Astronomy 350L

(Fall 2006)

The History and Philosophy of Astronomy

(Lecture 23: Steady State vs Big Bang)

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The University of Texas at Austin

Steady State vs Big Bang Universe

à Permanence vs change!

Parmenides

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

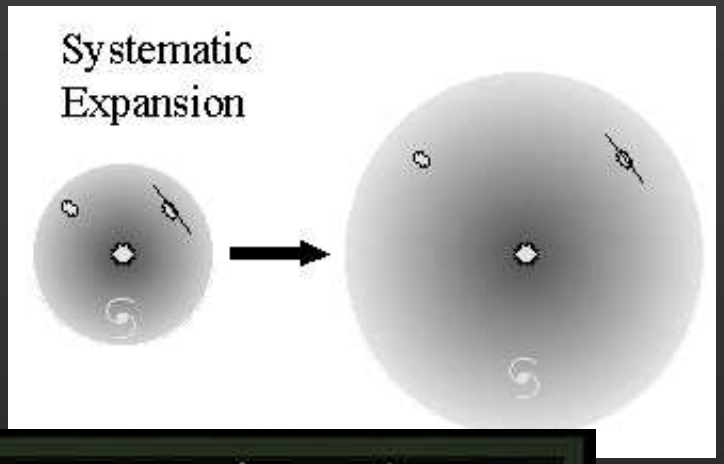
Heraclitus

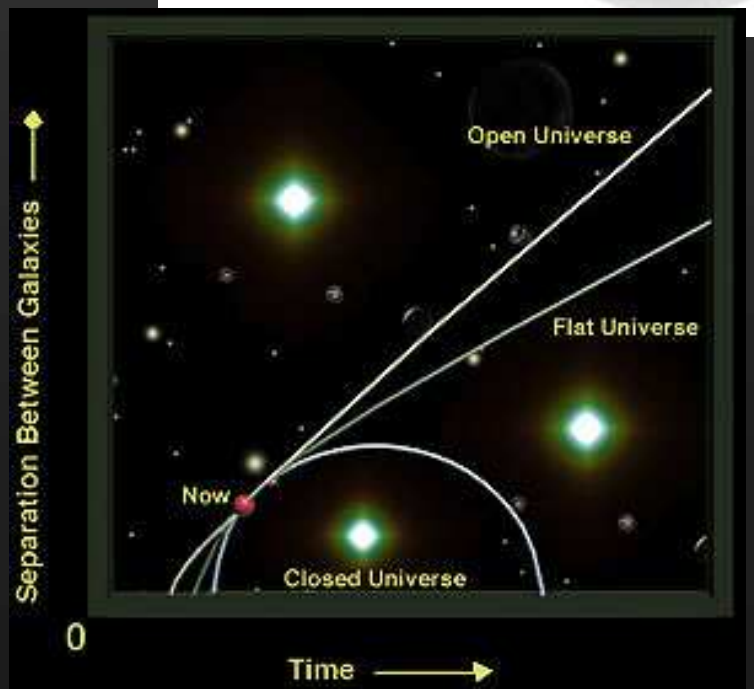
- everything is in perpetual flux!
- basic element: fire
- “Panta Rhei!”

Origin of the Big Bang Theory

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

Alexander Friedmann
(1888-1925)

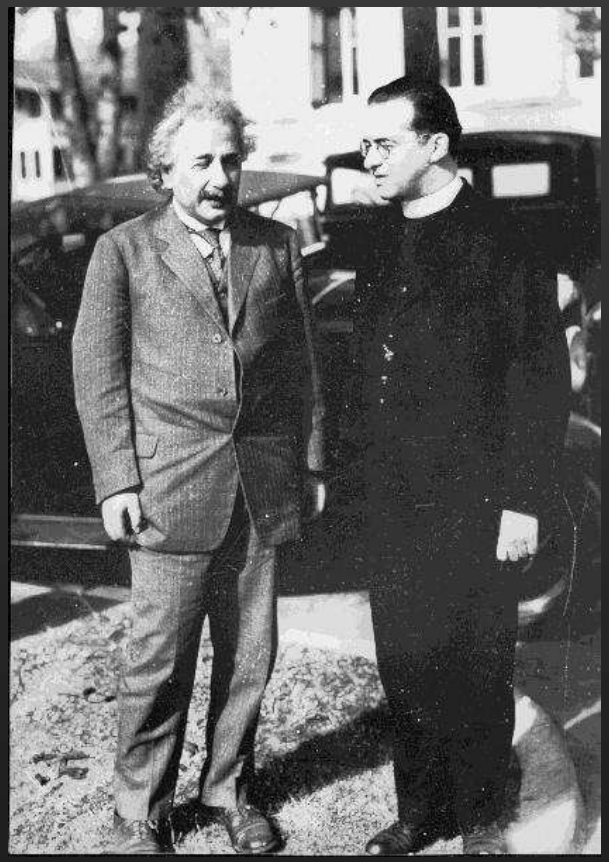




Origin of the Big Bang Model

- 1927: Lemaitre independently (re-) discovers the expanding-universe solutions of GR

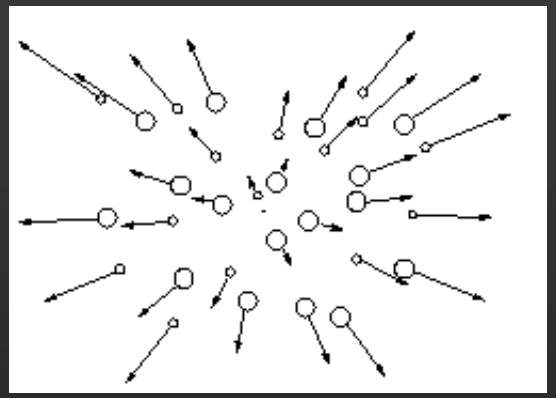
Abbe Georges Lemaitre (1894-1966)

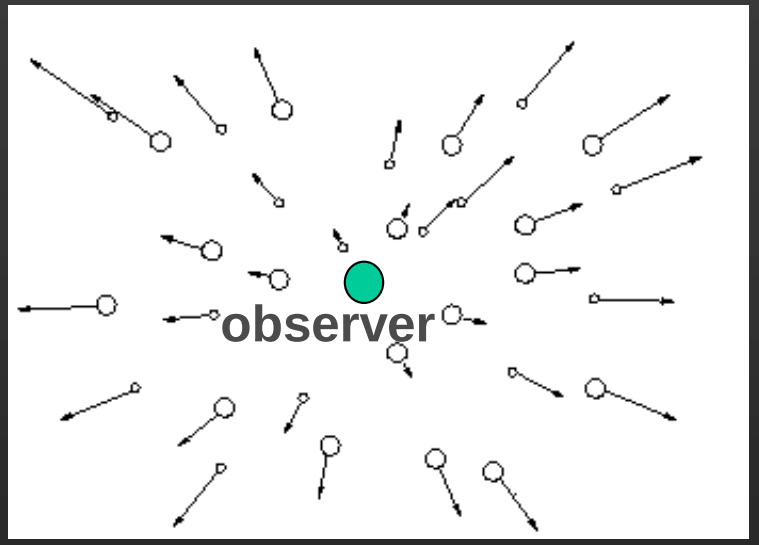


Lemaitre meets Einstein (Pasadena, 1933)

Origin of the Big Bang Model

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





Cosmic 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!

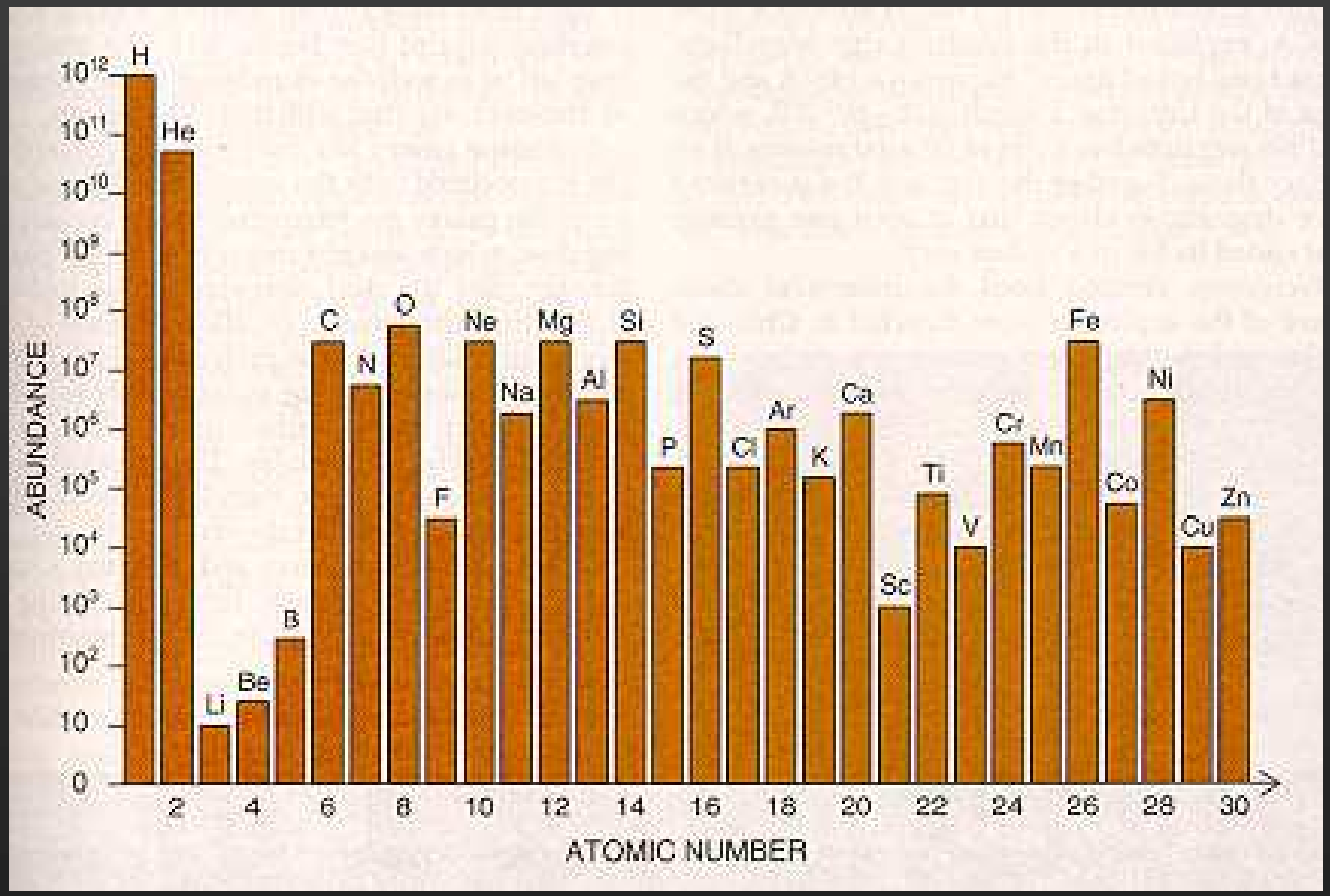
  à Lemaitre: "Father of the Big Bang"

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”)

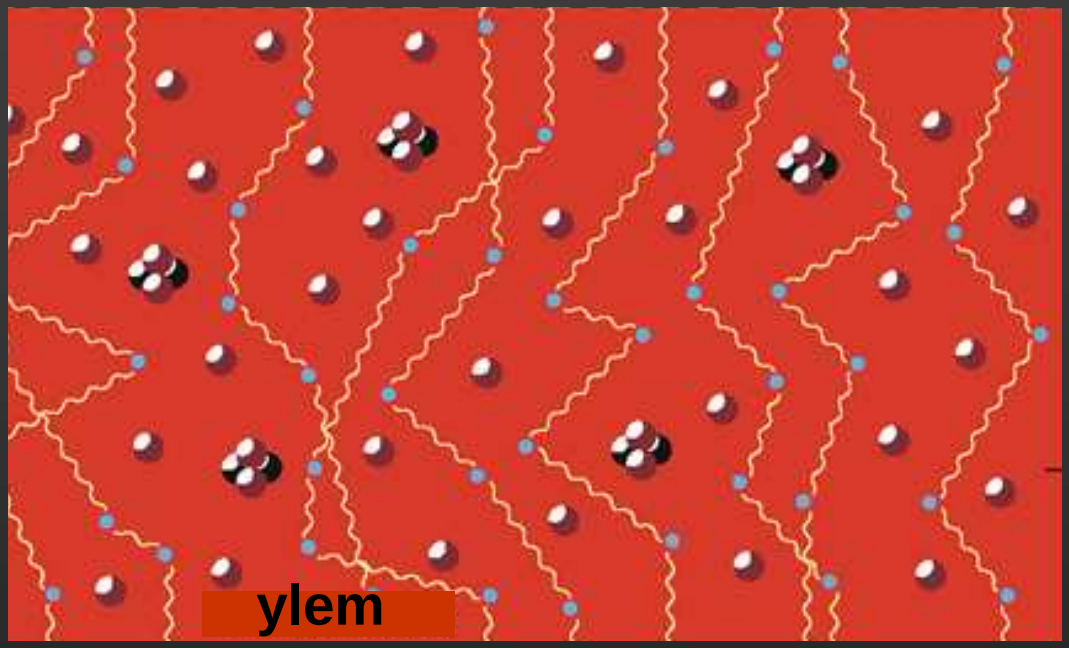
The Riddle of the Chemical Elements

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?

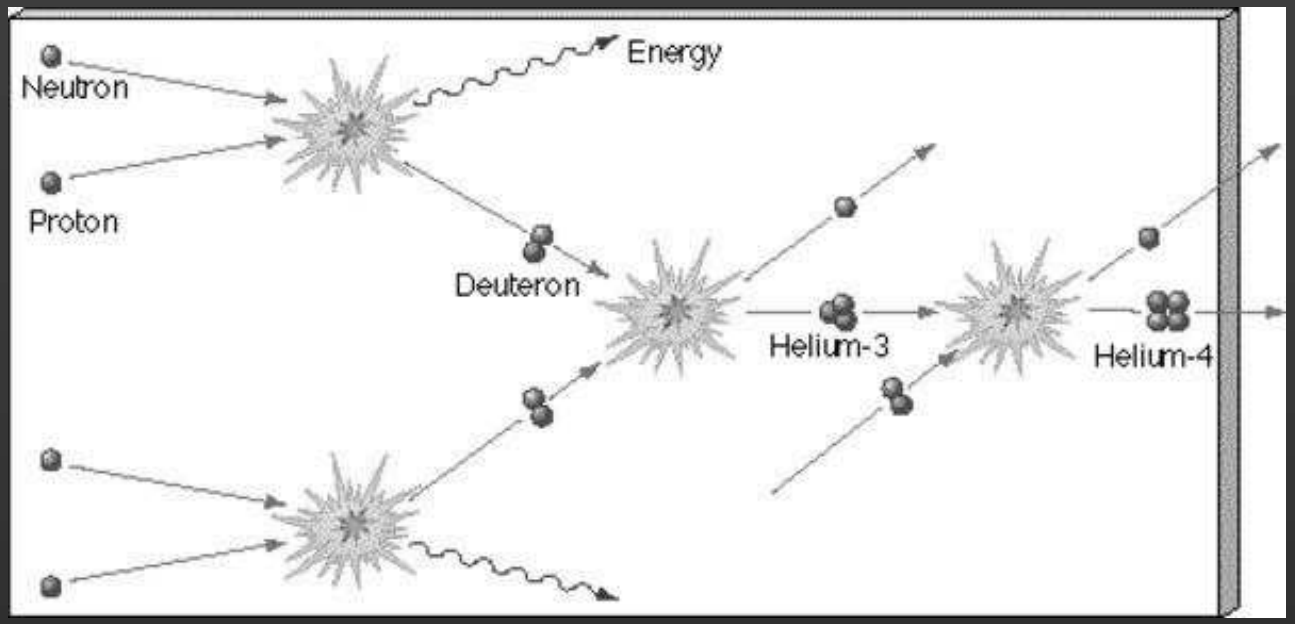
Big Bang Nucleosynthesis

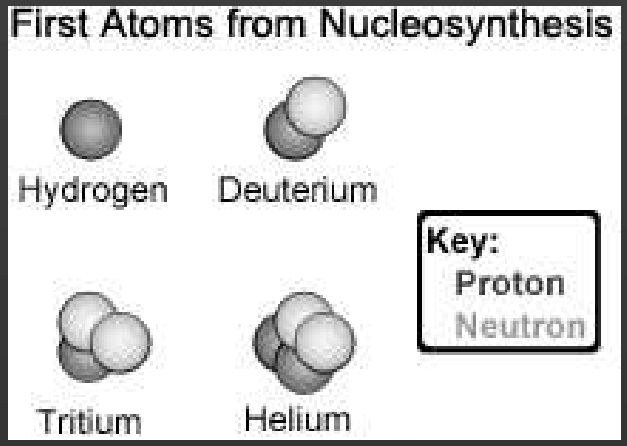


"Hot Big Bang"

- 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

Big Bang Nucleosynthesis



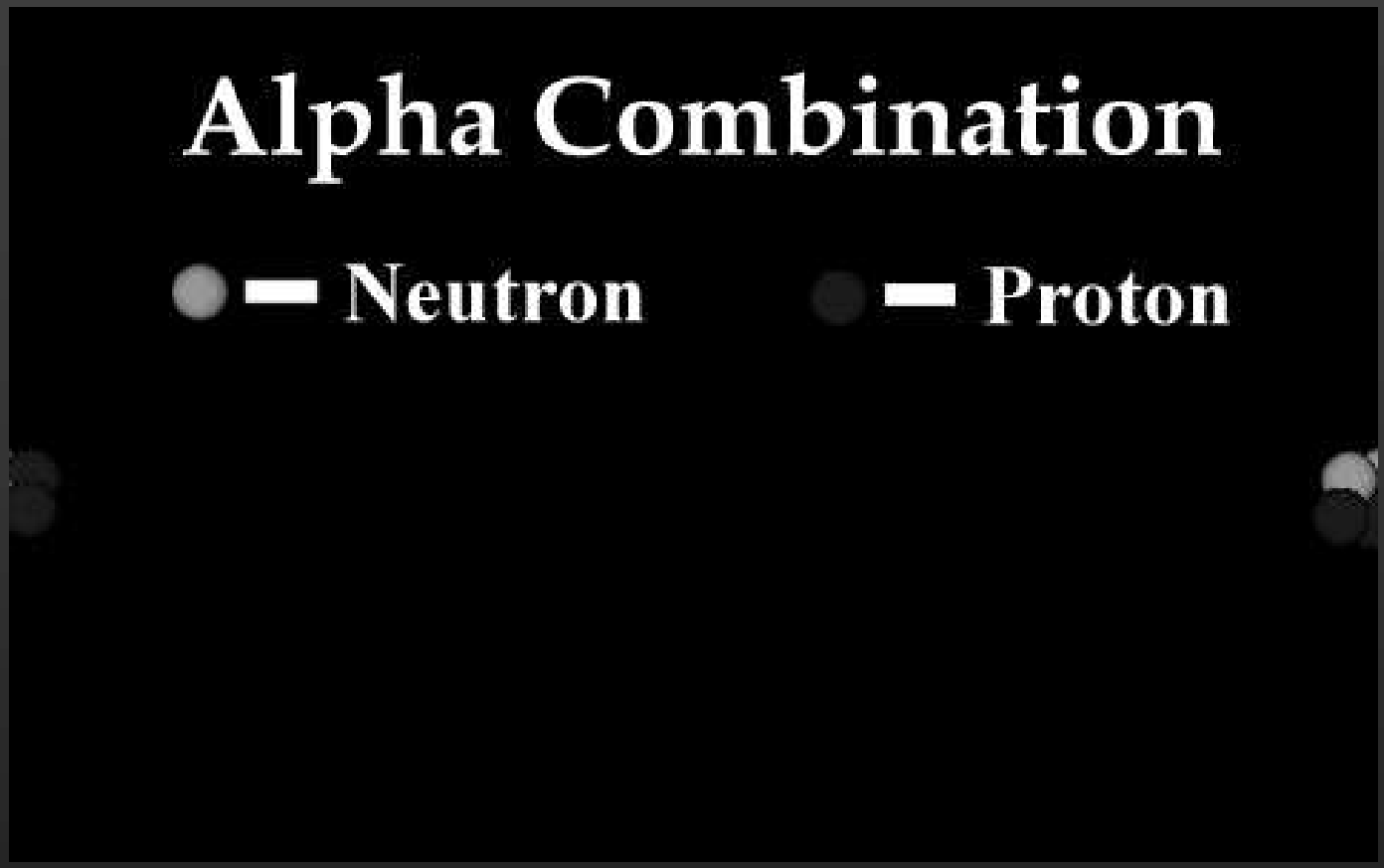


- Great success: Big Bang nucleosynyhesis can successfully explain Helium abundance (1 He atom per 10 H atoms)

- published (April 1, 1948) as Alpher, Bethe, & Gamow (the “alphabetical paper”: alpha, beta, gamma…)

Big Bang Nucleosynthesis

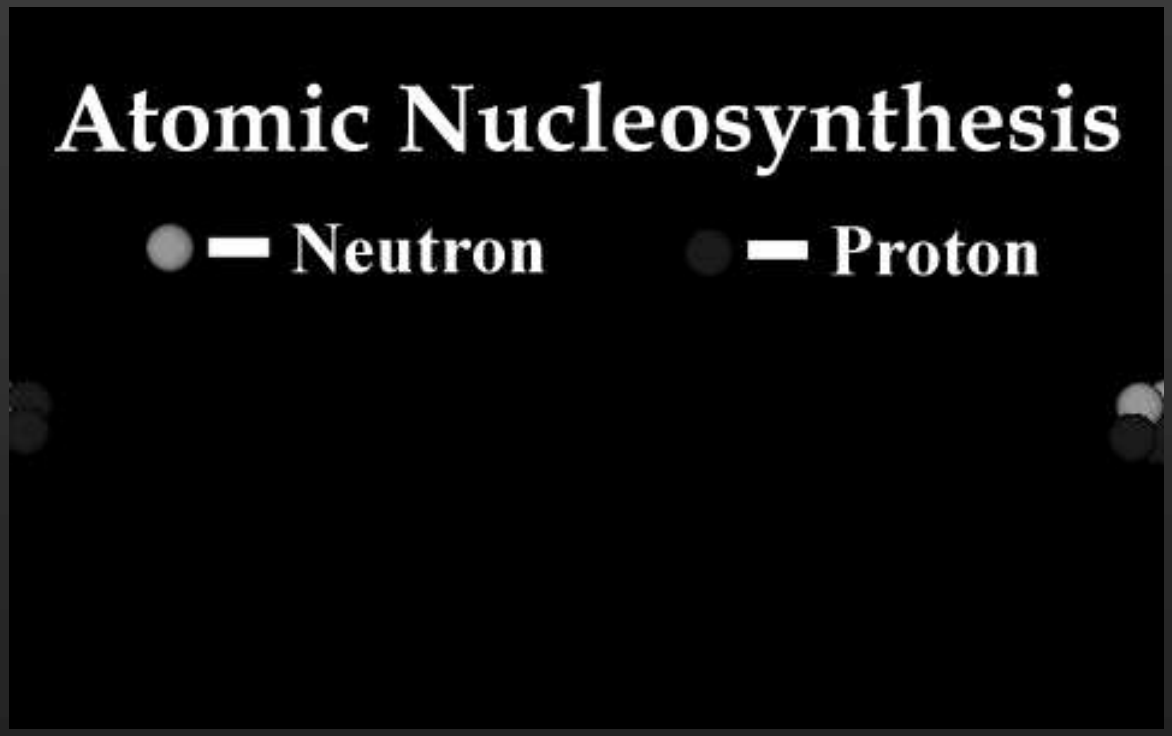
Big Bang Nucleosynthesis



- Big problem: theory doesn't work for heavier elements:
  - He+neutron, He+proton unstable!
  - He + He (à Be) unstable!

Modern View of Nucleosynthesis

1. **Hydrogen, helium: Big Bang**
2. **All other elements: Interior of stars**



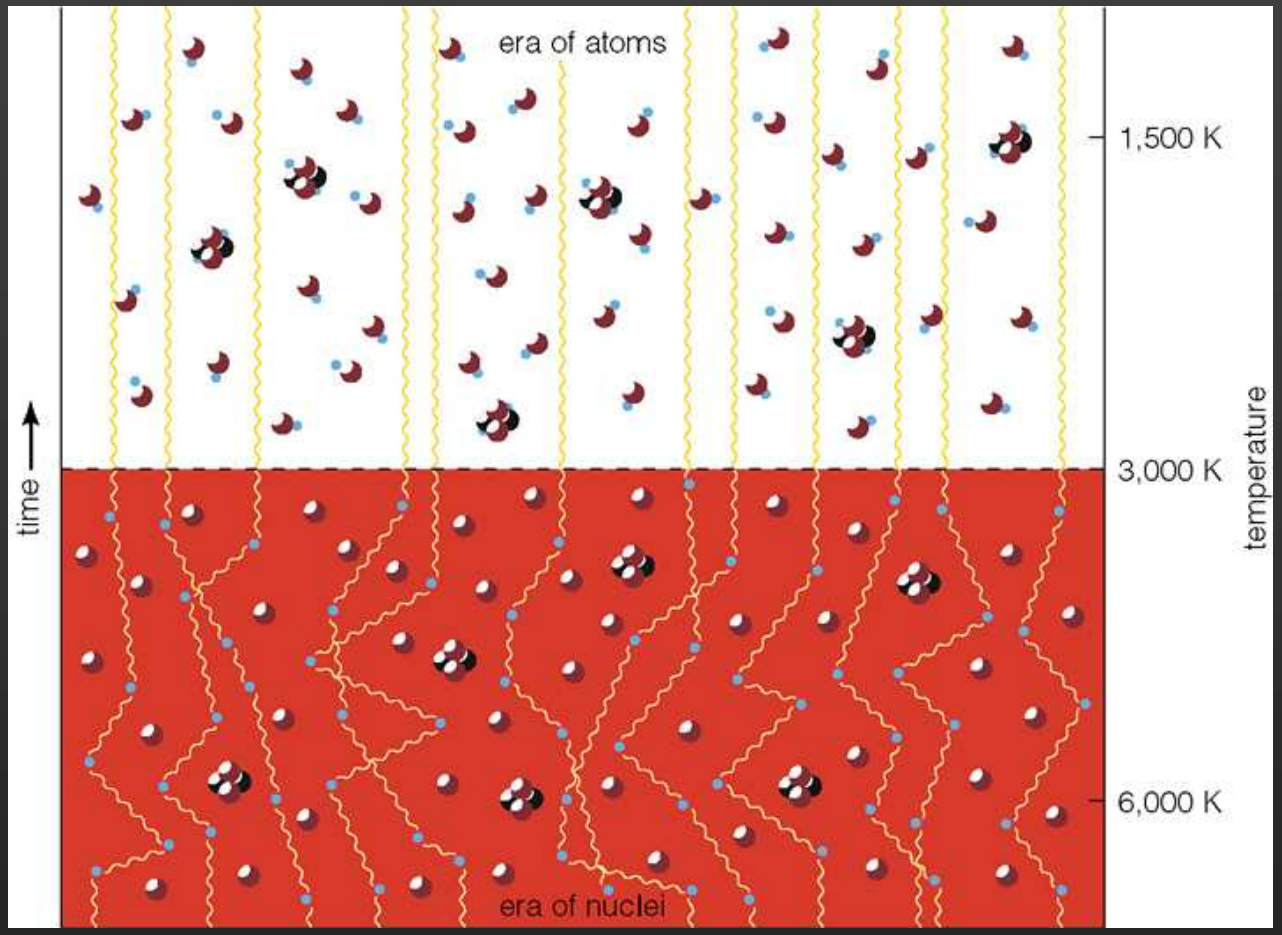
- Bridging the “Helium-carbon gap”:
  Triple-alpha process (Edwin Salpeter, 1952)

Modern View of Nucleosynthesis

- Successful theory of creating the elements in stars:
  - Burbidge, Burbidge, Fowler, & Hoyle (B^2FH 1957)

Predicting Cosmic Background Radiation

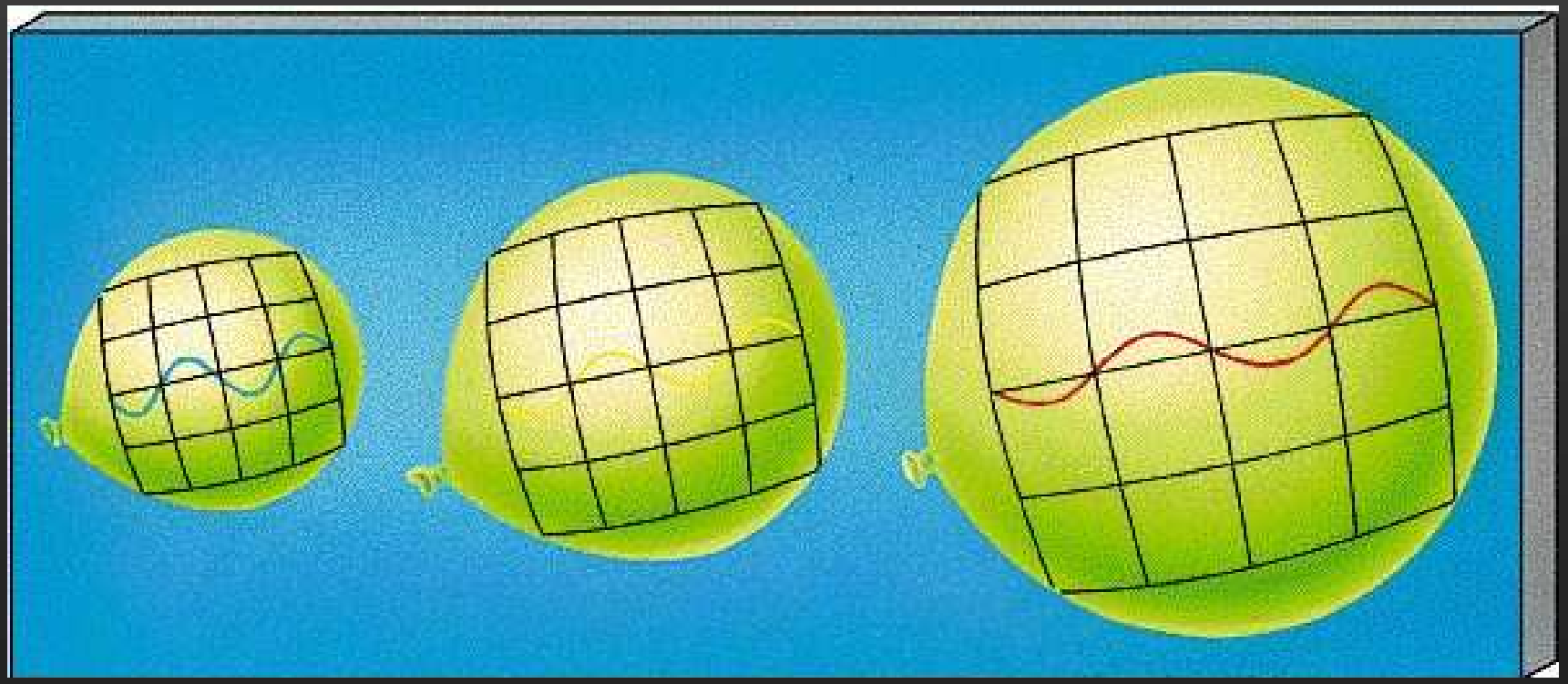
photons



- Big idea (Alpher and Herman 1948): Out of primordial fireball in early universe à 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???

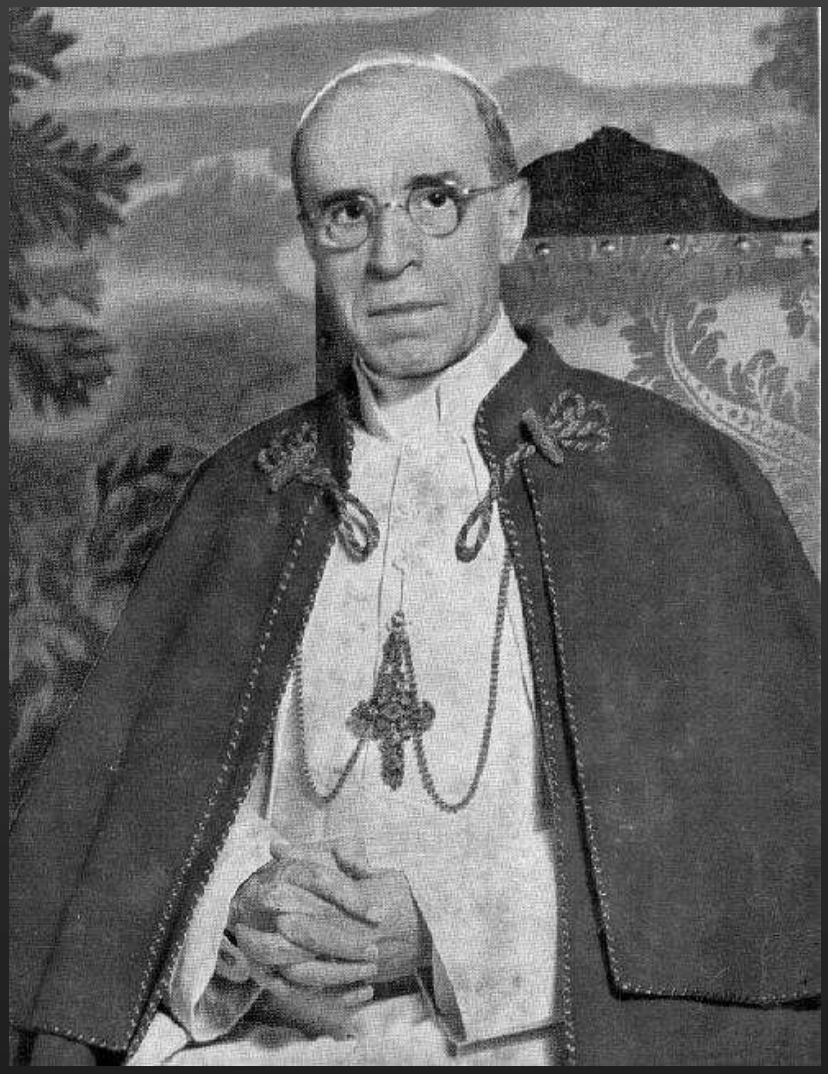
  (à CMB was eventually discovered in 1965 by serendipity)

  - failure to explain creation of elements beyond Helium!

  - breakdown of communication between theorists and experimentalists (radio astronomers)

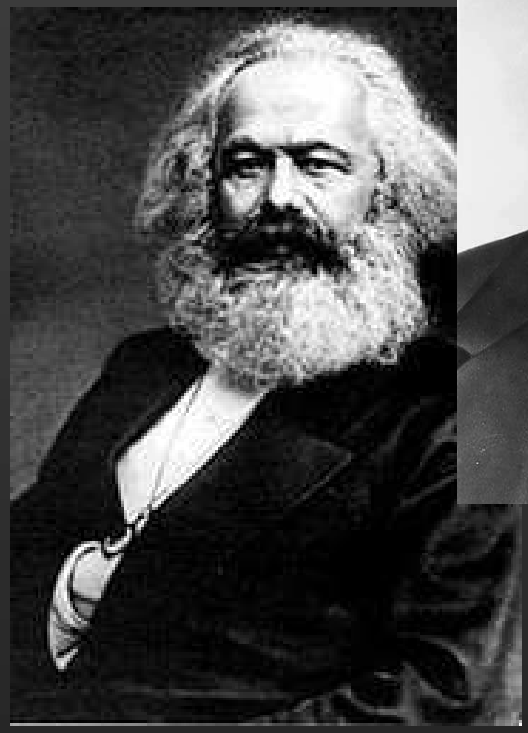
  - general disregard for anything related to “Early Universe”

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 à 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'!

Cosmic Age Problem

- recession speed = (Hubble) constant x distance
- $v = H_0 \times d$
- (H_0=500 km s^{-1} Mpc^{-1})
  - Hubble's original value

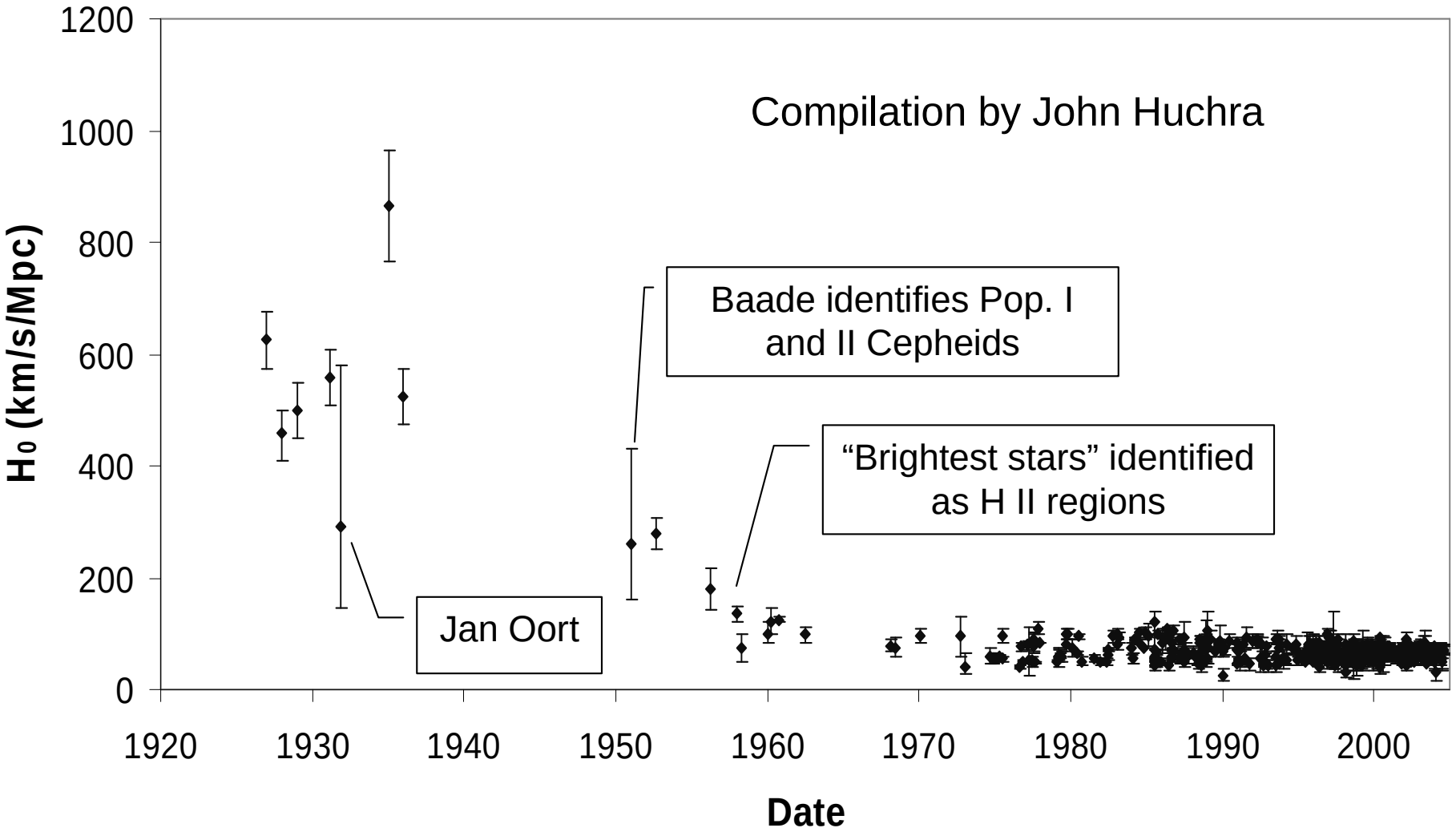
$$\text{time} = \frac{\text{distance to a given galaxy}}{\text{its velocity of recession}} = \text{age of the universe}$$

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

$$\text{for} \quad H_0 = 500 \frac{\text{km}}{\text{s Mpc}}, \qquad \frac{1}{H_0} = 2 \text{ billion years}$$

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

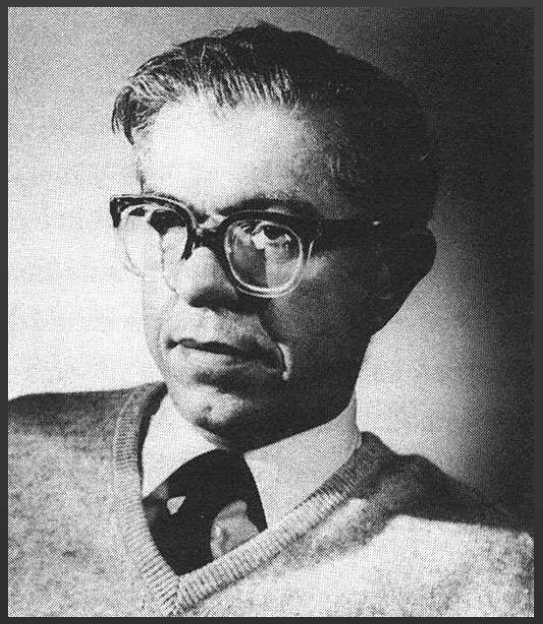
History of H_0



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”

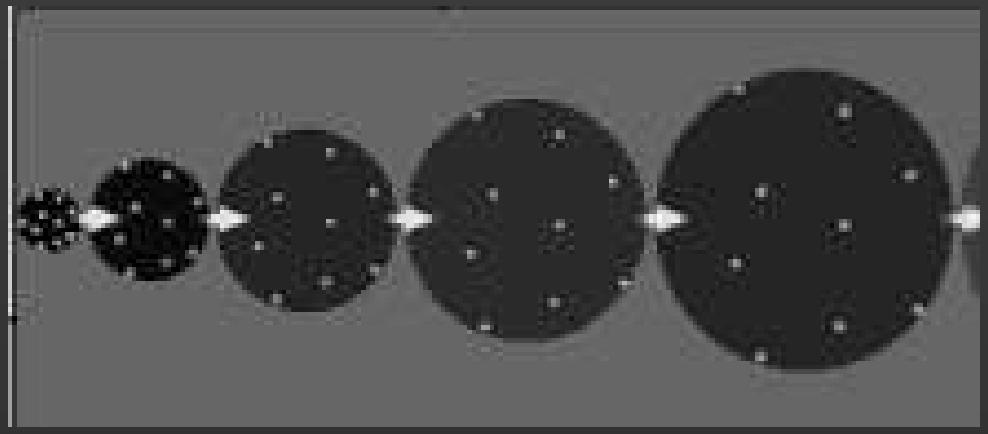
Fred Hoyle

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

- Both Hoyle and Gamow fought a PR battle!

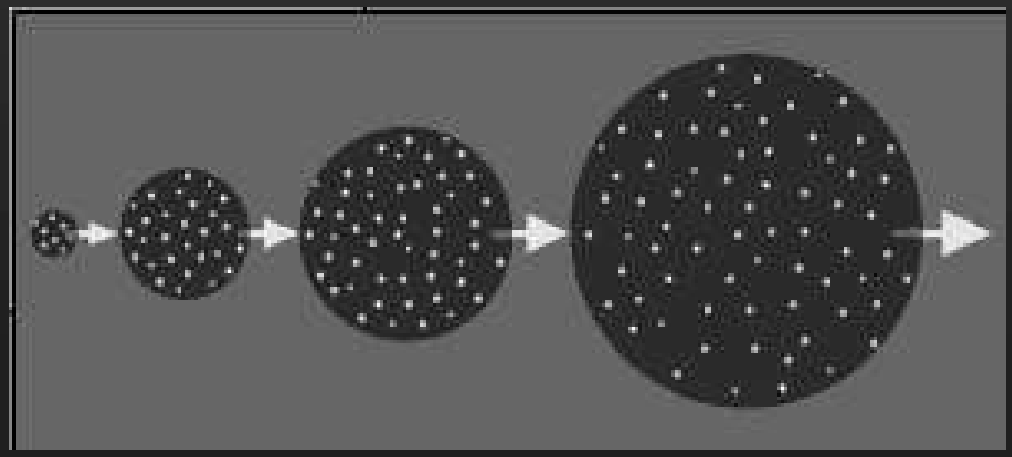
Steady State Alternative

Evolving universe (“Big Bang”)



- density changes with time
- past different from present
- beginning of time (“Big Bang”)

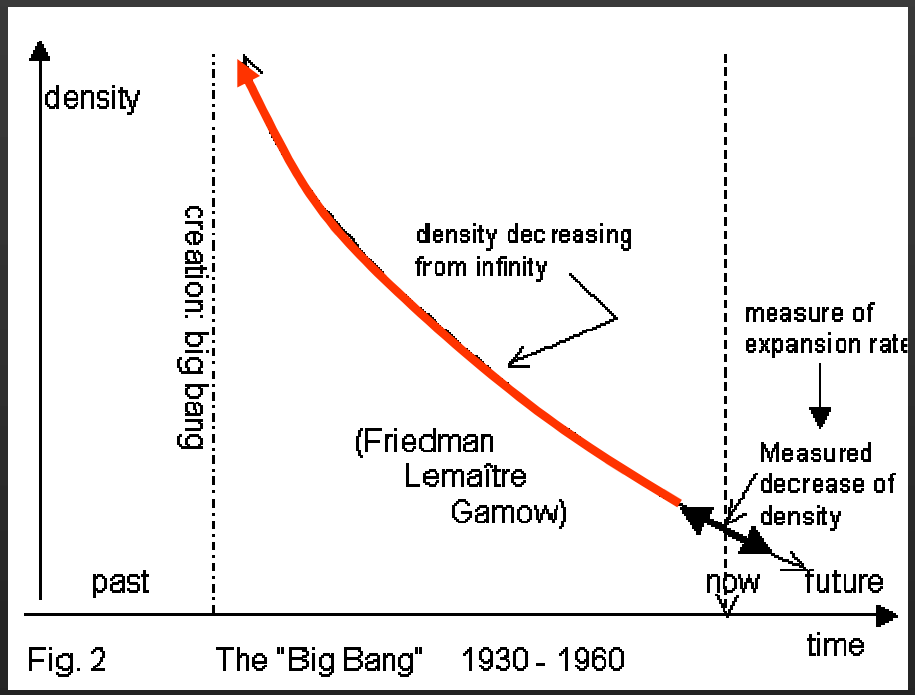
Steady state universe



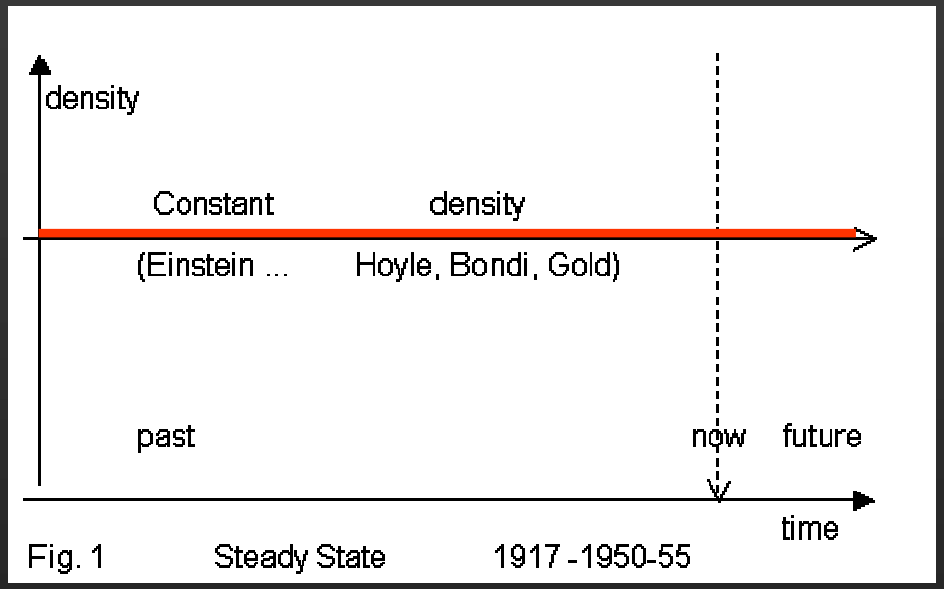
- density constant over time
- universe never changes
- no beginning of time

Steady State Alternative

- How does density change over time?



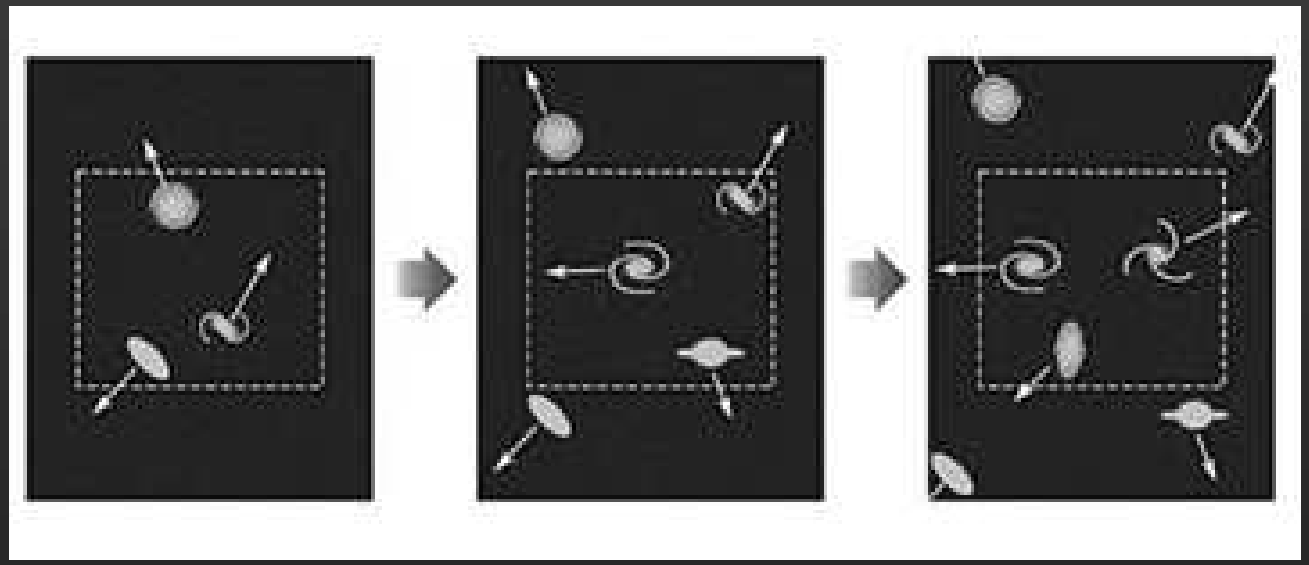
Evolving universe ("Big Bang")



Steady state universe

Steady State Alternative

- How can density be constant despite cosmic expansion?

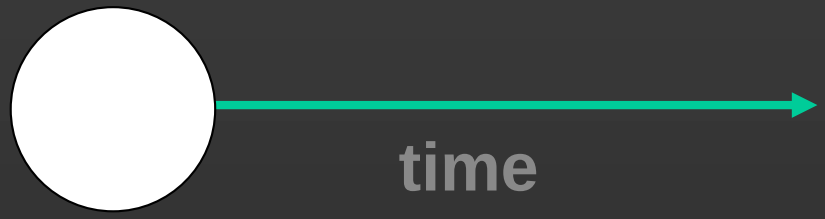


- continuous creation of matter (“C-field”)
- Need: 1 atom per liter per billion years

Steady State Alternative

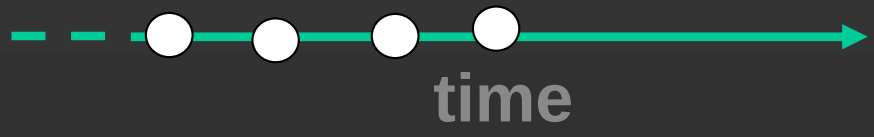
- How and when is matter created?

Evolving universe ("Big Bang")



- all of matter at beginning of time

Steady state universe

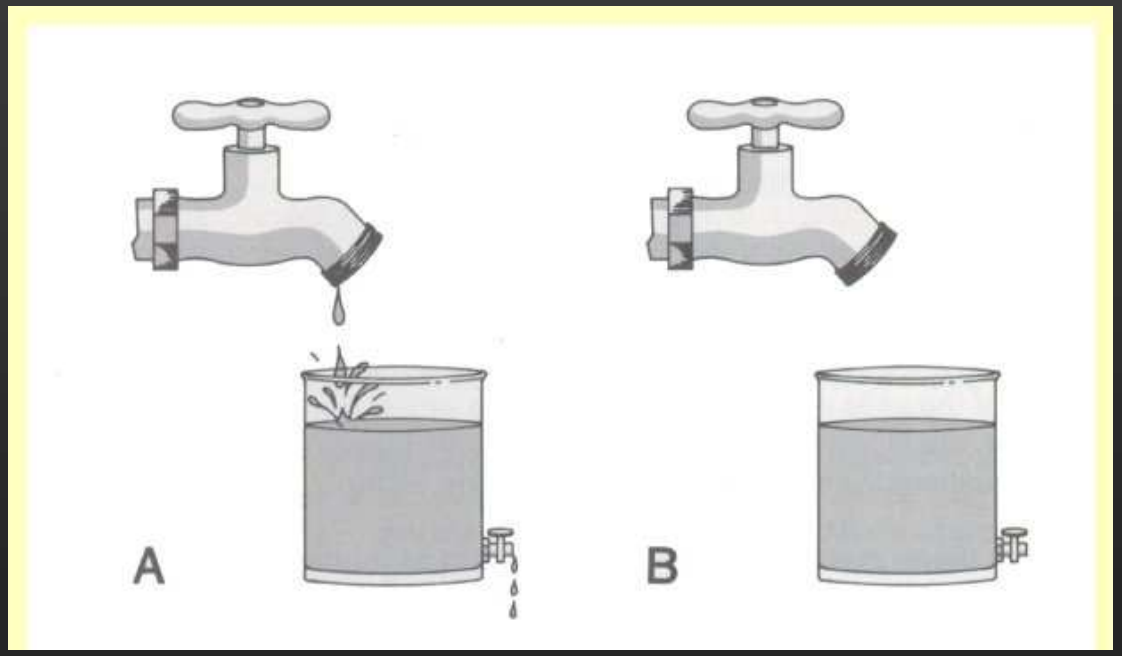


- small amounts of matter all the time

- For *both* models: matter is created out of nothing!

Steady State Alternative

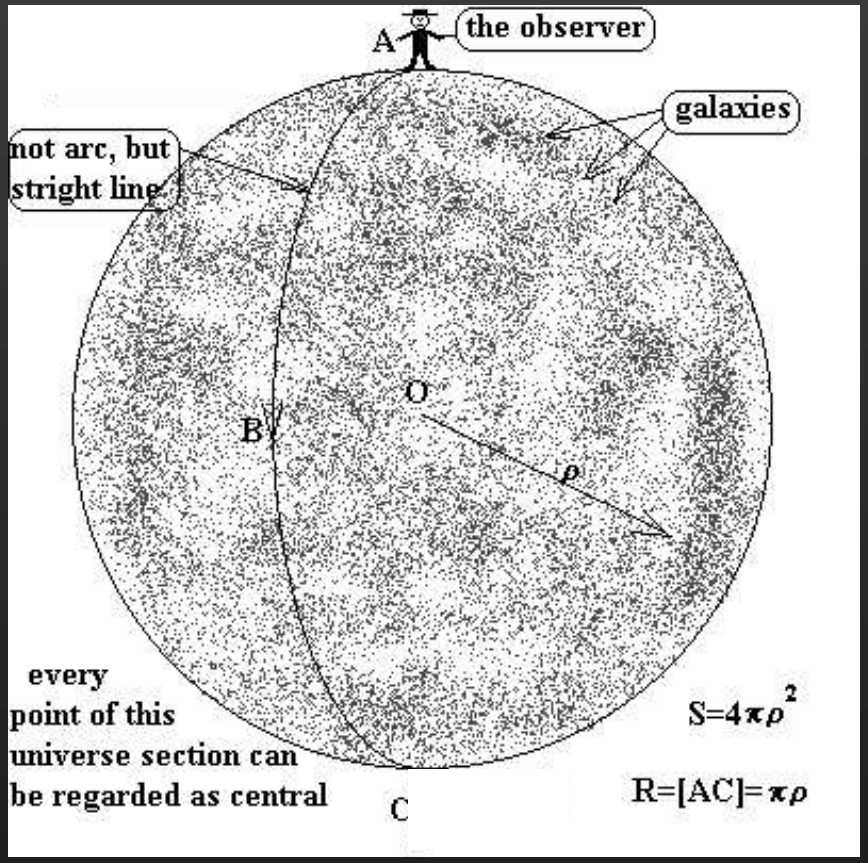
- steady-state equilibrium: Patterns remain, but matter flows constantly `through' them



- 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) à isotropy and homogeneity

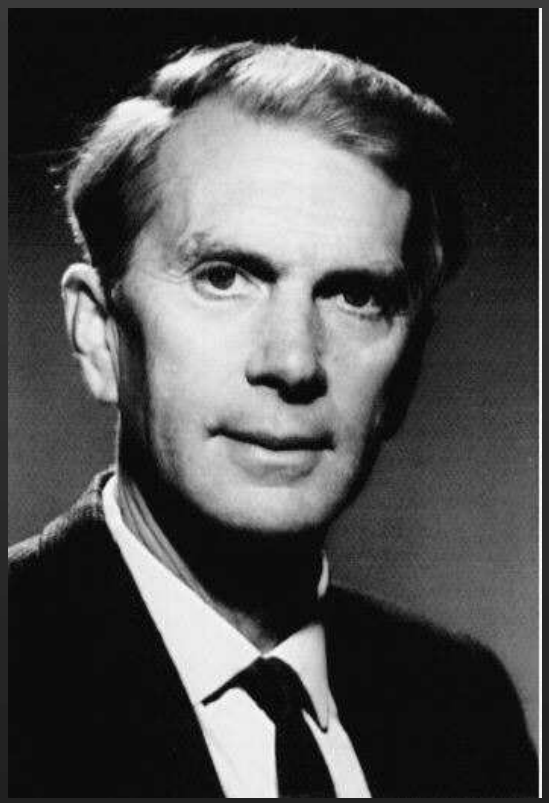
- perfect cosmological principle (PCP): universe looks *everywhere* and *everywhen* the same (homogeneity in space *and* time)

- aesthetic appeal of PCP because of higher symmetry

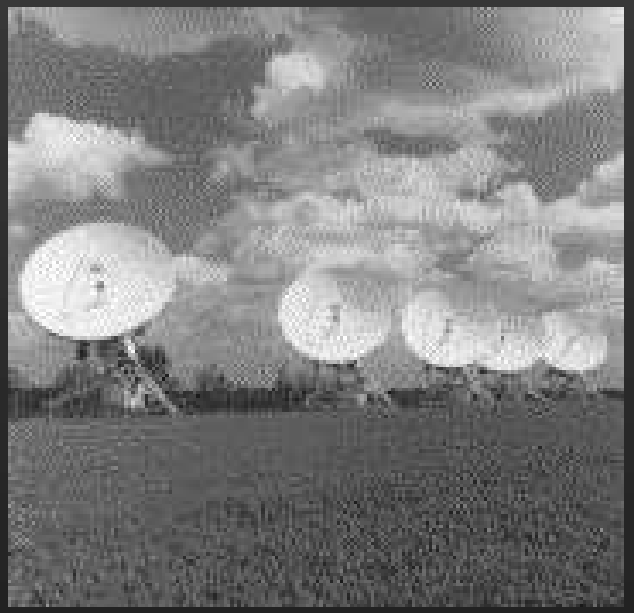
Steady State vs Big Bang

- Decision has to come from observations!

1. **Radio Galaxies and Quasars**



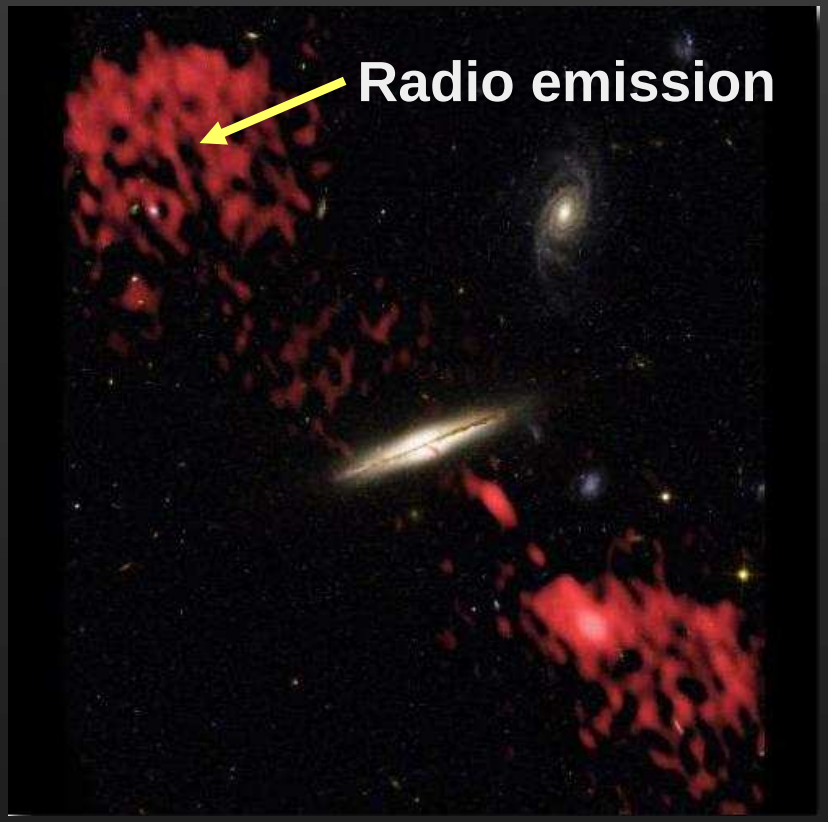
Martin Ryle (1918-84)



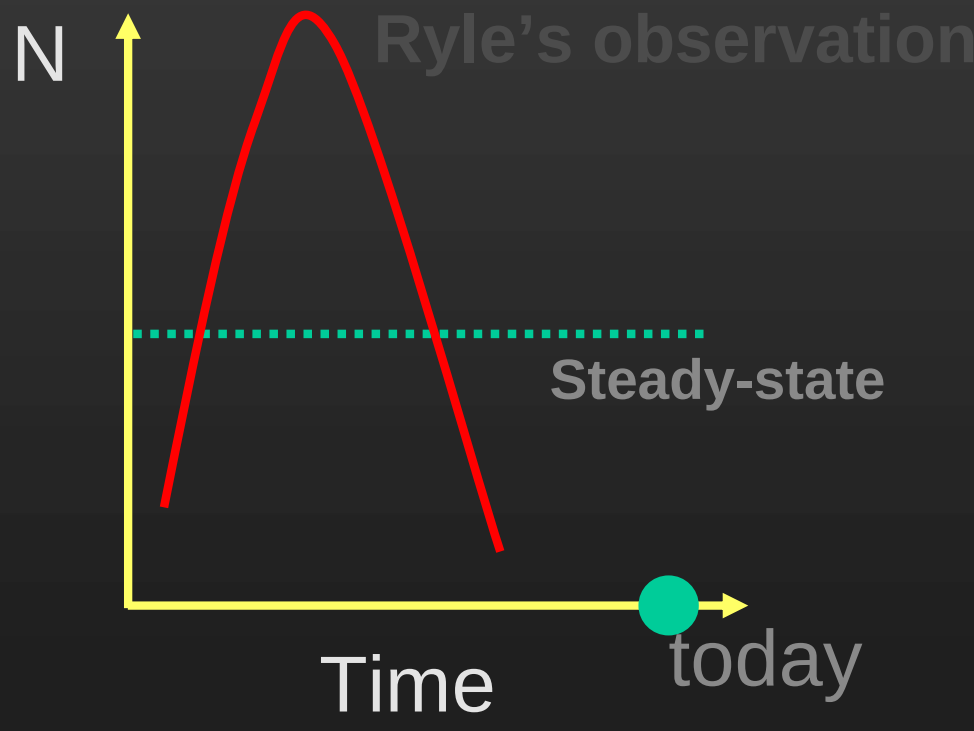
Cambridge (England) radiotelescope

Steady State vs Big Bang

- Decision has to come from observations!
  1. **Radio Galaxies (RGs) and Quasars**



Density of RGs vs time

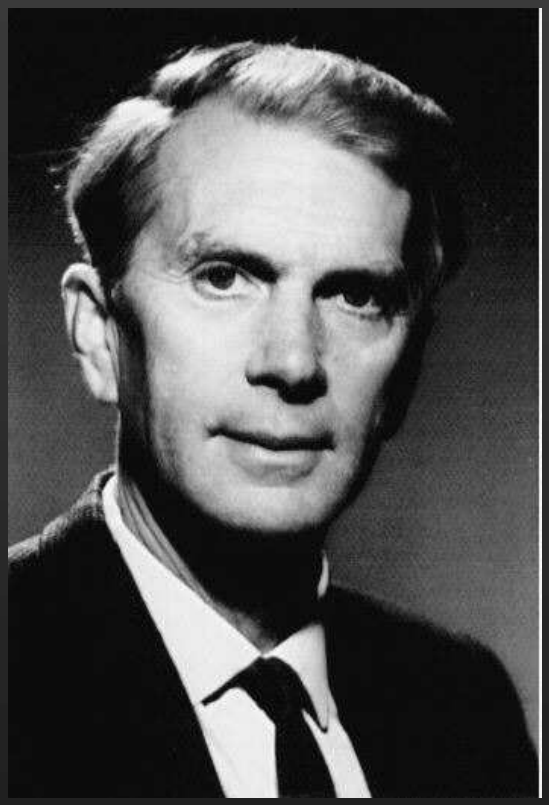


- radio galaxies
  (discovered in 1950s)

Steady State vs Big Bang

- Decision has to come from observations!

1. **Radio Galaxies (RGs) and Quasars**



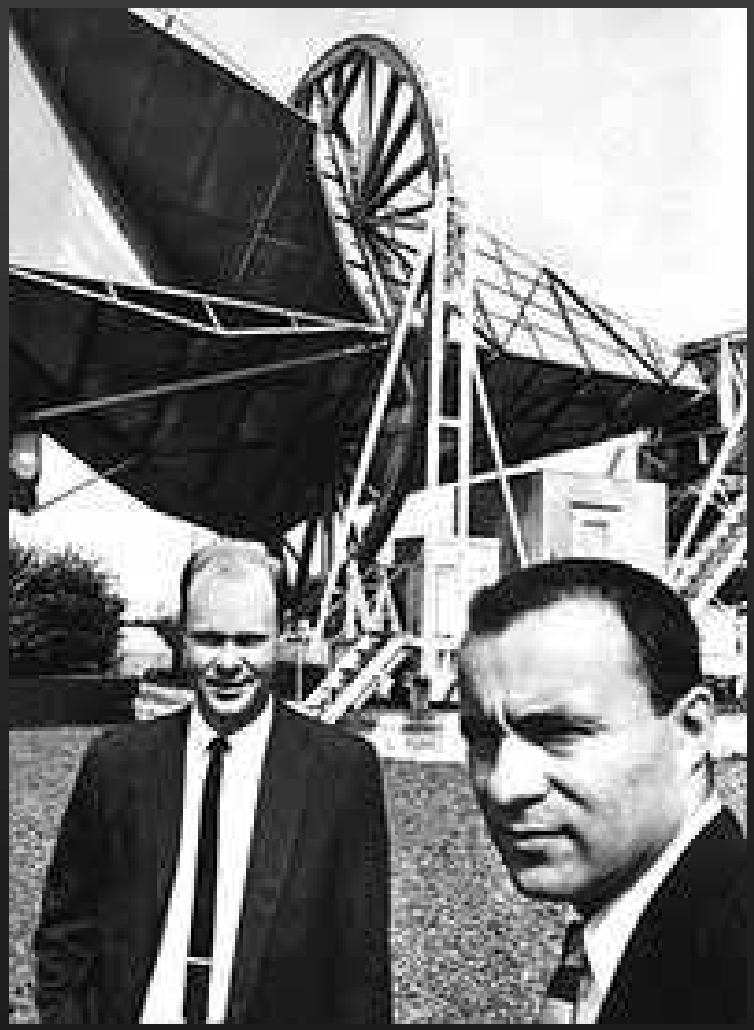
Martin Ryle (1918-84)

- 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

Steady State vs Big Bang

- Decision has to come from observations!

2. Discovery of Cosmic Microwave Background



Robert Wilson **Arno Penzias**

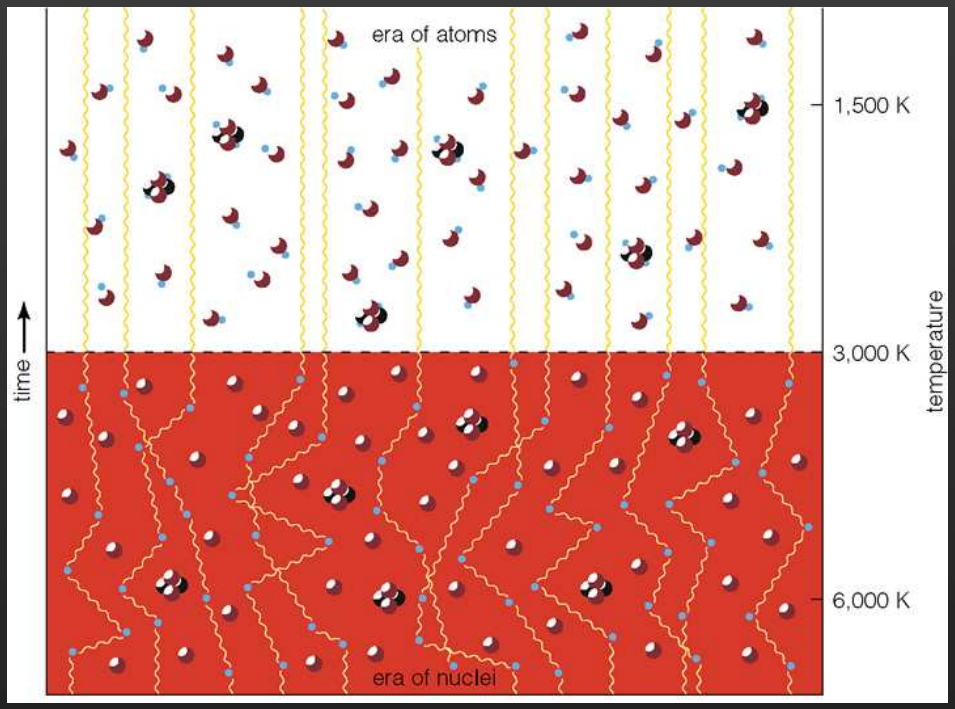
1965: Bell Labs Holmdel (NJ)
horn antenna

- Serendipitous discovery: There is unaccounted `noise' in microwave band!
- What is it???

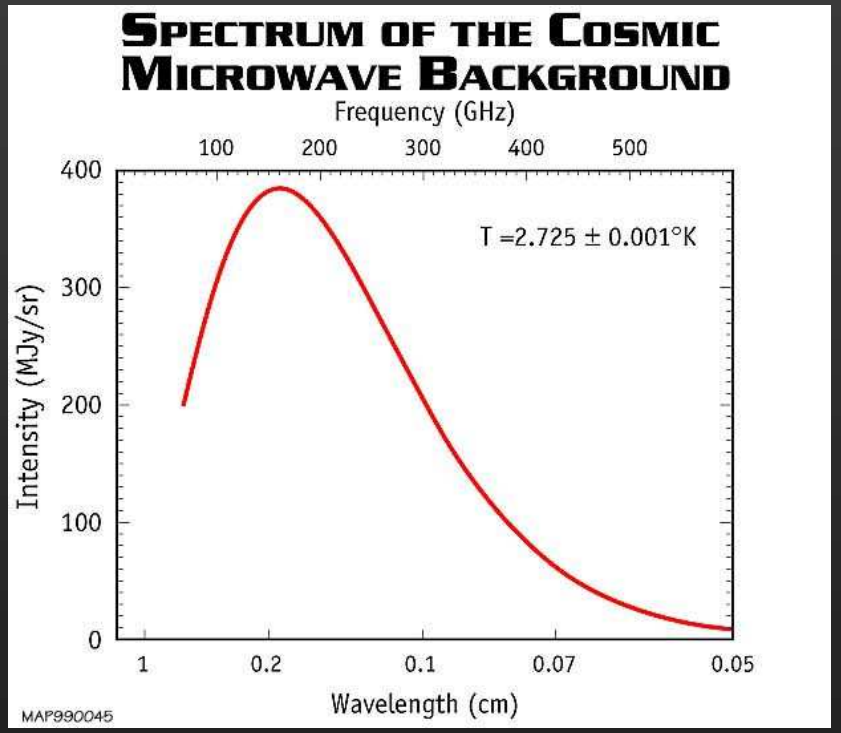
Steady State vs Big Bang

- 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)