The near-IR shape of the big blue bump emission from quasars: under the hot dust emission

Makoto Kishimoto\textsuperscript{1,2}, Robert Antonucci\textsuperscript{3}, Omer Blaes\textsuperscript{3}

\textsuperscript{1}Max-Planck-Institut für Radioastronomie, 53121 Bonn, Germany
\textsuperscript{2}SUPA (Scottish Universities Physics Alliance), Institute for Astronomy, University of Edinburgh, EH9 3HJ, UK
\textsuperscript{3}Physics Department, University of California, Santa Barbara, CA 93106, USA

Abstract.

One primary difficulty in understanding the nature of the putative accretion disk in the central engine of AGNs is that some of its key intrinsic spectral signatures are buried under the emissions from the surrounding regions, i.e. the broad line region (BLR) and the obscuring torus. We argue here that these signatures can be revealed by using optical and near-IR polarization. At least in some quasars, the polarization is seen only in the continuum and is not shared by emission lines. In this case, the polarized flux is considered to show the intrinsic spectrum interior to the BLR, removing off the emissions from the BLR and torus. We have used this polarization to reveal the Balmer-edge feature and near-IR spectral shape of the central engine, both of which are important for testing the fundamental aspects of the models.

1. The key, but hidden spectral signatures from the central engine

The radiative output of AGNs is dominated by the UV/optical component, often called the big blue bump (BBB). This is usually attributed to be from an accretion disk around a supermassive black hole, but the nature of this putative disk has not been well understood in many respects, i.e. there are unsatisfactory agreements between theory and observations (e.g. Antonucci 1988; Koratkar & Blaes 1999). However, there is certainly a big difficulty in the observational side. We still do not have the spatial resolution to isolate the central engine from the surrounding regions, most notably the broad-line region (BLR) and the obscuring torus. Consequently, the central engine’s spectrum is always mixed with the emissions from the BLR and torus, and some of the key, intrinsic spectral features of the central engine are almost impossible to uncover.

The hot dust thermal emission from the torus starts to dominate longward of \( \sim 1 \mu m \) (set by a dust sublimation temperature) and essentially hide the near-IR part of the BBB. This wavelength region is actually quite important, since disk models make a few key, well-known predictions at these long wavelengths. The spectral shape of a simple multi-temperature blackbody disk without any outer truncation asymptotically becomes as blue as \( f_\nu \propto \nu^{+1/3} \) at long wavelengths. This is also true in more sophisticated, bare-disk atmosphere models (e.g. Hubeny et al. 2000), and the limit is essentially reached longward of 1 \( \mu m \).
2. The polarization of Type 1 AGNs

The optical polarization which is probably the most familiar to many people in the field is the one seen in Type 2 AGNs. The broad emission lines are seen in the polarized flux in many of these, with polarization position angle (PA) perpendicular to the radio jet axis (Antonucci 1993). The interpretation is that the gas which resides outside the BLR, along the jet axis perhaps above and
The near-IR shape of the big blue bump

below the torus, scatters the light from the central engine and BLR into the line of sight (Fig.1a). Thus they both show up in the polarized flux.

What we want to utilize here is not the polarization in these Type 2s, but that in Type 1s. In those objects, a different, nuclear polarization component appears to dominate, quite plausibly and simply because the bright nuclear region inside the torus is directly seen. In many cases, the continuum is polarized typically at $P \sim 1\%$ level, with the PA parallel to the jet axis (e.g. Berriman et al. 1990). In many Seyfert 1s, the broad lines are also polarized in addition to the continuum, often at lower $P$ and at different PA than continuum (it rotates across the line wavelengths; e.g. Smith et al. 2004; see also Lira et al. in these proceedings). These imply that the scattering region is more or less similar in size to the BLR. The parallel polarization quite possibly indicates that the scattering region is in a flattened/equatorial optically-thin geometry having its symmetry axis along the jet direction (Fig.1b).

At least in some quasars, however, similar continuum polarization is seen without any line polarization — this is what we want to use. Since lines aren’t polarized, scattering is considered to be caused interior to the BLR (Fig.1c), by electrons (since the site is inside the dust sublimation radius). Then the polarized flux would in fact be an electron-scattered copy of the intrinsic spectrum of the central engine, with all the emissions from the BLR and torus eliminated!

3. Revealing the Balmer edge and near-IR spectral shape

We have first applied this idea for looking closely at the Balmer edge wavelength region in several quasars with spectropolarimetry. At the H\textbeta\ wavelength, we essentially do not see any line features in the polarized flux, which is the basis for the application of our idea (Fig.2a). Then we find that the Balmer edge is seen in absorption: there is a downturn at around 4000Å and an upturn at around 3600Å in the polarized flux spectra of all the five objects (Fig.2a). We interpret this Balmer-edge feature to be intrinsic to the central engine, indicating quite fundamentally that the big blue bump is indeed from a thermal and optically-thick emitter.

Then we have also been trying to accurately measure near-IR polarized flux to obtain dust-eliminated near-IR shape of the BBB. Fig.2b shows our first object, where the polarized flux is compared with the total flux shape from the optical to near-IR (note that it is one of the objects in Fig.2a). The near-IR polarized flux appears to be nicely removing the torus emission (and also perhaps the host galaxy light as well). The spectral index measured between $J$ and $K$ ($\lambda_{\text{rest}} = 0.9 – 1.6\mu$) in the polarized flux is $\alpha = +0.42 \pm 0.29 \ (f_\nu \propto \nu^\alpha)$, which is intriguingly consistent with the $\nu^{+1/3}$ limit. A model atmosphere spectrum without a disk truncation runs through optical to near-IR data points, though it fails in the near-UV side (Fig.2b). The data do not appear to show evidence for a disk truncation, based on the model spectrum for a disk truncated at the self-gravity-unstable radius. Of course we need more measurements to see if similar spectra are seen systematically in other objects, which will check the validity of our interpretation for the near-IR polarized flux.
Figure 2. (a) Optical spectropolarimetry of 5 quasars from Kishimoto et al. (2004). The solid line is the polarized flux in units of $10^{-18}$ ergs/cm$^2$/sec/Å. The dotted line is the total flux scaled to match the polarized flux at the red side. The wavelength of the Balmer discontinuity, 3646 Å, is indicated as a folded line in each panel. (b) The optical to near-IR SED for the quasar Ton202 in $\nu F_\nu$ with both axes in log scale. The top gray line is the optical total flux which is schematically connected by a thick gray dashed curve to the near-IR total flux shown in thin gray lines with square symbols. The solid black line and crosses are the optical and near-IR polarized flux, respectively, scaled to match the total flux at the red side in the optical. The near-IR total and polarized flux taken at a different epoch are shown in dotted lines and crosses. The gray wedge schematically shows the emission from the torus (plus possibly the host galaxy) which is removed by measuring the polarized flux. A disk atmosphere model without any disk truncation is shown in a smooth solid curve, while the dot-dashed curve is the same disk which is truncated at the self-gravity-unstable radius. From Kishimoto et al. (2005).

4. Conclusions

It seems that these polarization measurements are starting to delineate the fundamental aspects of the radiative output from the central engine. The results so far suggest that the big blue bump emitter at least resembles a standard disk in a few respects. We hope to explore its nature with further measurements.

References

Antonucci, R. 1988, in Supermassive Black Holes, ed. M. Kafatos (Cambridge: Cambridge Univ. Press), 26
Antonucci R., 1993, ARA&A, 31, 473
Berriman, G., Schmidt, G. D., West, S. C., Stockman, H. S., 1990, ApJS, 74, 869
Goodman J., 2003, MNRAS, 339, 937
Hubeny, I., Agol, E., Blaes, O., Krolik, J. H., 2000, ApJ, 533, 710
Kishimoto M., Antonucci R., Boisson C., Blaes O., 2004, MNRAS, 354, 1065
Kishimoto M., Antonucci R., Blaes O., 2005, MNRAS, 364, 640
Koratkar, A., Blaes, O. 1999, PASP, 111, 1
Smith J. E., Robinson A., Alexander D. M., Young S., Axon D. J., Corbett E. A., 2004, MNRAS, 350, 140