Photometric reverberation mapping
of Markarian 279

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Abstract. By using standard broad-band VRI photometry we were able to discriminate
the variations of the broad hydrogen alpha line from the continuum variations for the active
galaxy Mkn 279. Cross-correlating both light curves enabled us to determine the time lag of
the broad line variations behind the continuum and thus to determine the BLR size (about 8
light days). Our preliminary results are rather consistent with the spectroscopic reverberation
mapping results (about 12/17 days). This study is a part of an ambitious program to perform
photometric reverberation mapping and determine BLR sizes (respectively – the central black
hole masses) for more that 100 nearby AGN.
Key words: galaxcies: AGN – photometry

1. Introduction

Almost the only way to measure directly the super-massive black hole (SMBH)
in the centers of active galactic nuclei (AGN) is through a technique, called
reverberation mapping (a review by [Peterson & Horne 2004]). This technique
is based on the geometrical path difference between the ionizing continuum and
the broad line clouds, where the broad emission presumably originates, thus
leading to a certain time delay between the continuum and the line variations.
Measuring this delay provides an accurate estimate of the linear distance to
the broad line region (BLR). Thus, knowing the width of the lines (Keplerian
motion of the BLR clouds is assumed) and the distance, one can calculate the
mass inside the BLR, which is significantly dominated by the SMBH.

Although very promising, reverberation mapping technique has been ap-
plied so far for only about 50 AGN [Bentz et al. 2010]. The main obstacle here is
that the spectroscopic monitoring (neede to measure the emission line fluxes)
requires typically a 2-m class telescope. A number of reasons like restricted
telescope time, etc., make projects like this difficult to organize and perform,
especially what concerns the need of a dense monitoring. Fortunately, very
recently it has been developed a modification to this technique, called ***photo-
metric*** reverberation mapping [Haas et al. 2011, Chelouche & Daniel 2012],
which requires much smaller telescopes. The idea behind this novel approach
is to use narrow-band filters, cleverly centered on the emission lines and the
ambient continuum, instead of performing spectroscopic monitoring. Since the
line response time is much longer than the continuum response time, one can
successfully use the nearby optical continuum bands for a proxy for the cen-
tral UV/X-ray changes. For the brightest objects, photometric reverberation
mapping can successfully be performed with as small as 15-cm telescope [Haas
et al. 2011].

Recently, photometric reverberation mapping has been applied to a number
of objects [Edri et al. 2012, Nuñez et al. 2013, Nuñez et al. 2012, Carroll et al.
2013] with results very close to the spectroscopic ones.

In this work we report preliminary results of the photometric reverberation mapping technique applied to Seyfert 1 AGN Markarian 279.

2. Observations

We monitor photometrically on a regular basis Mkn 279 for the last ∼15 years using the 60-cm telescope of *Belogradchik Observatory*; 200-cm, 50/70-cm, and 60-cm telescopes of *Rozhen National Observatory* (Bulgaria); as well as 130-cm *Skinakas* telescope (Greece). All telescopes are equipped with CCD and $BVRI$ filter sets. Initially the object was in a rather bright state (years 1998 – 2007), but later faded significantly and remained in a low state during the years 2008 – 2012. $BVRI$ light curves of Mkn 279 are shown in Fig. 1. A total of about ∼240 photometric points with typical photometric errors between ∼0.01 (VRI bands) and ∼0.03 (B-band) were collected during the entire observational period. A portion of these data was published in a previous study [Bachev et al. 2004].
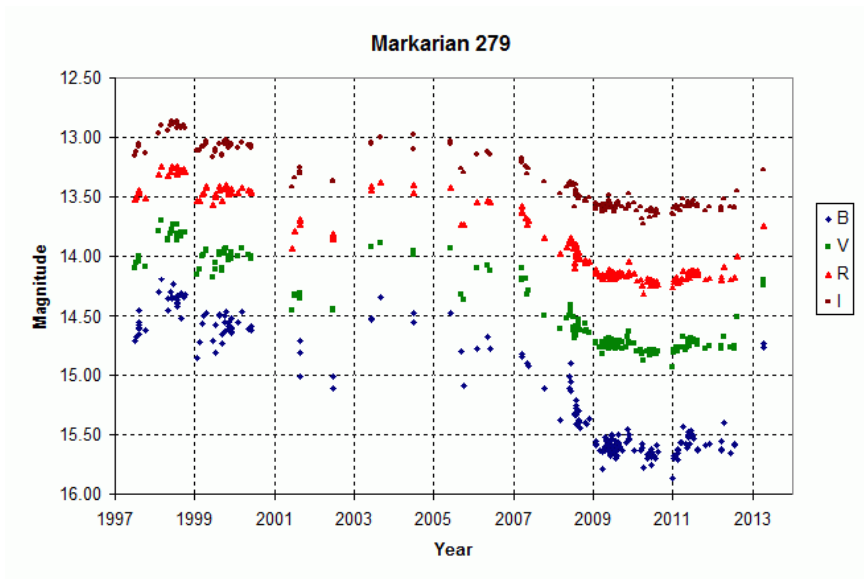

Fig. 1. $BVRI$ light curves of Mkn 279. All magnitudes are measured in an $8''$ aperture with no correction made for the host galaxy contribution and Galaxy extinction

3. Photometric reverberation mapping

Photometric reverberation mapping proved to be a successful technique for determining BLR linear sizes, especially if narrow-band filters, centered on the

lines of interest are used. As we traditionally monitored Mkn 279 with broad-band $BVRI$ filters, here we apply this technique using data, collected in these bands (so called **broadband** photometric mapping; [Edri et al. 2012]). Thus, the R-band flux can be considered as sum of the broad H_α and the continuum contributions, while V and I fluxes are proxies for the continuum (the constant narrow lines and the host galaxy do not affect this analysis). Fig. 2 shows the VRI filter transmittances superimposed on the Mkn 279 optical spectrum. B-band data is not used in this analysis due to generally larger photometric errors.
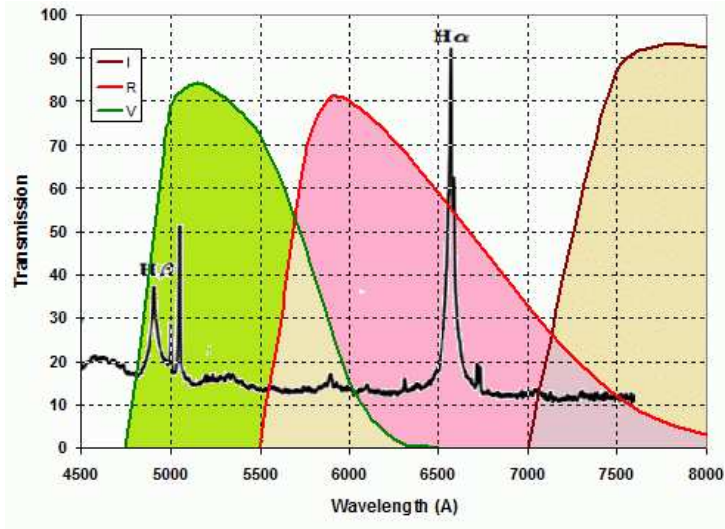

Fig. 2. VRI filter transmittances superimposed on the Mkn 279 optical spectrum. Note that broad H_β slightly affects the V-band

In order to find the time delay of the broad lines (H_α in this case), we therefore cross-correlate the continuum (represented as an average of V and I band fluxes in order to minimize the errors) and the R-band flux, subtracted by the already calculated continuum (appropriately scaled), which thus represents the pure H_α emission. In other words, we search for the maximum of the following function:

$$CCF(\tau) = \int_{-\infty}^{+\infty} (F_R(t+\tau) - F_{VI}(t+\tau)).F_{VI}(t)dt,$$

where F_R and F_{VI} are fluxes, based on the measured VRI magnitudes.

One can note that the broad H_β slightly enters the V-band, which, in principle may compromise the continuum measurement. However, due to the low transmittance of V-band filter there, as well as the fact that H_β influence is much weaker compared to H_α our understanding is that the effect is negligible.

4. Results

For this analysis we used only the first ∼70 observational points (years 1997.5 – 2000.5) since during this period the object was bright (low photometric errors), active (significantly variable on short time scales) and the monitoring cadence was good enough. To find the cross-correlation between unevenly spaced datasets, we used the interpolation cross-correlation method [Gaskell & Sparke 1986], where the missing parts were linearly interpolated. We found a clear maximum (Fig. 3) for $\tau \approx 8$ days. These first results are very encouraging as they are close to the spectroscopic reverberation values 12±3 days [Maoz et al. 1990] and 17±4 days [Bentz et al. 2009]. A detailed analysis, including uncertainty estimates, will be published elsewhere [Bachev et al. 2013].
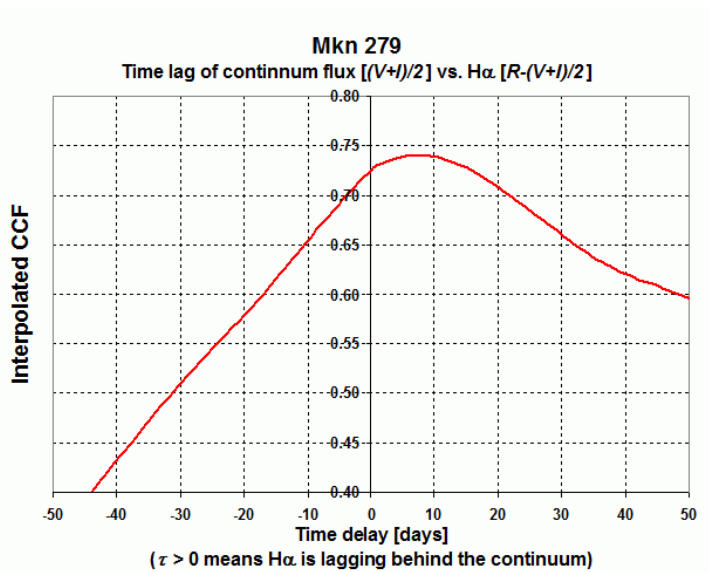

Fig. 3. Interpolated CCF, showing a delay of H_α behind the continuum for Mkn 279 of about 8 days

Thus, knowing the width of the broad lines (ν) as well as the linear distance to the BLR clouds (in this case ∼8 light days) and assuming virial motion, one can calculate the central black hole mass:

$$M_{BH} \cong \frac{c}{G}\tau.\nu^2,$$

which in our case gives $M_{BH} \approx 3.10^7 M_\odot$ (assuming $\nu \approx FWHM(H_\alpha) \approx$ 3050 km/s, our data, to be published elsewhere).

5. Conclusions

Photometric reverberation mapping, even applied to broad-band filters, proved
to be an effective, powerful, yet "cheap" technique for estimating the BLR size
and the central black hole mass. In this work we applied this technique to
the active galaxy nucleus Markarian 279, obtaining encouraging results, rather
close to the spectroscopic mapping results. These results indicate that a dense
enough photometric monitoring of AGN, even with relatively small instruments
can be productive and scientifically significant.

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