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OPTICAL OBSERVATIONS OF THE RADIO SOURCE 0735+178

R. F. CARSWELL, P. A. STRITTMATTER,* AND R. E. WILLIAMS
Steward Observatory, University of Arizona
T. D. KINMAN
Kitt Peak National Observatory,† Tucson, Arizona
AND
K. SERKOWSKI
Lunar and Planetary Laboratory, University of Arizona
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ABSTRACT

It is shown that the variable radio source 0735+178, which has no optical emission lines in its spectrum, varies substantially in both optical flux ($\Delta m_B \sim 1$ mag) and polarization (5–30 percent) on time scales less than a month. It is therefore assigned to the class of objects containing BL Lac and OJ 287. The spectrum of 0735+178 does, however, contain two sharp absorption features at 3981 and 3991 Å which are identified with the Mg II λ2798 doublet at a redshift $z = 0.424$. This confirms that 0735+178 is extragalactic with similar implications for other members of the class. The presence of highly redshifted absorption lines in 0735+178 also strengthens the hypothesis that these objects are similar to quasars.

Subject headings: quasi-stellar sources or objects — radio sources, variable — redshifts

I. INTRODUCTION

The radio source PKS 0735+178 (VRO 17.07.02) was first identified by Blake (1970) with a 15–16 mag neutral stellar object, and this identification was subsequently confirmed by Browne, Crowther, and Adgie (1973). Burbidge and Strittmatter (1972) reported that the object appeared to have a continuous optical spectrum. The radio source is known to be variable at frequencies above 6 GHz (Medd *et al.* 1972; Dent and Hobbs 1973). The radio spectrum shows an increase in flux with frequency to about 1 GHz but is fairly flat at higher frequencies (Blake 1970). The number of objects with properties broadly similar to 0735+178 now exceeds 20, of which BL Lac and OJ 287 are the best known and most thoroughly studied examples. They resemble quasars but rigorously are excluded from this category by definitions such as Schmidt's (1970) because they have no emission-line redshift. Indeed, it has been suggested that they may be galactic black holes (Pringle, Rees, and Pacholczyk 1973; Shapiro and Elliot 1974). This paper reports observations of 0735+178 which support the idea that these objects are extragalactic and similar in nature to quasars and N galaxies.

II. THE OBSERVATIONAL MATERIAL

A program of photographic photometry of 0735+178 was undertaken by one of us (T. D. K.) in 1971 November. The plate material has been obtained mainly with the KPNO 0.4-meter and 0.9-meter reflectors and has been measured with an iris astrophotometer using the sequence of comparison stars given by Wing (1973) for which the following B-magnitudes have been adopted: star A, 13.88; B, 15.48; C, 15.49; and D, 16.61. These values represent means of Wing's data and independent photoelectric measures obtained with the KPNO 2.1-meter telescope. The resultant light curve for 0735+178 (fig. 1) shows variations in B-magnitude of amplitude 0.5–1.0 mag in time scales of 10 to 20 days. Smaller variations are also present on a time scale of 1 day. This behavior is similar to that of BL Lac and OJ 287, and it is therefore of interest to compare them quantitatively. A measure of short-term variability is the rms variation σ between observations taken on adjacent nights. The results are given in table 1, where n denotes the number of pairs of nights used in calculating σ. The values of σ for 0735+178 and OJ 287 are similar, but both are significantly lower than those for BL Lac. The level of activity in BL Lac is, however, markedly different during two successive 2-year periods,

TABLE 1

INTER-DAY OPTICAL VARIABILITY FOR 0735+178, OJ 287, AND BL LACERTAE

Object	Epoch	σ (mag)	n
0735+178.....	1971 Nov.–1973 Dec.	±0.107	30
OJ 287*.....	1971 Apr.–1973 Apr.	0.121	89
BL Lac*.....	1968 June–1970 Sep.	0.298	71
BL Lac*.....	1970 Oct.–1972 Dec.	0.165	76

* Data taken from unpublished observations by T.D.K.

* Alfred P. Sloan Research Fellow.

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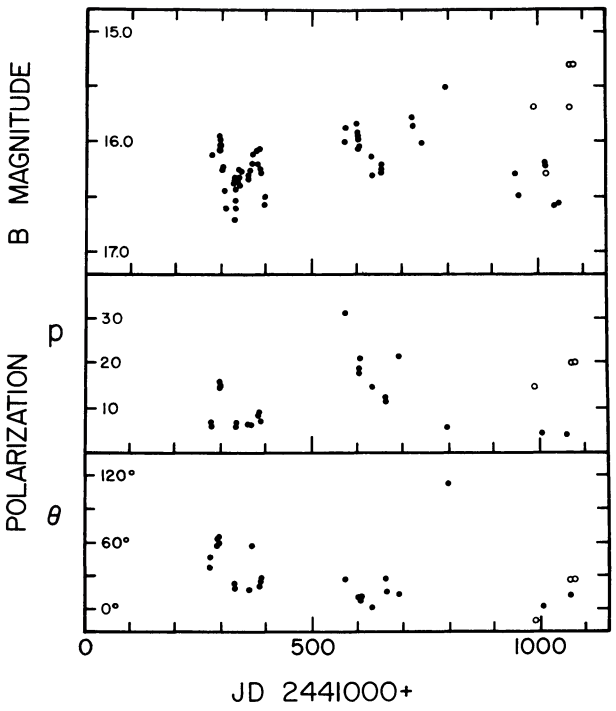

FIG. 1.—Variations in B-magnitude, percentage p, and position angle θ of polarization are plotted as a function of Julian date. Filled and open circles represent KPNO and LPL observations, respectively.

so that σ is not constant for any one object. Furthermore, the observed time scales are not necessarily intrinsic but would, for example, be increased by a factor $(1 + z)$ if the object has a redshift z. The short-term variability as measured by a parameter such as σ is therefore only a rather rough classification guide; nevertheless, it affords some indication of the similarity of these three objects.

UBV colors for 0735+178 have been determined by Wing (1973), who gives $U - B \simeq -0.43$ and $B - V \simeq 0.52$; our own measures are consistent with these values. There is some tentative evidence for small color changes, but this cannot be established with any certainty from the available data. The colors are similar to those of OJ 287, ON 231, and ON 235 (Strittmatter *et al.* 1972; Wing 1973). BL Lac is, however, redder, although this may be due in part to interstellar reddening, as the object lies at a low galactic latitude ($b^{II} = 10°$).

Optical polarimetry of 0735+178 has been carried out by two of us (T. D. K. and K. S.) using the KPNO polarimeter (Dyck and Sandford 1971) at the 2.1-meter reflector and the LPL polarimeter at the Catalina 1.5-meter telescope (Serkowski 1974). The results are plotted in figure 1 and clearly show that large changes both in the magnitude and direction of linear polarization occur in 0735+178 on time scales of 10 days. The polarization observed in 1972 September 13 ($p = 31 \pm 0.4\%$) is noteworthy in being, as far as we are aware, the highest yet recorded in objects of this type. Variable polarizations of 10 percent or more have been found in OJ 287, ON 231, ON 235, and BL Lac (Strittmatter *et al.* 1972; Kinman [unpublished observations]).

Spectroscopic studies of 0735+178 have been made (R. F. C., P. A. S., R. E. W.) using the Cassegrain spectrograph and RCA 33063 image-tube system at the Steward Observatory 2.2-meter telescope. A low-dispersion (240 Å mm^{-1}) spectrogram, SI 1075, was obtained in 1973 December in order to confirm the conclusion of Burbidge and Strittmatter (1972) that the object has a continuous spectrum. No emission lines were found in the range 3150–5700 Å. The spectrogram did, however, contain a suggestion of possible absorption near 4000 Å. Two higher-dispersion spectrograms, SI 1187 and SI 1213, were therefore obtained in 1974 January. SI 1187 is a multiple-order spectrogram obtained with the new "cross dispersion echellette" modification to the Cassegrain spectrograph (Carswell *et al.* 1974) and widened 0.3 mm. A pair of sharp absorption lines are visible at the blue and red ends of the tenth (43 Å mm^{-1}) and eleventh (39 Å mm^{-1}) orders, respectively. The measured wavelengths are listed in table 2. SI 1213 is a conventional spectrogram, also widened 0.3 mm, taken at a dispersion of 45 Å mm^{-1}. This spectrogram is reproduced in figure 2 (plate L4). The doublet is again clearly visible, and the measured wavelengths are given in table 2, together with the mean of the three determinations. The wavelength ratio (1:1.0025) agrees very well with that of the Mg II 2798 doublet. If this identification is correct, the corresponding redshift is $z = 0.424$. As far as we are aware, there are no common elements with resonance doublets near 4000 Å which have the appropriate splitting. If redshifts are allowed, then the Mg II 2798 doublet is, after Ca II H and K, the first commonly observed pair, and it has the correct splitting. No other commonly observed resonance doublet gives as good agreement (Si II λλ1190.4, 1193.3 is the best alternative fit, but the absence of Si II λ1260.5, not to mention Lα, makes this rather unlikely; in any case, this requires a still higher redshift). We cannot exclude the possibility that the observed doublet represents the same line in two redshift systems, but this seems rather contrived and would again probably require a higher redshift. We therefore feel that the Mg II identification is fairly secure.

A search was made for other absorption features; but, with the exception of a possible line at ~3350 Å, this attempt has so far proved unsuccessful. Further study is, however, required. A search for Fe II lines is especially important since these have been observed in both PHL

TABLE 2

MEASURED WAVELENGTHS

Plate	Line 1	Line 2
SI 1187 (10th order).....	3981.5	3991.1
SI 1187 (11th order).....	3981.1	3991.5
SI 1213.....	3982.0	3991.9
Mean.....	3981.5±0.3	3991.5±0.3

PLATE L4

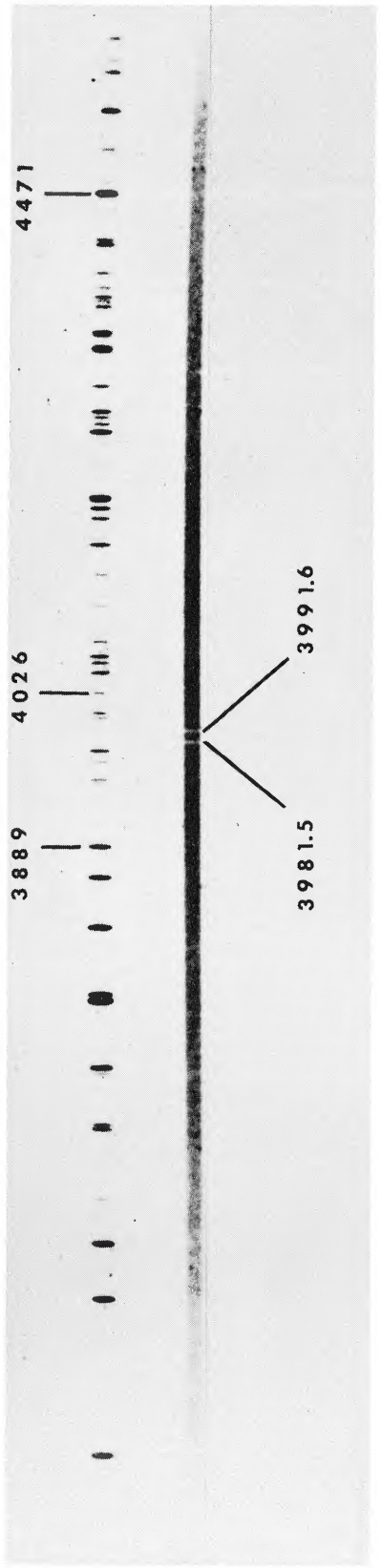

FIG. 2.—A reproduction of spectrogram SI 1213 of the variable source 0735+178

938 (Burbidge, Lynds, and Stockton 1968) and 1331+170 (Strittmatter *et al.* 1973), QSOs in which the Mg II absorption is particularly clear.

III. DISCUSSION

Observations of 0735+178 either published or presented in this *Letter* have established that the source (i) has a radio spectrum which peaks at ~1 GHz, (ii) is variable in intensity on a time scale of less than a month in the optical and at radio frequencies above 6 GHz, (iii) shows strong and variable polarization in the optical, (iv) is neutral in color, and (v) has no emission lines. These properties are characteristic of BL Lac, OJ 287, etc. and we therefore consider it reasonable to assign 0735+178 to this general class. If this is correct, the existence of a highly redshifted absorption system suggests that these objects are also extragalactic and very similar to quasars and N systems.

A potential problem of classification may arise here in that BL Lac and AP Lib have extended optical images on direct photographs whereas the other objects hitherto assigned to this class appear stellar. Furthermore, BL Lac and AP Lib are both redder than the objects showing no nebulosity. It is also interesting that BL Lac shows systematic variations in color with brightness while OJ 287 does not (Frohlich, Goldsmith, and Weistrop 1974). A possible explanation is that, in the stellar objects, only the varying presumably nonthermal continuum contributes significantly to the observed radiation whereas in BL Lac a substantial contribution arises from the redder and constant nebulosity. Objects like OJ 287 and 0735+178 may therefore bear the same relation to BL Lac and AP Lib as QSOs do to N galaxies such as 3C 371 (Sandage 1973). In this context it is interesting that Oke and Gunn (1974) have recently presented observations which suggest that the redshift of BL Lac itself may be $z \sim 0.07$. On this basis, one may speculate that the redshift of OJ 287 is large.

Comparison of OJ 287 type objects, including 0735+178, with the strongly variable quasars is also instructive. Oke, Neugebauer, and Becklin (1970) showed that in the range 0.3–2.2 μ the continuum spectral energy distribution of quasars could be represented by power laws $f_\nu \propto \nu^{-\alpha}$ with $+0.2 \lesssim \alpha \lesssim +1.6$. It is noticeable, however, that those which show strong and variable polarization (PKS 1510−08, 3C 297, 3C 345, 3C 446, and 3C 454.3) all have steep spectra (α = 1.1, 1.51, 1.50, 1.49, and 1.58, respectively). Steep power-law spectra in the optical are also characteristic of OJ 287, ON 325, ON 231, and (from its *UBV* colors) 0735+178. (The radio spectra of the quasars are rather diverse but, in contrast to the objects in the non–emission-line sample, often show an increase in flux toward lower frequencies.)

Although there is little doubt as to the redshift z_a of the absorption system in 0735+178, the redshift z_e associated with the continuum source remains undetermined. By analogy with quasars it seems unlikely that z_e is less than z_a; it might, however, be substantially greater. PHL 938 provides an outstanding example of such a case (Burbidge *et al.* 1968). Indeed, it is noteworthy that Mg II λ2798 is rarely seen in absorption in low-redshift QSOs and even when claimed to be present is usually a weak or doubtful feature. The Mg II λ2798 absorption doublet has, however, been observed quite clearly in a number of high-z QSOs, but only in absorption systems with redshifts substantially smaller than the emission system. On this analogy the continuum source in 0735+178 may very well have a redshift substantially greater than 0.424.

Objects like OJ 287 and 0735+178 appear to be very similar to the variable quasars except that they lack optical emission lines. The discovery of highly redshifted absorption lines in 0735+178 strengthens the case that both types of objects are really manifestations of the same basic phenomenon. Galactic models for objects like BL Lac, OJ 287, etc., can therefore almost certainly be ruled out. If redshifts are cosmological, the luminosity of 0735+178 is at least comparable with those of the brighter quasars. The rapid variations observed at higher radio frequencies, however, raise the by now familiar problems of radio source structure and/or redshift interpretation. (A discussion of the various options has been given by Jones and Burbidge [1973] for the case of 3C 454.3). No new or particularly severe problems are, however, presented by the case of 0735+178, at least on the basis of the presently available data. Kinman *et al.* (1974) have pointed out the difficulties in interpreting the observations of OJ 287 in terms of the conventional expanding models of variable radio sources. The problems would be compounded if (i) radio variability could be established at lower frequencies (the published observational data show considerable scatter even at 408 MHz), or (ii) the redshift of the continuum source could be shown to be substantially larger than 0.424. In either case strong (and useful) constraints could be placed either on the structure of the source or on its distance. Further observations of 0735+178, especially at lower radio frequencies to settle the question of variability, are urgently required; the absence of a radio component which increases in strength toward low frequency may facilitate such a search.

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