XXXII Annual Meeting
Division of Particles and Fields
Mexican Physical Society

Dark Matter and Neutrino detection with scintillating bubble chambers

by

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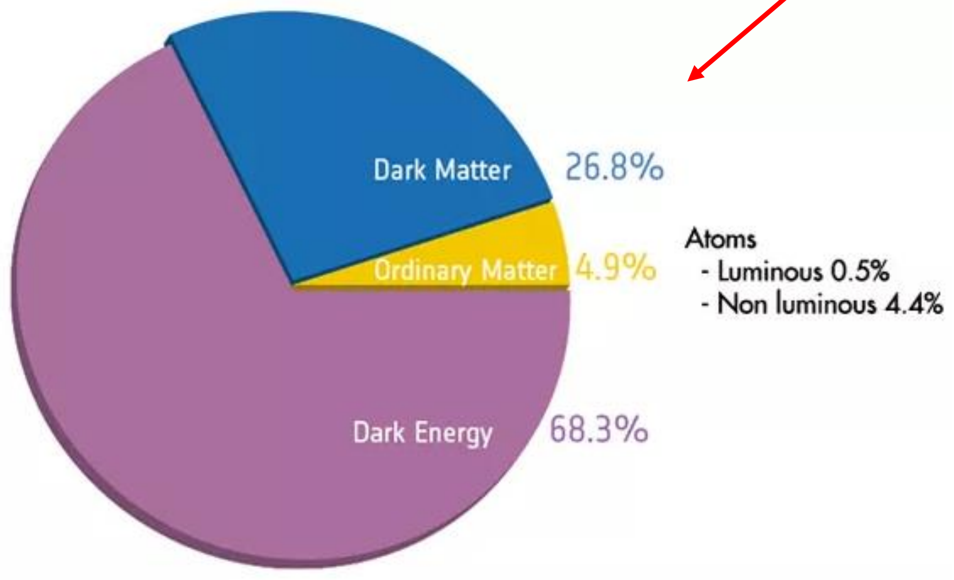
Content

- Direct detection of Dark Matter (DM)
- Neutrinos and its relation with DM
- Bubble chambers: new features
- Scintillating bubble chambers

Dark Matter



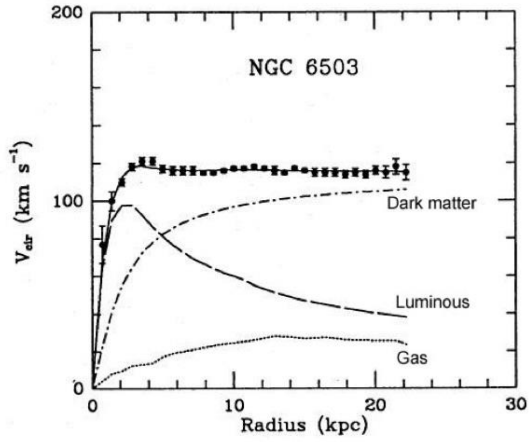
Planck Mission 2013, European Space Agency

CMB: power spectrum peaks analysis

- Hypothetical matter that don´t emit, absorb or scatter the electromagnetic radiation but show mass presence by its gravitational effect.
- Discrepancies between the gravitational and the luminous mass.

Some evidences of DM

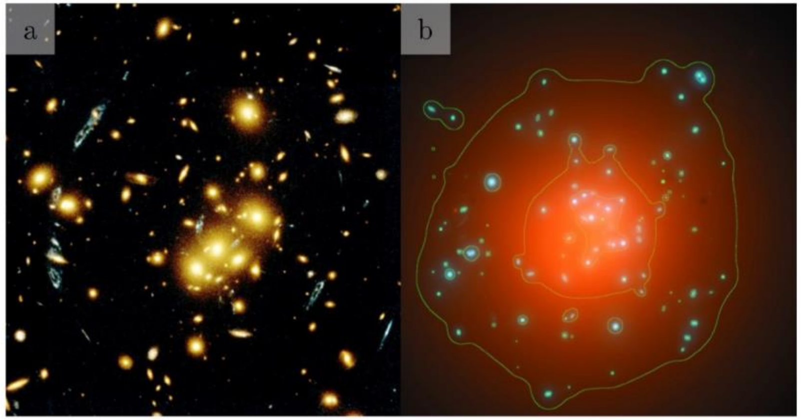
Rotation curves



K.G. Begeman, A.H. Broels, R.H. Sanders. 1991. Mon.Not.RAS 249, 523.

Strong Gravitational Lensing

(Galaxy cluster CL0024 + 1654)



Properties-candidate particles-detection methods

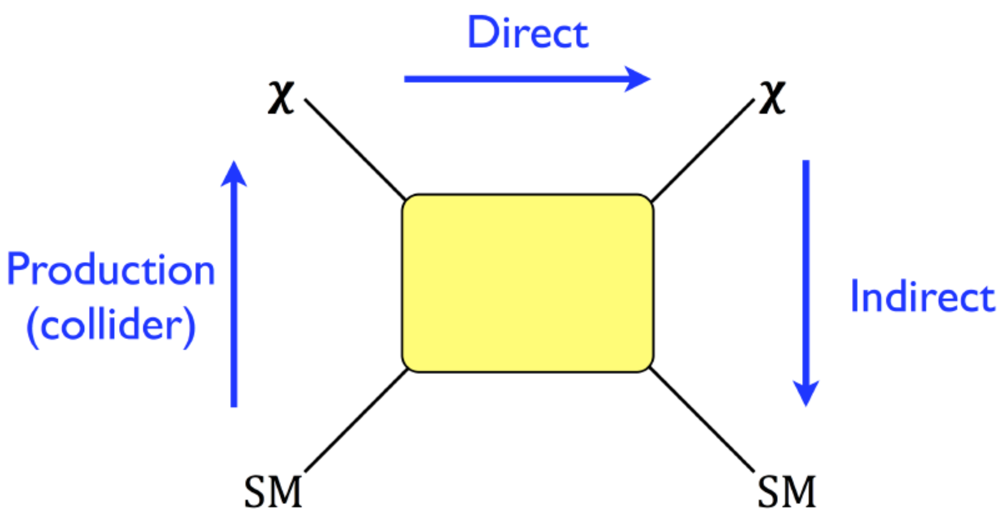
PROPERTIES

- Gravitationally interacting
- Stable or long-lived
- Cold or warm not hot (relativistic)
- Non-baryonic
- Electrically neutral
- No Color
- Feebly interacting

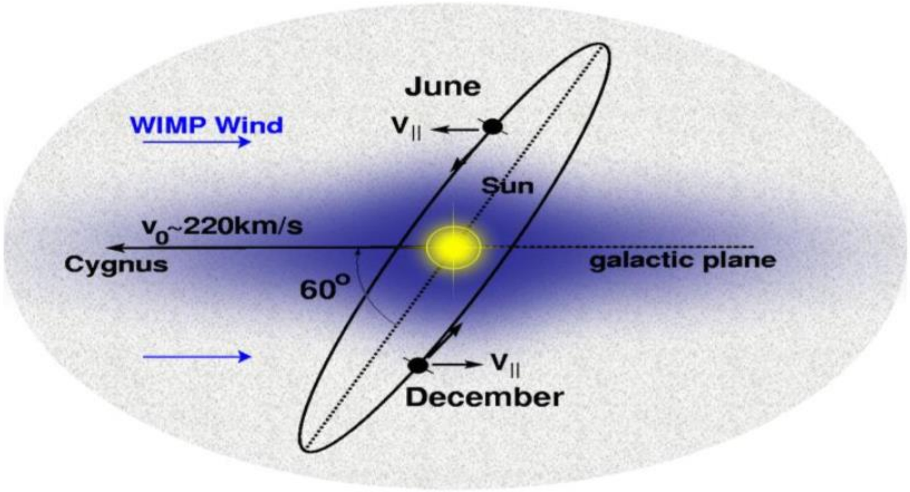
CANDIDATES

- **WIMPs** (*Weakly Interacting Massive Particles*): neutralino, axino, gravitino
- Axions
- Wimpzillas
- Kaluza-klein particle
- And many more….

DETECTION MECHANISM



SIGNAL: ANUAL MODULATION OF THE DETECTED EVENTS



Calculation rate (events/Kg/keV)

$$\frac{dR}{dE_R} = \frac{\rho_\odot}{m_N m_x} \int_{v_{min}}^{v_{max}} d\vec{v}\, f(\vec{v})\, v \frac{d\sigma}{dE_R}$$

$\boldsymbol{m_x}$: WIMP mass

$\boldsymbol{m_N}$: Target nucleus mass

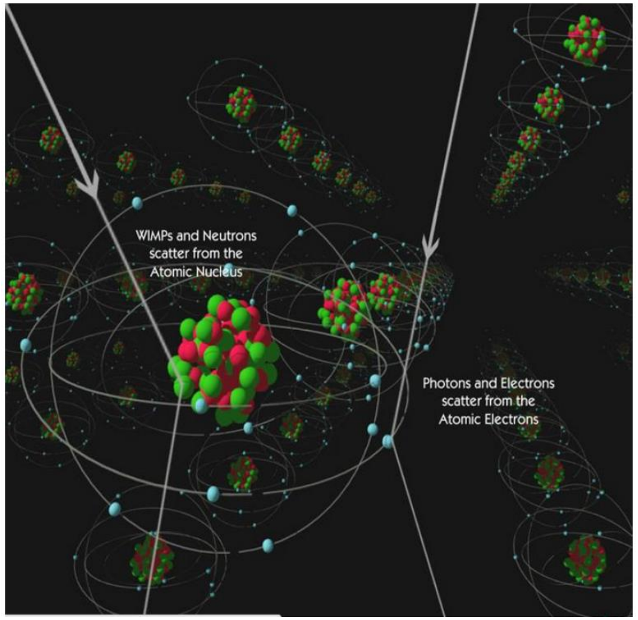
$\boldsymbol{\frac{d\sigma}{dE_R}}$: Differential scattering cross-section

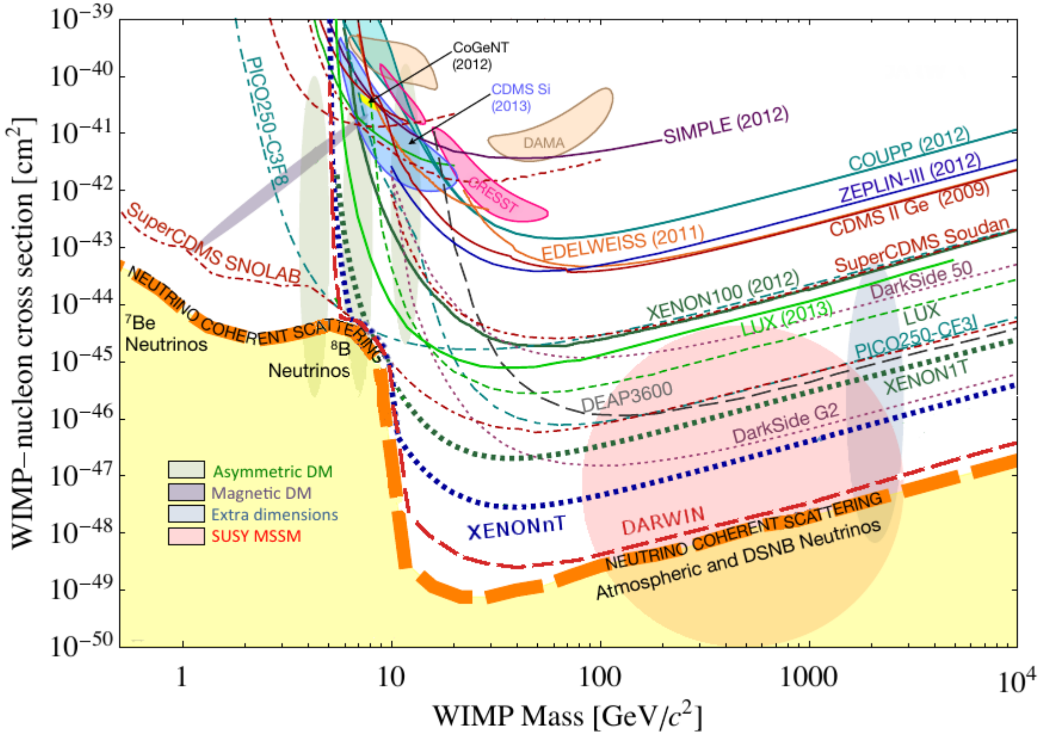
$\boldsymbol{v}$: WIMP mean velocity

$\boldsymbol{E_R}$: Nuclear recoil energy

$\boldsymbol{\rho_\odot}$: DM local density

$f[(\vec{v})]$: WIMP velocity distribution function





Neutrinos

Neutrinos are ideal particles for doing astronomy (weak interaction & almost no attenuation).

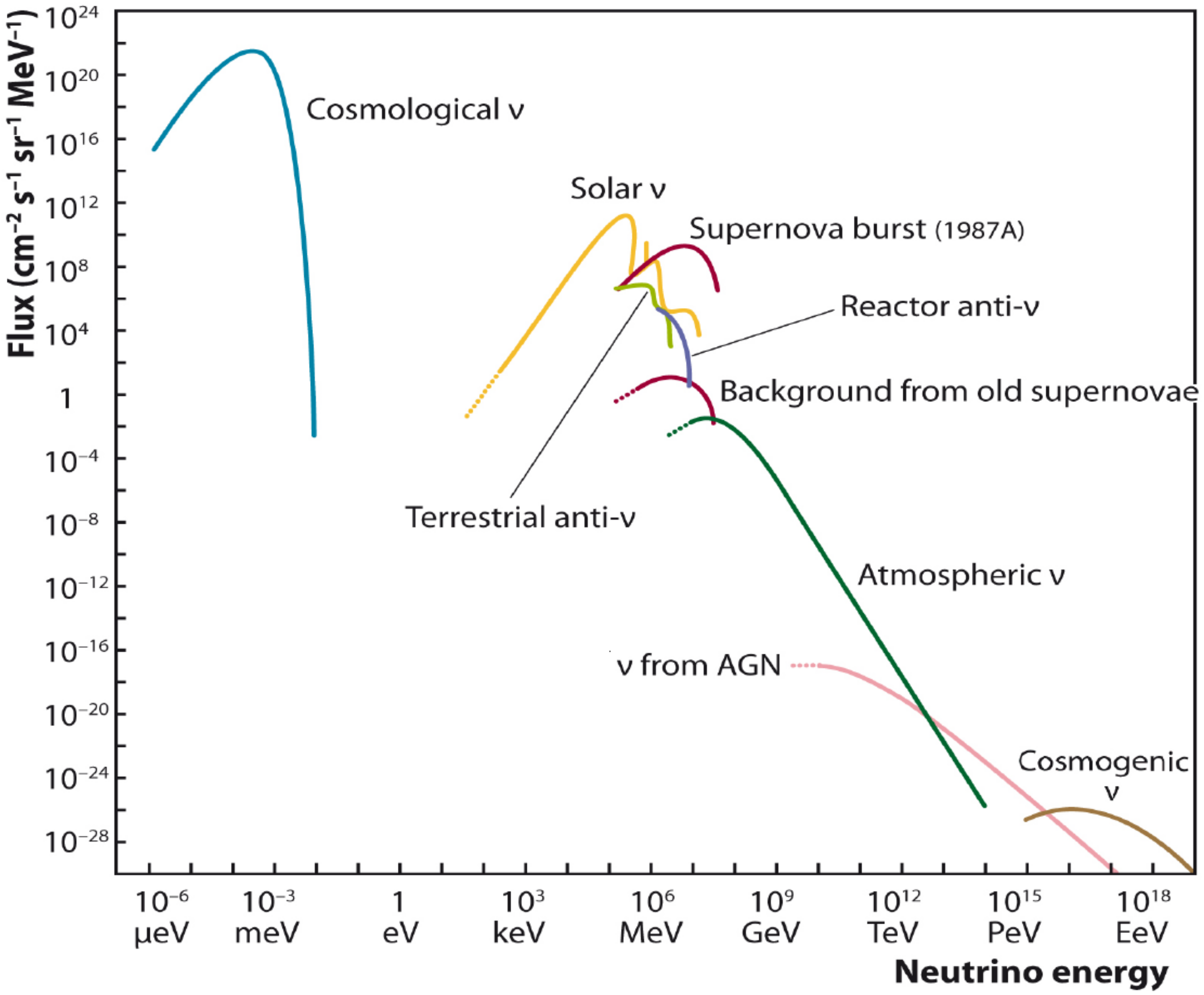
Allow to obtain details about the position, composition of astronomical objects + interactions happening there.

DM & neutrino physics fields are very related

The "neutrino floor" is an unavoidable background for the upcoming DM experiments.

Sterile neutrinos are competitive Dark Matter candidates.

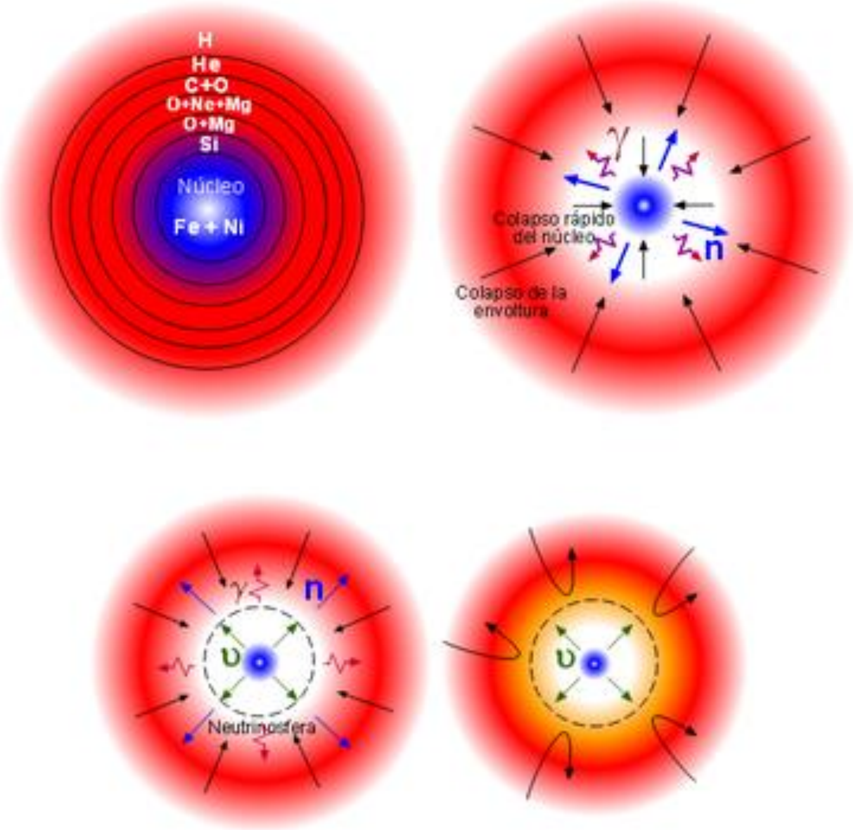
Measured and expected fluxes of natural and reactor neutrinos

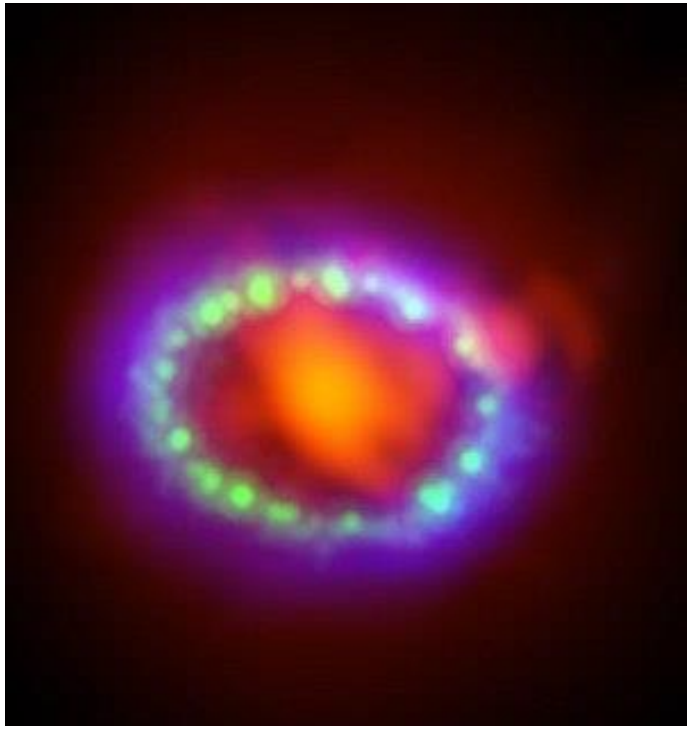


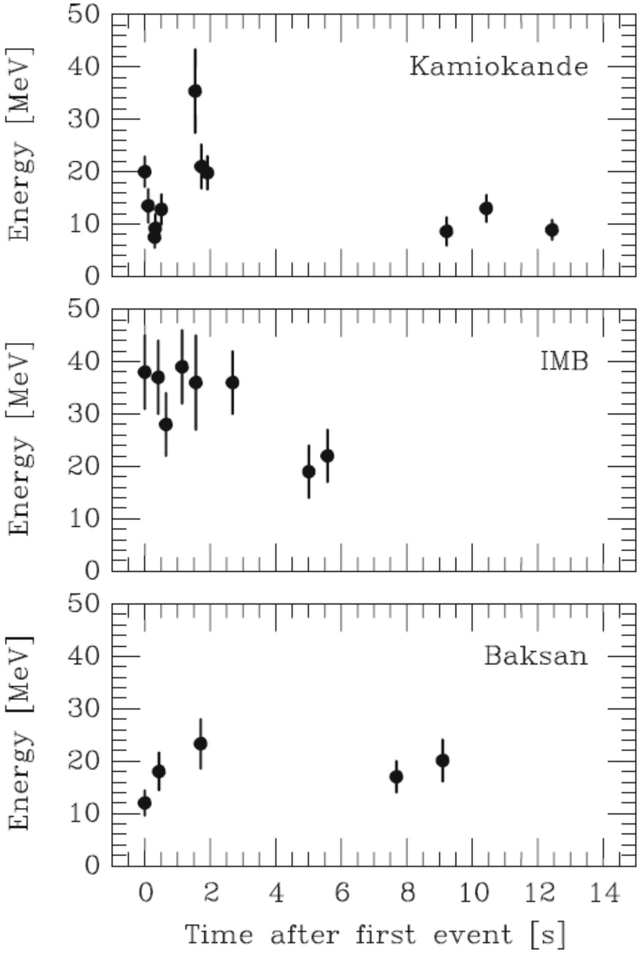
arXiv:1111.0507 [astro-ph.HE]

SNR 1987

SN neutrinos recorded by 3 underground experiments (SN 1987A)







Neutrino-driven mechanism is accepted to be the reason why SN explode

Electron capture produce a lot ν_e : 10^{58} with energies 10-40 MeV

H.-T. Janka (2017) arXiv:1702.08713v1

Bubble chambers: operating principle

A bubble chamber is a vessel filled with a superheated liquid used to detect particles moving through it.

As particles enter the chamber, a piston suddenly decreases its pressure, and the liquid enters into a superheated, metastable phase. Charged particles create an ionization track, around which the liquid vaporizes, forming microscopic bubbles.

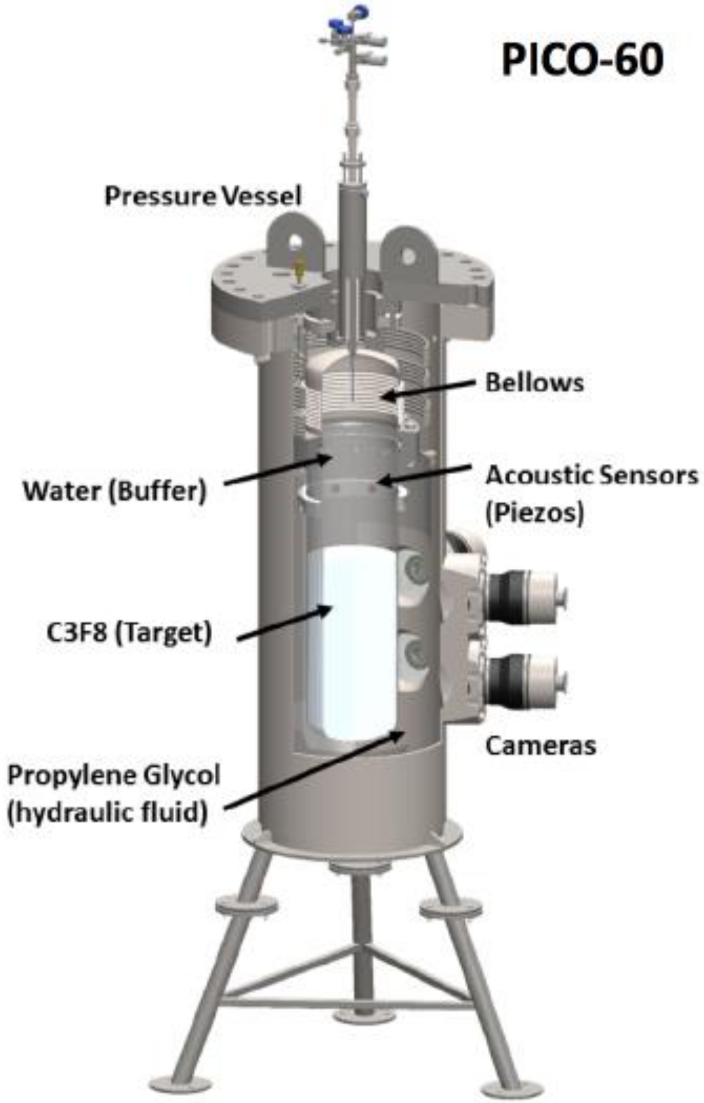
Bubbles grow in size as the chamber expands and later are photographed with several cameras mounted around (3D bubble position).

It was invented in 1952 by Donald A. Glaser, who was awarded the 1960 Nobel Prize in Physics.

Fermilab's bubble chamber

Today´s bubble chambers for dark matter search: PICO

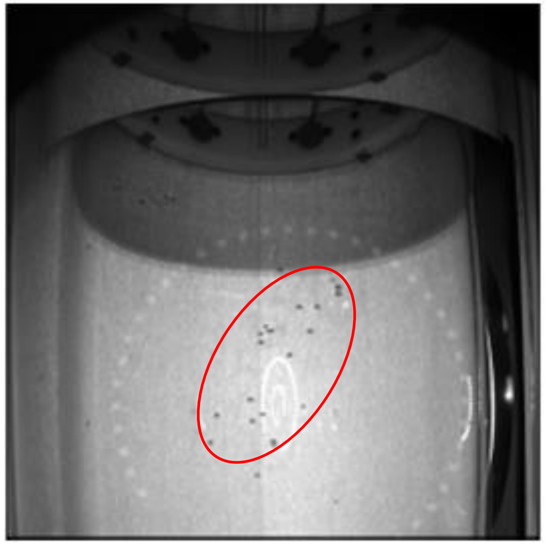
- Particles interacting evaporate a small amount of material: bubble nucleation
- Target material: superheated CF_3I, C_3F_8, C_4F_{10} (spin-dependent/independent)
- Four cameras record bubbles
- Eight piezo-electric acoustic sensors detect sound
- Background suppression: Underground, water shielding, clean materials.



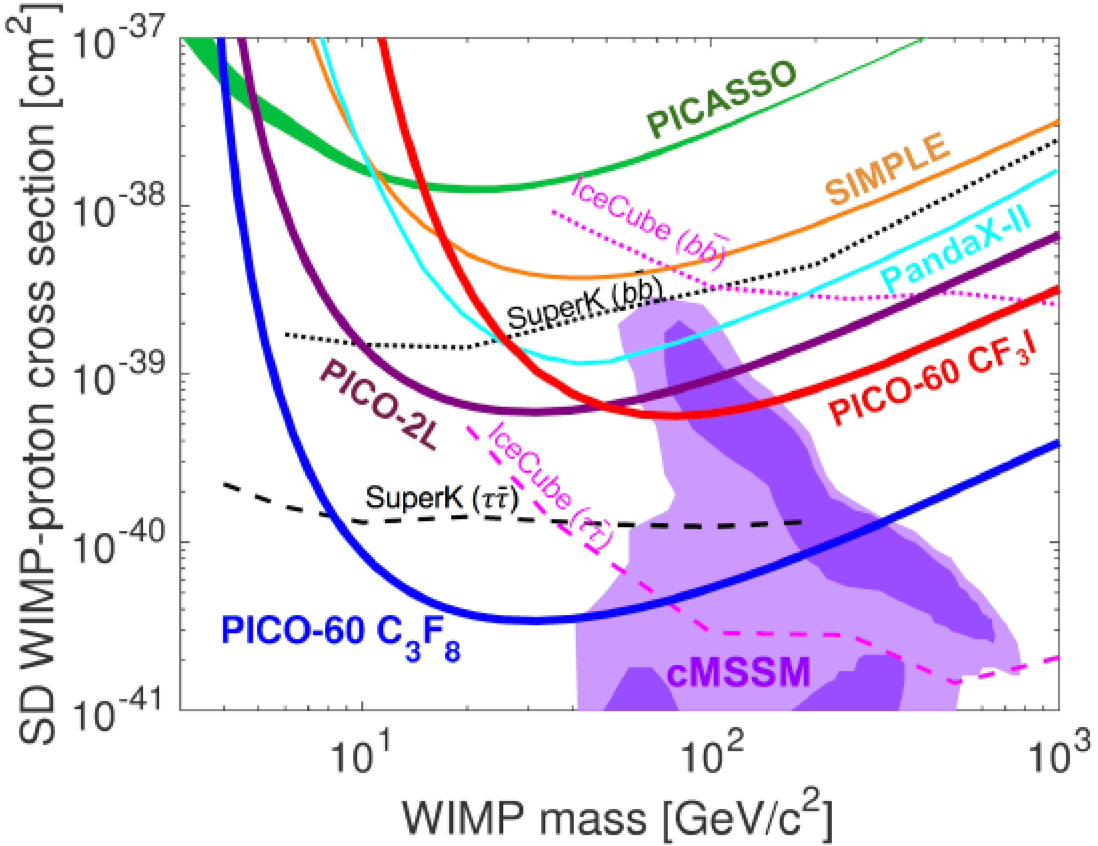
Background discrimination:

- Neutrons (multiple/single bubbles, NR, l ~ 20 cm)
- Alphas (acustic parameter, sigle bubble, NR, l ~ 40 µm track)

WIMP signal: 1 bubble, NR, large mean free path l > 10^{12} cm.



PICO exclusion curves



Phys. Rev. D 93, 052014 (2016)

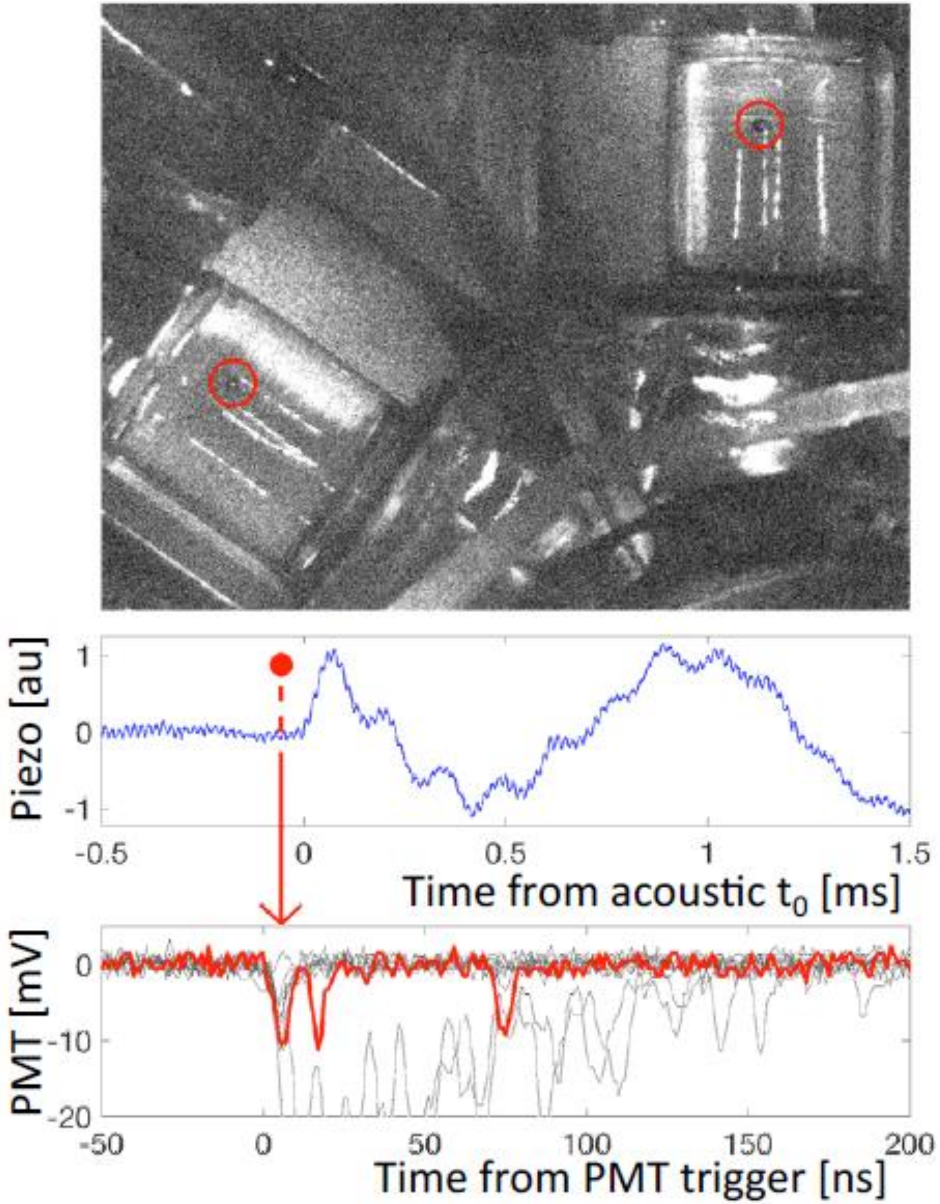
First demonstration of a Xeon scintillating bubble chamber

PRL 118, 231301 (2017)

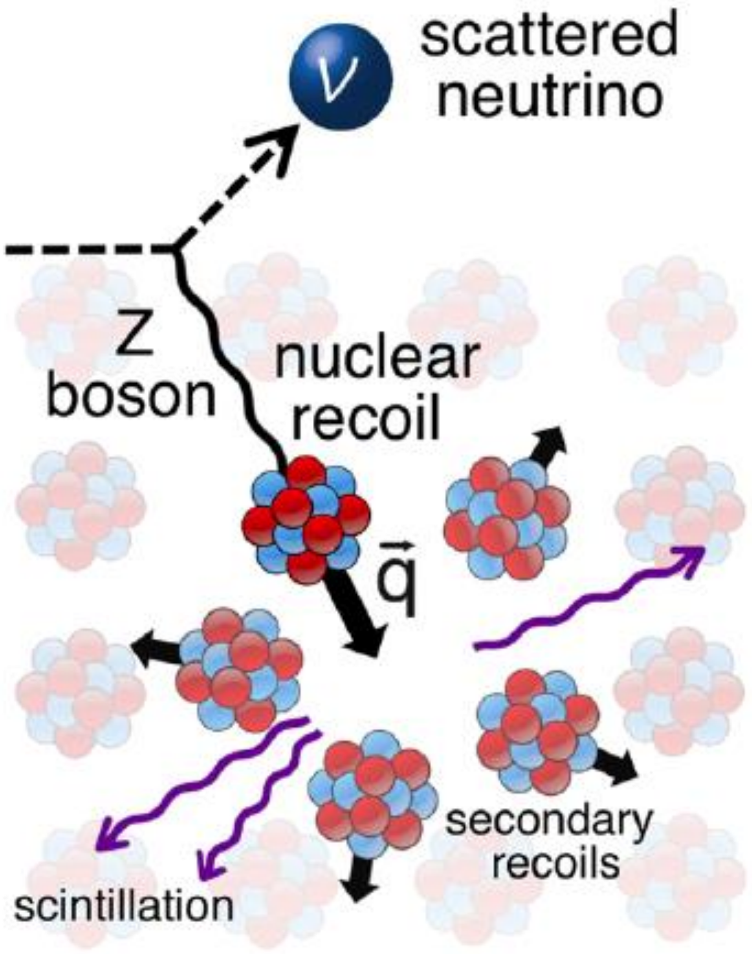
- A 30-g xenon bubble chamber has for the first time observed simultaneous bubble nucleation and scintillation by nuclear recoils in a superheated liquid.

- Instrumented with: a CCD camera for near-IR bubble imaging, a solar-blind photomultiplier tube to detect 175-nm xenon scintillation light, and a piezoelectric acoustic transducer to detect the ultrasonic emission from a growing bubble.

- Potential for direct dark matter search and detection of the interaction CEvNS.



First detection by the COHERENT experiment.
D. Akimov et al., Science 10.1126/science.aao0990 (2017).



CEvNS (*Coherent Elastic neutrino - Nucleus Scattering*):

A neutrino smacks (without losing energy) a nucleus via exchange of a Z, and the nucleus recoils as a whole.

Nuclear recoils energies < ~ 15 keV

$$\sigma \propto [A - Z]^2$$

Neutrino-flavor blind interaction!!!

Physics motivation

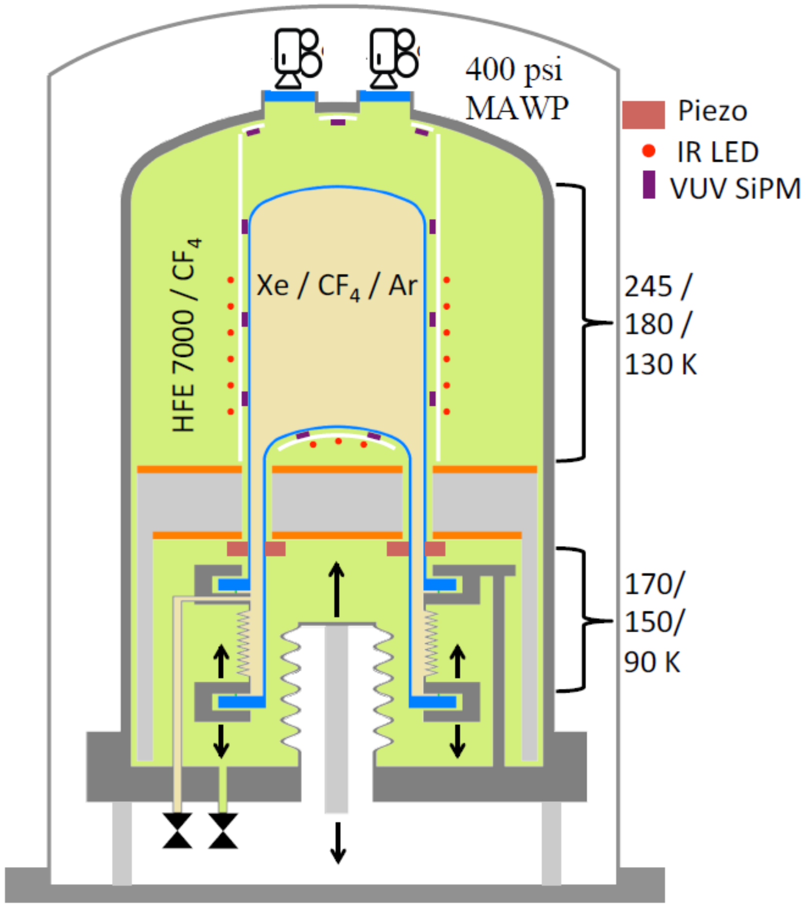
- Dark matter direct-detection background
- Potential BSM physics accessible to CEvNS experiments: non-standard neutrino interaction, new mediators, and large neutrino magnetic moment.
- A new tool for sterile oscillation searches
- Astrophysical signals (solar & SN)
- Supernova processes (opacity & nucleosynthesis)
- Nuclear physics: neutron form factors
- Nuclear reactors core monitoring

Project: a new bubble chamber 5 kg LAr + SiPM

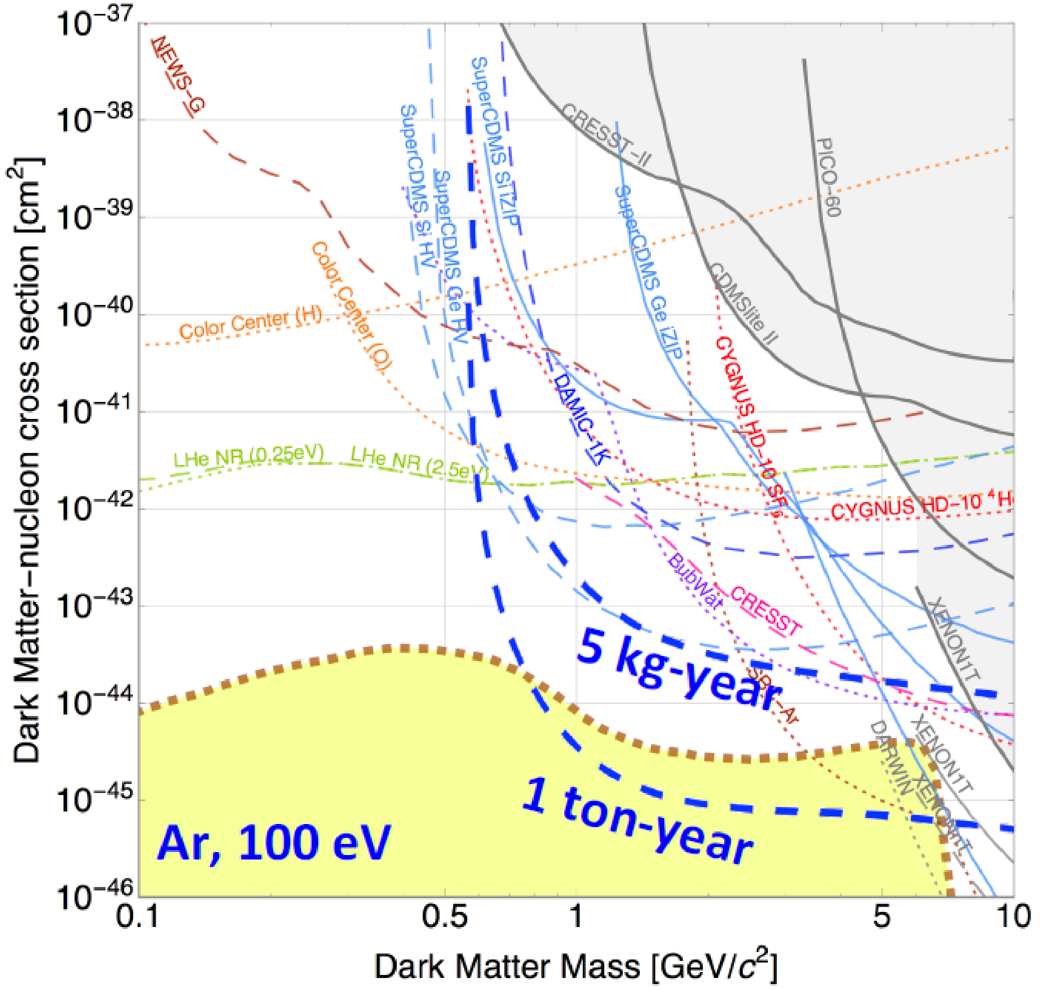
Work with: Northwestern University

- First ever *scalable* demonstration of a scintillating bubble chamber.
- Target argon recoil detection threshold of 100 eV, (sensitivity to GeV-scale WIMP dark matter and CEvNS).
- Development of a highly-efficient SiPM-based scintillation detection system compatible with bubble chamber photography and immersible in the pressurized thermal bath necessary for a large-scale bubble chamber.
- Wider range of operating pressures and temperatures than the prototype, allowing xenon, argon, and CF_4 targets to be superheated.
- Device with both the extreme (10^{-10}) electron recoil discrimination and the event-by-event energy resolution.

Schematic of the proposed detector



LAr scintillating bubble chamber sensitivity



M. Battaglieri et al. (2017) arXiv:1707.04591

RESEARCH ACTIVITIES

- Measure CEvNS cross-section.
- Compute the number of neutrinos from a near SN explosion with this experiment (1 ton).
- Explore low mass WIMPs (0.5 – 10 GeV/c²)
- Simulate the detector response to different particle sources for calibration.
- Test the SiPM response to high pressure an low temperatures.

Summary

1. Dark matter & Neutrino physics are two fields deeply interconnected in many aspects, including the detection techniques.

2. Bubble chamber technology have evolved since their invention, now it is employed for cutting-edge science (e.g. PICO).

3. It was demonstrated the first xenon scintillating bubble chamber, a promising new technology for the detection of weakly interacting massive particle dark matter and coherent elastic neutrino-nucleus scattering.

4. The next step: developing a scalable 5 kg LAr scintillating bubble chamber with a very low nuclear recoils detection threshold (~100 eV), strong electron discrimination and event-by-event energy resolution.

Thanks for your attention!!!