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DISCOVERY OF A NARROW LINE QUASAR

JOHN STOCKE AND JAMES LIEBERT
Steward Observatory, University of Arizona

AND

T. MACCACARO,[1] R. E. GRIFFITHS, AND J. E. STEINER[2]
Harvard-Smithsonian Center for Astrophysics
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ABSTRACT

We report the discovery of a stellar object with $z = 0.338$ and X-ray and optical luminosities typical of quasars but which has only narrow permitted and forbidden emission lines over the observed spectral range. The permitted (H) line full widths at half maxima are ~ 600 km s^{-1}, significantly larger than the forbidden [O III] values of ~ 400 km s^{-1}, but quite small compared with known quasars. The narrow line spectrum is high excitation ($T_{\rm eff} \sim 48{,}000$ K in the low density limit) and the Balmer lines appear recombinational. The object shows a steeper (redder) optical continuum than most quasars, but it is detected as only a weak radio source.

The object is X-ray selected, but it does not conform to relationships between Hβ parameters and X-ray flux previously claimed for a large sample of active galactic nuclei. We argue that any other "reddish" quasars with narrow lines like this one may not be found by the standard techniques for discovering quasars. Therefore, this object could be a prototype for a new class of quasar analogous to high luminosity Seyfert type 2 galaxies. But if such a class of objects exists, it cannot comprise more than $\sim 10\%$ of all quasars.

Subject headings: galaxies: Seyfert — quasars — X-rays: sources

I. INTRODUCTION

A stellar object with narrow permitted and forbidden emission lines redshifted to $z = 0.338$ has been discovered as part of an ongoing program to optically identify X-ray sources discovered in the *Einstein* Observatory "Medium Sensitivity Survey" (Maccacaro *et al.* 1981). The object marked in the finding chart (Fig. 1) and designated 1E 0449 − 184 is completely stellar on both the blue and red Palomar Sky Survey (PSS) plates, thus fitting the accepted morphological definition of a quasar (QSO). However, we are unaware of any previously discovered quasars with Balmer emission lines as narrow as those we report here. Likewise, the optical and X-ray luminosities exceed those of type 2 Seyfert galaxies, a class of objects with similar spectra. It lacks the radio and optical morphology of emission-line radio galaxies. Finally, it differs decisively from the so-called Sargent-Searle "extra-galactic H II regions" in its luminosity, emission-line excitation, and nonthermal continuum (Downes and Margon 1981).

In § II, we discuss the X-ray identification, the optical observations, and a VLA radio detection of the object. In both §§ II and III, we evaluate its relationship to quasars, active galactic nuclei (AGNs), and the X-ray background; in § IV, we discuss the potential difficulties with finding other such objects using standard optical and radio survey techniques.

II. OBSERVATIONAL RESULTS

a) The X-ray Identification

The Medium Sensitivity Survey (Maccacaro *et al.* 1981) consists of ~ 63 "serendipitous" X-ray sources found in Imaging Proportional Counter (IPC) fields at high galactic latitude ($|b_{\rm II}| > 20°$). These sources range in flux between 5×10^{-12} and 7×10^{-14} ergs s^{-1} cm^{-2} between 0.3–3.5 keV. Based upon optical identifications for 80% of the sample, the final composition is expected to include: quasars and distant Seyfert galaxies (AGNs) (60%), clusters and groups of galaxies (15%), "normal" galaxies (3%), and galactic stars (22%).

The identified optical counterpart to the source 1E 0449 − 184 is located 25 arcsec west of the X-ray position, well within the 1 arcmin, 90% confidence circle typical of the IPC nearly on axis (see Fig. 1). The only other object visible on the PSS within the 90% confidence circle lies 30 arcsec to the north and has been identified spectroscopically as a G star. This G star is much too faint to be the X-ray source: the X-ray flux would require it to have an X-ray–to–optical flux ratio $(f_x/f_v) \sim 1$, two to three orders of magnitude too large for the spectral type (Vaiana *et al.* 1981). Thus, we are confident that our identification of the object in Figure 1 as the X-ray source is correct.

[1] Also from the Istituto di Radiostronomia, CNR, Bologna, Italy.
[2] Visiting Astronomer, Cerro Tololo Inter-American Observatory, which is operated by the Association of the Universities for Research in Astronomy, Inc., under contract with the National Science Foundation. On leave from AIAG-Universidade de Sao Paulo, C.P. 30627, San Paulo, Brazil.

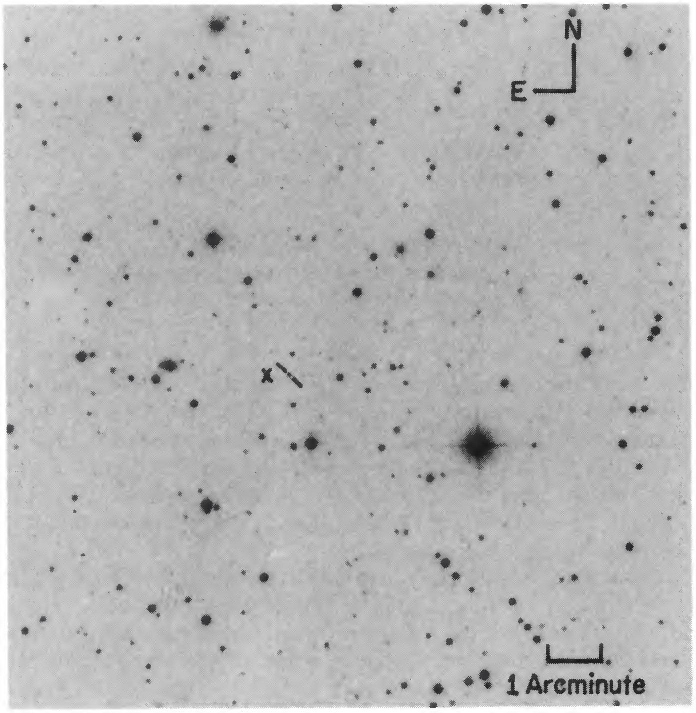

FIG. 1.—The field of 1E 0449 − 184. The cross indicates the centroid position of the IPC 60″ error circle (90% confidence) at position $\alpha = 04^h49^m26^s.3$, $\delta = -18°23'55''.0$ (epoch 1950.0). The quasar is between the tick marks. The bright star is SAO 149936.

The X-ray luminosity of this object is very high: log $L_x = 44.7$ ergs s^{-1} in the 0.3–3.5 keV IPC band ($H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$). This is two orders of magnitude brighter than Seyfert type 2 galaxies, higher than all but a few Seyfert type galaxies, but it is typical of low redshift quasars (Kriss, Canizares, and Ricker 1980; Grindlay *et al.* 1980; Chanan, Margon, and Downes 1981).

b) Optical Observations

In a deeper photograph of this field taken through "Gunn R" (Thuan and Gunn 1976) with a SIT vidicon system on the Palomar 1.5 m telescope, 1E 0449 − 184 appears extended 13 arcsec in the north-south direction (Green and Yee 1981), typical for quasars at this redshift (Wyckoff, and Wehinger, and Gehren 1981).

The spectrum of the quasar shown in Figure 2 was taken with the Steward Observatory 2.3 m telescope and intensified reticon spectrograph using a 600 lines mm^{-1} grating blazed at Hα yielding ~ 15 Å resolution. The observations were made through 2.5 arcsec holes during 1.5 arcsec seeing conditions. A second spectrum of 1E 0449 − 184 was taken at more favorable air mass through 2 arcsec apertures with the CTIO 4 m and SIT vidicon spectrograph. Attention is drawn to the narrowness (all lines unresolved at this resolution) of both the permitted and forbidden emission lines, the usually strong [O III] λ4363 blended with Hγ, the high excitation He II and Ne V features and the possible weak presence of the ultraviolet bump ($\lambda_0 \lesssim 3800$ Å). There is, however, no clear evidence for Fe II or other low excitation lines often seen in quasars and Seyfert type 1 galaxies. While there is no obvious broad component to Hβ in this spectrum, we cannot rule out a broad component with luminosity less than half the narrow line luminosity. Such a weak, broad component has been found in very high signal-to-noise spectra of X-ray emitting narrow line galaxies (Phillips 1979; Veron *et al.* 1980) and is generally strongest at Hα, a line shifted too far into the infrared for us to observe. Indeed, a weak, broad (FWZI ~ 6000 km s^{-1}) feature may be present at Hβ in our higher resolution spectrum shown in Figure 3. Thus, the spectrum resembles a Seyfert type 2 galaxy (or Seyfert type 1.9 galaxy in the Lick classification scheme; Osterbrock 1981), but at much higher optical and X-ray luminosities as described below. The continuum shows no evidence for an underlying galaxy absorption spectrum out to $\lambda_0 \sim 5300$ Å.

The line ratios and the Hβ flux are shown in Table 1. The redshift from the [O III] and hydrogen emission lines is $z = 0.3376 \pm 0.003$. The relative strengths of Hβ and Hγ are close to that expected in Case B recombination, suggesting that there is little or no reddening. A higher dispersion spectrum (7 Å resolution) also obtained with the Steward 2.3 m plus reticon spectrograph (Fig. 3) clearly resolves the Hγ and [O III] λ4363 and yields line widths (FWHM) of 630 and 430 km s^{-1} for the permitted and forbidden lines respectively; although these line widths are typical of Seyfert type 2 galaxies and

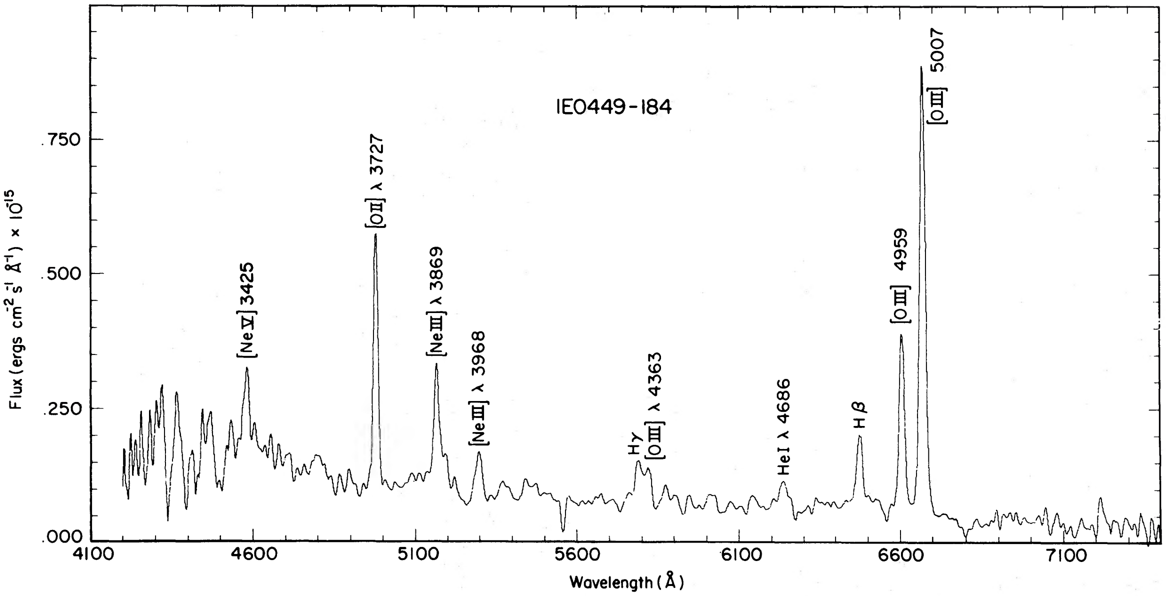

FIG. 2.—A low resolution ($\sim$ 15 Å) spectrum of 1E 0449 – 184. Notice that while a very broad component appears to be present at H_β, such a feature is enhanced by the presence of atmospheric λ6280 and λ6870 " B band " absorption at the extremes of such a feature.

narrow line radio galaxies (Koski 1978), it is atypical for such a large difference to exist between the widths of the permitted and forbidden lines (e.g., Weedman 1977). The ratio of [O III] λ4363 to [O III] λ5007 yields an excitation temperature of 48,000 K in the low density limit. This is as high as the most extreme Seyfert type 2 galaxies yet investigated (Koski 1978; Heckman and Balick 1979).

From the spectrophotometry in Figure 2, we obtain a V magnitude of 18.5 $\pm$ 0.1 which yields log l_0 (2500 Å) = 29.67 ergs s^{-1} Hz^{-1} corrected for galactic absorption (Wills and Lynds 1978). At $M_v = -23.5$, the optical luminosity of 1E 0449 – 184 is well below the mean for the entire Wills-Lynds sample but is typical for quasars in their list with $Z < 0.5$. By fitting a power law ($f_\nu \sim \nu^{-\alpha}$) to the observed continuum between 5400 and 7200 Å where atmospheric dispersion is small (and thus ignoring the ultraviolet bump), we obtain a very steep ($\alpha = 1.7$) slope through the optical. The calculated colors are: $B - V =$

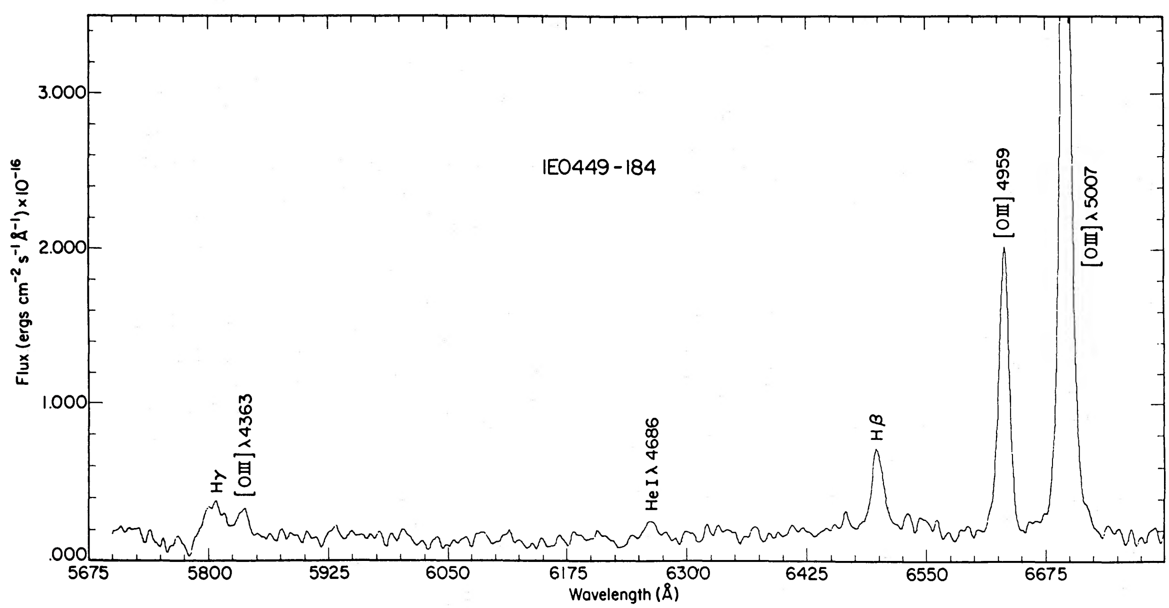

FIG. 3.—A higher resolution ($\sim$ 7 Å) spectrum of the narrow line quasar in the H_β to H_γ region. This spectrum clearly resolves H_γ and O III λ4363 and also shows the difference in equivalent width between the permitted and forbidden emission lines. Note the slight indication of a broad line component to H_β.

TABLE 1

LINE RATIOS AND Hβ FLUX

Line	Strength Relative to Hβ
[Ne v] λ3426	1.1
[O II] λ3727	3.8
[Ne III] λ3869..........	1.7
[Ne III] λ3967..........	0.75
Hγ	0.45
[O III] λ4363...........	0.30
He I λ4686.............	0.20
Hβ (narrow only)[a]	1
[O III] 4959	3.1
[O III] 5007	9.4

[a] Narrow Hβ flux: 2.5×10^{-15} ergs cm^{-2} s^{-1}.

+0.1 and an extrapolated $U - B = -0.2$. The UV bump observed in this object would add 0.2 magnitudes in B and thus could make it appear even redder in $U - B$.

These colors are much redder than most quasars of similar redshift, which typically have $U - B = -0.9$ (Wills and Lynds 1978). Likewise, only three of 84 QSOs whose energy distributions were measured by Richstone and Schmidt (1980) had steeper power-law fits over the range 0.33–1 μ. Generally, the known steep-spectrum quasars and BL Lac objects tend to be strong, variable radio sources, and optically variable and polarized (Stein, O'Dell, and Strittmatter 1976; Angel and Stockman 1980). However, steep power-law continua have also been found for X-ray emitting narrow line Seyfert galaxies. NGC 1068 ($\alpha = 1.8$; Boksenberg *et al.* 1978), NGC 4507 and NGC 5506 ($\alpha = 1.25$; Bergeron, Maccacaro, and Perola 1981), and NGC 7582 ($\alpha = 2.1$; Clavel *et al.* 1981) are the only narrow line Seyfert galaxies observed with *IUE* so far. In three of four cases, the UV spectra of these objects are dominated by narrow emission lines up to and including Lyα. The UV spectrum of NGC 7582 is featureless and highly reddened. If Mg II is weak and/or narrow in IE 0449 − 184—as it is in these Seyfert type 2 galaxies—it will contribute negligibly to $U - B$. Even if Mg II were as strong as in typical broad line quasars, the contribution is < 0.1 magnitude in $U - B$ (see Schmidt 1968, Table 4).

c) *The Radio Observation*

As part of a general investigation of Medium Sensitivity Survey sources, 1E 0449 − 184 was detected with the VLA at 6 cm, but at a flux level of only 1.1 mJy (Feigelson, Maccacaro, and Zamorani 1981). The source is unresolved, in clear contrast to the morphology of radio galaxies, but not atypical of Seyfert type 2 galaxies. The weak radio emission also discourages us from drawing further analogies with BL Lac objects, which otherwise also tend to have steep optical power laws and are lacking in broad emission lines.

Recently Smith and Spinrad (1980) have identified eight faint red stellar objects associated with 3C radio sources as low and intermediate redshift quasars ($z = 0.3$–1.7). These objects all have steep optical continua ($\alpha = 1.5$–3.5) with no strong evidence for internal reddening by dust. Two of these were originally classified as BL Lac objects, and four of the eight proved difficult to identify because their permitted emission lines are weak ($W_\lambda \sim 20$–30 Å). But even in the most extreme cases (3C 108 and 3C 422), the permitted lines in these quasars are much broader (FWHM > 1500 km s^{-1}) than in 1E 0449 − 184. Thus, these red quasars, comprising 15% of the full 3C quasar sample, are the objects most resembling radio-loud counterparts to 1E 0449 − 184.

III. OPTICAL, X-RAY, AND RADIO FLUX CORRELATIONS

In the manner of Zamorani *et al.* (1981) we have calculated two point spectral flux indices: radio-optical ($\alpha_{ro} = 0.25$) and optical = X-ray ($\alpha_{OX} = 1.15$) for comparison with the *Einstein* quasar survey. 1E 0449 − 184 is as luminous in X-rays relative to its optical brightness as the most X-ray luminous quasars and yet is extremely weak in the radio (see Zamorani *et al.* 1981, Figure 4). The extremely high $f_x/f_v \sim 5$ makes the "serendipitous" X-ray surveys the most likely method for discovering any other similar objects, the implications of which we explore in § IV.

Recently, Kriss, Canizares, and Ricker (1980) have published optical and X-ray data for a large sample of Seyfert galaxies (types 1 and 2). These authors proposed several correlations between the observed X-ray emission and various optical properties of Seyfert galaxies. These correlations have been extended to X-ray selected quasars by Grindlay *et al.* (1980) and Steiner (1981). Because of its high X-ray luminosity and very weak, narrow Hβ line, this object does not conform to the Hβ versus L_x and Hβ/[O III] versus L_x relationships shown in Figures 5*a* and 5*b* of Kriss, Canizares, and Ricker (1980). Although the addition of this one object cannot disprove these correlations, it does suggest that by plotting Seyfert types 1 and 2 galaxies (broad and narrow Hβ line objects) on the same plot, these authors may well be comparing "apples to oranges." It seems just as likely that for narrow line objects there is *no* correlation between either the width of Hβ or the Hβ/[O III] ratio and L_x over four orders of magnitude in L_x.

This does not imply anything about the reality of such relationships for broad line Seyfert galaxies and quasars alone. In another paper, one of us (Steiner 1981) has shown that for a subset of broad line Seyfert galaxies and quasars (those with strong Fe II emission), the width of Hβ and Hβ/[O III] *are* well correlated with L_x. Steiner (1981) also shows generally that there is no correlation between these quantities for narrow line objects, consistent with our results for 1E 0449 − 184. When very high signal-to-noise spectra are available for all Seyfert type 2 galaxies, these correlations, especially Hβ FWZI versus L_x should be reinvestigated using parameters appropriate to the weak broad line component in these objects.

The Kriss, Canizares, and Ricker (1980) paper also proposed correlations between both the blue nonthermal continuum flux and the Hβ flux with the X-ray flux. In their Figures 2*b* and 5*c*, the point for 1E 0449 − 184 falls just barely below and to the right of the Seyfert type 2 galaxies (X-ray flux = 0.08 μ Jy, log Hβ flux = -14.6 ergs cm^{-2} s^{-1}, and log (blue flux) = 1.1 m Jy assuming the latter is entirely nonthermal).

Since the procedure used to remove the stellar contribution to obtain the nonstellar flux can introduce significant errors into that quantity (Yee and Oke 1978), Seyfert type 2 galaxies have poorly defined nonstellar flux values since they have large stellar fractions. On the other hand, the narrow line quasar has a negligible stellar contribution so that its nonstellar flux value is not as uncertain as other narrow line objects. Therefore, we feel that the somewhat steeper slope (near 1:1) suggested by the position of 1E 0449−184 in Figure 2*b* of Kriss, Canizares, and Ricker (1980) is closer to the correct one both because of the argument above and because that slope is consistent with the slope for broad line objects at higher X-ray flux values. Similarly, if only the *broad* Hβ flux is used in Figure 5*c*, the indicated slope is again somewhat steeper than Kriss, Canizares, and Ricker (1980) suggest and again is close to 1:1 over the entire range of X-ray fluxes plotted. Of course, a larger sample of AGNs including many X-ray selected objects is necessary to accurately determine these slopes. Such a program is well worth the effort, since a very tight correlation between Hβ flux and nonthermal optical flux (slope 1:1) is already known to exist for all types of AGNs (Yee and Oke 1978; Yee 1980) and has physical significance for the emission-line region.

IV. ARE THERE MORE?

It is possible that 1E 0449−184 represents just the high luminosity extreme of the Seyfert type 2 galaxies and is an extremely rare object. On the other hand, if present radio, optical, and X-ray means for discovering quasars selectively discriminate against such objects, this may prove to be the first example of a new class of quasar, inconsistent with the luminosity distribution of normal Seyfert type 2 nuclei.

Since this object was discovered in an X-ray selected sample, it is worthwhile to look at the results and selection effects involved in such samples. At high X-ray flux in the all sky survey of *HEAO-1*, for example (see Piccinotti *et al.* 1981), for every Seyfert type 2 galaxy detected, three Seyfert type 1 galaxies were found. These Seyfert type 2 galaxies were typically nearby and thus extremely low in luminosity ($\sim 10^{42}$ ergs s^{-1}) relative to 1E 0449−184. In the *Einstein* "Medium Sensitivity Survey" (Maccacaro *et al.* 1981), only two out of 31 sources presently identified as AGNs has exclusively narrow lines. On the other hand, one of us (J. E. S.) has just recently found a very similar object in the field of a distant galaxy cluster (Steiner, Grindlay, and Maccacaro 1981). At $m_v \sim 18.2$ and $z = 0.20$, this second narrow line quasar is somewhat less luminous than 1E 0449−184 but again has no obvious broad line component to its emission lines.

In the deep surveys (see Giacconi *et al.* 1979), very few of the sources have been identified optically due to their extreme faintness. But in the Pavo fields, deep plates allow a determination of colors for candidate objects (Griffiths *et al.* 1981). In that field alone, for sources consistent with extragalactic objects by f_x/f_v values, 17 candidates have $J - F$ colors $\lesssim 1$, the remaining 3 have $J - F \sim 1.5$ (Griffiths *et al.* 1981). From the colors calculated in § II*b* of this paper, we estimate that $J - F$ color of 1E 0449−184 to be 0.4 ± 0.2. Thus, even though the colors of 1E 0449−184 are redder than the colors for most quasars, the photographic photometry in the Pavo fields does not yet clearly identify such objects. Additional photometry (e.g., U and N bands; see Koo and Kron 1981) or spectroscopy is needed to set limits on the number of narrow line objects at very faint X-ray fluxes.

Only five of 31 AGNs identified in the *Einstein* "Medium Sensitivity Survey" have $z > 1$, and almost all of the low redshift objects have $z < 0.5$. This low percentage ($\lesssim \frac{1}{6}$) of high redshift objects is verified by work on other "serendipitous" *Einstein* sources by Grindlay *et al.* (1980) and Chanan, Margon, and Downes (1981) and was in fact predicted theoretically from the X-ray log N–log S slope and the observed AGN luminosity functions by Fabian and Rees (1978). Given the low percentages of narrow line objects found among X-ray selected Seyfert galaxies and quasars ($\lesssim \frac{1}{10}$), a *single* example of a narrow line quasar with $z > 1$ is not overdue until close to 100 such sources had been investigated. Thus, at present, the X-ray surveys place no tight restrictions on the number of narrow line quasars except to suggest that they comprise $\lesssim 10\%$ of all quasars.

We now investigate whether there are any observational constraints on the hypothesis that a class of narrow line quasars exists with density/luminosity evolution similar to broad line quasars and comprising $\lesssim 10\%$ of all quasars at each cosmic epoch. Of course, there are hundreds of quasars with $z > 1$ discovered by radio and optical means. 1E 0449−184 is a very weak radio source typical of Seyfert type 2 galaxies. If very weak radio emission is typical of this class of quasar, then radio surveys will certainly not have previously found such objects.

On the other hand, if the Smith and Spinrad (1980) red quasars are the radio-loud counterparts to this object (see § II*c*), and if the radio surveys are unbiased as to optical properties, then 15% is the fraction of red quasars similar to 1E 0449−184 indicated by the 3C sample. The optical selection effects described below apply equally well to the Smith-Spinrad quasars as to radio quiet narrow-line quasars.

Most radio-quiet quasars have been selected by one of two main techniques: UV excess surveys and objective prism surveys. As described in § II, this object's optical slope ($U - B = -0.2$) is too steep to be found by UV excess surveys which cut off at $U - B \lesssim -0.4$ (Green and Schmidt 1978; Bracessi *et al.* 1980). If all the emission lines in 1E 0449−184 are as narrow as in the nearby Seyfert type 2 galaxies ($W_\lambda \lesssim 20$ Å except for Lyα), then it becomes difficult to detect such objects in objective prism surveys (Savage and Bolton 1979). Narrow-line galaxies detected in such surveys are bright and at very low redshift so the Hβ-[O III] complex has not shifted out of the III aJ passband at 5500 Å. Lyα does not reach the III aJ passband until $z \sim 2$ and is thus relevant only for very high luminosities. As noted in § II*b*, 1E 0449 − 184 could be like some low luminosity radio galaxies and Osterbrock "type 1.9" Seyfert galaxies in showing no obvious broad component to the Balmer series except at Hα (e.g., Osterbrock 1981; Ward *et al.* 1980). Unfortunately Hα is at 8780 Å in this object making it difficult to check this hypothesis. If Mg II were broad in this object, it is possible that many similar QSOs have already been discovered at higher redshift ($z \gtrsim 0.6$) where the (narrower) Hγ and Hβ lines are redshifted out of the visible region. However, if the steep Balmer decrement in the broad line region is due to reddening—as has been suggested for the radio galaxies—no broad component to the ultraviolet permitted lines would survive.

Since we have found that the Balmer emission line ratios are consistent with recombination theory, the expected strength of the narrow Lyα line in any high redshift analog is enormous. Thus, $z > 2$ narrow line quasars could be easily detectable by traditional objective prism surveys, but have *not* been to our knowledge. Unfortunately, the failure to detect such objects still does not preclude their existence because of the mean difference in optical slopes for broad and narrow line objects ($\alpha \sim 1$ and 2 respectively). Due to this difference, a narrow line quasar would be $\sim$ 1.5–2 magnitudes fainter at Lyα than a broad line quasar with the same optical-IR and X-ray luminosity. Given that almost all Lyα quasars found by objective prism techniques have apparent magnitudes of 17–18.5, narrow line objects of similar absolute luminosity will be in the range 18.5–20.5; a range not yet well surveyed for emission line objects.

Another competitive method for finding narrowline/red quasars is the four color photographic photometry technique of Koo and Kron (1981). While their results rule out red quasars in comparable numbers to blue quasars down to $m_J \sim 23$, they cannot as yet rule out a population of red quasars in the numbers suggested here.

Given the selection effects discussed above, it is not presently possible to determine whether 1E 0449 − 184 is a rare, high-luminosity Seyfert type 2 "fluke" that lacks gas at the right places to make a broad line QSO, or the prototype of an important new class of quasar, comprising $\lesssim 10\%$ of all quasars which has been difficult to discover up to now. If many more such objects exist, they will be most easily found as "serendipitous" X-ray sources.

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Note added in proof.—A near-ultraviolet spectrum of this object confirms the rather reddish extrapolated color quoted in § II*b* with a measured $U-B = -0.4 \pm 0.2$. Mg II λ2798 is present, although it is quite weak.

R. E. Griffiths, T. Maccacaro, and J. E. Steiner: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

James Liebert and John Stocke: Steward Observatory, University of Arizona, Tucson, AZ 85721