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# THE SPECTRUM AND LUMINOSITY OF THE LOW-REDSHIFT QSO 0241+622

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## ABSTRACT

We present spectrophotometry of the low-redshift ($z = 0.0438$) emission-line object recently identified with the X-ray source 4U 0241+61. The spectrum is that of a relatively normal QSO or Seyfert nucleus, although the Balmer lines are exceptionally broad, spanning 24,000 km $s^{-1}$ full width zero intensity. The continuum is severely reddened, as expected at this low galactic latitude ($b = 2°$), and prominent unredshifted interstellar absorption lines and bands are also present. The magnitude of the extinction correction is a dominant factor in ascertaining the nature of the object; this correction is estimated by five independent methods, which are in reasonable agreement, yielding $E(B-V) \approx 1.4$. For the $V = 16.4$ measured from our data, the derived absolute magnitude is $M_v = -25.3$. Thus 0241+622 has luminosity well within the range normally attributed to QSOs, and has the lowest redshift of any such object yet identified.

*Subject headings:* quasars — X-rays: sources

## I. INTRODUCTION

During the course of a systematic spectrophotometric survey of low-latitude X-ray source positions, aimed at new identifications of optical counterparts, a stellar, low-redshift emission-line object located at $\alpha_{1950} = 02^h41^m00.7$, $\delta = 62°15'28''$ ($l = 135°.64$, $b = 2°.43$) and associated with the faint X-ray source 4U 0241+61 was discovered. This identification, together with the precise X-ray position as well as the detection of an associated radio source, was the subject of an earlier report by Apparao *et al.* (1978), where a finding chart may also be found. In this *Letter* we present our spectrophotometry, and use these data to estimate the luminosity of this remarkable object. We confirm that (with the exception of the very small redshift!) 0241+622 shares the properties of normal quasars.

The data were obtained on 1977 December 4 UT, using the Robinson-Wampler Image-Tube Scanner (ITS) (Robinson and Wampler 1972; Miller, Robinson, and Wampler 1976) at the Cassegrain focus of the 3 m Shane reflector of the Lick Observatory. The grating employed yields resolution of 8–10 Å. Absolute flux calibration was achieved via observations of standard stars from Stone (1977). The resulting spectrum appears in Figure 1.

With several prominent exceptions, the spectrum is similar to those of numerous QSOs and Seyferts observed at Lick with the ITS. The forbidden lines yield a redshift $z = 0.0438 \pm 0.0001$; the centers of the broad permitted lines are consistent with this value, but obviously determine it less accurately. The width of the H$\alpha$ emission line is extraordinary, implying a full width zero intensity (FW0I) of 24,000 km $s^{-1}$ in the rest frame. This exceeds the H$\alpha$ emission widths of all the low-redshift QSOs measured by Baldwin (1975), and all Seyfert 1 galaxies observed by Osterbrock (1977). It seems unlikely that there is a substantial contribution to H$\alpha$ intensity from [N II]; such contamination is generally observed to be small in low-redshift quasars (Baldwin 1975), and the H$\alpha$/H$\beta$ decrement in 0241+622, derived below, is reasonable and does not imply a large correction. Unfortunately, [N II] $\lambda$6584 is redshifted precisely into the telluric B band and so a detailed examination of the H$\alpha$ profile is not possible. The widths of the H$\beta$ and H$\gamma$ emission lines are also consistent with this very large velocity, although their fluxes are drastically reduced by extinction, and both broad lines are marred by other features: [O III] in the red wing of H$\beta$, and the $\lambda$4430 interstellar band in the blue wing of H$\gamma$.

There are a handful of radio galaxies known to have comparable Balmer emission-line widths (Osterbrock, Koski, and Phillips 1975; Grandi and Osterbrock 1978), as well as a few high-redshift QSOs with comparable L$\alpha$ widths (Osmer and Smith 1976, 1977; Osmer 1977). It is also interesting that the Seyfert galaxy MCG 2-58-22, proposed as the optical counterpart of the weak X-ray source 2A 2302−088, has Balmer lines almost as broad (Ward *et al.* 1978). However, we can rule out a simple relationship between the presence of X-ray emission and Balmer line width. Dr. H. E. Smith has kindly provided Lick ITS scans of the X-ray object 2251−178 (Ricker *et al.* 1978), which shows Balmer widths of 10,300 km $s^{-1}$, slightly below the mean of Seyfert 1 galaxies given by Osterbrock (1977).

A possible broad emission feature near $\lambda_{obs} = 5550$ Å in our spectrum suggests an identification with the Fe II blend near $\lambda$5320, seen in many Seyferts and QSOs (Osterbrock 1977; Phillips 1977). Phillips finds that the width of this blended feature is generally comparable to the Balmer lines, and this is the case in our spectrum as well. The strong Fe II blend near $\lambda_0 = 4600$ Å (e.g., Phillips 1977, Fig. 3) is not obvious in our spectrum, although it falls in a weakly observed, steeply

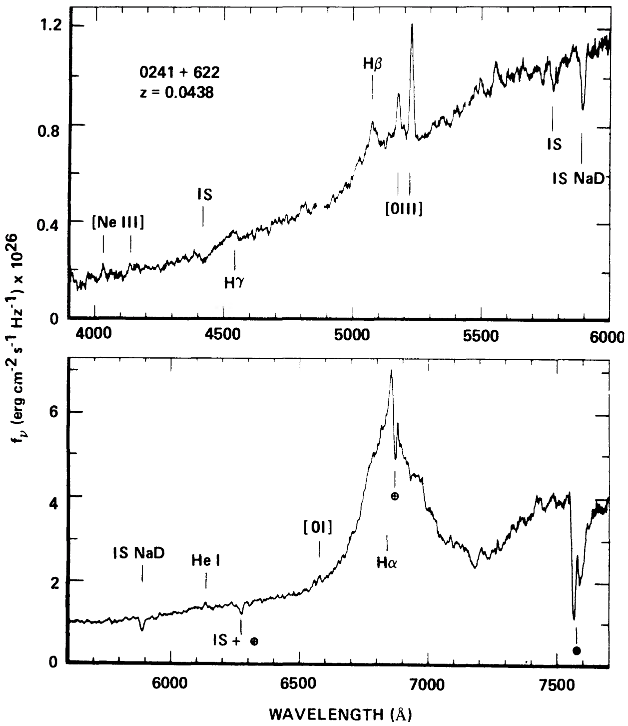


FIG. 1.—The spectrum of 0241+622, obtained on 1977 December 4 with the Lick Observatory 3 m Shane reflector. Note that, due to the intense Hα emission, the lower panel has one-fifth the intensity scale of the upper. The telluric A and B bands are marked, and the latter is responsible for marring the Hα emission profile.

falling section of continuum. The green emission feature in our spectrum seems unlikely to be [Ca v] λ5309, also sometimes seen in objects of this class (e.g., Shields and Oke 1975), as the observed line, if genuine, is too broad. The spectrum of 0241+622 obviously is deserving of detailed observation for weak features, a straightforward task for this bright object.

A distinguishing feature of the spectrum of 0241+622 is the presence of very prominent, unredshifted interstellar absorption lines and bands. In particular, λ4430, λλ5778/5780, Na D, and λ6284 are obviously present, and indicate that interstellar extinction in our own Galaxy is very important for this object. This is also confirmed by the steeply sloping continuum. Quantitative estimates of the extinction will be made below.

The ITS observations also provide color and magnitude estimates for 0241+622: we find $V = 16.4$, $(B - V) = 1.4$. Experience with the ITS indicates these estimates are normally accurate to $\pm 0.15$ mag, and the normalization agreement in the wavelength overlap region of the upper and lower panels in Figure 1, which are independent data obtained at different grating tilts, confirms this. These results are also in agreement with the KPNO 4 m video camera observations by Ford (1978) to within their respective errors. The data quoted here are more accurate than the estimates in Apparao *et al.* (1978), and supersede that work. The broad-band color, far redder than normal QSOs, again stresses the importance of extinction.

An understanding of the nature of 0241+622 obviously requires a knowledge of its absolute magnitude, and here we are faced with an interpretive difficulty uncommon for extragalactic objects: a severe local reddening correction. We have estimated the magnitude of this correction through a variety of independent methods.

## II. REDDENING ESTIMATES

### *a) Equivalent Widths of Interstellar Features*

Extensive high-resolution observations (Herbig 1975, and references therein) of reddened galactic stars have shown that there is a good correlation between color excess and the equivalent widths of interstellar bands. We have measured these equivalent widths on our spectra, and find for λλ4430, 5778/5780, and 6284 values of 3.75, 1.7, and 2.1 Å, respectively. For the (unresolved) Na D lines we find EW = 3.5 Å. The uncertainties in these values are very difficult to estimate, as they involve systematic rather than statistical problems. From the correlations of Herbig (1975) we infer a mean $E(B - V) = 1.4$ from λ4430 and λλ5778/5780. The λ6284 band is so prominent that it is doubtless severely contaminated by telluric $O_2$ (see Herbig 1975), and the upper limits it provides to interstellar extinction prove uninteresting.

The work of Bromage and Nandy (1973) on the variation of Na D strength with color excess shows that this correlation is much weaker than that of the diffuse interstellar bands. We thus do not attempt an extinction estimate from Na D, but note in passing that this feature appears significantly stronger in 0241+622 than in any of the reddened stars tabulated by Bromage and Nandy (1973).

### *b) Continuum Spectral Index*

The slopes of the optical continua of most QSOs are similar, and we may use this fact to estimate the extinction to 0241+622. Smith *et al.* (1977) have presented the continuum spectral index measured between 5000 and 7000 Å, $\alpha_{5000}{}^{7000}$, for 31 QSOs. The resulting mean value is $0.77 \pm 0.10$ (m.e.). Using the fit to the wavelength dependence of the interstellar extinction derived by Nandy *et al.* (1975), we have calculated the spectral index of 0241+622 implied by our observations, for a variety of assumed values of color excess. These results are tabulated in Table 1, and formally indicate that if $\alpha_{5000}{}^{7000}$ for 0241+622 is to equal the mean of the Smith *et al.* sample, $E(B - V) = 1.1$. While this extinction estimate is probably more accurate than simply using broad-band colors (due to emission-line contamination), it doubtless still suffers from a variety of systematic problems. The objects in the Smith *et al.* sample show considerable scatter in spectral index, presumably due both to intrinsic differences and to observational uncertainties. For example, the flattest spectra in the sample have $\alpha = 0$, which would imply $E(B - V) = 1.3$ for 0241+622. The accuracy of estimates by this method is also influenced by observational uncertainties in our spectrophotometry, by systematic problems in

TABLE 1

PARAMETERS OF 0241+622 AS A FUNCTION OF ASSUMED COLOR EXCESS

| $E(B-V)$ (mag) | $\alpha_{5000}{}^{7000}$ | $F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)$ | $L(\mathrm{H}\beta)$ ($10^{43}$ ergs s$^{-1}$) | $M_v$* |
|---|---|---|---|---|
| 0.0 | +4.4 | 16.2 | 0.03 | −20.7 |
| 0.5 | +2.7 | 9.6 | 0.15 | −22.4 |
| 1.0 | +1.0 | 5.6 | 0.69 | −24.0 |
| 1.1 | +0.67 | 5.1 | 0.94 | −24.3 |
| 1.2 | +0.34 | 4.6 | 1.3 | −24.7 |
| 1.3 | 0.00 | 4.1 | 1.7 | −25.0 |
| 1.4 | −0.34 | 3.7 | 2.4 | −25.3 |
| 1.5 | −0.67 | 3.3 | 3.2 | −25.7 |
| 1.6 | −1.0 | 3.0 | 4.4 | −26.0 |
| 1.7 | −1.3 | 2.7 | 6.0 | −26.3 |

* Assuming $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ and $R = 3.3$.

setting the continuum (both 5000 and 7000 Å are contaminated by Balmer lines in this object), and even by uncertainties in knowledge of the wavelength dependence of interstellar extinction.

### *c) Balmer Decrement*

Baldwin (1975) has obtained ITS spectrophotometry of a number of low-redshift QSOs, and his results indicate that the ratio $F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)$ is reasonably constant in these objects. From the 10 QSOs in his sample, we derive a weighted mean value of 4.2 ± 0.3 for this ratio; the result that the value of ~2.8 expected for simple radiative recombination is routinely exceeded now seems well established. We have computed the value of this decrement implied by our observations of 0241+622 for a variety of assumed values of color excess, again using the Nandy *et al.* (1975) extinction law. The scaling of the results with color excess is complex, as the Balmer lines are broad enough that the extinction varies noticeably across the extent of the line. These results are also tabulated in Table 1. If the H$\alpha$/H$\beta$ decrement in 0241+622 is close to the mean of objects in Baldwin's sample, the data in the table imply $E(B-V) = 1.3$ for our object. If we impose the restriction that the decrement not be permitted to dip below the value for radiative recombination, we also obtain a crude upper limit on the color excess, $E(B-V) \leq 1.7$.

### *d) Luminosity in* H$\beta$

The QSOs in the Baldwin (1975) sample show a curious clustering in their values of rest-frame H$\beta$ luminosity. For the 12 objects where this parameter is measured, we derive a mean value $L(\mathrm{H}\beta) = (4.86 \pm 1.88) \times 10^{43}$ ergs s$^{-1}$. However, one object, 3C 273, which is of course known to be extraordinary in a variety of respects, lies 11 $\sigma$ above this mean. If we exclude 3C 273, the remaining 11 objects yield very similar luminosities, $L(\mathrm{H}\beta) = (3.03 \pm 0.45) \times 10^{43}$ ergs s$^{-1}$, where the uncertainty quoted is again the mean error of the sample. We have derived the analogous quantity for 0241+622, and the results appear as a function of color excess in Table 1. Again the quantity does not scale as a simple exponential with color excess because of the differential wavelength dependence of the extinction law across the broad line. If $L(\mathrm{H}\beta)$ for 0241+622 is similar to the mean luminosity derived above, we infer $E(B-V) = 1.5$. The exclusion of 3C 273 is conservative for this argument in that it would raise the inferred color excess.

### *e) 21 Centimeter Emission Measurements*

A long succession of studies (Bohlin, Savage, and Drake 1978, and references therein) have established a good correlation between color excess and hydrogen column density in a given line of sight, especially for heavily reddened stars. Thus 21 cm emission measurements in this direction can provide a powerful probe of the color excess of 0241+622, particularly as no intragalactic velocity discrimination is needed; only the total column density is desired. A relevant measurement made essentially exactly on the position of 0241+622 is given by Weaver and Williams (1973). Dr. H. Weaver has kindly provided velocity-integrated values of the column density, $N_\mathrm{H}$, from the original data at a variety of spatial grid points in the vicinity. For 0241+622, $N_\mathrm{H} = 0.89 \times 10^{22}$ cm$^{-2}$. None of the 25 values within 1° of the object differs by more than 20% from this result, and 20 out of the 25 agree to within 10%, indicating that spatial irregularities of angular scale smaller than the 35′ beam are probably not a difficulty here.

We adopt the result of Bohlin, Savage, and Drake (1978), $E(B-V) = N(\mathrm{H\,I} + \mathrm{H_2})/5.8 \times 10^{21}$, and set $N(\mathrm{H_2}) = 0$. We thus derive $E(B-V) = 1.5$ in the direction of 0241+622. This is a lower limit for two reasons: we have neglected molecular hydrogen; and we have assumed that the 21 cm line is optically thin in this direction. We may conservatively compensate for our lack of information on the former point by noting that Savage *et al.* (1977) show that for *all* stars with $E(B-V) > 0.5$, the fraction of total hydrogen which is molecular always exceeds 0.1. Increasing the total column density by this amount raises the estimate to $E(B-V) = 1.65$ for our object.

None of the five separate extinction estimates discussed above is individually of extreme accuracy. However, they are relatively independent of each other, and yield reasonably consistent results. The method which is perhaps most uncertain, the continuum spectral index, yields the lowest extinction estimate, while probably the least ambiguous technique, the 21 cm emission measurement, yields the highest estimate. It is obviously impractical to derive a weighted mean from such diverse calculations. We subjectively adopt the working value $E(B-V) = 1.4$. For $R = A_v/E(B-V) = 3.3$ (Aannestad and Purcell 1973; Hackwell and Gehrz 1974; Herbst 1975), this implies $M_v = -25.3$ for 0241+622. The final column of Table 1 supplies values of $M_v$ for other assumed extinction corrections. We note that our adopted value of $A_v = 4.6$ agrees well with that determined for the nearby objects Maffei 1 (Spinrad *et al.* 1971) and 3C 58 (van den Bergh 1978).

## III. CONCLUSIONS

Our derived value of $M_v = -25.3$ lies well within the luminosity range normally attributed to quasi-stellar objects. It is, for example, near the average of both radio and radio-quiet QSOs discussed by Sandage (1972, Fig. 5), and also meets the suggested QSO definition of 1 mag brighter than the brightest cluster galaxy (Bahcall 1971; Bahcall and Hills 1973). The QSO 0241+622 is considerably more luminous than the very low-redshift "galaxy and quasar" ESO 113-IG 45 (West, Danks, and Alcaino 1978; Fairall 1977); it is also slightly closer than the ESO object.

Elvis *et al.* (1978) have proposed correlations between the X-ray luminosity of active extragalactic nuclei and various spectral parameters, and we may use this new object to test these proposals. The X-ray luminosity of 0241+622, $\sim 3 \times 10^{44}$ ergs s$^{-1}$ (Apparao *et al.* 1978), and Balmer line widths, 24,000 km s$^{-1}$ (present work), are consistent with their proposed relationship between these two quantities. However, our data do not fit their proposed correlation of X-ray luminosity with H$\alpha$ intensity. This quantity is somewhat extinction-dependent for 0241+622, but is of order $F(\text{H}\alpha) = 8 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$. To agree with the proposal of Elvis *et al.* (1978), the observed value would have to be at least a factor of 3 smaller, demanding $E(B - V) < 0.65$. Our data almost surely rule out this possibility.

In summary, we find 0241+622 to meet the classical definitions of a QSO: a stellar appearance, and luminosity far exceeding that of normal galaxies. It is a curious accident that this very low-redshift object is found almost exactly in the galactic plane. Were it located at high latitude, our data indicate 0241+622 would have $V = 11.8$, and almost surely would have been noticed years ago. Our detection of the object while searching for a (supposedly galactic) X-ray source verifies the prediction, made just prior to our observations, by Ward *et al.* (1978) that X-ray emission may be one of the most effective methods of locating radio-quiet QSOs.

Despite the extinction, the proximity and relative brightness of 0241+622 will obviously make this object uniquely valuable for observational tests of the relationship between galaxies and QSOs. Ford (1978) presents interesting data relevant to this next step.

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