PHOTOMETRIC CALIBRATION AND LARGE-SCALE CLUSTERING IN THE UNIVERSE

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1. Introduction

The machine measurements of UK Schmidt plates have produced two very large galaxy surveys, the APM survey and the Edinburgh-Durham Southern Galaxy Catalogue (or COSMOS survey). These surveys can constrain the power on large scales of $\geq 10h^{-1}$ Mpc better than current redshift surveys, simply because such large numbers, ≥ 2 million galaxies to $b_J \leq 20.5$, provide very high signal/noise in the estimated two-point correlation function for galaxies. Furthermore, the results for the three-dimensional galaxy two point correlation function, $\xi(r)$, obtained from the measured projected function, $\omega(\theta)$, should be quite robust for reasonable model number-redshift distributions, $N(z)$, for these magnitude limits (see, e.g., Roche et al. 1993). Another clear advantage of measuring $\omega(\theta)$ is that it is unaffected by the peculiar velocities of the galaxies, whereas they have an important effect on the corresponding $\xi(s)$ using galaxy redshift surveys.

In particular, the APM survey has been central to the many claims in the literature that the very attractive canonical cold dark matter model, which has held sway throughout the 1980s as *the* cosmological model for the formation of structure in the universe, is not supported by observational evidence. How severe the constraint of the APM results for $\omega(\theta)$ is can be seen, for example, from Fig. 2 of Efstathiou, Bond & White (1992). It has led to theorists considering the possibilities of variable biassing schemes with its increased number of parameters, a non-vanishing cosmological constant, mixed hot and cold dark matter models, and so on, to the bemusement of observers.

The important result that Maddox et al. (1990) found using the APM survey was that $\xi(r)$ has as much power between 10 - $20h^{-1}$ Mpc as it has between 0 - $10h^{-1}$ Mpc, i.e. that the 'break' in $\xi(r)$ occurs at $20h^{-1}$ Mpc. But, the results of Groth & Peebles (1977) using the Lick survey, a visually measured catalogue of ~ 1 million galaxies, found the break to be at $10h^{-1}$ Mpc and Collins, Nichol & Lumsden (1992) find 'significant power out to scales $\simeq 30h^{-1}$ Mpc' using the COSMOS survey. However, at the corresponding scales of 1 - 3° for a survey as deep as a $B = 20^m$ galaxy sample, $\omega(\theta)$ is only ≤ 0.01 and a small systematic error is enough to seriously affect it at these scales.

Unfortunately, calibration remains a problem with galaxy surveys and we shall be discussing this in Section 3. The COSMOS survey has been calibrated by a 'mixed' method, as both 'overlap matching' (see Section 2) and CCD calibrated galaxy sequences have been used. But,

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as we shall see from Section 3, unless there are a great number of such calibrated galaxies for a photographic plate, the zero-point errors will be $\sim 0\overset{\mathrm{m}}{.}1$ and this is enough to have a very significant effect on the position of the break in $\omega(\theta)$, whereas there are ~ 460 common galaxies in the overlap area of two adjacent Schmidt plates and, in principle, this should provide very accurate relative zero-pointing of the plates in the whole survey. Thus, because of the great difficulty to obtain the telescope time to acquire the necessary CCD galaxy photometry, Maddox, Efstathiou & Sutherland (1990) have chosen to calibrate the APM survey using overlap matching only. It makes the APM survey the most consistent and best specified survey to date; it enables them to investigate analytically the possible errors that may still be present in the survey.

However, in order to do so, a crucial assumption had to be made, and that is that the differences in the machine magnitudes as measured from two plates for galaxies in the overlap area have errors that are completely random and not correlated from plate to plate over the survey area. Although it seems a reasonable assumption to make, if it is relaxed, the data then also admits small residual zero-point errors in the APM survey that are significant enough to induce artificial power in the correlation function between the angular scales corresponding to $10 - 20h^{-1}$ Mpc (Fong, Hale-Sutton & Shanks 1992).

2. A Possible Systematic Error with the APM Zero-Points

Consider the overlap region of two plates, *i* and *j*. Let a particular galaxy in the region have APM measured magnitudes, m_i and m_j, respectively. Then if m_t is its true magnitude,

$$m_t = m_i + \varepsilon_i + C_i = m_j + \varepsilon_j + C_j$$

where C_i and C_j are the zero-points we wish to find, and ε_i and ε_j are the errors in the measurements of m_i and m_j.

Now, if the errors in the machine measures are simple random errors,

$$\langle\varepsilon_i\rangle = \langle\varepsilon_j\rangle = 0$$

and

$$T_{ij} \equiv \langle m_j - m_i\rangle = C_i - C_j$$

where the average is taken over galaxies in the plate overlap. In this case the overlap measures, T_{ij}, will give $C_i - C_j$, the relative zero-points between plates, accurately.

However, as is well known, Schmidt plates are not exactly uniform, and, in particular, there is a need to correct for the field response function, which from Fig. 2 of Maddox, Efstathiou & Sutherland (1990) can be seen to be irregular and asymmetrical. It is then possible that there is still a small residual error in the corrections giving rise to a systematic error, in which case

$$\langle\varepsilon_i\rangle \neq 0 \neq \langle\varepsilon_j\rangle$$

and

$$\begin{aligned} T_{ij} &= C_i - C_j + \langle\varepsilon_i - \varepsilon_j\rangle \\ &\equiv C_i - C_j + \Delta\varepsilon_{ij} \end{aligned}$$

If the $\Delta\varepsilon_{ij}$ are simple random errors, this is probably also covered by the Maddox, Efstathiou & Sutherland analysis. The fact that their analysis over the whole survey finds an rms error of $0\overset{\mathrm{m}}{.}06$ for the T_{ij}, when the overlap measure for an individual galaxy have an rms of $0\overset{\mathrm{m}}{.}26$ and there are ~ 460 galaxies in an overlap, does seem to indicate that there are systematic errors in the T_{ij}.

What would be unfortunate is if there is a component of the $\Delta\varepsilon_{ij}$ that is *correlated* over the whole survey, as this could be missed by their analysis. Consider, for example, the completely *hypothetical* situation depicted in Fig. 1, where there are no rms errors, all $T'_{ij} = 0$ and all $\Delta\varepsilon_{ij} = 0$, except those in the overlaps crossed by an arrow in Fig. 1 where $\Delta\varepsilon_{ij} = +e$, a constant. Then, plate overlap matching for this hypothetical example would give zero-points on the left hand side of these overlaps that are in error by e relative to those on the right hand side. Clearly, such an error would escape detection by any *internal* test. It would only be seen when plates on both sides have been *externally* calibrated to sufficient accuracy using, say, CCD calibrated galaxy sequences. It is a simple matter to generalize this example to give much more complicated situations.

Using the CCD calibrated galaxy sequences of Maddox, Efstathiou & Sutherland (1990), we have applied a new test, an analysis of variance (see, e.g., Armitage 1971), eschewing the assumption that the $\Delta\varepsilon_{ij}$ are entirely random and uncorrelated. We found an rms plate-to-plate residual error in the zero-points of $0\overset{\mathrm{m}}{.}084$, twice as large as the value estimated by Maddox, Efstathiou & Sutherland. Thus, although Maddox, Efstathiou & Sutherland have used their CCD sequences to show that the residual errors in the zero-points are consistent with their being of little significance, our results show that the CCD data are *also* consistent with a small rms error that is enough to give a 'corrected' $\omega(\theta)$ with a break scale corresponding to ~ $10h^{-1}$ Mpc, in agreement with the Lick catalogue estimate (Groth & Peebles 1977). Details of our analysis can be found in Fong, Hale-Sutton & Shanks (1992).

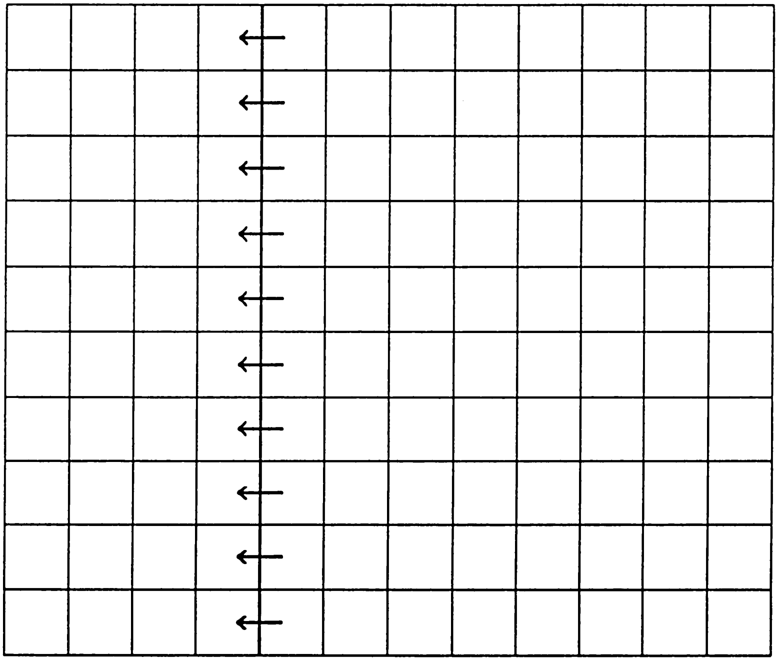


Figure 1. Hypothetical sky survey of 12 x 10 Schmidt fields, on which all the overlap measures $T'_{ij} = 0$, but with a constant systematic error for those overlaps marked by an arrow *only*.

3. The Problem of Calibration

To illustrate the task of calibrating photographic plates, we present here results using the PDS measurement of a IIa-O Schmidt plate and data from the APM survey and from COSMOS. However, the COSMOS data are not from the Edinburgh-Durham Southern Galaxy Survey, but are data that we have used for past Durham work and for which we have extensive CCD data.

Figure 2a shows a tight 45° linear correlation of the PDS magnitudes with CCD magnitudes, with an rms scatter of $0\overset{\mathrm{m}}{.}07$. This reflects the accuracy that can be achieved with a slow scan using a spot that has no halo.

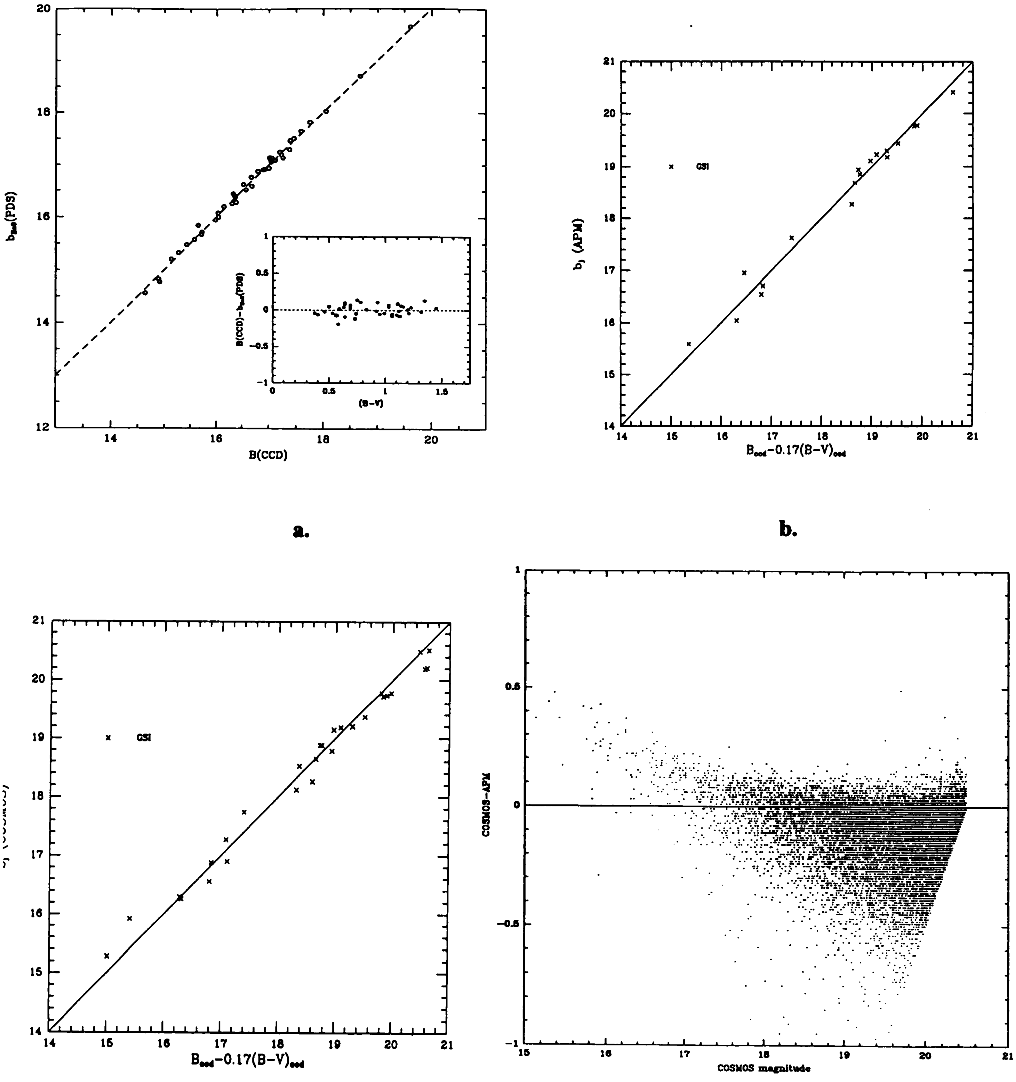
The fast measuring machines, APM and COSMOS, use a rapid raster scanning spot with a significant halo. It can be seen from Figs. 2b and 2c that the APM and COSMOS measures taken from IIIa-J plates of the Durham field, GSI (UKST field 345), are appreciably noisier than the PDS measures, having an rms scatter of $\sim 0\overset{\mathrm{m}}{.}2$. Interestingly, no scale errors for either the APM or COSMOS data are to be suspected from these plots. Thus, it comes as a surprise that when the APM and COSMOS measures were themselves intercompared, Fig. 2d, a clear scale error is seen to faint levels. It is even more surprising when we consider that these machines were designed to be linear for such faint images!

We hope this example is not too typical. Unfortunately, the exercise was limited to only 10 UK Schmidt fields, for which we had many CCD calibrated galaxies. The scatter in Figs. 2b and 2c is, indeed, typical for all 10 fields; but half of them had a scale error between APM and COSMOS. On one of these fields, it was also clear from the machine vs CCD comparison. Thus, it may simply be that with the GSI and similar fields there are small scale errors in both the COSMOS and the APM data which are not so readily apparent in the CCD comparisons, but which have opposite signs so that the error is compounded in the APM/COSMOS comparison in Fig. 2d. Nevertheless, what is clear is that CCD sequences containing very many galaxies are needed for any accurate external calibration of such APM and COSMOS galaxy data.

4. Conclusions

It can be seen from Fig. 1 of Fong, Hale-Sutton & Shanks that the CCD sequences cover only 39 of the 185 Schmidt fields in the APM survey and they clearly do not constitute a 'fair sample'. But, with our 'best' result using the available data giving a possible significant systematic error in the APM zero points and in view of the fact that the APM result for $\omega(\theta)$ is of such *cosmological importance*, it is vital that the survey should be externally calibrated. It is quite possible that their result is correct; but, until the calibration is rigorously validated, the APM result for the break in $\omega(\theta)$ must remain a particularly uncertain one.

Unfortunately, as we saw from Section 3, CCD sequences containing very many galaxies will be required to do so. Calibration is a hard and *very boring* business, and, consequently, telescope time allocation committees tend to ignore applications to carry out this *important task*. However, it is in the interest of Astronomy as a science that we do not "neglect such basic cautions as running controls, understanding the experimental apparatus and checking results", to quote from a recent book review in *Nature*. Of course, in Astronomy it is not such an easy task as in the laboratory to validate observational results; but the APM result is of such great scientific import that it seems to us important that telescope time is awarded for this purpose.



a. b.

c. d.

Figure 2. a) PDS vs. CCD galaxy magnitudes for a IIa-O Schmidt plate, b) APM vs. CCD galaxy magnitudes for a IIIa-J Schmidt plate of the Durham GSI field, c) as for b) using COSMOS magnitudes, d) the difference between COSMOS and APM magnitudes vs. the COSMOS magnitudes with the machine data as for b) and c).

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