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SPECTROSCOPY OF THE FUZZ ASSOCIATED WITH FOUR QUASARS

BRUCE BALICK[1]
University of Washington
AND
T. M. HECKMAN[1]
University of Maryland

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ABSTRACT

The spectroscopic properties of the "fuzz" near four quasars are consistent with starlight in a galactic environment at essentially the same redshift as the quasar. Apparently, then, the same processes that determine the redshifts of galaxies also determine the redshifts of quasars.

Subject headings: quasars — galaxies: redshifts — galaxies: stellar content

I. INTRODUCTION

After several decades, observations are beginning to place constraints on the nature of redshifts and the putative domiciles of quasars. The appearances, luminosities, and even colors of the fuzz surrounding several quasars are consistent with the speculation that quasars are associated with host galaxies at the distances implied by the redshifts of the quasar (Hutchings *et al.* 1981; Hutchings, Campbell, and Crampton 1982; Hutchings *et al.* 1982; Wyckoff, Wehinger, and Gehren 1981; Wyckoff *et al.* 1980; Stockton 1982). In one example at very low redshift ($z = 0.036$), Bothun *et al.* (1982*a*, *b*) and Hutchings, Campbell, and Crampton (1982) describe the environment of the quasar in considerable detail, including the detection of H I emission at the same redshift as the "quasar." Boroson and Oke (1982) have reported the detection of Balmer absorption lines in the fuzz of, and at the same redshift as, the QSO 3C 48. Searches for stellar absorption features in additional quasars could further elucidate the relationship between quasars and their hosts and, perhaps, indicate whether and how quasars and active galactic nuclei (e.g., Seyfert galaxies) are related.

We report here spectral features detected in the fuzz of four probable quasars spanning $0.036 \leqslant z \leqslant 0.37$. Until very recent deep images of these objects became available, these objects had (or would have) been classified as quasars according to conventional criteria. The goals of the program are to (1) determine the spectroscopic character (e.g., starlight) of the fuzz, (2) search for differences between the redshifts of the quasar and fuzz, and (3) investigate whether there are major and substantive differences in the conditions attending the presence of quasars and the "ordinary" active nuclei of nearby galaxies. Here we present first results from a successful exploratory survey.

II. OBSERVATIONS

The observations were conducted on 1981 December 26–27 using the Cryogenic Camera on the 4 m telescope of the KPNO. The first night was mostly cloudy, and the second night was clear. The seeing was $\sim 2''.5$ (FWHM) throughout the run. The Cryogenic Camera uses a cooled tensor interaction (TI) 800×800 chip behind a transmission grating prism in the 4 m Ritchey-Chrêtien spectrograph. A 3″ wide slit was used ahead of the transmission grating prism, and each pixel at the CCD spans $0''.8$ along the slit and 4.17 Å in the dispersion direction. The intrinsic resolution of the transmission grating prism spectrograph is nominally 15 Å. Because of this and the ~ 3 pixel seeing, most of the data from the CCD were convolved with a 3×3 pixel smoothing function in order to minimize pixel noise without appreciably degrading the spatial or spectral resolution of the data.

Observing and data calibration techniques followed standard procedures at KPNO. Multiple 30 minute exposures were obtained for each object. The redundancy of these exposures is used to identify and remove events caused by cosmic rays. In exposures of this length, bright sky emission lines (but not nuclear emission lines) saturate the detector. Additional details of the instrument and calibration procedures will appear in a subsequent paper.

The TI chip has an undulating (wrinkled) front surface. Consequently, an image cannot be projected onto the chip with uniform resolution, and night-sky

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[1] Guest Observer at Kitt Peak National Observatory (KPNO). The KPNO is operated by Associated Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

features measured at some point along the slit could not be removed at other points along the slit without the appearance of large residuals. A further associated problem is that the dispersion and point-spread function vary with chip position on characteristic scales of a few hundred pixels. For this reason no attempt was made to correct for scattered nuclear light from the off-nuclear spectra. Because of these problems and the fact that this exploratory run was very brief, a quantitative analysis of the present data is not warranted.

III. RESULTS AND DISCUSSION

In the remainder of this *Letter*, all wavelengths refer to $\lambda(1 + z)$, where z is the emission-line redshift of the nucleus unless noted otherwise. We further abbreviate north, south, east, and west as N, S, E, and W respectively. Position angles (P.A.) are measured eastward from north. The results for individual quasars are presented next, ordered by increasing redshifts.

0351+026 (z = 0.036).—Like many other quasars, 0351+026 was first discovered as a serendipitous X-ray source. It may also be described as a system of violently interacting low-luminosity ($M_B \lesssim -18$) galaxies with one very active member (Bothun *et al.* 1982*a*).[2] Spectra in the vicinity of 0351+026 and its companion galaxy ~ 13″ to the south are shown in Figure 1. (See also Bothun *et al.* 1982*a*; Hutchings, Campbell, and Crampton 1982. The extranuclear emission lines in this system evident in Fig. 1 are described in the former reference.) The only absorption line observed in the host galaxy of the QSO is at about 5900 Å, or within 500 km s^{-1} of the expected position of the Na I D line. The signal-to-noise ratios of the data do not allow a discrimination of a stellar or interstellar origin for the line. No other statistically significant absorption lines appear in the spectrum of the host galaxy.

Two statistically significant absorption features appear in the spectrum of the companion galaxy centered ~ 13″ S of the quasar. One line centroid is at about 4853 Å. It is tempting to identify this line as a stellar absorption line of Hβ. No Hα counterpart to the absorption line is observed; however, the strengths of stellar Balmer absorption relative to nebular Balmer emission lines is much less at Hα than at Hβ, so the Hα absorption line may be "filled-in" by Hα emission. The second line lies at 5040 Å and has no obvious identification in the rest frame of the nucleus. Unlike the Hβ line which is strongest at the nucleus of the companion, the λ5040 feature is strongest ~ 8″ S of the companion. Better data are essential to confirm the reality of both absorption features.

1059+730 (z = 0.089).—Like 0351+026 and 0845+378, attention was first drawn to 1059+730 because of its identification as a serendipitously discovered X-ray source (Chanan, Margon, and Downes 1981). The slit of the Cryogenic Camera was oriented along the major axis of the fuzz (Hutchings *et al.* 1982). Along this axis, the fuzz has an extent of 10″ from both sides of the nucleus. The spectra obtained at the nucleus and at offsets of ±2″.4 and ±4″.8 are shown in Figure 2.

A wide variety of absorption lines can be seen in all five spectra. These lines can be identified with the features of early K stellar spectral types (Pritchet and van den Bergh 1977). The relative line intensities resemble those seen in early-type galactic nuclei (Heckman, Balick, and Crane 1980) as well as four elliptical galaxies and some of the BL Lac objects reported by Miller (1981). The number of identified lines and their center wavelengths leave no room for doubt that the fuzz of this quasar consists of relatively late-type stars at the same redshift as the nuclear emission lines (i.e., the quasar).

Small but significant velocity differences as large as 500 km s^{-1} can be noted among the spectra in Fig. 2. The pattern of velocity offsets is consistent with, among other possibilities, an overall rotational pattern. The pattern is seen in all of the stronger absorption lines but not in the emission lines (these differences between the kinematics of absorption and emission lines can be entirely explained by the effects of seeing if, as the spectra suggest, the emission lines are entirely nuclear in origin). Rapid rotation of the stellar population is a characteristic of disk, but not elliptical, galaxies. The highly flattened morphology of the fuzz is further evidence that the host of 1059+73 is a disk galaxy.

0845+378 (z = 0.307).—This object was also first identified because of its X-ray emission, and its properties are typical of the other quasars discovered in this manner by Chanan, Margon, and Downes (1981). The deep image of 0845+378 published by Hutchings *et al.* (1982) shows the fuzz to have circular symmetry extending to at least 5″ (12 kpc).

The slit of the Cryogenic Camera was oriented at P.A. = 21° in order to include the nucleus of 0845+378 and a faint, peculiar looking, compact object 6″ SSW of the nucleus (no usable data were obtained on the latter object). Spectra obtained on the nucleus and at offsets of ±2″.4 along the slit are shown in Figure 3. As in the case of 1059+730, these spectra are averages over regions 2″.4 × 3″.0 on the sky with 15 Å resolution (FWHM) in wavelength. At a redshift of 0.307, many of the strongest stellar features are lost irretrievably in bright night sky lines. For example, the relatively strong absorption feature of Fe I + Ca I (λ = 5270) falls at the same observed wavelength as the atmospheric *B* absorp-

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[2] We note, however, that the redshift-corrected ratio of quasar-to-fuzz luminosity in 0351+026 is typical of the ratios found for much higher redshift QSOs by Hutchings, Campbell, and Crampton (1982): 0.4 for 0351+026 versus an average of 0.7 for the 24 higher z QSOs. Therefore, we refer to 0351+026 as a QSO.

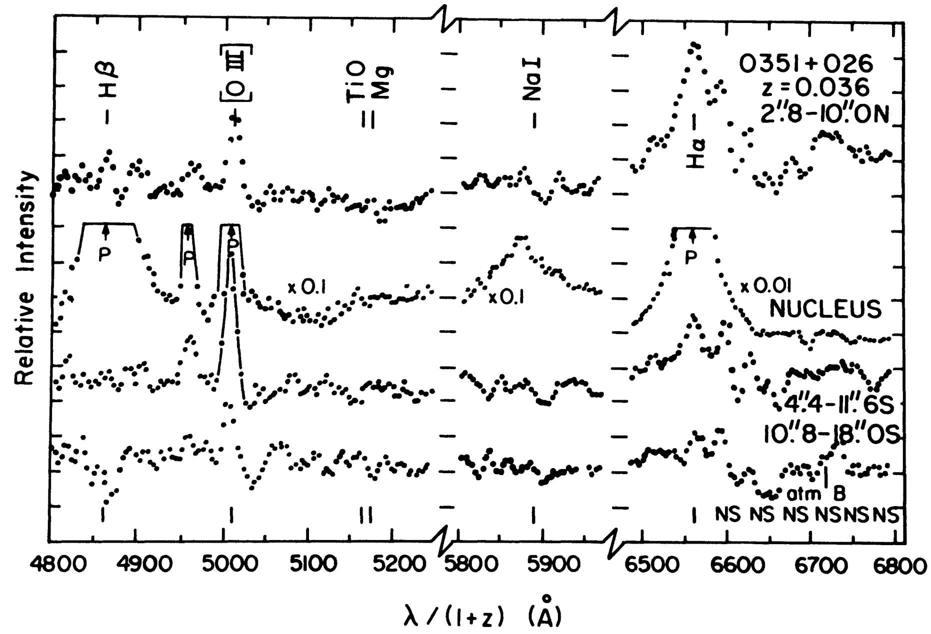

FIG. 1.—Selected portions of the spectra obtained for 0351+026 through apertures of effective size 7".2 along and 3".0 across the slit. The apertures are centered at the nucleus and at offsets 6".4 N, 8".0 S, and 14".4 S of the nucleus along the slit in P.A. = 4°. The wavelength scale is in the rest frame of the quasar's emission lines, and the instrumental resolution is ~ 15 Å (see text for details). The expected positions of various stellar and nebular lines are indicated and identified. The wavelengths of the peaks of truncated lines are shown by a *P*. *NS* and *atm B* stand for night-sky and atmospheric *B* absorption features respectively.

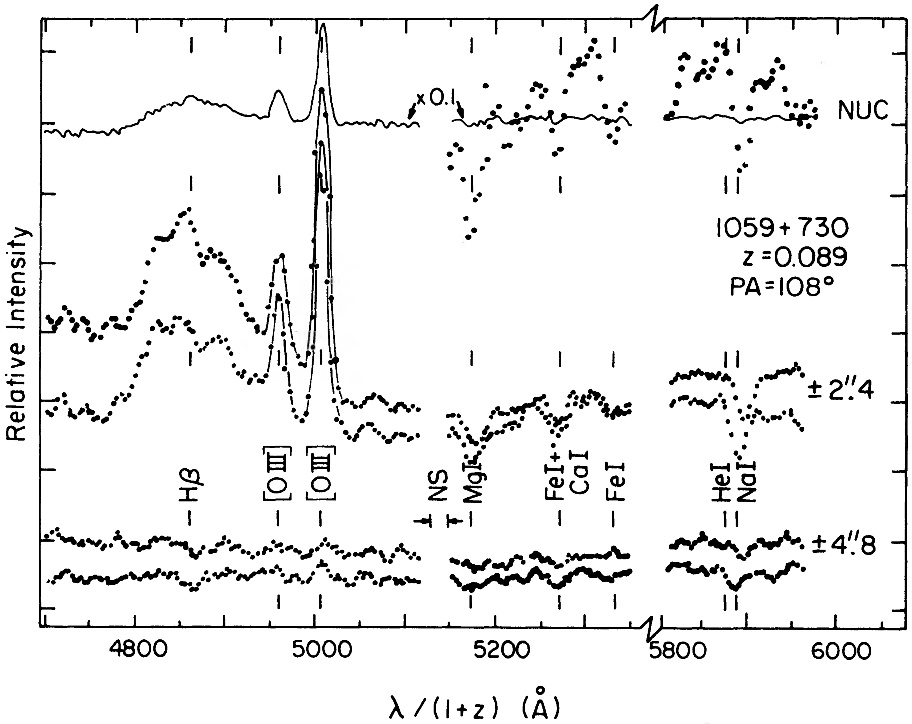

FIG. 2.—Selected portions of the spectra obtained for 1059+730 through apertures of effective size 2".4 along and 3".0 across the slit. The apertures are centered at the nucleus (NUC) and at offset positions ±2".4 and ±4".8 along the slit in P.A. = 108°. See legend of Fig. 1 for further details.

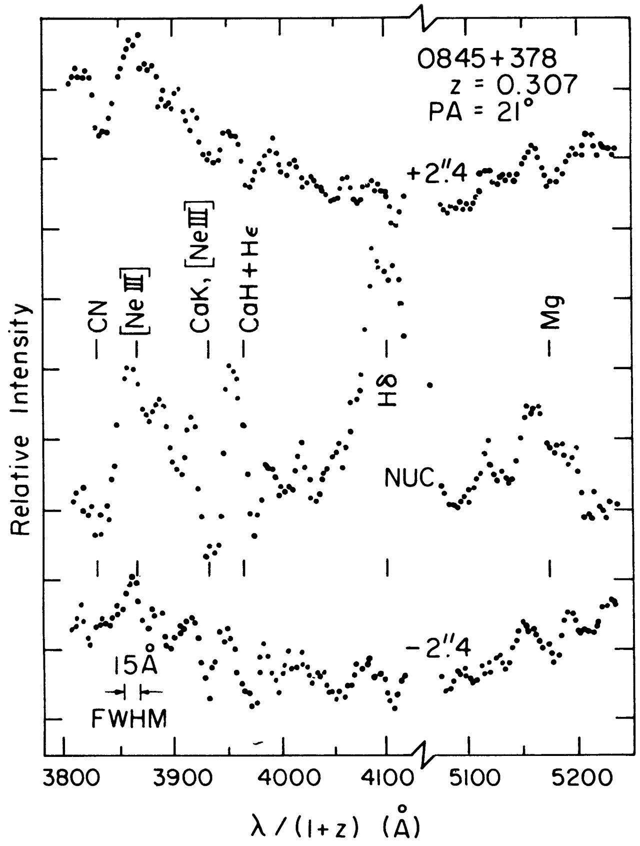

FIG. 3.—Like Fig. 2 for 0845+378 at aperture positions centered at the nucleus and at offsets of ±2″.4 in P.A. = 21°.

tion band, the Na I D line is blended with bright atmospheric emission lines of OH, and the *G* band lies on the shoulder of the heavily saturated λ5577 night-sky line.

Figure 3 shows a variety of statistically significant features in the spectrum of 0845+378: Ca II H and K and CN λ3830 at all three positions and Mg I λ5174 at the offset positions (Mg I λ5174 is probably confused with Fe II emission lines at the nuclear position). There may be doubts whether those features at the expected wavelengths of stellar absorption lines are real or gaps between emission lines. Therefore, we have scaled the nuclear spectrum by an *ad hoc* but smoothly varying function of wavelength and subtracted this spectrum from the offset spectra shown in Fig. 3. Scaling was chosen in order to minimize the intensities of emission lines in the residuals. The resulting spectra are of sufficient quality to demonstrate that the absorption features in the offset position are not gaps between nuclear emission lines. Further, the equivalent widths of the residual absorption lines are larger at the offset positions than at the nucleus (by ~ 50%), presumably reflecting the presence of a featureless nuclear continuum. Hence, these lines are probably stellar rather than interstellar in origin. We conclude that the fuzz around the QSO 0845+378 is starlight at essentially the same redshift as the quasar.

3C 48 (z = 0.368).—Although designated a quasar, it has long been known that 3C 48 is associated with nebulosity elongated N/S and extending some 10″ (Mathews and Sandage 1963; Sandage and Miller 1966; Kristian 1973). Spectroscopic observations demonstrated the presence of strong emission lines in the region 4″ to the N, and only weak continuum emission in the region 4″ to the S (Wampler *et al.* 1975). Boroson and Oke (1982) have recently detected stellar absorption features from regions 2″ N and S of the quasar.

We report here the detection of stellar absorption lines from a region 5″ to the S, but not from the corresponding region 5″ to the N. Qualitatively, the spectrum of this southern nebulosity strongly resembles the early-type absorption spectrum of the near-in regions as studied by Boroson and Oke (1982). Features in the spectrum can be identified with absorption lines of Hε, H8, and H9 corresponding to $z = 0.370 \pm 0.001$.

In agreement with Wampler *et al.* (1975), we find a region of spatially extended emission-line gas at ~ 5″ N, but *not* at 5″ S. The lines emitted in this northern nebulosity differ in both redshift (0.370 vs. 0.368) and width (≈ 15 Å vs. 40 Å) compared with the corresponding nuclear lines.

The distinction between the nebulosity to the N (emission lines only) and to the S (continuum only) is substantiated by unpublished video camera images, one in the light of [O III] λ5007 and one of the continuum. These data indicate that the southern nebulosity is actually a distinct "blob" with $M_v \sim -21$ (for $H_0 = 50$, $q_0 = 1/2$), some 2 mag fainter than the fuzz which surrounds 3C 48 (Boroson and Oke 1982).

To summarize, there are apparently three distinct components to the 3C 48 nebulosity: (1) a region of emission-line gas centered ~ 4″ N of 3C 48 (Wampler *et al.* 1975; this *Letter*); (2) a region of early-type stars located ~ 5″ S of 3C 48 (this *Letter*); and (3) a region of early-type stars of total extent ~ 4″–5″ centered on 3C 48 (Boroson and Oke 1982).

We would identify these three components with: (1) the type of extended emission-line nebulosity frequently associated with quasars and active galaxies (cf. Balick and Heckman 1982); (2) a companion galaxy with a hot (A-type) stellar population; and (3) the "host" galaxy of 3C 48, also apparently dominated by an A type population.

The resemblance between 3C 48 and 0351+026 (this *Letter*; Bothun *et al.* 1982*a*, *b*) is striking.

IV. GENERAL REMARKS AND CONCLUSIONS

It now appears clear that at least some (and probably all) low-redshift quasars are imbedded in fuzz whose size, morphology, absolute magnitude, and spectroscopic character are those of a galaxy. Thus, it seems virtually certain that quasars are the active nuclei of galaxies. Of course, this by itself is not a guarantee that quasars are at their cosmological distances. It does however eliminate that class of model in which anomalous redshifts arise only under the peculiar physical conditions at the site of the activity. If the redshift has a noncosmological origin, then fundamental and unknown physical laws must operate on a transgalactic scale (affecting companion galaxies as well as the host itself). Such an interpretation has been championed by Arp (1982).

Future work in the vein of this *Letter* should (in our view) concentrate on how the quasar phenomenon is triggered and sustained. Deep CCD imaging coupled with detailed spectroscopic investigation of a representative sample of quasars may allow us to move beyond the demonstration that quasars are imbedded in galaxies to the determination of what kind of galaxy is best at fostering a quasar in its nucleus.

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REFERENCES

Arp. H. C. 1982, *Ap. J.*, **256**, 54.
Balick, B., and Heckman, T. M. 1982, *Ann. Rev. Astr. Ap.*, in press.
Boroson, T. A., and Oke, J. B. 1982, *Nature*, **296**, 397.
Bothun, G. D., Mould, J., Heckman, T. M., Balick, B., Schommer, R. A., and Kristian, J. 1982*a*, preprint.
Bothun, G. D., Romanishin, W., Margon, B., Schommer, R. A., Chanan, G. A. 1982*b*, *Ap. J.*, **257**, 40.
Chanan, G. A., Margon, G., and Downes, R. A. 1981, *Ap. J.* (*Letters*), **243**, L5.
Heckman, T. M., Balick, B., and Crane, P. C. 1980, *Astr. Ap., Suppl.*, **40**, 295.
Hutchings, J. B., Campbell, B., and Crampton, D. 1982, *Ap. J.* (*Letters*), **261**, L23.
Hutchings, J. B., Crampton, D., Campbell, B., Gower, A. C., and Morris, S. C. 1982, *Ap. J.*, **262**, 48.
Hutchings, J. B., Crampton, D., Campbell, B., and Pritchet, C. 1981, *Ap. J.*, **247**, 743.
Kristian, J. 1973, *Ap. J.* (*Letters*), **179**, L61.
Mathews, T. A., and Sandage, A. R. 1963, *Ap. J.*, **138**, 30.
Miller, J. S. 1981, *Pub. A.S.P.*, **93**, 681.
Pritchet, C., and van den Bergh, S. 1977, *Ap. J.* (*Suppl.*), **34**, 101.
Sandage, A. R., and Miller, W. C. 1966, *Ap. J.*, **144**, 1238.
Stockton, A. 1982, preprint.
Wampler, E. J., Robinson, L. B., Burbidge, E. M., and Baldwin, J. A. 1975, *Ap. J.* (*Letters*), **198**, L49.
Wyckoff, S., Wehinger, P. A., and Gehren, T. 1981, *Ap. J.*, **247**, 750.
Wyckoff, S., Wehinger, P. A., Spinrad, H., and Boksenberg, A. 1980, *Ap. J.*, **240**, 25.

BRUCE BALICK: Astronomy Department, FM-20, University of Washington, Seattle, WA 98195

TIMOTHY HECKMAN: Astronomy Program, University of Maryland, College Park, MD 20742