So what is cosmology?
So what is cosmology?

The study of the Universe on large scales to determine its origin, evolution and, ultimately, fate…
So what is cosmology?

The study of the Universe on large scales to determine its origin, evolution and, ultimately, fate…

Or, to misquote Douglas Adams;

*Not much about Life, mostly it’s the Universe and Everything in it*
Powers of Ten
What do we know of the Universe?
What do we know of the Universe?

The Universe is expanding
What do we know of the Universe?

The Universe is expanding

The Universe is made of Dark Matter, Dark Energy and Baryons (atoms)
What do we know of the Universe?

The Universe is expanding

The Universe is made of Dark Matter, Dark Energy and Baryons (atoms)

The Universe is flat
What do we know of the Universe?

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The Universe is 13.8 billion years old
What do we know of the Universe?

The Universe is expanding

The Universe is made of Dark Matter, Dark Energy and Baryons (atoms)

The Universe is flat

The Universe is 13.8 billion years old

So how did we discover these facts?
The expanding Universe…

How do we know it’s expanding?
H + e-
The expanding Universe…
The expanding Universe…
The expanding Universe…
The expanding Universe…

At rest

Away

Faster…
The expanding Universe... Hubble

The expanding Universe... Hubble

\[ V = H_0 D \]
The expanding Universe... Hubble

We can determine the age of the Universe using $H_0$
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The Hubble time $t_H = 1/ H_0$
The expanding Universe… Hubble

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The Hubble time $t_H = 1/ H_0 \sim 1/ 70 \text{ [km/s /Mpc]}$
The expanding Universe... Hubble

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$\sim 13.8\ \text{billion years}$
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The expanding Universe... Hubble

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(However space has expanded during this time so the observable Universe is actually larger)
The expanding Universe… Hubble

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$\sim 13.8$ billion years

The Universe size is $\sim c \ t_H$

$\sim 13.8$ billion light years

(however space has expanded during this time so the observable Universe is actually larger)

What happens if $H_0$ is wrong…?
The expanding Universe... Hubble

If we go back in time, we see that all galaxies originate from a point of near zero size.
The expanding Universe… Hubble

If we go back in time, we see that all galaxies originate from a point of near zero size

Leads to a prediction of infinite density and temperature in the Early Universe…
The expanding Universe… Hubble

If we go back in time, we see that all galaxies originate from a point of near zero size.
ATOMS

Image credit: NASA/ HST
DARK MATTER
DARK MATTER
DARK MATTER
DARK ENERGY
Further away (dimmer) than expected
Cosmological Constant $\Lambda$
Current contents of the Universe

- Dark Energy: 74%
- Dark Matter: 22%
- Atoms: 4%
During inflation, the Universe expands exponentially, enlarging quantum fluctuations to size of the Universe. Afterwards, scales re-enter as the Universe expands…

Image credit: NASA/ WMAP Science Team
The fluctuations can be studied

Image credit: NASA/WMAP Science Team
Power spectrum signal as a function of scale; \( l = 180^\circ / \theta_{\text{obs}} \)
Hot plasma supports soundwaves
So how do we know what size the blobs are meant to be?
The first peak is a wave that just fits within the horizon…
For scales larger than the Universe nothing can collapse so flat
The Shape of the Universe

\( \Omega_0 > 1 \)

\( \Omega_0 < 1 \)

\( \Omega_0 = 1 \)

Image credit: NASA/ WMAP Science Team
The Shape of the Universe

Closed: \( \Omega_0 > 1 \)
Open: \( \Omega_0 < 1 \)
Flat: \( \Omega_0 = 1 \)

Image credit: NASA/ WMAP Science Team
The Shape of the Universe

BOOMERANG
The Shape of the Universe

Closed

Flat

Open

BOOMERANG
The Shape of the Universe

BOOMERANG

Flat
With thanks to Craig Booth

\[ Z = 12.9 \]
What’s the age..? 2 or 14 billion years old
Λ-CDM Cosmology

What’s the age..?  13.8 billion years old
Λ-CDM Cosmology

What’s the age..? 13.8 billion years old

Shape of the Universe..? Open, Closed or Flat
Λ-CDM Cosmology

What’s the age..? 13.8 billion years old

Shape of the Universe..? Flat
Λ-CDM Cosmology

What’s the age..? 13.8 billion years old

Shape of the Universe..? Flat

Dominant component..? Atoms, Dark Matter, Dark Energy
Λ-CDM Cosmology

What’s the age..? 13.8 billion years old

Shape of the Universe..? Flat

Dominant component..? then..? Dark Energy Dark Matter or Atoms
**Λ-CDM Cosmology**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>What’s the age..?</td>
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Λ-CDM Cosmology

Yet we’ve never known so little about our Universe
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96% of the Universe is ‘Dark’, i.e. unknown.
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Will the Universe continue expanding forever?
It depends if Einstein was right…
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Maybe even General Relativity is wrong…
Thanks – questions?