The broad-line region and dust torus size of the Seyfert 1 galaxy PGC50427.

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1. Introduction

The existence of a dusty structure with a torus-like geometry surrounding the broad-line region (BLR) and the central accreting super massive black hole (SMBH) play a fundamental role in the framework of an unified model for active galactic nuclei (AGN; Antonucci 1993). Its presence would explain the observed differences in the spectra of type 1 and 2 Seyfert galaxies together (Antonucci 1993). Its presence would explain the observed differences in the spectra of type 1 and 2 Seyfert galaxies (Antonucci 1993). Its presence would explain the observed differences in the spectra of type 1 and 2 Seyfert galaxies (Antonucci 1993).

Evidence for the surrounding hot dust torus rests on indirectly optical spectropolarimetric observations (e.g., Antonucci & Miller 1985; Barvainis 1987; Kobayashi et al. 1993). A direct detection of the putative dust torus is more difficult since the internal structure of AGNs is spatially unresolved using single telescopes. IR long- baseline interferometric observations have been able to determine the size of the dust torus for a few nearby AGNs (e.g., Wittkowski et al. 2004; Tristram et al. 2007; Pott et al. 2010).

The only method available to study the origin and morphology of the BLR and the dust torus independent of the spatial resolution of the instrument is Reverberation Mapping (RM, Lyutyi & Cherepashchuk 1972; Cherepashchuk & Lyutyi 1973; Blandford & McKee 1982; Gaskell & Sparke 1986; Peterson 1993; Peterson et al. 2004). In this method one measures the light travel time between the accretion disk (AD) and the BLR and/or hot dust. The hot AD produces a variable continuum emission, and this variability is observed with a time delay ($\tau_{BLR} = R_{BLR}/c$) in the studied broad emission lines of the BLR. Similarly, if the dust torus is located at some radial distance $R_{dust}$ around the hot AD it will reprocess the UV/optical radiation to thermal near-infrared (NIR) radiation with a characteristic time delay $\tau_{dust} = R_{dust}/c$. Reverberation mapping has revealed the size of the BLR, the black hole mass and Eddington ratios in about 50 AGNs (see Du et al. 2014 and references therein).

The torus reacts to the AD variability in a wide range of time, from days to decades (e.g., Glass 2004; Suganuma et al. 2006; Pozo Nuñez et al. 2014; Koshida et al. 2014). From dust
Fig. 1. The timeline of our campaign on PGC50427. The days in which the telescopes made observations are indicated by crosses.

Table 1. Characteristics of PGC50427

| α (2000) | δ (2000) | z | D_L (Mpc) | B - V | M_\text{abs} | A_u | A_B | A_R | A_r |
|----------|----------|---|-----------|------|-------------|-----|-----|-----|-----|
| 14:08:06.7 | -30:23:53.7 | 0.024 | 102.0 | 0.40 | -20.6 | 0.252 | 0.215 | 0.129 | 0.135 |

(1) Values from NED database, (2) Véron-Cetty & Véron (2010), (3) Schlafly & Finkbeiner (2011).

reverberation measurements, which are principally based on the cross-correlation analysis between the optical (V, 0.55 μm) and NIR (K, 2.2 μm) light curves, a correlation between the innermost radius of the torus and the square root of the optical luminosity has been shown (R_{\text{dust}} \propto L^{0.5}; Glass 2004, Minezaki et al. 2004, Suganuma et al. 2006, Koshida et al. 2014). The dust is heated by the accretion disk (AD) until up to its maximum sublimation temperature (∼1500K). The correlation and sublimation temperature are consistent with the theoretical prediction of the dust sublimation radius (R_{sub}; Barvainis 1992), but is systematically smaller by a factor of three than the sublimation radius R_{sub} predicted for graphite dust grains with a size of 0.05 μm in radius (Oknyanskij et al. 1999, Kishimoto et al. 2007). Some modified dust geometries involve BLR associated dust due to winds/outflows from the accretion disk (Konigl & Kartje 1994, Elitzur & Shlosman 2006, Czerny & Hryniewicz 2011).

Alternatively, theoretical simulations shows that an anisotropically illuminated dust torus, caused by an optically thick AD, places the inner concave region of the torus closer to the outer edge of the AD. Thereby increasing the response time of the torus, and thus explaining the systematic difference of the time delay with respect of the torus radius measured from time delay and from the sublimation temperature under an isotropically assumption (Kawaguchi & Mori 2010, Kawaguchi & Mori 2011). In the case of the Seyfert 1 galaxy WPVS48, Pozo Nuñez et al. (2014) argue that the sharp NIR echo observed is due to a geometrically and optically thick torus seen nearly face-on. In this scenario the observer only sees the facing rim of the torus wall, which lies closer to the observer than the torus equatorial plane and therefore leads to an observed foreshortened lag effect.

While great theoretical progress has been made, only a handful of observational measurements of the dust reverberation radius have been obtained during the last years. Moreover, as noted in Suganuma et al. (2006), the importance of simultaneous BLR and dust torus size measurements provide an important step forward to test and constrain the actual paradigm of unification for AGNs.

More recently, Photometric Reverberation Mapping (PRM) has been revisited and used as an efficient alternative to determine the BLR size, black hole masses and host-subtracted AGN luminosities (Haas et al. 2011, Pozo Nuñez et al. 2012, Pozo Nuñez et al. 2013). Through the combination of broad and narrow-band data, this method is used to measure the time delay between the triggering continuum variations and the BLR emission line response, which has previously been isolated by the subtraction of the underlying continuum determined from the broad-band filter data and/or through a single spectrum contemporaneous with the campaign.

Feature-rich PRM light curves allow us to infer the basic geometry of the BLR, whether it is spherical or disk-like, and can thus constrain the unknown geometrical factor needed in converting the time lag and velocity width into a black hole mass (Pozo Nuñez et al. 2014). Furthermore, the use of broad-band
data alone has been tested with satisfactory results \citep{Chelouche & Daniel 2012, Chelouche et al. 2012, Edri et al. 2012, Pozo Nuñez et al. 2013}. In this method, two suitable chosen broad band filters are used to trace the continuum variations and to catch the emission line and continuum with the removal of the continuum performed in the cross correlation domain. PGC50427 has been classified as a Seyfert 1 galaxy and is located at a distance of 102 Mpc \citep{Veron-Cetty & Veron 2010}. In this paper we present the results of a multi-year monitoring campaign carried out on the nucleus of the Seyfert 1 galaxy PGC50427. We use Photometric Reverberation Mapping in combination with dust-reverberation mapping to determine the black hole mass, the size of the BLR and dust torus for the first time in this source.

2. Observations and data reduction

The optical and near-infrared monitoring campaign of PGC50427 were carried out using the VYSOS-6, BEST-II, BMT and IRIS telescopes (for more details see Sections 2.1-2.2) located at the Universitätsternwarte Bochum observatory, near Cerro Armazones, the future location of the ESO Extreme Large Telescope (ELT) in Chile.

In addition to the photometric observations, one single epoch spectrum was acquired using the Robert Stobie Spectrograph (RSS) at the Southern African Large Telescope (SALT). The timeline of all the observations in our campaign is shown in Fig. 1.

PGC50427 lies at redshift $z = 0.0236$, therefore the H$\alpha$ emission line falls into the SHI 6721 ± 30 Åand 6700 ± 60 Ånarrow-band (NB) filters. The characteristics of the source and the galactic foreground extinction values are listed in Table 1. Figure 2 shows the position of the NB filters with respect to the H$\alpha$ emission line together with the effective transmission of the other optical filters used.

2.1. Optical monitoring

VYSOS-6

Broad-band Johnson B (4330 Å), Sloan-band r (6230 Å), and narrow-band SHI (6721 ± 30 Å, the position of the redshifted H$\alpha$ line) observations were carried out during a monitoring campaign between February 18 and September 01 of 2011, with the robotic VYSOS-6 telescope. The VYSOS-6 telescope consist of two 15 cm refractors (Takahashi TOA 150F Ortho-Apo-chromat Triplet) installed on a common equatorial mount (Bisque Paramount ME). Both refractors are equipped with an Apogee ALTA U16M 4096 × 4096 pixel CCD, providing a field of view (FoV) of about 2.7′ × 2.7′. More information about the telescope and the instrument has been published by \cite{Haas et al. 2012}.

The data reduction was standardized, including bias, dark current, flatfield, astrometry and astrometric distortion corrections performed with IRAF\footnote{IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.} in combination with SCAMP\footnote{http://www.astro.ruhr-uni-bochum.de/astro/sca/}

2.2. Monitoring Telescope (BMT)

Monitoring Telescope (BMT). The BMT telescope is equipped with a two-stage thernoelectric cooled 3072 × 2038 pixel CCD SBIG STL-6303, yielding a field-of-view of 41′ × 27′ with a pixel size of 9 μm. The data were reduced and calibrated following the same procedures as in the broad-band analysis. More information about the telescope and the instrument has been published by \cite{Ramolla et al. 2013}.

SALT

The optical spectrum of PGC50427 was observed using the 11 m Southern African Large Telescope (SALT) on May 10 2013 (Proposal Code: 2013-1-HETGU-001). The observations were performed with the Robert Stobie Spectrograph (RSS) mounted at the prime focus of the SALT. We used the PG0900 grating with a resolving power of 1065 at 6050 Å, and the spectrum covers a wavelength range between 3200 – 9000 Å. The spectrum was taken in two identical consecutive exposures of 10 min each through the 2′′ × 8′′ longslit PL 0200N001 at a parallactic angle. The detector was operated in normal readout mode with a 2 × 2 binning. A Xe spectrum was obtained after the object exposure for wavelength calibration. For flux calibration we observed the standard star G24-9. After the bias subtracted file provided by the SALT pipeline, we used standard IRAF routines for flat-field correction, cosmic ray rejection, 2D- wavelength calibration, night sky subtraction and flux calibration. For the 1-D spectrum, we combined 7 columns, corresponding to 1.7738′′ (0.1267″ per unbinned pixel). The reduced spectrum is shown in Fig. 2.
Fig. 2. SALT spectrum of PGC50427. For illustration, the band passes of the filters used for the photometric monitoring are shown (blue $B$-band, green $R$-band, orange $r_s$-band, red 670-band, and brown for SII-band). The NB 670 and SII catches the redshifted H$\alpha$ line, its flux is composed by the contribution of about 85% H$\alpha$ line and 15% continuum. Note that for actual flux calculations the filter curves are convolved with the quantum efficiency of the Alta U16 and SBIG STL CCDs cameras.

Fig. 3. Observed light curves of PGC50427, as well as for some of the reference stars in the field of view for the period between February 2011 and September 2011 (left) and for the period between February 2014 and August 2014 (right). The light curves are vertically shifted for clarity.
2.2. Near-infrared monitoring

IRIS

Near-infrared (NIR) $J$ (1.25 µm) and $K_s$ (2.15 µm, hereafter denoted as K) observations were carried out between May 20 and August 11 of 2013 using the 0.8 m Infrared Imaging System (IRIS) telescope. IRIS is equipped with a HAWAII-1 nitrogen-cooled detector array with $1024 \times 1024$ pixels, yielding a field-of-view of 12.5′ × 12.5′ and a resolution of 0.74″/pixel (Hodapp et al. 2010). Images were obtained by combining double cycles of 20 seconds exposure time acquired with the observing sequence object-sky-object. The images were reduced using IRAF routines. Because the sky background emission contribution is one of the most difficult step in NIR data reduction, the sky frames observed close to the AGN were subtracted from each science frame before flat-field and further corrections. One final image, resulting from the combination of all individual frames, is obtained in order to remove cosmic rays, hot pixels and negative residuals from the sky-subtracted science frames. The data reduction steps after the sky background subtraction and correction for cosmic rays, hot pixels and negative residuals, are the same as outlined for the VYSOS-6 telescope, including astrometry and astrometric distortion correction with SCAMP and SWARP. Light curves were calculated relative to 6 non-variable stars located on the same field having similar brightness as the AGN. Photometric calibration was achieved by using 4 high-quality flag (AAA) Two Micron All Sky Survey (2MASS) stars appearing in the same field as the AGN. As already noted for the optical treatment of the data (Pozo Nuñez et al. 2013), analysis for different aperture photometry was performed considering the proper minimization of the host-galaxy contribution and a 7″ diameter aperture was chosen for further analysis.

3. Results and discussion

3.1. Optical light curves and BLR geometry

The optical light curves for campaigns 2011 and 2014 are shown in Fig.3. The light curves are published at the CDS. In the campaign of 2011, the $B$-band shows a gradual flux increase by 20% from the beginning of March until a maximum is reached at the beginning of April (Fig.3, left). After this overall maximum, the fluxes undergo an abrupt drop by about 40% until the end of May. Between the beginning of June and the end of August 2011, the fluxes are steady. The $r$-band light curve follow the same features than the $B$-band light curve albeit with a smaller variability amplitude. The latter is expected due to the larger constant host-galaxy contribution. Moreover, the $r$-band also contains a contribution from the strong Hα emission line (Fig 2). The narrow SII-band light curve follows the continuum dominated broad-band light curves qualitatively, but we can see a 20 day delay compared to the continuum variability at the minimum observed at the end of June.

As already discussed in previous PRM studies, the narrow-band contains, in addition to the Hα line, a contribution of the varying AGN continuum, which must be removed before applying cross correlation techniques (Haas et al. 2011; Pozo Nuñez et al. 2012; Pozo Nuñez et al. 2013). In order to determine this contribution, we used the SII and $r$-band fluxes, previously calibrated to mJy, as is shown with the flux-flux diagram in Figure 4.

![Flux-flux diagram for the SII and r filter. Black dots denote the measurement pair of each night during campaign 2011. The red and green lines represent the average flux in the SII and r band respectively. Fluxes were measured using circular 7.5″ apertures. The data are as observed and not corrected for extinction.](image1)

![Same as Fig 4, but for 670 and R data obtained during campaign 2014.](image2)

The Hα line is contributing, on average, about 70% of the total flux enclose in the SII-band, while the continuum contribution ($r$-band) is about 30%. Following the usual practice of narrow-band PRM, we construct a synthetic Hα light curve by subtracting a fraction of the $r$-band light curve (Hα = SII − 0.3 r), as illustrated in Fig 6. The Hα light curve was used afterwards to estimate the time delay. For this purpose, we used the discrete correlation function (DCF, Edelson & Krolik 1988) to cross-correlate the continuum and the synthetic Hα emission line, taking into account the delay caused by the Hα line.
Fig. 6. Hα light curve (red) obtained after the continuum subtraction process performed on the SII light curve (black) during campaign 2011. The continuum fraction was obtained from the flux-flux diagnostic on the SII and r bands; see text for details.

Fig. 7. Same as Fig 6 but for 670 and R data obtained during campaign 2014.

The centroid of the cross-correlation between the B-band and Hα light curves shows a time delay of 20.5 days (Fig 8). Uncertainties in the time delay were calculated using the flux randomization and random subset selection method (FR/RSS, Peterson et al. 2004). From the observed light curves we create 2000 randomly selected subset light curves, each containing 63% of the original data points (the other fraction of points are unselected according to Poisson probability). The flux value of each data point was randomly altered consistent with its (normal-distributed) measurement error. We calculated the DCF for the 2000 pairs of subset light curves and the corresponding centroid. From this cross-correlation error analysis, we measure a median lag of $\tau_{\text{cent}} = 20.4^{+0.4}_{-1.0}$ B/Hα. Correcting for the time dilation factor $(1 + z = 1.0236)$ we obtain a rest frame lag of $19.9 \pm 0.68$ days B/Hα.

In the campaign of 2014, we see a steep B-band rise at the beginning of April by about 20% which is also observed in the R-band but with a smaller amplitude (Fig 3, right). In contrast to the steep B-band flux increase, the narrow 670-band rise appears stretched until the end of April with an amplitude of about 13%, suggesting a time delay of the Hα line of 15-20 days. After a period of constant flux, the B and R light curves show a small sharp bump in June of about 10%, which is observed about 15 days later.

Fig. 8. Cross correlation of B and Hα light curves for campaign 2011. The dotted lines indicate the error range ($\pm 1\sigma$) around the cross correlation. The centroid was calculated above the correlation level at $r \geq 0.8_{\text{max}}$. The histogram shows the distribution of the centroid lag obtained by cross correlating 2000 flux randomized and randomly selected subset light curves (FR/RSS method). The black shaded area marks the 68% confidence range used to calculate the errors of the centroid.

Fig. 9. Same as Fig 8 but for campaign 2014.
obtain a rest frame lag of 18 \( \tau \) and H\( \alpha \) the virial product kinematics of the BLR. Most of the results presented in previous campaigns suggest a disk- like BLR geometry with low inclination (Pozo Nuñez et al., in preparation), hence the use of emission line free continuum bands, for instance with the ultraviolet band.

### 3.2. Central black hole mass

Assuming that the BLR emitting gas clouds are in virialized motion around the central black hole, the mass of the black hole can be estimated as \( M_{\text{BH}} = f \cdot R_{\text{BLR}} \cdot \sigma^2 / G \). The velocity \( \sigma \) of the emission-line region is determined from the line dispersion \( \sigma^2 \) or from the full width at maximum (FWHM) of the line profile. The scaling factor \( f \) depends on the geometry and kinematics of the BLR. Most of the results presented in previous reverberation studies have been carried out considering only the virial product \( c \sigma^2 / G \), i.e. assuming a scaling factor \( f = 1 \) (Peterson et al. 2004, and references therein).

The broad H\( \alpha \) emission line is blended with the narrow H\( \alpha \) and [NII] \( \lambda \lambda 6548,6583 \) narrow emission lines. In order to remove the narrow components, we model the [SII] \( \lambda \lambda 6716,6731 \) doublet with a multi-Gaussian profile as described in Greene & Ho (2004). The model is shifted and scaled to fit the H\( \alpha \) + [NII] \( \lambda \lambda 6548,6583 \) narrow lines and subtracted from the observed broad H\( \alpha \) line profile as shown in Fig. 10. The ratio of the [NII] lines is fixed at the theoretical value of 2.96 and the relative positions of the narrow H\( \alpha \) and [NII] lines are determined by their laboratory wavelengths. After removing the narrow emission lines, the H\( \alpha \) profile was isolated by the subtraction of a linear continuum fit, obtained through interpolation between two continuum segments on either end of the line. Figure 10 illustrates the original H\( \alpha \) emission line profile together with the subtracted narrow emission line profiles. The velocity dispersion after removal of narrow lines is \( \sigma^\text{line} = 1020 \pm 8 \) km s\(^{-1}\), which has been corrected for instrumental velocity dispersion to obtain an intrinsic profile width. The feasibility of the use of single-epoch (SE) spectra for the black hole mass determination has been established in previous investigations. On average, uncertainties of \( \sim 30\% \) have been reported for black hole mass determination from single epoch spectra measurements (e.g. Vestergaard 2002, Woo et al. 2007, Denney et al. 2009).

Using the derived time delay \( \tau = 18.3 \) d for epoch 2014 and the velocity dispersion (with 30\% uncertainty), the virial black hole mass is \( M_{\text{BH}} = (3 \pm 2) \times 10^6 M_\odot \). Considering the factor \( f = 5.5 \pm 1.8 \), based on the assumption that AGNs follow the same \( M_{\text{BH}} - \sigma_\text{e} \) relationship (Onken et al. 2004), we determine a central black hole mass \( M_{\text{BH}} = (17 \pm 11) \times 10^6 M_\odot \).

Assuming a symmetric BLR, the dimensionless factor \( f \) depends on the unknown inclination of the BLR \( (f = \frac{\sin \iota}{\sin 30^\circ}) \). The optical and the H\( \alpha \) emission line variability observed in PGC50427 suggest a disk- like BLR geometry with low inclination \( i \leq 30^\circ \) (Pozo Nuñez et al., in preparation), hence the geometry-scaling factor \( f \) may be much higher than the commonly used \( f = 5.5 \). Therefore the black hole mass derived here should be considered as lower limit.
3.3. Host-subtracted nuclear luminosity and the BLR size – luminosity relationship

To determine the AGN luminosity free of host galaxy contributions, we applied the flux variation gradient (FVG) method, originally proposed by Choloniewski (1981) and later modified by Winkler et al. (1992). A detailed description of the FVG method on PRM data is presented in Pozo Nuñez et al. (2012). In this method the fluxes obtained through different filters and same apertures are plotted in a flux-flux diagram. The fluxes follow a linear slope representing the AGN color, while the slope of the nuclear host galaxy contribution (including the contribution from the narrow line region (NLR)) lies in a well defined range (0.4 < $f_{\text{host}}/f_{\text{AGN}} < 0.53$, for 8′/3 aperture and redshift $z < 0.03$, Sakata et al. 2010). The AGN slope is determined through a linear regression analysis. Averaging over the intersection area between the AGN and the host galaxy slopes yields the actual host galaxy contribution at the time of the monitoring campaign. Figure 12 shows the FVG diagram for the $B$ and $r$ fluxes corresponding to campaign 2011 and for the $B$ and $R$ fluxes corresponding to campaign 2013/2014 obtained during the same nights and through a 7′′ aperture. All the fluxes have been corrected for galactic foreground extinction.

The bisector linear regression method yields a linear gradient of $\Gamma_{BR} = 1.18 \pm 0.06, \Gamma_{BR} = 1.22 \pm 0.03$ and $\Gamma_{BR} = 1.10 \pm 0.05$ for campaigns in 2011, 2013 and 2014 respectively. The results are consistent, within the uncertainties, with the gradients obtained for other Seyfert 1 galaxies by Winkler et al. (1992) and Sakata et al. (2010). The AGN fluxes at the time of the monitoring can be determined by subtracting the host galaxy contribution from the total fluxes. The host galaxy subtracted average AGN fluxes and the host galaxy flux contribution of PGC50427 are listed in Table 2. Also listed in Table 2 are the interpolated rest frame 5100Å fluxes and the monochromatic AGN luminosity $L_{\lambda}(\text{AGN})$ at 5100Å obtained at the distance of 102 Mpc. The rest frame flux at 5100Å was interpolated from the host-subtracted AGN fluxes in both filters, assuming for the interpolation that the AGN flux at 5100Å was interpolated from the host-subtracted AGN fluxes, the e-folding frequencies in the X and Y bands, respectively. The error was determined by interpolation between the ranges of the AGN fluxes ±$\sigma$ in both filters, respectively.

The position of PGC50427 on the BLR size-luminosity diagram is shown in Figure 13. The values of other galaxies are taken from Bentz et al. (2013) and from previous photometric reverberation mapping campaigns (Haas et al. 2011, Pozo Nuñez et al. 2012, 2013). For this figure we converted the measured $H\alpha$ size into the size of the H$\beta$ BLR using the weighted mean ratio for the time lag $\tau(H\alpha) : \tau(H\beta) : 1.54 : 1.00$, obtained by Bentz et al. (2010) from the Lick AGN Monitoring Program of 11 low-luminosity AGN.

3.4. Infrared light curves and Dust-torus size

Figure 13 depicts the optical and near-infrared normalized light curves of the nucleus of PGC50427 obtained during the 2013 campaign. The light curves are published at the CDS. To deconvolve the host galaxy and the nuclear flux contributions, we used the flux variation gradient (FVG) method in the same way as described in Pozo Nuñez et al. (2014). The spectral energy distribution of the variable component remain constant with time, and in consequence the slopes obtained from the optical and NIR flux
AGN fluxes values \( f_{\text{AGN}} = f_{\text{total}} - f_{\text{host}} \) with uncertainty range \( \sigma_{\text{AGN}} = (\sigma_{\text{total}}^2 + \sigma_{\text{host}}^2)^{0.5} \).

| Campaign | Filter | Total (mJy) | Host (mJy) | AGN \( (1+z)5100\text{Å} \) (mJy) | \( f_{\text{AGN}} \) (mJy) | \( AL_{\text{LAGN}5100\text{Å}} \) \( (10^{38}\text{ergs}^{-1}) \) |
|----------|--------|-------------|-----------|----------------------------------|----------------|----------------------------------|
| 2011     | \( B \) | 2.71±0.12   | 0.91±0.17 | 1.80±0.20                        | 1.66±0.20      | 1.18±0.14                        |
|          | \( rs \) | 3.95±0.11   | 2.42±0.15 | 1.53±0.19                        |                |                                  |
| 2013     | \( B \) | 2.36±0.10   | 0.83±0.15 | 1.53±0.18                        | 1.40±0.17      | 1.00±0.12                        |
|          | \( R \) | 3.56±0.11   | 2.35±0.12 | 1.21±0.16                        |                |                                  |
| 2014     | \( B \) | 2.48±0.10   | 0.80±0.13 | 1.68±0.16                        | 1.72±0.17      | 1.22±0.12                        |
|          | \( R \) | 3.94±0.12   | 2.12±0.15 | 1.82±0.19                        |                |                                  |

The time delay between the AGN continuum and dust emission can be estimated by cross-correlation of the optical and NIR light curves yielding the average radius of the innermost dust torus. We correlated both the \( B \)- and \( K \)-band light curves and the \( B \)- and \( J \)-band light curves using the discrete correlation function (DCF, Edelson & Krolik 1988). The cross correlation of \( B/J \) shows two peaks, one small correlation peak around lag 19 days obtained above the correlation level at \( r \geq 0.4r_{\text{max}} \) and a major peak with a lag of 46 days obtained above the correlation level at \( r \geq 0.6r_{\text{max}} \), as shown in Figure 16. Similar features can be seen in the cross correlation of \( B/K \), a small correlation peak with a lag of 19 days, a major peak with a lag of 47 days, and an additional third and smallest peak with a lag of 67 days as shown in Figure 17. The NIR host galaxy corrected light curves show features of similar amplitude and sharpness as the optical host galaxy corrected light curves. In addition, the cross correlation are at nearly zero level at lag 0 days. One expects that if the dust distribution is spread at different line-of-sight distances, the observed echo will be smeared out in time and the \( J \) and \( K \) light curves will show a smoother variability. Therefore the observed

\[ 4 \text{ We note that the } R \text{-band also contains a small contribution from the strong } H_\alpha \text{ emission line.} \]
Rest frame time delay $\tau$ respectively. Correcting for the time dilation factor, we obtain a size-luminosity diagram. To obtain the optical dust torus size, the virial black hole mass and the host-subtracted AGN optical and NIR luminosity. The results are:

1. From the NIR light curves in 2013, we determine the black hole mass $M_{BH} = (17 \pm 11) \times 10^6 M_\odot$ assuming a geometrical factor of 5.5.
2. With the velocity dispersion obtained from a single epoch spectrum in 2013, we determine the black hole mass $M_{BH} = (17 \pm 11) \times 10^6 M_\odot$ assuming a geometrical factor of 5.5.
3. Using the flux variation gradient method (FVG) we determine the host galaxy subtracted optical AGN luminosity of $L_{AGN} = (1.18 \pm 0.14) \times 10^{43} \text{erg s}^{-1}$, $L_{AGN} = (1.00 \pm 0.12) \times 10^{43} \text{erg s}^{-1}$, and $L_{AGN} = (1.22 \pm 0.12) \times 10^{43} \text{erg s}^{-1}$.
4. From the NIR light curves in 2013, we determine a lag time of $\tau_{rest} = 45.7 \pm 1.47$ days and $\tau_{rest} = 46.7 \pm 2.15$ days for $B/K$, respectively. The relatively sharp dust echo observed in the NIR light curves argues in favor of a face-on torus geometry. The inferred inner size for the dust torus in PGC50427 suggest that the location of the thermal emitting region is located well outside the BLR which support the unified scheme of AGNs.

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Fig. 16. Cross correlation of $B$ and $J$ light curves. The dotted lines indicate the error range ($\pm 1\sigma$) around the cross correlation. The centroid was calculated above the correlation level at $r \geq 0.6\sigma_{corr}$. The histogram shows the distribution of the centroid lag obtained by cross correlating 2000 flux randomized and randomly selected subset light curves (FR/RSS method). The black shaded area marks the 68% confidence range used to calculate the errors of the centroid.

Fig. 17. Same as Fig. 16 but for $B$ and $K$ light curves.

NIR light curves of PGC50427 argues in favor of a face-on torus geometry.

The uncertainty of the lag time $\tau$ was estimated using the flux randomization and random subset-selection method (FR and RSS, Peterson et al. 2004). The median of this procedure yields $\tau_{cent} = 46.8^{+1.8}_{-1.5}$ days and $\tau_{cent} = 47.8^{+1.2}_{-1.3}$ days for $B/J$ and $B/K$, respectively. Correcting for the time dilation factor, we obtain a rest frame time-delay $\tau_{rest} = 45.7 \pm 1.47$ days and $\tau_{rest} = 46.7 \pm 2.15$ days for $B/J$ and $B/K$, respectively.

Dust-reverberation studies of Seyfert 1 galaxies have shown that the dust torus size obtained by the cross-correlation of the optical $V$ and $K$-bands is proportional to the square root of the optical luminosity $\tau \propto L^{1/3}$ (Suganuma et al. 2006, Koshida et al. 2014). Figure 18 shows the position of PGC50427 on the Dust-size-luminosity diagram. To obtain the optical $V$-band fluxes we interpolated the AGN $B$ and $R$ band fluxes.

4. Summary and conclusions

We have performed three monitoring campaigns between 2011 and 2014, as well as obtaining a SALT spectrum, of the Seyfert 1 galaxy PGC50427. We determined the broad line region size, the virial black hole mass and the host-subtracted AGN optical and NIR luminosity. The results are:

1. The cross-correlation of the H$\alpha$ emission line with the optical continuum during campaign 2011 yields a rest-frame time delay $\tau_{rest} = 19.9 \pm 0.68$ days. During campaign 2014 the cross-correlation of the H$\alpha$ emission line with the optical continuum yields a rest-frame time delay $\tau_{rest} = 18.3 \pm 1.03$.
2. The cross-correlation of H$\alpha$ emission line with the optical continuum yields a rest-frame time delay $\tau_{rest} = 18.3 \pm 1.03$.
3. The cross-correlation of H$\alpha$ emission line with the optical continuum yields a rest-frame time delay $\tau_{rest} = 18.3 \pm 1.03$.
4. The cross-correlation of H$\alpha$ emission line with the optical continuum yields a rest-frame time delay $\tau_{rest} = 18.3 \pm 1.03$.

4. From the NIR light curves in 2013, we determine a lag time of $\tau_{rest} = 45.7 \pm 1.47$ days and $\tau_{rest} = 46.7 \pm 2.15$ days for $B/J$ and $B/K$, respectively. The relatively sharp dust echo observed in the NIR light curves argues in favor of a face-on torus geometry. The inferred inner size for the dust torus in PGC50427 suggest that the location of the thermal emitting region is located well outside the BLR which support the unified scheme of AGNs.
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