ASTR 511

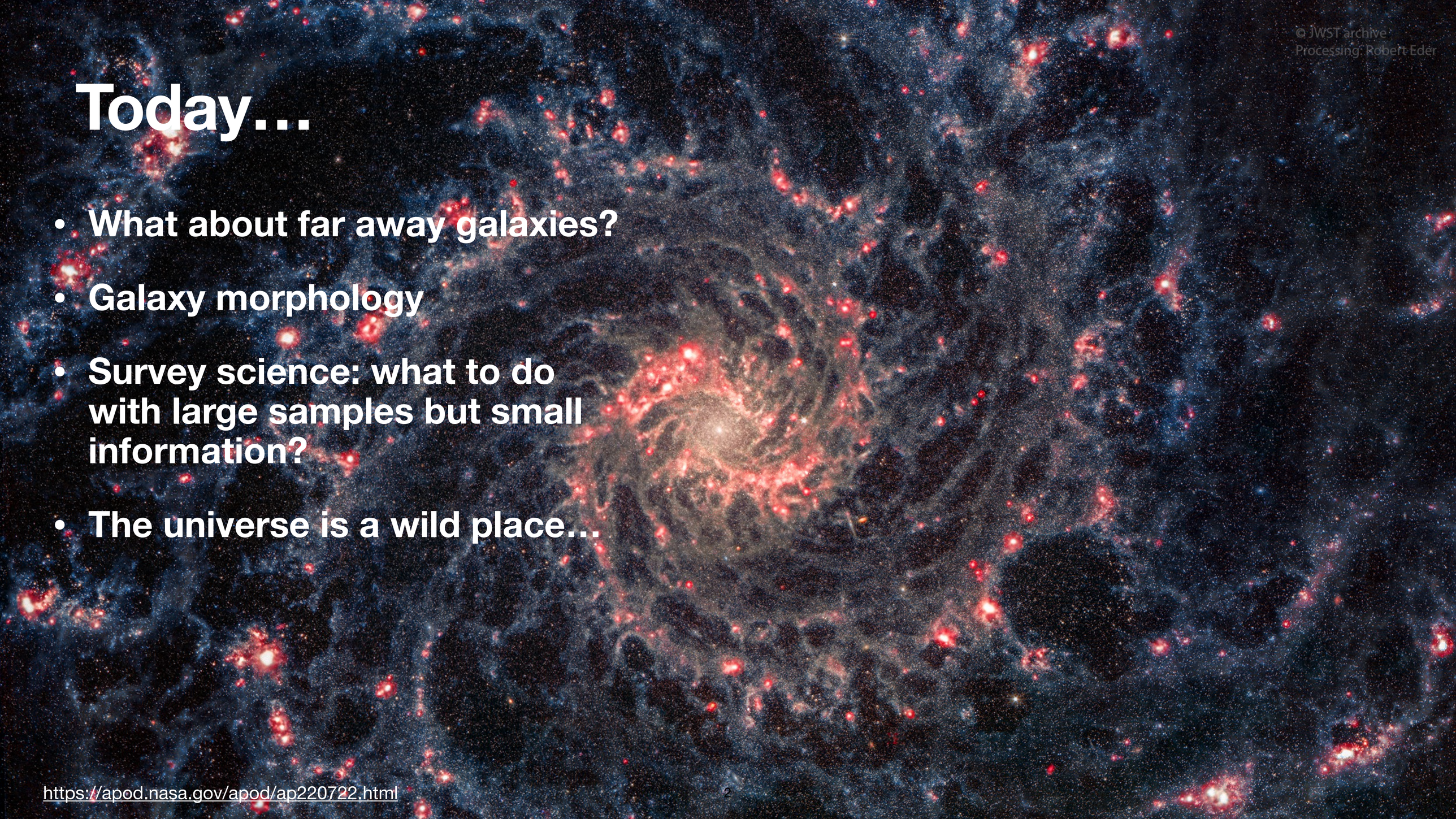
Galactic Astronomy

Lecture 13

Galaxy Morphology and Classification

Prof. James Davenport (UW)

Winter 2023

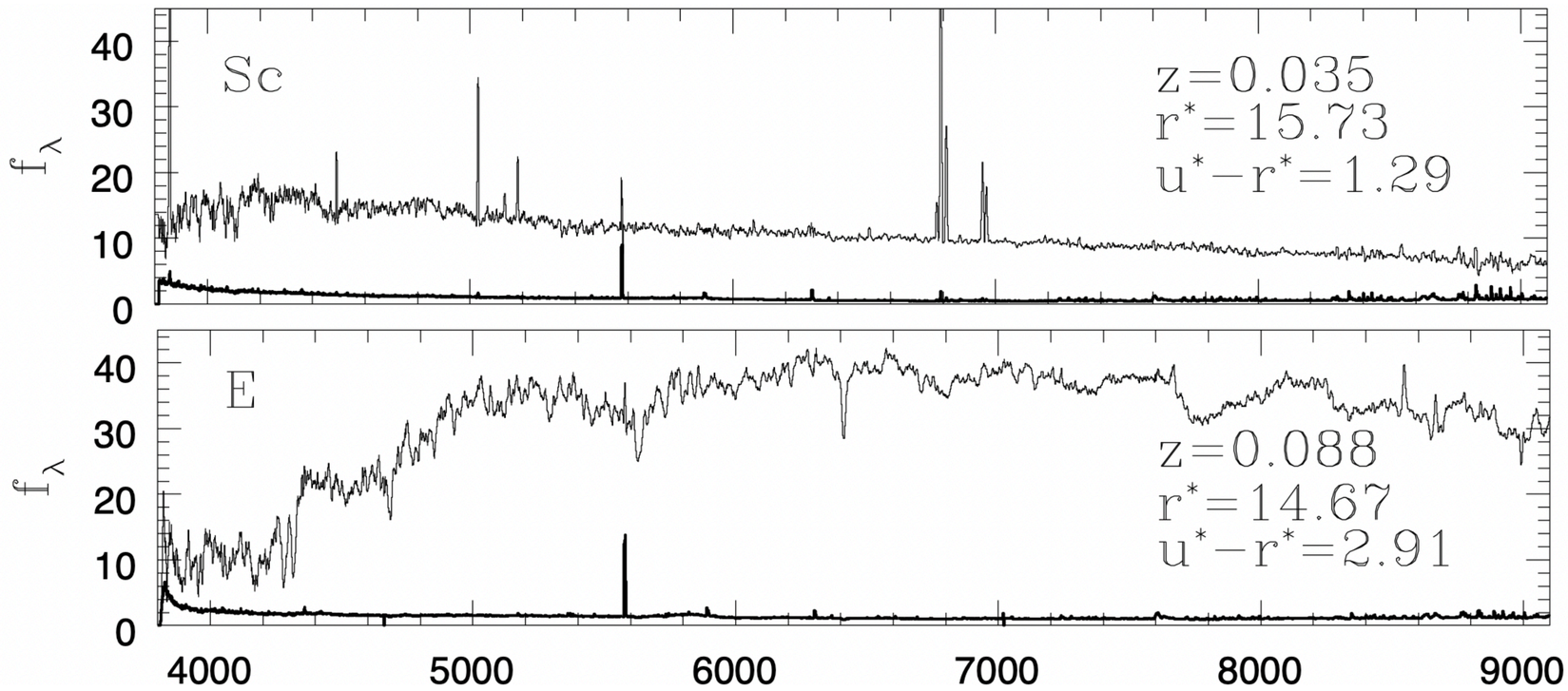


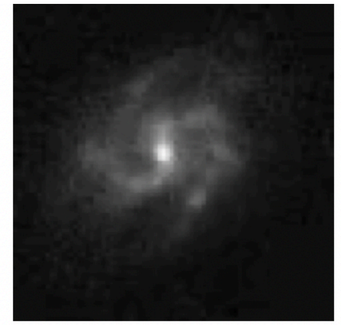
Today…

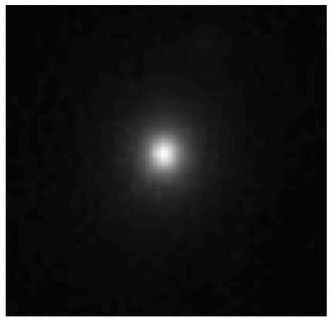
- What about far away galaxies?
- Galaxy morphology
- Survey science: what to do with large samples but small information?
- The universe is a wild place…

https://apod.nasa.gov/apod/ap220722.html

Thought Q: What goes in to a galaxy spectrum?

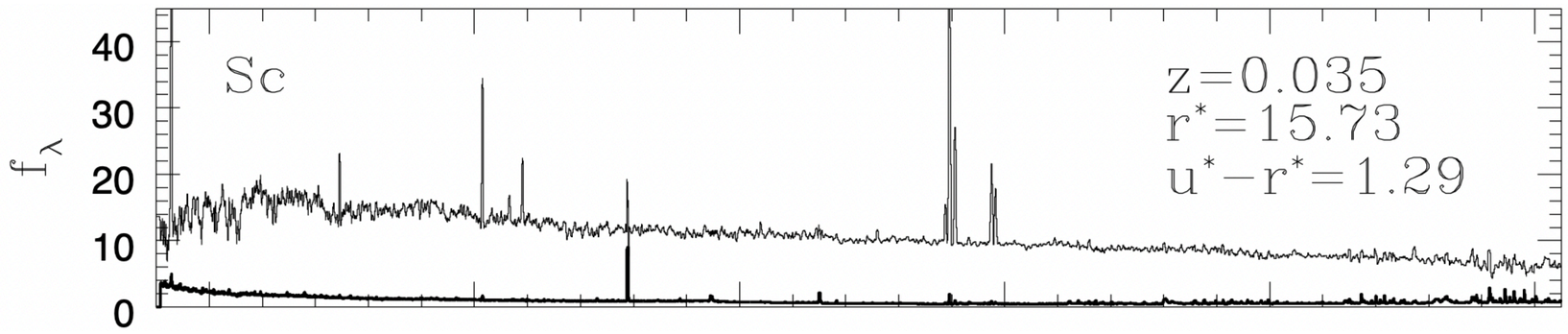


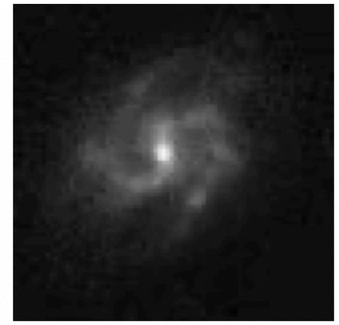




Strateva+2001

Thought Q: What goes in to a galaxy spectrum?



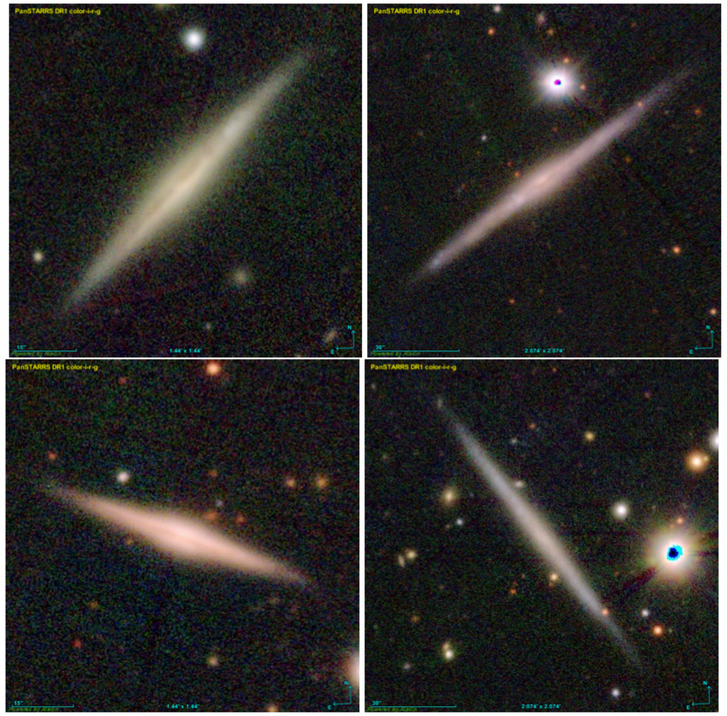


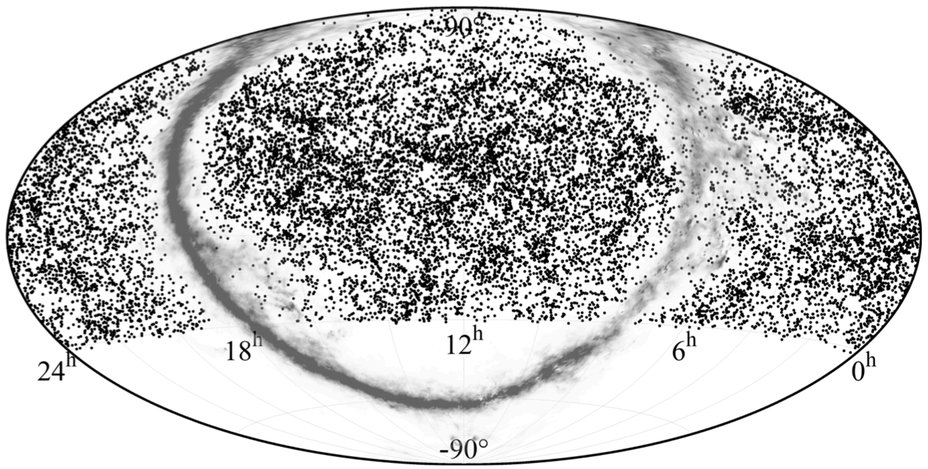
- Stars are the primary tracer of galaxy structure & history
- Can reproduce mostly reproduce galaxy spectrum by adding stars together (+ dust, redshift, etc)
- Most games you can play with stars can be applied to galaxies (e.g. [Fe/H], SFH, kinematics…)

Strateva+2001

Galaxies in Surveys

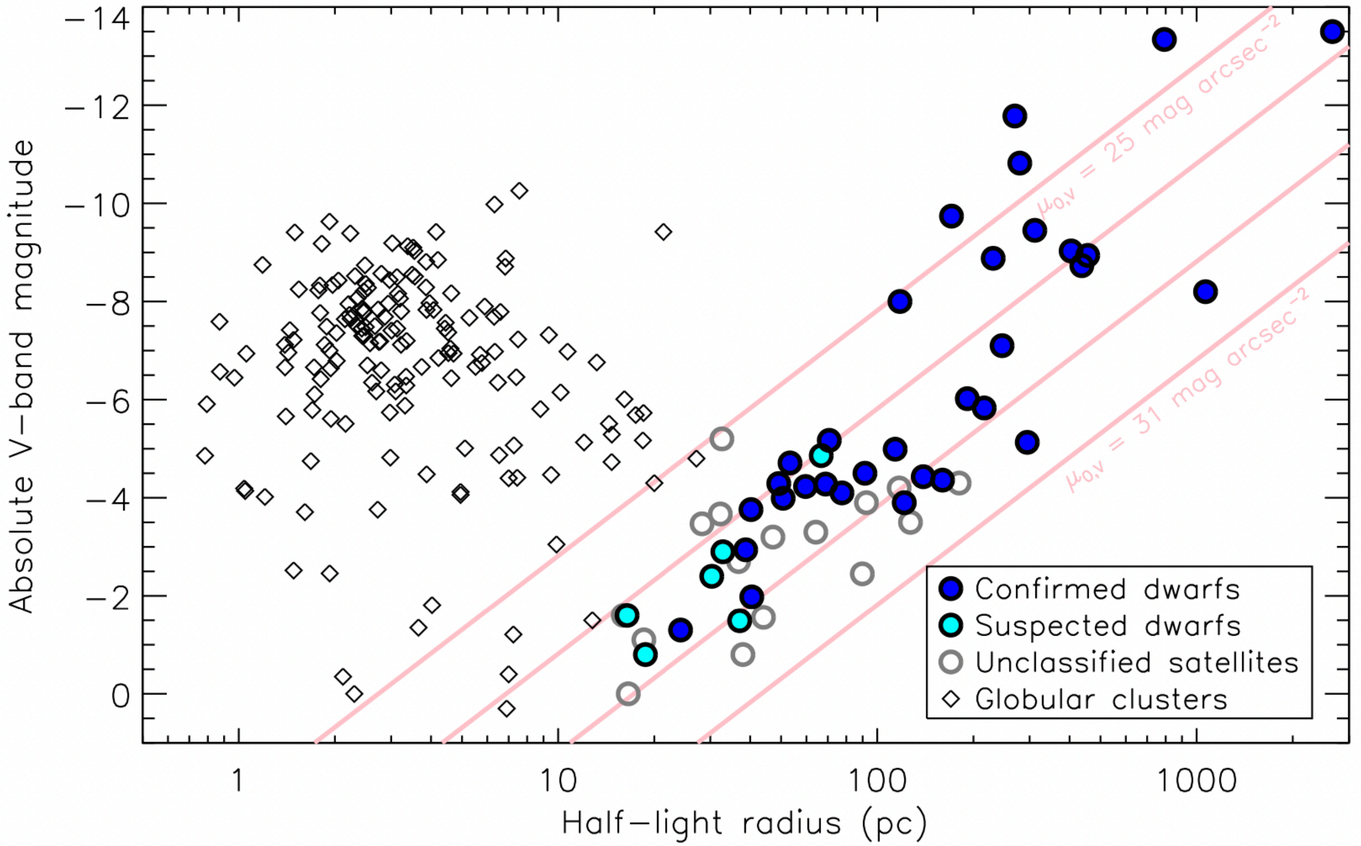
- Pre-SDSS era: datasets with ~1000 galaxies were considered good
- SDSS has +2 million galaxies with spectra, +200 million w/ photometry! (e.g. Beck+2016)
  - Plus other major datasets like PanSTARRS, HST, DECam
  - Amazing training data from https://data.galaxyzoo.org





Dwarf Galaxy vs Globular Cluster

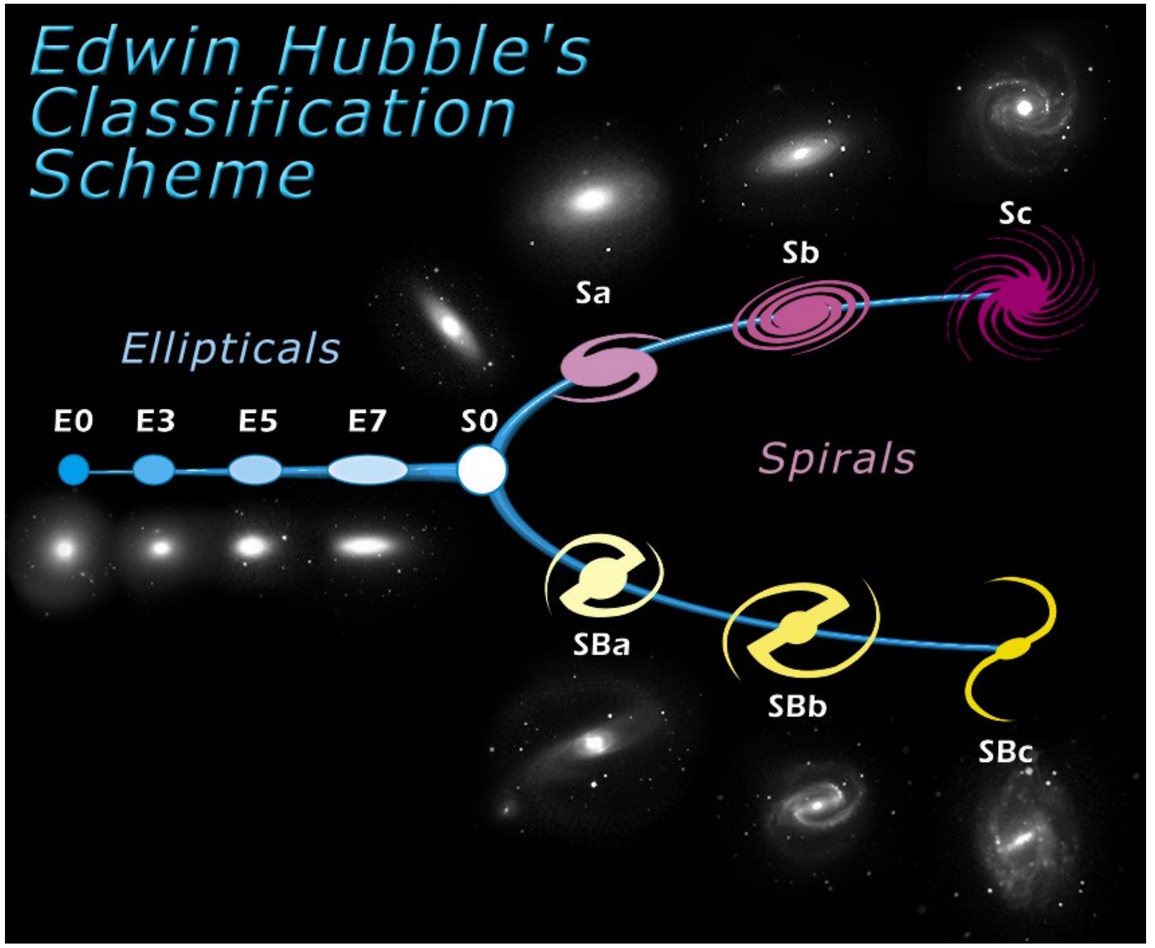
- There's definitely a range of parameter space they overlap
- GC's can have some DM
- Dwarf galaxies can have GCs



Simon (2019)

The Tuning Fork

- This is the classic galaxy classification scheme
- Left to right, sometimes called “early” and “late” type galaxies (e.g. by Hubble)
  - But never supposed to be any implied time axis… Classic
- Also: can assign numbers for plotting

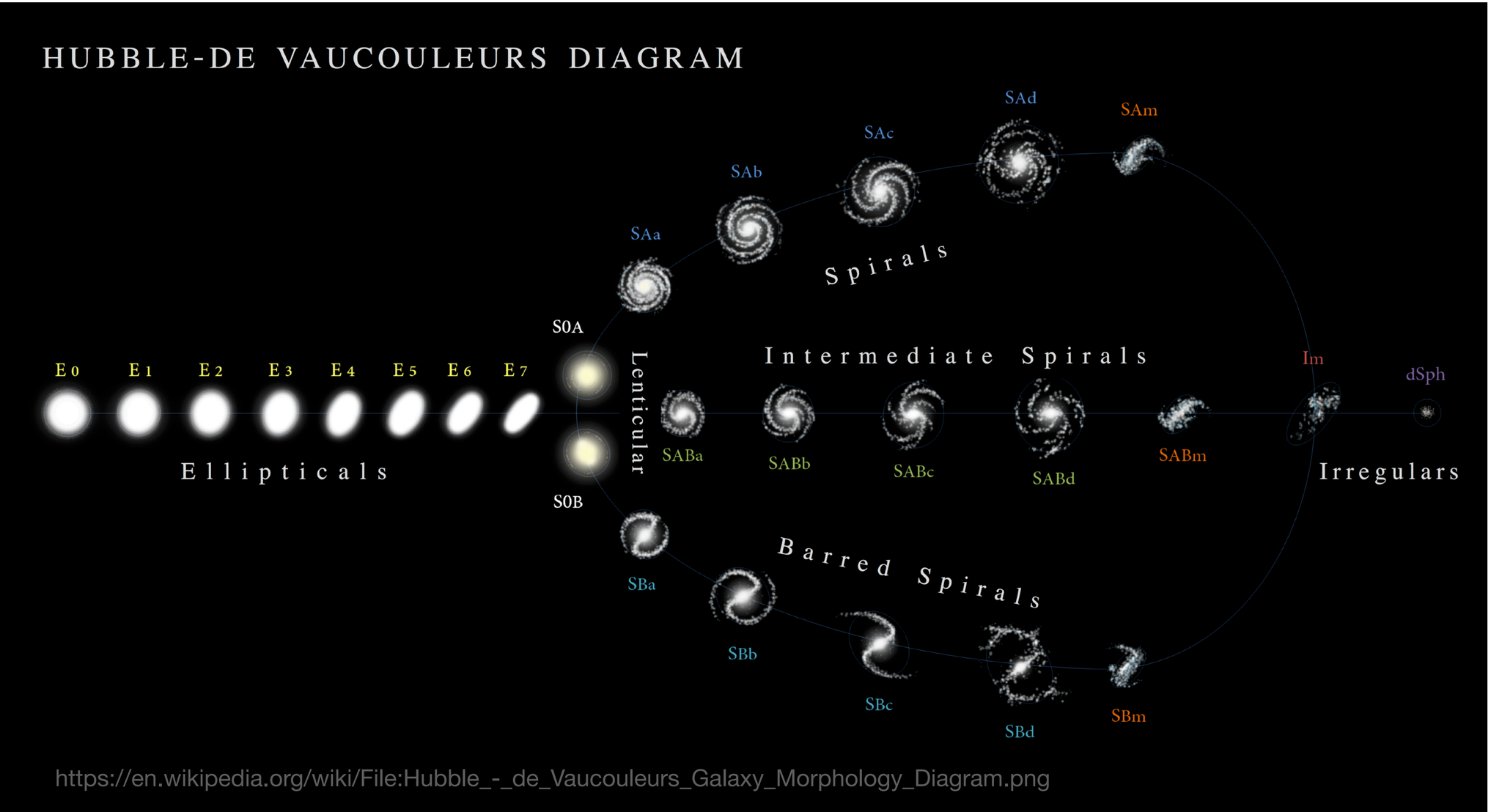


Numerical Hubble stage

Hubble stage *T*	–6	–5	–4	–3	–2	–1	0	1	2	3	4	5	6	7	8	9	10	11
de Vaucouleurs class[17]	cE	E	E^+	$S0^-$	$S0^0$	$S0^+$	S0/a	Sa	Sab	Sb	Sbc	Sc	Scd	Sd	Sdm	Sm	Im	
approximate Hubble class[20]	E			S0			S0/a	Sa	Sa-b	Sb	Sb-c	Sc			Sc-Irr	Irr I		

The Tuning Fork

- Some “improved” versions exist, which at least consider more galaxy types



https://en.wikipedia.org/wiki/File:Hubble_-_de_Vaucouleurs_Galaxy_Morphology_Diagram.png

Galaxy Morphologies (Shapes)

- Good things about the Tuning Fork
  - Can sort galaxies, put into similar categories, can use as prior for constraining e.g. simulations, maybe reason some classes are similar to eachother, etc.
- Many problems with the Tuning Fork
  - Lots of other galaxy classes to consider
  - Arbitrary class boundaries, not capturing all the possibly important properties
  - Galaxies may (do) change classes in time

Galaxy Morphologies (Shapes)

- Currently: there are approximately *a zillion* efforts to model, fit, & classify galaxies in big surveys, especially now with *Machine Learning*

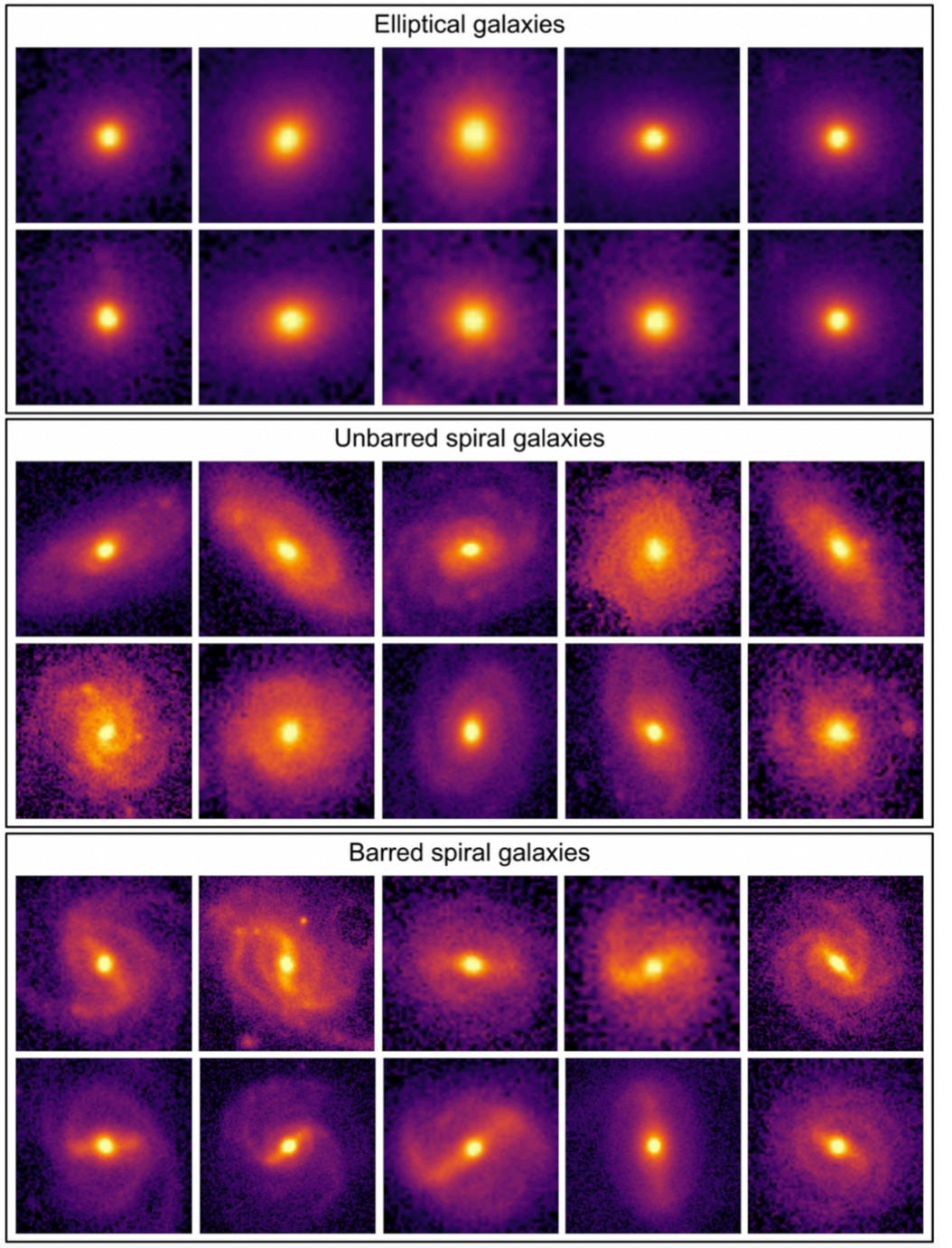
- Both from (multi-color) photometry, and spectra, +cross calibration, e.g. photo-z's! (Beck+2016)

- Also some great longterm projects with human classification e.g. Zooniverse (Lintott+2008)

  - Again: see amazing data at https://data.galaxyzoo.org

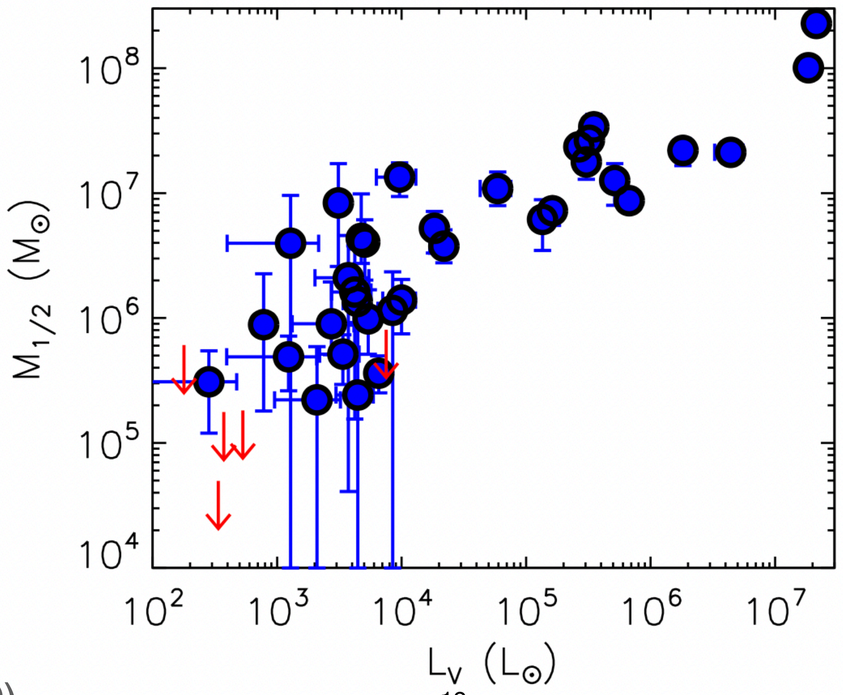
Galaxy Morphologies

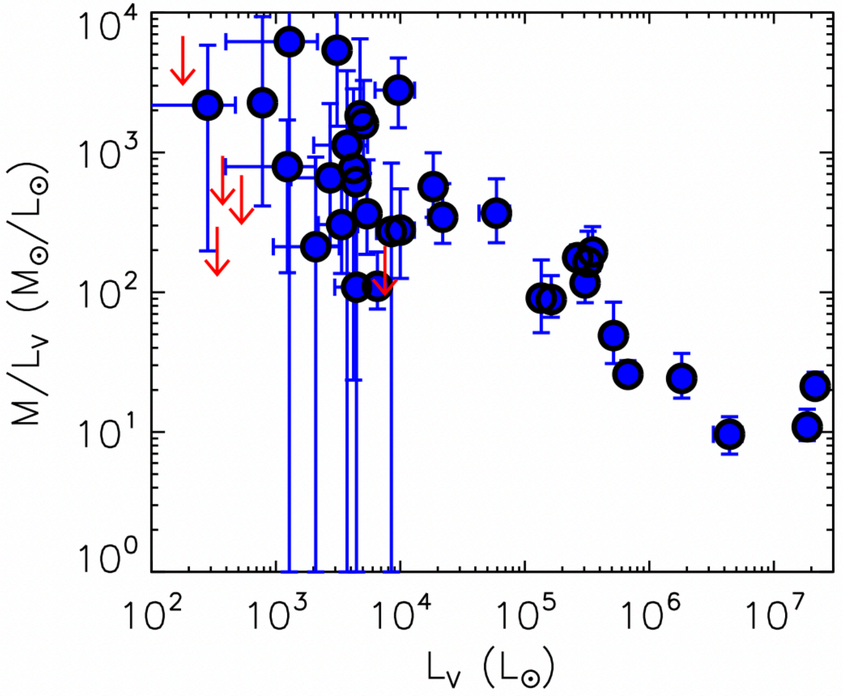
- Machine learning, esp. trained on Galaxy Zoo data, has gotten quite good at putting galaxy pictures into appropriate bins!
  - e.g. Kuminski+2014, Barchi+2020, and *so many others…*
  - Some studies put into detailed class through ML, some do detailed model fits, some do simple profile fits… lots of variety.



Mass to Light Ratios

- Dwarf galaxies have “too much” mass
- Dark matter dominated - the typical explanation
- *Or* just star formation burst with a top-heavy IMF?
  - Supported by [Fe/H] trends as well



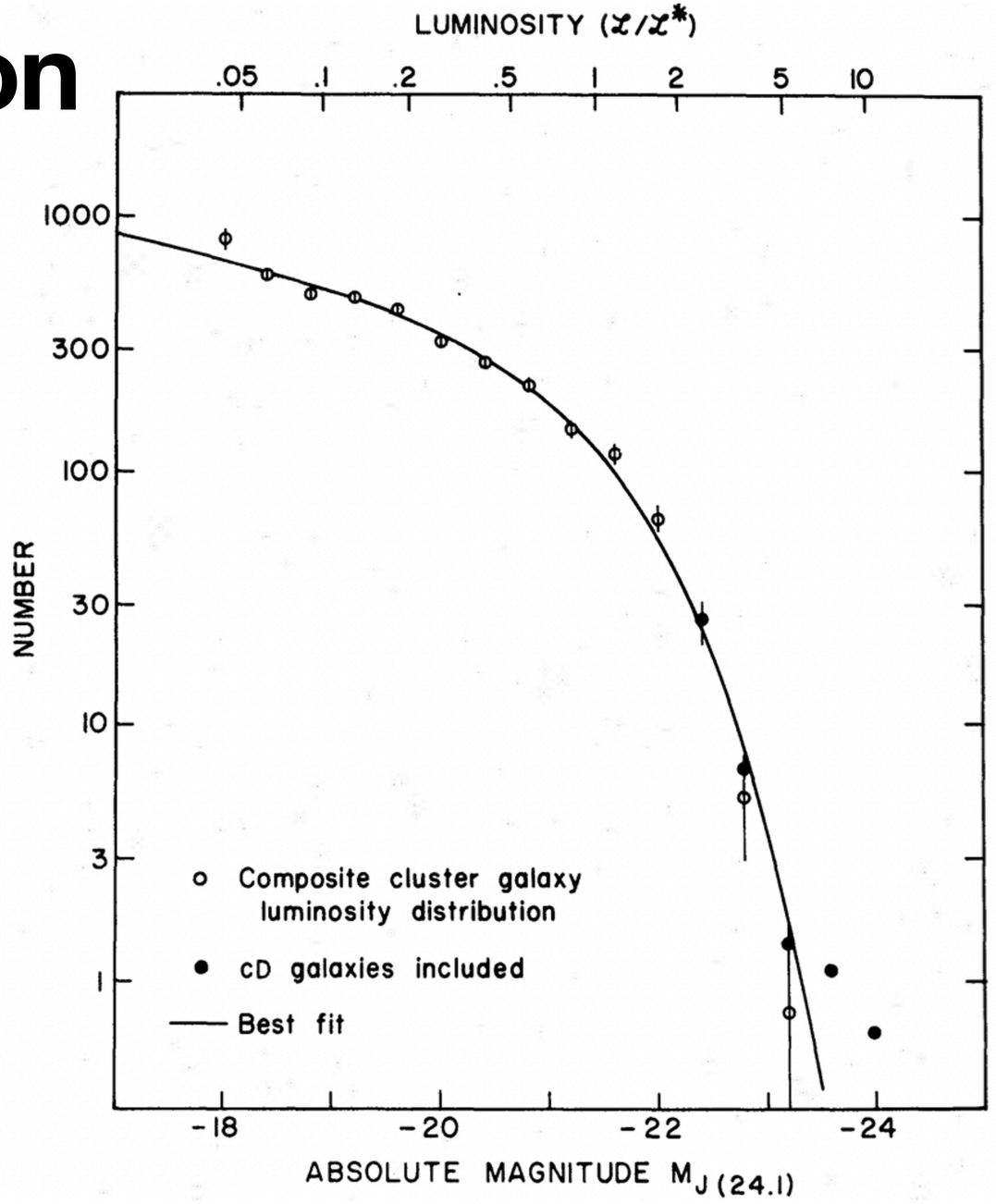


Simon (2019)

Galaxy Luminosity Function

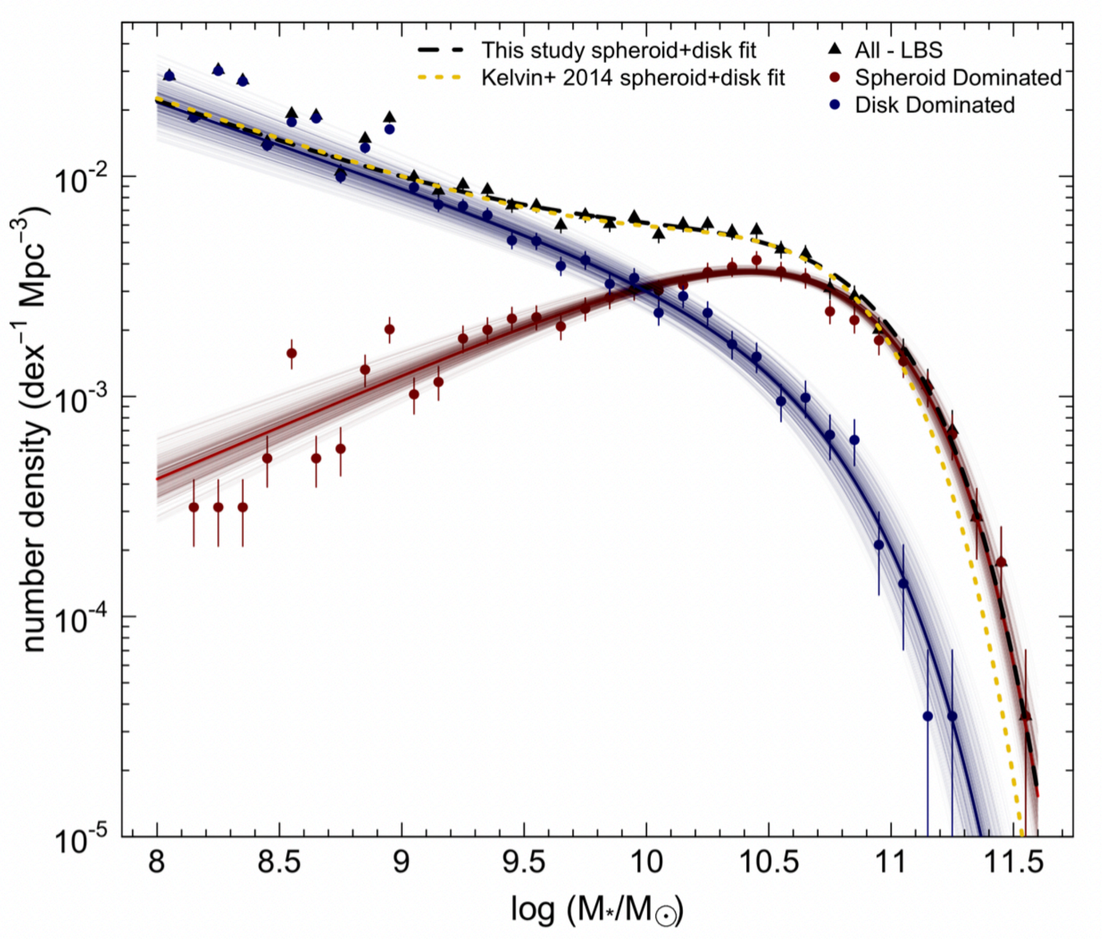
- Schechter (1976) function

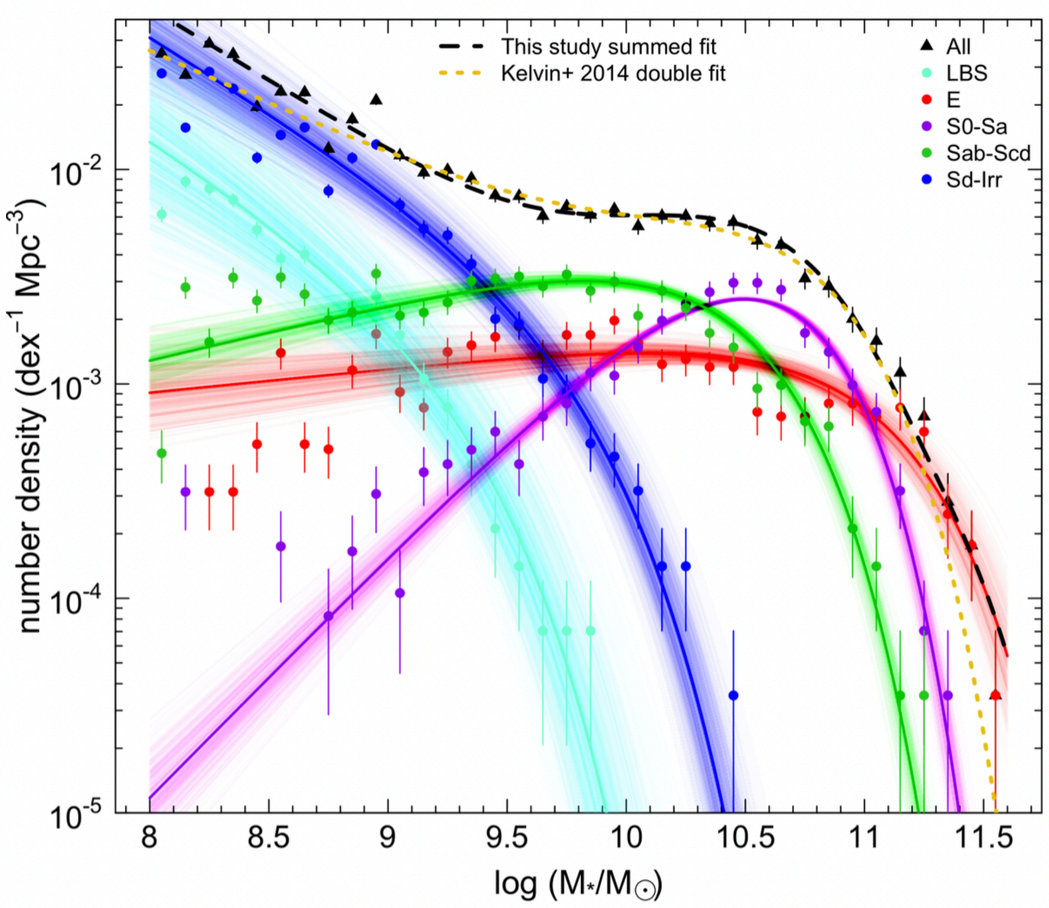
- Side note: Mass, Absolute Magnitude, Luminosity… all used rather interchangeably.
  - Sometimes velocity dispersion or radius also
  - This might concern you, if you think about e.g. Mass/Light Ratio



Galaxy Luminosity Function

- LF broken down by Galaxy Morphology types

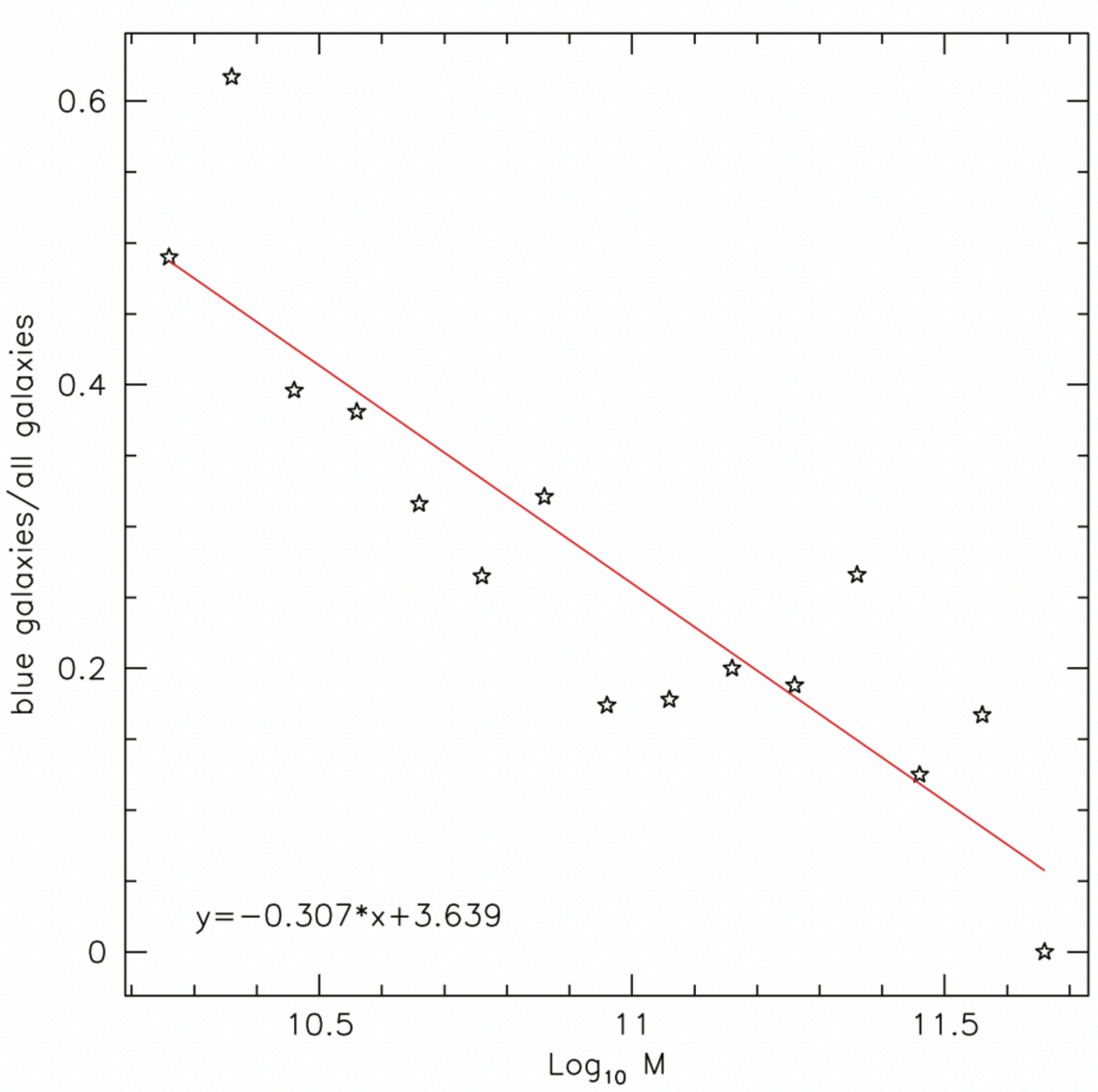




Moffett+2015

Galaxy Color

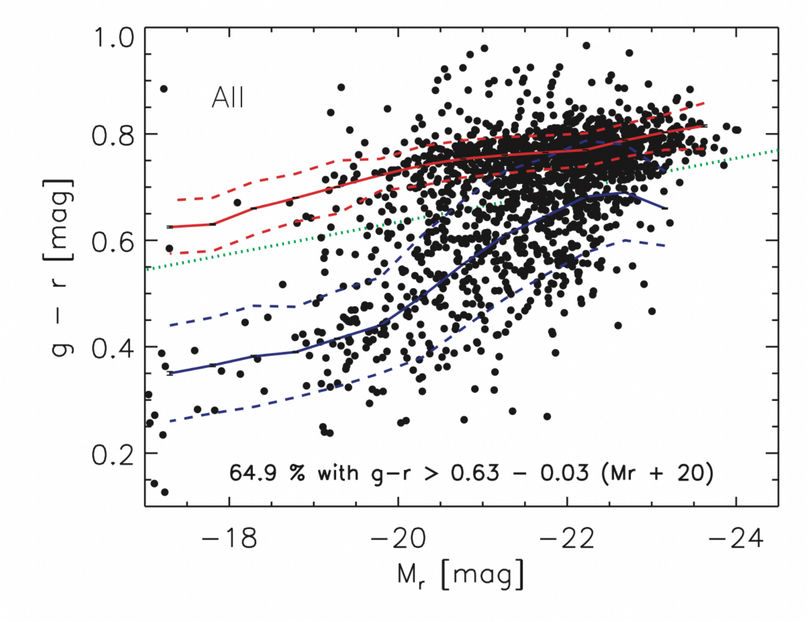
- Bigger galaxies are redder on average
- This is telling us something fundamental about HOW they are created!
  - Mergers & running out of gas



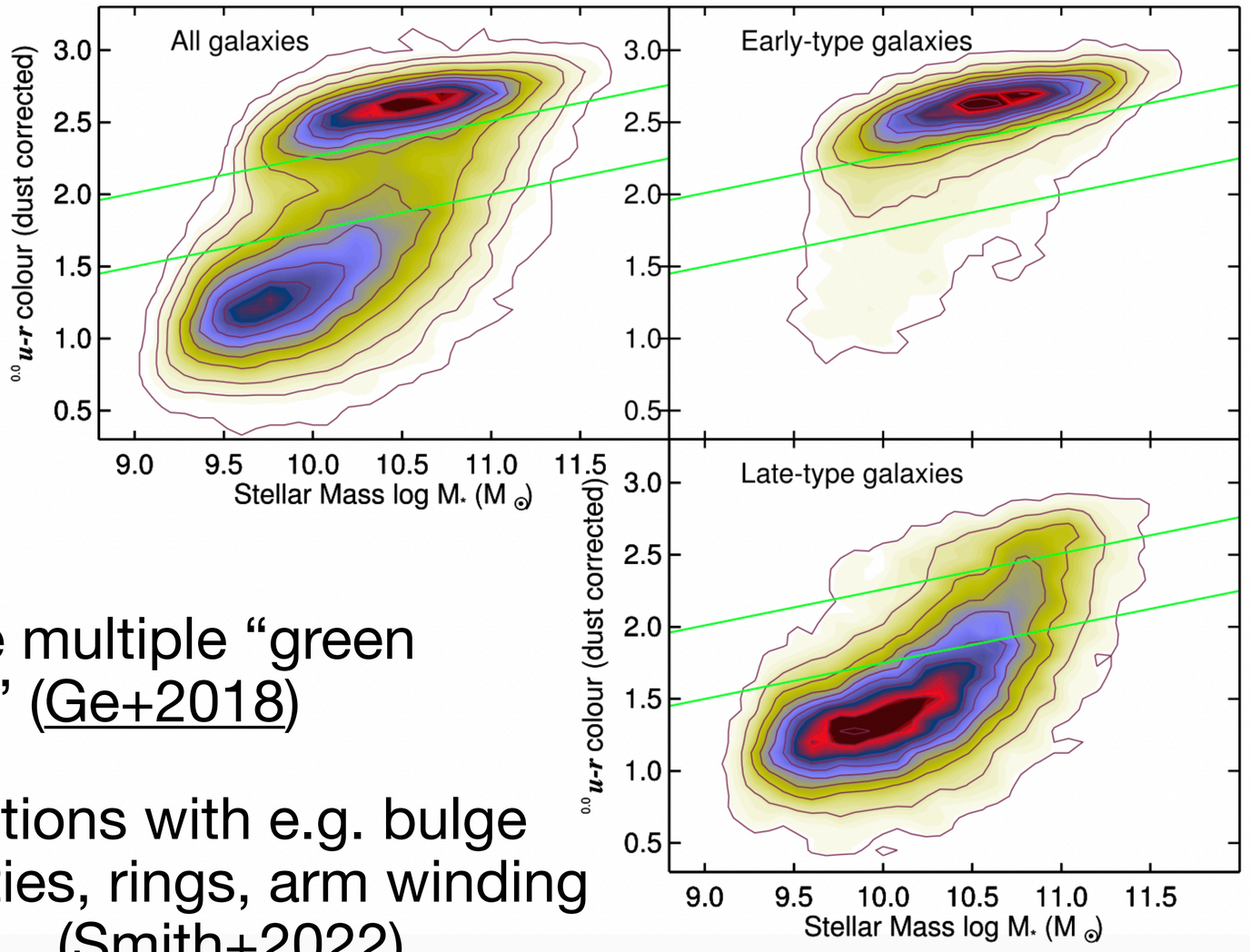
Vulcani+2011

Green Valley

- Galaxy Color-Magnitude Diagram (sorry stellar astronomers)
- A gap between blue & red: **green** (?)



Bernardi+2010

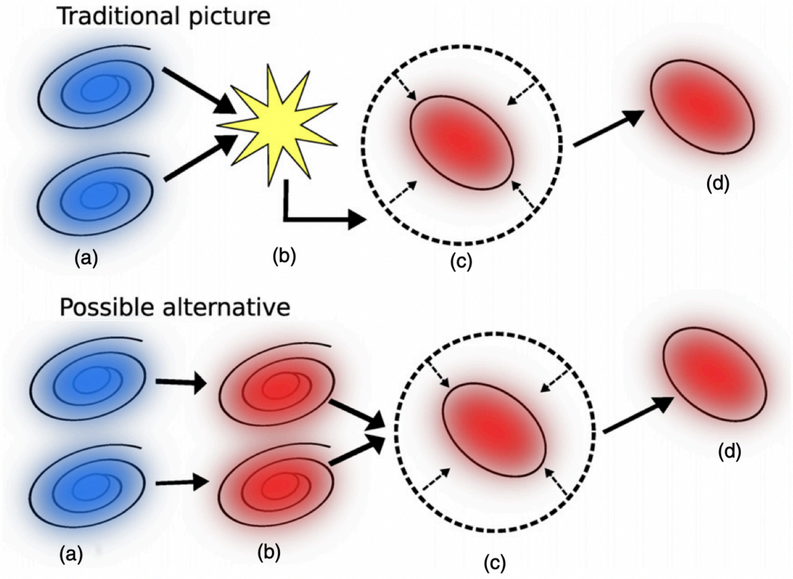


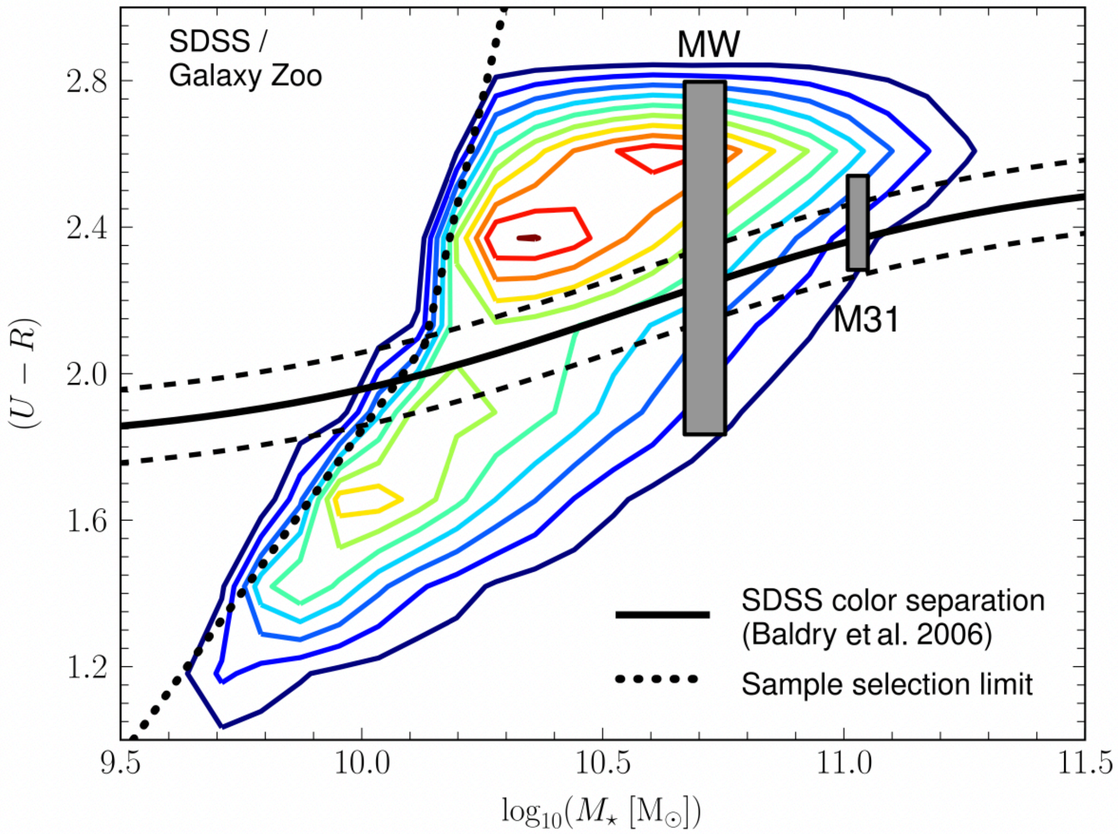
Schawinski+2014

- May be multiple “green valleys” (Ge+2018)
- Correlations with e.g. bulge properties, rings, arm winding angles… (Smith+2022)

Green Valley

- “Dry” mergers might explain green valley
- Andromeda, and maybe MWY are Green Valley galaxies
  - Fascinating to think in ~5Gyr our merger will be “dry”, *won’t* stoke star formation or AGN activity?!

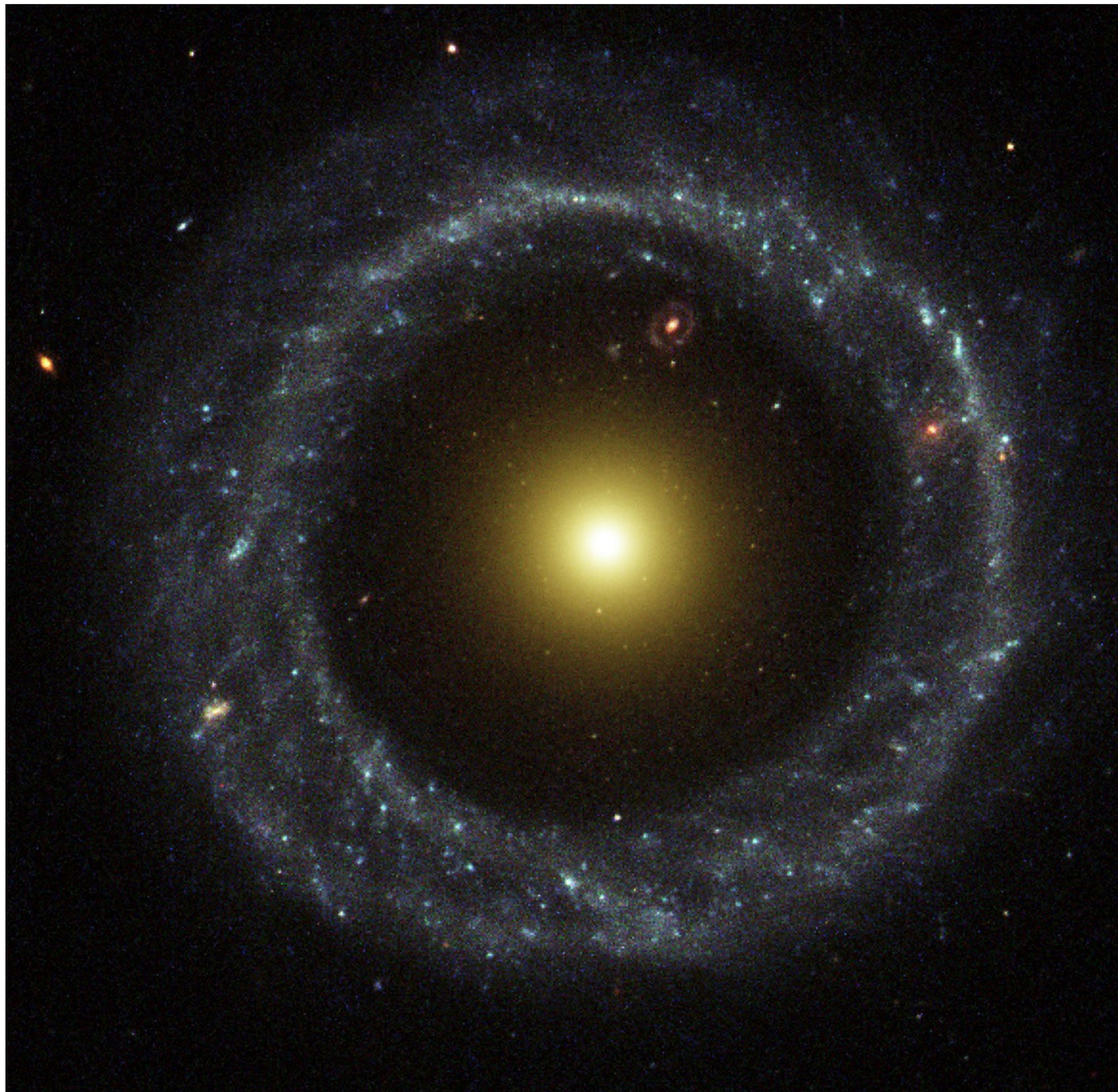




Mutch+2011

Other Types of Galaxies

- **Ring Galaxies (e.g. “Hoag’s Object”)**
  - Galactic collisions?
  - Funky accretion?
  - Bar shenanigans?

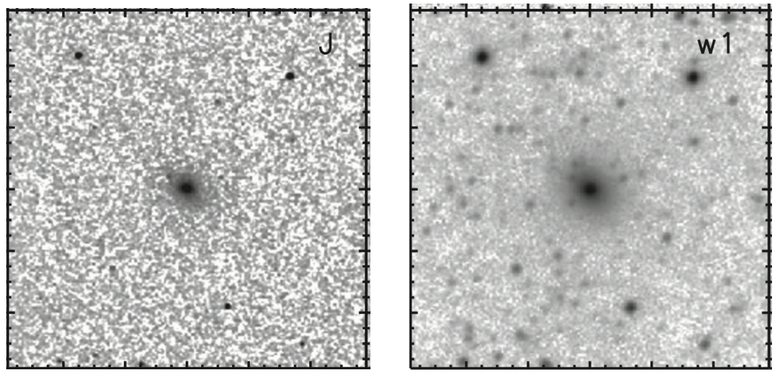


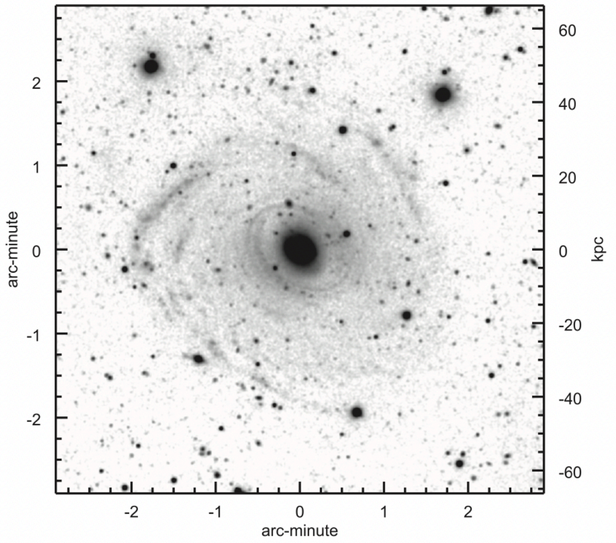
Other Types of Galaxies

- **Ring Galaxies (e.g. “Cartwheel Galaxy”)**
  - Galactic collisions?
  - Funky accretion?
  - Bar shenanigans?

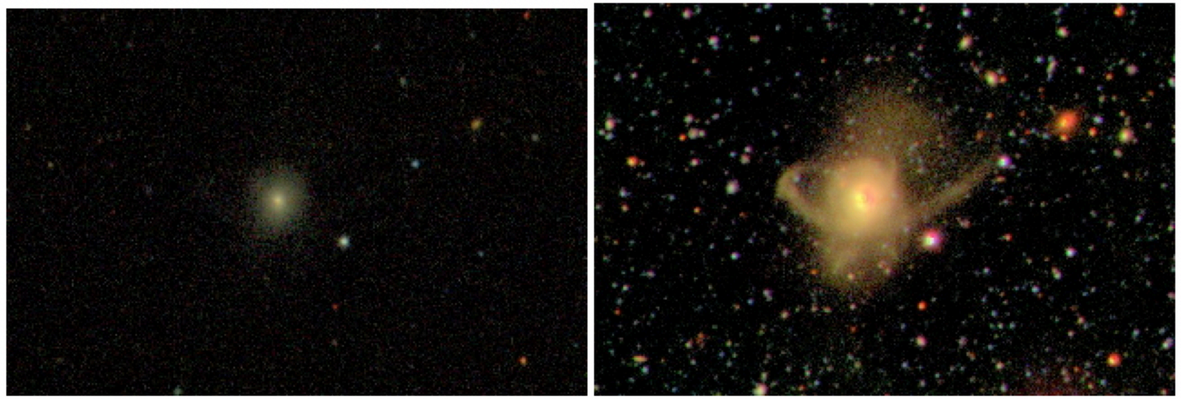
Other Types of Galaxies

- **Low surface brightness**
- e.g. UGC 1382, *was* classified as a small elliptical, actually a BIG low surface brightness spiral! (Hagen+2016)





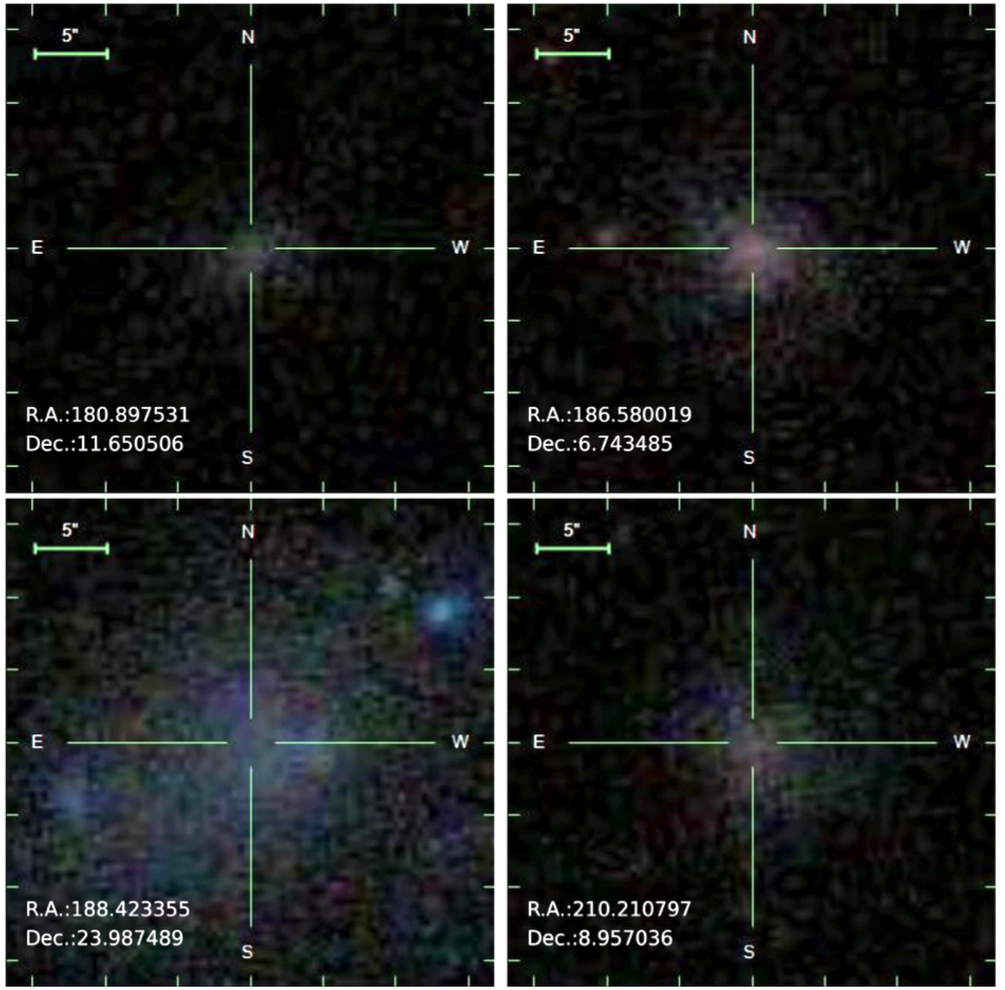
- **Going to see more of this from LSST, of course!**



https://www.lsst.org/sites/default/files/docs/sciencebook/SB_9.pdf

Other Types of Galaxies

- **Low surface brightness**
- Evidence for a class of “giant” LSB galaxies
- Machine learning getting better at picking out low surface brightness galaxy features, both for finding tails/ streams, and for picking out unusual galaxies!

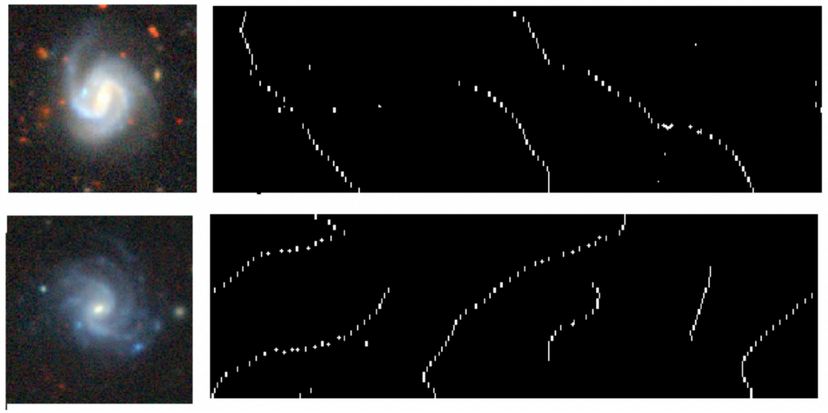


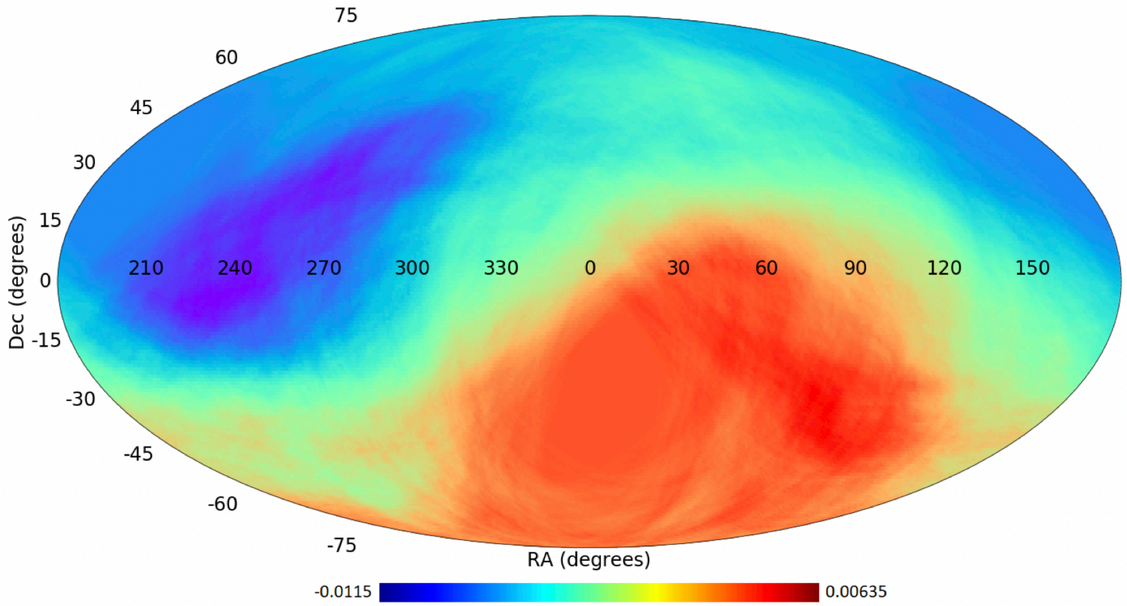
Yi+2022

Left vs Right Handed Galaxies…

- Cosmological anisotropy? Weird statistics?
- I’d love to see this repeated some more to explore the origin!

Shamir (2022)





$$\frac{R-L}{R+L}$$

See also e.g. Longo (2011)