Cosmology – Ian Lomas

This presentation

- Will be about 30 minutes long.
- Consists of 27 slides.
- Contains only one equation.
- Will be followed by a Q&A session.
- Will cover a lot of ground.
- Will still leave a lot of questions unanswered.

What is Cosmology? – a definition

- The study of the origin, evolution, and eventual fate, of the Universe.

- From the Greek, *kosmos* 'world' and *logia* 'study of'.

Ancient Cosmology

- Is as old as people looking up at the stars.
- The belief was that the Earth was the centre of the Universe.
- All other objects moved around the Earth.
- The stars were fixed in position.
- Some objects moved in the sky e.g. planets (the wanderers).


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Problems with this

- The planets followed complicated paths, sometimes going backwards.
- Copernicus proposed an alternative and started the Copernican Revolution.
- Telescopes allowed moons of other planets to be observed.

Modern Cosmology

- Einstein published his Theory of General Relativity in 1915.
- Modern cosmology started when Einstein applied his theory of General Relativity to the Universe in 1917.
- He believed in a static Universe and introduced Λ – the Cosmological Constant.
- Now for the equation: The Einstein Field Equations:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = -\mathrm{K}\, T_{\mu\nu}$$

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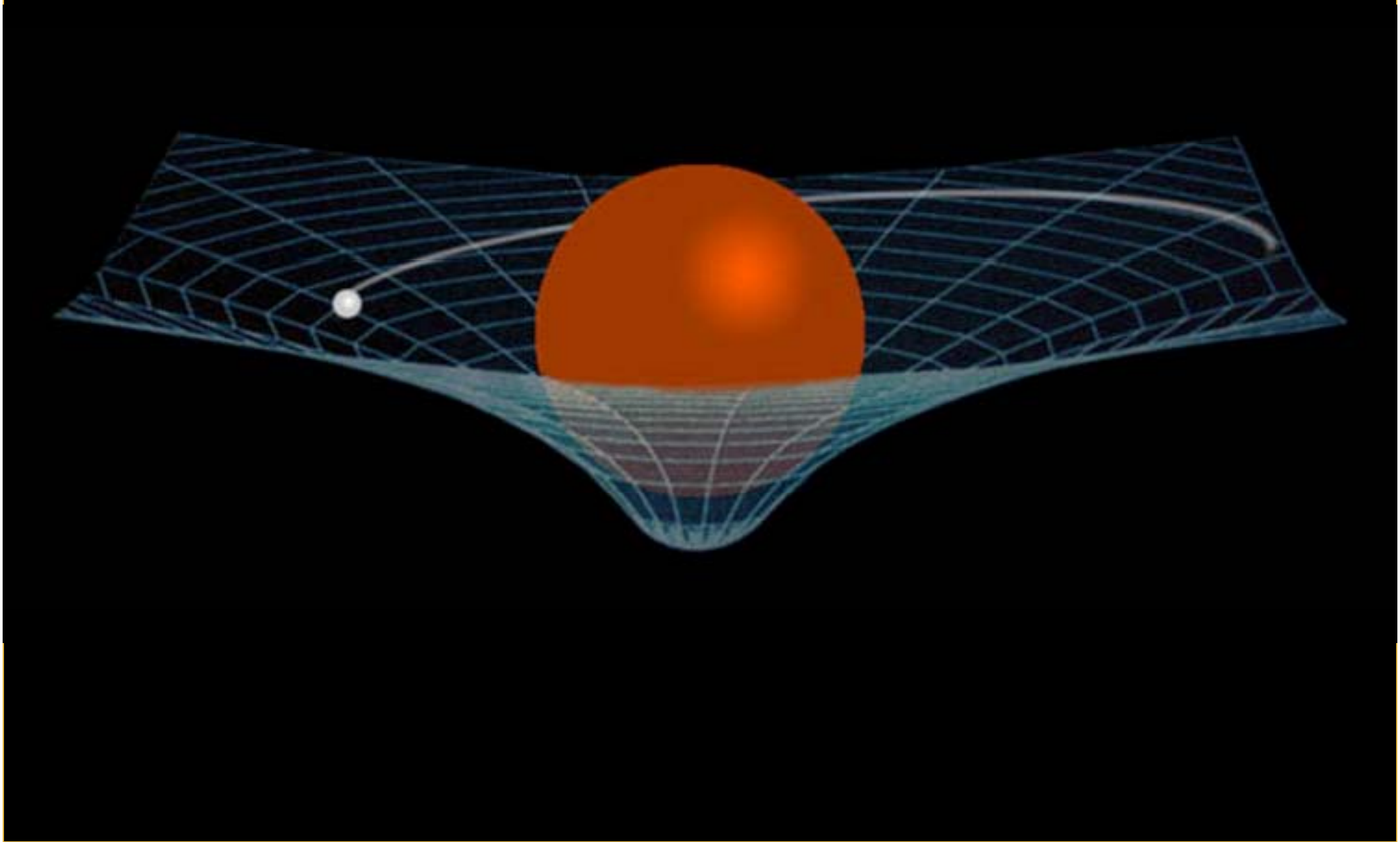
- The Left Hand Side of the equation - which represents the shape or curvature of spacetime,
- **IS RELATED TO:**
- The Right Hand Side of the equation – which represents the distribution of matter and energy in that spacetime.

What it means

- John Wheeler famously summarised this as:
  - Matter tells space how to curve,
  - Space tells matter how to move.



The next few slides will cover:

- The evolution of the Universe to the present.
- What it looks like now.
- What the future may hold.
- Some speculative ideas.

Major discoveries in cosmology

- Friedmann (1922) – the Friedmann equations.
- Hubble (1929) – the expanding Universe.
- Penzias and Wilson (1964) – the Cosmic Microwave Background (CMB).
- Guth, Linde and Steinhardt (early 80s) – inflation.
- Perlmutter, Riess and Schmidt (1998)– the accelerating expansion.

The Big Bang

- The beginning of the Universe.
- It took place around 13.8 billion years ago.
- ‘Something from nothing’.
- It was **NOT** a traditional explosion.


WRONG

The Friedmann equations

- Some assumptions were needed, e.g. the Universe is homogeneous and isotropic.
- Some complicated maths is also needed.
- From which, Alexander Friedmann derived his equations in 1922.
- They are complicated!

Why are they important

- They allow various types of universe to be modelled.
- These include universes that are:
  - static,
  - expanding (at a constant rate, or at an accelerating or decelerating rate),
  - bouncing.

The expanding Universe

- Edwin Hubble's observations of Cepheid variable stars in 1929.

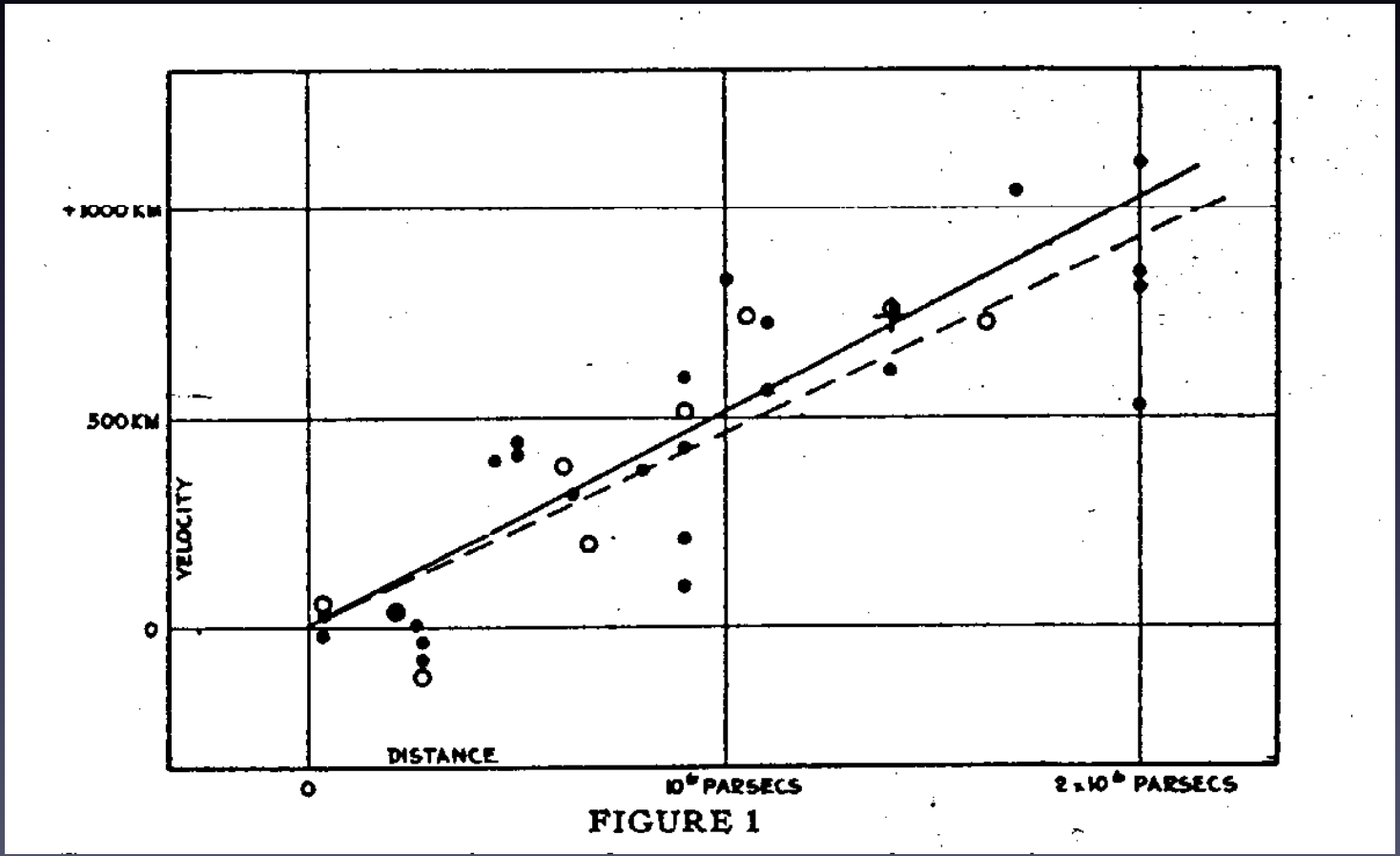


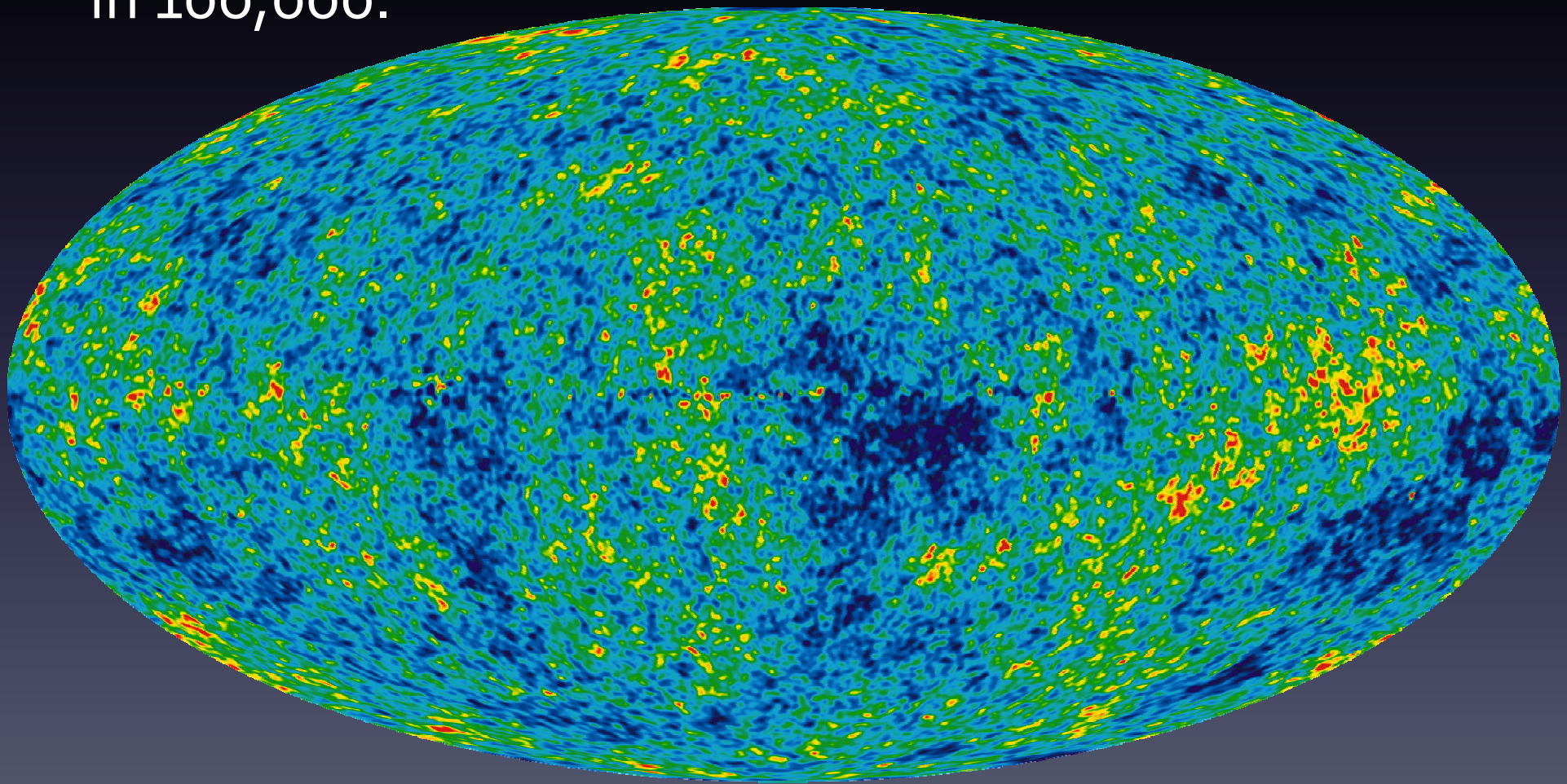
FIGURE 1

But what exactly is expanding?

- Wherever you are in the Universe, galaxies are moving away from you.
- Everywhere is at the 'centre' of the expansion.
- Space itself is expanding – not the planets, stars or galaxies.
- Do any of you know the balloon analogy?

The CMB

- Its average temperature is 2.7 K (about -270° C).
- It is VERY uniform, the variations are less than 1 part in 100,000.



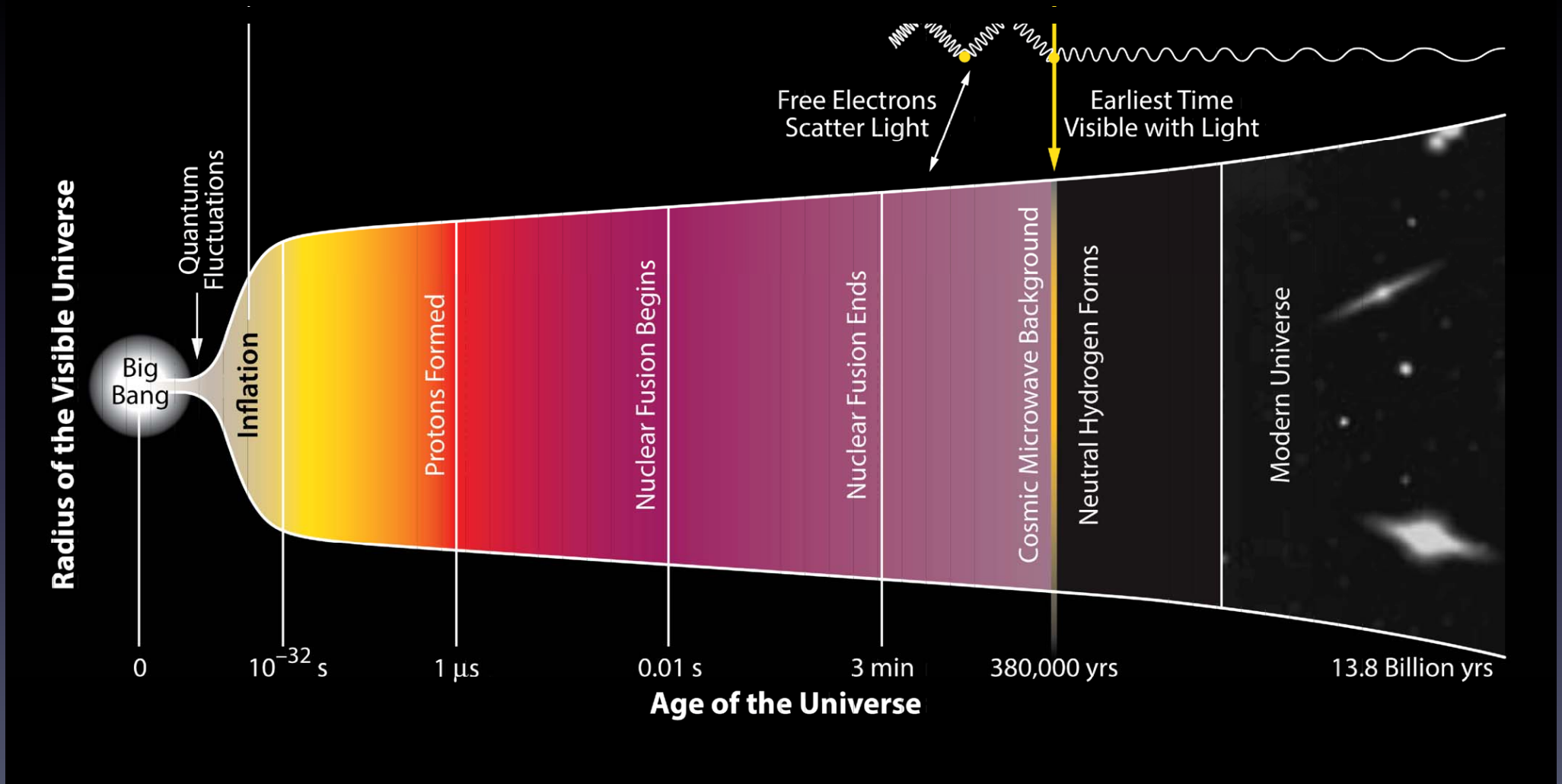
Inflation

- Inflation theory states that very soon after the Big Bang, the Universe expanded rapidly.
- It took place 10^{-32} seconds after the Big Bang.
- The Universe expanded by a factor of about 10^{26}.
- It helps to explain why the Universe is so uniform.

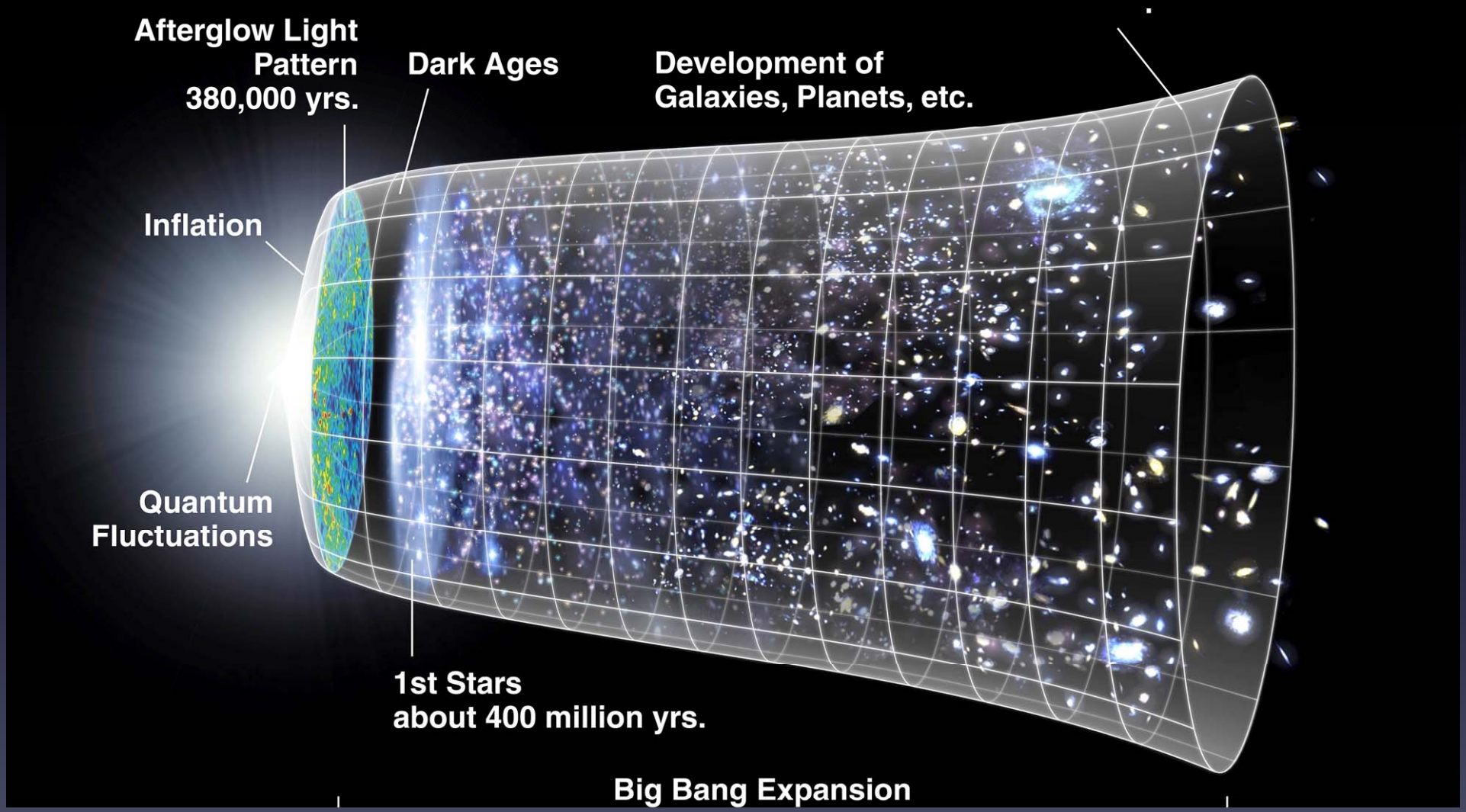
The accelerating expansion

- Observations of supernovae (exploding stars).
- The rate of expansion is accelerating.
- Gravity is losing out.

The evolution of the Universe



The evolution of the Universe



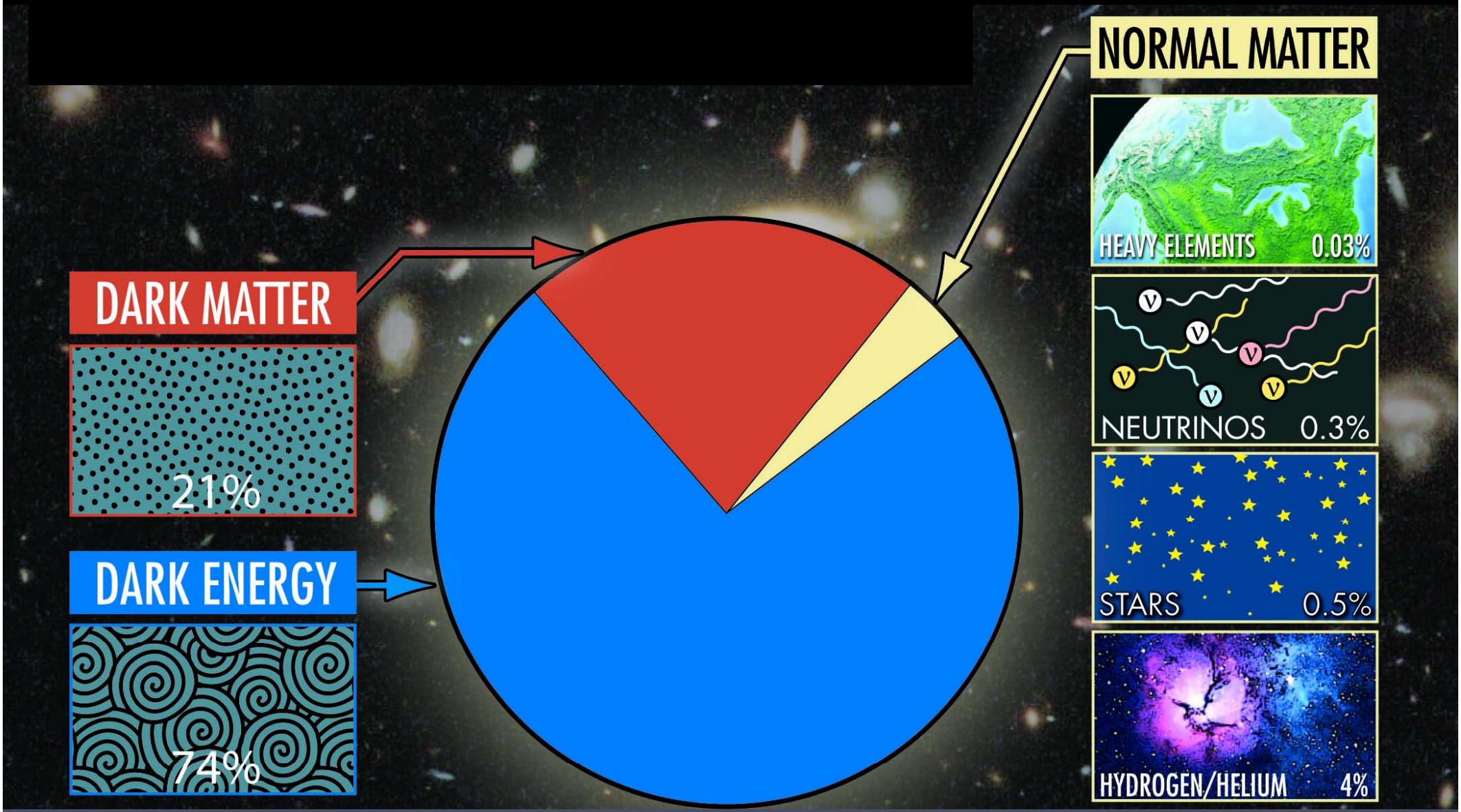
Dark Matter

- Comparing galaxies to the solar system – the rotation is not right.
- A halo of Dark Matter around each galaxy could solve the problem.
- Nobody knows what Dark Matter is, but it cannot be seen, hence it is called Dark.
- Its only effect seems to be through gravity.

Dark Energy

- And if Dark Matter is strange, Dark Energy is even more so!
- The rate of expansion of the Universe seems to be accelerating.
- This could be due to a repulsive force - Dark Energy.

The make up of the Universe



The future of the Universe

- A slow death.
- Galaxies move further and further apart.
- All the stars die out.
- The Universe becomes a cold, desolate place.
- But not for a long, long time.

Speculative ideas

- …and now into fantasy land!
  - Multiple universes.
  - A universe before ours.
  - Parallel universes.
  - One dimensional vibrating ‘strings’.
  - 11 dimensions.
  - Colliding membranes.