QUASARS AS SUPERMASSIVE BINARIES

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Paper n° 70

ABSTRACT

A number of quasars show the peaks of their broad emission lines at very different redshifts from their narrow emission lines. Two examples are illustrated. This difference could well be present to some degree in all quasars. Relative blueshiftings and redshiftings appear to be equally common. Some objects in addition show two displaced broad line peaks -- one blueshifted and the other redshifted. I propose that these displaced broad line peaks are the result of orbital motion of two supermassive objects, each with its own associated broad line region. Such binaries could arise in a number of ways during the evolution of a galactic nucleus. The observed velocities (∿3000 km/s) are consistent with the expected evolution of supermassive binaries as predicted by Begelman, Blandford and Rees (1980).

I. OBSERVATIONAL BACKGROUND

In this paper I want to draw attention to and examine what I regard as a very exciting aspect of quasar spectra[3] - namely that the peaks of the broad lines are not at rest with respect to the host galaxy. Isolated cases of broad emission lines being at very different redshifts from the narrow forbidden lines have been scattered through the literature for 15yrs now (the first cases were reported in Lynds 1968) but the phenomenon as a whole has received little attention. In a recent paper (Gaskell 1982) I investigated the wavelengths of various classes of emission lines in high luminosity quasars and showed that:

a) the high ionization broad lines appear to be systematically blueshifted with respect to the low ionization broad lines by ∿500 km/s (thus implying radial motions of the clouds) and

b) the narrow lines and the (low ionization) broad lines are usually at different redshifts, with relative blueshiftings and redshiftings being equally common.

In the present paper we will only be concerned with the second effect (the first is discussed at length in Gaskell 1982). Figs. 1 and 2 should hopefully remove any doubts in the reader's mind about the reality of this effect. In fig. 1 (0945+076) one can see an example of a broad line region (BLR) peak being blueshifted by 2100 km/s with respect to the narrow line region (NLR) and in fig. 2 (1404+285) one can see a BLR peak being redshifted by 2700 km/s. If one inspects spectra of quasars showing displaced BLR peaks one notices that in some of them there is a subsidiary BLR peak of (say) Hβ on the other side of the NLR component of Hβ. 1404+285 (fig.2) is an example of this. Since the secondary peak needs to be about a third of the strength of the main peak to be readily recognised it is likely that all quasars have a second peak present at some level. When the continuum (and hence emission lines) vary, the relative strengths of the two peaks can change. The well-known object 1845+797 (= 3C390.3) is a good example of this. In a Lick observatory spectrum taken in the summer of 1975 by Osterbrock, Koski and Phillips (1976, their fig. 5) the blueshifted peak

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[3] For brevity I shall use the word "quasar" to refer to *all* Seyfert 1 and broad line radio galaxies, and not just the highest luminosity ones.

"Quasars and Gravitational Lenses"; 24th Liège Astrophysical Colloquium, Institut d'Astrophysique, June 1983.

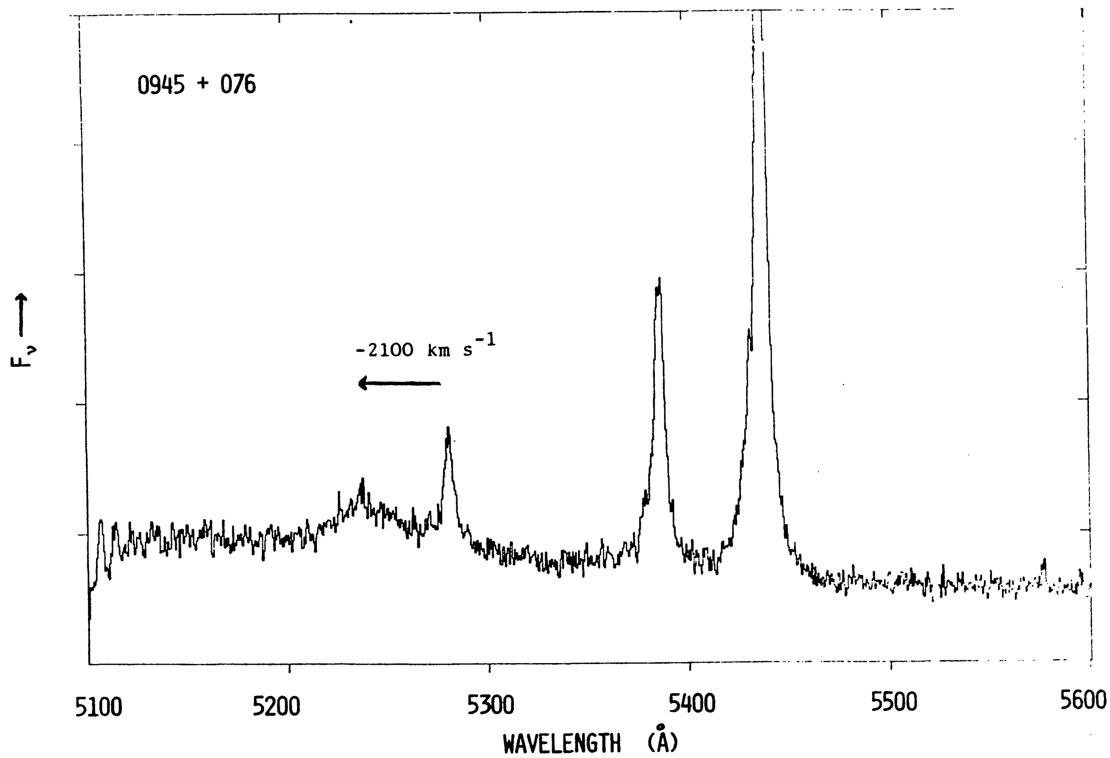

Fig. 1. Spectrum of 0945+076 taken with the MMT spectrograph at 2Å FWHM resolution, March 28-29, 1982 (feature in first 30 channels is spurious).

is stronger than the redshifted one, whilst in a MacDonald observatory spectrum taken in June 1980 (see Netzer 1982, fig. 2) the redshifted peak is clearly much stronger. As far as I know, no quasar has three BLR peaks.

An important question to settle at the outset is "are the narrow (forbidden) lines giving the true redshift?" For low luminosity nearby quasar-type objects the answer is almost certainly "Yes" to the accuracy with which we are concerned here. Comparison with other available measurements of the systemic velocity (e.g. 21cm line emission, stellar absorption lines, galactic rotation curves etc.) shows that 60% of NLR peaks are within 40 km/s of the systemic velocity and 95% are within 180 km/s (based on references in Whittle 1982). In no quasar showing displaced BLR peaks is there any evidence for forbidden-line emission at the redshift of the displaced BLR peaks. These results strongly imply that it is the *broad*-line peaks that are being displaced and not the narrow-line ones.

II. PROBLEMS WITH PREVIOUS EXPLANATIONS

The main two previous explanations of the displaced peaks in quasar spectra are *(i)* obscuration effects (Ferland, Netzer and Shields 1979; Capriotti, Foltz and Byard 1979) and *(ii)* light-echo effects (Capriotti, Foltz and Peterson 1982).

a) Obscuration Effects

A claim by Osterbrock (1977) that Seyfert 1 galaxies had a *systematic* asymmetry of their broad hydrogen lines led to what can be regarded as the "conventional" explanation of line peak displacements -- namely that one is seeing the combined effects of radial motions of the BLR clouds plus anisotropic emission and/or obscuration. Capriotti *et al.*(1979) have produced a number of quite convincing fits to quasar line profiles with a model having an expanding system of clouds each of which has a source of continuous opacity (such as dust)

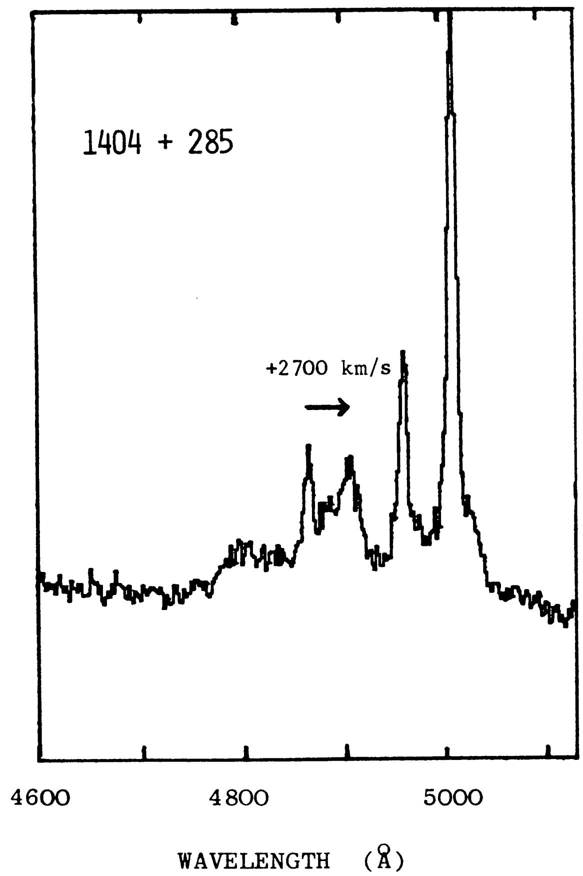

Fig. 2. MMT spectrum of 1404+285, dates and details as in fig. 1.

in the neutral zone. Unfortunately (for this explanation) the claim of a systematic broad line asymmetry has now been retracted (see Osterbrock and Shuder 1982) and as has been stated in section II above the line shifts are equally liable to go to the blue or to the red. In order to explain the profiles in figs. 1 and 2 with the obscuration model one would have to have some objects having inflow of the BLR while others would have to have outflow (with about equal probabilities).

b) Light-echo effects

If the velocity field of the BLR is ordered, pulses in the photoionizing continuum will give spikes in the BLR line profile. Capriotti *et al.* (1982) have produced realistic looking profiles by such a mechanism. The fundamental problem with this explanation is that *the peaks must move on a light-crossing time* (because the time-averaged line profile has to be the line profile corresponding to a non-varying continuum). For low luminosity objects the light-crossing times are known to be a few weeks (Lyutyi and Cherepashchuk 1973; Ulrich *et al.* 1983). For high-luminosity quasars they might be a hundred times longer. Although in objects with displaced BLR peaks the line profiles and continua do vary (as most quasars do) the *wavelengths of the displaced peaks do not vary over periods of many years*. 0945+076 (fig. 1) is a good example of this. A number of published spectra going back to 1967 show the blueshifted BLR peak to be in exactly the same place to within the measuring errors (∿200 km/s).

III. SUPERMASSIVE BINARIES

If the conventional explanations are untenable, what is going on? It would seem that there is some preferential bulk motion of the broad-line cloud system in one or two directions. The bulk motions of the BLR system(s) are, in all the cases observed so far, slower than the individual cloud velocities since the velocity displacement of the peaks is always less than the line width. A jet mechanism, such as that acting in the galactic object SS433, is therefore unlikely to be the explanation. I wish to propose that the bulk motions of the BLR cloud system(s) are due to orbiting supermassive objects, each one of which can have its own associated BLR. I will now try to argue that a supermassive binary (SMB) is quantitatively consistent with what is seen and also that the formation of such binaries is not only possible but even likely.

a) The model

The model I propose is essentially that proposed for other reasons by Komberg (1968) and Begelman, Blandford and Rees (1980, "BBR"): a quasar has two orbiting supermassive objects ("SMOs"; probably, although not necessarily, black holes). Each one of these independently contributes to the (variable) non-thermal continuum and each one has an associated BLR. Details of how each SMO produces its energy need not concern us and it does not matter whether the BLR clouds are bound to the SMOs or being radiatively accelarated away from them. This model is sufficiently straightforward that the main parameters can be set by simple observational considerations. The observed luminosity gives us the typical masses of the SMOs if we make the common assumption that they are radiating close to the Eddington limit. This gives $M \sim 10^7 - 10^9\ M_\odot$. For us to see distinct displaced BLR peaks in the profiles I would claim that the binary separation has to be at least as great as the typical size of the BLR. Photoionization and variability considerations set this to be 10^{17}-10^{18}cm radius. We can now calculate the maximum velocities we would expect to see and the answer is a few thousand km/s. This is obviously in excellent agreement with the observed velocities (the biggest known being 4100 km/s). For a randomly chosen quasar the displaced peak will be offset by less than this since the orbit is unlikely to be edge-on and we will observe the SMB at some random phase as well. The orbital period is of the order of a few centuries so radial velocity changes could be observable in a few decades.

b) Evolution of supermassive binaries

The evolution of SMBs has already been described by BBR. Although they consider the specific case of an SMB forming as the result of galactic mergers their results are applicable to SMBs in general. When a binary is fairly "soft" (>10pc separation) the SMOs spiral together under dynamical friction on a time-scale of about 10^6yrs until the velocity dispersion of the stars in the nucleus is significantly less than the orbital velocity. Dynamical friction is not efficient then and subsequent evolution of the "hard" binary proceeds more slowly. The orbit decays slowly on a timescale of 10^8-10^9yrs (see BBR for details). Ultimately gravitational radiation causes the orbit to decay rapidly when the orbital velocity becomes more than a few percent of the speed of light and the two SMOs will coalesce (Thorne and Broginsky 1976 have considered the possibility of detecting pulses of gravitational radiation from such mergers). The important point to draw from these evolutionary considerations is that an SMB spends most of its life (and is hence most likely to be seen) with an orbital velocity several times that of a typical stellar velocity dispersion (i.e. with an orbital velocity of a few thousand km/s). This is again in good agreement with the observed maximum velocities of displaced BLR peaks.

c) Formation of SMBs

In considering the formation of an SMB it is wise to remember that we do not know for certain how even *one* SMO forms! Another fact to remember is that nature likes to form binary systems (e.g. a good fraction of galaxies are in binary systems as are half the stars in the universe). An SMB could arise in several ways: by the breakup of a supermassive protostar (Begelman and Rees, 1978); as a metastable state in the evolution of a cluster of SMOs (Saslaw, Valtonen and Aarseth,1974); and as the result of a galactic merger (BBR). If one concedes that galaxy mergers take place and that a large fraction of galaxies have SMOs in them then it is *inevitable* that some SMBs will form. A cluster or multiple system of SMOs is not a stable system. Saslaw *et al.* (1974) have shown that for a general three body system one of the members will be ejected (the "gravitational slingshot"mechanism) leaving a binary. Note that hierarchical multiple SMOs binary systems (SMO analogues of the famous ε Lyrae stellar system) are not stable since the closest pairs will rapidly coalesce due to gravitational radiation. An SMB is the only metastable configuration of SMOs.

IV. A CONNECTION WITH RADIO STRUCTURE?

An important clue to consider is that the "best" cases of displaced BLR peaks seem to be in quasars with extended radio structure. It is well known that extended radio structure quasars have more asymmetric line profiles (Osterbrock, Koski and Phillips 1977; Miley and Miller 1979). I believe that this so-called asymmetry in nothing more than the presence of displaced BLR peaks and that these displacements are therefore most common in sources with extended radio structure. Since such quasars almost all occur in elliptical galaxies (at least those at low redshift) this is consistent with the BBR merger picture. It may well be that the presence of an SMB is essential for the formation of collimated large-scale radio jets. Indeed it has been argued by BBR and Whitmire and Matese (1981) in particular that quasars could be analogous to the galactic jet-producing binary SS433. Such models offer an explanation of the observed apparent precession of radio jets.

I wish to thank Mitch Begelman, Martin Rees and Linda Sparke for criticisms and discussions. Thanks are also due to the Multiple Mirror Telescope Observatory for granting guest observing time and to the British Science and Engineering Research Council for partial support of this work through grant SGC/15281.

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