

Galaxies



Koupelis : chapter 17
Openstax : chapter 26

1

Charles Messier (1730 - 1817)

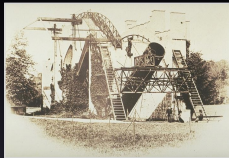
- comet hunter
- fixed "nebulae" a nuisance.
- the Messier catalogue
- what is the nature of these fixed "nebulae"?



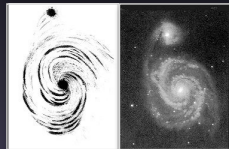
2

The Earl of Rosse

- Built the 'Leviathan' in 1845.
- largest telescope: 1,8 m in Ireland
- noted that the "nebulae" showed some structure.



Their nature and distances remained unclear for a long time...



3

Edwin Hubble (1889 - 1953)

3 achievements:

- Nebulae are located outside our Milky Way (distances using Cepheid variable stars)
- Morphological classification of the nebulae
- Nebulae (galaxies) move faster away from us (redshift) when they are at larger distances.

4

Edwin Hubble

Edwin Hubble (1924): Variable stars in Messier 31 demonstrate that this nebula is at a distance of a few million light years.



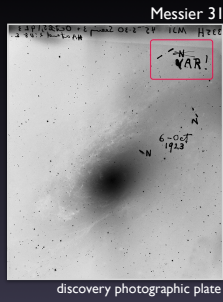
→ the discovery of the **Extra-Galactic Universe**

5

Edwin Hubble

Edwin Hubble (1924):
Variable stars in
Messier 31 demonstrate
that this nebula is at
a distance of a few
million light years.

→ the discovery of the
Extra-Galactic Universe



6

Andromeda Nebula

Great Nebula in Andromeda (M 31 - NGC 224)



7

The apparent diameter of the Moon, Messier 31,
and its two companions Messier 32 and NGC 205 (montage).



8

Spiral galaxies (spirals)
show a variety of morphologies and sizes



Usually contain lots of
gas, dust and young stars,
with a range of
star formation activities.

NGC 300



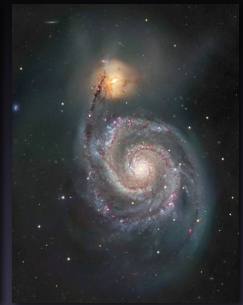
9

spiral galaxies

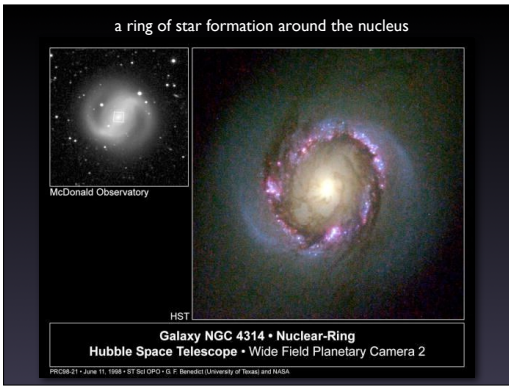
Messier 77



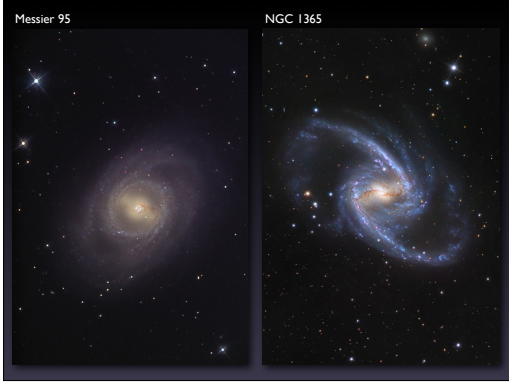
Messier 51



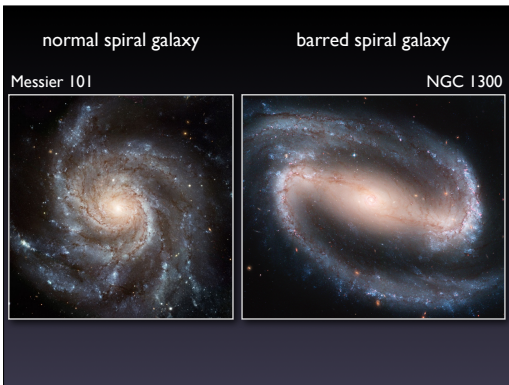
10



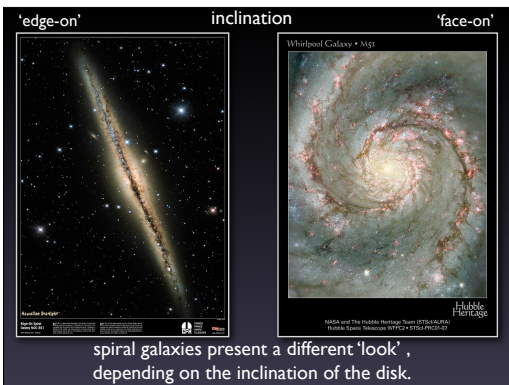
11



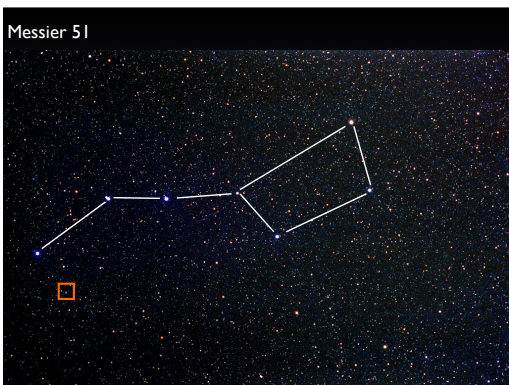
12



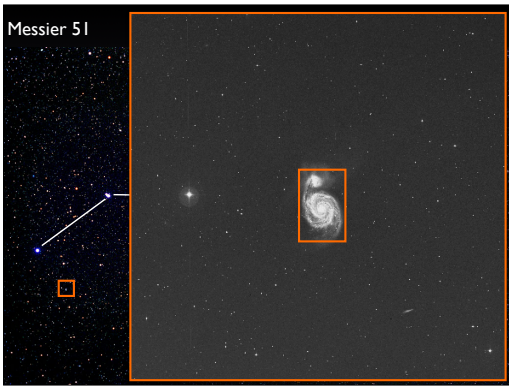
13



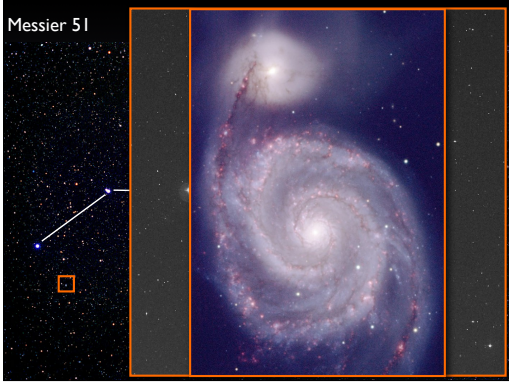
14



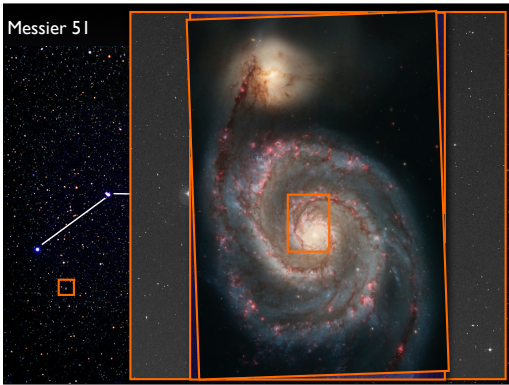
15



16



17



18



19



20



21



22



23



24



25

Messier 86
resemble rugby balls or flattened spheres

Elliptical galaxies

Messier 59



Elliptical galaxy in the Virgo cluster

Messier 32



Elliptical dwarf galaxy; companion of the Andromeda nebula

26

Irregular (dwarf) galaxies
the Magellanic Clouds



27

Large Magellanic Cloud (LMC)



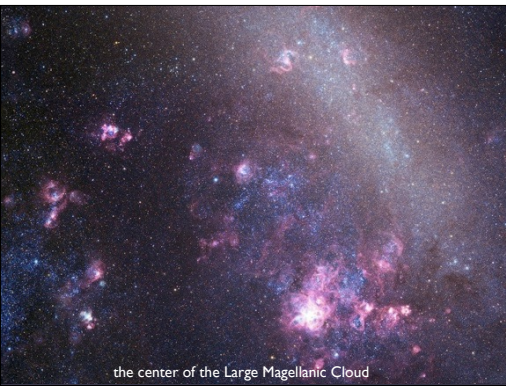
Small Magellanic Cloud (SMC)



only visible from the southern hemisphere

28

the center of the Large Magellanic Cloud

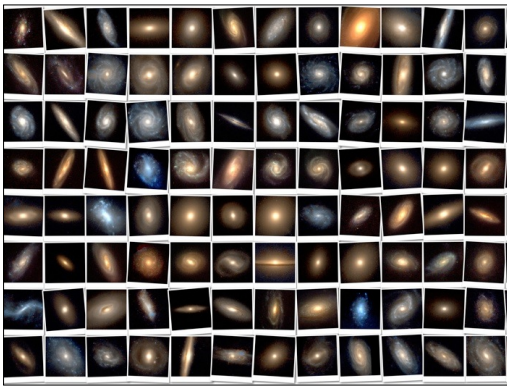


29

examples of other
irregular dwarf galaxies



30



31

Hubble's morphological classification

Hubble systematically classified the morphologies of galaxies:

- Dominance of bulge/spiral arms.
- Presence of dust and young stars.

normal spirals

'early-type' or elliptical galaxies

barred spirals

'late-type' or spiral galaxies

the 'tuning fork' diagram

32

Hubble's 'tuning fork', illustrated with real galaxies:

The Hubble Tuning Fork

Ellipticals

Lenticular S0

Unbarred spirals

Barred spirals

CG Credit: Karen L. Masters (JCS Portsmouth). Galaxies: SDSS gri colour images as used in Galaxy Zoo. GALAXY ZOO

33

Third achievement of Hubble: the discovery of the expanding Universe

- The recession velocity of a galaxy depends on its distance.

⇒ The Universe Expands

The Hubble law:

$$D [\text{Mpc}] = V [\text{km/s}] / H [\text{km/s} / \text{Mpc}]$$

with $H = \text{Hubble constant} = 70 [\text{km/s} / \text{Mpc}]$

Extragalactic distances are indicated with the redshift parameter Z .

34

The recession velocities (redshifts) are measured using emission or absorption lines in the spectra of galaxies.

$$Z = (\lambda_{\text{obs}} / \lambda) - 1$$

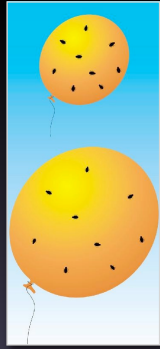
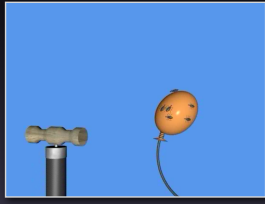
Are we located at the center of the Universe?

No!

Cluster	Galaxy in Millions of light years (Mpc)	Radial Velocities in km/s
Virgo	15 (19)	1200
Ursa Major	990 (330)	15,000
Coma Berenices	1440 (430)	21,000
Bode's	2740 (770)	36,300
Hydra	7960 (1200)	61,300

35

a 2-dimensional (curved) analogy for the expanding Universe



36



spiral arms

NGC 4622



Messier 51
gravitational interaction with a companion.

37

Star formation

The Andromeda nebula, a.k.a. Messier 31



optical



ultra-violet

A galaxy can have a very different appearance at different wavelengths!

38

Dust in galaxies

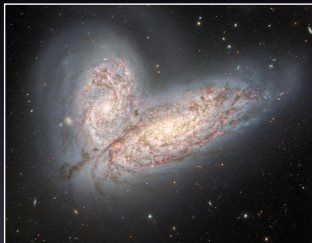
- almost always visible
- the amount of dust is hard to quantify
- important for the chemical processes in a galaxy



39

Dust in galaxies

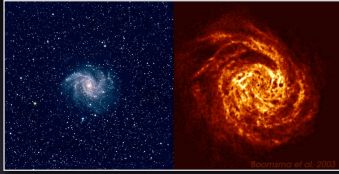
- almost always visible
- the amount of dust is hard to quantify
- important for the chemical processes in a galaxy



40

cool Hydrogen gas

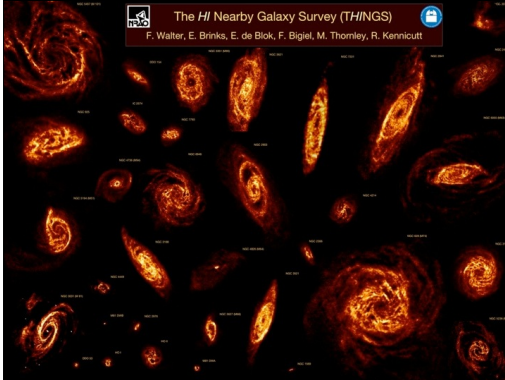
NGC 6946



radio map of
21 cm radiation

- Only visible with radio telescopes (21cm)
- Detectability was predicted by van de Hulst in 1944!
- It is distributed throughout the disk.
- Motions are very well measurable (Doppler-effect).

41

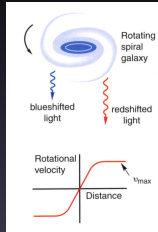


The *H I* Nearby Galaxy Survey (THINGS)
F. Walter, E. Brinks, E. de Blok, F. Bigiel, M. Thornley, R. Kennicutt

42

The rotation of a galaxy

- using the 21 cm line, the rotation of a galaxy is easy to measure, well outside the optically visible disk
- big surprise :
the outer gas disk rotates at the same speed as the inner gas disk
- How can this be explained?

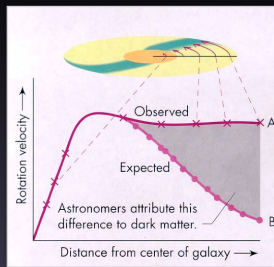


43

The rotation of gas-rich spiral galaxies

High rotation speeds in the outer parts can only be explained if there is more matter than just the visible stars and the ISM:

Dark Matter !



44

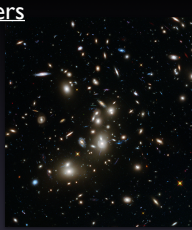
Dark Matter

- Inferred from the motions of the visible matter (stars and gas).
- What is it?
 - more gas and/or stars?
 - MACHO's (Massive Compact Halo Objects); loose planets, faint brown dwarfs, small black holes...?
 - something truly exotic?

45

Galaxy Groups and Clusters

- Galaxies are seldom isolated.
- They are distributed in small groups and clusters.
- The Universe : clusters, groups and voids.
- Galaxies interact with each other:
 - collisions (gravitational interaction)
 - merging (cannibalism)



46

Galaxy mergers

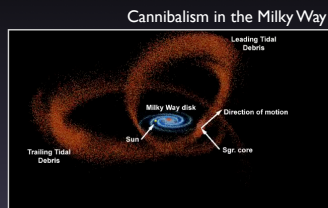
- Large galaxies 'eat' small ones.
- Remnants of the 'consumed' (dwarf) galaxy are often visible as a pattern in the distribution of the stars: 'stellar streams'



47

Sagittarius dwarf galaxy

- discovered recently (1994!)
- it's being 'eaten' by our galaxy.

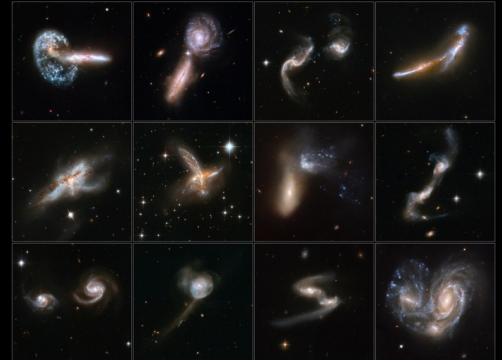


schematic computer simulation

48

Interacting Galaxies

Hubble Space Telescope • ACS/WFC • WFPC2



49

Galaxy collisions : simulation versus observations



50



51

Ring galaxies

- a star forming ring around a galaxy
- the result of a very peculiar collision

52

Ring galaxies

- a star forming ring around a galaxy
- the result of a very peculiar collision

53

the center of galaxy cluster Abell 1689

Galaxies are the building blocks of the Universe.

Areas of high density are usually occupied by elliptical galaxies:

Morphology - Density relation

54

the center of the Coma cluster

55

the center of de Hercules cluster



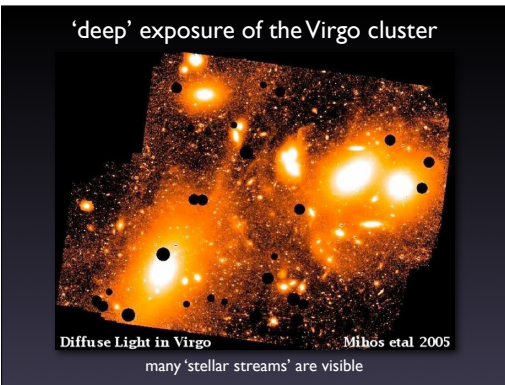
56

MACS J0717.5+3745



57

'deep' exposure of the Virgo cluster



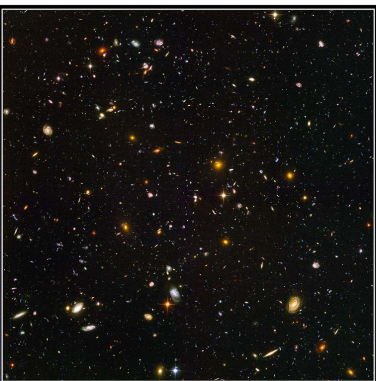
58

Hubble Ultra Deep Field:

galaxies visible in the farthest reaches of the Universe

This area represents only $\frac{1}{20,000,000}$ -th of the entire sky!

Every smudge is a galaxy...

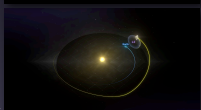
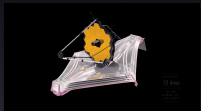


59

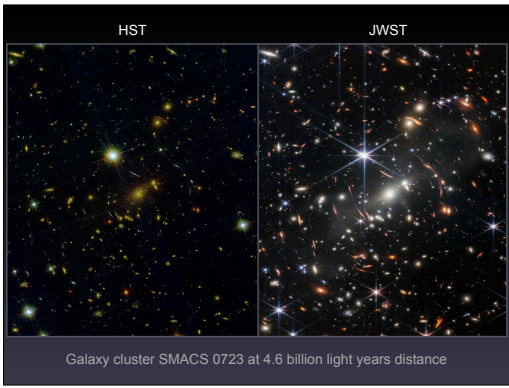
Latest development

- Looking further back in time. (James Webb Space Telescope)
- When did the first stars form?
- When did the first galaxies form?
- How did galaxies evolve over time?
- Study nearby galaxies in detail.
- What is the nature of Dark Matter?

JWST - launched December 25, 2021



60



61
