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Dynamical Structure of NGC 4486*

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ABSTRACT

The peculiar elliptical(EOp) galaxy NGC 4486 and two KOIII comparison stars HR5450, HR6935 were observed spectroscopically using the 74-inch telescope and Image Tube at Mt. Stromlo Observatory. From the Gaussian Broadening Function, broadened spectrum of two comparison stars were computed for the range between wavelength 4800Å and 5400Å. Velocity dispersions in the line of sight of M87 were obtained by visual fitting. The fitted velocity dispersion is 450 km/sec at the nucleus, 350 km/sec at $r = 12''$, and 300 km/sec at $r = 24''$.

Using the photometric data and the central value of velocity dispersion, we determined the mass of M87. From $r^{1/4}$ law and the Virial theorem the calculated total mass is $2.1 \times 10^{12}\ M_\odot$ and from the King model $M = 1.2 \times 10^{12}\ M_\odot$. And M/L ratio of M87 is about 30.

I. Introduction

Mass and mass to luminosity ratio are important to study the dynamical structure of extragalaxies. The mass of a spiral galaxy can be determined from the rotation curve. However in the elliptical galaxy, galactic mass comes from the velocity dispersion of individual stars because the total Kinetic energy of the system is in due to the random motion of each stars. The basic assumption is the equilibrium state of individual stars in the galaxy and we can apply the virial theorem to this system.

The EO type galaxy M87(NGC 4486) is the brightest giant elliptical galaxy in Virgo cluster and is known as a radio source Virgo A by Baade and Minkowski(1954). M87 has about 500 globular clusters(Sandage 1968) and there is evidence for mass ejection from the nucleus in the form of

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the strongly polarized optical jet(Baade 1956; Burbidge 1956; Felten 1968; Perola and Tarenghi 1980; Nieto and Lelievre 1982). From the surface brightness distribution Young et al. (1978) suggest the supermassive object in the central part of M87 and de Vaucouleurs and Nieto (1978) defined this galaxy as the outer corona and the inner nuclear region from the photographic plates. M87 is classified as EOp(T=–4) by the revised BGC and E1 by DDO catalogue. The distance to M87 Δ =13.6 Mpc by de Vaucouleurs(1975) or Δ =19.5 Mpc by Sandage and Tammann(1974). The basic elements of M87 are listed in Table 1.

Table I. The basic elements of M87

Coordinate (1950.0)	R.A.	$12^h 28^m.29$	(1)
	DEC.	$12°40'.1$	
	L	$283°.78$	
	B	$74°.49$	
	SGL	$102°.9$	
	SGB	$-2°.3$	
Morphological type	BGC rev type	E0p	(1)
	Hubble sequence type	–4	
	DDO	E1	
Distance (Mpc)	Δ	16	(2)
	Δ	13.6	(3)
	Δ	19.5	(4)
	Δ	11	(5)
Isophotal diameter	log D_{25}	1.86	(1)
(0.1)	log D_0	1.89	
Magnitude (mag)	m_H	$10^m.7$	(1)
	m_C	$9^m.89$	
	B_T	$9^m.565$	
	B_T^o	$9^m.565$	
	M_B	$-21^m.7$	(6)
	M_V	$-21^m.5$	(5)
Color indices	(B-V)	0.88	(1)
	(U-B)	0.53	
Radio index	RI	–3.51	(1)
Velocity (km/sec)	V(cz)	1257	(1)
	V_o	1180	
	V	1220	(7)

(1) Second References of Bright Galaxies
(2) de Vaucouleurs 1979
(3) de Vaucouleurs 1975
(4) Sandage and Tamman 1974
(5) Allen 1973
(6) Faber and Jackson 1976
(7) Humason et al. 1956

II. Data

To get the velocity dispersion of M87, we used spectroscopic plates using the 74-inch telescope equipped with the Image Tube at the Mt. Stromlo Observatory. The dispersion of plates is 100Å/mm and the wavelength range is 4000Å to 5900Å. Comparison source used here is the Ne-He spectrum. Observations were made at the nucleus, at 12″s, and at 24″s from the center.

Two comparison stars were observed for the use of the broadening and fitting the spectra. By the work of Morgan and Mayall(Mihalas and Binney 1981), the integrated spectra of M87 is similar to that of K type giant star, and our choice of KOIII stars HR 6935, HR 5450, was based on their works.

The basic elements for observation of two comparison stars are listed in table II.

Table II. Elements of the observed comparison stars

	R.A. (1950.0)	DEC.	V	B−V	Sp	V_r kms^{-1}
HR5450	$14^h 30^m 37^s$	$-45° 42'$	$5^m.36$	0.94	KOIII	-16
HR6935	$18^h 24^m 29^s$	$-2° 3'$	$5^m.44$		KOIII	28

III. Velocity dispersion

a) method

To get the velocity dispersion of the stellar system three methods can be used. First is the measurement of the radial velocity of bright stars in the system. Proper motion of individual stars is the second one, and the third method is the use of the integrated spectrum of the whole system(Mihalas and Binney 1981). The limitation of the observation and the large distance of external galaxies restricts the use of the former two methods. However the integrated spectrum reveals not only bright stars but faint objects in external galaxies, it is the best tool to get the velocity dispersion of these systems.

The macroscopic broadening agent which increases the width of spectra comes from effects of the rotation and instrument of individual stars. Apart from this, velocities of individual stars in a galaxy also cause the broadening(Burbidge et al. 1961a).

To determine the velocity dispersion the galaxy spectrum are compared visually with spectrum of comparison stars artificially broadened using Gaussian Broadening Function by varions amounts and the best fitting value is the velocity dispersion of the galaxy. Burbidge et al.(1961 a, b), Brandt and Roosen(1969), Richstone and Sargent(1972), Morton and Chevalier(1972, 1973), and Faber and Jackson(1976) determined the velocity dispersion of extragalaxies in this method.

b) Calculation of the velocity dispersion.

The Gaussian distribution of velocities of the individual stars in a stellar system can be converted to the intensity $I(\lambda_0, \sigma_r)$ as

$$I(\lambda_0, \sigma_r) = \int_{-\infty}^{+\infty} I_\lambda f(x)\,dx = \pi^{-\frac{1}{2}} \int_{-\infty}^{+\infty} I_x \exp(-x^2)\,dx$$

where $I(\lambda_0, \sigma_r)$ is the intensity observed at wavelength λ_0 and a velocity dispersion σ_r. I_x is the intensity x units away from (Burbidge et al. 1961a). To evaluate numerieally the integral above we used a composite sixth order polynomial approximation(weddle's Rule) to I_λ (cf. Burbidge et al. 1961a; Illing-worth 1973). I_x is in the form of equally spaced discrete value and define X_n for evaluation.

$$X_n = \frac{C}{\sqrt{2}\,\sigma_r\,\lambda_0}\, n\,\delta$$

Here δ is the wavelength interval between readings on the tracing, and n is the number of such intervals between λ_0 and the wavelength from which the Doppler-shifted contribution is being evaluated.

$$I(\lambda_0, \sigma_r) = \sum_{n=-s}^{n=+s} \frac{W_n}{N_s}\, I_{xn} \exp(-x_n^2)$$

where

$$N_s = \sum_{i=-s}^{i=+s} W_i \exp(-x_i^2)$$

and

$$W_0 = W_{\pm 6} = W_{\pm 12} = \dots\dots\dots\dots = 2,$$
$$W_{\pm 1} = W_{\pm 7} = W_{\pm 13} = \dots\dots\dots\dots = 5,$$

$$W_{\pm 2} = W_{\pm 8} = W_{\pm 14} = \ldots\ldots\ldots\ldots = 1,$$
$$W_{\pm 3} = W_{\pm 9} = W_{\pm 15} = \ldots\ldots\ldots\ldots = 6,$$
$$W_{\pm 4} = W_{\pm 10} = W_{\pm 16} = \ldots\ldots\ldots\ldots = 1,$$
$$W_{\pm 5} = W_{\pm 11} = W_{\pm 17} = \ldots\ldots\ldots\ldots = 5$$

In Figure 1 we display spectra of comparison stars and of three regions of M87 in wavelength 4700Å to 5500Å. From Figure 1 we know that the spectral line of M87 is shifted about 20Å by redshift of Doppler effect.

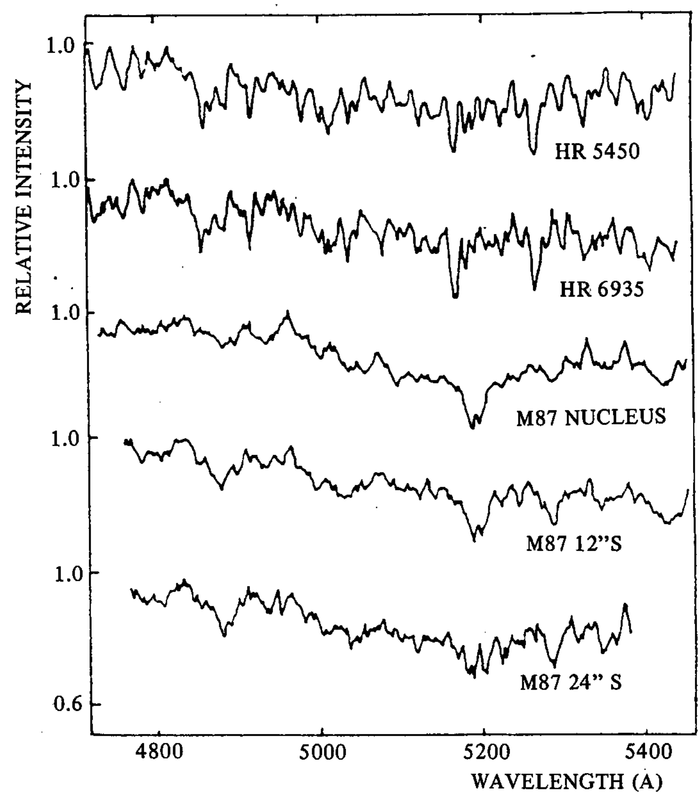
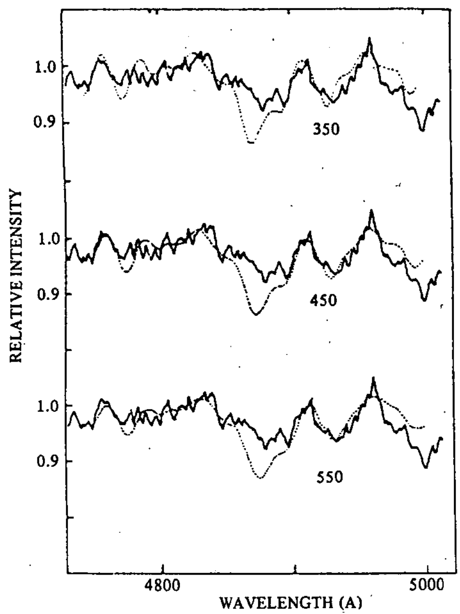


Fig. 1. The spectra of two comparison stars and M87.

When comparing the three M87 spectra, the differences in the line width suggests that the velocity dispersion in the outer regions of M87 is much lower than in the nucleus.

The representative absorption lines of KOIII type stars shown in this wavelength region are

H_β λ4861, Mgb λ5175, and FeI λ5270. Since these absorption lines are hardly affected by emission line from the center of M87, these lines are appropriate for fitting the spectra with broadened spectra of comparison stars. But Mgb line is blended with the wide band of MgI absorption and the velocity dispersion estimated in this region will include the considerable error. Figure 2a-h show the result from this chapter. All the spectra are normalized to 1.0 as indicated on the ordinate scale. The three wavelength regions selected for fitting are λ4719 to λ 4999(Region 1), λ4960 to λ5238(Region 2), and λ5917 to λ5495(Region 3). The three regions for galaxy spectrum (solid line) are shown fitted with the broadened star spectrum(dotted line). The comparison star and the velocity dispersion values used in broadened is given beneath each spectrum. The velocity dispersion adopted from this fitting procedure is tabulated in Table III.



2a. Region 1 at nucleus

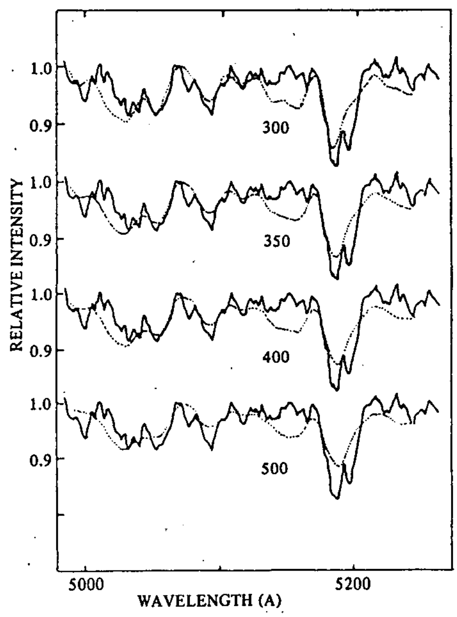


Fig. 2-b. Region 2 at nucleus

Fig. 2a. Fitting procedure for determination of velocity dispersion. Solid lines are the spectrum of M87, dotted lines are the broadened spectrum of comparison star. Different values of velocity dispersion are showed below the lines, in Km/sec.

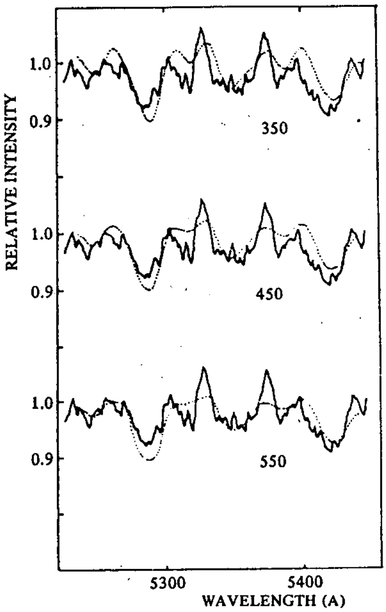


Fig. 2-c. Region 3 at nucleus

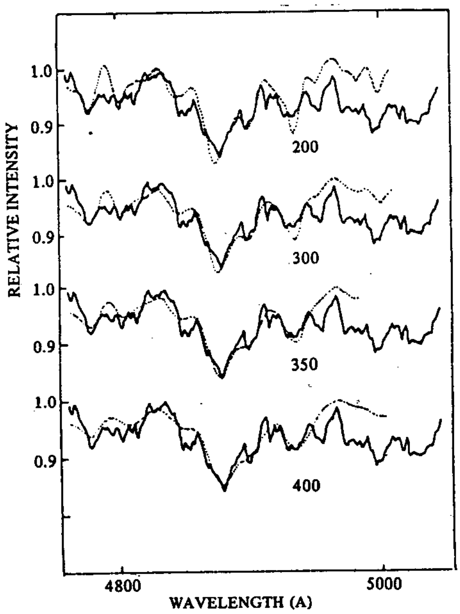


Fig. 2-d. Region 1 at r = 12"

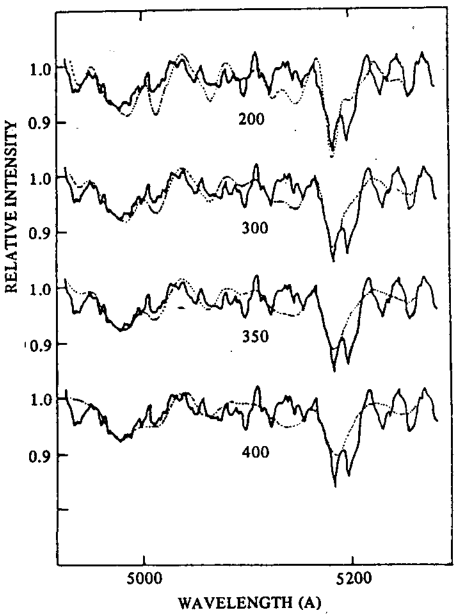


Fig. 2-e. Region 2 at r = 12"

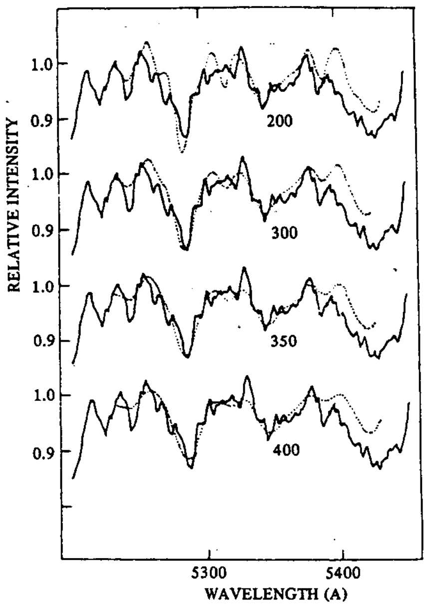


Fig. 2-f. Region 3 at r = 12"

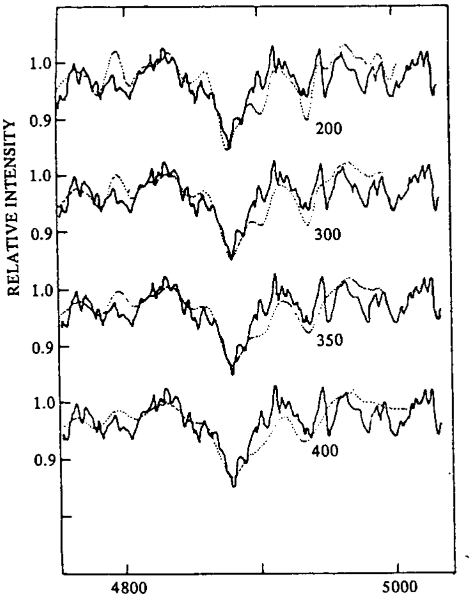


Fig. 2-g. Region 1 at r = 24"

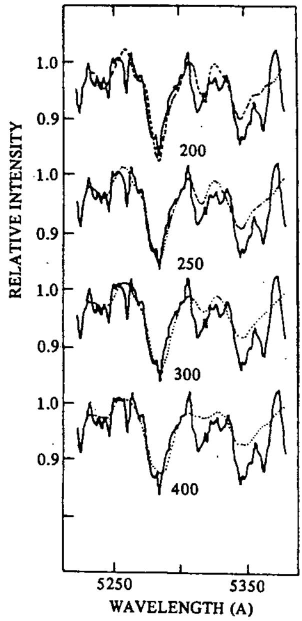


Fig. 2-h. Region 3 at r = 24"

Table III. The velocity dispersion of M87 (Km/sec)

	Nucleus	km/sec 12"	24"
region 1	450	350-400	300-350
region 2	400-500	300-350	
region 3	450	350	250-300

From Table III, the velocity dispersions in M87 are 450 Km/sec at the nucleus, 350 Km/sec at the r = 12″, and 300 Km/sec at the r = 24″. The fitting error in these values, results from the graphic resolution 1.03 Å, is ±31 Km/sec, but possible error in visual fitting may be a little more.

IV. Comparison with the other study

Brandt and Rossen(1969) obtained the velocity dispersion at the nucleus of M87 by method of Burbidge et al.(1961 a, b). Used data is the digitized spectrum obtained from tracing 103a0 plate with resolution 145 Å/mm at G-band(4308 Å). The velocity dispersion determined is 550 Km/sec at the nucleus and this value is simioar to the result of Minkowski ±490 Km/sec, within the fitting error ±70 Km/sec.

Under the study on the velocity dispersion and mass to luminosity ratio of elliptical galaxies, Faber and Jackson(1976) obtained the velocity dispersions of 25 elliptical galaxies. The velocity dispersions of M87 obtained are 310 ± 28 Km/sec in the Mgb region and 327 ± 27 Km/sec in the NaD region.

Sargent et al.(1978) studied the dynamical structure of the nuclear part of M87. In their study they determined the velocity dispersion of M87 as a function of radius by a Fourier method. The velocity dispersion at the edge of the core(r_c = 0ʺ.6) is 278 Km/sec, but deerease to 220 Km/sec when r = 72ʺ. Inside the core a sharp increase is observed, up to the velocity dispersion of M87 with radius. Curve (a) is the velocity dispersion predicted by the blackhole model fitted to the photometric data, (b) is the same model convolved with the seeing disk and slit size for the spectroscopic observations, and (c) is the king model that would pervail if the blackhole were absent.

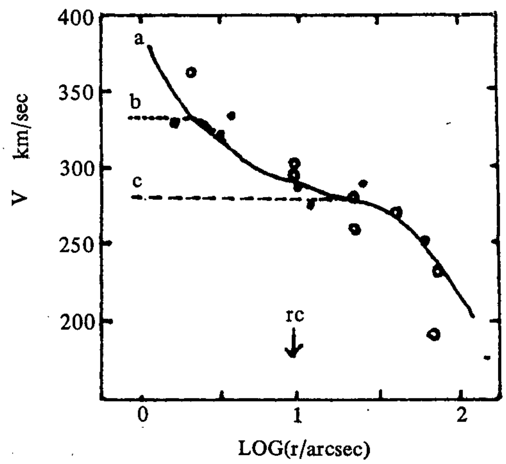


Fig. 3. The variation of velocity dispersion with radius(Sargent et al. 1978).

The velocity dispersions in this paper and another works are listed in Table IV for comparison. Table IV compares our velocity dispersions with the other values and shows that inside the core the result from Burbidge et al.(1961 a, b) is larger than the result from Fourier method. The value in this paper is similar to that of the other work using Broadening Function within the fitting error.

Table IV. Comparison with Other Studies

	Velocity dispersion		
radial distance	method 1	method 2	despersion
0″	490		(1)
	550		(2)
	315		(3)
	450		(4)
		350	(5)
2″		362	(6)
9″		286	(5)
11″		275	(6)
12″	350		(4)
13″		275	(6)
14″	300		(4)
24″		287	(6)
71″		232	(6)

method 1; Burbidge et al. (1961a.b)
method 2; Fourier

(1) Minkowski (Brandt and Roosen 1969)
(2) Brandt and Roosen (1969)
(3) Faber and Jackson (1976)
(4) This paper
(5) Dressler (1980)
(6) Sargent et al. (1978)

V. Summary

In this paper we determined the velocity dispersion of EO peruliar galaxy M87 using the data observed spectroscopically. The spectrum of M87 was compared with the artificially broadened spectrum of the comparison star using Gaussian Broadening Function for selecting the best match from visual fitting. Our result is compared with the other works. The velocity dispersion determined is 450 Km/sec at the center of M87, 350 Km/sec at $r = 12''$, and 300 Km/sec at $r = 24''$. The result at the center is similar to the other works from the same method within the fitting error (Sargent et al. 1978).

As we know in Table IV, the velocity dispersion at the center of M87 from the method of Burbidge et al.(1961 a, b) is 315 Km/sec to 550 Km/sec. This difference of results can be explained the uncertainty included in the method, the properties shown in central spectrum of M87 and the contamination effect of the spectrum due to high luminosity at the nucleus.

References

Allen, C.W. 1973, *Astrophysical Quantities*, 3rd ed.(London: Atlone Press), p. 273.

Baade, W.1956, *Ap. J.*, **123**, 550.

Baade, W. and Minkowshi, R. 1954, *Ap. J.*, **119**, 215.

Brandt, J. C. and Roosen, R. G. 1969, *Ap. J.*, **156**, L59.

Burbidge, G. R. 1956, *Ap. J.*, **124**, 416.

Burbidge, E. M., Burbidge, G. R. and Fish, R. A. 1961a. *Ap. J.*, **133**, 393.

____________________. 1961b, *Ap. J.*, **133**, 1092.

de Vaucouleurs, G. 1975, *In stars and Stellar System*, Vol. 9. ed. A. Sandage, M. Sandage and J. Kristian(Chicago: Univ. of Chicago Press).

__________. 1979, *Ap. J.*, **227**, 729.

Dressler, A. 1980, *Ap. J.*, **240**, L11.

Faber, S.M. and Jackson, R. E. 1976, *Ap. J.*, **204**, 668.

Felton, S.M. 1968, *Ap. J.*, **151**, 861.

Humason, M. L., Mayall, N. U. and Sandage, A. 1956, *Ap. J.*, **61**, 97.

Illingworth, G. 1973, Ph. D. Thesis. Australian National University.

Mihalas, D. and Binney, J. 1981, *Galactic Astronomy*(San Francisco: W. H. Freeman and Company).

Morton, D. C. and Chevalier, R. A. 1972, *Ap. J.*, **174**, 489.

_______________. 1973, *Ap. J.*, **179**, 55.

Nieto, J. L. and Lelievre, G. 1982, *Astr. Astrophys.*, **109**, 95.

Perola, G. C. and Tarenghi, M. 1980, *Ap. J.*, **240**, 447.

Richstone, D. and Sargent, W. L. 1972, *Ap. J.*, **176**, 91.

Sandage, A. R. 1968, *Ap. J.*, **152**, L149.

Sandage, A. R. and Tamman, G. A. 1974, *Ap. J.*, **194**, 559.

Sargent, W.L., Young, P. J., Boksenberg, A., Shortridge, K., Lynds, C. R. and Hartwick, F. D. A. 1978, *Ap. J.*, **221**, 731.

Young, P. J., Westphal, J. A., Kristian, J. and Wildon, C. P. 1978, *Ap. J.*, **221**, 721.