COMPOSITE PHOTOGRAPHY OF GALAXIES

STEWART SHARPLESS AND OTTO G. FRANZ
U. S. Naval Observatory
Washington, D. C.

INTRODUCTION

Most studies of the structure and stellar content of galaxies have concerned themselves with composite radiation within a rather broad wavelength interval. Conclusions drawn from such studies refer, therefore, to those stars which contribute most of the light. Zwicky,[1,2] on the other hand, has briefly described a composite photographic technique that makes it possible to isolate in a galaxy certain population components that do *not* contribute a major share of the light. Such a method is potentially an important one for the study of the morphology of galaxies; e.g., the illustration given by Zwicky brings out a spiral substrate of red stars in NGC 5194 which is not immediately discernible on the original plates.

The purpose of this paper is (1) to examine the technique and its validity in more detail than has been previously done, and (2) to illustrate some of the results of the technique. In a forthcoming paper a larger number of cases will be illustrated and discussed in greater detail.

THE METHOD

Briefly, two photographs taken in different spectral regions are required, and contact positives having the proper density and contrast are made from these. The positive corresponding to one spectral region is then superposed upon the negative corresponding to the other. Depending on their color, certain components of the galaxy are either depressed or reinforced in the composite photograph. In the discussion that follows, it will be assumed that the original negatives were taken in the ordinary photographic and photovisual regions.

For each of the two original negatives the linear part of the characteristic curve can be represented as follows:

$$D_{b-} \propto -\gamma_b B \quad (1)$$

$$D_{y-} \propto -\gamma_y Y \quad (2)$$

where D represents the photographic density, B and Y represent the blue and yellow magnitudes corresponding to an element of area on the plate approximately equal to the resolution, and γ is closely related to the contrast as ordinarily defined. If the blue negative is now copied onto a material having a contrast γ_c then the corresponding characteristic curve is

$$D_{b+} \propto +\gamma_b \gamma_c B \quad (3)$$

If this positive is then superposed upon the yellow negative, the combined density will be

$$\begin{aligned} D &= -\gamma_y Y + \gamma_b \gamma_c B + \text{const.} \\ &= \gamma_b \gamma_c (B - Y) + (\gamma_b \gamma_c - \gamma_y)\, Y + \text{const.} \end{aligned} \quad (4)$$

where the constant depends on the relative exposures, band widths, and effective wavelengths of the original negatives. Thus, from equation (4), we find that any isodensity contour on the composite corresponds to a straight line on the color-magnitude diagram of the surface elements of the galaxy. Let us assume that the emulsions were chosen such that γ_y and γ_b are the same and consider, in particular, the line

$$\gamma_b \gamma_c (B - Y) + \gamma_b (\gamma_c - 1)\, Y = S \quad (5)$$

where the constant S has been chosen such that the corresponding density of the composite exactly matches the density of the sky background. All areas on the color-magnitude diagram above this line will correspond to areas of density on the composite that are greater than that of the sky, while those areas on the color-magnitude diagram below the line will be cancelled in the composite. If, in equation (5), $\gamma_c = 0$, the color term vanishes and we have the simple case of a broad-band yellow photograph in which the density is related to the visual magnitude only. If, on the other hand, $\gamma_c = \gamma_y/\gamma_b = 1$, then the magnitude term of equation (5) vanishes and the density of the composite is a function of color only. This is the case discussed by Zwicky.[1,2] It will be shown here that the method reaches its greatest effectiveness for a value of γ_c between these two extremes.

It was found by trial and error that, for the particular filter-plate-exposure combinations used here, a value of $\gamma_c = 0.65$ was most effective. Also it was found that this value is rather critical since a variation of several tenths in γ_c had deleterious effects on the results. The reason for this can be seen on the basis of the above analysis and Figure 1, which contains a schematic color-magnitude diagram corresponding to the main population components of a galaxy. The actual details of such a diagram

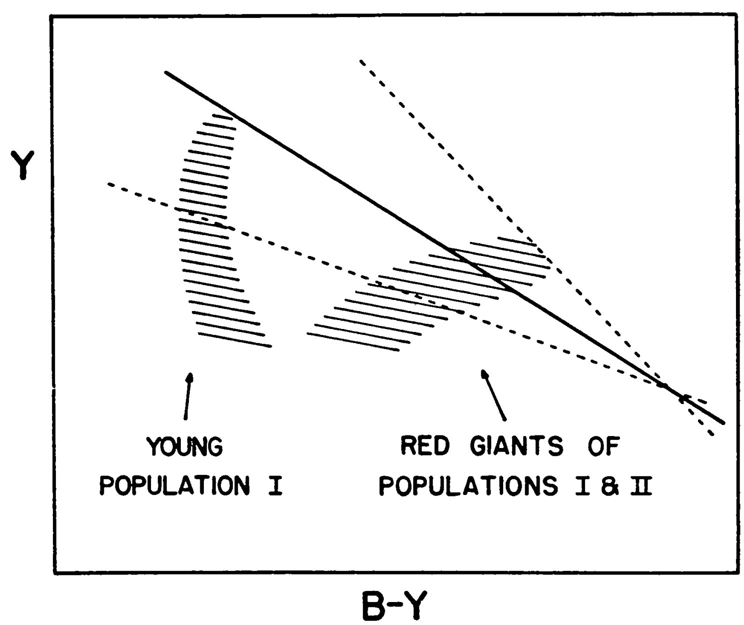
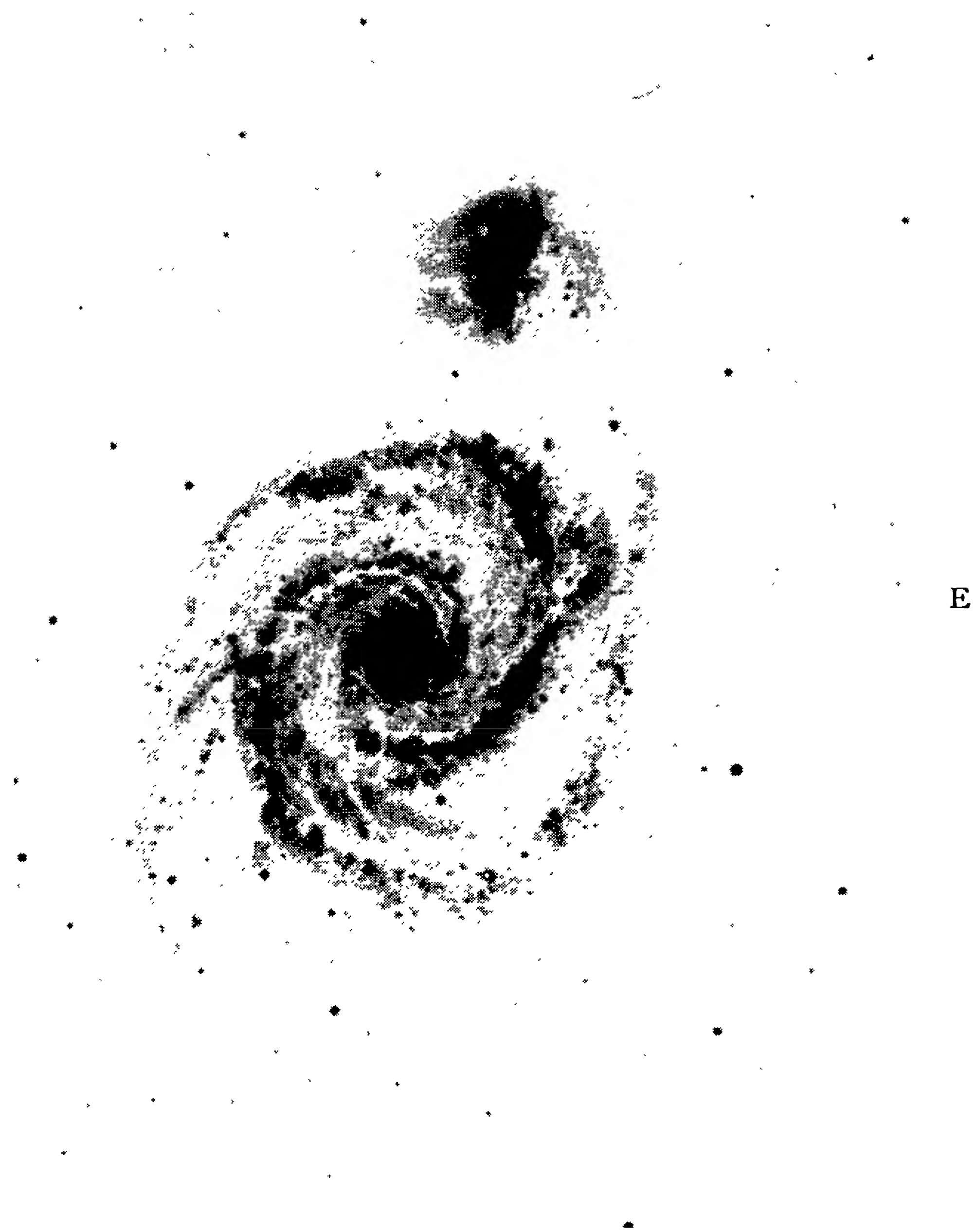


FIG. 1.—Schematic color-magnitude diagram corresponding to surface elements of a galaxy. The lines are explained in the text.

will vary from one galaxy to the next owing to differences in the relative amounts of the various components and the degree of resolution. The solid line represents the relation expressed by equation (5). The explanation of the sensitivity of the success of the technique to the value of γ_c is immediately evident. The light contributed by the brightest red giants corresponds to an area in Figure 1 above the line and appears strongly on the composite while the light contributed by the brightest blue stars corresponds to an area below the line and is cancelled in the composite. A major change in the slope of the line resulting from a change in the value of γ_c will include the areas corresponding to both components or exclude both of them (dotted lines). In either case, no discrimination would be obtained. For reasonable exposure times, the point of intersection of the lines corresponding to various values of γ_c will be in the area indicated. As Zwicky has already pointed out, any areas on the original plates which are saturated will appear saturated on the composite regardless of color. The analysis of the alternate combination, a blue negative and a yellow positive, is the same except that the slope of the line in Figure 1 will have the opposite sign and the discrimination will be in favor of the brightest Population I material.

The reproducibility of the results of this method is illustrated in Plates I through IV which contain respectively the blue and yellow photographs of NGC 5194/5 and the B^-Y^+ and B^+Y^- composites. The original negatives were obtained with the 40-inch Ritchey-Chrétien reflector of the Naval Observatory. The composites can be compared with those published by Zwicky for the same object[1,2] and it can be seen that they contain essentially the same information although ours are reproduced here at much lower contrast than his. The B^+Y^- composite (Plate IV) of NGC 5194 shows the substrate of red stars which resembles an S-shaped barred spiral. An interesting feature visible in Plate IV (and not visible in Zwicky's results owing to the higher contrast of his illustration) is the structure of NGC 5195. It has been described as an irregular of the M 82 type.[3] Its appearance on the B^+Y^- composite indicates a much greater degree of regularity in its structure than might be suspected on the basis of integral photographs alone. A well-defined bar is visible, and the over-all appearance is similar to objects ordinarily classified as SB0. This fact is not recognizable on integral photographs owing to the large amount of obscuring material in, or in front of, this system.

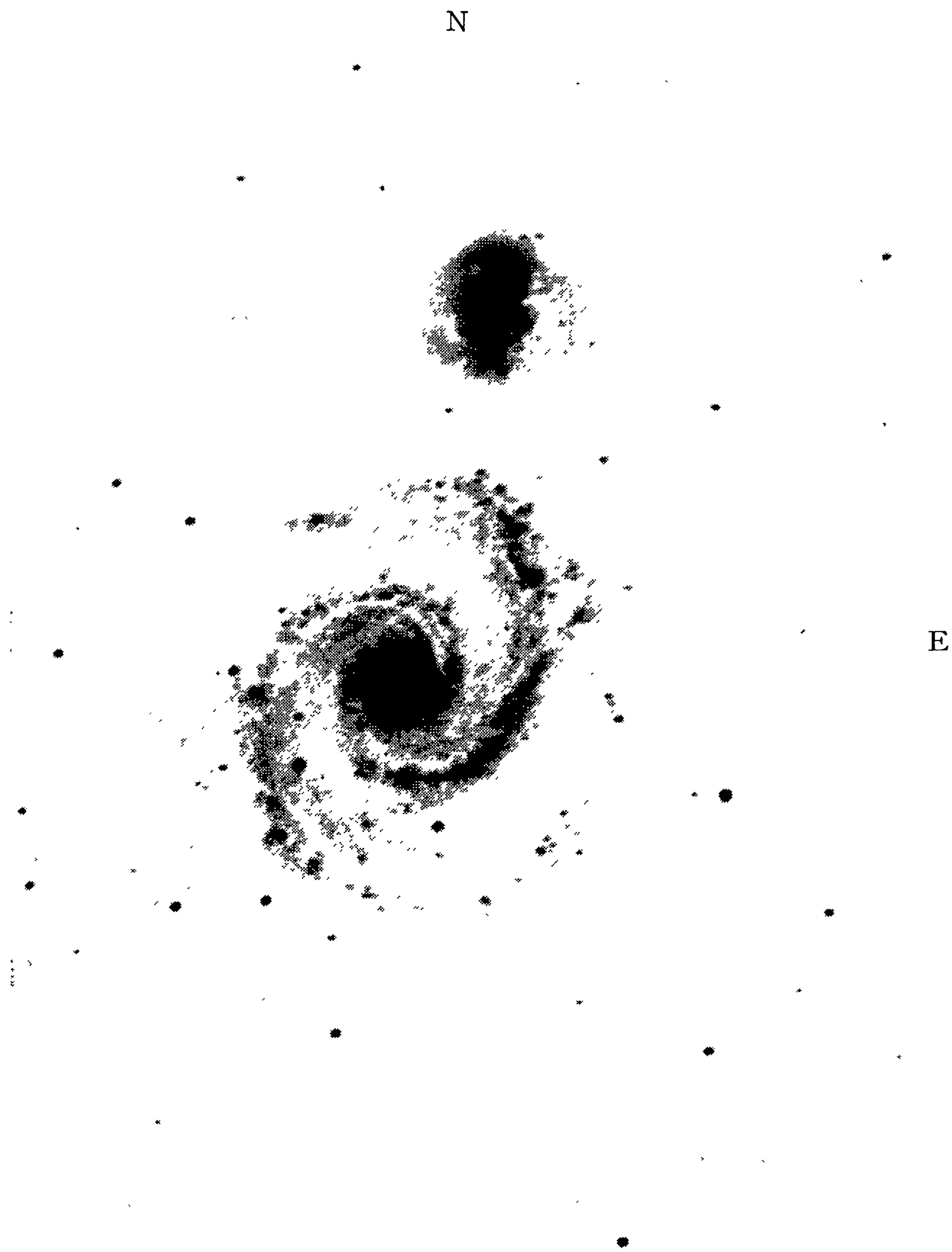
PLATE I



NGC 5194/5, Blue Negative

Eastman 103a-O emulsion, Schott GG 13 filter, 60-minute exposure with 40-inch Ritchey-Chrétien telescope. Scale: 6″.69/mm.

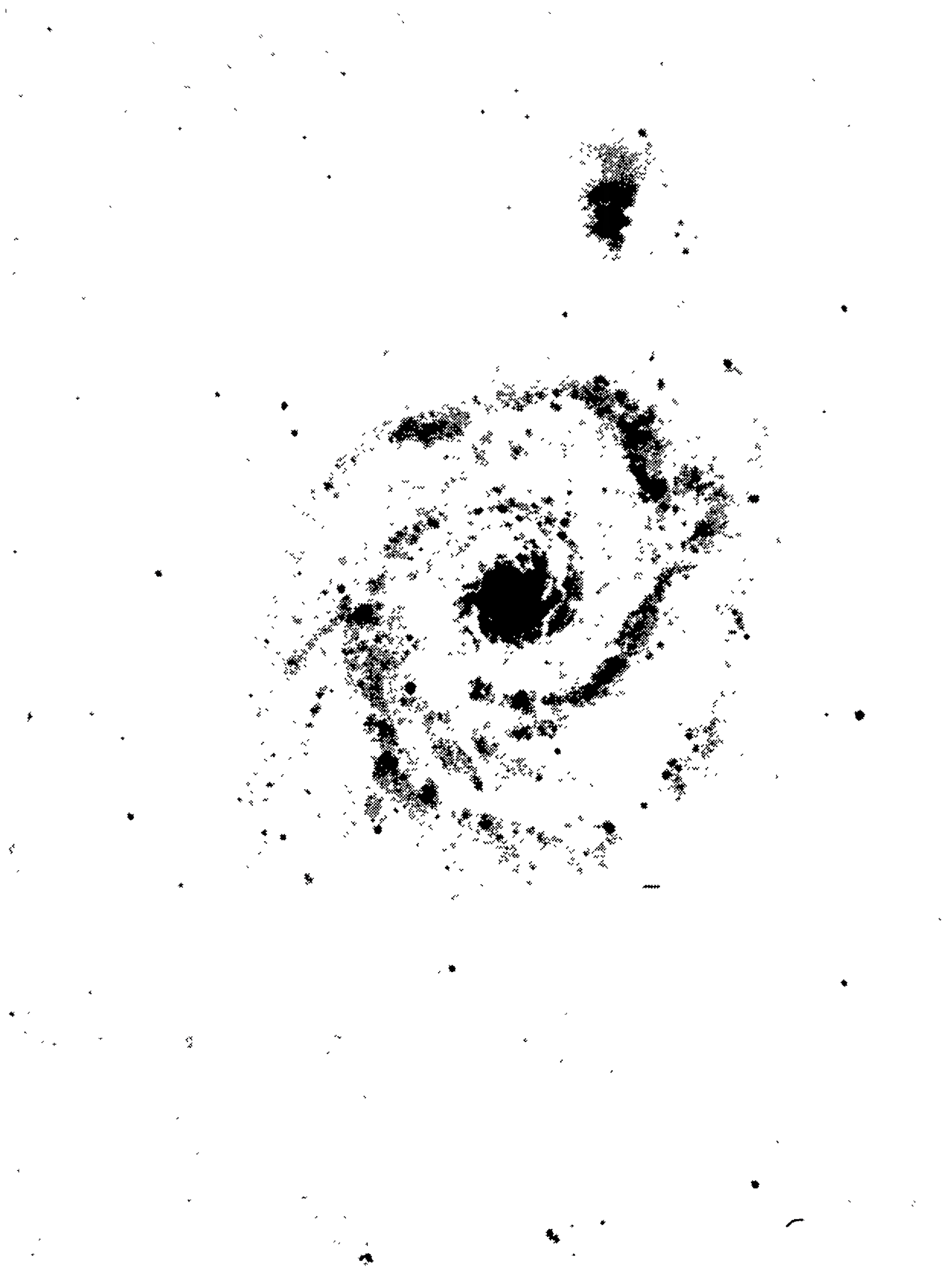
PLATE II



NGC 5194/5, Yellow Negative

Eastman 103a-D emulsion, Schott GG 11 filter, 180-minute exposure with 40-inch Ritchey-Chrétien telescope.

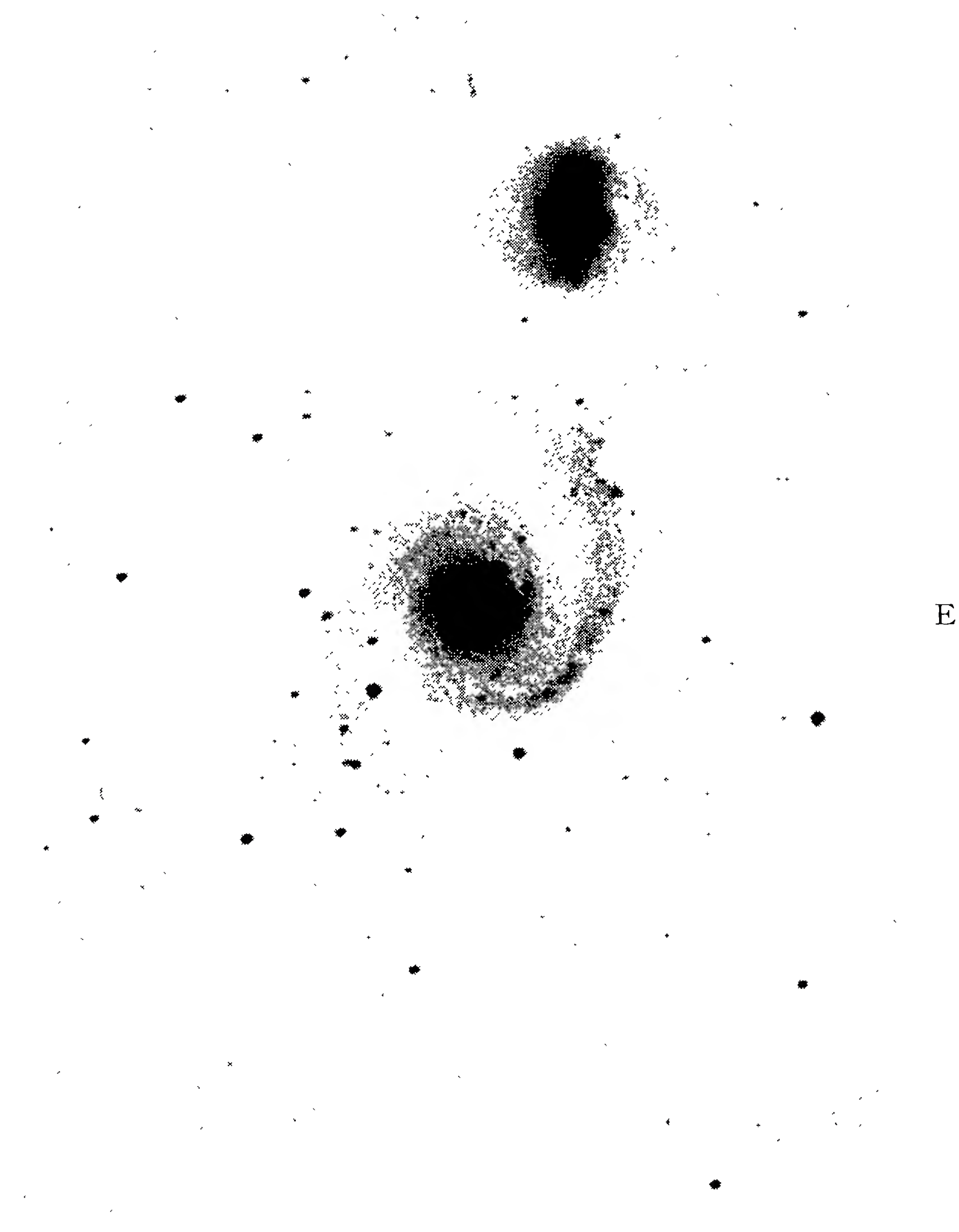
PLATE III



NGC 5194/5, Composite (B−Y+)

1963PASP...75..219S

PLATE IV

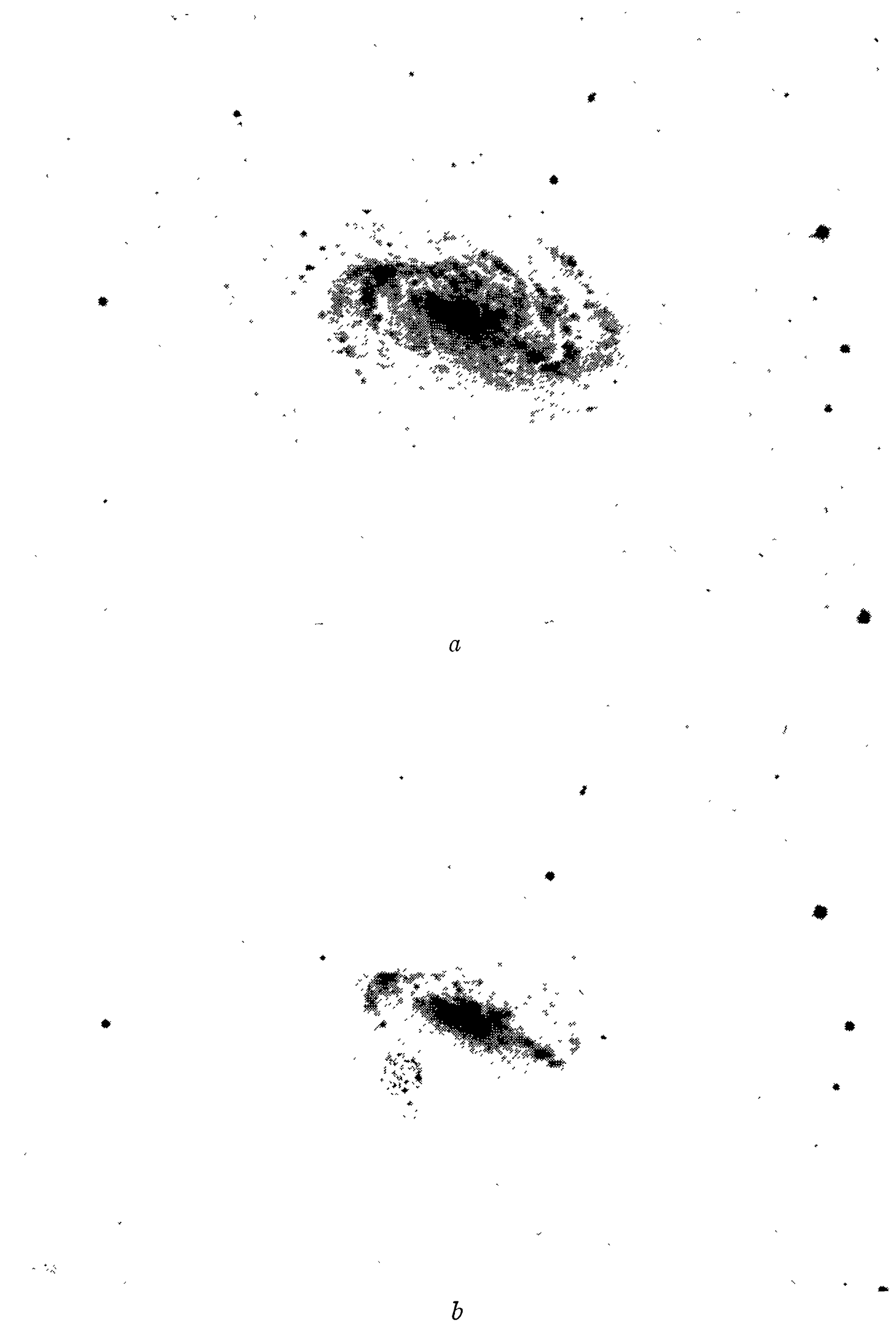


NGC 5194/5, Composite (B+Y−)

PLATE V

E

N

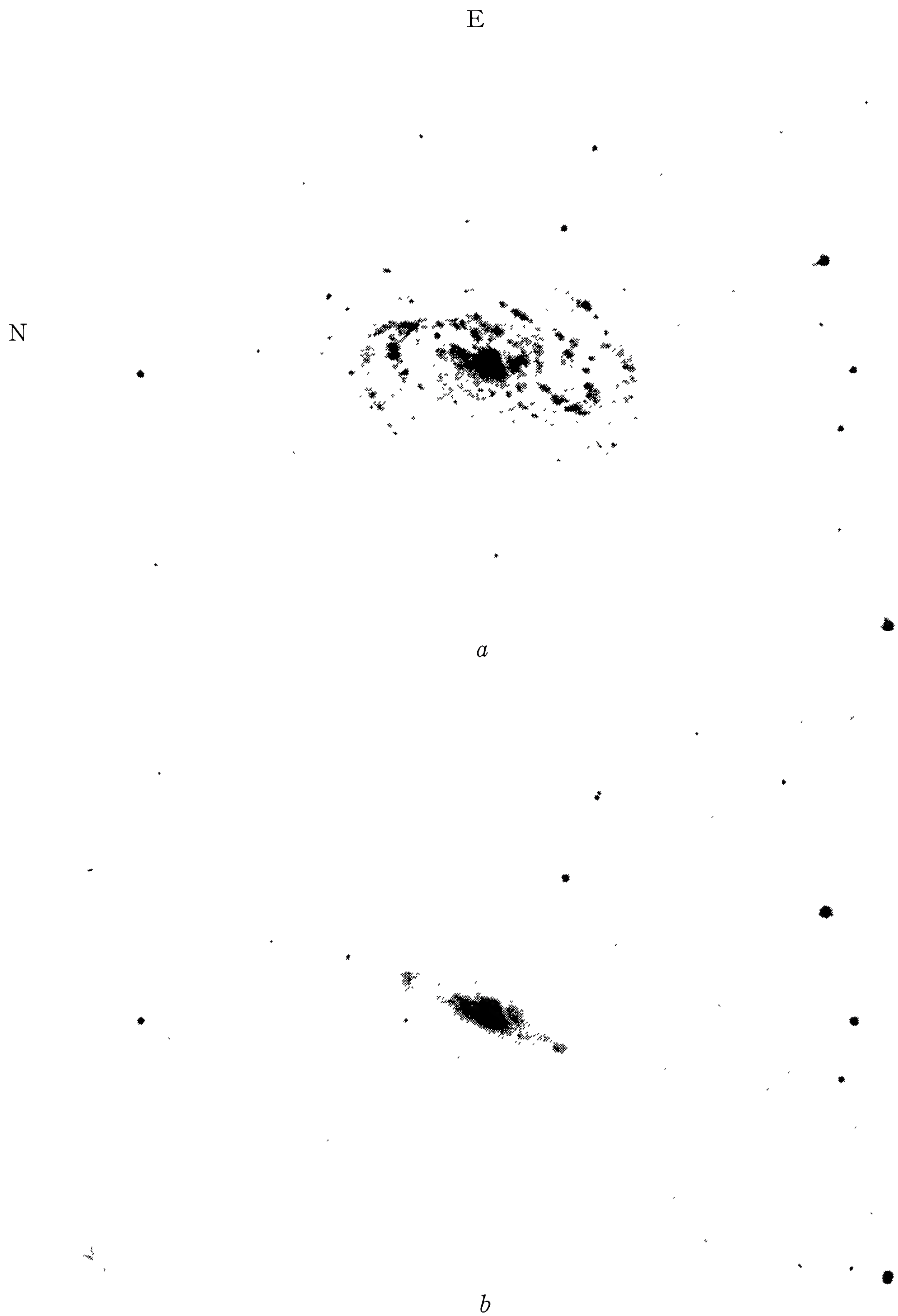


NGC 2903

(*a*), Blue negative: Eastman 103a-O emulsion, Schott WG 2 filter, 30-minute exposure with 100-inch telescope;

(*b*), Yellow negative: Eastman 103a-D emulsion, amber plexiglass filter, 60-minute exposure with 100-inch telescope. Scale: 6″.55/mm.

PLATE VI



NGC 2903

(*a*), Composite (B−Y+) ; (*b*), Composite (B+Y−).

A second example, NGC 2903, is shown in Plates V and VI. The original plates were obtained by one of us (S.S.) with the 100-inch telescope on Mount Wilson during March and April, 1953. Of particular interest is the B^+Y^- composite (Plate VI*b*) which brings out a barred structure with well-defined condensations at the extremities of the bar. Although this object is classified as Sc in the Hubble scheme,[3] it is apparent from the illustrations given here that a more realistic classification would place it in a region of the Hubble "tuning-fork" diagram which is intermediate between the classical Sc and SBc types.

The rotation curve of NGC 2903 has been studied by Burbidge *et al.* (Fig. 2 of their paper).[4] Their curve was obtained from spectrograms taken with the slit set at position angle 24°, which closely agrees with the position angle of the bar. It is of interest to note that the major features of this rotation curve can be related to structural features discernible in our composite photographs. The turn-over points of the curve coincide with those points where spiral arms trail off at each end of the bar. The large scatter in the radial velocities at the SW end of the rotation curve can be attributed to the fact that two separate arms emerge from two distinct condensations at the SW end of the bar. The conspicuous bump in the rotation curve on the NE side, between —20″ and —60″ from the center, can be related to spiral structure emerging from or projecting upon this portion of the bar. Apparently this irregularity in the rotation curve is manifested only in the nebular emissions (associated with spiral arms) and not in the calcium H line which originates from the older population making up the bar. The region between +20″ and +60″ from the center on the SW part of the rotation curve corresponds to that portion of the bar which appears least disturbed by projected or emerging spiral structure. Therefore no feature reflecting the bump on the NE side would be expected in the portion of the rotation curve corresponding to the SW side.

Figures 2 and 3 show schematically the relative arrangement of the young Population I material (solid lines) and the

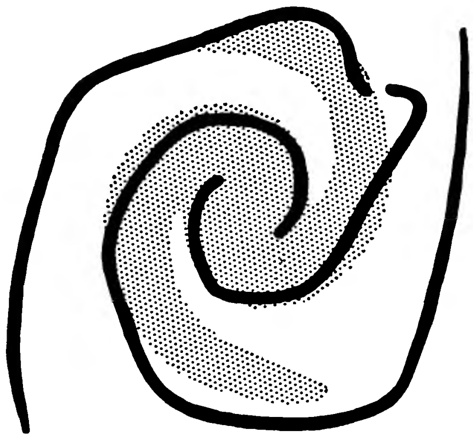


Fig. 2.—Schematic representation of NGC 5194 showing the population components isolated in Plates III and IV.

underlying barred structures (dotted areas) as traced from the composites shown here. Figure 2 shows that the S-shaped spiral visible in the B^+Y^- composite of NGC 5194 does not exactly coincide with the spiral structure as outlined by the young Population I material, the latter tending to be along the outer edge of the former. Figure 3 shows schematically the individual spiral arms of NGC 2903 as well as the underlying barred structure. Three distinct pairs of arms are visible, two of them forming bifurcations at the extremities of the bar. This strongly suggests a close dynamical connection between the barred struc-

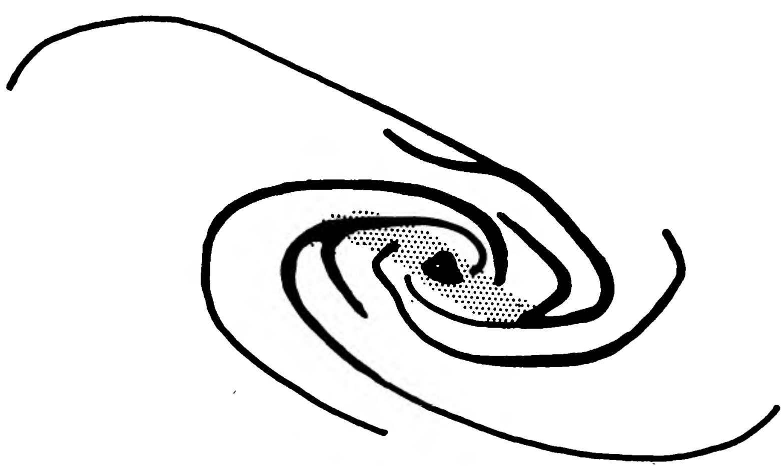


Fig. 3.—Schematic representation of NGC 2903 showing the population components isolated in Plates VI*a* and VI*b*.

ture and the spiral structure as though the bar itself may contain the locus of the formation of successive generations of spiral arms.

CONCLUSIONS

We conclude, with Zwicky, that the method of composite photography is a valid one for discriminating between certain old and young population components of a galaxy, that, with proper control of the photographic processes, the results are reproducible, and that certain morphological features which have a strong bearing on the classification of galaxies can be isolated and studied by means of this method.

---

[1] F. Zwicky, *Pub. A.S.P.*, **67**, 232, 1955.

[2] F. Zwicky, *Morphological Astronomy* (Berlin: Springer, 1957), p. 194.

[3] A. Sandage, *The Hubble Atlas of Galaxies* (Washington, D. C.: Carnegie Institution of Washington, 1961), p. 26.

[4] E. M. Burbidge, G. R. Burbidge, and K. H. Prendergast, *Ap. J.*, **132**, 640, 1960.