
Observing Galaxy Evolution

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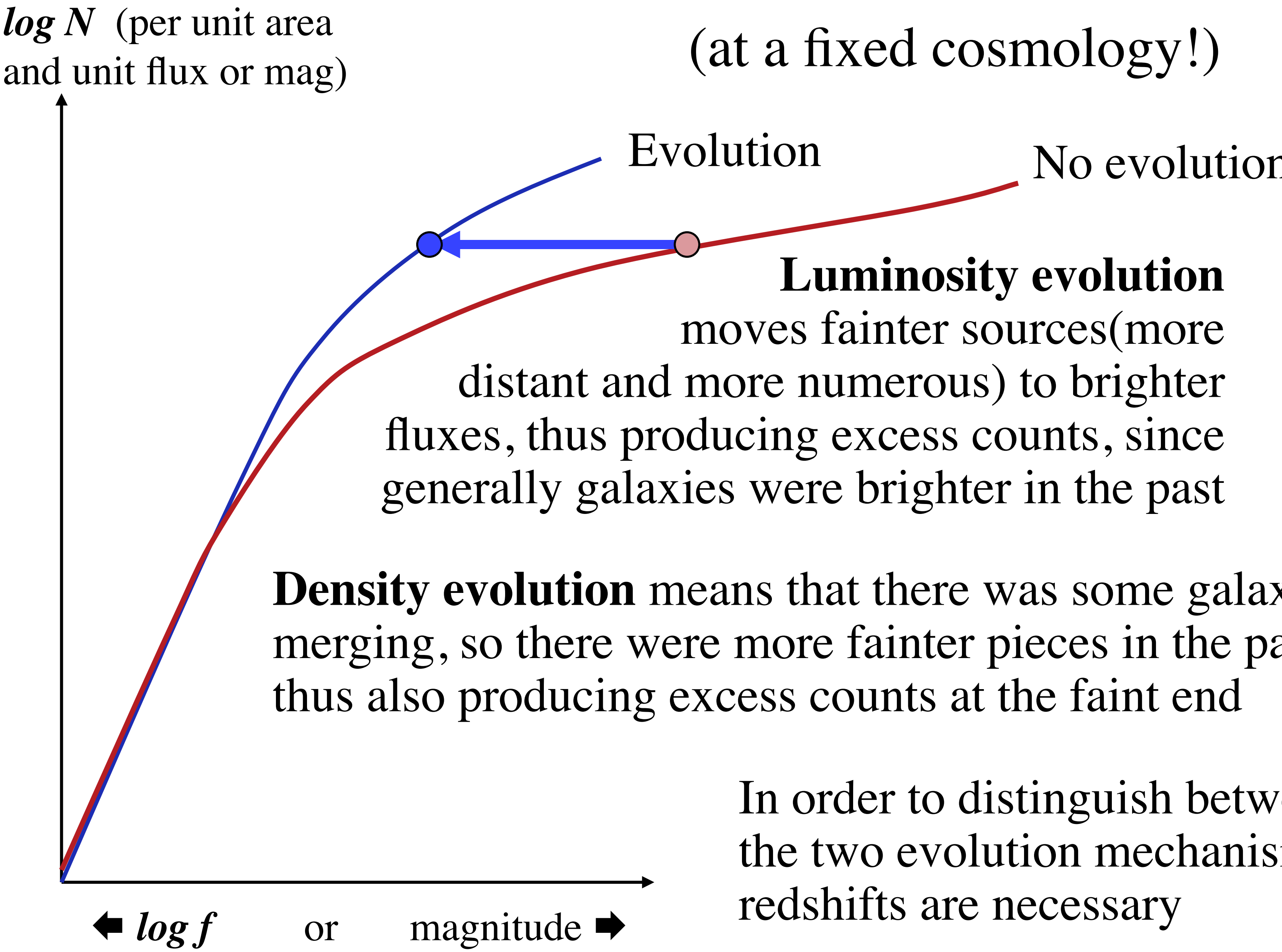
- If redshifts are not available, we can do source counts as a function of limiting flux or magnitude; and colors as a function of magnitude (acting as a proxy for distance - not a great approximation)
- But you really do need redshifts, to get a true evolution in time, and disentangle the various evolution effects
- The field is split observationally:
  – **Unobscured star formation** evolution: most of the energy emerging in the restframe UV, observed in the visible/NIR
  – **Obscured star formation**: energy from young stars reprocessed by dust to emerge in FIR/sub-mm
  – They have different limitations and selection effects

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

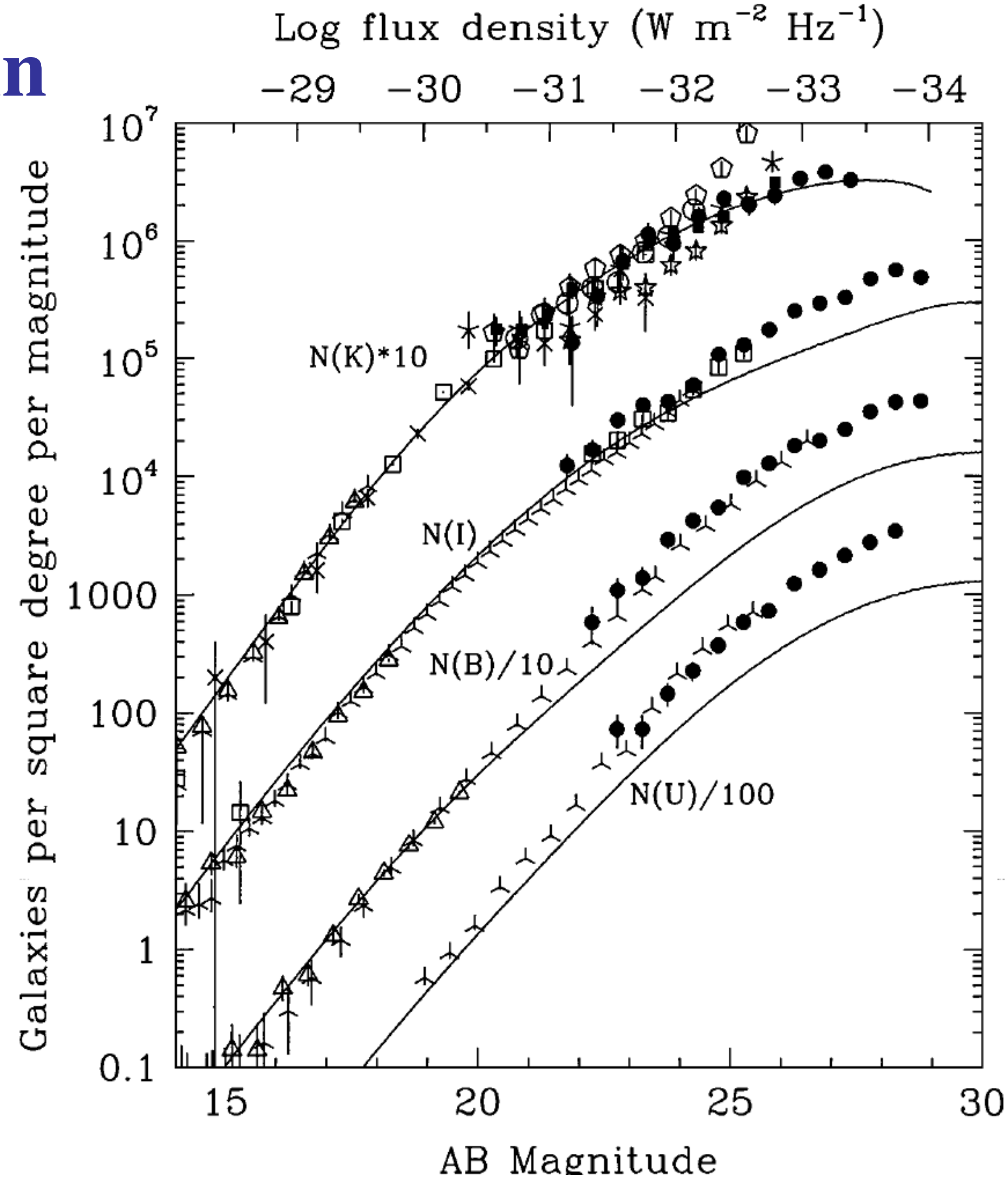
In order to distinguish between the two evolution mechanisms, redshifts are necessary

Galaxy Counts in Practice

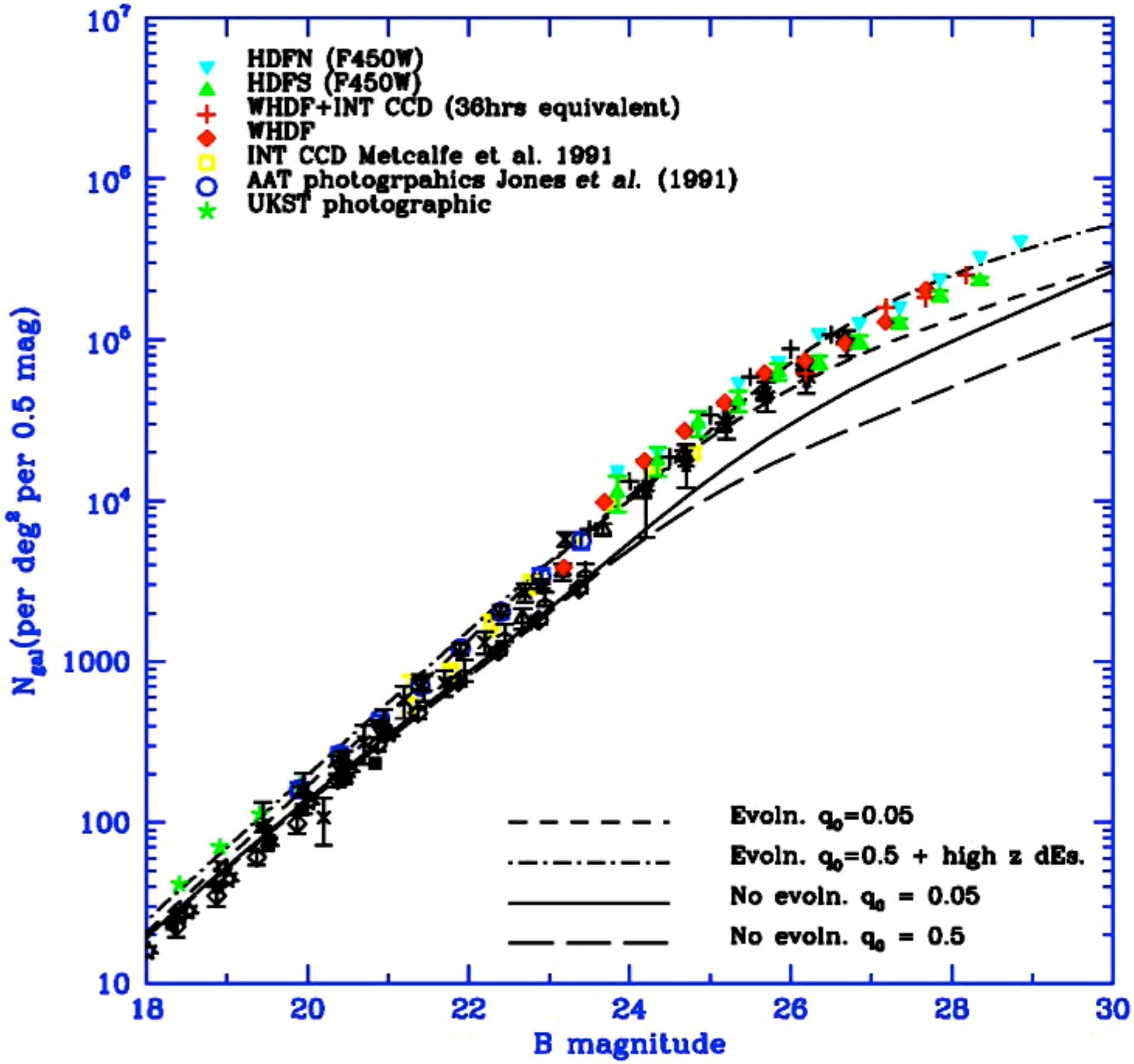
The deepest galaxy counts to date come from HST deep and ultra-deep observations, reaching down to ~ 29th mag

All show excess over the no-evolution models, and more in the bluer bands

The extrapolated total count is ~ 10^{11} galaxies over the entire sky



Galaxy Counts in Practice



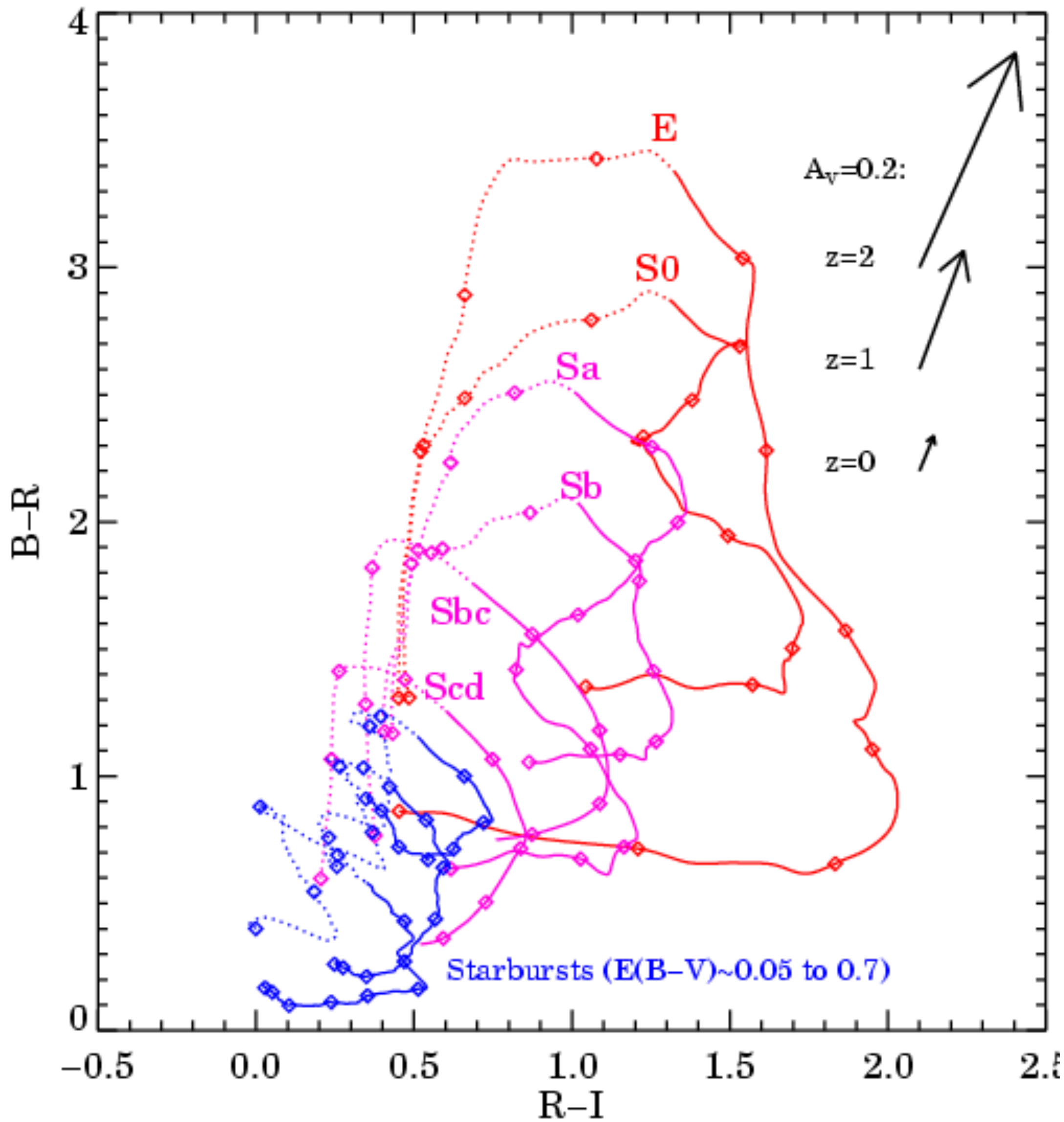
Observed counts demand some evolution, and favor larger volume (i.e., low Ω_m, $\Omega_\Lambda > 0$) cosmological models

We expect the evolution effects to be stronger in the bluer bands, since they probe UV continua of massive, luminous, short-lived stars

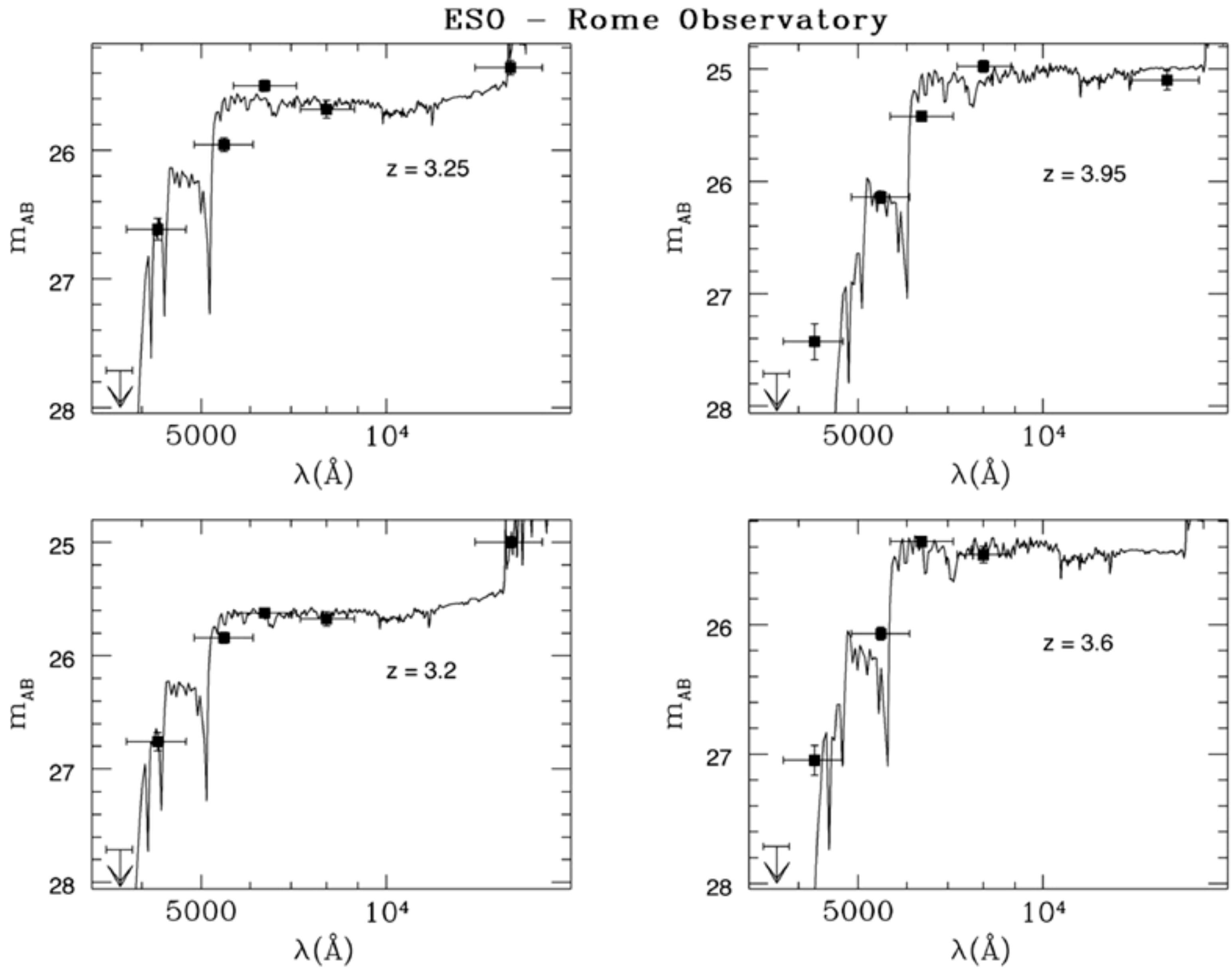
Faint Galaxy Colors

We can use the synthesis models to predict colors of galaxies at high redshifts, and then use color-color diagrams to select objects is some likely redshift range

This leads to an estimation of ***photometric redshifts***



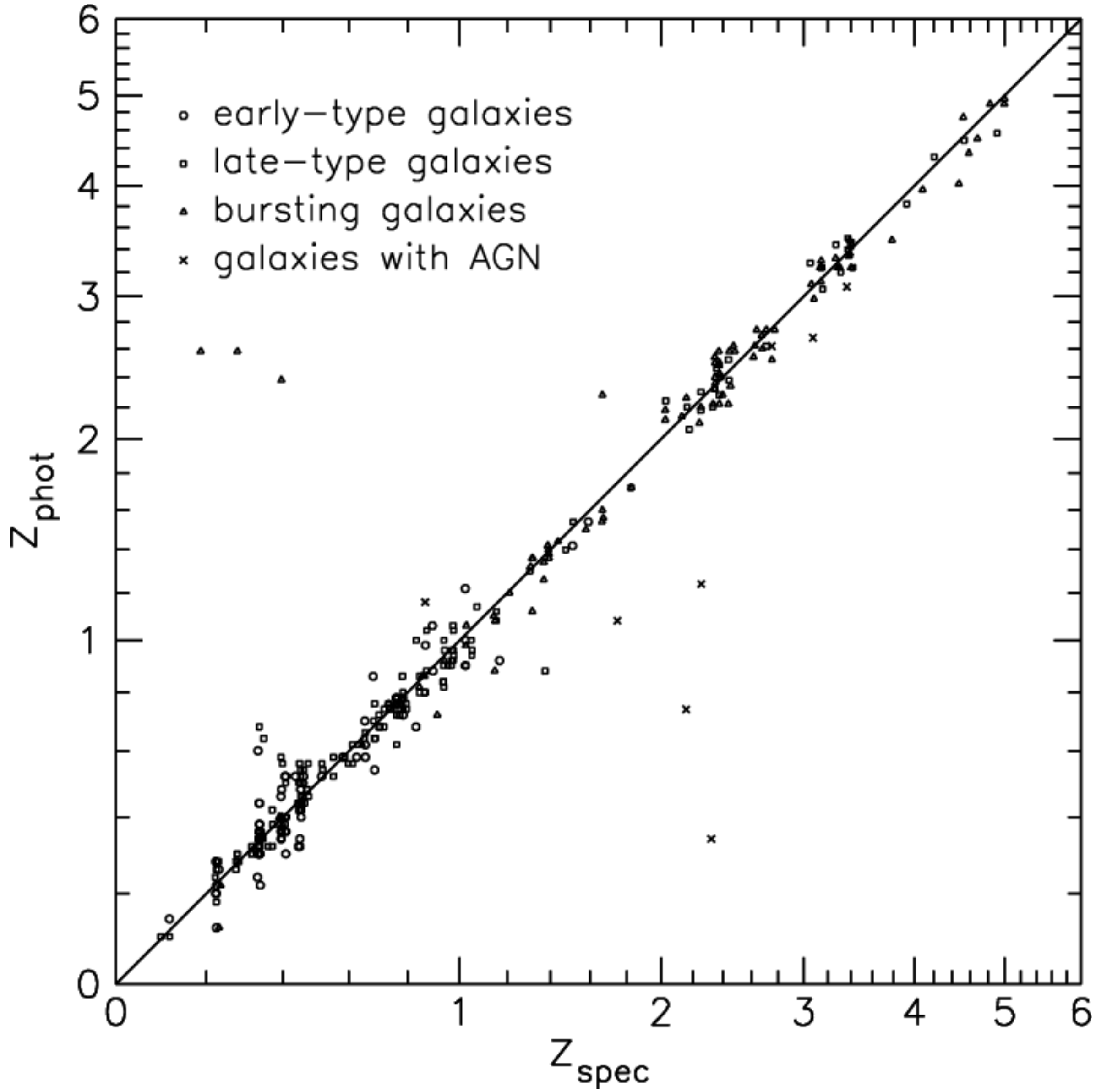
Examples of Spectral Energy Distributions Fits to Photometric Data



Photometric Redshifts

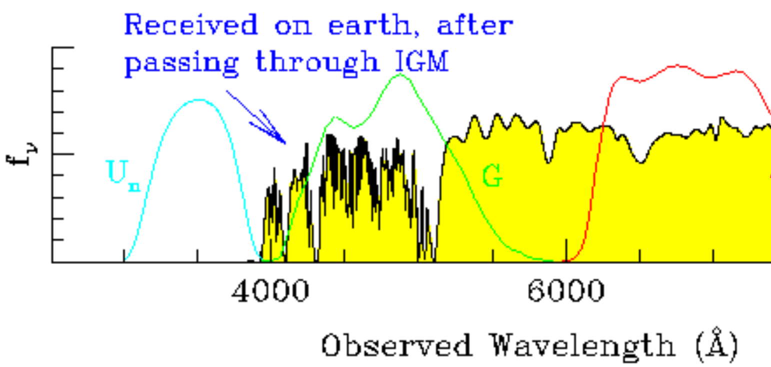
Given enough bands, and good photometry, one can do reasonably well, but some outliers will always happen

Still, this is a lot cheaper than doing real spectroscopy…

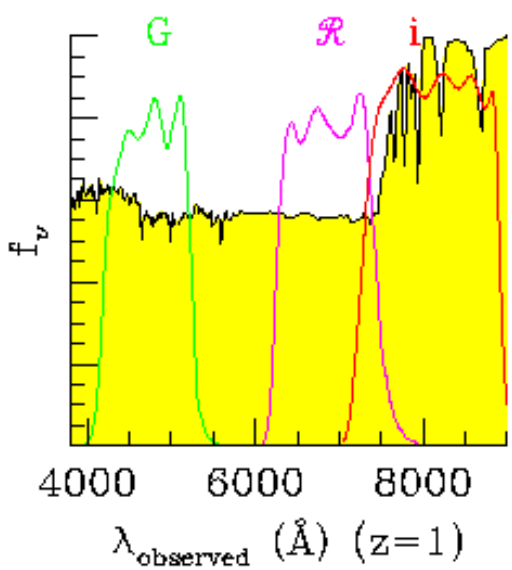


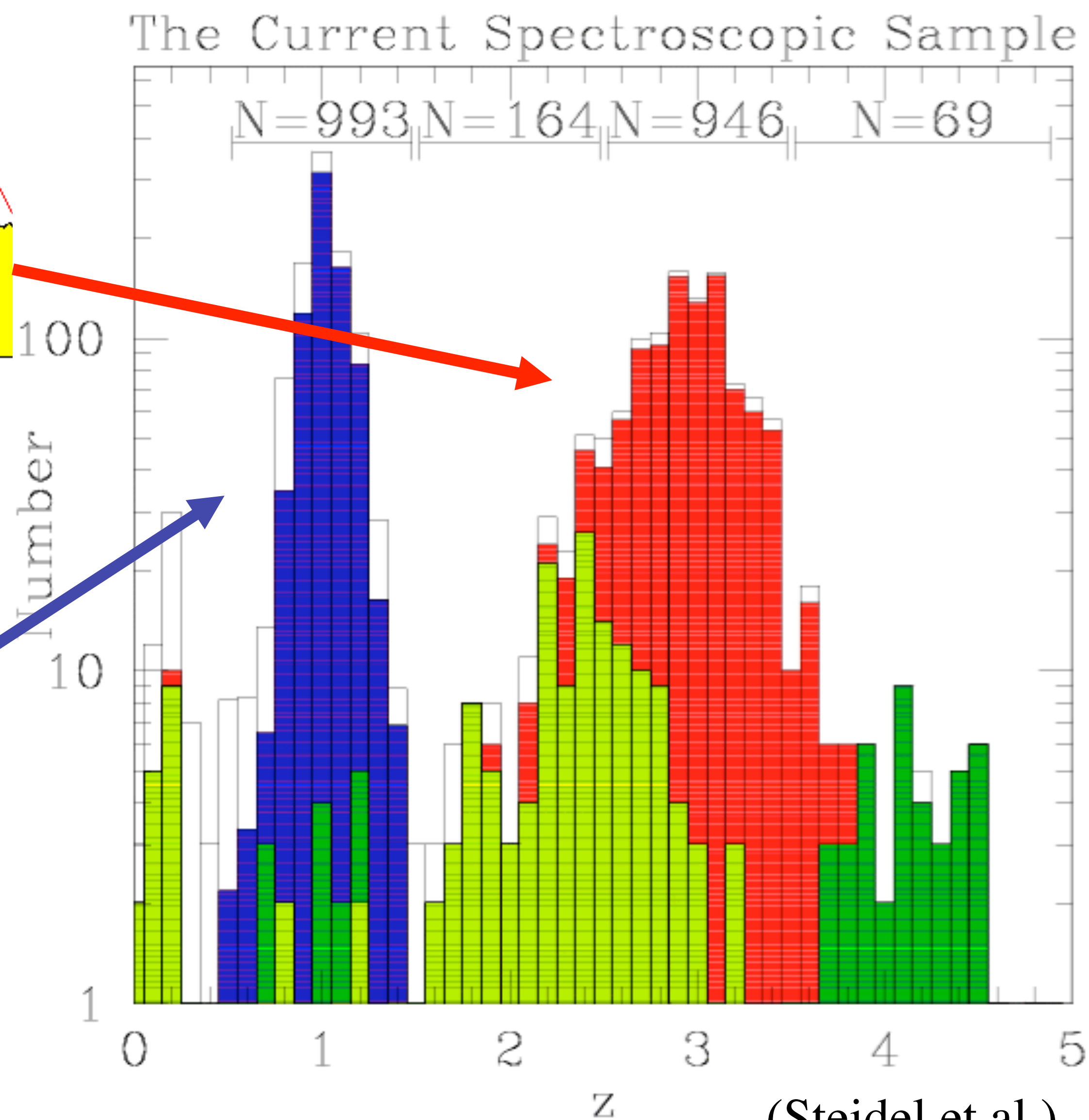
Presence of continuum breaks is an especially powerful in photometrically selecting galaxies in some redshift range

Lyman break



Balmer break

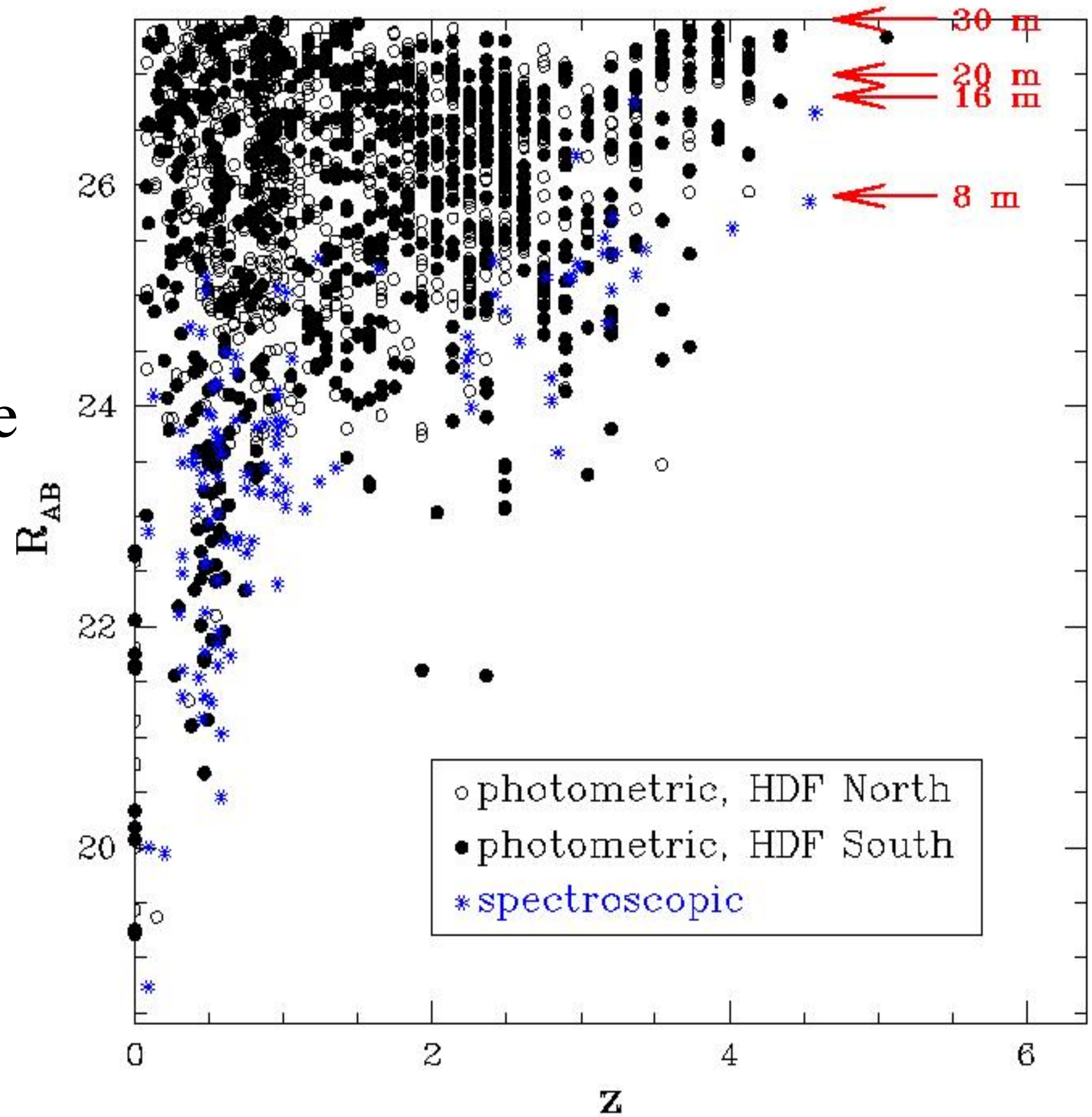




(Steidel et al.)

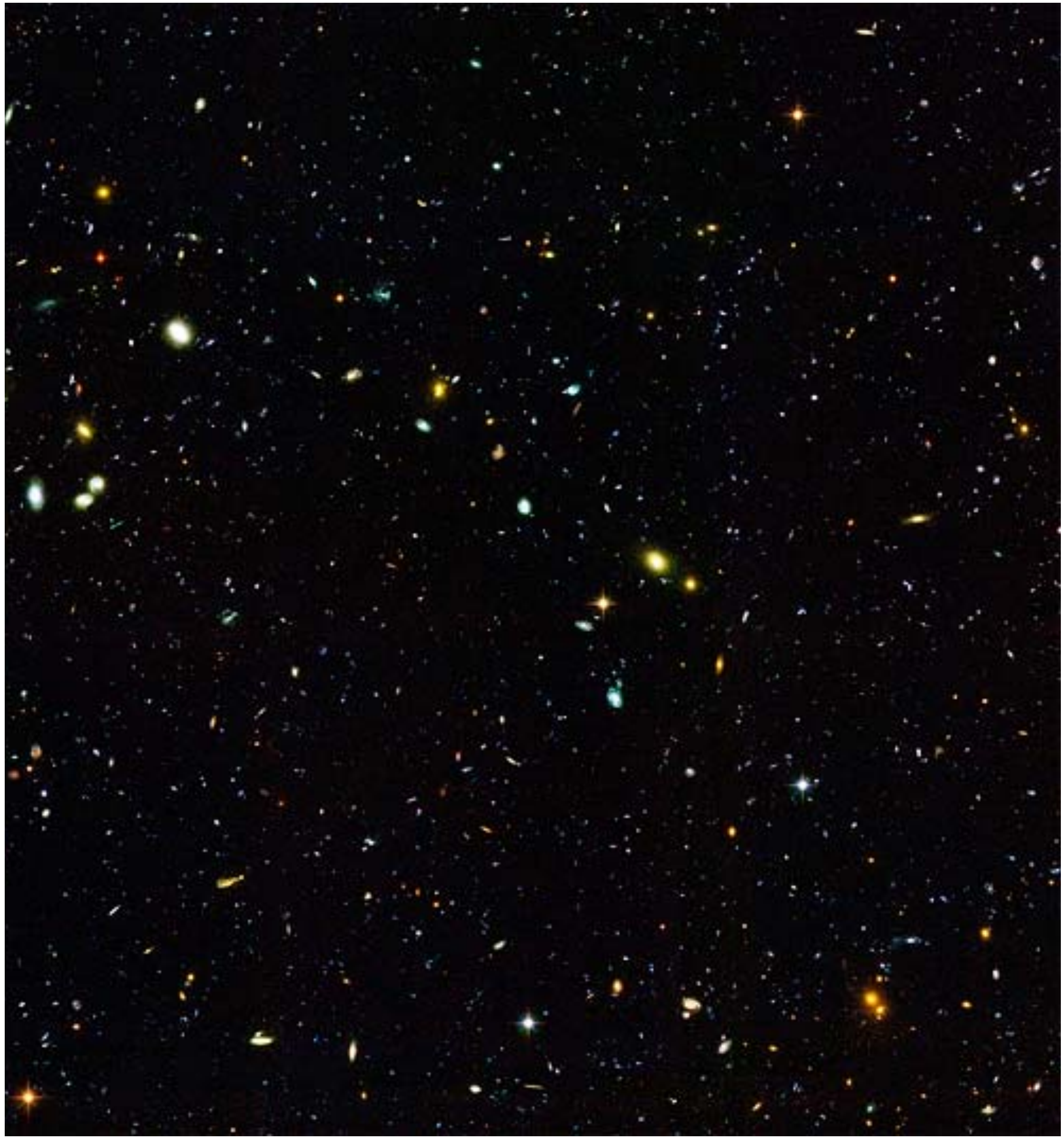
Deep Redshift Surveys

- To really understand what is going on, separate the effects of luminosity and density evolution, and break the degeneracy between distance and intrinsic luminosity at a given flux, we need redshifts
- To go beyond $z > 1$, we have to go faint, e.g. to $R > 23$ - 24 mag

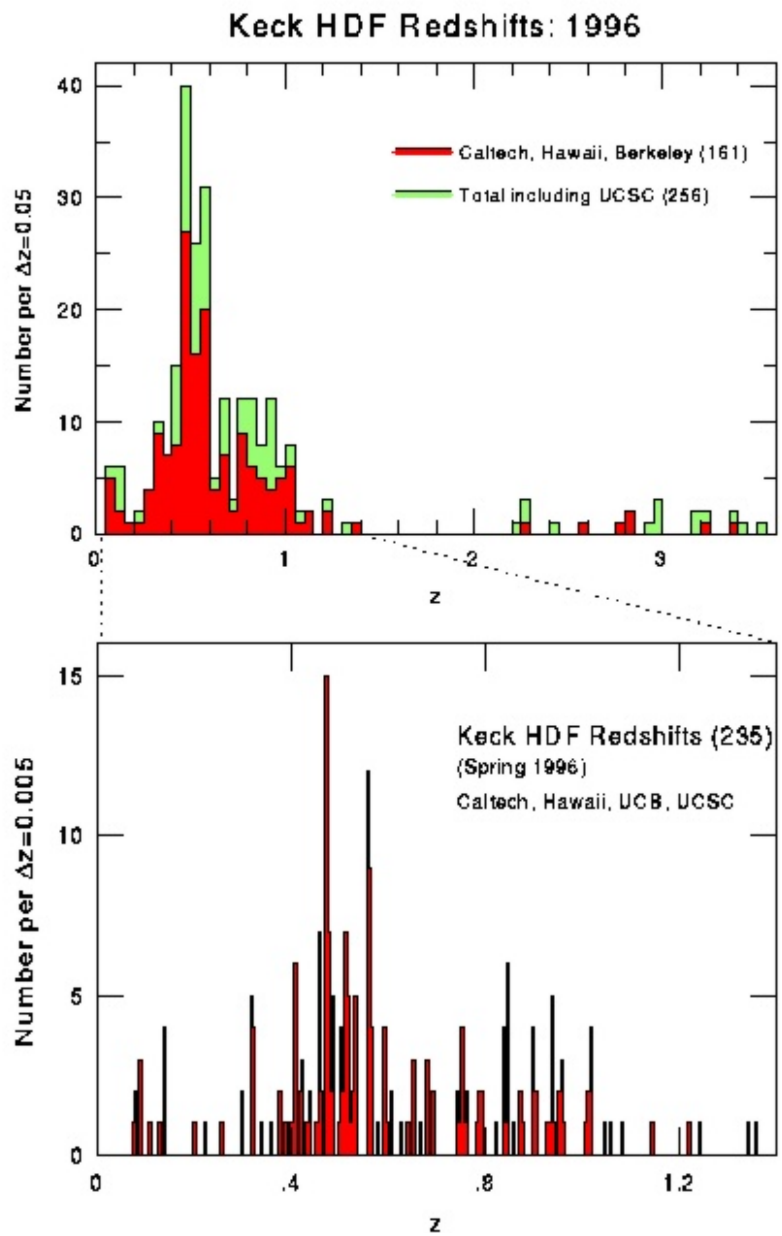


A proven powerful combination is to use deep HST imaging (e.g., HDF N and S, HUDF, GOODS field, etc.) and Keck or other 6 to 10-m class telescope for spectroscopy.

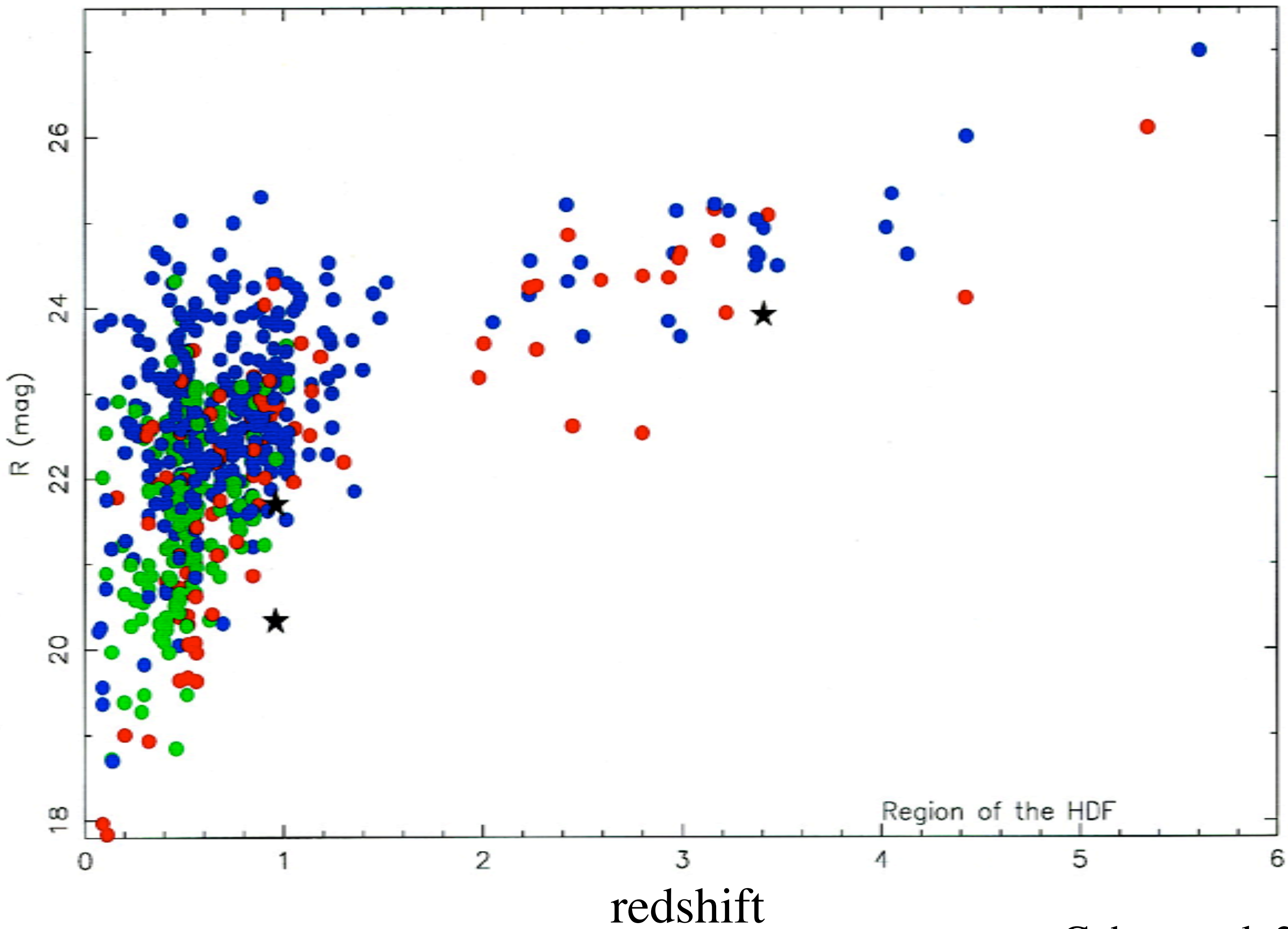
Various deep fields also have multi-wavelength data from Chandra, VLA, Spitzer …



Hubble Deep Field With Keck Redshifts



Hubble Deep Field: Redshift Distribution



Cohen et al. 2000

GOODS Field Redshifts

The Team Keck Redshift Survey of the GOODS- North Field

(Wirth et al. 2004)

Spectroscopic redshifts in the ACS-GOODS region of the HDF-N

(Cowie et al. 2004)

VIMOS VLT Deep Survey: redshifts in the CDFS

(Le Fevre et al. 2004)

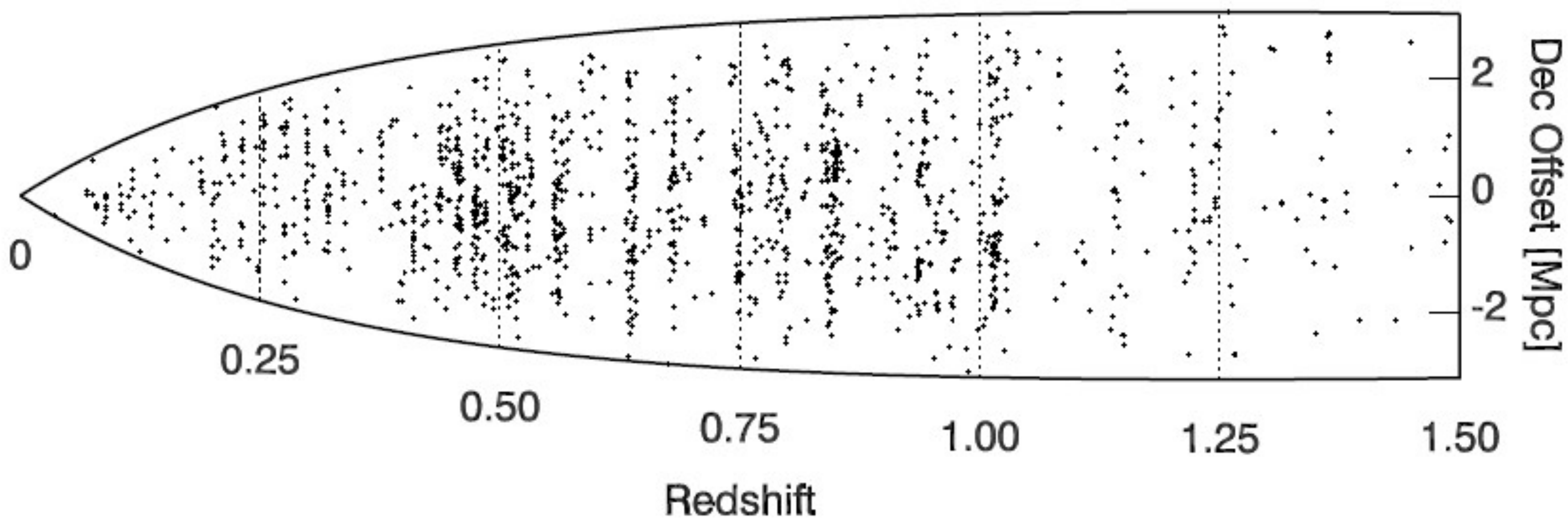
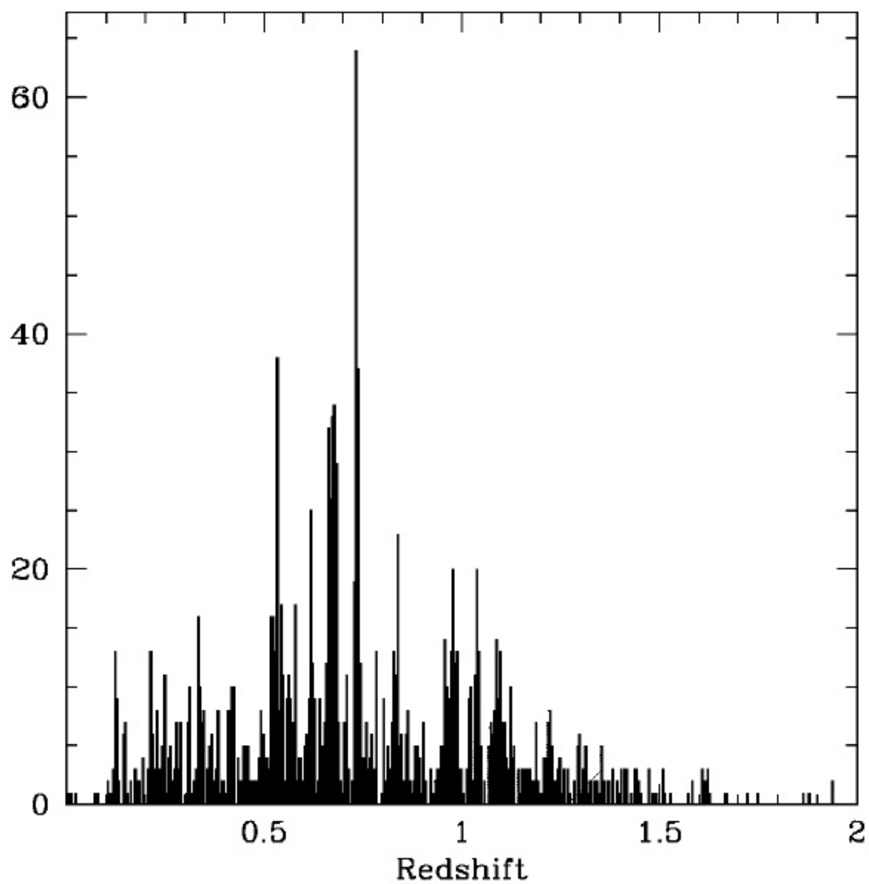
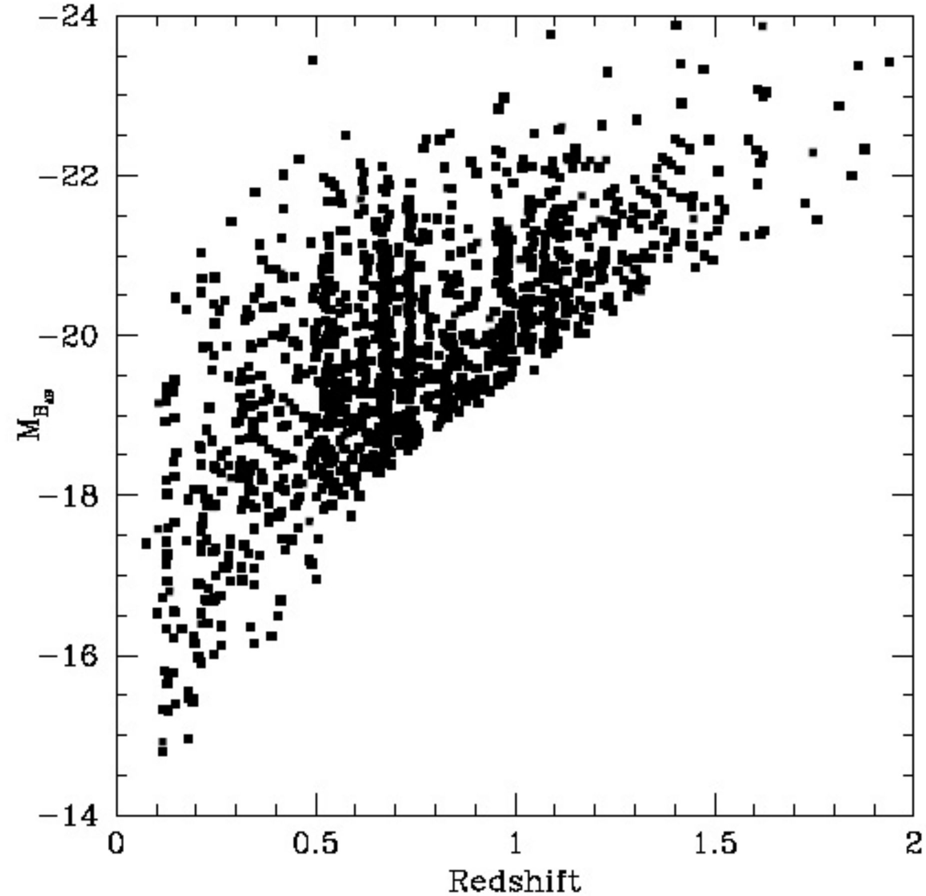


FIG. 16.— Pie diagrams showing the spatial distribution as a function of redshift for all galaxies with secure measurements in our survey. (a) Projected distance of each galaxy from the center of the GOODS-N field in the direction of Right Ascension vs. redshift. (b) Same, for Declination. In each plot, the outer envelope represents the linear separation corresponding to the 18′.4 width of the field at that redshift. Note the numerous walls correponding to peaks in the marginal distribution of redshifts seen in Fig. 15. Dotted lines indicate lines of constant redshift. Cosmological parameters $h_0 = 0.75$ and $q_0 = 0.5$ are assumed in computing the spatial offsets.

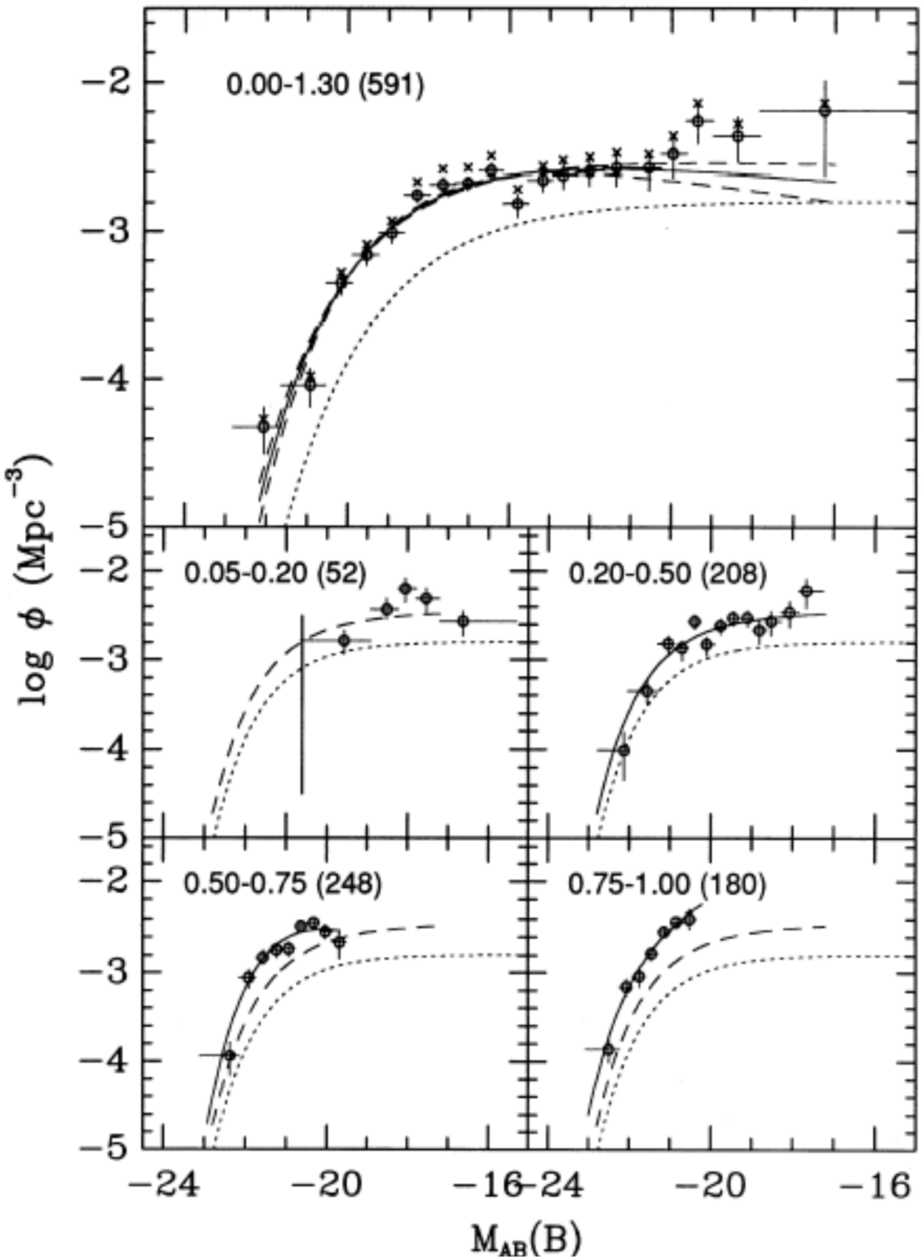
VVDS: redshift distribution of galaxies and absolute magnitude – redshift distribution





Modern deep redshift surveys reach ~ L_* galaxies out to z ~ 1

Evolution of Galaxy Luminosity Func.

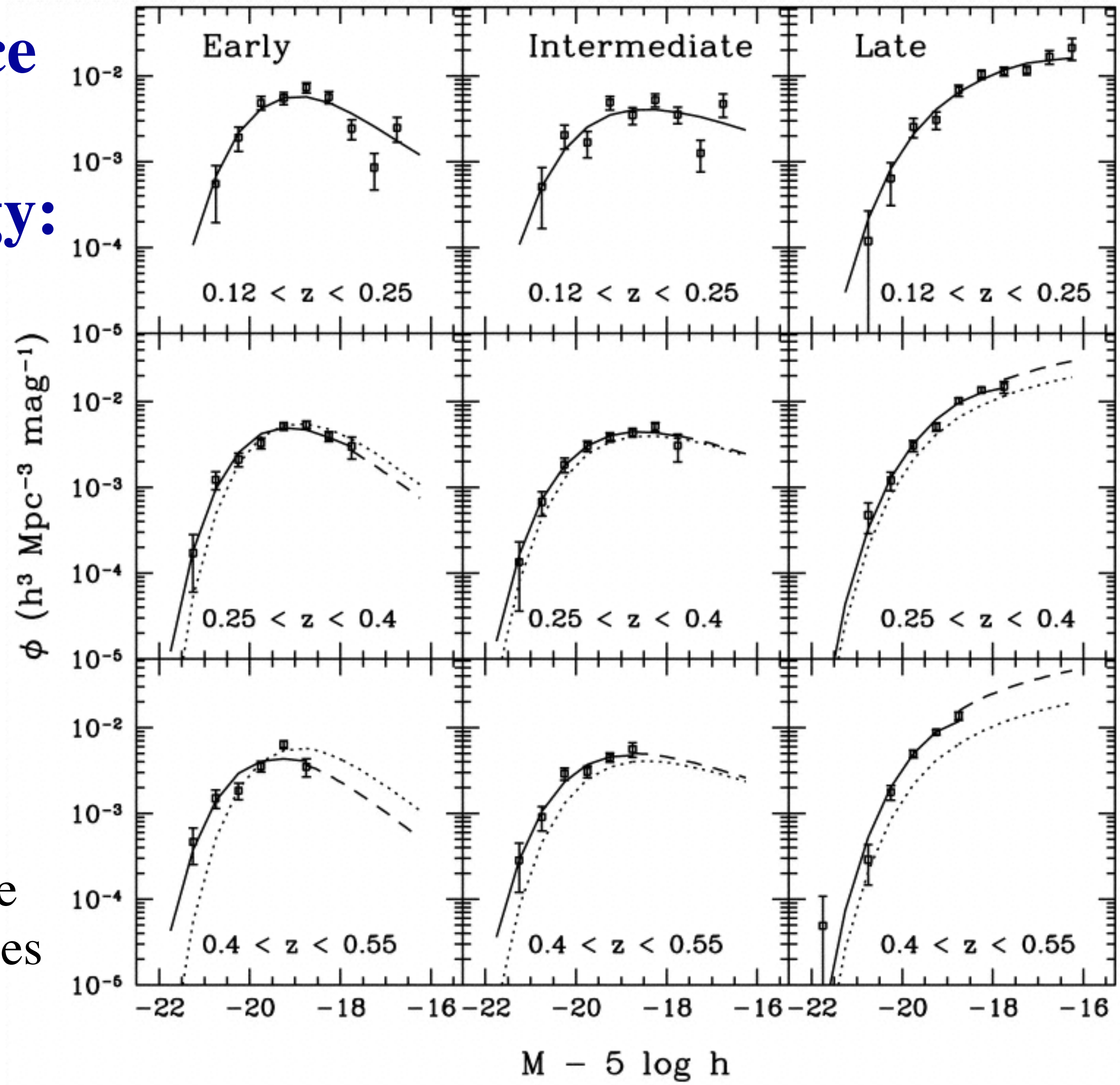


There as an overall brightening of galaxies at higher redshifts, but the effect is strongest for the dwarf galaxies at $z > 0.5$

The bulk of the regular, "Hubble sequence" galaxies did not evolve much since $z \sim 1$

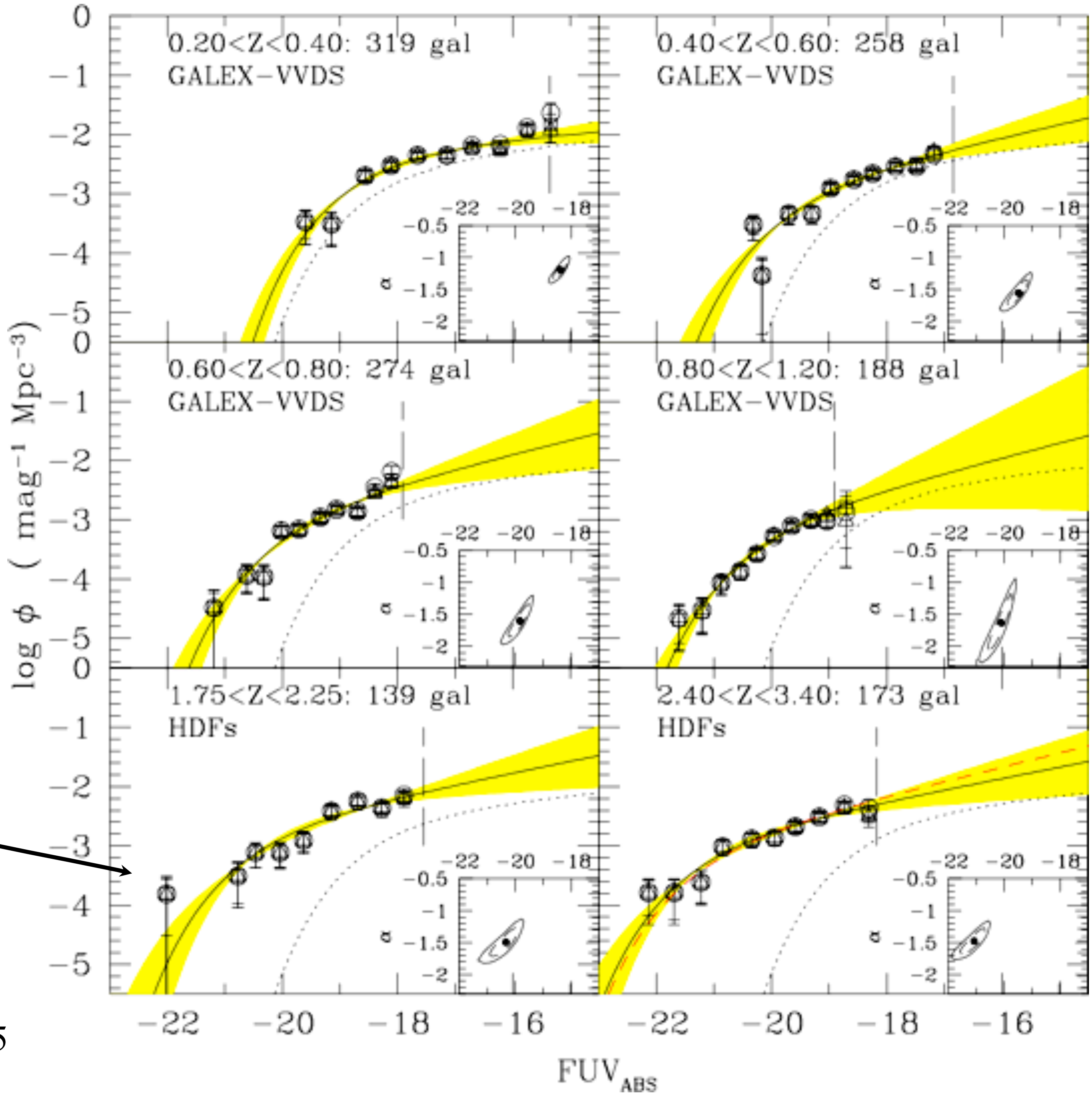
CFRS, Lilly et al. 1995

Dependence on the morphology:



Evolutionary effects are the strongest for the late Hubble types

But at higher redshifts, there is a brightening of the bright end of the LF



Arnouts et al. 2005

Next:

Galaxy Evolution: Some Results
and
Galaxy Evolution in Clusters