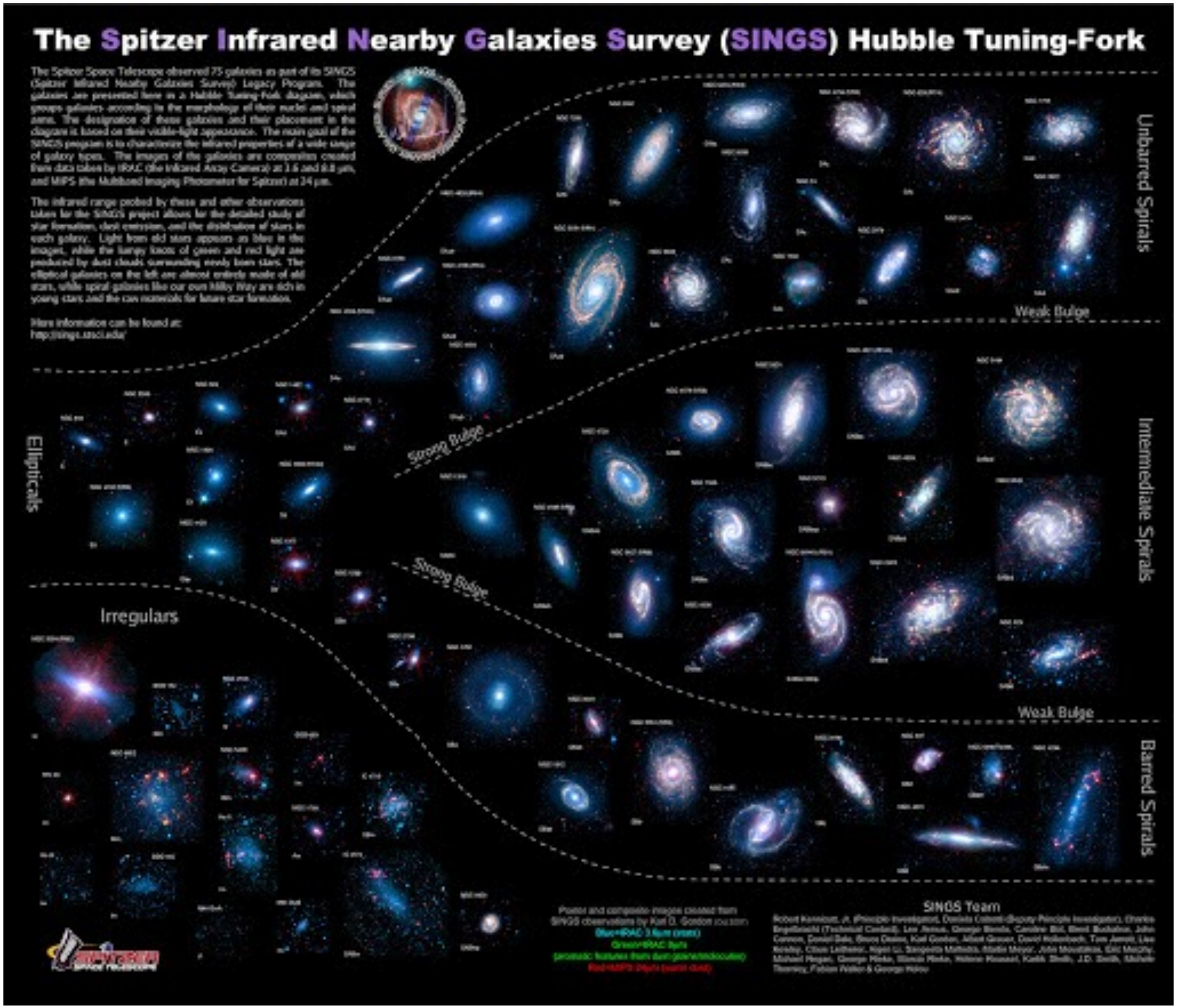
# Galaxy II— Physical properties of galaxies



The formation of a single large galaxy through time, from high redshift until the present day. This TNG50 galaxy will be similar in mass to Andromeda (M31) by redshift zero. Its progenitor experiences rapid star formation in a turbulent gas reservoir which settles into an ordered disk after z=2. A rather quiet late time assembly history without major mergers allows the galaxy to relax into an equilibrium balance of stellar feedback and gas accretion from its cooling circumgalactic medium. Insets show large-scale dark matter and then gas (lower left), and small-scale stellar and gaseous distributions (lower right). The main panel shows gas density, transitioning to gas metallicity during the brief pause and rotation.

Large scale structure

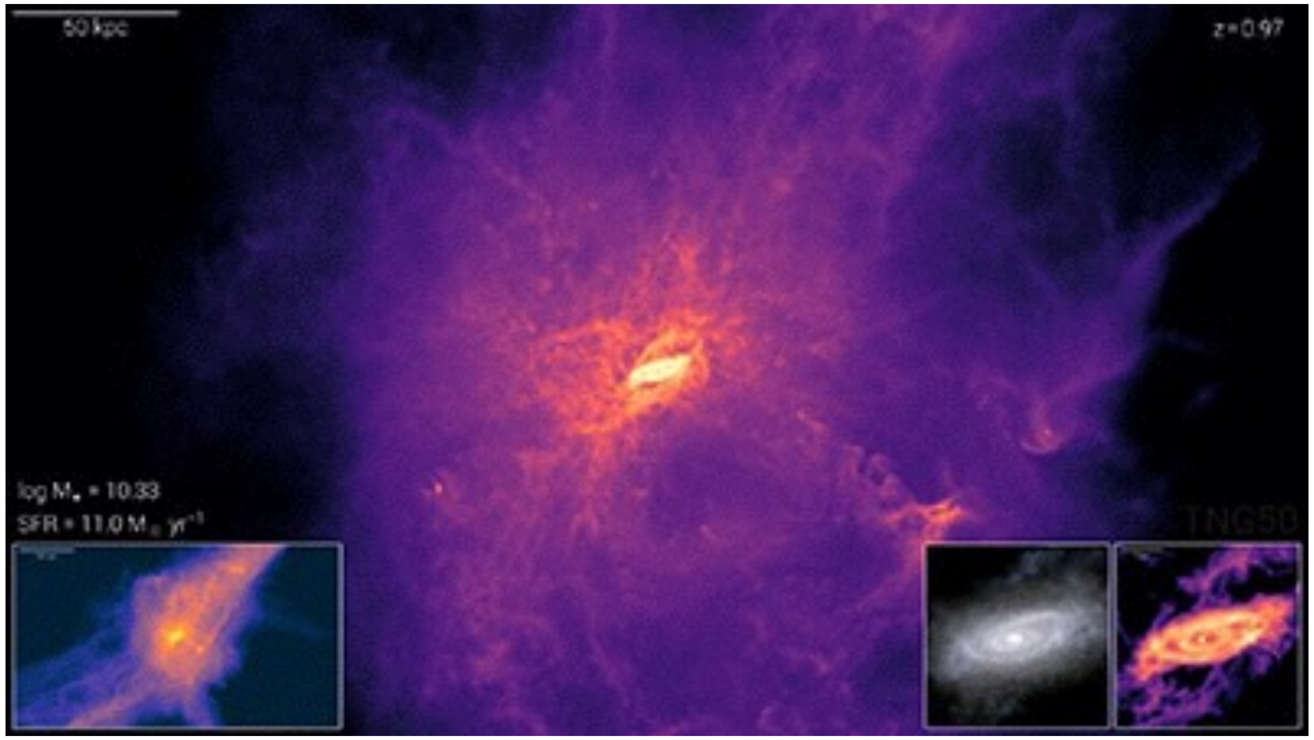
Stars

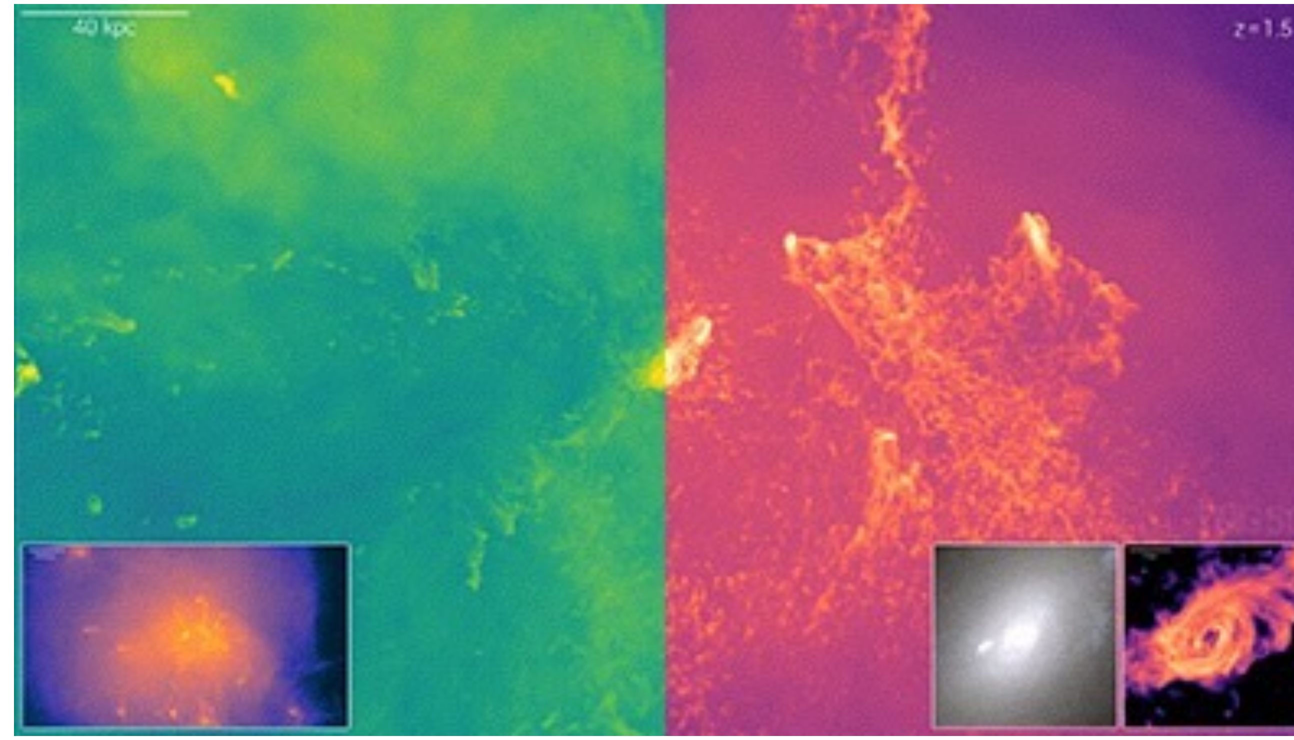
Gas (zoom-in)

The assembly of a single massive elliptical galaxy in TNG50, tracked through time from z=20 until late time. By redshift zero this system will merge into the BCG of a Virgo-mass galaxy cluster (1014 solar masses). The progenitor of this galaxy undergoes rapid star formation in a turbulent, extended disk until intermediate times, when it starts to quench due to the action of its central blackhole. Vigorous major and minor merger activity transforms it from a disk into an elliptical system; an extremely complex interplay of multi-phase gas processes in its circumgalactic medium is visible throughout. The inset in the lower left shows the large-scale environment, while insets in the lower right zoom into the central galaxy itself (gas and stars). We pause at z=1.5 and rotate around the inner halo, showing in order: gas metallicity, velocity field, radial velocity, and H-alpha light. We pause again at the end of the movie and show H-alpha light followed by magnetic field strength.

Large scale structure Stars Gas (zoom-in)

# Q: What are the quantities we can use to study galaxies?




How does a galaxy look like — Morphology
How do different components of a galaxy look like — Distribution of stars, metals, gas…
Is a galaxy interacting with other galaxies — Merging Status
How bright a galaxy is — Luminosity
What is the large scale structure that a galaxy is embedded — Environment

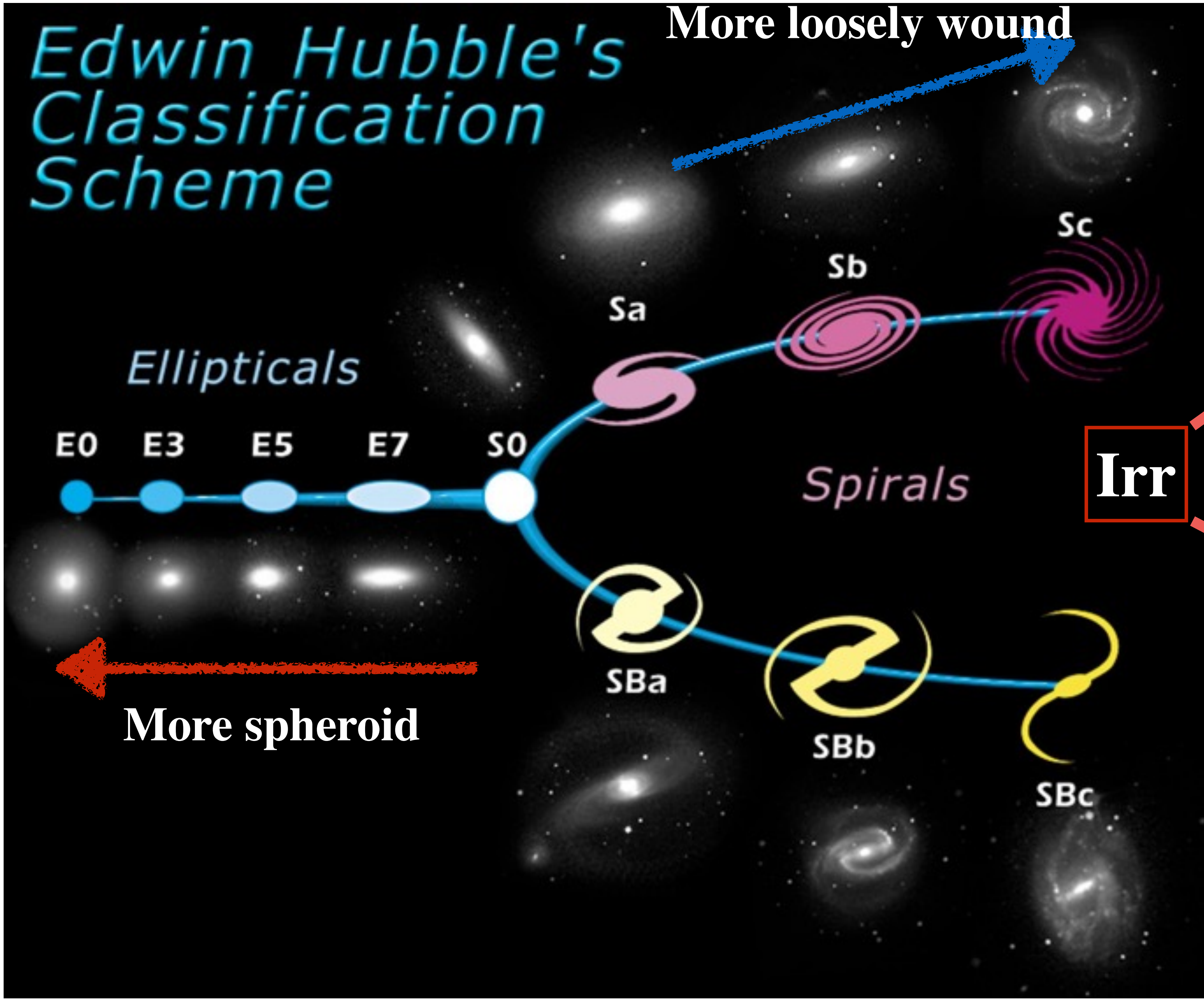
What are the motions inside a galaxy — ordered motion like rotation? random motion? or both?

What are the star formation properties of a galaxy — actively forming stars? being quiescent?

# Morphological Properties of Galaxies

# In yesterday's lecture,

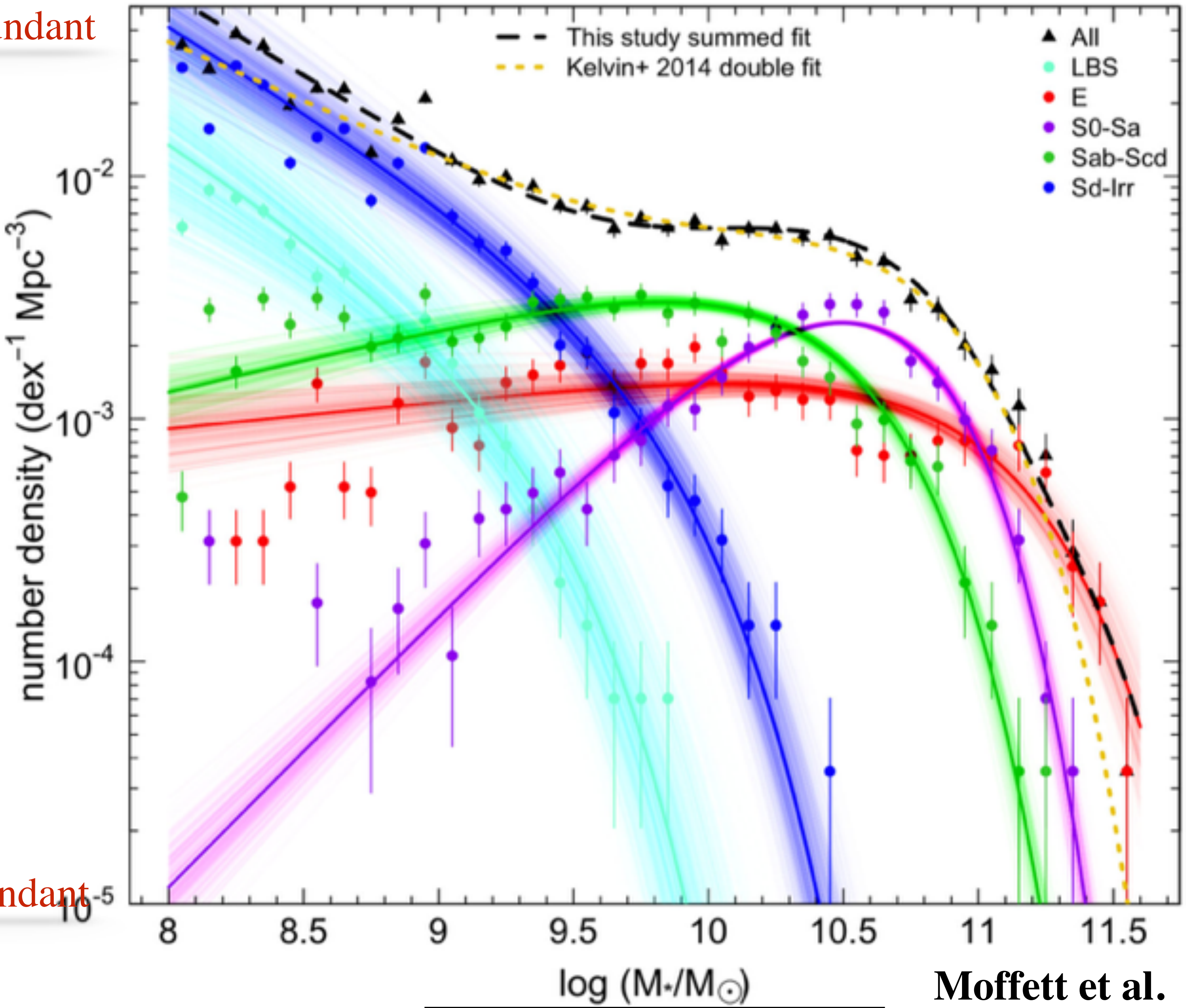
Morphology types




Irr

# Abundance of galaxies with different morphologies at z~0

More abundant




Abundance

Less abundant

Elliptical galaxies are more massive

Spiral galaxies are dominated at the intermediate mass range

Irregular galaxies are at the low-mass end

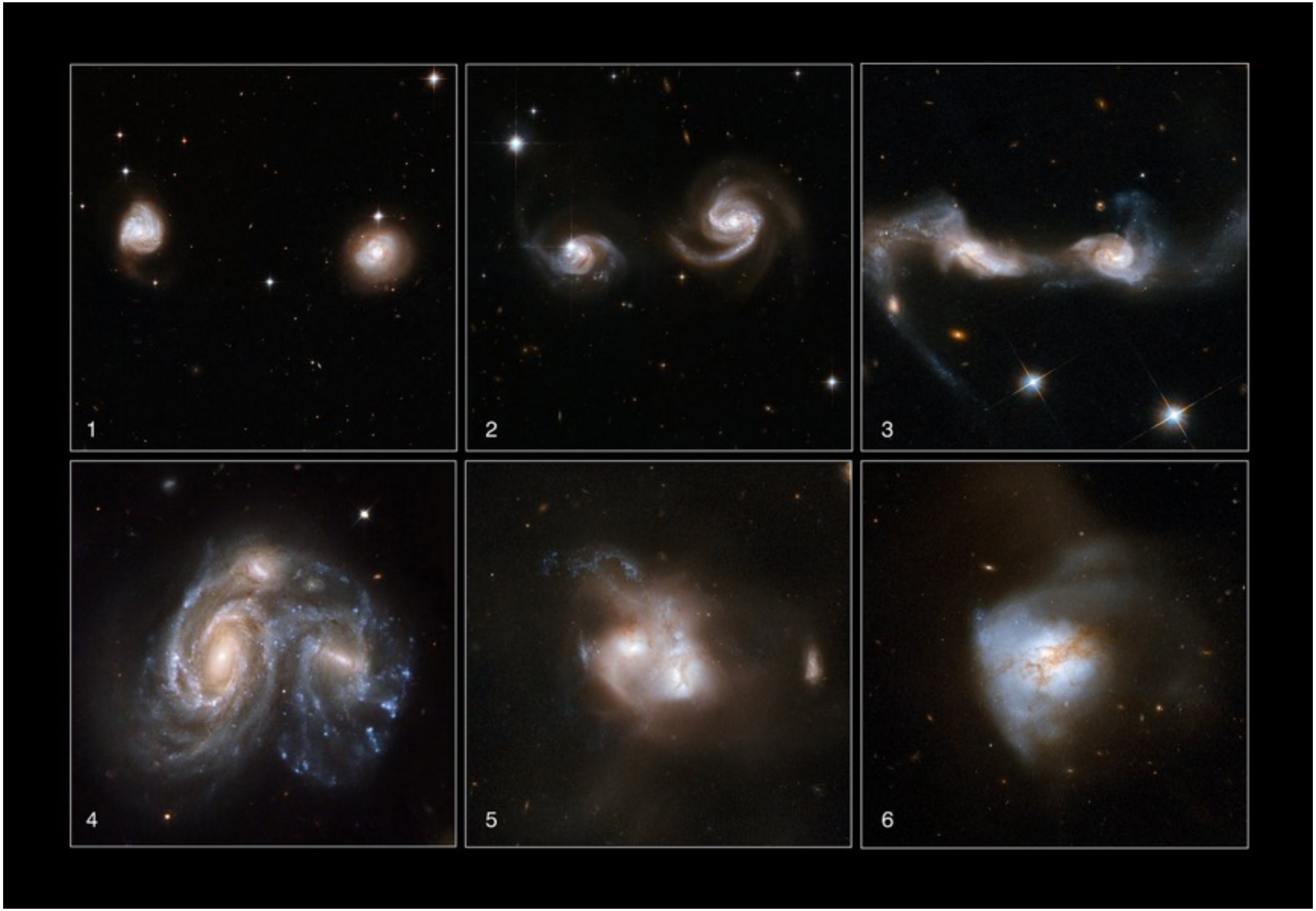
Moffett et al.

Less massive

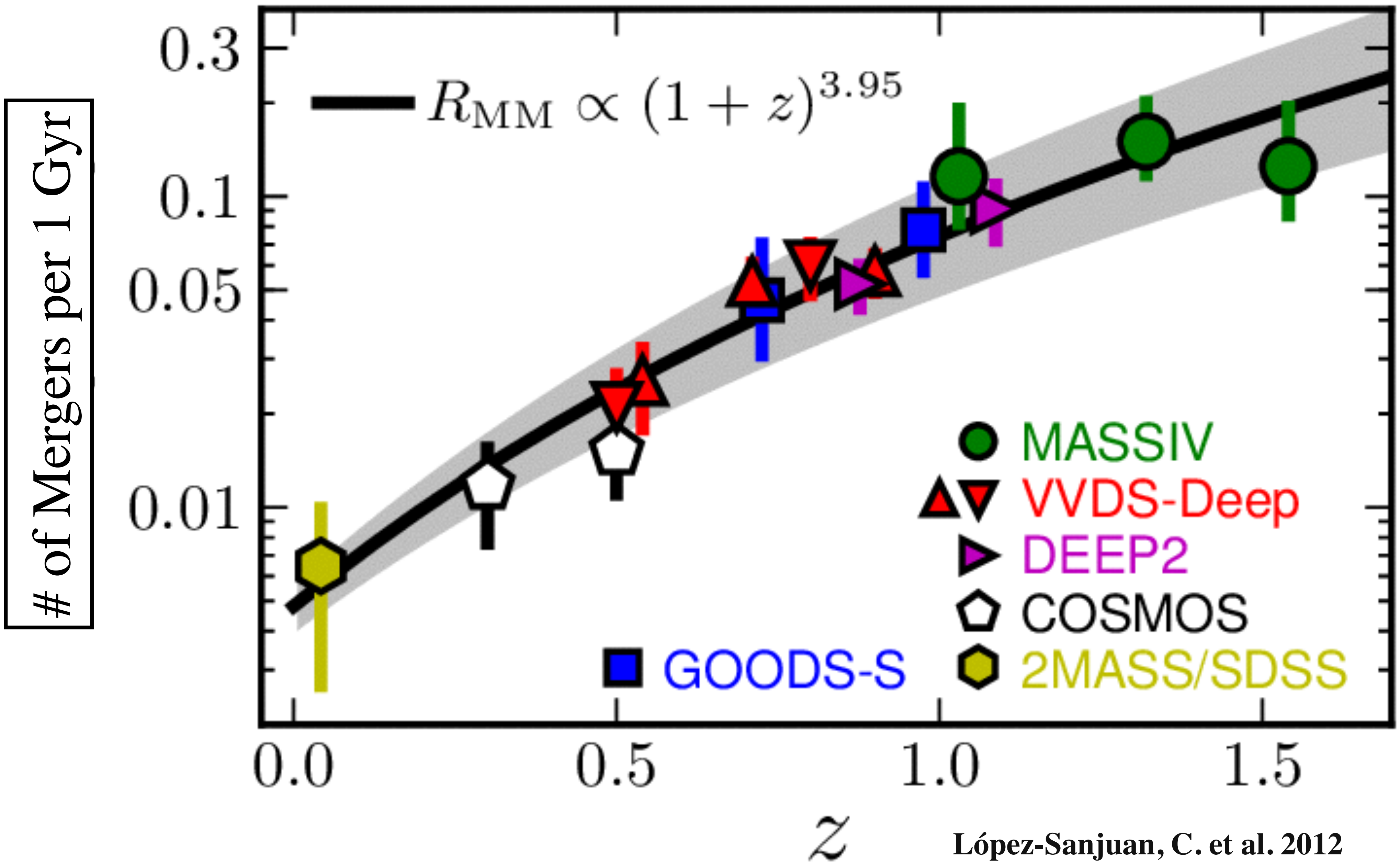
Galaxy stellar mass

More massive

# Merging/interacting or not?



# Merger rate at different epoch of the Universe




López-Sanjuan, C. et al. 2012

**Mergers are more frequent at high redshifts, i.e. the early Universe**

# Brightness of Galaxies


Q: how to quantify the brightness of this galaxy?

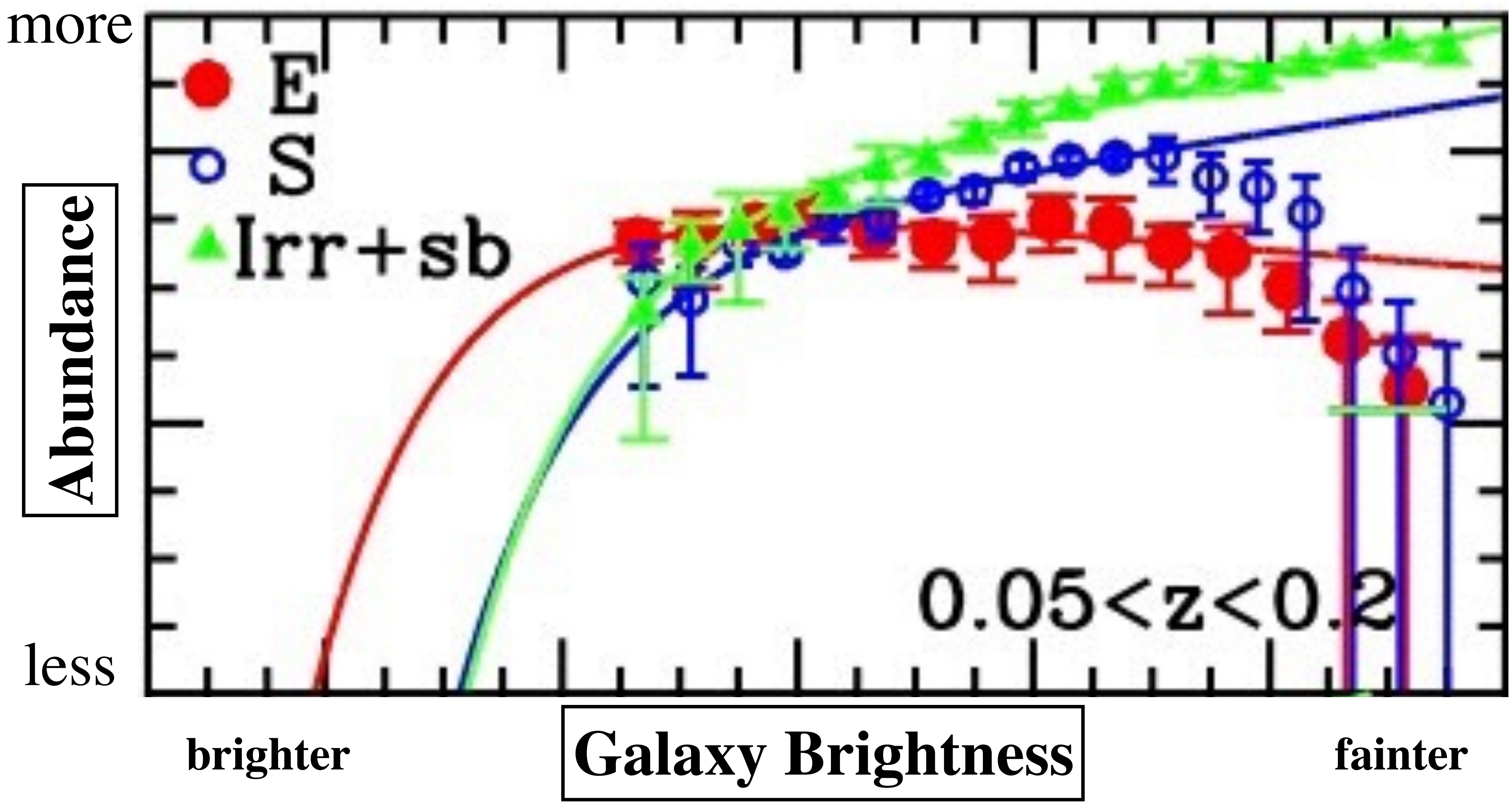
**Step I:**
**Define an aperture**

**Step II:**
**Count photons within that aperture**

**Step III:**
**Convert photon counts to energy**

**Repeat for other galaxies!**

Galaxy luminosity function at z ~ 0, i.e. nearby Universe
Count number of galaxies in each galaxy brightness bin

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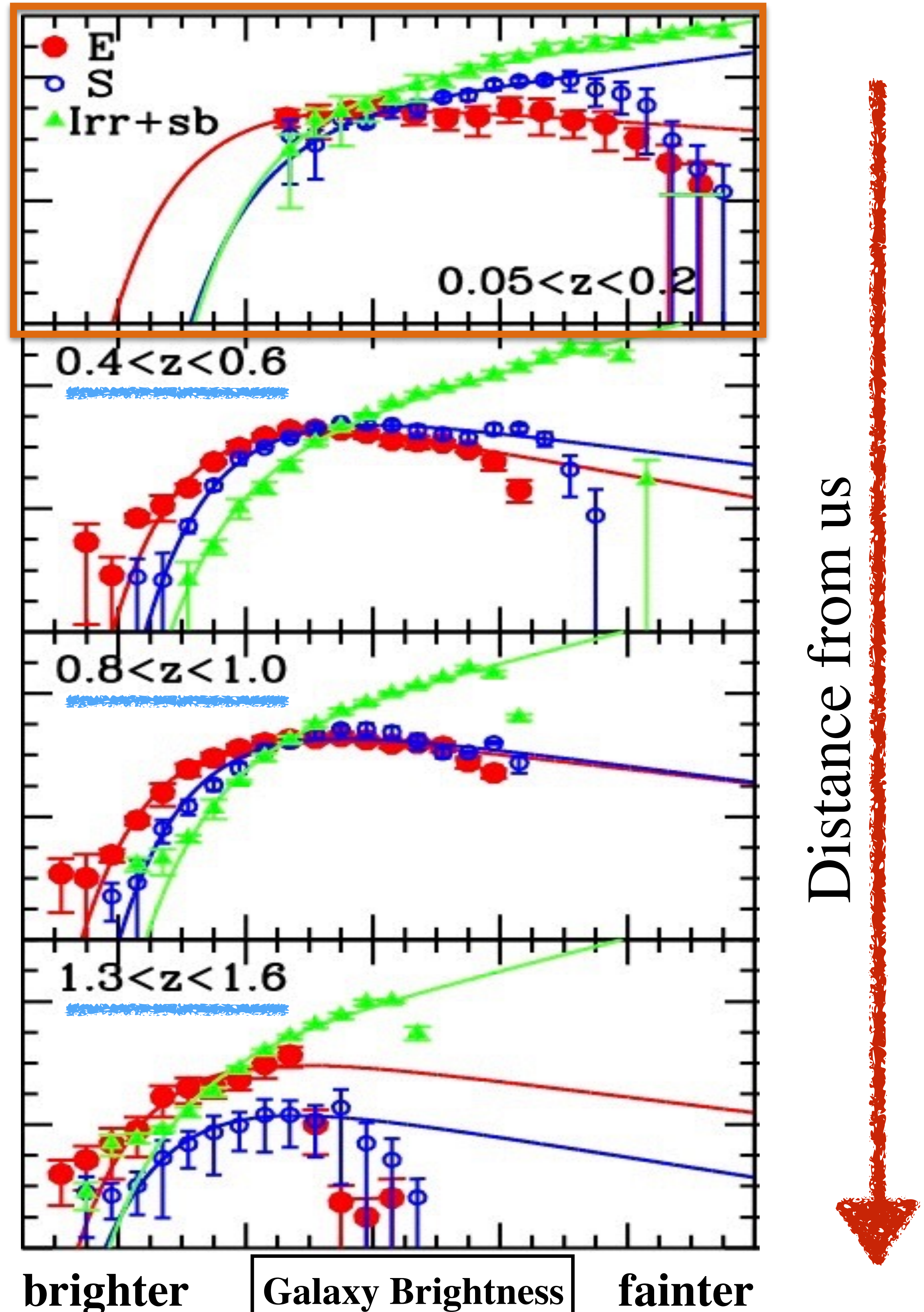
**True or False:**
**Elliptical galaxies tend to be brighter than spiral galaxies.** **True**

**True or False:**
**There are more bright irregular galaxies than faint irregular galaxies.** **False**

Galaxy luminosity function is different at the distant Universe!!!

Q: What can be learned from this figure?



$\boxed{\text{Environments of galaxies}}$

**What are the environments of galaxies —**

Galaxies are not distributed evenly thoroughout the Universe, but instead tend to congregate in groups and clusters. The 'environment' of a galaxy is described by how other galaxies are distributed in its immediate neighbourhood.

NGC821

**Isolated galaxies**: Galaxies are rarely found alone. Those that have no major companions (but may still have a few small satellites) are refered to as isolated.

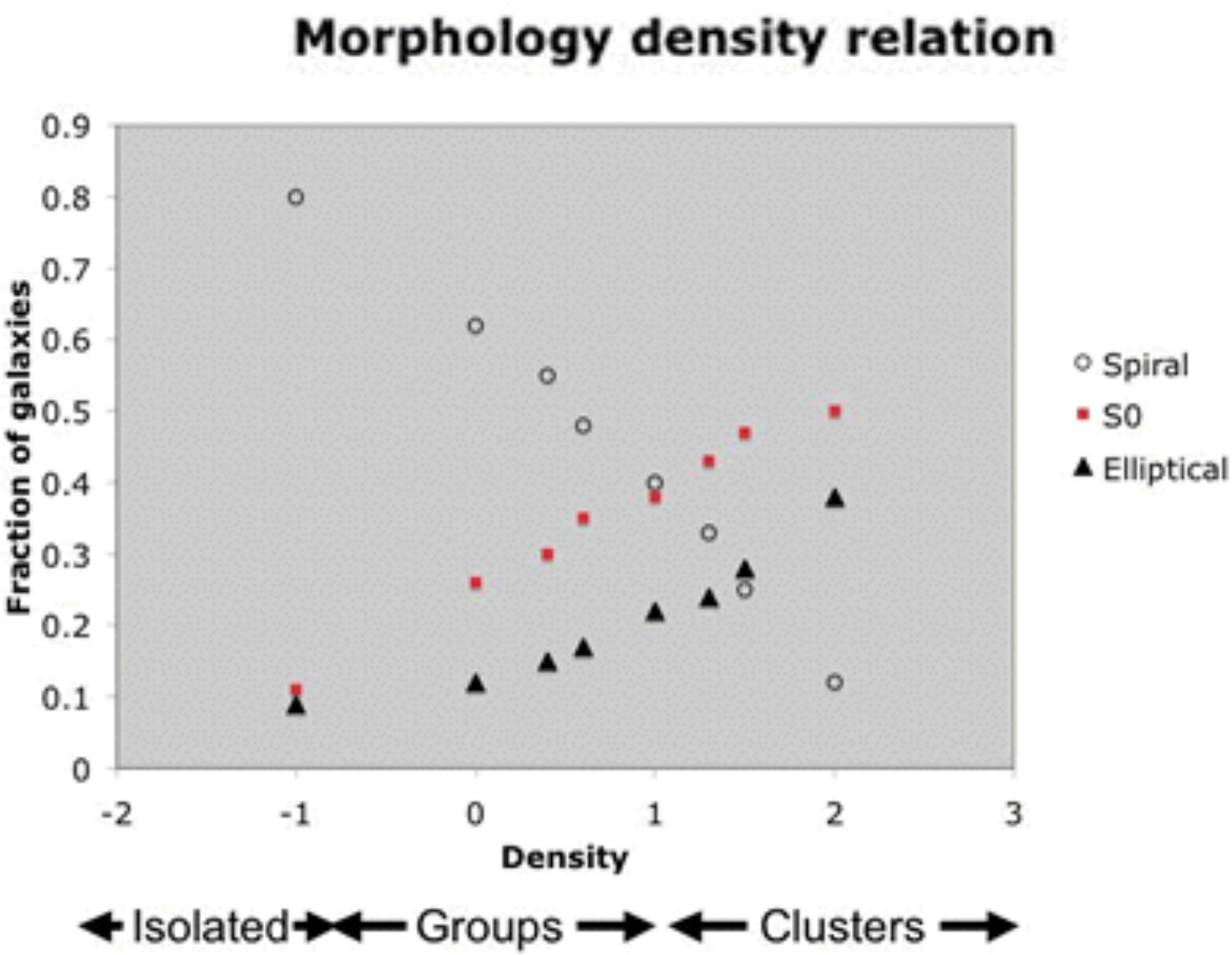
Leo group

**Galaxy groups** are by far the most common environment in which galaxies are found. While a group may contain up to 100 galaxies, only a few of these galaxies will be as massive as the Milky Way. The Local Group, which contains the Milky Way and Andromeda galaxies, is a fairly typical small group.

Coma Cluster

**Galaxy Clusters** may contain between a few hundred and several thousand galaxies, with potentially hundreds of galaxies as large as the Milky Way. This is perhaps the best studied of the galaxy environments, as many bright galaxies are observed per observation. The nearest, and best studied, major clusters are the Virgo and Coma clusters.

Environmental effects actually can affect galaxy evolution




**Q: What can be learned from this figure?**

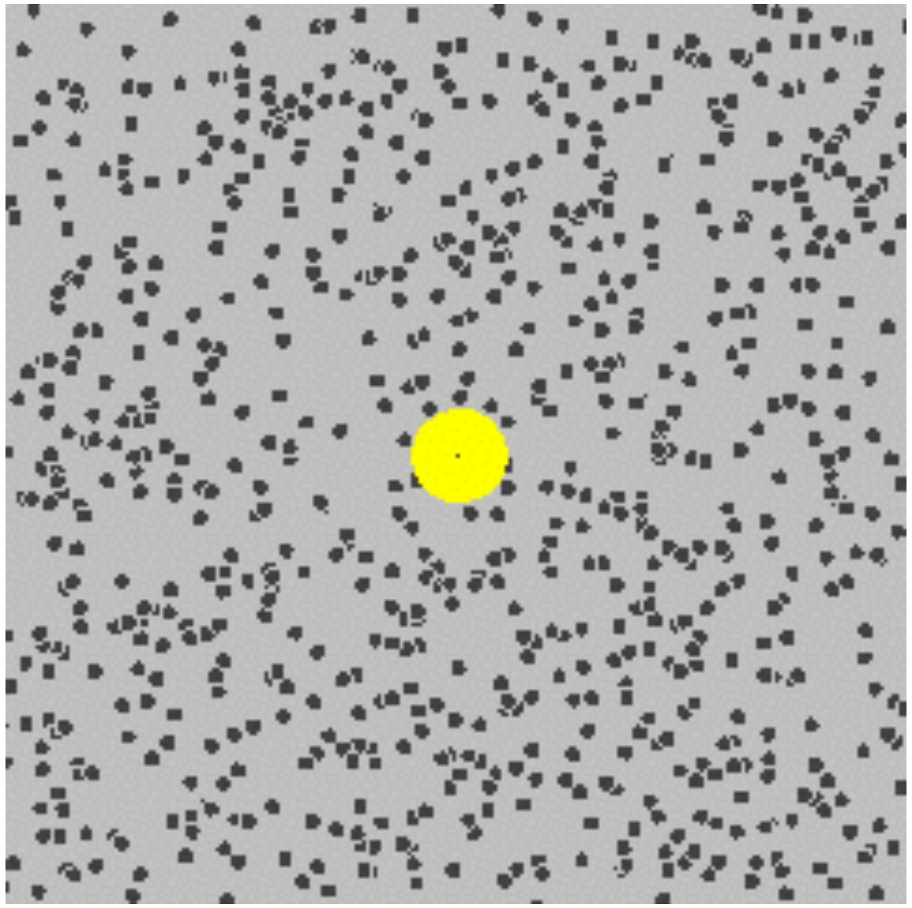
Elliptical and S0 galaxies are the majority in dense environments (groups, clusters). The majority of isolated galaxies are Spiral galaxies.

# Kinematic Properties of Galaxies

# Motions

## Random Motion

No coherent
velocity dispersion



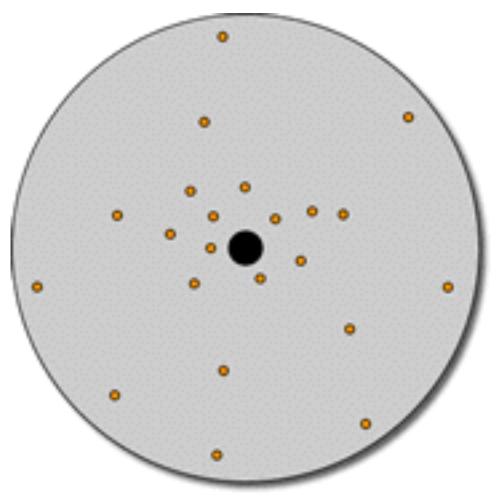
**Brownian motion illustration**

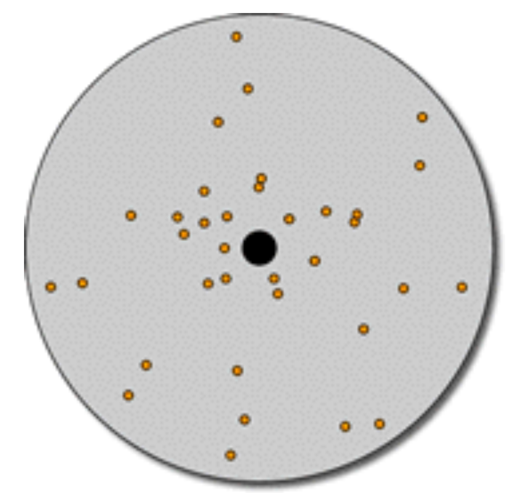
Credit:http://web.mit.edu/8.334/www/grades/projects/projects17/OscarMickelin/brownian.html

## Ordered Motion

Coherent
rotational velocity

# Motions in galaxies





Rotationally supported objects (**left**) have the majority of stars orbiting in the same direction. With velocity dispersion (**right**), approximately equal numbers of stars orbiting in all directions.

The stellar motions (orbits) which support a self-gravitating body against collapse can either be ordered or random. The most prevalent form of ordered motion is rotation, in which the majority of stars orbit in the same direction (e.g. the thin and thick disks of spiral galaxies). If a galaxy shows strong rotation it is said to be 'rotation supported'.

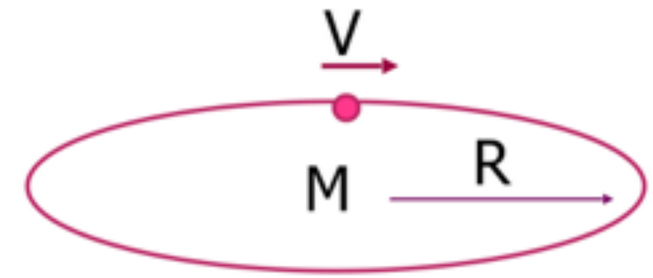
However, elliptical galaxies and the stellar halos and bulges of spiral galaxies possess little or no rotation. In these situations the stellar orbits are random, with as many stars orbiting in one direction as there are orbiting in another. Such galaxies are said to be 'velocity dispersion' (or pressure) supported.

While rotation can often be measured by simply determining the redshift at a number positions across the galaxy, the slightly more difficult measurement of velocity dispersion requires a measure of the velocity broadening of spectral lines.

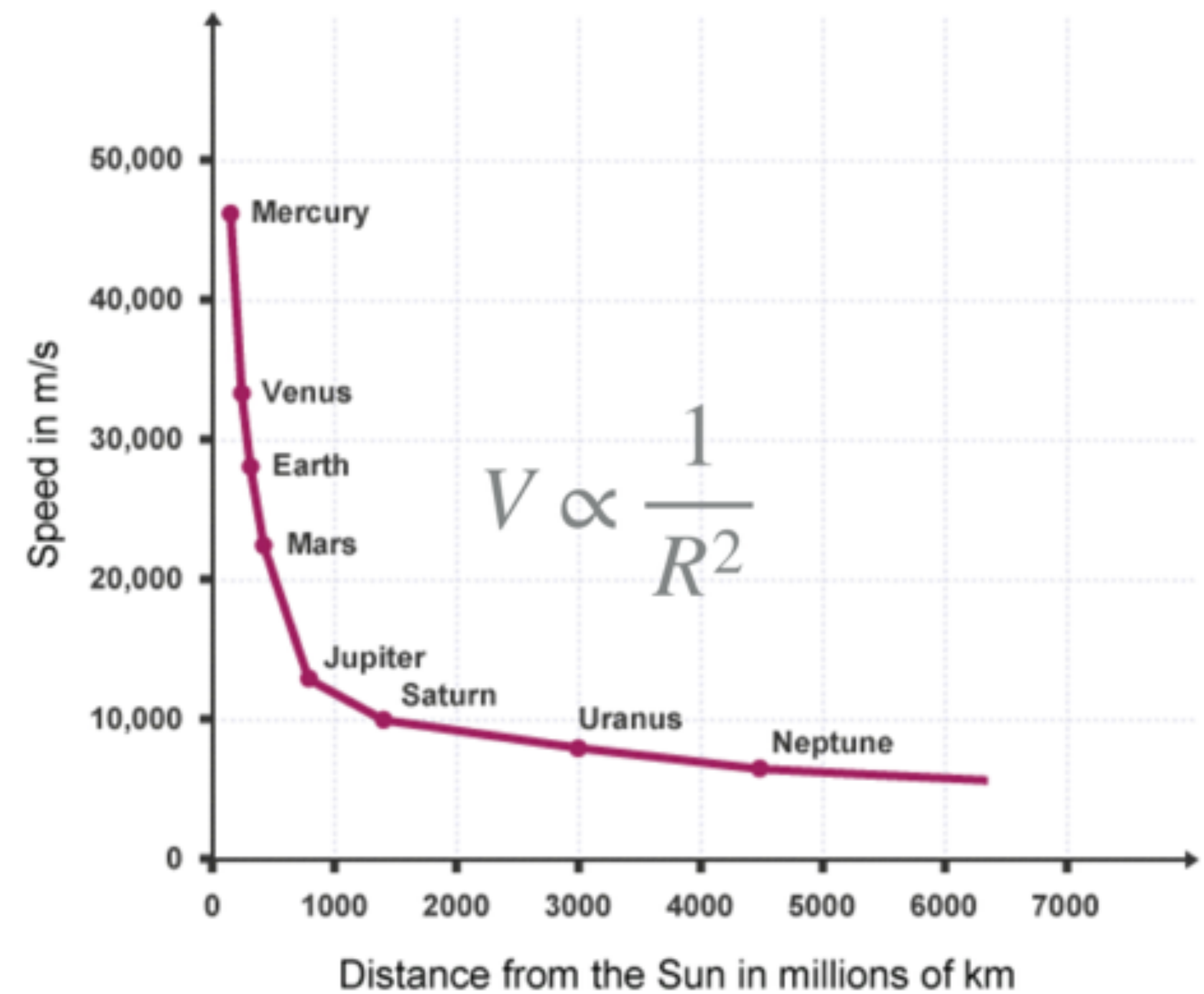
# Galaxy Rotation

## KEY CONCEPT! MASS AND MOTION

$$M(\text{enclosed}) = \frac{V^2 R}{G}$$




- If a star at a distance R from the center of the galaxy is moving with velocity V, then we can infer the mass that it must be orbiting around using :
- In other words, if we can measure the orbital velocity of a star at the edge of the galaxy, then we can estimate the Milky Way's mass!




Q: Solar mass estimation —
From the figure, we know that Jupiter's velocity and its distance from the Sun:

$$v \approx 1.2 \times 10^6 cm \quad R \approx 8 \times 10^{13} cm \quad G \approx 6.67 \times 10^{-8} cm^3 g^{-1} s^{-2}$$

$$M = \frac{V^2 R}{G}$$

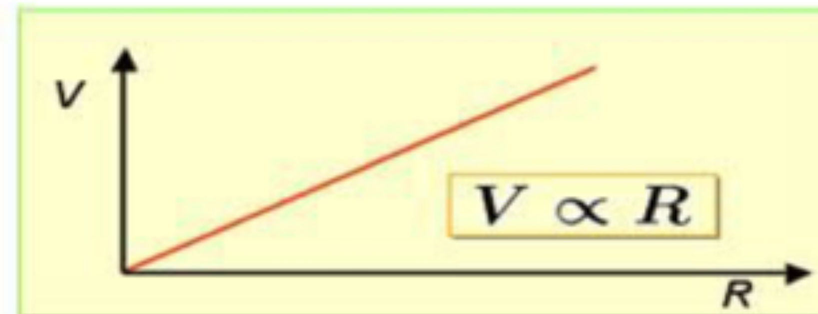
**M = ?**

$$M = \frac{(1.2\times10^6)^2 \cdot 8\times10^{13}}{6.67\times10^{-8}} g = \frac{1.2\times1.2\times8}{6.67} \cdot \frac{10^6\times10^6\times10^{13}}{10^{-8}} \approx 2\times10^{33} g$$

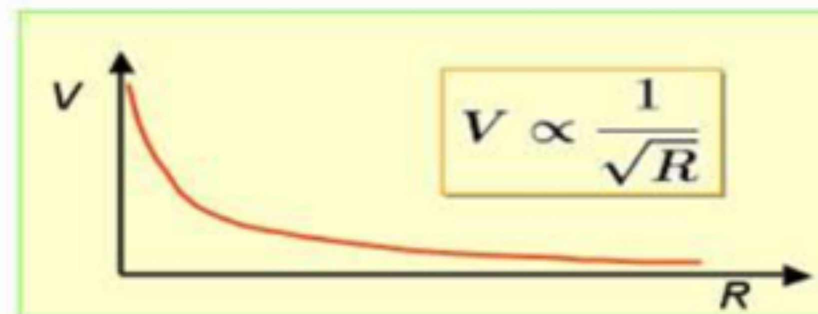
# Galaxy Rotation

## ROTATION CURVES

- What can we learn about studying rotation curves?
- We can infer the total amount of mass in the Milky Way!
- If only it were that simple…




Solid Body Rotation

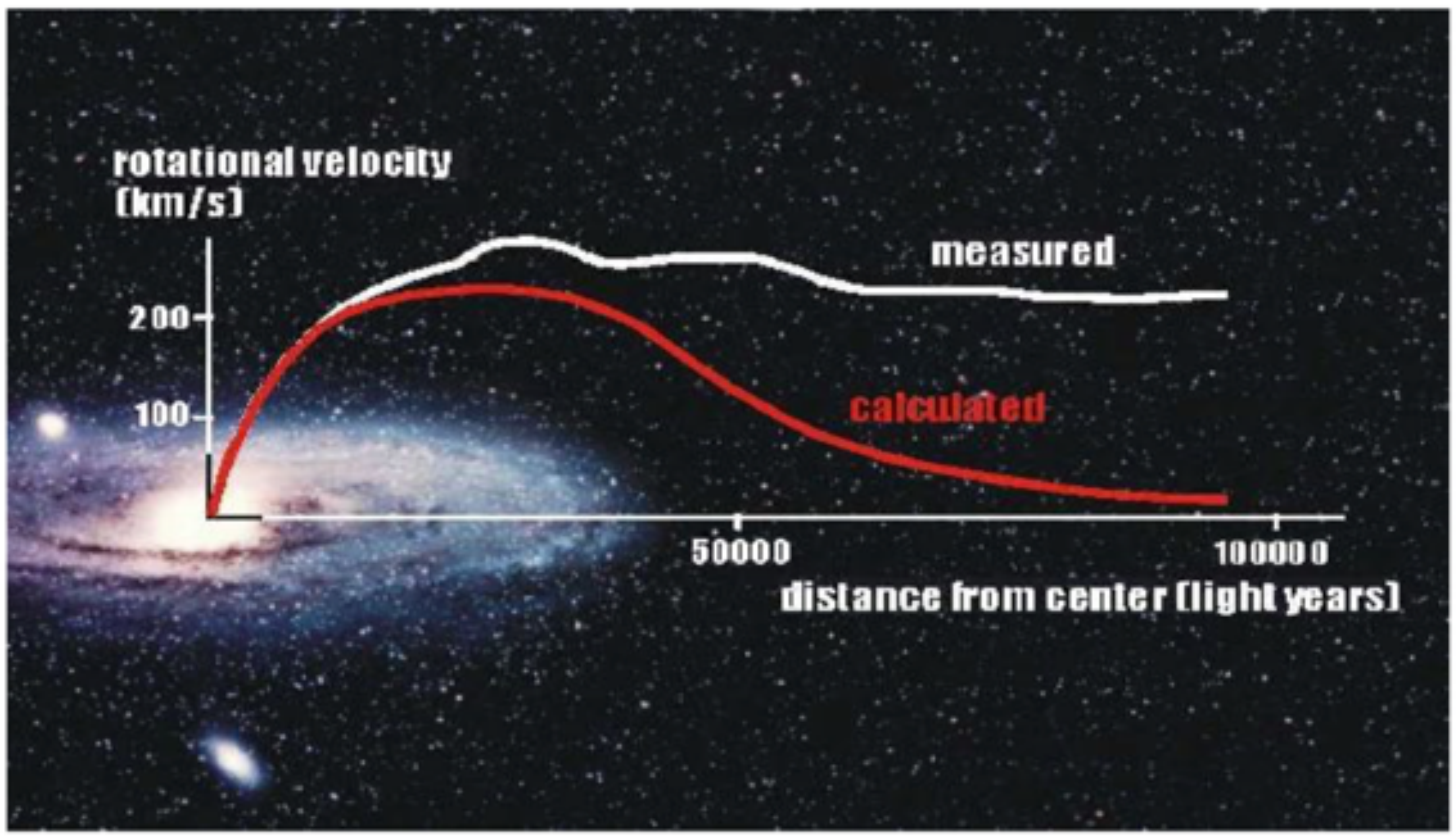


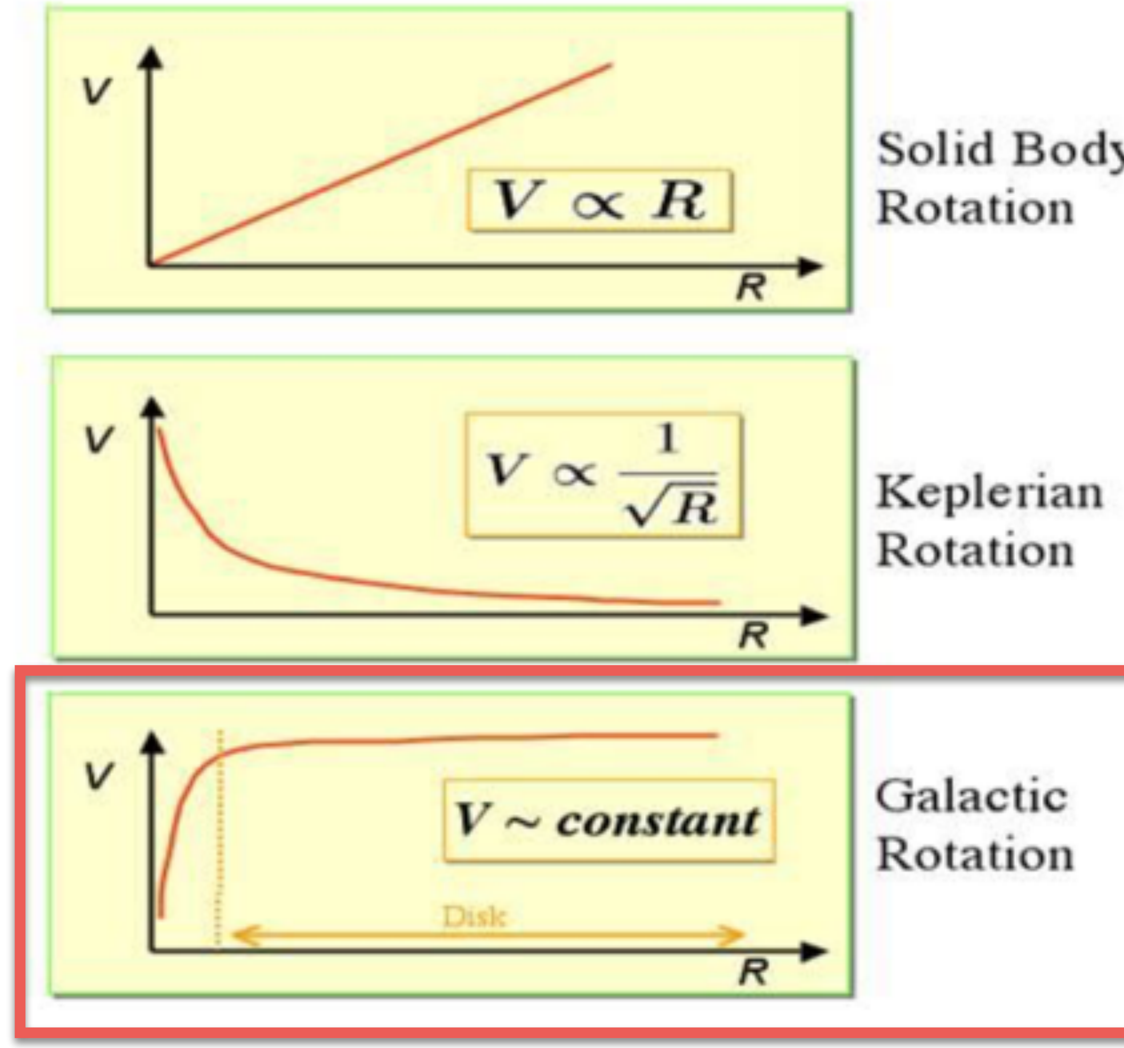

Keplerian Rotation

# Galaxy Rotation

## ROTATION CURVES

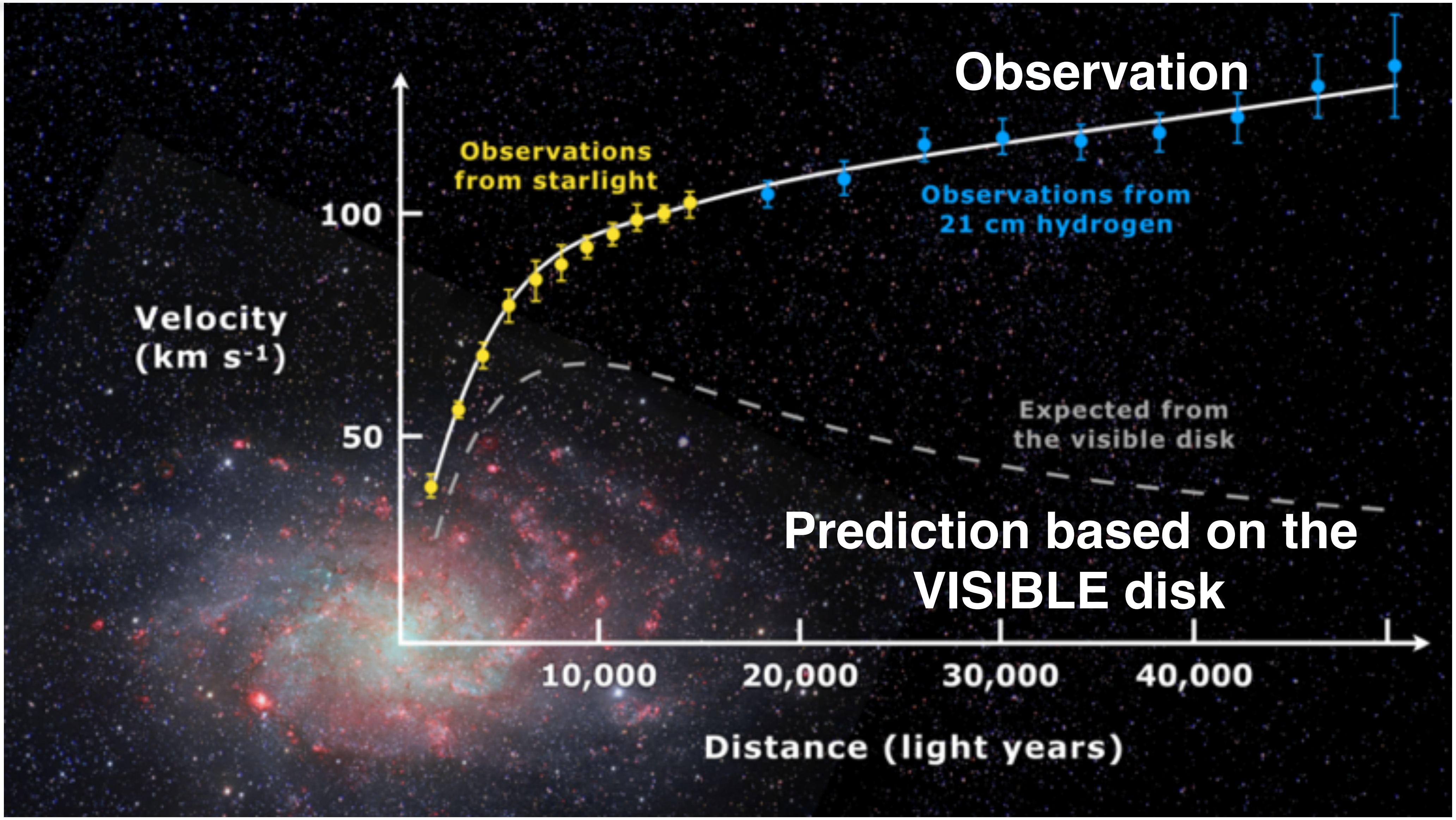
- If only it were that simple…

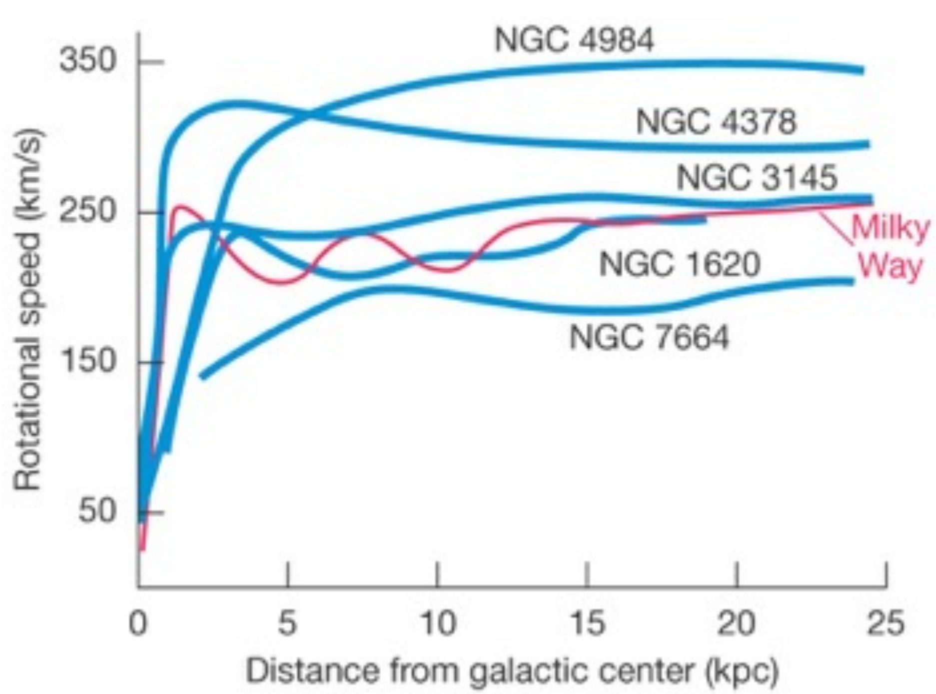



??????

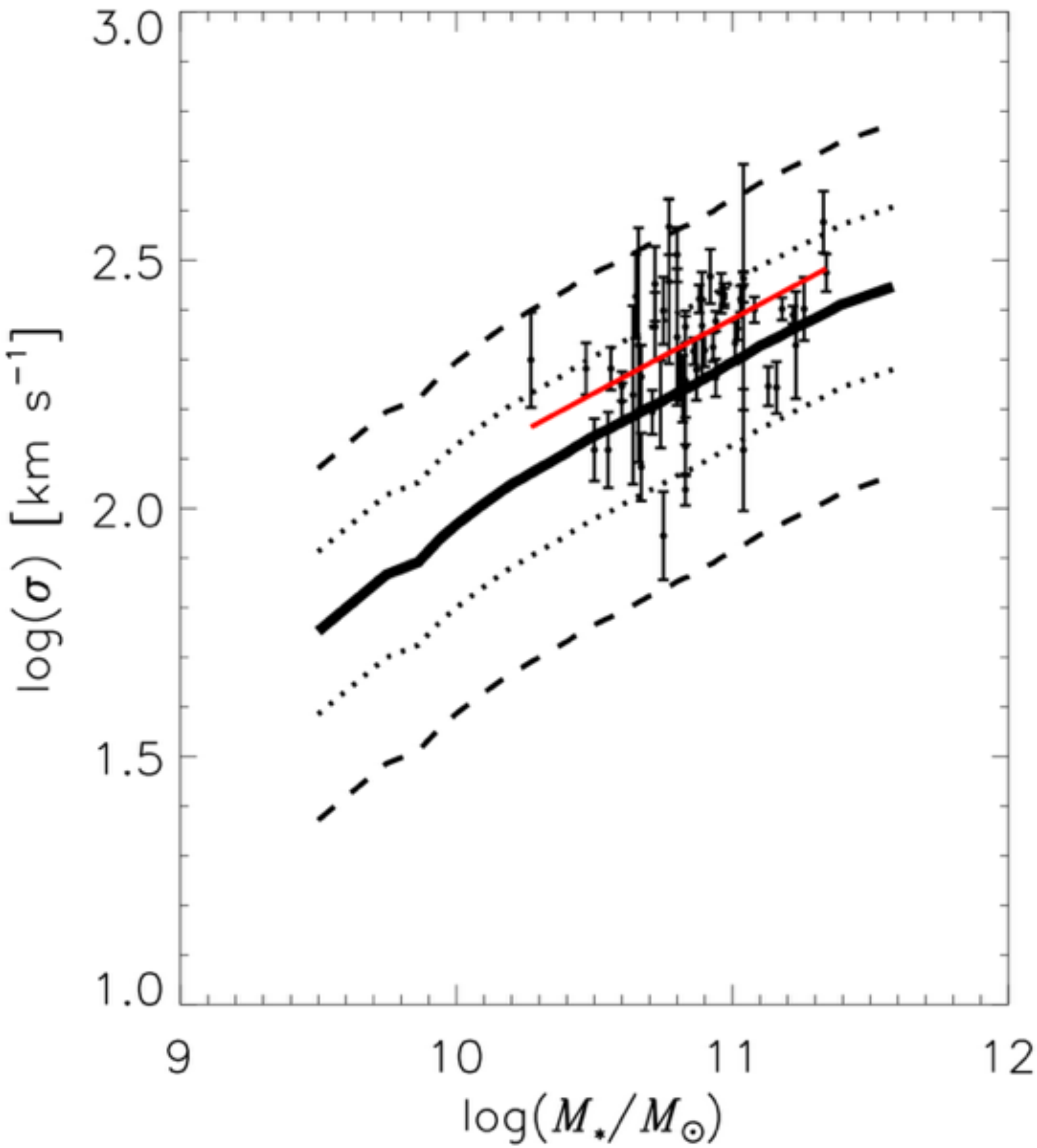
# Galaxy Rotation




There is INVISIBLE matter! Dark Matter!

# Galaxy Velocity Dispersion (random motion)

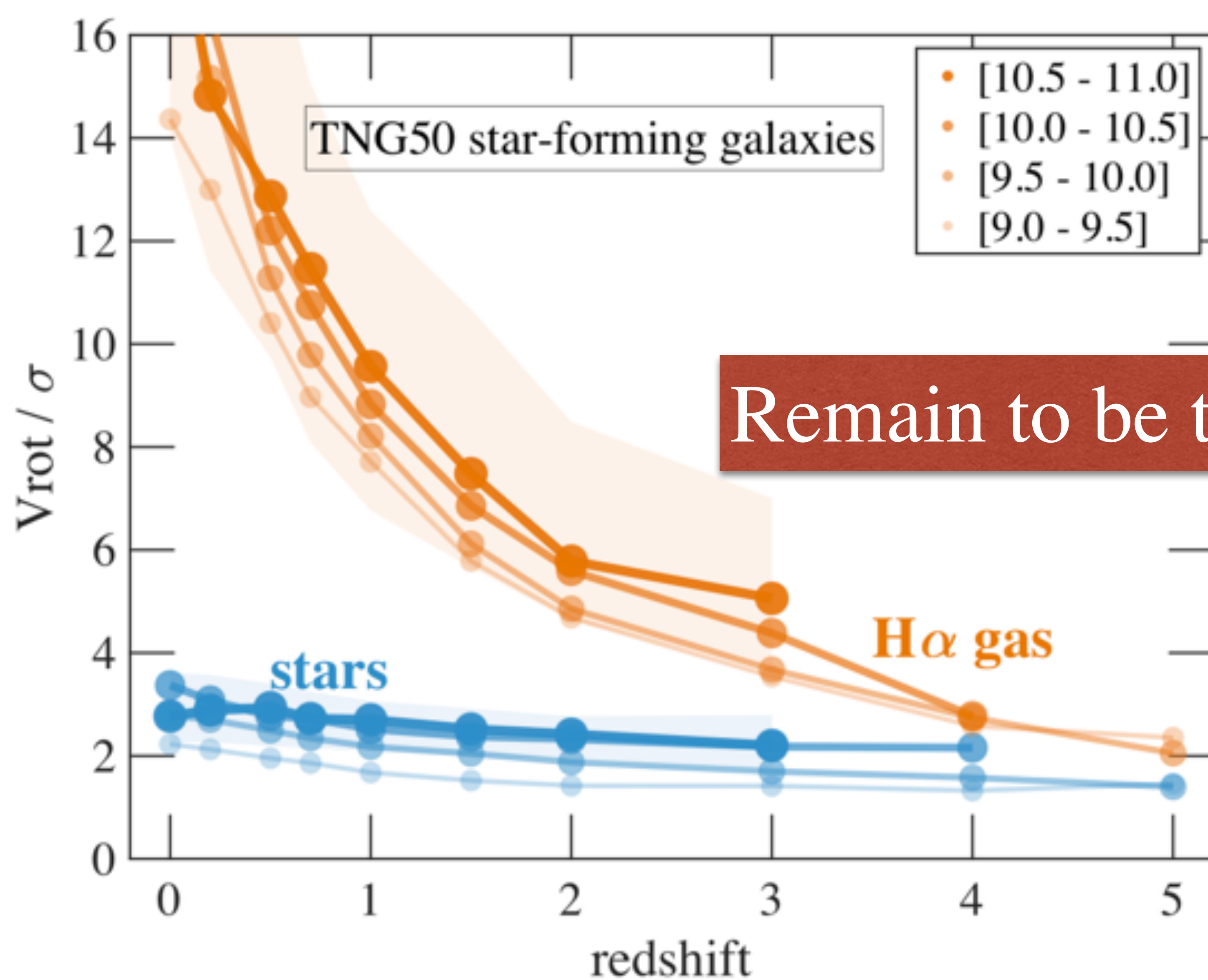



Velocity dispersion increases with galaxy stellar mass.

# Cosmological evolution of galaxy kinematics

Generally speaking, spiral galaxies are dominated by ordered motions (rotation), while elliptical galaxies are dominated by random motions (velocity dispersion).
To quantify the relative contribution of galaxy rotation and velocity dispersion, astronomers usually use the ratio of rotational velocity (Vrot) divided by velocity dispersion(σ), i.e. **Vrot/σ**.
An unknown: How do galaxy kinematics evolve across cosmic times?

## State-of-art Simulations show

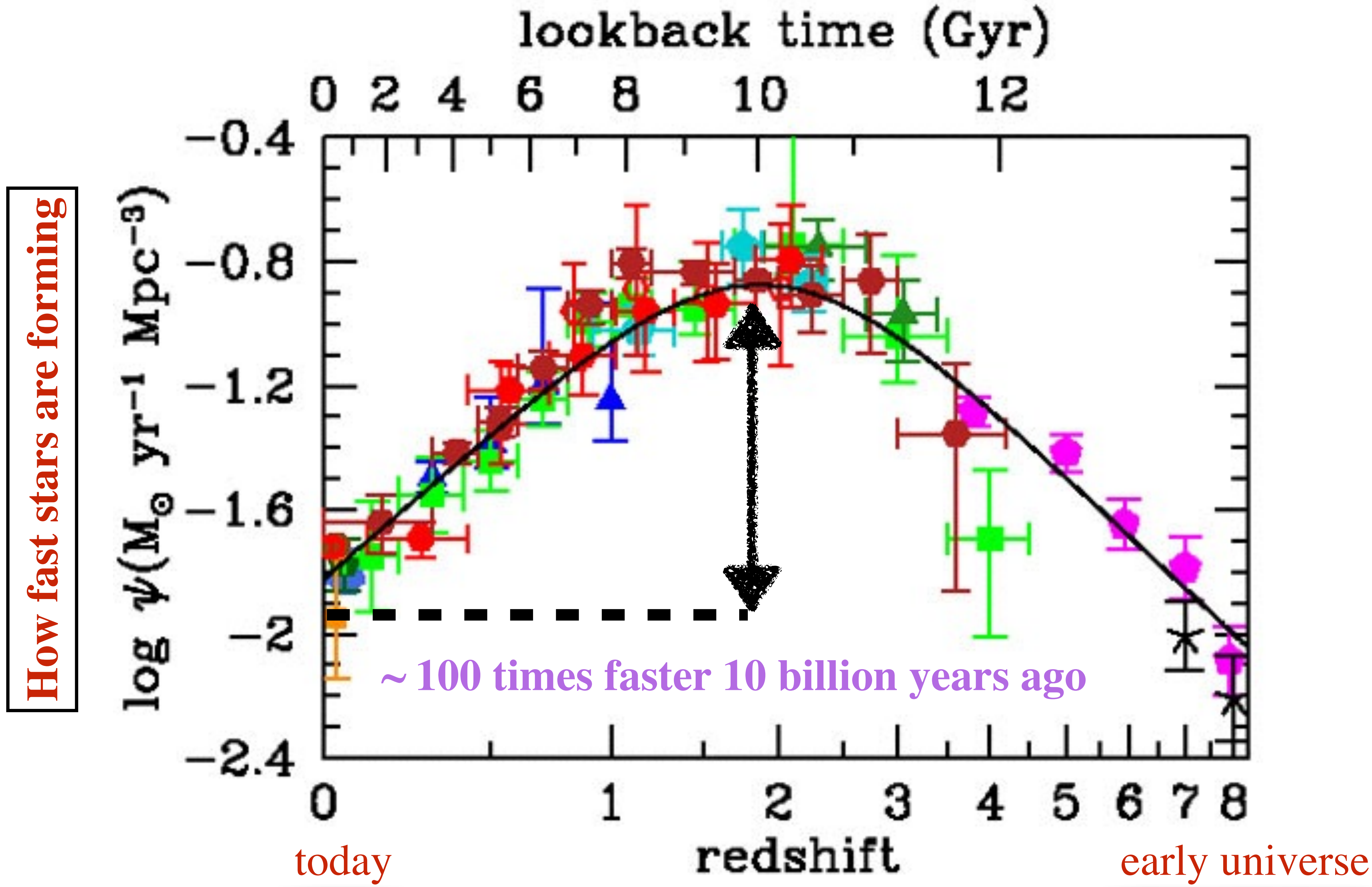



Remain to be tested by observations!

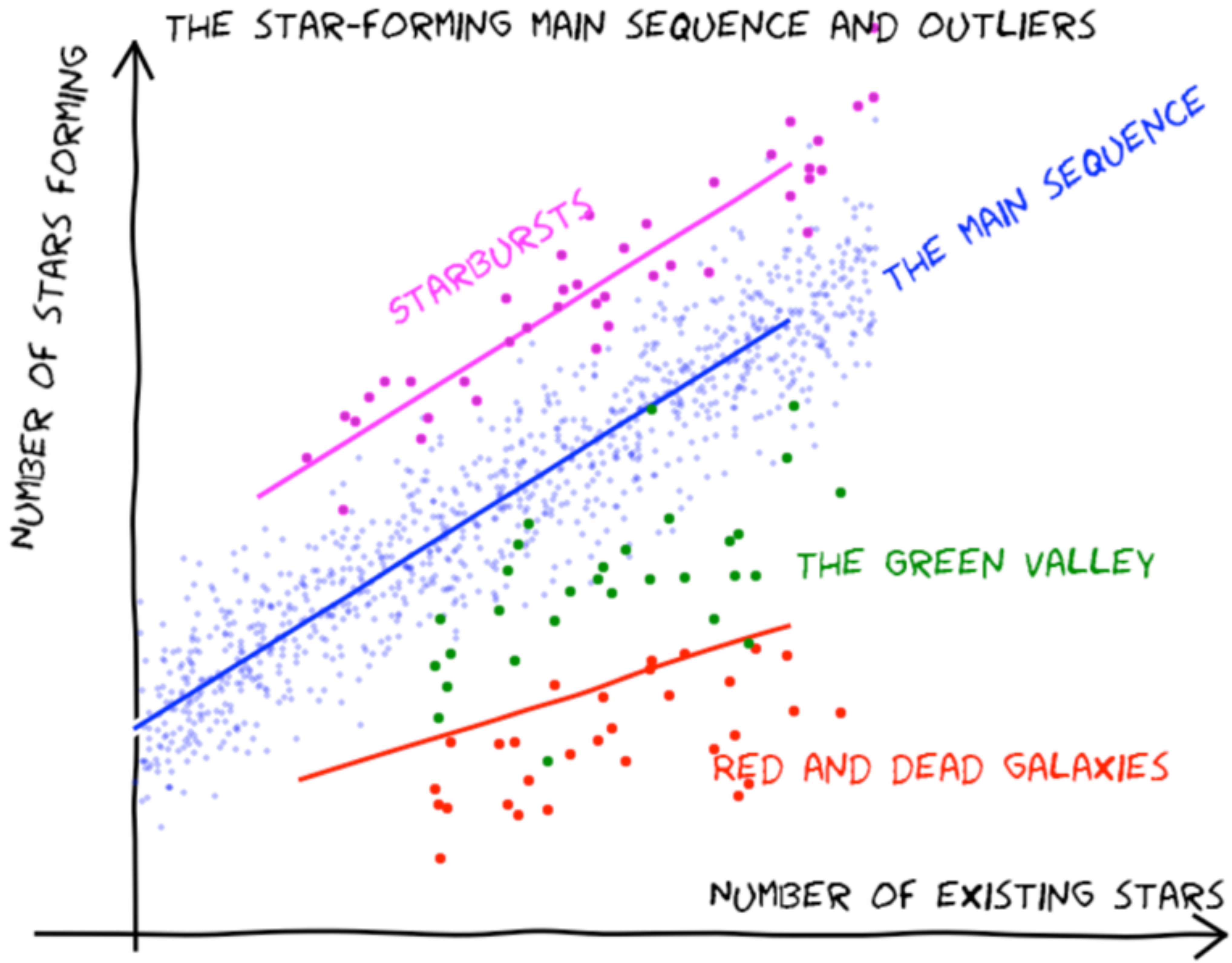
# Galaxy Star Formation Properties

Let's start by looking at averaged star formation properties of the Universe across cosmic times

**Cosmic star formation history**



Let’s now look at star formation properties in more details at different epochs (redshifts) of the Universe




Credit:https://people.lam.fr/buat.veronique/Veronique/Teaching_files/Lecture4.pdf

# Star forming main sequence