THE OPTICAL EMISSION-LINE SPECTRUM OF CYGNUS A

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ABSTRACT

Spectrophotometric measurements are reported of the radio galaxy 3C 405 = Cyg A, made using the image-tube image-dissector scanner on the Lick 120-inch (3 m) telescope. The measurements were reduced to energy units by comparison with scans of standard stars made with the same system on the same nights. The emission lines and continuum were measured in the spectral region λλ3346–6731 (in the rest system of Cyg A). The interstellar extinction was determined from the measured Balmer-line ratios, assuming a Case B recombination spectrum and the standard Whitford reddening curve, and the measured line and continuum strengths were corrected for this extinction. The corrected line strengths are discussed for the information they contain on the physical conditions and the energy-input mechanism to the ionized gas. Photoionization by stars is ruled out by the great strength of [O I], [N I], and [S II]. Shock-wave heating is ruled out by the [O III] temperature, unless a large amount of ultraviolet ionizing radiation is emitted in the shock. Published calculations of photoionization by a synchrotron spectrum, extending far into the ultraviolet, approximately match the observed emission-line spectrum. Likewise, the observed Crab Nebula spectrum approximately matches Cyg A, except for abundance differences, in agreement with the idea that Cyg A is photoionized by a power-law spectrum.

Subject headings: radio sources — galaxies, individual — galactic nuclei — spectrophotometry

I. INTRODUCTION

Cygnus A = 3C 405 is one of the brightest radio sources in the sky (Bolton and Stanley 1948), and was one of the first radio sources to be optically identified; it was identified with the brightest member of a cluster of galaxies (Mills and Thomas 1951; Baade and Minkowski 1954). Though Baade and Minkowski (1954) considered it to be two galaxies in collision, more recent research on the classification of galaxies has shown that Cyg A is a not untypical cD galaxy with a double nucleus (Matthews, Morgan, and Schmidt 1964; Bautz and Morgan 1970). It is possible that the double nucleus is an apparent result of the presence of a dust lane similar to that observed in the much nearer galaxy Cen A = NGC 5128, classified as DE3 by Matthews, Morgan, and Schmidt (1964).

The first spectrograms of Cyg A obtained by Baade and Minkowski (1954) showed that this object has a peculiar spectrum (for a galaxy), strong in forbidden emission lines, and with only a very weak continuum. Further observations by Schmidt (1965) showed that many, but by no means all, radio galaxies have these emission lines in their spectra, and that Cyg A may be regarded as a prototype of such objects. Its spectrum is qualitatively similar in many respects to the spectra of Seyfert galaxies (Baade and Minkowski 1954; Bautz and Morgan 1970), and the same types of lines are observed in many quasars (see, e.g., Burbidge and Burbidge 1967). Thus it is clearly important to understand the emission-line spectrum of Cyg A, not only for itself, but because it is probably related to many of these other objects.

The available optical information on Cyg A, derived from photofragment spectrograms taken at the Hale Observatories, has been collected and discussed by Mitton and Mitton (1972). Though their data are most interesting, they are necessarily qualitative, as they result from eye estimates made on uncalibrated spectrograms. In the present paper we report the results of our photoelectric spectrophotometry of Cyg A and the physical conclusions we can draw from it.

II. OBSERVATIONAL PROCEDURES

All the observational data reported in this paper were obtained with the image-tube scanner (Robinson and Wampler 1972, 1973) at the Cassegrain focus of the 120-inch (3 m) telescope, in the years 1972–1974. All except the last two series of observations were taken in 1972 and 1973 with the original borrowed spectrograph mentioned in those papers, using a single (pierced) 600 lines mm⁻¹ grating. The two entrance apertures were set at 0.70 × 1 mm, projecting to 2.7 × 4" on the sky, separated by 206. In order to avoid faint stars in the comparison (sky) channel, the instrument was rotated so that the long axis of the slits was in position angle 11° for most of the measurements of Cyg A, and the telescope was guided visually using the television slit-viewing system. It can be seen from the direct photographs published by Baade and Minkowski (1954) that most, but by no means all,