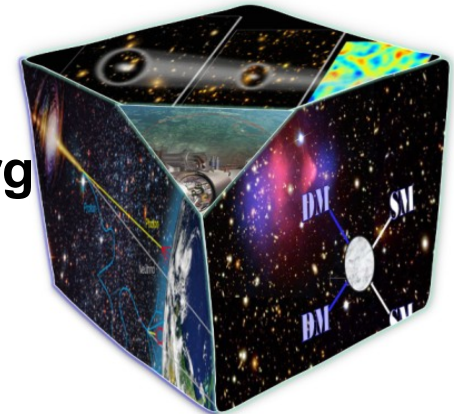
Hadronic Contributions to New Physics Searches

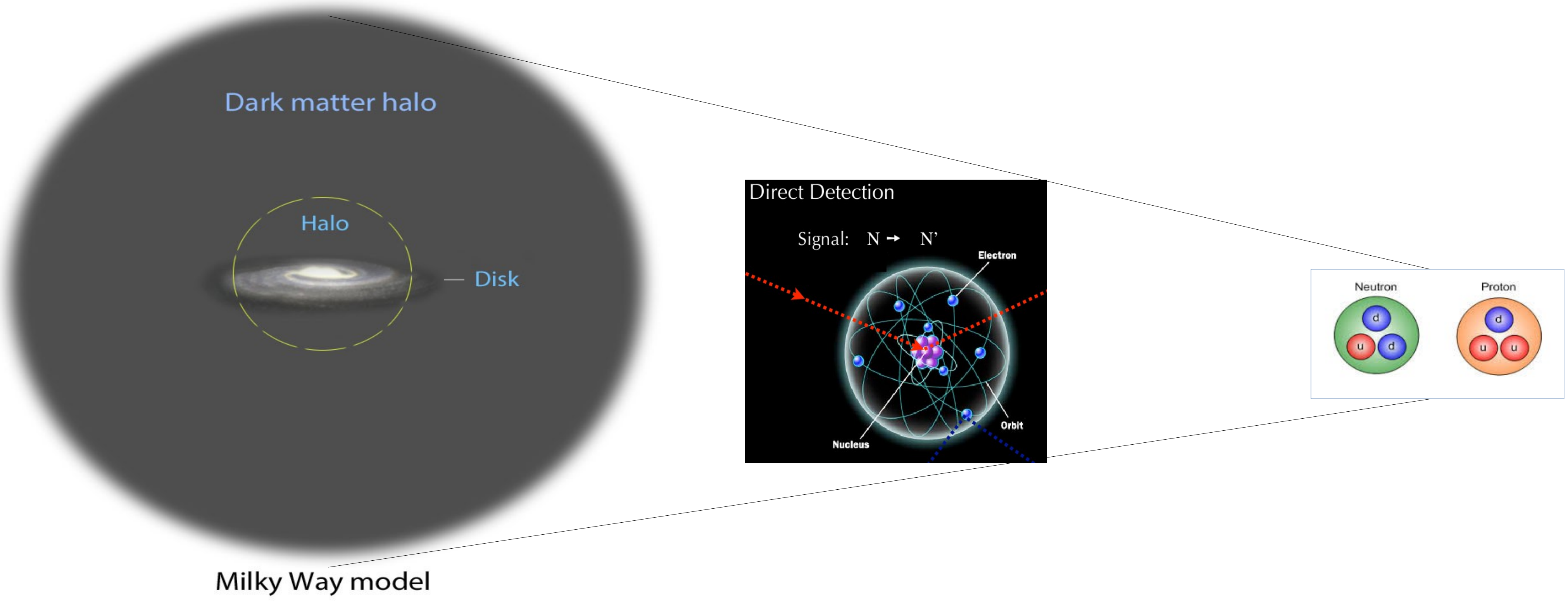
Searches of Dark Matter Overview

Farinaldo Queiroz
Max Planck Institute for Nuclear Physics - Heidelberg

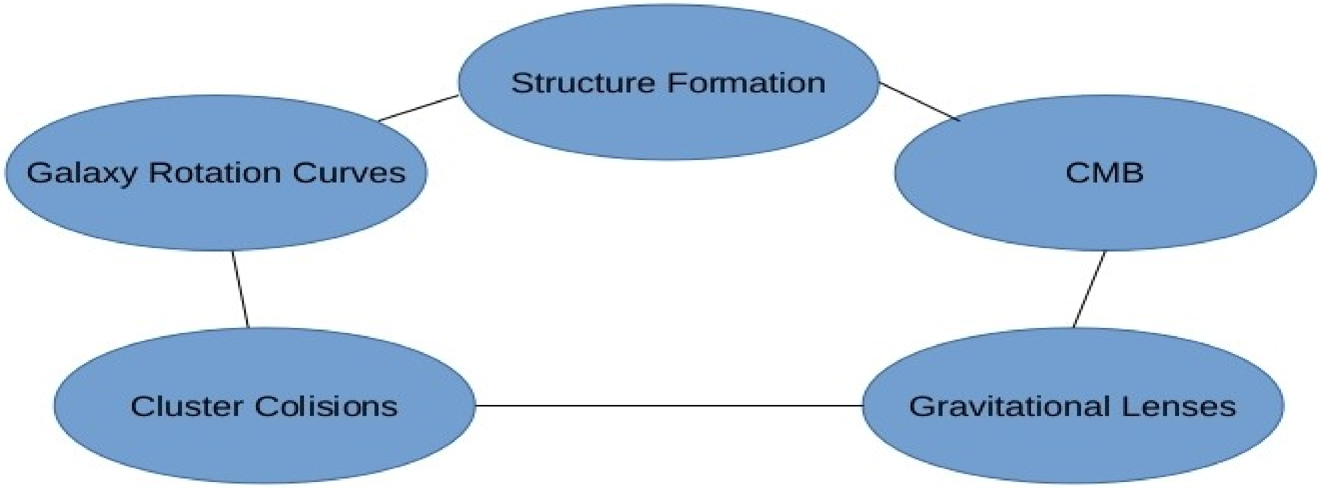


Take home message

Nature of dark matter → hadronic corrections under control!



Evidences for Dark Matter



First Evidence for Dark Matter

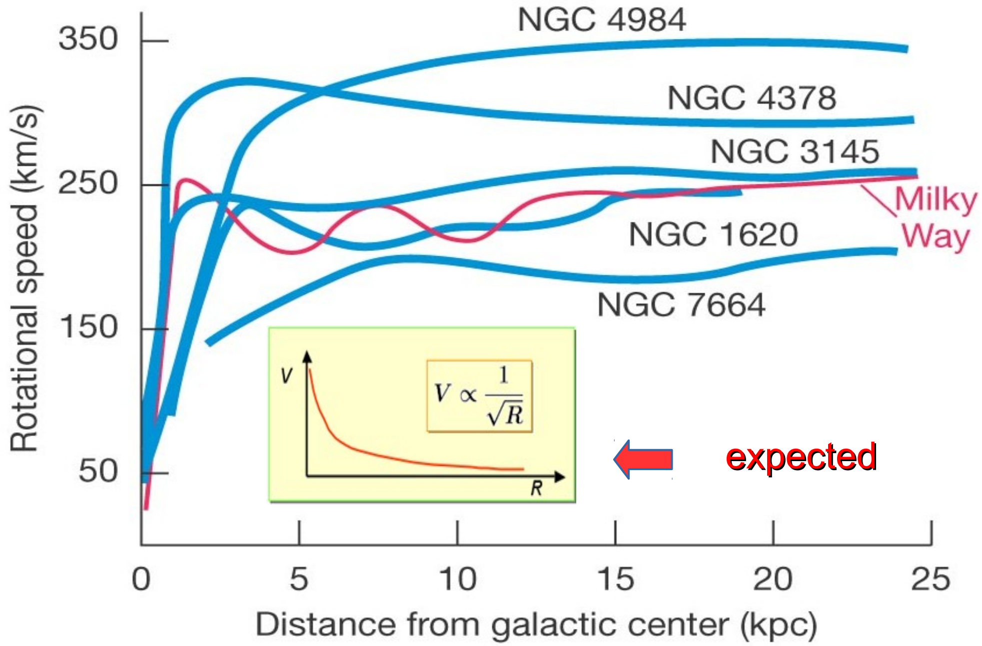
In 1933 Fritz Zwick used the virial theorem to **infer the existence of unseen matter** in the Coma galaxy cluster

"Spherical Bastards"

Coma galaxy cluster

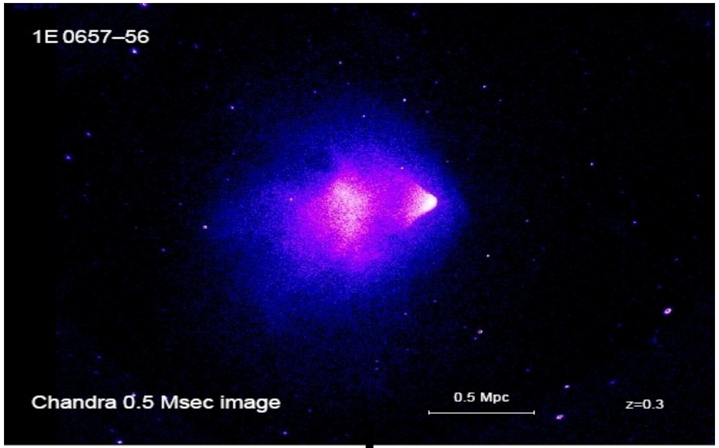
Galaxy Rotation Curves

In 1970s Vera Rubin+, **established the existence of dark matter** in galaxies by studying galaxy rotation curves

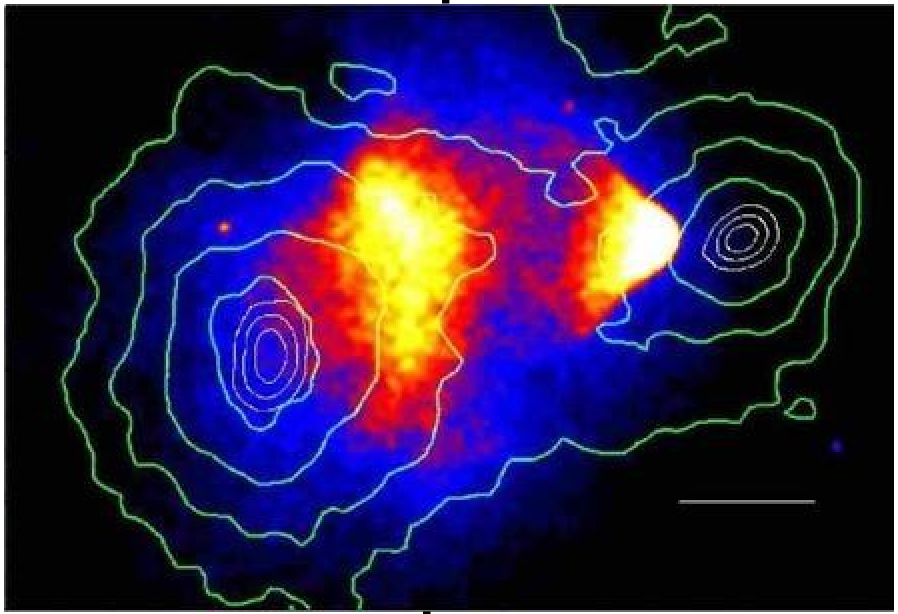


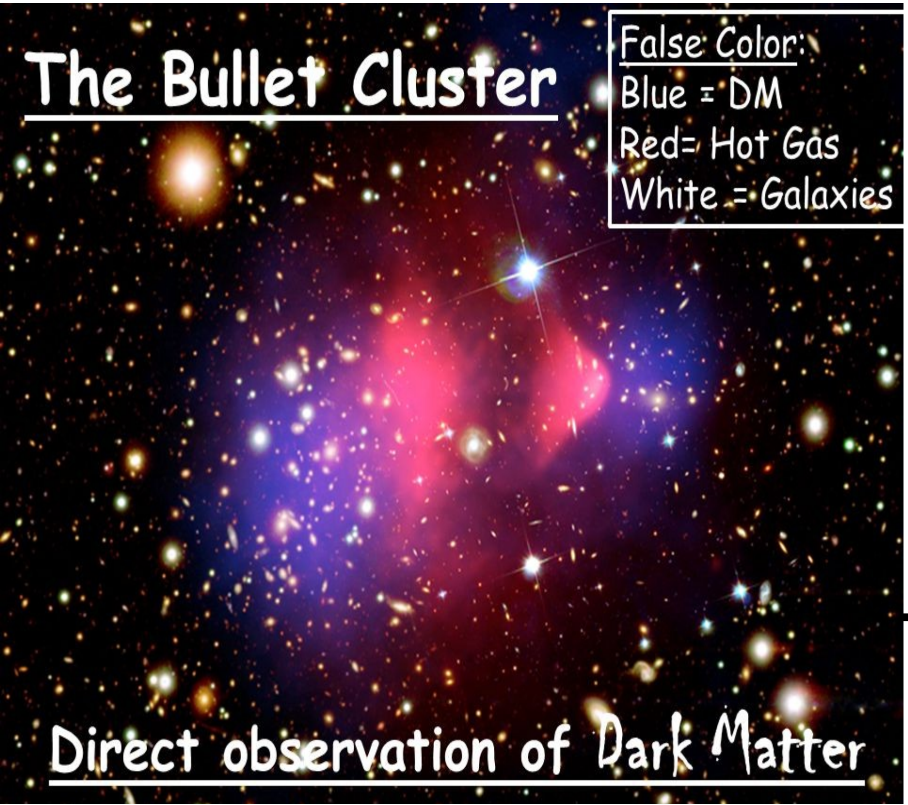
From then on the dark matter search took off

Cluster Collisions

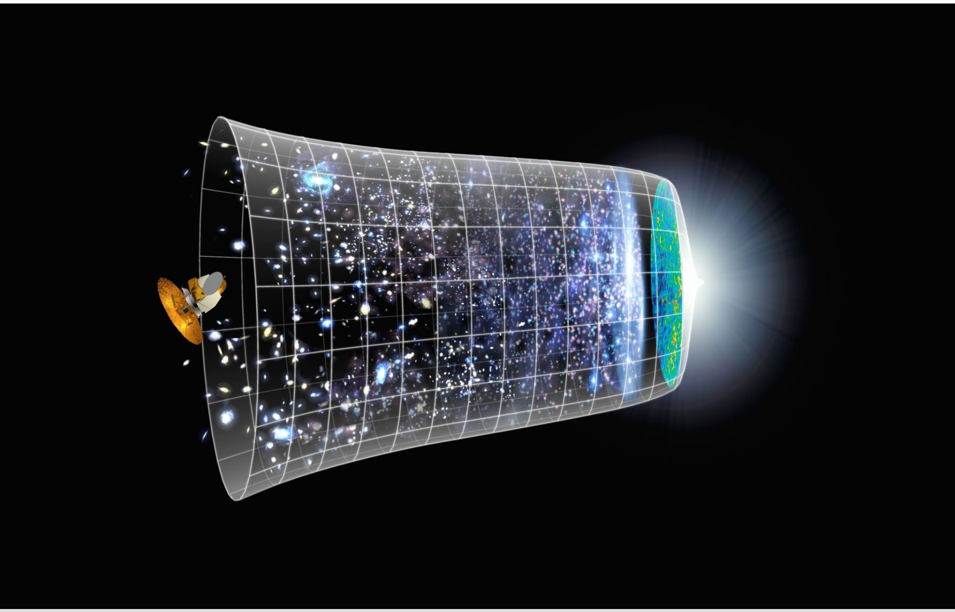


In 2006 Douglas Cowe+, **established the existence of dark matter** in cluster of galaxies and "excluded" classical MOND theories

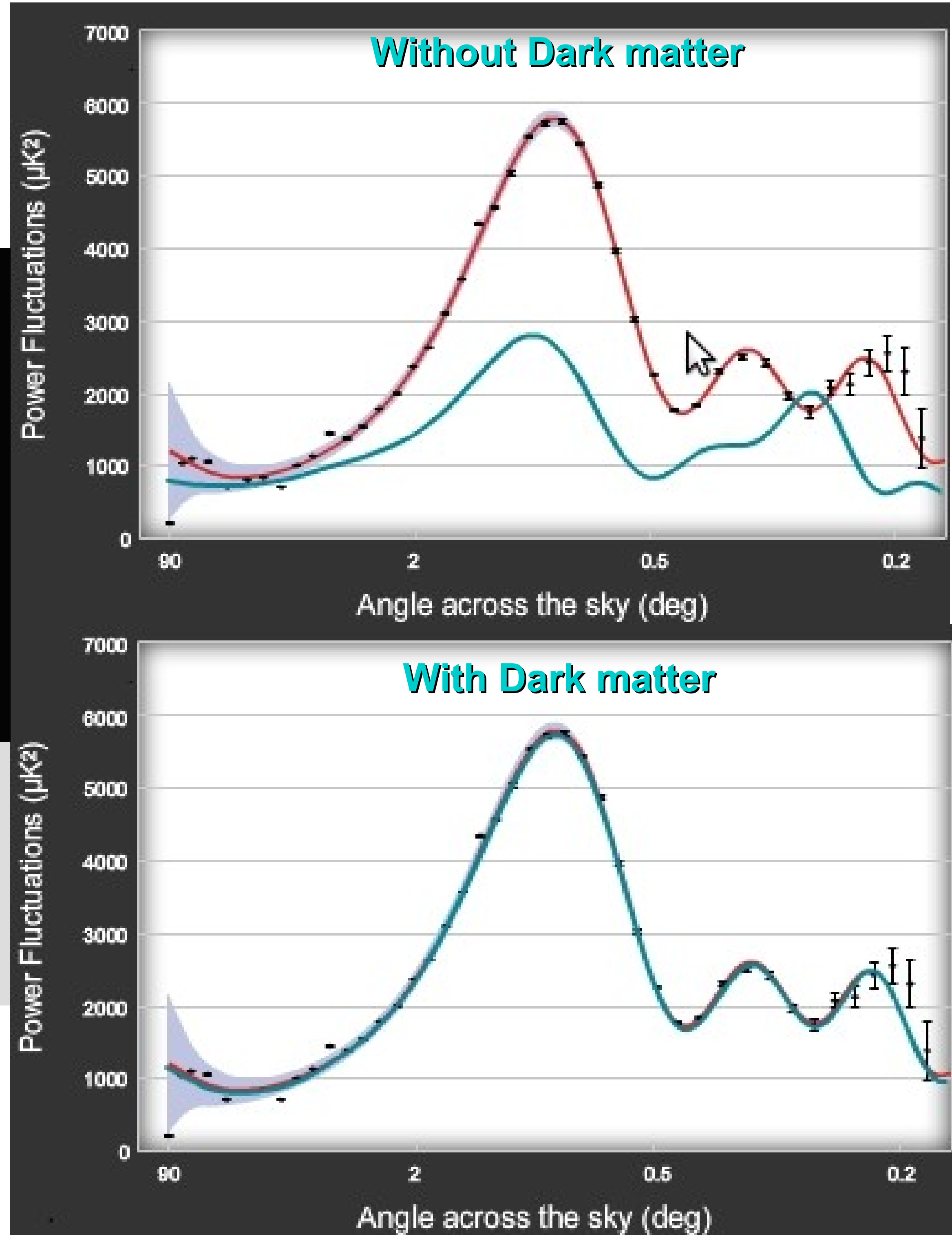




CMB



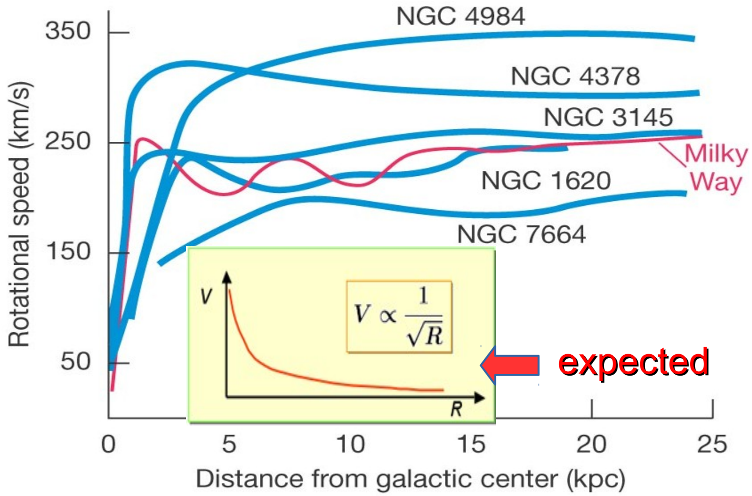
2013-2015 Planck satellite has confirmed the the existence of dark matter in early times of the universe history



Thus, the need for Dark Matter

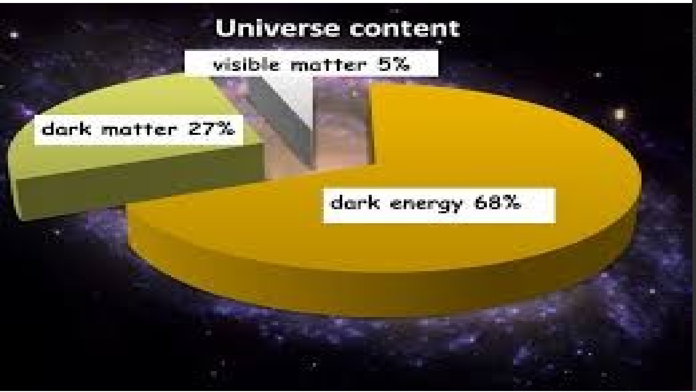
In 1933 Fritz Zwick used the virial theorem to infer the existence of unseen matter in the Coma galaxy cluster

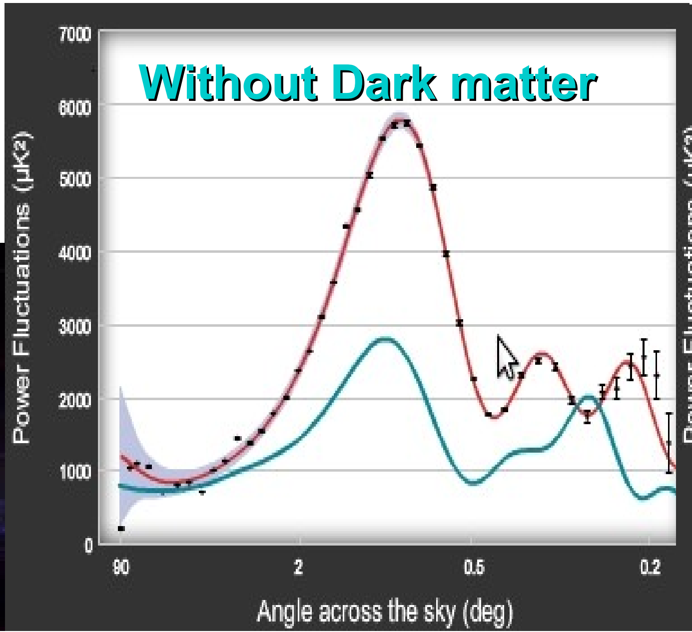
In 1970s Vera Rubin+, established the existence of dark matter in galaxies by studying galaxy rotation curves

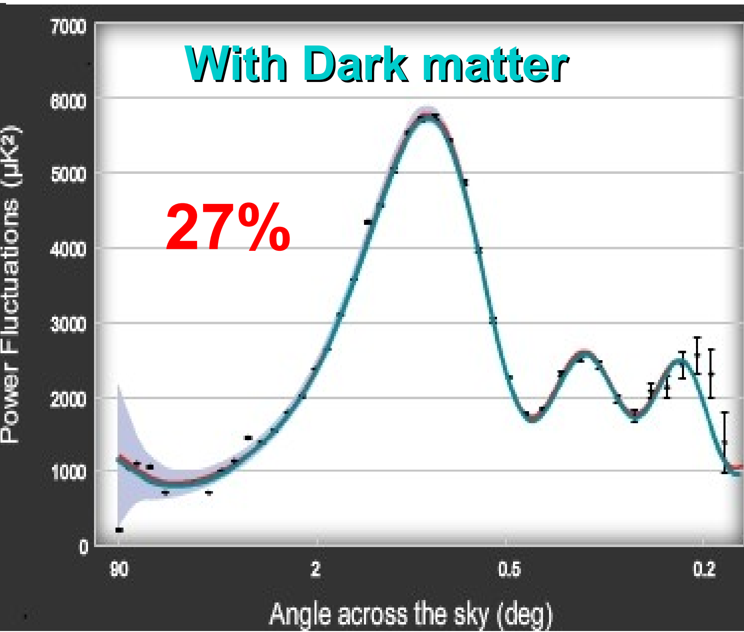


In 2003 the observation of the bullet cluster by Maxim Markevitch+

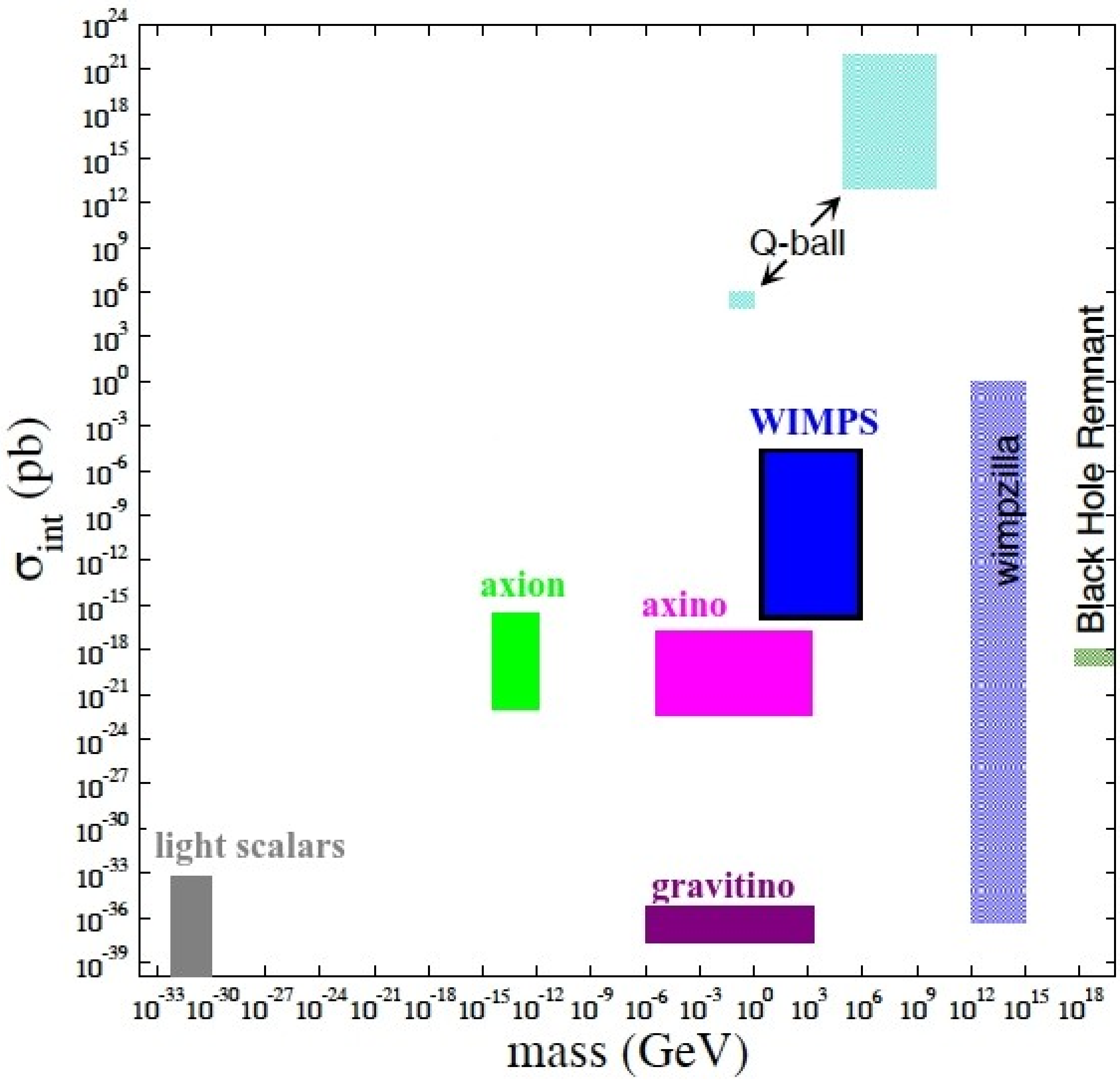
COBE (1990s), WMAP (2000s), PLANCK (2013) confirmed the existence of dark matter using CMB data







What is the Nature of Dark Matter?



Ultralight scalar

Berengut, Flambaum, King, Curran, Webb PRD 83 (2011) 1

Stadnik, Flambaum PRL 115 (2015)

Sterile Neutrino

Wong JPCS 718 (2016)

Axions

F. S. Queiroz. K. Sinha, W. Wester PRD 2014

Asymmetric Dark Matter

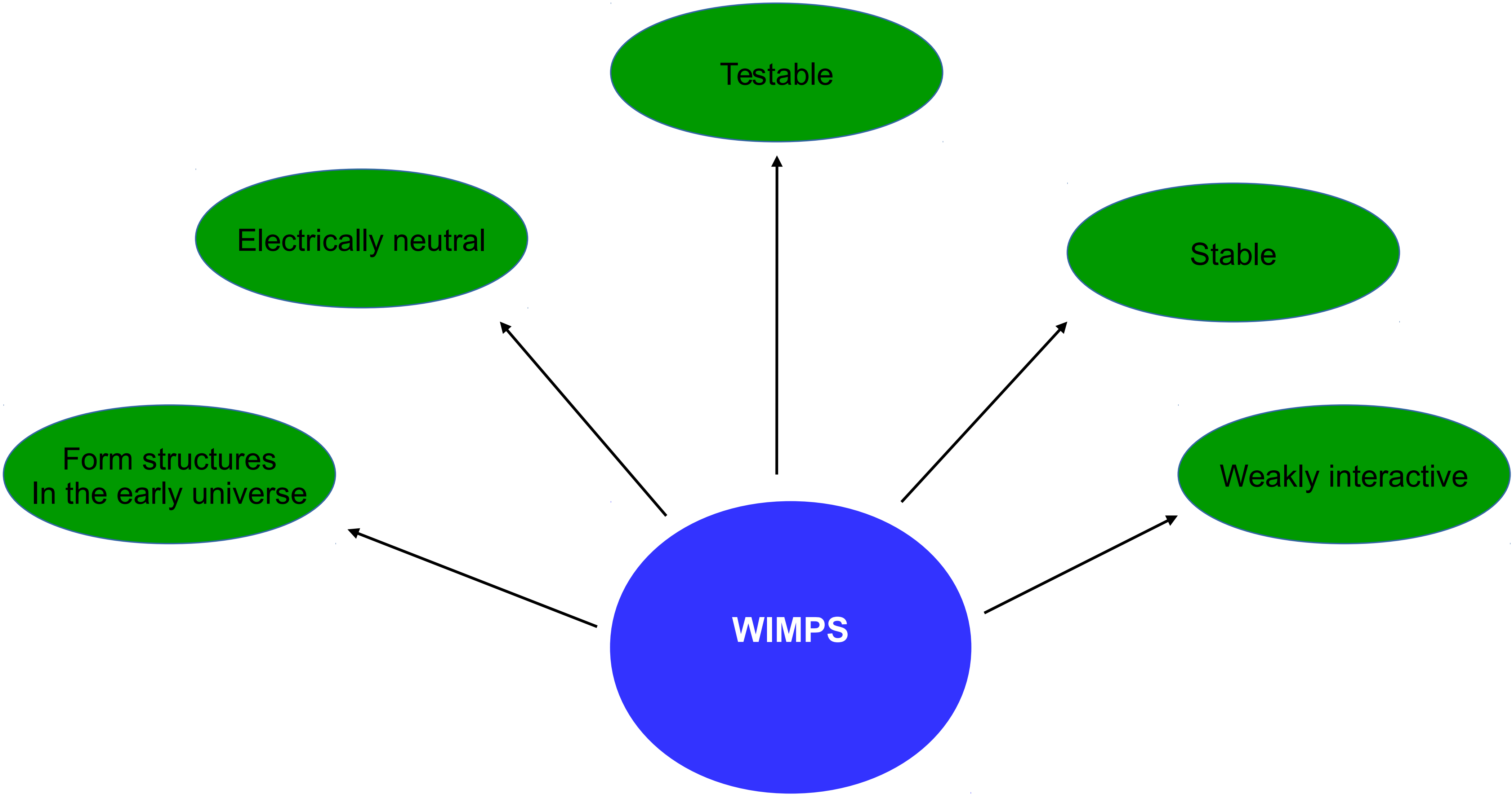
Petraki, Volkas. IJMPA 28 (2013)

Flavor Dark Matter – g-2

Review on g-2 and flavor violation
Lindner, Platscher, Queiroz – To appear in Physics Reports 2016

→ F. S. Queiroz. W. Shepherd PRD 89 (2014)

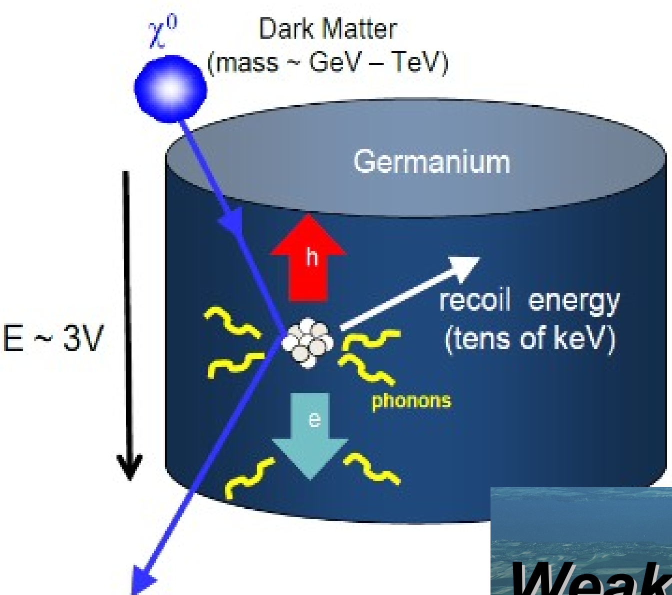
Most popular candidate

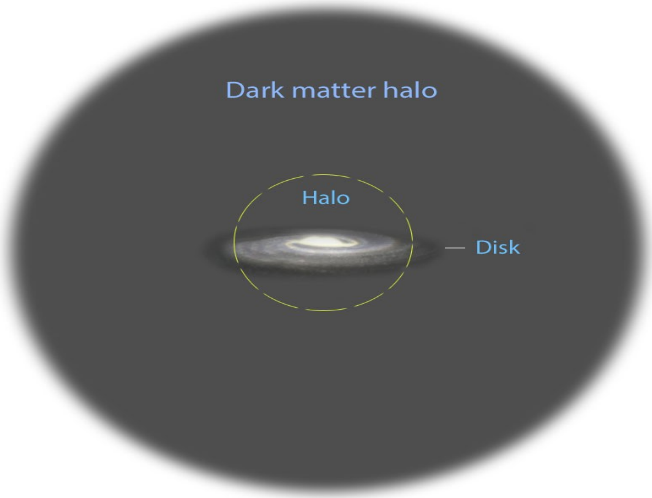


WIMPs can naturally fulfill all these requirements

How do we search for WIMPs ?

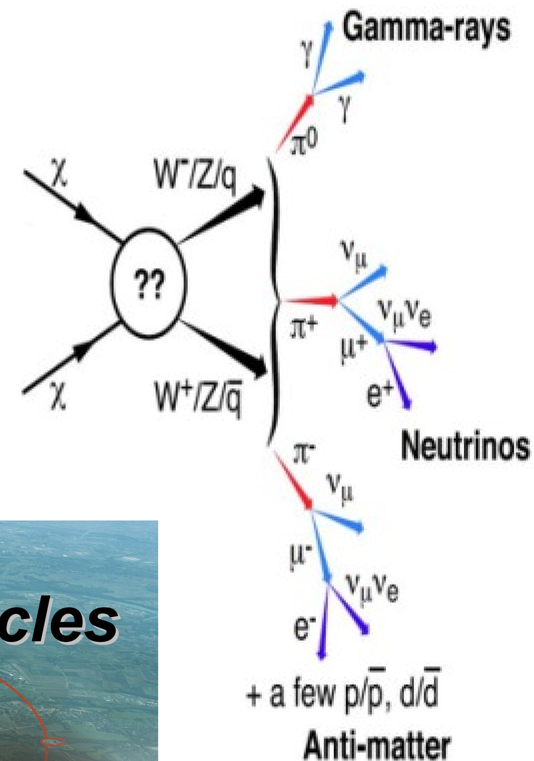
Direct Detection





Milky Way model

Indirect Detection

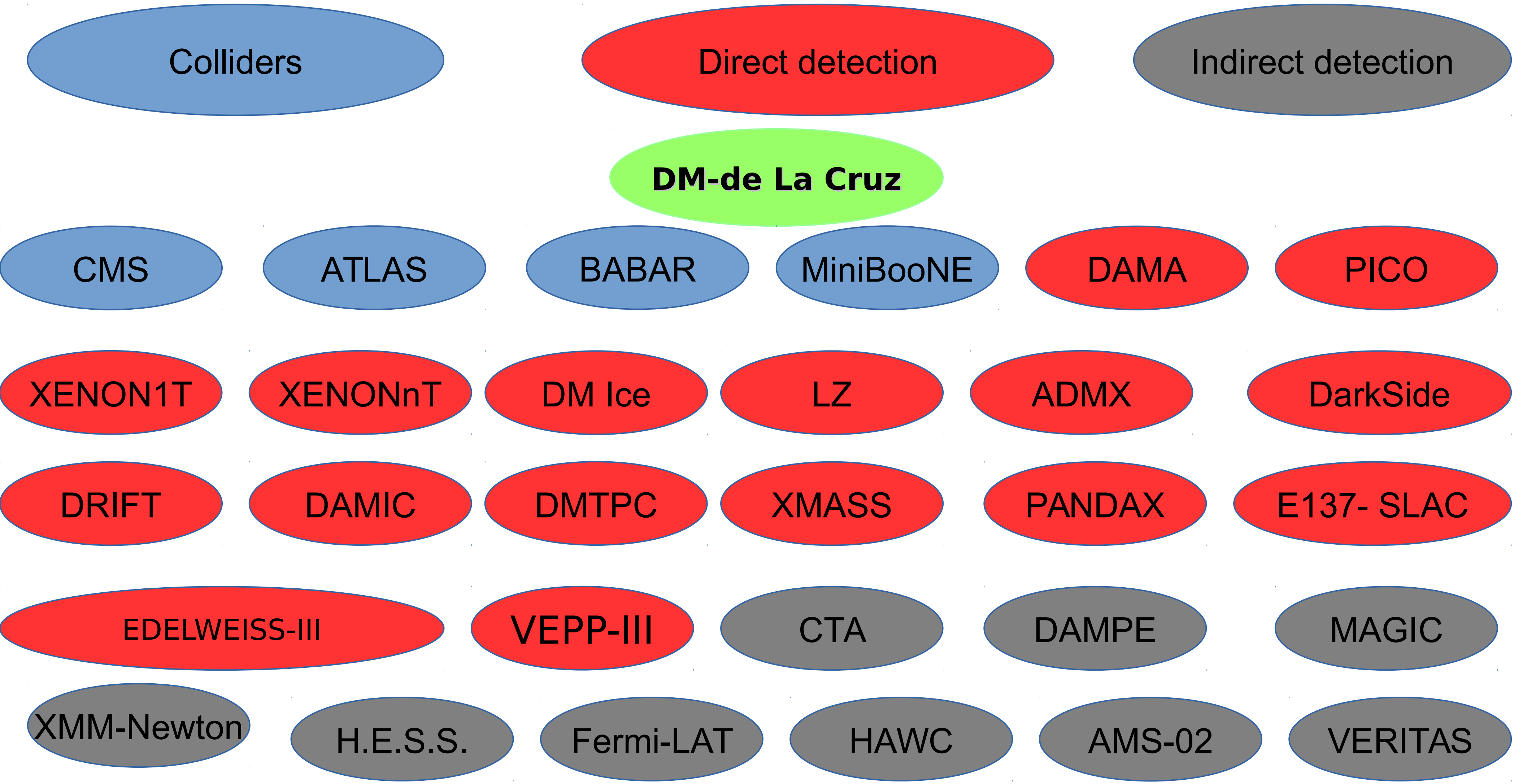


Collider

Experiments searching for Dark Matter

The nature of dark matter is one the most important open problems in science

We might be on the verge of unveiling it

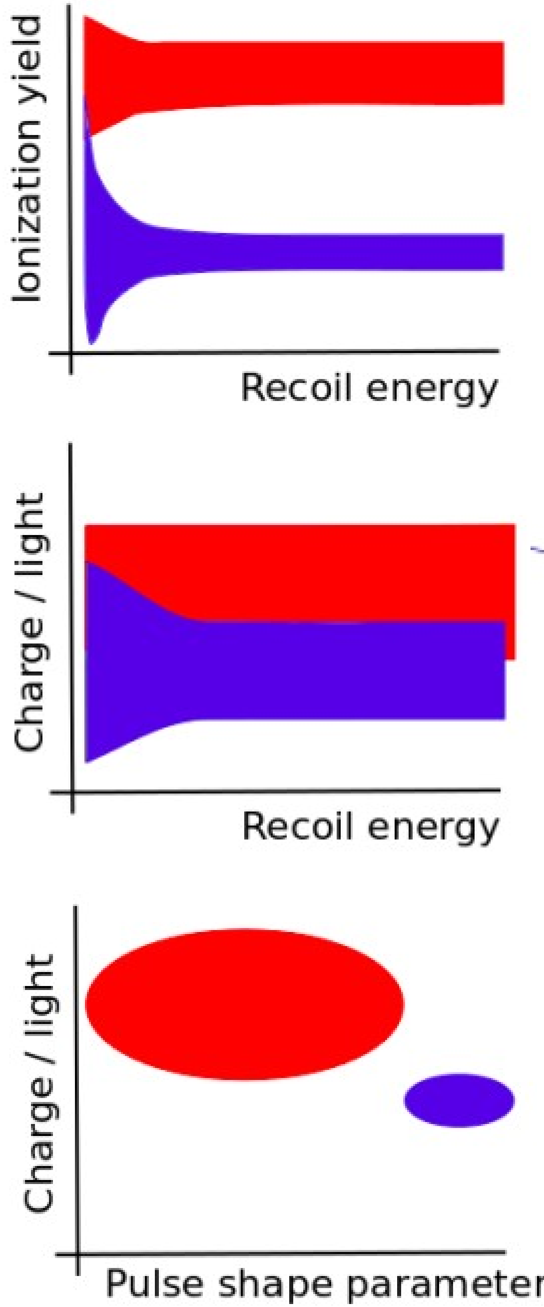


Basic Concepts

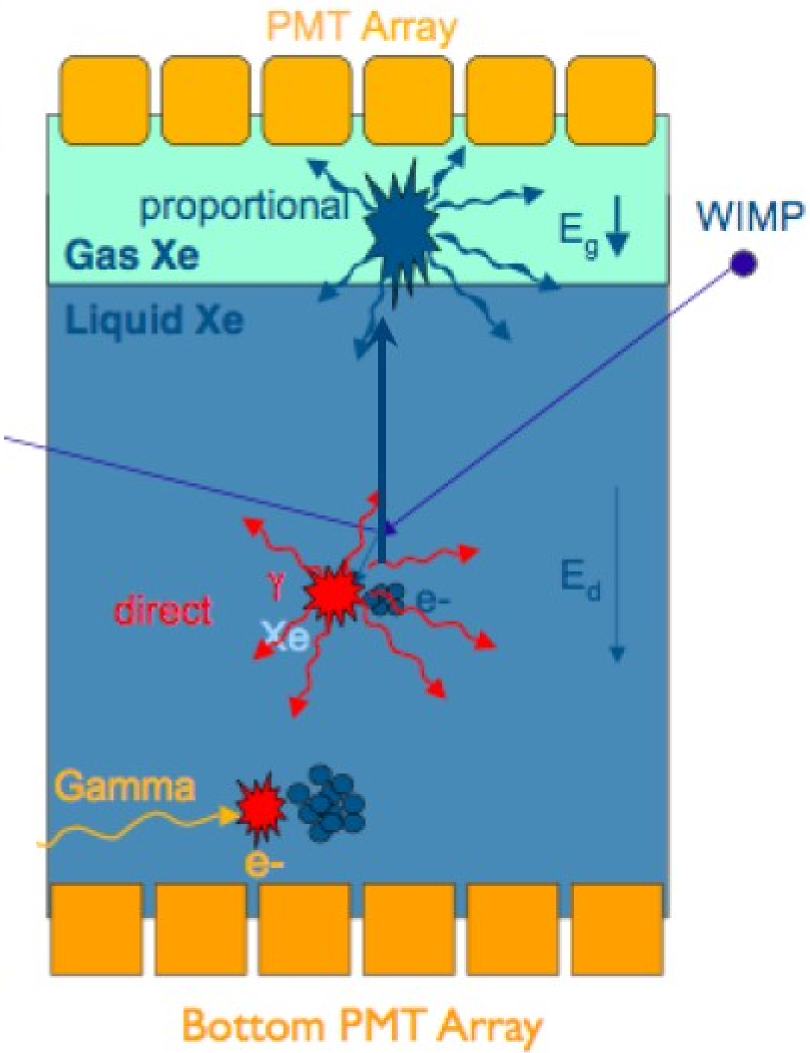
A. There is a smooth halo of dark matter particles in our galaxy described by a Maxwell Velocity distribution.

B. Due to the rotation of the Galactic Disk the solar system experiences an effective WIMP Wind, which lead to an annual Modulation due to Earth's orbital motion.

C. The nucleus is treated as a hard sphere described by the Helm form factor.



Direct Detection



$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, \mathrm{d}^3 v$$

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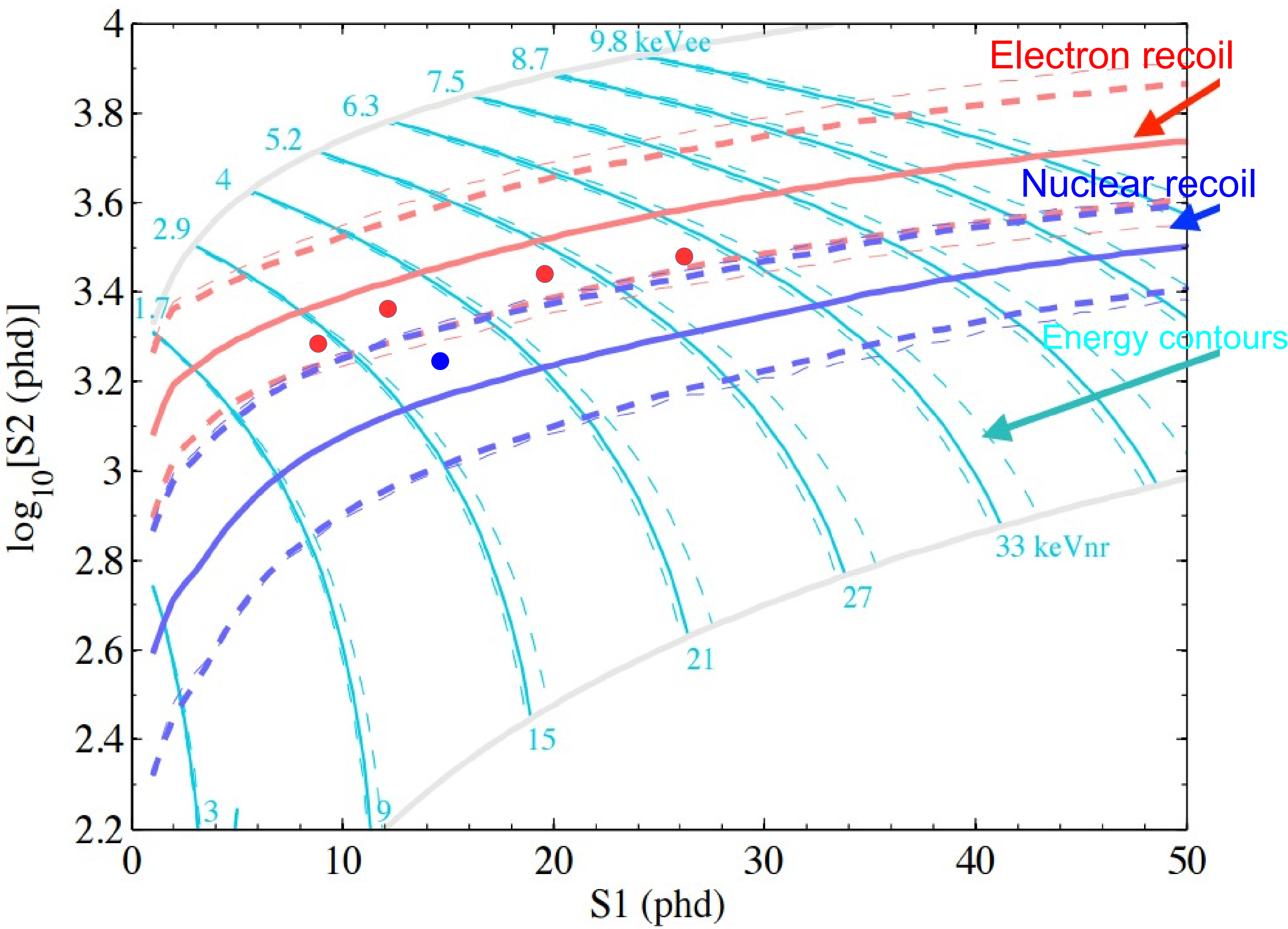

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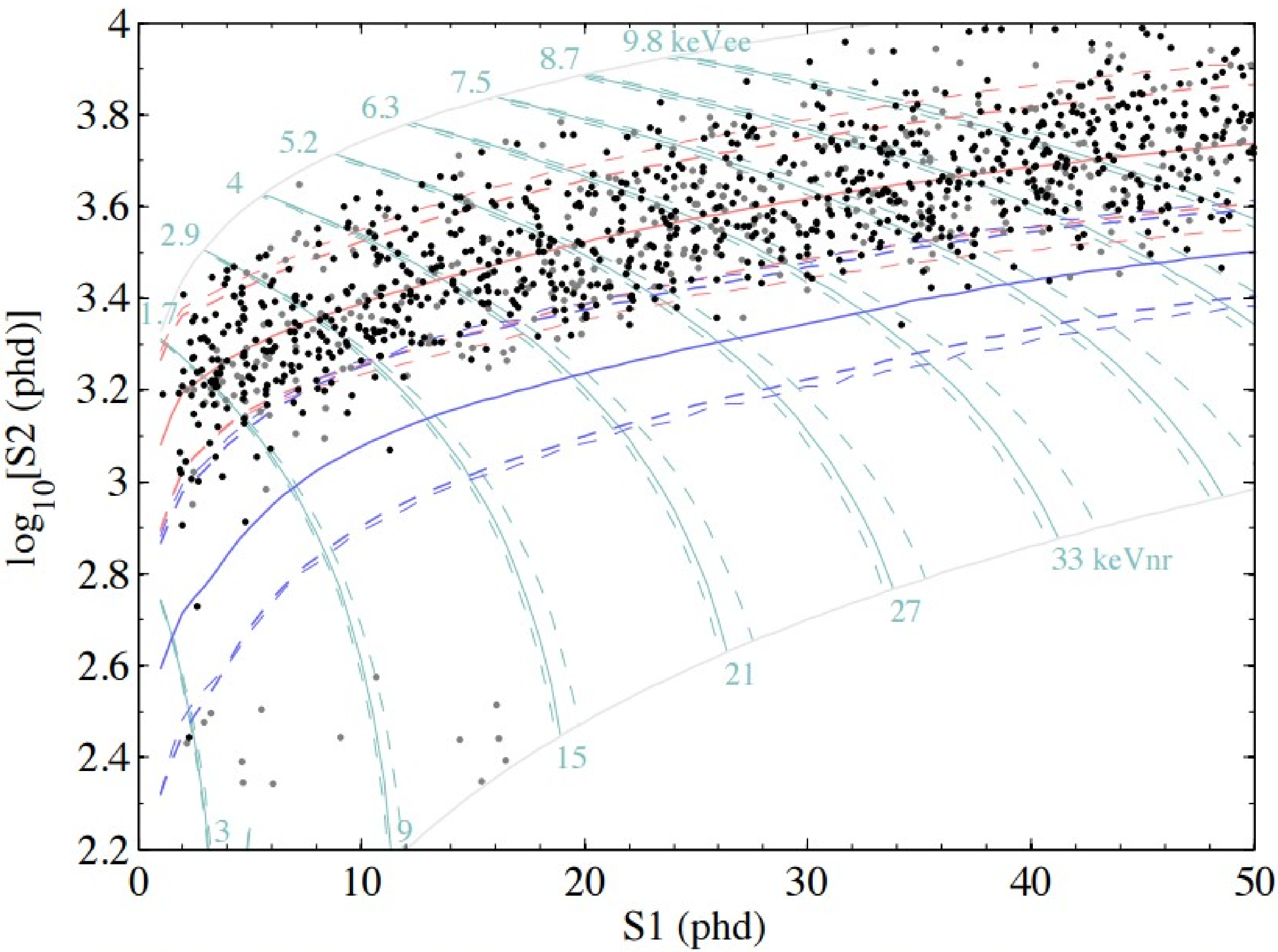

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Basic Concepts

Direct Detection

A. There is a smooth halo of dark matter particles in our galaxy described by a Maxwell Velocity distribution.

(Kelso+,1601.04725)

B. Due to the rotation of the Galactic Disk the solar system experiences an effective WIMP Wind, which lead to an annual Modulation due to Earth's orbital motion.

(Lee+,1308.1953; Del Nobile+, 1512.03961)

C. The nucleus is treated as a hard sphere described by the Helm form factor.

(Fitzpatrick+, 1308.6288/1405.6690)

Martin's talk

Differential scattering rate — Velocity distribution — Differential cross section

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, \mathrm{d}^3 v$$

Spin-Independent

$$\sigma_0^{\rm SI} = \sigma_p \cdot \frac{\mu_A^2}{\mu_p^2} \cdot [Z \cdot f^p + (A-Z) \cdot f^n]^2 \xrightarrow{f^p = f^n} A^2$$

Spin-dependent

$$\sigma_0^{\rm SD} = \frac{32}{\pi} \mu_A^2 \cdot G_F^2 \cdot [a_p \cdot \langle S^p \rangle + a_n \cdot \langle S^n \rangle]^2 \cdot \frac{J+1}{J}$$

Basic Concepts

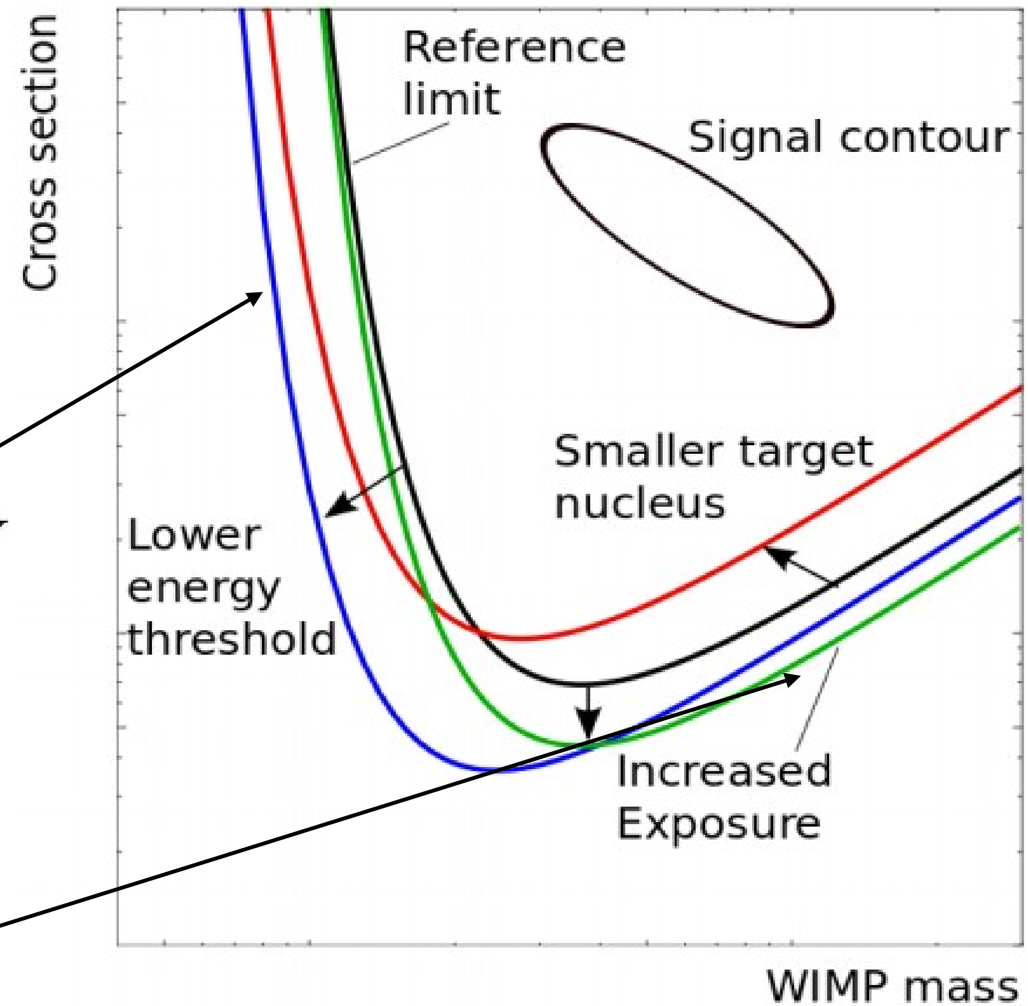
Direct Detection

Recoil Energy

$$E_r \propto \left(\frac{M_{DM} M_N}{M_{DM} + M_N}\right)^2 \frac{1}{M_N}$$

10 GeV WIMP:
- $M_N = 10 GeV \longrightarrow E_r = 5 KeV$
- $M_N = 100 GeV \longrightarrow E_r = 1.6 KeV$

Why do the limits look the way they do?



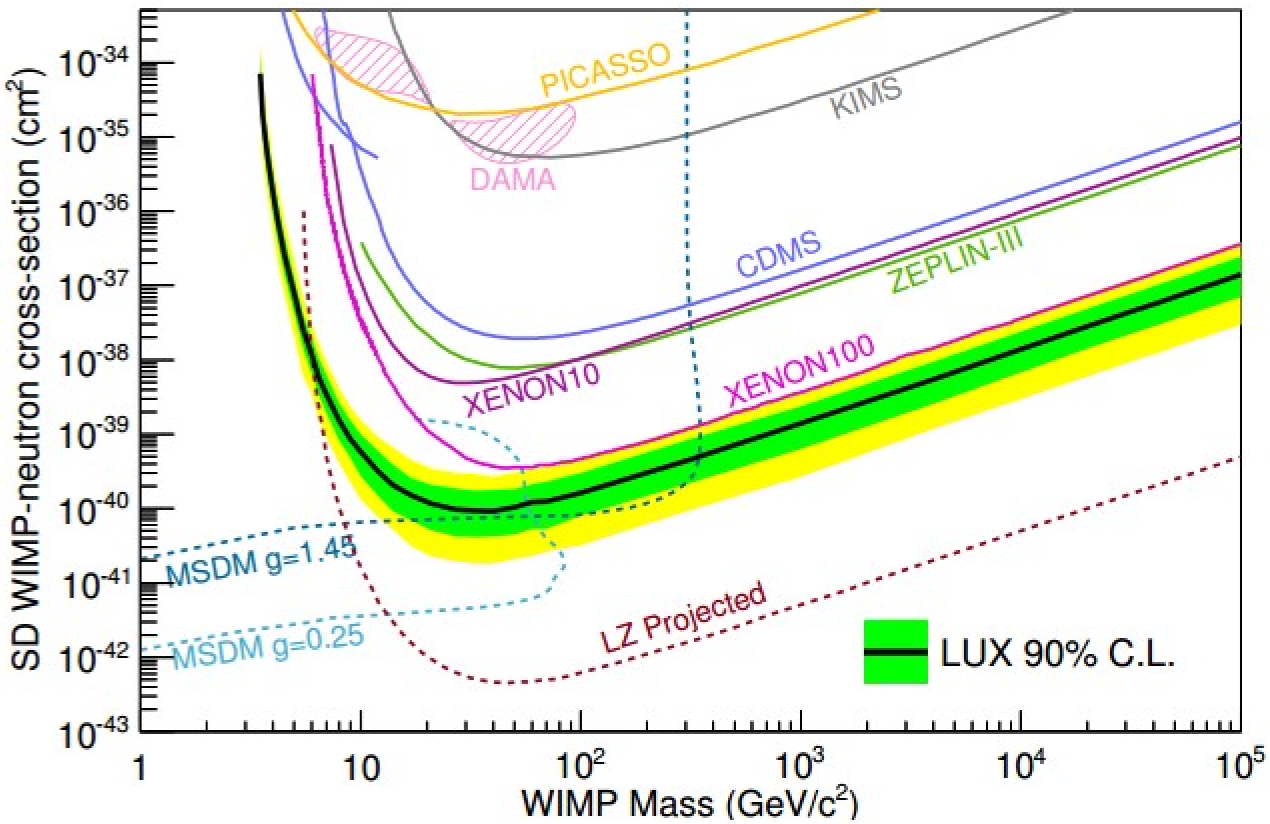
Undagoitia&Rauch 1509.08767

WIMPs number density

$$\rho_\odot = 0.3\, GeV/cm^3 = n_{DM} m_{DM}$$

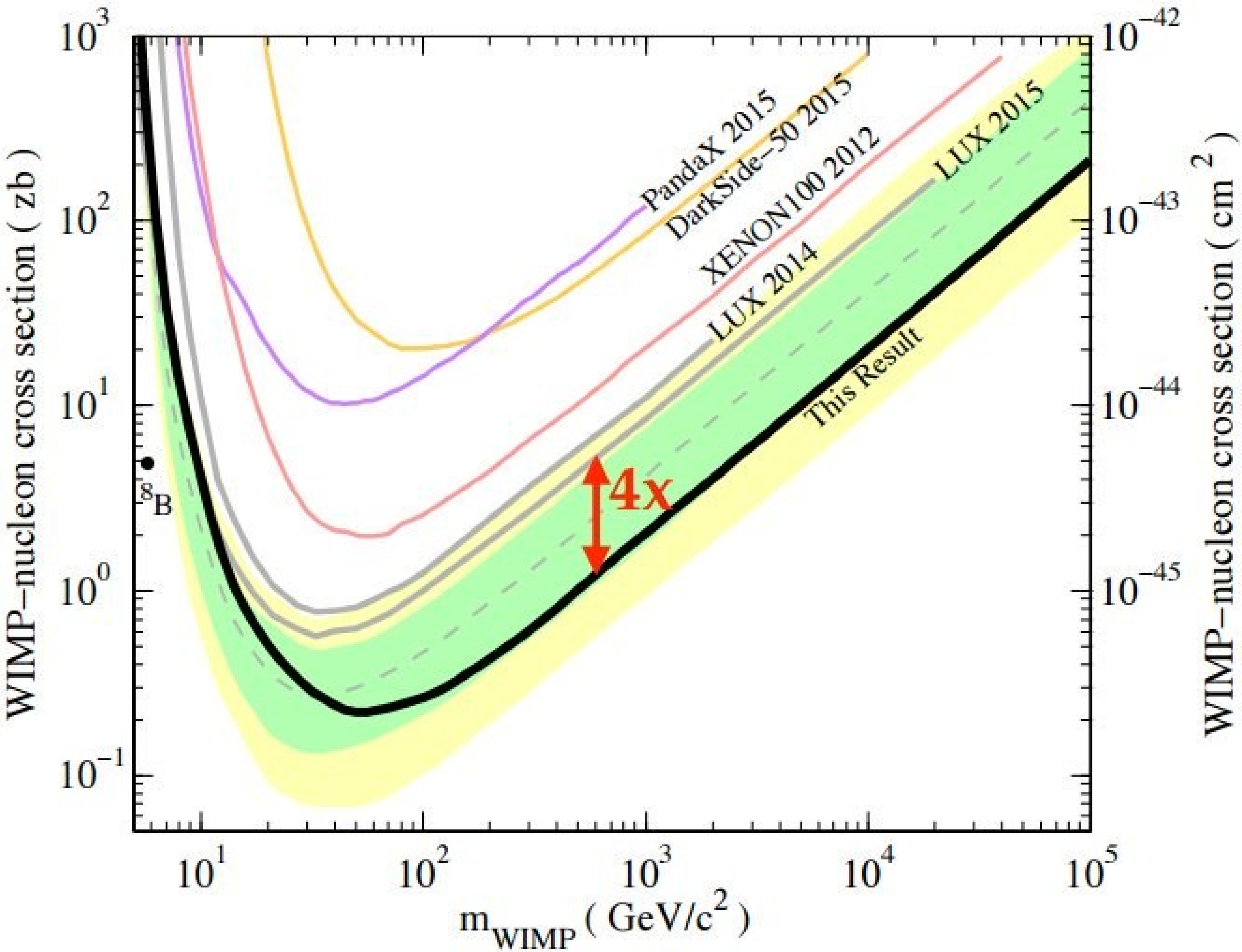
See talks by

LUX collaboration: Spin-Independent Scattering



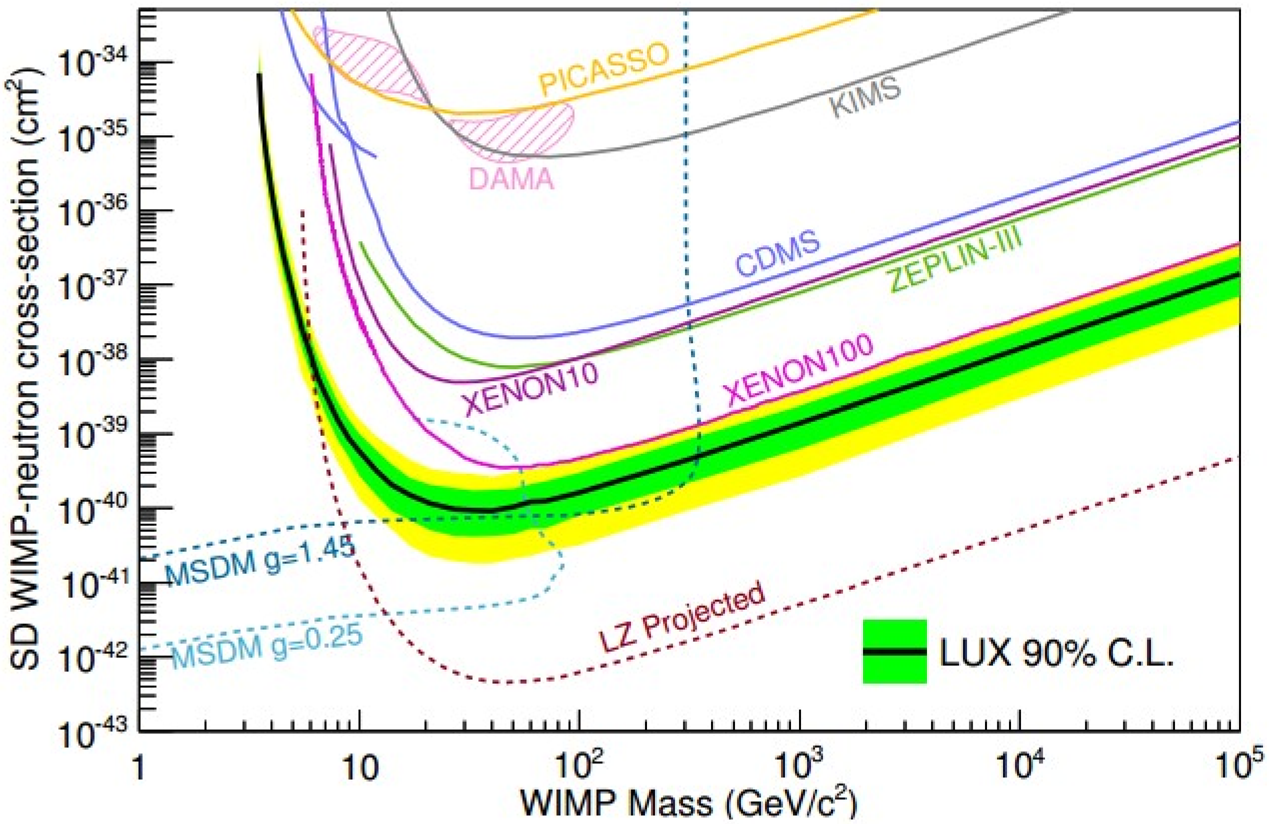
PRL 2016

LUX collaboration: Spin-Independent Scattering



IDM conference in UK – July 21, 2016

LUX collaboration: Spin-Dependent Scattering



PRL 2016

Collider Searches

Basic Concepts

A. Dark matter is cosmologically stable, therefore is "seen" as missing energy at colliders, mono-X searches.

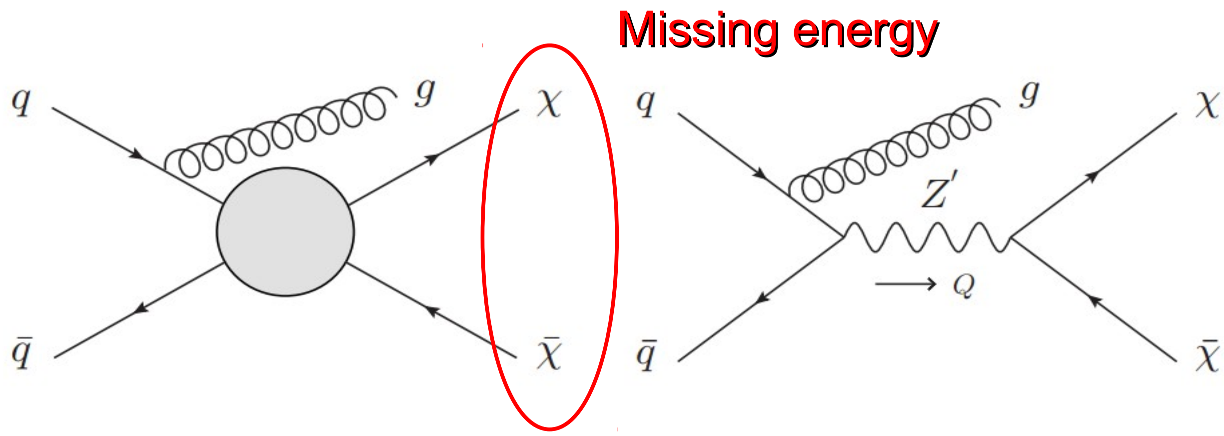
B. The observation relies on the detection of the accompanying particles/jets

C. Effective theory typically assumed. Use it wisely.

For a scan over several simplified dark matter models see:

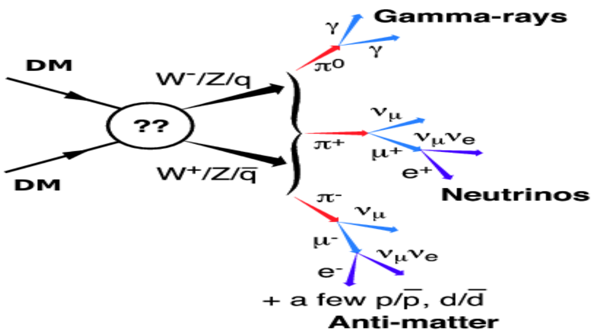
The ATLAS/CMS Dark Matter Forum, 1507.00966

Note:New resonance searches provide Stringent limits on new gauge bosons -often used as mediators between the dark and visible sectors.



Queiroz, *1605.08788*

Indirect Dark Matter Detection

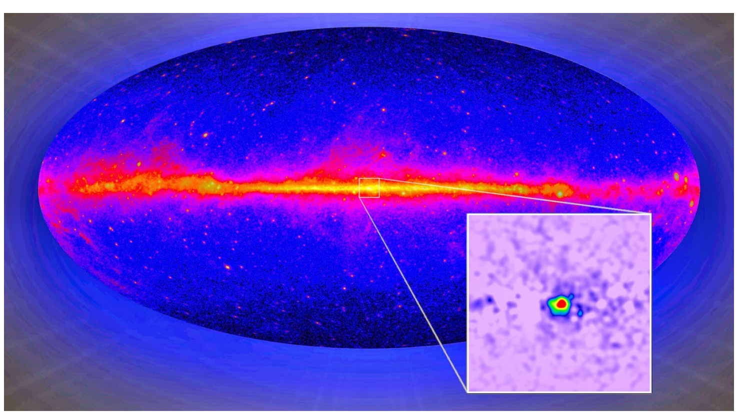


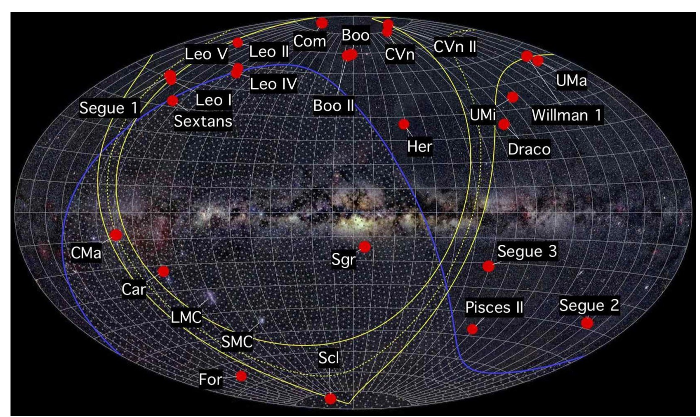
Dark Matter Indirect Detection

Dark Matter Signal = **Dark matter density** × **Particle Physics Input**

High density → **Galactic Center**

High density → **Dwarf Spheroidal Galaxies**





What's new?

Dark Matter Annihilation:Gamma-ray Excess at the Galactic Center

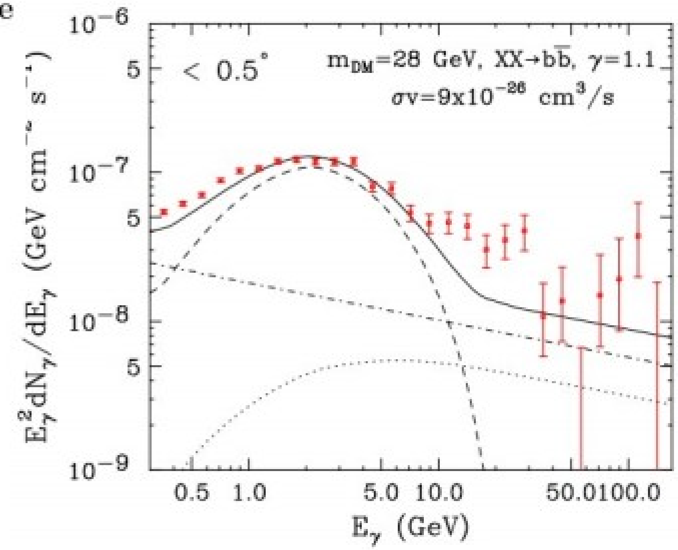
First observation (2009)

Possible Evidence For Dark Matter Annihilation In The Inner Milky Way From The Fermi Gamma Ray Space Telescope

Lisa Goodenough[1] and Dan Hooper[2,3]

[1] *Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003*
[2] *Center for Particle Astrophysics, Fermi National Accelerator Laboratory, Batavia, IL 60510*
[3] *Department of Astronomy and Astrophysics, University of Chicago, Chicago, IL 60637*

We study the gamma rays observed by the Fermi Gamma Ray Space Telescope from the direction of the Galactic Center and find that their angular distribution and energy spectrum are well described by a dark matter annihilation scenario. In particular, we find a good fit to the data for dark matter particles with a 25-30 GeV mass, an annihilation cross section of $\sim 9 \times 10^{-26}$ cm^3/s, and that are distributed with a cusped halo profile, $\rho(r) \propto r^{-1.1}$, within the inner kiloparsec of the Galaxy. We cannot, however, exclude the possibility that these photons originate from an astro-



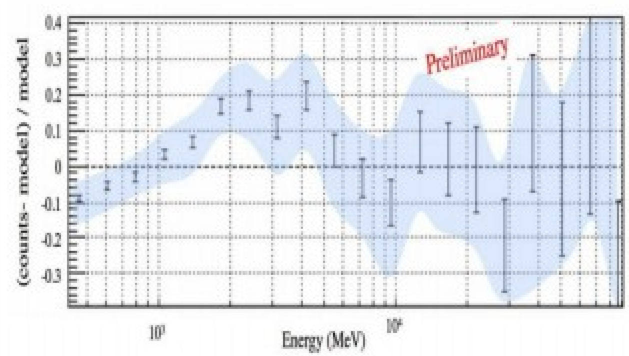
First Fermi-LAT team members – report (2009)

2009 Fermi Symposium, Washington, D.C., Nov. 2-5

Indirect Search for Dark Matter from the center of the Milky Way with the Fermi-Large Area Telescope

Vincenzo Vitale and Aldo Morselli, for the Fermi/LAT Collaboration
Istituto Nazionale di Fisica Nucleare, Sez. Roma Tor Vergata, Roma, Italy

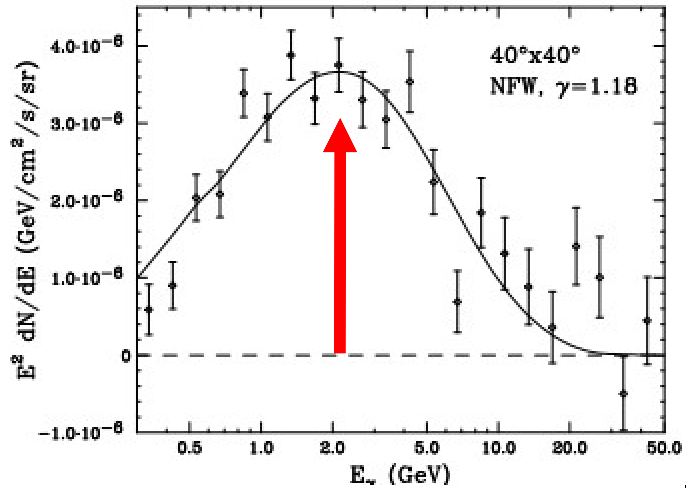
today, can account for the large majority of the detected gamma-ray emission from the Galactic Center. Nevertheless a residual emission is left, not accounted for by the above models.
An improved model of the Galactic diffuse emission and a careful evaluation of new (possibly unresolved) sources (or source populations) will improve the sensitivity for a DM search.



Peak at ~ 2 GeV

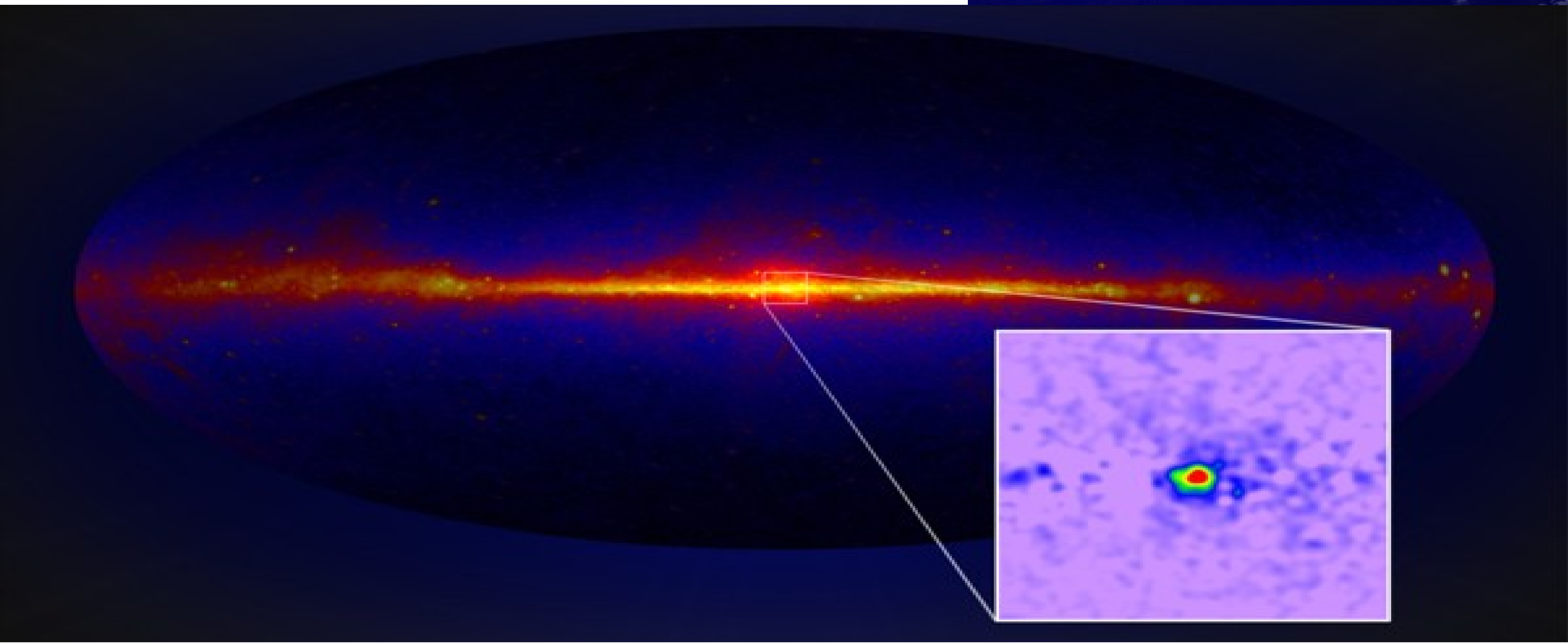
Confirmed by Fermi-LAT Collaboration!

Consistent with WIMPs annihilations: 10-50 GeV

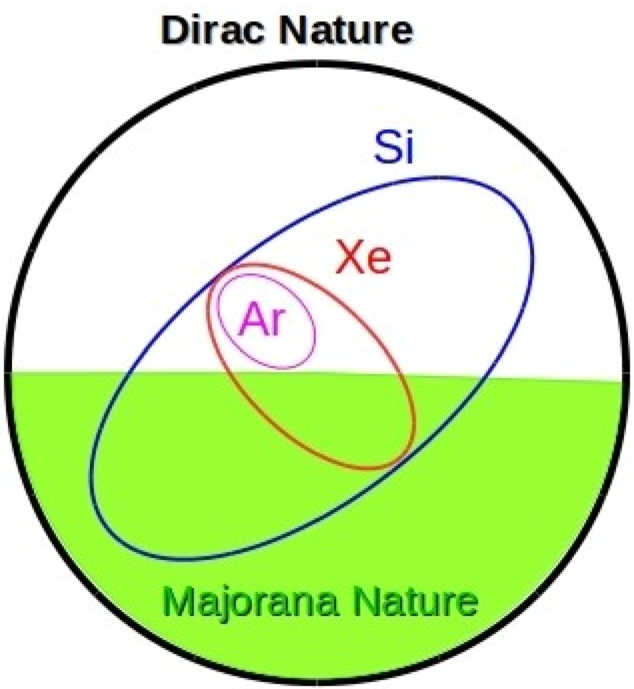


L. Goodenough, D. Hooper, arxiv:0910.2998

Fermi-LAT Collab. Astrophys.J. 819 (2016)



So what's the nature of dark matter?



Queiroz,Rodejohann,Yaguna 2016

50% accuracy

One needs to measure the scattering cross section at 50% level to able to determine the nature of dark matter

Good control over hadronic corrections

Conclusion

Nature of dark matter $\rightarrow$ hadronic corrections under control!

In order to determine the nature of dark matter we need to reach an accuracy of 50% on the scattering cross section, i.e. hadronic corrections under control!