

The future of the Universe



THE UNIVERSITY OF
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Government of Western Australia
Department of Education

The future of the Universe

The future of the Universe will be determined by the struggle between the momentum of its expansion and the pull of gravity.

Some say the world will end in fire,
Some say in ice.

Robert Frost (1920)

If you left your classroom and walked, climbed and swam in a straight line as far as possible, where would you end up?

After about 40 000 km, you would return to your starting place because the surface of the Earth is curved.



'Sunburst over Earth' by NASA
http://commons.wikimedia.org/wiki/File:Full_Sunburst_over_Earth.JPG

If you left Earth and travelled in a straight line as far as possible, where would you end up?

Cosmologists aren't sure.

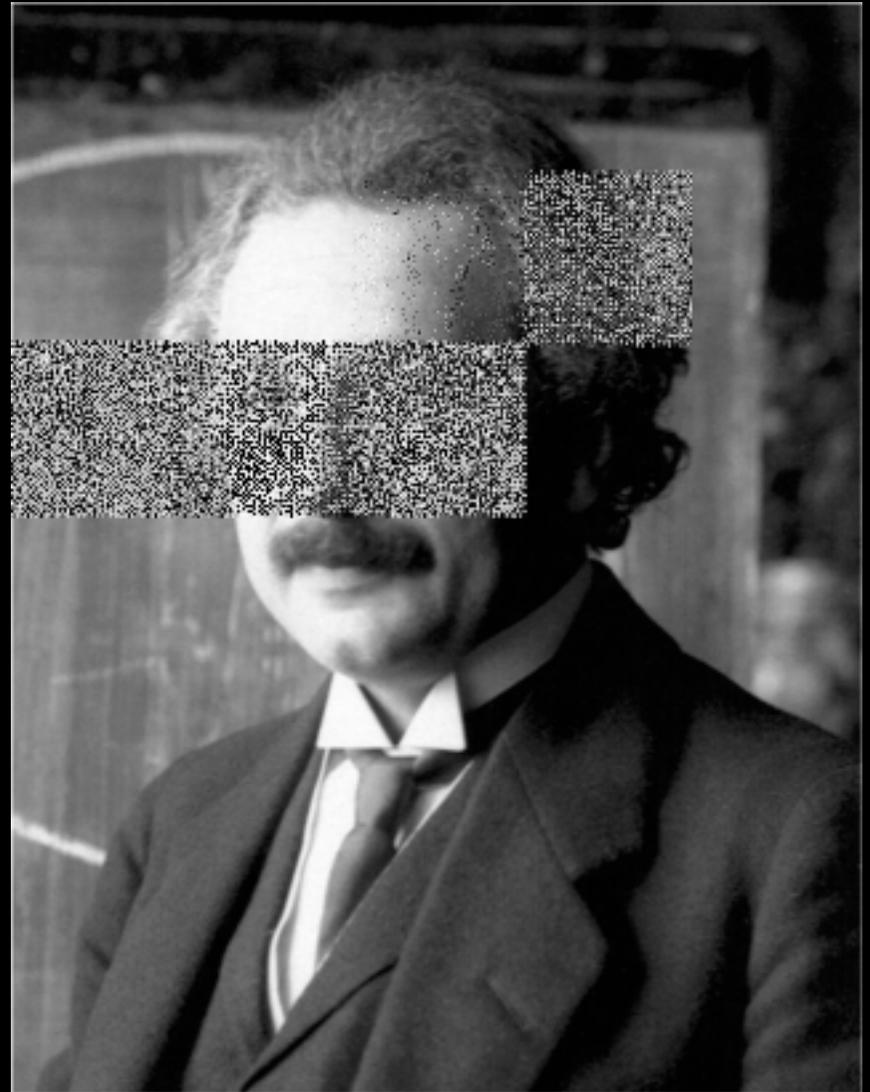
Some believe you can travel an infinite distance; others think you would end up back where you started.

It depends on the shape of the Universe.



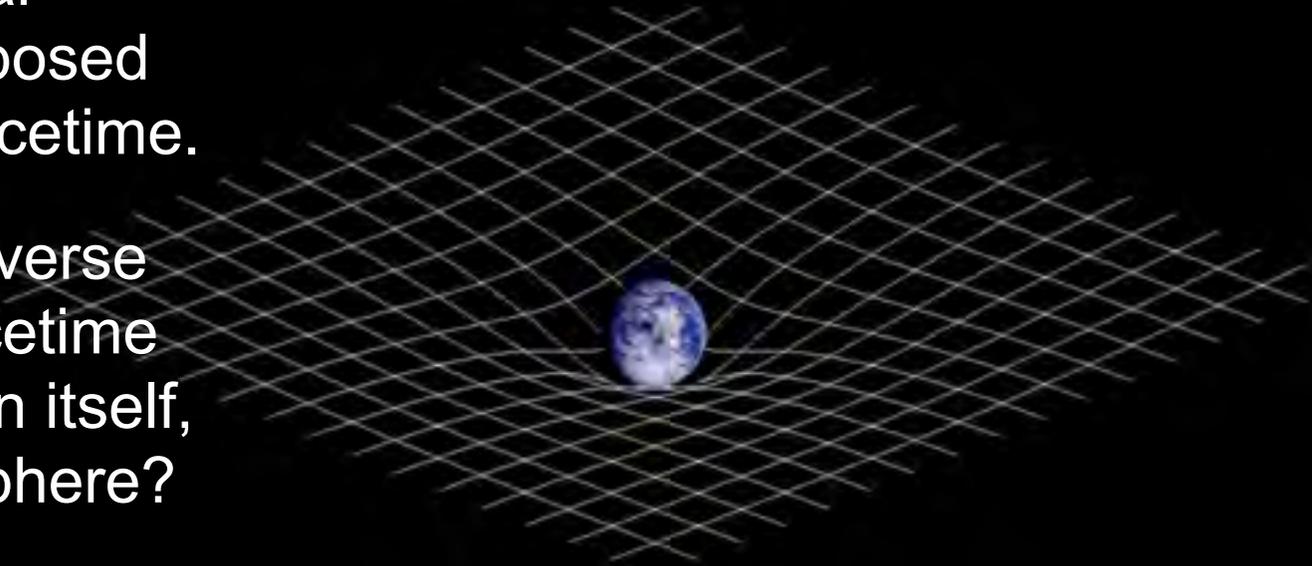
Curvature of space

- In the theory of general relativity, Einstein proposed that mass distorts spacetime.



Curvature of space

- In the theory of general relativity, Einstein proposed that mass distorts spacetime.
- Is the mass of the Universe enough to distort spacetime and make it close in on itself, like the surface of a sphere?
- Or will gravity stop the Universe expanding?



Predicting the future of the Universe

The future of the Universe depends on the density of matter and the effect of gravity on it.

So if we know its density we should be able to predict the shape and future of the Universe.

Our predictions are based on two major assumptions:

- the laws of physics are the same everywhere in the Universe, and
- the part of the Universe that we can see is typical of the whole Universe.

Critical density

- Critical density is the average density of matter required for the Universe to just halt its expansion
- but only after an infinite time.
- The critical density of the Universe is about 10^{-26} kg m⁻³
(approximately equal to 6 hydrogen atoms per cubic metre).
- This amazingly low value is more than ten million times lower than the density of the best vacuum ever achieved on Earth.

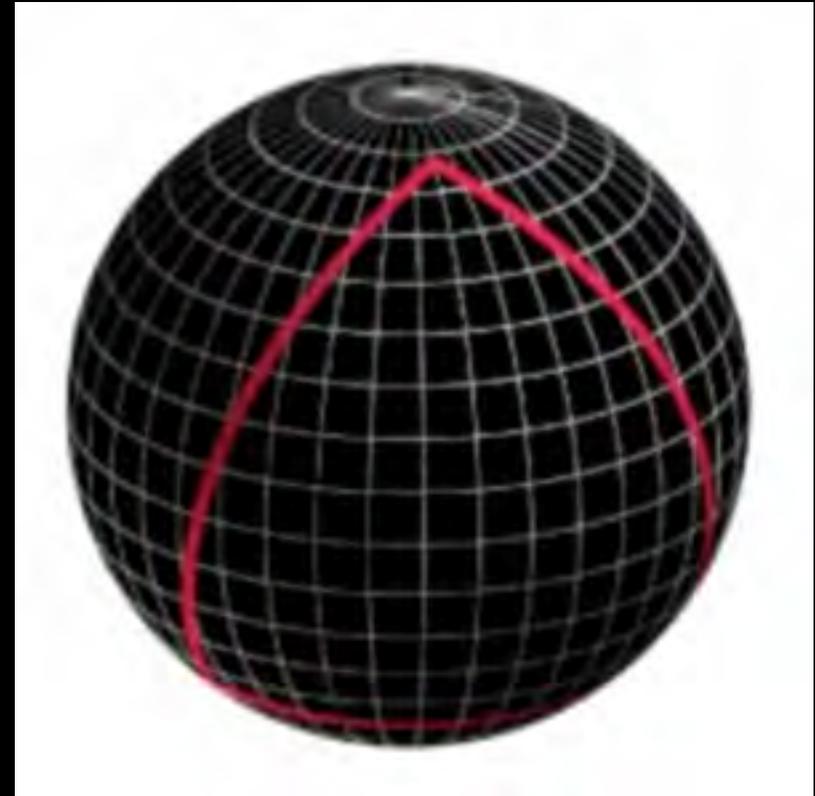
The future of the Universe

- There are three possible scenarios depending on how the density of the Universe compares to its critical density.
- The future of the Universe will be determined by the balance of its Big Bang expansion and the effect of gravity on its mass.
- Predict the outcome if the Universe is ...
 - more dense than critical density ...
 - less dense than critical density ...
 - equal to critical density ...

Scenario 1: closed Universe

If the density of the Universe is **greater than** critical density:

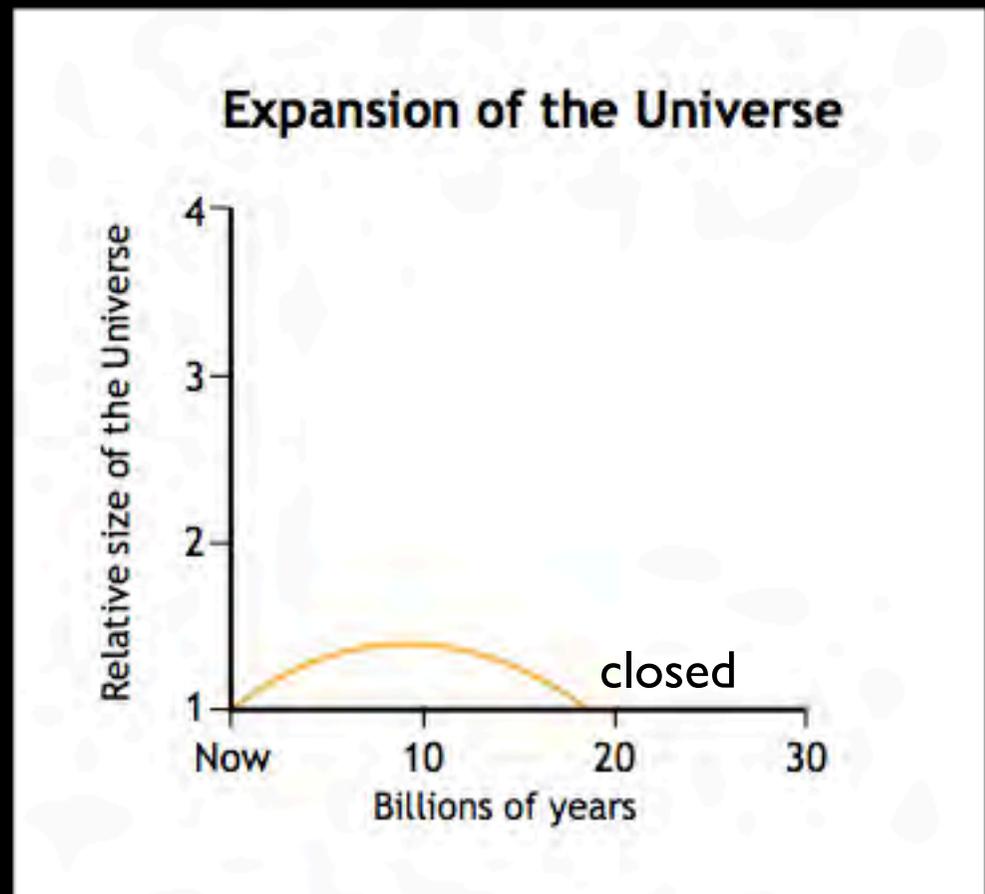
- gravity will be strong enough to stop its expansion and reverse it; and
- the Universe (spacetime) may be thought of as **closed**, like the surface of a sphere.



Future of a closed Universe

Eventually, gravity will cause a closed Universe to collapse back in on itself, ending in the 'Big Crunch'.

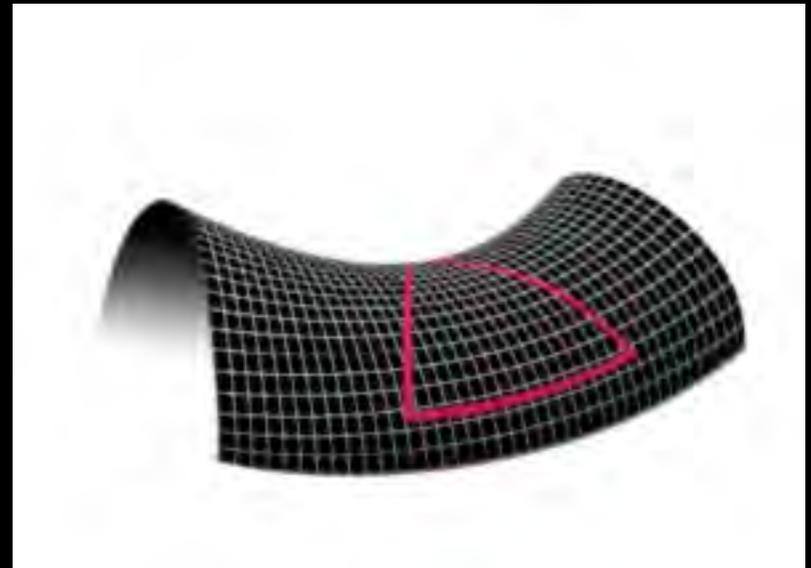
The orange curve represents the evolution of a closed Universe.



Scenario 2: open Universe

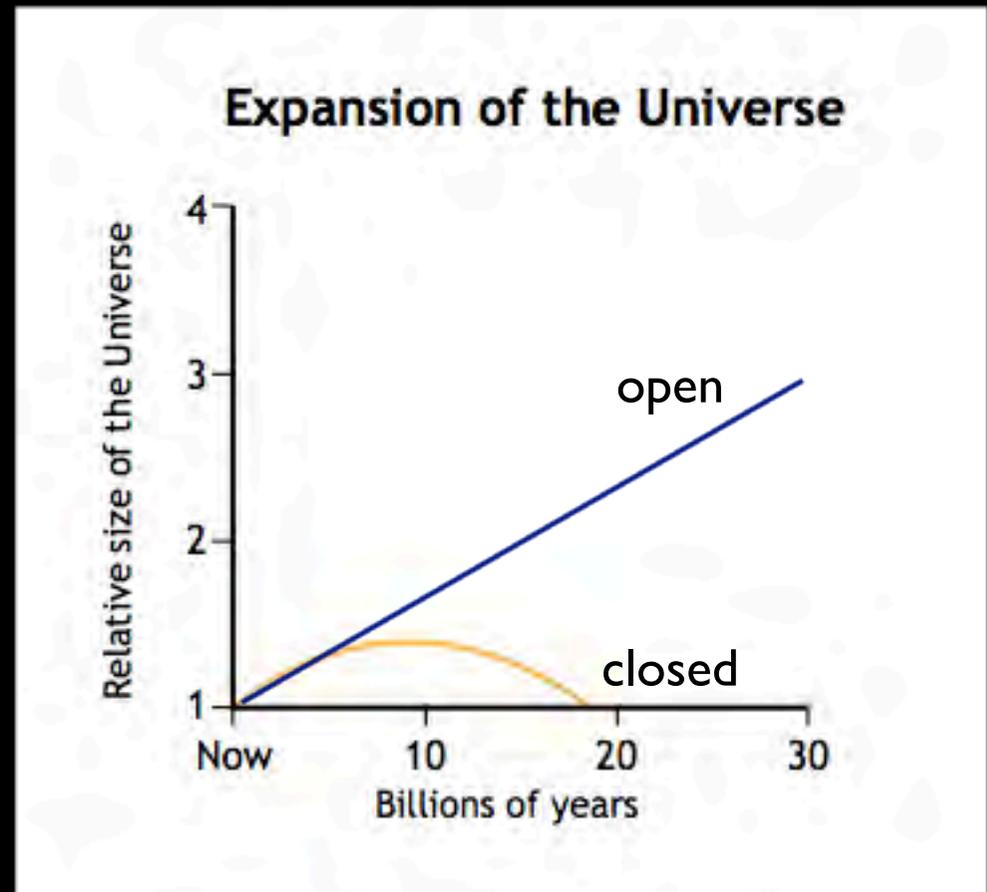
If the density of the Universe is **less than** critical density:

- gravity will be too weak to stop its expansion;
- the Universe will continue to expand forever at an ever-decreasing rate; and
- the Universe (spacetime) can be thought of as being **curved** like the surface of a saddle.



The future of an open Universe

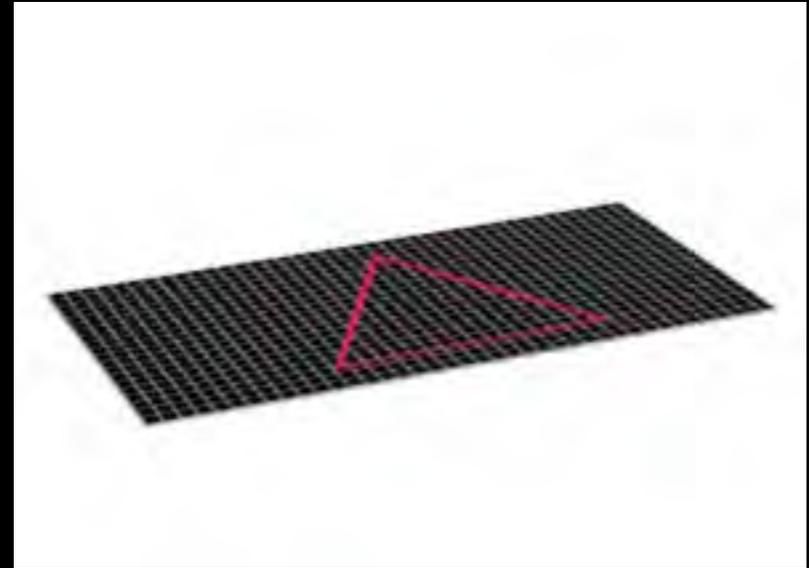
- As the Universe continues to expand, all stars and galaxies will exhaust their energy.
- The Universe will cool down, ending in the 'Big Chill'.
- The blue curve represents the evolution of an open Universe.



Scenario 3: flat Universe

If the density of the Universe is **equal to** critical density:

- gravity is just sufficient to stop its expansion – but only after an infinite time; and
- the Universe (spacetime) can be thought of as being **flat**.

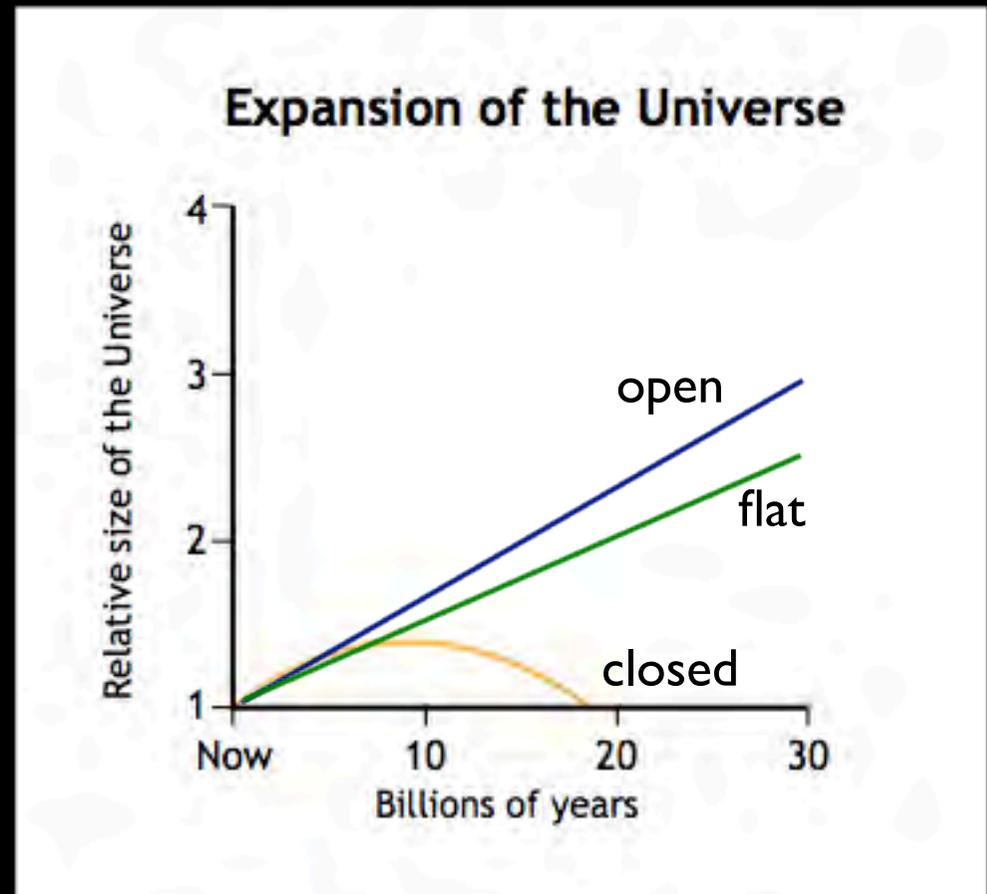


The future of a flat Universe

A flat Universe will also continue to expand at an ever-decreasing rate (but slower than an open Universe).

The green curve represents the evolution of a flat Universe.

Most cosmologists favour this as the predicted future of the Universe.



Which prediction is most likely?

- To make a reliable prediction about the shape and future of the Universe, cosmologists need to know its density.
- To do this, they need to know what the Universe is made of.
- They knew that it contained matter and radiation, but that wasn't all...

The missing mass problem

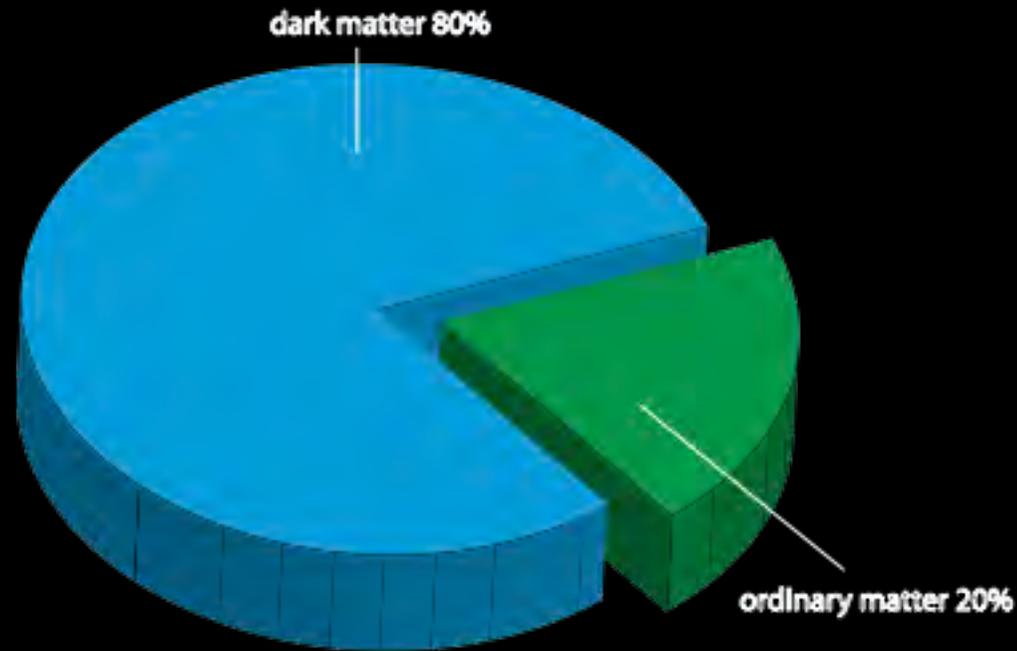
- In 1933, astronomer Fritz Zwicky studied the motions of galaxies near the outer edges of distant galaxy clusters.



The missing mass problem

- In 1933, astronomer Fritz Zwicky studied the motions of galaxies near the outer edges of distant galaxy clusters.
- He found they were rotating too fast for the visible mass of the cluster to stop them from flying away.
- He deduced that the cluster must have more mass, but it wasn't visible matter.

The missing mass problem

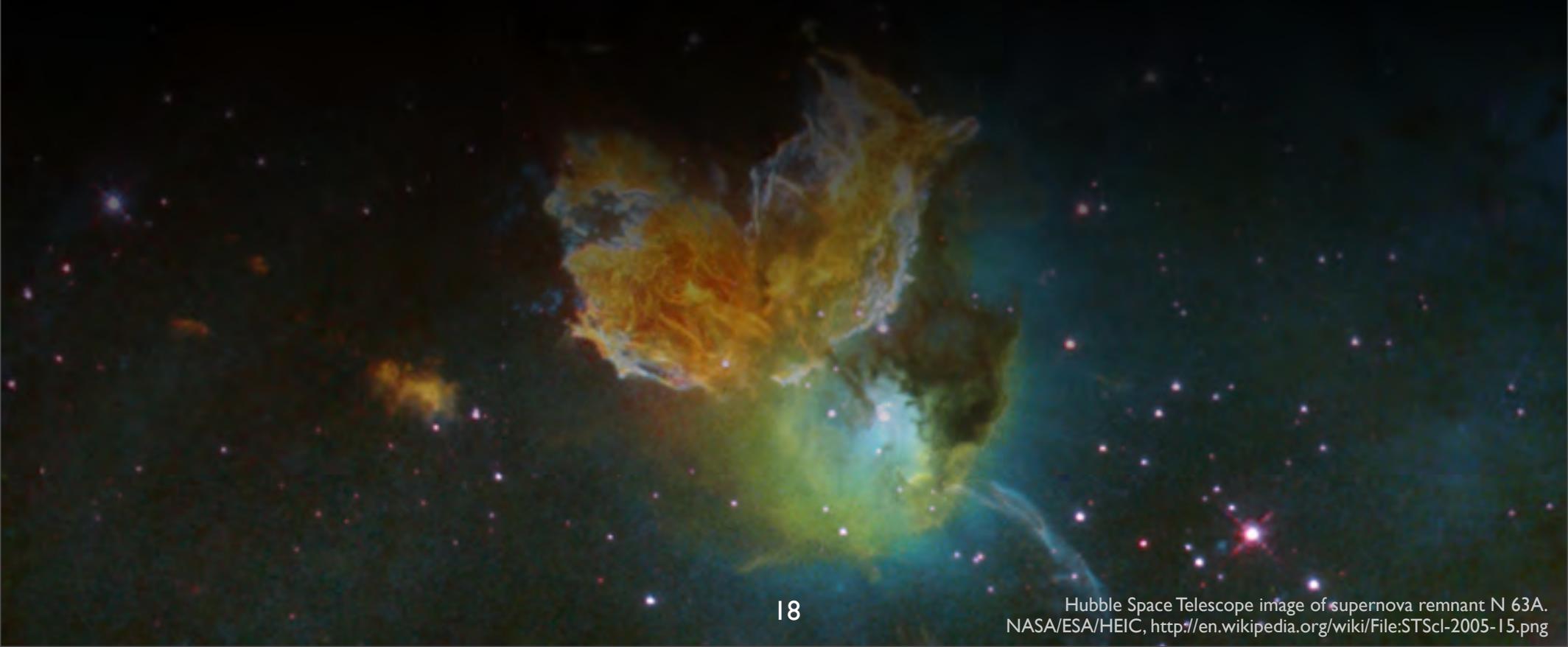


Dark matter

- By the 1970s, cosmologists began to realise that only large amounts of Zwicky's 'missing mass' could explain many of their observations.
- We now call the missing mass **dark matter**.
- Scientists are searching for dark matter to explain the motion of galaxies and to inform current theories about the origin and the future of the Universe.

Dark energy

- In the 1990s, astronomers found evidence that the **Universe is expanding at an accelerating rate.**
- To explain this, they introduced the idea of dark energy.

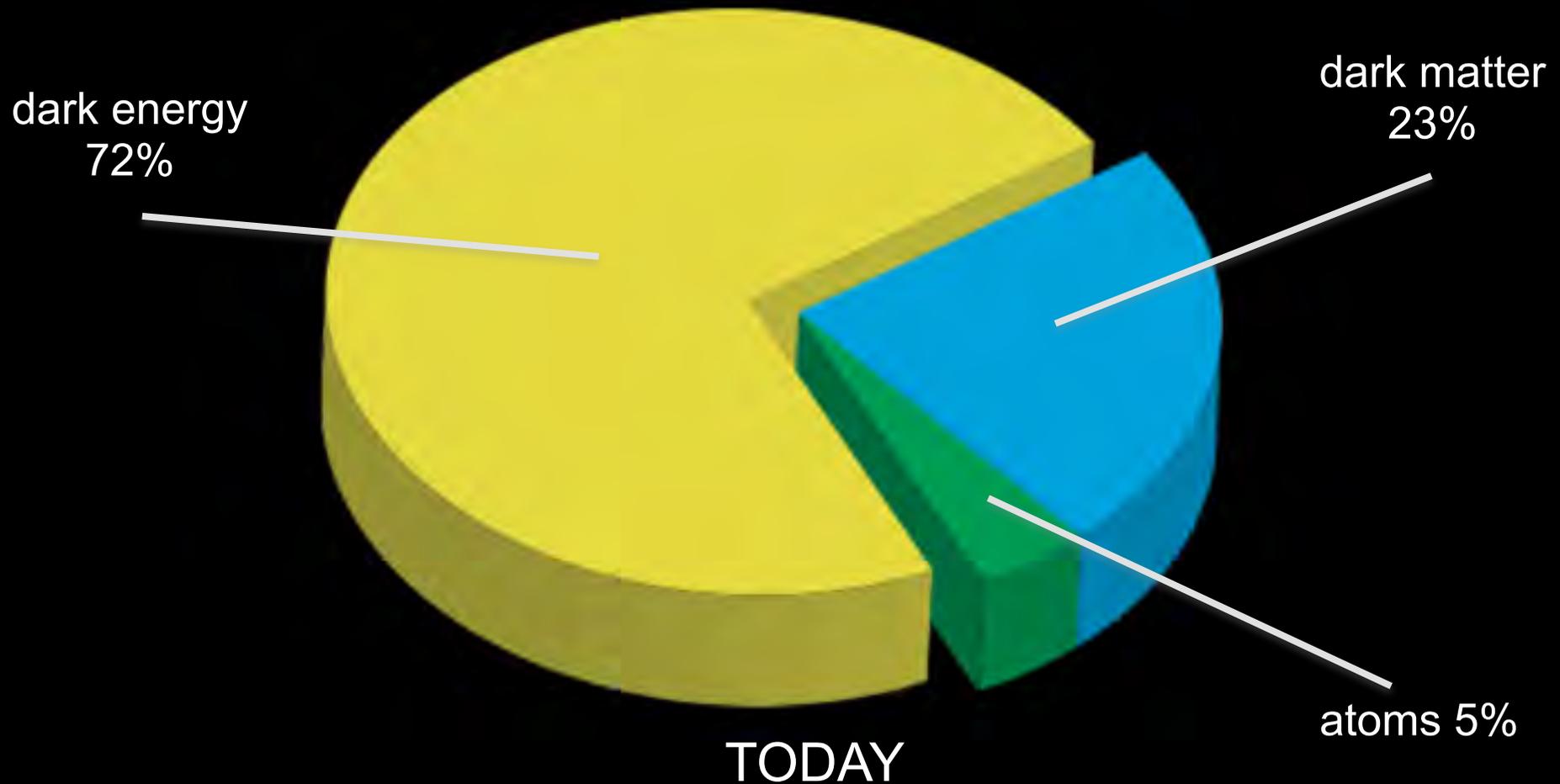


Dark energy

- Unlike gravity, which slows the expansion of the Universe, dark energy speeds it up.
- Dark energy is thought to have a gravitationally repulsive effect on matter.
- Dark energy will make the Universe expand exponentially forever, and its effects appear to increase as the Universe expands.
- Dark energy accounts for 72% of the mass of the Universe, but cosmologists are not agreed on what it really is.

Total mass-energy of the Universe

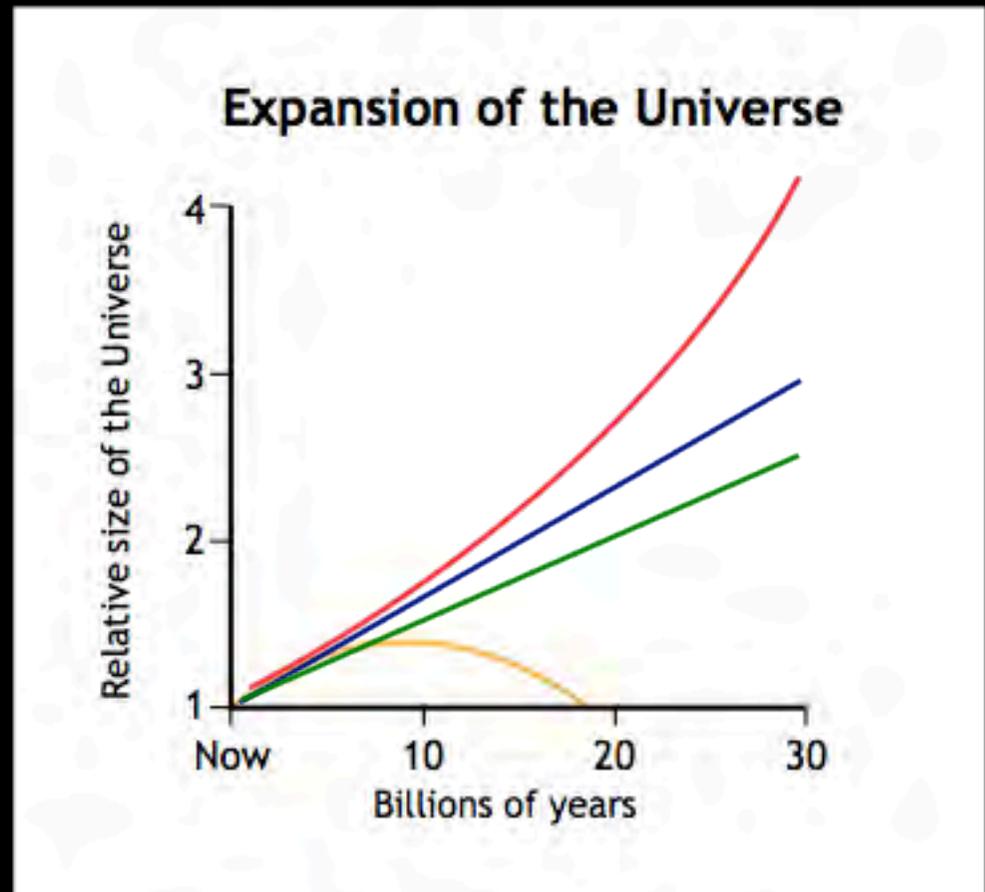
Cosmologists now believe that the composition of the Universe is:



Scenario 4

If the Universe is expanding at an accelerating rate (the red curve on the graph):

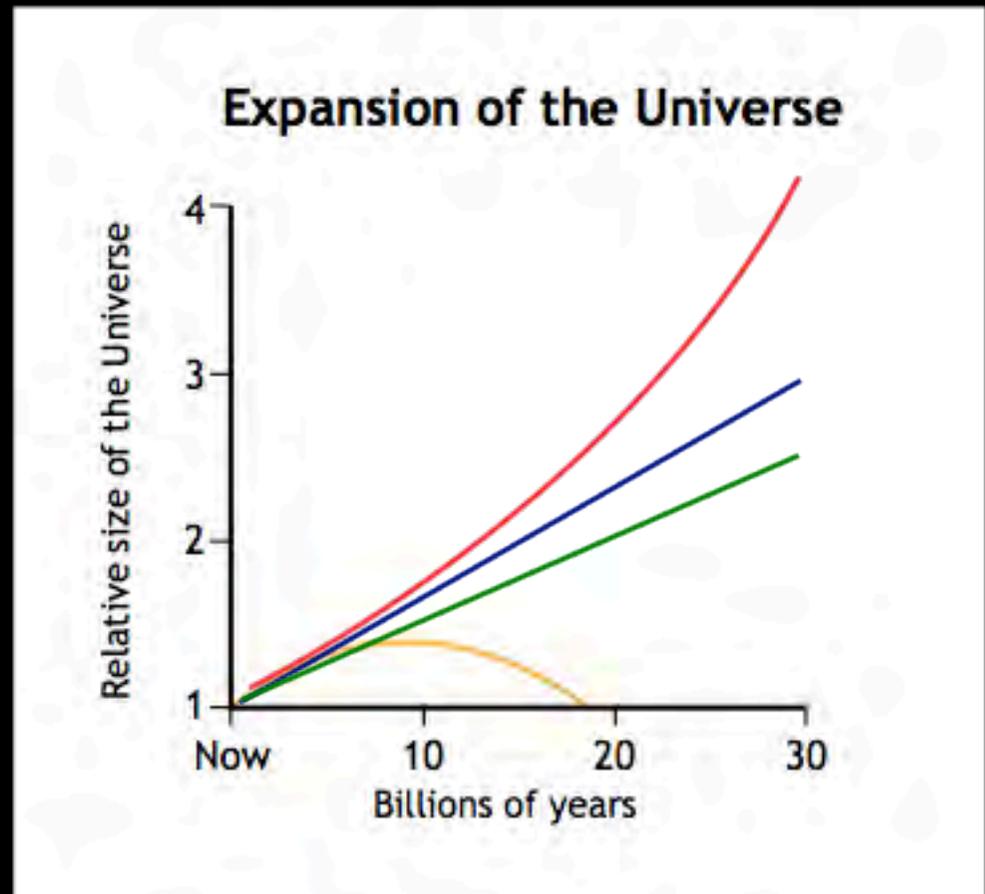
The galaxies we now see will recede out of sight, one by one.



Scenario 4

If the Universe is expanding at an accelerating rate (the red curve on the graph):

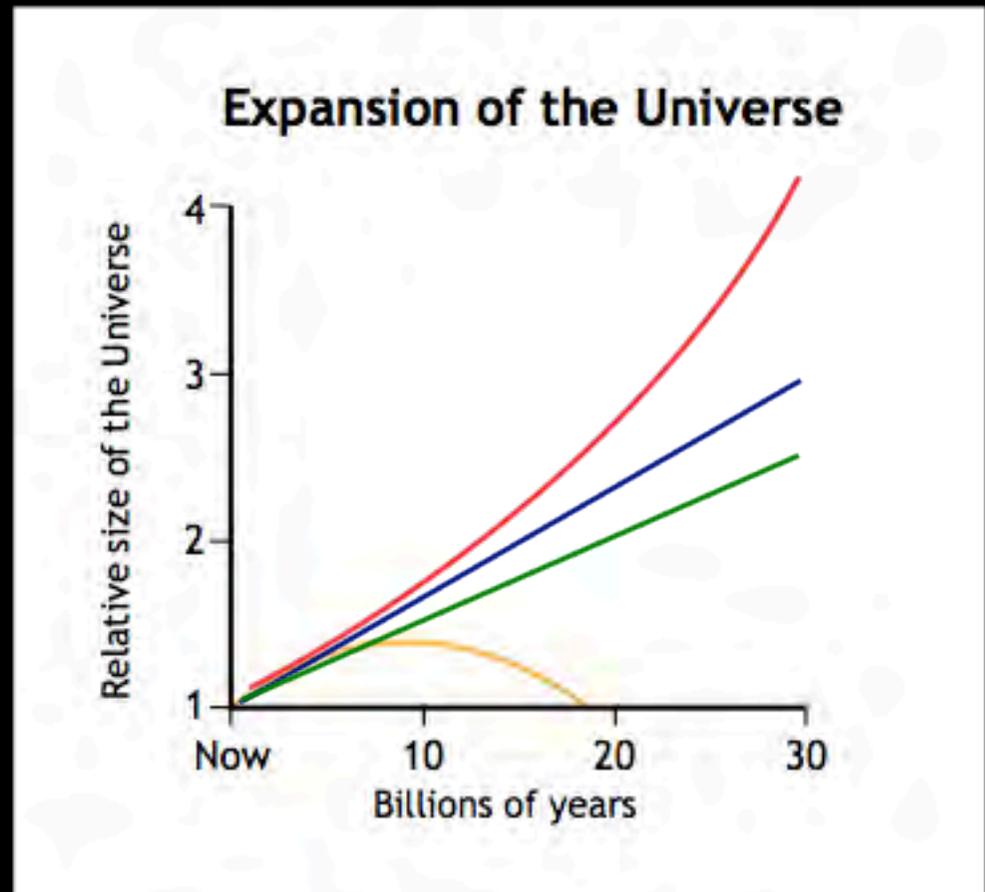
Billions of years from now, the Milky Way will be the only galaxy in sight.



Scenario 4

If the Universe is expanding at an accelerating rate (the red curve on the graph):

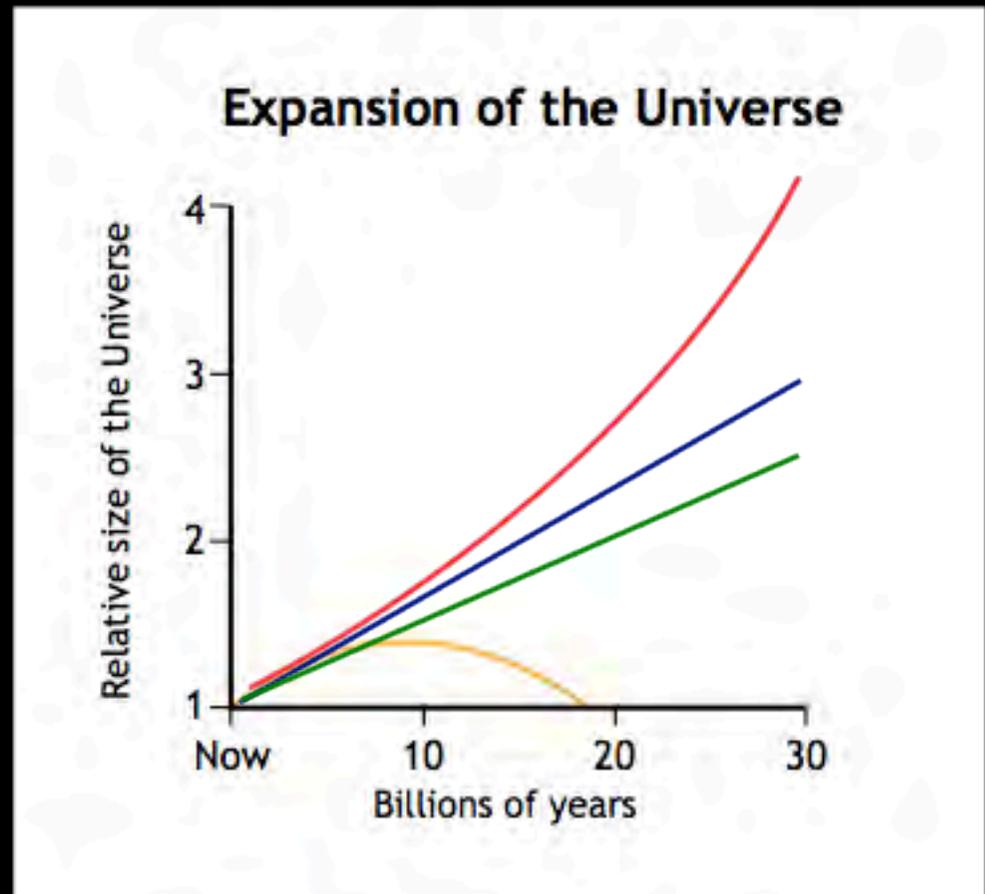
Our Sun will have shrunk to a white dwarf star that will provide little light and heat to Earth.



Scenario 4

If the Universe is expanding at an accelerating rate (the red curve on the graph):

Stars will burn out and collapse into black holes and the Universe will end up as a vast, empty, dark and cold place.



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