Colloque de l'Union Astronomique Internationale
N° 37 – DECALAGES VERS LE ROUGE ET EXPANSION DE L'UNIVERS

THE DISTANCE SCALE WITHIN THE LOCAL GROUP

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Toutes les techniques couramment utilisées pour déterminer les distances des galaxies proches sont passées en revue. Les résultats de cette étude sont résumés dans la table V. On remarque que l'augmentation de la distance des Hyades, suggérée récemment, a peu ou même n'a aucun effet sur l'échelle des distances extragalactiques. Ceci provient du fait que cette augmentation de la distance des Hyades est pratiquement compensée par une diminution de l'échelle des distances résultant de la prise en compte d'une abondance en métaux supérieure à la moyenne dans les étoiles des Hyades.

....and the uncertainty is estimated
to be of the order of 10 percent.
-Hubble and Humason (1931)

I. INTRODUCTION

The first modern discussion of the extra-galactic distance scale was by Hubble and Humason (1931). We now know that this first bold attempt to measure the size of the Universe failed and that the Universe is, in fact, five or possibly even ten times larger than Hubble and Humason believed. It is perhaps not generally realised that a major portion of this change was due to an increase in distance estimates for the members of the Local Group, which were used as stepping stones to the realm of the nebulae. The average distance of the seven brightest Local Group galaxies used by Hubble and Humason was only forty percent of that given by more recent distance determinations. Since many types of distance indicators, such as the brightest stars and HII regions, are still calibrated in nearby galaxies, the distance scale within the Local Group remains of paramount importance.

During the last decade it has become increasingly apparent that individual Local Group galaxies have different chemical compositions. As a result some distance indicators might have characteristic luminosities that differ slightly from galaxy to galaxy. To avoid systematic errors arising from such differences it is important to use as many distance indicators as possible to determine the distances to nearby galaxies.

II. CEPHEIDS

a. The Galactic Period-Luminosity Relation

The Cepheid Period-Luminosity relation remains one of the most powerful tools that astronomers have at their disposal for the measurements of distances to nearby galaxies. By combining data on eleven relatively short-period Cepheids, that are presently known to occur in open clusters, with those on three long-period Cepheids in associations, it is now possible to determine both the slope and the zero point of the Period-Luminosity relation in the Galaxy. This is clearly preferable to the procedure employed in older work in which fragmentary data on galactic Cepheids was used to obtain the zero point of a Period-Luminosity relation for which the slope was gotten from observations of Cepheid variables in the Magellanic Clouds.

Presently available information on galactic Cepheids in clusters and associations is summarised in Table I. The quoted intrinsic colours of Cepheids in associations were derived from (1) the photoelectric observations of Cepheids by Madore (1975), (2) the reddening values of Turner (1974, 1976a, b, 1977) determined from OB stars surrounding each Cepheid and (3) the E_{B-V} (B) /E_{B-V} (SpT) relation of Fernie (1963). For a variety of reasons the data on these association Cepheids are less accurate than are those for most of the Cepheids that are located in open clusters. For the cluster Cepheid V 367 Sct the fundamental period $P_0 = 6\overset{d}{.}2933$ was used in preference to the first overtone period $P_1 = 4\overset{d}{.}5163$ (Efremov and Kholopov 1975, Madore, Stobie and van den Bergh 1977).

In attempting to calibrate the Period-Luminosity relation I have not made use of Cepheids that are members of binary systems (Fernie 1967) because the luminosities and colours of these objects are generally less well-determined than are those for cluster Cepheids. For the same reason SU Cas, which is a member of a small association of reflection nebulae (van den Bergh 1966, Racine 1968 and Gieren 1976) has been excluded from the calibration. Furthermore I have excluded the Cepheids UY Per, VY Per, VX Per and SZ Cas (Sandage and Tammann 1969) because their association with h and χ Persei has never been established beyond reasonable doubt. The case of VY Per is further complicated by the fact that this object may be an overtone pulsator (Iben and Tuggle 1975). Finally I have preferred not to include RS Pup in Table I because a CTIO 4-m plate (see Figure 1) of this object leads one to suspect that the shell-like structures surrounding this variable may not have the high degree of circular symmetry that is required for Havlen's (1972) ingenious geometrical distance determination to be reliable.

The data on the galactic Cepheids in Table 1 have been plotted in Figure 2a. For the range $3 < P$ (days) < 50 covered by these observations the data are well-represented by the linear relation

$$M_{\langle V \rangle} = -1.18 - 2.90 \log P, \tag{1}$$

in which the symbol $\langle\ \rangle$ denotes an intensity mean and P is in days. The dispersion of individual points (calibration errors + intrinsic scatter) about the least squares regression line is 0.26 mag.

The intrinsic colours of Cepheids in open clusters and associations (see Figure 2b) are well-represented by

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TABLE I

DATA ON GALACTIC CEPHEIDS

Cepheid	Cluster/Association	Period	$M_{\langle V\rangle}$	$\langle B\rangle_0 - \langle V\rangle_0$	Reference
EV Sct	NGC 6664	$3^d.09$	-2.62	0.57	(1)
CEb Cas	NGC 7790	4.48	-3.20	0.56	(1)
CF Cas	NGC 7790	4.87	-3.08	0.66	(1)
CEa Cas	NGC 7790	5.14	-3.28	0.64	(1)
CV Mon	Anon	5.38	-3.35	0.64	(3)
CS Vel	Ru 79	5.90	-3.05	0.66	(4)
V367 Sct	NGC 6649	6.29	-3.82	0.49	(2)
U Sgr	M25	6.74	-3.93	0.55	(1)
DL Cas	NGC 129	8.00	-3.84	0.70	(1)
S Nor	NGC 6087	9.75	-4.03	0.73	(1)
TW Nor	Lyngå 6	10.79	-3.53	0.80	(5)
VY Car	Car OB1	18.93	-4.97	0.92	(6)
T Mon	Mon OB2	27.02	-5.50	0.96	(7)
SV Vul	Vul OB1	45.04	-6.00	1.06:	(8)

REFERENCES

(1) Sandage and Tammann (1969)
(2) Madore and van den Bergh (1975)
(3) Turner (1977)
(4) Harris and van den Bergh (1976)
(5) van den Bergh and Harris (1976)
(6) Turner (1976a)
(7) Turner (1976b)
(8) Turner (1974)

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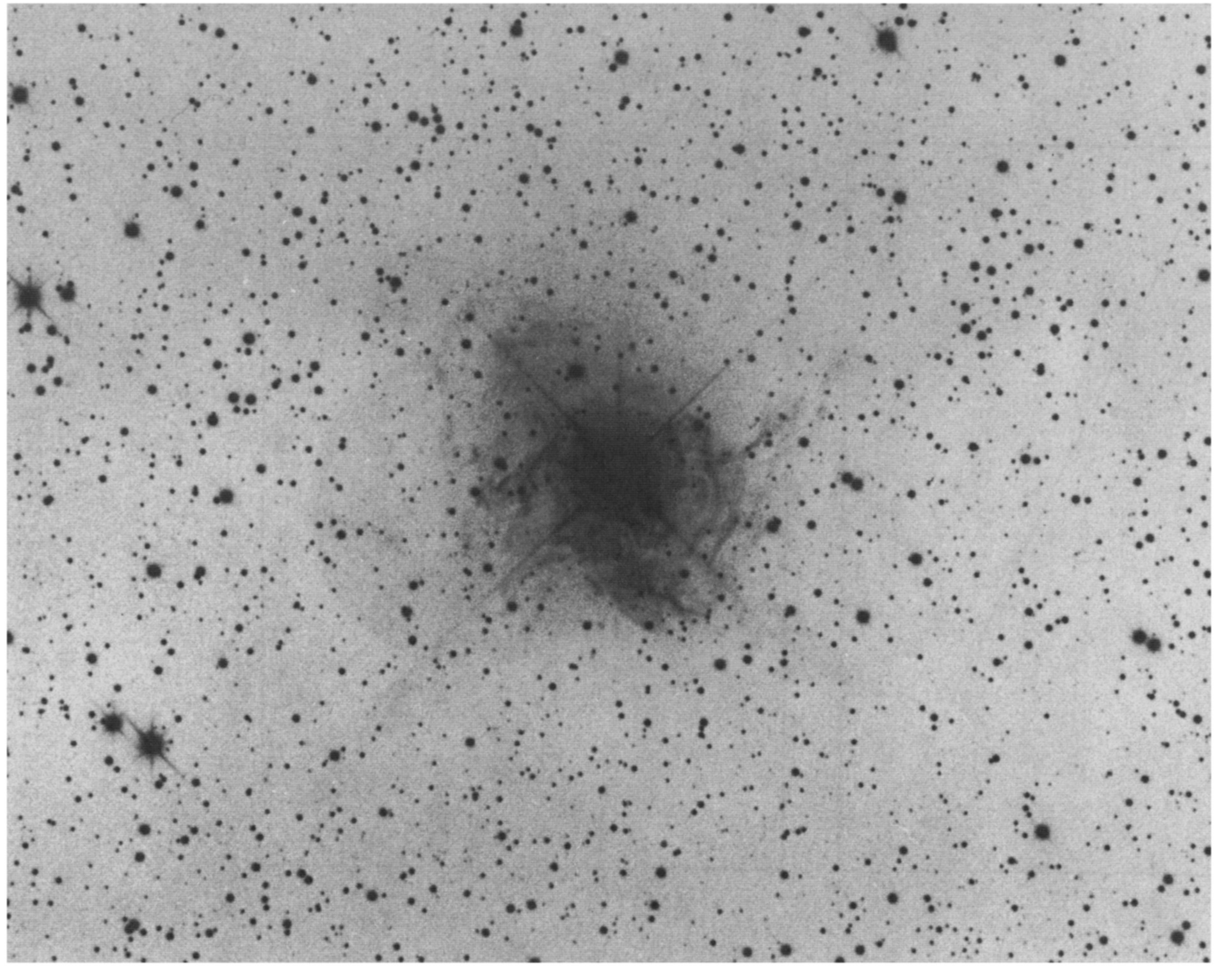

Fig. 1 - = Plate 000. Yellow (103aD + GG 495) exposure (30 min.) of the nebulosity surrounding RS Pup obtained with the 4-m telescope of the Cerro Tololo Observatory. The plate shows that the nebulous arches surrounding this long-period Cepheid are not strictly symmetrical.

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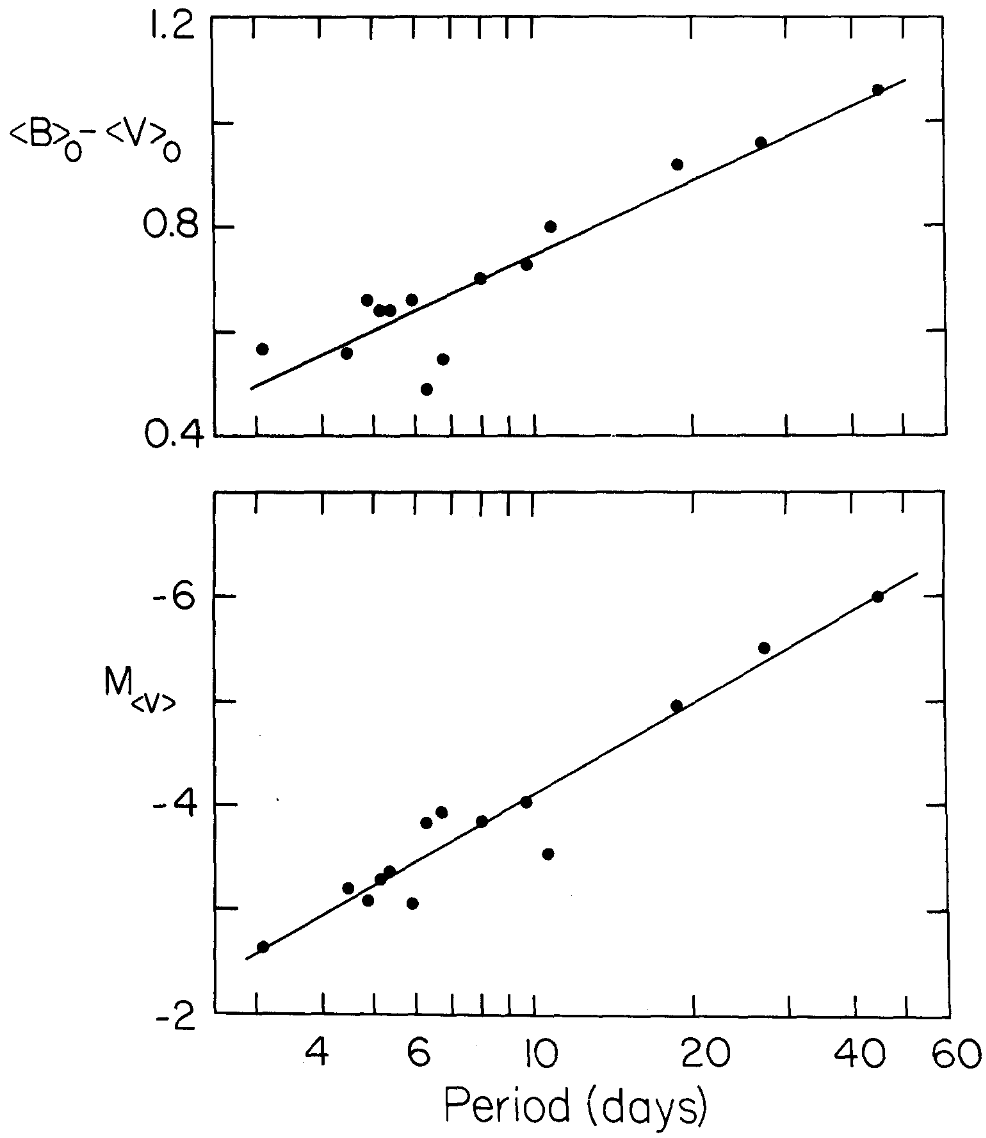

Fig. 2 - Period-luminosity (a) and period-colour (b) relations for Cepheids in galactic clusters and associations. The plotted regression lines represent Equations (1) and (2).

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$$C_o \equiv (\langle B\rangle - \langle V\rangle)_o = 0.27 + 0.48 \log P. \quad (2)$$

The colour dispersion abot this relation amounts to 0.06 mag. Equation (2) is rather similar to that derived by Fernie (1967) but differs significantly from that given by Sandage and Tammann (1968). For $P > 3^d$ Equation (2) yields intrinsic colours that are redder than does the relation

$$C_o = 0.37 + 0.264 \log P \quad (3)$$

that was used by Sandage and Tammann. At $P = 50^d$ the intrinsic Cepheid colours given by Equation (2) are 0.26 mag redder in B-V than are those obtained from Equation (3)! This very substantial difference has recently been discussed in considerable detail by Cannavaggia et al. (1976) and in references cited therein. The seriousness of this discrepancy is illustrated by the recent observations of the 27^d cluster Cepheid, T Mon, which are summarised in Table II. The data in this table suggest that $E_{B-V} \simeq 0.23$ which, with $\langle B\rangle - \langle V\rangle = 1.19$ (Madore 1975), yields $C_o \simeq 0.96$. This is identical to the value $C_o = 0.96$ obtained from Equation (2) but differs substantially from $C_o = 0.75$ predicted by Equation (3). This discrepancy is serious because an uncertainty of $\sim$0.2 mag in the intrinsic colours of long-period Cepheids (which are the only ones that are observable in distant galaxies) translates into an uncertainty of $\sim$0.6 mag in the distance modulus corresponding to an uncertainty of $\sim$30% in the distance.

b. The Cepheid Distance Moduli of Local Group Galaxies

i. The Andromeda Nebula

The best data on Cepheids in M31 are those by Baade and Swope (1963). Their observations for variables with $P > 6^d$ should be relatively unaffected by magnitude-dependent selection effects. From these data and Equations (1) and (2) we obtain $(m-M)_V = 24.58$ and $E_{B-V} = 0.07$. The latter value does not differ significantly from the galactic foreground reddening $E_{B-V} \simeq 0.10$.

ii. The Triangulum Nebula

According to Hubble (1936) the Cepheids in M33 appear to be 0.1 mag brighter in blue light than are those in M31. With $(m-M)_B = 24.65$ for M31 it follows that $(m-M)_B \simeq 24.55$ for M33. According to Sandage and Johnson (1974) M33 is reddened by $E_{B-V} = 0.06$, so that $(m-M)_V = 24.49$. Needless to say this result, which is based on observations by Hubble ca. 1925, is quite uncertain!

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TABLE II

RECENT REDDENING DETERMINATIONS OF T MONOCEROTIS

Method	E_{B-V}	Reference
Leiden 5-colour photometry	0.12:	Pel (1976)
Lick 6-colour photometry	0.24	Canavaggia _et al_. (1976)
Lick 6-colour photometry	0.21	Parsons and Bell (1975)
uvbyβ photometry of nearby stars	0.14-0.38	Schmidt (1975)
UBV + MK spectra	0.23 ± 0.09	Turner (1976b)

iii. IC 1613

The twenty-five Cepheids known in this dwarf galaxy (Sandage 1971) define a period-luminosity relation with a remarkably flat slope. Application of the Period-Luminosity-Amplitude relation of Sandage and Tammann (1971) to these data shows that the distance modulus obtained for IC 1613 depends on period. This observation indicates that either (1) the Cepheids in this metal-poor dwarf galaxy define a different period-luminosity relation than do those in the Galaxy or (2) the observations are affected by a magnitude scale error. Such scale errors are likely to be largest at faint magnitudes. I have therefore preferred to use only the Cepheids of longest period to derive the distance modulus of IC 1613. For six Cepheid variables with $10 < P(\text{days}) < 50$ Equation (1) yields $(m\text{-}M)_B = 24.53$, which with $E_{B-V} = 0.03$ (Sandage 1971), gives $(m\text{-}M)_V = 24.50$.

iv. The Magellanic Clouds

Figure 3 shows period-colour relations (Madore 1975, supplemented by Gascoigne 1969 and van Genderen 1977) for all Cepheids in the LMC and SMC that have been observed photoelectrically on the UBV system. The figure shows that the Cloud Cepheids with $P > 10^d$ have colours that are significantly bluer than those predicted from Equation (2). This effect is likely to be real because it shows up in both Gascoigne's photometry and in the more recent measurements by Madore and van Genderen. It is therefore concluded that either (1) the intrinsic colours of long-period Cepheids in the Clouds are significantly bluer than are those of their galactic counterparts or (2) the most recent determinations of the intrinsic colours of galactic Cepheids are too red. Since the observed effect amounts to $\sim$ 0.2 mag in B-V it is too large (cf. Bell and Parsons 1972) to be accounted for entirely in terms of a low average metallic line strength in Cloud Cepheids.

Figure 4 shows that the photoelectric data for Cloud Cepheids with $3 < P(\text{days}) < 50$ are adequately represented by Equation (1) and distance moduli $(m\text{-}M)_V$ of 18.70 and 18.90 for the LMC and SMC respectively.

Because the Cloud Cepheids with $P > 10^d$ appear to have colours that differ from those of their galactic counterparts different methods of distance determination (which are summarised in Table III) give quite different distance moduli.

For Cloud Cepheids with $P < 10^d$ possible systematic errors are still

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TABLE III

DISTANCE MODULI OF THE MAGELLANIC CLOUDS
DETERMINED FROM CEPHEIDS

Method	$(m-M)_V$	
	LMC	SMC
V vs. log P	18.70	18.90
B vs. log P*	18.50	18.65
P-L-C relation†	19.39	19.63
W vs. log P*‡	18.95	19.60

* Only variables with $P > 10^d$ used

† Using $M_{<V>} = -4.11 \log P + 2.52 [<B>_0 - <V>_0] - 1.86$. The colour coefficient in this relation was taken from Sandage and Tammann (1969) and E_{B-V} values of 0.05 and 0.03 were adopted for the LMC and SMC respectively.

‡ $<W> \equiv <V> - 3(<B>-<V>)$.

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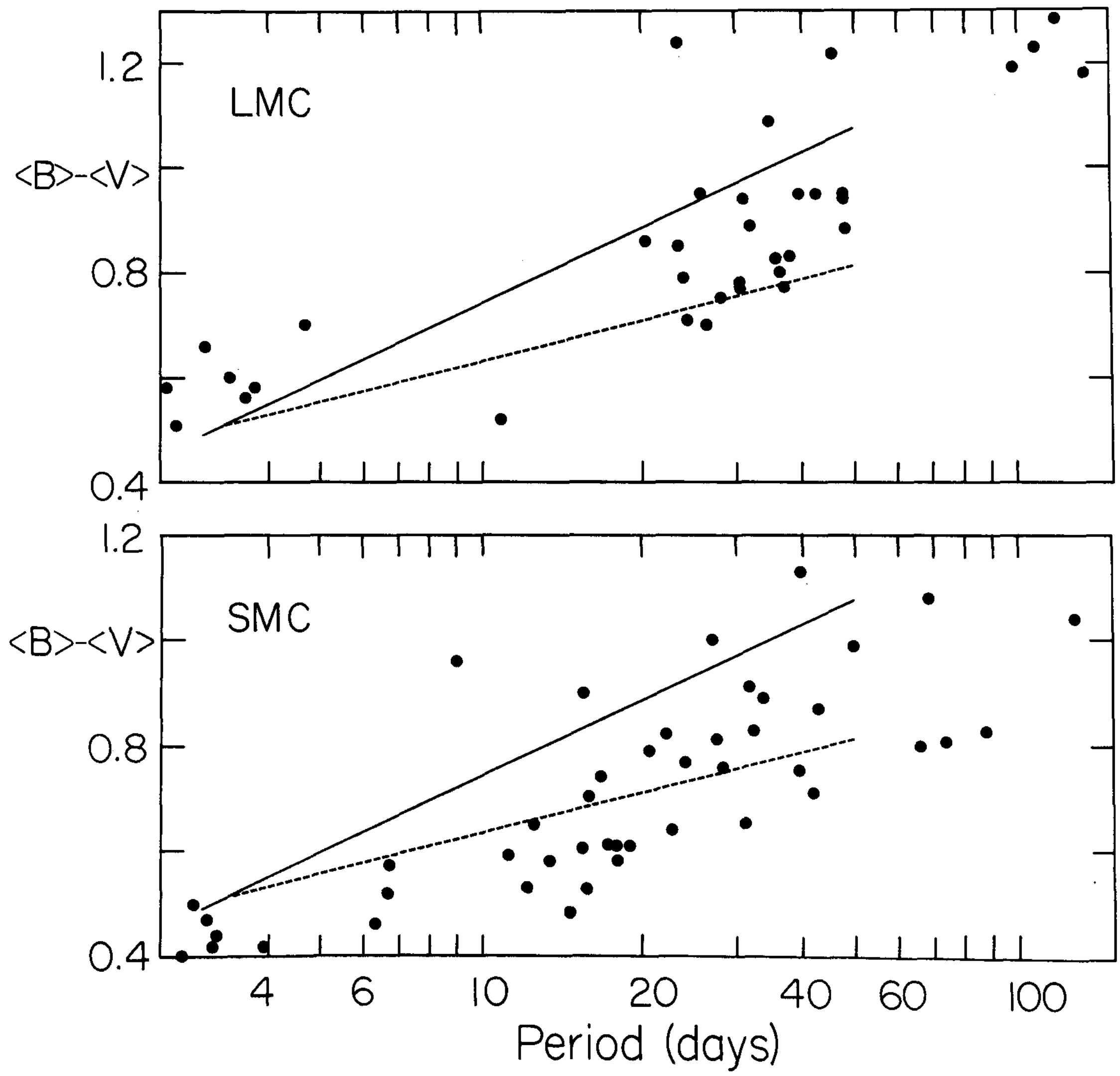

Fig. 3 - Period-colour relations for all photoelectrically observed Cepheids in the Magellanic Clouds. The continuous and dashed lines represent Equations (2) and (3) respectively. The plot shows that Cepheids in the Clouds are systematically bluer than their galactic counterparts.

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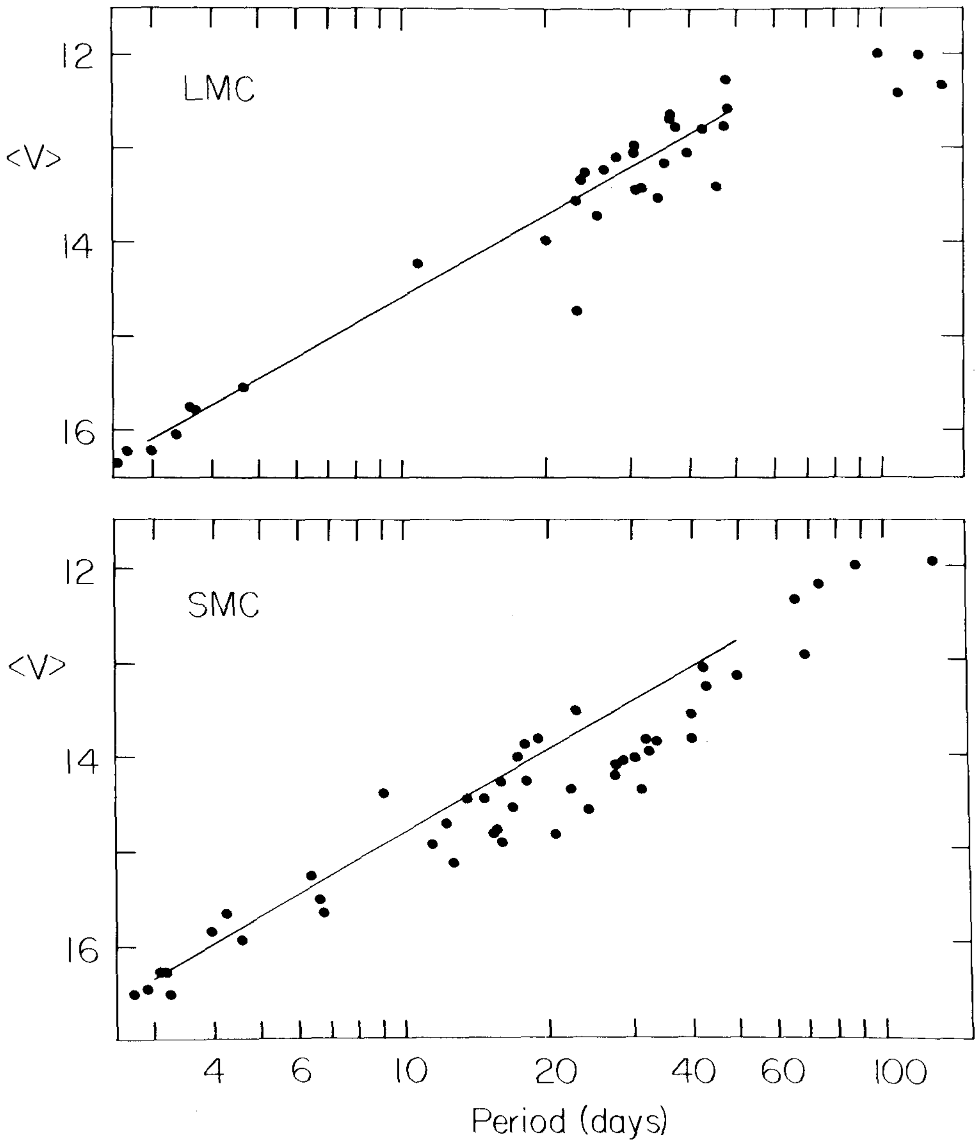

Fig. 4 - Period-luminosity relation for all photoelectrically observed Cloud Cepheids. Regression lines are Equation (1) shifted to $(m-M)_V = 18.7$ for the LMC and to $(m-M)_V = 18.9$ for the SMC.

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too large to draw significant conclusions from them. This is particularly regrettable because the intrinsic colours of short period Cepheids in galactic clusters now appear to be relatively well-determined.

v. NGC 6822

Application of Equations (1) and (2) to eleven Cepheids with $10 < P(days) < 50$ that have been observed by Kayser (1967) yields a distance modulus $(m-M)_V = 24.45$ and a reddening $E_{B-V} = 0.00$. The latter value differs from $E_{B-V} = 0.27 \pm 0.02$ that Kayser obtained from photoelectric photometry of forground fieldstars. If the photoelectrically calibrated photographic Cepheid photometry by Kayser is to be believed at the 0.2 mag level this result implies that the variables in NGC 6822 are intrinsically bluer than their galactic counterparts. In this respect they would then resemble the Cepheids in the Magellanic Clouds.

III. W VIRGINIS STARS

Application of the linear P-L-C relation for W Virginis stars obtained by Breger and Bregman (1975) (with $E_{B-V} = 0.10$) to the five Population II variables of known colour in M31 (Baade and Swope 1963) yields $(m-M)_V = 23.92 \pm 0.16$. Since the absolute magnitudes derived from this P-L-C relation do not depend critically on colour it follows that the low distance modulus obtained for M31 cannot be entirely attributed to systematic errors in the observations of the variables. A plausible suggestion by Demers and Harris (1974) is that the Period-Luminosity relation for W Virginis stars curves upwards at long periods. This interpretation receives some support from Figure 5 in which the W Virginis stars in M31 have been plotted with $(m-M)_V = 24.3$.

As van Agt (1967) has pointed out the W Virginis stars in dwarf spheroidal galaxies lie above the Period-Luminosity relation for the same class of variables in galactic globular clusters. Observations by Tifft (1963) suggest that the W Virginis stars in the SMC may resemble those in dwarf spheroidals.

IV. NOVAE

a. The Andromeda Nebula

The first nova in M31 was discovered by Ritchey (1917). In recent years major surveys of novae in the Andromeda Nebula have been published by

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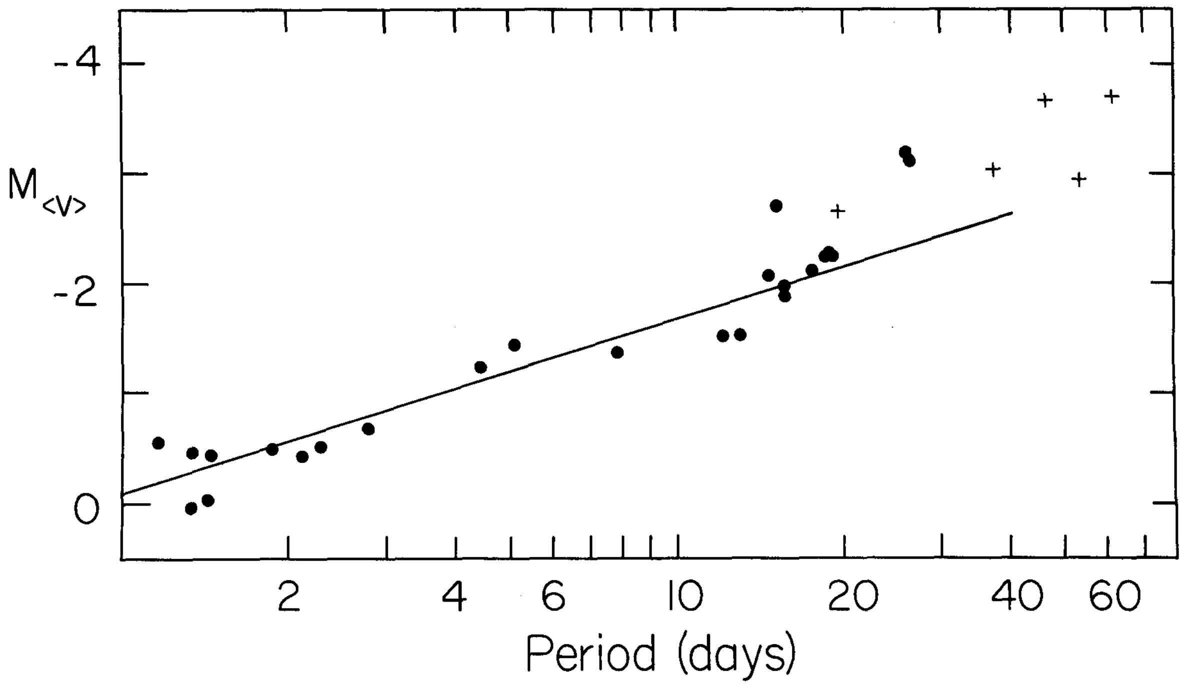

Fig. 5 - Period-luminosity relation for W Virginis stars in the Galaxy (•) and in M31 (+). The regression line is the Period-Luminosity relation of Demers and Harris (1974). The figure suggests that the Period-Luminosity relation curves upward for $P > 20^d$.

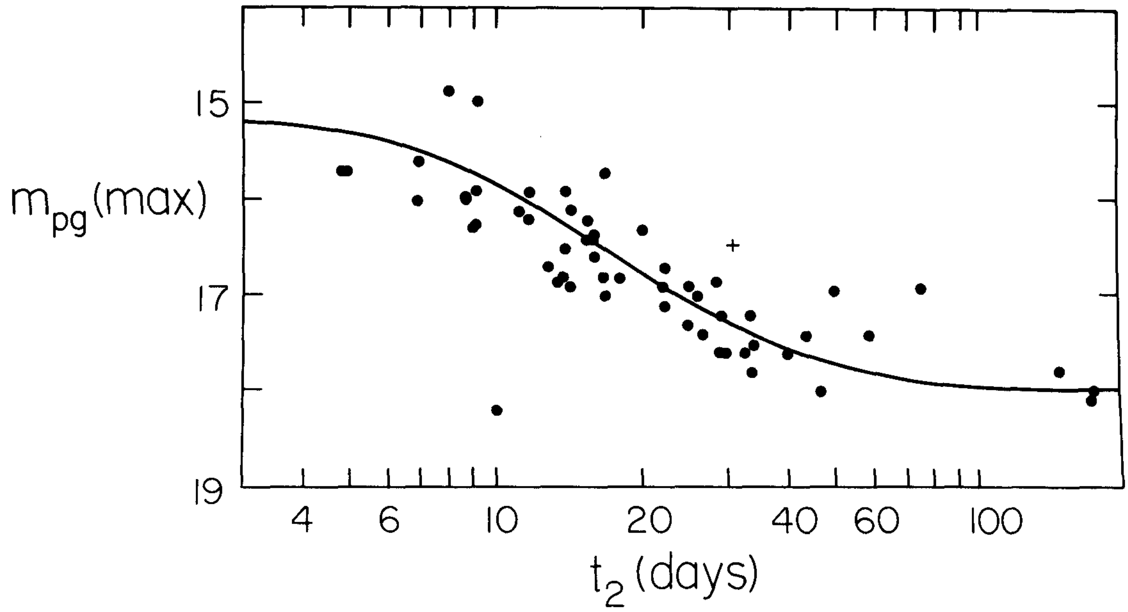

Fig. 6 - Relation between maximum magnitude and rate of decline for well-observed novae in M31. The cross represents a single nova in M33.

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Arp (1956) and by Rosino (1964, 1973). The relationship between maximum magnitude m_{pg}(max) and t_2, the time required for a nova to decline from maximum light by 2.0 magnitudes, that is derived from the results of Arp and Rosino is shown in Figure 6. After excluding a single (probably obscured) object the dispersion of individual novae about the adopted S-shaped relation between m_{pg}(max) and t_2 amounts to only 0.4 mag. Fitting the mean relation between m_{pg}(max) and t_2 for M31 to the relation M_{pg}(max) and t_2 for fifteen galactic novae yields $(m-M)_{pg} = 24.43 \pm 0.12$. The quoted mean error of this result does not include possible systematic errors in the adopted calibration for the absolute magnitudes of galactic novae that is based on unpublished results by Schmidt-Kaler (van den Bergh 1975). Considerable improvement in this calibration could be achieved by obtaining additional expansion parallaxes for galactic novae. A start on such a project has recently been made at Palomar. Figure 7 shows the unusually long-lived shell around Nova Persei 1901 as it appears on a recent Palomar 5-m telescope exposure.

b. The Triangulum Nebula

The rate at which novae occur in M33 is much lower than it is in M31. So far only a single good nova light curve (Rosino and Bianchini 1973) is available. Figure 6 shows that this object lies 0.9 mag above the mean m_{pg}(max) versus t_2 relation for M31 from which $(m-M)_B = 23.55 \pm 0.4$ in which the quoted mean error is the dispersion of individual novae about the S-shaped relation in Figure 6. Clearly it would be very desirable to obtain additional data to see whether the novae in M33 might perhaps be systematically brighter than those in M31.

c. The Magellanic Clouds

A total of eleven novae have been discovered in the Large Magellanic Cloud and four have so far been found in the Small Cloud. Most of the LMC novae were quite fast so that the coverage of their light curves is incomplete. Only in the case of Nova Mensae 1970b and Nova Doradus 1971a are extensive photoelectric observations available. For Nova Mensae the maximum was missed by 9 days so that B(max) is extremely uncertain. For Nova Doradus 1971a photoelectric observations (Ardeberg and de Groot 1973) are available within a few days of maximum. From the galactic calibration

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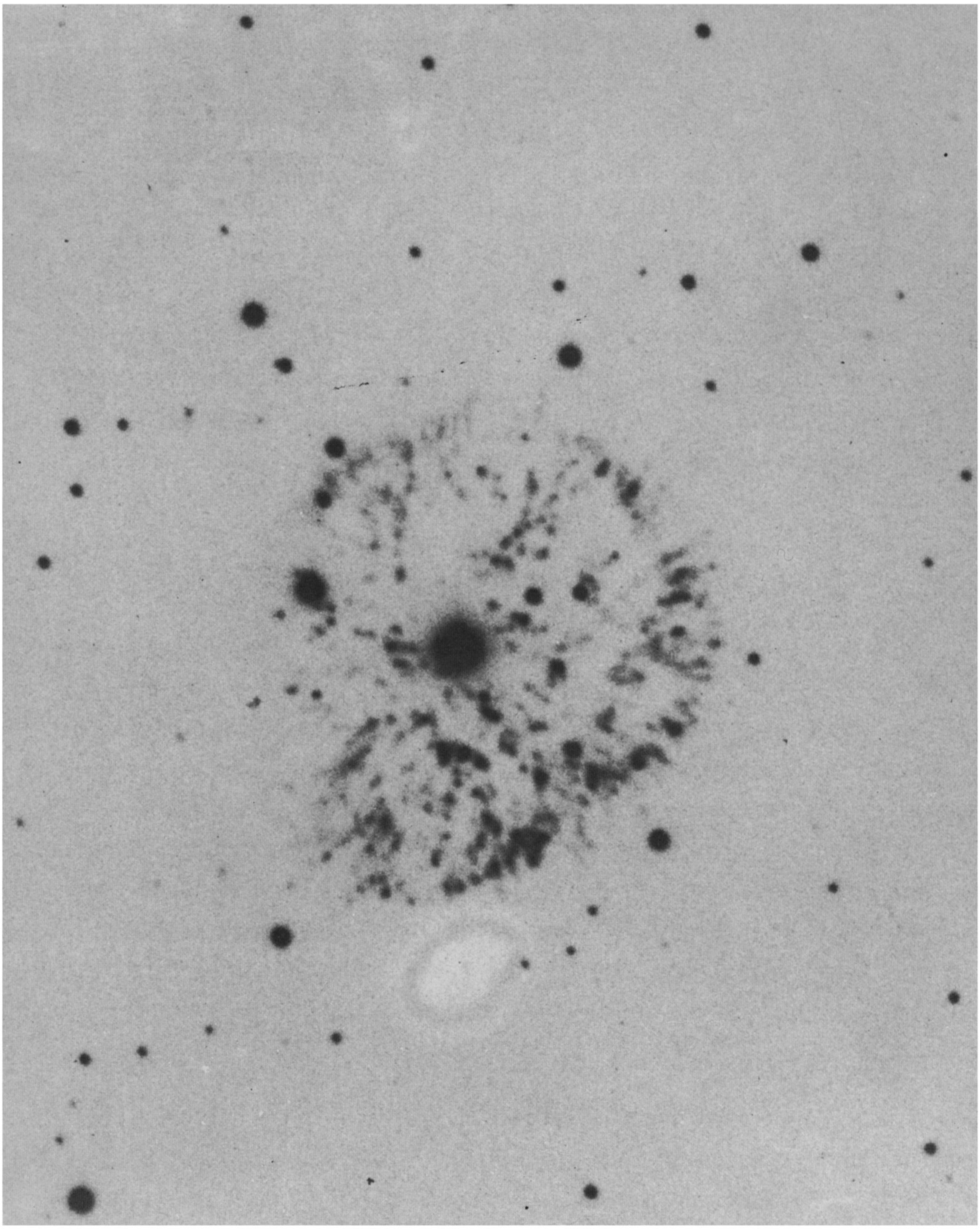

Fig. 7 - Red (103aE + RG2) exposure of Novae Persei 1901 obtained with the 5-m Hale telescope in 1974.

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of the B(max) versus t_2 relation this object, for which t_2 = 16.8 days, would be expected to have M_B(max) = -7.9. With B(max) = 11.86 this yields $(m-M)_B$ = 19.76. The blue colour of this nova near maximum light shows that this large apparent distance modulus cannot be due to absorption. In order to maximise problems associated with incompleteness of the light curve data it seems safest to use only those novae with $P > 10^d$ to estimate the distance moduli of the Magellanic Clouds. For four such novae in the LMC $(m-M)_{pg}$ = 19.28 ± 0.26 and for three novae in the SMC $(m-M)_{pg}$ = 19.39 ± 0.16 in which the quoted errors reflect only the internal dispersion of the distance moduli of individual novae. Taken at face value these results seem to indicate that the novae in the Magellanic Clouds might be slightly fainter than their galactic counterparts. Clearly it would be important to check on this point by strengthening the very scanty observational data that are presently available on novae in the LMC and SMC.

V. SUPERNOVAE

Mathewson and Clarke (1973a, b) have shown that galactic supernova remnants of known distance and supernova remnants in the LMC have surface brightnesses at 408 MHz that are related to their diameters by the relation

$$\Sigma_{408} = 6 \times 10^{-16} D_{pc}^{-3} \text{ W m}^{-2} \text{ Hz}^{-1} \text{ sterad}^{-1}. \qquad (4)$$

Application of this equation to the LMC yields a distance of 46 kpc, corresponding to $(m-M)_o$ = 18.31. This value is significantly smaller than the canonical distance of 55 kpc. This difference might be due to any one of the following causes:

(1) The average explosion energy of LMC supernovae could be slightly greater than it is in the Galaxy. Such a difference might, for example, arise if the fraction of Type II supernovae in the LMC is greater than it is in the Galaxy, or

(2) Due to incompleteness of the sample the LMC data might be deficient in supernovae of below average surface brightness. This would raise the mean surface brightness of the observed objects, or

(3) The adopted distances to galactic supernova remnants, many of which are poorly known, might be systematically too small by ∿20%.

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VI. DISTANCE DETERMINATIONS FROM RR LYRAE STARS

a. The Magellanic Clouds

For seventy-two field RR Lyrae variables near NGC 1783 Graham (1973) obtained a median blue magnitude $\langle \dot{B} \rangle = 19.35$. With $M_B^{\bullet} = +0.87$ (van Herk 1965) this yields $(m-M)_B = 18.48$, which corresponds to $(m-M)_V = 18.43$ if $E_{B-V} = 0.05$.

For sixty-nine field RR Lyrae variables near NGC 121 Graham (1975) gets $\langle \dot{B} \rangle = 19.79$ so that $(m-M)_B = 18.92$. Adopting $E_{B-V} = 0.03$ this yields $(m-M)_V = 18.89$ for the SMC. Although the absolute magnitude of RR Lyrae variables probably remains uncertain by $\sim$0.3 mag the difference of 0.46 mag between the distance moduli of the Clouds is probably quite secure.

Because van Herk's $M_B^{\bullet}$ (RR) value was determined from proper motions the present results are independent of both the uncertainties in the Hyades distance modulus (van Altena 1974, Hanson 1975) and of possible systematic differences between the positions of the age-zero main sequences of globular clusters and high velocity stars (Hartwick and Hesser 1972, Demarque and McClure 1976).

b. Dwarf Spheroidal Galaxies

Data on the distance moduli of the dwarf spheroidal members of the Local Group are summarised in Table IV. For the Draco, Leo II and Ursa Minor systems the quoted distance moduli are based on observed values of $\langle \dot{B} \rangle$, the median blue magnitude of RR Lyrae stars. The Leo I system was assumed (Hodge 1963) to have the same distance modulus as Leo II. For the Sculptor system the distance was derived from $\langle V \rangle_{RR} = 20.2$ (Hodge 1965) and $M_{\langle V \rangle}(RR) = +0.6$. Finally the distance modulus of the Fornax system is based on $V_{HB} \simeq 21.5$ (Demers and Kunkel 1976). Except in the case of And I, II, and III the adopted reddening values were taken from the cosecant law.

VII. THE BRIGHTEST GLOBULAR CLUSTER STARS

Four red clusters in the LMC are known to contain RR Lyrae variables and may therefore be considered true globular clusters. Colour-magnitude diagrams are available for three of these objects. The brightest red giants in these clusters occur at V = 16.4 (NGC 1466), V = 16.5 (NGC 1978) and V = 16.1 (NGC 2257). Spectroscopic observations by Andrews and

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TABLE IV

DISTANCES OF DWARF SPHEROIDAL GALAXIES

System	$\langle \dot{B} \rangle$	$(m - M)_V$	E_{B-V}	M_V	D(kpc)	References
Fornax	......	20.9	0.07	-12.5	135	1, 2
Sculptor	......	19.6	0.06	-10.4	75	3, 4
Leo I	21.5(?)	20.5(?)	0.08	-10.1(?)	110(?)	5, 6
Leo II	21.5	20.5	0.07	-8.5	115	7, 6
Draco	20.3	19.3	0.10	-8.3(?)	65	8
Ursa Minor	20.2	19.2	0.08	-8(?)	65	9
And I	......	24.5	0.10	-10.8	690	10, 11
And II	......	24.5	0.10	-10.8:	690	10, 11
And III	......	24.5	0.10	-10.8:	690	10, 11

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(1) Demers and Kunkel (1976)
(2) de Vaucouleurs and Ables (1968)
(3) Hodge (1965)
(4) Hodge (1966)
(5) Hodge (1963)
(6) Holmberg (1958)
(7) Swope (1967)
(8) Baade and Swope (1961)
(9) van Agt (1967)
(10) van den Bergh (1972a)
(11) van den Bergh (1972b)

Lloyd-Evans (1971) show that these clusters have integrated CH/Hγ spectral types F7 (NGC 1466) and F6-7 (NGC 1978), indicating that they have an intermediate metal abundance. Adopting $M_V \simeq -2.2$ and $\langle V \rangle = 16.3$ for the brightest globular cluster red giants in the LMC yields a distance modulus $(m-M)_V \simeq 18.5$.

The brightest red giants in NGC 121 (which is the only red cluster in the SMC that is known to contain RR Lyrae stars) have $V \simeq 16.7$. Adopting $M_V \simeq -2.2$ for these stars yields $(m-M)_V = 18.9$ for the SMC.

The main uncertainty in these results is that (cf. Hartwick and Hesser 1972, Demarque and McClure 1976) the luminosity of evolved giant stars may depend on a second parameter (He or CNO abundance?) in addition to metal abundance. Since the Magellanic Clouds and the Galaxy have had different evolutionary histories we have no guarantee that [Fe/H] and this second parameter will correlate in the same way in these three galaxies. The existence of giant stars with $B-V > 2.0$ in Cloud globulars may, in fact, provide evidence for precisely such a difference between the LMC and SMC on the one hand and the Galaxy on the other.

VIII. EQUIVALENT WIDTH OF THE BALMER LINES

Hutchings (1966) has determined the distance modulus of the Large Cloud form measurements of the equivalent width of Hγ in luminous early-type stars. He obtains $(m-M)_V = 17.9 \pm 0.1$ for B stars and $(m-M)_V = 18.5 \pm 0.2$ for the A stars in the LMC. For the SMC Hutchings gets $(m-M)_V = 18.1 \pm 0.1$ from B stars and $(m-M)_V = 18.47 \pm 0.24$ is obtained by Westerlund et al. (1963) for supergiants in the Wing of the SMC. Buscombe and Kennedy (1962) have published absolute magnitudes, based on Johnson and Iriarte's (1958) calibration of the equivalent width of Hγ, for eight early-type supergiants in the SMC. Giving half weight to uncertain observations these data yield $(m-M)_V = 18.7$ for the SMC. The unweighted means of the distance moduli obtained above are $(m-M)_V = 18.20$ for the LMC and $(m-M)_V = 18.44$ for the SMC.

These values for the Cloud distance moduli are significantly smaller than those that have been obtained using other techniques. This suggests that the Balmer lines in stars of a given absolute magnitude are stronger in the Clouds than they are in the Galaxy. This result is, no doubt, related to the results of Fehrenbach and Duflot (1972) and Fehrenbach,

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Duflot and Burnage (1972) who found that the SMC coutains a sizable group of early-type supergiants in which the hydrogen lines are unusually strong.

As yet we do not even have a hint as to the origin of this remarkable phenomenon.

Possibly a similar effect occurs in the (presumably metal-poor) outer regions of our Milky Way system. Havlen (1976) has noted that the Hβ distance moduli for distant early-type stars in Puppis are smaller than are the distance moduli obtained from main sequence fitting of UBV observations.

From a study of spectral gradients Divan (1973) obtains $(m-M)_V = 18.58 \pm 0.11$ for the LMC. The quoted uncertainty of this result does not take into account errors that might have arisen from extrapolation of the Meudon system to luminosities greater than those for which galactic calibration standards were available. Finally Osmer (1973) gets $(m-M)_V = 19.07 \pm 0.14$ from Hβ versus C_0 photometry of luminous stars in the SMC.

IX. MK LUMINOSITY CLASSIFICATION

Classifications on the MK system are available for a number of supergiants in the Magellanic Clouds. The data for ordinary supergiants of luminosity class Ia are subject to selection effects that tend to favour observation of stars with above average luminosity. For early-type stars of luminosity class Ia-0 the data by Feast, Thackeray and Wesselink (1960) should, however, be reasonably complete. For seven such stars a distance modulus $(m-M)_V = 18.7 \pm 0.3$ is obtained. The quoted mean error of this Large Cloud distance modulus does not include the uncertainty in the galactic calibration (Schmidt-Kaler 1965) of stars of luminosity class Ia-0.

According to Keenan (1972) the galactic supergiant HD8752 (G6 0) has a spectrum that fits exactly between those of HDE269723 (G4 0) and HDE268757 (G7 0). These two LMC stars have V = 9.91 and V = 10.09 respectively. HD8752 is situated near the edge of the association Cep OB1, and if it is a member, it would have $M_V = -8.9$. From $\langle V \rangle = 10.0$ and $M_V = -8.9$ it follows that $(m-M)_V = 18.9$. This value, which is based on only one galactic calibrating star, is consistent with that obtained from the data by Feast, Thackeray and Wesselink (1960).

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X. SUMMARY AND CONCLUSIONS

The data on the apparent visual distance moduli that have been obtained in previous sections are summarised in Table V. To obtain the quoted values of $<(m-M)_V>$ I have, more or less arbitrarily, assigned weight 3 to the Cepheid Period-Luminosity relation and to distances determined from RR Lyrae stars, weight 2 to distances obtained from W Virginis stars and novae and unit weight to all other types of distance determinations. Uncertain data, which are indicated by colons, have been given half their normal weight. The quoted mean errors for the final values of the distance moduli are derived from the dispersion of individual values about the adopted means.

The recently proposed revision to the Hyades distance scale (van Altena 1974, Hanson 1975) will affect some, but not all, of the distance estimates listed in Table V. The Cepheid distances obtained by cluster main sequence fitting depend to some extent on the adopted distance modulus of the Hyades. This will tend to increase the distance scale. This effect is, however, partly offset by the fact that the Hyades cluster is probably metal-richer than the average young cluster that contains a Cepheid. If young clusters are similar to nearby stars for which the most frequent value of $\delta(U-B) = +0.03$ (van den Bergh 1962), then, from Table 4 of Wildey *et al*. (1962), the blanketing correction $\Delta(B-V) \simeq 0.03$. This makes the cluster distance modulus too large by $\sim$0.15 mag, which almost exactly cancels the 0.13 to 0.18 mag correction to the Hyades distance modulus advocated by van Altena (1974).

The calibration of MK types and of Hβ and Hγ photometry depends somewhat on the adopted Hyades distance modulus but distances derived from RR Lyrae stars, novae and supernova remnants do not. In summary it appears that the distance scale within the Local Group is only weakly dependent on the adopted distance to the Hyades cluster.

XI. FUTURE WORK

The following types of observations would strengthen the distance scale within the Local Group.

(1) Determination of the intrinsic colours of galactic long-period Cepheids by a concerted effort to locate and study the sparse associations in which some of these objects are, no doubt, embedded.

TABLE V

SUMMARY OF LOCAL GROUP DISTANCE ESTIMATES

Method	Wt	LMC	SMC	M31	M33	NGC 6822	IC 1613
Cepheid P-L relation	3	18.70	18.90	24.58	24.49	24.45	24.50:
W Virginis stars	2			23.92			
Novae	2	19.23:	19.36:	24.33	23.49:		
Supernova remnants	1	18.36					
RR Lyrae stars	3	18.43	18.89				
Globular cluster giants	1	18.50	18.90				
Hβ and Hγ lines	1	18.20	18.44				
Spectral gradients	1	18.58					
C_p versus Hβ	1		19.07				
MK classifications	1	18.70					
$\langle(m-M)_V\rangle$		18.58 ± 0.08	18.91 ± 0.07	24.32 ± 0.11	24.24	24.45	24.5:
E_{B-V}		0.05	0.03	0.10	0.06	0.27	0.03
D(kpc)		48	58	630	640	510	760

(2) Determination of additional expansion parallaxes of galactic novae, photoelectric photometry of novae near maximum light and discovery of additional novae in the Magellanic Clouds.

(3) Photoelectric photometry of W Virginis stars in the Magellanic Clouds and discovery and observation of W Virginis stars with 10 < P(days) < 25 in the Andromeda Nebula.

(4) Modern observations of the Cepheids in M33, which might have characteristics intermediate between those of Cepheids in the Galaxy and in the Clouds, would also be of considerable importance.

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DISCUSSION

G. DE VAUCOULEURS: The discrepancy of Novae noted by van den Bergh is due to his use of maxima and possibly to his calibration. The m_{15} method (Buscombe and de Vaucouleurs 1955) and a revised calibration give moduli in agreement with other methods.

The following table compares distance moduli, μ_B, of the 6 Local Group galaxies after van den Bergh (vdB), de Vaucouleurs (GdV), and Sandage and Tammann (ST). There is agreement in the mean between the first two, the third departs by 0.4 mag. This is one source for the low value of H_o, other sources are in the extrapolation beyond the Local Group which will be discussed elsewhere.

Distance moduli in Local Group

μ_B	vdB	GdV	ST
LMC	18.63	18.73	18.91
SMC	18.94	18.95	19.35
M31	24.42	24.47	24.84
M33	24.30	24.59	24.68
6822	24.72	24.56	24.22
1613	24.53	24.27	24.46
Mean	22.59	22.59	22.99
Δ		.00	0.40

H. ARP: Are some of the discrepancies in Local Group distance indicators intrinsic? That is, are some of the phenomena different in different galaxies due to their different age or chemical composition? How certain are the discrepancies? Are you ready to accept intrinsic differences in these phenomena in different galaxies?

S. VAN DEN BERGH: Yes! There is strong evidence for colour differences between the Cepheids in the Magellanic Clouds and those in the Galaxy. Similarly, there are magnitude differences between the BL Her stars in galactic globular clusters and in dwarf spheroidal galaxies. Finally there seems to

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be some evidence in favour of the view that the m(max) versus t_2 relation for galactic and M31 novae differs from that in the Clouds.

M.E. BURBIDGE: The method of distance determination of the Magellanic Clouds that gave a particularly discrepant answer, compared with the other methods, was Hβ and Hγ intensities. Would you comment on this?

S. VAN DEN BERGH: Presently available evidence seems to indicate that early-type stars of a given magnitude in the Magellanic Clouds have stronger Balmer lines than do the galactic counterparts. There is presently a slight suspicion that distant (and presumably metal - poor) OB stars in the Vela region ($l \sim 245^{\circ}$) share the "magellanic hydrogen syndrom" which has been discussed by Fehrenbach and his collaborators.

G.O. ABELL: If I recall the last slide correctly, the moduli of NGC 6822 and IC 1613 derived by van den Bergh were from Cepheids alone. Now, according to de Vaucouleurs' summary table, the van den Bergh moduli for NGC 6822 and IC 1613 are <u>greater</u> than the Sandage-Tammann values (0.5 mag for 6822 and 0.07 mag for 1613); yet, if I understood de Vaucouleurs, he implied that the Cepheid calibration of Sandage-Tammann is too <u>bright</u>. Is this a contradiction or have I misunderstood?

S. VAN DEN BERGH: Such differences arise from the fact that the present period - colour relation for Cepheids differs from that adopted by Sandage and Tammann.

B.F. MADORE: I would like to make a comment in defense of the uniformity of classical Cepheid properties. Because the instability strip is of finite width in the colour-magnitude diagram two parameters are <u>simultaneously</u> required in order to specify the absolute magnitudes; this requires that, in the calibration, stringent attention must be paid to <u>three</u> independent parameters, the third parameter being the apparent filling of the instability strip. This is a selection effect which can enter very strongly into any comparison involving only two parameters. Thus, any simple comparison of intrinsic colour-period relation between two sets of Cepheids in different galaxies is dangerously succeptible, in the first instance, to selection effects. Under such circumstances it is perhaps premature to cite such differences as indicative of intrinsic differences in the nature of Cepheids themselves.

S.VAN DEN BERGH: Only distances derived from the period-luminosity relation are subject to such errors. The data compiled in Table III show that the Cepheid period - luminosity - colour relation gives discrepant distance moduli for the Magellanic Clouds. This shows that we are dealing with an intrinsic difference and not with a selection effect.

S.M. FABER: The relationships you showed between period and colour or period and luminosity for galactic Cepheids looked very tight. But there are only a few points available at the upper end for the brighter stars. Is it possible that the true scatter at the upper end is in fact as large as it is at the bottom and that the uncertainty in the derived slopes is rather large, so that perhaps the relations for galactic Cepheids are consistent, within the errors, with those in the other Local Group galaxies after all?

S. VAN DEN BERGH: The fact that the period - luminosity - amplitude relation of Sandage and Tammann gives a distance modulus for IC 1613 that depends on period shows that we are not dealing with a selection effect. Either there is a systematic error at the faint end of Sandage's magnitude sequence in IC 1613 or the slope of the period - luminosity relation in this very metal - poor galaxy differs from that in the Magellanic Clouds.

W.G. TIFFT: What distance modulus to SMC did you use for the W Vir star luminosity. It appears quite high in the calibration. The photometry should also be verified, incidentally.

S. VAN DEN BERGH: I used an SMC distance modulus $(m-M)_V$ = 18 91 (see Table V).

V. RUBIN: Since the Hubble-Humason study, we have lived through numerous revisions of the distance scale of the Local Group. What confidence do you have that we are now in the correct ball-park, or will there yet be major revisions?

S. VAN DEN BERGH: My guess would be that H_o lies within the range 40 to 90 km sec^{-1} Mpc^{-1} .

B.F. BURKE: Are the distance moduli given in the de Vaucouleurs - van den Bergh comparison independent, brought together for the first time today, or have you been corresponding on your values? I am thinking, of course, of the old statistical trap of optional stopping.

S. VAN DEN BERG: We used the same data and obtained (almost) the same results!

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