Mon. Not. R. Astron. Soc. **398,** L73–L77 (2009) doi:10.1111/j.1745-3933.2009.00714.x

SDSSJ092712.65+294344.0: a candidate massive black hole binary

M. Dotti,[1★] C. Montuori,[2] R. Decarli,[3] M. Volonteri,[1] M. Colpi[2] and F. Haardt[3]

[1]*Department of Astronomy, University of Michigan, Ann Arbor, MI 48109, USA*
[2]*Università degli Studi di Milano-Bicocca, Piazza della Scienza 3, 20126 Milano, Italy*
[3]*Università degli Studi dell'Insubria, Via Valleggio 11, 22100 Como, Italy*

Accepted 2009 July 5. Received 2009 July 2; in original form 2008 September 19

ABSTRACT

In this Letter, we explore the hypothesis that the quasar SDSSJ092712.65+294344.0 is hosting a massive black hole binary embedded in a circumbinary disc. The lightest, secondary black hole is active, and gas orbiting around it is responsible for the blue-shifted broad emission lines with velocity off-set of 2650 km s^{-1}, relative to the galaxy rest frame. As the tidal interaction of the binary with the outer disc is expected to excavate a gap, the blue-shifted narrow emission lines are consistent with being emitted from the low-density inhomogeneous gas of the hollow region. From the observations, we infer a binary mass ratio $q \approx 0.3$, a mass for the primary of $M_1 \approx 2 \times 10^9\,\mathrm{M}_{\odot}$, and a semimajor axis of 0.34 pc, corresponding to an orbital period of 370 years. We use the results of cosmological merger trees to estimate the likelihood of observing SDSSJ092712.65+294344.0 as recoiling black hole or as a binary. We find that the binary hypothesis is preferred being 100 times more probable than the ejection hypothesis. If SDSSJ092712.65+294344.0 hosts a binary, it would be the one closest massive black hole binary system ever discovered.

Key words: black hole physics – galaxies: kinematics and dynamics – galaxies: nuclei – quasars: individual: SDSSJ092712.65+294344.0.

1 INTRODUCTION

If massive black holes (MBHs) are ubiquitous in galaxy spheroids and galaxies experience multiple mergers during their cosmic assembly, MBH *binaries* (MBHBs) should be common, albeit transient features of galactic bulges. Observationally, the paucity of dual active nuclei points towards rapid inspiral of the MBHs down to parsec scales where they form a gravitationally bound pair (Mayer et al. 2007). After birth, the MBHB further hardens under the action of gas/dynamical and/or stellar torques (Begelman, Blandford & Rees 1980) and depending on their efficiency (Milosavljevic & Merritt 2001; Armitage & Natarajan 2002; Berczik et al. 2006; Colpi et al. 2007; Perets, Hopman & Alexander 2007; Sesana, Haardt & Madau 2007) the binary may remain in its hard state for a relatively long time, before coalescing under the action of gravitational waves.

MBHBs can coalesce shortly, and a clear prediction of general relativity is that the relic MBH receives a kick in response to the asymmetric pattern of gravitational waves emitted just prior coalescence. For slowly spinning MBHs recoil velocities of a few $\times 100\,\mathrm{km\,s^{-1}}$ were predicted, but recent numerical advances in general relativity have indicated that velocities as extreme as $\sim$4000 km s^{-1} can be attained for maximally rotating Kerr MBHs with spin vectors lying in the orbital plane (Schnittman & Buonanno 2007; Lousto & Zlochower 2009 and references therein). These velocities far exceed the escape speed even from the brightest galaxies and for this reason MBHs receding from their parent host have been considered as electromagnetic targets of a coalescence event (Loeb 2007; Volonteri & Madau 2008; Devecchi et al. 2009).

Recently, the quasar SDSS J092712.65+294344.0 (hereafter SDSSJ0927; Adelman-McCarthy et al. 2007) has been considered as the first candidate of a recoiling MBH by Komossa, Zhou & Lu (2008, KZL hereafter). SDSSJ0927 exhibits, in its optical spectrum, two distinct sets of lines offset by 2650 km s^{-1} relative to each other. The first set of narrow emission lines (NELs) has redshift $z = 0.713$ (identified by KZL as the redshift of the galaxy that hosted the MBH at its birth). We will refer to this set that is typical of an AGN as rest-frame NELs (rf-NELs; the red NELs in KZL). The rf-NELs do not show any evidence of ionization stratification (as in few other quasars), possibly because these lines are not resolved in the SDSS spectrum. The second set of lines comprises two blueshifted systems featuring different full width at half-maximum (FWHM): the broad Mg II and Balmer emission lines (b-BELs) with FWHM $\approx$ 4000 km s^{-1}, and the high-ionization narrow lines (b-NELs) with FWHM $\approx$ 460−2000 km s^{-1}, both consistent with a redshift $z = 0.698$. The b-BELs and b-NELs refer to a line system in coherent motion relative to the rest frame of the host, with a light-of-sight velocity of 2650 km s^{-1}. In KZL, the permitted b-BELs result from a broad line emission system gravitationally

★E-mail: mdotti@umich.edu

bound to the recoiling MBH, while b-NELs remain problematic for the reasons explained in Section 2.

The aim of this Letter is to suggest an alternative interpretation to SDSSJ0927: that SDSSJ0927 is an unequal-mass MBHB embedded in a circumbinary gaseous disc at the centre of its host galaxy. In Sections 3 and 4, we describe the main properties of the model that are requested to reproduce the observed properties of b-BELs. In Section 5, we discuss the possible origin of b-NELs and of their Doppler shift. In Section 6, we present our conclusions.

2 LIMITATIONS OF THE EJECTION HYPOTHESIS

The origin of the b-NELs and the likelihood of observing a recoiling MBH with a speed close to its maximum are the main concern of this section.

First, we note that the recoil hypothesis by KZL seems unable to explain all properties of the b-NELs observed in SDSSJ0927. The FWHM of the b-NELs is larger than that of the rf-NELs, and of typical FWHMs of NELs observed in AGNs. By contrast, the FWHM of b-NELs is not large enough to assure that the emitting gas is bound to the recoiling MBH, although this should be the case as the b-NELs have the same Doppler shift as the b-BELs. KZL suggest that the b-NELs are emitted by the gas shocked in the interaction of the MBH with the interstellar medium. In this case, however, there is no reason why the speed of the shocked gas should equal to that of the MBH (Devecchi et al. 2009). Alternatively, KZL consider that b-NELs are emitted in the outer part of the accretion disc with substantial radial spreading and/or in an unspecified kind of outflow. This last possibility was discussed in details by Bogdanovic, Eracleus & Sigurdsson (2009). They find that mass outflows strongly reduce the density of the inner regions of the accretion disc implying a low rate of gas accretion on to the MBH. In this case, the luminosity would be much weaker than observed, unless the kicked MBH is more massive than $5 \times 10^9\,\mathrm{M_\odot}$.

Secondly, we remark that the probability of observing an ejected MBH with the properties of SDSSJ0927 depends sensitively on the specific frequency associated to MBHB mergers able to form a remnant with the required large mass ($M_{\rm BH}$), and on the probability for the remnant to receive such a high recoil velocity, that is $v >$ 2500 km s^{-1} (we conservatively adopt this lower limit to the recoil velocity, which provides an upper limit to the detection probability). The latter constraint strongly depends on the MBH spin magnitudes and orientations with respect to the orbital plane, and on the mass ratio of the binary, $q \equiv M_2/M_1 \leqslant 1$ as illustrated in Fig. 1. We model the recoil using the two available fits to the recoil velocity based on the latest numerical relativity results (Lousto & Zlochower 2009). Non-spinning holes always recoil with velocities below 200 km s^{-1}, and the recoil increases with increasing spin. In general, the recoil is maximized for spin vectors lying in the orbital plane.

We can estimate the probability of detection of an ejection with $v > 2500\,\mathrm{km\,s^{-1}}$ by convolving the probability of large recoils (shown in Fig. 1) with the merger rate of MBHBs. We can compute the number of MBH coalescences observable across the entire sky, based on the merger rates by Volonteri, Haardt & Madau (2003) and Volonteri & Madau (2008). For a statistical sample of MBH mergers, our models provide the masses of the merging MBHs and the redshift of the event. We select coalescences in the redshift range $0.5 < z < 1$ (compatible with the redshift of SDSSJ0927), further imposing a total binary mass $M_{\rm BH} > 5 \times 10^8\,\mathrm{M_\odot}$ (i.e. the mass of the hypothetical recoiling MBH as discussed in KZL). Marginalizing over MBH masses and q, the highest rate of successful recoils,

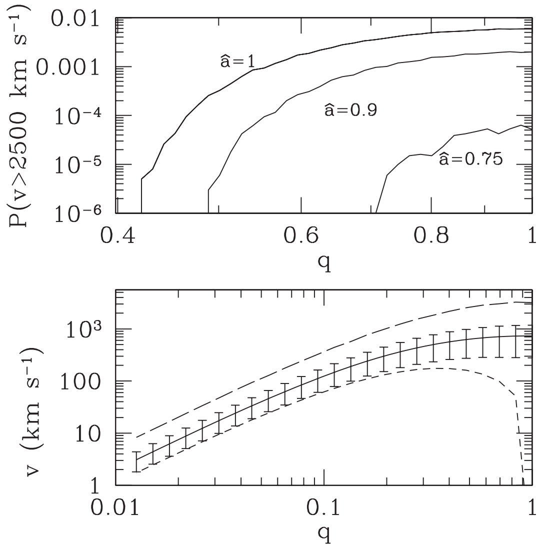

Figure 1. Bottom panel: recoil velocity as a function of the binary mass ratio $q \equiv M_2/M_1$, for maximally Kerr holes with $\hat{a} = 1$. Long-dashed curve: maximum recoil. Short-dashed curve: minimum recoil. Solid curve: mean recoil, with 1σ scatter. In all the cases, the recoil velocity is averaged over 10^6 orbital configurations for each q. Top panel: probability for recoils faster than $v > 2500\,\mathrm{km\,s^{-1}}$ as a function of q, for three representative spin values (both holes are assumed to have the same spin), assuming isotropic orbital parameters. No recoil with $v > 2500\,\mathrm{km\,s^{-1}}$ is possible for MBH spin parameters $\hat{a} < 0.65$.

$v > 2500\,\mathrm{km\,s^{-1}}$, is found by imposing maximal values for the dimensionless spin parameters, $\hat{a} = 1$ for both holes; the spins initially lie in the orbital plane pointing in opposite directions. The rate is $5 \times 10^{-6}\,\mathrm{yr^{-1}}$. The requirement that the b-NELs come from a spreading accretion disc however implies $M_{\rm BH} > 5 \times 10^9\,\mathrm{M_\odot}$. For these masses, the rate of events with $v > 2500\,\mathrm{km\,s^{-1}}$ decreases by one order of magnitude. This set of assumptions, maximizing the recoil over the orbital parameters, is mostly dependent on the mass ratio q. We need mass ratios $q \sim 1$ to obtain recoils above $10^3\,\mathrm{km\,s^{-1}}$. Equal mass mergers are however rare (e.g. Sesana et al. 2005; Volonteri & Madau 2008); the distribution of mass ratios for $M_{\rm BH} \geqslant 5 \times 10^8\,\mathrm{M_\odot}$ at $0.5 < z < 1$ peaks at $q = 0.3$ and decreases steeply at larger q. Assuming MBHs with equal spins, $\hat{a} = 1$, isotropically distributed, and $M_{\rm BH} > 5 \times 10^8\,\mathrm{M_\odot}$, the expected rate decreases to less than $10^{-6}\,\mathrm{yr^{-1}}$. The rate of ejections decreases drastically with decreasing spin magnitude, and it is zero for any orbital-spin configuration if $\hat{a} < 0.65$.

3 THE MBH BINARY MODEL

In our model, SDSSJ0927 hosts a MBHB surrounded by a circumbinary thin disc feeding the secondary MBH. In the tidal interaction of the binary with the gas a gap, that is a low-density region surrounding the binary, opens.

It is known that, for MBHBs with $q \sim 1$, M_2 is massive enough to strongly perturb the surrounding disc, creating over few orbital periods an annular low-density region, commonly referred as ‘gap’. During this phase most of the inner disc is accreted by the primary (Syer & Clarke 1995; Ivanov, Papaloizou & Polnarev 1999; Dotti et al. 2006b), preventing long lasting accretion events on to M_1.

As shown in Section 4, in order to explain the spectrum of SDSSJ0927, $q \approx 0.3$. Given this constraint, we expect that the tidal interaction of the binary with the viscous disc will leave M_1 in

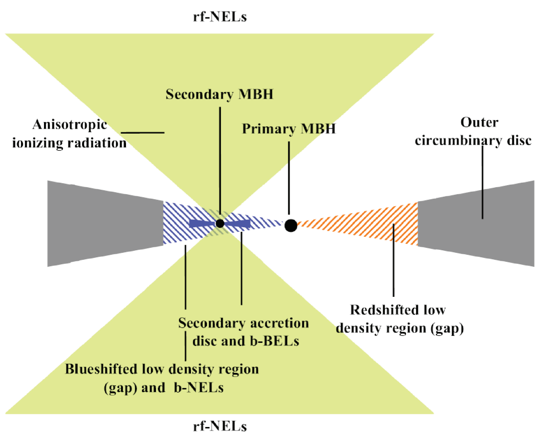

Figure 2. Sketch of the MBHB circumbinary disc structure in the nucleus of SDSSJ0927.

a state of low activity. M_2, remaining in closer gravitational contact with the inner rim of the outer disc, moves at low speed relative to the higher density reservoir of gas, thus sweeping up an accretion stream that inflows from the edge of the gap. This continuous refuelling supplies an accretion disc around M_2, and allows for luminous accretion events during the orbital decay of M_2 (Hayasaki, Mineshige & Sudou 2007; Cuadra et al. 2009). The position of the inner edge of the outer circumbinary disc for $q \approx 0.3$ (of interest for the scope of the paper) is known to lie between $\simeq$1.5–2a, where a is the semimajor axis of the MBHB. As for large q, migration occurs on time-scales much longer than the viscous time in the outer disc (Ivanov et al. 1999), this binary can be long-lived and we work under this hypothesis. A sketch of the model is shown in Fig. 2.

We will consider M_2 the only accreting MBH of the binary. In this model, the rf-NELs are emitted from the 'standard' large-scale narrow line region that extends around the binary for $\sim$1 kpc, while the b-BELs are produced in the broad line region gravitationally bound to M_2, and can be blueshifted or redshifted depending on the orbital phase of the secondary. The b-NELs come from a region of the gap near M_2, where forbidden lines are emitted because of the low density of the gas. Since M_2 and the gas orbiting in the gap at comparable annuli are subject to the same gravitational potential of M_1, both move with approximately the same Keplerian velocity. Accordingly, the same blueshift for the b-BELs and b-NELs can be explained if M_2 emits an anisotropic ionizing radiation normal to the plane of the discs so that the ionizing photons interact only with the gas in the gap near M_2. This is naturally achieved if, for example, the accretion flow around M_2 is a standard Shakura–Sunyaev accretion disc. Indeed, cosine-like behaviour of the thermal ionizing flux, coupled to the small solid angle subtended by the disc assures that the ionization parameter of the gap gas not in the immediate vicinity of M_2 is relatively low.

4 ORBITAL PARAMETERS

In this section, we use some of the observed properties of SDSSJ0927 (the blueshift and the FWHM of the b-BEL, and the monochromatic luminosity at 5100 Å) to constrain the dynamical properties of the hypothetical MBHB. The compatibility of the model with the other observed spectral features (in particular, the blueshift and the flux of the b-NELs) is discussed in Section 5. Given the large blueshift of the observed b-NELs and b-BELs, corresponding to a high velocity of the accreting MBH, we assume that the active MBH is M_2, the lightest hole, and that its mass is $6 \times 10^8\,\mathrm{M}_\odot$ as inferred in KZL. We will further assume that the binary is moving on a (quasi) circular orbit.

The first constraint to be verified is that the observed broad line region responsible for the b-BELs is bound to M_2, and is not tidally stripped by M_1. This condition can be rewritten as $R_{\rm BLR} < R_2$, where $R_{\rm BLR} \approx 0.1$ pc (KZL) is the radius of the BLR and R_2 is the Roche lobe radius of M_2. We estimate R_2 using the approximation in Eggleton (1983), and impose:

$$\frac{R_{\rm BLR}}{a} < \frac{R_2}{a} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1+q^{1/3})}, \tag{1}$$

where a is the semimajor axis of the MBHB.

The observed velocity, $v_{\rm obs}$, of M_2 depends on M_1, a, and the orientation of the plane of the binary in the sky:

$$v_{\rm obs} = v_2 \sin i \cos\phi = \sqrt{\frac{GM_2}{aq(1+q)}} \sin i \cos\phi, \tag{2}$$

where v_2 is the orbital velocity of M_2 relative to the centre of mass, $i \in [0^\circ, 90^\circ]$ is the angle between the line of sight and the direction normal to the orbital plane, and $\phi \in [0^\circ, 360^\circ]$ is the phase of the orbit. From equations (1) and (2), and assuming $\cos\phi = 1$ in order to minimize M_1, we obtain

$$\frac{GM_2}{v_{\rm obs}^2 R_{\rm BLR}} \sin^2 i > q^{1/3}(1+q)\frac{0.6q^{2/3} + \ln(1+q^{1/3})}{0.49}. \tag{3}$$

The fraction on the left-hand side of equation (3) is constrained by the observations while the right-hand side is a monotonically increasing function of q. Given the inclination i, equation (3) defines a maximum q, and a corresponding minimum M_1. We focus on the minimum mass of M_1, obtained for the largest value of $\sin i$, that is fitting all the observational constraints. Assuming that the unification model for AGNs (Urry & Padovani 1995) remains valid for this peculiar object, the observation of the b-BELs limits the maximum value of the inclination of the orbital plane to $i_{\rm max} \approx 40^\circ$, which implies $q \approx 0.35, a \approx 0.34$ pc, and $M_1 \approx 1.7 \times 10^9\,\mathrm{M}_\odot$, value consistent with the observed high mass end of the MBH mass function. These values correspond to an orbital period of 370 years. The time-scale for two MBHs in SDSSJ0927 to reach final coalescence due to gravitational wave emission is 3×10^9 yr, shorter than the Hubble time. If the binary model will be confirmed, this is proof of the existence of a dynamical process able to overcome the so called 'last parsec problem' and drive MBHBs to the final coalescence.

Using the FWHM of [O III] as a tracer of the stellar velocity dispersion, σ_*, and assuming the $M_{\rm BH}$–σ_* relation (Ferrarese & Ford 2005 and references therein), we obtain for M_1 a mass $\sim$3 orders of magnitude smaller than our estimate. This would be in contrast with the high luminosity of SDSSJ0927, which would imply extremely super Eddington luminosity ($\sim 10^3$ Eddington). On the other hand, in the MBHB scenario, the dynamics of gas may not be representative of the galactic potential, due to the recent galaxy merger.

To estimate the likelihood of the detection of a MBHB with the properties inferred by our model, we use the same theoretical merger-tree for cosmological MBHB used in Section 2. We again impose limits on the redshift range ($0.5 < z < 1$), but now the binary model constrains the masses of the binary members, rather than the mass of the remnant. We therefore compute the probability that an observer at $z = 0$ detects binaries with $M_1 > 1.5 \times 10^9\,\mathrm{M}_\odot$ and $M_2 > 5 \times 10^8\,\mathrm{M}_\odot$ across the entire sky. The observable merger rate corresponds to $\sim 10^{-4}$ binaries per year, a value 20 times larger than the expected rate of ejections obtained using the most favourable conditions for high kick velocity, as discussed in Section 2.

5 NARROW EMISSION FROM THE GAP

Our model suggests that the b-NELs are produced from the low-density gas in the gap region near M_2. This assumption explains the blueshift of these lines, as we discussed in Section 3. For consistency, we need to constrain the properties of the gas in the gap, and check if its physical status is consistent with the production of b-NELs and with the energy flux observed at these frequencies.

We assume that the gas in the gap is mostly ionized, so that we can derive the gas properties from the luminosity of the Balmer lines. Under the hypothesis of isotropic emission, the total luminosity of the Hβ line is

$$L_{\mathrm{H}\beta} = 4\pi D_L^2 F_{\mathrm{H}\beta} = h\nu_{\mathrm{H}\beta} n_{\mathrm{p}} n_{\mathrm{e}} \alpha_{\mathrm{H}\beta} V_{\mathrm{gap}}, \quad (4)$$

where $D_L = 4127$ Mpc is the luminosity distance of SDSSJ0927, $F_{\mathrm{H}\beta} = 1.9 \times 10^{-16}$ erg s^{-1} cm^{-2} is the flux of the b-NEL component of the Hβ line (that we obtained directly by fitting the rest frame, dereddened SDSS spectrum), h is the Planck constant, $\nu_{\mathrm{H}\beta}$ is the frequency of the Hβ photons, n_{p} and n_{e} are the densities of protons and electrons respectively, and $\alpha_{\mathrm{H}\beta}$ is the recombination coefficient. In order to estimate n_{e}, we need to constrain the volume of the emitting region, V_{gap}, that we assume to be half of the total volume of the gap in which M_2 resides (see discussion in Section 3)

$$V_{\mathrm{gap}} = 2\pi \int_0^{R_{\mathrm{gap}}} r^2 \frac{H(r)}{r}\, \mathrm{d}r, \quad (5)$$

where $H(r)$ is the thickness of the low-density gaseous structure at a radius r and $R_{\mathrm{gap}} \approx 2a$. We use the standard assumption that $H(r)/r = c_{\mathrm{s}}/v_{\mathrm{Kepl}}$, where c_{s} is the local sound speed of the plasma and v_{Kepl} is the Keplerian velocity of the gas due to the potential well of M_1. In this first estimate, we assume $T \approx 10^4$ K, that corresponds to $H(r)/r \approx 5 \times 10^{-3}$. Replacing this ratio in equation (5) and using equation (4) we obtain $n_{\mathrm{e}} \approx 8 \times 10^6$ cm^{-3}.

A different estimate for n_{e} can be obtained assuming that the vertical support of the low density gas in the gap is due to a supersonic turbulent motion of the plasma of the order of 1/2 the average FWHM of the b-NELs. In this second estimate, we assume $v_{\mathrm{turb}} \approx$ 200 km s^{-1}, corresponding to $n_{\mathrm{e}} \approx 2 \times 10^6$ cm^{-3}. We emphasize that these estimates must be considered as a lower limit because the gas can be clumpy (so that only a fraction of the irradiated gas will contribute consistently to the Hβ emission), and because the anisotropic radiation produced in the accretion disc of M_2 can irradiate less than 1/2 of the gap.

Both estimates of n_{e} are much smaller than the density expected for a standard α-disc around M_1 at $r \sim a$, indicating the presence of a gap, confirming our expectations. An additional, independent constraint on n_{e} can be obtained from the flux ratios of different Oxygen lines, in particular the [O II]$_{3727}$ doublet and the [O III]$_{4363,4959,5007}$ lines (see e.g. Osterbrock & Ferland 2006 and references therein). The ratio between the two components of the [O II] doublet cannot be employed here, since the lines are practically unresolved. We restrict our analysis to the [O III] lines. Since the b-[O III]$_{5007}$ and the rf-[O III]$_{4959}$ are blended, we assume a factor of 3 between the fluxes of the [O III]$_{5007}$ and [O III]$_{4959}$ lines in both systems (Osterbrock & Ferland 2006). We compare the observed line flux ratios to the expectations for a gas in photoionization equilibrium, which yields $T_{\mathrm{e}} = 10^4 - 2 \times 10^4$ K. For $T_{\mathrm{e}} = 10^4$ K, we obtain $n_{\mathrm{e}} = (2.5^{+1.0}_{-0.5}) \times 10^6$ cm^{-3}. This density is fully consistent with the predictions from the Hβ luminosity. Increasing $T_{\mathrm{e}}, n_{\mathrm{e}}$ decreases. At the maximum temperature allowed by the photoionization equilibrium, 2×10^4 K, the b-system has $n_{\mathrm{e}} = (4^{+2}_{-1}) \times 10^5$ cm^{-3}. Typically, [O III] lines are produced in regions with much lower density (narrow line regions, $n_{\mathrm{e}} \simeq 10^3$ cm^{-3}). SDSSJ0927 is indeed confirmed to be a peculiar system.

We check our results by calculating if the production of a forbidden line such as [O III] in such high-density regions is self-consistent. We therefore consider the contribution of both collisional excitations and de-excitations when computing the luminosity of [O III] lines. This calculation depends on the volume of the emitting region, on n_{e}, and on the density of [O III] ions, $n_{[\mathrm{O\,III}]}$. Via detailed equilibrium balance, with the temperatures and electron densities derived above, we find $n_{[\mathrm{O\,III}]} \simeq$ 2–4 orders of magnitude lower than n_{e}. This ratio is fully consistent with standard metallicities in quasars hosts.

This consideration can explain the presence of both Hβ and forbidden lines, but the [O II] doublet. [O II] emission is not consistent with such high densities because the [O II] critical density for collisional de-excitation is $n_{\mathrm{e}} \lesssim 10^4$ cm^{-3}. The detection of [O II] lines suggests that the gap is filled with an inhomogeneous, cloudy medium. The source of this inhomogeneity may be the competition between the gas inflow from the circumbinary disc and the periodic perturbation exerted by the MBHB (see, e.g. Hayasaki et al. 2007; Bogdanovic et al. 2009; Cuadra et al. 2009). In an inhomogeneously filled gap, Hβ lines are emitted in the highest density regions ($n_{\mathrm{e}} \gtrsim 2 \times 10^6$ cm^{-3}), while [O III] and [O II] lines are produced by intermediate (3×10^5 cm$^{-3} \lesssim n_{\mathrm{e}} \lesssim 3.5 \times 10^6$ cm^{-3}) and low ($n_{\mathrm{e}} \lesssim 10^4$ cm^{-3}) density regions, respectively.

6 DISCUSSION AND CONCLUSIONS

The binary hypothesis for SDSSJ0927 relies on a simple set of assumptions. We can relax the assumption of circular orbits, and assume a non-zero eccentricity ($e < 0.5$), expected to be present after gap opening (Armitage & Natarajan 2005; Dotti, Colpi & Haardt 2006a; Dotti et al. 2007; Cuadra et al. 2009). Eccentricities of this magnitude are still compatible with the binary model. Larger values are instead unlikely in SDSSJ0927: if the binary has a large eccentricity and M_2 is near apocentre, an extremely massive M_1 is needed to justify such a large orbital velocity. On the other hand, Shields, Bonning & Salviander (2009) set an upper limit on the change of the Doppler shift of the b-BEL system (<10 km s^{-1} yr^{-1}). In the binary scenario, this prevents M_2 to be caught too close to the pericentre. We note that assuming circular orbit and the set of MBHB parameters discussed above, the b-BEL system moves only of 4.2 km s^{-1} over three years, corresponding to an average shift of $\approx$1.4 km s^{-1} yr^{-1}.

SDSSJ0927 is clearly exceptional. Either it is the first example of an MBH ejected from its nucleus due to the gravitational recoil or it harbours one of the smallest separation MBHBs ever detected. Only the possible binary in OJ287 could have closer MBHs ($\sim$4.5 $\times$ 10^{-2} pc, Valtonen 2007). SDSSJ0927 would provide clear evidence that MBHBs can indeed reach coalescence in less than a Hubble time, and that Nature is able to solve the last-parsec problem. If the model discussed in this letter is confirmed, SDSSJ0927 will represent the first detection ever of emission from a circumbinary gap around an MBHB.

The proof of existence of binaries with such a small orbital separation is of extreme importance for gravitational wave experiments such as Laser Interferometer Space Antenna (LISA; Bender et al. 1994), and the Pulsar Timing Arrays (PTA; Sesana, Vecchio & Colacino 2008). Since our theoretical expectations for a binary with the characteristics of SDSSJ0927 are of order 10^{-4} (binary hypothesis) down to 10^{-6} (ejection hypothesis) per year, either we have been extraordinarily lucky or MBHBs are *more common* than predicted, opening exciting possibilities for LISA and PTA.

ACKNOWLEDGMENTS

The authors thank Michael Eracleous for making them aware of a similar paper that independently reaches similar conclusions on SDSSJ0927. We are also grateful to Bernadetta Devecchi, David Hummer, Ruben Salvaterra and Pete Storey for fruitful discussions. Support for this work was provided by grant SAO-G07-8138 C (MV).

REFERENCES

Adelman-McCarthy J. K. et al., 2007, ApJS, 172, 634
Armitage P. J., Natarajan P., 2002, ApJ, 567, L9
Armitage P. J., Natarajan P., 2005, ApJ, 634, 921
Bender P. et al., 1994, LISA, Laser Interferometer Space Antenna: ESA Assessment Study Report
Begelman M. C., Blandford R. D., Rees M. J., 1980, Nat, 287, 307
Berczik P., Merritt D., Spurzem R., Bischof H. P., 2006, ApJ, 642, 21
Bogdanovic T., Eracleus M., Sigurdsson S., 2009, ApJ, 697, 288
Colpi M., Dotti M., Mayer L., Kazantzidis S., 2007, in Livio M., Koekemoer A. M., eds, STScI Spring Symposium: Black Holes. Cambridge Univ. Press, Cambridge
Cuadra J., Armitage P. J., Alexander R. D., Begelman M. C., 2009, MNRAS, 393, 1423
Devecchi B., Dotti M., Rasia E., Volonteri M., Colpi M., 2009, MNRAS, 394, 633
Dotti M., Colpi M., Haardt F., 2006a, MNRAS, 367, 103
Dotti M., Salvaterra R., Sesana A., Colpi M., Haardt F., 2006b, MNRAS, 372, 869
Dotti M., Colpi M., Haardt F., Mayer L., 2007, MNRAS, 379, 956
Eggleton P. P., 1983, ApJ, 268, 368
Ferrarese L., Ford H., 2005, Space Sci. Rev., 116, 523
Hayasaki K., Mineshige S., Sudou H., 2007, PASJ, 59, 427
Ivanov P. B., Papaloizou J. C. B., Polnarev A. G., 1999, MNRAS, 307, 79
Komossa S., Zhou H., Lu H., 2008, ApJ, 678, L81 (KZL)
Loeb A., 2007, Phys. Rev. Lett., 99, 041103
Lousto C. O., Zlochower Y., 2009, Phys. Rev. D, 79, 064018
Mayer L., Kazantzidis S., Madau P., Colpi M., Quinn T., Wadsley J., 2007, Sci, 316, 1874
Milosavljevic M., Merritt D., 2001, ApJ, 563, 34
Osterbrock D. E., Ferland G. J., 2006, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei. 2nd edn. University Science Book, Mill Valley, CA
Perets H. B., Hopman C., Alexander T., 2007, ApJ, 656, 709
Schnittman J. D., Buonanno A., 2007, ApJ, 662, L63
Sesana A., Haardt F., Madau P., Volonteri M., 2005, ApJ, 623, 23
Sesana A., Haardt F., Madau P., 2007, ApJ, 660, 546
Sesana A., Vecchio A., Colacino C. N., 2008, MNRAS, 390, 192
Shields G. A., Bonning E. W., Salviander S., 2009, ApJ, 696, 1367
Syer D., Clarke C. J., 1995, MNRAS, 277, 758
Urry C. M., Padovani P., 1995, PASP, 107, 803
Valtonen M. J., 2007, ApJ, 659, 1074
Volonteri M., Madau P., 2008, ApJ, 687, L57
Volonteri M., Haardt F., Madau P., 2003, ApJ, 582, 599

This paper has been typeset from a TEX/LATEX file prepared by the author.