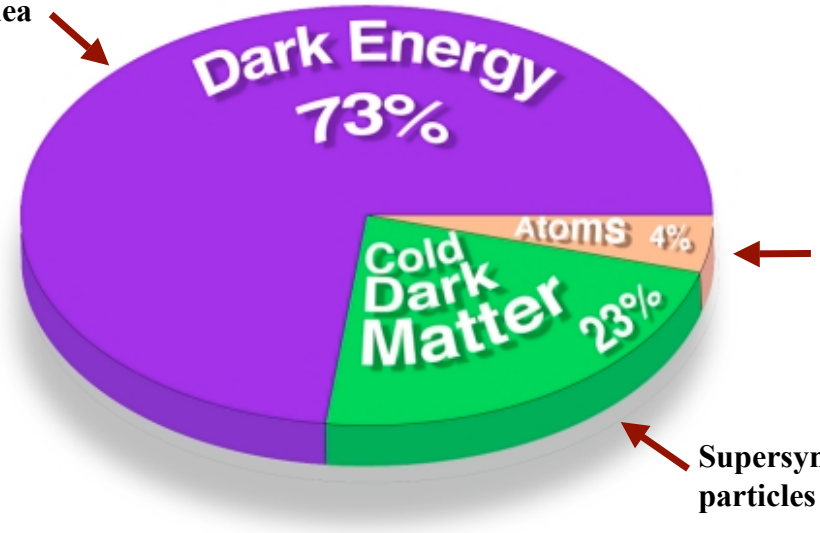
Particle Physics & Cosmology

Outline :

- The Cosmic Pie
- Dark Matter
- Supersymmetry
- Dark Energy
- Anthropic Principle

The Cosmic Pie

Nobody has the faintest idea



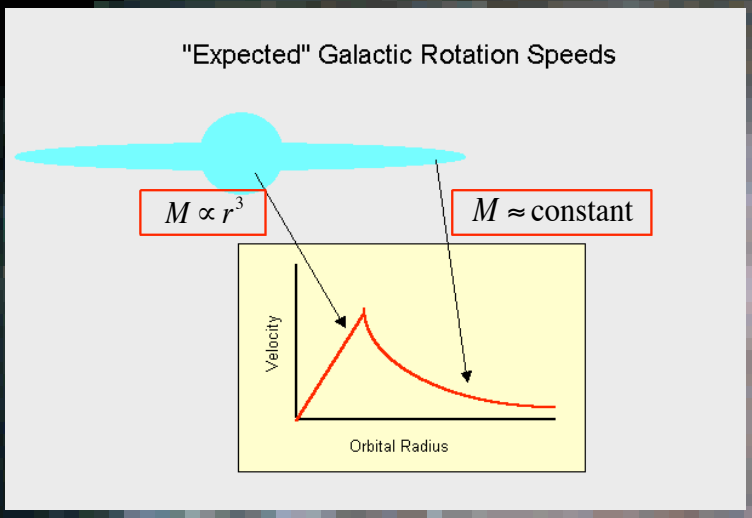
stars, dust etc.

Supersymmetric particles ?

Frankly, a bit embarrassing ...

Source: Robert Kirshner
Source: NASA/WMAP Science Team

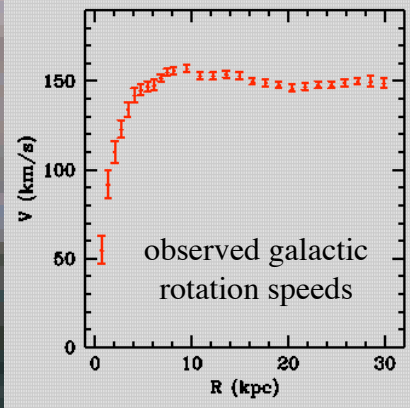
Dark Matter



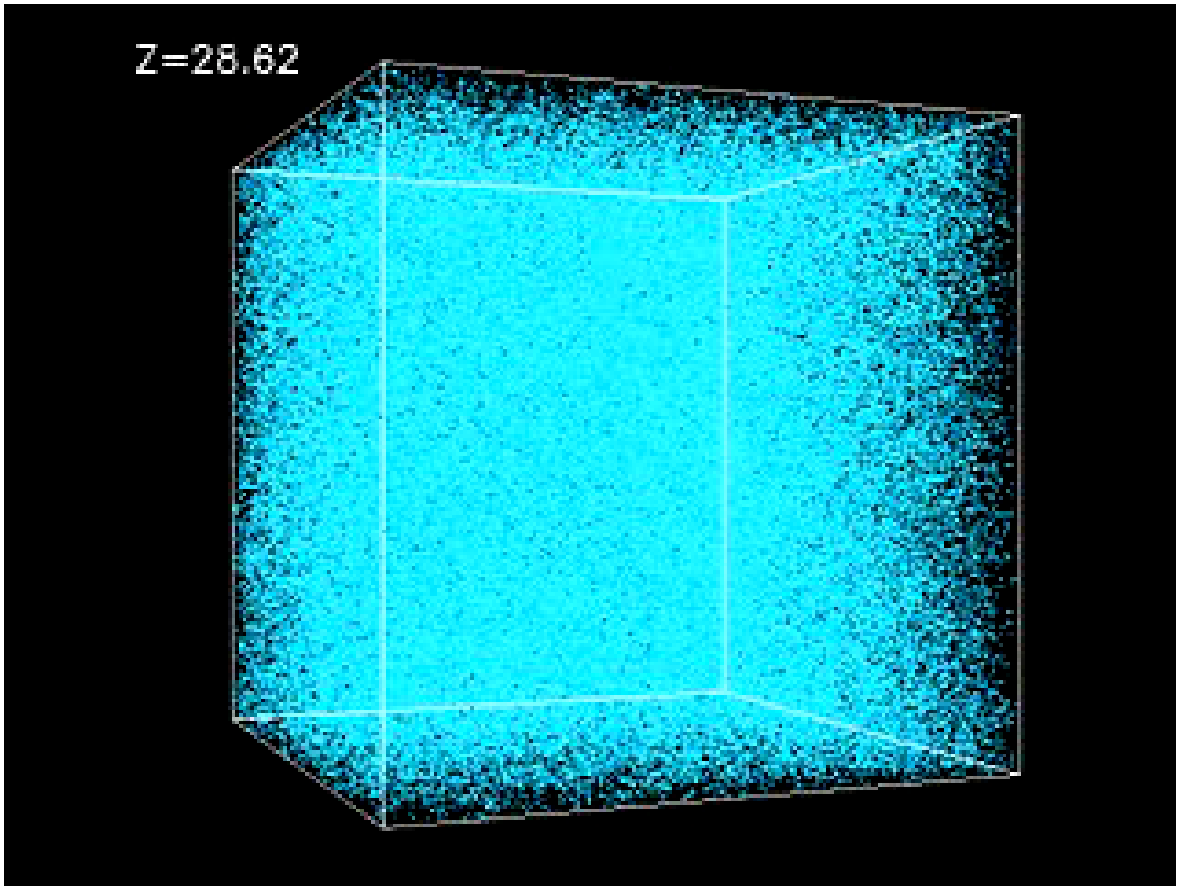
centripetal acceleration = **acceleration due to gravity**

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

$$v \propto \sqrt{M/r}$$

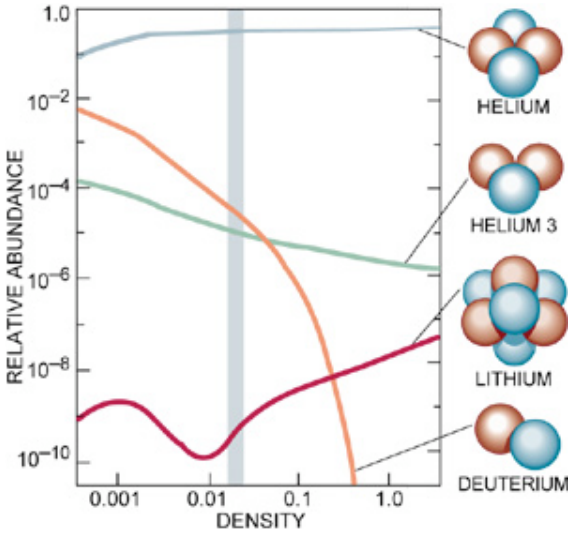


- Evidence for vast halos of invisible "dark matter" surrounding galaxies and galactic clusters.



Properties of Dark Matter

- It cannot be "baryonic" or strongly interacting.

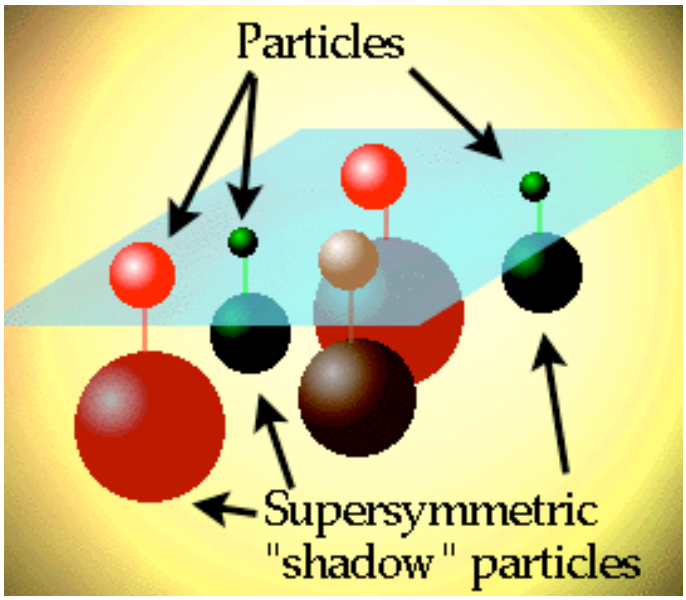


- It cannot be charged. Why ?
- It must be relatively heavy. Neutrinos are not massive enough.

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

SUSY ?

- A theory called "Supersymmetry" might provide the perfect dark matter candidate.



- Every particle in the Standard Model has a "supersymmetric" partner.

fermions SUSY **bosons**

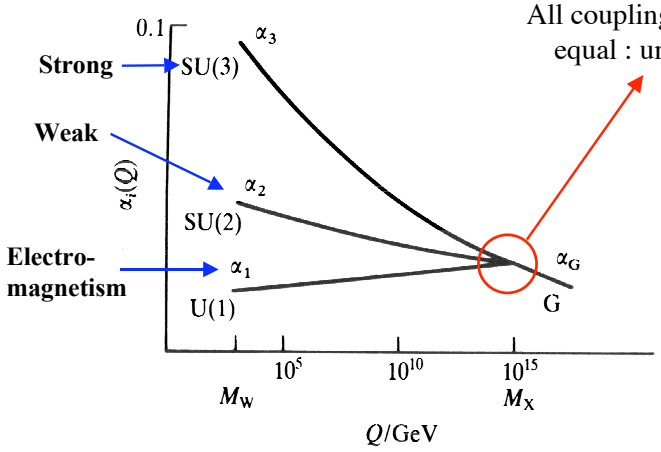
- In particular, the SUSY spectrum should contain WIMP's.
- But we've never seen a single super-symmetric particle.

OPTIMIST : half of the particles of the theory have already been discovered.

PESSIMIST : no evidence for Super-Symmetry whatsoever.

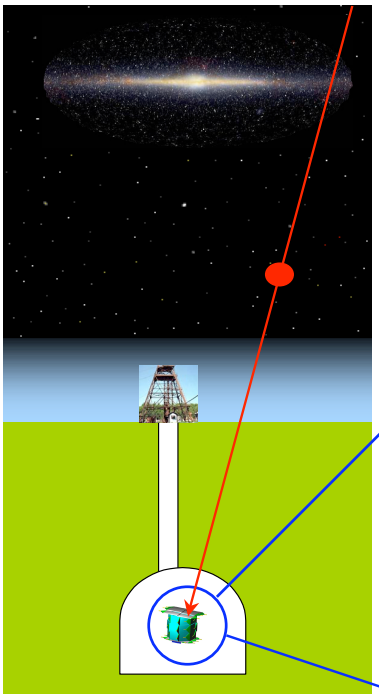
Why Do We Like SUSY ?

- Why do we like SUSY ?
- It solves various theoretical problems :
  - ➢ It avoid a "fine-tuning" problem whereby nature would have to have chosen the mass of the "bare" Higgs boson to 1 part in 10^{28} ….
  - ➢ It leads to "gauge-coupling" unification :

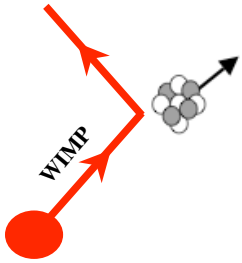


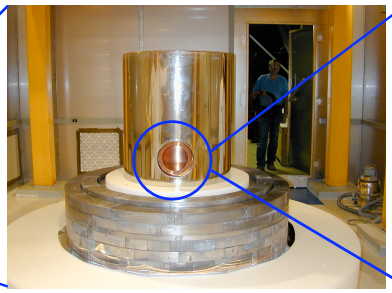
Direct Detection Experiments

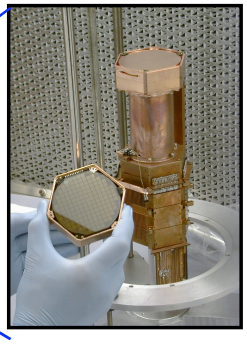
- 1 million **WIMP**'s per cm^2 per second, travelling at hundreds of kilometres per second.
- Every few hours or days, one of them might scatter off a nucleus.



- Experiments aim to detect the resulting nuclear recoil in various ways :
  - ➢ energy/phonons
  - ➢ light
  - ➢ charge
- So far no clear positive signal.

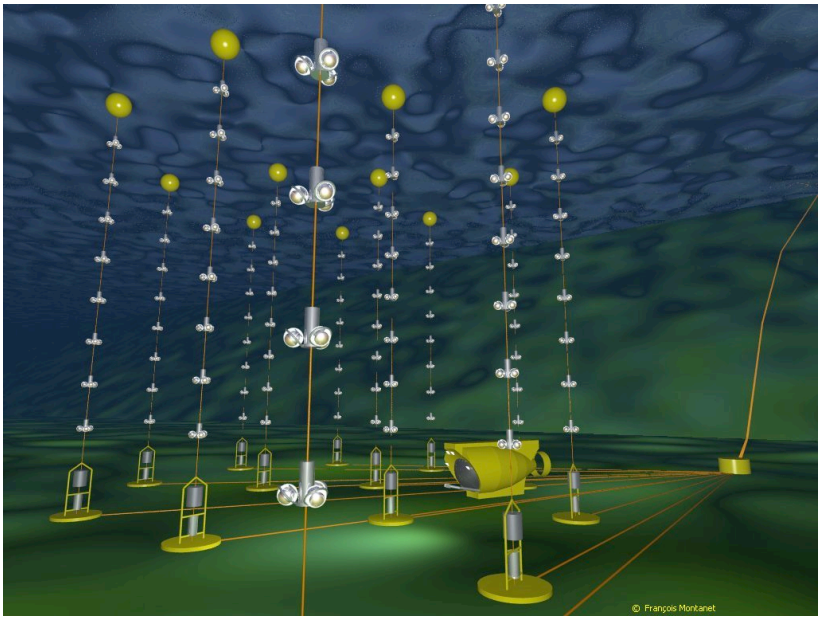


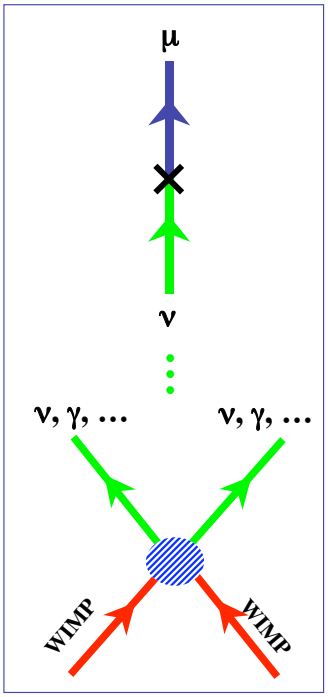


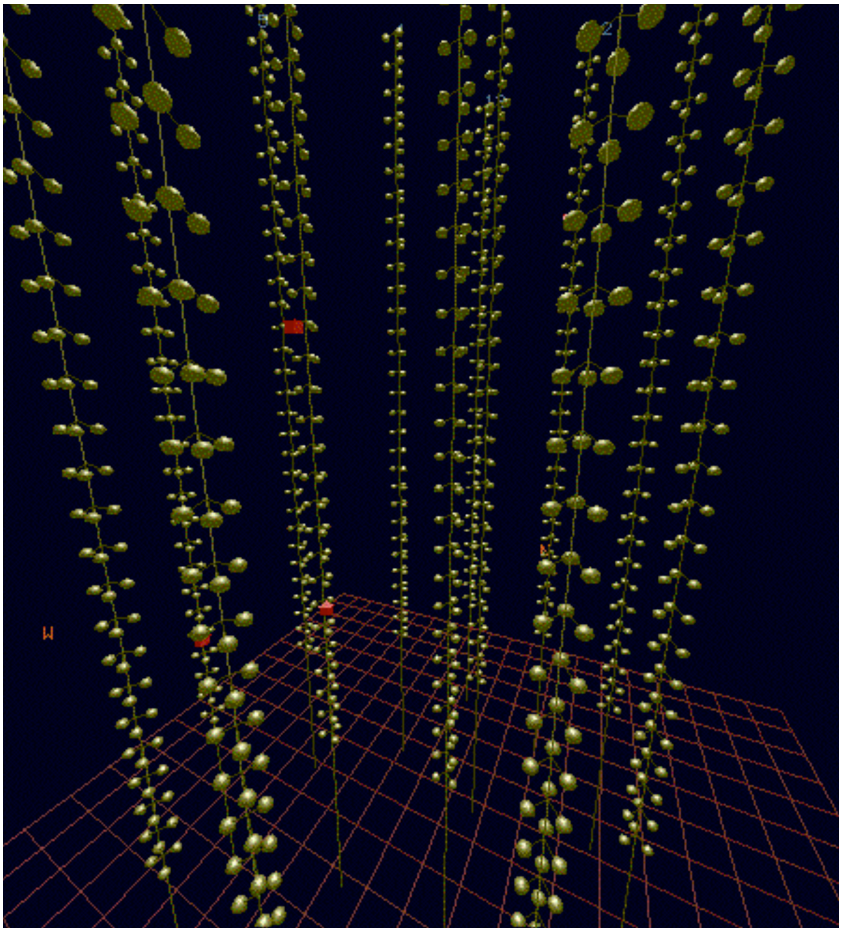


Indirect Detection Experiments

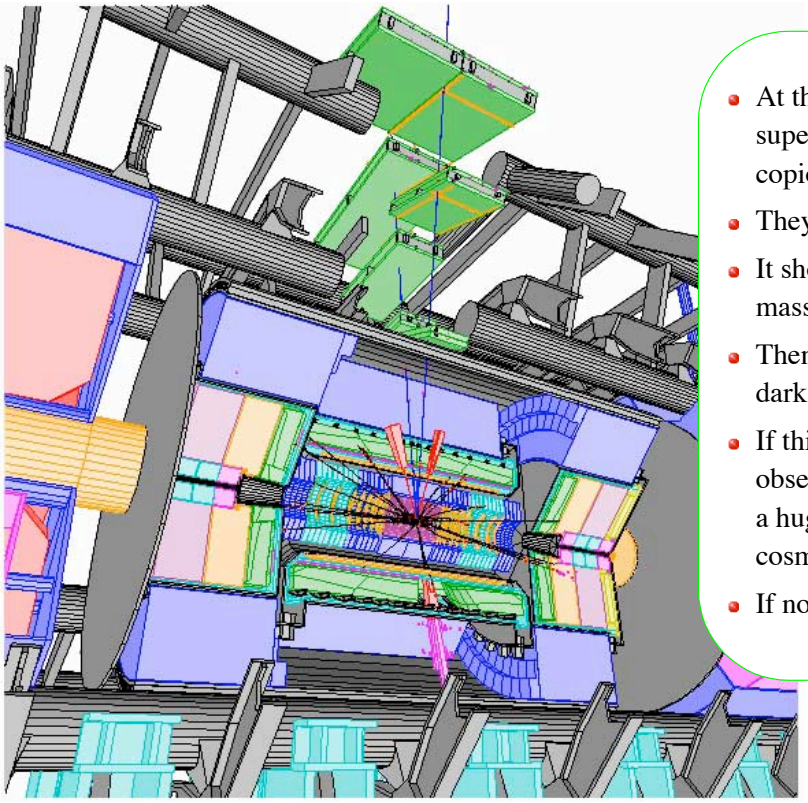
- The **WIMP**'s are expected to accumulate in the centre of the Sun or Galaxy, where they will occasionally self-annihilate. The resulting γ-rays could be detected by experiments on earth.
- Decay products will include highly energetic neutrinos, which can be detected in giant arrays (in water or ice) :



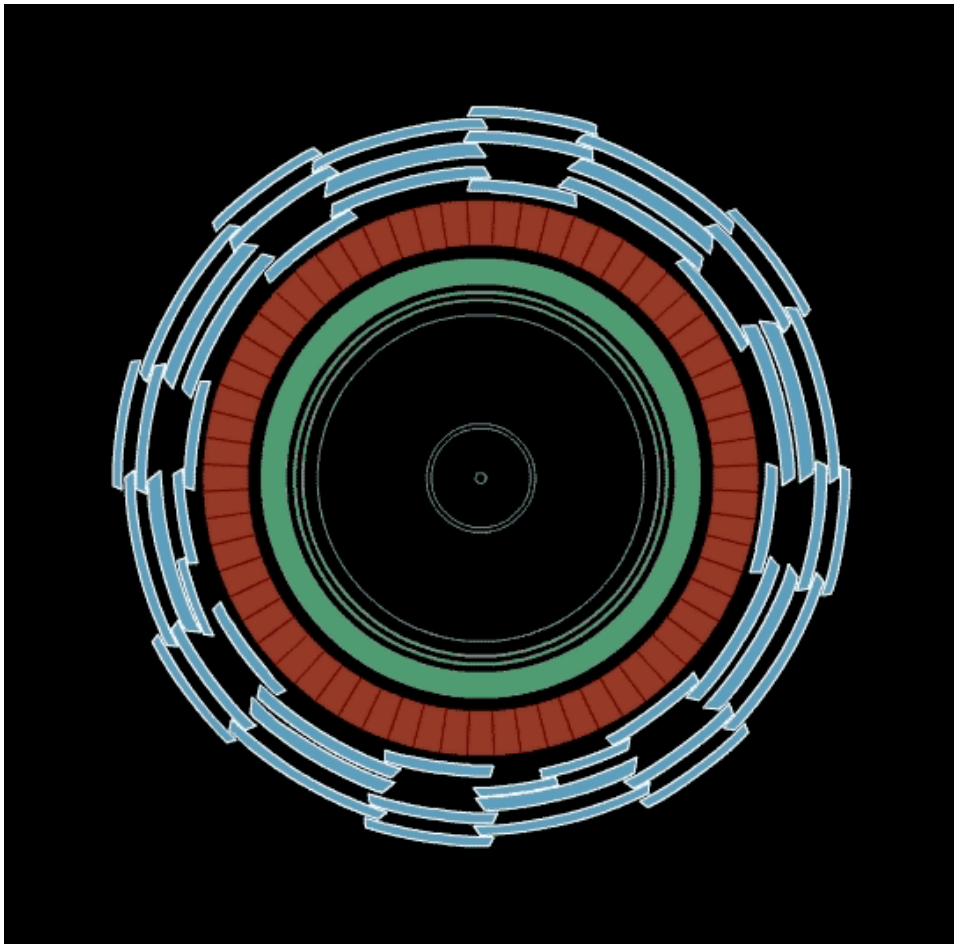




Creating Dark Matter in the Lab



- At the **L**arge **H**adron **C**ollider, supersymmetricparticles should be copiously produced.
- They will often decay to WIMPs.
- It should be possible to measure their masses and couplings.
- Then it would be possible to predict the dark matter density in the universe.
- If this comes out to be equal to the observed dark matter density that will be a huge triumph for particle physics & cosmology.
- If not ….



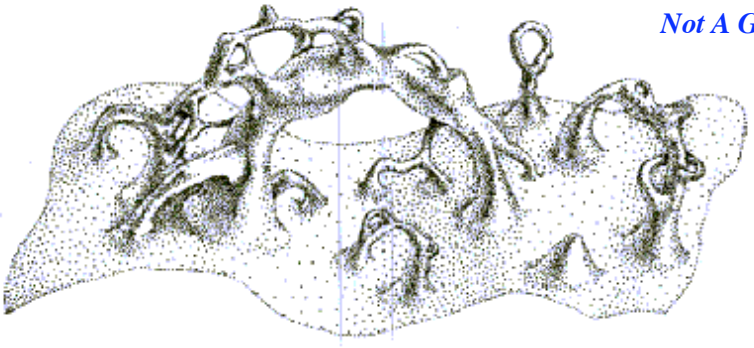
Dark Energy

- The total density of the universe is roughly equivalent to 1 hydrogen atom per m^3 - but 3/4 of is in the form of mysterious dark energy.
- The quantum vacuum is a complicated thing : Heisenberg's uncertainty principle allows particles & energy to briefly pop into and out of existence. These quantum fluctuations distort the small scale fabric of space-time : **Quantum Foam**.
- Although there is as yet no complete theory of quantum gravity, there are 2 "natural" values for the dark energy density :

$\Omega_\Lambda = 10^{120} \times \Omega_\Lambda^{observed}$ → natural scale of quantum vacuum fluctuations

$\Omega_\Lambda = 0$ → by some (unknown) symmetry principle

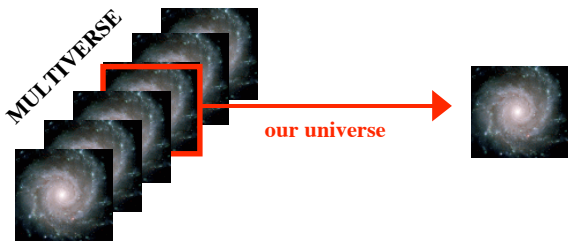
Not A Great Triumph of Physics !



Anthropic Principle

- The best theory we have of quantum gravity (or perhaps even a theory of everything) is String Theory.
- String Theory seems not to predict uniquely the energy density of the vacuum, or any other constants of nature.

- Most of the values that the constants of nature could take would not allow life (as we know it ?) to develop.
  - ➢ e.g. if the dark energy density was too large, the universe would tear itself apart too quickly for structure (and therefore life) to form.
- Maybe all possible combinations are realised in some kind of "multi-verse".
- Our universe is "picked out" because it has laws of physics & constants of nature suitable for the development of life.



"The laws of physics & constants of nature must be consistent with the ultimate development of observers"

Anthropic Principle

- But does this really ***explain*** the laws of physics that exist in our universe ?
- Or is it a giant cop-out ?

➢ This is the most heated conceptual debate currently in theoretical physics & cosmology.

Vacation Essay :

Write a short essay (no more than 1000 words) on one of the following topics :

1. An unsolved problem in modern physics.
2. A new technology made possible by recent advances in physics.

Contact me by email if you have any problems finding a topic.

Hand in the essay to Carol Farguson at Drayton House on Monday 9th January

Presentations :

Prepare a SHORT (5 min) presentation on your vacation essay topic. We will hear these in the SSM session on on Thursday 12th Jaunuary.
If you wish to use PowerPoint then please send me your presentation by email, or bring it along on a CD or Floppy Disk on January 12th.

HAPPY HOLIDAYS !