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Variability study of blazars with TAUVEX: scope and limitations

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Abstract. The study of variability in blazars is an important tool to understand their energetics. Such a study is required to be made in all bands of spectral energy distribution. Hence, we propose to make UV observations of blazars using the TAUVEX facility for sources in the region $|Dec| > 50°$. These observations will be complemented with simultaneous ground based observations in near IR, optical and radio frequencies using the facilities available in the country. The data will be used to study the nature of emission processes.

Keywords : (galaxies:) active – (galaxies:) BL Lacertae objects: general – techniques: photometry – ultraviolet: general

1. Introduction

Ultraviolet astronomy is a field in space astronomy that was explored in the sixties and seventies, largely by rocket experiments and even today this window is not well explored. As ultraviolet astronomy is an extension of visible spectrum towards short wavelengths, there will be intimate interactions with ground-based observations in the visible. IUE was one of the most successful ventures in UV, but limited to spectroscopic mode only. The GALEX mission is an important step in UV window which will provide important input to plan observations with TAUVEX.

Blazars are a subclass of active galactic nuclei (AGNs) characterized by rapid variability, high polarization, a compact radio structure and weak or absent emission lines. Flux variability has been detected in time scales ranging from a few tens of minutes to hours and days (Smith et al. 1987; Carini et al. 1992; Heidt & Wagner 1996; Jang &

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Miller 1997; Fan et al. 1997, 1998; Fan & Lin 2000; Kraus et al. 1999; Romero et al. 2000; Fan et al. 2001, Bottcher et al. 2005; Baliyan et al. 2005). Variability time scale put constraints on the size of the emitting region. The characteristics of variability are expected to get modulated due to immediate environment around the central engine e.g. due to beaming, non-homogeneous jet, torus, disk etc. Variability study is a very powerful tool to understand the physics of the nuclear region. So far not much information is available on the nature of variability in the UV spectral region. It is highly desirable to have continuous run of ultraviolet measurements on blazars for considerable time.

Spectral energy distribution (SED) of blazars show a double humped structure, one peaking in the IR-optical-UV region and the other in X-ray and gamma ray regions. Based on this the blazars are classified into two categories: High and low energy peaked blazars(HBLs & LBLs). In LBLs, the first component peaks in the IR to optical region whereas in HBLs, it peaks in the UV/X-ray region. The second component extends upto γ-rays, peaking at GeV energies in LBLs and at TeV energies in HBLs. The origin of the first component is attributed to synchrotron emission from high energy electrons in the relativistic jet. The high energy peak is generally attributed to Inverse Compton (IC) scattering of soft photons, though the origin of the soft photons that seed the IC component of blazar spectrum is not well understood. In case of HBLs the low energy peak lies in the UV/X-ray region, and hence it is important to have information on the detailed behaviour of HBLs in the UV spectral region.

In almost all cases it is found that a substantial fraction of the energy is emitted at γ-ray energies. The sources proposed for the study are rather the extreme type of blazars emitting large fraction of their power in gamma ray frequencies (Wagner & Wintel 1995) and showing large variations almost in entire range of frequencies - radio to γ-rays seen in a short time scale (Carini & Miller 1992; Heidt & Wagner 1996; Jang & Miller 1997). Strong and rapid variability seems to be a common property of these sources in the γ-ray band (e.g. von Montigny et al. 1995). The origin of the high energy is not clear. The correlated optical/UV and γ-ray variability observed in some objects (Wagner et al. 1995; Hartmann et al. 1996) indicates that the same population of electrons could be responsible for the flux in both bands, and suggests that the optical emission is due to the synchrotron process, while the γ-rays are produced by the inverse Compton process between highly relativistic electrons and soft seed photons. Study of Mrk501 by Joshi et al. (2000) supports this view. The origin of seed photons, the location and size of the emitting region(s) and the degree of relativistic beaming of the high energy radiation are not understood well. Regarding the origin of seed photons, there are several models (Marashi, Ghisellini, & Celotti 1992; Ghisselline & Madau 1996; Derner & Schlickeiser 1993; Sikora, Begelman & Rees 1994; Blandford 1993; Blandford & Levinson 1995; Wagner et al. 1995) but still the debate is open.

The rapid changes in flux density of BL Lac objects have mostly been investigated within the two different frame works (Wagner & Witzel 1995). The putative accretion disks wherein hot spots and other inhomogeneities lead to fluctuations (Wiita et al.

1991). Alternatively, shocks within the jets of BL Lac objects which are suggested to point towards the observer, may cause variability (Marscher & Gear 1985; Camenzind & Krockenberger 1992). In addition external causes, such as gravitational micro-lensing, bending of jets etc. may play a role. So far none of these models are able to explain the nature of variability over the entire electromagnetic spectrum. The proposed study might put constraints on the models. The blue bump in the energy distribution is attributed to radiation from the accretion disk. Also since UV emission is supposed to be from the central region, the study in UV will help to understand the inner region of these sources.

2. Variability study - its importance

Simultaneous monitoring (Heidt et al. 1997) in different energy bands is an important means of studying the physical processes in BL Lacertae objects. The time scales in the various frequency regions impose constraints on the sizes and relative locations of different constituents. In the absence of sufficient spacial resolution, indirect observations e.g. variability studies provide unique testing tools to understand the central structure of these AGNs. Multiwavelength monitoring programmes on these sources have revealed the complex behaviour of variability - sometimes the sources show strong activity in IR-optical-uv region but no activity in the radio region while at other times the strong activity has been detected in the entire electromagnetic range in the same source.

In recent past, several international monitoring campaigns have been organized, involving both ground and space observatories, with the aim of covering the electromagnetic spectrum from the radio to the γ ray energies. Based on these, the spectral energy distribution (SED) of blazars is currently explained in terms of two components - synchrotron emission from relativistic electrons in a magnetized plasma, accounting for the emission from radio to the X-ray band and the higher-energy emission produced by the up scattered photons in the inverse Compton process (seed photons being soft photons produced internally by synchrotron process). Several models for the emitting plasma have been proposed but the observations have not been able to favour fully any one of them. It is therefore very important to have long term simultaneous continuous observations in several wavebands with shortest possible sampling time to obtain correlated variations which, in turn, could be used to put stringent constraints on these models.

As an example, we discuss the case of PKS 2155-304 to emphasize the problems involved in understanding the physical process and how it can be tackled through densely sampled multi-waveband study. PKS 2155-304 is one of the brightest BL Lac sources having the synchrotron peak in the UV - soft X-ray range. This corresponds to the definition of high frequency peak BL Lac objects (HBL) (Padovani & Giommi 1995). The γ-ray spectrum is flat ($\alpha_\gamma \sim 0.7$ in the 0.1-10 GeV energy range), indicating that the Compton peak is beyond 10 GeV. Recently it has been detected in TeV band (Chadwick et al. 1999). Due to these characteristics, PKS 2155-304 has been the target of numerous multi-wavelength campaigns (Edelson et al. 1995; Urry et al. 1997).

This source is highly variable in the optical flux (e.g. Griffiths et al. 1979; Miller & McAlister 1983; Humuy & Maza 1987; Carini & Miller 1992), in the UV (e.g. Urry 1986; Edelson et al. 1992) and in X-rays (e.g. Sonyder et al. 1980; Morini et al. 1985; Treves et al. 1989). The typical time scales measured so far are several minutes to hours in the X-ray and days to weeks in the UV and optical. Within these time scales the amplitude of the variability reaches up by factors of 2 to 5 in the X-ray, UV and in the optical. Recently it was detected in γ-rays by EGRET (Vestrand, Stacy & Sreekumar 1995).

Treves et al. (1989) find that the overall spectral variability of PKS 2155-304 can be described by the standard SSC model for an inhomogeneous source. Wiita et al. (1991) explain the short term variability by flares or hot spots from an accretion disk. On the other hand Edelson et al. (1991) argue that at least the UV emission was not radiated from an accretion disk, because the time scales of the variability did not match the expectation from a standard accretion disk model. The results of two large multi-wavelength monitoring campaigns in 1991 and 1994 respectively (Edelson et al. 1995; Pesce et al. 1997; Pian et al. 1997) show that PKS 2155-304 display a different behaviour: recurrent flares on time scales of $\sim$0.7 days dominated in November 1991, whereas in May 1994 variability was characterized by two large outbursts. The available models are not able to explain such different patterns of variabilities. It is not clear whether variability characteristics on short time scales are related to spectral changes or the general brightness levels.

The optical and UV-monitoring campaigns in 1990 and 1994 (Heidt et al. 1997) also show similar behaviours. During the first run in June 1990 and the third run in September 1994, PKS 2155-304 showed night to night variations between 5% and 10%. During the observing run in September 1994, the object was close to its historically recorded maximum. During the second run in June 1990, the object was completely stable, indicating that extended periods of quiescence occur even in the most active BL Lac objects, irrespective of the long term flux levels. Variations in time scales of minutes are not detected during these runs.

We have been studying Mrk 501 and monitoring this source, as far as possible continuously, for variability studies. In co-ordinated optical polarimetry and high energy Gamma-ray Cerenkov observations on Mrk 501 during April 1997, we noticed increased polarization during a gamma-ray flaring activity. The study supports Synchrotron Self Compton (SSC) model and indicates the co-spatial emissions of optical and gamma-ray emissions in the jet (Joshi et al. 2000). Recently (June 2004) we detected large enhancements in the polarization of Mrk 501 with several rapid polarization flashes. It also showed several dips in the total intensity. These fluctuations appear to be due to local explosions while gradual increase is due to magnetic field alignment in a blob in the jet.

These results show that even a well studied BL Lac object with a high duty cycle of time scales of days may show quiescent stages. However, such information is lacking in the UV.

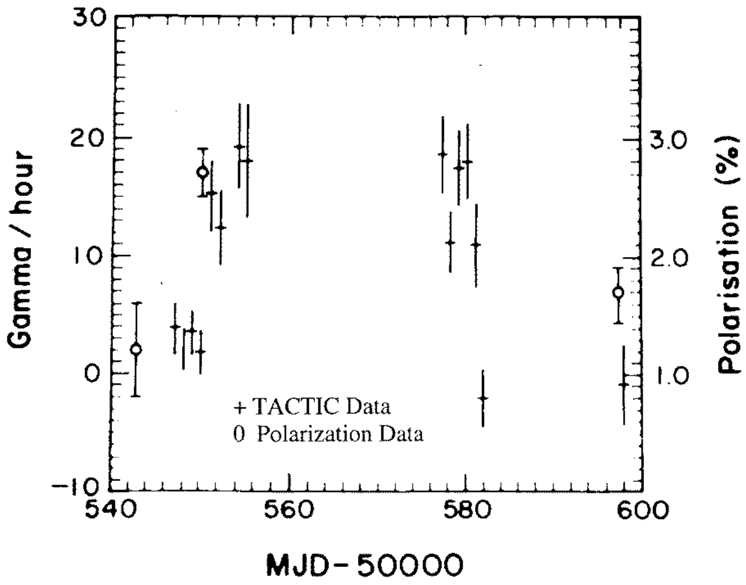

Figure 1. Simultaneous observations in the optical and TeV energies for Mrk 501.

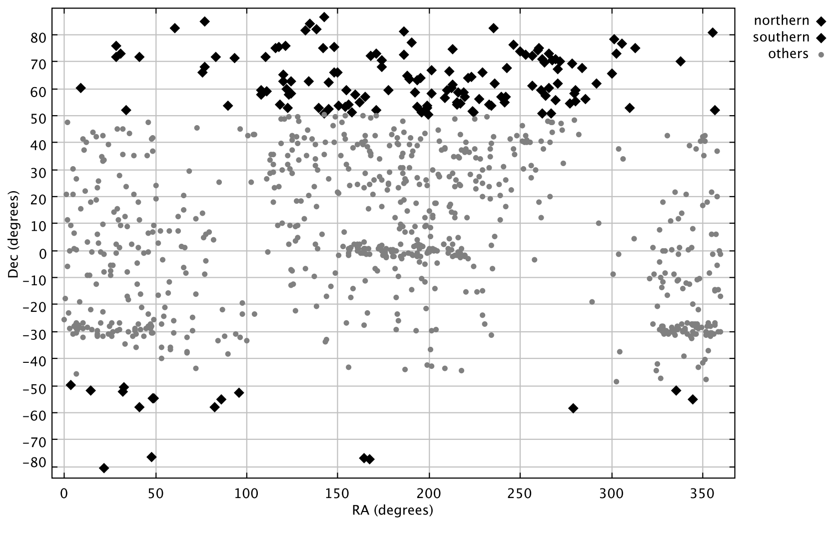

Figure 2. Distribution of BL Lac sources in the sky. Data taken from Veron & Veron catalogue.

3. Advantages and limitations

TAUVEX is an Indo-Israeli Ultraviolet Imaging Experiment that will image large parts of the sky in the wavelength regions between 1400 and 3200 Å. The instrument consists of three equivalent 20-cm UV imaging telescopes. Each telescope has a field of view of about $54'$ and a spatial resolution of about $6''$ to $10''$, depending on the wavelengths. TAUVEX will be launched into a geostationary orbit as part of ISRO's GSAT-4 mission towards the end of 2007 or beginning of 2008. More details are found at the website: http://tauvex.iiap.res.in/

3.1 Advantages

A few advantages in the UV window are listed below: i) Observations in the UV region longward of Lyman alpha, up to the atmospheric transmission limit of 3000Å, take advantage of the reduced sky background; ii) The sources best studied with a small aperture telescope are QSOs and AGNs, that radiate significantly in the UV; hence detecting them at high redshifts is not very difficult. iii) Survey in UV at a high declination region of the sky is very limited, TAUVEX is supposed to fill the gap.

3.2 Limitations

3.2.1 *Distribution of sources in the sky and observing plan*

From Veron & Veron catalogue we notice that there are large number of sources beyond the declination +50 and −50 deg. This is shown in Fig. 2. TAUVEX orbit being a geostationary orbit, northern/southern sources beyond Dec $\pm 50°$ will be available on the detector for a longer time. This is an important requirement to observe sources for variability. Therefore, we propose to concentrate on the high declination sources. Good number of sources are brighter than 16 mag for which observations with high S/N can be made.

Also we note from Fig. 2 that the number of sources detected in high declination region of the sky are low, which indicate the incompleteness of the previous surveys. TAUVEX survey will offer an opportunity to detect many new sources on the basis of their blue colour and the nature of variability. It is assumed that TAUVEX will make repeat observations in certain regions especially in the high declination regions.

Table 1. Estimate of counts and S/N ratio in various TAUVEX bands. Second and third columns are respectively counts per second and S/N ratio for 10 sec integration time.

Filter	c/s	S/N
tauvex_SF1	8.60	9.27
tauvex_NBF3	6.79	8.24
tauvex_SF2	32.17	17.93
tauvex_SF3	28.25	16.81
tauvex_BBF	166.4	40.79

3.2.2 *Detection limits*

Detectors onboard the TAUVEX are photon counting devices, hence the noise will be limited by photon statistics. The number of photo-electrons detected can be estimated using the formula:

$$N = \frac{F_\lambda \times \Delta\lambda \times q \times t}{h \times \nu},$$

where N is the number of photons detected; F_λ is the photon flux; q is the quantum efficiency; t is integration time; λ and $\Delta\lambda$ are wavelengths and filter passbands; h is Planck constant and ν is the frequency of UV light.

To calculate S/N ratio, we have used TEC, available at the TAUVEX website: *http://tauvex.iiap.res.in/htmls/tools/etc.php*

Taking a typical value (e.g. a bright source like 3C 273) of flux $\approx 10^{-13}$ ergs cm^{-2} s^{-1}Å^{-1}, we get S/N ratio in 10 sec integration time in different filters as is shown in Table 1.

Table 1 shows that for bright sources one can achieve good S/N in reasonably short integration time. Therefore, it should be possible to make worthwhile measurements for variability studies. In addition to this, one can use long integration to study long term behaviour of fainter sources.

4. Summary

- In order to understand the physical mechanism for the emission, there is great need to study a sample of blazars for the variability in UV window.
- There are a good number of sources beyond the declination +50 and −50 deg;
- We propose to concentrate on such high declination brighter than 16 mag sources for variability studies.

- The number density of sources detected in previous surveys in high declination region of the sky is very low, indicating incompleteness of the surveys. There is a good opportunity to detect several new sources using TAUVEX.

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