Astr 102: Introduction to Astronomy

Fall Quarter 2009, University of Washington, Željko Ivezić

Lecture 4:

Introduction to Galaxies

Outline

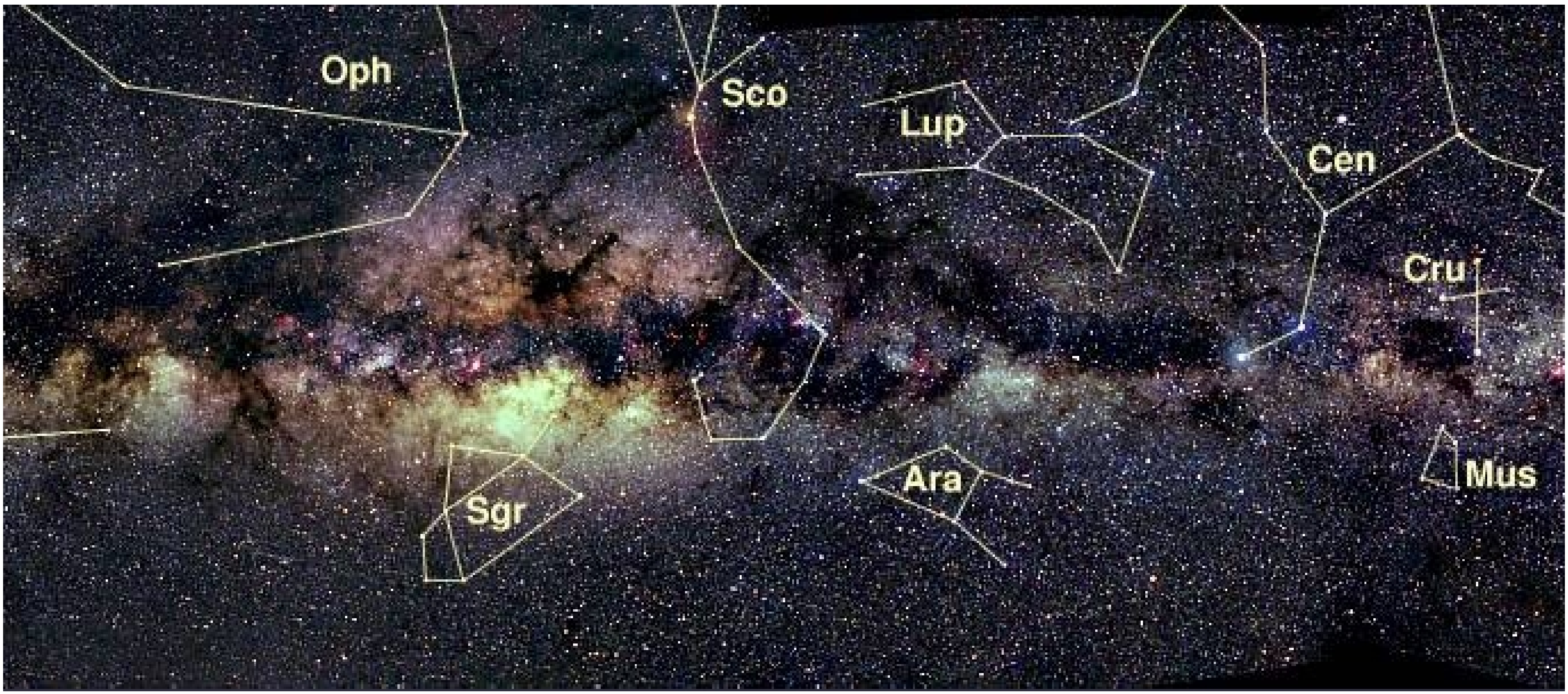
- A Little Bit of History
- Galaxy Types and Classification
- Galaxy Properties

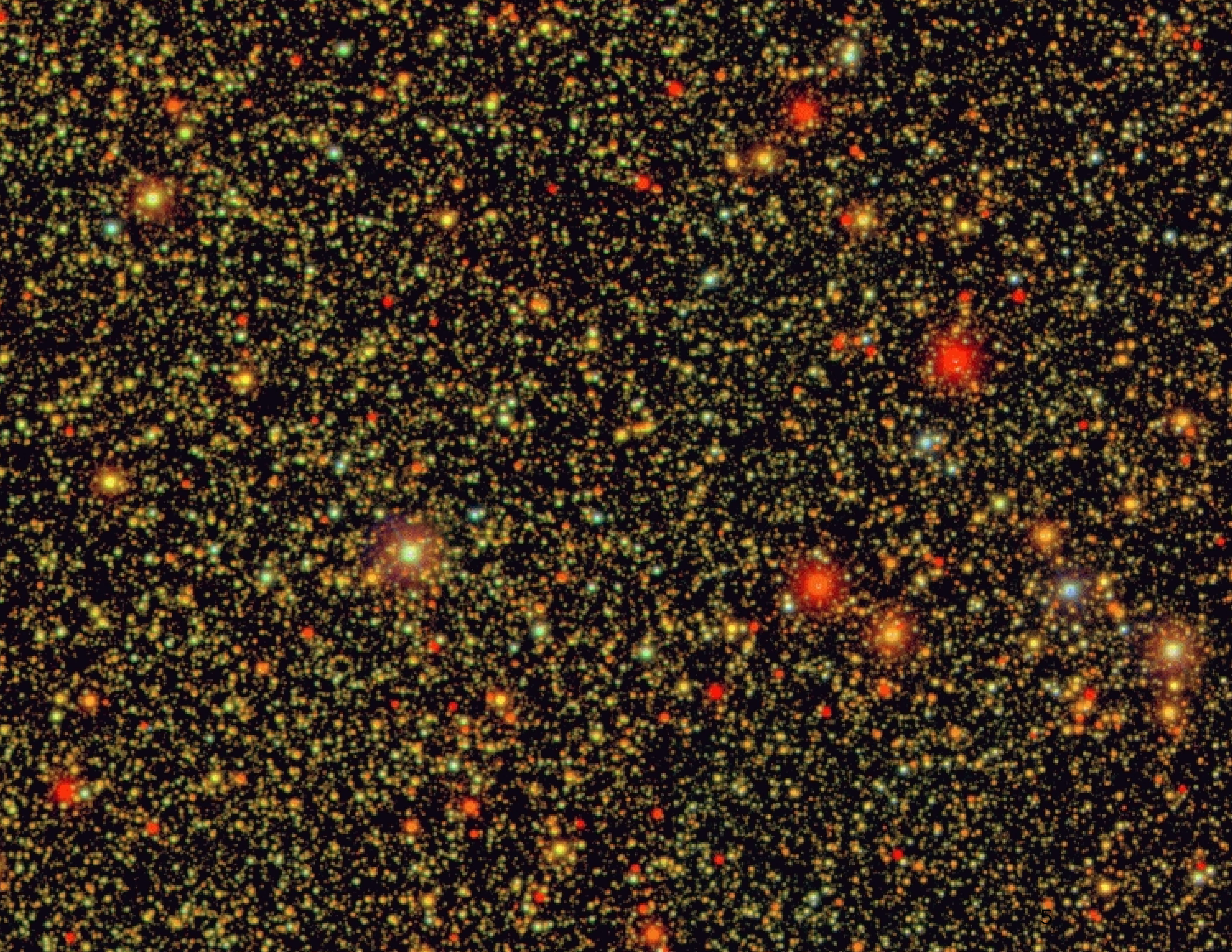
Good sites: http://www.seds.org/messier/galaxy.html

http://www.damtp.cam.ac.uk/user/gr/public/gal_home.html

Most important historical breakthroughs in galaxy research

- Around 1610: Galileo Galilei resolves the Milky Way into individual stars





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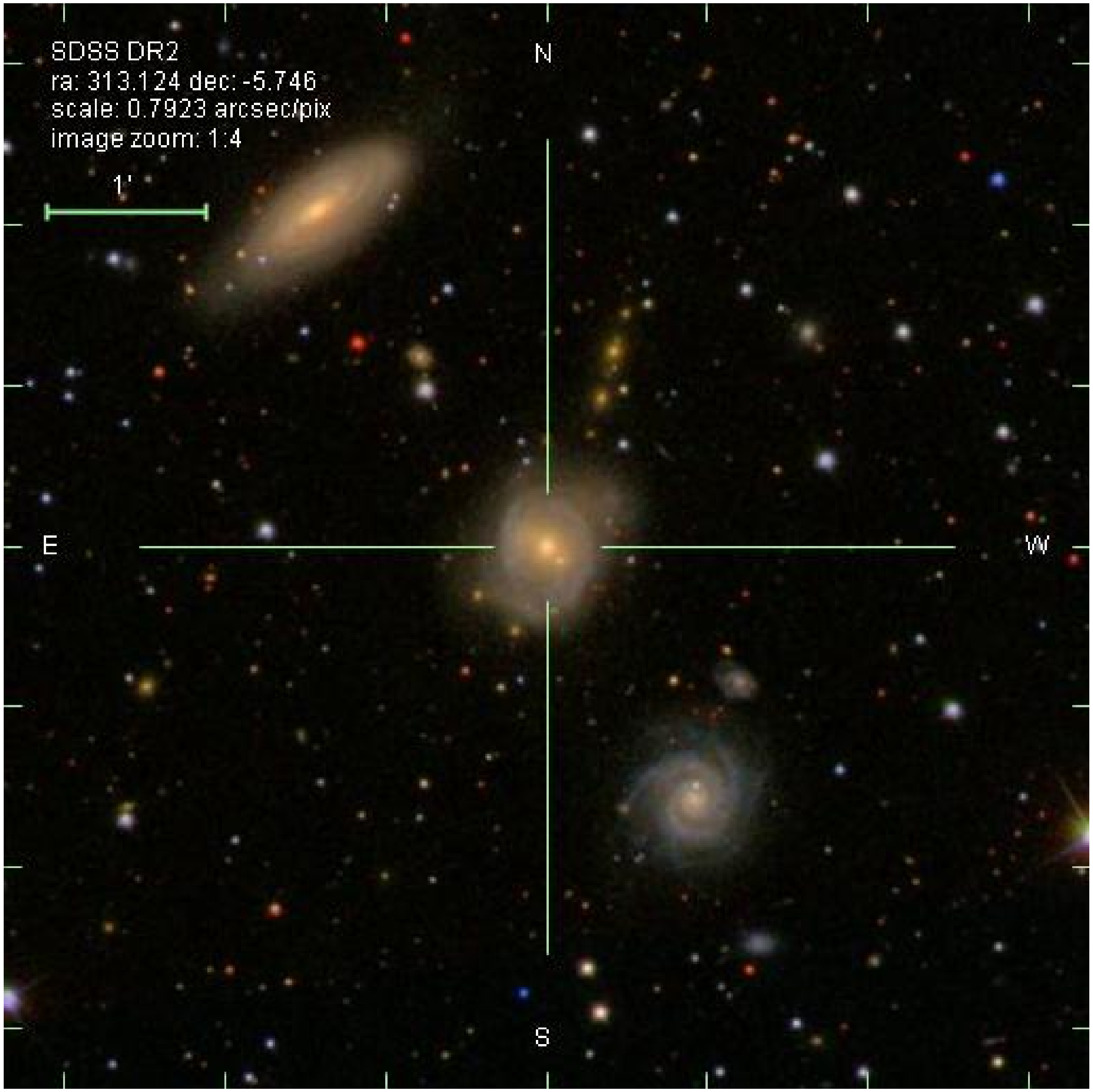
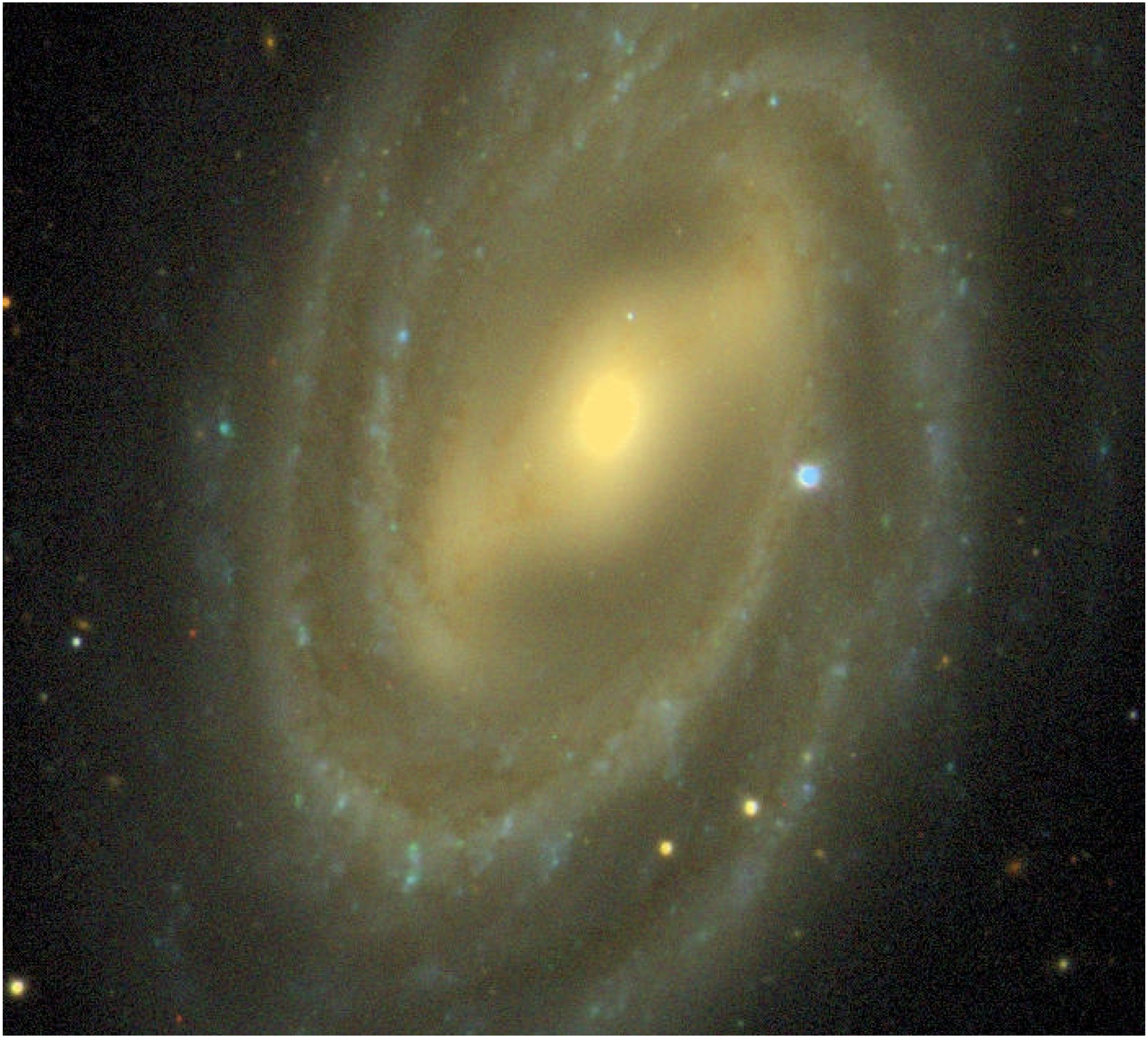
- Around 1850: William Parsons discovers spiral structure and proposes that some galaxies rotate

Lord Rosse in 1845 “discovered” spiral structure in M51 (this is an HST image of M51)



Not all spirals are alike!



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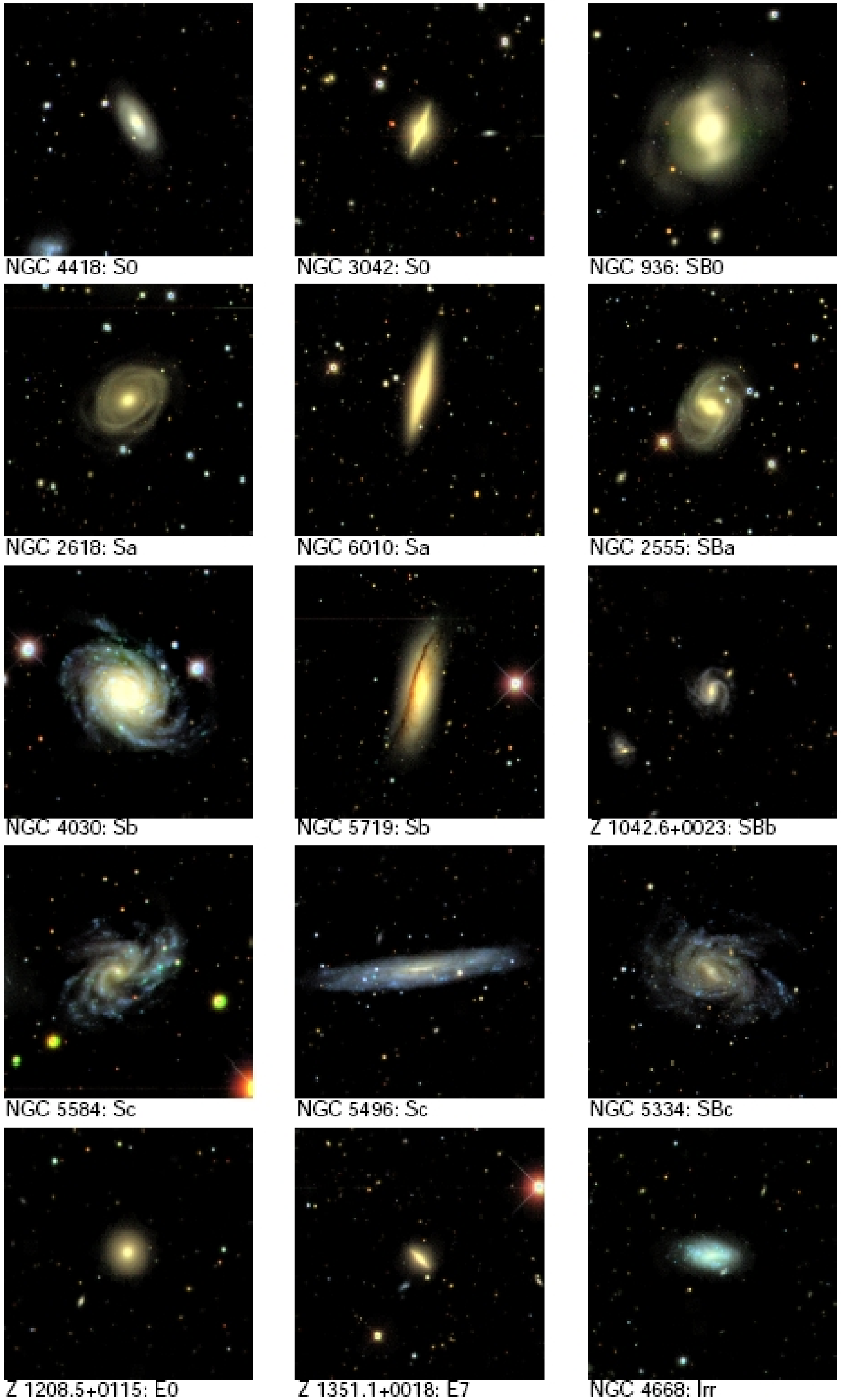
- Around 1850: William Parsons discovers spiral structure and proposes that some galaxies rotate
- 1923/24: Edwin Hubble resolves M31 and M33 into individual stars – confirms that they are galaxies just like our own
- 1929: Edwin Hubble discoveres the expansion of the Universe

- 1933: Fritz Zwicky claims the existence of "dark matter" based on observed speeds of cluster galaxies (*nobody believes him!* – for a rap song about this see astro-ph/9610003)

- 1970-1980: Vera Rubin's work on rotation curves of spiral galaxies – dark matter idea becomes widely accepted

Hubble's Classification of Galaxies

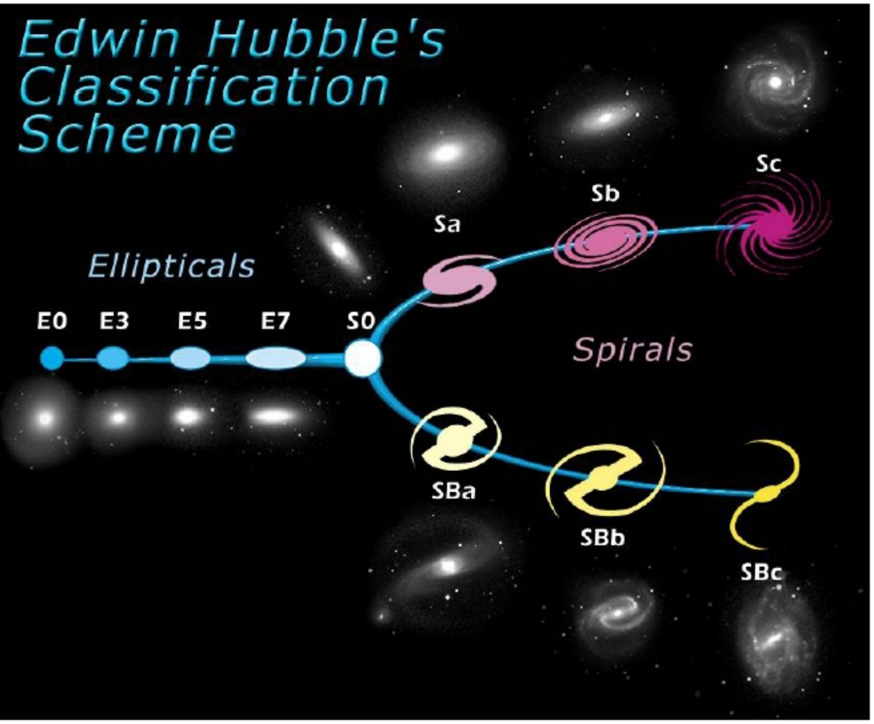


5 arcmin x 5 arcmin true-color g-r-i images from SDSS comissioning data.
Galaxy classification is from SIMBAD.

Galaxies

- Galaxies are (mostly) made of stars (also gas, dust, active galactic nuclei – AGN); hence have similar (but not identical!) color distributions
- They come in various shapes and forms (spiral vs. ellipticals; aka exponential vs. de Vaucouleurs profiles)
- Some host AGNs, some have high star-formation rates, some are very unusual (dwarf galaxies, mergers, etc.)
- We are interested in various distribution functions (e.g. for luminosity, colors, mass, age, metallicity, size, etc.) – the hope is to figure out how galaxies formed and evolved
- Nearest neighbors: the Andromeda galaxy (M31, in front of elevator!), Large and Small Magellanic Clouds, the Sgr Dwarf (may be more)

Hubble's Morphological Classification



- Broadly, galaxies can be divided into ellipticals, spirals, and irregulars
- Broadly, spirals are divided into normal and barred (similar frequencies): S and SB
- The subclassification (a, b, or c) refers both to the size of the nucleus and the tightness of the spiral arms. For example, the nucleus of an Sc galaxy is smaller than in an Sa galaxy, and the arms of the Sc are wrapped more loosely.
- The number and how tightly the spiral arms are wound are well correlated with other, large scale properties of the galaxies, such as the luminosity of the bulge relative to the disk and the amount of gas in the galaxy. This suggests that there are global physical processes involved in spiral arms.

- Primary classification criteria of commonly used Hubble-Sandage system:
  - Bulge-to-disk ratio (S0/Sa: 5 to 0.3, Sb: 1 to 0.1, Sc/Irr: 0.2 to 0)
  - Opening angle of spiral arms (Sa: 0 to 10, Sb: 5 to 20, Sc: 10 to 30 degrees)
  - Bars

- Physical parameters varying along the Hubble-Sandage system:
  - Stellar mass M increases from irregulars ($10^8 M_\odot$) to ellipticals ($10^{12} M_\odot$)
  - Specific Angular Momentum J/M of baryons increases from ellipticals to spirals
  - Mean age increases from irregulars through spirals to ellipticals (B-V increases from 0.3 to 1.0, mass-to-light M/L_B ratio increases from about 2 to 10)
  - Mean stellar density of spheroids increases with decreasing spheroid luminosity
  - Mean surface brightness of disks increases with luminosity
  - cold gas content increases along Hubble sequence (fraction of baryonic mass: 0 in E/S0, 0.1 to 0.3 in Sa to Sc, up to 0.9 in Irr)
  - hot gas content only significant in massive E (few percent of baryonic mass)

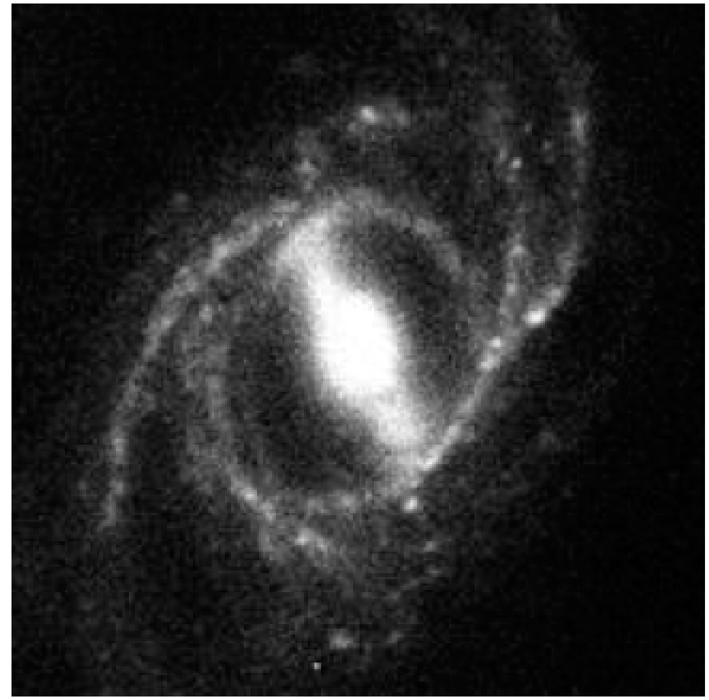
Spiral (Sa) Galaxies:

NGC 3223: Sa-galaxy

M 104 (Sombrero), Sa-galaxy
(P.Barthel, VLT)

Barred-Spiral (SBb) Galaxies:

M 95: SBb-galaxy



NGC 2523: SBb-galaxy

Irregular (Irr) Galaxies:

LMC: Irr-galaxy

SMC: Irr-galaxy

What galaxy characteristics can we measure?

- **Flux:** can be done at different wavelengths, leads to **colors** (determined by flux ratios; "spiral galaxies are blue, elliptical galaxies are red")

- **Luminosity:** when distance is known, together with flux gives luminosity (related to absolute magnitude, usually called M)

- **Size:** angular, and when distance is known, true (linear) size

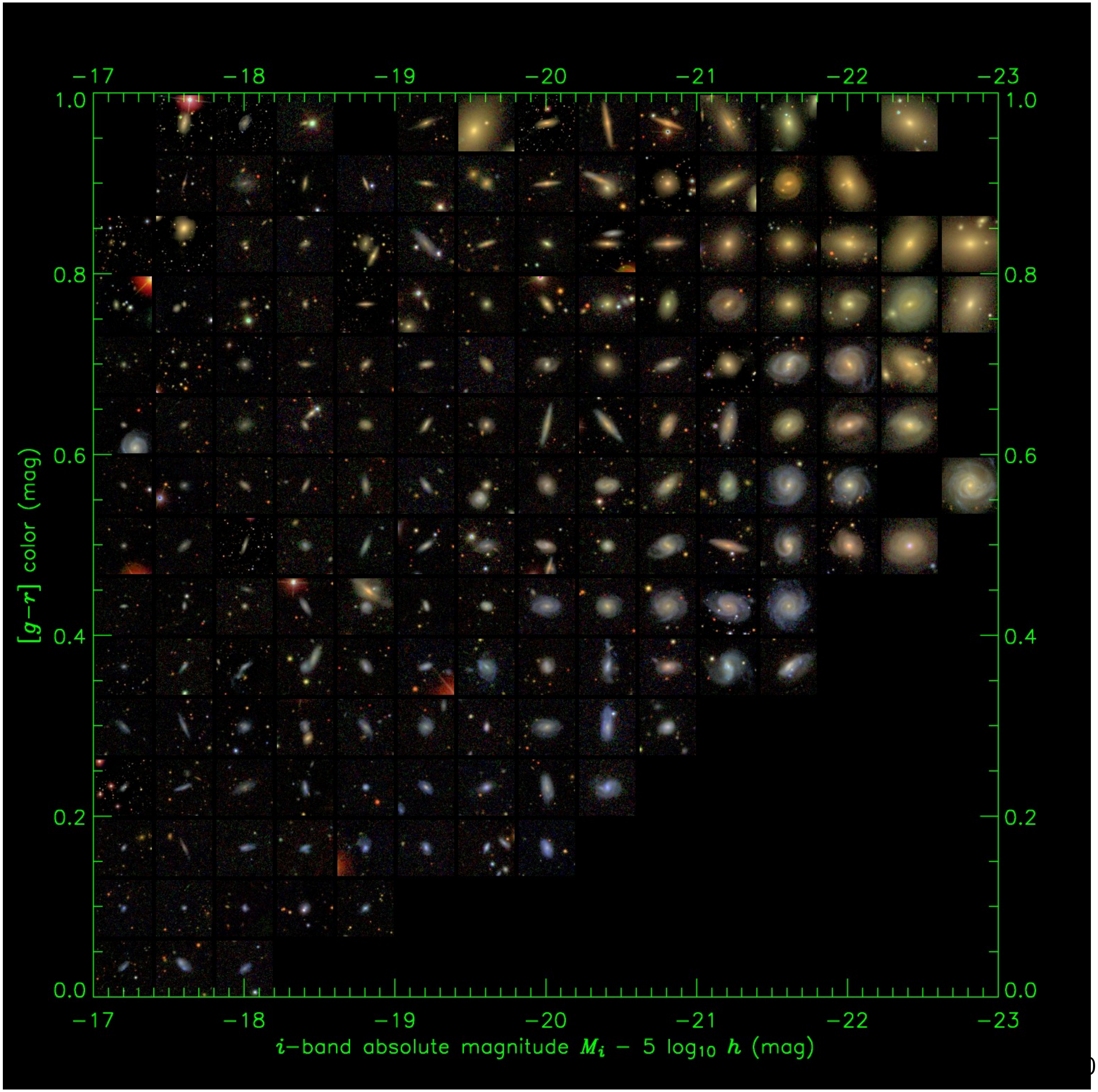
- **Shape of surface brightness profile:** varies with galaxy type, but fairly constant for a give galaxy type

- **Normalization of the surface brightness profile:** fairly constant for a given galaxy type, smaller spread than luminosity implies that the luminosity variation is mostly driven by variation in linear size

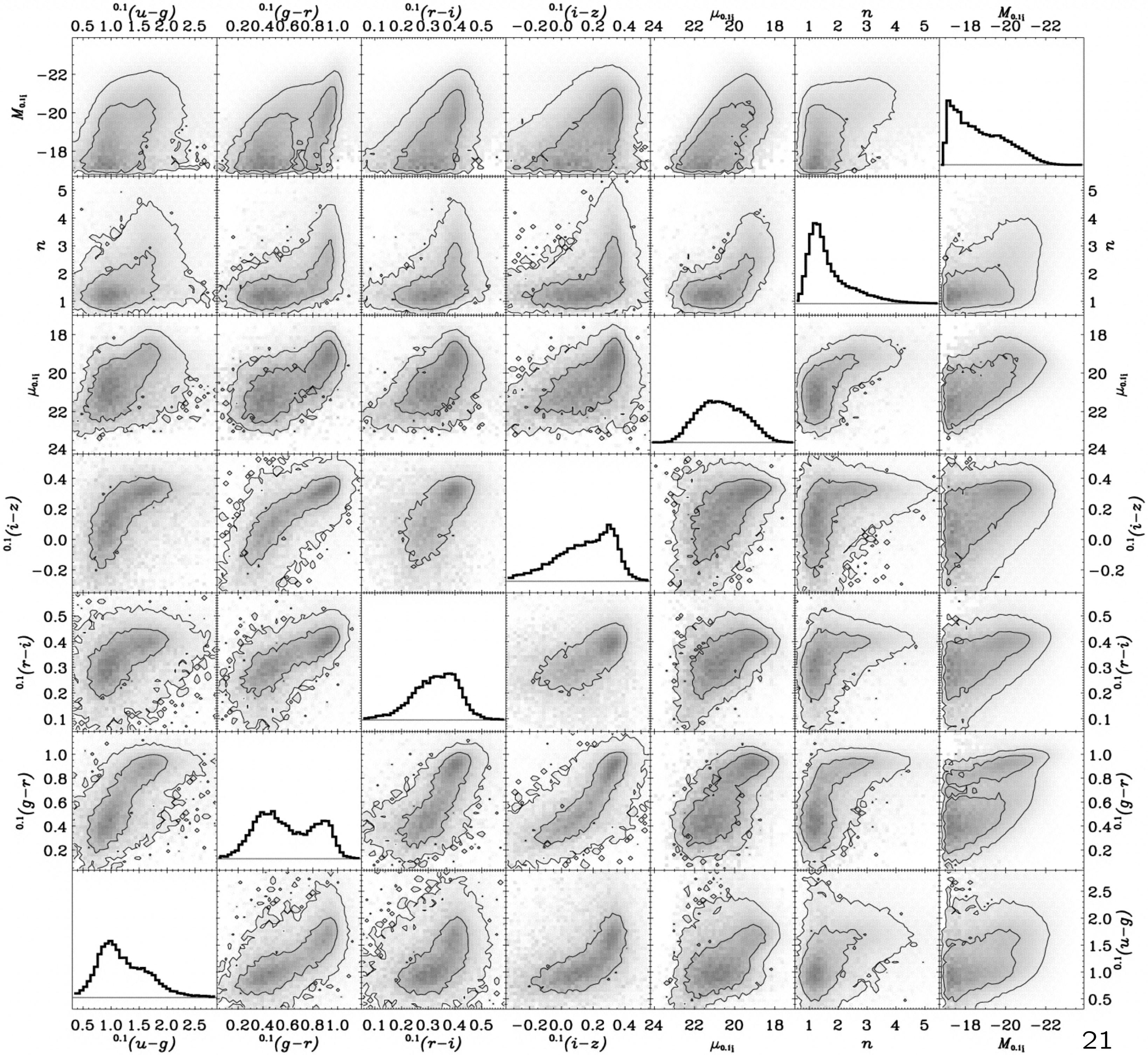
- **Kinematic quantities:** recession velocity (redshift), rotation velocity, velocity dispersion (must obtain spectra!)

- **Multi-wavelength observations:** by observing at wavelengths other than optical, can study dust, molecular gas, non-thermal radiation, derive star-formation rate, etc.

Next two plots: a summary of results for about a million galaxies from SDSS.

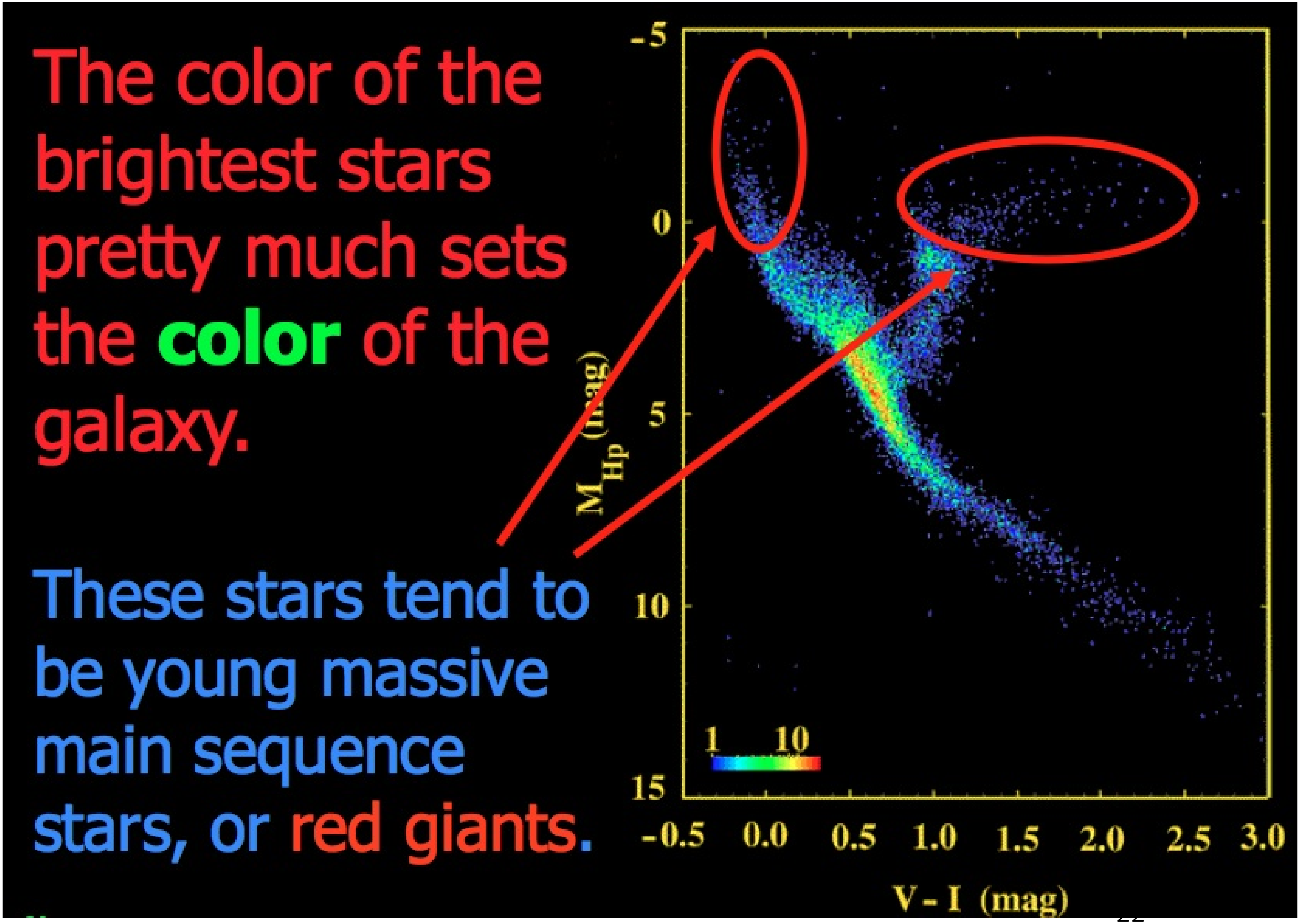


−17
−18
−19
−20
−21
−22
−23
1.0
0.8
0.6
0.4
0.2
0.0
[g−r] color (mag)
i−band absolute magnitude M_i − 5 $\log_{10}$ h (mag)



$^{0.1}(u-g)$
$^{0.1}(g-r)$
$^{0.1}(r-i)$
$^{0.1}(i-z)$
$\mu_{0.1i}$
n
$M_{0.1i}$

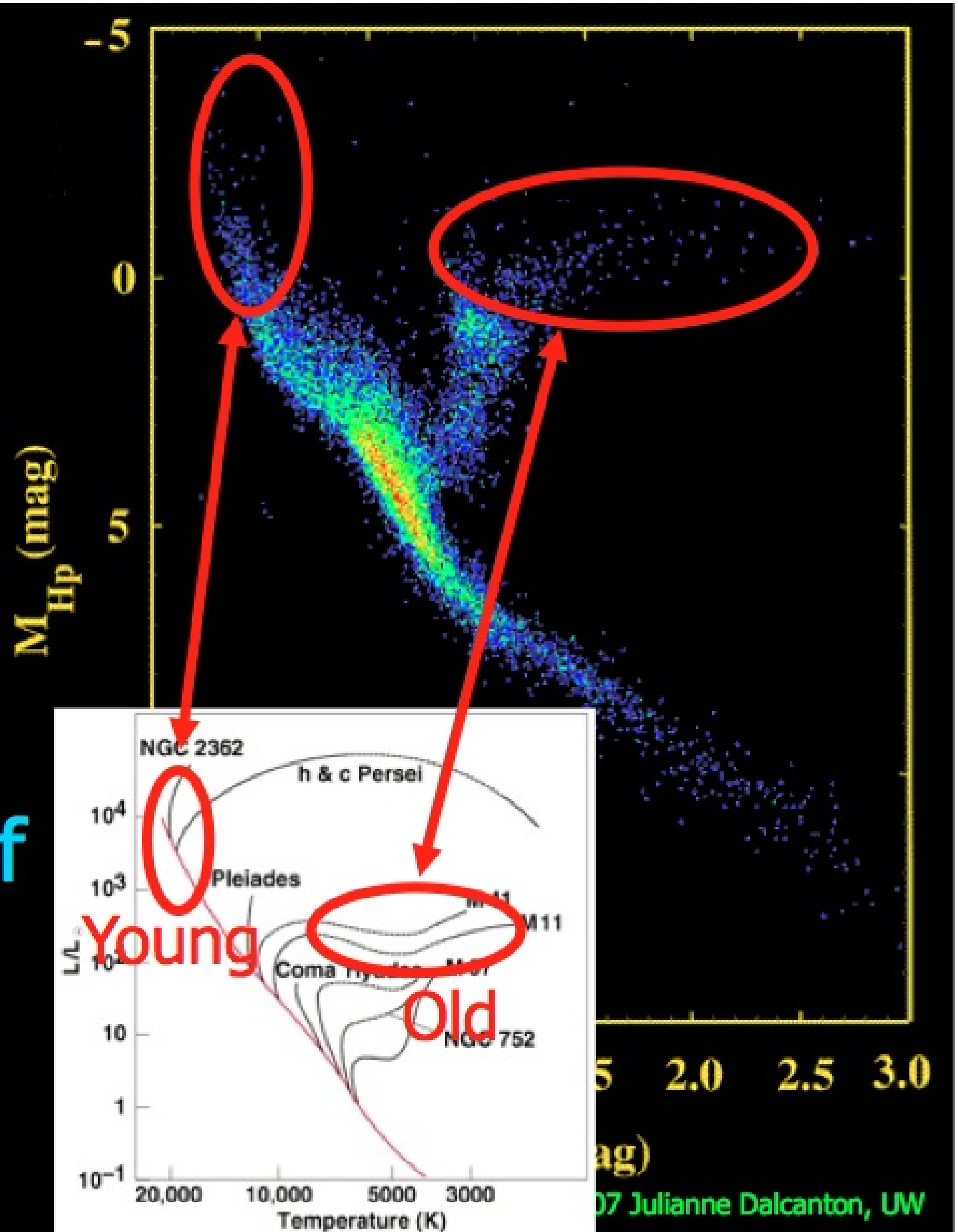
Why do galaxies have different colors?



Stars in galaxies have a range of ages!

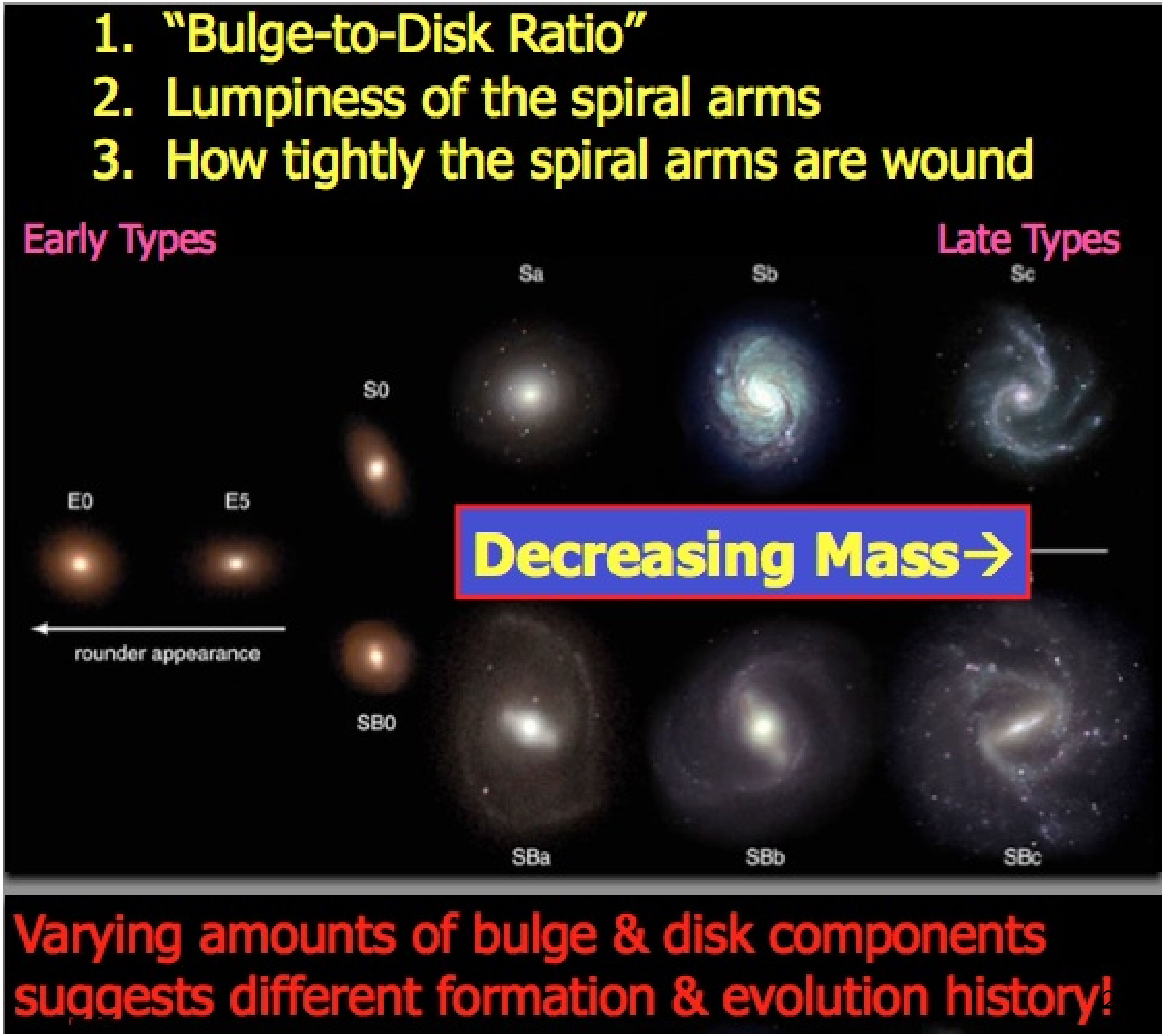
Galaxies have more complex stellar populations than single clusters.

They have a mix of stars formed at different times.



07 Julianne Dalcanton, UW

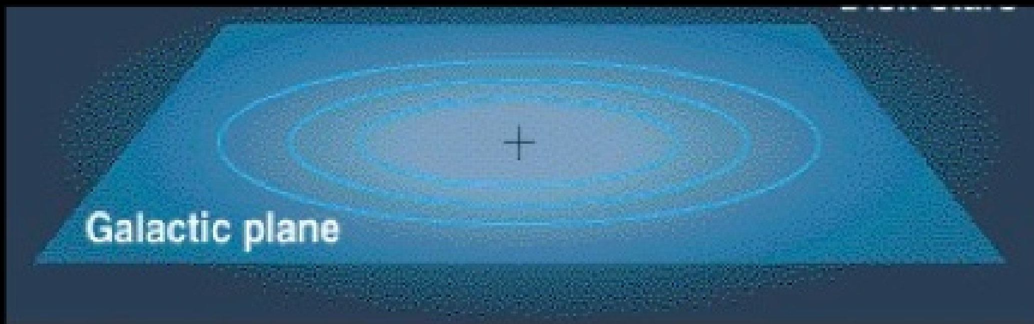
Galaxies have different masses!



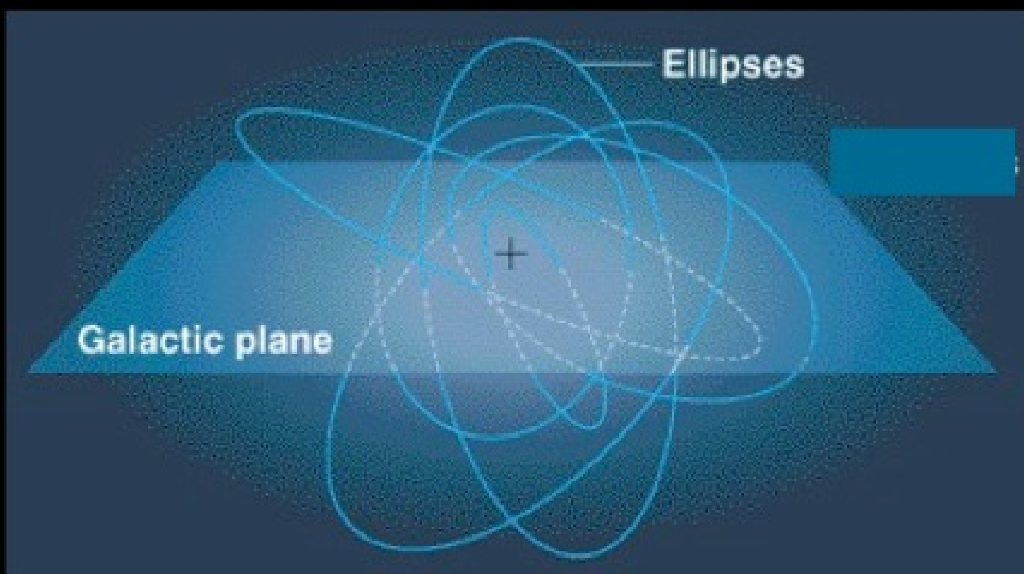
Ellipticals and Spirals have different “star formation histories”

Why do they have different structures?

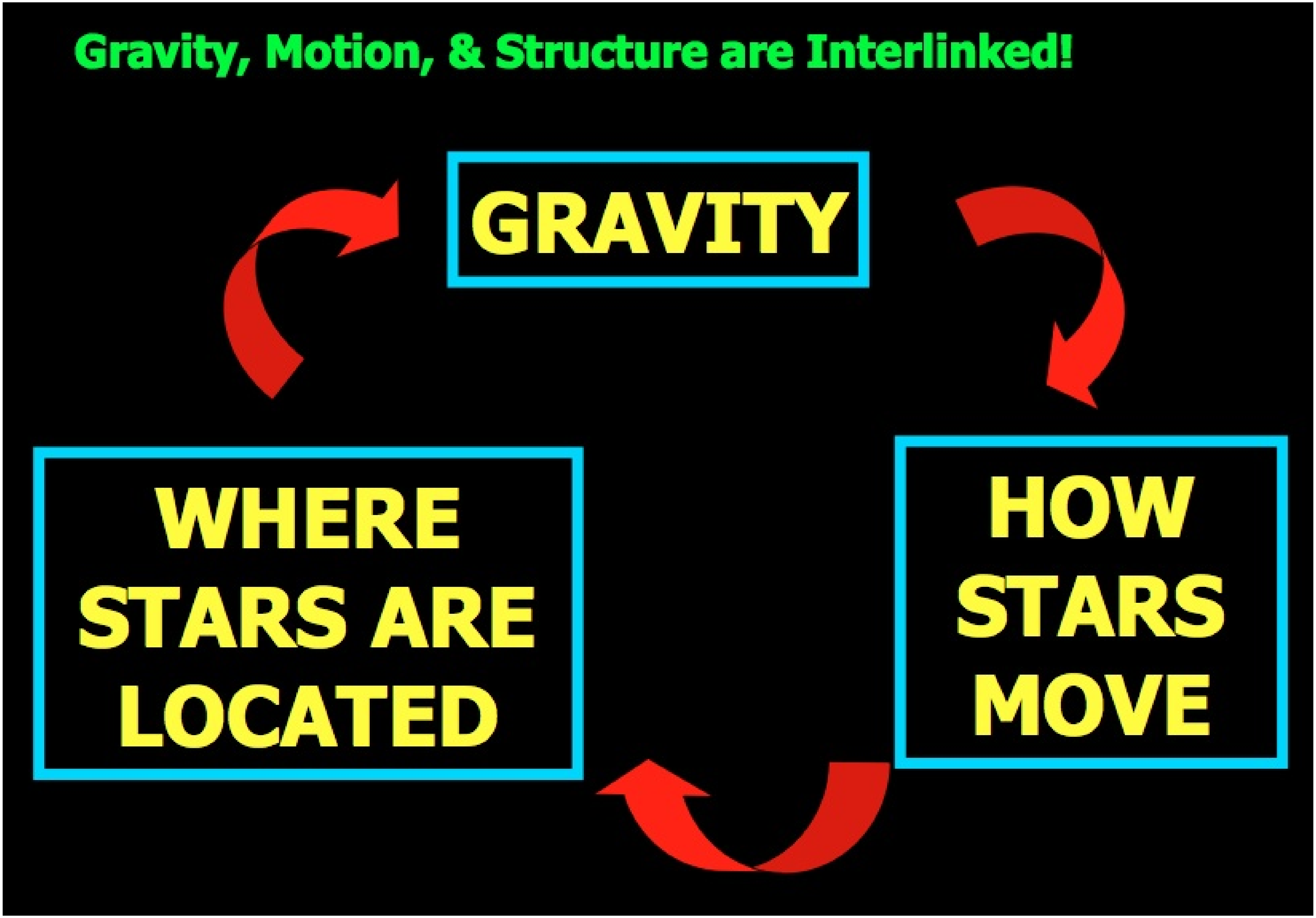
Stuff in Galaxies moves in two basic ways...



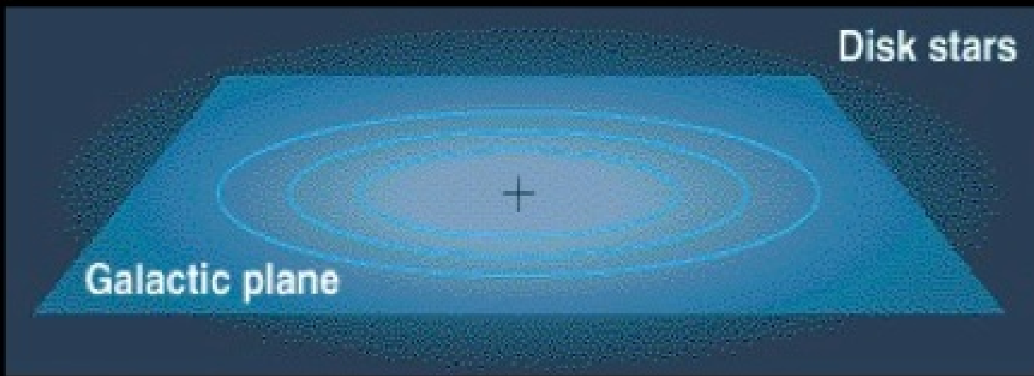
- Ordered Rotation

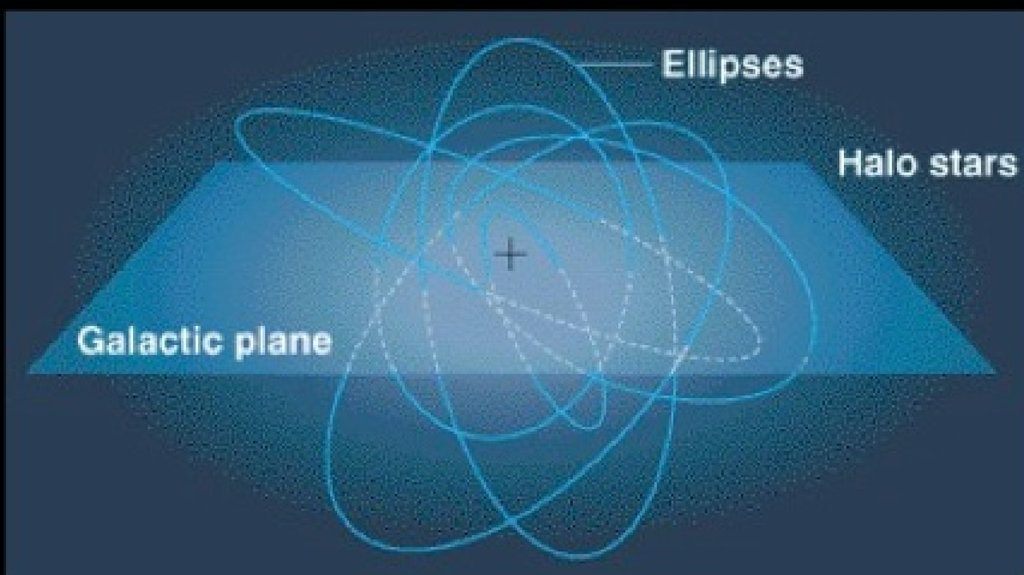


- Randomly

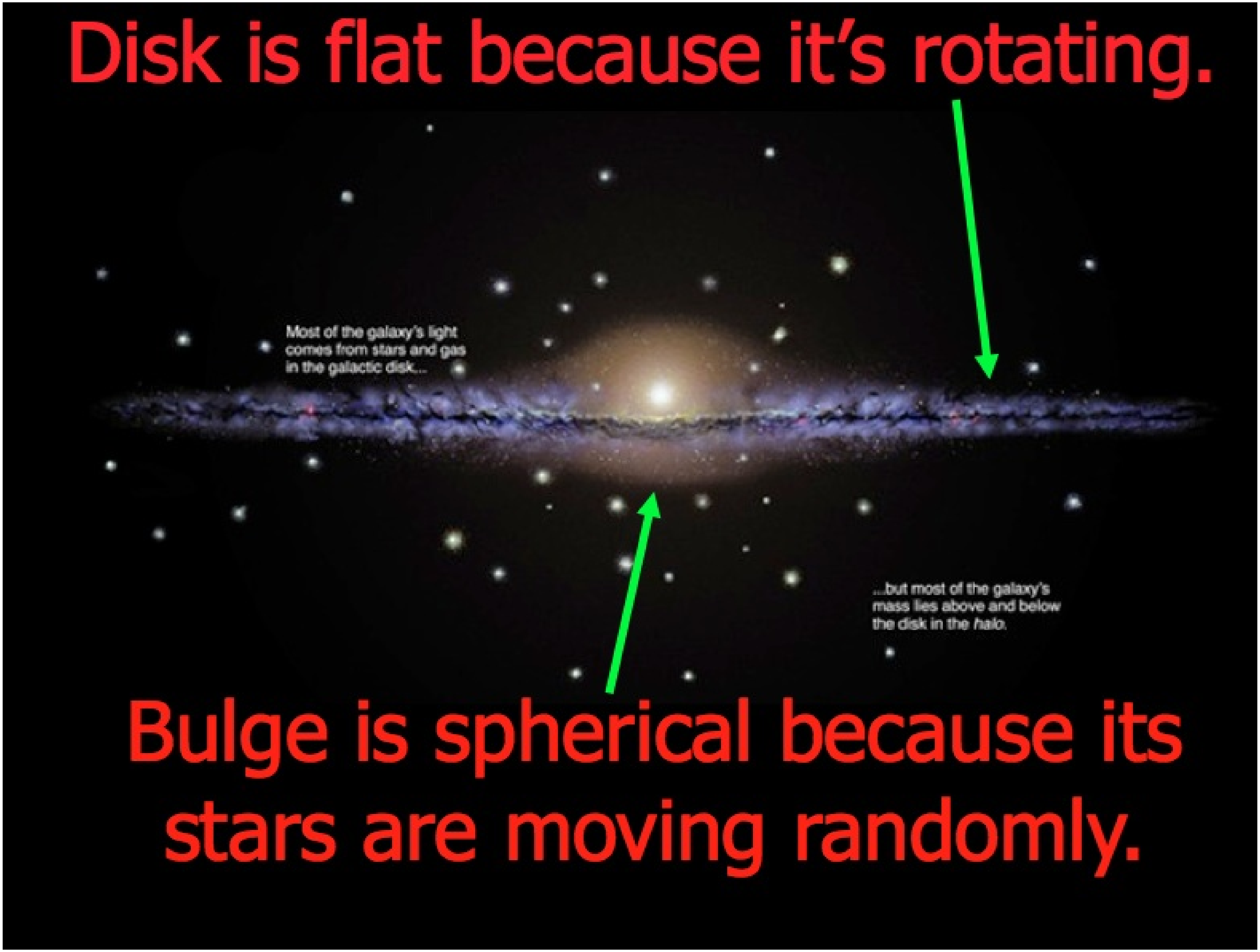

Gravity, Motion, & Structure are Interlinked!
GRAVITY
HOW STARS MOVE
WHERE STARS ARE LOCATED

Different Motion = Different Structures

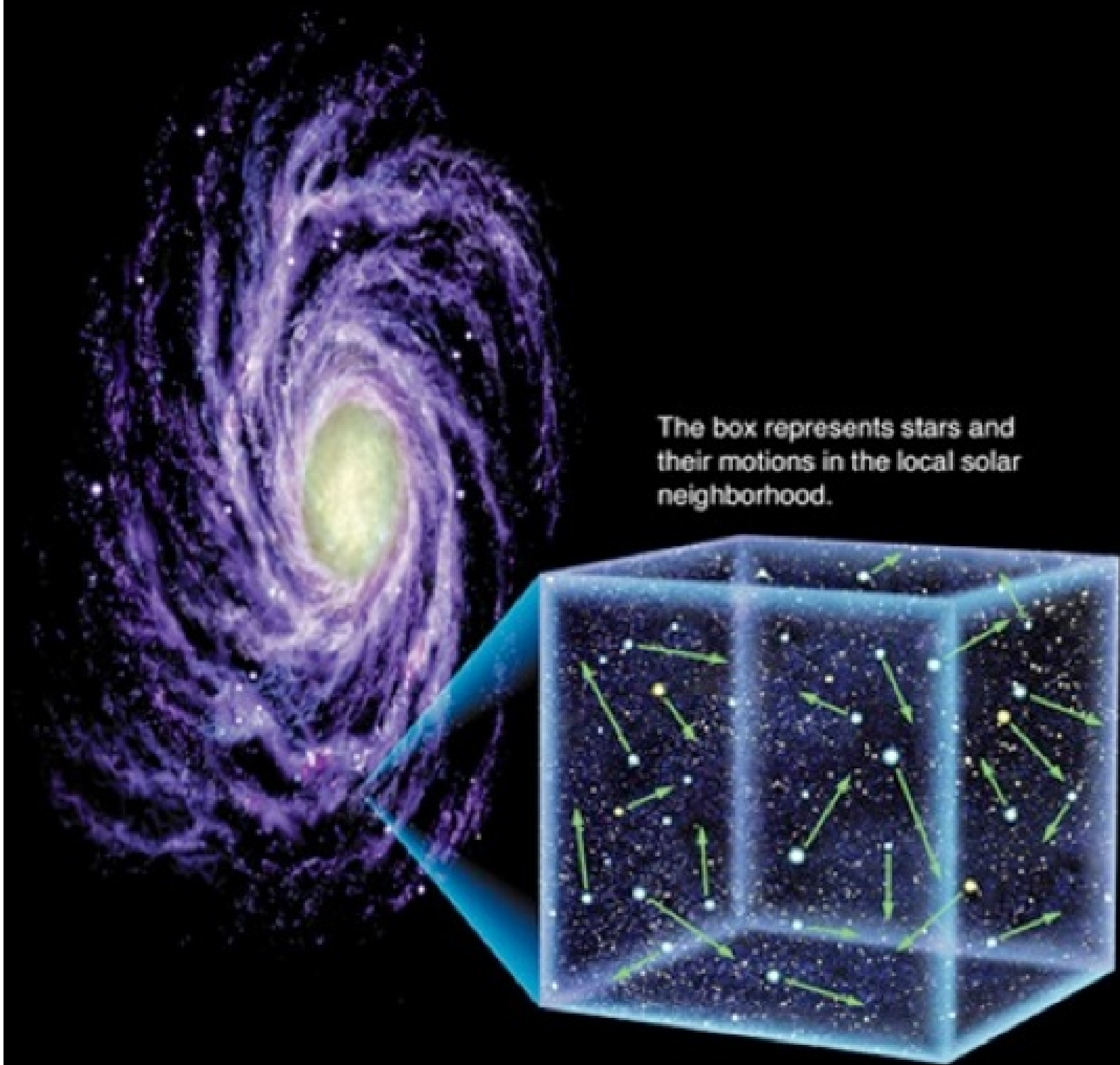




- Ordered Rotation
  - Makes **flat**, circular structures.
  - Spiral galaxy disks!
- Randomly
  - Makes 3-D, **spherical** structures
  - Spiral galaxy bulges and stellar halos, and elliptical galaxies!


Disk is flat because it's rotating.
Most of the galaxy's light comes from stars and gas in the galactic disk...
...but most of the galaxy's mass lies above and below the disk in the *halo*.
Bulge is spherical because its stars are moving randomly.

There are small random motions in addition to the rotation.



- Disks aren't perfectly thin!