Abstract.

Thermal models for the quasar Big Blue Bump generally lead to bound-free continuum features, which may be in absorption or emission. Searches for Lyman edges attributable to quasar atmospheres (in particular accretion disk atmospheres) have been ambiguous at best, but various relativistic and non-LTE effects may make them hard to detect.

The Balmer edge features tentatively predicted by such models might be easier to detect since they’d form farther out in the potential wells. These can be sought in certain cases using spectropolarimetry to remove the effects of atomic emission (i.e. the Small Blue Bump) from the spectrum. We do find apparent Balmer edges in absorption in several quasars using this method! Although the features we see are believable and apparently common, more data and more modeling are needed to verify that they are best interpreted as atmospheric Balmer edges.
1. Introduction

Early models of quasar accretion disks\(^1\) predicted strong Lyman edges in absorption, as expected for stars of moderately high temperature, due to source function gradients in the atmospheres (e.g. Kolykhalov and Sunyaev 1984). Any such edges aren’t easily seen (Antonucci, Kinney and Ford 1989 and later papers)\(^2\).

Changes in spectral slope do appear to be common in the vicinity of the Lyman limit (Zheng et al. 1995 and later papers). Such spectral breaks might be consistent with smeared out and/or Comptonized Lyman edge features (e.g. Lee, Kriss, & Davidsen 1992, Hubeny et al. 2000). However, detailed fits to the spectral break observed in 3C 273 with the latest disk atmosphere models still produce a local emission bump longward of the limit that is not in agreement with the data (Blaes et al. 2001), and other problem arise when fitting the reported spectral breaks as atmospheric edges (Kishimoto et al, in prep).

Accretion disk models place the ∼4000Å continuum around seven times farther out in the gravitational potential well for peak emissivity, compared with the Lyman edge region. This would greatly reduce relativistic smearing. Also since Balmer continuum absorption is not a resonance process, there is less chance of being fooled by intervening absorbing matter. In fact the distinction between atmospheric and foreground absorption becomes in part a semantic one in that case.

The Balmer edge behavior has never been discussed as a diagnostic of the quasar continuum emission mechanism because very strong Balmer continuum EMISSION and FeII features, attributed to the Broad Line Region, contaminate this wavelength region.

Very fortunately there is a way around the problem of contamination by atomic emission in some objects. These have slightly polarized BBBs, and UN-POLARIZED emission lines. The likely explanation is that there is some Thomson scattering interior to the BLR, which polarizes the BBB only.\(^3\)

Thus a plot of polarized flux can cleanly shave off the atomic emission. Published data of moderate SNR confirm that in these cases the Small Blue Bump

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\(^1\)It must be emphasized that almost all published accretion disk models are quasi-static and based on the Shakura-Sunyaev model. This is known to be qualitatively and quantitatively inconsistent with the observations of variability, spectral energy distributions and other properties. A sampling of references for this statement is the following: Alloin et al 1985, Antonucci 1988, 1999; Krolik et al 1991; Gaskell et al 2003; D vanden Berg 2003, these proceedings; O Blaes 2003, these proceedings. However, the models may indicate in a general way the behavior of optically thick thermal radiation in the case of energy deposition at large optical depth, especially if the emission follows the potential drop as in the Shakura-Sunyaev paradigm.

\(^2\)Also note that partial Lyman Limit Systems such as those of 5 0014+81 can give false positives for atmospheric edges (e.g. Fig 1a of Antonucci et al 1989 and the accompanying discussion). Thus no edges should be claimed to be atmospheric unless it has been shown that they lack accompanying narrow absorption lines. Candidates for broadened edges have generally failed this test, when the test has been made (Koratkar, Kinney and Bohlin (1992)).

\(^3\)We discuss the possibility that the observed polarization is due to a synchroton component (Schmidt and Smith 2002) in Kishimoto et al 2003. Here we just note that the existence of the edge feature in polarized flux requires that at least some of the polarization result form a thermal process.
is indeed unpolarized (e.g. Antonucci 1988; Schmidt and Smith 2000). With recent higher-SNR data from larger telescopes, we can determine the behavior of the BBB alone at the Balmer edge position.

2. Observations and Results

A total of around fifteen good moderate-redshift candidates for polarized continuum and unpolarized atomic emission have been taken from the literature. We observed two of these objects with the Keck I telescope on May 9, 2002 (UT), and reported the results in Kishimoto et al 2003. The object with the better data, Ton 202, clearly shows the polarized flux turning DOWN below 4000Å, just where the total flux turns UP because of the SBB.

Next we observed eleven quasars at the VLT Unit 3 (Melipal). These objects show a rich variety of interesting behavior, and some are unsuitable for our method because of substantial emission line polarization. For the suitable quasars, the polarized flux spectra show absorption edges similar to that of Ton 202 in at least two other cases (3C95 and 4C09.72)! The behavior thus seems rather widespread.

A second run with Keck I on May 4, 2003 (UT) uncovered a similar Balmer edge feature in two more objects. As noted by Schmidt and Smith 2000, the polarization of individual objects varies over time. This isn’t surprising since the scatterers must reside interior to or cospatial with the BLR.

3. Discussion

We often find that the polarized flux DECREASES at wavelengths below 4000Å, strongly suggesting that the BBB has such a feature, and is thus thermal emission from an optically thick source. It may be that the total flux of the BBB has no feature at this wavelength, but that instead the BBB percent polarization has the feature. This type of behavior occurs in some models (Laor, Netzer and Piran 1990; a rigorous calculation which gives rather different behavior in some part of parameter space was later published as Blaes and Agol 1996). Still the implication is optically thick thermal emission.

Although the observed Balmer edge behavior is qualitatively consistent with thermal model predictions, more data and more modeling are needed to ensure that this is the correct interpretation.

On a slightly different topic, a high point of the SDSS conference for us was a lunchtime discussion of the polarization of 2MASS quasars with Gary Schmidt. His group has observed these objects extensively (e.g. Smith et al 2003). The objects were selected for red J-K colors. Considering the nonzero redshifts, this means in practice that they were selected for LARGE RATIOS OF HOT DUST EMISSION TO BBB EMISSION. The polarization data are very remarkable! We’d have expected the 2MASS objects to be mostly reddened quasars, with polarization due to dust scattering or absorption. Dusty far-IR selected quasars behave this way in general (e.g. Hines et al 2001). Dust scattering typically produces very blue polarized flux spectra in the objects studied in that paper and in other similar objects, at least in the optical part of the spectrum. (The shorter wavelengths are often cut off by dust absorption.) None of the 2MASS
objects behave that way. However many 2MASS quasars are highly polarized: the percent polarization is often \( \sim 10\% \), rather than \( \sim 1\% \) as for our objects! In general the broad lines ARE polarized in objects selected this way, and so that this high polarization arises on BLR scales of larger. These properties make the interpretation of the spectropolarimetry very different from that of the low-polarization quasars described above.

Modest foreground reddening suppressing the BBB wouldn’t necessarily produce very red J-K colors since that wavelength interval is small and at relatively long wavelength; rather as noted above it could indicate a large ratio of dust emission to BBB emission. Actual optical/NIR SEDs will help to distinguish the two possibilities.

Over the lunchable we considered the possibility that the BBB emission is suppressed by foreground Thomson scattering. The (often very high) polarizations may be due to Thomson scattering as well. Large electron-scattering optical depths are very reasonable for quasars and luminous Seyfert galaxies. A powerful argument is that the scatterers in objects like NGC1068 provide an optical depth of 1\% due to electron scattering (Miller, Goodrich, and Mathews 1991; Antonucci et al 1994; Ogle et al 2003) and this polarization arises on \( \sim 100\text{pc} \) scales (Antonucci et al 1994; Capetti et al 1995). The outflowing scattering region is likely to be a wind which originates near the sublimation (or "ablation") radius of \(< 1\text{pc}\) (Krolik and Begelman 1986). Thus given the density law for winds, \text{THE OPTICAL DEPTH OF THE WIND IS OF ORDER UNITY} on pc scales. (Ferland et al, this meeting, also argue for such electron-scattering optical depths near the torus inner edge.) Thus NGC1068 would look like a luminous Seyfert 1 or weak quasar if seen from the polar regions, and would present a very substantial electron-scattering optical depth to the BBB-emitting region. Similarly many quasars show large X-ray absorption columns with little or no optical reddening and absorption. (e.g. Salvati and Maiolino 2000; Wilkes et al 2002). These observations are interpretable in the context of the scattering wind (Krolik and Kriss 2001).

A delightful aspect of the 2MASS spectropolarimetric observations is that the DIRECT, unpolarized line profile can often be seen simultaneously with the Thomson-scattered line profile! See for example 2MASS 222202.2 +195231 in Fig 2 of Smith et al 2003. Thus we can get an accurate temperature and outflow velocity, as well as a good idea of the electron-scattering optical depth. For the object mentioned, the electron temperature comes out to one million degrees (FWZI = 18,000 km/s) and the outflow velocity is around 4000 km/sec (G. D. Schmidt, 2003 p.c.). However, demonstration of large electron-scattering optical depth in front of many quasar BBBs will entail many observational tests.

To summarize, the polarization property is underexploited in this field, and it can provide many unique insights.

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4This paper actually finds an angle-averaged optical depth on \( \sim 100\text{pc} \) scales of order a percent, but within the ionization/scattering cone, a small covering factor of sight lines with much higher Thomson depth.
The Shape of the Big Blue Bump as Revealed by Spectropolarimetry

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