Wavelength Calibration of Objective Prism Plates by Transformation from Direct Plates

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Abstract

The zero points for galaxy redshift measurements from objective prism plates (dispersion 246 nm mm^{-1} at Hγ) are obtained through transformation of object positions from the corresponding direct plates. Approximately 1000 G-stars per plate, classified automatically, are used.

On the direct plate, positions in x and y are computed from intensity-weighted first moments. On the objective prism plate object positions are given in x through the Ca II-break at 400 nm and in y through marginal fits to the unwidened spectra. Redshifts are obtained from the difference between the expected and the measured Ca II-break positions in the galaxy spectra. The transformation equations include quadratic terms in the direction of dispersion. The inclusion of third-order and colour terms is discussed.

We present the transformation characteristics for three adjacent fields near the South Galactic Pole. The mean residuals are approximately 5 μm, corresponding to a redshift error of about 700 km s^{-1} at $z = 0$.

This is an extended version of the contribution presented at the IAU Colloquium No. 100 at Belgrade (Tucholke *et al.* 1988).

1 Introduction

The Muenster Redshift Project (MRSP), which is outlined in Horstmann (1988) and Schuecker (1988), investigates three-dimensional structures in the Universe using galaxy redshifts from low-dispersion objective prism plates. Presently, redshifts up to $z = 0.3$ with an accuracy of $dz = 0.01$ are reached for galaxies with m_J magnitudes $16^{\mathrm{m}}.0$ to $20^{\mathrm{m}}.5$ on plates taken with the UK Schmidt Telescope. As described by Gericke (1988), methods for the automatic detection of QSO's and the investigation of their distribution are developed.

2 Wavelength calibrations of objective prism plates

For the determination of redshifts free from systematic and large random errors, a proper choice of the wavelength reference point is of primary importance. The position of the IIIa-J emulsion cutoff, which is frequently used as reference point, depends on magnitude and colour and leads to systematic errors of 50 μm (Beard *et al.* 1986). This corresponds to a redshift error of $\leq 6500\,\mathrm{km\,s^{-1}}$ near the Ca II-break at 400 nm and of $\leq 11\,500\,\mathrm{km\,s^{-1}}$ at a highly redshifted Ca II-break above 500 nm, using the dispersion curve by Nandy *et al.* (1977). After correcting for the systematic effect there are still random errors of ≤ 20 μm, corresponding to $\leq 2600\,\mathrm{km\,s^{-1}}$ at 400 nm and $\leq 4600\,\mathrm{km\,s^{-1}}$ at 500 nm.

In order to avoid these difficulties, the MRSP uses the transformation from the direct plate positions of G-type stars to the positions of the Ca II-break in their spectra on the objective prism plate. The spectral appearance of the G-stars is similar to that of the majority of nearby normal galaxies. The stellar velocity dispersion $\leq 100\,\mathrm{km\,s^{-1}}$ is small compared to the redshift accuracy attainable for galaxies from objective prism plates.

3 The transformation model

A quadratic model is used to transform the direct plate positions (x, y) (x is measured in the direction of dispersion) to positions (x', y') on the objective prism plate:

$$\begin{aligned} x' &= a_0 + a_1 x + a_2 y + a_3 x^2 + a_4 xy + a_5 y^2 \\ y' &= b_0 + b_1 x + b_2 y + b_3 x^2 + b_4 xy + b_5 y^2 \,. \end{aligned} \tag{1}$$

The linear terms allow for zero point difference of the plate scans, relative rotation between the plates and differential refraction. The field distortions caused by the objective prism introduce quadratic terms with $a_3 \approx a_5$, the other quadratic terms are negligible. This transformation model has been applied successfully to astrometry and radial velocity measurements (Stock and Osborn 1980, Weis *et al.* 1981, Stock 1984, Stock 1986) and spectrophotometry (Clowes *et al.* 1980) from objective prism plates. A third order model, as discussed by Stock and Osborn (1980), was tested, but did not improve the data: The residuals remained the same, the additional terms were barely significant and the error of the other constants increased.

A colour term in x, however, might be important, because the spectral features on the objective prism plate are monochromatic, while the positions of the objects on the direct plate are affected by atmospheric dispersion. We estimate the size of this effect for the UK Schmidt Telescope using the colour–refraction curves given by Murray and Corben (1979) and Murray (1984). For objects of extreme colours, the displacement relative to the G-type stars used in the transformation amounts to $0\overset{''}{.}25$ at a zenith distance of 60°. This leads to a maximum error of the chosen reference feature of 3.7 μm. The actual error is negligible for most galaxies at low redshifts. For a redshift $z = 0.3$ the maximum error is $900\,\mathrm{km\,s^{-1}}$ and has to be corrected. As soon as our programme of colour measurement and spectral classification for all types of stars is finished, we shall compute the transformation equations for galaxies of high redshifts and for very blue objects from a wider range of stellar colours and with a colour term included in the transformation model.

4 Measurements and reductions

The observational material, on which the results of the MRSP are based so far, consists of film copies of direct and objective prism plates, taken with the UK Schmidt Telescope (IIIa-J emulsion, dispersion 246 nm mm^{-1} at Hγ). The direct plates are taken from the ESO/SERC-Atlas. The film copies were scanned with the PDS 2020 GM plus microdensitometer at the Astronomical Institute Muenster (mean positional accuracy for stellar positions 0.7 μm, Tucholke 1983). On each plate an area of 300×300 mm^2 ($5.5^\circ \times 5.5^\circ$) is measured.

The object positions on the direct plate are computed by first-order moments. They are intensity-weighted positions corresponding to those parts of the object which also contribute most of the light to the spectra. This leads to reliable measurements even for galaxies with complex light distribution, and with unusual colours of the brightest regions, when a colour term is taken into account. When the star positions are computed with the more time-consuming method of Gauss-fits to the density profiles, neither the constants nor the residuals of the transformation are significantly altered, because the accuracy is limited by the measurement of the Ca II-break.

The transformation stars are classified automatically through cross correlations of the rectified spectra and the application of a fuzzy set classifier (Schuecker 1988). To each candidate a normalized quality factor Q is assigned, whose value is a measure for the fuzzy set possibility of the object being a G-star. The use of objects with high Q values only excludes over- and underexposed spectra, which would lead to small magnitude-dependent effects presently neglected.

The half intensity point at the Ca II-break defines the reference point in the stellar spectra. The x'-position of this point is obtained by differential filtering and subsequent Gauss-fit to a small spectral range centered on the break. The y'−position is derived from a Gauss-fit to the marginal sum of the spectrum taken along the direction of dispersion. Errors in y' enter into the x'-position with less than 1 %.

5 Tests and results

The wavelength calibration method described above was applied to the ESO-SRC Atlas fields Nos. 351, 411, and 474 near the SGP. Initially $\approx 10^3$ G-star candidates were selected for each field. *Fig. 1* shows the distributions of these objects in the three fields. As required for a reliable transformation, the distributions are homogeneous. Small gaps in the distributions result from crowding with clustered objects (Sculptor dwarf galaxy in field 351, globular cluster NGC 288 in field 474; *Figs. 1a, c*, respectively), but these minor inhomegeneities do not significantly affect the quality of the transformation.

The G-star sample was cleaned iteratively from stars showing large residuals until the improvement of the mean residual fell below the preset limit of 1 %. As a test for the possible dependence of the transformation constants on plate position, the transformation was computed separately for the four plate quadrants and for three sections each in the directions of right ascension and declination.

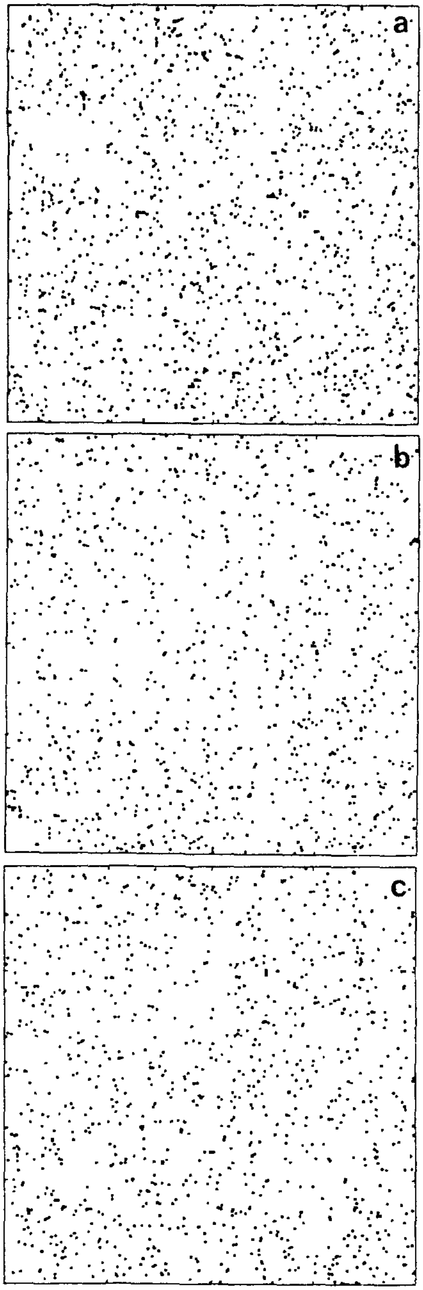

Fig. 1. (a) Distribution of G-star candidates selected for the ESO-SRC field No. 351. Note the overall homogeneous distribution. The gap in the NE quadrant is caused by overlap with the Sculptor dwarf galaxy. 10 mm correspond to 1°. North is up and east to the left.
(b) Same as above for ESO-SRC field No. 411.
(c) Same as above for ESO-SRC field No. 474. A gap in the distribution near the SE corner is caused by overlap with the globular cluster NGC 288.

Table 1: Transformation characteristics for field No. 474

Quadrant		Q	σ_x (arcsec)	σ_y (arcsec)	N_+	N_-
I	NE	0.75	0.42	0.37	237	32
II	SE	0.75	0.41	0.35	209	43
III	NW	0.75	0.34	0.32	238	36
IV	SW	0.75	0.38	0.32	224	31
All		0.80	0.37	0.36	575	70

Table 2: Mean residuals for three fields near the SGP

Field	N	N_+	σ_x (arcsec)	σ_y (arcsec)
351	1297	659	0.41	0.37
411	983	232	0.38	0.34
474	1050	575	0.37	0.36

As predicted by theory, the only significant quadratic terms in the transformation are a_3 and a_5, which are approximately equal. Table 1 shows the results for field 474, where the initial number of G-star candidates with $Q \geq 0.75$ was 1050. The residuals σ_x and σ_y of the transformation in arc seconds are listed along with the numbers N_+ and N_- of the stars kept and removed from the transformation for the four plate quadrants and for the whole plate. For the all-plate solution a higher quality limit Q was applied.

No significant differences in the transformations for the different plate quadrants are found. In the overlapping regions the different solutions agree within $0\farcs10$ to $0\farcs20$. The subdivisions of the field into right ascension and declination sections showed similar residuals and consistent transformation constants. We now routinely use the subdivision of the plate into four quadrants for the determination of the wavelength reference point.

Table 2 briefly summarizes the mean residuals of the all-plate solution for three fields. N denotes the total number of G-star candidates selected. A lower limit for the quality factor Q of 0.80 was used throughout.

The residuals in the dispersion direction x slightly exceed those in y. The accuracy in the determination of the wavelength reference point is limited by the measurement of the Ca II-break in the stellar spectrum. An error of $0\farcs39$ (mean σ_x of Table 2) corresponds to 5.9 μm on the plate and to a redshift error of $dz = 0.0024$ or $v = 820\,\mathrm{km\,s^{-1}}$ at $z = 0.0$ and $dz = 0.0047$ or $v = 1400\,\mathrm{km\,s^{-1}}$ at $z = 0.3$. This limits the accuracy attainable for the galaxy redshifts.

In the near future we will test the relative astrometric accuracy of original plates, glass copies and film copies (used here) from the UKST. It is possible, that the use of original plates not only reveals fainter objects, but also gives higher accuracy of the wavelength reference points.

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