The Performance of GALAXY

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1. *INTRODUCTION*

The GALAXY measuring engine was designed for the automatic measurement of glass photographic plates taken with Schmidt telescopes. These plates contain the negative images of tens of thousands of stars, with image sizes from 15 μm upwards. To carry out this task GALAXY works in two modes: search phase and measurement phase.

In search phase, GALAXY scans preset areas of the plate with a spot of light from a CRT in a linear raster scan. The transmission through the plate is monitored and each time the light spot crosses a star image, the reduction in transmission is recorded. The coordinates of the star are derived to a nominal accuracy of 16 μm and these coordinates output to paper tape.

In measurement phase, GALAXY reads the search phase coordinates for each star, drives the plate carriage to that position, and examines a small area of the plate with a CRT spot scan consisting of a set of concentric circles of diminishing radius. The transmission pattern is examined and phase signals used to drive servo motors to centre the star on the spiral scan. The transmission profile of the star is compared with a set of 1024 preselected "ideal" profiles. Measurement output consists of the star's coordinates to a nominal accuracy of 1 μm and the number of the ideal profile, the M number, to which the star profile is most closely matched.

As the assessment of search phase depends on the results of measurement phase, the performance of GALAXY in measurement phase will be discussed first.

2. *MEASUREMENT PHASE*

2.1 *Coordinate Datum*

The optical axes of the search and measurement optics are parallel and about 155 mm apart in the X direction. In order to relate coordinates in one phase with the other, it is necessary to use a special datum plate containing a "positive" star—a clear hole about 50 μm in diameter in an opaque background. The coordinates of this datum star are made the same in both modes.

2.2 *The Reference Block*

In order to measure drift in the coordinates and profiles, it is convenient to measure a set of stars—the reference block—at intervals throughout measurement. To specify the reference block, a suitable number, say 100 or 200, of selected stars have their coordinates measured to an accuracy of ± 5 μm with a conventional XY measuring engine. The reference block may contain stars of known magnitude, or position, or any other useful parameter.

To relate these coordinates to the GALAXY system, two fiducial marks on the plate are required. These marks can be stars on the plate, but on crowded Schmidt plates this is an awkward procedure. The procedure adopted is to affix small copper discs containing 50 μm pinholes to the emulsion side of the plate. The positions of these pinholes are also measured with the auxiliary XY engine.

The plate is then loaded in the special GALAXY plateholder. An individual plateholder is required for each size of plate. In order to maintain focus over the undulating and distorted surface of a Schmidt plate, the measurement optics is held at a fixed distance from the emulsion by allowing a special skid, the measurement nose, to rest on the emulsion. This part of the measurement optics is supported by an air bearing which reduces the downward force on the emulsion to 3 gm. The upper surface of the plateholder is thus required to be in the form of a continuous ramp up which the measurement nose can ride if so directed. For safety reasons, this situation excludes from measurement in GALAXY any broken or cracked plates.

When the automatic search datum procedure is complete, requiring 15 to 30 min, the special plateholder is loaded into the GALAXY XY carriage. The coordinates of the pinholes are found manually in the auxiliary mode of search calibration, using the display on the monitor oscilloscope.

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The two sets of coordinates of the pinholes are used in an off-line computer to determine the coordinate transformation required to give the search coordinates of the reference block stars in the GALAXY system. A paper tape with special begin and end markers is produced with the coordinates in the special GALAXY compressed code.

2.3 *Transmission Profiles*

After measurement datum has been set up, again requiring 15 to 30 min, the reference block stars can now be input in sequence and their positions and profiles measured.

Initially, the exact nature of the transmission profiles as measured by GALAXY was unknown. A reference block was prepared as described, consisting of a set of stars from the brightest to the faintest on the plate, *i.e.* the largest to the smallest image on the plate. These stars were examined one by one in measurement, print-out being inhibited until the profiles, displayed on the oscilloscope, were photographed.

It was apparent that radius is the sensitive parameter; the outer slope of the profile varies slowly. This behaviour of the profiles has been found on all plates examined so far, from refractors as well as Schmidt telescopes.

2.4 *The Weighting Function*

The final parameter to be determined for the ideal profiles is the width of the "weighting function", which determines the part of the profile over which comparison between the star and the ideal profiles is to be performed. Little information is gained from the saturated part of the profile, or from the grain noise outside the image. The critical part of the profile is where the transmission changes rapidly from high to low. The weighting function is preset to select the average width of this annulus of the profiles.

The set of ideal profiles can now be specified and complete measurement of stars performed.

2.5 *The Initial Aperture*

There is one further parameter of measurement phase to be determined. In measurement phase, the diameter of the full spiral scan is 256 μm, and the diameter of the smallest images on Edinburgh Schmidt plates is about 15 μm. In a crowded region, a considerable number of faint and brighter stars could lie within the area of the full spiral scan.

The initial aperture of the spiral scan must be reduced. Ideally it would match the smallest star image. (About 50 per cent of the stars on a Schmidt plate lie in the faintest magnitude of the range.) However, since the search phase accuracy is ± 16 μm and since also datum errors of ± 16 μm occur, it is at present necessary to have an initial aperture of 60 μm diameter. This will cause some confuusion of neighbouring images. With future improvements in the datum procedure, it is hoped to reduce the initial aperture.

2.5 *Background Fog Level Measures*

GALAXY can be directed to drive to specified points on the plate which are devoid of stars and there, provided the phase signals indicate there is nothing on which to centre, measure the background fog level. It has been found that, on Eastman Kodak IIaO and IIaD emulsions, this condition is very rarely satisfied, and the fog measure has had to be abandoned, as GALAXY centres on grain clumps a few micrometres across.

2.6 *Comparison of GALAXY M numbers with Iris Photometer Measures*

The set of 20 stars used to determine the star profiles were also measured with a Becker Iris Photometer. The GALAXY M numbers give much improved discrimination for the magnitudes of the faintest stars, where the iris photometer measures flatten out as the background fog level is approached. A typical mean GALAXY slope corresponds to $0\overset{m}{.}016$ per M number. At the faint end it is $0\overset{m}{.}02$ per M number. As mentioned in section 2.5, GALAXY continues measuring grain structures smaller than the faintest stars.

It should be noted that variations in emulsion sensitivity amount to $\pm 0\overset{m}{.}05$ and there would be no increase in information gain at present by increasing the sensitivity of the GALAXY star image size measurement.

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2.7 *The Accuracy of GALAXY Coordinate Measures*

It is now possible to determine the accuracy with which GALAXY measures the position of a star. Advantage is taken of the properties of the Edinburgh Schmidt telescope.

Firstly, the plates are circular and hence rotation of the plates in the plateholders is possible. Secondly, the large numbers of stars on a Schmidt plate enable the selection of a grid of stars, each star within about 1 mm of the corners of an equilateral triangular grid over the plate.

As the plate is rotated through 30° successively from 0° to 360°, the separations, from 10 to 70 mm, of pairs of stars give a detailed picture of the accuracy of the coordinate system.

The coordinates of the set of 80 stars were measured on the GRUBB PARSONS XY coordinate measuring machine, together with the two fiducial pinholes and the set of 20 stars covering the complete range of magnitude. These magnitude stars were placed at the beginning and end of the reference block containing the coordinate stars.

The measures were carried out on 30 June and 1 July 1969. The GALAXY measures at each orientation required about 10 min, but, because of the procedure of rotating the plate, determining the pinhole positions, carrying out the two separate datum procedures, and completing the necessary off-line computer run, the intervals between the actual measuring runs varied from 30 min to many hours, including one overnight of about 17 hr, during which GALAXY was switched off.

TABLE 1

MEAN DIFFERENCES BETWEEN SEARCH AND MEASURED COORDINATES

Date (1969)	Position	No. of stars	ΔX	r.m.s.	ΔY	r.m.s.
June 30	0°	73	9.0	1.6	−19.1	2.2
30	30°	73	3.6	1.7	−9.8	1.9
30	60°	73	−4.3	2.3	−22.9	1.6
30	90°	73	−12.7	2.1	−3.0	1.5
30	120°	73	−23.8	1.8	18.1	1.8
30	150°	73	−7.2	1.6	4.0	1.9
30	180°	73	−1.6	1.6	31.4	2.0
30	210°	73	5.0	1.9	18.1	1.8
July 1	240°	73	14.3	2.0	5.0	1.6
1	270°	73	24.2	2.3	8.8	2.0
1	300°	72	22.8	1.7	1.7	1.8
1	330°	73	24.7	1.7	−17.6	2.0
1	360°	73	8.0	1.5	−28.2	1.9

The shifts between the search coordinates and the actual measured coordinates are given in Table 1. (In the following Tables, the unit of distance is micrometres.) As mentioned above, part of the differences arise from the datum procedure.

The repeated measures of the magnitude stars at the beginning and end of each run give the drift over the interval of 10 min. These drifts are given in Table 2. (Units of dM are GALAXY M numbers.) The drifts over longer intervals will be given later.

TABLE 2

MEAN DRIFTS

Date (1969)	Position	No. of stars	dX	r.m.s.	dY	r.m.s.	dM	r.m.s.
June 30	0°	17	−0.1	0.2	0.0	0.3	−0.4	0.6
30	30°	17	+0.1	0.3	+0.5	0.5	−2.6	1.0
30	60°	17	−0.5	0.3	+0.4	0.3	+1.5	2.4
30	90°	17	+0.1	0.3	−0.1	0.4	−0.3	1.1
30	120°	17	−0.2	0.3	−0.5	0.3	+0.7	1.2
30	150°	17	−0.3	0.2	−0.2	0.3	−0.5	0.8
30	180°	17	−0.4	0.3	+0.2	0.3	−0.4	0.5
30	210°	17	−0.3	0.3	+0.2	0.4	−0.2	1.5
July 1	240°	17	−0.1	0.6	+0.2	0.8	+0.1	3.5
1	270°	17	+0.8	0.2	−0.2	0.2	−0.9	0.9
1	300°	17	+0.1	0.2	−0.1	0.2	+0.4	1.0
1	330°	17	−0.1	0.3	0.0	0.3	−0.7	1.1
1	360°	17	0.0	0.2	+0.4	0.3	−1.5	0.5

For the determination of the positional accuracy, the separations of 855 pairs of stars were used. It is assumed that the real separations of the pairs remained constant, the plate being kept in the GALAXY room which is temperature controlled at 20°C, ±0°.5.

For these 855 pairs, with a mean separation of 25.1 mm, the ratio of the GALAXY coordinate scale to that of the Grubb XY machine is 0.999975 *i.e.* 2.5 parts in 100 000. This is an error of better than 1 μm at the mean separation.

The separation, d(k), of a pair of stars, i and j, was derived at each orientation, k, from

$$d(k) = ([x(i) - x(j)]^2 + [y(i) - y(j)]^2)^{\frac{1}{2}}$$

with $1 \leqslant k \leqslant 13$.

The mean separation of a pair is $\bar{d} = \Sigma d(k)/13$, and the r.m.s. deviation in one coordinate per star is

$$e = \tfrac{1}{2}(\Sigma[d(k) - \bar{d}]^2/13)^{\frac{1}{2}},$$

where the factor of $\frac{1}{2}$ arises as there are 4 independent coordinates within the square root for d(k).

The numbers of stars with a given value of $\bar{e}$ are given in Table 3. The mean value of e is ±0.48 μm,

TABLE 3

NUMBERS OF STARS WITH GIVEN e

e	No. of stars
0.0	—
0.1	—
0.2	23
0.3	178
0.4	277
0.5	191
0.6	70
0.7	32
0.8	21
0.9	22
1.0	10
1.1	8
1.2	11
1.3	5
1.4	2
1.5	2
1.6	—
1.7	2
1.8	1
1.9	—
2.0	—

with an r.m.s. scatter of ±0.22 μm. The tail of large e comes from the brightest stars which are not so well measured.

The pairs of stars were divided into groups of stars with the same separation and orientation. For a group containing m stars, the mean separation is

$$\bar{D} = \Sigma \bar{d}/m.$$

The mean difference for the group at orientation k is

$$F(k) = \Sigma[d(k) - \bar{d}]/m \text{ for } 1 \leq k \leq 13.$$

The mean error for each group is $\bar{e} = \Sigma e/m$. The r.m.s. deviation in one coordinate per star at orientation k is

$$E(k) = \tfrac{1}{2}(\Sigma[d(k) - \bar{d}]^2/m)^{\frac{1}{2}}$$

in which the factor of $\frac{1}{2}$ arises as before.

Values of F(k) for various separations are given for each orientation in Table 4. The variation in F(k) can be interpreted as a non-orthogonality of the axes of 2 arcsec. The mean value of E(k) at each orientation is also given.

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TABLE 4

VALUES OF F(k) AND E(k)

Orientation	F(k) for 138 separations of ~10 mm	F(k) for 77 separations of ~30 mm	F(k) for 17 separations of ~70 mm	F(k) for 599 pairs, mean separation 22.45 mm	E(k) for same 599 pairs
0°	0.00	−0.06	0.18	−0.07	0.47
30°	0.01	0.03	0.24	0.02	0.46
60°	−0.03	0.01	−0.40	0.02	0.40
90°	−0.05	0.00	−0.40	0.00	0.46
120°	0.00	−0.05	−0.34	−0.10	0.46
150°	−0.07	−0.22	−0.48	−0.22	0.46
180°	−0.09	−0.39	0.15	−0.20	0.45
210°	0.10	0.21	0.41	0.11	0.47
240°	0.05	0.19	0.49	0.24	0.45
270°	0.07	0.20	0.36	0.10	0.47
300°	−0.03	−0.09	−0.22	−0.07	0.53
330°	−0.01	−0.09	−0.44	−0.07	0.56

The values of $\bar{e}$ for groups at various separations are given in Table 5. There is no deterioration with increasing separation up to 70 mm.

If star 1 appears in 5 pairs, the r.m.s deviation in one coordinate of the position of that star is given approximately by

$$E(1) = \Sigma[e(1)]/5.$$

The variation of E(1) with M number is given in Table 6. The majority of stars are measured uniformly well, but the accuracy deteriorates for the brighter stars, although remaining below 1μm. To improve these measures, the time for measuring a star was slightly increased.

TABLE 5

VALUES OF $\bar{e}$ FOR VARIOUS SEPARATIONS

Separation	$\bar{e}$
10 mm	0.41
17 mm	0.44
20 mm	0.46
30 mm	0.48
34 mm	0.48
40 mm	0.48
50 mm	0.48
52 mm	0.50
60 mm	0.46
70 mm	0.45

The speed of measurement phase is 4 sec per star, or approximately 900 stars per hour. Of these 4 sec, 2 sec are required to move the carriage to the search coordinates, and the remainder to centre the star and match profiles.

3. *SEARCH PHASE*

With performance in measurement phase established, attention was concentrated on search phase, with actual measurement being used to assess the results.

TABLE 6

VARIATION OF E(1) WITH M NUMBER

M number range	$\bar{E}(1)$
200 to 300	0.49
300 to 400	0.48
400 to 500	0.50
500 to 600	0.64
600 to 800	0.71
800 to 1023	0.94

The search scan is 8192 μm long and each scan can be monitored on the oscilloscope. A theshold level is set up manually, using the oscilloscope, which determines the faintness of the stars detected. Usually, all stars are required, and the threshold must be set at the edge of the noise from the photographic grain. Since the size distributions of stars and grain fluctuations overlap, some noise will be detected as stars.

3.1 *Search Phase Assessment*

In order to assess search phase, a "unit" area of 8192×4096 $(\mu m)^2$ was selected, covering the cluster h Persei. To V∼ 16, this area contains about 500 stars.

The number of objects detected was approximately 1000. (At this time there was a curvature of the search signal, which brought the ends of the scan below threshold, giving rise to many spurious detections. This curvature has since been corrected.)

With a CRT spot size on the plate of about 30 μm and the step in Y between successive scans being 16 μm, this area was searched, with the reference block used to test measurement phase incorporated automatically in the output paper tape at the start of the run and after every 900 stars.

Measurement datum was then set up and the search tape measured. The whole process required about 2 hr per run. Each day for 5 days, 4 complete runs were carried out, making 20 runs in all.

Unfortunately, one of these runs could not be used due to a paper tape punch fault. The runs were carried out from 5 to 11 August 1969, a weekend intervening. The measurement of run 12, the last run of the 3rd day, was actually performed first on the 4th day due to a fault.

3.2 *Reference Block Measures*

The shifts between the search coordinates of the reference block stars and their measured coordinates are given with the r.m.s. deviations about the shift, in Table 7. The shifts include a systematic part due to the pinhole measures being made manually and not by GALAXY itself. During actual production runs, allowance is now made for these shifts.

The repeated measures of the reference block at an interval of 1 hr enable the drift in X, Y, and M over this interval to be determined, Table 7.

TABLE 7

SHIFTS AND DRIFTS FOR THE REFERENCE BLOCK STARS

Run Nos.	No. of stars	Shift in X	r.m.s.	Shift in Y	r.m.s.	Drift in X	r.m.s.	Drift in Y	r.m.s.	Drift in M	r.m.s.
1	95	8.81	5.41	23.83	4.57	1.53	0.58	−0.40	0.66	−1.33	1.51
2	95	6.07	5.33	23.06	4.53	0.21	0.54	1.06	0.52	−1.37	1.48
3	95	9.03	5.34	23.09	4.43	0.89	0.37	2.06	0.63	−0.03	1.37
4	95	8.15	5.38	23.00	4.43	−0.17	0.43	1.97	0.64	0.79	1.37
5	95	4.68	5.37	27.67	4.48	0.99	0.59	0.35	0.66	−1.00	1.31
6	95	5.99	5.41	21.07	4.45	−0.35	0.54	1.20	0.70	−1.55	2.09
7	94	6.91	5.32	26.88	4.36	−0.21	0.54	2.01	0.64	−0.85	1.46
8	95	4.53	5.31	22.81	4.38	−0.18	0.43	1.20	0.67	0.18	1.44
9	95	4.60	5.31	23.82	4.59	2.16	0.59	−0.60	0.61	−1.72	1.36
10	93	1.80	5.48	30.27	5.55	0.29	0.65	0.85	0.57	−0.67	2.08
11	93	1.87	5.36	29.86	4.34	−0.43	0.56	1.87	0.69	−1.98	1.67
12	99	0.41	5.35	26.86	4.57	0.17	0.57	−0.11	0.68	−9.39	4.77
13	95	1.12	5.43	28.15	4.61	0.81	0.59	0.85	0.68	−1.66	1.65
14	—	—	—	—	—	—	—	—	—	—	—
15	96	5.14	5.37	27.72	4.41	0.36	0.58	1.58	0.66	−1.19	2.01
16	94	3.49	5.47	28.40	4.47	−0.01	0.43	0.96	0.65	−1.73	1.36
17	95	0.66	5.28	30.65	4.66	1.55	0.58	−0.38	0.62	−5.42	2.12
18	95	1.52	5.38	28.91	4.57	0.38	0.58	0.79	0.65	0.23	1.23
19	96	9.61	5.40	28.27	4.45	0.31	0.58	0.43	0.70	0.22	1.34
20	95	5.89	5.31	27.81	4.49	0.79	0.52	1.34	0.80	−1.68	2.23

The largest coordinate drifts are about 2 μm per hr, but are usually less. The drifts and r.m.s. deviations for runs 12 and 17 are unusually large. The daily record shows that these were the first runs on two particular days, and the large errors are due to insufficient time being allowed for the profile comparison circuits to settle down. In production runs, a suitable waiting interval is given to avoid this.

3.3 *Star Search Measures*

In order to assess search phase, it is convenient to plot the search and measurement coordinates on one graph. Also sketched in were the positions and sizes of all the stars visible in the area.

For the first run, typical of the series, 888 objects were found. Of these 386 were attributable to noise and 22 to emulsion defects. The remaining 480 measures are measures of 405 stars, 54 stars having 2 repeated measures, 9 having 3 repeats and one 4 repeats.

There were actually 512 stars in the area, *i.e.* the automatic GALAXY search phase found 79 per cent of the stars present. Performance was actually better as 19 stars with repeated measures were components of close pairs and it is probable that the large initial aperture, section 2.5, caused confusion of the images.

The mean differences between the search and measured coordinates were found for objects in ranges of 100 M numbers, together with the r.m.s. deviation about the mean difference. The mean values averaged over the 19 runs are given in Table 8.

TABLE 8

MEAN DIFFERENCES IN X AND Y FOR RANGES OF M

M range	No. of stars	dX	r.m.s.	dY	r.m.s.
0 to 99	174	−7.4	7.0	−0.6	6.4
100 to 199	457	−8.5	11.3	+4.9	11.8
200 to 299	181	−7.2	18.2	+13.1	13.0
300 to 399	82	−9.2	26.2	+13.8	13.9
400 to 499	36	−3.3	35.5	+10.3	21.2
500 to 599	24	−1.5	37.4	+1.3	27.8
600 to 699	27	+0.6	43.5	+3.8	30.7
700 to 799	7	−5.1	44.6	+3.5	30.9
800 to 899	1.3	−18.0	47.1	+50.6	27.0

The mean differences are small, except for the brightest stars, but the mean r.m.s. deviations increase with M number *i.e.* are proportional to the size of the star image, and X is worse than Y. These errors are a function of the proportion of the different locations on the star image which are output in search. The order of decreasing probability is star centre; east or west extremity; north or south extremity.

The GALAXY search phase therefore finds approximately 80 per cent of the stars on a Schmidt plate and the output coordinates generally lie within the star image and enable the measurement phase to find the star correctly.

4. *MEASUREMENT OF COMPLETE SCHMIDT PLATES*

Following the completion of the assessment of the performance of the search and measurement phases described in the previous sections, GALAXY was ready in October 1969 to begin measurement of complete Schmidt plates for astronomical programs.

For the first photometric program, a set of UBV plates of the cluster Stock 2 in Perseus, 3 plates in each colour, was chosen—the first of several overlapping fields in a large scale investigation of the galactic discontinuity at $l^{II} = 140°$.

Over the past ten months a team of 2 full time operators and several part time operators have been trained in the preparation of plates and the operation of GALAXY. The working hours of GALAXY have been increased from 40 hours per week to 24 hours 7 days a week: there are then available 168 hours per week and useful output is on average obtained from about 130 hours, although 160 hours has been achieved.

Approximately 1 million measurements have been made in these ten months. In a full year of suitable programs, GALAXY can measure 6 million images. The task of correlating the automatically measured positions and relative brightnesses of tens of thousands of stars on tens of photographic plates has to be undertaken.

From the outset, the philosophy that the reduction of the data must be carried out wholly by the computer, with the minimum of human intervention, was adopted.

A series of computer programs has been developed which performs this task The programs are operator orientated, giving him the necessary instructions for their implementation and containing checks at every stage to inform of operator errors.

This series of programs will now be briefly described, followed by performance figures.

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4.1 *Paper Tape Input*

This program inputs the Reference Block search coordinates followed by all the measurement tapes for one plate and stores them on magnetic tape. The tapes can be read in any order and at different times. The X, Y and M values of each Reference Block on a tape are compared with those of the first Reference Block on that tape and drifts are derived. Inspection of these drifts indicates the validity of the measures. Also output are a check on the operation of the punch, the areas of the plate measured, the numbers of stars and a table of M values.

4.2 *Mean Reference Block and Drift Corrections*

In order to correct the measures for machine drift the mean X, Y and M values are derived for each star appearing in all the measured Reference Blocks, giving the Mean Reference Block (MRB). The drift corrections of each individual Reference Block from the MRB are derived, assuming that it is linear in X and Y and a first order relationship in M.

4.3 *Application of Drifts*

The MRB is placed at the beginning of the magnetic tape, the individual Reference Blocks removed, and the actual measures corrected to the system of the MRB.

4.4 *Sort Stars in Y and Remove Repeats*

Search phase traverses the plate in lanes parallel to the Y axis 8192 μm wide in X. The stars are therefore in approximate order of Y in these lanes. They are sorted into exact order, searched for repeated measures of the same star and any repeats averaged. Repeated measures occur over the whole range of M, but the proportion increases as M increases. Also, objects with M too small to be a star are discarded.

This completes the sorting of the measures for an individual plate. It is now necessary to manipulate the data in preparation for combining plates. At the present stage of development, one particular plate is chosen as a "Master" plate and the coordinates of the stars on this plate adopted as standard. The coordinates of all the other plates are transformed to this system. It is intended that the coordinates of the Master plate will be aligned with celestial coordinates, but this has not yet been carried out. The errors of alignment are only a few degrees.

Further, the plates are obtained on different occasions and the star positions are therefore influenced by several effects, the principal one of which is refraction. At only 7° zenith distance, the differential refraction across the Edinburgh Schmidt plate field of 4° amounts to 15 μm—the size of the smallest images.

4.5 *Coordinate Transformation and Application of Refraction*

For the Master plate, only the correction for refraction is applied at present, and a MRB corrected for refraction is output to paper tape.

For the succeeding plates of an area, their MRB is approximately transformed to the Master system, the refraction correction is applied to the respective MRB and then an accurate transformation to the Master system derived. The individual star measures are then transformed and corrected for refraction.

The measures on all the plates are now available on one coordinate system, but the problem of identifying and combining measures of the same star on different plates, for the tens of thousands of stars, remains. As already described, the "unit search area" is 8192 μm in X and 4096 μm in Y, and such areas contain a few hundred stars on average. This is a convenient number for handling in the computer direct access store at one time and therefore the stars are sorted into exact areas of 8192×4096 $(\mu m)^2$, each area being labelled by the number of 8192 or 4096 μm increments from a fixed origin.

4.6 *Determine and Sort into the Area Elements*

For each star, its area element is derived from its coordinates and all the stars in each area element are brought together.

For the Master plate this is a trivial process but for the succeeding plates, which were originally searched at a slightly different orientation, neighbouring stars may be tens of thousands of measurements apart.

This process introduces boundary effects. A star with coordinates differing by a few tenths of a micrometre on different plates, lying on the boundary, will be sorted into two (or more, if on a corner) area elements. This condition is resolved later.

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4.7 *Sort Repeats in the Area Elements*

To conclude the preparation of the plate for combination with others, the stars in each area element are sorted into order of Y again and a further averaging of any repeated measures carried out.

4.8 *Combine Plates*

The Master plate is converted to the Catalogue format, and the succeeding plates combined in succession, all the stars in each area element in turn being brought together, examined, ordered and repeated measures combined to form the preliminary Catalogue.

After the Master plate, succeeding plates can be combined in any order, but all V measures are brought together, etc.

When the complete set of plates has been combined, there remains the boundary effect to be removed.

4.9 *Combine Boundary Stars*

All stars within a certain distance of the boundaries of the area elements are removed from the main Catalogue, sorted together and examined for repeated measures. Any repeats are combined correctly and all the stars returned to the correct area element.

4.10 *Magnitude Calibration*

The M values for the stars are now converted to magnitudes through a calibration. This calibration can be derived by fitting polynomials to photoelectric standards in the MRB's, or supplied manually. The smoother run of M number with magnitude provided by GALAXY compared with an iris photometer, section 2.6, makes the calibration curve easier to determine.

This completes the compilation of the Catalogue of GALAXY measures for the region.

5. *RESULTS OF THE DATA SORTING PROGRAMS FOR* 4 *PLATES*

Some of the parameters output by the set of programs described in Section 4 are given in Table 9.

TABLE 9

COMPUTER OUTPUT FOR 4 PLATES

Computer Program		Master Plate			
	Plate Number	861	860	863	862
1	Total Measures	38 463	40 060	35 752	33 899
	Number of Reference Blocks	50	52	49	45
2	Range of r.m.s. deviations for individual Reference Blocks about their drifts from the Mean Reference Block:				
	in X	0.35 0.60	0.37 0.48	0.38 0.90	0.36 1.15
	in Y	0.43 0.96	0.34 0.51	0.40 1.18	0.38 0.51
	and in M	1.1 3.8	1.0 1.9	1.0 4.5	0.9 2.3
4	Measures not stars	11 582	9182	5920	11 530
	Stars involved in repeats (1 or more)	1734	1728	1563	1832
	R.m.s. about means for repeats (μm) in X and in Y	0.32 0.35	0.29 0.30	0.42 0.34	0.42 0.32
5	R.m.s. between Master Mean Reference Block with refraction correction and MRB of plate with no refraction correction in X and in Y	—	1.88 2.24	2.65 2.17	2.46 2.65
	As above with both corrected for refraction	—	1.25 1.01	1.16 0.97	0.97 0.91
7	Further stars involved in repeats	3491	733	902	972
	Total stars	21 361	23 131	27 086	19 355
8	R.m.s. about mean position when combining measures from dif. plates in X and Y	—	1.19 1.09	1.53 1.52	1.77 1.50
	Total stars in Catalogue	21 361	31 947	41 057	44 789

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The output from Program 5, with both Mean Reference Blocks corrected for refraction, shows errors of about ± 1 μm r.m.s. This is compounded of small errors in the refraction correction and any emulsion shifts as well as the intrinsic positional accuracy.

This is also the case for the output from Program 8 where the mean r.m.s. deviation for all the measured stars scattered over the whole plate is ± 1.43 μm in either coordinate.

6. *CONCLUSIONS*

The performance of GALAXY has been described in both search and measurement phase and exceeds the specification for all parameters, except in the rate of measurement, 900 stars per hr against the specified 1000 stars per hr.

A system has been developed through which, given the photographic plates, together with with lists and charts of stars, (such as magnitude standards) required to be included in the Reference Block, the GALAXY team prepare the plates, supervise the measurement on GALAXY, and, using the R.O.E. computer system, produce a catalogue of positions and magnitudes.

The astrophysicist is then presented with an unparalleled quantity and quality of photometric and astrometric information with which to study the Universe.

DISCUSSION

F. E. ROACH: To what extent is the information being accumulated on magnetic tape at the Royal Observatory Edinburgh going to be accessible to astronomers other than the principal investigators? Other investigators may wish to interpret the data in some fashion quite different from the principal investigators, and not competitive with their aims.

N. M. PRATT: We are going to store the catalogues on magnetic tape and get the computer to ask questions. No formal policy on accessibility has been laid down yet.

M. J. CULLUM: What is the maximum density that the flying-spot scanner can cope with?

V. C. REDDISH: Up to density 2 before photons are not numerous enough; but of course we cannot measure plates with such a high background density.

A. BEHR: What is the total range of image sizes that can be measured? The smallest images on plates taken with large telescopes would be of the order of 100 μm diameter.

N. M. PRATT: There are three interchangeable optical systems, dealing with images in the ranges 15–160 μm, 30–710 μm, and 50–1750 μm.