

The broad line region and dust torus structure of the Seyfert 1 WPVS48

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Optical and near-mid-infrared reverberation mapping data obtained at Universitätssternwarte Bochum in Chile and with the Spitzer Space Telescope allow us to explore the geometry of both the H α BLR and the dust torus for the nearby Seyfert 1 galaxy WPVS 48. On average, the H α variations lag the blue AGN continuum by about 18 days, while the dust emission variations lag by 70 days in the J+K and by 90 days in the L+M bands. The IR echoes are sharp, while the H α echo is smeared. This together favours a bowl shaped toroidal geometry where the dust sublimation radius is defined by a bowl surface, which is virtually aligned with a single iso-delay surface, thus leading to the sharp IR echoes. The BLR clouds, however, are located inside the bowl and spread over a range of iso-delay surfaces, leading to a smeared echo.

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1. Introduction

The paradigm of active galactic nuclei (AGN) consists of an accreting black hole (BH) at the centre of the galaxy and an accretion disk (AD), which is surrounded by the broad line region (BLR) composed of clouds of ionized gas moving rapidly in the BH potential. Clouds located further out move slower and form the narrow line region (NLR). In the equatorial plane, the BLR is surrounded by a (clumpy) molecular dust torus [1].

The dust sublimation radius R_{sub} is defined as the smallest distance from the centre of the galaxy to the dust torus' surface [2]. However, [3] analysed data for a sample of Seyfert galaxies and found that the dust torus radius R_{τ_K} is almost 3 times smaller than the expected R_{sub} . This systematic deviation can be explained by a bowl-shaped dust torus geometry, proposed by [4]. In this model, the AD emission is assumed to be non-isotropic, declining from the polar direction towards the equatorial plane, so that the sublimation radius defines a convex bowl-shaped rim, which smoothly transitions into the AD (see Figure 1). Assuming the model in [5], the BLR clouds cover the bowl-shaped dust rim and they occupy the region between AD and dust torus.

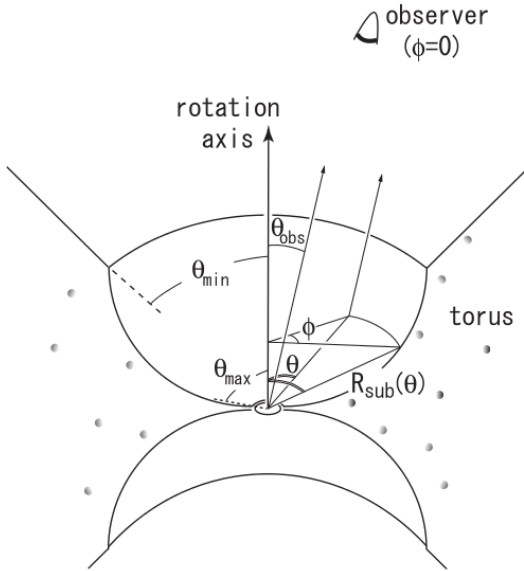


Figure 1: Bowl-shaped torus model from [4]. The dust sublimation radius R_{sub} depends on the polar angle Θ . $R_{sub}(\Theta)$ has a convex form resembling a bowl. The bowl dust torus covers a minimum opening angle Θ_{min} and a maximum opening angle of Θ_{max} . The AD emission anisotropy allows the torus's inner region to closely approach the central BH and AD in the equatorial plane.

Here, we explore the central geometry of the nearby Seyfert 1 galaxy WPVS 48 [8] and discuss a bowl-shaped BLR/dust torus model configuration. Previous data has already been analysed in [9], where WPVS 48 was shown to exhibit strong optical and near-infrared variations. It is located at redshift $z = 0.037$ and the FWHM of $H\alpha$ is 937 km/s. Since the central region of AGN cannot be spatially resolved on images, the reverberation mapping (RM) technique is applied. In particular, we use the Photometric Reverberation Mapping (PRM) method proposed by [6].

2. AD, BLR and Dust Light curves

WPVS 48 has been monitored for 6 months using the VYSOS-6, BEST-II, BMT and IRIS telescopes located at the Bochum observatory near Cerro Armazones, the future location of the ESO

Extreme Large Telescope (ELT) in Chile¹. The broad band optical filters B , V and R are employed to analyse the AGN continuum. A narrow band filter centered in 680 nm ($NB680$) monitors the broad $H\alpha$ emission line variation and the NIR filters (J , K) the variations of the hot dust. Additional MIR data obtained with the Spitzer Space telescope ($L = 3.6\mu m$ and $M = 4.5\mu m$) is used to investigate cooler dust. The flux calibrated light curves are shown in Figure 2.

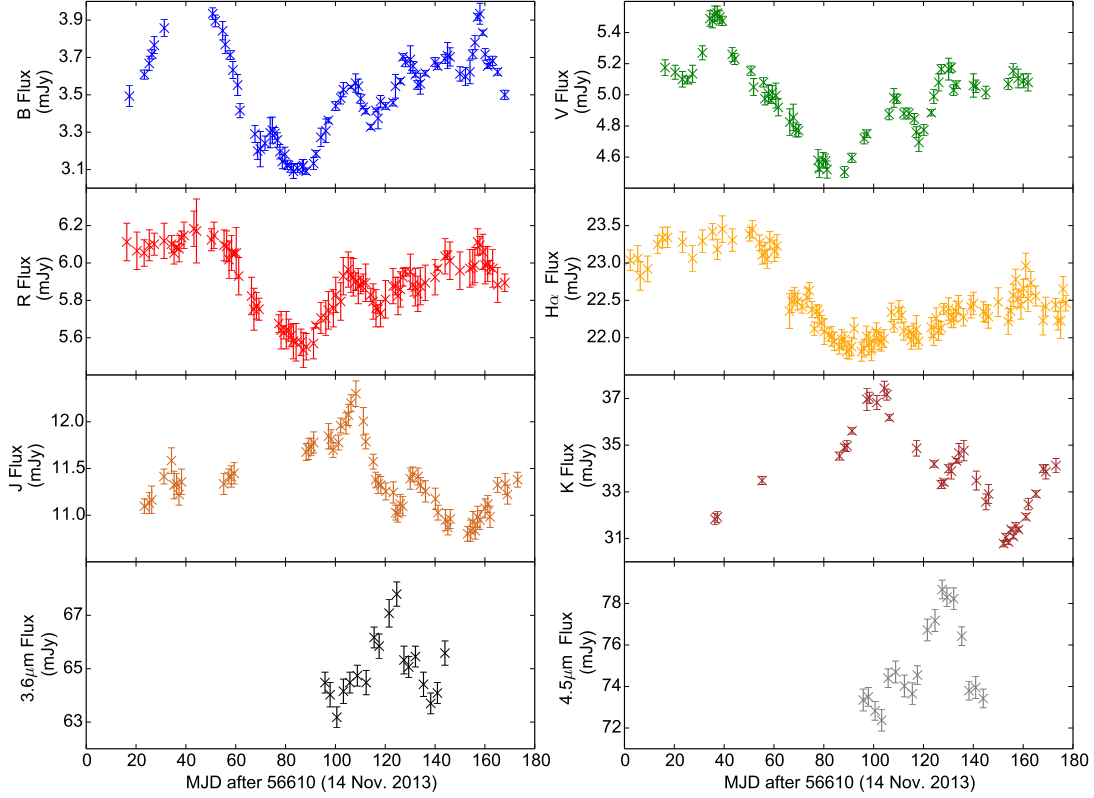


Figure 2: WPVS48 calibrated light curves, all corrected for galactic foreground extinction.

The B -band light curve shows a strong flux increase until $MJD \sim 56610 + 40$, then the flux decreases by almost 30% and reaches a minimum at $MJD \sim 56610 + 85$; afterwards, it begins to increase again. The V and R -band light curves show a similar variability pattern but the amplitude variation in R is less pronounced, probably due to a stronger host galaxy contribution. Since $NB680$ contains the contribution of the red continuum, a synthetic $H\alpha$ light curve is created by calculating $H\alpha = NB680 - R$ [6], which varies by less than 10%. The $H\alpha$ light curve shows a decline shifted by ~ 15 days from B and V . After the minimum is reached, the increase is less pronounced suggesting that the transfer function contains long lag contributions. The J and K light curves again show the same variability pattern as do B and V (shifted by ~ 70 days) and a large amplitude (almost 30%). The L and M -bands also show pronounced sharp variations shifted by ~ 20 days against J and K .

¹<http://www.astro.ruhr-uni-bochum.de/astro/oca/>

In order to obtain the time delay between the AGN-continuum and BLR/dust light curves we compute the Discrete Correlation Function (DCF) [7]. Figure 3 shows the DCF function for $B/H\alpha$ and B/K . We find an average time lag between $B/H\alpha$ of 18 days with a broad correlation function (between 0 and 40 days and a tail up to 60 days). The NIR filters show an average time lag of 70 days ($B/J - K$) and 90 days for MIR filters ($B/L - M$). The NIR light curves show a narrower and a larger correlation value than the $H\alpha$ light curve (see example in Figure 3), which is in accordance with a larger amplitude variation in the NIR filters than in the $H\alpha$.

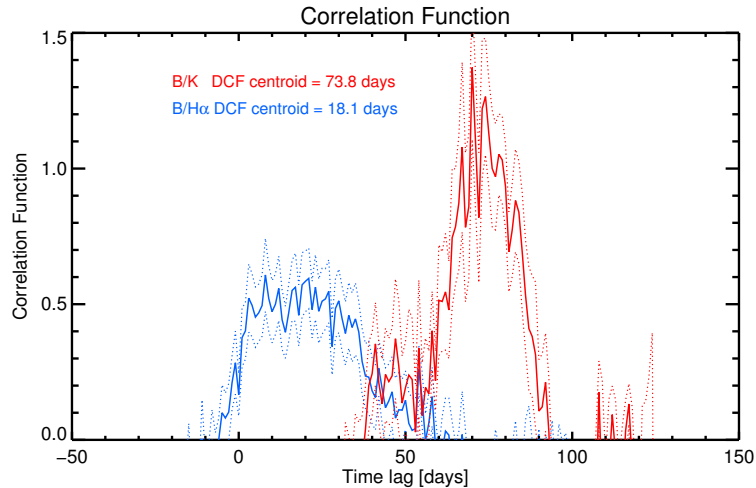


Figure 3: Correlation function for $B/H\alpha$ and B/K plotted with blue and red solid lines, respectively. The dashed lines indicate the error range ($\pm 1\sigma$) around the cross correlation.

3. Discussion: Bowl-shaped dust model

The observation of a smeared $H\alpha$ echo light curve (broad DCF) and sharp NIR-MIR echo light curves (narrower DCF) can be explained by a bowl-shaped central AGN geometry.

The fact that the hot and cooler dust light curves are quite sharp indicates that the observer looks at the system nearly face-on. In addition, the explanation for such a sharp echo could be that the emitting rim of a bowl-shaped dust torus is almost aligned with an iso-delay contour. If the $H\alpha$ BLR clouds are located above the bowl-shaped dust rim, they will be spread across a range of iso-delay contours and therefore will produce a smeared echo. This possible geometry for the central region of WPVS48 will be discussed in a forthcoming publication (Sobrinho Figaredo et al., in preparation).

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