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Extragalactic Astrophysics

Galaxies in the local Universe

Ciro Pappalardo

What did we learn?

What did we learn?

1. The observable in Astrophysics is the ‘photon’
2. Methods to count the photons
3. Electromagnetic spectrum
4. Magnitude and colors
5. Science
6. Phenomenological approach

Outline of the course

1. History
2. General concepts review
3. **Galaxies in the local Universe**
4. Galaxies kinematics and scaling relations
5. Star formation
6. Interstellar Medium
7. Distances and redshift
8. High redshift Universe
9. Final remarks and open debate

Nearby Galaxies: Why?

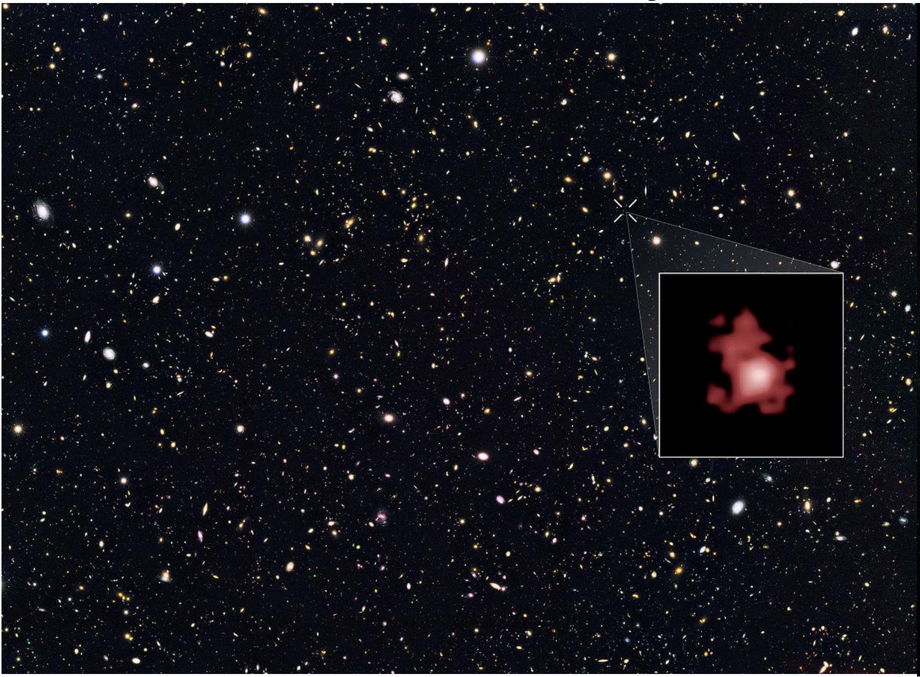
- Galaxies are not just systems of gravitationally bound stars and dark matter. There are various subcomponents: bulges, bars, discs, nuclear clusters and halos.

- Studies of the nearby universe encompass a region of approximately 20-30 Mpc in radius, where the distances allow a more detailed analysis.

- Our knowledge about structures, internal processes of galaxies comes from resolved analysis.

This area involves combining multi-wavelength data with theoretical models to define key physical processes that control the nature of galaxies.

GN-z11 in GOODS-North Survey



M81 (3.9 Mpc)

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GALAXY EVOLUTION

Cooling
(metallicity, halo structure, conductivity)

Star formation
(threshold, efficiency, initial mass function)

Dust
(formation,distribution, heating and cooling)

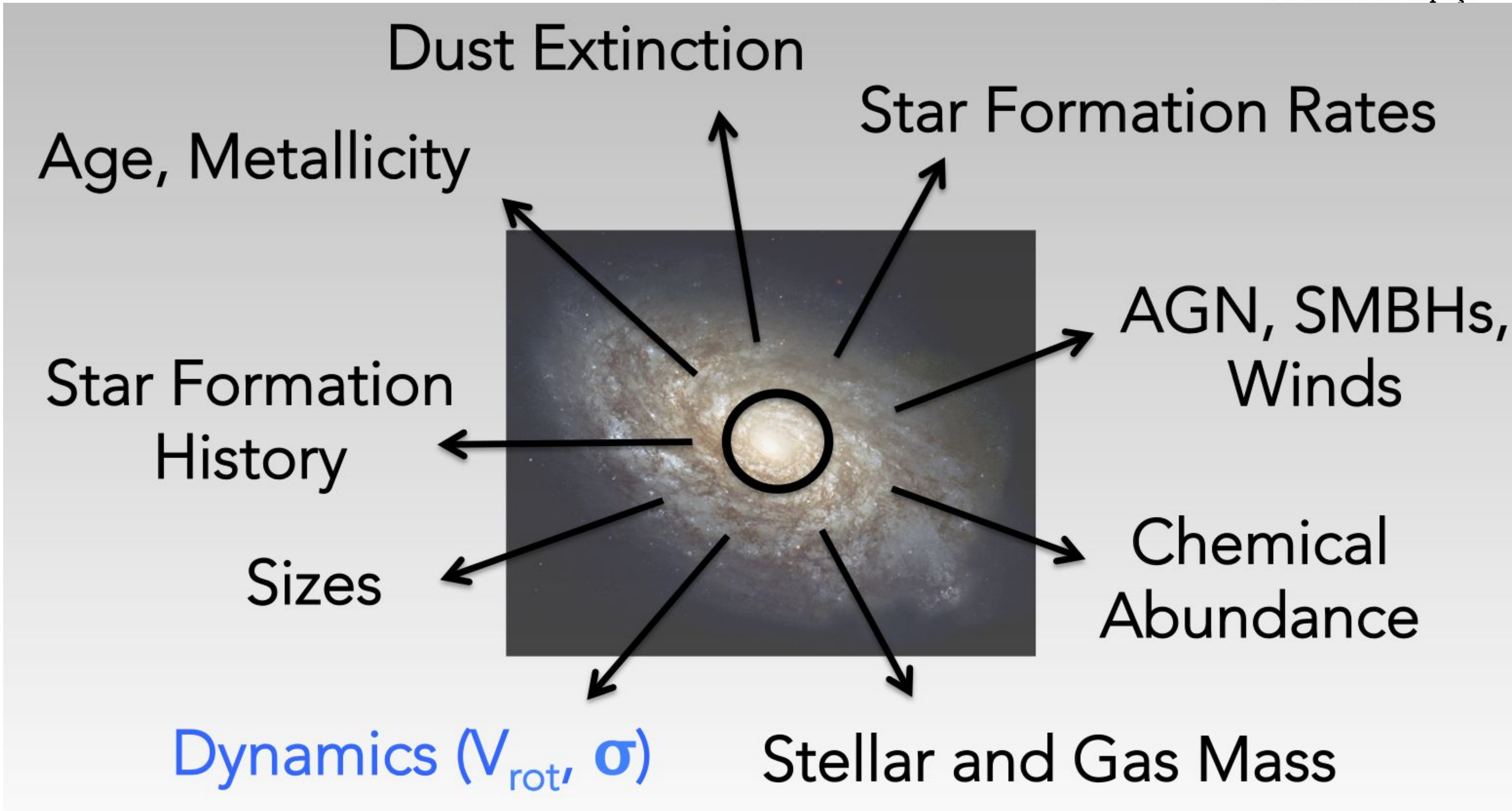
Mergers and Galaxy interactions
(morphological transformations, induced star formation)

SN Feedback
(IGM heating, IGM enrichment, efficiency, winds)

BHs and AGNs
(BH growth, quasar winds, radio bubbles)

Stellar evolution
(spectro-photometric evolution, yields,feedback)

Structural Parameters



Environment

Environment

First take home message: galaxies are similar to humans

Galaxy population

Galaxies, in average, does not like to live “alone”…..

Most of galaxies are not isolated systems.

Galaxy population

..they prefer to live in groups…….

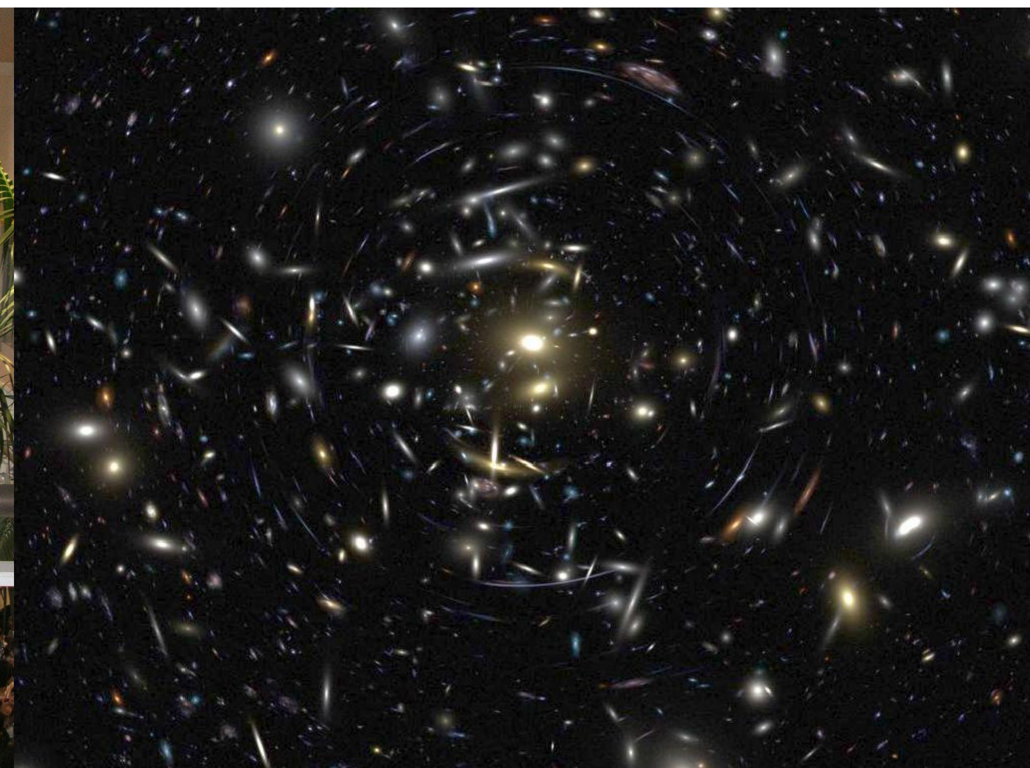
sometimes called “clan”.

A galaxy group is a system with less than 50 elements gravitationally bound.

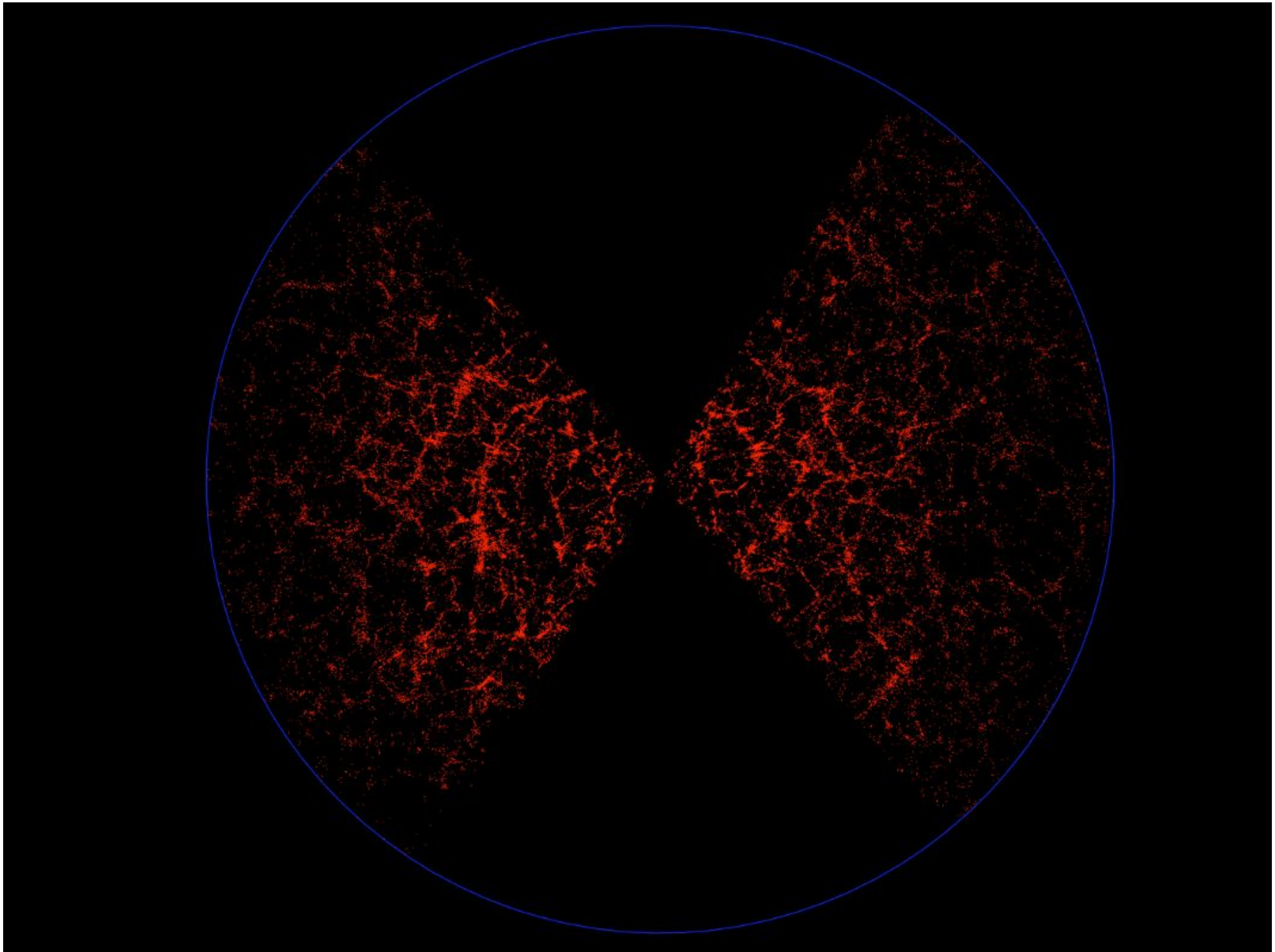
Galaxy population

..or in cluster…called in anthropological jargon SAI : “saturday afternoon at IKEA”.

A cluster is a system with hundreds (or thousands) of galaxies gravitationally bound within the hot intracluster medium (at temperature of ~10^6 K).



Large Scale distribution



Video LSS

Physical processes in cluster galaxies

Gravitational effects

- Galaxy-galaxy and galaxy-cluster tidal interactions.
- Harassment: combined effects of multiple close galaxy-galaxy interaction.

NGC4438 Krawford

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Merging effects on stars

Stars Collision during galaxies merging

Despite a Milky Way like galaxy has more than 3 $\times 10^{11}$ stars, the probability of stars collision during a merging episode are negligible. This can be proved in different ways (some example below):

- **almost-qualitative approach**

  The closest star to the Sun is Proxima Centauri, at a distance of 4.2 light years, which are:

  $4.2 \times (60 \times 60 \times 24 \times 365) = 4 \times 10^{13}$ km

  The diameter of the sun is $\approx 1.4 \times 10^{6}$ km, which implies that the distance to the closest star is $4 \times 10^{13} / 1.4 \times 10^{6} = 2.9 \times 10^{7}$ times bigger than the Sun diameter. If the Sun would be a tennis ball (6.5 cm), Proxima Centauri would stay at 1885 km (Monaco). Assuming that stars are homogeneously distributed along the disk it follows that considering only the stars a galaxy is essentially made of void.

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- **probabilistic approach**

  In analogy with the particles theory, a star moving within a galaxy spans a cylinder with volume $\pi(2R)^2 \cdot vt$, where R is the star radius, v is the star velocity, and t is the travel time within the galaxy, in other words the merging time (usually 1-2 Gyr).

  The number of star collisions during the merging (defined as Z) is directly proportional to the volume of the cylinder mentioned above and the number density of stars within the galaxy:

$$Z = (2R)^2\pi \cdot vt \cdot \left(\frac{N_{star}}{V_{gal}}\right) \tag{1}$$

  with N_{star} = number of stars in the galaxy considered, and V_{gal} = galaxy volume.

  Considering the Sun as a representative star in a galaxy, with the following values:

  - $R_\odot \sim$ 695 510 km
  - $v_\odot \sim$ 700 000 km/h
  - $t \sim 10^9$ yr

  and the galaxy of Andromeda assuming the following parameters:

  - $R_A = 1.1 \times 10^5$ ly
  - $H_A = 2.6 \times 10^3$ ly
  - $N_A = 10^{12}$

  we have:

$$Z = (2R)^2\pi \cdot vt \cdot \left(\frac{N_{star}}{V_{gal}}\right) = 4.5 \times 10^{-10} \quad \text{star coll. per Gyr} \tag{2}$$

  The probability of a collision for one star in the galaxy is the number of collision divided by the total number of stars:

$$P = \frac{Z}{N_A} = 4.5 \times 10^{-22} \tag{3}$$

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Gravitational effects

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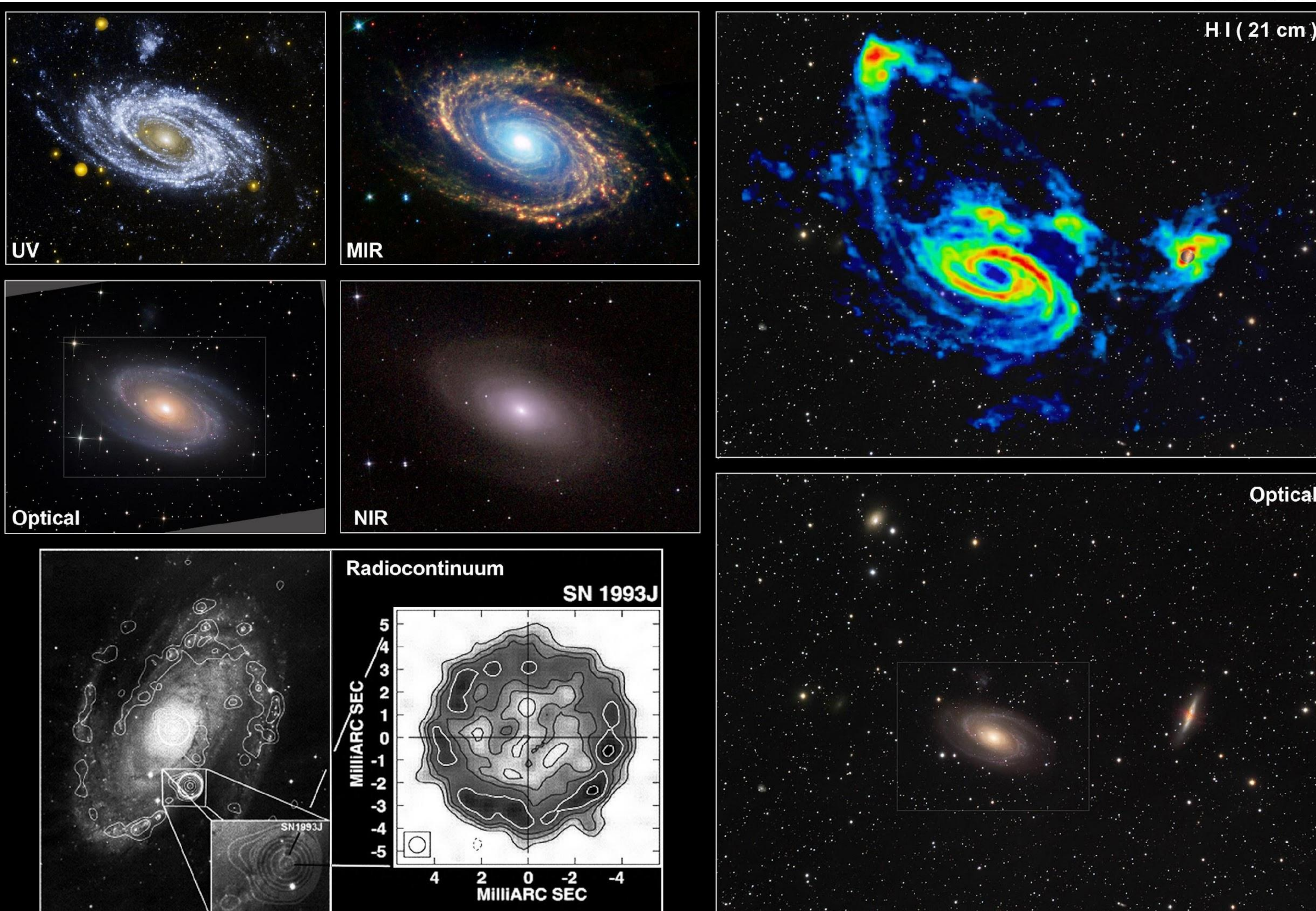
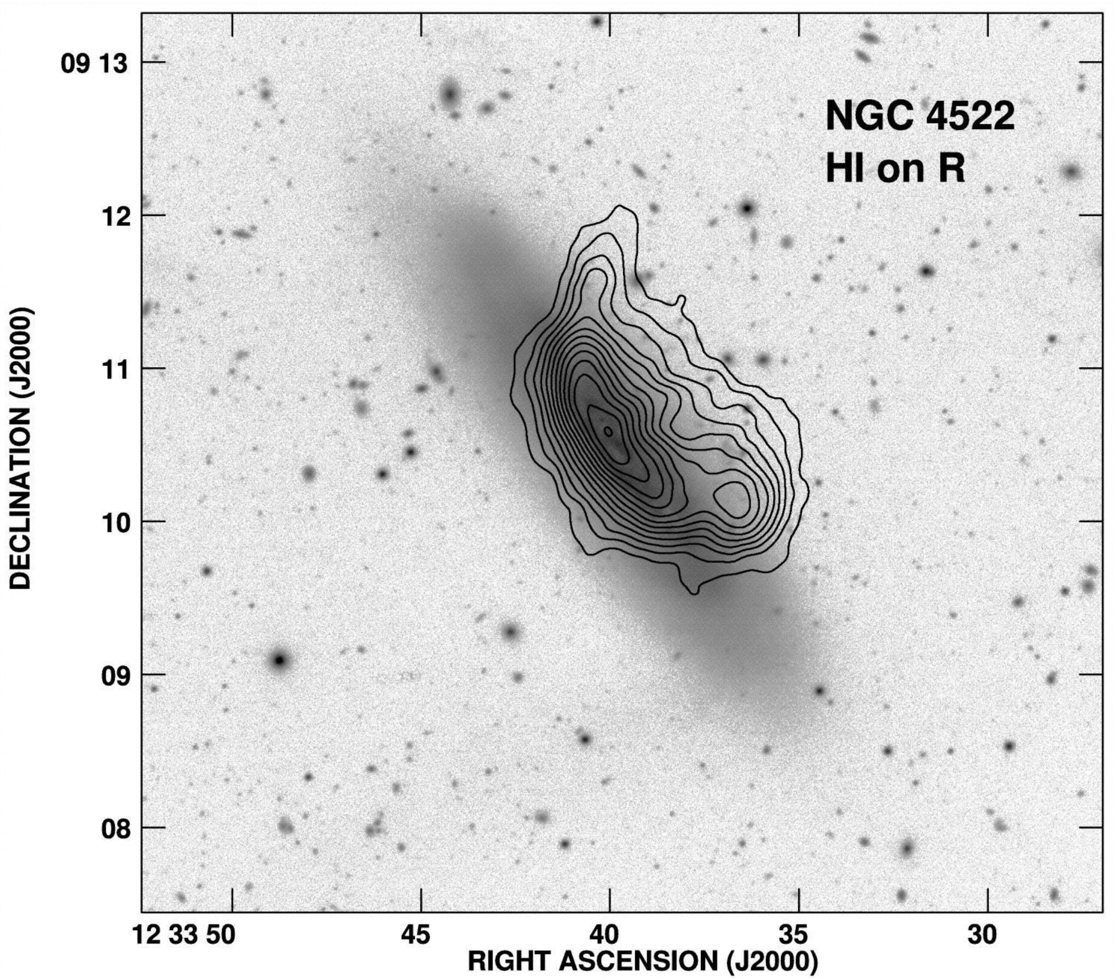
M81 Group


UV
MIR
Optical
NIR
H I (21 cm)
Optical
Radiocontinuum
SN 1993J
SN1993J
MilliARC SEC
MilliARC SEC
5 4 3 2 1 0 -1 -2 -3 -4 -5
4 2 0 -2 -4

Hydrodynamical effects

Involve the interaction within the ISM and the ICM: ram-pressure stripping, viscous stripping, thermal evaporation.

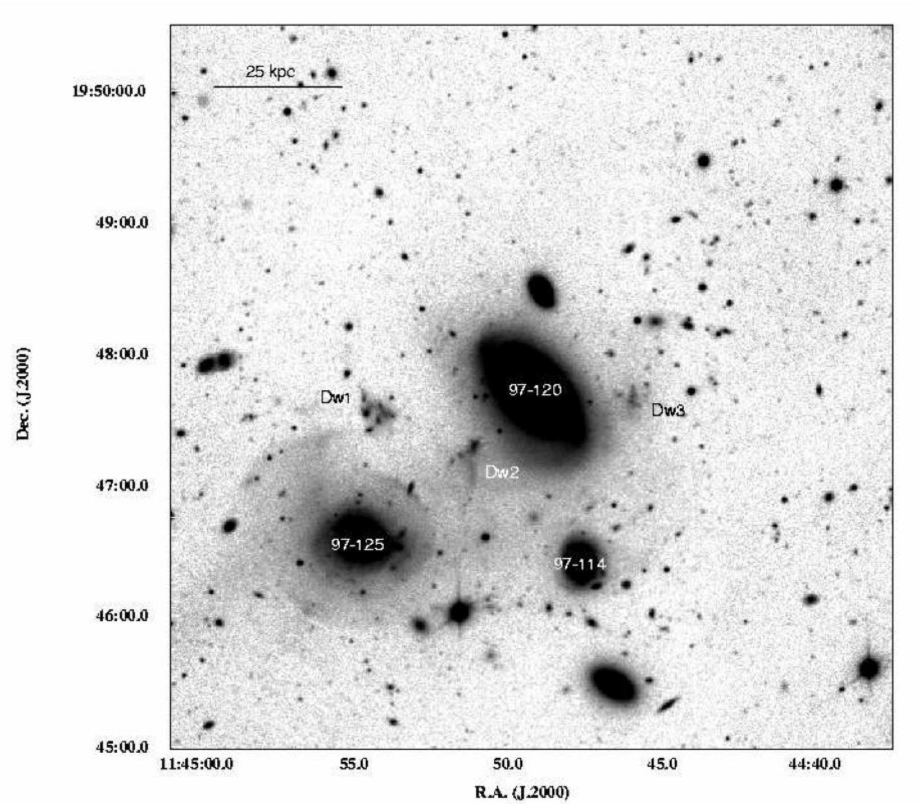
$$\rho_{IGM} V_{gal}^2 \geq 2\pi G \Sigma_{star} \Sigma_{gas}$$

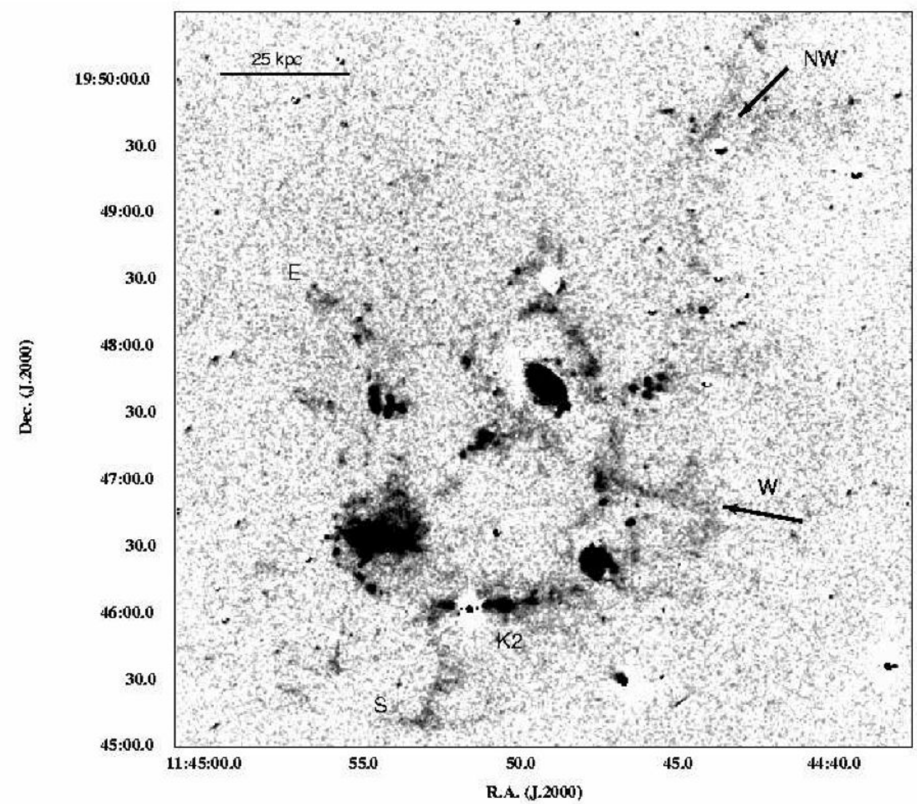


Kenney + 2004

Hybrid processes

Pre-processing. Image of blue infalling group in Abell 1367. R-band continuum and Halpha.

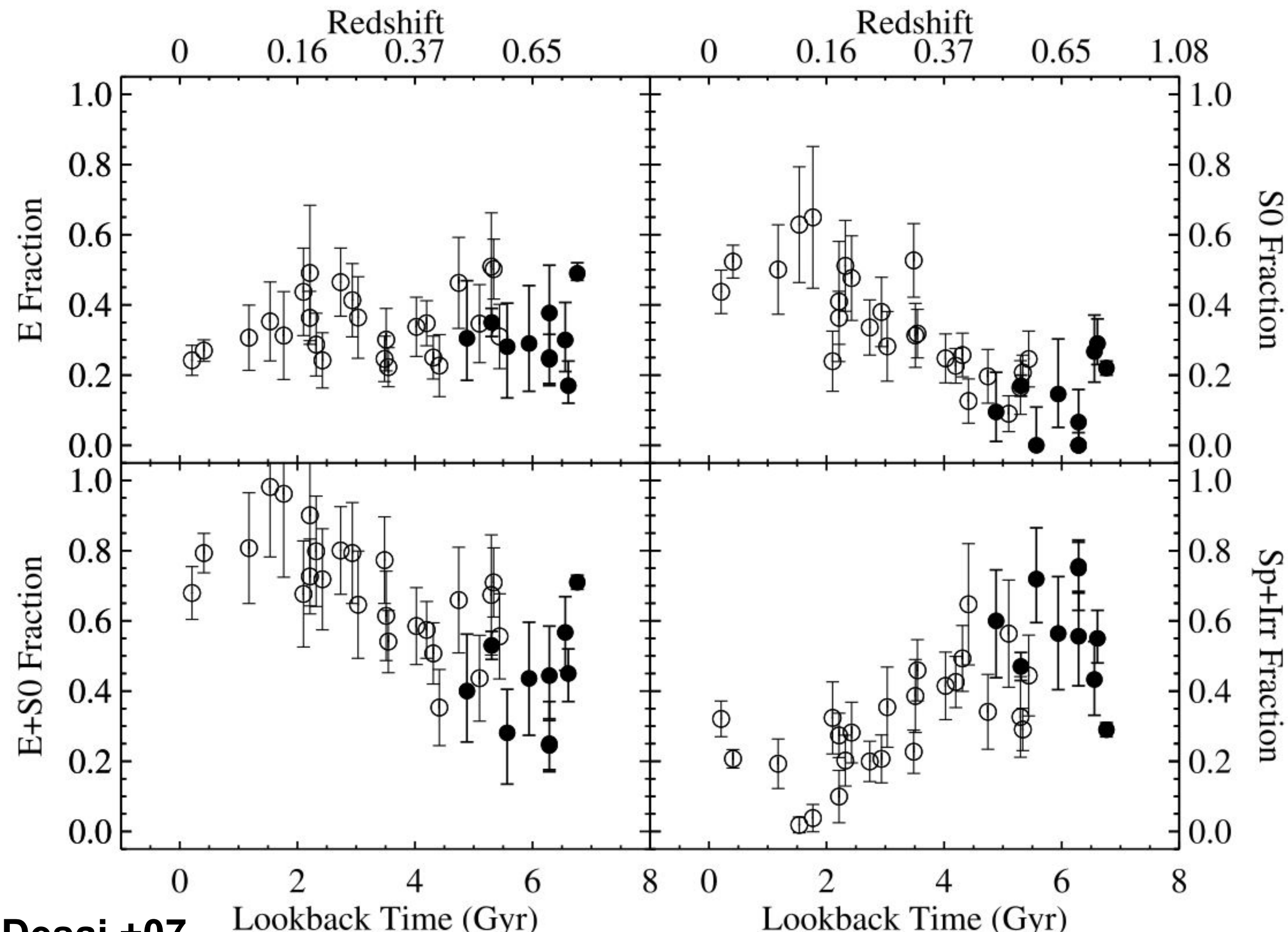




Cortese +06

Observations of cluster galaxies: Spiral-S0 connection

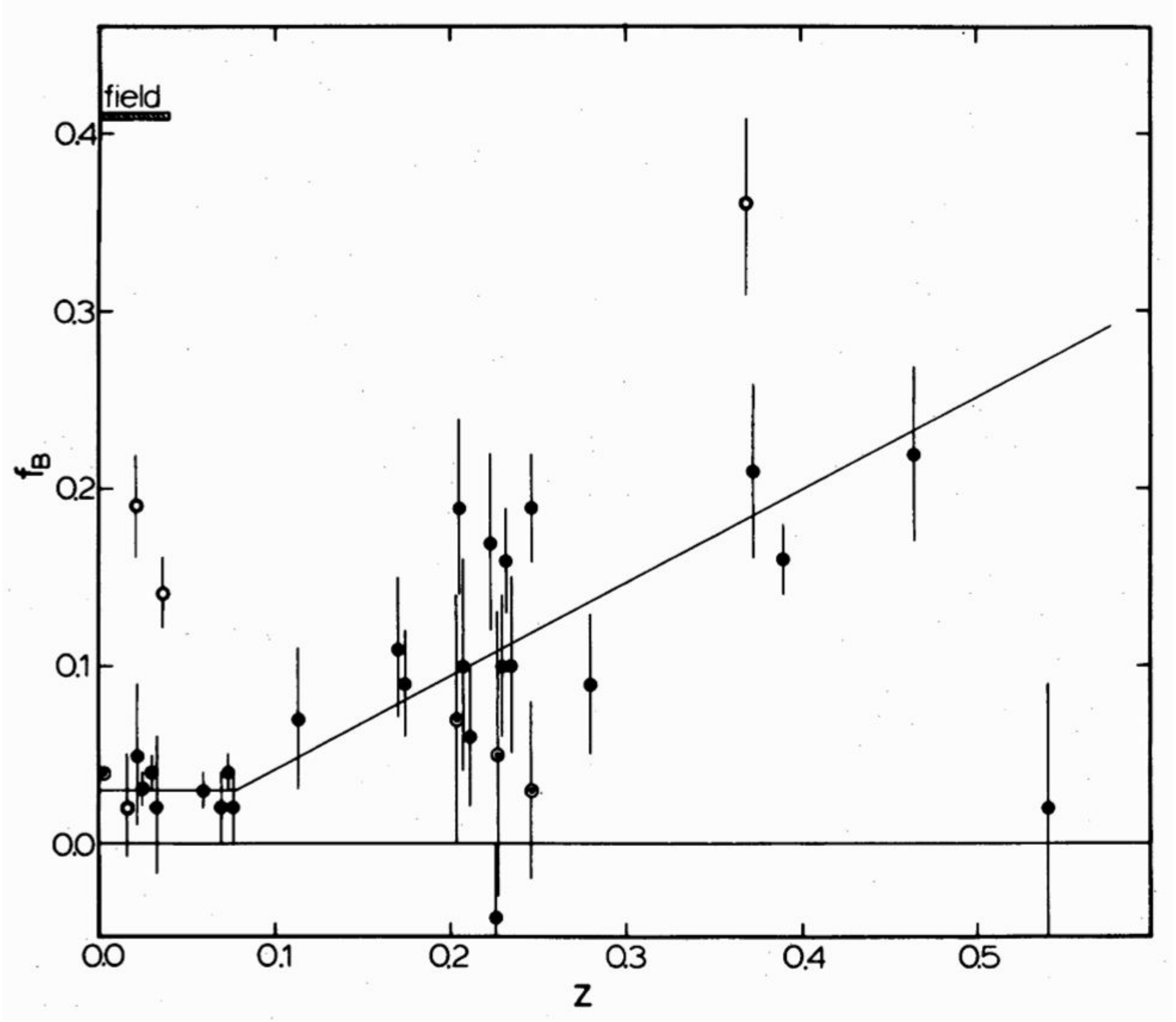
The number of S0 galaxies decreases at higher redshift, with a proportional increase of the spiral fraction.



Desai +07

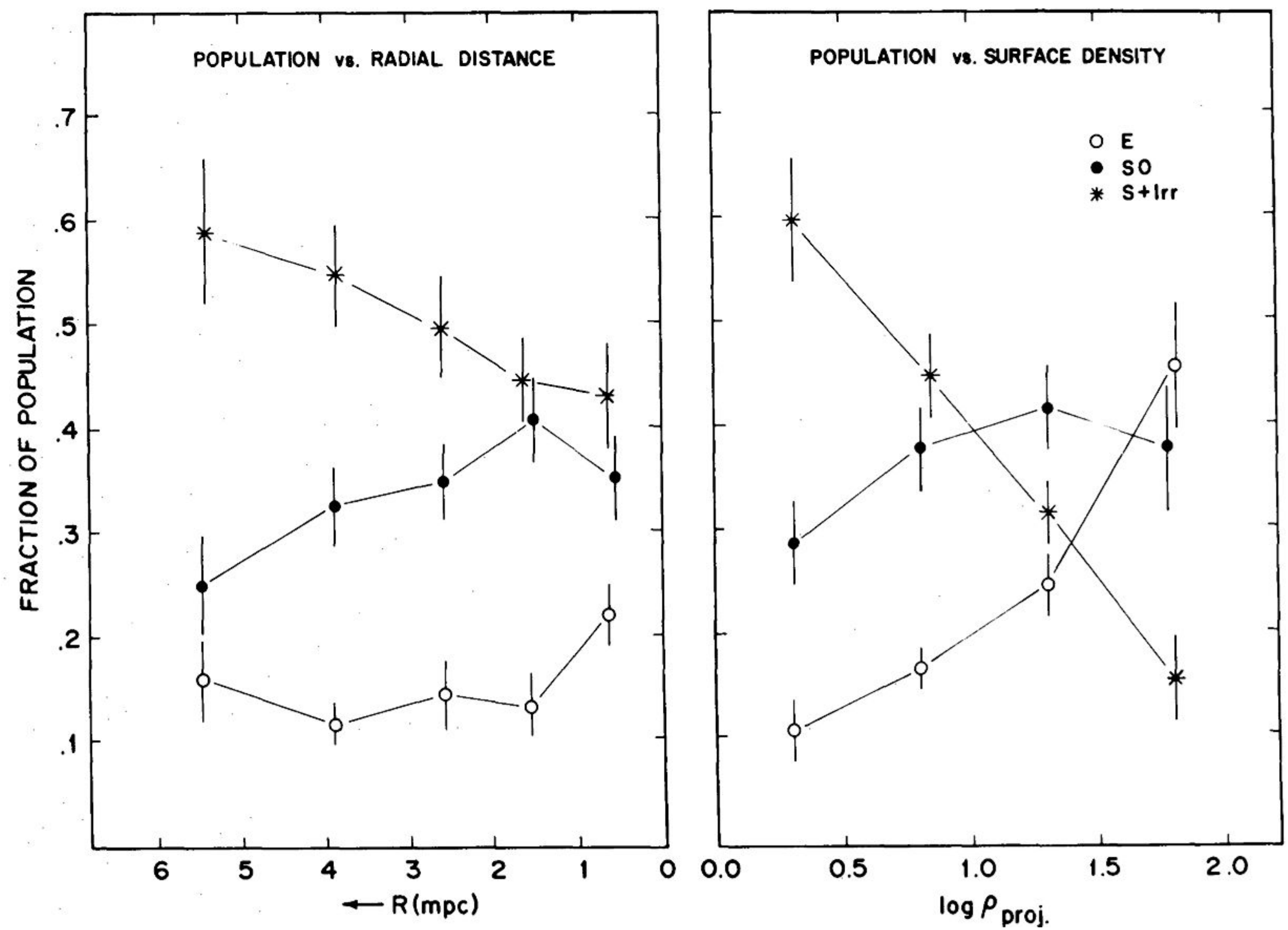
Observations of cluster galaxies: Star formation

Butcher-Oemler effect (Butcher & Oemler 1978,1984): the cluster at intermediate redshift have a higher fraction of blue star-forming galaxies



Observations of cluster galaxies: Morphology Density Relation

Dressler 1980: early-type galaxies increase with the galaxy density



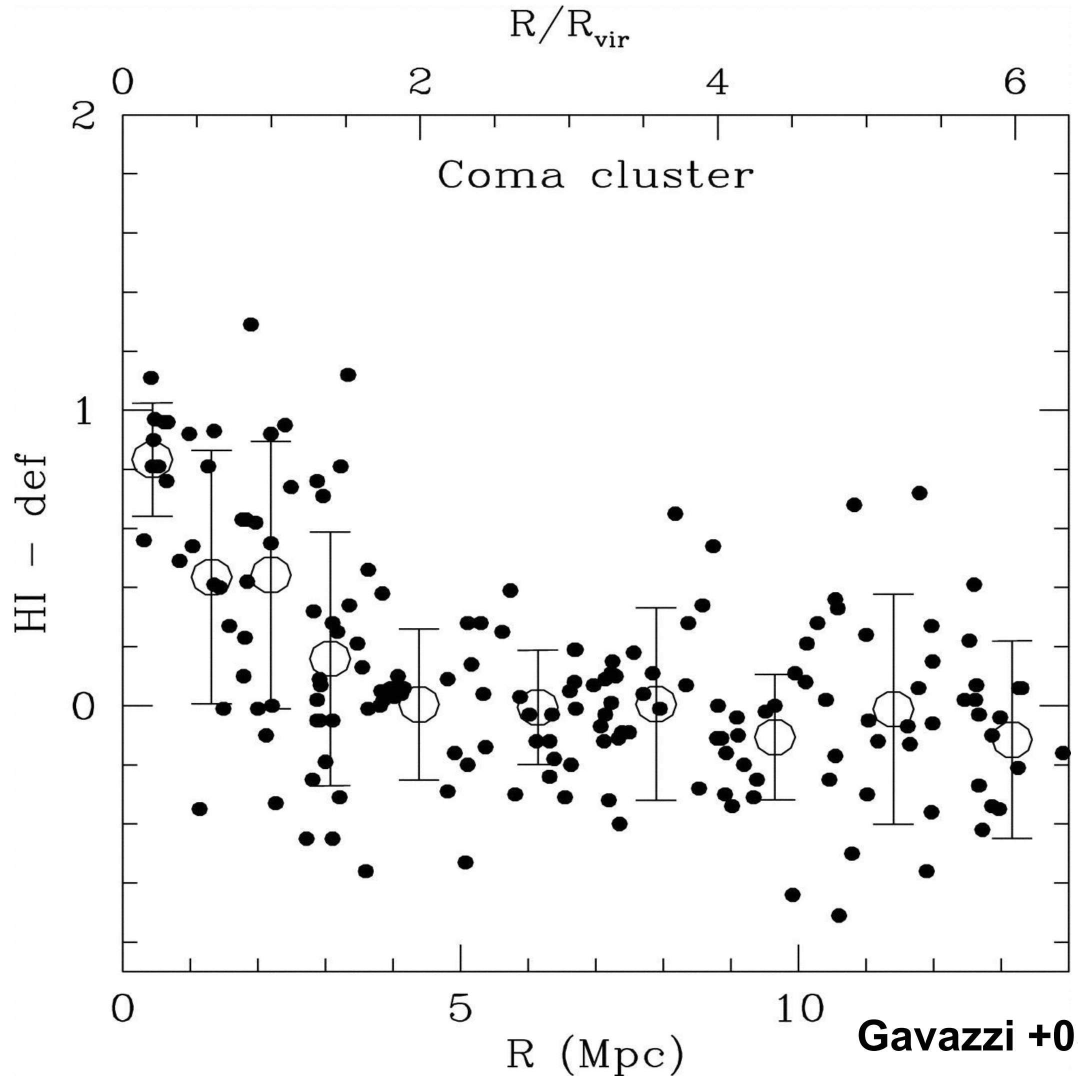
Observations of cluster galaxies: Atomic Hydrogen

Spiral galaxies are gas rich, sustaining star formation. HI extends beyond the optical disk, and is weakly bound to the galaxy's potential well.

Cluster spirals have on average lower quantities of HI with respect to their isolated counterpart.

To quantify this effect Haynes & Giovanelli (1984) defined a parameter: the HI-deficiency.

It is the logarithmic difference between the observed HI and the value that we should observe in isolated objects with similar size and morphology.



Gavazzi +05

Cluster of galaxies

up to 90 % DM

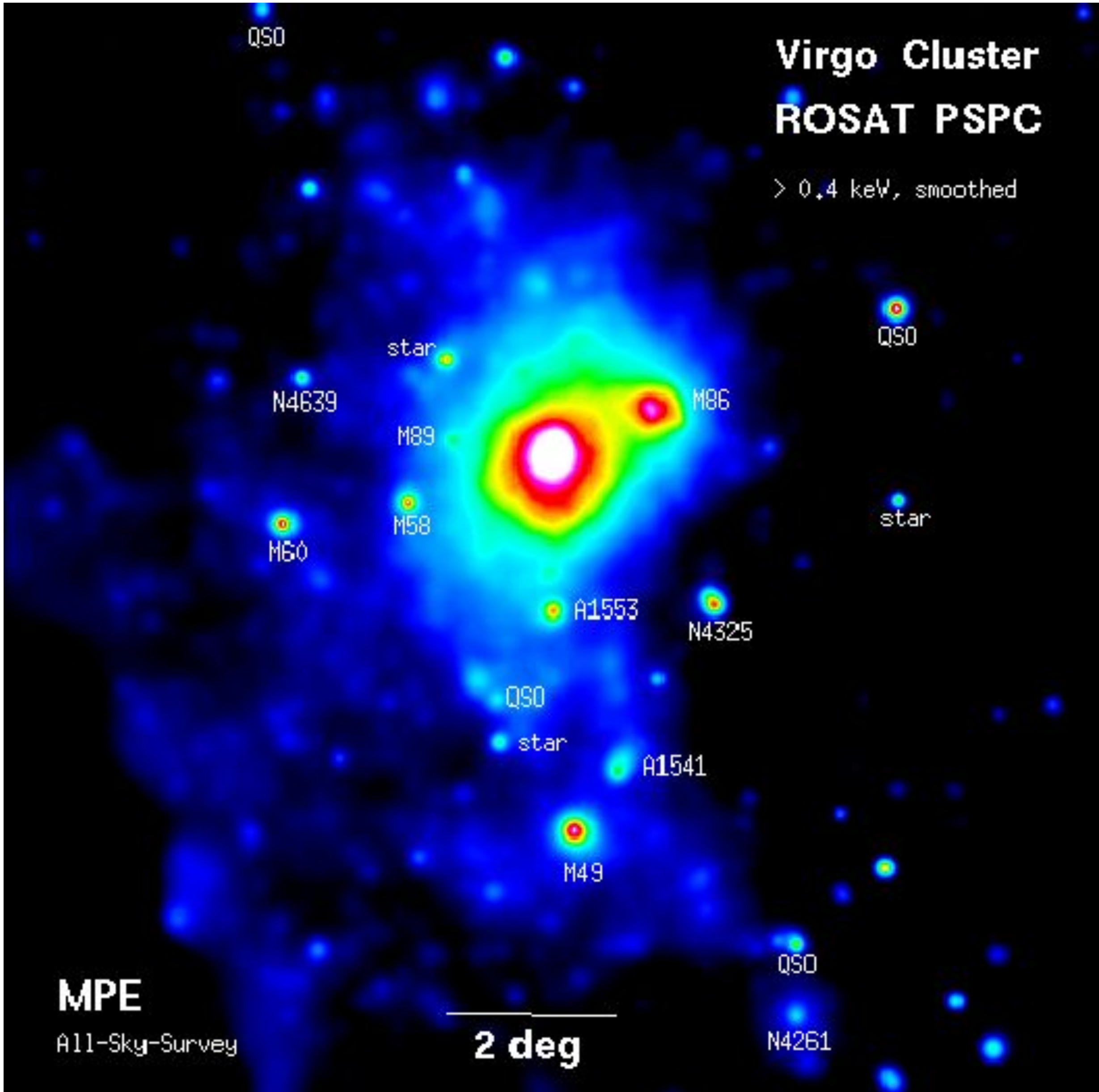
up to 30 % Hot ICM

few % galaxies

Temp ICM = 10 Million K

vel. Disp.: 400-700 Km/h

Radius = 1 - 3 Mpc



Schindler +99

Cluster of galaxies

Virgo

D ~ 17 Mpc

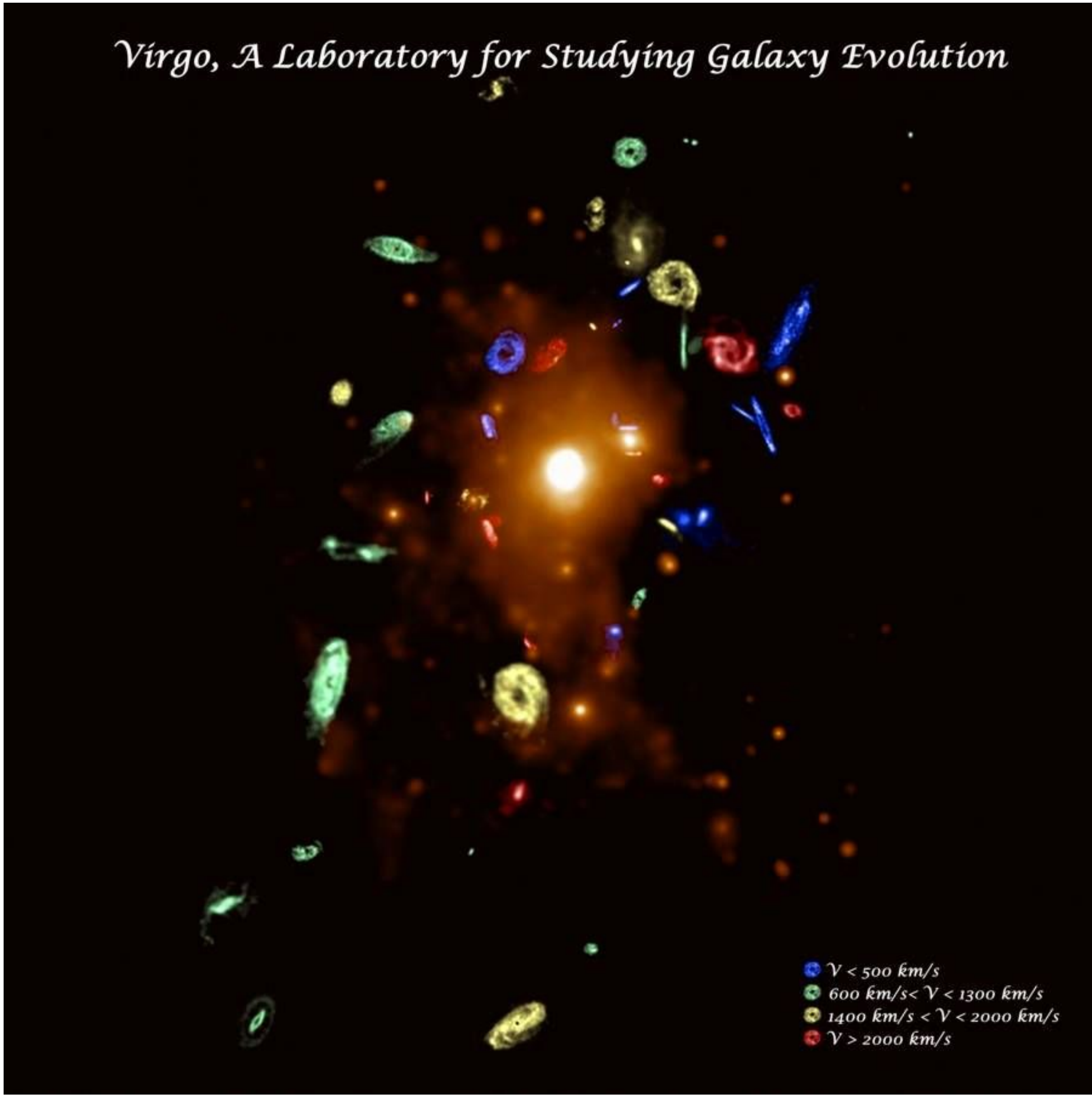
Mass = 10^{15} M_o

Radius = 2.2 Mpc

N gal = 1300 - 2000

Spiral rich

Dynamically young



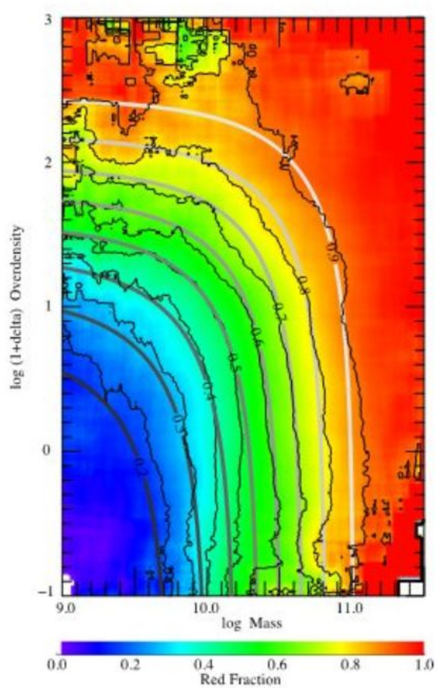
Chung +09

Quenching

- mass and environment quenching are separable, leading to the idea of two distinct processes of "mass quenching" and "environment quenching."

- environment quenching, at fixed over-density, does not change with epoch: the environment quenching occurs as large-scale structure develops in the universe through the cessation of star formation in 30%-70% of satellite galaxies.

- mass quenching appears to be a more dynamic process, governed by a quenching rate.

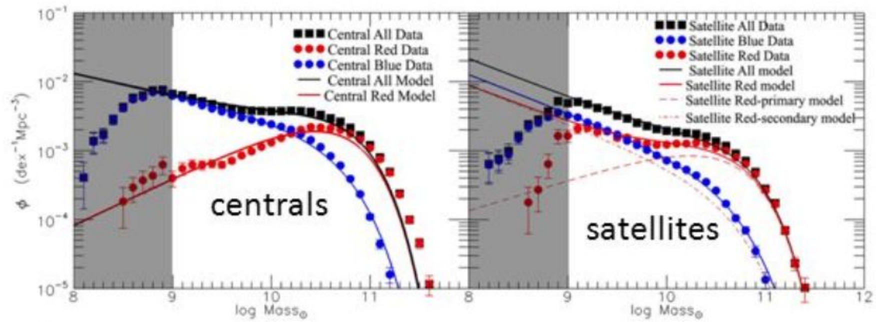


$$f_{blue}(m,\rho) = \left(1-\varepsilon_m(m)\right) \times \left(1-\varepsilon_\rho(\rho)\right)$$

NB ε_{sat} measures the differential effect of the environment on top of effect of mass (or vice versa).

Two "separable effects"

- Mass-quenching: Depends on mass but not environment
- Satellite quenching: Depends on environment but not on mass

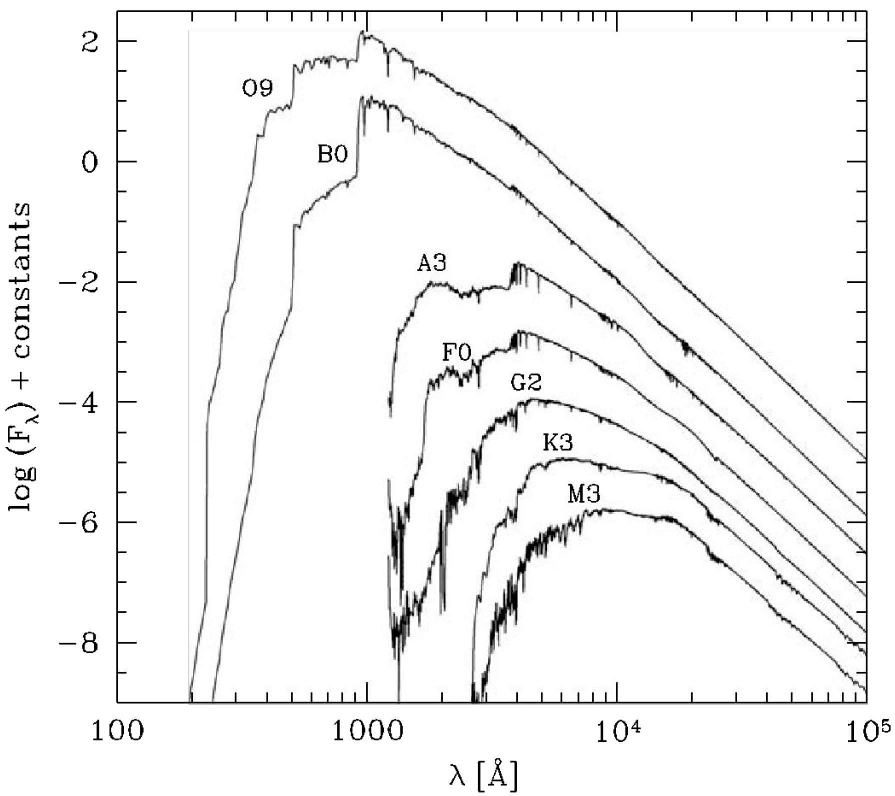


from Peng et al (2012)

But are they actually the same thing?

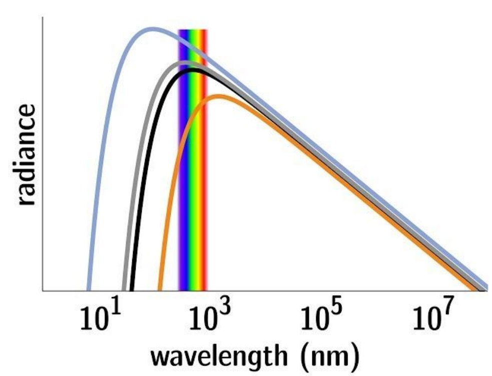
Harvard seq.

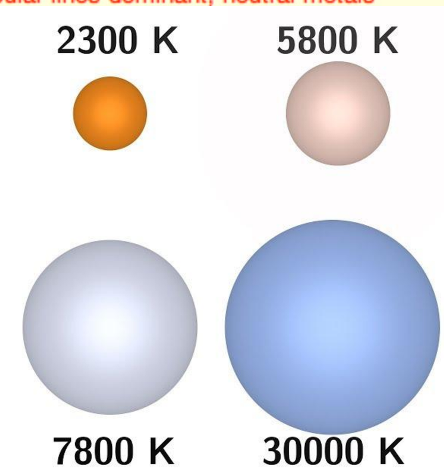
Interesting to see a comparison between stars and gal in terms of morphology. Stars are classified according to their temperature (Morgan-Keenan MK system) using the letters O, B, A, F, G, K, and M: from the hottest (O type) to the coolest (M type).



Harvard Spectral Sequence

Spectral Class	Characteristics
O	Ionized Helium and metals; weak Hydrogen
B	Neutral Helium, ionized metals, stronger Hydrogen
A	Balmer Hydrogen lines dominant, singly-ionized metals
F	Hydrogen weaker, neutral and singly-ionized metals
G	Singly-ionized Calcium most prominent, Hydrogen weaker, neutral metals
K	Neutral metals, molecular lines begin to appear
M	Titanium Oxide molecular lines dominant, neutral metals





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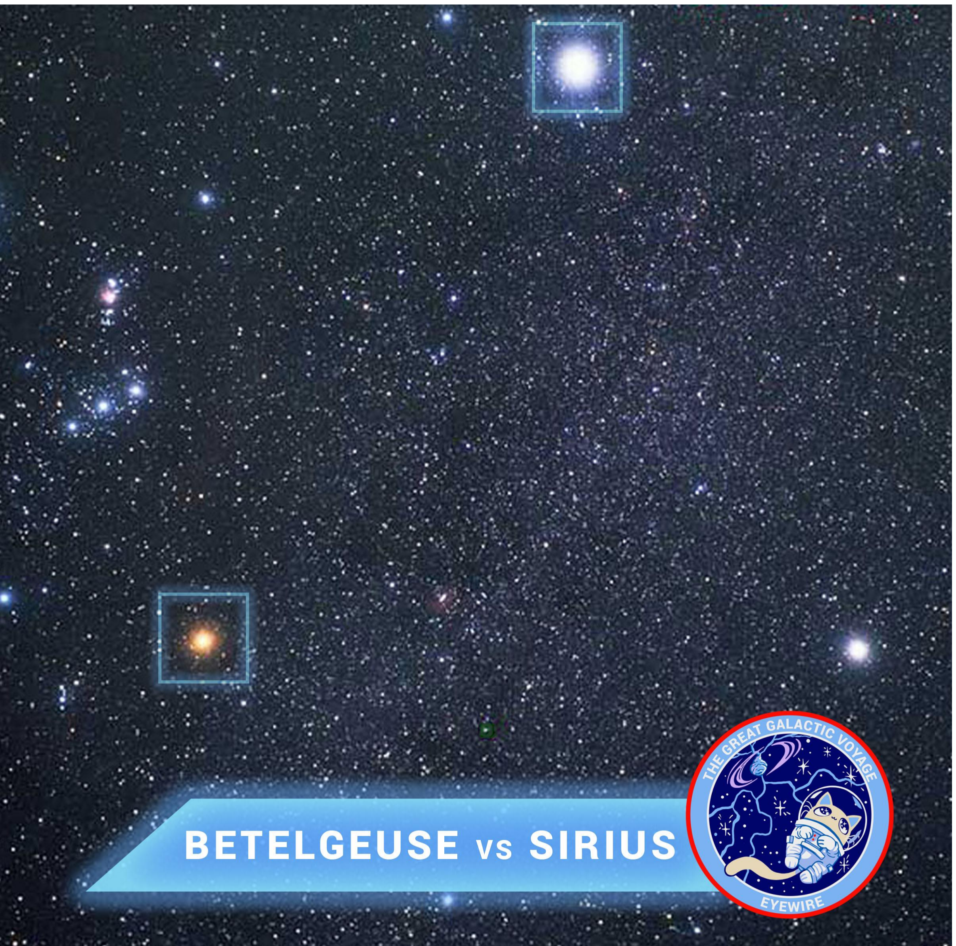

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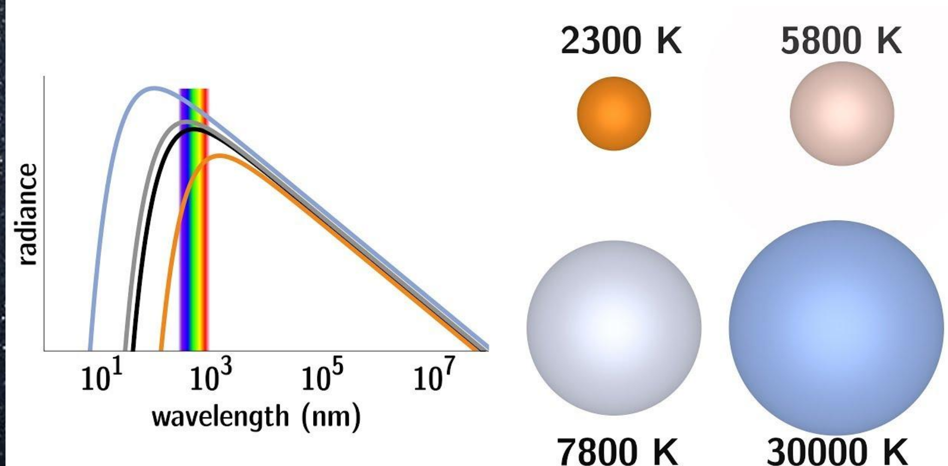
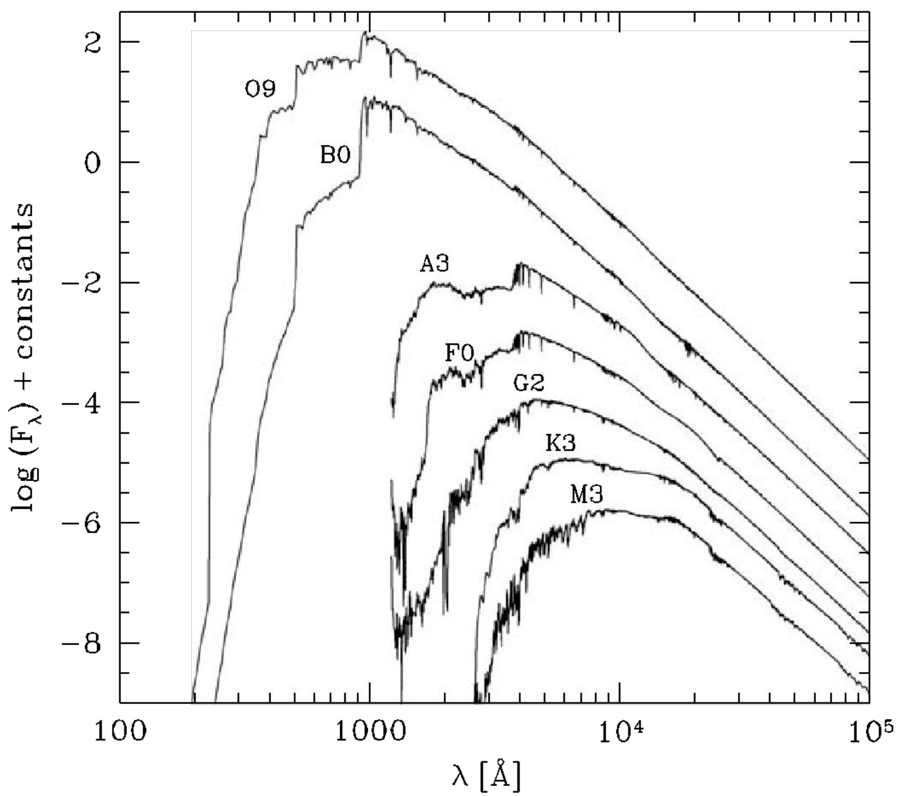
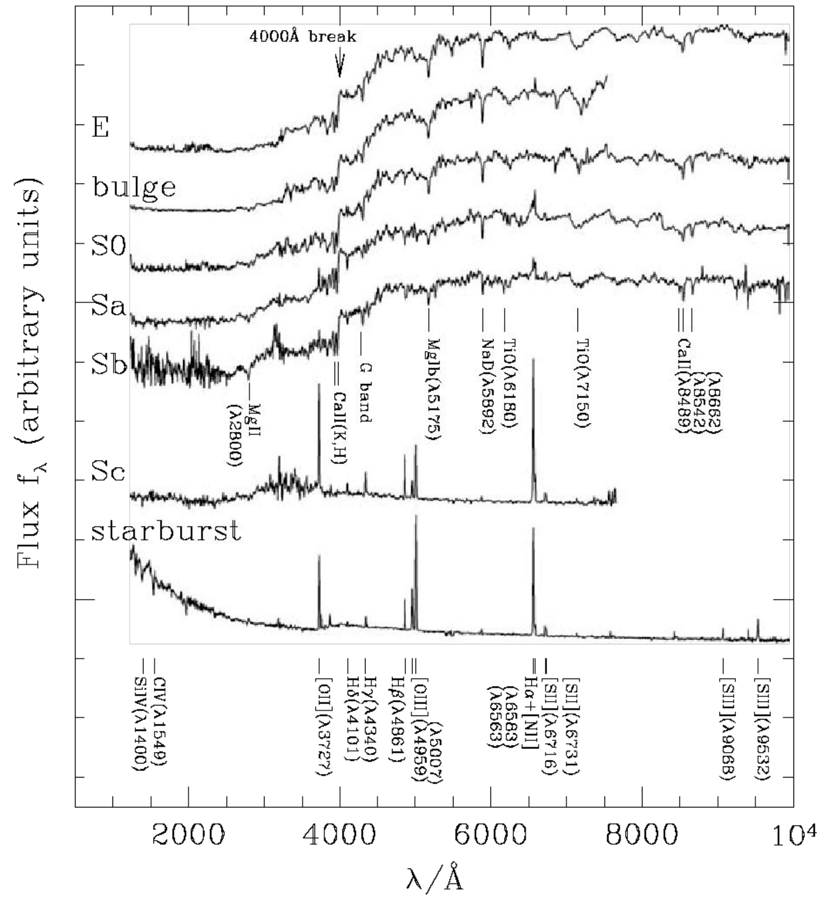


Galaxies star spectra

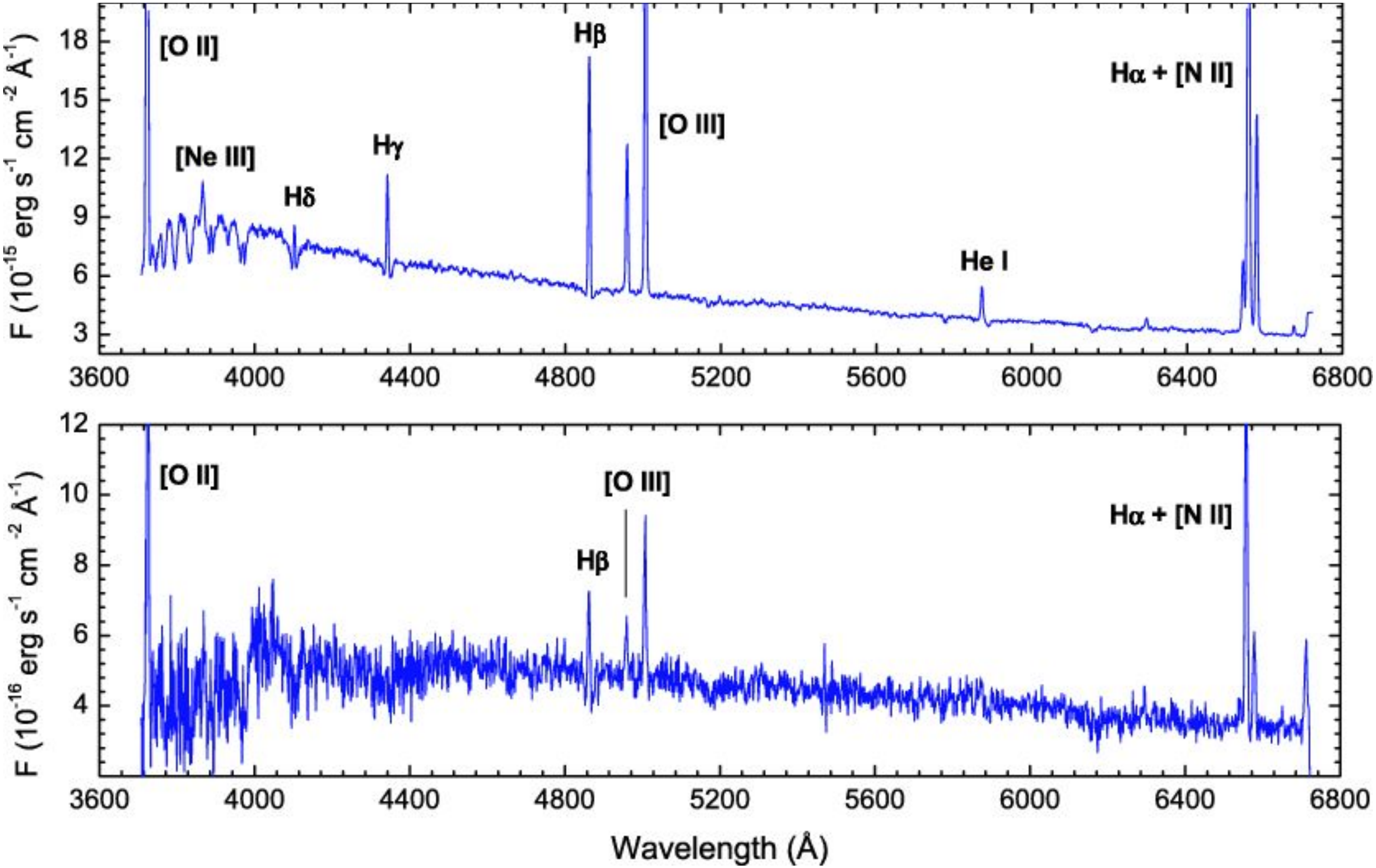
Interesting to see the comparison between stars and gal in terms of morphology. The spectra of galaxies look similar to stellar spectra, as they consist of the combined light of billions of stars.





Emission lines

See Cimatti et al. (2008) for non star-forming galaxies



SED galaxy

A spectral energy distribution (SED) shows how the energy output of a galaxy is distributed across the electromagnetic spectrum, meaning how bright the galaxy is at each particular wavelength. Galaxies consist of many different components, such as stars, gas and dust, and possibly active galactic nuclei.

- Young stars are very bright and emit most of their light in the ultraviolet and blue optical (visible) part of the spectrum
- Old stars emit most of their light in the red optical (visible) and near-infrared.
- The SEDs for elliptical (red curve) and spiral (Sd, blue curve) reflects the stellar population inhabiting the system. For starbursting galaxies, the SED peak in the infrared: Arp 220

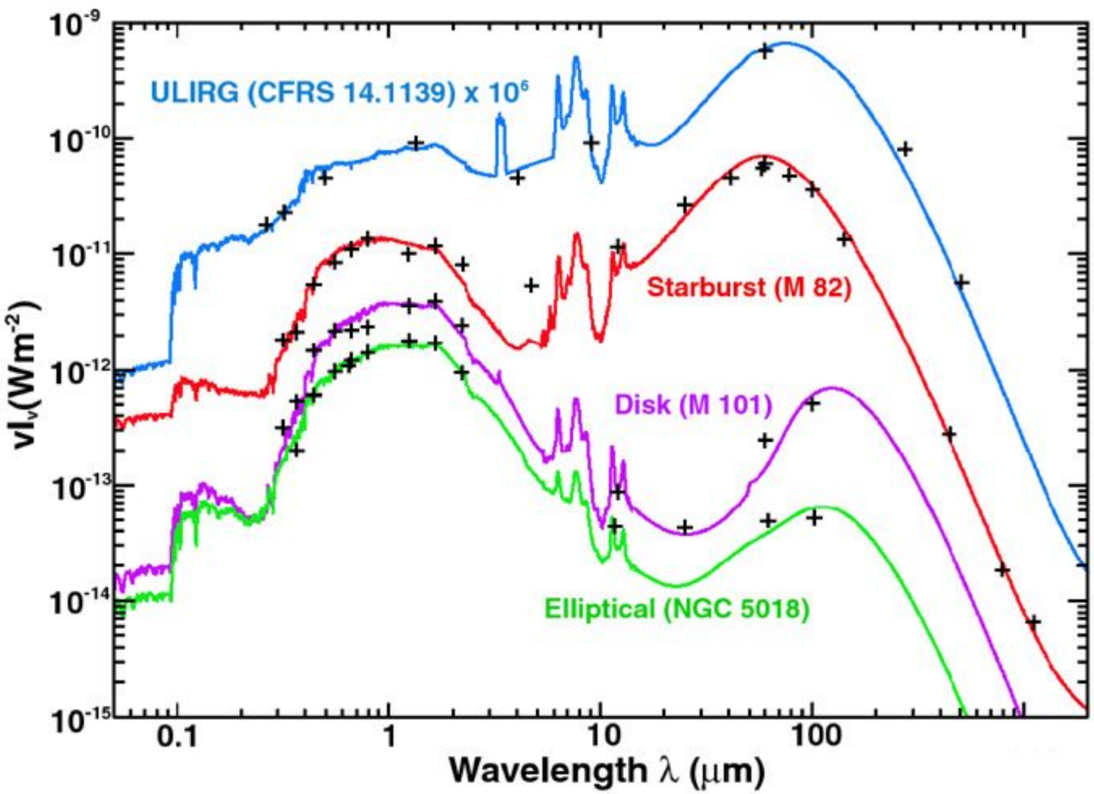
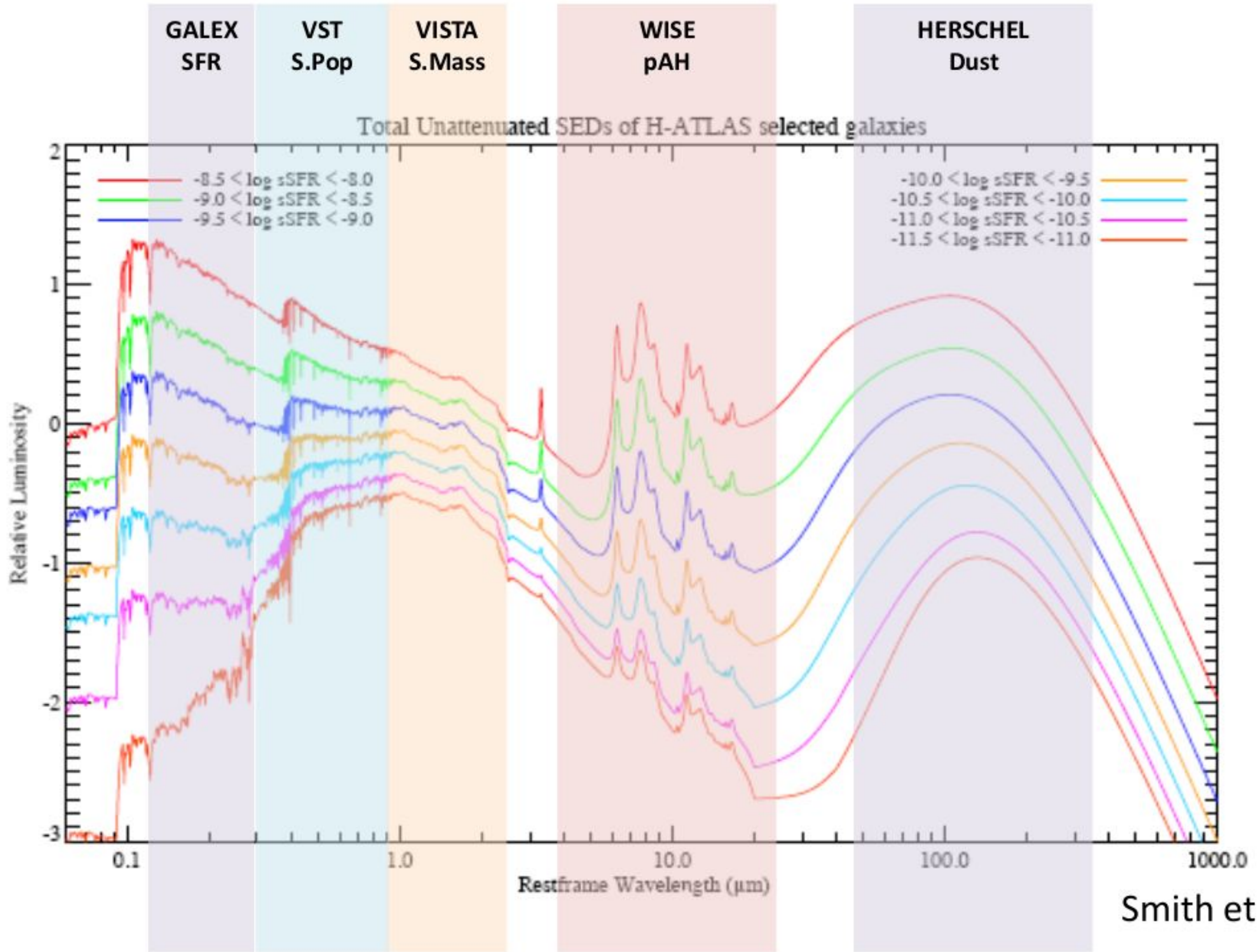


Fig 7.7 (P. Chanial, G. Lagache) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

SED galaxy

Typical SEDs for H-ATLAS galaxies are more sensitive to specific star formation rates. The optical–UV SEDs also become more reddened due to dust at higher redshifts.



Smith et al (2011)

What did we learn?

1. Galaxies are not isolated system: usually they are bounded in groups, clusters, or interacting systems
2. There are specific physical processes acting on galaxies within denser environment able to modify their shape
3. Galaxies in cluster have less star formation, are more gas poor and exist a correlation between morphology and the density
4. The way in which we can study such mechanisms can be spectral and SED analysis