

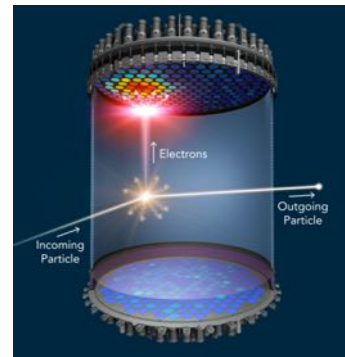


# The Search for WIMP Dark Matter with Massive Liquid Xenon Detectors

Prof. Dan Akerib

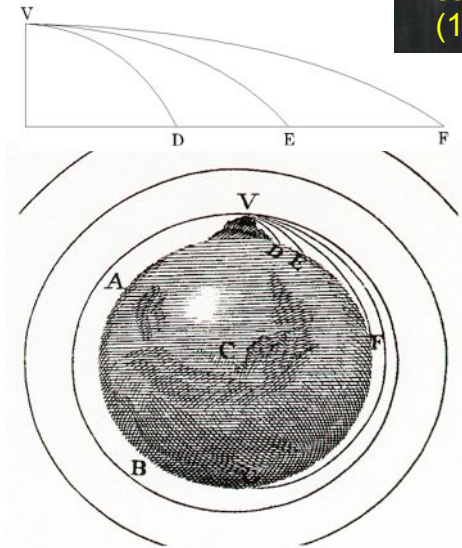
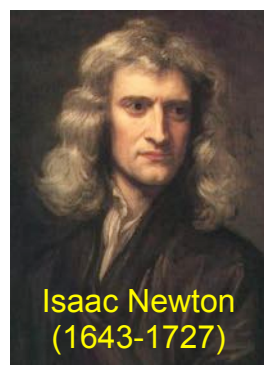
LUX-ZEPLIN Collaboration

XLZD Consortium

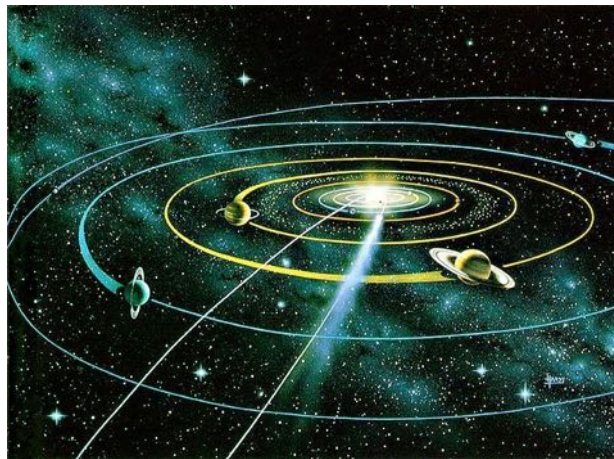
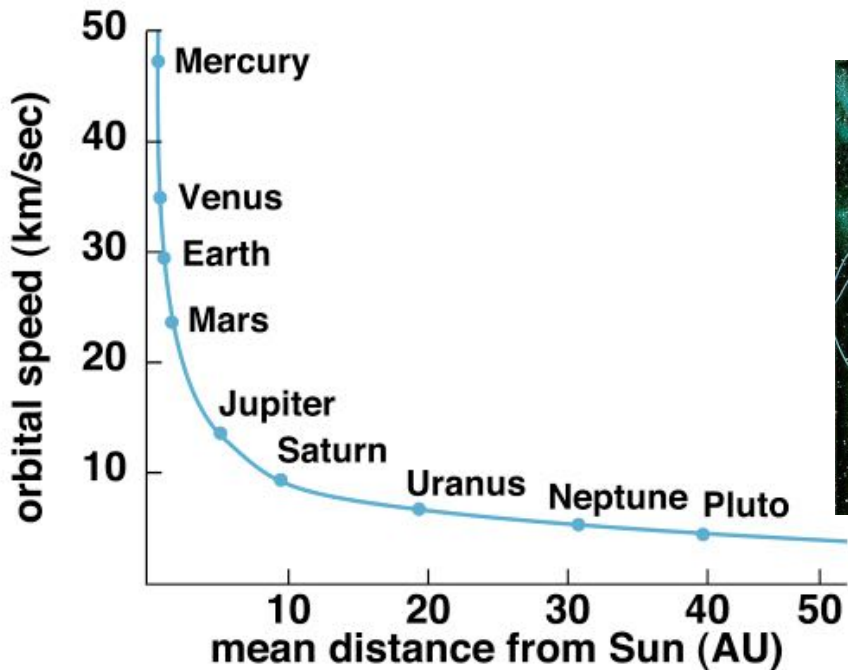


# The universe is mathematical

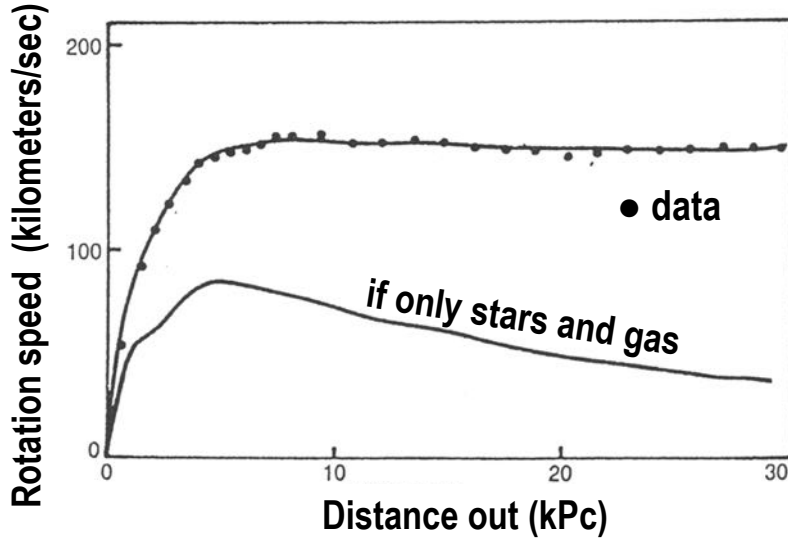
- 1665: Newton develops mathematical description of gravity.
  - (Also invents Calculus and physics while home from college during plague year)
- Allows us to put a man on the moon
- Flip a snowmobile (a South Dakota thing...)



# Weighing the Sun



# Weighing a Galaxy



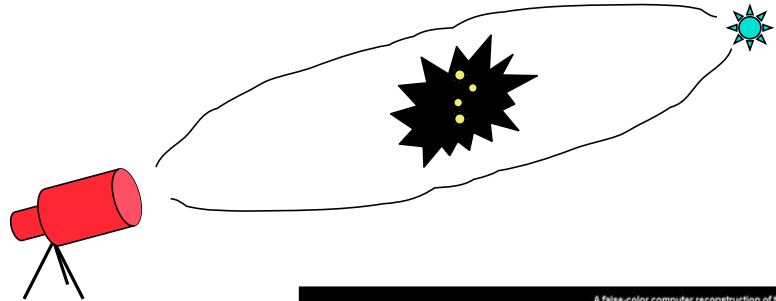
100 Billion stars bound by their mutual gravity



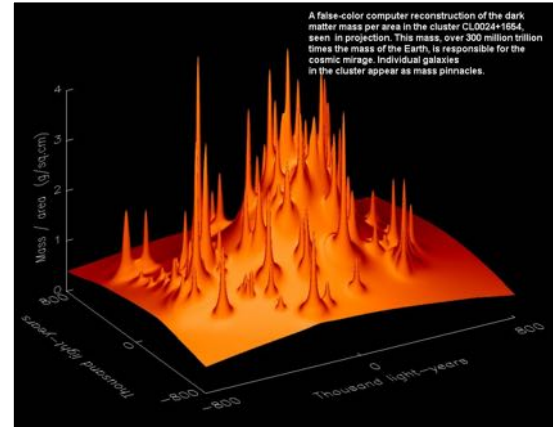
Vera Rubin -1970's

# Weighing Clusters of Galaxies

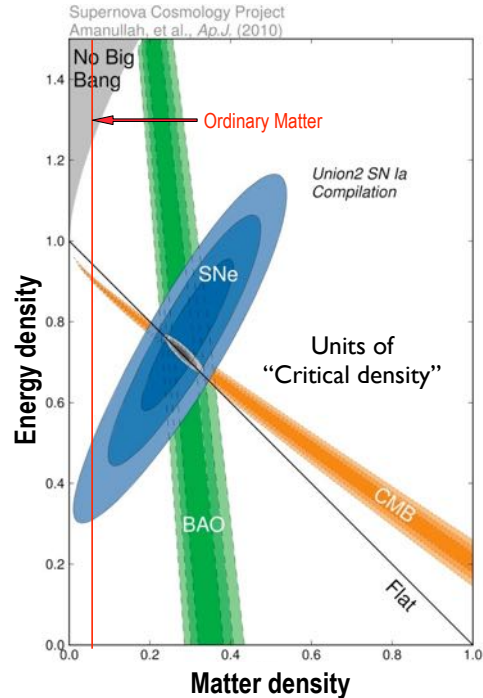
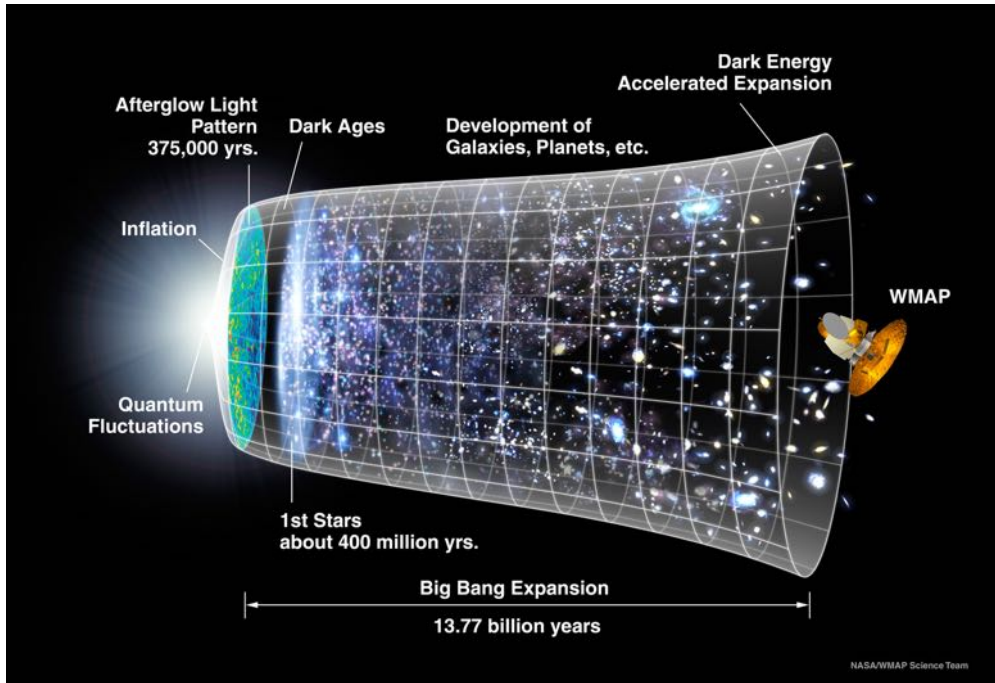
hundreds of galaxies bound together by mutual gravity



Fritz Zwicky  
1930's



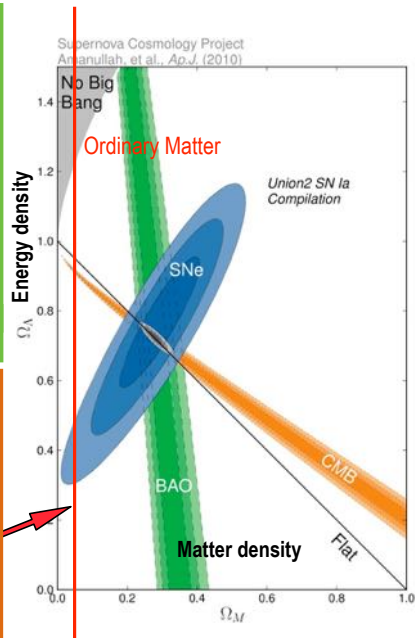
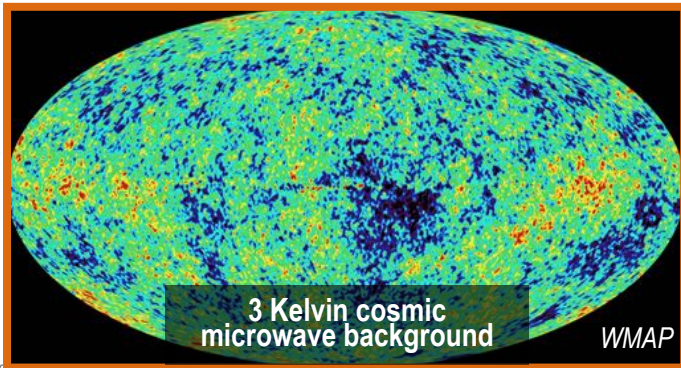
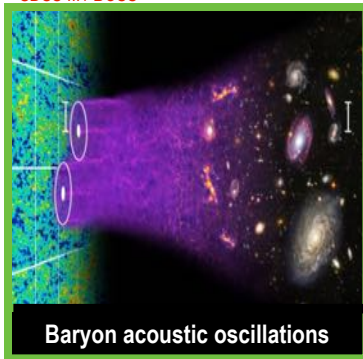
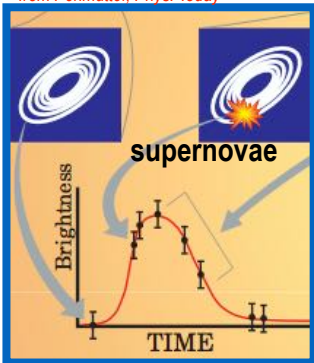
# Weighing the Universe: the Hot Big Bang Model



# Standard cosmology: Weighing the Universe!!

from Perlmutter, *Phys. Today*

SDSS-III / BOSS



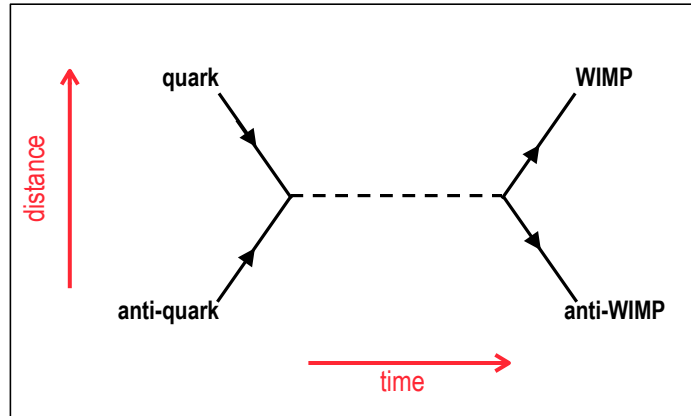
# WIMP Hypothesis: a new form of matter

WIMPs = weakly interacting massive particles

- Not enough protons and neutrons produced in the Big Bang
- Early Universe as Particle Factory

Convert energy to mass

$$E=mc^2$$



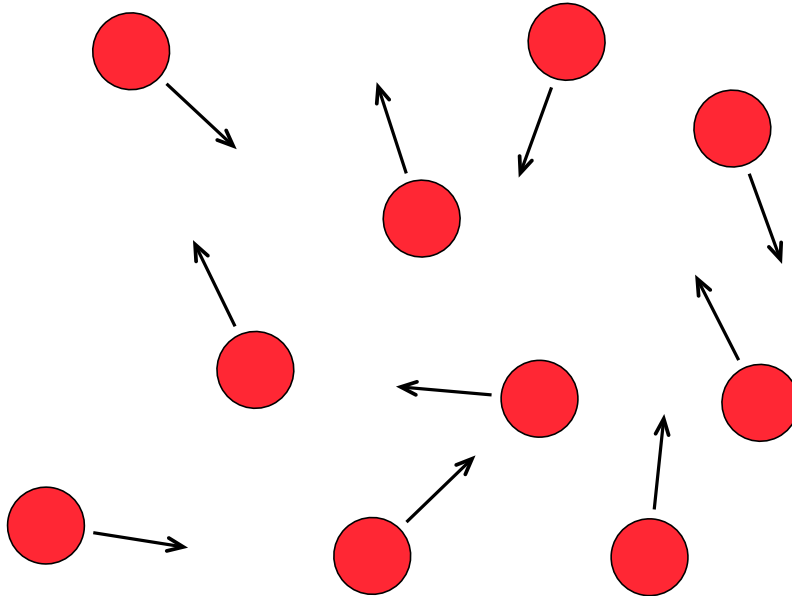
- **A new type of particle:** WIMPs = weakly interacting massive particles

**Massive: source of gravity**

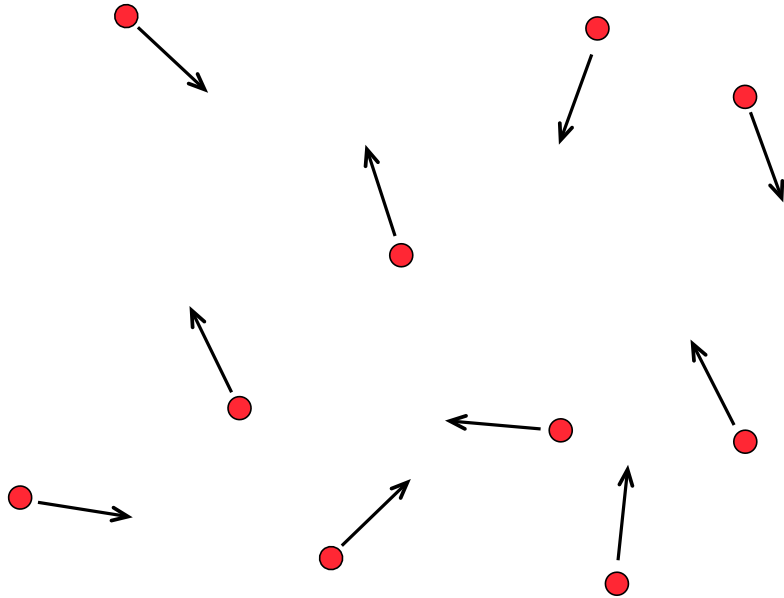
**Weakly-interacting: not star forming**



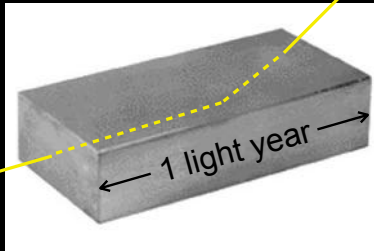
cross section  $\rightarrow$  annihilation rate



cross section  $\rightarrow$  annihilation rate

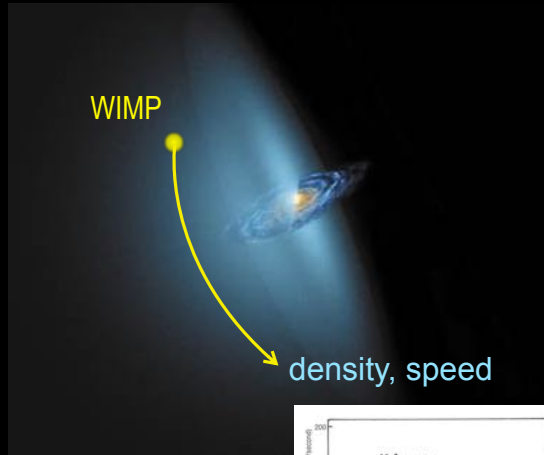


# Scattering experiment

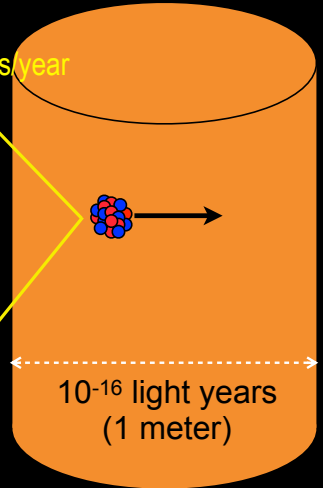


Cross section: WIMP scatters once in a light year of lead

dark matter halo

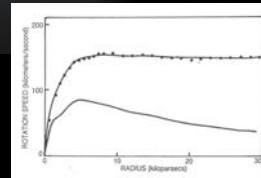


$10^{16}$  WIMPs/year



detector

Rate ~ few events / year

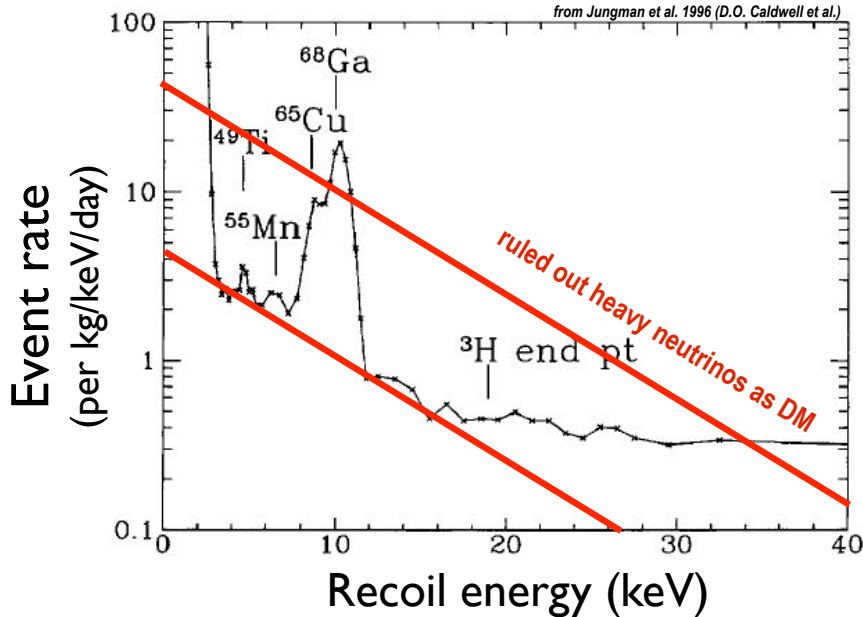


# Signal & background



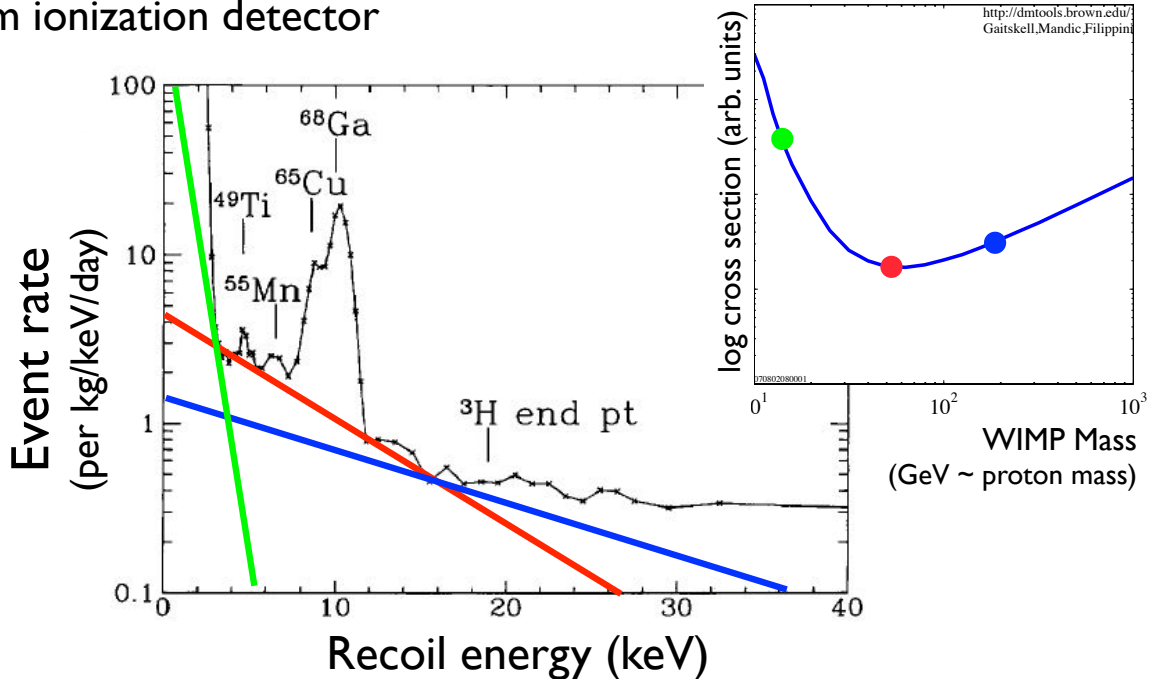
# WIMP search - c.1988

- Germanium ionization detector

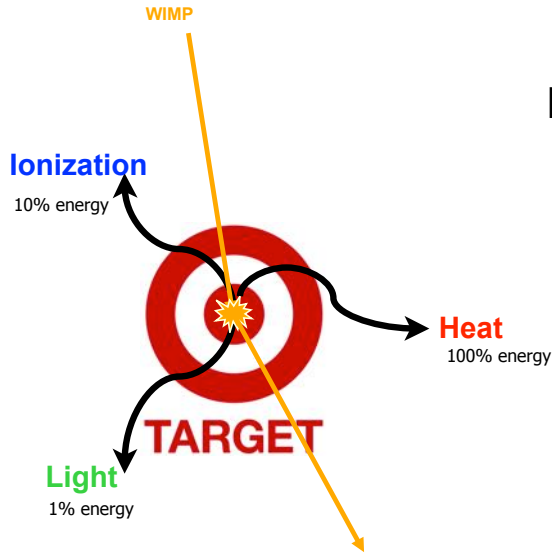


# WIMP search - c.1988

- Germanium ionization detector



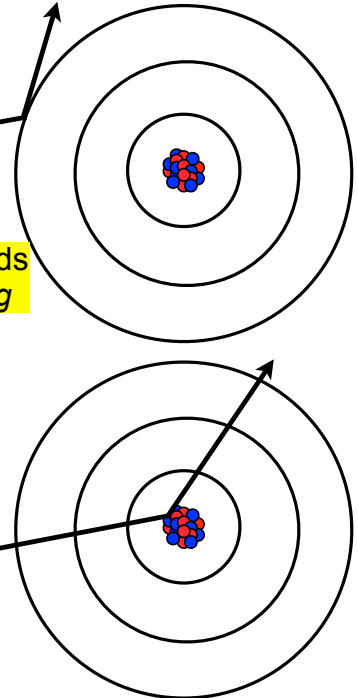
# Energy Deposition and Signal vs. Background



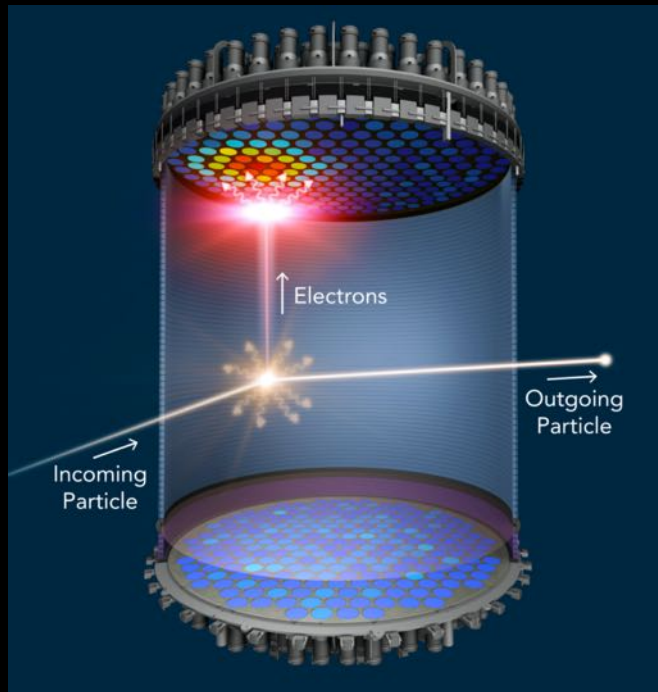
Electron recoil  
gamma rays  
beta decays

Radioactive backgrounds  
*relatively more ionizing*

Nuclear recoil  
WIMPs  
(and neutrons)

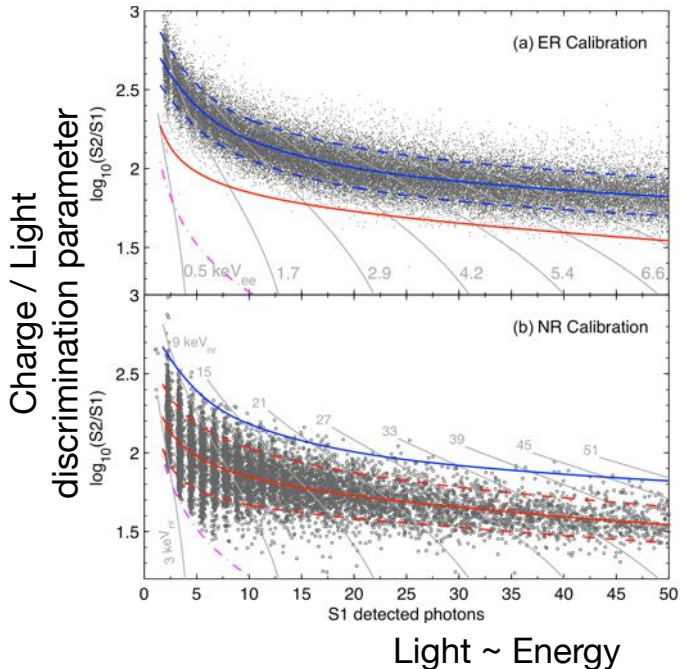


# Liquid Xenon Time Projection Chamber





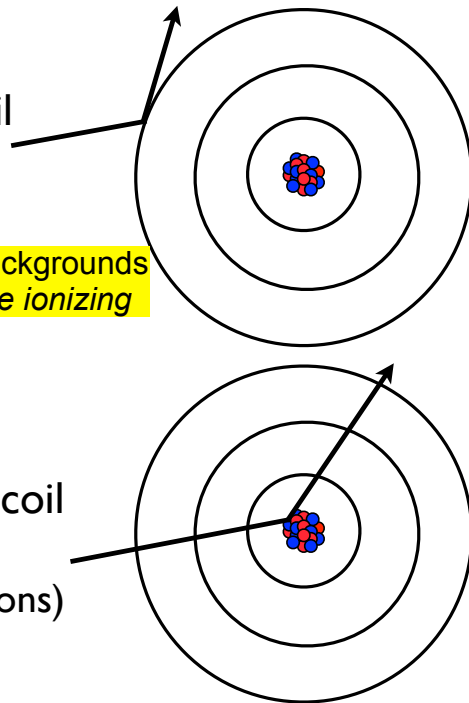
# Recoil discrimination



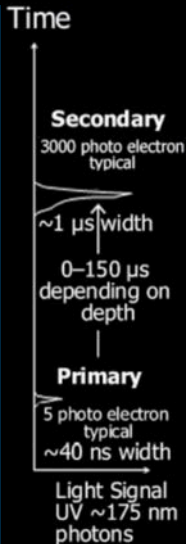
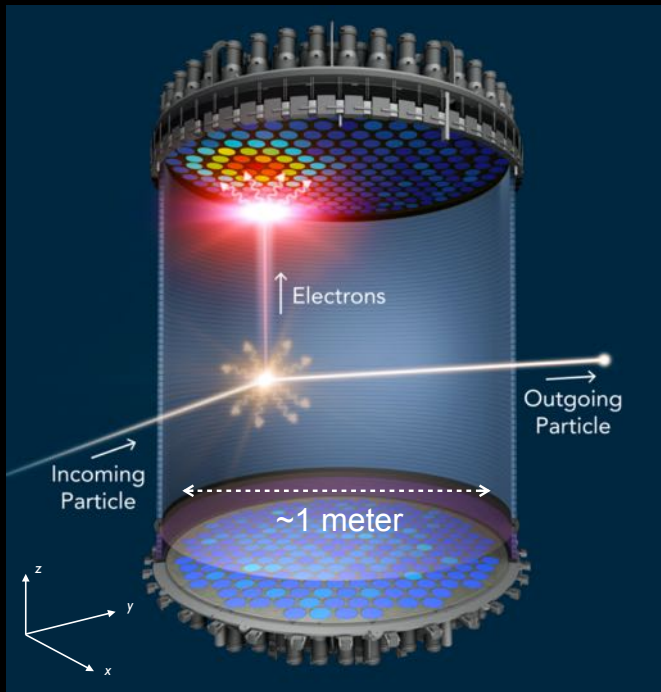
Electron recoil  
gamma rays  
beta decays

Radioactive backgrounds  
*relatively more ionizing*

Nuclear recoil  
WIMPs  
(and neutrons)



# TPC event position, length scale and self-shielding



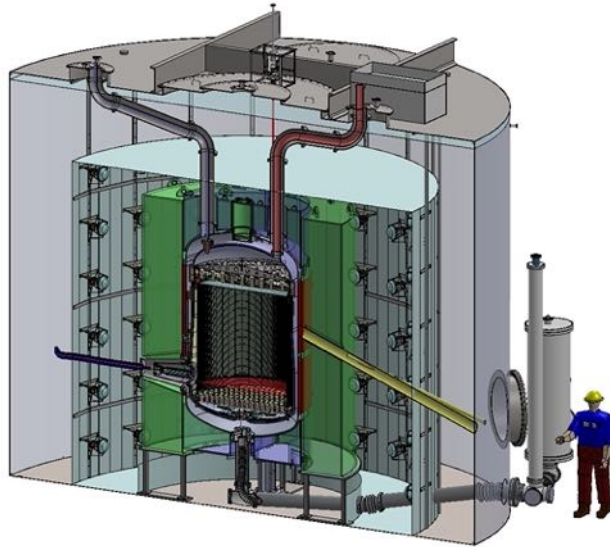
- Internal backgrounds very low
- Xenon can be ultra-purified
- No long-lived Xe isotopes
- Length scales
  - Detector ~ 1 meter
  - Gamma ray backgrounds ~ 10 cm

Isolate interior region to search for rare events of interest

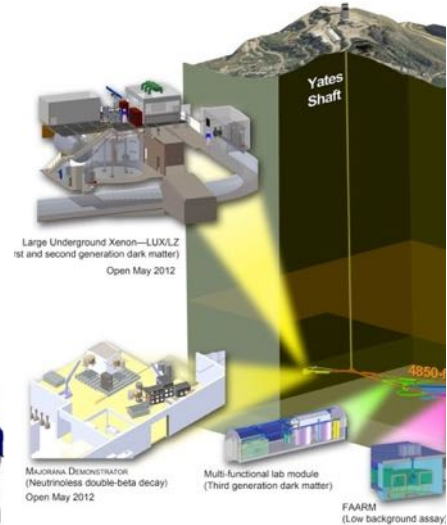
# The LZ experiment



**LXe TPC: 7 tonnes  
of active xenon**

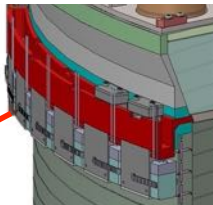
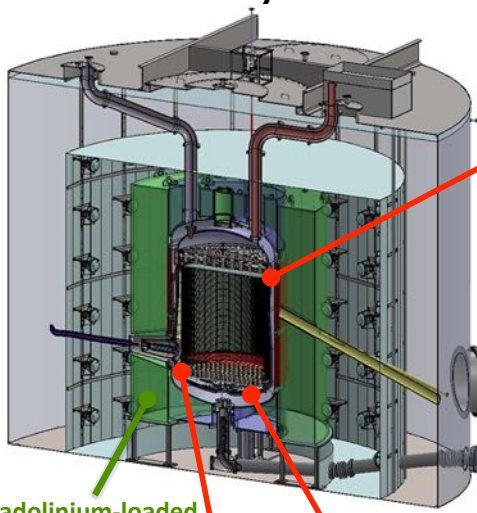


**Outer Detector System  
And Water Shield**



**Davis Cavern at 4850'  
Sanford Underground  
Research Facility  
Lead, South Dakota USA**

# Discovery Instrument: Outer Detector and Residual Backgrounds



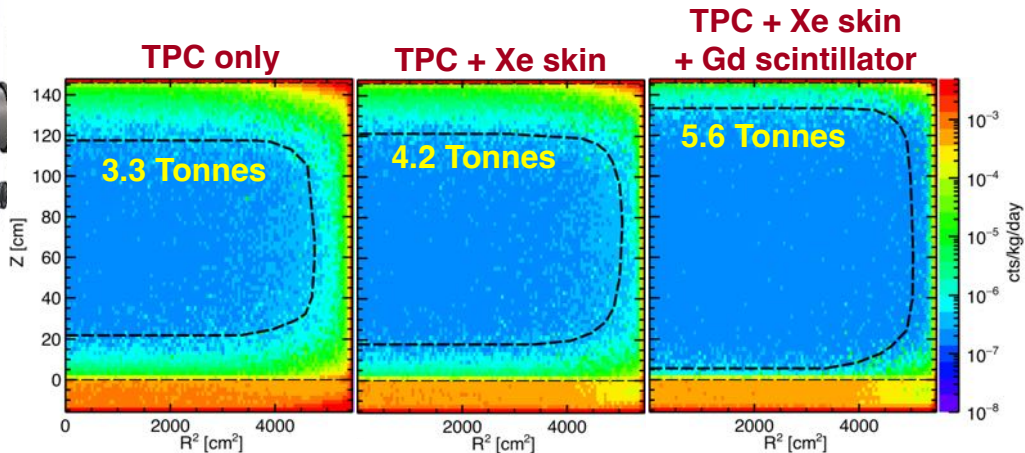
Skin PMTs

Two-component outer detector system - *in situ* neutrons and gammas measured

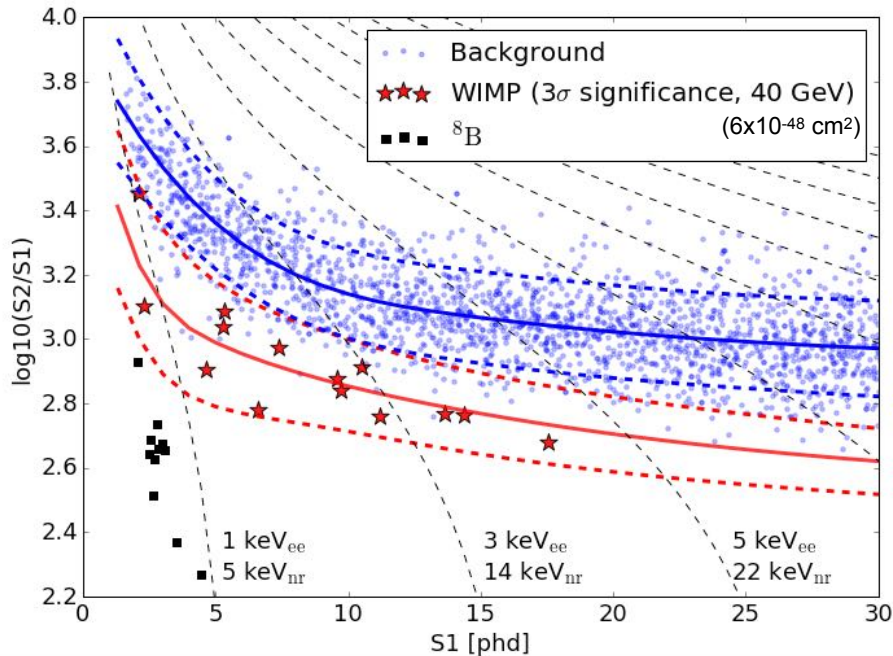
Gadolinium-loaded liquid scintillator

Dome PMTs

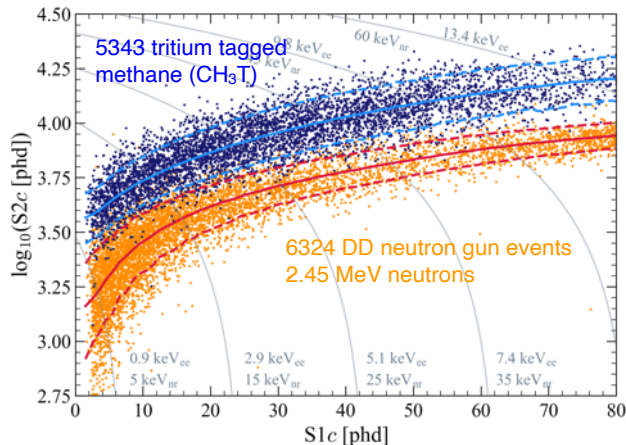
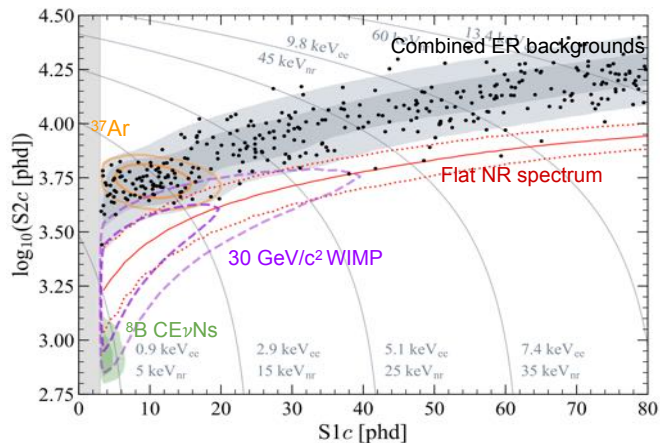
Skin PMTs



# 1,000 days of simulated LZ (innermost 5.6 T)

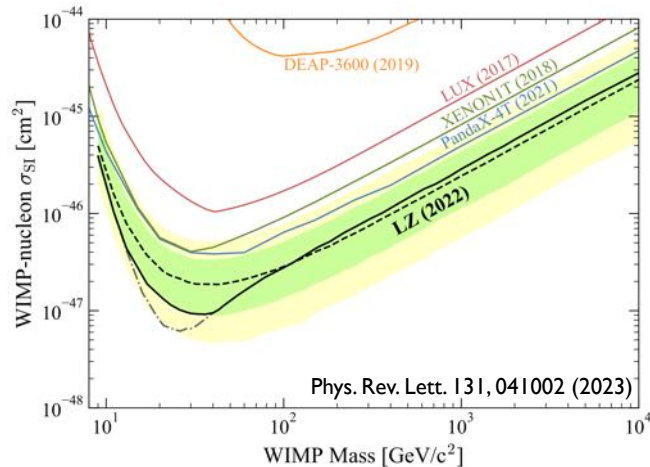
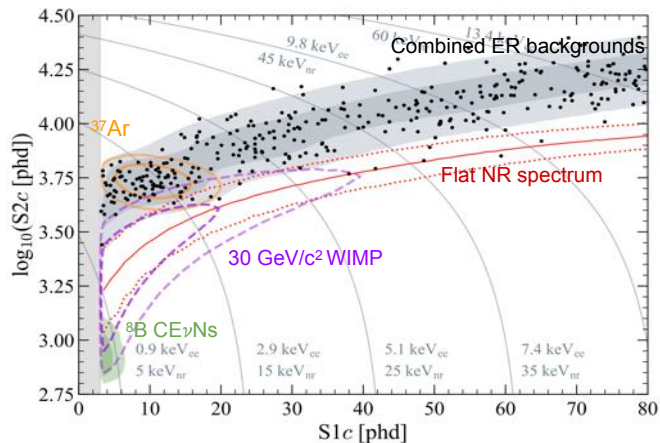


# First Science Run: 60 days



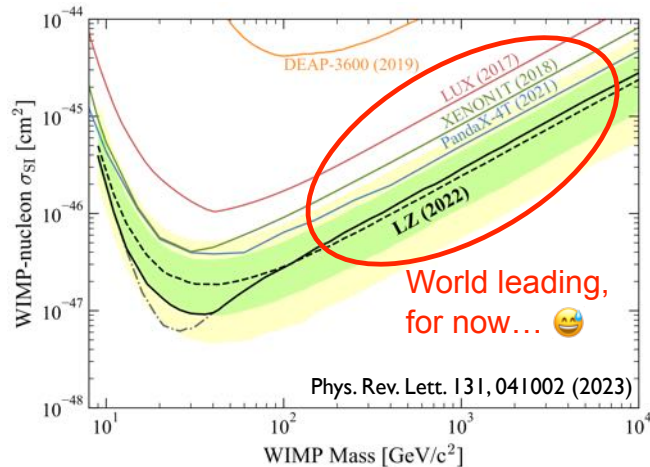
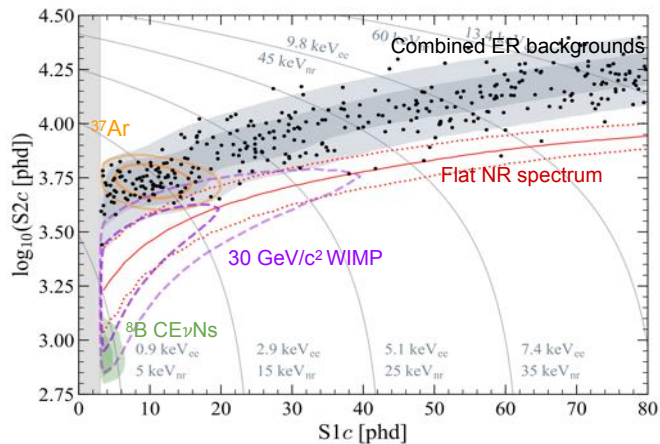
- 335 observed events, 60.3 live days, 5.5T fiducial volume
- Consistent with backgrounds based on ER calibrations and independent assessment for sources (eg, assays)
- Signal modeled from neutron calibrations

# First Science Run: 60 days



- Data consistent with background-only hypothesis
- WIMP-nucleon cross sections above the solid line are excluded with 90% confidence level
- Projected sensitivity Black dashed line - median of the sensitivity projections
- Data taking ongoing towards 1000 live days

# First Science Run: 60 days

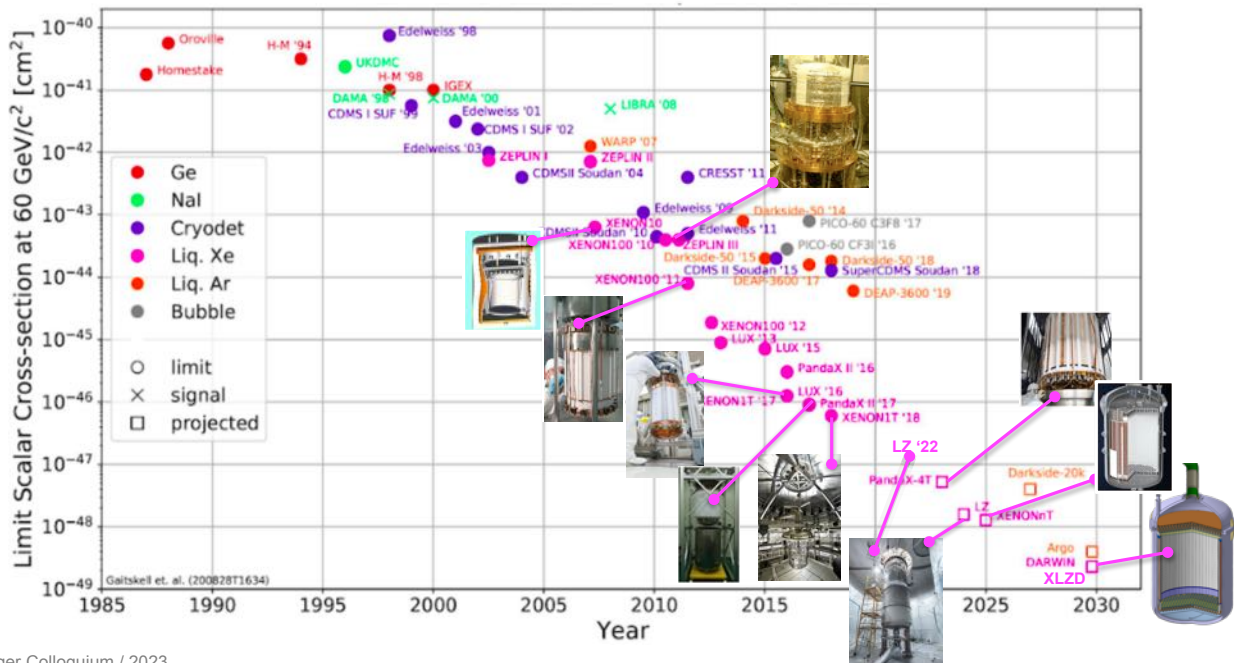


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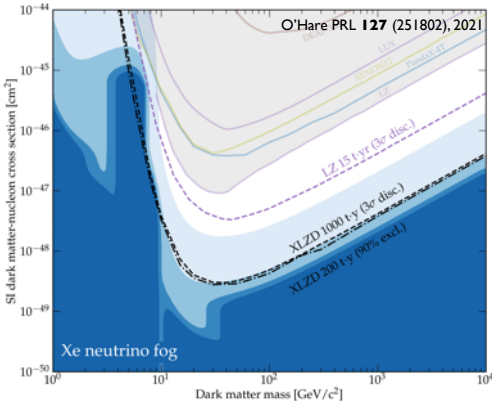
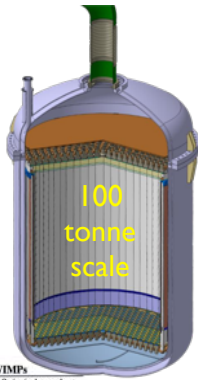
# Xenon detectors - world leading for 15 years & counting

LUX-ZEPLIN, XENON / DARWIN, PandaX → XLZD, PandaX

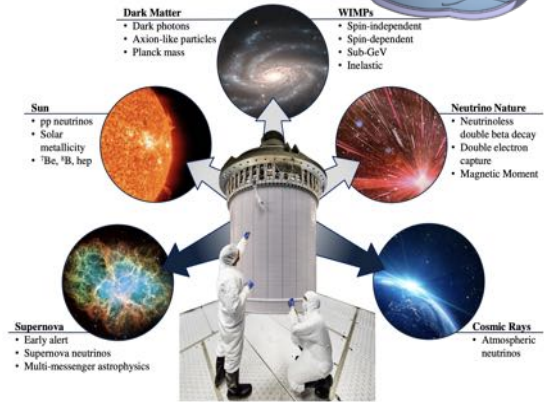


# LZ to XLZD: the definitive search for WIMPs

- Completing LZ ~ 2026-2028
  - 1000 live days + possible upgrades
- XLZD consortium formed among **XENONnT**, **LUX-ZEPLIN**, **DARWIN**
  - Search for WIMPs down to an irreducible background from astrophysical neutrinos
  - Broad science program, including various topics in neutrino physics



2nd XLZD Meeting - UCLA, April 2023

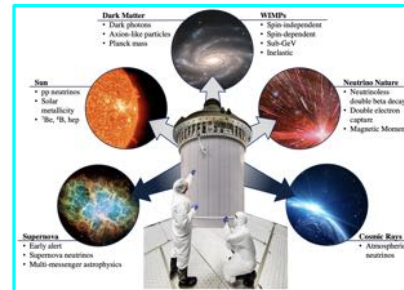
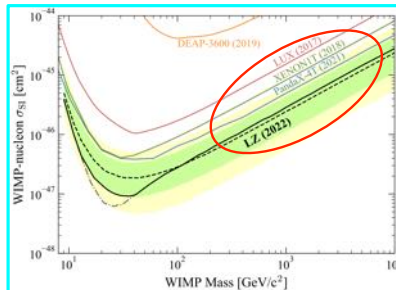
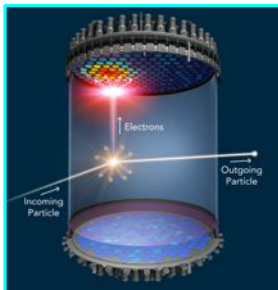
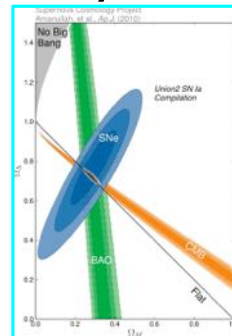


“A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics”

arxiv [2203.02309](https://arxiv.org/abs/2203.02309) / *J. Phys. G: Nucl. Part. Phys.*

# Summary: Dark Matter and WIMPs - a tractable mystery

- The predominant makeup of the Universe is a mystery
- Possible solution: the Milky Way's dark halo is WIMPs
- Liquid xenon TPCs: 15 years and counting
- XLZD is timely - merger of expert teams to build a new observatory



If WIMPs exist above the background of astrophysical neutrinos, we should observe them!