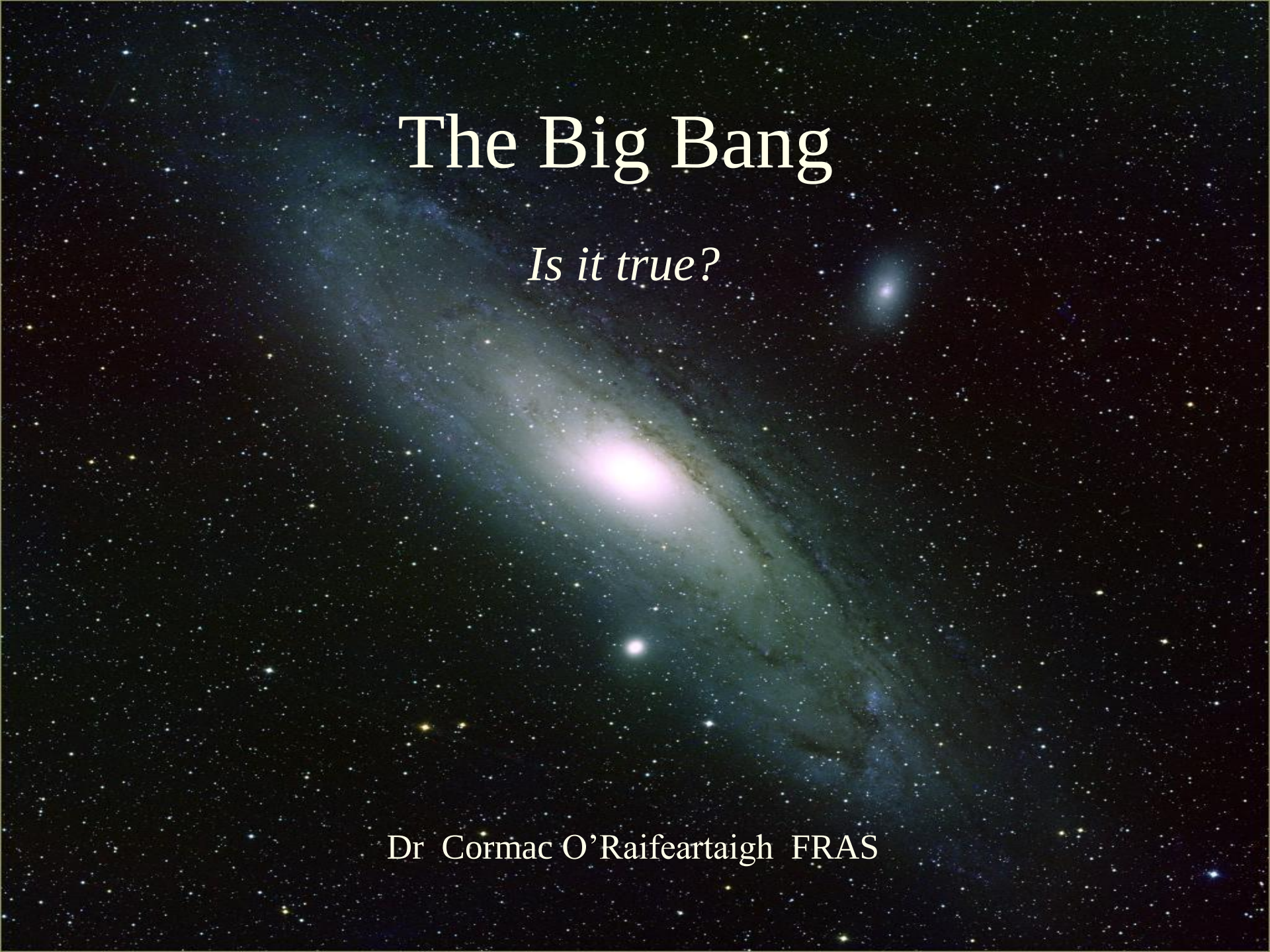


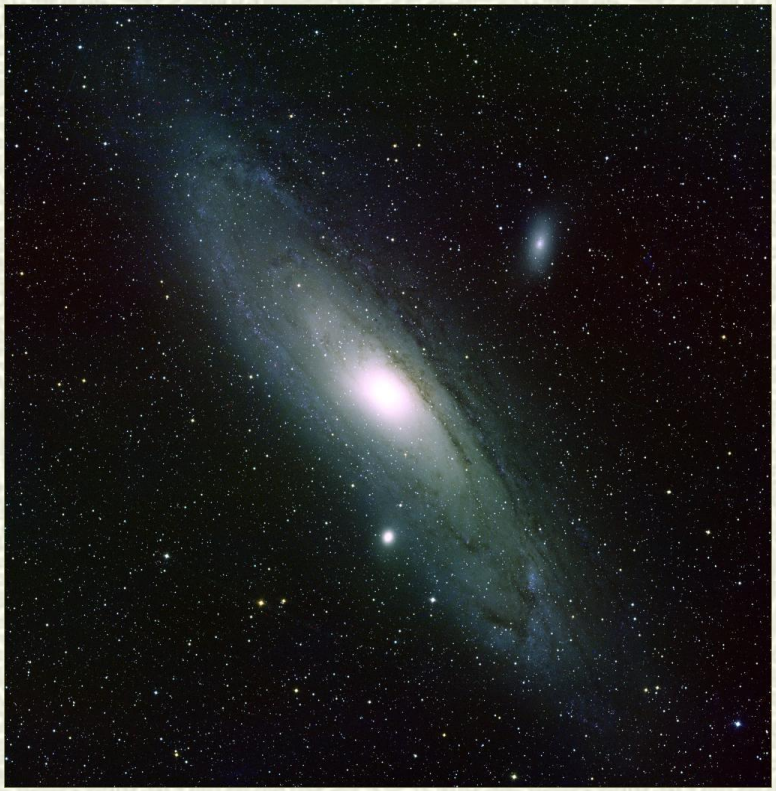
The Big Bang

Is it true?

Dr Cormac O'Raifeartaigh FRAS

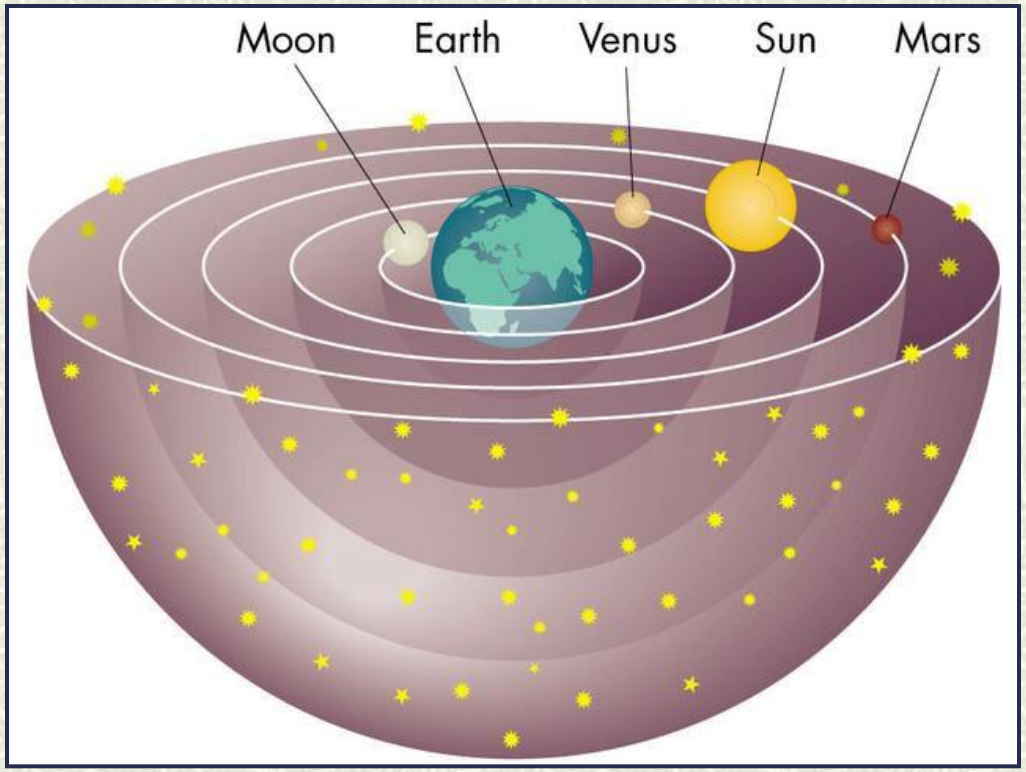
Cosmology: the study of the universe

- **How big is the universe?**
  Is it finite or infinite?
- **How old is the universe?**
  Is it eternal?
- **How did it begin?**
  How will it end?
- **What is the nature of time?**



Not science?

The Greek universe



Earth motionless

Centre of universe

All motion about earth

Stars quite close

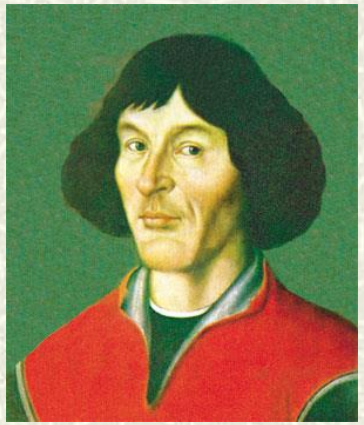
Aristotle (350 BC)
Ptolemy (200 AD)

Eternal universe

The Renaissance universe

Copernicus *(15th cent)*

Sun-centered system?



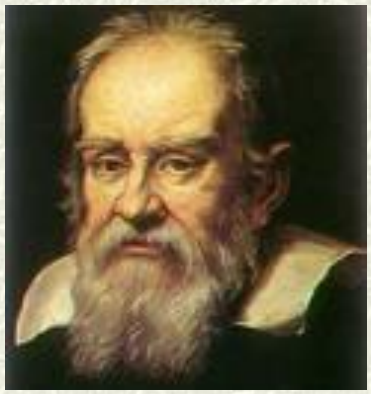
Kepler *(16th cent)*

Elliptical orbits of the planets

Galileo *(16th cent):* telescope

Moons of Jupiter, phases of Venus,

Does earth move as other planets?



Many solar systems?

Newton's universe

- Planet orbits due to gravity
- Gravity caused by sun's mass
- Attractive force
- Infinite, eternal universe

Newton (1642-1727)

Olber's Paradox?

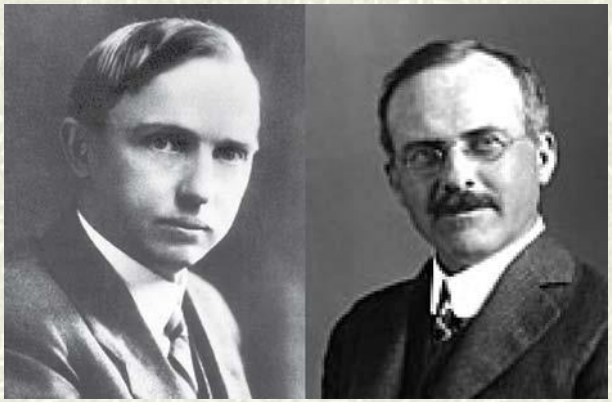
Astronomy (19th, 20th cent)

- Powerful telescopes
- Photography

Spiral nebulae

The great debate (1920)

Harlow Shapley vs Heber Curtis

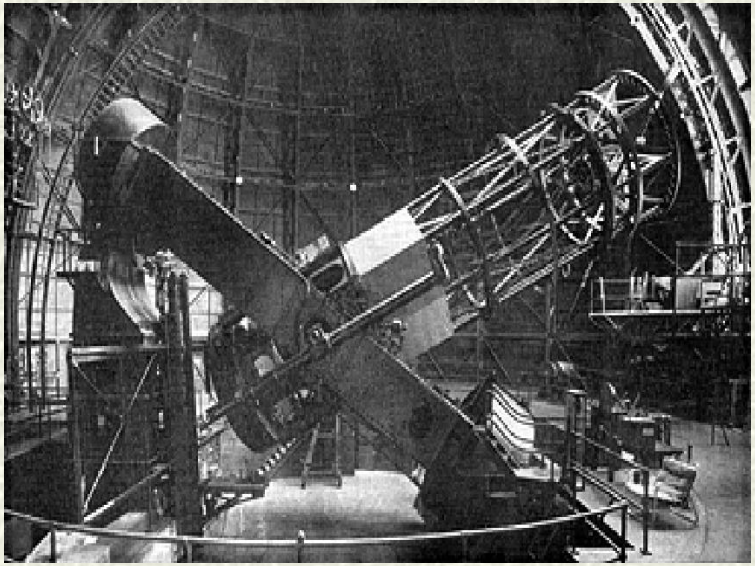


- Within the Milky Way?
- Distinct galaxies?

How big is the Universe?

The galaxies (1925)

Edwin Hubble



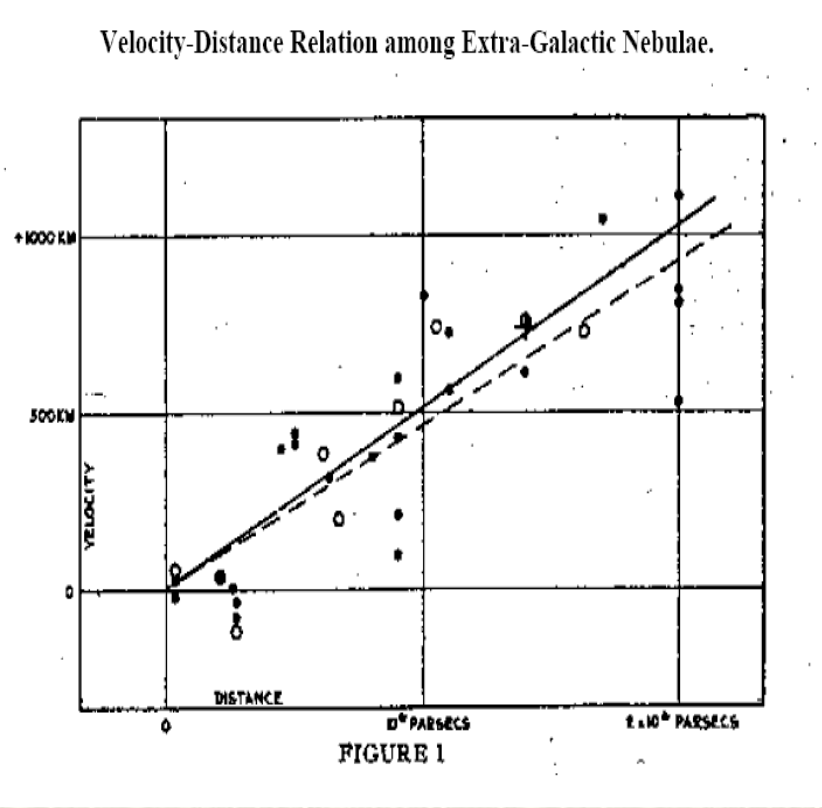
Hooker 100-inch reflector

- Cepheid stars in nebulae
- Standard candles
- Huge distance

Many galaxies

The runaway galaxies (Hubble)

- Galaxies moving away
- Investigated relation between distance and motion
- Hubble's Law (1929)



Far-away galaxies rushing away at a speed proportional to distance

$$v = H_o d$$

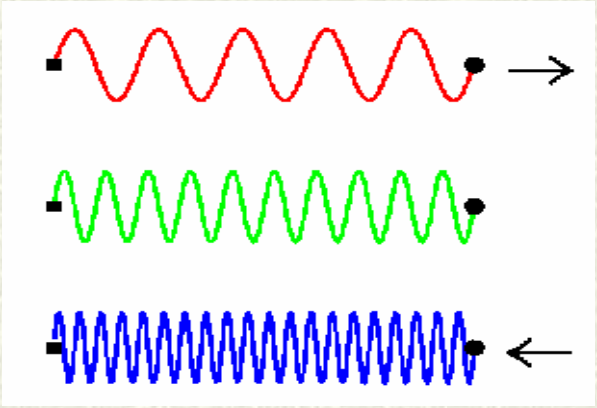
Motion of galaxies: redshift

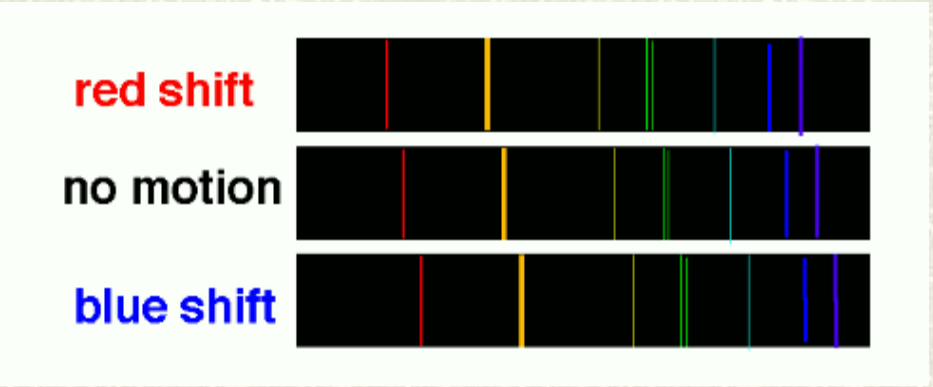
Vesto Slipher

frequency of light depends on motion of source relative to observer

Doppler Effect

measure motion of stars from light emitted





The runaway galaxies (Hubble)

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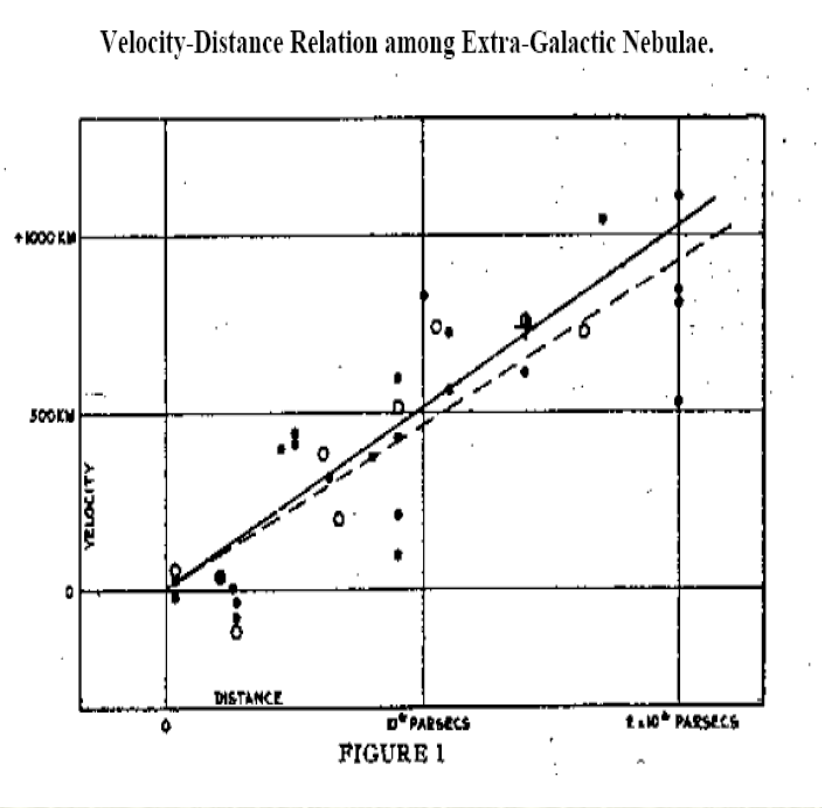


Far-away galaxies rushing away at a speed proportional to distance

$$v = H_o d$$

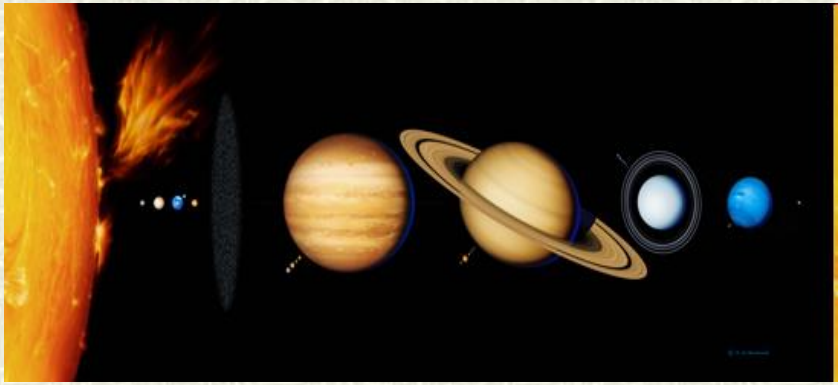
Explanation ?

Newton

- Gravity pulls in not out
- Space is fixed
- Time has no beginning

Isaac Newton

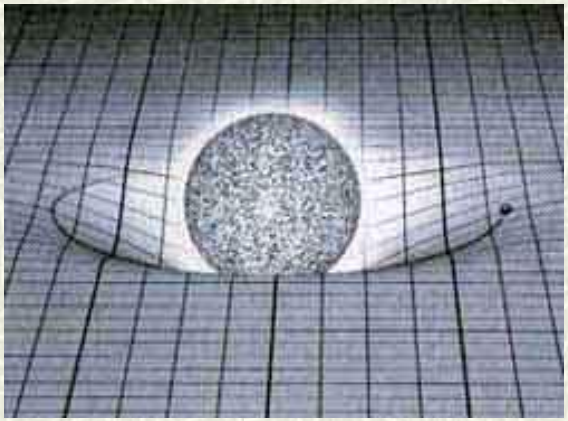
How can galaxies be receding?
What is pushing out?



Modern theory of gravity

General theory of relativity (Einstein, 1916)

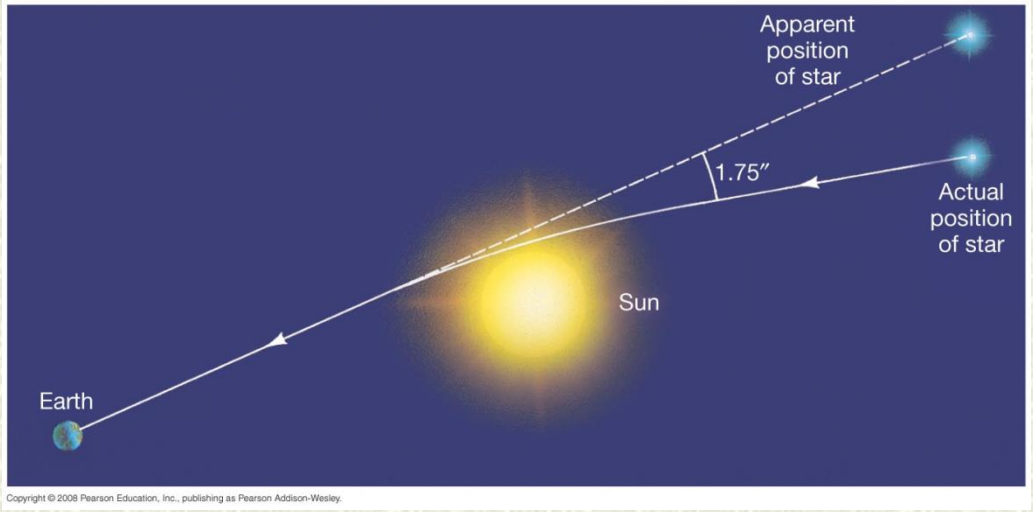
- speed of light = speed limit
- space + time not fixed
- affected by mass
- causes other mass to move



gravity = curvature of space-time

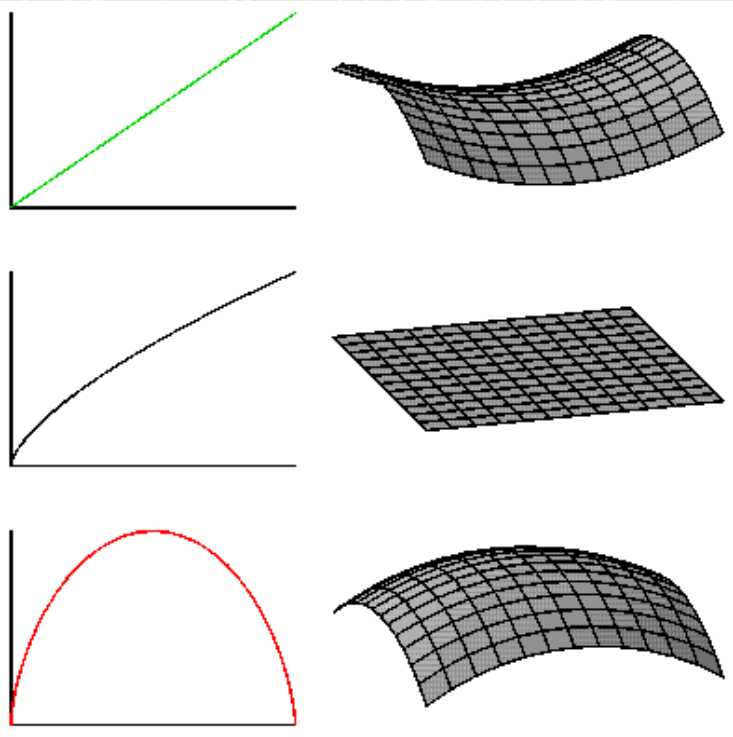
Evidence for general relativity

- Perihelion of Mercury
- Bending of light by gravity (1919)
- Black holes
- Time stretching by gravity
- *GPS*



Relativity and the universe

Apply Einstein's gravity to the cosmos



- Predicts **dynamic** Universe
- Space expanding, contracting

Einstein: static universe
Add cosmological constant λ

Friedmann: 3 possibilities $\Omega = d/d_c$
Depends on matter

Lemaître's universe (1927)

Fr Georges Lemaître

- **Einstein model not stable (1925)**

  New evolving solution : Einstein → de Sitter

- **Redshifts of galaxies = cosmic expansion**?

  Rate of expansion from mean distances and redshifts

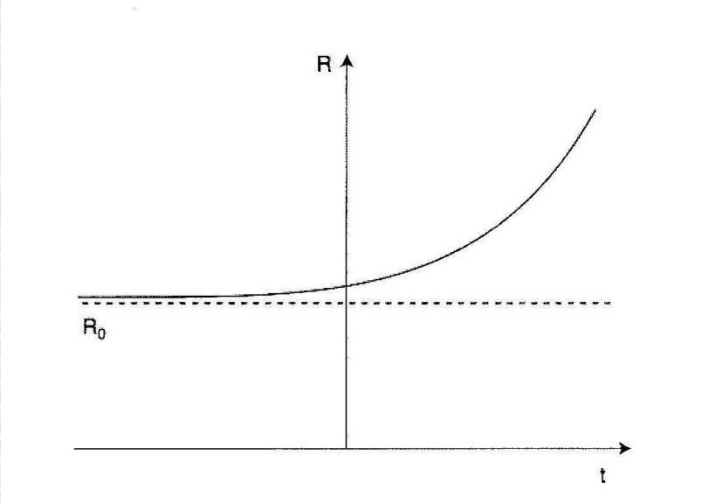
  H = 585 km/s/Mpc

- **No beginning: indefinite age**

  Starts from Einstein universe at t = - ∞

- **Rejected by Einstein (1927)**

  "Votre physique est abominable"



An expanding universe? (1930-)

- **RAS meeting (1930)**

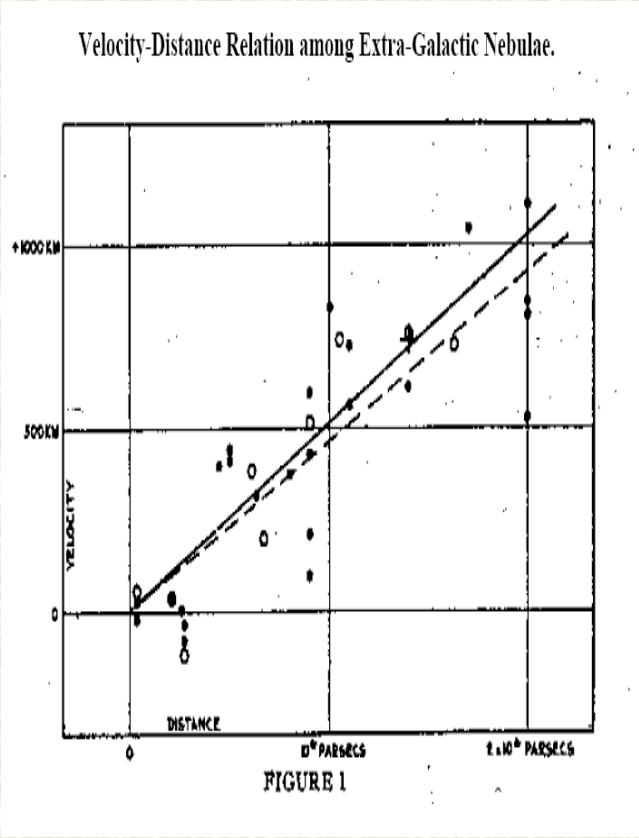
  Eddington, de Sitter
  Redshift/distance relation of the nebulae
  Static models don't fit
  New model required

- **Expansion of space-time metric?**

  Considered by many theoreticians
  If redshifts are velocities (Zwicky)
  If effect is non-local
  Not accepted by astronomers (Hubble)

- **Letter from Lemaître**

  Reminds Eddington of his 1927 model
  Eddington, de Sitter impressed



Cosmic expansion?

The expanding universe (1930 -)

- **Eddington (1930, 31)**

  On the instability of the Einstein universe
  The Eddington-Lemaître model
  Expansion caused by condensation?

- **de Sitter (1930, 31)**

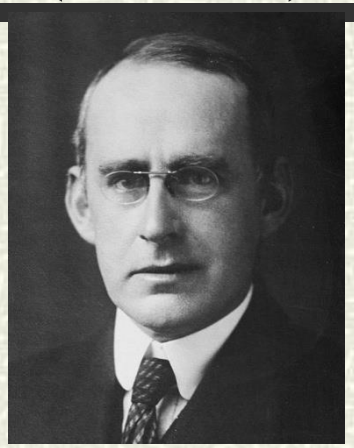
  Further remarks on the expanding universe
  Expanding universes of every flavour

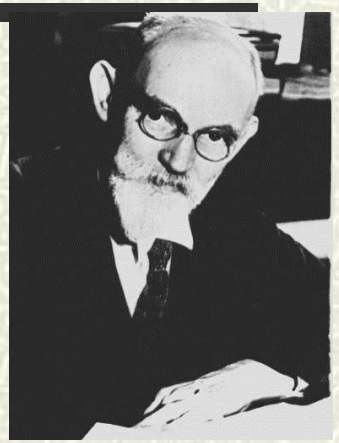
- **Tolman (1930, 31)**

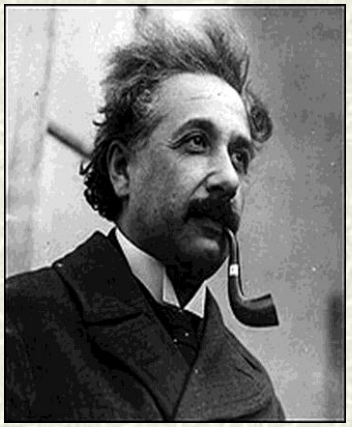
  On the behaviour of non-static models
  Expansion caused by annihilation of matter ?

- **Einstein (1931, 32)**

  Friedman-Einstein model $\lambda = 0, k = 1$
  Einstein-deSitter model $\lambda = 0, k = 0$







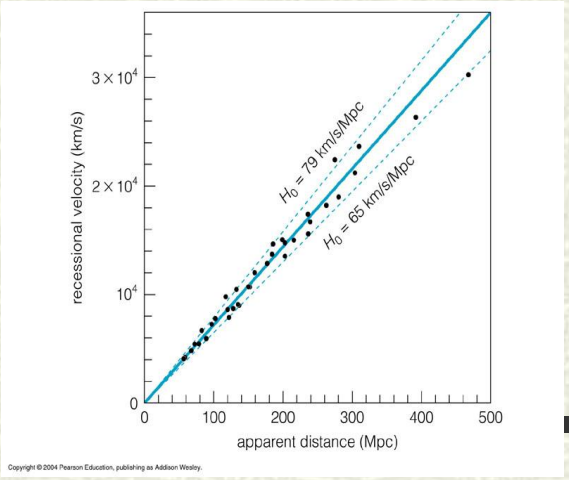
<u>If</u> redshifts represent expansion…
Evolving models

An origin for the universe?

- Rewind Hubble graph
- *U* smaller in the past
- Extremely dense, extremely hot
- Quantum beginning?

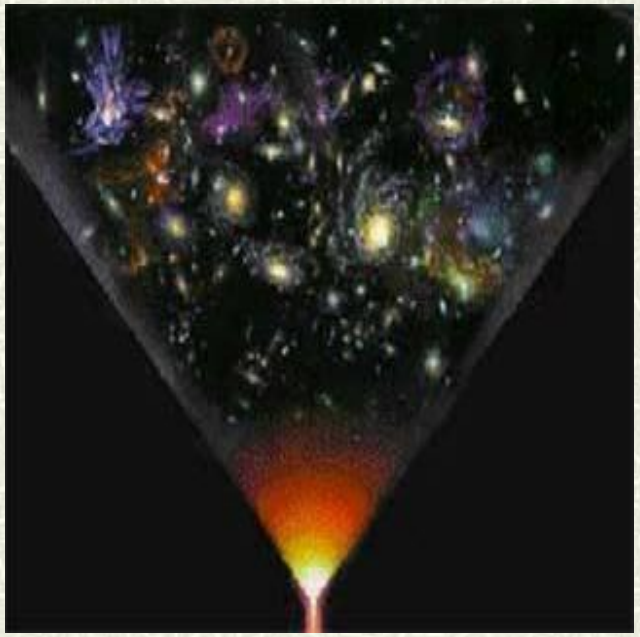
Fr Georges Lemaitre

Calculate age
Younger than the stars?



The ‘big bang’ model (1931)

- *U* originally concentrated in tiny volume
- Extremely dense, hot
- Expanding and cooling since



Wrong age (Hubble)

Singularity problem

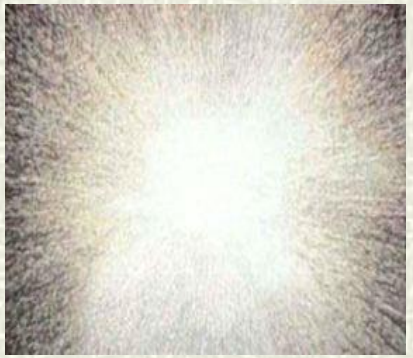
∞ density, ∞ temp at $t = 0$?

Additional evidence

- How did the chemical elements form?
- Nuclear physics (1940s)
- Not in the stars

Georges Gamow

- In Lemaitre's infant universe ?
- ***H***, ***He*** nuclei (*1 s*)



- *U* = 75% ***H***, 25% ***He***
- Agrees with observation

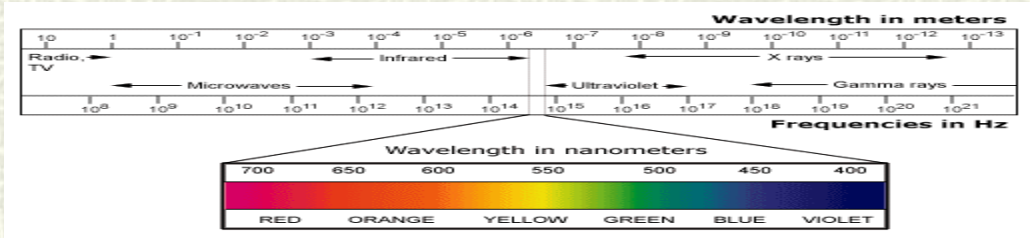
Heavier atoms formed in stars

Prediction: cosmic radiation?

- Radiation of infant universe
- Released when atoms formed
  (300,000 yr)
- Still observable today?
  Low temp, microwave frequency

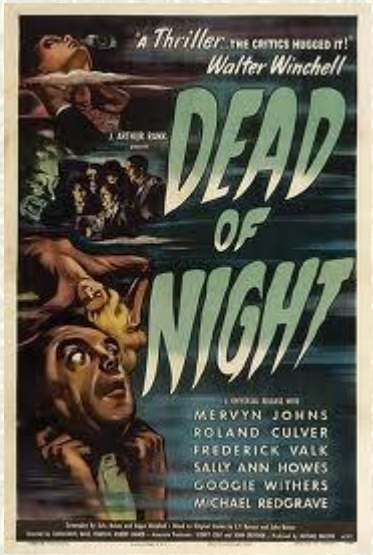
Alpher, Gamow and Herman

No-one looked (1940s)



Steady-state model (1950s)

Fred Hoyle



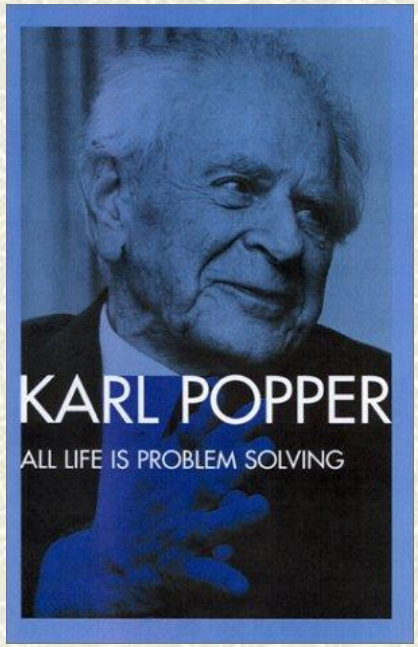
- Rival model
- Expanding universe

BUT

- Matter continuously created
- No beginning

Steady-State vs Big Bang (1950s)

- Continuous creation?
- Density of matter constant ?
- *U* unchanging, eternal ?
- Young universe similar to today ?



Falsification possible

Radio-astronomy (1960s)

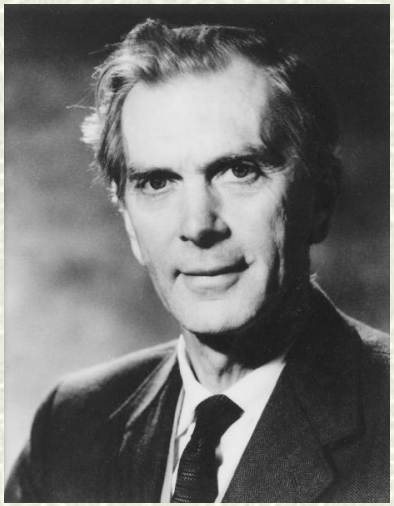
- Study most distant galaxies
- Compare with local galaxies

Cambridge
3C survey

- Density the same at all times? (SS)
- Or different? (BB)

Answer: <u>different</u>

End of steady-state model

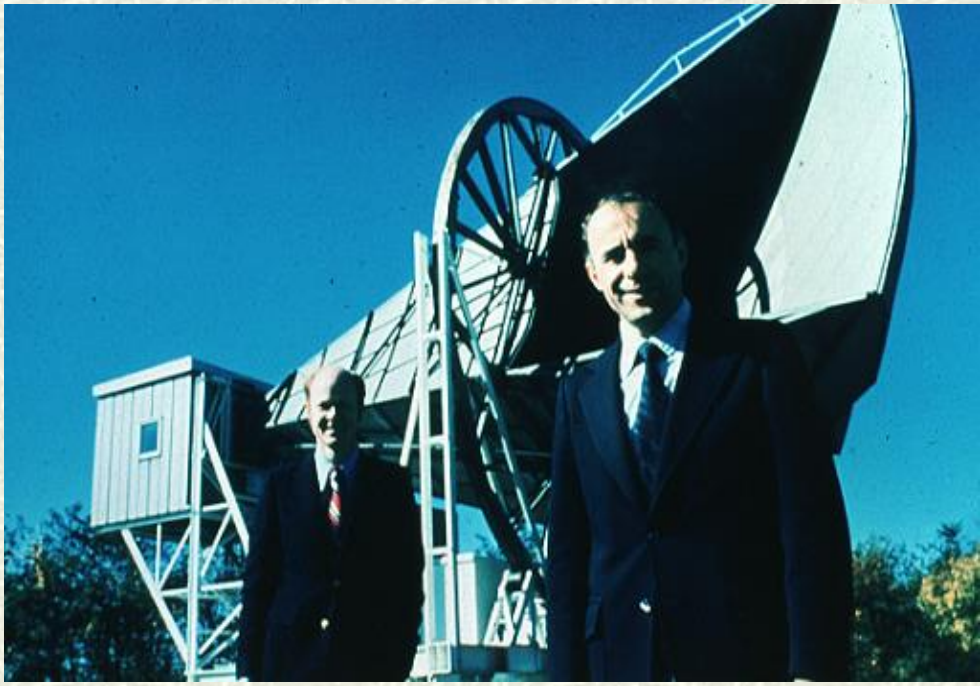


Martin Ryle

Bonus: cosmic radiation (1965)

CMB discovered accidentally

- Universal signal
- Low frequency (microwave)
- Low temperature (3K)

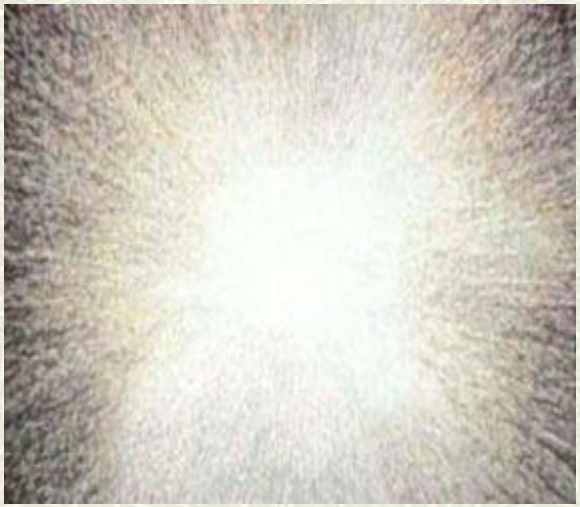


Penzias and Wilson

Echo of Big Bang!

BB model goes mainstream

The big bang – is it true?



Superhot, superdense

Expanding and cooling

√ ***1.*** The expansion of the *U*

√ ***2.*** The abundance of H and He

√ ***3.*** The evolution of galaxies

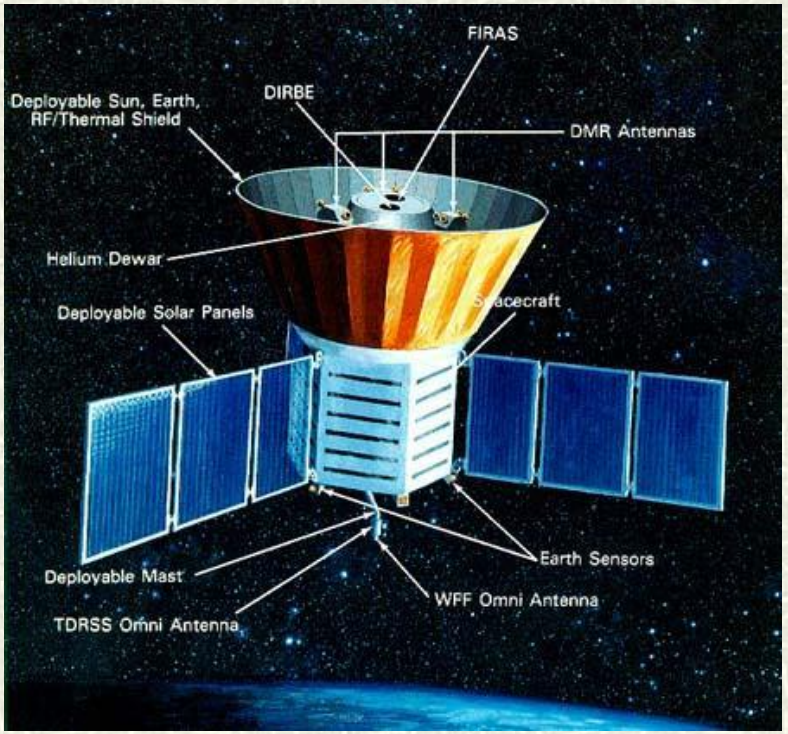
√ ***4***. The cosmic background radiation

How did it start?

Part II Modern measurements

- New measurements of CMB
- Full spectrum
- Comparison with theory

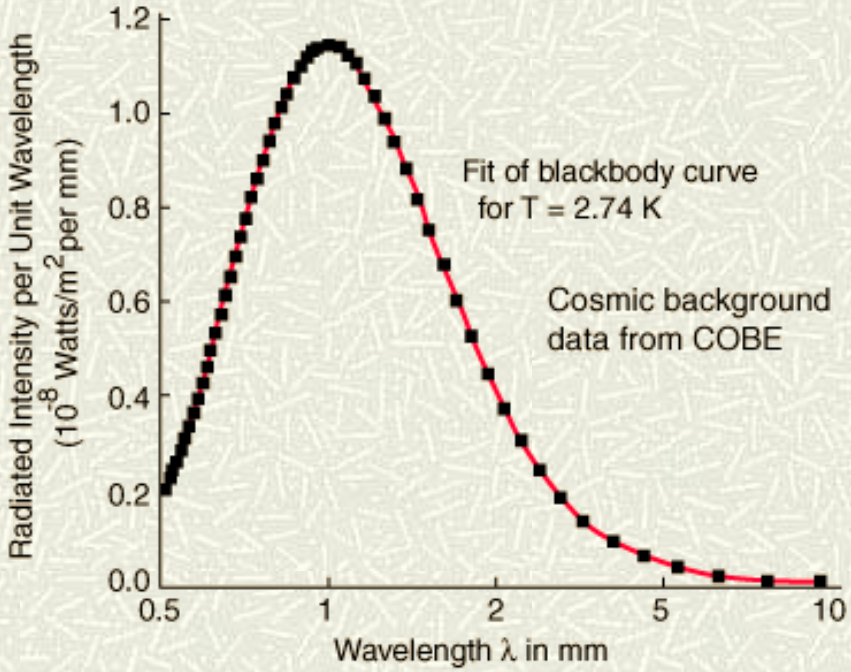
- Balloon experiments
- Satellite experiments



COBE satellite (1992)

COBE measurements of CMB

- Expected temperature
- Expected frequency
- Perfect blackbody spectrum



- *Radiation very uniform*
- *Galaxy formation?*
- *Variation of 1 in* 10^5

COBE (1992)

Nobel Prize 2006

Problems

Background radiation raised new questions

- Horizon problem *why so uniform?*
- Galaxy problem *how did galaxies form?*
- Flatness problem *fine balance?*

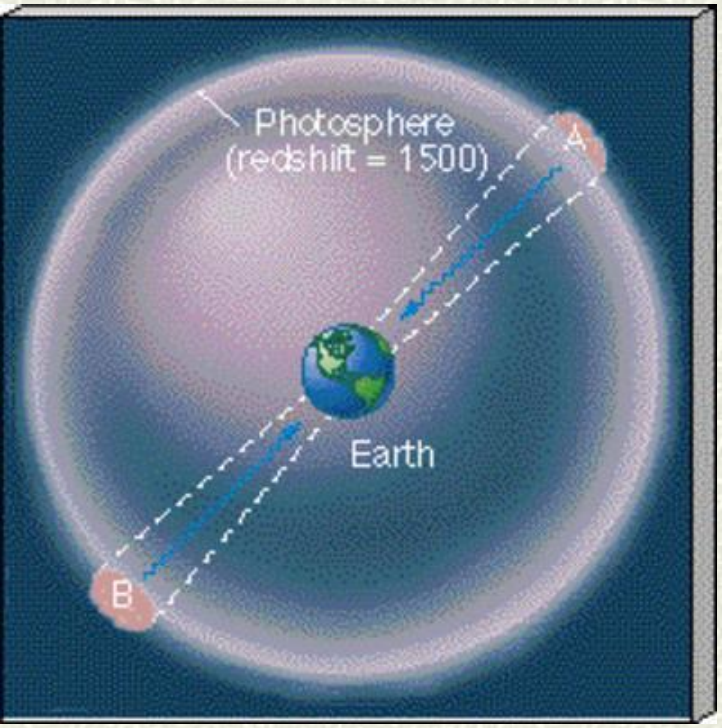
Stephen Hawking

Singularity problem

∞ density, ∞ curvature at $t = 0$?

quantum gravity?

The horizon problem



Two distant regions of background radiation have very similar temps

Why?

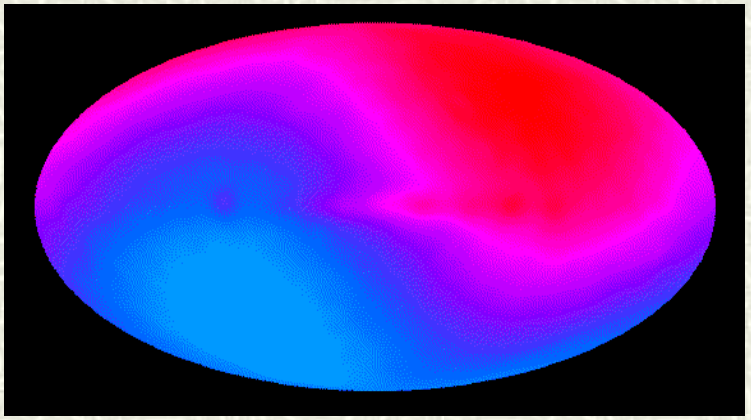
Too far apart to be causally connected

- Finite speed of light
- Finite age of cosmos

Is U too big?

Galaxy formation problem

- Microwave background smooth on large scale
- No obvious deviations from homogeneity (1 in 100,000)
- How did slight perturbations become galaxies?



The flatness problem

Slightest deviation from flatness

→

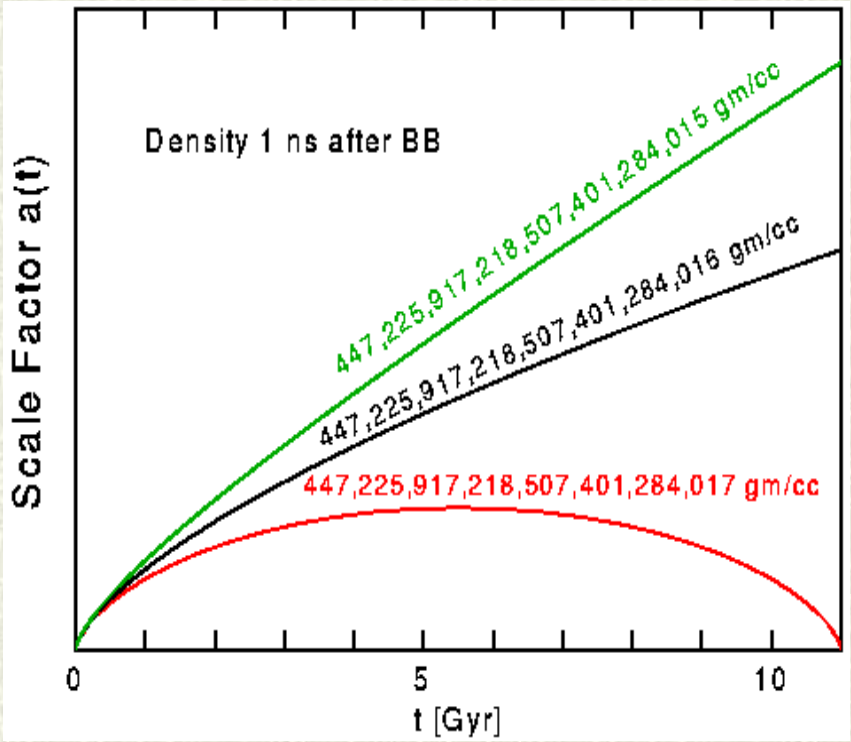
Runaway expansion or crunch

Not observed

Ω = 1

Why so finely balanced initially?

Astrophysics: ***Ω= 0.3 (matter)***



At t = 1 s, Ω = 1 to within 1:10^{15})

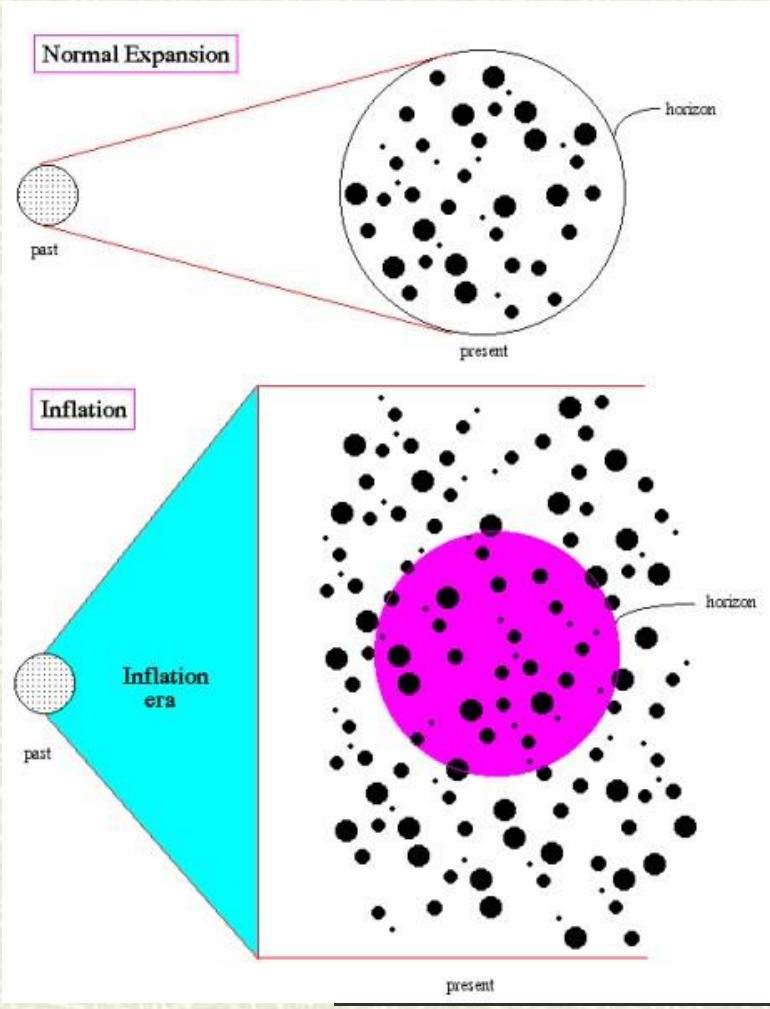
Solution: Inflation (1981)

- Initial **exponential expansion**
- Driven by *phase transition*

Repulsive force

- Expansion of 10^{26} in 10^{-32} s
- Smooths out inhomogeneities
- Smooths out curvature

'No hair' universe



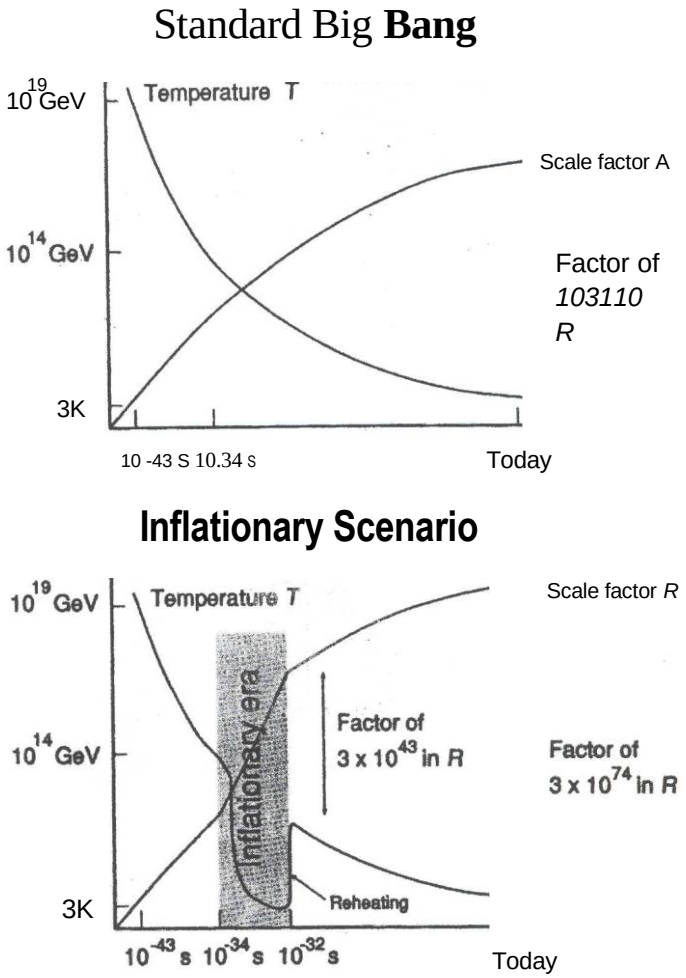
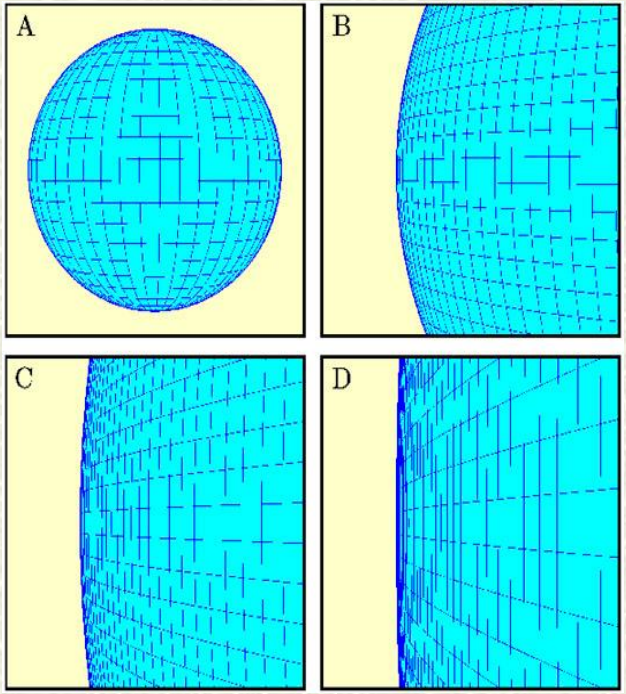


Figure 5.7. Comparison of the evolution of the scale factor and temperature in the standard Big Bang and inflationary cosmologies. The scale factor can be thought of as the distance between any two points which partake in the uniform expansion of the Universe.

The inflationary universe

- Solves flatness problem
  Geometry driven towards flatness
- Solves horizon problem
  Early U incredibly small
- Mechanism for galaxy formation
  Natural variations inflated



Ω = 1 ?

Conflict between theorists and experimentalists

Dark Matter

- First suggested in 1930s
- Stellar motion

normal gravitational effect but cannot be seen directly

- Explains motion of stars
- Explains motion of galaxies
- Explains gravitational lensing

Matter = OM (30%) + DM (70%)

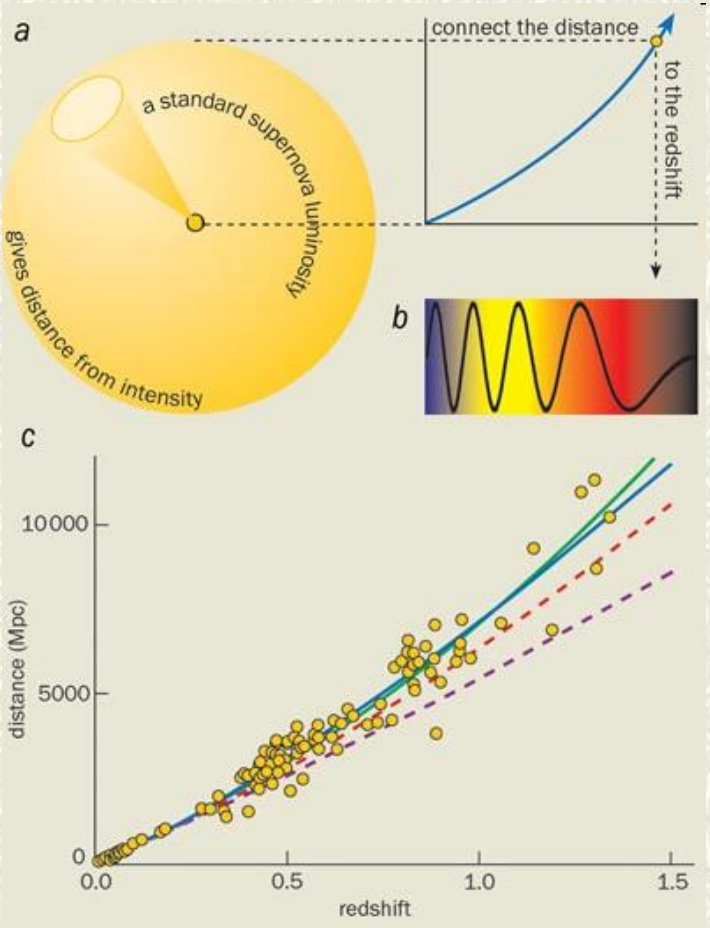
$\Omega = 0.3$

Also suggested by nucleosynthesis

Dark Energy (the return of λ)

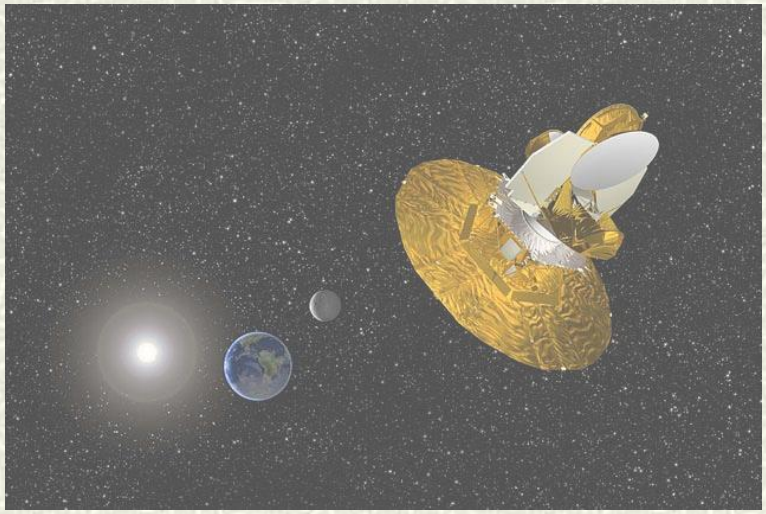
- Measurements of supernovae (1998)
- Furthest galaxies too far away
- Hubble expansion accelerating
- Geometry of *U* flat
- Support for inflation

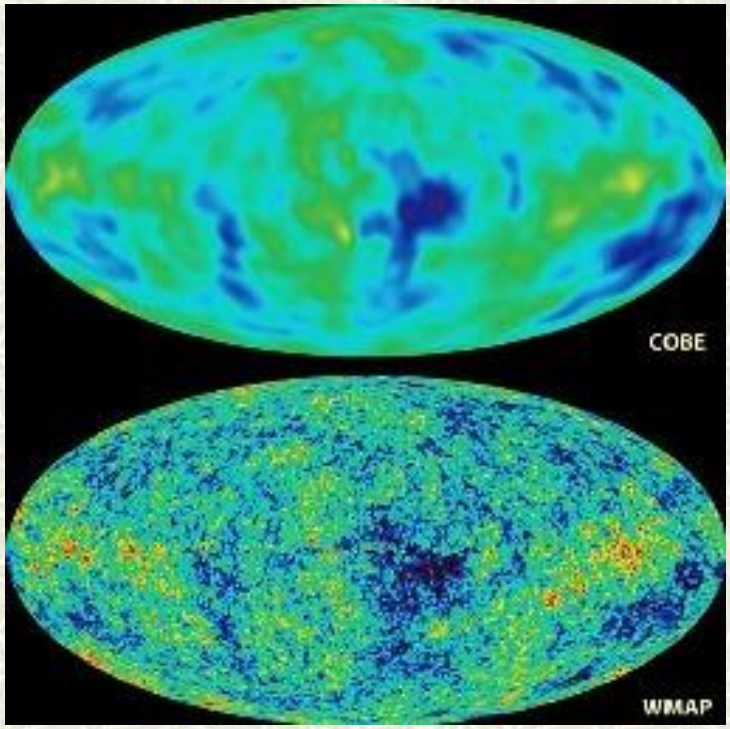
Caused by dark energy



WMAP Satellite (2002)

- Details of *CMB* spectrum
- Details of galaxy formation
- Details of flatness of *U*





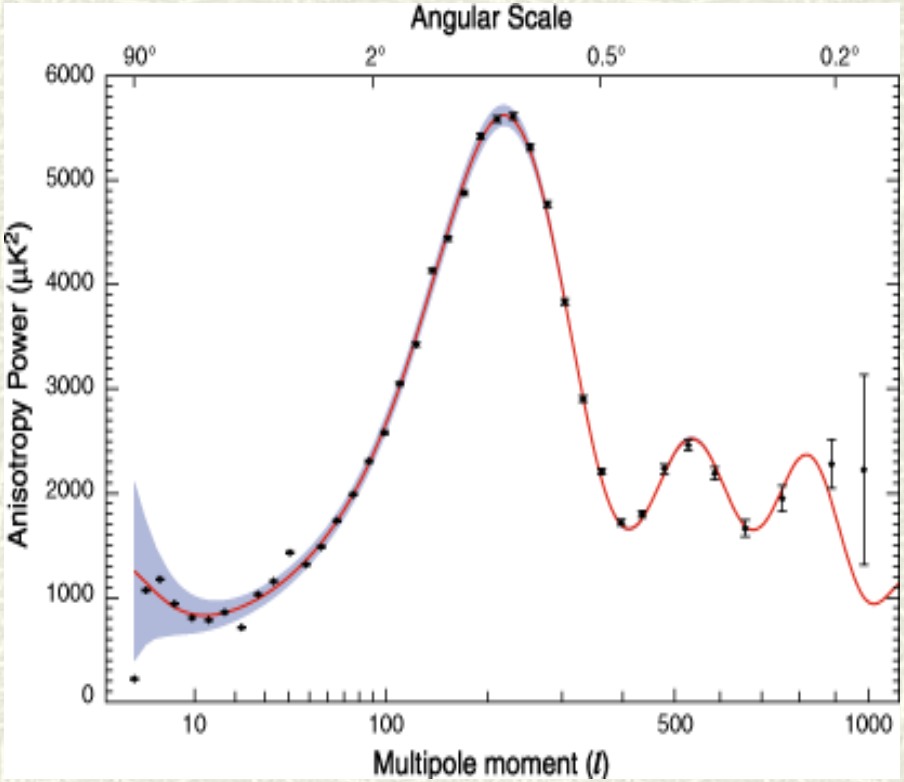
Cosmic microwave background

WMAP measurements of CMB (2005)

- Flat geometry (to 1%)
- Spectrum of *T* variations

Agreement with supernova data

Strong support for inflation



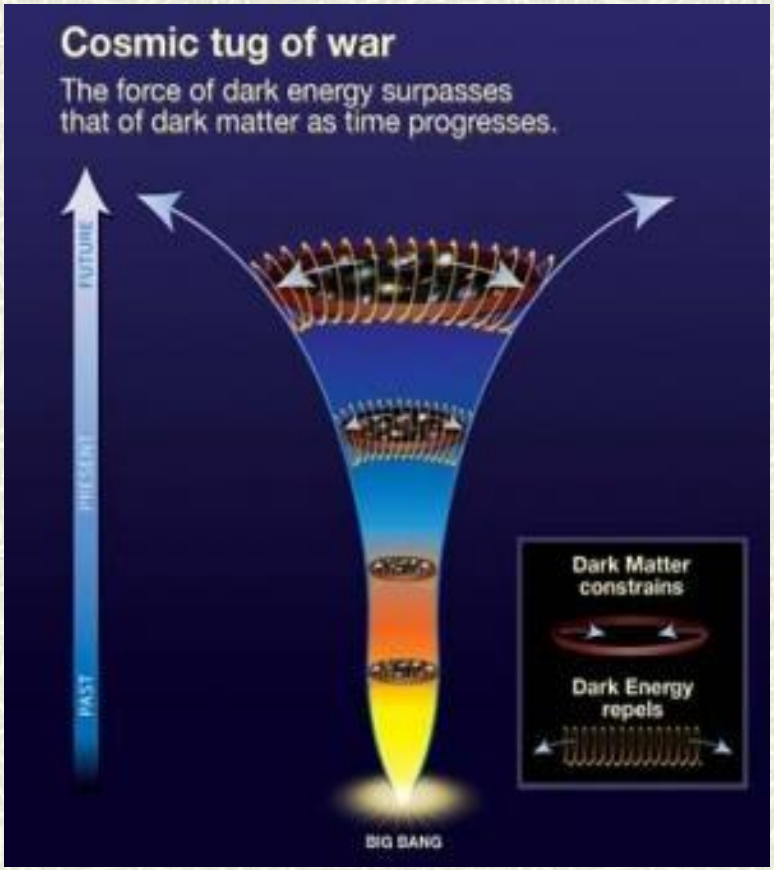
Fit to theory

Dark Energy

- Cosmological constant?
- Predicted by relativity
- Natural tendency of space to expand

- Energy of vacuum?
- Why so small?
- Why of similar density to matter?

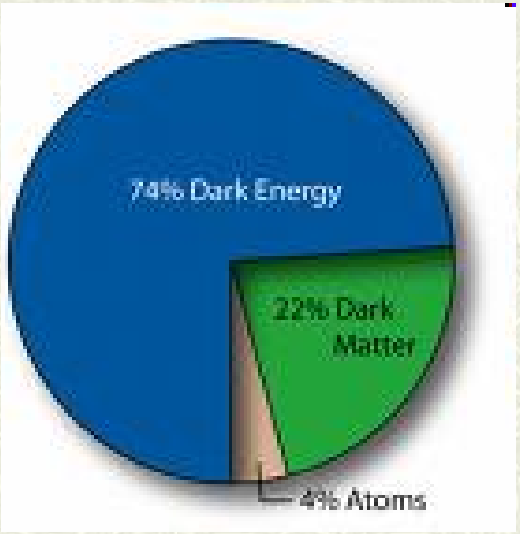
- Not well understood
- Fate of universe?



New big bang model: *Λ-CDM*

A flat, accelerating universe containing matter, dark matter and dark energy

1. Ordinary matter: 4% (astrophysics)
2. Dark matter: 22% (astrophysics)
3. Dark energy : 74% (supernova, CMB)



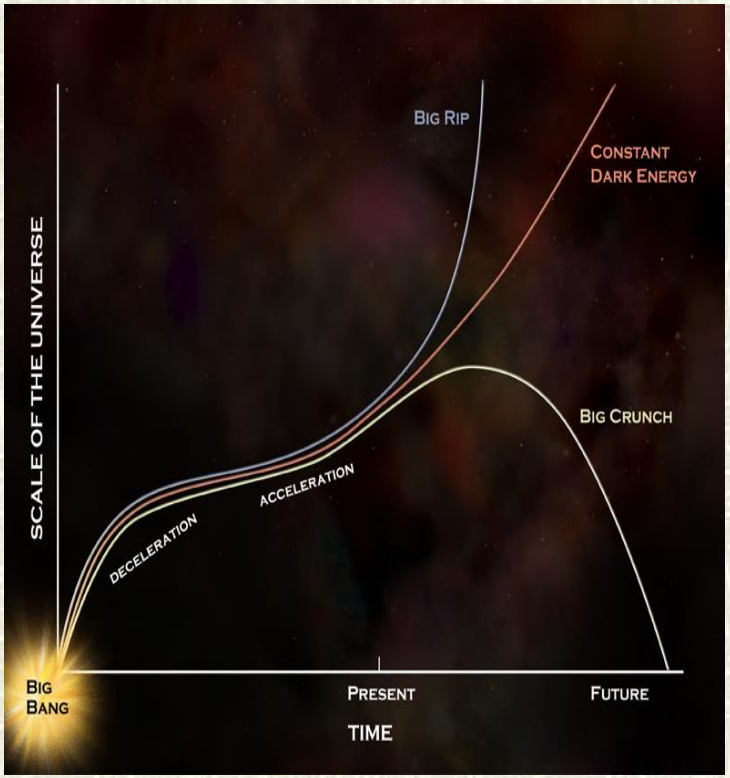
ΛCDM

Ω = 1

Putting it all together

Basic evidence (BB model)

- The expanding universe
- The abundance of the elements
- The evolving galaxies
- The cosmic background radiation



Modern measurements

- The CMB spectrum
- Inhomogeneties (galaxy formation)
- Flat Geometry (supernovae)

A flat, accelerating universe containing matter, dark matter and dark energy

Is it true? Problems

- Nature of dark energy?

  Fate of universe?

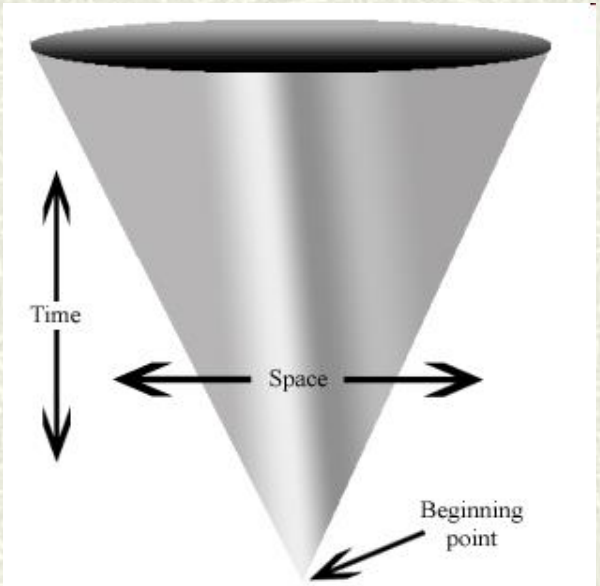
- Nature of dark matter?

- Which model of inflation?

  The multiverse

- What happened at time zero**?**

  Quantum gravity?



Something from nothing?

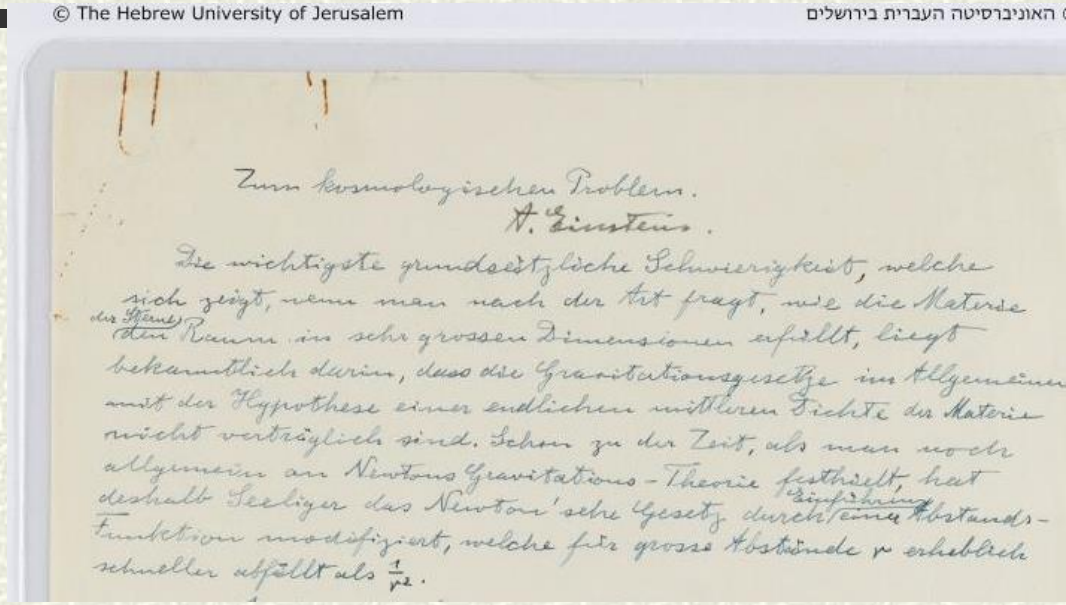
New: Einstein's steady-state model (1931?)

- **Cites Hubble's law**
  Stability of static universe?
- **Cites evolving models (Tolman)**
  Conflict with stellar ages

Q: Alternative solution

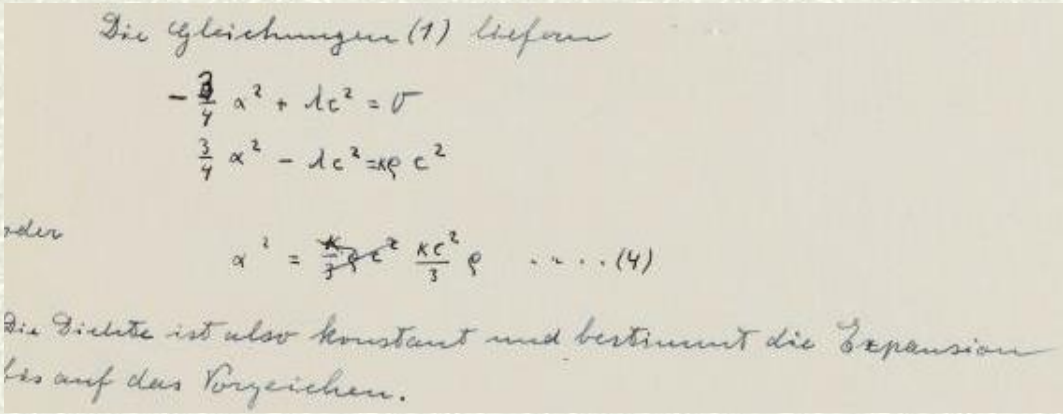
Expanding, unchanging cosmos?
Continuous creation of matter
Associated with λ - energy of space

- **Anticipates Hoyle model**
  Doesn't work: no creation term
  Explored and discarded



Zum kosmologischen Problem.
A. Einstein.

Die wichtigste grundsätzliche Schwierigkeit, welche sich zeigt, wenn man nach der Art fragt, wie die Materie den Raum in sehr grossen Dimensionen erfüllt, liegt bekanntlich darin, dass die Gravitationsgesetze im Allgemeinen mit der Hypothese einer endlichen mittleren Dichte der Materie nicht verträglich sind. Schon zu der Zeit, als man noch allgemein an Newtons Gravitations-Theorie festhielt, hat deshalb Seeliger das Newton'sche Gesetz durch eine Abstands-funktion modifiziert, welche für grosse Abstände r erheblich schneller abfällt als $\frac{1}{r^2}$.



Die Gleichungen (1) liefern

$$-\frac{3}{4}\alpha^2 + \lambda c^2 = 0$$

$$\frac{3}{4}\alpha^2 - \lambda c^2 = \kappa\rho c^2$$

oder

$$\alpha^2 = \frac{\kappa}{3}\rho c^2 \quad \frac{\kappa c^2}{3}\rho \quad \ldots\ldots (4)$$

Die Dichte ist also konstant und bestimmt die Expansion bis auf das Vorzeichen.

Einstein's steady-state model

- **Why does model fail?**

  *De Sitter model (9/4→ **-3/4**)*

  $\rho = 0$

- **How is matter formed?**

  No 'creation' term

- **Einstein's crossroads**

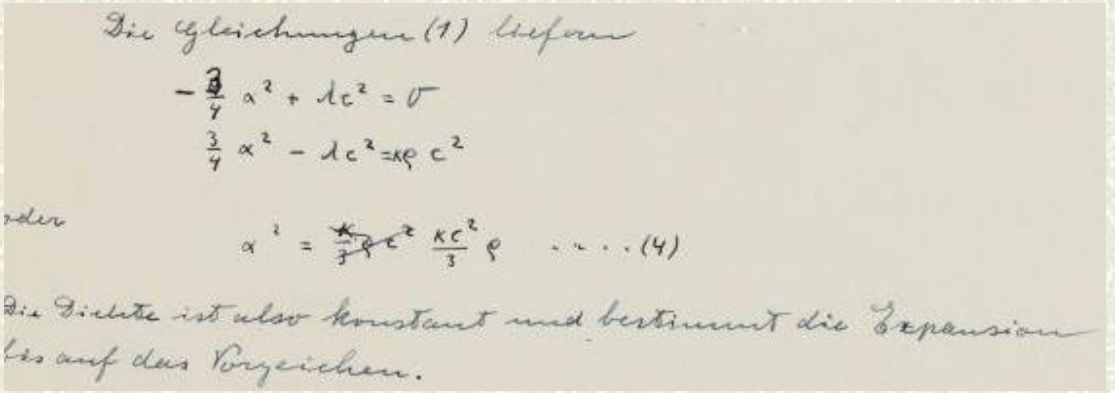
  Realised S-S model requires term

  Declined to add term to GFE

- **Evolving models**

  Less contrived

  Set $\lambda = 0$



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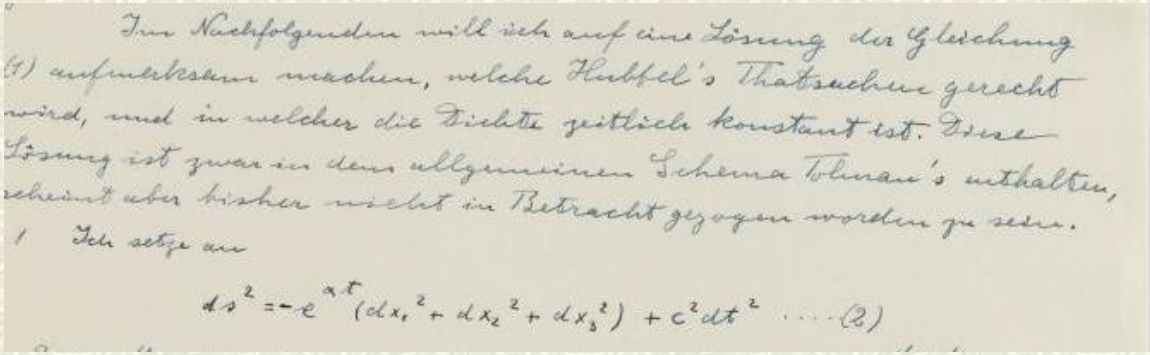
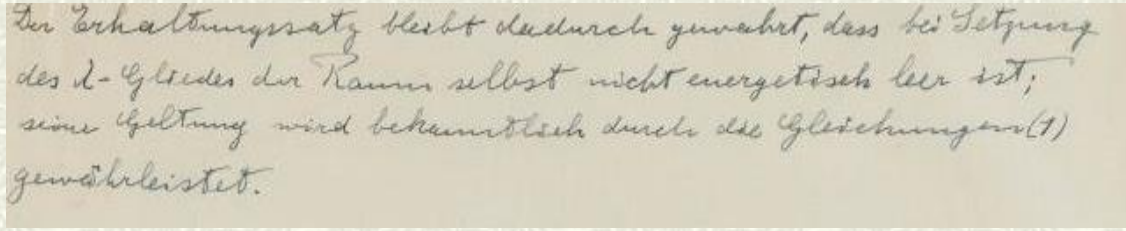


Im Nachfolgenden will ich auf eine Lösung der Gleichung (1) aufmerksam machen, welche Hubbel's Thatsachen gerecht wird, und in welcher die Dichte zeitlich konstant ist. Diese Lösung ist zwar in dem allgemeinen Schema Tolman's enthalten, scheint aber bisher nicht in Betracht gezogen worden zu sein.

Ich setze an

$$ds^2 = -e^{\alpha t}(dx_1^2 + dx_2^2 + dx_3^2) + c^2 dt^2 \quad \ldots\ldots (2)$$



Der Erhaltungssatz bleibt dadurch gewahrt, dass bei Setzung des λ-Gliedes der Raum selbst nicht energetisch leer ist; seine Geltung wird bekanntlich durch die Gleichungen (1) gewährleistet.

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Einstein's lost theory uncovered

Physicist explored the idea of a steady-state Universe in 1931.

Davide Castelvecchi

24 February 2014

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Einstein's Lost Theory Uncovered

The famous physicist explored the idea of a steady-state universe in 1931

nature

Feb 25, 2014 | By Davide Castelvecchi and Nature magazine

A manuscript that lay unnoticed by scientists for decades has revealed that Albert Einstein once dabbled with an

New Discovery Reveals Einstein Tried To Devise A Steady State Model Of The Universe

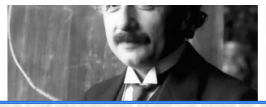
2 comments, 2 called-out + Comment Now + Follow Comments

Almost 20 years before the late Fred Hoyle and his colleagues devised the Steady State Theory, Albert Einstein toyed with a similar idea: that the universe was eternal, expanding outward with a consistent input of spontaneously generating matter.

An Irish physicist came across the paper last year and could hardly believe According to this week's article in Nature,

model of the universe very different to today's Big Bang Theory.

The manuscript, which hadn't been referred to by scientists for decades,



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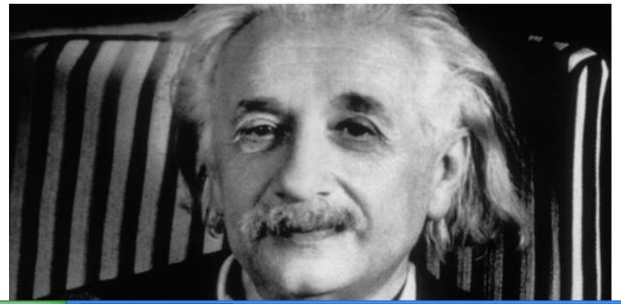
WIT researchers discover 'lost' Einstein model of universe

Scientists uncovered misfiled papers while searching Jerusalem university's online archive



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Einstein's steady-state model and cosmology today

- **Accelerated expansion (1998)**

  Supernova measurements

  Dark energy – positive cosmological constant

- **Einstein's dark energy**

  "The conservation law is preserved in that, by setting the λ-term, space itself is not empty of energy; its validity is well known to be guaranteed by equations (1)."

  Anticipates the discovery of an accelerated expansion

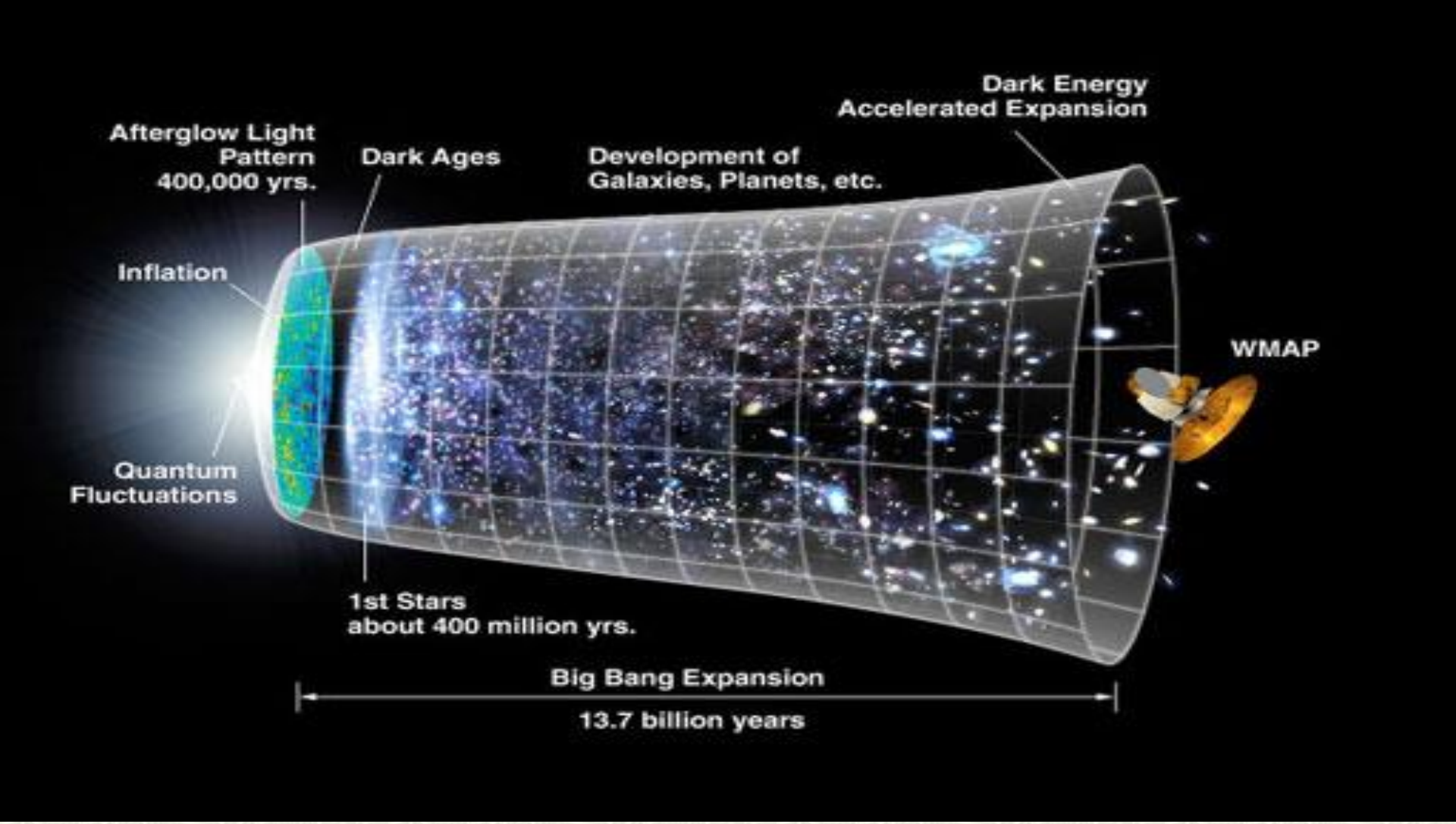
  Anticipates positive comological constant

- **De Sitter line element**

  $ds^2 = -e^{\alpha t}(dx_1^2 + dx_2^2 + dx_3^2) + c^2dt^2$ ...

  Identical to inflationary models

  Different time-frame



Further reading: The Big Bang (Simon Singh)
Antimatter (CÓR)