LOW-IONIZATION BALQSOS: WARM ULTRALUMINOUS GALAXIES AT HIGH REDSHIFTS

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A decade ago Sanders et al. (1988a, b) proposed a possible QSO formation scenario as a sequence of Galaxy Mergers → Ultraluminous IR Galaxies (ULIRGs) → Warm ULIRGs → QSOs. Since then, this proposal has become a paradigm against which all the subsequent observations will be compared. Fortunately for us, this paradigm makes two specific predictions: that is, 1) ULIRGs are powered by hidden AGNs, and 2) ULIRGs should be more abundant at $z \sim 2$, where the comoving density of optically-selected QSOs is sharply peaking up.

The observations testing the first prediction had been producing confusing results for a long time, but now the results seem to be finally converging. Most recently, the *ISO*-SWS spectroscopic study by Genzel et al. (1998) showed that 20–30% of ULIRGs they looked at seem to be predominantly powered by AGNs. In the meantime, based on their optical and near-IR spectra, Veilleux et al. (1997) concluded that 25–30% of ULIRGs show clear signs of AGN activities. Therefore, as long as we define ULIRGs as galaxies with $L_{\rm ir} > 10^{12}\ L_{\odot}$, the majority of these galaxies do not seem to be predominantly powered by AGNs.

The next question is whether the QSO formation scenario above is still valid when these new results are taken into account. Although not all of ULIRGs as originally defined seem to fit in this picture, it is possible that only a subset of them, namely higher-luminosity ones, are the progenitors of QSOs. Veilleux et al. (this volume) indicate that the AGN-dominated fraction increases rapidly at $L_{\rm ir} > 10^{12.3} L_{\odot}$. If this is the case, it might be only these higher-luminosity objects that will later become QSOs. Furthermore, these objects might be much more abundant at high redshifts.

Here, we try to test the validity of the paradigm by checking the second prediction, i.e. whether there is a large number of ULIRGs at high redshifts,

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especially at $z \sim 2$. To address this question properly, we need a large-area sensitive IR survey, which is not available for the moment. Therefore, what we are doing is to see if we can find a ULIRG-like population at high redshifts in the existing optically-selected samples.

To state the conclusion first, it now seems that a subset of Broad Absorption Line QSOs (BALQSOs) called Low-ionization BALQSOs are actually high-redshift analogues of Warm ULIRGs such as Mrk 231. Low-ionization BALQSOs are a class of QSOs which show broad UV absorption lines of low-ionization ions (Mg II, Al III) as well as those of the high-ionization species (C IV, Si IV) regularly seen in BALQSOs (Weymann et al. 1991). Since this classification is based on the restframe UV spectra, the majority of this population known so far are at high redshifts. These QSOs are known to be rare, comprising only $\sim$ 15% of BALQSOs and $\sim$ 1.5% of all QSOs. Over the past years, pieces of evidence have been accumulating that Low-ionization BALQSOs are dusty: they are common in *IRAS*-selected samples (Low et al. 1989), their UV continua show signs of moderate reddening (Sprayberry & Foltz 1992), and the absence or the extreme weakness of their [O III] 5007 Å line might be suggesting that the ionizing radiation is blocked before reaching the outer low density regions, where the formation of the forbidden line is possible (Boroson & Meyers 1992). Voit et al. (1993) suggested that Low-ionization BALQSOs are probably "young quasars in the act of casting off their cocoons of gas and dust," which is identical to the interpretation of ULIRGs by Sanders et al. (1988).

A direct link was made between Low-ionization BALQSOs and Warm ULIRGs when space UV spectroscopy showed that two of the nearby Warm ULIRGs are actually Low-ionization BALQSOs (IRAS 07598+6508 by Lipari et al. (1994b); Mrk 231 by Smith et al. (1995)). What we would like to do here is to make this connection at high redshifts by comparing the restframe optical spectra of Low-ionization BALQSOs with those of nearby Warm ULIRGs. We performed near-IR spectroscopy of Low-ionization BALQSOs, and found that they have typical characteristics of Warm ULIRGs in the sense that (1) they are dusty, and (2) they emit strong restframe-optical Fe II emission.

The dustiness of these QSOs is inferred from the large values of their Balmer decrement. Table 1 compares the Balmer decrement values of Low-ionization BALQSOs with those of normal QSOs. The measurements are from Egami et al. (1996) and Egami (1998). It is clear from the comparison that the Balmer decrement of a Low-ionization BALQSO is roughly a factor of two larger than that of a normal QSO. This is also in line with the absence of the [O III] 5007 Å line, probably indicating strong internal absorption of ionizing radiation. The most interesting case is Hawaii 167, whose Balmer decrement is as large as 13. Egami et al. (1996) interpret this object as a heavily dust-enshrouded young QSO whose internal reddening is so large as to completely extinguish the QSO light in the restframe UV, leaving only the UV light from its starbursting host galaxy.

TABLE 1. Balmer decrements of low-ionization BALQSOs

Object	Object type	z	$H\alpha/H\beta$
Q0059-2735	Low-ionization BALQSO	1.59	7.6
Q0335-3339	Low-ionization BALQSO	2.26	8.1
Q1011+0910	Low-ionization BALQSO	2.30	6.9
Hawaii 167	Low-ionization BALQSO	2.36	13
Q1246-0524	Normal BALQSO	2.25	4.0
Q1428+0202	Normal QSO	2.12	4.0

Another characteristic which links Low-ionization BALQSOs and Warm ULIRGs is their strong restframe-optical Fe II emission. Figure 1 shows that one of the low-ionization BALQSOs emits a very strong Fe II emission at 4924 Å; on the other hand, this line is much weaker or even completely absent in the spectra of normal QSOs at similar redshifts we have looked at. In fact, such a strong optical Fe II 4924 Å emission is a common property among Warm ULIRGs (Lipari 1994b). If the strong optical Fe II emission is coming from Type II supernovae as Lipari (1994a, b) suggests, then this might mean that the host galaxies of these objects are undergoing massive starbursts, which is consistent with the picture of Hawaii 167 suggested by Egami et al. (1996).

Based on the large Balmer decrements, the absence of the [O III] 5007 Å line, and the strong Fe II 4924 Å emission, we suggest that high-z Low-ionization BALQSOs are Warm ULIRGs. This indicates that at least a subset of the ULIRG population (i.e. the "Warm" variety) does exist at high redshifts. At present only a small number of Low-ionization BALQSOs are known, but it might simply be a selection effect of the optical surveys. A large-area sensitive IR survey is essential to properly access the abundance of such objects. The more important goal of such a survey is to pick up bona fide ULIRGs at high redshifts; these objects would not have been detected in the previous optical surveys because of their much redder (i.e. cooler) color. These surveys, however, were able to detect high-z Warm ULIRGs simply because they have flatter SEDs due to their less obscured central AGNs. It will be especially interesting if we can find more of Hawaii 167-like objects in which we can directly see the starlight from the starbursting host galaxy.

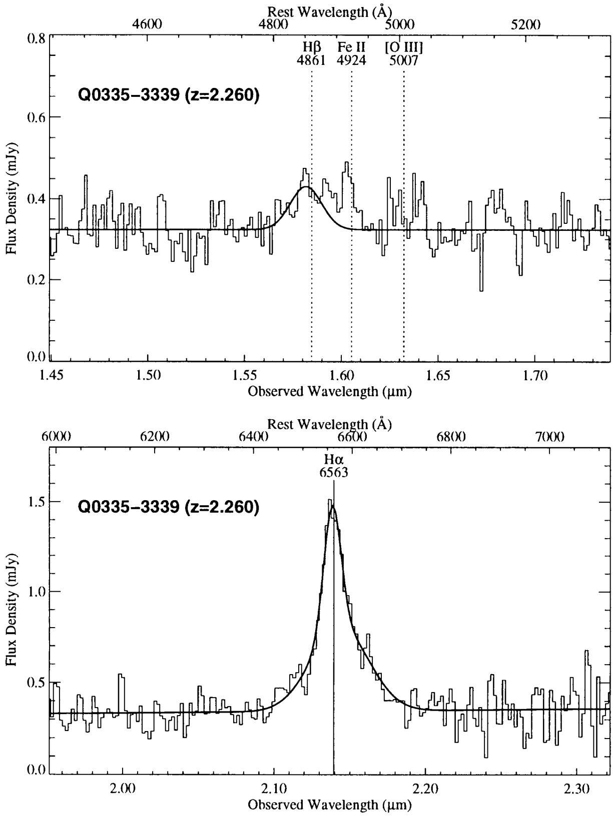

Figure 1. Near-IR spectra of Q0335-3339 taken with IRS on CTIO 4m telescope.

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