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The BLR structure and dust torus size of AGN - Implications from photometric and dust reverberation mapping campaigns.

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Abstract. Photometric reverberation mapping (PRM) is a novel method used to study the geometry of the broad emission-line region (BLR), black hole masses and host-subtracted luminosities of active galactic nuclei (AGN). We obtained high-quality sampling data with small (15 to 80 cm) robotic telescopes at the observatory of the Ruhr-University Bochum, located in the Atacama desert in Chile.

Key words: galaxies: active –galaxies: Seyfert –quasars: emission lines –galaxies: distances and redshifts –galaxies: individual: ESO399-IG20 –galaxies: individual: 3C120 –galaxies: individual: WPVS48

1. Introduction

PRM has been presented as an efficient tool to determine the BLR size, black hole masses and host-subtracted AGN luminosities (Haas et al. 2011; Pozo Nuñez et al. 2012, 2013a). Through the combination of broad and narrow-band data we measured the time-delay between the triggering AGN continuum variations and the emission line response in the BLR. A fundamental issue in PRM is to separate the host-galaxy contribution from the total AGN-luminosity. This can be achieved by the flux variation gradient method (FVG, see Pozo Nuñez et al. 2012 and its application on PRM data). This method can be easily applied to monitoring data and does not require high spatial resolution. In this paper we present a study of the BLR and dust torus geometry based on well-sampled PRM campaigns. We discuss the position of the objects in the BLR size – AGN luminosity diagram, and deviations of Seyfert-1 galaxies from the $M_{\mathrm{BH}} - \sigma_*$ relation.

2. Observations

Optical and near-infrared monitoring campaigns were carried out using multiple robotic telescopes (15 to 80 cm) located at the Universitätssternwarte Bochum observatory, near Cerro Armazones in Chile[1]. In addition to the photometric observations, spectroscopic monitoring were carried out using the Calar Alto Faint Object Spectrograph (CAFOS) instrument at the 2.2 m telescope on Calar Alto observatory, Spain.

3. Optical light curves and BLR geometry

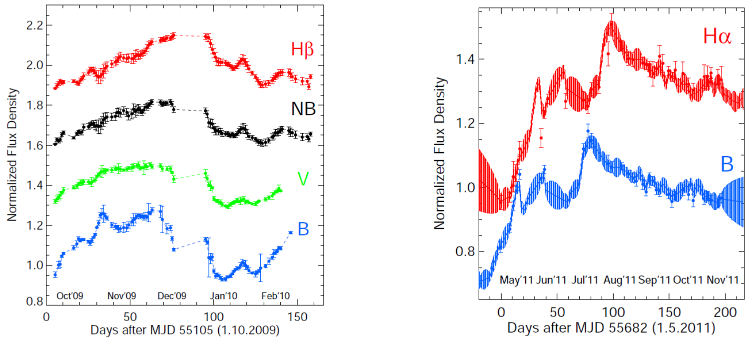

Figure 1. *Left*: 3C120 lightcurves 2009 – 2010, Hβ = NB − 0.5 V . *Right*: ESO399-IG20 lightcurves 2011, Hα = SII − 0.3 r.

The light curves of 3C120 and ESO399-IG20 (Fig 1) were obtained with a median sampling of 2-3 days in the B-band (Johnson 4330 ± 500 Å), V-band (Johnson 5500 ± 500 Å), r Sloan-band (6230 Å), the redshifted Hβ (OIII 5007 ± 30 Å) and Hα (SII 6721 ± 30 Å) lines. In the case of 3C120, the V band flux corresponds to $\sim$ 56% of the narrow band flux. Thus, we computed a Hβ light curve by subtracting a scaled V curve from the NB curve, i.e. Hβ = NB − 0.5 V (see Pozo Nuñez et al. 2012). For ESO399-IG20, the Hα line is contributing about 70% of the total flux enclosed in the SII-band, while the continuum contribution (r-band) is about 30%. Thus, we construct a Hα light curve by subtracting a third of the r-band flux, i.e. Hα = SII − 0.3 r (see Pozo Nuñez et al. 2013a). The continuum subtracted Hβ and Hα light curves are used afterwards to estimate the BLR size through cross correlation analysis. Correcting for the time dilation factor we obtain a rest frame lag τ_{rest} = 23.6 ±1.7 days for 3C120 and τ_{rest} = 18.2 ±2.29 days for ESO399-IG20.

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[1] http://www.astro.ruhr-uni-bochum.de/astro/oca/

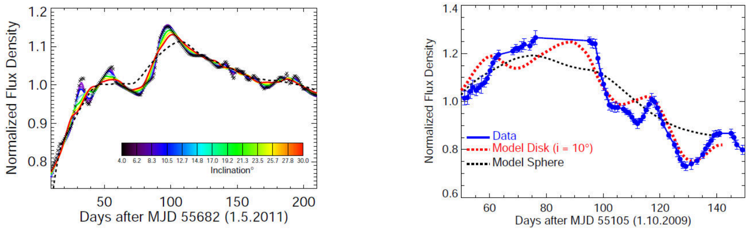

Figure 2. *Left*: Simulated Hα for ESO399-IG20. Disk-like BLR geometry, different inclinations in different colors. Black dotted the Hα simulated light curve for a spherical BLR. Original (black crosses). *Right*: Simulated Hβ light curve for 3C120. Original Hβ (blue filled circles). Original (red dotted line).

We have inferred the geometry of the BLR through the direct modeling of the results obtained from PRM. The observed continuum light curve was convolved with the time-delay function for the respective disk and sphere geometry to simulate the expected Hα/Hβ light curves (see Pozo Nuñez et al. 2013a,b). The results of the simulation are shown in Figure 2. A disk-like BLR model is able to reproduce the features of the original light curves. (Inclination of i=6°±3° for ESO399-IG20, i=$10 \pm 5°$ for 3C120)

4. The BLR size - luminosity relationship

Estimates of the BLR size and host-galaxy subtracted AGN luminosity in the literature have been derived from several spectroscopic RM campaigns and through host-galaxy modeling using high-resolution images from *HST*. In consequence, the relationship between the Hβ BLR size and the luminosity (5100Å) $R_{\rm BLR} \propto L^{\alpha}$ (Kaspi et al. 2000) has been improved considerably with the most recent slope of $\alpha = 0.519^{+0.063}_{-0.066}$ (Bentz et al. 2009). In Pozo Nuñez et al. 2012 we compared the results of PRM to those of spectroscopic RM in 3 objects (Fig 3). To refine the $R_{\rm BLR} - L$ relation, the host galaxy contribution has to be removed. For this purpose, the FVG method can be efficiently applied directly to the PRM monitoring data (see Fig 3).

5. Central black hole mass and the scaling factor of geometry for 3C120

Combining the velocity dispersion of the BLR gas (σ_V) with the BLR size allows us to estimate the virial BH mass using $M_{BH} = f \cdot R_{BLR} \cdot \sigma_V^2/G$, where G is the gravitational constant and the factor f depends on the geometry and kinematics of the BLR. By assuming that AGNs and quiescent galaxies follow the same $M_{BH} - \sigma_*$ relationship, Onken et al. (2004) showed that the scaling

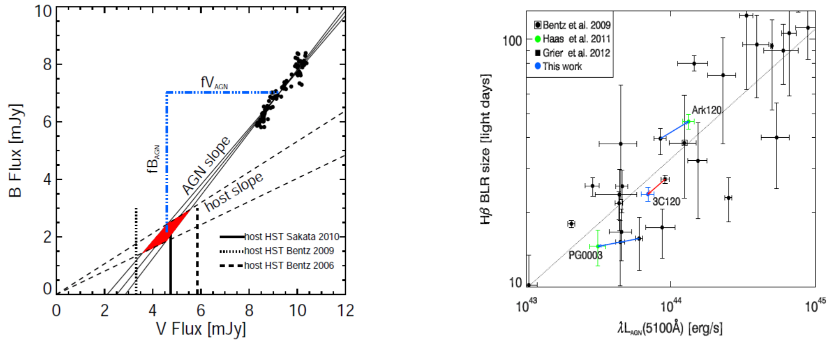

Figure 3. *Left*: FVG diagram for 3C120, dashed lines – range of host slopes determined by Sakata et al. (2010), intersection (red area) gives the host galaxy flux *Right*: Hβ BLR-size versus host-subtracted AGN luminosity.

factor (f) has on average a value of 5.5. The fact that 3C120 has a disk-like BLR geometry with $i = 10 \pm 5$ deg allows us to calculate a precise value for the scaling factor, $f = \frac{2 \cdot \ln 2}{\sin^2 i} = 46$. This value is about eight times higher than the statistical value obtained by Onken et al. (2004). In Pozo Nuñez et al. (2012) we estimated a virial mass $M_{\rm virial} = 10 \pm 5 \cdot 10^6\, M_\odot$. Using our $M_{\rm virial}$ as conservative approach and $f = 46$ the resulting black hole mass of 3C120 is $M_{\rm BH} = 460 \cdot 10^6\, M_\odot$. If this result of a disk-like BLR holds for Seyfert galaxies in general, then the determination of the f-factor used in black hole mass calculations can be remarkably improved. We find a strong deviation of 3C120 from the $M_{BH} - \sigma_*$ relation, which needs to be explained with future data. A detailed discussion and potential scenarios that could explain this important deviation can be seen in Pozo Nuñez et al. (2013b).

6. Near infrared light curves and dust torus size

Between 2013 January and May, we performed photometric RM of the Seyfert-1 galaxy WPVS 48 at redshift z = 0.0377. The B light curve of WPVS 48 show sharp continuum variation. After having realized the optical variations, end of 2013 March we started to measure the J and K light curves (Fig. 5). The NIR echo lags the triggering B-band variations by about 72 days. Strikingly, the dust echo is as sharp as the triggering variations. Likely explanations are: 1) The hot (1500 K) dust emission, if optically thin, comes from a nearly face-on dust torus with a small covering angle, and 2) If optically thick at J and K, we see only the surface of the dust torus with a convex geometry or a puffed-up inner rim (Pozo Nuñez et al. 2013c in preparation).

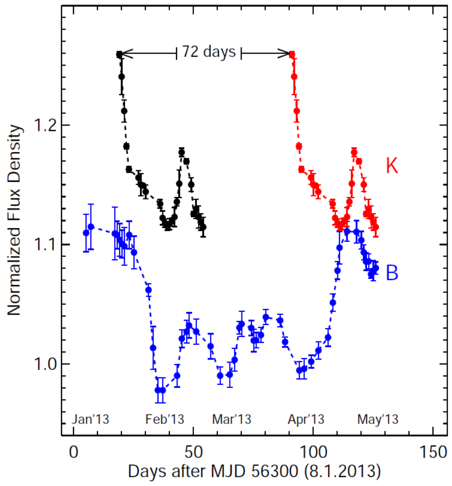

Figure 4. B- and K-band light curves of WPVS48 (blue and red colored). The B-band flux decline and rise in February 2013 correlates with decline and rise in the K-band light curve shifted back by ~72 days (black).

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