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Intra-night optical variability properties of X-ray bright Narrow-line Seyfert 1 galaxies

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Abstract: We present Intra Night Optical Variability (INOV) study of the 9 Narrow-line Seyfert 1 (NLSy 1) galaxies which are detected in X-ray at more than 3σ level. Our observations cover a total of 9 nights ($\sim$ 36 hr) with each NLSy 1 monitored for $\geq$ 3.5 hr in each night. After applying F-test to assess variability status of these sources, we found none of these sources to be variable. Such non-variability nature of X-ray detected NLSy 1 galaxies suggests the lack of jet dominance as far as X-ray emission is concerned. Higher photometric accuracy for these faint sources, achievable with the newly installed ARIES 3.6m DOT will be helpful.

1 Introduction

Narrow-line Seyfert 1 (NLSy 1) galaxies are a special class of lower-luminosity AGN, as defined by the width of the narrow optical Balmer emission line FWHM(Hβ)$<$ 2000 km s^{-1}, flux ratio of [O $_{III}$]$_{\lambda 5007}/H\beta$ <3 and strong permitted optical/UV FeII emission lines (Grupe et al. 1999, Goodrich et al. 1989, Shuder-Osterbrock et al. 1981, Osterbrock & Pogge et al. 1985). Observations suggest that NLSy 1 galaxies tend to have small black hole masses and high Eddington ratios, $R_{Edd} \equiv L_{bol}/L_{Edd} \simeq 1$ compared to the broad-line Seyfert galaxies and radio-quiet QSOs (Boroson et al. 2002). NLSy 1 galaxies show a phenomenal radio-loud/radio-quiet bimodality (Laor et al. 2000). The fraction of radio-loud NLSy 1 (RL-NLSy 1) galaxies with radio-loudness parameter[1] (R) $>$ 100 is very small ($\sim 2.5\%$), which has been a puzzle so far.

However, after the launch of the space telescopes such as the Large Area Telescope (LAT) on-board the Fermi Gamma-ray Observatory and many X-ray missions, dozens of NLSy 1 galaxies in high energy bands have been detected similar to blazars and radio galaxies. These radio-loud NLSy 1 galaxies have a flat radio spectrum and high brightness temperature, suggesting the presence of a relativistic jet in them like blazars and radio galaxies (Foschini et al. 2011, Zhou et al. 2003). They are also found to have a compact radio structure with a core-jet morphology (Doi et al. 2006). All these characteristics give a clear evidence for the presence of a relativistic jet in them (Abdo et al.

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[1]It is commonly defined as the rest-frame ratio of flux densities at 5GHz and at 4400Å (e.g. see Kellermann et al. 1989)

2009). One alternative strategy to verify the presence of jet activity would be to determine the INOV properties of these NLSy 1 galaxies, as it is well established that radio-loud jet dominated source blazars exhibit a distinctly stronger INOV, both in amplitude (ψ) and duty cycle (DC), as compared to quasars, especially to the majority of radio quiet ones. Indeed such a stronger INOV has been observed in a few γ-ray-loud NLSy 1 galaxies by Liu et al. (2010) and Paliya et al. (2013), arguing strongly for the presence of relativistic jets aligned close to the observer's line of sight. However such INOV information is still lacking for the subset of NLSy 1 galaxies which are detected in X-rays but not in γ-rays. As a result, it becomes important to understand whether this sub-class also has a jet dominance like the γ-ray detected NLSy 1, or they have a different mechanism, at least for producing the high energy emission as observed in X-rays. The impetus behind this work, therefore, is to characterize the INOV behavior of the X-ray detected NLSy 1 galaxies to understand the role of possible jet activity on their high energy X-ray emission.

2 Sample Selection

We have selected a sample of 18 radio-loud and radio-quiet NLSy 1 galaxies from the sample of 76 NLSy 1 galaxies studied by Foschini et al. (2011), which are detected at more than 3σ in X-rays. Additional selection criteria imposed by us to get these 18 sources out of a total of 76 sources are: (i) the objects should have a non-detection ($<3\sigma$) in the Gamma-ray based on Fermi LAT observations (ii) the declination of the objects should be $> -30°$ to ensure their visibility from the 1.3m Devasthal Fast Optical Telescope (DFOT) (iii) the objects should not be fainter than B=18 mag (iv) their images should not appear confused/distorted due to its neighboring objects.

This is especially relevant for our observations which involve taking a sequence of CCD exposures, to carry out the aperture photometry to determine the instrumental magnitudes of the monitored target and comparison stars in each frame and then produce the differential light curves (DLCs) of the monitored target, relative to at least two steady stars seen in the target's vicinity.

2.1 Observations and Data Reduction

The programme to determine the INOV properties of NLSy 1 galaxies, has been carried out using the 1.3m DFOT of the Aryabhatta Research Institute of observational SciencES (ARIES) located at Devasthal, India (Sagar et al. 2011). The entire monitoring of the 9 out of a total of 18 NLSy 1 galaxies was done in R band and each NLSy 1 was monitored continuously for $\geq$ 3.5 hr, except in the case of J1010+3003 for which the duration was a bit shorter (2.94 hr, Table 1). All the pre-processing of the raw images (bias subtraction, flat-fielding, cosmic-ray removal, and trimming) were done by using standard tasks in the Image Reduction and Analysis Facility (IRAF). The instrumental magnitudes of the NLSy 1 galaxies and stars in the image frames were determined by the aperture photometry technique (Stetson et al. 1987), using the Dominion Astrophysical Observatory (DAOPHOT).

2.2 Statistical Analysis of DLCs

In our statistical analysis, we have used the F-test which is based on the ratio of variances as, $F = variance(observed)/variance(expected)$ (Diego et al. 2010), with its modified version called the standard $F-test$ (hereafter $F^{\eta}-$test, Goyal et al. 2012) expressed as:

$$F_1^{\eta} = \frac{\sigma^2_{(q-s1)}}{\eta^2 \langle \sigma^2_{q-s1} \rangle}, \quad F_2^{\eta} = \frac{\sigma^2_{(q-s2)}}{\eta^2 \langle \sigma^2_{q-s2} \rangle}, \quad F^{\eta}_{s1-s2} = \frac{\sigma^2_{(s1-s2)}}{\eta^2 \langle \sigma^2_{s1-s2} \rangle} \tag{1}$$

where $\sigma^2_{(q-s1)}$, $\sigma^2_{(q-s2)}$ and $\sigma^2_{(s1-s2)}$ are the variances of the 'source-star1', 'source-star2' and 'star1-star2' DLCs and $\langle\sigma^2_{q-s1}\rangle = \sum_{\mathbf{i=0}}^{N} \sigma^2_{i,err}(q-s1)/N$, $\langle\sigma^2_{q-s2}\rangle$ and $\langle\sigma^2_{s1-s2}\rangle$ are the mean square (formal) rms errors of the individual data points in the 'source-star1', 'source-star2' and 'star1-star2' DLCs, respectively. η is the scaling factor taken to be 1.5 from Goyal et al. (2012).

The F^η-test is applied by calculating the F values using Eq. 1, and then comparing them with the critical F value, $F^{(\alpha)}_{\nu_{qs},\nu_{ss}}$, where α is the significance level set for the test, and ν_{qs} and ν_{ss} are the degrees of freedom for the 'source-star' and 'star-star' DLCs. Here, we set two significance levels, $\alpha = 0.01$ and 0.05, which correspond to confidence levels greater than 99 and 95 percent, respectively. If F is found to exceed the critical value adopted, the null hypothesis (i.e., no variability) is discarded to the corresponding level of confidence. Thus, we mark an NLSy 1 as *variable* ('V') if the F-value is found to be $\geq F_c(0.99)$ for both its DLCs, which corresponds to a confidence level ≥ 99 percent, *non-variable* ('NV') if any one out of two DLCs is found to have F-value $\leq F_c(0.95)$. The remaining cases are designated as *probably variable* ('PV'). The F^η-test values for the DLCs of each source with respect to star 1 and star 2 and their INOV status are given in column 6 and column 7 of Table 1.

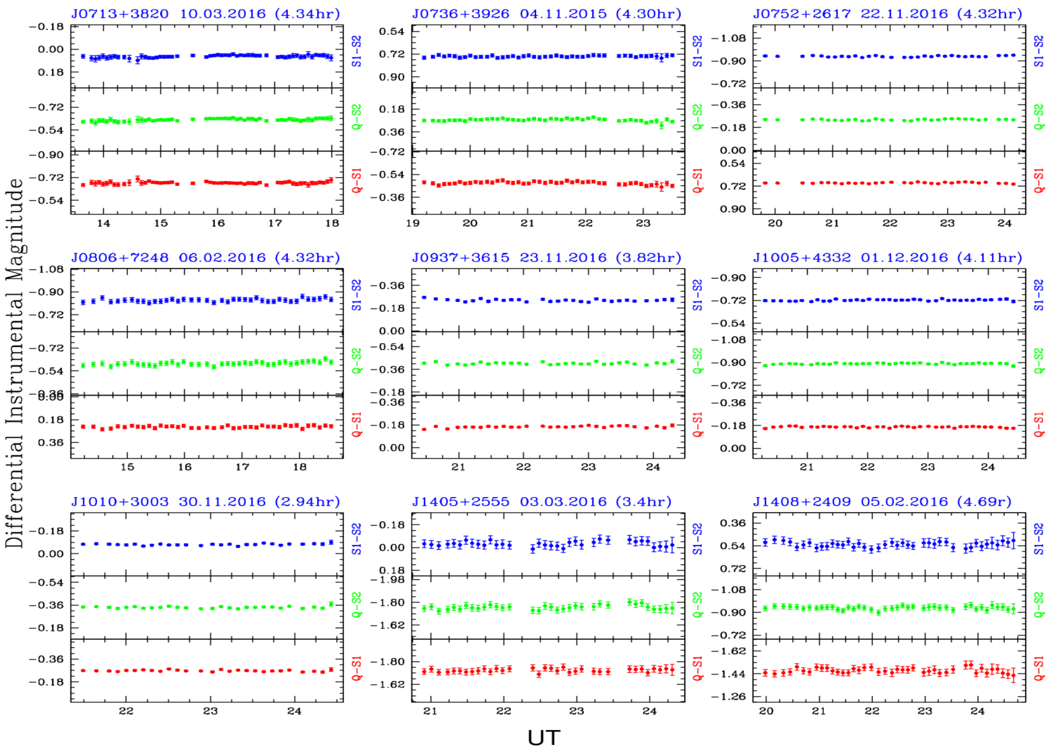

Figure 1: Differential light curves (DLCs) of the 9 NLSy 1 galaxies from our sample. The name of the NLSy 1 galaxy together with the date and duration of its monitoring are given at the top of each panel. In each panel, the upper DLC is derived using the two non-varying comparison stars, while the lower two DLCs are the 'NLSy 1-Star' DLCs, as defined in the labels on the right side as 'Q-S'.

3 Results and Conclusion

We have presented the differential light curves (DLCs) and INOV results for the 9 NLSy 1 galaxies, monitored during 9 nights each lasting more than ~ 3.5 hours in Fig. 1 and Table 1 respectively. In our sample, we did not find any of them to be variable after applying the robust statistical test. Such non-variability of X-ray detected but Gamma-ray undetected NLSy 1 galaxies suggests the lack of jet dominance as far as the X-ray emission from NLSy 1 galaxies is concerned. Higher photometric

Table 1: Observational details and INOV results for the set of 9 X-ray detected NLSy 1 galaxies.

NLSy1s	R.A.(J2000) (hh:mm:ss)	Dec(J2000) (° ′ ″)	z[a]	N[b]	F-test values F_1^{η},F_2^{η}	INOV status[c] F_{η}-test	R[d]	$\sqrt{\langle\sigma^2_{i,err}\rangle}$ (Q-S)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
J0713+3820	07:13:40.30	+38:20:39.83	0.123	55	0.19,0.23	Nv , Nv	20.00	0.02
J0736+3926	07:36:23.14	+39:26:17.88	0.118	46	0.29,0.40	Nv , Nv	03.00	0.02
J0752+2617	07:52:45.60	+26:17:35.88	0.082	31	0.62,0.43	Nv , Nv	02.00	0.01
J0806+7248	08:06:38.98	+72:48:20.53	0.098	41	0.19,0.23	Nv , Nv	41.00*	0.02
J0937+3615	09:37:03.02	+36:15:37.08	0.180	30	0.54,0.54	Nv , Nv	12.00	0.01
J1005+4332	10:05:41.85	+43:32:40.19	0.179	38	0.60,0.45	Nv , Nv	04.00	0.01
J1010+3003	10:10:00.70	+30:03:21.60	0.256	27	0.40,0.53	Nv , Nv	02.00	0.01
J1405+2555	14:05:16.22	+25:55:33.96	0.165	34	0.12,0.19	Nv , Nv	01.00	0.04
J1408+2409	14:08:27.82	+24:09:24.84	0.131	42	0.21,0.14	Nv , Nv	04.00	0.04

[a]Redshifts of the NLSy 1 galaxies, [b]Number of data points in each DLC, [c]V=variable, i.e., confidence level $\geq$ 0.99; PV=probable variable, i.e., $0.95 - 0.99$ confidence level; NV=non-variable, i.e., confidence level < 0.95, [d]Radio-loudness parameters, taken from Whalen et al. (2006), *taken from Zhou et al. (2002)

accuracy for these faint sources, achievable with the newly installed ARIES 3.6m DOT will be helpful in tightening this inference.

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