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THE CURIOUS CASE OF NGC 6908[1]

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ABSTRACT

The object NGC 6908 was once thought to simply be a surface brightness enhancement in the eastern spiral arm of the nearby spiral galaxy NGC 6907. Based on an examination of near-infrared imaging, the object is shown to in fact be a lenticular S0(6/7) galaxy hidden in the optical glare of the disk and spiral structure of the larger galaxy. New radial velocities of NGC 6908 [3060 $\pm$ 16 km s^{-1} (emission); 3113 $\pm$ 73 km s^{-1} (absorption)] have been obtained at the Baade 6.5 m and the du Pont 2.5 m telescopes at Las Campanas, Chile, placing NGC 6908 at the same expansion velocity distance as NGC 6907 (3190 $\pm$ 5 km s^{-1}), eliminating the possibility of a purely chance line-of-sight coincidence. The once-enigmatic asymmetries in the disk and outer spiral structure of NGC 6907 are now explained as being due to an advanced merger event. Newly discovered tails and debris in the outer reaches of this galaxy further support the merger scenario for this system. This pair of galaxies is a rather striking example of two objects discovered over 100 years ago, whose true nature was lost until modern detectors operating at infrared wavelengths gave us a new (high-contrast) look. Other examples of embedded merger remnants may also reveal themselves in the growing samples of near-infrared imaging of nearby galaxies, and a pilot study does reveal several other promising candidates for follow-up observations.

Key words: galaxies: interactions — galaxies: structure

Online material: color figures

1. INTRODUCTION

In his Catalogue of Nebulae, Herschel (1864) discussed two nonstellar, extended objects which were later added to the compilation of Dreyer (1888) and given their long-lasting designations, NGC 6907 and NGC 6908. Translated from the shorthand notation as published,[2] NGC 6907 was described as "considerably faint, considerably large, very little extended, very gradually a little brighter toward the middle, mottled, 3 stars preceding," and the eastern object, NGC 6908, was said to be "extremely faint, very small, little extended, Herschel 2076 (aka NGC 6907) preceding."

On the sky, the two objects discussed by Herschel are found only $\sim$40″ apart, a close pair by any standards, but otherwise unremarkable. With time these objects were observed again, not directly at the eyepiece of the telescope as was done by Herschel, but only after having been recorded on photographic plates and then visually reinspected by eye. What was revealed at that time was a single, much more expansive parent object, the galaxy NGC 6907, with a "massive" arm, asymmetrically placed to the east, and "certainly" to be identified with NGC 6908. From this point onward this nebulous object to the east lost its independent status and was absorbed into the galactic substructure of NGC 6907. Subsequent observers and classifiers agreed (e.g., Nilson 1974) that the dominant spiral galaxy NGC 6907 had an "asymmetric disk" and with "two massive, asymmetric arms," the more prominent one being seen to the east. After an abbreviated search for a cause of this imbalance Nilson made the point of saying in his notes that there was "no disturbing object visible." This, of course, suggests that the asymmetry was generated internally.

In the NASA/IPAC Extragalactic Database (NED), NGC 6907 is designated as SB(s)bc (from de Vaucouleurs et al. 1991 [RC3]) and has a published optical radial velocity of 3186 $\pm$ 8 km s^{-1} (da Costa et al. 1991). A search of NED over a circular area 1° ($\sim$700 kpc) in radius surrounding the galaxy reveals no objects with cataloged radial velocities near NGC 6907 itself. Locally, NGC 6907 is quite isolated,[3] although it is associated more widely with IC 4995 and IC 5005 in the group catalog of Maia et al. (1989).[4]

[1] Based on data obtained at the Magellan and du Pont telescopes, which are operated by the Carnegie Institution of Washington.

[2] In the cryptic empirical notation of the time, NGC 6907 was described as being `(cF, cL, vlE, vglbM, r, 3 st p)`, while the entry for NGC 6908 was `(eF, vS, lE, h 2076 p)`.

[3] The three closest "radial velocity confirmed" companions within a projected distance of 1 Mpc from NGC 6907 are IC 5005, ESO 527-G019, and IC 4999. They are, respectively, 61′ (760 kpc), 72′ (890 kpc), and 74′ (920 kpc) away from NGC 6907.

[4] We note in passing that a search over an even larger radial distance reveals a rather peculiarly cold structure: a sheet of galaxies 10° ($\sim$7 Mpc) in diameter, all clustered at $\sim$3100 km s^{-1}, having an rms velocity dispersion about the mean of only $\pm$52 km s^{-1}. In addition to NGC 6907 itself, the galaxies making up this sheet are IC 5005 (3112 km s^{-1}), ESO 527-G019 (3117 km s^{-1}), IC 4999 (3156 km s^{-1}), AM 2029-235 NED01 (3065 km s^{-1}), AM 2029-235 NED02 (3061 km s^{-1}), ESO 462-G025 (3057 km s^{-1}), ESO 462-G016 (3054 km s^{-1}), ESO 462-G028 (3017 km s^{-1}), and ESO 596-G030 (3110 km s^{-1}).

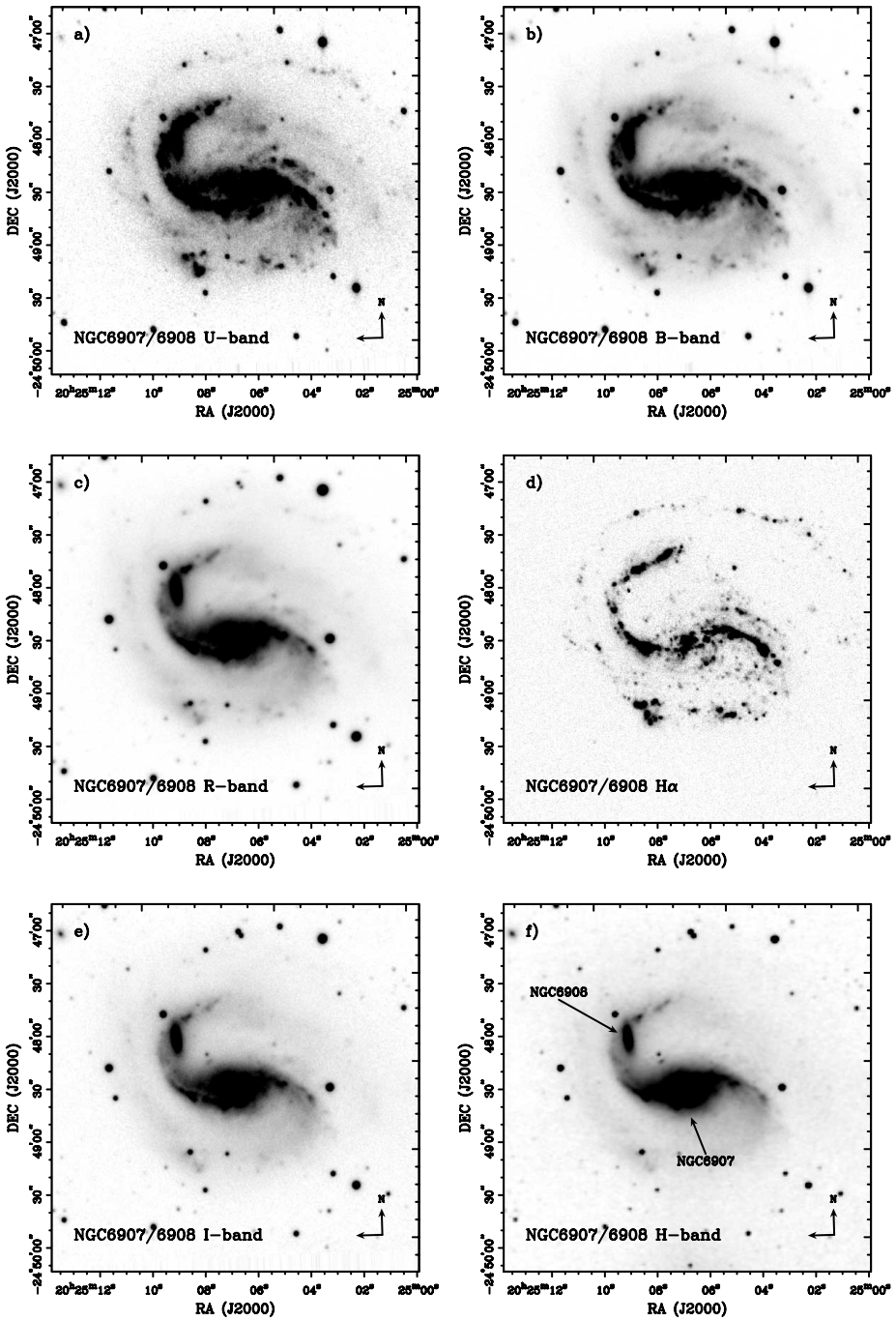

FIG. 1.—Multiwavelength comparison of images of NGC 6907 and NGC 6908 from the blue to the near-infrared. The top two panels are the *U* and *B* exposures. In both cases one can see the "massive" eastern (*left*) arm emphasizing the asymmetry in the spiral structure of the dominant galaxy, NGC 6907. In the middle left panel (*R*-band) the composite nature of the eastern arm is beginning to become apparent as the elliptical form of NGC 6908 starts to show itself. At progressively longer wavelengths (*I*- and *H*-band images; *bottom two panels*) the contrast between the (red) companion and the (blue) spiral arm becomes even more enhanced, and the companion is obvious beyond question. The middle right panel is a continuum-subtracted Hα image of the system. For all intents and purposes, the intruder, NGC 6908, has disappeared, but its effects are still rather dramatically present in the obvious discontinuity in the eastern arm delineated by the H II regions. At the position of NGC 6908 there is an abrupt change in the pitch angle of the arm, and beyond that point the H II regions take up a distinctly linear formation behind the intruder. Finally, it is noteworthy to point out the finely delineated arc of H II regions that define the outermost parts of the spiral structure of NGC 6907. They complete a full 360° wrapping of the optically less prominent western arm. In terms of bulk luminosity the eastern arm is dominant, but for total angular extent the western arm is by far the most extensive. For an expanded view of the Hα image, see Fig. 3. An RGB map of the *B*-, *R*-, and *H*-band images is shown in Fig. 5.

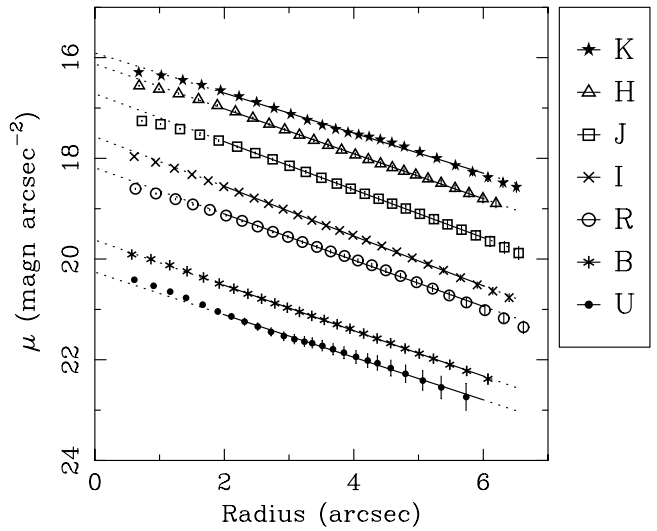

FIG. 2.—Multiwavelength radial light profiles of NGC 6908 derived from concentric elliptical isophote fitting. As can be readily seen, the falloff is exponential from the near-ultraviolet (*U*-band; *bottom profile*) well out to 2.2 μm (*K*-band; *top profile*), confirming that this object is an S0 disklike system, not an elliptical galaxy. Best-fitting lines are shown (*solid within the ranges used for the fit, dotted outside*).

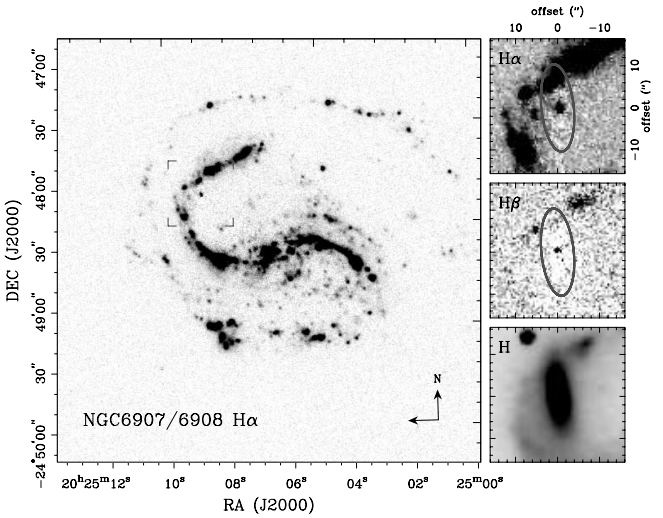

FIG. 3.—Hα image of NGC 6907/8. This continuum-subtracted image was obtained from the Anglo-Australian Telescope archive. The extent and asymmetry of the spiral structure are especially noteworthy. At the position of NGC 6907 the image has been expanded (*top right panel*), and two other wavelengths, continuum-subtracted Hβ (*middle right panel*) and the near-infrared *H*-band image (*bottom right panel*), are shown for comparison. In the hydrogen-line images the overplotted ellipse shows the continuum outline of the main body of NGC 6908. Clearly, the intruder shows nuclear emission in Hα and possibly in Hβ too. [*See the electronic edition of the Journal for a color version of this figure.*]

Until recently, NGC 6908 was classified in NED as being a PofG (Part of a Galaxy) consistent with the above comments that it was a high surface brightness part of the asymmetric eastern arm of NGC 6907. A picture of NGC 6907 taken in the *B* band is shown in Figure 1 (*top right panel*). Outside of the general catalogs there are no references in the modern literature to NGC 6908, except for its inclusion (without comment) in a search for companions to barred galaxies undertaken by Garcia-Barreto et al. (2003) using NED (after the reclassification) and the enigmatic identification of NGC 6908 with NGC 6907 in RC1 (de Vaucouleurs & de Vaucouleurs 1964). For all intents and purposes, then, NGC 6908 disappeared from the astronomical literature for the better part of the last century.

2. NGC 6908 REDUX

The primary objective of the present study is to reaffirm the individuality of NGC 6908 and to prove that it is indeed a galaxy in its own right, albeit one heavily implicated with the disk and spiral structure of NGC 6907. The first indication of its true identity came from multicolor imaging.[5]

The panels in Figure 1 progressively reveal NGC 6908 for what it is, and laterally show why it was so easy to mistake this object for an enhancement of the eastern arm of NGC 6907. The top right panel of Figure 1 shows what observers using *B*-band photographic plates would have been confronted with. As one moves progressively to longer and longer wavelength images the color contrast between NGC 6908 (an intrinsically red object) and the surrounding (intrinsically blue) spiral structure increases. By the time the *I*-band image is seen the identity of NGC 6908 is already clear. Indeed, the immediate visual impression from the near-infrared image is that NGC 6908 is a very early type galaxy, an E or S0 of rather large apparent flattening. Isophotometry of images at all available wavelengths confirms and quantifies this impression; outside of the central 4″ (where seeing effects are still important) the axial ratio *a*/*b* settles down to a value in the range 0.3–0.4 as measured in all seven bandpasses from *U* to *K*. This gives an integer ellipticity of 6–7.

3. NGC 6907/8: A NEWLY DISCOVERED INTERACTING PAIR

Having established the general nature of NGC 6908, the question naturally arises: Is this object a chance projection of a background galaxy along the line of sight, or is it truly involved in an ongoing interaction with the large spiral, NGC 6907? The asymmetry in the arm structure in NGC 6907 (NGC 6908 to the contrary) is still very suggestive of an interaction event, be it past or present.

The surface brightness profile of NGC 6908 is very close to a pure exponential at all wavelengths (see Fig. 2). This suggests that NGC 6908 is not a luminous elliptical (background or otherwise) but more likely a lenticular S0 system or even possibly a dwarf elliptical galaxy. However, the high extrapolated central surface brightness ($\mu_{B,0} = 19.6$ mag arcsec^{-2}; see Binggeli & Cameron 1991) and the lack of a significant nuclear excess, common to the majority of dwarf ellipticals of this luminosity (Ferguson & Binggeli 1994), favor the classification of NGC 6908 as a lenticular S0(6/7) galaxy.

In order to finally exclude the possibility of NGC 6908 being a projection of a foreground or background object along the line of sight of NGC 6907, on the night of 2002 August 1 we determined its recession velocity. On that date an optical spectrum was obtained at the 6.5 m Baade telescope at Las Campanas, Chile, using the Boller & Chivens camera with a 1200 line grating and a 0.9″ wide slit. Our 10 minute exposure quickly revealed a hydrogen absorption-line spectrum including forbidden [O II] emission at 3727 Å, and a subsequent reduction with respect to a K-star template gave a heliocentric radial velocity of 3113 ± 73 km s^{-1}. Since the parent galaxy, NGC 6907, has a published radial velocity

[5] The CCD imaging data of NGC 6907/8 used in this work are publicly available through the Isaac Newton Group (*UBRI* bands) and Anglo-Australian Telescope (Hα and Hβ) archives, the OSU Bright Spiral Galaxy Survey (deep *H* band; Eskridge et al. 2002), and the 2MASS Large Galaxy Atlas (*JHK*$_s$ bands; Jarrett et al. 2003).

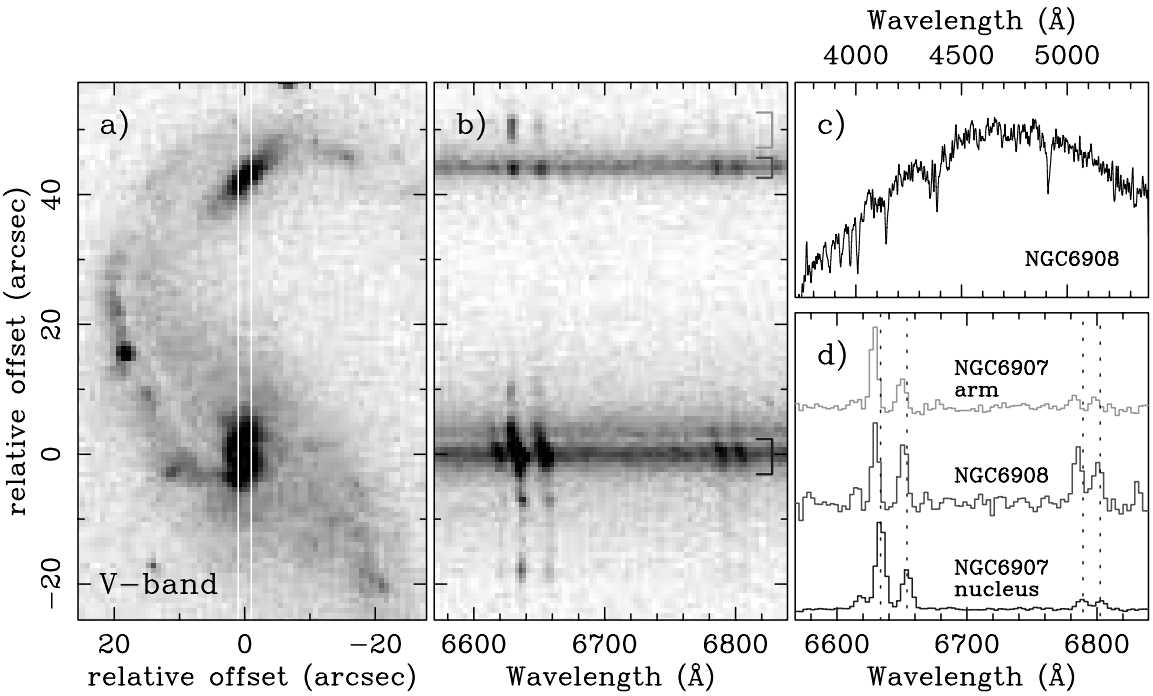

FIG. 4.—Long-slit spectra of NGC 6907 and NGC 6908. Panel *a* shows the position of the 2″ wide slit used at the du Pont 2.5 m telescope superimposed on a *V*-band image of the two galaxies. Panel *b* shows the sky-subtracted region of the spectrum (at the same spatial scale as panel *a*) used to determine the radial velocities, expanded to show only the wavelength region around Hα and the two sulfur lines. Square brackets to the right show the regions extracted for the radial velocity determinations, including a nearby H II region just above NGC 6908. Panel *c* shows the (un-flux-calibrated) hydrogen absorption-line spectrum of NGC 6908 taken at the Magellan telescope, while panel *d* shows the extracted emission-line spectra for the three objects (obtained at the du Pont Telescope), where the dashed vertical lines show the central wavelengths of Hα, [N II], and the two sulfur lines for the nucleus of NGC 6907 projected up and across the lines for the other two objects whose velocities are visibly lower. Each of the emission-line spectra are scaled to Hα so as to show the increased relative strength of the [N II] and [S II] lines in the nucleus of NGC 6908. [*See the electronic edition of the Journal for a color version of this figure.*]

of 3161 km s^{-1} (RC3) this was immediate and conclusive proof that the two galaxies are coincident in space. This conclusion was also confirmed by the presence of Hα and possibly also Hβ emission arising from the nucleus of NGC 6908, as seen in archival narrowband images (tuned to the redshift of NGC 6907) obtained at the Anglo-Australian Telescope (Fig. 3).

Follow-up observations of both NGC 6907 and NGC 6908 were later made at the du Pont 2.5 m telescope, also at Las Campanas, but this time using the long-slit capabilities of the Wide-Field Camera and spectrograph so as to simultaneously measure the absolute and differential velocities of the two galaxies. Those spectra are shown in Figure 4. The radial velocity derived from the emission lines in the spectrum of NGC 6908 is 3060 $\pm$ 16 km s^{-1}, while for the nucleus of NGC 6907 we obtain 3190 $\pm$ 5 km s^{-1}. This yields a velocity difference between the two systems of 130 $\pm$ 17 km s^{-1}. For $H_0 = 70$ km s^{-1} Mpc^{-1} the absolute magnitude

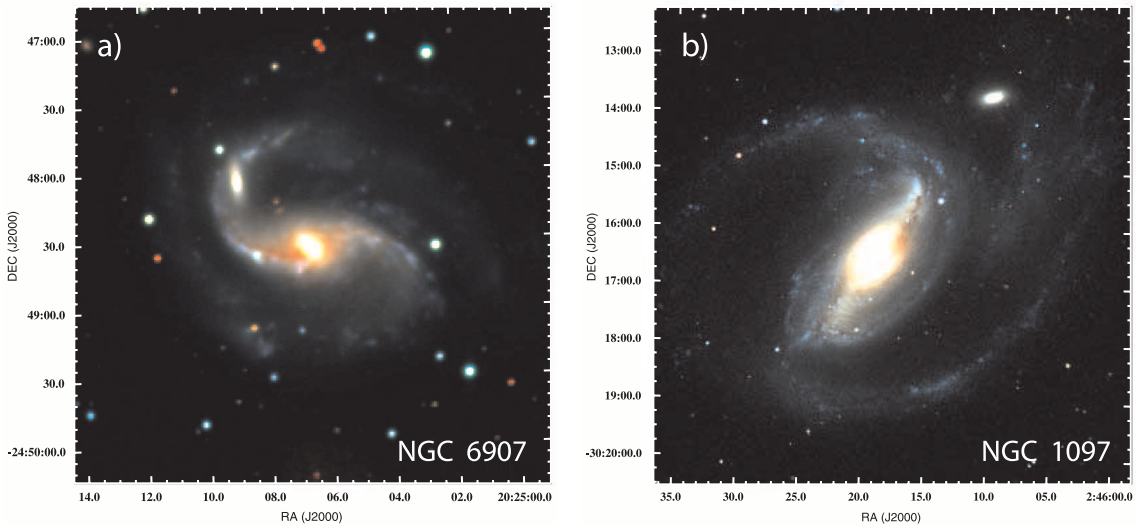

FIG. 5.—RGB color composite image of NGC 6907/8 produced by combining *H*- (*red*), *R*- (*green*), and *B*-band (*blue*) images. Note the difference in color between the northwest spiral arm of NGC 6907 and the S0 galaxy NGC 6908.

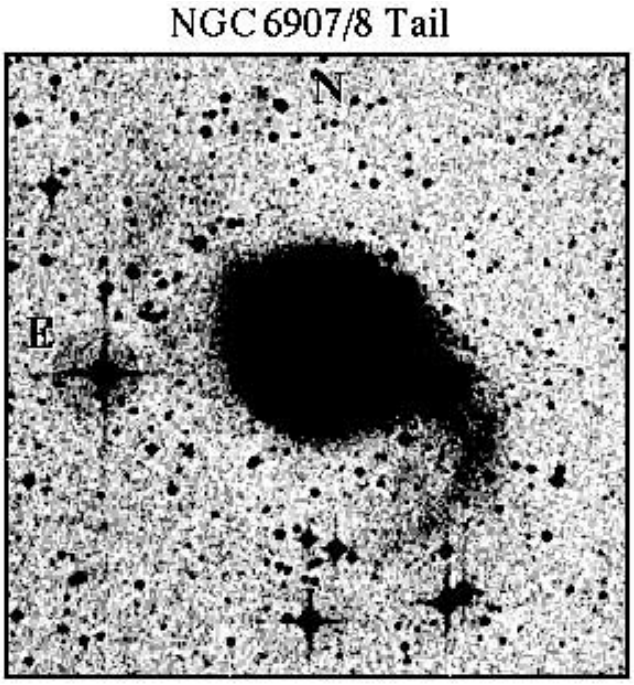

FIG. 6.—High-contrast POSS image of the outer regions surrounding NGC 6907/8. The one-armed spiral tail arcing from the north over to the west is clearly visible in this image. A more diffuse region of tidal debris is also visible to the northeast of the merging pair, arcing over to the northern edge of the image. The full field of view is 10′.

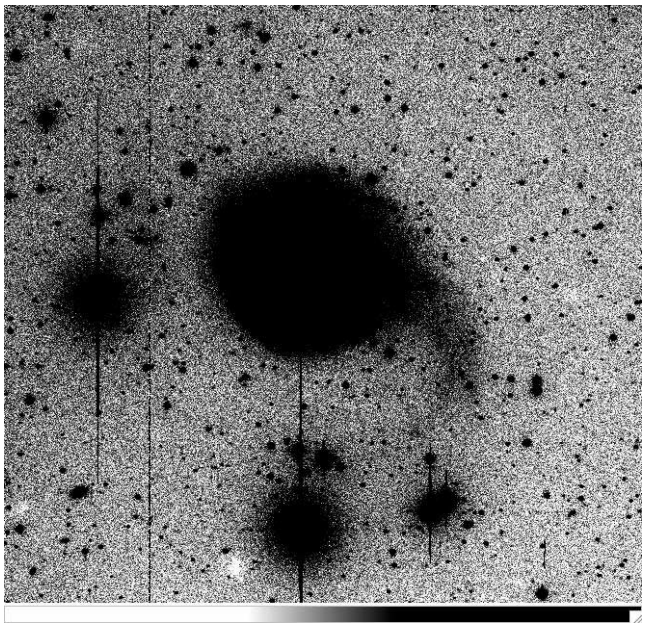

FIG. 7.—*R*-band CCD image of NGC 6907/8 taken with the du Pont 2.5 m telescope at Las Campanas. The low surface brightness tidal feature to the southwest of the main galaxy is confirmed in this independent image, taken at a longer wavelength than the POSS (blue) image reproduced in Fig. 6.

of NGC 6908 is $M_B = -17.4$ mag. The high [N II] λ6583/Hα ($\sim$0.9) and [S II] $\lambda\lambda$6717, 6731/Hα ($\sim$1.7) line ratios and relatively narrow emission lines (FWHM < 250 km s^{-1}) found in the spectrum of NGC 6908 suggest the existence of a Seyfert 2 or, more probably (considering the high intensity of the [S II] doublet), a LINER nucleus in this galaxy (e.g., Ho et al. 1997). Oxygen lines traditionally used in the classification of active nuclei ([O II] $\lambda\lambda$3726, 3729, [O III] λ5007, [O I] λ6300) were not detected by our spectroscopic observations. Although these line ratios are compatible with emission arising from a supernova remnant (SNR), the Hα luminosities of SNRs (especially those with high [S II]/Hα line ratios; see Blair & Long 1997) are well below the detection limits of both our imaging and our spectroscopic observations. Indeed, from the Hα equivalent width measured in the spectrum of NGC 6908 (Fig. 4), $\sim$4 Å, and the *R*-band surface brightness in the nuclear regions of this galaxy ($\sim$18.5 mag arcsec^{-2}; Fig. 2) we estimate the Hα luminosity of NGC 6908 (within the slit) to be roughly $\sim 10^{38.8}$ erg s^{-1}, which is well within the range of luminosities found in nearby LINERs (Terashima et al. 2000).

The sum of the evidence, both kinematic and morphological, suggests that the asymmetry in the disk and in the arm structure of NGC 6907 is due to an ongoing and rather highly advanced interaction with the low-luminosity S0(6/7) galaxy NGC 6908 at a (projected) velocity difference of $\sim$130 km s^{-1}. And, we suggest that the rather rare form (i.e., the large ellipticity) and moderate nuclear activity of NGC 6908 are also likely due to the interaction. Figure 5 shows a RGB composite map produced by combining the *B*- (*blue*), *R*- (*green*), and *H*-band (*red*) images of the NGC 6907/8 system. In addition to the dust lanes seen along the leading edges of the spiral arms (common in strongly barred Sb and Sbc galaxies like NGC 6907) this figure shows a dust lane crossing the western spiral arm of NGC 6907 almost perpendicular to it and extending well into the interarm region to the south of the galaxy nucleus (see also Sandage & Bedke 1994). We speculate that this feature might also well be a by-product of the interaction between NGC 6907 and NGC 6908.

Beyond the high surface brightness inner disk of NGC 6907 there is further evidence that a merger is under way. Figure 6 shows a $10' \times 10'$ image of the NGC 6907/8 pair cut from the Digitized Sky Survey and heavily stretched so as to emphasize very low surface brightness features. The evidence for an earlier phase in the interaction can be readily seen in the asymmetrically placed tail of debris found to be extending out from the northern part of the main body of the galaxy to the west and then down to the southwest. Even lower surface brightness regions can also be seen to the east folding over the galaxy clockwise to the north. Had the galaxy NGC 6907 been inspected first at this low a surface brightness level it is likely that a merger event would have been independently suggested. Figure 7 is a confirming image taken with a CCD camera mounted on the 2.5 m du Pont Telescope at Las Campanas, Chile. The tidal feature, although very faint and close in surface brightness to the night sky, is visible both in the blue (photographic) and in the red (*R*-band CCD) images, confirming its reality and general structure.

4. CONCLUSIONS

Once thought to be a relative brightening in the "massive" eastern spiral arm in the asymmetric spiral galaxy NGC 6907, NGC 6908 is revealed by near-infrared imaging to be, in fact, a low-luminosity ($M_B = -17.4$ mag) S0(6/7) galaxy, embedded in the disk of and strongly interacting with its larger spiral galaxy host, NGC 6907. This ongoing merger of two systems is almost certainly responsible for the observed asymmetries in the disk and the spiral structure of NGC 6907, as well as the strong, asymmetrical (tidal debris) tails seen at low light levels beyond the main body of the spiral. The present-day interaction may also plausibly account for the unusually large ellipticity and mild nuclear activity of NGC 6908 itself.

If this pair of galaxies was mistakenly overlooked, are there more examples of embedded companions in the disks of nearby spirals? It seems reasonable to suppose that there are some less spectacular

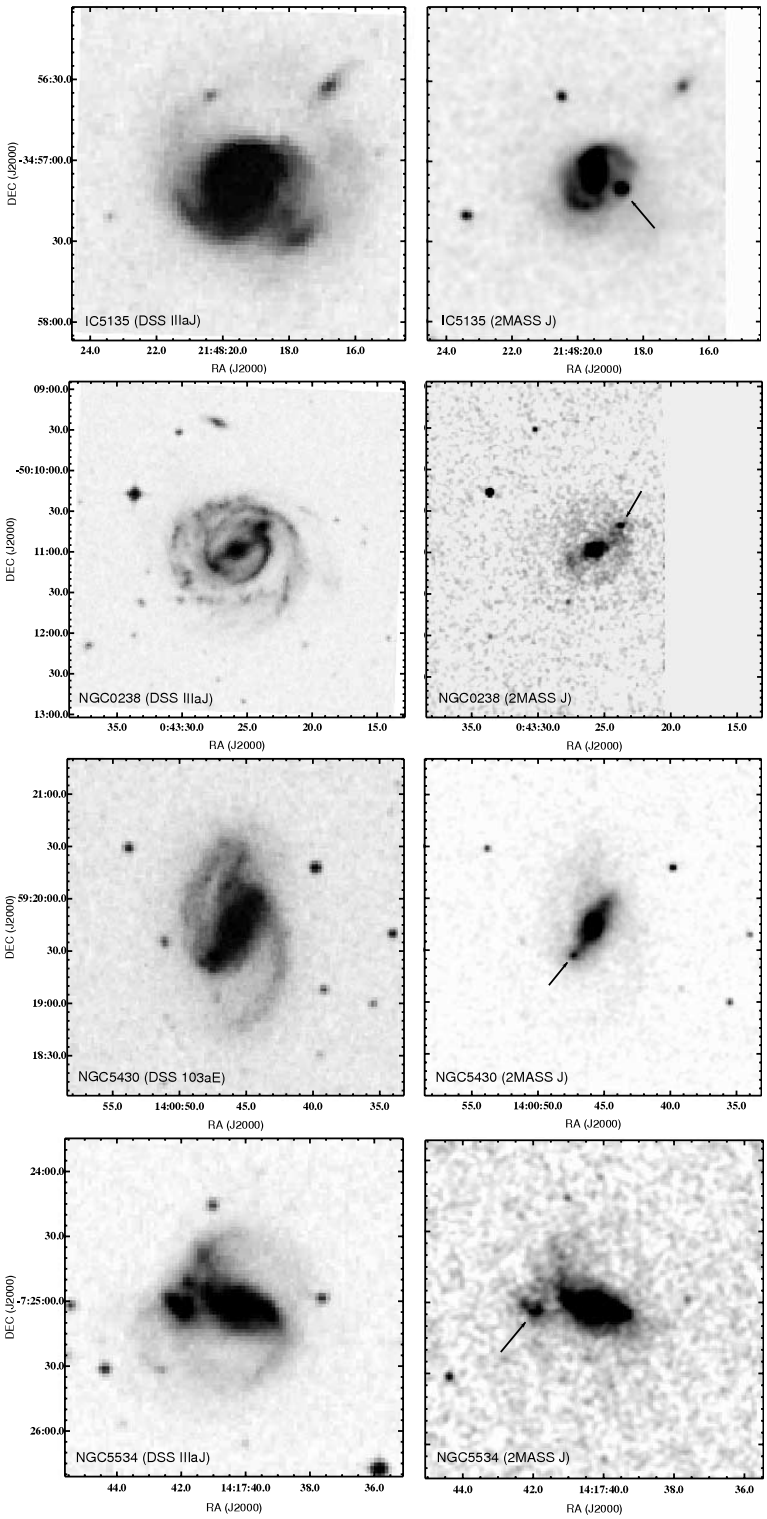

FIG. 8.—Selected examples of embedded companions discovered using long-wavelength archival images. The left panels show the optical images, and the right panels show the near-infrared discovery images.

examples, and some more highly advanced (more deeply embedded) ongoing mergers still awaiting revelation, even in relatively nearby galaxies already well studied at blueward wavelengths. As more near-infrared imaging of nearby galaxies becomes available it will be of interest to see whether this serendipitous discovery of an embedded merger remnant generalizes to a larger number of incidents or whether this is such a short-lived part of a rare event that it alone is our only local example.

Anticipating the results of a larger and more comprehensive survey (B. F. Madore 2007, in preparation) we can say that the answer to the above question is yes. The larger survey is based on the simultaneous visual inspection and intercomparison of both

the near-infrared and the optical images of the entire NGC galaxy sample. A few early examples, IC 5135, NGC 0238, NGC 5430, and NGC 5534, are given in Figure 8. These were found by inspecting the 2MASS near-infrared JHK_s images as made available by NED, many of which were originally published by Jarrett et al. (2003), and comparing them with online versions of their optical images from the POSS. New wavelengths reveal new phenomena.

The last word goes to de Vaucouleurs & de Vaucouleurs (1964; RC1) who comment that NGC 6907 is "slightly asymmetric, and similar to NGC 1097."The irony, of course, is that the asymmetry in NGC 1097 was, even then, clearly due to its interaction with its elliptical companion NGC 1097A, the latter being a radial velocity companion falling within 100 km s^{-1} of its parent galaxy and being clearly visible on any wide-field image of the system. So now the analogy is confirmed; at low surface brightness levels NGC 1097 shows many of the same signs of tidal debris coming from the earlier interaction phase as in NGC 6907. Had the companion, NGC 1097A, been along the same line of sight as one of the main spiral arms of NGC 1097, the correspondence between NGC 1097 and NGC 6907 would have been exact.

We thank Harold Corwin for his comments on early descriptions of these galaxies. This research made use of the NASA/IPAC Extragalactic Database, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

REFERENCES

Binggeli, B., & Cameron, L. M. 1991, A&A, 252, 27
Blair, W. P., & Long, K. S. 1997, ApJS, 108, 261
da Costa, N. L., Davis, M., Meiksin, A., Sargent, W. L. W., & Tonry, J. L. 1991, ApJS, 75, 935
de Vaucouleurs, G., & de Vaucouleurs, A. 1964, Reference Catalogue of Bright Galaxies (Austin: Univ. Texas) (RC1)
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Jr., Buta, R. J., Paturel, G., & Fouque, P. 1991, Third Reference Catalogue of Bright Galaxies (New York: Springer) (RC3)
Dreyer, J. L. E. 1888, MmRAS, 49, 1
Eskridge, P. B., et al. 2002, ApJS, 143, 73
Ferguson, H. C., & Binggeli, B. 1994, A&A Rev., 6, 67
Garcia-Barreto, J. A., Carrillo, R., & Vera-Villamizar, N. 2003, AJ, 126, 1707
Herschel, J. 1864, Philos. Trans. R. Soc. London, 154, 1
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJS, 112, 315
Jarrett, T. H., Chester, T., Cutri, R., Schneider, S. E., & Huchra, J. P. 2003, AJ, 125, 525
Maia, M. A. G., da Costa, L. N., & Latham, D. W. 1989, ApJS, 69, 809
Nilson, P. 1974, Uppsala Astron. Obs. Rep. 5
Sandage, A. R., & Bedke, J. 1994, The Carnegie Atlas of Galaxies, Vol. I (Washington: Carnegie Inst.)
Terashima, Y., Ho, L. C., & Ptak, A. F. 2000, ApJ, 539, 161