THE ASTROPHYSICAL JOURNAL, 236:366–372, 1980 March 1

DYNAMICS OF THE SHAHBAZIAN 1 GROUP OF GALAXIES

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Received 1979 July 16; accepted 1979 September 12

ABSTRACT

New spectroscopic observations of the Shahbazian 1 group of galaxies have been obtained with the digital spectrograph at the 5 m Hale telescope. From velocity differences between galaxies in the cluster and the virial theorem we have derived a mass-to-light ratio, in the V band, of 111 ± 15. We have also measured the internal velocity dispersions of three galaxies in the group. They are consistent with those of ordinary elliptical galaxies of comparable luminosity. This new spectroscopic evidence, coupled with recent photometric work, points to the conclusion that the group is composed of ordinary galaxies, contrary to earlier interpretations. The group is, however, extraordinary in the sense that it is about as dense as the center of the coma cluster, and that dynamical interactions which are typical of rich clusters may have been important in the history of Shahbazian 1.

Subject headings: galaxies: clusters of — galaxies: internal motions — galaxies: redshifts

I. INTRODUCTION

Robinson and Wampler (1973, hereafter RW) showed that Shahbazian's (1957) small cluster of red objects was a group of galaxies at a redshift of $z = 0.1168$. They obtained velocities for five galaxies, with the remarkable result that the velocity dispersion in the group was estimated as $\sigma = 62$ km s^{-1}, with an uncertainty in each galaxy velocity, δv, of about 80 km s^{-1}. When combined with rough photometry of the galaxies, the redshift indicated an absolute magnitude for the brightest galaxy near $M_v = -23.6$ ($H_0 = 50$ km s^{-1} is assumed in the present paper), which is at the bright end of the luminosity distribution for first brightest galaxies in rich clusters. The velocity differences and the virial theorem provided an estimate of the mass-to-light ratio near 1. These results led to the speculation that the galaxies in this group might be unusual objects (Arp, Burbidge, and Jones 1973, hereafter ABJ).

The idea that the galaxies might be unusual is also suggested by the appearance of the group. Approximately 20 members are in an area of 50″ × 100″ corresponding to 140 × 280 kpc at an angular diameter distance of 590 Mpc. Also, the individual galaxies appear to have high surface brightness on the Sky Survey plates.

As a result of these initial investigations, Shahbazian 1 has come to be known as a compact cluster of compact galaxies of extraordinary luminosities and unique mass-to-light ratios. In the present work, we show that most of these conclusions are not correct. While the group itself is about as dense as the center of a rich cluster like Coma, the galaxies themselves have ordinary compactness, typical luminosities, and mass-to-light ratios which are indistinguishable from those of elliptical galaxies. These assertions are based on published photometry plus new radial velocities and internal velocity dispersions obtained by us.

II. PHOTOMETRY

a) Are the Galaxies Very Luminous?

In the original work by RW, plates from the Crossley reflector were used along with count rates from the image tube scanner to estimate magnitudes for the galaxies. Recently, Thompson (1976, hereafter T76) has made photoelectric UBV measurements through a 10″.6 aperture of three galaxies in the group. Massey (1977, hereafter M77) has obtained photoelectric calibration of large reflector plates, and used a scanning microdensitometer to obtain isophotal magnitudes and surface brightness profiles for 16 group members. Shahbazian (1978, hereafter S78) has obtained 1 m Schmidt plates and used photographic transfers along with microdensitometer measures to obtain magnitudes and colors for seven galaxies.

We find very good agreement among the recent observations, and a large systematic error in the original rough photometry of RW. Generally, the galaxies are about 1.2 mag *fainter* than the RW estimates.

We adopt K-corrections (Pence 1976) of $K_v = 0.2$ mag for all the galaxies except galaxies 7 and 9 (using the numbering of RW) where the color ($B - V = 0.6$) suggests that the galaxies are spirals for which $K_v = 0.05$.

In Figure 1, we show the luminosity function for this group, based on Massey's photometry, and compare it to the luminosity function for galaxies outside rich clusters (Kirshner, Oemler, and Schechter 1979). Here it is simplest to use Massey's magnitudes in the "G" system (Wratten 4 + IIIa-J) which is similar to Kirshner, Oemler, and Schechter's (1978) "J" system.

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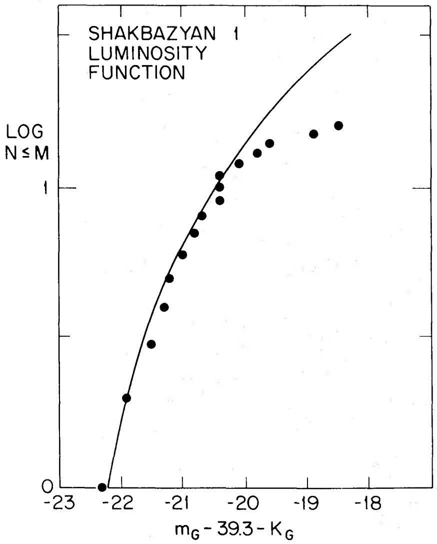

FIG. 1.—Integral luminosity function for Shahbazian 1. The solid points are the observed luminosity function, based on the G-band photometry by Massey (1977). The line represents the luminosity function for field galaxies derived by Kirshner, Oemler, and Schechter (1979). At the bright end, the Shahbazian luminosity function matches the field luminosity function, while the faint end shows too few galaxies. Since these galaxies have apparent magnitudes of 21–22, it seems plausible that they are present in the group, but unmeasured.

We see that the luminosity function is indistinguishable from the luminosity function for galaxies outside rich clusters when the galaxies are brighter than $M_G = -20$. Since this corresponds to $m_G \approx 20$, it seems plausible that a few faint galaxies with $m \approx 21$–22 have been omitted from the photometry, so that the deviation from the field luminosity function can be attributed to incompleteness. The alternative, a real deficiency of low-luminosity galaxies, can be tested by deeper photometry. The total visual luminosity in the group is about $4 \times 10^{11} L_\odot$, roughly $10L^*$, where L^* is the characteristic luminosity in Schechter's (1976) form for the luminosity function. Since the typical luminosity in a rich cluster is about 10 times larger, it seems appropriate to refer to Shahbazian 1 as a "group" rather than a "cluster." There can be no doubt that this group represents an extraordinarily large enhancement over the background. Since we have $4 \times 10^{11} L_\odot$ in a volume with a radius of roughly 166 kpc, the luminosity density is about $2 \times 10^{13} L_\odot$ Mpc^{-3}. Since the luminosity density for field galaxies is of order $10^8 L_\odot$ Mpc^{-3} (Kirshner, Oemler, and Schechter 1979), this group represents a contrast of a factor 10^5 over the background. We can compare this with the contrast of 10^3 for the groups in the catalog of Gott and Turner (1977). A more appropriate comparison is with the central luminosity density of the Coma cluster, where Rood *et al.* (1972) find $2 \times 10^{13} L_\odot$ Mpc^{-3} (for $H_0 = 50$).

b) *Are They Compact?*

The galaxies in this group were originally confused with stars, and this has led to the impression that the galaxies are unusually compact. In the 5 m plate by Arp shown in ABJ, it is possible to make the distinction between stars and galaxies, and detailed surface photometry by M77 shows that, when the galaxies in the group are compared to those in Kormendy's (1977) study, they are only ordinarily compact. Although S78 differs with this conclusion, Massey's work is much more detailed and is based on plates with larger scale, so that it is likely to be more reliable. Nevertheless, additional surface photometry of this group is definitely worth doing.

TABLE 1

OBSERVATIONS OF SHAHBAZIAN 1

Date (1977)	Galaxies on Slit	Exposure (s)
April 18..............	1, 2	4500
	1, 4, 5	5000
	3, 7	5000
April 19..............	9, 10	3000

c) *Spectroscopic Observations*

We used the digital spectrograph at the Hale 5 m reflector on 1977 April 18 and 19 to obtain two-dimensional spectra of galaxies in Shahbazian 1. As detailed in Table 1, the spectrograph was rotated for each exposure so that at least two galaxies from the group were on the 0″.91 × 55″ slit. Helium-neon comparison spectra were obtained before and after each exposure. Our wavelength coverage was 3800–5400 Å, with 512 picture elements of 3.2 Å each along the dispersion and about 40 picture elements of 1″.4 each along the slit.

Sensitivity variations along the slit and small-scale variations along the spectrum are removed using an exposure of an incandescent lamp. The spectra of bright stars are used to correct for S distortion; the helium-neon lines are used to remove slit curvature and to establish the wavelength scale. The scan lines which are well exposed for each galaxy are summed. Those which contain no galaxy data are used as measures of the sky and subtracted from the galaxy spectra.

d) *Redshifts and Dispersions from the Fourier Quotient Method*

We measure the redshift and internal velocity dispersion of the galaxies in the group by the Fourier quotient method described by Sargent *et al.* (1977, hereafter S^{2}BS) as modified by Schechter and Gunn (1979, hereafter SG). The spectrum of the galaxy is divided into bins of equal steps in ln λ: here $c\,\Delta \ln \lambda = 157.4$ km s^{-1}. We then assume that the observed galaxy spectrum $G(\ln \lambda)$ is the result of convolving the spectrum of a template star $T(\ln \lambda)$ with a Gaussian broadening function, and shifting it. We compute the discrete Fourier transform of each spectrum and divide to find the relative velocity dispersion, s, and the relative redshift, z. The systematic effects in this method are discussed in detail by S^{2}BS and by SG.

For our own data the method gave consistent redshift results that agree with direct wavelength measurements of the strong absorption lines, and also provided a useful statistical measure of the uncertainty in the redshift determination. A good measure of the velocity dispersion demands higher signal-to-noise, and was obtained for only three of our seven galaxies.

SG discovered a significant intensity-redshift correlation in data obtained with this spectrometer which is the result of accumulated charge on the target pulling on the electron beam as the target is read. They found that the amplitude of this effect corresponds to 0.4 pixel (80 km s^{-1}) per 2000 counts (typical of a nearly saturated image). For our data, this effect is negligible.

III. RESULTS

a) *Velocity Measures*

Table 2 provides a summary of the results of our analysis. We measure z, the redshift, and convert to a radial velocity using

$$v = c\left[\frac{(1+z)^2 - 1}{(1+z)^2 + 1}\right] . \qquad (1)$$

In the table, we give the velocity after correcting for the motion of the template star HD 133163 (-30.5 km s^{-1}; Griffin 1971), correcting for the motion of the Earth ($+22$ km s^{-1}) and for the contribution of galactic rotation (-9 km s^{-1}). (We note that the redshift, in units of km s^{-1}, cz, is incorrectly printed in RW as 29,700 km s^{-1}, and incorrectly printed in the English translation of S79 as $z = 0.1116$.) The positions given were measured with the two-coordinate Grant engine at KPNO on both the Sky Survey glass plates and on Kinman's 3 m prime focus plate.

Faber and Dressler (1977) have recently pointed out the importance of including the first-order relativistic effect in computing velocity dispersions in clusters.

To the accuracy required for this investigation, we take the intrinsic internal velocity dispersion, s, to be $(1 + z)^{-1}s'$, where s' is the measured velocity dispersion.

Comparing our results with those of RW, we find some similarities and some significant differences. For the four galaxies where RW had good data, we agree within the uncertainties for galaxy 1 and galaxy 4. Because galaxy 1 has [O II] 3727 emission, an accurate redshift is easy to obtain, independent of the Fourier quotient technique (which is useful only for absorption features. Thus it is gratifying, but not surprising, to find that we determine the same redshift by both methods, and that we agree with RW. In galaxy 4, our spectra show the G-band clearly, although it was not detected by RW. For galaxy 3, our redshift differs from that of RW by 0.0006, while a nominal 1 σ error would be about 0.0003. This is not an alarming difference; and while it is conceivable that we have underestimated the uncertainty in our radial velocity, our spectrum has good signal-to-noise and we have confidence in the measured redshift. A more serious problem arises with the redshift of galaxy 2. Here, RW find a redshift which is 0.0006 *larger* than for galaxy 1, while we find a redshift which is 0.0011 *smaller* than for galaxy 1. In our measurements, the two galaxies were on the slit at the same time and were reduced using the same comparison exposures so that no drifts can have taken place. In the raw vidicon image, and in direct comparison of the spectra (Fig. 2), there is no doubt that galaxy 2 has a *smaller* redshift than galaxy 1.

We have also observed galaxies 7 and 8 which are superposed. Almost all the light in our spectrum comes from galaxy 7, and therefore it is the redshift of that galaxy which we have measured. Here we disagree with RW by a large amount: we find a redshift which is smaller than theirs by 0.0064. The data from RW for galaxy 7 are very noisy whereas our own are comparable to those for galaxies 2, 3, 4, and 5. In Figure 3, we show that the best redshift for galaxy 7 is substantially smaller than the redshift of galaxy 1, by displaying the spectrum for galaxy 7 *after* shifting

TABLE 2

POSITIONS AND VELOCITIES OF GALAXIES

Galaxy (RW)	α (1950.0)	δ	z (RW)	z (this work)	v (km s^{-1})	s
1	$10^h52^m15^s.64$	+40°43′31″.0	0.1166	0.1168	32970 ± 60	291 ± 60
2	16.27	28.3	0.1172	0.1157	32678 ± 53	184 ± 57
3	16.25	10.8	0.1168	0.1174	33129 ± 38	...
4	14.27	01.4	0.1167	0.1166	32917 ± 92	361 ± 86
5	14.71	10.9	...	0.1153	32572 ± 125	...
6	17.18	12.5	...	...	...	...
7 and 8	18.00	36.5	0.1169	0.1105	31294 ± 115	...
9	17.93	44.5	...	0.1107	31347 ± 210	...
10	15.62	47.9	...	...	...	...
11	15.51	52.4	...	...	...	...
12	13.79	37.4	...	...	...	...
13	14.30	23.5	...	...	...	...
14	13.71	42 32.9	...	...	...	...
15	12.37	43 13.7	...	...	...	...
16	13.48	42 56.0	...	...	...	...
17	12.98	43 26.1	...	...	...	...

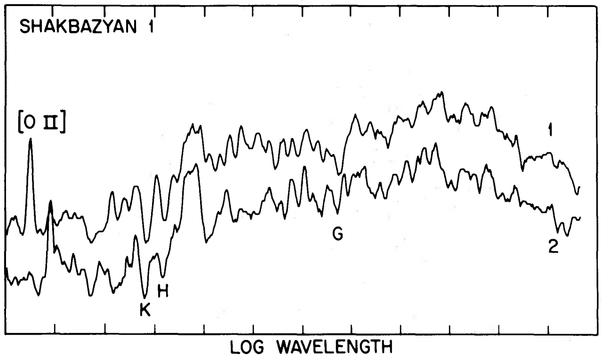

FIG. 2.—Spectra in logarithmic wavelength units for galaxies 1 and 2. Careful comparison of these two spectra shows that galaxy 2 has a significantly *smaller* redshift than galaxy 1. This is contrary to the result of Robinson and Wampler (1973). Our best estimate of the difference is $\Delta z = 0.0011$. The abscissa has thick marks at intervals of 0.01 in log λ, corresponding to 0.023 in redshift.

it by 0.063. The good correspondence seen here is destroyed if we use the relative shift of RW.

We have also measured redshifts for galaxy 5 and galaxy 9. The spectrum of galaxy 5 has good signal-to-noise, but galaxy 9 is by far the worst spectrum from which we were able to extract a redshift. Both our direct measurement of the spectrum and our Fourier quotient measurement suggest that the redshift for galaxy 9 is close to the redshift of galaxy 7. The spectrum is displayed in Figure 3, where the *shifted* spectrum is shown so the reader may judge whether a reasonable redshift has been determined. We note that very few photons were detected near H and K for galaxy 9, so that the redshift is determined by a longer wavelength region of the spectrum.

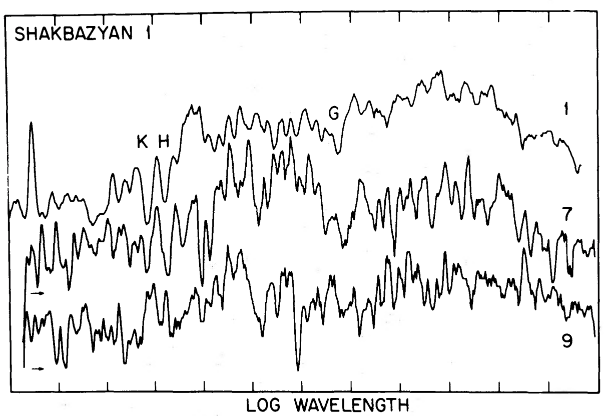

FIG. 3.—Shifted spectra of galaxies 7 and 9 compared to the observed spectrum of galaxy 1. Here we have shifted the spectrum of galaxy 7 by 0.0063, and that of galaxy 9 by 0.0061, so that they have the best match with galaxy 1. The arrows at the left of the spectra indicate the amount by which each spectrum has been shifted. The distance between tick marks on the abscissa is 0.01 in log λ, which corresponds to 0.023 in redshift. It is clear that without shifting galaxy 7, the match with galaxy 1 would be very poor. Galaxy 9 has very poor signal-to-noise near H and K, but near the G-band the statistics are not so bad. Our best value from the Fourier quotient technique gives a redshift for 9 which is very similar to that for galaxy 7.

b) The Virial Theorem

The previous applications of the virial theorem to this group by RW and ABJ have derived very small values of M/L. Here we employ a slightly more sophisticated method for applying the virial theorem (Kirshner 1977) and use the new set of redshifts. We assume that each galaxy has the same M/L so that the mass of each galaxy is just proportional to its luminosity. We compute the kinetic energy, taking proper account of the measuring errors through the method of Materne (1974), and we calculate the potential energy using the positions on the sky measured on Kinman's plate. In the spirit of § III*a*, we take into account first-order relativistic effects. For the virial theorem, this means converting from angular distances to linear distances with the correct "angular diameter distance," d_A. From Weinberg (1972) we have $d_A = (1 + z)^{-2} d_L$, where d_L is the luminosity distance. Unlike Materne, we do *not* assume that radial velocities in the cluster provide information about the distances of individual galaxies.

As shown in Table 3, we have done the virial analysis in several ways. First we use the redshifts measured by RW for the four galaxies where they had good data. We see that taking proper account of the measuring errors in a situation where the velocity differences are comparable to the measuring errors requires that the true kinetic energy be very low. Using our own measurements for these four galaxies leads us to believe that the errors quoted in RW may be somewhat underestimated, but in any event our own M/L for the same galaxies is only 6 ± 2.

In the original RW work, a poor measurement of galaxy 7 was included: but since the uncertainty in its velocity was larger than the velocity difference from the mean for the group, this had essentially no effect on the virial analysis. Our own measurement of galaxy 7 indicates that it has a large velocity difference, and this makes a substantial contribution to the estimated kinetic energy. We find an M/L of 67 ± 9. Because our data for galaxy 7 are good, and our uncertainty in the redshift is comparable to those for galaxies 4 and 5, we have confidence that this result is correct.

When we include all the galaxies for which we have radial velocities, we find a value of $M/L = 111 \pm 15$. The difference between this result and the value found by RW is not the result of any error on their part, but rather is due to the small sample of galaxies that they

TABLE 3

VIRIAL ANALYSIS OF SHAHBAZIAN 1

Data Source	Galaxies	M/L	$\langle\sigma^2\rangle^{1/2}$
RW............	1, 2, 3, 4	0.3 ± 0.8	47
This work.......	1, 2, 3, 4	6 ± 2	197
This work.......	1, 2, 3, 4, 7	67 ± 9	652
This work.......	1, 2, 3, 4, 5, 7, 9	111 ± 15	840

were able to measure. We might ask whether our own result might be as sensitive to an increased sample. In fact, it is impossible for an increased sample of redshifts to force M/L for this group back down to the levels measured by RW. Additional velocities can have relatively little effect on the kinetic energy contributed to the group by galaxies 7 and 9. While additional velocities are desirable, repeated measurements for galaxies 7 and 9 are more important in establishing the moderately large value of M/L seen by us.

The value of $M/L_v \sim 100$ compares reasonably well with measurements in loose groups of galaxies where $M/L_v \sim 30$ or in rich clusters of galaxies where $M/L_v \sim 250$ (see Faber and Gallagher 1979). It provides another piece of evidence that the galaxies in this group must be ordinary.

If we use the entire set of redshifts, we find that the group has a crossing time which is about 1/200 the Hubble time, for a harmonic radius of 166 kpc. Whether we use this measure, or the moment-of-inertia crossing time of Jackson (1975), we can be certain that this group has had plenty of time to settle into virial equilibrium. This impression is strengthened by the fairly regular shape of the group and the presence of the brightest galaxies near the center. Once we know M/L, we can calculate the mean mass density inside the harmonic radius, which is $\bar{\rho} \simeq 1.5 \times 10^{-25}$ g cm^{-3}. Again, we can compare this to the value found for the Coma cluster of $\bar{\rho} \approx 2.4 \times 10^{-25}$ ($H_0 = 50$, Rood *et al.* 1972). The qualitative similarity between Shahbazian 1 and the central region of Coma was pointed out in T76. We conclude that the galaxies in this group are not extraordinary, but the group itself is remarkably dense.

c) Velocity Dispersions

The evidence from photometry and from the dynamics of the group indicates that the galaxies are ordinary. Yet, the computed M/L is quite sensitive to the measurements for galaxies 7 and 9. We seek another way to test whether the galaxies in the group have extraordinary values of M/L. To do this, we employ measures of the central velocity dispersion obtained from the Fourier quotient method. As shown by Faber and Jackson (1976) and extended by S^{2}BS and SG, there is a correlation between the velocity dispersions in elliptical galaxies and their luminosities of the form $L \propto s^4$. For three of our galaxies, 1, 2, and 4, we have been able to measure s with a reasonable degree of confidence. From the colors of the galaxies and from inspection of the photograph by ABJ, we have confidence that these are all elliptical galaxies.

Schechter and Gunn have found that the core M/L_B for ellipticals is near 6, and there is no strong variation in M/L with luminosity. If the galaxies in Shahbazian 1 had much lower mass-to-light ratios, then they would have smaller velocity dispersions at a given absolute magnitude. If we make the crude assumption that all ellipticals have the same central surface brightness, then $s^4 \propto (M/L)^2L$.

TABLE 4

INTERNAL VELOCITY DISPERSIONS AND MAGNITUDES

Galaxy	s	M_B (observed)	M_B (predicted)
1	291 ± 60	−21.6	−21.8 ± 1.0
2	184 ± 57	−20.9	−19.8 ± 1.4
4	361 ± 86	−20.7	−22.7 ± 1.1

In Table 4, we compare the observed values of s and M_B with the values predicted by SG, based on their observations of ordinary elliptical galaxies. We see that, within the uncertainties, the galaxies in Shahbazian 1 have the *same* M/L as ordinary ellipticals. If we accept both this conclusion, and the results of the virial analysis, then we find that Shahbazian 1 is not immune to the problem of the "missing mass": the central regions of the galaxies have $M/L_v \sim 5$ (for $M/L_B \sim 6$) and the cluster may have $M/L_v \sim 100$.

IV. DISCUSSION

The evolution of galaxies in dense groups is of considerable interest. This group is unusually dense, and has the appearance of having relaxed. In particular, the group is moderately symmetric and has its largest galaxy near the center. In addition, there is a measurable amount of diffuse luminosity in the group. In these respects, this group resembles a rich cluster of galaxies.

On the other hand, the luminosity function for this group is not at all unusual and gives no strong indication of the effects of galactic cannibalism. Also, despite the great concentration of this group, and despite the presence of intragalactic matter, there are at least two galaxies, 7 and 9, which have the colors of spiral galaxies and a third, 12, which has no measured color but which has the appearance of a spiral (T76). To facilitate discussion, we have summarized some of the properties of the group in Table 5.

We now take a brief look at the results of investigations into galaxy interactions, and compare them to the data for Shahbazian 1.

TABLE 5

MEASURED AND DERIVED PROPERTIES OF SHAHBAZIAN 1
($q_0 = 0$, $H_0 = 50$)

Parameter	Symbol	Value
Redshift	z	0.116
Distance modulus	$m - M$	39.34 mag
Luminosity distance	d_L	736 Mpc
Total visual luminosity	L_v	$4 \times 10^{11} L_\odot$
Angular size	...	50″ × 100″
Angular diameter distance	d_A	590 Mpc
Linear size	...	140 × 280 kpc
Harmonic radius	r	166 kpc
Number of galaxies	...	20
Luminosity density	...	$2 \times 10^{13} L_\odot$ Mpc^{-3}
RMS velocity dispersion	σ	840 km s^{-1}
Characteristic space velocity	v	1450 km s^{-1}
Mass-to-light-ratio	M/L_v	$111 \pm 15\ M_\odot/L_\odot$
Mass density	ρ	1.5×10^{-25} g cm^{-3}

In an elementary way, we can estimate whether galaxy collisions have been important during the lifetime of this group. Because the typical galaxy velocities are large compared to the internal velocity dispersion in the galaxies, we take the cross section for significant collisions to be the geometrical cross section. Then, for 20 galaxies of radius R in a region with radius 160 kpc, we find the collision time, given a one-dimensional velocity dispersion of 840 km s^{-1}, to be

$$t = 6 \times 10^8 (R/10 \text{ kpc})^{-2} (\sigma/840 \text{ km s}^{-1})^{-1} \text{ years} . \quad (2)$$

The collision time is considerably shorter than the Hubble time. This makes it very likely that many of the galaxies have undergone collisions. In particular, while some of the small galaxies in the lowest density regions of the group may have avoided interactions, the largest galaxies and those in the densest regions can hardly have escaped.

What is the evidence that collisions have actually taken place? Hickson, Richstone, and Turner (1977) have shown that the diameter of the largest galaxy in a group is a strongly decreasing function of the mean intergalaxy separation. They attribute this effect to tidal stripping in galaxy collisions. We find for Shahbazian 1 that the diameter for galaxy 1 is roughly 40 kpc, and the typical value of the intergalaxy separation is about 100 kpc. This falls squarely among the values derived for groups by Hickson, Richstone, and Turner, and amid the values attributed to the effects of tidal stripping. Nevertheless, it seems unreasonable to infer merely from this coincidence that galaxy 1 must have undergone any rearrangement.

A more direct inference can be made from the diffuse matter in the cluster. The diffuse matter in the cluster has about 5% of the luminosity (M77) or about the luminosity of one galaxy.

Gallagher and Ostriker (1972) have computed the efficiency of galaxy collisions in producing the diffuse matter in rich clusters. They show that the mass accumulated in a cluster depends on the product $NT\eta$, where N is the number of galaxies, T the number of times a galaxy has crossed the cluster, and η is the surface density of galaxies in the cluster. Then, following their calculation, we can scale the results to the Shahbazian 1 group:

$$M(\text{Shah}) = M(\text{Coma}) \frac{N(\text{Shah})}{N(\text{Coma})} \frac{T(\text{Shah})}{T(\text{Coma})} \frac{\eta(\text{Shah})}{\eta(\text{Coma})}$$

$$M(\text{Shah}) = 6.5 \text{ galaxies} \times 1 . \quad (3)$$

Here, we assume N(Shah) of 20, N(Coma) of 2000, T(Shah) of 200, T(Coma) of 10, η(Shah) of 2×10^{-9} pc^2, and η(Coma) of 5×10^{-10} pc^2. The net result is that the mass shed by galaxies in Shahbazian 1 should be comparable to that lost by all the galaxies in the Coma cluster. Since the observed diffuse matter in the Shahbazian 1 group accounts for 5% of the light, we expect it has a mass of the order of 1 galaxy mass. It is well within the scope of the mechanism described by Gallagher and Ostriker to produce this diffuse material.

We can now ask whether the diffuse matter damps the orbits of the galaxies through dynamical friction. Following Chandrasekhar (1942), Spitzer (1962), and Tremaine, Ostriker, and Spitzer (1975), we write

$$T = \left(\frac{1}{v}\frac{dv}{dt}\right)^{-1}$$

$$\approx \frac{20 \times 10^9 [v/(1450 \text{ km s}^{-1})]^3}{[M_{\text{gal}}/(2 \times 10^{12} M_\odot)][\rho_{\text{diffuse}}/(7.5 \times 10^{-26} \text{ g})](\frac{1}{3} \ln \Lambda)} \text{ years} . \quad (4)$$

Here we have assumed that the M/L ratio for the diffuse matter is the same as it is for the galaxies, so that 5% of the light implies 5% of the mass density.

The dynamical friction time is just in the interesting range comparable to the Hubble time. If we have overestimated the typical galaxy velocity, or if the M/L for the diffuse matter is higher than for galaxies, then the effects of dynamical friction may be decisive in determining the present appearance of the group. One can speculate that the high density of the group may be the result of dissipation. This possibility is also suggested by the large extent of the diffuse matter as noted in M77—this material may have a very high kinetic temperature as a result of interactions with galaxies. It seems possible that detailed measurements of the distribution and color of the diffuse light in this group may shed some light on the dynamical processes at work.

If galaxy collisions have been important in the history of this group, it may seem surprising that three galaxies have survived as spirals. However, as Butcher and Oemler (1978) have shown, the spiral galaxy content is 10–20% even in highly concentrated rich clusters. Because the collision time in equation (3) is not extremely short, it seems reasonable that some galaxies whose orbits do not pass through the densest regions of the group may have evaded galaxy collisions and retained their gas.

V. SUMMARY

We have obtained new spectroscopic observations of galaxies in the Shahbazian 1 group which lead to the conclusion that the galaxies in the group have ordinary masses. This is the case both for a virial analysis of the galaxies' external motions and for measurements of the internal velocity dispersions. The earlier workers on this group came to a different conclusion because the sample of galaxies measured was small and because of a systematic error in photometry.

The extraordinary thing about the Shahbazian 1 group is its density. From the photometry and mean redshift we note that this group has 10^5 times the background luminosity density. From the virial analysis we find it has 10^4 times the closure density for $H_0 = 50$. In such a dense region, interactions among galaxies are likely and it seems plausible that the diffuse matter in this group is the result of galaxy collisions. A more mysterious fact is that the group appears to lack many outlying members, since galaxies moving with the Hubble flow will be bound to the group out to a distance of megaparsecs. More thorough photometry of the group, both to map the diffuse matter and to search for more galaxies in the group, seems well worth the effort.

We thank the Director of the Hale Observatories for granting valuable telescope time, J. B. Oke and Barbara Zimmerman for their energetic assistance, Gary Tuton for his patience and skill, Paul Schechter for his powerful program, Tom Kinman for the use of his plate, Roger Chevalier for his help, and the Alfred P. Sloan Foundation for its generous support.

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