Title: The Dark Side of Matter

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Abstract:

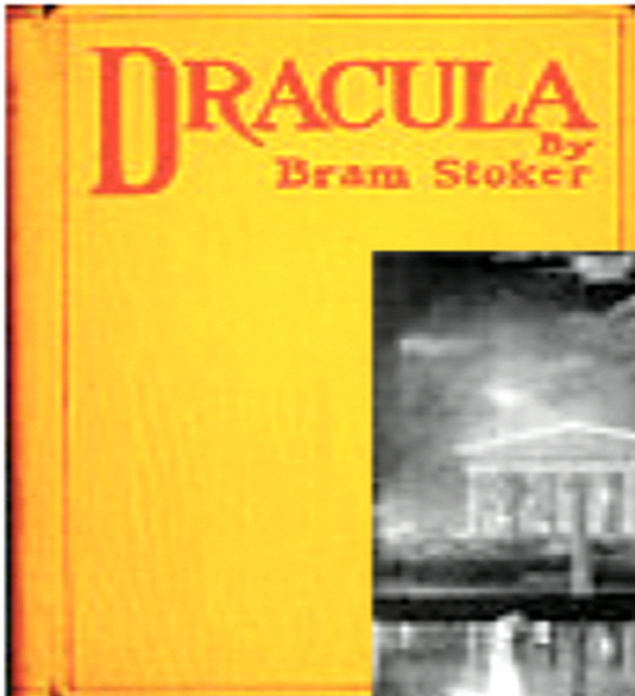
The Dark Side of Matter

Itay Yavin

McMaster University
Perimeter Institute

International Summer School for Young Physicists
17 July, 2013

1897



1897

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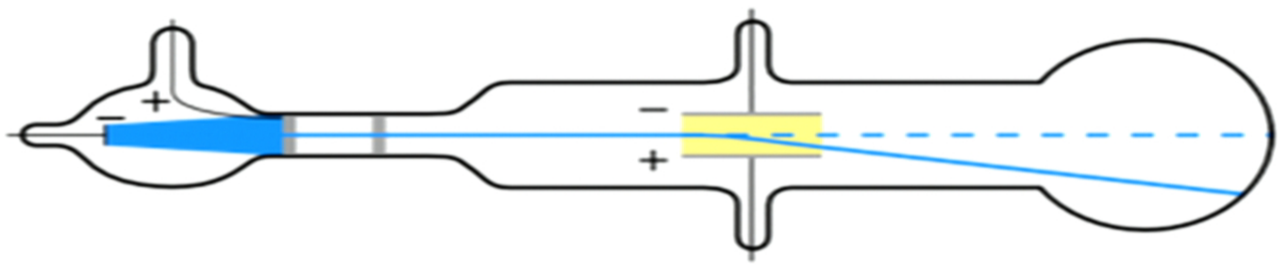
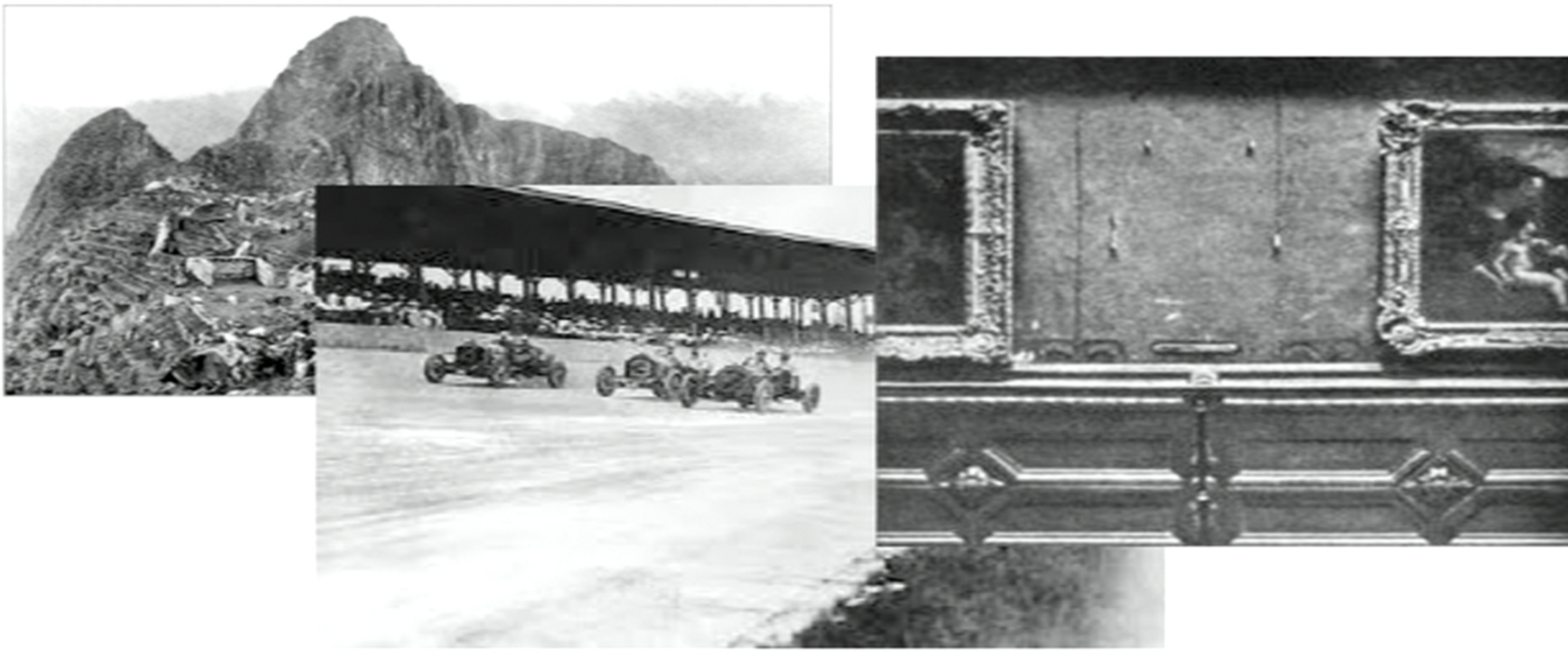
J. J. Thomson

Discovery of the Electron



1911



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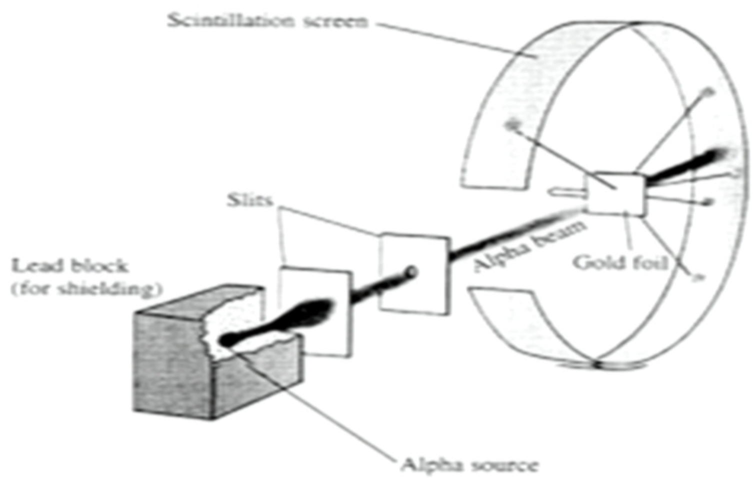

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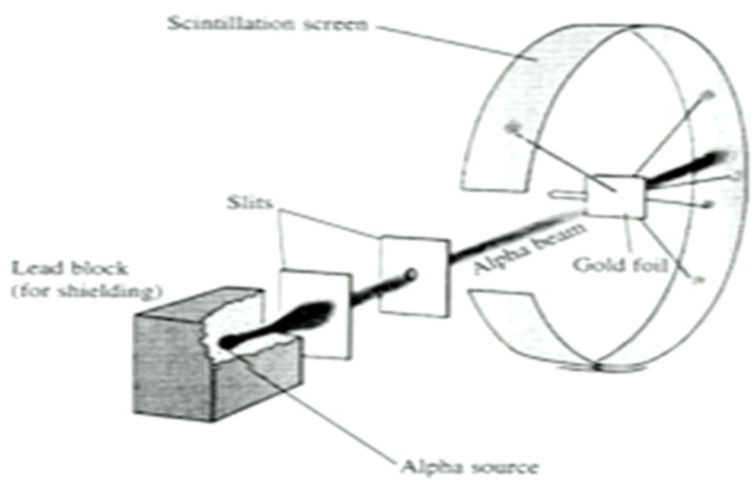

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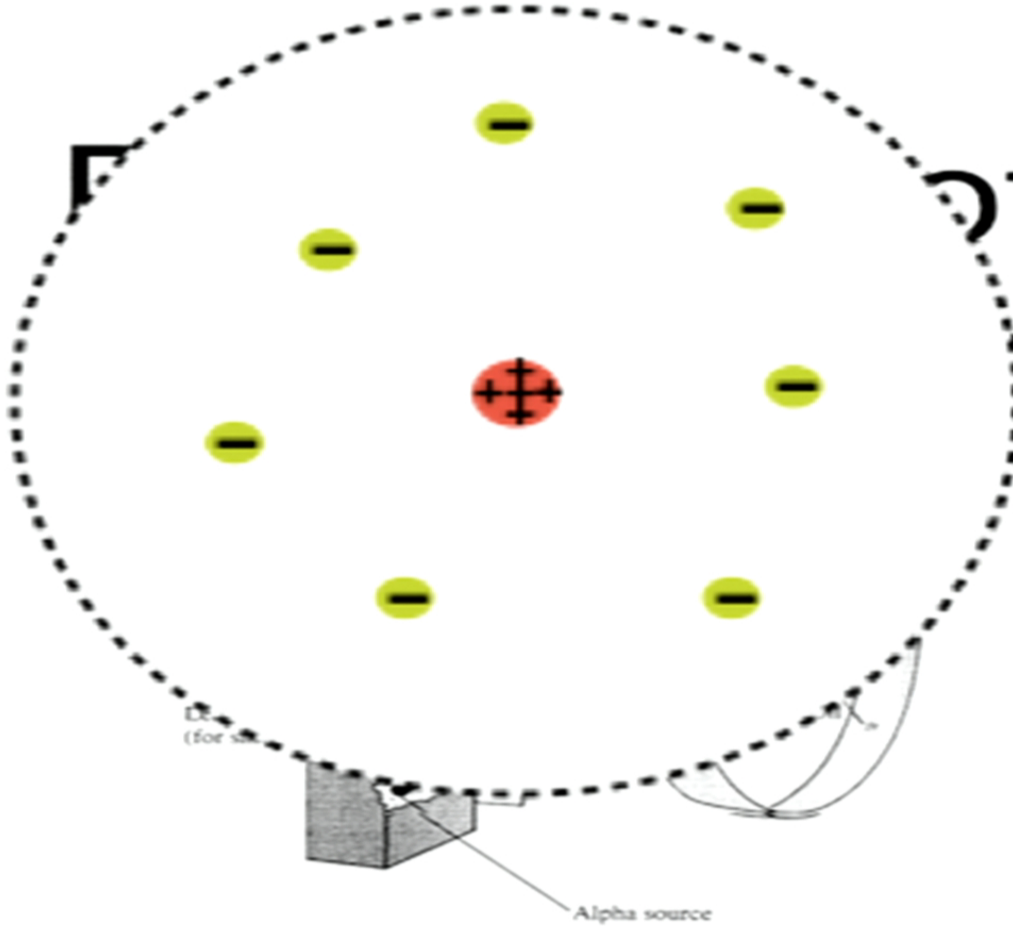

1913

Niels Bohr
(here chilling out with Einstein)

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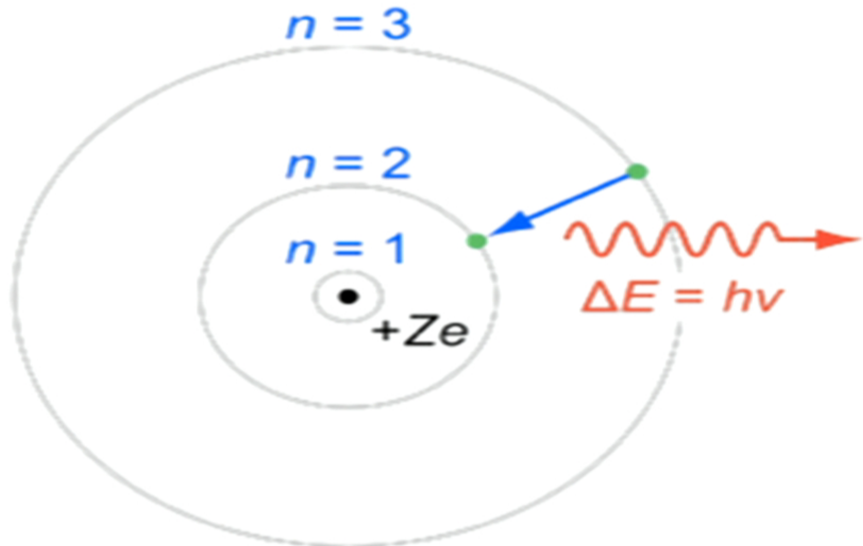
The Bohr Model of the Atom



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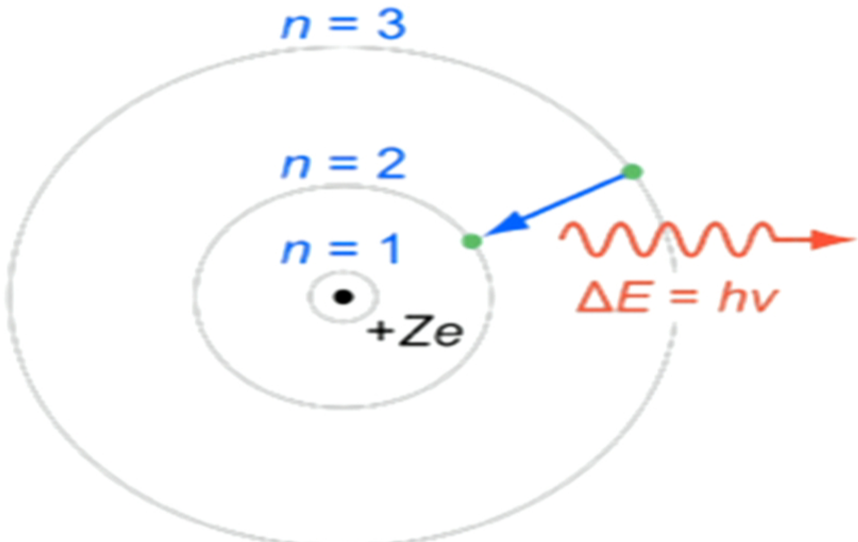

Quantum theory explains the stability of matter!

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Particle Physics & Quantum Field Theory

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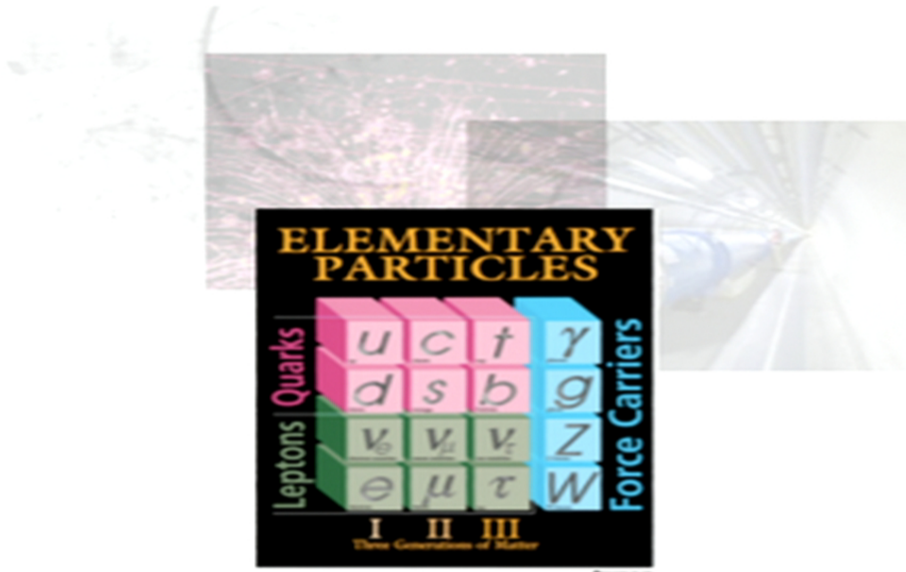

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Higgs Boson

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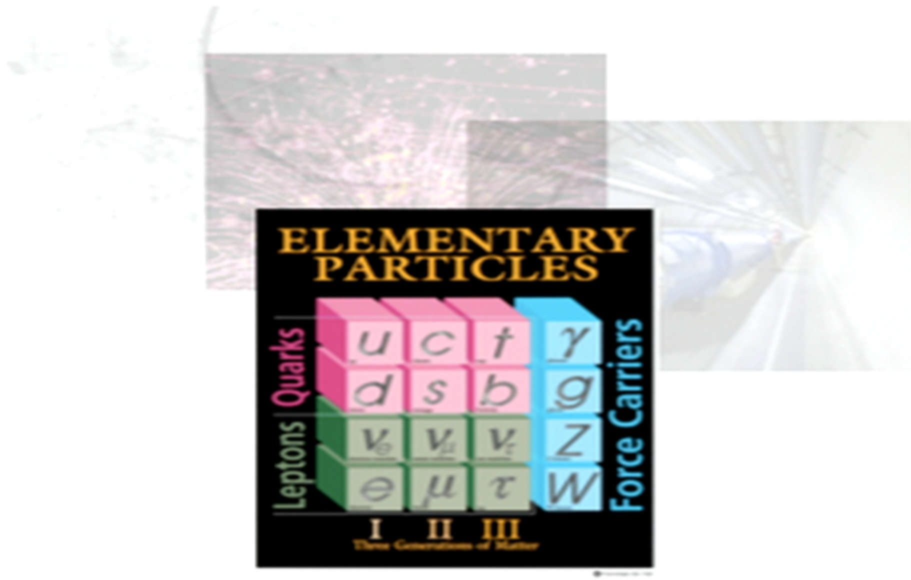

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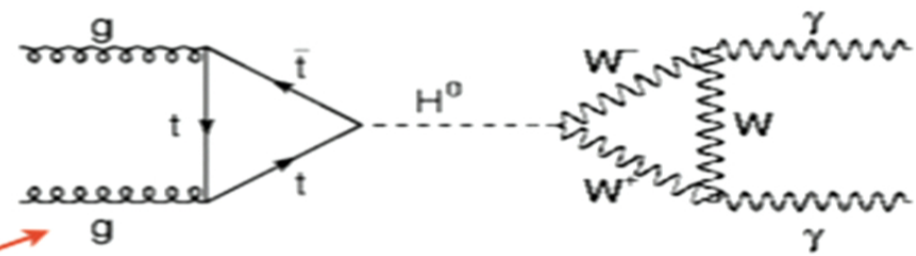
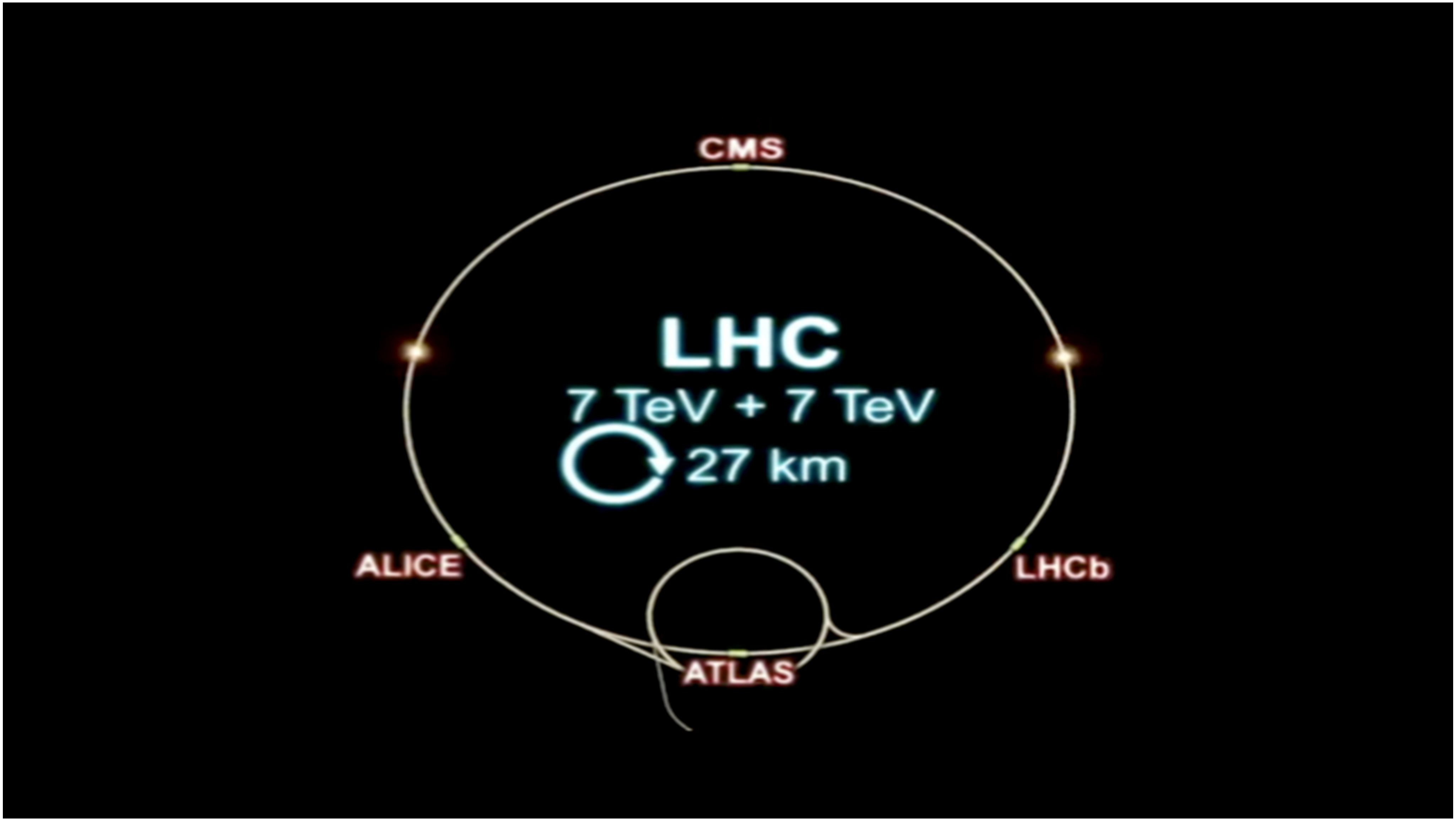



LHCb
ATLAS
CERN
CERN
SUISSE
FRANCE
CMS
LHC 27 km
6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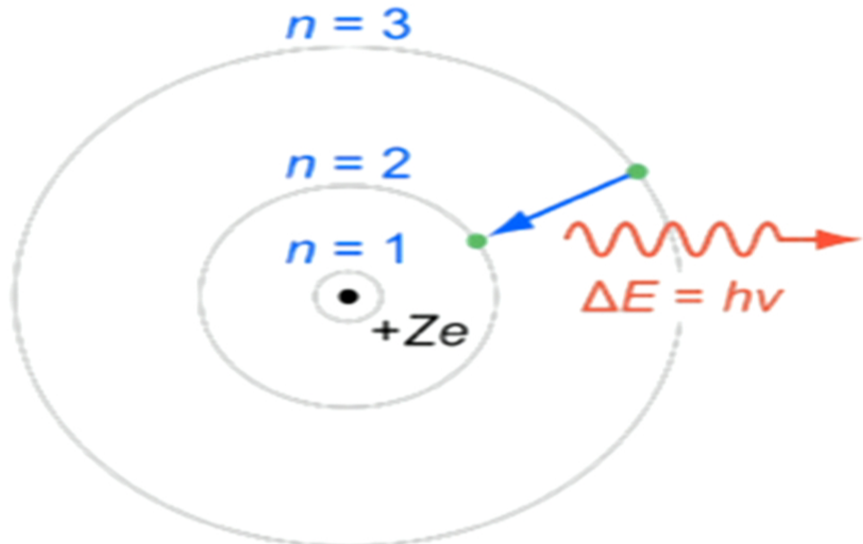

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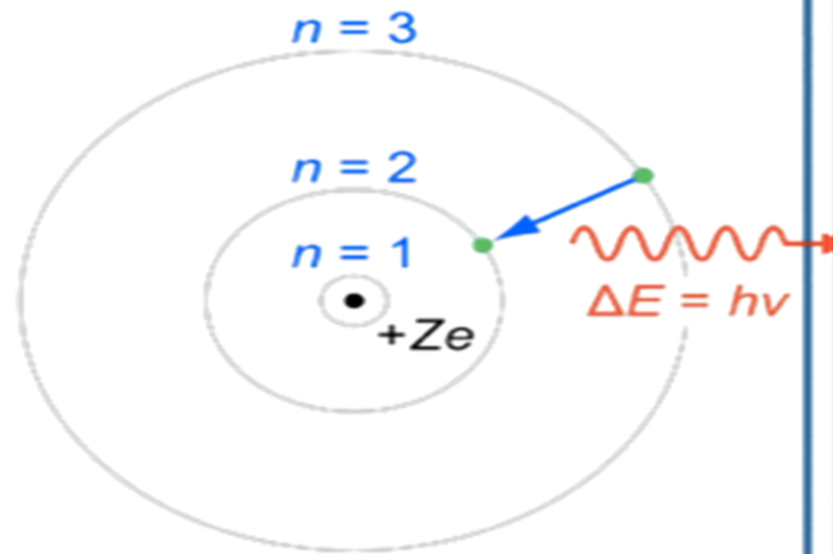
Atomic Barcode

Bohr's revolutionary proposal lead to one clear consequence, atoms are characterized by their emission and absorption lines,



9

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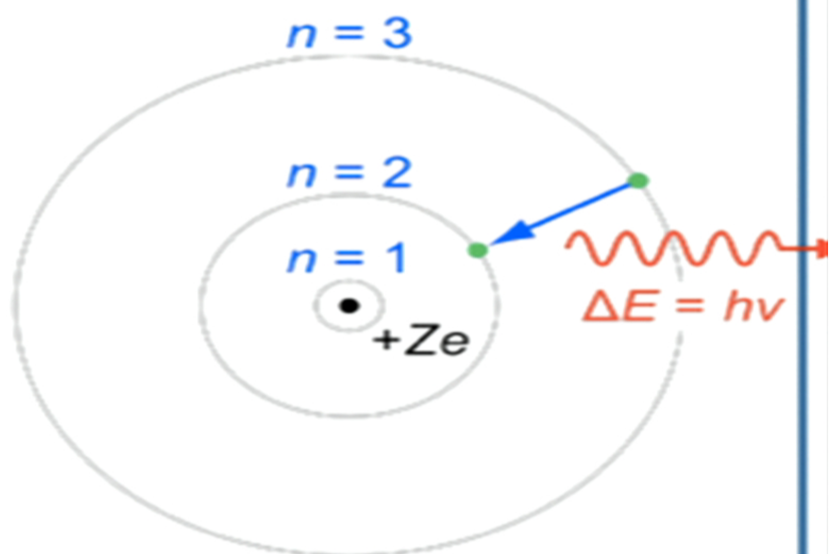

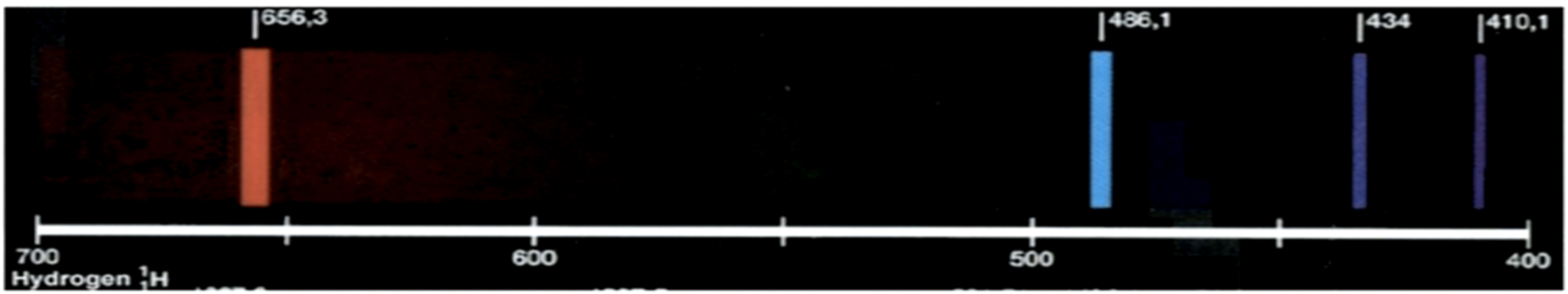

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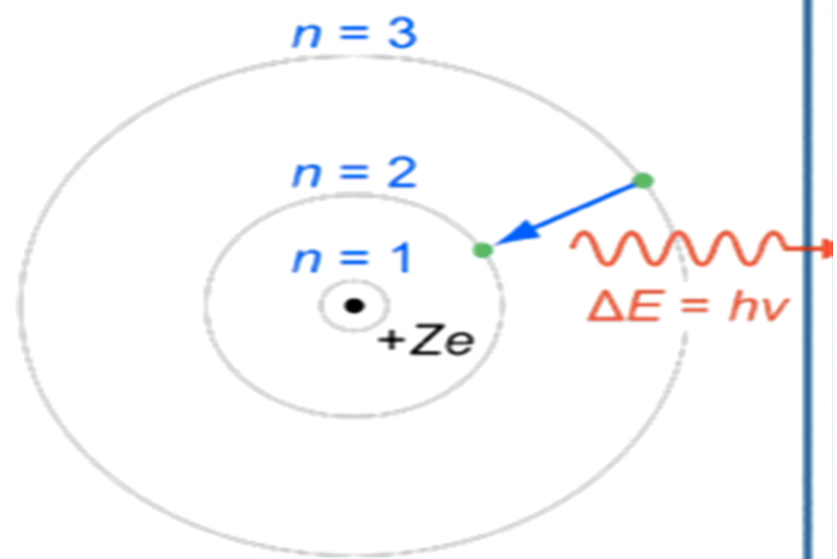
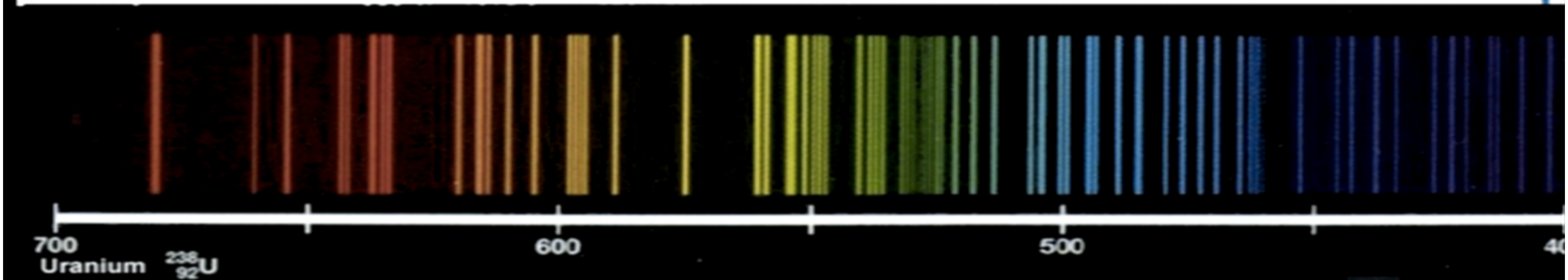
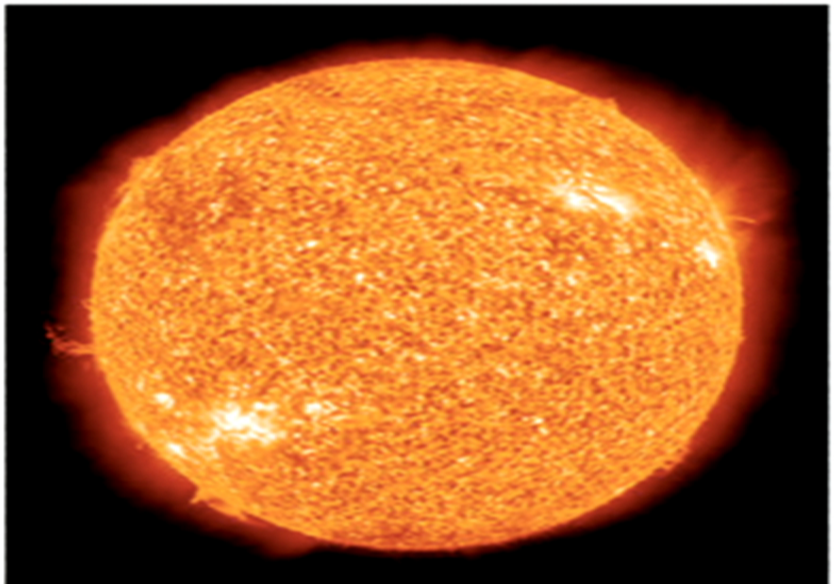
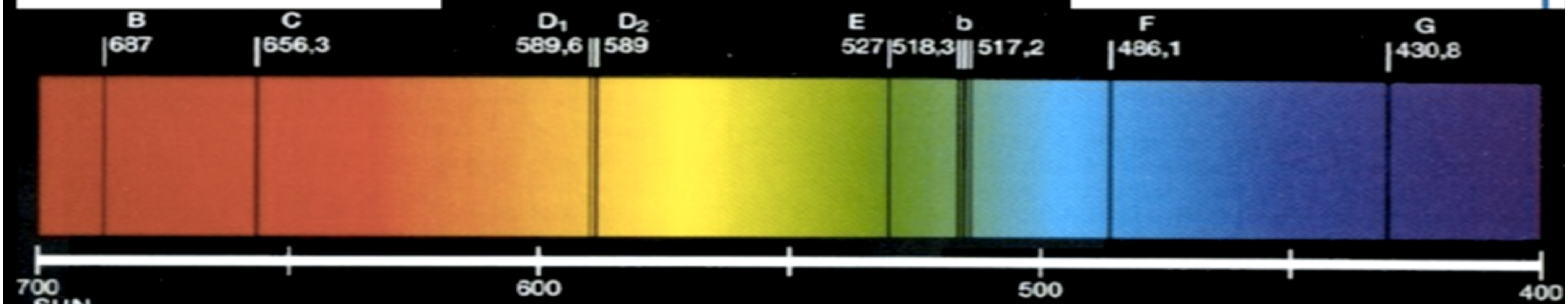


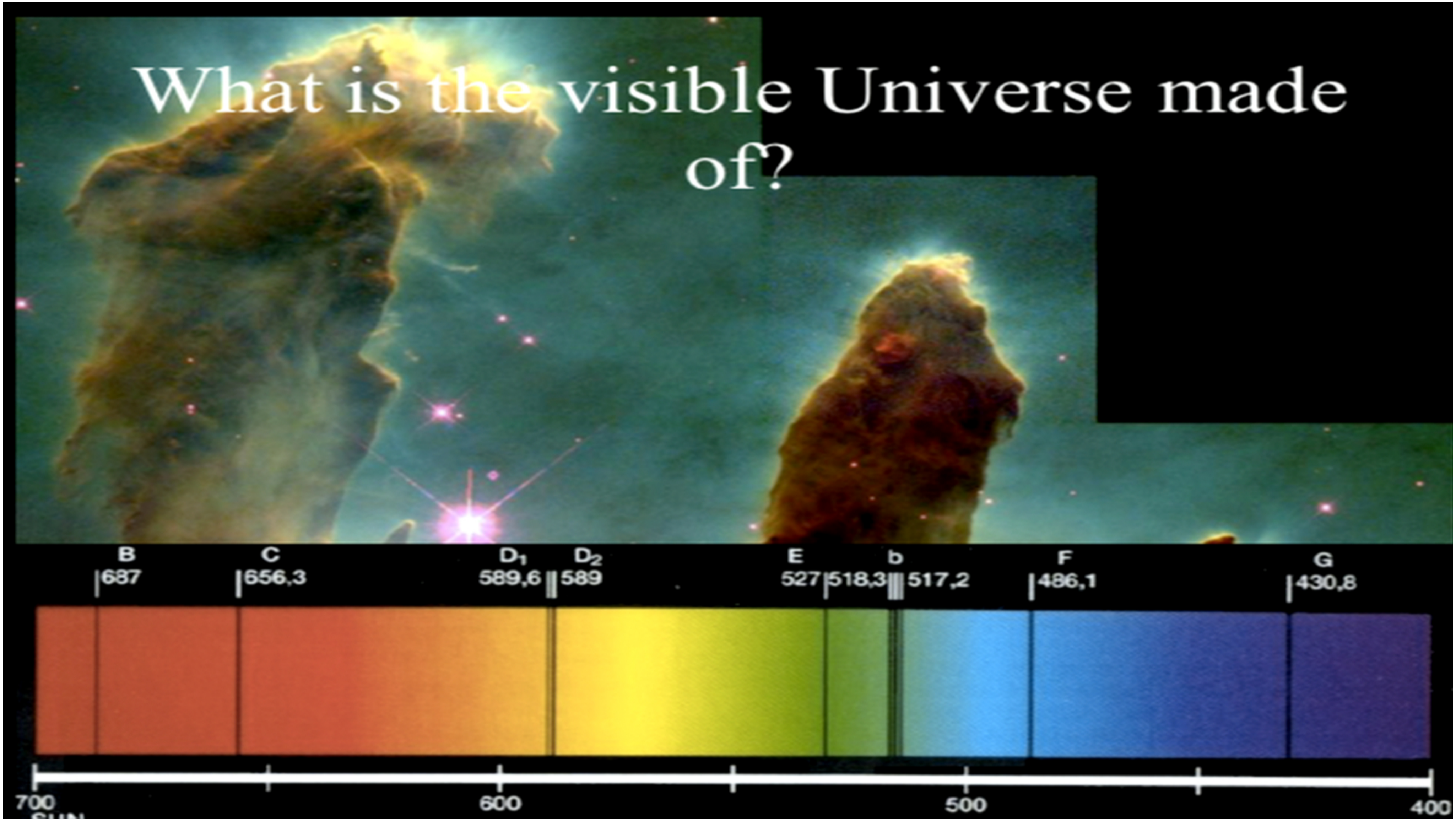


What is the Sun Made Of?



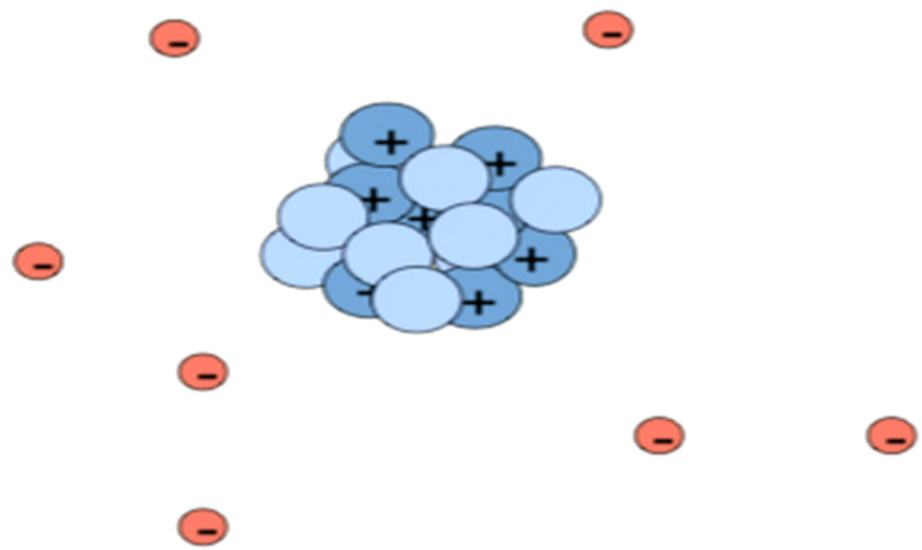


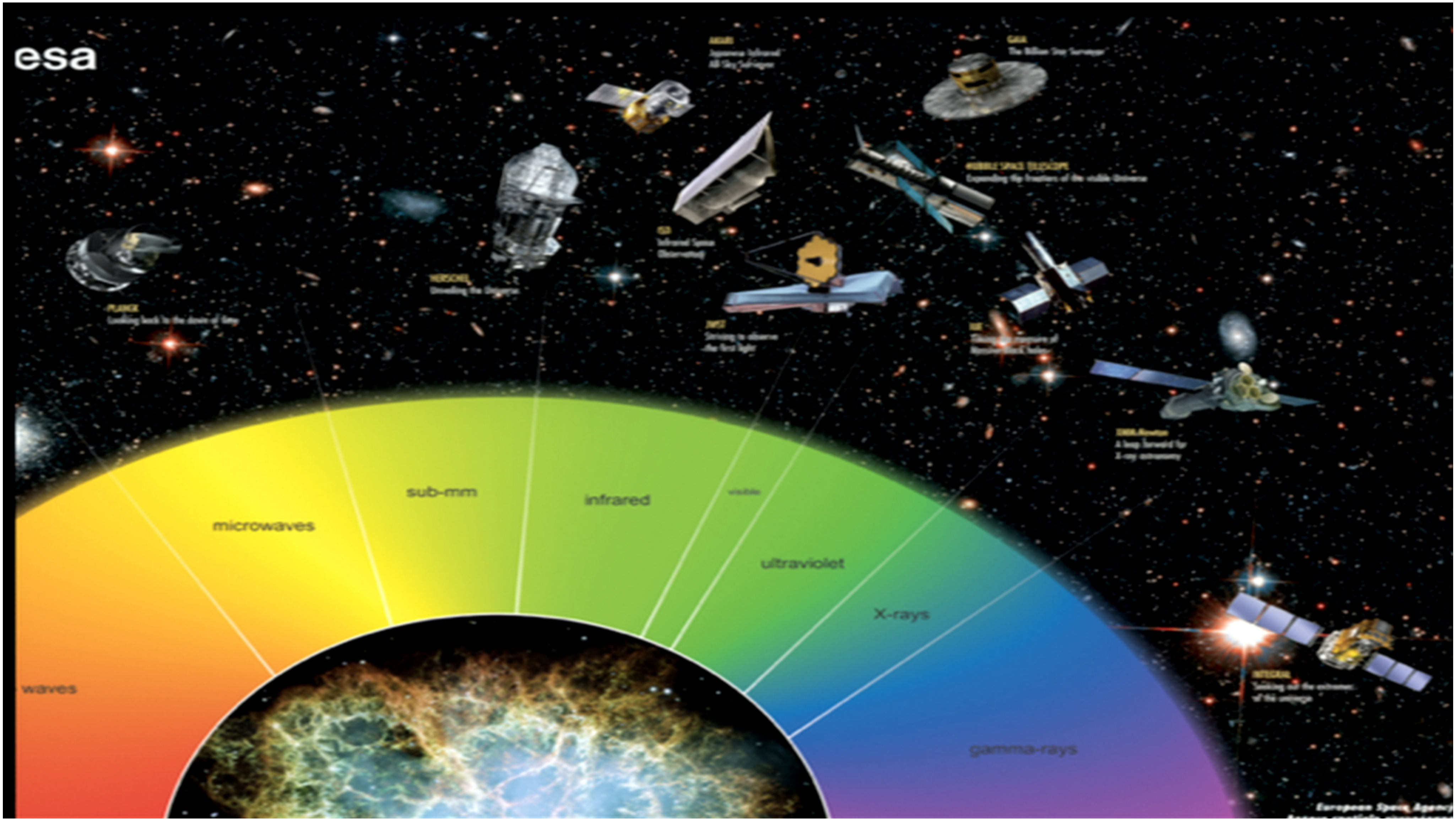
What is the visible Universe made of?

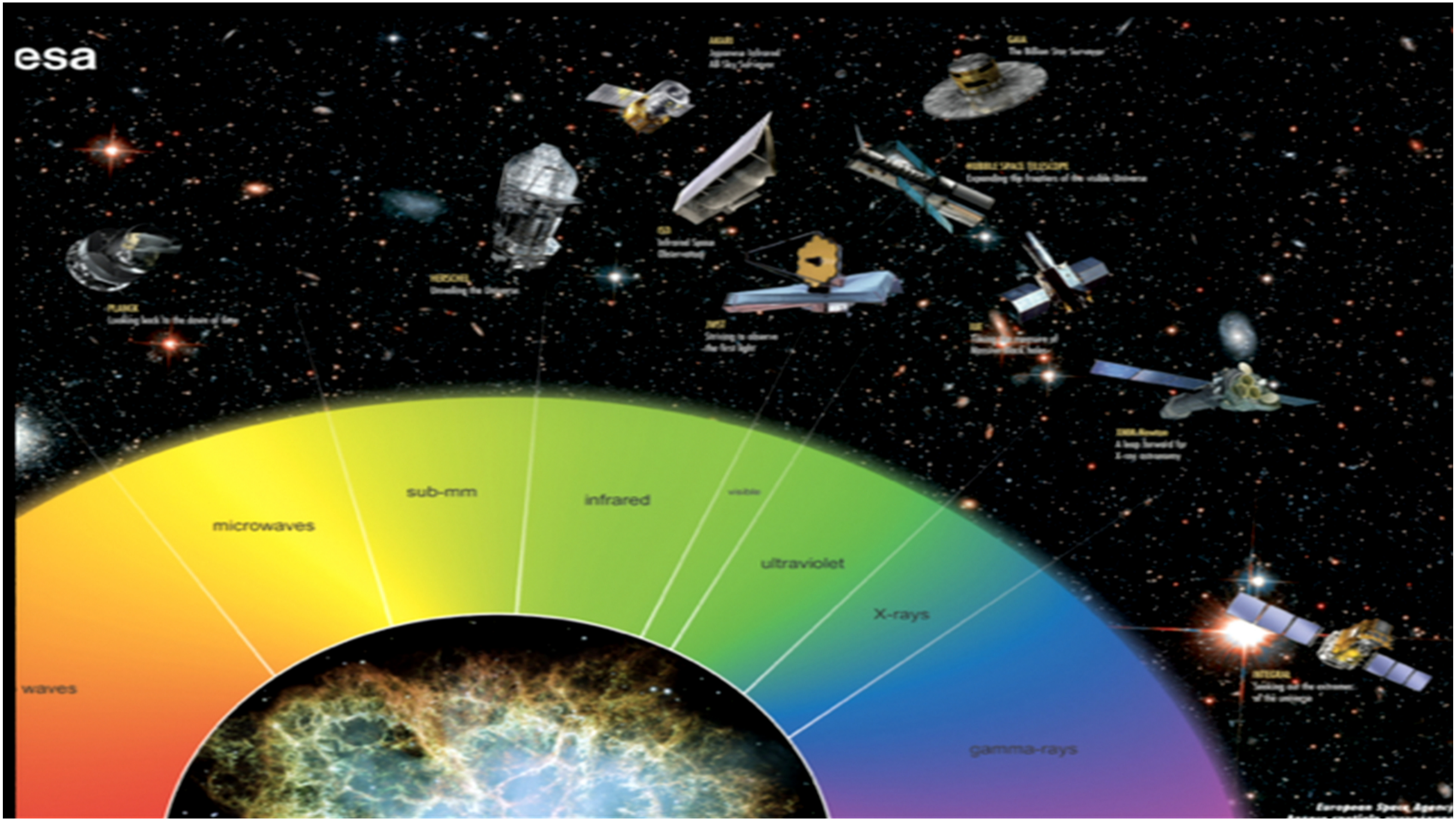


Matter

Matter as we know it is made out of particles which are charged. No matter how you put them, they will show up in the electromagnetic spectrum somewhere.




sub-mm
microwaves
infrared
ultraviolet
X-rays
waves
gamma-rays


microwaves
sub-mm
infrared
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X-rays
waves
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Doppler Effect

Maybe counter intuitively, velocities are much easier to measure than just about anything else via the Doppler effect and quantum mechanics.

Velocity Measurements

Atoms emit radiation in very particular frequencies. Assuming that atoms are the same everywhere, we can compare the spectrum of the Sun to any other spectra observed in the sky.

http://stokes.byu.edu/redshift.html

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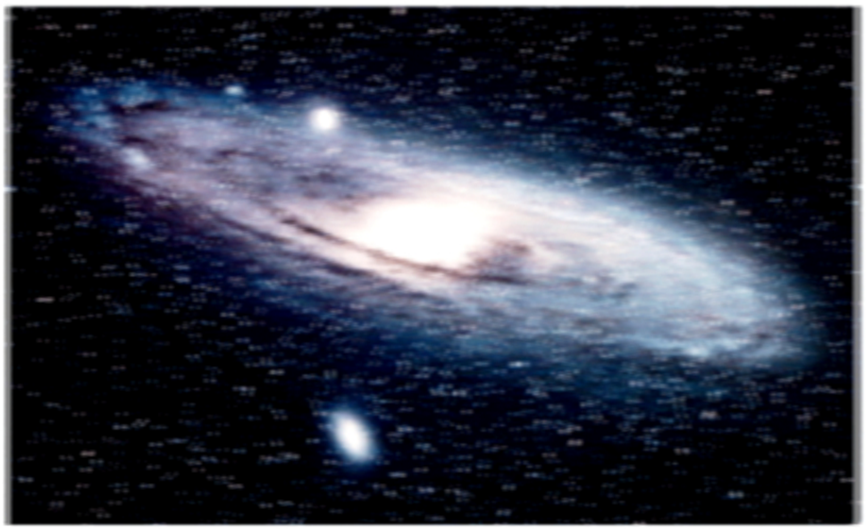
Rotation Curves



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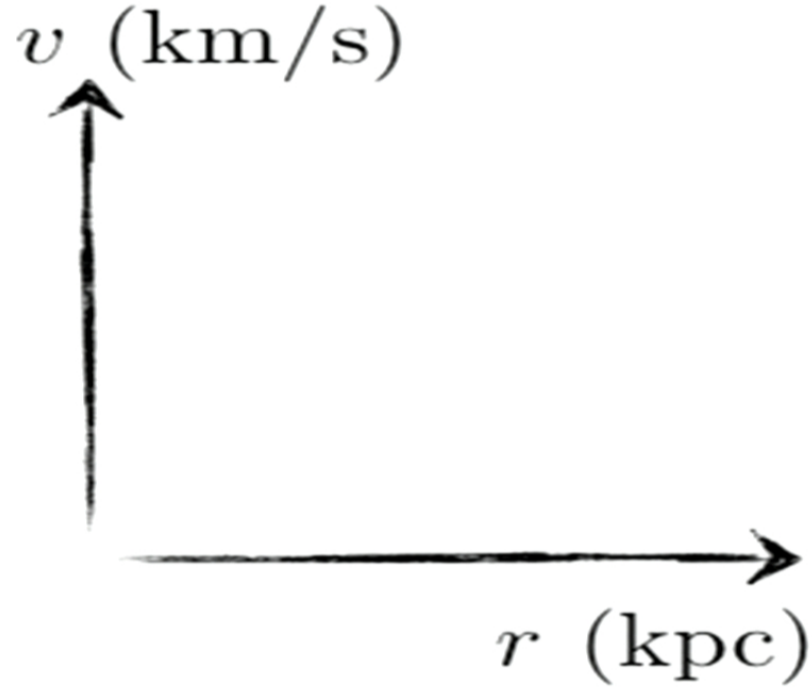

Mechanics

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$$\mathbf{F} = m\,\mathbf{a}$$

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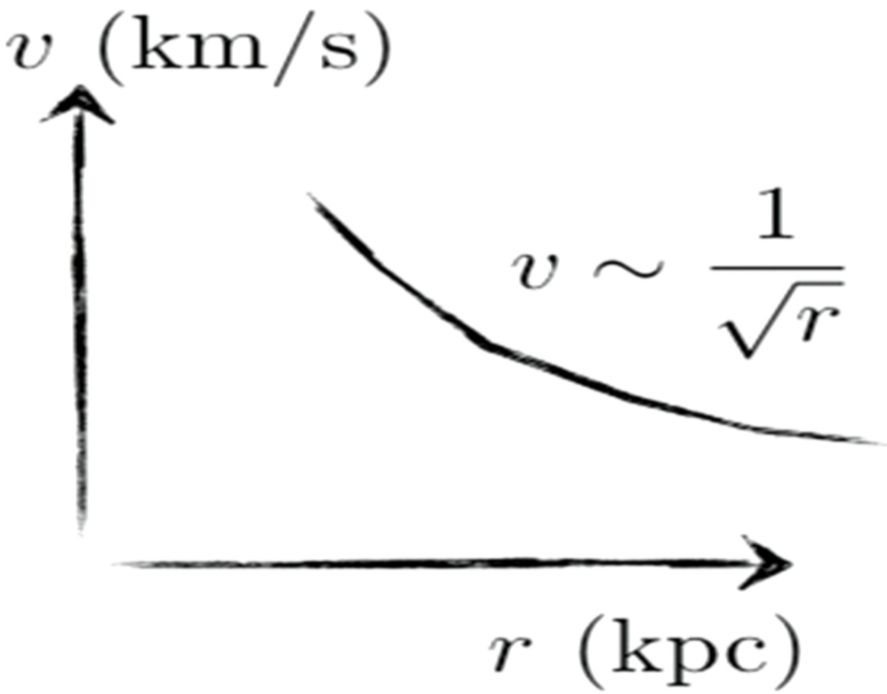
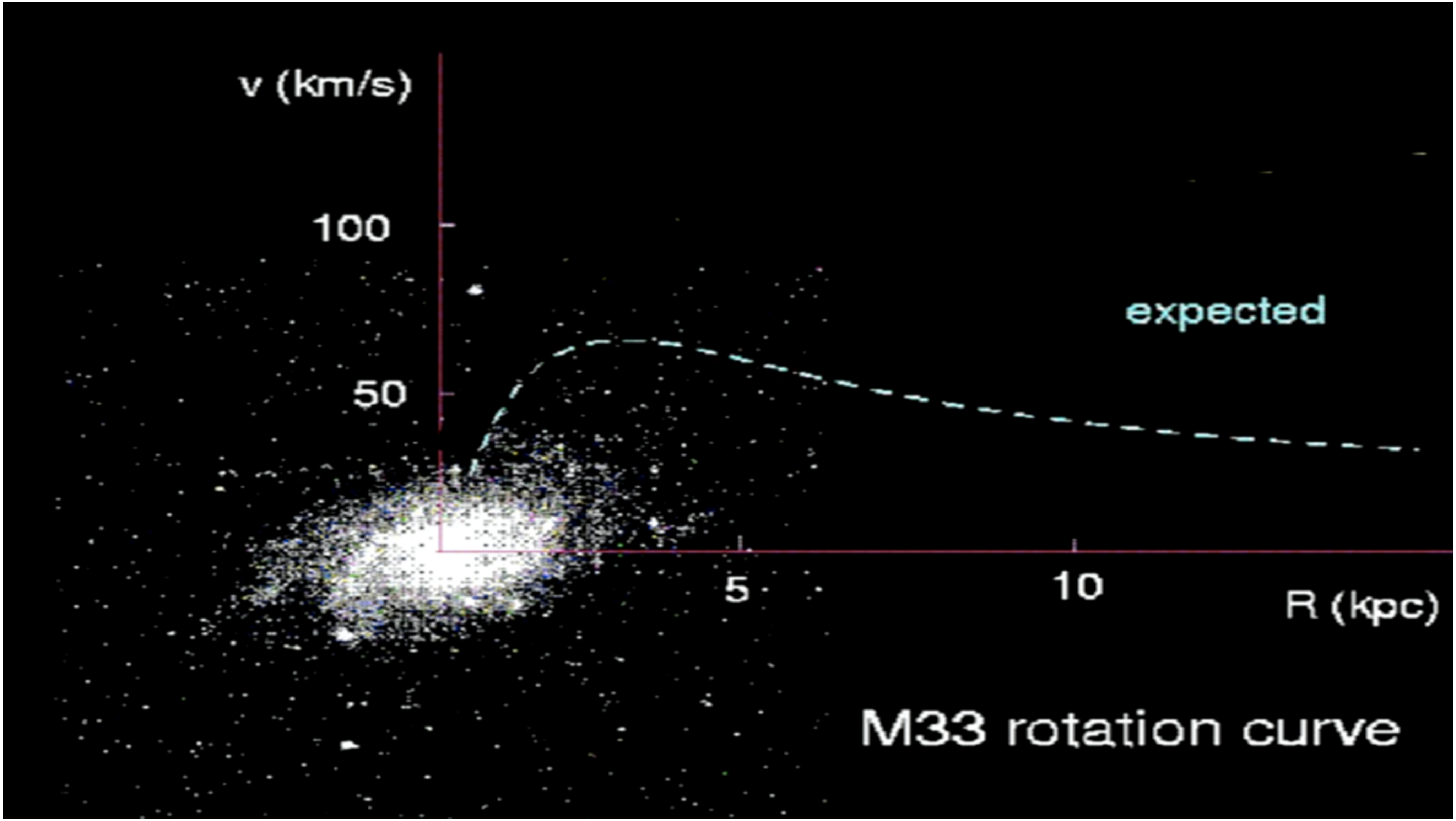
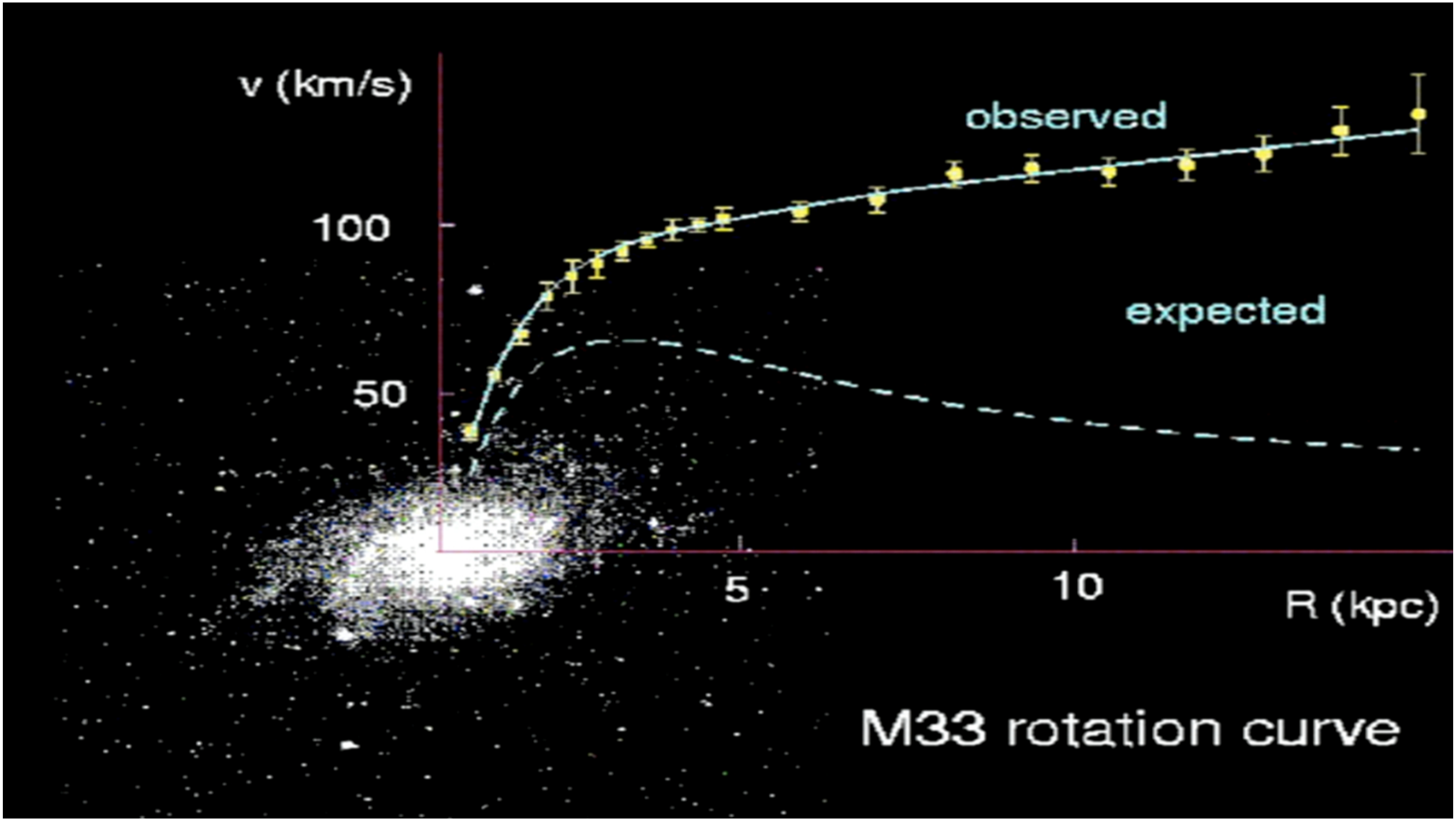
Expectations




v (km/s)
100
50
expected
5
10
R (kpc)
M33 rotation curve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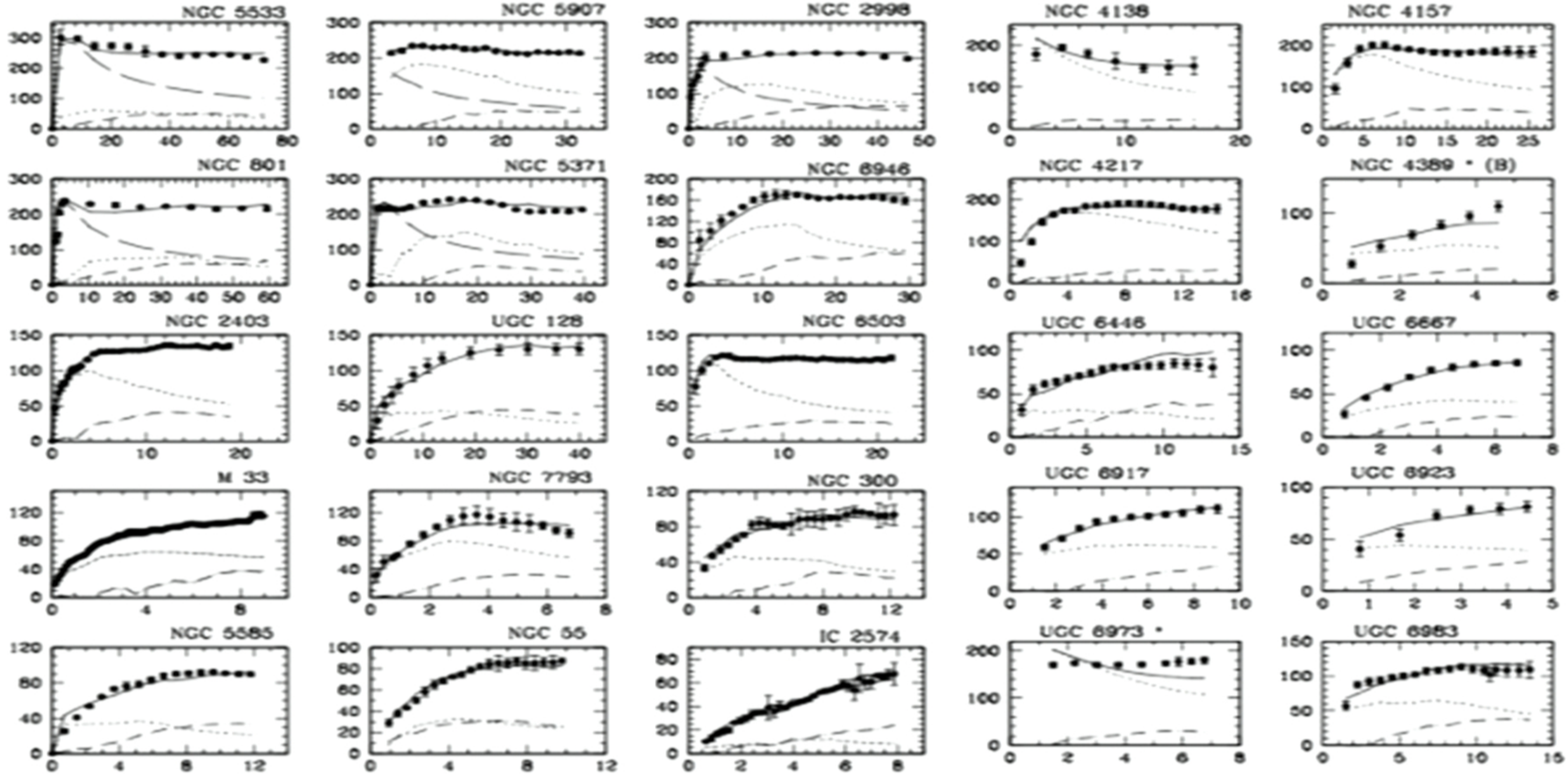
. . . and many more



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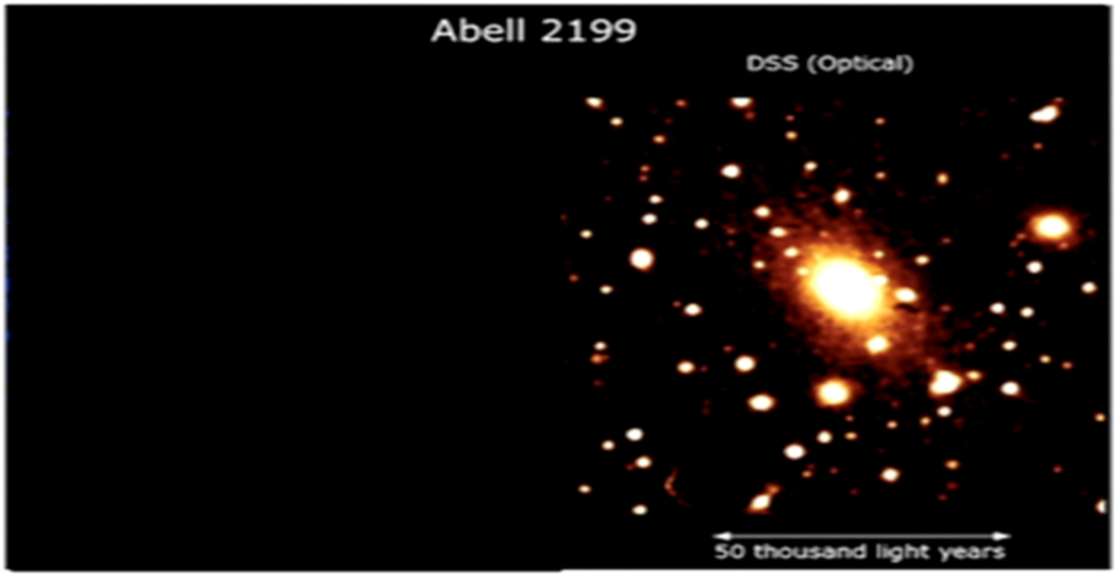
Dark Matter

The easiest thing to imagine is that we are simply missing some matter. It is called dark because we have so far failed to see it anywhere in the electromagnetic spectrum.



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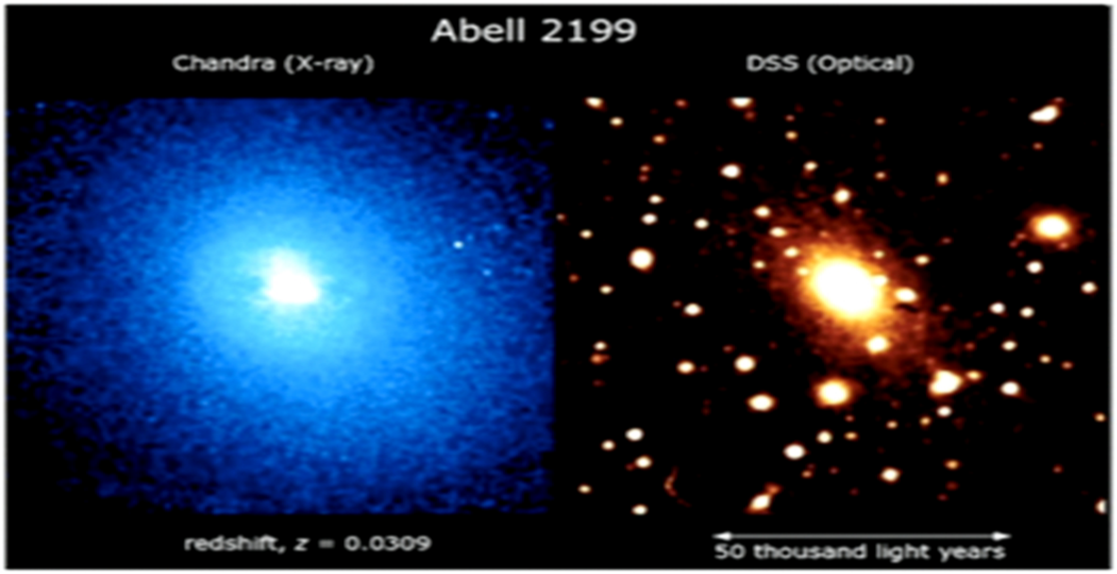

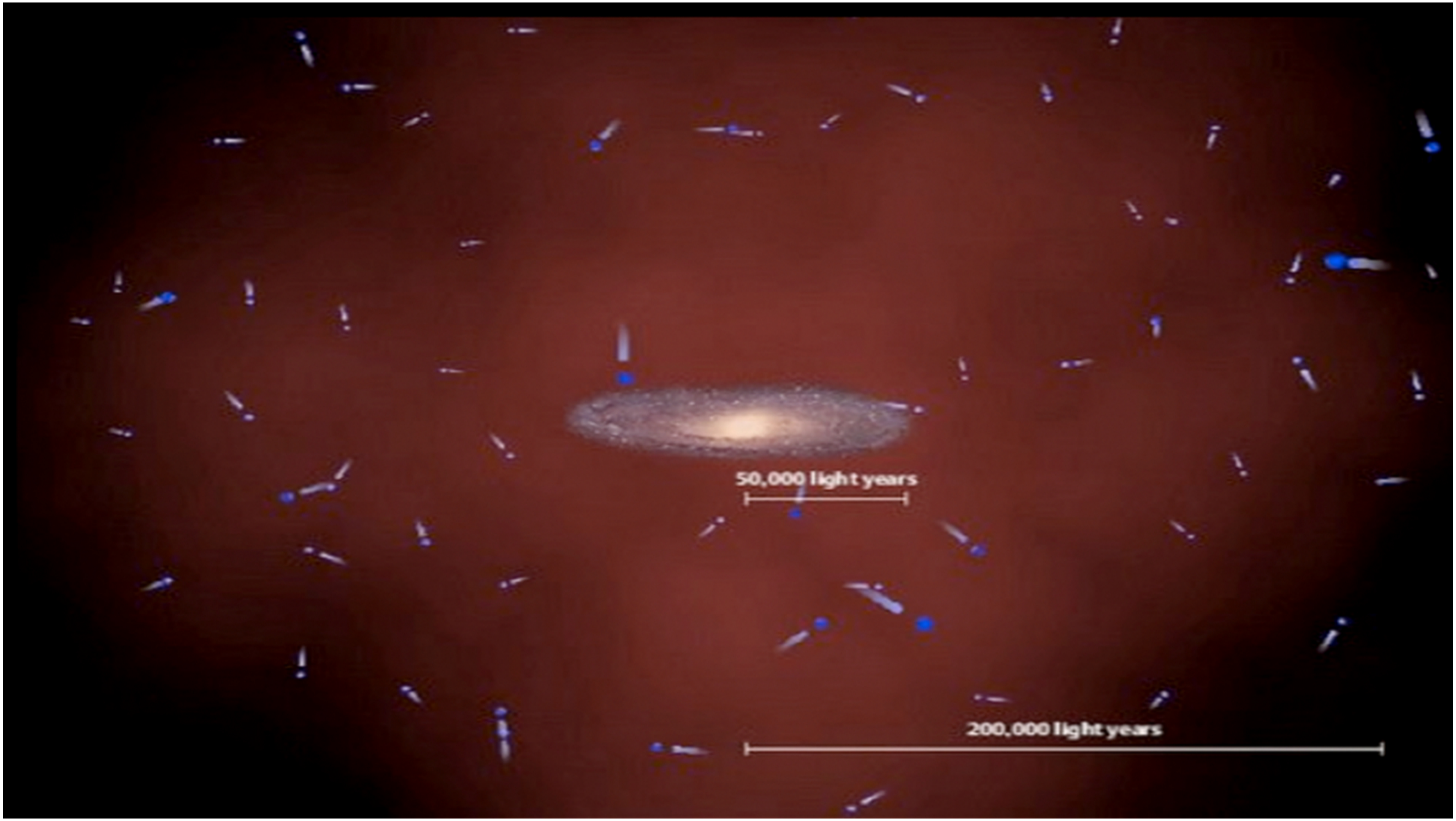
50,000 light years
200,000 light years


γ
g
W
e
μ
τ
Z


u c t γ
d s b g
ν ν ν W
e μ τ Z

Is it really matter?

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Maybe we are missing matter

Maybe Gravity is modified...

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M. Milgrom

MOdified Newtian Dynamics

$$G M a_0 = v^4$$

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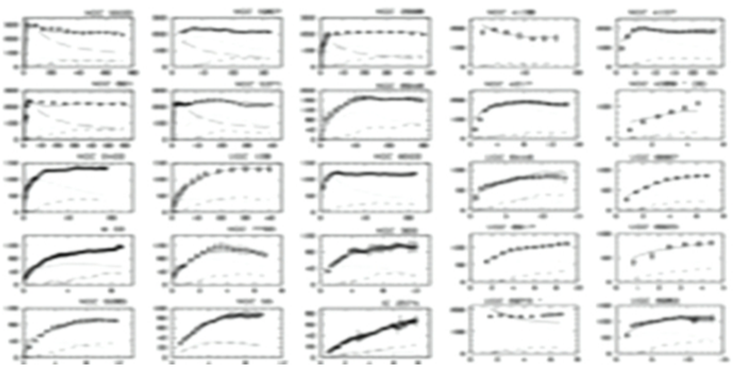
MOND - MOdified Newtian Dynamics

M. Milgrom proposed Modified Newtonian Dynamics as a way to explain the anomalous rotation curves. With J. Bekenstein they devised a relativistic version. S. McGaugh completed a large catalogue of galaxies where MOND works extremely well.



Pros

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- Shape of rotation curves.
- Predicted baryonic Fisher-Tulley relation.

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- CMB
- Bullet cluster

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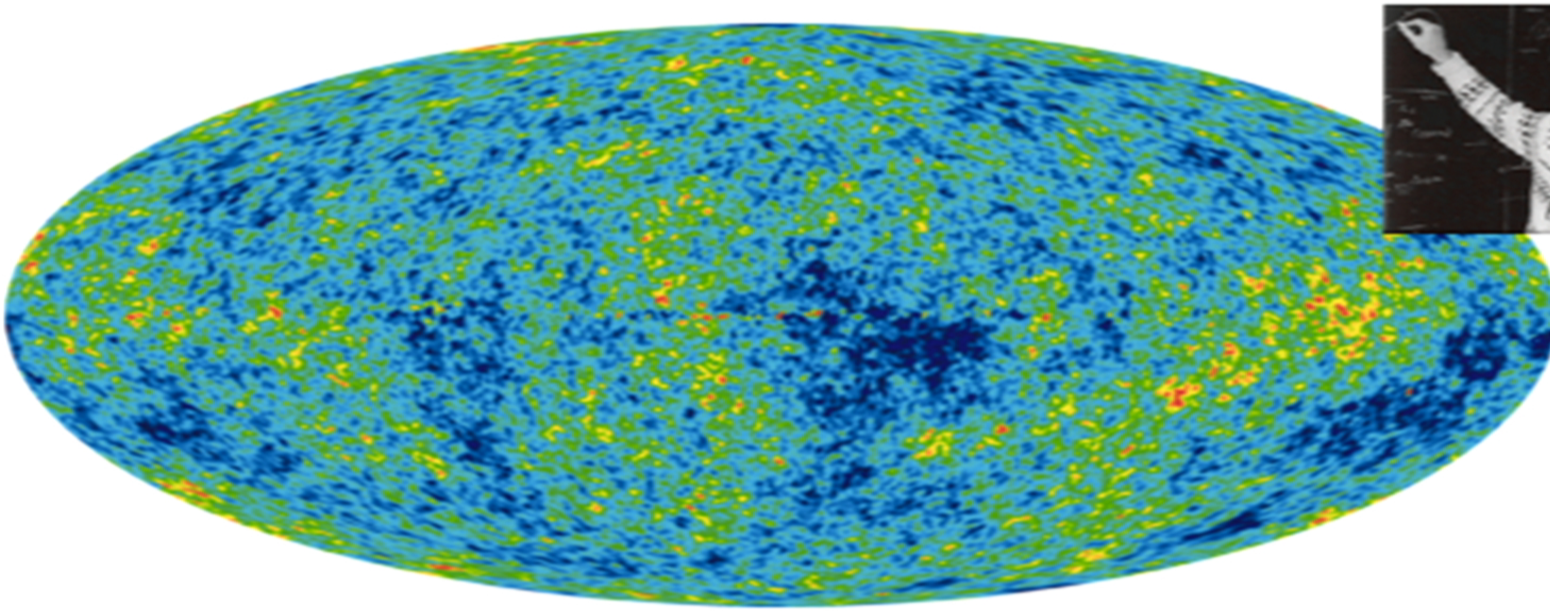
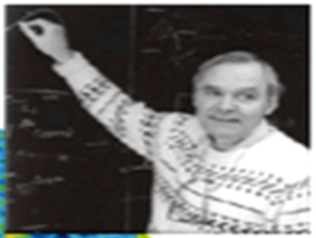
Could it be black holes? Could it be hot ionized gas? Does it really have to be a new fundamental particle?

Possibly, but the Wilkinson Microwave Anisotropy Probe (WMAP) says . . .





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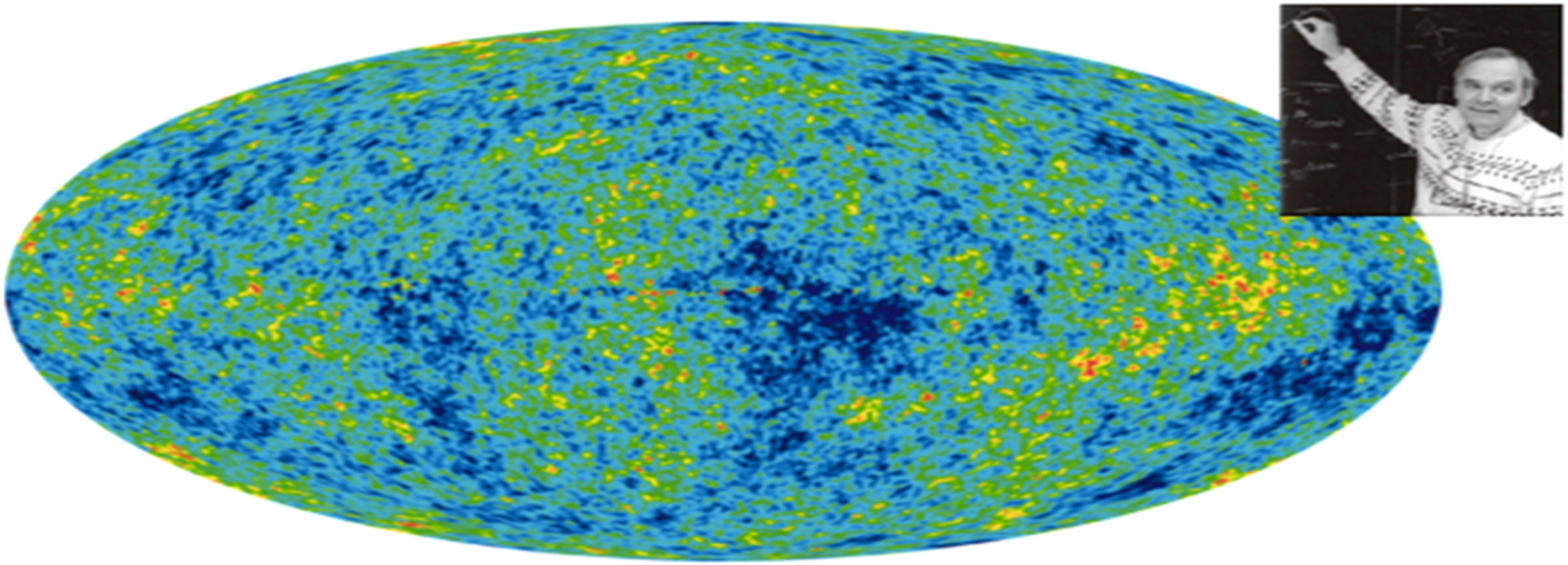

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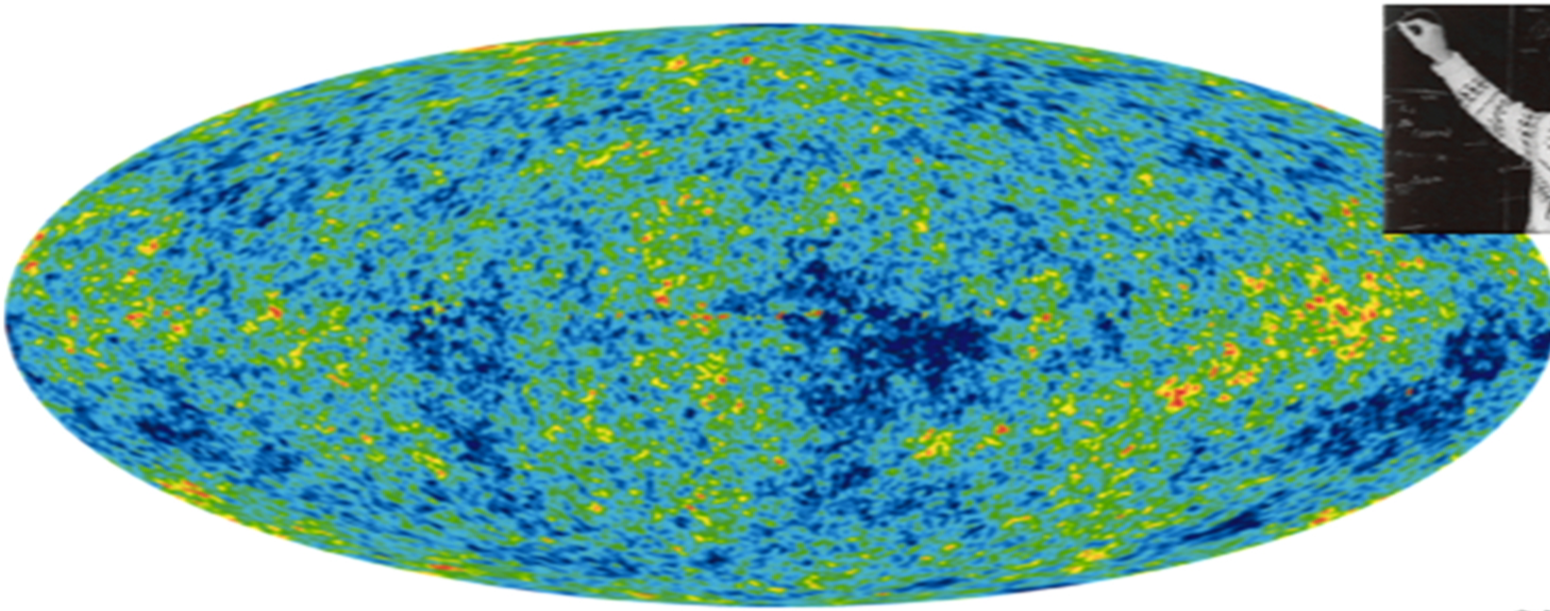

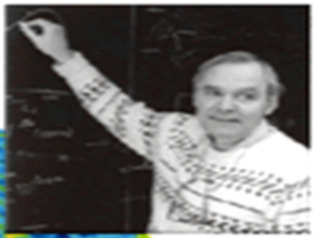

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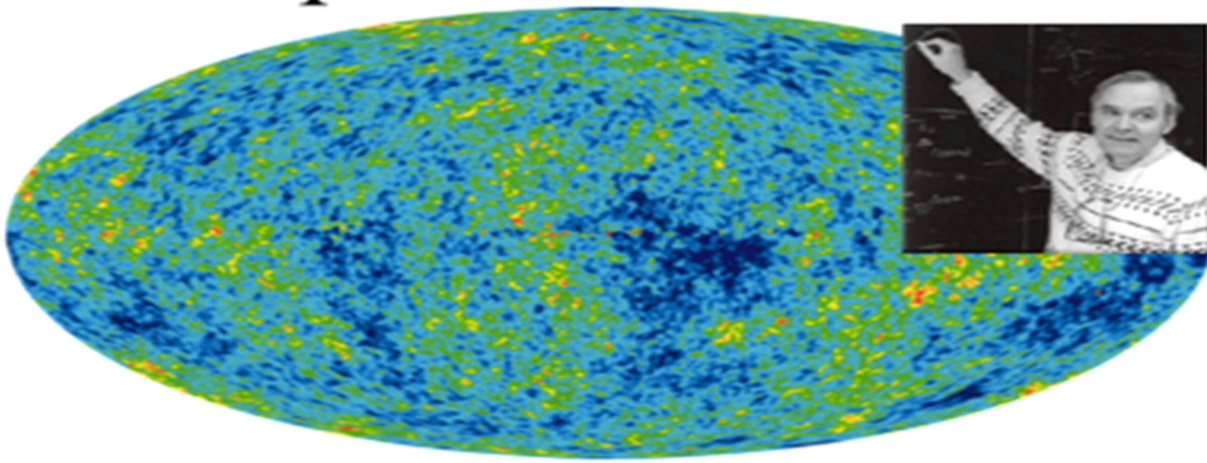

A snapshot of the universe as it was 100,000 years after the Big-Bang.

What kind of object is as old as the universe?

How can it stay dark?

How can there be so much of it?

Fundamental particles do it for breakfast

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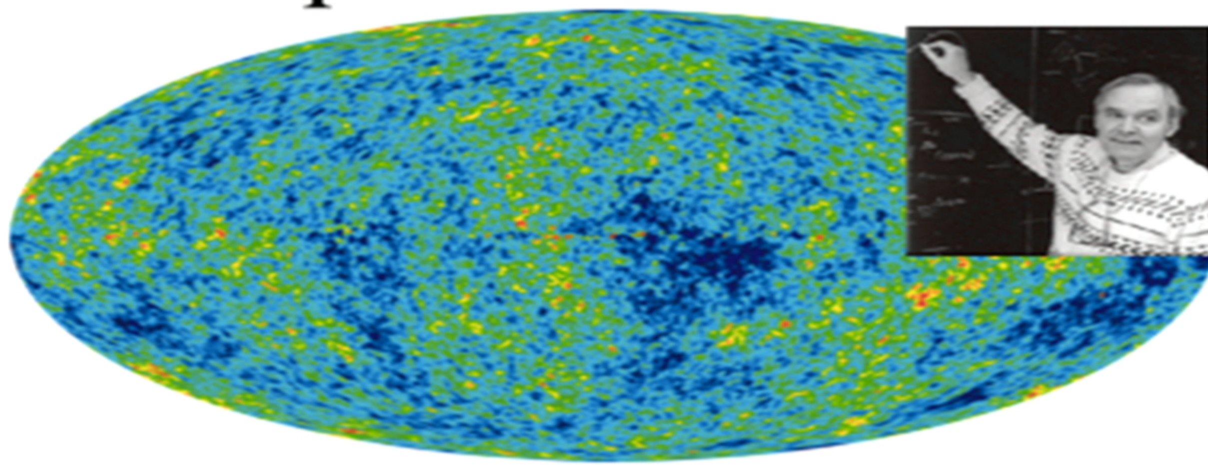

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How much of it near the Earth?

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$$\rho_{\rm DM} = 5 \times 10^{-22}\ {\rm kg/m^3}$$

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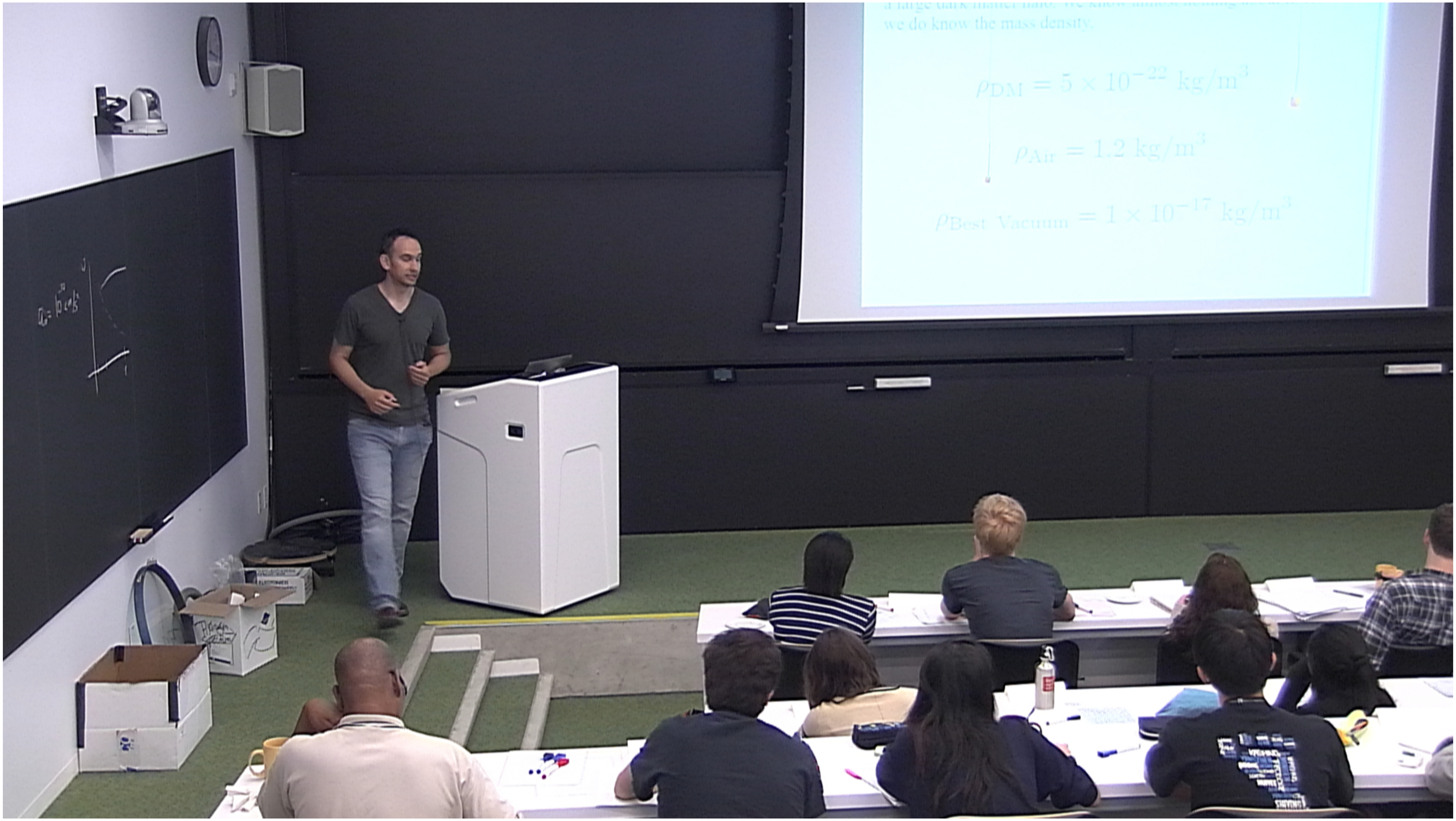
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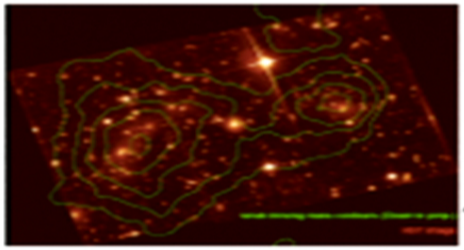
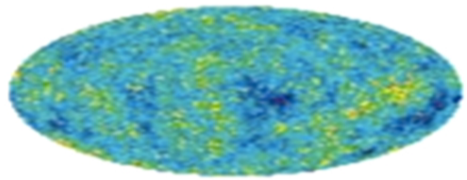
$\rho_{\rm Best\ Vacuum} = 1 \times 10^{-17}\ {\rm kg/m^3}$

Can We Test this Idea?

Bullet Cluster



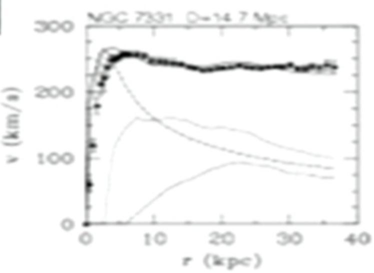
WMAP



Lensing Effects

New Fundamental Particle

Rotation curves



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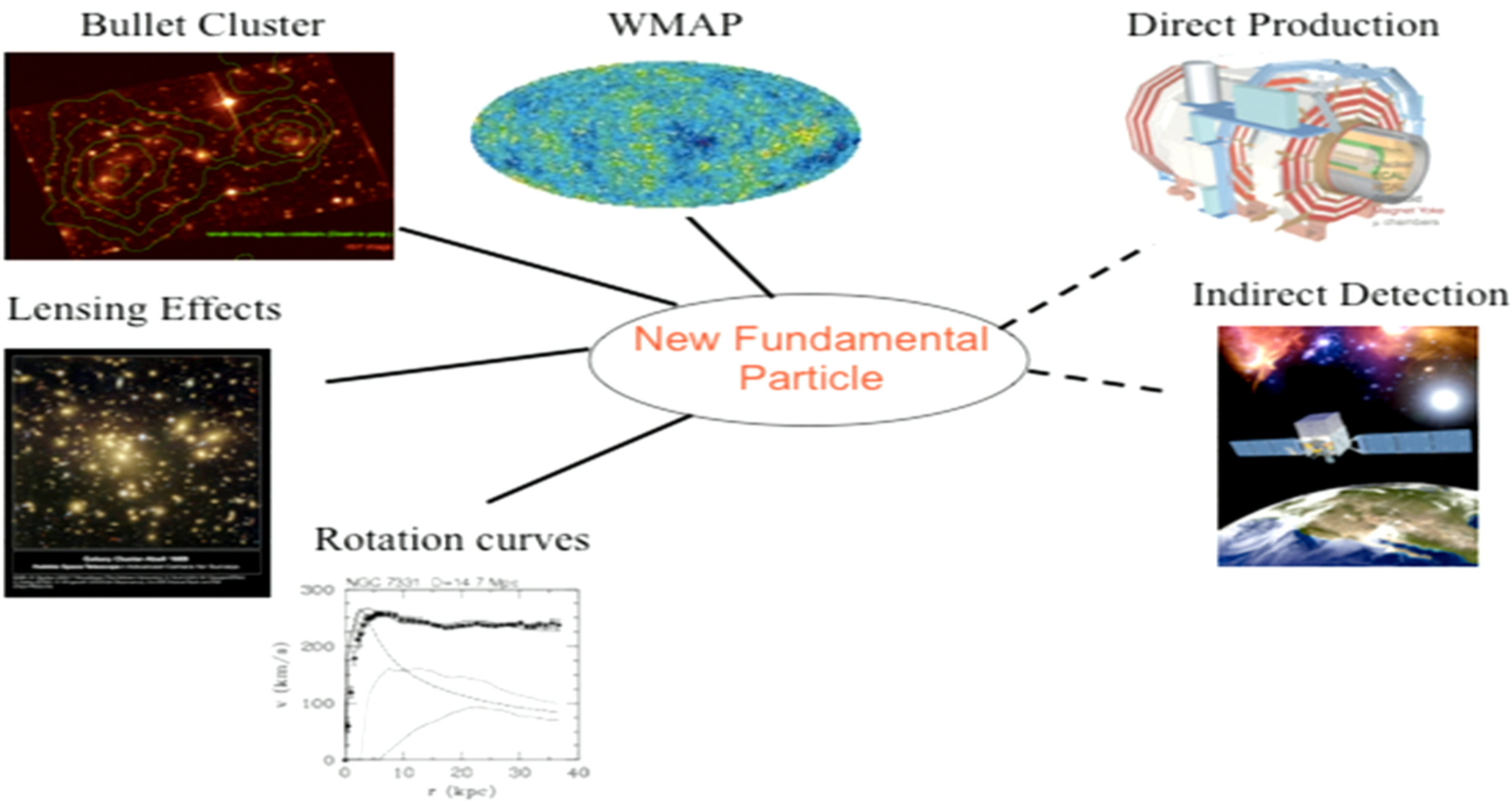

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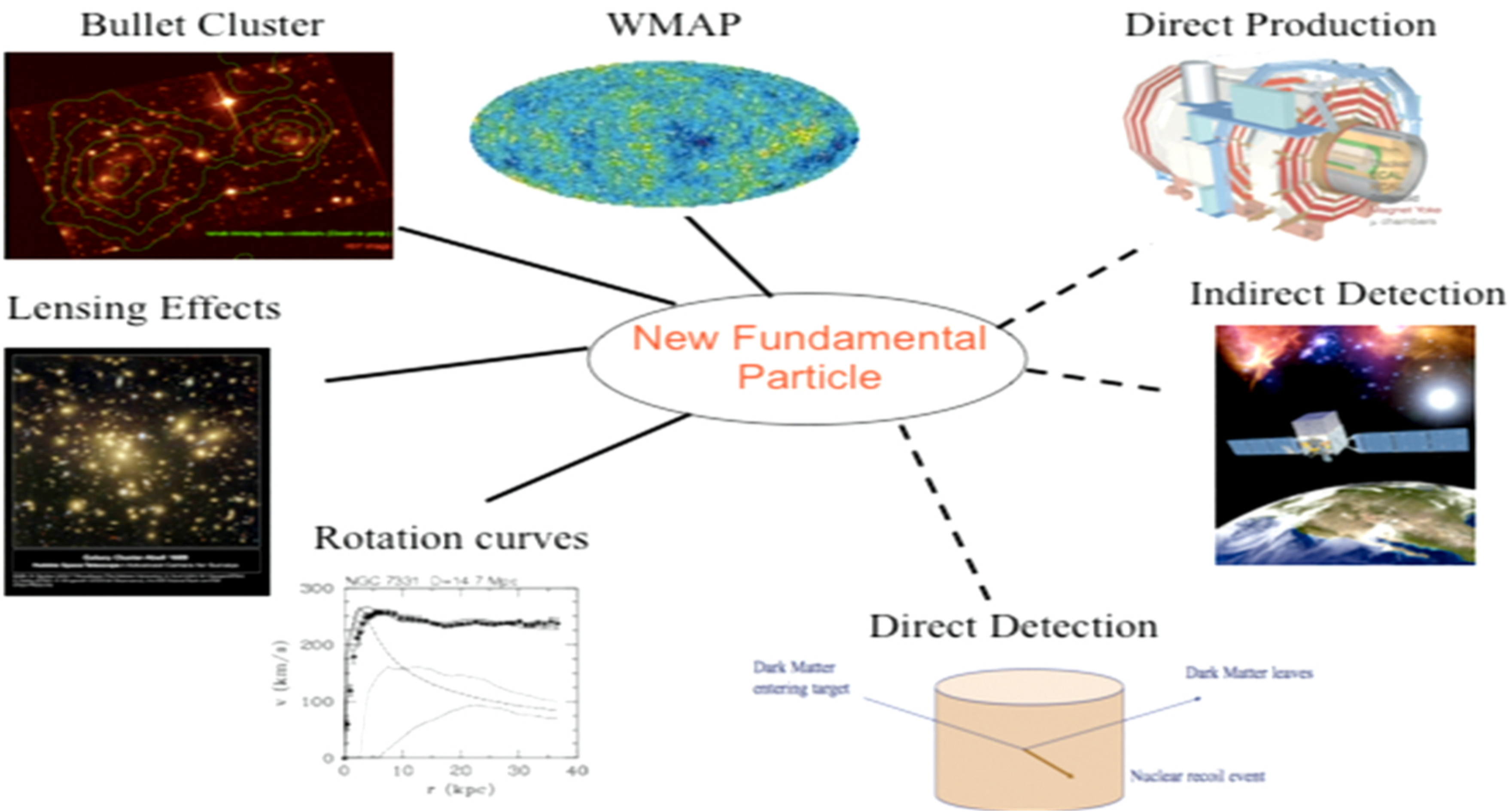
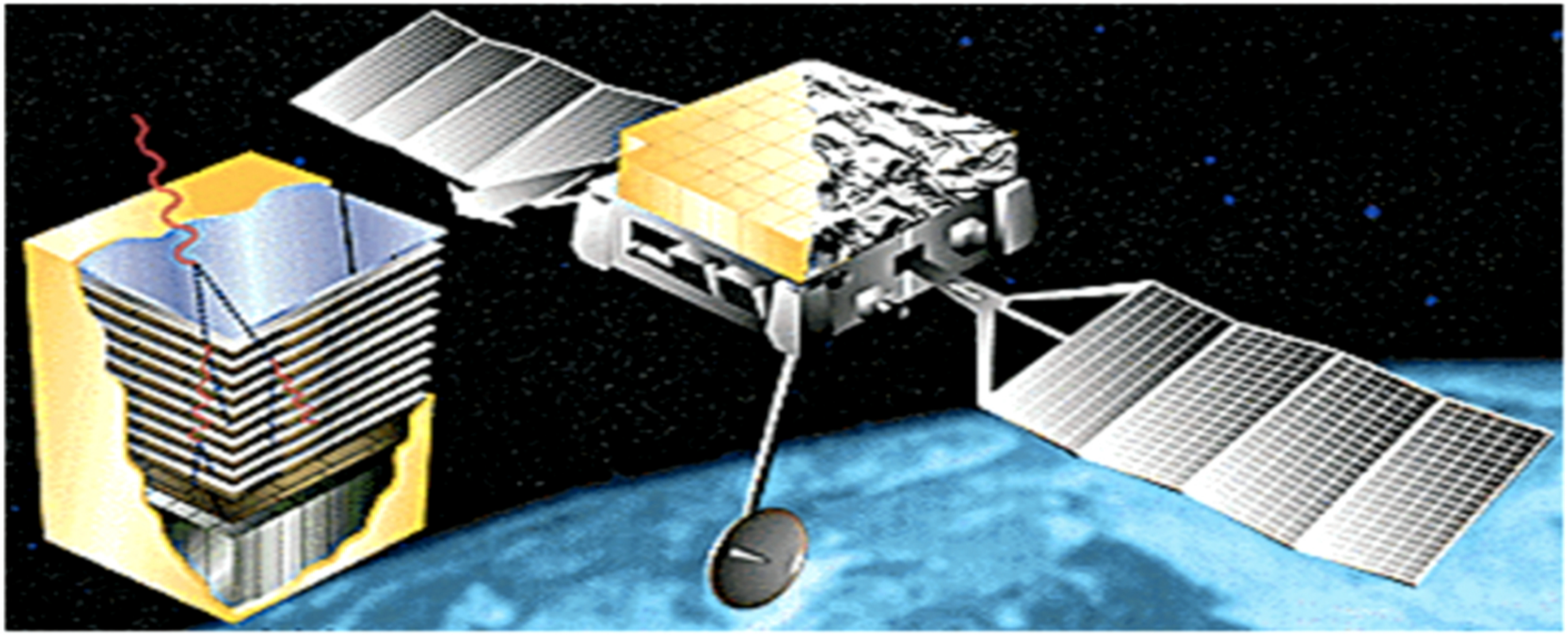


Is there an anti-Dark Matter?

If there is so much Dark Matter in the galaxy then maybe we can see it annihilate, after all we see normal matter annihilate (511 keV line).

Is there an anti-particle?

One of the best ways of observing such annihilations is with particle detectors in space.



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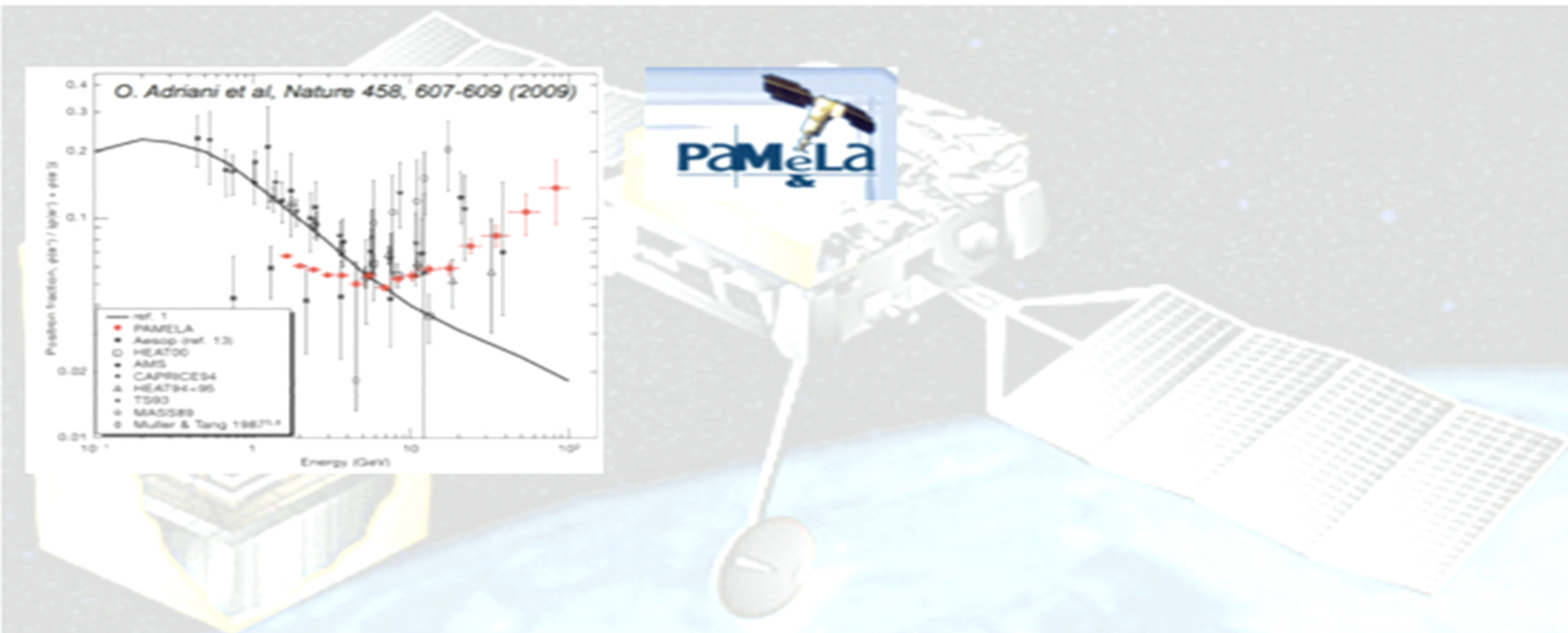

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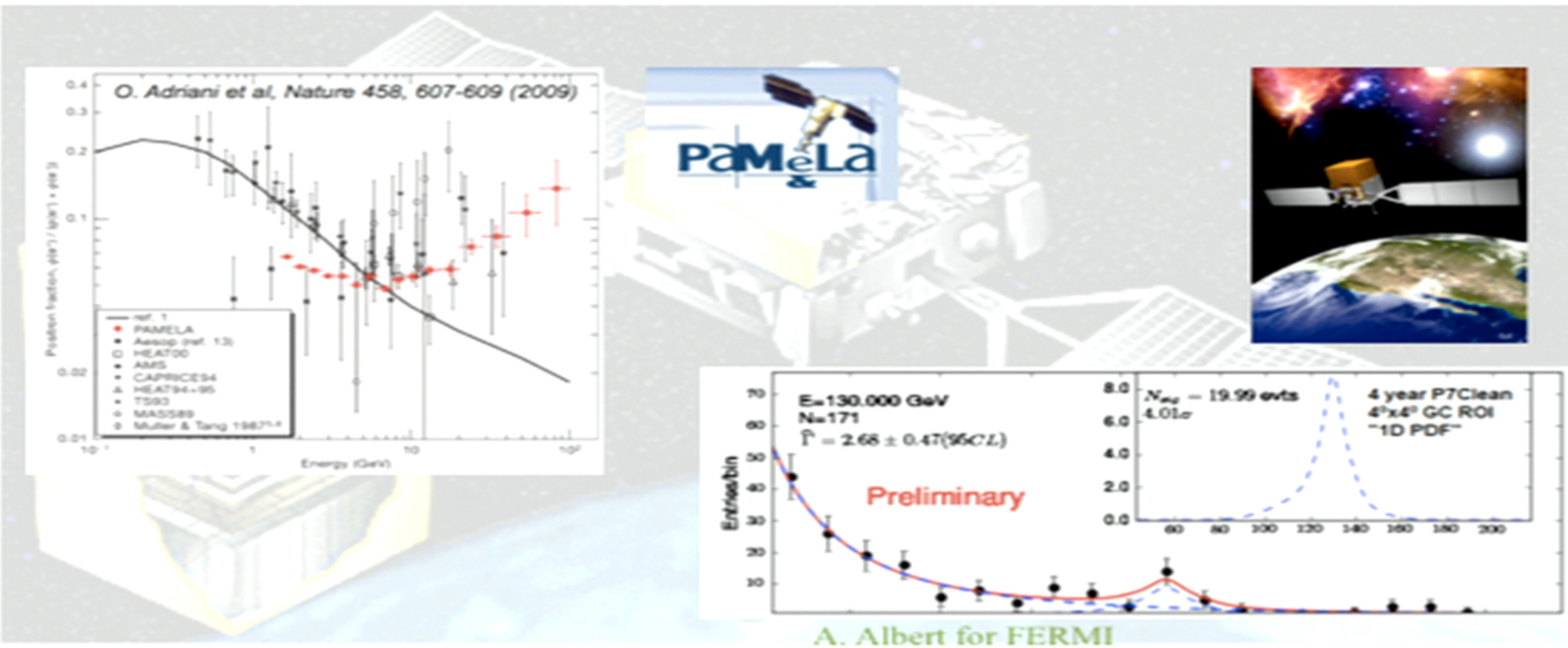
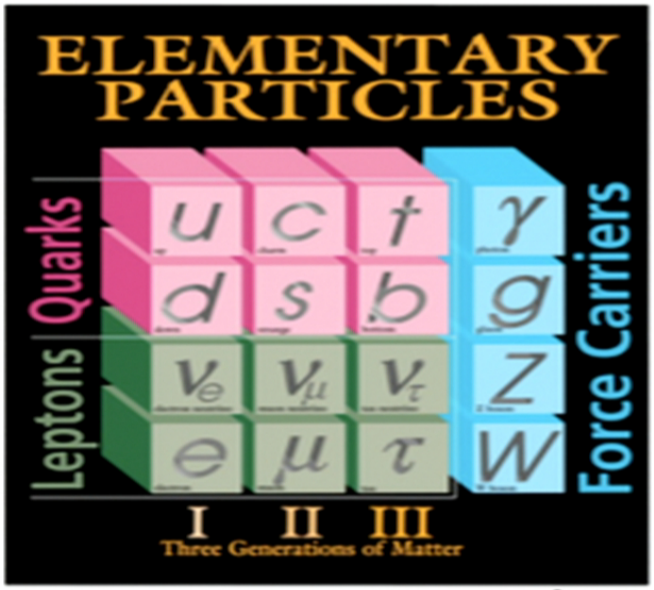


Is it a single species?

Whatever DM is composed of doesn't have to be a single entity. Even neutrinos come in three flavors. Could be composed of a variety of things.



The Standard Model is anything but simple

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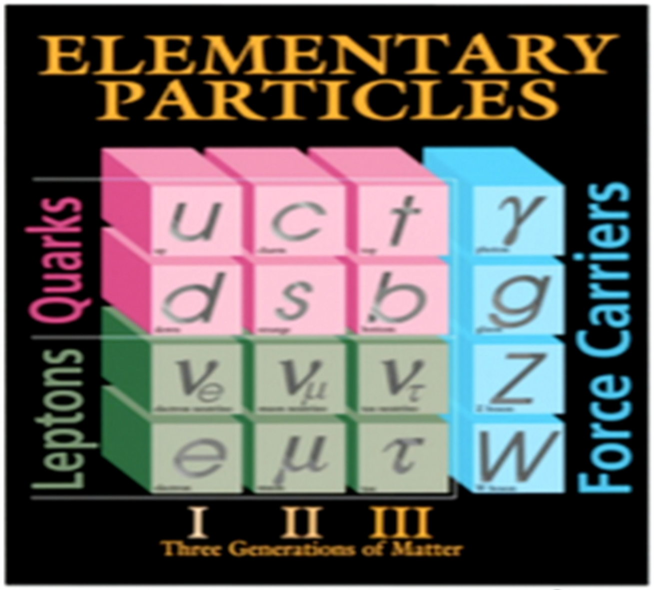

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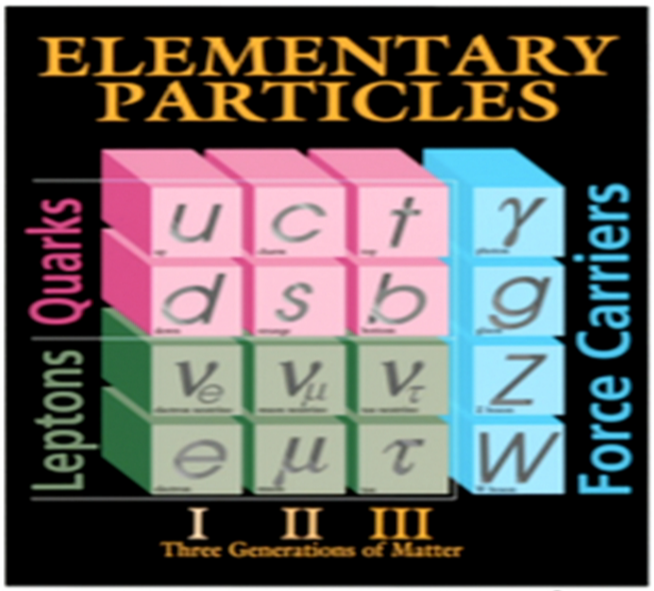

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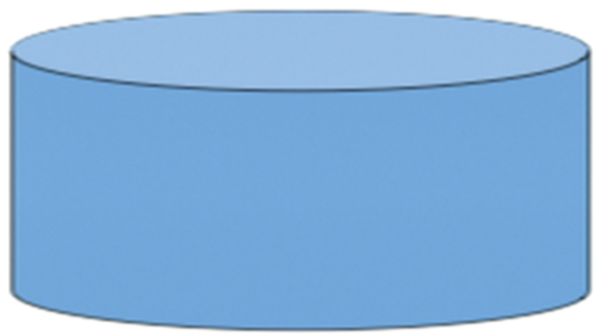

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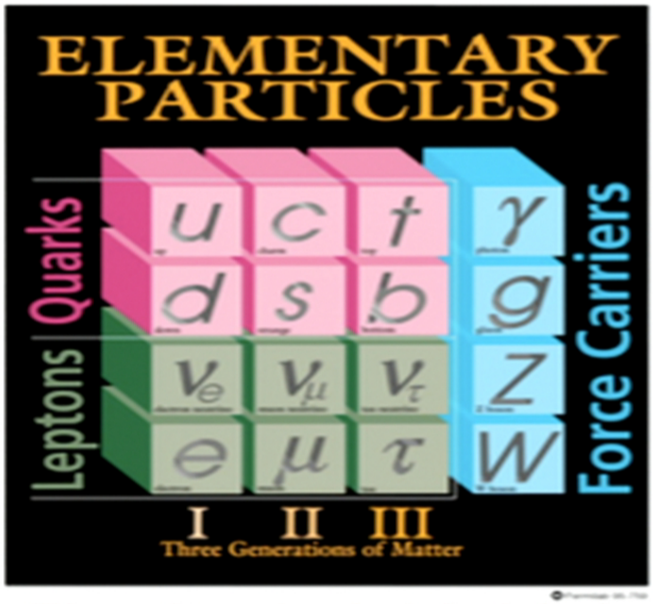
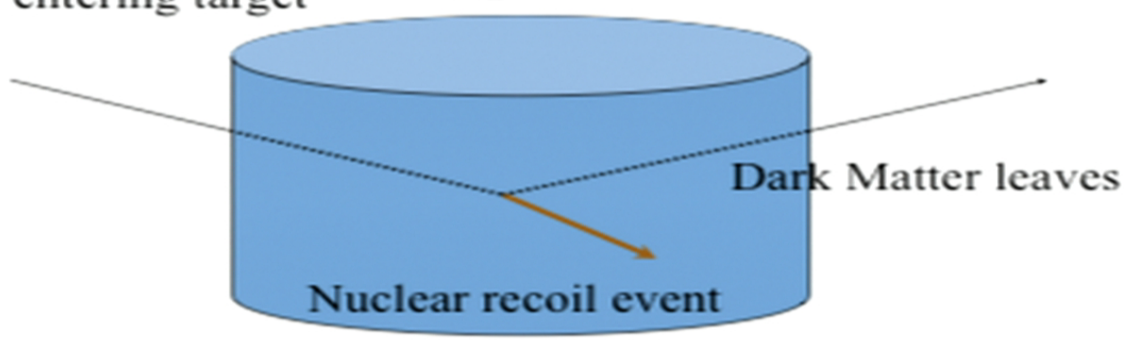


The Standard Model is anything but simple

Can be sensitive to many type of interactions.

Dark Matter entering target



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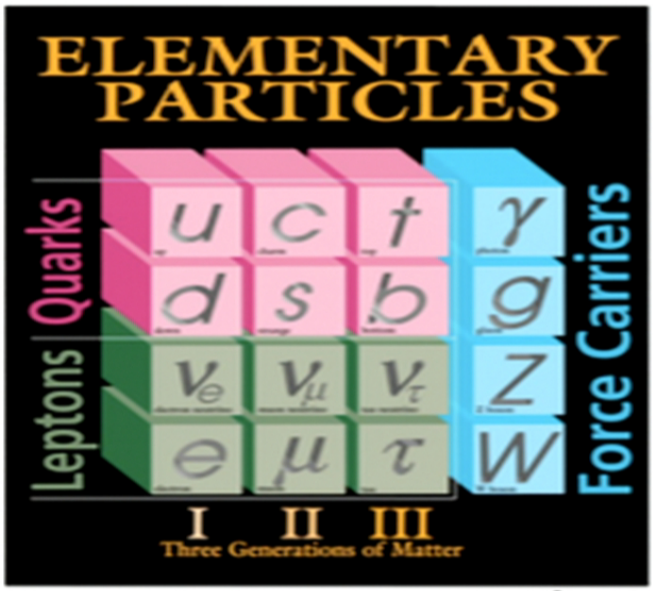

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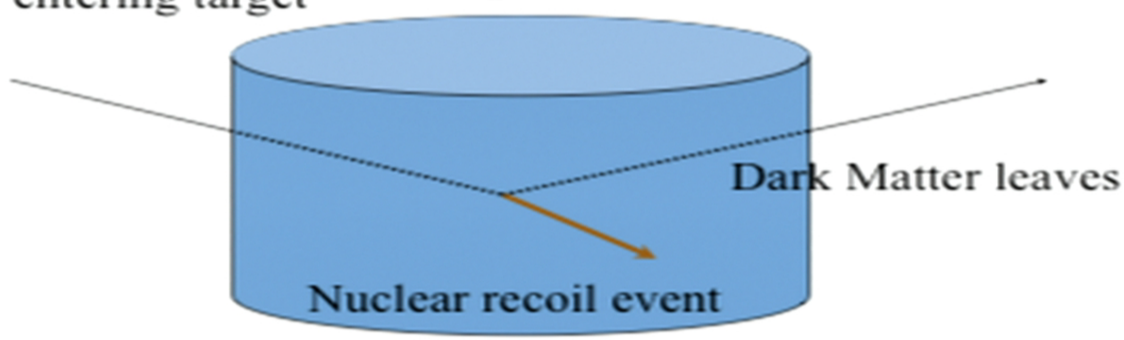

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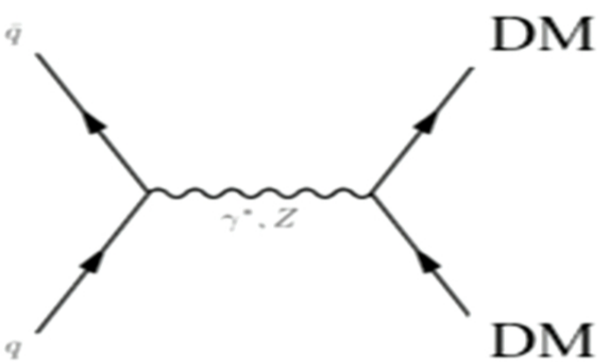

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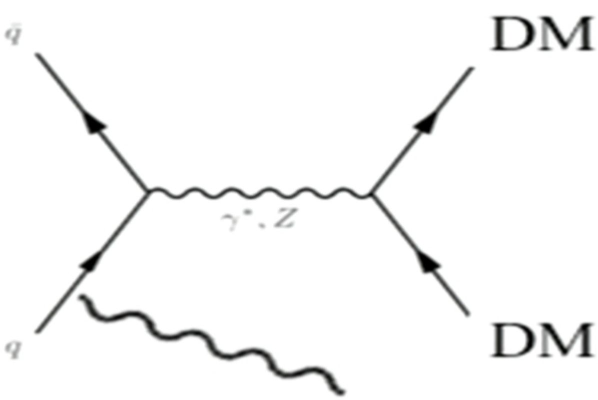

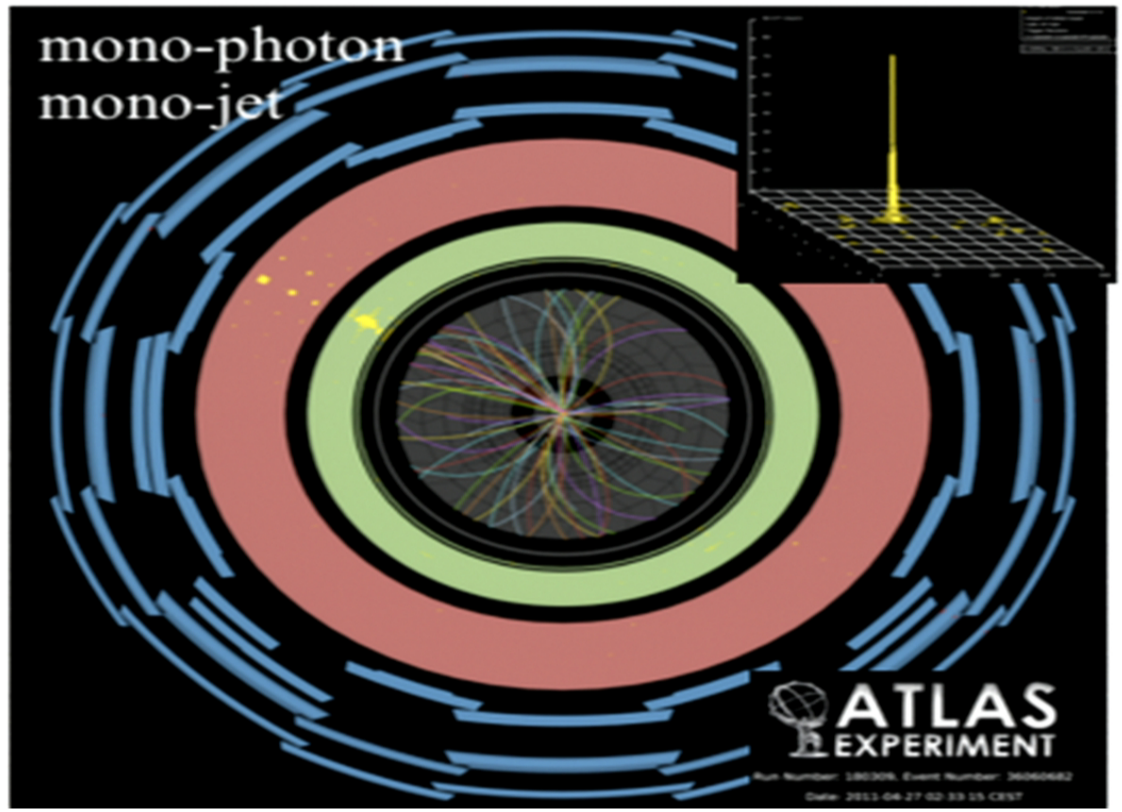

A Strange Picture