- PHAS 1202 Galaxies

1. Galaxy Classification

   Ellipticals
   Dwarf Ellipticals
   Spirals
   Barred Spirals
   Irregulars

2. Measuring Properties of Galaxies

   Distances
   Masses
   Dark Matter?

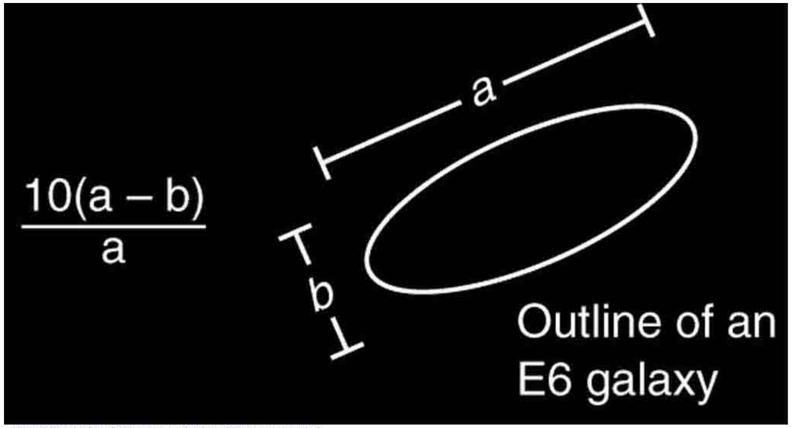
Galaxies are the fundamental constituents of the Universe

- cosmic engines that turn gas → stars and stars → gas
- No significant star formation occurs in intergalactic space
- relatively recent discovery (e.g.Hubble in late 1920's)
- can be classified by morphology (shapes and sizes)

Three Main Types of Galaxies:

- Ellipticals - *galaxies are pure bulge, no disk component*
- Spirals - *galaxies contain varying amounts of disk component*
- Irregulars - *galaxies are… Odd.*

Elliptical Galaxies



Names of E galaxies give their shape.
E0 is round. E6 is elongated.

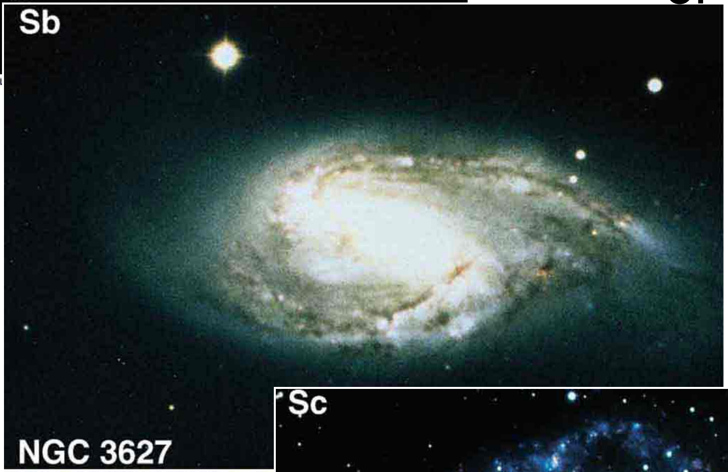
The way you name an E galaxy is to measure its "major" and "minor" axis and plug it into the formula above → projection effect

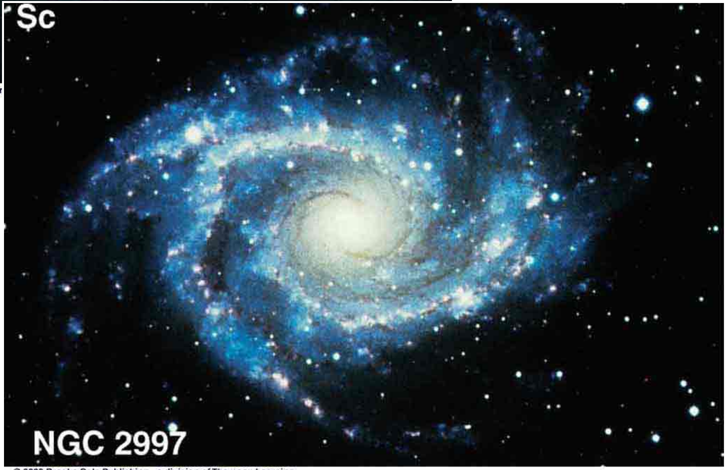
Spiral Galaxies

Spirals are classified by their relative amount of disk and bulge components.

We designate these Sa, Sb, Sc, in order of decreasing bulge to disk ratio.

More bulge





More disk

More disk means more star formation!

Barred spirals are called SBa, SBb, SBc

Spiral Galaxies:

- flattened systems that rotate
- orbits of stars and gas are "circular", rotating about disk axis
- star formation is on-going; it is can be fairly constant over the age of the galaxy
- gas and dust mass fraction is roughly 10-50% of full disk
- due on-going star formation, ages of stars widely range from age of galaxy to new
- spiral arms form as sustained density waves; where majority of star formation occurs

Ellipticals:

- spheriodal systems with little or no rotation
- orbits of stars are randomly oriented and highly eccentric (some are radial)
- star formation largely complete; gas consumed efficiently long ago
- ages of stars are mainly old; most as old as the galaxy
- very little to gas; it has been converted to stars already
- overall structure is smooth- no clumpy areas like analogous to spiral arms in disks

The small end of Galaxy Classification

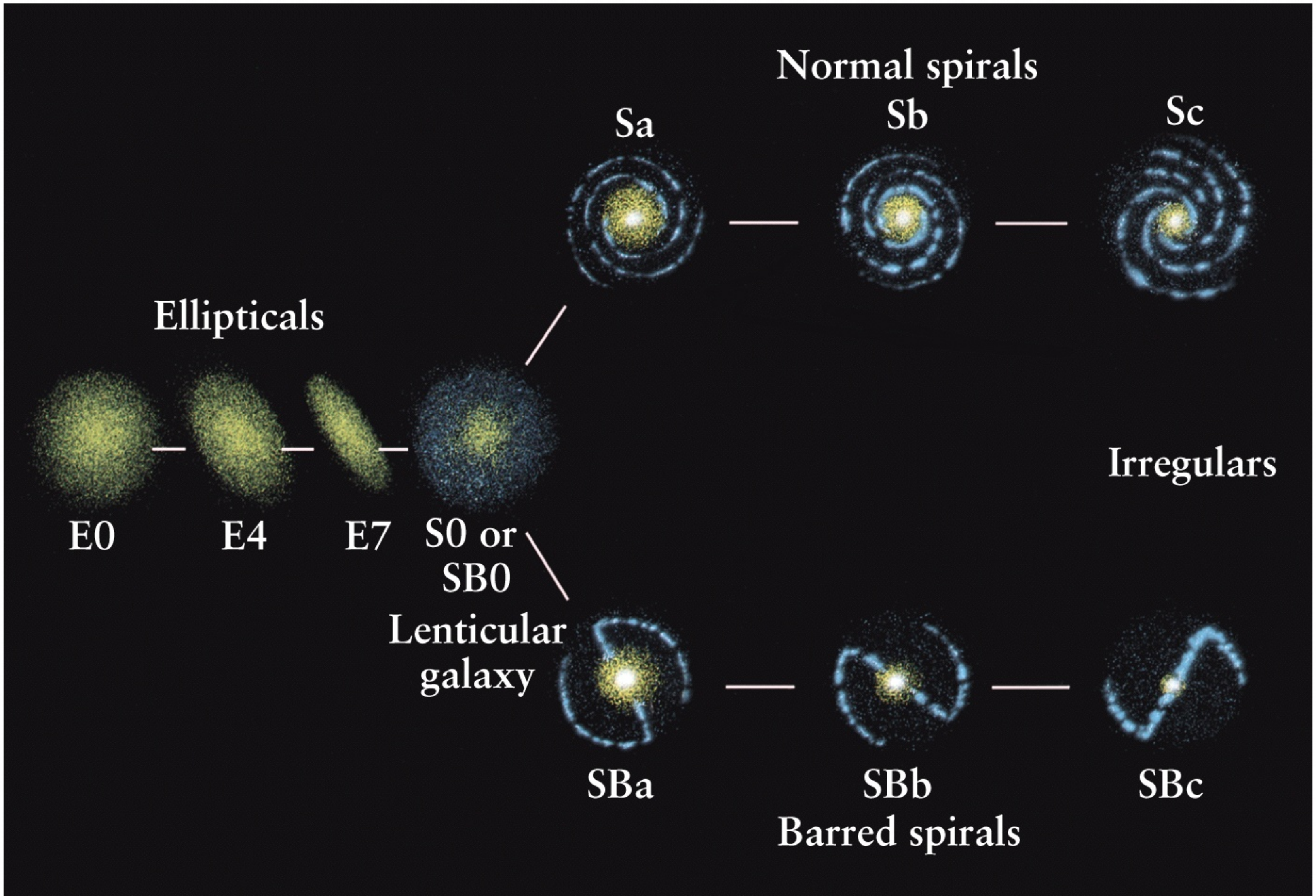
Dwarf Elliptical

Dwarf Irregular

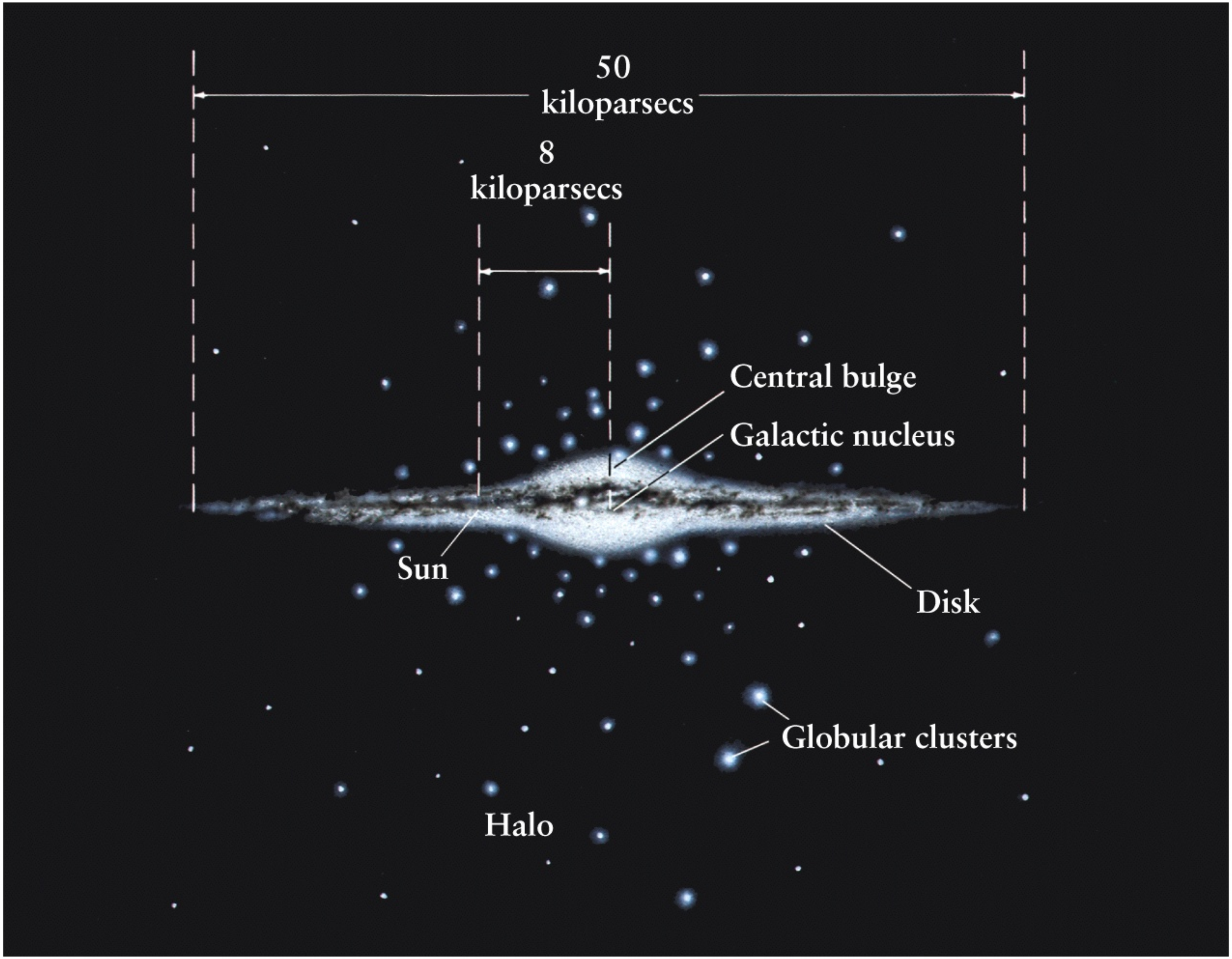
… and there are more of these types of galaxies than any other type!

There may be lots of them, but they are not very luminous or very massive

The Hubble 'tuning fork' diagram



The structure of the Milky Way Galaxy



Stellar Populations

- Blue disk stars = Population I
- Red bulge and halo stars = Population II

- Population I
  - lots of metals
  - Young and blue
  - Circular orbits

- Population II
  - metal poor
  - Old and red
  - Elliptical and tilted orbits

Our Galaxy:

A typical SBc spiral galaxy:

A central ‘bulge’ (Pop II), a disk (Pop I), embedded in a halo, totalling about 10^{11} to 10^{12} M_o

- **Disk**- 50 kpc across, ~1 kpc thick
(1 pc = 3.26 light-years) – Contains Spiral Arms

- **Nuclear Bulge**- ~6 Kpc across
Contains Nucleus of Galaxy
- **Halo**- ~100 kpc across
Contains Orbiting Globular Clusters
(13 biilion yr old stars!)

Galactic centre –

We measure the motion of stars through ‘proper motions’ (orbits projected onto the plane of the sky), and radial velocities (orbits projected along the line of sight).

Implied mass: $4x10^6$ M_o!

There is a black hole with a mass of 4 million suns at the centre of our Galaxy….and many (all??) other galaxies. These can “announce” themselves as Active Galactic Nuclei (AGN)

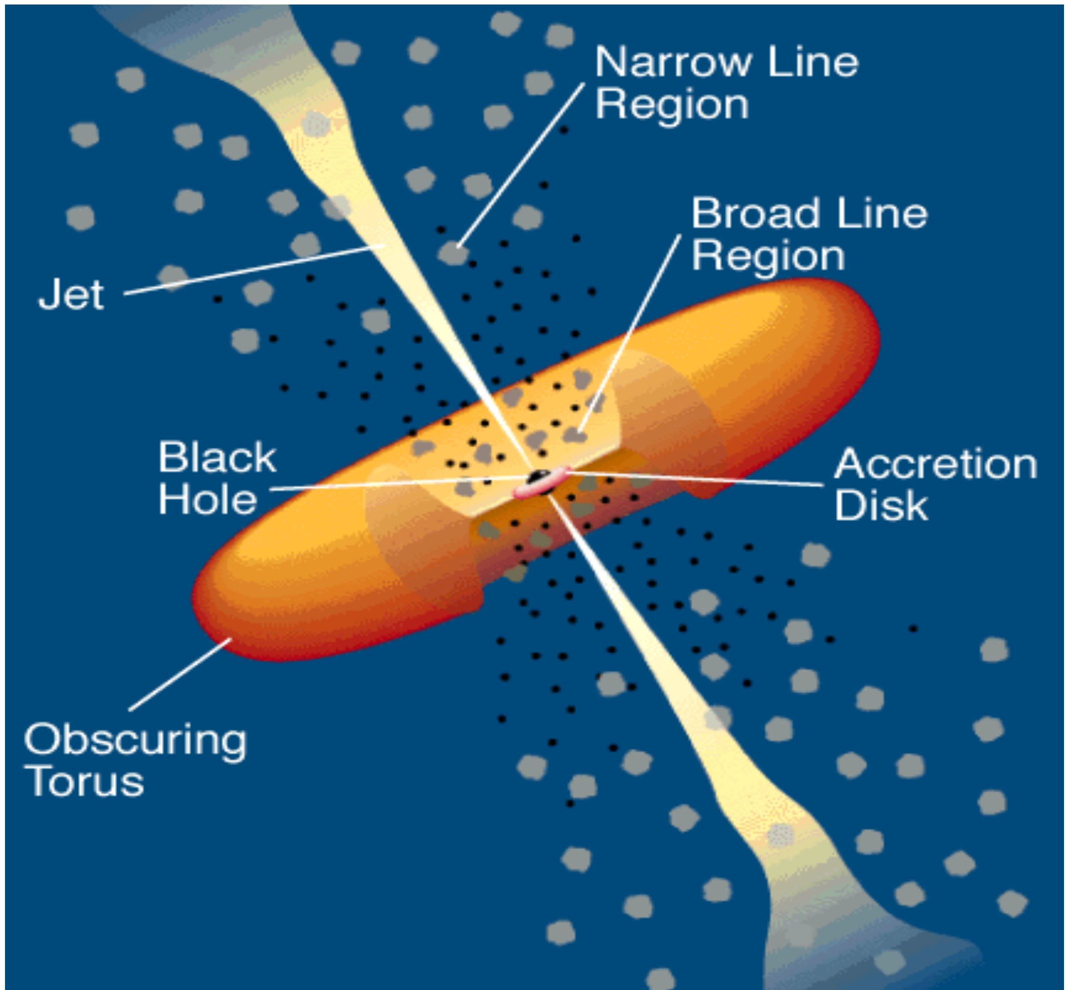
Most, perhaps all, other galaxies also host supermassive black holes at their centres. If these are accompanied by an accretion disk, they reveal themselves as **'Active Galactic Nuclei' (AGN) – such as Seyfert Galaxies, or Quasars.**

AGN shows nonthermal continua, and emission-line spectra

Supermassive black holes in Active Galactic Nuclei

(10^6 – 10^9 solar mass black holes)

....exciting stuff in year 3!

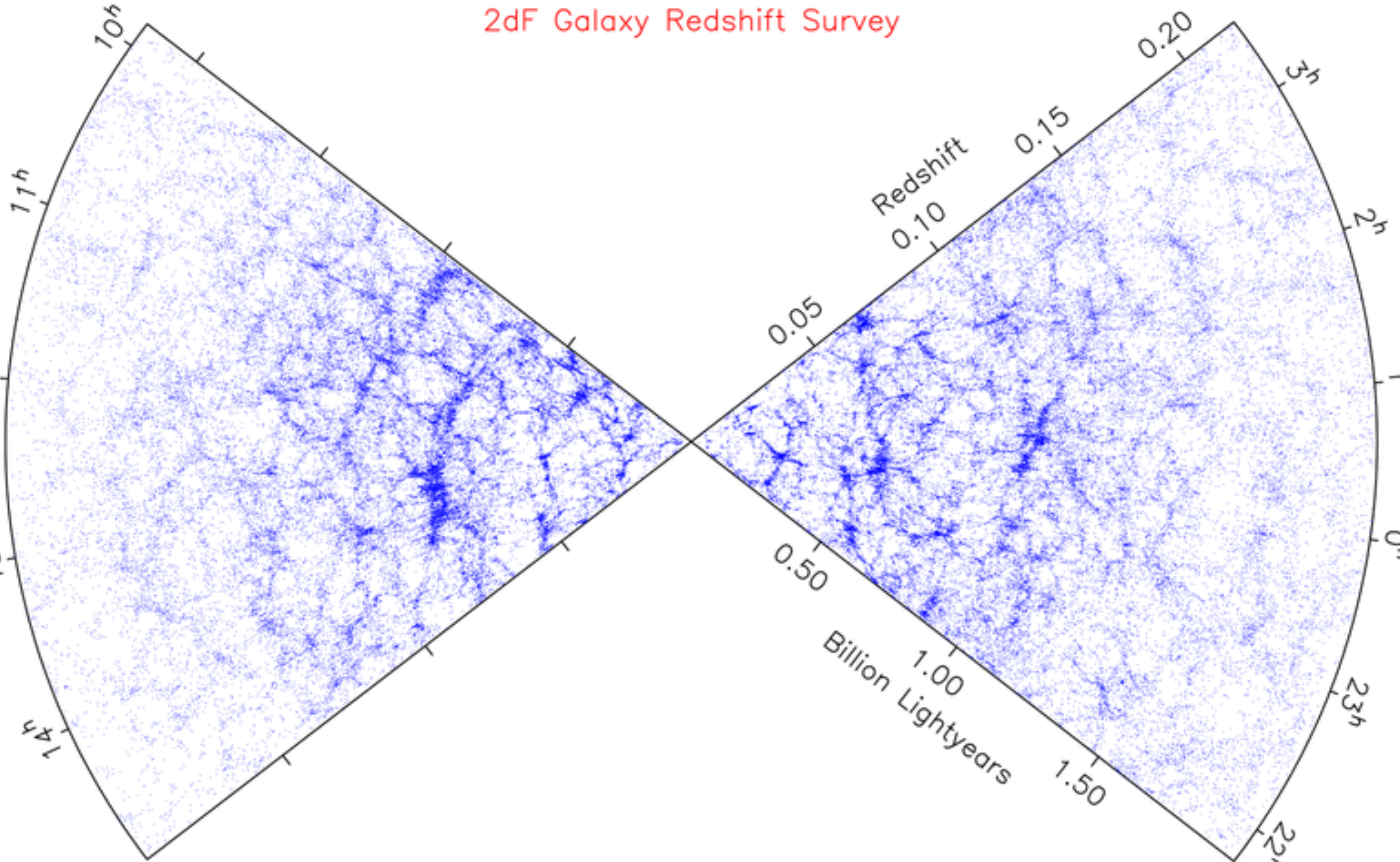


Clusters of Galaxies

Galaxies are rarely isolated, but tend to collect in gravitationally bound ensembles, from small ‘groups’ (few dozen galaxies) to large ‘clusters’ (thousands of galaxies).

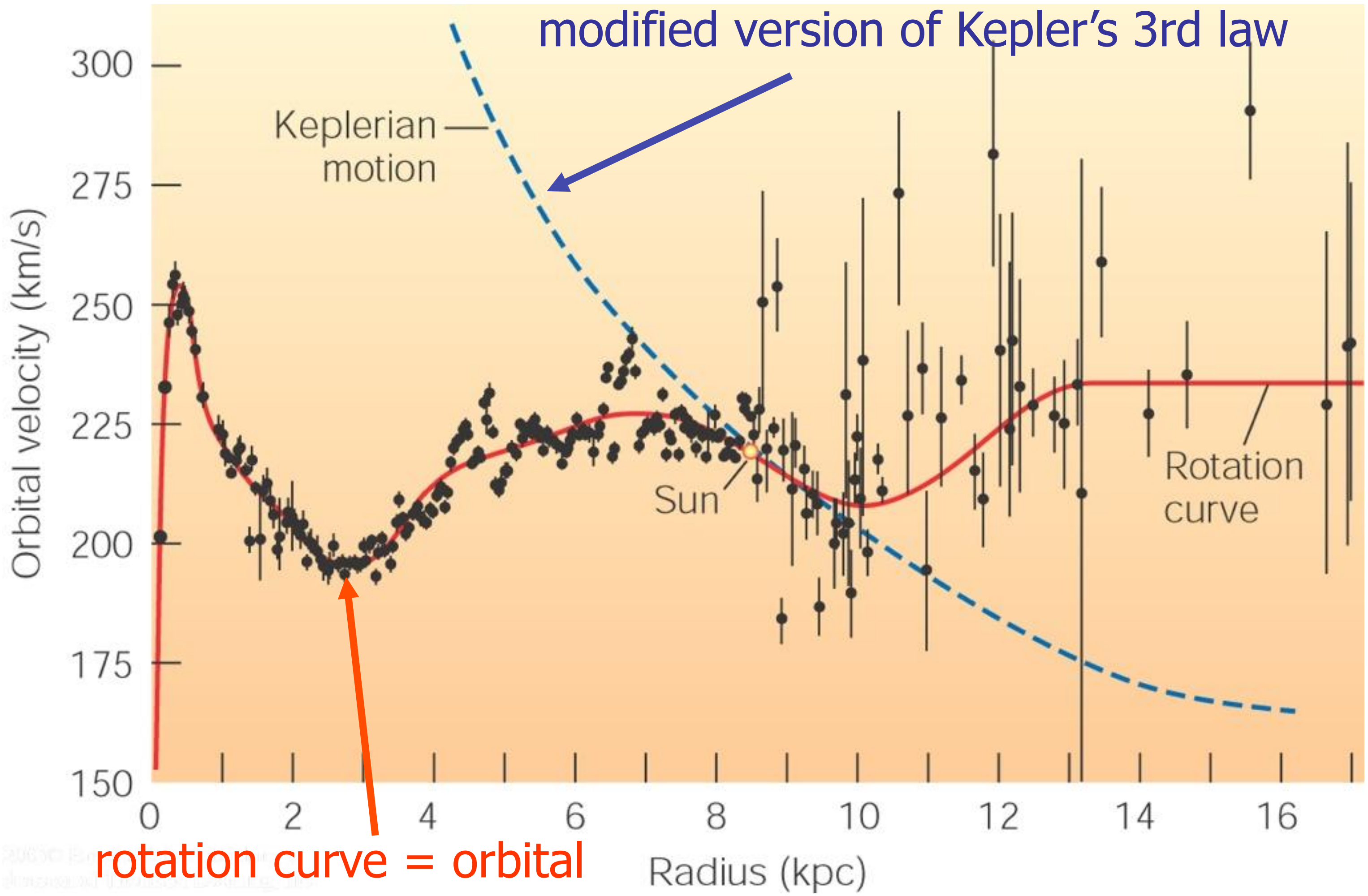
The environment influences galaxy evolution; clusters contain fewer spiral galaxies than does the ‘field’, and often have a giant elliptical (cD) galaxy at the centre

Large-scale structure: ‘superclusters’

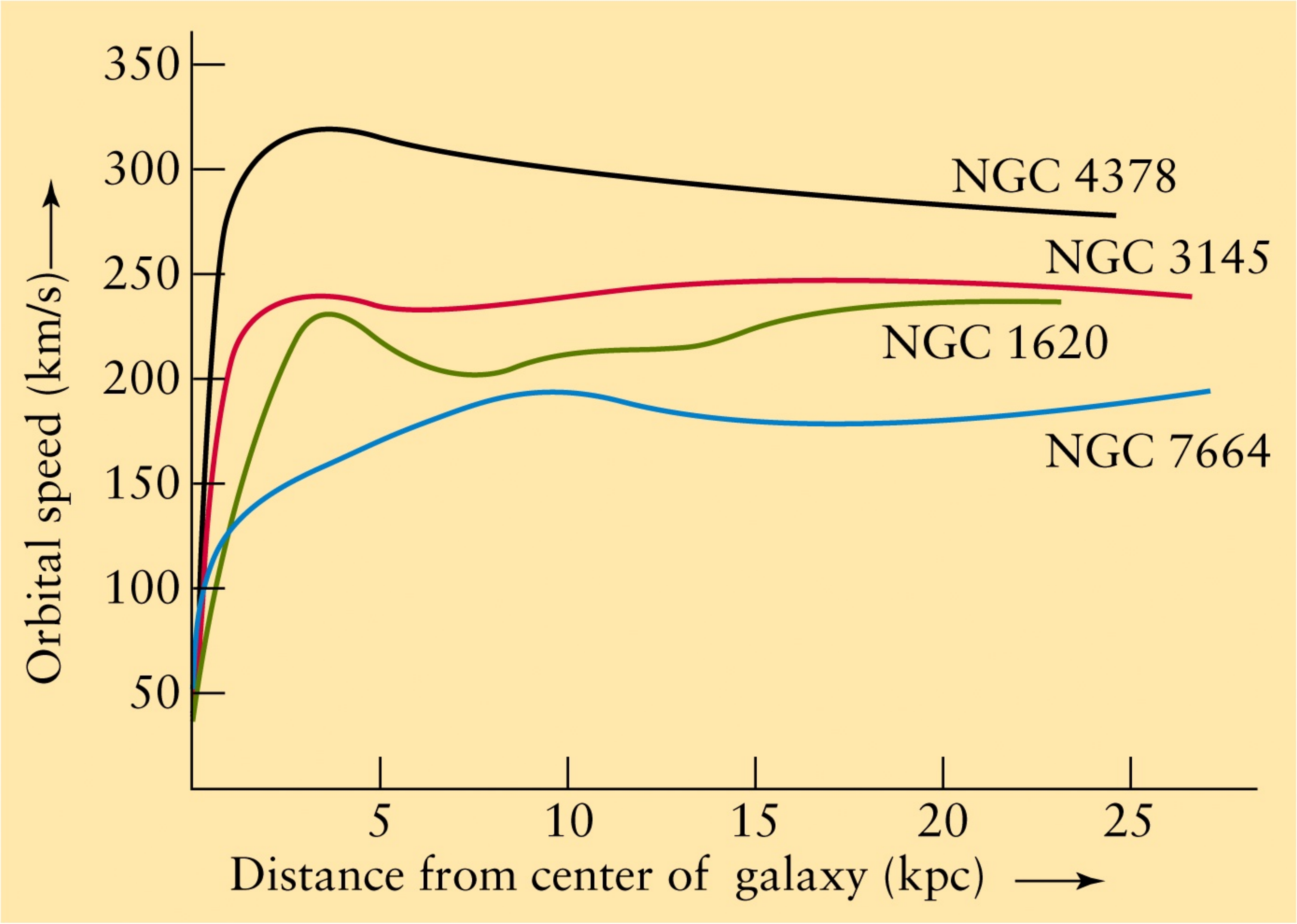


The Mass of the Milky Way

If all mass were concentrated in the center, the rotation curve would follow a modified version of Kepler's 3rd law



rotation curve = orbital velocity as function of radius



Dark matter is common in galaxies!!

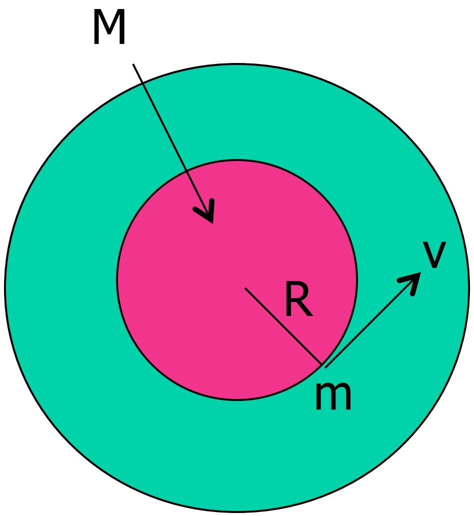
(INSERT) $M(R) = \int_0^R \rho(r)\, dV$

Motion at R depends only on M(R) = M
That mass behaves as if centrally concentrated

For an object with mass m at R, gravity must balance acceleration of circular motion

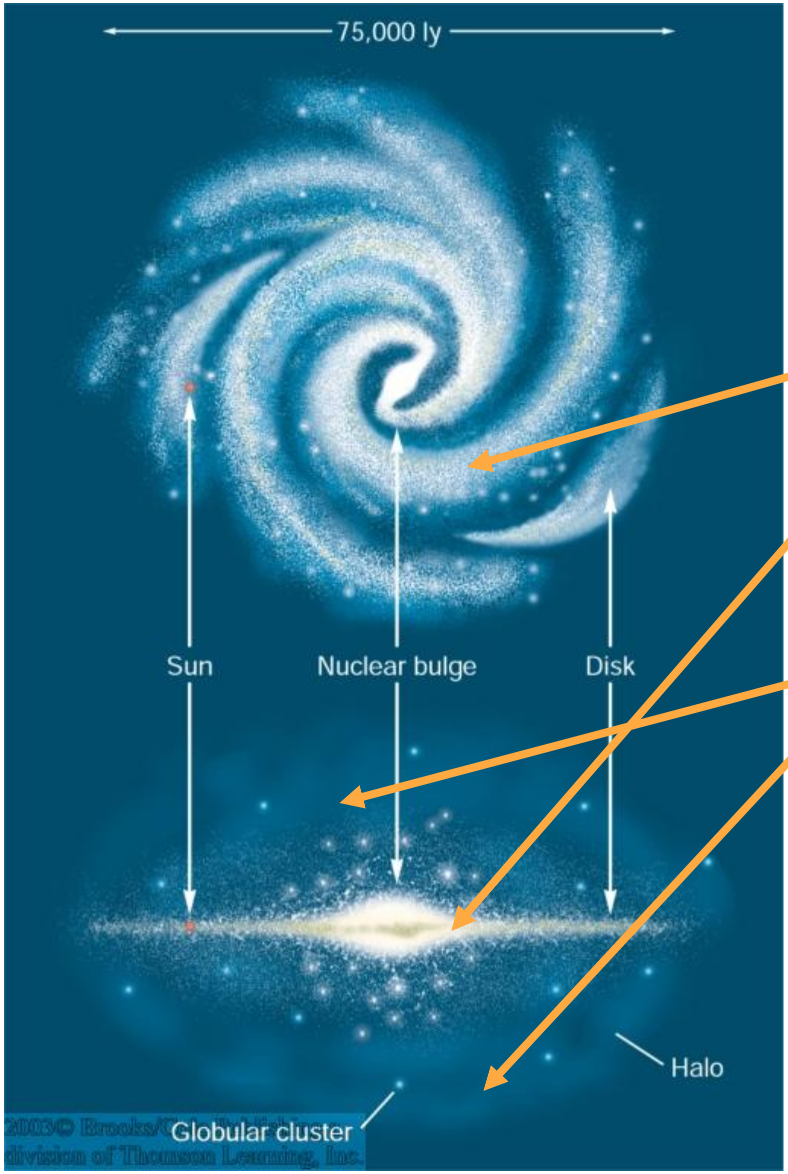
$$GM.m/R^2 = mv^2/R$$
$$M = v^2 R/G$$

Measure v(at R) and get M



i.e. Mass M(R) inside the orbit R

The Mass of the Milky Way (2)



Total mass in the disk of the Milky Way

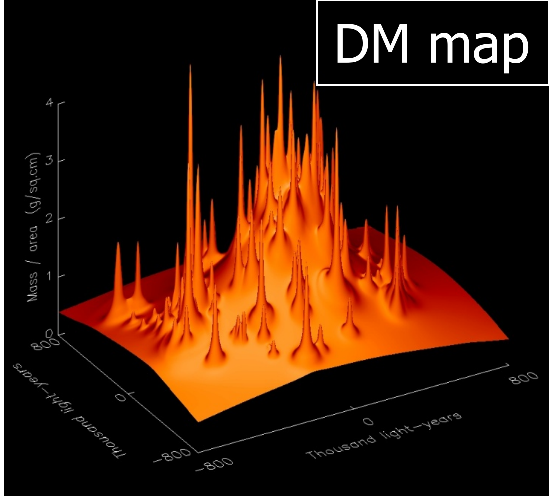
Additional mass in an extended halo

Most of the mass is not emitting any radiation:

Dark Matter!

Total mass ~ 10x visible mass

Dark matter lenses **(INSERT)**



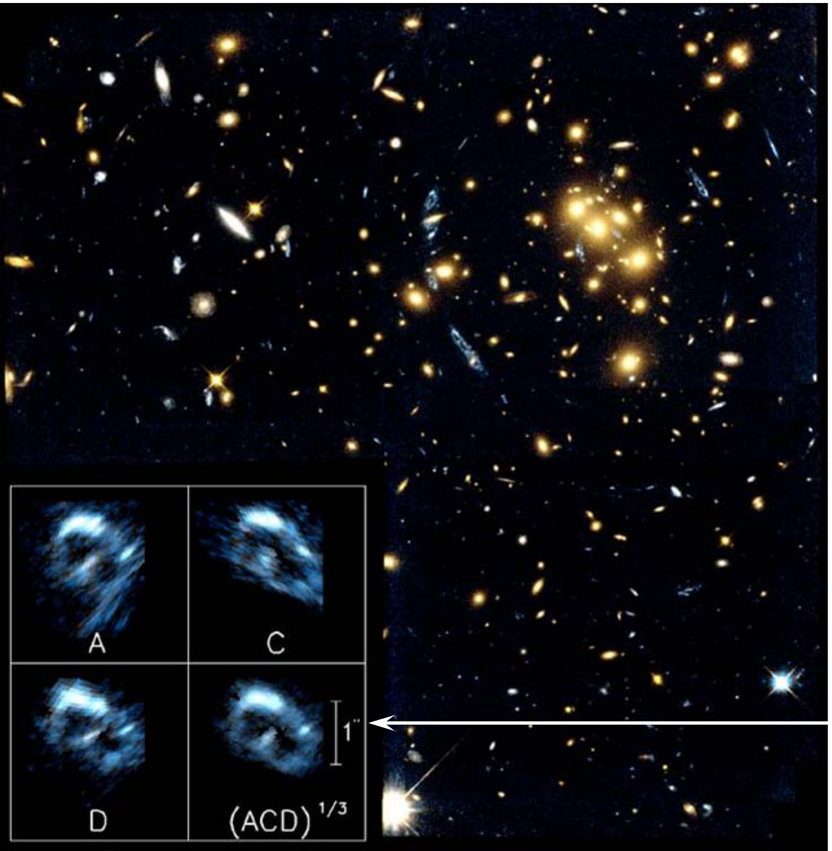
- rich clusters are gravitational lenses:

they magnify (& distort) background galaxies

use as "telescope" to study very distant galaxies

reconstruct distribution of dark matter

DM dominates mass → spread widely



Arcs of distant blue galaxies visible

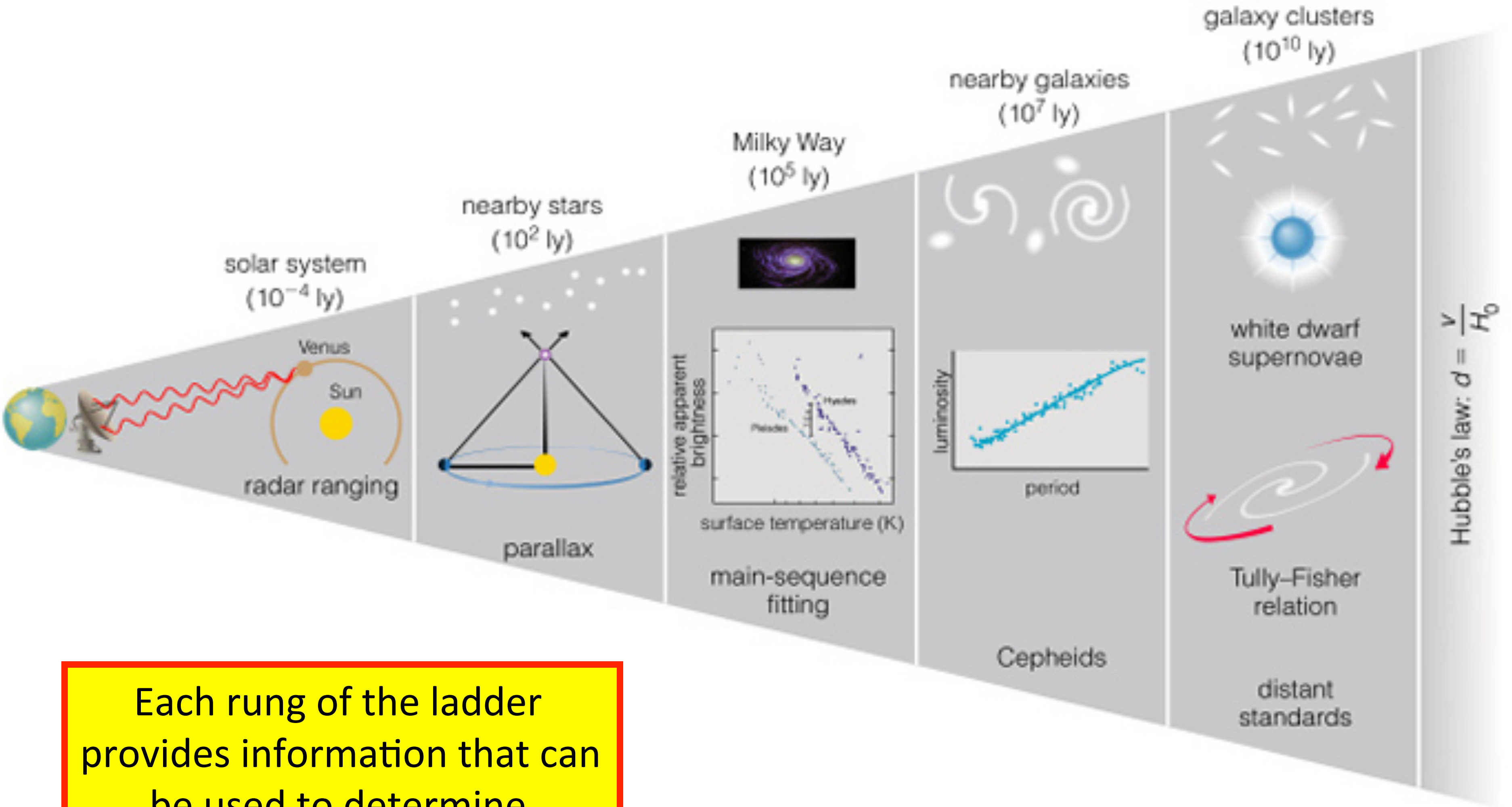
Remove distortion & image galaxy

X-ray observations

X-rays due to hot intergalactic gas →measure temp. → estimate gas pressure → hence the gravitational attraction ➔ total mass **>** mass of gas ➔ **DARK MATTER**

THE EXTRAGALACTIC DISTANCE SCALE

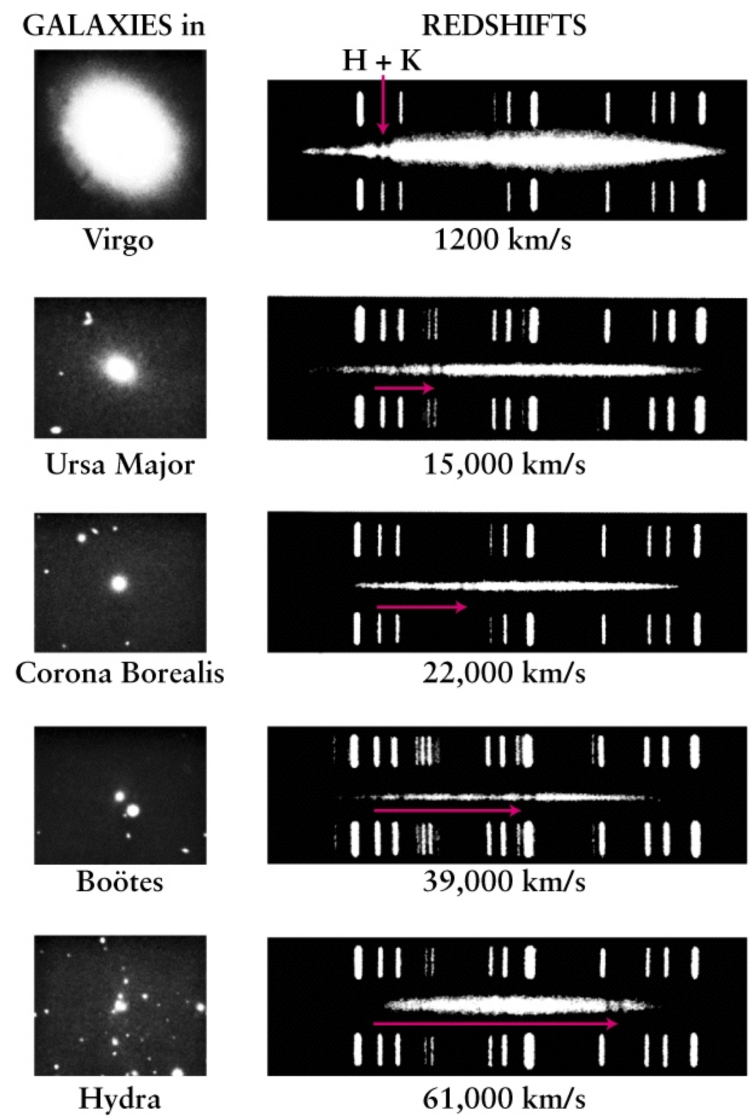
Getting the Distances to Galaxies is a "Big Industry"



Each rung of the ladder provides information that can be used to determine distances at the next higher rung.

1 parsec = 3.26 light-years

All distant galaxies are receding; their spectra are *red shifted*



See ealier notes: Redshift → velocity

$$\boxed{\frac{(\lambda - \lambda_0)}{\lambda_0} \equiv \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}}$$

Hubble Space Telescope Spies **Cepheid Variables – 'standard candle'**

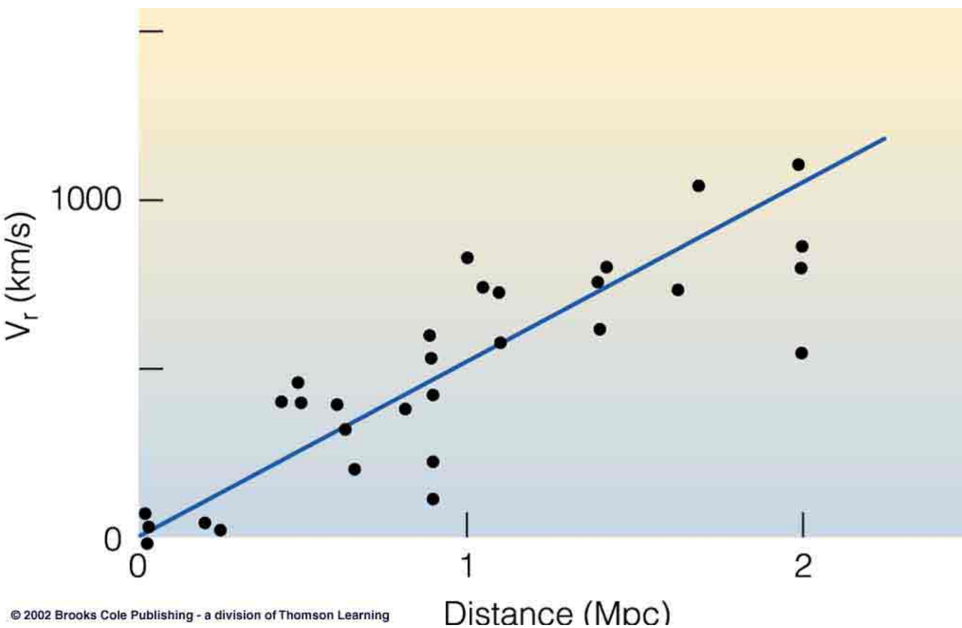
Luminsoity = constant x
Period of variability

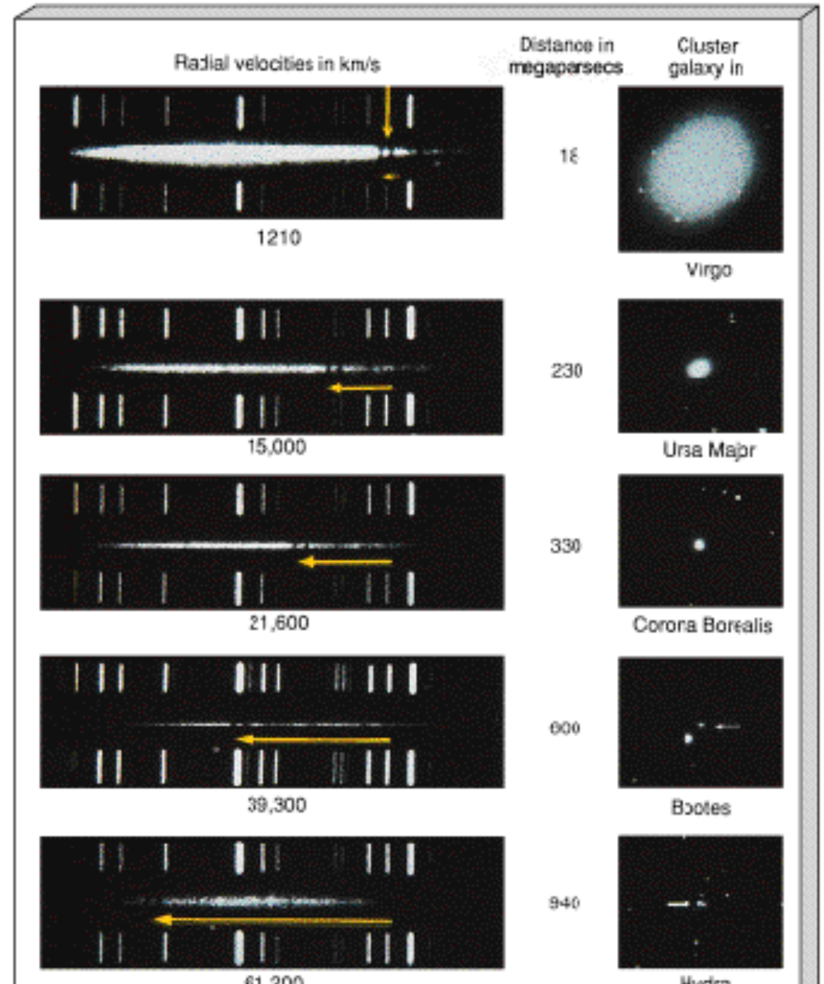
Distance from luminsoity, L and
Inverse square law of light

We can use e.g. Hubble Space Telescope to measure the distances to very distant galaxies because it can resolve individual stars. Then we can find the Cepheid variables ➔ **distance**

The Hubble Law

The further away a galaxy is, the greater is its redshift.





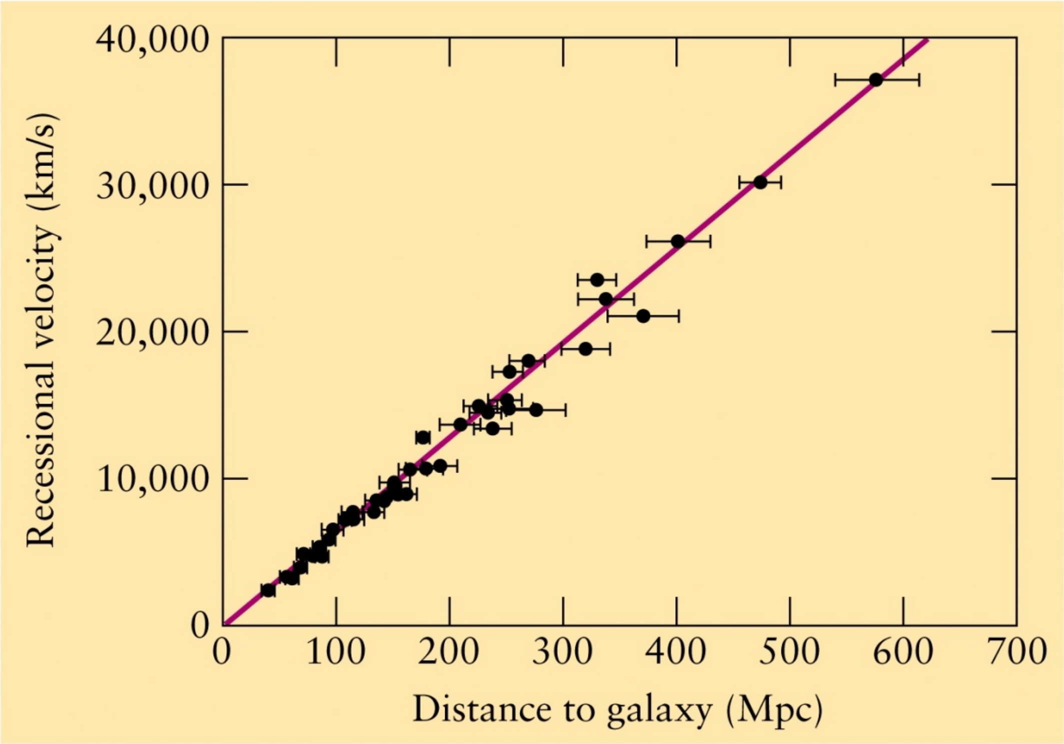
Red

Blue

(As you can see, it is not perfect.)

HST Key Project

Final result based on cepheids and cepheid-calibrated secondary methods: $H_0 \approx 72 \pm 8$ km/s/Mpc



Recession velocity, $v = H_0 \times$ Distance

Non-relativistic cases (PHAS1202):

$$1 + z \equiv \frac{\lambda}{\lambda_0} = \frac{\lambda_0 + \Delta\lambda}{\lambda_0} = 1 + \frac{\Delta\lambda}{\lambda_0}$$

Z = redshift

➔ Everything appears to be moving away from us, but in reality everything is moving away from everything (on cosmological scales; not true locally... Also, expansion of the universe does not mean expansion of the *contents* of the universe.)

→'Big Bang' model

Standard Candles

Type Ia Supernovae (SNe Ia) have become the principal distance indicator for the determination of distances on cosmological scales

Brightness tells us distance away (lookback time)

Redshift measured tells us expansion factor (average distance between galaxies)

Low Redshift Type Ia
Template Lightcurves