THE VARIABLE COMPACT GALAXY Zw 0039.5 + 4003

F. ZWICKY, J. B. OKE, G. NEUGEBAUER AND W. L. W. SARGENT
Mount Wilson and Palomar Observatories
Carnegie Institution of Washington
California Institute of Technology

AND

A. P. FAIRALL
McDonald Observatory, University of Texas

Received October 29, 1969

The optically variable compact galaxy Zw 0039.5 + 4003 has broad emission lines similar to those seen in Seyfert and N-type galaxies. The continuous spectrum shows no evidence of any stellar contribution and is probably largely nonthermal. The object has a redshift $z = 0.1026$ and an absolute visual magnitude of -21.6.

The first object suspected to be a variable compact galaxy was discovered by Zwicky (1965) on a 48-inch Schmidt plate centered on M 31. The object is located at $\alpha = 0^h39^m5$, $\delta = +40°03'$ (1950.0 (see Plate I)). Its apparent photographic magnitudes were respectively $m_p = 17.2$, 16.6, and 17.6 on November 22, 1964, January 28, 1965, and July 26, 1965. A preliminary survey of some hundred films and plates from Zwicky's Palomar collection from 1936 to 1968 shows the object to have been irregularly variable in the range $16^m0 < m_p < 18^m2$. Structurally, Zw 0039.5 + 4003 possesses a hard core about one second of arc in diameter and a faint halo three times as large. At first the possibility was entertained that the object was a faint galactic variable star superimposed by chance on the image of a distant galaxy. Before his retirement from the staff of the observatories, Zwicky made several unsuccessful attempts to obtain a spectrum of Zw 0039.5 + 4003. We show in the present paper that the object is indeed a galaxy with a variable nucleus. In addition we give data on its optical spectrum, continuum energy distribution, and its infrared continuum flux.

Several optical spectrograms of Zw 0039.5 + 4003 were obtained with the Cassegrain image tube spectrograph on the Hale telescope on the nights of September 5, 6, and 7, 1969. The spectrograms were

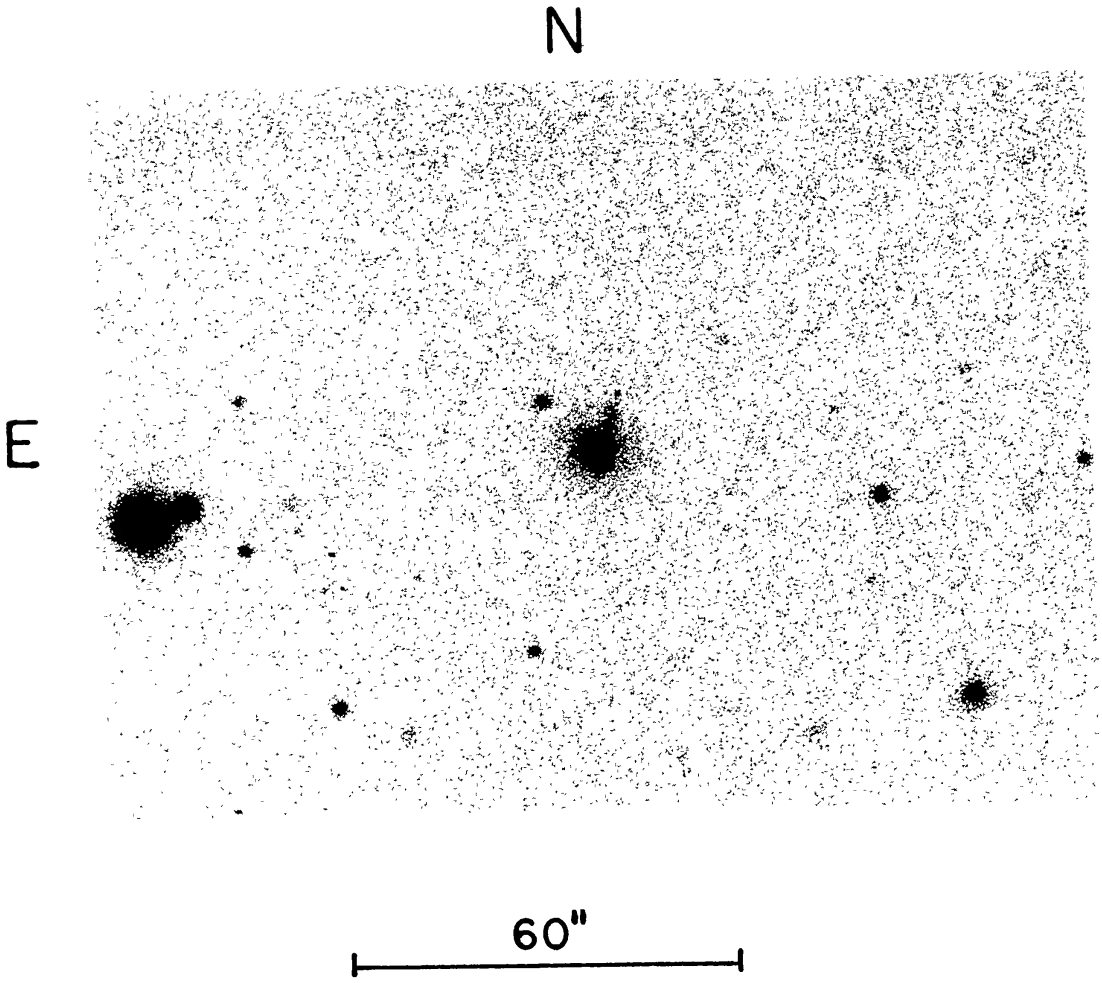

PLATE I

A direct photograph of Zw 0039.5 +4003 obtained by H. C. Arp at the prime focus of the 200-inch telescope on 103a-J emulsion. The conspicuous jet or plume has a projected length of 20 kpc.

widened to 0.3 mm by means of a rocking quartz block under the slit. They have a dispersion of 90 Å/mm and cover the wavelength range λλ 3600–6000. The spectrum of Zw 0039.5 + 4003 consists of emission lines on a smooth continuum. No absorption lines are observed. A list of the emission lines, together with their identifications, is given in Table I. The object has a redshift of $z = 0.1026$, corresponding to a distance of about 400 Mpc with $H = 75$ km sec^{-1} Mpc^{-1}. At this distance one second of arc corresponds to a projected distance of 2 kpc. The object appears stellar at the telescope so that most of the light comes from a region less than

TABLE I

EMISSION LINES IN Zw 0039.5 + 4003

λ	Ident.	λ_0	z
3688.0	[Ne v]	3342.9	0.1023
3776.2	[Ne v]	3425.8	.1022
4110.3	[O II]	3727.5	.1027
4265.4	[Ne III]	3868.7	.1025
4290.2	He I	3888.6	.1032
4375.6	[Ne III]	3967.5	.1027
4522.8	Hδ	4101.7	.1027
4787.3	Hγ	4340.5	.1029
4812.2	[O III]	4363.2	.1029
5359.1	Hβ	4861.3	.1024
5467.2	[O III]	4958.9	.1025
5520.5	[O III]	5006.8	0.1026

2 kpc in size. As is commonly the case with Seyfert and N-type galaxies, the Balmer lines are much broader than the forbidden lines in the spectrum of Zw 0039.5 + 4003. The widths of the Balmer lines at half-maximum intensity are about 80 Å or 5000 km/s, while the forbidden lines have widths of about 15 Å or 850 km/s. The Balmer lines have weak cores which have the same width as the forbidden lines.

The absolute spectral energy distribution of Zw 0039.5 + 4003 has been obtained from 0.33 to 2.2 μ. Below λ 10,000 observations were made with the photoelectric multichannel spectrometer (Oke 1969*a*). The spectrum was observed on August 11/12, 1969 with a bandpass of 80 Å for $\lambda < 5900$ and 160 Å for $\lambda > 5900$. On August 14/15 the whole spectrum was again observed but with bandpasses of 40 Å and 80 Å. The brightness of the object corresponded to a visual magnitude of 16.5 and did not change. Broad-band observations in the infrared were made with a photometer described by Becklin and Neugebauer (1968). Measurements with a bandpass 1.5–1.8 μ ($\lambda_{eff} = 1.65\,\mu$) were obtained on August 16/17 and August 17/18, 1969. Data with a bandpass 2.0–2.4 μ ($\lambda_{eff} = 2.2\,\mu$) were secured on August 15/16 and August 17/18, 1969.

The resulting absolute energy distribution is shown in Figure 1 where $\log f_\nu$ is plotted against $\log \nu_0$. The fluxes f_ν in ergs sec^{-1} cm^{-2} Hz^{-1} are based on the calibrations given by Becklin (1968). The rest frequency $\nu_0 = \nu(1 + z)$ where z is the redshift. In the far red, below $\log \nu_0 = 14.63$, and in the ultraviolet above $\log \nu_0 = 14.92$, all observations are averaged. For the remaining data only the higher resolution points are shown. The standard deviations for the spectrophotometric data are less than 0.025 in $\log f_\nu$ over the whole range except between $\log \nu_0 = 14.75$ and 14.80 and below $\log \nu_0 = 14.55$ where the errors are 0.04.

The absolute energy distribution for Zw 0039.5 + 4003 bears a striking resemblance to that of the N-type or Seyfert galaxy 3C 120 (Oke, Sargent, Neugebauer, and Becklin 1967) which also resembles the QSO B264 and the QSRS 3C 323.1 (Oke 1969*b*). The emission line strengths relative to the continuum are similar in 3C 120 and Zwicky's object. Both objects show a flattening of the continuum in the ultraviolet. In the case of the Seyfert galaxy NGC 4151, Oke and Sargent (1968) showed that this was due to bound-free hydrogen recombination beyond the Balmer jump.

While 3C 120 is a strong, variable radio source, the Zwicky object is not in any radio source catalog. A particularly fine limit can be put on radio emission from the Zwicky object because it lies in the area covered by the 5C 3 catalog ((Pooley 1969) a survey of a region centered on M 31, made at a frequency of 408 MHz). The weakest sources in this survey have flux densities $S_{408} = 0.012$ flux units; no source is listed at the position of Zw 0039.5 + 4003.

If one assumes a Hubble constant of 75 km/sec^{-1} Mpc^{-1} and a cosmological model with $q_0 = +1$, the absolute flux at a rest wavelength of 5000 Å from the Zwicky object is 1.69×10^{29} ergs sec^{-1} Hz^{-1}. This can be compared with a flux of 1.30×10^{29} ergs sec^{-1} Hz^{-1} for 3C 120. The absolute visual magnitude, with no K correction, is $M_v = -21.6$ as compared with -21.3 for 3C 120. The upper limit for the magnitude of the background galaxy, if it is normal, is approximately -20.1, corresponding to an apparent visual magnitude of 18.1. The fact that the visual magnitude of Zw 0039.5 + 4003 has been observed at times near this value suggests that the bright nucleus, which at present is responsible for most of the observed radiation, may almost disappear at times.

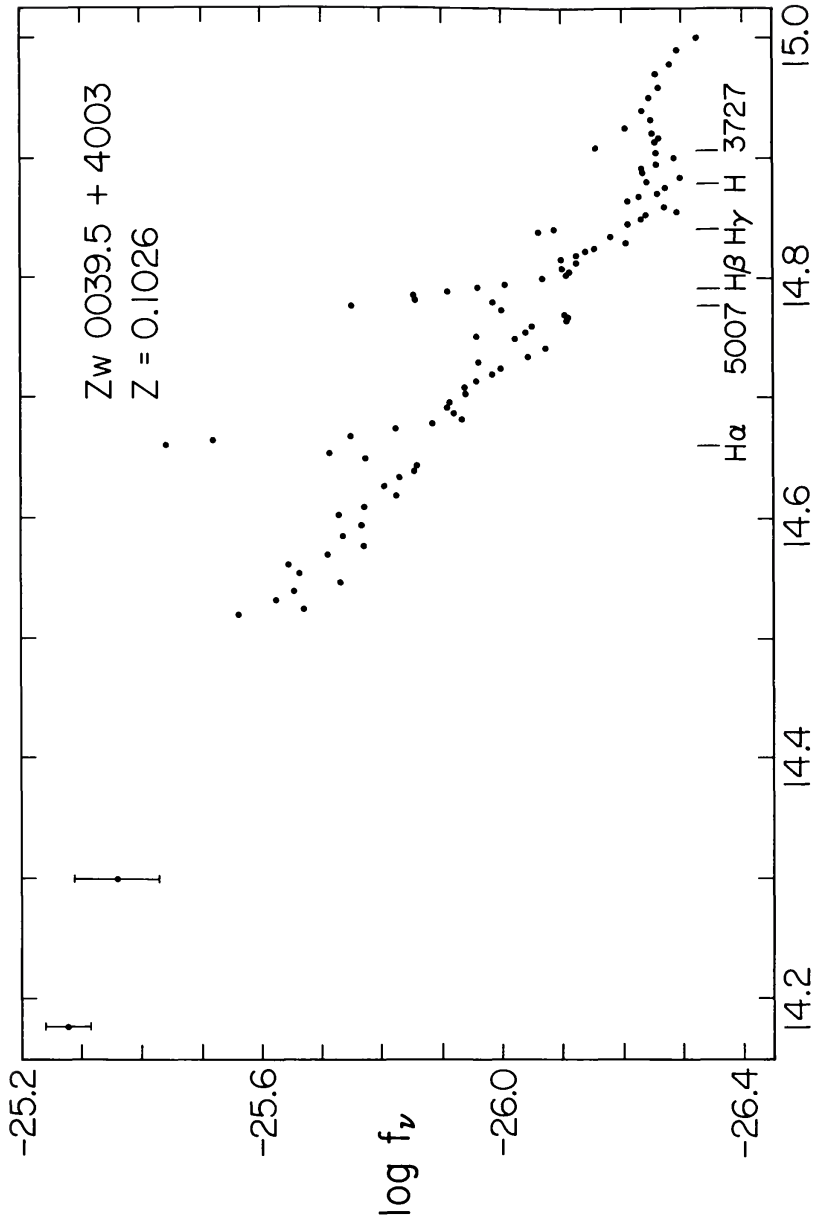

FIG. 1 — The absolute spectral energy distribution of Zw 0039.5 + 4003. The flux f_ν is in units of ergs sec^{-2} cm^{-2} Hz^{-1} and ν_0 is the rest frequency in Hz. The positions of the stronger emission lines and the H line of Ca II are shown.

This research was supported in part by Grant NGL 05-002-007 from the National Aeronautics and Space Administration and by Grant DA-ARO-D-31-124-G705 of the Advanced Research Projects Agency. We wish to thank Dr. G. P. Garmire and Mr. G. Tuton for assisting with the observations.

REFERENCES

Becklin, E. E. 1968, Dissertation, California Institute of Technology.
Becklin, E. E., and Neugebauer, G. 1968, *Ap. J.* **151**, 145.
Oke, J. B. 1969*a*, *Pub. A.S.P.* **81**, 11.
—— 1969*b*, *Ap. J. (Letters)* **158**, L9.
Oke, J. B., and Sargent, W. L. W. 1968, *Ap. J.* **151**, 807.
Oke, J. B., Sargent, W. L. W., Neugebauer, G., and Becklin, E. E. 1967 *Ap. J. (Letters)* **150**, L173.
Pooley, G. G. 1969, *M.N.R.A.S.* **144**, 101.
Zwicky, F. 1965, in *Carnegie Institution of Washington Yearbook* No. 64, p. 33.