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THE REDSHIFT OF THE BL LACERTAE OBJECT PKS 0548−322

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ABSTRACT

The halo around the BL Lacertae object PKS 0548−322 has been observed spectrophotometrically. The scans show absorption lines from a population of late-type stars with redshift of 0.069. This result makes it seem unlikely that the object is physically associated with a surrounding cluster of galaxies with a mean redshift of 0.04. An absolute visual magnitude of −22.45 is now derived for the combined light of the nucleus and the surrounding halo. The observations are consistent with the object being a luminous giant elliptical galaxy having a compact nucleus with a spectral energy distribution which can be represented by a power law with a spectral index $\alpha = 2 \pm 0.5$, each component contributing about equally to the observed luminosity in the B-band.

Subject headings: galaxies: redshifts — BL Lacertae objects

I. INTRODUCTION

The radio source PKS 0548−322 was found and identified with a 16th magnitude galaxy by Shimmins and Bolton (1974) during a 2700 MHz survey with the Parkes 64 m telescope. They measured the flux $S(2700) = 0.31$ Jy, and later Disney (1974) measured a 5000 MHz flux $S(5000) = 0.23$ Jy. If the object is assumed not to have varied in the interval between these observations, then the radio spectral index is $\alpha = 0.5$. This value, however, should clearly not be taken too seriously until more radio measurements have been made. The object shows a stellar nucleus on the blue Palomar Sky Survey print.

UBV photometry through a 30″ diaphragm (Disney 1974) yielded $V = 15.5 \pm 0.1$, $B - V = 0.57 \pm 0.02$, and $U - B = -0.30 \pm 0.03$. Disney also showed that the optical spectrum of the nucleus is continuous with no absorption or emission features. These observations suggested that the object be placed in the same class as BL Lac and AP Lib. Attempts to record the spectrum and measure the velocity of the halo surrounding the nucleus were unsuccessful, but Disney noted that PKS 0548−322 is projected onto the center of a cluster of galaxies which he showed to have a mean redshift of 0.042. The similarity of the angular sizes of the halo and cluster galaxies was used to argue that PKS 0548−322 is a cluster member.

In view of the dual importance of determining the distances to BL Lacertae objects and of positively demonstrating cluster membership, it was decided to use the 3.9 m Anglo-Australian Telescope to attempt to measure the redshift of the halo around PKS 0548−322. The recent controversy over the distance to BL Lacertae itself (Oke and Gunn 1974; Baldwin *et al.* 1975; Thuan, Oke, and Gunn 1975) makes the application of this technique to another object in the same class particularly desirable.

II. OBSERVATIONS

All of the observations reported here were made with the image dissector scanner (Robinson and Wampler 1972) attached to the fast spectrograph at the f/15 focus of the Anglo-Australian Telescope (AAT). The star and sky apertures were 2″ in declination by 4″.5 in right ascension with their centers separated by 20″ in right ascension. For consecutive integration periods the roles of star and sky apertures were reversed in the usual way. During the observations of the nebulosity, the center of the aperture was placed 2″.5 away from the nucleus on a north-south line. During periods of very good seeing (0″.5) the nucleus appeared stellar on the slit-viewing television system at the AAT. The spectral resolution of the scanner was 4.5 Å (FWHM) over the whole spectral range. The observations are listed in Table 1.

From comparison with standard stars measured with the same system on the same night it is estimated that the mean observed surface brightness of the halo within the 2″ × 4″.5 aperture, centered 2″.5 to the

TABLE 1

OBSERVATIONS

Date	Object	Wavelength Coverage (Å)	Integration (min)	Seeing (arcsec)
1975 Nov 24/25	Nucleus	5600–7500	48	2
1976 Jan 7/8...	Halo 2″.5 N	5350–7250	96	2
1976 Jan 8/9...	Halo 2″.5 S	3800–5700	96	<1
1976 Jan 8/9...	Nucleus	3800–5700	32	<1

south of the nucleus, is 22.0 ± 0.2 mag arcsec^{-2} in the *B*-band.

Both blue and red scans of the halo show the presence of absorption features which are readily identified with lines to be expected from a population of late-type stars. The mean redshift of the system, determined from the Ca II H and K lines, the G-band, Hβ, the Mg I *b*-lines and Na I D-lines, is 0.0689 ± 0.0008. Figure 1 shows the blue scan of the halo and nucleus. For comparison purposes a scan of a bright galaxy (NGC 1512), observed on the same night with the same system, is shown with a wavelength scale expanded by the factor [1 + z(0548−322) − z(1512)] and shifted by the appropriate amount. The intensity scale is such that the halo shows a flat continuum. The bluer color of the nucleus is apparent.

Figure 2 shows the region around 6300 Å from the red scan of the halo. This is shown before and after sky subtraction in order to illustrate the close coincidence between the redshifted sodium D-lines (mean wavelength 6298.5 Å) and the [O I] night-sky line λ6300.2. At this redshift the separation between the Mg I *b*-lines and the [O I] auroral line λ5577.4 is many times our spectral resolution (see Fig. 1).

The data from each individual integration period (4, 8, or 16 minutes) were carefully examined for the presence of image-tube ion events before sky subtraction and combination into the final scans. The stronger absorption features, i.e., Ca II H and K and the *b*-band, are clearly visible in the independent data from the left and right apertures of the scanner. The Mg I *b*-band also appears in the red scan of the halo.

Absorption features identified with the Mg I *b*-band and Na I D-lines at a redshift of 0.069 can also be seen in the nuclear scans, though with a much reduced equivalent width. If these are interpreted as resulting from starlight accepted by the entrance aperture together with light from the compact nucleus, then the ratio of equivalent width in halo and nucleus gives the proportion of starlight contaminating the nuclear spectrum at this wavelength. This assumes, of course, that there is no strong gradient of stellar population within 3″.5 of the nucleus. It is found that the continuous spectrum of the nucleus alone contributes 80 percent of the total light at a rest wavelength of 5900 Å. At 4000 Å the fraction is much closer to 100 percent.

If it is assumed that the spectral energy distribution of the halo is the same as the mean giant galaxy of Oke and Sandage (1968), then we can derive the energy distribution of the nucleus alone after subtracting the stellar contribution from the nuclear scan. If this nuclear energy distribution is represented by a power law $f_\nu \propto \nu^{-\alpha}$ over the observed wavelength 3800–5700 Å, then the spectral index $\alpha = 2 \pm 0.5$, the uncertainty

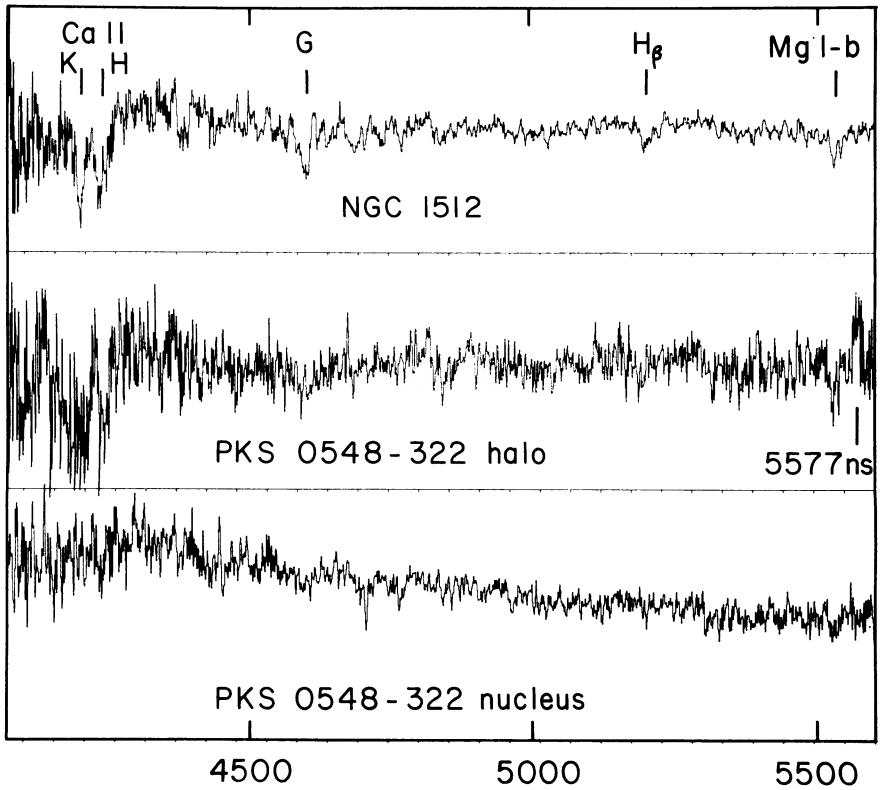

FIG. 1.—The blue scans of the halo and nucleus of PKS 0548−322 compared with NGC 1512. The scan of the comparison galaxy has been expanded and shifted in wavelength to compensate for the redshift difference. The intensity scale is such that the halo shows a flat continuum. In this and in Fig. 2 the abscissa shows the observed wavelength scale.

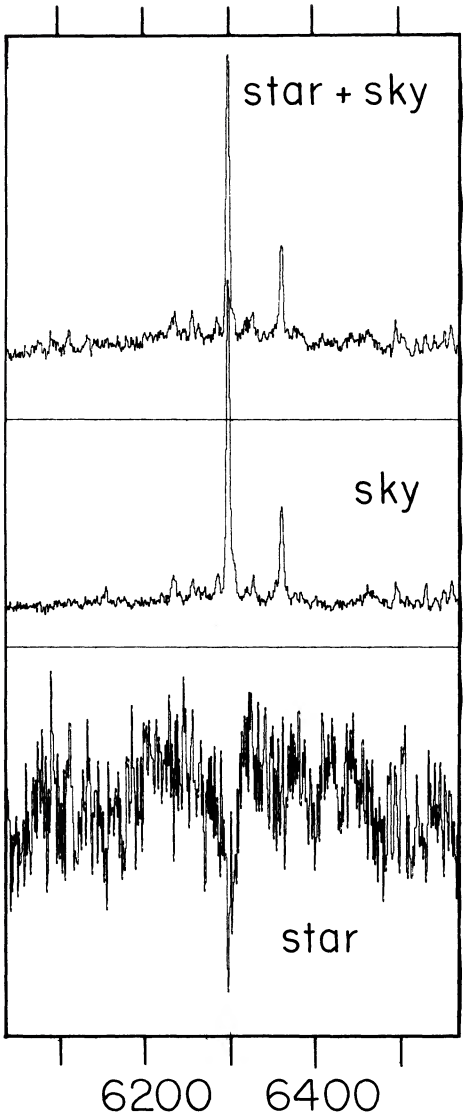

FIG. 2.—Part of the red scan of the halo of PKS 0548−322. This is shown before and after sky subtraction in order to demonstrate the close wavelength coincidence between the [O I] night-sky emission λ6300.2 and the absorption feature which we identify with the sodium D-lines at a redshift of 0.069.

being an estimate of the error which can result from the use of small photometric apertures. The power law is simply a way of representing the spectrum over a limited wavelength range: the data are not sufficient to show that the nucleus actually has this form of spectrum.

III. DISCUSSION

The large difference in redshift, corresponding to 8100 km s^{-1}, between PKS 0548−322 and the cluster of galaxies onto which it is projected rules out the possibility of cluster membership. There are thus no confirmed instances of BL Lacertae objects being physically associated with clusters of galaxies.

If we use $H_0 = 60$ km s^{-1} Mpc^{-1}, the distance to PKS 0548−322 is 340 Mpc and, using Disney's (1974) photometry, the absolute visual magnitude of the combined nucleus and galaxy is −22.45. The diameter of the halo is about 15″ on the red Palomar print, which corresponds to 25 kpc at this redshift. From our observations of the surface brightness of the halo and its angular extent we estimate that the nucleus contributes approximately one-half the total light of the system in the *B*-band and, because of its bluer energy distribution, somewhat less than half the total light at *V*. The underlying galaxy then has an absolute visual magnitude close to −22, which makes it comparable with the most luminous of giant elliptical galaxies.

More observations should be made of PKS 0548−322 to check for radio and optical variability; in particular the radio spectral index is an important parameter needed to relate this to other members of the BL Lacertae class. Infrared and further optical observations of the nucleus should be carried out in order to determine the shape of the energy distribution at high frequencies.

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