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DYNAMICS OF THE PERSEUS CLUSTER OF GALAXIES

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ABSTRACT

Carnegie image-tube spectra obtained in November 1970 with the 84-inch telescope of the Kitt Peak National Observatory have yielded radial velocities for forty-two more galaxies in a central region of the Perseus cluster. This brings the total number of known velocities to forty-nine. Since their frequency distribution of velocities is nearly Gaussian, we treat the entire sample as cluster members. The average velocity (relative to the Local Group of galaxies) is $\langle V_0 \rangle = 5460 \pm 200$ km s^{-1}. The standard deviation is $\sigma_{V_0} = 1420 \pm 140$ km s^{-1}, the largest of any cluster studied up to the present.

NGC 1265, a prominent galaxy whose membership is indicated by radio observations, has a radial velocity $V_0 = 7660$ km s^{-1} which is 2370 km s^{-1} larger than the velocity of NGC 1275, the luminous Seyfert member. To prevent the escape of NGC 1265, and to stabilize the cluster, its mass must be about $10^{15}\ M_\odot$. Otherwise, the large-velocity dispersion and the asymmetrical structure of the cluster imply instability, with an expansion age about 3×10^8 years, which seems to be in conflict with the observed late-type spectra.

I. INTRODUCTION

The Perseus cluster of galaxies (see Fig. 1 [Pls. 1 and 2]) is remarkable in many respects: (1) Its core is far from spherical; a prominent chain of galaxies contains three of the four brightest members: NGC 1275, NGC 1272, and IC 310. The other most luminous galaxy, NGC 1265, is relatively isolated at 27′ northwest of NGC 1275. The last three named are nonthermal radio sources and form an isosceles triangle. (2) NGC 1275, the brightest member, is a Seyfert galaxy whose nuclear radial velocity is close to the mean velocity of the cluster. The filamentary material departing from the nucleus shows two velocities, one equal to the nuclear velocity and one 3000 km s^{-1} larger. These filaments may have originated in violent nuclear activity (Minkowski 1957; Burbidge and Burbidge 1965; Lynds 1970). (3) Recent radio observations at 408 and 1407 MHz by Ryle and Windram (1968) show physical interaction between NGC 1275, NGC 1265, and IC 310. The outer radio contours of the latter two are tailed away from NGC 1275, and the radio center is displaced from the optical center away from NGC 1275.

Only seven velocities are given in the reference catalog of de Vaucouleurs and de Vaucouleurs (1964). Because the dynamics of the cluster is so poorly known, an observational program of measuring radial velocities was undertaken last year.

II. OBSERVATIONS AND RESULTS

Spectra of forty-three galaxies were obtained in November 1970 at Kitt Peak National Observatory with the Carnegie image-tube Cassegrain spectrograph attached to the 84-inch telescope, dispersion 250 Å mm^{-1} over the wavelength range 3500–6000 Å. The focus of the spectrograph was optimized for $\lambda = 4000$ Å, and whenever possible the slit was oriented so as to cross two galaxies (Fig. 2 [Pls. 3 and 4]). Radial velocities were measured with a digitized two-screw Grant comparator and UNIVAC 1108 computer. The galaxies were selected according to their luminosity, except along the chain, where a more complete coverage was attempted (Figure 1). Most of the spectra ob-

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1971ApJ...168..321C

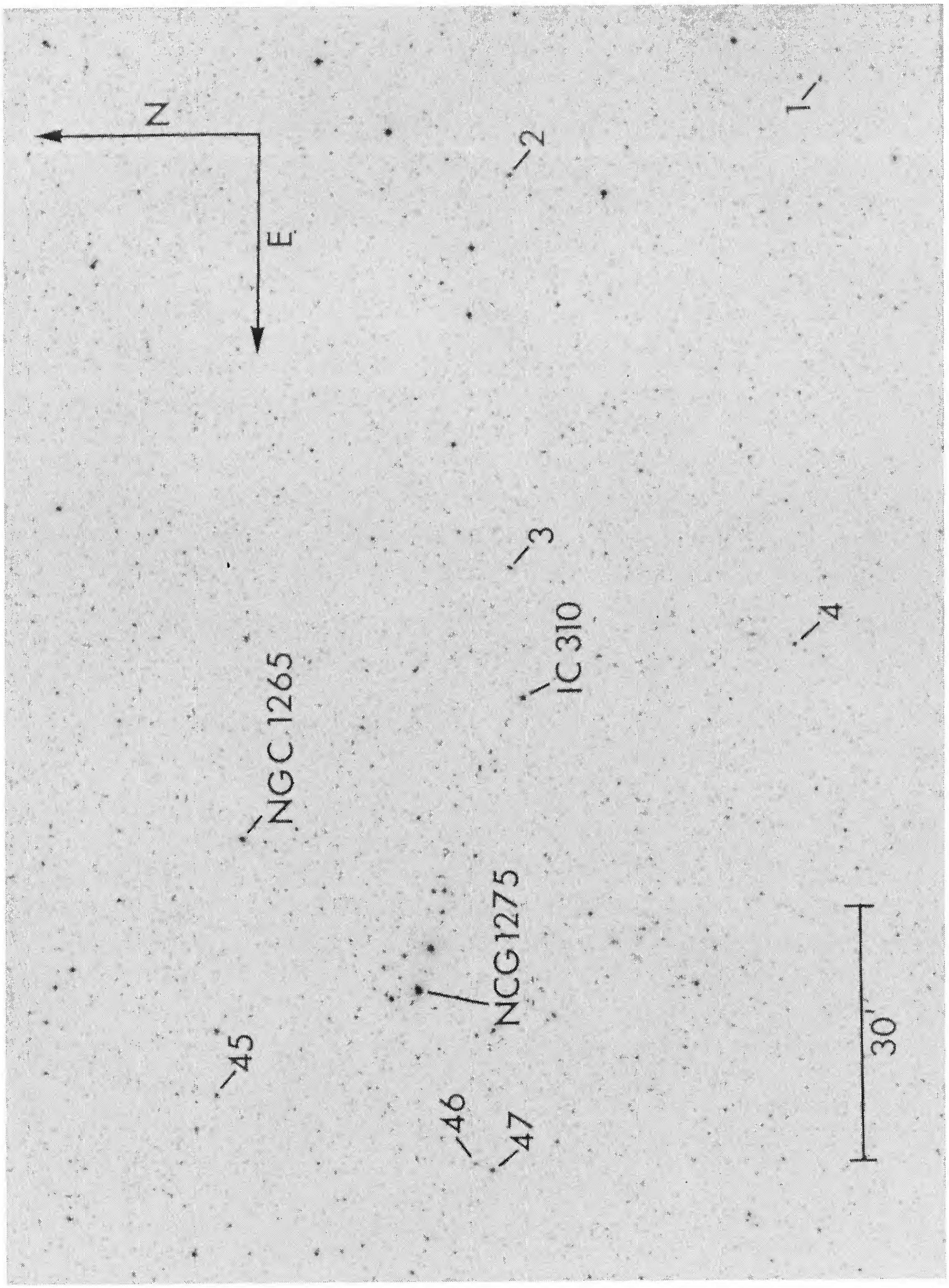

FIG. 1*b*.—Identification chart for the Perseus cluster of galaxies (© 1957, National Geographic Society—Palomar Observatory Sky Survey).

CHINCARINI AND ROOD (*see* page 321)

1971ApJ...168..321C

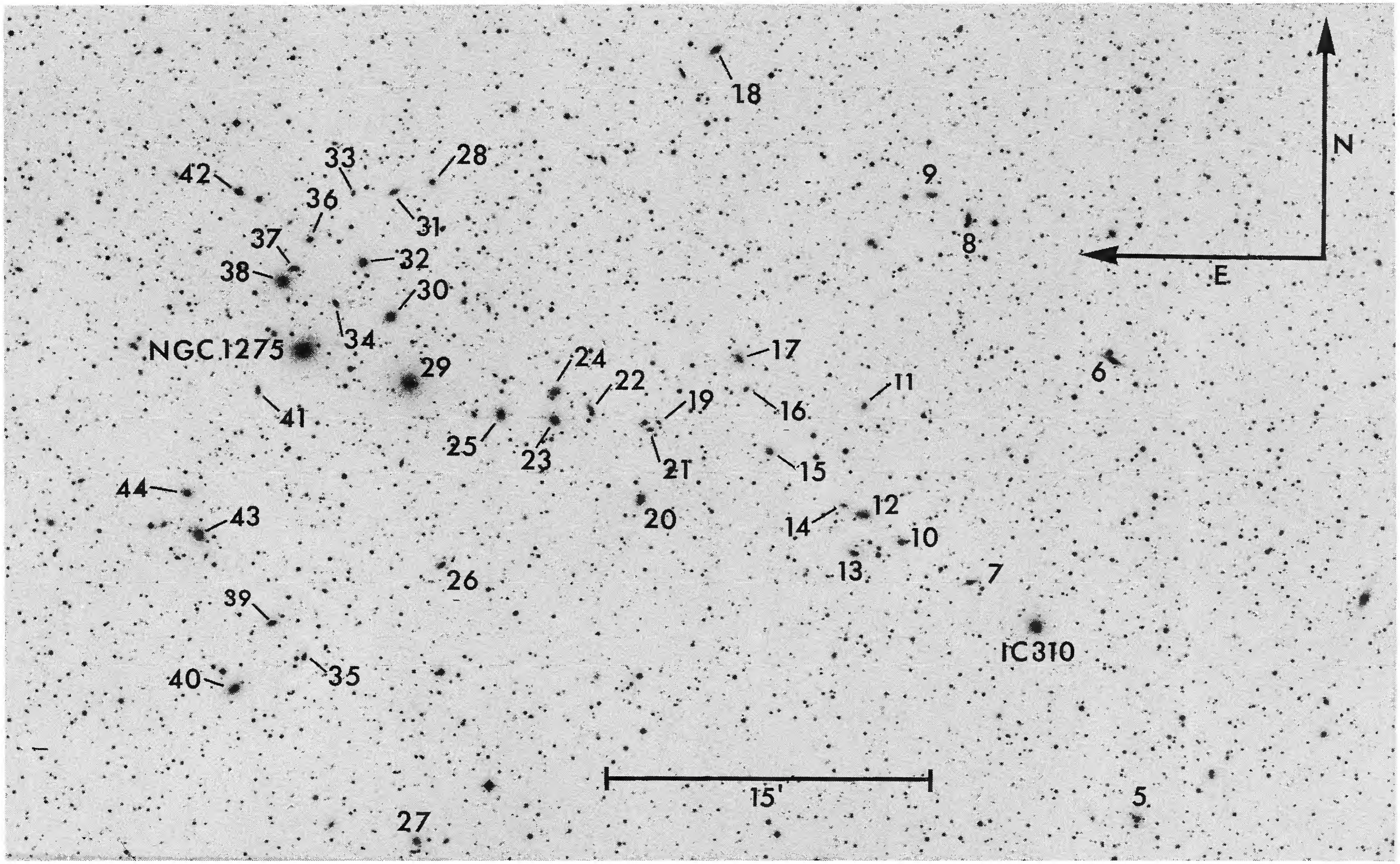

FIG. 2*b*.—Identification chart for the Perseus cluster of galaxies (© 1957, National Geographic Society—Palomar Observatory Sky Survey)

CHINCARINI AND ROOD (*see* page 321)

served are of late type showing the H- and K-lines of Ca II, and the G-band. Weak λ3727 [O II] emission was detected in two galaxies, one of which is an outlying galaxy. One spectrum is very weak and the line identification is uncertain; its velocity has been excluded from the analysis.

The radial velocities, referred to the Local Group of galaxies, and other data are given in Table 1. The radial velocities, rounded off to the nearest 100 km s^{-1}, are also presented in Figure 3 (Plate 5). These are based on the H- and K-lines of Ca II. G-band velocities are in good agreement, but were not averaged in, because the G-band is too far from the optimum focus. Our sample of forty-nine velocities is well represented by a Gaussian frequency distribution (Fig. 4). On the basis of this, together with estimates of the number of foreground and background galaxies, we treat the entire sample as cluster members.

Figures 2–4 clearly show that the velocity range in the cluster is extraordinarily large. The standard deviation is $\sigma_{V_0} = 1420 \pm 140$ km s^{-1}, the largest of any cluster we know of. Figure 3 does not reveal any clear correlation between velocity and position, although the velocities of galaxies midway between NGC 1275 and IC 310 along the chain seem small, and higher velocities seem to be clustered on the east side of IC 310 and north of NGC 1275.

The mean velocity of the cluster is $\langle V_0 \rangle = 5460 \pm 200$ km s^{-1}, which is within 200 km s^{-1} of the velocities of NGC 1275 and IC 310. The velocity of NGC 1265, however, is 2200 km s^{-1} larger than the cluster mean!

For each of the forty-nine galaxies, the distance R from NGC 1275 and the major and minor axes (a and b) were measured from a print of the red Palomar Sky Survey plate. Ellipticity (ϵ) was calculated, and apparent magnitudes for the brighter galaxies were obtained from Zwicky and Kowal (1968). Results of the search for correlation between $\langle V_0 \rangle$, σ_{V_0}, and R, m_p, ϵ are given in Table 2. The small mean velocity for $10' \leq R \leq 25'$ reflects the small velocities near the center of the chain. The bright galaxies ($m_p \leq 14.5$) have a small mean velocity also, possibly because one or more are foreground objects. The velocity dispersion seems to be larger than average for galaxies which are nearest to NGC 1275, and for the flatter galaxies. Further data are required to establish the statistical significance of these tentative conclusions.

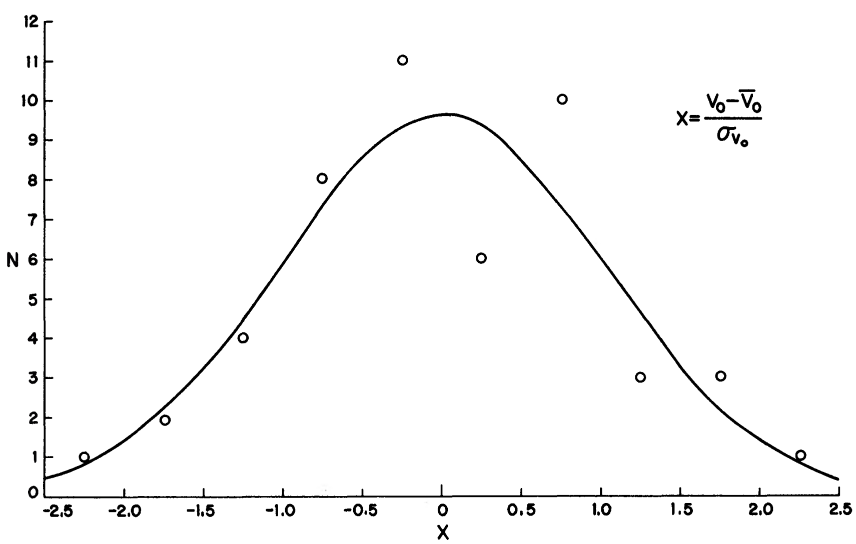

FIG. 4.—Velocity frequency distribution of forty-nine Perseus galaxies identified in Figs. 1 and 2. Curve represents a Gaussian with the velocity dispersion of the sample

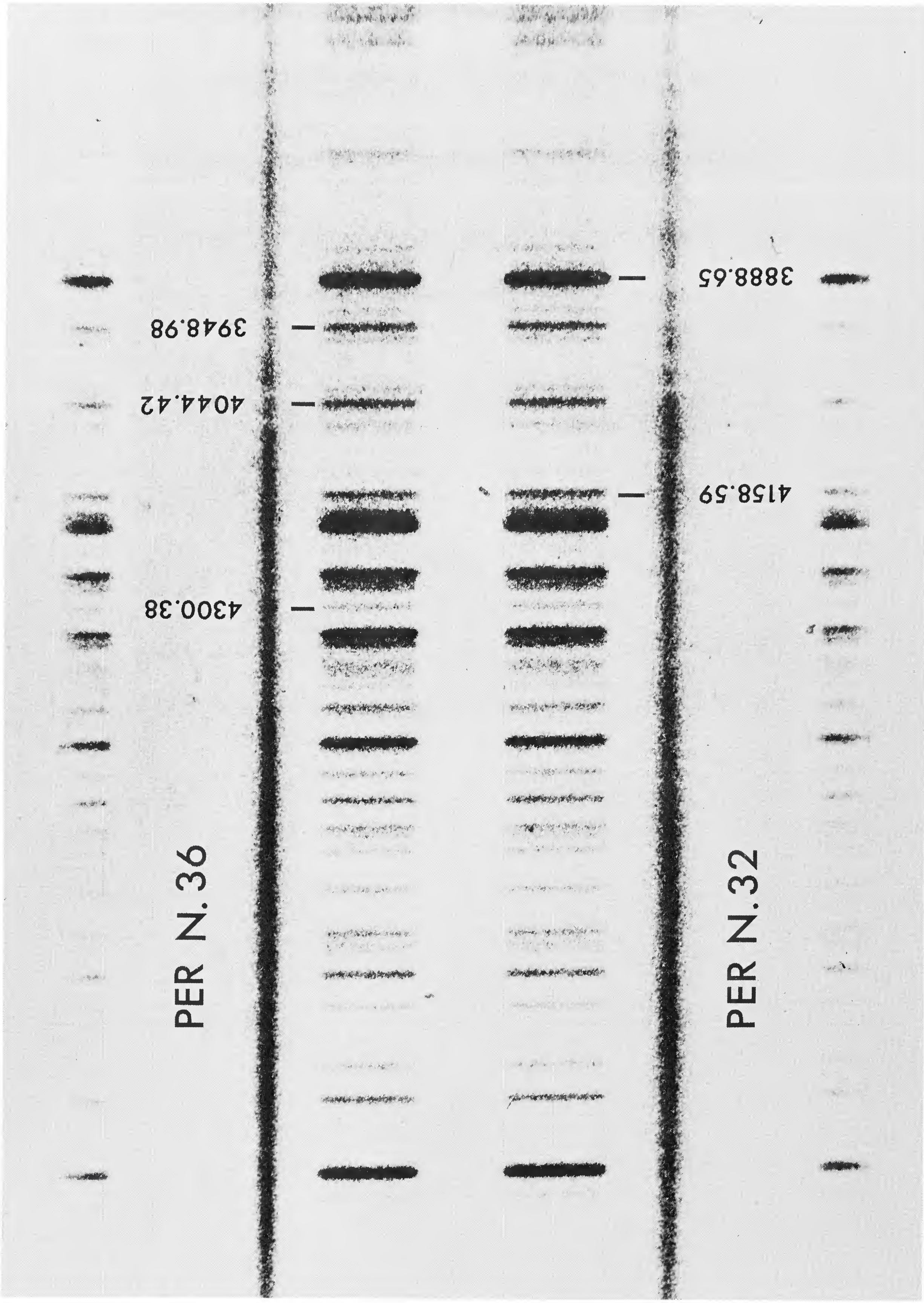

FIG. 3.—Spectrogram of Perseus galaxies No. 32 and No. 36 with He-Ne-Ar comparison spectra. Ca II absorptions visible.

CHINCARINI AND ROOD (*see* page 322)

TABLE 1

VELOCITIES (V_0), MAGNITUDES (m_p), DISTANCE FROM NGC 1275 (R), AND ELLIPTICITY (ϵ) OF GALAXIES IN THE PERSEUS CLUSTER

No.	NGC	α (1950)	δ (1950)	V_0 (km s^{-1})	m_p*	R (′)	ϵ
(1).........	292†=1887†	3^{h}07^{m}0	40°35′	3140‡	14.3	117	0.6
(2).........	1224	3 08.0	41 11	5174	15.5	96.5	0.3
(3).........	1250	3 12.0	41 10	6317	14.2	50.6	0.8
(4).........	309†	3 12.8	40 38	4357	14.9	59.2	0.0
(5).........	...	3 13.0	41 00	6411	...	44.2	0.3
(6).........	...	3 13.2	41 21	4867	14.7	37.7	0.8
	310†	3 13.4	41 08	5328	14.3	36.4	0.0
(7).........	...	3 13.7	41 10	6477	15.7	32.7	0.8
(8).........	...	3 13.7	41 27	7351	15.0	31.4	0.6
(9).........	...	3 13.9	41 28	6075:	...	29.9	0.4
(10).........	...	3 14.0	41 12	5960	...	29.0	0.1
(11).........	...	3 14.2	41 18	4783	...	26.1	0.3
(12).........	1260	3 14.2	41 13	5640	14.2	27.0	0.5
(13).........	...	3 14.2	41 11	6561	...	27.0	0.4
(14).........	...	3 14.3	41 13	6077	...	26.1	0.4
(15).........	...	3 14.6	41 16	4423	15.4	22.2	0.3
(16).........	...	3 14.7	41 19	4861	...	20.7	0.4
(17).........	...	3 14.7	41 20	3365	...	20.3	0.5
(18).........	312†	3 14.8	41 34	4923	14.9	23.7	0.6
(19).........	...	3 15.0	41 17	3529	...	16.9	0.4
	1265	3 15.1	41 40	7656	14.7	26.9	0.3
(20).........	...	3 15.1	41 14	6471	15.3	17.1	0.5
(21).........	...	3 15.1	41 17	5053	...	16.6	0.6
(22).........	...	3 15.3	41 17	3457	15.7	13.7	0.5
(23).........	1267	3 15.5	41 17	5230	15.4	12.2	0.0
(24).........	1268	3 15.5	41 18	3243	14.5	12.0	0.1
(25).........	1270	3 15.7	41 17	5036§	14.4	9.7	0.3
(26).........	1271	3 15.9	41 10	5855	15.4	11.7	0.4
(27).........	...	3 16.0	40 58	8007	...	23.1	0.1
(28).........	...	3 16.0	41 28	6323	...	9.8	0.3
(29).........	1272	3 16.1	41 18	4303§	14.5	5.1	0.1
(30).........	1273	3 16.2	41 21	5485§	14.7	4.4	0.2
(31).........	...	3 16.2	41 27	7980‡	15.5	8.4	0.6
(32).........	...	3 16.3	41 24	4568	15.2	4.9	0.1
(33).........	...	3 16.4	41 27	8565	...	7.5	0.5
(34).........	1274=1907†	3 16.4	41 22	6578§	15.1	2.7	0.4
(35).........	...	3 16.5	41 06	5518	...	14.1	0.5
	1275	3 16.5	41 20	5291§	13.0	0.0	0.1
(36).........	...	3 16.5	41 25	7473	...	5.1	0.3
(37).........	1277	3 16.6	41 23	5105§	14.9	3.7	0.5
(38).........	1278	3 16.7	41 22	6246§	14.4	3.4	0.3
(39).........	...	3 16.6	41 07	3710	...	12.6	0.5
(40).........	...	3 16.8	41 04	4337	15.6	15.9	0.3
(41).........	...	3 16.7	41 18	7390	...	2.8	0.6
(42).........	1281	3 16.8	41 27	4371	15.0	7.8	0.5
(43).........	1282	3 17.0	41 11	2321	14.3	9.8	0.3
(44).........	1283	3 17.0	41 13	6845	15.6	8.5	0.2
(45).........	313†	3 17.6	41 42	4548	15.1	26.3	0.3
(46).........	1293	3 18.4	41 13	4247	15.0	21.5	0.1
(47).........	1294	3 18.5	41 11	6667	15.1	22.8	0.2

NOTE.—A colon indicates that the line identification is uncertain.
* Values from Zwicky and Kowal (1968).
† IC.
‡ Weak λ3727 [O II] emission.
§ Value from de Vaucouleurs and de Vaucouleurs (1964).

TABLE 2

MEAN, DISPERSION, AND NUMBER OF VELOCITIES OF GALAXIES SEPARATED ACCORDING TO DISTANCE FROM NGC 1275 (R), APPARENT MAGNITUDE (m_p), AND ELLIPTICITY (ϵ)

Range	Mean Velocity (km s^{-1})	Dispersion (km s^{-1})	N
$0' \leq R \leq 10'$	5870 ± 400	1670 ± 300	16
$10' < R \leq 25'$	4880 ± 320	1460 ± 250	17
$R > 25'$	5660 ± 290	1190 ± 210	16
$m_p \leq 14.5$	4690 ± 440	1600 ± 360	10
$14.5 < m_p \leq 15.5$	5570 ± 280	1210 ± 200	19
$m_p > 15.5$	5730 ± 350	1590 ± 250	20
$\epsilon \leq 0.2$	5350 ± 360	1290 ± 250	13
$0.3 \leq \epsilon \leq 0.4$	5460 ± 320	1370 ± 230	18
$\epsilon \geq 0.5$	5540 ± 380	1630 ± 270	18
Total	5460 ± 200	1420 ± 140	49

III. DISCUSSION

The Perseus cluster of galaxies has at least three unstable characteristics: (*a*) its core has a nonspherical shape, (*b*) its brightest member is a Seyfert galaxy, and (*c*) there is radio emission showing interaction between two members and relativistic particles ejected from the Seyfert galaxy. Any connection between these characteristics and the dynamics of the cluster would be of cosmological significance.

We first estimate the mass of the cluster, assuming that it is stable. One determination of the mass is based on the velocity of escape. NGC 1265, shown by Ryle and Windram (1968) to be physically interacting with NGC 1275, has a radial velocity 2200 km s^{-1} larger than the cluster mean. If NGC 1265 is bound to the cluster by a radially symmetric mass distribution with centroid near NGC 1275, then its projected distance from the centroid is 0.6 Mpc (if a value of 75 km s^{-1} Mpc^{-1} is used for the Hubble constant) and the mass of the cluster is greater than $3 \times 10^{14} M_\odot$. Projection factors further increase this limit by a factor of 4.7, on the average. Therefore, it is likely that the mass of the cluster is greater than $10^{15} M_\odot$. This estimate, however, is sensitive to uncertainties in the adopted model and centroid for the cluster.

If the mass-weighted space-velocity dispersion of the cluster is $\sigma_V = \sqrt{3}$ (1400 km s^{-1}), and the harmonic mean radius $\langle R \rangle \approx 1$ Mpc,[1] then the "virial theorem mass" is $M_{\mathrm{VT}} = \sigma_V^2 \langle R \rangle / G \approx 10^{15} M_\odot$.

Such a large cluster mass either gives an average mass of 10^{12}–$10^{13} M_\odot$ for the individual galaxies, found frequently in clusters and groups of galaxies (see, e.g., Limber 1961; Karachentsev 1966; de Vaucouleurs 1968; Rood, Rothman, and Turnrose 1970), or requires the presence of a great amount of unobserved mass between the galaxies observed in the cluster. We are not inclined to admit this possibility of adequate intergalactic mass in the cluster (e.g., neutral or ionized hydrogen), because of analyses by Woolf (1967) and Turnrose and Rood (1970). The large "mass" of the Perseus cluster therefore is explained with difficulty if the cluster is bound, and may suggest instability.[2]

[1] $\langle R \rangle = 1$ Mpc is typical for rich clusters. A more accurate value must await a detailed study of the mass distribution of the Perseus cluster.

[2] However, for the Coma cluster of galaxies the mass discrepancy is smaller, and there are various independent factors indicating that the cluster is stable (Rood and Turnrose 1968; Rood 1969; Rood *et al.* 1971).

The Perseus cluster's prominent chain of galaxies could form from a collapsing gaseous mass in an expanding universe (Oort 1970). However, it is difficult to understand how this chain could persist for times exceeding several crossing times (a few times 10^8 years). The chain and its irregular velocity field are compatible with a young (less than 10^9 years) unstable cluster. The total translational kinetic energy ($\sim 10^{62}$ ergs) of all the galaxies in the Perseus cluster is 100 times larger than the energy of the particles which produce the radio emission from the cluster, and 10000 times the kinetic energy of the gas ejected by NGC 1275 (Burbidge and Burbidge 1965).

A clear connection between the instability of the cluster and the violent phenomena observed in some of its members has not been found. In summary: (i) NGC 1275 shows a filamentary structure (Crab Nebula type) with some emission patches receding from it at 3000 km s^{-1}. Relative to NGC 1275 and IC 310, NGC 1265 has a radial velocity of 2350 km s^{-1}. (ii) Several high-velocity galaxies seem to be clustered on the north side of NGC 1275. (iii) The 3000 km s^{-1} emission patch of NGC 1275 is at an angle of 30° to the direction of NGC 1265, and the radio contour axis of IC 310 is about 28° away from the line to NGC 1275. (iv) The center of the cluster, indicated by its radio emission, is within the NGC 1275–NGC 1265–IC 310 triangle. (v) The major axis of the cluster radio contours is almost perpendicular to the chain of galaxies.

It seems that the velocity observations indicate violent expansion, and the chain might imply an asymmetric explosion (Noerdlinger 1970). The absence of emission features in the galaxy spectra may indicate that the gas has been driven out of the galaxies by relativistic particles ejected from NGC 1275 and other radio galaxies.

In conclusion, we have evidence indicating that the Perseus cluster is unstable with expansion age about 3×10^8 years, but the cluster galaxies have mainly absorption late-type spectra.

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REFERENCES

Burbidge, E. M., and Burbidge, G. R. 1965, *Ap. J.*, **142**, 1351.
Karachentsev, J. D. 1966, *Astrofisika*, **2**, 81 (English transl. 1967, *Astrophysics*, **2**, 39).
Limber, D. N. 1961, *Problems of Extragalactic Research*, ed. G. C. McVittie (New York: Macmillan Co.), p. 239.
Lynds, R. 1970, *Ap. J.* (*Letters*), **159**, L151.
Minkowski, R. 1957, *Radio Astronomy*, I.A.U. Symposium No. 4, ed. H. C. van de Hulst (Cambridge: Cambridge University Press), p. 107.
Noerdlinger, P. D. 1970, *Ap. J.* (*Letters*), **159**, L17g.
Oort, J. H. 1970, *Science*, **170**, 1363.
Rood, H. J. 1969, *Ap. J.*, **158**, 657.
Rood, H. J., Page, T. L., Kintner, E. C., and King, I. R. 1971 (in preparation).
Rood, H. J., Rothman, V. C. A., and Turnrose, B. E. 1970, *Ap. J.*, **162**, 411.
Rood, H. J., and Turnrose, B. E. 1968, *Ap. J.*, **152**, 1057.
Ryle, M., and Windram, M. D. 1968, *M.N.R.A.S.*, **138**, 1.
Turnrose, B. E., and Rood, H. J. 1970, *Ap. J.*, **157**, 773.
Vaucouleurs, G. de. 1968, in *Stars and Stellar Systems*, Vol. **9**, ed. A.and M. Sandage (Chicago: University of Chicago Press) (in press).
Vaucouleurs, G. de, and Vaucouleurs, A. de. 1964, *Reference Catalog of Bright Galaxies* (Austin: University of Texas Press).
Woolf, N. J. 1967, *Ap. J.*, **148**, 287.
Zwicky, F., and Kowal, C. T. 1968, *Catalog of Galaxies and of Clusters of Galaxies*, Vol. **6** (Pasadena: California Institute of Technology).