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LETTER

Letter to the Editor

Extended emission-line gas in the high luminosity, low redshift QSO E1821+643

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Abstract. The luminous RQQ E1821+643 has many properties of radio-loud quasars but is classified as radio-quiet. We have obtained an off-nuclear spectrum which shows extended emission line gas (EELG) associated with the QSO. The luminosity in extended [OIII] is about 2 orders of magnitude higher than what is typically found for radio-quiet QSOs, and is in the range of luminosities typical of radio-loud quasars. The luminosity of the EELG is another property that E1821+643 has in common with RLQs. There is no evidence for a cooling flow, suggesting that the extra-nuclear gas results from tidal interaction.

Key words: AGN – quasars – host galaxies – extended emission line gas – tidal interactions – cooling flows

1. Introduction

The QSO E1821+643 ($V = 14.2$, $z_{em} = 0.297$, $M_V = -27.1$) is the brightest low redshift ($0.3 > z > 0.1$) object after 3C 273. In contrast to 3C 273, it is classified as radio-quiet on the basis of radio luminosity and nuclear [OIII] line luminosity (Kolman et al. 1991, Lacy, Rawlings & Hill 1992).

Hutchings & Neff (1991) have found that the host galaxy is red, featureless and very large, with an estimated diameter of 75 kpc. The host galaxy appears to be elliptical whereas the host galaxies of RQQs are mostly spirals (eg. Bahcall et al. 1996). Hutchings & Neff (1991) also noted that the nucleus is located slightly off-center, which is also the case for 3C 273 (Tyson et al. 1982); these authors further pointed out that E1821+643 and 3C 273 are very similar objects, except that E1821+643 is radio-quiet.

E1821+643 is located in a cluster of galaxies of richness class ≥ 2 (Lacy, Rawlings & Hill 1992). Schneider et al. (1992) have obtained low resolution spectra of eight galaxies within $1'$ of the QSO; six of these galaxies are within $1000\,km\,s^{-1}$ of the redshift of the QSO. So E1821+643 is associated with a cluster of galaxies of richness normally thought to be typical of RLQs.

The radio flux density of E1821+643 is high enough to allow mapping the object at high resolution. Such observations have shown that E1821+643 has a core/jet structure like RLQs (Lacy, Rawlings & Hill 1992, Papadopoulos et al. 1995, Blundell & Lacy 1996, Blundell et al. 1996). Therefore Blundell et al. (1996) suggested that this RQQ contains a scaled down version of the compact central engine producing the radio emission in RLQs.

Thus, E1821+643 is a luminous QSO with many features of radio-loud quasars, but for some reason, it is radio-quiet. One might hope to find clues to this phenomenon from studies of the environment of the AGN. Here, we present the first spectroscopic observations of its extra-nuclear gas.

2. Observations, data reduction and results

The observations were obtained with the new focal reducer MOSCA at the 3.5 m telescope on Calar Alto, Spain. The instrument is installed at the Ritchey-Chretien focus of the telescope. A collimator forms a parallel beam in which analyzers such as filters, grisms or a Fabry Perot etalon, used as tunable narrow-band filter, can be inserted. A camera focuses the image onto the detector at an image scale of 3 pixel/arcsec for $15\mu m$ pixels. A 2048^2 CCD gives a field of view of $11\overset{'}{.}3 \times 11\overset{'}{.}3$. The instrument is very efficient: the throughput exceeds 30% both in direct imaging and spectroscopic modes.

In April 1997 three spectra were obtained: one nuclear spectrum, exposed for 500 sec, and two off-nuclear spectra at the same position $2\overset{''}{.}5$ north of the nucleus, exposed for 1800 sec each. The offset was chosen as a compromise between minimizing scattered light from the nucleus and maximizing the light collected from the host galaxy. The seeing was $1\overset{''}{.}2$ during the observations, and a slit width of $1\overset{''}{.}5$ was used for all spectra. The slit was oriented east-west. A grism covering the spectral range from $\lambda\lambda 4200 - 8500$Å at a resolution of 12.9Å was used.

Standard MIDAS routines were used for the data reduction, which included bias subtraction, flat-fielding with dome flats and wavelength calibration by means of HgArNe comparison spectra. The off-nuclear spectra were combined into one spectral image. Observations of the spectroscopic standard star Feige 56 were used for flux calibration, but due to thin clouds during the observations the absolute fluxes are uncertain. The sky was fitted by polynomials perpendicular to the direction of dispersion and

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subtracted. One-dimensional spectra of the nucleus and the host galaxy were extracted by summing in the spatial direction.

Light spilled over from the nucleus into the host galaxy was removed by scaled subtraction of the nuclear spectrum from the host galaxy spectrum, where the scaling factor was determined interactively by requiring that the broad emission lines subtract fully out of the host galaxy spectrum. It was found that the variation of the nuclear contamination along the slit is negligible and therefore a constant scaling factor was used. The one dimensional spectra of the nucleus and the host galaxy are shown in Fig. 1. Emission-line measurements from these spectra are summarized in Table 1. Redshifts, equivalent widths (EW) and fluxes were measured by fitting gaussians and a linear continuum to the lines; since the nuclear Balmer lines are very asymmetric, their redshifts are not given. The fluxes of the nuclear emission lines are systematically lower by 12% (mean over all lines) than those given by Kolman et al. (1991), which may be due to the non-photometric observing conditions. Since their equivalent widths are lower by 55% than those given by Kolman et al. (1991), the continuum of the QSO must have varied between 1991 and 1997. Kolman et al. (1993) had found optical variability on the 6% level.

Two-dimensional spectra of the extended emission line gas have been derived by subtracting the 2-dimensional nuclear spectrum from the 2-dimensional host galaxy spectrum with the same scale factor as derived in the 1-dimensional case. This image is free of nuclear emission and shows a continuum of stars and extended emission lines. On this image, the continuum was approximated by applying a median filter in the direction of dispersion and then subtracted. The resulting image thus is continuum free and contains only the emission lines of gas (Fig. 2).

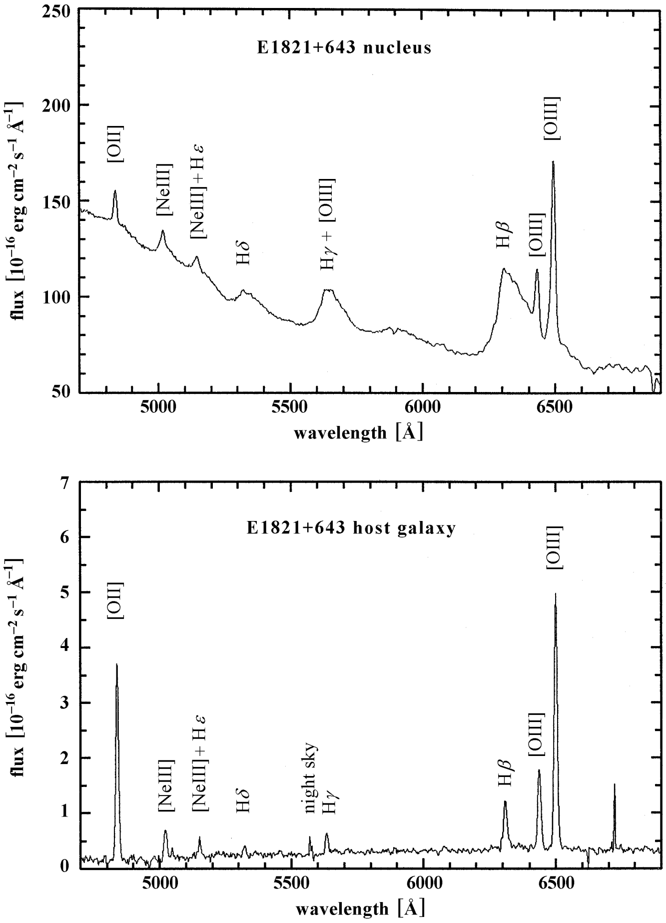

Fig. 1. Spectra of the nucleus and host galaxy of E1821+643 taken 2.″5 north of the nucleus.

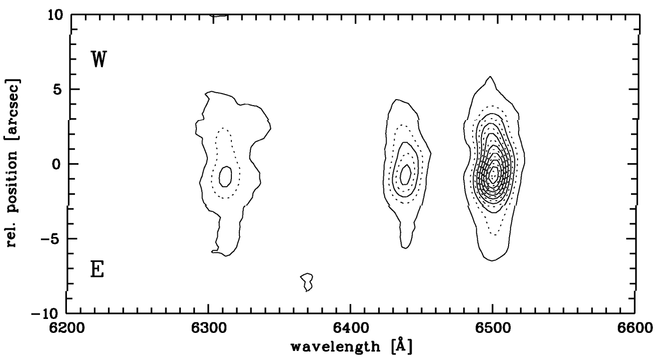

Fig. 2. Spatially resolved $H\beta$ and [OIII] lines in E1821+643 2.″5 north of the nucleus. The isophotes are linearly spaced. The zero point of the ordinate is nearest to the nucleus.

3. Discussion

The spectrum of the host galaxy of E1821+643 is dominated by the emission lines, the continuum is very weak. There is no indication of MgI b λ5175 or HI stellar absorption lines.

The ratios of the emission lines of the host of E1821+643 indicate photoionization by a power law continuum, from the diagnostic diagrams of Baldwin et al. (1981) and Veilleux & Osterbrock (1987). Thus, the extended emission-line gas is presumably ionized by the nuclear continuum.

In their systematic studies of the spectra of QSO and quasar host galaxies, Boroson et al. (1982), Boroson & Oke (1982) and Boroson et al. (1985) have found that these spectra fall into two groups: line objects, which have weak blue continua and strong emission lines, and continuum objects, which have red continua and weak emission lines. The spectrum of the host galaxy of E1821+643 clearly belongs to the line objects. The separation of the host galaxy spectra into the two groups correlates with properties of the nuclei such as radio morphology and spectral index, FeII emission and appearance of the Balmer lines. E1821+643 has all but one property of the line objects: the nuclear forbidden emission lines are strong, the Balmer lines are bumpy and the FeII emission is weak. In contrast to the line objects, however, E1821+643 is radio-quiet.

From the measured fluxes given in Table 1 the luminosities in the emission lines can be calculated. Taking $H_0 = 75\, km\, s^{-1}\, Mpc^{-1}$, $q_0 = 0.5$, we obtain $L_{[OIII]} = 3.9 \cdot 10^{43}\, erg\, s^{-1}$ for the nucleus and $L_{[OIII]} = 8.5 \cdot 10^{43}\, erg\, s^{-1}$ for the host, where we have assumed that the emitting region is a disk centered on the nucleus and thus 15% of it was actually covered by the spectrograph slit. The emission line flux for the host was therefore scaled by the factor 1/0.15. In their extensive study of emission line gas around QSOs, Stockton & MacKenty (1987) found that strong extended [OIII] is present only for objects with strong nuclear [OIII]; E1821+643 thus follows this correlation. However, Stockton & MacKenty (1987) further found a correlation between the presence of extended ionized gas and radio emission; the radio-quiet QSOs in their sample all have $L_{[OIII]} < 10^{42}\, erg\, s^{-1}$. The luminosity of the extra-nuclear [OIII] is therefore an additional property that the radio-quiet QSO E1821+643 shares with radio-loud quasars.

Falcke et al. (1995) have analysed the correlation between accretion disk luminosity and radio emission for a sample of quasars, where they used UV and emission line luminosities as indicators for the disk luminosity. Given that the nucleus in E1821+643 is the source of ionization of the extra-nuclear gas, the luminosity of the extended [OIII] is a better indicator of the disk luminosity than the luminosity of the nuclear [OIII]. Since the extra nuclear [OIII] is brighter by a factor of 2, the position of E1821+643 in the $\nu L_\nu - L_{disk}$ diagram of Falcke et al. (1995) is moved even further into the region occupied by RQQs, corroborating the classification of E1821+643 as radio-quiet object.

It is generally assumed that the hosts of RLQs are elliptical and the hosts of RQQs are disk galaxies. However, HST imaging has found examples of RQQs hosted by ellipticals (Bahcall 1996). E1821+643 is the clearest case of a RQQ living in an environment typical for radio-loud objects. Why then is E1821+643 radio-quiet? If the energy source for the radio jets is the extraction of rotational energy of a spinning Kerr black hole via electromagnetic fields (Blandford & Znajeck 1977), then E1821+643 may be radio-quiet because the black hole has not been spun-up or the magnetic fields are too small. However, it is also possible that E1821+643 has been radio-loud in the past but is radio-quiet now. The lifetime of the spin-down process is inversely proportional to the mass of the black hole: $t_8 = 16.7 M_8^{-1} B_4^{-2}$ where M_8 is the mass of the black hole in units of $10^8 M_\odot$ and B_4 is the magnetic field in units of $10^4 G$ and t_8 is the spin-down time in 10^8 years (Blandford 1990). From fits of thin accretion disk models to the UV part of the spectrum, Kolman et al. (1991) derived a black hole mass of $M = 3\,10^9\, M_\odot$, which gives a lifetime of only $t_8 = 0.5\, B_4^{-2}$ years. This is shorter than the timescale for indicators of tidal interactions to dissappear. The synchroton time scale $t_s = \frac{\gamma m_e c^2}{P_e}$ for the extended radio structures to die away is of the same order: $t_s = 1.6\,10^7 B_{10\mu G}^{-2} \gamma_4^{-1}$ years where $B_{10\mu G}$ is the magnetic field in units of $10\mu G$ and γ_4 the Lorentzfactor in units of 10^4.

The spatial extent of the line emitting region as shown in Fig. 2 is 43 kpc and thus covers a major fraction of the area of the galaxy. The extent of the EELG is comparable to that found in Seyferts and QSOs (eg. Wilson 1992). The EELG is slightly more extended to the east.

The radial velocity of the extra nuclear gas decreases to the east by $120 km\, s^{-1}$. The width of the lines, corrected for the instrumental resolution as derived from airglow lines, is $\approx 600\, km\, s^{-1}$. There is therefore little evidence for rotation, but since we have only one slit position, this is not conclusive.

Table 1. Emission Line Measurements. The fluxes are given in units of $10^{-16} \mathrm{erg\, s^{-1}\, cm^{-2}}$, equivalent widths are in Å.

		nucl.			host	
identification	flux	EW	z	flux	EW	z
[OII] λ 3727	234	1.7		48	340	
[NeIII] λ 3868.7	380	3.1	0.297	7.7	40	0.298
[NeIII]λ3968, Hϵ	180	1.5		3.5	16	0.298
Hδ λ 4102	460	4.9		2.5	10	0.298
Hγ λ 4340	980	22.0		4	14	0.298
Hβ λ 4861	7450	111		16	45	0.298
[OIII] λ 4958.7	465	5.3	0.297	20	52	0.298
[OIII] λ 5006.8	1240	25.0	0.297	69	190	0.298

The width of the emission lines indicates a velocity dispersion in agreement with the observation of Hutchings & Neff (1991) that the host galaxy of E1821+643 is in the final stages of interaction or merging.

Tidal interactions or mergers of gas-rich galaxies are often invoked to explain the origin and structure of the extended emission line gas around AGN's. As stated above, Hutchings and Neff (1991) have indeed found morphological evidence for these processes in E1821+643. Alternatively, the extended emission line gas may have been deposited by a cooling flow; it has been shown that this process is occuring in the hosts of at least some radio-loud quasars (Fabian et al. 1988, Crawford & Fabian 1989). In these cases the pressures are similar to those found in nearby cooling flows, and the pressure profiles of the extended emission around the quasars are as expected for a gas confined in a hot intra-cluster medium. The host cluster of E1821+643 is very X-ray luminous (Hall 1997). Its X-ray radial profile is slightly better fitted by a Gaussian plus a King profile than by a King profile alone, which Hall et al. (1997) take as evidence for a barely resolved cooling flow.

The cooling flows require an outward decrease of pressure and hence an outward increase of the $[\mathrm{OIII}]5007$ / $[OII]3727$ line ratio. However, the spatial profiles of the $[\mathrm{OIII}]5007$ and $[\mathrm{OII}]3727$ lines in E1821+643 are virtually identical (Fig. 3). The line ratio varies erratically by $\pm 12\%$ in the inner 4 arcsec; especially there is no outward increase of the line ratio. Our optical data therefore do not give evidence for a cooling flow, but rather suggest that the extended emission line gas in E1821+643 resulted from the tidal interaction/merger indicated in the morphology of the host galaxy.

The discrepancy between optical and X-ray data may be due simply to the fact that we have measured only 1 slit position. On the other hand, the deviation of the cluster profile from a King-profile in the X-ray is only marginal. Furthermore, it may not due to a cooling flow. As Hall et al. (1997) have noted, E1821+643 has significant flux below 912Å, implying either an HI density lower by 4 orders of magnitude than in other cooling flows or reionization of the gas in a cone pointing towards us. More data are needed to prove or disprove the existence of a cooling flow.

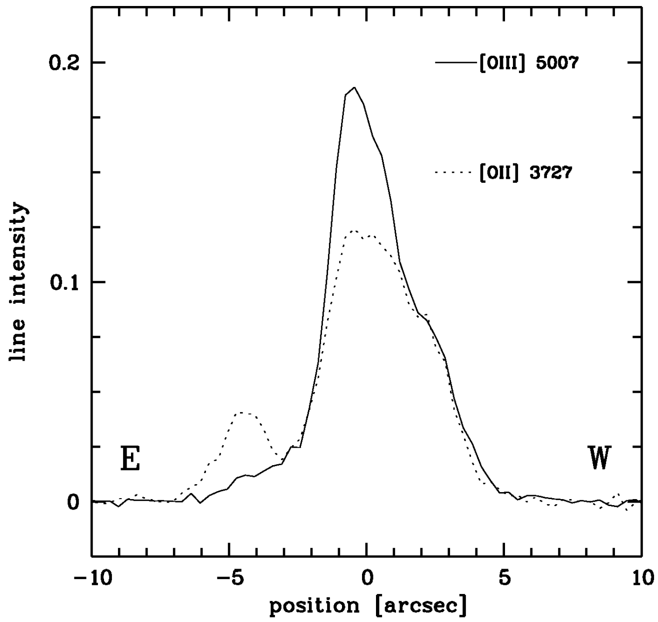

Fig. 3. Spatial intensity profiles of the [OIII]λ 5007 and [OII]λ 3727 lines. The abscissa corresponds to the ordinate of Fig. 2.

4. Summary

The luminous QSO E1821+643 has several features which are usually found in RLQs such as an elliptical host galaxy, surrounding cluster of Abell richness class 2, and core/jet structure in the radio. For some reason, however, this object is radio-quiet.

An off-nuclear spectrum shows extended emission line gas. The appearance of the spectrum as well as the [OIII] luminosity are typical for RLQs but not for RQQs, adding another feature this QSO has in common with RLQs.

Comparison of [OIII] and [OII] line profiles gives no evidence for a cooling flow, so the extra-nuclear gas probably results from a tidal interaction or merger process.

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References

Bahcall J.N., Kirhakos S., Schneider D.P., 1996, ApJ 457,557
Baldwin J.A., Phillips M.M., Terlevich R., 1981, PASP 93, 5
Blandford R.D., 1990, Active Galactic Nuclei, eds. J.-L. Courvoisier & M. Mayor, Spinger Berlin, p.161
Blandford R.D., Znajeck R.L., 1977, MNRAS 179,433
Blundell K.M., Lacy M., 1996, MNRAS 274, L9
Blundell K.M., Beasley A.J., Lacy M., Garrington S.T., 1996, ApJ 468, L91
Boroson T.A., Oke J.B., 1982, Nature 296, 397
Boroson T.A., Oke J.B., Green R.F., 1982, ApJ 263, 32
Boroson T.A., Oke J.B., 1984, ApJ 281, 555
Boroson T.A., Persson S.E., Oke J.B., 1985, ApJ 293, 120
Crawford C.S., Fabian A.C., 1989, MNRAS 239,219
Fabian A.C., Crawford C.S., Johnstone R.M., Allington-Smith J.R., Hewett P.C., 1988, MNRAS 235, 13p
Falcke H., Malkan M.A., Biermann P.L., 1995, A&A 298, 375
Hall P.B., Ellingson E., Green R.F., 1997, AJ 113, 1179
Hutchings J.B., Neff S.G., 1991, AJ 101, 2001
Kolman M., Halpern J.P., Shrader C.R., Filippenko A.V., 1991, ApJ 373, 57
Kolman M., Halpern J.P., Shrader C.R., Filippenko A.V., Fink H.H., Schaeidt S.G., 1993, ApJ 402, 514
Lacy M., Rawlings S., Hill G.J., 1992, MNRAS 258, 828
Papadopoulos P.P., Seaquist E.R., Wrobel J.M., Binette L., 1995, ApJ 446, 150
Schneider D.P., Bahcall J.N., Gunn J.E., Dressler A., 1992, AJ 103, 1047
Stockton A., MacKenty J.W., 1987, ApJ 316, 584
Tyson, J. A., Baum, W. A., Kreidl, T., 1982, ApJ 257, L1
Veilleux S., Osterbrock D.E., 1987, APJS 63,295
Wilson A., in 'Physics of Active Galactic Nuclei', eds. W.J. Duschl & S.J. Wagner, Springer Verlag Heidelberg, 1992, p.307