Portals to the Dark Side of the Universe

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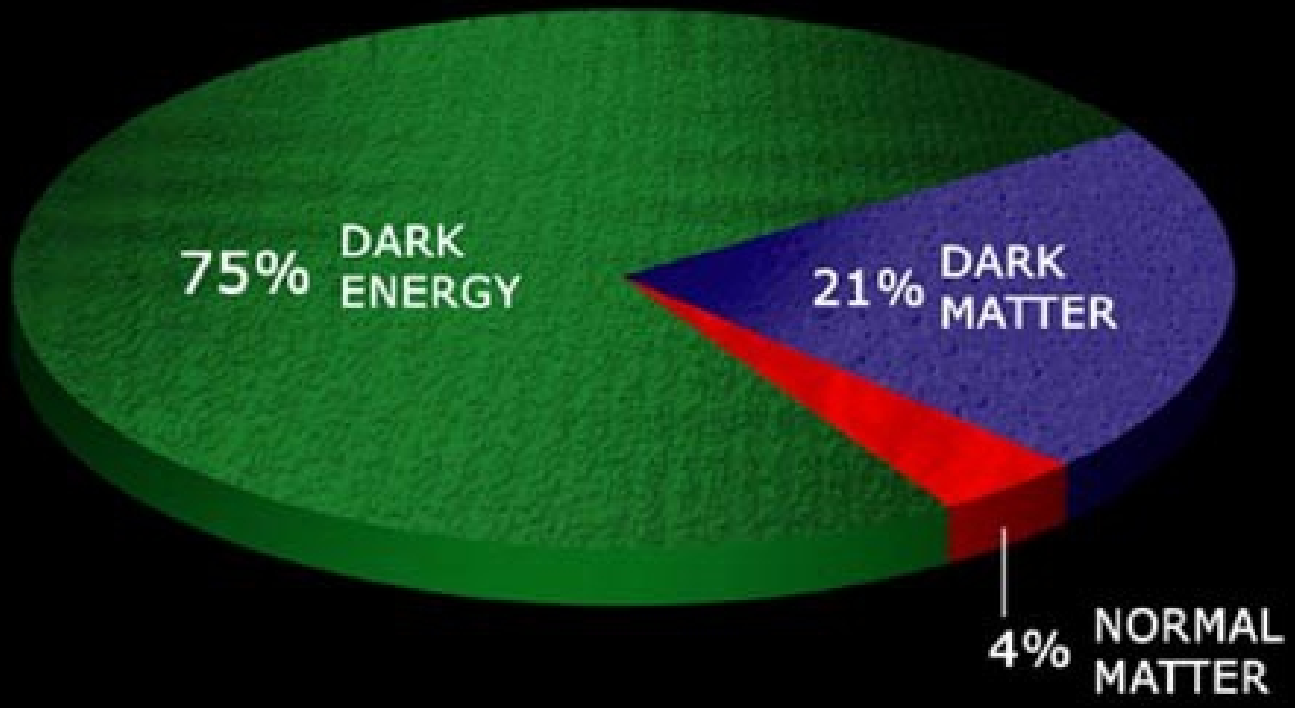
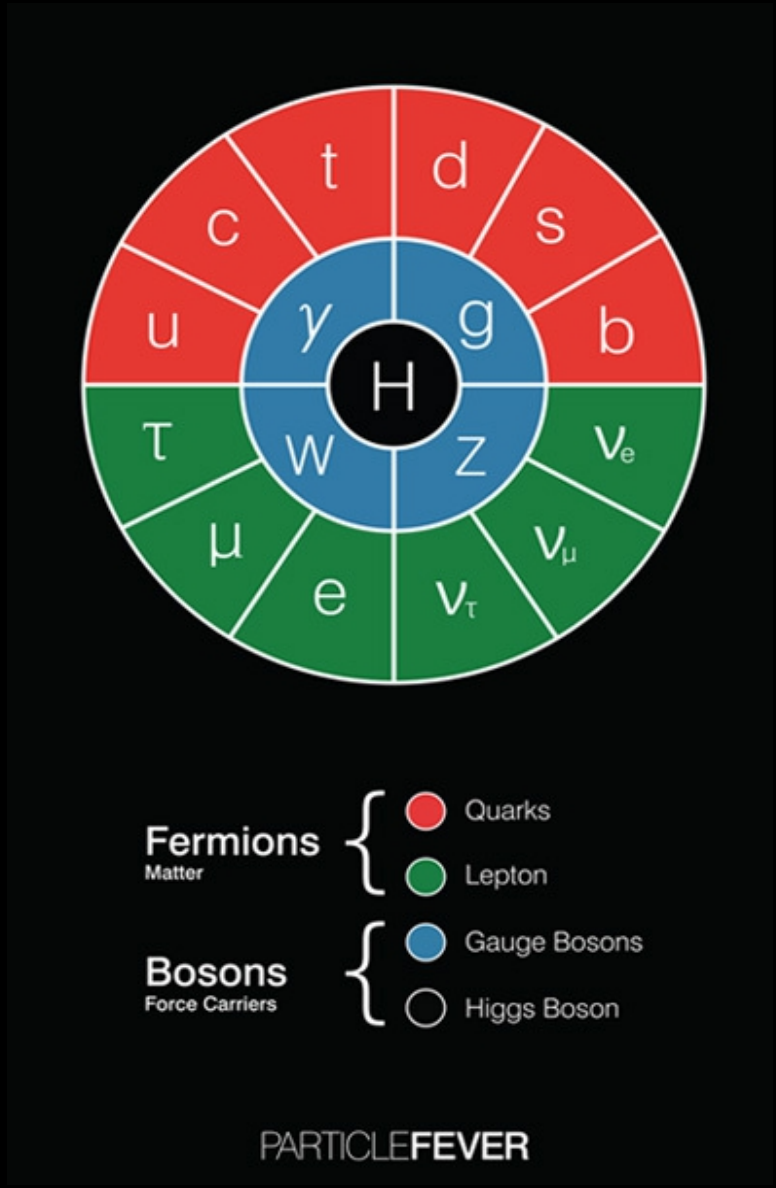
(Portal: Gateway or entrance)

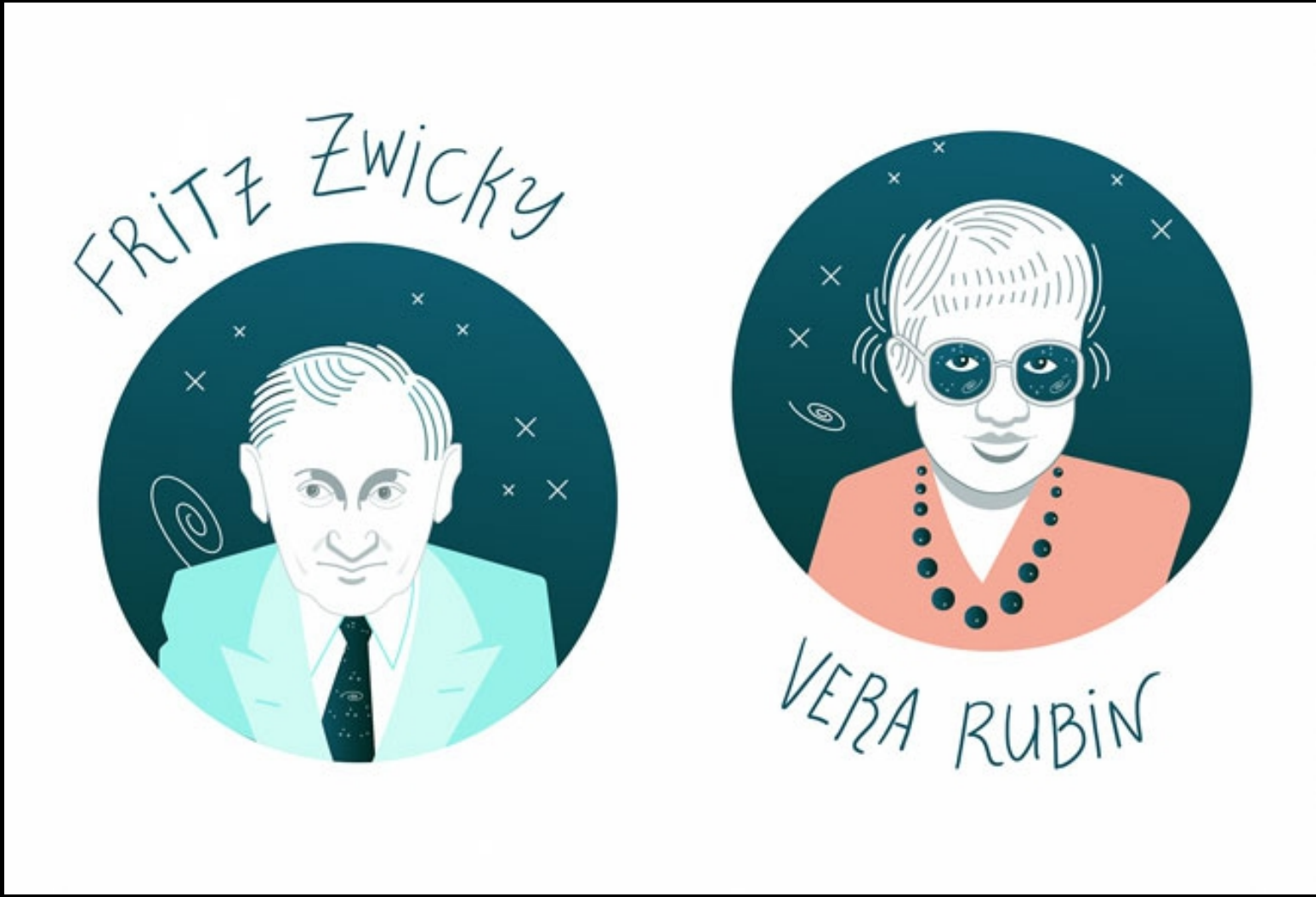
Pie Chart of Universe



“Normal” Particles



Dark Matter: proposed in 1930's Reproposed in 1970's



Zwicky's evidence for dark matter

Astrophysicist Fritz Zwicky calculated that the Coma cluster, one of the densest known galaxy clusters, needed to contain about 400 times its apparent mass--otherwise it would fly apart.

Courtesy of: Jim Misti, Misti Mountain Observatory

Rubin's Evidence for dark matter

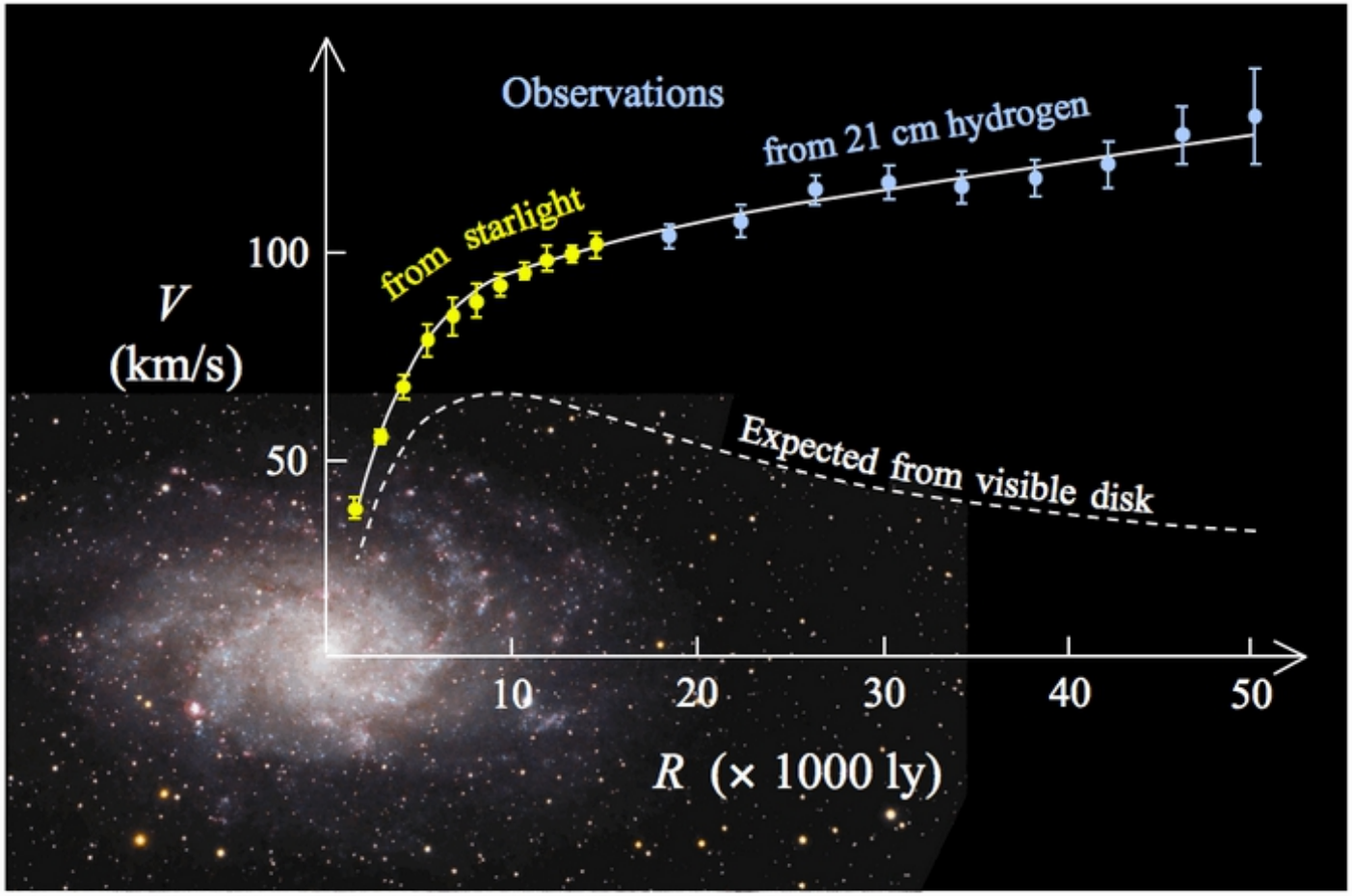


Image credit: Wikimedia Commons user Stefania.deluca.

Most of the Galaxy is Dark

Image credit: NASA, ESA, and T. Brown and J. Tumlinson (STScI).

We can use gravitational lensing to detect dark matter

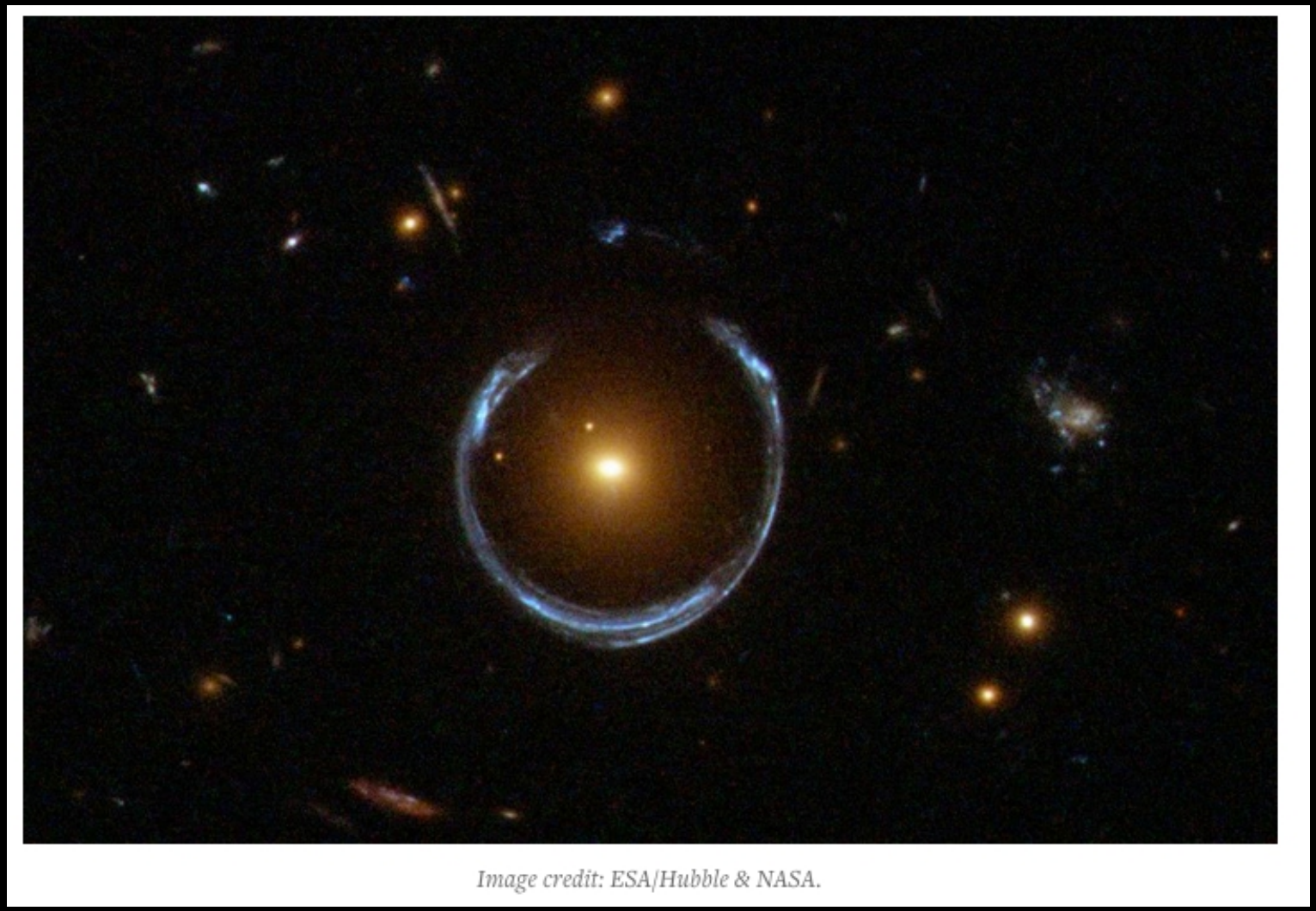


Image credit: ESA/Hubble & NASA.

Detecting dark matter with lensing

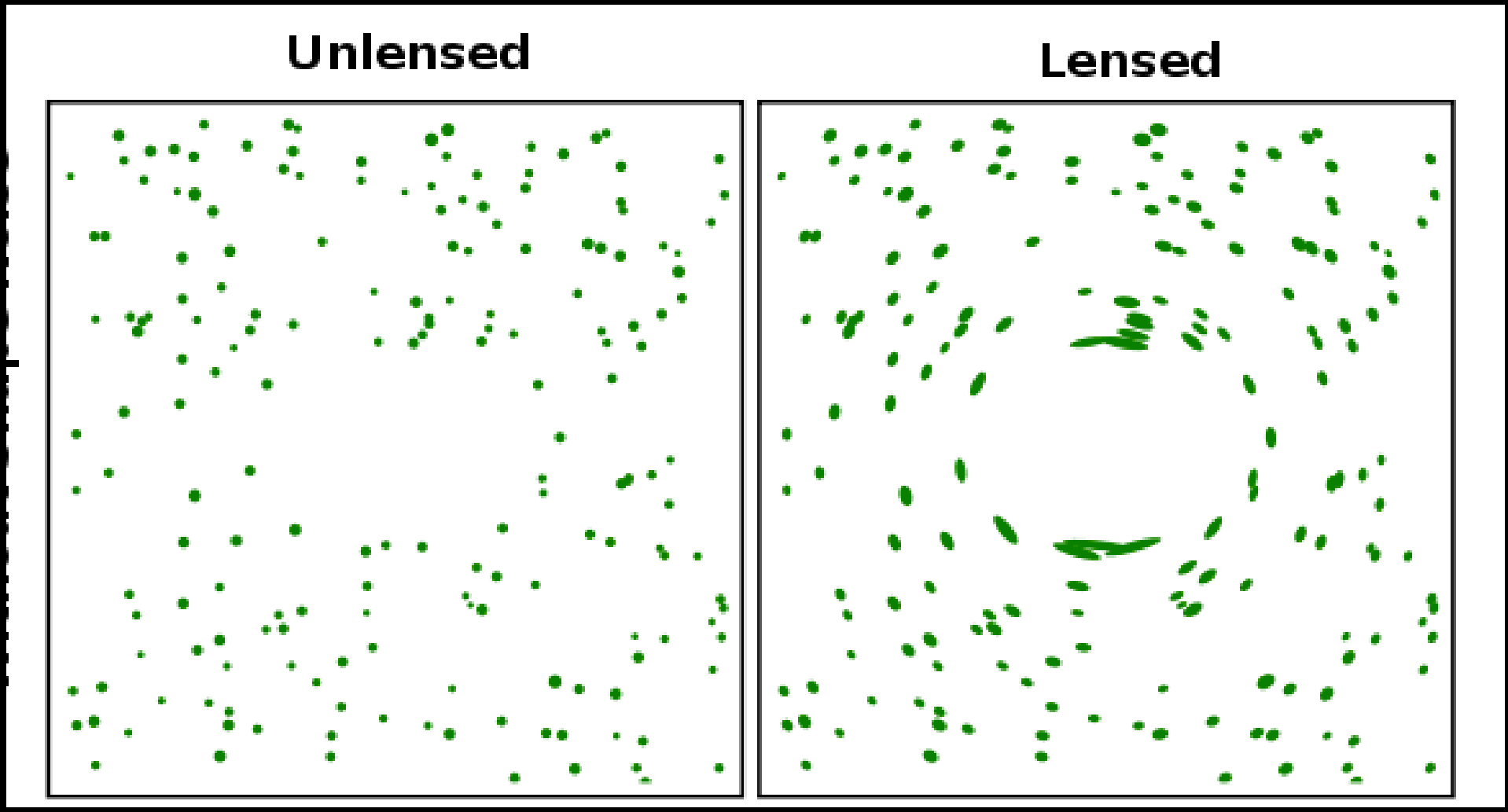


Image credit: Wikimedia Commons user TallJimbo

Ordinary Dark Matter, Modified Gravity or new kind of particle?

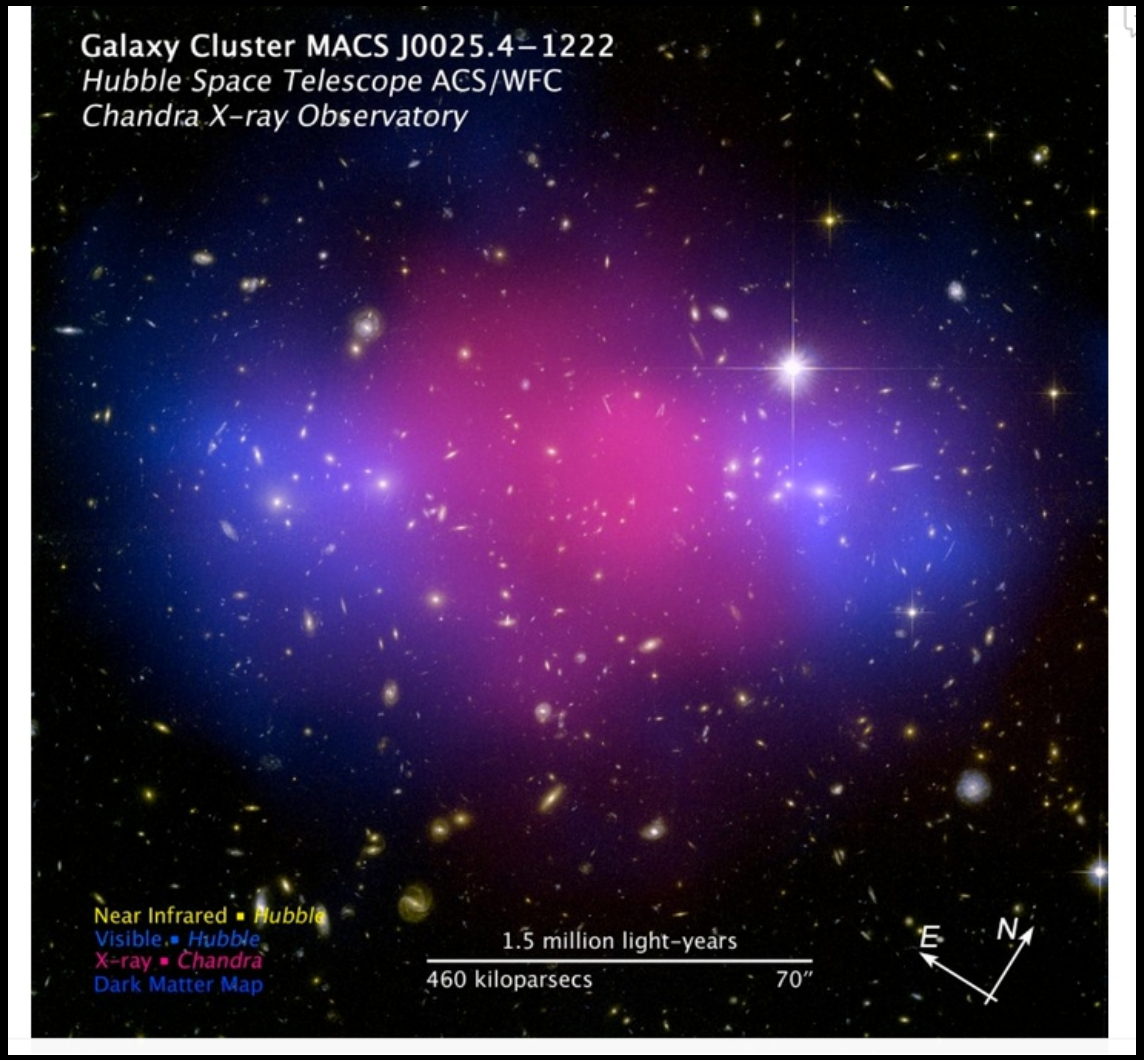
- Most ordinary matter doesn't shine (hydrogen gas clouds)
- We could imagine changing laws of gravity at large distances instead of a new form of matter
- Dark matter is different from ordinary matter: Collisionless?
- How can we test collisional properties of dark matter?

“Bullet Cluster”: colliding galaxy clusters

Trainwreck Cluster

Image credit: X-ray: NASA/CXC/UCDavis/W.Dawson et al; Optical: NASA/STScI/UCDavis/W.Dawson et al.

Musket Ball Cluster



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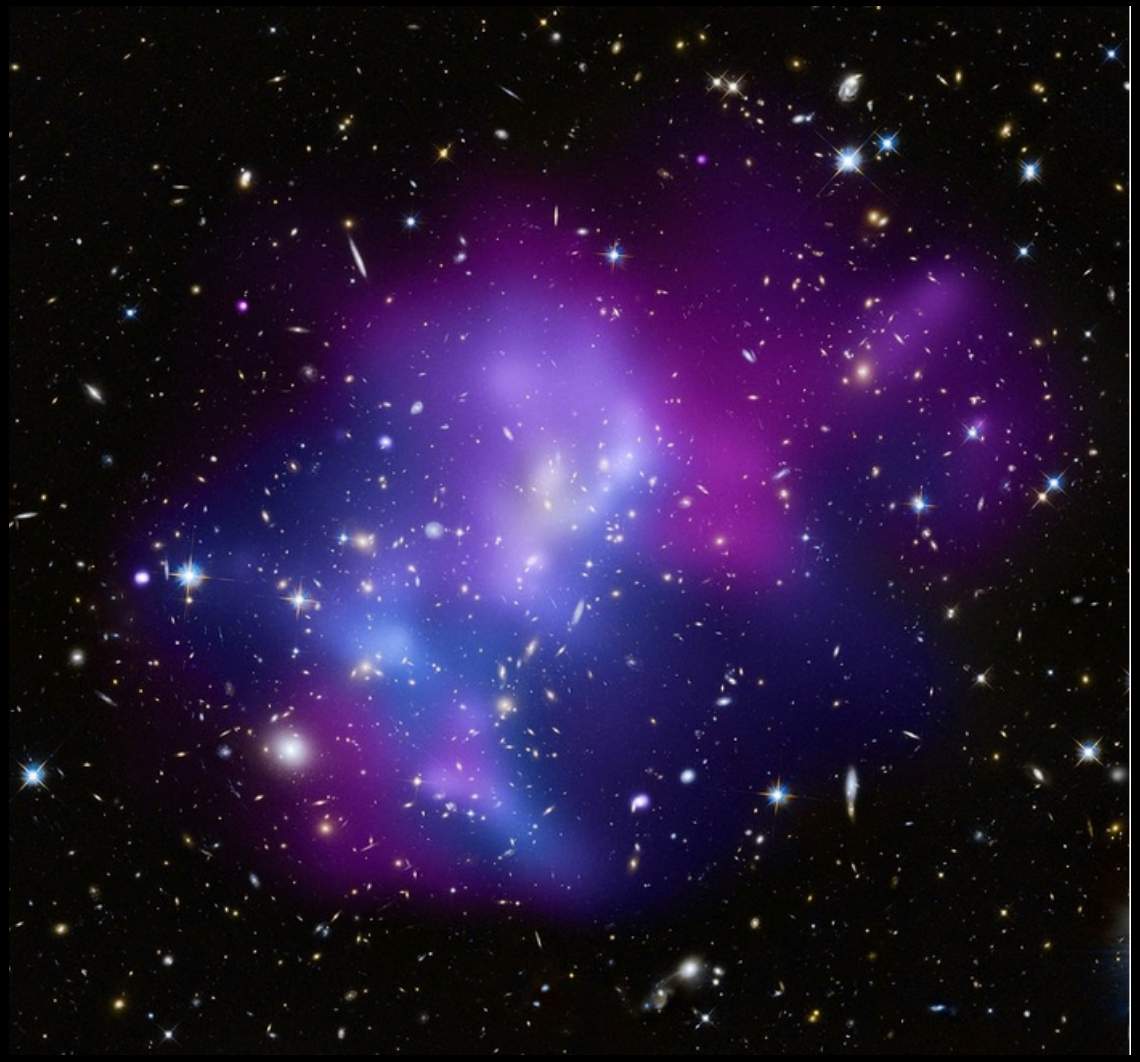


On a smaller scale

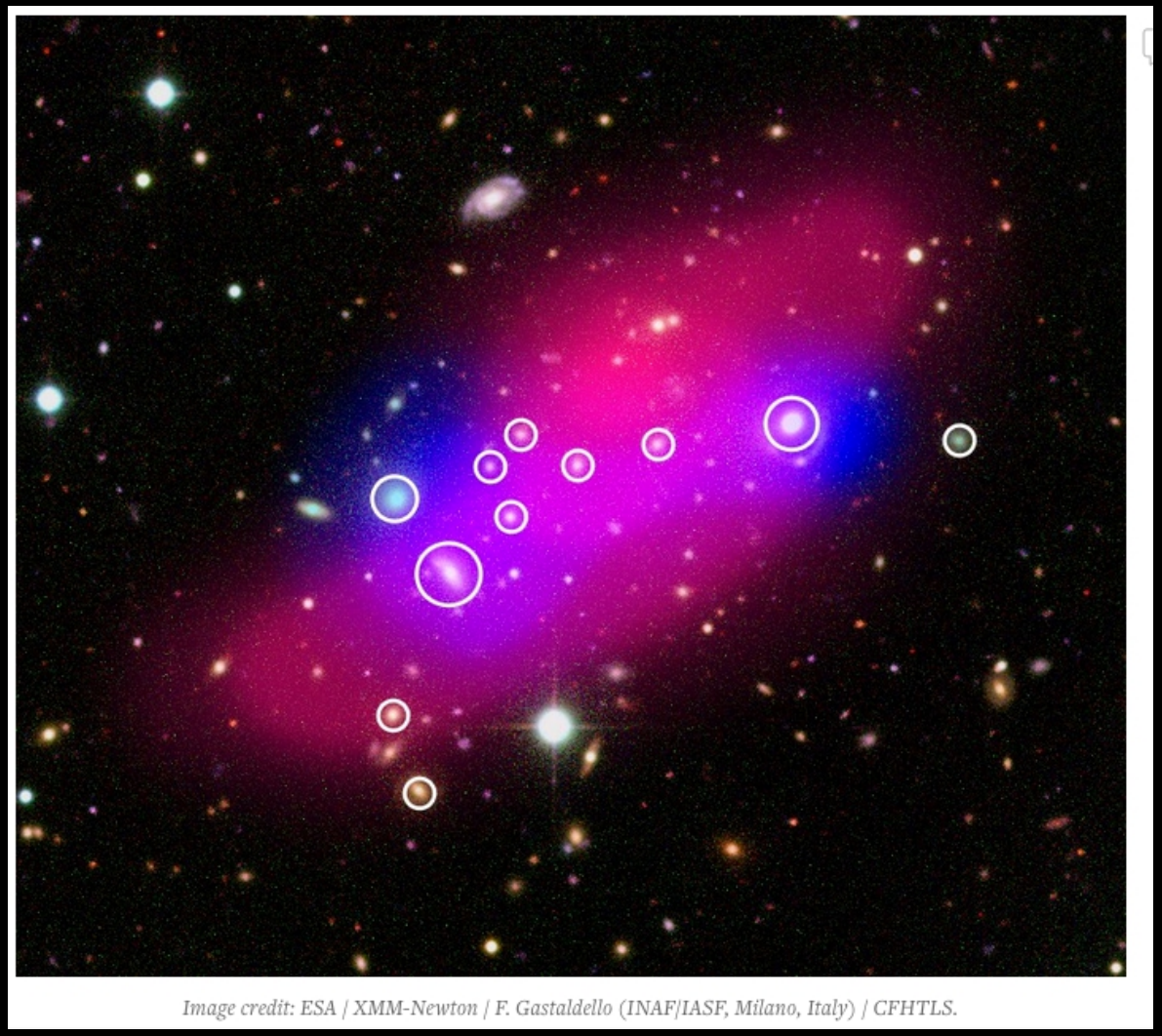


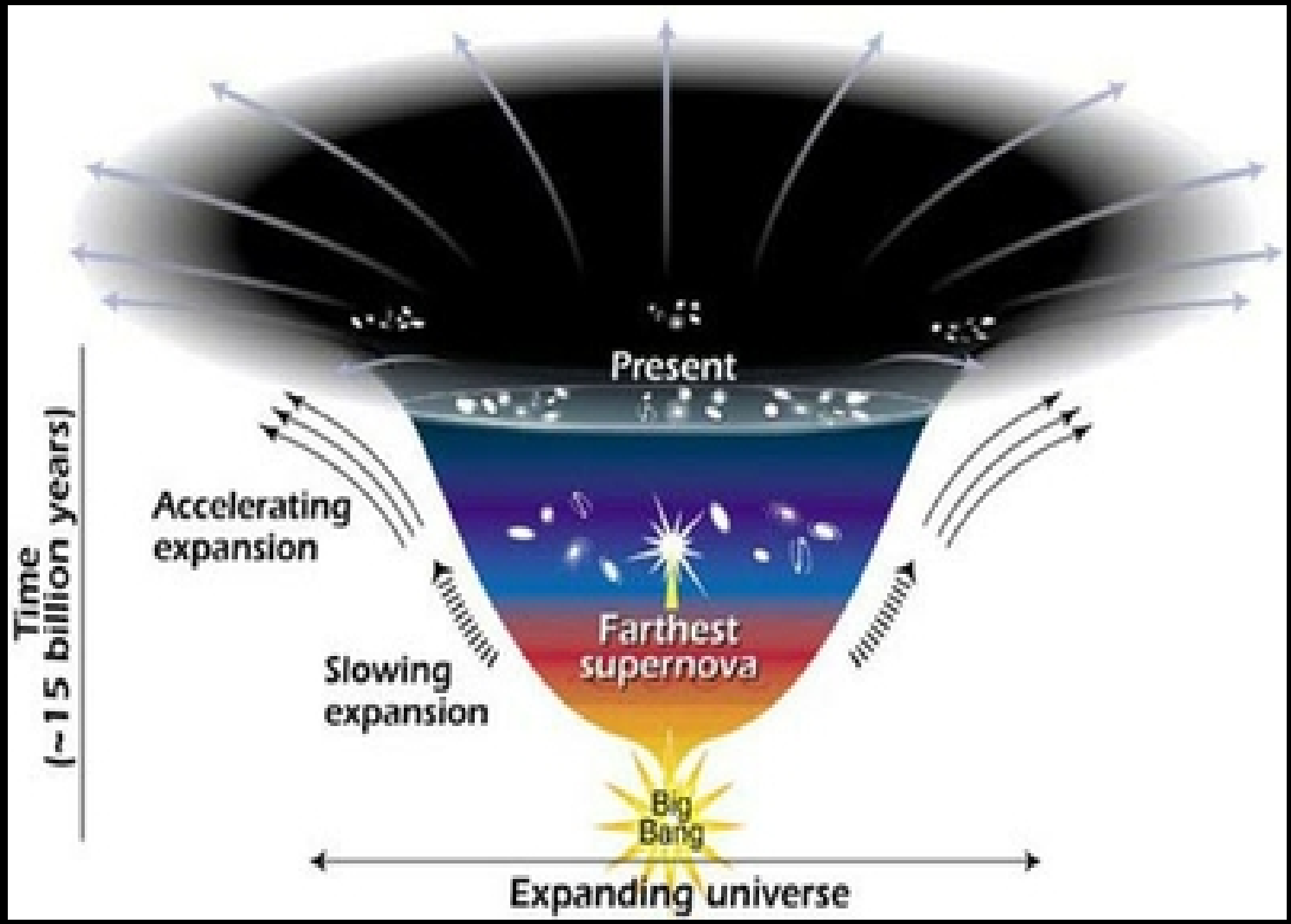
Image credit: ESA / XMM-Newton / F. Gastaldello (INAF/IASF, Milano, Italy) / CFHTLS.

We have discovered Dark Matter

- There is an unseen source of gravitating matter which is collisionless (at least, small collision cross section compared to gas)
- Not made of atoms!
- Beyond the standard model of particle physics
- Gravity is only known portal
- Can we find others?

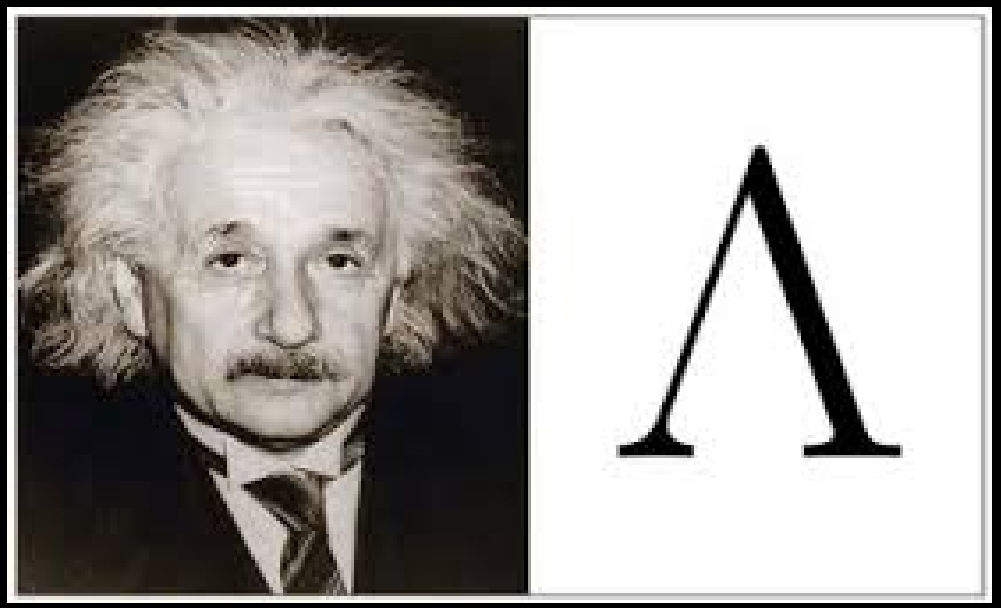
A new particle (or particles?)

Dark Matter=Some stuff that gravitates, is pressureless=cold (not moving very fast) collection of weakly interacting particles


Present
Accelerating expansion
Slowing expansion
Farthest supernova
Big Bang
Time (~15 billion years)
Expanding universe

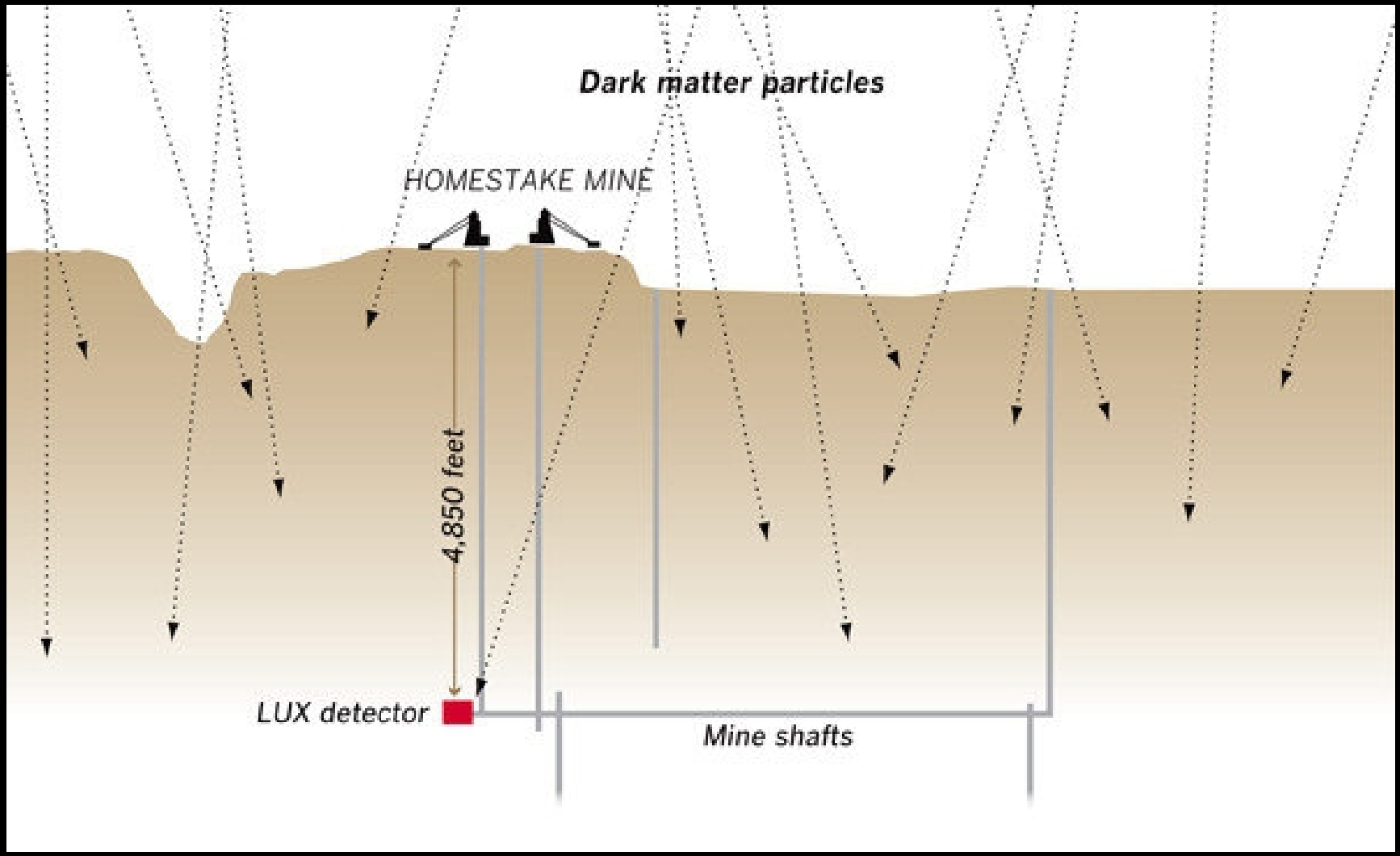
Why does empty space expand?

- New form of energy with negative pressure (tension)? Not usual particles.
- Modify Gravity on large scales?
- Property of space itself?
  (Einstein's Cosmological Constant)



We don't know much more

Dark Matter Direct detection searches



2 Km underground in Sudbury

Weakly Interacting Massive Particle

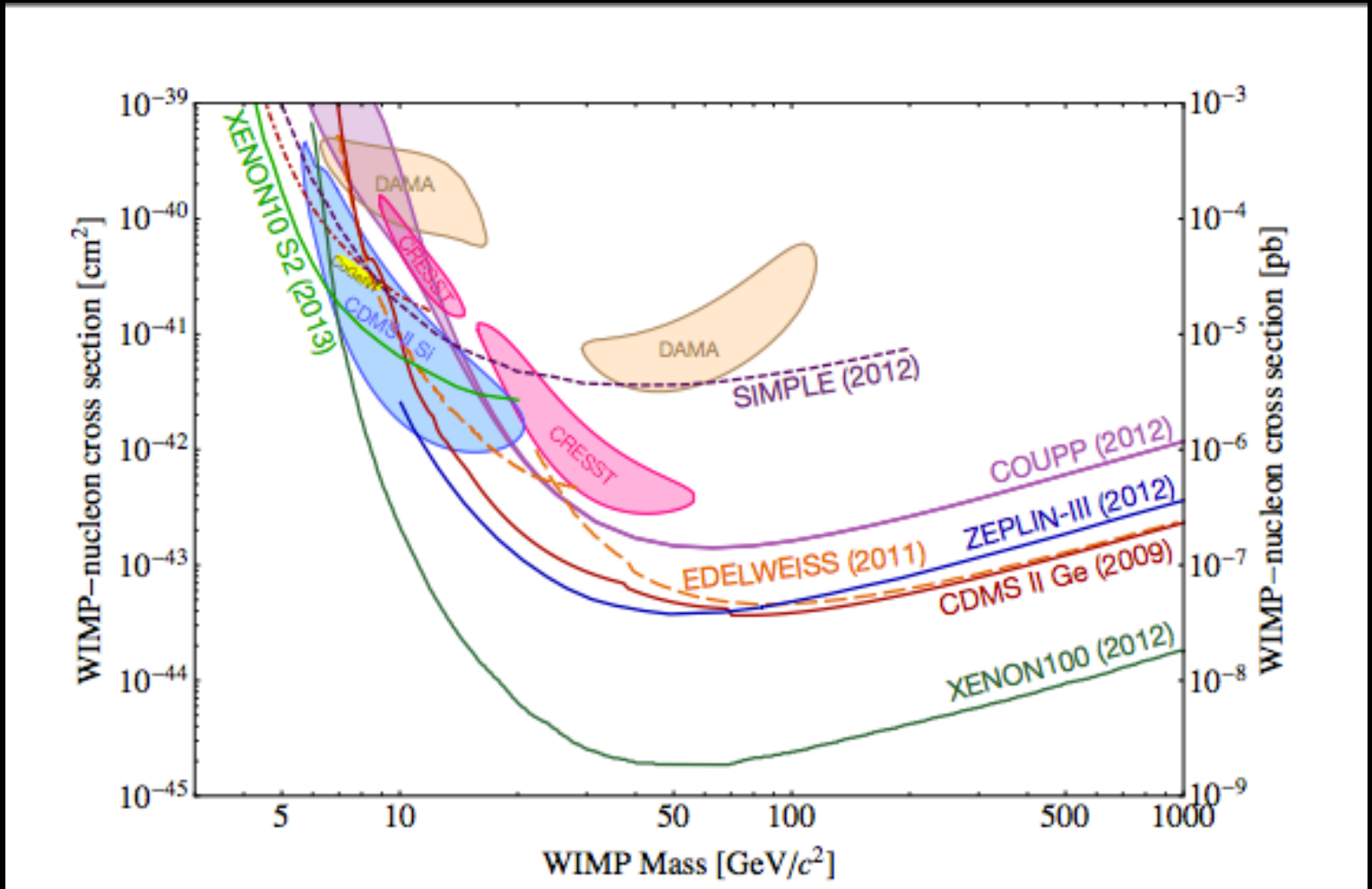


Figure 4-1. *Constraints on spin-independent WIMP-nucleon cross sections as a function of WIMP mass*

The hunt intensifies

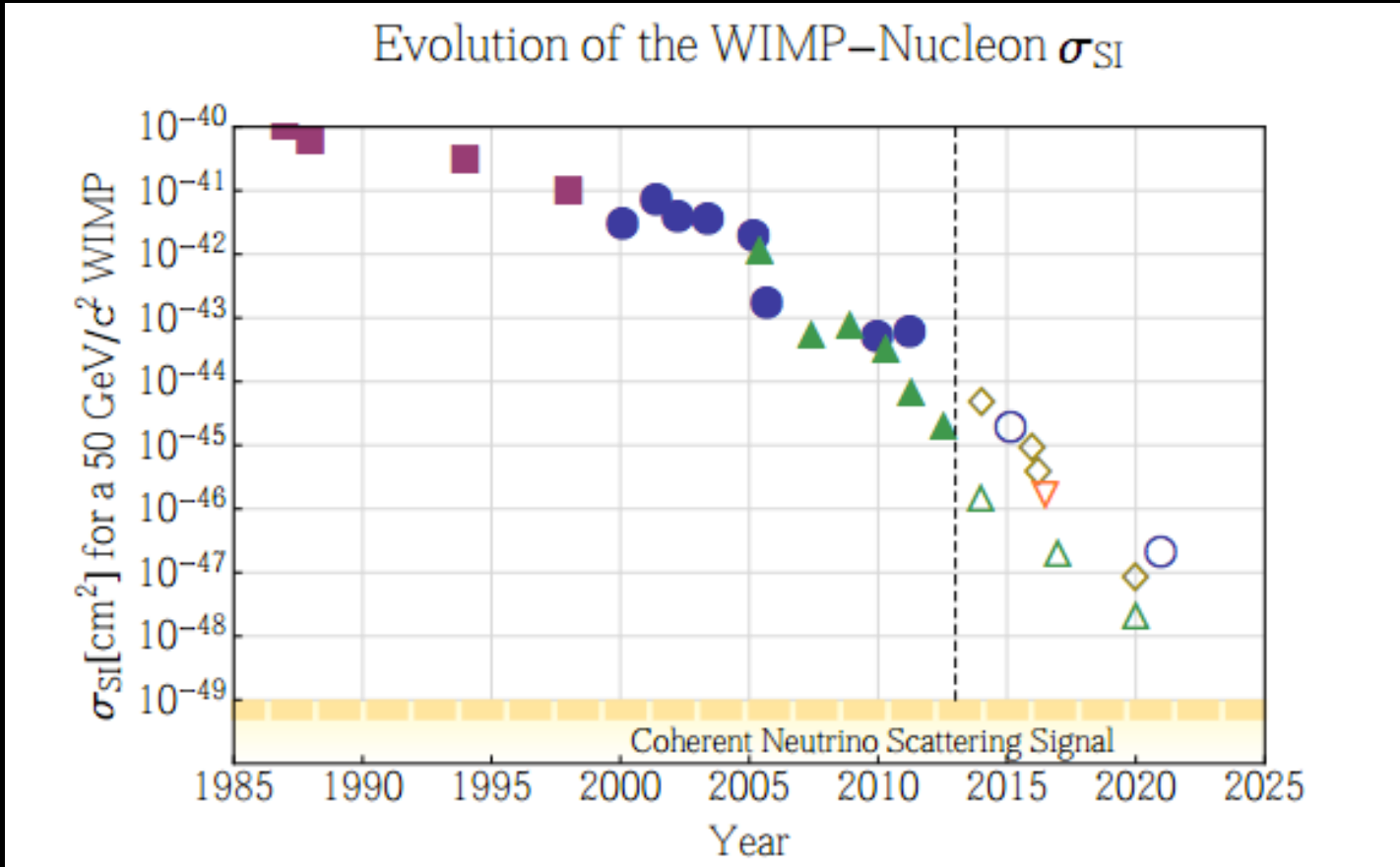


Figure 4-3. *Spin-independent limits for the major WIMP direct detection experiments (solid) and their projected sensitivity (open) for spin independent cross sections for a 50 GeV/c^2 mass WIMP. The shapes correspond to technologies: cryogenic solid state (blue circles), crystal detectors (purple squares), liquid argon (brown diamonds), liquid xenon (green triangles) and threshold detectors (orange inverted triangle).*

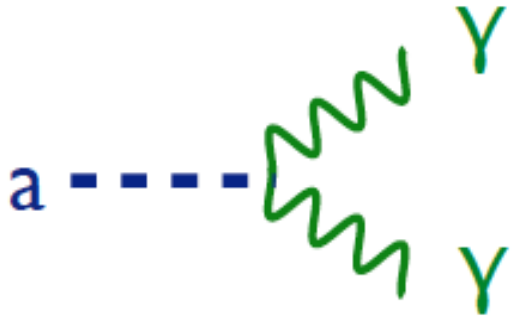
Axions
very light, couple to photons

Hunt for the dark matter axion

If axions are the dark matter, they are all around us. How can we detect them?

ADMX experiment @ the UW:

Sikivie-type cavity experiment:
makes use of axion - 2 photon coupling (E.B)



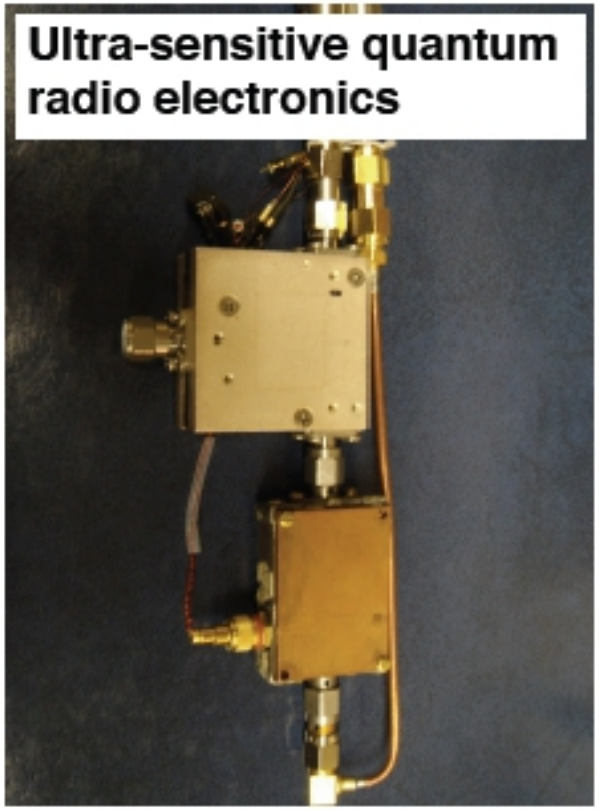
- High Q tuneable EM cavity
- High B field (8 Tesla)
- cosmic axion + B field stimulates emission into E mode photon
- Search for E mode excitation, scanning cavity resonance frequency through possible values for $m_a/2$.

From recent Particle Physics Project Prioritization Panel (P5) Report

"There are many well-motivated ideas for what dark matter could be. These include weakly interacting massive particles (WIMPs), gravitinos, axions, sterile neutrinos, asymmetric dark matter, and hidden sector dark matter. The masses and interaction strengths of these candidates span many orders of magnitude, and, of course, the dark matter could be composed of more than one type of particle."

ADMX: The Axion Dark Matter eXperiment, an ultra-sensitive search for dark-matter axions

The magnet and microwave cavity convert Milky Way axions into a very weak radio signal



The weak radio signal is detected by electronics so sensitive it would easily provide your cell phone 4 bars on Jupiter

lab visit 08Apr14 LJR 3

Leslie Rosenberg, 2014

Other possibilities for dark matter

- Sterile ν
- Hidden Sector
  - Self-interacting…
- Asymmetric
- Q-balls
- WIMPZILLAS
- Black holes

Dark Matter Experimental landscape (from Snowmass)

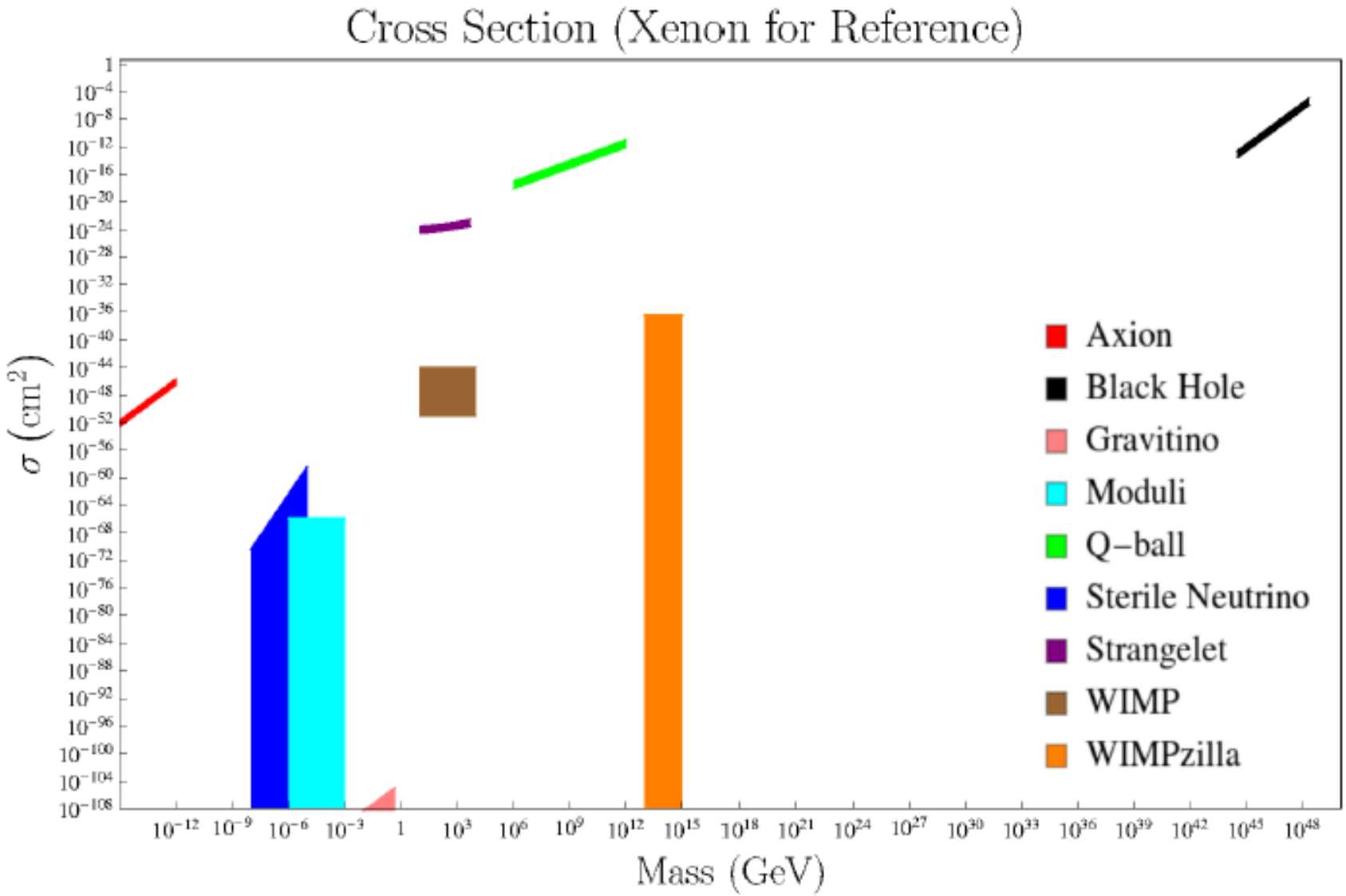
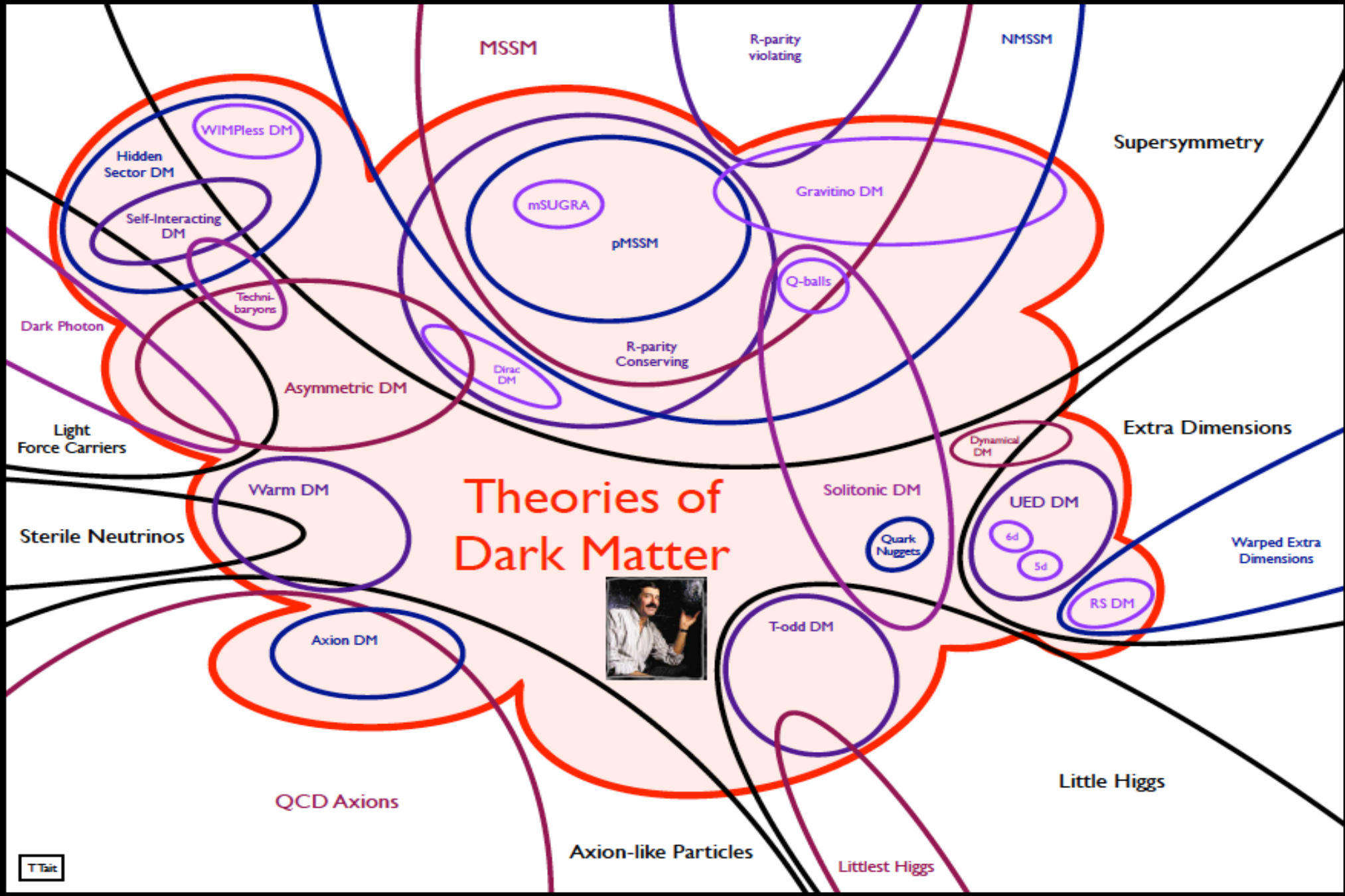
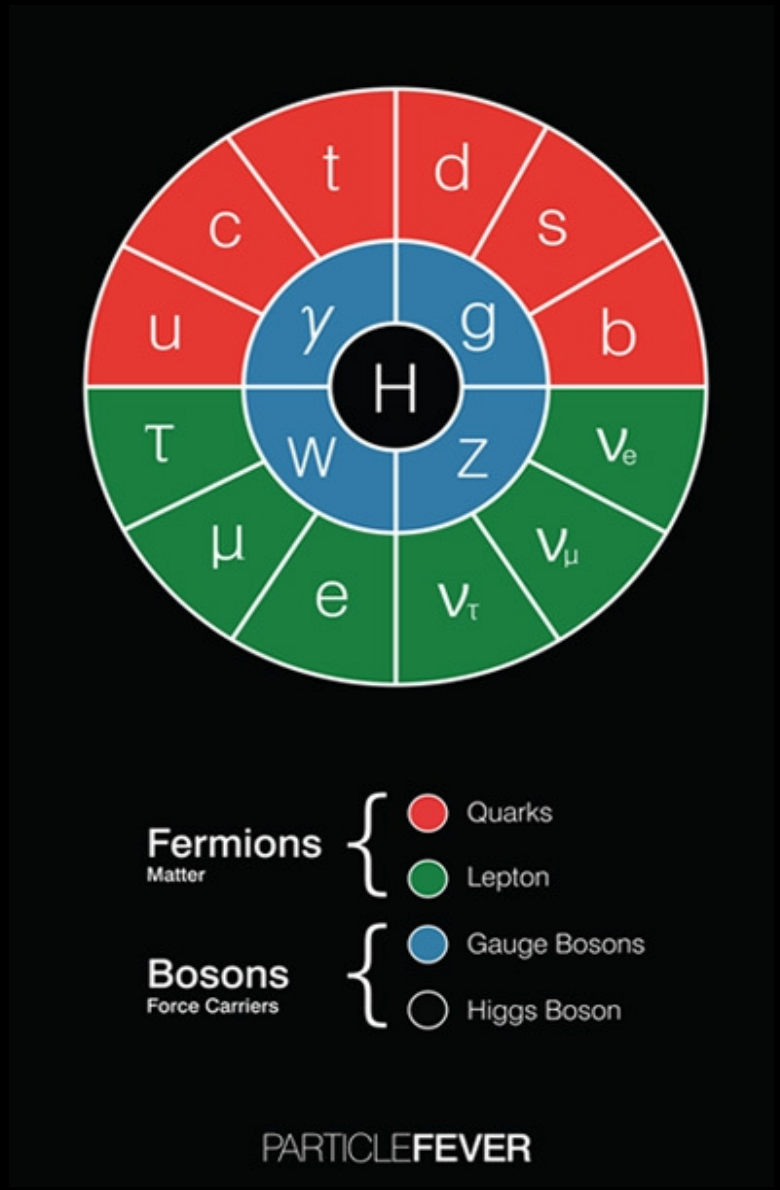


Figure 1. *Graphical representation of the (incomplete) landscape of candidates. Above, the landscape of dark matter candidates due to T. Tait. Below, the range of dark matter candidates' masses and interaction cross sections with a nucleus of Xe (for illustrative purposes) compiled by L. Pearce. Dark matter candidates have an enormous range of masses and interaction cross sections.*

Dark Matter Theory landscape (From Tim Tait)

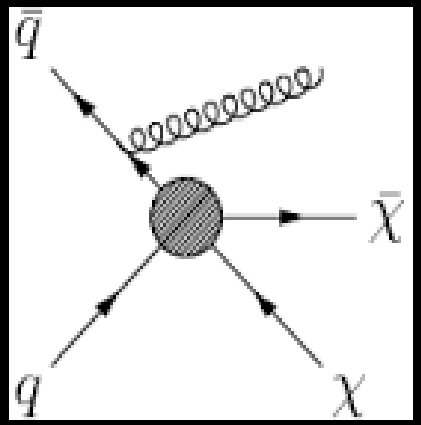


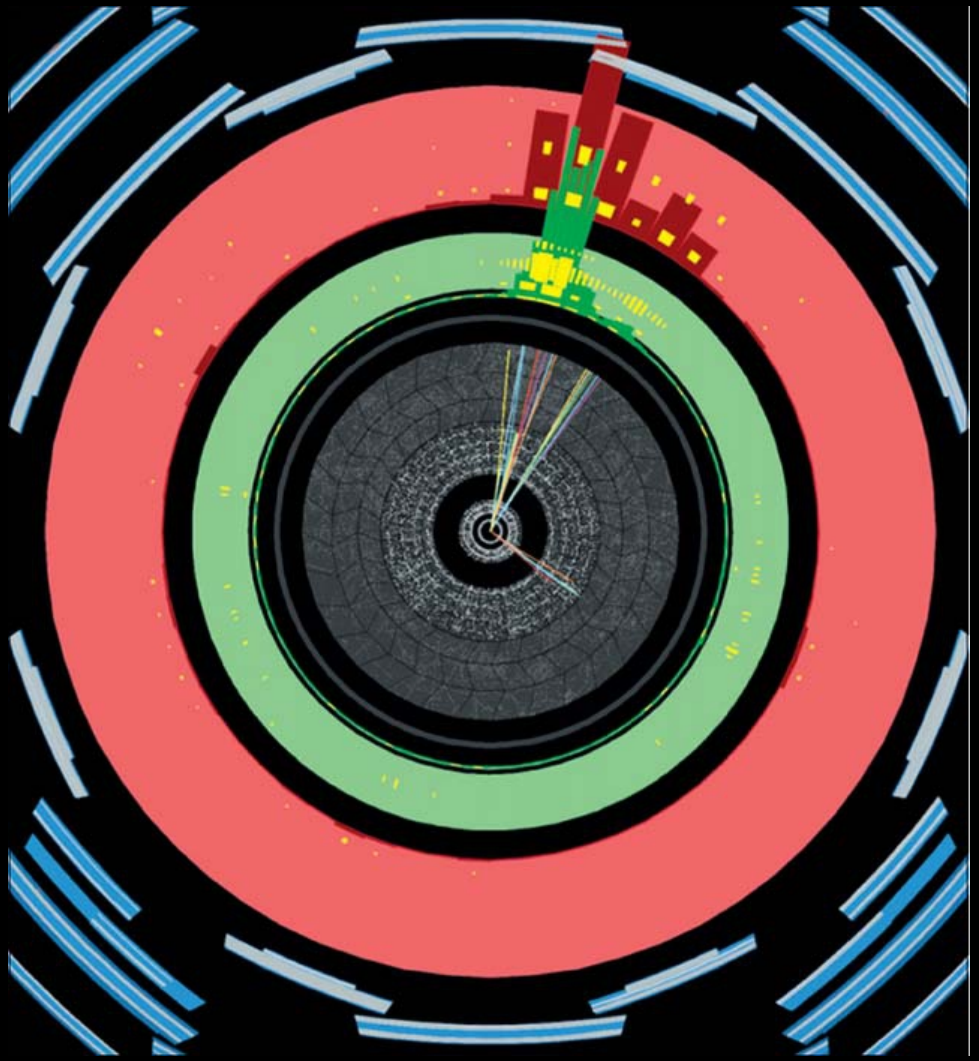
Is the Higgs a Portal?



In the Standard Model
The Higgs is the "mass giver", and couples to Everything with mass
Does it interact with Dark Matter?

How to find Dark things at the LHC

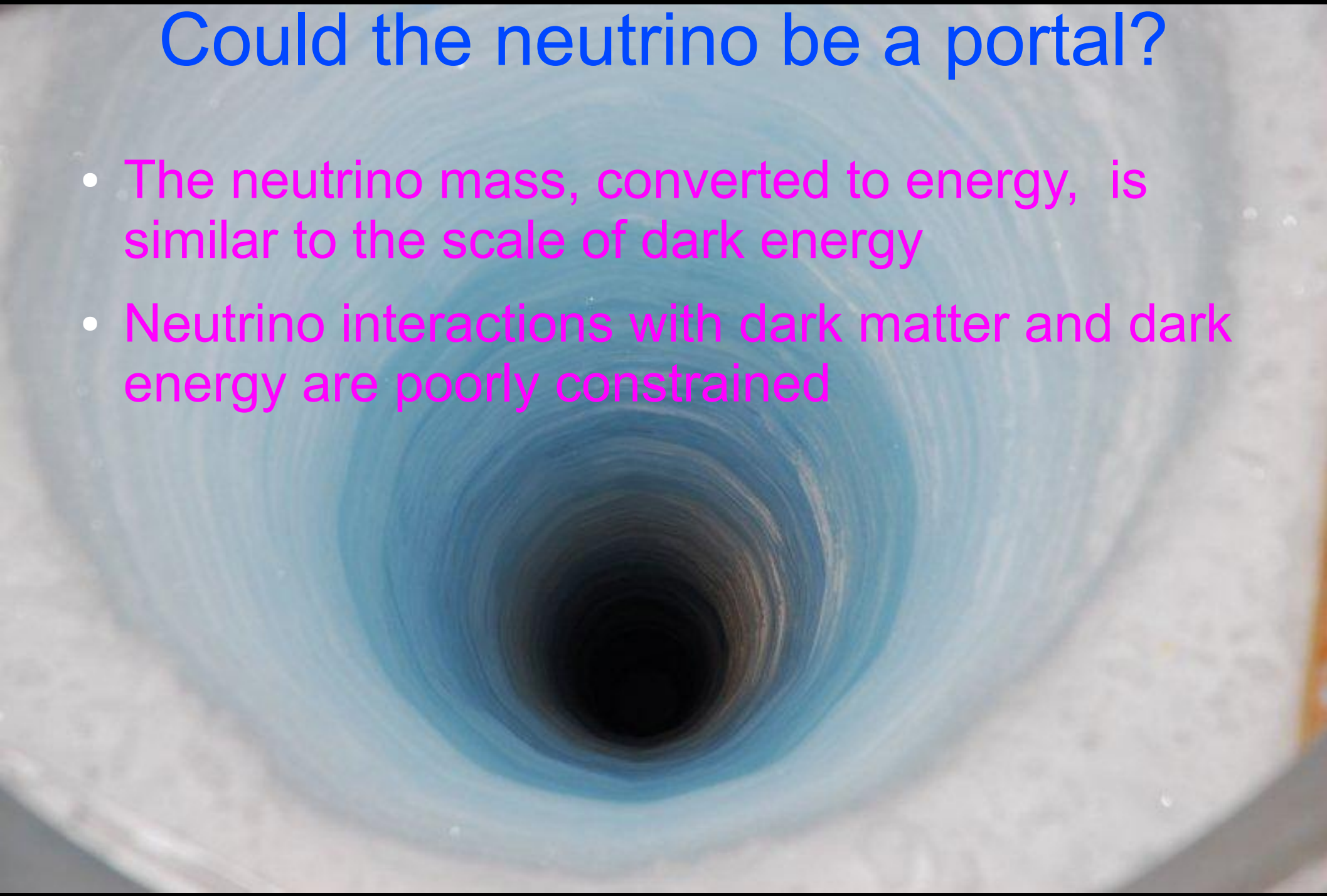




Dimensional Analysis
New physics at low scale?

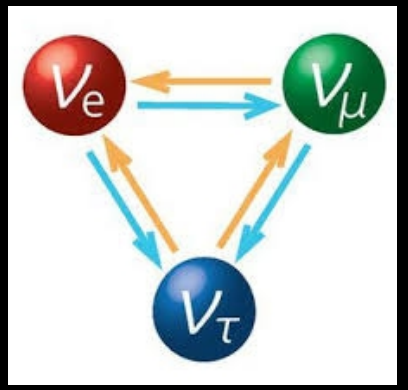
$$\left(\Lambda = \left(2.6 \times 10^{-3}\right)^4 \text{ eV}^4\right)$$

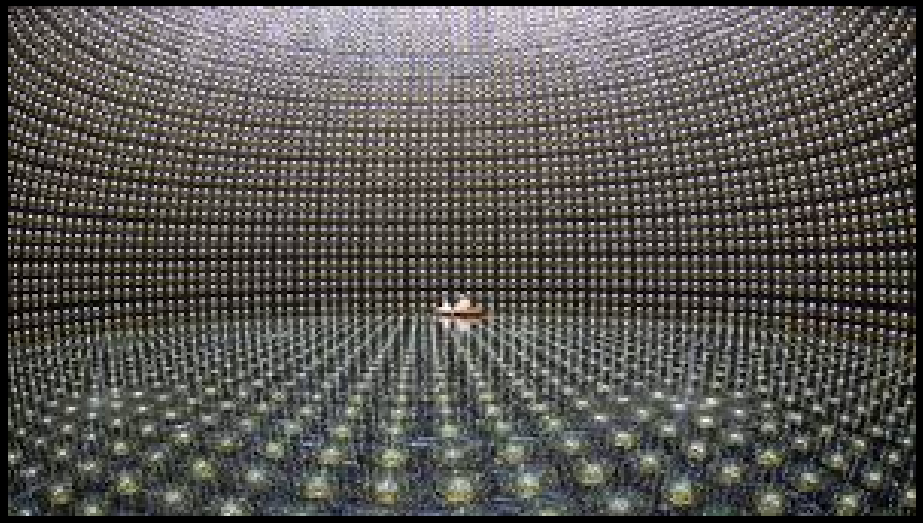
Could the neutrino be a portal?



- The neutrino mass, converted to energy, is similar to the scale of dark energy
- Neutrino interactions with dark matter and dark energy are poorly constrained

New ν interactions

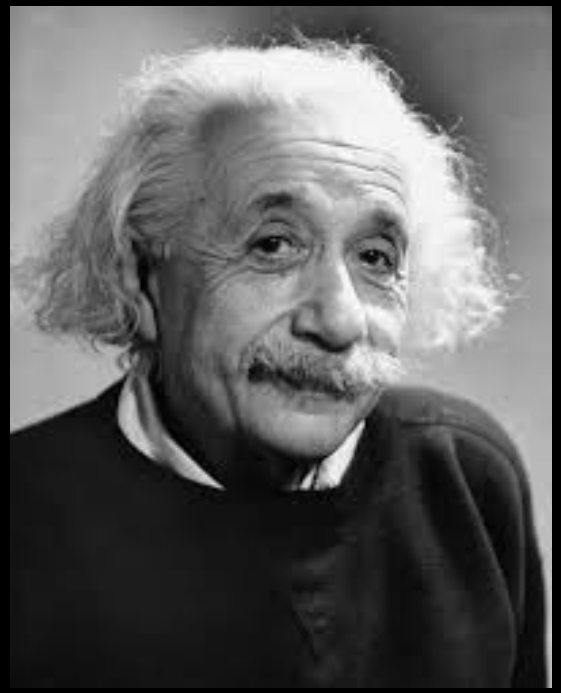




Why study the dark universe?

The most beautiful thing we can experience is the mysterious. It is the source of all true art and science.

Albert Einstein



- http://www.slac.stanford.edu/econf/C1307292/docs/CosmicFrontier.html

SNOWMASS 2013

Cosmic Frontier

hapter 4: Cosmic Frontier
onveners: J. L. Feng and S. Ritz

Vorking Group Summary (arXiv:1401.6085)

ubgroup Reports:

4.	WIMP Dark Matter Direct Detection	1310.8327
5.	WIMP Dark Matter Indirect Detection	1310.7040
6.	Non-WIMP Dark Matter	1310.8642
7.	Dark Matter Complementarity	1310.8621
8.	Dark Energy and CMB	1309.5386
9.	Cosmic Probes of Fundamental Physics	1310.5662