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THE COLOR STRUCTURE AND THE DISTRIBUTION OF NEUTRAL HYDROGEN WITHIN MESSIER 51

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ABSTRACT

Blue and Visual photographic plates of Messier 51 have been digitally analyzed to give computer produced B-V maps of M51. This material is compared with the preliminary Westerbork 21 cm neutral hydrogen data. These data indicate a correspondence between the neutral hydrogen contours and the bluest regions of M51. The existence of a ring of blue stars in the nucleus of M51 is reported.

Key Words: Messier 51, B-V maps, 21 cm contours

INTRODUCTION

A subject of continuing interest and controversy involves the question of star formation in spiral galaxies (Bok 1972, 1973; Piddington 1973a, 1973b). The density wave theory of Lin and Shu (1964), and the density shock wave theory of Roberts (1969) have been contrasted with the magnetic field models of galactic star formation of Piddington (1969). A fundamental test of these theories involves the placement of regions of neutral hydrogen (HI) with respect to the optical spiral arm structure. Recent 21 cm HI data from the Westerbork array (Oort _et al._ 1973) makes it possible to investigate this question. Data for the spiral galaxy Messier 51 (NGC 5194) appears somewhat confusing at first glance. In November 1972, Dr. Ernst Raimond presented B. J. Bok with a preliminary outline of the distribution of neutral atomic hydrogen for M51. Plate VII shows an overlay of the Westerbork contours onto an optical photograph of M51. The correspondence of spiral arms with 21 cm data indicated by the density wave theory is not obvious (Piddington 1973c). It is thus of interest to investigate in detail the spiral structure of M51 with regard to color as well as intensity and to compare the color data with the radio data. In order to accomplish this a digital analysis of the color (B-V) structure of M51 was undertaken; the results are reported in the present paper.

I. The Data

On the night of 24 March 1973, two plates were taken of M51 using the Cassegrain direct camera of the Steward Observatory 90" reflector. The plate scale of this instrument is 9".98/mm. The emulsions and filters were chosen so as to approximate the UBV system. Plate I is the Blue plate and Plate II the Visual plate. Plate data is listed in Table 1. The moon was in its last quarter phase during these exposures, so the sky background was rather high. Seeing was excellent and consistent between both exposures. Spot sensitometer calibrations for the entire range of densities occurring on the plates were placed on the plates prior to the exposures.

II. Reduction

Previous composite works on M51 (Zwicky, 1955; Sharpless and Franz, 1963) had involved the use of photographic subtraction; it is described in detail by Zwicky (1955). This technique is excellent for providing color data on regions of the plate which are exposed to densities on the linear part of the photographic response curve, however, it is possible to obtain accurate photometric color data over only a small range of densities. Furthermore, the difficulty in matching two plates with respect to photographic response renders results at best accurate relative to one another. Thus colors so obtained are practically useful only for qualitative analysis. The effects of the sky background are difficult to separate from effects produced by the object under investigation. Thus for galaxies, which have enormous ranges of intensity and many faint areas which are not much brighter in intensity than the sky background, composite imagery produces limited information. Finally, the complicated photographic procedures involved render photographic composite imagery rather undesirable. These problems have all been discussed in detail by Wray (1970).

Conversely the use of conventional photoelectric photometry similar to de Vaucouleurs (1958) work on M31, and work on M51 by Baum (1966), suffers from the low spatial accuracy obtainable by such methods, since the photoelectric aperture must be large to eliminate seeing effects, real fine structure is unobservable.

The development of high speed digital scanning microphotometers makes it possible to overcome some of these difficulties and it enables the analysis of large amounts of data to be made in a reasonable amount of time with high spatial resolution. This was the approach chosen for the analysis of M51.

The plates were scanned with a 100 μ square aperture using the Kitt Peak National Observatory Photometric Data Systems (PDS) Model 1010A Microdensitometer. This corresponds to a 1" resolution on the plates. A region 10 cm by 10 cm centered on M51 was scanned, corresponding to a 17!1 square. As a result over 10^6 data points were obtained. The thirteen calibration spots were scanned in a similar manner. These densities were fitted with a polynomial to convert measured densities to true intensities. A least squares fit of a third order polynomial was found to give 5% accuracy over a range of intensities of 500. The basic data were converted from densities to intensities using this polynomial technique on the Kitt Peak National Observatory CDC 6400 computer. The relative Blue and Visual intensities were adjusted using the photoelectric color data of the nuclear regions of M51, as published by de Vaucouleurs (1961). From the data it was possible to produce B-V maps of M51 and of the surrounding sky. Problems inherent in photographic plates render the colors so produced accurate to only ±0.2 magnitudes. The resulting data are shown in Plate III, where the darkest areas correspond to B-V = $0^m.0$, and the lightest to $+2^m.0$. Clearly, Plate III shows that the sky is indeed blue! By averaging the intensities over a small region of clear sky on the plate it was then possible to determine the sky brightness in Blue and Visual light and subtract the sky brightness from the remaining data. The colors so produced are displayed in plates IV and V for all regions 10% above the sky background, which is reproduced in black in both plates. Plate IV shows the blue regions from a B-V of $0^{m}.0$ as light areas. Similarly Plate V shows the red areas from a B-V of $+2^{m}.0$ as light regions. These plates were produced using the light emitting diode playback capability of the Kitt Peak PDS machine.

Since the data are available in digital form, it is possible to display the distribution of regions of a well-defined range of color within M51. Plate VI shows those regions of M51 which are bluer than B-V = + $0^{m}.5$. The outer regions of the galaxy show the effect of sky background noise. However, within the galaxy itself blue regions are readily visible. In Plate VII the preliminary Westerbork contours presented to Bok by Raimond are shown. Plate VIII shows these contours overlaid on the blue B-V plate (Plate IV). Finally, Plate IX shows the Westerbork contours overlaid on Plate IV, the plate showing the distribution of the bluest regions within M51.

III. Discussion

Several tentative conclusions can be drawn from this material. While the 21 cm data on Plate VII do not match very well the optical photograph, as noted by Piddington

(1973c), they do appear to match to a better degree the distribution of the bluest regions of M51. In most of the locations where strong 21 cm emission exists, there seem to be blue stars. This is shown especially well on Plate IX, where only the bluest regions are displayed. This is somewhat in contradiction to Oort *et al.* (1973) who expressed the opinion that the 21 cm emission lies generally to the outside of the blue spiral arms. However, since the 21 cm data were available only in preliminary form, it is impossible to make firm conclusions. When the 21 cm data appear in digital form, it will be possible to check these hypotheses with the aid of mathematical cross-correlations.

Plates IV and V are similar in appearance to the previous composite plates of Zwicky (1955) and of Sharpless and Franz (1963). However, by the use of the technique described in this paper, one is not limited to a narrow range of brightness. Studies become possible involving both the brightest and faintest regions. Two features are notable. A very blue inner ring just outside the nucleus of M51 is apparent on Plate VI. The lack of 21 cm emission from this region is significant. However, two sets of spiral arms appear to leave this ring on opposite sides of the nucleus. Both incipient arms seem to be closely associated with 21 cm emission. Another notable feature appears on Plate V, on which the red areas are displayed as brightest. The nebulosity surrounding NGC 5195 appears quite clearly as an extended red structure. While these blue and visual plates do not reach as faint a sky background as recent Kitt Peak 4-meter photos by C. R. Lynds (1973) for the same region, which show this extended feature very clearly, this red feature is clearly visible in Plate V. Its B-V of $+1^{m}.5$ to $+2^{m}.0$ suggests that it may consist mostly of late type stars, possibly expelled from NGC 5195 by interactions with NGC 5194. From this study is does appear that analyses similar to the above can be useful in investigations of faint diffuse regions of all types.

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TABLE 1

Plate #	Type	Filter	UT Start	Exposure Time
1072	Kodak IIa-O	GG13	07:35	60 minutes
1073	Kodak IIa-D	GG14	09:08	75 minutes

PLATE CAPTIONS

Plate I	Blue 90" photograph of Messier 51, 60-minute exposure.
Plate II	Visual 90" photograph of Messier 51, 75-minute exposure.
Plate III	B-V map of M51 and the sky; B-V=+$2^{m}.0$ is white, B-V=$0^{m}.0$ is black.
Plate IV	B-V map of M51 with the sky subtracted; B-V = $0^{m}.0$ is white, the sky is black, B-V = $2^{m}.0$ is also black.
Plate V	B-V map of M51 with the sky subtracted; B-V = $2^{m}.0$ is white, the sky is black, B-V = $0^{m}.0$ is also black.
Plate VI	B-V map of M51 with the sky subtracted; only those regions of M51 with B-V < $0^{m}.5$ are shown as white.
Plate VII	21 cm preliminary Westerbork contours, overlaid on a visual photograph of M51.
Plate VIII	21 cm Westerbork contours overlaid onto Plate IV, the blue B-V map of M51.
Plate IX	21 cm Westerbork contours overlaid onto Plate VI, the regions of M51 with B-V < $0^{m}.5$.