THE ASTROPHYSICAL JOURNAL, 267:L25–L28, 1983 April 1

THE DISTANCE TO M33 BASED ON A NEW STUDY OF ITS CEPHEIDS

ALLAN SANDAGE AND GEORGE CARLSON[1]
Mount Wilson and Las Campanas Observatories of the Carnegie Institution of Washington
Received 1982 October 27; accepted 1982 December 10

ABSTRACT

Blue light curves and periods between 37 and 3 days for 13 Cepheids in a clear, far outlying region of M33 give a well-defined period-luminosity (*P-L*) relation whose slope and scatter are the same as the corrected data for Hubble's original Cepheids and for Cepheids in the Large Magellanic Cloud. The apparent blue distance modulus of M33 is $(m - M)_{\rm M33}^{AB} = 25.35$, determined by applying an adopted *P-L* relation to the data. A consequence of this distance, which is larger by ~ 0.7 mag than adopted heretofore, is to make the use of red supergiants as distance indicators more complicated than previously believed. The new M33 data, combined with newly discovered, brighter red stars in M101, suggest a dependence of the red supergiant luminosity on the luminosity of the parent galaxy, if M_B (galaxy) is brighter than ~ −19. Other consequences concerning the Hubble constant are beyond the scope of this *Letter*.

Subject headings: galaxies: individual — galaxies: Local Group — stars: Cepheids

I. INTRODUCTION

A program was started in 1950 with the Hale 5 m reflector on Cepheid variables in M33 as a step to improve Hubble's distance scale within the Local Group (Hubble 1925, 1926, 1929). The next steps were designed as outward extensions of the scale to distances where the expansion rate could eventually be redetermined directly (Hubble 1951; Sandage 1958; Sandage and Tammann 1974, hereafter ST 1). Although the first remote step to NGC 2403 (Tammann and Sandage 1968) was made before the work on M33 was completed and the scale was subsequently carried to larger distances with little weight on M33, the apparent modulus of this galaxy remains important for the calibration of certain indicators such as red supergiants and the bright blue variables (Hubble and Sandage 1953). We have begun again the study of M33 and report here new data on its distance obtained by photometry of some of its Cepheids.

II. CEPHEID DATA

A field south-preceding the nucleus of M33 has been photographed during the past 30 years with the Hale 5 m telescope and more recently with the 1.5 m Bowen wide-field Carnegie reflector at Palomar. The area, centered at R.A.(1950) = $1^{\rm h}30^{\rm m}06^{\rm s}$, decl.(1950) = $+30°18'$, of ~ 16 arcmin^2 size, is rich in variables. Blinking two-plate pairs produced ~ 100 candidate variables, of which those that are either certain or highly probable are marked in Figure 1 (Plate L3), identified by prefix letters that designate nine subregions of the field. Data have been completed on 13 of these stars and are the subject of this *Letter*.

Comparison stars were marked about each variable to provide standards that individually calibrate each plate. The Argelander step-scale method of eye estimates was used for the photometry. Magnitudes of the comparison stars were measured relative to the direct photoelectric sequence in the area that was determined earlier for this purpose (Sandage and Johnson 1974). The photometric details for the Cepheids and the comparison stars will be published when the area has been studied more completely.

Periods and light curves on the *B* photometric system are listed in Table 1 and shown in Figure 2. The one star in common with Hubble is E7 (= Hubble 35). His period was recovered without initial reference to his value; the slight difference in the values is due to our longer interval (~ 30 years here, ~ 6 years for Hubble). The final column lists the blue amplitude in magnitudes.

III. DISTANCE TO M33 FROM CEPHEIDS

a) *The P-L Relation*

The data in Table 1 are plotted in the *P-L* relation of Figure 3*a*. Two stars, D54 and B8, are suspected to be overtone pulsators, based on their small amplitudes and sinusoidal curves. They are plotted as crosses with their periods increased by 1.42, consistent with the theoretical value of $P_1/P_0 \approx 0.7$ (cf. Simon, Cox, and Hodson 1980, and earlier references therein).

The *P-L* relation for Hubble's (1926) Cepheids is shown in Figure 3*b* as corrected to the present *B* photo-

[1]Normally at Department of Physical Sciences, Citrus College, Azusa, California.

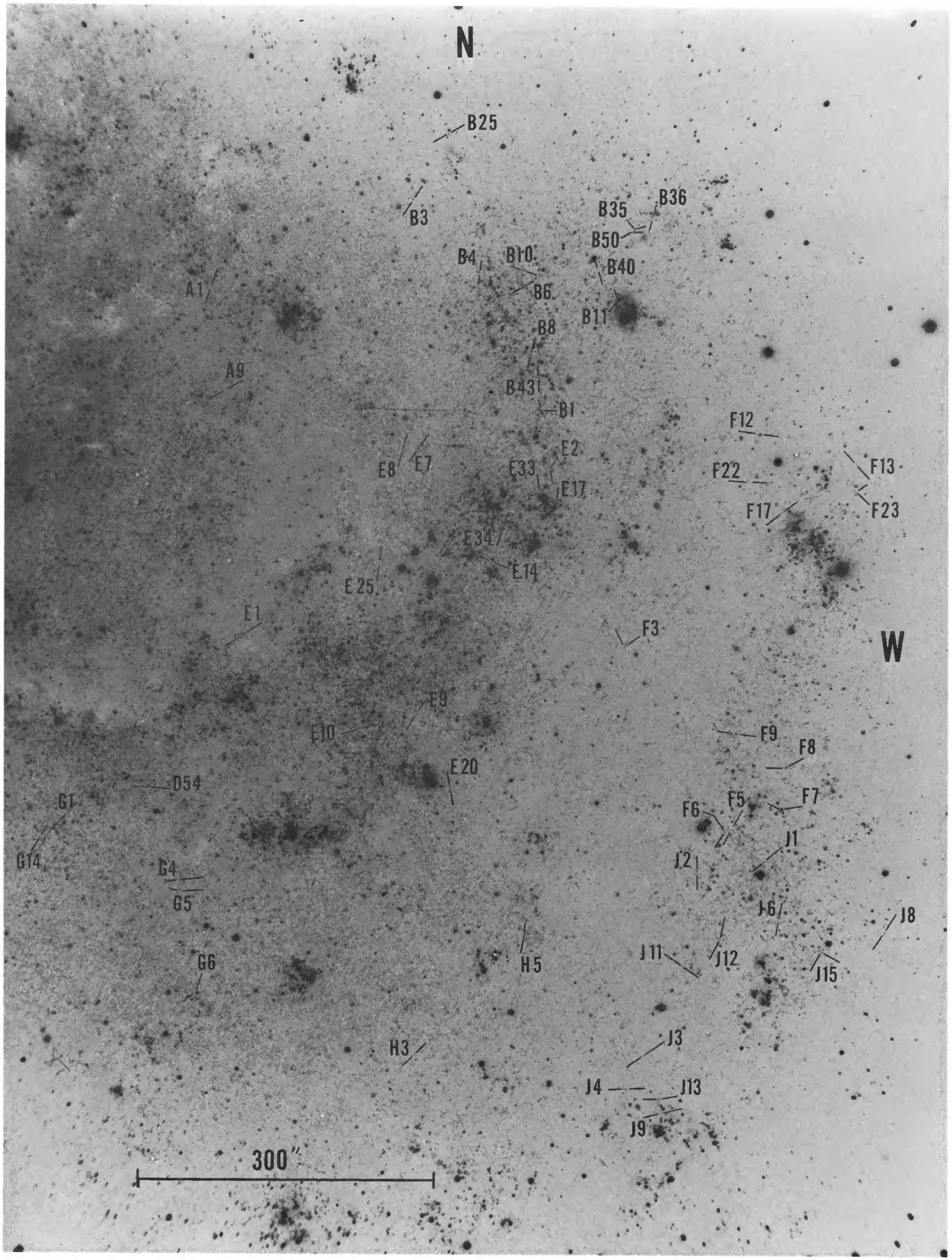

FIG. 1.—Reproduction of a blue 103a-O + GG 13 Hale 5 m reflector plate of the M33 variable star field 25. Those candidate stars that are either certain or probable variables are marked, based on blinking but two-plate pairs.

SANDAGE AND CARLSON (*see* page L25)

TABLE 1

PHOTOMETRIC PARAMETERS FOR 13 CEPHEIDS IN M33

Star	P(days)	log P	B_{max}	B_{min}	B_{med}	$\langle B \rangle$	A_B
B1	37.6179	1.575	19.6	20.8	20.2	20.2	1.2
E7	30.50935	1.484	19.7	21.5	20.6	20.7	1.8
G6......	26.3218	1.420	19.4	22.0	20.7	20.8	2.6
F8	21.2764	1.328	20.1	22.4	21.25	21.3	2.3
F12	18.48228	1.267	19.8	21.3	20.55	20.6	1.5
F9	18.0955	1.258	20.8	22.0	21.4	21.4	1.2
G14	17.5576	1.244	20.5	23.0	21.75	21.8	2.5
G4......	13.0022	1.114	20.4	21.2	20.8	20.8	0.8
E14	12.8247	1.108	20.4	22.4	21.4	21.4	2.0
G5......	8.7849	0.944	21.0	21.7	21.35	21.4	0.7
D54[a] ...	8.7415	0.942	21.0	21.6	21.3	21.3	0.6
A1	8.5406	0.931	20.6	22.4	21.55	21.6	1.8
B8[a]	3.2325	0.510	21.8	22.5	22.15	22.2	0.7

[a]D54 and B8 may be first overtone pulsators. If so, $P_0 \approx 1.4P_1$, where P is the listed value.

metric system by redetermining the magnitudes of his individual comparison stars (Sandage 1983).

We have divided Hubble's variables into three groups according to whether or not they are in clear or apparently dusty regions (see legend to Fig. 3). There is no systematic difference in Figure 3*b* within the three classes.

Figure 3*c* shows the *P-L* relation from the data of Martin, Warren, and Feast (1979, Table 3, hereafter MWF) for the Large Magellanic Cloud (LMC). The envelope lines in all three parts of Figure 3 have the same width of ± 0.55 mag. The scatter for M33 is not larger than for the LMC. We take this to mean that there is negligible internal *differential* absorption either in Hubble's Cepheids or in ours because (1) the size of the scatter is what is expected due to the intrinsic effect of the finite width to the instability strip alone (Sandage 1958), (2) MWF's data show negligible differential reddening for *their* Cepheids, and (3) field 25 here in M33 is far from the center, similar to areas in other galaxies, such as field IV of M31, IC 1613, Sextans A, etc., which have small or negligible internal absorption.

b) The M33 Distance Modulus

In the absence of color data, we must use the *P-L* rather than the *P-L-C* relation to obtain the distance, but then, of course, we must accept the larger intrinsic scatter of ± 0.6 mag. As long as the instability strip is uniformly filled, this should cause no difficulty.

We adopt the *P-L-C* relation of MWF, made brighter by 0.08 mag to correct for a Hyades modulus of 3.29 and applied to galactic Cepheids of known intrinsic $\langle B \rangle^\circ - \langle V \rangle^\circ$ color (Fernie 1967*a*; Dean, Warren, and Cousins 1978) to obtain the equivalent *P-L* relation, whose equation is

$$M_B = -2.20 \log P - 1.38. \qquad (1)$$

The derivation is discussed in detail elsewhere (Sandage 1983). Equation (1) agrees with the *P-L* relation of Sandage and Tammann (1968, Table A1) at $\log P = 0.8$, but becomes systematically *fainter* at longer periods, reaching a difference of 0.26 mag at $\log P = 1.6$ (i.e., the slopes of the two *P-L* relations differ). The MWF relation is calibrated not only with Cepheids in galactic clusters which depend on the Hyades distance, but also via radii determinations by Balona (1977), following a method by Fernie (1964, 1965). The MWF zero point contains Hyades information with only $\sim 1/3$ weight. We have used MWF's brighter zero point which makes equation (1) agree exactly with that of Fernie (1967*b*) in the mean over the period range $0.6 \leq \log P \leq 1.6$. Fernie's is a fundamental calibration using radius information only, and hence is independent of the Hyades modulus.

Fitting this *P-L* relation to the M33 data, using Hubble's at half-weight, gives

$$(m - M)^{AB}_{M33} = 25.35. \qquad (2)$$

Sandage and Tammann (1974, Table 2) adopted $(m - M)^{AB}_{M33} = 24.68$ for their first step; hence equation (2) is 0.67 fainter. This is so large a difference as to raise questions of reliability. Tests of the modern magnitude scales in M31 and M33 compared with those of Hubble show that M33 should be ~ 0.4 mag farther than M31 (Sandage 1983), rather than 0.1 mag closer as given by Hubble. Applying equation (1) to Baade and Swope's (1963) M31 data gives $(m - M)^{AB}_{M31} = 24.83$, which is 0.5 mag brighter than for M33, close to what is expected. This test confirms that the two modern magnitude scales for M31 and M33 are now in the proper ratio but does not test the zero point of the *P-L* relation which may still be an open question (e.g., Schmidt 1980*a*, *b*, 1981, 1982). This yet controversial problem

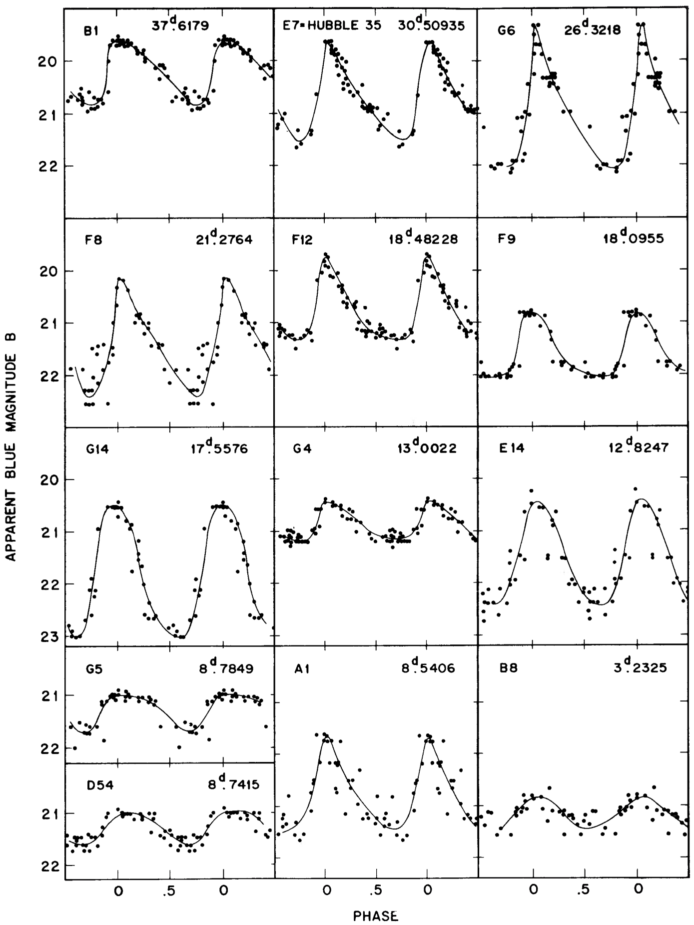

FIG. 2

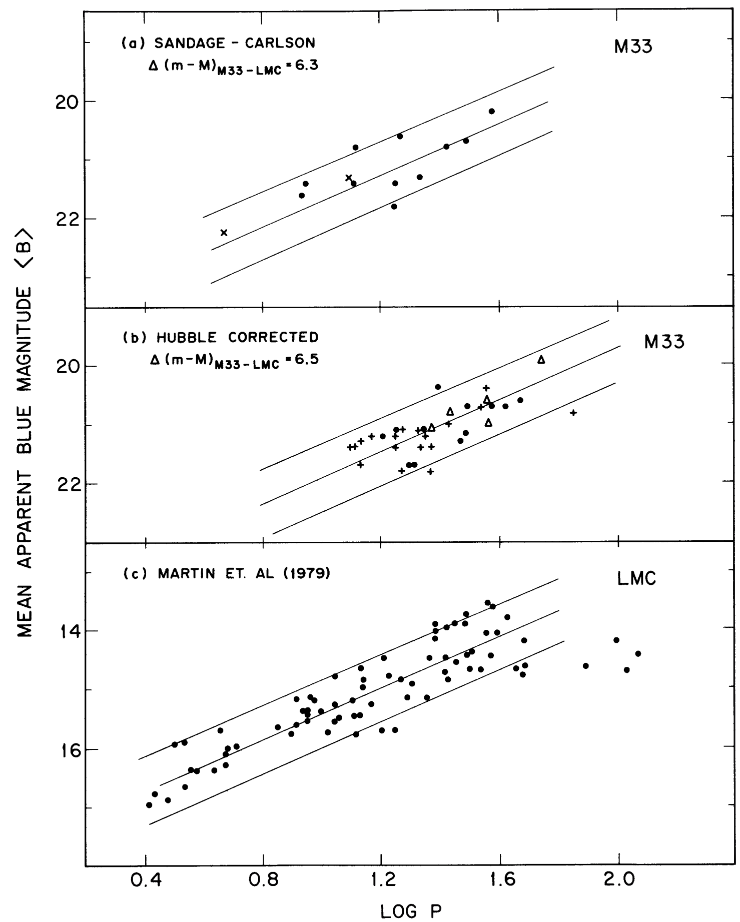

FIG. 3

FIG. 2.—Light curves for 13 of the candidate variables marked in Fig. 1

FIG. 3.—(*a*) *P-L* relation for stars in Table 1. (*b*) *P-L* relation for Hubble's Cepheids corrected to the *B* photometric scale. Circles are stars in no obvious obscuration; triangles are uncertain as to obscuration, while crosses are near regions of dust or are on high background. (*c*) *P-L* relation for the LMC Cepheids of MWF. The difference in the apparent blue modulus between M33 and LMC, found by sliding (*a*) and (*b*) over (*c*), is indicated in (*a*) and (*b*).

makes it prudent to consider equation (2) as provisional, albeit our preferred value.

c) Consequences

We mention here only one consequence of the larger distance. The brightest red supergiants are now no longer at $M_V \approx -8.0$ in M33, based on $(m - M)^{AB}_{\rm M33} = 24.68$. Remeasurements of the M33 plates show $\langle V(3) \rangle = 16.63$ for the mean of V(max) of the variables R211, R96, and R244, close to the value given by Humphreys and Sandage (1980). From equation (2) and using $E(B - V) = 0.03$ (McClure and Racine 1969; Sandage 1983) gives $(m - M)^{AV}_{\rm M33} = 25.32$, making $M_{\langle V(3) \rangle} = -8.7$ for the three brightest red supergiants. This increase from -8.0 makes their use as distance indicators more complicated than originally believed (Sandage and Tammann 1982). However, remeasurements now in progress show $\langle V(3) \rangle = 20.3$ for M101, giving $M_{\langle V(3) \rangle} = -8.9$ in that galaxy. This suggests that, for galaxies brighter than $M_B(\text{gal}) \approx -19$, there may be a dependence of red supergiant luminosities on the luminosity of the parent galaxy. This point will be discussed in detail when the measurements in M101, NGC 2403, and NGC 300 have been completed.

The more far-reaching effect of equation (2) on the Hubble constant via other methods is beyond the scope of this *Letter*.

We wish to acknowledge the detailed help of the many Palomar night assistants on the Hale 5 m reflector in obtaining the M33 plates since 1950, and the mountain crew that kept the telescope operating. We also wish to thank John Bedke of the Observatories photo lab for the many needed working prints, and Nancy Tomer for the diagrams.

We are grateful to Eileen Clark for her help with the computations of the periods and light curves for some of the variables, and to the Citrus College Computer Center for generously making available their facilities, used for the period determinations.

Finally, it is a pleasure to thank Professor G. A. Tammann for many discussions on the details and the implications of these new data.

REFERENCES

Baade, W., and Swope, H. H. 1963, *A.J.*, **68**, 435.
Balona, L. A. 1977, *M.N.R.A.S.*, **178**, 231.
Dean, J. F., Warren, P. R., and Cousins, A. W. J. 1978, *M.N.R.A.S.*, **183**, 569.
Fernie, J. D. 1964, *Ap. J.*, **140**, 1482.
______. 1965, *Ap. J.*, **142**, 1072.
______. 1967*a*, *A.J.*, **72**, 422.
______. 1967*b*. *A.J.*, **72**, 1327.
Hubble, E. 1925, *Ap. J.*, **62**, 409.
______. 1926, *Ap. J.*, **63**, 236.
______. 1929, *Ap. J.*, **69**, 103.
______. 1951, *Proc. Amer. Phil. Soc.*, **95**, 461.
Hubble, E., and Sandage, A. 1953, *Ap. J.*, **118**, 353.
Humphreys, R. M., and Sandage, A. 1980, *Ap. J. Suppl.*, **44**, 319.
Martin, W. L., Warren, P. R., and Feast, M. W. 1979, *M.N.R.A.S.*, **188**, 139.
McClure, R. D., and Racine, R. 1969, *A.J.*, **74**, 1000.
Sandage, A. 1958, *Ap. J.*, **127**, 513.
______. 1983, *A.J.*, submitted.
Sandage, A., and Johnson, H. L. 1974, *Ap. J.*, **191**, 63.
Sandage, A., and Tammann, G. A. 1968, *Ap. J.*, **151**, 531.
______. 1974, *Ap. J.*, **190**, 525 (ST 1).
______. 1982, *Ap. J.*, **256**, 339.
Schmidt, E. G. 1980*a*, *A.J.*, **85**, 158.
______. 1980*b*. *A.J.*, **85**, 695.
______. 1981, *A.J.*, **86**, 242.
______. 1982, *A.J.*, **87**, 650.
Simon, N. R., Cox, A. N., and Hodson, S. W. 1980, *Ap. J.*, **237**, 550.
Tammann, G. A., and Sandage, A. 1968, *Ap. J.*, **151**, 825.

George Carlson: Department of Physical Sciences, Citrus Community College, 18824 East Foothill Boulevard, Azusa, CA 91702

Allan Sandage: Mount Wilson and Las Campanas Observatories, 813 Santa Barbara Street, Pasadena, CA 91101-1292