Astronomy 350L
(Fall 2006)

The History and Philosophy of Astronomy

(Lecture 23: Steady State vs Big Bang)

Instructor: Volker Bromm
TA: Jarrett Johnson

The University of Texas at Austin
Steady State vs Big Bang Universe

Permanence vs change!

Parmenides

- change is illusion!
- time has no beginning
- “What is, cannot not be!”

Heraclitus

- everything is in perpetual flux!
- basic element: fire
- “Panta Rhei!”
Origin of the Big Bang Theory

- 1922: an expanding universe (solving Einstein’s equations of General Relativity without cosmological constant)

Alexander Friedmann (1888-1925)
Origin of the Big Bang Model

• 1927: Lemaitre independently (re-) discovers the expanding-universe solutions of GR
Origin of the Big Bang Model

• Lemaitre: Imagine that you run expansion of universe backwards in time!

• in distant past: universe was *much* denser and hotter!
Origin of the Big Bang Model

• 1931: Lemaitre’s “Primeval Atom”:
  • Primeval atom: super-heavy, radioactive!
  • Radioactive decay somehow triggers expansion!
    Lemaitre: “Father of the Big Bang”
Origin of the Big Bang Model

- George Gamow
  1904 (Odessa) – 1968 (Boulder)

- distinguished career in nuclear physics (“tunnel effect”)

- 1948: theory of Big Bang nucleosynthesis (with R. Alpher)

- famous popularizer of science (“Mr. Tompkins in Wonderland”)
The Riddle of the Chemical Elements

Abundance vs atomic number

- Hydrogen and helium by far the most abundant cosmic elements
- Why: 1 He atom per 10 H atoms?
- Why are all the other elements so very rare?
Big Bang Nucleosynthesis

- Big idea (Alpher and Gamow 1948): Synthesize all elements during earliest, hot and dense, phase

- Raw material = “Ylem”: primordial soup of protons, neutrons, electrons, and photons
• Great success: Big Bang nucleosynthesis can successfully explain Helium abundance (1 He atom per 10 H atoms)

• published (April 1, 1948) as Alpher, Bethe, & Gamow (the “alphabetical paper”: alpha, beta, gamma...
Big Bang Nucleosynthesis

Ralph Alpher

Robert Herman
• Big problem: theory doesn’t work for heavier elements:
  - He+neutron, He+proton unstable!
  - He + He (Be) unstable!
Modern View of Nucleosynthesis

1. Hydrogen, helium: Big Bang

2. All other elements: Interior of stars

• Bridging the “Helium-carbon gap”: Triple-alpha process (Edwin Salpeter, 1952)
Modern View of Nucleosynthesis

- Successful theory of creating the elements in stars:
  - Burbidge, Burbidge, Fowler, & Hoyle (B²FH 1957)
• Big idea (Alpher and Herman 1948): Out of primordial fireball in early universe an intense sea of photons that is still around us today
Predicting Cosmic Background Radiation

• Expansion of Universe stretches light towards longer wavelength (i.e., redder and less energetic)

• Cosmic background today: redshifted into microwave region of electromagnetic spectrum!
Predicting Cosmic Background Radiation

• Prediction (1948): Cosmic microwave background (CMB) at a (radiation) temperature of ~ 5 Kelvin

• Why was CMB not discovered then???
  ( CMB was eventually discovered in 1965 by serendipity)

  - failure to explain creation of elements beyond Helium!
  - breakdown of communication between theorists and experimentalists (radio astronomers)
  - general disregard for anything related to “Early Universe”
Vatican endorses the Big Bang

- Pope Pius XII (1939 – 58)
  - Eugenio Pacelli

- 1951: official endorsement
  - speech `The Proofs for the Existence of God in the Light of Modern Natural Science’

- Big Bang = moment of Creation
Soviet Union bans the Big Bang

- Marxism-Leninism
- philosophy: dialectical materialism
- materialism no creation of matter out of nothing (matter, and therefore the universe, must have existed forever!)

- Soviet scientists endorsing Big Bang were sent to `Gulag`!
• recession speed = (Hubble) constant x distance

\[ v = H_0 \times d \]

• \( H_0 = 500 \text{ km s}^{-1} \text{ Mpc}^{-1} \)
  - Hubble’s original value

\[ \text{age of the universe} = \frac{1}{H_0} \]

for \( H_0 = 500 \text{ km s}^{-1} \text{ Mpc}^{-1} \), \( \frac{1}{H_0} = 2 \text{ billion years} \)

• Age of the universe (in Big Bang model) shorter than estimated age of the Earth (~4 billion years)!!!
History of $H_0$

Compilation by John Huchra

- Baade identifies Pop. I and II Cepheids
- “Brightest stars” identified as H II regions

Jan Oort
The Steady State Alternative (1948)

- Hermann Bondi (1919-2005)
- Thomas Gold (1920-2004)
- Fred Hoyle (1915-2001)

- worked out at Cambridge University, England
Hoyle coins the term “Big Bang”

- 1950: BBC radio interview
- derogative term for rival theory to his own steady-state
- before that, “Big Bang” was called “dynamic evolving model”

Fred Hoyle

- Both Hoyle and Gamow fought a PR battle!
Steady State Alternative

Evolving universe ("Big Bang")
- density changes with time
- past different from present
- beginning of time ("Big Bang")

Steady state universe
- density constant over time
- universe never changes
- no beginning of time
Steady State Alternative

- How does density change over time?
Steady State Alternative

- How can density be constant despite cosmic expansion?

- Continuous creation of matter ("C-field")

- Need: 1 atom per liter per billion years
Steady State Alternative

• How and when is matter created?

Evolving universe ("Big Bang")

- all of matter at beginning of time

Steady state universe

- small amounts of matter all the time

• For both models: matter is created out of nothing!
Steady State Alternative

• steady-state equilibrium: Patterns remain, but matter flows constantly `through’ them

• A: steady state: pattern (here: volume) doesn’t change

• B: static case: nothing changes (e.g., Einstein’s Universe)
Einstein’s Eternal (and static) Universe

- 1917: Einstein constructs model of the universe that is eternal and static

- balance between attractive gravity and repulsive cosmological constant (“anti-gravity”)

- finite but without boundary (spatially closed)
Steady State Alternative

- steady-state theory obeys *perfect cosmological principle*

- cosmological principle: universe looks *everywhere* the same (on average) isotropy and homogeneity

- perfect cosmological principle (PCP): universe looks *everywhere* and *everywhen* the same (homogeneity in space and time)

- aesthetic appeal of PCP because of higher symmetry
Steady State vs Big Bang

• Decision has to come from observations!

1. Radio Galaxies and Quasars

Martin Ryle (1918-84)  
Cambridge (England) radiotelescope
Steady State vs Big Bang

• Decision has to come from observations!

1. Radio Galaxies (RGs) and Quasars

- radio galaxies (discovered in 1950s)

Density of RGs vs time

Time

Today

Steady-state

Ryle’s observation

N
Steady State vs Big Bang

• Decision has to come from observations!

1. Radio Galaxies (RGs) and Quasars

   • RGs and quasars were more numerous in the past!

   • Ryle’s observations contradict steady-state model, but are in accordance with Big Bang

   • Ryle wins 1974 Nobel Prize in Physics

Martin Ryle (1918-84)
Steady State vs Big Bang

• Decision has to come from observations!

2. Discovery of Cosmic Microwave Background

1965: Bell Labs Holmdel (NJ) horn antenna

• Serendipitous discovery: There is unaccounted `noise’ in microwave band!

• What is it???
Steady State vs Big Bang

• Decision has to come from observations!

2. Discovery of Cosmic Microwave Background

• Gamow’s old Big Bang fireball prediction!

• a perfect thermal (‘blackbody’) spectrum!
Steady State vs Big Bang

• In 1940s and 50s, two rival models of cosmology:
  - “Big Bang” (Gamow, Alpher, and Herman):
    - universe started out in exceedingly dense and hot state
    - Hydrogen and Helium are created in first few minutes
    - universe is strongly evolving
  - Steady State (Hoyle, Bondi, and Gold):
    - universe had no beginning
    - continuous creation of matter

• Decision by observations in favor of Big Bang
  - Redshift distribution of radio galaxies and quasars (Ryle)
  - discovery of cosmic microwave background (Penzias/Wilson)