The University Of Sheffield.

The Dark Side of the Universe

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Macclesfield Astronomical Society
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http://antwrp.gsfc.nasa.gov/apod/image/0104/horsehead_hubblenoao_big.jpg

What Is Dark Matter ?

And why is it interesting ?

This is not dark matter! It absorbs light, so you can see it.

Dark matter is as dark as anything can be. It NEITHER emits NOR absorbs detectable amounts of light.

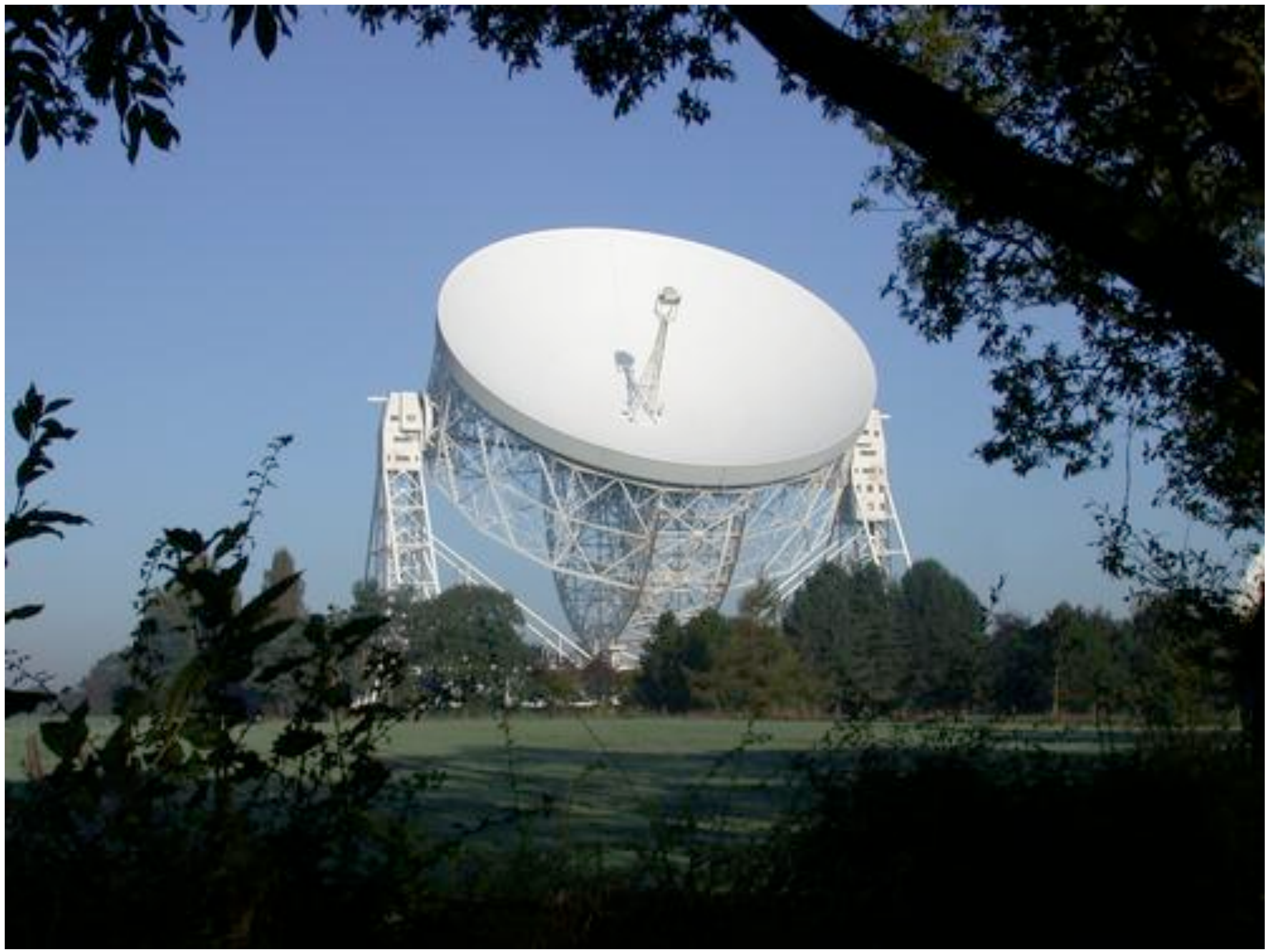
If we can't see it, how do we know it is there?

~3' (10kpc).

NGC 3198 (in Ursa Major, 9.1Mpc away from Earth)

We can determine the speed of rotation of material about the centre of the galaxy. We can plot this speed against distance from the galactic centre.

21cm wavelength = 1.4GHz frequency.



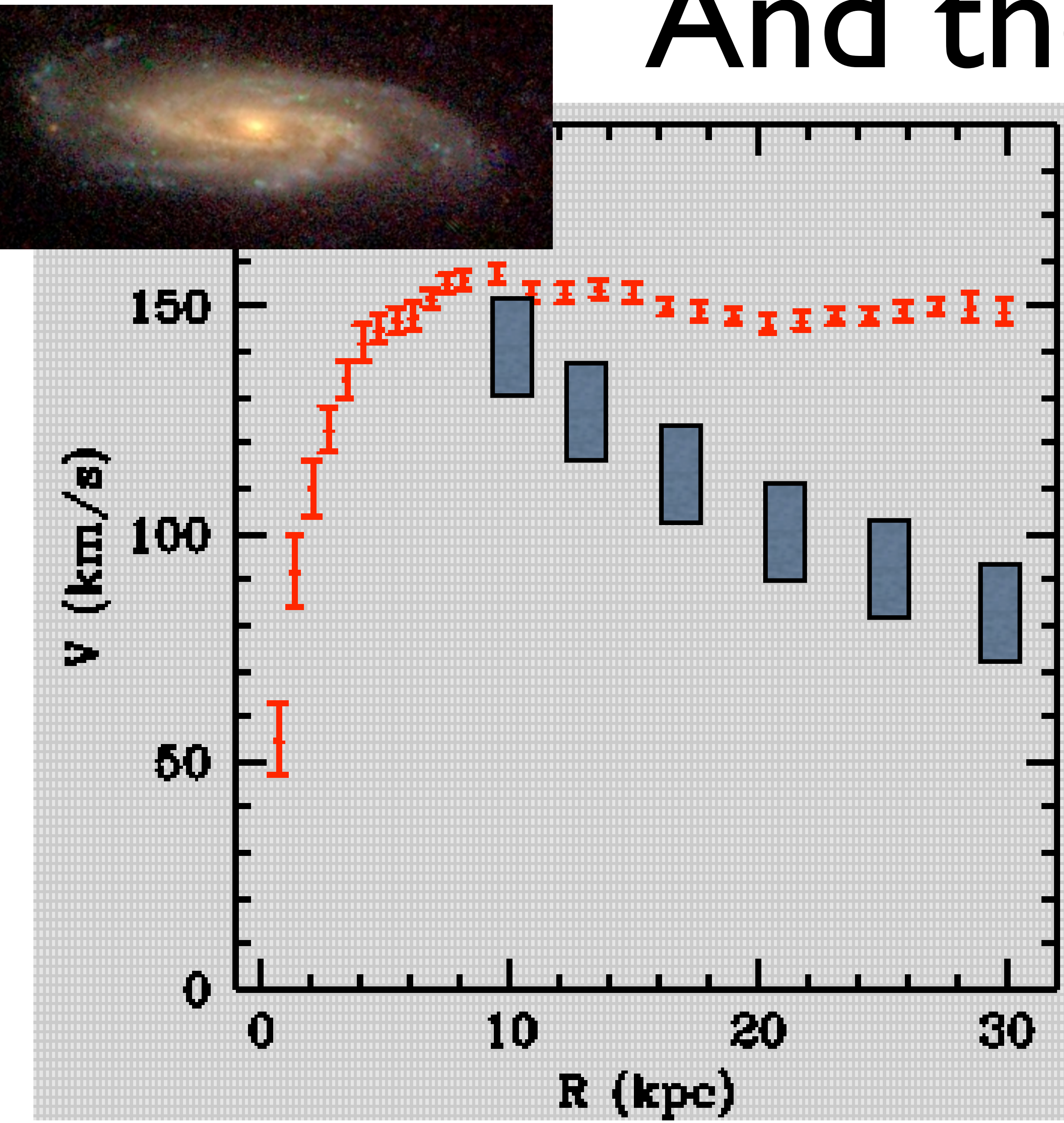
Astronomy with the 21cm Hydrogen Line

Still not large enough...

That’s more like it...

Very large array - New Mexico

And the result is:



BUT: this does not agree with the predictions of Newtonian classical mechanics and Kepler's laws !

UNLESS:
The galaxy is much larger than the visible disk, and about ten times as massive!

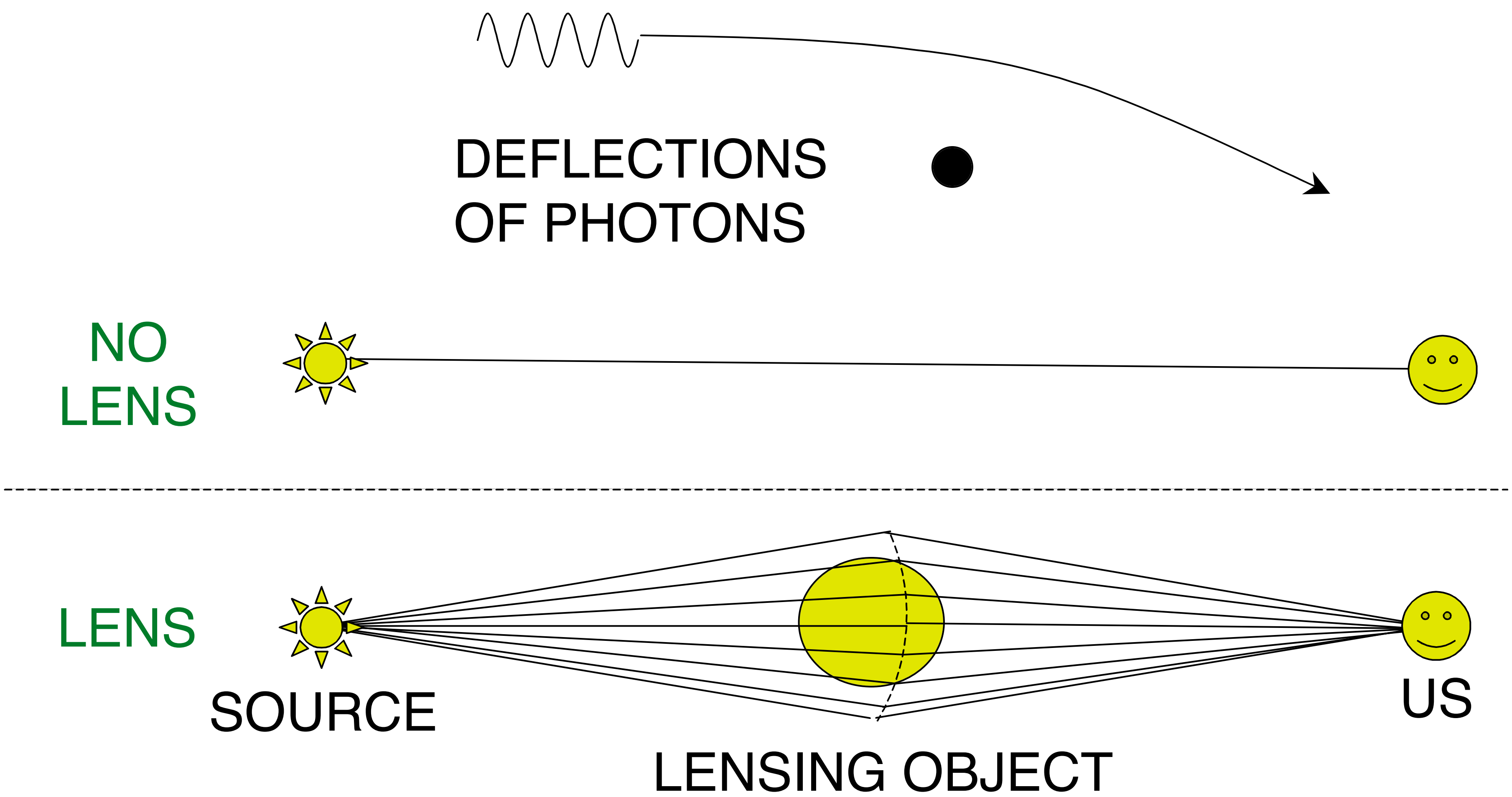
[Begeman et al. Astronomy & Astrophysics **223** , 47 (1989)]

■ ADDED BY YOURS TRULY FOR ILLUSTRATIVE PURPOSES

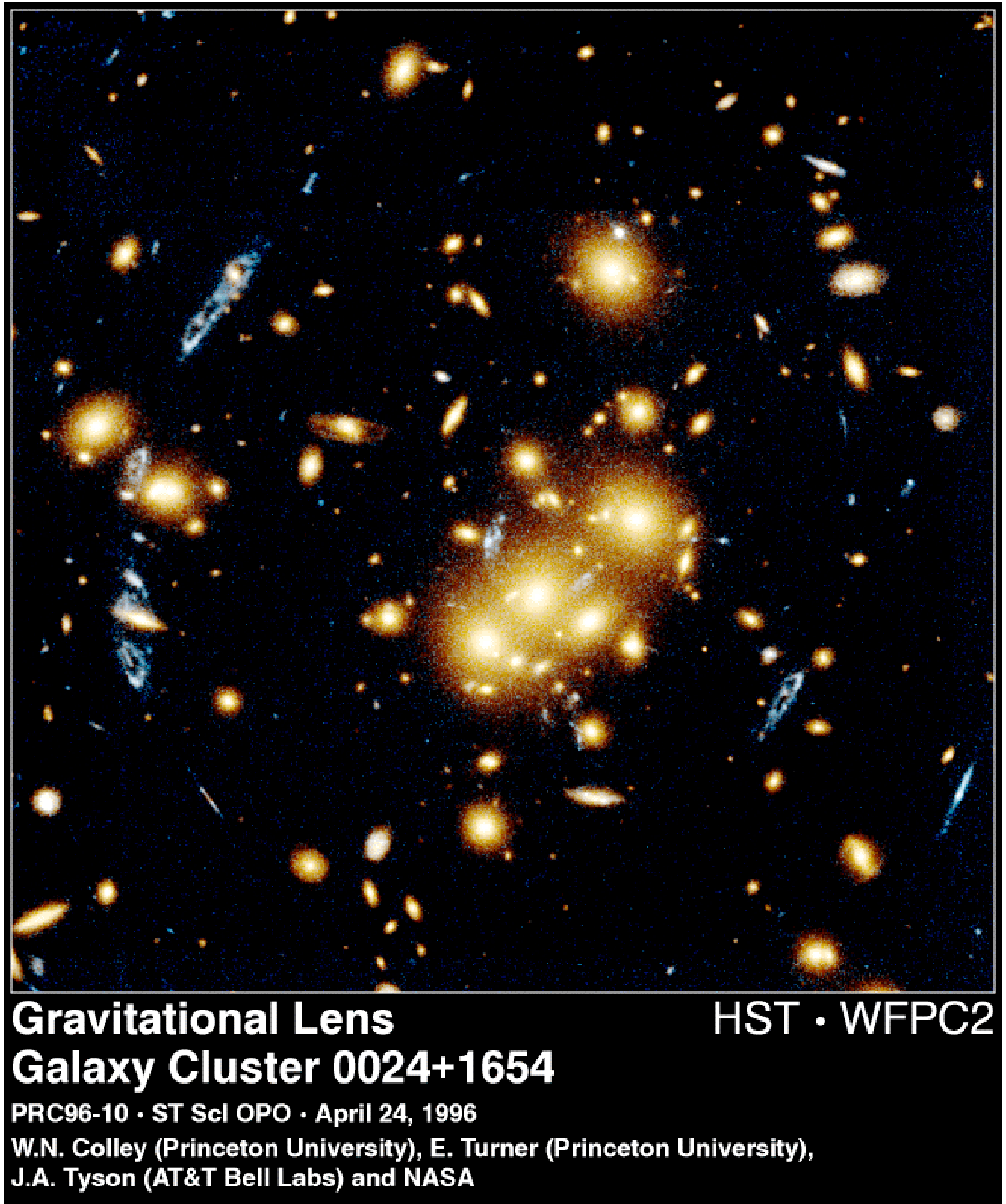
Gravitational Lensing

NEWTON - Gravitational fields cause bending of particle trajectories

EINSTEIN - Gravitation Fields cause the trajectories of photons in light beams to bend as well !

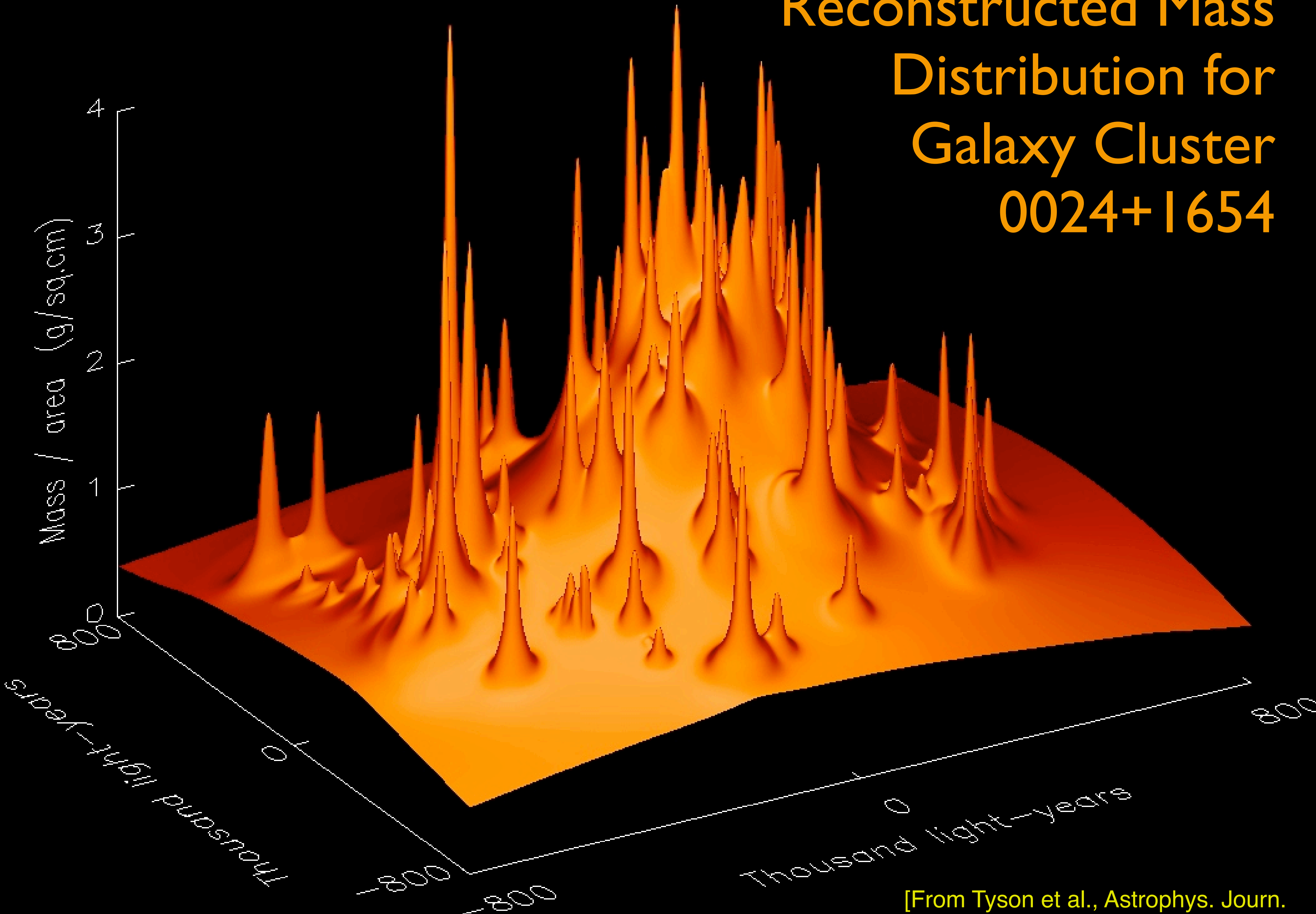


⟵ 336 h^{-1} kpc, 1 arc min. ⟶



Gravitational Lensing by Galaxy Clusters

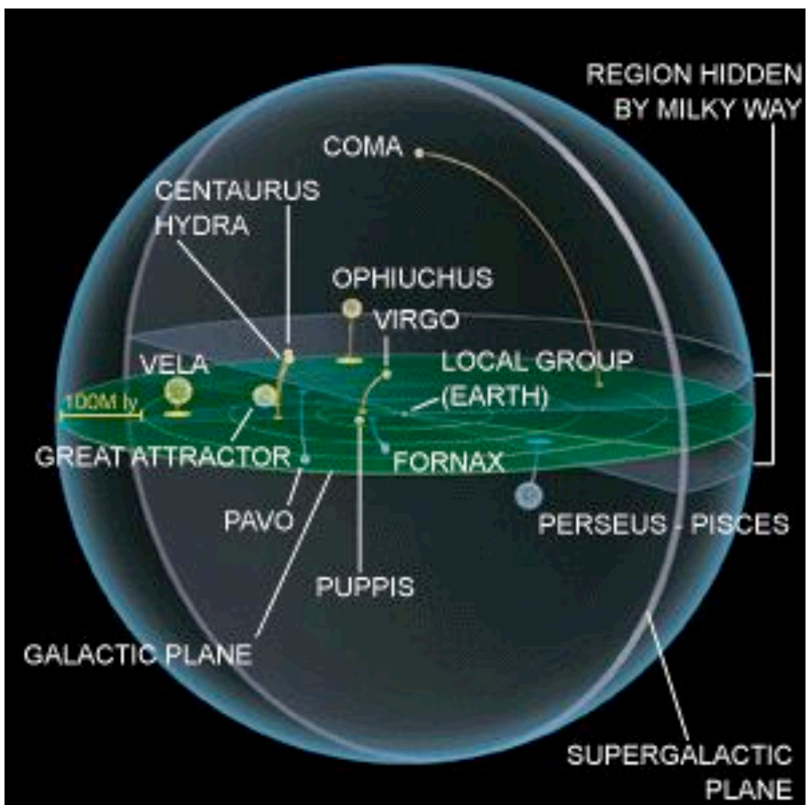
Reconstructed Mass Distribution for Galaxy Cluster 0024+1654



[From Tyson et al., Astrophys. Journ. **498**, L107-L110, 1998 May 10]

Peculier Velocity Measurements

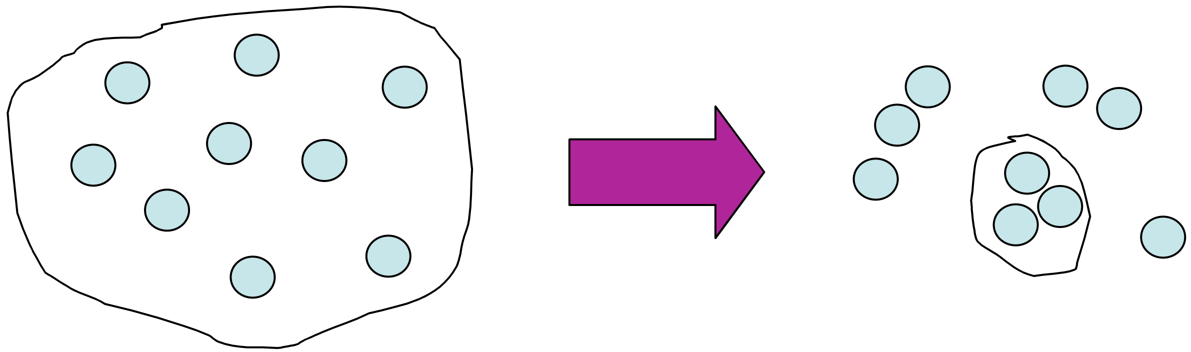
Peculier velocities are motions ‘above and beyond’ what is expected from Hubble expansion. They occur due to gravitational fields of massive bodies



Typical peculier velocity of local group objects towards great attractor, 600-1000km/s. Inferred mass of attractor, 10^{15}-10^{16} solar masses

Structure Formation

How did the universe end up with so much beautiful structure ? Gravitation did it !



Other forces like electromagnetism cannot do this because the positively and negatively charged particles are interspersed

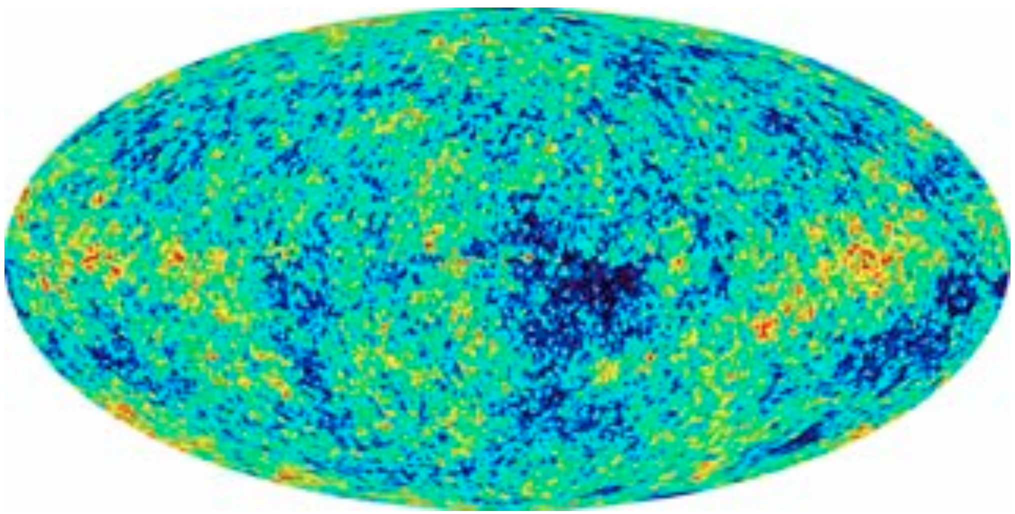
Dark matter is particularly effective at seeding the formation of structure because its non-gravitational interactions are feeble, so its dynamics can be dominated by gravity.

A recent structure formation simulation

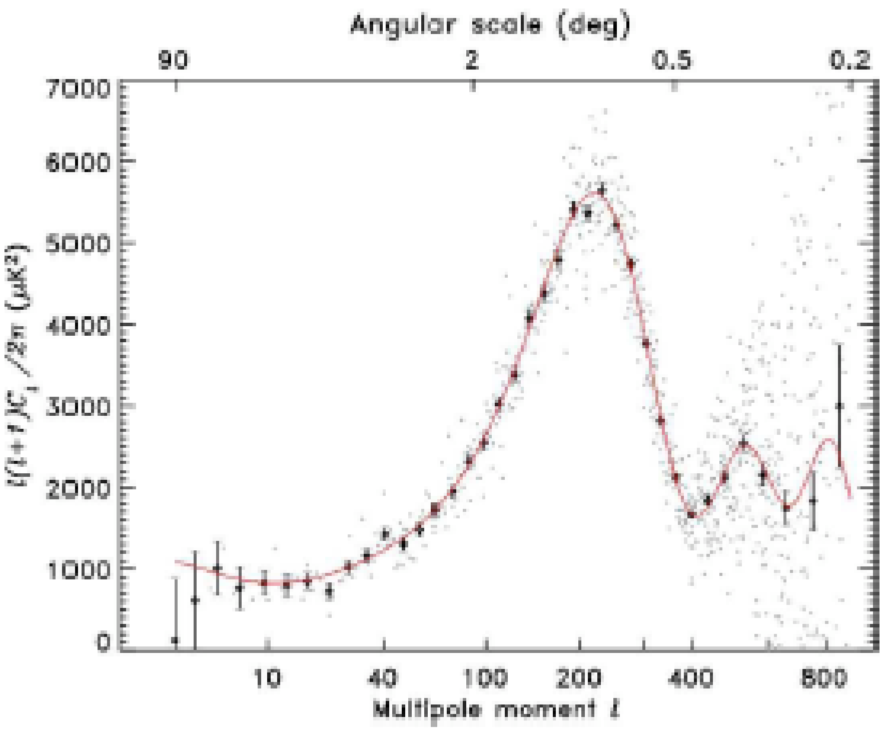
From the research group of Ben Moore,

http://krone.physik.unizh.ch/~moore/

WMAP Satellite Results



size of fluctuation



larger ← angular scale on sky ← smaller

Results

$$\Omega_{\rm VM} = 5\%$$
$$\Omega_{\rm DM} = 24\%$$
$$\Omega_{\Lambda} = 71\%$$

http://map.gsfc.nasa.gov/

Dark Energy

- You may have heard about this. I don't like the name. It fails to convey just how odd this contribution to physics is.

Consider a bottle of gas....the more molecules of gas in the bottle, the greater the positive pressure trying to push the walls out. Not dark energy, though!

Dark Energy, aka the 'Cosmological Constant'

The second name was assigned by the first person to invoke its existence - Einstein.

Second weird property. The total energy in dark energy is proportional to the volume of empty space (vacuum) in the universe. As the universe expands, its total energy increases

Third wierd property. For objects separated by huge distances from us (like very far off supernovae), the 'dark energy' tends to (effectively) force objects to accelerate apart, opposing the pull of gravity. This is actually how it was first discovered in experiments.

We don't understand it !

Ideas for Dark Matter

1. Conventional Astronomical Candidates

For example: brown dwarfs, low luminosity stars.

All of these candidates are made of ordinary matter, ATOMS. Ruled out because it's hard to make that much ordinary matter. People talk about NUCLEOSYNTHESIS BOUNDS - it is hard to synthesize that many nuclei in the early universe.

Besides, it is hard to form as much structure as we see in the universe with only ordinary matter as your building block - its self interactions are too strong, washing out any initial inhomogeneities that might form structure until too late in the universe's evolution.

Particle Candidates

There are lots of elementary particles other than the usual protons, neutrons, and electrons, but only a very few make good candidates for dark matter.

Candidates need to remain stable for at least 10^{14} years

have feeble couplings to other matter, except for gravitation.

have been produced in large numbers in the early universe.

be capable of seeding structure in the universe consistent with observations today.

Neutrinos

Masses of a less than 1 millionth that of an electron, electrically neutral, produced in nuclear reactions, for example, in the sun, in supernova explosions, in the big bang.

Known to exist ! Known to be plentiful in the universe.

BUT - they inhibit formation of structure, because they are produced thermally in nuclear reactions. Therefore they are 'hot', or 'high kinetic energy' particles, which therefore do not easily form bound states through gravitational interactions. RULED OUT as dark matter.

Exotic Particle Candidates

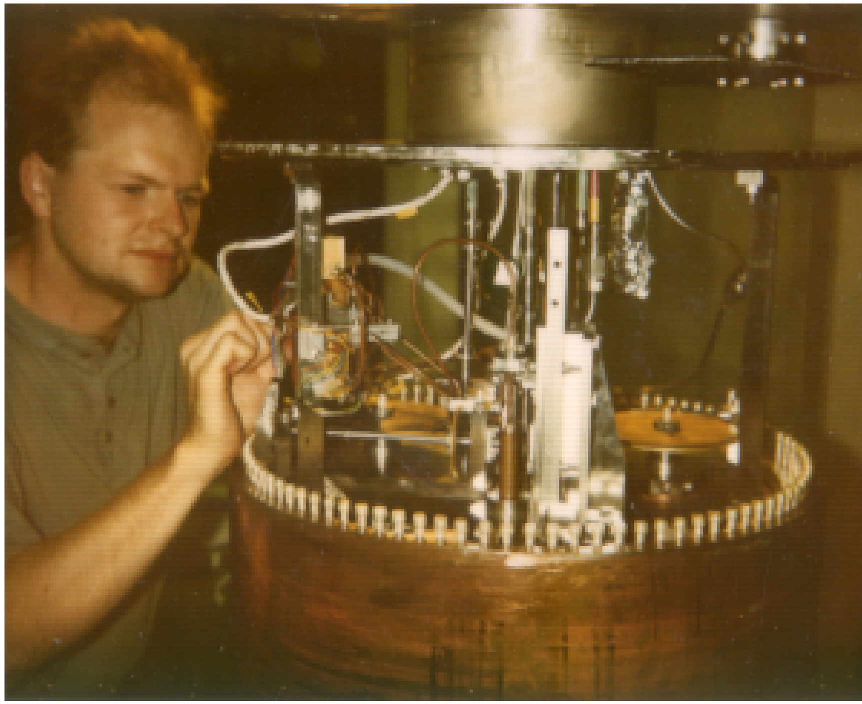
Axions - masses of around 1 thousanth-billion-billionth that of an electron, or about 10^{-45} kg. Not known to exist. Extension to the standard model of particle physics. ~10 thousand billion per litre at our location

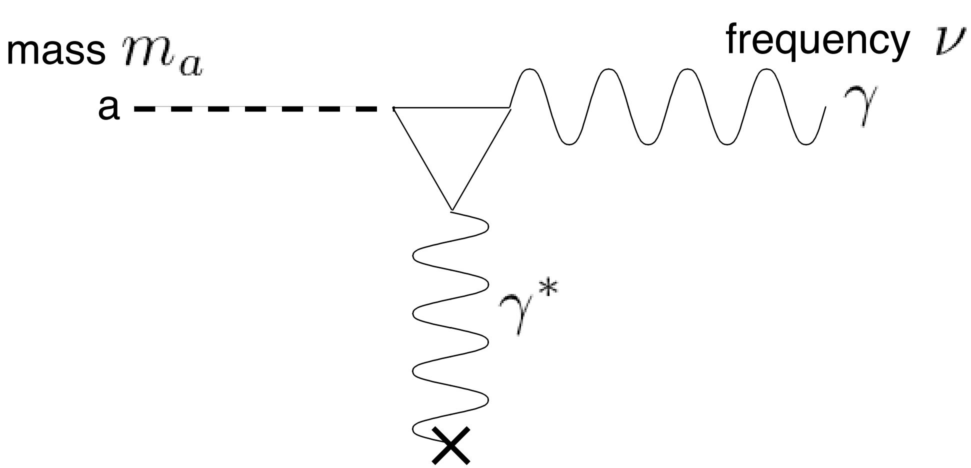
WIMPs - mass similar to that of a medium to heavy weight nucleus - hundreds of atomic mass units. A few tens per litre at our location. Part of a huge extension (supersymmetry) to the standard model of particle physics

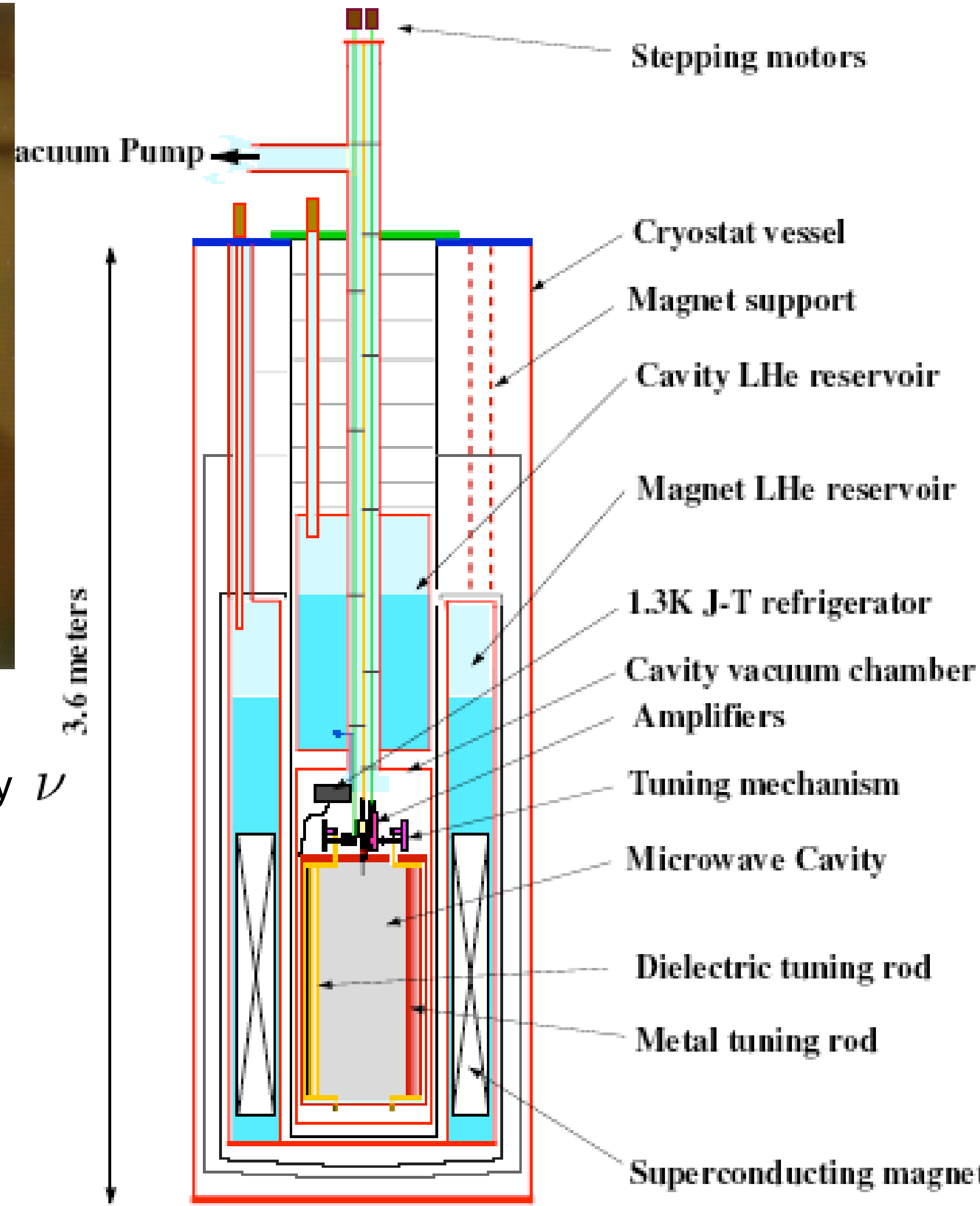
...other candidates: Kaluza klein particles, scalar particles from little Higgs theories, axinos...

Most experimental interest is focussed on WIMPs and axions

Axion Searches

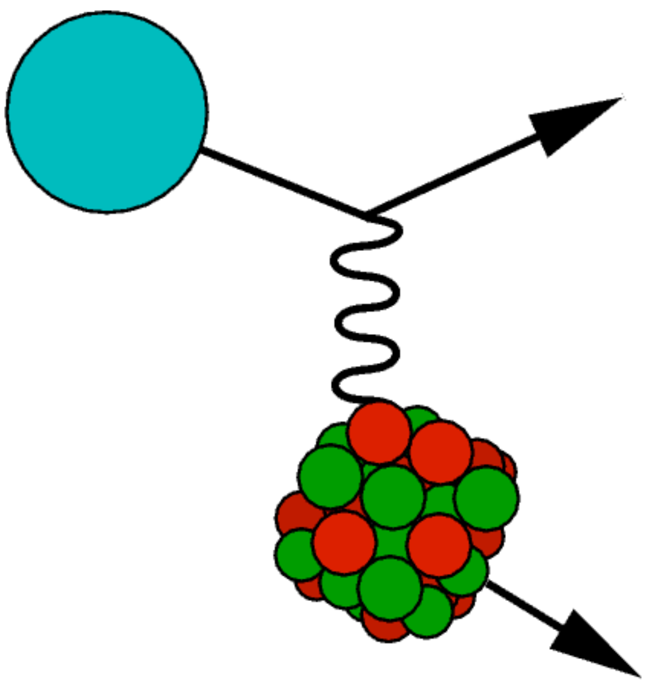






Weakly Interacting Massive Particles

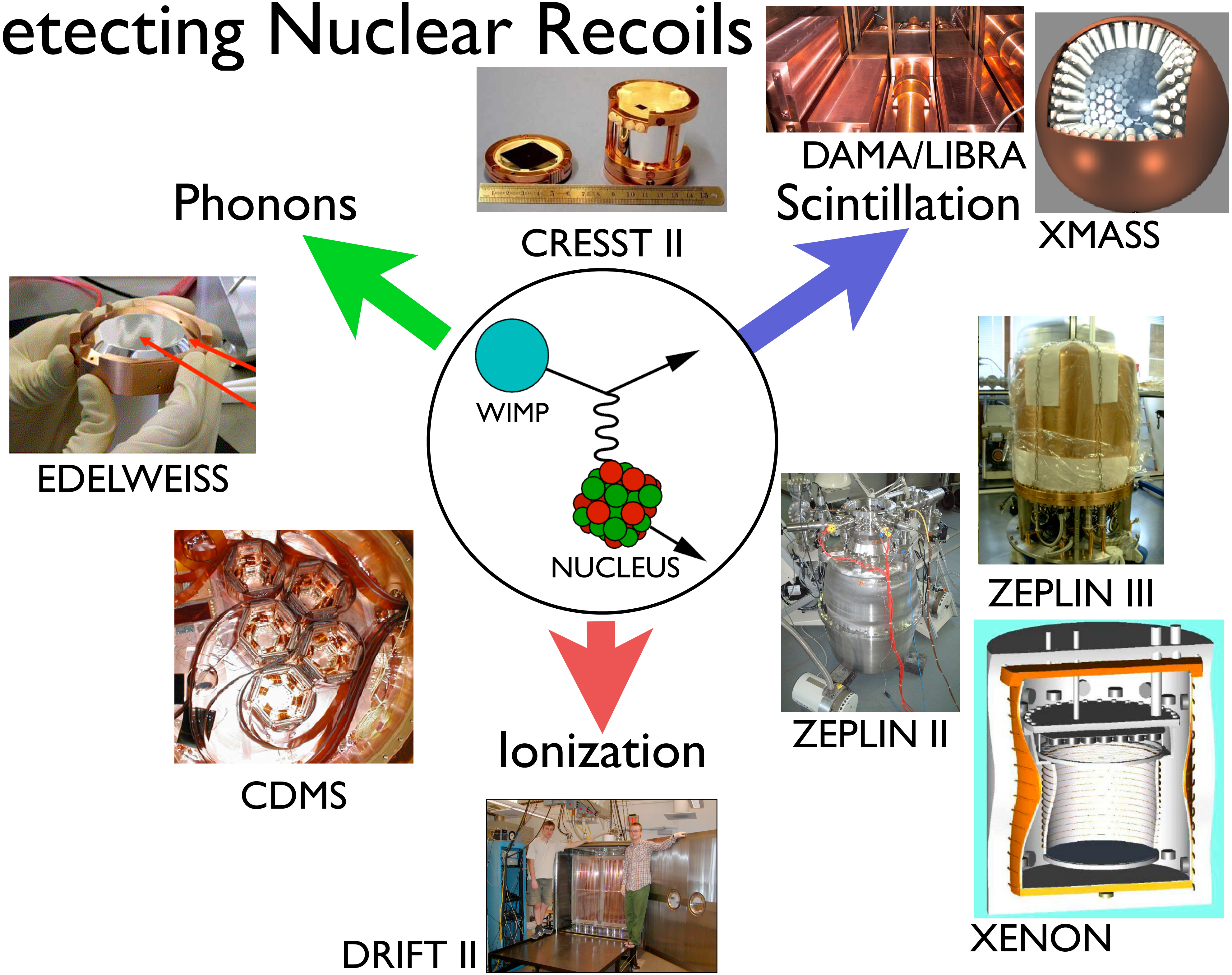
A WIMP is a general term for a heavy particle whose non gravitational interactions are feeble because they involve the creation of a very heavy particle by 'borrowing' energy through the uncertainty principle.



Unlike axion searches, WIMP searches rely on the interaction of a SINGLE particle with a detector.

The detector is a nucleus, such as xenon.

Detecting Nuclear Recoils



Backgrounds - what unwanted guests excite the detector ?

Cosmic rays - showers of particles from space.

Radioactive isotope decays near or in the detector.

Neutrons - scatter off nuclei

...just like WIMPS! Good shielding, radiopure detector.

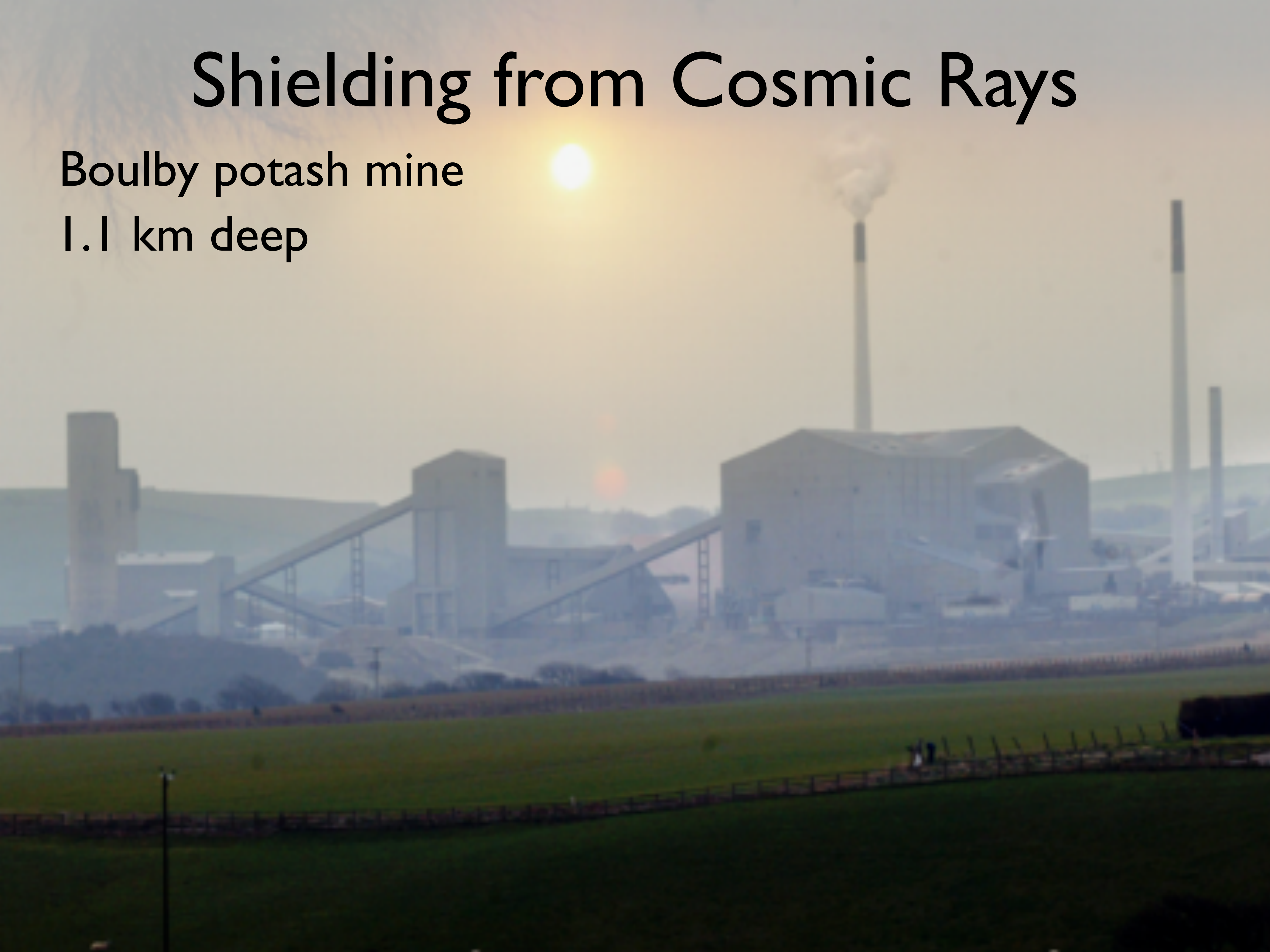
Gamma rays - scatter off electrons

...high rate, but scatter off electrons. discrimination techniques.

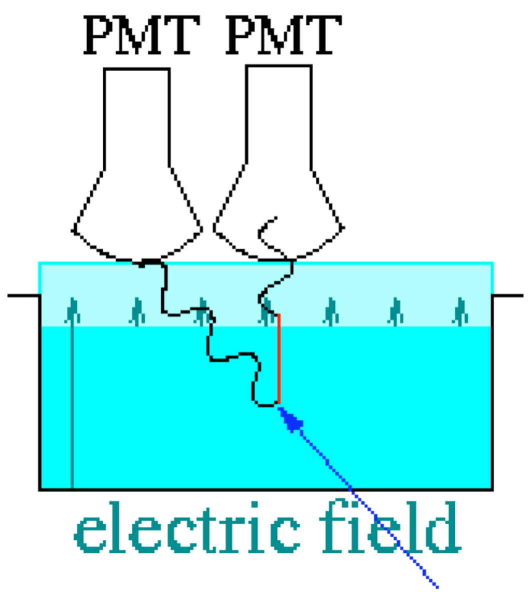
Shielding from Cosmic Rays

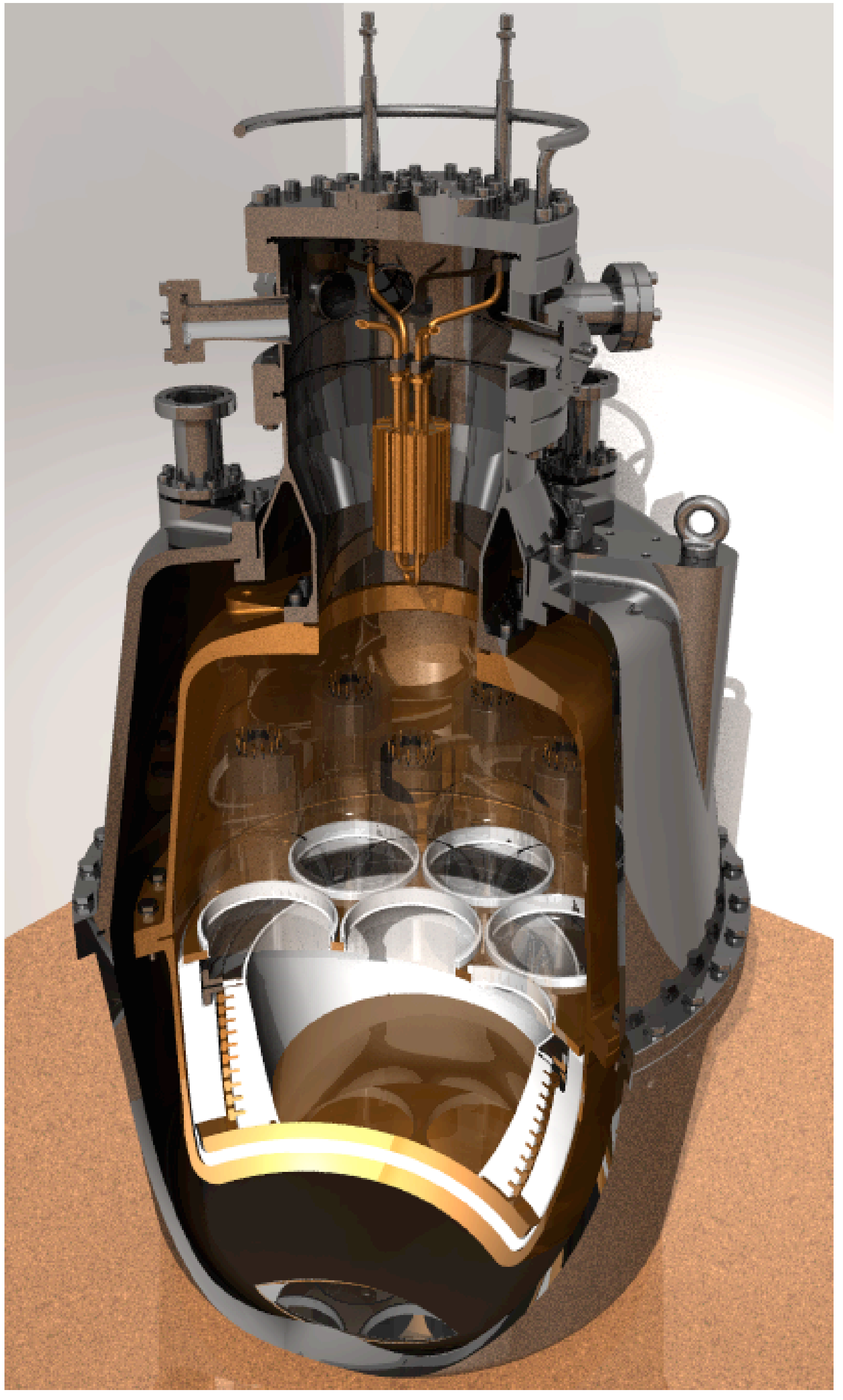
Boulby potash mine

1.1 km deep

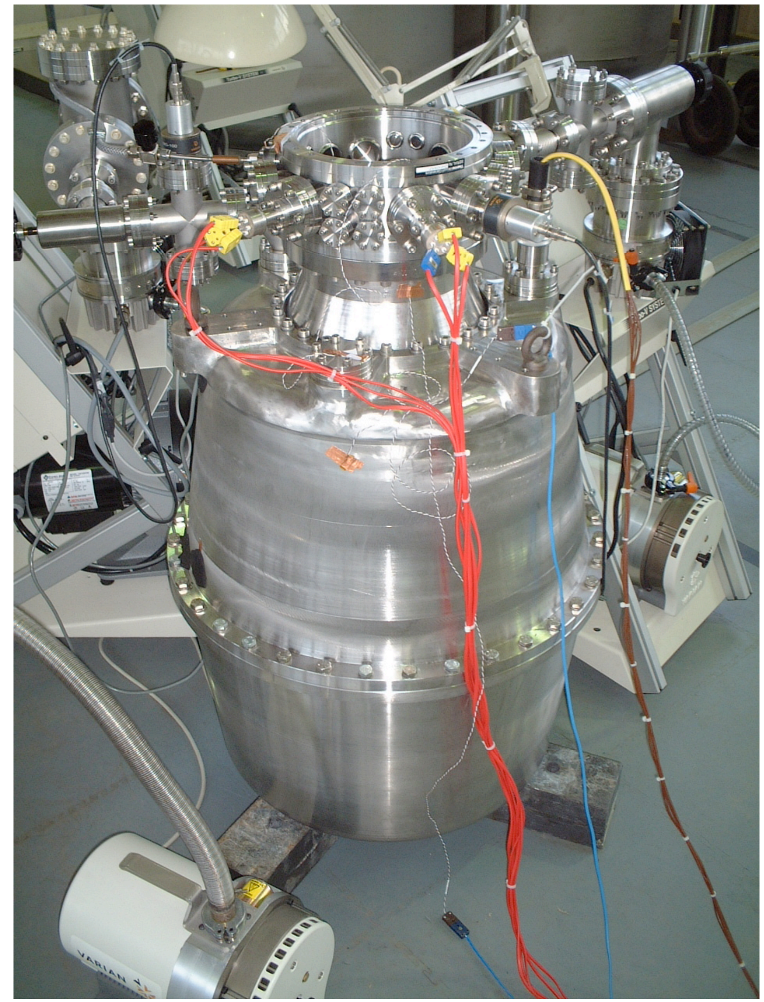


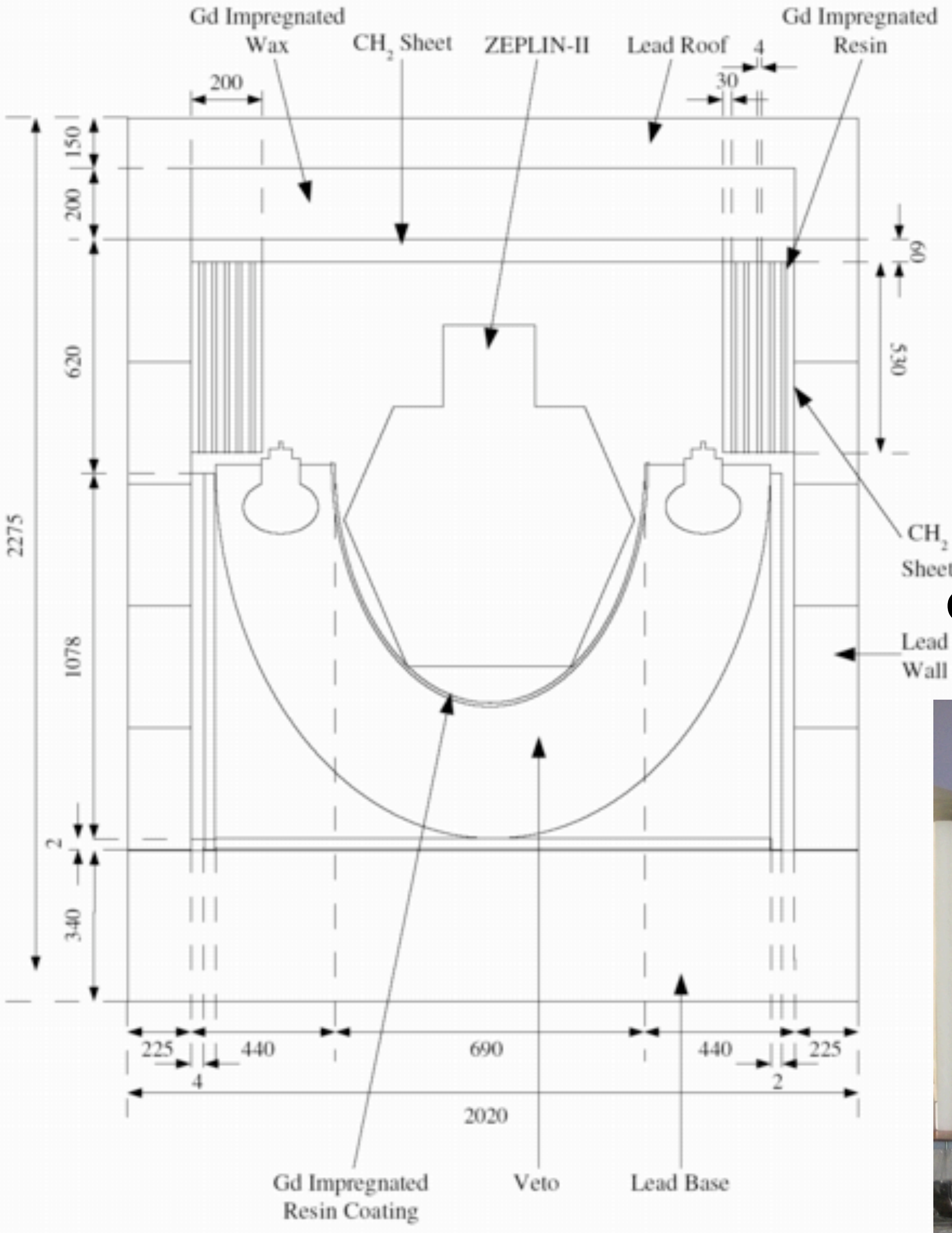
Zeplin II - A liquid xenon light/charge detector





Zeplin II Installation





More Shielding

Lead to shield against gamma rays

Wax & plastic to slow down (moderate) neutrons

Conclusions

- For current physical models of the universe to make sense, roughly a quarter of its mass must be invisible matter.
- The cosmological consant term comprises 70%, and this fraction is very poorly understood.
- The alternative is a complete rewrite of the laws of physics, including Newton's laws.
- Experiments to try and detect dark matter are underway! They are very hard, but a lot of fun. Thanks for listening !