Bull. Astr. Soc. India (2000) **28**, 395-396

Study of quasar broad emission region from spectroscopy of multiple images

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Abstract. Using the high resolution radio observations and analysis of the broad emission lines as well as continuum in the optical spectra of the multiple images of quasars, we provide a method to probe the structure and dynamics of the broad emission region of AGNs. From the study of the system 1422+231 we establish that the optical and radio emission of the source originate from two different regions.

Key words : AGN : broad absorption lines; gravitational lensing

The flux ratio, line strength and Doppler profile of broad emission lines in the multiple images observed in gravitationally lensed systems are in general not same, the major reason for which is the non-negligible size of the emission region. If the angular separation of the source from the caustic (which delineates the regions of different image multiplicities) is comparable to the size of the line emission region, the images could be merging in the broad line though they may be distinct in the continuum. By modelling the line emission and comparing the observed flux ratio as well as Doppler profile, it is possible to infer the structure of the broad line emission region in addition to providing stringent tests of the gravitational lens models. The *magnification of the source* should be estimated based on the part of the *spectrum which could originate near enough to the central source* rather than use the broad band images as being done conventionally.

Archival data from HST was obtained for the two lens systems Q1422+231 and PG1115+080 and some emission line free region could be selected in each spectrum inspite of heavy contamination by the numerous lines. For the lens 1422+231, the continuum region between 6000 and 6500 $\AA$ was wide enough to determine the continuum flux ratios to be $A : B : C =$ 0.76±0.06 : 1 : 0.48±0.07. After subtracting the continuum, some of the board lines could be studied, and we recover the accepted results for the flux in $Ly\alpha$, namely, $A : B : C = 0.9 : 1 : 0.5$. However, the line profiles are different, specially between the brightest images, which turns out to be a key feature to study the source size. In the case of 1115+080 the broad band flux ratio between the brightest images is reported as ~ 0.68 while we find the value at the emission free region to be ~ 0.55. From this analysis we establish that in both cases.

The continuum flux ratio between the images is different from that of various line emissions, the variation being most prominent in the brightest pair of images.

There is difference in the Doppler profiles of the emission lines when the flux ratio varies between radio and the optical or IR.

Here we address the lens models through the singularity theory with the simplest kind of *unfolding* and using fairly generic properties of the lens, we are able to construct models which explain most of these features. A crucial input that determines the shape of the lens (and through it, the scale length of its mass distribution) is the ratio of the magnification of the two near-merging images, which should be between -0.5 and -1 depending upon the source position. A value very different from unity for this ratio is indicative of a highly asymmetric lens of usually large scale length. The difference in the observed fluxes of the two brightest images are naturally explained in our model and the predicted milliarcsecond scale jet type of structure could test the reliability of the model. But in this generic study of the lens, the scale of the source plane cannot be fixed without having external input on the scale length of the lens galaxy and hence the size of the emission region cannot be derived. An important outcome is that the **centre of flux of the three images will correspond to three different points of the source and consequently, the position and fluxes for the emission from the inner region of the source is essential to construct a trustworthy model of the lens system**. Salient results of the analysis are :

1. Emission line has three components - a) Continum from the interior which has flux ratio $A : B : C = 0.71 : 1 : 0.48$. b) Bulk of emission peak and its high wavelength wing from an extended region. c) A part of the wing from near the centre or the jet which should contribute to VLA scale radio emission.
2. Weak emission from line like Si IV are probably from regions away from the jet and towards the otherside wing of the Ly alpha emission. Accurate velocity difference between Ly alpha and Si IV will confirm this speculation and together with the radio jet, determine the size of the line emission region.
3. The magnification of the point source, position and flux of strong line like the Lyman alpha along with radio frequency data could enable construction of testable lens models from which the structure of the line emission regions can be studied.
4. For the systems we studied, a smooth approximation for the Lyman alpha emitting region fits well, indicating that clouds having a range of velocities contribute equally.
5. The optical continuum and the radio core do not originate from the same region.

Prospects : High resolution study of the multiple images of lens systems offer a number of probes to different problems in cosmology. (e.g. the absorption by intervening clouds to trace the chemical evolution of small scale structures at medium to high redshifts; the source variability to study the emission line region of AGNs and scale length of the Universe through the time–delay between the multiple images). *High resolution analysis of the emission lines in multiple images of lens systems to probe the structure of active galactic nuclei at parsec scales will be a highly rewarding field of astronomy in the coming years.*