An Interpretation of Radio-loud – Radio-quiet QSO Differences

Beverley J. Wills

Department of Astronomy, University of Texas at Austin, Texas, 78712

Abstract. Here we speculate on what observations are telling us about the difference between radio-loud and radio-quiet QSOs. The observations are (i) the relation between ultraviolet-optical luminosity and ‘jet power’, (ii) the dependences of emission and absorption line spectra, and the spectral energy distribution, on radio core-dominance, assumed to be an indicator of orientation, (iii) the spectral differences between radio-loud and radio-quiet QSOs, and (iv) the inverse relation between the strength of broad, blended Fe II multiplets and [O III] λ5007, and the apparently-related association between Fe II strength, reddening, broad absorption lines, and scattering polarization. We present and discuss a picture in which there are two main variables: (i) the inclination of the plane of the host galaxy to the axis of the inner jet (the central engine’s rotation axis), and (ii) the angle of the line-of-sight to this rotation axis. The radio-loud QSOs are those with jets aiming away from the plane of the host galaxy.

1 Introduction

Some hypotheses proposed to explain why ~90% of QSOs\(^1\) are radio quiet include (i) an evolutionary phenomenon where radio-loudness is a short-lived phase in the existence of all QSOs, or a series of short-lived phases (Schmidt 1970), (ii) the result of differences in mass concentration in the host galaxy nucleus (Heckman 1983), (iii) the result of fundamental angular momentum differences (Wilson & Colbert 1995), (iv) the result of poorly-collimated sub-relativistic wind in radio-quiet QSOs (RQQs) (Boroson, Persson & Oke 1985).

Some hypotheses simply discuss conditions under which jets might form, but do not attempt to explain all known differences between radio-loud QSOs (RLQs) and RQQs. We take a different approach, by first examining the relation between ultraviolet-optical luminosity and jet power (see the chapter, Accretion and Jet Power). There, we concluded that jet power (represented approximately by unbeam radio power) is directly related to the Big Blue Bump luminosity, for RLQs and RQQs, while the radio luminosity is a factor of ~1000 less in the RQQs. Then we argued that the generally great similarity of the Big Blue Bump, non-synchrotron X-ray emission, and the emission

\(^1\) ‘QSO’ refers to all luminous AGN (L > 10\(^{11}\) L\(_\odot\)), H\(_0\) = 100 km s\(^{-1}\) Mpc\(^{-1}\). A radio-loud QSO is one having F\(_{5000}\)/F\(_{4400}\) > 10, where F is the rest frame flux-density in mJy. Such strong radio emission is assumed to indicate powerful radio jets.
line spectra implied a very similar central engine mechanism, independent of radio-emission. This, together with the relations between unbeamed radio and Big Blue Bump luminosity, led us to the hypothesis that the central engines of RQQs and RLQs (fueling, accretion, and power available to generate a jet) are essentially identical. There is some theoretical support for this, but no single hypothesis is clearly favoured.

2 Direct Interpretation of Observations

Apart from the radio emission, observed differences in photon energy distribution, emission-line spectra and absorption spectra may lead to clues concerning the collimation and propagation of luminous radio jets. In the previous chapter *Jets and QSO Spectra* we summarized the most significant relations between radio emission and these ultraviolet–optical properties, and suggested a consistent picture for the nuclear gas.

For RLQs, we noted that there are dependences of emission-line profiles and line strengths on the jet inclination, implying that emission regions are symmetric about the jet (rotation) axis — in particular BLR gas velocities are larger perpendicular to the jet. Dependences of profile asymmetry on inclination imply axisymmetric obscuration and an axisymmetric velocity field. Thus we suggested that dust shielded from the central ionizing continuum by BLR gas is responsible for revealing high-ionization axial (polar) outflow in core-dominant RLQs, and low-ionization equatorial outflow in lobe-dominant RLQs. This equatorial outflow ties in with associated absorption outflows and increased reddening in lobe-dominant RLQs. The low-latitude reddening is probably associated with hot AGN dust as well as the interstellar medium of the host galaxy. The inner edge of a dusty torus, at the evaporation radius for iron-rich grains, may shield from our view Fe II rich gas produced there, explaining why Fe II blends appear weaker in lobe-dominant RLQs.

These interpretations for RLQs conjure up the dusty-torus model for RQQs proposed by Weymann et al. (1991), in which BAL clouds are ablated from the surface of the torus and accelerated, by thermal wind and radiation pressure. BAL QSOs are just those where the high-velocity outflow lies along the line-of-sight. However, we have little evidence, so far, for axisymmetry in RQQs.

Further observational differences between RLQs and RQQs are seen in the inverse relation between the strengths of [O III] $\lambda$5007 emission from NLR gas at many pcs to Kpcs from the center, and the high-velocity Fe II emission from the BLR. RLQs lie at the strong [O III] – weak Fe II end of this relation, and the BAL QSOs at the weak [O III]– strong Fe II end. In this sense the BAL QSOs represent ‘extreme RQQs’. We favour an explanation for this relation in terms of relative covering by dense, high-speed, Fe II-rich gas. The lower the covering by dusty low-ionization BLR gas, the more photons are able to escape to ionize the more-distant, low-density, NLR gas.
Fig. 1. A hypothesis for the different ultraviolet-optical properties of radio-loud and radio-quiet QSOs. The RLQs have jets, and ionization cones formed by the shadow of a dusty torus, in a direction away from the highest concentrations of low-ionization gas and dust in a galaxy, whereas the opposite is true for radio-quiet QSOs. In a planar, axisymmetric, distribution of broad emission line (BLR) gas, RLQs’ ionizing photons excite gas out of the plane, to distances of several Kpc. In radio-quiet QSOs, the NLR gas is partly shielded from ionizing photons by high-optical-depth broad line gas (Fe II emitting), that is ablated from heated grains near evaporation temperature. We show a warped torus whose inner regions are perpendicular to the radio axis.
3 A Possible Model

The ultraviolet–optical differences between RQQs and RLQs can be summarized as follows. Compared with RLQs, RQQs appear to be associated with more emission from low-ionization gas (Fe II) and show evidence for more line-of-sight reddening and high-velocity outflowing (BAL) gas. The presence of a hot, dusty, environment with low- and high-ionization (BAL) outflows along the line-of-sight therefore has something to do with lack of powerful radio emission. If radio-loud and radio-quiet central engines are so similar, why should a line-of-sight effect be so important? It must be that RQQs’ central engines are located in a similar nuclear environment, but one in which the observer is more likely to view the central engine through dusty, low- and high-ionization outflows.

We suggest that, for QSOs of the same Big Blue Bump luminosity, the same power is available to feed jets, that a ‘jet axis’ exists in both RLQs and RQQs, and that the observations can be accounted for by two main variables – one, the inclination of the jet axis to the line-of-sight, and the other, the inclination of the jet axis to the plane of the host galaxy. These possibilities are illustrated in Fig. 1. The edges of the ‘ionization cone’ within which the NLR can be excited are defined by the shadow of a dusty, inner torus. In several well-observed, but low-luminosity cases, the cone is fairly symmetric about the jet axis (N4261, Circinus: Urry & Padovani 1995). In the radio-loud case the jet axis is, in some observations of FR II radio galaxies, perpendicular to the plane of the host galaxy (Ekers & Simkin, and references therein; Heckman et al. 1985), or a dust lane, or even parallel to the rotation axis of the host galaxy or extended emission-line gas. In RQQs the inner regions may be symmetric about the jet axis, but the outer ‘torus’ may warp to match the galaxy plane; a synchrotron photon and high-energy particle beam may pound dense gas and dust in the inner regions, ablating Fe II-rich gas that shields the NLR. The range of possible inclinations of the jet axis to the plane of the galaxy could be quite large, depending on the vertical thickness of dense material near the nucleus. This geometry would determine the relative numbers of RLQs and RQQs. The geometry need not even be as simple as illustrated, for example, in the case of merging galaxies.

Our proposed picture could explain differences in inclination dependence. A wider range of viewing angles available for the inner parsec could explain the jet–observer inclination-dependence of axisymmetric emission regions in RLQs compared with RQQs. RLQs’ ‘illumination cones’ are well-defined by the dusty torus and are free of the Galactic plane. Still, grazing views of the torus can result in associated absorption and reddening. Reddening can also result from a low-latitude view of the galactic plane, especially if the jet–cone axis is tilted towards the observer and the galactic plane. Jet–observer inclination dependence for RQQs is less easily defined because galactic obscuration is important, and the ‘torus’ geometry may be more complex. Greater nuclear dust-covering may result in stronger Fe II emission. The inverse Fe II–[O III]
relation — increasing [O III] and decreasing Fe II emission — could result as the angle between the jet–cone axis and the galactic plane increases, illuminating more, distant, low-density NLR gas. This also explains the weaker Fe II and stronger NLR emission in RLQs.

The dustier, low-ionization absorption environment seen towards RQQs may not be only a jet–galactic plane inclination dependence. It has been commonly thought that powerful radio-loud AGN occur in elliptical galaxies, and the radio-quiet AGN occur in spirals (Hutchings et al. 1989). This would tie in nicely because spiral galaxies are thought to be, more often, richer in gas and dust. This host-galaxy dichotomy has also been suggested to relate to the nuclear and host galaxy mass (Heckman 1983) or angular momentum (Wilson & Colbert 1995) hypotheses for the generation and maintainance of powerful radio jets, and it would be necessary to measure all three parameters (mass, angular momentum, and dusty, low-ionization environment) to disentangle these hypotheses. We note that elliptical galaxies can contain significant amounts of dust. There are apparently RQQs in elliptical hosts (Disney et al. 1995), and radio-loud sources in spiral galaxies, although tidal tails produced by mergers that are thought to fuel AGN, could be mistaken for spiral arms. Are RQQs ever found in ellipticals? Hubble Space Telescope imaging may provide the answer.

Why the lack of powerful jets in RQQs? We suggest that this has something to do with the inner jet being within the galactic plane — perhaps lack of collimation as a result of greater mass densities, or perhaps related to orientation of the jet and galactic magnetic fields. Radio cores may appear weaker as a result of absorption by highly-ionized nuclear plasma. It may be a problem that light relativistic fluid jets are likely to propagate unimpeded through the galactic plane (Leahy, this workshop).

Tests of such a picture could be to investigate, by radio and optical-ultraviolet imaging, polarimetry, and spectroscopy, the relative orientation of some RQQs’ weak jets, possible illumination cones, and host galaxy orientation. One could look for absorption in the nuclear, radio-core spectrum, and investigate its possible relation to absorption seen in the optical, ultraviolet and X-ray regions.

Having found significant differences between the spectra of RLQs and RQQs, one could question our original assumption of the similarity of the central engines of RLQs and RQQs. However, we might argue that the greatest differences we find are probably in gas thought to exist at least ∼ 1 pc from the central engine.

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