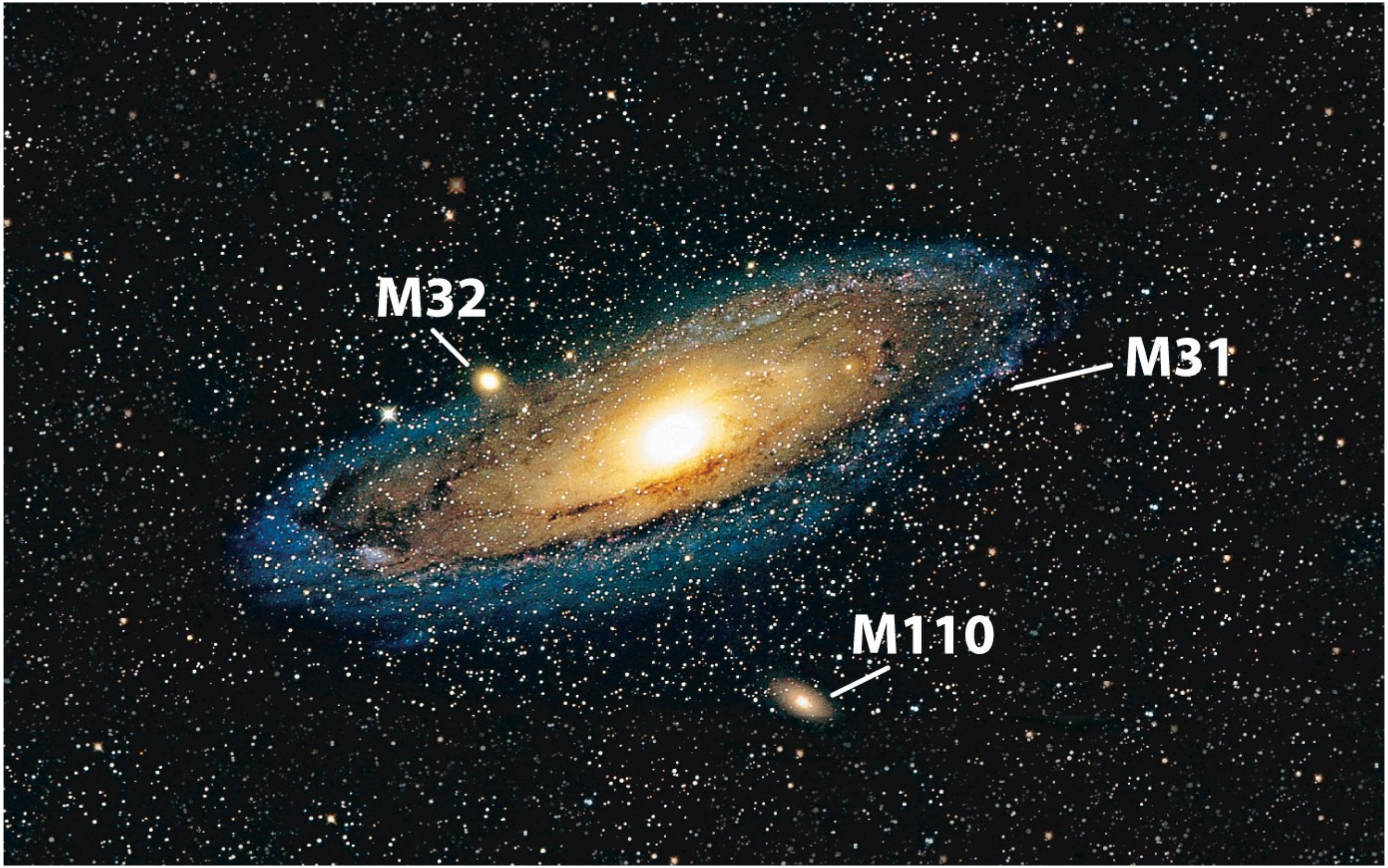
Galaxies

- 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


M32
M31
M110

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

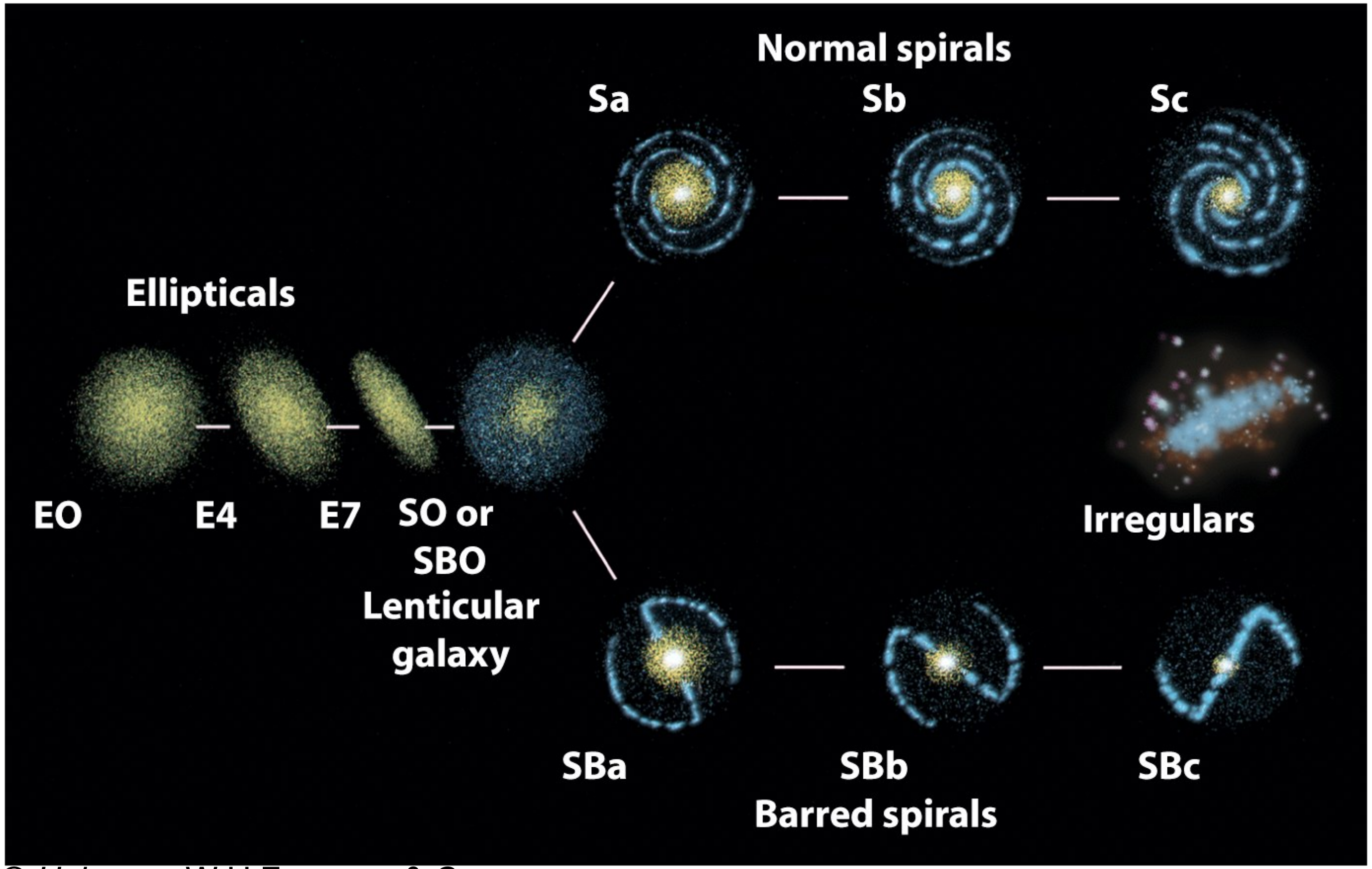
- No regular structure
- Contain plenty of gas and dust and blue stars
- Mixture of Population I and II
- Usually relatively small

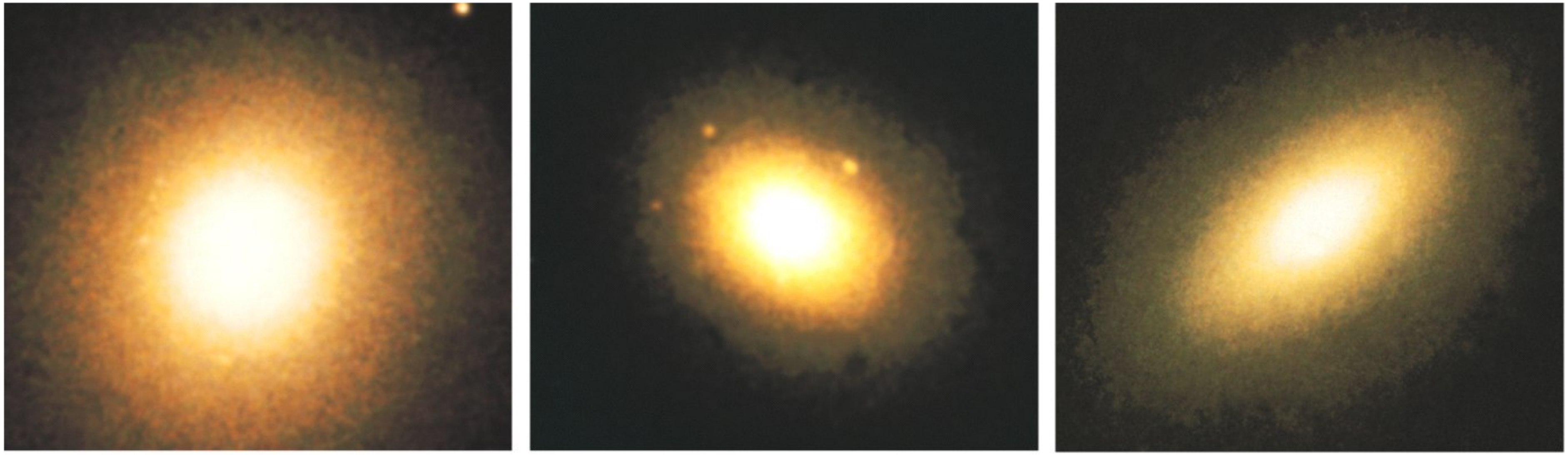
IC10: credit line: Adam Block/NOAO/AURA/NSF

Irregular galaxy NGC 4214. Credit NASA HST

Galaxy Classification

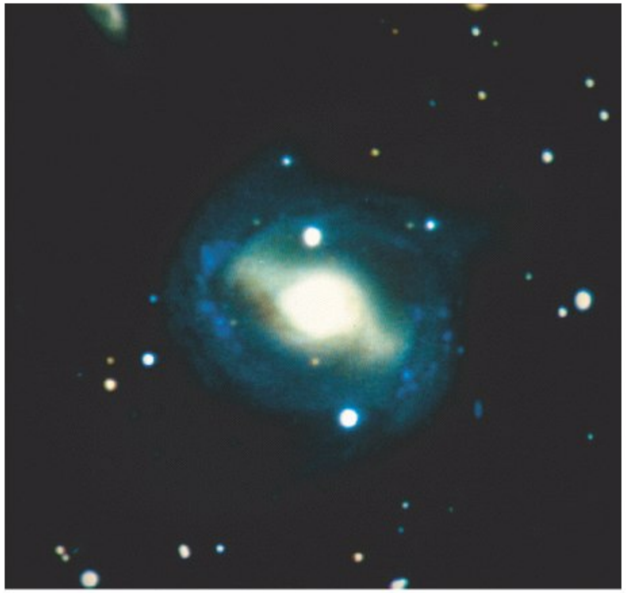
- Galaxies are classified according to Hubble's tuning fork diagram





(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

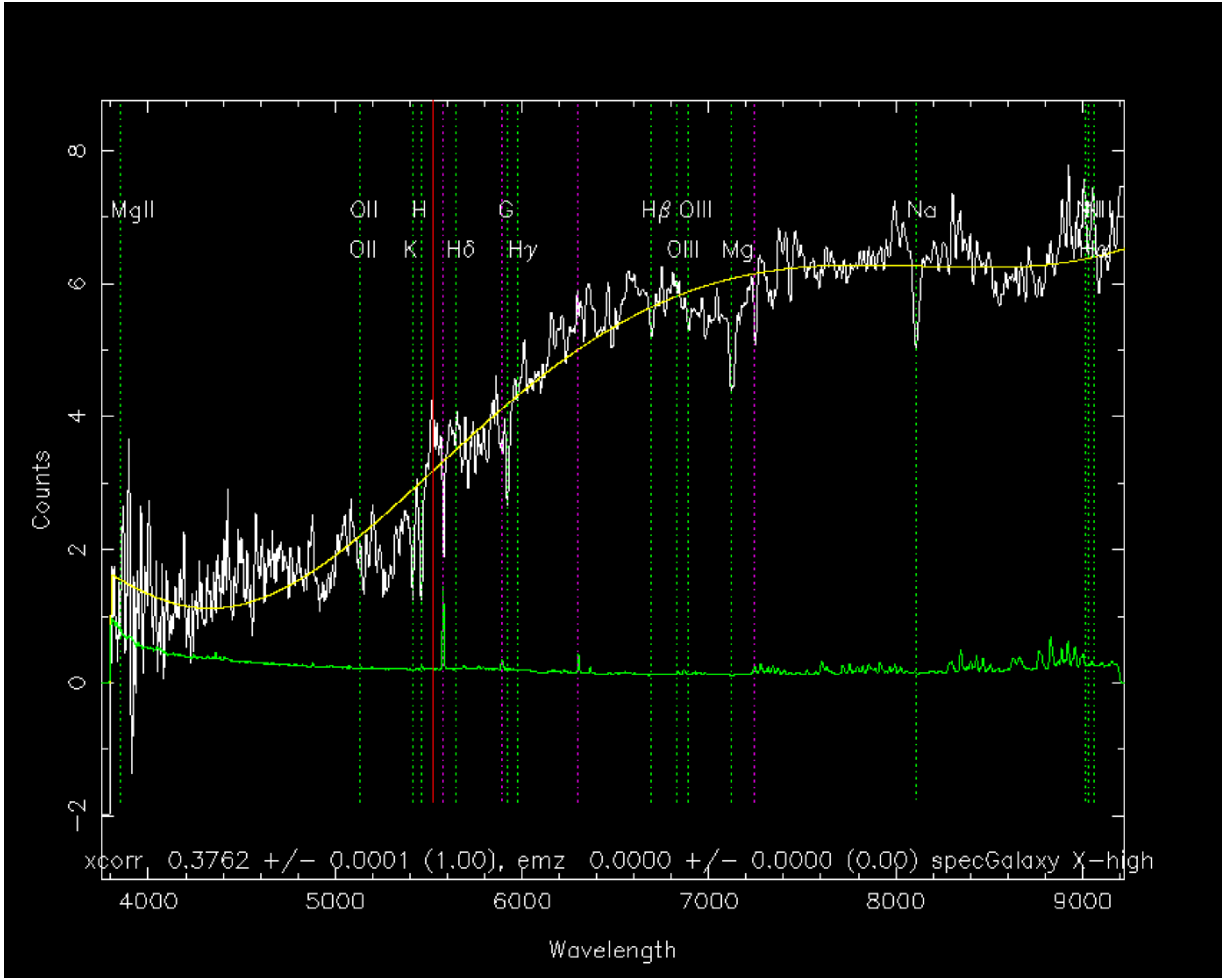
$$z = \frac{\lambda_{obs} - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0}$$

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 relativistic Doppler formula could be used to get v)



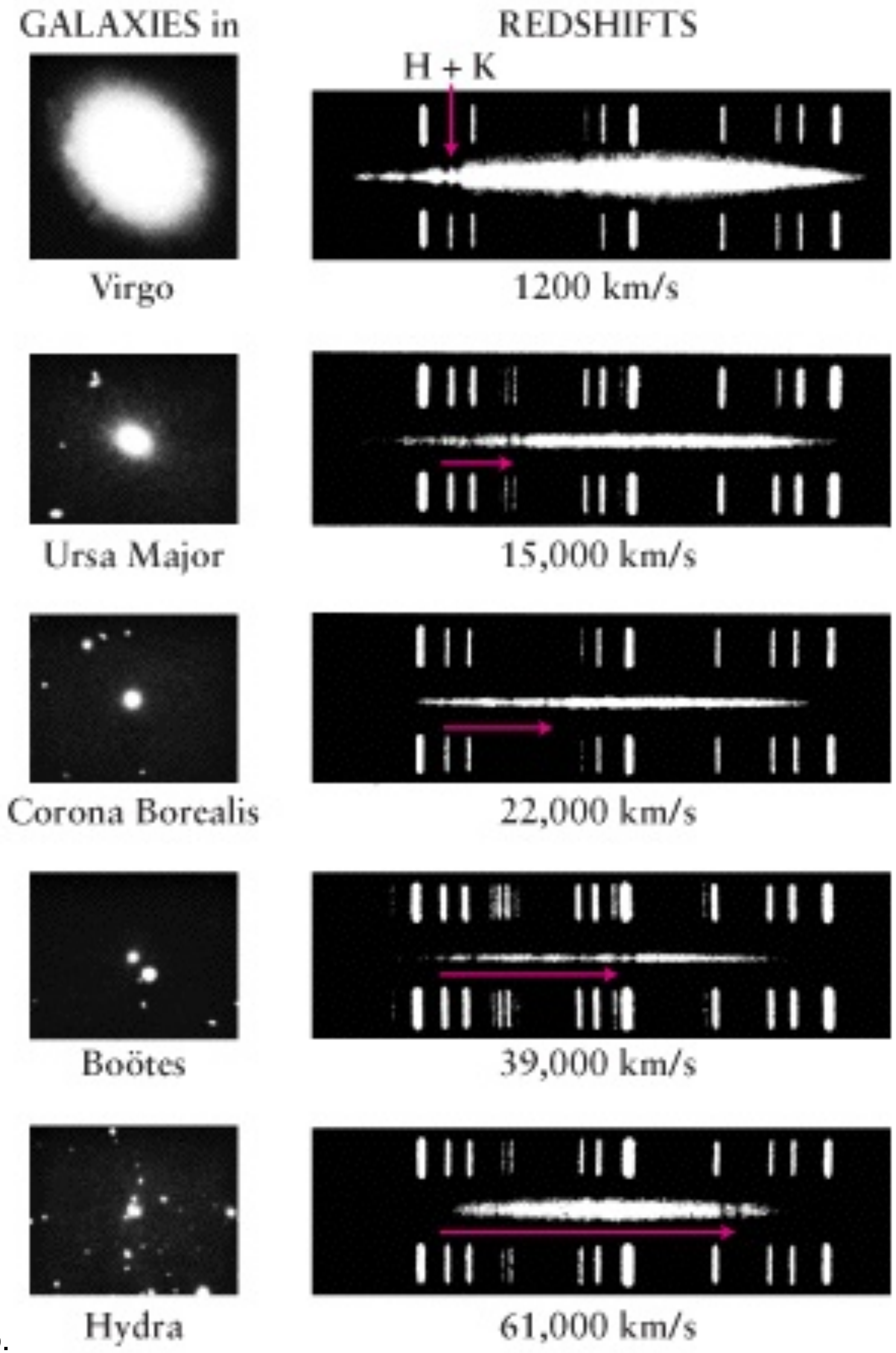
A spectrum of a galaxy at redshift 0.376 from the Sloan Digital Sky Survey www.sdss.org

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.

$$v = H_0\, d$$

- H_0 is Hubble’s constant
- Now officially Hubble-Lemaître Law

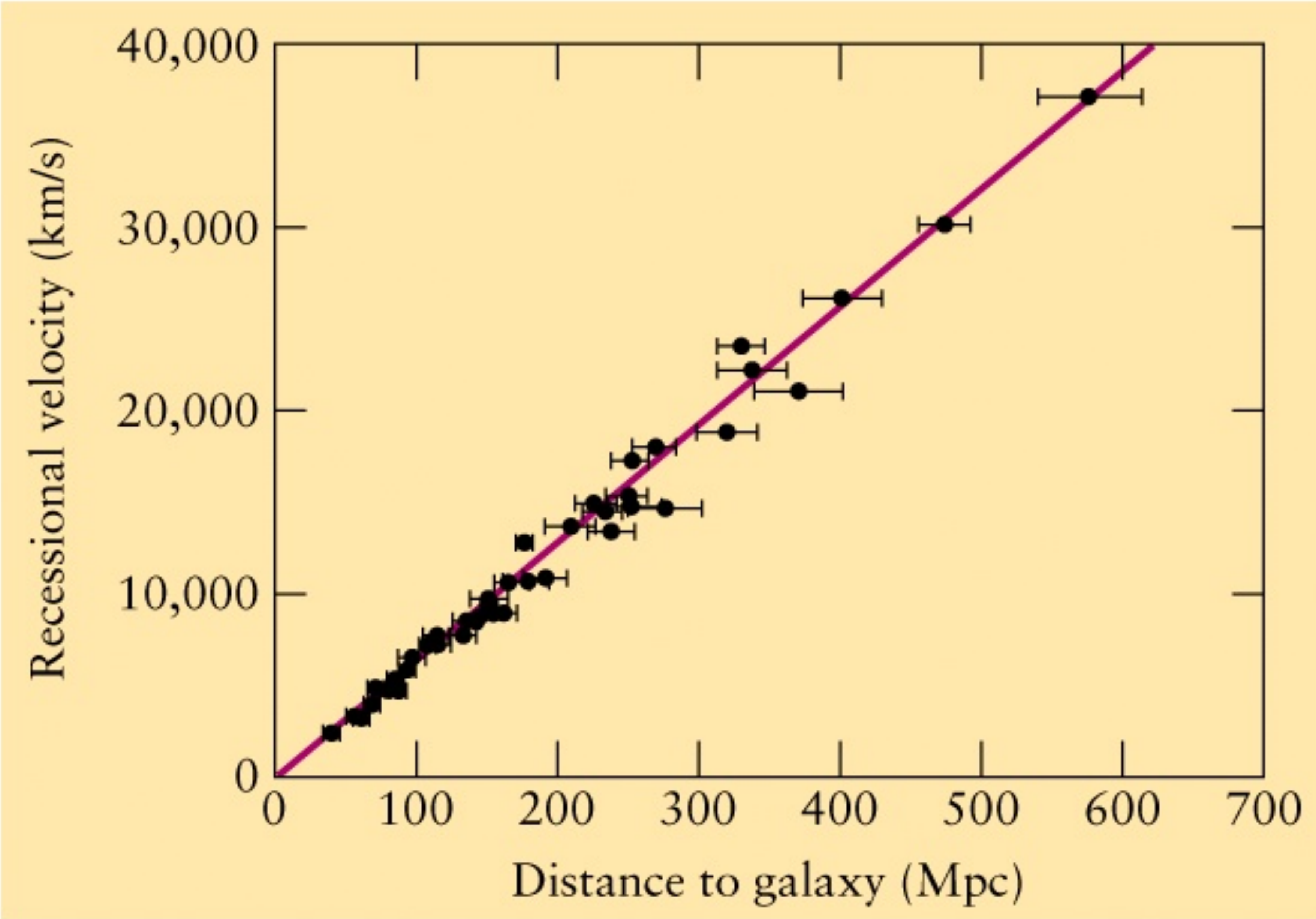

GALAXIES in
REDSHIFTS
H + K
Virgo
1200 km/s
Ursa Major
15,000 km/s
Corona Borealis
22,000 km/s
Boötes
39,000 km/s
Hydra
61,000 km/s

Hubble's Constant

- To determine H_0 the distance to galaxies must be found independently
- This is done using standard candles
- The current best value is

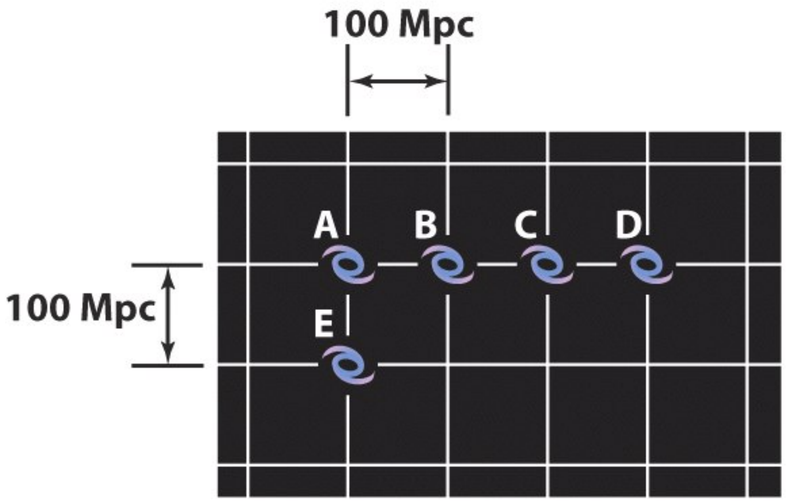
$$H_0 = 68 \pm 2 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

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

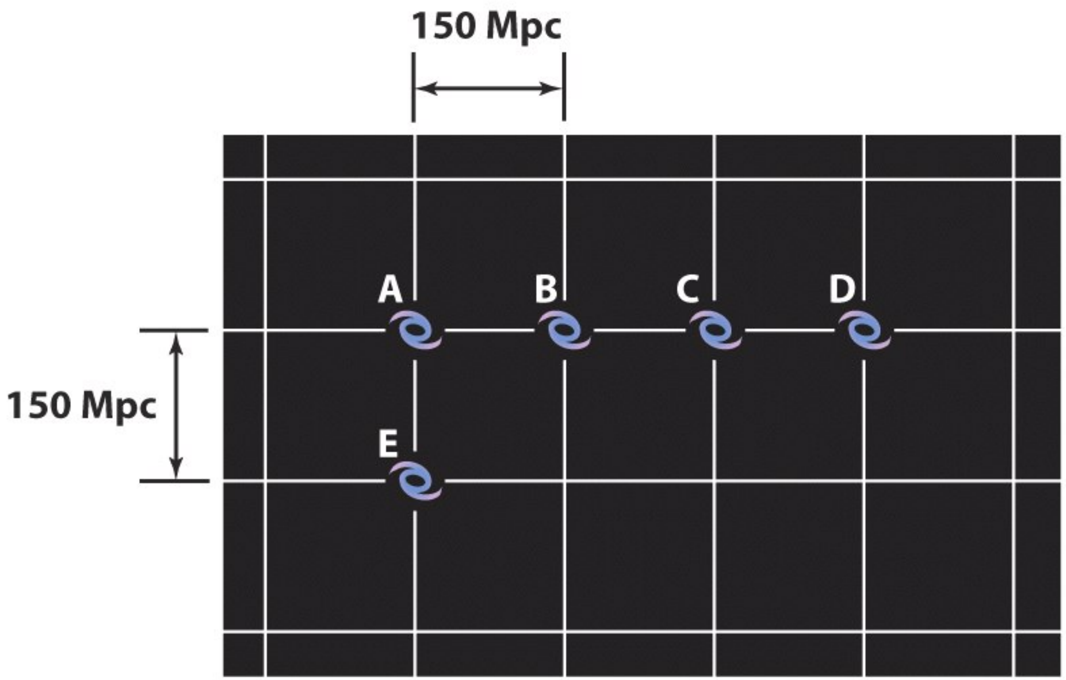

Recessional velocity (km/s)
40,000
30,000
20,000
10,000
0
0
100
200
300
400
500
600
700
Distance to galaxy (Mpc)

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



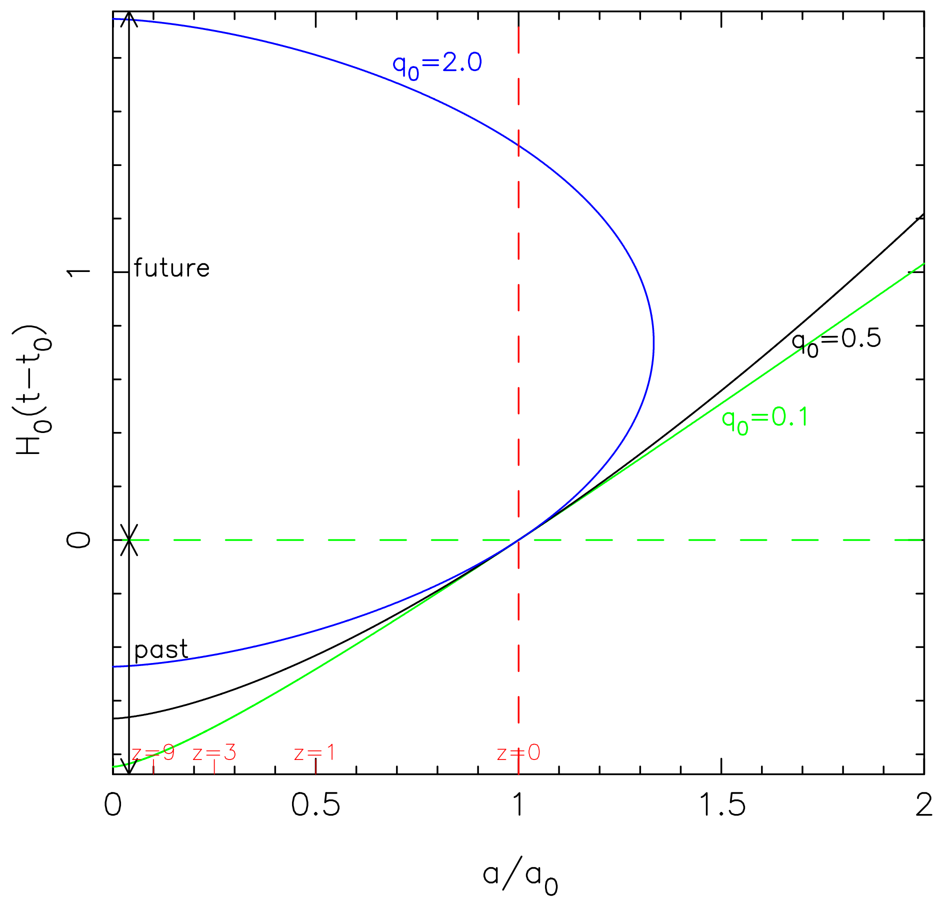
(b) The expansion of the universe spreads the galaxies apart

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
- Described by the scale factor of the Universe, which obeys Friedmann equation

$$\left(\frac{\dot{a}}{a}\right)^2 + \frac{k}{a^2} = \frac{8\pi}{3}\rho + \frac{\Lambda}{3}$$

No cosmological constant

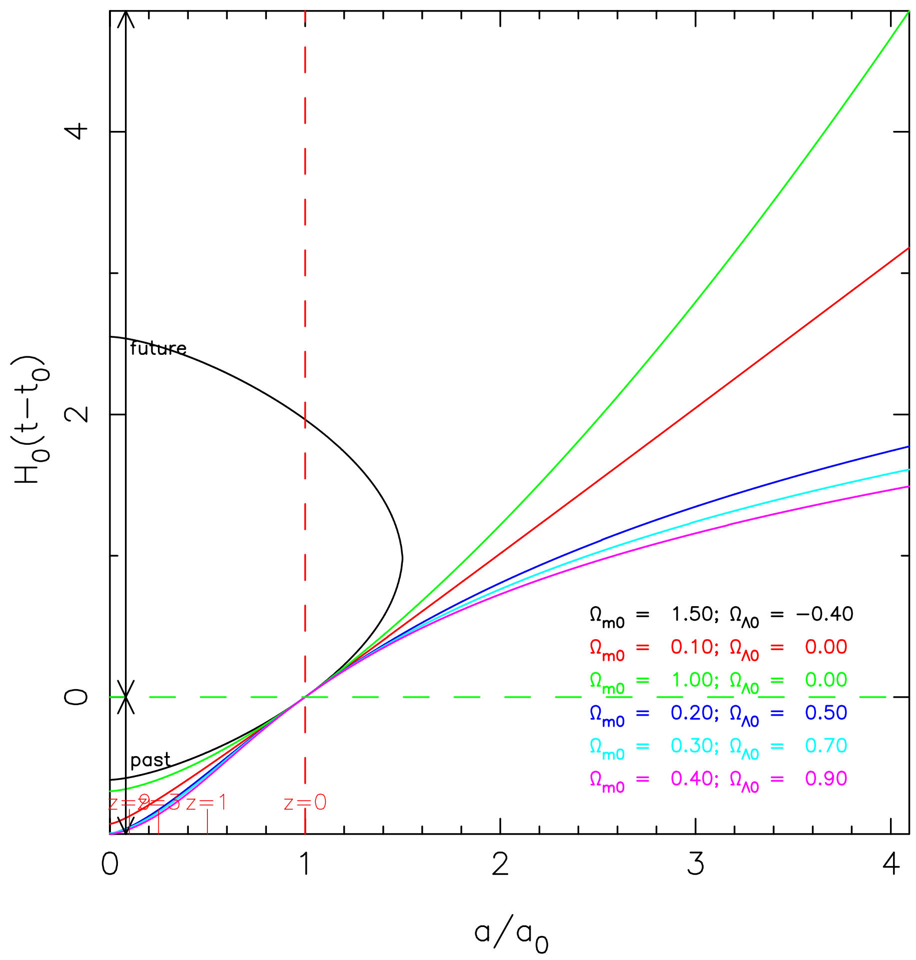


Solutions all show Big Bang, from a = 0, with decelerating expansion.

The Big Bang

- We now have measurements showing that $k = 0$ to high accuracy, and $\Lambda > 0$
- Only 25% of density is made up of ordinary (“baryonic”) matter, the rest is the dark matter that keeps structures bound in the Universe
- Solution for scale factor now looks different

With cosmological constant



Accelerating expansion is best fit to data.

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