Close supermassive binary black holes

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It has been proposed that when the peaks of the broad emission lines in active galactic nuclei (AGNs) are significantly blueshifted or redshifted from the systemic velocity of the host galaxy, this could be a consequence of orbital motion of a supermassive black-hole binary (SMBB)[1]. The AGN J1536+0441 (=SDSS J153636.22+044127.0) has recently been proposed as an example of this phenomenon[2]. It is proposed here instead that J1536+0441 is an example of line emission from a disk. If this is correct, the lack of clear optical spectral evidence for close SMBBs is significant, and argues either that the merging of close SMBBs is much faster than has generally been hitherto thought, or if the approach is slow, that when the separation of the binary is comparable to the size of the torus and broad-line region, the feeding of the black holes is disrupted.

Galaxies grow through mergers, and as all massive galaxies contain supermassive black holes, the formation of SMBBs will be common[1,3,4]. Close SMBBs, with orbital velocities $\sim 0.01c$, are expected to last long enough to be observed[1,3]. It was proposed[1] that such close binaries could be detected from velocity shifts of their broad-line region (BLR) line profiles, and pointed out that velocity shifts of the peaks of low-ionization broad lines are common[1,4,5].

There are two testable predictions of this model: first, the radial velocities of the peaks in the line profiles will shift on the orbital timescale of the SMBB[6], and second, as all AGNs vary, if there are two separate BLRs, the line fluxes of the two peaks will vary independently[7]. The prototypical displaced BLR peak AGN 3C 390.3 fails both these tests. The radial velocity signature of orbital motion has been detected[6,8] but the velocity changes are incompatible with an SMBB and are instead consistent with orbital motion of features in a non-azimuthally-symmetric disk. The peaks in 3C 390.3 initially seemed to be varying independently on timescales longer than the light-crossing timescale[7], but an SMBB is strongly ruled out by better-sampled monitoring[9,10], which shows that on a light-crossing time the peaks vary simultaneously as expected for a disk. The longer timescale profile changes in these AGNs are consistent with orbital motion of clumps in a disk[11]. The profiles are consistent with theoretical line emission profiles expected from disks[12], but the disks are generally not azimuthally symmetric and it is common for one peak to be significantly stronger than the other[1,4,5,12].

The Balmer lines of J1536+0441 have a strong blueshifted peak[2]. The Hβ profile is shown in Fig. 1. Boroson and Lauer[2,13] interpret J1536+0441 as a SMBB. I argue here, however, that just as the Balmer line profiles in previous SMBB candidates have been shown to be due to disk emission, so too the Balmer line profile of J1536+0441 probably arises from disk emission. This has also been independently proposed[14,15].

Although J1536+0441 represents an extremum among AGNs selected as 'quasars' by the SDSS, its line profiles are not unique among AGNs in general. The AGN 0945+076, for example, has shown a nearly identical Hβ profile (compare Fig. 1 with the Hβ profile of 0945+076[1]). To qualitatively illustrate the non-uniqueness of J1536+0441, Fig. 1 includes part of the scaled Hβ profile of the well-known disk emitter Arp 102B. Fitting disk models to theoretical double-peaked profiles invariably shows that there is an extra component of gas at the systemic velocity[12], so the spectral region with a width corresponding to that of the high-velocity wings of the [O III] 5,007 Å line has been excluded around rest-frame Hβ. The width of the Arp 102B spectrum has been reduced by 34% to make the velocity of the blueshifted peak in J1546+0441 match that of the blueshifted peak in the mean Arp 102B spectrum. This is well within the range of line widths seen among disk-like emitters. The uncertainty in the width scaling is about ±5%. The flux has been scaled by minimizing residuals

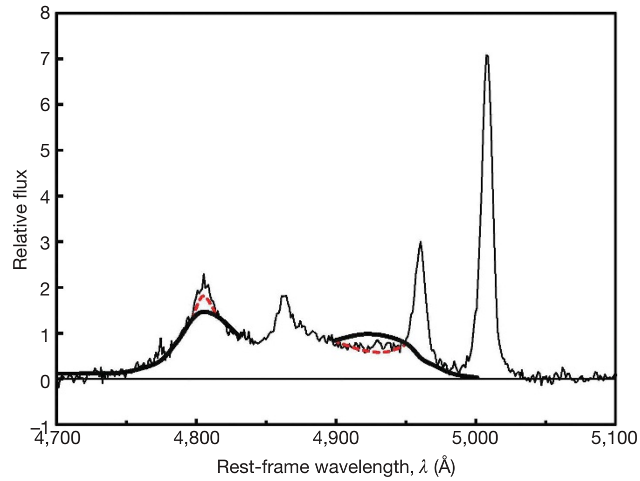

Figure 1 | Comparison of the continuum-subtracted SDSS spectrum of the Hβ region of J1536+0441 (thin black line) with the mean Hα profile of Arp 102B from 1992 to 1996 (smooth thick black line). The latter is taken from the mean spectrum in figure 3 of ref. 11 and scaled as described the text. The dotted red lines illustrate the effects on the peaks in the Arp 102B profile if they are changed by 1σ (based on the r.m.s. spectrum in figure 4b of ref. 11). The contribution of lower-velocity gas at the systemic velocity in Arp 102B has been omitted.

away from the peaks of the broad lines and away from the contaminating [O III] 5,007 Å lines. The profiles of broad disk-like lines vary strongly, so we do not expect a perfect match between any two objects a given time. The peaks of Arp 102B are particularly variable[11]. The differences in the peak fluxes are only about 1σ from the scaled Arp 102B mean profile (Fig. 1). More recent spectra of J1546+0441[13,15] (especially of Hα) show better agreement in the red peak.

Clearly, the most rigorous test of the competing hypotheses is line profile variability[2,13]. If this verifies that the Hβ profile of J1536+0441 is the result of normal disk emission, it has significant implications for the evolution of SMBBs, as J1536+0441 is the only candidate so far for a sub-parsec SMBB out of ~17,500 AGNs with $z < 0.70$ in the SDSS[2,13]. Because SMBB formation must be common, the absence of clear evidence for close SMBBs in AGNs needs to be explained. It suggests either that the lifetime of close SMBBs is considerable shorter than originally thought, or that they are long-lived and have their feeding interrupted so that activity is greatly reduced.

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Boroson and Lauer reply

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Gaskell[1] makes the point that the profile of the Balmer lines in the candidate binary supermassive black hole[2] AGN J1536+0441 bears some similarity to those that are thought to arise from disk emission in other objects. He further argues that two predictions of the competing binary black-hole hypothesis are (1) radial velocity changes that are interpretable in terms of the binary orbit, and (2) line fluxes in the two peaks that vary independently.

The similarity to disk emitters has been bolstered by subsequent spectroscopic observations[3,4], which show a red extension to the line profiles. However, the degree of similarity is debatable; the sharpness and strength of the blue peak and the presence of a central broad component make the line profiles in J1536+0441 unusual, if not unique. When sharp peaks are seen in objects thought to be disk emitters, these peaks are transient. As the simple disk emission models do not reproduce these characteristics at the extreme levels seen in J1536+0441[5], it is unclear whether their presence excludes the disk interpretation or not.

It is certainly true that the strongest evidence for determining the nature of this object will come from spectroscopic monitoring to detect radial velocity changes and flux changes within the line profiles. Initial evidence is inconclusive[3,4], in that no changes have been detected over a little less than one year. This finding excludes some of the orbital parameter space, but not that interpretation. Several more years of unchanging fluxes and velocities would push both explanations into uncomfortable areas, as the material in the disk must be orbiting as well.

It may be that J1536+0441 is a single AGN with an emission line profile resulting from a disk configuration of material. There are credible arguments for and against that hypothesis as well as the possibility that the system is a bound system of two supermassive black holes. Whichever the case, Gaskell is correct that the presence of at most one such object out of a sample of 17,500 has interesting implications for the process by which supermassive black holes merge.

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