THE ASTROPHYSICAL JOURNAL, 395:L41–L43, 1992 August 10

ULTRAVIOLET IMAGING TELESCOPE OBSERVATIONS OF THE ScI GALAXY NGC 628 (M74)

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Received 1992 March 31; accepted 1992 May 20

ABSTRACT

Ultraviolet images of NGC 628 at 1520 and 2490 Å show that the nucleus has an oblong appearance and that the arms and disk exhibit features not seen in blue or Hα images. Aperture photometry of the nucleus gives results that are compatible with observations in other bandpasses and with models. The spiral arms appear more symmetrical in the UV than in other colors; in particular, two gaps are seen on either side of the nucleus. Combined UV and radio data appear to support a large-scale collective phenomenon, perhaps a quasi-static spiral structure mechanism, as being the dominant mode of spiral formation in this galaxy. We report the detection of a low surface brightness object at a distance of 7.6 southwest of the nucleus.

Subject headings: galaxies: individual (NGC 628) — galaxies: spiral — H II regions — ultraviolet: galaxies

1. INTRODUCTION

NGC 628 (M74) is a multiple-arm ScI galaxy with a Holmberg radius of 6′ which is viewed nearly face-on (inclination angle 5°–7°; Shostak & van der Kruit 1984). Its apparent magnitude, corrected to a face-on orientation, is $B_T^0 = 9.48$ (de Vaucouleurs, de Vaucouleurs, & Corwin 1976). We use the frequently adopted distance of 10 Mpc. Although an isolated galaxy of fairly normal appearance, NGC 628 exhibits some intriguing features upon closer examination. Radio observations (Briggs 1982; Wevers, van der Kruit, & Allen 1986) show an unusually large disk of neutral hydrogen extending out to a radius of 20′. The complex velocity structure seen in the gas is interpreted as a warp in the outer disk caused by an interaction with another galaxy, although no suitable candidates are discernible in the vicinity of NGC 628 (Kamphuis & Briggs 1991). At optical wavelengths certain large-scale irregular features are seen, of which the most notable is an M-shaped discontinuity in the northwestern spiral arm. The presence of large-scale irregularities in an otherwise smooth and regular spiral form is puzzling and has led to a variety of models and interpretations (Hayward 1964; Schulman & Seiden 1986). We present preliminary results from analysis of the vacuum ultraviolet images of NGC 628 taken with the Ultraviolet Imaging Telescope (UIT).

2. OBSERVATIONAL DATA

NGC 628 was observed in two pointings on 1990 December 6 by UIT during the *Astro-1* mission. A detailed description of UIT and its calibration, operation, and standard reduction procedures is given in Stecher et al. (1992). Ten exposures were made of NGC 628. Each image covers a 40′ field and is digitized to a resolution of 1.″14 pixel^{-1}. The two longest exposures made with the near-ultraviolet (NUV) and far-ultraviolet (FUV) cameras were measured and analyzed for the present discussion. The NUV image is UIT frame NUV0161 and has exposure time 530 s. It was made with NUV filter 1, which has an effective wavelength for flat spectra $\lambda_{\rm eff} = 2490$ Å. Magnitudes derived from it are called m_{249}. The FUV image, UIT frame FUV0172, was made with FUV filter 1 and has exposure time 514 s and $\lambda_{\rm eff} = 1520$ Å; magnitudes derived from it are called m_{152}. Coaligned 20′ parts of these images, with north at the top and east to the left, are displayed in Figures 1 and 2 (Plates L23 and L24) with a logarithmic intensity function.

3. NUCLEAR REGIONS

A contour map of the innermost 60″ of the NUV image of NGC 628 is shown in Figure 3. The threshold intensity has been arbitrarily selected to isolate the nuclear bulge from the spiral arms. The highest intensity peak is a foreground star, as can be confirmed by its stellar appearance in the Hα image published by Hodge (1976). The overall appearance of the bulge is patchy and noncircular. A comparison of our UV image with the near-infrared image of Zaritsky & Lo (1986) shows some similarities, although our contour data show a more pronounced elongation and tilt of the semimajor axis toward the northeast. Our result is consistent with the findings of Zaritsky & Lo that NGC 628 has a nonaxisymmetric nuclear bulge which can lead to molecular gas motions and infall toward the nucleus. However, there is no evidence of star formation activity in the nuclear region (Pronik 1973; Turnrose 1976; Pogge 1989), despite the report of a significant CO concentration (Adler & Liszt 1989). Our resolution is insufficient to identify the dust lanes reported in the IR images of Zaritsky & Lo (1986).

Turnrose (1976) has computed a stellar synthesis model for the nucleus of NGC 628 based on scanner measurements of the central 10″. Convolution of his optimal model with our passbands leads to an expected $(m_{152} - m_{249})$ color index of -0.92 mag. Our measured color index is -0.01 ± 0.10 mag, which, if taken at face value, would indicate a color excess $E(B-V) = 1.47$ for the Galactic reddening curve of Savage & Mathis (1979). However, H I observations of the nucleus (Shostak & van der Kruit 1984) give $E(B-V) = 0.04$, while H I observations of the surrounding disk give up to

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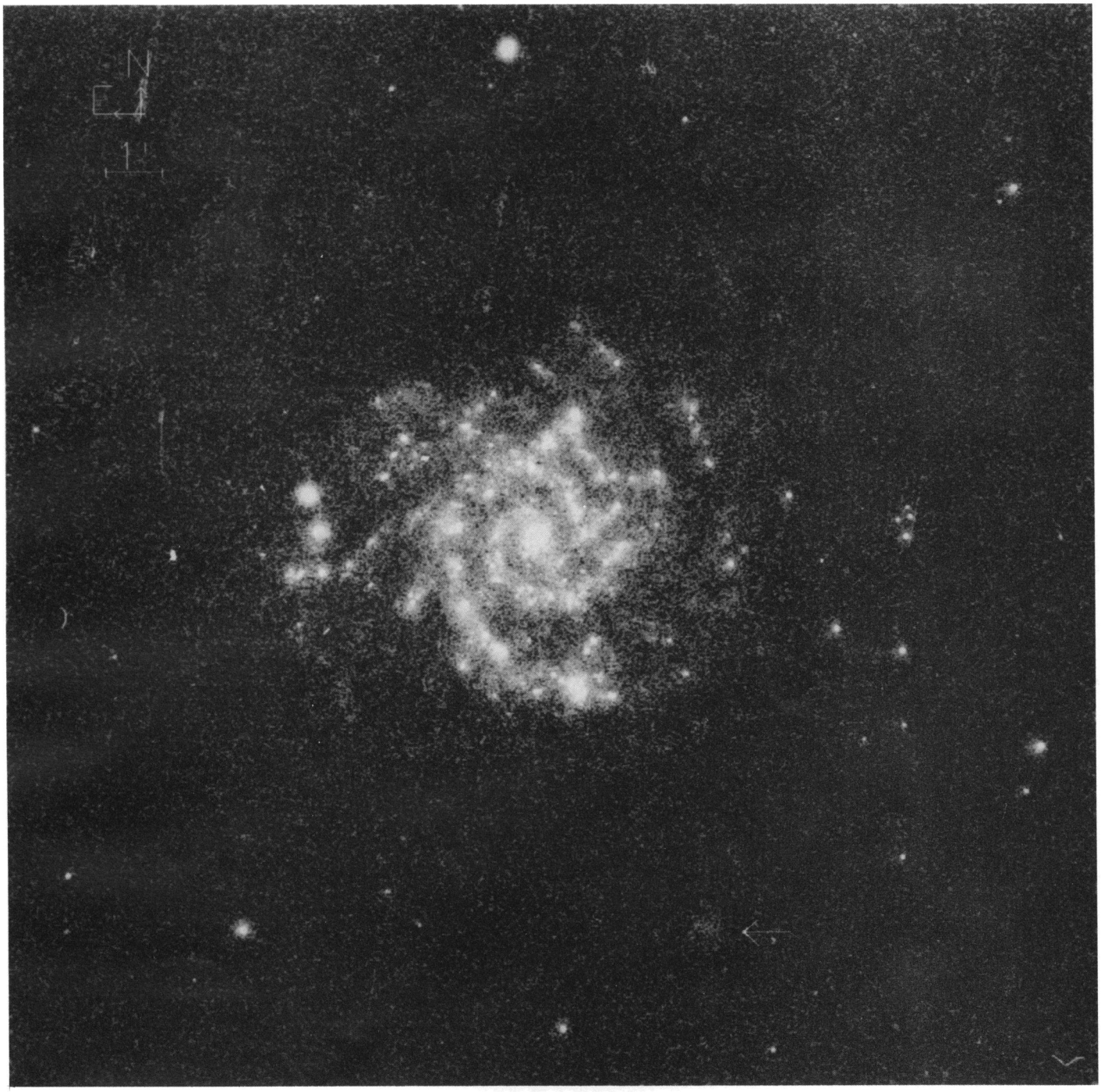

FIG. 1.—UIT flat-fielded, linearized, and calibrated 530 s exposure of NGC 628 made with the near-UV detector through the broad-band (A1) filter, which has an effective wavelength for flat spectra of 2490 Å. North is at the top, and east is to the left; the field is 20′ across, and the image is displayed with a logarithmic transfer function. The faint object pointed out by the arrow is discussed in the text.

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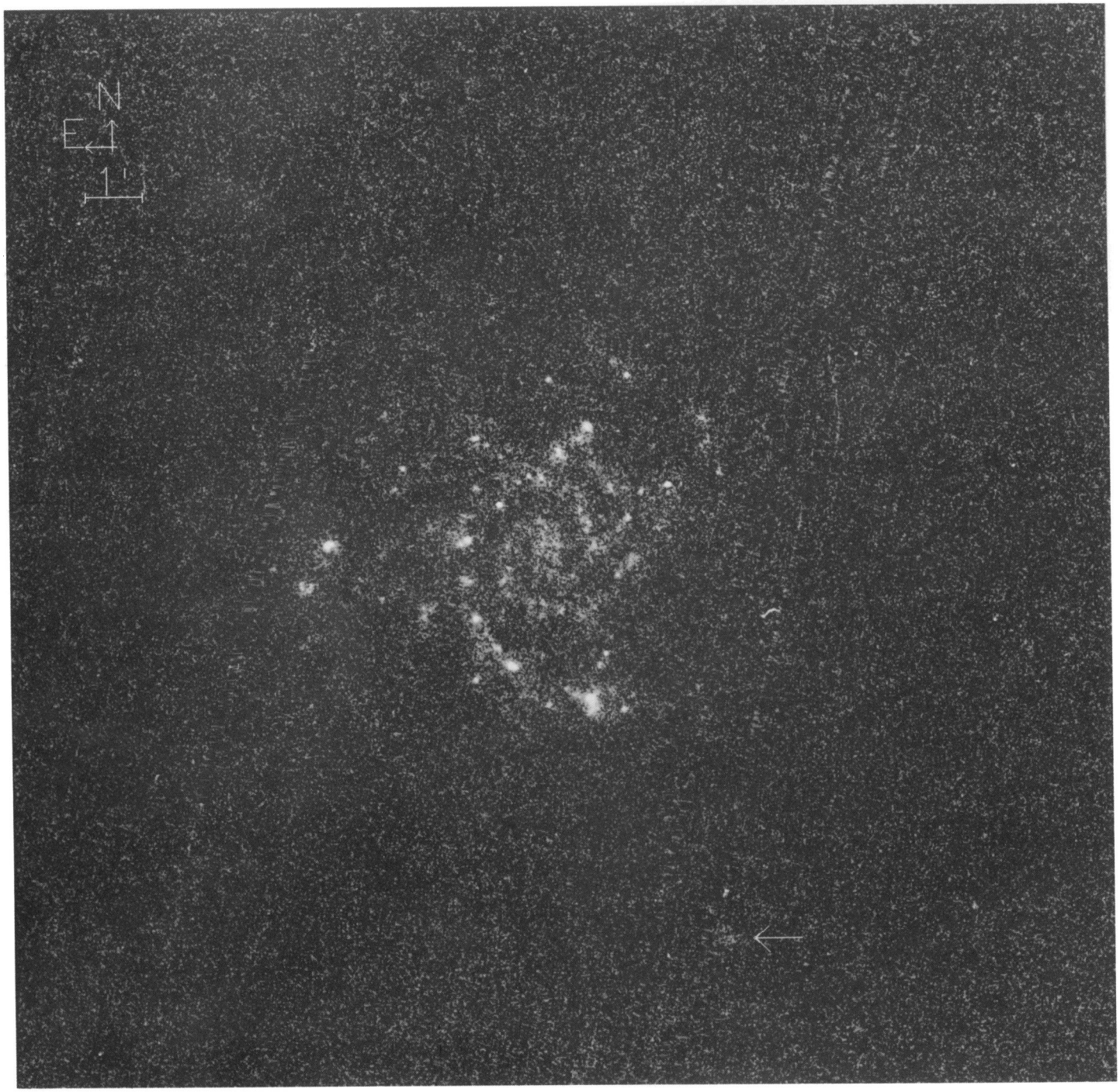

FIG. 2.—UIT flat-fielded, linearized, and calibrated 514 s exposure of NGC 628 made with the far-UV detector through the broad-band (B1) filter, which has an effective wavelength for flat spectra of 1520 Å, displayed as in Fig. 1.

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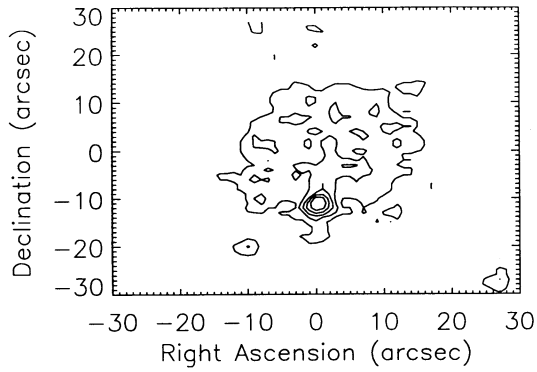

FIG. 3.—Contour map of the central 60″ of the NUV image of Fig. 1. The contours are separated by factors of $\sqrt{2}$, and the lowest contour is arbitrarily chosen to separate the nucleus from the surrounding galaxy. The bright object at (0″, −10″) is a foreground star.

$E(B-V) = 0.23$. CO observations of the nucleus give $E(B-V) = 0.31$ using a Galactic CO/H_2 ratio (Adler & Liszt 1989). This discrepancy is almost certainly explained by some details of the models of Turnrose (1976) which contain a small component of upper–main-sequence stars, but the scanner data are fitted nearly equally well by a model which has no O–B stars. We have modified the Turnrose model to have no O or B stars, finding that it has a color index $(m_{152} - m_{249})$ of −0.01, in good agreement with UIT observations. We conclude that O and B stars are not present in NGC 628's nucleus.

4. DISK AND ARMS

We have used a modified version of DAOPHOT to identify sources in the UV images with peak values greater than 3 σ (sky) and of angular extent 6″ or greater. A total of 134 nonstellar sources were found. Comparison with a computer-generated overlay of H II region positions based on the extensive tabulation of Hodge (1976) shows that within the area of overlap all our sources have exact or nearby (<2″) Hodge counterparts. This is as expected: a UV image and an Hα narrow-band image should correlate. Image sizes should in general be smaller in the UV, since ionized regions will be more extended if the optical depth in the dust is small. A comparison of our UIT data with an Hα image kindly supplied by P. Hodge largely bears out this expectation. We list below a number of notable differences:

1. The source at 157″ south and 71″ west of the nucleus is Hodge source H627 and is merged with another component of similar size but slightly less bright to the south. The southern component is conspicuously absent in Hα. The UV color $(m_{152} - m_{249})$ of the northern component is −0.65; the UV color of the southern component is −0.83. These are approximately the UV colors of unreddened B8 V and B5 V stars, respectively.
2. The sources at 156″ south and 105″ west are H621 and H622 and are much brighter in the UV (relative to nearby sources) than in Hα. The UV color of H621/H622 is −0.49, approximately the color of an unreddened B9 V star.
3. The source at 87″ south and 157″ west is H520 and is much brighter in Hα (relative to nearby sources) than in the UV. Its UV color is 0.40, approximately that of an A2 V star, although its FUV flux is near the faint limit for the image.

The characteristics of these objects may generally be explained by the small sensitivity of our UV color $(m_{152} - m_{249})$ to the temperatures of the hottest stars which dominate the flux of H II regions, the large sensitivity of Hα flux to those temperatures, and varying internal extinction in H II regions. To first order, Hα flux measures ionizing flux from H II regions, and $(m_{152} - m_{249})$ is the observed UV continuum color. A number of other H II regions exist where the morphology and brightness are different in the UV compared with the optical. We are preparing a more detailed study of this phenomenon and its possible implications.

5. SPATIAL MORPHOLOGY

To study the overall structure of NGC 628 in the UV, we display a composite picture consisting of a contrast-enhanced NUV image superposed on a version of itself rotated by 180° around the nucleus (Fig. 4 [Pl. L25]). Two features can be discerned:

1. The main body of the outer northwest arm (the middle of the M-shaped feature) coincides fairly well with the rotated southeast arm. Heretofore, the outer northwest arm has been considered an intrinsically irregular feature formed either as a result of some catastrophic event (Hayward 1964) or as a natural consequence of the stochastic star formation process (Schulman & Seiden 1986). Our composite picture suggests that the outer northwest arm, while undoubtedly associated with some irregular spurs and discontinuities, is part of an original "grand design." The appearance of the spiral structure of NGC 628 in the UV is more symmetric than in the optical (see, for example, Elmegreen 1990).
2. Two symmetrically placed gaps or regions of low UV intensity are seen at approximately 3′ separation from the nucleus at position angles 90° and 270°. The gaps are present in the visual and Hα images but are harder to discern because of higher disk background levels and consequently lower contrast at optical wavelengths. There is an apparent symmetry in the placement and widths of the gaps.

A number of physical processes have been suggested to explain the formation of multiple-arm galaxies such as NGC 628 (Elmegreen 1990): (1) a combination of spiral density wave (SDW) packet in the inner disk and transient events causing spiral formation in the outer parts; (2) stochastic self-propagating star formation (SSPSF) in a rotating medium; and (3) quasi-static spiral structure (QSSS), a mixture of constructive and destructive interference of several density wave modes throughout the disk.

Our observations suggest that a global or collective (rather than localized) mechanism is at work that imposes large-scale order in NGC 628. This interpretation is consistent with radio observations showing that optical and H I spiral arms in the disk coincide and that the H I arms continue far beyond the Holmberg radius (Briggs & Kamphuis 1991). The UV data therefore support the QSSS (Bertin et al. 1989; cf. Fig. 8 therein) as being the dominant mechanism for spiral formation. The SSPSF and SDW mechanisms may be present on a smaller scale, perhaps causing the formation of spurs and feathers between the main arms.

We caution that our result is based on only one sample at present. The possibility cannot be ruled out that the perceived "symmetry" is of accidental origin, since there are other unpaired gaps in the UV image. Nevertheless, the finding is intriguing and suggests that ultraviolet imaging may be a powerful tool in understanding the mechanisms that govern the form of galaxies.

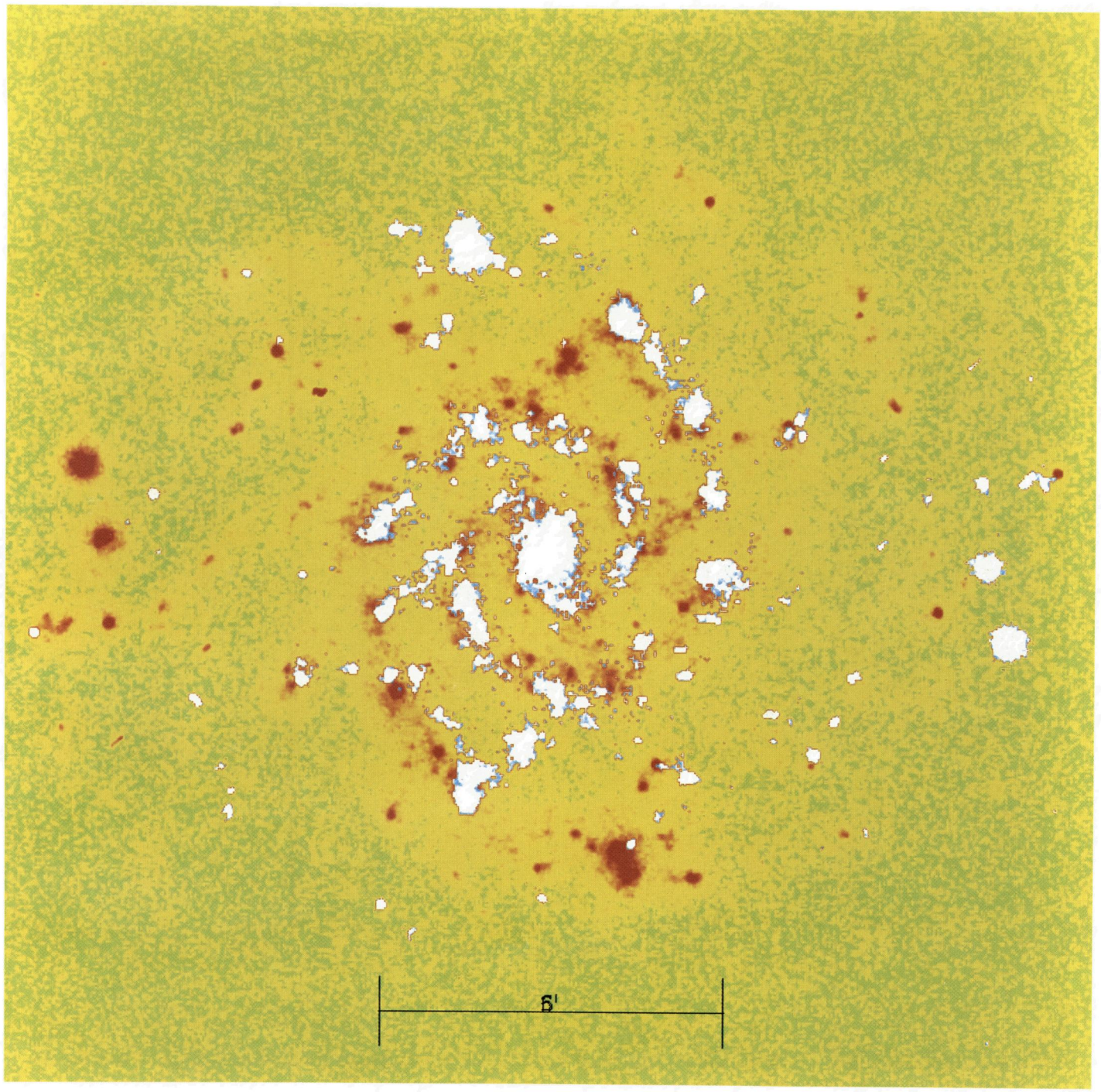

FIG. 4.—NUV image of NGC 628 (*in red*) superposed on a version of itself rotated 180° (*in white*). The outer northwest arm (the middle of the M-shaped feature) coincides fairly well with the rotated southeast arm, and the appearance of the spiral structure of NGC 628 in the UV is more symmetric than in the optical. There are two symmetrically placed gaps or regions of low UV intensity on either side of the nucleus at approximately 3′ separation on a diameter at position angle 90°.

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6. OUTLYING REGIONS

We report the detection of a low surface brightness extended object centered at 178″ west, 411″ south, or 7.6 southwest of the nucleus (indicated by arrows in Figs. 1 and 2). The object has an oblong shape, is approximately 70″ north-south by 5″ east-west, and does not appear on the Palomar blue and red sky survey plates. It is present in both frames NUV0161 and FUV0172, which were made with different detector systems, and is stationary when the two images are blinked against each other. The measured integrated magnitudes in a circular aperture of diameter 80″ are $m_{249} = 16.7$ and $m_{152} = 15.3$, with estimated uncertainties of 0.3 mag in each; the UV color is that of an O star. The uncertainties are primarily due to the uncertainty in sky measurements, since the net mean surface brightness of the object is well below sky levels of 24.7 and 25.6 mag arcsec^{-2}, respectively.

This object is a likely low surface brightness companion of NGC 628. H I observations with the VLA have shown the presence of two high-velocity gas complexes in the outer gas envelope of this galaxy with a large extension to the southwest (Kamphuis & Briggs 1991). A possible interpretation is that NGC 628 is in the process of accreting a gas-rich dwarf irregular galaxy, although searches in the optical have not yielded any promising candidates (Briggs 1986). We plan future ground-based deep CCD and H I observations to study this object, which has the characteristics of faint objects likely to be detected by UIT against the dark UV sky (O'Connell 1987).

7. CONCLUSIONS

Our UV data show that NGC 628 has an oblong nucleus with a color that is compatible with that expected from optical spectral synthesis. Identified UV sources generally coincide with Hα sources. Two features seen in the UV but not evident in the optical suggest that the galaxy is more more symmetrical than previously thought. A preliminary interpretation of our data suggests that spiral structure formation in NGC 628 is a large-scale collective phenomenon. We detect a faint blue object to the southwest of NGC 628 at 1.3 times the Holmberg radius.

Hundreds of people contributed to the success of the *Astro-1* mission and the UIT experiment, and we gratefully acknowledge them collectively here. We thank F. Briggs, P. Hodge, and S. Shore for helpful discussions; we also thank Paul Hodge for making available to us a negative of his Hα images. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. Funding for the UIT project has been through the Spacelab Office at NASA Headquarters under Project 440-51. Portions of this work were performed under NASA contracts NAS 5-29375, NAS 5-30440, and NAS 5-31230.

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