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

Composition of Matter

- 16% Stuff we know about
- 84% Stuff we don’t

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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**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? #2**

**Stars in Galaxies**

All galaxies rotate

How fast are the stars moving?

Use the Doppler effect

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.
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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?

What Is the Evidence? #2

Without dark matter

With dark matter

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
**What Is the Evidence? #3**

**Gravitational Lensing**

The (distorted) images ⇒ 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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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

If you can't explain it simply, you don't understand it well enough.
– Albert Einstein

How strong is this size of clumpiness

- Observed CMB
- Simulation

Large clumps → → → → → Small clumps
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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

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
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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

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

Super-Kamiokande

Cerenkov Radiation
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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.

**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 gas → acoustic shock wave

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
Does It Matter?

What are the consequences?

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