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Optical Variability Studies of the Galaxy Mrk 6 (IC 450)

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Abstract

In this work, the light curve of the Seyfert galaxy Mrk 6 constructed from photometric observations in the B, V, and R_c filters over the period from 5 April 2016 to 1 February 2026 is presented and analyzed. Over the entire monitoring interval (2016–2026), the variability amplitude of the light curve reaches $\Delta B = 1.9$ mag, $\Delta V = 1.5$ mag, and $\Delta R_c = 1.4$ mag. During 2024–2026, the galaxy exhibits synchronous photometric variability in the B, V, and R_c filters with an amplitude of ~ 0.3 mag. The study also uses spectroscopic observations obtained on 15 and 22 November 2025 and 16 February 2026 at the Shamakhy Astrophysical Observatory (Azerbaijan), as well as on 9 January 2026 at the Fesenkov Astrophysical Institute (Kazakhstan). The fluxes of the Hβ emission line were calibrated using the [O III] λ5007 line, ensuring consistent relative calibration of the spectral data. The radius of the broad-line region R_{BLR} was taken to be equal to the average time delays (lags), amounting to ≈ 20 light-days for the Hβ line and ≈ 28 light-days for the Hα line.

Keywords: active galactic nuclei; Seyfert galaxies; Mrk 6; photometric measurements; spectral data; light curve; emission lines

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1. Introduction

Markarian 6 (IC 450) is an intermediate-type active galactic nucleus (Sy 1.0–1.5) that exhibits pronounced variability in the optical, ultraviolet, and X-ray bands. Sergeev & Doroshenko (2003) [1,2] analyzed the optical spectral variability of the Mrk 6 nucleus during 1970–1991 and showed that the Hβ emission line lags behind the continuum by an average of 13 ± 6 days . The long-term UBV photometric variability of Mrk 6 was investigated by Doroshenko (2003) [2] using combined data from 1970–2002, where the variability amplitudes were found to be $U \approx 1.6^{\mathrm{m}}$, $B \approx 1.1^{\mathrm{m}}$, and $V \approx 0.8^{\mathrm{m}}$. In a subsequent large-scale monitoring campaign (1992–2008) based on reverberation mapping, lags of $\approx 21 \pm 1.9$ days for Hβ and ≈ 27 days for Hα were obtained [3], and the mass of the central black hole was estimated as $\sim (1.8\text{–}2.0) \times 10^8\ M_\odot$ [3]. Analysis of XMM–Newton data showed that the X-ray absorption has a multi-component and variable nature [4]. Schurch & Griffiths reported significant changes in the absorption between observations and proposed a clumpy or partially ionized structure of the absorbing material [5]. More recent studies have confirmed the presence of ionized X-ray winds (UFO/WA) in Mrk 6 [6], while long-term X-ray monitoring has revealed multi-timescale temporal and spectral variability of the nucleus [7]. Spectropolarimetric data indicate a short lag between the polarized and total continuum, suggesting a compact scattering region and a complex internal structure of the BLR [8]. VLBA observations show that the nuclear jet has a curved, multi-component morphology,

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and that the energy of the large-scale radio cavities is driven by AGN jet activity [9]. IFU spatially resolved spectroscopic studies have revealed extended structures of ionized gas and their connection with AGN emission [10], while spectral variations on hourly timescales confirm strong turbulence and inhomogeneous dynamics in the BLR [11,12]. Thus, Mrk 6 is a suitable target for multiwavelength comparative analysis of the BLR structure, the multilayered nature of the absorbing medium, and the optical–X-ray–radio connections. Building on the results of previous long-term monitoring [13,15], this paper presents a comprehensive variability analysis of Mrk 6 using photometric observations starting from 5 April 2016 and supplemented with new data from the current year.

2. Materials and Methods

Photometric observations of the Seyfert galaxy Mrk 6 were carried out at the Tien Shan Astronomical Observatory (TShAO) of the Fesenkov Astrophysical Institute using the Zeiss-1000 "East" telescope ($F = 6600$ mm, $D = 1$ m). The angular field of view of a single CCD frame is $19' \times 19'$.

Since 2016, observations and image acquisition have been performed using the Alta F16M CCD camera (4096×4096 pixels, 9 μm pixel size), which was operated until November 2021. From mid-2022 onward, observations have been conducted with the U9000D9 CCD camera in combination with Astrodon BVR_c filters. The angular scale of the CCD frames was $0.56''$/pixel after 2016 and $0.752''$/pixel after 2021.

The spectra of Mrk 6 were obtained with the 1.5 m AZT-20 telescope at the Fesenkov Astrophysical Institute. Its spectrograph is equipped with volume phase holographic gratings and an EMCCD camera. Additional spectral observations of the galaxy were carried out with the 2 m telescope at the Shamakhi Astrophysical Observatory. Wavelength calibration was performed using comparison lamp spectra of He, Ne, and Ar. Absolute flux calibration relied on spectra of standard stars with known energy distributions. Spectral data reduction was performed using the IRAF (Image Reduction and Analysis Facility) software package developed at the National Optical Astronomy Observatory (NOAO).

Photometric observations of Mrk 6 were obtained during 2016–2026. The galaxy brightness was measured using differential aperture photometry with nearby comparison stars. The photometric reduction was performed using the MaximDL Pro 6 [14] software package with an aperture radius of $6''$. Instrumental magnitudes were transformed to the standard B, V, and R_c photometric system using the standardization equations described in Shomshekova et al. (2017) [18].

For each observing night, 5–7 CCD frames were obtained in each filter, and the instrumental magnitudes and their uncertainties were calculated as mean values over the corresponding series of frames. The resulting photometric errors are therefore small and are listed in Table 1.

The root-mean-square (RMS) error was calculated for each image and is also presented in Table 1. The maximum magnitude variations in each filter were determined as the difference between the observed maximum and minimum brightness values on the corresponding light curves; no averaging near the extrema was applied.

3. Results

The results of our new photometric observations obtained between 14 November 2024 and 1 February 2026 in the B, V, and R_c filters are presented in Table 1. The observations show that the variability of the galaxy in the B, V, and R_c filters is synchronous in nature. Over this interval, the brightness amplitudes are 0.35 mag in the B filter, 0.27 mag in the V filter, and 0.28 mag in the R_c filter. Over the entire monitoring period from 2016 to 2026, the total variability amplitude of the light curve reaches 1.9 mag in the B filter, 1.5 mag in the V filter, and 1.4 mag in the R_c filter. The maximum brightness of the galaxy was recorded on 17 January 2017.

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Table 1. New photometric observations of Mrk 6 obtained in 2024–2026.

Date	JD–2,400,000	$B \pm \sigma_B$	$V \pm \sigma_V$	$R_c \pm \sigma_{R_c}$
14 November 2024	60629	15.613 ± 0.016	14.667 ± 0.006	14.238 ± 0.004
2 December 2024	60647	15.639 ± 0.023	14.659 ± 0.005	14.226 ± 0.004
24 December 2024	60669	15.618 ± 0.011	14.650 ± 0.004	14.217 ± 0.004
10 January 2025	60686	15.602 ± 0.013	14.644 ± 0.005	14.220 ± 0.003
4 March 2025	60739	15.605 ± 0.014	14.660 ± 0.006	14.231 ± 0.004
6 December 2025	61016	15.949 ± 0.027	14.923 ± 0.010	14.495 ± 0.006
22 December 2025	61032	15.876 ± 0.022	14.823 ± 0.007	14.390 ± 0.004
5 January 2026	61046	15.816 ± 0.020	14.776 ± 0.005	14.349 ± 0.003
9 January 2026	61050	15.843 ± 0.011	14.796 ± 0.004	14.370 ± 0.003
20 January 2026	61061	15.867 ± 0.021	14.836 ± 0.007	14.405 ± 0.004
28 January 2026	61069	15.864 ± 0.015	14.812 ± 0.005	14.386 ± 0.004
1 February 2026	61073	15.867 ± 0.023	14.796 ± 0.008	14.373 ± 0.004

For completeness of the analysis, we used all photometric data obtained starting from 5 April 2016 together with new observations of the galaxy Mrk 6. Figure 1 presents the light curve constructed in three photometric filters over the period from 5 April 2016 to 1 February 2026. The light curve includes data from Shomshekova et al. (2019) [13], covering the interval 2016–2019, where a decrease in the object brightness by approximately 0.9 mag was reported during 2017–2019. Photometric observations presented in Shomshekova et al. (2025) [15] for the period from November 2019 to February 2024 confirmed this trend: after reaching maximum brightness in early 2017, the object faded by approximately 1 mag by the beginning of 2018. In addition, comparison of archival and recent spectral data revealed that the additional component in the blue wing of the Hα line, detected in the 1976 spectra, is also present in the 2024 spectra, with a radial velocity of about 2450 km s^{-1} (Shomshekova et al., 2025) [15].

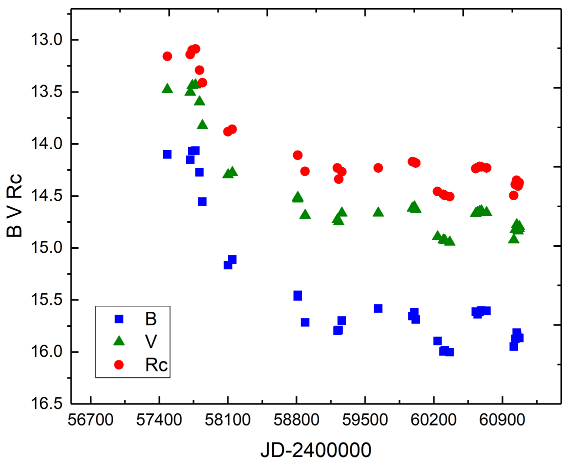

Figure 1. Light curves of MRK6 obtained in 2016-2026.

For an independent verification of the variability amplitude, data from the ASAS-SN and ZTF survey programs were used. According to the ASAS-SN data in the V filter for the period from 25 January 2014 to 29 November 2018, the variability amplitude is about 0.6 mag. The ZTF photometric data in the g and r filters were transformed to the V system using the relation

$$V = g - 0.578\,(g - r) - 0.003. \tag{1}$$

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After the transformation, the variability amplitude of Mrk 6 during the period from September 2018 to 22 November 2023 was found to be about 0.7 mag, as shown in Figure 2.

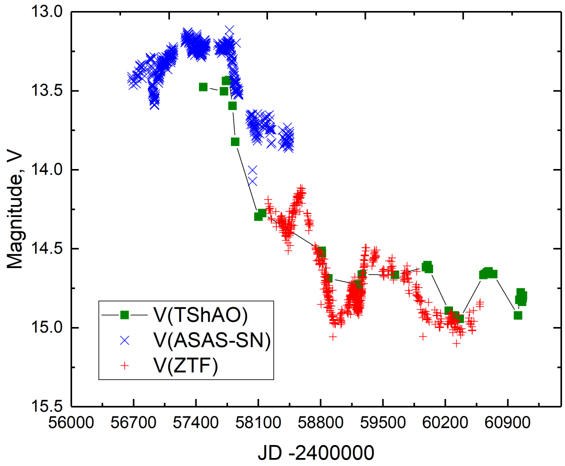

Figure 2. Independent verification of the optical variability of Mrk 6 using ASAS-SN V-band data (2014–2018) and ZTF g, r photometry transformed to the V system. The observed amplitudes are ∼0.6 mag and ∼0.7 mag, respectively.

Figure 3 presents the color indices $(B-V)$ and $(V-R_c)$. The mean color indices are $(B-V)_{mean} = 0.94$ and $(V-Rc)_{mean} = 0.41$. All values are given without correction for interstellar reddening.

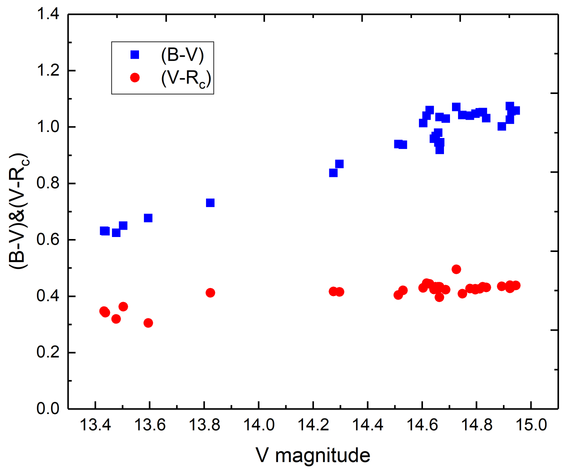

Figure 3. Color–magnitude relation of Mrk 6 in $(B-V)$ and $(V-R_c)$.

3.1. Results of Spectroscopic Observations

Spectroscopic observations were carried out at the Shamakhy Astrophysical Observatory (ShAO) on 15 November 2025 (exposure time 2400 s) and 22 November 2025 (exposure time 3600 s). The spectra were obtained in the wavelength range $\lambda\lambda$ 4100–7000 Å with a spectral resolution of $R \approx 1170$. The dispersion was 5.6 Å mm^{-1} with 3×3 binning. The spectrum of the standard star is shown in Figure 4.

Additional spectroscopic observations were performed on 9 January 2026 at the Assy-Turgen Observatory. In the Hβ region, a diffraction grating of 2400 lines mm^{-1} was used, providing a spectral resolution of $R \approx 5235$ with 1×1 binning and an exposure time of 600 s. In the Hα region, a grating of

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1800 lines mm^{-1} was used, yielding a spectral resolution of $R \approx 2078$ with an exposure time of 600 s. The spectral profiles are presented in Figure 5.

For each observation, three spectra of the standard star were recorded with short exposures (4–10 s). The spectrophotometric standard HD 33541 was observed at approximately the same zenith distance as the target galaxy to minimize atmospheric extinction effects. The energy distribution of the standard star spectrum was taken from the Gaia DR3 catalog [17].

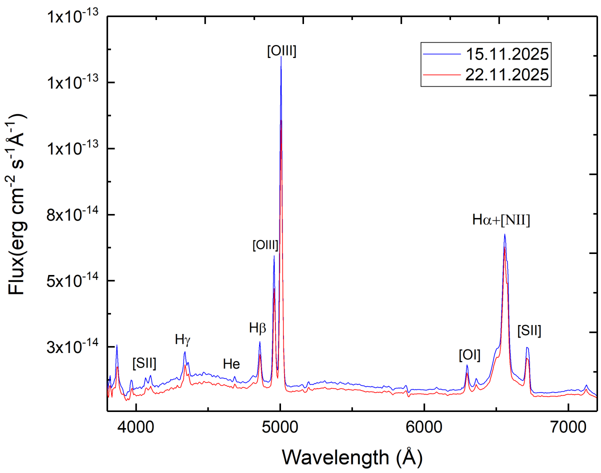

Figure 4. Optical spectrum of Mrk 6 in the wavelength range λ4000–λ7000 Å, obtained with the 2 m telescope at the Shamakhy Astrophysical Observatory (Azerbaijan).

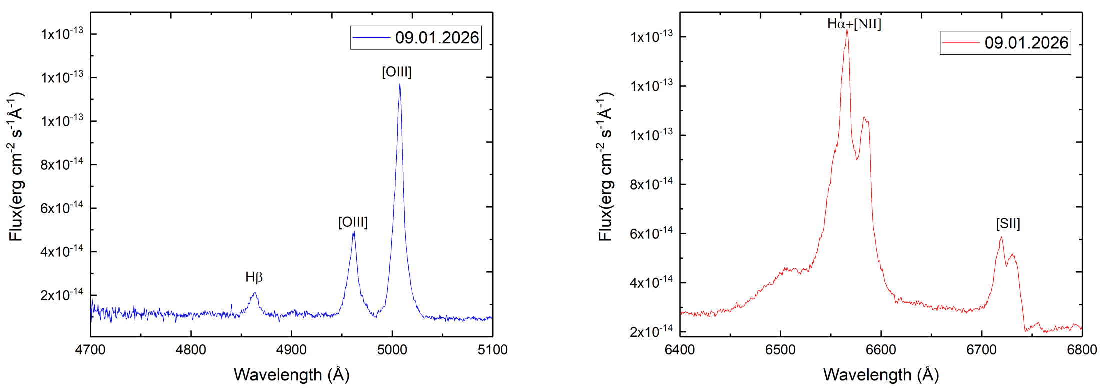

Figure 5. Optical spectra of Mrk 6 obtained with the 1.5 m telescope of the Fesenkov Astrophysical Institute. The left panel shows the Hβ spectral region covering the wavelength range $\approx$ 4700–5100 Å, while the right panel presents the Hα region in the range $\approx$ 6400–6800 Å.

All spectra used to determine the fluxes of the broad emission lines were processed following standard reduction procedures, including correction for atmospheric absorption, Galactic interstellar extinction, redshift correction, and absolute flux calibration using spectrophotometric standards within the IRAF software package. The full width at half maximum (FWHM) of the emission lines was determined by Gaussian fitting using the `splot` task in IRAF. The results are presented in Table 2.

Table 2. Measured parameters of emission lines in the spectrum of Mrk 6.

Date	$\lambda_{\rm center}$ (Å)	Continuum Flux	Line Flux	EW (Å)	gfwhm (Å)	FWHM (km s^{-1})
15 November 2025						
	4086.3	9.6×10^{-15}	1.8×10^{-13}	19	53	3868
	4342.5	1.3×10^{-14}	3.4×10^{-13}	26	38	2634
	4858.6	1.1×10^{-14}	3.6×10^{-13}	32	22	1368
	4957.9	1.2×10^{-14}	8.9×10^{-13}	75	17	1043
	5006.0	1.1×10^{-14}	2.5×10^{-12}	218	19	1122
	6297.8	9.0×10^{-15}	2.1×10^{-13}	24	23	1088
	6560.8	1.2×10^{-14}	3.1×10^{-12}	264	54	2465
	6717.1	1.0×10^{-14}	4.7×10^{-13}	47	27	1202
22 November 2025						
	4087.494	6.8×10^{-15}	1.6×10^{-13}	24	56	4134
	4343.973	9.9×10^{-15}	2.7×10^{-13}	27	39	2681
	4858.609	9.3×10^{-15}	2.9×10^{-13}	31	22	1353
	4958.104	9.6×10^{-15}	7.1×10^{-13}	74	18	1075
	5005.929	9.1×10^{-15}	2.1×10^{-12}	230	19	1136
	6297.865	7.6×10^{-15}	1.7×10^{-13}	22	21	1013
	6560.97	9.5×10^{-15}	2.7×10^{-12}	281	53	2409
	6717.499	8.5×10^{-15}	3.8×10^{-13}	45	27	1185
9 January 2026						
	4862.402	1.1×10^{-14}	1.2×10^{-13}	11	12	721
	4961.252	9.9×10^{-15}	4.7×10^{-13}	47	13	785
	5006.963	9.7×10^{-15}	1.2×10^{-12}	126	12	743
	6567.251	3.1×10^{-14}	4.2×10^{-12}	137	45	2071
	6724.208	2.4×10^{-14}	8.7×10^{-13}	37	26	1160
16 February 2026						
	4348.272	6.5×10^{-15}	1.6×10^{-13}	25	42	2874
	4860.209	7.6×10^{-15}	1.6×10^{-13}	21	22	1383
	4960.229	7.1×10^{-15}	4.6×10^{-13}	56	19	1173
	5008.325	6.5×10^{-15}	1.2×10^{-12}	183	17	1013
	6300.006	5.2×10^{-15}	7.4×10^{-14}	14	21	995
	6367.047	5.5×10^{-15}	2.4×10^{-14}	4	24	1146
	6561.164	6.8×10^{-15}	1.2×10^{-12}	182	47	2166
	6715.397	6.7×10^{-15}	2.6×10^{-13}	39	27	1198

In Table 2, the flux of the [O III] λ5007 line was used as an internal calibrator in the analysis of the Hβ line variability, while in the red spectral region the fluxes of the [S II] $\lambda\lambda$6717, 6731 lines were used to normalize the fluxes of the Hα+[N II] complex.

To quantitatively estimate the size of the broad-line region (BLR) at different epochs, we calculated the monochromatic continuum luminosity at λ5100 Å (L_{5100}) using the luminosity distance to Mrk 6 of $D_L = 81$ Mpc and applied the empirical R–L relation from the referenced study. The results are summarized in Table 3. The characteristic BLR size varies approximately from 16 to 22 light-days at different observing epochs.

Table 3. Fluxes of the Hβ line and their normalization using the [O III] λ5007 internal calibrator.

Date	JD–2400000	Flux(Hβ) (erg s^{-1} cm^{-2})	Flux [O III] λ5007 (erg s^{-1} cm^{-2})	Flux(Hβ) corr (erg s^{-1} cm^{-2})
15 November 2025	60995	3.6×10^{-13}	2.5×10^{-12}	2.8×10^{-13}
22 November 2025	61002	2.9×10^{-13}	2.1×10^{-12}	2.7×10^{-13}
9 January 2026	61050	1.2×10^{-13}	1.2×10^{-12}	1.9×10^{-13}
16 February 2026	61088	1.59×10^{-13}	1.20×10^{-12}	2.3×10^{-13}

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Table 4. Continuum flux at 5100 Å, monochromatic luminosity, and BLR size estimates for Mrk 6.

Date	F_{5100} (erg cm^{-2} s^{-1} Å^{-1})	$\lambda L_\lambda(5100)$ (erg s^{-1})	$R_{\rm BLR}$ (light-days)	Telescope
15 November 2025	1.1×10^{-14}	3.96×10^{43}	22	ShAO, 2 m
22 November 2025	9.1×10^{-15}	3.15×10^{43}	20	ShAO, 2 m
9 January 2026	9.7×10^{-15}	3.37×10^{43}	20	FAI, 1.5 m
16 February 2026	6.52×10^{-15}	2.60×10^{43}	16	ShAO, 2 m

4. Discussion

The light curve of the galaxy Mrk 6 for the period 2016–2026 is presented and discussed. Based on Figure 1, an estimate of the host-galaxy contribution was performed. As an approximate estimate of the host contribution at the minimum activity state of the active galactic nucleus (AGN), the minimum brightness values in each filter on the light curves were adopted. The minimum brightness was observed on 17 January 2017, when the magnitudes were $B = 14.065$, $V = 13.433$, and $R_c = 13.086$.

The observed color indices in Figure 2 show that $(B - V)$ varies in the range of approximately 0.63–1.07, whereas the $(V - R_c)$ index remains significantly more stable and is concentrated around ~ 0.43. This indicates that the variability is stronger in the blue part of the spectrum, while the red region varies more weakly.

To account for the host-galaxy contribution, its flux was estimated from the minimum brightness levels on the light curves in each filter, assuming minimal AGN activity at these epochs. The magnitudes were converted to fluxes using the standard zero-points of the Johnson–Cousins photometric system [19].

As a result, the following host-galaxy fluxes were obtained:

$$F_{\mathrm{host},B} \approx 1.51 \times 10^{-14}, \quad F_{\mathrm{host},V} \approx 1.59 \times 10^{-14}, \quad F_{\mathrm{host},R_c} \approx 1.27 \times 10^{-14}\ \mathrm{erg\ cm^{-2}\ s^{-1}\ ^{-1}}. \quad (2)$$

The spectral analysis shows that the characteristic velocities of the gas clouds, estimated from the full width at half maximum (FWHM) of the Hβ and Hα emission lines, lie in the range of $\approx$ 1200–2500 km s^{-1}. The emission-line widths were measured using the `IRAF/splot` task (gfwhm option 2) from the mea[n spectra without explicit decomposition into broad and narrow components.

We analyzed spectral data acquired on November 15 and 22 following the methodology detailed in [16]. Spectral analysis indicates that the characteristic gas cloud velocities—estimated from the Full Width at Half Maximum (FWHM) of the Narrow Line Region (NLR) Hβ and Hα emission lines—are approximately 1093$\pm$40 km s^{-1}. The mean FWHM values for the Broad Line Region (BLR) were determined to be 4630$\pm$230 km s^{-1} for Hβ and 4530$\pm$12 km s^{-1} for Hα; these were adopted as proxies for the virial velocity of the BLR gas. Based on average time delays (lags) of $\approx$20 light-days for Hβ and $\approx$28 light-days for Hα, we defined the BLR radius (R$_{BLR}$). Adopting a redshift of z=0.01904 and H$_0$=70 km s^{-1} Mpc^{-1}, the distance to Mrk 6 is estimated at D $\approx$ 81 Mpc. Applying a virial calibration factor of f$\approx$1.1 [21,22], the central supermassive black hole mass is calculated as M$_{BH}$ $\approx 0.92\times10^8$ M$_\odot$ (from Hβ) and M$_{BH}$ $\approx 1.24\times10^8$ M$_\odot$ (from Hα). These results for time delays and velocity dispersions are in good agreement with previously reported values [3,20]. The value of and M$_{BH}$ is somewhat two times lower than that reported in [3].

5. Conclusions

New photometric observations obtained between 14 November 2024 and 28 January 2026 are presented, demonstrating synchronous variability of the galaxy in the B, V, and R_C filters with an amplitude of about 0.3 mag in all bands. The galaxy light curve over an 11-year monitoring period was also analyzed. For an independent verification of the variability amplitude, data from the ASAS-SN and ZTF survey programs in the V filter were used.

The radius of the broad-line region R_{BLR} was taken to be equal to the average time delays (lags), amounting to ≈ 20 light-days for the Hβ line and ≈ 28 light-days for the Hα line. The obtained results are in good agreement with those reported by other authors.

Author Contributions: Conceptualization, methodology and visualization, S.S. A.S. and G.A.; formal analysis, A.S.; S.S.; validation, A. T., G.A. and S.S; investigation, S.S., A.S. and D.M..; resources, I.R., N.H. and D.A.; data curation, G.A., S.S. and A.T.; writing—original draft preparation, review and editing, S.S., A.S. and D.M.; project administration and funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript

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