Bull. Astr. Soc. India (2005) **33**, 181–188

# Monitoring of AGNs for variability from MIRO

K. S. Baliyan,* U. C. Joshi and S. Ganesh
*Physical Research Laboratory, Ahmedabad 380 009, India*

**Abstract.** As a long term programme, a sample of blazars is being monitored from Mt Abu Infrared Observatory (MIRO). Blazars are the radio-loud AGNs with polarized, highly luminous and rapidly variable non-thermal continuum emission ranging from radio to $\gamma$ rays, from a relativistic jet. The emission shows variability at several time scales. Radio through $\gamma$-ray spectral energy distribution (SED) of blazars exhibits two broad humps- first at UV/optical, considered to be due to synchrotron emission from the relativistic electrons, and second one in the region extending from X-ray to $\gamma$-rays whose origin is less understood. Long term multi-wavelength monitoring of the blazars for variability is the key to obtain information on the geometry of the jets and the physical processes responsible for the high energy emissions. Here we report monitoring of several blazars using 1.2 m IR telescope and discuss recent results on some of them. In particular, PKS0716+714 and 3C66A have shown intense activity and continued in bright phase during 2003-04, drawing worldwide attention for a co-ordinated monitoring campaign.

*Keywords* : AGN:Blazars – multiwavelength – variability – non-thermal emission – relativistic jet

## 1. Introduction

Active Galactic Nuclei (AGN) are enigmatic objects producing very high luminosities in a very compact volume. BL Lac objects and flat spectrum radio quasars (FSRQs) are AGNs commonly unified in the class of blazars. The members of this subclass are characterized by non-thermal continuum spectra, a high degree of linear polarization, rapid variability in flux and polarization at all wavelengths and radio jets often exhibiting superluminal

*e-mail:baliyan@prl.ernet.in

motion (Blandford and Rees 1978). Many of these sources have also been detected in high energy ($> 100 MeV$) gamma-rays by the EGRET instrument on board CGRO (Mattox, Hartman and Reimer 2001). In the framework of relativistic jet model, the low energy (radio-optical/UV) emission from these sources is interpreted as synchrotron emission from nonthermal electrons in the relativistic jet. The high-frequency (X-ray - $\gamma$-ray) emission could either be produced via Compton upscattering of low frequency radiation by the same electrons responsible for the synchrotron emission (leptonic jet model; Bottcher 2002), or due to hadronic processes (Muke et al., 2003). The overall radio to $\gamma$-ray spectral energy distributions (SEDs) of blazars exhibit a broad two hump structure (Fassati et al., 1998). The first peak occurs either in the IR/optical (low energy blazars) or in the UV/X-ray region (high energy peaked blazars). These are also called red or RBL and Blue or XBL, respectively, based upon peaking energy or detection criteria. The second spectral component extends from X-ray to $\gamma$-ray (GeV/TeV), and its origin is less understood but, as mentioned above, is considered to be inverse Compton (IC) scattering of low energy photons. Origin of these photons is not very clear- they can be internal (synchrotron self Compton, SSC) or external (External Compton) to the jet. A detailed study of the multifrequency blazar flux variation may provide considerable information on the emitting region dynamics. Keeping this in mind, several multiwavelength blazar monitoring campaigns have been conducted on several sources where observatories in different parts of world participate. These are often co-ordinated with observations from space borne facilities at many wavelengths. Such efforts enable study of correlation among flux variations in different bands which is of uttermost importance to shed light on the physical processes responsible for the emission.

The monitoring of blazars for their variability study at the Physical Research Laboratory started much before the commissioning of the 1.2m Infrared Observatory at Mt. Abu in 1995. It would not be out of context to note the efforts of Prof. M. R. Deshpande and one of us (UCJ) who took this up as one of the most challenging problems of all times - to understand the energy mechanism of AGNs. Initially the optical polarimeter at the Arizona Observatory was used to monitor OJ287 and later on we designed and fabricated our own optical polarimeter (Deshpande et al., 1985) which was used at Kavalur Observatory and UPSO(Nainital) to study several BL Lac objects. These studies from MIRO and other observatories resulted in a series of publications( Kulshrestha et al., 1984;1987, Baliyan et al., 1996, Deshpande et al., 1997, Joshi et al., 2000, Baliyan et al., 2001, Joshi et al., 2002). One of the important result was detection of 20 minute variability time scale and its implications (Kulshrestha et al., 1984, Baliyan et al., 1996) in BL Lac object OJ 287. In addition to optical polarimeter, optical CCD (1kx1k) and near infrared array camera, NICMOS-3 are also used for the monitoring of a sample of blazars. Now we have data on several objects (OJ 287, BL Lac, Mrk 421, Mrk 501 etc) spawning almost a decade and are being put together to generate light curves. Here we will discuss a BL Lac object, PKS0716+714, which had been the subject of intense worldwide multiwavelength monitoring campaign recently. We participated in this campaign by monitoring PKS0716+714 in J, H and K' near infrared bands during 2003-04.

The source was consistently in bright phase and underwent several outbursts during the course of observations.

## 2. PKS0716+714

BL Lac object PKS0716+714 is from S5 catalog of strong sources performed at 4.9 GHz (Kuhr et al., 1981). It has a compact core-jet structure and a VLBI study suggests different components moving at slightly different velocities (Bach et al., 2003). It was also confirmed as BL Lac source, 3EG J0721+7120, in the 3EG EGRET survey (Nolan et al., 2003). The polarization at optical was found to be variable on short time scales, with possible quasi-periods of 12.5, 2.5 and 0.14 days (Impey et al., 2000). As of now, no spectroscopic observation has detected any feature in its spectrum. The redshift of 0.44, determined using observational features, eg. starlike appearance, absence of host galaxy, small angular size etc, still remains unconfirmed. For the first time, Bierman et al., (1981) reported variability in magnitude, polarization and polarization angle. This variability coupled with featureless continuum designated it as a BL Lac object. A UBVRI photopolarimetric study was carried out by Takalo et al., (1994) during two nights who noticed a variable , high, wavelength dependent polarization. Sagar et al., (1999) performed a BVRI monitoring in 1994. For the first time, intra day variability (IDV) was detected by Heidt and Wagner (1996) who also noticed a 4 day periodicity in the source variation. Nesci et al., (2002) did a 52 night monitoring and reported typical variations of 0.02 mag per hour. Ghissellini et al., (1997) detected a spectral flattening when the flux was high during rapid flares. They interpreted it as due to the presence of two processes operating in the source. The first process- energy injection in a large region, remained stable over a few months time scale. It caused achromatic long term flux variation. Fast variations, on the other hand, were suggested to be due either to the curved trajectory of relativistic electrons emitting blob or very rapid electron injection and cooling processes.

In order to ascertain whether the fast radio variations were due to propagation effects (interstellar scintillation) or an intrinsic phenomenon, this source was monitored in optical and radio, simultaneously (Quirrenbach et al., 1991). Some correlation in the strong flux variations were noticed between two wavebands but without any definite answer. Wagner et al., (1996) found a close correlation between optical and radio and possibly between the optical and X-ray bands. Recently, Raiteri et al., (2003) reported optical (1994-2001) and radio (1978-2000) observations on PKS0716+714, using various bands. They mention variations by 1.5 and 2.0 mag in optical region. They also reported a 2.3 mag increase in 9 days in October 2000, highest level of brightness, not only for this source but for blazar class.

Though the low energy peak in the SED of PKS0716+714 falls almost in the near IR region, there are almost no observations in this window. Where the thermal radiation from hot dust may account for the infrared emission in most of the radio quiet AGNs, emission through IR wavebands in blazars is mainly nonthermal. Since this source emits significant energy in this waveband, we decided to monitor the source from Mt Abu using 1.2m telescope and NICMOS-3 IR array. Later we also joined the worldwide efforts through WEBT campaign on this source. What is of more importance to understand the energetics of the blazars is the simultaneous multiwavelength studies of the variability with shortest possible sampling times.

## 3. Observations and data analysis

PKS0716+714 is being monitored now for more than three years, mostly in near infrared. Here we report observations from October 2003 to April 2004 when the source was in an unusually bright phase. The observations were made at the f/13 1.2m telescope equipped with NICMOS-3 IR array camera at the Mt Abu Infrared Observatory (MIRO). It is a HgCdTe detector with 256x256 pixels and a plate scale of 0.98" per pixel. The filters used are J($1.2\mu$), H($1.65\mu$) and K'($2.12\mu$) and most of the observations are made with 4'x4' FOV in order to accommodate several comparison stars in the same frame for better calibration. Care is taken that the source remains in the same quadrant of the array detector to avoid quadrant to quadrant variation in the detector characteristics to affect the results. Apart from the source observations, dark frames are taken every night. Observations are carried out in such a way as to improve signal to noise ratio while skirting the saturation problem.

Data was reduced and analysed using standard techniques- IRAF and home developed scripts. Images at one location were combined to improve S/N and photometry was performed using aperture photometry. Same aperture was kept for the PKS0716+714 and comparison stars and instrumental magnitudes were obtained for all objects present in the field. The source magnitude is obtained as the average of those derived with respect to all the comparison stars in the individual frame. Typical photometric errors in the respective bands are less than $0.03\ (J), 0.03\ (H)$ and $0.05(K')$. The calibration values for the stars are taken from 2MASS. It should be noted that 2MASS photometric values are for Ks ($2.16\mu m$) while we have used K' ($2.12\ \mu m$) band for observations. We estimate an error of not more than 0.04 mag, less than the typical photometric error in K' band, due to this factor which we have not tried to correct.

## 4. Results and discussion

Our light curves for the PKS0716+714 are one of the longest duration in the near infrared bands and are presented in Fig.1. Major outbursts occurred around 1 November 2003, 28 December 2003, 26 January 2004 and March 2004 (WEBT-private communication). However, our data do not provide full coverage of these outbursts. We notice an increase of about 1.6 mag between December 10, 2003 and January 26, 2004 in J, H and K' bands. It appears that December 2003 and January 2004 outbursts occurred between these two dates. Since we do not have observations in this duration, their behavior in NIR can not be described. The light curve appears as the superposition of fast flares lasting a few days on a modulated base level in all three bands.The figure also shows fading of the source during December 10 - 12, 2003 by about 0.5 mag with a further decrease in magnitude by 0.3 mag on December 18, 2003. We nicely capture the decay part of the January 26, 2004 flare, which decays through February 2004, slowly ending in a short flare. Also plotted in Fig. 2 are light curves in three bands during the night of December 12, 2003. We have studied nightly variations of the source on several nights but all of them are not discussed here. We do not notice any significant intra day variation (IDV) on any night during the whole monitoring campaign. However, we hasten to add that no definite conclusion should be drawn based on the present data. May be our nightly monitoring period was not long enough and we might also have missed the nights source varied overnight. In our observations, all the three bands, J, H and K', show almost same pattern. We do not have complete observations during March 2004 outburst but catch it's decaying part in April observations where source is still above average brightness level.

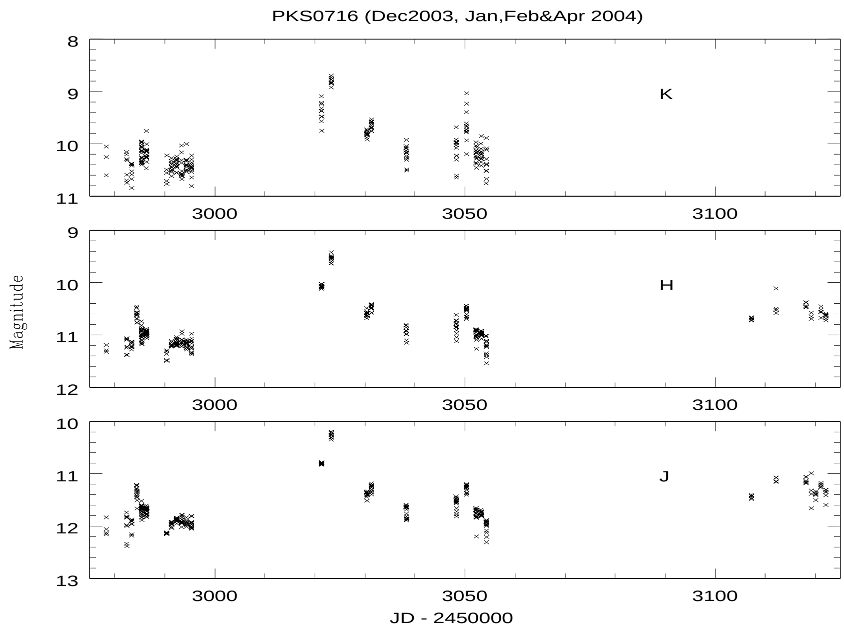


**Figure 1.** Variations in the near infrared J, H and K' bands during December 4, 2003 to April 20, 2004. Brightening of PKS0716+714 by more than 1.5 mag is noticeable during Dec.03-Jan.04.

We notice that colour index (J-H) decreases, albeit slightly, when source brightens from its level on Dec.18, 2003 to Jan. 16, 2004. The bluer when brighter trend continues during Jan. 18-26, 2004 variations as well. This inference is drawn without correcting for extinction. The statistical analysis of light curves in three bands do not reveal presence of any time lag.

The constant variability amplitude (of about 1.0 mag) in magnitudes implies flux variation amplitude to be proportional to flux level and can be explained as due to Doppler beaming factor, $\delta = [\tau(1 - \beta Cos\theta)]^{-1}$, where $\tau$ is the Lorentz factor of the bulk motion of emitting electrons in the jet with $\theta$ as the viewing angle. The intrinsic flux is relativistically enhanced by a factor of $\delta^3$. This change could be due either to energetics or geometrical reasons or a combination of both. Longer duration data is required to pin point the process.

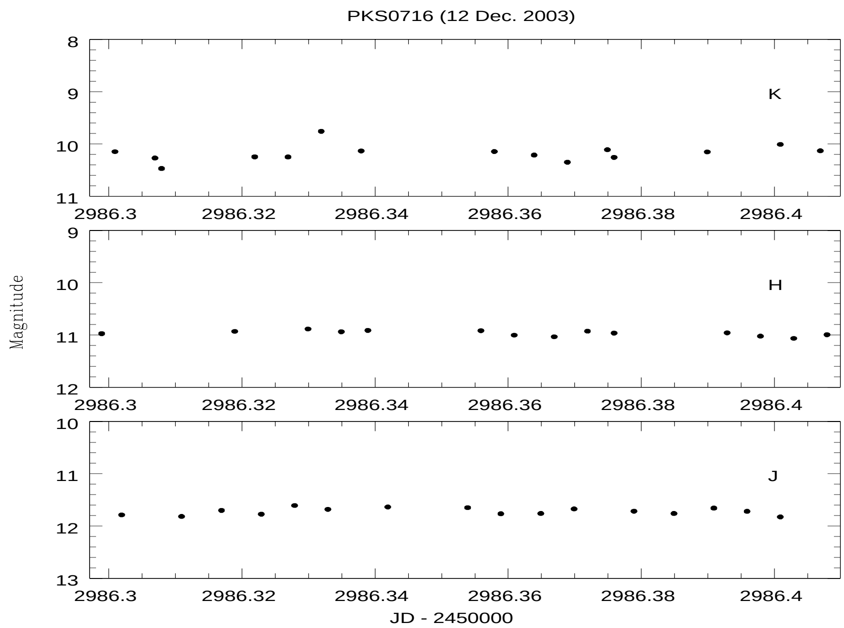


**Figure 2.** Light curve for PKS0716+714 on December 12, 2003 in near infrared, J, H and K' bands.

## 5. Conclusions

Here we have presented one of the longest duration light curves of the BL Lac object PKS0716+714 in near IR from Dec. 2003 to April 2004. The source was consistently in bright phase during the monitoring. On the long term brightened base level, variations on short time scales are superposed. There is an increase of more than 1.5 mag between Dec. 19, 2003 and Jan. 26, 2004, which is due to the Dec. 2003/Jan 2004 outbursts. Several enhancements of the order of 0.3 - 0.5 mag are also noticed over couple of days time scale without any clear periodicity. Studying short time scale behavior and looking for spectral changes while following complete outburst may be the key to pin down the basic emission mechanism. From light travel time arguments, $R \leq c.\Delta_t$, where $\Delta_t$ is variability time scale in source frame, emission regions appear to be of the order of solar system. No short term time scale variations during a single night of observation are detected above 1-$\sigma$ error level. All three near infrared bands show similar behavior, except that due to poor S/N ratio, K' band light curve showed large spread.

It is possible that the variations are partly intrinsic and partly due to rotating helical jet. Here jet inhomogeneity causes time lags in the flux variation at diverse wavelengths, since different frequency emitting portions of the jet acquire the same viewing angle at different times. We, however, note that all the three near IR bands, J, H and K', show similar pattern in their light curves. Because of the limited time coverage in NIR, the present data are not enough to perform any useful statistical operation to determine time scales. A longer duration monitoring in this window is underway. However, we believe that the data reported here will be very useful for a multiwaveband study.

## Acknowledgements

The authors would like to thank Ms C.R. Shah for the photometry and MIRO staff for assistance in observations. This work is supported by the Department of Space, Government of India.

## References

Bach, U., et al., 2003. in Proceedings, Second ENIGMA Meeting, Eds. C.M. Raiteri and M. Villata, Pino Torinese, Italy, p.104.
Baliyan, K.S., Joshi U.C., and Deshpande M.R., 1996, *APSS*, **240**, 195.
Baliyan, K.S., et al., 2001, *BASI*, *29*, 421.
Bierman, P. et al., 1981, *ApJ*, **247**, L53.
Blandford, R.D. and Rees M., 1978, *in Pittsburg Conference Proceedings*, p328.
Bottcher, M., 2002, *in proc."The Gamma-ray Universe"*, **XXII** MAM.
Deshpande, M.R., et al., 1985, *BASI*, **13**, 157.
Deshpande, M.R., Joshi U.C., and Baliyan K.S. 1997, *APSS*, **258**, 9.
Fassati, G., et al., 1998, *MNRAS*, **299**, 433.
Ghissellini, G., et al., 1997, *A&A*, **327**, 61.
Heidt, J., and Wagner S.J., 1996, *A&A*, **305**, 42.
Impey, C., et al., 2000, *AJ*, **119**, 1542.
Joshi, U.C., Baliyan K.S., and Ganesh S. et al., 2000, *BASI*, **28**, 409.
Joshi, U.C., Baliyan K.S., and Ganesh S., 2002, *BASI*, **30**, 301.
Kuhr, H., et al., 1981, *AJ*, **86**, 854.
Kulshrestha, A.K., et al., 1984, *Nature*, **23**, 133.
Kulshrestha, A, Deshpande, M. R., and Joshi, U. C. 1987, *AAS*, **71**, 565.
Mattox, R. J., Hartman R.C. and Reimer O., 2001, *ApJS*, **135**, 155.

Mucke, A., et al., 2003, *Astropart. Phys.*, **18**, 593.
Nolan, P.L., et al., 2003, *ApJ*, **597**, 615.
Nesci, R., Massaro E., and Montagni F., 2002, *PASA*, **19**, 143.
Quirrenbach, A., et al., 1991, *ApJ*, **372**, L71.
Raiteri, C.M., et al., 2003, *A&A*, **402**, 151.
Sagar, R., et al., 1999, *A&AS*, **134**, 453.
Takalo, L.O., Sillanpaa A., and Nilsson K. 1994, *A&AS*, **107**, 497.
Wagner, S.J., et al., 1996, *AJ*, **111**, 2187.