

The Constantly Changing Hubble Constant

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Find the presentation at

<https://tinyurl.com/bycke8v6>

Interactive content

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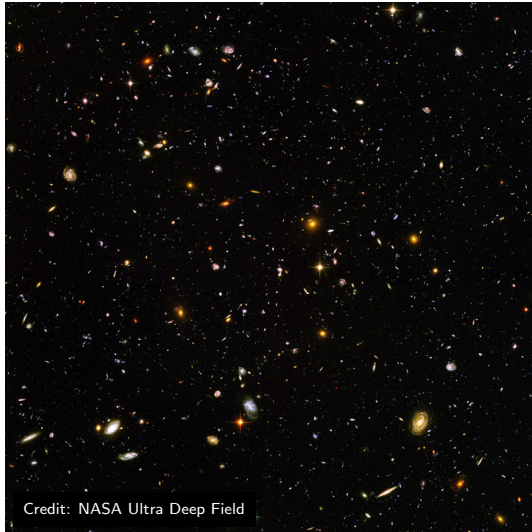
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The Universe is expanding!

- ▶ But what does this actually mean?
- ▶ How do we know it is expanding?
- ▶ Why is it expanding?
- ▶ How fast is it expanding?
- ▶ Are cosmologists completely realistic about the uncertainties in their results?

How do we know?

- ▶ Everywhere we look, distant galaxies are receding; more distant galaxies are receding faster.
- ▶ So either we are at the centre of a cosmic conspiracy, or all the space between all the galaxies is expanding.



Credit: NASA Ultra Deep Field

Is the solar system expanding? Are we expanding?

Go to www.menti.com (code 9850 5737) and choose one possibility:

1. Yes, a lot
2. Yes, but only a tiny amount
3. No

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Is the solar system expanding? Are we expanding?

- ▶ Other forces - molecular forces between the molecules in your body, and gravitational forces between the Sun and the planets - are far more than strong enough to overcome the effect of cosmic expansion.

- ▶ Gravity is even strong enough to keep the Andromeda Galaxy from receding from us.



Credit: David Dayag

- ▶ It's only the furthest objects - where gravity becomes negligible - that recede.

What does *recession velocity* actually mean?

- ▶ We say 'distant galaxies are moving away from us'. This is informal language.
- ▶ They aren't really moving, they just appear to be - because the intervening space is expanding.
- ▶ Sometimes this makes a difference - for example, the recession velocity can exceed the speed of light.

So how fast is the expansion?

- ▶ For every additional distance of one megaparsec, there's an additional recession velocity of about 70 kilometers per second.
- ▶ So the expansion speed is about 70 kilometers per second per megaparsec.
- ▶ One megaparsec is about three million light years. It's the typical distance between galaxies.
- ▶ 70 kilometers per second is about 150,000 miles per hour.

So how fast is the expansion?

Start with:

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Start with:

13.5 million years later:

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Start with:

13.5 million years later:

Continental drift is about six times faster...

H_0

- ▶ The current expansion rate is called the *Hubble constant* or *Hubble parameter* and is denoted ' H_0 '.
- ▶ The ' H ' commemorates Edwin Hubble (1889-1953), who was one of the first to measure it.
- ▶ The ' 0 ' refers to today. The expansion rate was different in the distant past.



Credit: Johan Hagemeyer

Who first had the idea that the Universe is expanding?

Go to www.menti.com (code 9850 5737) and choose one possibility:

1. Erwin Rommel
2. Edwin Hubble
3. Edgar Allan Poe

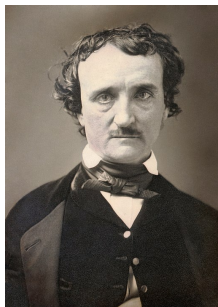
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History

- ▶ In 1848 Edgar Allan Poe published *Eureka*, which included a description of expanding space.



Credit: Public domain

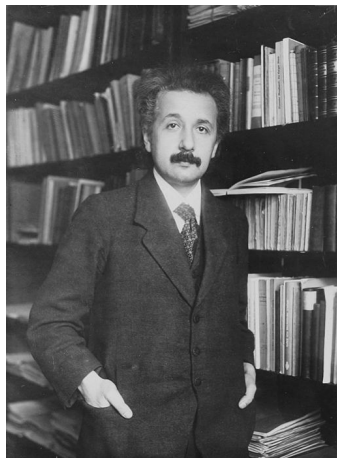
- ▶ Expansion is not obvious without large telescopes and so isn't usually part of pre-modern cosmologies. Full understanding only came in the 20th century.

Why does the Universe expand?

- ▶ Science is not so good with 'why?' questions...
- ▶ There's an *initial condition*: the Universe started expanding at the Big Bang.
- ▶ The later behaviour of the expansion (does it slow down? speed up?) then depends, essentially via gravity, on *what's in the Universe*.

Why does gravity play a role?

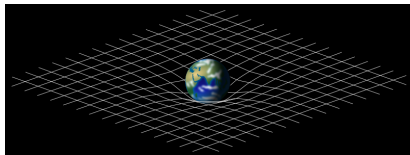
- ▶ *General relativity*, our modern theory of gravity, is due to Einstein (1916).



Credit: Paul Ehrenfest

Why does gravity play a role?

- ▶ Remember *mass* and *energy* are the same ($E = mc^2$).
- ▶ Mass/Energy *bends* spacetime, essentially changing distances and angles.



Credit: Mysid

Why does gravity play a role?

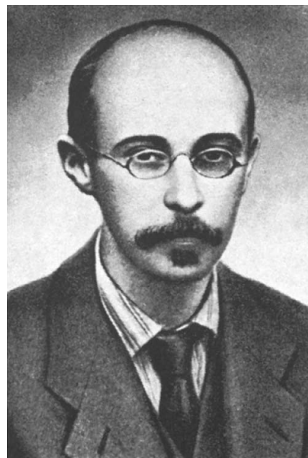
- ▶ This 'changing of distances and angles' works locally; the distorted spacetime governs how objects move, and this leads e.g. to the apple falling from the tree.

Why does gravity play a role?

- ▶ This 'changing of distances and angles' works locally; the distorted spacetime governs how objects move, and this leads e.g. to the apple falling from the tree.
- ▶ But it also works on the Universe as a whole - mass/energy can cause distances to change *everywhere* in the Universe - and in particular can lead to increasing distances everywhere. This is the expansion that we see.

Contents of Universe control expansion

- It was Alexander Friedmann (Алекса́ндр Алекса́ндрович Фри́дман) (1888-1925) who first realised this (1922).



Credit: Public domain

What if we go backwards in time?

- ▶ George Lamaître (1894-1966) realised that if the Universe was expanding then it must, at an earlier stage, have been very small; he thereby invented the idea of the 'Big Bang'.



Credit: Public domain