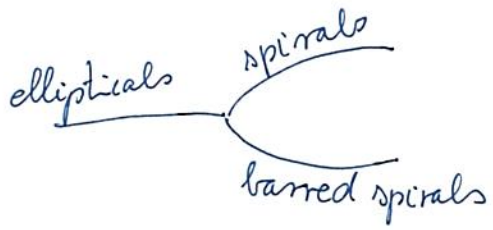
(1.) Summary - Extragalactic astrophysics

Types of galaxies: - spiral : young stars, lots of ISM
based on morphology - elliptical : old stars, no ISM
- irregular

→ ellipticals have further sub types and spirals ⇒ Hubble classification
Hubble tuning fork



Luminosity function: describes how many galaxies there are as a function of luminosity → we find that there are more small (less luminous) galaxies → the function that describes the distribution is the Schechter function

Environment: the fraction of spiral galaxies is lower in galaxy clusters compared to the field → gas loss and galaxy transformation in clusters

types of environment: galaxy clusters: hundreds or thousands of galaxies gravitationaly bound

galaxy groups: from a few to a few hundred gravitationaly bound
Milky Way - in the local group

field: few galaxies, not gravitationaly bound

void: basically no galaxies

Physical characteristics of galaxies

ellipticals: old stars (population II), no interstellar medium, no star formation
stars have random motions → velocity dispersion

Faber-Jackson relation: relation between the velocity dispersion and the luminosity

(2) spiral galaxies: younger stars, interstellar medium → star formation
→ bluer colour
→ in the disk stars rotate (mass of the stars are in the disk)
→ the HI rotates in the disk too
↳ can be used to map rotation (doppler-shift of the line)
↳ can construct the rotation curve
⇩
also flat rotation curve → dark matter

Tully-Fisher relation: relation between rotational velocity and the luminosity

measurment of HI in galaxies:
- systemic velocity of the galaxy (line centre)
- total HI flux → total HI mass
- doppler broadening of line → rotation → dynamic mass

} can get these from the spectrum

Hubble-flow - due to the expansion of the Universe galaxies are moving away from us: Hubble law: $v = h_0 D$ (D: distance)
↳ calculate distance

(v: Hubble flow velocity; h_0: Hubble constant)

Galaxy transformation in galaxy clusters or groups
- various mechanisms can remove gas from galaxies in clusters
↳ tidal interaction (gravitational interaction)
→ ram pressure stripping (hydrodynamic interaction)
→ starvation (running out of gas)

⇩

can transform a gas rich, star forming spiral into a a gas poor elliptical over time

Galaxy transformation and growth trough mergers:
→ major merger (mass is similar)
→ minor merger (one galaxy has much smaller mass)

③ Active galaxies (AGN) → active galactic nucleus

↳ many historic types:

Seyfert galaxies - spirals / Seyfert 1 with broad emission lines
Seyfert 2 with narrow emission lines

radio galaxies - giant elliptical galaxies with intense radio emission: core + jet + lobe structure

→ synchrotron radiation

→ jet from the supermassive black hole in the centre

↳ jet hits the intergalactic gas → forms lobes

Quasars: quasi stellar radio object

↳ very bright radio emission, look like a star

↳ compact emission

↳ very far away → very bright

powerful emission from a really small region

⇩

nucleus of a galaxy

Quasi stellar objects: QSO

→ a quasar but only optical emission = radio quiet quasar

⇕

vs. radio loud quasar

superluminar motion: due to projection effects the relativistic moving jets of AGN can appear to move faster than light

- relativistic beaming: the jet pointing towards us and moving relativistic appears brighter compared to the one moving away from us.

AGN are powered by a supermassive black hole in the centre of galaxies.

- AGN activity can happen when the black hole is accreting significant amount of mass
- The Schwarzschield radius defines the size of the black hole
  ~ on the order of the Sun - Earth distance
  ~ $10^8 M_\odot$

④ Syncrotron radiation from the jets → magnetic fields must be important
↳ jet is perpendicular to the accretion disk

⇒ unified model of the AGN:
- accreting black hole with accretion disk
  - torus (gas + dust)
  - jet (or no jet)
  - fast moving clouds - broad lines
  - slow moving clouds - narrow lines

→ depending on the viewing angle we see different types of emission
↳ different traditional classification

Galaxy clusters : gravitationaly bound structures
↳ galaxies move around the centre → velocity dispersion inside the cluster

dark matter in the cluster → most of this dark matter is not inside the galaxies (30% of it in galaxies)

→ intra cluster gas : hot and very diffuse → X-ray observations
↳ bremsstrahlung
↳ rampressure from this gas → rampressure stripping of cluster galaxies

→ measurment of Fe in the intra cluster gas → already enriched gas

Large scale structure :
- → large surveys of galaxy distribution (distance from hubble-flow)
- → galaxies are in groups → clusters → superclusters → filaments
- → there are bubble like voids with no galaxies
- → on very large scales the matter distribution of the Universe is uniform

→ gravity pulls galaxies into structures that then get pulled towards larger structures trough filaments

(5.) Gamma ray bursts GRBs

↳ very energetic explosions observed in gamma rays
- → a few seconds to a few hours
- → isotropic distribution → extragalactic
- → afterglow in many wavelengths (optical, X-ray etc....)

types:

short: < 2 s → merger of binary neutron star ~~with bla~~ or neutron star - black hole merger
↓
e.g. gravitational wave detection + kilonova

long: > 2 s → core collapse supernova

ultra long: > 10000 s → an extreme version of the previous two ↑
very few observed

Fast Radio Bursts: FRB

- → very short (milliseconds) burst of radio emission
  - → mostly extragalactic
  - → most likely related to pulsars, but origin is yet unknown