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Letter to the Editor

A new HST image of Cygnus A

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Abstract. We present a new HST image of Cygnus A, taken in the V-band. This image includes both continuum and lines of [OIII], and shows the major, northwestern and southeastern components, together with the weaker central component. Filamentary structure is present at this resolution of 0.″045. This structure runs generally parallel to the radio jet and may be due to mechanical excitation of the gas in shocked regions, possibly combined with photoionization by a hidden quasar-like nucleus. The image shows clearly the reddened region near the centre seen by other authors. The darker region within the northwestern component, previously claimed to be a result of passage of the radio jet, is more likely to be a result of dust obscuration. The central component is extended and bears some resemblance to the apex of a conical structure; similar structures in other galaxies have been claimed as evidence for light from a hidden nucleus escaping along a restricted range of solid angle. In addition, a number of blobs and condensations are seen within all the above structures, some of which may be stellar in origin.

Key words: Galaxies:active – galaxies:individual: Cygnus A – galaxies:nuclei

1. Introduction

Cygnus A, as the archetypal powerful radio galaxy, has received much attention in recent years with the advent of new techniques such as spectropolarimetry, high-sensitivity imaging in the blue spectral range and sensitive UV spectroscopy. The optical identification (Baade & Minkowski 1954) showed a nebula containing two bright condensations, separated by 2″ along a NW–SE axis: Baade & Minkowski proposed that these condensations were actually two galaxies in collision. More recently it has been shown that there are three components, including a central blob lying between the two bright condensations and about 1″ distant from them both. The northwest component emits strongly in emission lines (e.g. van den Bergh 1976), whereas the southeastern component is stronger in continuum emission. The central component (Thompson 1984) has been suggested to be close to the galaxy nucleus (Vestergaard & Barthel 1993). Research has recently focussed on whether Cygnus A actually contains a hidden quasar nucleus in the central region. Although no broad Balmer Hα, Hβ lines are seen in scattered light by spectropolarimetric methods (Goodrich & Miller 1989: Jackson & Tadhunter 1993), it has recently been claimed (Antonucci, Hurt & Kinney 1994) that a broad MgII line is detected by ultraviolet spectroscopy with the Hubble Space Telescope (HST). This would suggest that a hidden quasar nucleus is indeed present, and that light from it is being scattered into our line of sight outside the plane of an optically thick torus which blocks our direct view. Antonucci et al. suggest that the scattering medium is dust, since the blue scattering function of dust would allow scattering of MgII preferentially over the Balmer lines which lie further to the red. However, the featureless blue continuum which is seen over the central regions of the source is probably not predominantly scattered light, both because of the low levels of polarization (Tadhunter et al. 1990) and because the equivalent width of broad Hβ is well below that of most quasars (Stockton et al. 1994). Further complications are unavoidable due to the presence of distributed dust in the central regions, where Shaw & Tadhunter (1994) find an increase in reddening between the two major components.

Ground-based images in V, R, I and Z (Vestergaard & Barthel 1993), u, b, v, r, v′, K′, Hα/[NII], [NII], Hβ, [SII] and [OIII] (Stockton et al. 1994) and with the pre-1993 aberrated HST near 3500Å (Jackson et al. 1994) have begun to reveal more of the inner structure of the galaxy. The nuclear component is seen to be extended to the southwest, and two "dust fingers" (Vestergaard & Barthel 1993) appear to cause obscuration NNW and SSE of the central optical component, in between it and the two other optical components. Lynds et al. (1994) have obtained more recent HST pictures and report a "chaotic arrangement of dust and bright patches, some of which are blue and are probably star-forming regions".

Here we present a new Hubble Space Telescope (HST) V-band image of the central region of Cygnus A. This band is strongly affected by redshifted [OIII] emission.

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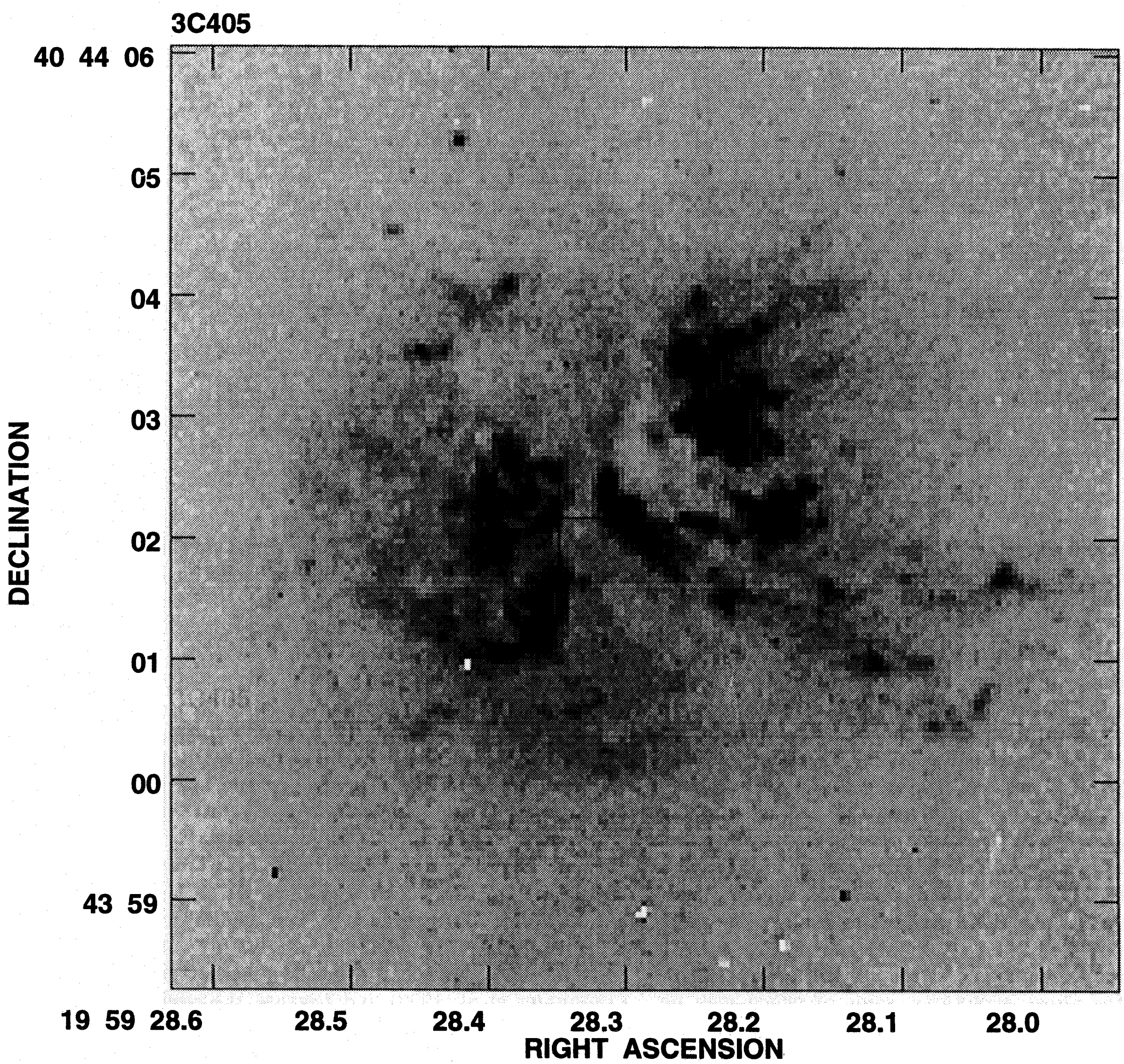

Figure 1. The new HST image of Cygnus A, greyscaled from 0 to 8.75×10^{-17} erg cm^{-2} s^{-1} pix^{-1} (0-25 PC counts pix^{-1}). The radio core position has been taken from the private communication from Carilli & Perley to Vestergaard & Barthel 1993. The brightest condensations of the central HST component are measured by GASP astrometry at STScI to be $19^h59^m28.311^s$, $40°44'02''.450$ and $19^h59^m28.313^s$, $40°44'02''.361$. However, the accuracy of the GASP astrometry with respect to the radio reference frame is $0''.5$: the data are therefore consistent with the radio core being coincident with the central optical component. The arms of the cross, representing the nominal radio core position, are each $0''.5$ long.

2. Observations

The observations were obtained on 1994 September 9 with the Wide-Field & Planetary Camera (WFPC2), which was installed in 1993 December as part of the correction to the HST optics. The Planetary Camera (PC) chip, which has a scale of 0.0455 arcsec pixel^{-1}, was used together with the F555W filter. This sampling limits the resolution of the image, since the diffraction-limited resolution is about 0.045 arcsec. The filter approximates to Johnson V and contains continuum emission together with emission from the strong [OIII]$\lambda\lambda$ 4959,5007 doublet. An exposure time of 45 minutes was used, broken into three exposures of 15 minutes each to allow removal of cosmic rays. Cosmic ray removal was performed using the IMCOMBINE task in the IRAF package of the U.S. National Optical Astronomy Observatory and analysis using this together with the U.S. National Radio Astronomy Observatory AIPS package. The image is presented in figure 1, and the corresponding contour image in figure 2. The flux in an aperture of diameter $9''.4$ is approximately 5.6×10^{-16} W m^{-2}, which should

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be compared with the 1.6×10^{-16} W m^{-2} measured by Osterbrock & Miller (1975) in [OIII] alone in the same aperture. The total contribution of [OIII] to the image is therefore of the order of 20%. However, ground-based imaging suggests that the relative contribution of [OIII] will rise in the central region. The three major optical components have a total flux of 1.3×10^{-16} W m^{-2}, and the [OIII] contribution is probably >50% in this region.

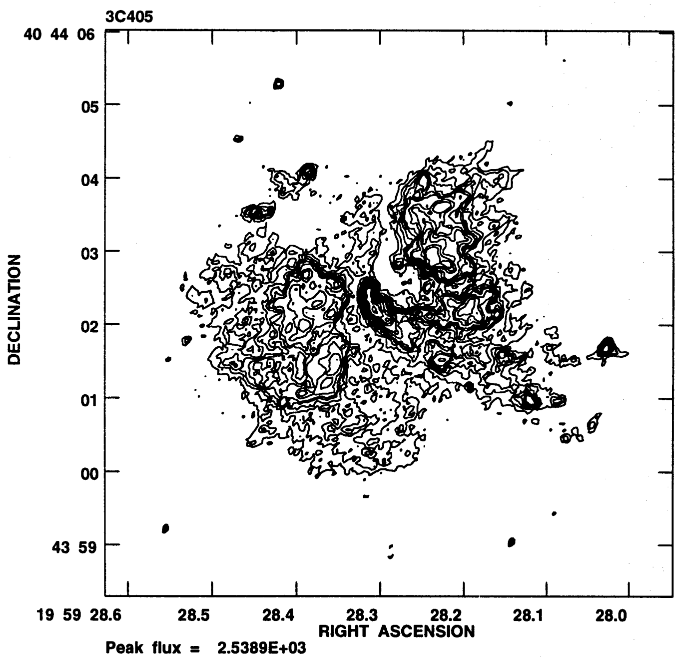

Figure 2. A contour image of Cygnus A. Contours are given at count levels 10,12, 14, 16, 18, 20, 25, 30, 40, 50, 60, 80, 100, 150, 200, 300, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000, where one count = 3.55×10^{-18} erg cm^{-2} s^{-1} pix^{-1}

3. Discussion

The new image shows much detail not previously visible. The northwestern component is complex and filaments trail from it: these filaments are probably composed of [OIII] line emission. The split previously remarked upon by Jackson et al. (1994) which runs through the northwestern component in a direction parallel to the radio jet (p.a. ~105°), is also confirmed. It joins on to a region of very low surface brightness between the northwestern and central components. The central component itself is clearly seen to be elongated in a southwesterly direction. It has a ragged edge on the side toward the northwestern component and a smoother edge, of a shape rather reminiscent of the opening of a cone, on the other side. There are numerous condensations in the filaments that stream from the northwestern component.

The southeastern component also contains much complex structure. The "channel" through the component suggested by Jackson et al. (1994) seems actually to be present. Its PA of about 130° is inconsistent with that of the radio jet (~105°) and we conclude that it is probably not associated with passage of the jet. Again, some filamentary structure is visible, and condensations are also seen.

3.1. Filaments

One of the major new components visible at this high resolution are the filaments in the northwestern component, which run parallel to the radio jet but at some distance (up to 1 arcsec, or ~1 kpc) away from it. They are strongly suggestive of shock excitation, which has been suggested and modelled in the case of Centaurus A (Sutherland et al. 1993). However, their distance from the radio jet implies that they cannot be a direct result of interaction between the radio jet and the medium of the radio galaxy.

Two possibilities suggest themselves. The first is that the filaments represent shocked areas where the cocoon of the radio jet is interacting with the external medium. In such areas we would expect to see line emission, consistent with the current results. We would also expect to see kinematically disturbed gas (e.g. Sutherland et al. 1993), which is in agreement with the high-velocity component to the [OIII] line observed by Tadhunter (1991). This is an energetically possible scenario, since the bulk kinetic energy flow in the jet is probably 6-9$\times10^{38}$ W (Roland et al. 1988), whereas the total energy in emission lines in each filament is about 10^{35} W (assuming this to be about 20 times the flux in [OIII], cf. Osterbrock & Miller (1975)). One would therefore need to arrange conversion of the bulk energy of the jet to line emission with an efficiency of <0.1% in order to explain the filaments. The requirements become more stringent if one attempts to explain the entire NLR via cocoon-IGM interaction, as here > 1% efficiency is required.

The second possibility is that the filaments are photoionized by a hidden quasar nucleus in the centre of Cygnus A. The filaments stream away from the direction of this putative hidden nucleus. This can be explained, for example, in terms of gas blown outwards by radiation pressure. If we suppose that a quasar of bolometric luminosity ~10^{39} W (e.g. Stockton et al. 1994) were present at the nucleus of Cygnus A, and assuming a distance of 1 kpc between the nucleus and the filaments, the radiation pressure acting on the clouds should be around 3×10^{-10} Pa, comparable to the gas pressures of a few times 10^{-10} Pa normally found in the centres of similar "cooling-flow" clusters (e.g. Fabian 1989). More plausibly, the filaments may be blown out by a wind such as is proposed in starburst objects (e.g. Tomisaka & Ikeuchi 1988; Armus et al. 1990).

3.2. Dust

Shaw & Tadhunter (1994) found considerable evidence for reddening in Cygnus A by use of slit spectroscopy parallel to the radio jet (at a position angle of 105°) and just north of the central component. The region of increased reddening can be seen directly at this high resolution, and corresponds to the region of very low surface brightness between the central and NW components. It is also seen in the images of Stockton et al. (1994), particularly their *b* image, although the detailed structure is not clear in this image. The implied reddening in this region is about two magnitudes. It joins on to the "channel" in the NW component, and hence the channel may be simply

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due to dust obscuration rather than the passage of a radio jet as suggested by Jackson et al. (1994). This is supported by the observation at this high resolution that the channel is not completely straight, and it may therefore be difficult to explain as the remnant of a radio jet's channel.

3.3. Evidence for cones?

Cygnus A has previously been claimed as an example of light escaping from a hidden nucleus along a cone of solid angle unobscured by a nuclear torus (e.g. Vestergaard & Barthel 1993). It is difficult to test this in optical images, because of the obvious presence of patchy dust. It is plausible that the edge of a "cone" is defined by the central component, which together with the northwest blobs encloses an area that is somewhat suggestive of a conical structure. For reasons already summarised, the optical continuum cannot be solely due to scattering of this light, but the emission line clouds could be found along a region of solid angle that sees the central photoionizing continuum directly: this appears to be the case in other objects such as NGC 5252 (Tadhunter & Tsvetanov 1989). The opening angle of the cone is defined by the structure in the central component, which is better defined at this high resolution, and is now seen to be about 110°. It should be said, however, that this is a plausibility argument only. It is also possible that most of the optical structure, including the shape of the central component, is defined by a patchy dust lane. Further high–resolution imaging in blue line–free continuum bands is needed to resolve this question.

3.4. Blobs

Lynds et al. (1994) remark on blue, bright patches in the image. We confirm the existence of numerous bright condensations, both in the northwest component and to the north of the southeast component. The latter lie outside the opening angle of any possible ionization cone and therefore their emission cannot be ascribed to photoionization by any hidden quasar. This supports the hypothesis by e.g. Goodrich & Miller (1989) that at least some of the blue continuum is due to young stars.

4. Conclusion

We have presented the most detailed optical image yet of Cygnus A. Full interpretation must await high-resolution images in different emission lines, which will be observed with the HST in the next year. However, a number of new features are visible and existing features are confirmed. We confirm the dust region seen by Stockton et al. (1994) and Shaw & Tadhunter (1994) and see it extending into, and being associated with, the "channel" in the northwestern component. Filamentary structure is seen to extend from the major emission-line components. Bright condensations within these structures may be stellar in origin. Finally, the morphology of the central component is clearer: it is definitely extended, and its smoothness on the southeastern edge, together with its shape, leads to the tentative suggestion that it may be the edge of an "ionization cone". Emission line imaging, and imaging in blue line–free continuum, should test this idea further.

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