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THE SCULPTOR DWARF SPHEROIDAL GALAXY

I. DISCOVERY AND IDENTIFICATION OF VARIABLE STARS

by

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THE SCULPTOR DWARF SPHEROIDAL GALAXY
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ABSTRACT

All 602 variable stars in the Sculptor dwarf spheroidal galaxy which have been discovered by the author and by previous investigators are identified. Positions are given in rectangular coordinates relative to the center of the distribution of the variables at RA (1950) = $0^h57^m44^s \pm 2^s$, Dec (1950) = $34^\circ0'23'' \pm 20''$.

For 64 variables preliminary periods are given.

The estimated total number of variables in the Sculptor galaxy is 1050 ± 80.

INTRODUCTION

The discovery of the dwarf galaxy in Sculptor by Harlow Shapley (1938 a) and the subsequent discovery of a similar object in Fornax (Shapley 1938 b) came when the interest of astronomers was focussed strongly on the significance of the sequence of galactic forms. They consequently attracted considerable interest.

In the Local Group ten Sculptor-type galaxies are now known. Table I includes the recently discovered dwarf spheroidal galaxy in Carina (Cannon, Hawarden and Tritton 1977).

TABLE I
SCULPTOR-TYPE GALAXIES

Name	l	b	Remarks
Fornax	237°	– 66°	Shapley (1938 a)
Sculptor	286	– 83	Shapley (1938 b)
Leo I	226	+ 49	Wilson (1955)
Leo II	219	+ 67	Wilson (1955)
Ursa Minor	103	+ 45	Wilson (1955)
Draco	86	+ 35	Wilson (1955)
Carina	260	– 22	Cannon et al (1977)
Andromeda I	122	– 25	van den Bergh (1972)
Andromeda II	129	– 29	van den Bergh (1972)
Andromeda III	119	– 26	van den Bergh (1972)

Nowadays the study of the dwarf spheroidal galaxies, especially of those nearest to us, contributes to investigations of stellar evolution and the evolution of the Local Group. (Norris and Zinn 1975, Lynden Bell 1976, Mathewson and Schwarz 1976). However knowledge about the stellar content and more specifically the numerous variable stars is still incomplete for these systems, as shown in review papers about the dwarf spheroidals by van den Bergh (1968, 1975), van Agt (1973) and Hodge (1971).

This report is a first contribution in an extended study of the variable stars in the dwarf spheroidal galaxy in Sculptor.

Distance And Dimensions

Shapley (1938 a) assumed correctly, on the basis of his scanty preliminary data, that the stellar population of the Sculptor galaxy was in many respects comparable with that of galactic globular clusters. On the assumption that the brightest stars in the Sculptor galaxy would have an absolute photographic magnitude of about $M_{pg} =$ 1.5, Shapley (1938a) derived a distance of 80 kpc.

Baade and Hubble (1939) observed the Sculptor galaxy with the 100-inch Mount Wilson telescope and were the first to discover, on a small number of plates, two variables thought to be W Virginis stars and 38 RR Lyrae variables, the latter visible close to the plate limit and only when they were near maximum luminosity.

On the basis of the observed mean maximum luminosity $m_{pg} = +19.12$ for the RR Lyrae stars, Baade and Hubble (1939) derived a distance of 84 kpc for the Sculptor galaxy. For these stars they assumed a semi-amplitude of 0.5 mag. and a median absolute magnitude of $M_{pg} = 0.0$ Later corrections to the sequence in SA 68 (Stebbins, Whitford, Johnson 1950) used by Baade and Hubble for the transfer to Sculptor were balanced by the shift of the median absolute photographic magnitude for RR Lyrae stars to fainter values so that Baade and Hubble's value of the distance (Hodge 1965) remains almost unaltered.

The two bright cepheids in Sculptor discovered by Baade and Hubble belong to a class of cepheids whose period-luminosity law differs from that of the cepheids in globular clusters (Baade and Swope 1961, van Agt 1973, van den Bergh 1975). Such anomalous cepheids with $P < 10$ days are also found in other dwarf spheroidal galaxies of the Local Group and are brighter than the BL Herculis variables of population II with P less than 10 days in galactic globular clusters. Provisional periods for these anomalous BL Her variables in the Sculptor cluster were determined by Miss Swope (Shapley 1939) and used by Shapley for a new distance determination of 76 kpc. In view of the uncertainties involved, this result is in agreement with his earlier estimate (Shapley, 1938 a) and with the value derived by Baade and Hubble (1939).

Hodge (1965) derived the first C – M diagram for the Sculptor dwarf spheroidal galaxy but it did not reach the horizontal branch. From the luminosities of the giant branch stars, the two anomalous BL Her stars, and the three RR Lyraes observed at maximum luminosity near the limit of his plates Hodge (1965) estimated a distance of 88 ± 7 kpc.

Kunkel and Demers (1977) recently derived a new distance of 78.3 kpc for Sculptor from the luminosity of the horizontal branch stars in the region of the variable gap in their C–M diagram. Their determination essentially confirms the results of the earlier investigators.

The apparent diameter was first determined by Shapley (1938 a) from star counts. Shapley's observations indicate an apparent radius of at least 40 arcmin but they do not exclude a radius of as much as 60 arcmin. From star counts Hodge (1965) derived a limiting radius of 53 arcmin, a value consistent with Shapley's result. At the distance of 78.3 kpc Hodge's angular radius yields a linear diameter of 2.4 kpc.

The variable stars reported on here extend up to distances from the center of the Sculptor galaxy of 60–70 arcmin. These values are in reasonable agreement with Shapley's conclusion that the Sculptor system might have a radius as large as 60 arcmin.

The dwarf spheroidal galaxies have many characteristics in common with globular clusters and at the same time show remarkable differences (van den Bergh 1975, van Agt 1973). The dwarf spheroidal galaxies are obviously considerably larger, but so far no transitional object with respect to linear dimension has been found.

Observations

Thackeray observed the Sculptor dwarf spheroidal galaxy during the observing seasons of 1948, 1949, 1950 and 1951 with the 74-inch Radcliffe telescope. His aim was specifically to investigate and discover variable stars in the central part of the dwarf galaxy. The surface density of the stars in the central region is sufficiently low to permit resolution of individual stars.

As a preliminary result Thackeray (1950) reported 237 variable stars and he derived provisional results on periods for 33 of them. He estimated the total number of variables to be 700. Our investigation of the variable stars in the Sculptor dwarf galaxy is a continuation of Thackeray's survey and for this purpose Thackeray kindly put his plates and reductions at our disposal. Considering both the number of variable stars marked by Thackeray in the central part of the galaxy and the dimensions of the system a bountiful harvest of variable stars was expected from the outset of our investigation.

In 1965 Sidney van den Bergh obtained a series of plates on the Sculptor system with the 48-inch Palomar Schmidt. In 1970 Christine Coutts obtained additional observations with the 24/36-inch Curtis Schmidt of the University of Michigan installed at Cerro Tololo, Chile. Helen Sawyer Hogg started the blinking of these plates at the David Dunlap Observatory. This material was turned over to me when I arrived at that Observatory on leave from the Department of Astronomy at the Nijmegen University, the Netherlands. I continued the series of Curtis Schmidt plates at Cerro Tololo in 1971. In addition Serge Demers put at our disposal the plates of Sculptor obtained by him with the same telescope in 1968 and 1969.

The field of the Curtis Schmidt telescope is well suited for observations of an extended object such as the Sculptor dwarf galaxy. On the plates taken with this telescope, which has a plate scale of $96\overset{''}{.}6$/mm, inspection of the individual stars is possible even in the central region of this galaxy. This is due in part to the low surface density of stars and in part to the use of Kodak IIIa-J emulsion which partly overcomes the limit to linear resolution set by the small plate scale. To reach sufficiently low limiting magnitudes the plates are typically exposed for two hours. This leads to a reduction of the resolution in time of the brightness variations, especially for the variables with the shortest periods. For the c-type RR Lyrae with periods between 5 and 11 hours the exposures integrate a considerable part of the light curve. Obviously there is a reduced possibility of detection of the shortest period variables as a consequence of the long exposure time.

The photographic observations available to the author are listed in table II. They cover the period from 1938 to 1971. The earliest ones are the plates obtained by Baade (1939) and Hubble (1939). The large number of observations listed in table II provides a good time base for period determination.

TABLE II
GENERAL LIST OF PHOTOGRAPHIC OBSERVATIONS OF THE SCULPTOR DWARF SPHEROIDAL GALAXY.

Telescope	Observer	Year	Emulsion,Filter	Number of Plates	Scale of Plates	Exposure Time (min)
100 - inch Mount Wilson	Baade, Hubble	1938	various combinations	9	16″.2/mm	90 - 120
	Baade	1945	103aE	1		106
	Baade	1946	103aE	1		90
74 - inch Radcliffe	Thackeray	1948	103aO none	1	22″.5/mm	typical exposure time
	Thackeray	1949	103aO none	43		60 min
	Thackeray	1949	103aD none	1		120 min
	Thackeray	1950	103aO none	34		
	Thackeray	1951	103aO none	7		
48 - inch Palomar	v.d. Bergh	1965	103aD WR 12	4	67″.5/mm	12 - 15
	v.d. Bergh	1965	103aO WR 47	2		10
	v.d. Bergh	1965	103aO GG 13	2		12
	v.d. Bergh	1965	103aE RG 1	1		45
	v.d. Bergh	1969	103aD WR 12	1		15
	v.d. Bergh	1969	IIIaJ WR 4	1		30
24/36 - inch CTIO	Demers	1968	IIaO GG 13	3	96″.6/mm	60
	Demers	1968	IIaD GG 14	3		120
	Demers	1969	IIIaJ GG 13	8		120
	Demers	1969	103aE NG 2	1		120
	Coutts	1970	IIIaJ GG 13	11		120
	Coutts	1971	IIaD GG 14	1		30
	van Agt	1971	IIIaJ GG 13	26		120
	van Agt	1971	IIaO GG 13	1		60
60 - inch CTIO	van Agt	1971	103aO GG 13	2	18″/mm	75

During the observing run of 1971 the author also obtained a small number of photographic transfers to the sequences set up in Kron 3 (Walker 1970) and in NGC 121 (Tifft 1963) to extend the sequence in the Sculptor dwarf galaxy that had been obtained by Hodge (1965) to fainter limits. Two such transfers were also obtained with the 60-inch telescope at Cerro Tololo and used for the same purpose (van Agt 1973). A comparison of the photoelectric sequence of Kunkel and Demers (1977) and preliminary results from the photographic transfers does not show any serious discrepancies.

Discovery And Identification

From among the Curtis Schmidt plates available at the end of 1970 and listed in table III, selection of pairs for blinking was made on the basis of time interval, plate quality and limiting magnitude (table IV). The plate combinations were all blinked on the Zeiss blink comparator of the David Dunlap Observatory. The work was carried out without reference to preceding variable star searches by Baade and Hubble (1939), Thackeray (1950) and Helen Sawyer Hogg (1970). In all, 521 stars were marked by the author as variable or as being suspected of brightness variations.

The 602 variable stars discovered both by previous investigators and the author are listed in table V. They are numbered in chronological order of discovery.

The variable stars numbered 1 through to 26 are those first found by Baade and Hubble (1939). Baade and Hubble identified (1939) only 10 variable stars out of the 40 they discovered. On an unpublished chart of the Sculptor system Baade identified

TABLE III
List Of The 1969-1970 Curtis Schmidt Plates.

CTIO Plate Nr.	Date	Exp.Time	Emulsion	Filter	Remarks
5084	Sept 18, 1969	120 min	103aE	NG 2	
5166	Oct 12, 1969	120	IIIaJ	GG 13	baked plate
5168	Oct 12, 1969	120	IIIaJ	GG 13	baked plate
5176	Oct 13, 1969	120	IIIaJ	GG 13	baked plate
5184	Oct 14, 1969	120	IIIaJ	GG 13	baked plate
5186	Oct 14, 1969	120	IIIaJ	GG 13	baked plate
5190	Oct 15, 1969	120	IIIaJ	GG 13	baked plate
5197	Oct 16, 1969	120	IIIaJ	GG 13	baked plate
5643	Dec 13, 1969	90	IIIaJ	GG 13	baked plate
7093	Aug 4, 1970	120	IIIaJ	GG 13	
7095	Aug 4, 1970	120	IIIaJ	GG 13	
7111	Aug 6, 1970	120	IIIaJ	GG 13	
7113	Aug 6, 1970	120	IIIaJ	GG 13	
7128	Aug 7, 1970	120	IIIaJ	GG 13	
7130	Aug 7, 1970	120	IIIaJ	GG 13	
7142	Aug 8, 1970	120	IIIaJ	GG 13	
7144	Aug 8, 1970	120	IIIaJ	GG 13	
7161	Aug 9, 1970	120	IIIaJ	GG 13	
7163	Aug 9, 1970	120	IIIaJ	GG 13	
7180	Aug 10, 1970	120	IIIaJ	GG 13	

TABLE IV
PLATE PAIRS FORMED FOR BLINKING
FROM THE 1969-1970 CURTIS SCHMIDT OBSERVATIONS.

Plate Pair Nr.	CTIO Plate Nr.	Time Interval
1	7093 , 7180	$6^d.086$
2	7130 , 7163	2 .001
3	7093 , 7095	.312
4	5166 , 5186	2 .126
5	5176 , 5184	1 .019
6	7093 , 7163	5 .097
7	5168 , 7130	299 .097
8	5166 , 7130	299 .232
9	5176 , 7130	298 .202

16 more however. For the remaining variable stars reported by Baade and Hubble no identification could be traced.

The variable stars numbered 27 through 241 are the ones newly discovered by Thackeray (1950) on the plates obtained with the Radcliffe telescope. These did not include plates off-set from the center of the dwarf galaxy. Variable stars farther from the center than approximately 20 arcmin therefore remained undetected.

In the preliminary search for variables on the Curtis Schmidt plates Helen Sawyer Hogg discovered 49 new variable stars. These objects have been assigned the numbers 242 through to 290.

The remaining stars, numbered through to 603, are the new variable stars discovered by the author. The star number 474 was subsequently found not to be a variable star and consequently has been eliminated from table IV. The total number of variable stars listed in table IV is therefore 602.

Kunkel and Demers (1977) found from their photographic photometry that their star 213 shows widely discrepant magnitudes on both B and V plates. They suspected this star to be variable; it is identified by Kunkel and Demers (1977) in their figure 5 as Star V. On the Radcliffe plates the photographic image of this object is in general not compatible with star images of similar photographic density. On recently obtained photographic observations at the prime focus of the 3.6 meter telescope of the European Southern Observatory at La Silla, Chile, this object under good seeing conditions is resolved as a faint galaxy. Widely varying magnitudes can be expected if such an object is mistaken for stellar and measured on plates obtained under not identical seeing conditions.

The variable stars listed in table V are identified by their number on Plates I, II, III, IV, V and VI. On all these Plates, directions on the sky and the scale are indicated.

The stars marked with "f" in column 5 of table V are those farthest away from the center of the Sculptor galaxy and not within the area that is represented in plate VI.

Center

Counts have been made of all the variables listed in table V in strips 60″ wide placed over the galaxy in the directions of right ascension and declination. The maxima of the counts in the strips orientated in this way led to the adopted position for the center of the distribution of the variable stars at RA (1950) = $0^h57^m44^s \pm 2^s$, Dec (1950) = $-34°0'23'' \pm 20''$.

Coordinates Of The Variables

The coordinates were calculated from plate positions determined with the measuring facility of the projecting blink-comparator of the Department of Astronomy of the University of Nijmegen, the Netherlands (van Agt, 1972). The plate constants were derived from standard coordinates using a plate-scale of 96″.6/mm.

The rectangular coordinates are given for each of the 602 stars in columns 2 and 3 of table V. These coordinates are quoted in seconds of arc and are relative to the adopted center of the distribution of the variable stars.

The accuracy in the x and y coordinates, corresponding respectively to right ascension and declination, is ± 4 arcsec.

Completeness

The total number of discoveries of variable stars in a series of plate comparisons and the average number of times that each variable was found have been used by van Gent (1933) to derive the probability *w* of discovering a variable star on each plate pair of the series and N, the total number of variable stars which can be expected to be present in the field investigated. In each of the nine intercomparisons, N was calculated by applying van Gent's method (van Gent, 1933, Plaut, 1965, Hoffmeister 1970). The results are given in table VI.

TABLE VI
The Discovery Probability And Expected Number Of Variable Stars.

Number of Intercomparisons	Discovery Probability w (van Gent 1933)	Total of Variables Expected N (van Gent 1933)
1	–	–
2	0.152	650
3	0.160	692
4	0.207	631
5	0.206	682
6	0.182	773
7	0.162	805
8	0.141	839
9	0.129	897

There is a tendency for the discovery probability w to decrease as more and more plate pairs are intercompared. Hoffmeister (1933) pointed out that this decrease indicates the existence of a dispersion in the discovery probability among the variable stars. This dispersion is not taken into account in van Gent's method, which is based on the assumption that the discovery probability for each variable in the field is the same on each plate pair. There are a number of parameters to which the discovery probability of a variable star can be related. The effects of the apparent brightness of the stars, the shape of the light curve and the range of the brightness variations have been investigated by a number of authors (Kviz 1956, Kiang 1962, Plaut 1953). Also variations in the quality of the plate pairs and changes in the attitude of the observer may cause variations. In a general way the decrease of the discovery probability can be explained by the fact that during the first intercomparisons those variables will be found which have large discovery probability and in later intercomparisons essentially those variables are left which have small discovery probability (Hoffmeister 1933). Of the variables discovered by Baade 92% were rediscovered. Of those found by Thackeray in his extensive survey of the central region, 71% were rediscovered.

Kviz (1959) and Kiang (1962) have pointed out that the net effect of not taking into account variations in the discovery probability is an overestimate of w and thereby an underestimate of N. Richter (1968) in an extension of van Gent's method found that for RR Lyrae variables the total number of variables N computed with van Gent's method should be increased by a factor of 1.2 when one takes into account systematic effects on the discovery probability. From a semi-empirical method Plaut (1966) derived essentially the same factor.

From the preliminary periods and the average median luminosities of the variables in Sculptor it is safe to conclude that most of the variables are RR Lyrae stars. In view of the limited data on the variable stars at this time it is not possible to analyse the blink statistics with either Richter's or Plaut's method. For the time being we therefore simply adopt Richter's factor of 1.2 for extrapolating the results of table VI to obtain a somewhat more realistic total number of variables in the dwarf galaxy of 1050, with an estimated mean error of 80. The low linear resolution of the Curtis Schmidt plates in combination with the increased surface density of stars in the central region of Sculptor reduces the discovery probability relative to the outer regions of the system. The somewhat lower completeness factor derived from the number of rediscoveries of Thackeray's variables is not in disagreement with our completeness arguments.

The RR Lyrae Stars

At the present stage of the reductions, preliminary results on the periods for some of the variable stars are reported. In column 4 of table V periods for 64 stars are given. These periods have been determined by Thackeray and his co-workers Jackson, Shuttleworth and Wesselink, all of whom took part at certain stages in the reductions, and by the author. In column 5 of table V initials indicate to whom each period determination should be attributed. The variable stars for which periods have been determined are located in the central region of the dwarf galaxy because so far only the Radcliffe observations have been used for this.

Among those with periods, 51 are ab-type RR Lyrae stars and 9 have c-type RR Lyrae star characteristics. Although it is expected that the shortest period c-type RR Lyrae are under-represented in the discoveries, due to the long exposure times of the observations, it is evident that c-type RR Lyrae stars in Sculptor are not as scarce as in the Draco dwarf galaxy where they number about 4% of the number of RR Lyrae stars, (Baade and Swope 1961). The frequency distribution of the periods of the RR Lyrae stars in the Sculptor galaxy is smooth, does not show double maxima and is in general very similar to the period-frequency diagram of the galactic globular cluster NGC 5272 (Messier 3), (van Agt 1973, Cacciari and Renzini 1976, Thackeray 1950).

The mean period of the 51 ab-type RR Lyrae stars is P = $0^d.567$. The shortest period in this sample of ab-type RR Lyrae stars is P = $0^d.482$ (V66) and the longest is P = $0^d.836$ (V88).

The mean periods of the ab-type RR Lyrae stars in four dwarf spheroidal galaxies are listed in table VII together with the number of ab-type RR Lyrae stars from which each mean period was determined.

TABLE VII

MEAN PERIODS OF ab-TYPE RR LYRAE IN DWARF SPHEROIDAL GALAXIES

Name	$\overline{P}$	Number of ab-type
Sculptor	$0^d.567$	51
Draco	0 .611	126
Ursa Minor	0 .636	21
Leo II	0 .592	64

Evidently the distribution of the mean periods of ab-type RR Lyrae stars in dwarf spheroidal galaxies does not follow the concept of the two period-groups observed for the RR Lyrae stars in galactic globular clusters by van Agt and Oosterhoff (1959). The mean period for the long period group (group I) is $\overline{P}$ = $0^d.647 \pm 0.015$ and for the short period group (group II) is $\overline{P}$ = $0^d.549 \pm 0.010$.

THE ANOMALOUS BL HERCULIS STARS

The variable stars V25 (= Baade-Hubble A), V26 (= Baade-Hubble B), and V119 belong to the class of anomalous BL Her stars which also have been discovered in other dwarf spheroidal galaxies in the Local Group (Swope 1968, Baade and Swope 1961, van Agt 1967). Similar variable stars are probably present in the Small Magellanic Cloud (van Agt 1973, Graham 1975). Zinn and Dahn (1976) report that V19 in the galactic globular cluster NGC 5466 might well belong to the class of anomalous BL Her stars, if indeed this variable is a member of the cluster. The anomalous BL Her stars are brighter by approximately 0.5 – 1.0 m_{pg} at the same period than the cepheids in the galactic globular clusters (van Agt 1973, Baade and Swope 1961, van den Bergh 1975).

Kunkel and Demers (1977) recently determined the photometric properties of the Baade-Hubble variable stars A and B (V25 and V26). They are located in the C – M diagram of the Sculptor dwarf galaxy about 1.4 mag above the horizontal branch and are about half a magnitude brighter than the population II cepheids in galactic globular clusters of the same period.

Plates obtained recently at the prime focus of the 3.6 meter telescope of the European Southern Observatory show that V92, formerly classified as an anomalous BL Her star (van Agt 1973), is an optical double. One component is variable, the other is a star of similar mean luminosity. When unresolved, such an object would appear to have a luminosity in the range of the anomalous BL Her stars.

On the basis of the presently available data Norris and Zinn (1975) and Demarque and Hirschfeld (1975) offer a hypothesis to explain the observed period-luminosity relation for the anomalous BL Her stars. They suggest that these stars belong to a younger population of stars than the majority in the same dwarf spheroidal galaxy, which itself was formed independently of and after the collapse of our galaxy. Renzini, Mengel and Sweigart (1977) suggest, however, that if higher masses are assumed for the anomalous BL Her stars, mass-transfer within binary systems in the dwarf spheroidal galaxies also is a hypothesis in agreement with the observational evidence.

Long-Period and Red-Irregular Variable Stars

V544 located at about 14 arcmin north of the center of the Sculptor dwarf galaxy is bright on Curtis Schmidt plates taken in August 1970, but faint on plates taken in the same month one year earlier. Eye estimates of the variable star on the Radcliffe plates, where the star is in an unfavorable position close to the plate border, show the variable going through a maximum in 1949. The time of rise to maximum and the time of decline to minimum is of the order of 120 days. A longer period of 150 days is possible.

V97 is identical to the extremely red star numbered 453 in the list of Hodge (1965) of stars measured for the C – M diagram. In his C – M diagram this variable star is located at B – V = 2.16 mag., toward the red of the brightest stars of the giant branch. Eye estimates indicate a range in luminosity of approximately 0.6 m_{pg}. V97 is not among the stars measured by Kunkel and Demers (1977).

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TABLE V
VARIABLE STARS IN THE SCULPTOR DWARF SPHEROIDAL GALAXY: COORDINATES AND PRELIMINARY PERIODS.

NR	X″	Y″	Period	Remarks
1	− 455.	184.	$P = {}^{d}.532$	Th
2	− 413.	93.		
3	52.	410.		
4	− 250.	108.		
5	53.	72.	$P = {}^{d}.484$	Th, vA
6	− 91.	− 150.		
7	191.	161.	$P = {}^{d}.285$:	Th
8	26.	− 49.		
9	− 46.	− 211.		
10	43.	− 196.	$P = {}^{d}.515$	vA
11	46.	− 215.	$P = {}^{d}.561$	vA
12	251.	− 119.		
13	− 5.	640.	$P = {}^{d}.340$	Th
14	− 612.	− 95.		
15	− 239.	280.		
16	10.	416.		
17	− 310.	− 94.		
18	− 53.	139.	$P = {}^{d}.289$	vA
19	145.	290.	$P = {}^{d}.639$	Th
20	199.	53.		
21	155.	− 134.	$P = {}^{d}.588$	vA
22	− 52.	− 590.		
23	192.	− 440.	$P = {}^{d}.510$	Th
24	363.	− 282.		
25	− 94.	560.	$P = {}^{d}.925$	Baade A, Th, vA
26	193.	− 276.	$P = 1^{d}.35$	Baade B, Th, vA
27	1149.	− 102.		
28	1076.	183.		
29	897.	610.		
30	895.	600.		
31	778.	355.		
32	813.	− 456.		
33	728.	119.	$P = {}^{d}.343$	vA
34	702.	− 109.	$P = {}^{d}.662$	vA
35	699.	− 95.	$P = {}^{d}.526$	vA
36	683.	− 474.	$P = {}^{d}.624$	vA
37	582.	237.		
38	556.	268.	$P = {}^{d}.502$	vA
39	578.	− 84.	$P = {}^{d}.506$	vA
40	572.	− 548.		
41	512.	− 50.	$P = {}^{d}.547$	vA
42	503.	51.	$P = {}^{d}.596$	vA
43	495.	75.	$P = {}^{d}.617$	vA, J
44	501.	− 314.		
45	496.	− 519.		
46	453.	117.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
47	485.	− 483.	$P = {}^{d}.526$:	Th
48	472.	− 440.	$P = {}^{d}.565$	Th, vA
49	402.	263.		
50	401.	− 356.	$P = {}^{d}.545$	Th
51	387.	− 134.		
52	377.	− 354.		
53	327.	50.	$P = {}^{d}.660$	Th
54	360.	− 497.	$P = {}^{d}.640$	Th
55	326.	− 339.		
56	293.	129.	$P = {}^{d}.567$	Th
57	253.	596.	$P = {}^{d}.541$:	vA
58	250.	480.		
59	249.	− 61.		
60	217.	259.	$P = {}^{d}.593$	Th
61	198.	377.		
62	216.	66.		
63	236.	− 337.	$P = {}^{d}.542$	Th
64	185.	398.		
65	193.	239.		
66	166.	450.	$P = {}^{d}.482$	vA
67	145.	655.		
68	155.	368.	$P = {}^{d}.506$	J, Sh
69	164.	− 190.		
70	139.	53.	$P = {}^{d}.663$	Th
71	136.	46.	$P = {}^{d}.519$	Th
72	144.	− 31.	$P = {}^{d}.548$	Sh, W
73	112.	565.		
74	101.	159.	$P = {}^{d}.488$	vA
75	64.	46.	$P = {}^{d}.504$:	Sh, vA
76	56.	12.	$P = {}^{d}.500$	Th
77	12.	438.	$P = {}^{d}.533$	J
78	33.	− 27.	$P = {}^{d}.587$	Th, Sh, W
79	42.	− 157.		
80	73.	− 441.		
81	− 23.	693.	$P = {}^{d}.560$	Sh, vA
82	20.	− 158.	$P = {}^{d}.570$	Sh
83	− 18.	41.	$P = {}^{d}.531$	Sh
84	− 6.	− 239.		
85	− 22.	− 128.		
86	− 25.	− 247.		
87	− 42.	33.		
88	− 71.	237.	$P = {}^{d}.836$	vA
89	− 50.	− 231.		
90	− 23.	− 372.		
91	− 75.	92.	$P = {}^{d}.618$	Th, vA

TABLE V (continued)

NR	X″	Y″	Period	Remarks
92	– 89.	138.	$P = ^{d}.503$	vA
93	– 97.	381.		
94	– 80.	– 186.		
95	– 84.	5.		
96	– 99.	7.		
97	– 102.	– 41.		red irr.
98	– 96.	– 232.		
99	– 112.	– 165.		
100	– 141.	105.		
101	– 152.	162.	$P = ^{d}.487$	vA
102	– 172.	321.		
103	– 169.	292.		
104	– 214.	– 98.		
105	– 228.	39.		
106	410.	306.		
107	195.	183.	$P = ^{d}.307$	Th
108	86.	– 108.		
109	1137.	176.		
110	– 206.	– 397.		
111	– 248.	– 80.		
112	– 232.	– 425.		
113	– 268.	– 69.		
114	– 333.	576.		
115	– 311.	– 7.		
116	– 315.	– 27.		
117	– 323.	– 302.		
118	– 371.	406.		
119	– 376.	191.	$P = 1^{d}.15$	bright, Th, vA
120	– 358.	– 246.		
121	– 408.	301.		
122	– 411.	30.		
123	– 402.	– 170.	$P = ^{d}.566$	vA
124	– 385.	– 469.		
125	– 460.	– 249.	$P = ^{d}.495$	vA
126	– 538.	343.		
127	– 508.	– 598.		
128	– 580.	– 345.		
129	– 614.	171.		
130	– 690.	413.		
131	– 687.	– 532.		
132	– 745.	118.		
133	– 761.	239.		
134	– 805.	– 466.		
135	– 895.	– 316.		
136	819.	354.		
137	749.	629.		

TABLE V (continued)

NR	X"	Y"	Period	Remarks
138	764.	48.	P = $^{d.}$619	vA
139	726.	− 17.		
140	722.	− 207.		
141	700.	31.		
142	585.	716.		
143	514.	462.		
144	535.	− 93.	P = $^{d.}$350	vA
145	558.	− 61.	P = $^{d.}$523	Sh, W
146	479.	− 157.		
147	452.	83.		
148	466.	− 262.		
149	487.	− 522.		
150	434.	− 239.		
151	421.	− 80.		
152	425.	− 123.		
153	411.	− 136.		
154	402.	− 83.		
155	376.	112.	P = $^{d.}$550 :	Th
156	355.	97.	P = $^{d.}$509	Th
157	344.	133.	P = $^{d.}$293	Th
158	378.	− 588.		
159	320.	− 32.	P = $^{d.}$672	Th
160	319.	158.	P = $^{d.}$515	Th
161	343.	− 193.		
162	274.	394.		
163	240.	− 18.		
164	273.	− 283.		
165	166.	731.		
166	213.	− 14.		
167	212.	− 391.		
168	179.	− 54.		
169	151.	199.		
170	133.	162.		
171	136.	− 7.		
172	94.	521.		
173	232.	− 765.		
174	75.	445.		
175	115.	− 235.		
176	113.	− 315.		
177	70.	− 140.		
178	52.	− 32.		
179	45.	− 20.	P = $^{d.}$715	vA
180	− 10.	437.		
181	43.	− 121.		
182	− 66.	375.	P = $^{d.}$360	Th

TABLE V (continued)

NR	X″	Y″	Period	Remarks
183	− 25.	− 36.		
184	− 5.	− 700.		
185	− 48.	− 571.		
186	− 102.	239.		
187	− 126.	668.		
188	− 113.	282.		
189	− 110.	36.		
190	− 124.	47.		
191	− 139.	− 16.		
192	− 93.	− 676.		
193	− 167.	154.		
194	− 185.	415.		
195	− 179.	294.		
196	− 199.	533.		
197	− 192.	190.		
198	− 150.	− 492.		
199	− 220.	165.	$P = {}^{d}.573$	vA
200	− 236.	556.		
201	− 159.	− 645.		
202	− 224.	− 301.		
203	− 242.	− 176.		
204	− 228.	− 526.		
205	− 357.	494.		
206	− 337.	38.		
207	− 386.	− 15.		
208	− 371.	− 579.		
209	− 423.	16.		
210	− 390.	− 536.		
211	− 459.	72.		
212	− 489.	− 105.		
213	− 481.	− 762.		
214	− 569.	349.		
215	− 633.	369.		
216	− 669.	145.		
217	− 665.	− 24.		
218	− 731.	− 26.		
219	− 727.	− 284.		
220	− 766.	− 612.		
221	822.	− 426.		
222	− 312.	− 109.		
223	253.	− 327.		
224	287.	225.		
225	469.	− 151.		
226	132.	174.		
227	− 689.	89.		
228	535.	− 240.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
229	− 77.	− 135.		
230	− 568.	− 45.		
231	− 79.	66.		
232	− 549.	21.		
233	− 23.	345.		
234	− 223.	− 173.	$P = {}^{d}.642$	vA
235	524.	− 47.	$P = {}^{d}.379$:	vA
236	− 50.	132.		
237	− 69.	257.		
238	− 583.	187.		
239	176.	448.		
240	− 759.	229.		
241	− 32.	241.		
242	− 321.	1224.		
243	212.	372.		
244	134.	1036.		
245	193.	1096.		
246	− 909.	− 945.		
247	− 909.	− 525.		
248	− 779.	− 448.		
249	916.	− 517.		
250	− 990.	− 10.		
251	− 799.	201.		
252	− 1010.	583.		
253	− 876.	766.		
254	− 865.	803.		
255	− 1015.	810.		
256	− 702.	1190.		
257	− 515.	− 256.		
258	− 644.	− 289.		
259	− 484.	472.		
260	− 715.	− 197.		
261	− 59.	− 1228.		
262	− 464.	444.		
263	− 78.	529.		
264	− 128.	− 4.		
265	29.	− 706.		
266	36.	− 691.		
267	288.	− 724.		
268	106.	− 206.		
269	11.	315.		
270	843.	− 561.		
271	654.	− 480.		
272	392.	757.		
273	510.	785.		
274	715.	570.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
275	1011.	408.		
276	948.	− 169.		
277	813.	− 543.		
278	1038.	− 827.		
279	959.	6.		
280	747.	337.		
281	883.	404.		
282	997.	521.		
283	720.	648.		
284	934.	676.		
285	772.	1111.		
286	928.	988.		
287	781.	410.		
288	1130.	− 474.		
289	1308.	− 961.		
290	− 385.	1039.		
291	204.	− 389.		
292	− 45.	130.		
293	− 106.	− 78.		
294	− 755.	− 20.		
295	− 494.	− 250.		
296	− 569.	180.		
297	− 847.	188.		
298	− 889.	75.		
299	− 290.	225.		
300	− 764.	589.		
301	− 1570.	− 356.		
302	− 1556.	84.		
303	− 1085.	13.		
304	− 2881.	277.		
305	1851.	− 16.		uncertain var.
306	1700.	23.		
307	2504.	98.		
308	3173.	1093.		
309	53.	− 408.		
310	− 2.	− 485.		
311	− 489.	− 375.		
312	355.	12.		
313	225.	148.		
314	832.	192.		
315	944.	29.		
316	− 446.	261.		
317	− 374.	838.		
318	292.	578.		
319	575.	578.		
320	− 204.	962.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
321	439.	1158.		
322	1463.	875.		
323	1769.	1117.		
324	3063.	921.		
325	564.	− 942.		
326	− 1297.	− 1052.		
327	− 2089.	− 2059.		
328	1690.	− 543.		
329	155.	− 789.		
330	− 250.	− 529.		
331	− 291.	− 526.		
332	− 312.	− 899.		
333	− 683.	− 790.		
334	− 1267.	− 457.		
335	− 1893.	− 209.		
336	− 1067.	− 576.		
337	237.	− 1206.		
338	− 3217.	− 2130.		
339	− 581.	− 2871.		
340	982.	115.		
341	1283.	275.		
342	408.	− 206.		
343	− 288.	1295.		
344	− 152.	2070.		
345	376.	− 451.		
346	79.	30.		
347	− 398.	265.		
348	− 1627.	205.		
349	− 841.	− 329.		
350	− 828.	− 155.		
351	263.	− 256.		
352	1116.	− 149.		
353	907.	− 1010.		
354	798.	918.		
355	600.	1320.		
356	− 653.	1660.		
357	− 574.	1554.		
358	1657.	1990.		
359	482.	1958.		uncertain var.
360	− 957.	1952.		
361	− 1809.	1286.		
362	− 1789.	1210.		
363	− 1568.	369.		
364	386.	− 59.		
365	228.	− 243.		
366	79.	− 255.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
367	− 62.	− 378.		
368	51.	− 131.		
369	− 362.	− 432.		
370	92.	− 552.		
371	− 507.	− 434.		
372	− 866.	− 446.		
373	− 1354.	− 790.		
374	− 1731.	− 1078.		
375	− 2537.	− 2028.		
376	− 15.	− 1109.		
377	1905.	− 1378.		
378	− 638.	− 2047.		
379	− 2102.	− 3723.		
380	421.	476.		
381	97.	1.		
382	− 50.	− 233.		
383	− 13.	118.		
384	− 6.	− 164.		
385	134.	− 229.		
386	6.	− 299.		
387	− 299.	− 70.		
388	− 318.	60.		
389	− 578.	39.		
390	− 423.	− 265.		
391	− 208.	1228.		
392	− 288.	653.		
393	− 847.	919.		
394	352.	679.		
395	618.	598.		
396	357.	372.		
397	− 1998.	159.		
398	− 1659.	− 6.		
399	− 1139.	262.		
400	− 829.	− 478.		
401	− 717.	494.		uncertain var.
402	− 567.	559.		uncertain var.
403	− 484.	195.		
404	− 647.	− 142.		
405	− 593.	− 104.		
406	70.	75.		
407	34.	− 3.		
408	319.	69.		
409	377.	142.		
410	629.	− 242.		uncertain var.
411	734.	32.		
412	1859.	23.		uncertain var.

TABLE V (continued)

NR	X″	Y″	Period	Remarks
413	3006.	192.		
414	1008.	− 227.		
415	837.	43.		
416	− 177.	− 744.		
417	430.	− 618.		
418	509.	− 828.		
419	55.	− 606.		
420	761.	− 622.		
421	− 942.	− 994.		
422	− 470.	− 952.		
423	634.	− 882.		
424	623.	− 901.		
425	778.	− 150.		
426	− 88.	− 442.		
427	− 10.	27.		
428	− 153.	− 1111.		
429	− 165.	− 949.		
430	− 888.	− 437.		
431	− 1078.	− 264.		
432	825.	− 1093.		
433	2033.	244.		
434	107.	− 440.		
435	543.	381.		
436	173.	− 380.		
437	1090.	− 157.		
438	1151.	− 164.		
439	166.	− 682.		
440	43.	− 616.		
441	− 235.	− 613.		
442	1020.	− 1067.		
443	− 2229.	− 1141.		
444	3272.	− 1258.		
445	2184.	− 1913.		
446	− 7.	208.		
447	65.	218.		
448	39.	154.		
449	− 49.	311.		
450	− 625.	− 78.		
451	− 355.	11.		
452	− 95.	− 114.		
453	− 69.	54.		
454	− 58.	11.		
455	− 982.	− 27.		
456	− 1322.	305.		
457	1047.	615.		
458	418.	517.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
459	− 591.	126.		
460	− 909.	236.		
461	− 3516.	− 142.		
462	− 13.	478.		
463	1056.	487.		
464	798.	491.		
465	164.	859.		
466	198.	239.		
467	366.	39.		
468	468.	− 124.		
469	274.	− 77.		
470	− 94.	935.		
471	− 91.	1401.		
472	− 69.	1245.		
473	− 555.	1216.		
475	− 308.	123.		
476	− 491.	240.		
477	− 366.	− 304.		
478	381.	− 1042.		
479	− 1838.	− 2335.		
480	1479.	− 1233.		
481	− 784.	− 20.		
482	− 1519.	576.		
483	− 1823.	634.		
484	− 1459.	− 828.		
485	− 861.	− 951.		
486	1635.	91.		
487	1178.	− 260.		
488	1115.	− 255.		
489	978.	303.		
490	540.	260.		
491	486.	215.		
492	− 82.	− 410.		
493	205.	− 413.		
494	− 364.	− 299.		
495	− 674.	− 539.		
496	− 857.	− 557.		
497	− 307.	1019.		
498	− 102.	31.		
499	− 482.	− 11.		
500	− 410.	434.		
501	− 725.	− 405.		
502	− 780.	− 358.		
503	− 2561.	− 898.		
504	− 480.	562.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
505	931.	964.		
506	775.	719.		
507	− 56.	86.		
508	− 246.	− 56.		
509	− 366.	56.		
510	− 602.	− 198.		
511	576.	− 790.		
512	733.	− 243.		
513	611.	− 1911.		
514	707.	− 2389.		
515	− 587.	− 115.		
516	− 659.	− 364.		
517	− 544.	− 339.		
518	− 220.	− 50.		
519	− 395.	50.		
520	− 1457.	− 250.		
521	− 1376.	122.		
522	− 355.	− 424.		
523	− 115.	− 370.		
524	103.	− 395.		
525	277.	− 688.		
526	165.	− 429.		
527	1033.	457.		
528	3627.	1661.		
529	1683.	2025.		
530	1941.	1166.		
531	1165.	918.		
532	449.	873.		
533	− 271.	658.		
534	− 958.	689.		
535	− 1585.	818.		
536	1441.	− 249.		
537	1637.	− 129.		
538	1313.	32.		
539	− 238.	− 246.		
540	603.	− 318.		
541	951.	− 809.		
542	924.	316.		
543	− 456.	1068.		
544	− 111.	866.		LP
545	280.	435.		
546	− 1472.	− 879.		
547	− 990.	− 1218.		
548	− 717.	− 562.		
549	− 311.	− 75.		
550	− 87.	− 708.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
551	48.	− 971.		
552	− 288.	− 178.		
553	2638.	− 202.		
554	− 407.	816.		
555	− 1764.	254.		
556	− 975.	− 5.		
557	283.	138.		
558	306.	− 455.		
559	− 1401.	215.		
560	− 1788.	9110.		f
561	− 7014.	4894.		f
562	− 402.	4658.		f
563	− 1822.	4005.		f
564	1867.	4050.		f
565	− 3900.	2613.		
566	4722.	2231.		
567	− 868.	2039.		
568	− 637.	760.		
569	3623.	1934.		
570	531.	740.		
571	1865.	908.		
572	4150.	1068.		
573	− 2626.	873.		
574	434.	25.		
575	352.	302.		
576	− 24.	372.		
577	2032.	− 70.		
578	3547.	241.		
579	− 2587.	− 974.		
580	− 1820.	− 668.		
581	− 1310.	− 386.		
582	91.	− 902.		
583	547.	− 32.		
584	2783.	− 234.		
585	1155.	− 570.		
586	− 3030.	− 1954.		
587	2895.	− 2235.		
588	544.	− 3283.		
589	− 866.	− 4293.		f
590	2839.	− 3990.		f
591	4291.	− 5002.		f
592	− 2817.	− 5650.		f
593	− 921.	− 6133.		f
594	7258.	− 7025.		f
595	3721.	− 6907.		
596	− 1708.	521.		

TABLE V (continued)

NR	X″	Y″	Period	Remarks
597	– 295.	382.		
598	– 1486.	– 809.		
599	1161.	– 38.		
600	– 131.	1030.		
601	– 4691.	9683.		f
602	274.	113.		
603	– 2016.	1127.		

PLATE I

Identification of the variable stars in the central region of the sculptor dwarf spheroidal galaxy. The scale (60″) is indicated in the upper right hand corner.

PLATE II
Identification of the variable stars in the NW quadrant. The scale (120″) is indicated.

PLATE III
Identification of the variable stars in the NE quadrant.

PLATE IV
Identification of the variable stars in the SE quadrant.

PLATE V

Identification of the variable stars in the SW quadrant.

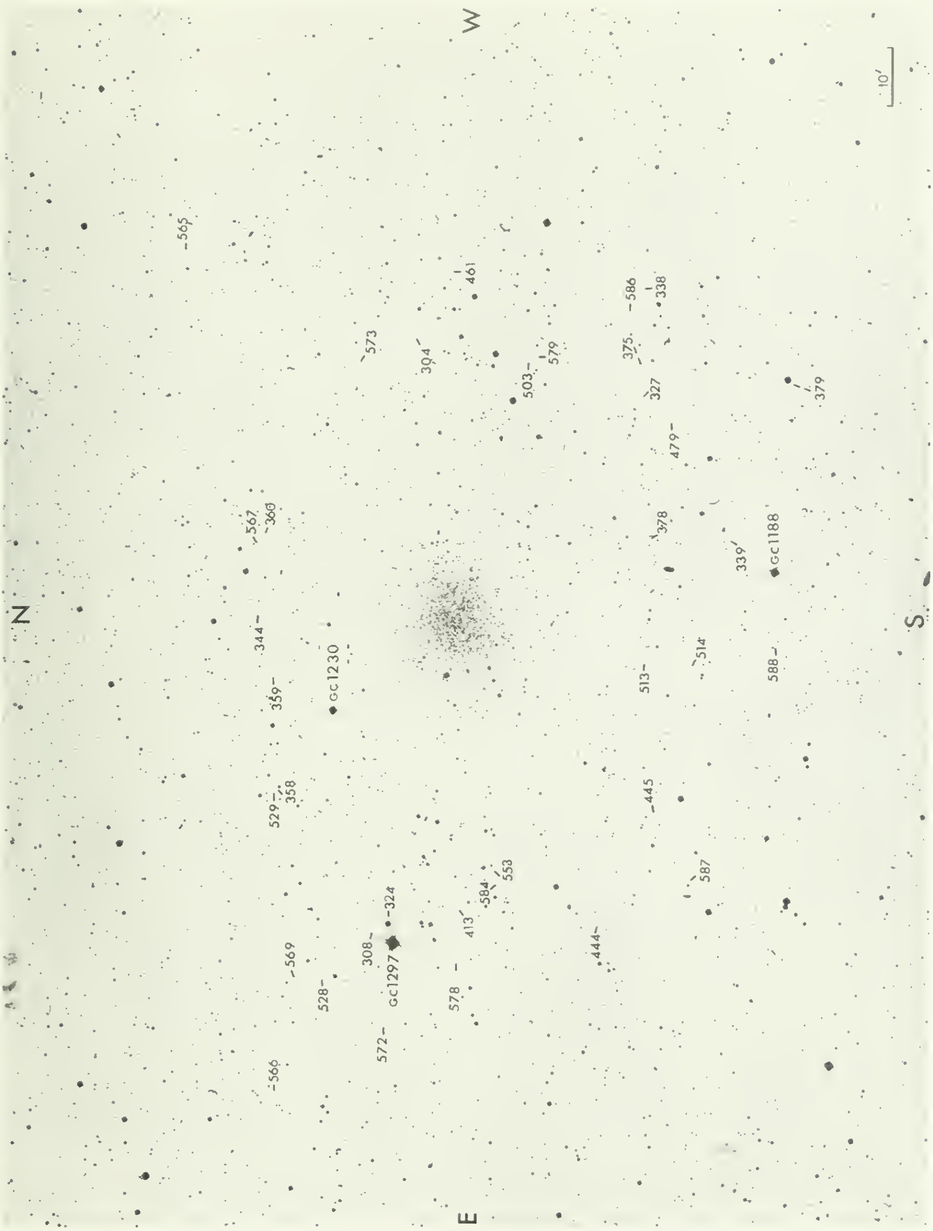

PLATE VI
Identification of the majority of the variable stars in the outer regions of the Sculptor dwarf galaxy.
The scale (10 arcmin) is indicated.