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ASTR 312

What Makes Up the Most Mass in the Universe?

A. Stars

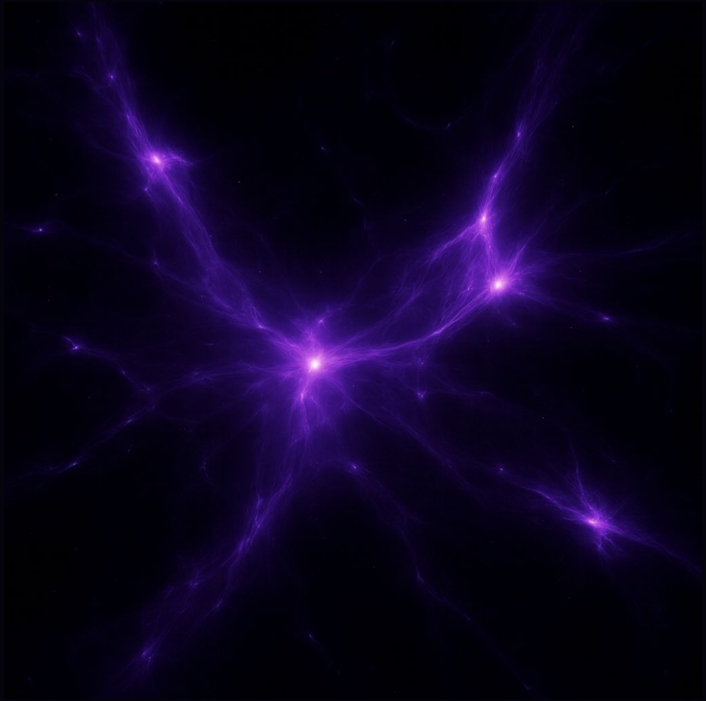
B. Black Holes

C. Planets

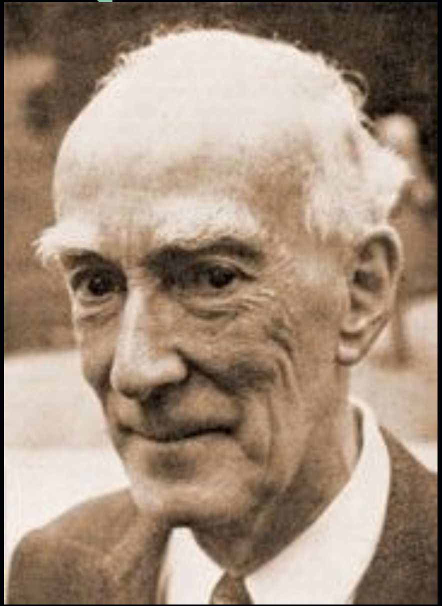
D. Galaxies

E. Dark Matter

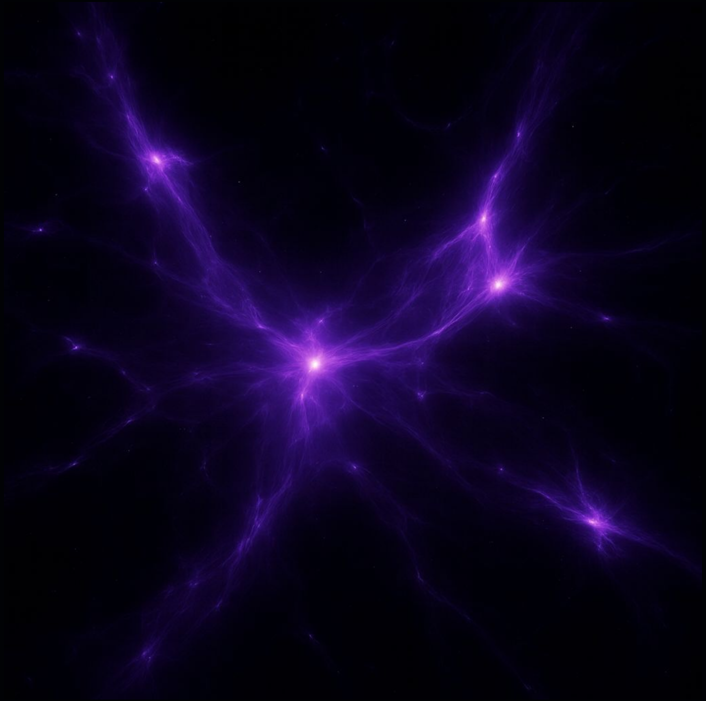
Dark Matter - is the invisible glue that holds the universe together



When Galaxies Move Too Fast…



Jan Oort (1900-1992)
Figure 1: Photo of Jan Oort. Retrieved from https://www.pas.va/en/academicians/deceased/oort.html



Fritz Zwicky (1898-1974)
Figure 2: Photo of Fritz Zwicky. Retrieved from https://en.wikipedia.org/wiki/Fritz_Zwicky

Figure 3: The image of the Coma Cluster. Retrieved from https://science.nasa.gov/missions/hubble/hubbles-sweeping-view-of-the-coma-cluster-of-galaxies/

Vera Rubin: Confirmed the Invisible

- Measured how stars move inside galaxies
- Found “flat rotation curves”
- Outer stars moving just as fast as inner stars
- Impossible without hidden mass

Vera Rubin (1928-2016)
Figure 4: Photo of Vera Rubin. Retrieved from https://en.wikipedia.org/wiki/Vera_Rubin

Expected vs. Observed Velocity

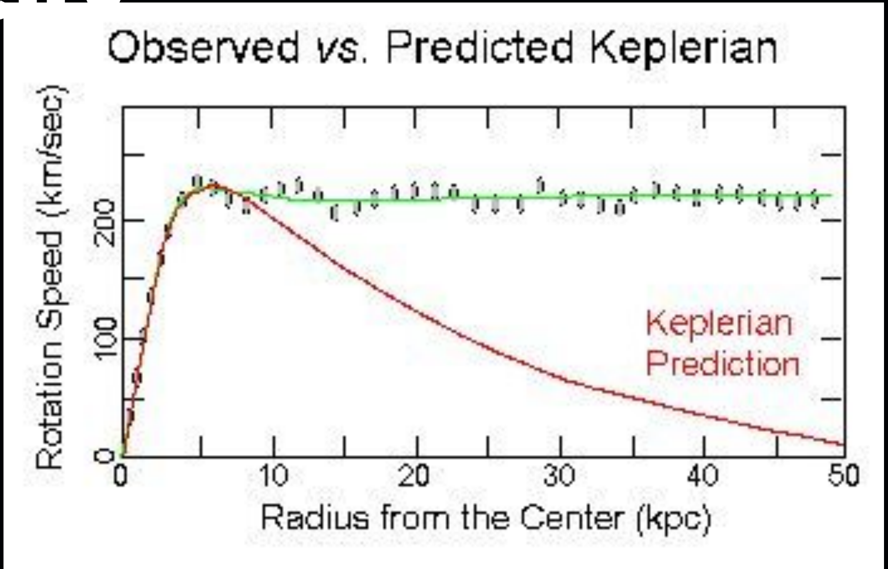


Figure 5: Observed vs Predicted speed graph. Retrieved from: https://www.astronomy.ohio-state.edu/pogge.1/Ast162/Unit6/dark.html

Dark Matter Evidence

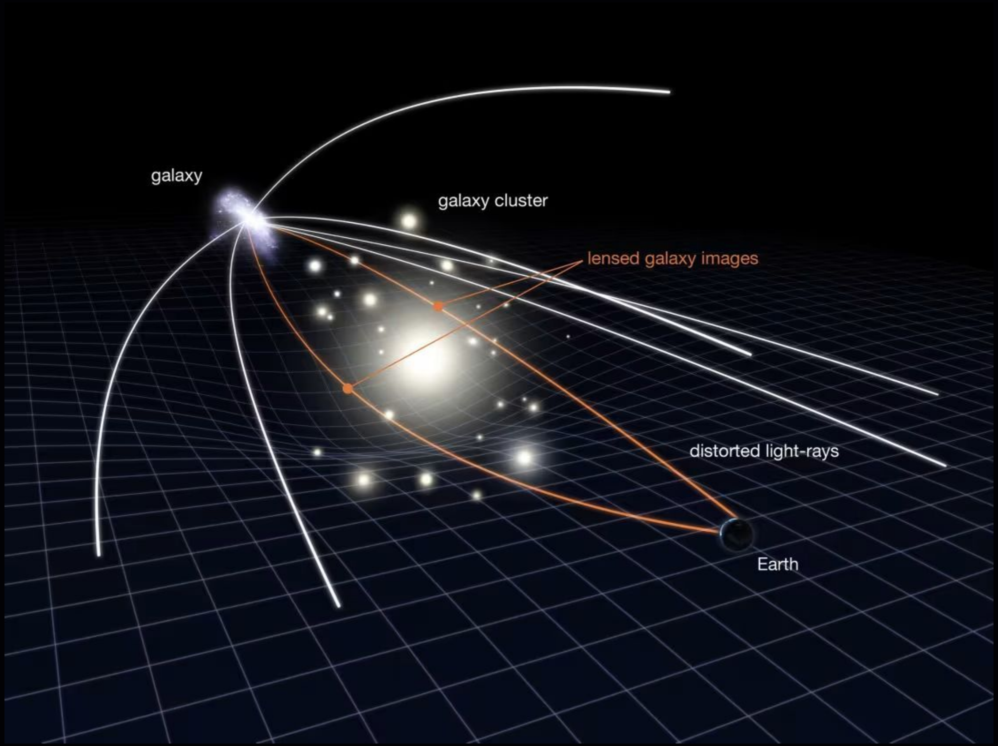


Figure 6: The explanation of Einstein Ring. Retrieved from:
https://www.nbcnews.com/science/space/hubble-captures-einstein-ring-rcna1753

Einstein Ring

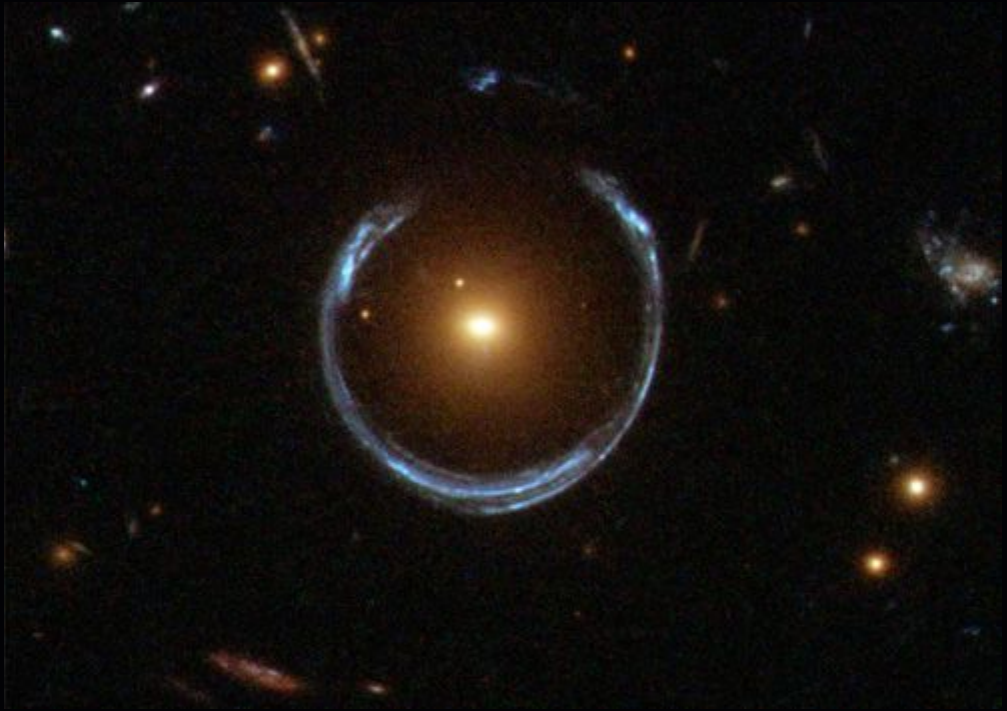


Figure 7: The image of Einstein Ring. Retrieved from https://science.nasa.gov/image-detail/einstein-ring-lrg-3-757/

Einstein Cross

P. Cox et al. - ALMA (ESO/NAOJ/NRAO)

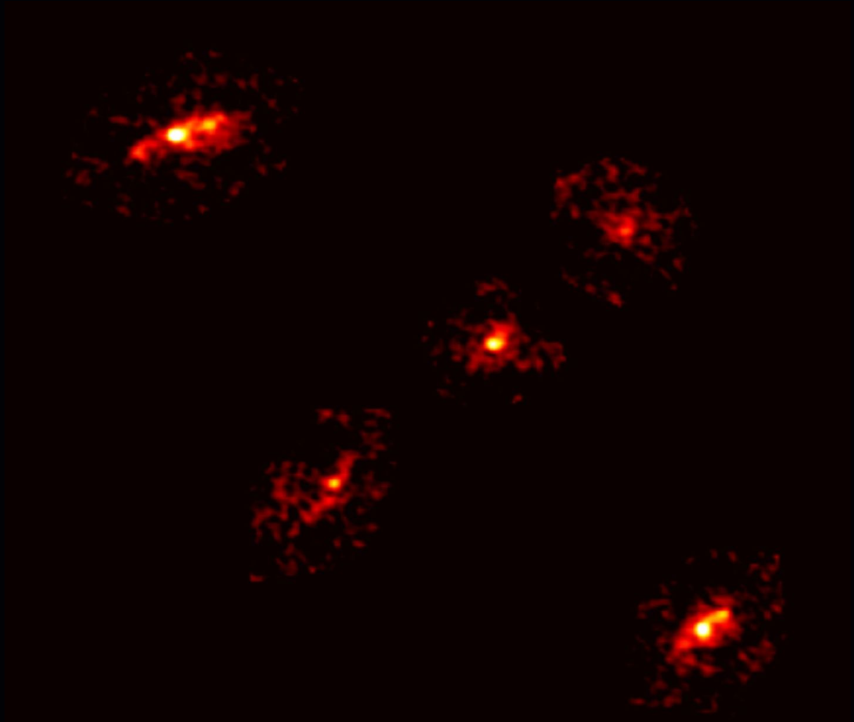


Figure 8: The image of Einstein Cross. Retrieved from https://www.almaobservatory.org/en/press-releases/an-exceptional-einstein-cross-reveals-hidden-dark-matter/

What Could Dark Matter Be?

The most popular candidates are the following:

- WIMPs (Weakly Interacting Massive Particles)
- Axions
- Sterile Neutrinos
- MACHOs (Massive Astrophysical Compact Halo Objects)

WIMPs (Weakly Interacting Massive Particles)

Heavy particles

Do not experience electromagnetic force

Do not experience the strong nuclear force

Might experience the weak nuclear force

Figure 9: Background Image
Retrieved from https://svs.gsfc.nasa.gov/10955

Why are WIMPs a Candidate?

Figure 10: Background Image. Retrieved from https://physicsworld.com/a/dark-matters-secret-identity-wimps-or-axions/

Axions

- Extremely light particles
- Do not interact with photons
- Created to explain a physical phenomenon but turned out to be perfect dark-matter candidates
- Do not feel the strong nuclear force

Figure 11: Background Image. Retrieved from aasnova.org/2017/08/16/can-radio-telescopes-find-axions/

Why are Axions a Candidate?

MISALIGNMENT

ADMX

Figure 12: Background Image. Retrieved from
www.advancedsciencenews.com/swirling-clouds-of-axions-around-neutron-stars-could-help-scientists-detect-dark-matter/

Sterile Neutrinos

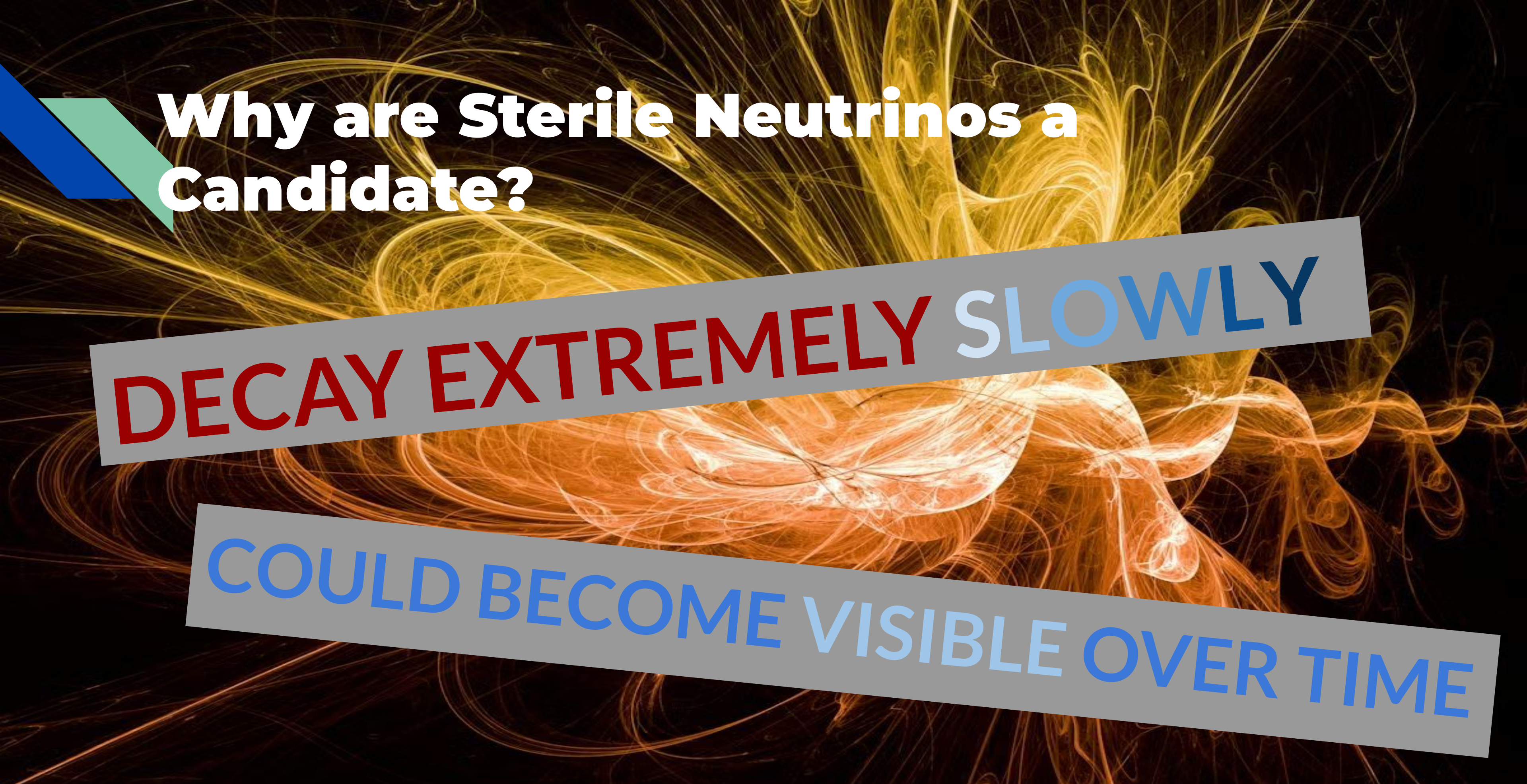
Most likely have a mass of a few keV

Do not experience electromagnetic force

Do not interact via the weak force at all, unlike regular neutrinos

Figure 13: Background Image. Retrieved from
www.newscientist.com/article/mg25233600-100-sterile-neutrinos-could-explain-dark-matter-if-we-can-find-them/

Why are Sterile Neutrinos a Candidate?



DECAY EXTREMELY SLOWLY

COULD BECOME VISIBLE OVER TIME

Figure 14: Background Image.
Retrieved From: www.inverse.com/innovation/what-a-neutrino-experiment-means-for-new-physics.

MACHOs - Massive Astrophysical Compact Halo Objects

Actual astrophysical objects

- **Failed stars**
- **Low mass stars**
- **Black holes**
- **Planets or similar celestial objects**

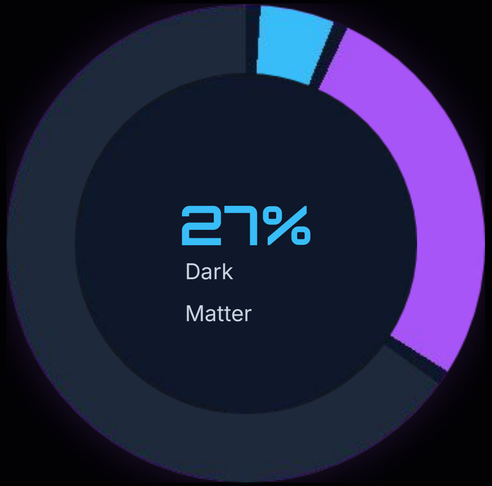
Figure 15: Background Image.
Retrieved from astrobites.org/2020/09/08/machos-weight-class/.

Why are MACHOs a Candidate?

WE KNOW THEY EXIST!

Figure 16: Background Image. Retrieved from jcschroder.com/phy111/machos.htm

The Cosmic Energy Budget



The Universe Breakdown

5% Normal Matter (Stars, Gas, Us)

27% Dark Matter (The invisible glue)

68% Dark Energy (Expansion force)

Evidence comes from the Cosmic Microwave Background (CMB) and gravitational lensing (Gohd, 2025).

Why Does It Matter?

Galaxy Formation

Dark matter provided the necessary gravitational "scaffold" for galaxies to form rapidly in the early universe (Springel et al., 2005).

Cosmology

It is a fundamental parameter of the Lambda-CDM model, determining the large-scale structure and expansion history of the universe (Blumenthal et al., 1984).

New Physics

It requires physics beyond the Standard Model. Discovering its particle nature would revolutionize our understanding of reality.

The Noble Gas Approach

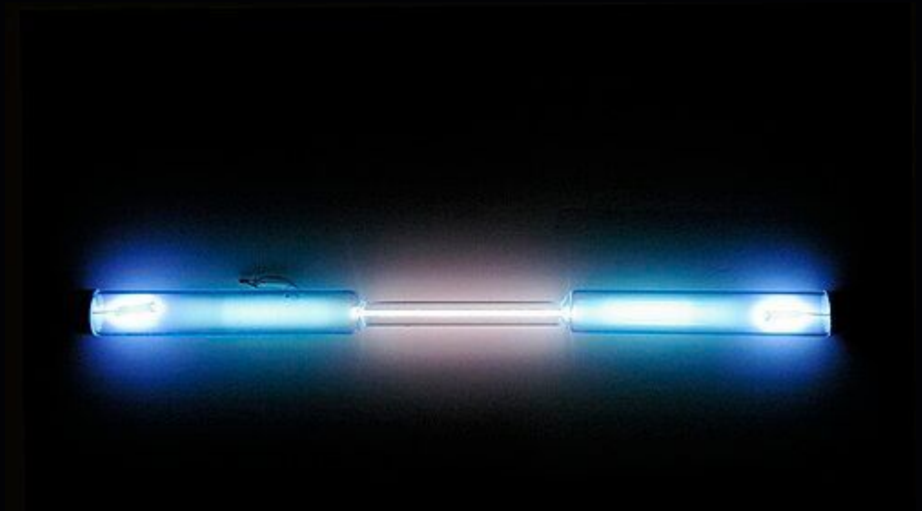


Figure 17: Image of Noble Gas Krypton in a Tube
Retrieved from:
https://upload.wikimedia.org/wikipedia/commons/thumb/5/50/Krypton_discharge_tube.jpg/500px-Krypton_discharge_tube.jpg

Supercooled Sensitivity

To catch a ghost, you need a quiet trap. Detectors are filled with supercooled noble gases like **Liquid Xenon and Krypton (Aalbers et al., 2023)**.

- **Why Noble Gases?** They are chemically inert and dense, maximizing the probability of particle interaction (Aalbers et al., 2023).
- **Key Players:** The **Budker Institute of Nuclear Physics** in Novosibirsk is a major hub for developing the advanced technology required for these low-background detectors.

The Hunt Continues

Direct Detection Experiments

The LUX-ZEPLIN (LZ) experiment operates deep underground to shield sensitive liquid xenon targets from cosmic ray interference (Mount et al., 2017).

As of 2024, no significant excess signal has been observed, prompting the development of larger detectors and the consideration of alternative candidates beyond WIMPs (Aalbers et al., 2023).

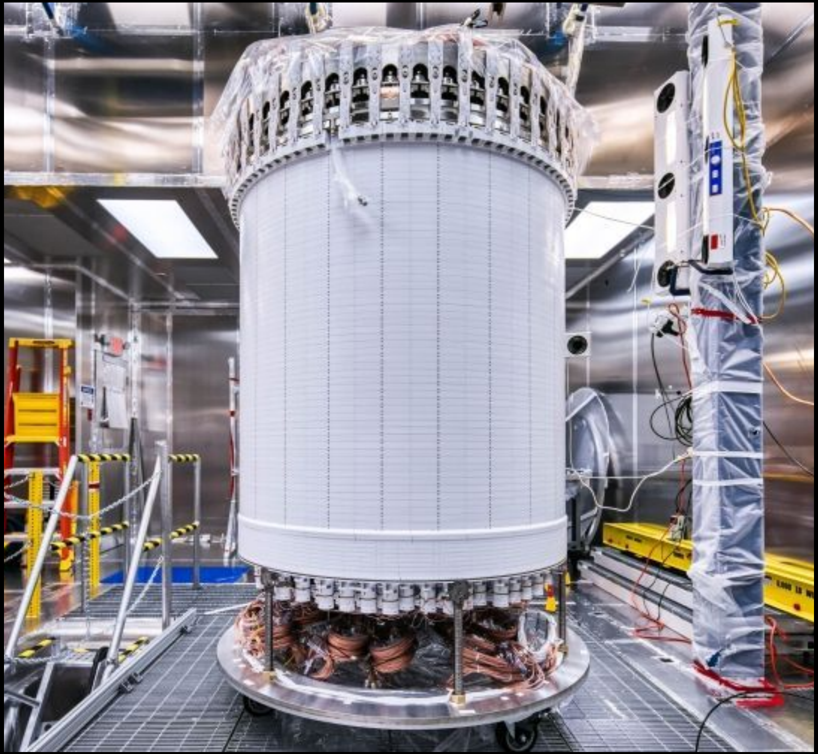


Figure 18: Image of the LZ central detector
Retrieved from:
https://www.llnl.gov/article/48766/lux-zeplin-dark-matter-detector-sanford-underground-research-facility-delivers-its-first

Making the Invisible

⚛Particle Accelerators

If we can't catch it, can we make it? Facilities like the **Large Hadron Collider (LHC)** search for dark matter production by analyzing proton collisions for "missing transverse momentum (Collaboration, 2024). Momentum that disappears without a trace, implying a Dark Matter particle escaped the detector.

Future Colliders

A new **electron-positron** collider is currently planned in Novosibirsk. Unlike the messy collisions of protons, it will utilize electron-positron collisions to explore specific dark sectors with higher precision than hadron colliders.

A Lesson in Patience

⏳

The Neutrino Parallel

The search for dark matter mirrors the history of the **neutrino** , which was postulated by Pauli in 1930 to preserve energy conservation but not detected until 1956 (Cowan et al., 1956).

Like Dark Matter, they are ghostly, abundant, and barely interact with normal matter.

This historical precedent suggests that the detection of weakly interacting particles requires significant time and technological maturity.

Chronology of the Invisible

- **1933 — Fritz Zwicky**: Observes the Coma Cluster. Coins "Dunkle Materie"
- **1970s — Vera Rubin**: Confirms flat galaxy rotation curves
- **2000s — Cosmology**: CMB data confirms Dark Matter is ~27% of universe
- **2004 — Presenters**: Amitoj, Artem and Holden were born
- **Today — The Hunt**: Direct detection (LZ) and alternative theories.

Questions?

Thank you for listening.

ASTR 312 Group 3 | Holden, Artem, Amitoj