Are Disappearing Dwarfs Just Lying Low?

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Abstract

Recent redshift surveys have shown that the excess galaxies seen in faint galaxy number counts (above those expected given the local galaxy luminosity function) are not evolved giants at high redshifts, but low to moderate luminosity objects at more modest redshifts. This has led to the suggestion that there was once an additional population of dwarf galaxies which has since disappeared, i.e. there is non-conservation of galaxy number. Here we investigate the possibility that these disappearing dwarfs have actually evolved to become the population of very low surface brightness galaxies which is now being detected in nearby clusters.

Key words: galaxies:photometry - galaxies:luminosity function - galaxies:evolution

1 The Problem

It has been known for many years (e.g. Kron 1978, Peterson et al 1979) that at faint magnitudes the number-magnitude counts of galaxies exceed the expectations for a non-evolving galaxy population, based on the locally observed luminosity function. More recently redshift surveys (Broadhurst, Ellis & Shanks 1988 = BES; Colless et al 1990 = CETH; Cowie, Songaila & Hu 1991 = CSH; Colless et al 1993) have shown that the excess (generally blue) galaxies are not very distant evolved giants which have been brightened sufficiently to enter the surveys, but relatively nearby dwarfs, thus requiring high volume densities of galaxies. Indeed, at the extreme limits reached in the counts in recent years (e.g. Tyson 1988; Metcalfe et al 1991 = MSFJ; Metcalfe, Shanks & Fong 1992), it has been claimed that there is just not enough total volume in a standard (i.e. zero cosmological constant) universe out to \( z \simeq 3 \) (where the Lyman continuum break enters the optical bands) to hold all the observed galaxies, whatever their distances and brightnesses if they have the same volume density as conventionally assumed for present day galaxies (Koo 1989; Fukugita et al 1990).

It has therefore been suggested by CSH and others (e.g. Babul & Rees 1992) that at moderate redshifts (around 0.5, say) there must have been a large additional population of dwarf galaxies which is no longer present. The suggestions summarised by Lacey (1991) and Guiderdoni (1993) are that these dwarfs have since merged to form today’s giant galaxies, that they have self-destructed as a result of the supernova explosions after their active star forming phase, or that they have faded so much that they are now invisible. Here we investigate in more detail a case (discussed briefly in Phillipps 1993a) which is akin to the third of these, namely that the medium redshift dwarfs have faded to become the present day population of low surface brightness galaxies (LSBGs) which are turning up in increasing numbers and at increasingly faint surface brightnesses in recent surveys (e.g. Binggeli, Sandage & Tammann 1985; Impey, Bothun & Malin 1988 = IBM; Irwin et al 1990 = IDDP; Schombert et al 1992; Turner et al 1993 = TPDD).

2 Disappearing Dwarfs
2.1 Numbers

Consider first how many dwarfs we require. According to the counts reviewed by CSH, the surface density of galaxies to a B magnitude limit of 26.5 is about $2.5 \times 10^5$ per square degree. Now the corresponding total volume out to $z = 3$ is $2.2 \times 10^7$ Mpc$^3$ for an $\Omega = 1$ universe with $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ (i.e. $h = 0.5$ in the usual notation). Thus the minimum volume density of observable galaxies required is about $0.012$ per Mpc$^3$. This is then to be contrasted with the canonical value of about $0.0006$ for galaxies brighter than $L_*$ (we assume the characteristic magnitude for giants to be about $M_* = -21.3$ in $B$, see below). If instead we concentrate on the galaxies seen at slightly brighter magnitudes which are (just) accessible to redshift surveys, at $B = 24$, then there are about $2 \times 10^4$ galaxies per square degree. CSH note that half of these lie at $z < 0.5$. Using the volume out to $z = 0.5$ we get a mean observable volume density over this region of about $10^4/10^6 \simeq 0.01$. Note that the limiting magnitude $B = 24$ corresponds, at $z = 0.5$, to an absolute magnitude $M_B = -19.0 - K_2(0.5)$, where $K_2(z)$ is the spectrum dependent part of the k-correction (i.e. excluding the bandwidth term). We therefore need a density of approximately $0.01$ galaxies per Mpc$^3$ brighter than $M_B = -19$ (i.e. around $M_* + 2.3$) even if $K_2(0.5) \simeq 0$. Of course many of the galaxies are nearer than $z = 0.5$ so some absolutely fainter galaxies will also be included in the counts, while using a low $\Omega$ model can also alleviate the problem (though only slightly for redshifts less than 0.5). Hence this is a worst case analysis in terms of trying to find enough dwarfs to fit the counts.

If we consider first a 'standard' local luminosity function (eg. Phillipps & Shanks 1987; Efstathiou, Ellis & Peterson 1988; Loveday et al 1992 = LPEM), viz. a Schechter (1976) function with $\phi_\ast = 0.0022$, $M_\ast = -21.3$, $\alpha = -1.1$ (again assuming $h = 0.5$), then we only reach the necessary density of 0.01 galaxies per cubic Mpc at $M \simeq M_\ast + 6.5 \simeq -14.8$. Thus, if we assume a roughly flat spectrum for a star forming dwarf (eg. Cowie et al 1988) (ie. no spectral k-correction term), then we require over 4 magnitudes of brightening by $z = 0.5$\[1]. For a higher local normalisation this could be lowered slightly, but even so this simple calculation confirms the view (as in Lacey’s (1991) review) that it is unlikely that the dwarfs could have faded enough over the available time interval for this scheme to work, in the standard picture (see also Guiderdoni & Rocca-Volmerange 1991, Lacey et al 1993).

However, at present-day magnitudes around $-15$ many galaxies are of low (or very low) surface brightness and are therefore missing from conventional luminosity functions. (That is, they fail to meet the criteria for inclusion in a sample based on isophotal magnitude or diameter: see Sandage, Binggeli & Tammann (1985) for a discussion of a famous historical instance of this effect). It now appears (Sandage et al 1985; Phillipps et al 1987; IBM; Impey & Bothun 1989; IDDP; Ferguson 1990) that, at least in clusters, allowing for these LSBGs steepens the faint end of the luminosity function considerably. Schade & Ferguson (1994) suggest that this may be true in the field too. (See also Marzke et al (1994) and Marr (1994) for field galaxy LFs with evidence for a turn up at the faint end). At magnitudes fainter than about $-17.5$, the effective value of $\alpha$ is about $-1.5$ or even steeper. Driver et al (1994a = DPDMD) discuss in more detail the question of such steep faint end slopes, which are theoretically expected on quite general grounds (see eg. White & Frenk 1991; Lacey et al 1993; Kauffmann, White & Guiderdoni 1993). Note particularly that in such models the overall LF no longer has a simple single Schechter function form (Binggeli, Sandage & Tammann 1988; Ferguson & Sandage 1991; Driver et al 1994b). In this case, even with a relatively low normalisation for the bright end ($\phi_\ast = 0.0018$) we get 0.01 galaxies per Mpc$^3$ brighter than about $M_B = -16.5$ (depending on the exact point where the steep part of the LF cuts in; again see DPDMD for a discussion). This then leads to a much more reasonable requirement of $\leq 2.5^m$ of brightening at $z = 0.5$. Recall that we have deliberately chosen worst cases throughout, so the actual evolution required may be less than this. Indeed, DPDMD considered the option of fitting the number counts using an extremely steep faint end slope for the present-day LF and no evolution (see also Guiderdoni 1992; Koo & Kron 1992; Koo, Groewall & Bruzual 1993), though this may run into the problem of seriously underpredicting the mean redshift at faint magnitudes.

The most recent redshift surveys do now appear to show direct evidence for a change in the LF shape with $z$ (Ellis 1994; Colless 1994), thus indicating some sort of mass dependent evolutionary process along the general lines originally suggested by BES (see also Cole, Treyer & Silk 1992). We therefore wish to consider as a next simplest model (after no evolution and general luminosity evolution), the case where we have only simple fading of the (steep) dwarf component of the LF.

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1Notice that this rate of evolution would be sufficient for almost all the galaxies visible at say $z \simeq 0.1$ to still be visible at $z \sim 0.5$, i.e. the evolutionary brightening almost completely counteracts the increasing distance modulus. The observable galaxy density would therefore remain more or less fixed and the 'worst case' assumption would be close to the truth.
2.2 Fading

Next consider the levels of fading which might be reasonable for a dwarf galaxy between \( z = 0.5 \) and the present. If the dwarfs are seen in a star-forming dI like state (eg. Lin & Faber 1983, Tyson & Scalo 1988, Davies & Phillipps 1988) they can be expected to fade by about 2.5\( \text{m} \) over the \( 6 \times 10^9 \) years look-back time since \( z = 0.5 \) according to models of simple ageing of starbursts (eg. Wyse 1985; Guiderdoni & Rocca-Volmerange 1987; Charlot & Bruzual 1991). This rate would then be sufficient to produce even the 'worst case' evolution considered above.

If we assume that the fading occurs at a fixed galaxy size (eg. Bothun et al 1986, Evans et al 1990; though see also Colless et al 1994), the decay in surface brightness is exactly the same as that in total luminosity. Thus galaxies could have had central surface brightnesses around 22.5 \( B \mu \) (ie. \( B \) magnitudes per square arc second) as dIs and have faded to become LSBGs with central surface brightnesses around 25 \( B \mu \). These would be just barely detectable in dedicated local LSBG surveys (eg. IBM, IDDP). Anything with a dI surface brightness (at \( z = 0.5 \)) at or below 24 \( B \mu \) (which is apparently quite common, see eg. TPDD) would by now be quite invisible locally (unless it was a satellite of our Galaxy).

It is worth remarking as a general point (Phillipps 1993a; see also McGaugh 1994; Lacey et al 1993) that while distant galaxies are frequently surveyed with extremely low isophotal thresholds around 29 \( B \mu \) (eg. Tyson 1988; Metcalfe et al 1992; Tresse et al 1993), corresponding to an intrinsic surface brightness \( \sim 27.5 B \mu \) allowing for cosmological dimming, virtually nothing is known about local galaxies at surface brightness levels below about 25 \( B \mu \), the deliberate LSBG searches in the Fornax and Virgo Clusters (eg. IBM, IDDP) being the only real exceptions. This paradoxical situation can obviously have important implications when trying to interpret the faint counts in terms of evolutionary rates. Clearly a galaxy with an intrinsic central surface brightness around 26.5 \( B \mu \) which should be readily observable in the deep counts (its observed surface brightness will be about 1\( \text{m} \) above the limiting threshold), with any evolutionary fading at all will not be included in any local census. This loss of galaxies nearby because of their low surface brightness as well as magnitude may therefore further reduce the amount of evolution actually needed to generate the apparent increase in numbers at fainter magnitudes/larger redshifts. We explore this more quantitatively in section 3.2.

3 Fading Dwarf Models

3.1 Luminosity Functions and Evolution

To make a more rigorous assessment of the viability of the simple fading dwarf picture, we construct a model with a two component LF as advocated in DPDMD. The first component is a standard Schechter function for the giants with \( \alpha = -1 \) and \( M* = -21 \), but cut off at the faint end (cf. Sandage et al 1985). For added simplicity we take this to be non-evolving. The lack of evolved very distant giants already limits the allowed evolution to be less than 1 magnitude by \( z = 1 \) (Colless 1993). The normalization \( \phi_s(\text{giant}) \) is chosen so as to obtain a fit to the counts at \( B = 18 \) to 20. The second, dwarf, component has the steep slope (\( \alpha = -1.5 \)) discussed earlier, a present day \( M* = -18 \) (ie. 3 magnitudes or a factor 16 fainter than for giants) and an amplitude relative to the giant LF which we leave as a free parameter. This is equivalent to being able to choose the absolute magnitude at which the dwarfs begin to dominate the overall LF (see DPDMD).

We now want to allow this population to fade at a rate consistent with that expected after a starburst of duration, say, 1 Gyr (a reasonable lifetime for the star forming phase of a dwarf galaxy, see Davies & Phillipps 1987). As a straightforward, easily parameterised form we model this as an exponential fall off in luminosity with time (see also Cole et al 1992), as commonly adopted for the variation of the star formation rate (eg. Guiderdoni & Rocca-Volmerange 1987). This then translates to an evolutionary correction (in magnitudes) which is linear with look-back time, ie. \( \Delta m \propto \Delta t \). Since for an Einstein-de Sitter universe, \( t \propto (1+z)^{-3/2} \), for convenience we can write the evolutionary correction as \( \Delta m = 4\beta \Delta t/t_0 = 4\beta/[(1+z)^{-3/2}] \). Note that if \( \beta = 1 \) the fading since \( z = 0.5 \) is 1.8 magnitudes, while if \( \beta = 1.5 \) this rises to 2.7 magnitudes, so this would be the range that one might expect for dwarfs fading after a burst of star formation (cf. Wyse (1985), Guiderdoni & Rocca-Volmerange (1987) and, especially, Olofsson (1989) who considers low metallicity systems). Note, too, that this form of the evolution avoids excessive values at high \( z \) (cf. Phillipps 1993b) since the evolution soon flattens out beyond \( z \sim 0.5 \). In terms of the number of dwarfs we would see, the fact that only the power law tail of the dwarf LF is
important means that, say, $2^m$ of fading is essentially equivalent to decreasing the normalization of the dwarf LF by a factor $\Phi(M+2)/\Phi(M) = 10^{0.4(-a-1)\times2} = 2.5$.

To see if such a simple model can fit the observations, we take as our key constraints (i) the faint end of the local LF, (ii) the shape of the $B$ band number counts faintwards of $B = 20$ and (iii) the redshift distributions at $B \approx 21, 22$ and $23.5$. We could, of course, attempt to introduce further constraints by using, in particular, the $K$ band number counts (eg. Gardner, Cowie & Wainscoat 1993). However, the number counts at $K$ are much less steep than at $B$, so present less of a 'problem'. Less evolution and/or less dwarfs are needed and would, indeed, be expected from the evolution models (see eg. Phillipps 1993b) and the fact that the dwarfs are generally blue so contribute relatively little to counts at longer wavelengths (eg. DPDM).

If for the moment we ignore the (un)detectability of low surface brightness objects (ie. we consider only total magnitudes), then it is easy to generate these various distributions. Figures 1a-e show the predictions for a basic model with $\beta = 1$ and a normalization $\Gamma = \phi_\alpha^*(\text{dwarf})/\phi_\alpha^*(\text{giant}) = 1$, chosen to give a respectable overall fit compared to the recent data (from LPEM, MSFJ, BES, CETH and CSH, respectively). Notice that the redshift distributions, in particular, follow the observations quite closely. The distribution at $B = 23$ to 24 is notable for its very large width; galaxies are almost equally likely to be at redshifts anywhere between 0.1 and 0.6. This is generally true for the other models, below, too. The local LF is perhaps not quite as flat as LPEM’s best fit model in the range $-18$ to $-16.5$ but it is nevertheless a perfectly good fit to the data points. However, it can be seen that the count slope is still not sufficiently steep at $B > 23$ (though remember we are using $\Omega = 1$ which does make it harder to match the slope).

We can now alter the evolutionary rate and the present dwarf to giant ratio to try to improve these fits. If we set $\Gamma = 2$, ie. double the number of dwarfs, we obviously get higher counts at faint magnitudes, and from figure 2b we can see that the fit to the counts is now very good (compared to the scatter in the data points). The redshift distributions (not shown) are still in fairly satisfactory agreement with observation, though rather more low $z$ objects are predicted at $B = 21$ than are actually seen. However the fit to the LPEM LF is much poorer, with significantly too many galaxies at $M_B = -18$ to $-16.5$ (see figure 2a).

Another potentially successful alternative is to increase the evolutionary rate. If we set $\beta = 1.5$ (keeping $\Gamma = 1$) then we again obtain an excellent fit to the number counts (even to the slight inflection at $B = 21$ and the curvature around $B = 24$; see figure 3b). The local LF remains the same as before (figure 1a), but now the redshift distributions at $B = 22$ and $23.5$ develop tails to large $z$ which are not seen in the data (figures 3d and 3e). Statistics of the gravitational lensing of faint background objects by clusters at different redshifts suggest that this lack of high $z$ objects may also extend to even fainter magnitudes (see Small, Ellis & Fitchett 1994). We might try to remove this problem by cutting the evolution off at $z \approx 0.7$, eg. by assuming a peak in the star formation at that epoch, but this destroys the previously excellent fit to the faint counts (figure 4b) since an increasing fraction of the galaxies at $B > 23$ were at high $z$ in this model (eg. figure 3e).

Metcalfe et al (1994a,b) have emphasised that if there is a redshift cut-off (or more generally if there is no significant tail to high $z$) then the slope of the very faint counts should reflect the slope of the LF. This suggests as another alternative a dwarf LF with $\alpha = -1.75$, similar to those in DPDM, Guiderdoni (1991) and Lacey et al (1993). This does indeed provide an excellent fit to the faint counts (figure 5b) but even after fading, there are still too many local dwarfs (figure 5a), so this model shares the same problems as the non-evolving dwarf dominated model of DPDM.

Thus it appears that none of the models which give good fits to the number counts are simultaneously good fits to the redshift survey data and/or the local LF. However, there remains the question of surface brightness bias in the nearby data, as mentioned at the end of section 2.

3.2 Surface Brightness Effects

For more realistic modelling, then, we should also allow for the loss of galaxies due to low surface brightness (cf. Phillipps, Davies & Disney 1990; Lacey et al 1993; McGaugh 1994). For simplicity we will assume that galaxies are detectable if their central surface brightnesses are above some threshold (as in eg. Tresse et al 1993). In practise most surveys would also require that the isophotal size, magnitude

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2Even in an extreme dwarf dominated model, such as in DPDM, the counts brighter than this are mostly due to the giants. Fits to this part and possible evolutionary effects on it are discussed by Maddox et al (1990), Eales (1993) and Lonsdale & Chokshi (1993).
and/or signal to noise ratio exceeded some threshold too (see eg. Phillipps & Disney 1986; IDDP; Yoshii 1993; TPDD; DPDMD) but we ignore this added complication here. (It is dealt with in more detail in papers by Bristow & Phillipps and Ferguson & McGaugh currently in preparation). We also ignore the effects of atmospheric seeing (eg. Ellis, Fong & Phillipps 1977; Yoshii 1993).

To make the surface brightness corrections we need to assume some form for the bivariate distribution of galaxy central surface brightness (or intensity $I$) and scale size $a$ (see Phillipps et al 1990). If we take the relations discussed in IDDP (see also Bothun, Impey & Malin 1991), viz. $n(a, I)da dI \propto a^{-2}I^{-1}da dI$ for $I \leq I_{max}$ (which self-consistently gives an $L^{-3/2}$ luminosity function), then we can easily calculate the fraction $f$ of the galaxies at any $L$ which are also brighter than some surface brightness limit $I_{min}$. Although the total numbers clearly increase towards low surface intensities (ie. there are many LSBGs), the preponderance of small galaxies means that at fixed $L$ most of the galaxies have small $a$ but values of $I$ towards the top of its range. This is therefore by no means an extreme model, as far as invoking surface brightness selection is concerned. In fact, since $a^2 \propto L/I$, we will have

$$n(L, I) dL dI = n(a, I)(\partial a/\partial L)_I dL dI$$

$$\Rightarrow n(L; > I_{min}) dL \propto \int_{I_{min}}^{I_{max}} I^{-1}(I/L)I^{-1/2}L^{-1/2}dL dI$$

$$\propto L^{-3/2} (I_{max}^{1/2} - I_{min}^{1/2}).$$

Clearly the total LF is just given by this expression with $I_{min} = 0$, so the fraction of galaxies above any $I_{min}$ is simply

$$f = 1 - (I_{min}/I_{max})^{1/2},$$

independent of $L$. Thus the effect is equivalent to an overall renormalisation of the dwarf LF by the factor $f$. Of course, this is only an approximation to the actual observational situation, where, as noted above, other factors besides the central surface brightness itself are likely to influence the selection for a sample. (Essentially it amounts to assuming that the selection boundary is a horizontal line in the $(L, I)$ plane, rather than a somewhat curved one, as in eg. TPDD’s figure 3, where the effective limiting $I_{min}$ changes by about 0.5 $B\mu$ across a 4 magnitude range in $I$).

Since the observed $I_{max}$ depends on $z$ because of evolution, cosmological dimming etc., this could mimic an extra evolutionary correction within a given survey (for instance, less galaxies might pass the surface brightness test at $z = 0$ if they have faded substantially). However, it turns out that with realistic fading rates, as above, the evolutionary changes to the surface brightness more or less cancel with the cosmological dimming, so in any one survey (ie. for fixed $I_{min}$) there will be no significant effect (since $I_{max}$ is also approximately fixed). The more important effects therefore arise between surveys, since generally deep surveys have a much fainter limiting isophote than local surveys (Phillipps 1993a; McGaugh 1994; Schade & Ferguson 1994). For instance, if we take $I_{max}$ to correspond to 22.5 $B\mu$ (IDDP) then for surveys with isophotal thresholds around 24.5 $B\mu$ (appropriate for most local luminosity function determinations), 25.5 $B\mu$ (for moderately faint redshift surveys), 26.5 $B\mu$ (deep redshift surveys) and 29 $B\mu$ (very faint counts), we get values of $f$ of, respectively, 0.60, 0.75, 0.84 and 0.95. Incorporating these corrections clearly enables us to have more dwarfs in the deeper data without affecting the local LF. Figures 6a-e show such a model, with $\beta = 1, \Gamma = 2$, ie. the ‘standard’ amount of evolution and a high true number of dwarfs. As expected this leads to a better allround fit than the previous models since in terms of the counts we essentially have the $\Gamma = 2$ model from above, but for the local LF the effective $\Gamma$ is only 1.2, that is almost half the dwarfs have too low a surface brightness to be included. A very similar fit to the counts is achieved if we allow slightly more evolution (eg. $\beta = 1.25$) and reduce the local dwarf numbers somewhat ($\Gamma = 1.75$), thus improving the (already acceptable) fit to the LPEM data. Figure 7 shows how the LF would look at different redshifts under our ‘best’ model of figure 6. This might be compared with recent observations reported by Eales (1993), Colless (1994) and Ellis (1994) or Lilly (1994) who variously claim evolution in $\phi_M, \alpha$ or $M_\star$.

3If we require the central surface brightness to exceed the limiting isophote by a at least 0.5 $B\mu$ (a reasonable value in practice, see eg. TPDD) then the figures for $f$ reduce further to 0.50, 0.68, 0.80 and 0.94. Conversely, if we increased the bright limit to correspond to, say, 21.5 $B\mu$ (eg. van der Kruit 1987, Phillipps et al 1987) the $f$s would increase again. However, we would class these objects with our ‘normal’ galaxy population.
4 Discussion

Several authors (eg. Ostriker 1990; Delcanton 1993; Roukema & Yoshii 1993) have recently outlined reasons why the otherwise attractive merger picture (eg. Rocca-Volmerange & Guiderdoni 1990; Broadhurst, Ellis & Glazebrook 1992; Carlberg 1992) may not be the answer to the large numbers of dwarfs seen at moderate redshifts but not today. It is therefore still important to consider models which do conserve galaxy numbers. As non-evolving standard (ie. giant dominated) models, evolving giant models and non-evolving dwarf dominated models all appear to be ruled out (the first from the numbers, the other two from the redshift distributions), the next simplest model to try is probably the dwarf dominated model with uniform fading of the dwarf component. This is somewhat simpler than the original BES model which has progressively more evolution for fainter and fainter systems or those of Cole et al (1992) where the LF slope evolves directly. Although physically based on the possible evolution of star forming dwarfs, it is still a fairly phenomenological model, rather than a completely ab initio physical model such as those attempted by Lacey et al (1993) or Kauffmann et al (1993), for instance. Nevertheless it shares, in practice, many of the attributes of the Kauffmann, Guiderdoni & White (1994) model based on the hierarchical merger of CDM halos, wherein dwarf galaxies form most of their stars prior to the merger of their halos with those of larger galaxies and then fade at a rate equivalent to that assumed above.

Our results suggest that fading of a large dwarf population - galaxies going from star forming bright irregulars to quiescent low surface brightness dwarfs - can indeed account for the various observational constraints in a consistent way, even if $\Omega = 1$. The required rate for the fading ($\beta \approx 1 - 1.25$) corresponds to 1.8 to 2.2 magnitudes since $z = 0.5$, in excellent agreement with theoretical modelling of post starburst evolution of stellar populations. The corresponding e-folding time for the luminosity is close to 3 Gyr (for our assumed cosmology). In general, it need not be the case that the evolution of the LF follows that of the individual galaxies. However, if the galaxies share an evolutionary e-folding time scale then this will in fact be so, at least after the point where most of them have started fading. Thus for the current approximation to be valid, all we really require is that many dwarfs had already experienced their major star forming episodes and had begun to fade by $\sim 6$ Gyr ago. This would again be in line with the hierarchical models aluded to above, where small halos suffer mergers with larger systems at fairly early epochs.

In order to simultaneously fit the steep number count slope yet have no high redshift galaxies requires a large density of dwarfs (since the evolution can not be too strong). In order to reconcile this with the brighter redshift surveys and the local LF then requires a model with a significant bias against nearby dwarfs due to their low surface brightness. A simple calculation based on the bivariate brightness distribution seen for dwarfs in the Fornax cluster provides the basis for a quantitative assessment of this effect and shows that it is indeed sufficient to remove the remaining discrepancy. If this model is correct then we should expect to see a turn up in the field LF soon after the last well determined point of current surveys and to find significant numbers of low surface brightness field galaxies. Furthermore, we would predict that when redshift surveys are able to probe even deeper than currently possible we should continue to see primarily star forming (irregular ?) low mass systems at a wide range of redshifts.

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Figure Captions

**Figure 1.** Model predictions for the basic model with $\alpha$(dwarf) = $-1.5$, $\beta$ = 1, $\Gamma$ = 1 (see text for definitions). Panel (a) shows the overall $z = 0$ LF (solid curve) compared to the data points taken from LPEM. Dotted and dashed curves show the separate contributions from giants and dwarfs. Panel (b) shows the observed $B$ band number counts, as summarised in MSFJ and DPDMD (various symbols) compared to the model predictions. Also shown is the contribution the dwarfs would make if they were non evolving (long dashed curve). Panels (c), (d) and (e) give the predicted redshift distributions compared to the data for the magnitude ranges 20.5 to 21.5 (BES), 21.5 to 22.5 (CETH) and 23.0 to 24.0 (CSH). The number of missing redshifts is indicated by the size of the box labelled “incompleteness”.

**Figure 2.** As figure 1 but for $\beta$ = 1, $\Gamma$ = 2.

**Figure 3.** As figure 1 but for $\beta$ = 1.5, $\Gamma$ = 1.

**Figure 4.** As figure 3 (ie. $\beta$ = 1.5, $\Gamma$ = 1) but with a cut-off to the evolution at $z = 0.7$.

**Figure 5.** As figure 2 (ie. $\beta$ = 1, $\Gamma$ = 2) but with $\alpha$ = $-1.75$.

**Figure 6.** As figure 2 (ie. $\beta$ = 1, $\Gamma$ = 2) but with surface brightness selection effects taken into account as described in the text.

**Figure 7.** The 'observed' LF at various redshifts for our best fitting model (as per figure 6).