

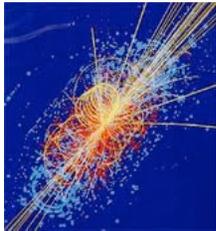
Dark Matter

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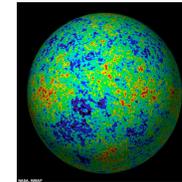
Teacher Academy
06/27/2014

Physics at Different Scales

Particle Physics



Cosmology



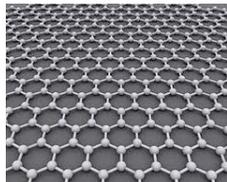
Nuclear Physics



Astronomy



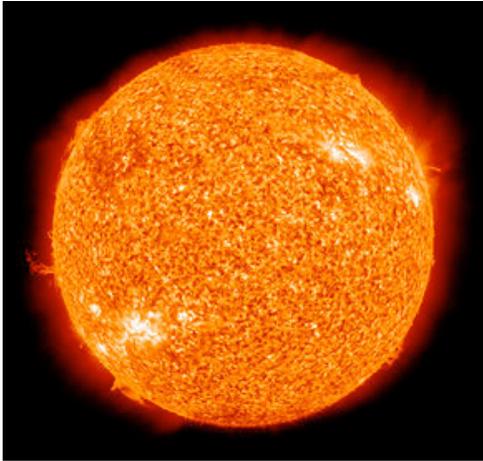
Condensed Matter
Physics



Biophysics



Large Scale Frontier



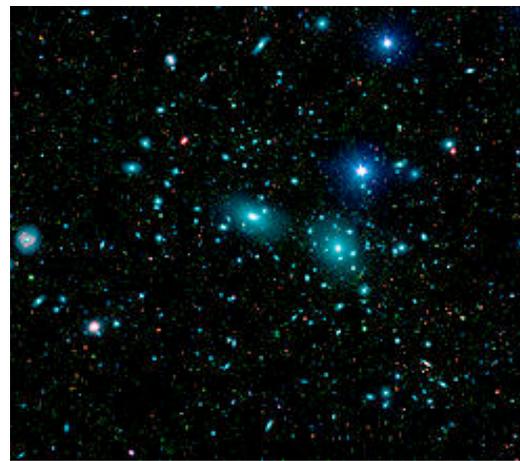
Stars

$\sim 10^{11}$ m



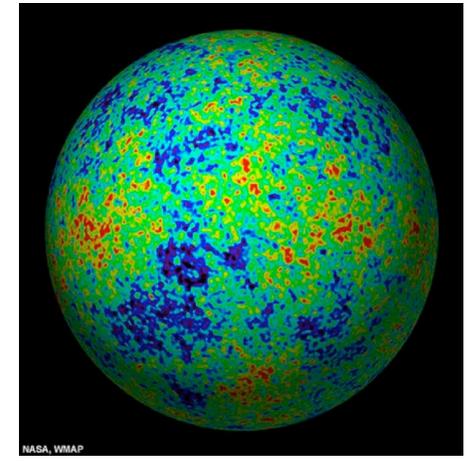
Galaxies

$\sim 10^{21}$ m



Clusters

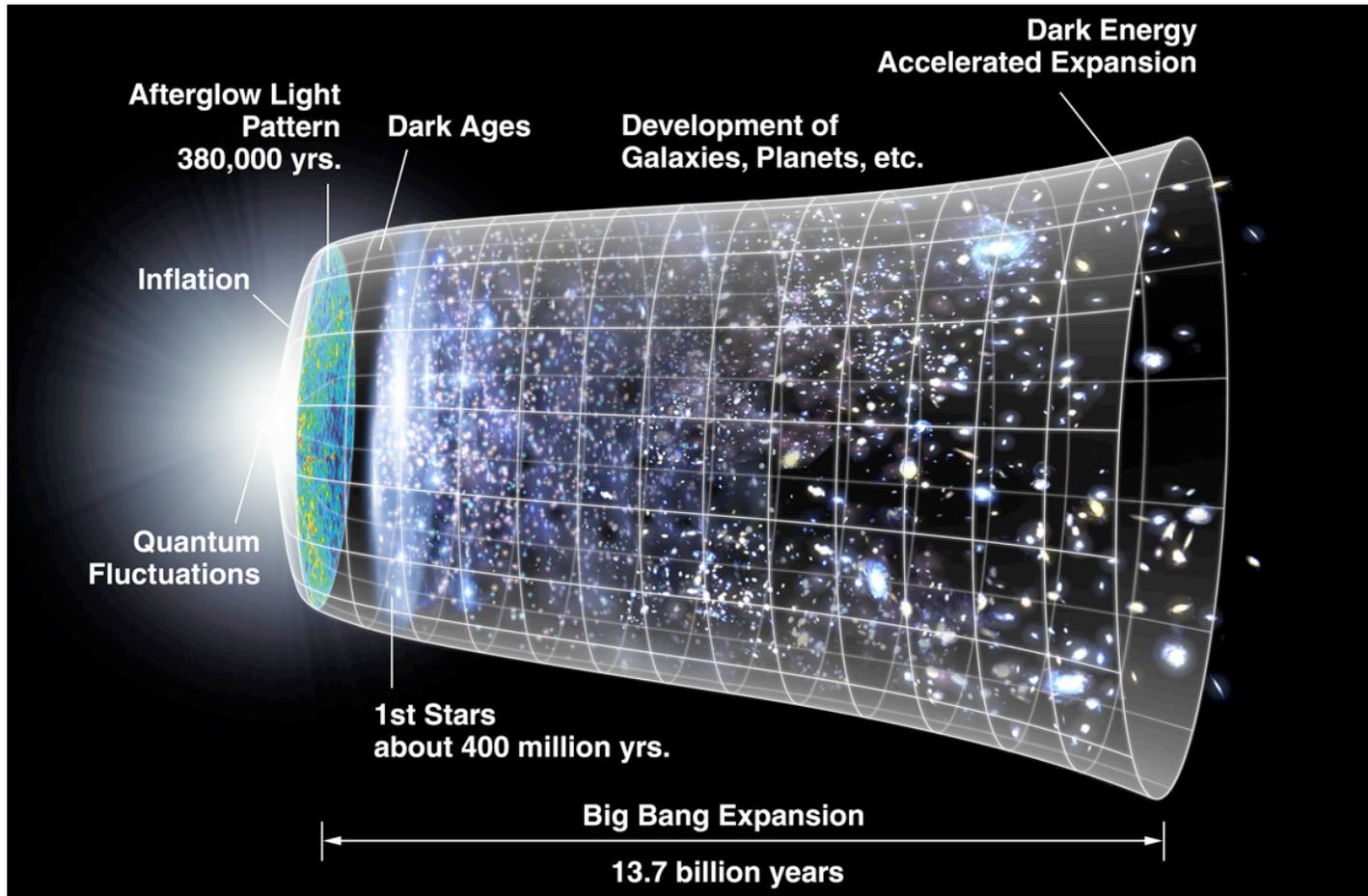
$\sim 10^{23}$ m



Observed
Universe

$\sim 10^{26}$ m

History of the Universe



- We try to understand the universe as a whole

Evidence for Dark Matter

- Galaxy clusters



In the 1930's Fritz Zwicky found that the galaxies in the Coma cluster were moving too fast to be contained by the visible matter

Evidence for Dark Matter

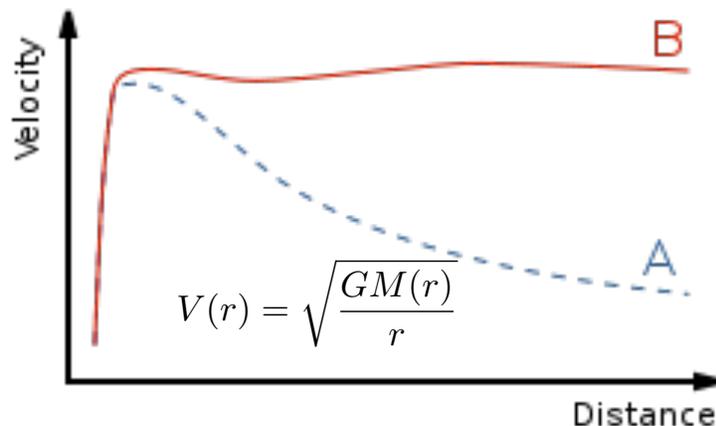


Evidence for Dark Matter

- Spiral galaxies (Rotation curves of galaxies)

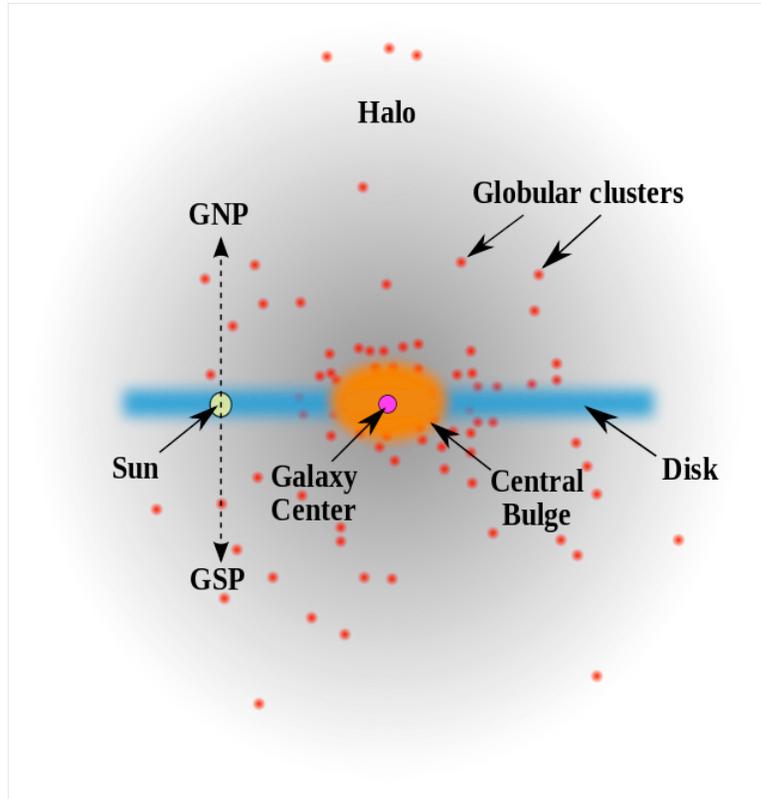


Vera Rubin and her collaborators (1970s)



- Expect v drops beyond luminous region
- Find v is nearly a constant
- The discrepancy is resolved by dark matter

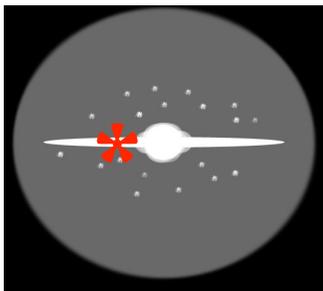
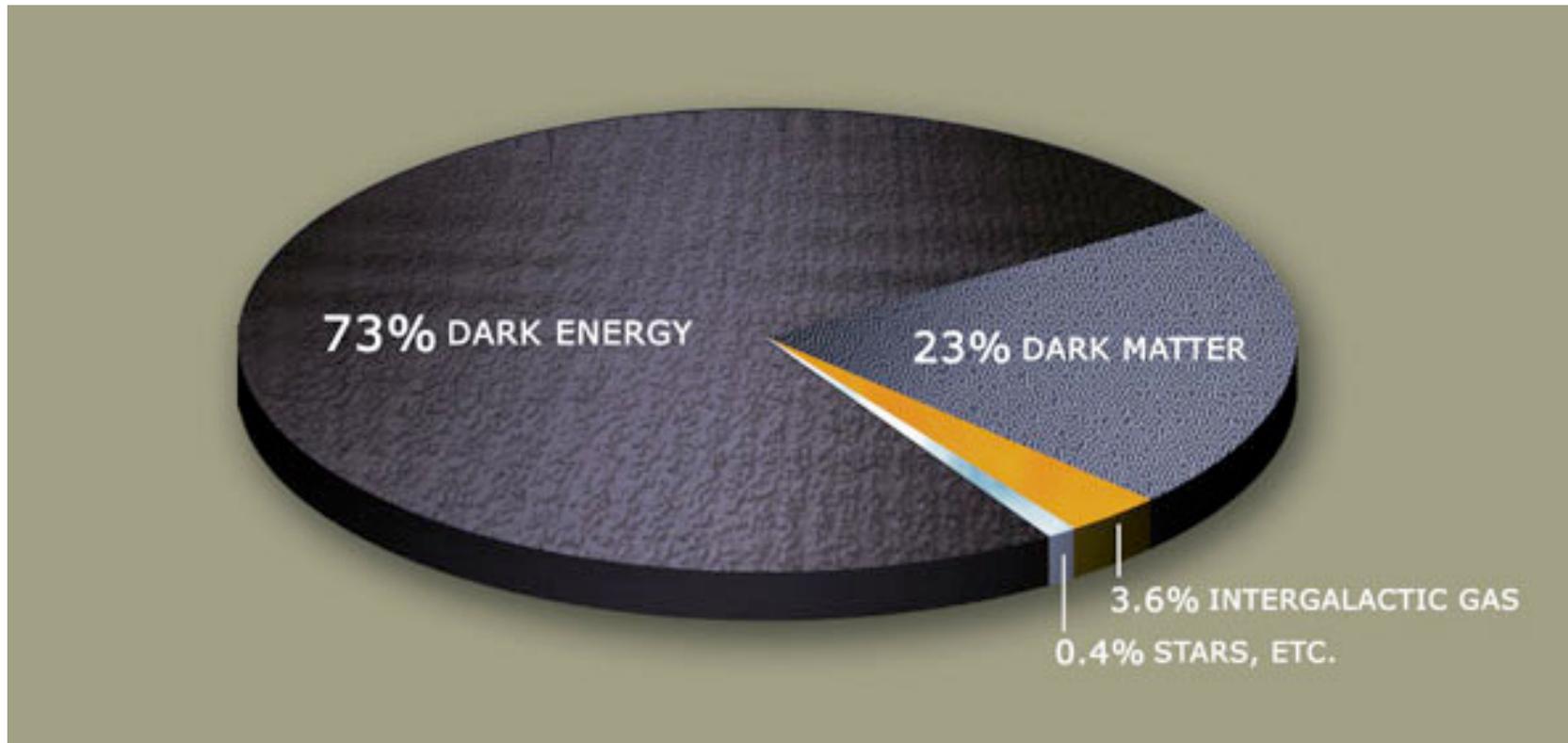
Milky Way Dark Halo



Dark halo mass: $\sim 10^{12} M_{\text{sun}}$

Total stellar mass: $\sim 6 \times 10^{10} M_{\text{sun}}$

Components of the Universe

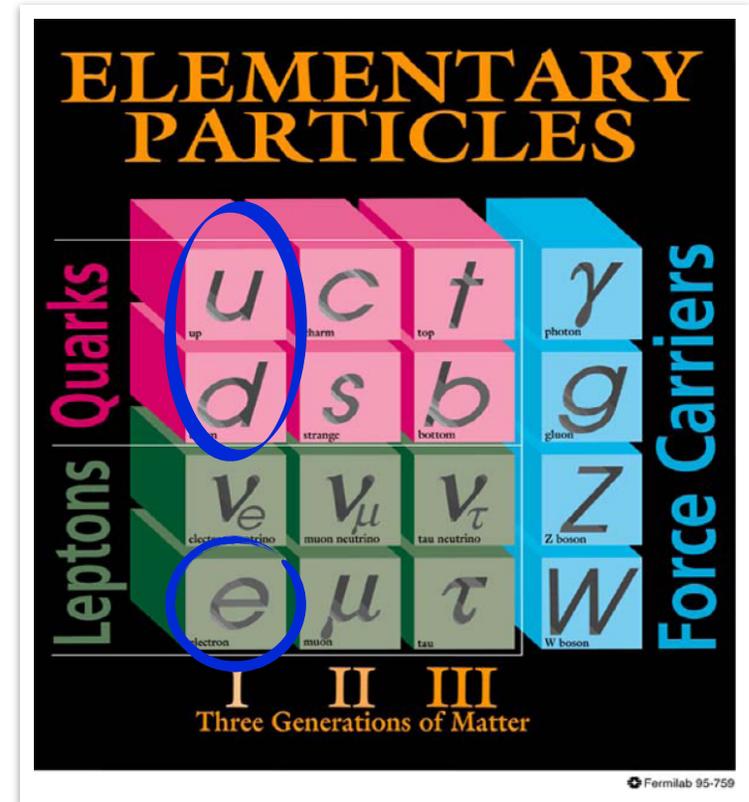
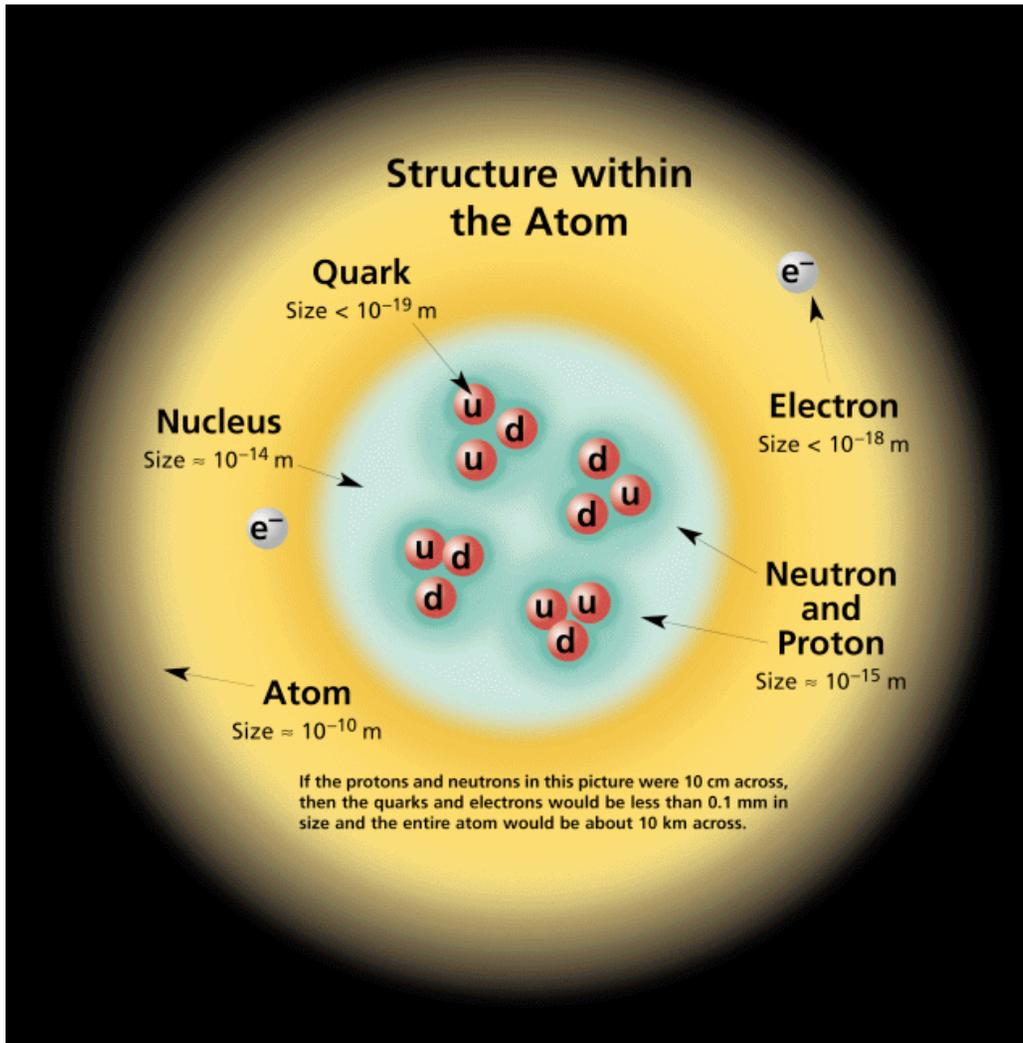


local dark matter information:

density: about one particle per coffee cup
(if the mass is 100 times the proton mass)

velocity: about 220 km/s

Small Scale Frontier



Size: about 10^{-10} m

Fundamental Interactions

Gravity

Gravity is represented by an apple and a portrait of Isaac Newton.

Electromagnetism

Electromagnetism is represented by a lightning bolt striking the ocean.

Weak

$n \rightarrow p e^- \bar{\nu}_e$

A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.

Strong

Strong interaction is shown as a nucleon containing two up quarks (u) and one down quark (d) held together by gluons.

PHOTON γ

His eyes red from traveling so fast, the **PHOTON** is a quanta of visible light, a wave/particle that communicates the electromagnetic force, traveling at the speed of light (dub). With a mass and electric charge of zero, it also carries microwaves, radio waves and x-rays.

Acrylic felt with poly fill for minimum mass.

\$9.75 PLUS SHIPPING

GLUON g

The 'glue' of the strong nuclear force, the **GLUON** is the force that communicates the strong force, which holds quarks together. It has no mass or electric charge.

Acrylic felt with poly fill for minimum mass.

\$9 PLUS SHIPPING

W BOSON W^-, W^+

The **W BOSON** is a messenger particle which communicates the weak force. Unlike the photon and gluon bosons, it has a mass. Like the Z boson, it is one of the most short-lived particles known, with a mere 10^{-25} second lifetime. It can be negatively charged (W^-) or positively charged (W^+). Luckily you can have both, as they're double-sided.

3-SIDE **W+ side**

Z BOSON Z

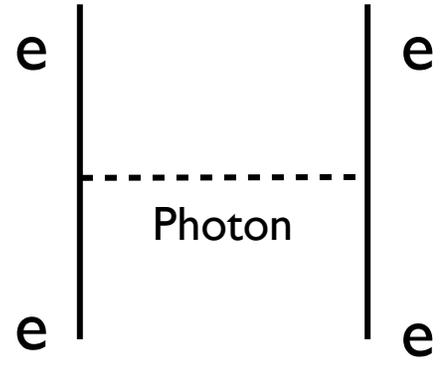
The **Z BOSON** is a very massive carrier particle for the weak force. Unlike its siblings the W^+ / W^- particles, the Z is neutrally charged. Lasting only 10^{-25} seconds, the Z quickly decays into other particles. Discovered in 1961, the Z has allowed physicists to test for the study of electroweak theory.

GRAVITON G

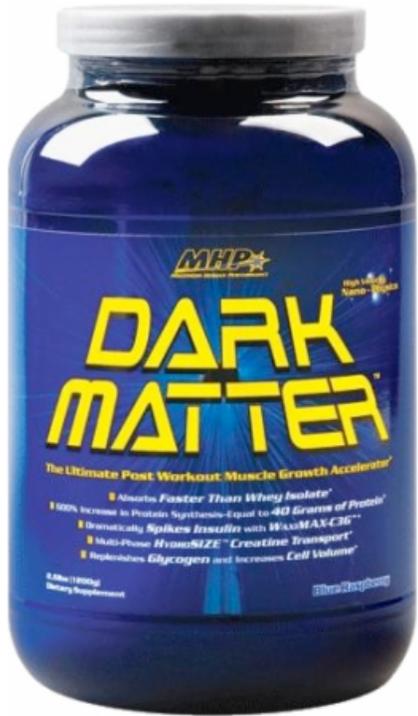
The **GRAVITON** is a particle not yet observed. It communicates the force of gravity and is the smallest bundle of the gravitational force field. Some theorists believe gravitons can travel between frameworks. Lucky T'll feel!

Acrylic felt with poly fill for minimum mass.

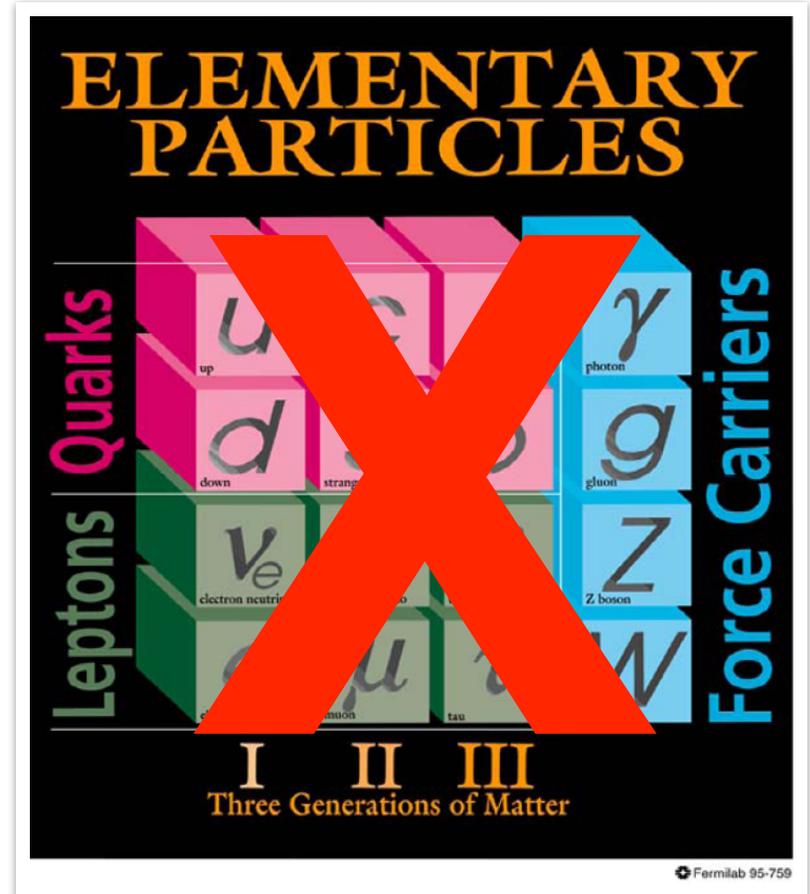
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Dark Matter Properties

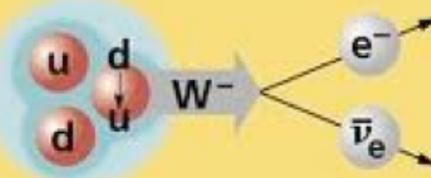
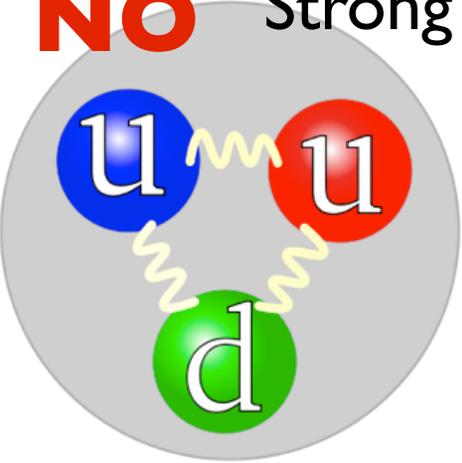


- Not luminous
- Not short-lived
- Not hot
- Not baryons



The successful standard models of cosmology and particle physics are **inconsistent**

Dark Matter Interactions

 <p>Gravity YES</p> 	<p>Electromagnetism NO</p> 
<p>$n \rightarrow p e^- \bar{\nu}_e$ Weak Maybe</p>  <p>A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.</p>	<p>NO Strong</p> 

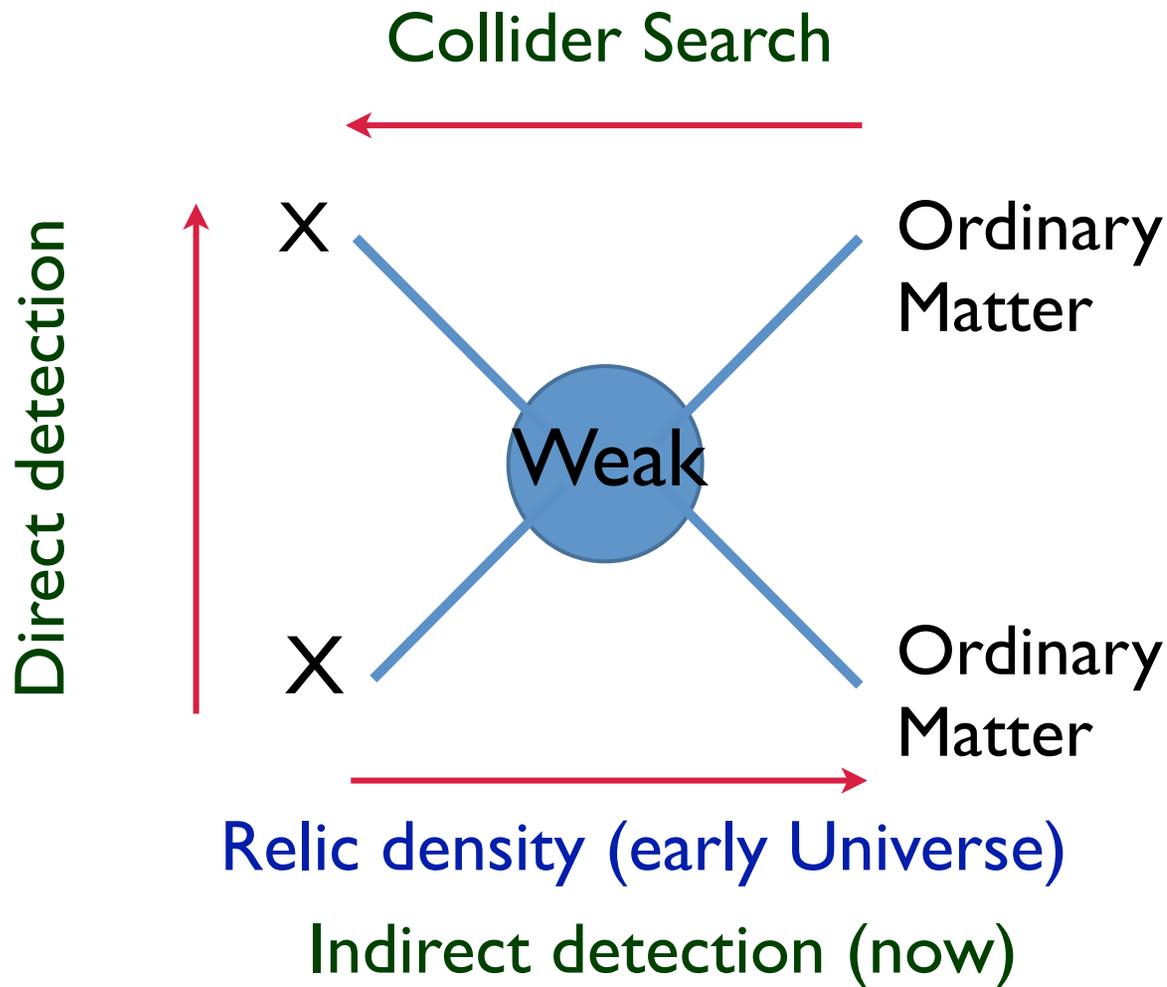
Dark matter candidate:

- Add a new massive particle X
- Interacts with us through the weak interaction

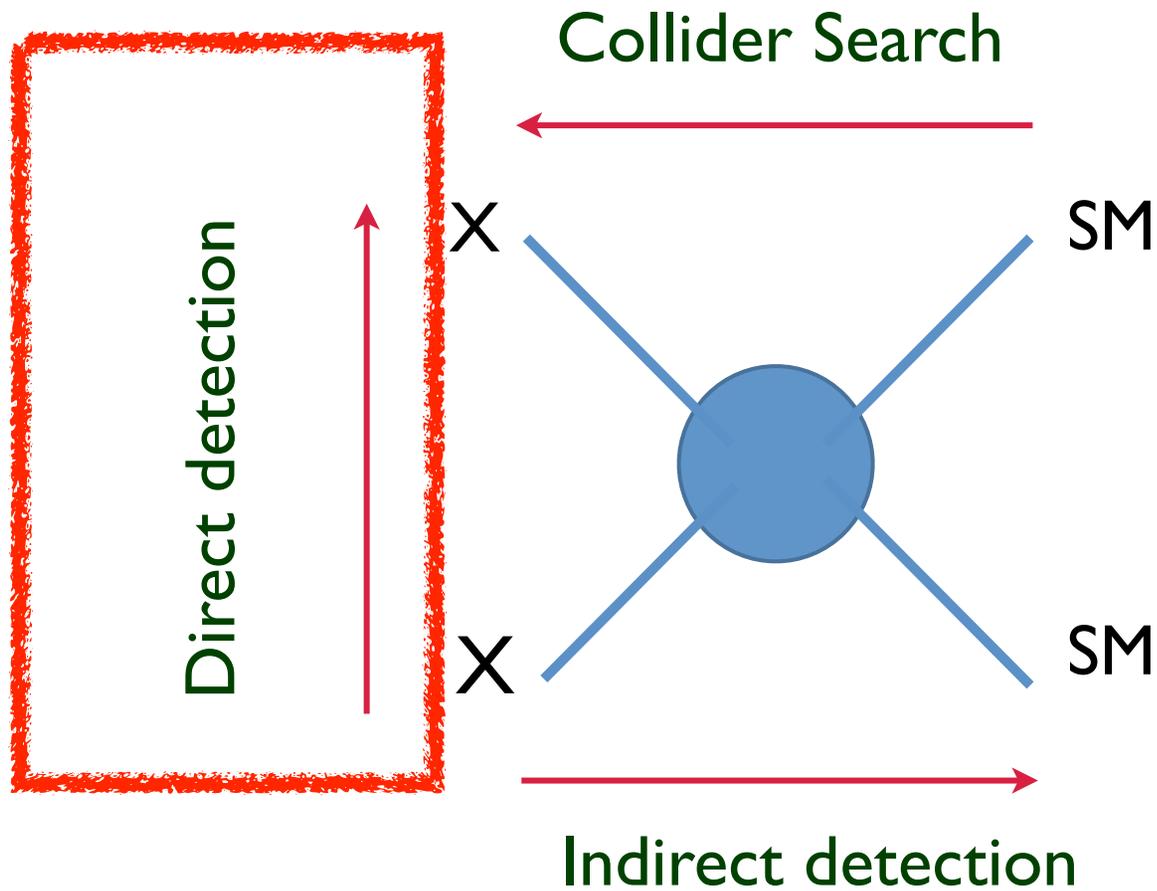
Weakly-Interacting Massive Particle (WIMP)

The WIMP Paradigm

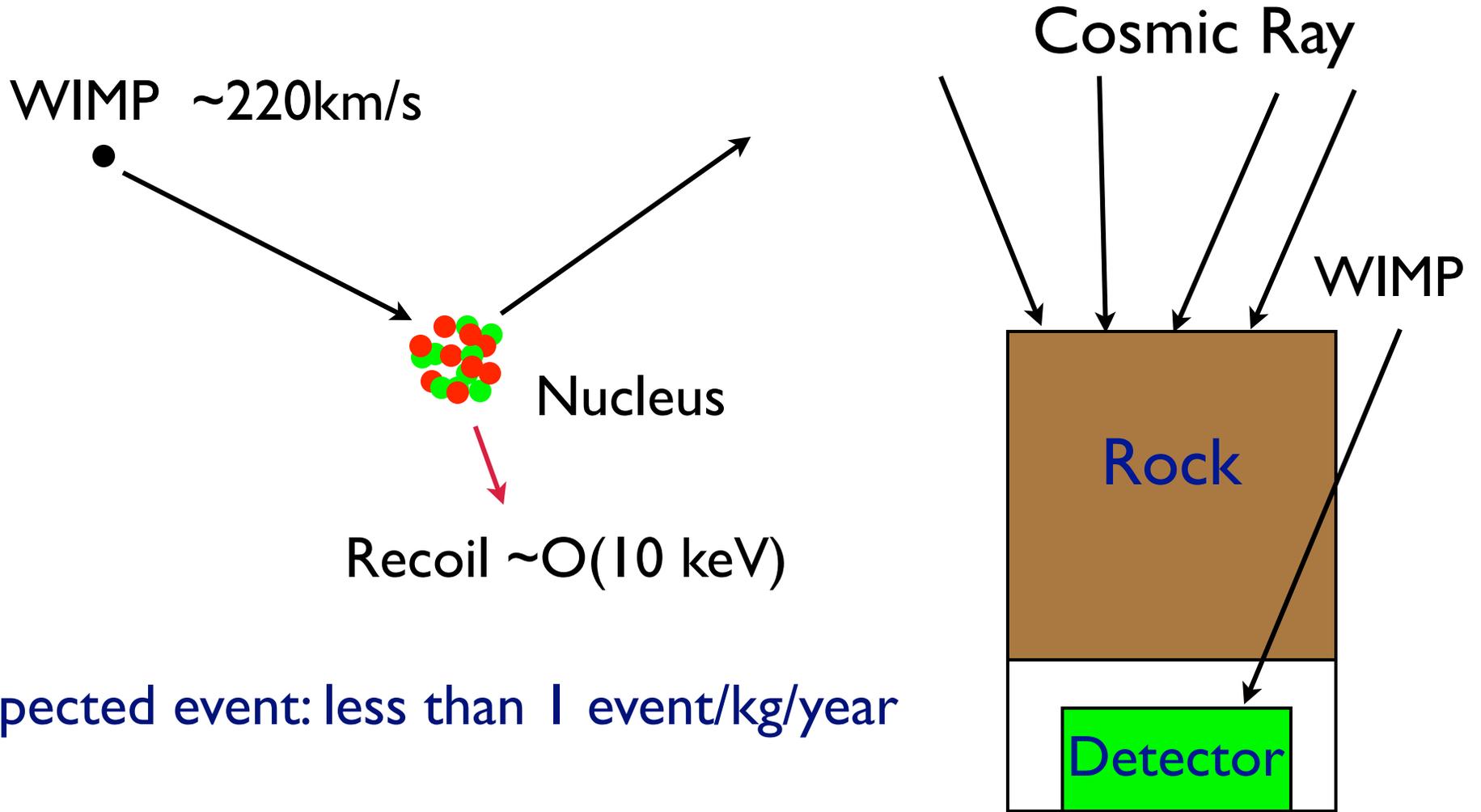
- The WIMP Miracle



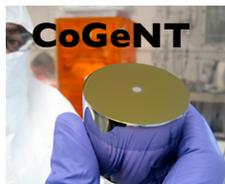
Direct Detection



Direct Detection

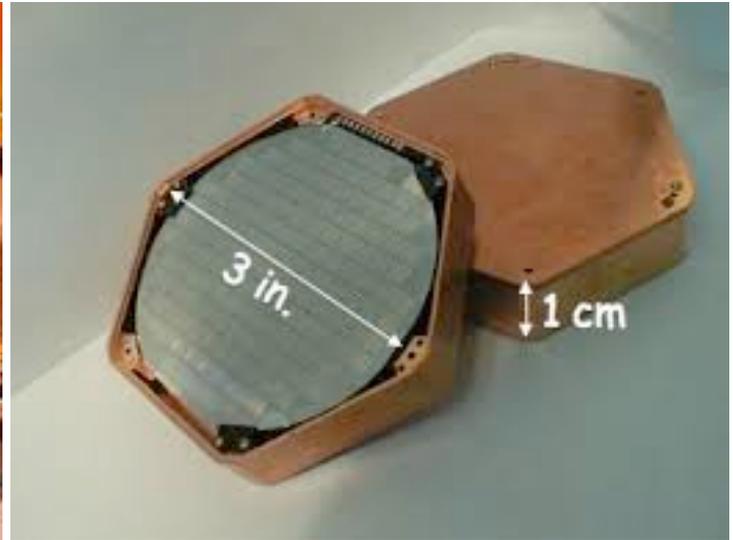


Expected event: less than 1 event/kg/year

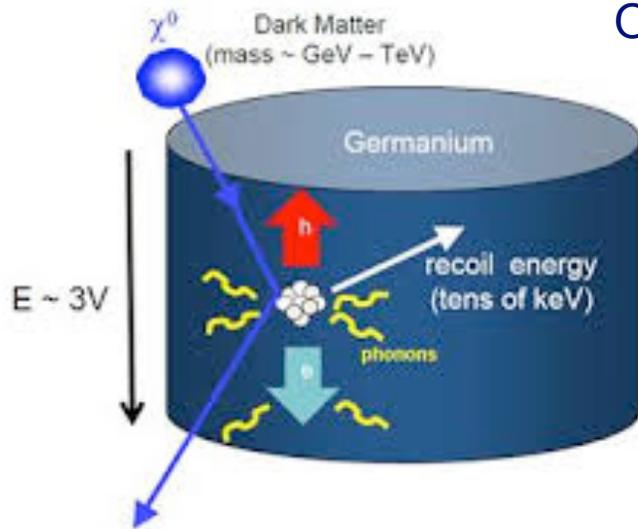


Direct Detection

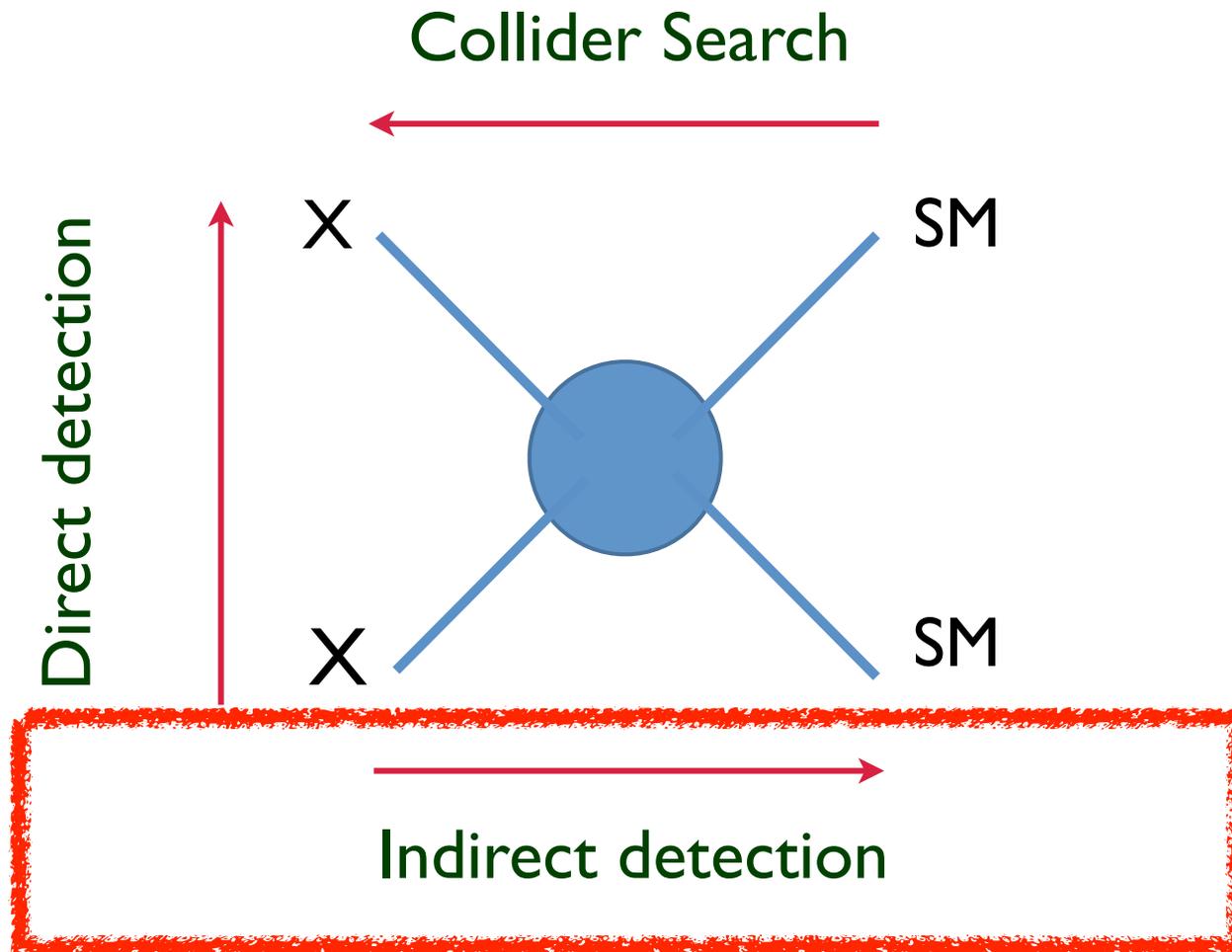
- Cryogenic Dark Matter Search (CDMS)



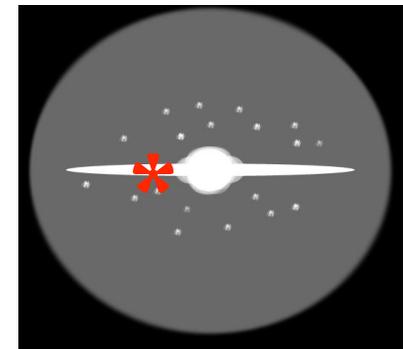
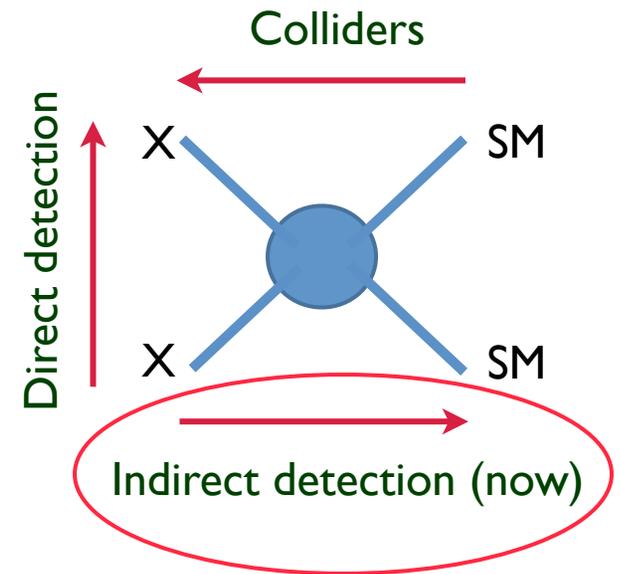
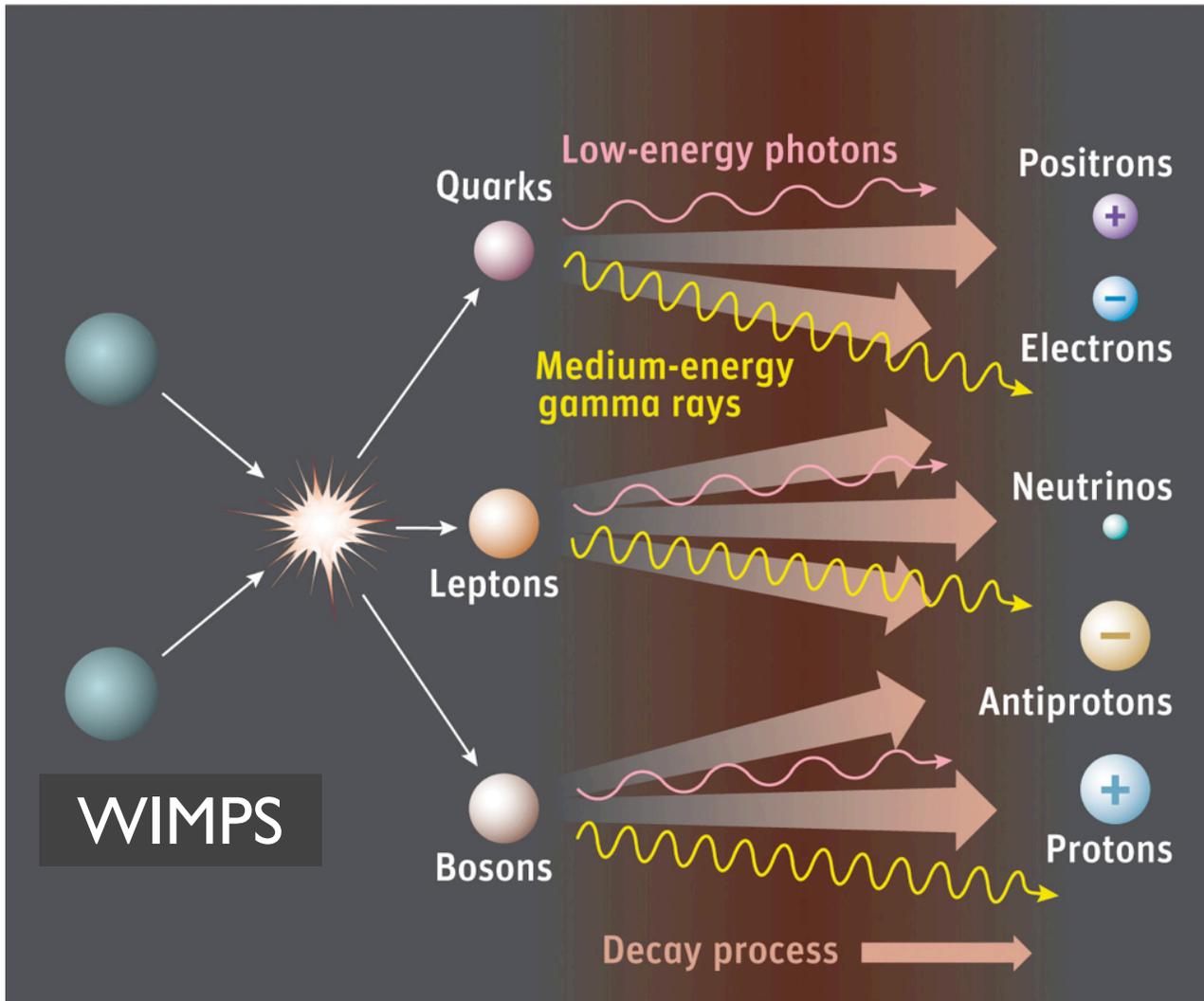
Operating at milli-Kelvin temperatures in a mine in Minnesota



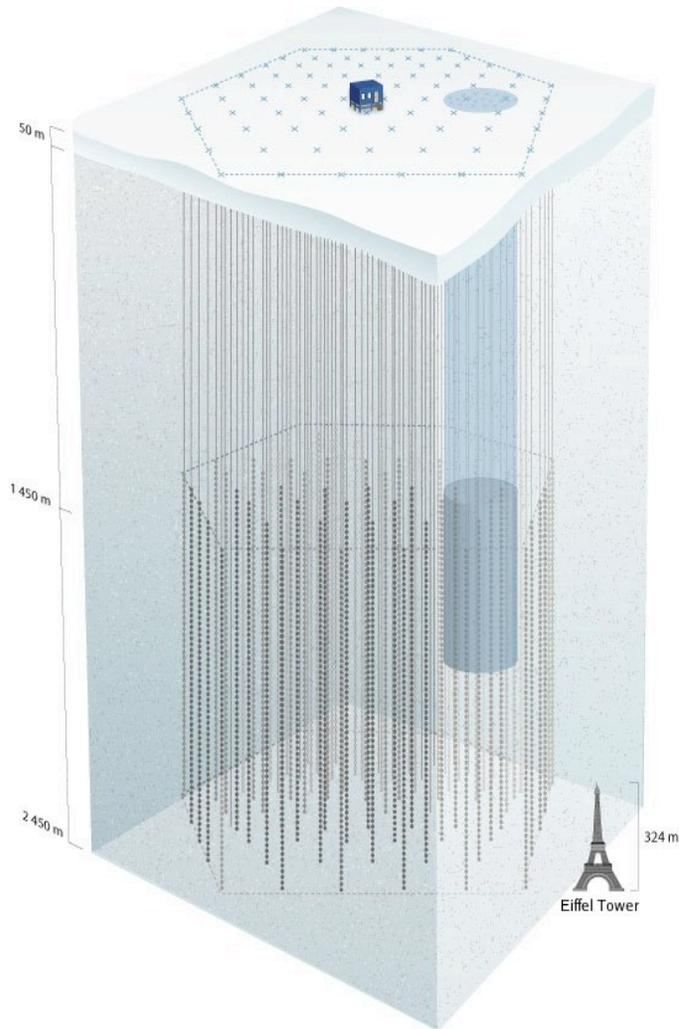
Indirect Detection



Annihilation Signals

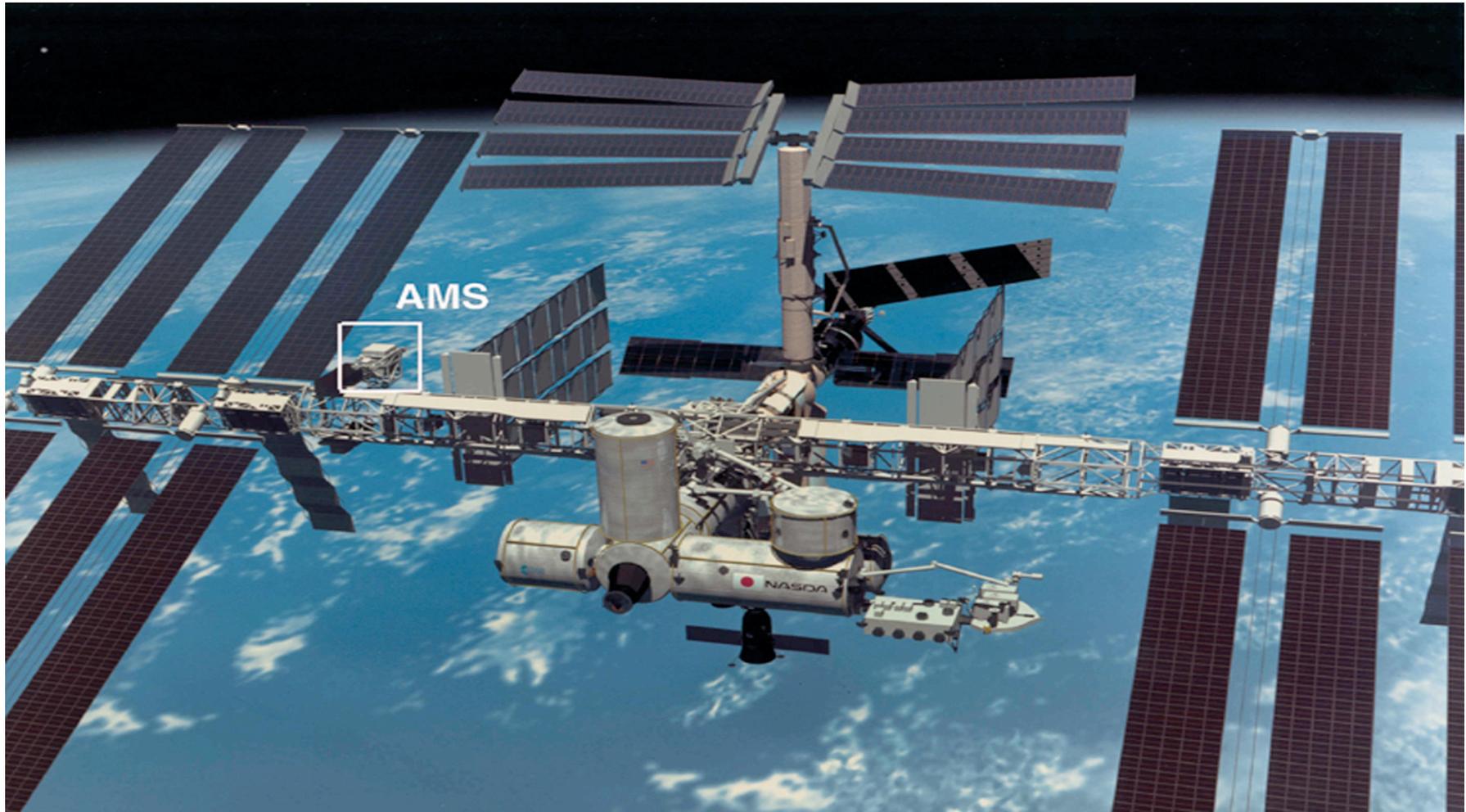


IceCube at the South Pole



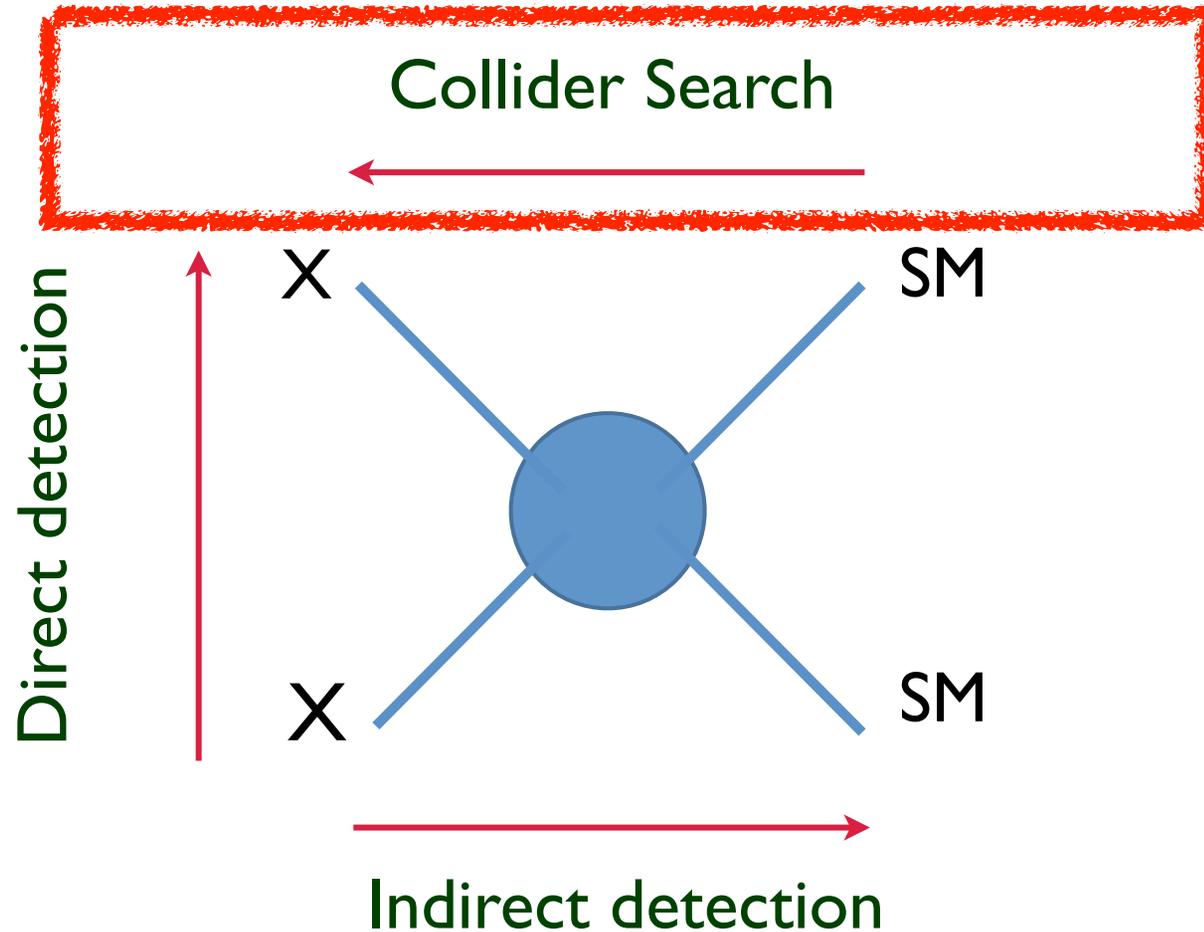
Look for neutrinos from dark matter annihilation

International Space Station



Look for electrons/photons from dark matter annihilation

Collider Search

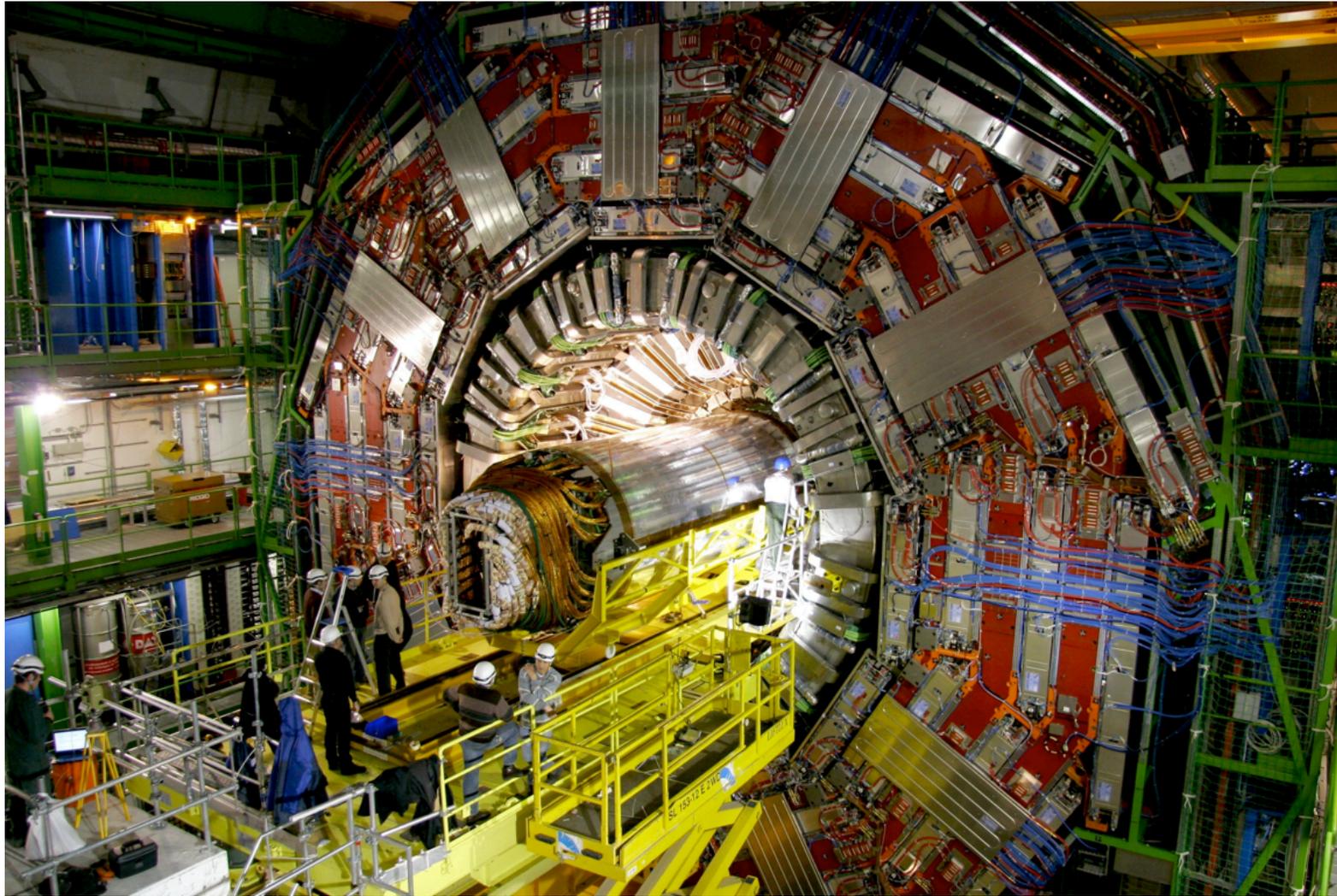


Large Hadron Collider

Colliding protons at 99.999999% the speed of light

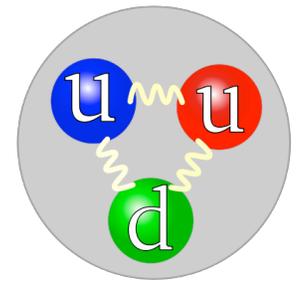
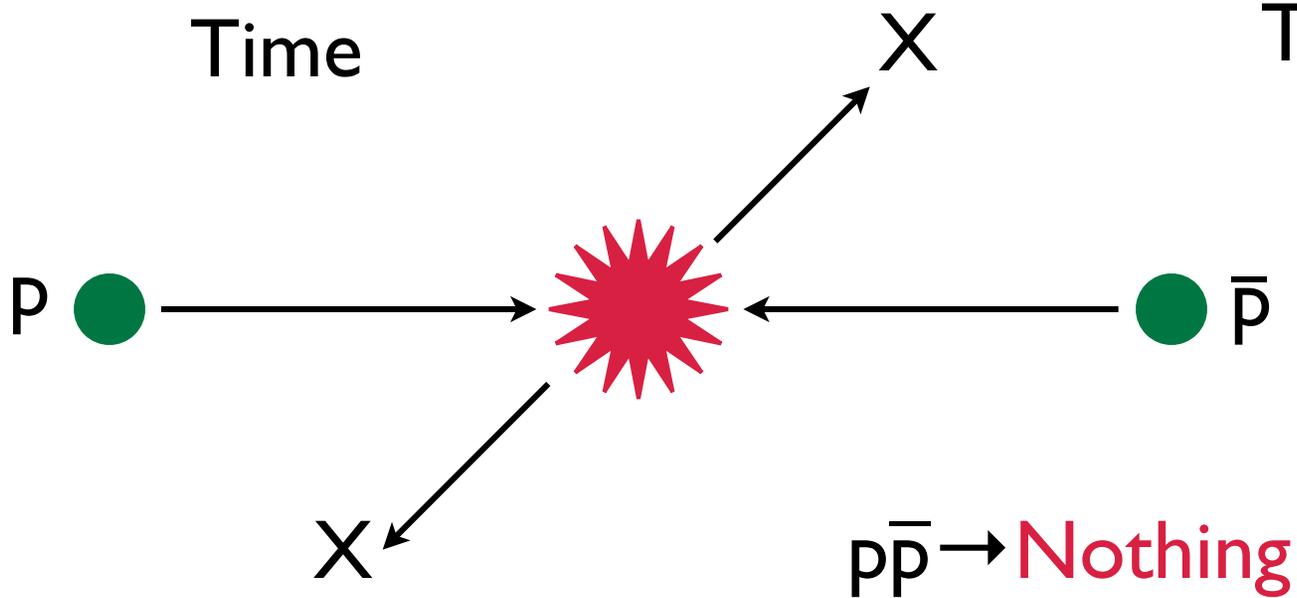
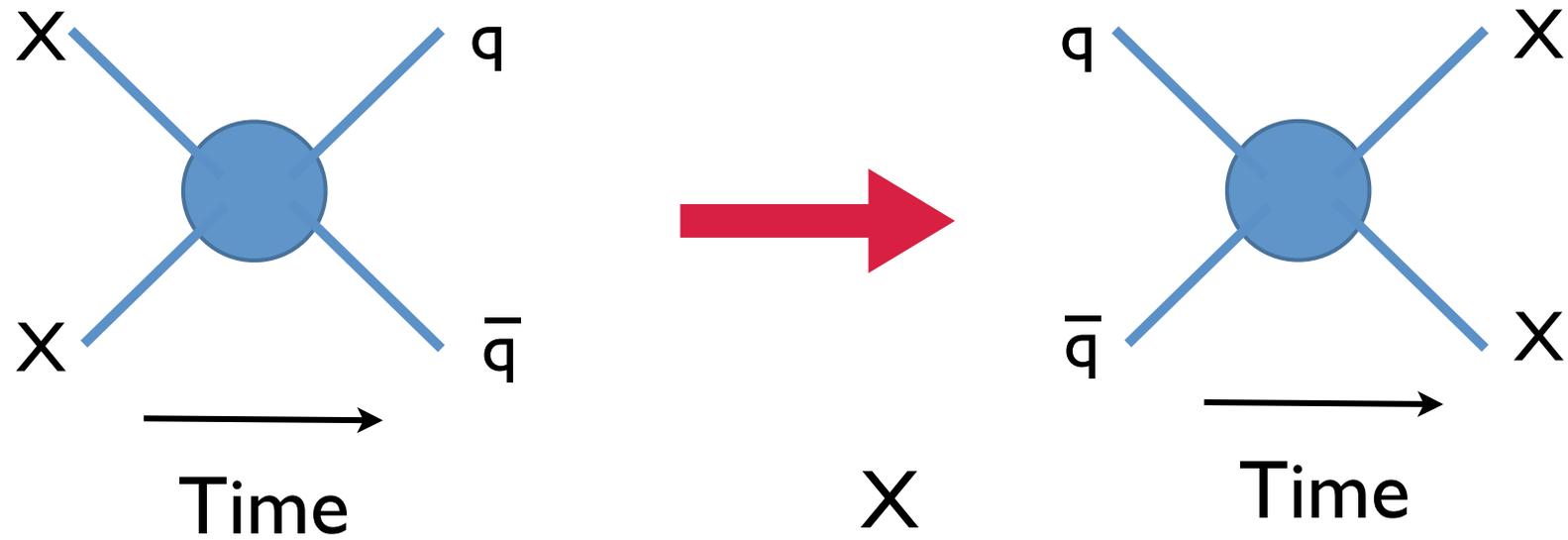


Detector at the LHC

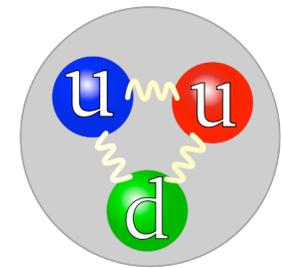
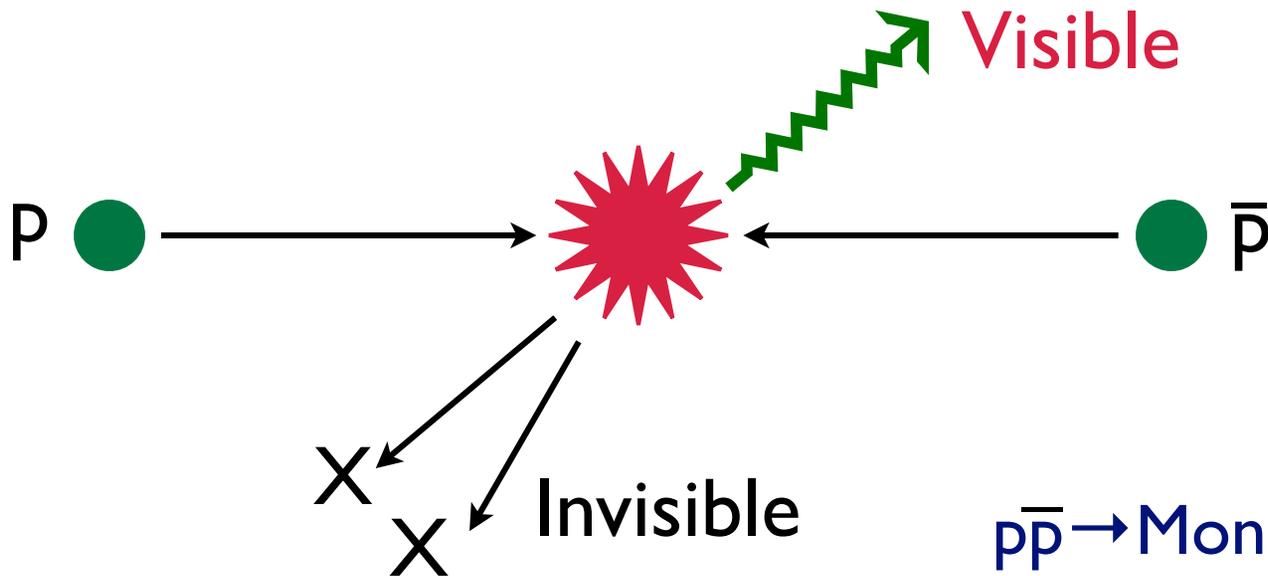
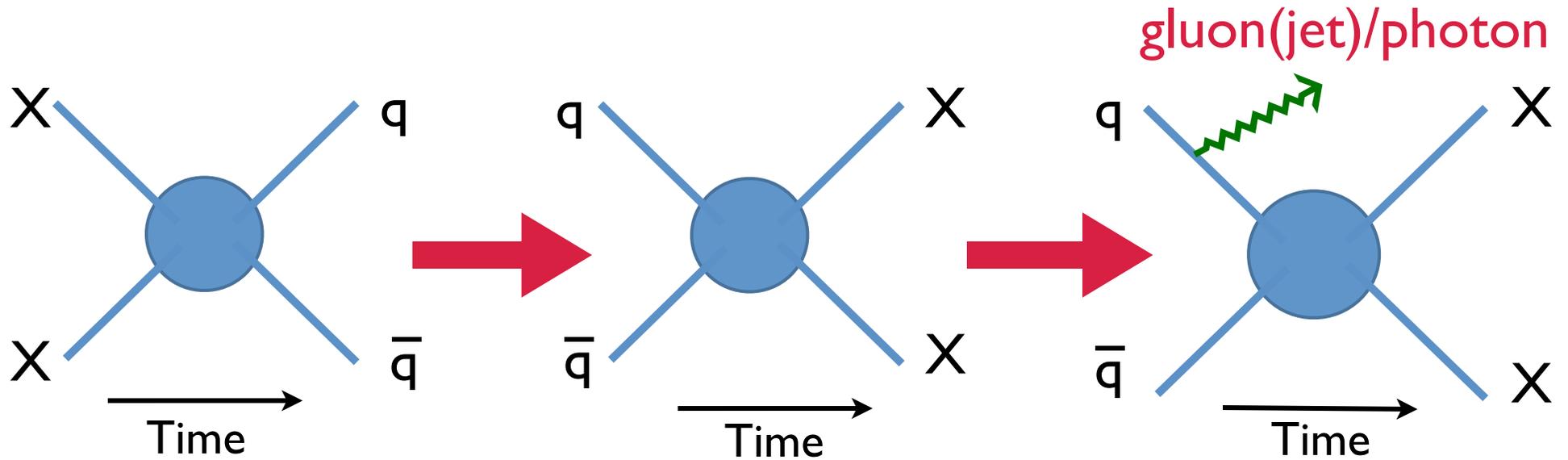


More than 10,000 tonnes

Dark Matter at Colliders



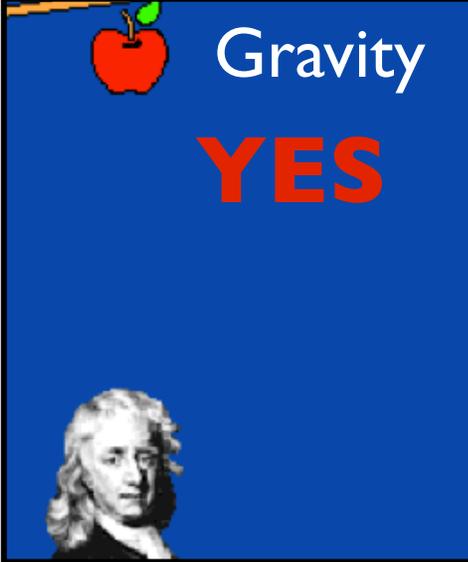
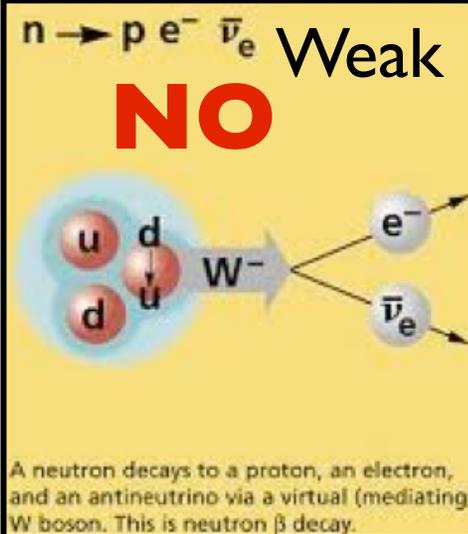
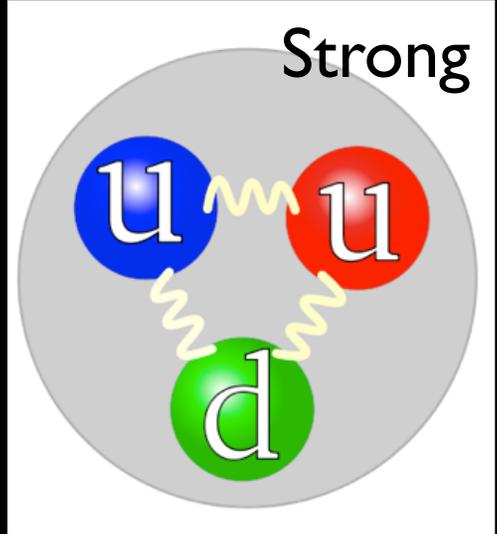
Dark Matter at Colliders



$p\bar{p} \rightarrow \text{Monojet} + \text{Missing Energy}$

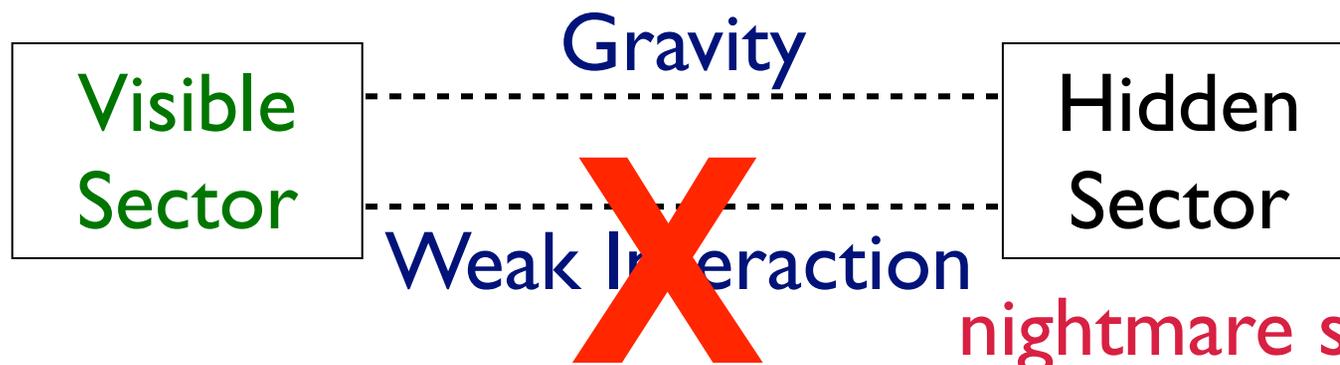
Beyond the WIMP Paradigm

- WIMPs are a good dark matter candidate
- Physicists are searching for WIMPs
- But what if dark matter is not a WIMP...

 <p>Gravity YES</p>	 <p>Electromagnetism NO</p>
<p>$n \rightarrow p e^- \bar{\nu}_e$ Weak NO</p>  <p>A neutron decays to a proton, an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β decay.</p>	<p>Strong</p> 

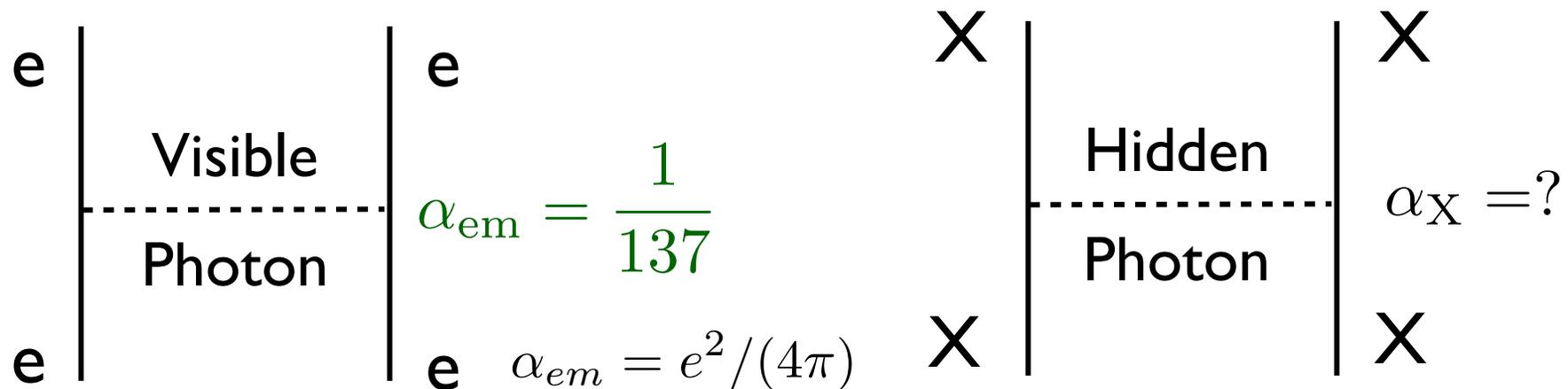
Beyond the WIMP Paradigm

- Hidden sector dark matter



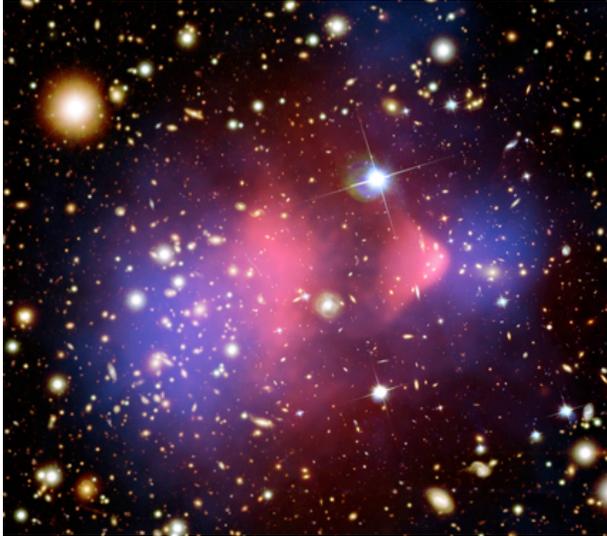
nightmare scenario?

- An example: hidden charged dark matter

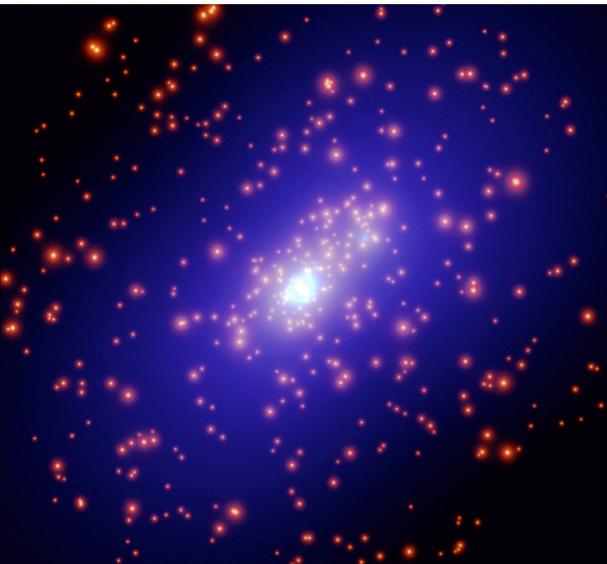


Self-interacting Dark Matter

- Self-interactions can affect dark matter dynamics

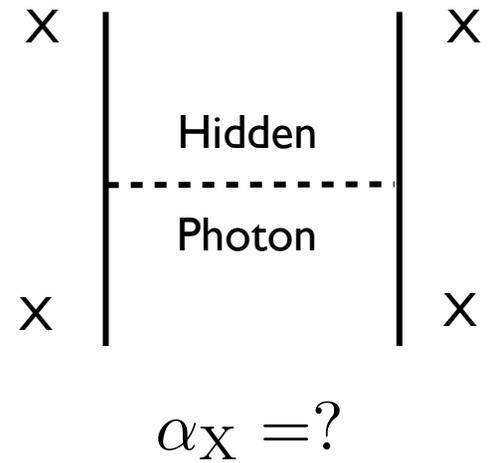
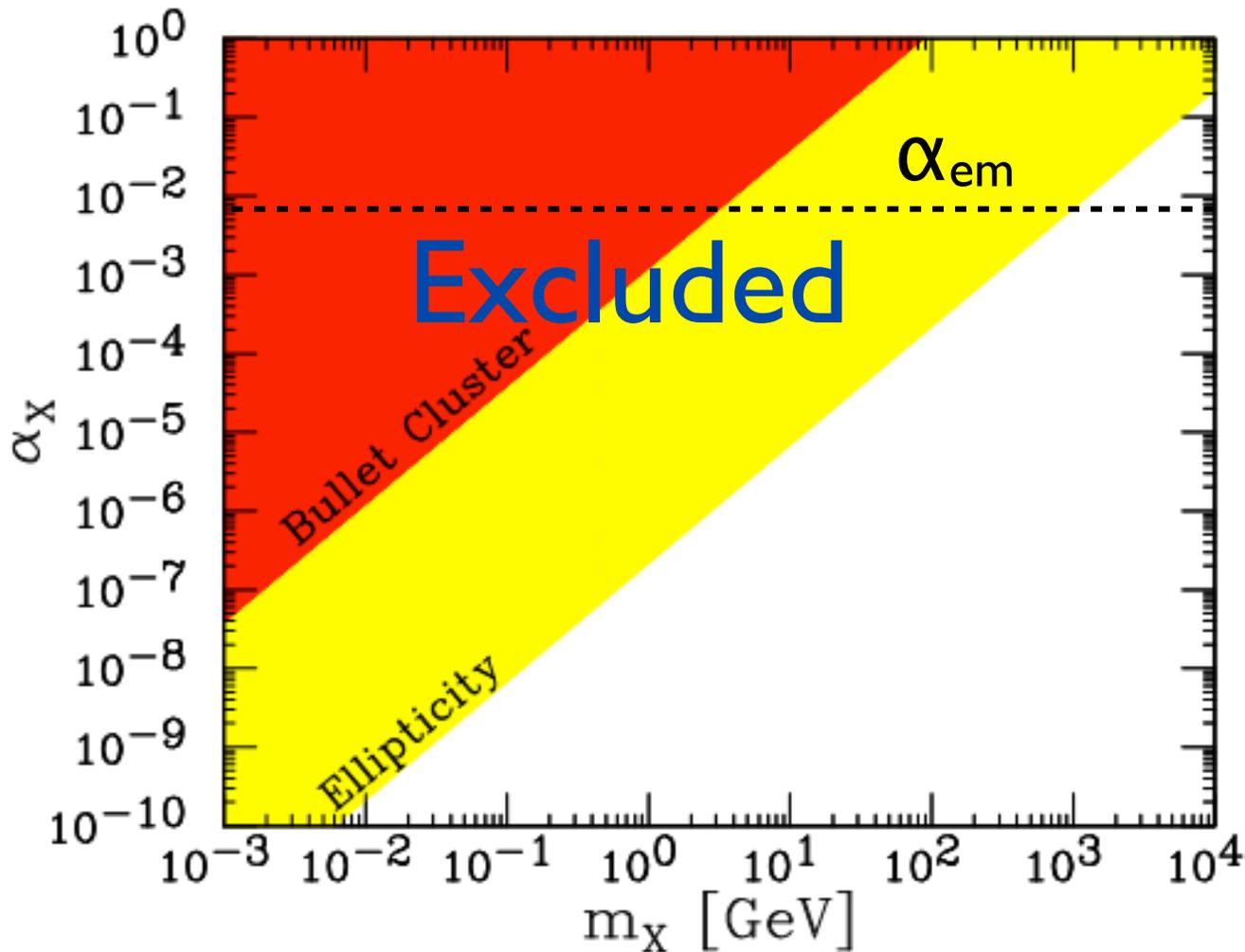


The self-interacting dark matter can behave like hot gas



randomize the dark matter velocity dispersion; lead to **spherical** dark halos

Limit on the Hidden Charge



Summary

- We have two successful theories of the large and small, but they are not consistent
- A quarter of the universe is dark matter, but we don't know what it is
- We have some ideas and many search experiments are underway