THE ASTROPHYSICAL JOURNAL, 279:L47–L49, 1984 April 15

HIGH-RESOLUTION IMAGING FROM MAUNA KEA: CYGNUS A

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Received 1983 August 23; accepted 1984 January 10

ABSTRACT

A high-resolution image of Cygnus A was obtained using a computer-controlled active mirror autoguider. The CCD image, with FWHM = 0″.65, reveals considerable structure in the central 2 kpc of Cygnus A: (1) an elliptically shaped region that contains the central radio source, (2) a concentrated knot that looks like an extra galaxy nucleus, which appears in the projection within 900 h^{-1} pc of the central radio component, and (3) some indication that the central region around the radio source contains a patchy dust distribution. As originally suggested by Baade and Minkowski, Cygnus A is best described as a collision of galaxies. With the improved resolution, Cygnus A shows only cursory resemblance to Centaurus A.

Subject headings: galaxies: individual — radio sources: general

I. INTRODUCTION

On those nights when the seeing is at its best on Mauna Kea, the largest contribution to image size comes from random image wander of a tiny image core. This image wander is induced by atmospheric wave-front tilts in the 15 km of atmosphere above the telescope, and the frequency spectrum of image motion is dominated by the lowest frequencies. To fully exploit those nights of best seeing, a special autoguiding instrument has been designed and constructed. The instrument contains a computer-controlled active mirror capable of removing image motion with amplitudes greater than 0″.2 and frequencies less than 50 Hz. Further description of the instrument is given by Thompson and Ryerson (1983). The Cygnus A data described below were collected during the first commissioning run of the instrument. While the image of Cygnus A is excellent by standards of average ground-based astronomy, there is every reason to expect further improvement in resolution once the image stabilizing instrument is brought into full working order.

The best previously published optical images of Cygnus A are presented in two papers, one by Baade and Minkowski (1954) and the other by van den Bergh (1976). In the first, Baade and Minkowski assert that the Cygnus A system is two galaxies in collision, the primary evidence being the curved (hence, tidally distorted) appearance of two prominent nuclear features within Cygnus A. In the second, van den Bergh shows that the system may be more complex than a tidal encounter since most of the optical line emission seems to be concentrated in a northwest nuclear feature, while a southeast nuclear feature is predominantly a source of ordinary continuum light. Both analyses are based on photographs with images of FWHM ~ 0″.8–1″.0.

Hargrave and Ryle (1974) determined an accurate position for the central radio source in this predominantly double-lobed radio object. They found that the central source lies *between* the two optical features mentioned above, and there appeared to be no detectable radio emission coming from either of the two optical condensations. This observation requires Cygnus A to be more complex than Baade and Minkowski's simple double galaxy encounter since the radio emission is presumably coming from the true nucleus of the galaxy. Additional evidence that the true nucleus lies hidden between the two optical lobes comes from Kronberg, van den Bergh, and Button (1977), who point out that the centroid of the extended cD envelope of this galaxy also lies between the two prominent optical features. The situation is clarified by the high-resolution image presented with this *Letter*, since there appears to be a third, less prominent feature at the center of Cygnus A coincident with the radio position.

II. OBSERVATIONS

The observations reported here were made with the University of Hawaii 2.24 m telescope on Mauna Kea. At the Cassegrain focus were mounted the Image Stabilizing Instrument System (ISIS) followed by the Galileo/Institute for Astronomy three-phase CCD. To provide light simultaneously for both the guide probe and the CCD, an achromatic beam splitter (mounted within the ISIS) divided the light between the two focal planes. Guide signals were taken from a star 75″ north of Cygnus A. This star (with estimated brightness m_B = 13.5 from the Palomar Sky Survey via King and Raff 1977) was measured continuously in intervals of 11 ms, thus providing a guide signal rate of 90 Hz. Both the guide signal and the light to be imaged were passed through similar broad-band V filters. One of the standard features of the ISIS is an active shutter which opens or closes (currently at a rate of 6 Hz) based on the image size measured by the guide probe. For this particular image of Cygnus A, the shutter trip level was set so that the shutter remained open for approximately 80% of the 20 minute exposure time.

The Galileo/Institute for Astronomy CCD system is described in detail by Hlivak *et al.* (1982). Under ordinary conditions, the lack of short-wavelength sensitivity of the three-phase CCD would mute the filter shape of the V bandpass. However, following a new procedure originally described by Janesick and Elliot (1983) and expanded upon by Hlivak, Henry, and Pilcher (1983), the CCD was flooded with ultraviolet light prior to cool-down. This greatly boosts the short-wavelength sensitivity and makes the CCD response flat over the filter bandpass.

The data were taken on 1983 May 21 (UT) as the object made its transit across the meridian. Its air mass was 1.070, a significant point because image quality deteriorates as the zenith angle increases. The CCD frame was processed in a standard way with "bias" subtraction to correct for voltage offset in the readout electronics, with "dark" frame subtraction, and finally with division by a flat field frame obtained by illuminating the inside of the dome. Image quality was measured to be FWHM = 0''.65 from north-south profiles of the two brightest stars located just east of Cygnus A.

III. RESULTS

Figure 1 (Plate L2) shows three different intensity cuts through the Cygnus A image. All three were photographed from the TV monitor of the Institute for Astronomy image-processing system. Figure 1*a* displays only the high-intensity features; three items are particularly notable. First, contrary to the results of previous studies, considerable structure does exist between the two optical lobes. There is an elongated region which stretches in the east-west direction for approximately 2'' (position angle 74° north through east). In the middle (but slightly offset to the eastern side) of this region is a bright spot which may be the true Cygnus A nucleus. Second, the optical lobe located on the northwest is dominated by a bright, symmetrically shaped, concentrated knot that has the appearance of a second galaxy nucleus. Stretching off to the south of this knot is a curved structure that bears resemblance to a tidal tail. Both features show smooth intensity distributions. Note that this northwest lobe is the region where van den Bergh (1976) identified strong 5007 Å line emission. Third, the optical lobe on the southeast retains the crescent shape recognized by Baade and Minkowski (1954) and by van den Bergh. However, it seems to show considerable fine structure—just at the resolution limit of this study—as if the region contains numerous dust clouds. Its curved shape and dusty structure are reminiscent of star-forming regions, and although no evidence for a young stellar population appears in any of the spectroscopic studies (Osterbrock and Miller 1975), van den Bergh identified continuum radiation at this location.

TABLE 1

RADIO AND OPTICAL POSITIONS

Feature	R.A. (1950)	Decl. (1950)
Radio nucleus	$19^h57^m44^s.43 \pm 0^s.02$	$+40°35'46''.3 \pm 0''.2$
Bright optical knot closest to center ...	19 57 44.47 ± 0.02	+40 35 46.1 ± 0.2
Nucleus with tidal tail	19 57 44.37 ± 0.02	+40 35 47.0 ± 0.2

The position of the radio source as determined by Hargrave and Ryle (1974) is given in Table 1. Also listed are positions of various features measured from the CCD frame. For the CCD positions, the reference coordinate system was defined by using star positions given by Griffin (1963). Figure 2 (Plate L3) is an enlargement of the central region which shows the location of the central core radio source relative to the optical object. Typical uncertainties in the radio position are ±0''.1 to ±0''.2. For the optical position, the formal fit to the four Griffin stars was excellent (< 0''.05). However, the Griffin stars themselves have a positional uncertainty of ±0''.2 (cf. Kronberg, van den Bergh, and Button 1977). The combined rms errors are barely consistent with the radio source being coincident with the semiobscured bright spot 0''.46 east of the indicated radio source location.

To interpret the physical conditions in the nuclear region, measurements of the optical luminosity are useful. Such measurements are given in Table 2. These *V*-magnitudes were calibrated using photoelectric observations described by van den Bergh (1976) and take into account the sky background as measured well outside the galaxy's halo. The magnitudes of the nuclear features are contaminated, however, by the ordinary galaxy light of Cygnus A in the line of sight. No attempt will be made to interpret these data, since any interpretation must include the complex effects of the dust distribution and the variation in the relative balance between continuum and line emission from one nuclear feature to another. Even so, it is interesting that the line to continuum ratio can be calculated for the *V* bandpass by using results of Osterbrock and Miller (1975) for a 2''.7 × 4''.0 square aperture encompassing nearly all nuclear features. Line emission, entirely dominated in this bandpass by [O III] 4959 Å and 5007 Å, contributes 40% of the flux, while the continuum contributes 60%.

TABLE 2

V PHOTOMETRIC MEASUREMENTS

Feature	Square Aperture Size (arcsec)	*V* Mag.	Contribution (%)
Nucleus with tidal tail (on northwest)	1.5	19.2	17
Emission region (on southeast)	2.0	19.1	19
Central elliptically shaped region	1.5	19.3	16
Total area	5.0	17.3	100

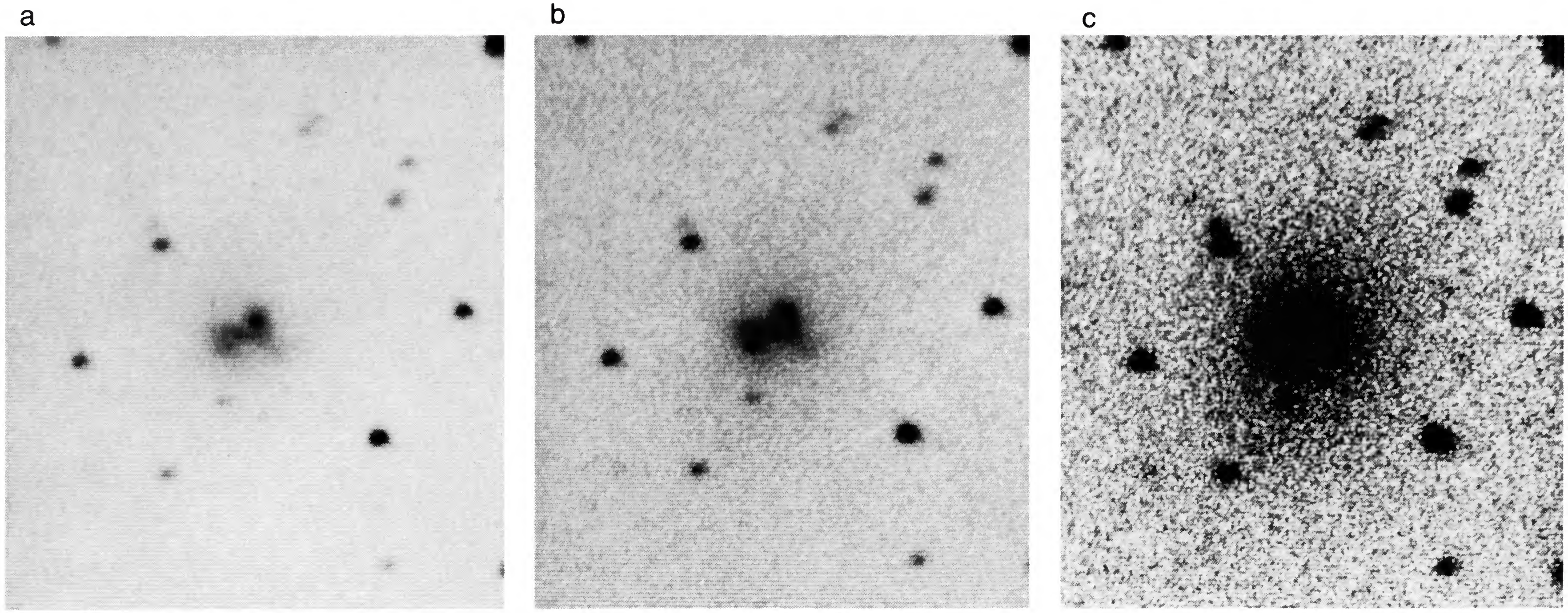

FIG. 1.—Three different intensity levels of the same CCD image of Cygnus A show: (*a*) the brighter features in the galaxy's inner core; (*b*) at somewhat lower intensity levels, the image resembles previously published images; and (*c*) at the lowest intensity level, the full extent of the galaxy halo is apparent. An overall view of this kind shows how different Cygnus A is from Centaurus A. Each picture covers an area 31″ × 36″ with north at the top, east to the left.

THOMPSON (*see* page L48)

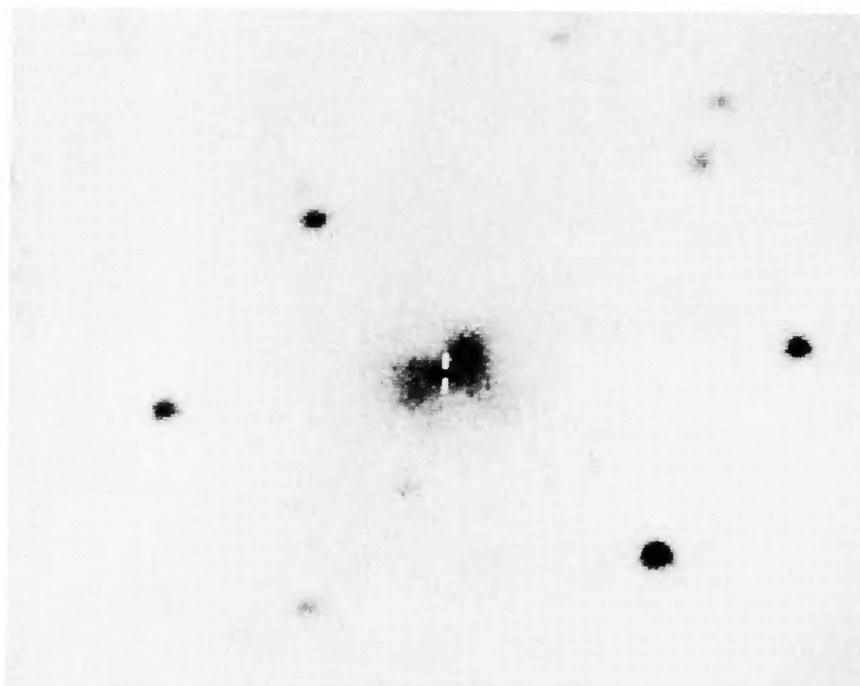

FIG. 2.—Superposed on a 4 × enlargement of Fig. 1*a* are markers to show the location of the central radio source in Cygnus A

THOMPSON (*see* page L48)

IV. CONCLUSIONS

1. The powerful radio galaxy Cygnus A has its own unique structure and bears little resemblance to Centaurus A. The purported similarity between these two objects has been cited often (Bertola and Galletta 1978; Kotanyi and Ekers 1979; Osterbrock 1983), and Centaurus A and Cygnus A have been used together to define a class of smooth elliptical galaxies which are bisected by a prominent dust lane. While Cygnus A seems to have a dusty nuclear region, the double nucleus is, most likely, a true physical double rather than an illusion caused by dust.

2. The nature of the second "nucleus" (the knot located on the northwest) remains enigmatic. While its appearance on the CCD frame looks smooth, as if it contains stars, van den Bergh (1976) reports that the knot and its curved tail are dominated by [O III] 5007 Å line emission rather than by continuum radiation. If this knot is a mass concentration, then its close proximity to the true nucleus ($1''.1 = 900\ h^{-1}$ pc) indicates that the powerful radio source may have been initiated by this intruding object.

I acknowledge continued contributions toward the Image Stabilizing Instrument System by Herb Ryerson and John Jefferies, assistance with the CCD camera by Bob Hlivak and the CCD group, and support at the telescope from both the day crew and telescope operators. I also thank Alan Stockton for useful comments on an earlier draft of the manuscript. This research was supported in part by the University of Hawaii Research Council.

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