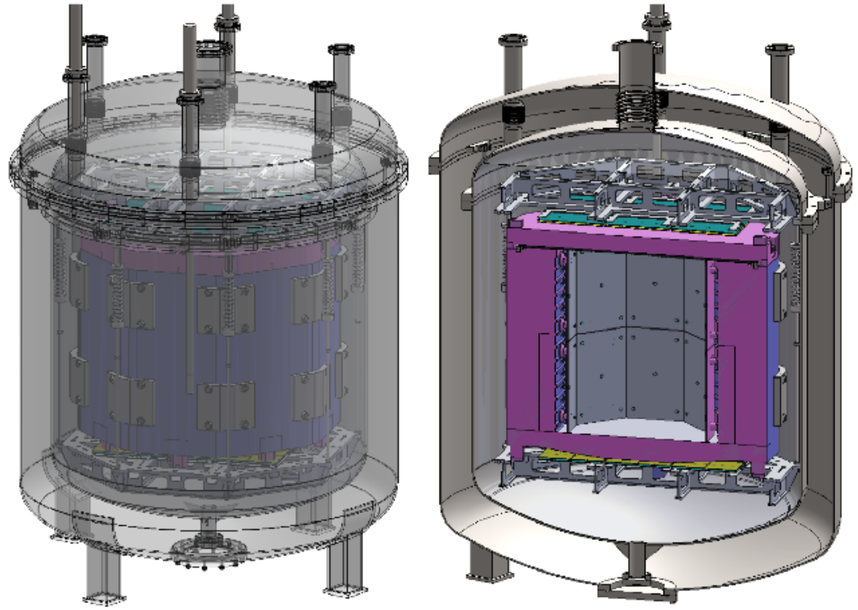


Assembly and test of the Cryogenic System at LNGS



Preliminary assembly of the Acrylic Mockup TPC for DarkSide-20k

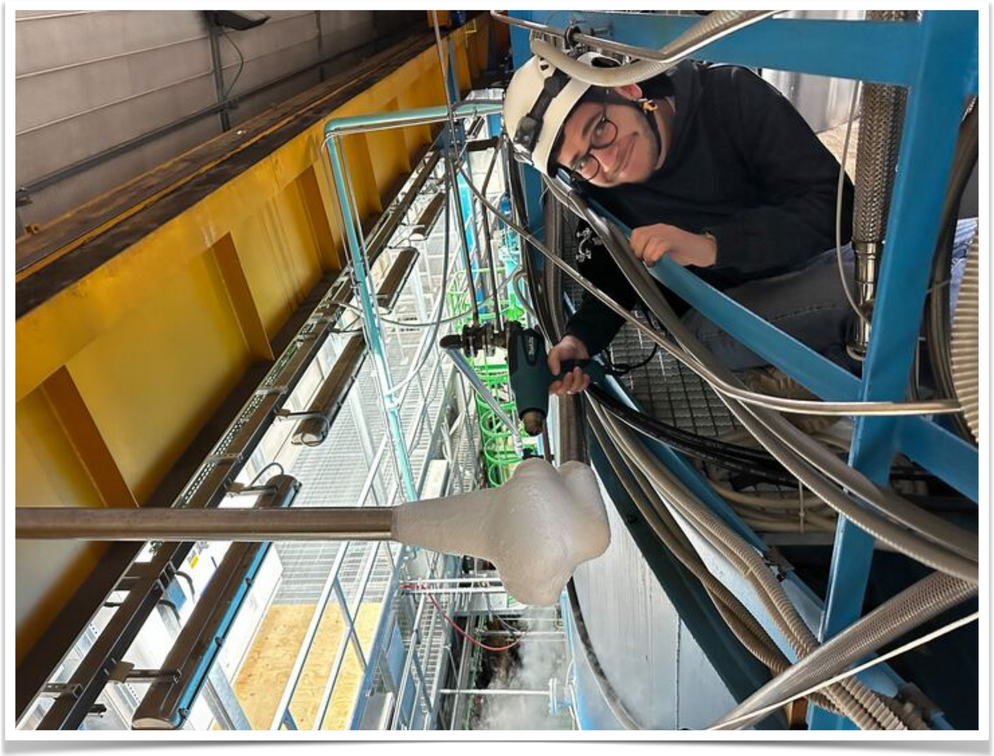
Liquid Argon!



Preparation for the future assembly, cooldown and test of the Acrylic Mockup TPC

Conclusions

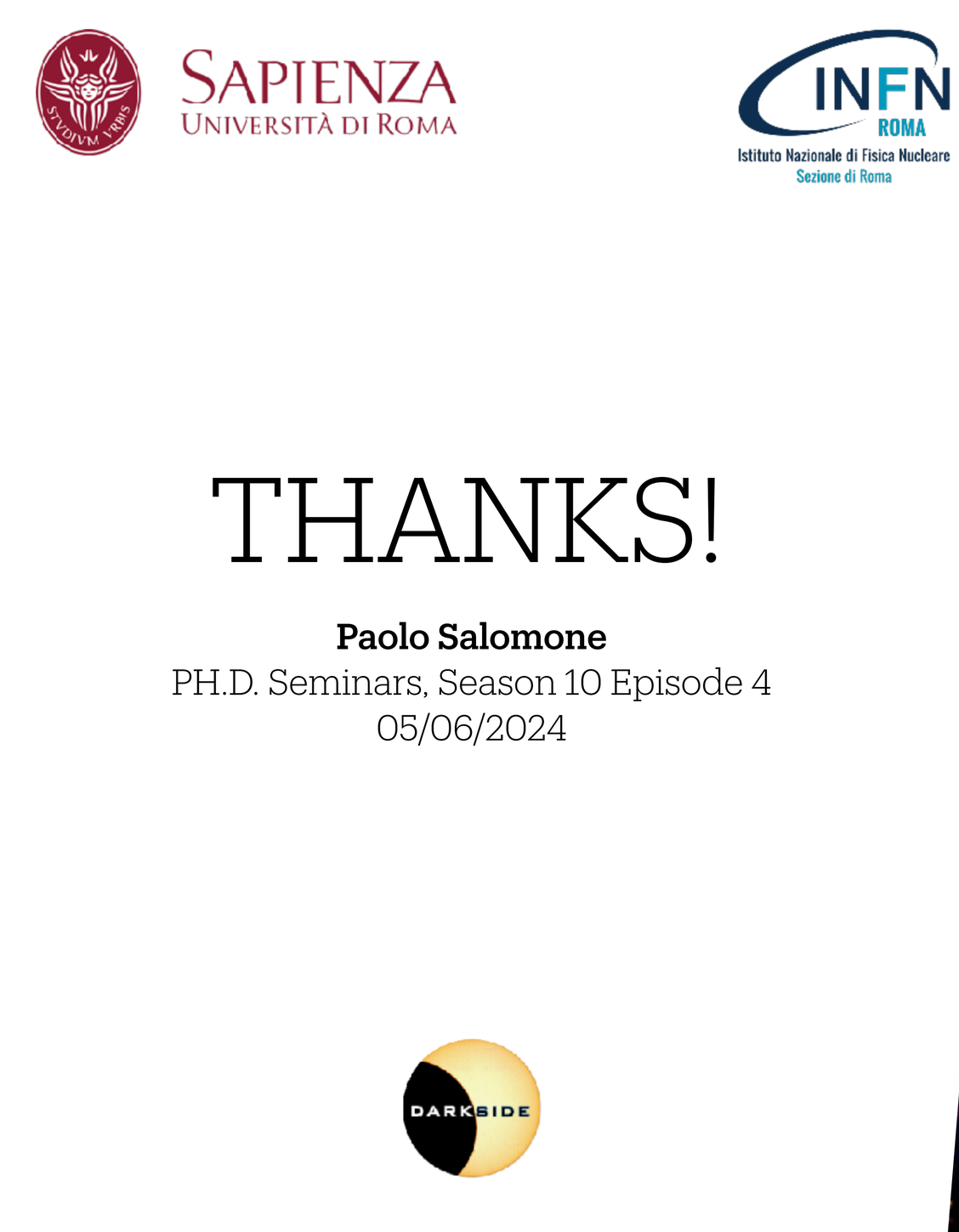
- There is compelling evidence for the **existence of dark matter**. Although our understanding of its nature and distribution is still **incomplete**!
- Present and future experiments (collectively, the direct, indirect and collider searches) may be able to shed **new light** on the physics and astrophysics of dark matter.
- Stay tuned for updates from **DarkSide**!



True essence of being a Ph.D. Student

References

- A History of Dark Matter - Gianfranco Bertone and Dan Hooper - https://arxiv.org/abs/1605.04909
- WIMP Dark Matter Direct-Detection Searches in Noble Gases - L. Baudis - https://arxiv.org/abs/1408.4371
- TASI lectures on dark matter models and direct detection - Tongyan Lin - https://arxiv.org/abs/1904.07915
- DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon - DarkSide Collaboration - https://arxiv.org/abs/1802.07198
- The XENONnT Dark Matter Experiment - XENON Collaboration - https://arxiv.org/abs/2402.10446



THANKS!

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