Non-accelerator searches for dark matter

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Why? (observational evidence for dark matter)

What? (dark matter candidate)

How? (experiments)

Observational evidence for dark matter

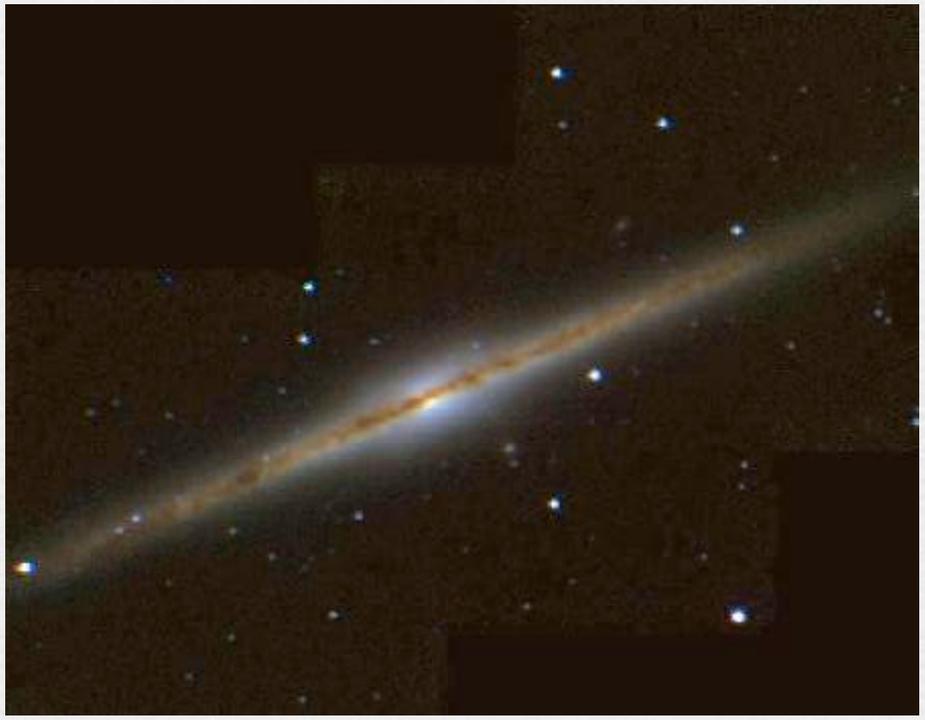
i) in spiral galaxies:

‘face on’

Whirlpool galaxy

[image credit: Hubble Space Telescope]

‘edge-on’



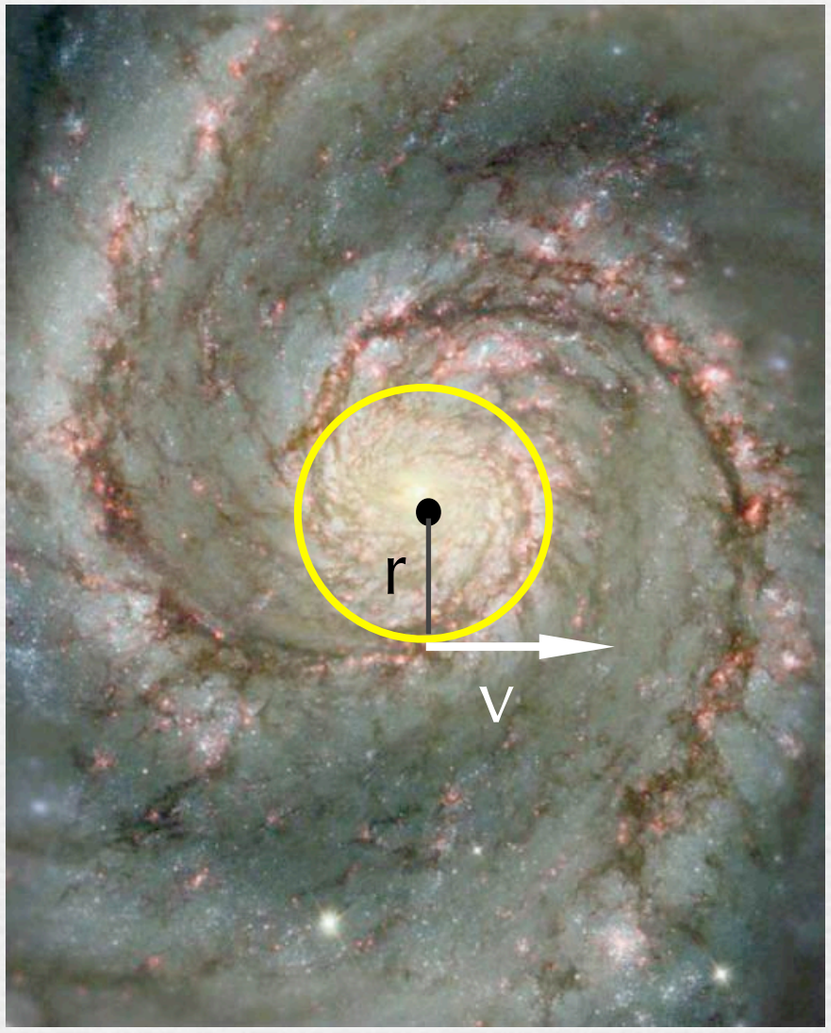
NGC891

[image credit: NOAO]

Observational evidence for dark matter

i) in spiral galaxies:

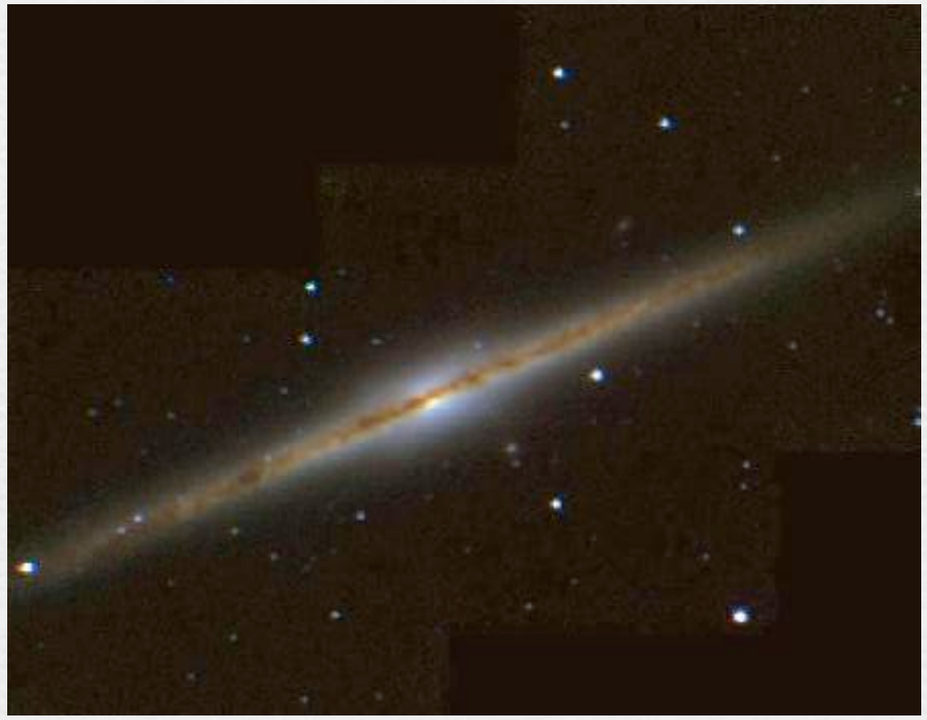
‘face on’



Whirlpool galaxy

[image credit: Hubble Space Telescope]

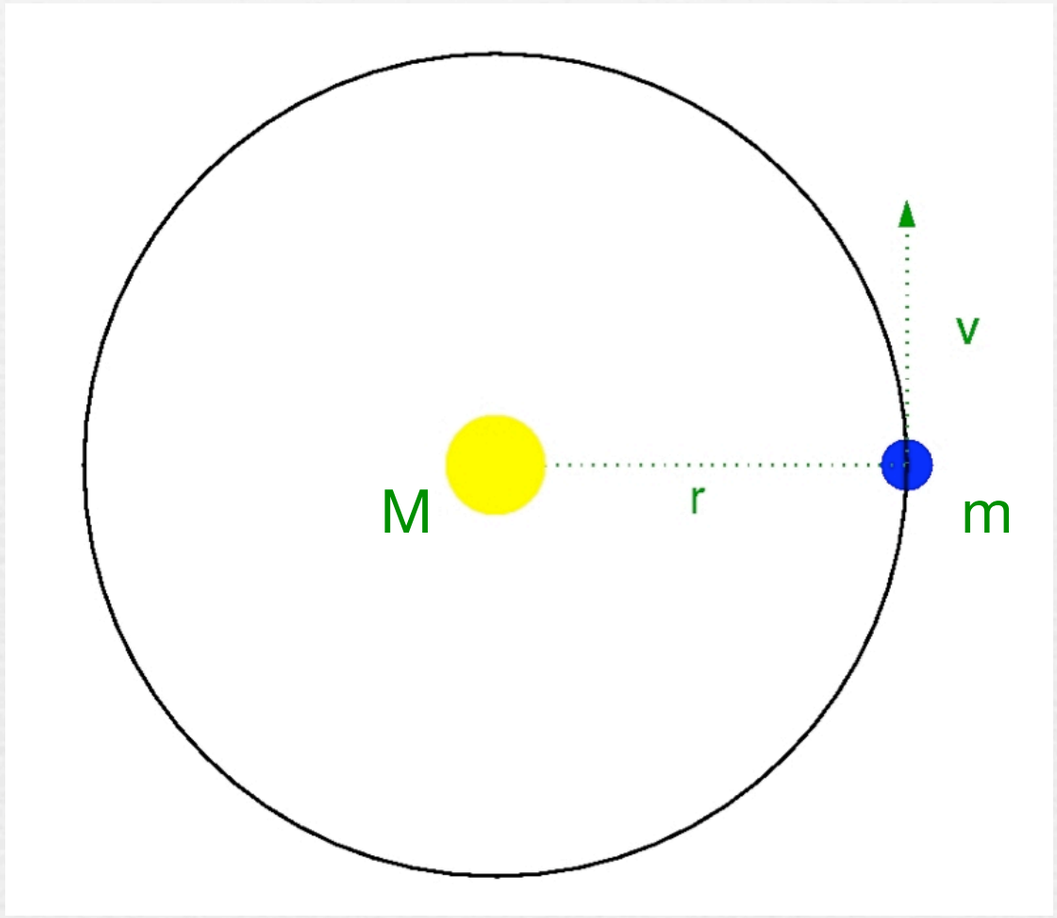
‘edge-on’



NGC891

[image credit: NOAO]

Circular motion



Newton's 2nd law of motion:

$$F = ma$$

Newton's law of gravitation:

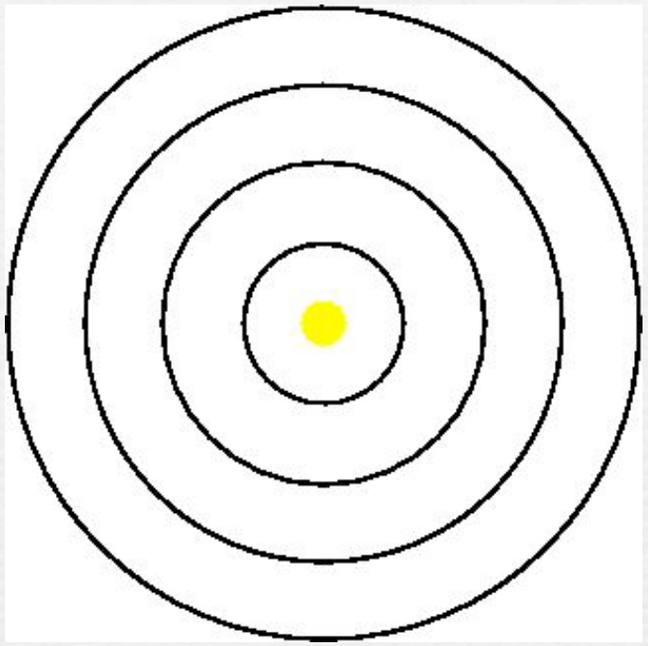
$$F = \frac{GMm}{r^2}$$

Circular acceleration:

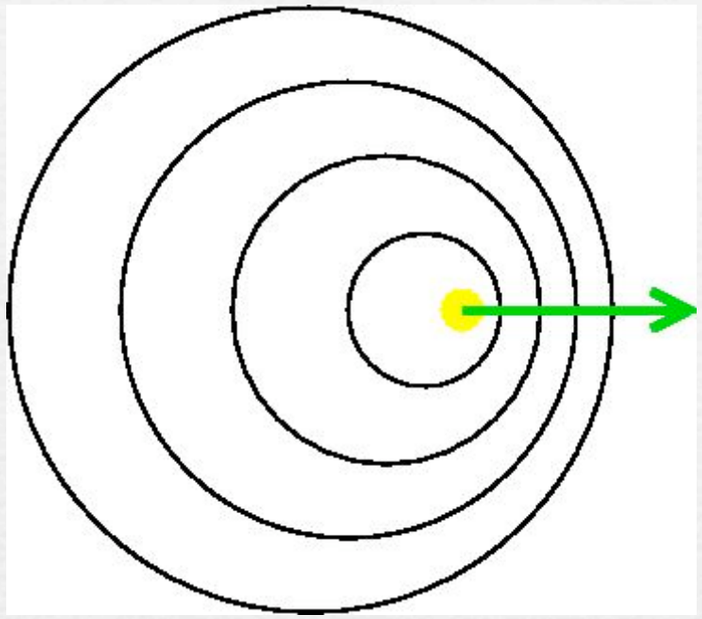
$$a = \frac{v^2}{r}$$

$$\frac{GM}{r^2} = \frac{v^2}{r} \quad \Rightarrow \quad v = \sqrt{\frac{GM}{r}}$$

Doppler effect:

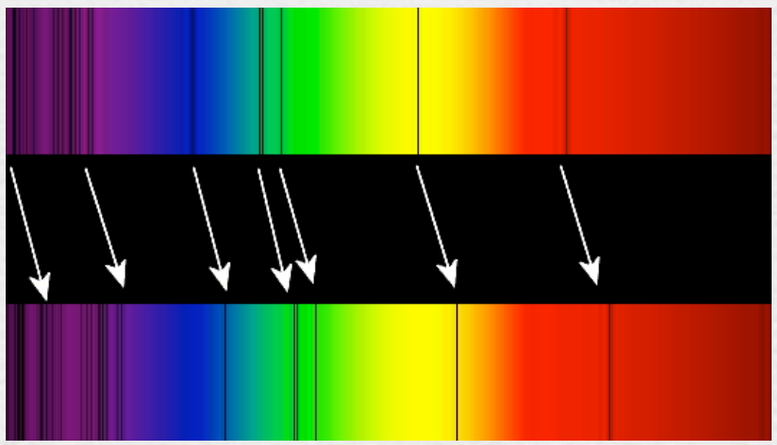


Stationary source

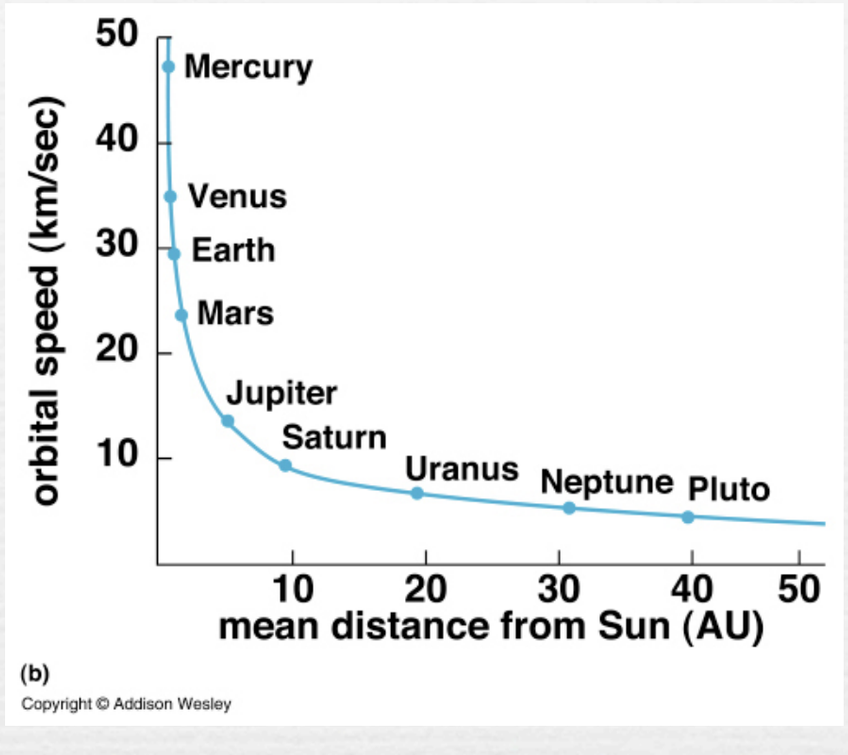


Moving source

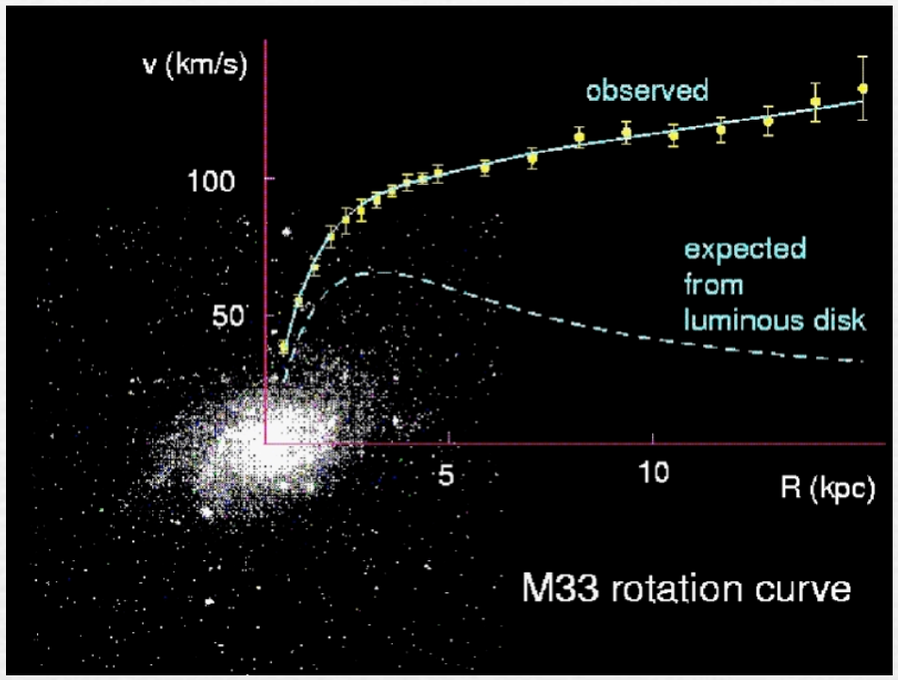
Pitch of sound shifts up/down. Colour of light blue/red shifted.



Orbital speeds of planets in solar system



Rotation curve of M33



[Bergstrom]

$$v = \sqrt{\frac{GM}{r}}$$

$$v_{\rm rot}(r) \sim \text{constant} \quad \Rightarrow \quad M(<r) \propto r$$

If Newton's laws are correct, galaxies are surrounded by invisible halos of dark matter.

ii) in galaxy clusters

Coma cluster

[Misti Mountain Observatory]

contains > 1000 galaxies

Zwicky

Dark matter required to ‘bind’ galaxies together in cluster.

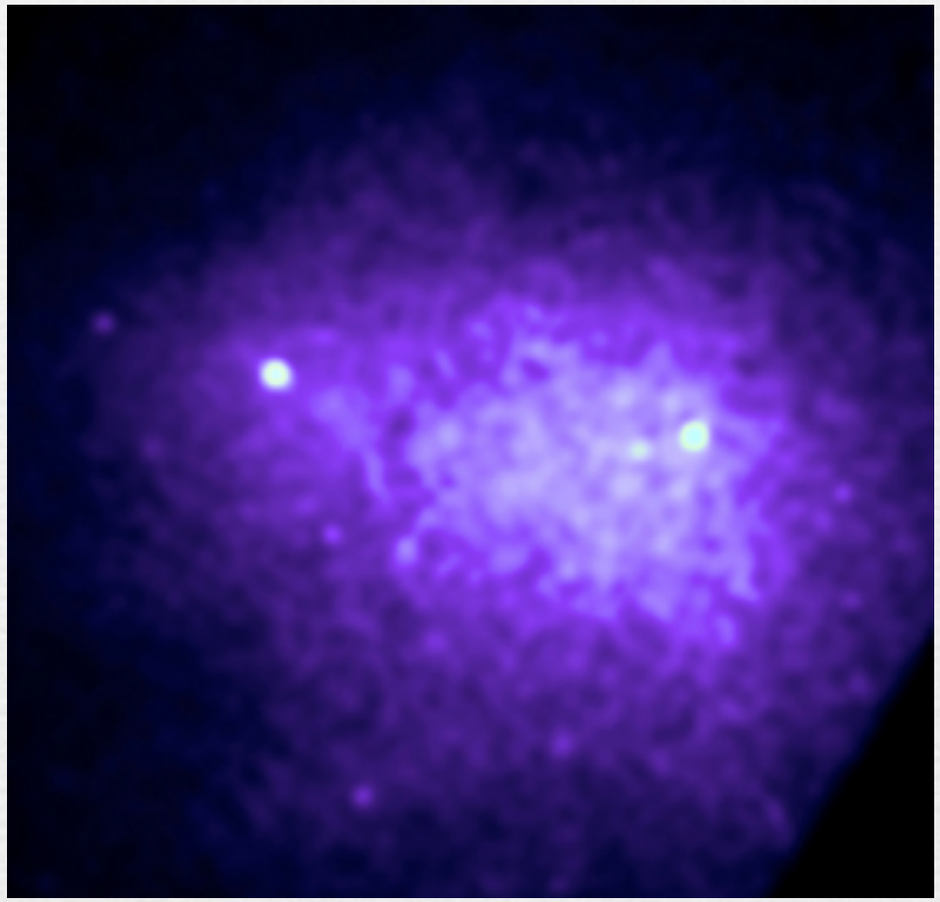
[galaxies are otherwise moving too fast and would fly apart]

Coma cluster

[Misti Mountain Observatory]

X-ray image

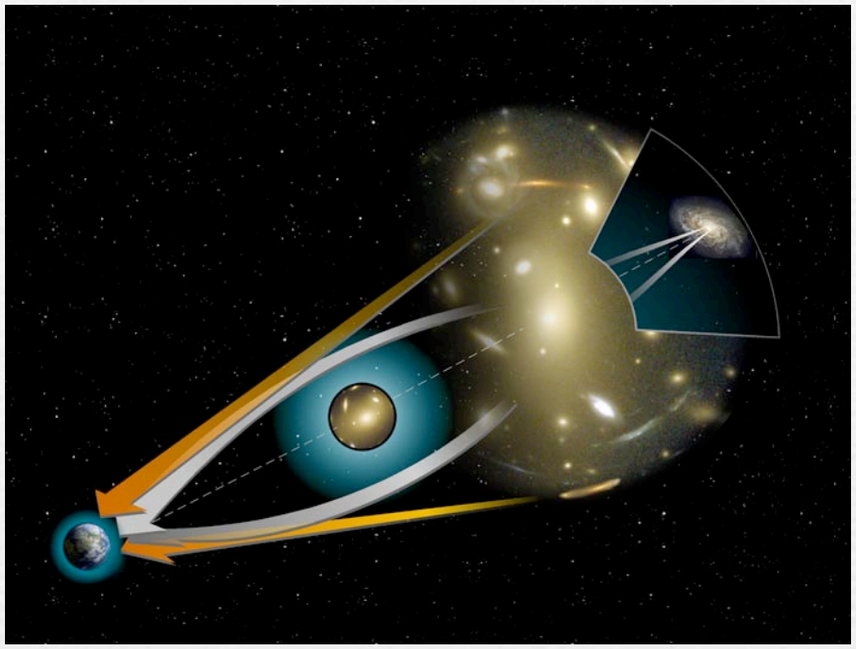
[Chandra]

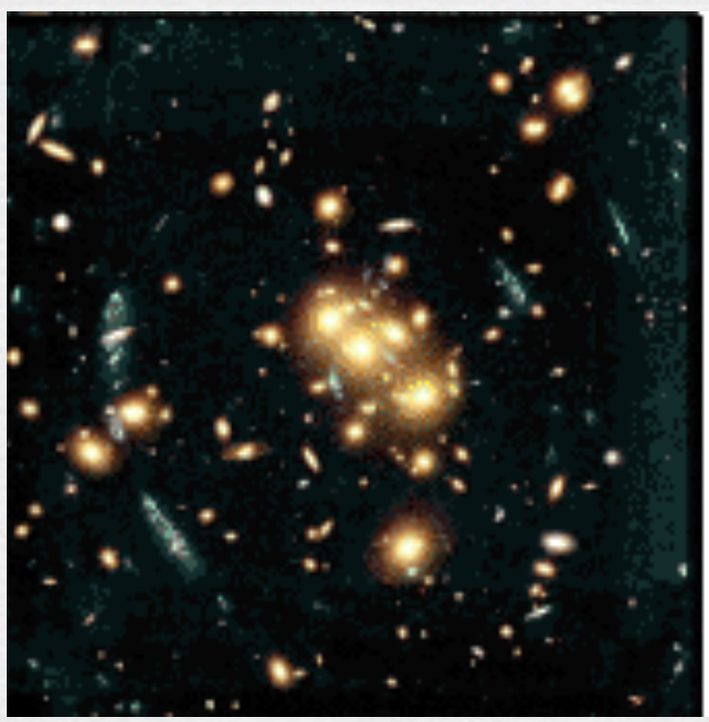


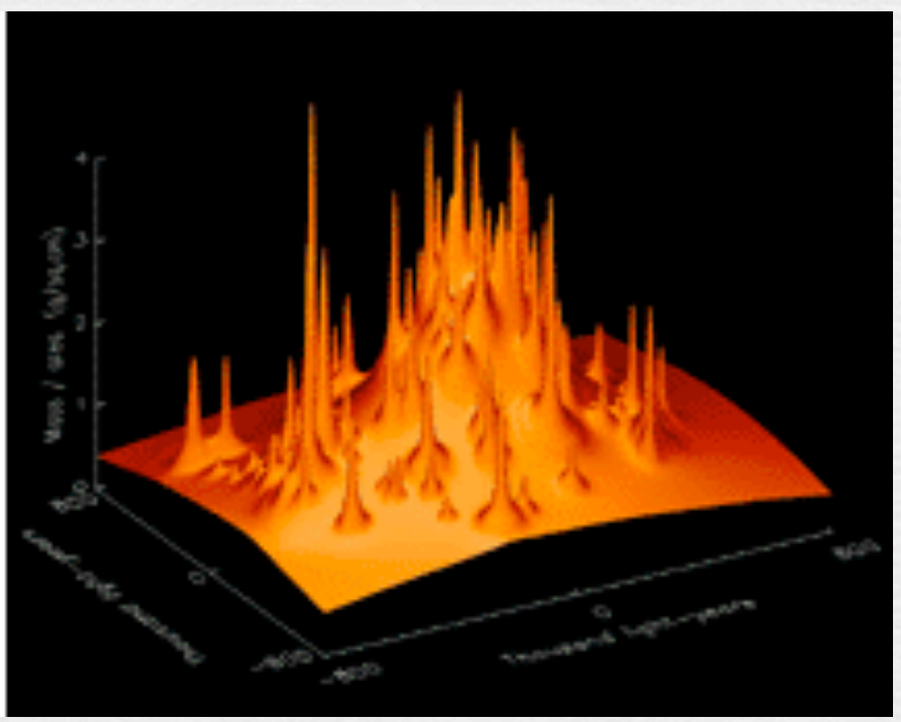
Dark matter also required to confine hot X-ray emitting gas.

Gravitational lensing (bending of light):

(from distant galaxy by massive galaxy cluster along line of sight)







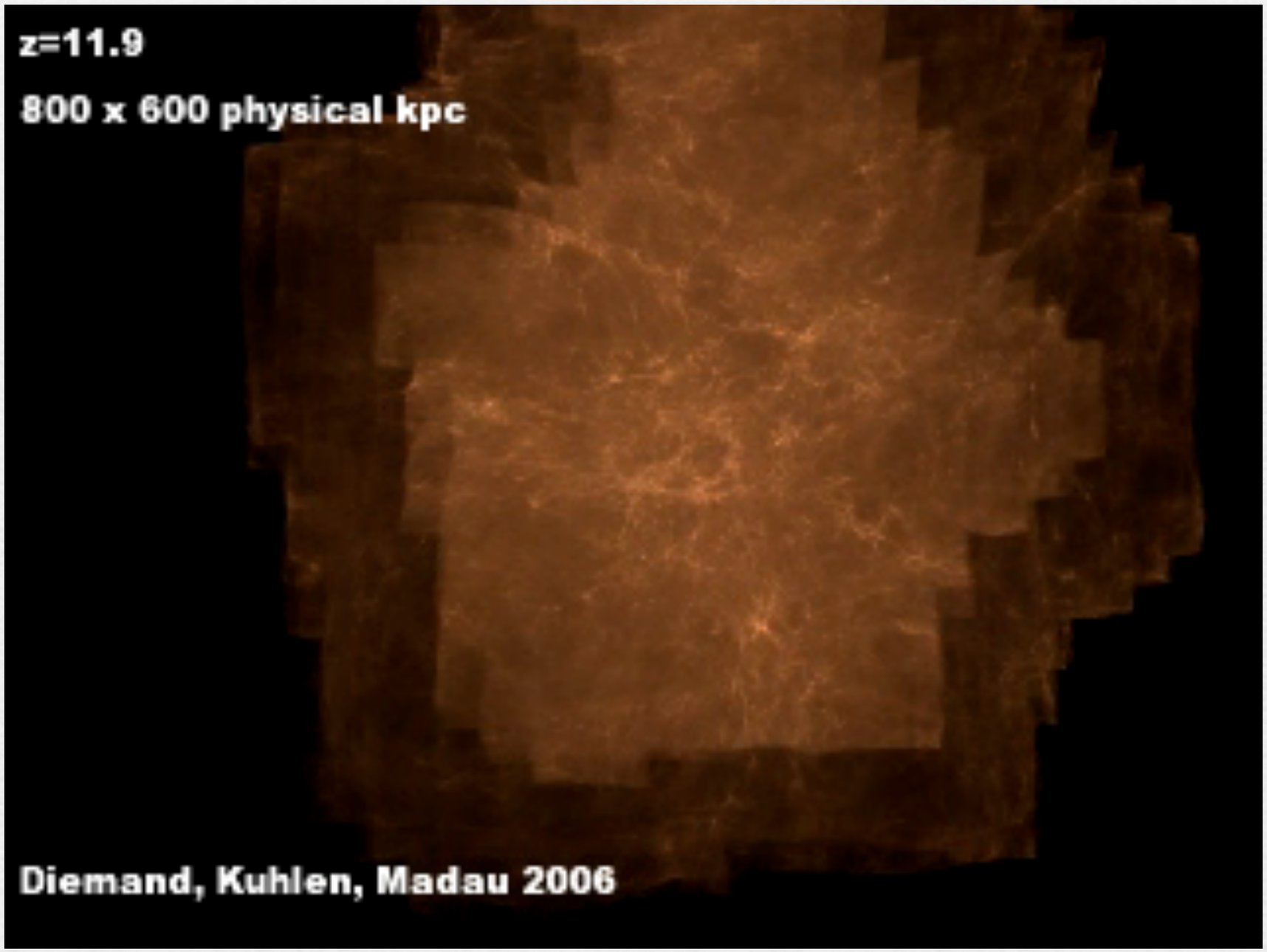
[Bell labs]

Using distorted images of distant galaxy can map the matter distribution within the cluster.

iii) in the Universe

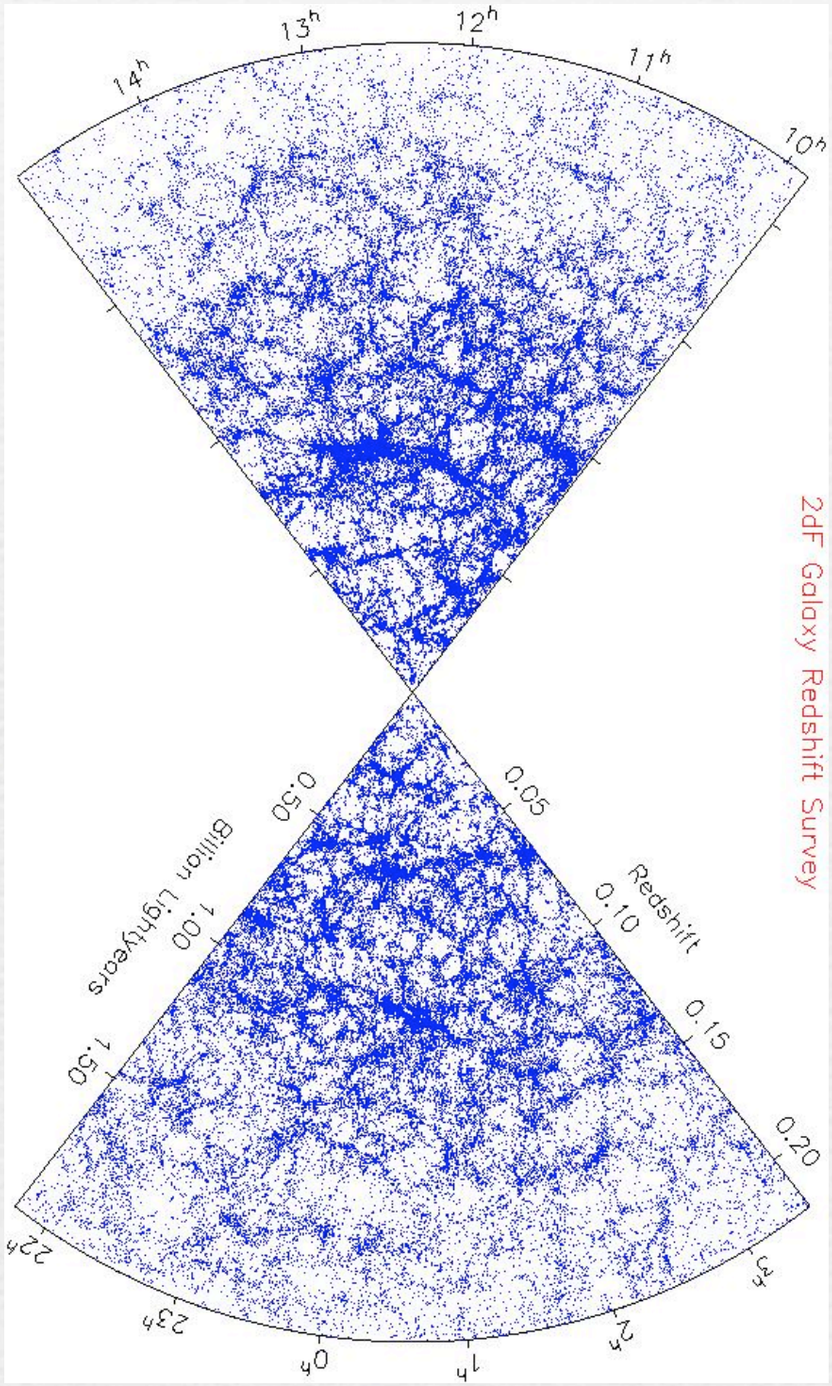
Large scale structure formation:

Super computer simulation of how large scale structure (galaxies, galaxy clusters...) form.



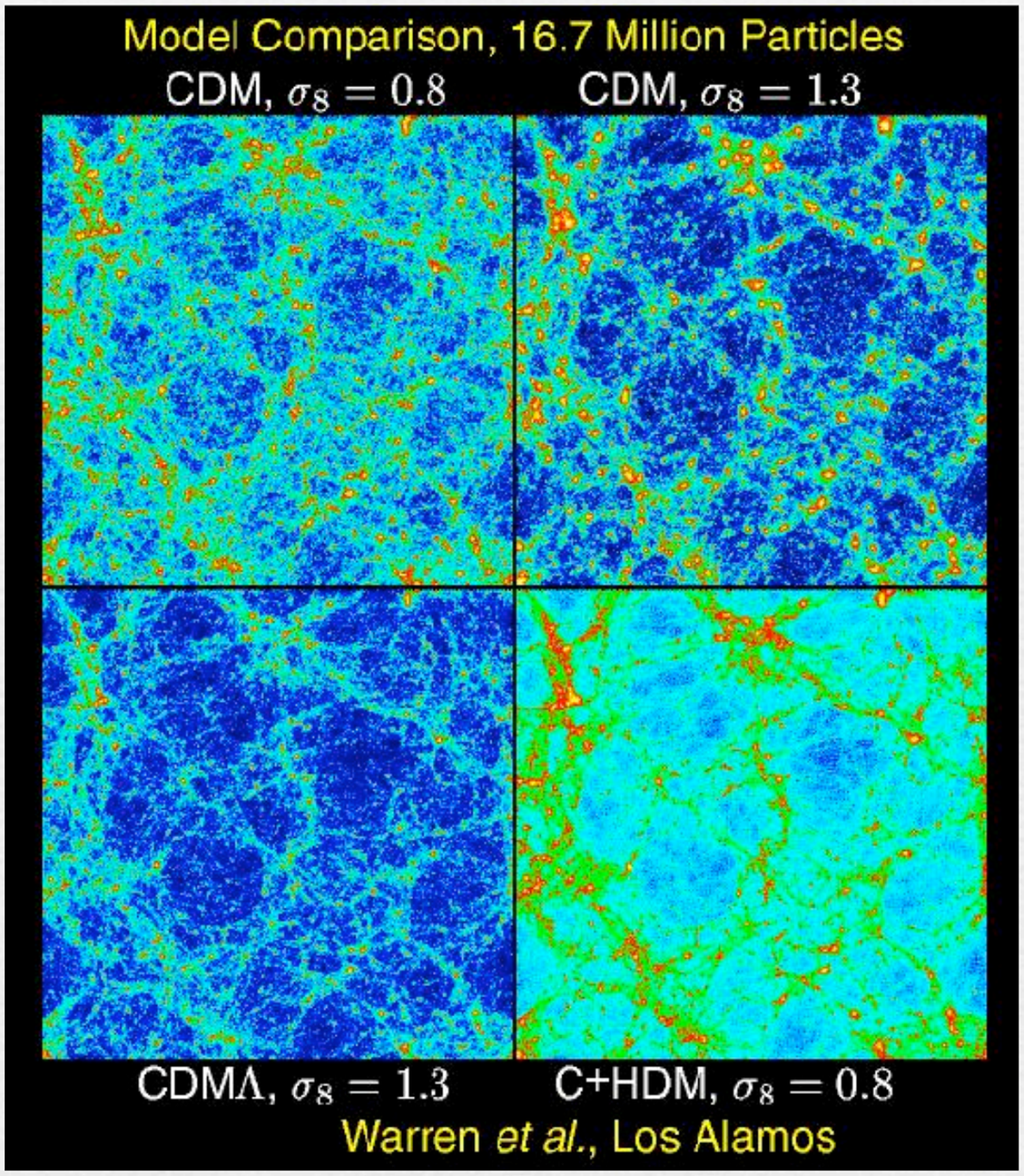
Compare observations of galaxy clustering with computer simulations.

2dF galaxy red-shift survey

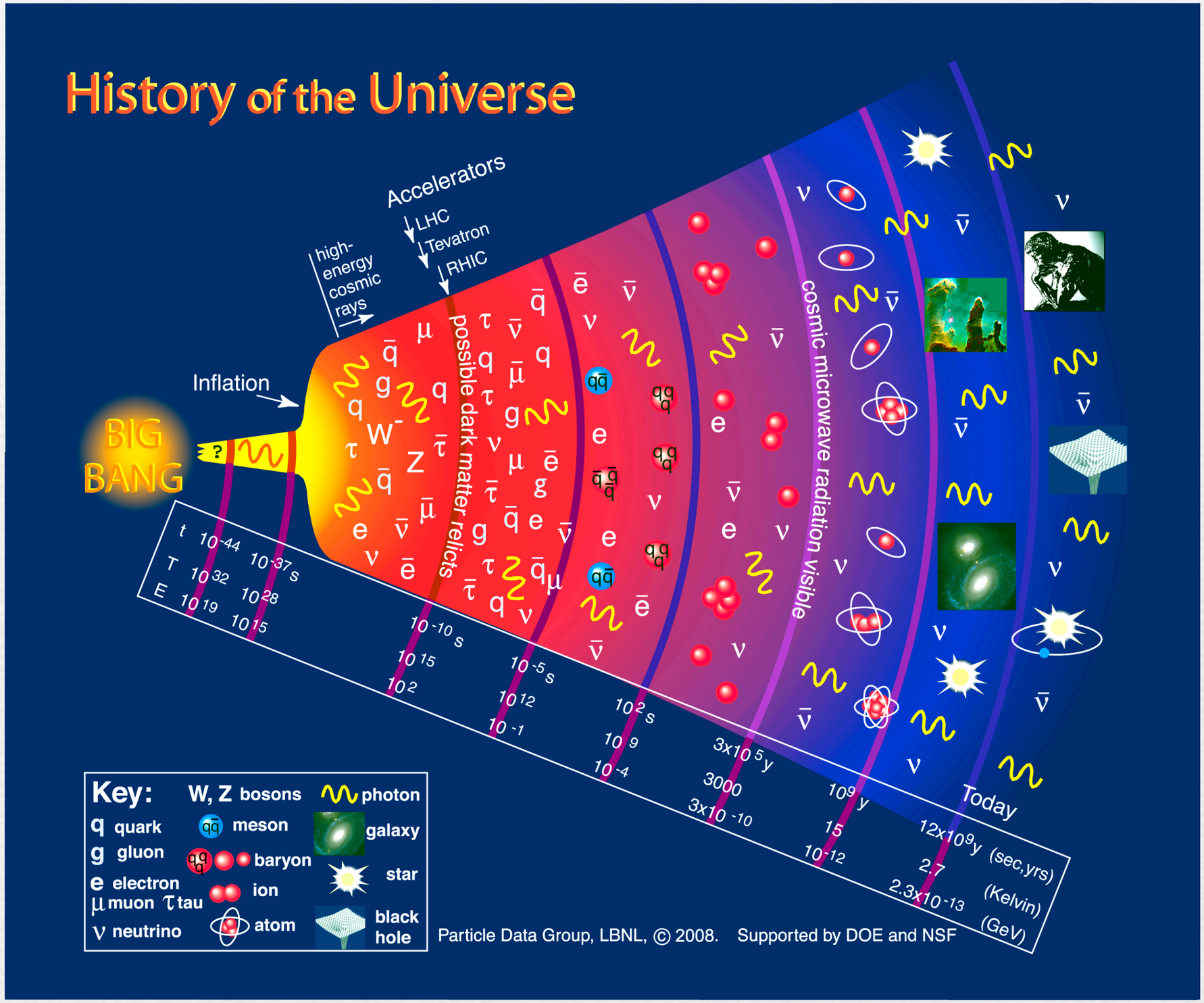


250, 000 galaxies

Computer simulations



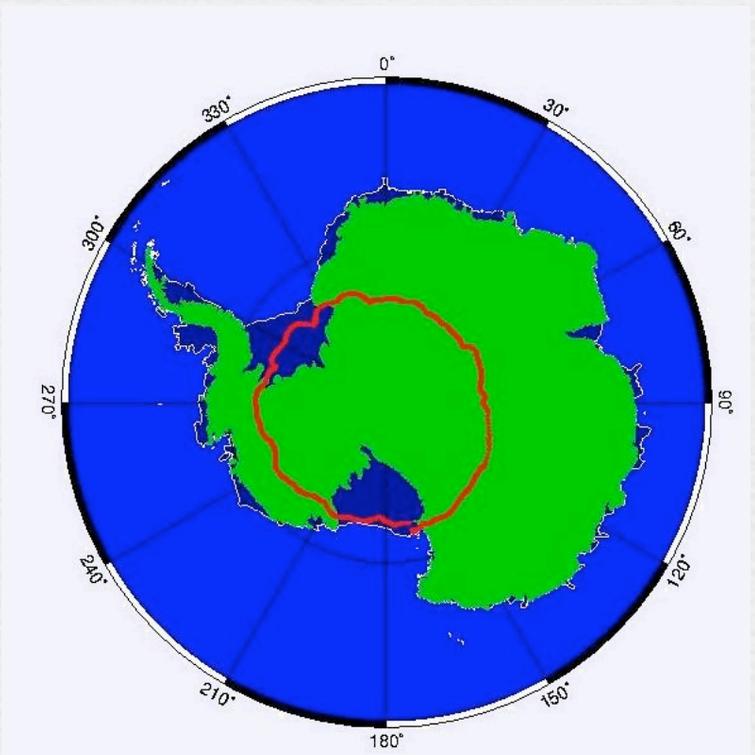
Cosmic microwave background (CMB) radiation: Relic of Big Bang

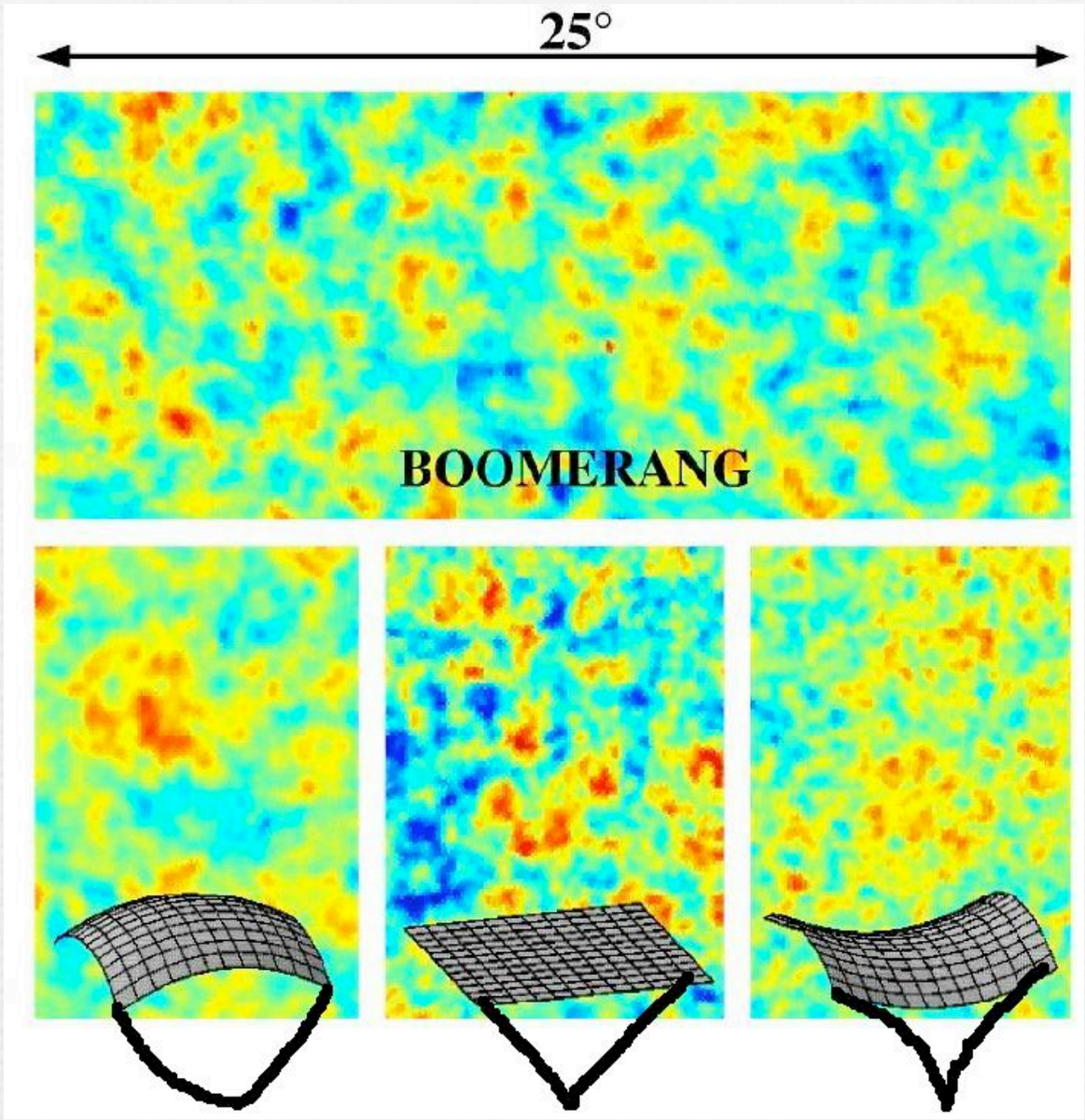


CMB has small fluctuations (anisotropies) from which structures later form.

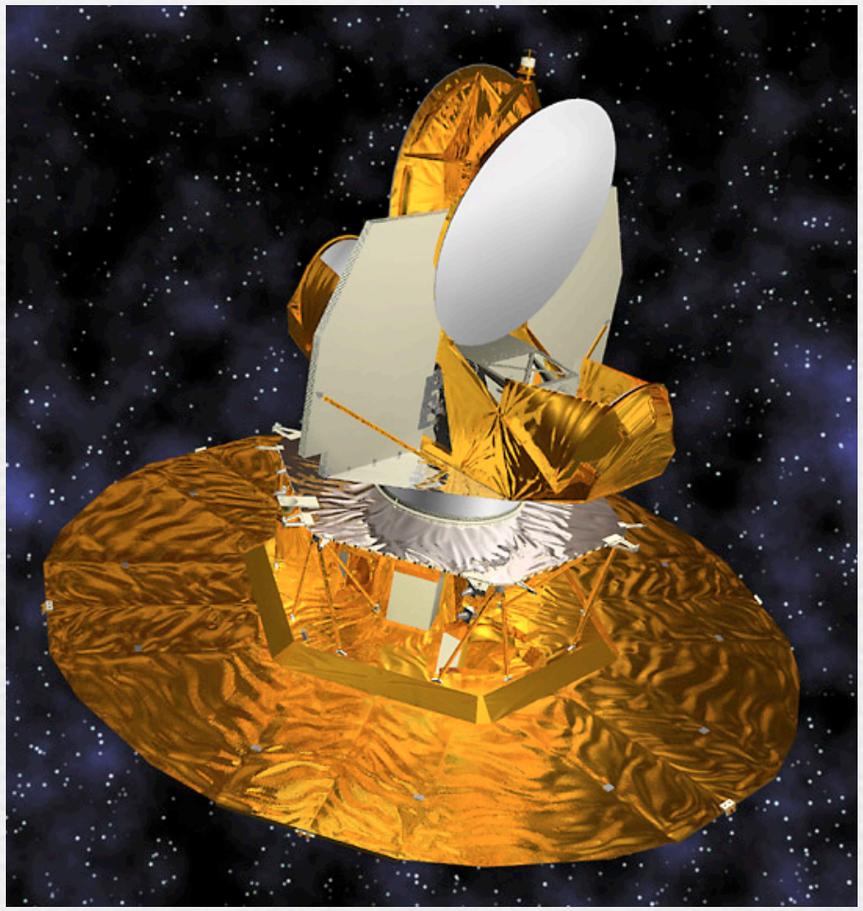
Details depend on properties (including contents) of Universe.

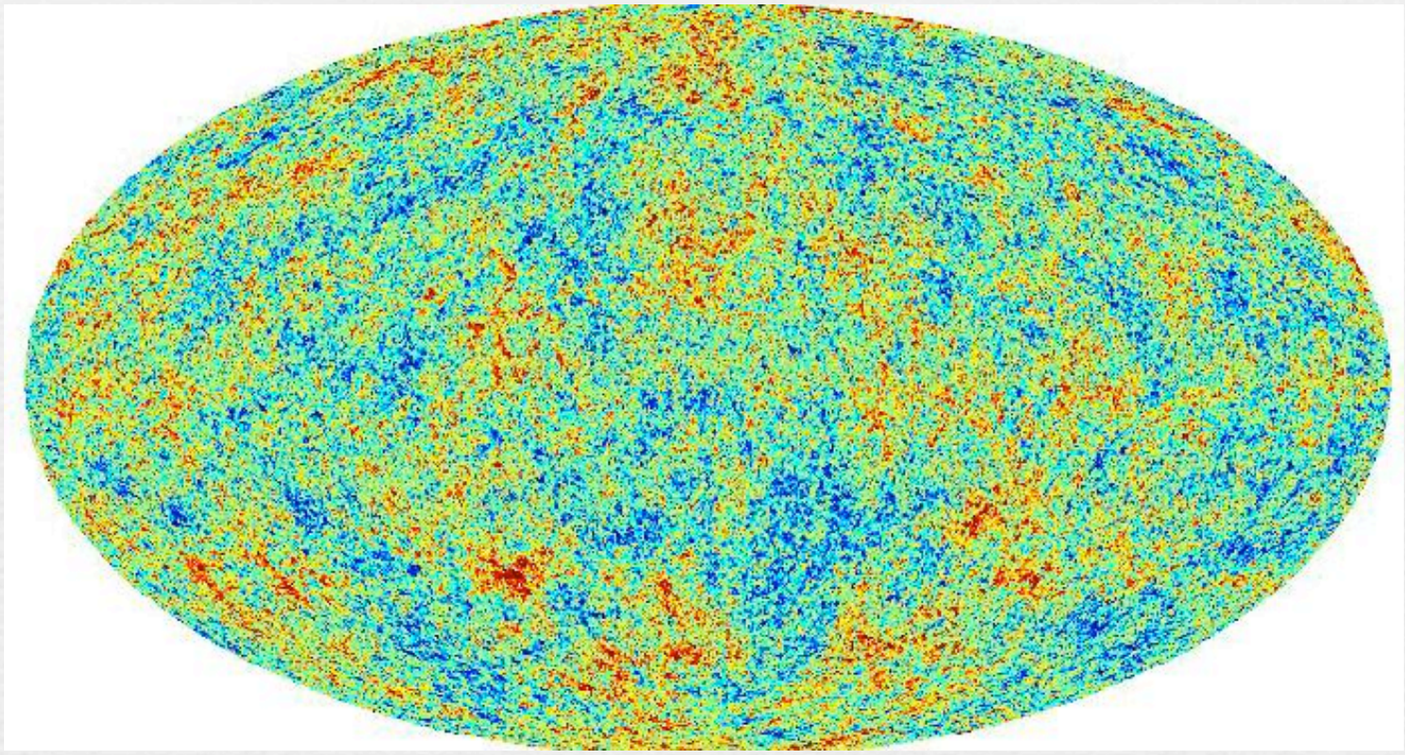
BOOMERANG

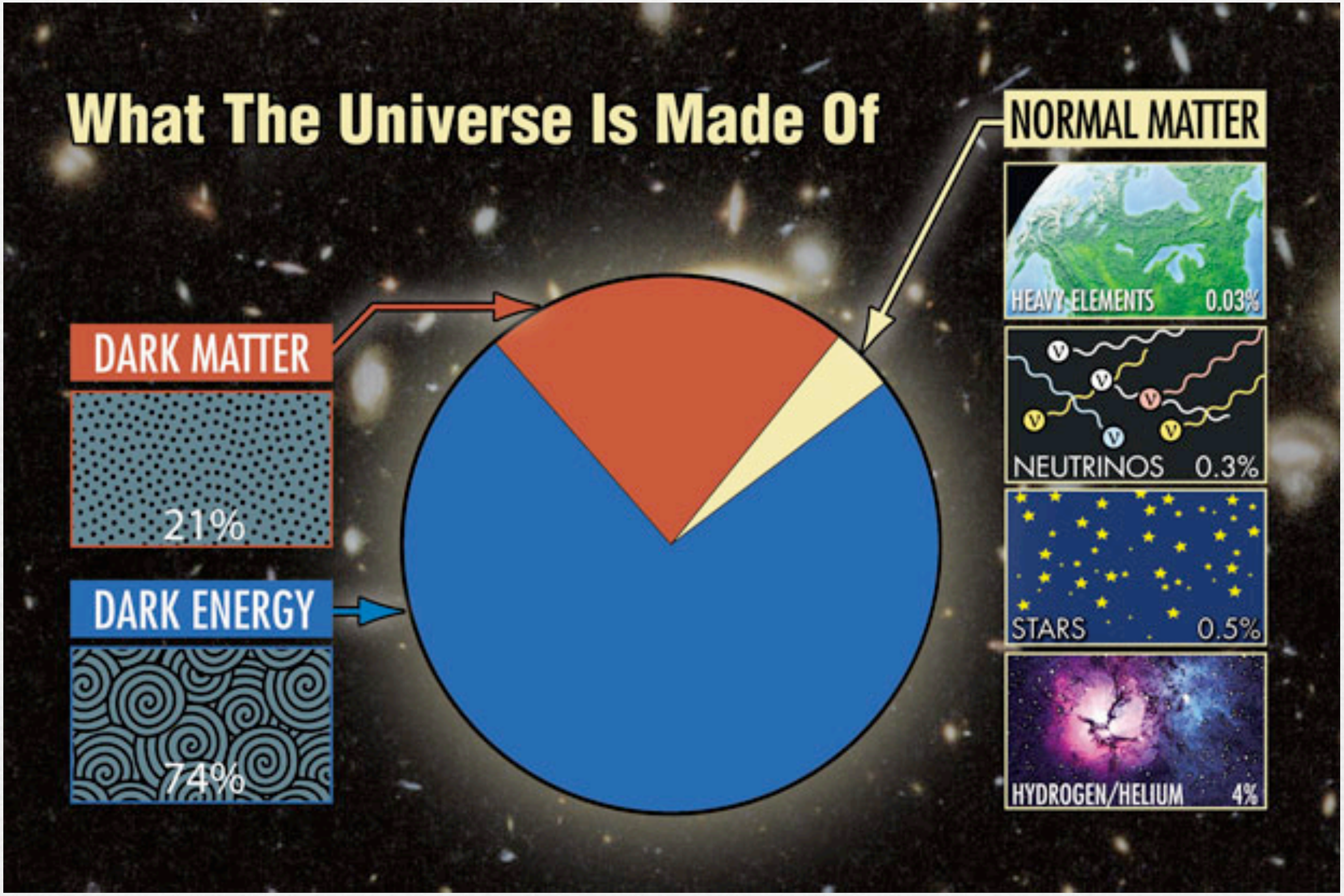




WMAP satellite






What The Universe Is Made Of
NORMAL MATTER
HEAVY ELEMENTS 0.03%
NEUTRINOS 0.3%
STARS 0.5%
HYDROGEN/HELIUM 4%
DARK MATTER
21%
DARK ENERGY
74%

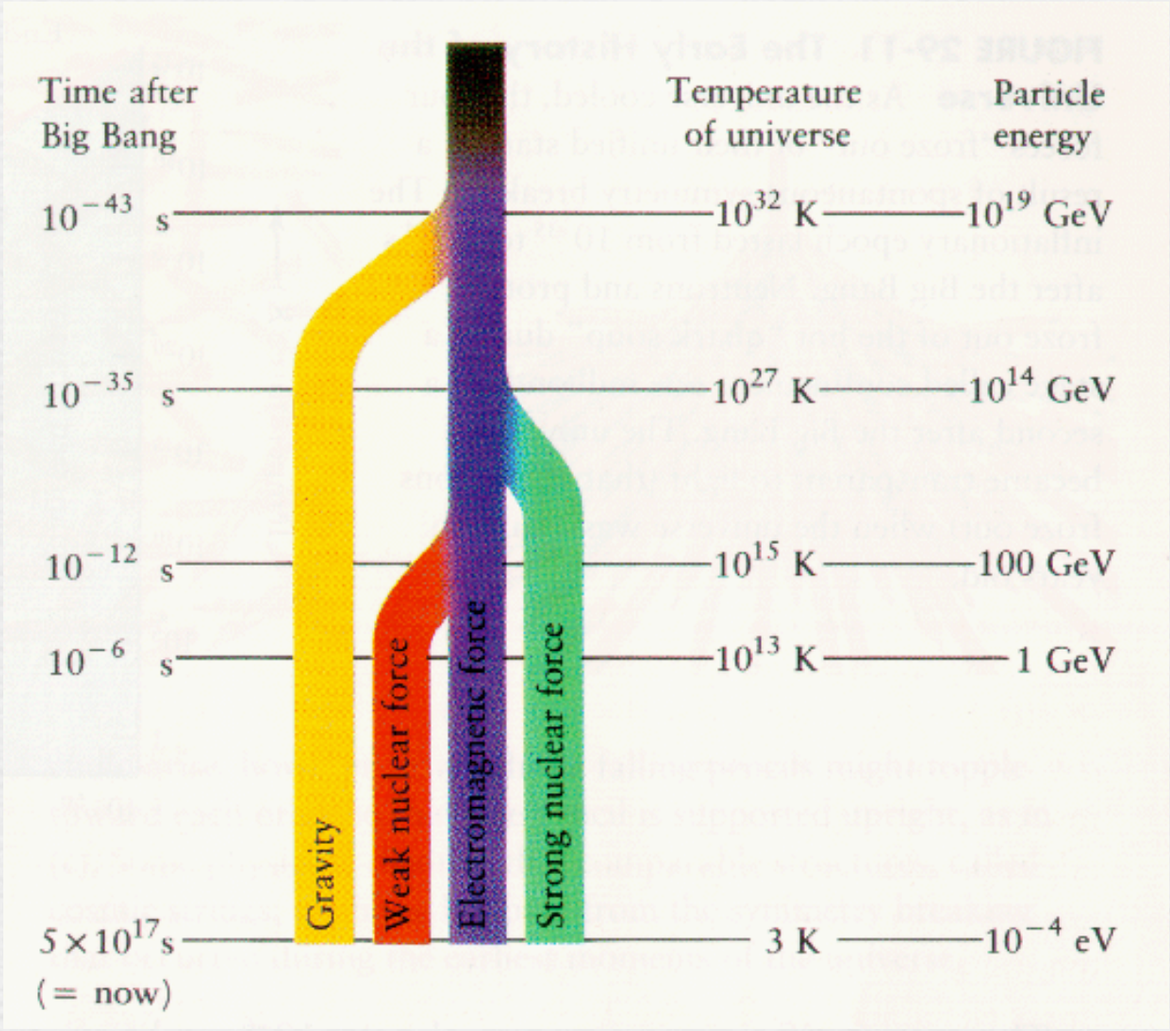
Dark matter candidates

Weakly **I**nteracting **M**assive **P**article**s**

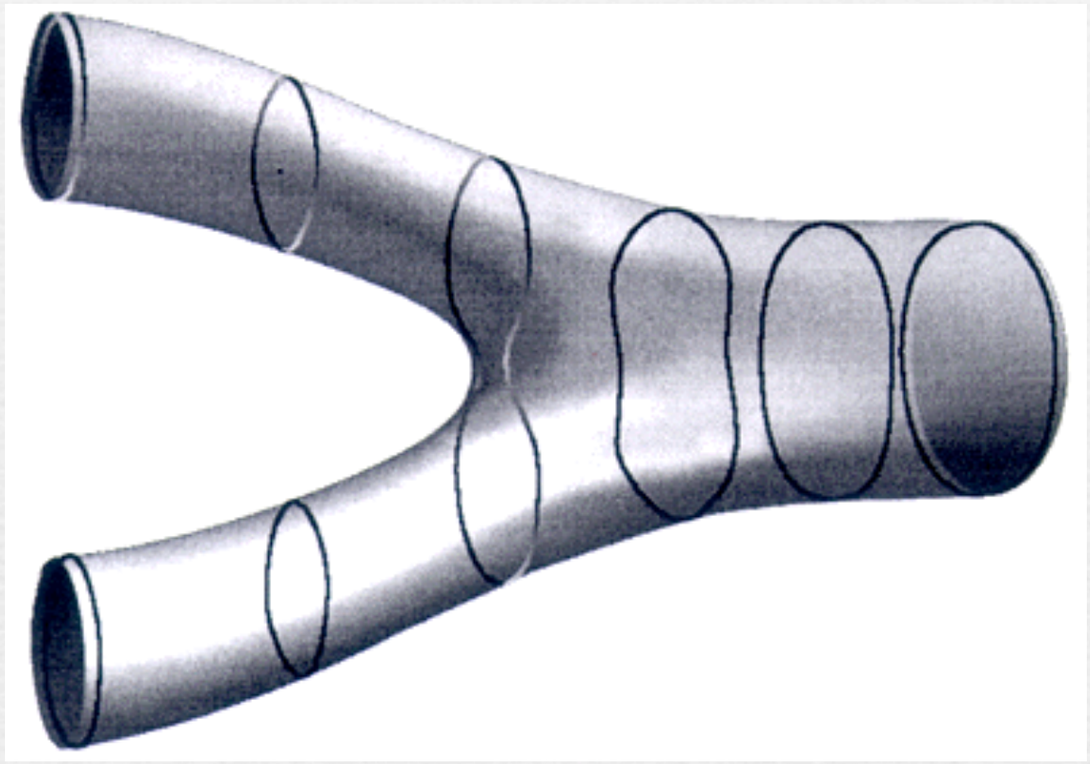
Properties: massive (~100-1000 times the mass of a neutron)
only interact weakly with normal matter (uncharged)

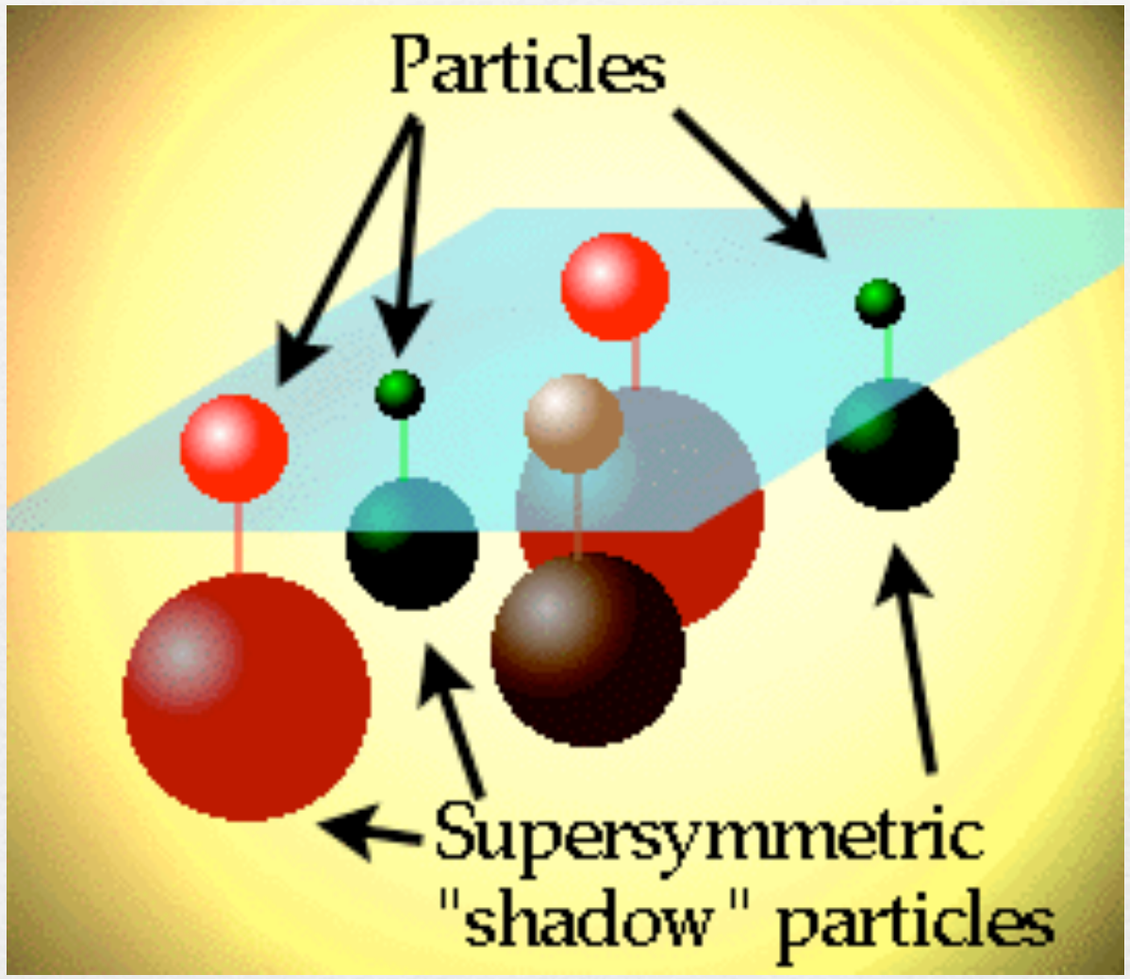
Is there any reason for WIMPs to exist?

Yes - particle physics models (such as string theory) which attempt to unify the fundamental forces predict that WIMPs should exist.



‘Cartoons’

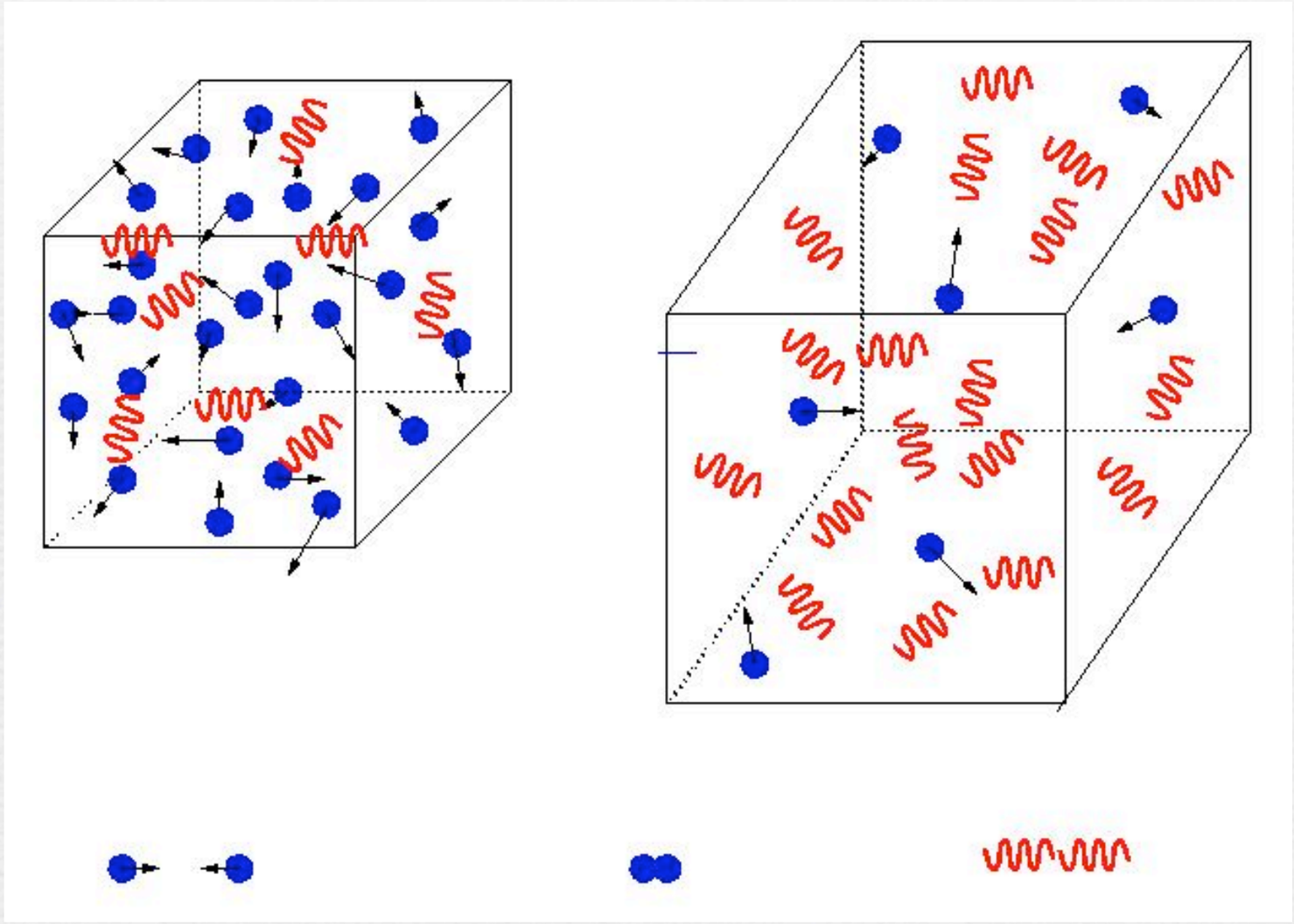




Particles interacting
in string theory

The early Universe is very dense and WIMPs collide with each other and annihilate (and photons can collide and create WIMPs).

As the Universe expands the WIMP density decreases, the WIMPs stop colliding and annihilating and the total number of WIMPs becomes constant.



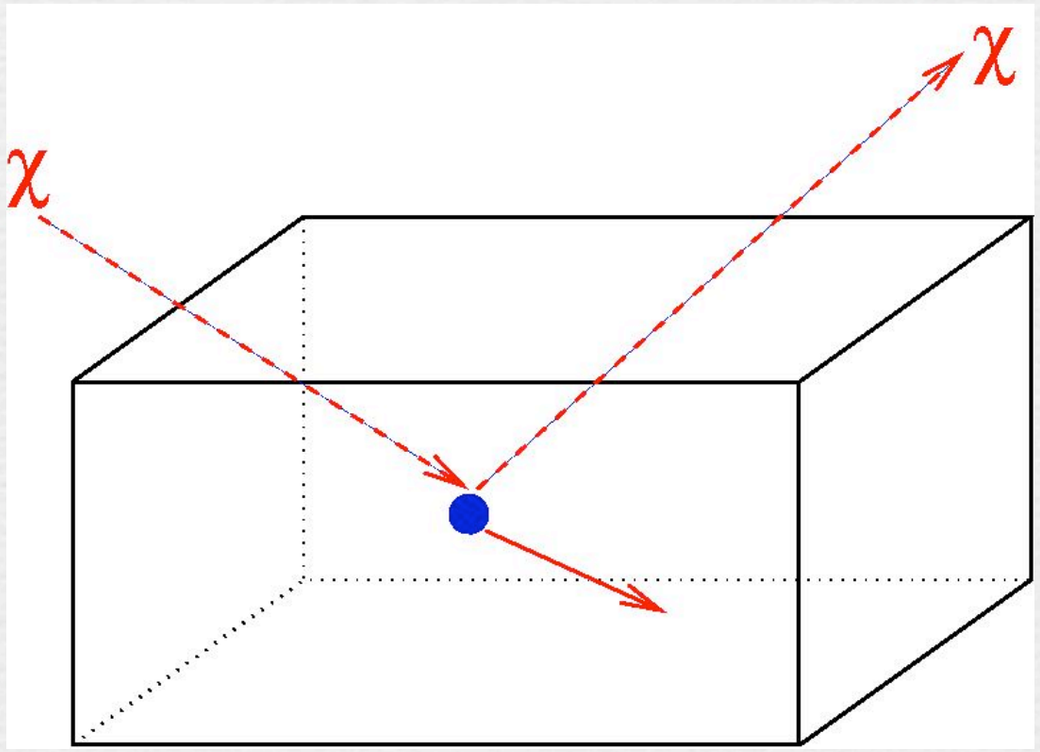
The number of WIMPs left over is just right for them to be the dark matter.

Dark matter detection experiments

Direct detection (in the lab)

Try and detect WIMPs in the Milky Way's halo when they pass through a detector.

(like a microscopic game of pool with an invisible cue ball!)



Detect recoil energy via ionisation, scintillation and/or rise in temperature.

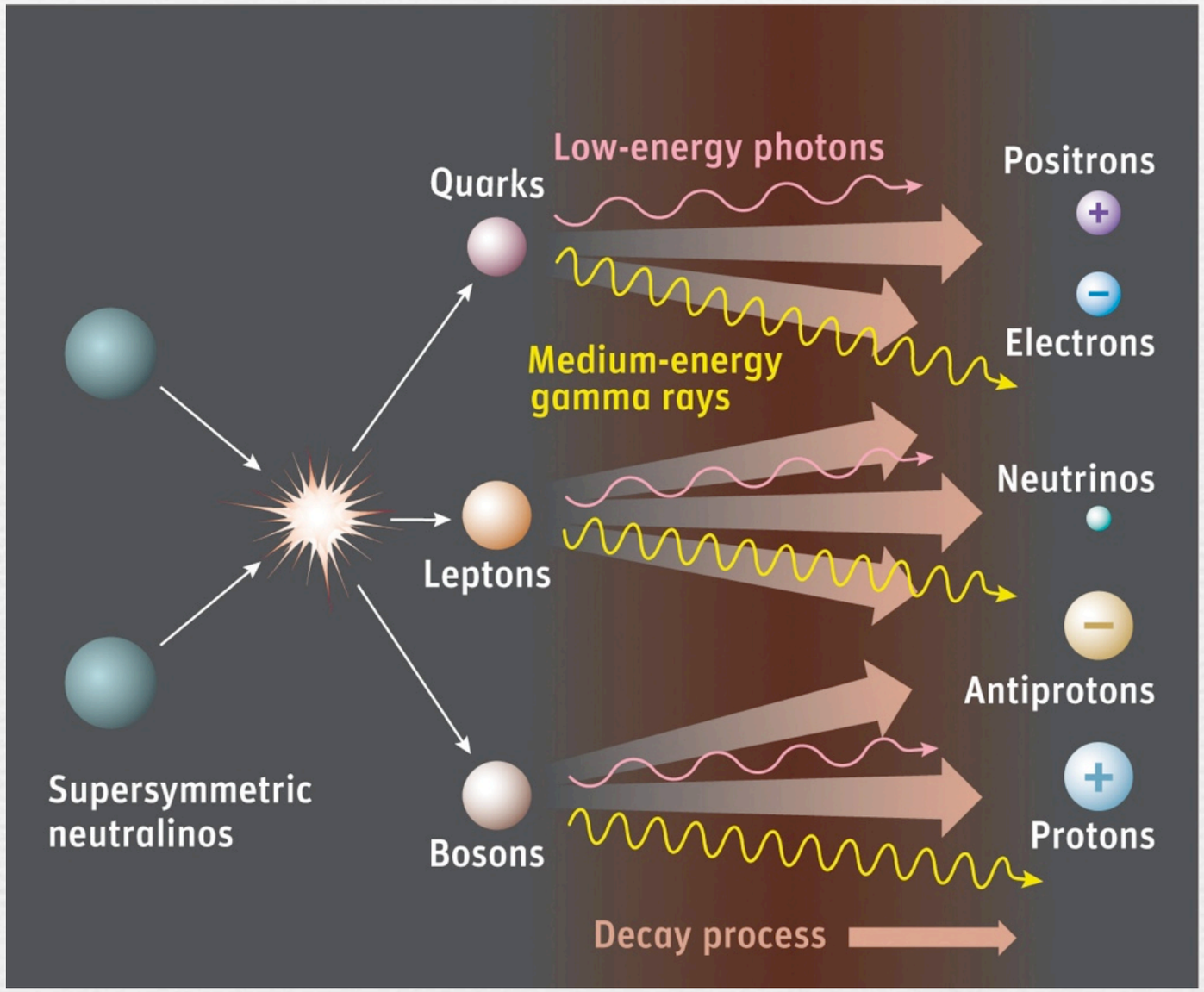
Go deep underground (to block out backgrounds which can mimic WIMPs):

Boulby mine (working potash mine, north-east England) + many other labs around the world.

Zeplin detector (made of liquid Xenon)

Indirect (astrophysical) detection

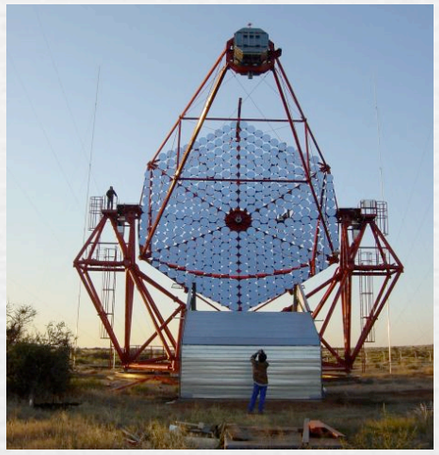
WIMPs in dark matter halos annihilate producing high energy gamma-rays and anti-particles.



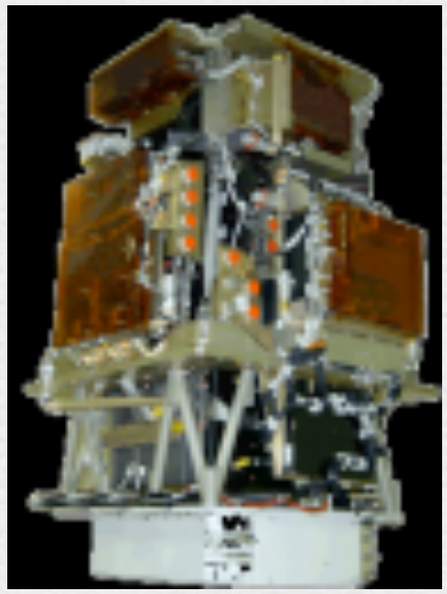
Fermi

(gamma-rays)

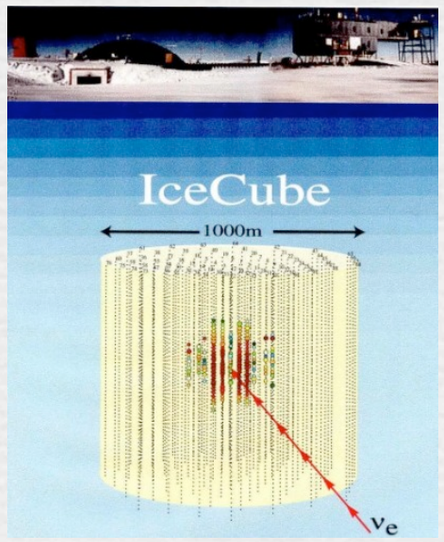
Air Cherenkov telescopes



PAMELA
(positrons & anti-protons)



IceCube
(neutrinos)



Summary

❇ There is lots of astronomical evidence that galaxies are surrounded by halos of dark matter and most of the matter in the Universe is dark *and* exotic.

❇ Particle physics gives us a good dark matter candidate:

Weakly **I**nteracting **M**assive **P**articles.

❇ WIMPs are being searched for in labs deep underground and by telescopes. If they exist they may well be detected within the next few years.