Galaxies

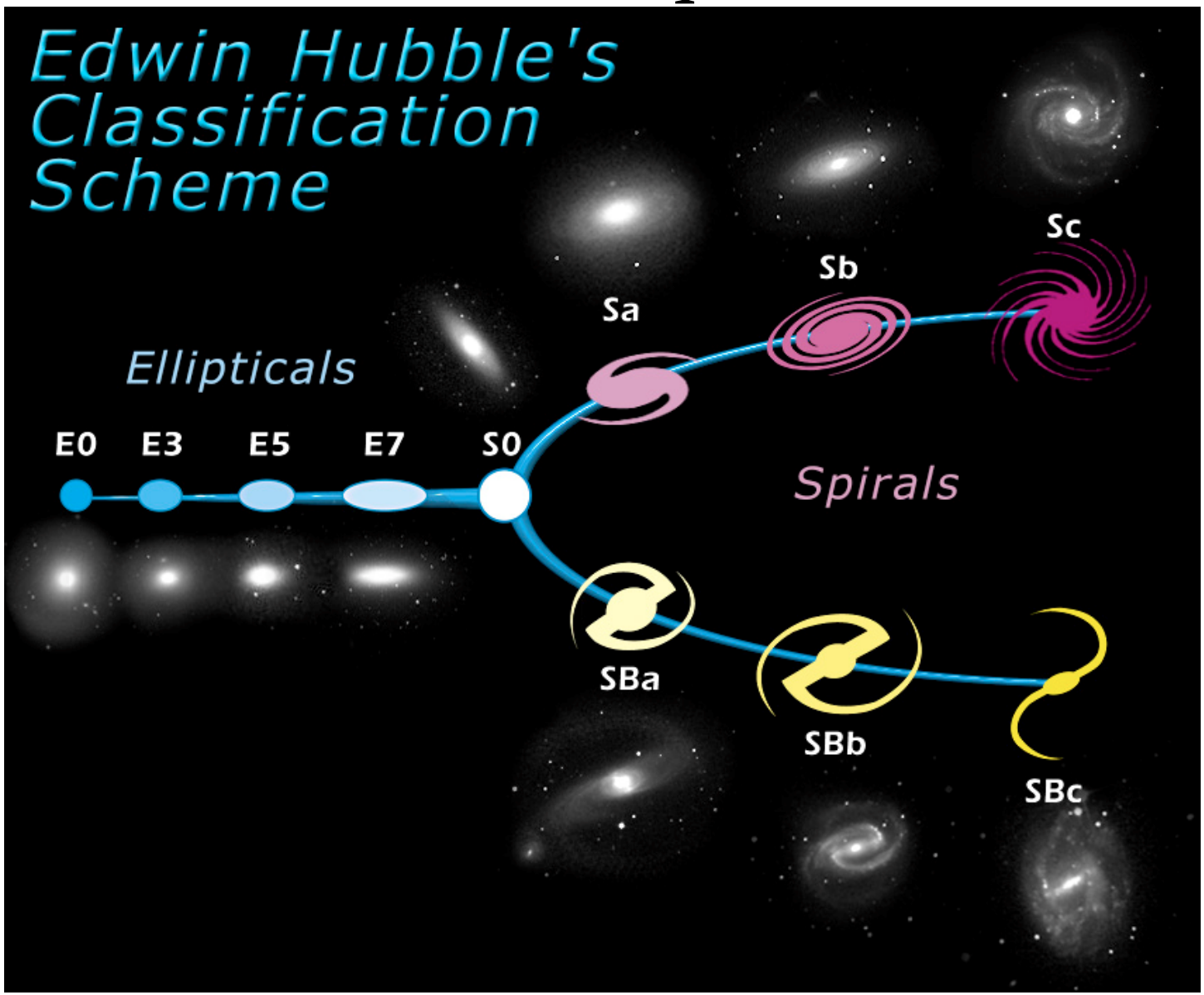
•Aim to understand the characteristics of galaxies, how they have evolved in time, and how they depend on environment (location in space), size, mass, etc.

•Need a (physically) meaningful way of describing the relevant properties of a galaxy.

•One of the most striking properties of galaxies is their variety in morphologies

•Hubble introduced his classification scheme based on the appearance of a galaxy in the “optical” band.

Hubble sequence



Fundamental criteria behind the Hubble sequence

- Classes are E(0-7), S0, Sa, Sb, Sc, Sd, Irr

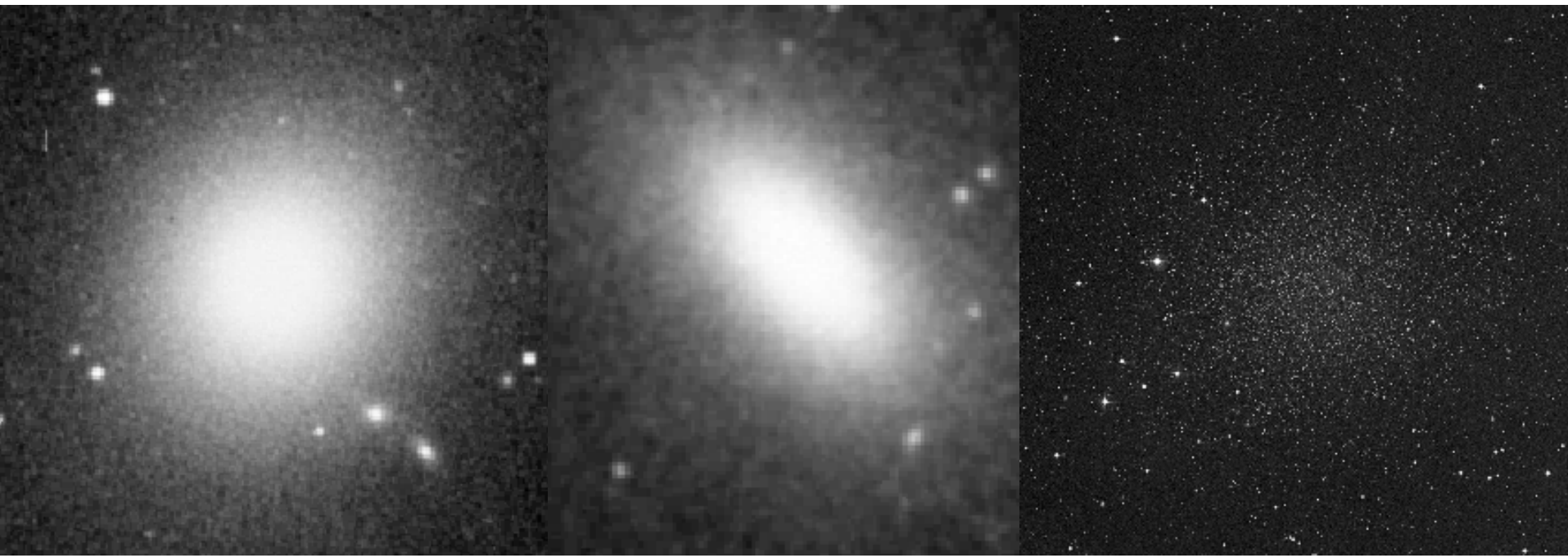
- Three criteria:
  - Primary: small-scale lumpiness due to star formation now (current SFR) The Hubble sequence is a sequence in present-day star formation rate
  - Secondary: Bulge (spheroid) to disk ratio (B/D)
  - Tertiary: Pitch-angle (PA), prominence, and number of spiral arms

- Not all galaxies belonging to a given class satisfy all the criteria for the class; for example, there are Sa galaxies with small bulges

- The Hubble Sequence doesn't satisfy all desires of a classification scheme. E.g. there are many galaxies (peculiars) don't fit

Elliptical galaxies

•smooth and structureless
•projected shapes: from round to cigar shaped (E0 to E7)
•Giant and dwarf galaxies: divided according to total luminosity (or mass)
•dwarf Spheroidals: very low stellar density

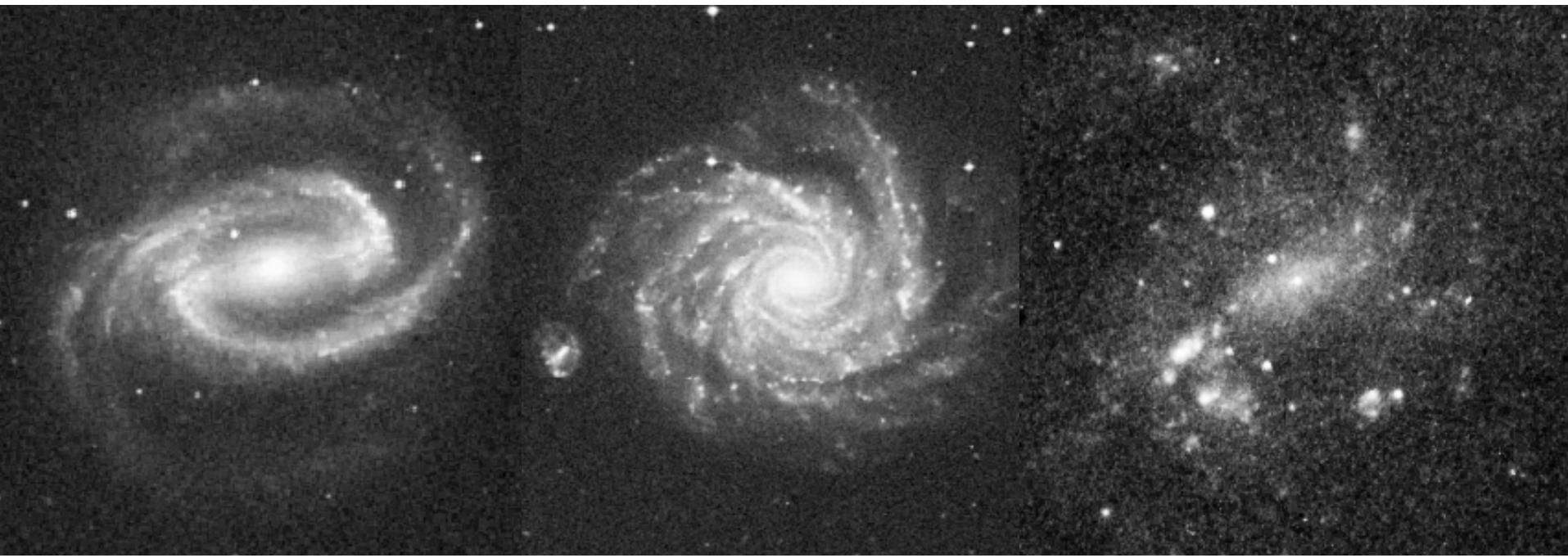


Lenticular: S0s and SB0s

- smooth bright central concentration
- and a less steeply falling bright component (resembling a disk)

Disks

- from Sa to Sd (and SBa to SBd)
- contain a bulge (resembling an E) and a thin disk with spiral arms
- divided in subclasses according to
  - relative importance of the bulge and disk
  - tightness of the spiral arms winding
  - degree to which the spiral arms are resolved (into stars and HII regions)

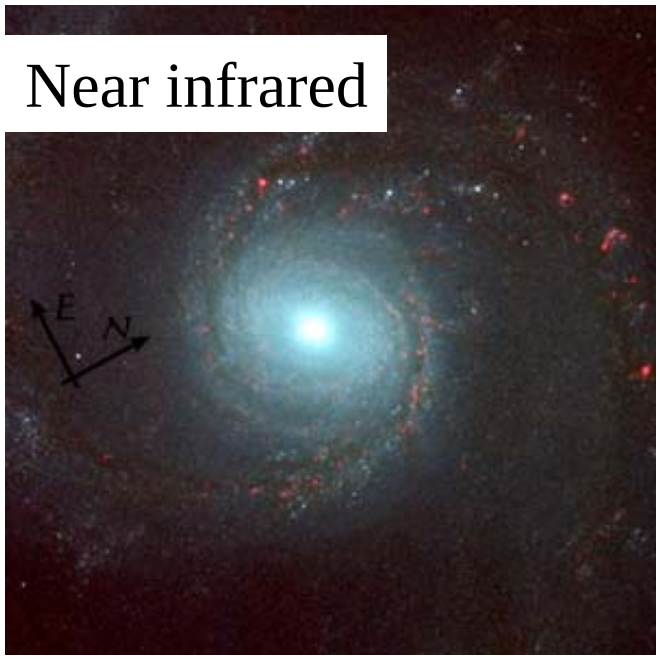


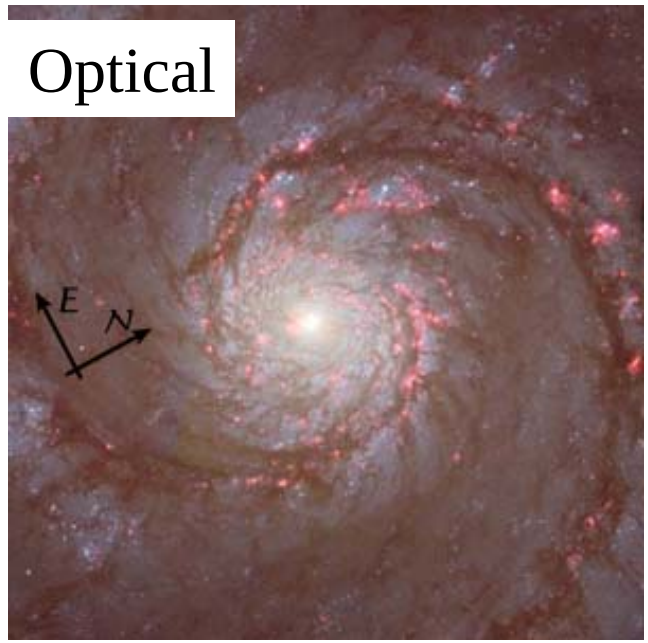
Irregulars

Asymmetrical; typical example are the Magellanic clouds

Morphological classification of galaxies: wavelength matters!

The morphology of a galaxy may vary with waveband (different appearance in optical, UV, radio) or spectroscopically (high vs low resolution).



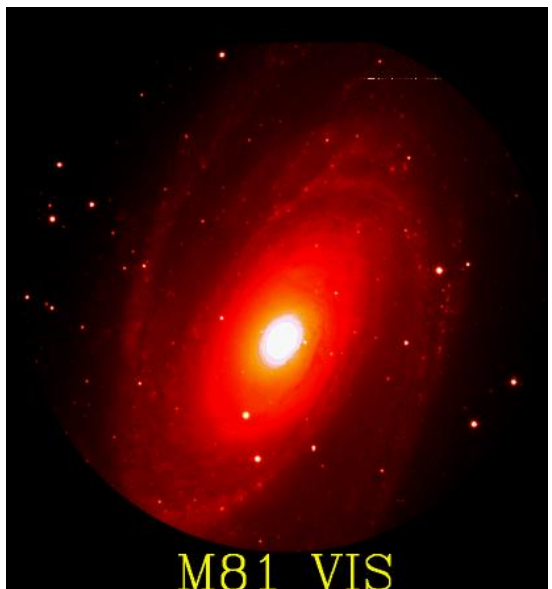


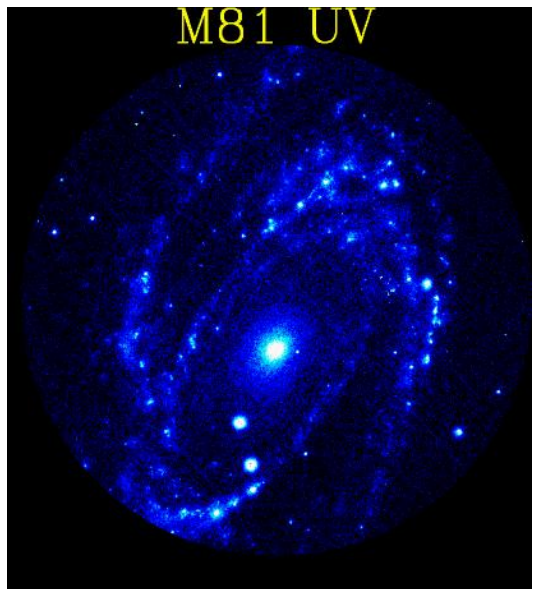
Galaxy M51 observed with the Hubble Space Telescope in different wavebands. Since clouds are more transparent in the near-IR the stellar distribution is better delineated on the left picture.

More considerations on the classification

- Important to recall that the Hubble sequence is based on optical appearance.

- When attempting to classify a set of images, it is fundamental that this set is homogeneous:
  - for each galaxy in the set one needs same wavebands
  - Critical for comparison of objects at high and low redshifts: rest-frame images are needed. A galaxy at z=1 observed in the R-band should be compared to a z=0 galaxy observed in the U-band





Notice how different the galaxy looks like in the UV (it would probably not be classified as an Sb). If M81 would have been at z=1, it would look like in the right image.

Hubble sequence: more than a morphological classification scheme

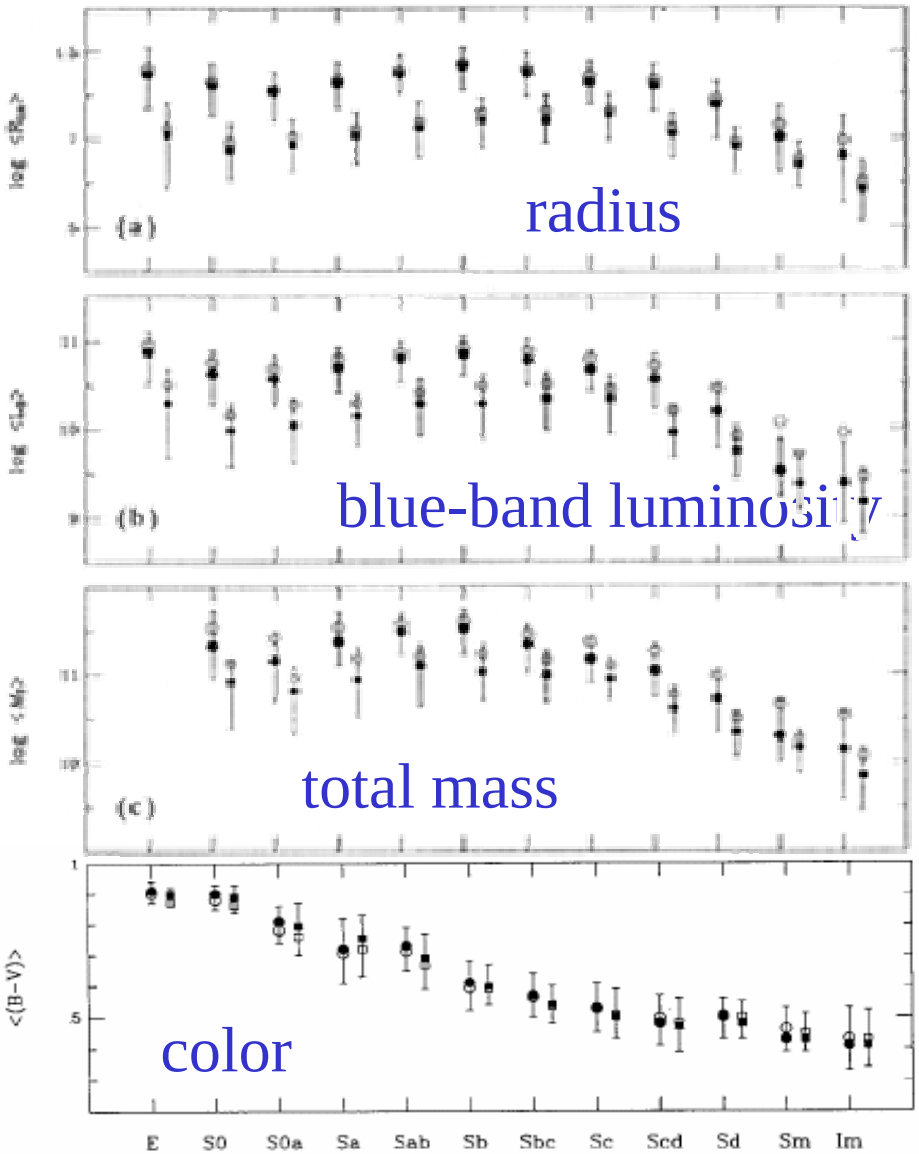
- The Hubble classification, based purely on morphology, also discriminates among other galaxy properties:
- There is a correlation between Hubble type and age of the dominant population of stars, the HI content and the environment in which these galaxies are found

- **Early type galaxies**: (E and S0) ~ 20% of all field galaxies
  - no current star formation
  - redder (implying older stars)
  - primarily in galaxy clusters (high density environments)

- **Late type galaxies**: (S) ~ 75% of all field galaxies
  - show star formation activity
  - bluer (younger stars)
  - mostly found in the field

More correlations in the Hubble sequence

Early type late type



The Luminosity Function of Galaxies

- The **luminosity function** is defined as the number of galaxies per unit luminosity (or magnitude) bin.
- This has been characterized by the **Schecter function**:

$$\Phi(L)dL \sim L^{\alpha} e^{-L/L_*} dL$$

where $\mathbf{L_*} \sim 2\text{x}10^{10}\ L_{\odot}$, **(**$\mathbf{M}_{*,B} \sim -21$ mag) and $\alpha \sim 1\text{-}1.5$

Fairly universal, but there are significant variations of the luminosity function depending on environment (ie field galaxies versus cluster galaxies).

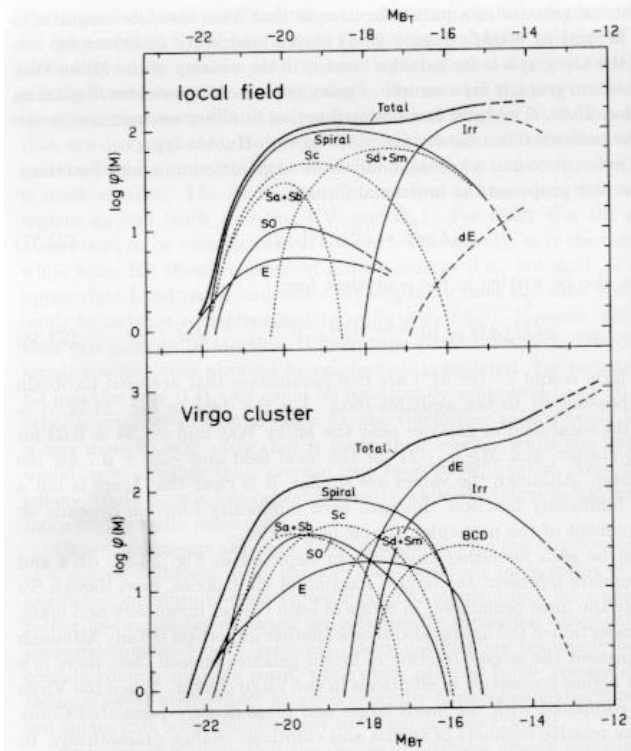


Figure 23.34 Luminosity functions for two samples of galaxies. The top panel is based on a sample of galaxies near our Galaxy and the bottom panel is for galaxies located in the Virgo cluster of galaxies. The zero point of the $\log_{10}\phi(M)$ axis is arbitrary. (Figure from Binggeli, Sandage, and Tammann, *Annu. Rev. Astron. Astrophys.*, *26*, 509, 1988. Reproduced with permission from the *Annual Review of Astronomy and Astrophysics*, Volume 26, ©1988 by Annual Reviews Inc.)

Physics behind the Hubble sequence

- The fractional mass of HI to the total galaxy mass increases as one goes from E to S galaxies, implying that the fuel for star formation also increases, so the SFR should increase from early to late types
  - Caveat: There are large disk galaxies with an extremely large mass of HI that show very little star formation (SF depends on more variables than total HI mass)

- This can be seen (roughly) from colors as function of type:
  - early-types are red (~ no SF)
  - late-types are blue (lots of SF)

- Note that the Hubble type also correlates with mass (large B/D often implies large mass). This may be understood if mergers were important to build up early-type galaxies.

Static, evolving or evolutionary sequence?

- The Hubble classification was *initially suggested to be an evolutionary sequence*:
  - galaxies on the left part of the tuning-fork (E's) would evolve into the right-hand side types (S's). This is why we often speak of *early-type* and *late-type* galaxies.

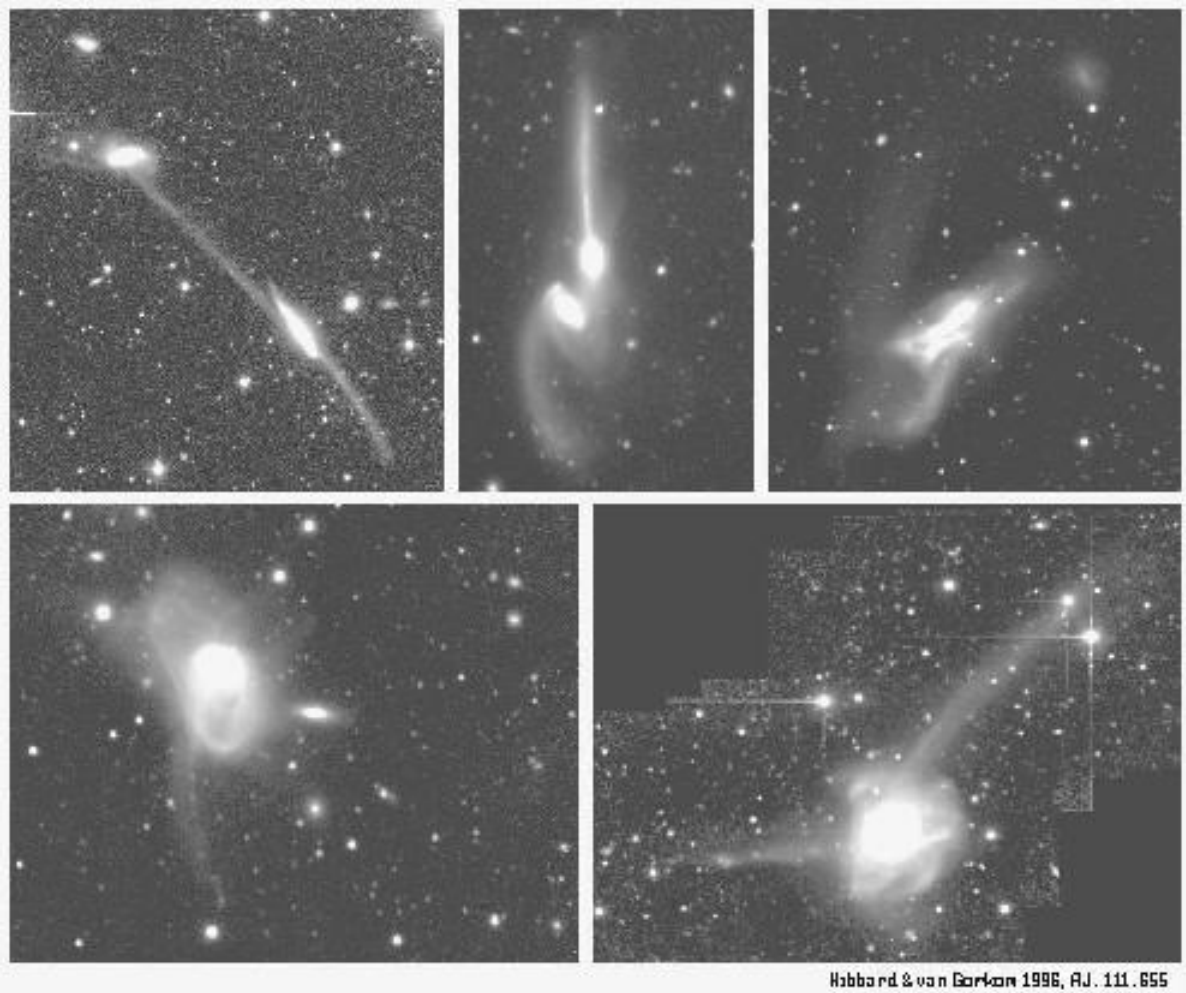
- This interpretation is incorrect (ages, [Fe/H], galaxies without bulges).

- Many processes can change the morphology of galaxies; thus, morphological type of a galaxy can change in time

- Processes affecting the morphology:
  - minor interactions with other galaxies, environment
  - mergers of galaxies

→ **Hubble classification is "not static"**

Collision between two disk galaxies

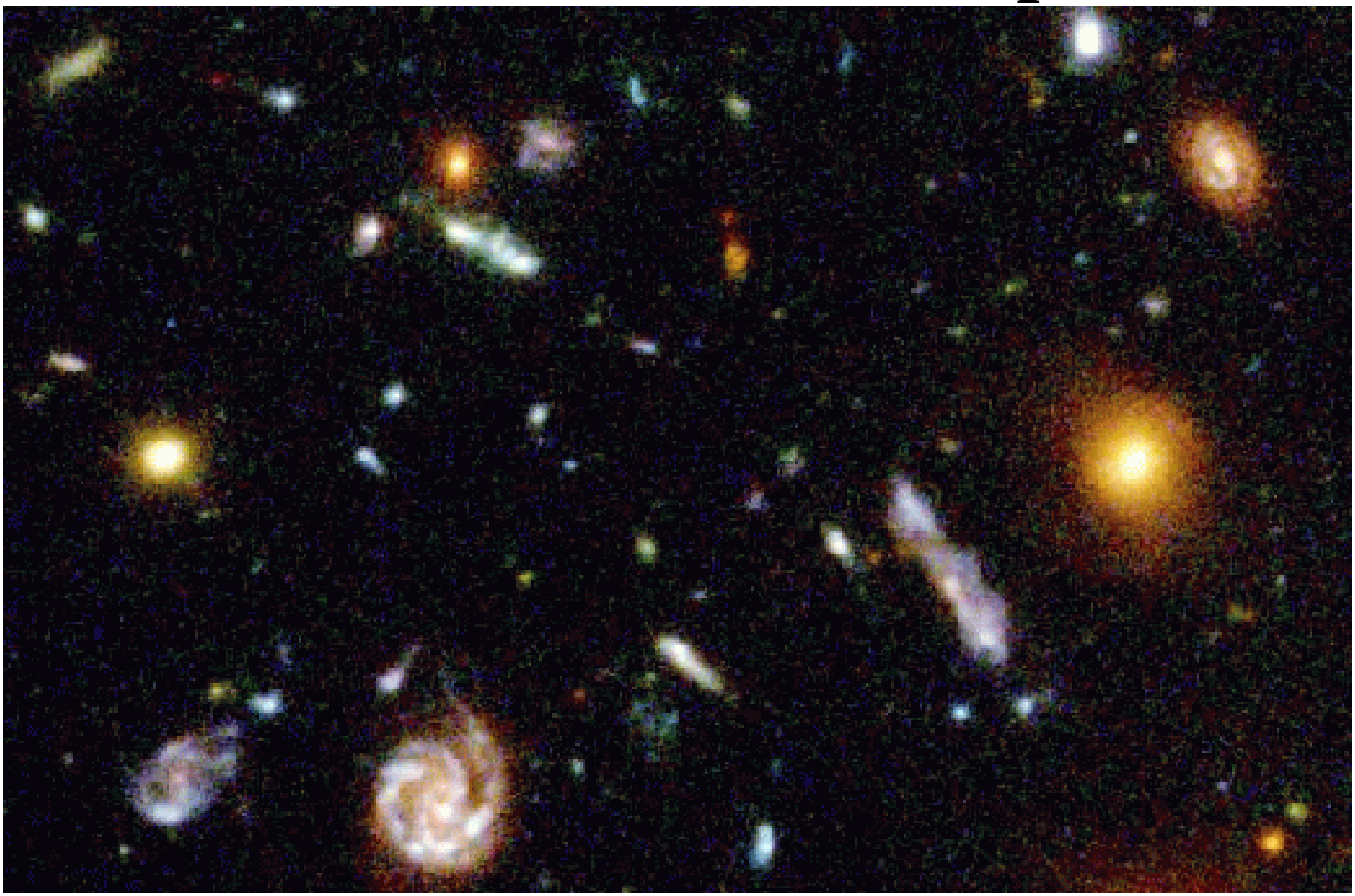


Peculiar galaxies: do not fit into the Hubble sequence. They show

- distortions of bulges and disks by gravitational processes
- gas and dust in systems where unexpected, often unrelaxed
- starbursts

Nearly all due to mergers or interactions with other galaxies

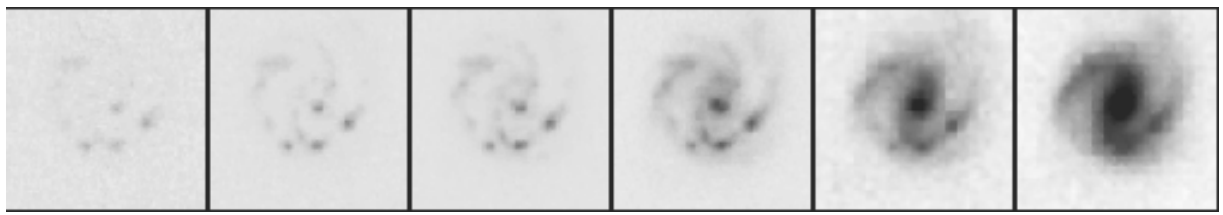
The distant universe: deep fields



Hubble's classification is based on what we see today, in the "nearby Universe". Is it useful to describe the high-z universe?

High-z universe

- Few issues to confront:
  - distances are required to understand both the sizes and ages of the galaxies
  - distances require redshifts AND cosmological parameters
  - distant galaxies are younger than those used to define the Hubble Sequence
  - more peculiar galaxies are observed: could be due to patchy star formation (expected because of younger age) or to interactions being more frequent (denser Universe)
  - resolution is poor compared to local galaxies and usually limited to a few bandpasses, and not necessarily those observed for nearby galaxies



More considerations for the high-z universe

- When looking at different redshifts: can attempt to do the same morphological classification as for nearby galaxies

- It is probably more relevant to understand:
  - what will be the fate of those high-z galaxies? Will they become an E or an S today?
  - Or, working backwards in time, how did a galaxy that we observe today look like in the past?
  - How did the Milky Way look like at z=1, 2, ...5? Was it always a spiral? Was it ever bulge dominated (i.e. an E)?

Galaxies: some questions

- What determines that a galaxy has a given type?
- Why are there correlations between the properties of a given galaxy (such as size, colour, environment, etc)?
- How do such correlations arise?

In this course we will study the properties of galaxies

- Learn how we measure their properties
- How to derive ages
- How to measure shapes
- What determines the colour, e.g. if a galaxy is red, what does it mean?