INVESTIGATIONS OF BROAD LINE REGION STRUCTURE AND KINEMATICS USING VARIABILITY

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Gaskell and Sparke (1986) showed that one can determine the sizes of BLRs more accurately that the mean sampling interval by cross-correlating the continuum flux time series with a line flux time series. The position of the peak in the cross-correlation function (CCF) and its shape give an indication of the BLR size. The technique is explained in detail in Gaskell and Peterson (1987). The widely propagated misunderstanding is that the method involves simply interpolating both time series and cross-correlating them (in which case the CCF is dominated by the cross-correlations of "made-up" data). Actually the method involves cross correlating the *observed* points in one time series (continuum, say) with the linear interpolations of the other series (line flux). The line flux time series must always be smoother than the continuum time series it is derived from. We have usually employed the method with the interpolation done both ways round and averaged them (to reduce errors due to the interpolation) and we can intercompare the two results (to investigate errors).

The errors in the positions of the peaks are similar to the errors in cross correlation radial velocities and are well understood theoretically. Separate analyses of independent data sets and extensive Monte Carlo simulations all confirm the theoretical errors. Comparison of the sampling window auto-correlation function and the continuum auto-correlation permits one to see where the method will fail due to undersampling.

Using this method Gaskell and Sparke (1986) verified that BLRs were considerably smaller than had been expected from photoionization models (such as G. J. Ferland's CLOUDY). They also found evidence that

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the low ionization gas came from further away from the ionizing source than the high ionization gas. Gaskell (1988) used the method to show that the BLR gas motion in NGC 4151 was dominated by gravity and that the gas was probably infalling. We have recently extended this work to a number of other quasars and we summarize some of our results here. We have looked at UV data for NGC 5548, the brighter quasars Fairall 9 and 3C 273. For these we find that the sizes of the BLRs are also smaller than expcted. We find that the BLR size scales approximately with the square root of the luminosity. For all three of these objects radial outflow of the BLR gas is excluded and the high ionization gas appears to be inflowing. In Fairall 9 (Koratkar and Gaskell, 1988) as in NGC 4151 the BLR appears to be somewhat stratified with the low ionization gas apparently in chaotic or circular motion about twice as far from the center as C IV. We find that the masses of the black holes correlate with luminosity.

The validity of the Gaskell and Sparke approach (and hence of results obtained by it) has been challenged by a number of people, most notably Edelson and Krolik (1988) who give the implication that *all* results obtained in the Gaskell and Sparke (1986) manner are spurious! Part of these objections are based on a misunderstanding of the real nature of quasar variability (see Peterson 1988) and part on the application of a misleading method of calculating correlations. They propose using the *discrete correlation function* (DCF) approach to calculating cross-correlations. This is very conservative in that the DCF is only defined for lags where there is a match up of points in the two series.

We have found that the DCF method will ignore interesting variability and is weighted heavily towards periods of intense monitoring (where nothing might have happened). The problems are almost completely hidden when the DCF is binned and one can get the false impression that nothing can be learnt. This is the reason Edelson and Krolik fail to find the clear peak in the NGC 4151 C IV/continuum cross-correlations function which Gaskell and Sparke (1986) had found. If one excludes a period of intense monitoring where almost nothing happened one finds a peak in the unbinned DCF at around 8 days, in good agreement with Gaskell and Sparke (1986).

In defense of our own approach we would emphasise that it gives consistent results for different objects, different lines, different epochs, different telescopes and different times and that the errors, which can be calculated in a variety of ways, are well understood. Correlated errors (which produce a bias towards small timescales) are rarely a problem, can readily be recognized and can be corrected for.

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DISCUSSION

PENSTON I think we are now at the stage that radio astronomers were when they talked of "visibility functions." We are talking about the CCF when we are really interested in the kernel of the integral which relates the continuum to the line variations. Now it may be this is not a Fourier problem for, if the kernel is zero for negative lags, one should use Laplace transforms to invert the equations (if the mathematical methods exist). But I'm sure that radio astronomers who are expert in mapping know how to solve our problem. I think an MEM method which takes into account the incompleteness of data sampling (cf. the coverage of the u-v plane) is what we need and the radio astronomers can tell us how to do it!

GASKELL A radio astronomer tells me he thinks radio methods are not relevant. Work on using Fourier inversion methods is in progress.