

clicker Quiz #12

Which of the following statements is **FALSE**?

- A. Black holes emit Hawking radiation which can be characterized as black-body radiation with a temperature that is proportional to the black hole's mass
- B. The event horizon or Schwarzschild radius of a black hole, the region over which it is capable of trapping light (radiation), is proportional to the black hole's mass
- C. "A black hole has no hair" is a statement that describes the loss of identity of matter when it is swallowed by a black hole
- D. The gravitational field of a black hole extends out to an infinite distance

clicker Quiz #13

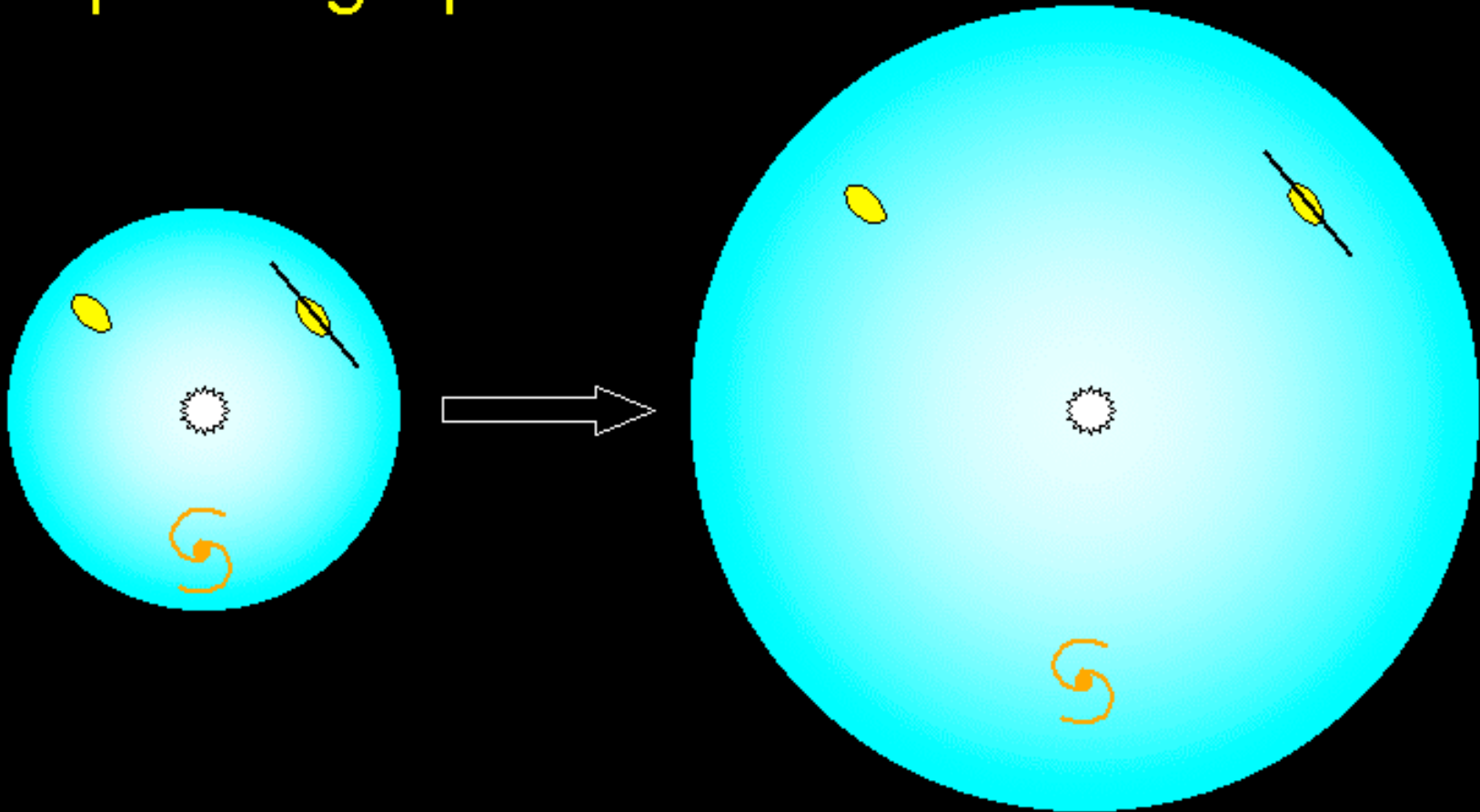
Which of the following statements is **FALSE**?

- A. Radio jets and lobes are lit up by synchrotron radiation produced by charged particles moving along spiral paths in a magnetic field
- B. The typical mass of a super-massive black hole that powers the nucleus of a quasar is about five million times the mass of our Sun
- C. The light-emitting region of a typical quasar is roughly comparable in size to our Solar System
- D. Quasars and AGNs can be 10 to 1000 times more luminous than our Milky Way galaxy
- E. Most galaxies have massive black holes at their centers

Expansion of the Universe

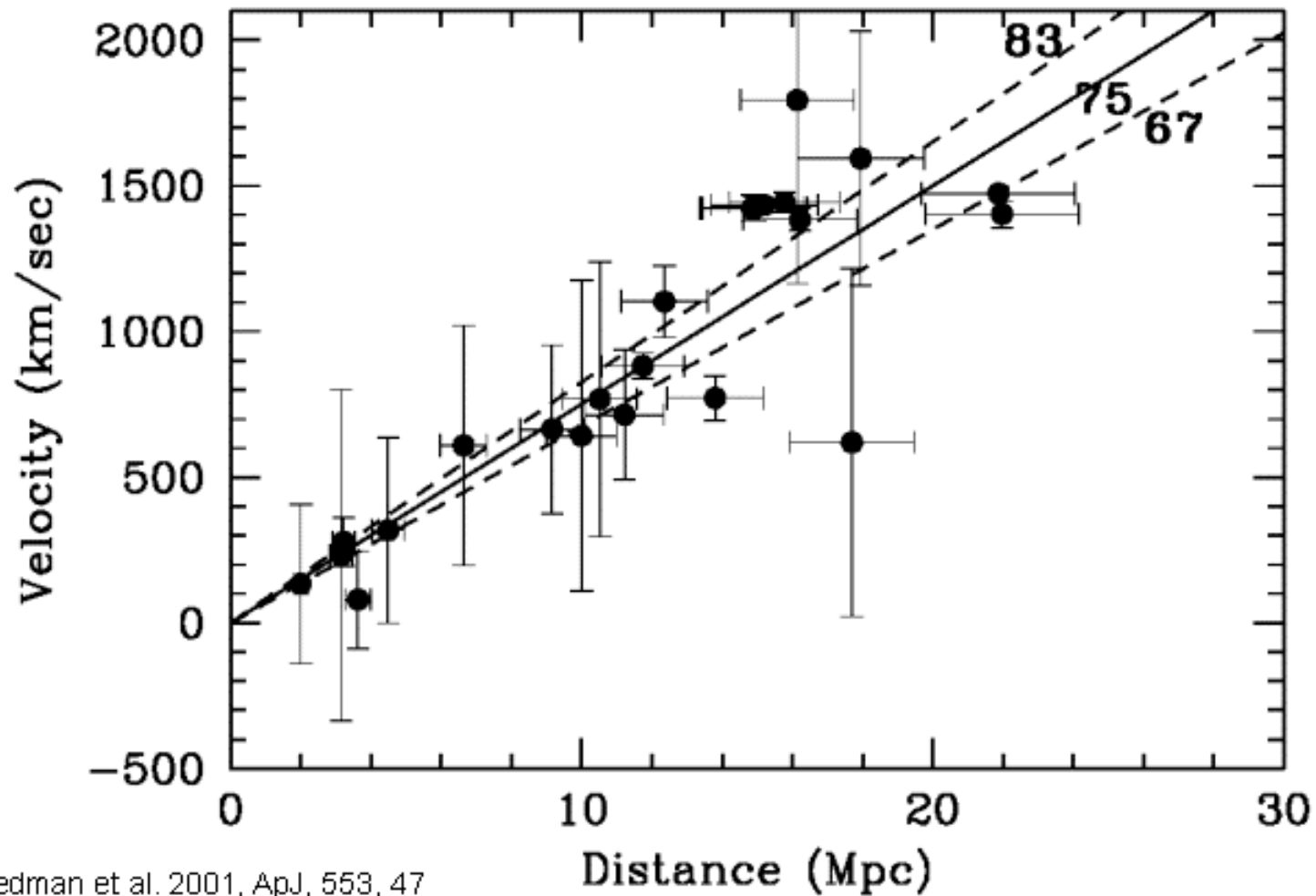
- Natural consequence of the basic field equations of the General Theory of Relativity (GTR)
- When GTR was first developed in the 1920s, everyone thought the Universe was **static**
- Albert Einstein's static solution: He arbitrarily introduced a **cosmological constant Λ** (later called it his “greatest blunder”)
- Edwin Hubble's observations of receding galaxies led to the discovery that the Universe is **expanding**
- Hubble's law: $v = H_0 d$ — where
 $H_0 \sim 70 \text{ km/s/Mpc}$ (Hubble constant)

Expanding Space-Time



Universe 2x larger
Galaxies are 2x further apart

Freedman et al. (2001) – HST Key Project



Freedman et al. 2001, ApJ, 553, 47

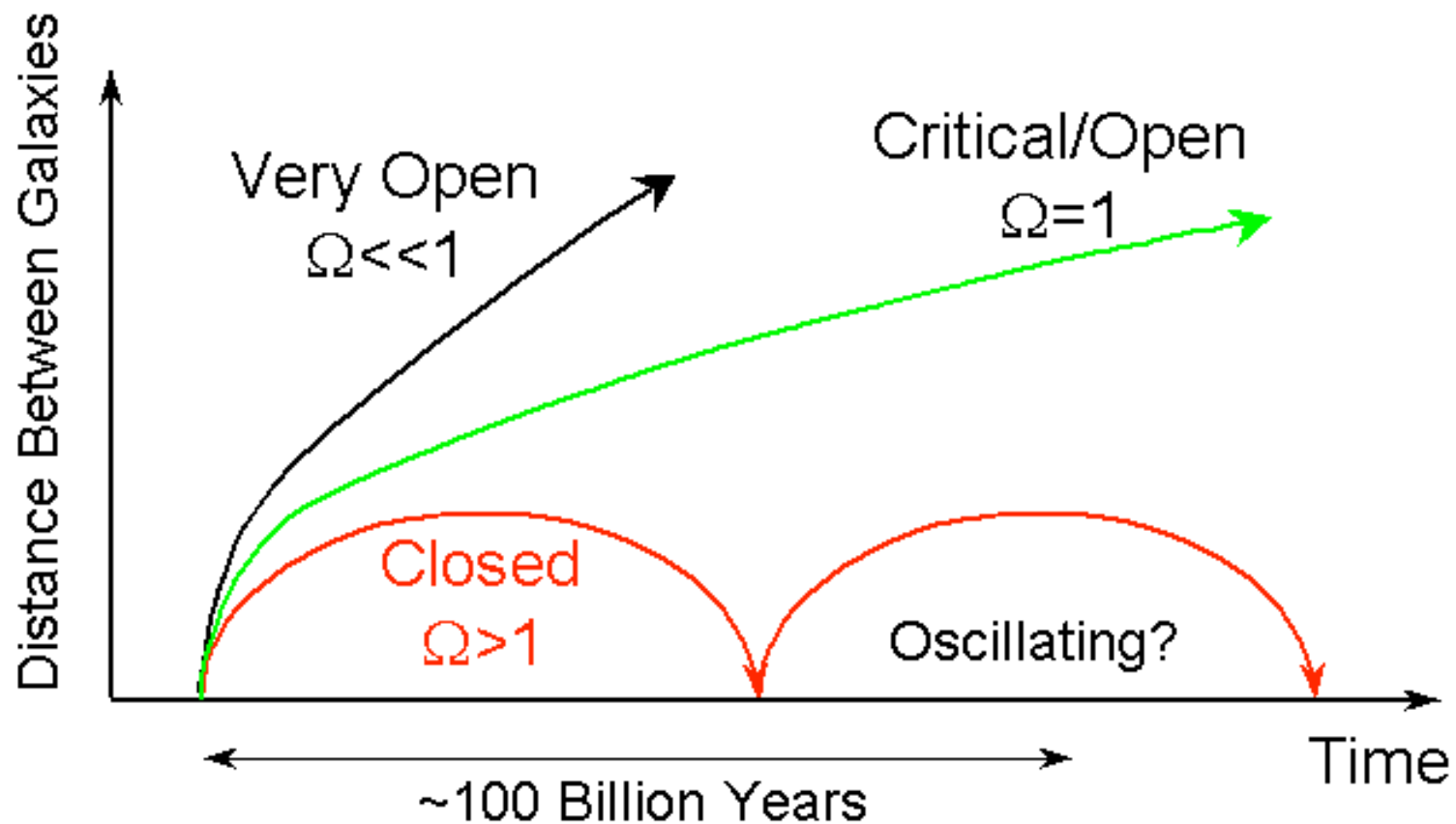
Nature of the Universal Expansion

- Hubble's law implies the Universe is expanding **uniformly**
- Expansion of Universe can be thought of as the **expansion of space itself**
- Observed redshift of distant galaxies — wavelength of photons **“stretched”** by the expansion of space
- **Not everything is expanding** — if it were, we couldn't detect the expansion since our rulers would be expanding in proportion to everything else in the Universe

The Big Bang

- Reverse extrapolation of Universal expansion → There must have been an instant of **infinite density** and **temperature** → The **BIG BANG!**
- Phrase “Big Bang” was derisively coined by Fred Hoyle, but the name stuck!
- It was **not** like an explosion: it happened **everywhere!**
- Universe has a finite age: $t \sim 1 / H_0$
- We are **not** allowed to ask the question: What happened **before** the Big Bang?

Histories for $\Omega_{\Lambda}=0$



The Future of the Universe

- Is the expansion **slowing down** (i.e., decelerating) because of the mutual **gravitational attraction** of all the matter in the Universe?

.....Or.....

- Is the expansion **speeding up** (i.e., accelerating) because of a repulsive **anti-gravity** force (analogous to Einstein's cosmological constant Λ)?
- One of the most exciting developments of the last decade is the discovery that the Universal expansion rate is actually **ACCELERATING!**

clicker Quiz #14

Which of the following statements is **TRUE**?

- A. Hubble's discovery that most distant galaxies are receding from us tells us that we are at the center of the Universe
- B. The Universe started with the Big Bang and will end in the Big Crunch
- C. The expansion rate of the Universe is speeding up because of a repulsive anti-gravity force
- D. The Andromeda galaxy is moving away from the Milky Way galaxy as a result of the expansion of the Universe