Going Deep Underground For Dark Matter

Daniel Kodroff
QuarkNet – Physics in and Through Cosmology
July 10, 2024

Outline

1. My Journey in Physics
2. Lessons learned
3. A Week in the Life of An Experimental Physicist

Break...

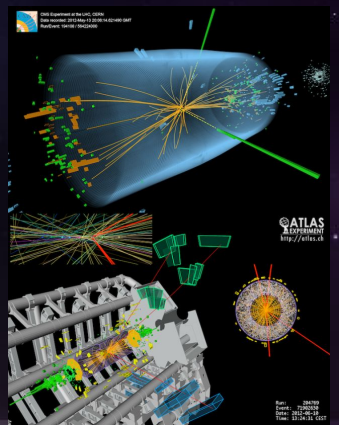
4. Dark Matter
5. LZ Dark Matter Experiment

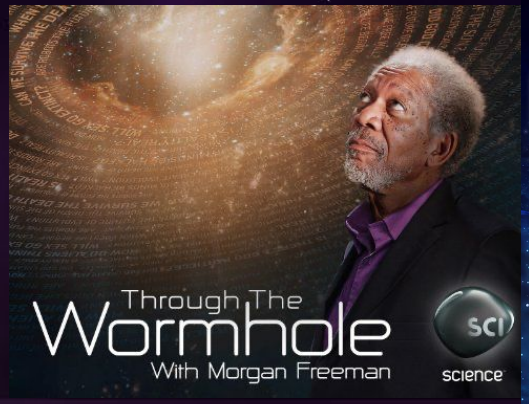
My Journey in Physics

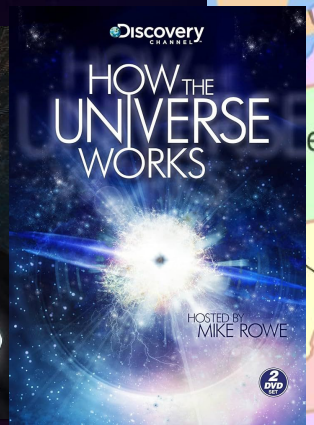
Born and raised outside Philadelphia

Interest in astrophysics and particle physics from documentaries and popsci articles and news

Discovery of Higgs Boson in 2012







My Journey in Physics

Undergraduate at Lafayette College in Easton, PA

Home of Crayola factory!

Started with intent to be mechanical engineer focusing on aerospace

→ Wasn't for me 😢 → Switch to Physics 😁

My Journey in Physics

Undergraduate at Lafayette College in Easton, PA

First research experience working on astrophysics project studying neutral-hydrogen line
1420 MHz → FM Radio

Using radio-data from Arecibo Telescope

Ultimately fatal hurricane damage in 2017 and cable breaks in 2020

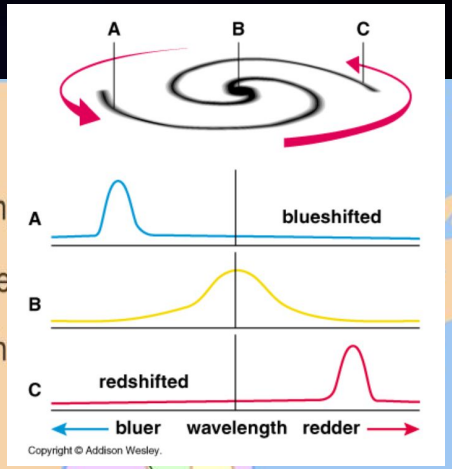
My Journey in Physics

Undergraduate at Lafayette College in Easton, PA

First research experience working on astrophysics project studying neutral-hydrogen line
1420 MHz → FM Radio

Study the rotation curves of galaxies!

→ First time coding (in IDL)
→ First exposure to Dark Matter!
→ First time working in physics collaboration!
→ First time presenting research!



My Journey in Physics

Junior Year opportunity to participate in NSF REU (research for undergraduate) program at William And Mary College in Williamsburg, VA

Research on neutrino beam at Fermilab for neutrino oscillation measurements in MINERvA experiment

→ First experiment running simulations!
→ Learned C++, ROOT, Geant4
→ First particle physics experiment!

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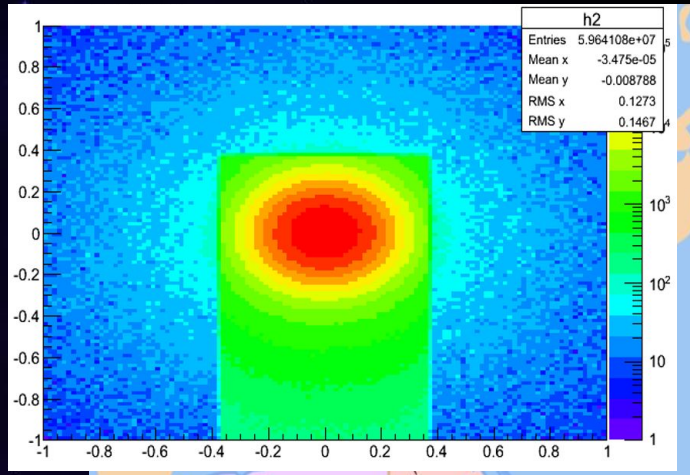
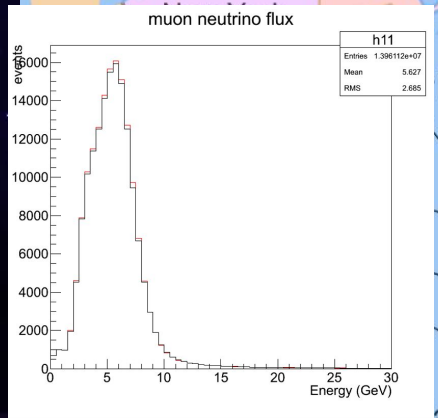




My Journey in Physics

Back to Lafayette...

Seniors Honors Thesis at Lafayette on neutral hydrogen

LAFAYETTE COLLEGE

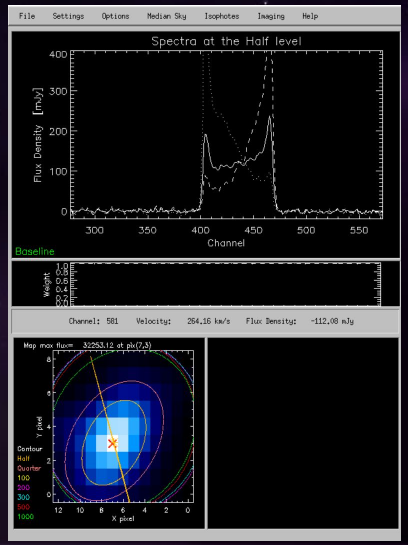
A Determination of the Angular Momentum of Galaxies in the ALFALFA Survey

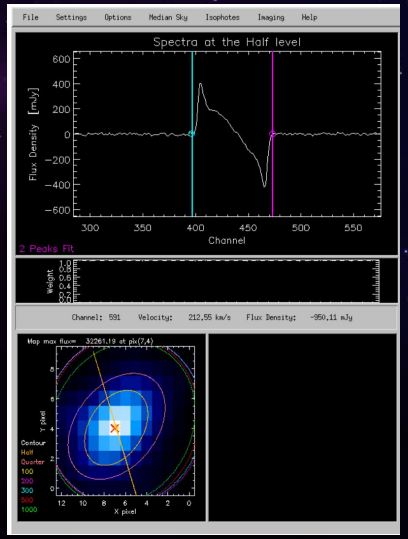
by

Daniel Scott Kodroff

A thesis submitted in partial fulfillment for the Honors Bachelors of Science in Physics

May 2017





My Journey in Physics

Graduate Lafayette… What's next???

Wanted to do research, but wasn't sure what path to take

Grad school? Get a job in lab? Go into commercial industry?

My Journey in Physics

Cold-contacted professors and labs looking for any lab-related research position

Found Post-baccalaureate research position at UMass Amherst

My Journey in Physics

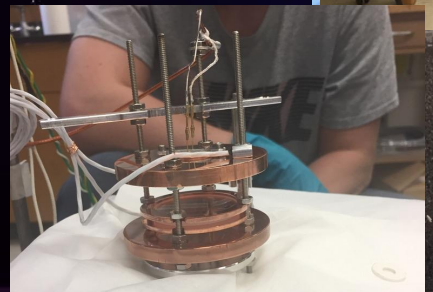
Research on silicon-based photosensors for nEXO experiment (neutrinoless double beta decay)

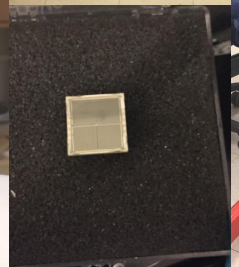
→ First experience working in any research lab

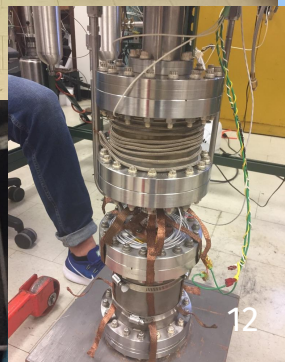
→ Working with xenon circulation and cryogenic systems

→Photosensors (silicon photomultipliers)

→ Hardware and software (python) work!







My Journey in Physics

Now ready for graduate school and a dedicated physics research project

Start grad school at Penn State

My Journey in Physics

PhD at Penn State on LUX-ZEPLIN dark matter experiment (more on that later…)

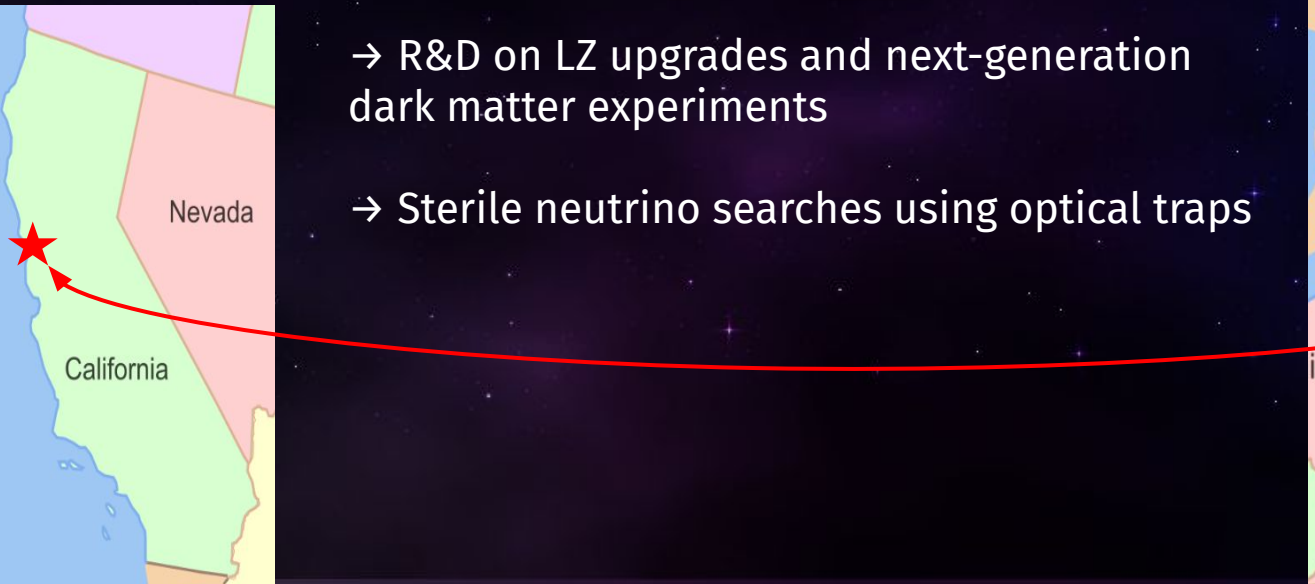
My Journey in Physics

Start Postdoc at LBNL in 2023

→ Continue dark matter research on LZ

→ R&D on LZ upgrades and next-generation dark matter experiments

→ Sterile neutrino searches using optical traps

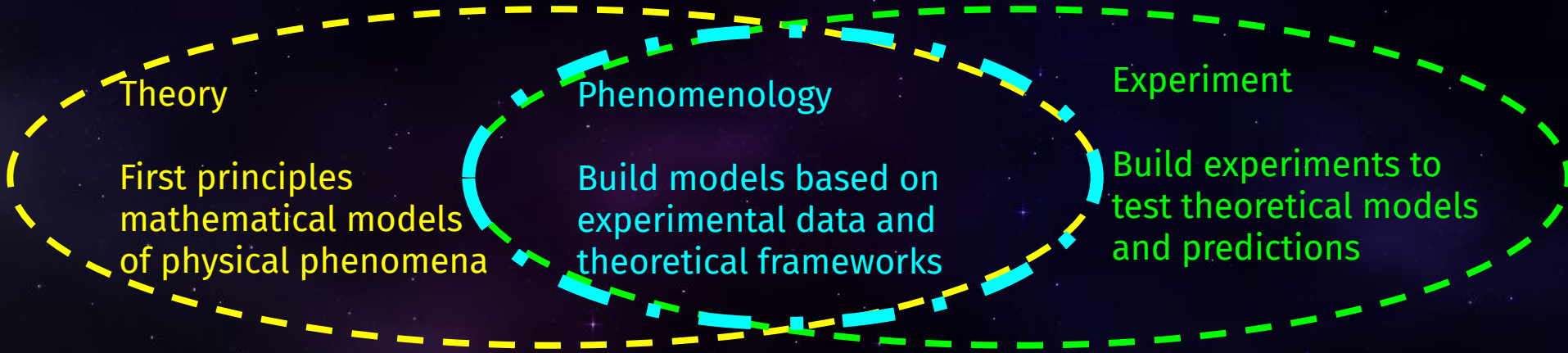


Lessons Learned

- Participate in any research/lab experience you can
- Learn new skills
  - Most of the skills I learned (software+hardware) were learned on the job, not through a formal course
- Say yes to travel and research opportunities
  - I never got to see the Arecibo telescope
- Don’t be afraid to reach out to professors/researchers
  - Opens doors, makes new connections, shows ambition/interest
- Be curious, get interested, and dive deep into subject - whatever that is!!!

Types of Physicists

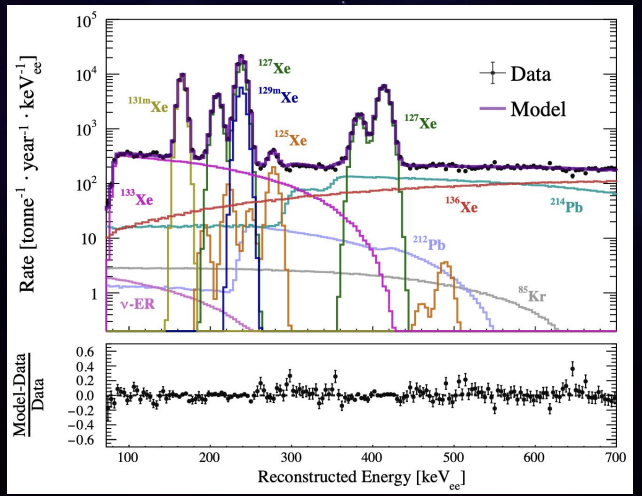
In my biased opinion...



A Week in the Life of An Experimental Physicist

Analyze experimental data

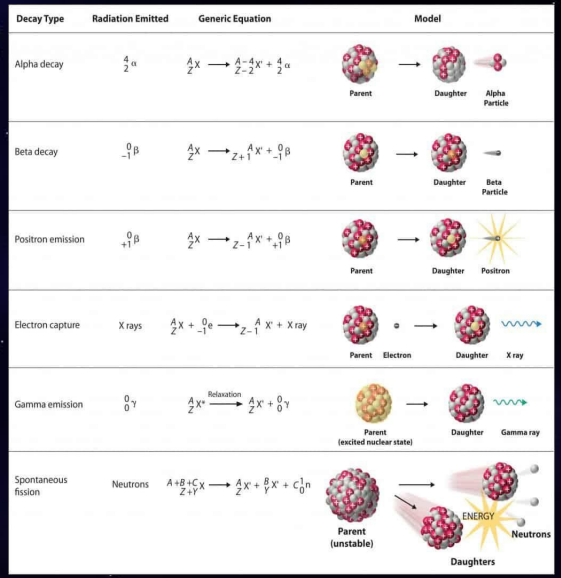
- Big physics experiments collect lots of data which much be analyzed
  - LZ produces 1 TB/day and few PB/yr
  - Bash, Python, C++, ROOT all common coding languages
- What's happening in your detector!!!
- Make pretty plots to illustrate your findings!



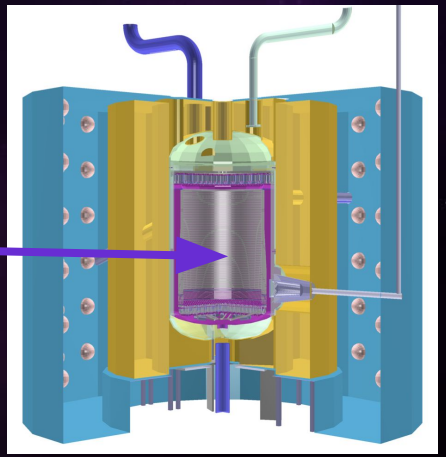
A Week in the Life of An Experimental Physicist

Perform simulations of experimental phenomena

- Make predictions of what's going to happen in your detector and compare to data
- Build a model your detector (like minecraft on steroids)



Electron, alphas, positrons, gammas, neutrons, muons

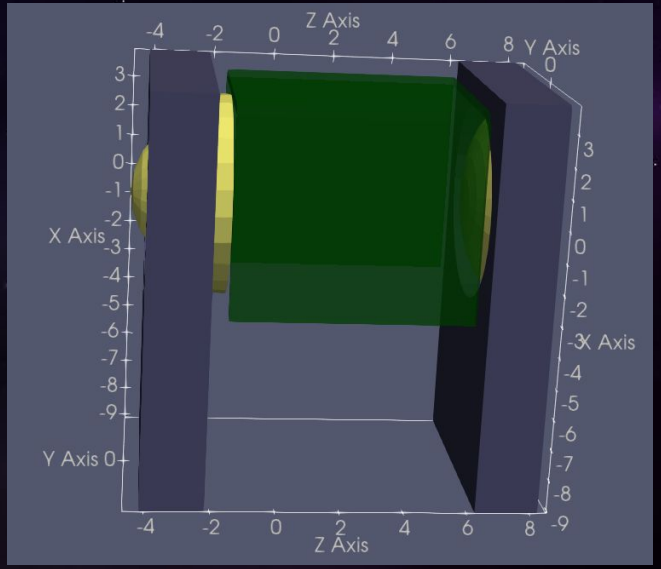


model of LZ detector

A Week in the Life of An Experimental Physicist

Design, Build, and Test new detectors experiments

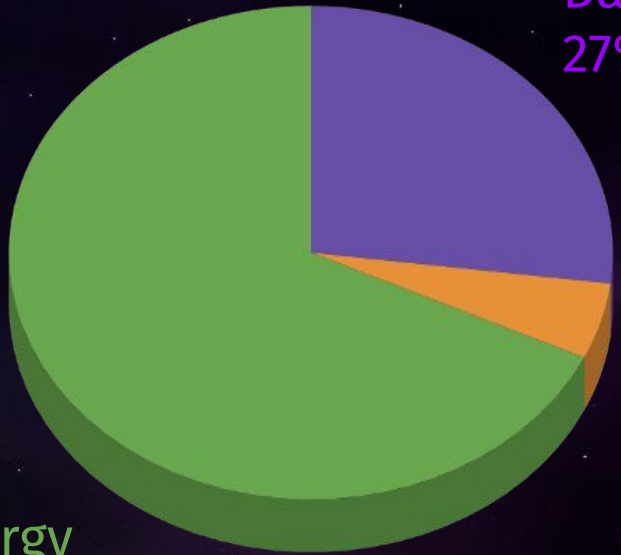
Design new detector and test its performance



Build Small-scale tests of upgrade to current LZ detector

Break...

What is The Universe Made of?



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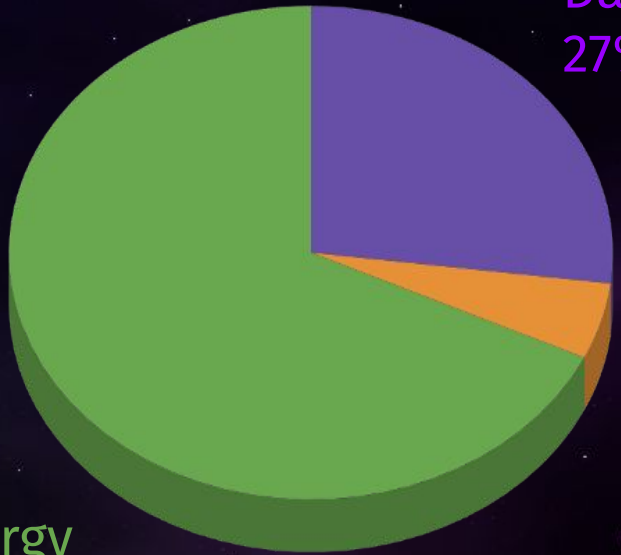
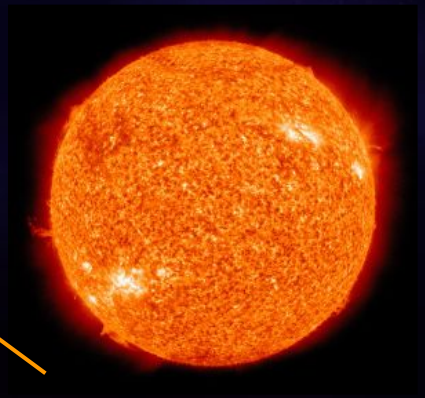


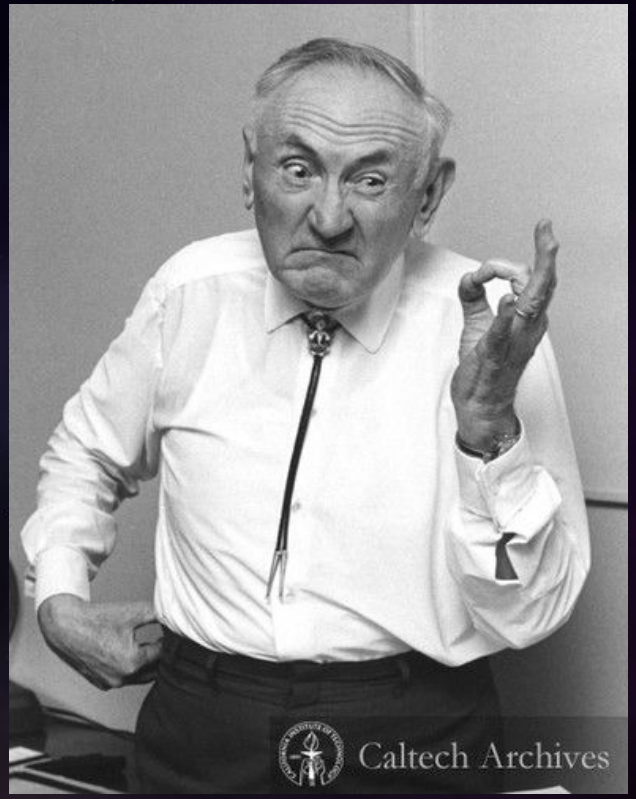
Dark Matter
27%

Visible Matter
5%

Dark Energy
68%



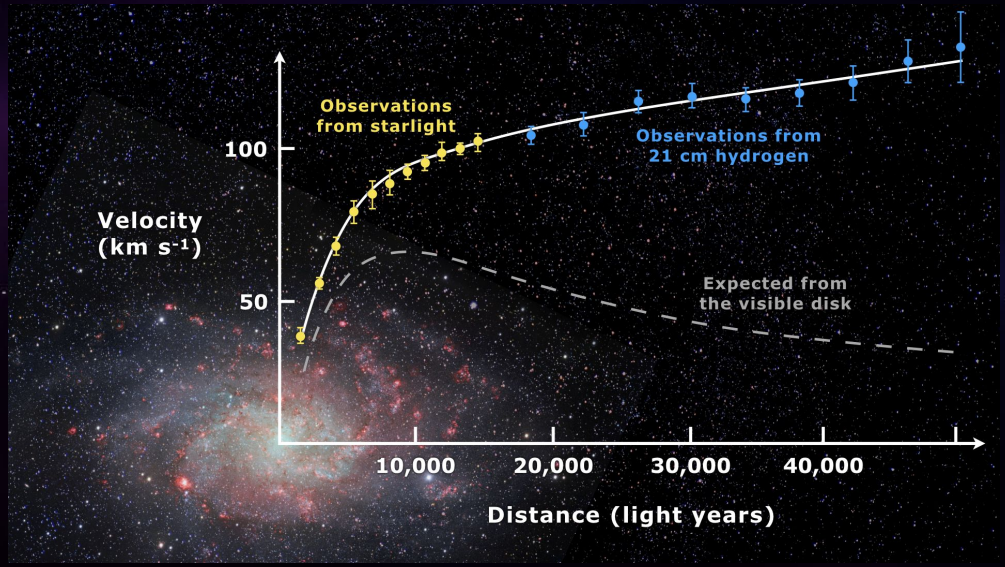
First Hint of Dark Matter



- In the 1930s, Fritz Zwicky performed measurements of velocities of galaxies within Coma Cluster
- The amount of visible light is proportional to mass
- Galaxies move faster than expected ⇒ must be “missing” mass

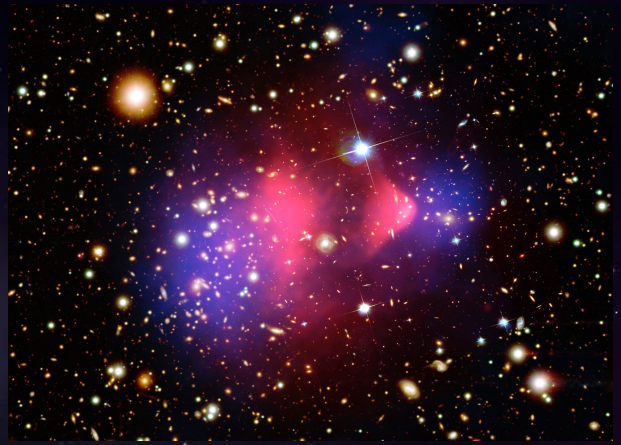
More Evidence

- In the 1970s, Vera Rubin measured galactic rotation curves using visible light and neutral hydrogen lines
- Galactic rotation curve don't "fall off" as expected, must be non-visible halo of dark matter in galaxies

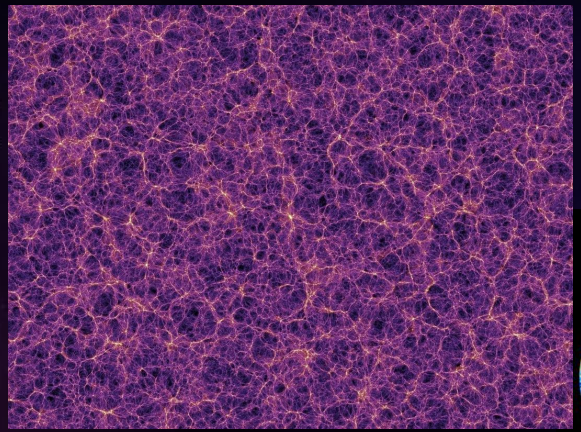


That's Not The Only Evidence

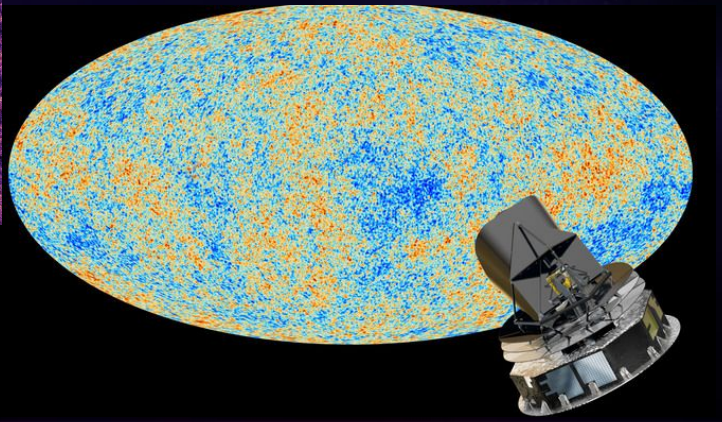
Bullet Cluster



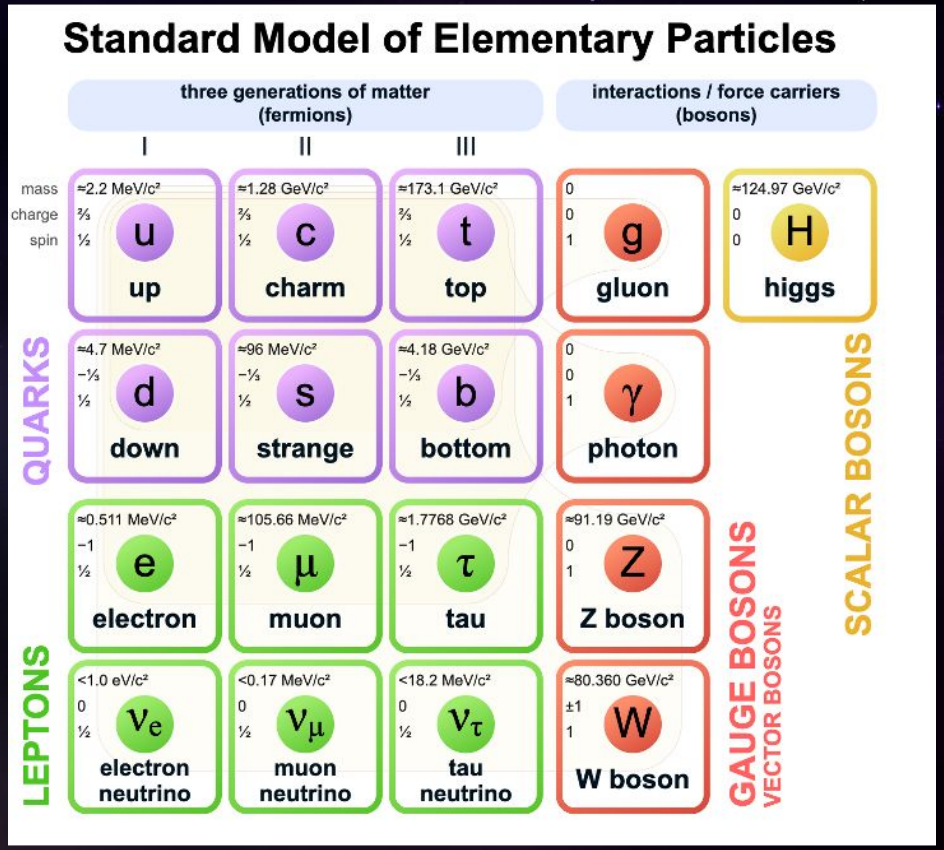
Large-scale structure
of the Universe



Cosmic Microwave Background

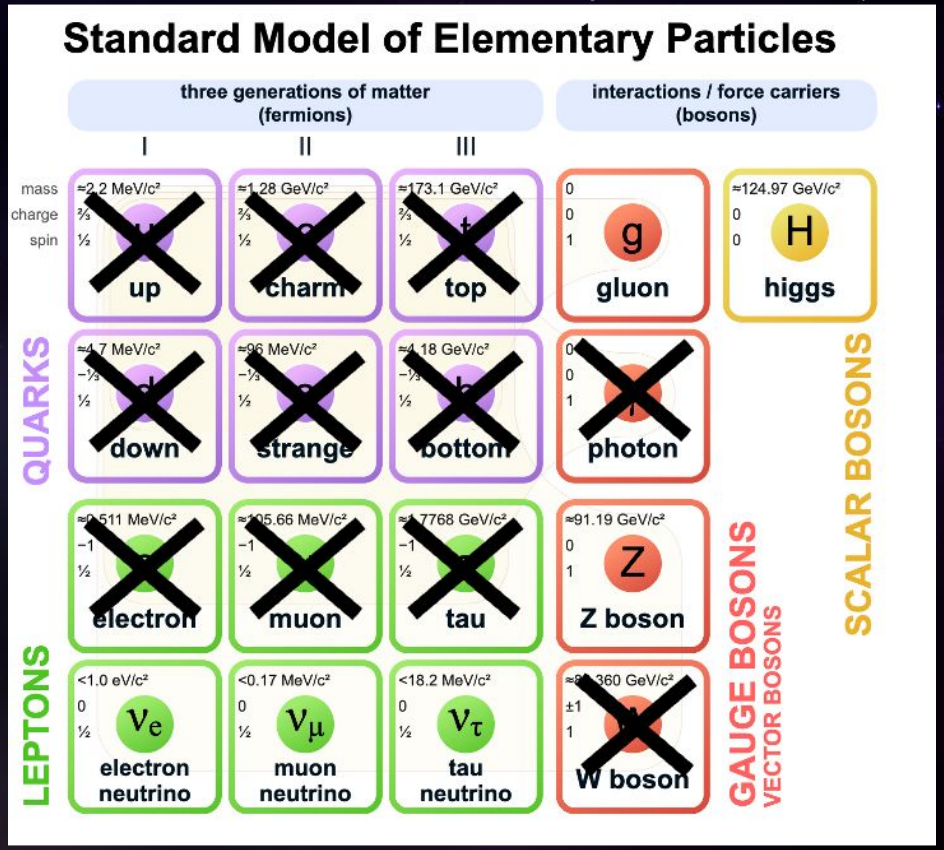


What is Dark Matter?



Can dark matter be any of the fundamental particles we already know about?

What is Dark Matter?



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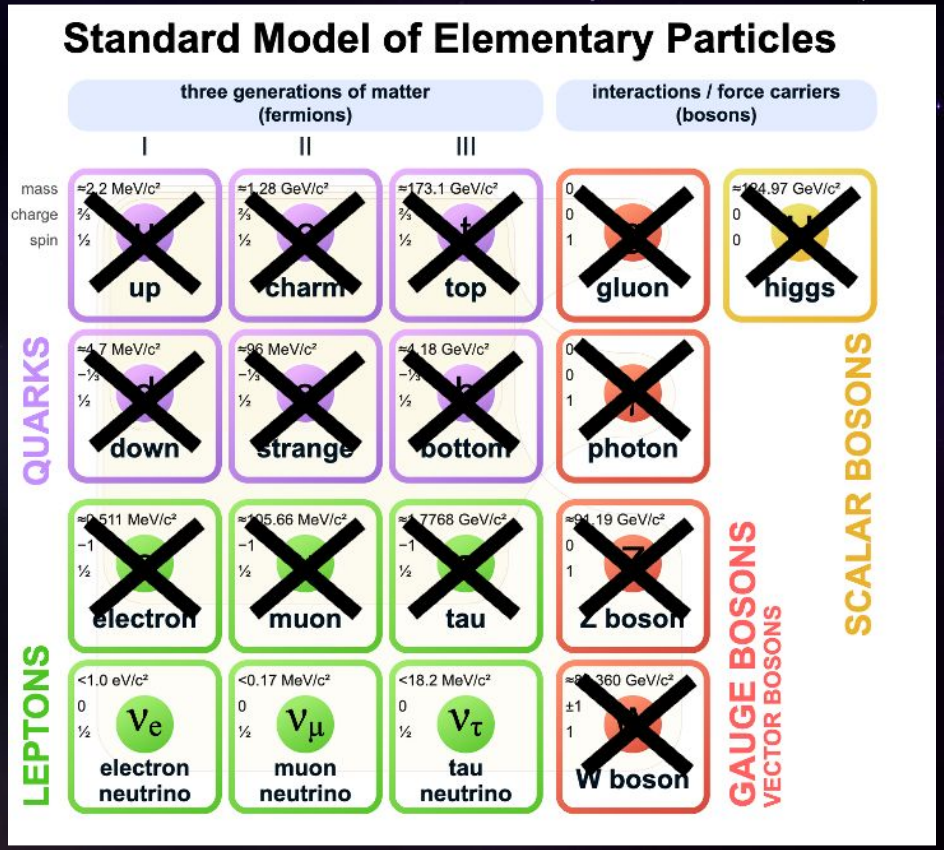
→ Dark matter is dark (no electric charge, no interaction with light)

What is Dark Matter?



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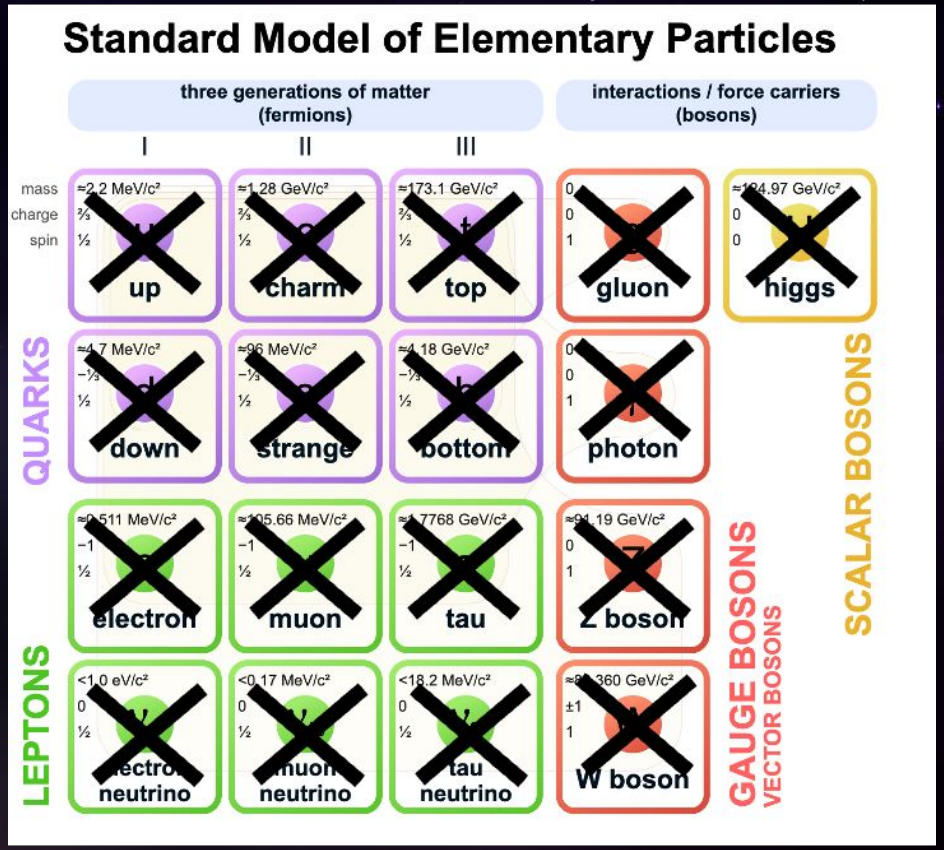
What is Dark Matter?



Can dark matter be any of the fundamental particles we already know about?

→ Dark matter is dark (no electric charge, no interaction with light)

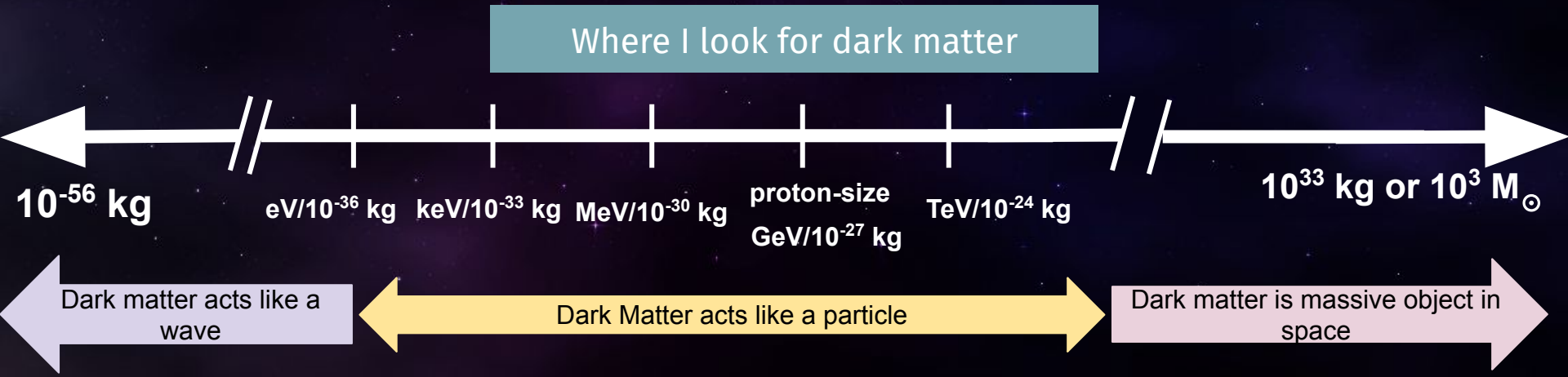
→ Dark matter is long-lived (observed in both early and later Universe)

→ Dark matter is cold (slow moving, non-relativistic)

What is Dark Matter?

Something new! But what?

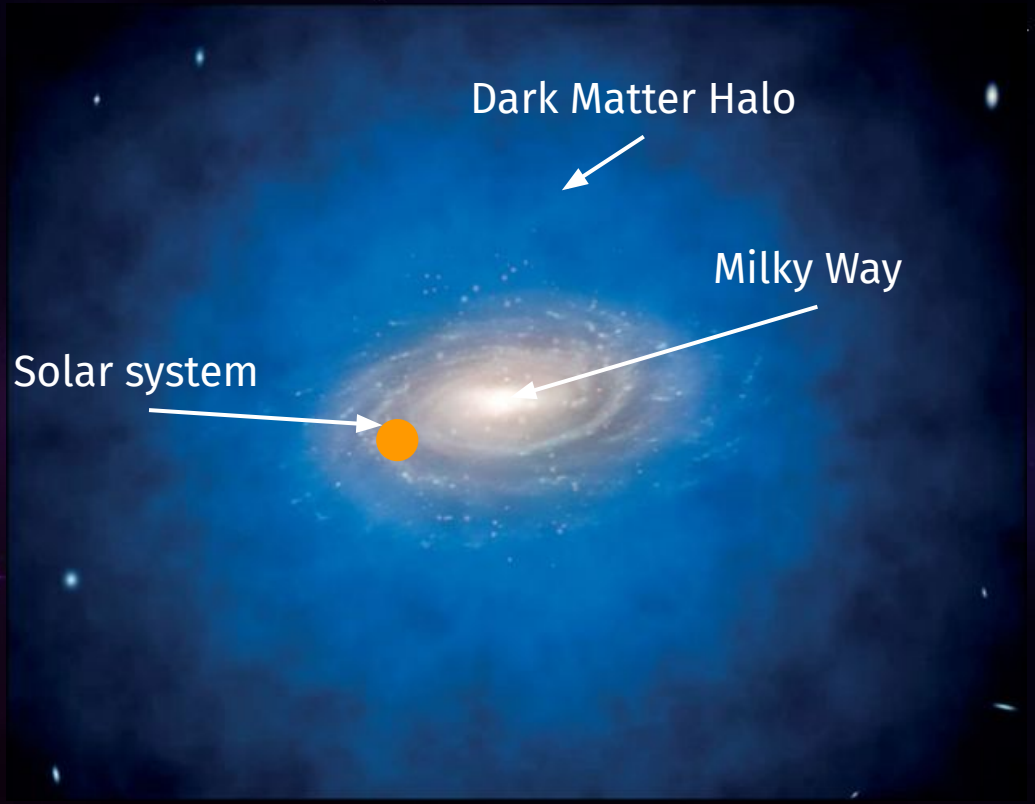
Popular theoretical model is WIMP (weakly interacting massive particle)



Where Is The Dark Matter?

Dark Matter is everywhere!

Earth is constantly “flying” through a dark matter “wind”



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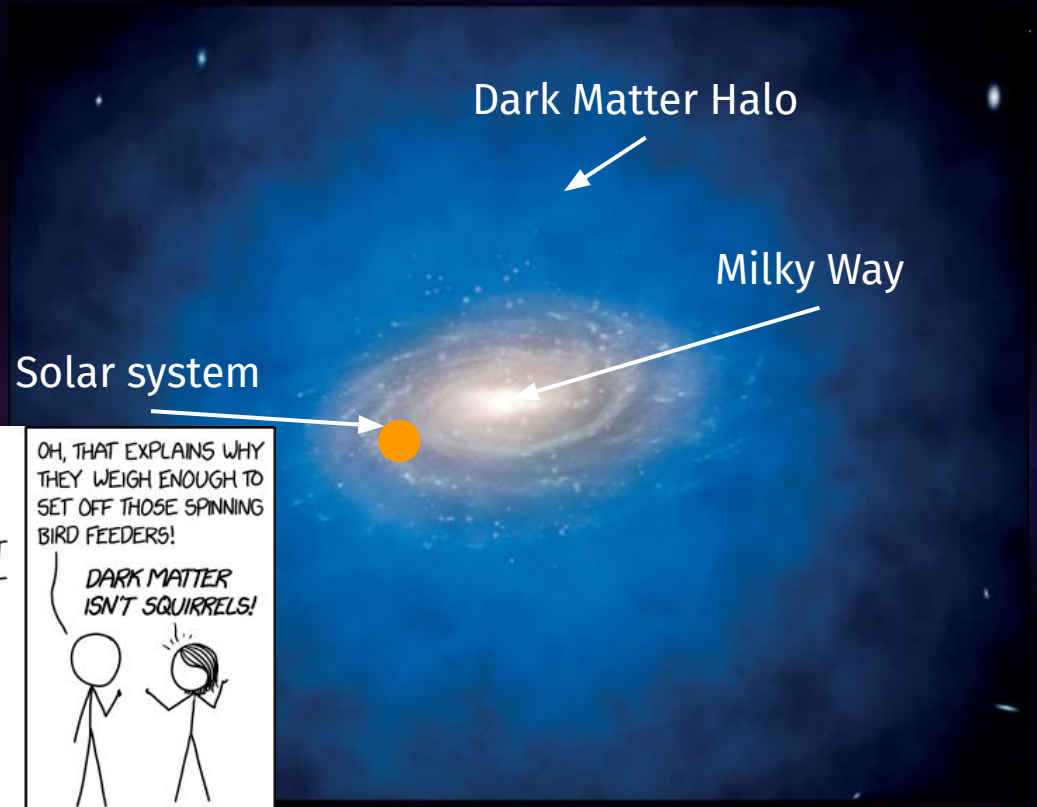
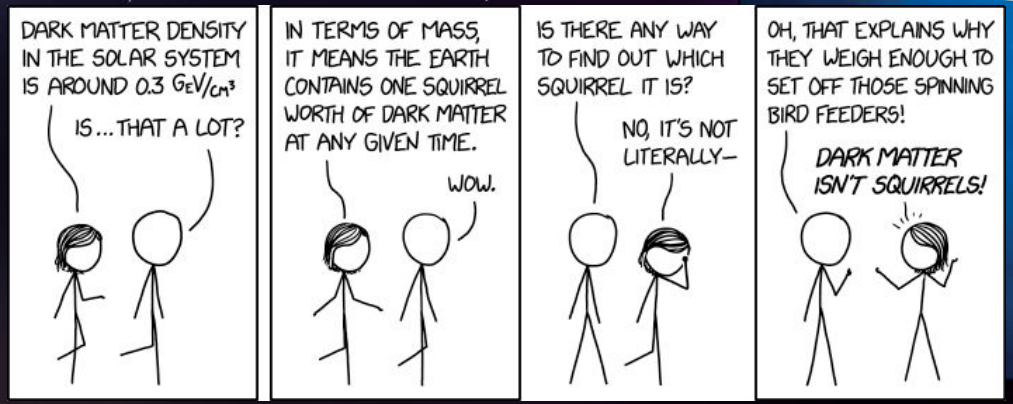
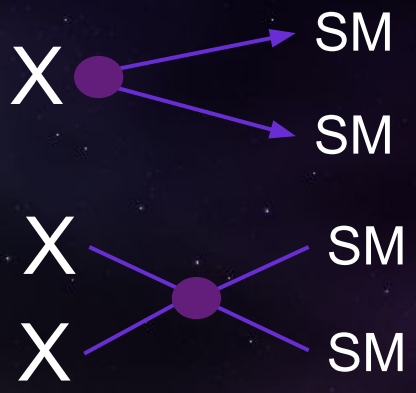


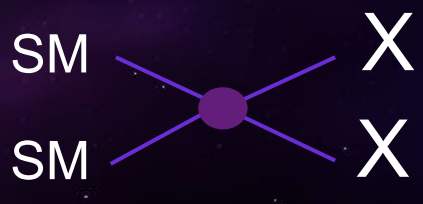


How Can You Look For Dark Matter?

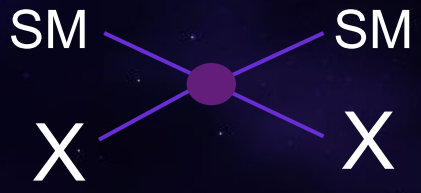
From Space Radiation
(Indirect Detection)



At Colliders
(Production)

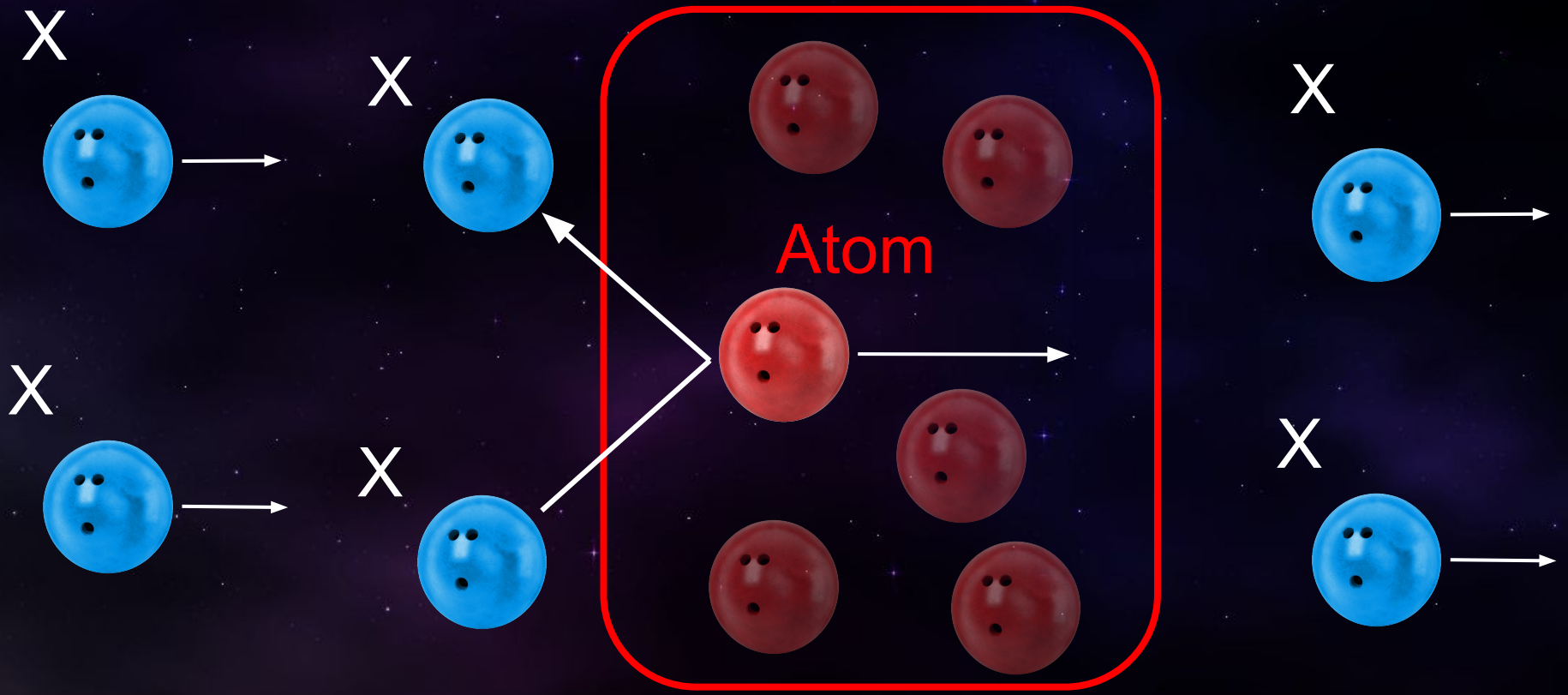


Directly On Earth
(Direct Detection)



SM = Standard model particle

Direct Detection of Dark Matter



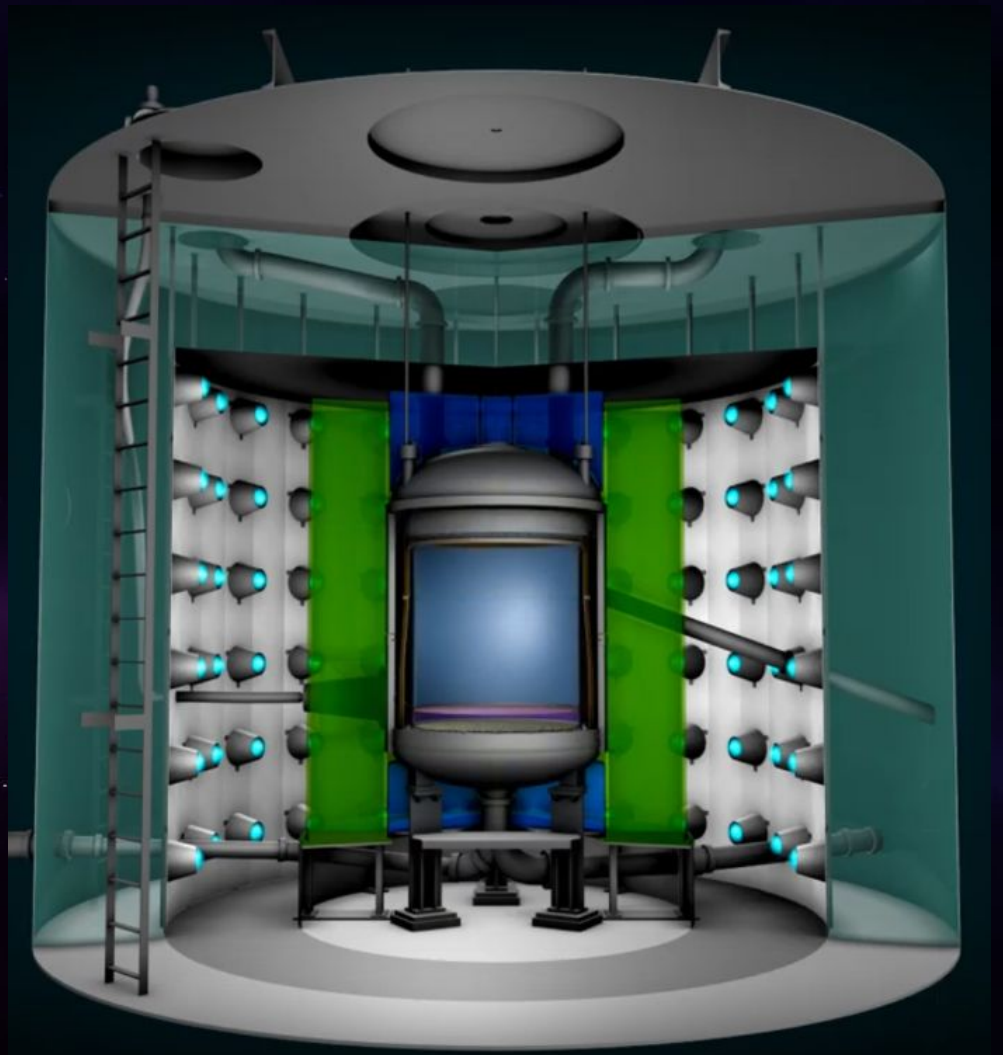
Build a detector and wait for dark matter to hit it

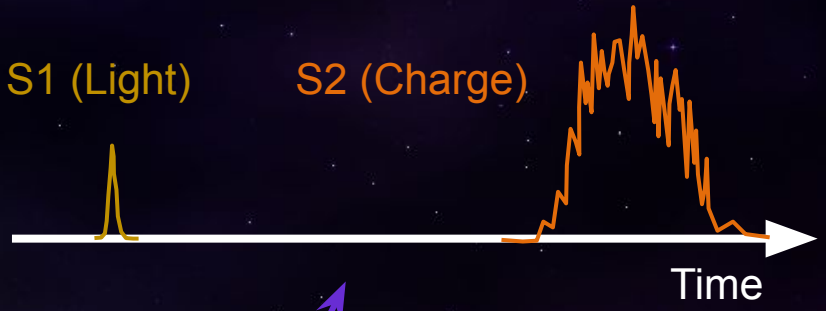
The LZ Detector

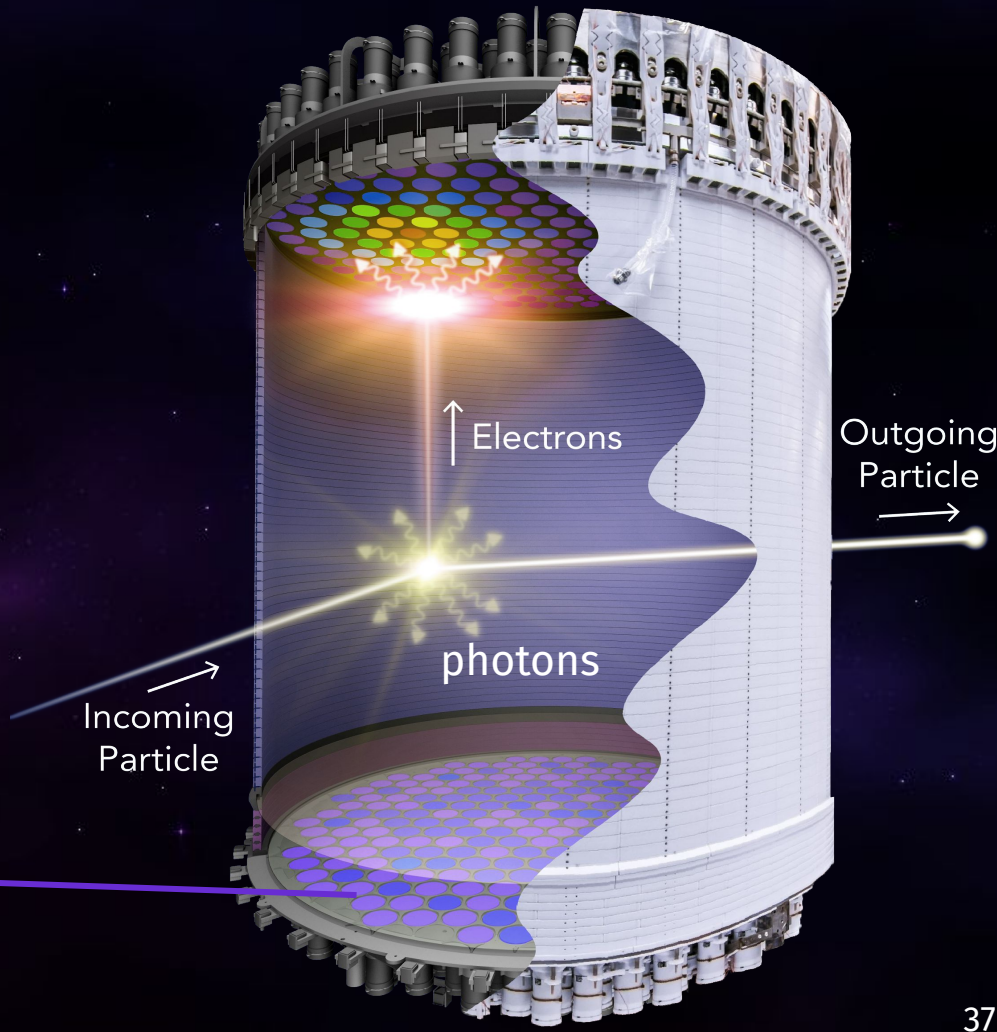
LZ = LUX-ZEPLIN

Uses 7 tonnes of xenon as detector!

Xenon dark matter detectors have been in use for over 20 years!

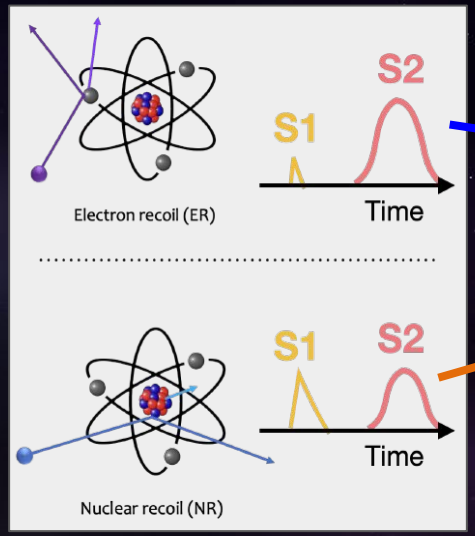


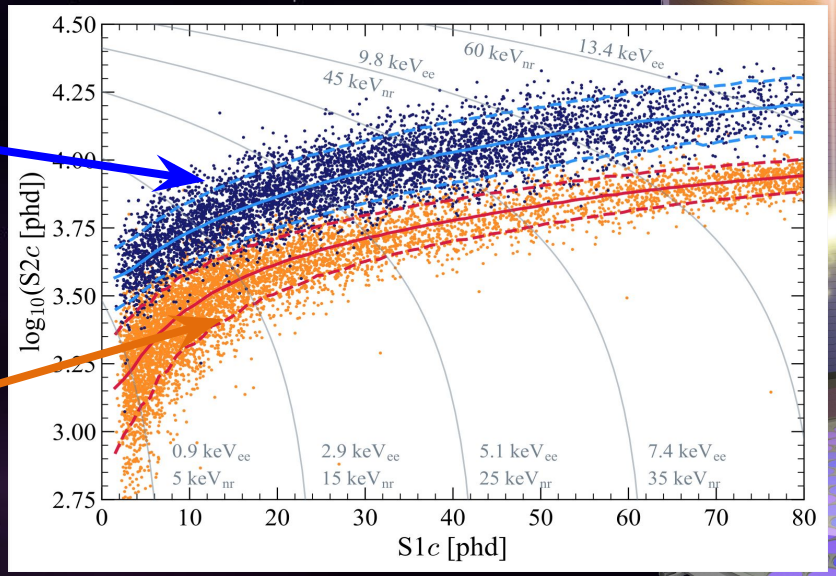

S1 (Light)
S2 (Charge)
Time


Electrons
Outgoing Particle
photons
Incoming Particle

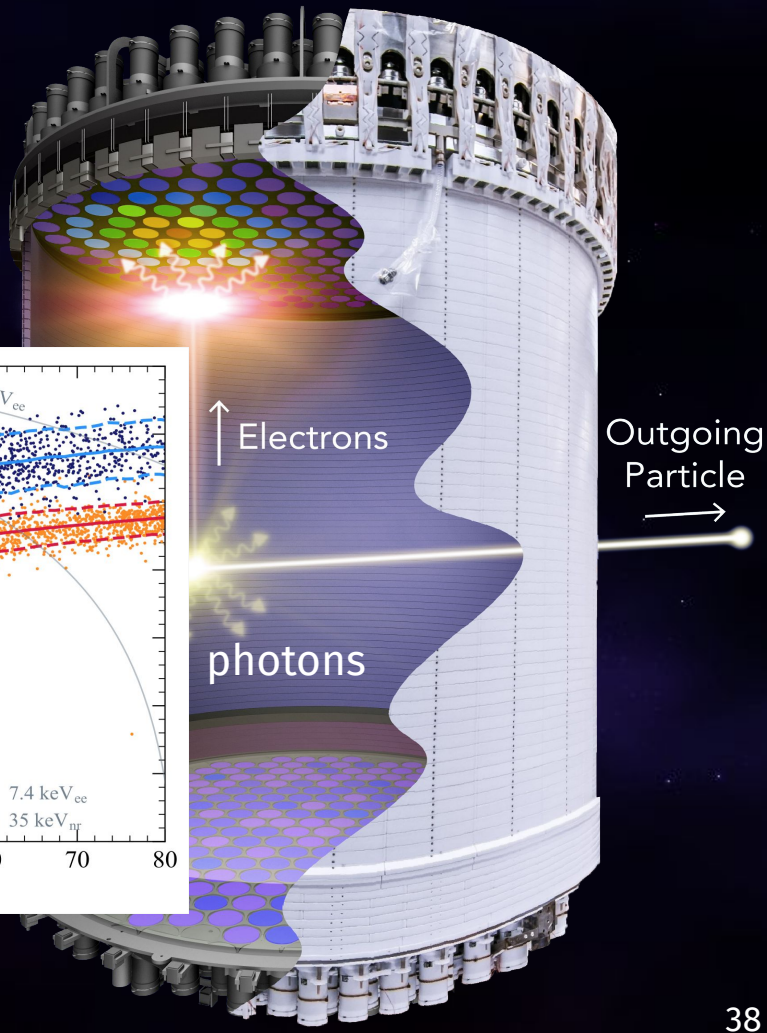
Anything that's not dark matter is background

Hit xenon electrons → electron recoil

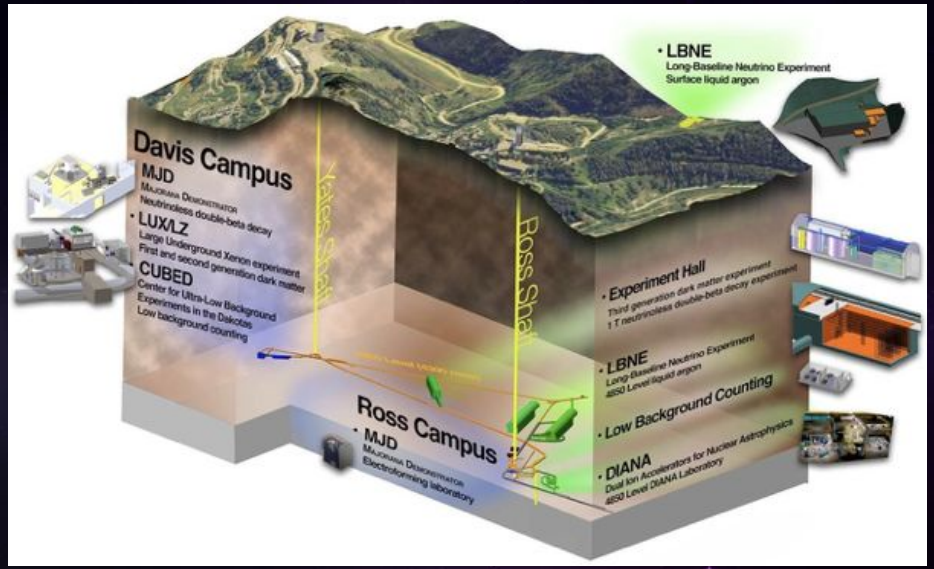




DM hits xenon nucleus → nuclear recoil

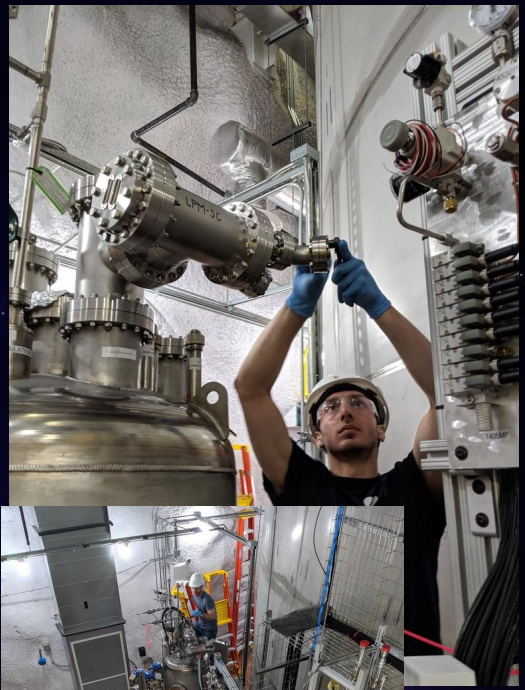


Going Deep Underground

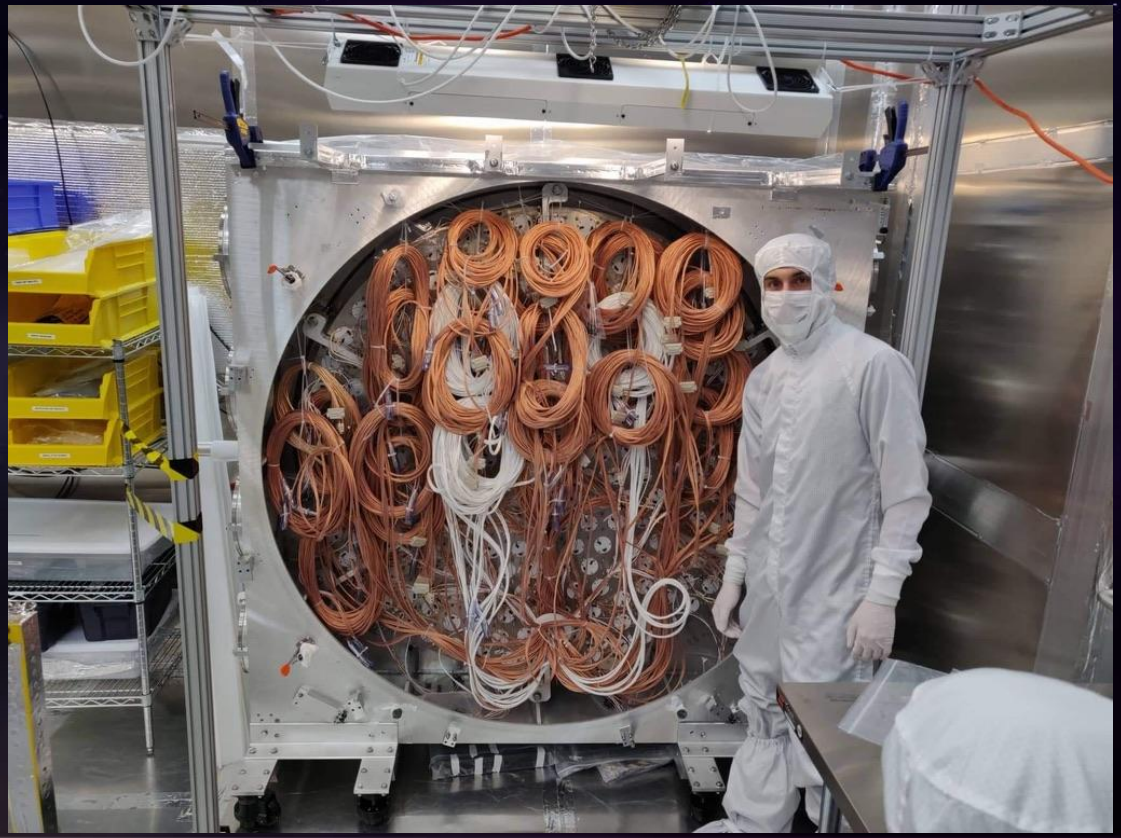


LZ is located ~ 1 mile underground at the Sanford Underground Research Facility (SURF) in Lead, South Dakota

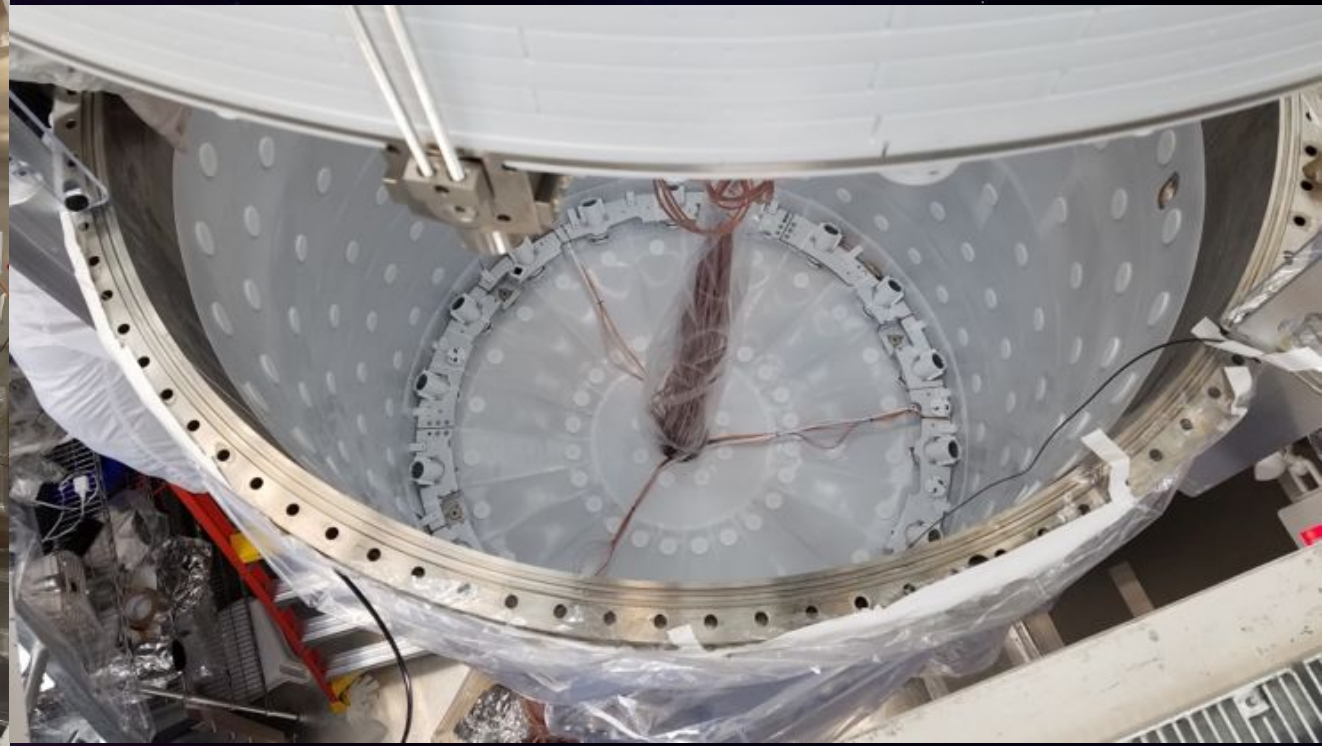

DANGER
Persons Working in Shaft
Welcome to the Yates Shaft
Gateway to the 4850 Level
Sanford
Underground Research Facility
Dakota Science and Technology Authority
North Cage
DANGER
Persons Working in Shaft

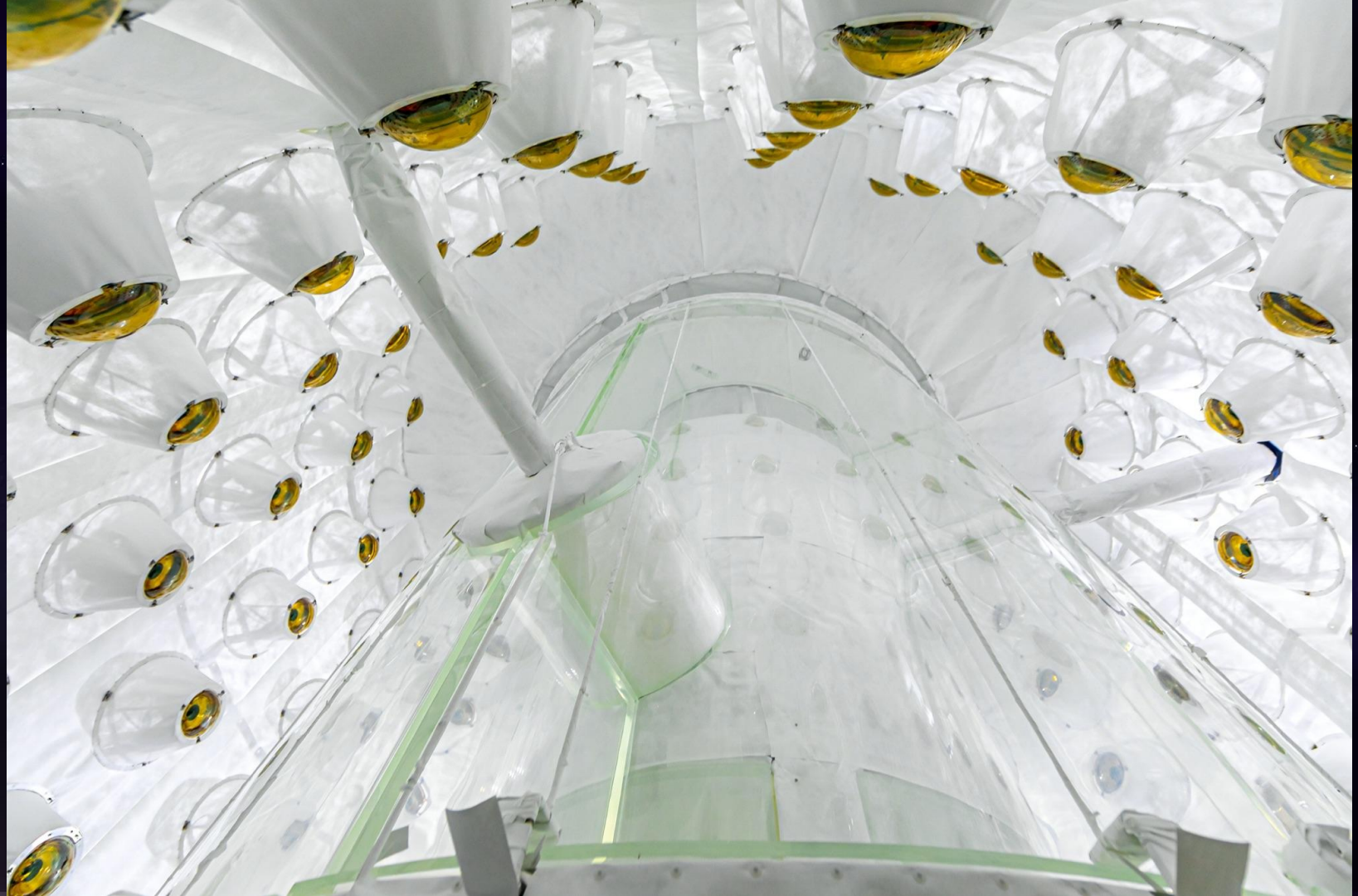

LPM-30


EXIT



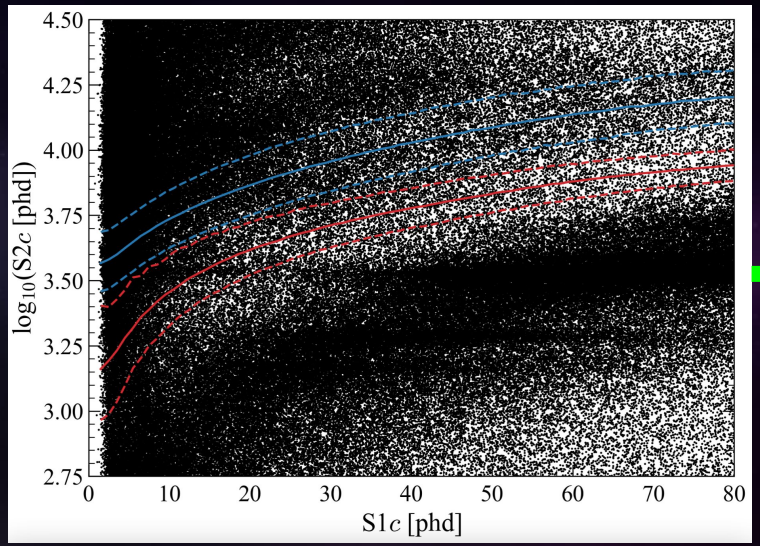

EXIT

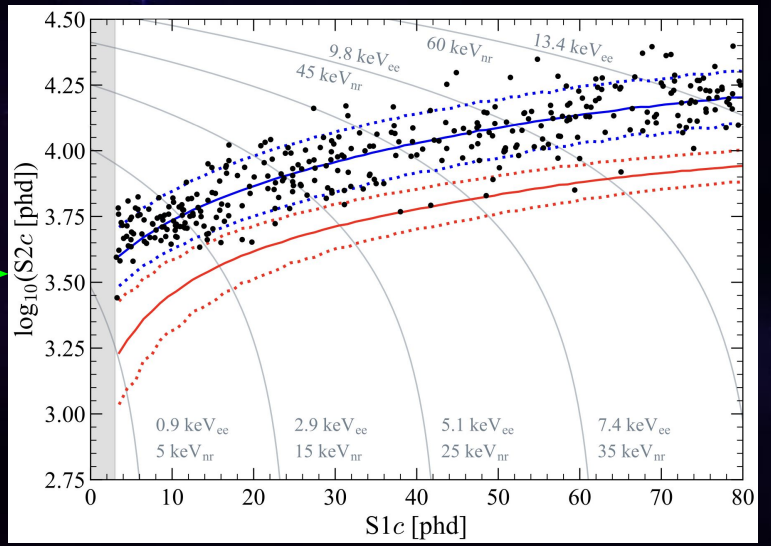




Now Run the DM Experiment

And analyze the data...



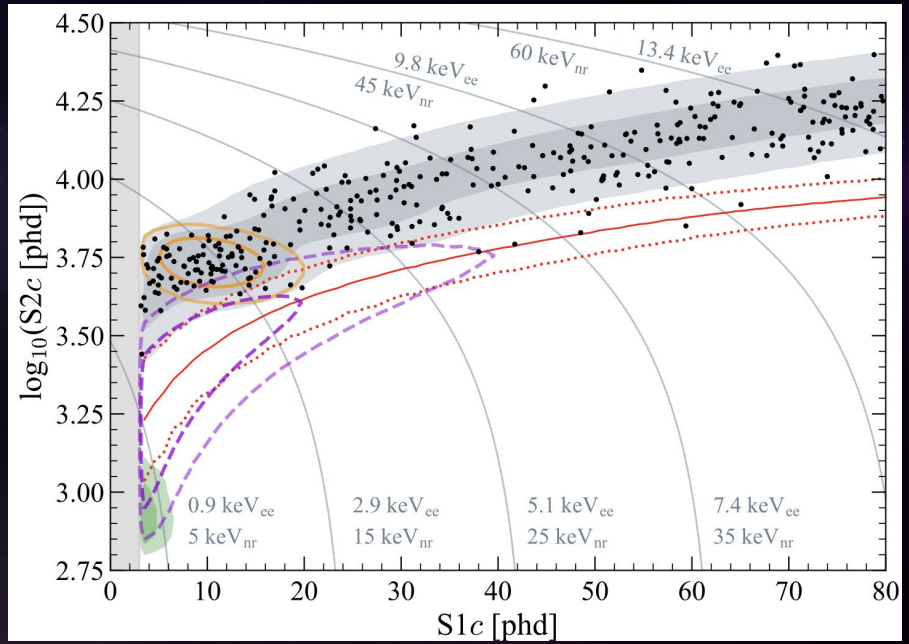


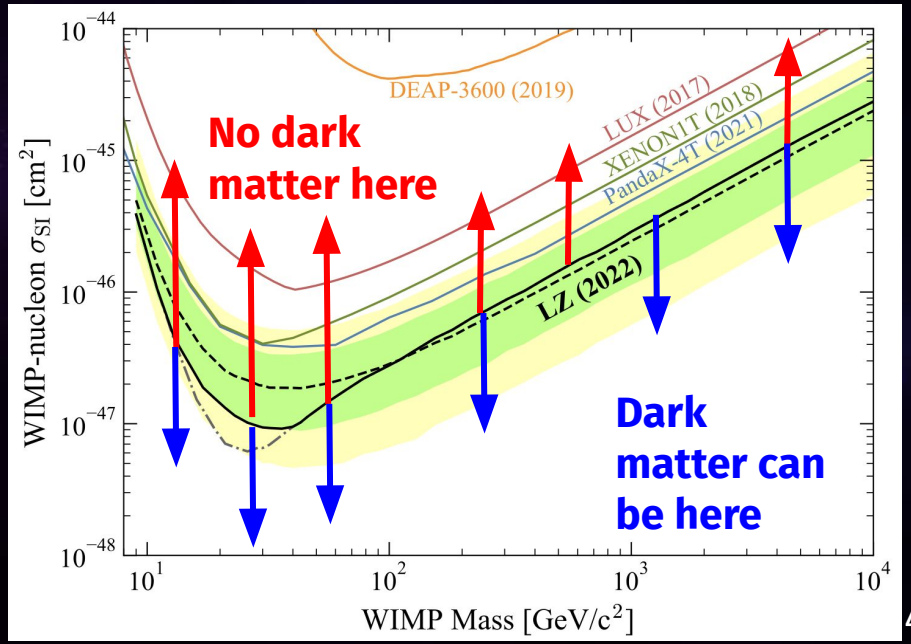
And Look For Dark Matter

No dark matter found in first results 😢

Need to keep running the detector!

Discussions of upgrades and next-generation detector already under-way





LZ In The Media

Recently Featured in PBS Nova Episode:
Decoding the Universe: Cosmos
https://www.pbs.org/wgbh/nova/video/decoding-the-universe-cosmos/

Video of Assembly of Detector
https://www.youtube.com/watch?v=-lWpXx_ovb4

Infotainment by SLAC
https://www.youtube.com/watch?v=bKCsiK4ZZBY

LZ and SURF by Wired
https://www.youtube.com/watch?v=JiOYgHSKcs4&list=PLh7LC5geWXGH19OH3o_COCiY0ppU67LEH&index=6

Presentation of First Results
https://www.youtube.com/watch?v=bN3GGWlqAp0

Thank You!!!

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

250 scientists, engineers, and technical staff

@darkmatter

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
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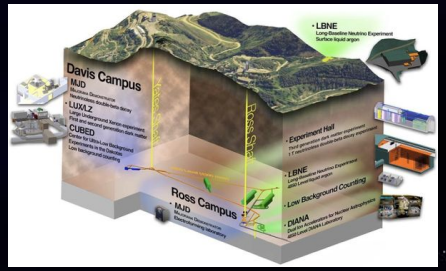

8” PMTs to detect scintillation from GdLS

Acrylic Vessels holding Gd Liquid Scintillator for neutron veto

Cathode high voltage feedthrough

Xenon circulation

7 tonne Xe TPC

Water tank for detector shielding

Pitched conduit for neutron calibrations

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