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IMAGES IN THE ROCKET ULTRAVIOLET: THE STARBURST IN THE NUCLEUS OF M83

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ABSTRACT

Ultraviolet images of the SAB(s)c I–II galaxy M83 (NGC 5236) obtained with a rocket-borne telescope in broad bandpasses centered at 1540 Å and 2360 Å show a bright resolved nuclear source which accounts for approximately 20% of the flux of the galaxy in both bandpasses. Low-resolution *International Ultraviolet Explorer* spectra of this source reveal an energy distribution similar to that of the starburst nucleus of NGC 7714. Strong blueshifted absorption lines can be interpreted as evidence for a nuclear wind powered by supernovae.

Observations from UV, X-ray, optical, and far-infrared bandpasses are consistent with a starburst approximately one-sixth as strong as that in M82. A scaling of the M82 models of Rieke *et al.* predicts that the nucleus of M83 contains 10^6 to 3×10^7 $M_\odot$ in young stars and has a supernova rate of approximately 0.01 yr^{-1}.

Subject headings: galaxies: individual — galaxies: nuclei — ultraviolet: general

I. INTRODUCTION

The SAB(s)c I–II galaxy M83 (NGC 5236) is an interesting object for UV studies, since infrared and optical observations suggest that vigorous star formation activity is taking place, both in the spiral arms and in the nucleus (Talbot, Jensen, and Dufour 1979; Telesco and Harper 1980; Pastoriza 1975). The young OB/H II complexes are conspicuously strong UV sources. As the nearest barred galaxy, M83 is important for our program of high-resolution UV imagery of a diverse range of galaxy types. M83 was observed on the first flight of our new ultraviolet imaging telescope on Black Brant flight 27.059 at 6:15 UT 1982 April 17. This *Letter* reports the results of an investigation of the nature of the bright nuclear source (Evans 1956; Pastoriza 1975) using our image data and spectra from the *International Ultraviolet Explorer* (*IUE*) satellite.

II. OBSERVATIONS

a) *Rocket*

Our rocket-borne ultraviolet imaging telescope, a prototype for our Spacelab instrument (Stecher *et al.* 1978), is an f/9.0 Ritchey-Chrétien telescope with a primary diameter of 38 cm. Images of M83 were obtained by two cameras, with effective wavelengths for hot stars near 1540 Å and 2360 Å and bandpasses of 350 Å and 880 Å respectively. The flight data and associated laboratory calibration frames were digitized and reduced following the general procedures described by Bohlin *et al.* (1982) and were also used for M5 (Bohlin *et al.* 1983), observed on the same flight as M83.

Figure 1 (Plate L5) is the 25 s exposure of M83 from the short-wavelength camera. The prominent nuclear source accounts for 0.16 ± 0.03 of the total flux from the galaxy in the short-wavelength bandpass and 0.20 ± 0.03 of the total flux in the long-wavelength bandpass, implying that the UV "color" of the nuclear source is similar to that of the galaxy as a whole.

The observed FWHM of the nuclear source is 10″ for both bandpasses, while the FWHM of the brighter stars is 7″.5, indicating that the source is resolved, with a true FWHM in the range from 5″ to 10″. This corresponds to a size of 90–180 pc for an assumed distance to M83 of 3.75 Mpc (de Vaucouleurs 1979), consistent with previously published optical, infrared, and radio data (Pastoriza 1975; Rieke 1976; Cowan and Branch 1982; Condon *et al.* 1982) and with the size inferred from the observed width of the *IUE* spectra perpendicular to the dispersion direction. As an SABc galaxy, M83 has a moderately conspicuous bar at visual wavelengths extending from the nucleus approximately 2′ along the major axis. There is little UV emission from the bar region, as expected from the general lack of star formation in bars (e.g., Burbidge and Burbidge 1960).

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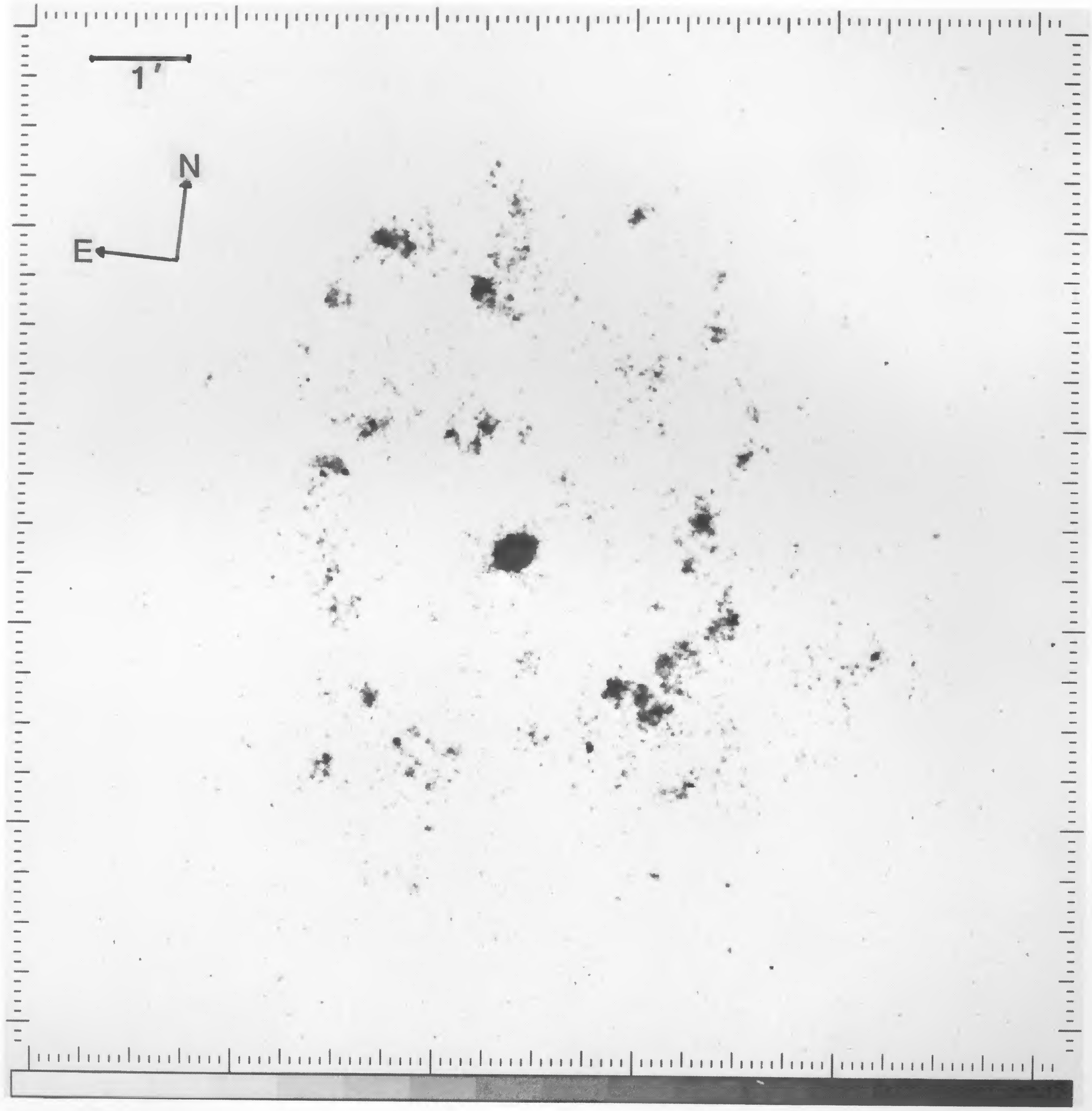

FIG. 1.—Rocket photograph of M83 in the 1540 Å band with a 25 s exposure time. Each division on the axes is 5 pixels (100 μm on the original) with a plate scale of 50 pixels arcmin^{-1} as indicated. The nucleus contributes 16% of the flux of M83 in this bandpass.

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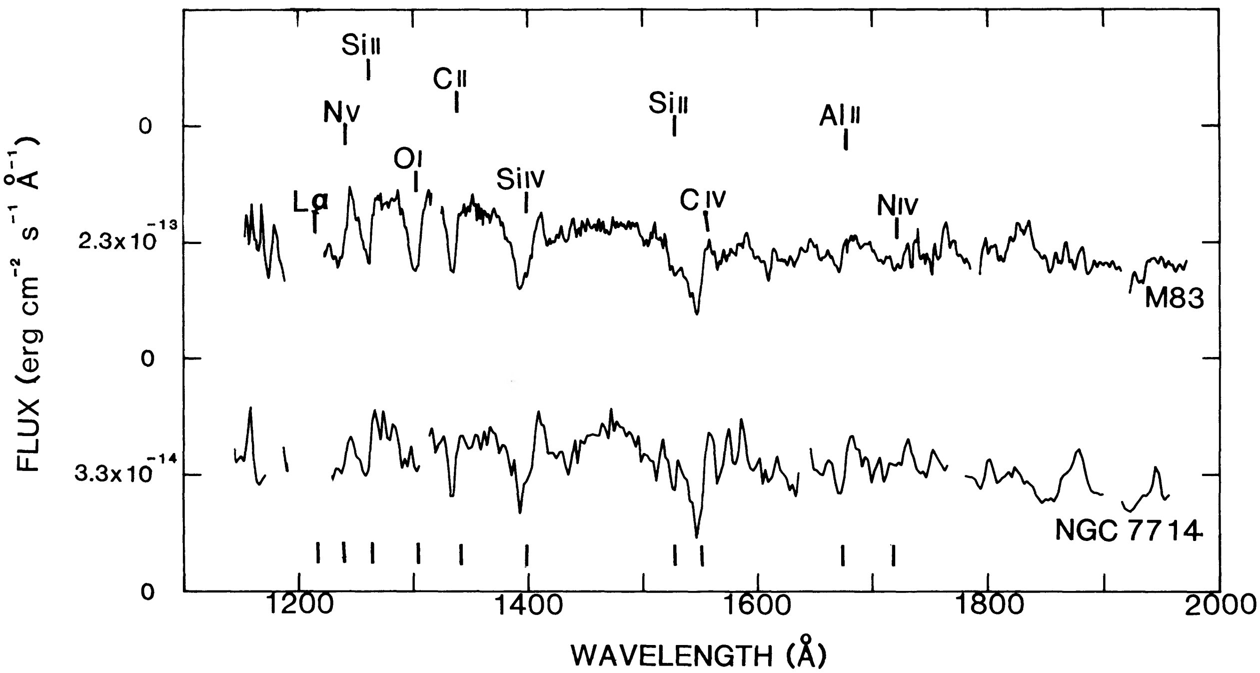

FIG. 2.—*IUE* SWP spectra on an observed absolute flux scale for the nuclei of M83 and NGC 7714. Image sequence numbers for these mean spectra are: for M83, SWP 17097 and 17507; and for NGC 7714, SWP 3953. Wavelength scales have been corrected for systemic velocities relative to the local standard of rest (LSR). The LSR wavelengths of lines mentioned in the text are indicated.

b) *International Ultraviolet Explorer*

In order to further define the properties of the nucleus, we obtained *IUE* low-dispersion spectra from both SWP and LWR cameras on 1982 July 29. Figure 2 is our SWP spectrum combined with data from the National Space Science Data Center archives. The SWP spectrum of the nuclear source in NGC 7714, called the prototype starburst by Weedman *et al.* (1981), is shown for comparison. M83 has strong absorption lines of N V (λ1240), Si II (λ1260), O I (λ1302), C II (λ1335), Si IV (λ1397), C IV (λ1550), and Mg II (λ2797). Weaker lines of Si II (λ1527), Al II (λ1671), and N IV (λ1718) are also present. The higher excitation lines are blueshifted by about 1000 km s^{-1} relative to the systemic velocity of 500 km s^{-1}. Redshifted emission components may be present for the C IV and Si IV lines.

The high-excitation absorption lines also appear strongly in the spectrum of NGC 7714, again blueshifted by approximately 1000 km s^{-1} with respect to the systemic velocity of 2833 km s^{-1}. In the case of NGC 7714, the emission lines are interpreted by Weedman *et al.* (1981) as evidence for an association of early-type stars undergoing typical mass loss. The N V, Si II, C II, and Al II lines are present in NGC 7714, as well. The LWR spectra of both galaxies show strong Mg II λ2797 absorption but have no interstellar extinction feature at 2200 Å. A striking similarity exists between the *IUE* spectra of M83 and NGC 7714, in both the continua and the lines.

III. DISCUSSION

Although the *IUE* spectrum of M83 does not show evidence for significant dust absorption at 2200 Å, observations in other bandpasses indicate that considerable dust must be present. Pastoriza (1975) reports an $H\alpha/H\beta$ ratio of 3.9, implying a total visual extinction of $A \sim 1$, assuming an intrinsic $H\alpha/H\beta$ ratio of 2.8 appropriate for radiative recombination in case B (Pengelly 1964) and the Whitford reddening curve in the visible. Lebofsky and Rieke (1979) report an optical depth of 1.59 in the 10 μm silicate absorption feature, implying an optical depth of $\gtrsim 30$ in the *V* bandpass for an extinction curve similar to that in the solar neighborhood. These contrary estimates of the extinction may be reconciled if the dust and the sources of UV and optical emission are distributed throughout the source (Rieke *et al.* 1980; Leibowitz 1973).

The strong similarity between the UV spectra of the nuclei of M83 and NGC 7714 suggests that M83 is also a starburst. Telesco and Harper (1980) measured a flux in the far-infrared ($\lambda \sim 30$–300 μm) equivalent to a luminosity of $5 \times 10^9 L_\odot$ at a distance 3.75 Mpc, or approximately one-sixth of the far-IR luminosity of the central region of M82. Rieke *et al.* (1980) modeled the observed activity in M82 as a starburst whose radiation is primarily absorbed by dust grains and reradiated in the far-infrared. The observed IR and radio luminosity must be produced by no more than 3×10^8 $M_\odot$, a constraint imposed by the rotation curve of M82. Therefore, the best model of Rieke *et al.* (1980) employs a mass function truncated below 3.5 $M_\odot$.

Weedman *et al.* (1981) modeled the nucleus of NGC 7714 by scaling the preferred M82 model of Rieke *et al.* (1980) to produce the Lyman-continuum luminosity they inferred from the observed Hβ flux. A truncated initial mass function (IMF) is again necessary to produce the required luminosity without requiring more than 10^9 $M_\odot$ in young stars. We adopt a similar procedure, scaling the Rieke *et al.* models A–I to give total luminosities of 5×10^9 $L_\odot$, equal to the observed far-infrared luminosity of the M83 nucleus. These models imply a supernova rate of 0.01–0.02 yr^{-1}, a mass in young stars of 10^6 to 3×10^7 $M_\odot$, and Lyman-continuum luminosity in the range from 5×10^{51} to 3×10^{52} photons s^{-1}. The models differ primarily in the form of the initial mass function. Model A has the IMF for the solar neighborhood with stars in the 0.09 $M_\odot$–31 $M_\odot$ range, while models B–I employ a truncated IMF with lower mass limits ranging from 1.25 $M_\odot$ to 8 $M_\odot$. Unlike the cases of M82 and NGC 7714, model A cannot be rejected for M83, since the total mass in young stars required is less than 10^8 $M_\odot$. The scaled model starbursts predict near-infrared emission from red giants and supergiants consistent within ± 0.5 mag with the $K = 8.3$ mag small aperture measurement of Glass (1973).

Five supernovae (SNRs) have been observed in M83 since 1923, one in the nuclear region in 1968 (Wood and Andrews 1974). Given the inferred supernova rate of approximately 0.01 yr^{-1} and assuming the lifetime of an observable supernova remnant as an X-ray or radio source to be approximately 10^4 yr, there should be approximately 100 observable SNRs in the nucleus of M83. Estimating the X-ray luminosity of a typical SNR at approximately 10^{36} ergs s^{-1} (Weedman *et al.* 1981), we predict $L_x \sim 10^{38}$ ergs s^{-1}, compared with approximately 10^{39} ergs s^{-1} observed by Fabbiano, Trinchieri, and Macdonald (1983). Since the X-ray source appears to be considerably more extended than the 5″–10″ starburst region, the measured flux should be regarded as an upper limit for this nucleus. From a similar argument, we expect a radio flux at 20 cm of 30–70 mJy from SNRs and thermal emission from H II regions compared to an observed value of 100 mJy (Condon *et al.* 1982). We conclude that the available UV, optical, X-ray, radio, near-infrared, and far-infrared data are all consistent with the starburst model. Unlike the cases of M82 and NGC 7714, the lower luminosity of the nucleus of M83 permits low-mass stars and an IMF similar to that in the solar neighborhood.

The inferred large number of SNRs in a region approximately 100 pc in dimension implies that a newly formed SNR expanding at approximately 1000 km s^{-1} will encounter another remnant after about 10^4 yr. In this situation, the expanding remnants may interact to produce a nuclear-scale wind, which ejects $\gtrsim 0.1$ $M_\odot$ yr^{-1} into the halo. Such a picture is in agreement with the large velocities inferred from the UV absorption-line spectrum.

Enhanced star formation is commonly observed in the nuclei of barred spirals. Sersic and Pastoriza (1967) found 20 examples of bright nuclei (including M83), all of which are barred, in a complete sample of 136 nearby spiral galaxies. Tubbs (1982) has investigated star formation in barred sprials, concluding that gas flowing inward along the bar provides the raw material for continued nuclear star formation. He suggests that the gas flow and the existence of the bar may be the result of a gravitational perturbation caused by an encounter with another galaxy. Weedman *et al.* (1981) ascribe the activity in NGC 7714 to interaction with NGC 7715. Other examples of galaxy interactions occurring together with enhanced star formation are cited by Rieke *et al.* (1980) and Larson and Tinsley (1978). In the case of M83, the only plausible candidate for such an encounter is NGC 5253, a disturbed irregular S0 galaxy also showing evidence of enhanced star formation (Osmer, Smith, and Weedman 1974; Moorwood and Glass 1982). If NGC 5253 is also at a distance of 3.75 Mpc, rather than the 2.0 Mpc favored by de Vaucouleurs (1979), the angular separation from M83 of approximately 2° corresponds to a distance of approximately 100 kpc. For a relative velocity of approximately 100 km s^{-1}, the two galaxies could have had a close encounter approximately 10^9 years ago. Interaction between M83 and NGC 5253 has previously been suggested as an explanation for distortions in the outer regions of M83 detected in 21 cm maps (Rogstad, Lockhart, and Wright 1974) and the enhanced star formation in NGC 5253 (Moorwood and Glass 1982; van den Bergh 1980).

In summary, rocket images and *IUE* spectra of M83 are interpreted as evidence for starburst activity in the nucleus of this galaxy. Since the fractional contribution of starbursts to the total galactic light is greater in the UV than at longer wavelengths, future UV observations can be made to study the frequency of the occurrence of this phenomenon. Such statistical information will lead to a better understanding of the physical conditions associated with regions of enhanced star formation.

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