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of AE Aqr and SS Cyg and, in general, to such dwarf variables has been noted (Kraft 1958). Very similar disturbances have been observed in AE Aqr (Lenouvel 1957) and light variations as large as 0.5 magnitudes have previously been recorded in T CrB (Walker 1957).

PHILIP A. IANNA

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U.S. NAVAL OBSERVATORY
FLAGSTAFF STATION

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# REDSHIFTS OF THE QUASI-STELLAR RADIO SOURCES 3C 47 AND 3C 147

The purpose of this letter is to communicate the identifications of the radio sources 3C 47 and 3C 147 as quasi-stellar objects with large redshifts. The positions of the radio sources given in Table 1 were determined in the course of an extensive program of

TABLE 1

OBSERVED DATA FOR 3C 47 AND 3C 147

| Source | $\alpha(1950)$ | $\delta(1950)$ | $S$(400 Mc/s) $10^{-26}$ Wm$^{-2}$ (c/s)$^{-1}$ | $n$ |
|---|---|---|---|---|
| 3C 47: | | | | |
| Radio | $01^h33^m40\overset{s}{.}6\pm1\overset{s}{.}0$ | $+20°41'56''\pm8''$ | 12 9±0 5 | −0 89±0 04 |
| Opt. | 01 33 39 8±0 2 | +20 42 11 ±3 | | . |
| 3C 147: | | | | |
| Radio | 05 38 44 1±0 5 | +49 49 39 ±3 | 46 3±2 3 | −0 56±0 06 |
| Opt | 05 38 43 5±0 1 | +49 49 43 ±1 | . | . . |

position determinations carried out with the California Institute of Technology twin interferometer in the Owens Valley. The declinations have been published by Read (1963), the position of the optical object in 3C 147 by Griffin (1963). The table also gives the flux density at 400 Mc/s and the spectral index (Kellermann 1963). Existing interferometric data on 3C 47 (Maltby 1962; Allen, Anderson, Conway, Palmer, Reddish, and Rosen 1962) show that it may have a halo of 2′ in diameter containing 75 per cent of the flux and a core of 4″ diameter. Alternatively, the source may be a double with a component separation of about 70″. The source 3C 147 is probably a double with separation $2\overset{''}{.}4$, each component being smaller than 1″, but a possible alternative is an elliptical distribution with axes of $1\overset{''}{.}9$ by less than 1″ (Rowson 1963).

The position of the radio source 3C 47 practically coincides with that of a starlike object of visual magnitude 18; this object is notably blue on the plates of the National Geographic Society–Palomar Observatory Sky Survey. Spectra taken with the prime-focus spectrograph of the 200-inch telescope with a dispersion of 400 Å/mm in November, 1963, showed emission lines at λλ 3986, 4885, and 5510. These wavelengths could be represented to within a few Ångstroms (Table 2) on the assumption that they are

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lines of Mg II, [Ne V], and [Ne III], with a redshift $z = (\lambda - \lambda_0)/\lambda_0$ of 0.425. On this basis the $N_1$ line of [O III] would be expected at 7135 Å. Two spectra taken on 103a-U plates in December, 1963, did show the line at 7136 Å, as well as the fainter $N_2$ line of [O III]. The fact that Hβ was not detected must be due to the low speed of both F and U plates at the wavelength of interest. A broad band of emission observed around 6200 Å is a blend of Hγ and the λ 4363 line of [O III]. The widths of the other lines are about 20 Å. The λ 3727 line of [O II] is quite weak. The λ 3346 line of [Ne V], which should be about three times fainter than the one at λ 3426, is suspected on one of the plates. The λ 3968 line of [Ne III] is seen quite weakly, as expected; its wavelength has not been measured.

With a Hubble constant H of 100 km/sec per Mpc the nominal distance $czH^{-1}$ of 3C 47 becomes 1275 Mpc, and its absolute visual magnitude about −23. This object clearly belongs to the class of *quasi-stellar radio sources*, such as 3C 273 (Schmidt 1963) and 3C 48 (Greenstein and Matthews 1963). These objects of stellar appearance have optical luminosities considerably larger than those of the brightest galaxies.

TABLE 2

WAVELENGTHS AND IDENTIFICATIONS OF EMISSION LINES IN 3C 47

| λ | Identif | $\lambda_0$ | 1 425 $\lambda_0$ |
|---|---|---|---|
| 3986 | Mg II | 2798 | 3987 |
| 4885 | [Ne V] | 3426 | 4882 |
| 5310 | [O II] | 3727 | 5312 |
| 5510 | [Ne III] | 3869 | 5513 |
| 6200 | Hγ, [O III] | 4340, 4363 | 6185, 6217 |
| 7072 | [O III] | 4959 | 7066 |
| 7136 | [O III] | 5007 | 7135 |

The position of the radio source 3C 147 is close to that of a compact group of three faint stars, of visual magnitudes about 18, 19, and 20. At first the twentieth-magnitude object was suspected to be a galaxy related with the radio source. A spectrum in the blue with the slit across it and the eighteenth-magnitude object taken in October, 1962, showed no emission lines in the fainter object. The spectrum of the brighter object appeared to have unusually high brightness in the ultraviolet relative to that in the blue. Spectra taken subsequently in the visual region showed several emission features near 5800 Å. The first spectra seemed to indicate that the emission features were variable in wavelength and intensity; as a consequence, a considerable number of spectra, mostly with a dispersion of 400 Å/mm, was taken of this object. The weak, low-contrast emission features are determined by a small number of grains in the unwidened spectra. Some of the weak emission lines originally suspected have not been found on subsequent plates and most probably do not exist. Variability in the lines that do exist has not been confirmed.

Two emission lines exist without any doubt. Their observed wavelengths are 5760 and 5976 Å. The width of the lines is about 30 Å. All individual measures of wavelengths are given in Table 3. There are two values of the redshift $z$ for which these two lines can be identified with emission lines often seen in planetary nebulae, radio galaxies, and quasi-stellar objects. If $z = 0.229$ the lines would be identified with the λ 4686 line of He II and Hβ, respectively. The intensity ratio of the lines does not favor this explanation: the line at 5760 Å is two to three times stronger than the one at 5976 Å; however, the He II line is usually much fainter, and never brighter, than Hβ in planetary nebulae. All available spectra were searched for other lines at the wavelengths predicted on the

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basis of the above redshift. None were found, notably not those of [O III] and [Ne V] that are always seen in high-excitation planetaries and radio galaxies that show the He II line. The combined evidence makes the above value for the redshift quite unattractive.

The alternate value of the redshift is 0.545, on which basis the two lines are identified with the λ 3727 line of [O II] and the λ 3869 line of [Ne III], respectively. A search for other lines to be expected on the basis of this redshift was moderately successful. The λ 3968 line of [Ne III] could be found near 6130 Å on four exposures. Individually uncertain measurements were made of an emission feature near 5290 Å on four plates, and of a feature near 4840 Å on two plates (cf. Table 3). The wavelengths of these emissions correspond closely to that of the λ 3426 line of [Ne V] and that of the λ 3133 line of O III, respectively. Although the reality of these emissions on each individual plate is uncertain, the small range in measured wavelengths and the fact that the five features

TABLE 3

INDIVIDUALLY MEASURED WAVELENGTHS AND IDENTIFICATIONS OF EMISSION LINES IN 3C 147

| Plate No | Wavelength (Å) | | | | |
|---|---|---|---|---|---|
| N 1818(1) | | 5291: | 5760 | 5976 | |
| (2) | | | 5762: | 5981: | |
| 1852 | . . | | 5754: | 5980: | |
| 1854(1) | 4843: | .... | 5758 | 5972: | ... |
| (2) | 4836 | 5287 | 5755 | 5975 | 6127 |
| (3) | | | 5762 | ... | |
| 1856 | | | 5759 | 5976 | . |
| 1858 | | . | 5762 | 5975 | 6126: |
| 1860 | | 5288: | 5763 | 5970 | |
| 1879 | | ... | 5757 | ... | .. |
| 1882 | | 5296: | 5762 | 5976 | 6136 |
| 2132 | | | 5761 | 5978 | 6137 |
| Mean λ | 4839: | 5290: | 5760 | 5976 | 6132 |
| Identif. | O III | [Ne V] | [O II] | [Ne III] | [Ne III] |
| $\lambda_0$ | 3133 | 3426 | 3727 | 3869 | 3968 |
| 1 545 $\lambda_0$ | 4840 | 5293 | 5759 | 5977 | 6130 |

detected are those that are strongest in the relevant range of wavelengths in the planetary nebula NGC 7027 (Aller, Bowen, and Wilson 1963) leave little doubt that the redshift $z = 0.545$ is indeed correct. This redshift is the largest one determined so far, exceeding that of 3C 295 (0.461, Minkowski 1960) by about 20 per cent. The corresponding nominal distance $czH^{-1}$ of 1635 Mpc yields an absolute visual magnitude of about $-25$, where we have corrected for about 1 magnitude absorption in the Galaxy (Sandage 1964).

Redshifts are now available for four quasi-stellar radio sources. The main results are collected in Table 4. The "size" given is the separation of the two components of the radio source on the assumption that it is indeed double. The radio luminosities have been computed by integration of the power law for the flux density to an assumed emitted frequency of $10^{11}$ c/s. The lower emitted cutoff frequency was assumed to be $10^7$ c/s unless stated otherwise in Table 4. The major uncertainty in the calculated radio luminosities comes from the uncertainty in the upper cutoff frequencies. Both luminosities and linear sizes have been computed on the basis of an evolving world model with zero cosmological constant and deceleration parameter $q_0 = 0$ (Sandage 1961).

All four sources are seen to have very large radio luminosities, of the same order as that of the most powerful radio galaxies Cyg A, Her A, and 3C 295. The quasi-stellar

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source 3C 147 has the largest radio luminosity, $2 \times 10^{45}$ erg/sec, equal to that of the intrinsically brightest radio galaxy, 3C 295. The radio spectrum of 3C 147 shows marked curvature at the low-frequency end (Conway, Kellermann, and Long 1963). The total optical luminosities of the objects depend to a large extent on the bolometric correction. They probably range roughly from $10^{45}$ to $10^{46}$ erg/sec, and are for each source larger than the radio luminosity. Sandage has measured the colors of all these objects and will discuss them shortly.

The source 3C 47 is the weakest member of the group, both in radio output and in optical luminosity; it also has the largest radio size and might be the oldest member of the group. In addition it has a straight spectrum at low frequencies, unlike the other quasi-stellar sources. The optical flux for 3C 47 falls on or above a straight-line extrapolation of the unusually steep radio spectrum. This is quite different from the other quasi-stellar objects for which the optical flux is well below the straight-line extrapolation (Matthews and Sandage 1963).

TABLE 4

DATA FOR FOUR QUASI-STELLAR RADIO SOURCES WITH KNOWN REDSHIFTS

| Source | $z$ | $M_v$ | $L$ (Radio)* (erg/sec) | "Size" (Radio) (kpc) |
|---|---|---|---|---|
| 3C 47 | 0 425 | −23 | 1 $5\times10^{44}$ | 250 |
| 3C 48. | 367 | −25 | 4 $7\times10^{44}$ | < 3 |
| 3C 147 | 545 | −25 | 2 $0\times10^{45}$ | 10 |
| 3C 273 | 0 158 | −26 | 3 $1\times10^{44}$ | 40 |

* Computed by integration between emitted frequencies of $10^7$ c/s and $10^{11}$ c/s, except for the following lower limits of observed frequency: $10^8$ c/s for 3C 48, $5 \times 10^7$ c/s for 3C 147, $10^9$ c/s for component B of 3C 273

The optical spectra of these four quasi-stellar objects vary more among themselves than those of radio galaxies (Schmidt 1964). The λ 3727 line of [O II] is prominent in 3C 48 and 3C 147, weak in 3C 47, probably absent in 3C 273. The λ 2798 doublet of Mg II first found in 3C 273 is also prominent in 3C 48, clearly present in 3C 47, but weak or absent in 3C 147. These differences are presumably due to variations in ionization, excitation, electron temperature and density (Greenstein and Schmidt 1964). A practical consequence is that the redshift of a quasi-stellar object cannot be determined with reasonable certainty from a single emission line only. For that reason an attempt by Shklovsky (1963) to determine the redshift of the quasi-stellar radio source 3C 286 from a single emission line (Schmidt 1962) must be considered premature until at least one other emission feature has been detected and identified.

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MAARTEN SCHMIDT
THOMAS A. MATTHEWS

February 28, 1964
MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY
AND
OWENS VALLEY RADIO OBSERVATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

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