Point spread function tails and the measurements of diffuse stellar halo light around edge-on disc galaxies

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Accepted 2008 May 28. Received 2008 May 15; in original form 2008 April 3

ABSTRACT

Measuring the integrated stellar halo light around galaxies is very challenging. The surface brightness of these haloes is expected to be many magnitudes below dark sky and the central brightness of the galaxy. Here, I show that in some of the recent literature the effect of very extended Point Spread Function (PSF) tails on the measurements of halo light has been underestimated; especially in the case of edge-on disc galaxies. The detection of a halo along the minor axis of an edge-on galaxy in the Hubble Ultra Deep Field can largely be explained by scattered galaxy light. Similarly, depending on filter and the shape one assumes for the uncertain extended PSF, 20–80 per cent of the halo light found along the minor axis of scaled and stacked Sloan Digital Sky Survey (SDSS) edge-on galaxy images can be explained by scattered galaxy light. Scattered light also significantly contributes to the anomalous halo colours of stacked SDSS images. The scattered light fraction decreases when looking in the quadrants away from the minor axis. The remaining excess light is well modelled with a Sérsic profile halo with shape parameters based on star count halo detections of nearby galaxies. Even though, the contribution from PSF scattered light does not fully remove the need for extended components around these edge-on galaxies, it will be very challenging to make accurate halo light shape and colour measurements from integrated light without very careful PSF measurements and scattered light modelling.

Key words: methods: data analysis – galaxies: fundamental parameters – galaxies: haloes – galaxies: spiral – galaxies: structure.

1 INTRODUCTION

In recent years, we have begun to appreciate the importance of galaxy stellar envelopes as tracers of the hierarchical galaxy formation process. Hierarchical models in a Λ cold dark matter (ΛCDM) context predict that the stellar envelopes around galaxies are created from many disrupted satellites, where size, shape, amount of substructure and metallicity of the envelope principally depend on the primordial power spectrum, the reionization epoch, the star formation history of accreted dwarfs and the total dark matter mass of the host galaxy (e.g. Bekki & Chiba 2005; Bullock & Johnston 2005; Abadi, Navarro & Steinmetz 2006; Purcell, Bullock & Zentner 2007). The discovery of the Sagittarius Dwarf currently being disrupted by the Milky Way (Ibata, Gilmore & Irwin 1994) and the highly structured envelope around M31 (e.g. Ferguson et al. 2002; Ibata et al. 2007) has given much credence to the hierarchical model. While these observations were performed using resolved stars, many measurements of galaxy haloes have been attempted using integrated light (e.g. Morrison, Boroson & Harding 1994; Fry et al. 1999; Wu et al. 2002; Zibetti & Ferguson 2004; Zibetti, White & Brinkmann 2004). These observations are very difficult, as the halo light is typically at least a factor of 10⁴ below sky level, and therefore careful attention has to be paid to flat fielding and sky subtraction. Here, I investigate another effect that has sometimes been underestimated in integrated light studies: the effect of scattered light in extreme Point Spread Function (PSF) tails when examining edge-on galaxies.

The effect of convolving a PSF with a spherical light distribution can be fairly well estimated. For instance, with an elliptical galaxy the light in the central region will be dispersed by the generally broader PSF shape. Further out, the light distribution is nearly unaffected as the PSF shape is steeper than the slowly declining galaxy profile. By overplotting the PSF on the measured light distribution normalized to the same central brightness, one gets a fairly good impression of which radii are affected by light convolution.

For edge-on galaxies, the procedure is not as simple as the luminosity profile perpendicular to the disc can be steeper than the outer tails of the PSF. Close to the midplane of the galaxy the vertical light distribution will still be modified by a point-source-like convolution; however, farther away we are less dominated by the local light. Instead the light scattered from the whole disc – not just the central core – significantly contributes to the measured distribution.
at large-scale heights. To estimate this contribution at more than two scale lengths above the disc (about 6–15 scale heights), one should not use a PSF profile normalized to the central surface brightness of the edge-on galaxy, but instead normalized to the total brightness of the galaxy. Calculating the actual scattered light contribution at any point is obviously best determined by convolving a 2D model of the intrinsic light distribution with a full 2D PSF.

Another problem arises when studying galaxy haloes from stacked galaxy images, scaled to a common size, in order to reach fainter levels. One can estimate the PSF of the stack by combining appropriate stellar images from each field, scaled by the same factor as the galaxy in the frame. However, for a typical sample selection the distribution of scaling is not symmetric and highly biased towards the scales near the selection limit of the sample. The distribution of scaled PSF images is therefore strongly skewed, and meaning that combining the PSFs using median or mean values gives very different results. Assuming that the galaxies are very similar after scaling, no such skewed distribution is present and median and mean combining should give very similar results.

In this paper, I investigate a few cases in the literature where the effects of PSF convolution with edge-on galaxies have been underestimated. I will also show that the colour measurements of the envelopes around galaxies can be strongly affected by scattered light. In particular, in Section 2, I will show the effect of PSF convolution on the light distribution around an edge-on galaxy in the Hubble Ultra Deep field (HUDF; Beckwith et al. 2006) as measured by (Zibetti & Ferguson 2004). In Section 3, I estimate the scattered light effect on the stacked SDSS image analysis of Zibetti et al. (2004). Finally, in Section 4, I summarize my conclusions and give a few recommendations.

2 HUDF GALAXY

Comparing the PSF and minor-axis galaxy profile normalized to the same central brightness leads to an underestimate of the contribution from PSF scattered light. However, this method has appeared in the literature and been used to argue that scattered light will not contribute to the halo light measurement (e.g. Fry et al. 1999; Zibetti & Ferguson 2004). Fry et al. (1999) were unable to detect a halo around NGC 4244 to their limiting surface brightness and therefore their discussion of scattered light was rather moot. (The NGC 4244 halo has now been detected by resolved star count measurements; de Jong et al. 2007b; Seth et al. 2007). Zibetti & Ferguson (2004) do, however, detect an extra component around a disc galaxy in the HUDF and report anomalous colours for this extended component.

The HUDF galaxy studied by Zibetti & Ferguson (2004) is a highly inclined disc galaxy at a redshift of about 0.32 with at best a small bulge. Zibetti & Ferguson (2004) carefully removed the contribution from contaminating (mainly background) sources around the galaxy and extracted the luminosity profiles in wedges along the major and minor axes. They determined profiles for all HUDF Hubble Ultra Deep field Space Telescope (HST)/Advanced Camera for Surveys (ACS) passbands (F435W, F606W, F775W, F850LP, termed B, V, i, and z hereafter for simplicity) and these data points are reproduced in Fig. 1.

To estimate the contribution from scattered light at large radii, I use a standard disc-galaxy model (e.g. as used by van der Kruit 1988). I represent the radial distribution with an exponential disc projected edge-on, which accurately matches the inner profile. However, the observed distribution shows a clear break in exponential scale length at 2.9 arcsec independent of wavelength. Such breaks have been seen many times before (e.g. van der Kruit 1979; Pohlen & Trujillo 2006). The light beyond the break I model with another exponential distribution, but with shorter scale length. The inner scale length varies from ~2.3 arcsec in B to 0.9 arcsec in i and z. The scale lengths beyond the break do not vary with wavelength within the uncertainties. I model the vertical distribution with a sech² distribution, which is a reasonable compromise between the theoretical sech² distribution and the more centrally concentrated exponential-like distribution observed in the near-infrared (de Grijs et al. 1997). Choosing a different vertical profile does not significantly change the results. Major and minor axis profiles of this model before PSF convolution are shown as dashed lines in Fig. 1.

To calculate the observed distribution from the model distribution the PSF needs to be determined out to a radius of about 10 arcsec.

Figure 1. Minor (left-hand side) and major (right-hand side) axis surface brightness profiles of the edge-on HUDF galaxy. The data points are derived from Zibetti & Ferguson (2004). The profiles for the different bands are coded in different colours and symbols and are offset in order to avoid confusion, as indicated by the legend. The input galaxy model is shown by black-dashed lines for the different passbands. Thin solid lines indicate cross-cuts through the B- and z-band PSFs (arbitrarily normalized), whilst thick lines show the convolved galaxy model using the same colours for the different passbands as used for the data points.
Such an extended PSF cannot be accurately measured from the HUDF itself as there are too few bright stars. I therefore used the TinyTim HST PSF modelling software to create artificial PSFs for each passband. These model PSFs were checked against some bright stars in a number of unrelated F606W and F814W images and found to match the outer profiles accurately to at least 5 arcsec. The model galaxy was rotated with respect to the model PSFs by approximately the same amount as the real galaxy. Crosscuts through the centre of the TinyTim PSFs in the direction of the galaxy major and minor axes are shown for the F435W and F850LP filters in Fig. 1. Comparison between the two filter profiles shows that the PSFs are quite similar within 0.8 arcsec, but at larger radii they begin to diverge. This disparity can lead to artificial colour gradients when the convolved light distribution is significantly contaminated or dominated by scattered light.

Finally, I show in Fig. 1 the model galaxy convolved with the PSFs for all passbands as thick solid lines. The extended minor-axis profile seen at heights greater than 1 arcsec from the midplane in the $i$ and $z$ bands can be fully explained by scattered light from the inner disc. On the southeast (negative $z$) side there is a small excess in the $V$ band that might be real, for instance due to small blue background galaxies seen here, but this component would have very remarkable colour properties (e.g. $V-i < 0$). It could also be due to the asymmetry in the main disc-light distribution not modelled here or to some imperfections in the PSF models at that scale. The $B$ band shows excess light beyond my model on both sides of the disc that could be a real halo detection, but these data points are very close to the sky background limit and would again result in some remarkable colours, this time mainly on the northwest side. Clearly, a large fraction of the light seen on the minor axis in excess of the sech distribution is due to scattered light from the extended PSF.

The major axis profiles tell a different story. There seems to be a clear excess of light beyond 6 arcsec radius compared to the truncated disc model. The PSF models would need to be significantly wrong to explain this excess. The points beyond 6 arcsec radius have large uncertainties, but assuming they are correct, we cannot tell from these measurements whether this light is due to a more spherical halo or due to the disc changing scale length yet again. It does however show that, in cases where scattered light may be significant, the best place to look for a (flattened) halo is, maybe counter-intuitively, not along the minor axis, but in the four quadrants away from the major and minor axes. These are the areas where the contribution from the main disc and from scattered light will be smallest.

Zibetti & Ferguson (2004) also presented colour profiles of this HUDF galaxy and argued that the halo had anomalous colours starting at 1 arcsec above the disc, that is the radius where the scattered light contribution starts to become significant. While the observed colour profiles could in principle be checked against the convolved model, it turns out that the expected colour profiles depend critically on the details of the calculated PSFs (especially the diffraction spikes that are hard to model) and the assumed galaxy light and colour distribution. The galaxy has clear small scale-colour variations due to dust extinction and local star formation that is not incorporated into the model. Therefore, the colour gradients observed in the main disc are not predicted, even though the PSF can induce some colour gradients at scale height less than 1 arcsec. Additionally, the observed $i-z$ colour gradient cannot be explained in detail here, as the PSFs only deviate significantly beyond 2 arcsec. Unfortunately, both the galaxy and PSF models lack enough detail to make firm colour predictions on such small scales, especially because I do not have the background galaxy mask to select exactly the same halo areas. Because the light at large radii is so much dominated by scattered light, even small changes in PSFs, galaxy model, or masks can lead to large changes in derived halo colour. The models are, however, consistent with the data, given the (large) errors of the observations and taking these limitations into account. Scattered light most likely contributes to the observed anomalous colours.

3 SDSS IMAGE STACKING

Zibetti et al. (2004) combined 1047 images of edge-on galaxies to reach $\mu \sim 31$ r-mag arcsec$^{-2}$, with similar depths in the $g$ and $i$ band. The SDSS images were scaled, using a characteristic scale size for the galaxies, and combined using an approximation for the mode of the pixel values in the image stack. The resulting galaxy light distribution was modelled by a double exponential disc (exponential in radial and vertical direction) convolved with the effective PSF, derived from similarly stacked star images. An extra component in addition to the convolved galaxy model was clearly detected that followed a power-law radial-light distribution with an axial ratio of about 0.6. However, Zibetti et al. (2004) may have underestimated the effective PSF at large radii, probably due to the procedure used to stack the stellar images and due to the way they extrapolated the PSF profile to large radii.

Zibetti et al. (2004) selected their edge-on galaxy sample from the ‘Large-Scale Structure Sample 10’ of galaxies compiled by Blanton et al. (2005) from the SDSS in 2002 April (about the size of SDSS DR2). Their sample selection was based on cuts by minimum luminosity and isophotal diameter as well as an isophotal flattening criterion. Visual inspection removed further unsuitable candidates, reducing the first cut sample of 1221 galaxies to a final sample of 1047. After removal of contaminating sources the galaxy frames were rotated to align the major axis and scaled radially to a common characteristic size in the $i$ band. The final halo results were nearly independent of whether Petrosian, half-light, isophotal radii or exponential scale lengths were used as reference, and I will use Petrosian radii from here on. As a common reference for radial scaling Zibetti et al. used the median scale size of the sample as expressed in pixels, where each pixel is 0.396 arcsec in the SDSS. The images were combined using an approximation of the mode of all pixel values in the stack at a given position:

$$\text{approximatemode} = 3 \times \text{median} - 2 \times \text{average},$$

where the median and average images were created from the median and (sigma clipped) average values of the stack values.

Zibetti et al. (2004) followed the same procedure to calculate an effective PSF for the image stacks. They present their final stacked PSFs for 4 passbands as modelled by a Gaussian core and an exponential tail. However, their PSF models are presented out to only 15–22 pixels (depending on filter), while their observations stretch to about 100 pixels. The raw PSF profiles are not shown and we cannot be sure whether the exponential tail is a good approximation at radii larger than 20 pixels. I have therefore recreated the stacked PSFs in order to calculate galaxy models out to the last measured point.

3.1 Determining SDSS PSFs

The largest galaxies in the sample are several times larger than the median value used for scaling reference and so both the galaxy and associated PSF will be shrunk by a large factor before stacking. Thus, to create a stacked PSF out to 100 pixels, as used in the
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3.2 PSF stacking and effective PSFs

As far as possible I have reproduced the procedure of Zibetti et al. (2004) to create effective PSFs. I applied the same selection criteria to the Large-Scale Structure Sample 10 (minus eye inspection), used the Petrosian radii to scale the 1D PSFs radially, and used the central galaxy luminosities to scale the PSFs in intensity. The radial scaling was done so as to conserve surface brightness, not total luminosity of the stellar PSF profile, as was done for the galaxies.

When I combine these scaled PSFs with the mode approximation of equation (1), I get negative values at most radii. The empirically derived mode approximation of equation 1 only produces reasonable results if the value distribution is not too skewed (Kendall & Stuart 1977). While this is probably true for the scaled galaxy stack (assuming that the galaxies are self-similar), this is not true for the scaled stars in the absence of noise. The apparent scale size distribution of the galaxies is strongly skewed to small angular sizes, and hence the scaled stellar profile intensities will be strongly skewed, exacerbated by the steep profile shape. PSFs stacked with mode approximation are clearly a poor representation of the true effective PSF. Using the median intensity at each radius instead results in a profile nearly identical to the input PSF. This is to be expected as everything is scaled to the median characteristic galaxy scale size and just as many PSFs are scaled smaller as are scaled larger. The intensity scaling is a small effect compared to the radial scaling due to the steepness of the PSF profile. Using the average value at each radius results in a profile that is a smoothed version of the original PSF, with some of the central light distributed to larger radii.

Fig. 2 shows typical SDSS PSFs for the $g$, $r$, and $i$ bands (which are, as mentioned before, virtually identical to the median stacked PSFs), together with the average stacked PSFs and the stacked PSFs as determined by Zibetti et al. (2004) using the mode approximation. The average stacked PSFs are clearly more extended than the original (and hence median stacked) PSFs. However, the Zibetti et al. (2004) stacked PSFs are much more compact than the typical PSFs of SDSS images, especially between 3 and 10 pixels and at radii larger than 20 pixels. This is unlikely to happen when stacking radially scaled PSFs with conservation of surface brightness. The compactness of their PSFs at small radii therefore seems to be the result of the mode approximation that is incorrect for such skewed intensity distributions. The sharper cut-offs of their PSFs at larger radii is due to the exponential extrapolation where a power law seems more appropriate. It is not entirely clear which effective stacked PSF method is most representative of the final galaxy stack. The only correct way of doing this is to create models of each individual galaxy, convolved with the image PSF, and stack these models. This is beyond the scope of this paper and I will use the averaged stacked PSFs as the best representation of the final galaxy stack PSF. In the analysis in the next section I will indicate how galaxy halo measurements are affected by using a different choice of PSF [i.e. median stacking or Zibetti et al. (2004) stacking].
and star counts not effected by HST 2008 RAS, MNRAS r band, where a large fraction of the light at heights greater than band (left-hand side), g C r band (middle) and 388, 2008 The Authors. Journal compilation can be fully ascribed to the difference in´r band (right-hand side). Symbols represent the data as presented by Zibetti et al. (2004) with distances from the centre and offsets in surface brightness indicated by the legends. The dashed line shows the minor axis light profile of the galaxy model before convolution. The dotted line shows the average stacked SDSS PSF. The thick coloured solid lines show the vertical cuts at the four different radii through the convolved disc only model, the thin lines have an added Sérsic profile halo as described in the text.

3.3 Modelling SDSS stacked galaxy profiles

In Fig. 3, I show the data from fig. 6 of Zibetti et al. (2004), which shows the luminosity profiles of the stacked galaxy images parallel to the minor axis at four distances from the centre. I model these light distributions with a similar model galaxy as used for the HUDF case, with an exponential radial distribution and a sech vertical distribution. In this case I do not include a break in the radial-luminosity distribution, even though I will show it is necessary to explain the light profiles. For simplicity I use the same scale length and height for all filters, even though the fit could be somewhat improved by varying the scale lengths with wavelength. The minor axis input light profile is shown, as well as the effective PSFs used to convolve the models. Finally, I show profiles of the convolved 2D model at each of the four vertical cuts.

The models show that significant amounts of light are found at large radii due to PSF scattering. This is especially true for the i band, where a large fraction of the light at heights greater than 15 pixels above the midplane could be due to scattered light. The cuts farther away from the centre and profiles in the g and r-passbands have more light in excess of the scattered light profiles, but are still often within a magnitude (a factor of ~2) of the model profile. Between 15 and 40 pixels above the midplane, where the data are most reliable, about 50 per cent of the light comes from scattered g and r, increasing to about 80 per cent in i. Clearly, any accurate modelling of this excess light requires a thorough understanding of the scattered light profile. The most successful detection is most likely to occur in the four quadrants away from the major and minor axes. The model overpredicts the luminosity near the midplane of the profile farthest from the centre, whilst matching the data near the midplane for the other three radii. A break in the radial profile is necessary between the third and the fourth profiles to explain the light distribution. Such a break will somewhat increase the significance of the halo detection in the outer most profile.

Using the median effective PSFs, the model profiles are still within 1 mag of the data. The median stacked PSF yields a slightly larger dip between 10 and 30 pixels, which is smoothed out when using average stacking. The Zibetti et al. (2004) model PSFs do not explain the light at radii larger than 30 pixels as they cut off exponentially, but at these larger radii their effective PSF is unlikely to be correct.

The remaining difference between the observations and the convolved disc model can be explained by adding a halo of a form that is typical of what is found by the GHOSTS survey (de Jong, Radburn-Smith & Sick 2007; de Jong et al. in preparation). The GHOSTS survey measures halo shapes from HST star counts not effected by PSF convolution. The typical halo envelope can be parametrized by a Sérsic (1968) profile:

\[ \Sigma_{\text{eff}}(r) = \Sigma_{\text{eff}} e^{-r^{b_1}(r/r_{\text{eff}})^{1/n} - 1}, \]

(2)

with \( n = 5.5 \), the effective radius enclosing half the luminosity \( r_{\text{eff}} \) equal to a third of the disc scale length, and the effective surface brightness at this radius \( \Sigma_{\text{eff}} \) equal to a tenth of the central surface brightness of the disc. The halo has a flattening of vertical-overmajor axis of 0.65. The result of adding this additional halo component to the model is shown by the thin solid lines in Fig. 3. This shows that the remaining excess can indeed be explained by a halo profile that is typical for nearby massive disc galaxies. However, due to the uncertainty in the PSF convolution it will be very challenging to invert this process and derive halo parameters from the integrated light measurements.

Zibetti et al. (2004) found that the detected halo light showed very anomalous colours, especially in r–i. In Fig. 4, I reproduce their minor axis colour profiles with my PSF convolved model. The colour gradient seen in r–i can be fully ascribed to the difference in PSF between r and i, as the intrinsic light distribution has no colour gradient at all. The anomalous extra scattered light component in the i-band PSF causes the strong colour gradient. The very good agreement between r–i model and data strongly suggests that the average stacked PSF is a fair approximation for the effective PSF. The model also predicts a colour gradient in g–r between 10 and 35 pixels. No clear trend is seen in the data, but the errorbars at these radii are so large that the model is consistent with the data. On the other hand, only about 50 per cent of the light is due to scattering in these passbands according to the model, therefore the observed colour gradient is expected to be less than the model prediction if there is no intrinsic colour in the galaxy. Indeed, adding the typical GHOSTS Sérsic halo to the models as described above reduces the
colour gradients, relatively more in $g-r$ than in $r-i$. This shows that the scattered light still dominates the colours in $r-i$ for a reasonable halo profile.

Using the median stacked PSFs instead of the average stacked PSFs yields model-colour gradients on the minor axis that are much steeper beyond 10 pixels than observed. Such a steep gradient would need to be compensated by a significant real halo component with no colour gradient. The Zibetti et al. (2004) PSFs produce a very steep colour gradient starting at 5 pixels and a real halo would need to dominate at these radii to reduce the scattered light colour effect.

4 CONCLUSIONS

Measuring the exact halo light distribution around edge-on disc light from the integrated light distribution is very challenging. In addition to careful flat fielding and removal of fore- and background sources, particular attention has to be paid to the effect of scattered light from the central disc. Specifically, for edge-on galaxies it is not sufficient to compare the galaxy minor axis light profile with the PSF profile; at large heights above the disc scattered light is contributed from the whole galaxy, not just the centre, and a full convolution of a 2D model is needed to assess the scattered light contamination. Basic modelling suggests that the minor axis may not be the optimum place to detect a halo, but for a flattened halo one should look in the quadrants away from the major and minor axis where scattered light contribution from the disc is smaller relative to the halo.

I find that the extended component seen along the minor axis of an HUDF edge-on galaxy can almost fully be explained by scattered light. The observations of Zibetti & Ferguson (2004) for this galaxy do show an extended component along the major axis that cannot be explained by scattered light. Similarly, the halo detection around stacked SDSS edge-on galaxies reported by Zibetti et al. (2004) has a significant scattered light contamination, especially along the minor axis and in the $i$ band. Depending on the assumed best method to create a stacked PSF the contamination along the minor axis in the $i$ band can amount to 80 per cent of the light, in the $g$ and $r$ bands 50 per cent. The contamination decreases with other PSF assumptions and going to one of the quadrants, but the PSF uncertainties make it hard to derive accurate stellar halo properties. The excess light seen on top of the disc only model is consistent with a Sersic law halo with parameters typical of those found by the GHOSTS survey de Jong et al. (in preparation).

The anomalous minor axis halo colours reported by Zibetti & Ferguson (2004) and Zibetti et al. (2004) are consistent with originating from scattered light contamination. In particular, the colour gradients reported by Zibetti et al. (2004) can be modelled by an extended PSF as calculated from the average of the observed scaled SDSS PSFs. There seems to be no need to invoke extreme stellar population to explain these colours as proposed by Zackrisson et al. (2006). The expected contribution from a typical GHOSTS halo is so small in the $i$ band that it has only a small effect on the predicted colour gradient.

There have been other reports of anomalous galaxy stellar halo colours. Lequeux et al. (1996, 1998) report thick disc or halo $BVr$-band colours of edge-on galaxy NGC 5907 that are only consistent with colours of elliptical galaxies, that is an old, metal rich stellar population. In this case the errors are unlikely to be due to scattered light; the thick disc is detected at about a factor of $10^4$ below the central brightness at about 80 arcsec above the midplane, while the PSF is already $10^2$ below peak brightness at 16 arcsec radius. Not even a factor of 10 enhancement of the scattered light effect due to the edge-on disc configuration can make up that difference. Similarly, the red haloes reported around Blue Compact Galaxies (see e.g. Zackrisson et al. 2006, and references therein) are not caused by scattered light. The galaxies are too large compared to the PSF and the haloes show substructure different from the central galaxy that is unlikely to be due to the substructure in the PSF.

Unfortunately, the examples of Zibetti & Ferguson (2004) and Zibetti et al. (2004) are close to the limit where scattered light is no longer significant and slightly larger objects would have avoided problems. The HUDF does not contain a larger edge-on galaxy that would render scattered light unimportant. However, the SDSS study could now be repeated on a sample of larger galaxies as the area surveyed by SDSS has nearly tripled since the Zibetti et al. (2004) study. Ideally, such a study would use only a small range of scale sizes to avoid large spatial scaling corrections and uncertainties in the effective PSF. Taking about a two times as large an isophotal selection limit would probably suffice, especially in the $g$ and $r$ bands.

While measuring halo properties from integrated light remains plagued with large uncertainties, we do have a technique that allows us to accurately measure the stellar envelopes around galaxies. By performing star counts of resolved stellar populations, we can measure equivalent surface brightnesses to very faint limits as spectacularly demonstrated for M31 and M33 (e.g. Ibata et al. 2007). These observations are not affected by scattered light and only minimally by flat fielding errors. The main limitations of this method lie in fore- and background contaminating objects and low-number statistics (too few bright stars at very low-surface brightnesses/densities). Very few massive, highly inclined galaxies can be studied with ground-based resolution, but HiST allows a much larger sample of galaxies to be studied. Indeed, preliminary results from the GHOSTS survey show conclusively that most large galaxies do have very extended stellar envelopes, with envelope size likely depending on galaxy mass and bulge-to-disc ratio (de Jong et al. 2007a; de Jong et al. in preparation).

ACKNOWLEDGMENTS

I thank Stefano Zibetti, Annette Ferguson and Simon White for very constructive comments on an earlier version of this manuscript that improved its final quality. I am grateful to Michael Blanton for...
providing a machine readable version of the SDSS Large-Scale Structure Sample 10. I thank David Radburn-Smith for a critical reading of a previous version of this manuscript. Eric Zackrisson provided feedback that improved my appreciation of the intricacies of the red halo phenomenon. I acknowledge Eric Bell for making this paper see the light of day.

Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the US Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/.

The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory and the University of Washington.

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