On BLR Size Estimates in Reverberation Models

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Following the approach of Melnikov & Shevchenko (2008), we explore how the nonlinearity in the emission-line luminosity L_l of a broad-line region cloud, in its dependence on the ionizing continuum flux F_i incident on the cloud, affects estimates of the size of the broad-line region by means of cross-correlation methods. We show that the estimates obtained by straightforward cross-correlation of emission-line and continuum light curves can significantly underestimate the BLR size. We demonstrate examples of direct reverberation modelling of AGN emission-line light curves taking into account the nonlinearity of the "L_l–F_i" relation. This nonlinearity allows one to explain the differences in the time lags for different lines. Cross-correlation estimates of the BLR size turn out to be small in comparison to the estimates obtained by the direct reverberation modelling.

The mass of the black hole (BH) in the center of the BLR is usually calculated by the formula (see, e.g., Bentz *et al.* 2006) $M_{BH} \approx fc\tau\Delta V^2/G \approx fR\Delta V^2/G$, where τ is the time lag for an emission line, R is the BLR radius, ΔV is the width of the emission line, c is the speed of light, and G is the gravitational constant. The factor f depends on the geometry, inclination, and dynamics of the BLR. Here the BLR radius is set to be equal to $c\tau$, as it is commonly done; the uncertainty is included in f. Note that this formula is valid, if the virial theorem is valid: in particular, the size of the BLR should be constant.

A hypothesis on possible variability of the BLR size of NGC 4151 was put forward by Kaspi *et al.* (1996), Peterson *et al.* (2002), and other researchers on the basis of cross-correlation analysis of optical spectral variability data at different time intervals of observations. Our reverberation modelling of the Hα light curve data of Kaspi *et al.* (1996) gives the value of the BLR radius matching the majority of the BLR size estimates of other authors. This removes necessity of any special physical interpretation of the small value of the cross-correlation time lag in Hα for these light curve data. In particular, the hypothesis by Kaspi *et al.* (1996) that the physical size of the BLR at the moment of their observations was an order of magnitude less than usual is not necessary. This strengthens the validity of the BH mass estimates, which are based on the validity of the virial theorem. Indeed, the dynamical timescale (determined from the width of the lines) in the BLR can be of the same order or even exceed the timescale of hypothetical variations of the BLR size (according to Kaspi *et al.* 1996, the latter timescale is less than 2000 days). If the size variability caused by external disturbances on such short timescales is absent, then the virial mass estimates are presumably valid.

References

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