INFRARED ARRAY IMAGING OF THE "HOT-SPOT"

GALAXY NGC 2903

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Abstract. Previous studies of NGC 2903 at a variety of wavelengths have indicated that considerable starburst activity is occurring within this galaxy. Due to its relatively large spatial extent and infrared luminosity, NGC 2903 is ideally suited for infrared image analyses. The JPL/SISEX infrared CCD and Galileo/IfA 500×500 optical CCD were used to image the nuclear region of NGC 2903 in K (2.2 μm) and V (0.55 μm), respectively. The (2.2 μm)/(0.55 μm) flux ratio has been used in this program to map the reddening across the nucleus of this galaxy.

I. INTRODUCTION

Approximately 15% of all bright spiral galaxies exhibit some form of peculiar structure in their nucleus (Sérsic and Pastoriza 1965, 1967; Sérsic 1968). Sérsic has investigated a variety of such galaxies and appropriately classified them as "hot-spot" galaxies due to the luminous knots of material they often have around their nuclei (Sérsic 1973). Interestingly, the overwhelming majority of spirals found to have hot-spot nuclei also have bars (Sérsic and Pastoriza 1965, 1967). Though the dynamical association of bars with hot-spots is poorly understood, this relationship demands further study through high-resolution imaging. Noncircular motions have been found in many hot-spot galaxies, including NGC 1365 (Burbidge, Burbidge, and Pendergast 1962) and NGC 1808 (Burbidge and Burbidge 1968; Arp and Bertola 1970). Such peculiar nuclei have stellar components characterized by F and G stars, with late-type stars dominating the longer wavelength stellar emissions (Pastoriza 1973). The gas in most hot-spots appears to be of "normal" composition (Osmer, Smith, and Weedman 1974). Also, steep Balmer decrements are often found in hot-spots, indicating large amounts of obscuring dust within these features.

In the case of NGC 2903, star formation appears to be occurring throughout the nuclear region and not just in the hot-spots (Wynn-Williams and Becklin 1985). The ratio of 10 μm to free-free flux is unusually high in the core, which Wynn-Williams and Becklin (1985) attribute to emission from extremely small grains that are heated to high temperatures through single UV photon absorption and subsequently lose energy through infrared emission. Alloin's
(1973) discovery of emission lines from the nucleus indicates the presence of hot stars exciting nearby gas. Oka et al. (1974) followed up Alloin’s spectroscopic efforts and concluded that the knots are composed of a mixture of late- and early-type stars with intervening hot dust and ionized gas. Radio emission originates from approximately the same 20″ nuclear area as the infrared emission with little detailed correspondence between these two sources. Nonthermal radio emission (though some free-free radiation has been detected), with a spectral index of about −0.8, is dominant (Wynn-Williams and Becklin 1985).

Overall the nucleus of NGC 2903 appears to be a rather chaotic structure that is best explained as an energetic star formation region. Such starburst activity would account for the large infrared luminosity of the nucleus through hot dust (measured to be $7 \times 10^9 L_\odot$ from 3-100 μm by Telesco and Harper 1980) as well as the observed radio continuum through HII regions and supernovae. To gain further insight into the detailed structure of the hot-spots of NGC 2903, we made high-resolution images of this galaxy’s nucleus at 0.55, 1.0, and 2.2 μm. This broad wavelength coverage permitted the mapping of obscuring dust throughout the nucleus and revealed subtle structural features within all of the hot-spots.

II. OBSERVATIONS

All of the CCD images were produced at the University of Hawaii’s 2.2 m telescope. The V (0.55 μm) and 1 μm images were made at the IF/10 focus by Wynn-Williams and Becklin (1985) with the Galileo/IfA 500×500 CCD (Hlavy et al. 1982, 1983), while the K-band (2.2 μm) image (500 sec) was taken at the f/35 focus with the JPL/SIPEX IRCCD (Capps et al. 1987). The fortuitous combination of pixel sizes (52×52 μm for the IRCCD and 15×15 μm for the optical CCD) and focal ratios at the telescope’s two foci yielded identical image scales of 0.145 arcsec/pixel to within ~1% so that no pixel shrinking through software was required.

The V and 1 μm frames were processed in the usual manner, i.e., they were bias subtracted and divided through by a normalized flat field. The IRCCD image is actually a mosaic made from 6 individual frames. The faintest nuclear regions in the K image were detected at the ~2 σ level by each pixel. When evaluated over a seeing resolution element (~1″ or ~100 pixels), such faint regions were therefore detected at the ~20 σ level. A description of the processing steps appears in Hodapp et al. (1987).

Wynn-Williams and Becklin (1985) found that the nucleus (as identified by Oka et al. 1974; see Figures 1 and 2) remains spatially fixed from 0.55 to 2.2 μm. Consequently, extracts from each image were made and registered with respect to the nucleus (resulting in frames that are 130×83 pixels in size). Only visual inspection and contour plots were used in the frame-to-frame registration process, resulting in an estimated ±3 pixel (±0.4″) error while registering on the diffuse nucleus.

III. RESULTS

Imaging results are presented in Figures 1 through 6. K-band imaging of the central region of the galaxy reveals the dust-covered nucleus. The entire nuclear region is heavily obscured in the V image but gains prominence with respect to the surrounding hot-spots in the
Fig. 1. V band image
Fig. 2. 1 μm image
Fig. 3. K band image

Fig. 4. K/V image ratio
Fig. 5. K/1μm image ratio

2" = 80 pc = 14 pxl

Fig. 1 through 5. The nuclear region of NGC 2903 is presented in the above V, 1 μm, and K band images.
Fig. 6. A color enhanced version of the K/V image ratio is presented above to depict more clearly the variable extinction across the nucleus.
1 and 2.2 μm images. The nucleus was found to have a peak K-band surface brightness of about 13.4 ± 0.2 mag/arcsec², while the fainter regions to the northwest and southeast of the nucleus have surface brightnesses of about 15.5 mag/arcsec² in K (the V and 1 μm images are not calibrated absolutely). Extending to the north and south of the nucleus are several hot-spots. Oka et al. (1974) have identified knots C and D to be line-emitting regions, both of which are easily visible in the V image. The prominence of C in only the V band indicates that this knot is relatively unobscured by dust. Overall, the frames indicate that the patchy appearance of the nucleus is due to variations in both extinction and stellar populations. There is little correspondence between any of the features in the presented CCD frames and the aforementioned 6 and 20 cm radio maps produced by Wynn-Williams and Becklin (1985).

The (2.2 μm)/(0.55 μm) and (2.2 μm)/(1 μm) image ratios yield color information about the hot-spots in the sense that more reddened material appears brighter in the accompanying images. Detection at 0.55 μm, 1 μm, and 2.2 μm was at a significant enough level throughout the frames (a minimum of 20 σ in the K image) that the detail evident in the ratioed frames can safely be interpreted as real and not an artifact of processing. The variation of reddening that is evident in these image ratios is probably caused by the distribution of dust throughout the nuclear region. Interestingly, such material appears well organized, with some rotational shearing indicated. The luminous material that is north of the nucleus is a region of intense star formation whose existence has been confirmed in the line emission study of Oka et al. (1974). Knot C virtually disappears in the (2.2 μm)/(0.55 μm) and (2.2 μm)/(1 μm) frames, while the nucleus and the material northeast of the nucleus appear to be the most reddened objects in the entire core region.

IV. DISCUSSION

The variable extinction depicted in the ratioed images is in basic agreement with studies performed on other "hot-spot" galaxies (Osmer, Smith, and Weedman 1974). Deep photographs of such galaxies often show spiral dust lanes extending into their nuclei (Evans 1964; Sandage 1961). Sharpless and Franz (1963), using blue- and yellow-sensitive photographic emulsions, demonstrated the existence of a bar extending through the nucleus of NGC 2903. Simkin (1975) used U and V sensitive emulsions and this composite print technique to confirm the existence of a bar of obscuring material. She concluded that the bar is quite thick and dominates the entire inner disk region. It is oriented at an angle of 43° with respect to the line of nodes and has a position angle of 28° ± 2°. Assuming a nuclear color that is dominated by K giants yields a difference in internal visual extinction of about 2.0 magnitudes between the nucleus and the northwest and southeast corners of the accompanying K image. Osmer, Smith, and Weedman (1974), using the reddening of hydrogen emission lines, found V band extinctions ranging from 0.1 to 4.0 magnitudes in the 8 "hot-spot" galaxies they studied. It should be noted, however, that the extinction determined through visual lines (Hα and Hβ in the case of Osmer, Smith, and Weedman 1974) tends to be less than that determined through infrared measurements since the latter tends to penetrate deeper into heavily obscured areas. Both non-circular velocities and radial inward streaming motion of the nuclear gas and stars were found in Simkin's (1975) velocity field study of NGC 2903. The peak in the rotational velocity curve according to Simkin (1971) is about 6" away from the core, i.e., at the position of the star formation region that is north of the nucleus. In the context of Simkin's results, the spiral shape of the dust in the nucleus that is evident in the (2.2 μm)/(0.55 μm) image (Fig. 6) translates
into solid body rotation inside the northern star formation region and differential motion outside this feature.

V. CONCLUSIONS

A (2.2 µm)/(0.55 µm) image ratio was used to generate a high-resolution map of the reddening across the nucleus of NGC 2003, thereby revealing previously unseen structures. In particular, such a ratio clearly depicts a well-organized region of dust covering most of the nucleus. Rotational shearing is evident in this dust at points in transition between solid body and differential rotation.

Overall, multicolor imaging suggests that the patchy appearance of the nucleus is due to variations in both extinction and stellar populations. There is little detailed correspondence between the features imaged in this program and the 6 and 20 cm radio maps produced by Wynn-Williams and Becklin (1985). The northern star formation region and nucleus appear to be the most heavily reddened objects in the entire core, as the latter has a visual extinction of about 2.0 magnitudes.

References