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GALAXY PHOTOMETRY I. TECHNIQUES

W. G. Tifft
Steward Observatory
University of Arizona
Tucson, Arizona 85721

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Abstract

Techniques for the derivation of nuclear magnitudes in galaxies are summarized. A new method for rapid estimation of nuclear magnitudes by iris photometry is presented and evaluated. It is concluded that with proper calibration, nuclear magnitudes for galaxies in clusters may be estimated with an uncertainty of about ± 0.1 magnitude.

I. Introduction

Accurate photometry of an extended object with steep light gradients is a difficult task at best. If only a few objects are involved, direct photoelectric techniques are available. Such detailed precision studies provide what might be called a "calibration" aspect of galaxy photometry. If a large number of objects, especially faint objects in one region, must be photometered, then a "production" phase of photometry is required which with presently available instrumentation almost certainly requires photography. If precision must be high, the production aspect of galaxy photometry can be immensely time consuming. If a large number of objects must be photometered without the highest possible precision, an "estimation" phase of photometry is possible. The first objective of this paper is to summarize the requirements and approaches to the various phases of galaxy photometry to lay the ground work for programs underway at the Steward Observatory. Secondly, this paper presents a technique for accurate estimation of "nuclear magnitudes" of galaxies in clusters.

Two types of magnitudes for a galaxy appear to be of special significance. The first type is the isophotal m_n , or, in the limit, the total magnitude m_∞ . The second type is a "nuclear" magnitude, $m(R)$, which is most simply defined as the magnitude through some specific circular aperture of size R which is relatively small compared to the size of the galaxy. The size may be defined in various ways. The most common approach is to vary the aperture inversely with galaxy distance to refer to a constant volume or spatial cylinder through each galaxy. In a cluster of galaxies, a constant aperture would be used while between clusters or individual field galaxies an aperture inversely proportional to redshift is usually used. The full significance of nuclear magnitudes and colors as astrophysical quantities is not well known but it is quite apparent that they contain a great deal of information which we at present can only poorly understand. Two prime examples from the work of this author include the studies of nuclear colors and light gradients (Tifft, 1969, 1970) and the redshift-nuclear magnitude-morphology correlations (Tifft, 1971, 1972a, 1973).

Some techniques of galaxy photometry permit the direct determination of total magnitudes. These methods include extrafocal or fabry photometry and schraffierkassette photography. These procedures will not be considered here since they provide no information on the light distribution, hence no information on nuclear magnitude.

II. Calibration

The majority of accurate magnitudes and colors of galaxies available today have been derived from direct photoelectric observations through specific circular apertures. By interpolation a nuclear magnitude $m(R)$ for any radius in the measured range can be derived and by ext-apolation through "aperture corrections" based upon typical luminosity profiles an isophotal or total magnitude can be derived with reasonable precision. A recent discussion of such procedures has been given by Sandage (1972a, 1972b). Unfortunately, except for relatively nearby large galaxies, apertures small enough to give nuclear magnitudes directly have rarely been used. The process of finding nuclear magnitudes usually requires photographic determination of intensity distributions which are then integrated out to specific radii for which photoelectric photometry exists for some of the galaxies. This procedure establishes the zero point of the intensity calibration. The individual intensity distributions may then be integrated to any specific radius within the resolution limit of the photography available.

In a few cases, direct area scans or intensity profiles have been derived for galaxies photoelectrically. Techniques include drift scans, individual point by point photometry (for example, Miller and Prendergast, 1962), and newer techniques of scanning by image dissectors (Tifft, 1972b), and digital image tubes or television (for example, Crane, 1972). Eventually, improved data handling techniques may make some of these last mentioned methods suitable for limited "production" purposes, however, it is likely that for some time they will remain primarily useful as calibration procedures and methods of investigating specific astrophysical problems.

A third type of calibration procedure employs electronography. Photoelectric calibration by $m(R)$ measurement is required to fix the zero point, however, the intensity scale is not distorted through the usual uncertain photographic calibration procedures. Ables and Ables (1972a, 1972b) have shown how effective the procedure can be. At the present time, the most accurate practical method of calibration of production photometry appears to be electronography of a few objects with zero point from direct $m(R)$ photoelectric photometry. This may be supplemented with any direct intensity profile data available.

III. Production

Given a suitable calibrated photographic plate of a galaxy or group of galaxies, a variety of techniques are available for systematic photometry. The most obvious technique is complete general isophotometry with integration over the appropriate parts of the image for which photometry is desired. When the light distribution is irregular, some form of this approach which samples all parts of the image individually is obviously required. One of the most extensive studies of this type was carried out by Holmberg (1958). If the galaxies show a concentric elliptical light distribution, the photometry can be considerably simplified without much loss in accuracy. The normal procedure is to trace the major and minor axis profiles and define a series of isophotal ellipses. Integration outward then yields direct isophotal magnitudes which have been denoted $m(A)$. This technique has been applied to the Coma cluster by Rood and Baum (1967, 1968).

By following a simple procedure using elliptic integrals, $m(A)$ values may be directly converted to $m(R)$. A modification of the axial scanning technique has been proposed by Oemler (1973) where the major axis is scanned first with a small aperture and then with a long slit which in effect integrates along the minor axis direction.

A new technique, which is actively under development at the Steward Observatory, involves the use of an image dissector to rapidly perform an accurate two dimensional scan of galaxy images. The digital map is then rectified and integrated directly to yield whatever type of photometry is desired. The primary correction required aside from the usual transmission-intensity conversion is a correction for signal induced background which tends to fill in the dark areas with spurious signals. Appropriate convolutions with spread functions determined by point or edge scans can be used to rectify the image. The technique will be described in detail in later papers as it achieves practical applications. Some preliminary discussion has been given by Tifft (1972b). This same rectification procedure can in principle be used to correct image distortion which may be present in a photograph and may vary over the field. Stellar images in this case provide a direct determination of the blur function.

IV. Estimation

The most obvious means of magnitude estimation for galaxies involves a direct visual image intercomparison perhaps using a set of "standard" sample images (flyspanker). The method is subjective and hard to assess for accuracy. One device which is commonly available and simple to use in stellar photometry is the iris photometer. It would be convenient if this device could be used to estimate magnitudes, however, because of the wide variety of sizes in galaxies and the wide range of central concentration it is not obvious that iris photometry would be very useful. Iris measurements of galaxies in clusters were first made at Steward Observatory to select galaxies for redshift measurement to some reasonably homogeneous nuclear magnitude limit. In order to compare against true magnitudes, an investigation was carried out in the center of the Coma cluster which is the only cluster having extensive detailed photometry available (Rood, et. al., 1973). A V plate (103a-D + GG14) exposed at the 90-inch (225 cm) Cassegrain focus for 30 minutes was used. The Steward Observatory 90-inch (225 cm) telescope operates at f/9 with a plate scale of 10 "/mm. In 30 minutes the sky background is barely discernable and only the nuclei of galaxies are prominent. The telescope is well suited to nuclear region studies but is poorly suited to total magnitude work without image enhancement equipment.

All galaxies in the Rood and Baum field I (1967) were measured on the semi-automated Cuffey iris photometer at the Steward Observatory and correlated against $V(4.8)$ and V_{25} magnitudes for the galaxies as tabulated by Rood, et. al., (1973). The result is shown in figure 1. The correlation between iris measurement and $V(R)$ is excellent with two exceptions noted below; the relationship with V_{25} is poorer. The magnitude dispersion of $V(R)$ about the mean iris curve is 0.09 for $V(R) > 17.5$. For $V_{25} > 16.5$, the dispersion is 0.22.

All the galaxies in the sample studied are of type E or SO, hence,

Figure 1

Comparison between magnitudes derived from iris photometry and detailed photometry of E and S0 galaxy images in the Coma cluster. Two discordant points are indicated by arrows and are discussed in the text. There is no dependence of residual on morphological type between E and S0 objects.

are morphologically very similar. No dependence of magnitude residual on morphological type is detectable. This is not surprising since in photometric nuclear properties there are no significant distinctions between the E and SO types (See Tifft, 1969). If iris techniques are applied to spiral or irregular galaxies, which tend to show a lower ratio of nuclear to outer region intensity than ellipticals, some systematic deviations might be expected. The Coma cluster does not contain significant numbers of such galaxies to investigate. It appears therefore that within clusters dominated by elliptical galaxies iris estimates of nuclear magnitudes can be done with good precision. A procedure as used in stellar photometry is indicated; a standard sequence of a few objects can be used for calibration of iris photometry until precise detailed image scanning can be completed. This type of photometry appears to be completely adequate for preliminary redshift-magnitude correlation studies of clusters. Band spacings of 0.7 magnitudes are typical in the Coma cluster.

Two deviant points appear in figure 1. They are the objects RB9 and RB102 which in accord with the detailed photometry of Rood, et. al., (1973) are the two most compact objects in the sample observed. Spectra are not available yet for these two faint objects; it is possible that they are stars and not galaxies. Inspection of the 90-inch (225 cm) telescope plate which was taken under good seeing conditions gives no convincing evidence that the objects are not stellar. A comparison between the f/9 90-inch (225 cm) telescope plate and the f/3 200-inch (508 cm) telescope from plates III and VII of Rood and Baum (1967) is of interest. Galaxy RB9 lies close to RB11 which is the faintest galaxy presently observed (Tifft, 1973). On the f/9 plate, RB11 appears clearly diffuse and distinctly fainter than RB9 which is essentially stellar. On the f/3 reproductions, RB11 is distinctly brighter than RB9 and this is reflected in the RB magnitudes. This difference dramatically illustrates the existence of the halo of RB11 which is well recorded only on the f/3 plates. A faint star appears on the plates between RB9 and RB11 and slightly east. On the f/3 plate RB9 is brighter than the star while at f/9 it appears fainter. This comparison suggests that RB9 does have a small halo compared to a true stellar image. It is also possible that some variability in luminosity is present, however, an explanation in terms of amount of halo light recorded appears more likely.

Examination of all other galaxies in the Coma region in the $V(4.8)=17$ to 18 range does not reveal any other highly compact objects like RB9 and RB102. It seems likely that neither the RB or iris magnitudes are likely to be too reliable for such objects which appear, however, to be rare objects if they are in fact galaxies at all. Study of these objects is continuing.

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