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暗蓝星系计数的过剩问题

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摘 要

人们在极暗蓝星等处观测到数目巨大的星系，远比星系的无演化模型预计的多。随后的观测和理论发展进一步丰富了对暗蓝星系过剩问题的研究。B,K 波段的星等计数、红移计数、颜色计数、成团性等的观测是这一问题的主要观测约束。理论方面，纯光度演化模型能解释 B 波段计数，但却使红移分布过大，并且需要非标准宇宙学。而若采取具有 Λ 的平坦宇宙学或开放宇宙又与 K 星等计数观测矛盾。因此，星系的数目演化是一个成功模型所必需的，或者是星系并合模型；或者是附加星系族模型，即曾存在过一新星系族，后来又消失了；或者是无演化模型中附近的光度函数用错了，应该在暗端包括更多的低面密度星系。不过从暗蓝星系问题得到的宇宙学及星系演化结论是很模糊的，尽管目前主流的观点认为是蓝矮星系造成了暗蓝星系的过剩。

关键词 星系：一般：暗蓝星系

The Problem of the Excess of Faint Blue Galactic Counts

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Abstract

The number of galaxies detected at faint blue magnitudes is much larger than predicted by no evolution model of galaxies. Both observational and theoretical work that followed have enriched the study of the excess of faint blue galaxies. Major observational constraints are B and K band galactic number counts: redshift and color distribution: and clustering of galaxies. Although the pure luminosity evolution model can account

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for the excess, the theory predicts too large a redshift distribution and requires a non-standard cosmology, while a flat cosmology dominated by Λ or an open universe is in conflict with K band observations. Thus the number evolution of galaxies is a necessary element, either the merging model, or the additional population model which involves a new population of galaxies that once existed and disappeared afterwards, or a new no evolution model which has added low-surface-density galaxies at the faint end of nearby luminosity function. Nevertheless, the conclusion from the study of faint blue galaxies is still very vague, although it is generally believed that the blue dwarfs cause the excess.

Key words galaxies: general: faint blue galaxies

1 The Problem of the Excess of Faint Blue Galactic Number Count

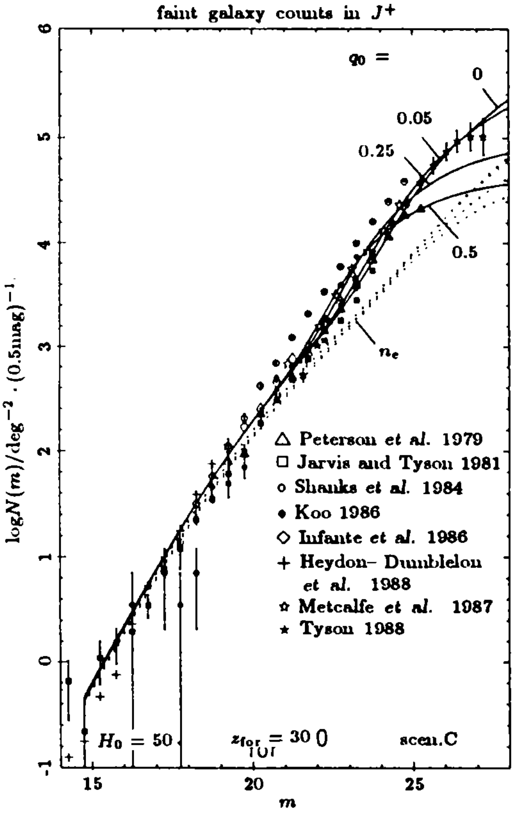

Fig.1 The excess of B band number counts. Dashed line denotes NE model. Solid line is PL model. $q_0 = 0.05$ model fits the best[8].

1.1 The origin of the problem

With the development of CCD technique, galactic number counts have extended to $m_B = 27$[1–3] and the most recent observation has reached $m_B = 28$[4]. If the observed distant galxies are assumed to be the same as the nearby galaxies, i.e., no evolution(NE) model, galactic number counts honestly detect cosmological geometry. NE model predicts well at bright magnitudes $m_B < 19$. At $19 < m_B < 24$, the observed count slope is 0.4–0.6, while NE model predicts 0.3. The excess becomes evident. At $m_B = 24$ there is 3–5 times of excess. At $m_B = 27$ the excess of number count relative to NE model is 5–10 times. This is the problem of the excess of faint blue galactic number count. Fig.1 shows such an excess. For review articles see references [5 – 7].

1.2 The development of the problem

In theory, there are four ways to explain the excess: (1) Luminosity evolution of galaxies[8,9], which enables more distant galaxies observable. (2) Nonstandard cosmological model , either an open universe [8,9] or a universe with Λ[10−13], to increase the available cosmological volume. (3) Number evolution of galaxies, either an additional population[11,14,15] or merging progenitors of present galaxies[12,13,16−21], to predict more galaxies in the past. (4) Adoption of a new nearby luminosity function(LF)[5,22,23]. Because LF in usual NE model has't included a substantial amount of low-surface-density galaxies[22,24−26], which may be observable in faintest B band surveys.

In observation, galactic number counts have been extended to U[27−31], R[1,3,32], I[1,2,33,34] and K[35] bands. Recent developments of infrared observation have reached $m_{\rm K} = 23$. The observed count curve of K band agrees well with NE model, which is a drastic contrast with the excess in B band and acts as a strong constraint for the efforts to explain the excess. The general tendency is that the longer the wavelength of the observation, the less the count excess. Meanwhile, complete samples of color observation exists for $m_{\rm B} = 24$[3,6,31,36], which manifest a shift towards blue and the existence of some very blue galaxies.

Another strong constraint for the excess problem is the redshift distribution[37,38]. Fig.2[8] and Fig.3[39] display the distributions. The observed mean redshifts agree with NE model, and strongly exclude the luminosity evolution of bright galaxies. The complete sample of $m_{\rm B} > 22.5$ shows a redshift distribution[3,8] between $0 < z < 0.7$ with a maximum of 19% incompleteness. And the recent observation[40] reduces the possible $z > 0.7$ galaxies to 4.5%. A small complete sample to $m_{\rm B} = 24$ gives similar results[6], which derives $< z >= 0.24$ for $m_{\rm B} = 23 - 24$, as predicted by NE model.

The study of the clustering property of faint blue galaxies is another aspect. The observed angular correlation function has revealed weak clustering[41−46], smaller than extrapolated from present clustering of the normal galaxies. This may suggest the property of a new additional population, otherwise we have to reconsider the evolution of clustering.

2 Various Efforts to Interpret the Excess

2.1 Pure luminosity model

Luminosity evolution of galaxies should be included in any realistic model because the stars in a galaxy do evolve and the star formation rate was larger in the past. Population synthesis[13,47−52], which is based on stellar evolution theory, has been the major method to investigate luminosity and color evolution. By assuming initial mass function(IMF) and star formation rate(SFR), we can synthesize the spectrum and luminosity of galaxies from those of stars, using stellar tracks in HR diagram. In recent years, convective overshooting and mass loss have been discovered to be substantial in stellar evolution.

New stellar tracks[53–56] may improve the results of population synthesis[13,51,52].

As there are a lot of uncertainties in treating number evolution, the first model to account for the faint blue galaxies is pure luminosity(PL) model which assumes no number evolution and all the evolution of a galaxy is in luminosity.

For counts of $m_B < 24$, PL model predicts observation well and is little influenced by uncertainties in SFR, IMF, or q_0. For counts of $m_B > 24$, the influence of cosmological geometry becomes evident. The standard flat cosmology with PL model for galaxies is strongly excluded because, for $q_0 = 0.5$, the count curve displays too early and too low a plateau which can't be eliminated by choosing appropriate SFR and/or IMF. The only way for PL model to succeed is to give up $q_0 = 0.5$. In reference [8], $q_0 < 0.15$ is required and the best fit happens when $q_0 = 0.05$ and galaxies formed earlier than $z_f = 30$ (Fig.1)

Besides abandoning $q_0 = 0.5$ and requiring z_f large, PL model is fatally challenged by the observation of redshift distribution. Because distant galaxy is more luminous in PL model, there would be a high redshift "tail" in redshift distribution. But the observed data follows a NE model distribution, similar to the nearby dwarfs instead of distant ones. Such a problem may be alleviated if the incompleteness and selection effects, which more easily lose the distant ones, are considered. But the redshift distribution of PL model is still too large (Figs.2,3).

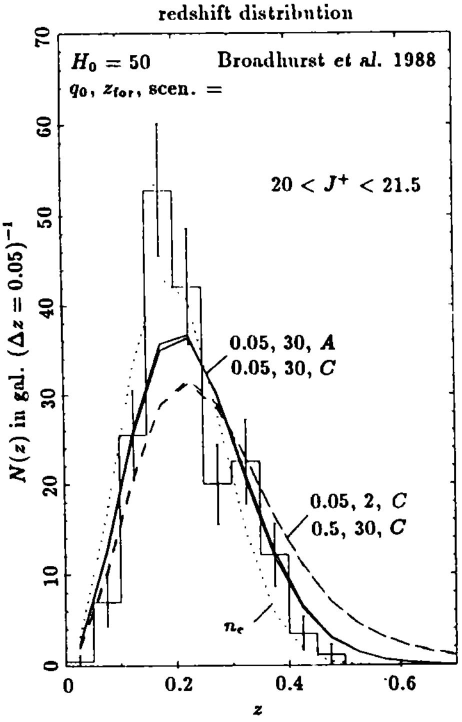

Fig.2 Redshift distribution of $20 < B < 21.5$ sample. Dotted line is NE model. Others are PL models[8].

Still another problem for PL model is that K band observation favors $q_0 = 0.5$. The way by lowering q_0 to increase cosmological volume to make up the $m_B > 24$ counting inadequateness of PL model would cause excessive counts in K band.

2.2 Nonstandard cosmology

The theory of nuclear synthesis predicts baryon density of $\Omega_b h^2 = 0.010 - 0.015$, and the nature of nonbaryonic dark matter isn't quite clear, thus an open cosmology $\Omega_0 < 1$ is still a possibility. In addition, the constraint from Coma cluster is $0.1 < \Omega_0 < 0.3$[57]. On the other hand, estimates of the age of globular clusters and determination of Hubble constant favor an open universe or a cosmology with positive cosmological constant[58]. Such nonstandard models increase the available volume and thus explain the excess of the counts.

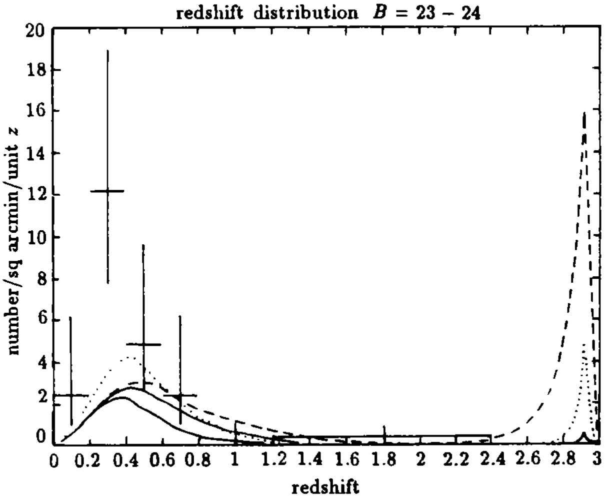

Fig.3 Redshift distribution of $23 < B < 24$ sample. Solid lines are $q_0 = 0.5$ models (NE and evolution). Dashed line has $q_0 = 0.02$, dotted line denotes the model with Λ, both are with luminosity evolution[39].

For the purpose of definiteness, NE or PL model of galaxies is used when using nonstandard cosmological models. This discussion has, in fact, returned to the initial motivation of investigating galactic number counts, i.e., the excess of counts carries the information about cosmology. Various cosmological models have been used to explain the excess of B band counts. Extensive work[10–13] has been done on open universe ($\Omega_0 < 1$, Fig.1) or flat universe with $\Lambda(\Omega_0 + \Omega_\Lambda = 1)$. Furthermore, quasi-steady state cosmological model also claims a large number of blue galaxies[59].

Major constraint is from K band number count (Fig.4[39]). Nonstandard models predict more counts than observation and cause the observation "inadequate". K luminosity reflects light from old stars, which more honestly traces the cosmological geometry, whereas B band is at ultraviolet for larger redshift and reflects stochastic properties of young stars. The present K counts surpport $\Omega_0 = 1$ standard cosmology.

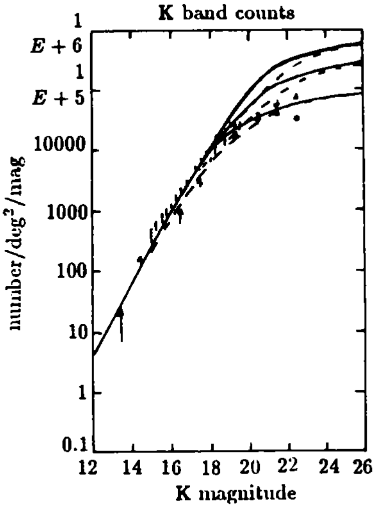

Fig.4 Number counts of K band. Dashed is the NE model. Solid line is with luminosity evolution. Three sets of curves correspond to $q_0 = 0.5, 0.05$ and the model with Λ, respectively[39].

Nonstandard cosmologies predict too many counts and cause observation “inadequate”. In astrophysics we lack mechanisms to “dim” galaxies, and inadequateness of observation is even harder to explain than “excess”.

2.3 Merging model of galaxies

Using mergers to explain the B band excess is an attractive way to extrapolate from present day galaxies. There were more galaxies in the past and present galaxies were in their merger progenitors. Number evolution is often parameterized as a power law[13,16,17]: $n(z) = (1+z)^m$*coefficient; or exponential function of time[18]: $n(z) = \exp(\frac{Q\delta t}{\beta t_0})$*coefficient; or sometimes even more complicated forms[19,20].

The merging models can be divided into two categories: (1) Adopting relatively normal evolution of galactic luminosity[17,18]. Merging induced star formation is assumed to have been averaged in the study of the star formation history of normal galaxies. Merging means more progenitors. Merging effects are in the definition of “a galaxy” when counting the galaxies. Guiderdoni & Rocca-Volmerange[17] describe merging process of bright galaxies under the assumption of self-similarity and mass conservation. They directly use the luminosity evolution from population synthesis[50,60] and model the Hubble types of bright galaxies by varing a time scale of an exponential form. (2) Adopting luminosity evolution of interacting galaxies[13,19]. Merging process and merging progenitors mean more interacting galaxies in the past. These burst-induced and very blue galaxies have caused the excess of the counts. But the “merger progenitors” make trivial contribution to the excess when not involved in bursting behavior. Merging reflects itself in inducing more star bursts (Fig.5[13]). Colin *et al.*[13] model the process by adding a population of interacting galaxies to Hubble types, which have luminosity and energy spectrum of the observed strong interacting galaxies and of which the number increases with redshift as normal galaxies.

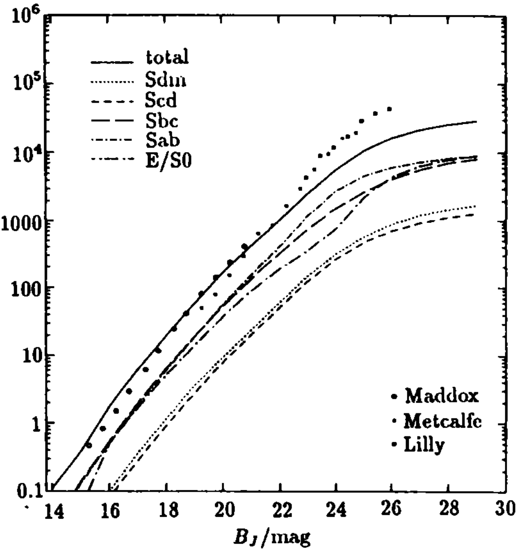

Fig.5 B band excess is explained by merging model[13].

Merging makes the past galaxies smaller and more numerous and the two cancels each other to the first order. Thus merging can’t explain the excess problem unless the galactic luminosity evolution doesn’t follow NE model. It is the luminosity evolution that causes the number evolution to manifest itself on the second order. It is also due to the different luminosity evolution in

B and K bands that merging model can interpret the excess of B band without causing K band observation inadequate.

Merging can also lower the redshift distribution of a sample. What we see at faint magnitudes are nearby small galaxies instead of distant big ones. From the merger point of view, galactic number counts detect only a small fraction of cosmological volume and thus ineligible to discuss cosmologies.

Several problems of merging model are: (1) The thin disks of spirals dynamically exclude any significant mergers[61]. It is thus postulated that disks form after the last merger[62,63] or merging happens selectively in early types[64]. (2) The red color of ellipticals give strong constraint on the last star formation. It is still unknown whether or not the star formation required by a successful merging model could be included in the "normal" luminosity evolution. (3) The clustering study of faint blue galaxies shows weak correlation, while ellipticals are strong correlation systems, in clusters instead of fields. (4) Whether or not the merging rate needed could agree with the observation of nearby interacting galaxies[65–68]? The observed nearby merging rate is 0.005–0.020G·yr^{-1}.

2.4 Additional population model

Redshift distribution reveals that the mass of the galaxies in excess is small, while multi-color observation reveals their blue colors. Thus a new population of galaxies is postulated, which are not included in the statistics of nearby luminosity function and bursted around $z = 1$, with a rise of blue luminosity to be visible as very blue galaxies. Cowie *et al.*[6] treat a complete sample of 22 galaxies limited to $m_{\rm B} = 24$ with redshift and K band observation. They discover 6 out of 11 galaxies of $\rm B = 23 - 24$ are K band dwarfs of $M_{\rm K} > -22$, which are blue dwarfs of around $0.01 M_\odot$ at low redshifts: $< M_{\rm K} >= -21.3$, $< z >= 0.24$, $< \rm B - K >= 3.4$.

Additional population can easily explain B and K counts, as well as observations of redshift, color, and clustering. Cole et al.[11] introduced two methods to add the additional population. One way is to assume flat spectrum galaxies (f_ν =const.), which disappear gradually after $z = 0.7$. Using LF of Schechter form:

$$\phi^*_{\rm new} = 6.0 \times 10^{-2}(\frac{0.7}{z} + 1)^{-1} h^3 \cdot {\rm Mpc}^{-3}, \quad M^*_B = -18.0 + 5\ {\rm log}h, \quad \alpha = -1.1 \qquad (1)$$

Or they are dark halos of CDM model, described by Press-Schechter mass function. Their blue luminosity evolution follows an exponential decay:

$$\frac{M}{L} = 120 \exp[t(z)/3.5{\rm Gyr}](\frac{M_\odot}{L_\odot}) \qquad (2)$$

The major shortcoming of the additional population is that its success relies solely on a "ghost" population which is poorly detected and constrained by present observation.

We are not certain how they appear and disappear. Some recent work has added to the reality of such a hypothesized population, which mainly concern whereabouts of these post-burst galaxies:

(1) IMF is not a universal function. It may cut off at a larger low-mass limit[69]. The corresponding mechanism is that SN explosions of massive stars expel the gas. forbidding the formation of low mass stars. This is a natural mechanism to quench all the stars. The doubt lies at whether or not IMF is as supposed.

(2) They merge into the present normal galaxies, somhow like a merging model. The question is whether or not the normal galaxies can accomodate these blue galaxies. Reference [70] discusses how large the last star burst is, which E/SO's may have experienced.

(3) As a consequence of SN explosion and mass loss, these additional population become extended and low-surface-density dwarfs. In spite of their existence, they escape the nearby detections. In other words, LF of NE model is not complete[22].

The progenitors of bursting galaxies may be: (1) Clouds with small ν in CDM model, which are generally in fields($\nu > \nu_{\rm th}$ clouds form normal galaxies). They bursted around $z = 1$ and dimmed afterwards[71]. (2) The gaseous low-mass galaxies in LF may burst for several times[19].

2.5 New NE model

This method is thought by some researchers as the most elegant way to solve the problem of excess because it doesn't involve nonstandard cosmology and abnormal galactic evolution. The key is that our knowledge of nearby galaxies is not complete. As the light of a galaxy comes from a surface distribution and every luminous distant point leaves an extended image on the plate, we may have lost some or even all the luminosity of a galaxy because we have to set artificially some observation criterion for luminosity and geometrical size for the purpose of higher signal-to-noise value. For this reason our galactic catalogue may have lost many low-surface-density galaxies and our LF should have a steeper faint end slope. Adopting LF as Schechter form:

$$N(L){\rm d}L = KL^{\alpha}e^{-\frac{L}{L_*}}{\rm d}L \qquad (3)$$

The survey of Efstathiou *et al.*[72] shows $\alpha = -1.07 \pm 0.05$, while in some clusters $\alpha = -1.25$[73]. In fact, α may be even steeper (Fig.6[22]). Furthermore, our knowledge of galactic number density is still vague due to large scale structure; and dividing a continuum of galaxies into types may cause some doubts, especially, types would be more meaningful if also descibed by colors[5]; and the functional forms of LF may be different from Schechter's[13].

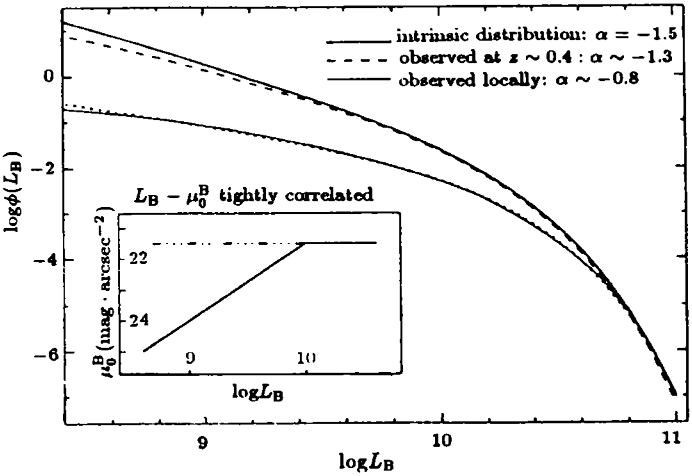

Fig.6 Selection bias of observation makes α appears flattened[22].

According to the new NE model[5,22], we can constitute a NE model within the uncertainties of the present galaxies, which can solve the problem of the excess of faint blue galaxies. The "excess" is caused by our misunderstanding of nearby galaxies. The main element for successful NE model is that LF should include more low mass galaxies, which are blue or were blue, which are seen in faint B band surveys and ignored by nearby observation algorithms.

3 Overview

1988–1990 may be viewed as the first stage of the problem of the excess of faint blue galaxies. PL models of galaxies and open cosmologies were the major concern. 1990–1992 may be the second stage. With the developement of K band number count and redshift observation, the excess was realized to be caused by low mass blue galaxies lying at relatively low redshift (i.e., $z = 0.4$). The terminology of "faint blue galaxy" changed into "blue dwarfs". Various hypothesis were proposed which has caused revisions of traditional scenario of galactic evolution. Efforts were devoted to accomodate a drastic galactic evolution, mainly number evolution, at low redshift. 1992–1994 may be the third stage which was an exaustive and retrospective development of the second stage. "blue dwarfs" were studied by population synthesis method. Selection bias intrinsic in observation were analyzed. Nearby ($z = 0$) galaxies were reconsidered with caution.

Two notable trends are: (1) "bursting" view of merging model is coalescing with "merging into" view of additional population. (2) The faint end of LF is redefined in new NE model to include "blue dwarfs", which is already similar to the treatment of the additional population model.

In short, the current idea is that blue dwarfs cause the excess of faint blue galaxies. These dwarfs may have merged into present galaxies; or are still extant and should be included in local LF but ignored by observation selection. Before the blue dwarfs are fully understood, the problem of faint blue galaxies is still an open question.

Appendix

Useful equations for galactic number counts may be referred to reference [8]. Galaxies are generally divided into types. Each type is assigned a luminosity function $\Phi_j(M_\lambda)$. Within unit solid angle, the number of type j galaxies lying between redshift interval $[z, z+\mathrm{d}z]$ and magnitude interval $[m, m+\mathrm{d}m]$ are:

$$\mathrm{d}^2 A_j(m_\lambda, z) = \Phi_j(M_\lambda)(1+z)^3 \frac{\mathrm{d}V}{\mathrm{d}z} \mathrm{d}m_\lambda \mathrm{d}z \tag{4}$$

in which $\frac{\mathrm{d}V}{\mathrm{d}z}$ is the volume per solid angle of shell $[z, z+\mathrm{d}z]$, depending on cosmological model. Redshift and the luminosity evolution of galaxies enter the equations through the conversion of the absolute magnitude M_λ and apparant magnitude m_λ.

The total galactic number at m_λ per magnitude per solid angle is an integration over z:

$$N(m_\lambda) = \sum_j \int_0^{z_{\max,j}} \frac{\mathrm{d}^2 A_j(m_\lambda, z)}{\mathrm{d}m_\lambda \mathrm{d}z} \mathrm{d}z \tag{5}$$

in which $z_{\max,j} = \min(z_\mathrm{f}, z_\mathrm{L})$. z_L is the redshift when Lyman continuum enters λ passband. z_f is the redshift of galactic formation. The redshift number count winthin magnitude $[m_{\lambda_1}, m_{\lambda_2}]$ is:

$$N(z) = \sum_j \int_{m_{\lambda_1}}^{m_{\lambda_2}} \frac{\mathrm{d}^2 A_j(m_\lambda, z)}{\mathrm{d}m_\lambda \mathrm{d}z} \mathrm{d}m_\lambda \tag{6}$$

If the color of type j galaxy at redshift z is $c_j(z)$, the color number count per color interval within magnitude $[m_{\lambda_1}, m_{\lambda_2}]$ is:

$$N(c) = \sum_j \int_{c<c_j(z)<c+dc} \mathrm{d}z \int_{m_{\lambda_1}}^{m_{\lambda_2}} \frac{\mathrm{d}^2 A_j(m_\lambda, z)}{\mathrm{d}m_\lambda \mathrm{d}z} \mathrm{d}m_\lambda \tag{7}$$

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