Accretion around supermassive black holes: the detection of the Balmer edge signature from quasars

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The ultraviolet/optical continuum of quasars is thought to be from an accretion flow around a supermassive black hole, and it dominates the radiative output of quasars. However, the nature of this emission, often called the Big Blue Bump, has not been well understood. Robust evidence for its thermal nature would be a continuum opacity edge feature intrinsic to this component, but this has not been clearly confirmed despite the predictions by many models. We are now developing and exploiting a new method to detect the Balmer edge of hydrogen opacity. The method overcomes for certain objects the major obstacle of the heavy contamination from emissions outside the nucleus by taking the polarized flux spectrum. If our interpretation of the polarized flux is correct, our data show that the Big Blue Bump emission has a Balmer edge in absorption, indicating that the emission is indeed thermal, and the emitter is optically thick.

§1. introduction

The ultraviolet/optical continuum radiation of quasars, which is often called the Big Blue Bump, is thought to be from an accretion flow around a supermassive black hole. The radiative output of quasars is dominated by this component, and thus it is a crucial component to understand the accretion flow. This radiation is often assumed to be an optically thick and thermal emission from an accretion disk. However, continuum edge features, which are key predictions of many models for the atmospheric emission from accretion disks, have not been confirmed satisfactorily.¹,² Identifying these features would prove the thermal nature of the emission in the first place, and thus it is of fundamental importance.

There have been intensive and unsuccessful searches for broadened Lyman edge discontinuities, starting with Ref. 3. Later some slope changes have been found around 1000 Å in some individual cases and composite spectra.⁴–⁶ This could be related to the opacity change at the Lyman edge which is severely smeared by relativistic effects. However, in detail, even state-of-the-art atmosphere models are not in a good agreement with the observed feature.² In addition, a foreground absorption possibility certainly complicates the interpretation of the spectral features in this wavelength region.

The Balmer edge wavelengths can be more advantageous in these two respects: (1) the spectral smearing would be less effective in the context of accretion disk models, since this longer wavelength feature originates from much farther out in the gravitational potential well; (2) the Balmer edge wavelengths are less vulnerable to
a foreground absorption possibility since the Balmer features are not resonant ones unlike the Lyman features. However, the emissions from outside the nucleus, i.e. the broad-line region (BLR) and outer regions, heavily contaminates this Balmer edge wavelength range. These are high-order Balmer emission lines and Balmer continuum in emission as well as broad FeII emission lines, collectively called the small blue bump.

There is a way to overcome this obstacle, however. Many normal quasars show a small polarization ($P \sim 1\%$), which can be used at least in some cases to eliminate any unwanted contamination from outside the nucleus, as we describe below.

§2. Observations and results

We have so far observed 16 quasars spectropolarimetrically with 8-10m telescopes. Firstly, two quasars were observed with the Keck telescope in May 2002. The results have been published in Ref. 7) (Paper I). Then, 11 quasars were observed with the Very Large Telescope (VLT) in September 2002 and three more new quasars were observed with the Keck in May 2003 together with a re-observation of one of the quasars observed in May 2002. The details of these VLT and second Keck results will be published in Ref. 8) (Paper II). Here, we show the most favorable five objects for our Balmer edge investigation in Fig.1 taken from Paper II. We note that the polarized flux spectra of these five quasars were published in Ref. 9) but with a lower S/N, so that the edge feature described below was not clear.

The polarization spectra $P(\lambda)$ (not shown here) of these quasars show a clear decrease at the broad emission line wavelengths,7)–9) so that essentially no emission line shows up in the polarized flux spectrum $P \times F_\lambda$ (note the distinction between $P$ and $P \times F_\lambda$) to a high S/N as shown in Fig.1. Just around shortward of $\sim 4000\AA$ where the small blue bump emission starts in the total flux spectrum, the polarization spectra again show a clear decrease (not shown here), indicating that the small blue bump is also unpolarized.7)–9) Thus, the polarized flux is essentially confined only to continuum, and the emission from the BLR seems to be all unpolarized (Fig.1).

In all these five cases, this emission-line-free polarized flux seems to show a Balmer edge feature in absorption. The spectral slope of the polarized flux at the wavelengths longward of $\sim 4000\AA$ is essentially the same as that of the continuum in the total flux, but at $\sim 4000\AA$, there is a slope down-turn, which is considered to be the start of the Balmer edge feature. Then, there also seems to be a slope up-turn at $\sim 3600\AA$. The edge feature seems to be broadened possibly due to a rather high velocity dispersion.

§3. Discussion and conclusion

The continuum-confined polarization seen in these objects is quite in contrast to Seyfert 2 galaxies where the continuum and the broad emission lines are both polarized. Based on this, the polarization is thought to occur due to scattering outside the BLR.10) However, in our cases, the emission from the BLR is not polarized. Therefore, the polarization is considered to occur interior to the BLR. Thus, the po-
The Balmer edge of quasars

Fig. 1. Our spectropolarimetric data for five quasars taken with the Keck and VLT. The solid line represents the polarized flux, and the dotted line is the total flux scaled to roughly match at the red side. The left panel is in $F_\lambda$ and the right in $\nu F_\nu$ with both axes in log scale. The wavelengths are in the rest frame of each quasar. Note that the data for all the objects except Ton 202 have been corrected for the interstellar polarization in our Galaxy.

The polarized flux is likely to show the intrinsic spectral shape of the emission from interior to the BLR, scraping off all the other contaminating emission from outside.

The cause of the polarization is not still clear, but probably it involves some form of electron scattering. Dust scattering is not likely, since the region which
is causing the polarization is thought to be interior to the BLR and thus within the dust sublimation radius. The scattering region could be the atmosphere of the putative accretion disk around the central black hole (though see more discussions in Paper I). Alternatively, it could be a diffuse optically-thin region surrounding the emitter of the Big Blue Bump. In either of these simplest cases, the Balmer edge feature seen in absorption in the polarized flux is intrinsic to the Big Blue Bump emission. In this case, the feature indicates that the emission is indeed thermal, and the emitter is optically thick.

However, some alternative explanations for the observed polarized flux are not ruled out, as discussed in Paper I. Briefly, the feature might have been imprinted in some foreground region or in the scattering/polarizing region itself. However, a simple foreground absorption is unlikely due to the general lack of a huge, corresponding Lyman edge absorption in the total flux. If the Balmer edge feature were to be imprinted in-situ when the polarized flux is formed in the scattering region outside the Big Blue Bump emitter, then the distinction from the case of the atmospheric feature might be just semantic, since the scattering region should be optically thick, and should have a large velocity dispersion to produce a large broadening in the edge feature.

In the re-observation of Ton 202 in May 2003, which is one year apart from the observation shown in the top panels of Fig.1, we did not detect such a dramatic feature. The details are presented in Paper II, but this is apparently due to polarization variability. This is not unexpected, since, as we discussed above, the polarization is thought to originate from a quite compact region, at least comparable to or smaller than the size scale of the BLR.

In conclusion, the edge feature is most simply interpreted as an intrinsic feature of the Big Blue Bump emission, showing its thermal and optically thick nature. However, we cannot rule out some alternative interpretations, and we need more data and modeling to confirm that our interpretation is correct.

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