ASTR 511

Galactic Astronomy

Lecture 14

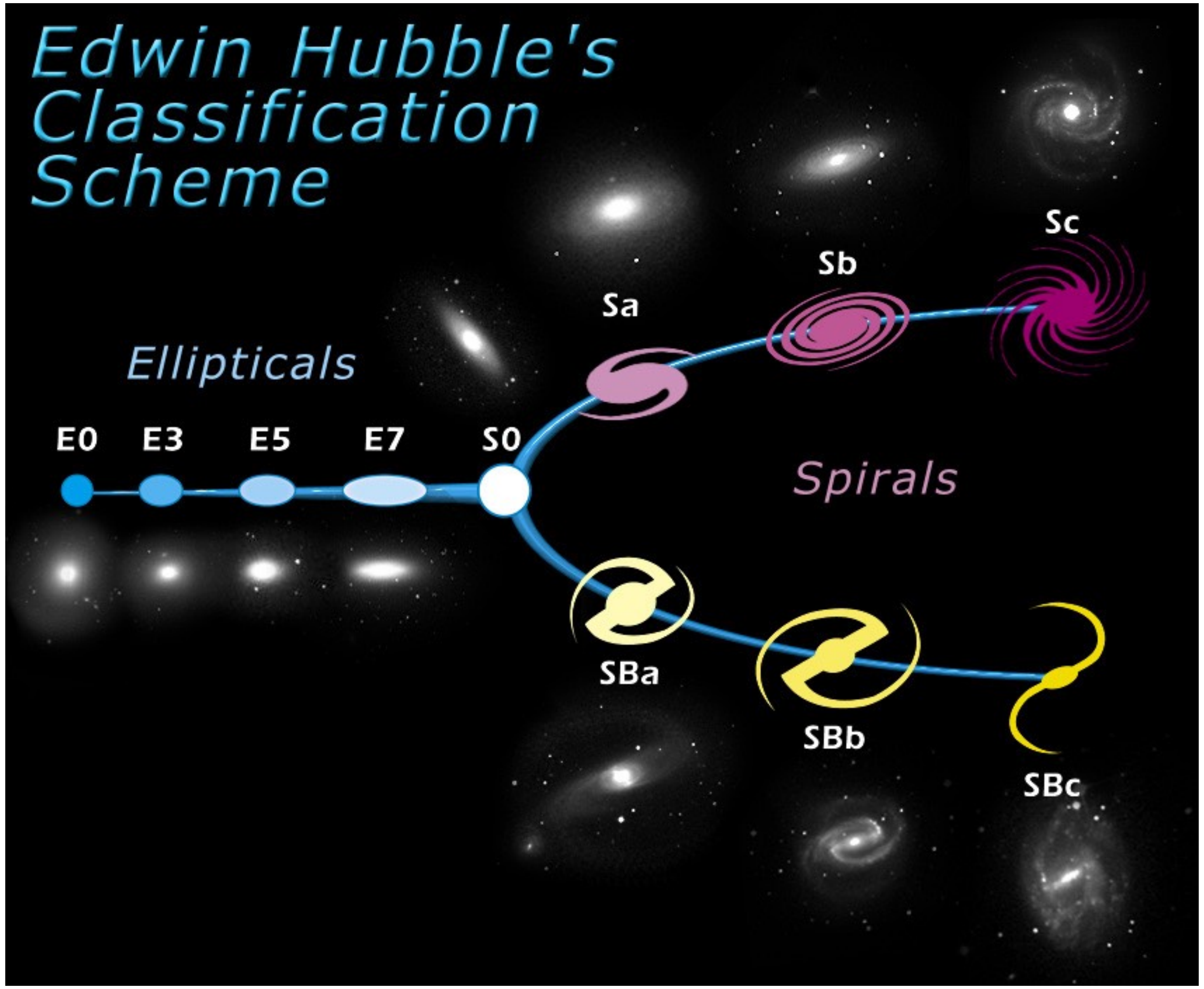
Ellipticals

Prof. James Davenport (UW)

Winter 2023

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		

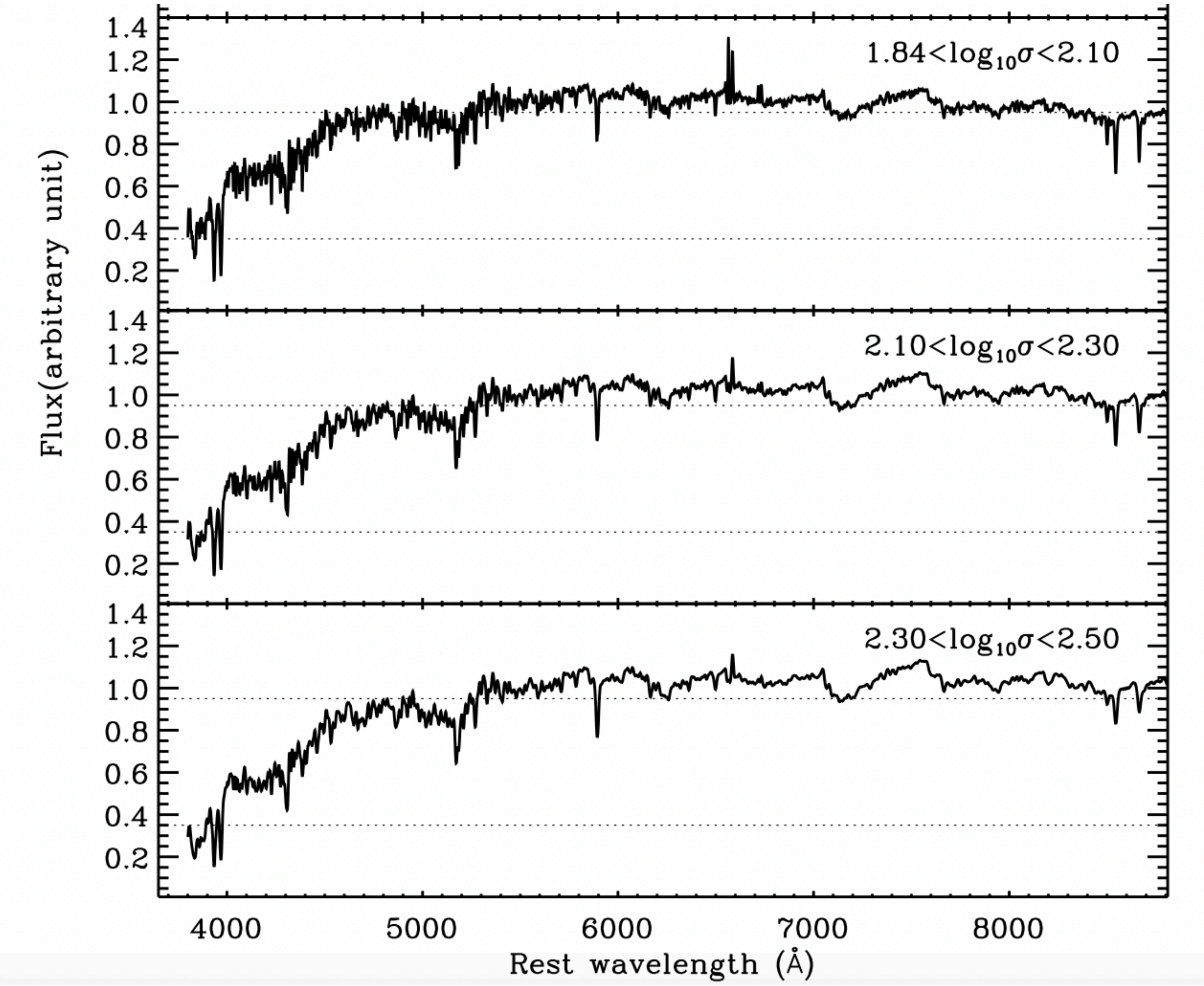
Elliptical Galaxies

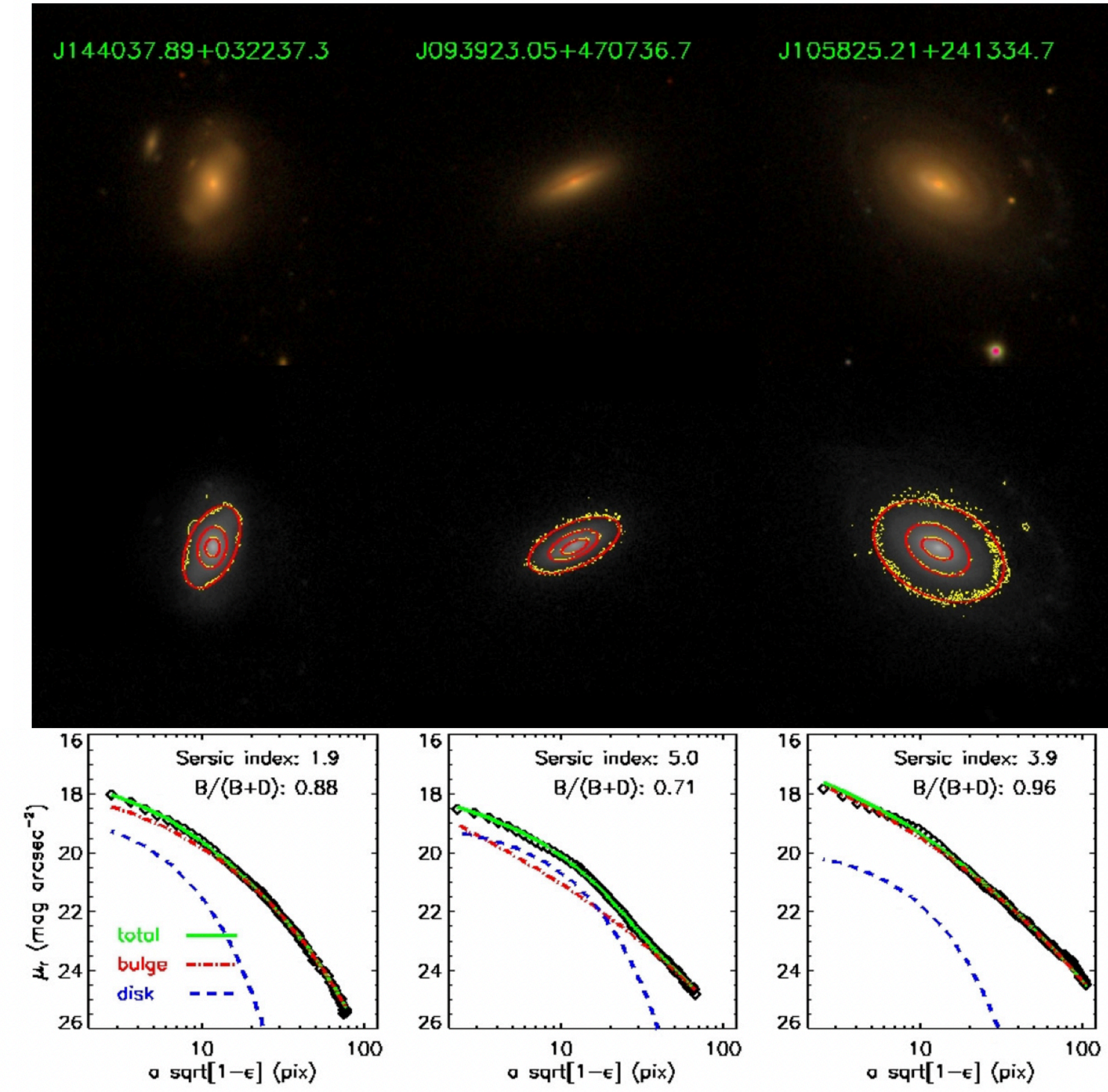
- Elliptical or triaxial shape
- (Usually) no strong dust lanes
- 10-15% of galaxies are true ellipticals (i.e. no spiral structure)
- They're interesting, even if they seem boring or "red and dead"

[source]

Elliptical Galaxies

- Well fit by relatively simple models, e.g. a Sersic profile (Zhu+2010)
- Spectra look like red stars, a bit rich in α-elements (think: old stellar pops!)





Elliptical Galaxies

- Probably a few classes of galaxies we call "elliptical"
- Mass dependent!
- Also maybe different formation channels (spoiler: merger history)

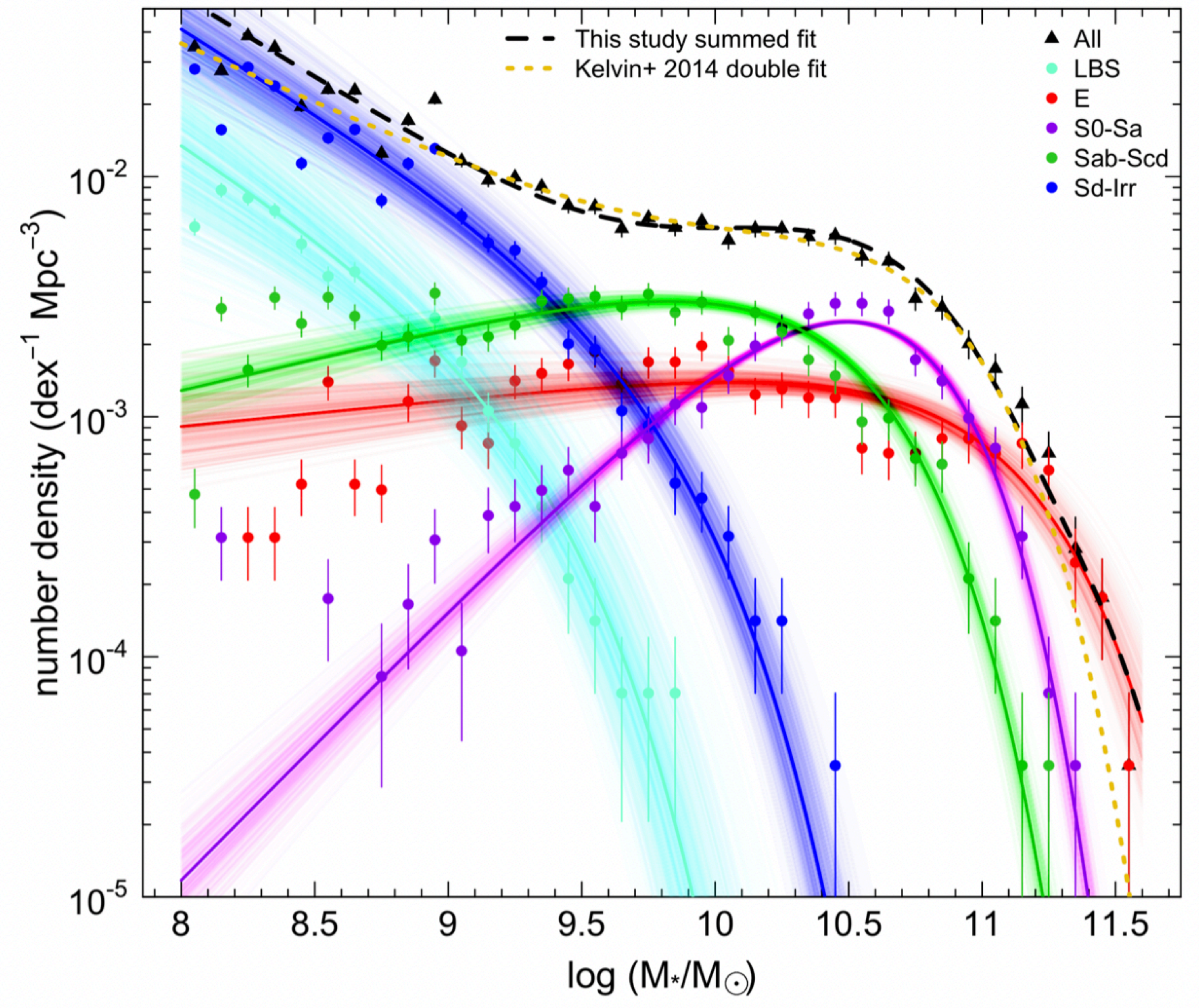
Giant ellipticals ($M_V \lesssim -21.5 \pm 1$ for $H_0 = 70$ km s^{-1} Mpc^{-1}) generally
(1) have Sérsic function outer profiles with $n > 4$;
(2) have cores; i. e., central missing light with respect to the outer Sérsic profile;
(3) rotate slowly, so rotation is of little importance dynamically; hence
(4) are anisotropic and modestly triaxial;
(5) are less flattened (ellipticity $\varepsilon \sim 0.2$) than smaller ellipticals;
(6) have boxy-distorted isophotes;
(7) mostly are made of very old stars that are enhanced in α elements (Figure 2);
(8) often contain strong radio sources (Figure 3), and
(9) contain X-ray-emitting gas, more of it in more luminous galaxies (Figure 3).

Normal ellipticals and dwarf ellipticals like M 32 ($M_V \gtrsim -21.5$) generally
(1) have Sérsic function outer profiles with $n \simeq 2$ to 3;
(2) are coreless – have central extra light with respect to the outer Sérsic profile;
(3) rotate rapidly, so rotation is dynamically important to their structure;
(4) are nearly isotropic and oblate spheroidal, albeit with small axial dispersions;
(5) are flatter than giant ellipticals (ellipticity $\varepsilon \sim 0.35$);
(6) have disky-distorted isophotes;
(7) are made of younger stars with little α-element enhancement (Figure 2);
(8) rarely contain strong radio sources (Figure 3), and
(9) generally do not contain X-ray-emitting gas (Figure 3).

- Kormendy (2016)

Galaxy Luminosity Function

- **Lots of these classes are not classic spirals!!**
- Sd-Irr: maybe disk, but irregular (think LMC)
- Little Blue Spheroids (LBS)
  S0-Sa (very weak disk)
  Elliptical
- **By mass: spiral/disk only 30%!**



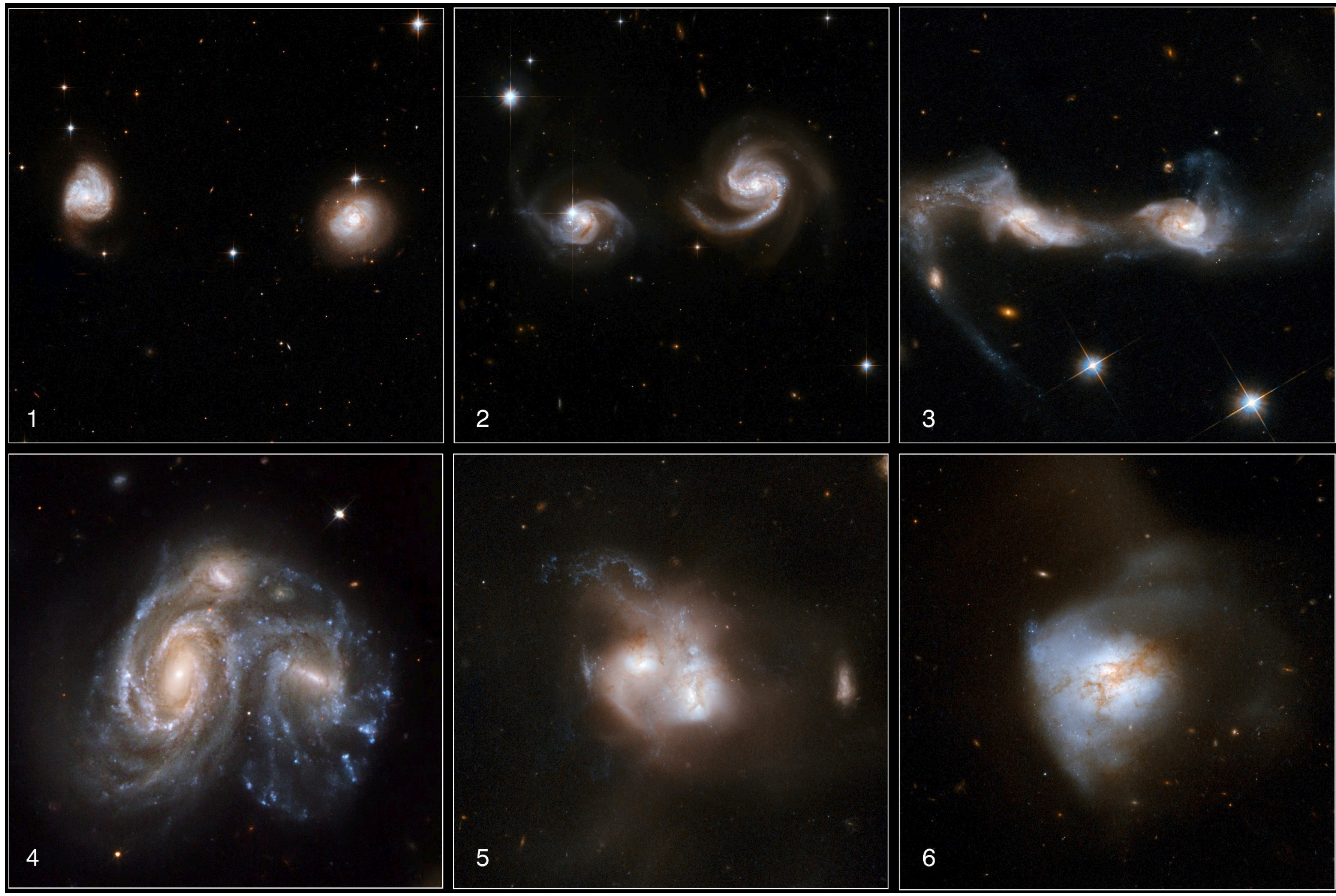
Moffett+2015

Elliptical Galaxies: Origin

Mergers

Elliptical Galaxies: Origin

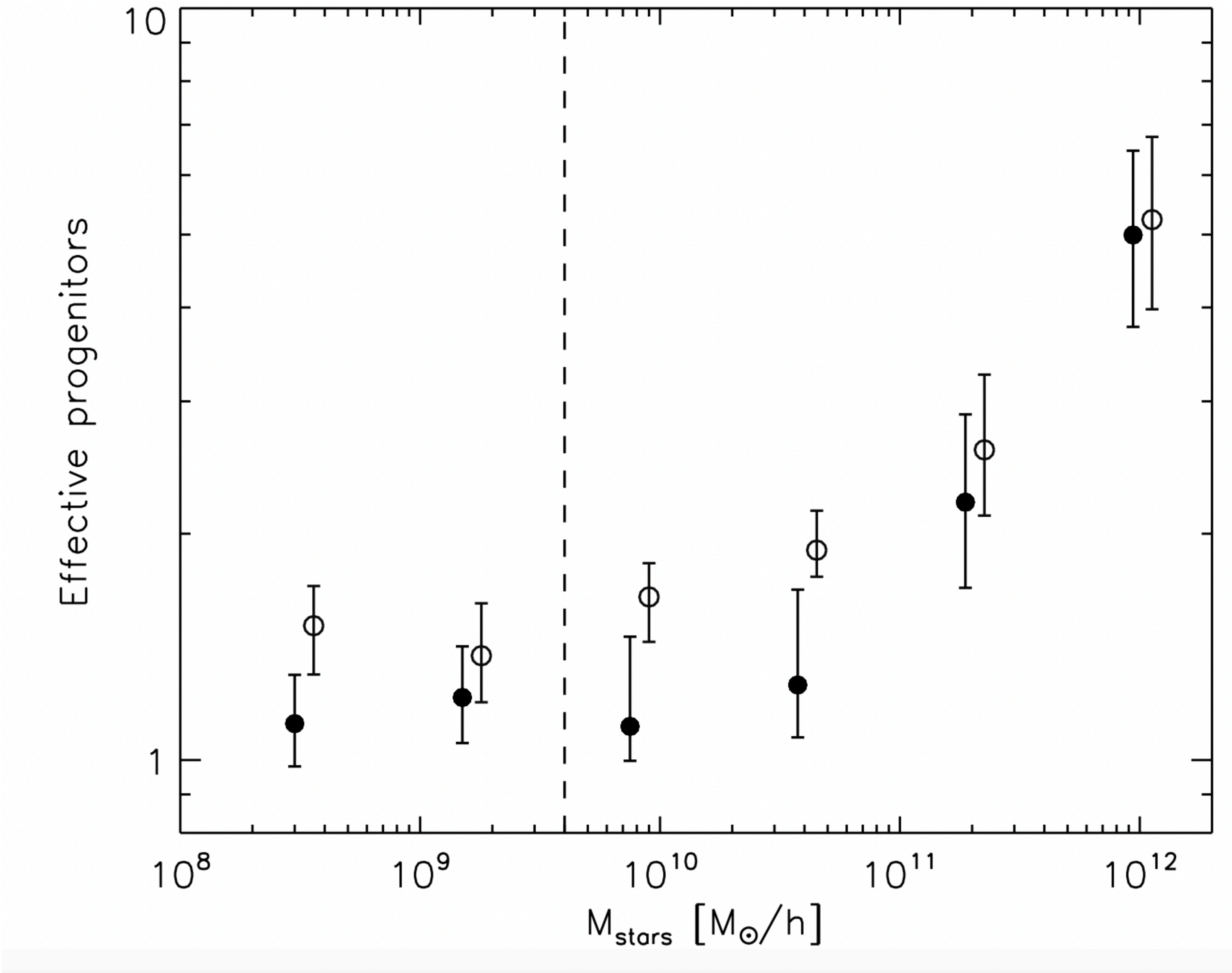
- This is the classical picture we have, primarily driven by “**major mergers**”
    - i.e. 2 MWY-type Galaxies mass ratios near 1
- Result is spheroidal, stars all on (mostly) radial orbits
    - Total (or near total) loss of MWY-like structures (e.g. disk)

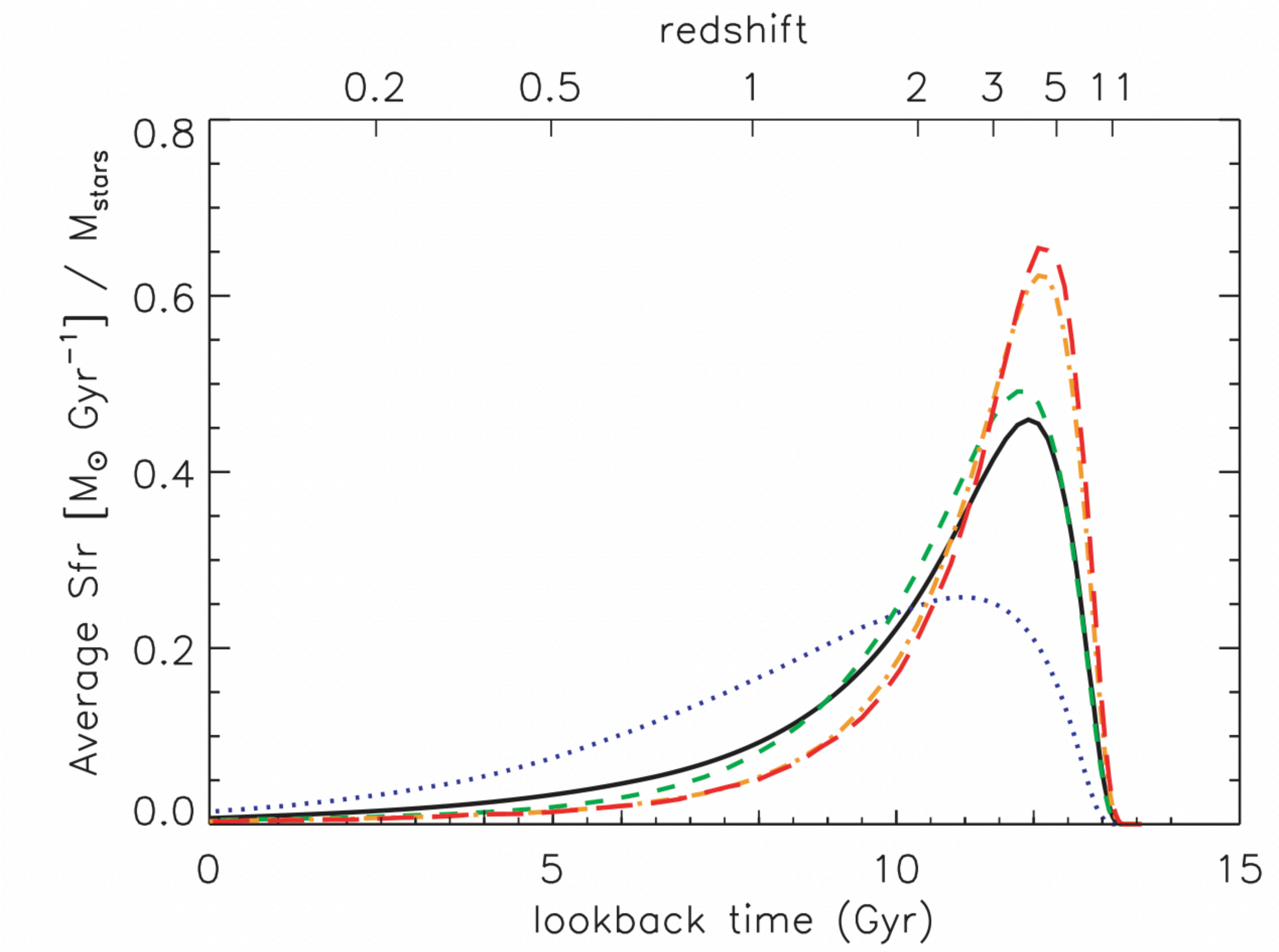


ESA/HST

Elliptical Galaxies: Origin

- Not that many mergers needed to form ellipticals - just gotta get the gas out!
    - Hot or "dry" mergers (i.e. gas used up before merger)

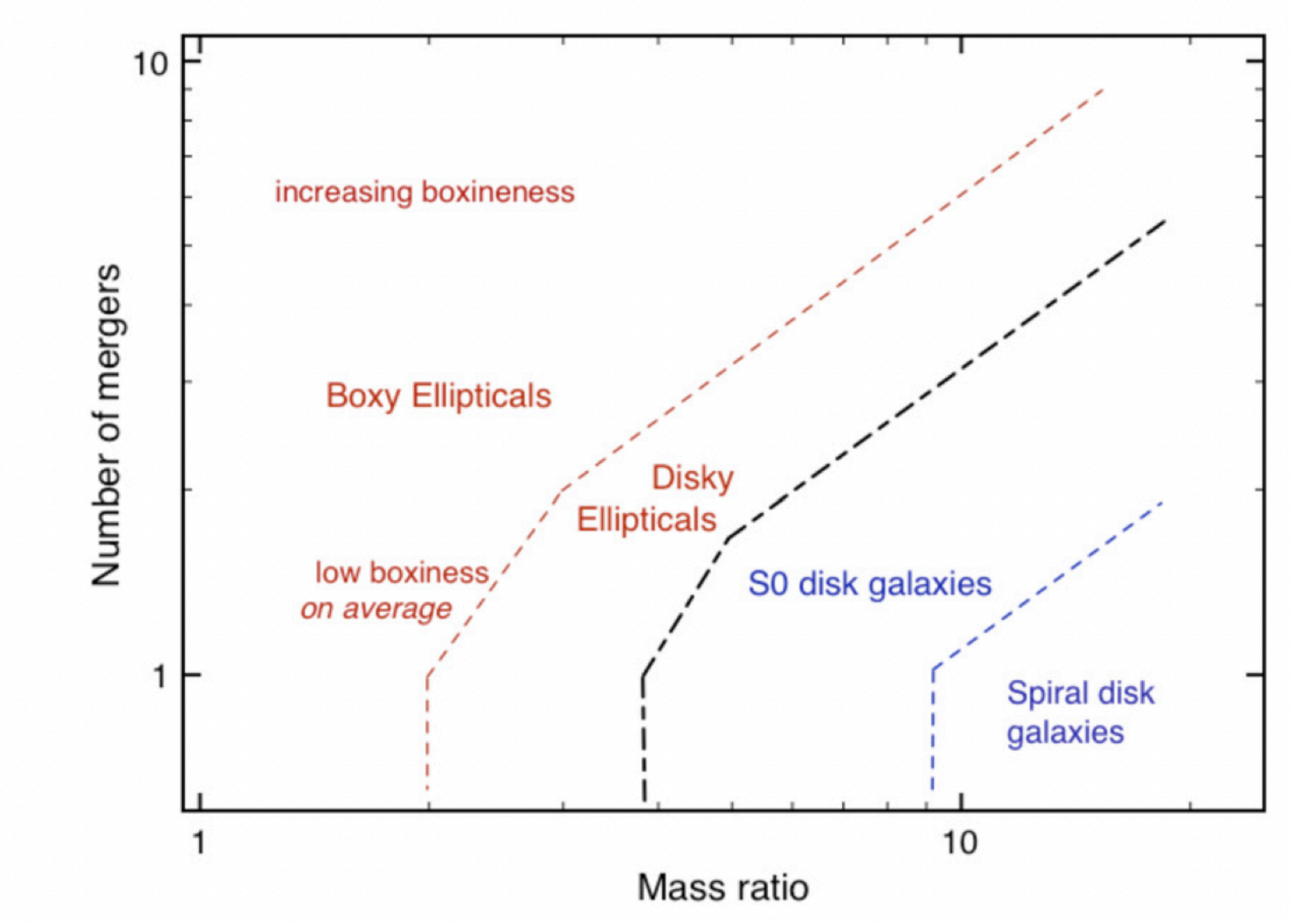




De Lucia +2006

Elliptical Galaxies: Origin

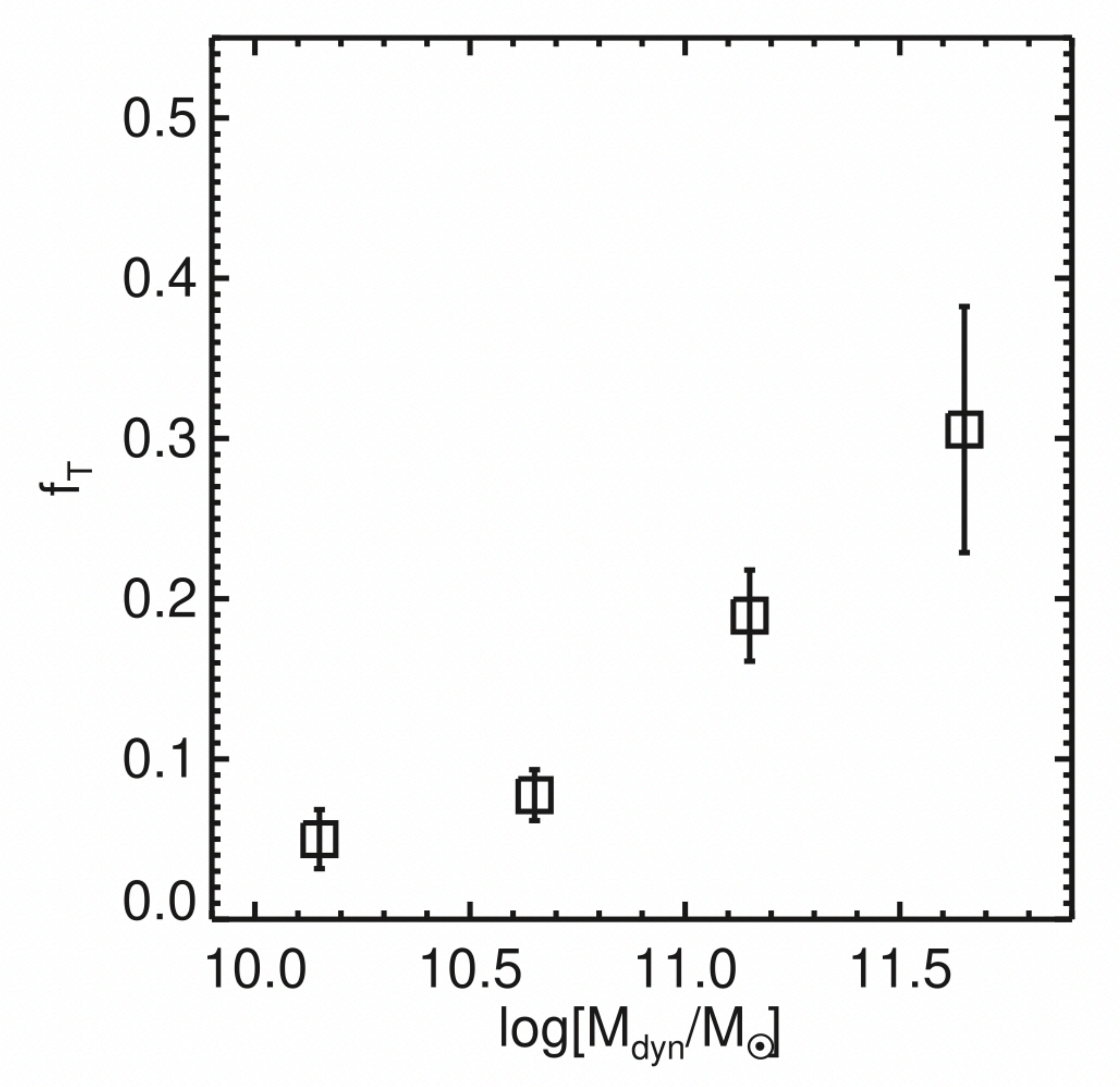
- Mergers form elliptical galaxies… but not JUST major mergers!
- Many minor mergers can create sphere-dominated galaxies
- Its almost too easy to form ellipticals galaxies have lots of mergers (see the MWY!), so it must also accrete lots of cold gas and form its own stars, or else why so many spirals?!

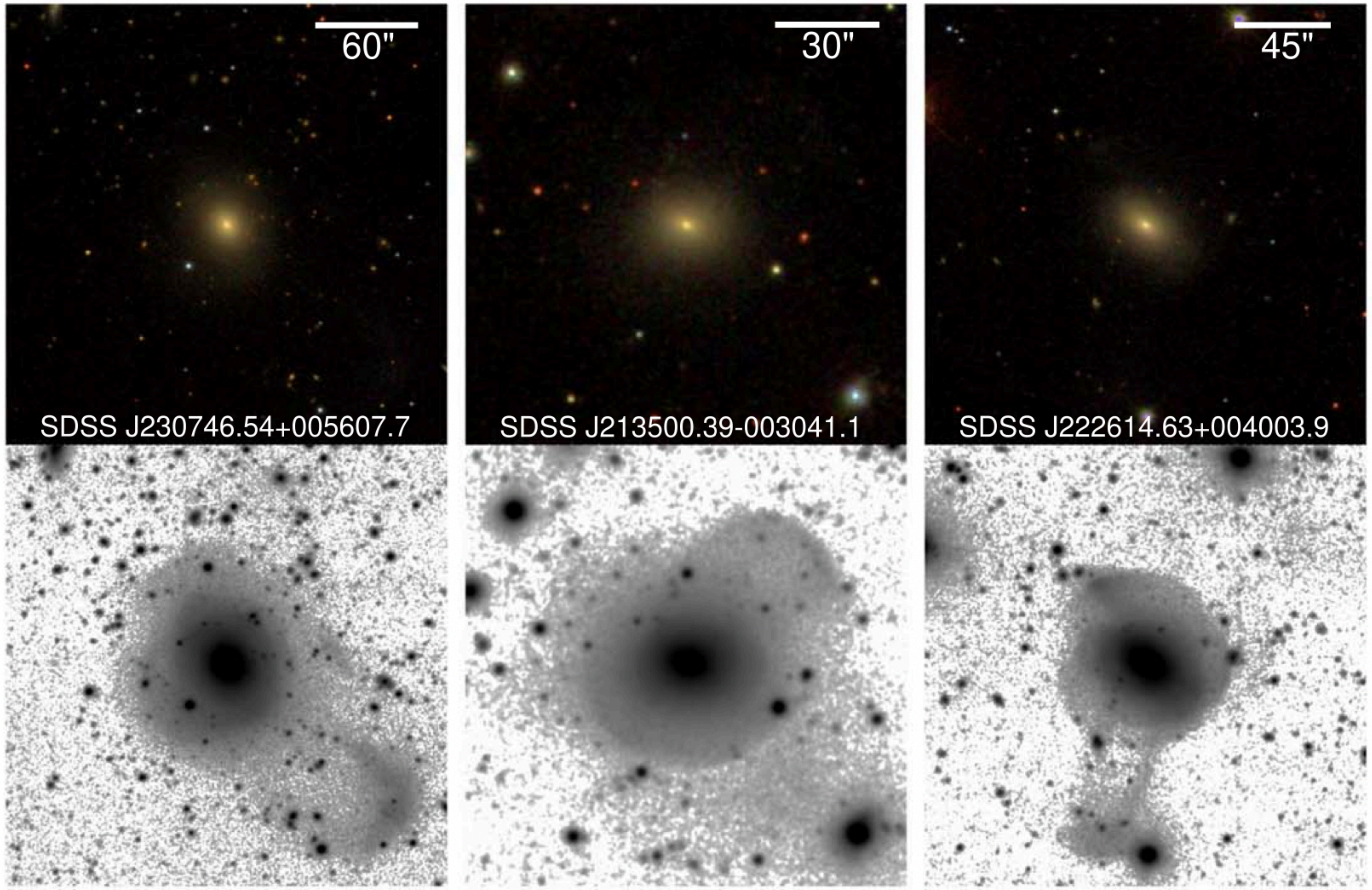


Bournad+2007

Tidal Streams?

- If mergers are the key, then shouldn't we see tidal features? (streams, arms, etc)
- YES! But not *tons* ($t_D < 3$ Gyr)

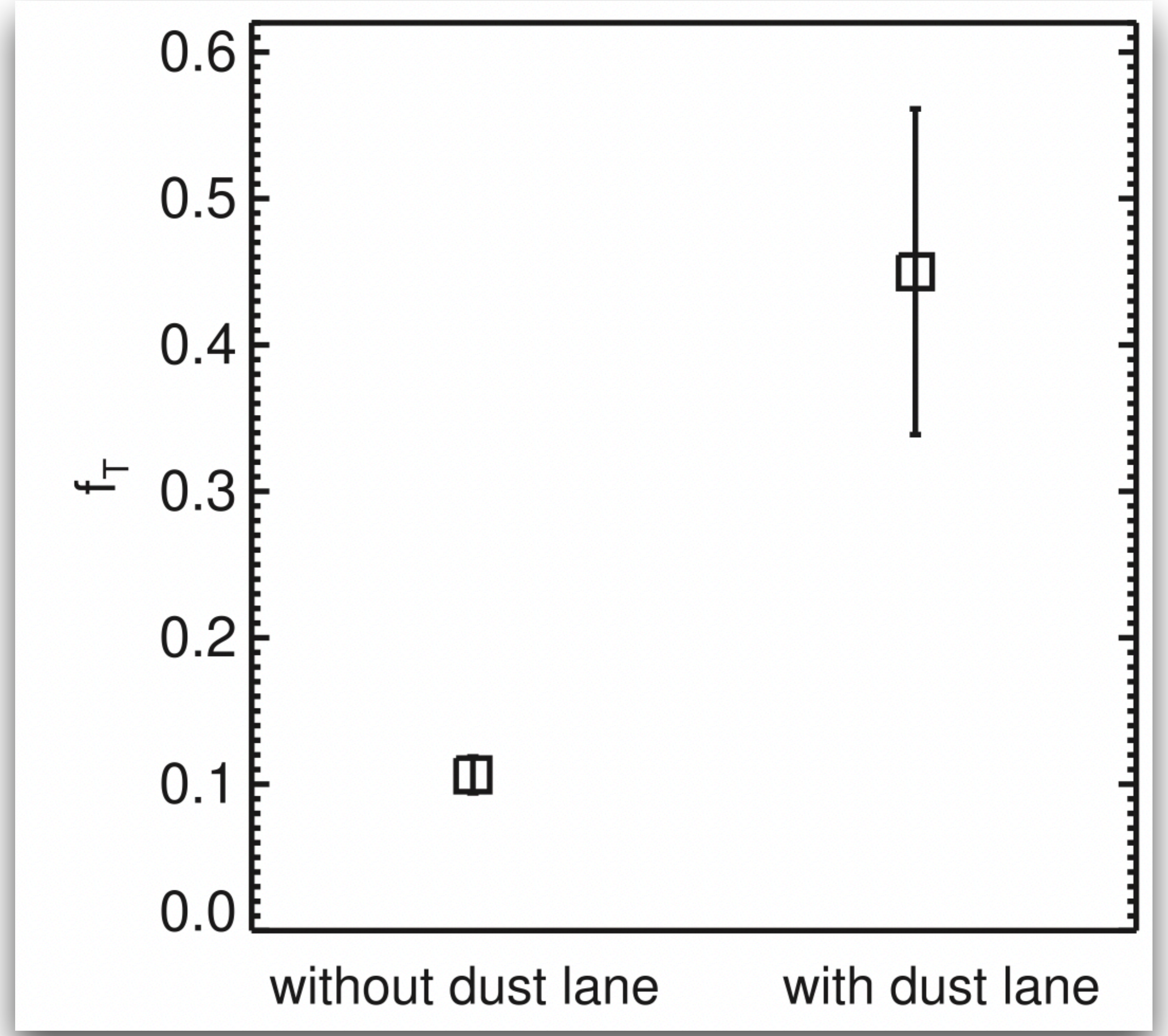


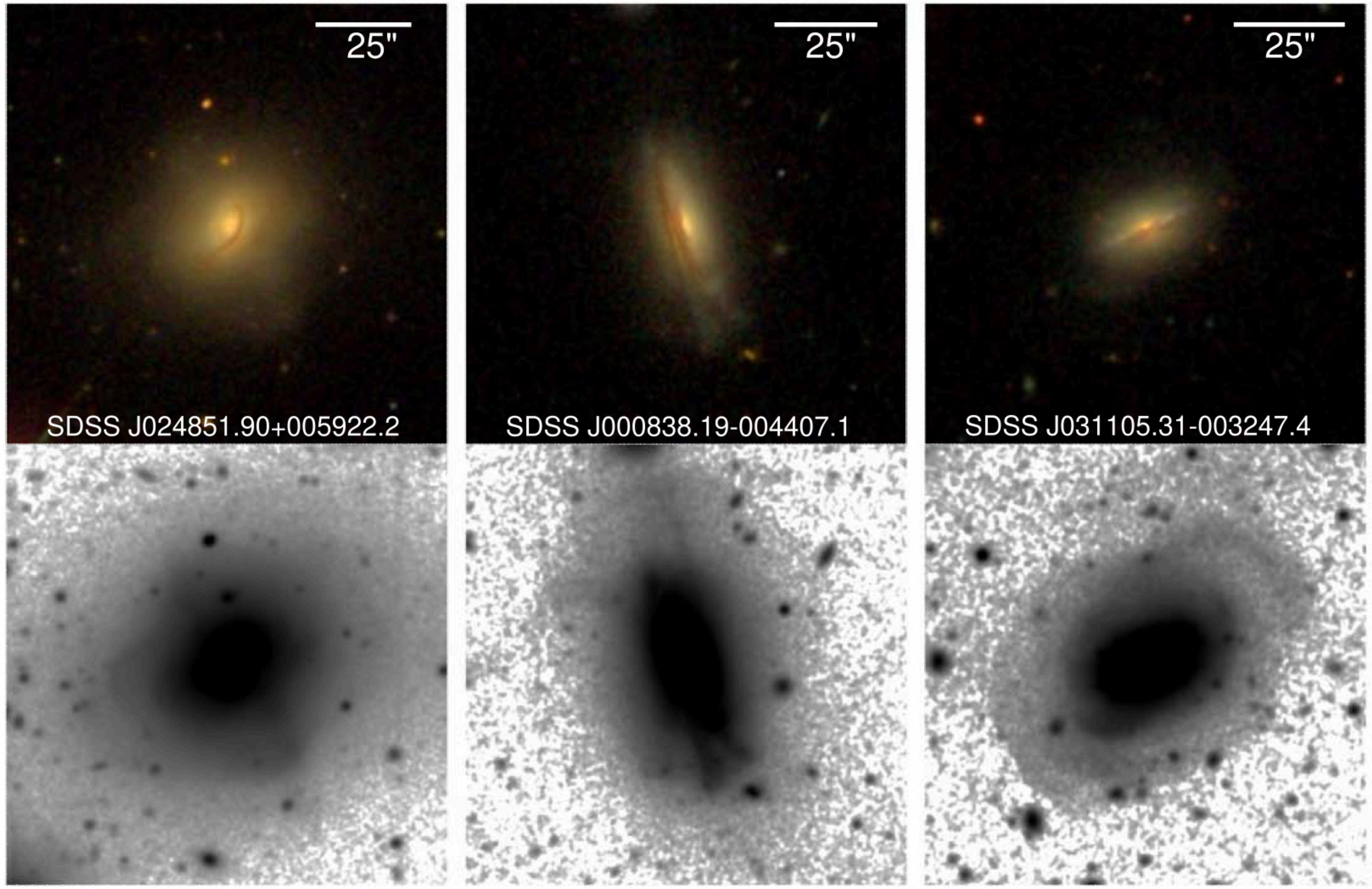


Yoon & Lim (2020)

Tidal Streams?

- More prominent for ellipticals with dust lanes, or bluer colors





Yoon & Lim (2020)

Elliptical Galaxies vs. Bulges

- Are bulges just elliptical galaxies inside disks?
- Sometimes! (e.g. Sa galaxies)
- Review chapter by Kormendy (2016)
- Disks might be able to make bulges themselves, but probably usually the result of mergers early in galaxy history
- Then disk forms by accretion of cool gas (and minor mergers)

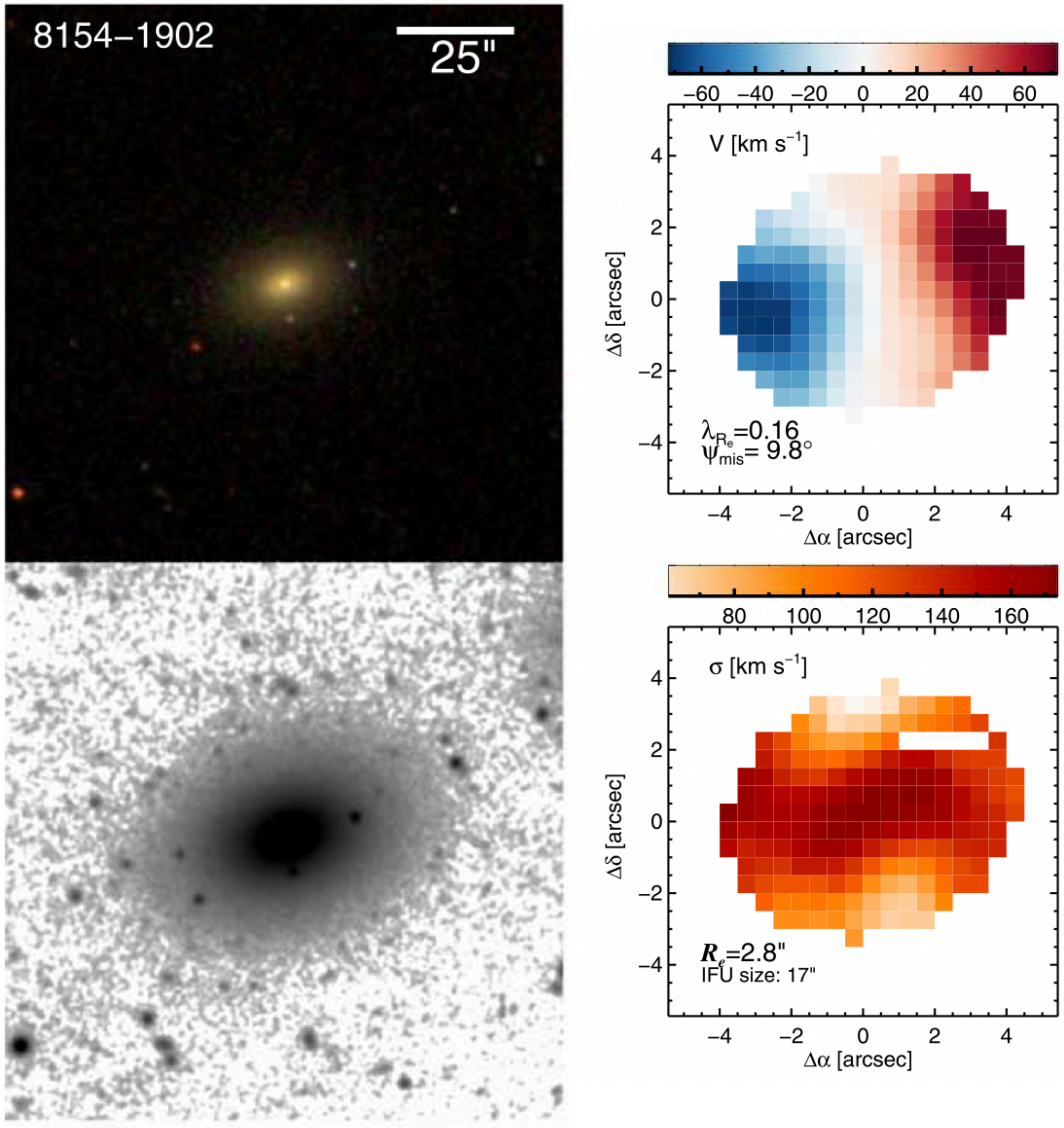
Elliptical Galaxies vs. Bulges

- Kormendy (2016) review has some good high-level takeaways on the state knowledge of Ellipticals
- Says key challenges is not just forming E's, but also bulges, spirals, etc, over +1000x range in mass, and with many overlapping regimes
- Also suggests we blame feedback (esp. AGN) for too much currently
  - Good areas for both future theory & observations!

Elliptical Galaxies

- Typically show net rotation

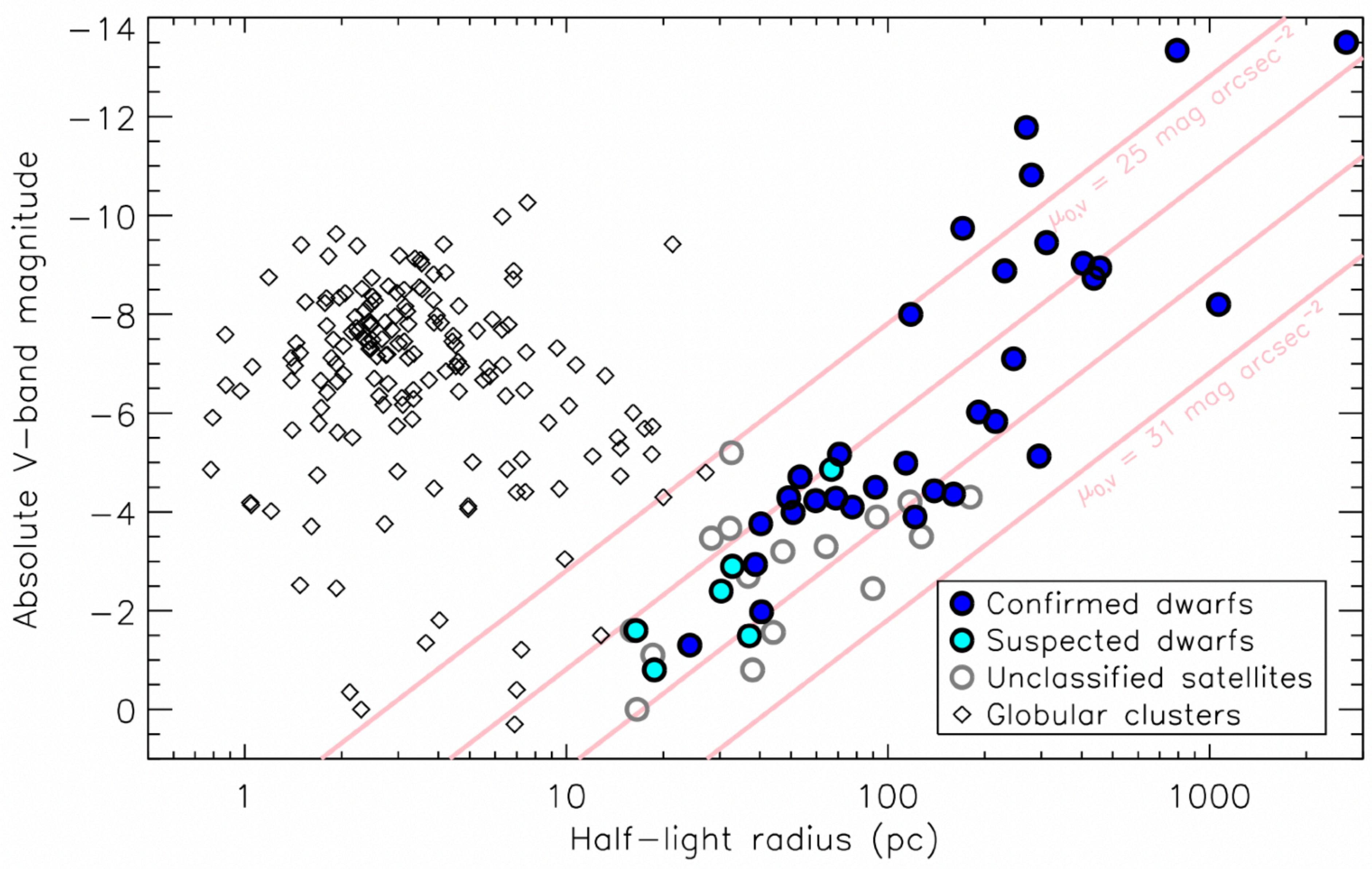
- Higher velocity dispersion in center (orbiting SMBH!)



Yoon+2022

Simon (2019)

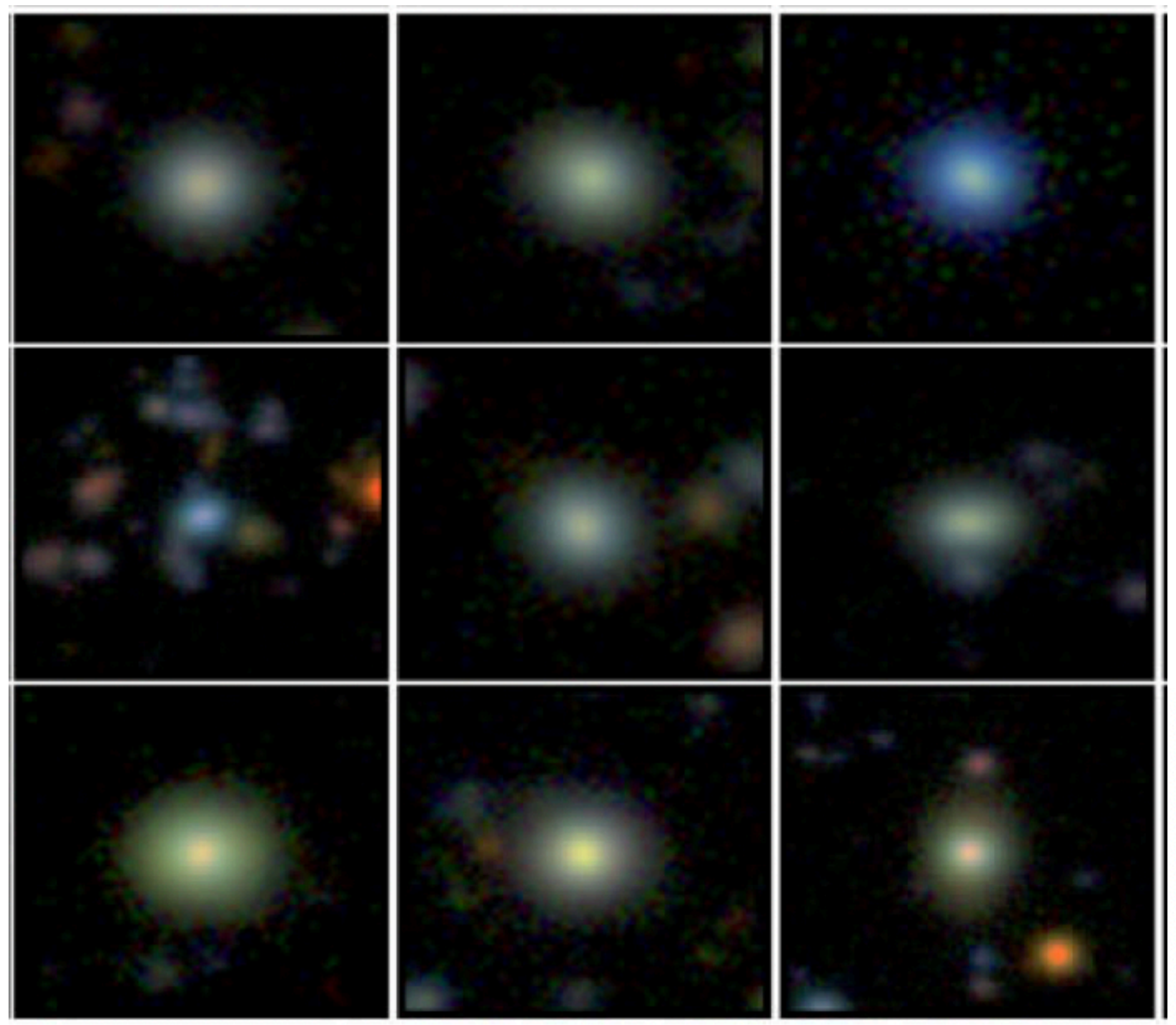
Elliptical Galaxies: Dwarf



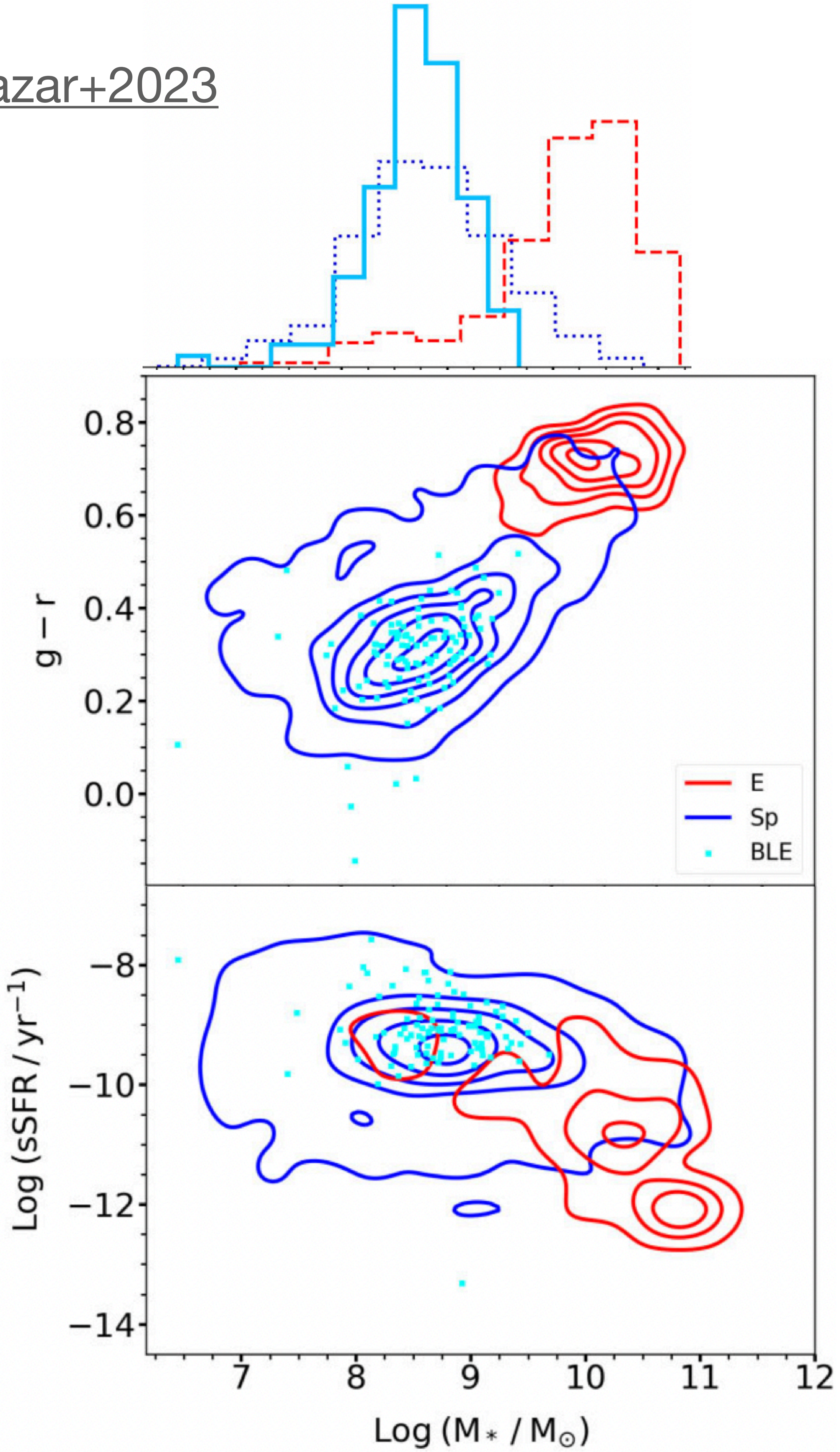
- Less well studied, mixed up with spheroidals, and some overlap with globular clusters!
- Can be red or blue
- Can have rapid rotation, making them oblate (Pedraz+2002)

Elliptical Galaxies: Blue?

- There *are* red spirals & blue ellipticals, just more rare!
- Blue ellipticals: typically small, may just be young, experiencing burst of SF
- Massive blue ellipticals may exist, but could just be optical illusion at high redshift (e.g. George 2023)

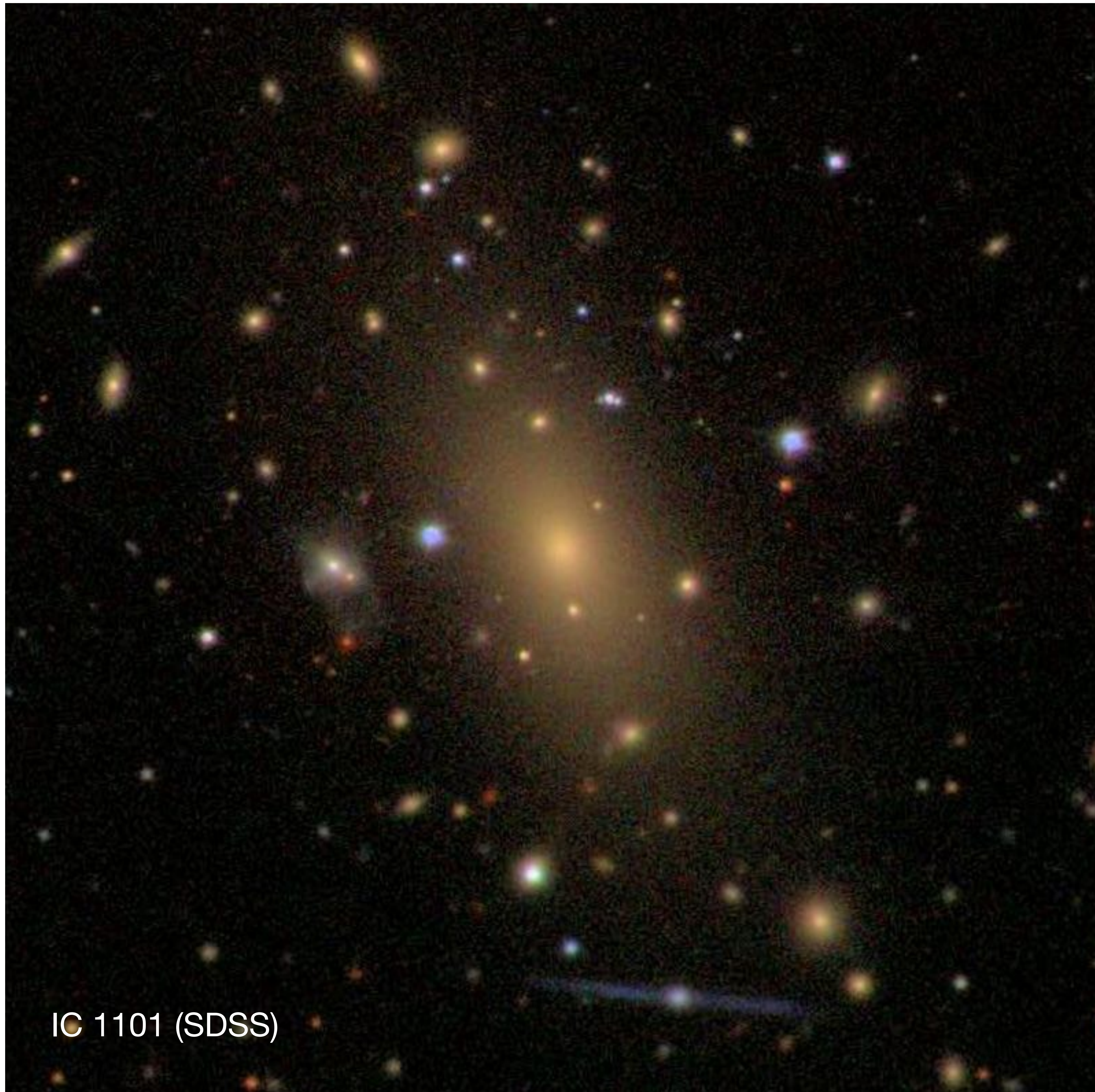


Lazar+2023



Brightest Cluster Galaxy (BCG)

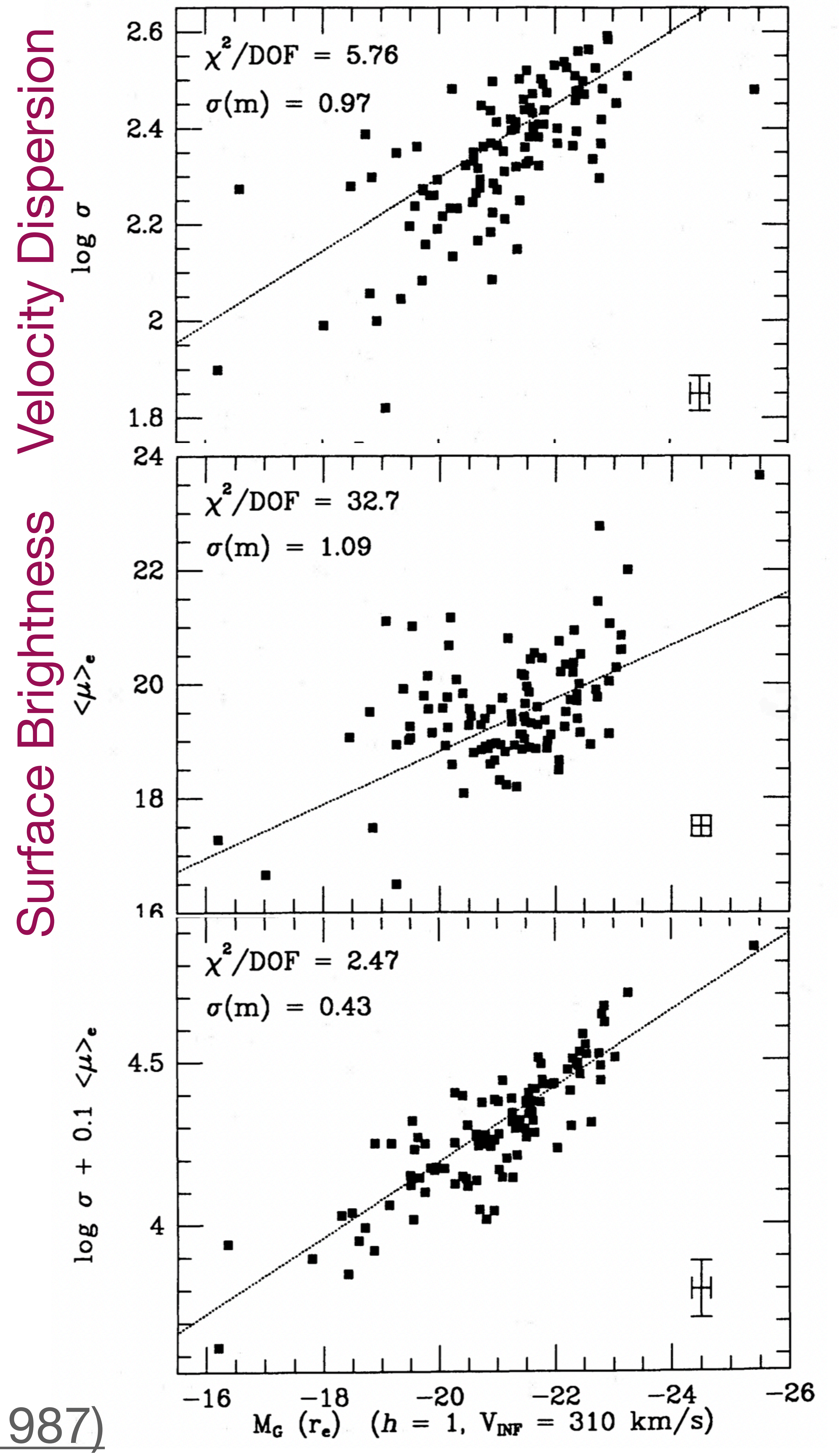
- Sometimes called the *bright central galaxy*
- The most massive galaxies
- Found in centers of galaxy clusters
- Can have boxy isophotes (shapes)
- Why no star formation?
  - Hierarchical merger history
  - AGN feedback in the feeder galaxies (De Lucia & Blaizot 2007)



IC 1101 (SDSS)

Fundamental Plane

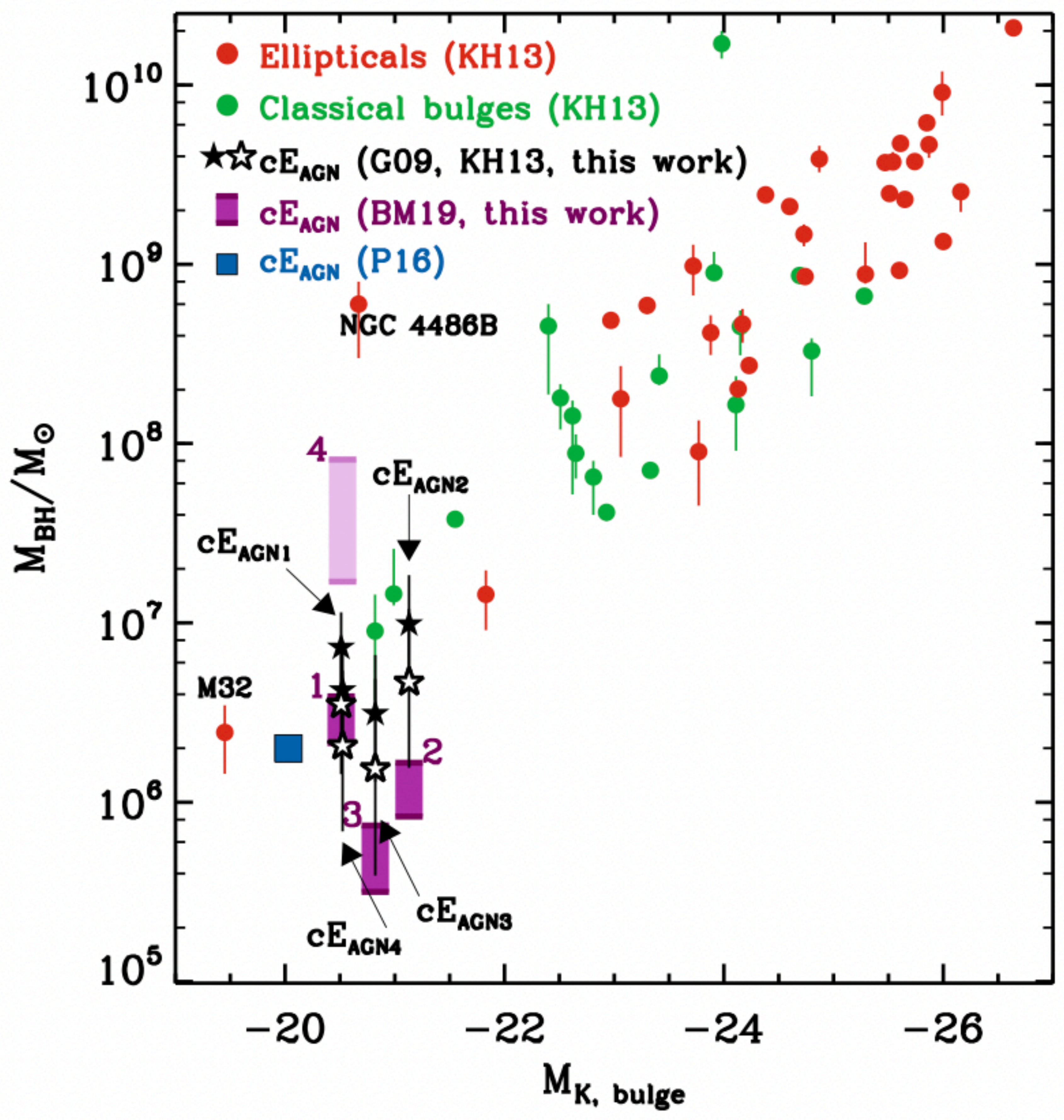
- Connects luminosity with mean surface brightness and central velocity dispersion
- More luminous (massive) galaxies have larger velocity dispersions
(**Faber-Jackson** Relationship, akin to Tully-Fisher)
- Massive galaxies have larger radii, lower surface brightness
- Use: estimating luminosity using measurable quantities (σ_V and $\langle\mu\rangle$), giving improved distances for ellipticals!



 Djorgovski & Davis (1987)

AGN in Ellipticals?

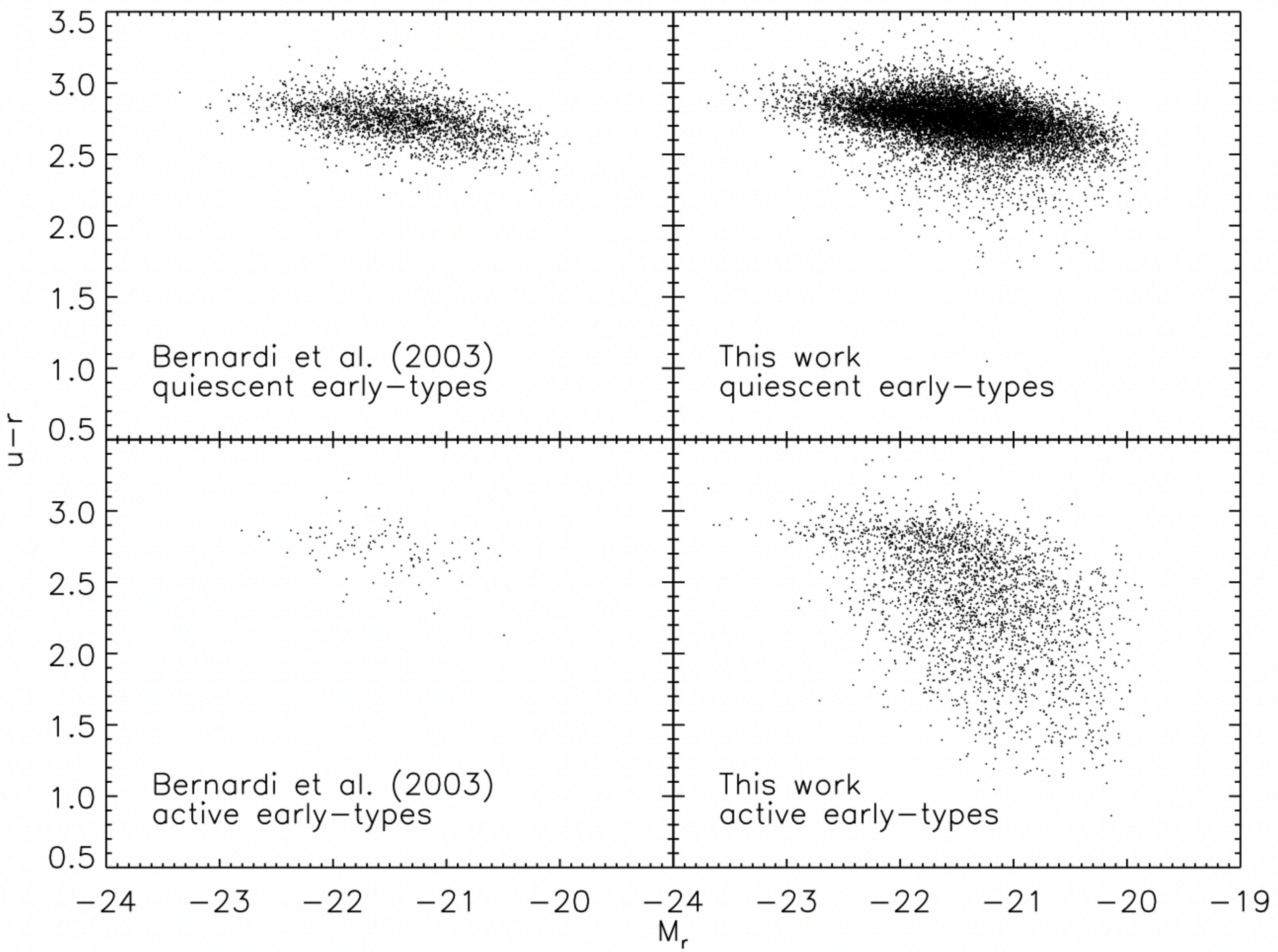
- Origin of compact Ellipticals still debated
  - Are they the core of a stripped galaxy? If so, might expect BH mass & activity to look like original galaxy
- AGN can be found in compact Ellipticals!
- These are rare, but follow expected trends for normal small galaxies, and for AGN (e.g. are in isolated environments like most AGN, not preferentially in mergers)



Rey+2021

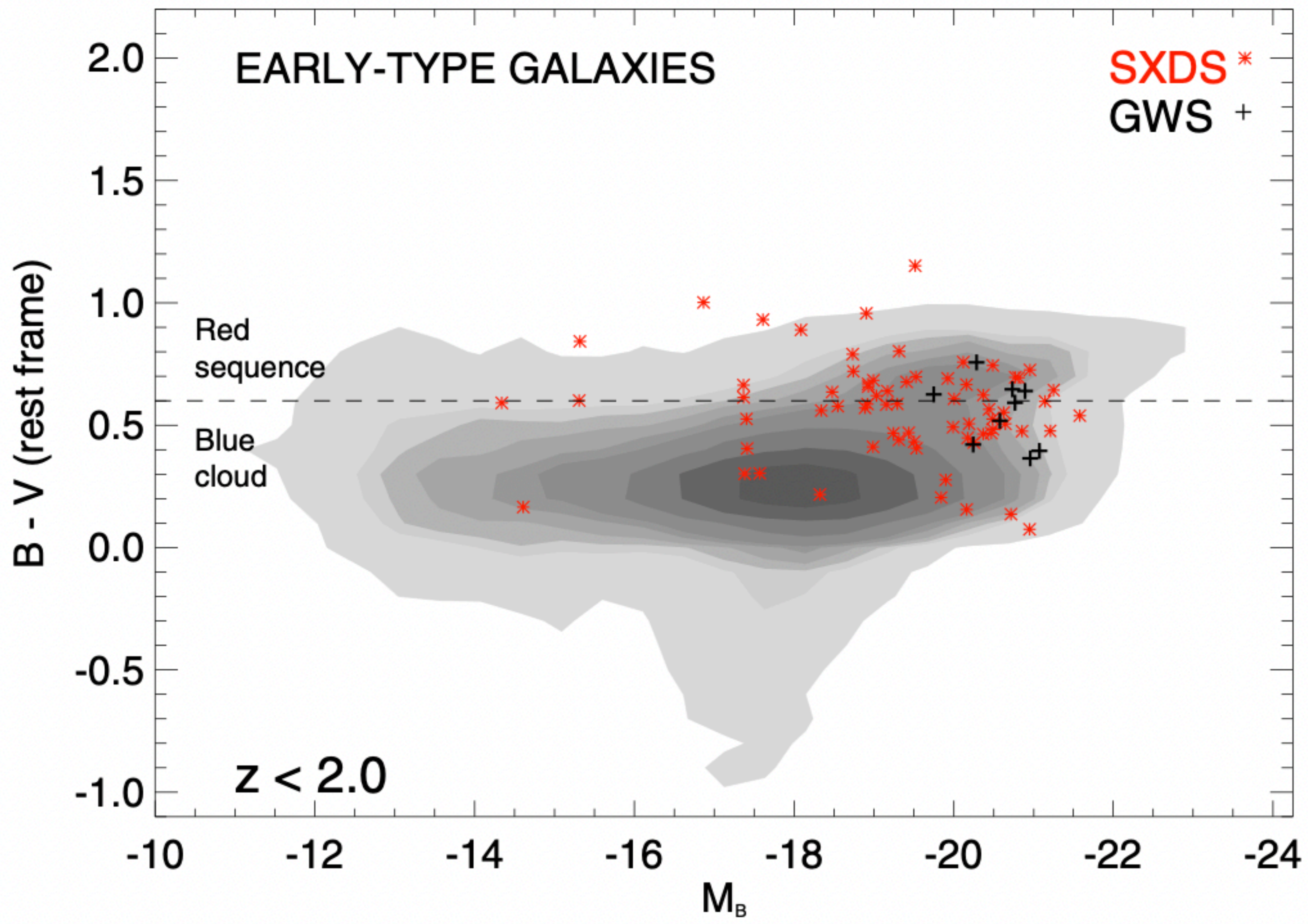
AGN in Ellipticals

- Early type galaxies of all masses can host AGN
- AGN a source of major feedback & ionization (i.e. inhibit star formation), but not the *only* form of feedback! (Schawinski+2007)



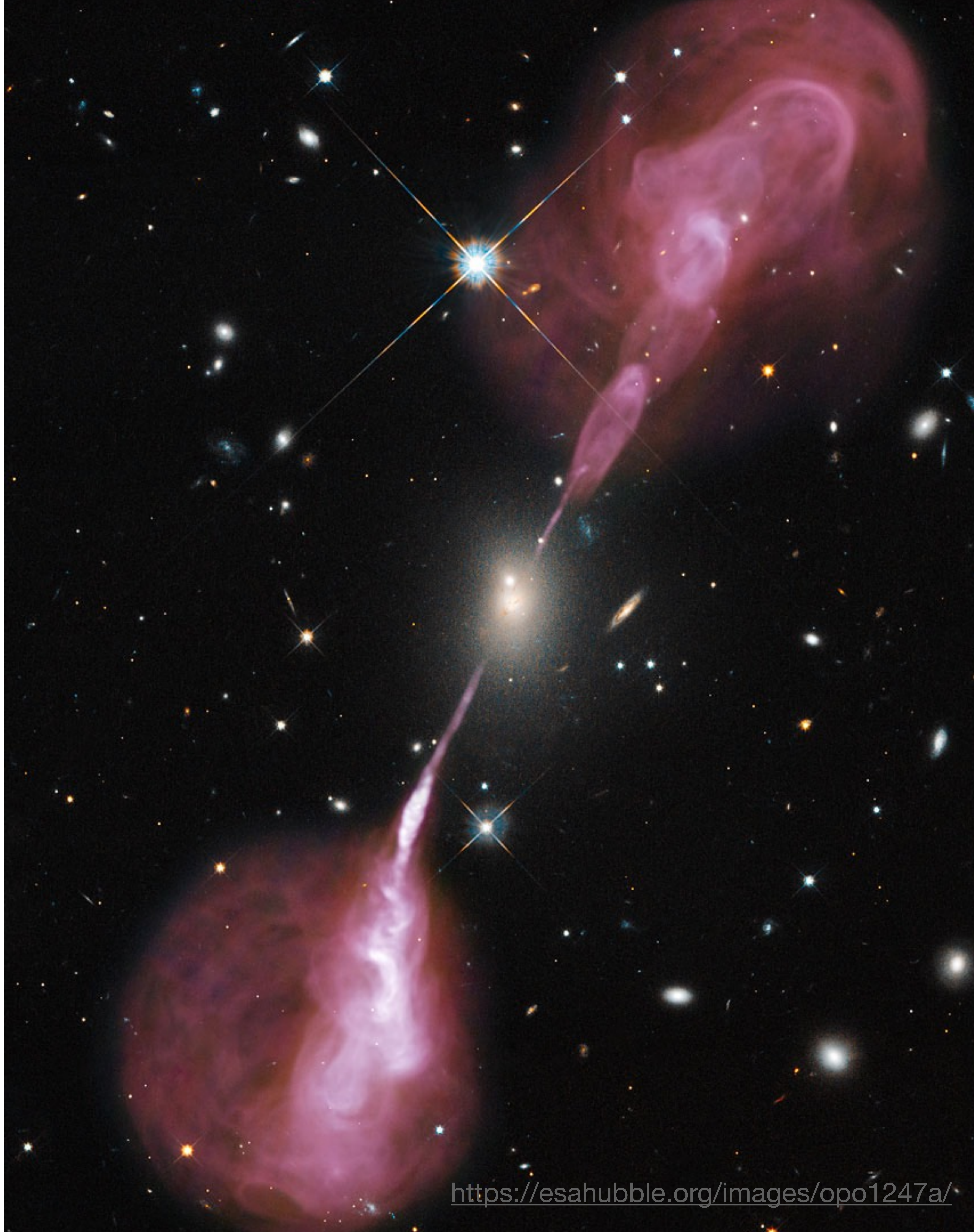
AGN in Ellipticals

- AGN can occur in the "Green Valley" (for early and late type galaxies) (Pović+2012)
- Maybe triggered by mergers, AGN helping create the quenching (feedback) needed to cause galaxies to cross the Green Valley



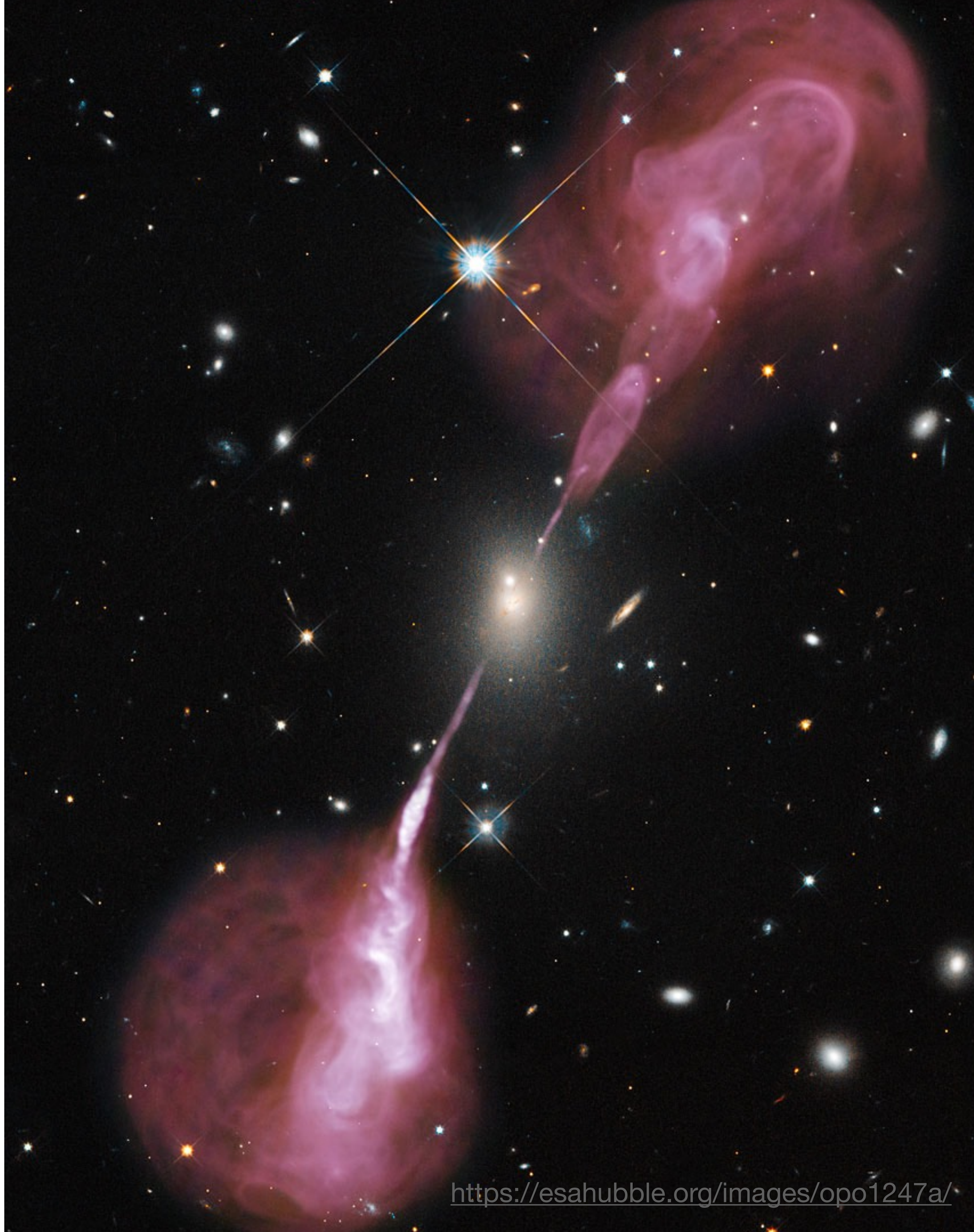
Radio Galaxies

- Have (very) large radio lobes or jets
- Almost always from elliptical galaxies, driven by SMBH (AGN)
- Hercules A (shown here) a VERY massive elliptical, also surrounded by X-ray halo (e.g. Boccardi+2017)


https://esahubble.org/images/opo1247a/

Radio Galaxies

- So much more to explore here…
  - LINERS, Seyferts, AGN & Quasars
- Lots of multi-wavelength work (high energy, x-ray, and radio)
- Accretion powered astrophysics rocks!



Next Time

- Reminder: no class Thursday
- **Friday @ 10AM, PAB 360 (computer lab)**
  ~13 prospective grads will be there
- Galactic Astronomy in the Next Decade