SPECTRA AND OTHER CHARACTERISTICS OF INTERCONNECTED GALAXIES AND OF GALAXIES IN GROUPS AND IN CLUSTERS. I

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ABSTRACT

Some of the pertinent characteristics of four double galaxies have been investigated. The two component galaxies in each of these systems are separated by two to five times their diameters, and they are interconnected and surrounded by intergalactic luminous formations. The symbolic velocities of recession and the apparent dimensions and luminosities of the various parts of these systems were determined, and, from them, *indicative absolute dimensions*, *luminosities*, and *masses* were derived. These lie within rather narrow limits. This result may be interpreted as meaning that only galaxies of a certain size and mass can, on collision or otherwise, give rise to extended luminous intergalactic formations. Further data on similar systems and on larger groups of galaxies will be presented shortly. With data of this kind it appears possible to establish a relative extragalactic distance scale. Furthermore, information on the important problem will be obtained relating to the ratio of the total luminous to the total dark mass in associations of increasing size.

A. PLAN OF RESEARCH

During the last two years we have photographed the spectra of a considerable number of interconnected galaxies and member galaxies of groups and clusters. Most of the plates were obtained with the prime-focus spectrograph of the 200-inch telescope at a dispersion of 185 A/mm. The results of these investigations will be published in a series of articles, of which the present one is the first.

While the composition and the structure of groups and of clusters of galaxies is being studied in a parallel series of investigations, the analysis of the spectra in our files is being carried out with the following purposes in mind.

1. The dispersion of the redshifts of the components of interconnected galaxies, as well as within groups and clusters of galaxies is being studied.

2. Assuming that the differences of redshifts observed between individual galaxies in a group are caused by differences in actual radial velocities, limits for the products $h\mathfrak{M}_t$ are being established, were $\mathfrak{M}_t$ is the total mass of the group or cluster and h is the scale factor in the universal redshift-distance relation, as defined by the equations (1) and (2).

3. The study of the values of $h\mathfrak{M}_t$ of ever larger groups and clusters allows us to draw conclusions about the relative contributions of individual galaxies and of intergalactic matter to the total mass $\mathfrak{M}_t$ of the respective groups.

4. The study of the values of the products $h\mathfrak{M}_t$ of structurally similar and equally populated groups at different distances, in conjunction with the corresponding redshifts, furnishes the means for establishing whether or not the relation between the redshifts and the distances is linear, quite independent of any knowledge about the absolute distance scale.

5. Within the context of the analyses presented here, there are two significant ratios which are independent of the distance scale factor h. These ratios are $\mathfrak{M}_t/D$, where D is the absolute distance of the galaxy or cluster in question, and L/D^2, where L is the absolute luminosity of a galaxy or a cluster of galaxies. However, L/D^2 may be indirectly dependent on h if either interstellar or intergalactic absorption is present.

L/D^2 is equal to the directly measured apparent luminosity and consequently is independent of h only if there is no interstellar or intergalactic absorption whatever.

6. Since we believe that the determination of the extragalactic distance scale at the present time is still subject to severe uncertainties, we shall base all of our conclusions on the following definite but flexible premises:

a) If the universal redshift displaces a spectral line of the terrestrial wave length λ by the amount $\Delta\lambda$, we shall call $V_s = c\,\Delta\lambda/\lambda$ the symbolic radial velocity of the galaxy in question, where c is the velocity of light in vacuum.

b) We assume that, on the average, the distance D is a function of V_s only, such that

$$D = \frac{V_s}{H}, \tag{1}$$

where the redshift scale factor H, for small values of V_s/c, is a constant, while for larger values of V_s/c it may show some increasing dependence upon V_s.

c) For the redshift scale factor we shall write

$$H = hH_0 , \tag{2}$$

where H_0 is equal to 100 km/sec per million parsecs, that is, $H_0 = 3.33 \times 10^{-18}$ sec^{-1}, and h is a pure number of the order of unity. Hubble's original value for h is equal to 5.5. While h may be uncertain by as much as a factor 5, we need not at the present time attach ourselves to any definite value of h. For the purpose of visualizing orders of magnitude, however, we think of h as being unity. For the distance D of a remote galaxy we write

$$D = 10^4 \frac{V_s}{h}, \tag{3}$$

where D is obtained in parsecs if we substitute the symbolic velocity of recession in units of kilometers per second.

Interconnected galaxies may conveniently be separated into three classes, namely, (α) galaxies in close contact, (β) galaxies which are separated by distances equal to from one to five diameters of their main bodies, and (γ) galaxies very widely separated but still visibly interconnected galaxies.

The present paper contains the results of our observations for several of the interconnected galaxies of class (β). In subsequent papers the results on additional interconnected galaxies as well as on groups and clusters of galaxies will be given.

B. RESULTS ON INTERCONNECTED GALAXIES

I. THE DOUBLE INTERCONNECTED GALAXY AT R.A. $9^h55^m49^s$ AND DECL. $+29^\circ06'.0$ (1950)

A photograph obtained with the 200-inch telescope of this system, which is sketched in Figure 1, may be found in the article on "Multiple Galaxies" by F. Zwicky in Volume **53**, page 383, of the *Handbuch der Physik* (Berlin: Springer Verlag 1959).

Pairs of galaxies interconnected by a luminous bridge and a plume or filament extending beyond one of the two galaxies are very common. We estimate that over those regions of the sky which can be explored from Palomar more than ten thousand interconnected multiple galaxies can be found on 48-inch Schmidt plates of limiting exposure. Perhaps one thousand systems are morphologically similar to the system shown in Figure 1. Three spectrograms of this system were obtained with the slit covering the two galaxies but extending in different cases to the points P and P'. We hoped that this procedure would allow us to decide on how far the spectral features could be traced along the intergalactic bridge, as well as along the first part of the plume extending to the southwest (and later to the south).

a) Spectra

(i) *Galaxy A*.—In the spectrum of this north-following galaxy A, which is of the structural type S0, the H and K lines and the G band, in absorption, can be clearly distinguished and their positions measured relative to the lines of the comparison spectrum (He + H). Likewise, the line λ 3727 of O II appears strongly in emission. The spectral type of galaxy A is estimated to be G5. The symbolic velocities of recession V_s, as derived from the three spectrograms, are V_s = 6376, 6441, and 6418 km/sec. The mean value, therefore, is

$$V_s(\text{A}) = +6409 \text{ km/sec} , \tag{4}$$

and the standard deviation δV_s (A) = 27 km/sec. This deviation is somewhat larger than might be expected from the quality of the spectra obtainable with our equipment.

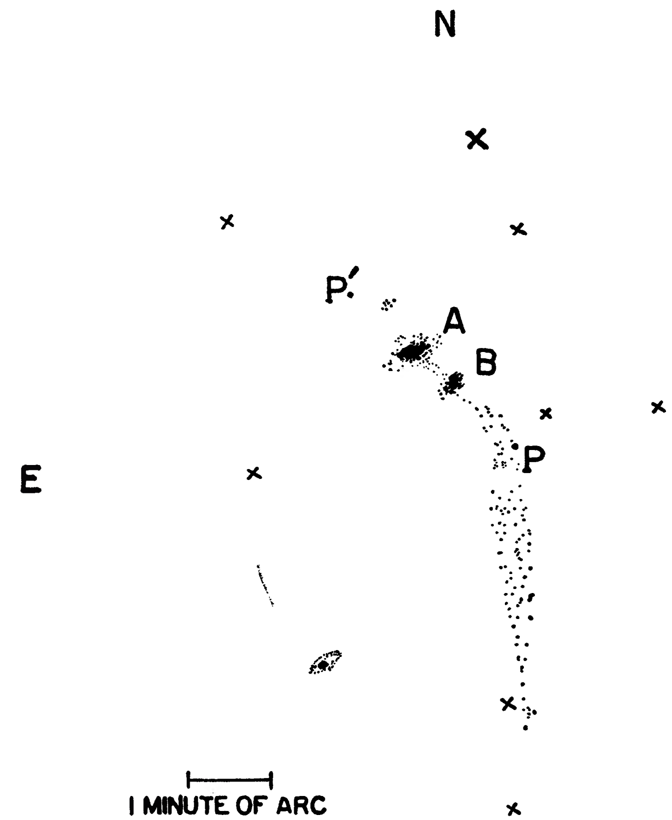

FIG. 1.—Sketch of the interconnected double galaxy at R.A. $9^h55^m49^s$ and Decl. +29°06′ (1950)

This is due in part to the fact that a long slit was used and that one of the spectra is not in the best focus. Furthermore, and most important, the slit of the spectrograph could not have been in exactly the same position relative to the image of the galaxy for the three exposures. Since the rotational velocity of galaxy A is rather high, as we shall see, the slight uncertainty in the location of the slit increases the uncertainty in the value derived for V_s.

Since all lines are inclined with respect to the lines of the comparison spectrum, we conclude that galaxy A is rotating. If the angle of inclination of the spectral line of wave length λ on our plate is γ, the component ω_z of the angular velocity normal to the plane, which is defined by the line to the observer and the connecting line between the two galaxies, is given by equation (5),

$$\omega_z = 20625 \frac{c h H_0 \delta}{\lambda s V_s} \tan \gamma , \quad (5)$$

where δ is the dispersion of our spectrum in angstroms/mm and s is the angular scale in seconds of arc per mm for the image of the object on the spectrogram; λ must thus be expressed in units of angstroms, c and V_s in units of km/sec, and H_0 in $\sec^{-1}$. In our case (using the 3-inch camera and the grating 63B of the prime-focus spectrograph of the Hale telescope), we have

$$\delta = 185 \text{ A/mm} , \qquad \text{and} \qquad s = 41.8 \text{ seconds arc/mm} , \quad (6)$$

where δ is the dispersion of the spectrogram. For the inclination of the emission line λ 3727 in the spectrum of our galaxy A, we find $tg\ \gamma = \frac{1}{13}$. Inserting all of these values, we obtain from equation (5)

$$\omega_z (\text{A}) = 2.84 \times 10^{-15} h \sec^{-1} . \quad (7)$$

This corresponds to a time of revolution of our galaxy of

$$\tau_R (\text{A}) = \frac{70.4}{h} \text{ million years} . \quad (8)$$

The differential radial velocity from one end of the galaxy to the other, as indicated by the emission line λ 3727, is of the order of $\Delta V_s = 440$ km/sec. The H and K lines are similarly inclined, but so interwoven with neighboring night-sky lines that a determination of γ and V_s from them is not feasible.

(ii) *Galaxy B.*—This galaxy, which is of the elliptical type, has a spectrum of type G8. Only the absorption features H and K and the G band are measurable, while the emission line λ 3727 is absent. From the three spectrograms we derive, for the symbolic velocities of recession V_s, the values 6210, 6214, and 6284 km/sec, with a mean value

$$V_s (\text{B}) = +6236 \text{ km/sec} \quad (9)$$

and a standard deviation of 32 km/sec.

The inclination of the H and K lines relative to the lines of the comparison spectrum is present but not marked enough to make possible a reliable determination of the angular velocity component ω_z(B).

For the average symbolic velocity of recession of the whole system we adopt the value

$$V_s = \tfrac{1}{2} [V_s (\text{A}) + V_s (\text{B})] = +6323 \text{ km/sec} . \quad (10)$$

(iii) *Plume and bridge.*—As to the spectrum of the luminous bridge and the section of the large plume between galaxy B and the point P, the H and K lines and the G band can be traced from galaxy A to the point P within a very weak continuum, although the latter corresponds to a surface brightness as faint as the twenty-fourth photographic magnitude per square second of arc or less. Although faint luminous surface sources are difficult to photograph directly because of the lack of sharp boundaries and contrasts, this is not true for abrupt spectral features within these faint sources of light. As a consequence, surprisingly enough, the absorption and emission lines in the spectra of the faint luminous formations between and around some galaxies are far more readily distinguishable than might have been expected. Since in the present case the emission line λ 3727, in contradistinction to the mentioned absorption lines, does not extend across the bridge connecting galaxies A and B, we conclude that the luminosity of this bridge is primarily due to stars. If gases are present also, the bridge does not contain enough hot stars to excite these gases to observable fluorescence.

b) Apparent and Absolute Dimensions

All measures of apparent dimensions are from 200-inch plates.

(i) *Galaxy A*.—The major and the minor axes are, in seconds of arc,

$$\alpha(\mathrm{A}) = 28''.58\ , \qquad \beta(\mathrm{A}) = 14''.68\ , \tag{11}$$

and, in absolute measure, with the parsec as the unit,

$$a(\mathrm{A}) = \frac{8745}{h}\ \text{parsecs}\,, \qquad b(\mathrm{A}) = \frac{4492}{h}\ \text{parsecs}\,. \tag{12}$$

(ii) *Galaxy B*.—The magnitudes of the major and minor axes are

$$\alpha(\mathrm{B}) = 11''.12\ , \qquad \beta(\mathrm{B}) = 8''.12\ , \tag{13}$$

or, in absolute measures,

$$a(\mathrm{B}) = \frac{3403}{h}\ \text{parsecs}\,, \qquad b(\mathrm{B}) = \frac{2485}{h}\ \text{parsecs}\,. \tag{14}$$

(iii) *Dimensions of the whole system*.—The separation of the two galaxies is equal to 35''.7 of arc, or

$$d = \frac{10925}{h}\ \text{parsecs} = \frac{3.40\times10^{22}}{h}\ \text{cm}\,, \tag{15}$$

and the total extent of the whole system is 334'', or

$$L = \frac{102100}{h}\ \text{parsecs}\,. \tag{16}$$

Substituting $V_s = 6323$ km/sec, the distance of our system becomes

$$D = \frac{63.2}{h}\ \text{million parsecs} = \frac{1.95\times10^{26}}{h}\ \text{cm}\,. \tag{17}$$

c) Luminosities

(i) *Galaxy A*.—The apparent photographic magnitude of this galaxy is $m_{\mathrm{pg}} = +15.2$, and the absolute photographic magnitude, with D in units of parsecs, is

$$M_{\mathrm{pg}} = m_{\mathrm{pg}} + 5 - 5\log_{10} D - \Delta m\ , \tag{18}$$

where the loss in brightness, Δm, which is due to interstellar and to intergalactic absorption, is as yet unknown but might lie in the range from 0.4 to 0.6 mag. Inserting the values $D = V_s/h\,H_0$, with $V_s = +6323$ km/sec, and $m_{\mathrm{pg}} = +15.2$, we obtain, for the absolute photographic magnitude of galaxy A, the value

$$M_{\mathrm{pg}}(\mathrm{A}) = -18.8 + 5\log_{10} h - \Delta m\ . \tag{19}$$

(ii) *Galaxy B*.—The apparent photographic magnitude is $m_{\mathrm{pg}} = +16.0$, and the absolute photographic magnitude consequently, given by equation (19), is

$$M_{\mathrm{pg}}(\mathrm{B}) = -18.0 + 5\log_{10} h - \Delta m\ . \tag{20}$$

(iii) *The intergalactic formation of bridge and plume.*—As mentioned before, the surface brightness of the bridge is estimated at $m_{pg} = +24$ per square second of arc in the brighter areas. Bridge and plume cover an area of about 1500 square seconds of arc, and the integrated photographic magnitudes of these formations is thus about $m_{pg} = +16.0$ or roughly the same as the magnitude of galaxy B.

d) The mass-distance ratio $\mathfrak{M}_t/D$

From equations (4) and (9) we find that the differential radial velocity between galaxies A and B is

$$\Delta V_s = 173 \text{ km/sec} . \tag{21}$$

The absolute velocity difference, therefore, is

$$v = f \Delta V_s , \quad \text{where} \quad f \geq 1 . \tag{22}$$

If the system were a physical double in a stationary state, we should have

$$\frac{\mathfrak{M}_t}{d} = \frac{v^2}{G}, \tag{23}$$

where $\mathfrak{M}_t$ is the total mass of our system and G is the universal gravitational constant. While $\mathfrak{M}_t$ and d are both inversely proportional to the distance-scale parameter h, the ratio $\mathfrak{M}_t/d$ is independent of h and directly derivable from observational data, provided that the differences ΔV_s in the symbolic velocities of recession of *neighboring, galaxies* represent *real* velocity differencs and provided that Newton's law of gravitation is strictly valid for the separations involved. Substituting $d = D \sigma$ in equation (23), where the angular separation σ of the two galaxies is expressed in radians, we obtain, for the mass-distance ratio of our system,

$$\frac{\mathfrak{M}_t}{D} = \frac{v^2 \sigma}{G}. \tag{24}$$

Substituting the values for v and σ, we find

$$\frac{\mathfrak{M}_t}{D} = 7.79 \times 10^{17} f^2 \text{ gm cm}^{-1} . \tag{25}$$

For the total mass $\mathfrak{M}_t$ of the system we may write, after substituting D from equation (17),

$$\mathfrak{M}_t = \frac{1.52 \times 10^{44} f^2}{h} \text{ gm} , \tag{26}$$

or, in terms of the mass of the sun, $\mathfrak{M}_\odot = 2 \times 10^{33}$ gm,

$$\mathfrak{M}_t = \frac{7.6 \times 10^{10} \mathfrak{M}_\odot f^2}{h} . \tag{27}$$

If the two galaxies are escaping from one another, the value for M_t could be smaller than that given by equation (26). This, however, is not probable for our system, since the differential velocities within galaxy A ($\Delta V_s = 440$ km/sec) are even greater than the differential radial velocity of 173 km/sec between the two galaxies.

II. THE DOUBLE INTERCONNECTED GALAXY AT R.A. $12^h03^m13^s$ AND DECL. $+31°21'$ (1950)

A photograph of this system is reproduced in Figure 2. The most remarkable features of the system are as follows: (*a*) The outlines of the bridge and of the plume are remark-

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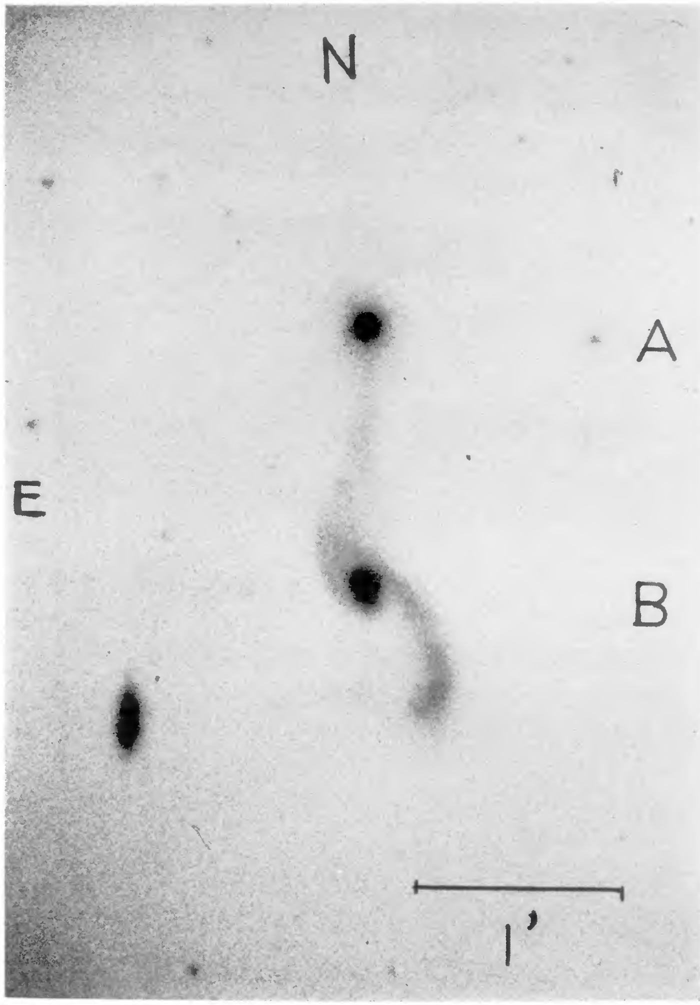

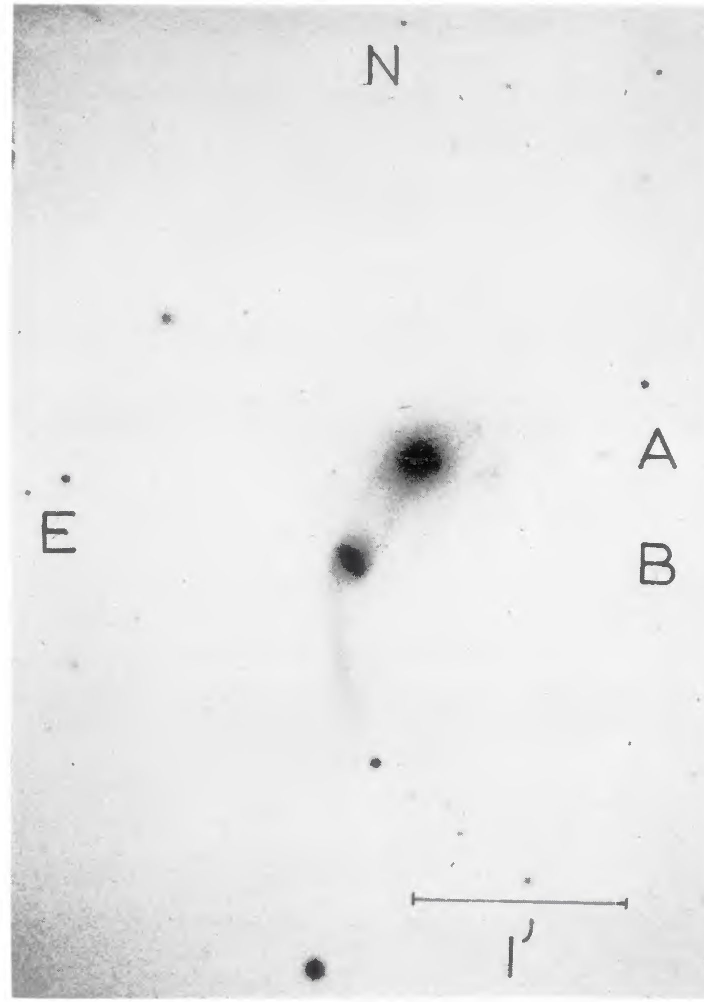

FIG. 2.—Interconnected double galaxy at R.A. $12^h03^m13^s$ and Decl. $+31°21'$ (1950). 200-inch telescope photograph on emulsion type 103*a*-O, exposure 20 minutes at seeing 1−. Scale as indicated.

FIG. 3.—Interconnected double galaxy at R.A. $12^h13^m46^s$ and Decl. $+28°25'22''$ (1950). 200-inch telescope photograph, exposure time 20 minutes on emulsion 103*a*-O at seeing 3. Scale as indicated.

ably distinct. Both the bridge and the plume have a width of about 10 seconds of arc, which is approximately equal to the diameters of the central bodies of the two galaxies. (*b*) Except for the bridge and the plume, only exceedingly faint outlying formations surround the very compact central bodies of the two component galaxies. (*c*) The color of both the bridge and the plume is fairly blue, comparable with that of an average spiral galaxy of color index +0.3.

a) *Spectra*

(i) *Galaxy A*.—This northern component galaxy is globular, that is, of structural type E0, and its spectrum of type G5. Four lines including H and K could be measured, but no emission lines are discernible. The value derived for the symbolic velocity of recession is

$$V_s(\mathrm{A}) = +7010 \text{ km/sec}, \tag{28}$$

and the standard deviation $\delta V_s = 32.5$ km/sec. No clearly measurable inclination of the spectral lines can be detected. Consequently, no value for the rotational velocity of this galaxy can be derived.

(ii) *Galaxy B*.—This southern component galaxy, which is of the structural type Sa or S0, with the plume and the bridge being the extensions of two broad washed-out spiral arms, has a spectrum of type F8. The positions of four lines were measured, yielding a symbolic velocity of recession

$$V_s(\mathrm{B}) = +6894 \text{ km/sec}, \tag{29}$$

with a standard deviation $\delta V_s = 34.4$ km/sec. The spectrum shows two emission lines—λ 4340 [Hγ] and λ 3727 [O II]—the first one weak and the second very strong. The emission line λ 3727 extends in the direction of the bridge along about one-tenth of its length. While it does not show any measurable inclination through the central body of the galaxy itself, its wing extending along the bridge is markedly inclined toward the shorter wave lengths, actually in the direction opposite to that indicated by the values of V_s of the two galaxies.

From equations (28) and (29) we obtain, for the average V_s of our system

$$V_s = +6952 \text{ km/sec}, \tag{30}$$

and, for the differential symbolic radial velocity of the two component galaxies,

$$\Delta V_s = 116 \text{ km/sec}. \tag{31}$$

We consequently conclude from equation (3) that the distance of the system is

$$D = \frac{69.5}{h} \text{ million parsecs}. \tag{32}$$

(iii) *The bridge and the plume*.—Our spectrogram is not exposed sufficiently to allow us to distinguish any features in the spectra of the bridge and the plume. These formations, however, seem to possess sufficient surface brightness to produce readable spectra when photographed on a night of low sky glow with the prime-focus spectrograph of the Hale telescope.

b) *Apparent and Absolute Dimensions*

(i) *Galaxy A*.—The major and the minor axes in angular measure are

$$\alpha(\mathrm{A}) = 10''.56, \quad \beta(\mathrm{A}) = 9''.56, \tag{33}$$

and, in absolute measure,

$$a\,(\mathrm{A}) = \frac{3569}{h}\ \text{parsecs}\,, \qquad b\,(\mathrm{A}) = \frac{3231}{h}\ \text{parsecs}\,. \tag{34}$$

(ii) *Galaxy B.*—The major and the minor axes in angular measure are

$$\alpha\,(\mathrm{B}) = 15''.23\ , \qquad \beta\,(\mathrm{B}) = 10''.45\ , \tag{35}$$

and, in absolute measure,

$$a\,(\mathrm{B}) = \frac{5148}{h}\ \text{parsecs}\,, \qquad b\,(\mathrm{B}) = \frac{3532}{h}\ \text{parsecs}\,. \tag{36}$$

(iii) *Dimensions of the system.*—The separation of the two galaxies is 73″, or

$$d = \frac{24670}{h}\ \text{parsecs}\,. \tag{37}$$

The length of the plume is 45″.6 or $15400/h$ parsecs, and the total extension of the system is about 130″, or

$$L = \frac{43900}{h}\ \text{parsecs}\,. \tag{37a}$$

c) Luminosities

(i) *Galaxy A.*—The apparent photographic magnitude of this galaxy is $m_{\mathrm{pg}} = +15.7$. The absolute photographic magnitude is obtained from equation (18) by inserting m_{pg} and the value of the distance from equation (32). Therefore,

$$M_{\mathrm{pg}}\,(\mathrm{A}) = -18.5 + 5\log_{10} h - \Delta m\ , \tag{38}$$

where the total loss Δm in magnitude by interstellar and intergalactic absorption must be determined for the particular direction in which our system lies.

(ii) *Galaxy B.*—The apparent brightness is $m_{\mathrm{pg}} = +15.6$, and therefore

$$M_{\mathrm{pg}}\,(\mathrm{B}) = -18.6 + 5\log_{10} h - \Delta m\ , \tag{39}$$

assuming that the value of Δm is the same for both galaxies.

(iii) *The bridge and the plume.*—The total area covered by the plume and the bridge is of the order of 1100 square seconds of arc. Estimating the average surface brightness of these formations at +23.0 photographic magnitudes per square second of arc, their integrated brightness becomes $m_{\mathrm{pg}} = +15.4$, and their absolute photographic magnitude equal to $M_{\mathrm{pg}} = -18.8 + 5\log_{10} h - \Delta m$, or somewhat brighter than either one of the two galaxies.

d) The Mass-Distance Ratio $\mathfrak{M}_t/D$

From equations (28) and (29) we have, for the differential radial velocity of galaxies A and B,

$$V_s = 116\ \text{km/sec}\ . \tag{40}$$

The absolute velocity difference, equation (22), therefore, is $v = f \times \Delta V_s$, where $f \geq 1$, and, from equation (24), the mass-distance ratio is

$$\frac{\mathfrak{M}_t}{D} = 7.20 \times 10^{17} \times f^2\ \text{gm/cm}\,. \tag{41}$$

For the total mass $\mathfrak{M}_t$ of the system we obtain, after substituting the distance D from equation (32),

$$\mathfrak{M}_t = \frac{1.55 \times 10^{44} f^2}{h} \text{ gm}, \tag{42}$$

or, in terms of the mass $\mathfrak{M}_\odot$ of the sun,

$$\mathfrak{M}_t = \frac{8.0 \times 10^{10} \mathfrak{M}_\odot \times f^2}{h}. \tag{43}$$

This expression, except for a numerically different constant h, is practically identical with the total mass derived for the interconnected double galaxy discussed in Section I of this paper.

III. THE DOUBLE INTERCONNECTED GALAXY AT R.A. $12^h13^m46^s$ AND DECL. $+28°25'22''$ (1950)

A photograph of this system is reproduced in Figure 3. The most remarkable features of this system are as follows: (*a*) the outlines of the plume extending south from galaxy B are distinct and its surface brightness quite uniform; (*b*) the bridge is indistinct and disrupted; (*c*) galaxy A is surrounded by a luminous cloud which contains several bright condensations.

a) *Spectra*

(i) *Galaxy A*.—This north-preceding galaxy is of a peculiar type S0, and its spectrum is of type G5. Ten lines were measured, including a strong emission line λ 3727. The value derived from the symbolic velocity of recession is

$$V_s(\text{A}) = +6571 \text{ km/sec}, \tag{44}$$

and the standard deviation is $\delta V_s = 34.4$ km/sec. Some rotation of the galaxy is indicated by a very slight inclination of the lines, which, however, is too small to be accurately measurable. While the H and K lines, as well as the G band, seem faintly traceable along the bridge, the emission line λ 3727 does not extend beyond the confines of the central disk of galaxy A.

(ii) *Galaxy B*.—This south-following member galaxy of our double system is an Sb spiral, and its spectrum is of type G0. The spectrogram not being sufficiently exposed, only three lines could be measured, including the emission line λ 3727 at medium strength. The value obtained for the symbolic velocity of recession is

$$V_s(\text{B}) = +6618 \text{ km/sec}, \tag{45}$$

and the standard deviation $\delta V_s = 78.7$ km/sec.

The average value for V_s of the whole system, therefore, is

$$V_s = \tfrac{1}{2}[V_s(\text{A}) + V_s(\text{B})] = +6595 \text{ km/sec}, \tag{46}$$

and the distance, from equation (3), is

$$D = \frac{66}{h} \text{ million parsecs}. \tag{47}$$

b) *Apparent and Absolute Dimensions*

(i) *Galaxy A*.—The major and minor axes in angular measure are

$$\alpha(\text{A}) = 22''.46, \quad \beta(\text{A}) = 20''.0, \tag{48}$$

and, in absolute measure,

$$a(\text{A}) = \frac{7187}{h} \text{ parsecs}, \quad b(\text{A}) = \frac{6400}{h} \text{ parsecs}. \tag{49}$$

(ii) *Galaxy B.*—The major and the minor axes in angular measure are

$$\alpha(\mathrm{B}) = 12''.56\ , \qquad \beta(\mathrm{B}) = 8''.00\ , \tag{50}$$

and, in absolute measure,

$$a(\mathrm{B}) = \frac{4020}{h}\ \text{parsecs}\,, \qquad b(\mathrm{B}) = \frac{2560}{h}\ \text{parsecs}\,. \tag{51}$$

(iii) *Dimensions of the whole system.*—The separation of the two galaxies is 35″.9, or, in absolute measure,

$$d = \frac{11490}{h}\ \text{parsecs}\,. \tag{52}$$

The length of the plume is 35″.0, or $11200/h$ parsecs, and the total extension of the system is about 82″.3 of arc, or

$$L = \frac{26350}{h}\ \text{parsecs}\,. \tag{53}$$

The total area covered by the luminous plume, the bridge, and the clouds is of the order of 850 square seconds of arc.

c) Luminosities

(i) *Galaxy A.*—The apparent photographic magnitude is $m_{pg} = +14.8$. Therefore, from equations (18) and (47), the absolute photographic magnitude is

$$M_{pg}(\mathrm{A}) = -19.3 + 5\log_{10} h - \Delta m\ , \tag{54}$$

where Δm is the loss of magnitude because of interstellar and intergalactic absorption.

(ii) *Galaxy B.*—We have $m_{pg} = +15.8$, and therefore

$$M_{pg}(\mathrm{B}) = -18.3 + 5\log_{10} h - \Delta m\ . \tag{55}$$

(iii) *Bridge, plume, and outlying clouds.*—These formations, covering an area of about 850 square seconds of arc, with an average surface brightness of 23.5 photographic magnitudes per square second of arc, thus have a total brightness corresponding to $m_{pg} = 16.0$, and an absolute photographic magnitude $M_{pg} = -18.1 + 5\log_{10} h - \Delta m$, or somewhat fainter than galaxy B.

d) The Mass-Distance Ratio $\mathfrak{M}_t/D$

From equations (44)–(45) we find, for the differential radial velocity of galaxies A and B,

$$\Delta V_s = 47\ \text{km/sec}\ . \tag{56}$$

According to equations (22) and (24), it follows that

$$\frac{\mathfrak{M}_t}{D} = 5.76 \times 10^{16} f^2\ \text{gm cm}^{-1}\,. \tag{57}$$

For the total mass $\mathfrak{M}_t$ of the system we thus find

$$\mathfrak{M}_t = \frac{1.17 \times 10^{43} f^2}{h}\ \text{gm}\,, \tag{58}$$

or, in terms of the mass $\mathfrak{M}_\odot$ of the sun,

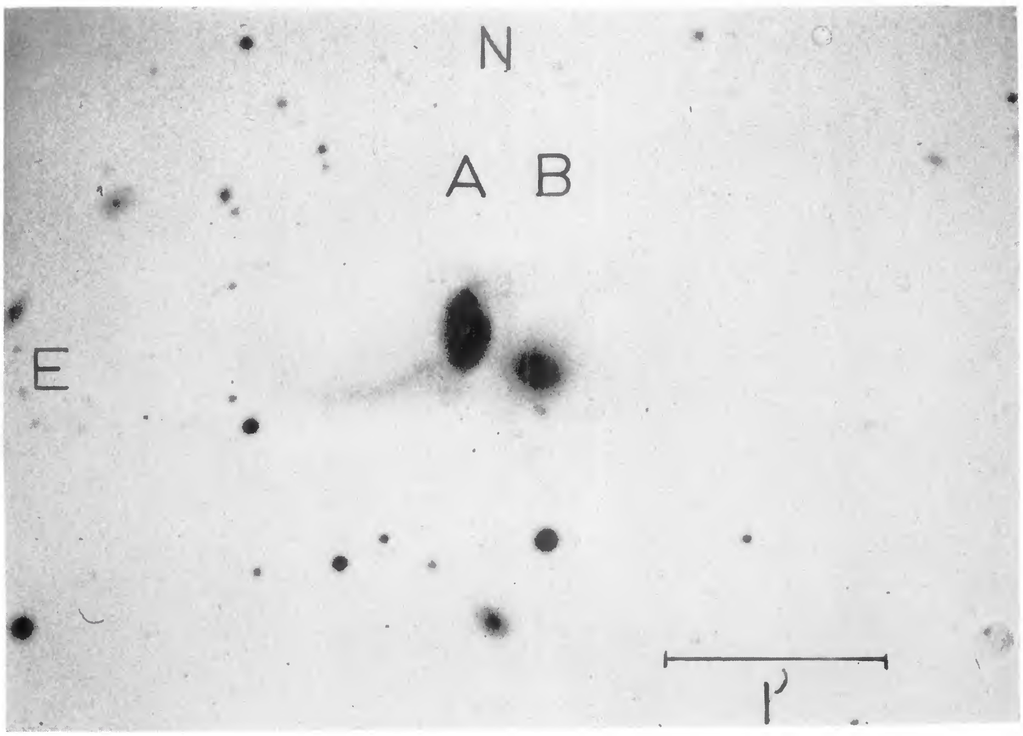

FIG. 4.—Double galaxy at R.A. $11^h04^m40^s$, Decl. $+18°42'$ (1950). 200-inch telescope photograph on emulsion 103a-D behind Schott GG11 glass filter. Exposure time 30 minutes at seeing 1.

$$\mathfrak{M}_t = \frac{0.6 \times 10^{10} \mathfrak{M}_\odot f^2}{h}. \tag{59}$$

IV. THE DOUBLE GALAXY AT R.A. $11^h04^m40^s$ AND DECL. $+18^\circ42'$ (1950)

A photograph of this system is reproduced in Figure 4. This system is structurally different from the three double galaxies previously discussed. There is no pronounced luminous bridge between A and B. Two extended plumes protrude out of the north-following galaxy A, which is of a peculiar type S0, consisting of two concentric disks, the outer of which contains two pronounced luminous knots. The elliptical galaxy B is surrounded by irregularly distributed luminous matter.

a) Spectra

(i) *Galaxy A.*—The spectrum is of type G0. Four lines could be measured, including the bright emission line at λ 3727. From these measures the symbolic velocity of recession is

$$V_s(\mathrm{A}) = +8211 \text{ km/sec}, \tag{60}$$

with a standard deviation of 77 km/sec. The spectral lines do not show any measurable inclination, and no estimate of the angular velocity of this galaxy can be made.

(ii) *Galaxy B.*—The spectral type is G2. Four lines were measured, including the emission line at λ 3727, yielding the value for V_s of

$$V_s(\mathrm{B}) = +7982 \text{ km/sec}, \tag{61}$$

with a standard deviation of 80 km/sec. Again no inclination of the spectral line is measurable. No spectrum of the outlying luminous formations was obtained.

The average value for V_s is

$$V_s = \tfrac{1}{2}[V_s(\mathrm{A}) + V_s(\mathrm{B})] = 8096 \text{ km/sec}, \tag{62}$$

and the distance of the system according to equation (3), is

$$D = \frac{81 \times 10^6}{h} \text{ parsecs}. \tag{63}$$

b) Apparent and Absolute Dimensions

(i) *Galaxy A.*—The major and the minor axes in angular measure are

$$\alpha(\mathrm{A}) = 25''.5, \qquad \beta(\mathrm{A}) = 14''.1, \tag{64}$$

or, in absolute measure,

$$a(\mathrm{A}) = \frac{10000}{h} \text{ parsecs}, \qquad b(\mathrm{A}) = \frac{5540}{h} \text{ parsecs}. \tag{65}$$

(ii) *Galaxy B.*—The major and the minor axes in angular measure are

$$\alpha(\mathrm{B}) = 15''.6, \qquad \beta(\mathrm{B}) = 11''.7, \tag{66}$$

or, in absolute measure,

$$a(\mathrm{B}) = \frac{6130}{h} \text{ parsecs}, \qquad b(\mathrm{B}) = \frac{4600}{h} \text{ parsecs}. \tag{67}$$

(iii) *Dimensions of the whole system.*—The separation of the two galaxies is 22''.2, or, in absolute measure,

$$d = \frac{8720}{h} \text{ parsecs} . \tag{68}$$

The length and width of one luminous plume are, respectively, 36″ and 3″.3, and for the other 23″ and 2″. Including the cloud around the elliptical galaxy B, all luminous outlying formations cover about 220 square seconds of arc. The greatest extent of the whole system is about

$$L = \frac{27000}{h} \text{ parsecs} . \tag{69}$$

c) *Luminosities*

(i) *Galaxy A*.—The apparent photographic magnitude is $m_{pg} = +15.1$ and, therefore, from equations (18) and (63),

$$M_{pg}(A) = -19.5 + 5 \log_{10} h - \Delta m . \tag{70}$$

(ii) *Galaxy B*.—For galaxy B we have $m_{pg} = +15.7$, and it follows that

$$M_{pg}(B) = -18.8 + 5 \log_{10} h - \Delta m . \tag{71}$$

(iii) *Outlying formations*.—With an average estimated surface brightness corresponding to 23.5 photographic magnitudes per square second of arc, the outlying areas of 220 square seconds of arc have an integrated apparent photographic magnitude of +17.6 and an absolute magnitude of −16.9, much fainter than the two galaxies.

d) *The Mass-Distance Ratio* $\mathfrak{M}_t/D$

From equations (60) and (61) we find, for the differential radial velocity of galaxies A and B,

$$\Delta V_s = 229 \text{ km/sec} . \tag{72}$$

From equations (22) and (24), it therefore follows that

$$\frac{\mathfrak{M}_t}{D} = 8.43 \times 10^{17} f^2 \text{gm cm}^{-1} . \tag{73}$$

For the total mass $\mathfrak{M}_t$ of the system we thus find

$$\mathfrak{M}_t = \frac{2.11 \times 10^{44} f^2}{h} \text{ gm} , \tag{74}$$

or, in terms of the mass $\mathfrak{M}_\odot$ of the sun,

$$\mathfrak{M}_t = \frac{1.05 \times 10^{11} \mathfrak{M}_\odot f^2}{h} . \tag{75}$$

C. SUMMARY AND CONCLUSIONS

For purposes of intercomparison of similar groups and of clusters of galaxies, we introduce as convenient new concepts an *indicative distance* or length L^*, an *indicative absolute luminosity* M^*, and an *indicative mass* $\mathfrak{M}^*$. These are defined as

$$L^* = Lh , \tag{76}$$

in accordance with equations (1) and (2);

$$M^* = M - 5 \log_{10} h + \Delta m , \tag{77}$$

in accordance with equation (19); and

$$\mathfrak{M}^* = \frac{\mathfrak{M}h}{f^2}, \tag{78}$$

in accordance with equation (22), (23), and (76). The three indicative quantities can be derived from direct observation. From them the absolute values of distances, luminosities, and masses may be obtained if h, $\Delta\, m$, and f can be determined. The indicative quantities for the four double galaxies discussed in this paper are listed in Table 1.

TABLE 1*

INDICATIVE CHARACTERISTICS, AS DEFINED BY EQUATIONS (76), (77), AND (78), OF FOUR INTERCONNECTED DOUBLE GALAXIES

	SYSTEM			
	I	II	III	IV
R.A. (1950)	$9^h55^m49^s$	$12^h03^m13^s$	$12^h13^m46^s$	$11^h04^m40^s$
Decl. (1950)	$+29°06'.0$	$+31°21'.0$	$+28°25'.4$	$+18°42'.0$
V_s (in km/sec)	6323	6952	6595	8096
D^* (in 10^6 parsecs)	63.2	69.5	66 0	81.0
d^* (in parsecs)	10925	24670	11490	8720
a^* (A)	8745	3569	7187	10000
b^* (A)	4492	3231	6400	5540
a^* (B)	3403	5148	4020	6130
b^* (B)	2485	3532	2560	4600
L^*	102100	43900	26350	27000
M^* (A)	−18.8	−18.5	−19.3	−19.5
M^* (B)	−18.0	−18.6	−18.3	−18.8
M^* (IG)	−18.0	−18.8	−18.1	−16.9
$\mathfrak{M}_t^*$ (in $10^{10}\,\mathfrak{M}_\odot$)	7.6	8.0	0.6	10.5

* D^* = indicative distance of the system. d^* = indicative separation of the two component galaxies. a* and b* = indicative major and minor axes of the individual galaxies. L^* = indicative maximum over-all dimension of the system. M^* = indicative absolute photographic magnitude. $\mathfrak{M}_t^*$ = indicative mass of the entire system expressed in units of $10^{10}\,\mathfrak{M}_\odot$. IG = intergalactic formation.

It is seen from Table 1 that these systems, which, except for obvious and similar morphological features, were chosen at random, show some remarkable similarities in their absolute characteristics. These similarities may become important for our understanding of the evolution of galaxies and of groups of galaxies. Also, more extensive data on interconnected double galaxies may enable us to make relative distance estimates by mere inspection.