An overview of direct detection of dark matter

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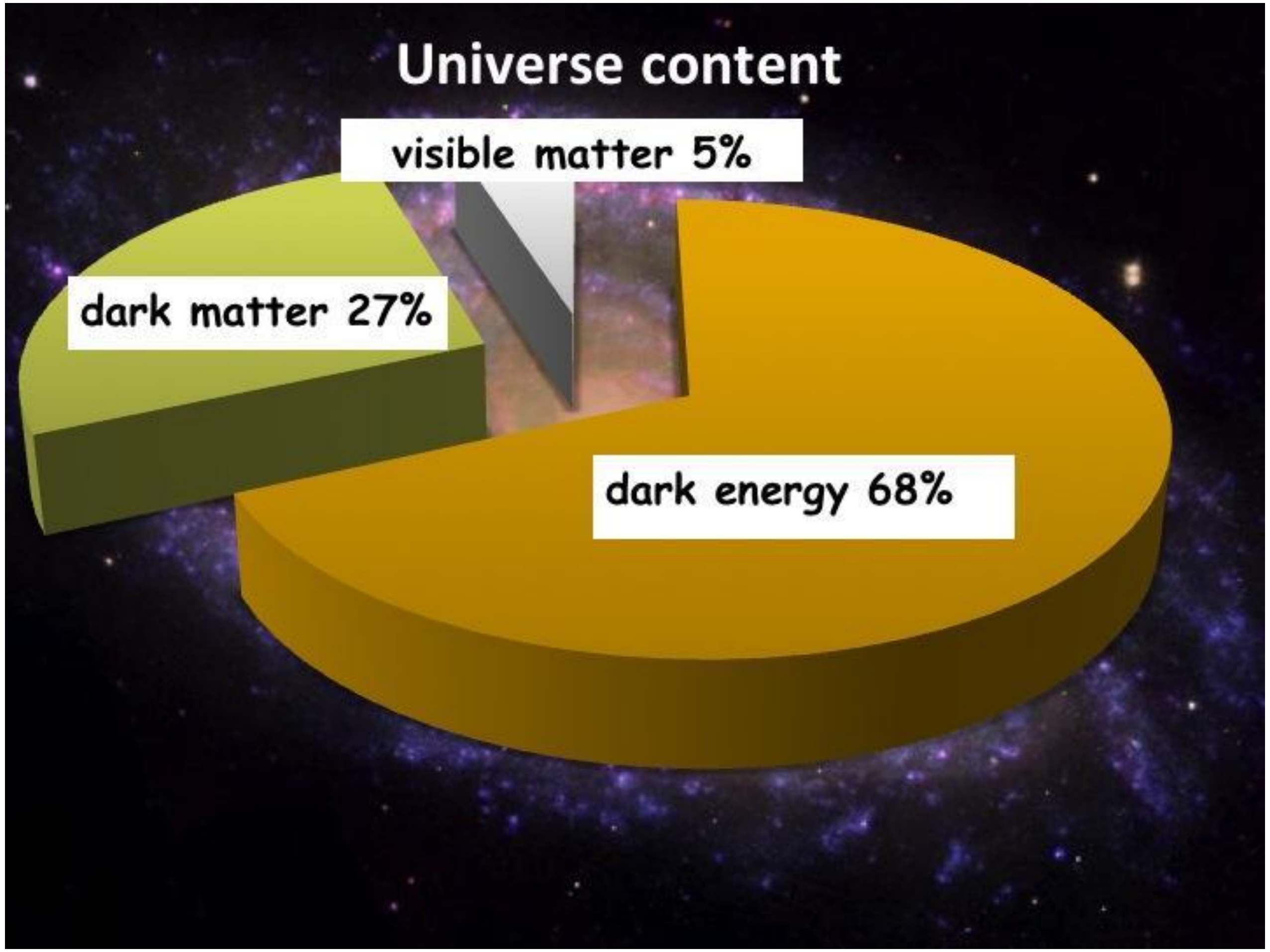
Outline

- Introduction and evidence of dark matter
- Detection techniques
- Direct detection
- Current sensitivities
- Future detectors
- Conclusion

The universe

- Visible matter (5%): Anything we can see, emits electromagnetic (EM) radiation.
- Dark matter (27%): No EM interaction, may interact with weak gravitational force.
- Dark energy (68%): Repulsive force, against the gravity, causes the universe to expand at an accelerating rate.



Cosmic microwave background (CMB)

- Discovered in 1964 by Arno Penzias and Robert Wils
- Electromagnetic radiation
- Residue from an early stage of the universe

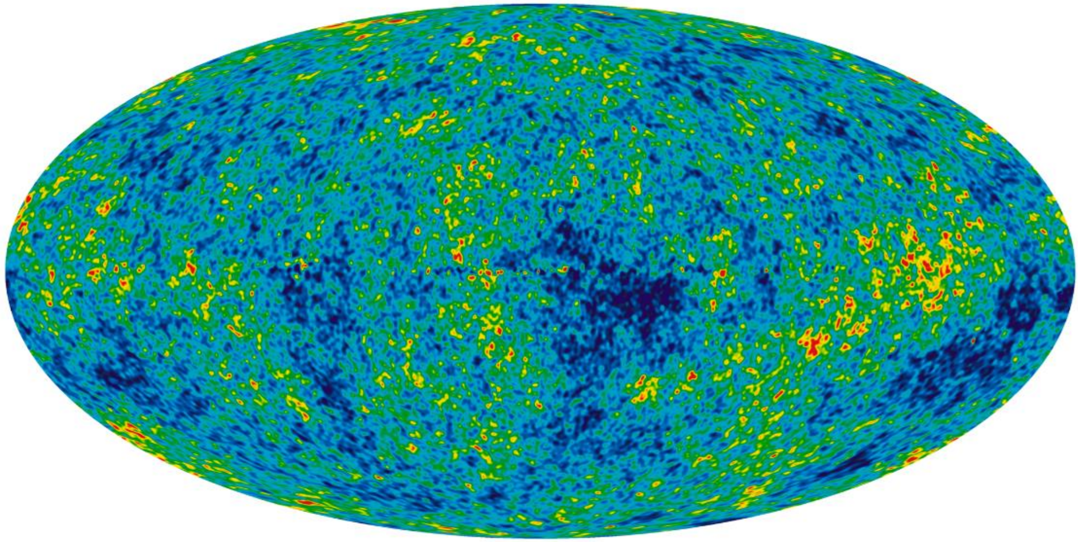
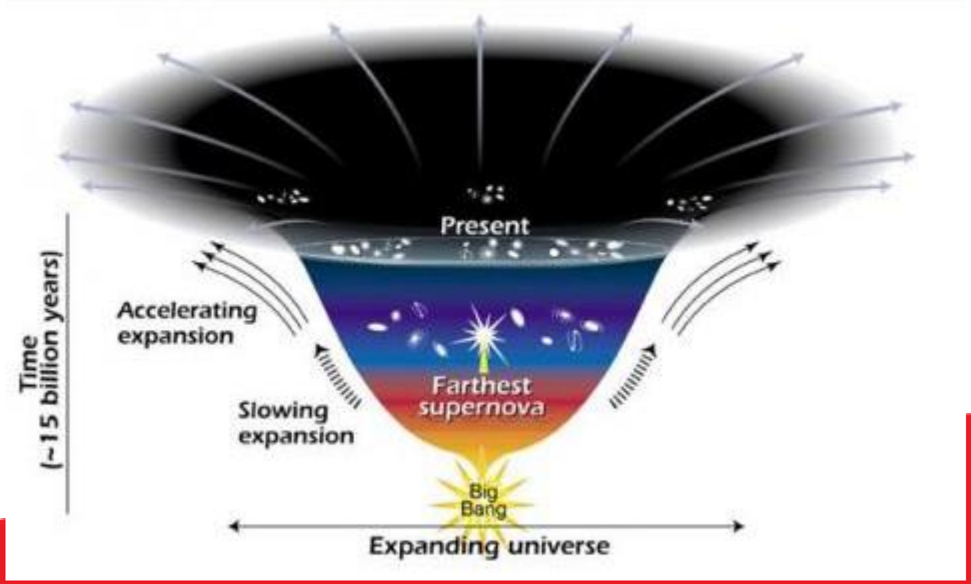


FIGURE 1.1: The detailed full-sky picture of the infant Universe created from nine years of WMAP data [20]. This shows that 13.7 billion year old temperature fluctuations within ±0.2mK and different color refers the density inhomogeneities.

The discovery of CMB guide us to accept the Big Bang theory and production of dark matter.



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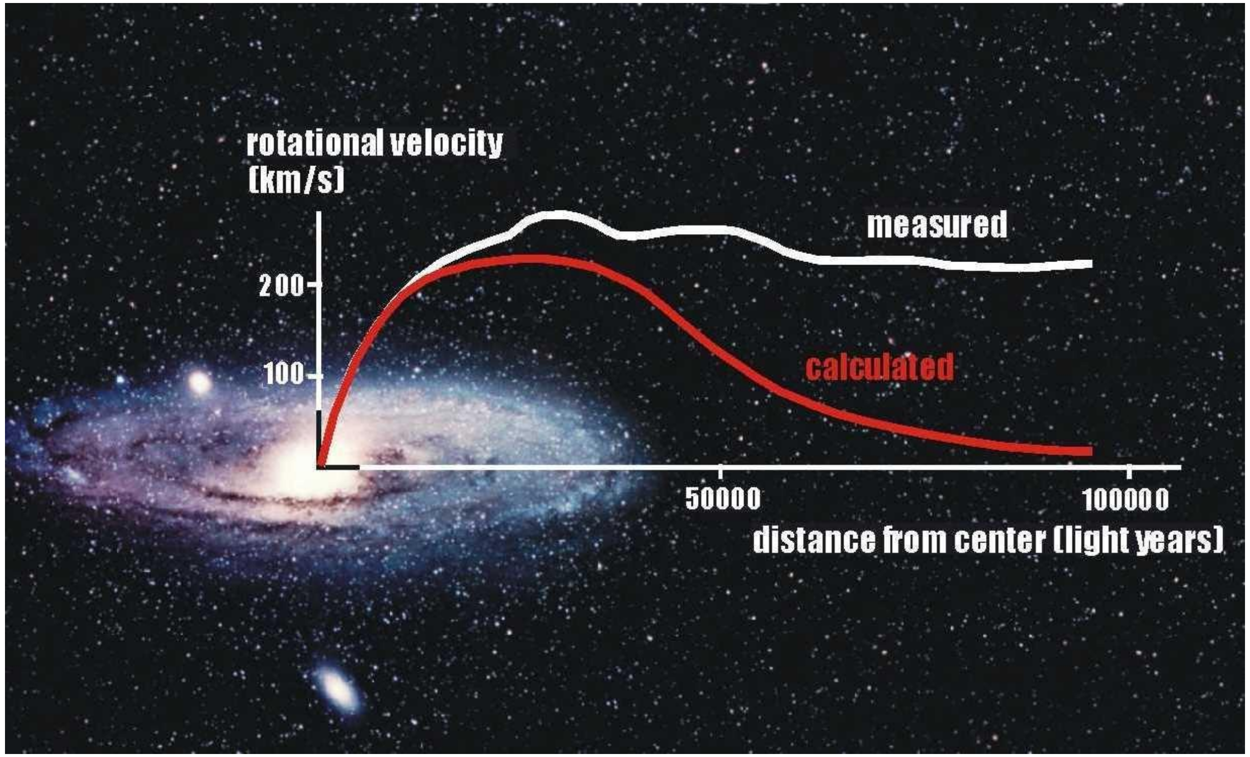
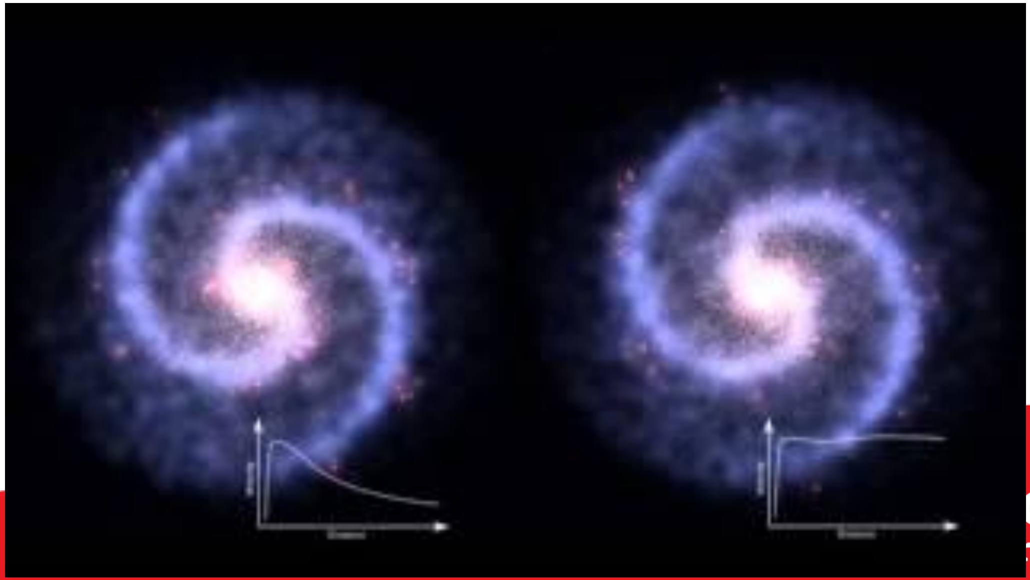
Galaxy rotation curve

$$v(r) = \sqrt{\frac{GM(r)}{r}},$$

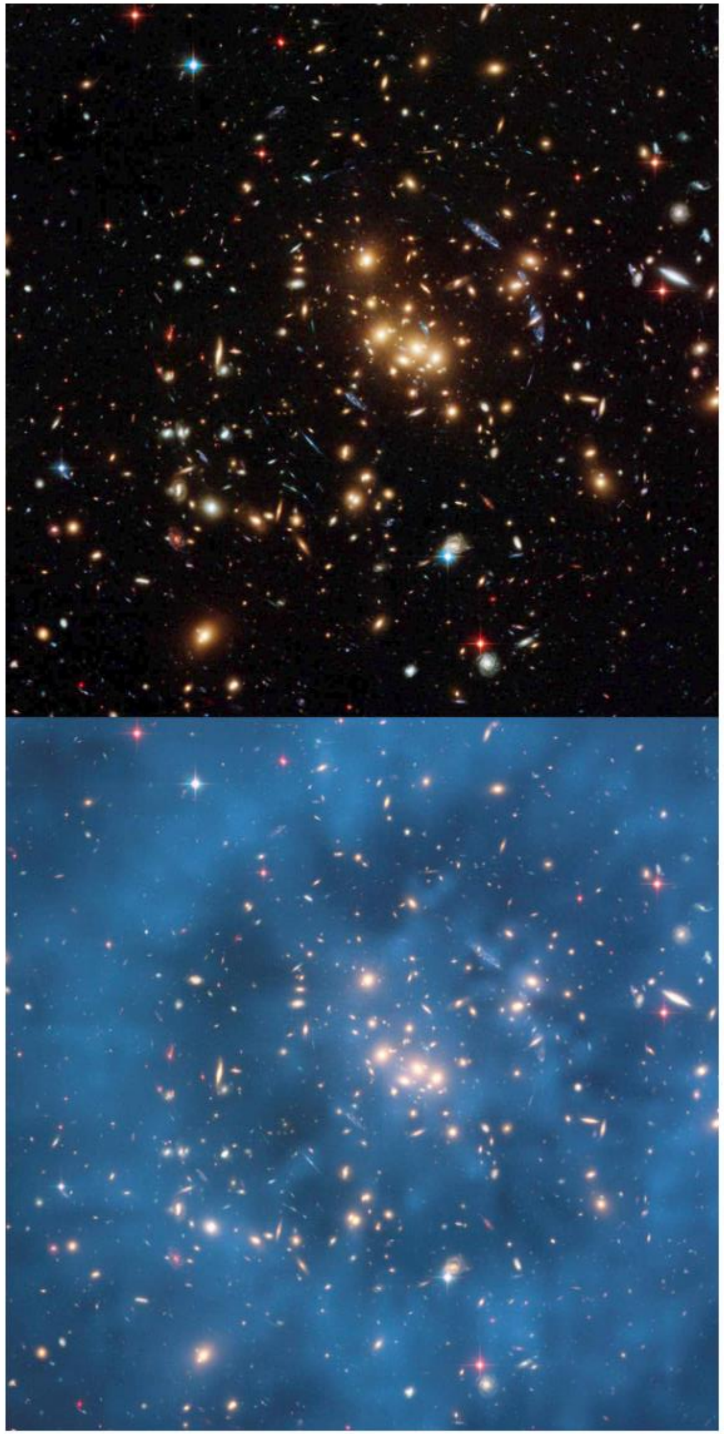
- Rotation curve should decrease inverse square root with distance
- Observational curves of visible parts of the galaxy do not decreases
- Large gap between observation and expected curve leads towards the gravitational effect of dark matter





Gravitational lensing

- Gravity effect of dark matter
- Massive celestial body (eg. galaxy cluster) causes a sufficient curvature of spacetime for the path of light around it to be visibly bent, as if by a lens.



On the top is a Hubble Space Telescope image of the galaxy cluster Cl 0024+17. On the bottom is the same image overlaid with a map of the cluster's mass distribution.

The ring-like structure evident in the map is one of the strongest pieces of evidence to date for the existence of dark matter.

Dark matter candidates

- Neutral
- Stable particles
- Massive enough for structure formation

Candidates are in different orders of magnitude of mass.

It is everywhere, do you feel it?
Density of human being ~ 1000 kg/m3
Density of dark matter ~10^-21 kg/m3
If you add all dark matter inside all human being on earth, it is less than single nanogram.

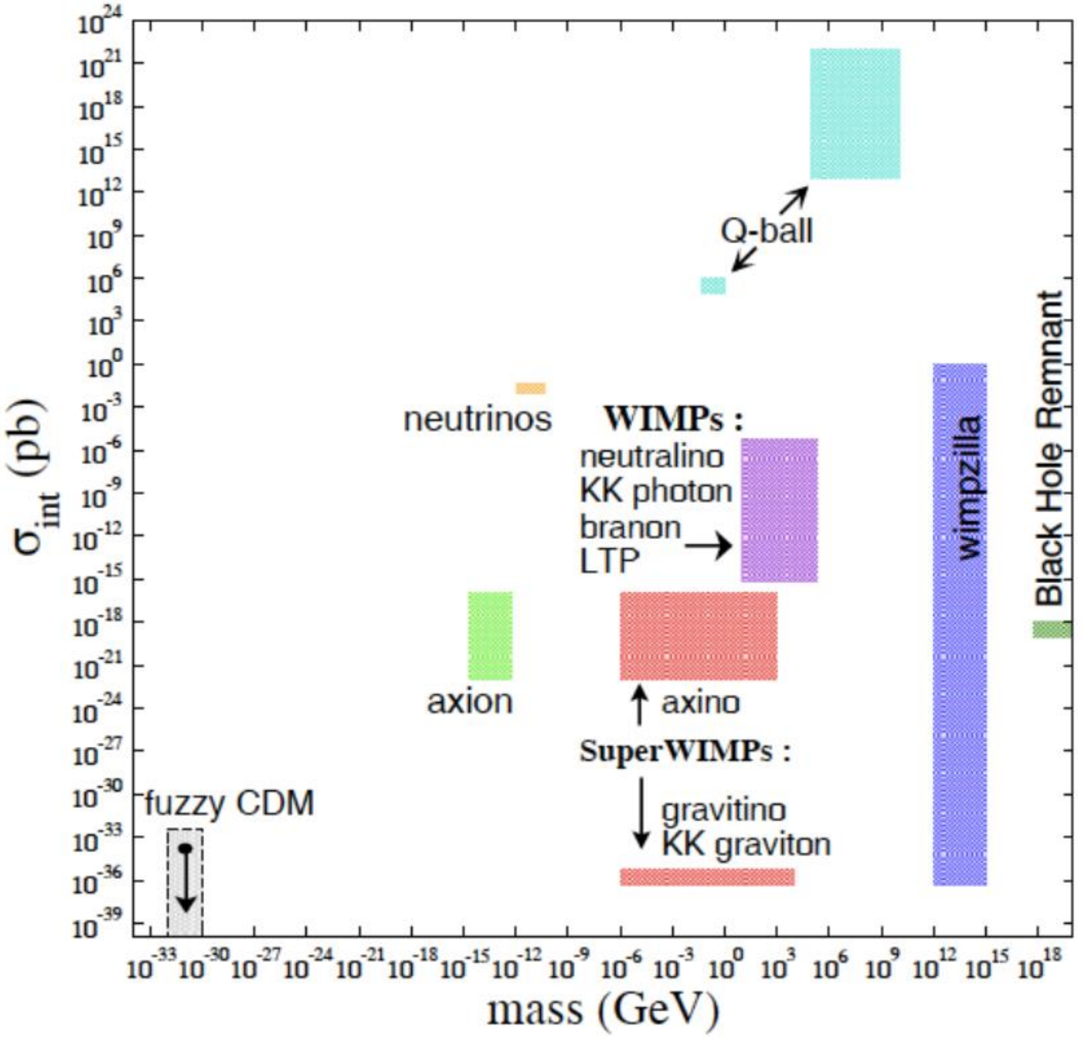


FIGURE 1.11: Estimated loci of select dark-matter models in the space of candidate mass in GeV versus dark-matter-candidate–nucleon interaction cross section in pb [88].

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Dark matter modulation

- The relative velocity between DM particles in galactic halo and detectors varies over the year.
- Approximately sinusoidal modulation for the recoil rate of DM at keV energies.
- Peaks at early June.

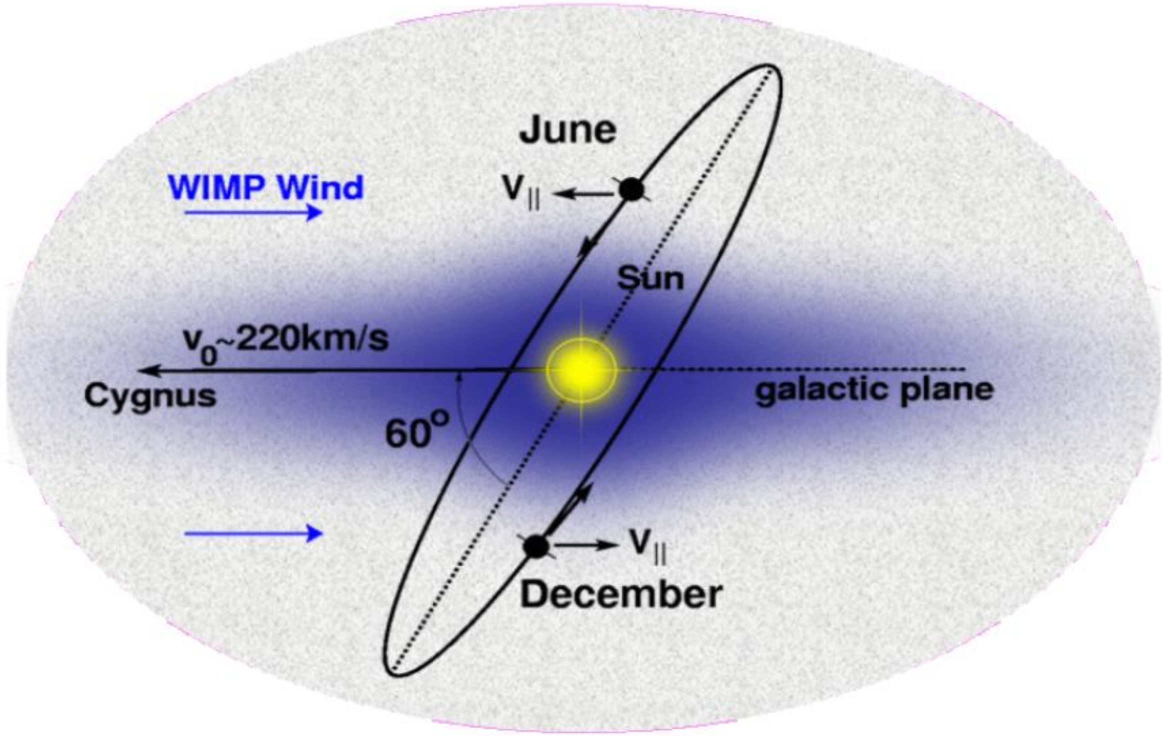
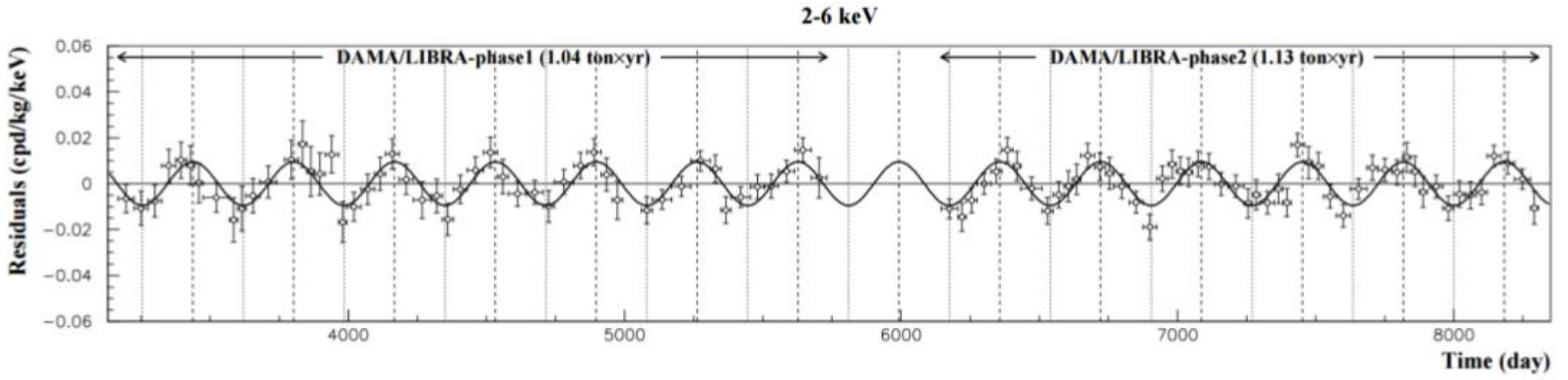


FIGURE 1.18: An Illustration of Earth's relative velocity to WIMPs current which arise annual modulation in dark matter signal [83]



Direct detection experiments

Dark matter interact with the detector material, energy transform

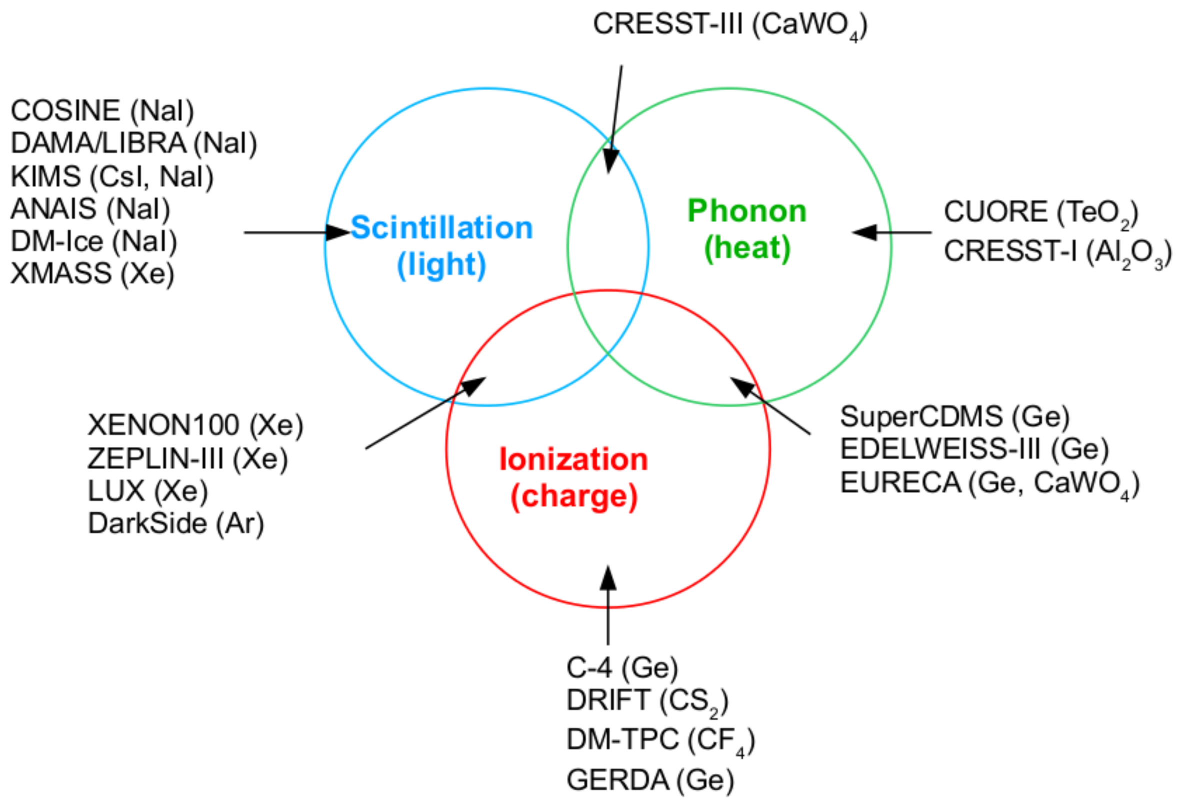
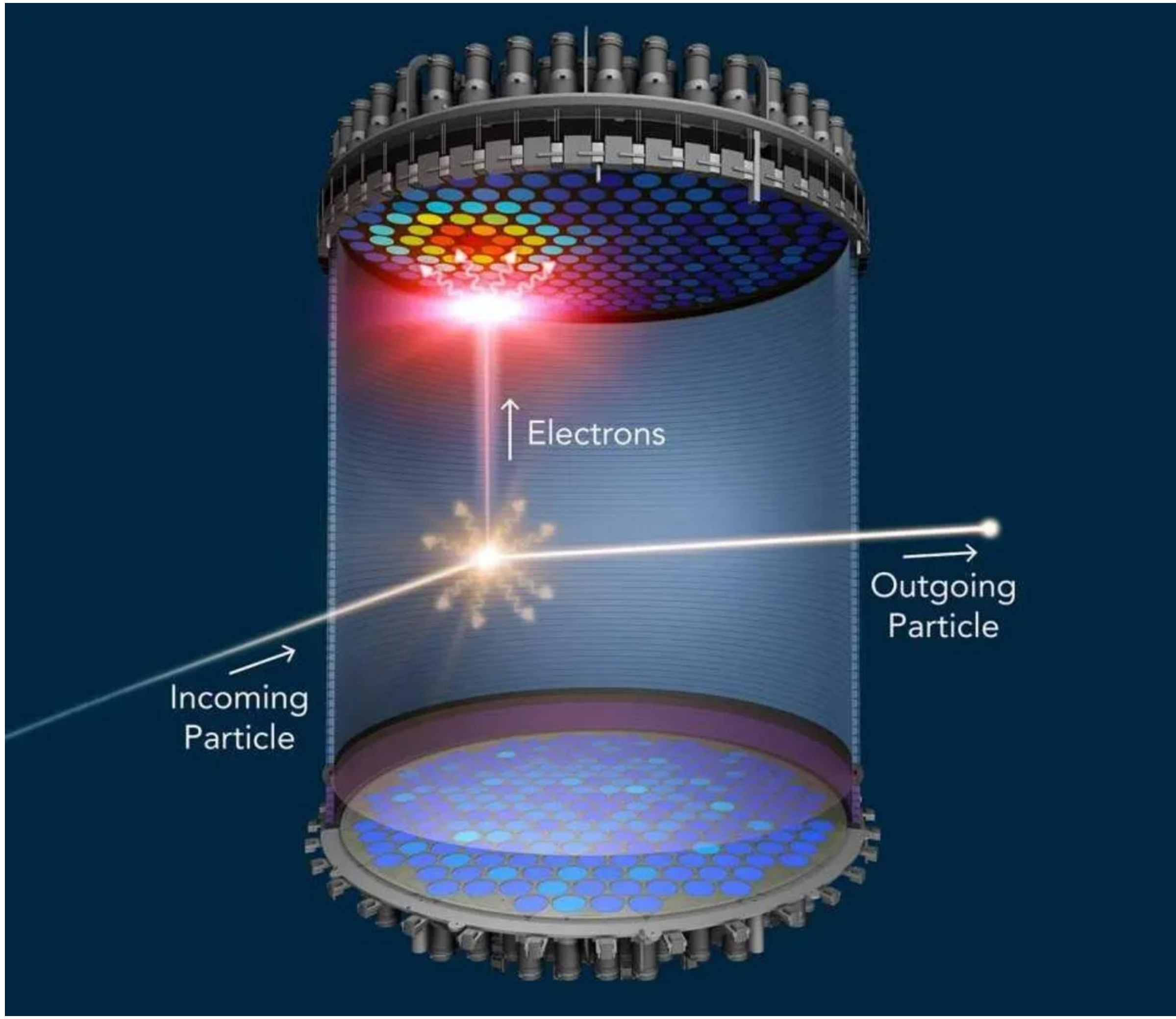


FIGURE 1.19: Different dark matter direct detection experiments classified by their detection technique



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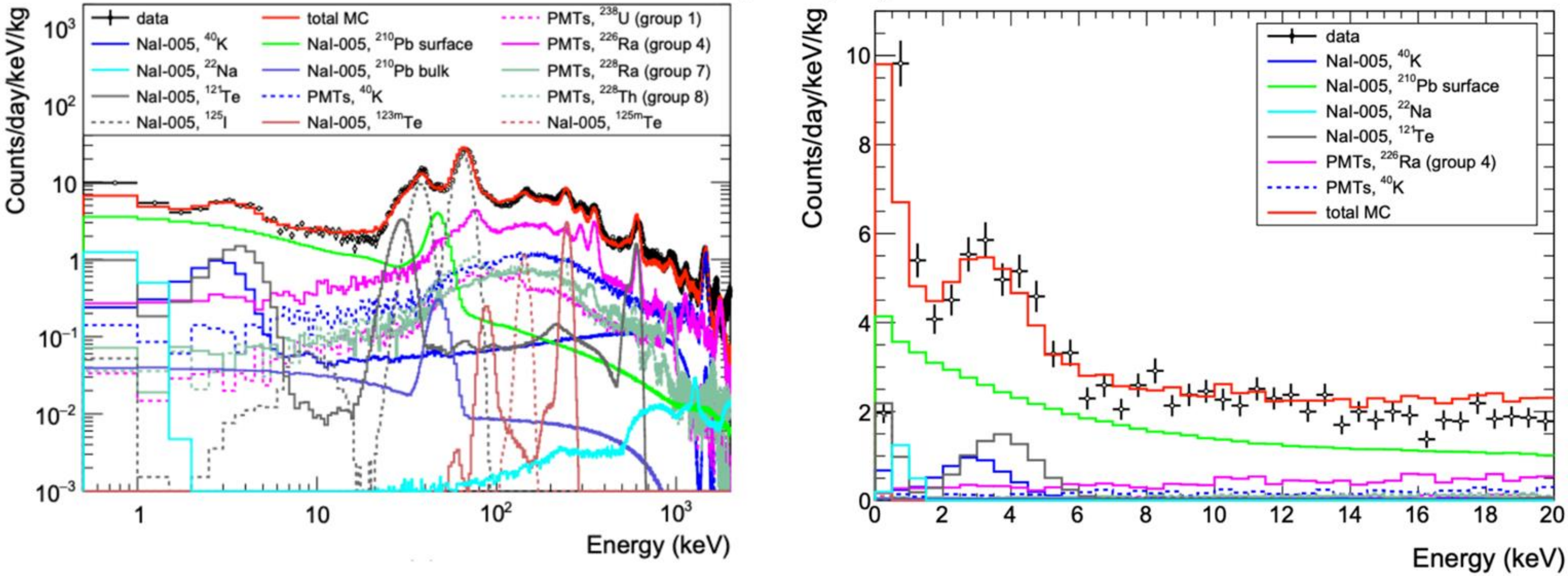
Discovery

- ➢ Record particle interaction signal from the detector
- ➢ Identify the background and dark matter signal (simulate all possibl background sources)
- ➢ Plot the extracted signal vs time (annual modulation)
- ➢ Calculate the mass, cross section of DM from the extracted signal
- ➢ No signal, detector sensitivity

Eur. Phys. J. C (2017) 77:437



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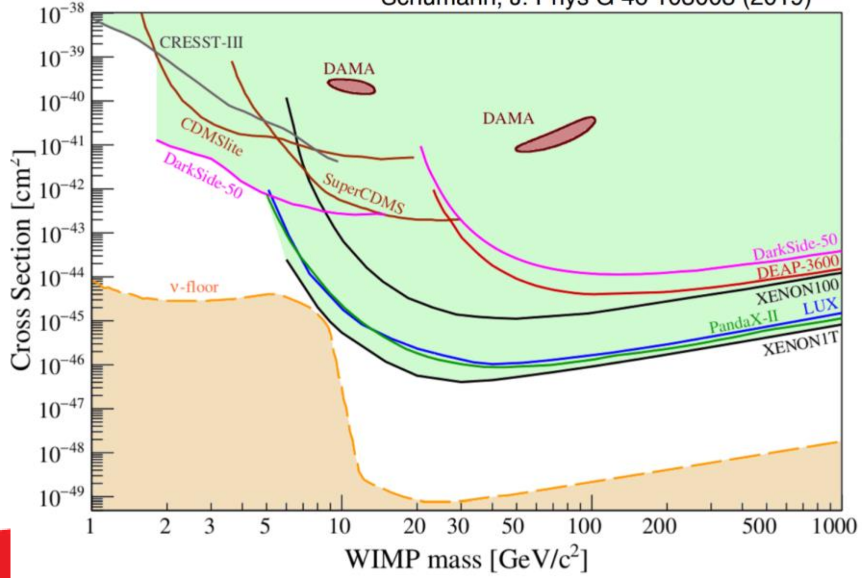

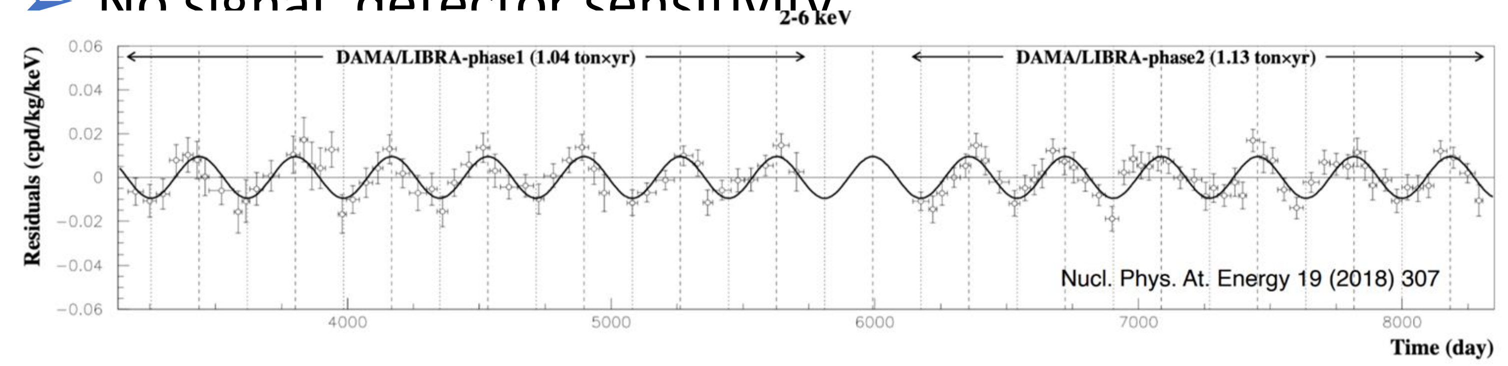

Nucl. Phys. At. Energy 19 (2018) 307

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Challenges

- Background noises: Deep underground / outer space (not on the surface of the earth)
- Large cross section: Multi hundred tons of detector materials
- Technologies: DAQ, ns timing resolution, analysis toolkits, simulation, material purity
- Resources: Multi billion dollar financing, international collaboration

COSINE-100 collaboration

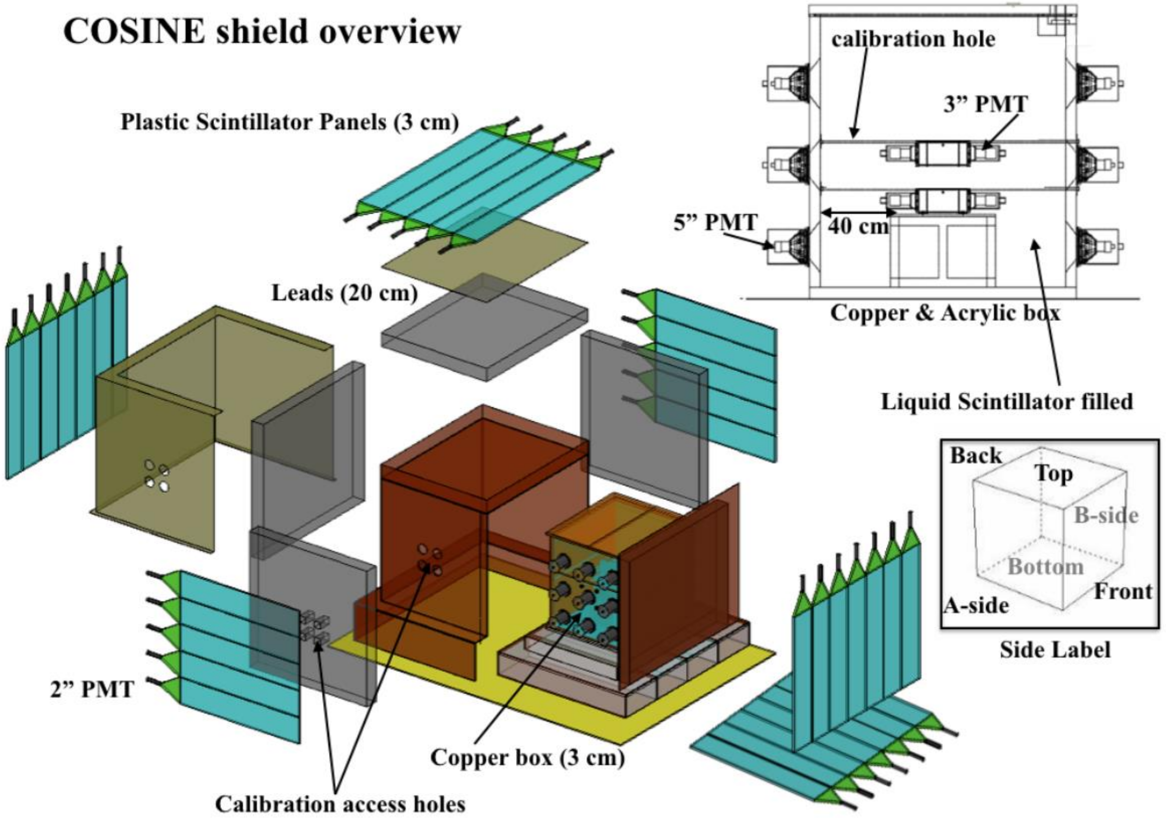
Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.

KIMS + DM-ICE → COSINE

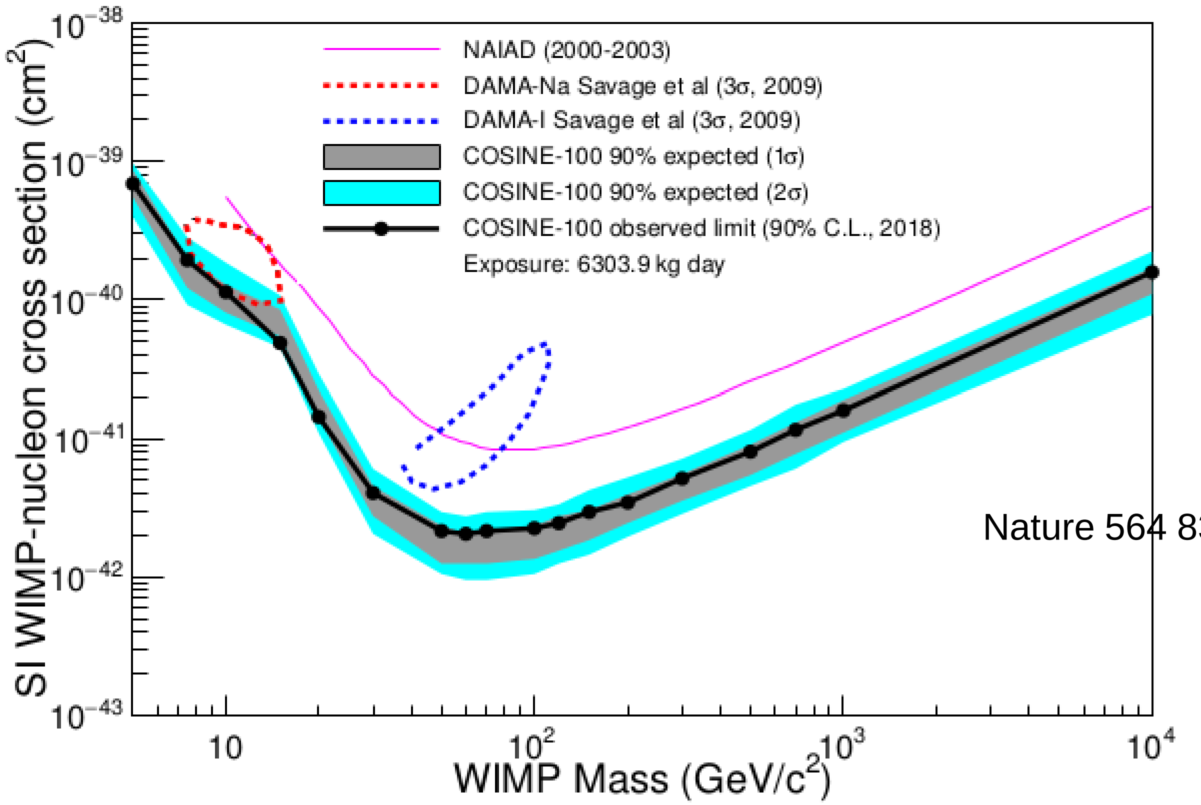
COSINE station

COSINE detector

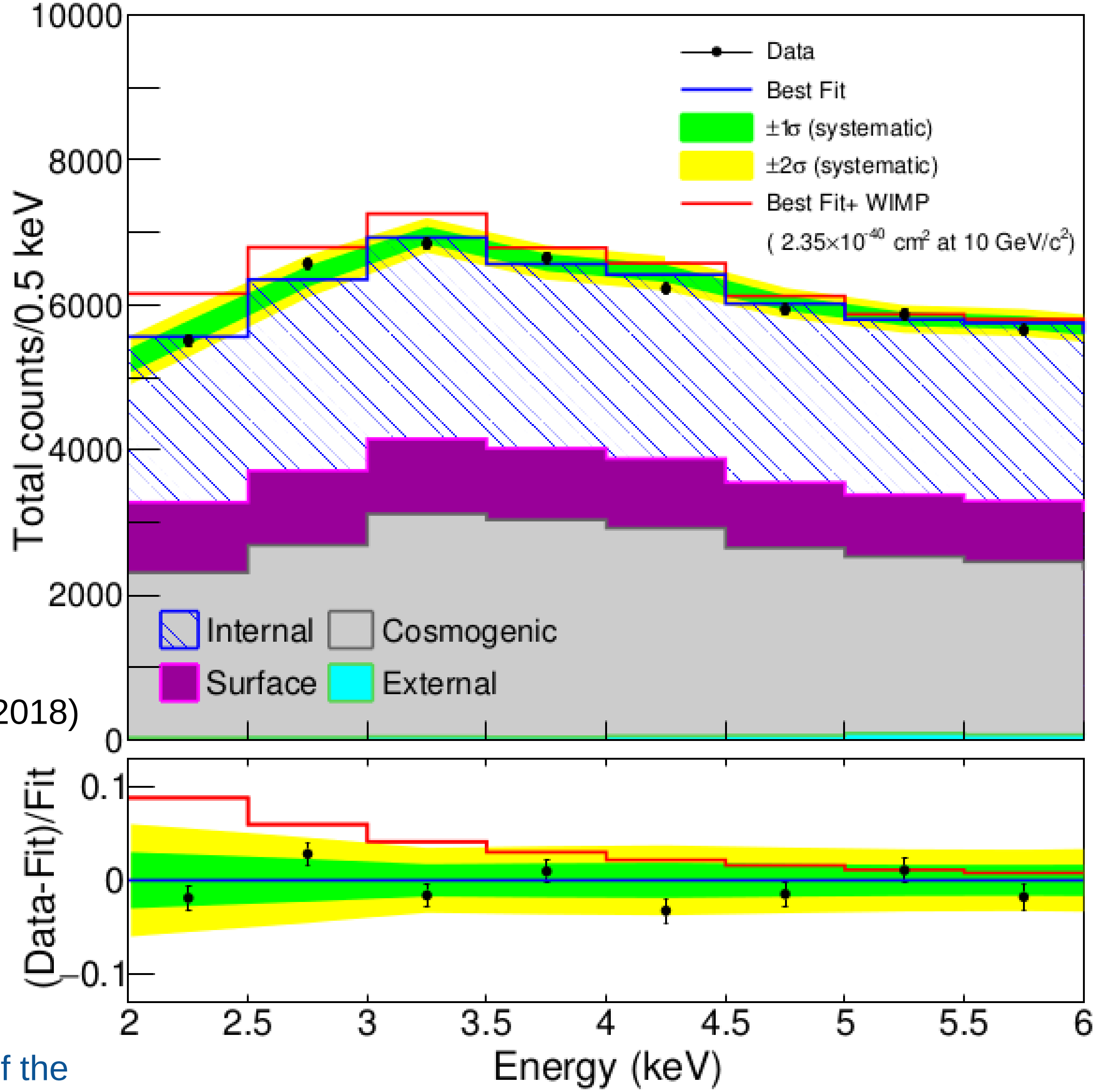
- 8 NaI(Tl) crystals (100 kg) fully immersed in LAB based liquid scintillator.
- Liquid scintillator works as external gamma and neutron veto.
- Covered the detector with plastic scintillator panels (muon veto).



COSINE results



Nature 564 83-86 (2018)



This result shows inconsistency between COSINE data and the interpretation of the DAMA/LIBRA signal in the specific context of the standard WIMP halo model.

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DEAP collaboration

~100 researcher in Canada, Germany, Italy, Mexico, Poland, Russia, Spain, UK, USA

University of Alberta

AstroCeNT
Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences

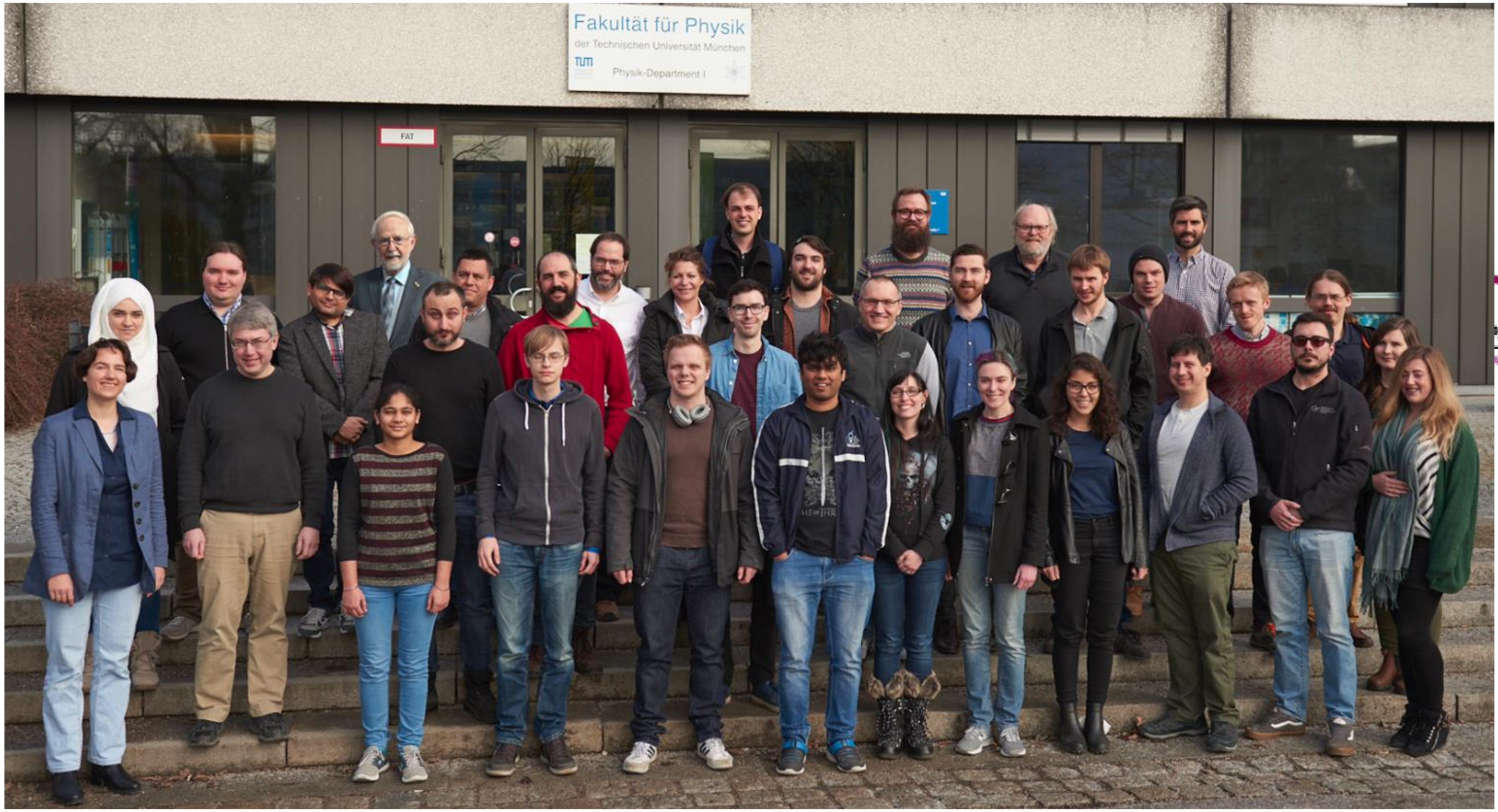
Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

Carleton University
Canada's Capital University

INFN
Istituto Nazionale di Fisica Nucleare

Johannes Gutenberg Universität Mainz JG|U

National Research Center "Kurchatov Institute"



Queen's University

Royal Holloway University of London

Particle Physics
Rutherford Appleton Laboratory

SNOLAB

US
University of Sussex

TRIUMF

Gobierno de España
Ministerio de Economía, Industria y Competitividad

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Laurentian University
Université Laurentienne

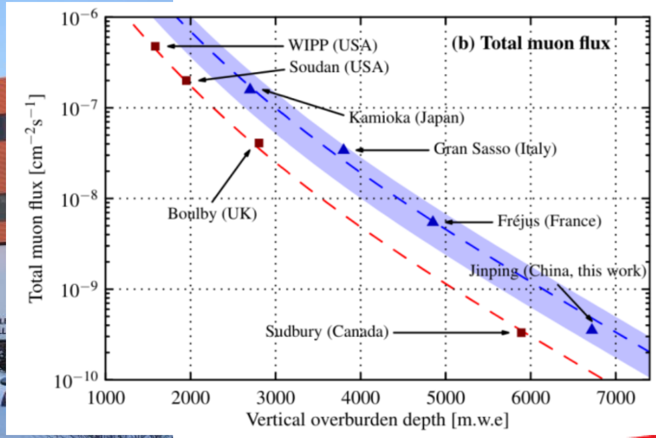
IF
Instituto de Física UNAM

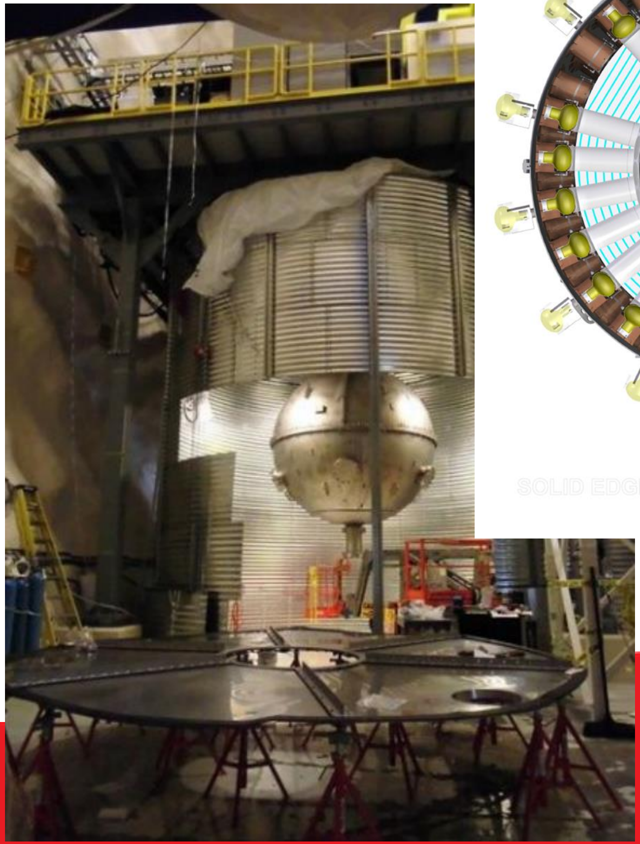
Princeton University

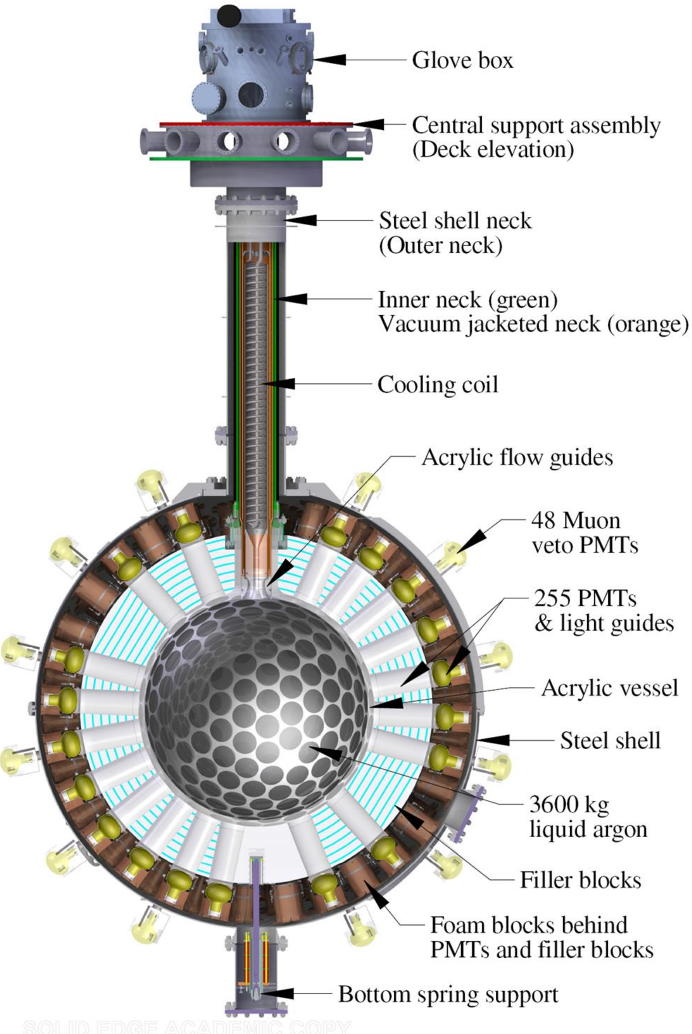
Technical University of Munich
TUM

DEAP site

- The detector is located at SNOLAB in Sudbury Ontario, world’s deepest clean lab.
- A deep underground laboratory which uses the 2.2 km of rock overburden (provides a ~6 k.m.w.e overburden)

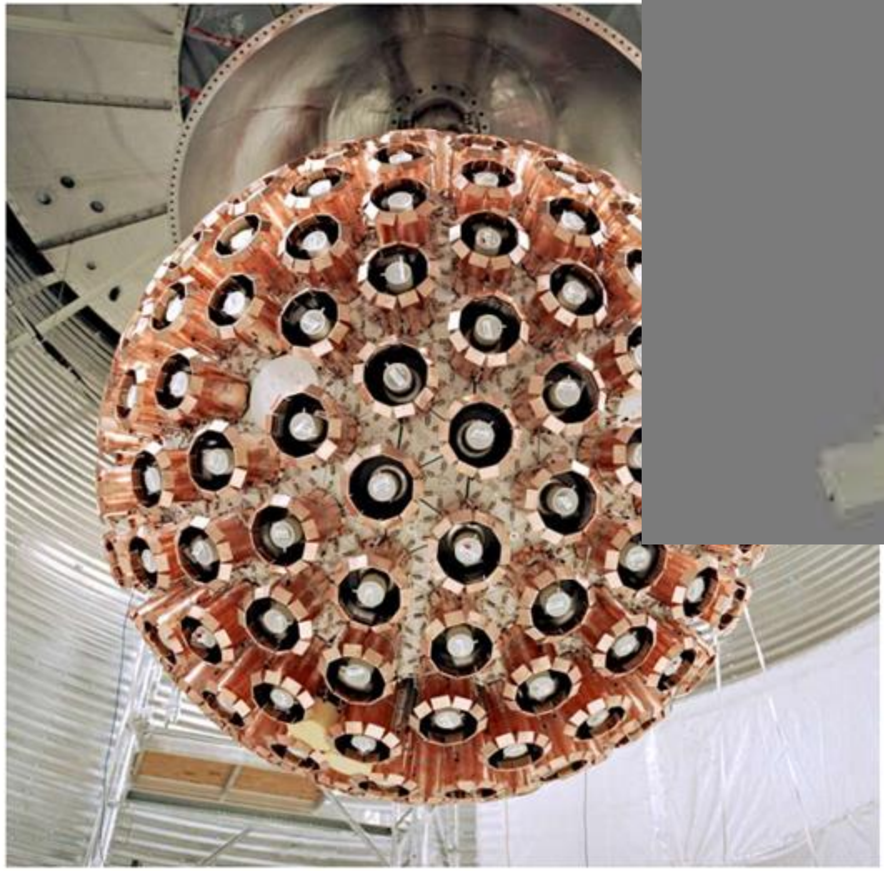


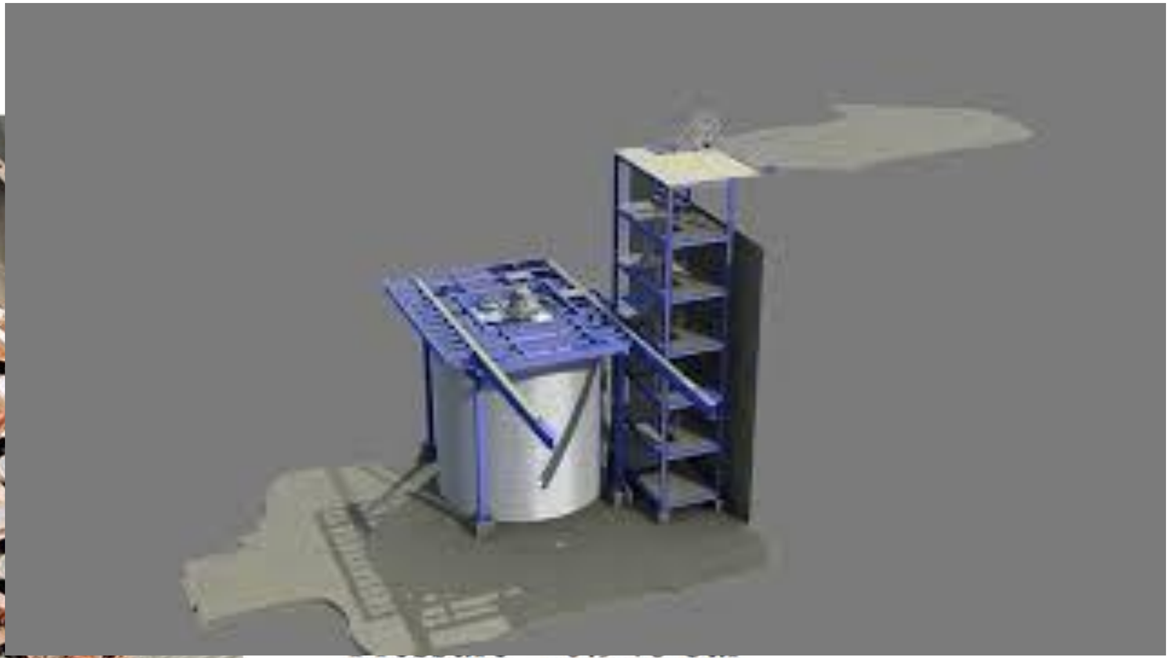




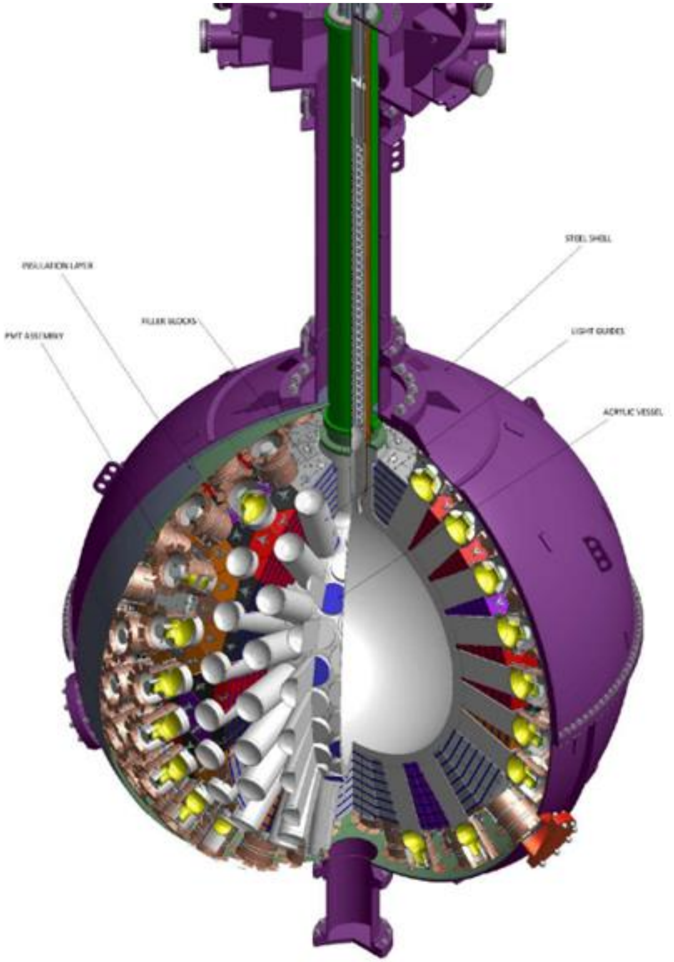
Detector

- DEAP-3600 is the largest running liquid argon detector designed for the dark matter search
- 3279 ± 96 kg of **Liquid Argon**





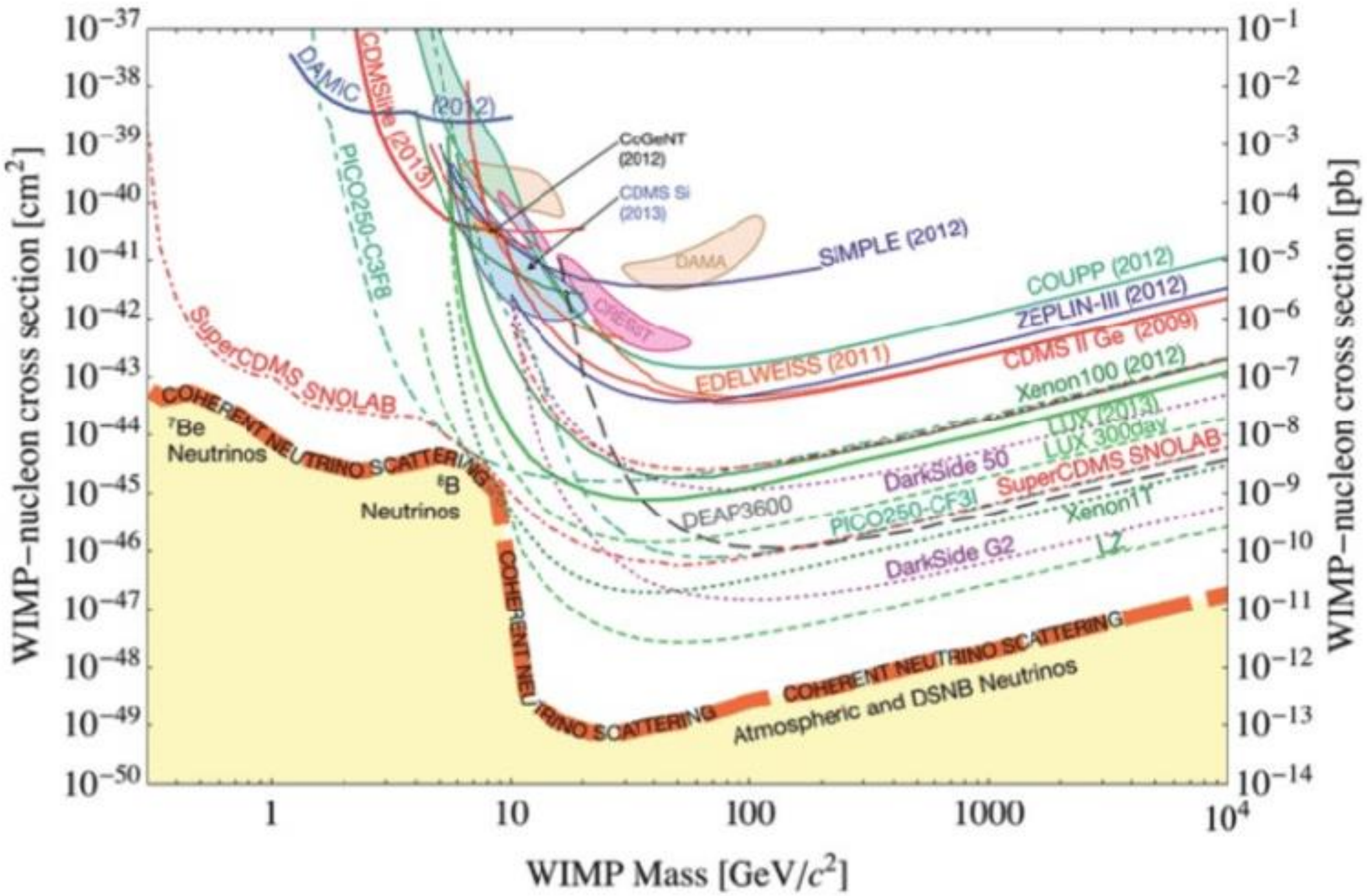
- Density: 1.4 g/cm³
- Scintillation light yield in DEAP: 7.1 photoelectrons (PE)/keV_{ee}



Astroparticle Physics 108 (2019) 1-23

Results of DEAP

- ➢ World's leading cross section limit on Argon detector.
- ➢ Analysis is ongoing for 3 years data-set.
- ➢ Some parts of the hardware is upgrading and detector will be run for 2 more years after the upgrade.



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Future detectors

Many large scaled detectors are on the pipeline for next generation.

Argo

300 tons of liquid argon.

Purposed location (under discussion): SNOLAB, Sudbury, Canada

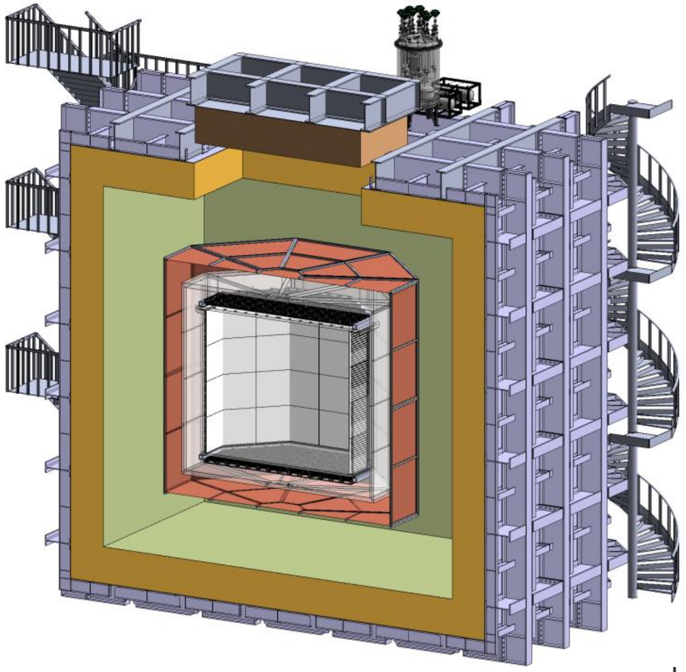
Data starts: ~ 2040

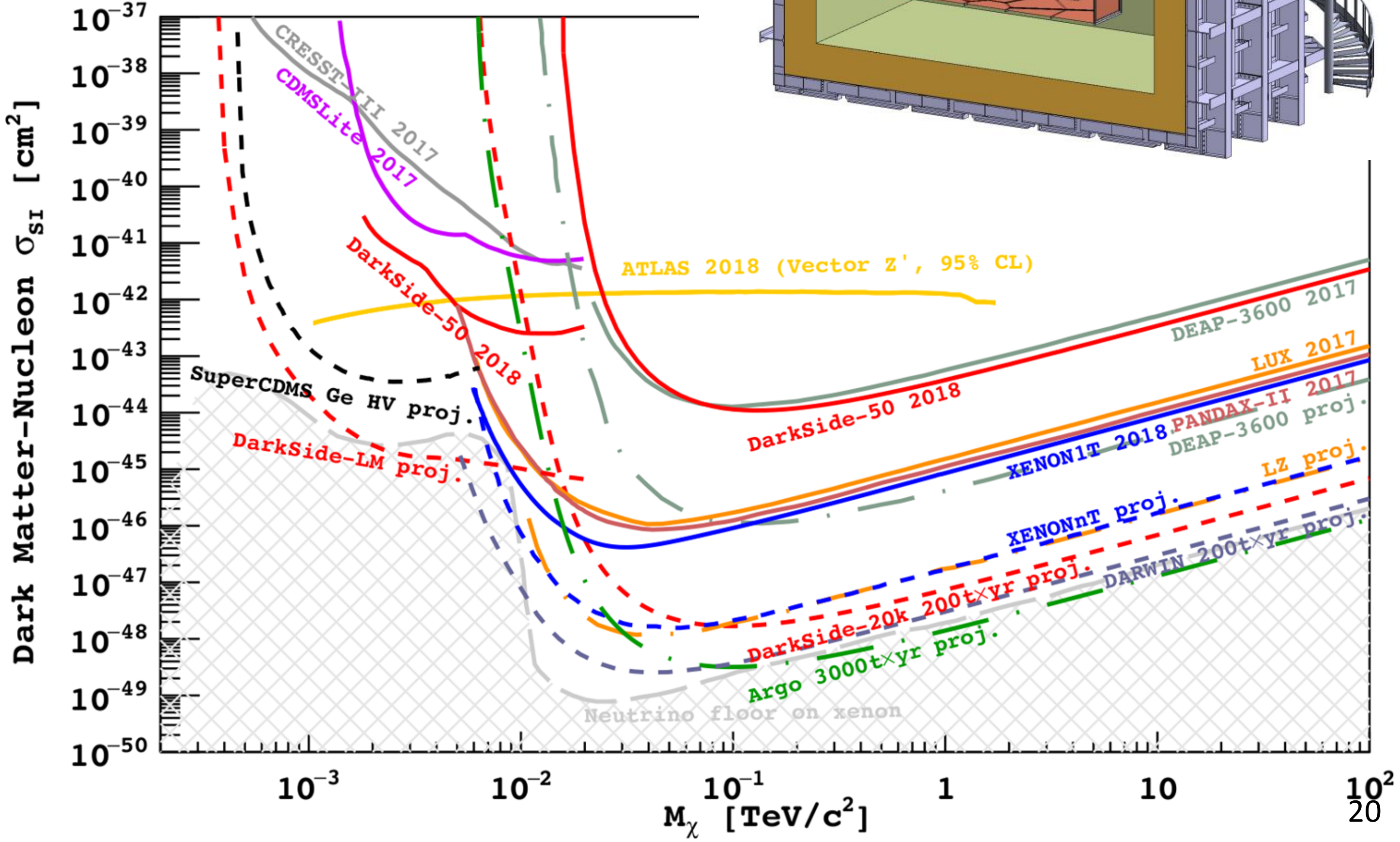
Darkside-20k

20 tons of liquid argon

Location: LNGS, Italy

Data starts: ~ 2030





Conclusion

- Dark matter is still hiding with us despite of 50 years of effort
- Worldwide collaboration is ongoing for the dark matter detection
- Large scaled, advanced tech future generation's detector are on the horizon
- Stay tuned: dark matter will no longer dark, it will be visible soon

Thank you

BACKUP

Direct astronomical observation

- When two galaxy cluster collide, stars were not affected
- Hot plasma clustered in the center drove into one another and emitted x-ray
- The mass of the cluster distributed on either side

Explanation of dark matter: dark matter and galaxies passed through each other and the hot plasma clustered was block by electromagnetic interactions and interweaves in the center

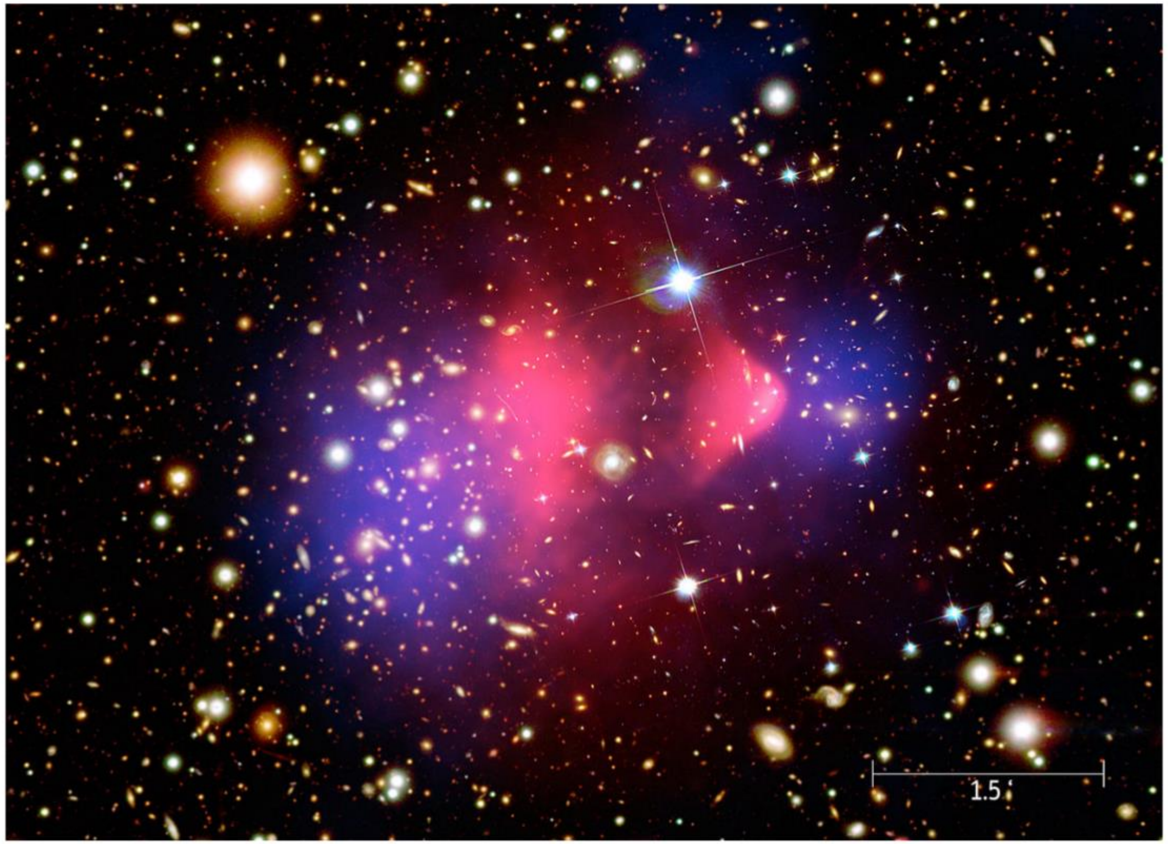
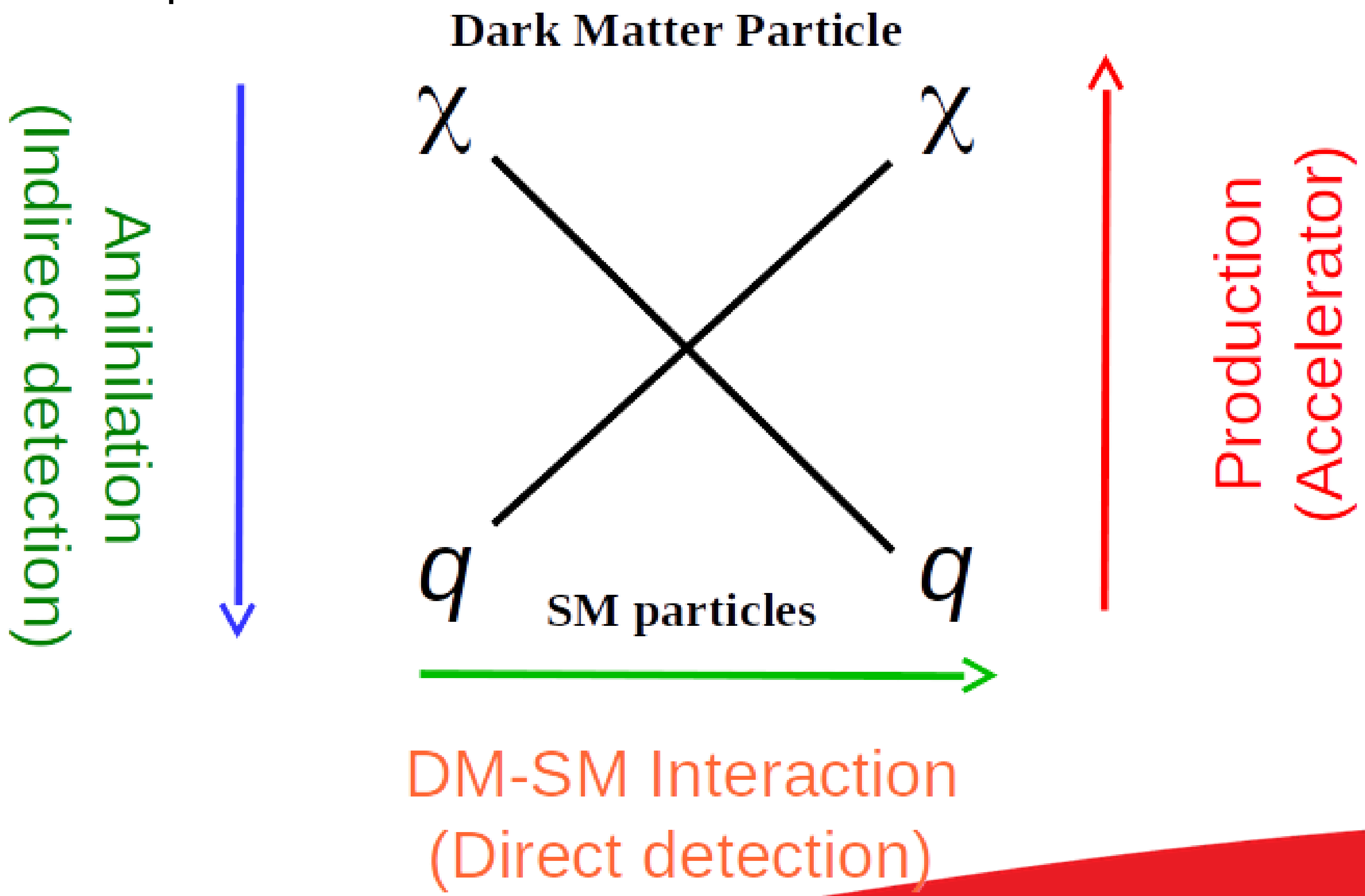


FIGURE 1.7: Galaxy cluster 1E 0657-556, also known as the Bullet cluster. Hot plasma detected as X-ray regions from Chandra is seen as two pink lumps. An optical image from Magellan shows the galaxies and mass regions inferred from Hubble (blue).

Search methods

DM particles can interact with standard model (SM) particles, annihilate or decay to SM particles, and can be produced in accelerator.



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