Astrophysics and Nuclear Astrophysics
(LPHY2263)

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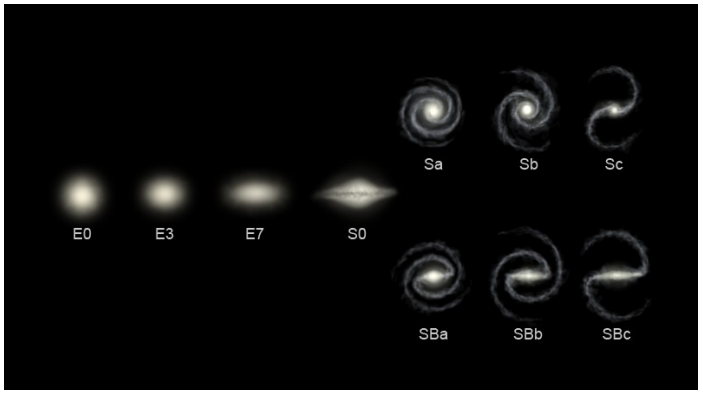
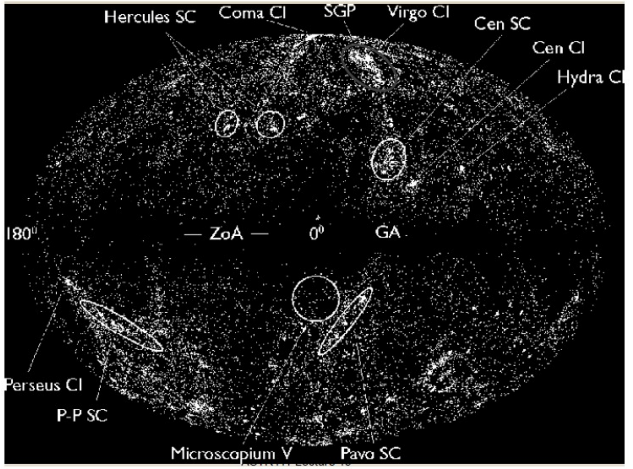
Chapter #7

- Galaxies
  - Types of galaxies
  - Galactic mass profiles
  - Clusters and superclusters
  - Quasars

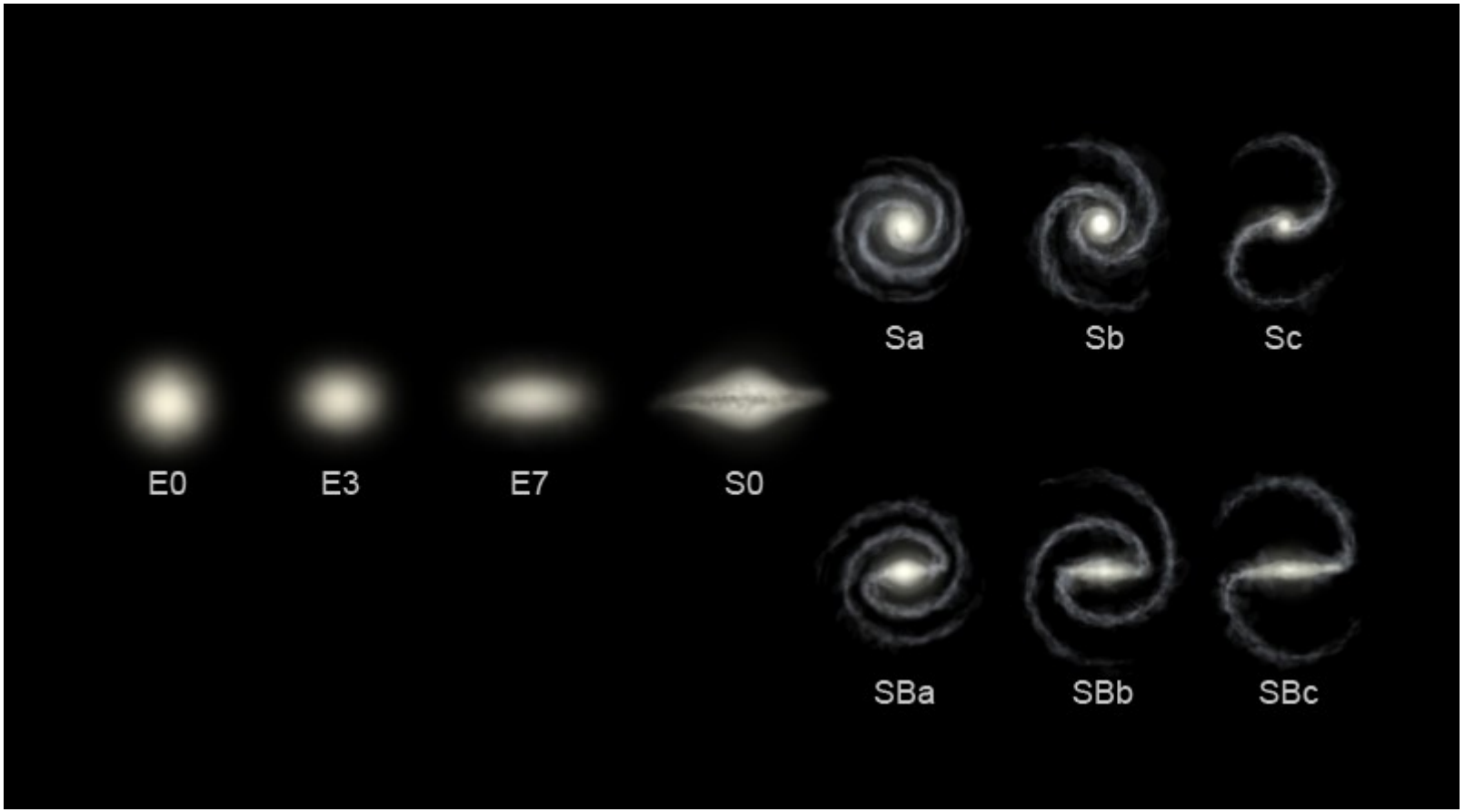




What is a galaxy

- A system bound by gravity, composed by:
  - Stars
  - Interstellar medium of gas and dust
  - Cosmic rays
  - Dark Matter (to be explained later)
- Typical diameters: 1000 to 100,000 parsecs
- Typical number of stars: 10^7 to 10^{12}
  - Milky Way and Andromeda: ~200×10^9 stars
- The observable Universe is estimated to contain 200×10^9 galaxies

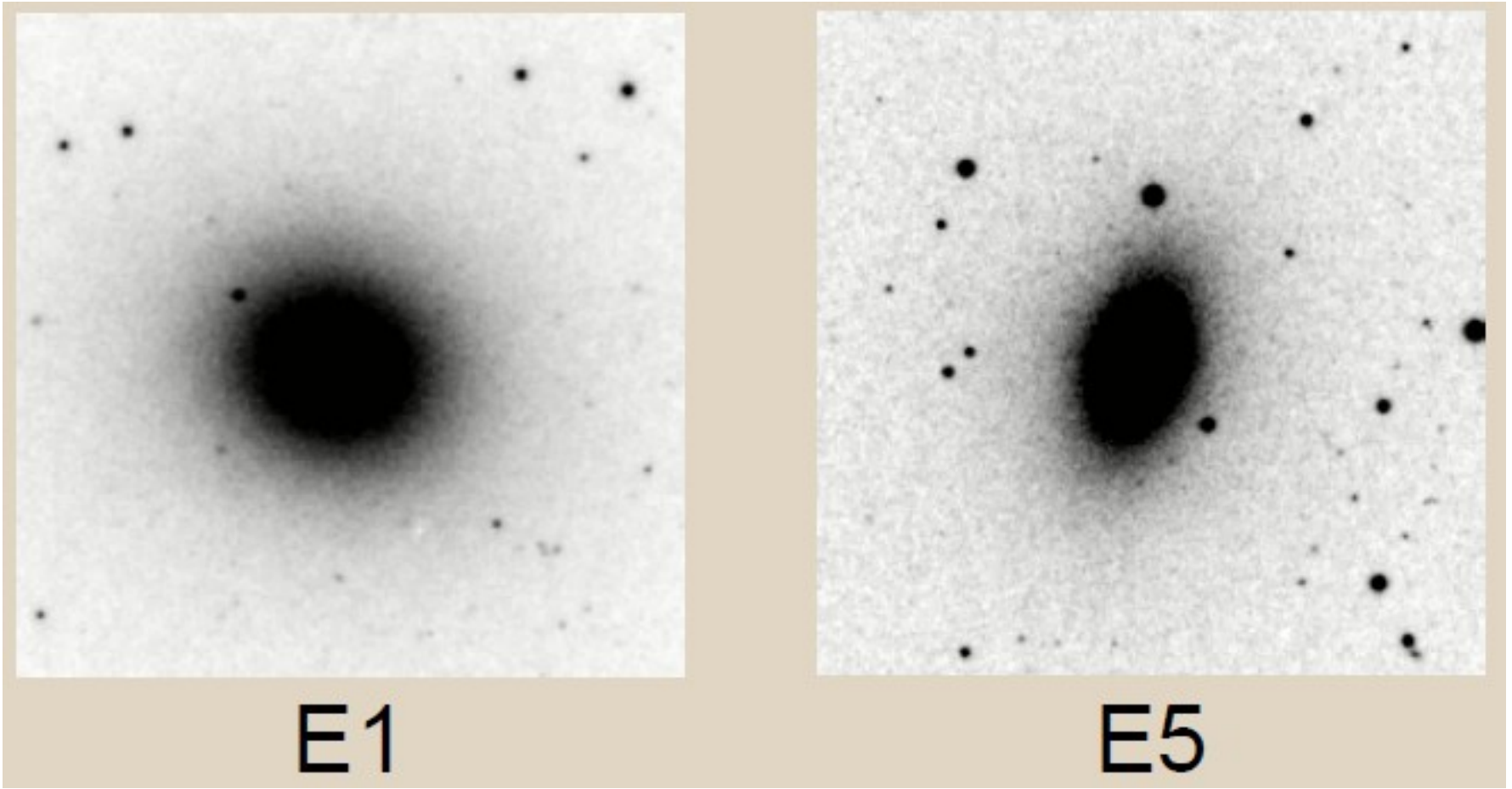
Types of galaxy



Hubble's classification system

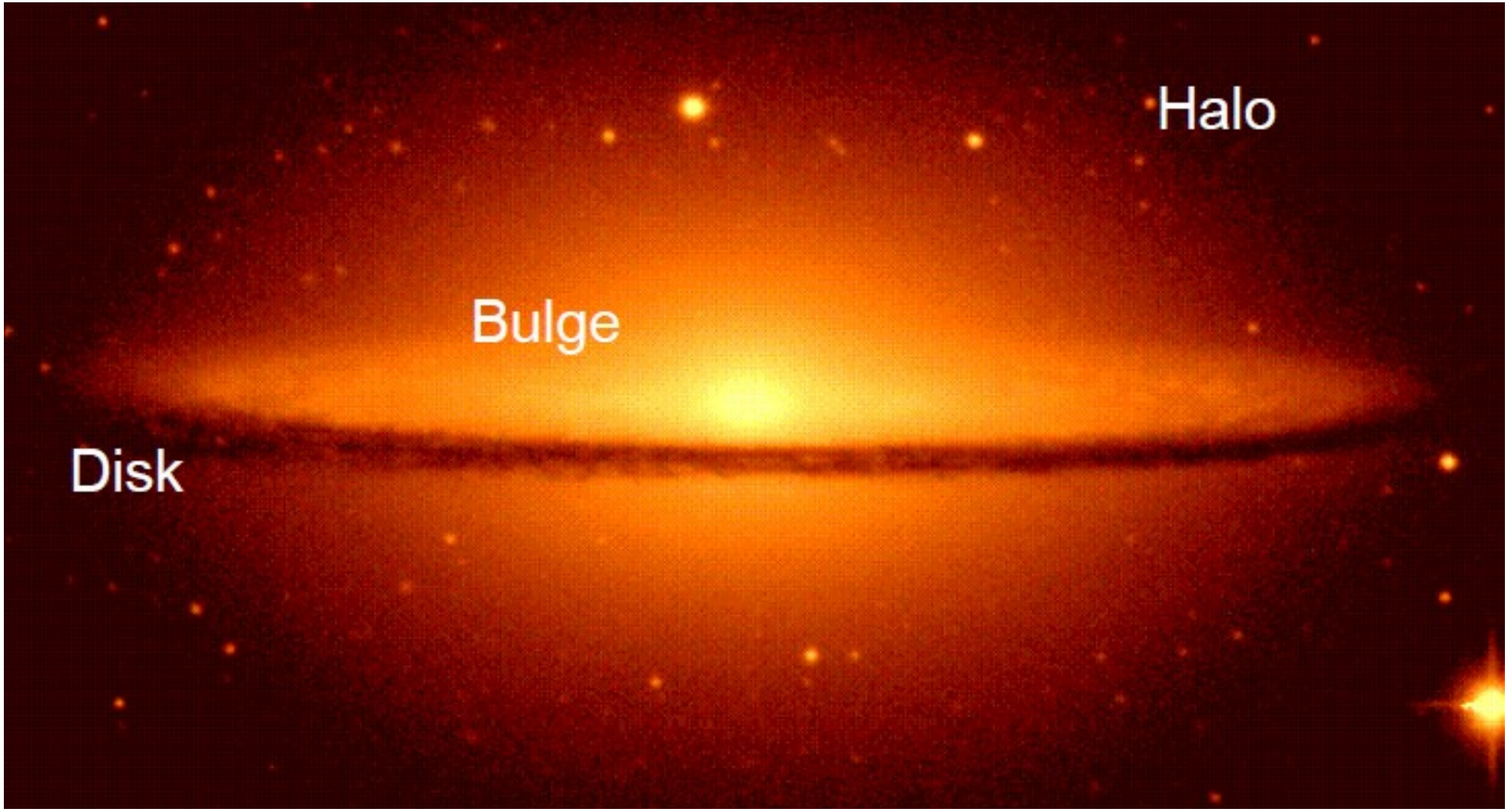
Elliptical galaxies (~20%)

- Ranging from E0 (nearly spherical) to E7 (very elongated) in Hubble's classification
- Their appearance shows little structure
- They typically have relatively little interstellar matter
- Consequently also reduced rate of new star formation
- So they are dominated by older, more evolved stars that are orbiting the common center of gravity in random directions
- Low abundances of heavy elements because star formation ceases long ago


E1
E5

Spiral galaxies (~75%)

- A spiral galaxy has the visible stars arranged on a double spiral shape
- Rotating disk of stars and interstellar medium, with a central bulge of older stars with little gas and dust
- Hubble's classification: type S, followed by a letter (a, b, or c) that indicates the degree of tightness of the spiral arms and the size of the central bulge
- Sa: tightly bound, poorly defined arms and relatively large core region; Sc: open and well-defined arms, and relatively small core region
- Depending on rotation speed, the disk can be flat or have a large central bulge



Sombrero galaxy (M104)

What are the spirals

- Spiral arms are "density waves"
  - As stars move through an arm, the velocity of each stellar system is modified by the gravitational force of the higher density
  - Imagine a "wave" of slowdowns "moving" along a highway full of moving cars
- The arms are visible because the high density facilitates star formation, and therefore they harbor many bright and young stars
- Shape is a "logarithmic spiral" ($r=ae^{b\theta}$); theoretically it can be explained as coming from a disturbance in a uniformly rotating mass

Barred spiral galaxies

- Most spiral galaxies have a linear, bar-shaped band of stars that extends outward to either side of the core
- Hubble's classification: type SB, followed by a lower-case letter (a, b or c) that indicates the form of the spiral arms (same as the categorization of normal spiral galaxies)
- Bars are thought to be temporary structures that can occur as a result of a *density wave* radiating outward from the core, or else due to a *tidal interaction* with another galaxy

Milky Way

- Our galaxy is a large disk-shaped barred-spiral galaxy
- Diameter: ~30 kiloparsecs
- Thickness: ~1 kiloparsec
- It contains about 2×10^{11} stars
- Total mass: ~6×10^{11} times the mass of the Sun

Irregular galaxies (~5%)

- Many other shapes are observed
- Usually they can be explained by collisions between galaxies, or strong tidal effects between them
- An example of this are the "ring galaxies", which are though to occur when a smaller galaxy passes through the core of a spiral galaxy

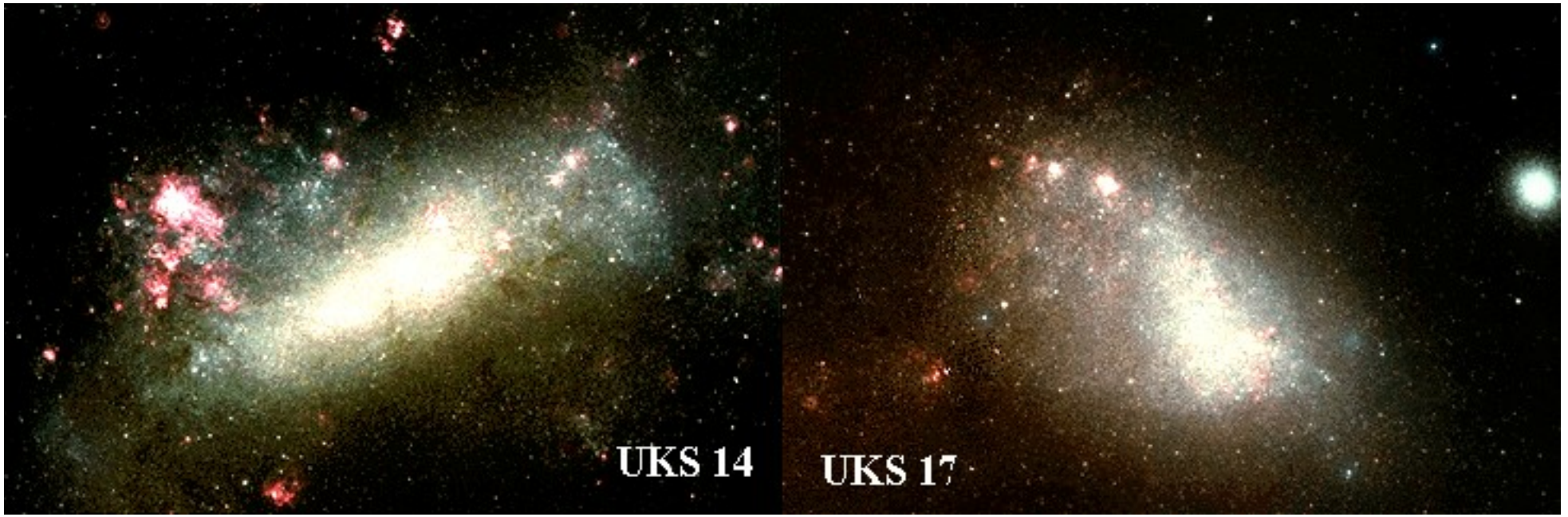
Hoag's Object, an example of a *ring galaxy*

NGC 5866, an example of a *lenticular galaxy*

Interactions

- Most galaxies are separated by only ~20 times their typical diameters
- Therefore collisions are not rare, and strong gravitational interactions are very frequent
- Compare with typical inter-star distance: ~10^7 times a typical star's radius
- Galaxies may encounter (*) other galaxies several times in their history
  - (*) i.e., interact significantly

Galactic "satellites"



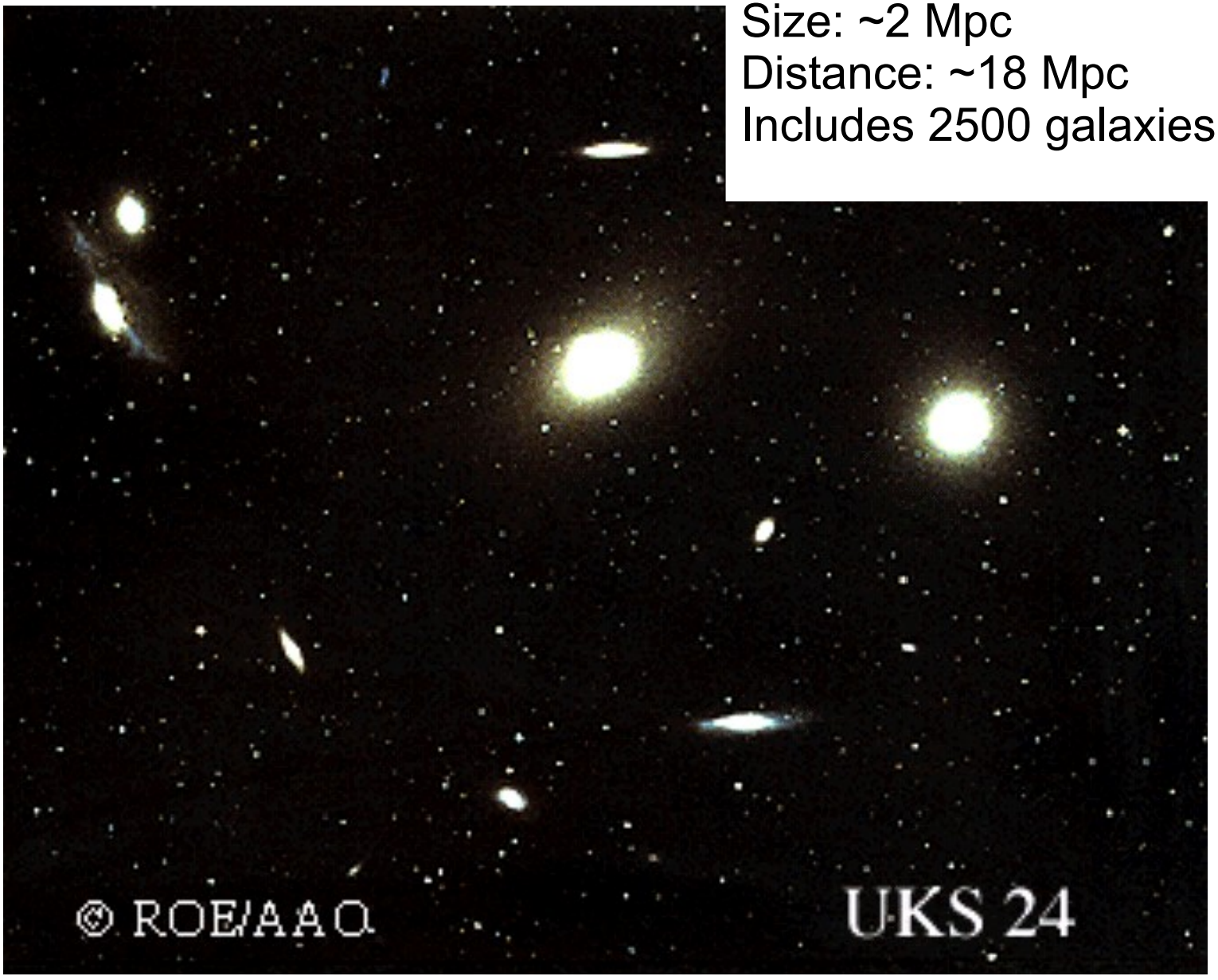
Large Magellanic Cloud Small Magellanic Cloud

Both are dwarf irregular galaxies, orbiting around the Milky Way

Galaxy groups and clusters

- Most galaxies are found in *groups* or *clusters*
- From *a few* to some *thousand* of galaxies
- Sizes: from 1 to 10 Megaparsecs
- Milky Way belongs to the Local Group, a group of ~30 galaxies, ~1 Mpc, centered around Milky Way and Andromeda, composed of:
  - 4 spirals
  - 15 ellipticals
  - 13 irregulars

Virgo cluster



Size: ~2 Mpc
Distance: ~18 Mpc
Includes 2500 galaxies

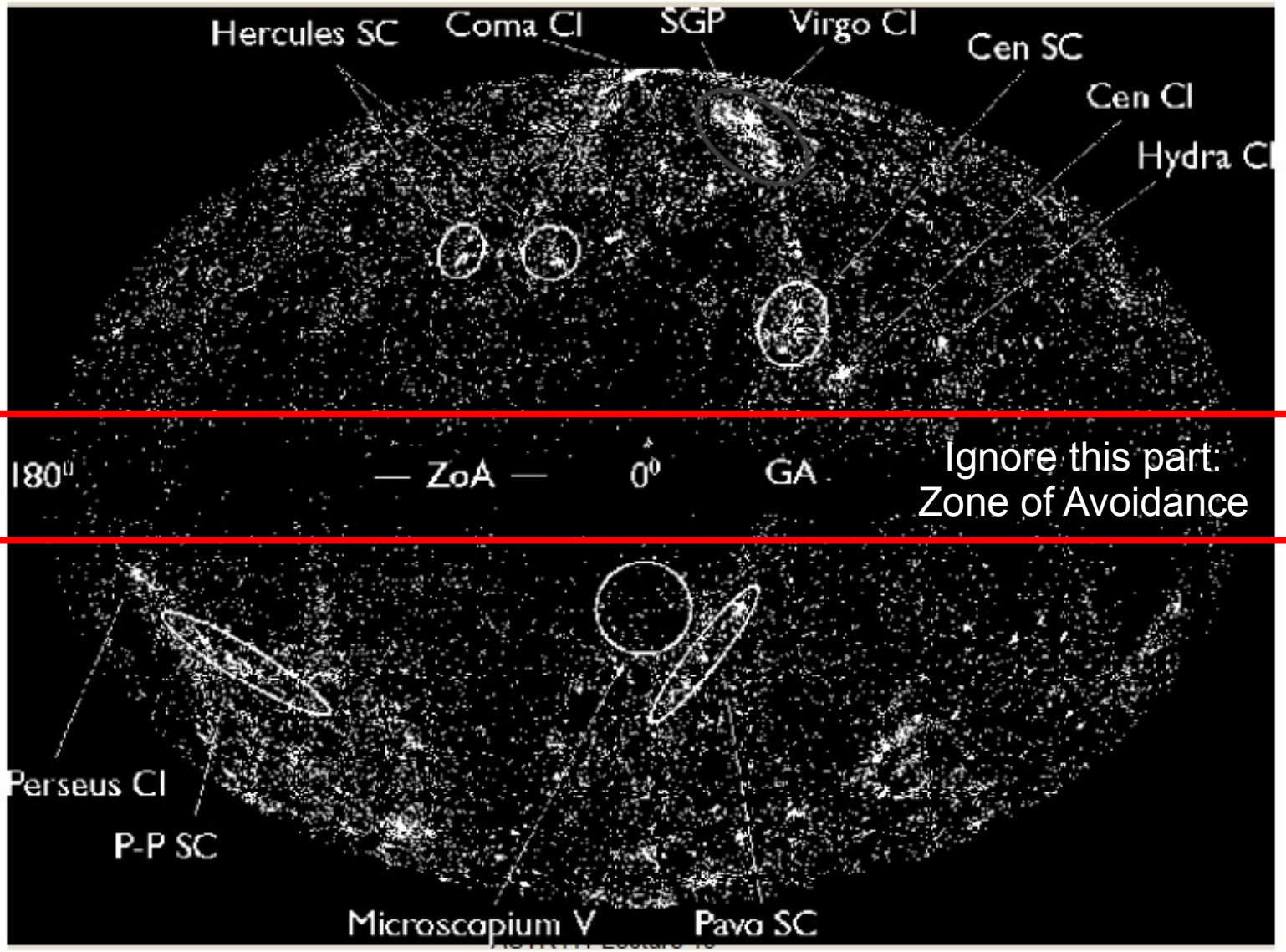
Superclusters

- Clusters of clusters
- Sizes up to ~50 Mpc
- 90-95% of volume is empty space
- Long and filamentary shapes

The Local Supercluster

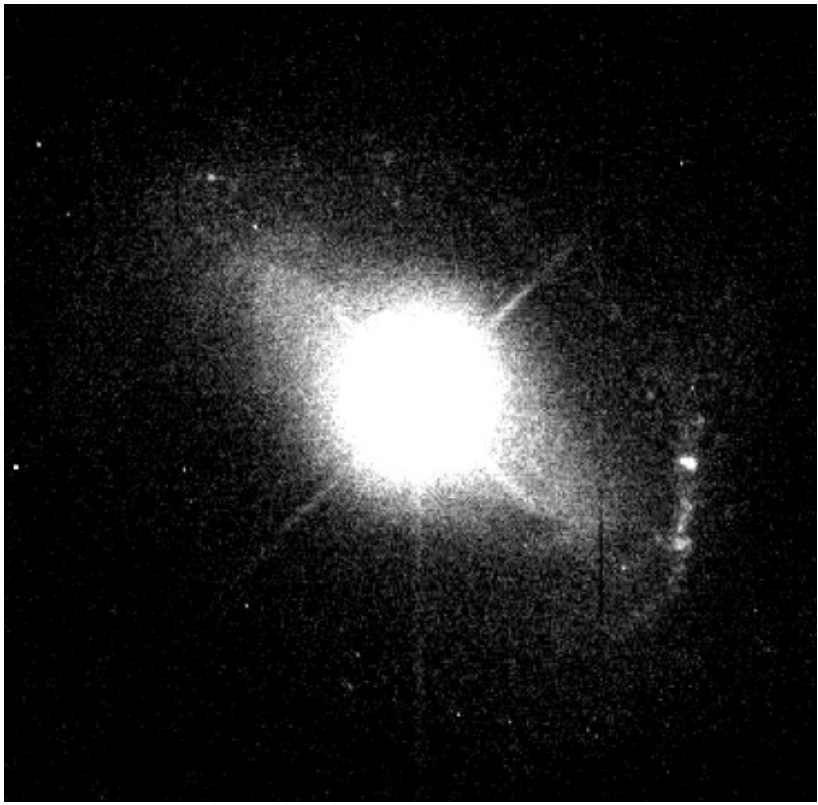
- Roughly centered on the Virgo cluster
- Our Local Group is at the periphery, orbiting around the center
- Size: ~20 Mpc
- Only ~5% of its volume is occupied by galaxies

Sheets, filaments, voids



Active galactic nuclei (AGN)

- ~1% of the galaxies have active nuclei, i.e., very bright (sometimes brighter than the rest of the galaxy)
- These bright nuclei are very compact
  - Only a few light-days of size
- Strong and broad emission lines from hot and dense gas
  - *Question: why also broad?*



AGN discoveries

- 1943: Seyfert galaxies
  - First 6 AGNs observed (by C.Seyfert) with strong and broad emission lines coming from a compact and bright nucleus
- 1950s: Radio galaxies
  - The first radio telescopes found very intense radio emissions from some very faint galaxies
  - They also have broad emission lines
  - Some of them are observed to emit "jets" of gas
- 1960s: Quasars (Quasi-Stellar Radio Sources)
  - They were enigmatic for several years

Quasars (1)

- Intense, point-like radio sources
- In the visible spectrum, photographs showed quasi-stellar objects with some fuzziness
- Their spectra were weird: full of broad, unrecognized emission lines
  - In the end it was understood that those are normal Hydrogen lines, but with very extreme redshifts (more about that later)
  - $\Rightarrow$ they are extremely distant
  - $\Rightarrow$ they are extremely luminous
- The fuzziness is due to the rest of the galaxy around it!

Quasars (2)

- Quasars are the most luminous objects known in the Universe
  - The brightest are as brilliant as 10^{14} times the Sun
  - They emit in the spectrum from radio to gamma rays
- Variable
  - Visible light varies on a timescale of days
  - X-rays can vary over a few hours
- The brightest quasars are among the most distant known objects in the Universe
  - They tell us about the Universe on very large scales
  - And also about very ancient ages

Supermassive Black Holes (SMBH)

- Plausible energy source for quasars and AGNs in general: accretion of matter onto a SMBH
  - Note: probably also most "normal" galaxies have a central black hole
  - AGN's SMBH would have 10^6-10^9 M_{sun}
  - It would consume O(M_{sun}) per year
- Gravitational energy from the infalling matter would convert into kinetic energy of the molecules of the accretion disk
  - It would glow because it is hot
- It can act as a particle accelerator