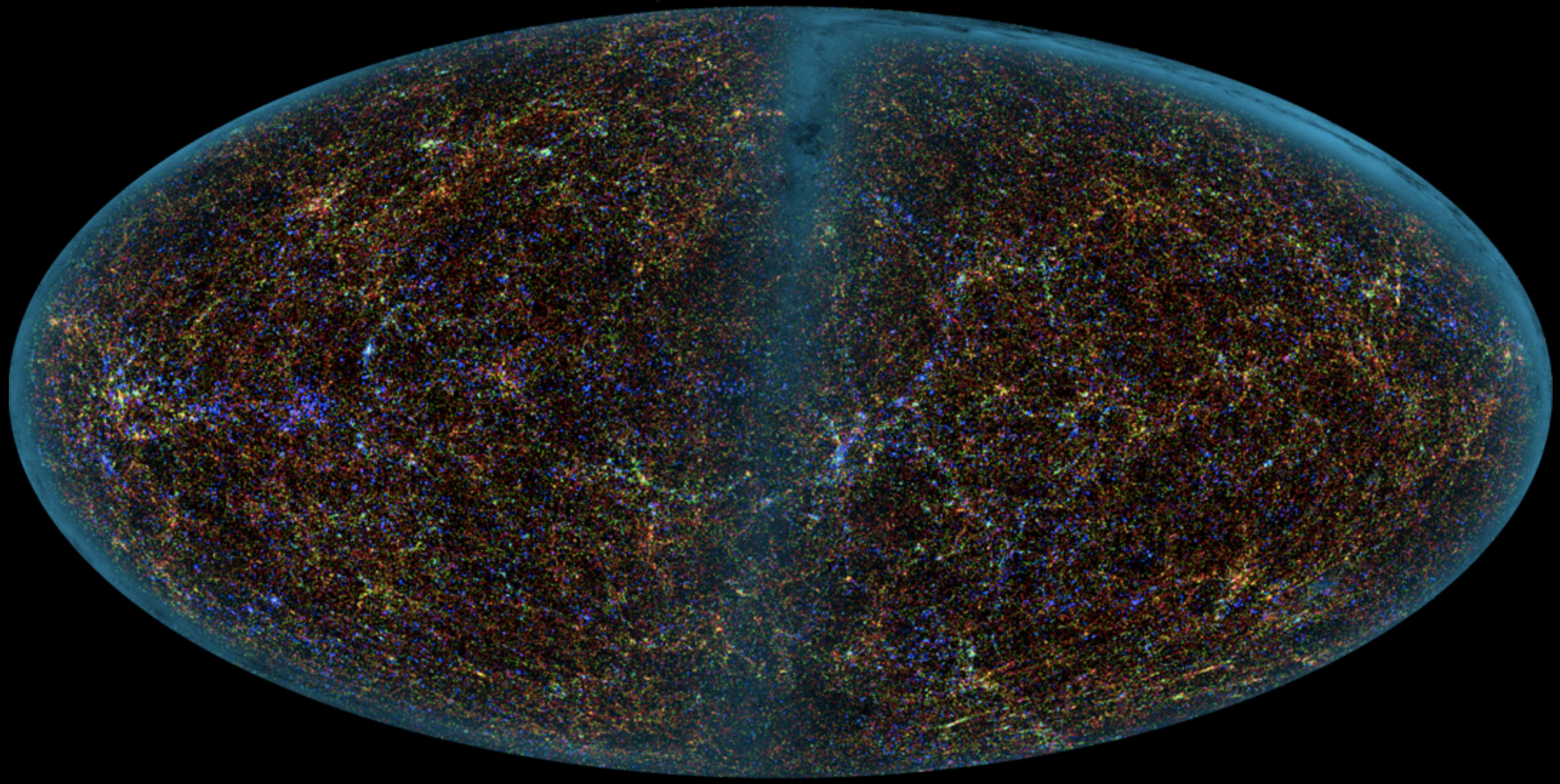
Cosmology
and Large Scale Structure



Today

Observational Tests

Number Counts

e.g., Galaxy N(m), N(z)

Galaxy selection

Homework 2 due

22 September 2022

http://astroweb.case.edu/ssm/ASTR328/

Observational Tests

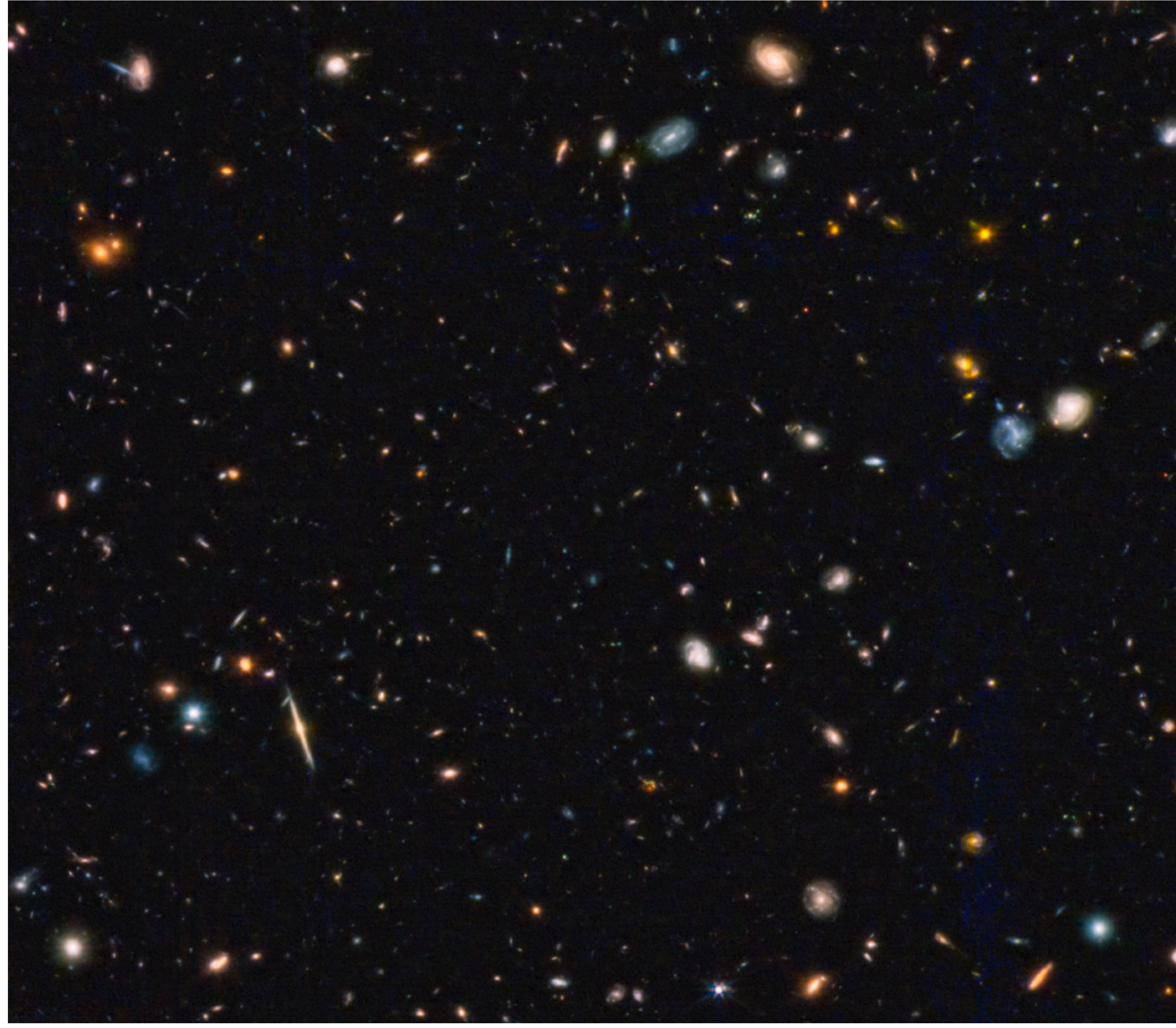
Five Classic Tests

• Luminosity-redshift relation	$D_L - z$	Standard Candle
• Angular size-redshift relation	$D_A - z$	Standard Rod
• Number-redshift relation	$N(z)$	Source counts with redshift
• Number-magnitude relation	$N(m)$	Source counts with magnitude
• Tolman test	$\Sigma(z)$	Surface brightness not distance independent in Robertson-Walker geometry

"Galaxies are the building blocks of the universe"
- Jim Peebles

It is easier for a camel to go through the eye of a needle than to understand cosmology without understanding galaxies
- Matthew 19:23

- Number-redshift and Number-magnitude relations



Since the volume depends on curvature, source counts N(m) provide a test

For sources of luminosities L and constant comoving number density $\Phi(L)$,

$\underbrace{\text{comoving number density}}_{\text{homogeneity, no evolution}}$

Number-redshift:

$$N(<z) = \frac{4\pi}{3H_0^2} z^3 \int_0^\infty \Phi(L) \left[1 + \frac{3}{2} z(1+q_0)\right] dL$$

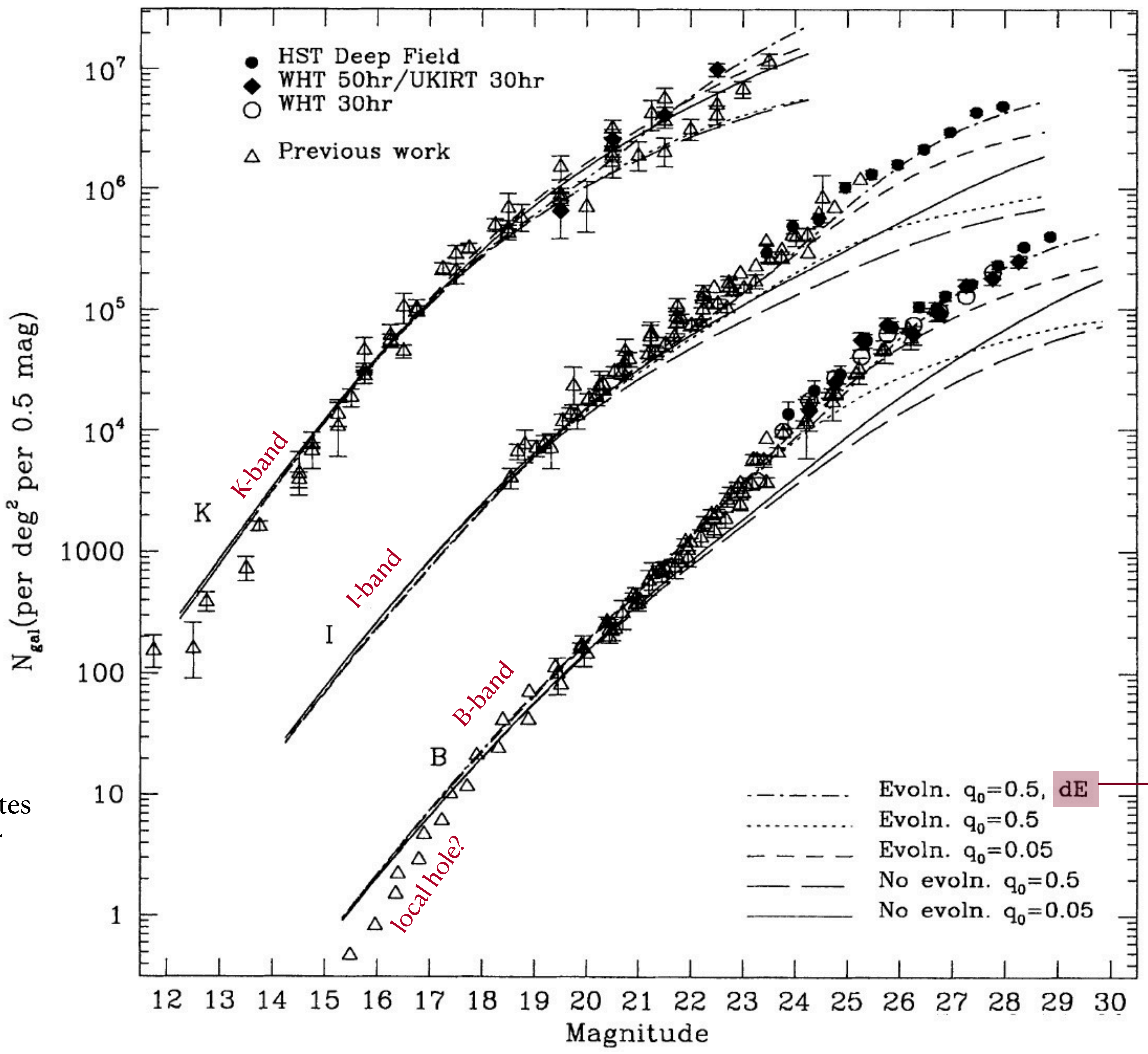
Number-magnitude:

$$N(<f) = \frac{4\pi}{3} (4\pi f)^{-3/2} \int_0^\infty \Phi(L) \left[1 - 3H_0 \left(\frac{L}{4\pi f}\right)^{1/2}\right] L^{3/2} dL$$

Historically, radio source counts in the 1960s played an important role in excluding the Steady State cosmology.

Number-magnitude:

Metcalfe et al. (1996)

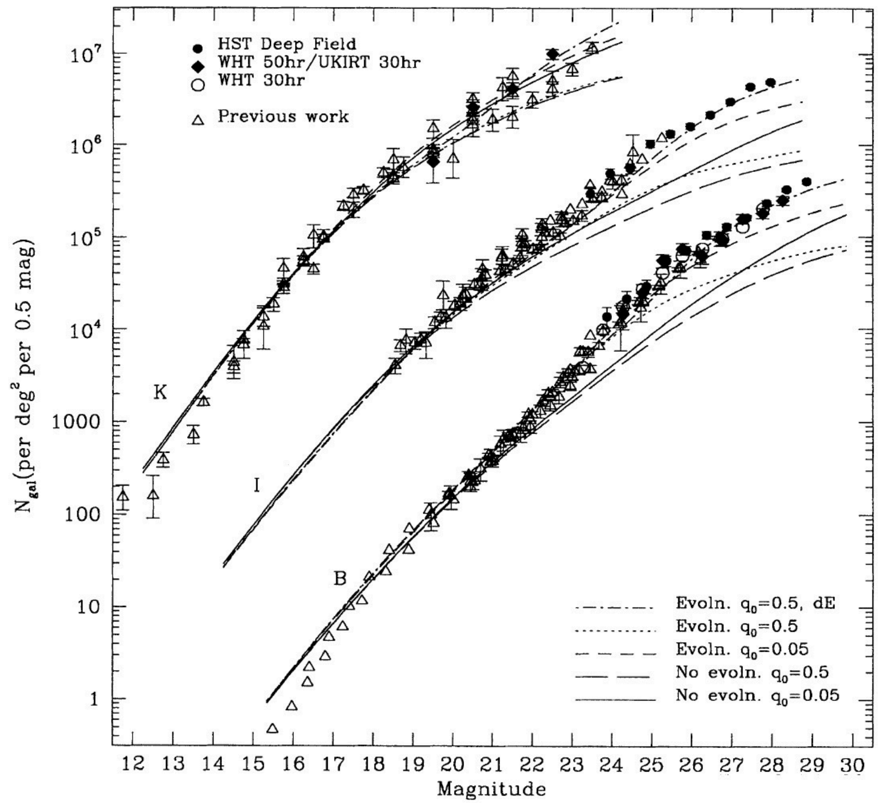


"The fit of the $q_0 = 0.5$ model is improved when an extra high redshift galaxy population (dE) with constant star formation rate (SFR) at $z > 1$ and rapidly fading at $z < 1$ is invoked."

A "no evolution" model extrapolates the locally measured Schechter function to high redshift.

Number-magnitude:

Metcalfe et al. (1996)



Only test that does not explicitly require redshift information.
Basically integrate over all the relevant distributions.

$$A(m,T) = A_0 \int_0^z D(z,T)\Phi(M,T)dV(z,q_0)$$

Density distribution (e.g., non-uniform large scale structure)

Luminosity function n(L)↔Φ(M)

Volume element (cosmological)

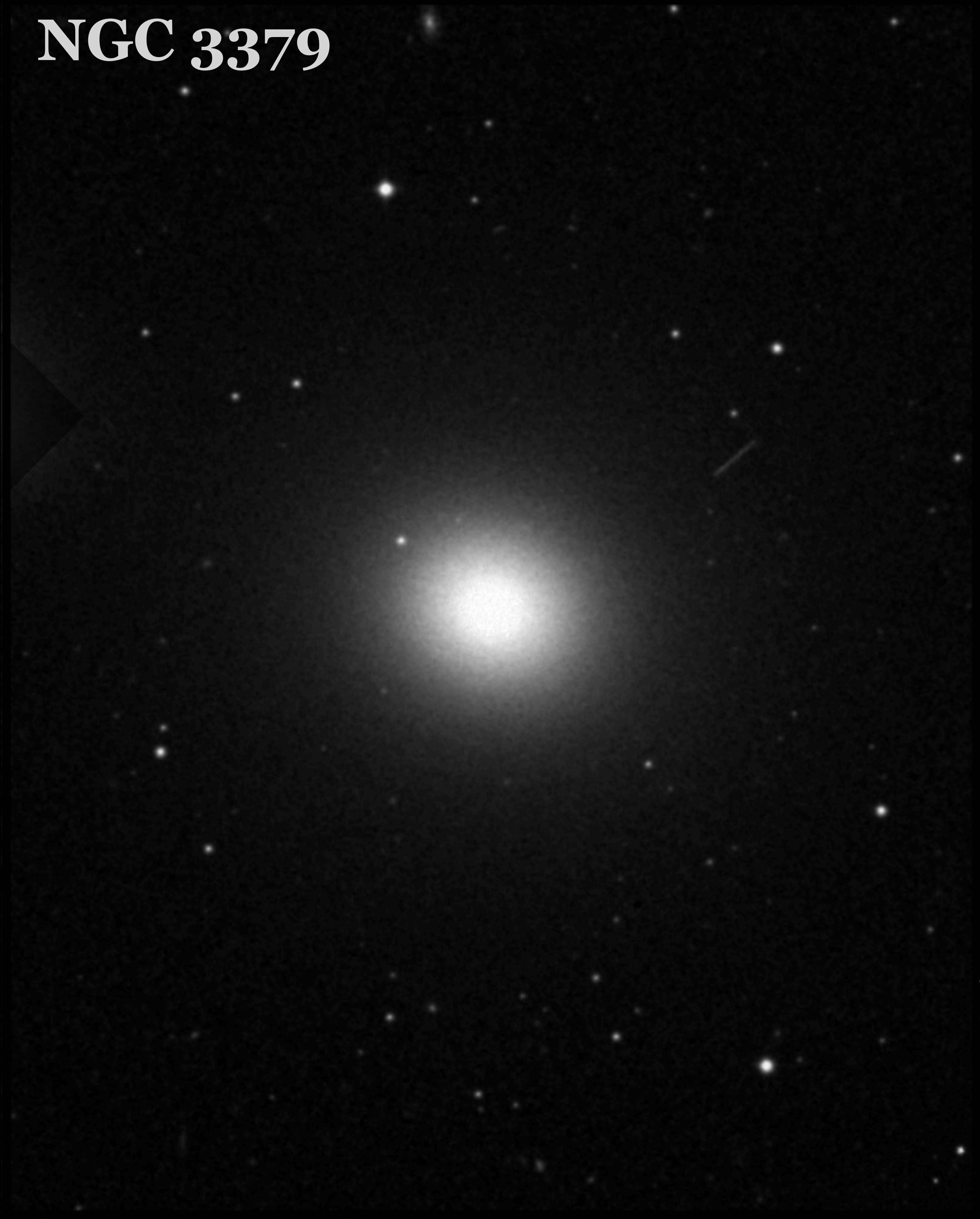
$$N(m,T) = \int_T \int_0^m A(m,T)dTdm$$

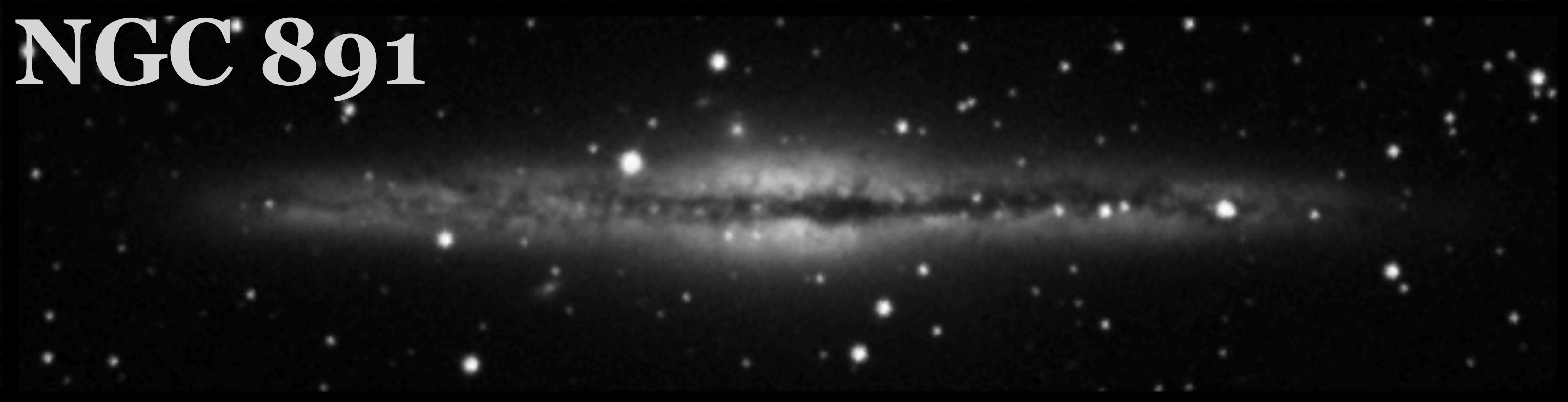
For sources of type *T* and magnitude *m*.

We can only get at the volume element if we understand the other terms and their redshift evolution.

Galaxy Morphology

Early Types
(Ellipticals)





Late Types
(Spirals & Irregulars)

Ellipticals
3D ellipsoids
pressure supported,
dynamically hot: V/σ small

Spirals
2D disks
rotationally supported,
dynamically cold: V/σ large

Schechter function

$$\Phi(L) = \Phi^* \left(\frac{L}{L^*}\right)^{-\alpha} e^{-L/L^*}$$

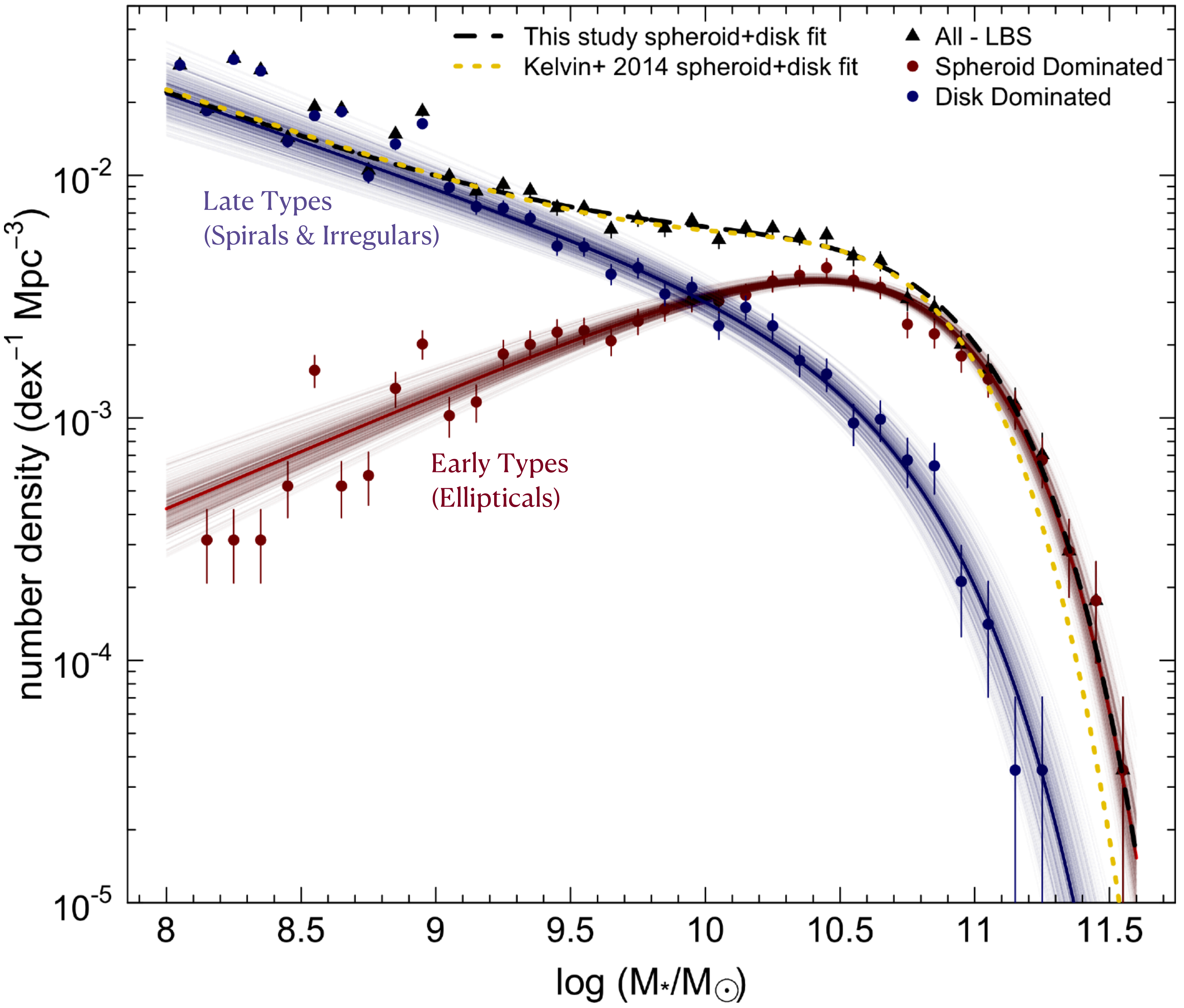
L^* Characteristic luminosity

Φ^* Characteristic number density

α Faint end slope

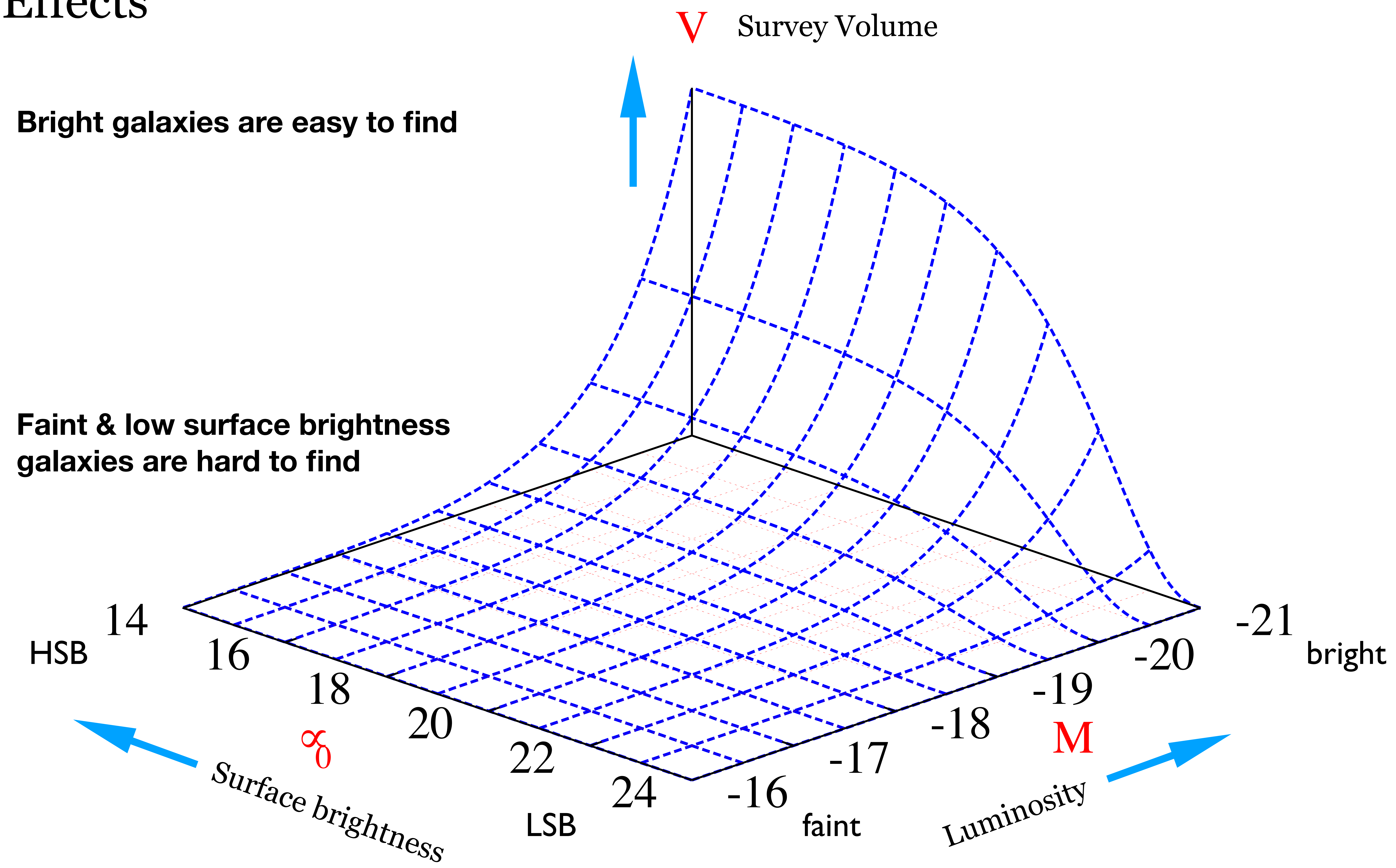
Population	log(M^* $h_{0.72}$/$M_\odot$)	α	ϕ*/10^{-3} (dex^{-1} Mpc^{-3} $h_{0.7}$3)
Early Type	10.74 ± 0.026	0.525 ± 0.029	3.67 +0.20
Late Type	10.70 ± 0.049	1.39 ± 0.021	0.855 +0.10

Galaxy mass function from the GAMA survey



Moffett et al. 2016, MNRAS, 457, 1308

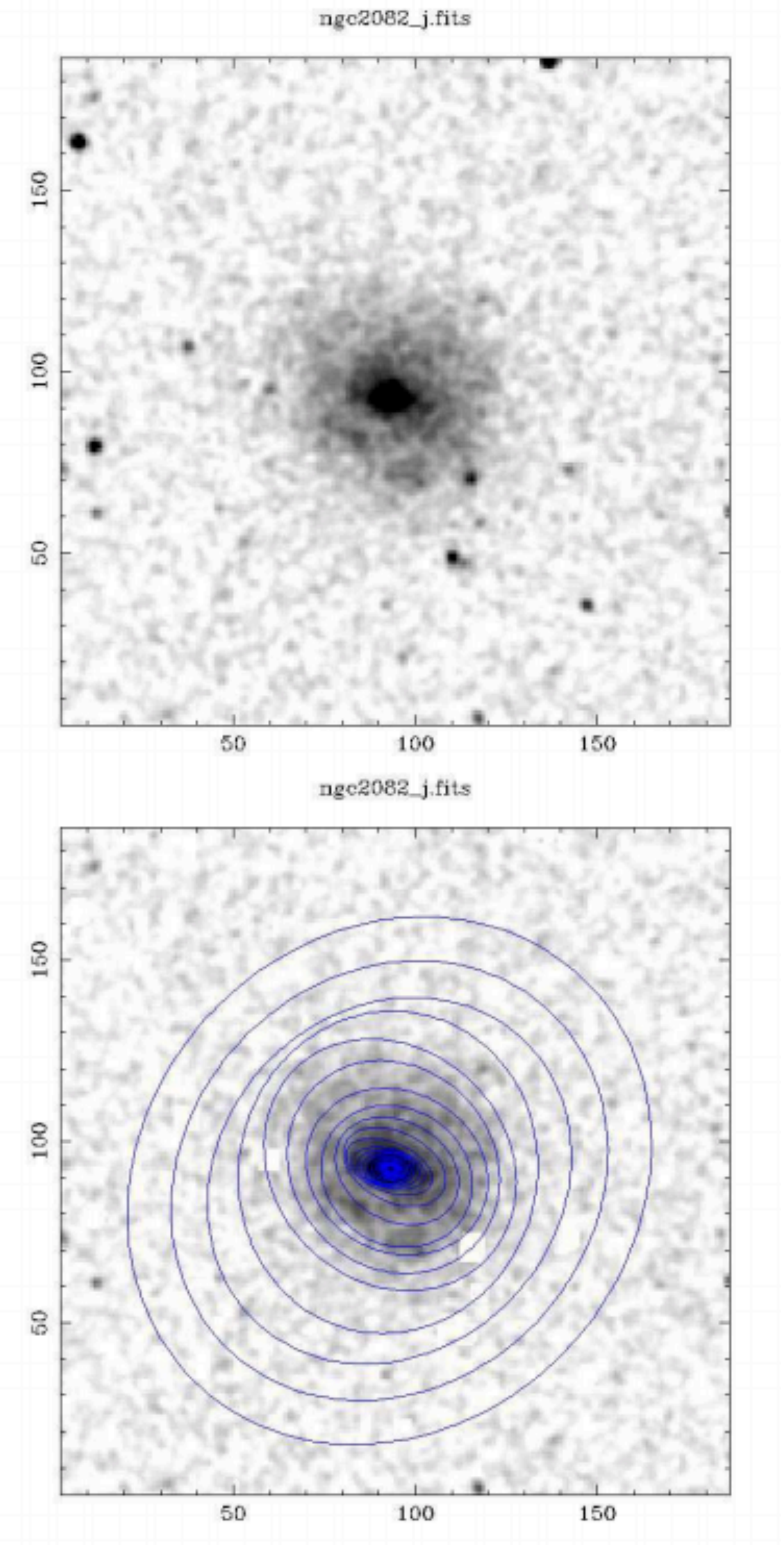
Selection Effects



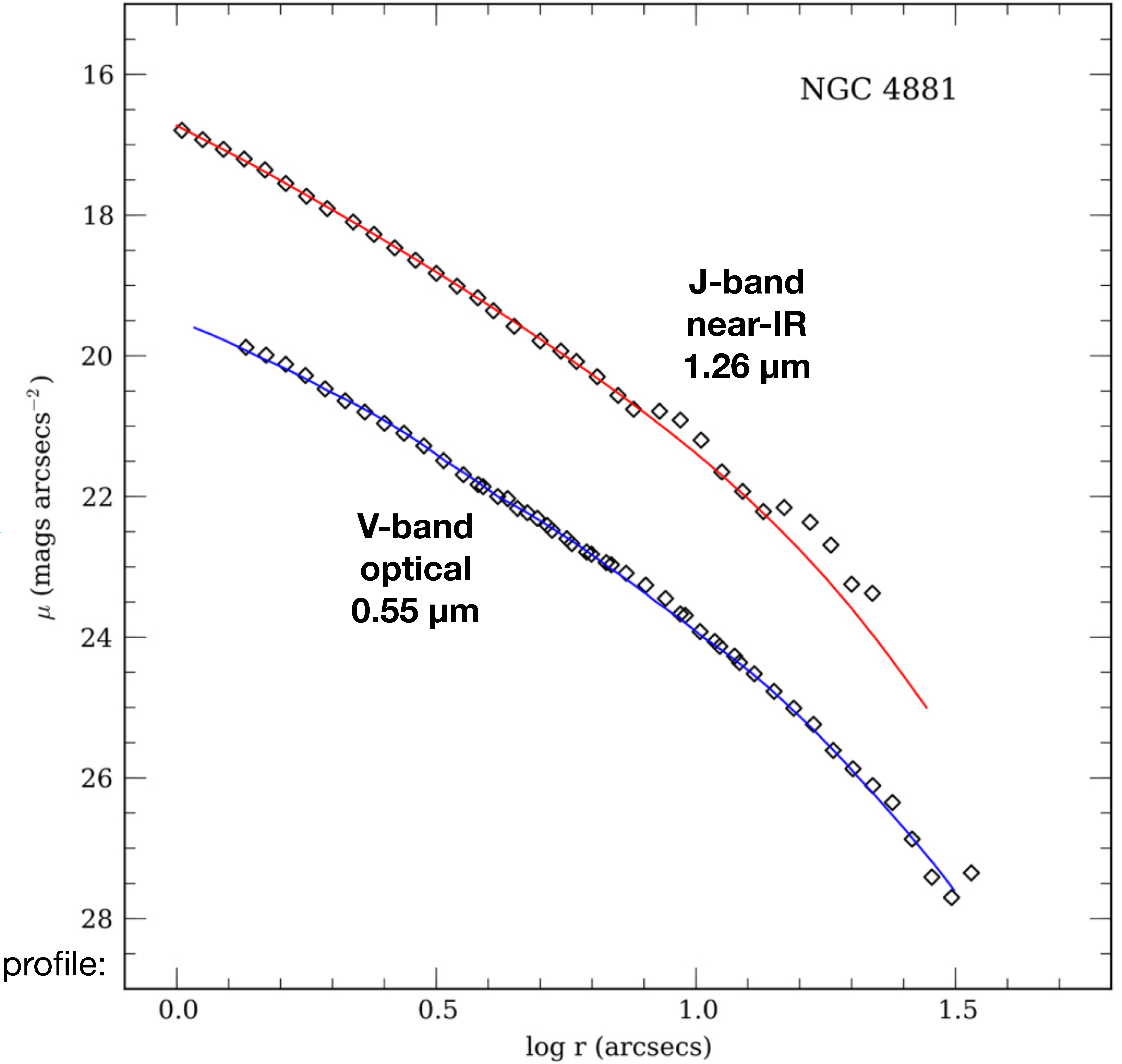
Quantitative Surface photometry

Elliptical galaxies typically fit with de Vaucouleurs profiles.
Spiral galaxies typically fit with exponential profiles.

Schombert (2007) arXiv:astro-ph/0703646



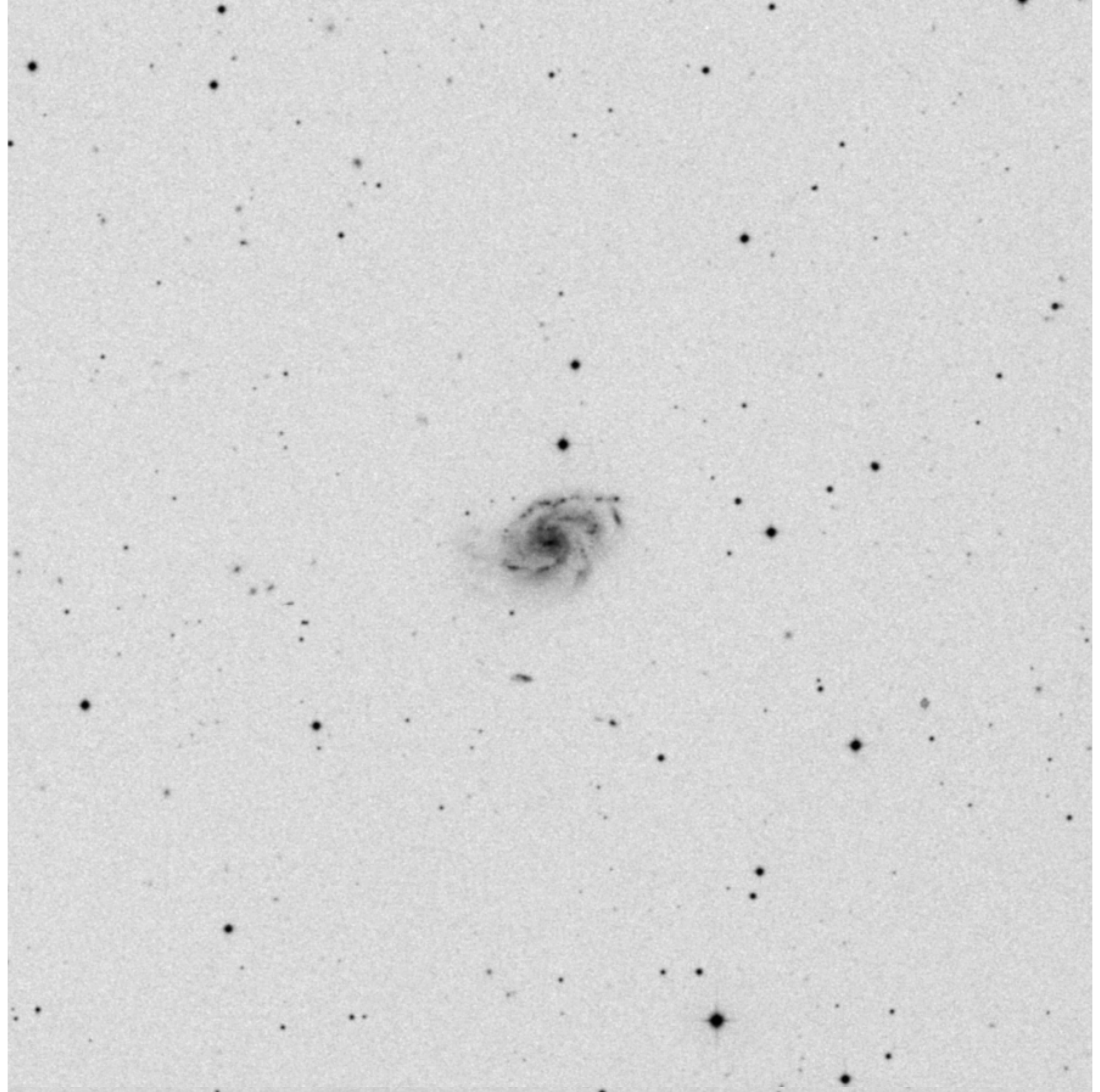
Fit ellipses, derive surface brightness profile:

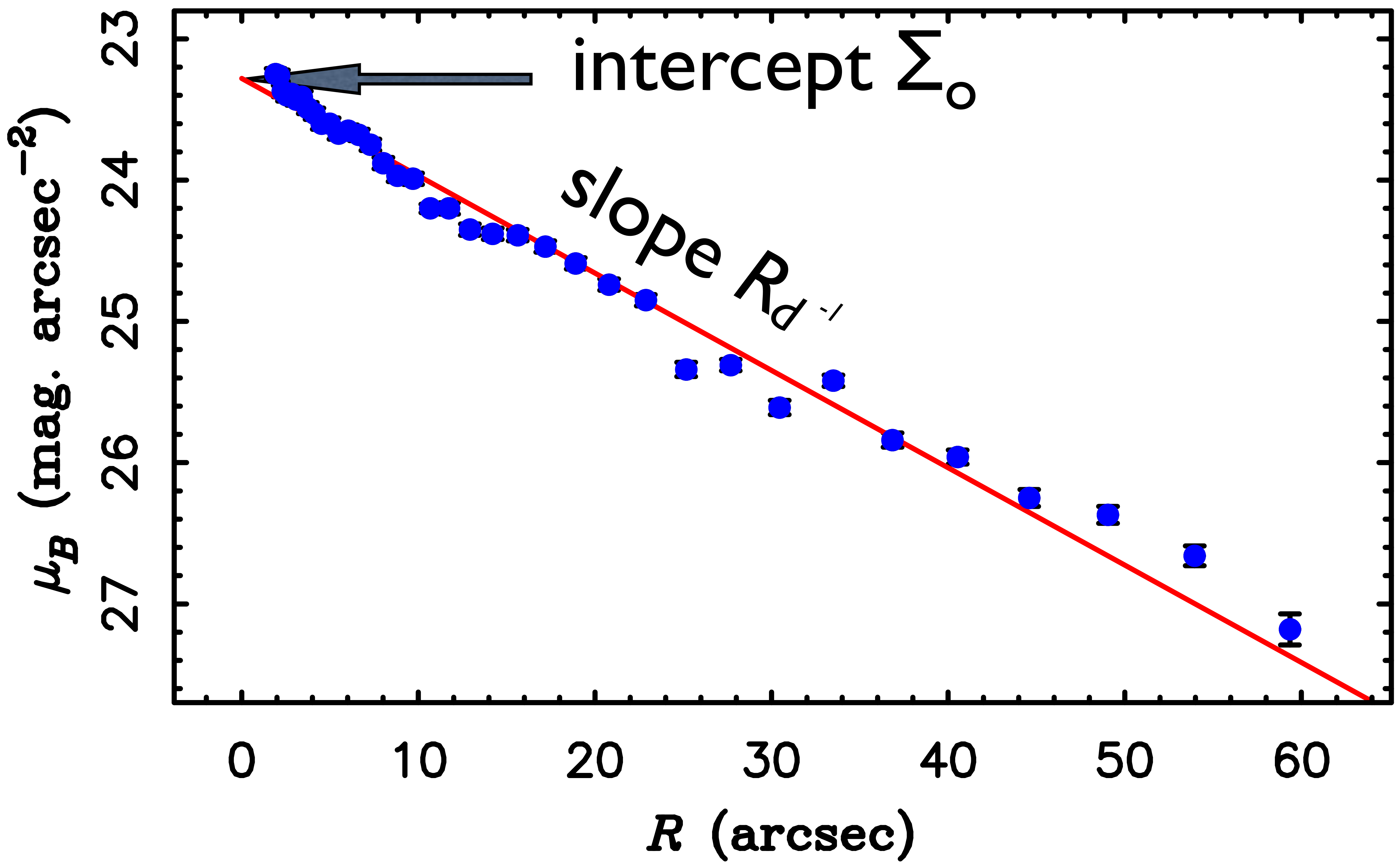


Disk galaxies
(Spirals+Irrs)

High Surface Brightness Galaxy

HSB

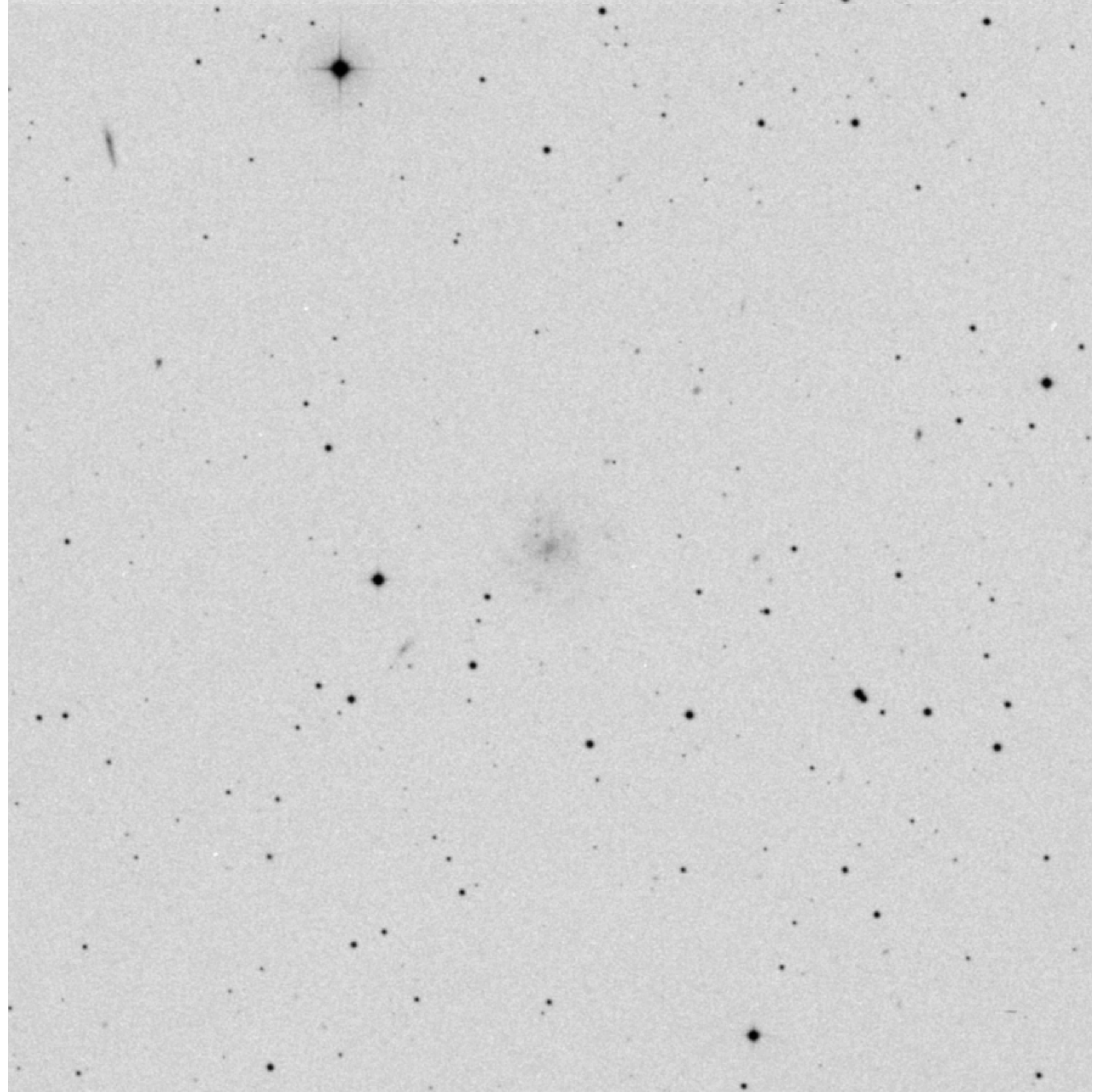




$$\Sigma(R) = \Sigma_o \, e^{-R/R_d}$$

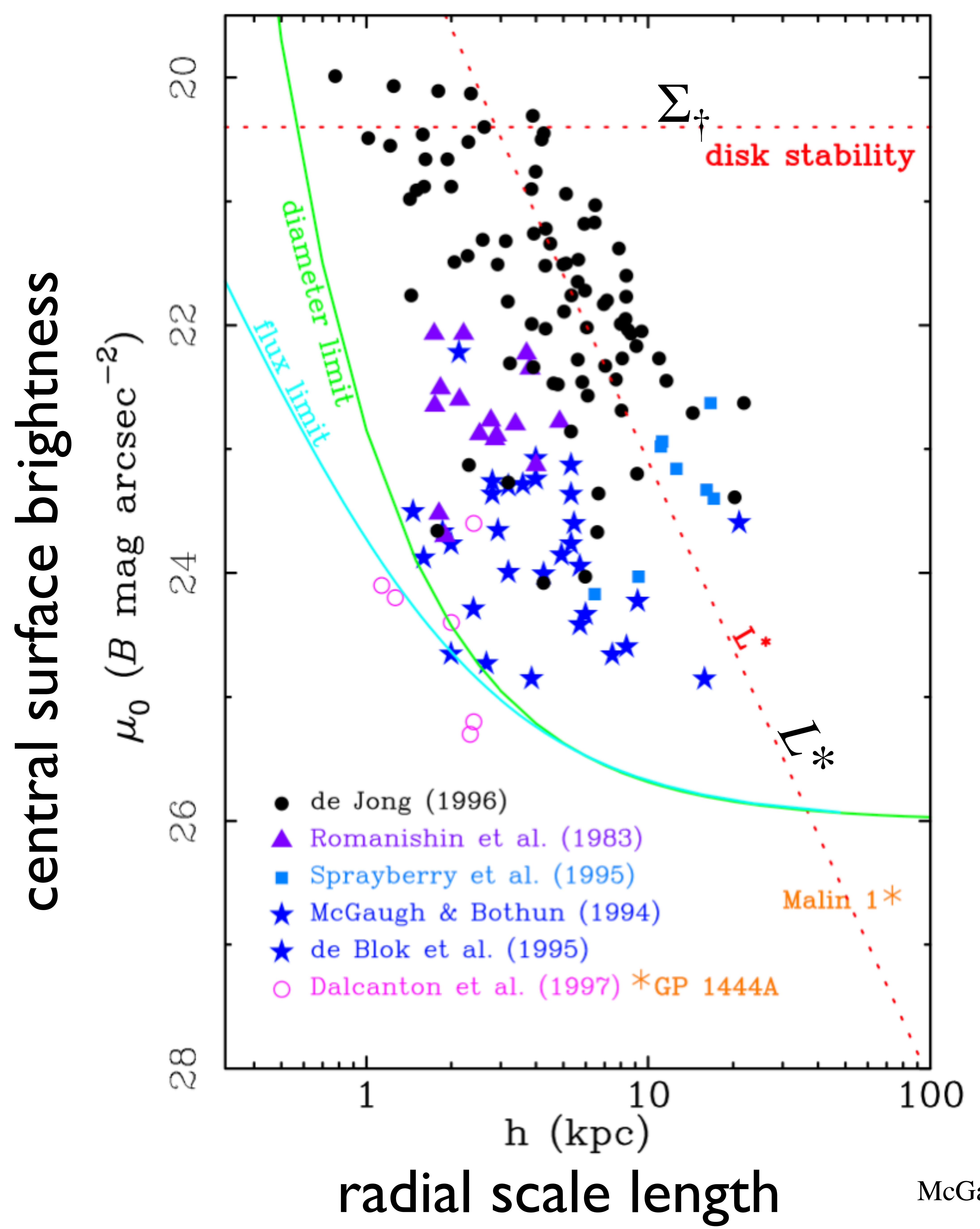
Azimuthally averaged light distribution
approximately exponential for spiral disks.

LSB



Low Surface Brightness Galaxy

Disk galaxies (Spirals+Irrs)



Galaxies exist all over the size-surface brightness plane up to maximums in luminosity $L*$ and surface brightness $\Sigma_\dagger$

No minimums known - lower boundaries set by selection effects.

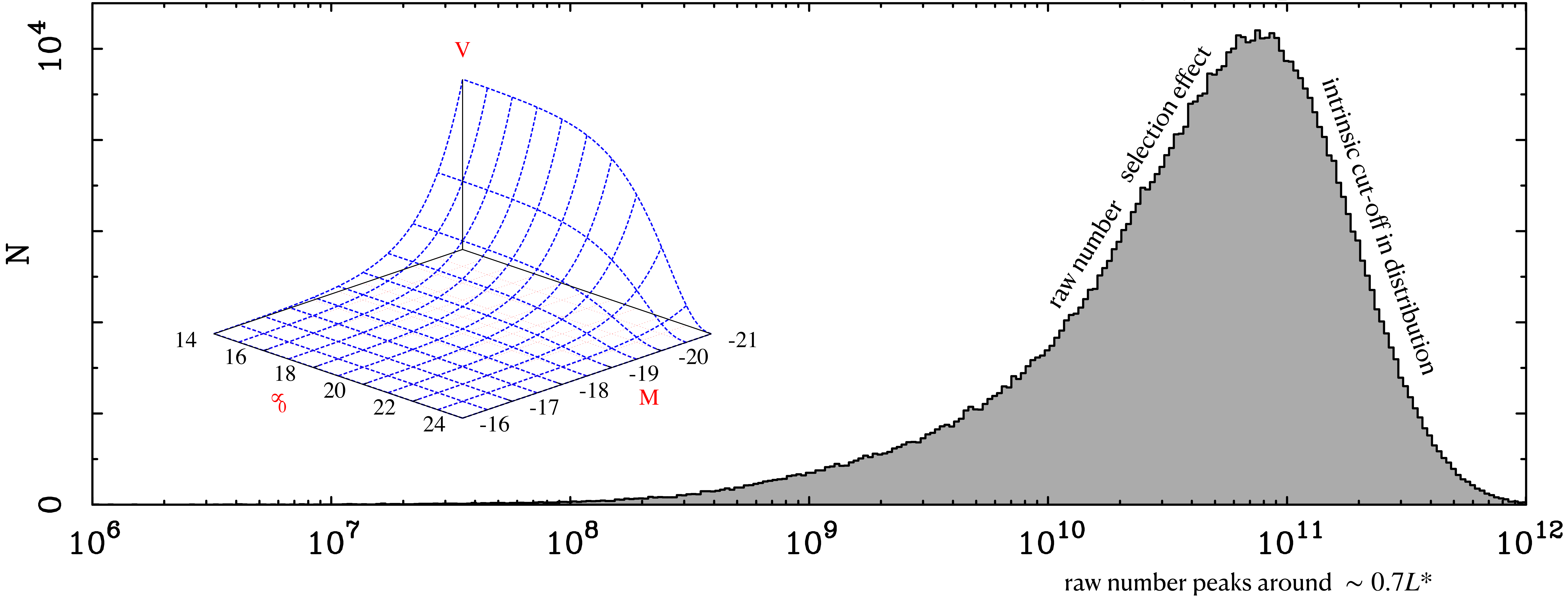
Note that galaxies of a given luminosity exist over a wide range of size and surface brightness. Galaxies are **not** a single parameter sequence in mass.

McGaugh (1999) IAU 171: ASP 170, 19 (arXiv:astro-ph/9810363)

Selection effects in galaxy surveys -
the number of galaxies in the Sloan survey as a function of mass

Faint and low surface brightness galaxies are hard to see. Only detected over a small volume.

Bright galaxies are easy to see. Are detected over a large volume. This is highly unrepresentative.



Galaxy mass function from the GAMA survey

The intrinsic *numbers* of galaxies increase with decreasing mass after volume correction.

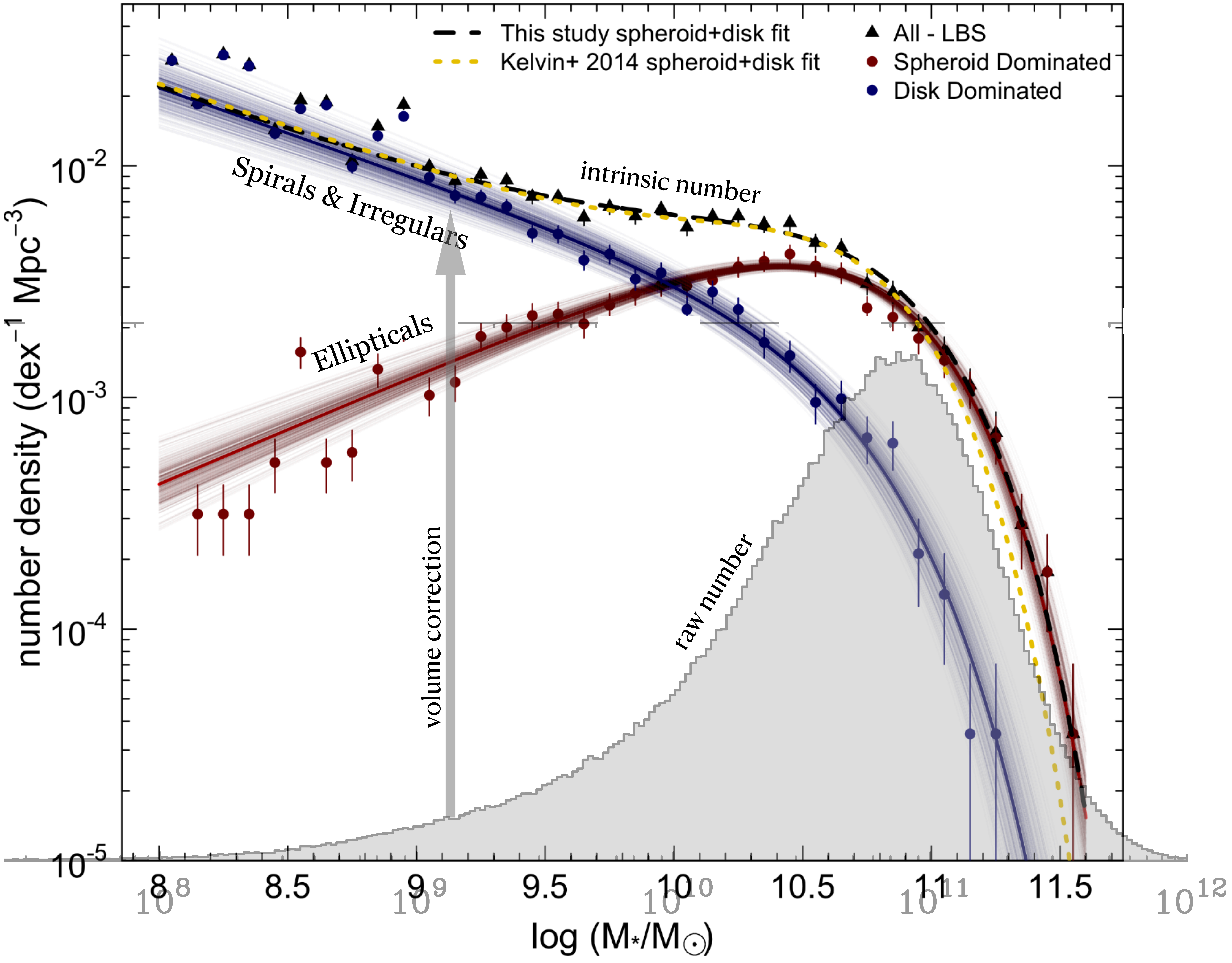
Most *mass* is in the most massive galaxies.

Luminosity density

$$j = \int_0^\infty L\Phi(L)dL = \Phi^* L^* \Gamma(2-\alpha)$$

Incomplete Γ function of order unity for $\alpha < 1.5$; diverges for $\alpha = 2$.

$$j \approx \Phi^* L^*$$



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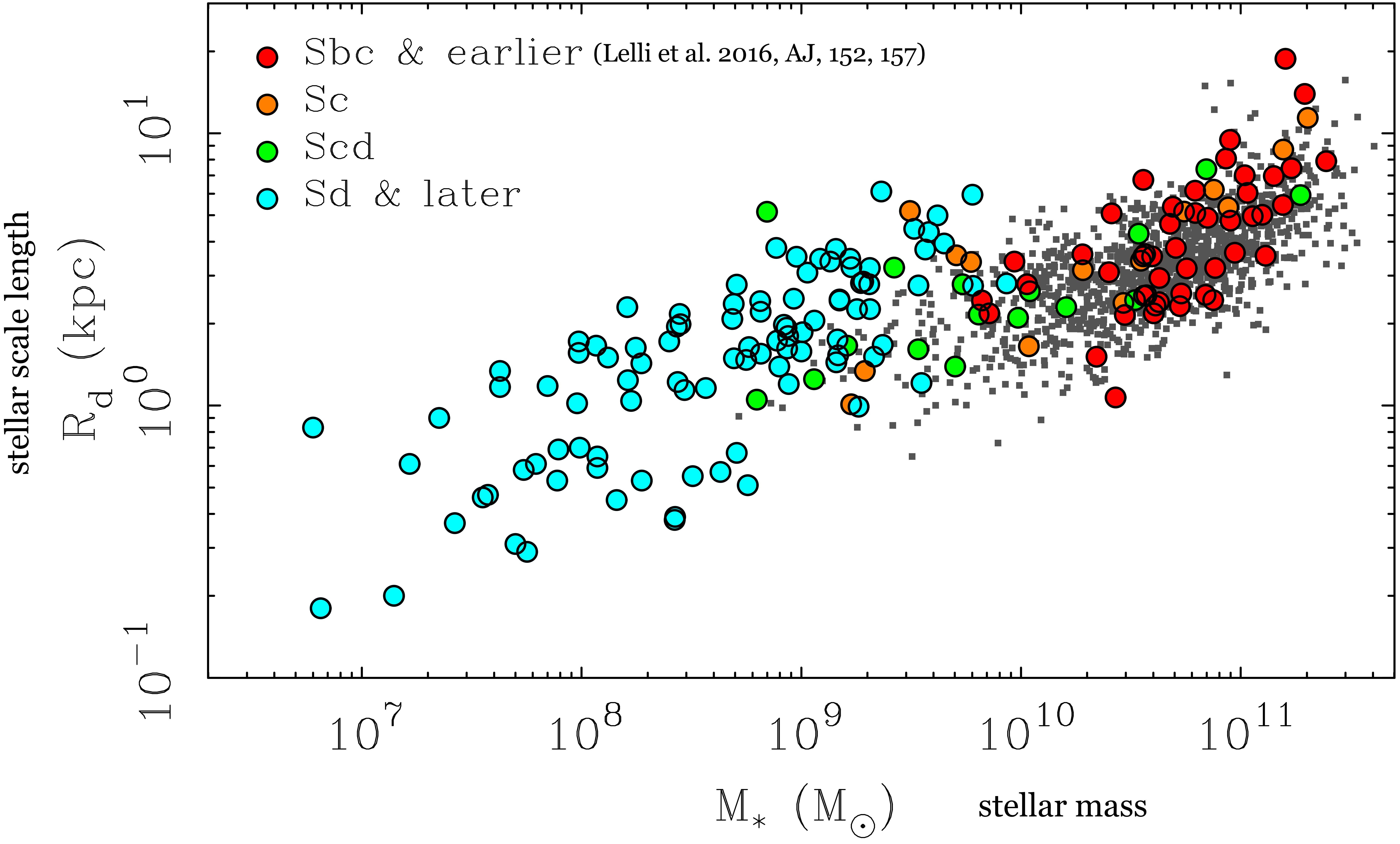
Magnitude selected samples are biased towards bright galaxies.

They underrepresent dwarf and LSB galaxies.

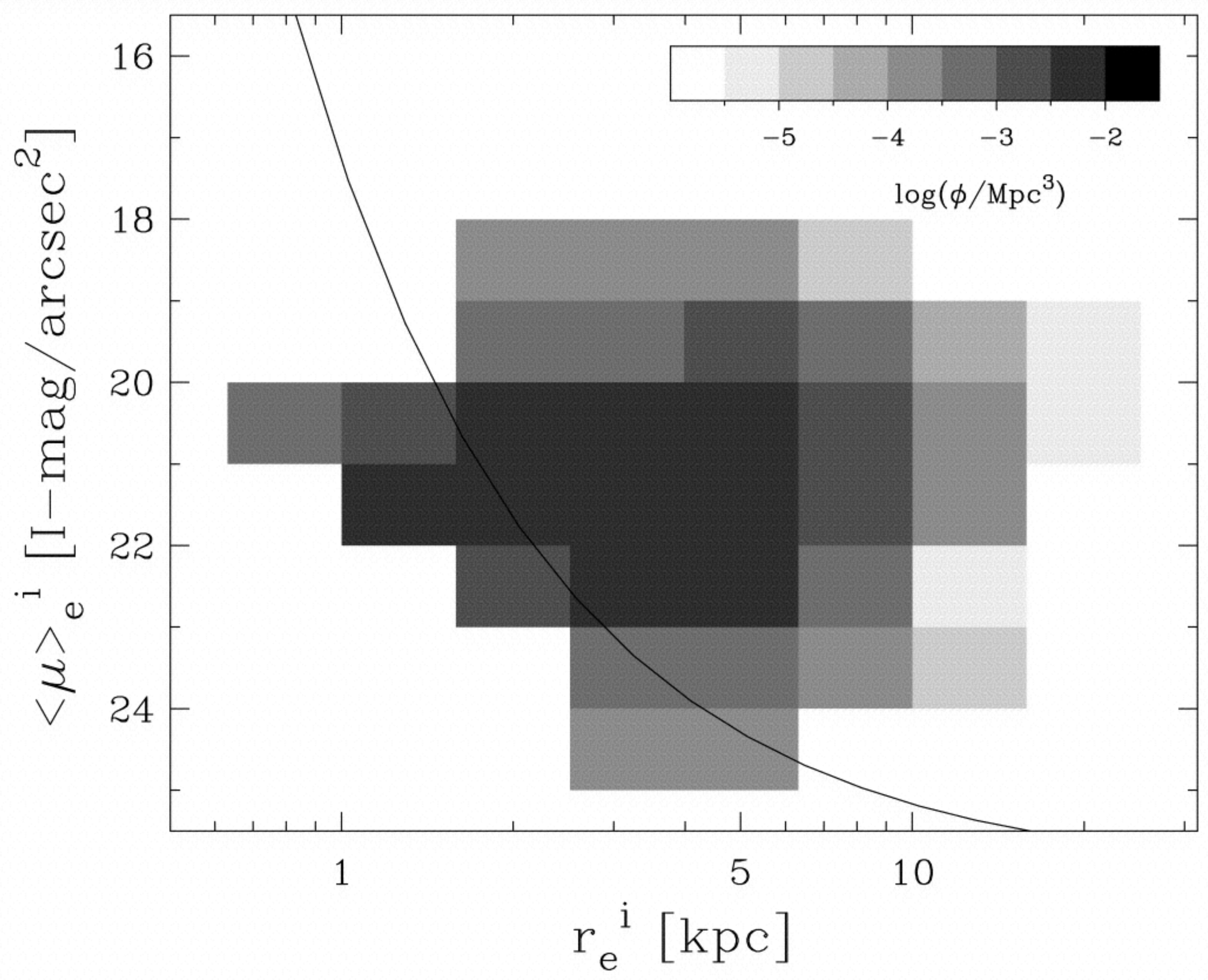


In general, one would like to know the bivariate distribution of size and surface brightness.

This is the 2D projection of a 3D plot with number density illustrated by the shading.

The luminosity function is an integral over the bivariate distribution: $L \propto \Sigma_e R_e^2$.

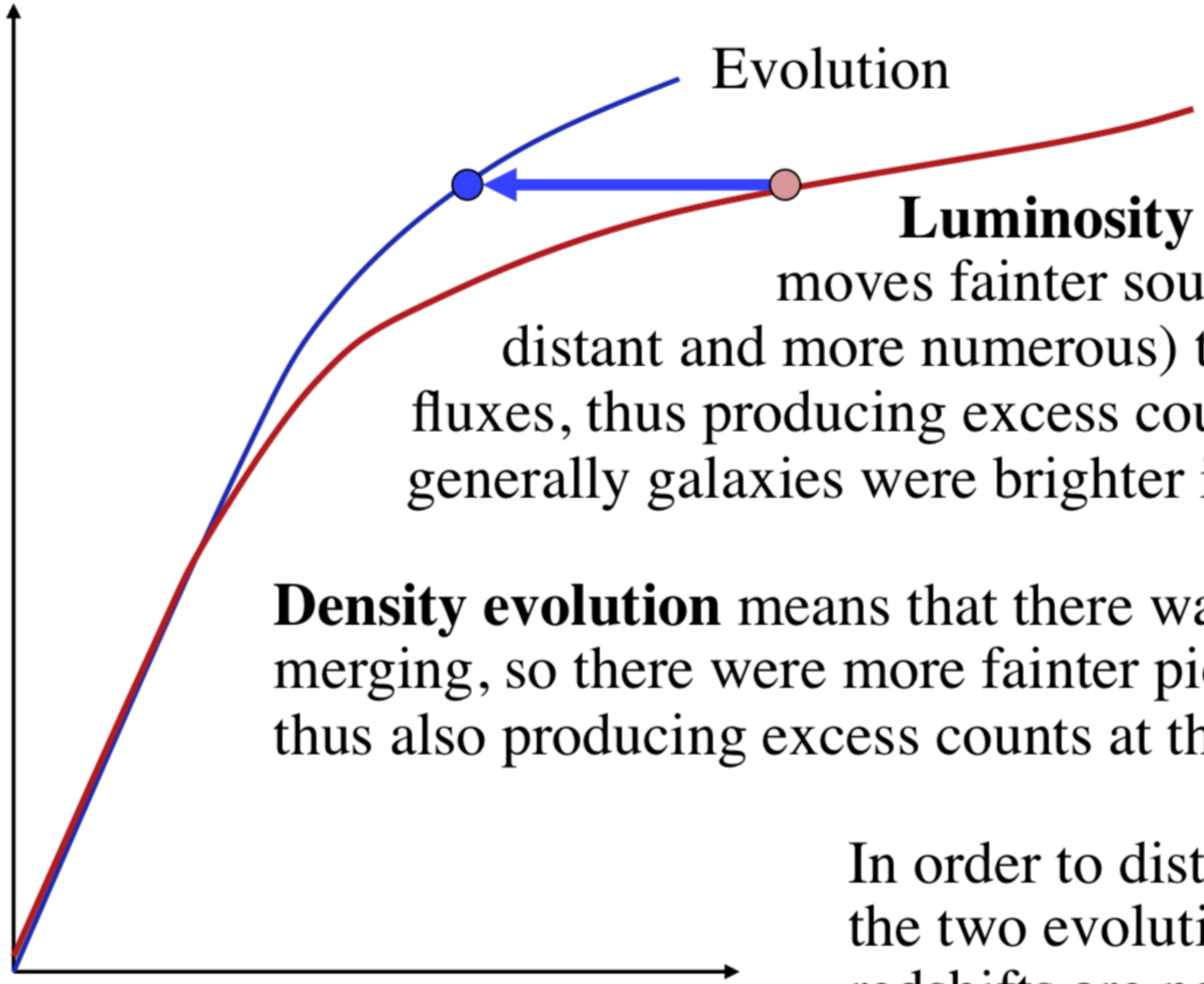
Can employ more parameters to more fully describe galaxies. E.g., this plot is restricted to morphological types Sb - Sdm.



Bivariate space density distribution of Sb-Sdm galaxies as a function of effective surface brightness and effective radius from de Jong & Lacey (2000, ApJ, 545, 781).
The line indicates the 20 Mpc sample selection limit for face-on exponential disks. To the left of the line we are limited by small number statistics and local density fluctuations.

Source Counts: The Effect of Evolution

(at a fixed cosmology!)



Luminosity evolution moves fainter sources(more distant and more numerous) to brighter fluxes, thus producing excess counts, since generally galaxies were brighter in the past

Density evolution means that there was some galaxy merging, so there were more fainter pieces in the past, thus also producing excess counts at the faint end

In order to distinguish between the two evolution mechanisms, redshifts are necessary

Djorgovski (2017)

What We Need

- Stellar theory predicts the evolution or (***stellar tracks***) or stars of a given mass. There is some variation among different theoretical models
- Observations give us ***libraries of stellar spectra*** as a function of age, mass, metallicity, etc.
- We need the ***initial mass function (IMF)*** of stars
- All of these are uncertain at very low metallicities and high stellar masses
- We have to assume some ***star formation rate (SFR)*** as a function of time. Popular choices include a sharp burst, a constant SFR, or an exponentially declining one:

$$\frac{\partial M}{\partial t} \propto \exp\left(-\frac{t}{\tau}\right)$$

Djorgovski (2017)

Galaxy Evolution

SSP: evolution of simple stellar population in which all stars are born at the same time.