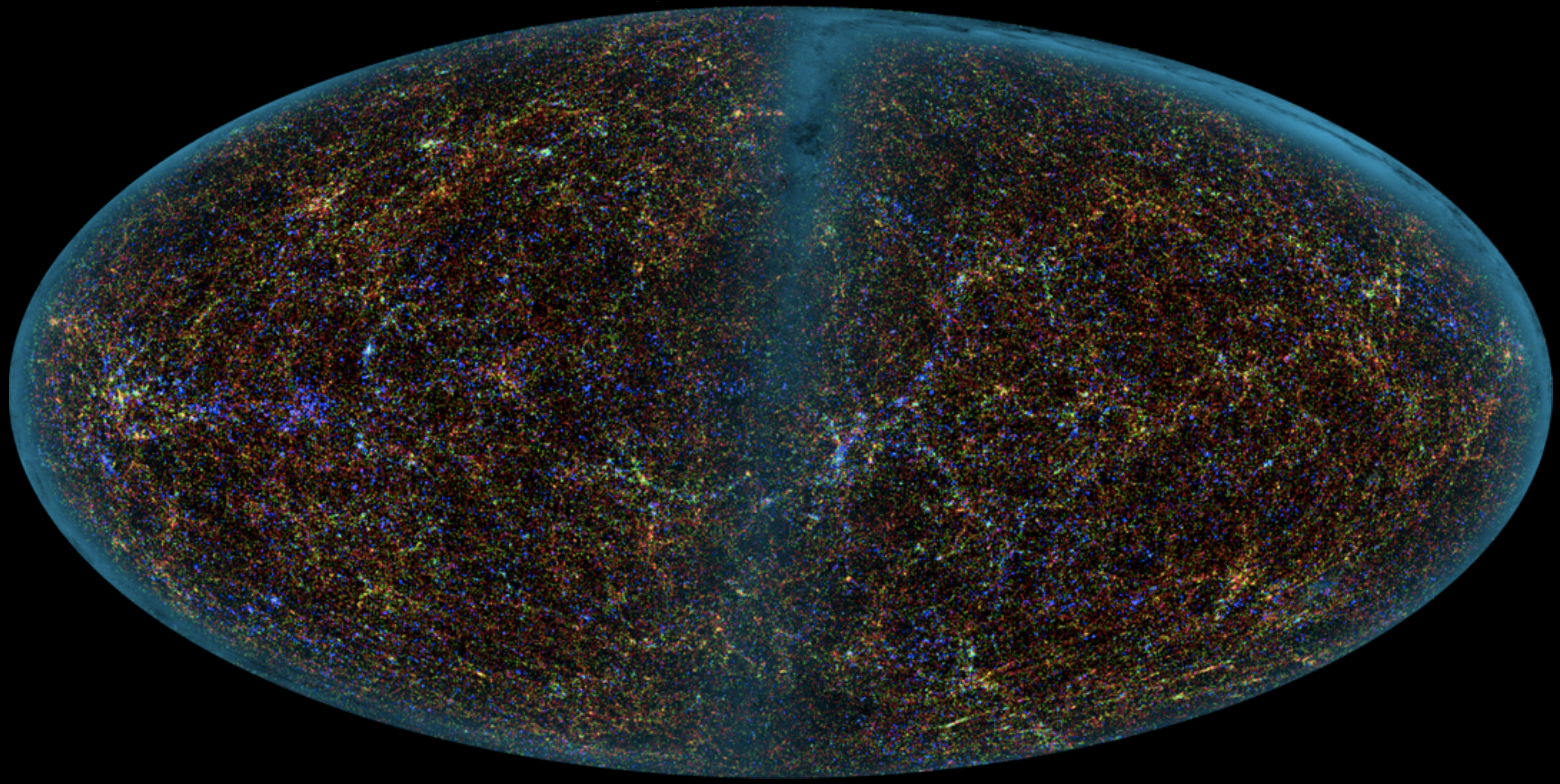
Cosmology

and Large Scale Structure



Today

Number counts

N(m); N(z)

Luminosity Functions

28 September 2020

http://astroweb.case.edu/ssm/astr328/

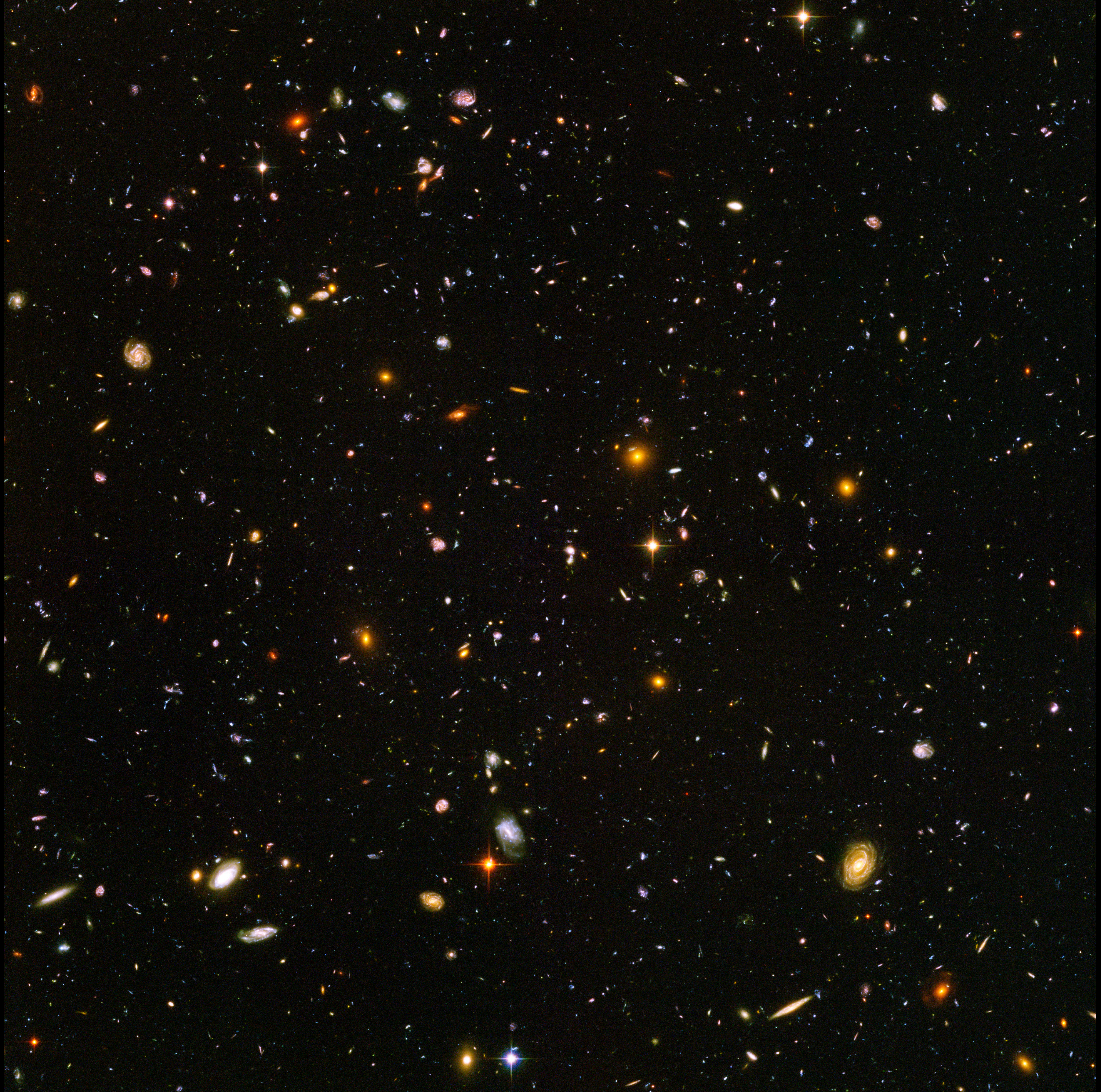
Observational Tests

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

Hubble Ultra Deep Field

3' x 3'



Robertson-Walker metric

$$ds^2 = -c^2dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + \sin^2\theta d\phi^2)\right]$$

Volume

$$V = a^3\int_0^r \frac{r^2dr}{\sqrt{1-kr^2}}\int_0^\pi \sin\theta d\theta \int_0^{2\pi} d\phi$$

integrates to

$$V = \frac{4\pi}{3}(ar)^3 f(r) \qquad f(r) = \begin{cases} \frac{3}{2}\left[\frac{\sin^{-1} r}{r^3} - \frac{\sqrt{1-r^2}}{r^2}\right] \\ 1 \\ \frac{3}{2}\left[\frac{\sqrt{1+r^2}}{r^2} - \frac{\sinh^{-1} r}{r^3}\right] \end{cases} \quad \text{for} \quad k = \begin{cases} 1 \\ 0 \\ -1 \end{cases}$$

in terms of the proper distance

$$D_p = a(t) \int_0^r \frac{dr}{\sqrt{1 - kr^2}}$$

we can make the Taylor expansion

Sandage (1988, ARA&A, 26, 561)

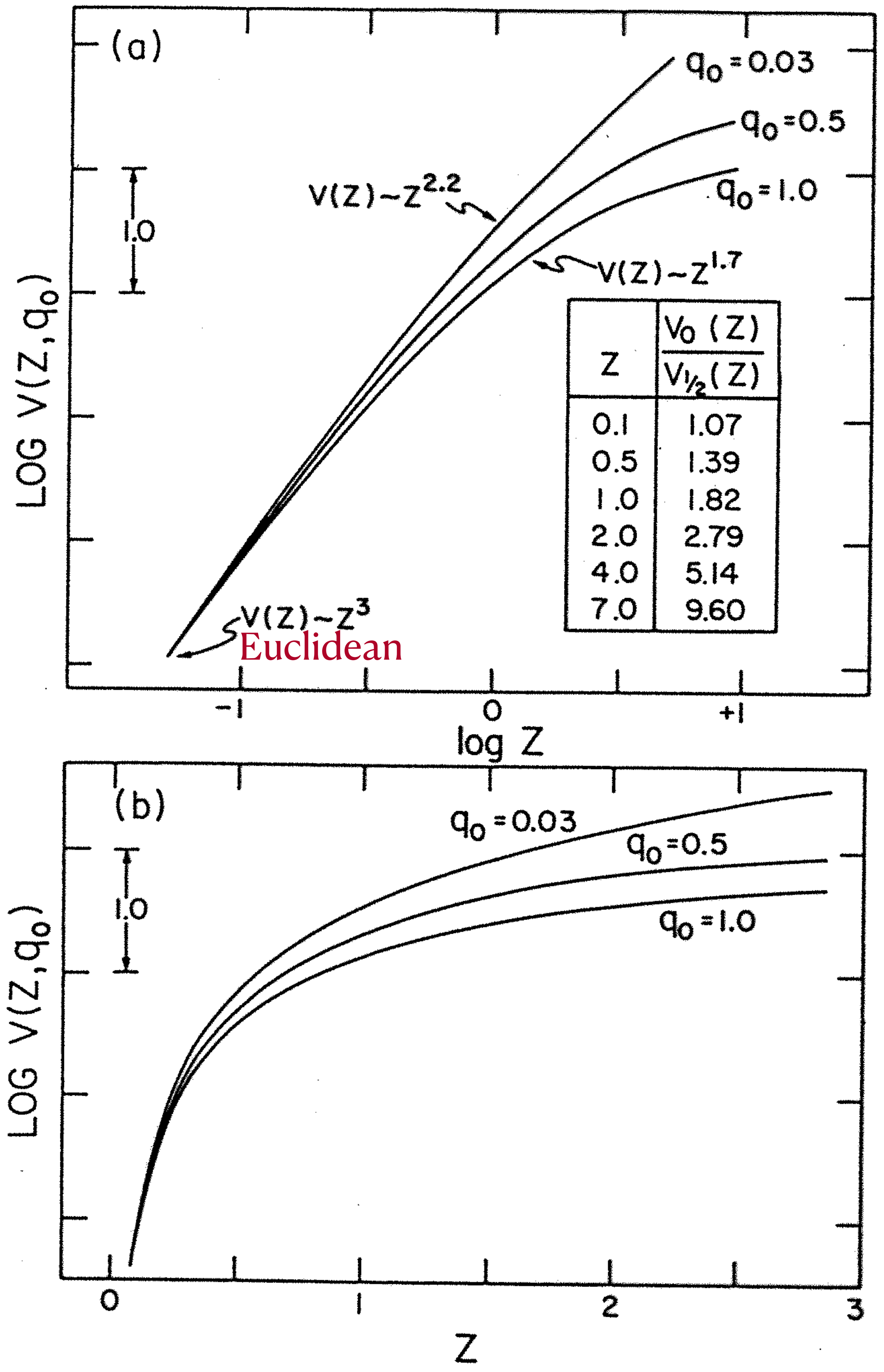
$$V = \frac{4\pi}{3} D_p^3 \left[1 - \frac{k}{5} \left(\frac{D_p}{R} \right)^2 + \mathcal{O} \left(\frac{D_p}{R} \right)^4 \right]$$

$\frac{k}{R^2}$ is the curvature of space

Note that the volume increases as the curvature becomes more negative,
so a closed universe is “small”
and an open universe is “big”

Sandage 1988, ARAA, 26, 561

predicted N(<z)



Z	$V_0(Z)/V_{1/2}(Z)$
0.1	1.07
0.5	1.39
1.0	1.82
2.0	2.79
4.0	5.14
7.0	9.60

as q_0↓, V↑

Figure 1 Theoretical $N(z, q_0)$ relations for three values of q_0. Plotted is the integral count, i.e. the total number of galaxies in a complete (volume-limited) sample that have redshifts smaller than z. Parts (*a*) and (*b*) are the same function but plotted as log z (*a*) and z (*b*).

A portion of the Hubble Ultra Deep Field at full resolution

Since the volume depends on curvature, source counts provide a test

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

Number-redshift:

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

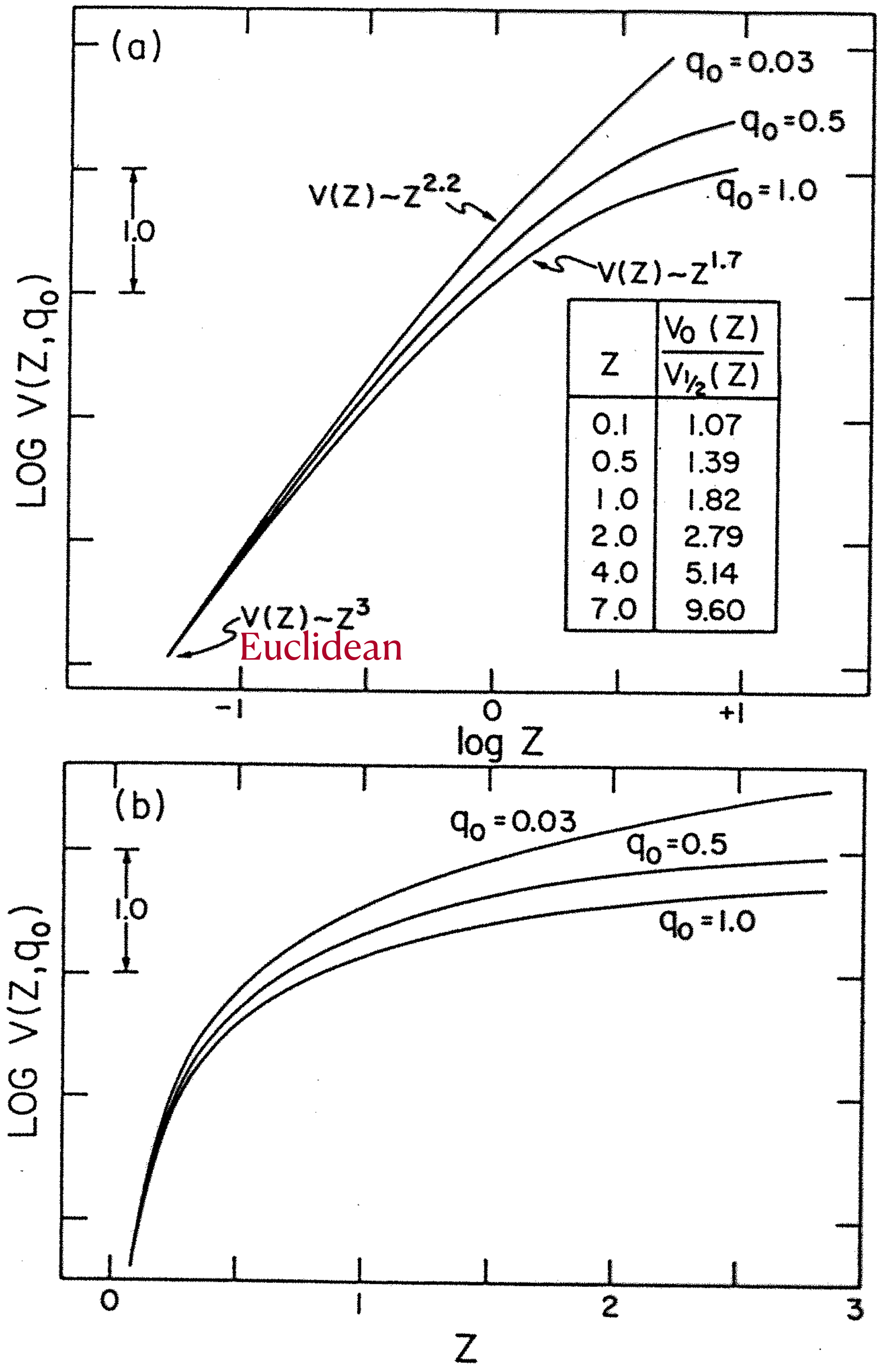
Number-magnitude:

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

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

Sandage 1988, ARAA, 26, 561

predicted N(<z)



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as $q_0 \downarrow$, $V \uparrow$

Figure 1 Theoretical $N(z, q_0)$ relations for three values of q_0. Plotted is the integral count, i.e. the total number of galaxies in a complete (volume-limited) sample that have redshifts smaller than z. Parts (*a*) and (*b*) are the same function but plotted as log z (*a*) and z (*b*).

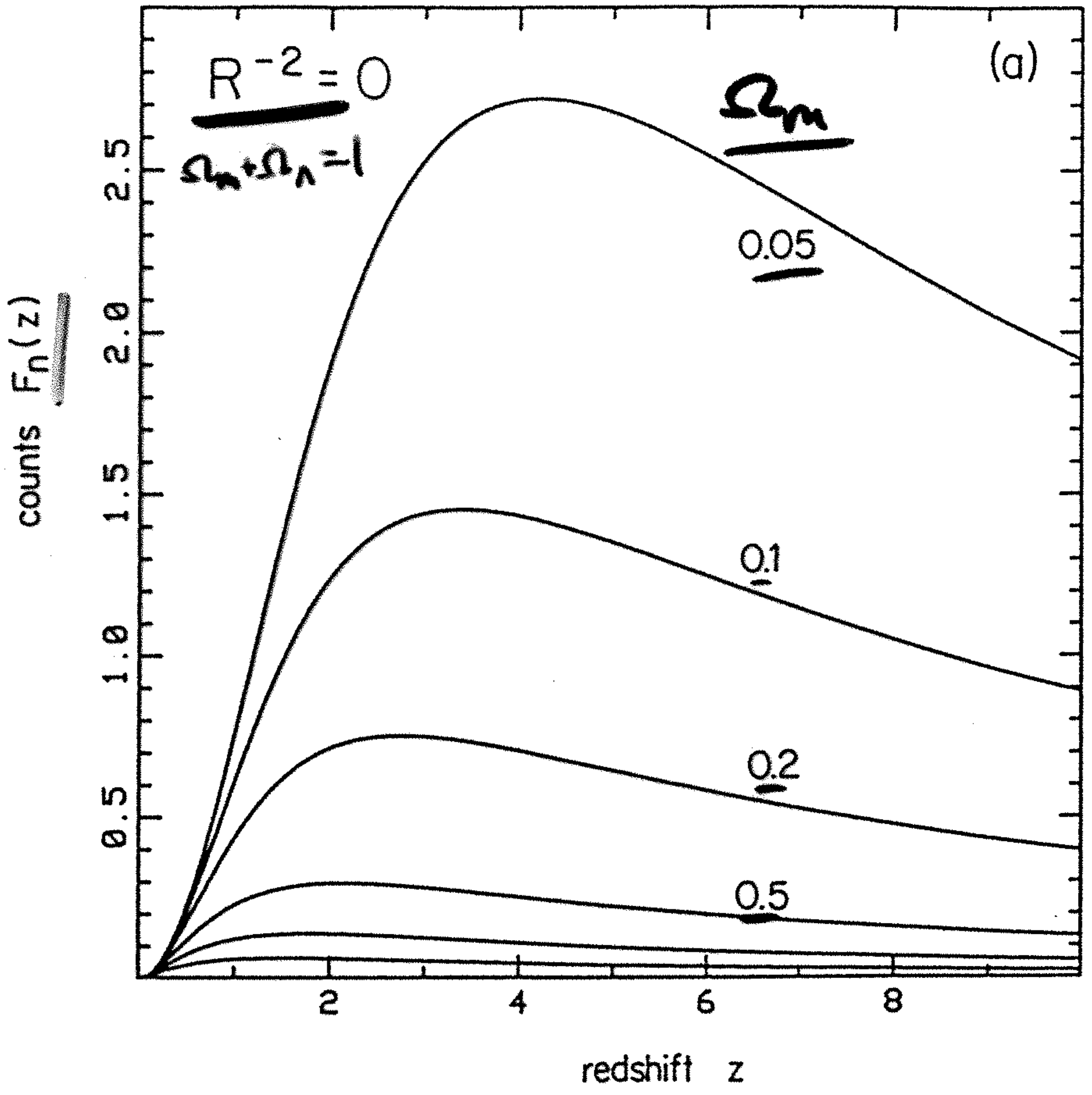
Peebles 13.8

Differential counts $\frac{dN}{dz}$

Peebles

Figure 13.8. Counts as a function of redshift. The vertical axis is the dimensionless function $F_n(z)$ in dN/dz in equation (13.61). The parameters are arranged as in figure 13.1.

Flat



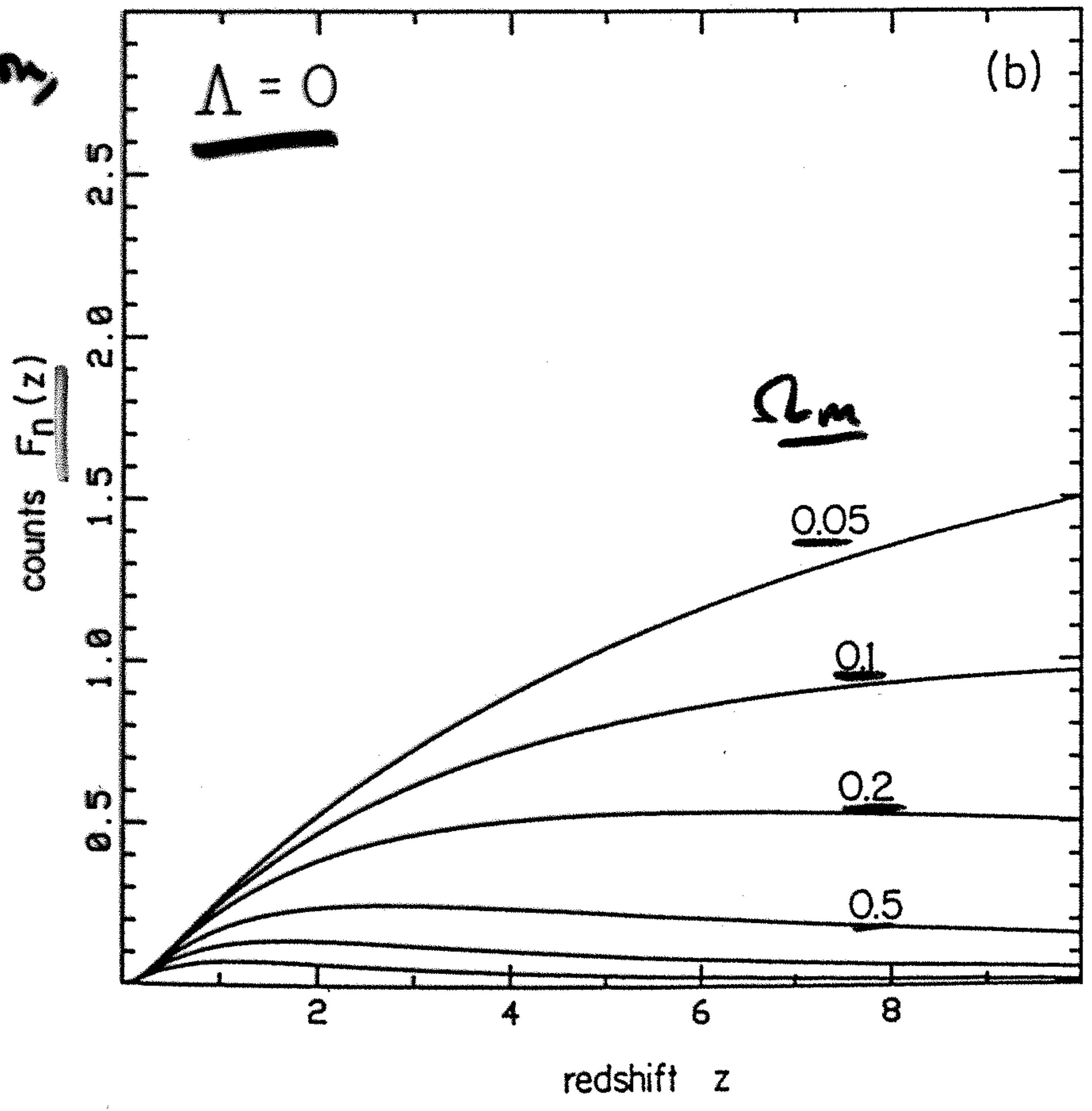
for number conservation,

$$n = n_0 \left(\frac{R_0}{R}\right)^3$$

$$\frac{dN}{dz} = n_0 \frac{F_n(z)}{H_0^3}$$

$$F_n(z) = \frac{[H_0 R_0 r(z)]^2}{E(z)}$$

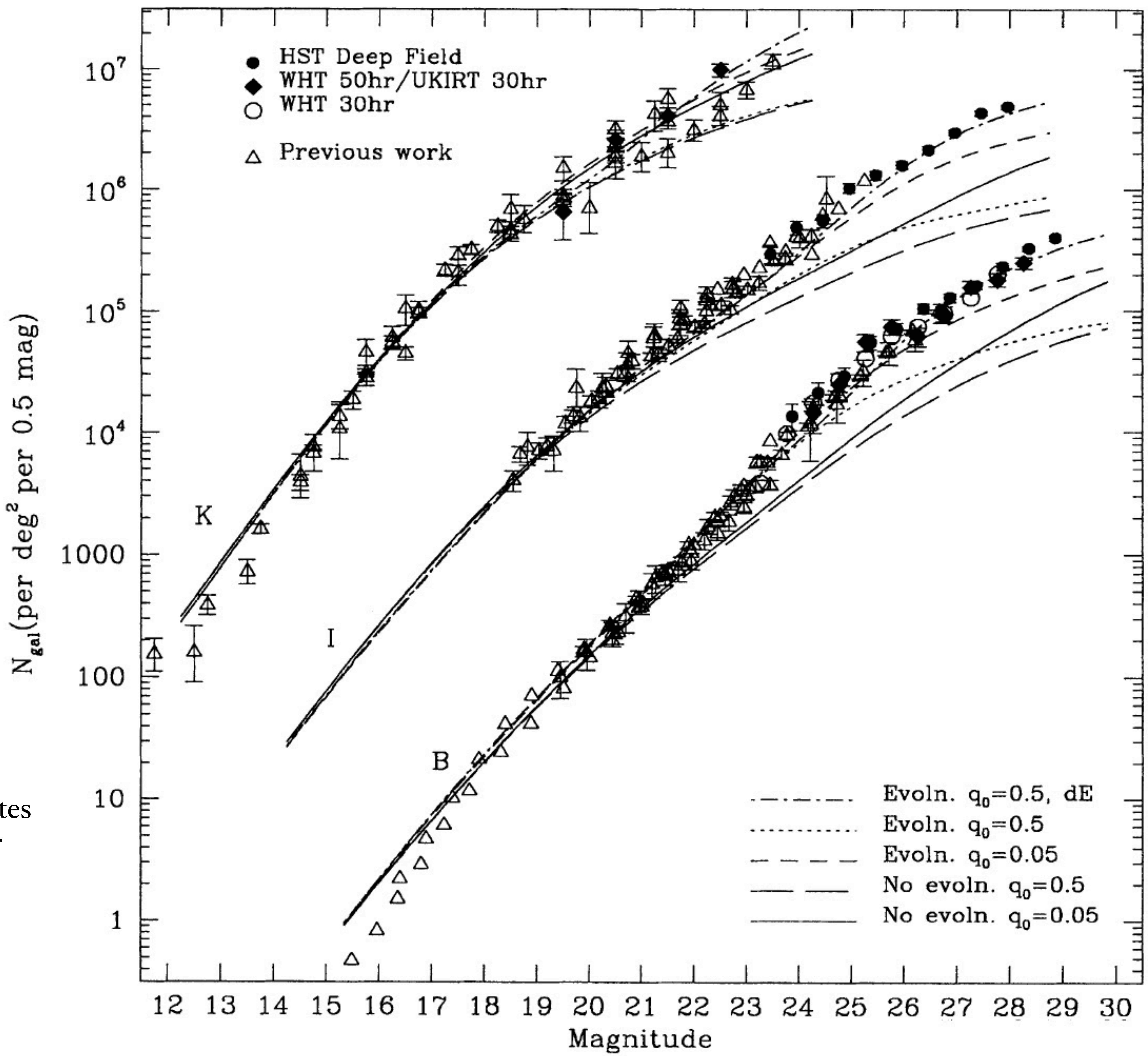
No cosmological constant



Differential counts $\frac{dN}{dz}$

Number-magnitude:

Metcalfe et al. (1996)



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

Number-magnitude:

Metcalfe et al. (1996)

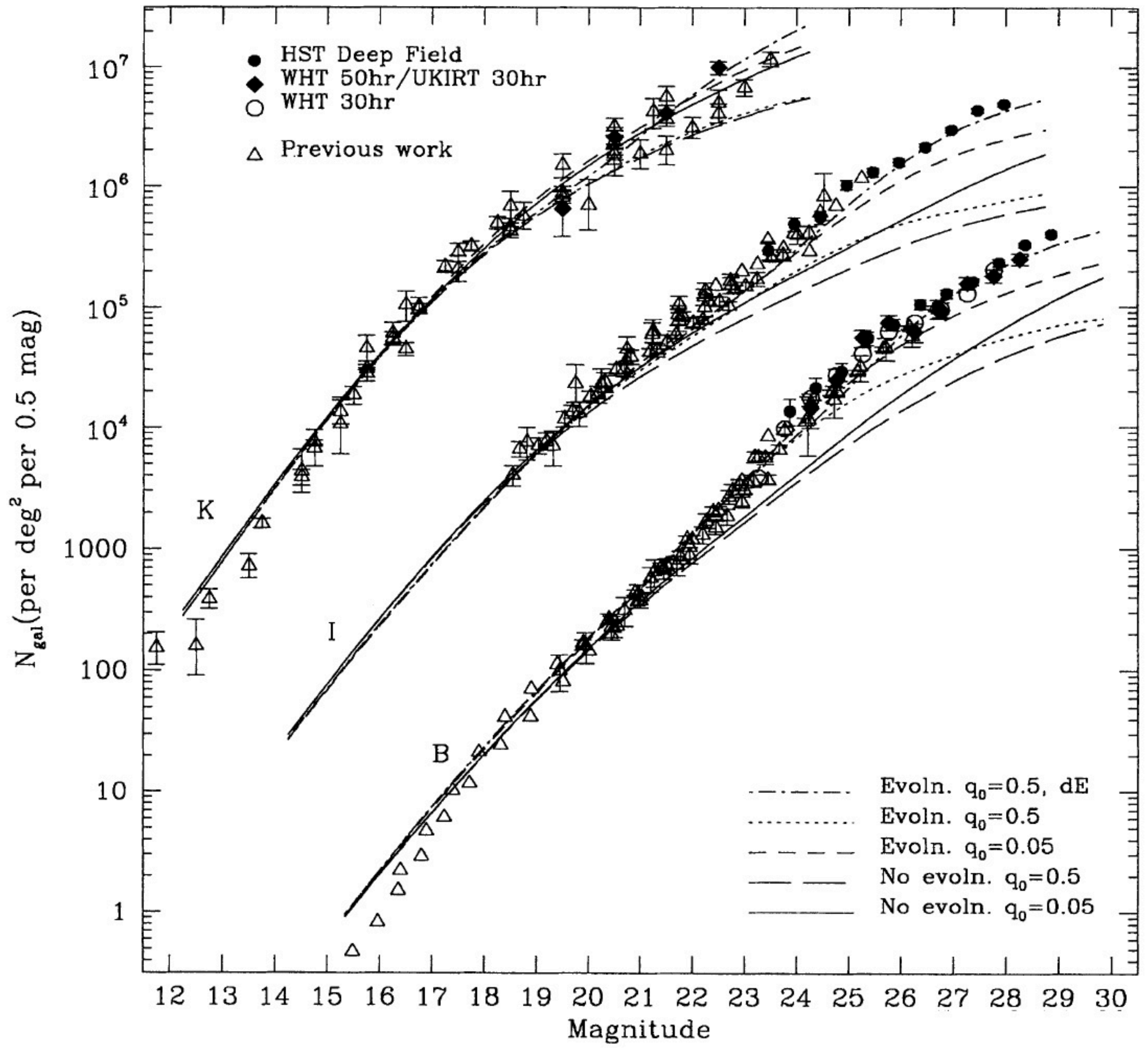
Only test that does not explicitly require redshift information.
Basically integrate over all the relevant distributions.

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

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.

Schechter function

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

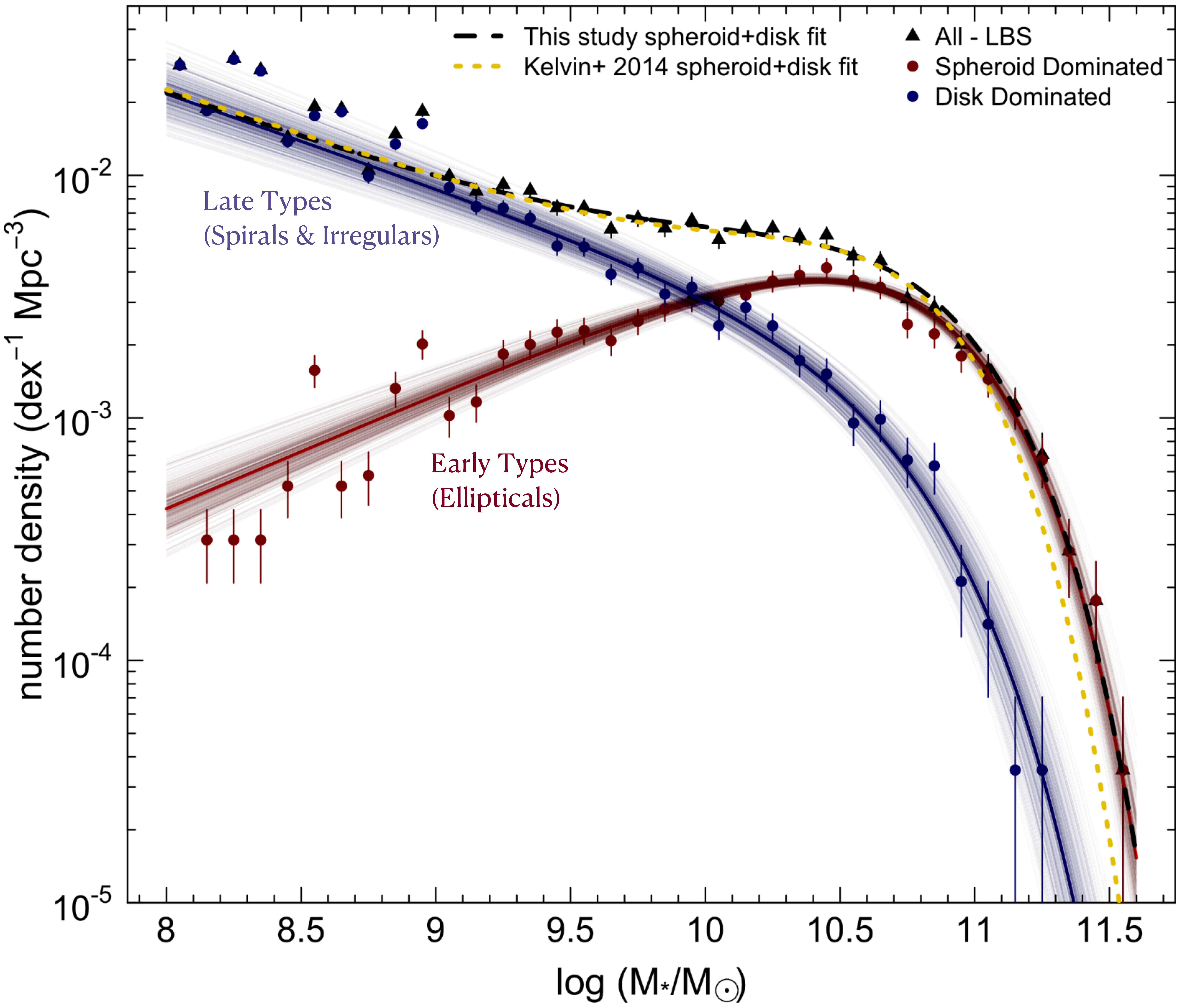
L^* Characteristic luminosity

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

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Number-redshift:

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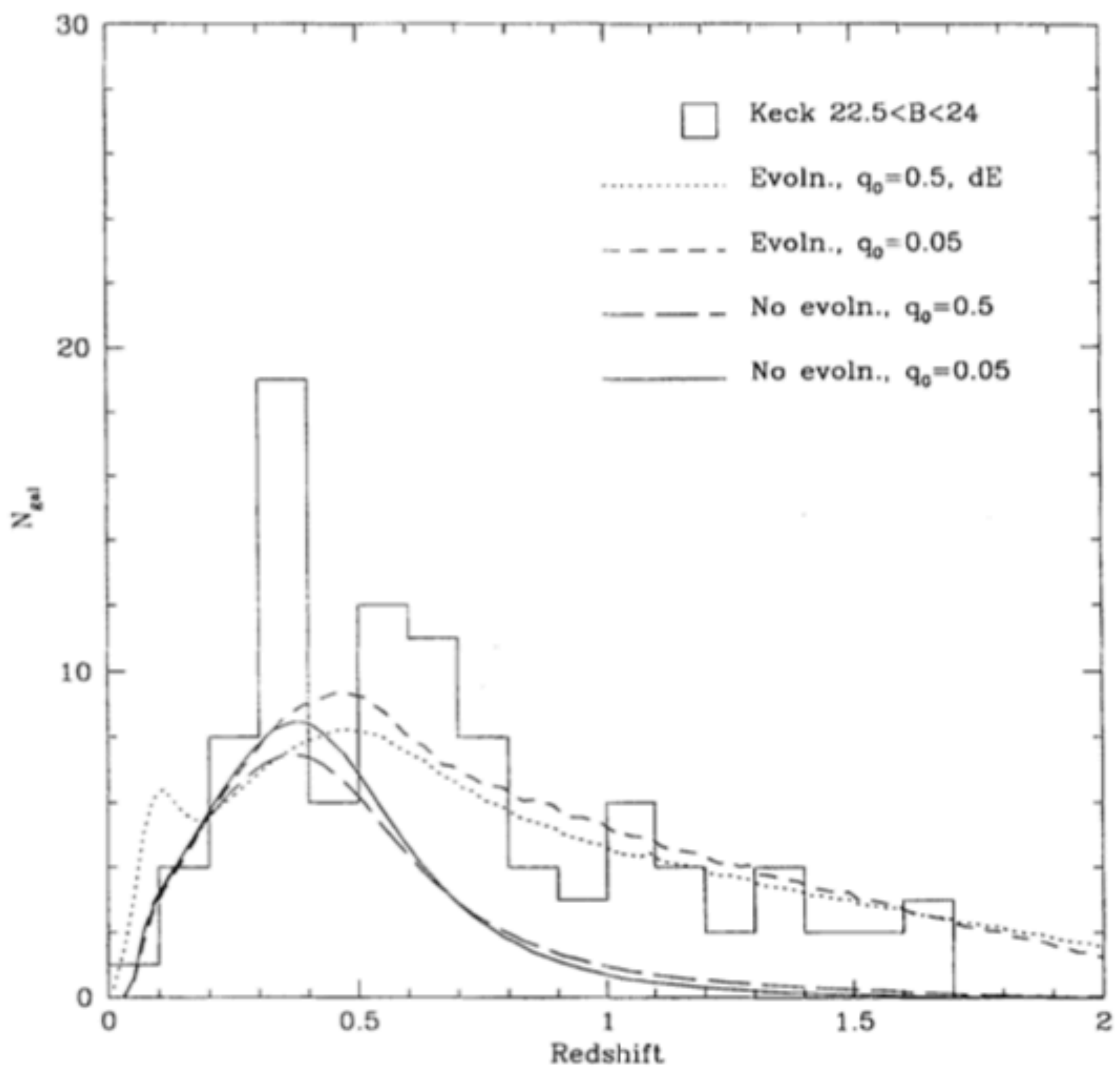


FIG. 2 The galaxy number–redshift distribution, $n(z)$, for $22.5\,\mathrm{mag} < B < 24\,\mathrm{mag}$ implied by new redshift data acquired on the Keck Telescope (refs. 6, 7). The observed $n(z)$ is clearly more extended than the non-evolving models with either $q_0 = 0.05$ or $q_0 = 0.5$. The extended redshift distribution is well fitted by our evolutionary models whose parameters are described in Fig. 1 legend.

Large Scale Structure is apparent in the non-smoothness of N(z).

Galaxies evolve!
Certainly in luminosity,
probably also in number.

So a single Schechter fcn doesn't suffice.
All of these terms matter.

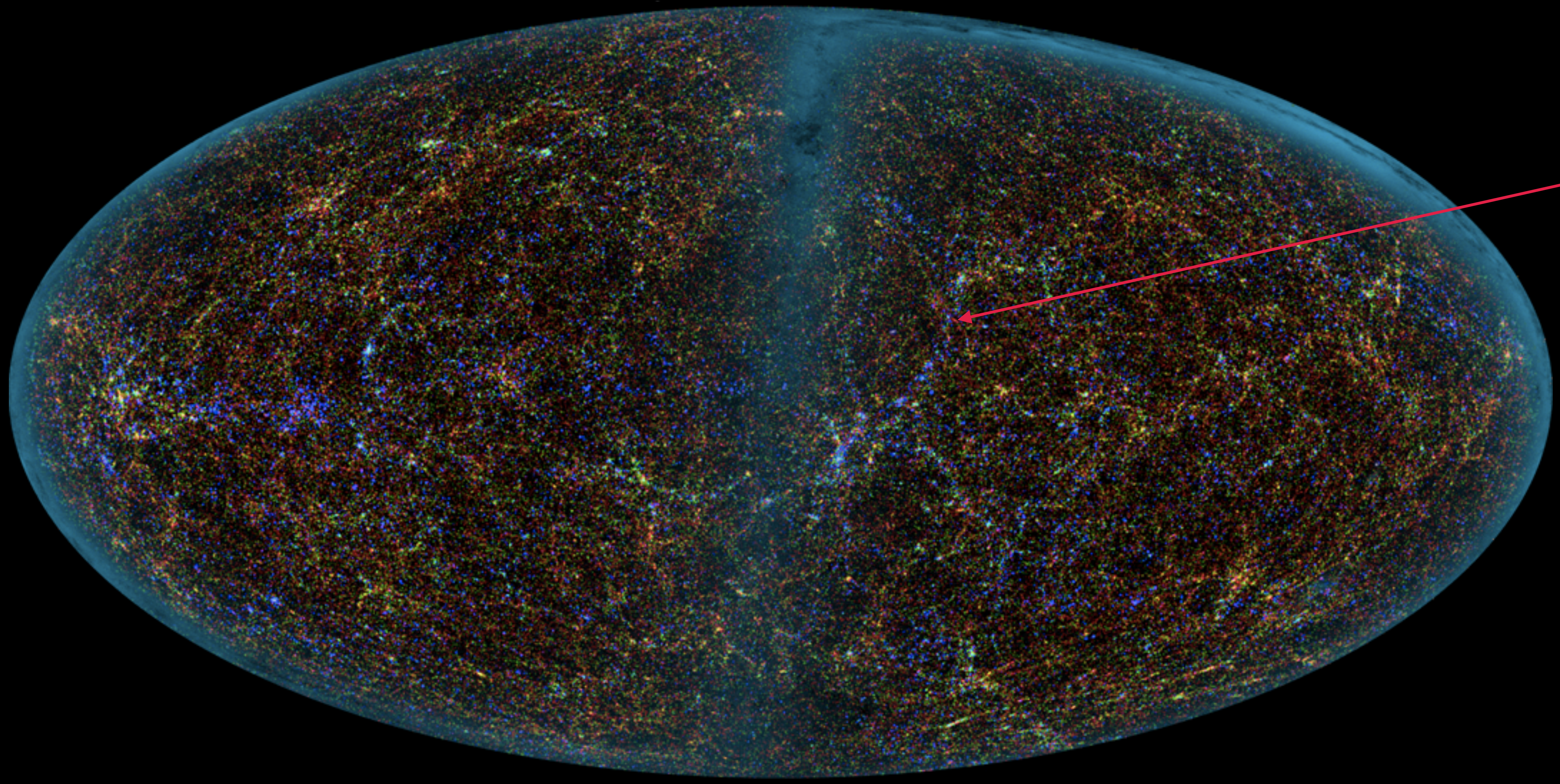
$$A(m, T) = A_0 \int_0^z D(z, T)\Phi(M, T)dV(z, q_0)$$

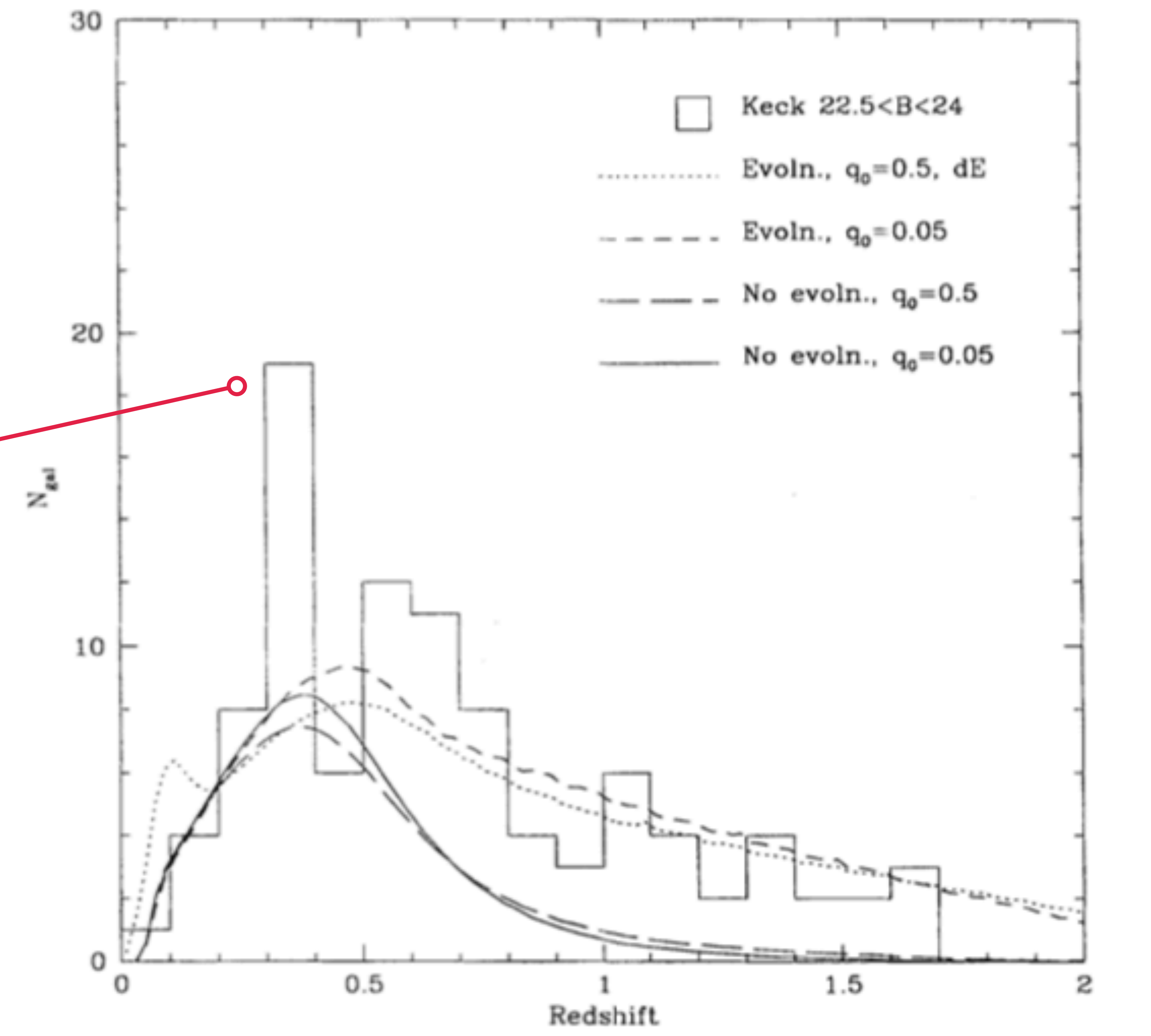
Density distribution (e.g., non-uniform large scale structure)

Luminosity function n(L)↔Φ(M)

Volume element (cosmological)

Spikes in N(z) correspond to filament & voids along the line of sight





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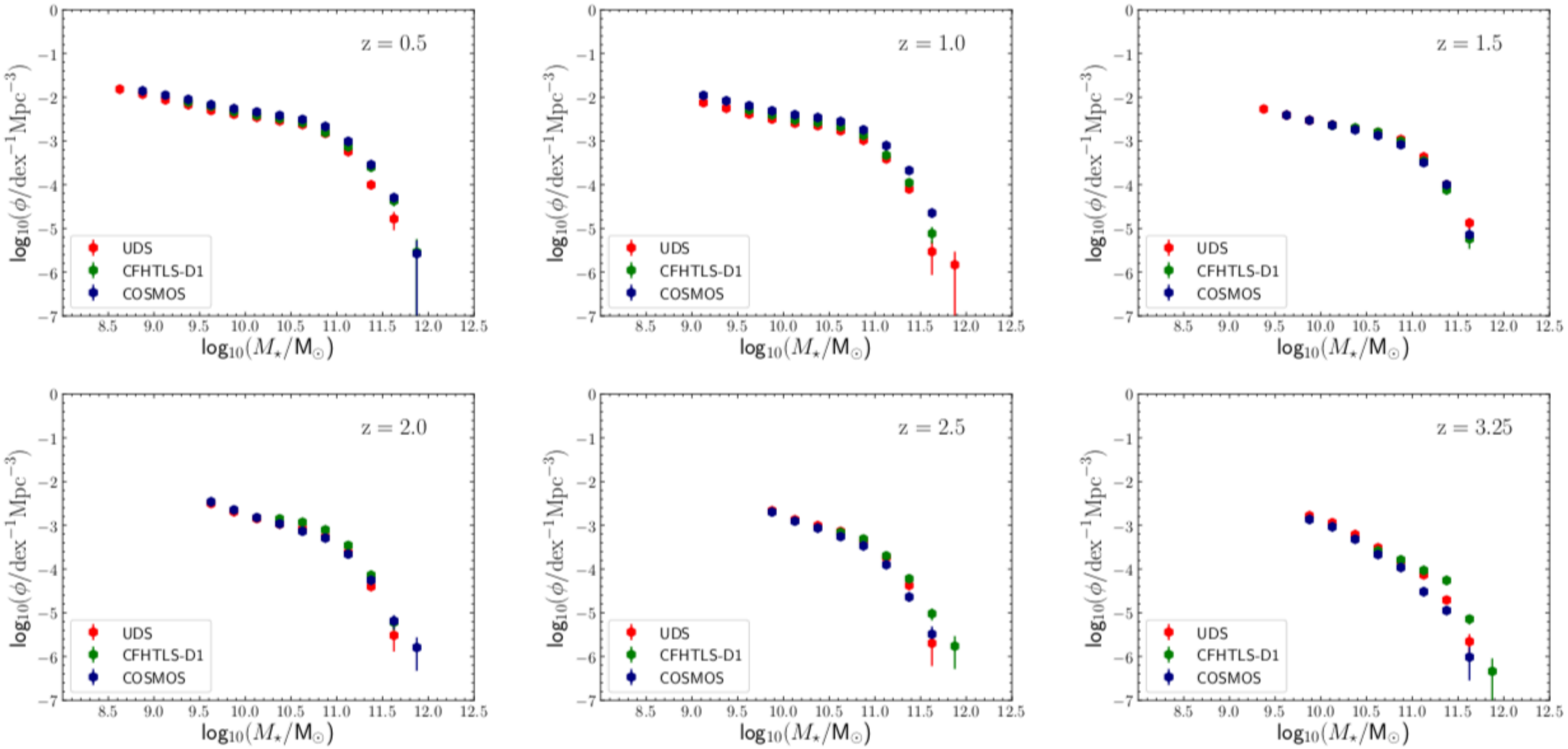

Figure 3. A comparison of how the observed GSMF evolves as a function of redshift in our three, degree-scale, survey fields. In this plot the number density uncertainties are simply the Poissonian counting errors. The availability of three, non-contiguous, degree-scale survey fields allows an empirical measurement of the level of cosmic variance in the high-mass end of the GSMF (see text for discussion).