Astronomy 537

Lecture 12: Ellipticals

Journal Class

- **Observational Evidence of AGN Feedback**
- Fabian 2012

Discussion leader: **Sarah Stamer**

Note: To encourage discussion everybody must pose at least one question during the group discussion

Key concepts:

Elliptical galaxies: structure

Fundamental plane

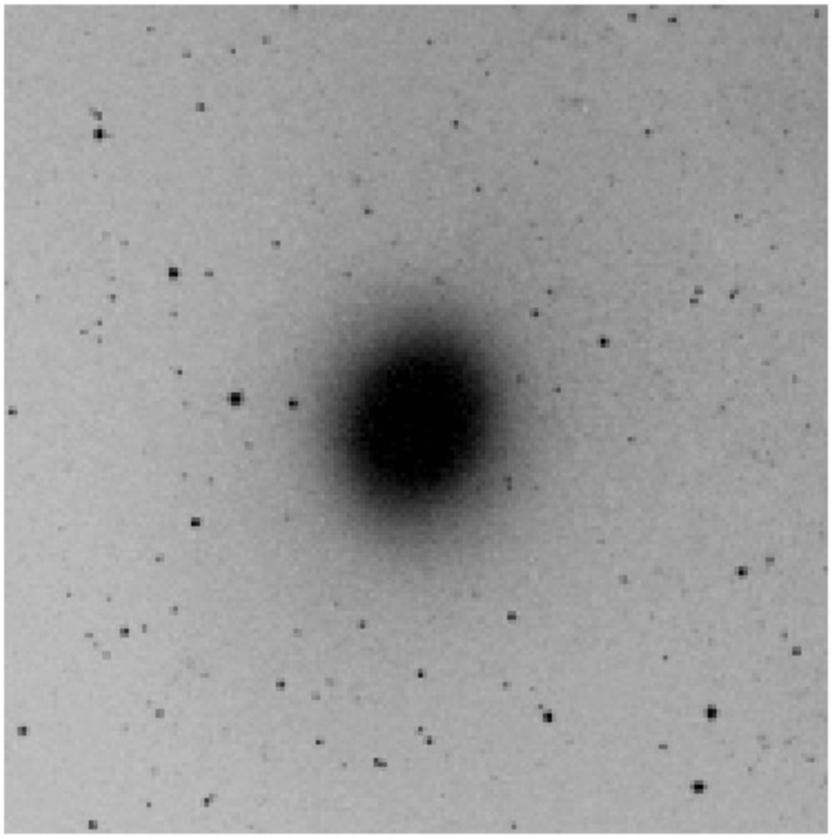
Faber-Jackson relation

Luminosity Functions of Galaxies

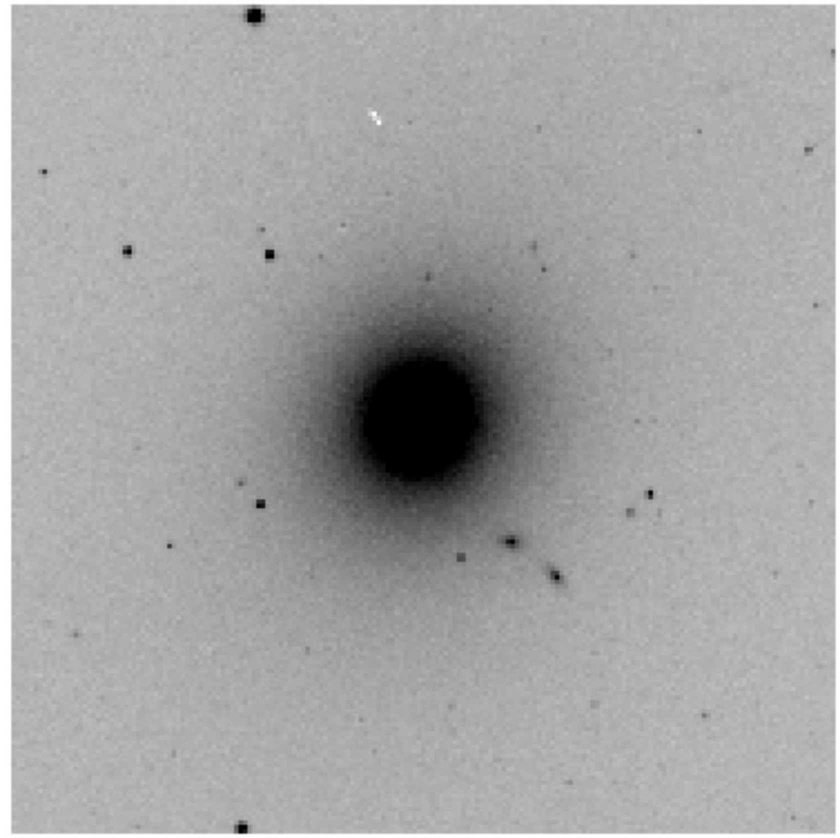
- Generally no star formation
- Little dust
- Regular morphologies
- Supermassive black holes at their nuclei
- Large range in properties:
    - luminosity
    - surface brightness profile
    - rotation rate

Huge Range in Elliptical galaxy luminosity

M32

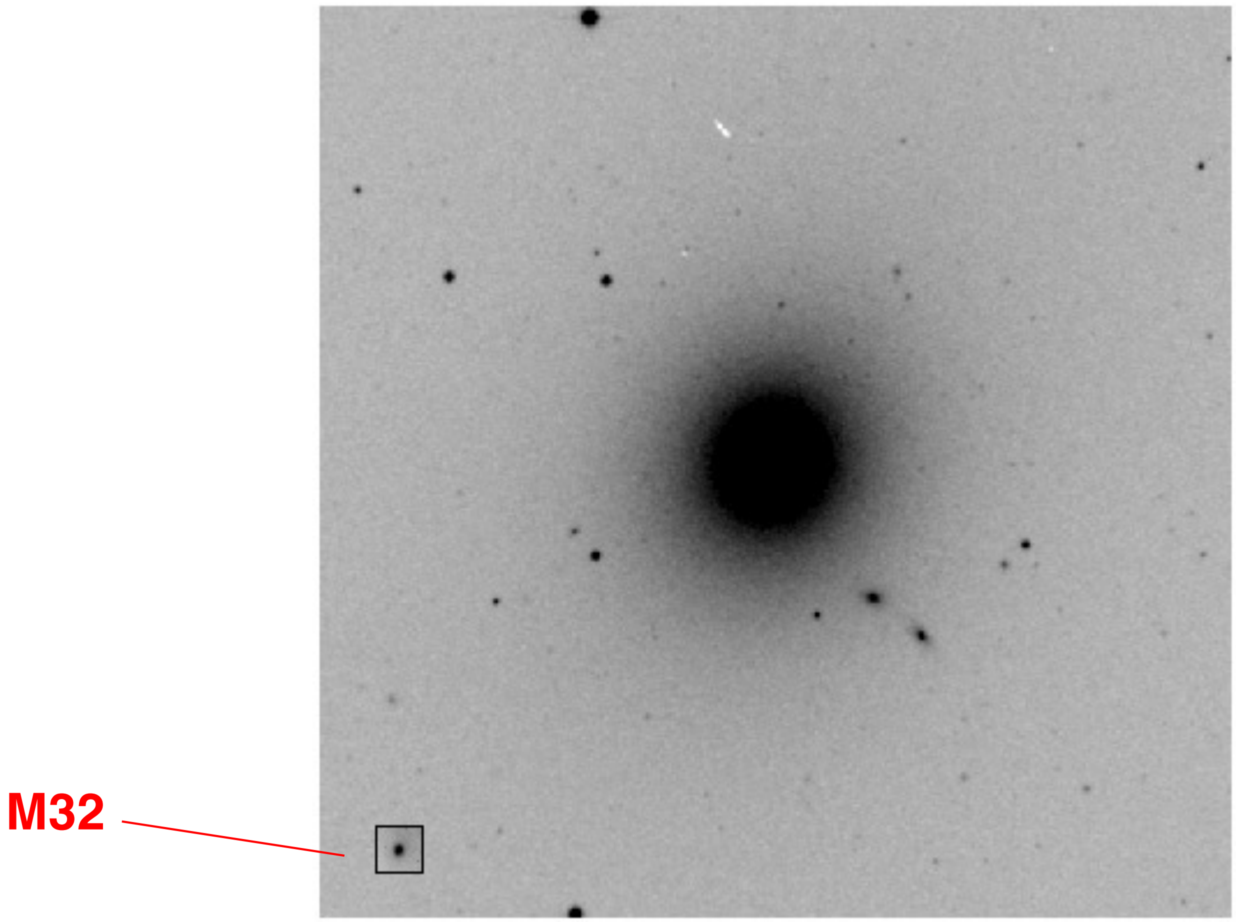


M87



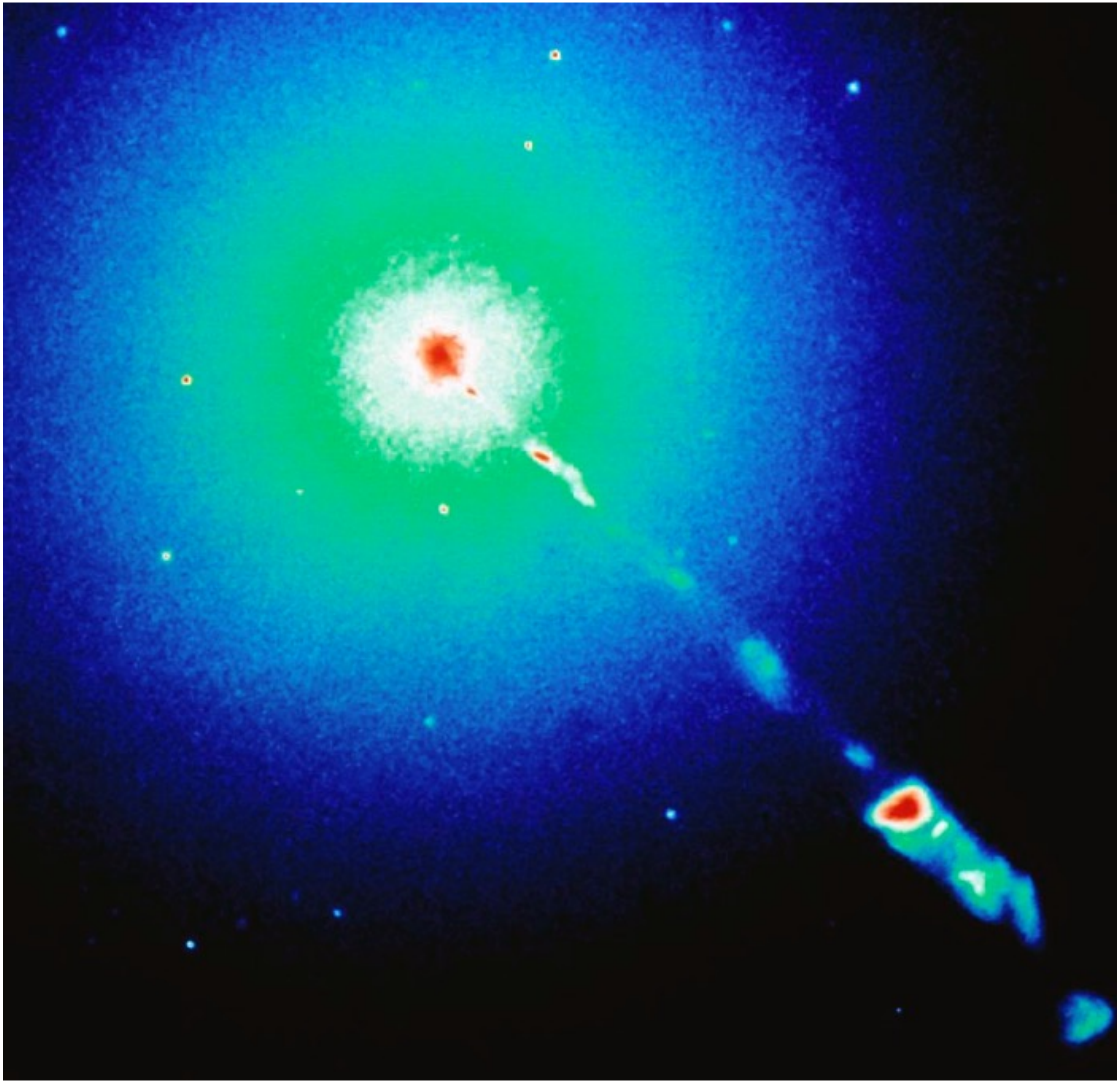
M32 and M87 side by side as they appear in the sky. Both images are 10’ x 10’

Huge Range in Elliptical galaxy luminosity



M32 and M87 with M32 scaled to appear as it would at the distance of M87.

The radio jet in M87



cD galaxies

- largest and brightest
  - up to 1 Mpc across
  - 10^{13}-10^{14} $M_{\odot}$

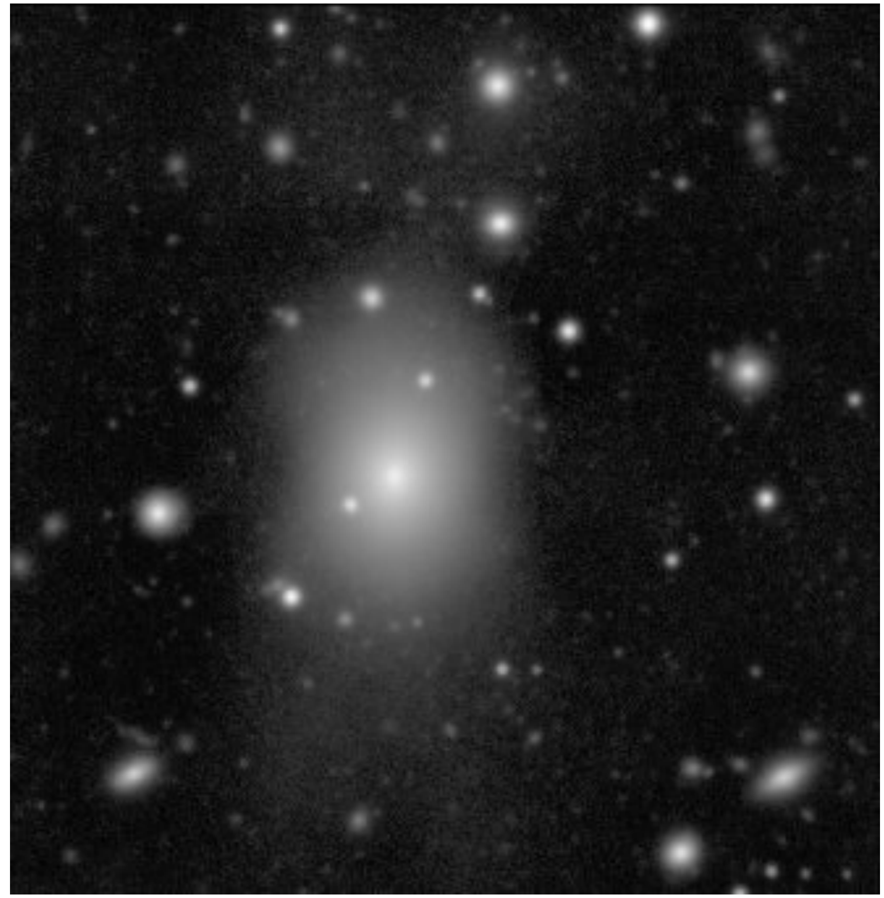
- High surface brightness core

- Extended, diffuse envelopes (including X-ray halo)

- Large amounts of globular clusters

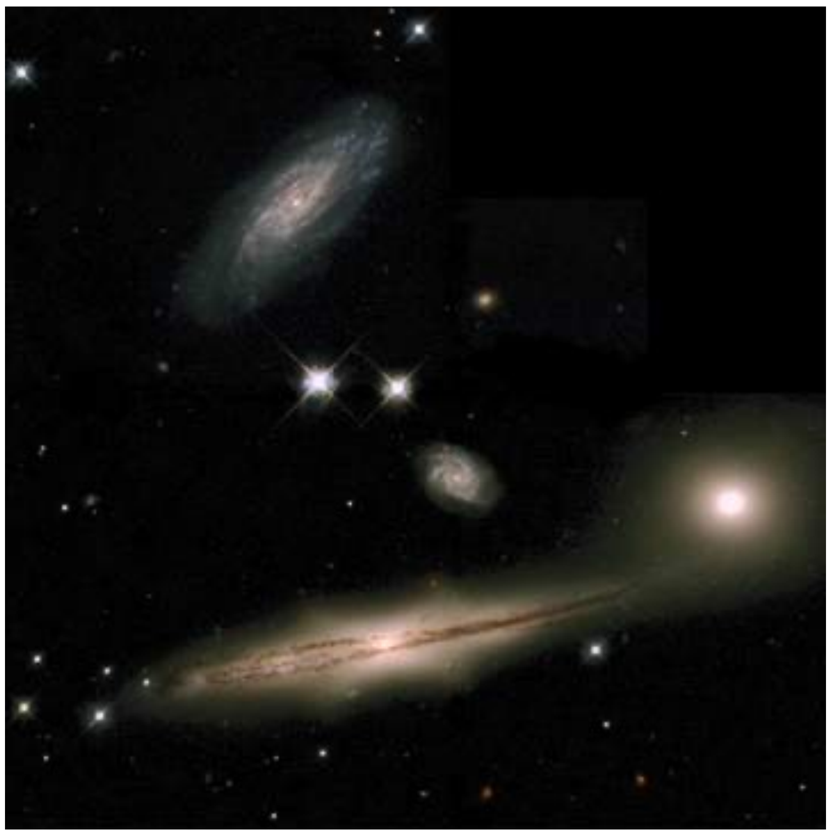
- High mass-to-light ratio

- Located at cores of galaxy clusters



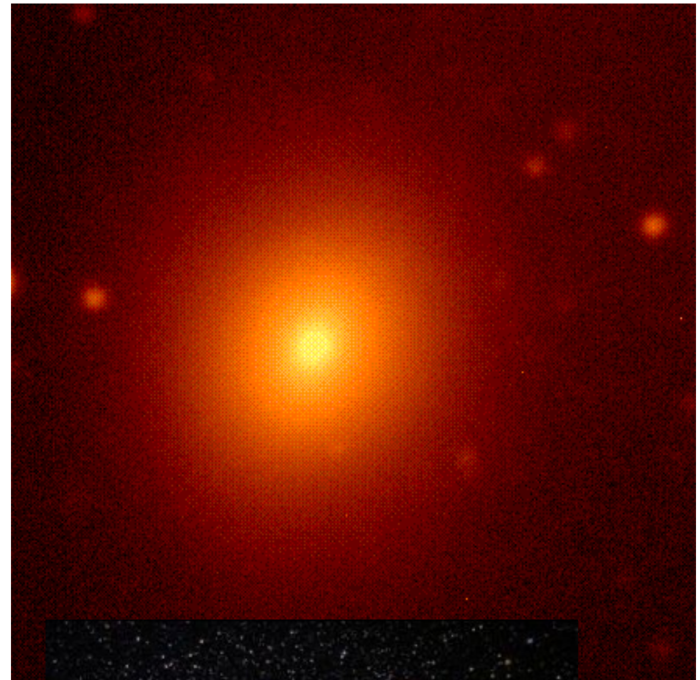
Normal elliptical galaxies

- gE - giant ellipticals
- E - intermediate luminosity
- cE - compact ellipticals
- SO and SBO galaxies are often grouped with ellipticals.



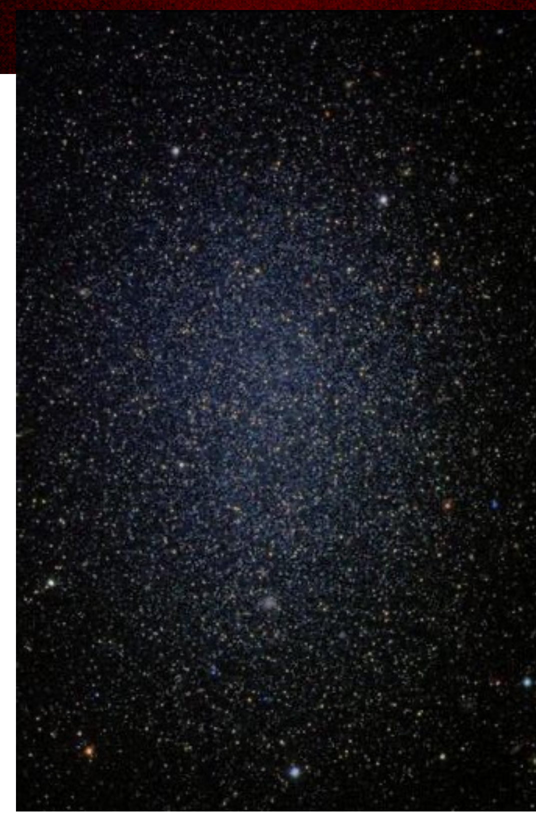
Dwarf ellipticals (dEs)

- lower surface brightness than cEs
- 10^7-10^9 $M_\odot$
- 1-10 kpc diameters



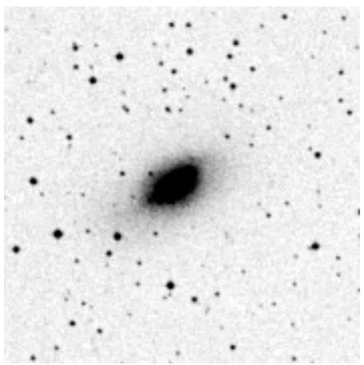
Dwarf spheroidals (dSphs)

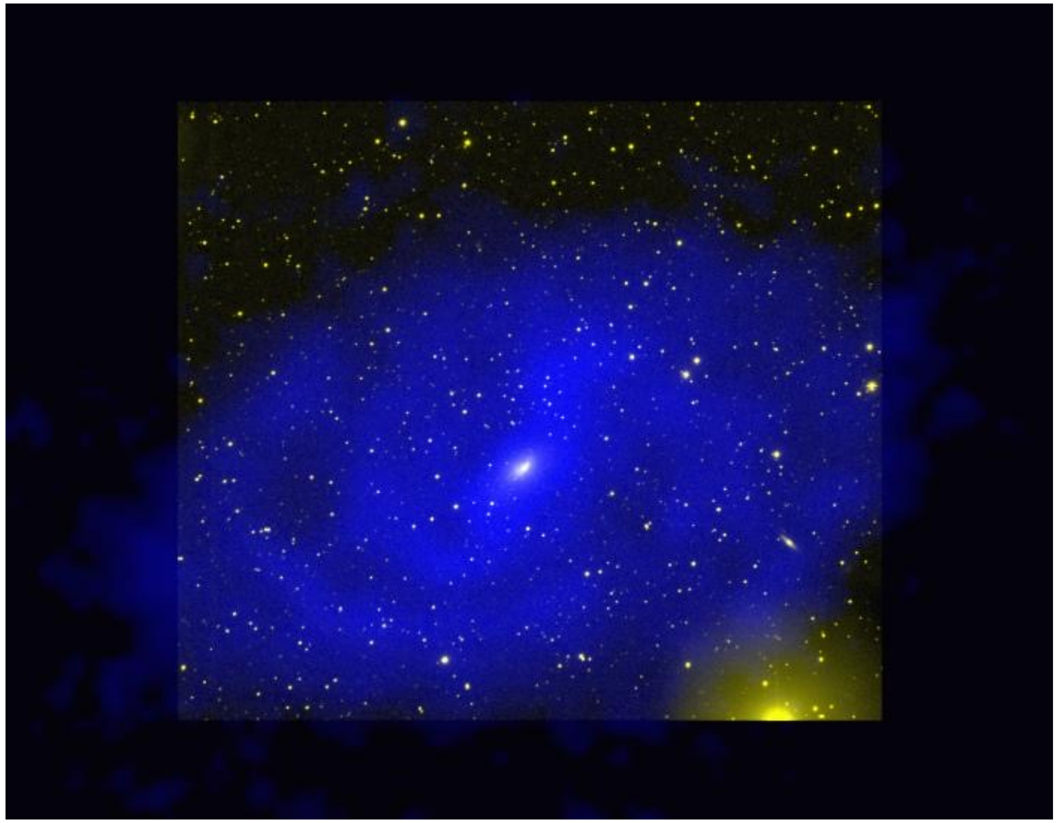
- extreme dEs
- only visible in the Local Group
- 10^7-10^8 $M_\odot$
- 0.1-0.5 kpc diameters



Blue Compact Dwarf galaxies (BCDs)

- Small galaxies which are unusually blue
- Vigorous starformation, plenty of gas
- Low mass-to-light ratios
- $\sim 10^9\ M_\odot$
- < 3 kpc diameters



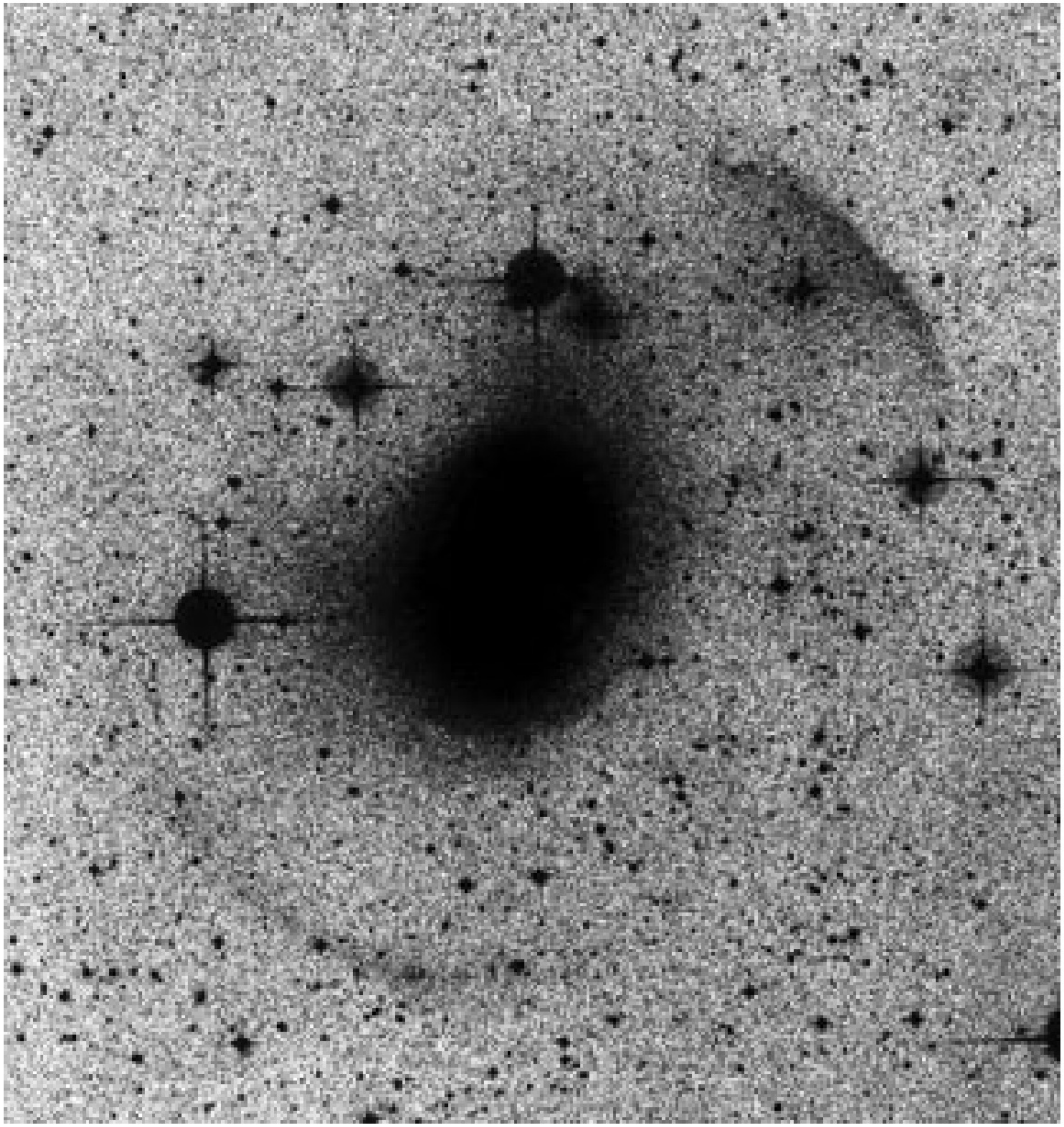


A few properties

	cD	E/S0	dE	dSph	BCD
log $(M/M_{\odot})$	13-14	8-13	7-9	7-8	~9
Diameter (kpc)	300-1000	1-200	1-10	0.1-0.5	<3
M/L_B	>100	10-100	~10	5-100	0.1-10

Profile:					
$r^{1/4}$ law	x	x			
exponential			x	x	

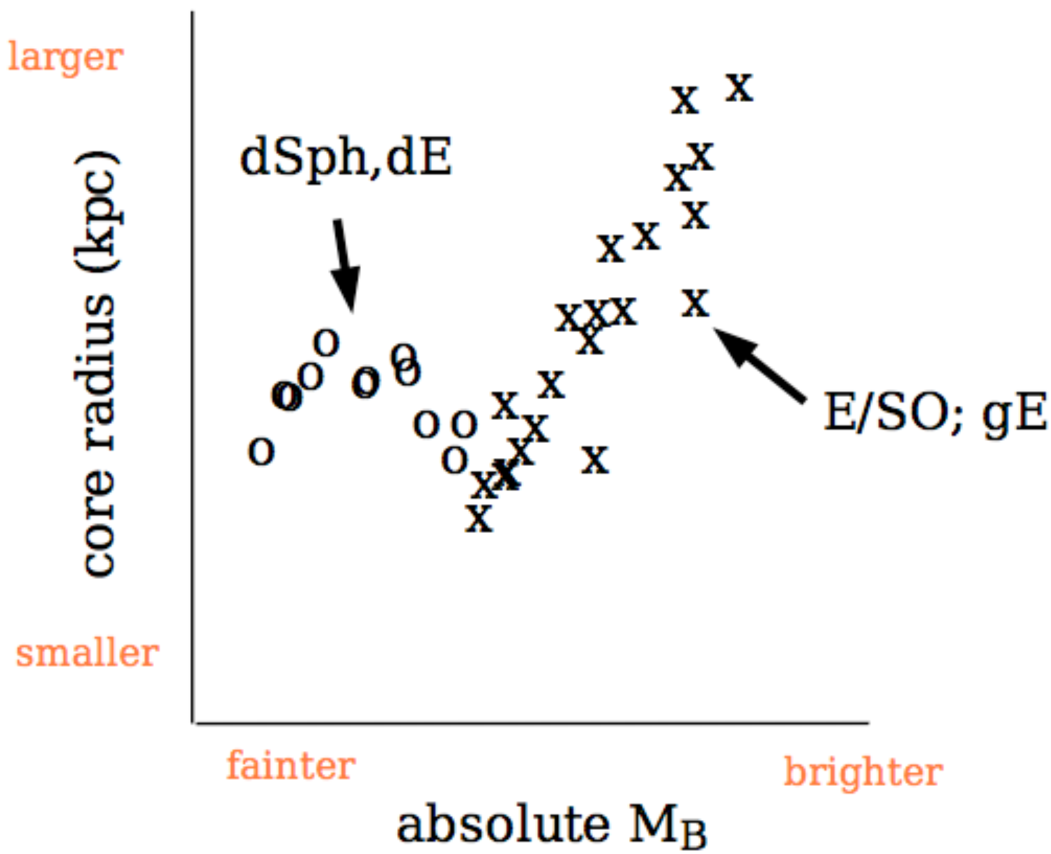
Basically a sequence in *size.* Much different from the spiral sequence.



NGC 1344

Observed correlations

Not fully understood, compares to the HR diagram.



Photometry of ellipticals

With HST we can study the nuclei of elliptical galaxies:

- Luminous ellipticals show central cores
- Mid-sized ellipticals show central cusps

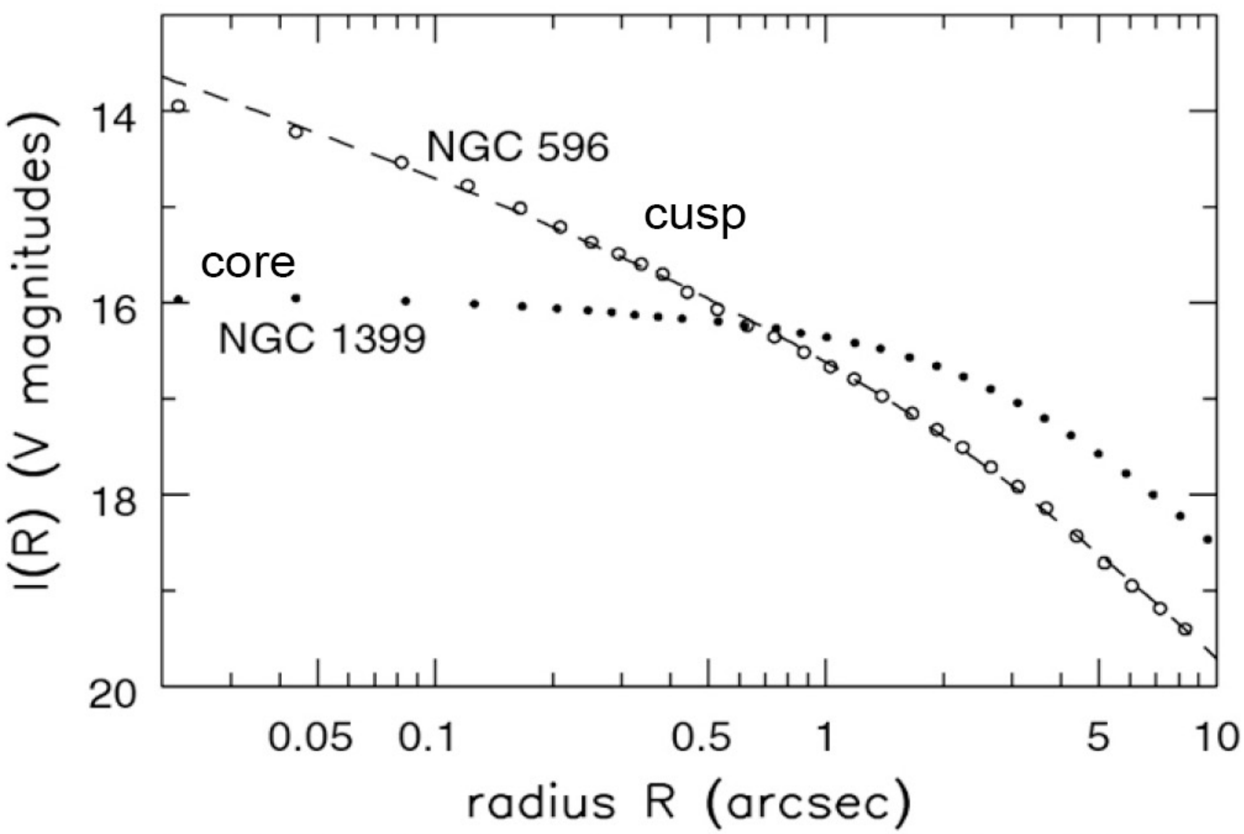
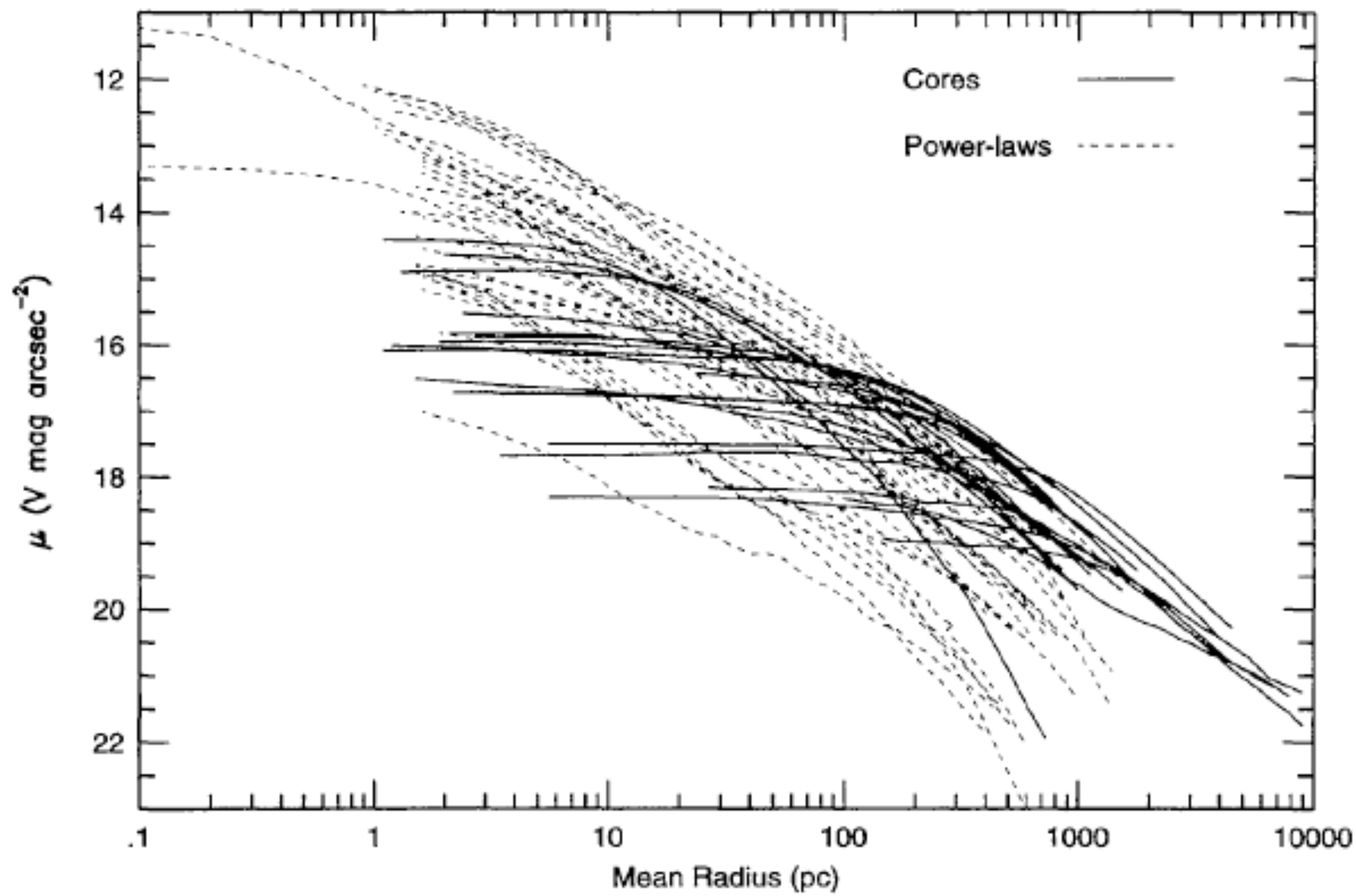


Fig 6.7 (T. Lauer) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

V-band surface brightness profiles of 55 ellipticals, Faber et al 1997. Observed with WFPC1.

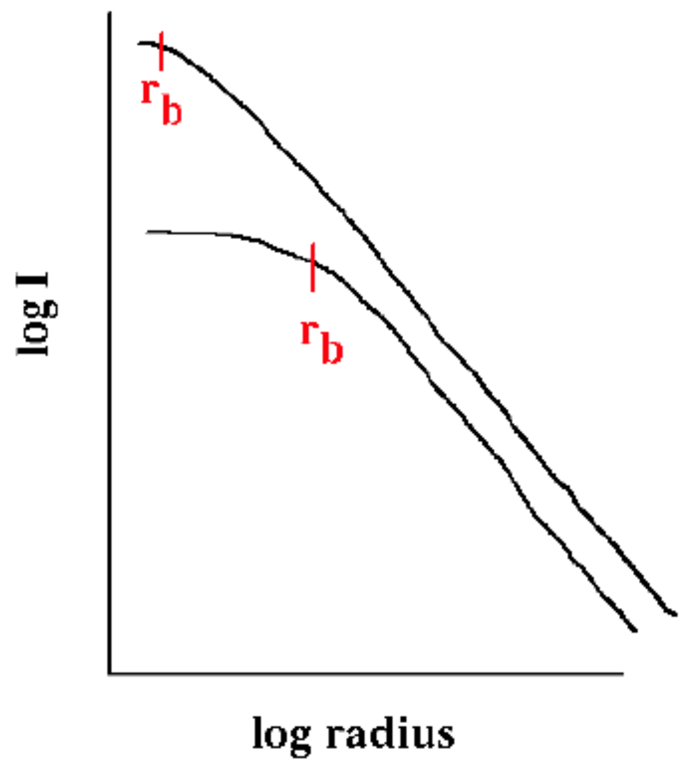


Break radius

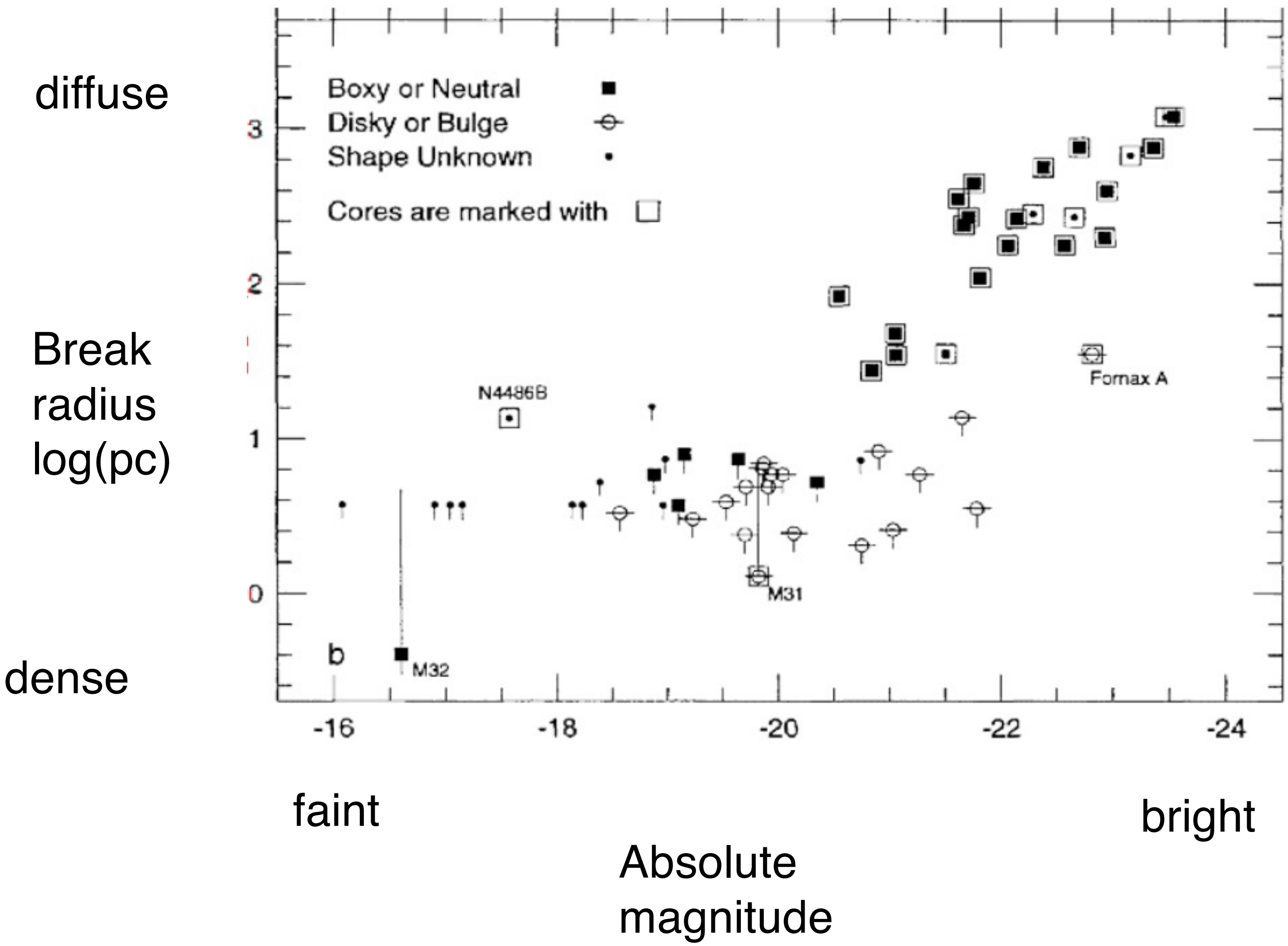
$$I(r) = I_b 2^{(\beta-\gamma)/\alpha} \left(\frac{r_b}{r}\right)^{\gamma} \left[1 + \left(\frac{r}{r_b}\right)^{\alpha}\right]^{(\alpha-\beta)/\gamma}$$

- r_b is the break radius (change of slope in power law)
- I_b is the surface brightness at the break radius.

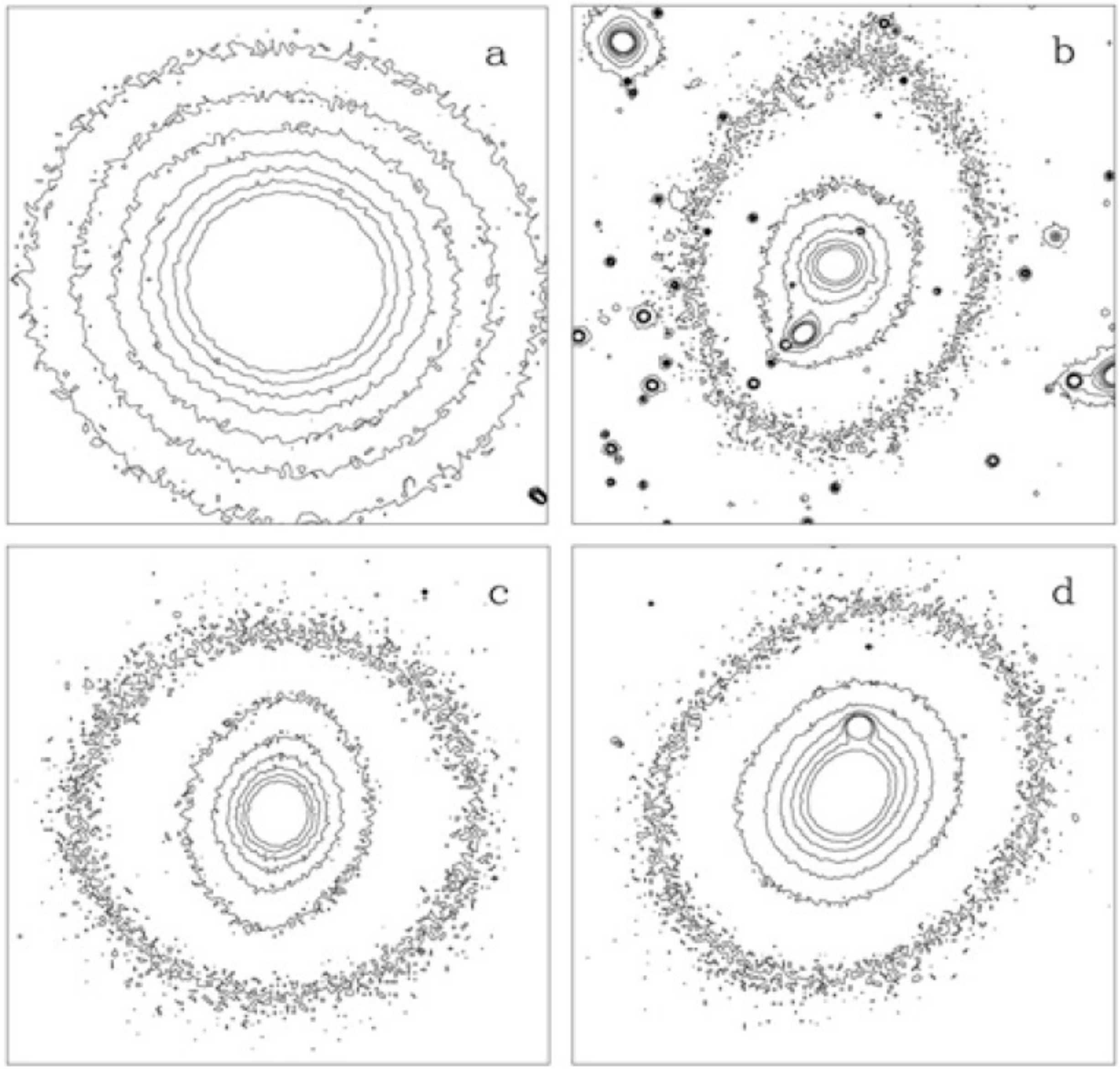
- α defines shrapness of transition
- β defines the outer slope
- γ defines the inner slope



Break radius versus luminosity



Isophotes



Twisted

Disklike

Boxy

Fig 6.1 (R. de Jong) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Faber-Jackson relation:

In 1976, Faber & Jackson found that

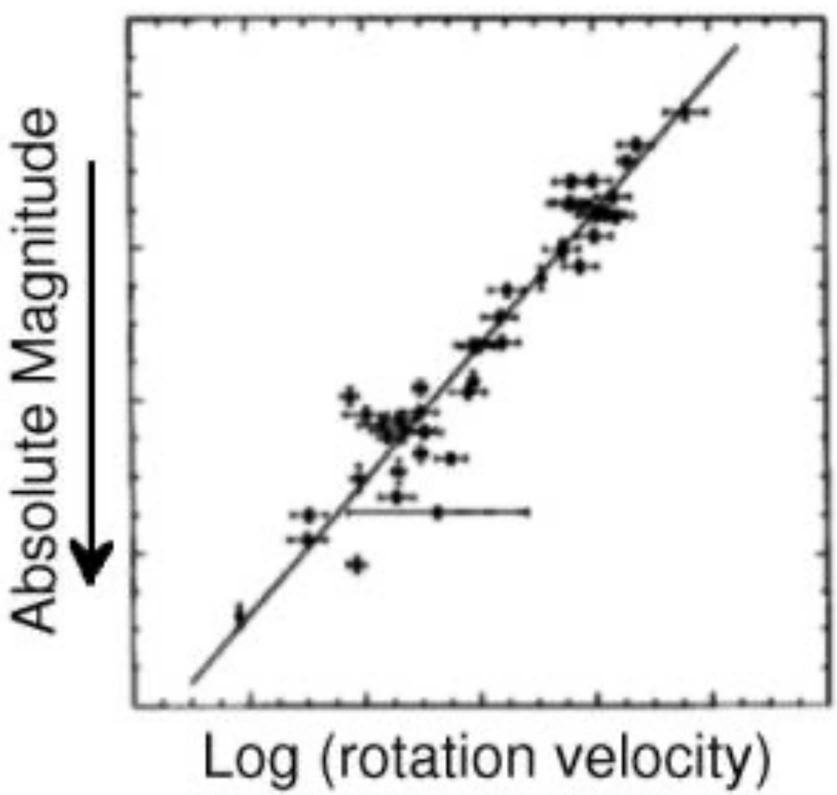
- $$L \propto \sigma^4$$

- More luminous galaxies have deeper potentials
- Can show that this follows from the Virial Theorem
- Why is this relationship useful?
- There is a large scatter - a second parameter?

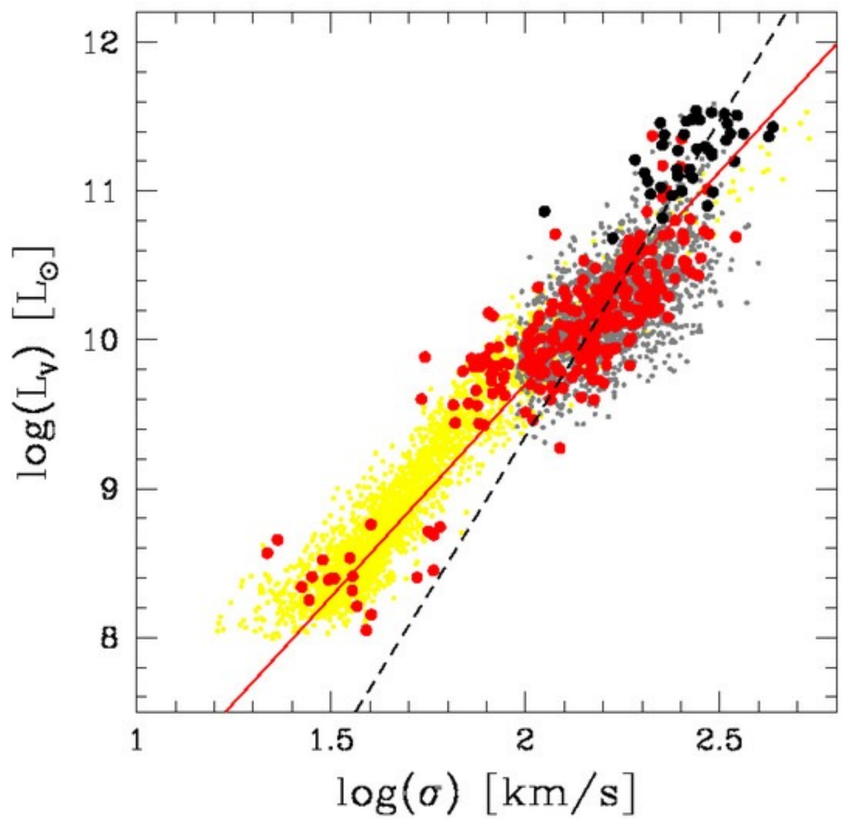
Faber-Jackson relation:

In 1976, Faber & Jackson found that $L \propto \sigma^4$

Tully Fisher (disk galaxies)



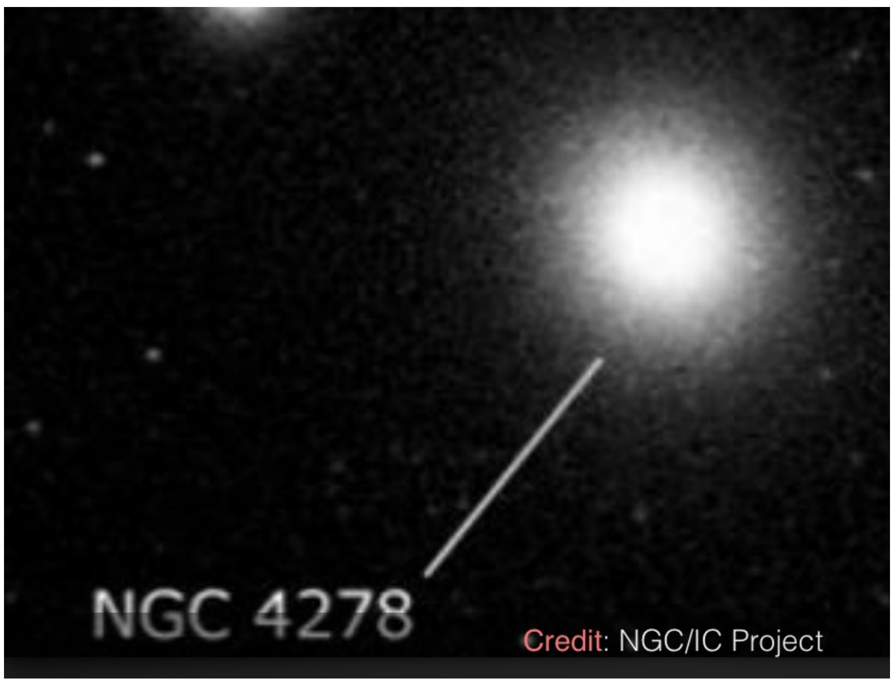
Faber Jackson (Es)



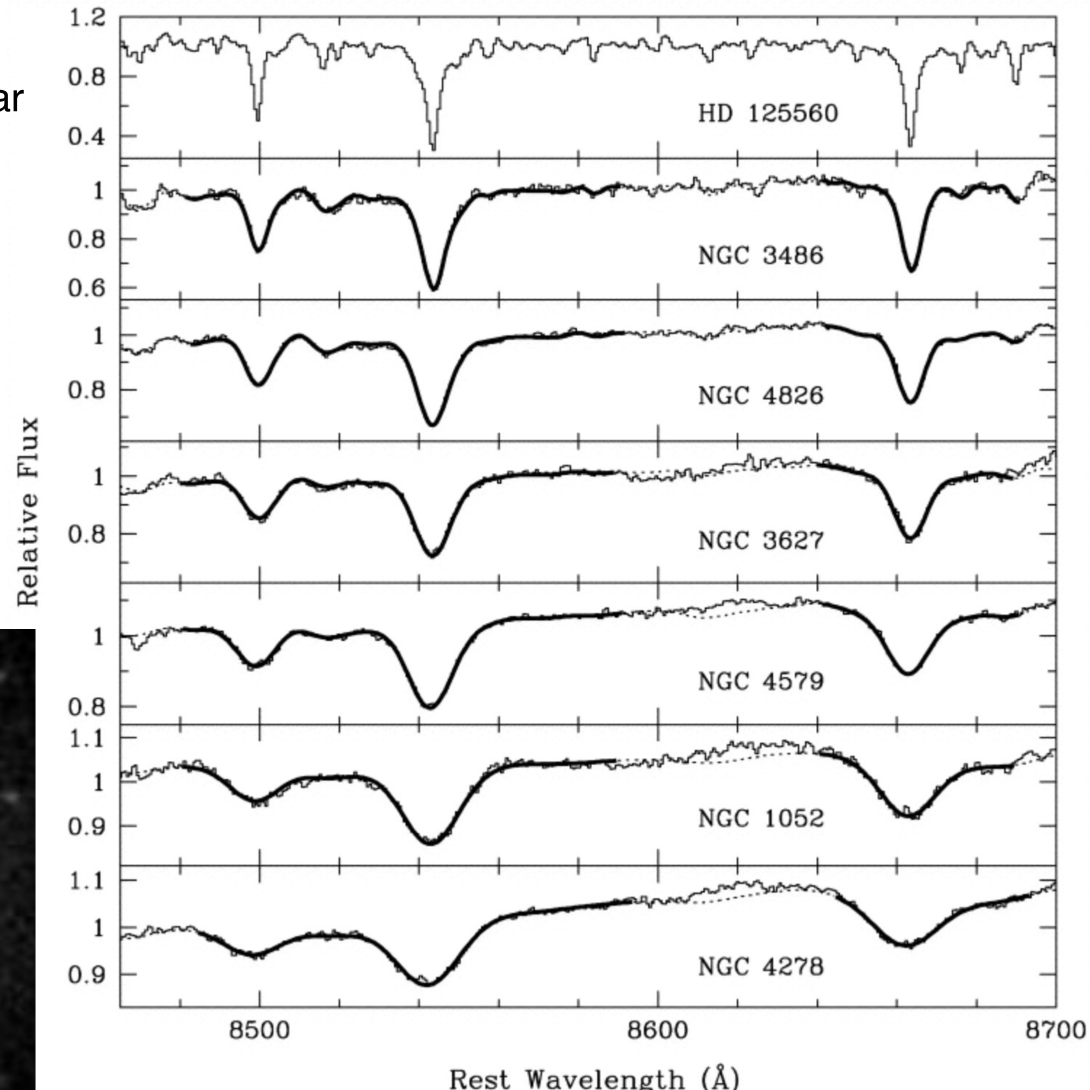
Measuring E Galaxy Masses

- Gravitational Lensing
- Virial Theorem

$M = \sigma^2 R/G$



Ca II Triplet

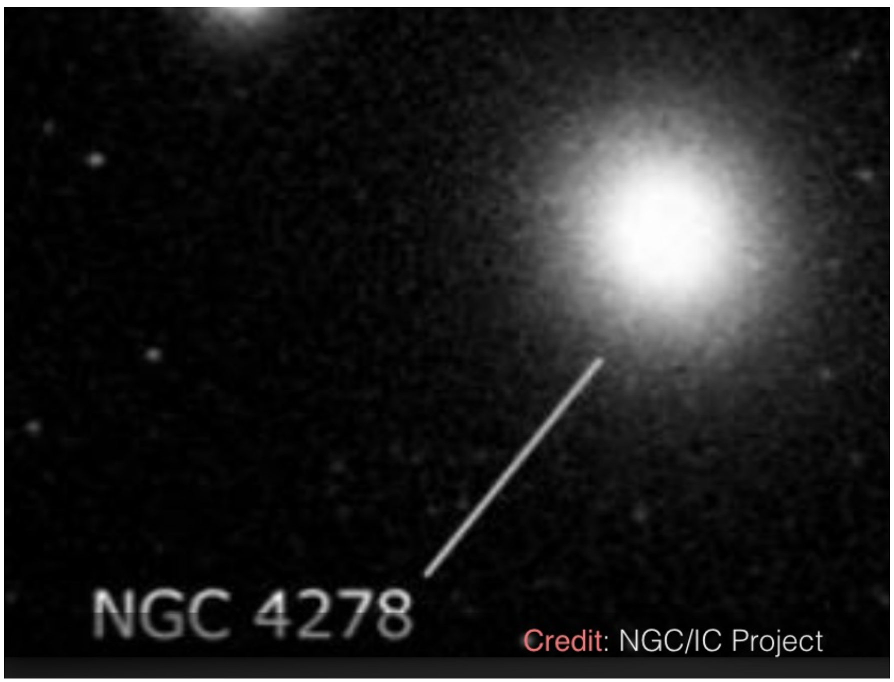


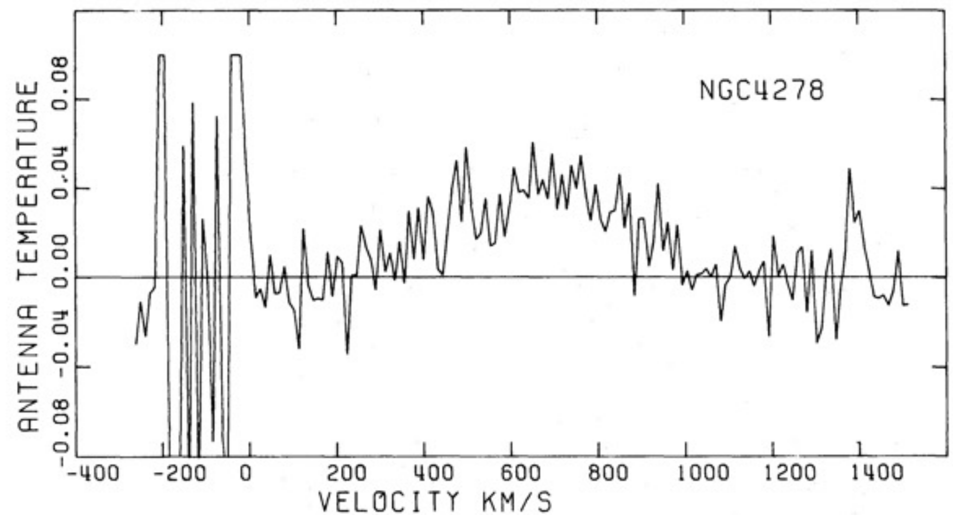
Barth et al. 2002

Worksheet:

Using the Virial Theorem: $M \sim R\sigma_r^2$

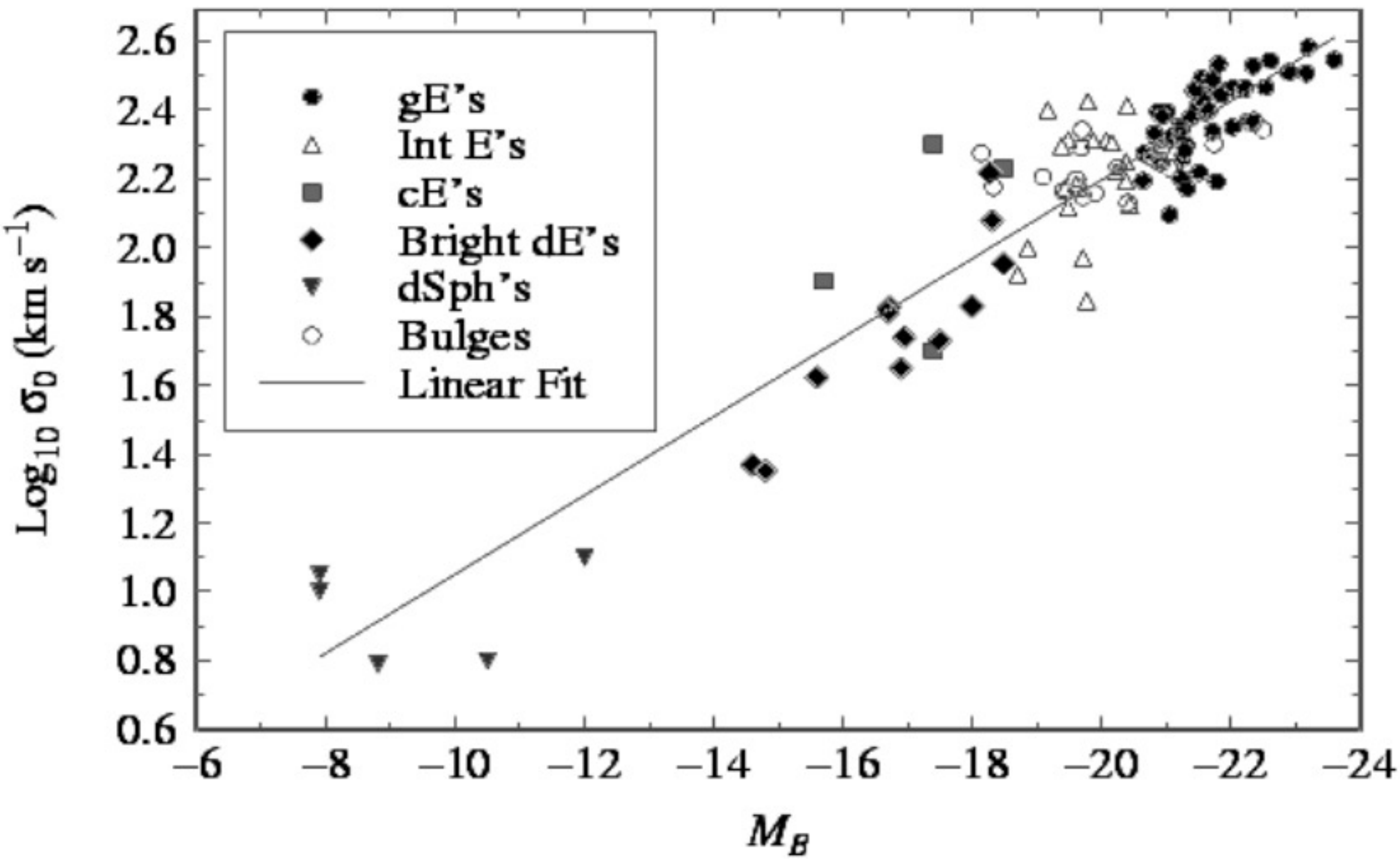
Estimate the mass of NGC4278 using the HI observations and galactic diameter of 240 arcseconds





Gallagher et al. 1977

Faber-Jackson relation



Fundamental plane

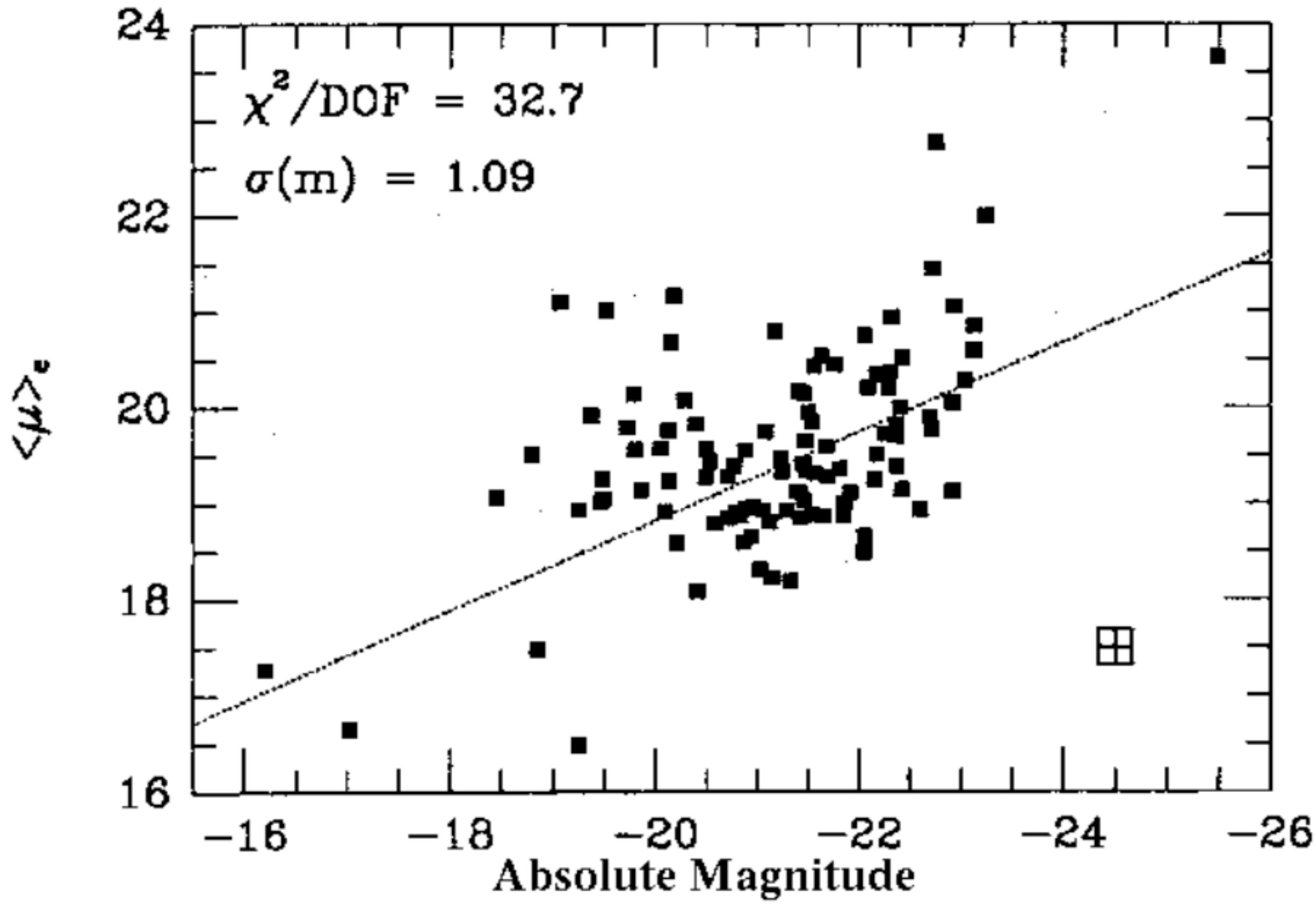
- Missing parameter is the effective radius. Four observables:
  - Luminosity
  - Effective radius
  - Mean surface brightness
  - Velocity dispersion

- Fit a *fundamental plane* through the observables
  - $r_e \propto \sigma^{1.24} < I >^{-0.82}$

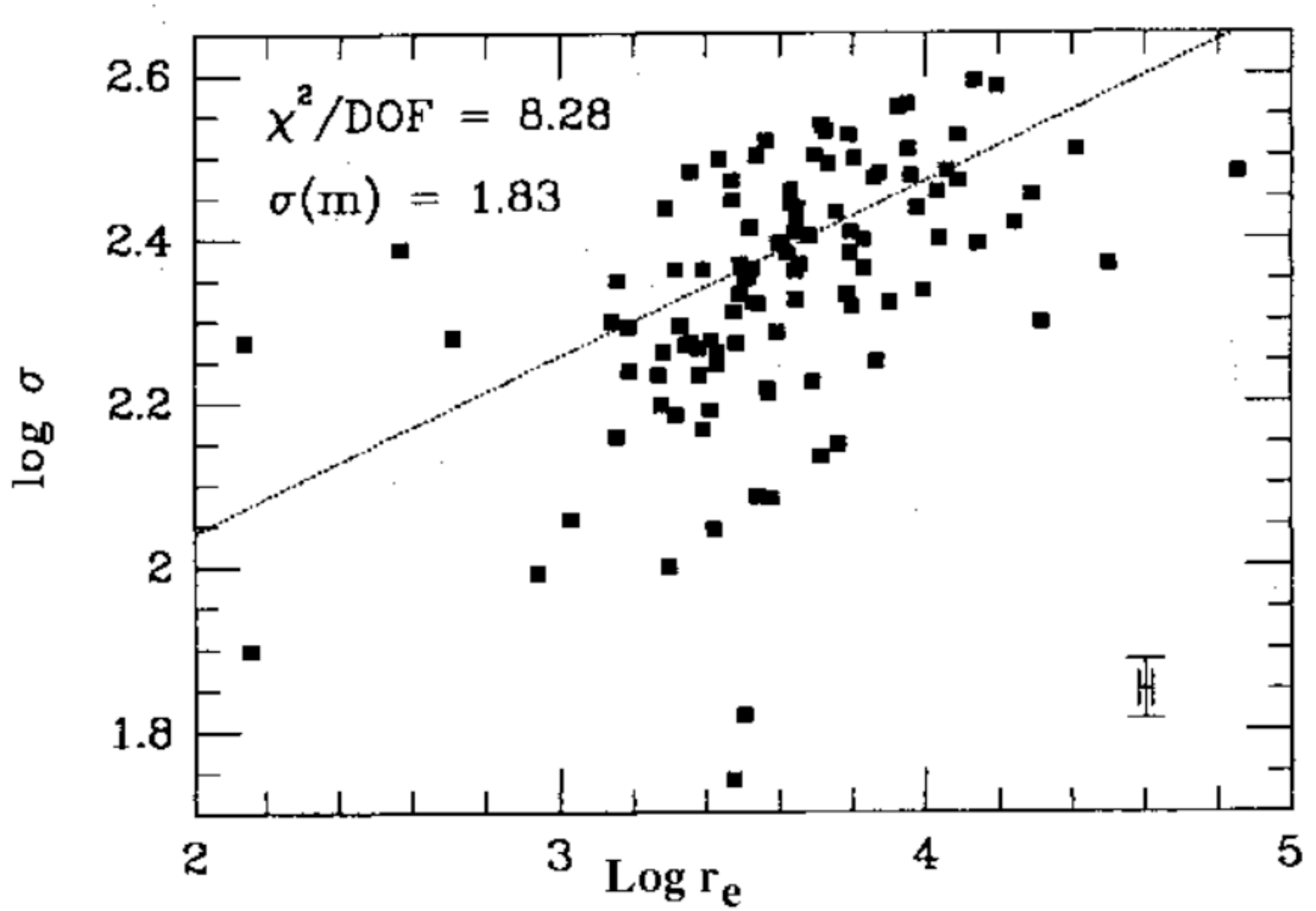
    $L \propto \sigma^{2.65} r_e^{0.65}$

- Any model of galaxy formation must reproduce this relation

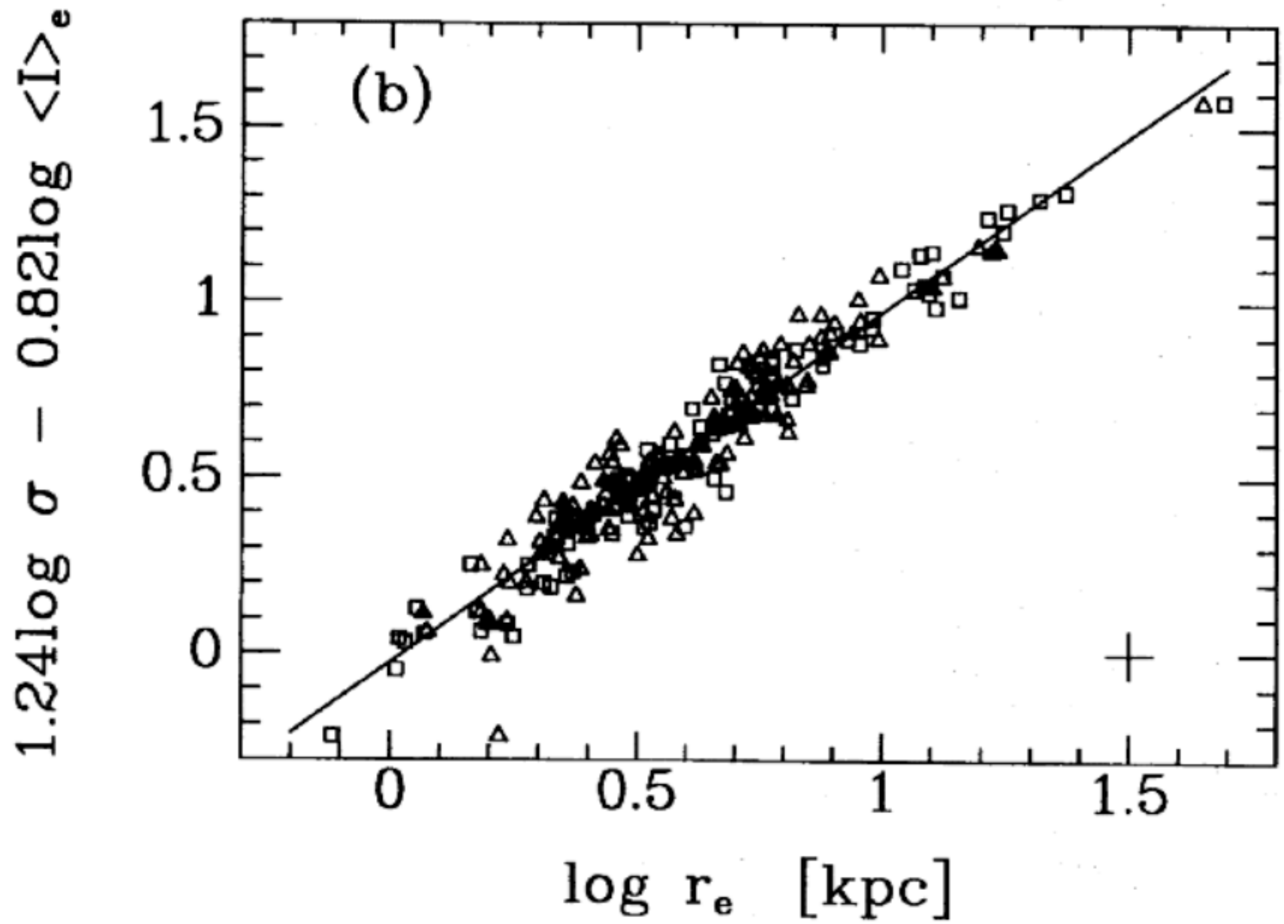
Surface brightness versus luminosity



Velocity dispersion versus effective radius



The fundamental plane



Luminosity functions of galaxies

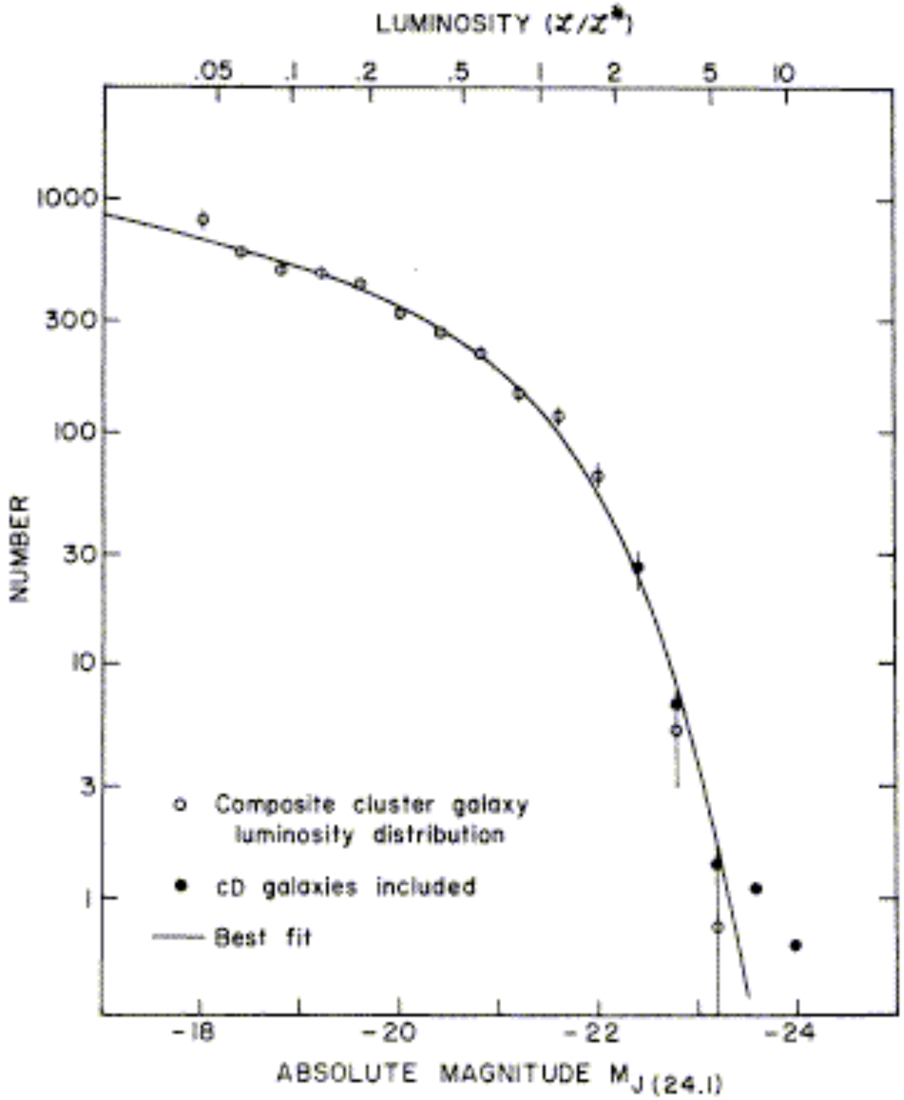


FIG. 2.—Best fit of analytic expression to observed composite cluster galaxy luminosity distribution. Filled circles show the effect of including cD galaxies in composite.

Schecter 1976

Binggeli's (1987) cartoon of Paul Schechter and his function.

Luminosity functions of galaxies

Log of number of galaxies
per unit volume between
M and M+dM

Binggeli et al 1988

Schechter luminosity function:

$$\phi(L)dL \propto L^{\alpha} e^{-L/L_*} dL$$

$\alpha, L*$ vary with galaxy sample

Field L* ~ 10^{10} Lsun

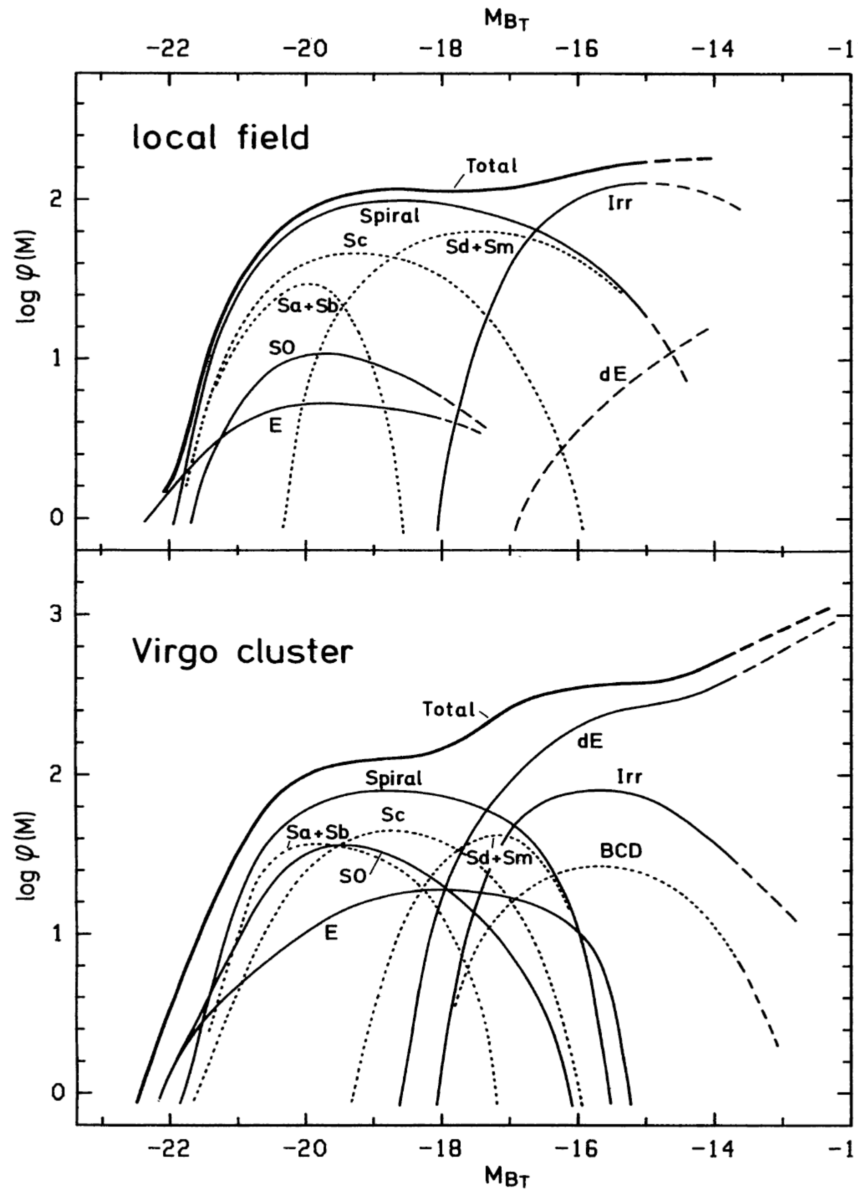
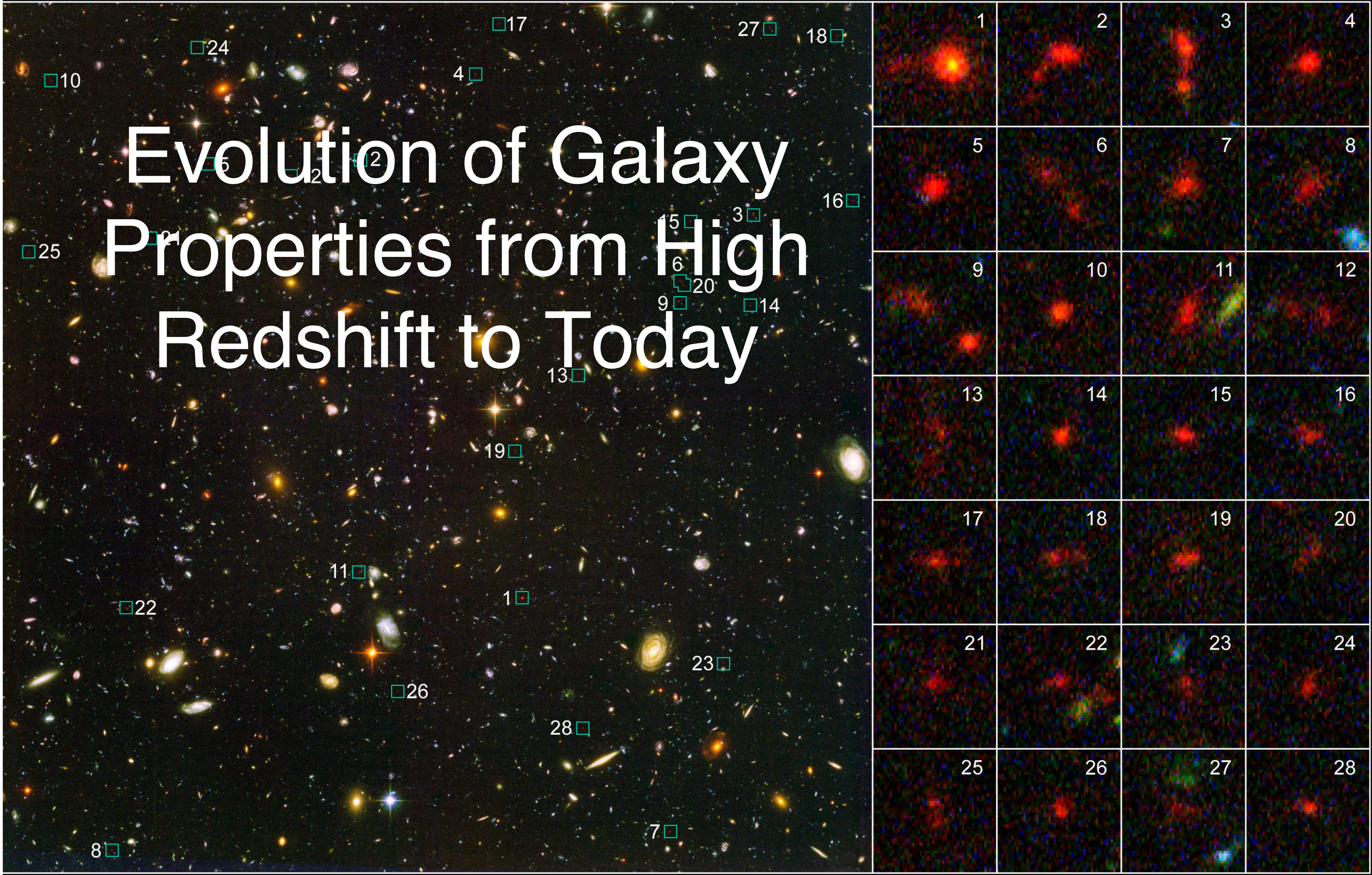


Figure 1 The LF of field galaxies (top) and Virgo cluster members (bottom). The zero point of log $\varphi(M)$ is arbitrary. The LFs for individual galaxy types are shown. Extrapolations are marked by dashed lines. In addition to the LF of all spirals, the LFs of the subtypes Sa + Sb, Sc, and Sd + Sm are also shown as dotted curves. The LF of Irr galaxies comprises the Im and BCD galaxies; in the case of the Virgo cluster, the BCDs are also shown separately. The classes dS0 and "dE or Im" are not illustrated. They are, however, included in the total LF over all types (heavy line).

Evolution of Galaxy Properties from High Redshift to Today



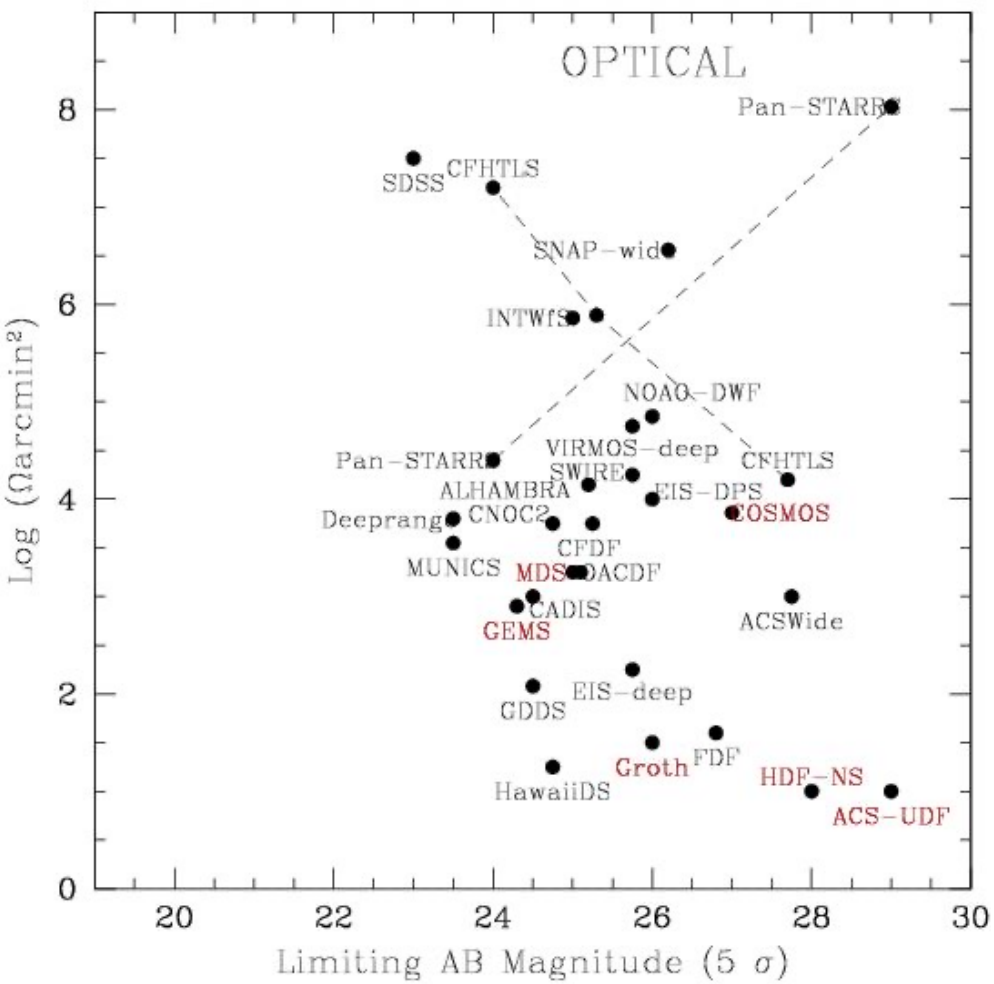
Distant Galaxies in the Hubble Ultra Deep Field

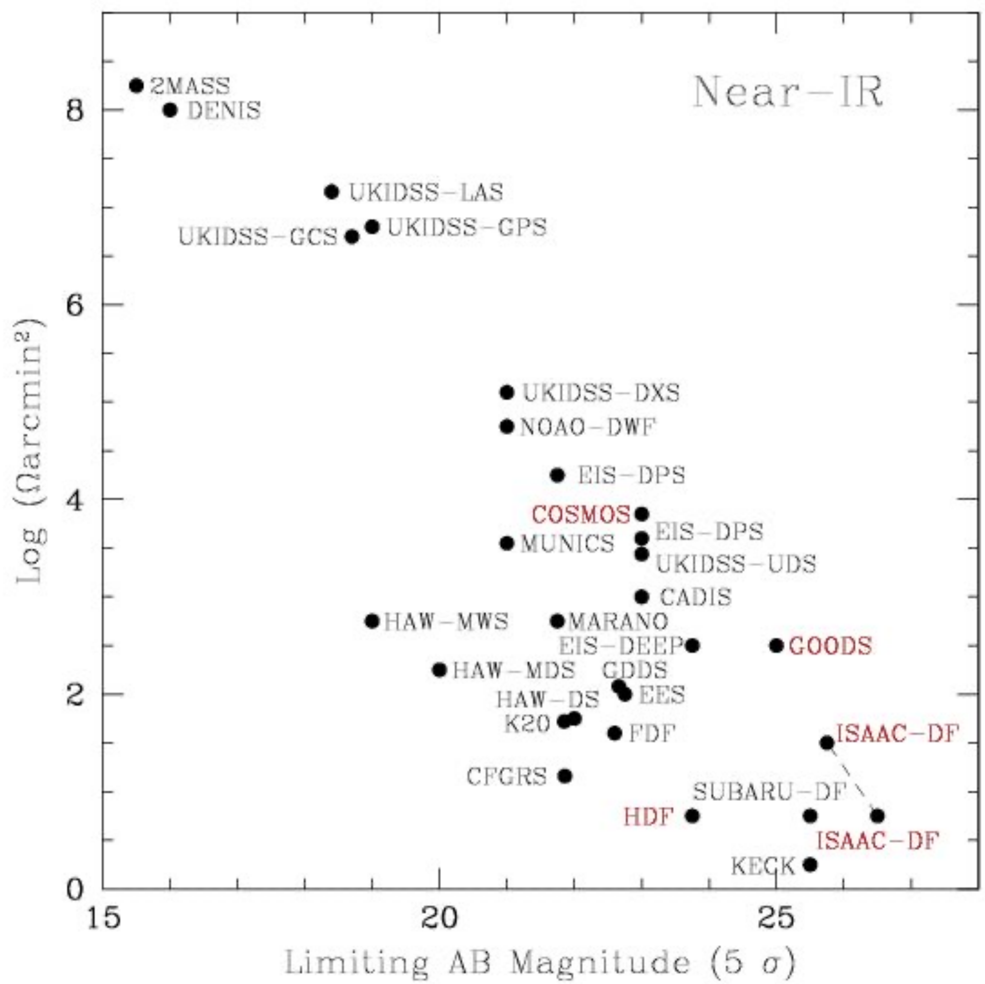
Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)

STScI-PRC06-12

Galaxy Surveys: Optical & NIR



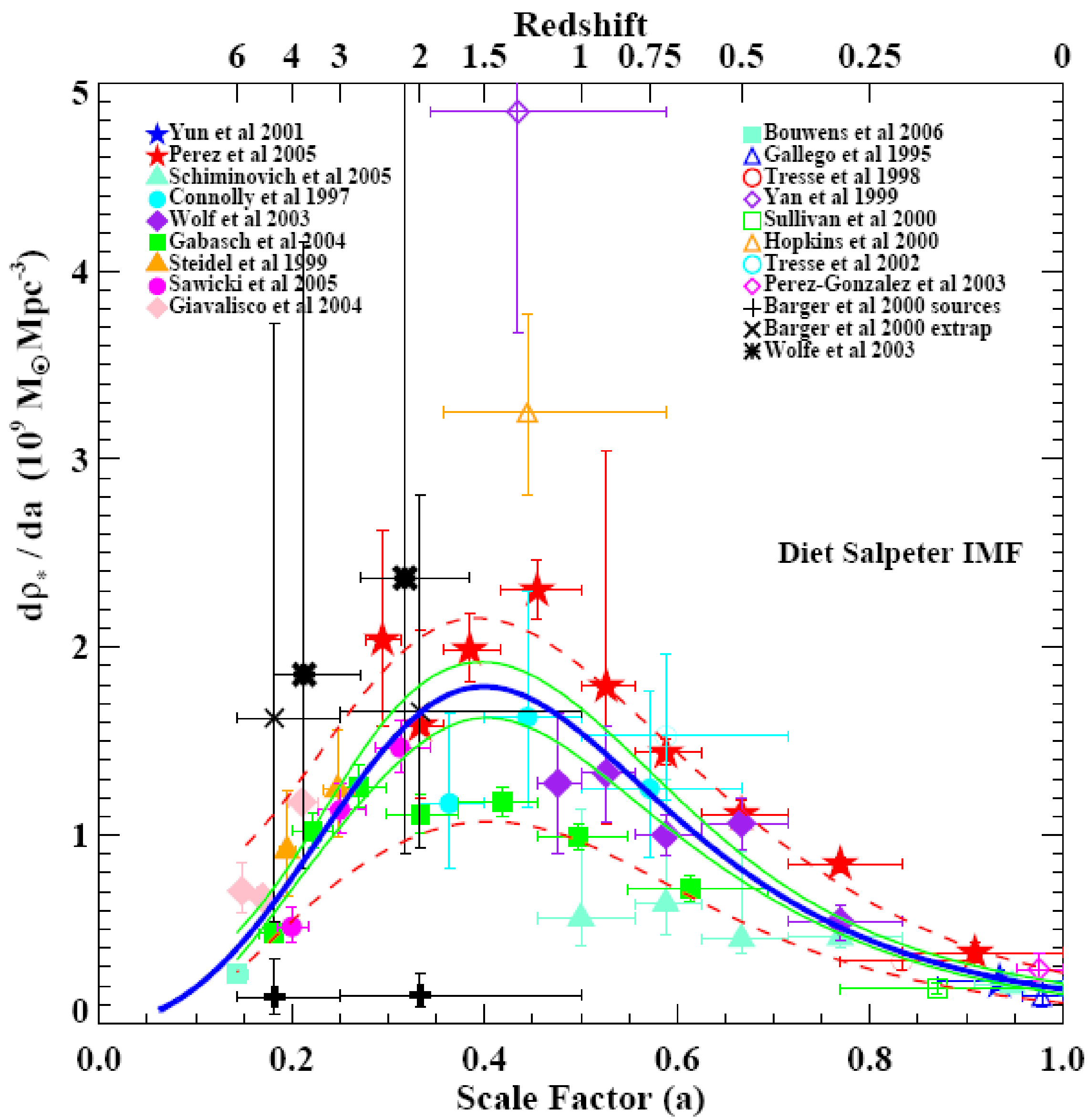


From Mara Salvato's web page

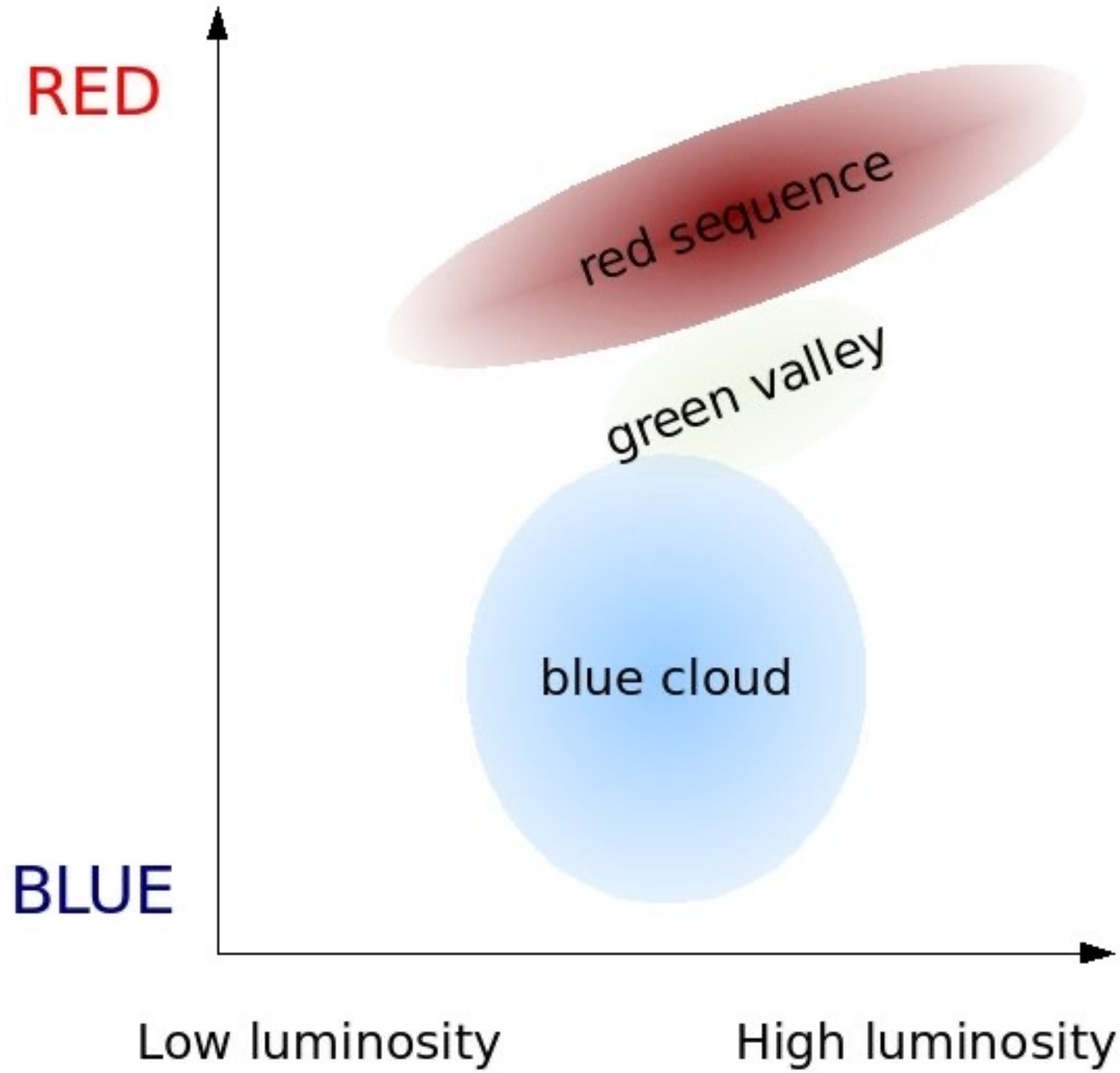
Lilly-Madau Plot

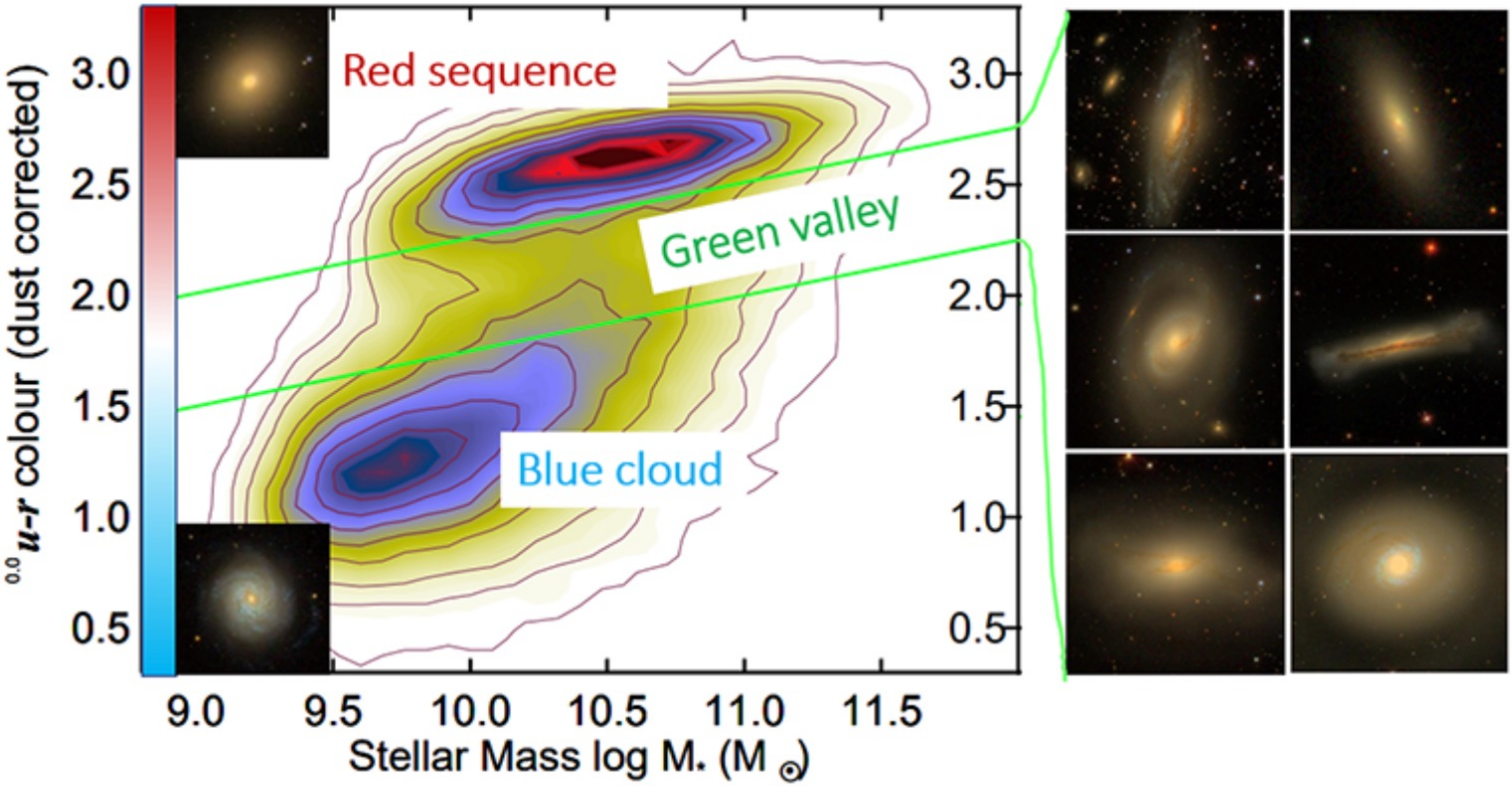
- Fair amount of scatter, but for z>1 it is at the ~50% level now.
- Half the stars formed by z~1.7.
- Many issues: Dust? IMF? Sample overlap?

Fardal et al 2006



Galaxy Color-Magnitude Diagram

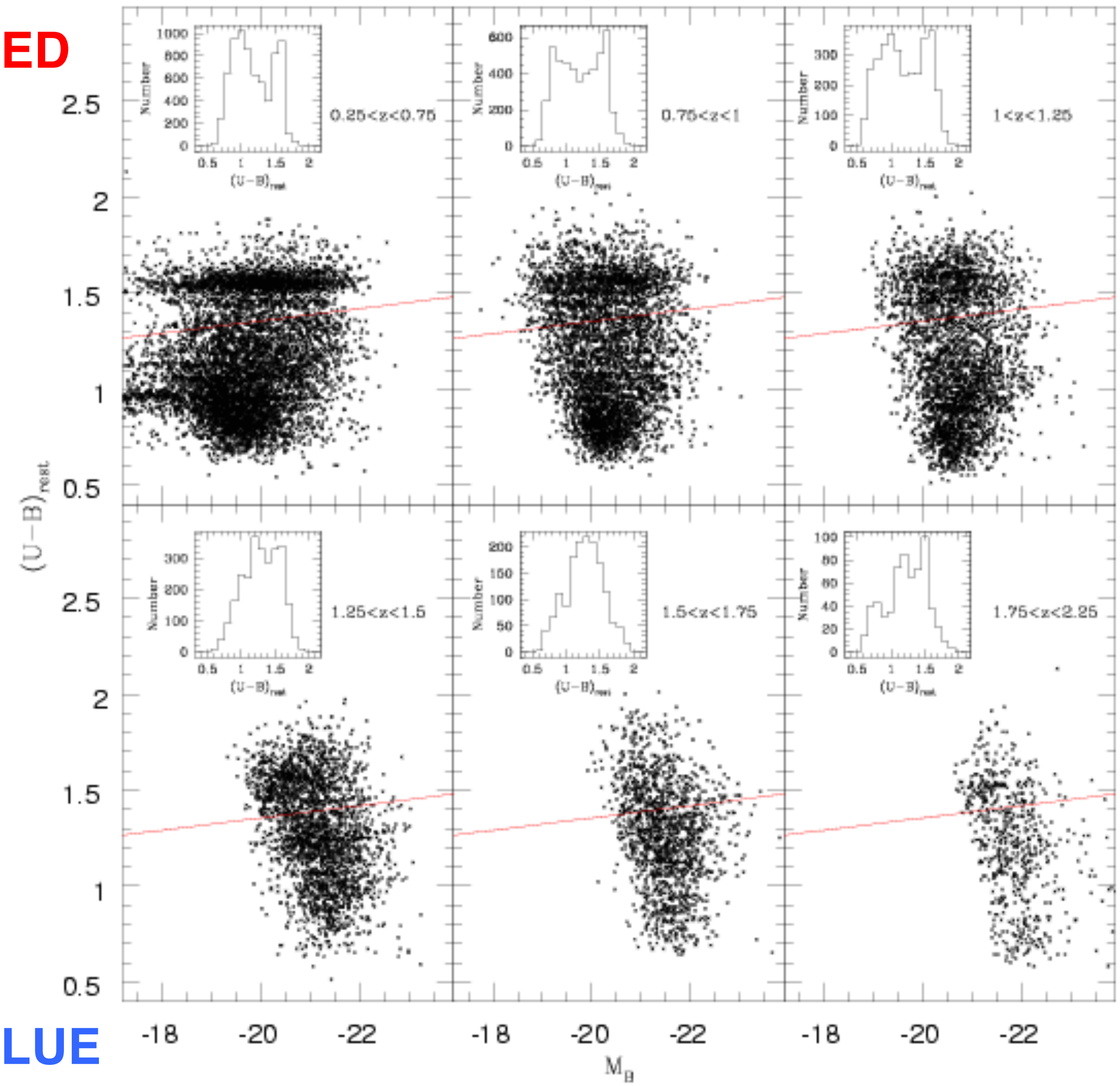




Some Green Valley Galaxies
Salim et al. 2014

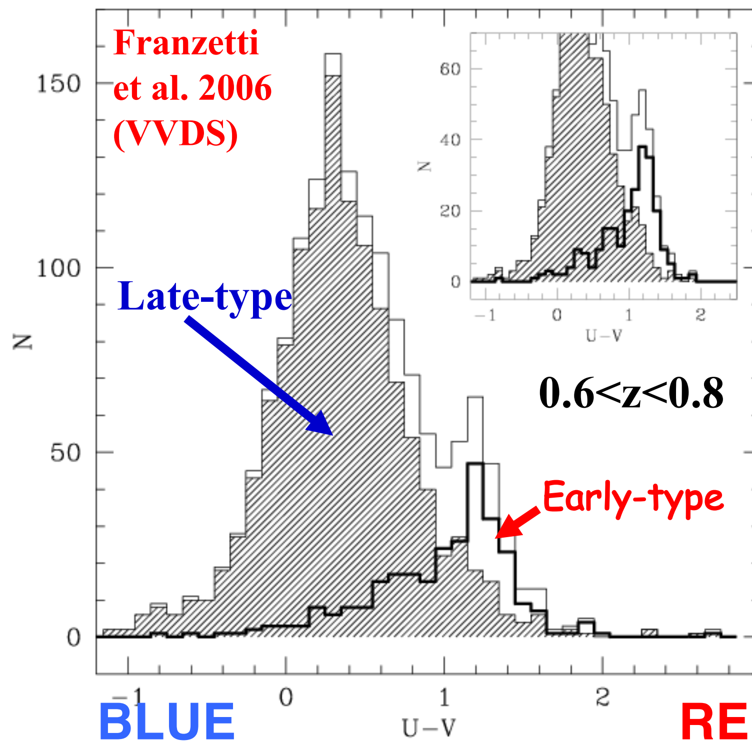
0 < z < 1 : Red sequence, blue cloud, green valley ?

RED



BLUE

Cirasuolo et al. 2006 (UKIDSS)

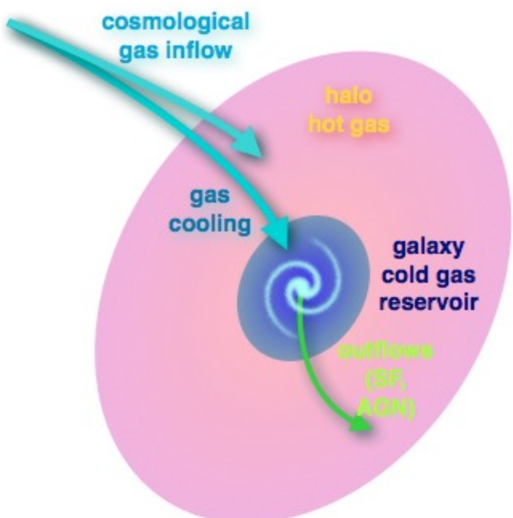


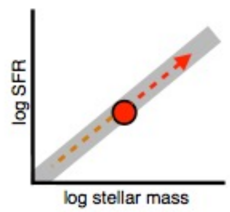
BLUE RED

Color bimodality to z ~ 1 (Bell et al. 2004)
Disappears beyond z ~ 1.5 ?
(Wuyts et al. 2006, Cirasuolo et al. 2006…)
Reliability ? Contamination ?
See also the degeneracy of ERO colors
(e.g. Cimatti et al. 2002, 2003, Moustakas et al. 2004, Stern et al. 2006)

Late-type galaxy star formation quenching schematic

(1) prior to t=0

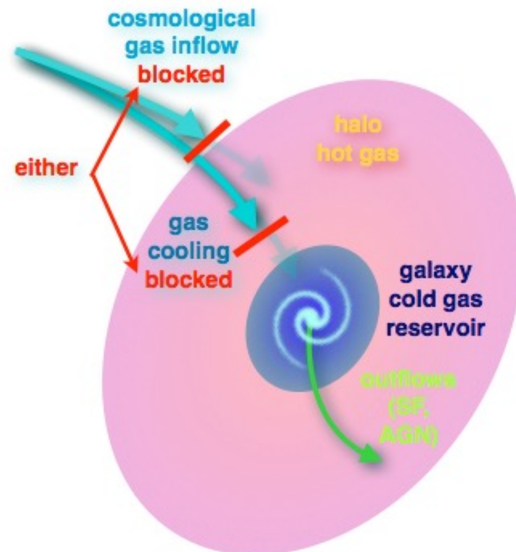


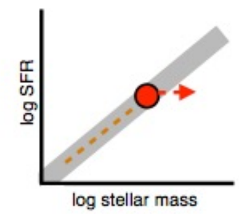


Galaxy is on main sequence
$M_{stellar} \sim SFR^{\beta}$

Inflows balance outflows: system in quasi-equilibrium (Bouche+10; Lilly+13)

(2) t=0, quenching event



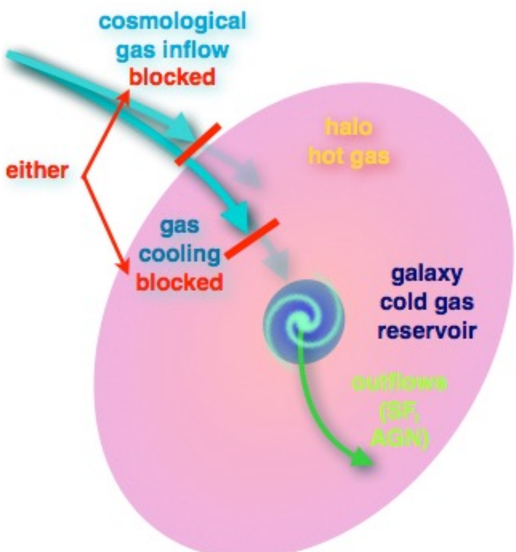


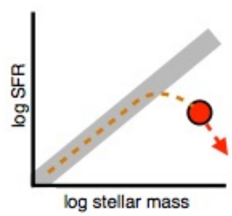
Either cosmological inflows or cooling from halo are stopped, galaxy gas reservoir is now no longer replenished

Galaxy leaves main sequence

SFR = εMgas/τdyn

(3) t~100-1000 Myr past quenching

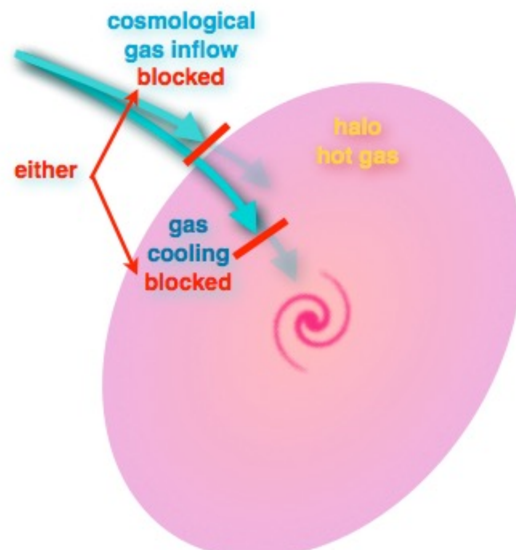


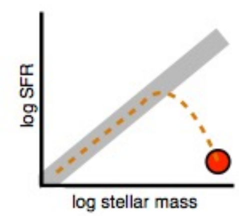


SFR goes into exponential decline, galaxy enters green valley

Gas reservoir is slowly used up

(4) t~ several Gyr past quenching





Several Gyr later...

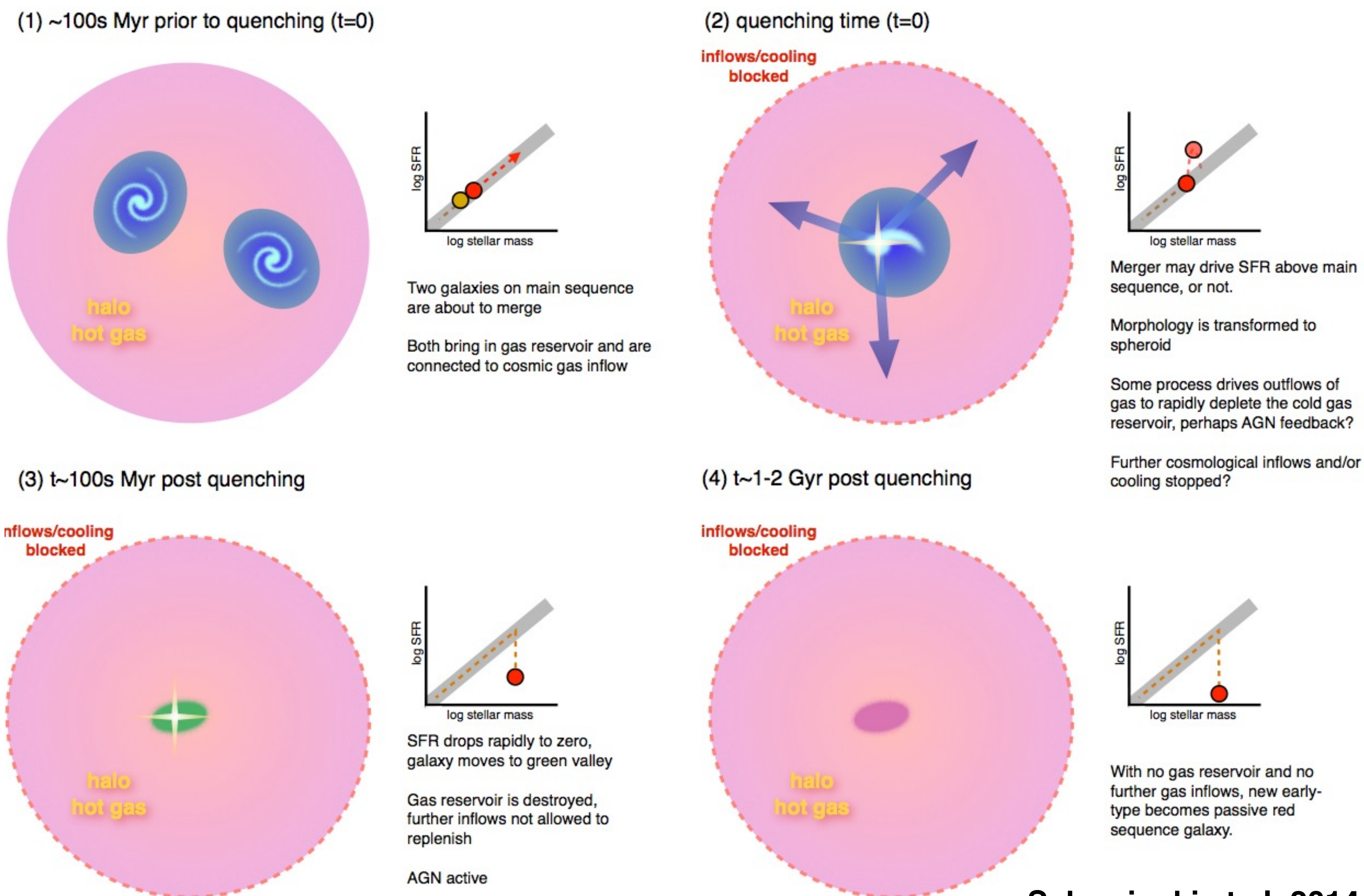
Passive, red spiral galaxy

No morphological transform-ation > "red spiral"

Very low SSFR

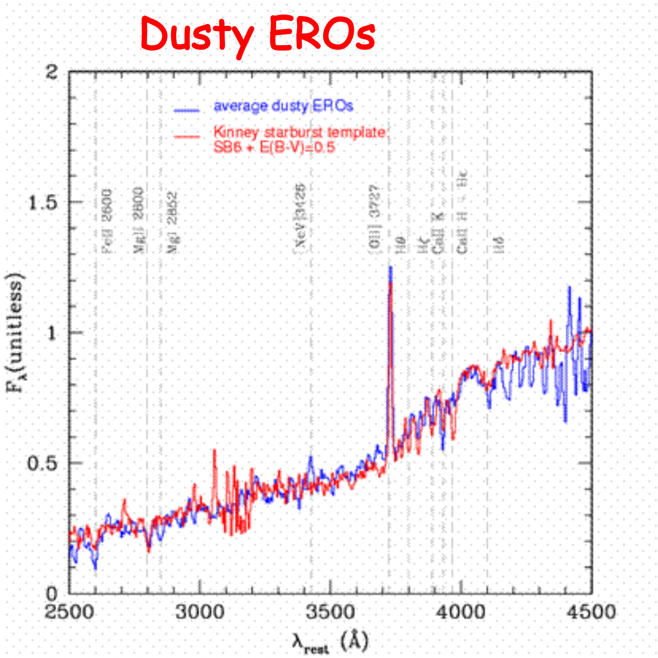
Schawinski et al. 2014

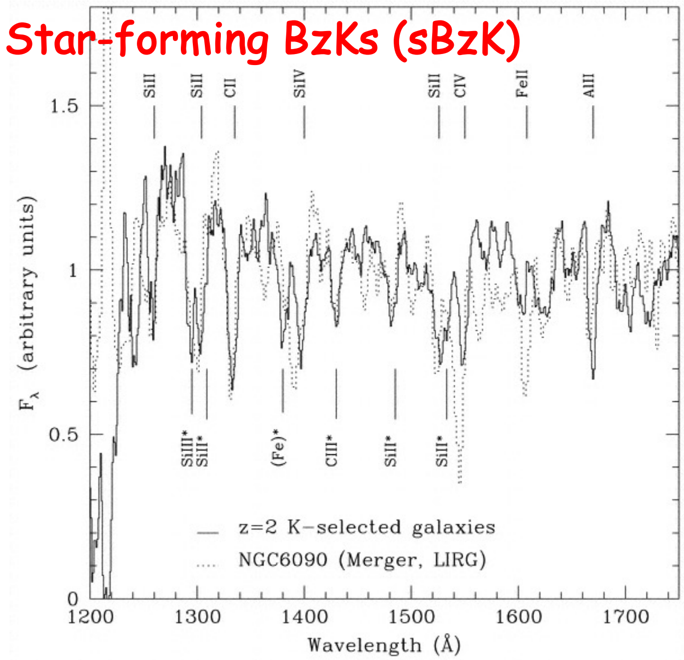
Early-type galaxy star formation quenching schematic

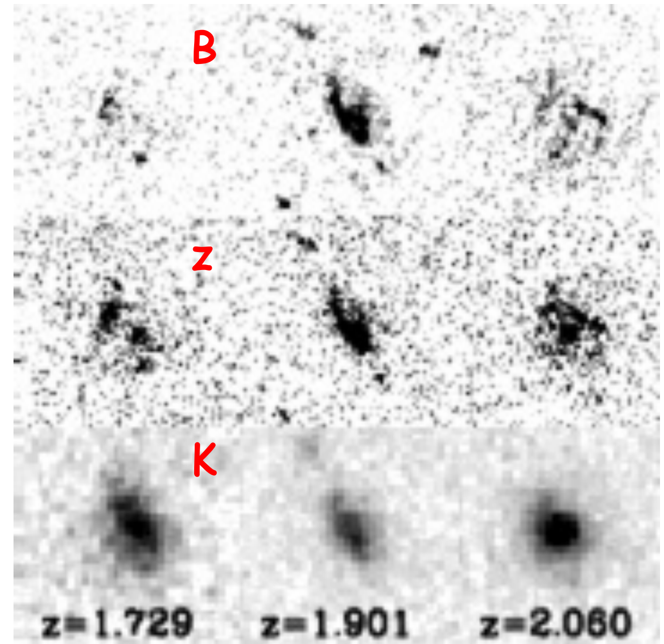


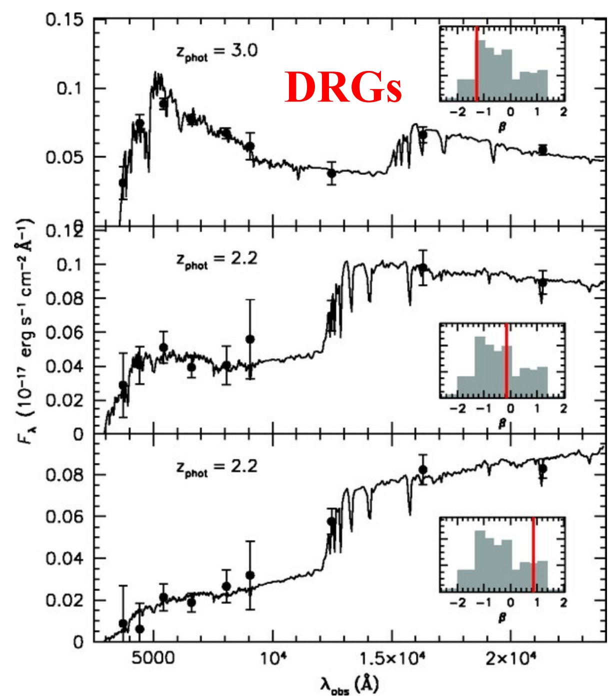
Schawinski et al. 2014

Beyond z ~ 1 : NIR-selected star-forming galaxies





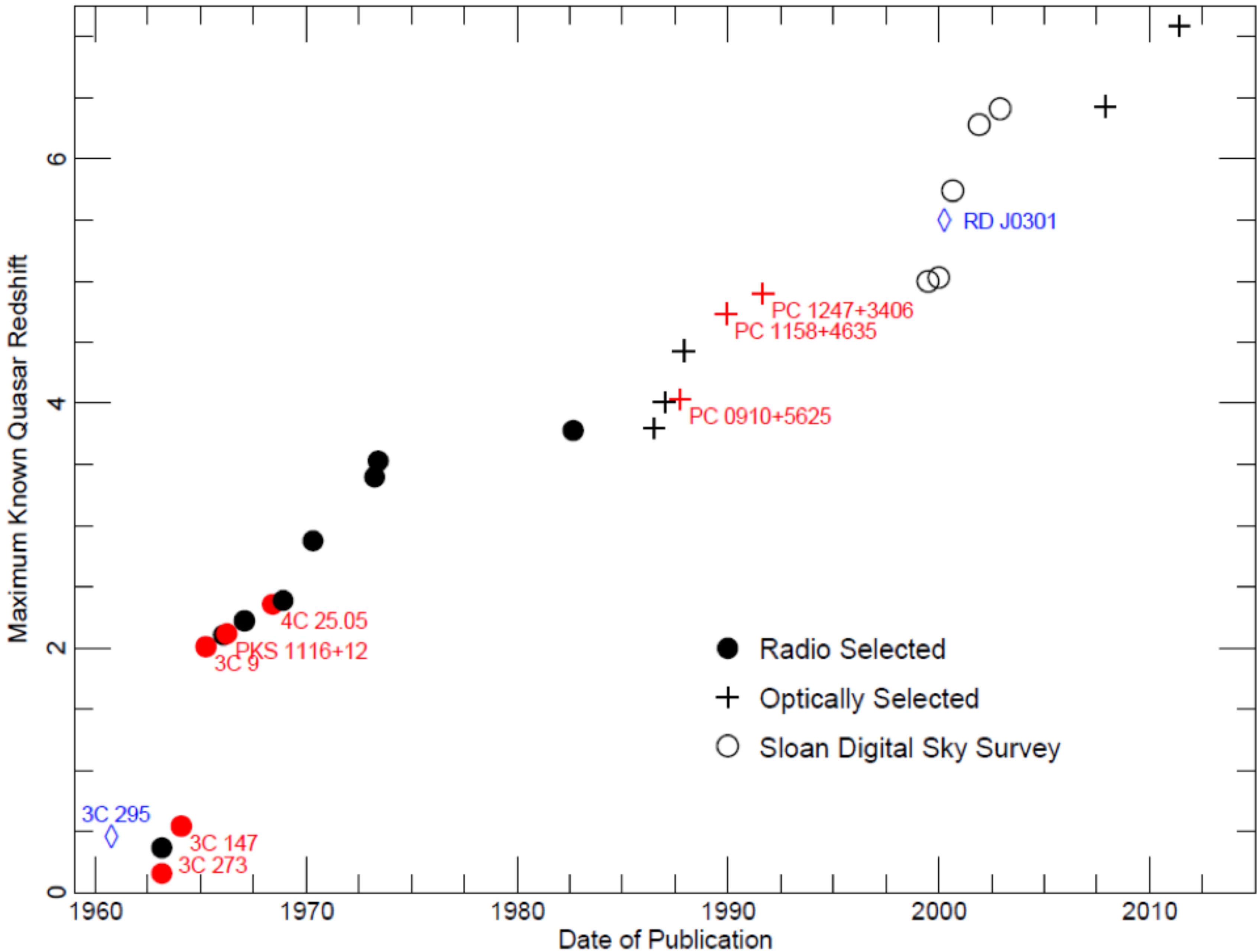




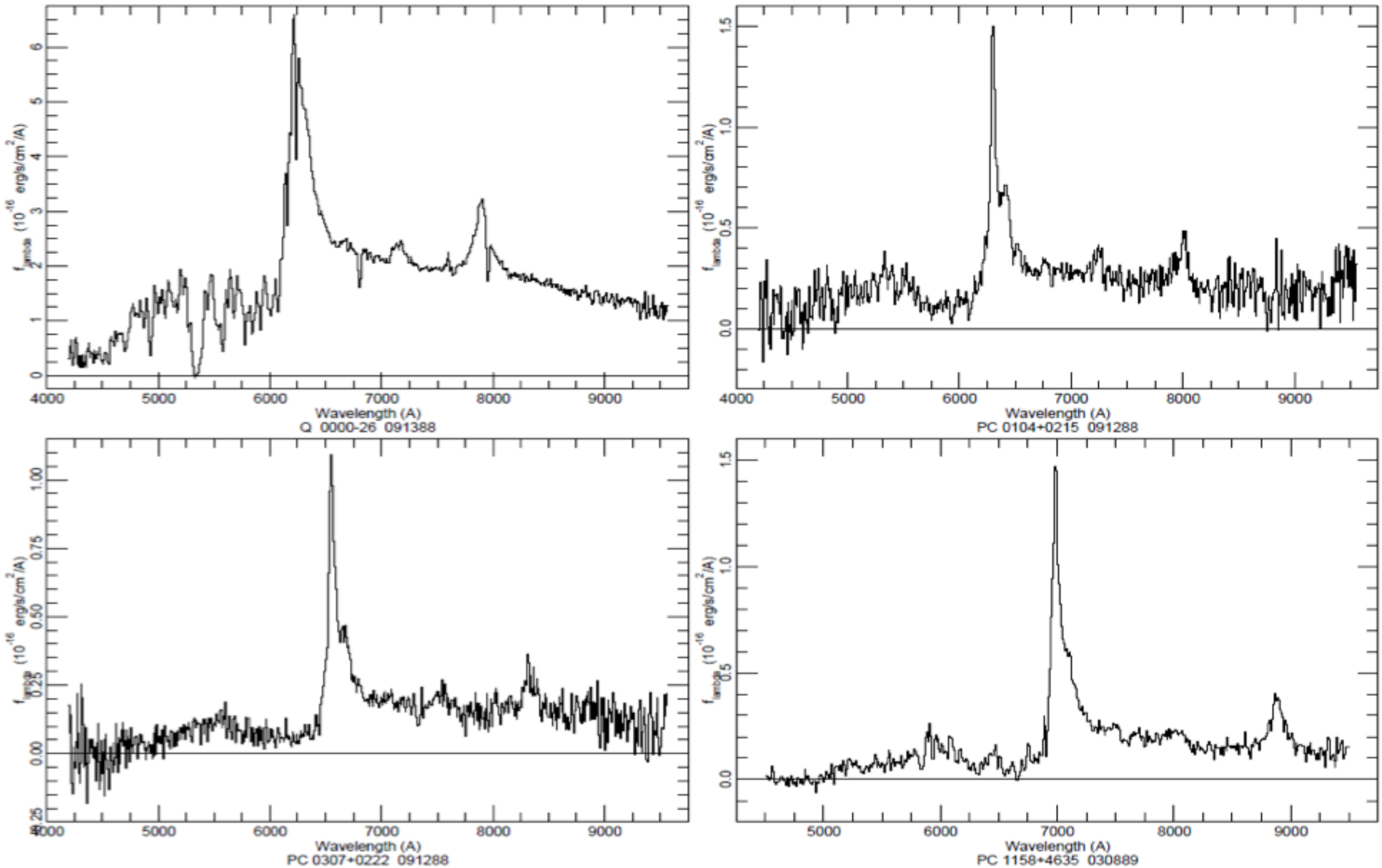
1 < z < 3
SFR up to ~ 200+ Msun/yr
Most sBzKs and some DRGs are ULIRGs
Stellar masses up to ~ 10^{11} Msun
High specific SFR
Nearly solar metallicity
Merger morphology in rest-frame UV
sBzK & DRGs strongly clustered (r_0 ~ 8-11 h^{-1} Mpc)

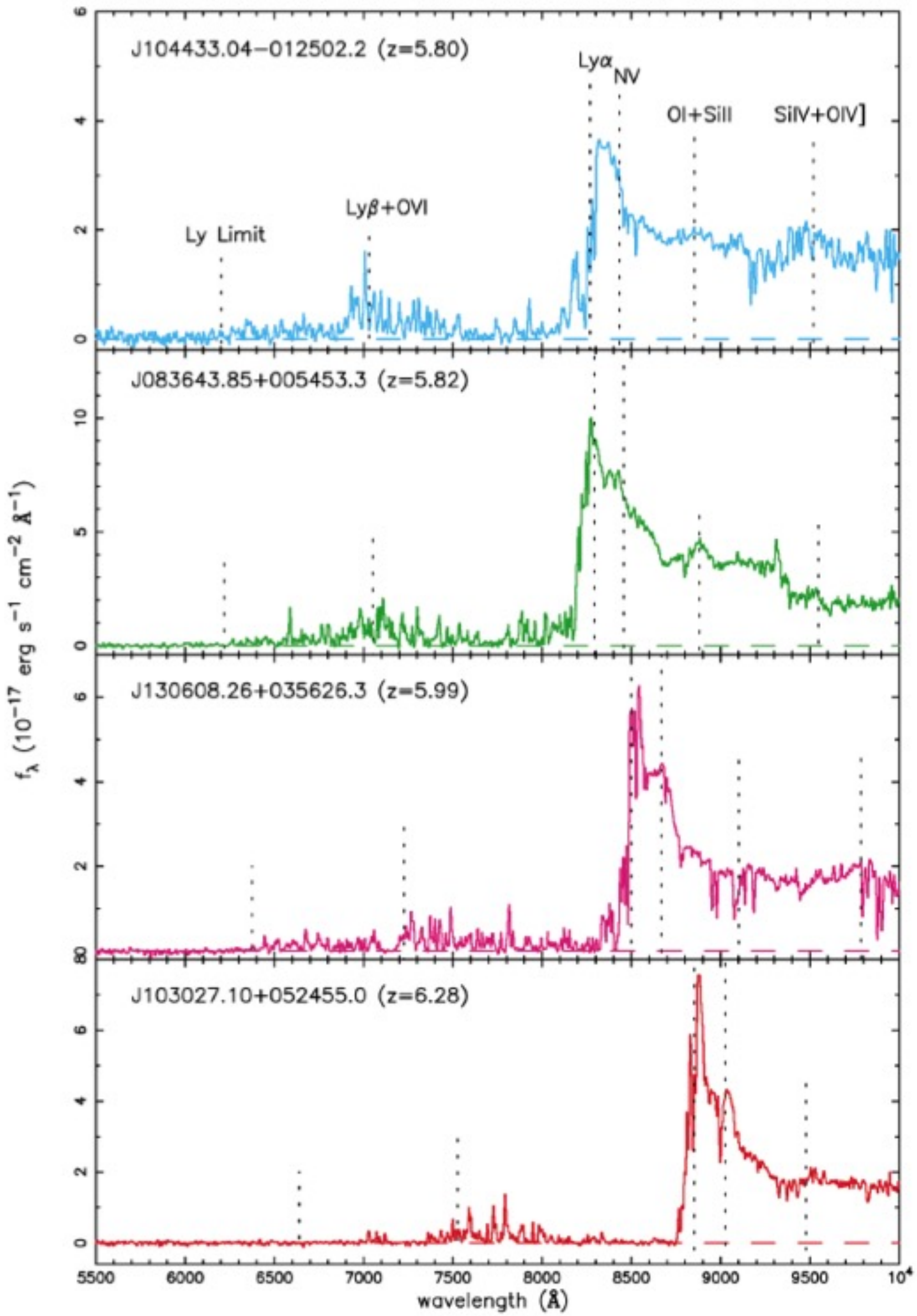
Cimatti et al. 2002, 2003, Daddi et al. 2004a, 2004b, 2005; De Mello et al 2004, Dannerbauer et al. 2005, Kong et al. 2006, Franx et al. 2003, Forster-Schreiber et al. 2004
van Dokkum et al. 2005, Webb et al. 2006, Papovich et al., Doherty et al., Yan et al.
Grazian et al. 2006, Quadri et al. 2006, Foucaud et al, Grazian et al. 2006

High Redshift Quasars



Indications of rapid increase of H I Opacity at z ~ 4

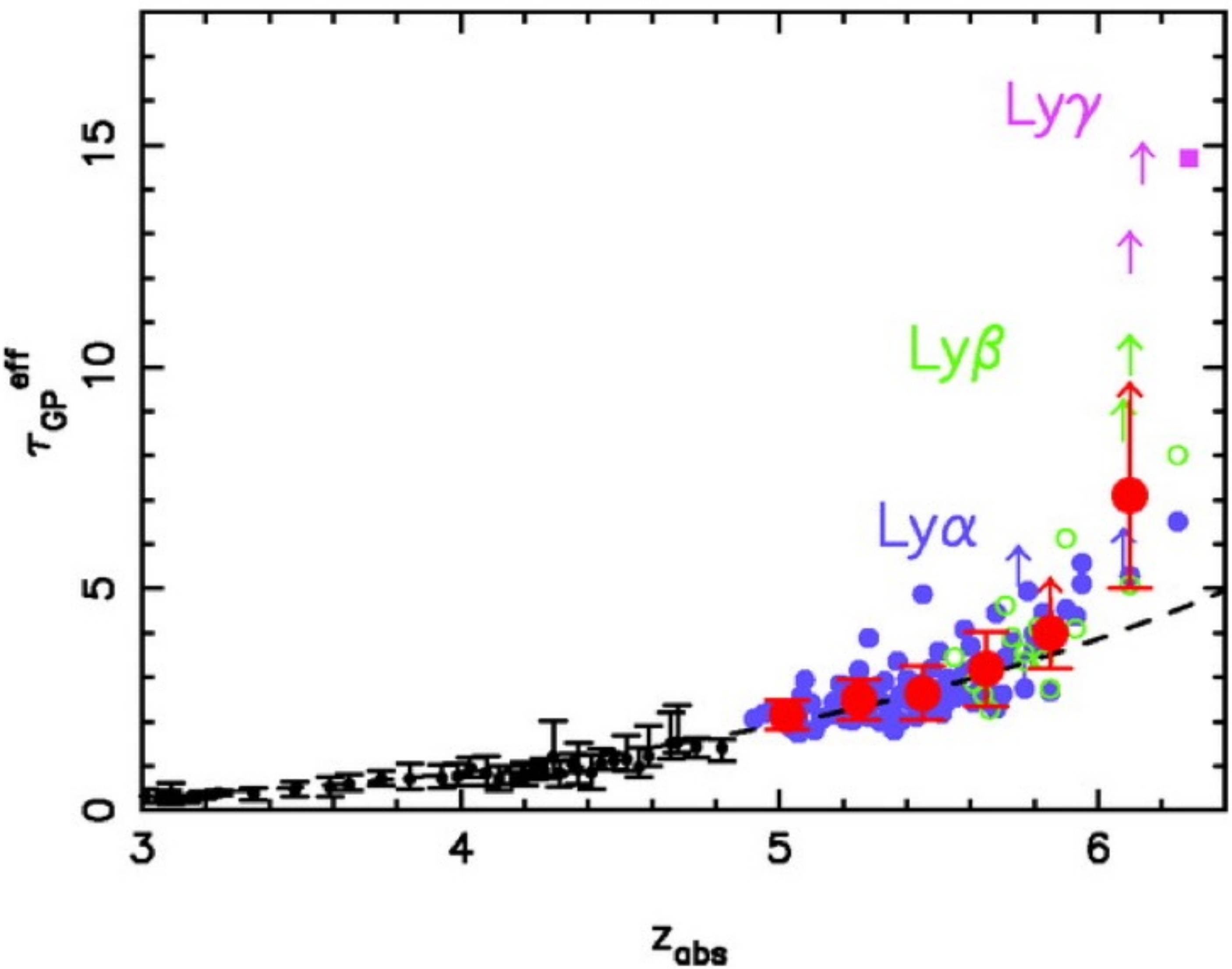




Detection of Gunn-Peterson Troughs in z ~ 6 Quasars in 2001

Becker et al (2001)

Rapid increase in H I Opacity at z ~ 6



Fan et al (2006)

What we have Learned

- The number density of quasars drops dramatically at $z > 3$
- Billion solar mass black holes can form within a billion years of the big bang
- The Epoch of Reionization (EoR) ends around $6 < z < 8$ after which the Universe is fully ionized (again)