A QUANTITATIVE EVALUATION OF THE GALAXY COMPONENT OF THE COSMOS AND APM CATALOGS

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ABSTRACT

We have carried out an independent quantitative evaluation of the galaxy component of the COSMOS/UKST southern sky object catalog (SSC) and the APM/UKST J Catalogue (APM). Using CCD observations, our results corroborate the accuracy of the photometry of both catalogs, which have an overall dispersion of about 0.2 mag in the range 17 ≤ bj ≤ 21.5. The SSC presents externally calibrated galaxy magnitudes that follow a linear relation, while the APM instrumental magnitudes of galaxies, calibrated only internally by the use of stellar profiles, require second-order corrections. The completeness of both catalogs in a general field falls rapidly fainter than bj = 20.0, being slightly better for APM. The 90% completeness level of the SSC is reached between bj = 19.5 and 20.0, while for APM this happens between bj = 20.5 and 21.0. Both SSC and APM are found to be less complete in a galaxy cluster field, where completeness reaches 90% in the ranges bj = 19.0–19.5 and bj = 19.5–20.0, respectively. Galaxies misclassified as stars in the SSC receive an incorrect magnitude because the stellar ones take saturation into account, besides using a different calibration curve. In both cases, the misclassified galaxies show a large diversity of colors, which range from typical colors of early types to those of blue star-forming galaxies. A possible explanation for this effect is that it results from the combination of low-sampling resolutions with properties of the image classifier for objects with characteristic sizes close to the instrumental resolution. We find that the overall contamination by stars misclassified as galaxies is <5% to bj = 20.5, as originally estimated for both catalogs. Although our results come from small areas of the sky, they are extracted from two different plates and are based on the comparison with two independent data sets. We conclude that both the SSC and APM can be a particularly valuable resource for extragalactic studies in the southern hemisphere once their limitations are taken into account.

Key words: catalogs — galaxies: fundamental parameters — techniques: image processing

1. INTRODUCTION

The field of observational cosmology has benefited from the large galaxy catalogs compiled as a result of high-speed machine measurements of photographic plates, such as the catalogs generated using the APM and COSMOS machines. However, the advantage of having large areas of sky is somewhat offset by the limited dynamic range and inhomogeneities of the emulsions and the need for systematic control of the developing process, as well as by the limitations due to the digitization procedure. Metcalfe, Fong, & Shanks (1995), for instance, presented evidence of systematic errors in the photographic photometry performed by COSMOS and APM, which are important for objects with high surface brightness.

In the course of a survey we are carrying out to study the SC-16 and SC-17 superclusters identified by Abell (1961), we found other systematic effects that are present in the COSMOS/UKST southern sky object catalog (SSC; Yentis et al. 1990b; Drinkwater, Barnes, & Ellison 1995) and in the APM/UKST J Object Catalogue (hereafter APM; Maddox, et al. 1990b). This effect is a systematic loss of bona fide galaxies at fainter magnitudes when compared with other catalogs derived from photographic photometry using the same plate material and with independent CCD photometry. This paper is divided as follows: in § 2 we describe the data acquisition and catalogs; § 3 shows the results from the comparison between the SSC and APM with catalogs derived from Photometric Data systems (PDS) scans and ESO Imaging Survey, (EIS, e.g., Nonino et al. 1999) data; and §§ 4–5 conclude the text, respectively, with a discussion and a summary.

2. DATA

2.1. COSMOS Catalog

The first catalog we consider in this work is the SSC, derived from the COSMOS scans (MacGillivray & Stobie 1984) of glass copies of the UKST/SERC J-band survey plates, which is available on-line from the Anglo-Australian Observatory. The slit size used in these scans was 16 μm × 16 μm, corresponding to 1′08 × 1′08 on the sky (see Table 1 for a summary of sampling rates and seeing for all catalogs). Object detection and classification were performed with the basic COSMOS algorithms (MacGillivray & Stobie 1984; Thanisch, McNally, & Robin 1984; Heydon-Dumbelton, Collins, & MacGillivray 1989; Beard, MacGillivray, & Thanisch 1990), using a threshold of 2 times the background standard deviation (σ), which corre-

1 Partly based on observations at Complejo Astronomico El Leoncito (CASLEO), operated under agreement between the Consejo Nacional de Investigaciones Científicas de la República Argentina and the National Universities of La Plata, Córdoba and San Juan; European Southern Observatory (ESO), under the ESO-ON agreement to operate the 1.52 m telescope; and Observatório do Pico dos Dias, operated by the Laboratório Nacional de Astrofísica (LNA).
2 Current address: UCO/Lick Observatory, University of California, Santa Cruz, 95064.
3 Available, respectively, at http://www.aao.gov.au/cosmos/yentis.html and http://www.ast.cam.ac.uk/~apmcat.
sponds to a surface brightness limit of about 25.5 $b_J$ arcsec$^{-2}$, and considering an object whenever it contains more than four pixels. The instrumental magnitudes of SSC stars are corrected for saturation using a function that takes into account the area of the object and its position on the plate. The area is considered because it is directly related to the stellar magnitude (e.g., Bucclark & Irwin 1984) and is independent of saturation (except for very bright stars, in which diffraction spikes and ghost halos appear). The object position is also taken into account because the saturation level is subject to field effects, such as geometrical vignetting and intrinsic changes in sensitivity of the emulsion across the plate (Hawkins 1988). As described by Yentis et al. 1992, the SSC had two procedures for the photometric calibration. As described by Yentis et al. 1992, the SSC had two procedures for the photometric calibration. The first was the use of the stellar profiles (M. Irwin 1992b), with a minimum area for each object of 16 pixels and the saturation detection threshold is 2 $b_J$ above the local sky background intensity, $p$. The FWHM of stellar objects measured on the plate is about 2.3 arcsec. The scanned region comprised an area of 200 $b_J$ arcsec$^{-2}$, with a minimum area for each object of 16 pixels (Maddox et al. 1988b). The isophotal magnitudes are corrected for position-dependent field effects for each plate (geometrical vignetting and differential desensitization). These corrected instrumental magnitudes are then internally calibrated by the use of the stellar profiles (M. Irwin 1999, private communication). Corrections on a plate-to-plate basis are calculated and added to the instrumental magnitudes so that the final ones are uniform throughout the survey (Maddox, Efstathiou, & Sutherland 1990a). The internal accuracy of APM magnitudes was estimated to be about 0.1–0.2 mag up to $b_J$ 20.5 (Maddox et al. 1990b), while externally they were estimated to be accurate to 0.3 mag, becoming worse toward the brighter side. This is due to the use of the calibration based on stellar profiles, which tends to make galaxy magnitudes artificially brighter. The APM positions have internal uncertainties of 0.1 and external ones of 0.5. Completeness estimates were 90%–95% and contamination estimates were 5%–10% up to $b_J$ 20.5 (Maddox et al. 1990b).

2.3. PDS Catalog

An ESO copy on film of the UKST/SERC IIIa-J plate (field 535) was digitized with the PDS 1010A microdensitometer of the Observatório Nacional using a square pixel size and step of 10 $\mu$m, which corresponds to a sampling rate of 0.67. The FWHM of stellar objects measured on the film is about 2.3 arcsec. The scanned region comprised an area of 30' x 30' (0.25 deg$^2$) centered at $\alpha_{2000} = 23^h07^m33^s$ and $\delta_{2000} = -22^\circ33'$, containing two neighboring galaxy clusters, A2534 and A2536. The FOCAS package (Jarvis & Tyson 1981; Valdes 1982) was adopted to perform the object detection and galaxy/galaxy classification. The threshold level was 3 $\sigma$ above the local sky background intensity, corresponding to an isophotal limit of about 25.0 $b_J$ arcsec$^{-2}$. An object was considered only if it comprised a minimum of 12 pixels. The absolute calibration was done using $B$ and $V$ CCD galaxy magnitudes from images obtained at the 1.60 m telescope of the Observatório do Pico dos Dias (OPD), Brasópolis, Brazil. A sequence of 26 galaxies located in the central region of A2534 had aperture magnitudes measured, using the IRAF/DAOPHOT package, spanning from $b_J$ 18.0 to 21.5. We have chosen a 4' radius aperture as a compromise to avoid a significant loss of light for the brighter objects, while minimizing the background noise for the fainter ones. Similar aperture magnitudes were measured in the FOCAS catalog. The final calibration of the scan data (both stars and galaxies) was performed using the color equation obtained by Blair & Gilmore (1982):

$$b_J = B - 0.28(B - V) ,$$

See http://www.ast.cam.ac.uk/~apmcat.

See http://www.ast.cam.ac.uk/~apmcat.

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### TABLE 1

| Catalog | Source         | Band | Digitization | Reduction* | Sampling Rate | Seeing |
|---------|----------------|------|--------------|------------|---------------|--------|
| SSC     | UKST/ESO plate | $b_J$| COSMOS       | COSMOS     | 1:08          | $<3^{ab}$|
| APM     | UKST/ESO plate | $b_J$| APM          | APM        | 0:54          | $<3^{ab}$|
| PDS     | UKST/ESO film  | $b_J$| PDS          | FOCAS      | 0:67          | 2:3$^c$|
| EIS     | NTT CCD        | $B, V$| ...          | SEextractor| 0:27          | 1:0/2:0/9|
| Suppl1  | OPD CCD        | White light | ... | FOCAS | 0:29 | 1:0 |
| Suppl2  | ESO Schmidt plate | $R$ | APM          | APM        | 0:54          | 1:5    |

* Object detection and classification.

 Typical seeing for UKST survey plates (Heydon-Dumbleton, Collins & MacGillivray 1989).

 FWHM of stellar profiles in the PDS area.
where our $B$ and $V$ CCD magnitudes are in the standard Johnson-Cousins photoelectric system, the passbands used in our CCD observations being in agreement with those tabulated by Bessell (1990). The uncertainty in our calibrated $b_j$ magnitudes is estimated to be about 0.15 mag. The total magnitudes that were finally used from this catalog were measured with the FOCAS growing area process, which considers the surface brightness inside an object area 20% larger (Jarvis & Tyson 1981). We should note that our stellar magnitudes are not strictly correct if brighter than $b_j = 19.0$, since no saturation correction has been applied and the calibration used for all objects was that determined for galaxies.

To estimate the reliability of the detection and classification of images by FOCAS, we compared part of our PDS catalog with a CCD-derived one that will be described below as the Supplementary Catalog 1. This comparison allowed us to estimate that the FOCAS classification is reliable (completeness $\sim 95\%$) for galaxies with magnitudes up to $b_j = 21.5$.

2.4. EIS Catalog

A fourth catalog, also taken as an external and independent check, is that derived from multicolor CCD imaging for the ESO Imaging Survey. In particular, we used the catalog for Patch B, which is located at the south Galactic pole ($\alpha_{2000} = 00^h 51^m 00^s$ and $\delta_{2000} = -28^\circ 54' 00''$, field 411), in $B$ and $V$ bands (Prandoni et al. 1998). The EIS frames have a pixel size of $0.27'$ and the median seeings are $1.2'$ and $0.9'$, respectively, for $B$ and $V$ bands. Patch B is composed of a sequence of 150 overlapping images of $9' \times 8.5'$, from which we selected 32 unintersecting frames. The corresponding area is 0.68 deg$^2$. Object detection and classification were performed with SExtractor (Bertin & Arnouts 1996), using a 0.6 $\sigma$ threshold (corresponding to $\sim 26.8$ $B$ arcsec$^{-2}$ and $\sim 26.4$ $V$ arcsec$^{-2}$ surface brightness limits) and a back-propagation neural network, fed with isophotal areas and peak intensity of the profiles, for separating stars and galaxies. EIS data were calibrated directly from Landolt (1992a, 1992b) standard stars, for frames observed in photometric conditions. Both Patch B catalogs are about 95% complete in detection to $B = V = 23.0$ (Prandoni et al. 1998). We adopted a stellarity index of 0.75 to separate stars from galaxies in the EIS catalogs, and the final completeness limit is estimated to be $B = V = 22.0$. The transformation from $B$ and $V$ EIS magnitudes to the $b_j$ system was made using equation (1). The original $B$ and $V$ EIS magnitudes were first converted to the Johnson-Cousins system using the relations presented in Prandoni et al. (1998):

$$B = B_{EIS} + 0.161 (B - V)_{EIS},$$

and

$$V = V_{EIS} - 0.057 (B - V)_{EIS}. \tag{2}$$

Down to $b_j = 21.5$, about 90% of the $B$-band objects had a corresponding match in the $V$-band data, while the classification was coincident in more than 95% of the cases.

2.5. Supplementary Catalogs

Two other catalogs were used as supplementary ones, each comprising only the PDS area. The first Supplementary Catalog was generated from a set of three CCD images obtained with the OPD 1.60 m telescope, exposed with no filters (aiming to get more light in less time) under an $\sim 1''$ seeing. These images targeted the central parts of the clusters A2534 and A2536. Each image covers an area of $3.9 \times 5.6$, while the pixel size of these frames corresponds to $0.29'$. This catalog was obtained using FOCAS, and was used in this work only as an additional and better-quality source for the classification of objects in the area measured with the PDS.

The second Supplementary Catalog is in the $R$ band, derived from an ESO Schmidt Telescope plate, which was digitized and processed with the APM. This catalog was calibrated using 14 galaxies that have CCD $R$ magnitudes, five measured at the OPD 1.60 m telescope and nine from Cunow & Wargau (1994). This catalog was used to obtain the $b_j - R$ color index for objects in the PDS region.

3. COMPARISON BETWEEN CATALOGS

3.1. Number Counts of Galaxies in the PDS Area (Field 535)

The number counts of galaxies in the PDS area, in the three $b_j$-band catalogs (PDS, SSC, and APM), are shown in Table 2 and Figure 1a. Table 2 also shows the number counts for stars and the total numbers of detected objects, including objects classified as faint (on SSC) and merged (on APM). Because SSC objects fainter than $b_j \sim 21.5$ are no longer separated into galaxies and stars, being simply classi-
fied as faint, the number counts of galaxies and stars are small in the last magnitude bin in the table (21.5 ≤ \( b_j < 22.0 \)).

Considering the total counts to \( b_j = 21.5 \), the PDS and SSC show about the same number of objects, indicating that they achieve a similar efficiency in detection. The APM, however, has lower counts, but this is a consequence of a zero-point difference, which will be described in more detail in § 3.3. By correcting the magnitudes of the APM catalog for this offset (this means taking the counts up to \( b_j = 22.0 \)), all the three catalogs show roughly the same total counts. However, the behavior of the galaxy and star counts are quite different in each catalog. For the PDS, the total number of galaxies is more than twice that of the SSC and APM. Also, the galaxy differential counts increase approximately exponentially for this catalog until the limit considered, as expected from its estimated completeness (see Fig. 1). For the SSC, on the other hand, the differential galaxy counts reach a maximum in the bin 20.0 ≤ \( b_j < 20.5 \), which may indicate that the successful classification of objects does not reach much beyond this limit. The most intriguing counts are those of APM: they are flatter than the others, having a larger number of galaxies in the brighter bins and a smaller number in the fainter ones, as compared with the other two catalogs. This effect may be explained, for the brighter side, by the use of the magnitude calibration for stars as mentioned in § 2.2, where galaxy magnitudes are made artificially brighter. Another possible contribution, more effective for the fainter side, may be due to the fact that the APM catalog that we use for this region was not derived from scans of field 535 but from the adjacent field 604, since the original plate was not available at the time this work was being carried out. In this northern plate, the PDS region is located close to its edge, and some photometric and/or classification effects might still be present, despite the corrections applied to APM objects\(^7\) as described in § 2.2.

3.2. Number Counts of Galaxies in the EIS Area (Field 411)

To ensure that the differing number counts found in the previous section are not an effect unique to the PDS Catalog, we made an independent check on the SSC and APM, using the EIS Catalog, which probes a different part of the sky, reaches a fainter magnitude limit, and has overall a better classification than the other catalogs because of the quality and sampling rate of the CCD data. The number counts for the EIS field are listed in Table 3 and illustrated in Figure 1b, which shows, at the faint end, that they are well reproduced by a straight line of slope 0.49 on a logarithmic scale, as expected for field galaxies in this magnitude range (see, e.g., Metcalfe et al. 1991). Again, SSC counts have a maximum in the bin 20.0 ≤ \( b_j < 20.5 \), while APM has flatter counts in the bright end. From the figure, one can see that APM also presents lower counts for \( b_j \) fainter than 20.0. This effect is unlikely to be caused by the overestimation of magnitudes described above, because the stellar saturation correction becomes very small at these magnitudes.

3.3. Distribution of Magnitudes

The comparison between magnitudes derived from the SSC and APM catalogs with those of the EIS are displayed, respectively, in Figure 2a–2b. Objects classified in both catalogs as galaxies are represented by solid circles, those classified as stars, by points, and those for which the classifications disagree, by crosses. The figure shows that each object type occupies a different locus according to its match. Polynomial fits to the distributions in Figure 2a are displayed in Figure 2c, as well as the median values and rms of the distributions for each magnitude bin. The overall rms are \( 0.19, 0.22, \) and \( 0.28, \) respectively, for galaxies in both (solid line), stars in both (dotted line), and EIS galaxies classified as stars in SSC (dashed line). Because of the correction applied to stellar magnitudes in SSC, described on § 2.1, the distribution of magnitudes for stars was expected to be linear, meanwhile it is best represented by a second-order polynomial fit, implying that the saturation correction is not entirely effective. The distribution of galaxy magnitudes,

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\( b_j \) refers to the Johnson \( b \) magnitude, \( J \) to the Cousins \( J \) magnitude, and \( M \) to the Johnson \( M \) magnitude.

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\(^7\) See http://www.ast.cam.ac.uk/~apmcat.
TABLE 3  
NUMBER COUNTS FOR EIS AREA (FIELD 411: 0.68 deg²)

| RANGE OF $b_J$ MAGNITUDES$^a$ | EIS |         | EIS |         | EIS |         |
|-------------------------------|-----|---------|-----|---------|-----|---------|
|                               | Gals. | Stars | Total$^{b,c}$ | Gals. | Stars | Total$^{b,d}$ | Gals. | Stars | Total$^{b,e}$ |
| < 17.0                       | 2    | 202    | 205 | 2    | 252    | 254 | 25    | 152    | 200 |
| 17.0–17.5                    | 0    | 50     | 256 | 1    | 55     | 310 | 10    | 47     | 262 |
| 17.5–18.0                    | 6    | 49     | 311 | 4    | 69     | 383 | 19    | 52     | 339 |
| 18.0–18.5                    | 28   | 57     | 397 | 25   | 74     | 482 | 26    | 47     | 420 |
| 18.5–19.0                    | 36   | 69     | 505 | 39   | 85     | 606 | 26    | 72     | 527 |
| 19.0–19.5                    | 53   | 81     | 643 | 61   | 111    | 778 | 53    | 98     | 690 |
| 19.5–20.0                    | 84   | 112    | 842 | 90   | 142    | 1010 | 84    | 130    | 922 |
| 20.0–20.5                    | 133  | 128    | 1113 | 139  | 165    | 1314 | 123   | 176    | 1243 |
| 20.5–21.0                    | 218  | 146    | 1499 | 132  | 192    | 1638 | 180   | 204    | 1631 |
| 21.0–21.5                    | 419  | 157    | 2128 | 115  | 240    | 1993 | 242   | 313    | 2198 |
| 21.5–22.0                    | 688  | 135    | 3069 | 14   | 37     | 2535 | 276   | 515    | 3006 |
| TOTALS                       | 1667 | 1186   | 3069 | 622  | 1422   | 2535 | 1064  | 1806   | 3006 |

$^a$ Each catalog is considered in its original magnitude system.
$^b$ The totals are cumulative.
$^c$ Including objects with noncoincident classification on the two EIS bands.
$^d$ Including objects classified as faint.
$^e$ Including objects classified as merged.

Fig. 2.—Comparison between (a) EIS and SSC magnitudes, and (b) EIS and APM magnitudes. The symbols denote the match in classification in each pair of catalogs. (c–d): Polynomial fits to the three types of objects with different symbols in (a) and (b), respectively. Error bars represent the dispersion estimates of each distribution.
on the other hand, is very well represented by a linear relation. The relation between the SSC and CCD galaxy magnitudes, in the range $17.0 \leq b_J \leq 21.5$, is

$$b_J^{\text{EIS}} = -0.43 + 1.027b_J^{\text{SSC}}. \quad (4)$$

The different inclinations and zero points between both distributions may be explained by the presence or absence of the saturation correction and the distinct calibration procedures. The behavior of the magnitude distribution of EIS galaxies classified as stars in SSC is completely distinct from the other two. This effect may be explained by the fact that galaxies have larger areas than a star of the same magnitude, yet receive the area-dependent magnitude correction as stars, so that the correction they are subjected to is excessively large in spite of the fact that they practically do not have saturated pixels.

Figure 2b shows the comparison between EIS and APM. As for the SSC, the APM magnitudes also received a correction to linearize stellar magnitudes based on their profiles. However, the correction was applied to the instrumental magnitudes of all objects, including galaxies. A direct consequence of this is that the galaxies do not follow a linear relation, with their locus bending toward the brighter APM magnitudes. The EIS galaxies classified as stars in APM follow the same distribution above but, as they appear at fainter magnitudes, it is not as evident as with the SSC. We also show in Figure 2d of the polynomial fits to these three distributions. The overall dispersions are 0.24, 0.13, and 0.22, respectively, for galaxies in both, stars in both, and EIS galaxies classified as stars in APM. The relation of APM and EIS galaxy magnitudes, obtained in the range $17.0 \leq b_J \leq 21.5$, is given by the expression

$$b_J^{\text{EIS}} = 27.21 - 1.476b_J^{\text{APM}} + 0.0566[b_J^{\text{APM}}]^2. \quad (5)$$

When compared with PDS, the SSC and APM magnitudes show similar behavior, except that the stars in PDS are not corrected for saturation and so their distribution is curved in the same way as the one for the galaxies in Figure 2b, but with a shallower inclination. Another effect found in this last comparison is that the APM magnitudes for the PDS area (extracted from the edge of field 604 instead of field 535) have a shift of about 0.5 mag near $b_J = 21.5$. So, returning to Table 2, the number counts that should be considered for the comparison with PDS and SSC is the one at $b_J = 22.0$.

### 3.4. Completeness Estimates

Since we have mapped the magnitude differences between catalogs and defined the zero points, we are able to estimate the real completeness and contaminations of SSC and APM in the areas we studied, based on the comparison of these catalogs with EIS and PDS. These estimates are shown in Table 4 and Figure 3. The $\sim 5\%$ of EIS objects with non-coincident B and V classification were excluded to guarantee reliability in the EIS catalog classification. In addition, we should note that slightly less than $5\%$ of the objects in the other two catalogs may have been lost in the matching procedure. From the table and figure, we note that both SSC and APM start to loose galaxies in the brighter bins, although completeness estimates for $b_J < 19.0$ do not have enough statistical weight because of the small number of objects. Fainter than $b_J = 19.5$, the SSC completeness drops quickly, reaching a level of 90% in the bin $19.5 \leq b_J < 20.0$, and 65% around $b_J = 21.5$. The APM

![Fig. 3.—Integrated completeness and contamination levels for SSC and APM as compared with EIS data. The features near $b_J = 17.5$–18.0 may be an artifact of small-number statistics.](image)

### TABLE 4

Completeness of the SSC and APM according to the PDS and EIS Catalogs

| RANGE OF $b_J$ MAGNITUDES | $\times$ PDS | $\times$ EIS | $\times$ PDS | $\times$ EIS |
|---------------------------|-------------|-------------|-------------|-------------|
|                           | Diff. | Integr. | Diff. | Integr. | Diff. | Integr. | Diff. | Integr. |
| <17.0                     | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 50.0  | 50.0  |
| 17.0–17.5                 | 0.0   | 50.0  | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 50.0  |
| 17.5–18.0                 | 88.9  | 80.0  | 66.7  | 75.0  | 100.0 | 100.0 | 100.0 | 75.0  |
| 18.0–18.5                 | 100.0 | 88.9  | 92.6  | 88.6  | 100.0 | 100.0 | 95.2  | 92.0  |
| 18.5–19.0                 | 100.0 | 94.9  | 88.6  | 88.6  | 100.0 | 100.0 | 100.0 | 96.3  |
| 19.0–19.5                 | 87.5  | 91.1  | 100.0 | 93.5  | 90.3  | 95.2  | 100.0 | 98.0  |
| 19.5–20.0                 | 80.0  | 84.8  | 90.4  | 92.2  | 84.6  | 89.0  | 97.2  | 97.6  |
| 20.0–20.5                 | 61.8  | 75.6  | 75.9  | 85.8  | 72.3  | 82.0  | 93.0  | 95.8  |
| 20.5–21.0                 | 34.4  | 61.8  | 61.6  | 76.5  | 51.0  | 70.7  | 83.9  | 90.9  |
| 21.0–21.5                 | 11.8  | 48.3  | 40.5  | 64.0  | 31.5  | 56.4  | 69.5  | 81.4  |
completeness is less steep, reaching the 90% level at least 0.5 mag deeper than SSC.

Although the area used in the comparison with EIS is almost twice as large as that used with the PDS, the latter contains two clusters at $z \approx 0.2$, therefore a higher galaxy density (see also the bump on galaxy counts in Fig. 1a). Because of this, the completenesses of the SSC and APM relative to PDS are smaller than when considered relative to the EIS. The 90% completeness level is reached by the SSC in the range $b_J = 19.0–19.5$, and $b_J = 19.5–20.0$ by the APM. As clusters tend to concentrate more early-type galaxies than the general field does and because this type of galaxy may be more easily confused with stars, this implies that the efficiency of image classification by SSC and APM could be less successful in such fields.

Our results show that, as far as the contamination by misclassified objects is concerned, both catalogs have small fractions of stars classified as galaxies, $<3\%$ up to the adopted magnitude limit. However, as the regions we examined are located at high galactic latitudes, where the star density is small, it is possible that this contamination rate may increase as one goes toward lower galactic latitudes.

3.5. What Are the Misclassified SSC and APM Objects?

We present in Table 5 and Figure 4 a subsample of the brightest objects with conflicting classifications that are contained in both the PDS and SSC catalogs. The images displayed in Figure 4 are from the PDS digitization of the copy on film of the UKST plate and contained in a small SSC magnitude range ($18.4 < b_J < 18.7$). The objects in the table and figure are organized according to their classification in the catalogs as follows: those classified as galaxies in both (objects 1–5), those classified as galaxies in PDS and as stars in SSC (6–10), and finally, those which are stars in both (11–15). Concerning the classification, objects 1–5 (Fig. 4; left column) are obviously galaxies, while 11–15 (right column) actually look like stars. The objects 6–10 (middle column) cannot be readily classified by eye, although they show a flatter surface brightness profile, more typical of galaxies. Some of the objects in this table were observed spectroscopically, and measured redshifts are listed in Table 5. Details about these observations and the remaining data will be presented elsewhere. For two of the SSC “stars,” which were classified as galaxies in the PDS Catalog, the spectra reveal that the PDS classification is correct. The spectra for these galaxies are displayed in Figure 5.

To characterize further properties of the galaxies misclassified as stars in SSC and APM, we separated objects with conflicting classifications into three groups: those classified as stars only in SSC; those classified as stars only in APM; and those classified as stars in both. In principle, this last group may have some contamination from real stars misclassified as galaxies by PDS. The results can be seen in Figure 6, where $b_J$ magnitudes are plotted against FOCAS core magnitudes, measured from the brightness of the nine central pixels: PDS against SSC in Figure 6a and PDS against APM in Figure 6b. The PDS galaxies classified as stars in both SSC and APM (open squares) occupy a region slightly above the stellar locus (dots) in both panels. On the other hand, PDS galaxies classified as stars in only one of the catalogs (crosses) occupy the locus of real galaxies (filled circles).

The $b_J - R$ color distribution for the five subgroups (galaxies in all catalogs, stars in all, PDS galaxies classified as stars in both APM and SSC, and PDS galaxies classified as stars in either APM or SSC) is presented in Figure 7. The magnitude interval is restricted to $19 < b_J < 21$ to minimize effects of saturation and detection incompleteness. The probability of each subgroup pair being derived from the same parent distribution ($P_{K3}$) was calculated through the Kolmogorov-Smirnov (KS) test, and the results are summarized in Table 6, which identifies the samples, the

### Table 5

| Object | Coordinates | Classification | $b_J$ Magnitude |
|--------|-------------|----------------|-----------------|
|        | $a_{2000}$ | $b_{2000}$ | PDS | SSC | PDS | SSC | $a \times b$ | $z$ | Obs. |
| 1 ...... | 23 06 41.25 | -22 53 10.2 | g | 1 | 18.06 | 18.48 | 8.3 x 3.7 | ... | ... |
| 2 ...... | 23 07 44.59 | -22 31 08.9 | g | 1 | 18.09 | 18.52 | 7.3 x 4.2 | 0.1080 | 1 |
| 3 ...... | 23 07 53.68 | -22 38 23.9 | g | 1 | 18.53 | 18.61 | 9.5 x 4.4 | 0.1060 | 2 |
| 4 ...... | 23 07 46.68 | -22 27 30.7 | g | 1 | 18.65 | 18.40 | 8.2 x 6.8 | 0.1971 | 3,4 |
| 5 ...... | 23 07 25.43 | -22 27 26.6 | g | 1 | 18.69 | 18.65 | 5.6 x 5.1 | ... | ... |
| 6 ...... | 23 07 19.23 | -22 52 52.0 | g | 2 | 19.67 | 18.56 | 3.7 x 2.9 | 0.1689 | 4 |
| 7 ...... | 23 08 31.98 | -22 42 30.7 | g | 2 | 19.68 | 18.42 | 4.0 x 2.5 | ... | ... |
| 8 ...... | 23 07 26.27 | -22 25 01.5 | g | 2 | 19.71 | 18.42 | 3.4 x 3.0 | ... | ... |
| 9 ...... | 23 06 40.80 | -22 17 13.8 | g | 2 | 19.84 | 18.58 | 3.5 x 3.0 | 0.1377 | 4 |
| 10 ...... | 23 06 37.02 | -22 43 47.5 | g | 2 | 19.96 | 18.62 | 3.3 x 2.9 | ... | ... |
| 11 ...... | 23 07 52.12 | -22 49 33.9 | s | 2 | 19.07 | 18.48 | 3.4 x 2.8 | ... | ... |
| 12 ...... | 23 07 22.41 | -22 15 20.9 | s | 2 | 19.19 | 18.56 | 3.2 x 2.6 | ... | ... |
| 13 ...... | 23 06 37.73 | -22 49 38.8 | s | 2 | 19.35 | 18.42 | 3.4 x 3.0 | ... | ... |
| 14 ...... | 23 06 52.30 | -22 49 56.9 | s | 2 | 19.48 | 18.53 | 3.3 x 2.9 | ... | ... |
| 15 ...... | 23 06 59.64 | -22 25 51.1 | s | 2 | 19.48 | 18.63 | 3.7 x 2.6 | ... | ... |

**Note:** Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

* Code g or 1 means galaxy; s or 2 means star.
* Major (a) and minor (b) axes in arcseconds.
* Site of observation or reference: 1 means CASLEO, Argentina; 2 means OPD, Brazil; 3 means Ciardullo, Ford, & Harms 1985; 4 means ESO, Chile.
* Mean velocity; difference of only 9 km s$^{-1}$ between the two measurements.
number of members in each sample, the KS coefficient and $P_{KS}$ values. PDS galaxies classified as stars only by the SSC or the APM catalogs, have a good chance of being galaxies. The PDS galaxies classified as stars by both SSC and APM have a 21% probability level of being actual stars.

For some of the PDS galaxies that were misclassified as stars by the SSC and/or APM, we have CCD images. A representative subsample of these is presented in Figure 8, while the parameters are presented in Table 7. The left column of Figure 8 shows the PDS image while the right

Fig. 4.—Digitized images of the sample of objects belonging to both the PDS and the SSC catalogs listed on Table 5. Left: Objects classified as galaxies in both catalogs. Middle: Objects classified as galaxies in PDS and stars in SSC. Right: Objects classified as stars in both catalogs.
column shows the white-light CCD image for the same object. Also shown are the FOCAS isophotes which, because of a plotting artifact, are shifted 1 pixel upward relative to the object images. The visual inspection shows that up to $b_J = 21$, all PDS galaxies classified as stars in either SSC or APM seem to be real galaxies. A similar analysis for PDS galaxies classified as stars in both SSC and APM shows that about 70% are indeed real galaxies in CCD frames, while the remaining 30% resemble stars.

By obtaining spectra for all objects in the range $16.5 < b_J < 20.2$ in an area containing the Fornax cluster field, Drinkwater et al. (1999) identified some compact galaxies that were classified as stars in the APM catalog. Drinkwater et al. (1999) also showed that these galaxies tend to have blue colors, high luminosities, and strong emission lines. In the case of galaxies misclassified as stars in the SSC, although some may be indeed this kind of object, compact galaxies cannot account for all. The two objects for which we have spectra do indeed present emission lines (Fig. 6), but cannot be considered being particularly strong. The luminosities of these galaxies are in general smaller than the Drinkwater et al. (1999) compacts. The galaxies misclassified in the SSC have colors that are spread over the range $0.5 < b_J - R < 2.5$, while the Drinkwater et al. (1999) galaxies are, in general, bluer ($0.2 < b_J - R < 1.4$).

4. DISCUSSION

From the analyses presented in the previous section, we conclude that the success rate for the classification of faint objects by the high-speed machines COSMOS and APM is smaller than that in catalogs derived from CCD photometry and from PDS scans. Both the SSC and the APM begin to lose galaxies around $b_J = 19.5$.

As the PDS data are extracted from the same material (the facts that SSC and APM come from glass copies of the original plates and that the PDS catalog comes from a film one does not affect the instrumental resolution significantly), we are led to suppose that the discrepancy in efficiency may be related to the digitization process and/or the classification algorithms and procedures. Concerning digitization, the different resolutions may partially explain the lower efficiency of SSC, since the effective resolution (pixel size combined with sampling rate) used for this

### Table 6

| PDS Galaxies                  | Number | $\times$ Galaxies in All (139) | $\times$ Stars in All (177) |
|-------------------------------|--------|--------------------------------|-----------------------------|
| Stars in SSC only             | 91     | KS 0.091 $P_{KS}$ 75.5          | $P_{KS}$ 0.158 10.1         |
| Stars in APM only             | 53     | KS 0.082 $P_{KS}$ 95.8          | $P_{KS}$ 0.132 47.9         |
| Stars in both SSC and APM    | 45     | KS 0.225 $P_{KS}$ 6.4           | $P_{KS}$ 0.178 20.7         |
| Galaxies in all              | 139    | KS 0.029 $P_{KS}$ 100.0         | $P_{KS}$ 0.187 0.9          |

* The numbers in parentheses refer to the size of each sample.
catalog is 1.5 times lower than that of the PDS and 2 times lower than the APM. Another effect that could explain the misclassified galaxies may be related to the classification procedures. The SSC, for example, uses the so-called parametric classifier, which takes into account the scatter of certain combinations of parameters, such as the area and the maximum intensity, with the magnitude. On the other hand, the classifications of the PDS catalog come from FOCAS, which uses the “resolution” classifier of Valdes (1982). This classifier is based on the point-spread function (PSF) of stellar profiles in the image, and, in the case of the PDS scans, the PSF was optimized specifically for this region of the plate. Our results are thus in accordance with those of Weir & Picard (1992), who found that the “resolution” approach achieves a better performance than the “parametric” approach used by the SSC (and

TABLE 7

| OBJECT | \(x_{2000} \) | \(\delta_{2000} \) | Classification* | \(b_J\) Magnitude | \(a \times b \) |
|--------|-------------|-------------|----------------|----------------|-------------|
| 1...... | 23 07 44.23 | -22 26 31.8 | g | 20.23 | 19.37 | 3.3 \times 2.3 |
| 2...... | 23 07 43.51 | -22 33 32.5 | g | 20.37 | 19.72 | 3.4 \times 2.2 |
| 3...... | 23 07 41.46 | -22 43 19.5 | g | 20.38 | 19.58 | 2.8 \times 2.5 |
| 4...... | 23 07 48.31 | -22 28 16.1 | g | 20.39 | 19.82 | 3.3 \times 2.2 |
| 5...... | 23 07 34.71 | -22 42 07.3 | g | 20.46 | 19.51 | 3.9 \times 2.1 |

Note.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

* Code g or l means galaxy; s or 2 means star.

b Major (a) and minor (b) axes in arcseconds.
COSMOS). The profile classification of APM may also be considered a “parametric” procedure.

Even though the digitization resolution seems to be the dominant factor to jeopardize the classification efficiency, we are not able to produce a controlled experiment, involving all the processes on the same data, to determine the relevance of the instrumental resolution and the classification algorithms.

5. SUMMARY

We have compared high-speed machine-based catalogs that are available on-line, SSC and APM, with catalogs
generated from a slow machine, PDS, and from CCD data (EIS). Each of the catalogs used independent algorithms for detection and classification of object images.

The comparison with the PDS catalog gave the qualitative results: the scanning resolution and/or the nature of the classification algorithm may determine the efficiency of the machine to separate galaxies and stars. With the same photographic material, the PDS 0.7 sampling rate and FOCAS “resolution” classifier achieved a better performance than the SSC 1.1 sampling rate and the “parametric” classifier. APM, although not tested for the same plate material, with a 0.5 sampling rate and a classifier similar to the “parametric” one achieved intermediate results.

The comparison with EIS is the most robust and gives us some quantitative results. Concerning the galaxy photometry, we find that calibrated data from the SSC have a linear magnitude system and a small dispersion, about 0.2 mag. The APM data also present this small dispersion but, because they are not calibrated photometrically and have had a stellar source correction applied, they cannot be taken at face value. We find that APM galaxy magnitudes do not follow a linear relation and require second-order corrections. The SSC catalog is 90% complete for galaxies down to $b_J = 19.5–20.0$, beyond which the completeness drops rapidly. The APM catalog is 90% complete for galaxies down to $b_J = 20.5–21.0$. These completenesses become slightly lower when a cluster field is considered due to the higher proportion of early-type galaxies, which, because of their steeper profiles, are more likely to be misclassified as stars. The misclassified galaxies encompass a large color range ($0.5 \leq B_J - R \leq 2.5$), which includes typical colors of blue high-luminosity star-forming compacts to those of normal early-type galaxies. Our results also show that for the high galactic latitude fields we considered, the proportion of stars misclassified as galaxies is less than 3% up to the adopted magnitude limit.

Although these results were obtained in two small areas of the sky, they demonstrate that both the SSC and APM catalogs are valuable resources for extragalactic research since their limitations are taken into account.

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Note added in proof.—(1) In a paper of G. A. Mamon (astro-ph/9908163), in which he compares the SSC data with that of the DENIS IJK Survey, in the range $13 < b_J < 17.5$, he finds that the completeness of SSC is less than 80% at $b_J = 17.5$ and even worse for magnitudes brighter than this. These results corroborate ours and are complementary for the brighter magnitudes.

(2) Recent spectroscopic observations for the other three misclassified galaxies in Table 5 (objects 7, 8, and 10) confirmed their galactic nature, with redshifts 0.0772, 0.1599, and 0.1214, respectively, all obtained at the ESO 1.52 m telescope, Chile.

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