The big bang – is it true?

Theory, models and evidence in 20\textsuperscript{th} century physics

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The big bang model

- \( U \) was once superdense and superhot
- Expanding and cooling over time

The evidence

- The runaway galaxies; the abundance of the elements
- The distribution of the galaxies; the background radiation

The theory

- Cosmology and the general theory of relativity

What does a historian do?

- Review how models develop
- Consider roads not taken
1st evidence: Hubble’s law

- The recession of the galaxies
- Linear relation between redshift (velocity) and distance
- Hubble’s Law (1929)

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

\[ v = H_0d \]
Motion of galaxies: redshift

*frequency* of light depends on motion of source relative to observer

**Doppler Effect**

measure motion of stars and galaxies from light emitted

*Vesto Slipher (1915)*
The distance of the galaxies

- Identification of Cepheid variables stars in spiral nebulae (1925)
- Use of Leavitt period-luminosity method
- Nebulae far beyond Milky Way
- Distinct galaxies
Explanation for runaway galaxies?

**Newton**

- Gravity pulls in not out
- Space is fixed

*How can galaxies be receding?*

*What is pushing out?*
Modern theory of gravity

**General theory of relativity (Einstein, 1915)**

- space + time not fixed
- **spacetime**
- affected by motion
- affected by mass

\[ G_{\mu\nu} = -kT_{\mu\nu} \]

*gravity = curvature of space-time*
Relativistic cosmology

- **Alexander Friedman (1922)**
  - *Time-varying solutions for the cosmos*
  - Expanding or contracting universe

- **Evolving universe**
  - *Time-varying radius and density of matter*
  - Rejected by Einstein

- **Georges Lemaître (1927)**
  - Relativistic universe of expanding radius
  - Agreement with emerging astronomical data
  - Also rejected by Einstein

Why?
The paradigm shift (1930)

- RAS meeting (1930)
  Eddington, de Sitter
  If redshifts are velocities and effect is non-local

- Hubble’s law = expansion of space?
  Static models don’t fit data
  Dynamic relativistic models required

- Friedman-Lemaître models accepted
  Time-varying radius
  Density of matter decreases

Evidence now favourable
The Friedman-Einstein model

- Einstein’s first expanding model (1931)
  Friedman model with cosmological constant set to zero
  First English translation

- Use Hubble to extract parameters
  Cosmic radius $R \sim 10^8$ LY
  Density of matter $\rho \sim 10^{-26}$ g/cm$^3$
  Timespan of expansion: $10^{10}$ yr

- Numerical error in calculations
  Source of error not clear

- Made clear on Oxford Blackboard
  Nature of error clear on blackboard
The first ‘big bang’ model (1931)

- Expanding $U$ smaller in the past
- Rewind Hubble graph to ‘origin’
- Extremely dense, extremely hot
- Explosive beginning at $t = 0$?
  
  *Expanding and cooling ever since*

*Fr Georges Lemaître*

*Not accepted*
A second piece of evidence

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

- In Lemaître’s infant universe?
- \( H, He \) nuclei (1 s)

- \( U = 75\% H, 25\% He \)
- Agrees with observation

*Big bang nucleosynthesis*
A third piece of evidence?

- Radiation from infant universe
- Released when atoms formed (300,000 yr)
- Still observable today?
  
  Low temp, microwave frequency
  
  No-one looked (1948); why not?

Alpher, Gamow and Herman
Steady-state model (1950s)

- Rival model
- Expanding universe

**BUT**

- Matter continuously created
- No beginning

Fred Hoyle
A famous debate (1950-1965)

- Bitter debate between BB and SS
- Radio-astronomy: study most distant galaxies
- Compare with local galaxies

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

**Answer:** different

*End of steady-state model*
Bonus: cosmic background radiation

CMB discovered accidentally

- Universal signal (1965)
- Low frequency (microwave)
- Low temperature (3K)

Echo of Big Bang!
Einstein’s lost theory uncovered
Physicist explored the idea of a steady-state Universe in 1931.

Davide Castelvecchi
24 February 2014

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

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

The manuscript, which hadn’t been referred to by scientists for decades,
The big bang – is it true?

√ 1. The expansion of the $U$

√ 2. The abundance of H and He

√ 3. The distribution of galaxies

√ 4. The cosmic background radiation

Superhot, superdense

Expanding and cooling over time
Cosmology today

- **Satellite measurements of CMB**
  *No interference from atmosphere*

- **Expected temperature**
  *Expected frequency*

- **Full spectrum**
  *Perfect blackbody spectrum*

- **Perturbations**
  *Variation of 1 in $10^5$*

*COBE satellite (1992)*

- **Radiated Intensity per Unit Wavelength**

  - Fit of blackbody curve for $T = 2.74$ K
  - Cosmic background data from COBE
Detailed big bang model: $\Lambda$-CDM

A universe containing ordinary matter, dark matter and dark energy

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

$\Omega = 1$
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

\[\text{Matter} = \text{OM (30\%)} + \text{DM (70\%)}\]

\[\Omega = 0.3\]

Compatible with nucleosynthesis
Dark energy

- Furthest galaxies too far away
- Cosmic expansion **accelerating**
- Energy of vacuum?
- Not well understood

*Predicted in 1917*
The big bang model - problems

- **Nature of dark energy?**
  - *Role in BB?*

- **Nature of dark matter?**
  - *Particle experiments?*

- **The singularity problem**
  - *What banged?*
  - *What does time zero mean?*

*Intersection of history with today’s science*