Optical and Near Infrared photometry of Mrk 501

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1 Observations and data reduction

We performed optical and near infrared observations of Mrk 501 using the 2.12 meter telescope of the Observatorio Astrofísico Guillermo Haro[1] (OAGH) located in Cananea, Sonora, México, 30 km south of the Sonora-Arizona border. Observations in the JHK$_s$ bands were performed using the near infrared camera CANICA, equipped with a Rockwell Hawaii 1024×1024 detector, on nine epochs between March 26 and June 13, 2008. The sky conditions were reported as clear, although with high wind in some occasions. Aperture photometry was performed for six apertures equal to 10, 15, 20, 30, 40 and 44 CANICA pixel radii, which correspond to a scale plate of 0.32 arcsec/pix. Zero point photometric errors were estimated to be about 0.03 magnitudes, while statistical errors on individual measurements can be taken to be 0.003 mag.

[1]latitude 31°03′11″ North; longitude 110°23′02″ West

Optical BVRI photometry was performed using the OAGH direct camera composed of a filter wheel and a Versarray CCD of 1152×1124 pixels, cooled through a Cryotiger closed helium cycle system. The scale plate was 0.16"/pixel with typical FWHM images of 1.6". Observations were made on a single epoch, March 29, 2008, or JD$\simeq$2454555.0. The observing conditions were described as excellent of (no) cloud cover and atmospheric seeing. We acquired six cuasi-consecutive images on each filter with individual exposure times of 60s, 30s, 10s and 30s for the BVRI filters respectively. Image data reduction was performed using the NOAO-PHOT IRAF routines. BVRI images were calibrated using Landolt fields SA 98 and PG 1633+099 [1]. Systematic zero point calibration errors were estimated from mutual comparison of standard stars and found to be {0.08, 0.05, 0.03, 0.03} magnitudes for the BVRI colours, respectively. Statistical errors on individual measurements as given by IRAF are less or equal to 0.002 magnitudes. Aperture photometry was performed using the same apertures as for the NIR images to Mrk 501 and to four "witness" stars.

Zero magnitude BVRI fluxes and wavelengths are from [2]. Zero magnitude JHK$_s$ fluxes and wavelengths have been estimated directly with CANICA calibration of Vega and agree well with [4] and [3].

2 Radial profiles and central fluxes

We fitted radial profiles with the flux inside a ring of inner and outer radii r_{j-1} and r_j given by

$$F_j = a \left[\exp\left(-\frac{r_j}{r_0} \right) - \exp\left(-\frac{r_{j-1}}{r_0} \right) \right], \tag{1}$$

with $\{a, r_0\}$ parameters to fit minimizing the difference between data and fit. The central aperture is excluded from the fit, as the aim is to interpolate the galaxy flux within it. We calculated fit parameters a and r_0 for each passband using all the data. When considering a single observation the normalization a is varied by a factor close to unity such as to give the same integrated flux for the host galaxy, excluding the central aperture. The fit parameters for the mean data of each different colors are shown in table 1.

The mean fluxes for the host galaxy and AGN are tabulated in table 2. An AGN spectrum is shown in figure 1, using the JHK$_s$ observations closest to the optical data. The fitted AGN flux peaks in the R band and declines

Color	λ_c (μm)	a (mJy)	r_0 (arcsec)
B	0.44	6.52± 0.03	5.75
V	0.55	12.41± 0.04	5.87
R	0.64	17.89± 0.05	5.68
I	0.79	26.70± 0.10	5.47
J	1.25	41.75± 0.14	4.06
H	1.61	59.94± 0.18	3.96
K_s	2.15	48.33± 0.36	3.84

Table 1: Exponential fits to Mrk 501 host galaxy.

towards the NIR. The host galaxy shows redder colors, with the integrated flux (including the interpolation to the central aperture) increasing from 6 mJy in the B band to close to 60 mJy in the H band, where it is maximum. As a result the contrast of the central nuclei is larger in the optical than in the infrared.

Flux light curves were constructed for the different bands. The BVRI observations were made within two hours and can be used to test microvariability. The JHK_s observations span and interval of 80 days, testing variability on larger time-scales. Given the different fluxes for different colors, the optical data can be put together on a single light curve only if expressed in terms of $F/<F>-1$, the deviation of the flux relative to the mean, as shown in figure 2. Although the photometric errors are well below 1%, the measurements on the AGN have errors close to 4% as they represent the differential between the measurement and the fit in the central aperture. In any case we can assert that we do not see flux variations larger than 0.2 mJy for time-scales smaller than 10 minutes, the span of a given sequence on a particular filter.

The near infrared data cover individual observations separated by intervals between 10 and 20 days (figure 3). A rapid increase in flux is clearly observed between dates 4590 and 4597, when JHK_s fluxes increased by a factor of 2.5, from $\lesssim 4$ mJy to $\lesssim 10$ mJy, within a week. The J band shows a later decrease to fluxes below 3 mJy, which is not clearly present in the H and K_s data.

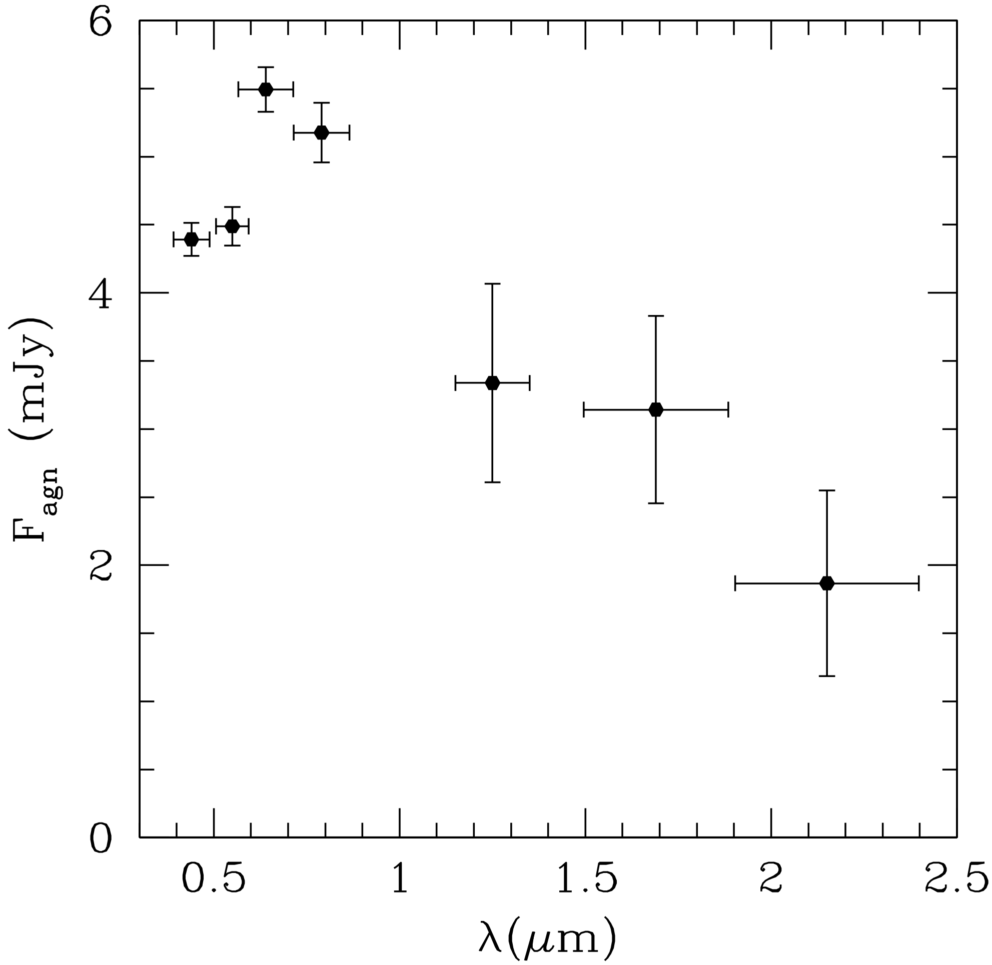

Figure 1: AGN spectrum using optical data of epoch 5445 and JHK$_s$ data of epoch 5442. The error bars in the NIR are larger as the optical data uses six observations on a single epoch while NIR is for a single observation on the closest epoch. The V band flux shows somewhat low for a smooth fit.

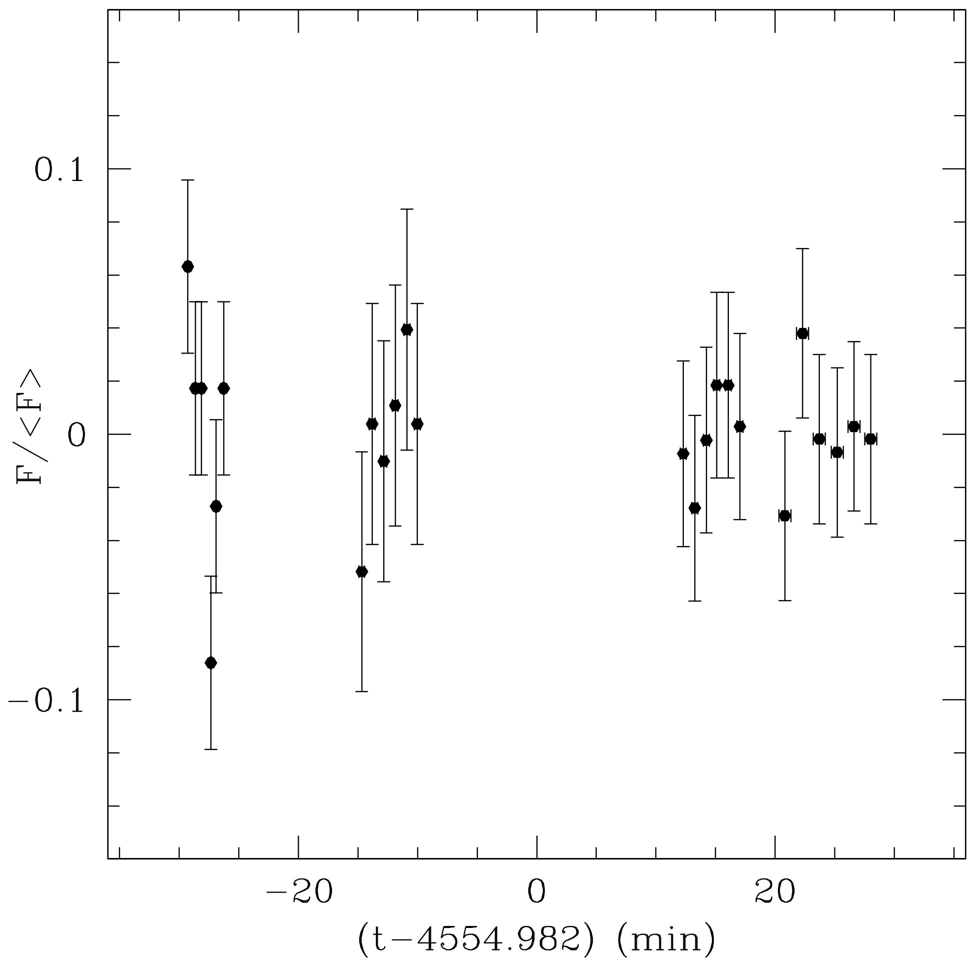

Figure 2: Variability of the flux of the central nuclei of Mrk 501 in the optical band. The sequence of observations was R, I, V, B. Flux variations are below statistically significant levels, although a flux decrease between the end of the first sequence of images and the start of the second one is suggested..

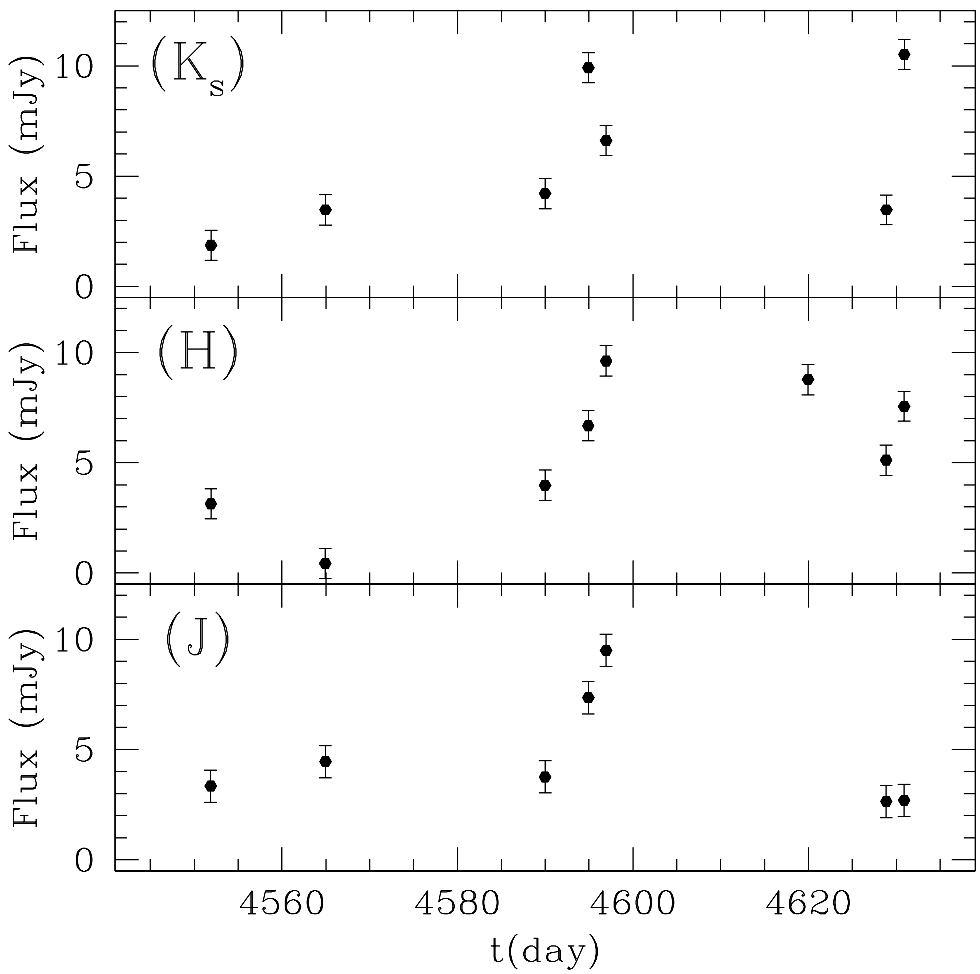

Figure 3: Variability of the flux of the central nuclei of Mrk 501 in the near infrared band. A flux increase is clearly seen between JD 2 544 580 and 2 545 000 relative to measurements from $\sim$ 30 days earlier. The last data points show a decrease in J, not observed in the H and K_s bands..

		Flux measured		Flux fitted		
Color	λ_c (μm)	Total (mJy)	outside (mJy)	outside (mJy)	host (mJy)	AGN (mJy)
B	0.44	10.34	3.17	3.17	5.95	4.39± 0.12
V	0.55	15.77	6.07	6.07	11.28	4.49± 0.14
R	0.64	21.88	8.69	8.69	16.39	5.49± 0.16
I	0.79	29.85	12.84	12.84	24.67	5.18± 0.22
J	1.25	45.03	17.65	17.67	40.45	4.60± 0.50
H	1.61	63.61	24.98	25.00	58.23	5.40± 0.48
K_s	2.15	52.54	19.73	19.76	47.10	5.47± 0.55

Table 2: Fluxes measured and fitted for the Mrk 501 host and central nuclei. The "outside" values refer to the flux added for $3.2 \leq r('') \leq 14.08$. Individual observations are normalized in terms of the "outside" flux.

3 Summary and future work

We observed Mrk 501 in the optical and near infrared, with six observations within an hour for a single epoch in the BVRI bands and several individual observations separated by tens of days and covering the Julian Day interval between 2 454 552 and 2 454 631 in the JHK_s bands. A quasi-simultaneous optical and near infrared spectrum shows a 0.4-2.5 μm peak in the R band, at around 0.64 μm, with all fluxes below 6 mJy.

The optical data shows no evidence of microvariability larger than 5% or 0.2 mJy for time-scales of minutes to tens of minutes. In contrast, the near infrared observations show fluxes varying from less than 2 mJy up to 10 mJy, including an increase in flux by a factor of 2.5 within 7 days.

More work can be made in terms of the host galaxy substraction. An exponential surface brightness, $dF \propto e^{-r/r_0} r\ dr$, should represent the data but the fit was found to be not so accurate as a direct exponential (expression 1). Furthermore, aperture photometry uses circular apertures, while in practise the host galaxy is noticeably elliptical. The images have good spatial resolution and lend themselves to a more accurate fit, which can be composed of a two dimensional elliptical exponential surface brightness with a central point source.

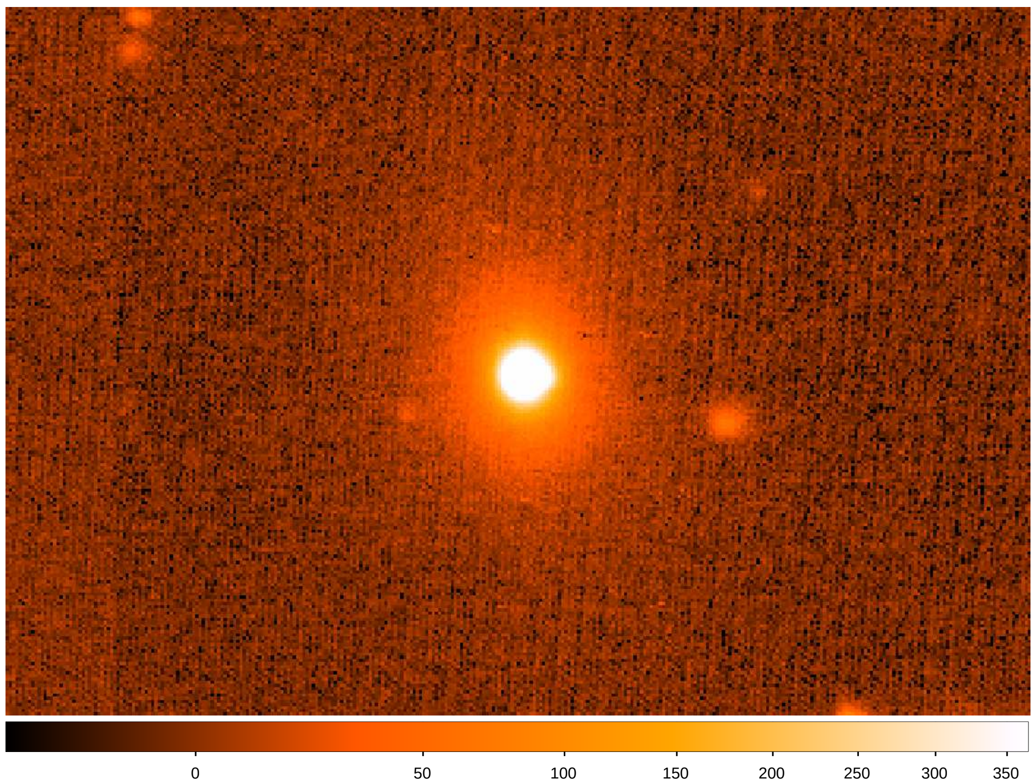

Figure 4: J image of Mrk 501. The host galaxy is clearly seen, with an elongated shape..

References

[1] Landolt, A., 1992, AJ 104, L304.

[2] Bessell, M.S, 1979, PASP 91, 543.

[3] Bessell, M.S, and Brett, J.M., 1988, PASP 100, 1134.

[4] Campins, H., Rieke, G.H., and Lebofsky, M.J., 1985, AJ 90, 896.