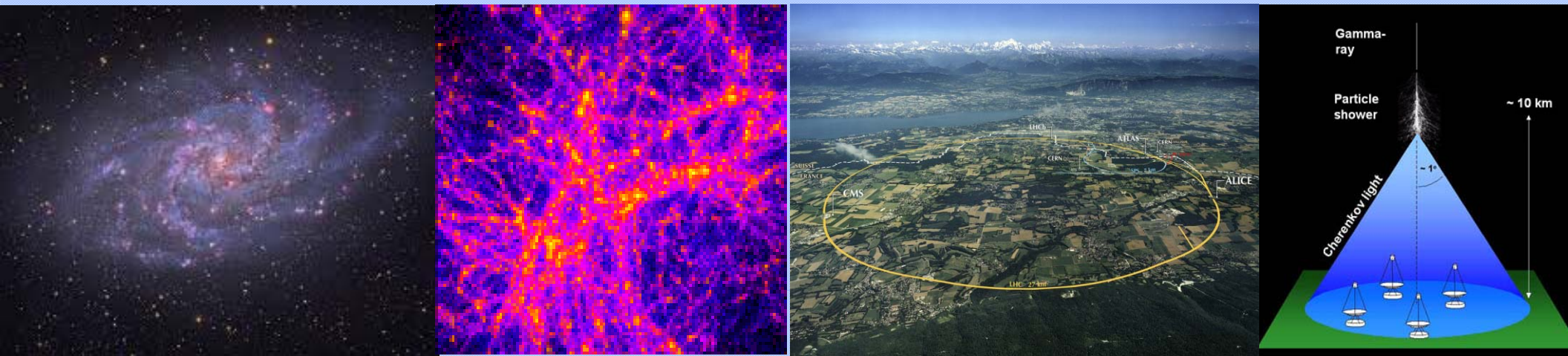


Hunting for the Dark Matter of the Universe



USC Engineering Honors Colloquium
26 April 2013

Rene A. Ong (UCLA)

Outline

- What is Dark Matter ?
- How do we know it's there ?
- What could it be and how are we trying to understand it ?
- Summary

Dark Matter: an Introduction

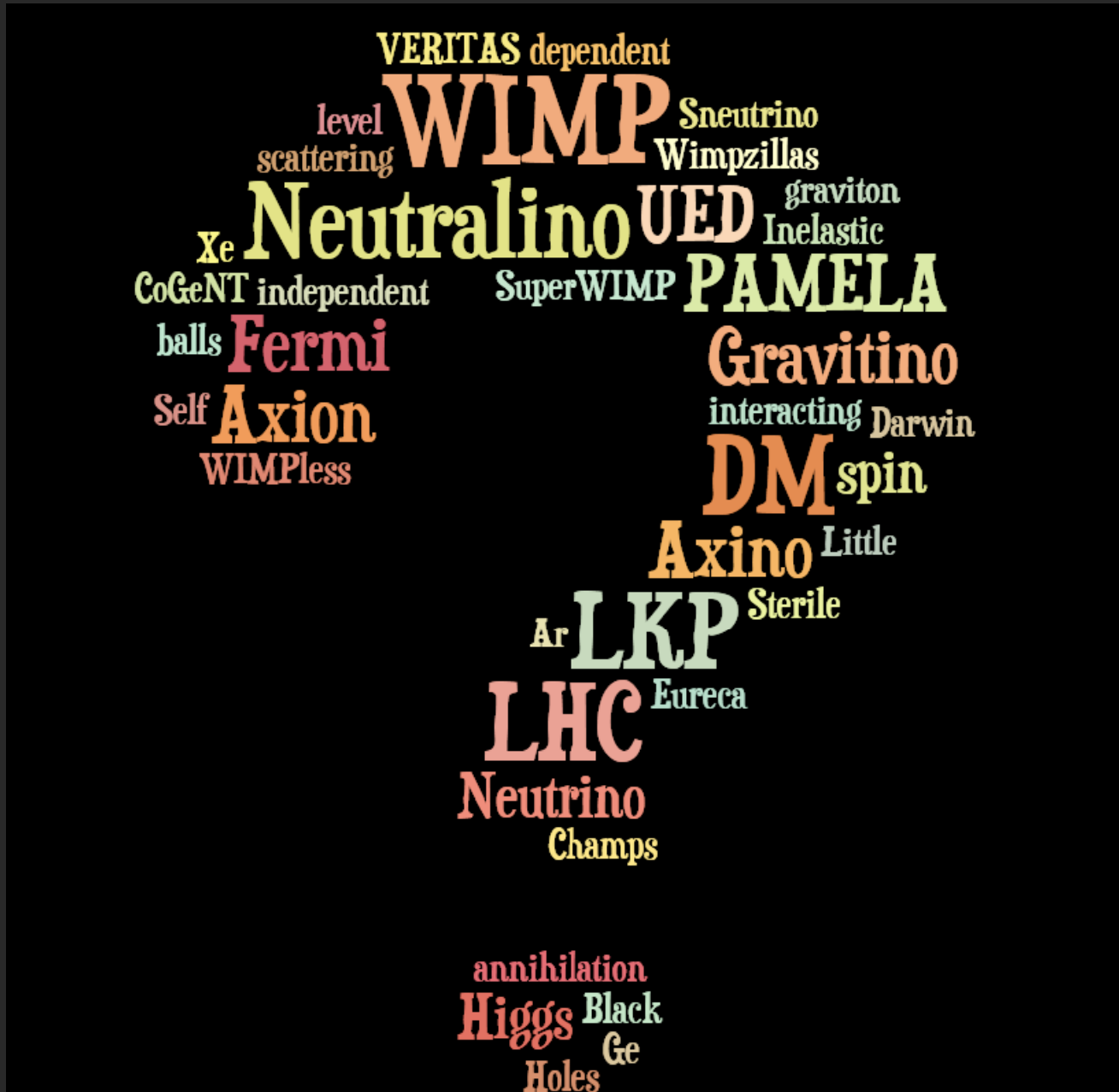
As far as we can tell, we are surrounded by a mysterious, unknown substance known as dark matter (DM).

DM is subject to the gravitational force but is not composed of any known material (e.g. atoms).

Roughly 80% of the mass in the universe is dark. What we see (ordinary atoms) comprises only ~20% of the mass.

So ... what is it ?

It is completely unknown !



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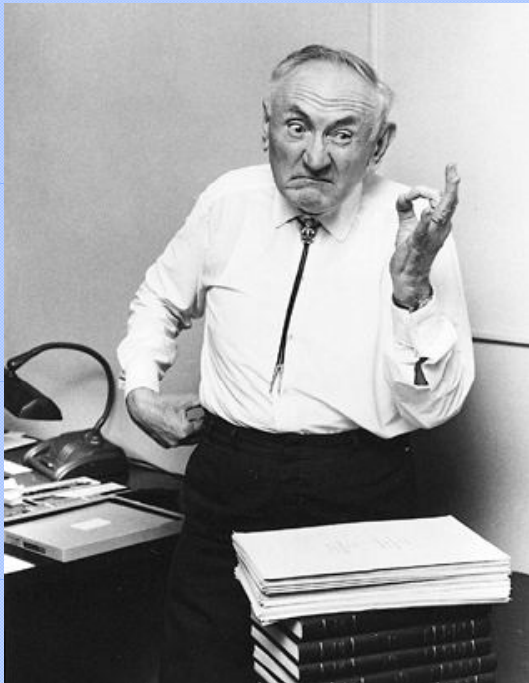
How do we know it's there ?

The main evidence comes from studying the Gravitational forces in astrophysical systems.

Fritz Zwicky (1898-1974)

Studies of galaxy clusters in 1930's

Found galaxy motions not consistent with estimate mass.



Fritz Zwicky



18" Schmidt Telescope



Coma galaxy cluster

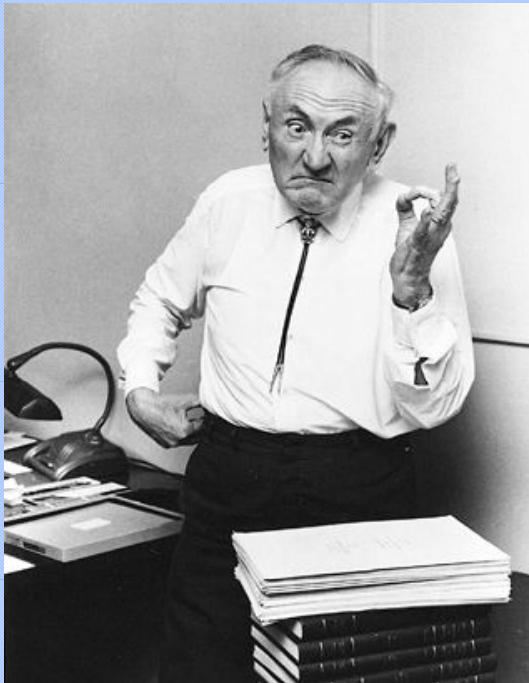
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Spiral Galaxies

Spiral Galaxies provide some of the best evidence for DM.



Step Back for a Moment ...

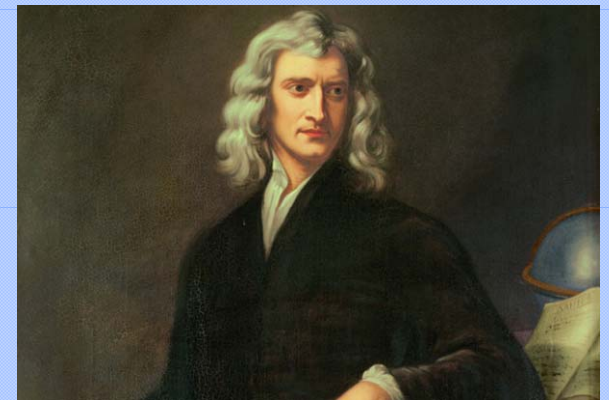
A reminder about Gravity:

Gravitational force F between two masses, M and m :

$$F = G \frac{M m}{r^2}$$

Newton's Constant

Distance between masses



Isaac Newton
(1642-1727)

Applied to our Solar System

- The Sun (M) is most of the mass in the Solar System. The planets (m) have much less mass.
- Use:

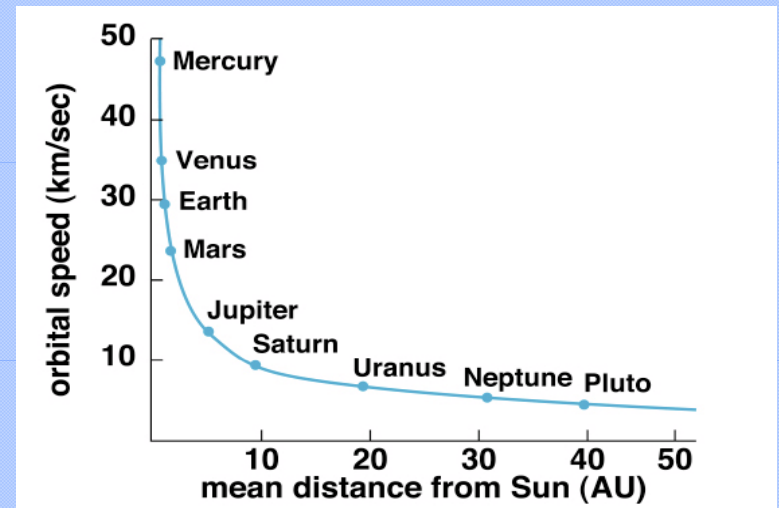
Law of Gravity 2nd Law of Motion

$$F = G M m / r^2 = m a = m v^2 / r$$

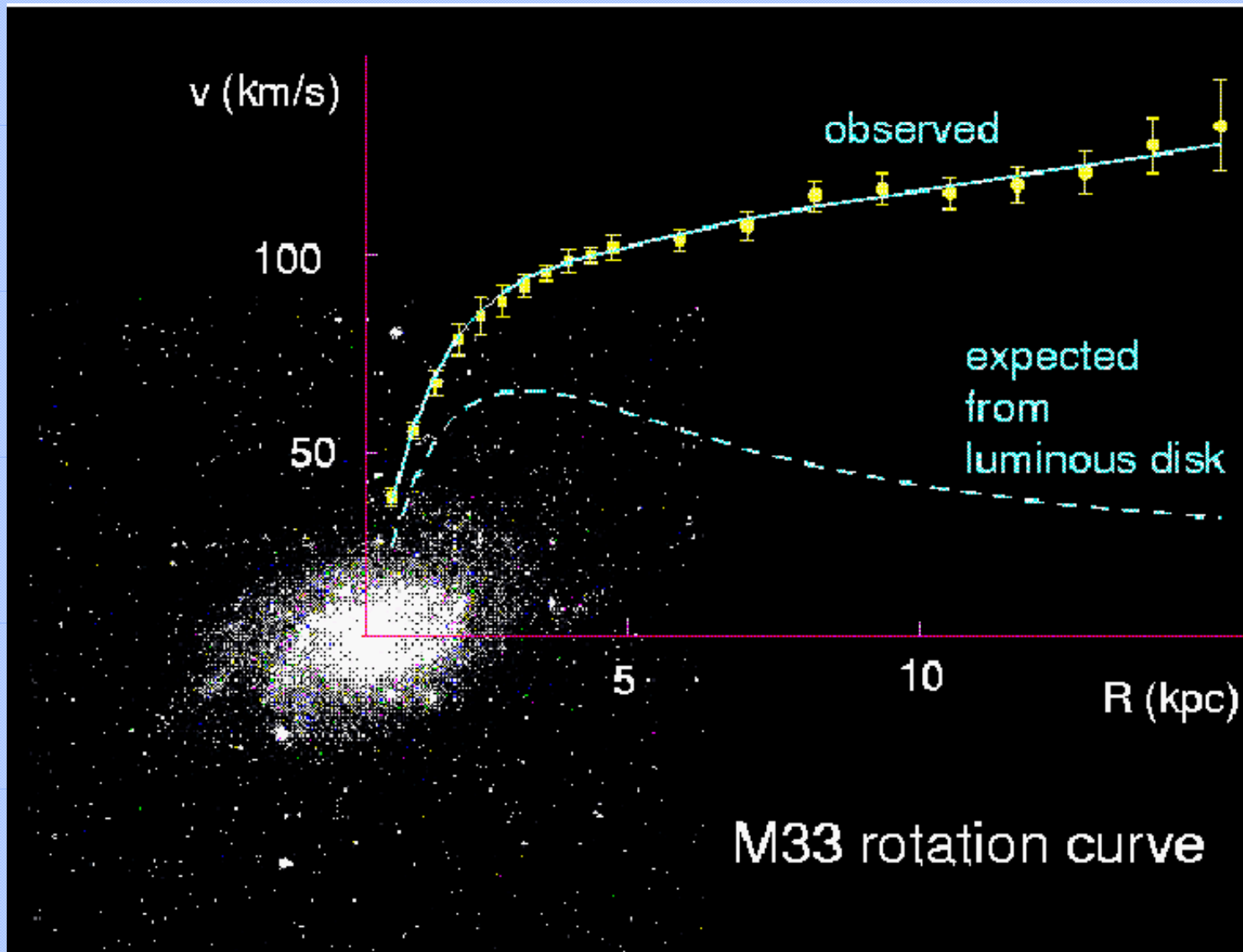
$$v^2 = G M / r$$

M = Enclosed mass

Expect the speed to fall with increasing distance :
("rotation curve")



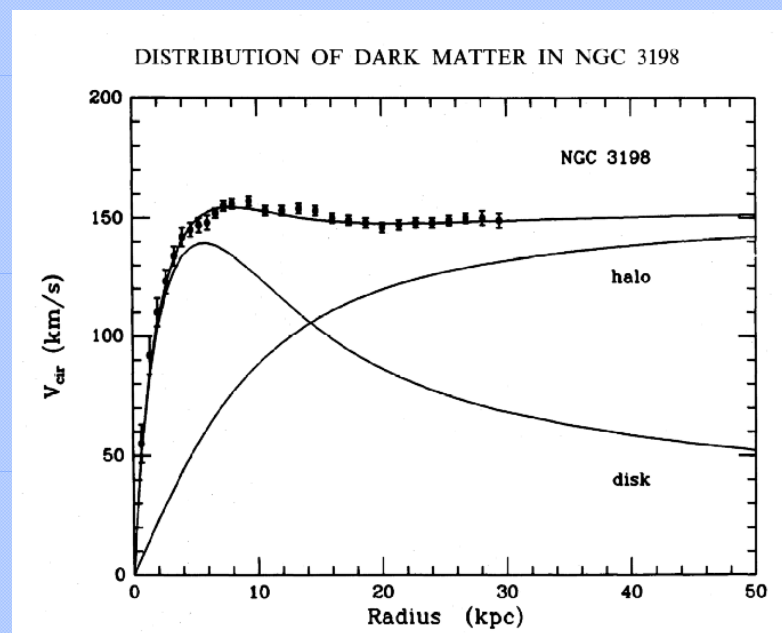
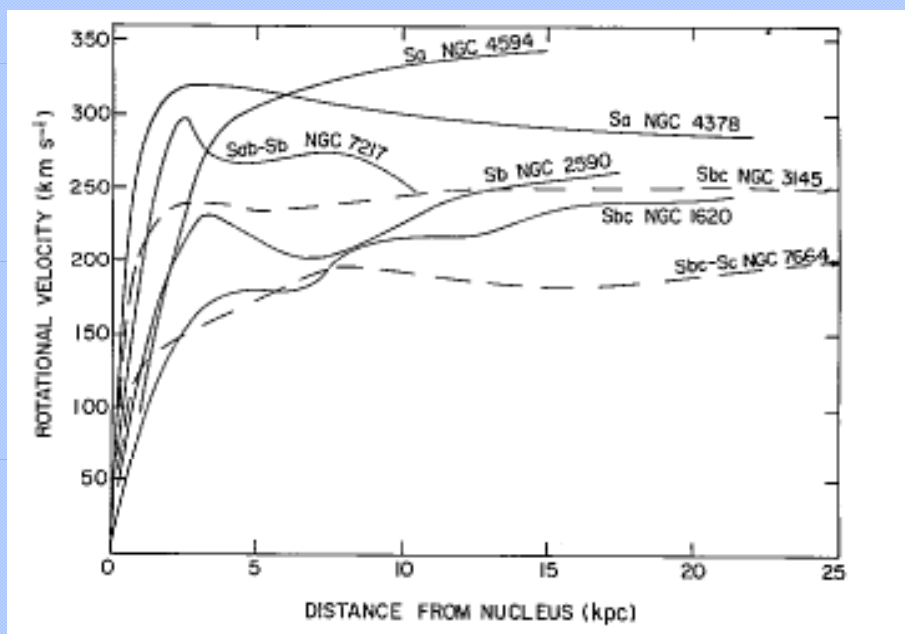
Applied to Spiral Galaxies



“Flat” Rotation Curve: completely unexpected !

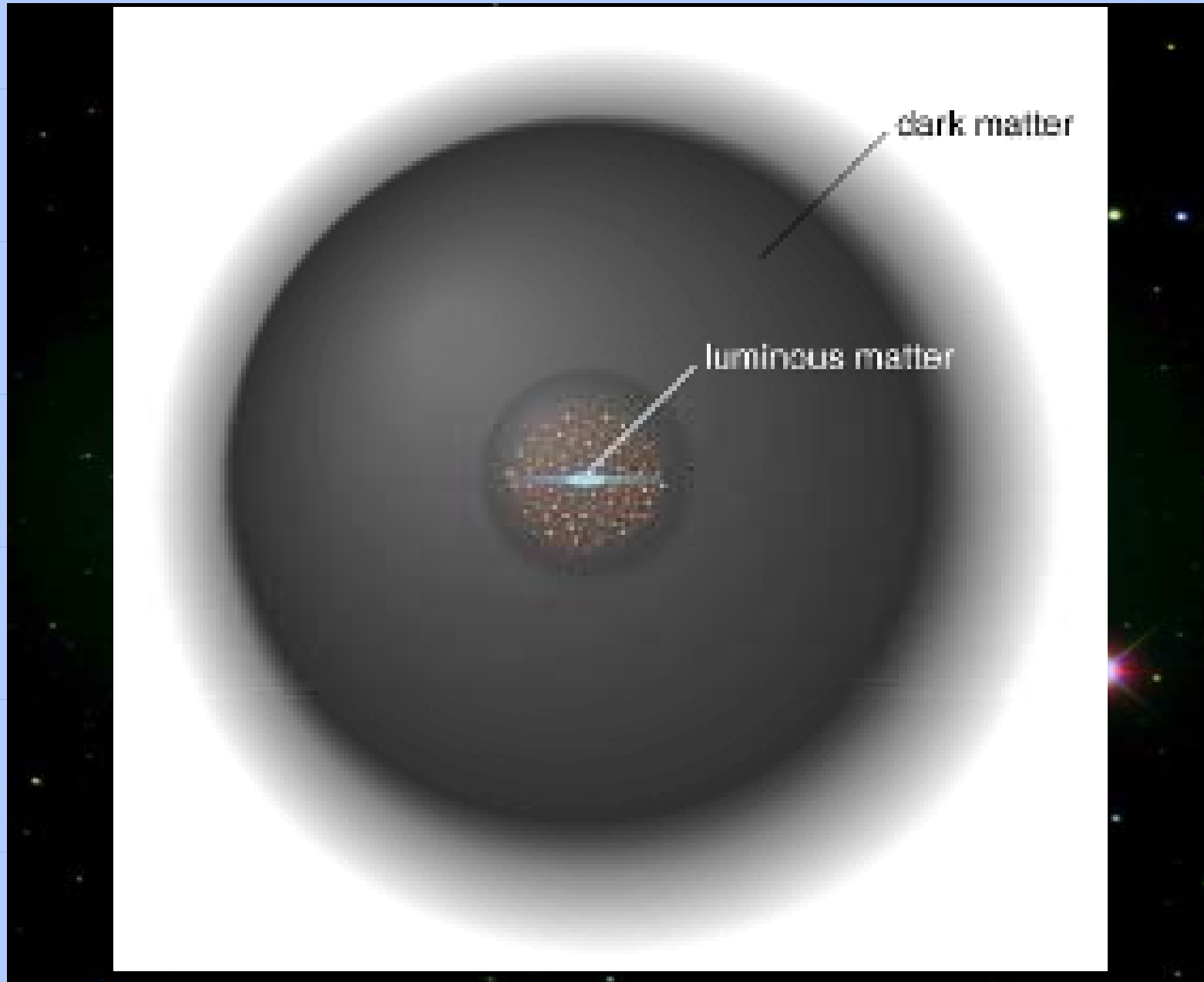
Universal Effect

Rotation curve for every galaxy has the same problem !



And ... extended to many other systems ...

Dark Matter Halo



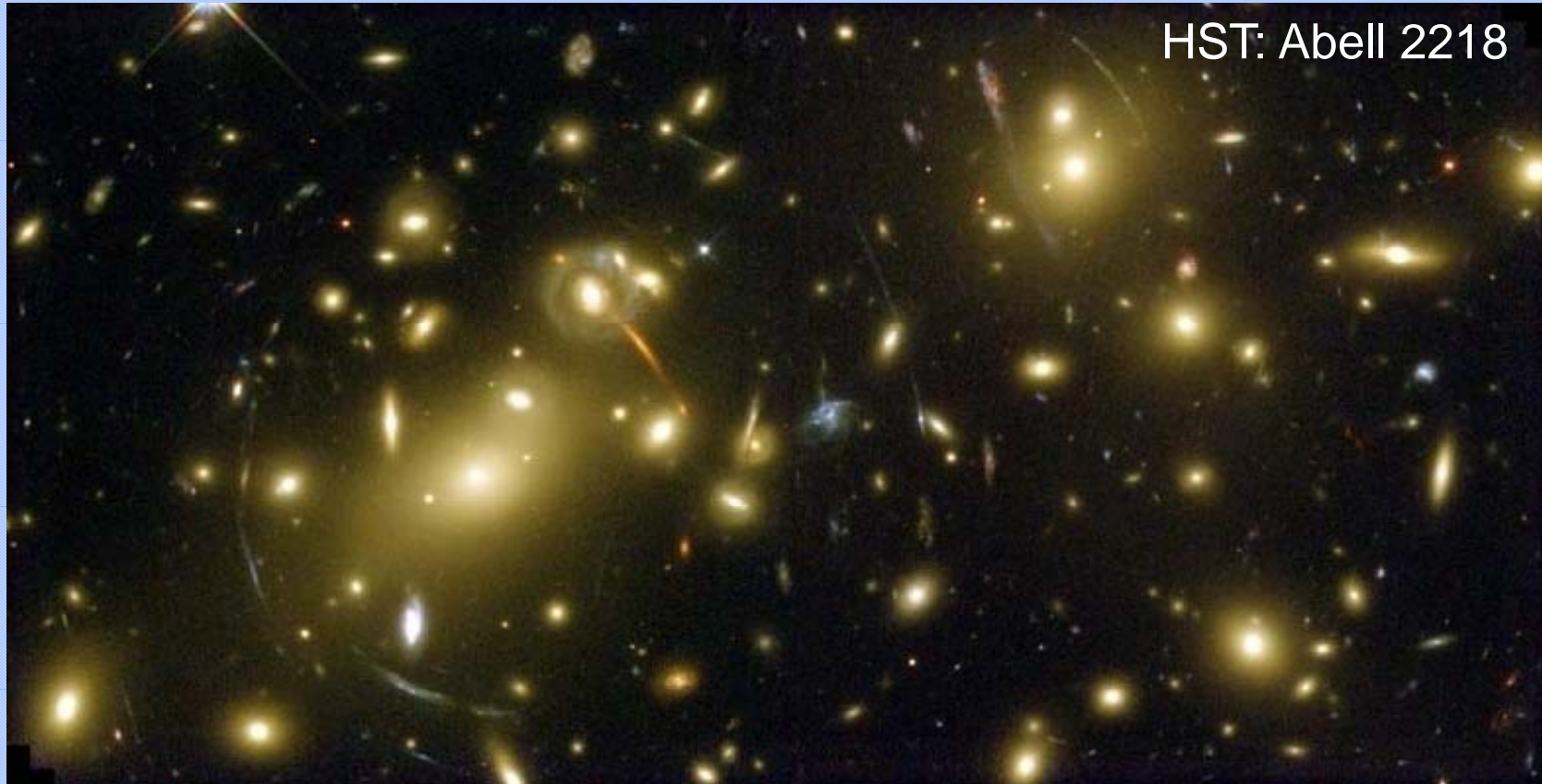
But ...

What if ...

Our understanding of
gravity is wrong ?!

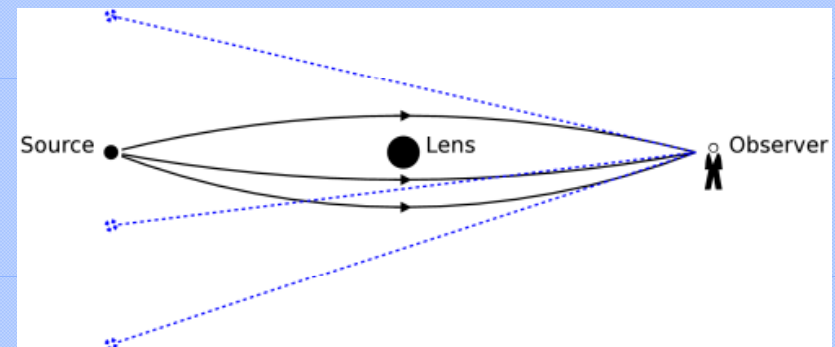
$$F = G \frac{M m}{r^2}$$

More Evidence !



Gravitational Lensing:

Light from distant galaxy is bent by closer object. Difficult to explain in “modified gravity”.



So ...

Gravity probably correct.

$$F = G \frac{M m}{r^2}$$

... and Dark Matter exists.

Outline

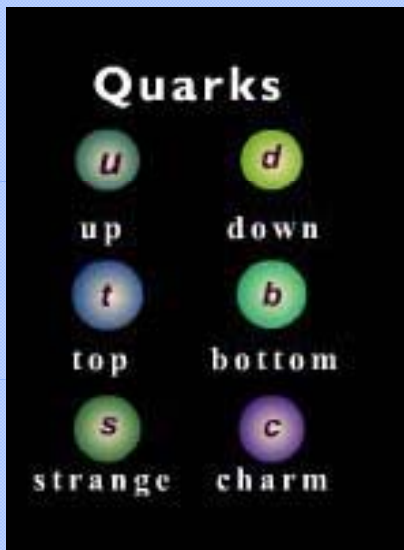
- What is Dark Matter ?
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- Summary & Future

Not Ordinary Matter

As far as we can tell, DM is not made up of ordinary matter:

i.e. not stars, gas, planets, dust, etc.

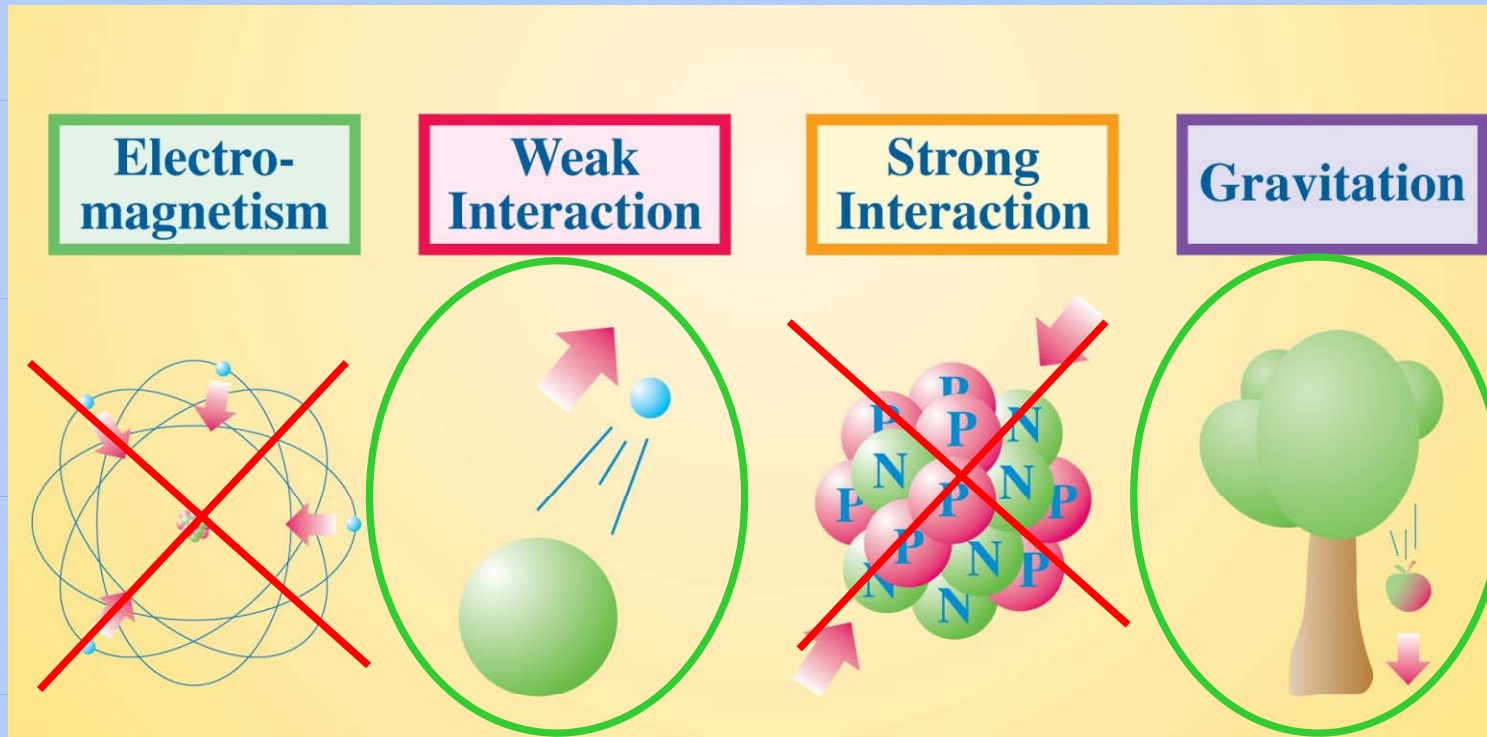
Fundamental particles (that we know about):



Protons/neutrons made from quarks
Atoms made from protons/neutrons/electrons.

DM is not these !

Fundamental Forces

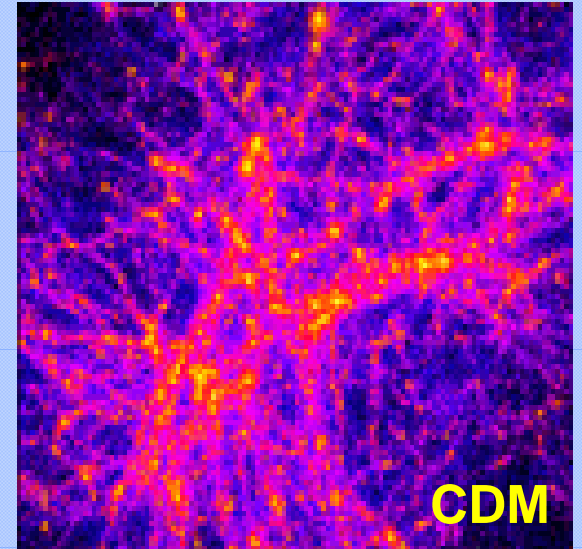


As far as we can tell,
DM does not experience **EM** and **Strong** forces.
Gravity ... yes.
Weak Interaction ... maybe.

DM Possibilities

After considerable (~30 years) of work, we have strong evidence for the following:

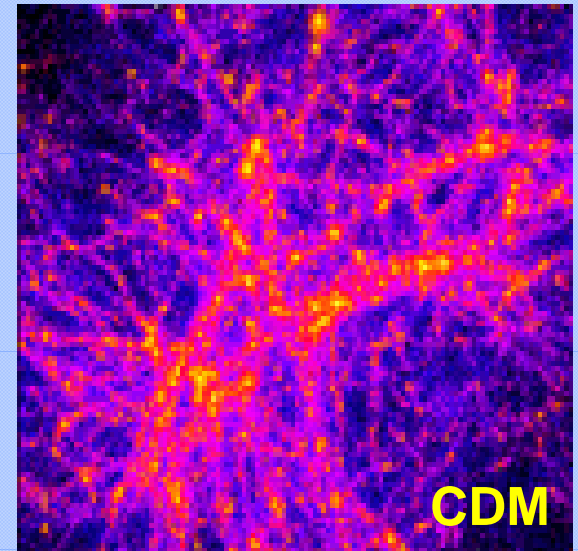
- DM is not made of ordinary matter.
- DM is moving slowly
 (“cold” or non relativistic).
- DM could be a new particle.



DM Possibilities

After considerable (~30 years) of work, we have strong evidence for the following:

- DM is not made of ordinary matter.
- DM is moving slowly
 (“cold” or non relativistic).
- DM could be a new particle.



→ **Something fundamentally different about our Universe.**

Theory: a number of good possibilities exist, but the most heavily studied is ...

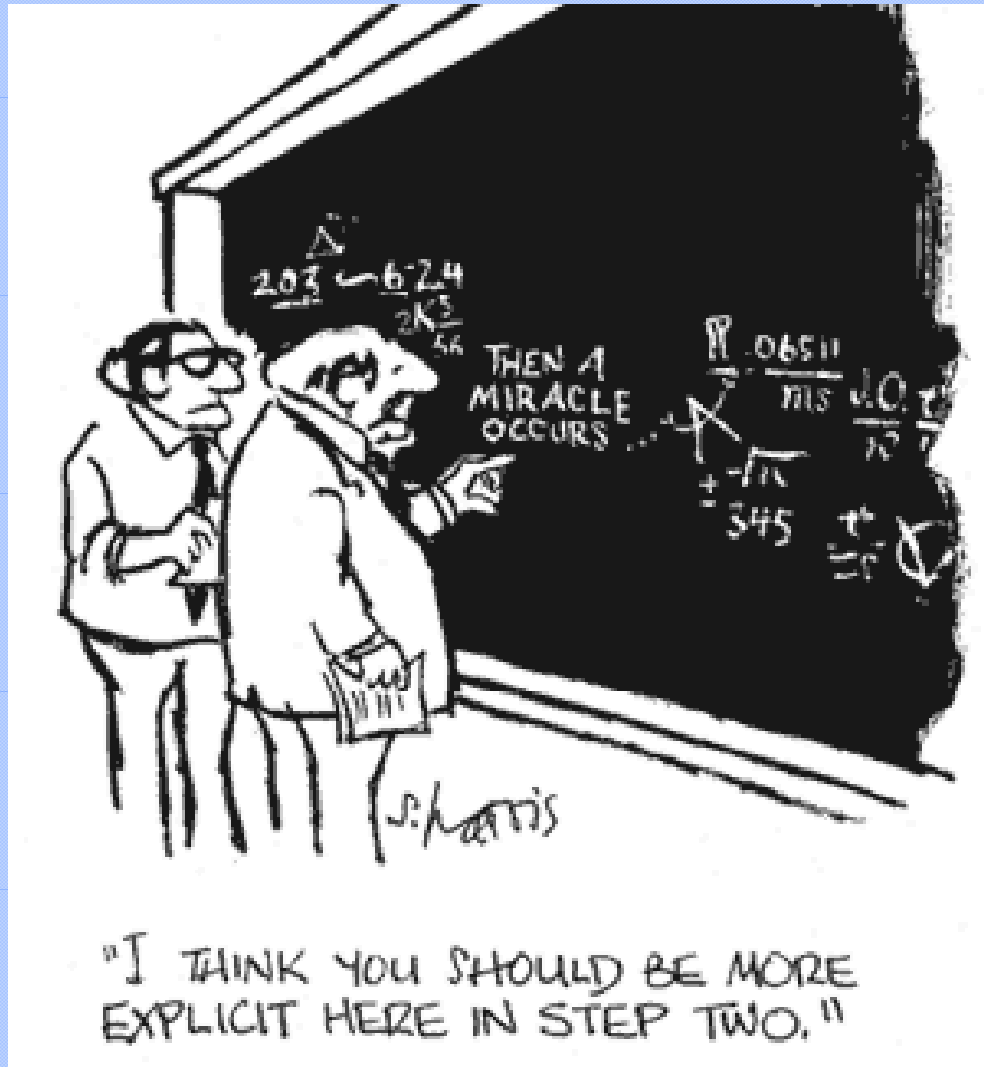
Weakly Interacting Massive Particle

(WIMP)

A WIMP is a new particle that:

- experiences weak and gravitational forces.
- has a mass of $\sim 5 - 1000$ times proton mass.
- requires new physics, needed to solve basic problems in particle physics.
- and ... solves the DM problem.

“WIMP Miracle”



Is it too good to be true (TGTTBT) ? !

But, this is not a theoretical exercise ...

Experiments are required !

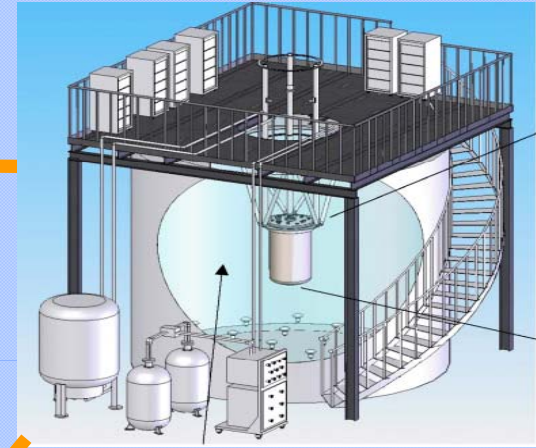
The Grand DM Challenge

**Produce DM particle
in accelerators**



Large Hadron
Collider (LHC)

Detect DM in Laboratory



e.g. Xenon Detector

**Astrophysical
DM Detection**

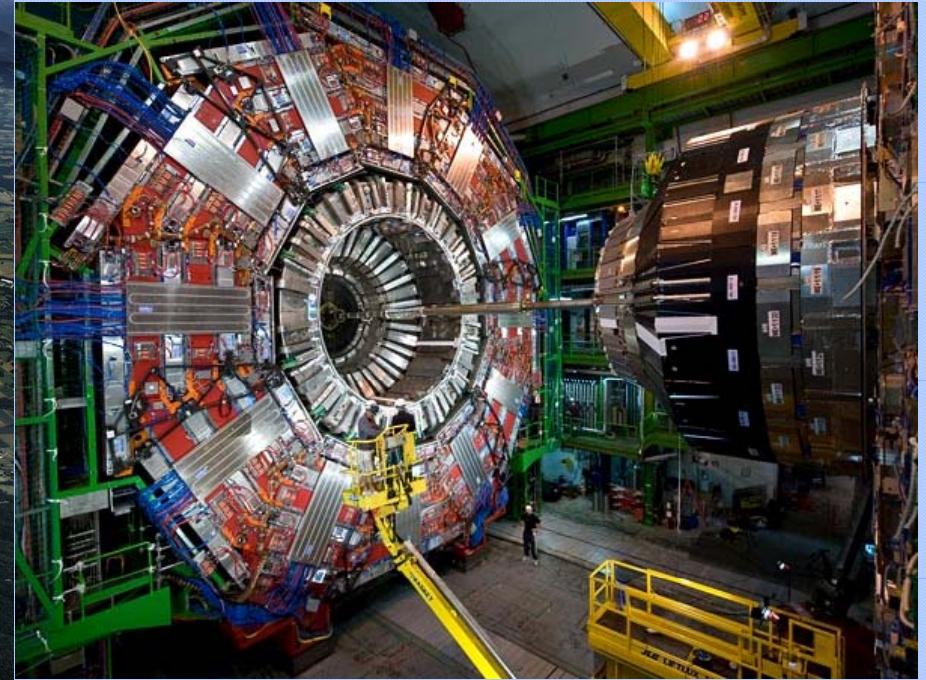


e.g. VERITAS
Telescope

Producing DM in Accelerators

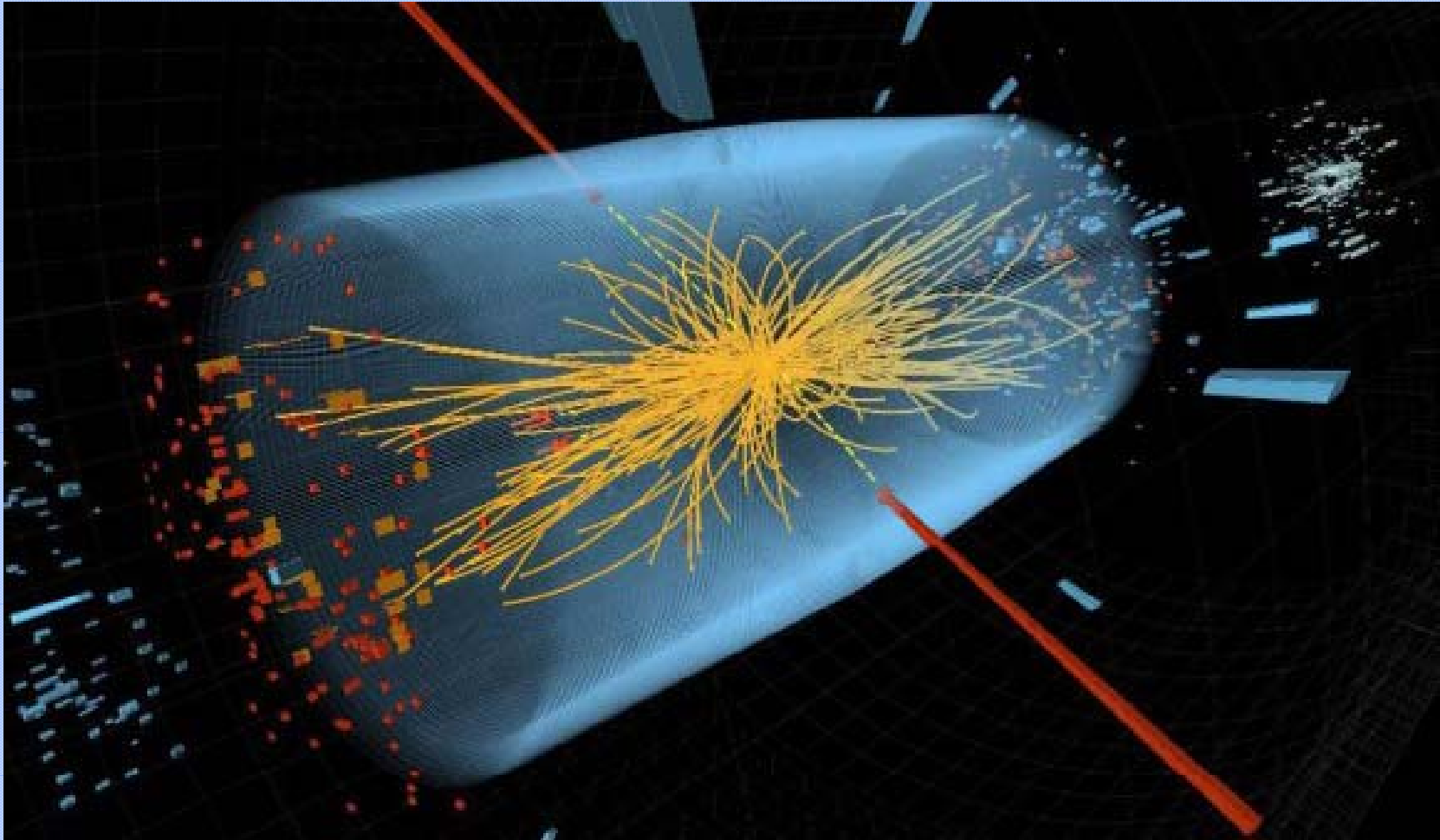


Large Hadron Collider (LHC)
at CERN (Switzerland)



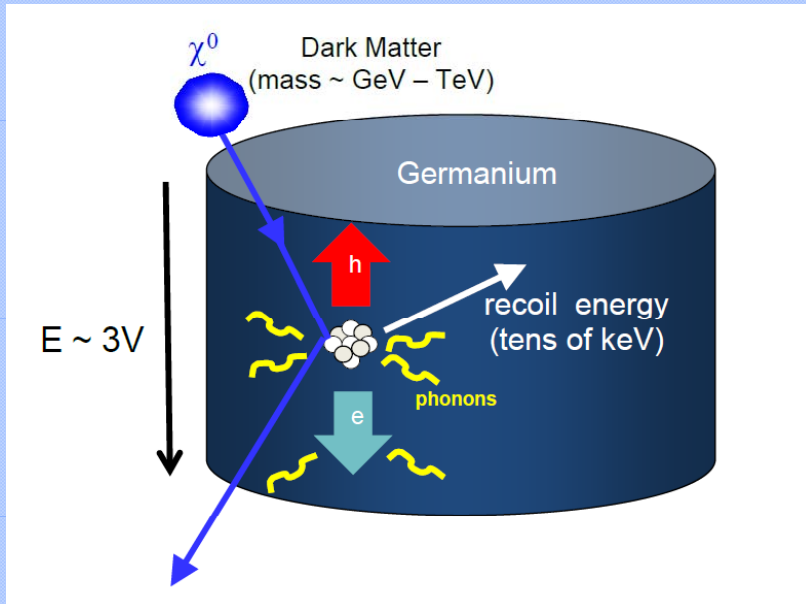
CMS Detector:
Collaboration of ~2000 physicists

Producing DM in Accelerators

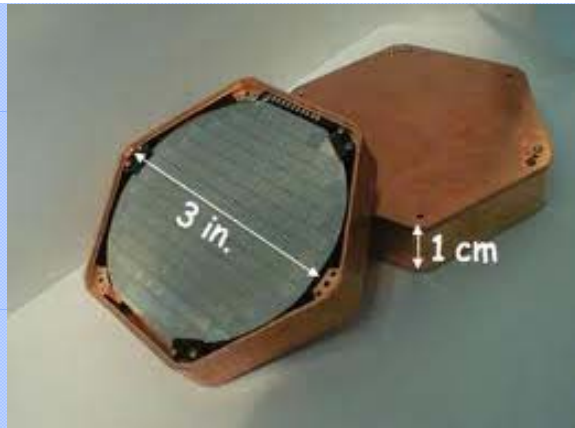
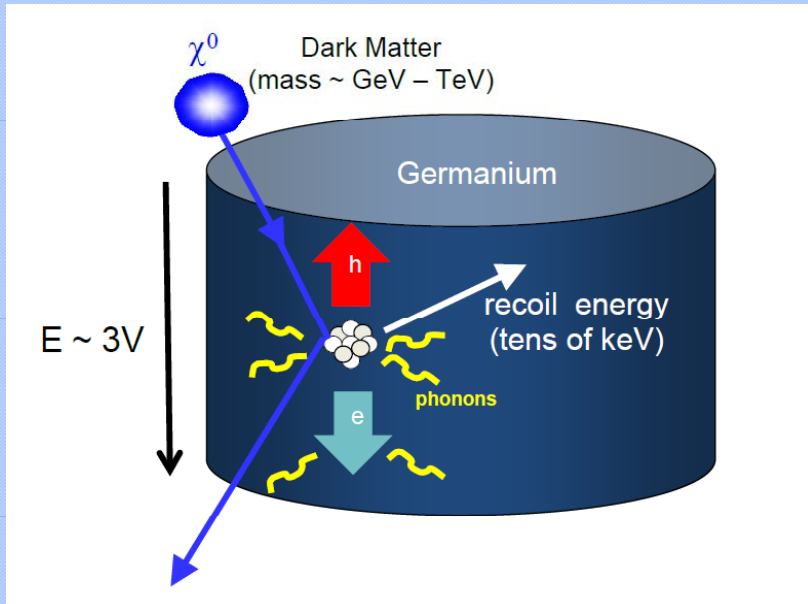


Strategy: Look for lots of missing energy
→ signals a new weak particle

Detect DM in Laboratory



Detect DM in Laboratory

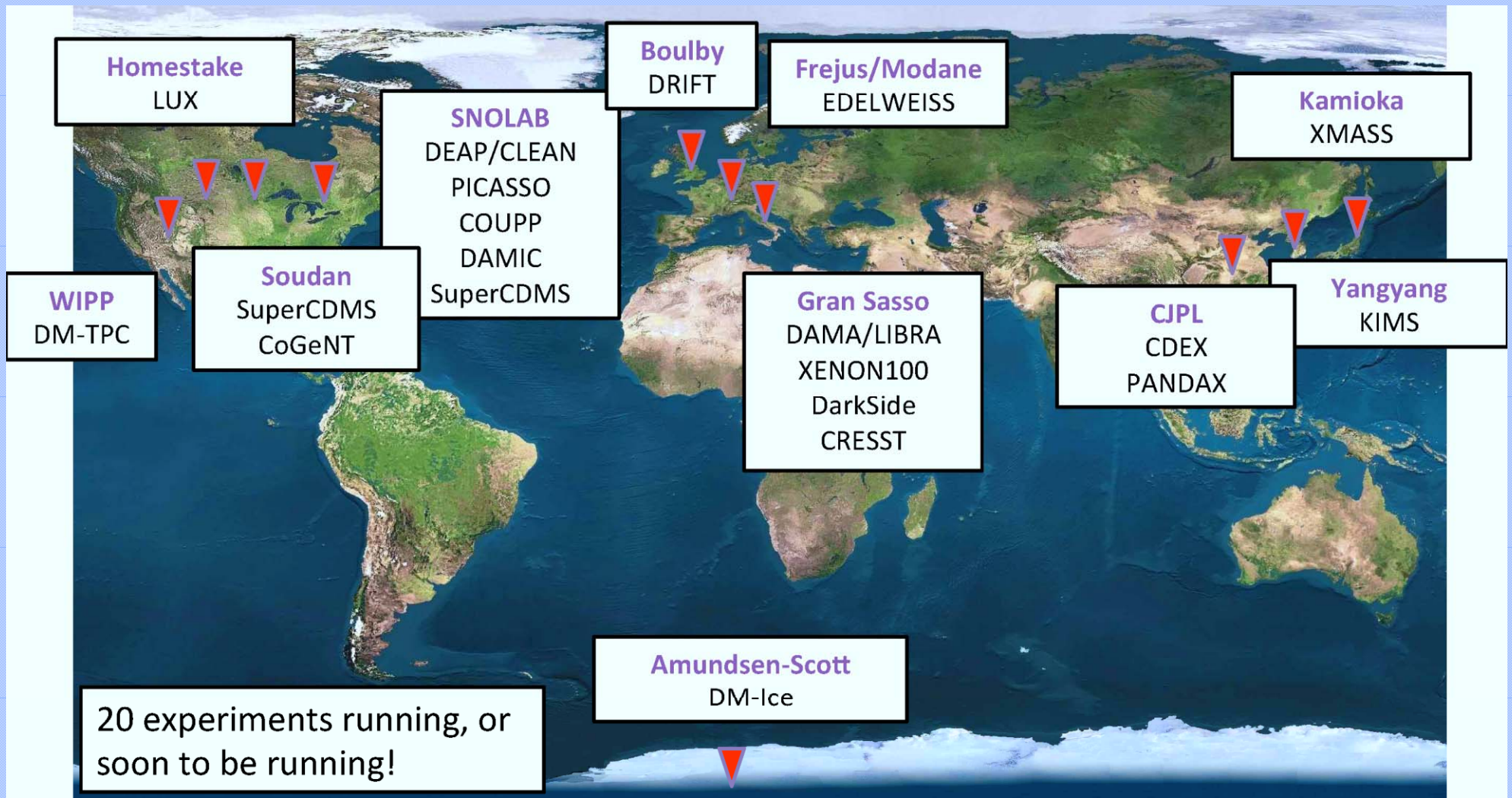


CDMS Detector in
Soudan Mine (Minnesota)

Strategy: Look for small energy deposition
in underground detector.

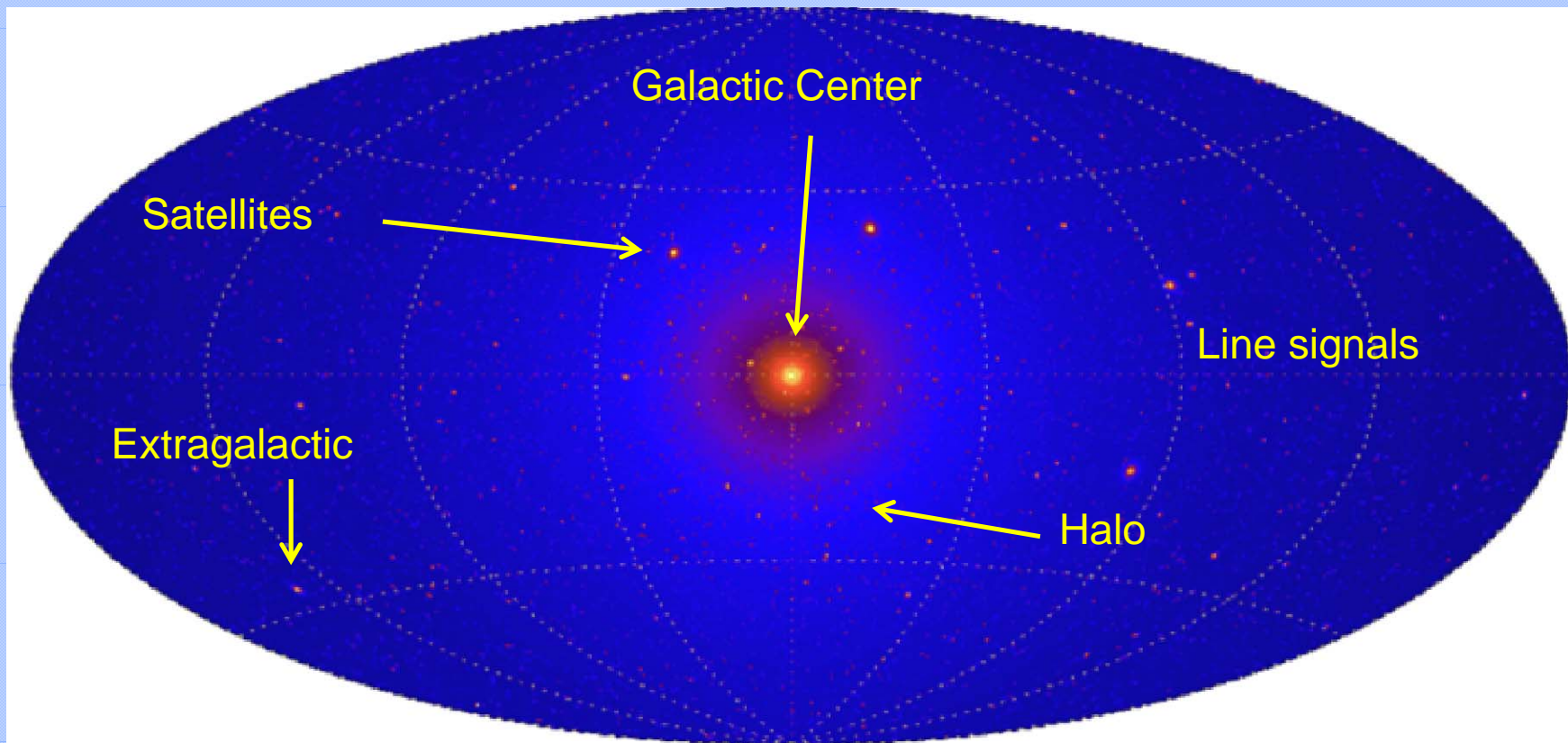
Detect DM in Laboratory

Worldwide race to discover Dark Matter !



Astrophysical DM Detection

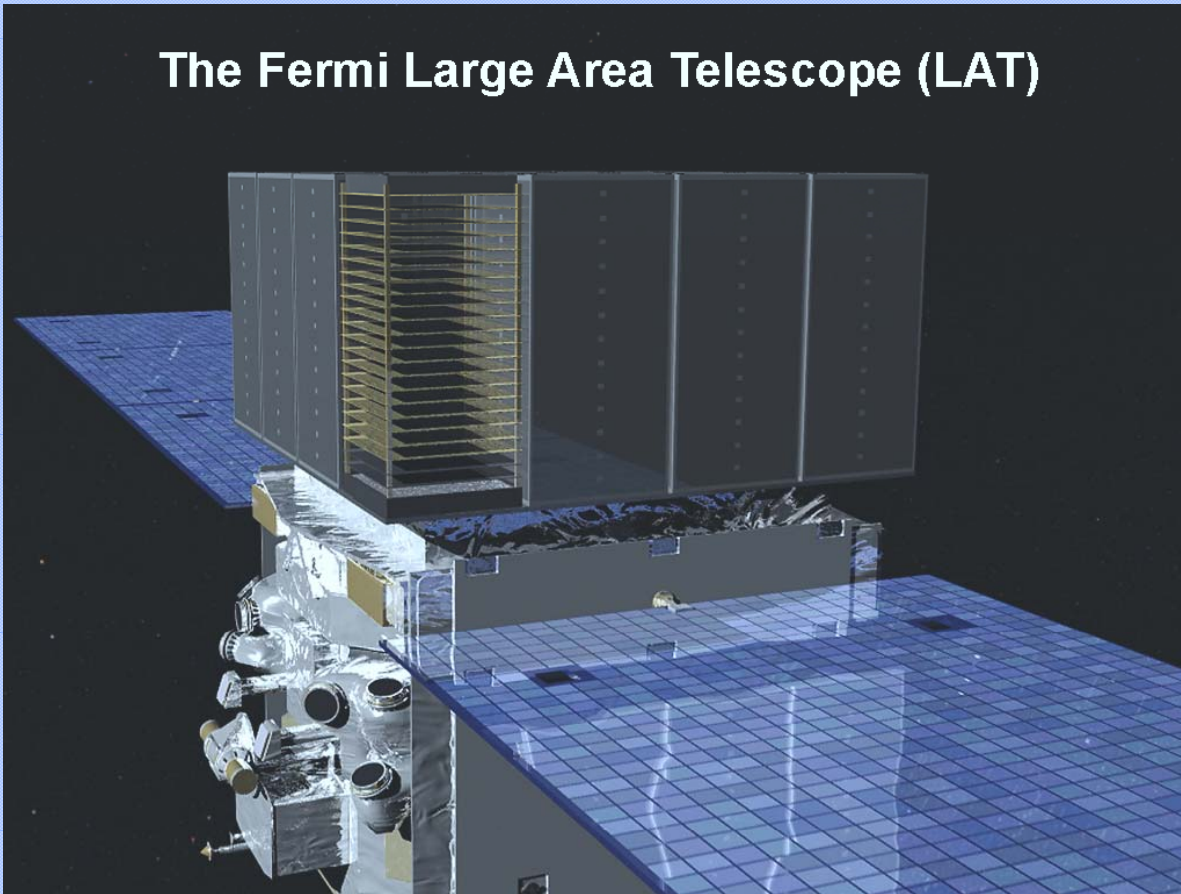
Strategy: Look for DM annihilations to give gamma rays or other particles



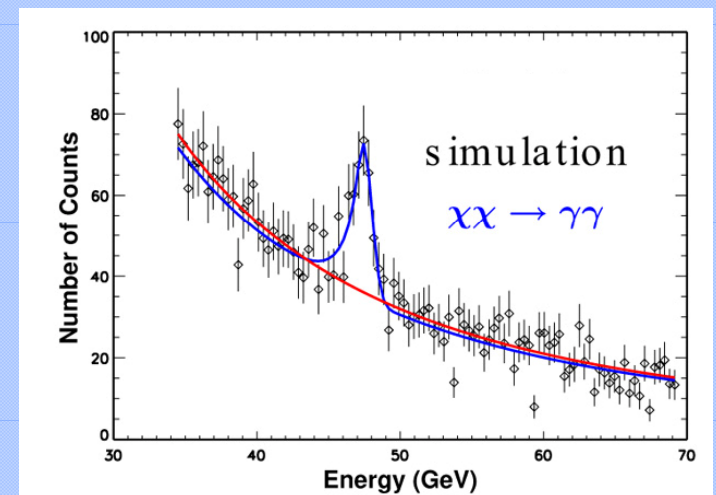
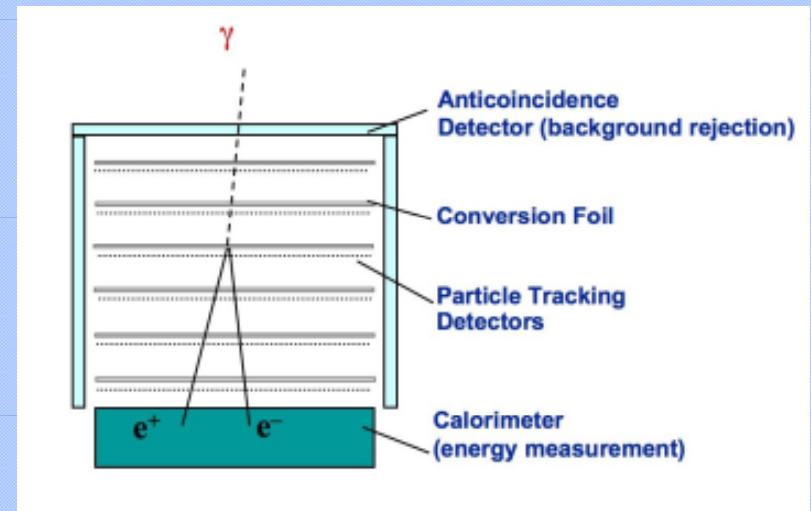
Dark matter map of sky in gamma rays (simulation!)

Astrophysical DM Detection

The Fermi Large Area Telescope (LAT)



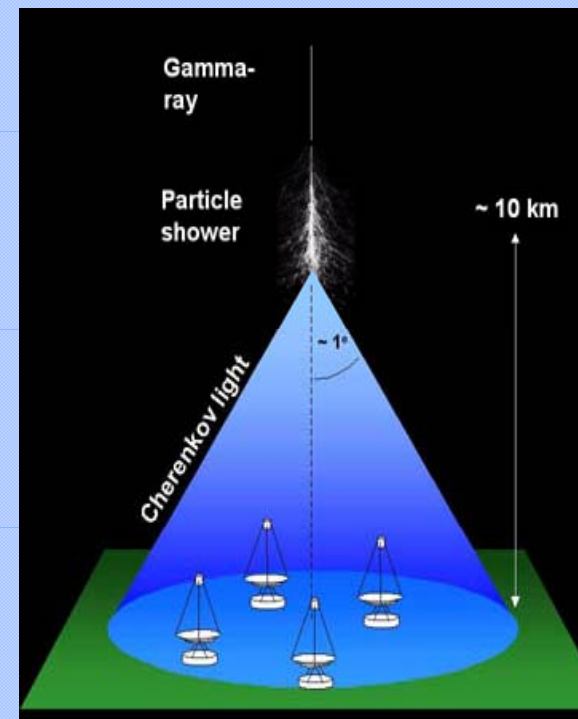
Fermi Gamma-ray Space Telescope



Astrophysical DM Detection



VERITAS Ground-Based
Gamma-Ray Telescope
(Arizona)



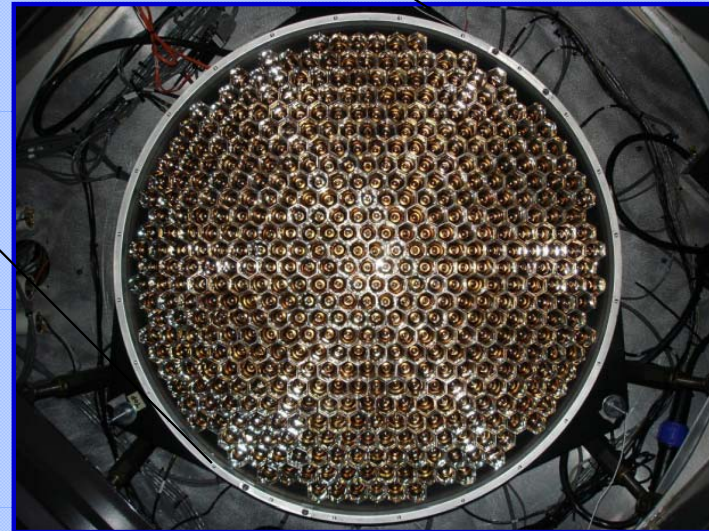
A VERITAS Telescope



12m reflector, f1.0 optics



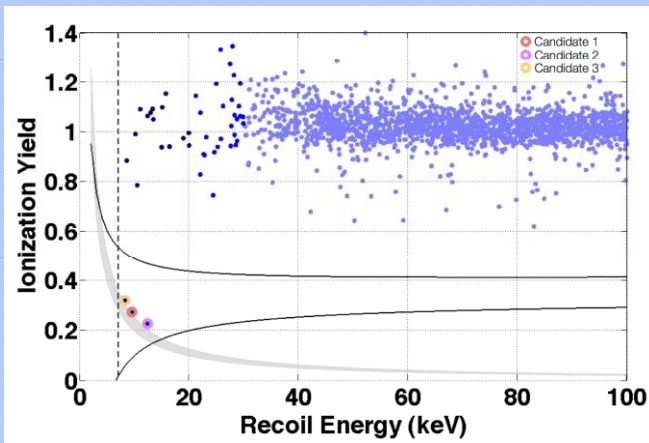
350 Mirror Facets



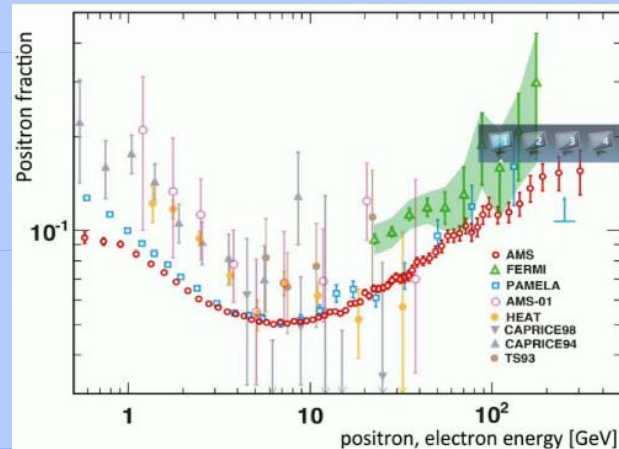
500 pixel Camera

Results for Far

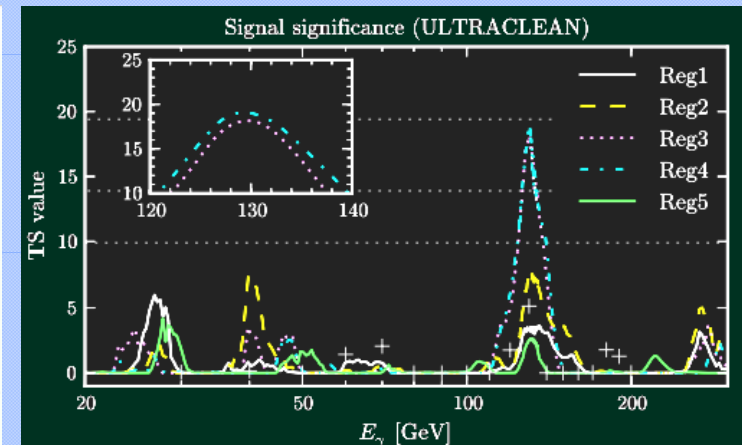
- Lots of results produced from many experiments
- **So far, only intriguing hints of DM detection, but no confirmed signals.**



CDMS
(April 2013)
3 events in WIMP band



AMS
(March 2013)
Rising positron fraction



Fermi
(March 2012)
Line Signal at 130 GeV

Importance of Engineering

Mechanical Engineering and Material Science

- Precision construction of hardware (mirrors, detectors, telescopes,...), often to sub- μm level.
- Accurate metrology to have good coordinate systems.
- Development of new materials & adhesives.

Electrical engineering & Computer Science

- Generally custom-made high-speed analog and digital design.
- Computing requirements (software, hardware) that push, and drive, the state-of-the-art.

These are just a few examples...

Summary

- Dark Matter is very well established from many astrophysical measurements.
- Dark Matter comprises 80% of the mass of the Universe and is not made of ordinary matter. One of the deepest questions in science is: what is the universe made of?
- Dark Matter could be a new particle and thus indicate something fundamentally new in our understanding.
- Grand worldwide effort to discover particle Dark Matter.
- **Exciting times are ahead !**

“The real voyage of discovery consists, not in seeking new landscapes, but in having new eyes.”

Marcel Proust (1871-1922)

Further Information

- General DM discussion:

A quick search of the web will find many.

- LHC experiments:

<http://home.web.cern.ch/about/experiments>

- Super CDMS detector:

<http://cdms.berkeley.edu/>

- Fermi-LAT telescope

<http://fermi.gsfc.nasa.gov>

- VERITAS telescope

<http://veritas.sao.arizona.edu/>

- <http://www.astro.ucla.edu/~rene/>

