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Detecting the Low Surface Brightness Universe: the Extragalactic Background Light and LSB Galaxies

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Abstract.

Individual sources are detected ideally to a confusion limit at a given wavelength, but there is still much information beyond that. Absolute background brightness measurements provide a crucial constraint to models describing the undetected population of sources in the distant – and/or low surface brightness – universe. We calculate how much low surface brightness galaxies (LSB) would contribute to the the overall extragalactic background light (EBL) and review the status of EBL measurements in the optical and infrared wavelengths. To be able to push deeper the detection limits on very faint sources a fluctuation analysis method is introduced. The use of these different approaches together is essential when studying the very faint and low surface brightness universe.

1. Introduction

During the past few years the Hubble Space Telescope and the new generation of 8-meter class ground based telescopes have dramatically quickened the pace of detecting ever fainter and more distant sources in the universe. Consequently the study of galaxy evolution has all but entered into a renassaince era. However, when analyzing these faintest sources, the question still remains: are we truly detecting everything that there is to detect? For example, are the dark areas in the Hubble Deep Field (HDF) really empty? Are we underestimating the light which we do see?

One possibility is that some of the light is absorbed by dust along the line of sight and reradiates in another part of the spectrum. This problem is best studied in the far infrared and submillimeter wavelengths and, indeed, has recently produced some exciting results with SCUBA and ISO (Hughes et al. 1998, Barger et al. 1998, Elbaz et al. 1998). On the other hand the light might still be in the observed waveband, but either severely underestimated or just not detected as objects. This can well arise because of the *low surface brightness* nature of objects.

However, even if the light from individual sources is underestimated for some reason, it is counted in the *total* light coming from that region of sky.

The study of the integrated background has been very fruitful (in the X-ray, for example) and is now beginning to bear results in the far infrared using the COBE data (eg. Guiderdoni et al. 1997, Hauser et al. 1998). In the optical and near infrared few results have so far been obtained due to the relative faintness of the extragalactic background sky (eg. Mattila 1990, Bernstein 1998). Figure 1 summarizes the current observational status from UV to mid-IR.

In the following sections we discuss the detection of individual galaxies including LSB galaxies, the LSB contribution to the EBL, and fluctuation analysis methods to analyze confusion limited images.

2. Detecting galaxies

Counting galaxies is a tricky business. Regardless of the source extraction method used, incompleteness due to noise characteristics and overlapping galaxies must be corrected, as well as compensating the photometry for aperture size and isophotal limit effects. All of these effects become all the more complicated in the presence of LSB's (Dalcanton 1998).

To study the completeness effects of detecting faint galaxies we produced four different simulated images (seeing FWHM = 2.5 pixels) that include the same input source counts, but have different faint end cut-offs. What information can be extracted from these ideal (infinite integration time) images? Fig. 2 shows the differential extracted number counts (BEST magnitudes, SExtractor v.2.0.8; Bertin & Arnouts 1996). It is evident that the images are confusion limited, because the same number of sources are detected in all four images, even though there are three orders of magnitude more input sources in image d than there are in image a.

The dotted vertical lines show the flux levels where the areal density of objects equals 50, 25, and 1 beams per source. Incompleteness sets in at about 50 beams per source and at 25 the observed counts are already 70 % incomplete. The exact behaviour of the completeness limit is complex and depends on the slope of the intrinsic source counts in addition to sky noise and the extraction algorithm.

Realistic selection effects on galaxy surveys including LSB effects have been investigated by eg. Davies et al. (1994), Ferguson & McGaugh (1995), and Dalcanton (1998). Ferguson & McGaugh present models A and B where the LSB population is assumed to have either of the following properties: model A) central surface brightness μ_0 is not correlated with luminosity L, or model B) μ_0 decreases with L (constant size relation). The first indicates that there are large, luminous LSB galaxies in the local universe, which would go undetected in galaxy surveys. This assumption increases modestly the normalization of the luminosity function (LF) of galaxies. With the second assumption one can easily hide large *numbers* of faint LSB's beyond detection limits – hence the result is a steep faint end slope for the LF. For case B, Ferguson & McGaugh find that even though the intrinsic normalization of LF more than doubles and the faint end slope steepens to -1.8, the observed number counts would still be consistent with current observations.

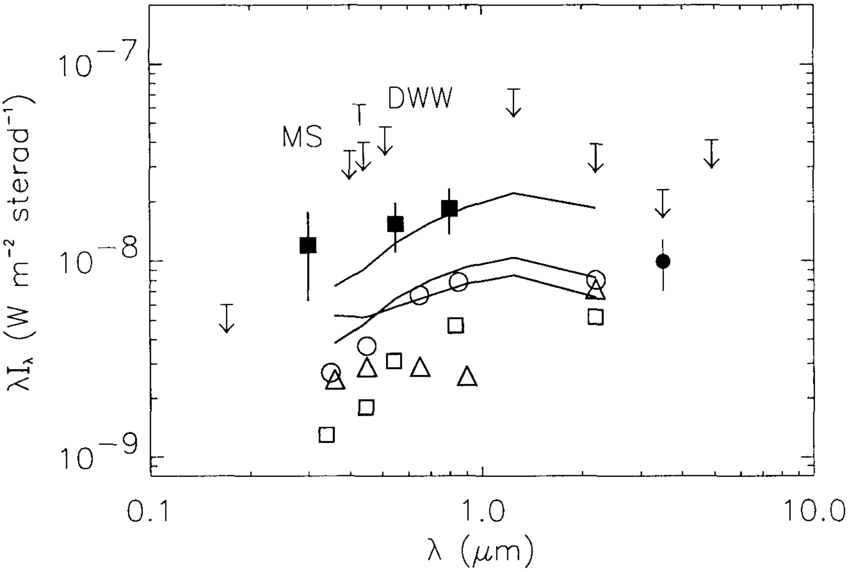

Figure 1. EBL in the UV to mid-IR wavelengths. Lower limits to EBL can be obtained by integrating observed number counts of galaxies: Tyson (1995, triangles), Cowie (1994, open squares), and the deepest counts to date from the HDF (Pozzetti 1998, circles). Models of different galaxy populations are overplotted as solid lines. The two lower curves have extra populations of dwarfs or some extra luminosity evolution and the highest curve has LSB's included; see text for details. Direct measurements of the optical EBL by Bernstein (1998, and these proceedings) are shown with filled squares, and various upper limits as arrows: Mattila (1990, MS), Toller (1983, T), Dube et al. (1979, DWW), and Armand et al. (1994) in the UV. The recent tentative detection of 3.5 μm background by Dwek & Arendt (1998) using DIRBE data is shown as a filled circle. This measurement is dependent on an assumed K-band background: if the K-band EBL would be at the highest model curve, the 3.5 μm measurement would rise by a factor of 1.4. The arrows in the IR are DIRBE data from Hauser et al. (1998). There have also been attempts to estimate the EBL using indirect methods via fluctuations of the background: Vogeley (1998) arrived at basically the same value as the integrated HDF point at 0.8 μm, and Kashlinsky et al. (1996) NIR estimations from DIRBE-data lie just above the direct DIRBE upper limits.

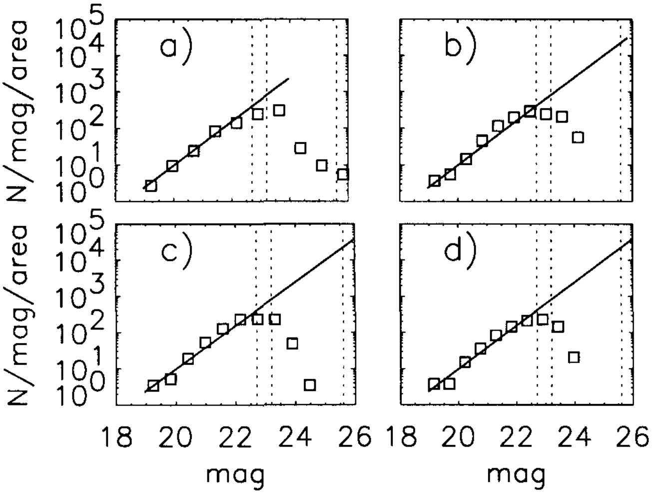

Figure 2. Observed differential number counts (squares) for four different input source counts (solid line). The intrinsic slopes are all euclidian, but the faint end cut-offs are different – in c and d the cut-offs are at 29 and 30.5 mag, respectively. The dotted lines refer to surface densities of objects; see text.

To show the effects of LSB sources in galaxy counts, we have constructed two simulated deep images of a populaton of disk galaxies. The model is simple: galaxy counts with a slope of d(log(N))/d(mag) = 0.4 have been turned into an image using a relation between angular size and apparent magnitude appropriate for pure disks

$$r_0 \propto 10^{(-0.12\times m)}.$$

The relation is normalized using data in Roche et al. (1995). Another image is made using the same relation, but multiplying the scale size r_0 of *each* galaxy by three. This produces LSB galaxies which have central surface brightnesses 2.2 magnitudes lower than the corresponding galaxies in the first image. Thus the model mimics the LSB galaxies of model B of Ferguson & McGaugh.

Figure 3 shows the extracted number counts from each case, compared to the input source counts. There is a 2 magnitude difference in the completeness level between the simulated 'normal' disks and LSB disks. In terms of total number of galaxies, 75% of the galaxies detected in the first simulation were *not* detected after they were turned into LSB galaxies. This fraction naturally depends on the slope of the intrinsic counts, but nevertheless the incompleteness is very significant. Without careful consideration of selection effects due to surface brightness any galaxy catalog will remain suspect.

Note that these are purely confusion limited images with no sky or system noise added. We find an excess brightening of sources near the confusion limit, contrary to the usual expectation of underestimating fluxes at faintest detection levels in noise-limited images.

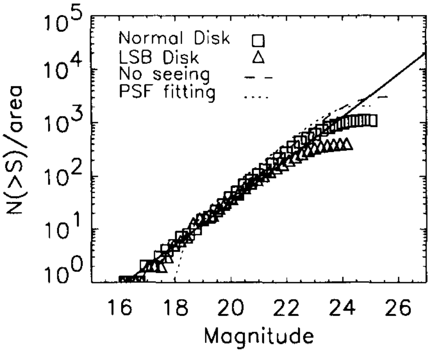

Figure 3. Cumulative number counts extracted from simulated images with normal disk galaxies only (squares) and with LSB's (triangles). The images have been convolved with a $1''$(2.5 pixel) FWHM Gaussian to include a seeing effect in the images. For comparison, the counts from a non-convolved image are shown as a dashed line, and the dotted line represents the normal disks extracted using a PSF-fitting method like DAOPHOT (intended for unresolved objects).

3. Contribution of LSB galaxies to EBL

A completeness limit will always be reached for detecting galaxies individually unless there are actual blank areas on the sky. Therefore, it would be very informative to measure the flux, ie. the EBL, coming out of these 'blank areas'. Originally the measurement of EBL was thought of as a powerful cosmological test, since the total EBL varies as a function of cosmological parameters. Later it was realized that evolutionary effects of galaxies actually affect the EBL more than those changes due to cosmology (eg. Tyson 1995, Davies et al. 1997).

The lower limit for the total EBL can be easily calculated by integrating together all the flux coming from individually detected galaxies. Figure 1 shows some of these integrations: Cowie (1994, open squares), Tyson (1995, triangles), and the HDF (compiled in Pozzetti et al. 1998, circles).

We have also plotted in Fig. 1 the EBL originating from three models of galaxy populations. The models are constructed so that they fit the available number counts (see Väisänen 1996 for details). The lowest line, dubbed 'EDP' in Väisänen (1996), includes pure luminosity evolution and some extra brightening of late type spirals looking back to $z \sim 1$, as well as a population of blue dwarf galaxies. The middle curve ('BBG') is an extreme dwarf-dominated case where all of the 'blue excess' in the faint counts is explained by blue dwarf galaxies.

It is interesting to note that the EBL from both of these galaxy models start to converge to about the level of the total light from the HDF, approximately $\nu I_\nu = 4 - 8$ nWm^{-2}str^{-1} between B and I bands. This is because the slopes of the number counts at the faintest end at all wavelengths (except, perhaps, U-band) are shallow enough that fainter sources would not contribute significantly to the EBL, even if the number counts continue to rise below the detection limits.

So, is all the light in the universe seen in the HDF? The result changes significantly only if we somehow underestimate the light coming from the galaxies. Dust is one contributing factor, but will not be discussed here. The two models introduced above are ideal in the sense that every galaxy that is brighter than a given total magnitude limit would be detected. The upper-most curve in Fig. 1 is a calculation based on model B of Ferguson & McGaugh (1995; 'FMB-LE' in Väisänen 1996). As mentioned above, this takes into account actual detection effects and results in an increase of the intrinsic normalization of the LF and steepening of the faint end of the LF.

In this extreme, but not impossible, case one finds a doubling of the EBL in the UV to near IR wavelengths compared to 'standard' ultra deep, number count fitting, galaxy models. Intriguingly this level is close to the observational results of Bernstein (1998). New galaxy population modeling by Jimenez & Kashlinsky (1998) also predict total fluxes at this level, higher than most previous models. The tentative measurement at 3.5 μm (Dwek & Arendt 1998) is also consistent given the dependancy of this detection on the K-band EBL value. Nevertheless, the highest curve in Fig. 1 can be considered as the upper limit of LSB contribution to the EBL. Generally, even a very large population of LSB's would not be expected to contribute very much to EBL because most of them are also expected to be faint. They contribute more to space density of galaxies, and if their M/L ratios are high as some studies suggest (Impey & Bothun 1997), they could contribute more significantly to the baryonic mass of the universe.

As a final example we estimate the 'lost' amount of EBL due to disk galaxy and LSB selection effects, for the models shown in Fig. 3. The integrated EBL from the differential number counts corresponding to these curves can be calculated using

$$I_{\rm EBL} \propto \int N(m) 10^{-0.4m} dm.$$

If one would take the turnover of detected sources to be intrinsic, and not a selection effect, one would estimate the EBL to be 72% and 25% of the true EBL in the simulated disk-galaxy and LSB-disk dominated universes, respectively. Of course these models are extreme since *only* LSB's (or only disks) were present, but on the other hand, many LSB's are expected to be of much lower surface brightness than the 2 mag/$''$difference of this simulation.

4. Fluctuation analysis

Until a consensus value for EBL is reached at a given wavelenght, there is motivation to try to push the source counts deeper than the detection limits. This is possible by using fluctuation analysis, that is, using the statistical properties of the background sky produced by galaxies that are not detected individually.

One such fluctuation analysis method is the $P(D)$-analysis, which has been succesfully used in radio and x-ray wavelengths (Scheuer 1974, Condon 1974). It is most sensitive to sources at about one beam per souce level. We have investigated a different technique using the variances of pixels in an image. As shown in Väisänen & Tollestrup (1998), it can be a useful tool in deriving number counts from the one beam per source level to flux levels brighter than the confusion

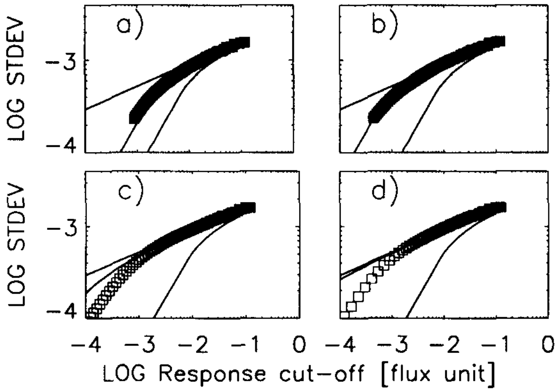

Figure 4. 'Confusion curves' for the same models as in Fig. 2. The standard deviation of all pixels in an image below a cut-off pixel value (or response) is plotted against that cut-off value. By modeling this curve, either analytically or by a Monte Carlo simulation, one is able to fit the observed confusion curve and find models which are consistent with the data. See text for description of the solid curves.

and completeness limits, ie. bridging the number counts between $P(D)$ analysis and direct source counts.

For the same models as in Fig. 2, Fig. 4 shows a plot (squares) of the standard deviation of all pixels in an image below a cut-off flux density. The middle solid curve represents the analytically calculated relation using the same input counts (the differences are due to some specific simplifications, eg. the pixel size was not taken into account in this analysis). The upper-most curve shows how the 'confusion curve' behaves if the model source count slope would continue to infinity, and the lowest curve is the case if it would roll over at the magnitude where the extracted counts turn sharply down (see Fig. 2).

Without going into details, it should be clear that in its simplest form one can generate a set of simulated images with differing faint flux cut-offs and find the best fitting model to the data. The 'observed' curves in panels c and d cannot be separated from each other, but since case b still has a unique curve, we can predict the source count cut-off at least down to the 1 source per beam level. Obviously the slope of the counts affects the confusion curve, so that can be fitted as well. Our simulations suggest that slope variations of about 0.03 (log N - mag slope) can be easily differentiated with this method down to one source per beam flux levels.

5. Summary

Detecting individual galaxies is practical to a surface density of 25-50 beams per source. However, photometry above this limit can still be severely biased due to surface brigtness and confusion effects, especially in the presence of LSB's. On the other hand, an accurate EBL measurement would yield a powerful constraint on the nature of faint extragalactic sources. The maximum LSB contribution to the EBL is estimated to be about the same amount as from normal galaxies. Until a definite value for EBL in optical and near infrared wavelengths is measured, fluctuation analysis methods are very useful in trying to constrain the properties of the faintest universe.

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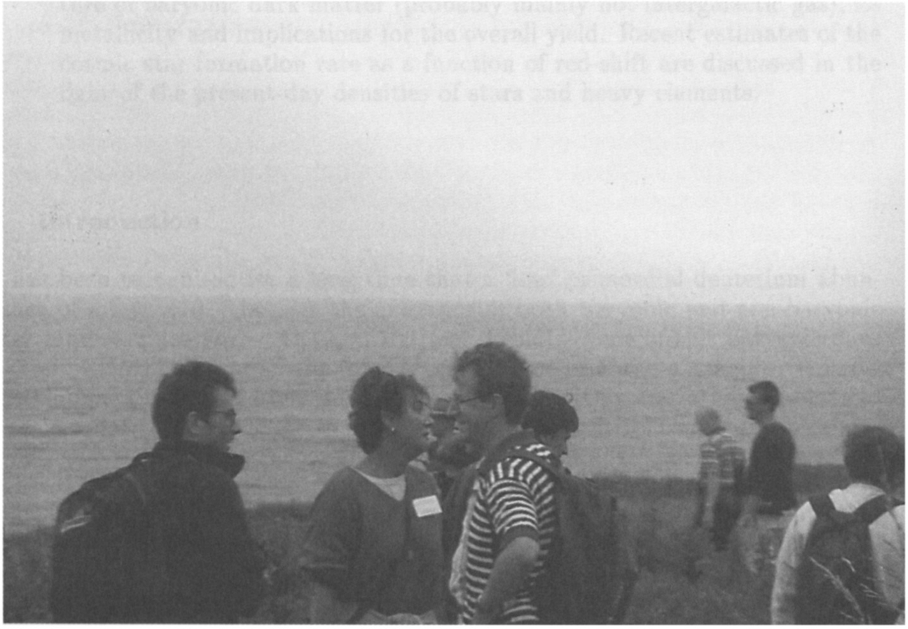
Searching for LSB - VII



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