The Components of a Spiral Galaxy-a Bit of a Review- See MBW chap 11

Disks: we have discussed this in the context of the Milky Way

Rotationally supported, lots of gas, dust, star formation occurs in disks, spiral arms

Origin in CDM models (sec 11.2) : disk galaxies form in halos with high angular momentum and quiet recent assembly history, ellipticals are the slowly-rotating remnants of repeated merging events. Disks, form out of gas that flows in with similar angular momentum to that of earlier-accreted material

Bulges:

- somewhat spheroidal featureless (no spiral arms, bars, rings etc) that stick out of the disk plane,
- mostly old stars (not much dust or star-forming regions),
- kinematically hot, i.e. dynamically supported by the velocity dispersion of their stars- but they do rotate more significantly than ellipticals

  Origin (sec 11.5)
- thought to form via mergers (i.e. accretion of usually smaller external units)- disks reform later after merger by accretion of gas.

- Major Review: A very dense article

  Dawes Review 4: Spiral Structures in Disc Galaxies; C. Dobbs and J Baba arxiv 1407.5062

- While they overstate it a bit they say

'The majority of astrophysics involves the study of spiral galaxies, and stars and planets within them, but how spiral arms in galaxies form and evolve is still a fundamental problem. Major progress in this field was made primarily in the 1960s, and early 1970s, but since then there has been no comprehensive update on the state of the field.'

Major Workshop -The 2016 STScI Spring Symposium convened experts in state-of-the-art observational programs and theoretical simulations to address the question: ***What physical processes shape galaxies?***"

- "In the twenty years since the original Hubble Deep Field, striking advances in both ground- and space-based observational surveys and theoretical simulations have revealed the complex evolution of galaxies over much of the history of the universe.
- Subsequent generations of surveys have recorded the rise of spheroidal galaxies and the decline of disks and mergers, and young star-forming galaxies just the first billion years.
- New slit and IFU spectroscopy capabilities from the ground have demonstrated the key interplay between galaxy kinematics and their morphological structures, and new facilities at long wavelengths are providing improved tools for studying the kinematics and structures of the gas and dust content of galaxies.
- At the same time, theoretical studies have had remarkable success reproducing many characteristics—e.g., star formation histories, structural morphologies, and distribution functions—of the galaxy population over local and distant cosmological volumes.

- A simple reminder...

From Chaisson

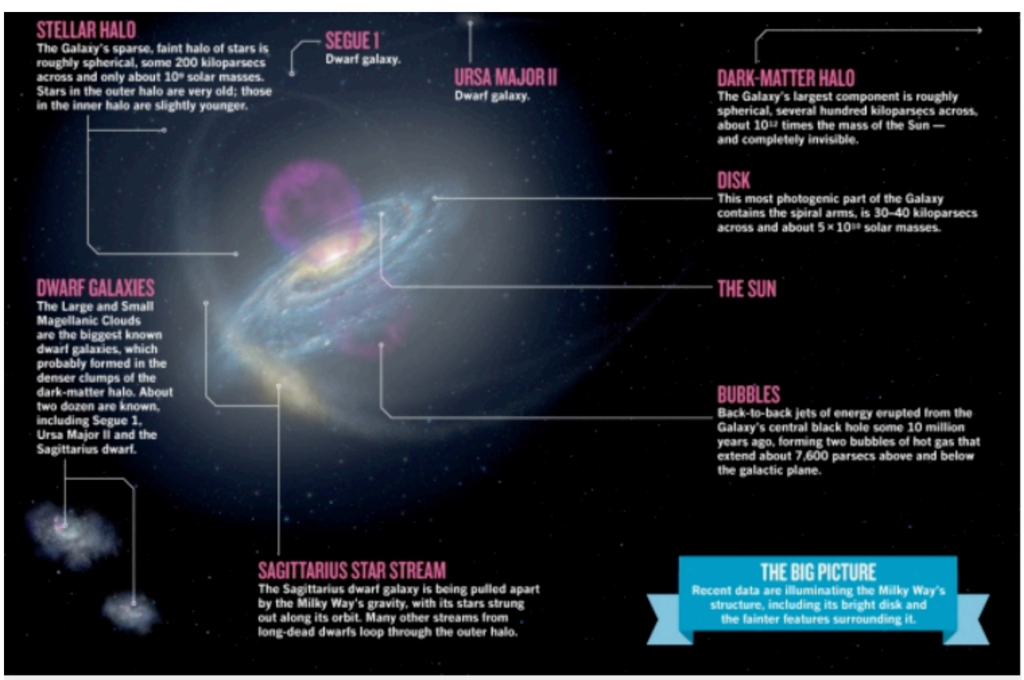
TABLE 23.1 Overall Properties of the Galactic Disk, Halo, and Bulge

GALACTIC DISK	GALACTIC HALO	GALACTIC BULGE
Highly flattened	Roughly spherical—mildly flattened	Somewhat flattened and elongated in the plane of the disk ("football shaped")
Contains both young and old stars	Contains old stars only	Contains both young and old stars; more old stars at greater distances from the center
Contains gas and dust	Contains no gas and dust	Contains gas and dust, especially in the inner regions
Site of ongoing star formation	No star formation during the last 10 billion years	Ongoing star formation in the inner regions
Gas and stars move in circular orbits in the Galactic plane	Stars have random orbits in three dimensions	Stars have largely random orbits but with some net rotation about the Galactic center
Spiral arms	No obvious substructure	Ring of gas and dust near center; Galactic nucleus

Top Level Summary-Spirals

- Galaxies have a wide variety of morphologies, from spheroids , disks with and without bars and irregular galaxies.
- Their physical properties (e.g. gas content, average stellar age, the rate of current star formation, mass etc) correlate with morphology.
- disks are predominantly rotationally flattened structures
- spheroids have shapes largely supported by velocity dispersion.

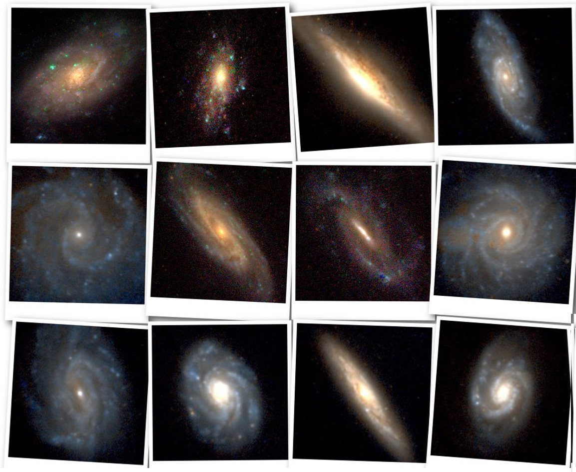
- Conventional theoretical 'wisdom' : disks form at the center of dark matter halos as a consequence of angular momentum conservation during the dissipational collapse of gas (Fall & Efstathiou 1980) , spheroids result predominantly from merger events
- Thus morphology is a transient feature of the hierarchical formation of a galaxy:
  - a disk galaxy may be transformed into a spheroidal one after a major merger, but could then re-form a disk through further gas accretion only to be later disrupted again by another merger



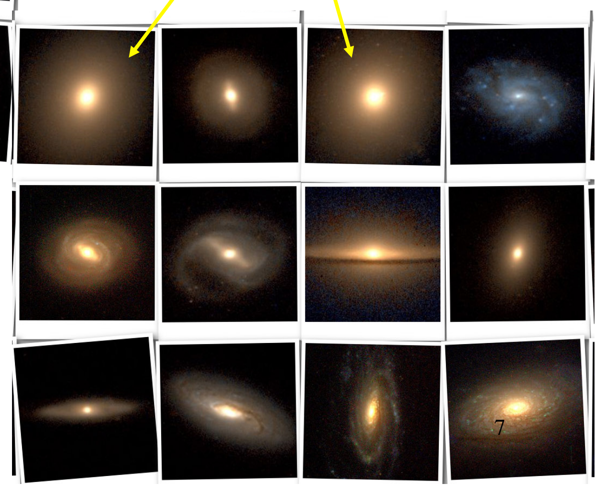
- http://www.nature.com/news/galaxy-formation-the-new-milky-way-1.11517

A Bit of the Galaxy Zoo

Mostly disk…



Mostly spheroid…



- Disk-bulge separation is tricky and influenced by inclination angle and dust and wavelength observed (disks standout in the blue, bulges in the red)

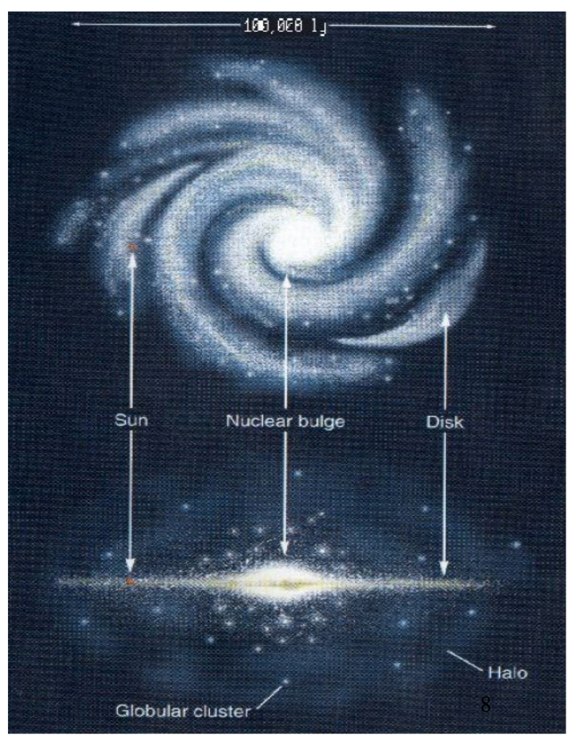
Spirals

- Composed of 3 components
  - disk
  - bulge
  - halo
- Bulge-oldish stars-tends to be metal poor
- Disk - young stars

  The disk contains a large quantity of gas & dust, the bulge essentially none

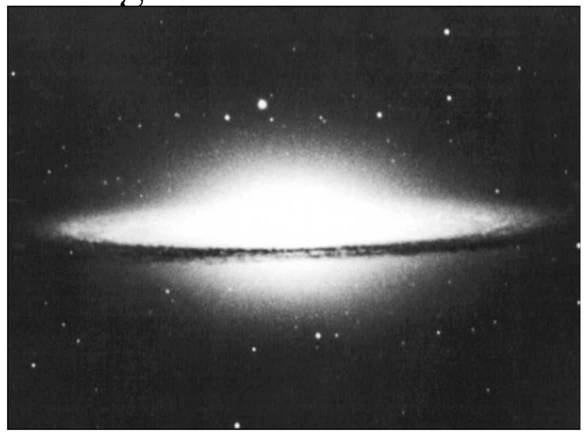
  Disks are cold (rotationally supported)

  Bulges are 'hot' supported by random motions
- The rotation curves of spiral galaxies rise like a solid body in the central regions, then flattens out (i.e., v(r) = constant). This flattening is due to the presence of a **dark matter halo**.



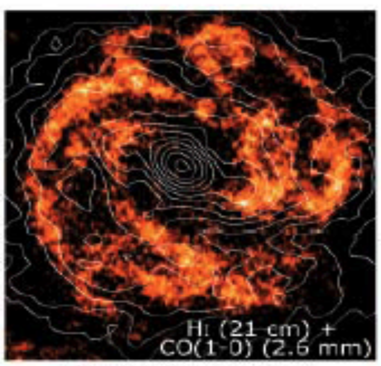
Physical Difference Between Bulges and Disks

- Spiral galaxies
  - the stars in the disk have lots of angular momentum and a wide variety of ages.
  - stars in the bulge tend to be old, have little angular momentum and have low metallicity*
    - (globular clusters may be part of this population)
- Disks are rotationally supported (dynamically cold)
- Bulges are dispersion supported (dynamically hot)

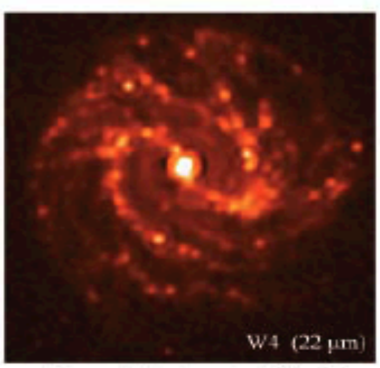


•* while superficially elliptical galaxies 'look like' bulges their stars are frequently metal rich, not metal poor.

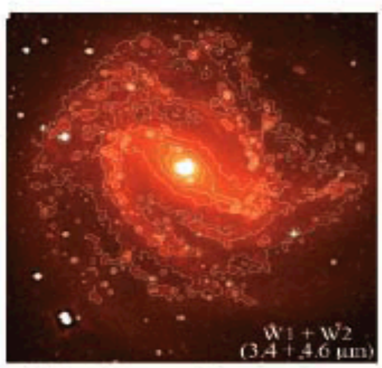
M 83: from Gas to Stars



Neutral gas is the *reservoir*, molecular gas fuels the star formation

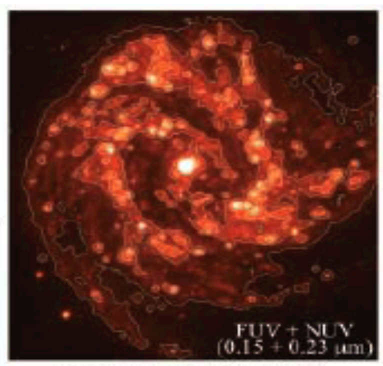


Very small dust grains efficiently reprocess energy from star formation

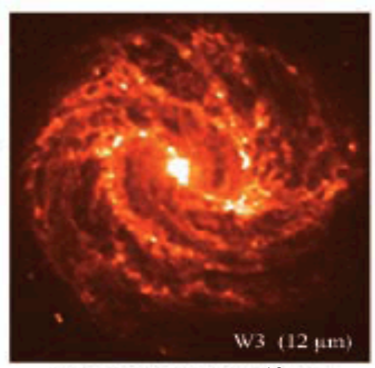


Evolved star population constitutes the *Stellar Backbone*

Spiral galaxies are panchromatic objects- different physical process are best shown in different wavebands



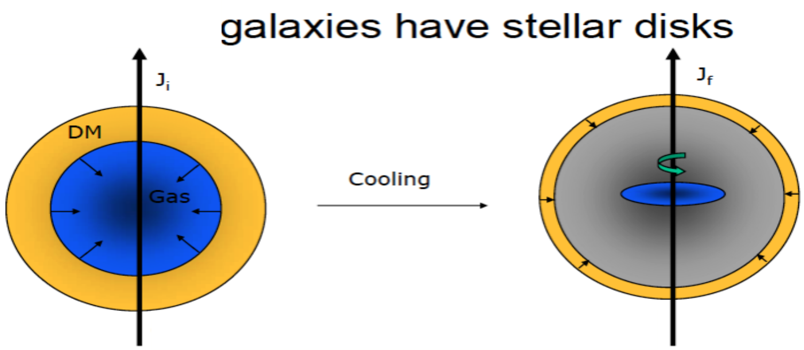
Young hot stars represent the current epoch of star formation



Excited PAH molecules due to *ISM heating* by hot stars

Simple Model of Why Galaxies Have Disks

- A circular orbit has the lowest energy for an initial angular momentum J- thus since angular momentum is conserved, if the in falling gas loses energy (cools) will tend to form a disk
- If stars form from dense gas they will also be in a disk.



Formation of Spiral Galaxy

Forming disks-The Bigger Picture

A natural way to form them is through the dissipational collapse of a gas cloud with some initial angular momentum.

- Consider a gas cloud for which radiative cooling is very effective
- The cloud will radiate away its binding energy and contract, causing it to approach a state in which its energy is as low as possible
- The cloud will conserve its angular momentum producing . a rotating disk, since in such a configuration the angular momenta of

  all mass elements point in the same direction.

In sec 11.4.2, the effects of angular-momentum transfer which depends on the effective viscosity of the disk material are shown to be important.

In the absence of viscosity or non-axisymmetric structure, each mass element of the cloud will conserve its own specific angular momentum, so that the end state is a disk with surface density directly related to the initial angular momentum distribution of the cloud.

Angular Momentum

- Consider stars on a circular radius (r_0): $v^2/r_0 \sim GM/r_0^2$

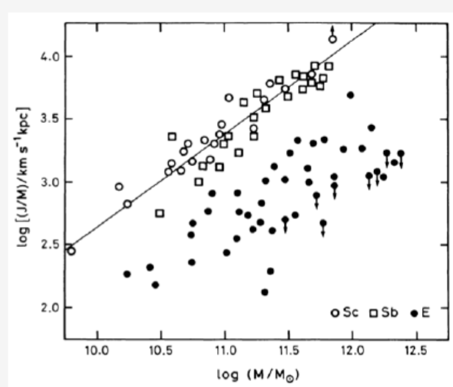
  or $\mathbf{v \sim (GM/r_0)^{1/2}}$
- Approximate angular momentum J

$J \sim Mvr_0 = r_0 GMr_0)^{1/2} \sim K(GM^3 r_0)^{1/2}$

- where K depends on the distribution of matter, for a rotating exponential disk K~1.109 (Freeman 1970)
- Disk structure is governed by angular momentum distribution

Specific Angular Momentum vs Mass

Fall 1983

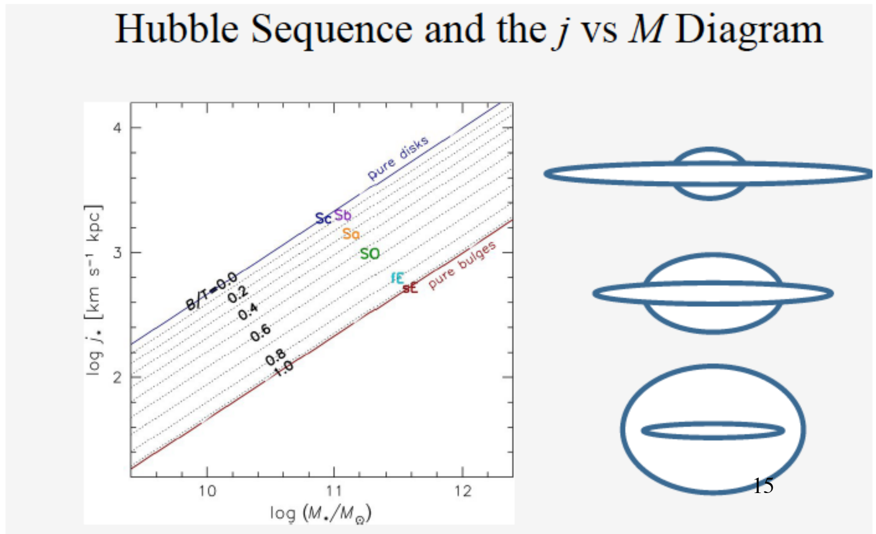


$j = J/M \ \alpha \ M^{\alpha}$ with $\alpha \approx 0.7$

S and E galaxies offset by ~6x

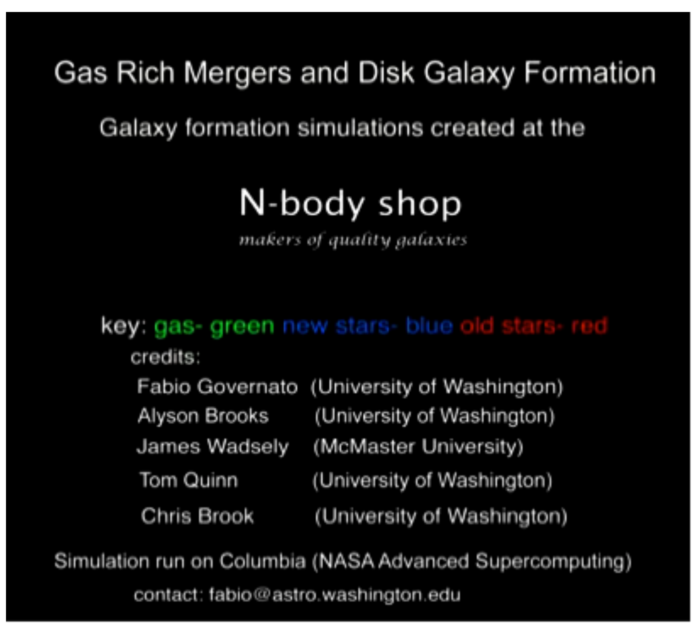
- The J vs M diagram is a physics-based alternative to the morphology-based Hubble sequence
- galaxies of intermediate types have intermediate j at each M.

M. Fall 2014



However In A Hierarchical Universe Things are More Complex

- Formation of a spiral galaxy



The Big Picture- Two Populations

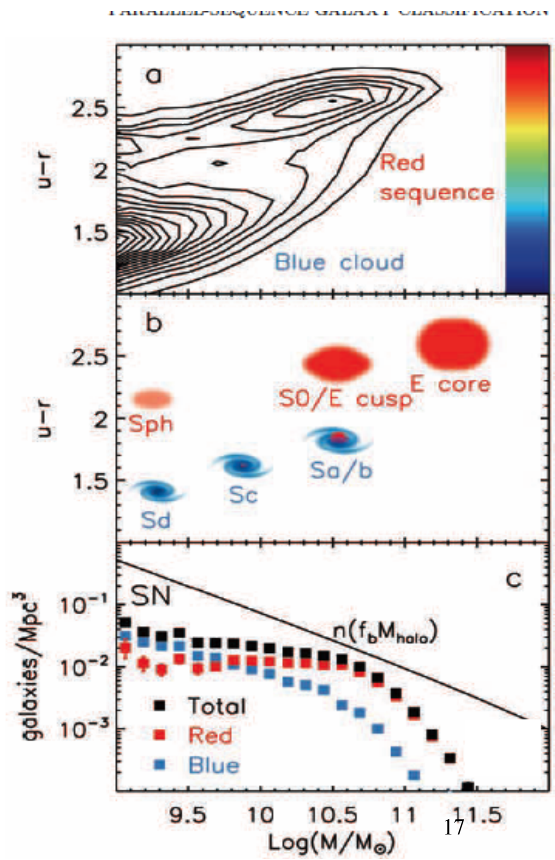
- top panel color distribution vs mass of a large sample of local galaxies from the SDSS

  Middle panel is the morphologies that dominate at each mass

  bottom panel shows the galaxy **mass function** divided by color- the **spirals are mostly blue** (some S0s are red) (Cattaneo et al 2009)-

  spirals tend to be less massive than ellipticals

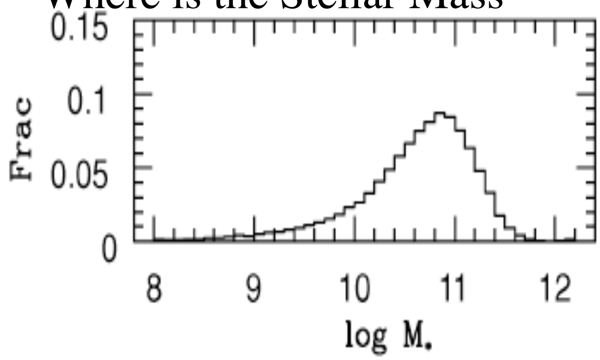
  the black solid line is the prediction from cold dark matter theory of the number density of halos vs mass- <u>notice does not agree with the galaxy mass distribution</u>

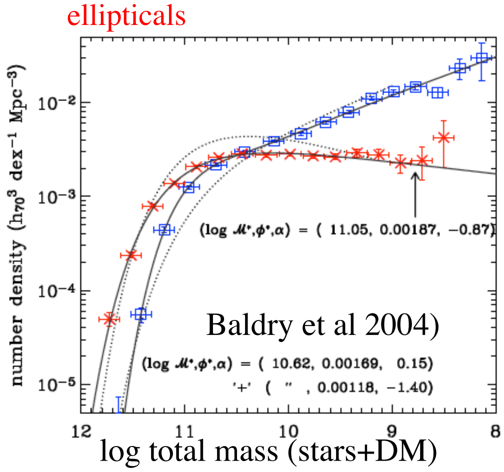


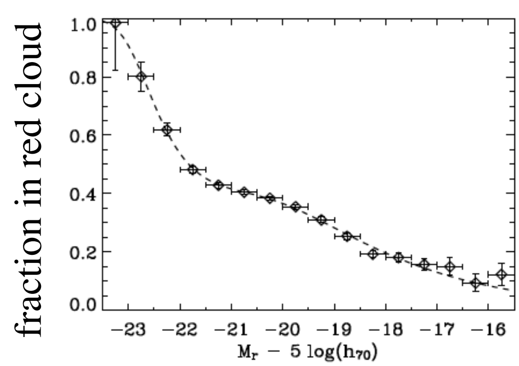
- The stellar mass **integrated over ALL galaxies** lies mostly between

  log $M_{\odot}$=10.5-11.4
- In what galaxies does the stellar mass lie?
  - most **massive** galaxies are red (ellipticals)
  - at lower masses there is an increasing ratio of **spirals** to ellipticals

Where is the Stellar Mass

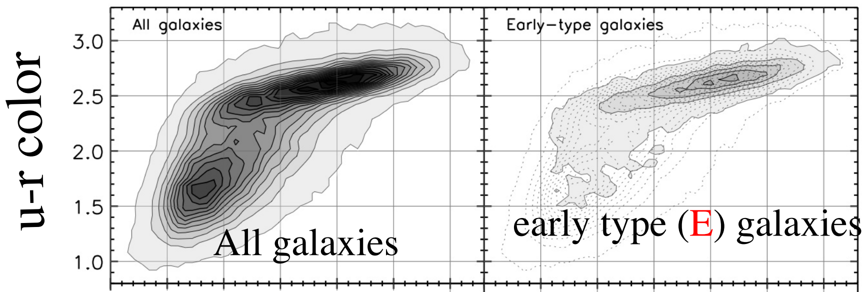






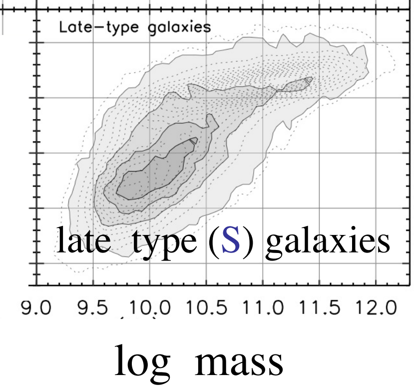
absolute mag

Morphology/ Color and Mass



A result of the 'Galaxy Zoo' project- eyeball classification of 10s of thousands of galaxies by citizen scientists Combination of <u>morphology</u>, mass and **color**

Spirals less massive, bluer at a given mass than ellipticals



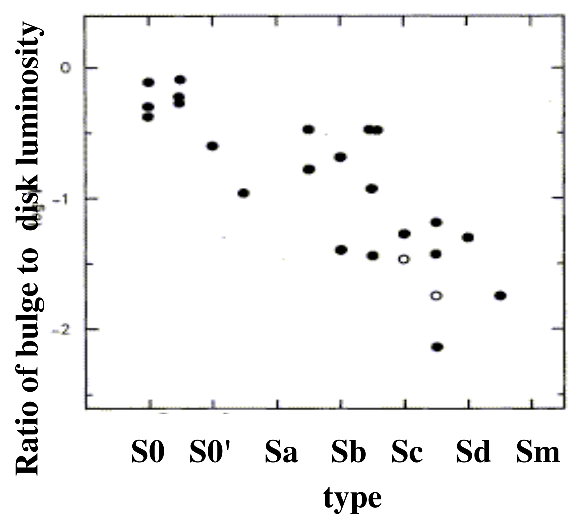
- **Strong relation of mass, color and morphology**

Schawinski 2010

Spirals

The Hubble type of a spiral correlates with

- bulge/disk luminosity ratio
- relative content of cool gas (H I)
- mass concentration
- stellar population (how many young/ old stars)
- nuclear properties-AGN
- chemical abundances in the ISM
- star formation history and integrated stellar spectrum
- bulges of spirals tend to have old stars, disks younger stars
- *A lot of the detail depends on what wavelength one observes in (e.g. the UV favors hot young stars, the IR dust, x-rays hot gas and binaries)*



color vs morphological type