

# Dark Matter – Why Is It Dark? Does It Matter?

**Dark Matter**

Why Is It Dark?  
Does It Matter?

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The 5th Wave      By Rich Tennant

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"After the discovery of 'antimatter' and 'dark matter', we have just confirmed the existence of 'doesn't matter', which does not have any influence on the Universe whatsoever."

2

Composition of Matter

● Stuff we know about  
● Stuff we don't

● H and He  
● Stars

What is THIS?

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3

Dark Matter

Why is it dark?	matter and light
What is the evidence?	galaxies in clusters stars in galaxies gravitational lensing cosmic background
What is it?	MACHOs WIMPs
Does it matter?	cosmic evolution

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4

# Dark Matter – Why Is It Dark? Does It Matter?

## Why Is It Dark?

### Simple answer

It's dark because it's not light

### More useful answer

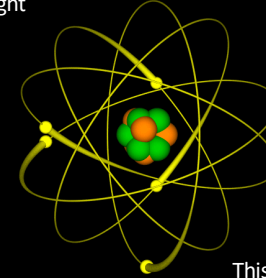
It does not behave the same way as 'ordinary' matter, which

- interacts through the electromagnetic force
- emits and absorbs electromagnetic waves (light)
- can be detected through its interaction with light

Dark matter does none of these

## 'Ordinary' Matter

Everything we see around us  
is made from atoms that  
emit or absorb light



This is how we visualise  
atoms with electrons buzzing  
around a nucleus like bees



## What Is the Evidence? #1

### Galaxies in Clusters

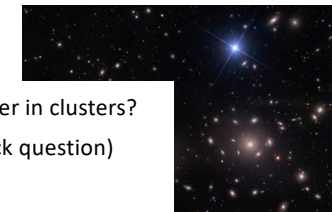
What holds galaxies together in clusters?

Gravity (no, it wasn't a trick question)

Gravity depends on mass

Mass can be estimated from luminosity:

- Measure the galaxy brightness
- If we understand stars, then...
  - we know the number of stars (roughly)
  - we know the mass of all the stars (roughly)
  - we know the mass of the galaxy (roughly)



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## What Is the Evidence? #1

### Galaxies in Clusters

Do this for all the galaxies in the cluster  
We now have an estimate of the mass  
... and hence the gravity

As early as the 1930s it was realised that the gravity calculated in this way is **not enough** to keep the cluster together – the galaxies should have drifted apart long ago.

Something is wrong!



## What Is the Evidence? #1

### Galaxies in Clusters

Using the luminosity to find the mass seems to underestimate the mass by a huge factor.

It's as if there is some additional mass, that is not luminous, that is providing the extra gravity that is needed to keep the cluster intact, binding the galaxies together.

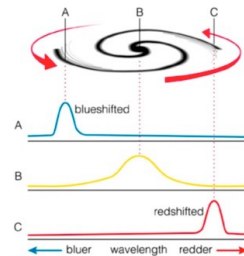
Let's call this ... "**Dark Matter**" ... that sounds pretty cool.



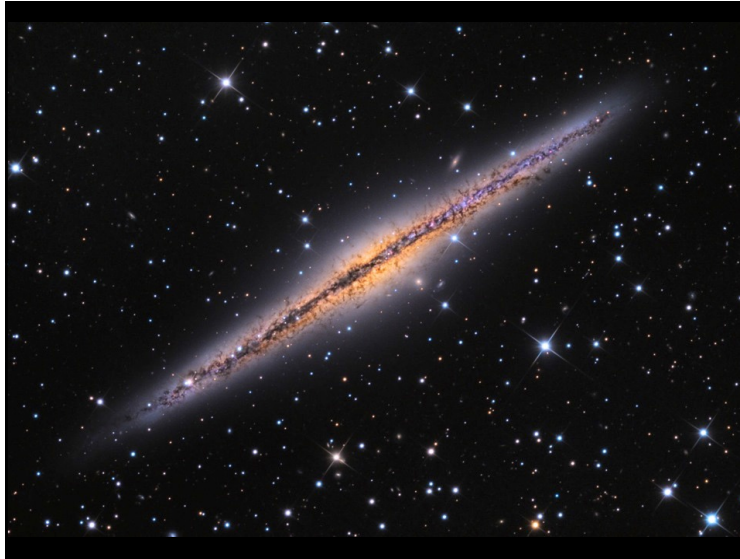
## What Is the Evidence? #2

### Stars in Galaxies

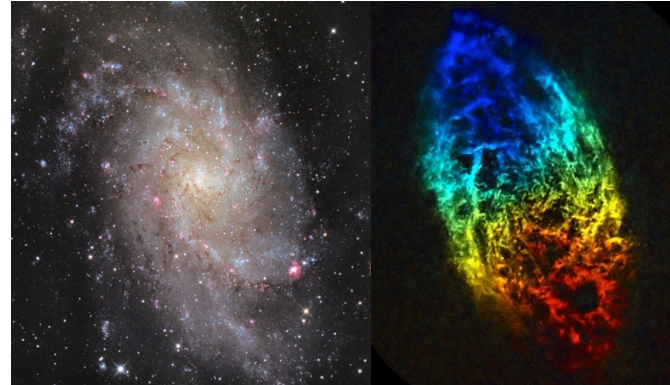
All galaxies rotate  
How fast are the stars moving?  
Use the Doppler effect



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## What Is the Evidence? #2

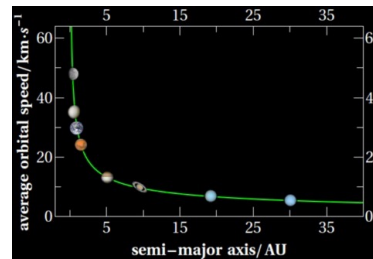


## What Is the Evidence? #2

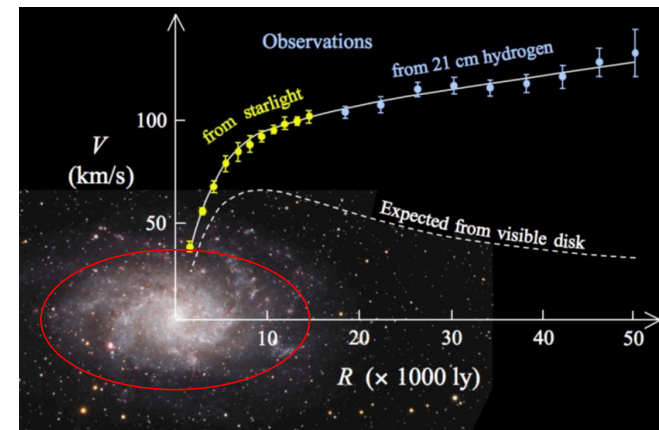
### Stars in Galaxies

What do we expect to see for the orbital velocity?  
How should it vary for stars further from the centre?

If all the mass keeping an object in orbit is *inside* the orbit...



## What Is the Evidence? #2



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## What Is the Evidence? #2

### Stars in Galaxies

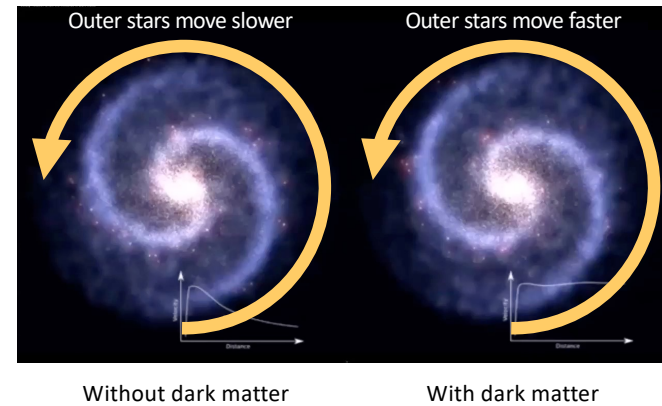
It's as if there is some additional mass, that is not luminous, that is providing the extra gravity that is needed to keep the stars (or gas) orbiting at high velocities, even a long way outside the visible "edge" of the galaxy.

"Dark Matter" again?



17

## What Is the Evidence? #2



18

## What Is the Evidence? #3

### Gravitational Lensing

This body of evidence is quite unlike the previous two

We can calculate mass from its gravitational effect,

... not on galaxies in a cluster, or stars in a galaxy

... but on light itself

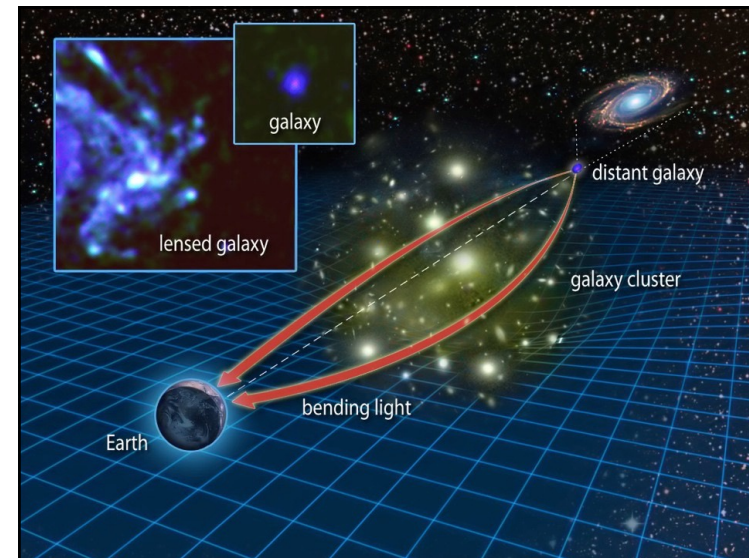
But dark matter does not interact with light, right?

It does not emit or absorb light, that is true

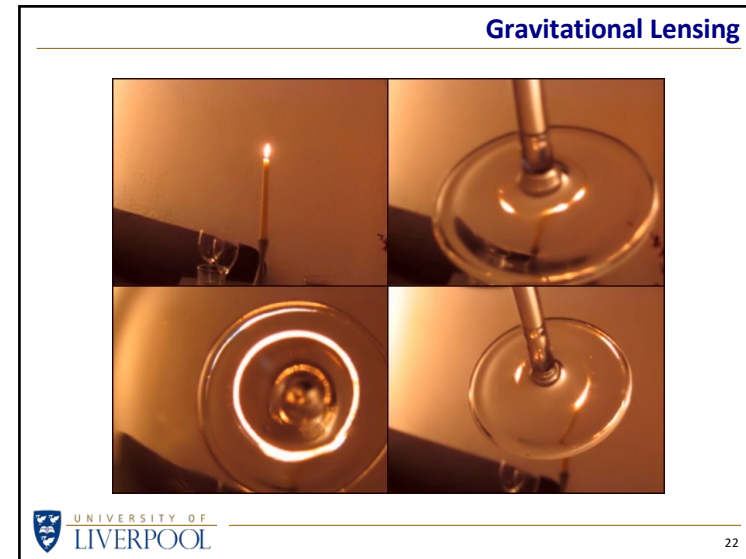
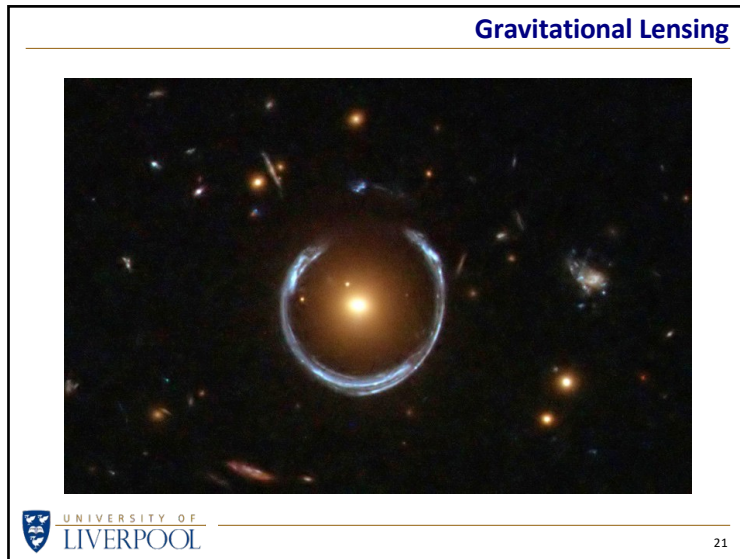
However, dark matter has mass  $\Rightarrow$  gravity  $\Rightarrow$  bend light



19



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What Is the Evidence? #3

**Gravitational Lensing**

The (distorted) images  $\Rightarrow$  the mass distribution in the 'lens'

We find this is more than we can see in the lens

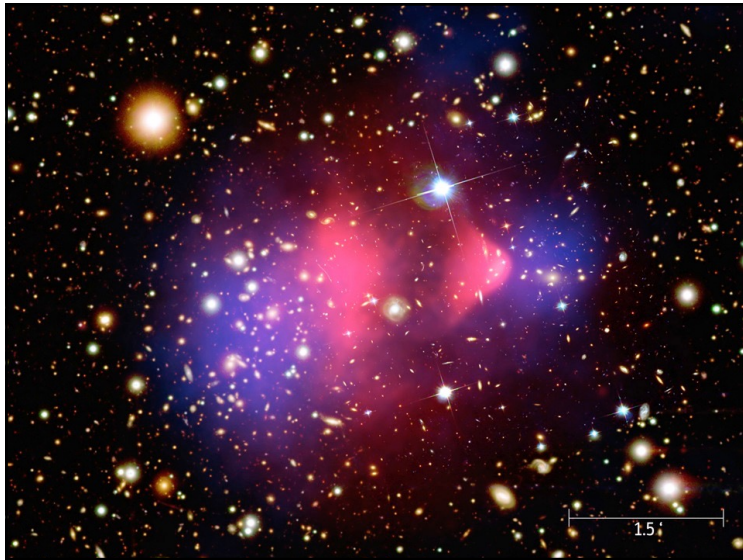
It's as if there is some additional mass, that is not luminous, that is providing the extra gravity that is needed to bend the light and produce the distorted images.

"Dark Matter" again?

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24

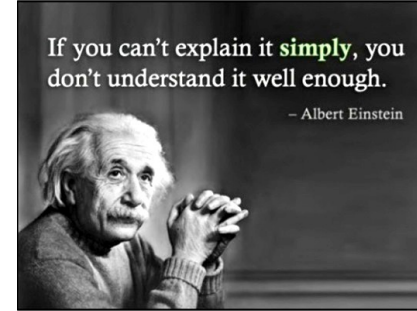
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## What Is the Evidence? #4

If you can't explain it **simply**, you don't understand it well enough.

– Albert Einstein

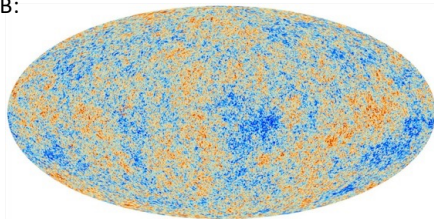


## What Is the Evidence? #4

### Cosmic Microwave Background

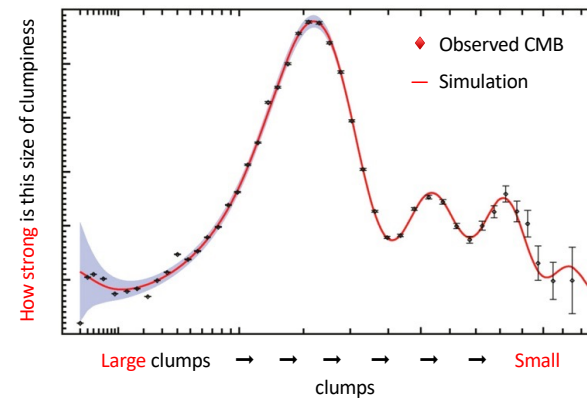
The fourth and final strand of evidence is not easy to explain

The CMB:



The degree of granularity – the "clumpiness" – depends on the relative amounts of ordinary matter and dark matter

## Quantifying the Clumpiness



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## What Is It?

OK, I'm convinced.

There's a lot of evidence that there is something dark out there.  
But... what *is* it?

There are two main candidates for the composition of DM...

### MACHOs

Massive Astrophysical Compact Halo Objects

### WIMPs

Weakly Interacting Massive Particles

## Galaxy Halo



## MACHOs

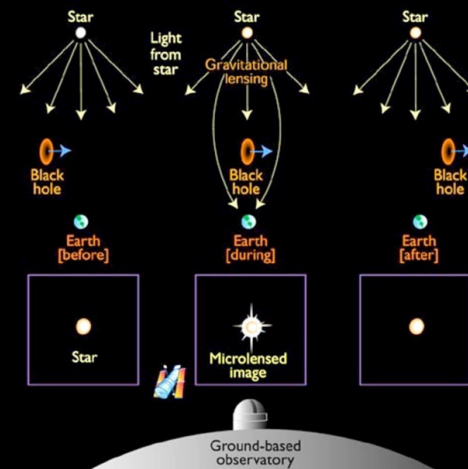
### MACHOs

Massive Astrophysical Compact Halo Objects

Bodies composed of 'normal' matter that emits no light  
Black holes, neutron stars, white dwarf stars

How can they be detected? Gravitational microlensing

## Gravitational Microlensing by Black Hole





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## MACHOs

### MACHOs

Massive Astrophysical Compact Halo Objects

Bodies composed of 'normal' matter that emits no light  
Black holes, neutron stars, white dwarf stars

How can they be detected? Gravitational microlensing

At most, MACHOs account for a few % of Dark Matter



33

## WIMPs

### WIMPs

Weakly Interacting Massive Particles

Interact through gravity, but not electromagnetism  
Similar to neutrinos, but much much heavier and slower

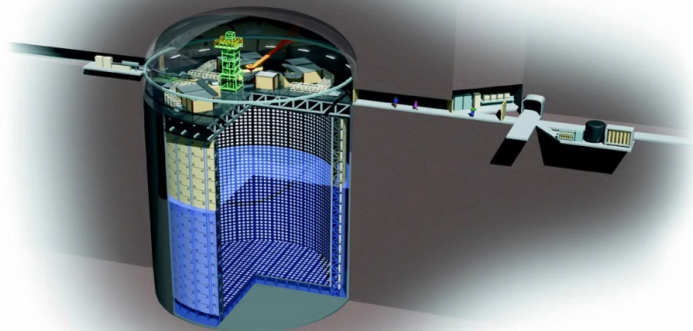
Born in the Big Bang (see "The Beginning of Everything")  
Annihilation of DM and anti-DM particles now very rare

WIMPs could be captured by the Sun  
... and annihilate with each other to make neutrinos



34

## Super-Kamiokande



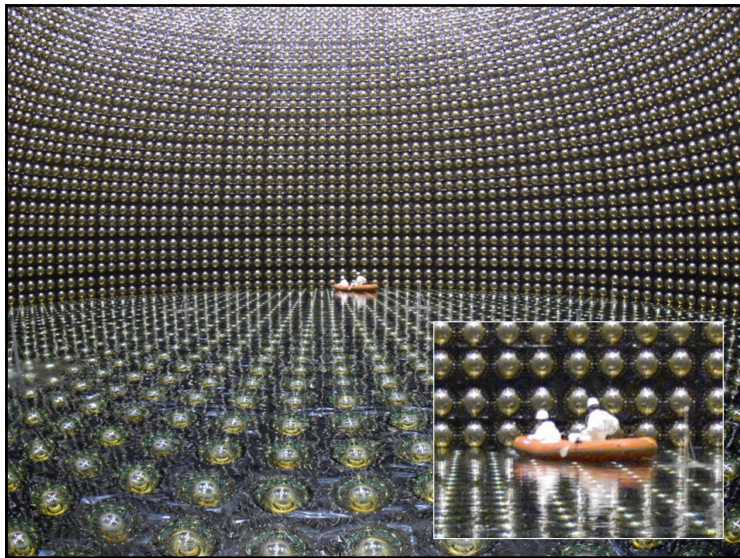
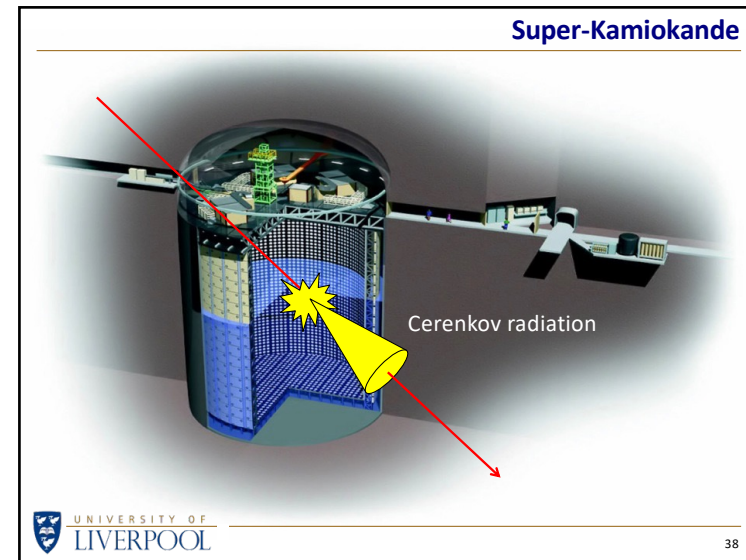
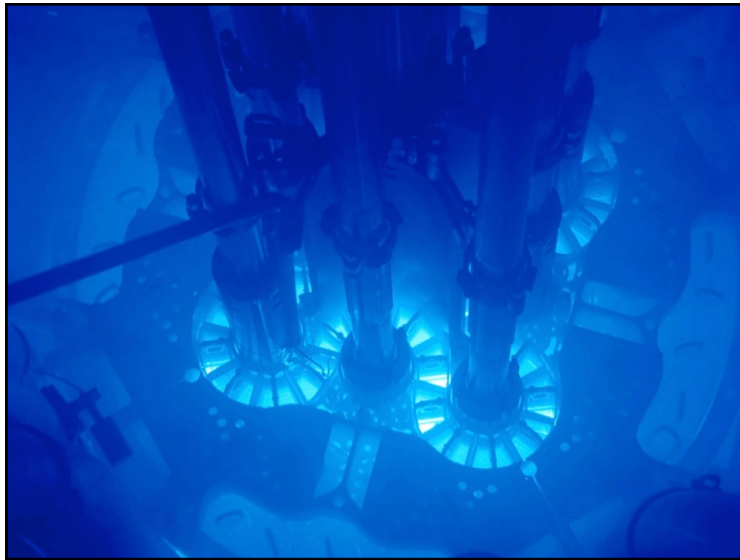
35

## Cerenkov Radiation

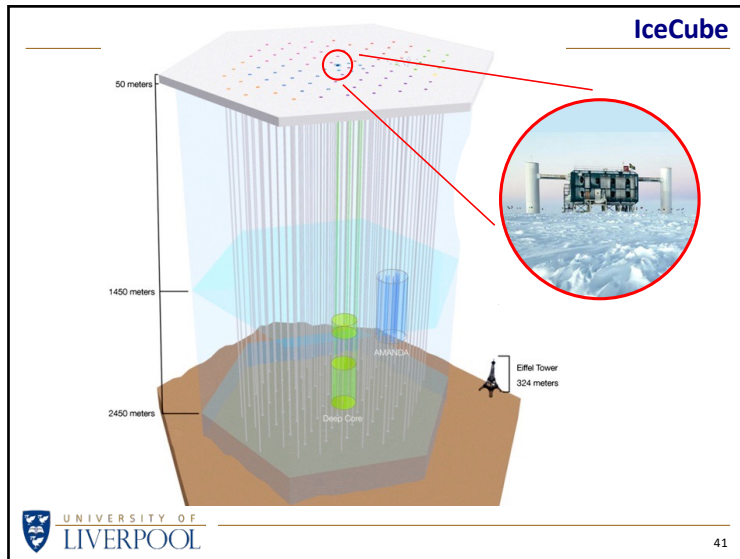


36

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## Gamma Rays

**WIMPs**

As well as being concentrated (locally) in the Sun ... there might be a lot of them at the centre of the Milky Way

DM annihilation would produce very energetic gamma rays

There are experiments planned to search for these

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## Cerenkov Telescope Array

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## WIMP Detection

### CDMS – Cryogenic Dark Matter Search

GeSi crystals with a superconducting skin  
Detect vibrations produced by atom being "kicked" by WIMP

### DRIFT – Directional Recoil Identification From Tracks

1000 litres of low pressure gas  
An atom hit by a WIMP can recoil by mm, making a track

### PICASSO – Project in Canada to Search for Supersymmetric Objects

Freon bubble chamber with 200µm bubbles in gel matrix  
WIMPs turn liquid bubble to gas ⇒ acoustic shock wave

## WIMP Detection

There are many other attempts to detect DM directly...

**CRESST** in Gran Sasso, Italy

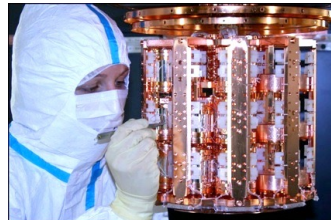
**DAMA** in Italy

**DEAP** at SNOLAB, Canada

**EDELWEISS** in France/Italy

**SIMPLE** in France

**WARP** at LNGS, Italy



Many of these experiments have observed "events" ...  
... but many are contradictory or not yet confirmed

## Alternatives

There is another possibility ...

- We have misunderstood how gravity works
- Hence we only *seem* to need dark matter

Maybe gravity works differently on the scale of

- The Universe
- The Galaxy
- The Solar System and smaller

There is a theory called Modified Newtonian Dynamics (MOND)  
However, it generates more problems of its own

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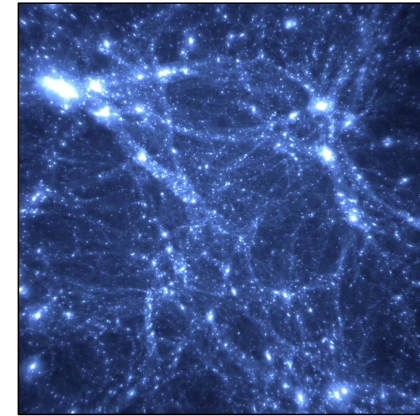
## Does It Matter?

### What are the consequences?

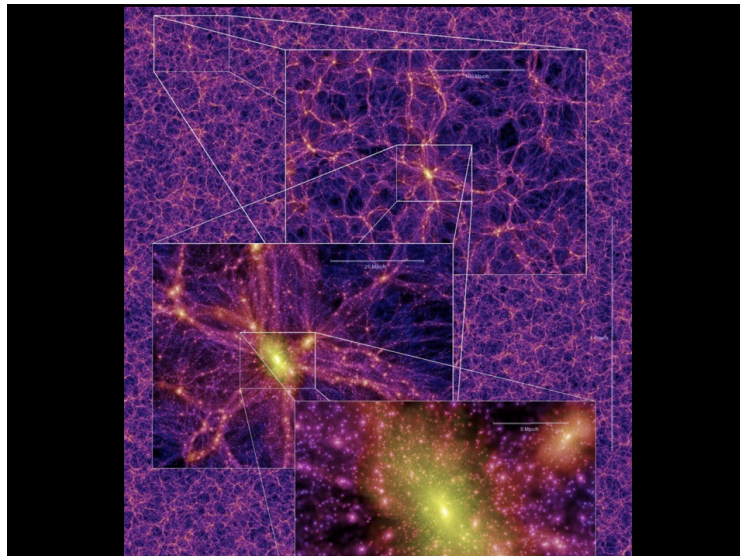
Simulations  $\Rightarrow$  galaxy distributions similar to observations  
Without dark matter, matter doesn't "clump" enough

## Cosmic Web

When the very early Universe was the size of a golf ball it had very small variations in density ('dimples')...



...and over billions of years these collapsed into a cosmic web of filaments and voids.



# Dark Matter

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[www.liverpool.ac.uk/~sdb/Talks](http://www.liverpool.ac.uk/~sdb/Talks)

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