Tracing dark energy with quasars

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The nature of dark energy, driving the accelerated expansion of the Universe, is one of the most important issues in modern astrophysics. In order to understand this phenomenon, we need precise astrophysical probes of the universal expansion spanning wide redshift ranges. Quasars have recently emerged as such a probe, thanks to their high intrinsic luminosities and, most importantly, our ability to measure their luminosity distances independently of redshifts. Here we report our ongoing work on observational reverberation mapping using the time delay of the Mg II line, performed with the South African Large Telescope (SALT).

1 Introduction

Dark energy (DE), estimated to constitute about 70% of the universal mass-energy content today, is one of the crucial ingredients of the standard cosmological model. Since the first observational evidence of the accelerated expansion thanks to Supernovae Ia (SNeIa), various efforts have been undertaken to understand the nature of this phenomenon. On the observational side this requires designing ever more precise measurements, and various probes have been proposed and used to study DE. Quasars, currently detected at redshifts up to $z \sim 7$, are ideally suited to this task thanks to their very high intrinsic luminosity and large number density. However, using them as standard candles in a similar way to SNeIa, requires knowing their individual absolute luminosities (Watson et al., 2011). Determining the latter is possible through the measurement of the time delay between the variable nuclear continuum and emission lines (Czerny et al., 2013), or by analysing the shape of the lines to measure the BLR size. Here we focus on the first of these methods, which is possible by measuring the delay of the Hβ line, performed first for nearby Active Galactic Nuclei (AGN) (Clavel et al., 1991; Peterson, 1993; Reichert et al., 1994; Chelouche & Daniel, 2012; Bentz et al., 2013). The time delays in quasars are of the order of a few years, so the observations require sparse monitoring over an extended period of time.

2 Method

The work reported here is based on a simple mechanism of the broad line region (BLR) formation, presented in Czerny & Hryniewicz (2011), which explains how the

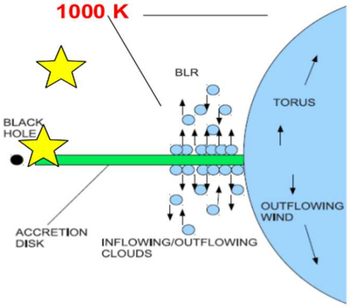

Fig. 1: Broad line region as failed dusty wind; for details see Czerny & Hryniewicz (2011).

size of BLR depends on the absolute monochromatic luminosity: $R_{\rm BLR} = {\rm const}\ L_v^{1/2}$. In our method we assume that: (*i*) we know the redshift of the source; (*ii*) the optical/UV continuum is generated in the inner part of the accretion disk surrounding the central black hole, while the broad emission lines are produced in another disk region, in clouds above the accretion disk as shown in Fig. 1. Dust leads to outflow and forces the material to rise high above the disk, the dust cannot however survive in temperatures much higher than 1000 K. Strong radiation field destroys the dust (through evaporation) and the material falls back without a driving force. More accurately, this mechanism is proposed for the low ionization line part of the BLR, like Hβ and MgII, which do not show a systematic shift in velocity with respect to the narrow line region (NLR). Using the observational method of reverberation mapping we measure the BLR size, which allows us to determine the absolute monochromatic luminosity of the quasar. Comparing the latter with the *observed* monochromatic flux from photometry, we obtain the luminosity distance and are able to locate the source on the distance–redshift diagram.

Until present, we have collected observations of three quasars at redshift $z \sim 1$, and part of this work is already published (Hryniewicz et al., 2014; Modzelewska et al., 2014). Spectra of two sources, CTS C30.10 and HE 0435-4312, are shown in Fig. 2. This project requires using the MgII line, and our studies are pioneer in this respect, as such monitoring has never been done before. Data obtained so far with the South African Large Telescope (SALT) show that we achieve the required accuracy (below 2%) of the MgII measurement to determine its variability (Modzelewska et al., 2014; Sredzinska et al., 2016), and simulations indicate that the program can give the accuracy of 0.06–0.32 mag in the distance modulus for each of the concerned quasars (Czerny et al., 2013).

3 Discussion

Our method is very promising for DE studies, as it can easily reach to much higher redshifts than available with supernovae (ground-based observations of SNeIa hardly reach beyond $z = 1$). On the other hand, such reverberation studies require very large time spans, as at least 5 years of systematic observations are needed to estimate the emission line delay with respect to the continuum. High-quality data from SALT give us the opportunity to accurately model the emission line shape. This provides us with a new tool for cosmological analyses which aim at understanding the mystery of dark energy.

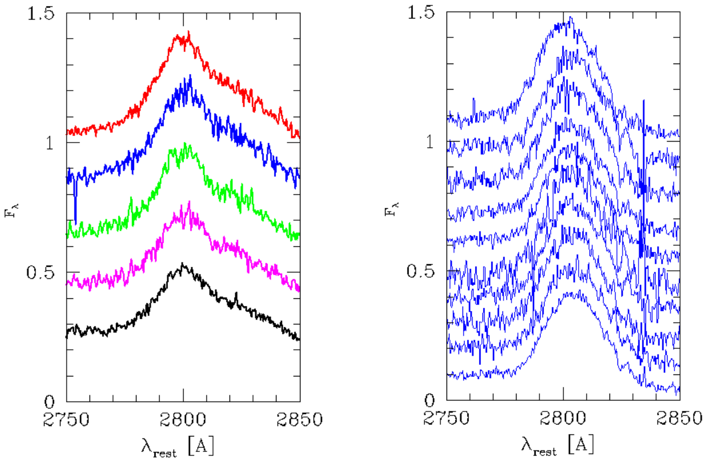

Fig. 2: SALT spectroscopy of the MgII emission line for the quasar CTS C30.10 (*left*) and HE 0435-4312 (*right*). The collected data cover respectively 15 months and 3 years of observations.

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