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# articles

## 0957+561 A, B: twin quasistellar objects or gravitational lens?


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*0957+561 A, B are two QSOs of mag 17 with 5.7 arc s separation at redshift 1.405. Their spectra leave little doubt that they are associated. Difficulties arise in describing them as two distinct objects and the possibility that they are two images of the same object formed by a gravitational lens is discussed.*


SPECTROSCOPIC observations have been in progress for several years on QSO candidates using a survey of radio sources made at 966 MHz with the MkIA telescope at Jodrell Bank. Many of the identifications have been published by Cohen *et al.*[1] with interferometric positions accurate to ~2 arc s and a further list has been prepared by Porcas *et al.*[2]. The latter list consists of sources that were either too extended or too confused for accurate interferometric positions to be measured, and these were observed with the pencil-beam of the 300 ft telescope at NRAO, Green Bank at $\lambda$ 6 cm and $\lambda$ 11 cm. This gave positions with typical accuracy 5–10 arc s and the identifications are estimated as ~80% reliable.

The list of Porcas *et al.* includes the source 0957+561 which has within its field a close pair of blue stellar objects, separated by ~6 arc s, which are suggested as candidate identifications. Their positions and red and blue magnitudes, $m_R$ and $m_B$, estimated from the Palomar Observatory Sky Survey (POSS) are given in Table 1 and a finding chart is given in Fig. 1. Since the images on the POSS overlap, the magnitude estimates may be of lower accuracy than normal, but they are very nearly equal and object A is definitely bluer than object B. The mean position of the two objects is 17 arc s from the radio position, so the identification is necessarily tentative.

## Observations

The two objects 0957+561 A, B were observed on 29 March 1979 at the 2.1 m telescope of the Kitt Peak National Observatory (KPNO) using the intensified image dissector scanner (IIDS). Sky subtraction was used with circular apertures separated by 99.4 arc s. Some observational parameters are given in Table 2. The spectral range was divided into 1,024 data bins, each bin 3.5 Å wide, and the spectral resolution was 16 Å. After 20-min integration on each object it was clear that both were QSOs with almost identical spectra and redshifts of ~1.40 on the basis of strong emission lines identified as C IV $\lambda$1549 and C III] $\lambda$1909. Further observations were made on 29 March and on subsequent nights as detailed in Table 2. By offsetting to observe empty sky a few arc seconds from one object on both 29 and 30 March it was confirmed that any contamination of the spectrum of one object by light from the other was negligible.

**Table 1** Positions and magnitudes of 0957+561 A, B

| Object | RA | Dec (1950.0) | $M_R$ | $M_B$ |
|---|---|---|---|---|
| 0957+561A | 09 57 57.3 | +56 08 22.9 | 17.0 | 16.7 |
| 0957+561B | 09 57 57.4 | +56 08 16.9 | 17.0 | 17.0 |

0028–0836/79/0279—0381$01.00

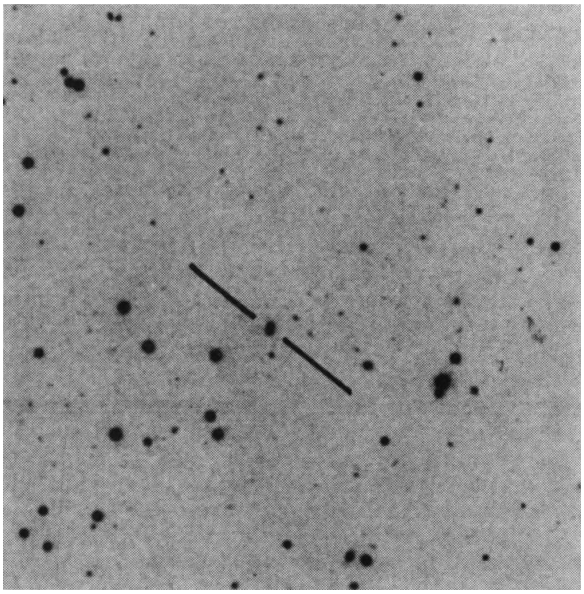

**Fig. 1** Finding chart for the QSOs 0957+561 A and B. The chart is 8.5 arc min square with the top right hand corner north preceding and is from the E print of the POSS.

On 1 April the spectral range was altered slightly by tilting the grating to cover the anticipated redshifted wavelength of Mg II $\lambda$2798 which was just beyond the limiting wavelength on previous nights.

The spectra obtained on 1 April are shown in Fig. 2. Data on observed spectral lines are given in Table 3. These were taken from the spectra using the interactive picture processing system (IPPS) which makes a linear interpolation between two selected continuum points and calculates the centroid and equivalent width of the emission above the interpolated line. Data from all three nights were used in compiling Table 3; that on 1 April had double the signal-to-noise ratio of the other two nights and was weighted accordingly. The O IV] $\lambda$1402 line is outside the spectral range of Fig. 2 but was present in data taken on the other two nights. Although we believe that Mg II $\lambda$2798 is detected in the data of Fig. 2 for 0957+561B, and He II $\lambda$1640 is also detected taking into account all three nights' data, the low signal-to-noise ratio and poorly defined continuum prevent us deriving useful observed wavelengths or equivalent widths.

The data on the C IV $\lambda$1549 and C III] $\lambda$1909 lines are much more accurate than those on the other lines and we believe the r.m.s. errors in the observed wavelengths of the centroids of these lines are not greater than 3 Å while the r.m.s. errors in the equivalent widths are estimated to be 7 Å. Within the limits of observational error, the corresponding lines in each object are identical in observed wavelength and equivalent width. For each object there is a difference in the redshift derived from the C IV and C III] lines which is significantly greater than the combined r.m.s. error in each. This may be associated with the problem of giving a precise meaning to the redshift of a broad line of somewhat irregular shape. The mean values of the redshift from the C IV and C III] emission lines are 1.4054 for A and 1.4047 for B, the difference being within the errors of measurement.

Although no attempt was made to carry out accurate spectrophotometry, some characteristics of the continua seem fairly well defined. Below about 5,300 Å they appear to have identical shapes, with QSO A brighter than B by 0.35 mag. Above 5,300 Å, however, the flux from B rises more steeply than that from A and they are equal at ~6,500 Å. These results are consistent with the magnitude estimates of Table 1.

The pair of QSOs provides unusual opportunity to investigate the origin of absorption lines in QSO spectra, a matter which is still in dispute. Accordingly, spectra having a resolution of about

**Table 2** List of IIDS observations with 2.1 m telescope

| Date (1979) | Aperture (arc s) | Seeing (arc s) | Spectral range (Å) | Integration time, each object (min) |
|---|---|---|---|---|
| 29 March | 3.4 | 4 | 3,200–6,700 | 40 |
| 30 March | 1.8 | 1 | 3,200–6,700 | 20 |
| 1 April | 3.4 | 3 | 3,500–7,000 | 60 |

2 Å were obtained of both QSOs on 30 March using the image tube spectrograph attached to the Univerity of Arizona 2.3 m telescope. As in the observations described above, the seeing during the observations was sufficiently good for contamination of the spectrum of one QSO by the light from the other to be negligible. A portion of the tracings of the two plates covering the C IV emission line region is shown in Fig. 3. The absorption lines which have been identified are indicated on the figure, and the measured wavelengths (using a Grant measuring engine) are presented in Table 4, with the corresponding redshifts. The wavelengths of the C IV emission lines given in Table 4 were measured from the tracings by smoothing over the noise and finding the centre of symmetry for each line. Comparison with Table 3 shows that the agreement in wavelength for the C IV emission lines between the two sets of observations is within the errors of measurement.

Low ionisation absorption systems (ones with Si II and Al II strengths >C IV strengths) are clearly present at $z_{abs} = 1.390$ in both QSOs. Even in the low resolution IIDS spectrum of QSO A there is clear evidence for Fe II $\lambda$2383 and Mg II $\lambda$2798 absorption. Fe II $\lambda\lambda$2600 and 2344 are possibly also present. Weak and possibly real absorption lines also appear in the image tube spectrum at $\lambda$3536.1 and $\lambda$3835.1 of QSO A. The features at $\lambda$3835.1 and $\lambda$3844.0 have a separation close to that of the Mg II doublet (at redshift 0.372). However, $\lambda$3844 is already identified with Fe II $\lambda$1608 in the 1.390 system so that the evidence for Mg II at 0.372 is not convincing. In QSO B, the

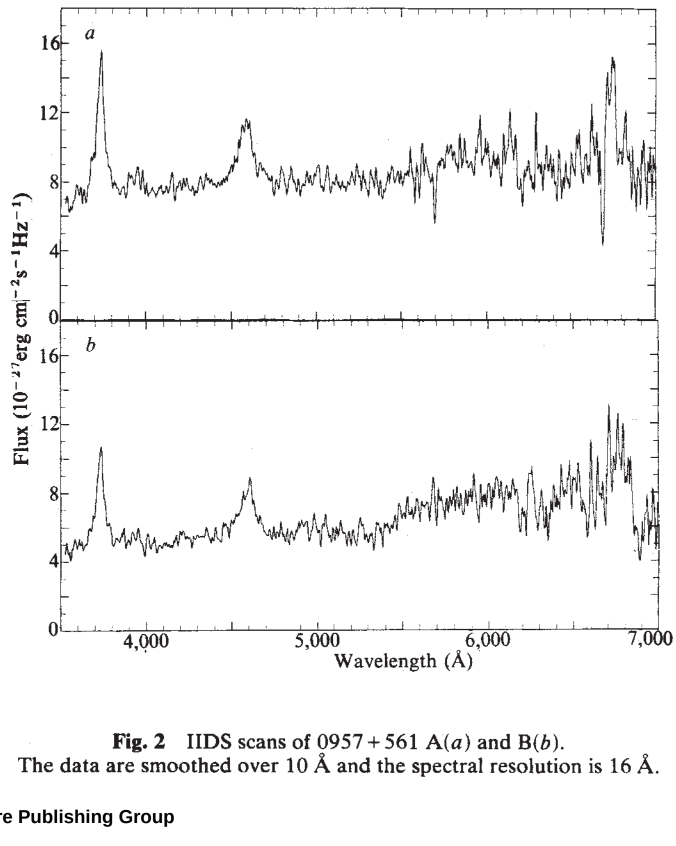


**Fig. 2** IIDS scans of 0957+561 A($a$) and B($b$). The data are smoothed over 10 Å and the spectral resolution is 16 Å.

absorption lines seem to be weaker than in QSO A on the basis of both the plate and IIDS data and none are seen in the low resolution spectrum. Unfortunately, a dust speck on the mask used to suppress image tube noise obliterated the Si II line in the spectrum of this object.

The difference between the two absorption redshifts amounts to a velocity difference $\Delta V_{abs}(B-A)$ of only about +45 km s$^{-1}$. However, in addition to the errors in estimating the line centres, somewhat larger errors occur in the zero point of the wavelength scales from plate to plate amounting typically to 100 km s$^{-1}$. As a result the difference between the absorption line redshifts in QSO A and QSO B cannot be considered significant.

The image tube data on the C IV emission lines give a velocity difference $\Delta V_{em}(B-A)$ of +265 km s$^{-1}$. This is also subject to the zero point error, but the major source of error is the uncertainty of ~1.5 Å (=120 km s$^{-1}$) in estimating the position of each line centre. The IIDS data on the C IV and C III] lines permit two independent estimates of the velocity difference leading to a mean $\Delta V_{em}(B-A) = -95$ km s$^{-1}$ with an error slightly larger than for the image tube data. Combining both sets of data, the resulting $\Delta V_{em}(B-A)$ is $+120 \pm 150$ km s$^{-1}$. Again, the difference between the emission redshifts in the two QSOs cannot be considered significant.

**Table 3** Wavelengths, equivalent widths (EW) and derived redshifts from IIDS 2.1 m observations

| | $\lambda_{em}$ | O IV] 1402 | C IV 1549 | He II 1640 | C III] 1909 | Mg II 2798 |
|---|---|---|---|---|---|---|
| A | $\lambda_{obs}$ (Å) | 3373 | 3729.5 | 3938 | 4584.5 | 6739 |
| | EW (Å) | 24 | 68 | 11 | 54 | 28 |
| | z (vacuum) | 1.407 | 1.4082 | 1.402 | 1.4026 | 1.409 |
| B | $\lambda_{obs}$ (Å) | 3376 | 3728.7 | Present | 4582.6 | Present |
| | EW (Å) | 26 | 70 | — | 55 | — |
| | z (vacuum) | 1.409 | 1.4077 | — | 1.4016 | — |

The differences $z_{em} - z_{abs}$ for each QSO based on Table 4 are not affected by the zero point error. They correspond to relative velocities of 2,170 km s$^{-1}$ and 2,400 km s$^{-1}$ for A and B respectively. The relative velocities each have an error of ~120 km s$^{-1}$ due to the uncertainty in the emission line centres. Thus the difference in relative velocities of 230 km s$^{-1}$ seems somewhat larger than the measuring error.

Therefore, either the absorption redshifts, or the emission redshifts may be equal, but possibly not both.

Finally, a plate was obtained on 2 April with the University of Arizona 1.5 m telescope. The seeing was relatively poor (~2.5 arc s), but the two images were well resolved and their measured separation was 5.7 arc s.

## Discussion

The great similarity in the spectral characteristics of these two QSOs which have the same redshift and which are separated by only 6 arc s seems to constitute overwhelming evidence that the two are physically associated, regardless of the nature of their redshifts, and we do not think that a useful *a posteriori* statistical test of this assertion can be carried out. In the rest of the discussion, however, we shall assume the QSO redshifts are cosmological. The same similarities further suggest that we may be dealing with a single source which has been split into two images by a gravitational lens. We shall consider this possibility after examining the more conventional explanation involving two distinct QSOs.

In the conventional interpretation of two adjacent QSOs we must either regard it as a coincidence that the emission spectra are so nearly the same, or assume that the initial conditions, age and environment influencing the development of the QSOs have been so similar that they have evolved nearly identically. For $q_0 = 0$ and $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$ the projected linear separation corresponding to $\theta = 5.7$ arc s is 68.5 kpc. The difference

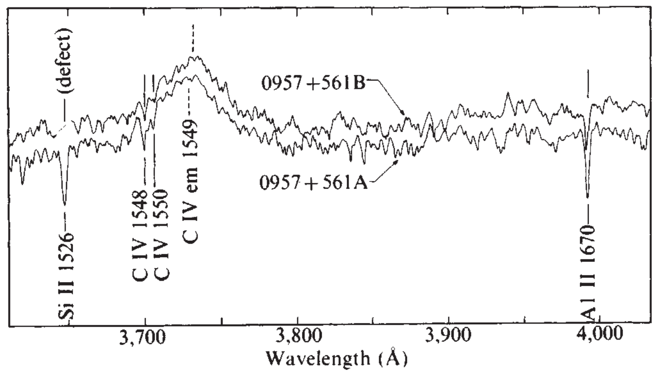


**Fig. 3** Microdensitometer tracings of portions of the spectra of 0957+561 A and B. Original dispersion of the plates was 47 Å mm$^{-1}$. The solid lines mark the position of absorption features in the two QSOs and the dashed lines mark the adopted centres of the C IV emission line.

between emission line velocities is well within the dispersion in velocities found by Stockton[3] between QSOs and associated galaxies, and the masses implied by orbital motion are of the order of $10^{11} M_{\odot}$ (because of the errors in $\Delta V$, this is more like an upper limit).

The conventional interpretation of the sources as two QSOs requires additional coincidences to explain the absorption line systems regardless of the mechanism invoked to explain the absorption. Weymann *et al.*[4] have described three classes into which absorption systems found in QSOs in this redshift range may be placed. The first class involves ejection of material from the QSO. If the ejection of the two systems were caused by the two QSOs separately it would be an additional coincidence that the ejection velocities were so similar. If the lines arose from radial ejection by one of the QSOs, then the nearly identical redshift of the two absorption systems (the difference between which we take to be $\lesssim 150$ km s$^{-1}$) requires a rather small angle between the direction of motion of the ejected cloud and the line of sight to the second QSO against which the cloud is projected. This implies a distance of the ejected material from the ejecting QSO of ~185 kpc. This in turn implies exceedingly large masses and energies for the ejected material for reasonable covering factors. This argument is very similar to that made by Wolfe *et al.*[5] for the 21 cm absorption in 3C286.

The second class of absorption involves intervening clouds associated with a cluster in which the QSOs are embedded. The velocity differences between the emission and absorption systems of A, B are typical of this class, but we must either ascribe the agreement in redshift of the two absorption systems to chance or assume that the two absorption systems are part of a common halo associated with a galaxy in the same cluster. An unusual feature if this last alternative is true is that the ionisation state is very low for this class. In the survey of Weymann *et al.* only one of about 20 absorption systems was a low ionisation system similar to those in A, B. The third class of absorption involves cosmologically distant intervening material. Neither the agreement in redshift of the systems in A and B nor their low

**Table 4** Wavelengths, identifications, and derived redshifts from image-tube spectra, 2.3 m observations

| Object | 0957+561A | | 0957+561B | |
|---|---|---|---|---|
| Identification | $\lambda_{air}$ | z (vacuum) | $\lambda_{air}$ | z (vacuum) |
| — | 3536.4 | — | — | — |
| Si II 1526 | 3648.2 | 1.3903 | (defect) | |
| C IV 1548 | 3699.9 | 1.3905 | 3700.1 | 1.3906 |
| C IV 1550 | 3705.9 | 1.3904 | 3707.4: | 1.3914: |
| C IV 1549 (em) | 3728.9: | 1.4078: | 3732.2: | 1.4100: |
| — | 3835.1 | — | — | — |
| Fe II 1608 | 3844.0 | 1.3905 | — | — |
| Al II 1670 | 3992.9 | 1.3905 | 3993.6 | 1.3909 |

ionisation is then especially remarkable, but we must then ascribe to chance the fact that the intervening material happens to be at a redshift so near to the emission redshift.

We now consider the possibility that a gravitational lens is operating. The theory of gravitational imaging in a cosmological context has been considered elsewhere (see ref. 6 and refs therein) and we simply quote the main results of applying this theory. The following are the relevant parameters involved in considering the gravitational lens hypothesis: the angular separation of the images, the shape of the images and their sizes, and the amplification of the two images. There is no evidence on the plate taken on 2 April or on the POSS for any departure of the images from stellar images. The magnitude difference between A and B (Table 1) is ~0.3. mag and this is confirmed by our observations.

The 0.3 mag difference between the two components requires that the amplification of QSO light is ~4 for the brighter image, and thus implies a normal luminosity for the QSO. (This is also suggested by the absence of a strong narrow component in the C IV emission which might be expected if the source were a strongly amplified Seyfert nucleus.) The maximum angular size of the lens is only ~8 times that of the object, so we should not expect to resolve it on the sky.

If the matter responsible for the gravitational imaging is far from the QSO, then, from simple euclidean space calculations we estimate that at redshift $z_L$ its mass must be $\sim 10^{13} z_L M_{\odot}$, and require that it be contained in a radius $\leqslant 30$ kpc. If a galaxy is the cause, then a lower limit of $z_L \sim 0.1$ is likely from its absence on our plate material. However, the centre of such a galaxy must be within ~0.5 arc s of the direct line between the QSO and the observer. The chance of finding such an alignment with a massive elliptical galaxy obtained by folding in our mass requirement with Schechter's[7] luminosity function (with a mass-to-light ratio of 30) is roughly $10^{-5}$, although the precise number depends quite strongly on the magnitude differences and angular separations allowed. Thus, while such coincidences must be very rare, it is not out of the question that we should have one example in the ~1,000 QSOs known.

An apparent objection arises from the difference in the shapes of the continua between the two QSOs. It is possible that differential reddening along the two light paths may be responsible. Note that the observed break at 5,300 Å corresponds to an emitted wavelength of 2,200 Å in the rest system of the QSOs. This is the wavelength of a well known resonance in interstellar extinction by dust in our Galaxy, and a model can be constructed to explain the observed continuum ratio incorporating the 2,200 Å feature at the redshift of the QSOs. This would imply that the intrinsic flux from B exceeds that from A.

Further observations would shed light on the gravitational lens hypothesis. If the flux from the object is variable, the light curves of the two images should be similar but with a relative time delay due to the difference in path lengths. The lag depends on the details of the geometry, but with the parameters discussed above would be expected to be of the order of months to years. Determination of the radio structure would also clearly be of great value.

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Since submission of this article we have heard that on 19, 20, and 21 April the two QSOs were observed by N. Carleton, F. Chaffee and M. Davis (of the Smithsonian Astrophysical Observatory) and R.J.W. using the SAO photon-counting reticon spectrograph attached to the SAO–UA multiple mirror telescope. The observations covered the range 5,900–7,100 Å with a resolution of 4 Å FWHM. Details will be reported elsewhere, but the main results are: (1) to within the measuring errors the Mg II emission lines have the same profiles and observed equivalent widths (85 and 76 ± 12 Å for A and B respectively) and the same redshift (1.4136 ± 0.0015 for both). (2) Absorption lines due to Fe II λλ2586, 2599, Mg II λλ2795, 2802 and Mg I λ2852 are present in both objects but are somewhat stronger in A. The mean heliocentric redshifts of the two absorption systems are 1.3915 for A and 1.3914 for B. A cross-correlation analysis confirms that the difference in the two adsorption redshifts is remarkably small and corresponds to a velocity difference of $7 \pm 10\ \mathrm{km\ s^{-1}}$. These observations strengthen the case for a gravitational lens.

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# The moving emission features in SS433 require a dynamical interpretation

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*New spectrophotometry of SS433 shows that the variable-wavelength emission features discovered by Margon et al. are due to the simultaneous presence of material having a substantial redshift and a substantial blueshift. A magnetic interpretation for the features is also ruled out by polarimetric measurements. Implications for dynamical models are discussed.*

STEPHENSON–SANDULEAK 433 is an emission line object which has recently been identified as the optical counterpart of the X-ray source A1909+04 (ref. 1) and has been associated with a compact radio source and the supernova remnant W50 (refs 2–4). However, the discovery by Margon *et al.*[5] of the highly variable-wavelength emission lines has sparked intense interest in this object. Margon *et al.* found several broad, unidentified emission features which showed daily changes in intensity, profile and wavelength, with positional changes of up

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