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The nature of the HE0450−2958 system

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ABSTRACT

Magain et al. argued that the host galaxy of the quasar in HE0450−2958 is substantially underluminous given the quasar brightness. Using kinematical information from the spectra of the quasar and the companion galaxy, an ultraluminous infrared galaxy, we test the hypothesis that the black hole powering the quasar was ejected from the companion galaxy during a merger. We argue that the ejection model is unlikely, since the kick velocity required to remove the black hole from the galaxy is $\gtrsim$500 km s^{-1}, inconsistent with the presence of narrow emission-line gas at the same redshift as the quasar nucleus. We also show that the quasar in HE0450−2958 has the spectral characteristics of a narrow-line Seyfert 1 galaxy and calculate a mass for its black hole that is roughly an order of magnitude smaller than that estimated by Magain et al. The predicted luminosity of the host galaxy is then consistent with the upper limits inferred by those authors.

Key words: black hole physics – galaxies: active – galaxies: interactions.

1 INTRODUCTION

HE0450−2958 is a bright quasar at redshift $z = 0.285$. *Hubble Space Telescope* (*HST*) images revealed that the system is double, with an ultraluminous infrared galaxy (ULIRG) situated ∼1.5 arcsec from the quasar (Boyce et al 1996; Canalizo & Stockton 2001). Recently, Magain et al. (2005) reported that the host galaxy of the quasar is substantially underluminous, based on the quasar's luminosity and on a likely value for $M_\bullet$, the mass of its nuclear supermassive black hole (SBH). Magain et al. proposed either that the quasar host galaxy is dark, or that an otherwise 'naked' SBH had acquired gas while moving through intergalactic space.

Here, we examine these hypotheses in light of additional evidence from the spectra of the quasar and the companion galaxy. The quasar in HE0450−2958 has the spectral characteristics of a narrow-line Seyfert 1 galaxy (Osterbrock & Pogge 1985). We infer a much smaller luminosity for the host galaxy, consistent with the upper limits derived by those authors. We also critically examine the most natural model for a 'naked' SBH, namely, an SBH that was ejected from the companion galaxy during the merger that created the ULIRG. We show that the ejection model can be securely ruled out, regardless of the origin of the kick, since the quasar spectrum indicates the presence of narrow emission-line gas extending out to a distance of ∼1 kpc from the nucleus that is moving at the same velocity as the broad-line gas. The narrow-line gas could not have remained bound to the SBH if it were ejected from the companion galaxy.

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2 SPECTRAL ANALYSIS

HE0450−2958 was observed during 2001 November 27 using the ultraviolet (UV) Focal Reducer and low-dispersion spectrograph (FORS1) on Unit Telescope 1 of the Very Large Telescope (VLT) (PI: M. Courbin). The instrument was operated in MOS mode with a long-slit position angle of ∼55°. This allowed the contributions from the ULIRG, quasar and the nearby G-type star to be gathered simultaneously in slit no. 9. In total, five spectra were obtained of HE0450−2958: three of 1200-s duration using the 600B grism centred at 4620 Å, and two of 1800-s duration using the 600R (6270 Å) and 600I (7940 Å) grisms. These data, including all relevant calibration files, were retrieved from the VLT data archive.[1]

The data were reduced using standard IRAF[2] routines. Bias and flat-field subtraction were carried out before wavelength calibration with HeArNe arcs. Cosmic ray subtraction was facilitated with a median combine, in the case of the three 600B exposures, and with a median filter and rigorous visual inspection in the 600R and 600I cases. Background subtraction was performed by removing a third-order polynomial fitted to the sky components in the spatial direction. Flux calibration was carried out by fitting a 5700-K (G-type) blackbody spectrum to the observed star, and scaling to the

[1] http://archive.eso.org/
[2] IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation (NSF).

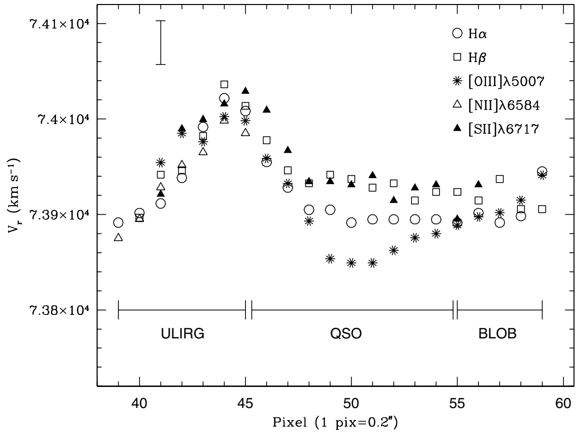

Figure 1. Radial velocities obtained from the peak wavelengths of the strongest emission lines along the slit. The locations of the galaxy, quasar and 'blob' identified by Magain et al. (2005) are indicated.

fluxes observed through the high-resolution channel of the advanced camera for surveys aboard the *HST* (no. 10238, PI: Courbin).

Fig. 1 shows the velocities derived from the peak wavelengths of the strongest emission lines along the slit; the regions dominated by the ULIRG, the quasar and the Magain et al. (2005) 'blob' are indicated. In the region dominated by the galaxy, the velocities show the pattern of a rotation curve, with peak-to-peak amplitude of ∼140 km s^{-1}. This value seems small for such a luminous galaxy, but the *HST* image suggests that the orientation of the slit, aligned to include the star, quasar and ULIRG, is far from the major axis of the galaxy. According to the rotation curve, the systemic velocity of the galaxy is 73 950 ± 20 km s^{-1}. In the region dominated by the quasar, the velocities obtained from the Hα, Hβ, [N II]λ6584 and [S II]λ6717 emission lines do not vary within the uncertainties, and the average value is 73 920 ± 20 km s^{-1}, indicating a blueshift relative to the systemic velocity of the galaxy of only 30 km s^{-1}, consistent within the errors with zero. The [O III]λ5007 emission line is blueshifted relative to the other emission lines by approximately 60 km s^{-1}. However, such a blueshift in [O III]λ5007 is often observed in active galactic nucleus (AGN) (Nelson & Whittle 1995; Boroson 2005; Bian, Yuan & Zhao 2005). In the region dominated by the emission of the blob, this blueshift is not observed, and the velocities derived from the [O III] emission line are the same as those obtained from the other lines. In summary, our measurements show similar systemic velocities for the ULIRG, quasar and blob.

The optical spectrum of the galaxy (Fig. 2) shows a number of absorption-line features, in particular, high-order Balmer lines indicative of an intermediate-age (∼10^8 yr) stellar population. In order to better quantify the age of the stellar population and to obtain an estimate for the stellar velocity dispersion, we performed a spectral synthesis using the code STARLIGHT of Fernandes et al. (2005). This code uses a basis of stellar population templates, each one corresponding to a given metallicity and age, to synthesize the galaxy spectrum, and it gives as output the contribution of each template to the total light at λ4020 Å; the internal reddening and the velocity dispersion. The contribution of the quasar, which contaminates both the continuum and the emission lines of the galaxy spectrum, has also been included in the synthesis. The results of the synthesis (Fig. 2) yield the following contributions to the light of the ULIRG at λ4020: ∼25 per cent from the quasar continuum, ∼8 per cent from stars in the ionizing phase $t < 10^7$ yr, ∼52 per cent from stars in a ∼10^8 yr post-starburst and ∼15 per cent from older stars. The synthesis thus strongly points to a major burst of star formation

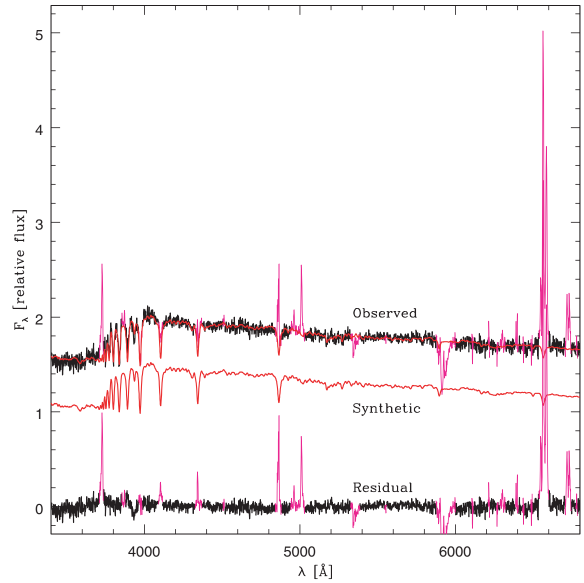

Figure 2. Optical spectrum of the ULIRG, together with the synthetic spectrum and the residual between the two. Thin lines mark regions which have been excluded from the fits (emission lines, sky residuals and bad pixels). All spectra are normalized at 4020 Å and shifted vertically for clarity. The synthetic spectrum is ploted twice: superimposed on the galaxy spectrum and shifted vertically.

∼10^8 yr ago, plus some residual, ongoing star formation. The total stellar mass is ∼9 × 10^{10} M$_\odot$. The internal reddening is $A_V \sim 0.6$ mag, which is a little less than half the $A_V \sim 1.5$ mag deduced from the Balmer decrement (H α/H $\beta \sim 4.6$) in the residual spectrum (Calzetti, Kinney & Storchi-Bergmann 1994). The velocity dispersion is $\sigma = 190 \pm 25$ km s^{-1}.

3 EJECTION HYPOTHESIS

The low luminosity of the quasar host, coupled with its proximity to a ULIRG, leads naturally to the hypothesis that the SBH powering the quasar was ejected from the ULIRG following a merger. Two ejection mechanisms have been discussed: gravitational radiation recoil during the coalescence of a binary SBH (Favata, Hughes & Holz 2004); or a gravitational slingshot involving three SBHs, if the merger happened to bring a third SBH into the centre of a galaxy containing an uncoalesced binary (Mikkola & Valtonen 1990).

The quasar is displaced 1.5 arcsec from the centre of the ULIRG, corresponding to a projected separation of ∼6.5 kpc. This is much greater than the galaxy's half-light radius implying an ejection velocity $V_{\rm kick}$ comparable to the central escape velocity from the galaxy $V_{\rm esc}$. The distribution of mass around the companion galaxy of HE0450−2958 is unknown. However, Tacconi et al. (2002) find that the light distributions in a sample of 18 ULIRGs are reasonably well fit by de Vaucouleurs profiles with effective (projected half-light) radii of $R_{\rm e} \approx 1$ kpc, similar to those of luminous E galaxies. They derive kinematical masses of $0.3 \times 10^{11} \lesssim M \lesssim 5 \times 10^{11}$ M$_\odot$, consistent with the estimate presented above from population synthesis. The mean stellar velocity dispersion in their sample is 180 km s^{-1}, also consistent with the estimate presented above. We accordingly modelled the baryonic mass distribution around the ULIRG as if it were a normal, spherical E galaxy of mass $M_{\rm gal}$, and used the empirical correlations between E-galaxy mass, luminosity, effective

Table 1. Mass models.

	Galaxy			Halo			Both
	M (10^{11} M$_{\odot}$)	R_e (kpc)	V_{esc} (km s^{-1})	M (10^{12} M$_{\odot}$)	$r_{1/2}$ (kpc)	V_{esc} (km s^{-1})	V_{esc} (km s^{-1})
Model 1	0.15	1.10	440	2.0	200	500	664
Model 2	1.50	1.43	1520	2.0	200	500	1597

radius and Sersic index (Magorrian et al. 1998; Graham & Guzmán 2003; Ferrarese et al. 2005) to derive its gravitational potential.

Table 1 gives the parameters of two mass models for the companion galaxy. Model 1 has a baryonic mass of 1.5×10^{10} M$_{\odot}$, roughly the mass of an $M_B \approx -18$ dE galaxy and a factor of $\sim$2 *smaller* than the smallest ULIRG mass inferred by Tacconi et al. Model 2 has $M_{gal} = 1.5 \times 10^{11}$ M$_{\odot}$, the stellar mass of a $M_B \approx -20$ E galaxy, and close to the average mass of the galaxies in the Tacconi et al. sample. We also included a dark matter halo; because the contribution of dark matter to the gravitational force on scales $\lesssim$10 kpc is probably much less than that of the baryons, we considered only a single halo model. As templates for the dark matter, we considered the four 'galaxy-sized' haloes in the Diemand, Moore & Stadel (2004) Lambda cold dark matter (ΛCDM) simulations, which have virial masses in the range $1.0 \times 10^{12} \leqslant M_{DM} \leqslant 2.2 \times 10^{12}$ M$_{\odot}$. Fits to $\rho(r)$ for these haloes are given in Graham et al. (2005); based on these fits, central escape velocities lie in the range $480 \leqslant V_{esc} \leqslant 600$ km s^{-1}, and the ΔV in climbing to 10 kpc is $210 \leqslant \Delta V \leqslant 310$ km s^{-1}. Our adopted halo model (Table 1) had a mass of 2.0×10^{12} M$_{\odot}$ (virial mass 1.1×10^{12} M$_{\odot}$), half-mass radius 200 kpc and central escape velocity $\sim$500 km s^{-1}, similar to model G1 in Diemand et al. (2004). By comparison, the virial mass of the Milky Way halo is believed to be 1–2 $\times 10^{12}$ M$_{\odot}$ (Klypin, Zhao & Somerville 2002).

In de Vacouleurs-like mass models, the ΔV in climbing from the very centre out to a distance of a few pc can be considerable due to the high nuclear density (e.g. Young 1976). The mass distribution of the companion galaxy following the merger is unknown on these small radial scales, and in any case, the SBH would carry with it the mass of the inner pc, modifying the potential. Accordingly, we placed the SBH initially at a distance of 10 pc from the galaxy centre when computing post-ejection trajectories.

Fig. 3 shows the results. As expected, kicks of $\sim$500 km s^{-1} (Model 1) and $\sim$1500 km s^{-1} (Model 2) are required in order for the SBH to climb a distance of 10 kpc from the centre of the galaxy. *This result essentially rules out radiation recoil as the origin of the kick*, since the maximum amplitude of the recoil is believed to be less than 500 km s^{-1} (Merritt et al. 2004) and probably not more than 250 km s^{-1} (Blanchet, Qusailah & Will 2005). Three-body recoils might still work, however, the largest ΔV in a three-body interaction is experienced by the *smallest* body. But Fig. 3 constrains *any* ejection model in a number of other ways.

(1) A large V_{kick} implies a large velocity, $V \gtrsim 300$ km s^{-1}, as the SBH moves past its current position. This is hard to reconcile with the essentially zero radial velocity difference between quasar and galaxy, unless the ejection velocity is fine tuned or nearly perpendicular to the line of sight.

(2) The time for the kicked SBH to reach a distance of 10 kpc is much shorter than 10^8 yr, unless it is now on its return from an apocentre distance greater than 10 kpc; however, this again requires fine tuning of the gravitational potential and/or kick velocity. But the starburst occurred $\sim 10^8$ yr ago; thus, either the true separation of the SBH from the ULIRG is much greater than 10 kpc, or the ejection was delayed until a time of $\sim 10^8$ yr after the starburst.

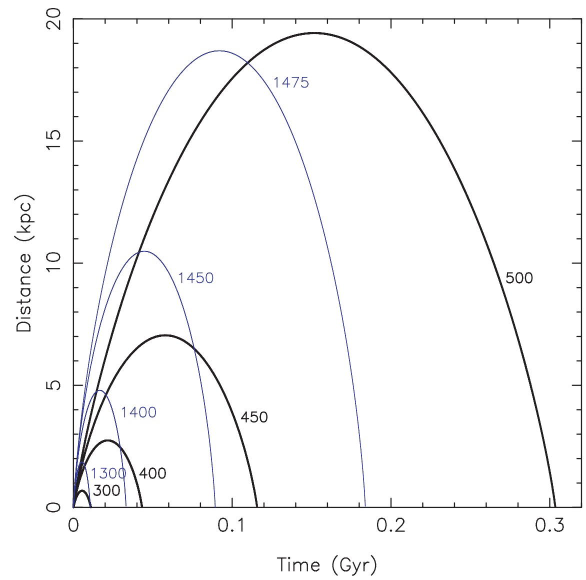

Figure 3. Trajectory of a kicked SBH in two models for the mass distribution of the companion galaxy (Table 1). Black (thick) curves: Model 1 and blue (thin) curves: Model 2. Curves are labelled by V_{kick} in km s^{-1}.

(3) A large V_{kick} implies that the ejected SBH will carry very little mass with it as it departs the galaxy. Material orbiting the SBH with velocity $v \gg V_{kick}$ before the kick will experience the kick as an adiabatic perturbation and will 'instantaneously' acquire the specific momentum of the SBH. This argument suggests that the SBH will carry with it the mass contained initially within a region whose size is less than r_{eff}, the radius at which the orbital velocity around the SBH is equal to V_{kick}, or

$$r_{eff} = \frac{GM_\bullet}{\sigma^2}\left(\frac{V_{kick}}{\sigma}\right)^{-2} \approx 10 M_8 \sigma_{200}^{-2}\left(\frac{V_{kick}}{\sigma}\right)^{-2} \text{ pc}, \quad (1)$$

with $M_8 \equiv M_\bullet/10^8$ M$_{\odot}$ and $\sigma_{200} \equiv \sigma/200$ km s^{-1}. Since $M_8 \approx 1$ (see below) and $V_{kick} \gtrsim 3\sigma$ (Fig. 3), the entrained region will be of the order of 1 pc or less in size. This is probably sufficient to include the broad-line region (BLR) gas, which is expected to have a size $\sim$0.3 pc based on the empirical scaling relation between BLR size and 5007- Å luminosity (Greene & Ho 2005; Kaspi et al. 2005), but not larger structures.

4 SIZE OF THE NARROW-LINE REGION

The radius of the narrow-line region (NLR) can be estimated from the ionization parameter and density of the emitting gas and the ionizing luminosity of the quasi-stellar object (QSO). For an ionizing photon luminosity, Q, the ionization parameter in gas of density n at a distance r from the source can be defined as $U = Q/(4\pi R^2_{\rm NLR}\, nc)$. We estimate the ionizing photon luminosity by extrapolating the slope of the far UV (∼600–1200 Å) continuum as determined by Scott et al. (2004) from *FUSE* observations. After corrections for interstellar extinction and absorption, Scott et al.'s power-law ($f_\nu \propto \nu^{-\alpha}$) fit yields a spectral index $\alpha = -1.2 \pm 0.1$ and a flux at 1000 Å of 5.25×10^{-27} erg s^{-1} cm^{-2} Hz^{-1}. HE0450−2958 has a steep soft X-ray continuum, with a photon index $\Gamma = 3.1$ in the 0.1–2 keV *ROSAT* band (Brinkmann, Yuan & Siebert 1997). Therefore, we extrapolate the UV power law to a high-energy cut-off of 0.1 keV. Adopting a luminosity distance of 1458 Mpc (assuming $H_0 = 71$ km s^{-1} Mpc^{-1} and a matter density parameter $\Omega_{\rm m} = 0.27$), the integration yields $Q \approx 1.2 \times 10^{56}$ photons s^{-1}.

The values of U and n were inferred from diagnostic line ratios measured from the spectrum of the quasar, which was extracted from an aperture of width 10 pixels (2 arcsec) in the spatial direction. The only potentially significant source of contamination is the nearby star, but this contributes <1 per cent of the flux density in the aperture. The Galactic extinction in the line of sight to HE0450−2958 is $E(B - V) = 0.015$ mag (Schlegel, Finkbeiner & Davis 1998), implying corrections ⩽5 per cent to the optical fluxes. There is no evidence for significant intrinsic reddening of the quasar spectrum.

The gas density was obtained from the relative intensities of the [S II]λλ 6717, 6731 doublet. Although partially blended in the spectrum, Gaussian fits to the lines are well constrained and yield a ratio $I_{6717}/I_{6731} = 1.01 \pm 0.05$. This corresponds to a density $n \approx 1000$ cm^{-3}.

We determined the ionization parameter from the ratio of the [O II]λ3727 and [O III]λ5007 lines (Baldwin, Phillips & Terlevich 1981). The intensity ratio measured from the spectrum is $I_{3727}/I_{5007} = 0.13 \pm 0.05$. Using the empirical relation between this ratio and the ionization parameter given by Penston et al. (1990), we obtain $U \approx 0.014$. This value is broadly consistent with the more recent photoionization models presented by Groves, Dopita & Sutherland (2004).

Combining estimates for Q, n and U, we arrive at a radius $R_{\rm NLR} \approx 1.5$ kpc. This represents a spatial average, since we have used integrated fluxes of emission lines representing different ionization states. Moreover, the relationship between U and I_{3727}/I_{5007} is somewhat model-dependent and extrapolating the far UV power law is, at best, a crude (although conservative) representation of the extreme UV continuum. Based on these considerations, the inferred value of $R_{\rm NLR}$ may be uncertain by a factor of ∼2. Even given the uncertainty, however, it is clear that $R_{\rm NLR}$ exceeds $r_{\rm eff}$ by roughly two orders of magnitude. It is unsurprising that the NLR in a relatively luminous quasar extends to a few kpc. Direct imaging of bright, low-redshift quasars in [O III] with *HST* reveals extended emission ranging from 1.5 to 10 kpc from the nucleus (Bennert et al. 2002). A NLR sufficiently compact to remain bound to the SBH would necessarily have extreme physical conditions: the product nU would have to be a factor of 10^4 greater than is implied by the spectral diagnostics. The spectrum would be dominated by high-ionization, high-critical density lines; we would not expect to see either the [O II] or the [S II] doublets.

Such a large size for the NLR rules out the possibility that the NLR gas would remain bound to the SBH after ejection from the ULIRG. Post-ejection accretion of the NLR gas from a cloud is also unlikely, since the radius of the Bondi accretion column, $r_{\rm acc}$, is given by an equation similar to equation (1), after replacing $V_{\rm kick}$ by the relative velocity between SBH and gas cloud, implying $r_{\rm acc} \ll 1$ kpc unless the ejected SBH has fortuitously matched velocities with the cloud.

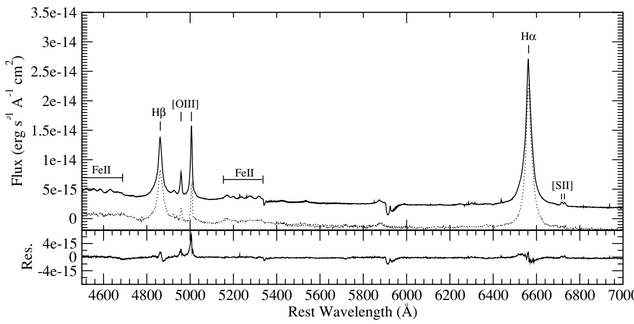

Figure 4. Comparing the quasar spectrum with that of PG1211+143, a radio-quiet quasar with steep *X*-ray spectral index that is classified spectroscopically as a NLS1 (Constantin & Shields 2003). HE0450−2958 is plotted in absolute flux units, PG1211+143 in absolute units minus 5×10^{-15} erg s^{-1} Å^{-1} cm^{-2}. Residuals are plotted along the bottom with a solid straight line highlighting zero.

5 MASS OF THE BLACK HOLE AND IMPLICATIONS FOR THE HOST GALAXY LUMINOSITY

As shown in Fig. 4, *HE0450−2958 exhibits characteristics which unambiguously identify it as a narrow-line Seyfert 1* (NLS1; Grupe 2004). Specifically, its broad Balmer lines have values of full width at half-maximum (FWHM) ≈1300 km s^{-1} (the conventional definition requires FWHM < 2000 km s^{-1}; Osterbrock & Pogge 1985), it has strong optical Fe II emission features and, as already noted, it has a steep soft X-ray photon continuum. The currently favoured picture of NLS1s is that they represent an extreme AGN population characterized by relatively low-mass SBHs but high accretion rates (Peterson et al. 2000; Boroson 2002) – possibly substantially super-Eddington (Boller 2005). It follows that estimating $M_\bullet$ from the quasar luminosity assuming a sub-Eddington accretion rate, as was done by Magain et al. (2005), is likely to be misleading. Here, we adopt what we consider to be a more robust approach, and estimate a virial mass based on the velocity dispersion (v) and radius ($R_{\rm BLR}$) of the BLR: $M_{\rm BH} \sim v^2 R_{\rm BLR}/G$ (Wandel, Peterson & Malkan 1999; Kaspi et al. 2000; Vestergaard 2002).

In this method, the BLR velocity dispersion is derived from the broad-line widths while the BLR radius is inferred from the radius–luminosity relation derived from reverberation mapping (Kaspi et al. 2000; Peterson et al. 2004). Here, we use the recent revision of Kaspi et al. (2000)'s virial formula presented by Greene & Ho (2005). This requires measurements of the Hβ FWHM($v = \sqrt(3)/2 \times$ FWHM) and the continuum luminosity at 5100 Å (λL_{5100}). Our measurements of these quantities yield FWHM(Hβ) ≈1270 km s^{-1} and $\lambda L_{5100} \approx 4.6 \times 10^{45}$ erg s^{-1}, respectively.[3] Inserting these values into equation (5) of Greene & Ho, we obtain $M_{\rm BH} = (9 \pm 1) \times$

[3] Our value of FWHM(Hβ) may be underestimated if there is a significant contribution to the line flux from the NLR. If we assume that the narrow Hβ has a flux 10 per cent that of the [O III]λ5007 line (a value typical of Seyfert galaxies) and the same width, the FWHM of the *broad* Hβ line is ≈1500 km s^{-1}. This would increase our inferred black hole mass by about 20 per cent, but does not alter our conclusions.

10^7 M$_\odot$. Greene & Ho's alternative virial formula, which employs the luminosity and FWHM of the broad Hα line yields a consistent result, albeit with greater uncertainty: $M_{\rm BH} = (6^{+5}_{-3}) \times 10^7$ M$_\odot$. These masses are subject to a systematic uncertainty of a factor of $\sim$3 related to the poorly known structure, kinematics and aspect of the BLR (e.g. Onken et al. 2004). Nevertheless, at face value, the virial method yields an SBH mass that is an *order of magnitude* less than the value $M_\bullet \approx 8 \times 10^8$ M$_\odot$ adopted by Magain et al. (2005).

The host galaxies of NLS1s are spirals, but relatively little is known about their systematic properties. The tight correlation between bulge velocity dispersion and SBH mass that characterizes quiescent elliptical galaxies and bulges (Ferrarese & Merritt 2000) also appears to be valid for the bulges of active galaxies, including NLS1s (Ferrarese et al. 2001; Botte et al. 2005). Adopting $M_\bullet = 9 \times 10^7$ M$_\odot$, we infer a bulge velocity dispersion $\sigma \approx 180$ km s^{-1}. Near-infrared (near-IR) bulge luminosities also correlate tightly with $M_\bullet$ (Marconi & Hunt 2003); we infer a K-band absolute magnitude for the stars in the bulge of $M_{K,\rm bulge} \approx -23.4$. Visual bulge magnitudes are more poorly correlated with $M_\bullet$. Adopting the Ferrarese & Ford (2005) relation gives an absolute blue magnitude $M_{B,\rm bulge} = -18.9 \pm 0.5$; alternately, applying a $B - K$ colour correction of 4.0 to M_K (Peletier & Balcells 1996) gives $M_{B,\rm bulge} \approx -19.4$. Computing $M_{B,\rm bulge}$ directly from σ via the Faber & Jackson (1976) relation gives a similar value. Even more uncertain is the predicted total (bulge plus disc) luminosity of the host. Visual disc-to-bulge ratios for early-type spiral galaxies, the most common morphological type for Seyferts (Whittle 1992), are typically $\sim$1.5 (Simien & de Vaucouleurs 1986), yielding a total visual magnitude $M_V \approx -21$. While very uncertain, this estimate is 2.0–2.5 mag fainter than Magain et al. (2005)'s estimate ($-23.5 \leqslant M_V \leqslant -23.0$) based on a $\sim$10$\times$ larger assumed value of $M_\bullet$, and consistent with their conclusion that the host galaxy must be at least 4–5 mag fainter than the quasar ($M_V = -25.8$).

6 CONCLUSIONS

The HE0450−2958 system consists of a ULIRG that experienced a major starburst $\sim$10^8 yr ago, situated at $\sim$7 kpc projected separation from a quasar having the spectral characteristics of a narrow-line Seyfert 1; the line-of-sight velocity difference between the two systems is consistent with zero. The quasar host, presumably a disc galaxy, contains a SBH with mass $\sim$10^8 M$_\odot$ and its absolute magnitude is predicted to be $M_V \approx -21$, consistent with the upper limits on the quasar host luminosity cited by Magain et al. (2005). The SBH that powers the active nucleus appears to be accreting at a super-Eddington rate, $L/L_{\rm E} \approx 3$, similar to the accretion rates inferred in other NLS1s. Ejection of the SBH from the ULIRG is unlikely for a number of reasons, the strongest of which is the presence of narrow emission-line gas at the same redshift as the quasar nucleus; this gas could not have been retained if the SBH was ejected from the companion galaxy. We find no compelling evidence that the quasar in HE0450−2958 is either a 'naked' SBH ejected from its host galaxy, or it has an anomalously dark host galaxy.

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