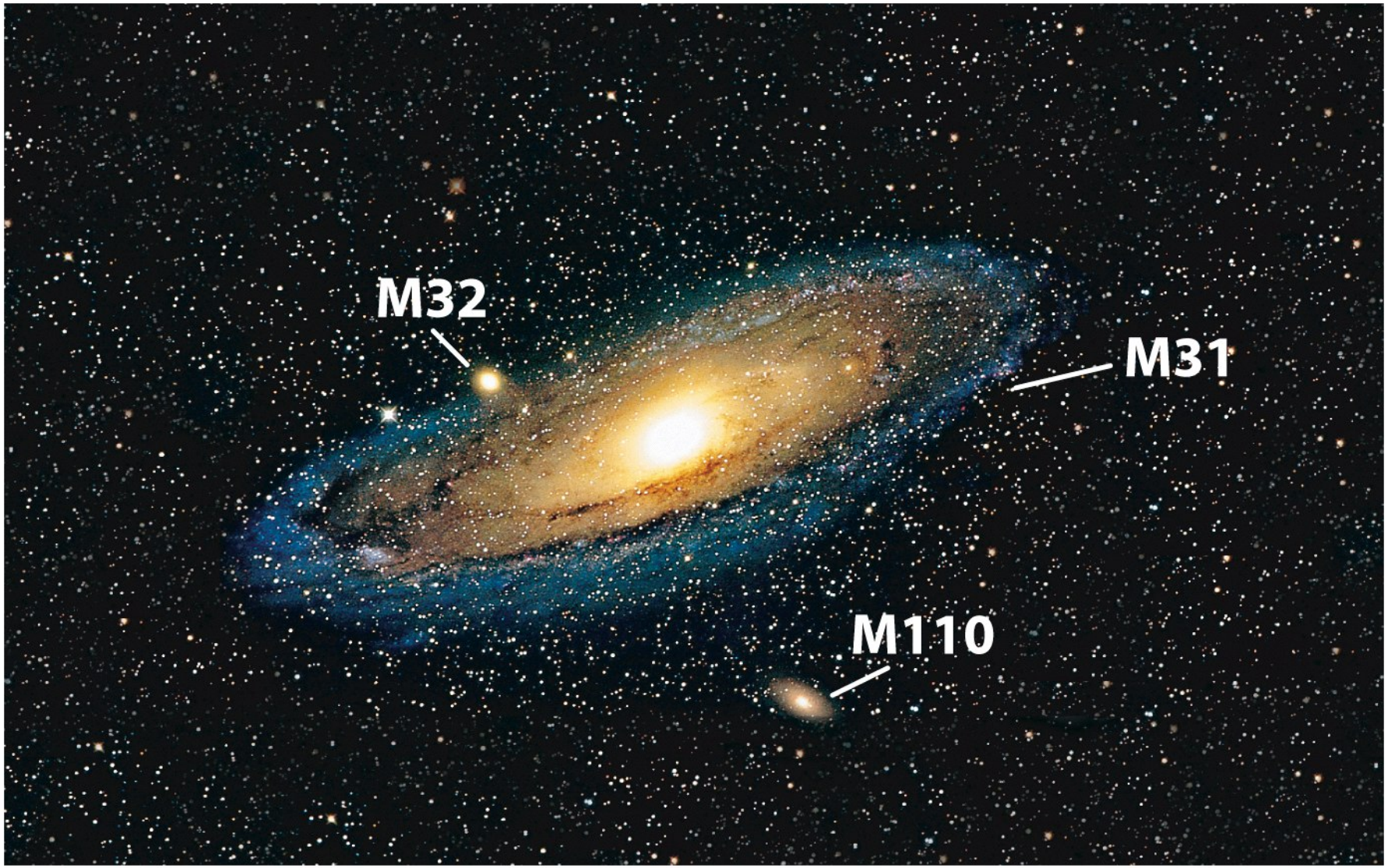
Galaxies

- Galaxy Types
- Hubble's Tuning Fork Diagram
- Redshift
- Expansion of the Universe and the Big Bang

Galaxies

- A galaxy is a gravitationally bound collection of stars, gas and dust
  - e.g. our Galaxy contains of order 10^{11} stars
- Usually isolated in space, although can interact with near neighbours
- The main visible component of the Universe



Galaxy Types

- Galaxies are seen in three major types
  - Spirals
  - Ellipticals
  - Irregulars

Spiral Galaxies

- Rotating *disc* dominated by spiral arms
- Spiral Arms are
  - rich in young, hot, blue stars, i.e. Population I
  - rich in gas and dust
  - where formation of new stars takes place

Credit: Gemini Observatory, GMOS Team

- An elliptical concentration of stars at the centre is called the *bulge*
- Bulge is rich in red stars – Population II and old Population I

- Also come in *barred* form where the two arms originate from the ends of a central linear feature of bulge-like stars

Credit: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

Elliptical Galaxies

- Elliptical collections of red stars – Population II and old Population I
- Smooth variation in intensity
- Very little gas & dust
- Little organized rotation
- Come in both giant and dwarf forms

Leo I

Dwarf Elliptical

Irregular Galaxies

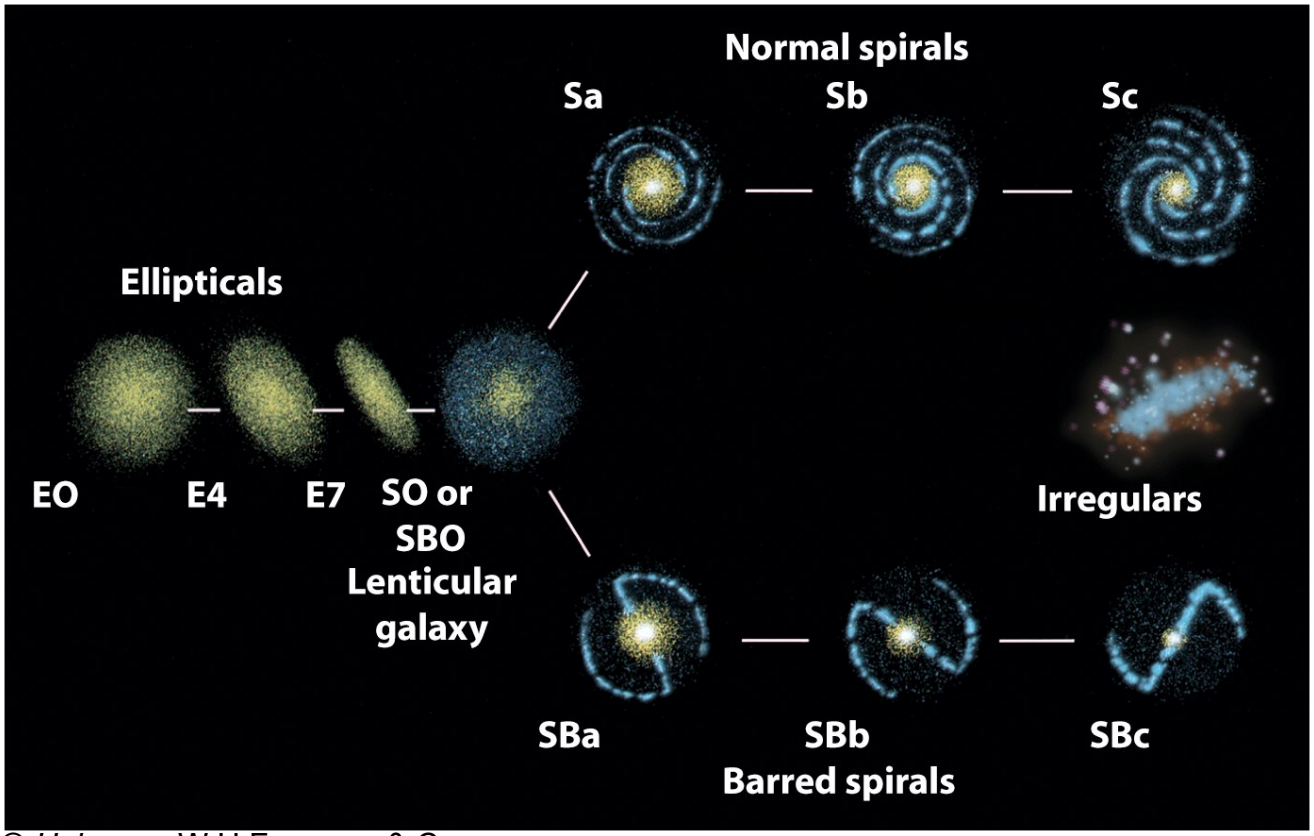
- No regular structure
- Contain plenty of gas and dust and blue stars
- Mixture of Population I and II
- Usually relatively small

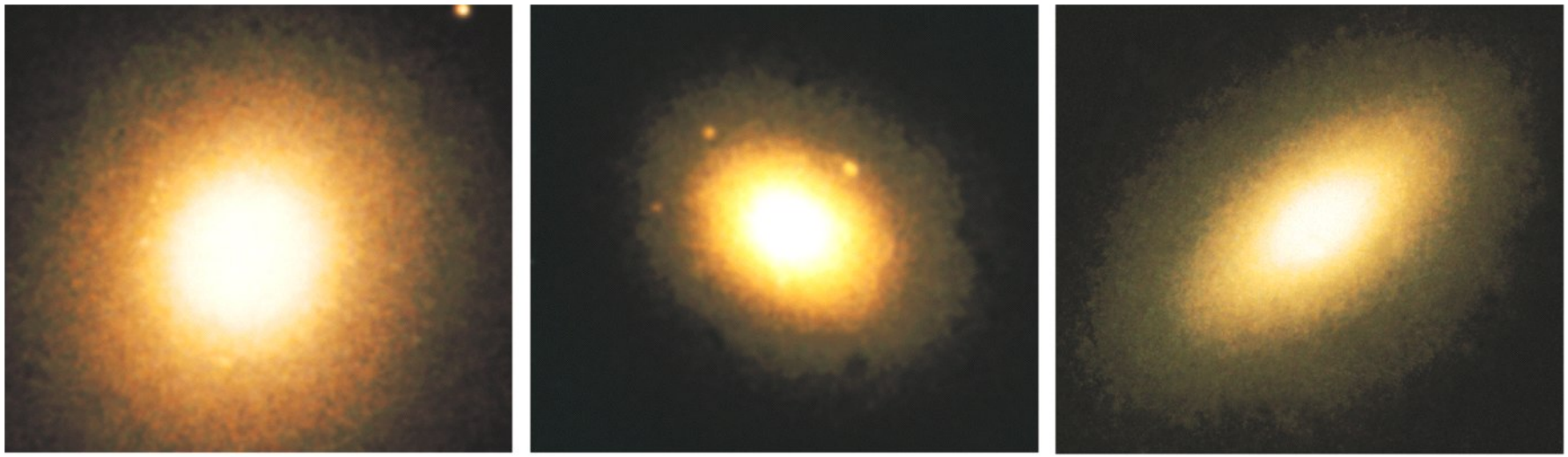
IC10: credit line: Adam Block/NOAO/AURA/NSF

Irregular galaxy NGC 4214. Credit NASA HST

Galaxy Classification

- Galaxies are classified according to Hubble's tuning fork diagram





(a) E0 (M105) (b) E3 (NGC 4365) (c) E6 (NGC 3377)

(a) Sa (NGC 1357)

(b) Sb (M81)

(c) Sc (NGC 4321)

(a) SBa (NGC 4650) (b) SBb (M83) (c) SBc (NGC 1365)

Lenticular galaxy M102: Credit: AURA/NOAO/NSF

Redshift

- The radial velocity of a galaxy can be measured using the Doppler shift
- Redshift, *z*, is defined by

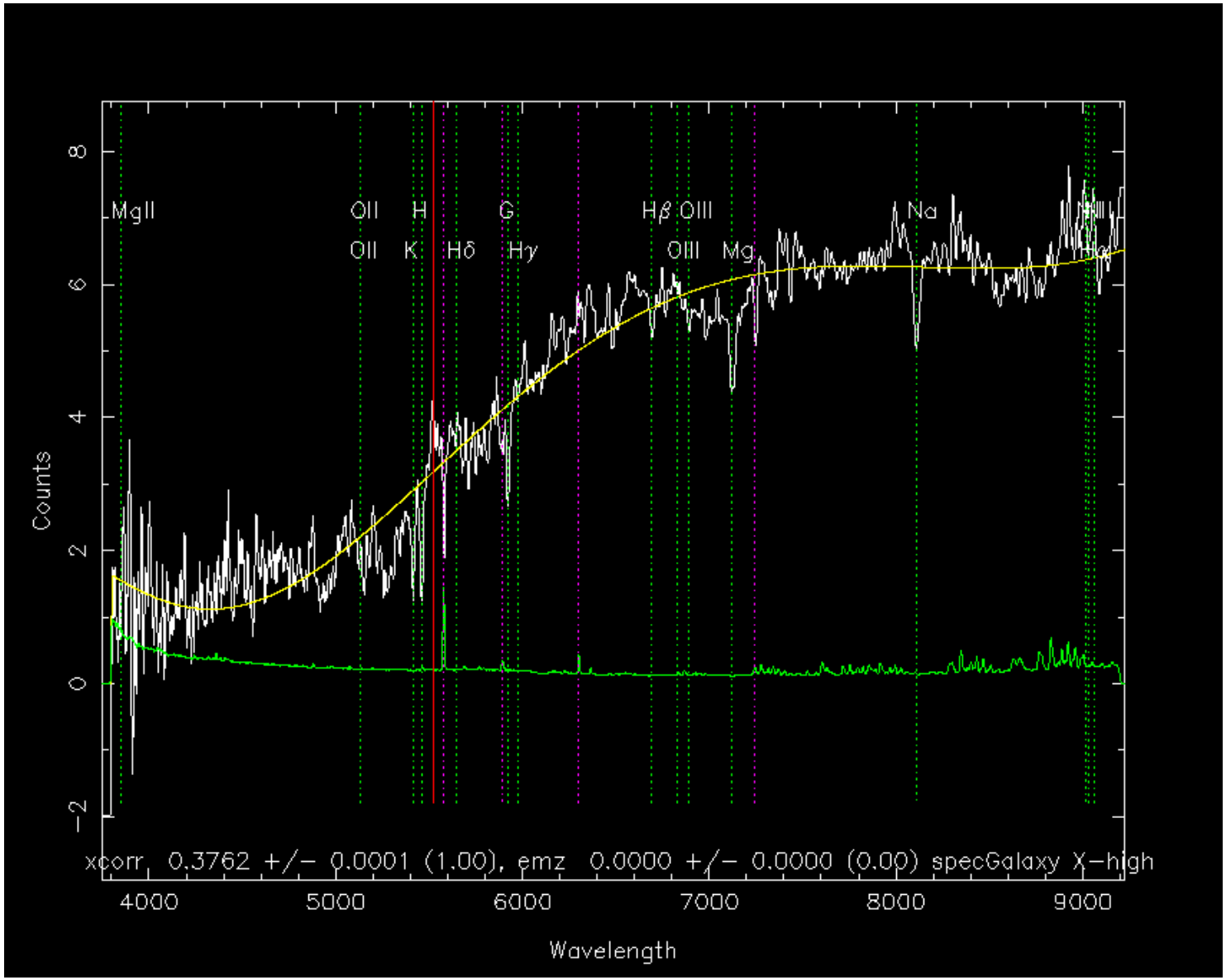
$$z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0}$$

where the λ_{obs} is the observed wavelength of spectral features in the galaxy spectrum and λ_0 is the rest wavelength

- The radial velocity is related to redshift by

$$v = \frac{\Delta\lambda}{\lambda_0} c = cz$$

- (Note as velocities become comparable to the speed of light a different relativistic formula must be used)



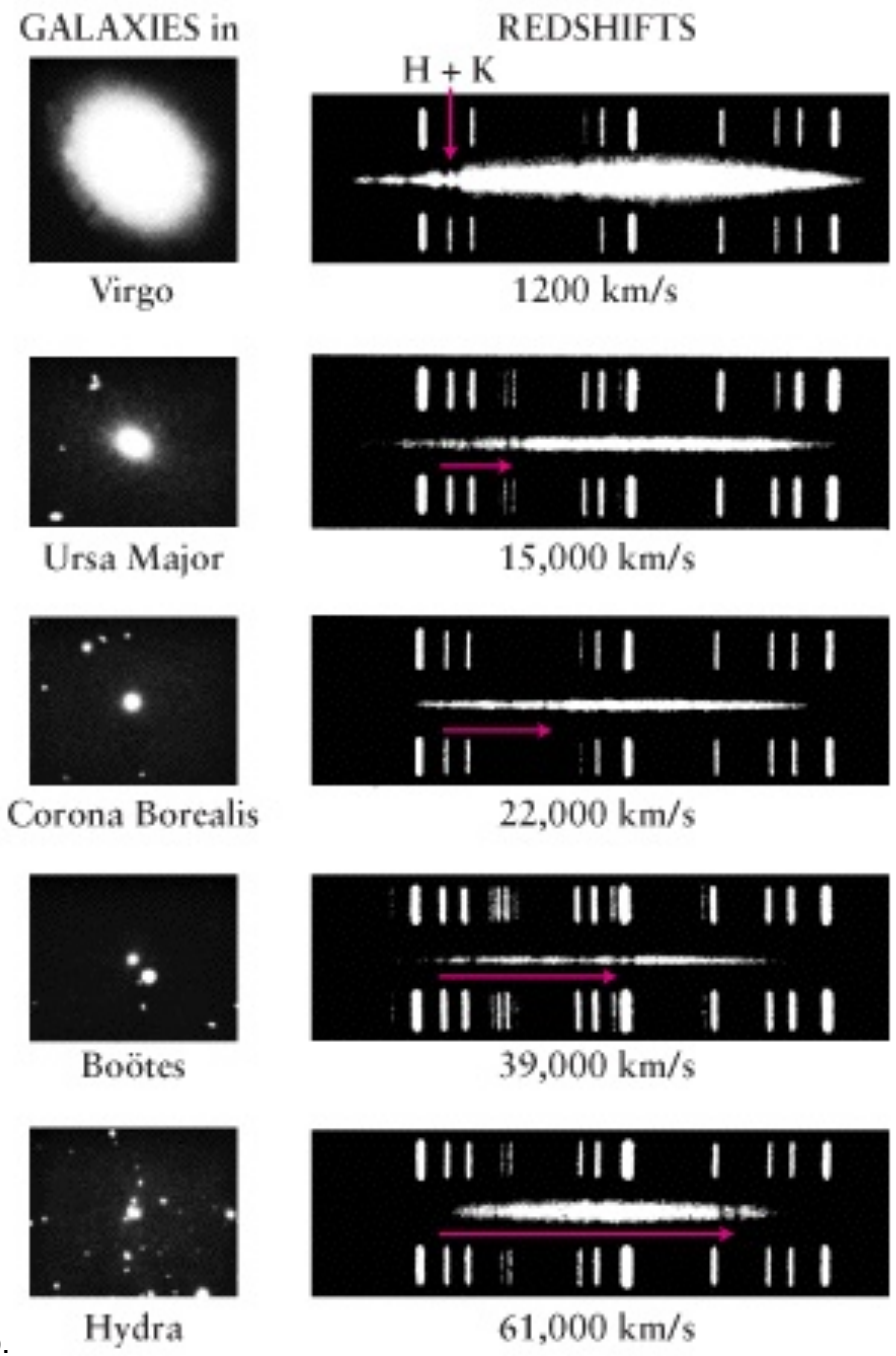
A spectrum of a galaxy at redshift 0.376 from the Sloan Digital Sky Survey www.sdss.org

Hubble's Law

- Hubble found that the majority of galaxies have redshifted lines
- He also found that further away the galaxy the higher the redshift and the radial velocity, i.e.

$$v = Hd$$

where H is Hubble's constant

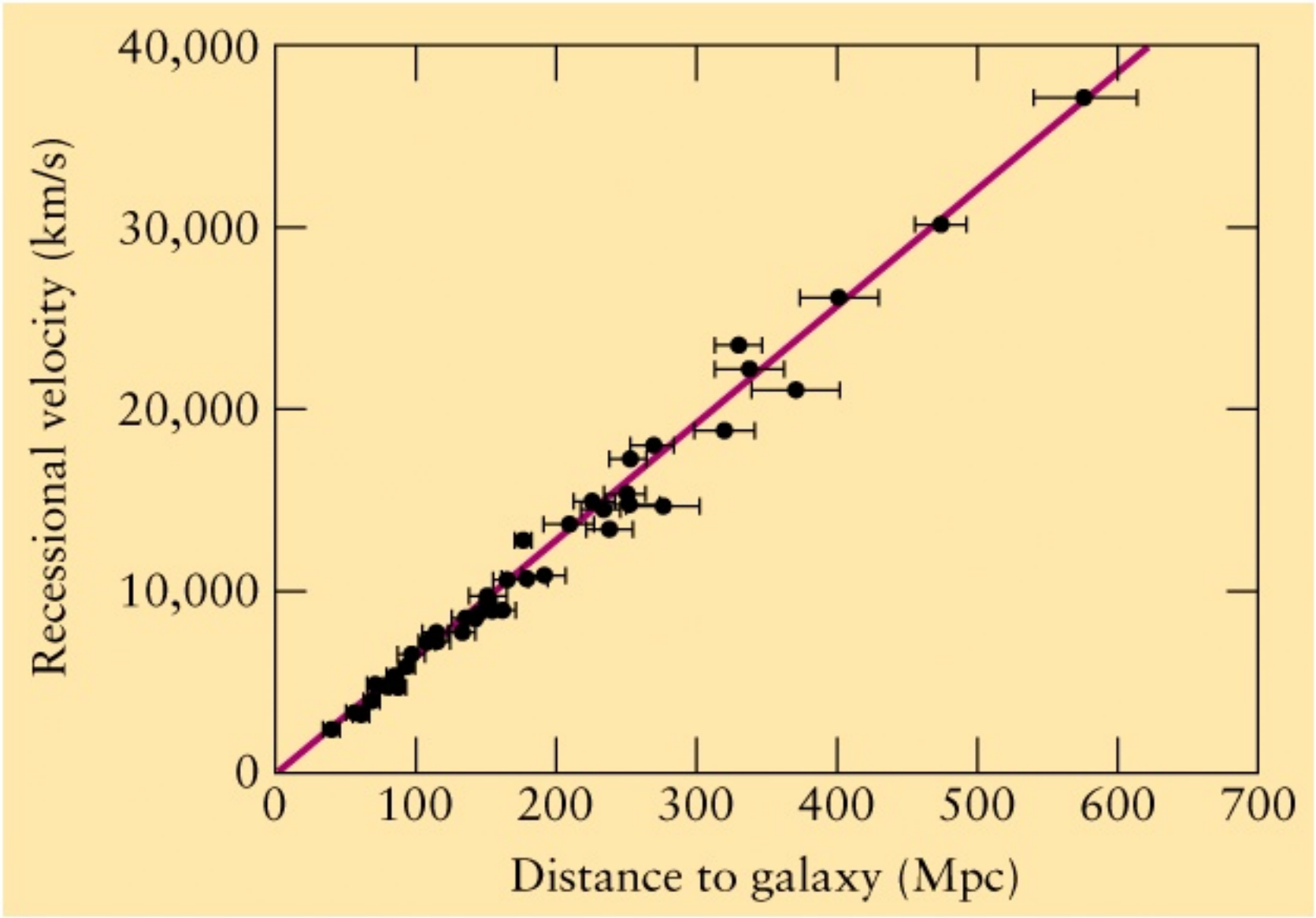


Hubble's Constant

- To determine *H* the distance to galaxies must be found independently
- This is done using standard candles
- The current best value is

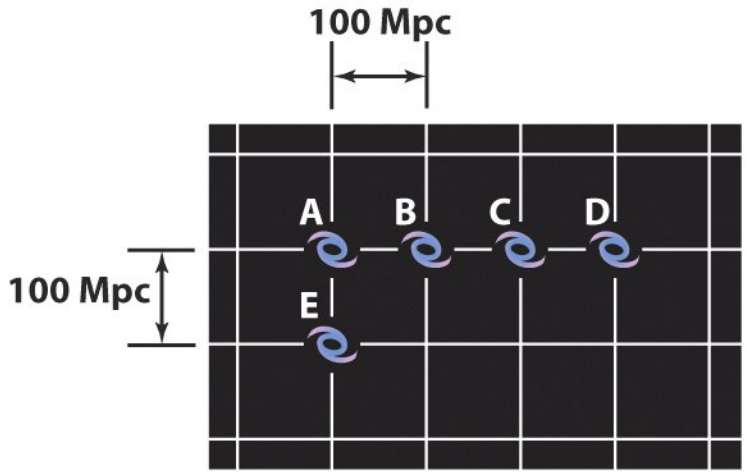
$$H_0 = 68 \pm 2 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

- (The subscript 0 indicates the value of *H* at the current age of the Universe)

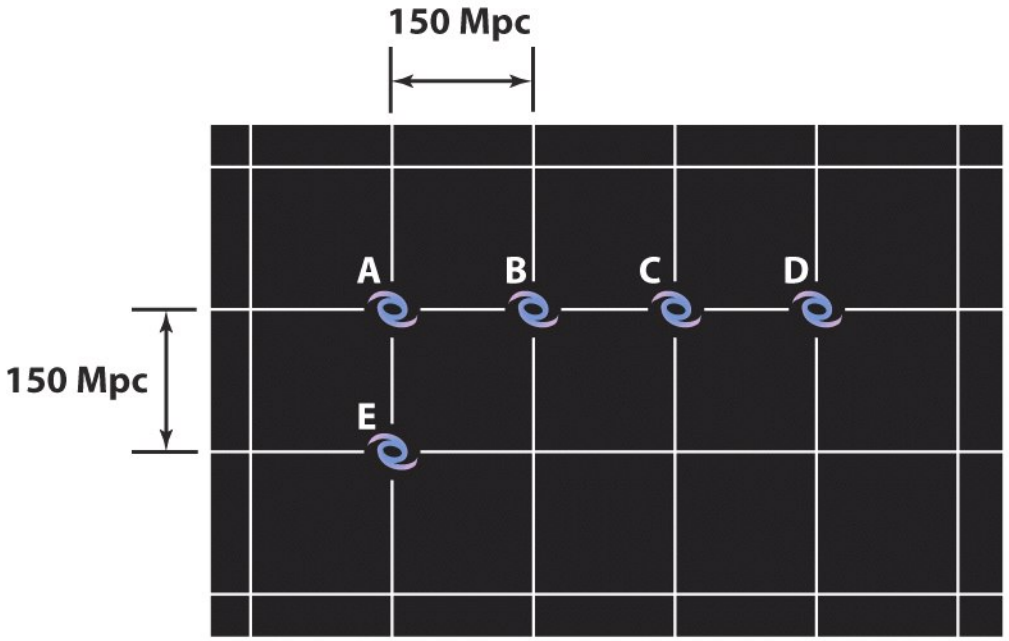


Expansion of the Universe

- The simplest explanation for Hubble's law is that the Universe is uniformly expanding
- The galaxies are not rushing through space but space itself is expanding
- We are not at a special location



(a) Five galaxies spaced 100 Mpc apart



(b) The expansion of the universe spreads the galaxies apart

The Big Bang

- As we go back in time all galaxies (all matter) will get closer and closer together
- Matter will get denser and hotter
- Eventually all of space occupied a very small volume – in fact a singularity (like a black hole)

Summary

- Galaxies can be classified as either spirals, ellipticals or irregulars
- Hubble's tuning fork diagram is a convenient memory aid but is not an evolutionary sequence
- More distant galaxies are receding faster
- We live in an expanding Universe that started with a Big Bang