Dark Matter Detection Experiments

Physkiss-3

Sanskriti Chitransh
22nd June, 2020

What is Dark Matter?

- Measurements by Planck and WMAP demonstrate that nearly 85% of the Universe matter density is dark [1]
- Evidence from observation of DM's effects on baryonic matter

Some open questions:

1. What is the mass of the DM?
2. What is the strength of matter-DM interactions?

Astrophysical properties

- Use galaxies and interactions therewith to determine distribution
- Rotation curves:

$$v_c(r) = \sqrt{\frac{GM}{R}}$$

$$\rho(r) \propto \frac{M(r)}{r^3} \sim \frac{1}{r^2}$$

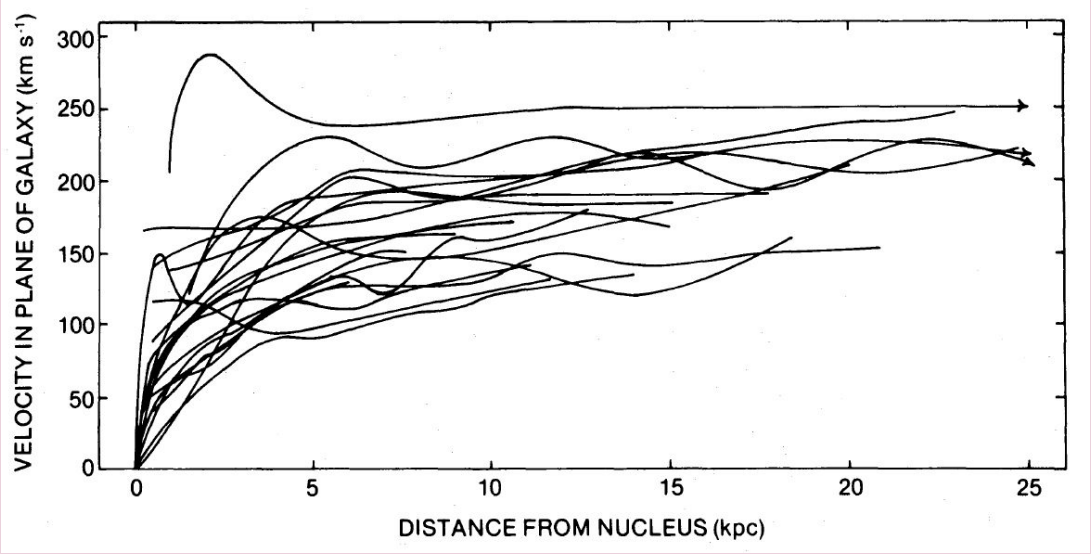


Image from [2]

Metadata

- Stellar kinematics constrain : $M_{halo} \sim 10^{12} M_{\odot}$ and local DM density: $\rho_0 \sim 0.3 GeV/cm^3$
- Average DM velocity from Virial theorem: $\langle v \rangle \sim 200 km/s$ (non-relativistic)
- Most commonly used velocity distribution is the Standard Halo Model:

$$f(\mathbf{v}) = \begin{cases} \frac{1}{N_{esc}} \left(\frac{3}{2\pi\sigma_v^2}\right)^{3/2} e^{-3\mathbf{v}^2/2\sigma_v^2} & : |\mathbf{v}| < v_{esc} \\ 0 & : \text{otherwise} \end{cases}$$

[3]

WIMPs

- 23% of all matter is Cold DM. **WIMPs** or Weakly Interacting Massive Particles are prime DM candidates
- Yet undiscovered, stable weakly-interacting massive particle
- Assumed to be thermally produced in the early universe and now moving with non-relativistic velocities [4]

Direct Detection

- **Cryogenic crystal detectors** use semiconductor detector arrays at millikelvin temperatures
  ~Measure the ionization and phonons produced in particle interactions in the germanium and silicon crystal substrates
  ~Used by CDMS, EDELWEISS
- **Noble gas scintillators** detect atoms "knocked about" by WIMPs using scintillating material
  ~Light pulses are generated by the moving atom and detected with PMTs
  ~ Used by DEAP at SNOLAB, XENON100

- **Crystal scintillators** use crystal scintillators
  ~Used in DAMA/LIBRA
- **Bubble Chambers** use droplets of superheated liquid that are suspended in a gel matrix
  ~Energy is deposited in a droplet by ionizing radiation which undergoes a phase transition and becomes a gas bubble that is detected
  ~Used by PICASSO

Comparison

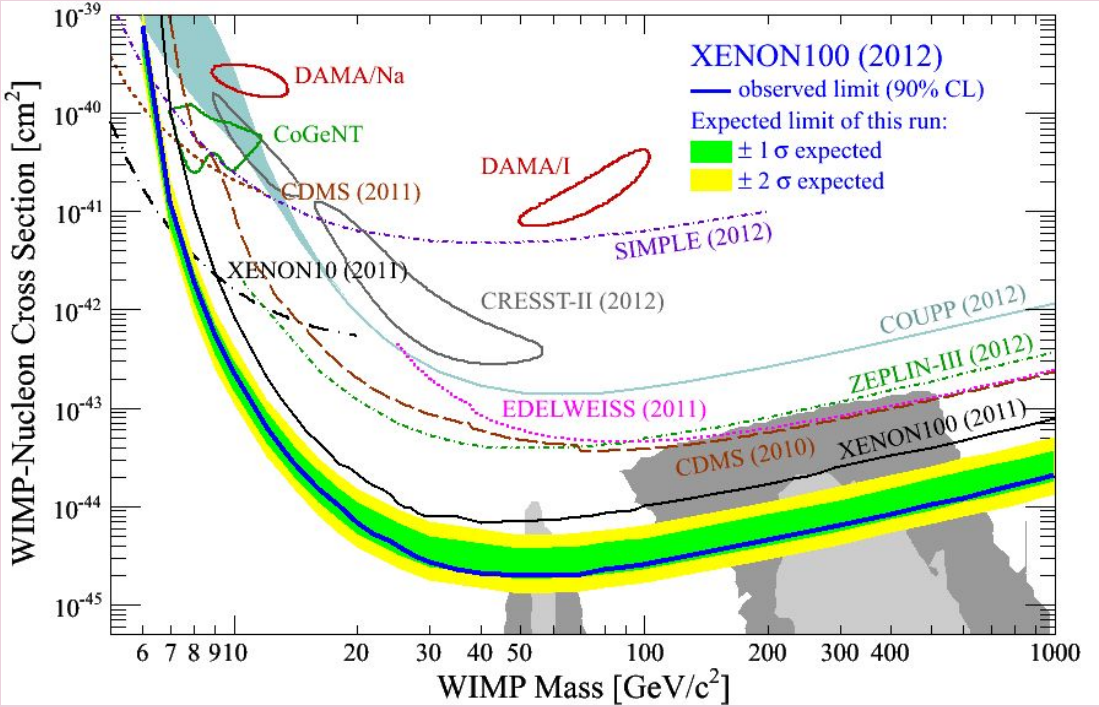
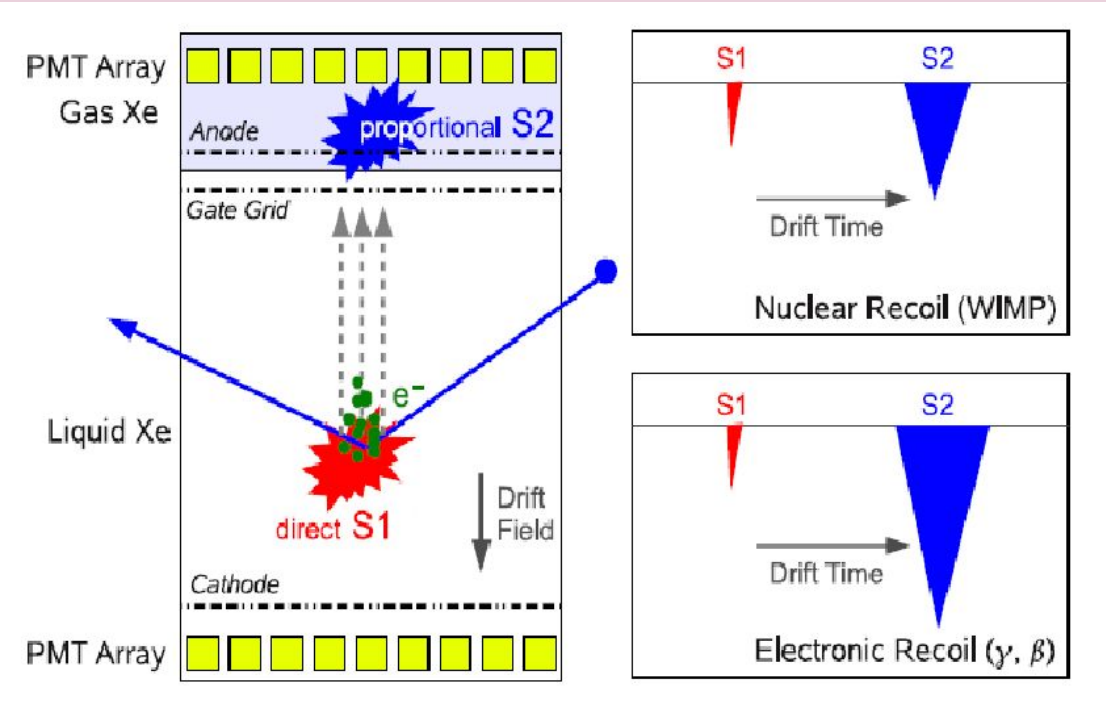


Image from [5]

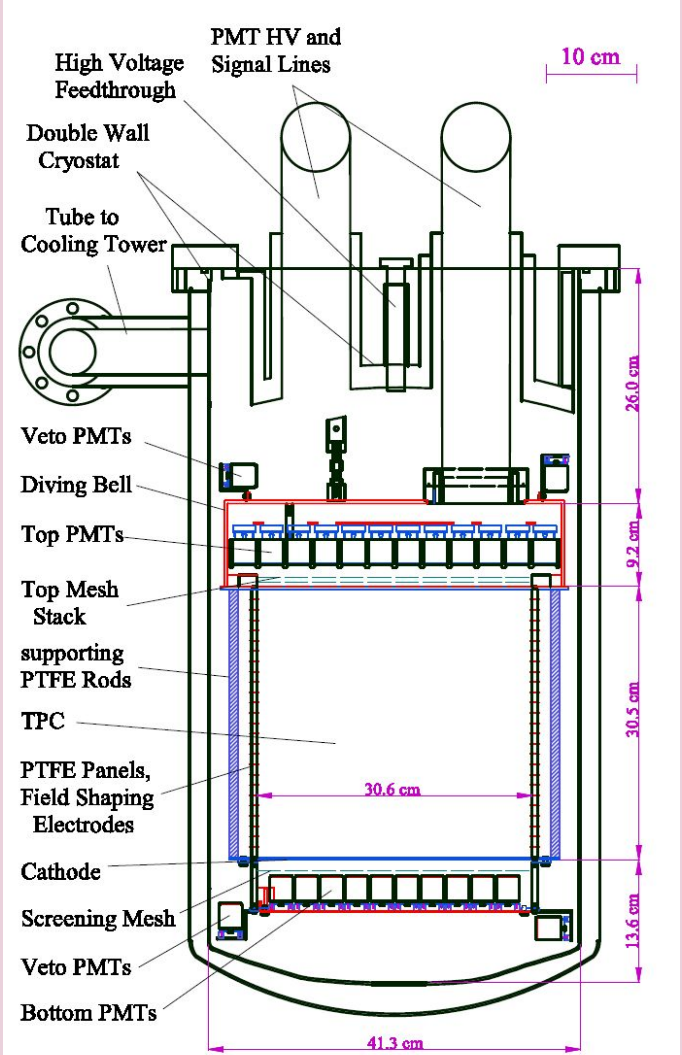
Detection with Liquid Xenon

Image from [6]



XENON100 design

Image from [6]



References

1. Planck Collaboration, et al. "*Planck* 2015 Results: XIII. Cosmological Parameters." *Astronomy & Astrophysics*, vol. 594, Oct. 2016, p. A13. *DOI.org (Crossref)*, doi:10.1051/0004-6361/201525830.
2. Luminosities and Radii, from NGC 4605 /R = 4kpc/ to UGC 2885 /R = 122 Kpc/." *The Astrophysical Journal*, vol. 238, June 1980, p. 471. *DOI.org (Crossref)*, doi:10.1086/158003.
3. Lisanti, Mariangela. "Lectures on Dark Matter Physics." *New Frontiers in Fields and Strings*, WORLD SCIENTIFIC, 2017, pp. 399–446. *DOI.org (Crossref)*, doi:10.1142/9789813149441_0007.
4. Schumann, Marc. "Direct Detection of WIMP Dark Matter: Concepts and Status." *Journal of Physics G: Nuclear and Particle Physics*, vol. 46, no. 10, Oct. 2019, p. 103003. *DOI.org (Crossref)*, doi:10.1088/1361-6471/ab2ea5.
5. *The XENON Dark Matter Project*. http://xenon.astro.columbia.edu/XENON100_Experiment/. Accessed 21 June 2020.
6. Aprile, E., et al. "The XENON100 Dark Matter Experiment." *Astroparticle Physics*, vol. 35, no. 9, Apr. 2012, pp. 573–90. *DOI.org (Crossref)*, doi:10.1016/j.astropartphys.2012.01.003.

Thank you!