Dark Matter Review

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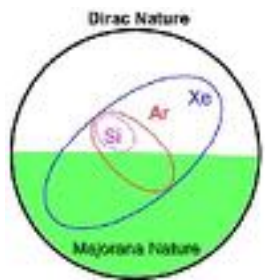
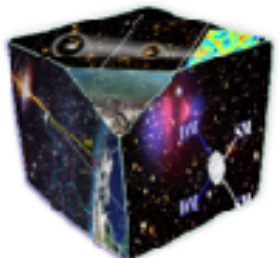
&
ICTP-SAIFR Fellow



Dec 3, 2018



Darkwin: Dark Matter and Weak Interactions - September 2-13, 2019

dark matter, neutrino physics, model building, flavor violation etc...

INTERNATIONAL INSTITUTE OF PHYSICS

Federal University of the Rio Grande do Norte

Dark Universe - October 21-25, 2019

dark matter, inflation, leptogenesis, baryogenesis, neutron stars, phase transition

ICTP SAIFR

International Centre for Theoretical Physics South American Institute for Fundamental Research

Darkwin: Dark Matter and Weak Interactions - September 2-13, 2019

dark matter, neutrino physics, model building, flavor violation etc...

Dark Universe - October 21-25, 2019

dark matter, inflation, leptogenesis, baryogenesis, neutron stars, phase transition

Take Home Messages

1. Dark matter research is a multidisciplinary endeavor

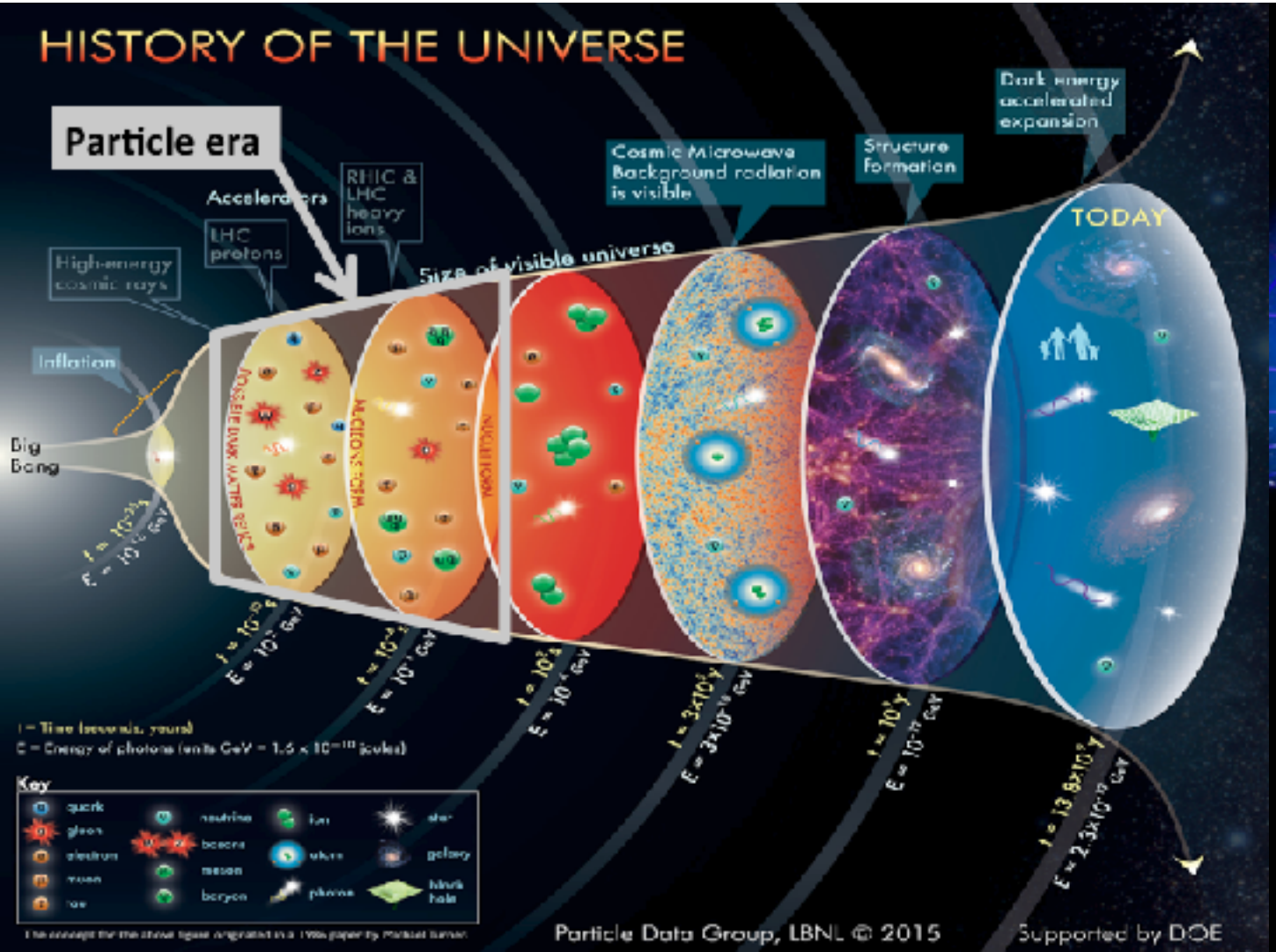
2. We might be on the verge of unveiling its nature

Spin 0
Mass 300 GeV
CP even

Dark Matter is key to the evolution of our universe

Temperature ~ $\frac{1}{\text{size}}$ Early Universe ⟷ Hot Universe

Something had to decouple early enough and start forming clumps of matter that evolved with time and formed galaxies



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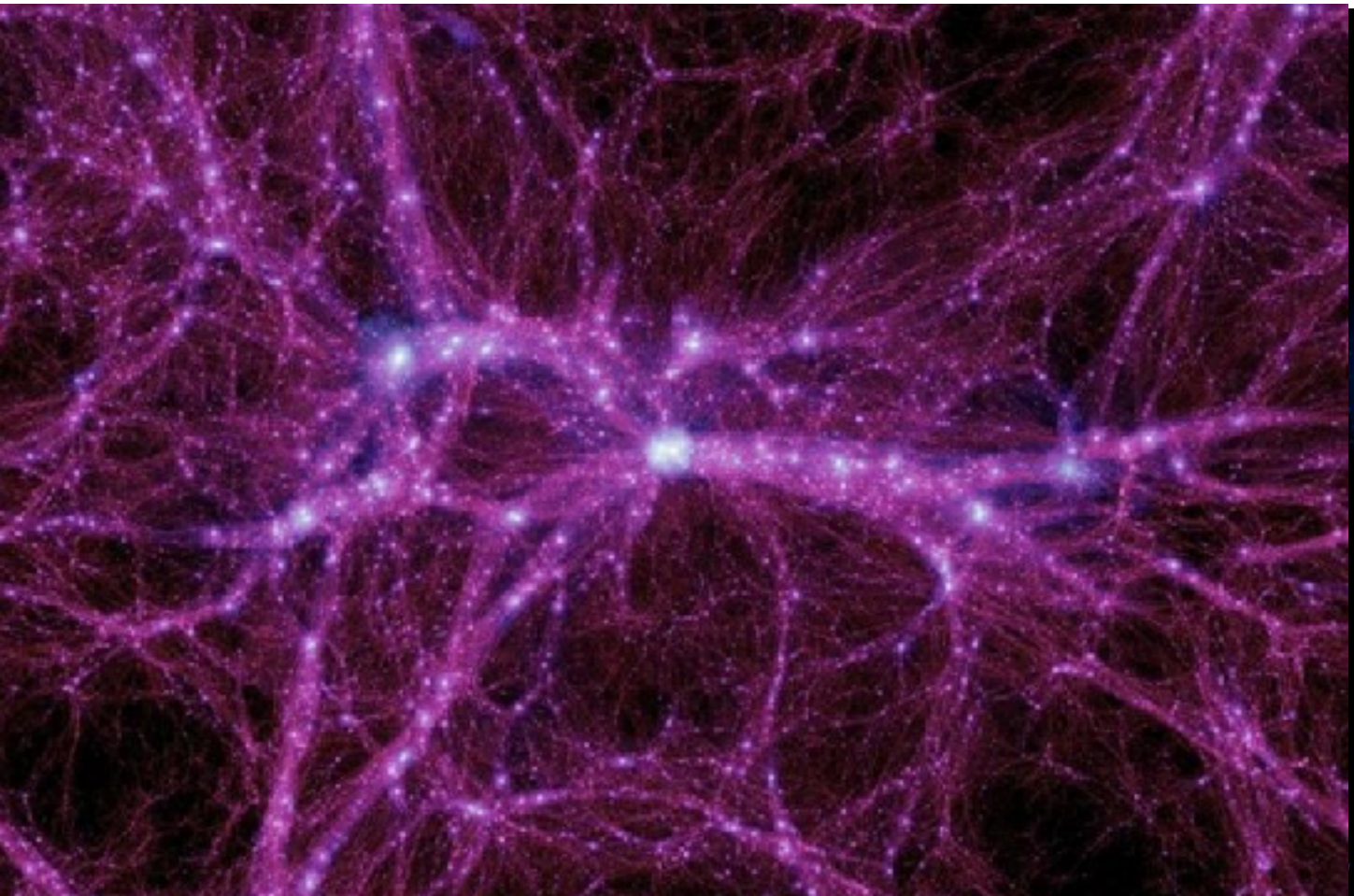


Dark Matter in Galaxies

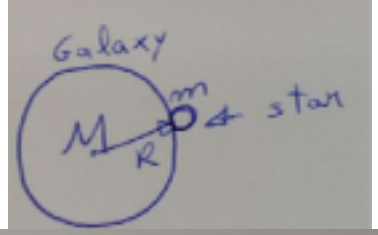
Galaxy Rotation Curves

From then on the dark matter search took off

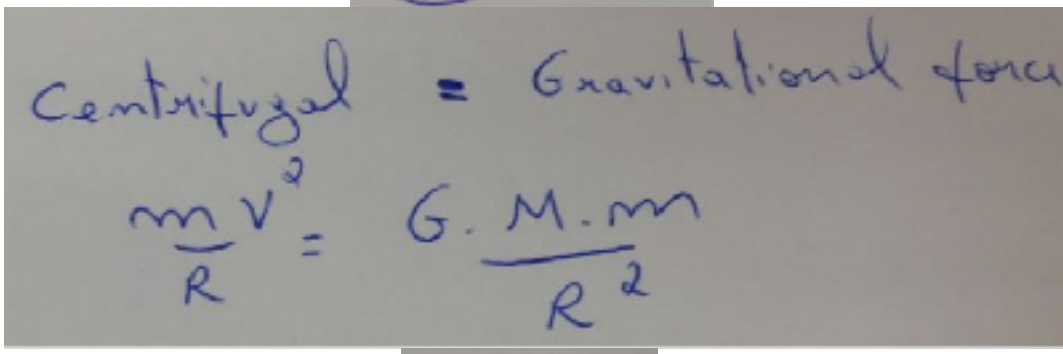
In 1970s Vera Rubin+, established the existence of dark matter in galaxies by studying galaxy rotation curves

We know that!

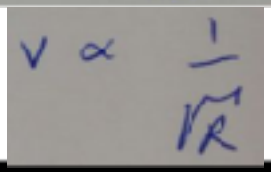
Step 1

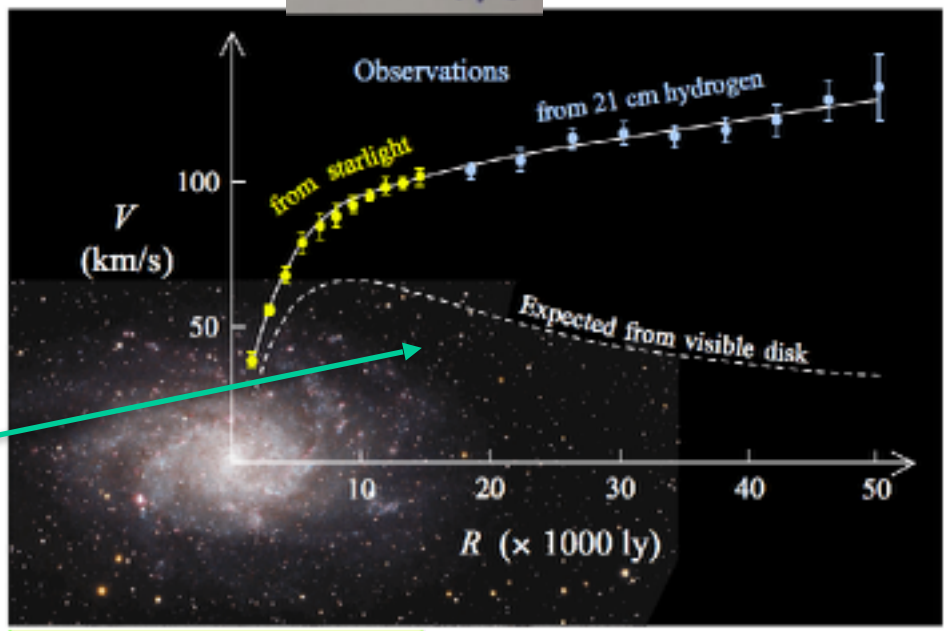


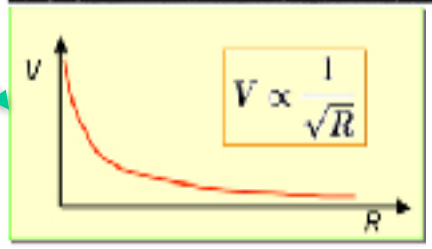
Step 2



Step 3

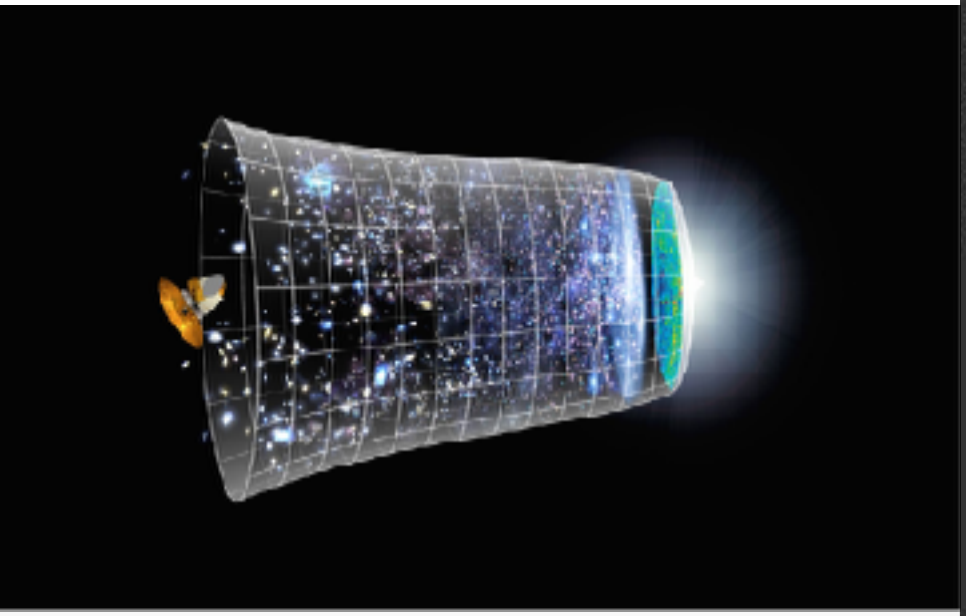






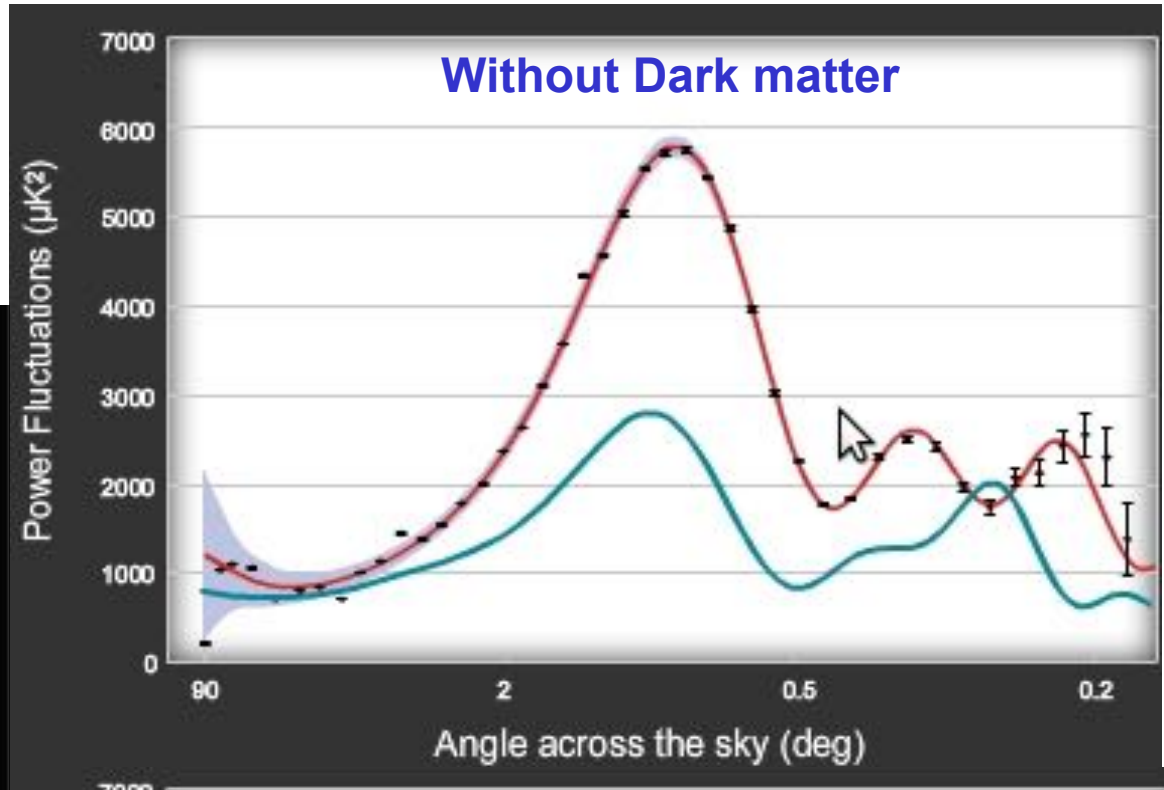
Dark Matter in the CMB

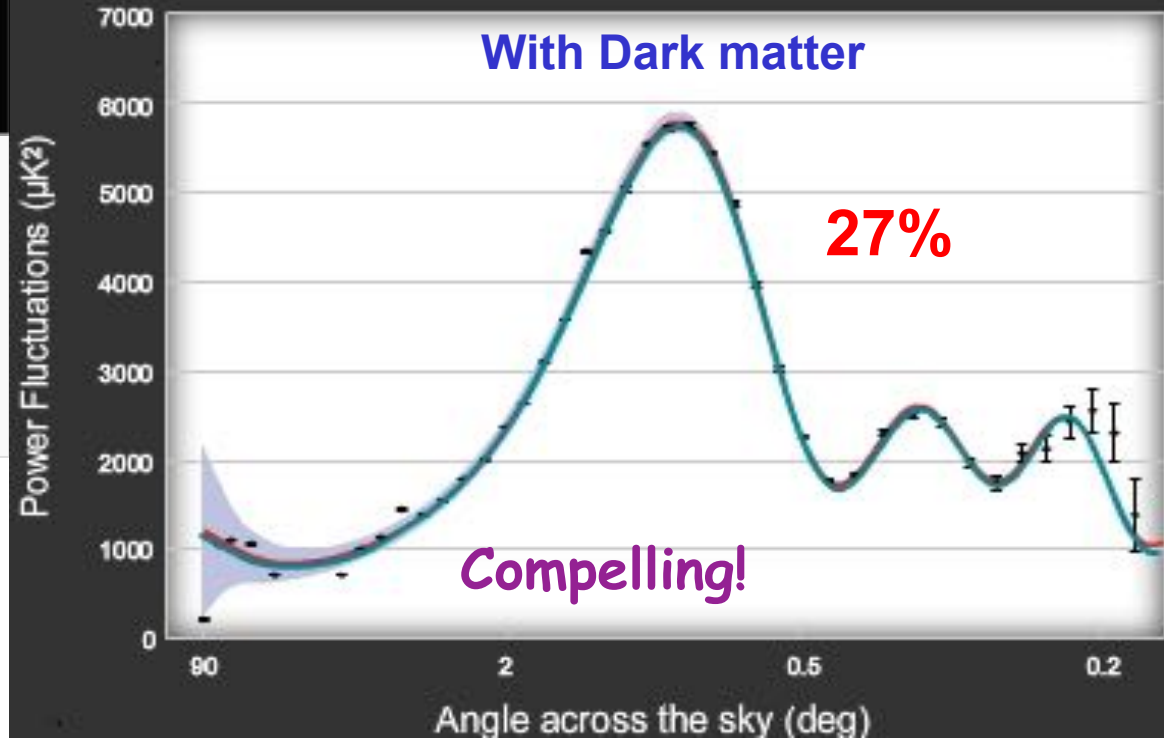
CMB



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

https://wmap.gsfc.nasa.gov/resources/camb_tool/index.html

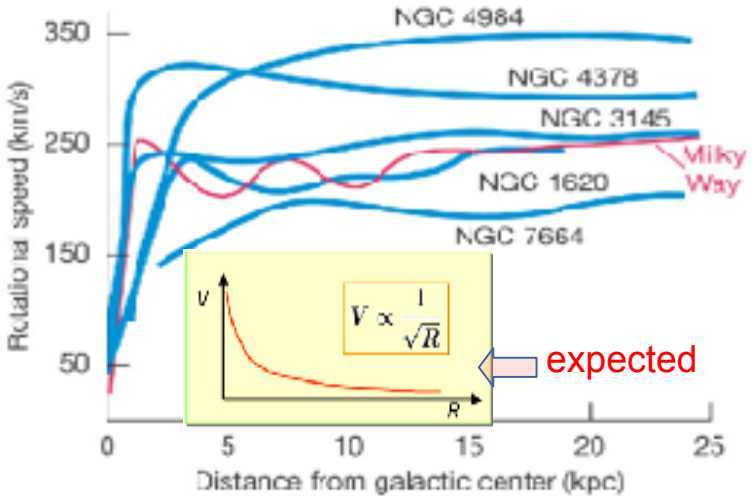




Thus, the need for Dark Matter

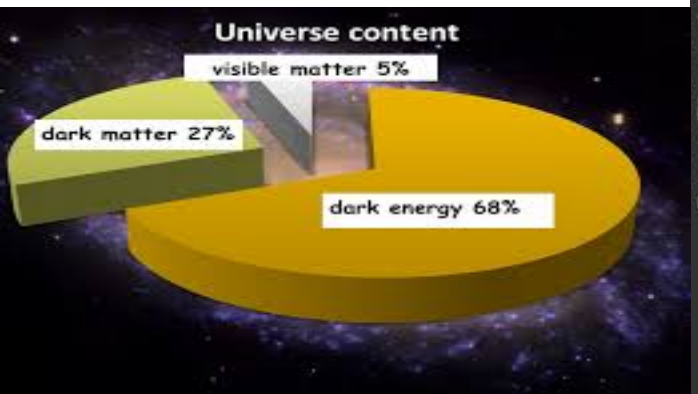
In 1933 Fritz Zwick used the virial theorem to infer the existence of unseen matter in the Coma galaxy cluster

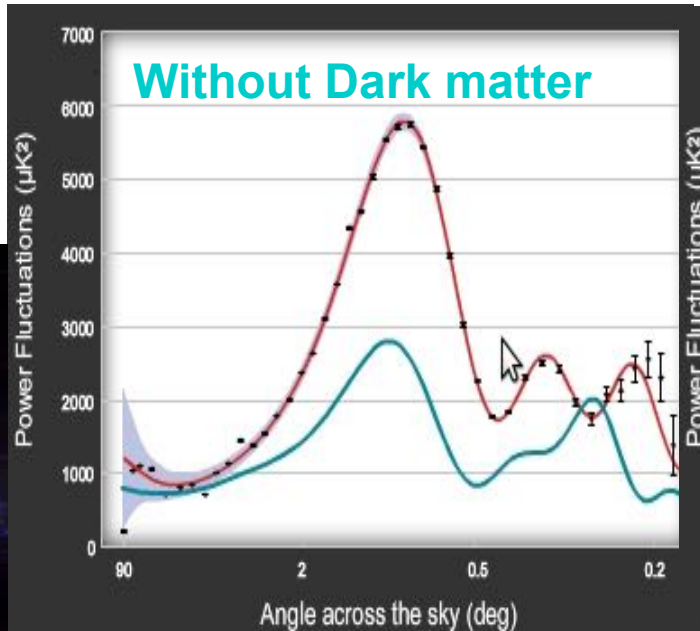
In 1970s Vera Rubin+, established the existence of dark matter in galaxies by studying galaxy rotation curves

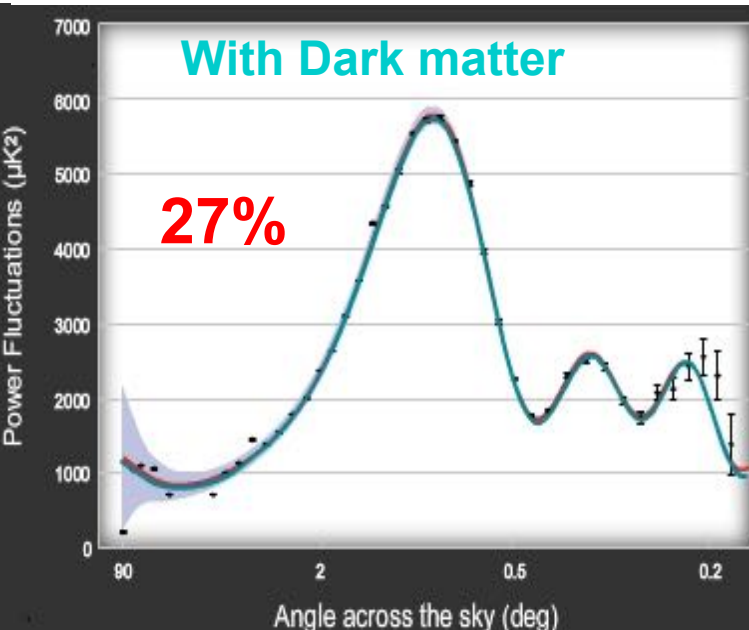


In 2003 the observation of the bullet cluster by Maxim Markevitch+

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



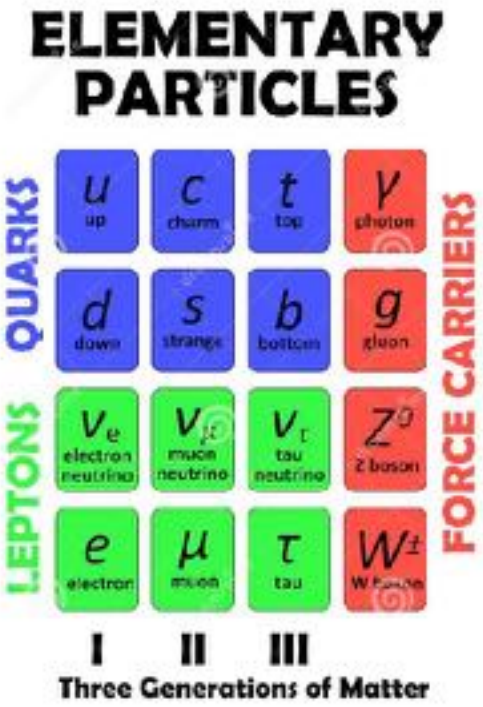




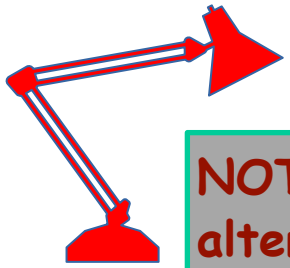
Dark Matter as a particle

Everything around us is ruled by fundamental laws of nature

Laws of nature as described in terms of elementary particles



Hence, it is plausible to assume that dark matter can also be described by elementary particles

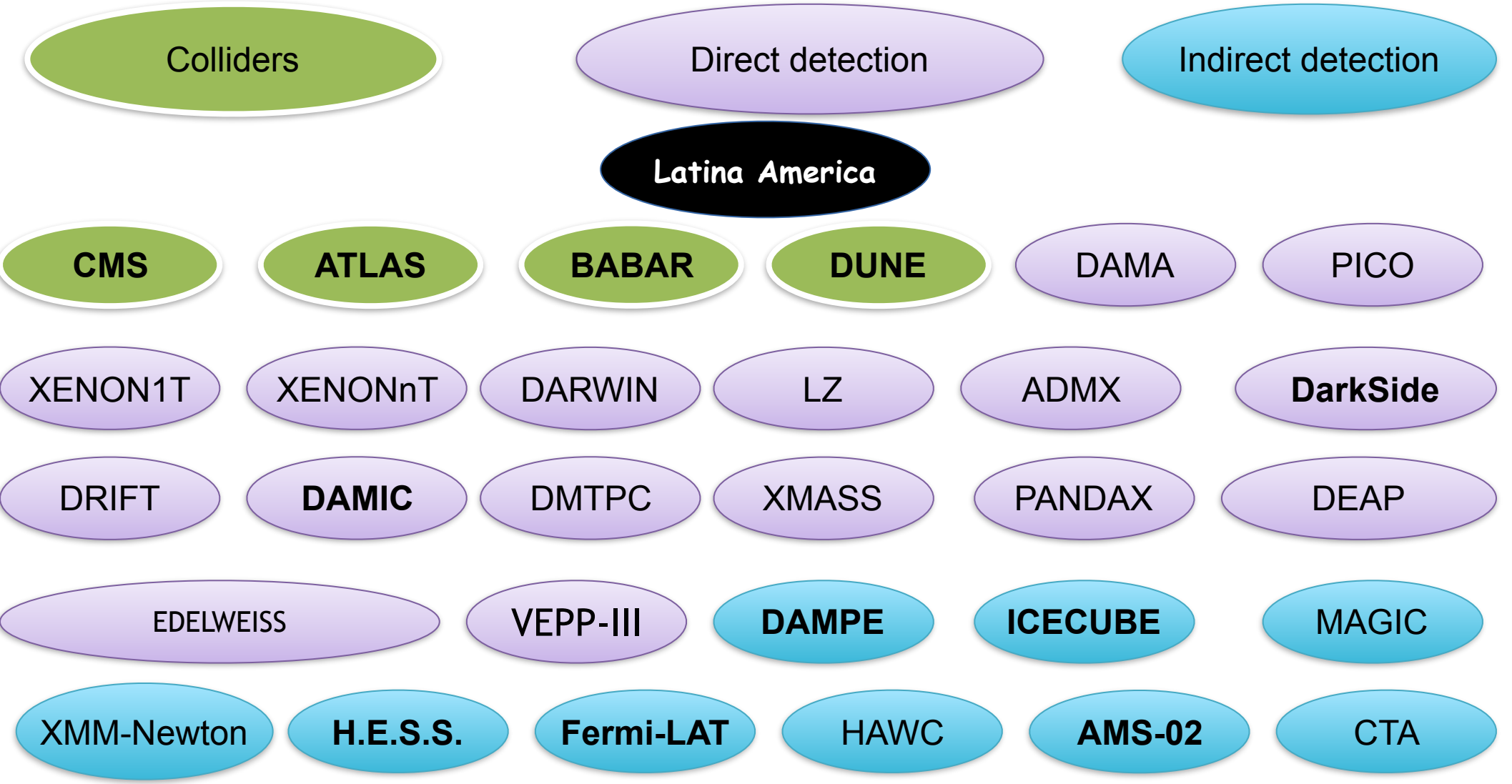


NOTE: Almost every single alternative explanation for dark matter has failed

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



How do we search for dark matter particles?

Collider

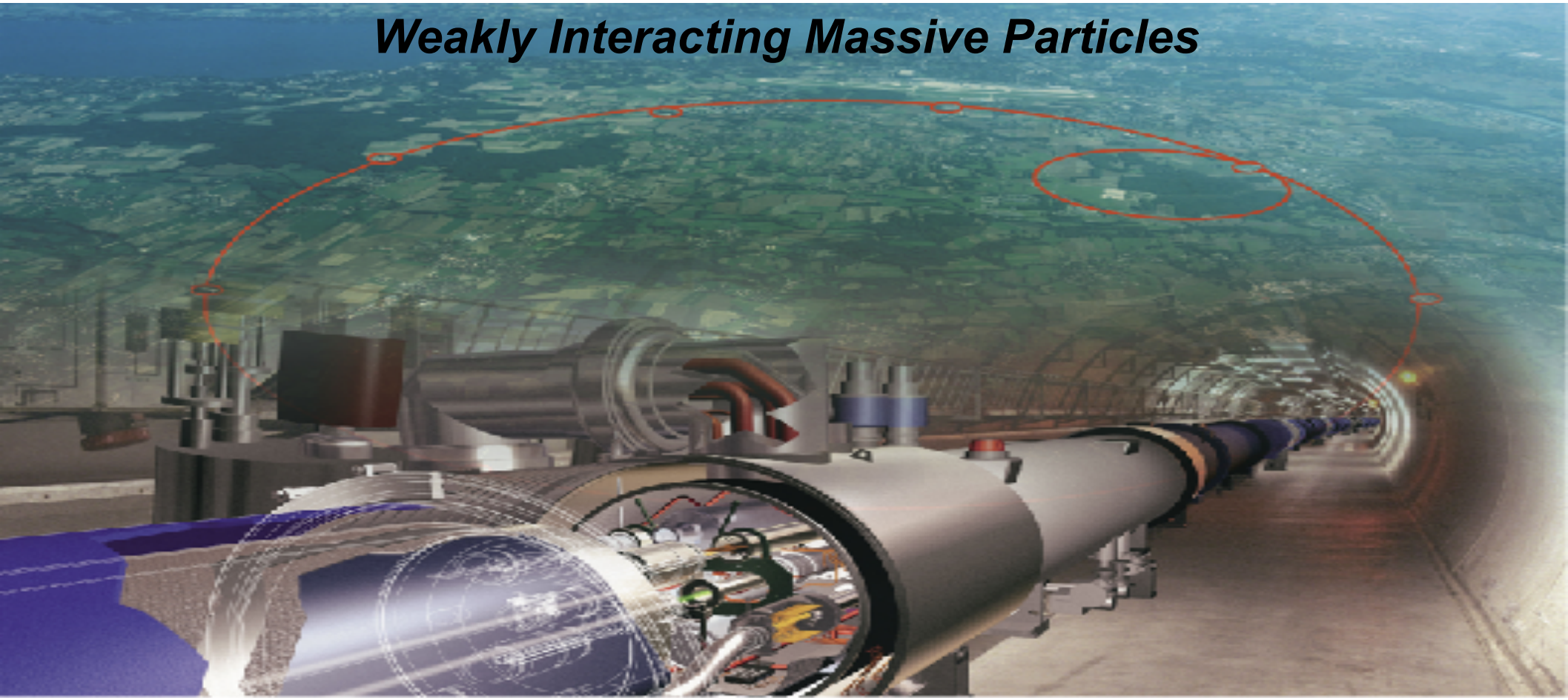
Weakly Interacting Massive Particles

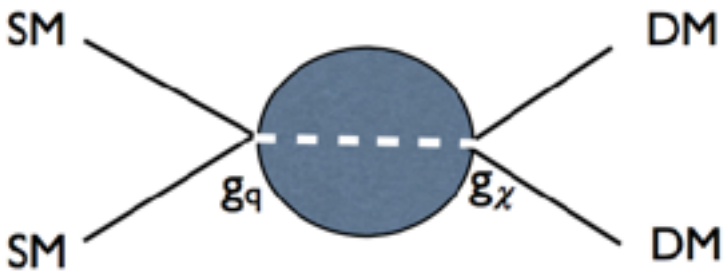
X

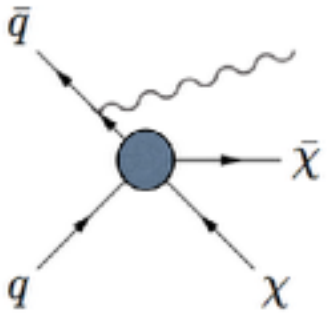
X

How do we search for dark matter particles?

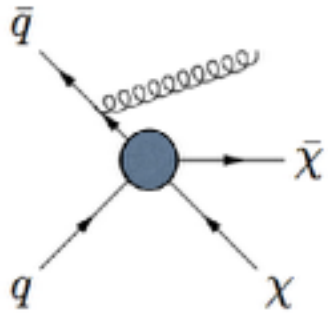
Collider







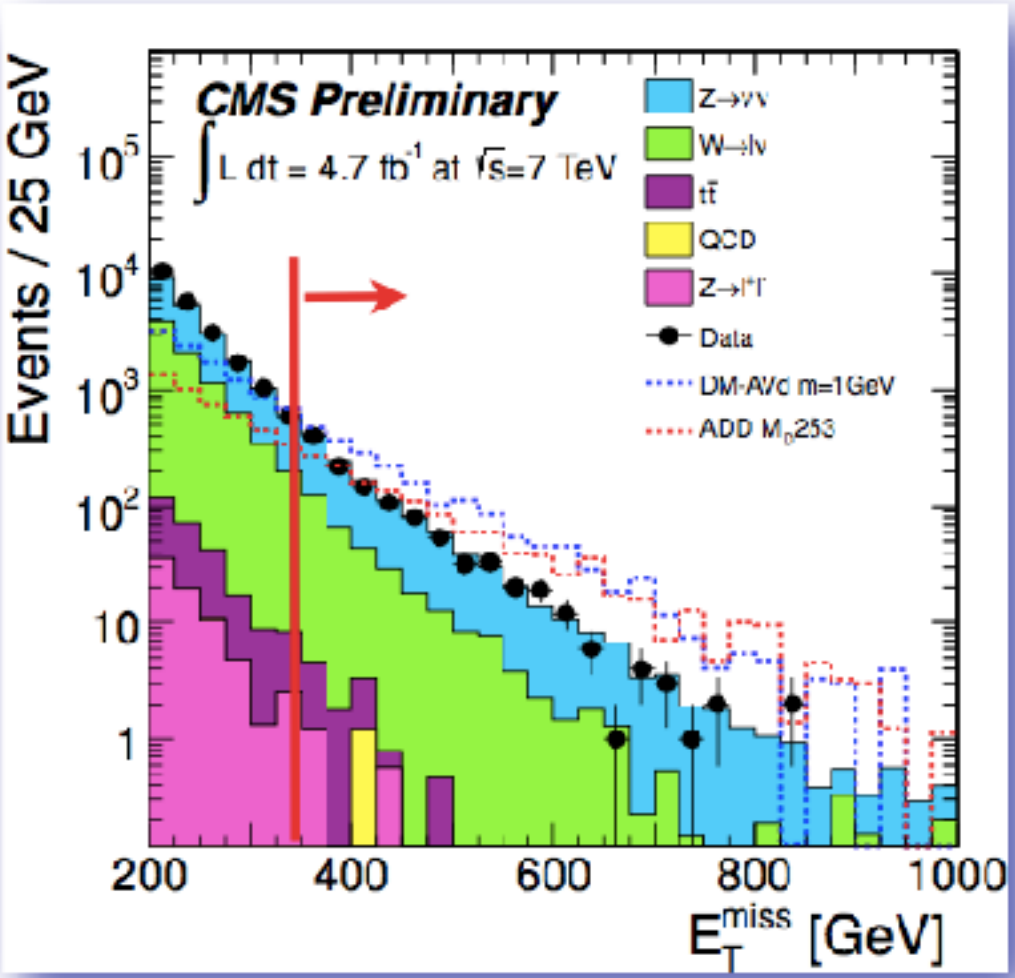
monophoton +MET

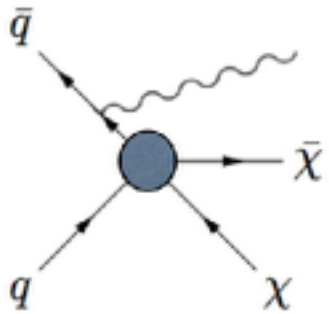


monojet +MET

How do we search for dark matter particles?

Collider





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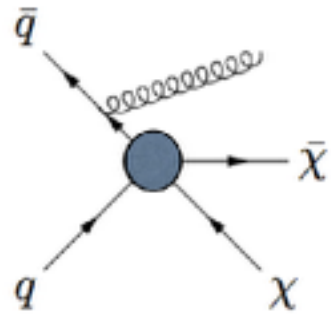
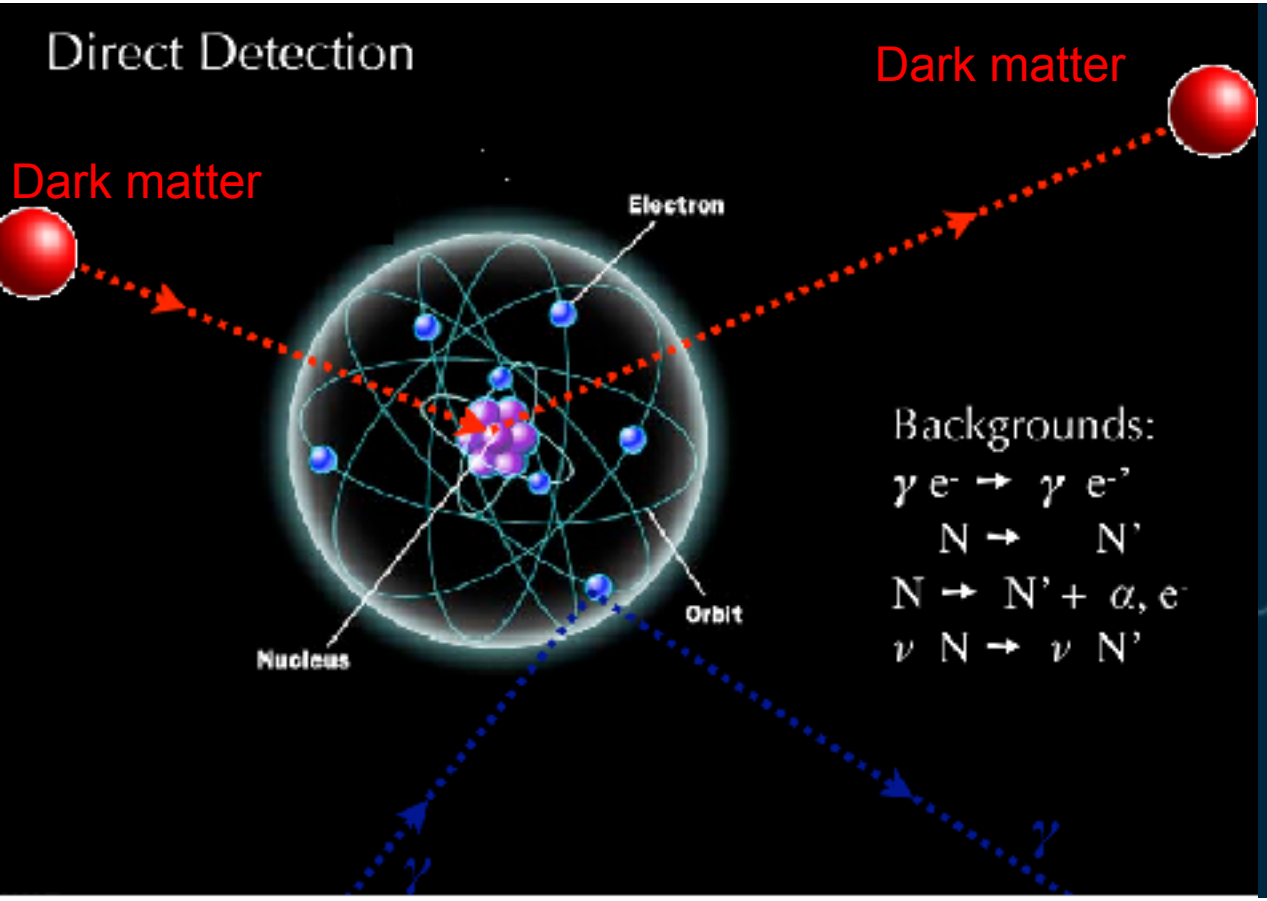
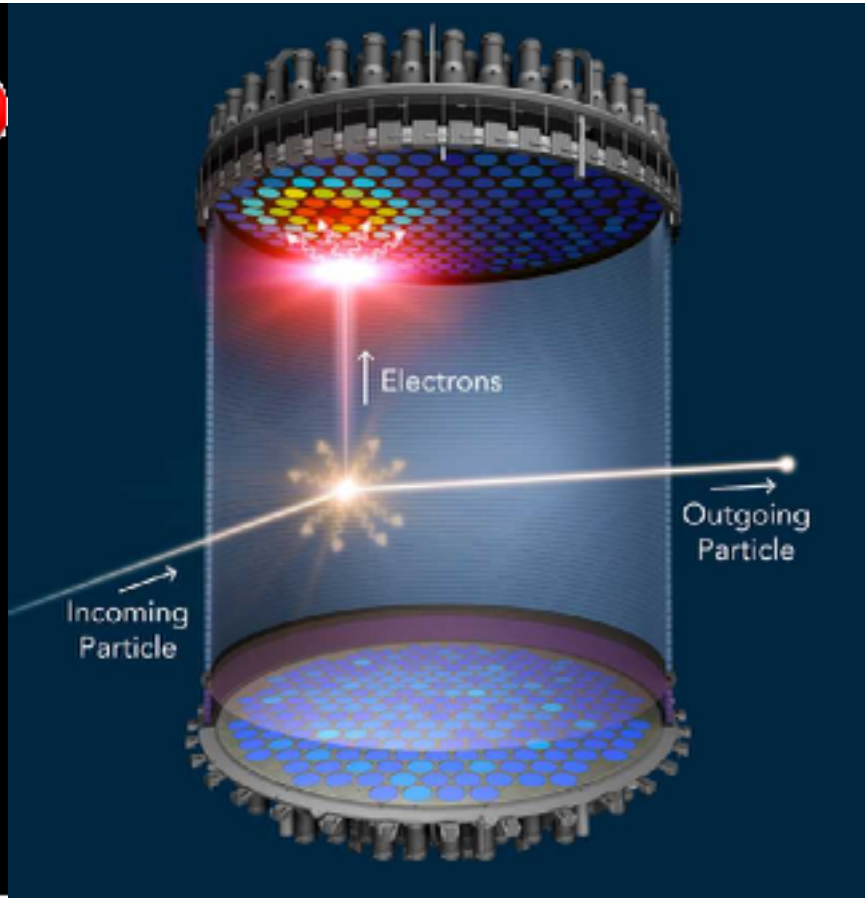


monojet +MET

How do we search for dark matter particles?

Direct Detection

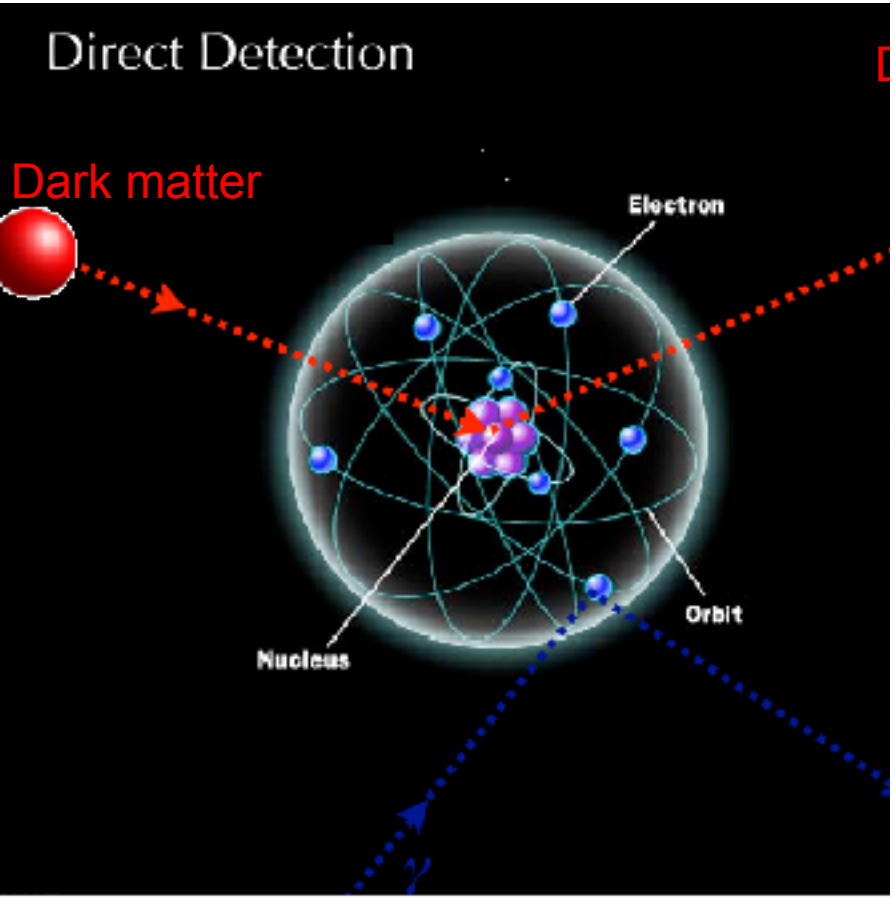


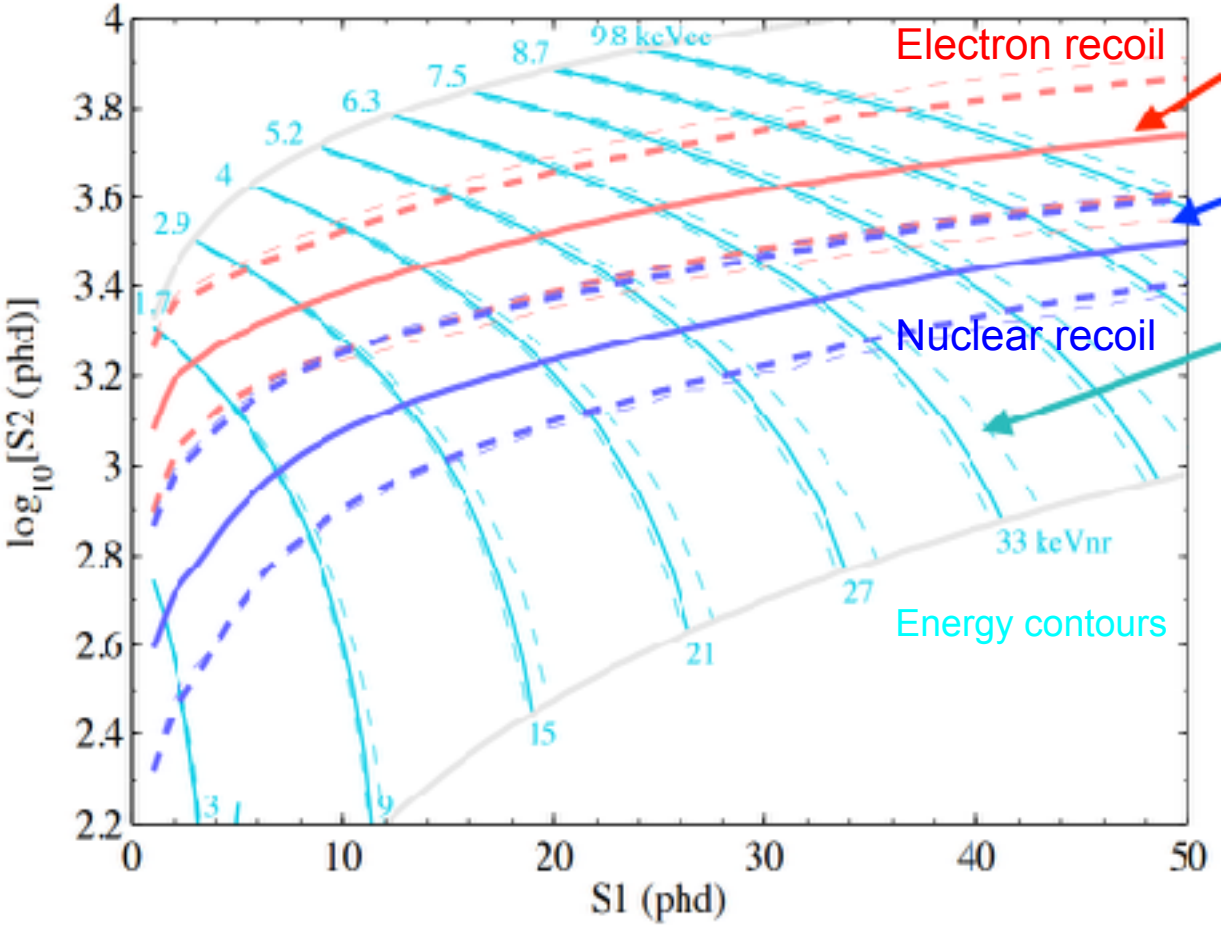


Latino Americans are involved in many of these experiments

How do we search for dark matter particles?

Direct Detection

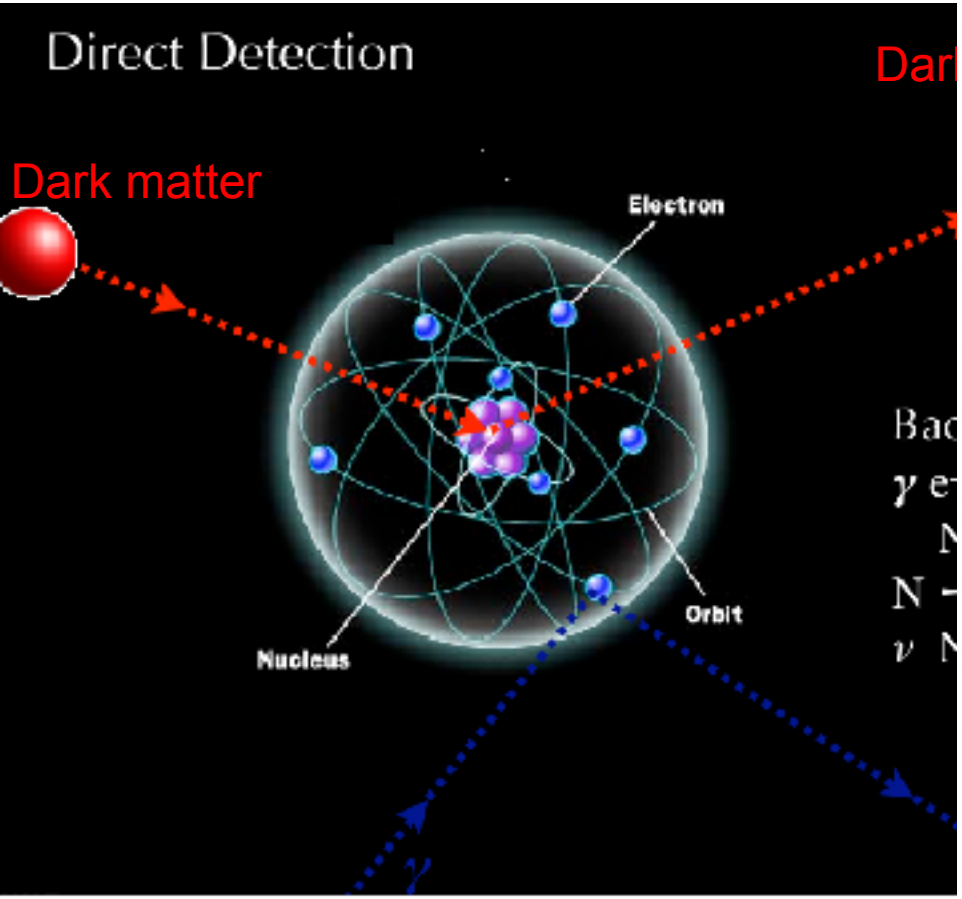




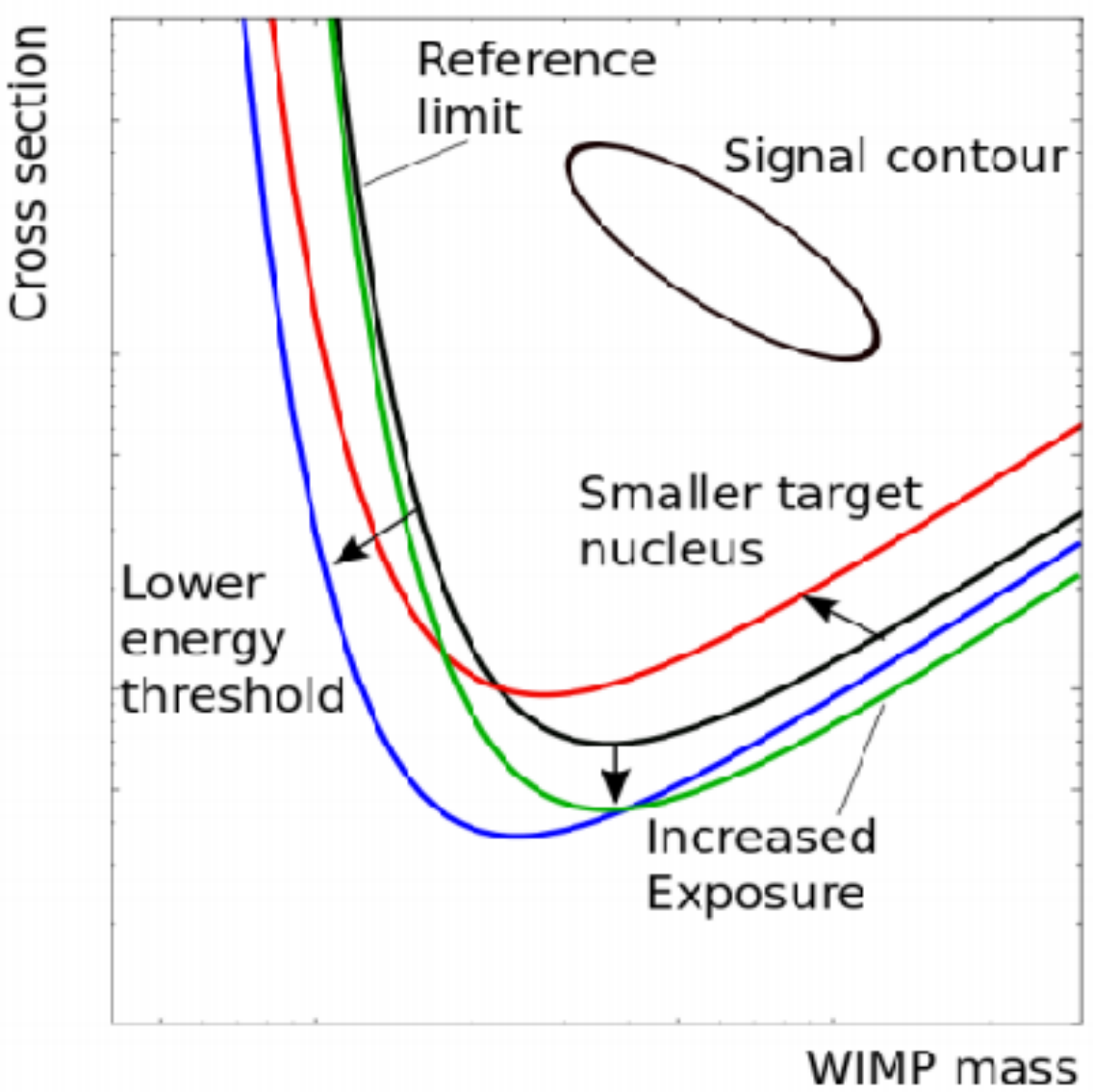
$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\ \mathrm{d}^3 v$$

How do we search for dark matter particles?

Direct Detection



Understanding the limits…



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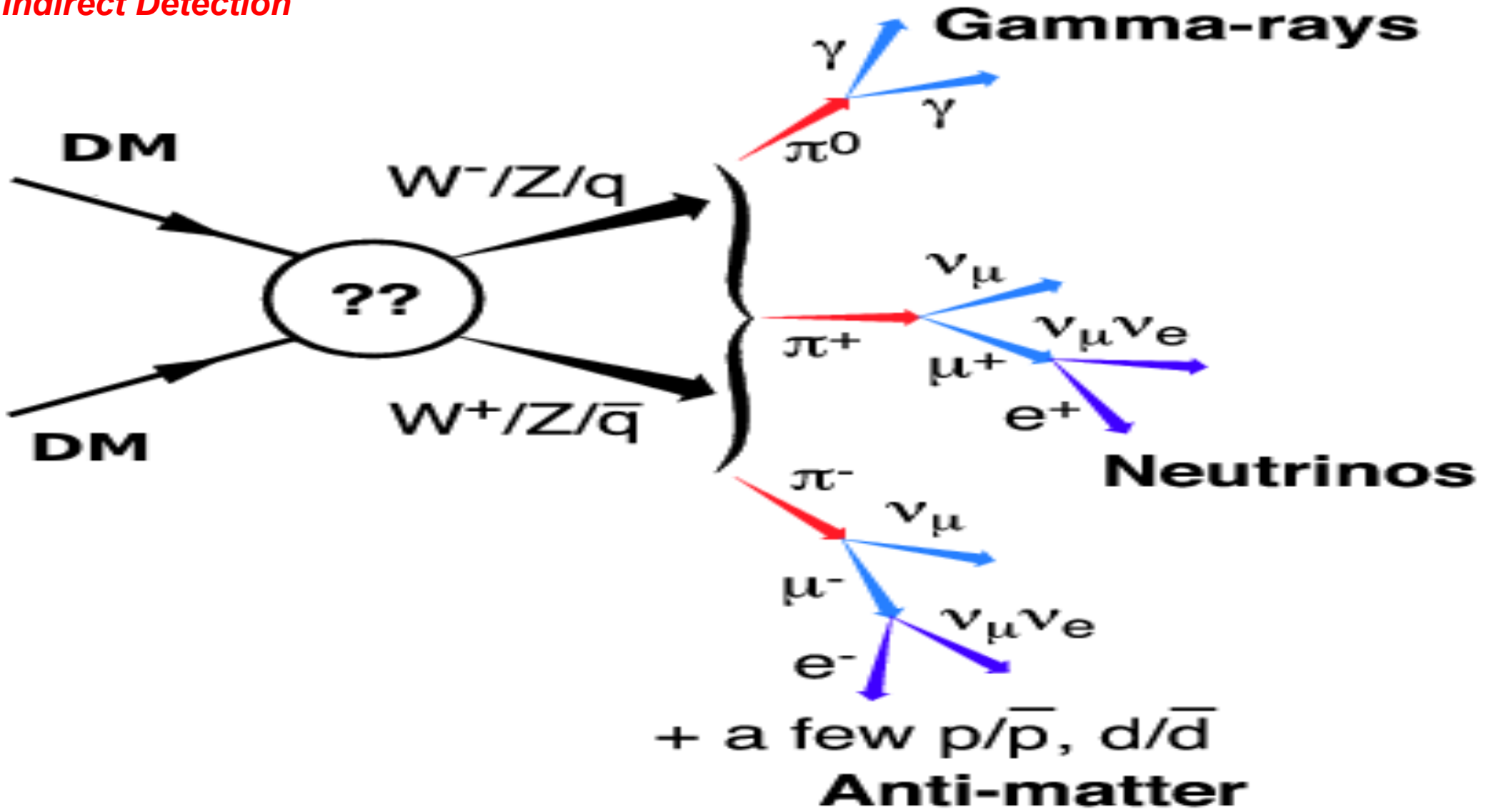
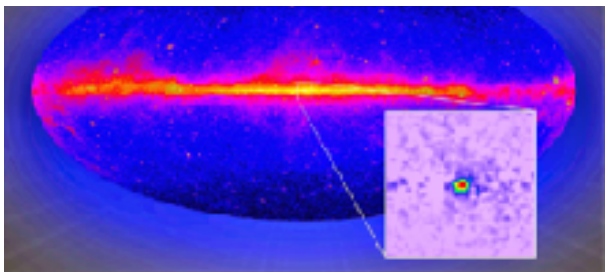
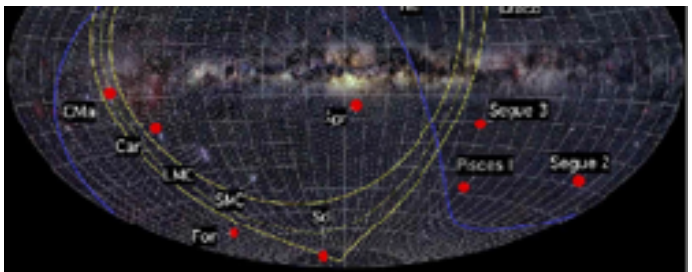
How do we search for dark matter particles?

Indirect Detection







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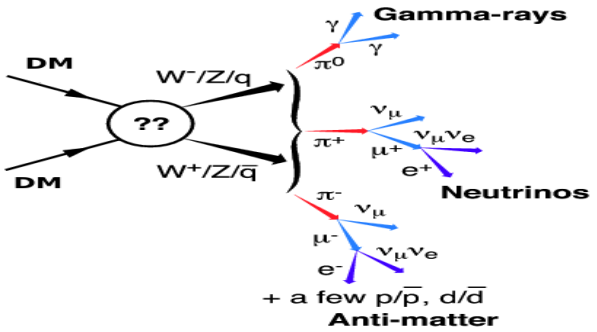
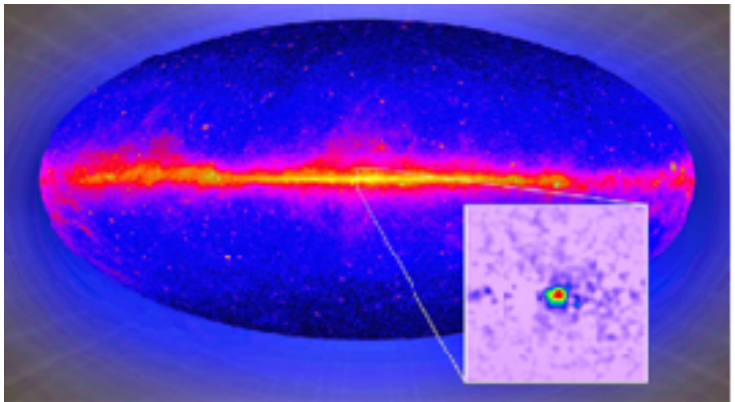
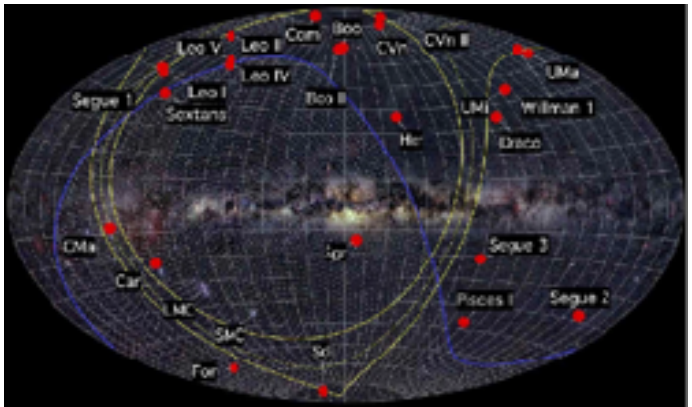


Dark Matter Signal = **Dark matter density** × **Particle Physics Input**

High density → **Galactic Center**

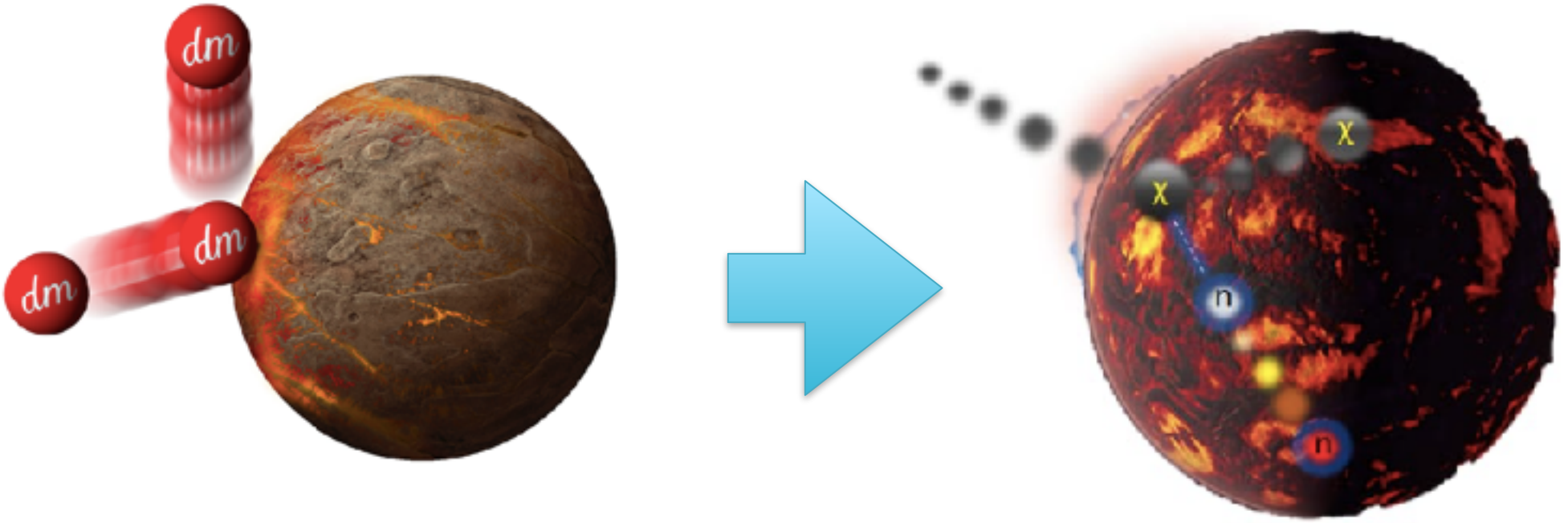
High density → **Dwarf Spheroidal Galaxies**





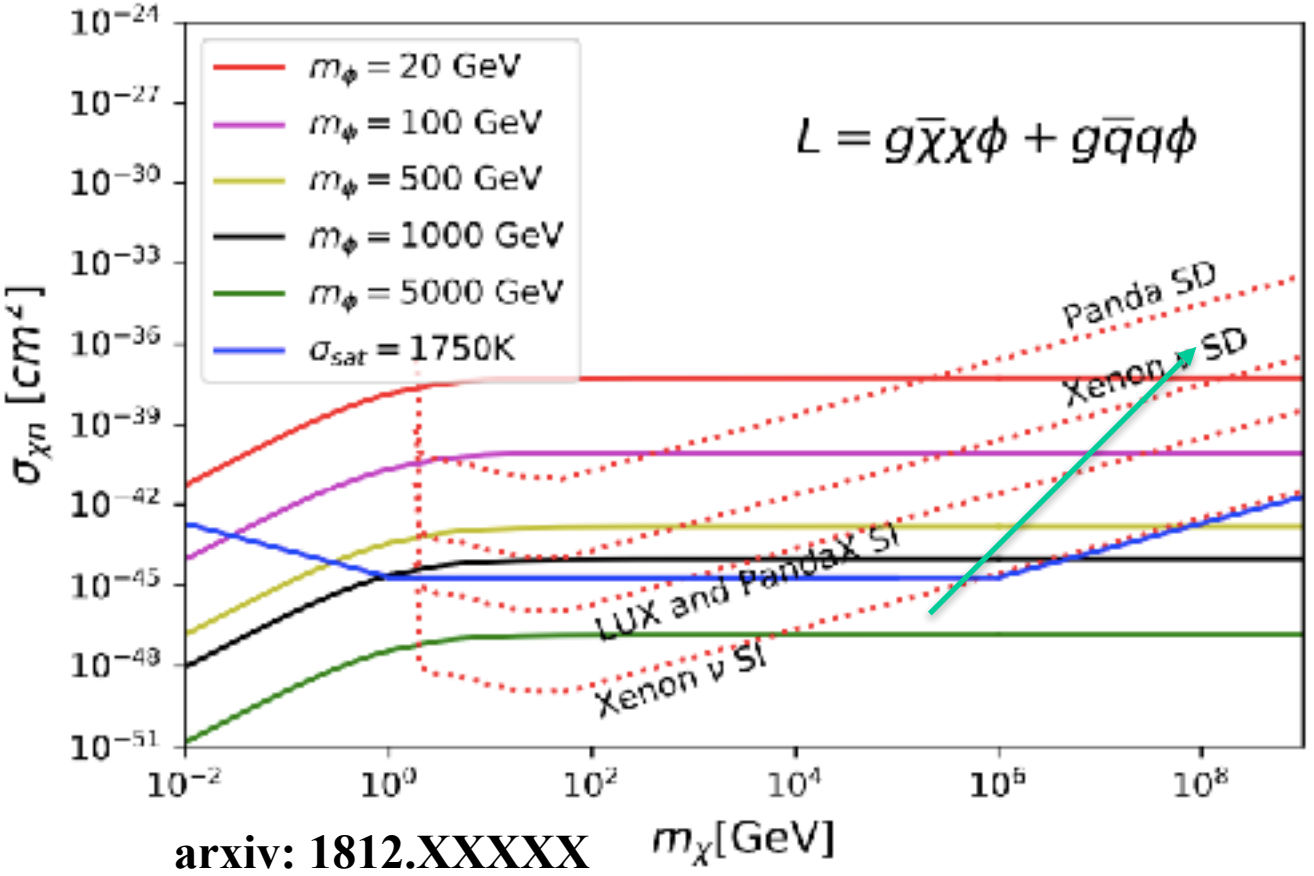
How do we search for dark matter particles?

Neutron Star Spectroscopy:New Method

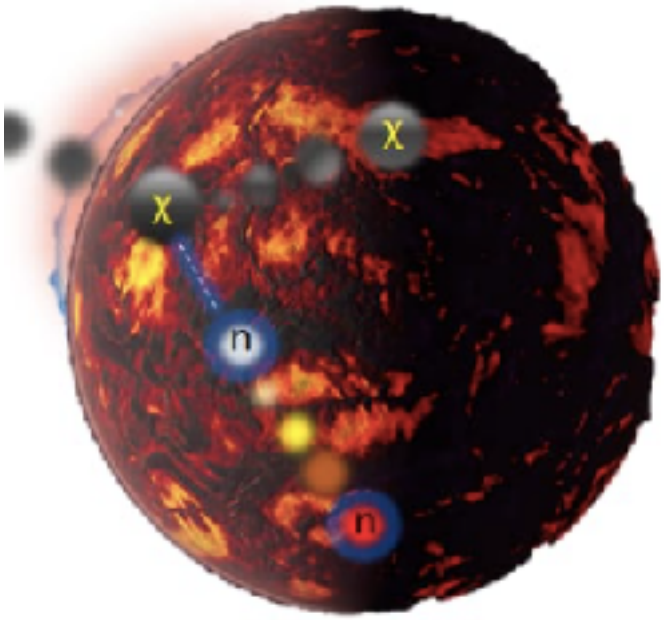


How do we search for dark matter particles?

Neutron Star Spectroscopy



arxiv: 1812.XXXXX



$$T_{NS} \sim 1750 f^{1/4}[K]$$

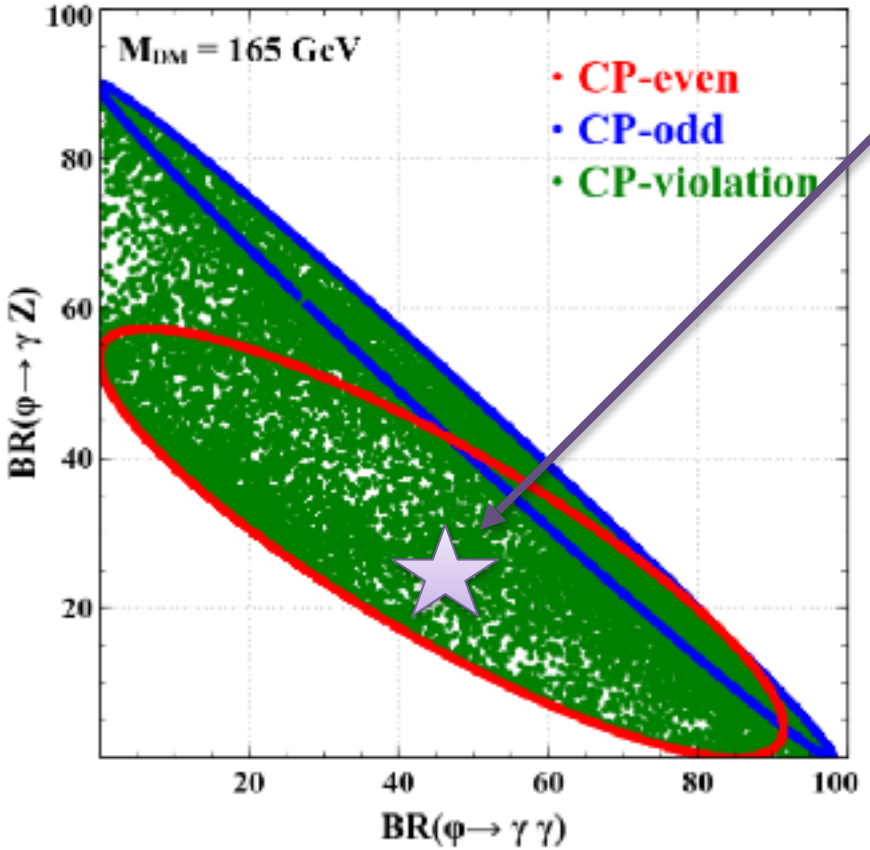
This function encodes the particle physics input

Sounds good, but what about Its nature?

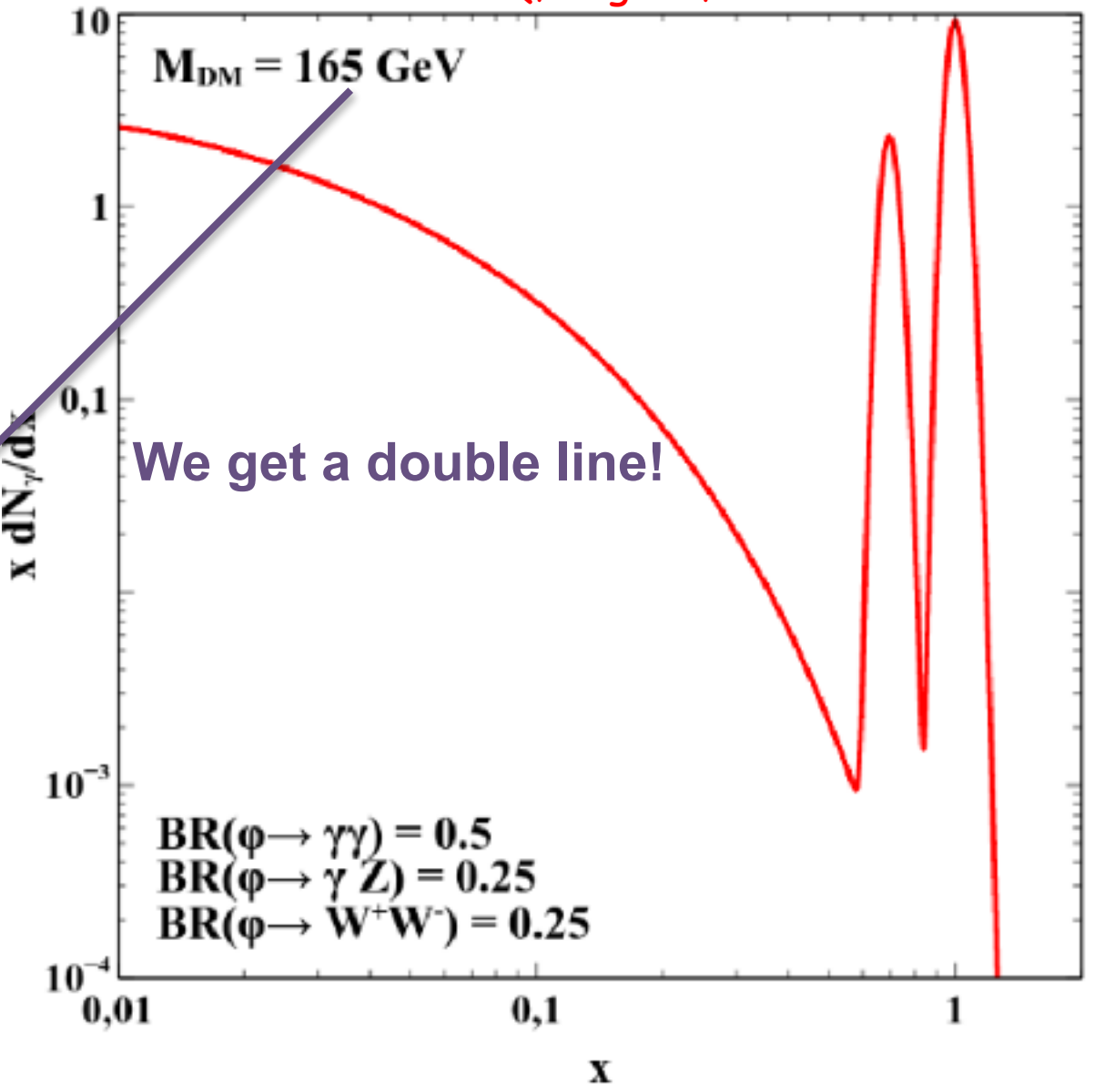
Attempt 1

Gauge-invariant decaying scalar field

$$\mathscr{L} = \frac{a}{M_{pl}}\varphi B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{b}{M_{pl}}\varphi B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{c}{M_{pl}}\varphi W^{I}_{\mu\nu}W^{I\mu\nu} + \frac{d}{M_{pl}}\varphi W^{I}_{\mu\nu}\tilde{W}^{I\mu\nu}$$



FSQ, Yaguna, arxiv: 1811.03530



Sounds good, but what about Its nature?

Attempt 2

Starting from

$$\sigma_{SI}^{M} = \frac{4\mu_{\chi}^{2}}{\pi}\left[\lambda_{p}^{M} Z + \lambda_{n}^{M}(A-Z)\right]^{2}$$

Two measurements lead to

$$\left[\lambda_{p}^{M} Z_X + \lambda_{n}^{M}(A_X - Z_X)\right]^{2} = \frac{\pi\tilde{\sigma}_X}{4\mu_{\chi}^{2}},$$

$$\left[\lambda_{p}^{M} Z_Y + \lambda_{n}^{M}(A_Y - Z_Y)\right]^{2} = \frac{\pi\tilde{\sigma}_Y}{4\mu_{\chi}^{2}}.$$

Using different targets

$_{54}$Xe	$_{32}$Ge	$_{14}$Si
128 (1.9%)	70 (21%)	28 (92%)
129 (26%)	72 (28%)	29 (4.7%)
130 (4.1%)	73 (4.7%)	30 (3.1%)
131 (21%)	74 (36%)	
132 (27%)	76 (7.4%)	
134 (10%)		
136 (8.9%)		

arxiv:1610.06581

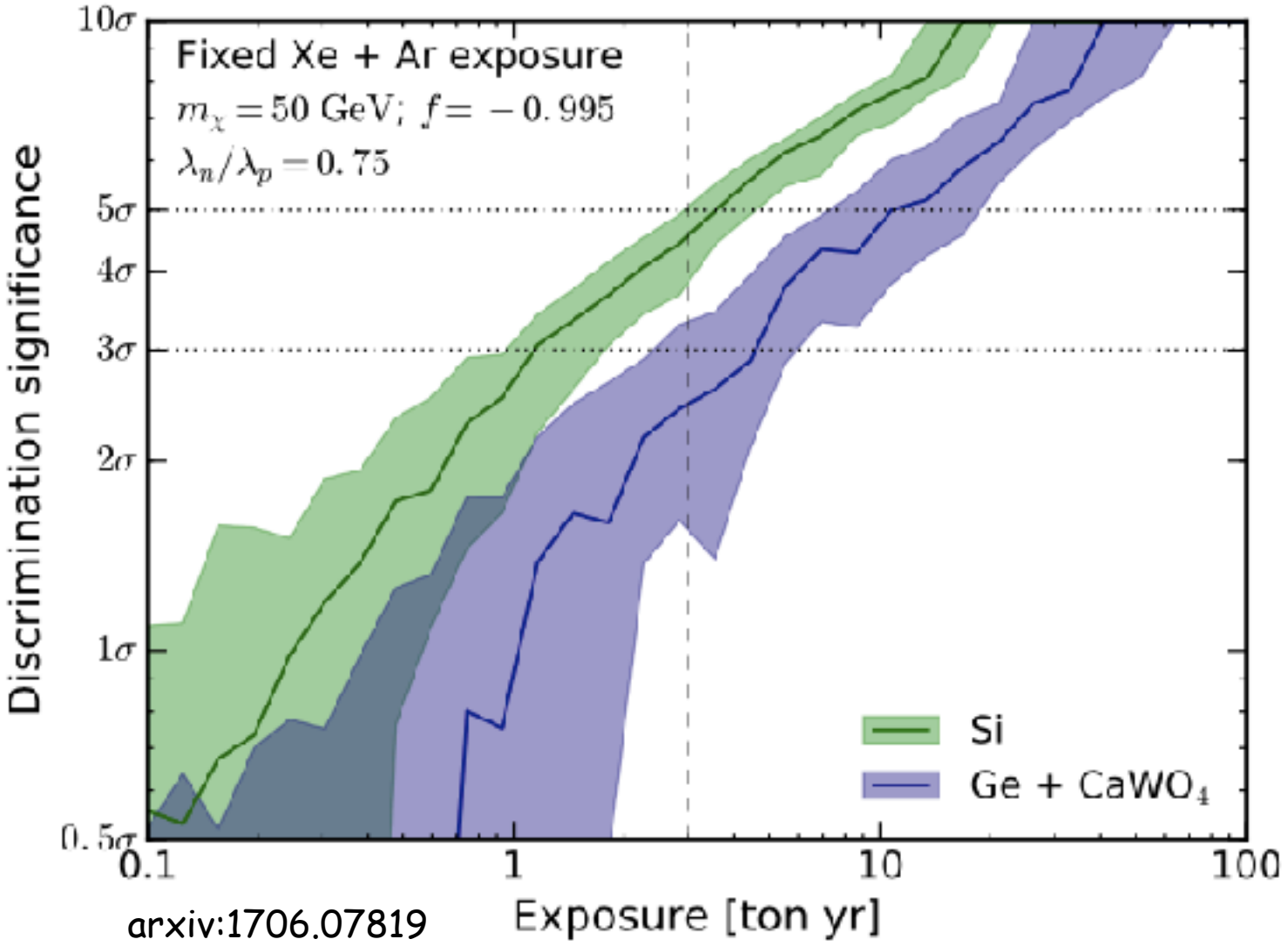
Sounds good, but what about Its nature?

Attempt 2

Starting from

Two measurements lead to

Using different targets



arxiv:1706.07819

$$f = (\lambda_p^D \lambda_n^D + \lambda_p^{\overline{D}} \lambda_n^{\overline{D}})/(2\lambda_p \lambda_n)$$

Take Home Messages

1. Dark matter research is a multidisciplinary endeavor

2. We might be on the verge of unveiling its nature

Muchas gracias!

Spin 0
Mass 300 GeV
CP even