

The Constantly Changing Hubble Constant

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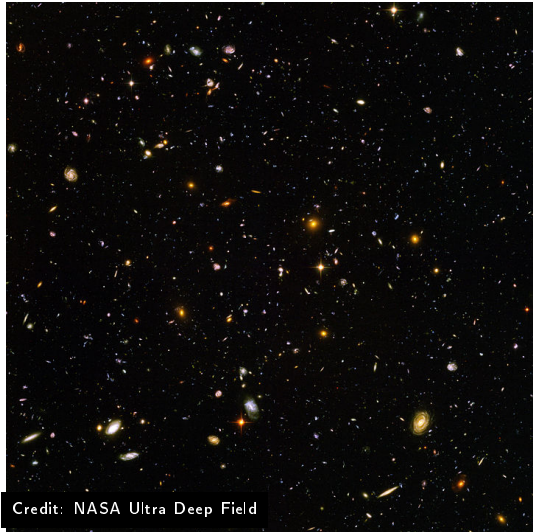
You are invited to go to www.menti.com and enter code
14 11 05 9.

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 14 11 05 9) 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.

Which 'Ed' first had the idea that the Universe is expanding?

Go to www.menti.com (code 14 11 05 9) and choose one possibility:

1. Edmond Halley
2. Edwin Hubble
3. Edgar Allan Poe

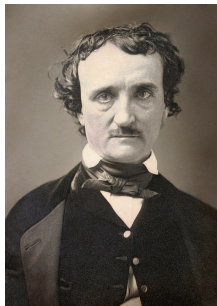
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History

- ▶ 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.

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.

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13.5 million years later it will be 1% longer:

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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.



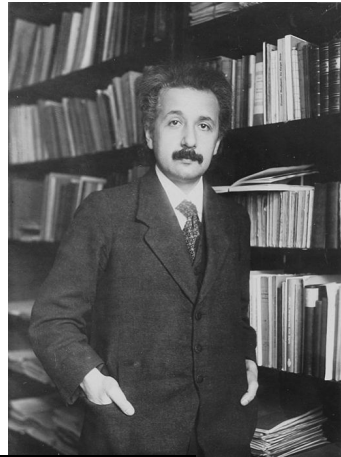
Credit: Johan Hagemeyer

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?

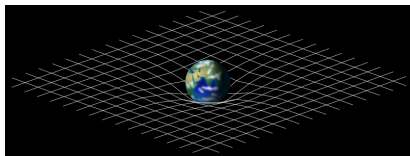
- ▶ *General relativity*, our modern theory of gravity, is due to Einstein (1916).



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?

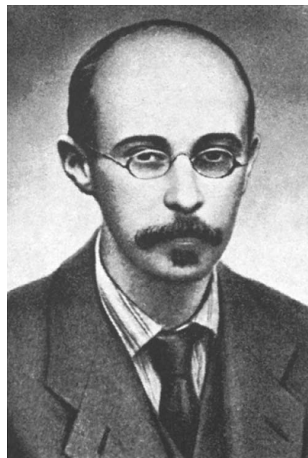
- ▶ This 'changing of distances and angles' works locally; the distorted spacetime governs how objects move, and this leads e.g. to the apple falling from the tree.

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 Lemaître (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

How do we measure the expansion rate?

- ▶ In theory it's easy: find a distant galaxy, measure its recession velocity and its distance, and take the ratio.
- ▶ Example: a galaxy is receding at 1600 kilometers per second and is 20 megaparsecs away;
then H_0 is 80 kilometers per second per megaparsec.

For a distant galaxy, which is harder to measure?

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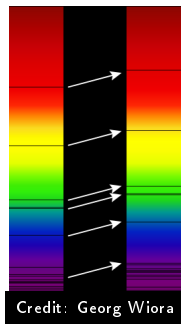
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Can use redshift to measure recession velocity

- ▶ Light from distant galaxies gets streeeetched by the expansion; this makes it turn redder.
- ▶ It's fairly easy to measure the amount of red-shifting, as spectral lines are a convenient reference point. The redshift then immediately gives the velocity.



Where to find the document

- ▶ You can find the presentation at
<https://tinyurl.com/bycke8v6>

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