

Why is the Night Sky Dark?

'Cosmology'

- Studies of the universe as a whole...

Today...

- Brief history of ideas (Early Greeks → **Big Bang**)
- The **expanding** universe (Hubble, Relativity, density & destiny)
- An alternative theory: The 'Steady State' model



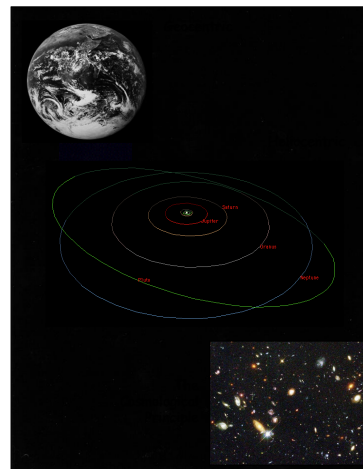
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A brief history of Ideas...

Are we in a special place?

- Early Greeks (BC)
 - 'Geocentric' - Earth centred
- Copernicus (1543 AD)
 - 'Heliocentric' - Sun centred
- Newton (1600s AD)
 - Governed by law of gravity
- From Newton on (1600s → now)
 - We're NOT in a special place.
 - The universe looks the same from everywhere and in all directions ('**Cosmological Principle**').



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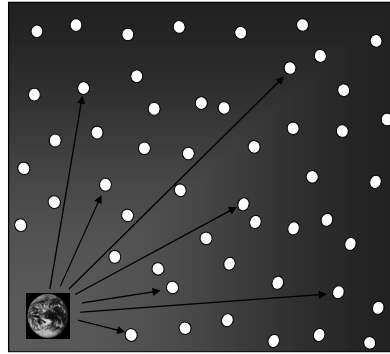
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A brief history of Ideas...

Why is the night sky dark?

Olbers' Paradox

- Pre-1930's the universe was widely thought to be infinite, eternal and static...
- But if so...
 - 'Why is the night sky dark?'
(Heinrich Olbers ~ 1800's AD)
- Expect:
 - Sky as bright as surface of average star!
 - Overall temperature of sky > 3000K!
- Something is WRONG!



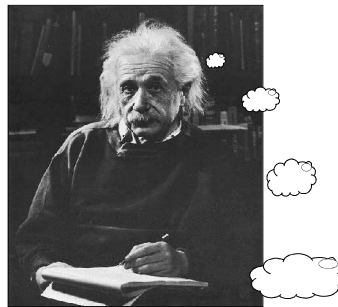
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A brief history of Ideas...

Einstein's Universe

- Special & General Relativity (Early 1900s)
 - Revolutionary new descriptions of space, time, gravity and the universe.
- Einstein's model of the Universe assumed:
 - The Cosmological Principle
 - The universe is **STATIC**
- He invented the cosmological constant (Λ) to allow static universe in General Relativity
 - Note that he could have predicted expansion!



$$H^2 = \frac{8\pi G}{3}\rho - \frac{\kappa}{R^2} + \frac{\Lambda}{3}$$

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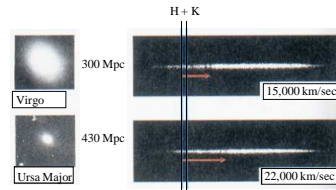
A brief history of Ideas...

Hubble's Expanding Universe!

- 1929 -Edwin Hubble's analysis of light spectra of distant galaxies revealed the universe is

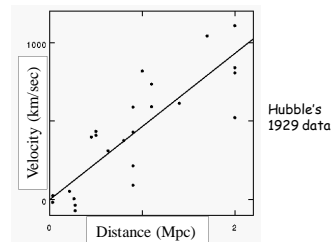
expanding...

- Doppler effect shows:
Redshift \propto Velocity
- Hubble's Law:
Velocity \propto Distance



- Einstein concedes: The universe IS expanding.

- The introduction of Λ was his "greatest blunder"!



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A brief history of Ideas...

Current Thinking: The Big Bang

The universe is expanding & cooling after an initial 'explosion' ~14 billion years ago.



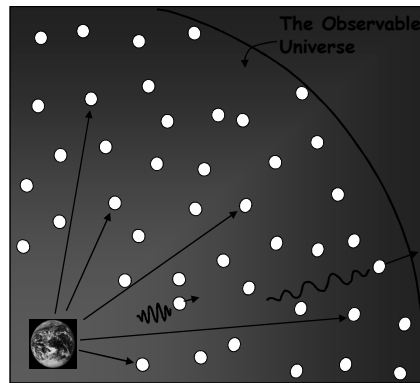
Next lecture - 'The 1st 400,000 years'

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How does the Big Bang theory solve Olbers' paradox?

- Olbers' paradox assumes the Universe is Infinite, Eternal and Static.
1. The Big Bang universe is NOT eternal.
 - So the observable universe is not infinite.
 2. The Big Bang universe is NOT static.
 - Light from distant objects cools as the universe expands



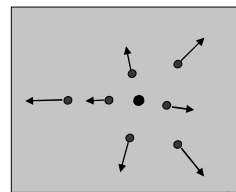
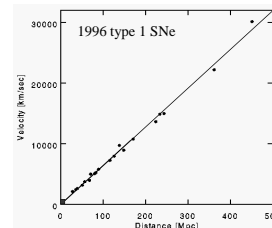
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The Expanding Universe

Hubble's findings revisited.

- Modern measurements of distant galaxies confirm Hubble's findings
 - Hubble's Law: $V = H_0 \times D$
 - H_0 = Hubble's Constant
 - Recent estimates:
 $H_0 \sim 70 \text{ km.s}^{-1}.\text{Mpc}^{-1}$
- Does Hubble's law go against the cosmological principle?
 - No - the appearance of everything receding from US would be the same anywhere..



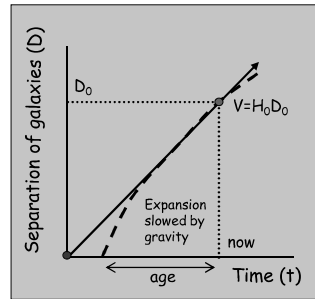
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The expanding universe...

The age of the universe

- Hubble's law can be used to calculate the age of the universe:
 - If expansion (V) is constant:
 $\text{Age} = D_0/V$
 $= 1/H_0$
 - If $H_0 \sim 70 \text{ km.s}^{-1}.\text{Mpc}^{-1}$
Age ~ 14 billion years
- Age is less if expansion is slowed by gravity
 - With $\Lambda=0$, would expect age ~ 9 billion years
 - (With $\Lambda>0$, age goes back to ~ 14 billion years - see later)



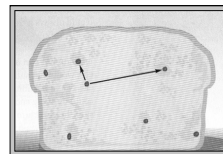
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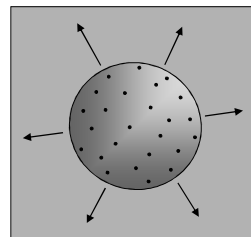
The expanding universe...

What does the expansion look like?

- Not like a normal explosion
- Not IN a particular place AT a particular time.
 - Big bang thought to be the beginning of time itself.
 - Expansion OF space not WITHIN space.
- Hard (very hard) to visualise.



Raisins in bread analogy



Surface of balloon analogy

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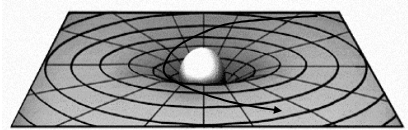
The expanding universe...

Einstein's Relativity

Special Relativity (1905)...

Concerns motion, space, time & the speed of light.

- The speed of light (c) is always constant ($3 \times 10^8 \text{ m s}^{-1}$)
- Nothing can go faster than c .
- Space & time are not independent.
- Mass & energy are related: $E = mc^2$



General Relativity (1915)...

Concerns motion, space-time, gravity and mass.

- Mass WARPS Space-time.
- Warping perceived as gravity

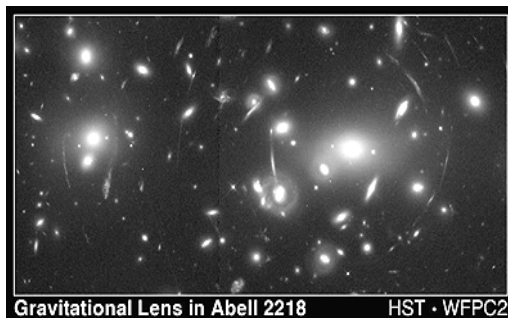
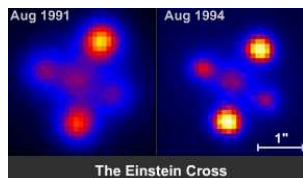
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The expanding universe...

Evidence for General Relativity

- General Relativity predicts light is bent by massive objects



'Gravitational Lensing'

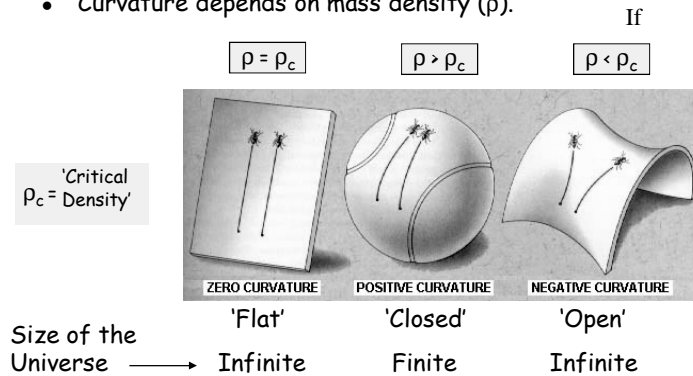
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The expanding universe...

Curvature of the Universe

- General relativity says:
 - Space-time in the universe is *CURVED!*
 - Curvature depends on mass density (ρ).



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The expanding universe...

What about the future?

- But...
 - BEWARE OF THE COSMOLOGICAL CONSTANT!
- (See later!)

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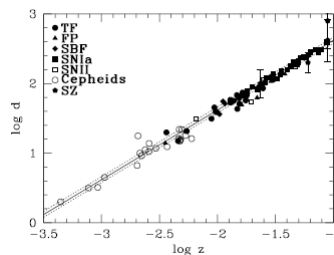
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Summary so far...

- Brief history of ideas..
 - The Cosmological Principle: The universe looks the same in all directions and in any location.
 - Olbers' Paradox: If the universe is infinite, eternal and static - 'Why is the night sky dark?'
 - Now believe the universe is in a state of expansion and cooling after an initial 'Big Bang' ~14 billion years ago.

Summary so far...

- The expanding universe:
 - Distant objects are receding according to Hubble's law ($V=H_0D$).
 - The Big Bang is not like a normal explosion.
 - ◆ Expansion OF (not WITHIN) space
 - ◆ Big bang = beginning of time
 - Einstein's Relativity describes gravity, space, time and the structure of the universe.
 - The Age and Fate of the universe dependant on density (ρ)



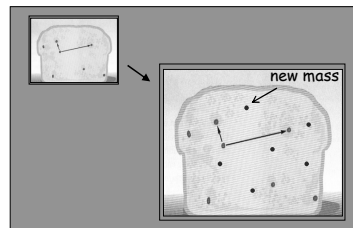
An alternative model?

The Steady State Model

- So far we know...
 - Distant objects receding according to Hubble's Law
 - Structure of universe described by General Relativity.
- Is the Big Bang the only Model that fits?
- The Steady State Model...
 - There was no big bang
 - The universe has always looked same as it does now.
 - It is infinite but expanding
 - Mass is created as space expands



Fred Hoyle (1915-2001)



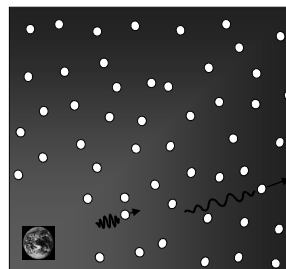
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An alternative model?

The Steady State Model

- Does the Steady State model also solve Olbers' Paradox?
 - Yes... Light is cooled by expansion
- Big Bang or Steady State?
 - Any evidence for change over time?
 - Any evidence for hot beginnings?



3rd lecture - 'Vital statistics of the Universe'

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