The first measurement of the Mg II line delay in a quasar at redshift ~ 1

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Since 4 years we perform reverberation monitoring of three quasars with the Southern African Large Telescope (SALT). Finally, we are able to give the preliminary estimate of the time delay for one of the quasars, CTS C30.10. The time delay of Mg II line with respect with continuum variation is 1050 days, longer than the expected value. This is in contradiction to recent claims that the sources with relatively high Eddington ratio show in general much shorter time delays than expected. This measurement has consequences for the black hole mass determination in high redshift sources, as it extends the scaling relation between the mass, line width and the monochromatic luminosity obtained for nearby AGN. This also opens the way to apply quasars for distance determination and to constrain the expansion rate of the Universe and the character of the dark energy.

1 Introduction

Dark energy is the most challenging problem of the present day astronomy and physics. Observational arguments accumulated since 70' now convincingly show that the Universe expansion is accelerating, and thus some mysterious medium prevents the gravity to slow it down. All current measurements are basically consistent with the simplest option of cosmological constant. This, in turn, limits the possibilities of deeper interpretation of the dark energy nature. The main goal nowadays is to detect some departures from the constant, for example in the form of time evolution of dark energy. However, precise measurements are highly limited, not simply by statistical errors, but also by the biases, and those are unresolved.

Therefore, new alternative methods are now being developed in order to achieve more precise, unbiased results. Among those methods, there are several possibilities of studying a Universe expansion with quasars. Quasars are not standard candles as SNe Ia, but it is possible to determine an absolute luminosity of each quasar from some measurements, independent on redshift, and this allows to put them onto the Hubble diagram. One of those ideas is based on the time delay of the Broad Emission Lines with respect to the continuum. According to the studies of the nearby active galaxies, this delay is proportional to the square root of the absolute luminosity. This relation is supported by the model of the Broad Line Region formation (FRADO - Failed Radiatively Accelerated Dusty Outflow; Czerny & Hryniewicz, 2011; Czerny et al., 2015, 2017), in which the proportionality constant is given by the dust sublimation temperature. Furthermore, quasars do not show significant evolution of metallicity up to redshift 6, and they cover a broader range

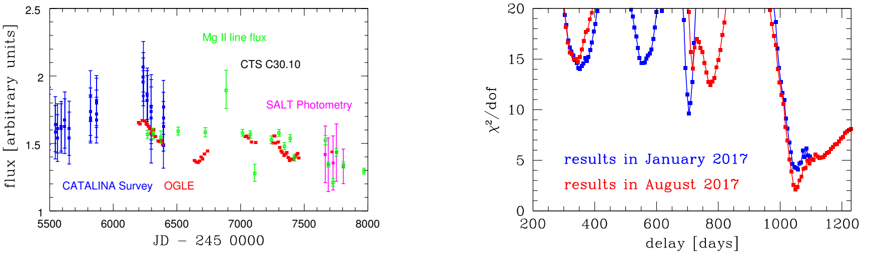

Fig. 1: Left: Lightcurves (Mg II and photometry) for the quasar CTS C30.10 ($z = 0.90052$). Right: The delay determination based on χ^2 method (Czerny et al., 2013), minimum marks the solution.

of redshifts, from nearby sources to distant quasars, which is essential for accurate absolute luminosity measurements.

2 Quasar reverberation measurements with the telescope SALT

In 2012 we undertook the reverberation measurements of a selected sample of quasars at redshift $z \sim 1$ with SALT (see Fig. 1). We selected three most promising objects. The expected delay was about 600 days, so we planned to collect 5 observations a year, for five years (Czerny et al., 2013). With 20 measurements per object by now we are approaching the goal. We analysed each spectrum carefully, doing decomposition of the continuum into disk power law component, Mg II 2800 Å line, and Fe II pseudo-continuum modelled using several theoretical templates from Bruhweiler & Verner (2008). Line decomposition and variability was discussed in detail by Hryniewicz et al. (2014); Modzelewska et al. (2014) and Średzińska et al. (2017). We also supplemented the OGLE monitoring of the selected sources with a few quite successful photometric measurements from SALT/SALTICAM, scaled to OGLE data. This allowed us to obtain the monochromatic luminosity at 3000 Å (rest frame) and the Mg II line luminosity. This data is shown in Fig. 1, left panel. Next we used the χ^2 method to determine the time delay of the Mg II line with respect to the continuum (see Czerny et al., 2013, for technical details and the comparison of different methods).

3 Measured time delay for CTS C30.10

The best value of the time delay for the source CTS C30.10 is 1050 days. There are more than one minimum on the curve (frequent problem in AGN monitoring due to the red noise character of the variability) but with time the minimum around 1050 days become deeper, and the others are relatively shallower so we are convinced now that the 1050 days delay is a proper value. However, we will continue monitoring since the measured delay is not much shorter yet than the duration of the campaign (1700 days). This is the first delay measured for Mg II line of the source at such high redshift.

4 Cosmological applications

One source offers at best a pilot insight into the possible results. However, even for one source we can now convert the measured delay into the absolute luminosity. Taking into account the source redshift $z = 0.90052$, the delay in the quasar rest frame is 550 days. Using the dust temperature of 900 K from Czerny et al. (2016) the obtained intrinsic monochromatic flux at 3000 Å is equal $5.13 \times 10^{46}\,\mathrm{erg\,s^{-1}}$. This value, in combination with the observed mean brightness of 17.1 mag in the observed V band, gives the observed flux $3.73 \times 10^{-12}\,\mathrm{erg\,s^{-1}}$, and the luminosity distance 10.1 Gpc. This is more than expected from the standard model for that redshift (6.1 Mpc). Our luminosity distance would require extreme parameter values of the Universe, like e.g. $\Omega_\mathrm{m} = 0.1$, $\Omega_\Lambda = 1.5$.

5 Future progress

More sources with delay measurement are needed to strengthen our result. They will be coming from several groups, we also have two more quasars to analyse. In addition, still more attention has to be given to the BLR structure. Mg II line is generally thought to form a bit further out than Hβ line. Larger line formation radius would reduce the luminosity distance.

Acknowledgements. The project was partially supported by the Polish Funding Agency National Science Centre, project 2015/17/B/ST9/03436/ (OPUS 9).

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