Broad absorption line quasars have the same cool dust emission as quasars without BALs

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Abstract.

The results of a sub-millimeter survey of SDSS broad C iv absorption line quasars is discussed. It is found that the sub-millimeter flux distribution of BAL quasars is similar to that of non-BAL quasars. This is consistent with the idea that all quasars contain broad absorption line regions, but only a fraction of them are visible along our line-of-sight. The observations are inconsistent with BAL quasars being observed at a special evolutionary epoch co-inciding with a high star-formation rate and dust mass.

1. Introduction

About 15% of optically-selected quasars show metal absorption systems with huge blue-shifted velocities of several thousand kms$^{-1}$. These broad absorption lines (BALs) are attributed to outflows located close to the accretion disk. The similarity of the continuum and line emission of BAL and non-BAL quasars motivates the hypothesis that BAL quasars are not intrinsically different from other quasars. The presence of BAL features in a fraction of quasars can be explained by a difference in viewing angle if the sub-relativistic outflow at the origin of the BAL features is not isotropic (Weymann et al. 1991). The popular notion that the outflow is preferentially located close to the edge of the torus surrounding the supermassive black hole has found support in spectropolarimetric measurements (Goodrich & Miller 1995; Cohen et al. 1995). However, studies of radio-loud BAL quasars, in which the radio properties give some information on the orientation, appear at odds with this simple orientation model (Becker et al. 2000). The other main contender as an interpretation of the BAL phenomenon is the evolutionary scenario of Briggs et al. (1984) in which all quasars pass through a BAL phase for $\sim 15\%$ of their active lifetimes. The small sizes of the radio lobes in radio-loud BAL quasars (Becker et al. 2000) is suggestive of the BAL phase co-inciding with an early stage of quasar activity – perhaps removing a shroud of gas and dust from the nuclear region.
The sub-millimeter emission from quasars comes from optically-thin, cool dust and is therefore orientation-independent. It is also likely heated by young stars in starbursts which will evolve over the lifetime of the quasar. It is therefore the prime wavelength in which to discriminate between the orientation and evolutionary explanations of the BAL phenomenon. If all quasars contain BALs, then BAL quasars would be expected to have the same sub-millimeter properties as non-BAL quasars. But if the BAL phenomenon is a phase that all quasars go through, and is connected with the termination of large-scale star-formation, then the sub-millimeter emission should differ between BAL and non-BAL quasars. It is assumed that $H_0 = 70 \, \text{km s}^{-1} \, \text{Mpc}^{-1}$, $\Omega_M = 0.3$, $\Omega_\Lambda = 0.7$.

2. A sub-millimeter survey of broad absorption line quasars

We have observed with the JCMT a sample of BAL quasars selected from the SDSS EDR BAL sample of Reichard et al. (2003). The sample was designed to be as similar as possible to BAL quasars which do not show broad absorption lines which had already been observed at either the JCMT (Priddey et al. 2003) or IRAM (Omont et al. 2003). Here we briefly summarize the BAL sample selection: redshift range $2 < z < 2.6$, RA range $10^h - 18^h$, $\text{CIV}$ balnicity index $\text{BI} > 200$ km s$^{-1}$, dereddened absolute $B$-band $M_B < -26.6$. Full details of this project are given in Willott, Rawlings & Grimes (2003).

The entire sample of 30 BAL quasars was observed in photometry mode with the SCUBA bolometer array at the JCMT from February to June 2003. We achieved our aim of reaching an rms sensitivity at $850 \, \mu\text{m}$ lower than $3.33$ mJy (i.e. $3\sigma = 10$ mJy) for all the BAL quasars observed. This sensitivity matches that obtained in the observations of the non-BAL comparison sample. Eight BAL quasars were detected at the $> 2\sigma$ level (four of which are securely detected at the $> 3\sigma$ level). The detected quasars span a range of $z$, $M_B$ and balnicity index. Although one can use the observed sub-mm flux to obtain an estimate of the far-IR luminosity, there are many uncertainties in this calculation. Since the relationship between flux and luminosity does not change much over the redshift range we are interested in for realistic dust spectral energy distributions, we will use the flux rather than luminosity in further analysis.

3. Comparing the sub-millimeter fluxes of BAL and non-BAL quasars

We carried out a variety of statistical tests on the sub-mm flux distributions of the BAL and non-BAL quasar samples. The aim was to determine whether there is any difference between these two types of quasar. The tests included sample statistics, such as the median, mean and weighted mean flux of each sample. No evidence for a difference between BAL and non-BAL quasars was found in these tests. The mean $850 \, \mu\text{m}$ fluxes of the BAL quasars is $2.56 \pm 0.67$ mJy and for the non-BAL quasars it is $3.34 \pm 0.64$ mJy.

Due to the large number of $850 \, \mu\text{m}$ upper limits in both samples, we also use survival analysis statistical tests which can account for these limits (Feigelson & Nelson 1985; Isobe, Feigelson & Nelson 1986). To minimise the number of upper limits, we consider sources with $\text{snr} > 2$ to be detections for these tests. We wish to determine whether the $850 \, \mu\text{m}$ flux distributions of the BAL and
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Figure 1. $850\,\mu\text{m}$ flux-density against absolute magnitude for the BAL quasar sample (filled circles) and the non-BAL control sample (open triangles). Error bars show the $1\sigma$ uncertainty on the measured fluxes. The dotted line illustrates a positive correlation between sub-millimeter flux and optical luminosity where a difference in $M_B$ of 1 equals a change in $S_{850}$ of a factor of 1.5.

non-BAL quasars are different. Using a variety of tests (the Gehan, logrank and Peto-Prentice tests), the returned probabilities that the fluxes of the BAL and non-BAL samples are drawn from the same distribution lie in the range (54-99%). Again, we find no evidence that BAL and non-BAL quasars differ in their sub-millimeter fluxes.

In Fig. 1 we plot the sub-millimeter fluxes of the BAL and non-BAL quasars as a function of their absolute optical magnitude. Due to the fact that the non-BAL quasars come from samples with a brighter optical magnitude limit than the SDSS, the absolute magnitudes of the non-BAL quasars are brighter than those of the BAL quasars by about one magnitude. We have to be careful that a correlation between sub-millimeter flux (luminosity) and optical luminosity is not affecting our results. For example a positive correlation between optical and sub-millimeter luminosity combined with enhanced sub-millimeter luminosity in BAL quasars could have led to the observed result that the two samples have indistinguishable sub-millimeter flux distributions.

The question of whether there is a correlation between the sub-millimeter and optical luminosities has been addressed before (Priddey et al. 2003; Omont et al. 2003) and the consensus is that there is no measurable correlation. We use the survival analysis bivariate correlation tests to assess the significance of any correlations in these datasets. We find no significant correlation in the BAL quasar sample, but a very significant anti-correlation in the non-BAL sample of 41 quasars. The reason that we have now detected this positive correlation...
between the sub-millimeter and optical luminosities may be that by combining the samples over a restricted redshift range we have disentangled luminosity and redshift effects.

For the purposes of our BAL quasar survey we wish to know if the existence of a correlation between $S_{850}$ and $M_B$ could affect our findings. The median absolute magnitude of the BAL sample is $M_B = -27.2$ and for the non-BAL sample it is $M_B = -28.2$. Therefore, we scale the observed sub-millimeter fluxes of the BAL sample by a factor of 1.5 (except for those with negative flux) to simulate the effects of a correlation with slope similar to that observed in the non-BAL sample (and plotted in Fig. 1). We repeated the two sample tests with these scaled BAL fluxes and the comparison sample of non-BAL quasars. The probabilities that the sub-millimeter fluxes of the BAL and non-BAL samples are drawn from the same distribution are 14% and 27%. This test shows that, even after allowing for the effects of a weak correlation between sub-mm flux and $M_B$, there is not a significant difference between BAL and non-BAL quasars.

Our observations and analysis have shown that quasars with broad absorption lines show the same sub-millimeter properties as quasars without broad absorption lines. What does this tell us about the nature of the BALs and the evolution of quasars? Since sub-millimeter emission is optically-thin there should be no orientation dependence of sub-millimeter emission. Our finding that the sub-millimeter emission is not related to the presence of a BAL is therefore consistent with the orientation hypothesis that all quasars contain BALs, but only a fraction of them are visible along our line-of-sight. Our results are inconsistent with a model in which the presence of BALs is associated with a special epoch in quasar/galaxy evolution co-inciding with a large dust mass and a high star-formation rate. However there are other evolutionary models which could be made consistent with our data. For a fuller description of this project and its implications the interested reader is referred to Willott et al. (2003).

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