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SIMULTANEOUS OPTICAL AND IR MONITORING OF THE SEYFERT NUCLEUS NGC 7469[1]

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RESUMEN

Presentamos resultados de un monitoreo de cuatro noches del núcleo Seyfert NGC 7469 en busca de microvariabilidad. En el visible usamos la misma instrumentación y las mismas técnicas de análisis de datos y errores que en el monitoreo previo (reportado en Dultzin-Hacyan et al. 1992 —citado como trabajo 1—). El resultado fue negativo: no encontramos microvariabilidad (en contraste con el trabajo 1). Durante dos noches pudimos monitorear también en el cercano IR a 1.65μm (banda H) y encontramos variabilidad significativa (7.8σ) con $\Delta H \sim$ 0.39 mag en un intervalo de tiempo Δt = 1.65 hrs durante la primera noche y evidencia marginal (2.5σ) de variación con $\Delta H \sim$ 0.12 mag en Δt = 1.04 hrs durante la segunda noche. Este resultado observacional debe tomarse con cautela, y es importante confirmarlo con observaciones futuras, aunque esto no es fácil debido al carácter altamente transitorio de la microvariabilidad. Se discuten brevemente algunos modelos

ABSTRACT

We present results of a four night's optical monitoring of the Seyfert nucleus NGC 7469 in search for microvariability. At visible wavelengths we used the same instrumentation, data and error analysis as in a previous monitoring (Dultzin-Hacyan et al. 1992 —paper 1—) and found (as opposed to the result of paper 1) a negative result: no microvariability. During two nights, simultaneous monitoring was done at 1.65 μm (H band) and significant (7.8σ) variations with $\Delta H \sim$ 0.39 mag were observed in Δt = 1.65 hrs during the first night and marginal evidence (2.5σ) of variability with ΔH = 0.12 mag in Δt = 1.04 hrs during the second night. This observational result should be taken with caution and it is important to confirm it with future observatios, although this may not be easy, due to the transient character of microvariability. We briefly discuss some models.

Key words: **GALAXIES–NUCLEI — GALAXIES–PHOTOMETRY — GALAXIES–SEYFERT**

1. INTRODUCTION

The first report on what we now call "microvariability" (small amplitude variations in less than a day) for an AGN dates back to 1963. In a now classical paper on optical large scale quasar variability, Matthews & Sandage (1963) reported also "short term fluctuations" with amplitude ΔV = 0.044 mag (the time resolution of the observations was 15 min) while the brightness of a control star remained constant within ΔV = 0.007 mag. Why such discovery went practically unnoticed is a mystery, but we believe it possible that when these or other authors tried to reproduce the observations, the flickering was simply not there any more. In fact, we now know that the random onset and disappearance of microvariability is precisely one of its characteristics.

One can find, in relatively old literature, repeated claims for intraday small optical variations (e.g., Racine 1970; Bertaud et al. 1973). However, a number of other investigators attempted to confirm the presence of these rapid variations but failed (e.g. Kiplinger 1973, 1975; Miller & McGimsey 1977). Blazar OJ287 is a unique case for which evidence (again controversial) for periodicity in this rapid variations exists (see Kinzel, Dickman, & Predmore 1988 for and excellent summary on the observed periodicities).

[1] Based on observations collected at the Observatorio Astronómico Nacional, San Pedro Mártir, B.C., México.

It is clear that the question has long remained controversial. Presently, however, several observational improvements such as CCD photometry and multiwavelength simultaneous observations have made it possible to establish quite firmly the existence of variations in timescales of less than a day for Blazars in the optical region (e.g., Miller, Carini, & Goodrich 1989; Carini et al. 1991; Doroshenko et al. 1992), as well as in the radio region (e.g., Quirrenbach et al. 1989; Quirrenbach 1991). In some cases simultaneous observations at different frequencies have also confirmed the existence of microvariability: Wagner (1991) and Krichbaum, Quirrenbach, & Witzel (1992) in radio and optical; Wagner & Witzel (1993) in radio, optical and X rays; Kidger & de Diego (1992) and Doroshenko et al. (1992) in optical and near IR; Miller et al. (1992) in optical and *UV*. Photopolarimetric observations have also shown intraday variability in degree of polarization and position angle (Kikuchi 1992; Takalo et al. 1992; Joshi & Deshpande 1992). It is also clear by now, that much of the controversy in the past was due to the fact that the phenomenon is transient: the onset and disappearance of microvariability occurs in timescales of days (e.g., Wolstencroft, Gilmore, & Williams 1982; Lyutyi et al. 1989; Miller & Carini 1991; Joshi & Deshpande 1992).

In the case of Seyfert galaxies, there are, to our knowledge, 3 Seyfert 1 galaxies studied for microvariability: NGC 4151, for which Lyutyi et al. (1989) found microvariability with $\Delta V \sim 0.05$ mag in $\Delta t \sim$ 15–30 min during 5 nights out of 13, while Lawrence et al. (1981) found a negative result; NGC 4051 for which no optical nor IR variability was found while it varied strongly in X-rays (Done et al. 1990) and finally, Aslanov et al. (1989) first reported optical microvariability for NGC 7469 and this result was recently confirmed by Dultzin-Hacyan et al. 1992 (hereafter paper 1). After performing a very thorough error analysis, these latter authors found variations with mean amplitude values of $\Delta m \sim 0.04$ mag in mean timescales $\Delta t \sim$ 13 min during 4 nights out of 5 (during the last night the flickering was marginal within the error bars).

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Optical Observations

The optical observations were done with the 1.5-m telescope at San Pedro Mártir, Baja California, México, using a Strömgren photometer (Schuster & Nissen 1988). The observations were done during the nights 11–14 September, 1991, using exactly the same instrumental setting, acquisition and reduction techniques as well as the same error analysis as in the previous (1990) monitoring (paper 1). This analysis includes errors due to the difference in brightness between comparison stars and nucleus (and among the comparison themselves), that is, background sky corrected photon statistics; errors due to possible miscentering and/or misguiding of the nucleus, these errors can be due to the loss of light from the nucleus and changing contributions of the underlying galaxy (which comprises about 100 arcsec in the sky and is thus much larger than the 20 arcsec diaphragm used). And, finally, errors due to changes of seeing and microscale atmospheric transparency. A difference with respect to the previous monitoring is that we used stars C2 and C4 —instead of C1 and C2— (from Penston, Penston, & Sandage 1971), with m_V = 10.92 and m_V = 12.67, respectively (m_V for the star-like nucleus of NGC 7469 was $\sim$ 13). Another difference is the lower time resolution, 12 min for these observations; since we have considerably fewer points (measurements) per night, as compared with the previous monitoring (paper 1), the errors are considerably larger this time. Mean differential errors are $\sigma_{(nucleus-C2)} \leq 0.021$ mag and $\sigma_{(C4-C2)} \leq 0.012$ mag, including (adding up in the usual quadratic way) photometric errors, errors due to miscentering and misguiding (contribution of the underlying galaxy) and also the effects of seeing (plus scintillation and microscale atmospheric extinction). These latter errors for underlying galaxy and microscale atmospheric conditions remained of the same order as in paper 1: $\sigma_{(seeing+galaxy)} \leq$ 0.005 (see paper 1 for details on the analysis' methods).

2.2. IR Observations

During the nights 11 and 13 September, 1991 we were able to do also IR monitoring with the 2.12-m telescope, also at the Observatorio Astronómico Nacional in SPM coupled with an InSb IR photometer (Roth et al. 1984). The H (1.6 μm) band was chosen, since the nucleus is brighter in this band. The time resolution of the IR observations is between $\sim$ 30 and $\sim$ 50 min (depending on the sequence and the need to recenter), because in order to attain photometric errors of typically $\sigma_{(phot)} \sim 0.04$ mag, integrations of 20–30 min were needed. Having picked up the IR signal in the usual way, our aim was to avoid guiding errors greater than 4 arcsec (the diaphragm was 14 arcsec), which may cause spurious variations due to the contribution of the underlying galaxy, which in the IR is considerably larger than in the optical; the error due to the galaxy in the H band is $\sigma_{(gal)} \sim 0.04$ mag for an offset of 5 arcsec —large as compared to 0.002 mag ($2\sigma_{(gal)}$ = 0.004 mag) in the optical —see paper 1 and also Kidger & de Diego (1992) for a detailed derivation of the correction method for the underying galaxy. For this reason, careful recentering was done frequently. Also the frequent observation of two control stars: nearby stars SAO 127929 and SAO 127930 (the latter, C1 from Penston et al. (1971), could be used to guide at the eyepiece), enabled us to check the photometric stability of the night. The mean differential total errors (all effects included and added up in the usual quadratic way) for the first night were $\sigma_{(nucleus-control)} \sim 0.05$ mag and $\sigma_{(C1-C)} \sim 0.03$ mag and for the second (larger number of measurements) $\sigma_{(nucleus-control)} \sim 0.05$ mag and $\sigma_{(C1-C)} \sim 0.02$ mag.

3. RESULTS AND DISCUSSION

3.1. Optical Observations

In order to establish the reality of brightness fluctuations, we proceeded as in paper 1, that is, to consider a brightness fluctuation "significant" when two criteria were fulfilled simultaneously: (a) amplitude variations above 3σ for the nucleus minus comparison star (NGC 7469–C2), and (b) mean amplitude variations within 1σ for the difference between comparison stars (C4–C2) during a time interval larger and encompassing the corresponding interval for the fluctuation in NGC 7469–C2.

Not a single significant fluctuation was found during the four nights' monitoring campaign (18.4 hours of observations). A typical differential light curve is shown in Figure 1. The data resemble those of the last night of the previous monitoring (August 22, 1990), when the microvariability observed during the previous nights disappeared and we were able to see only marginal fluctuations: $\Delta m \sim 0.028$ mag (at a 3σ level). One marginally significant fluctuation was observed on September 13, 1991 with $\Delta m \sim 0.048$ mag (at a 2.7σ level). We insist on the fact that we have larger errors this time, and thus we would not be able to pick up fluctuations of Δm (on the average) ≤ 0.05 mag at a 3σ level. We recall that typical fluctuations in paper 1 had $\Delta m \sim 0.04$ mag ($\geq 4\sigma$). However, we also reported in paper 1 variations as large as $\Delta m = 0.081$ mag (in timescales of hours), no such variations (which would be well above 3σ) are observed during our 1991 monitoring.

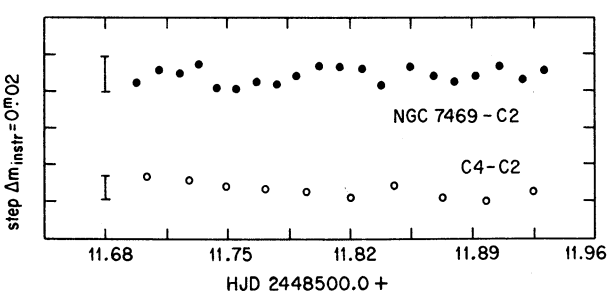

Fig. 1. Differential light curves in instrumental magnitudes. The error bars include the mean photometric error and errors due to the contribution of the underlying galaxy and microscale seeing and atmospheric transparency changes. C_2 and C_4 are constant brightness control stars.

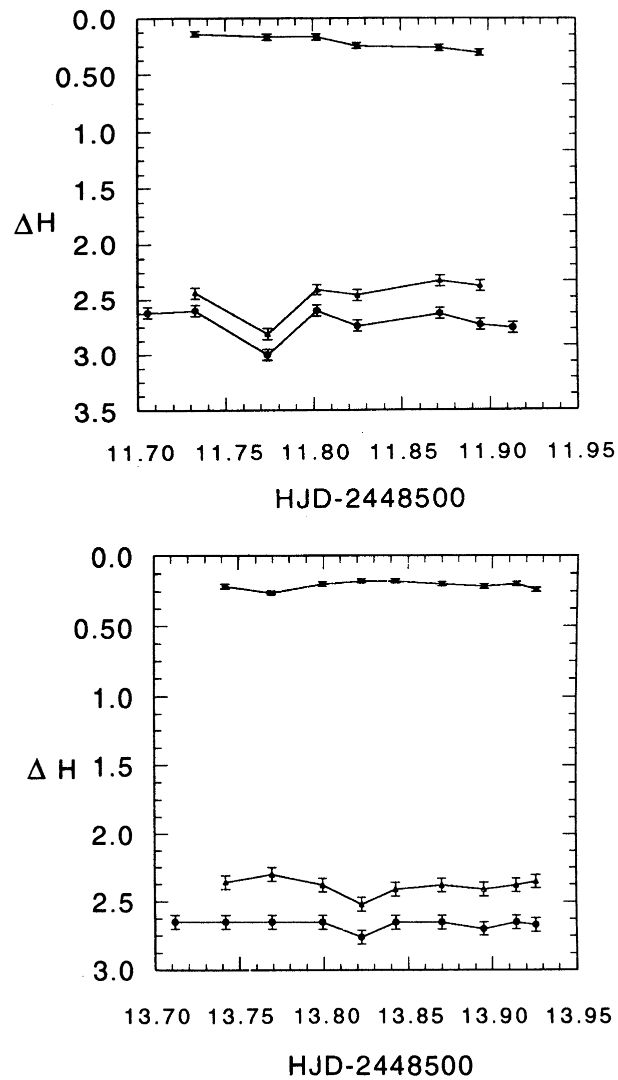

Fig. 2. We plot 3 differential light curves for each night: Squares trace the difference between the control stars, triangles and circles trace the difference between the nucleus and each control star. The observation of the nucleus and control stars was not simultaneous (but close) and thus an interpolation was made to adjust the curves. Error bars are as in Figure 1.

3.2. IR Observations

The data are shown in Figure 2. On the night of September 11, 1991 we observed a strong variation with ΔH = 0.39 mag which occurred in Δt = 1.65 hrs. This variation is far above the error bars (7.8 σ). On the next night of observations (September 13), only a marginally significant (2.5σ) variation of ΔH = 0.12 mag in Δt = 1.04 hrs was observed and in what follows we will analyze only the implications of the first variation.

First of all, we must acknowledge that variability results based on just a single point should, evidently, be taken with caution, perhaps only as indication that further monitoring with better time resolution, is needed. With all the precautions described in (§ 2.2.), we have, however, reasonable confidence that the observed variations may be real. If so, we can estimate the involved change in luminosity. The total luminosity of the above mentioned scale of about 6 000 sec, cannot be accurately calculated in the absence of information on either spectral index, multiaperture photometry or bandwith of the variation. A conservative estimate is possible by considering only the observed magnitude in the H band. For z = 0.017 and H_o = 75 km s^{-1} Mpc^{-1}, the absolute average luminosity is $L_{\mathbf{mean}} = 1.55 \times 10^{45} \times \Omega/4\pi$ erg s^{-1}, with Ω the solid angle in which the source emitted the variable radiation. In the dip we have $L_{\mathbf{dip}} = 1.10 \times 10^{45} \times \Omega/4\pi$ erg s^{-1} and thus a ΔH = 0.39 mag implies a variation of $\Delta L = 4.5 \times 10^{44}$ erg s^{-1}, and $\Delta L/\Delta t = 9.06 \times 10^{40}$ erg s^{-2} (Δt = 5958 sec) assuming no anisotropy; and this is more than one order of magnitude below the highest possible rate, $\Delta L_{\mathbf{Edd}}/\ \Delta t$ (see paper 1).

Previous reports on near IR microvariability exist, to our knowledge, only for blazars: Wolstencroft et al. (1982) report variations for OJ287 of 0.5 mag in $\Delta t \sim 30$ min and 1.0 mag in $\Delta t \sim 50$ sec! (J band). When they estimate the maximum luminosity and minimum time scale from a massive black hole with an assumed maximum efficiency of ~ 10% in converting mass inflow to observable radiation emitted isotropically (according to Fabian 1979), they end up with a strong inconsistency which requires strong relativistic and/or anisotropic effects in the source. This is not only possible, but expected in a blazar. If we apply the same analysis to our data, according to Fabian (1979) the minimum time-scale for variation is given by $\Delta t \geq L$ (erg s^{-1})/2$\times$10^{41} s, we obtain $\Delta t \geq 2\,250$ s, and thus we *do not* need to invoke relativistic and/or anisotropic effects for this Seyfert nucleus. The question is: what is the origin of this IR fluctuation not seen in the optical

Kidger & de Diego (1992) report an optical monitoring of blazar Mkn 501, also during two nights they were able to monitor simultaneously in the near IR (K band). Although in general the variations in the visible are larger ($\Delta B > \Delta K$), on one night a significant flickering (considered real with a formal probability of 99% by the authors) was observed in K which was *not present* in the optical.

The largest observed amplitude was ΔK = 0.16 mag in $\Delta t \sim 52$ min (see their Figure 2). If the variations in K (seen on July 25, 1989 and which are very similar to those observed later in B on August 14, 1989) were genuine, one would expect them to have an amplitude in the visible of around 0.5 magnitudes if they were due to the (same) non-thermal source. In fact, however, the B light curve displayed almost no scatter. And this is exactly the same situation for the NGC 7469 observations discussed here. A model of local accretion disc instabilities such as the one discussed by Mangalam & Wiita (1992), although in principle could account as well for IR microvariability, would imply also the almost simultaneous appearance of optical variability (and with slightly larger amplitude), aside from the fact that it predicts flares rather than antiflares.

Let us examine the suggestion made for the case of Mkn 501 (Kidger & de Diego 1992) that this kind of observation could imply the existence of a third component of the near IR emission (apart from the galaxy and a possible non-thermal one): the most likely explanation would be a comparatively cool outer region of the accretion disc which emits principally in the near IR; perhaps a dust torus emitting reprocessed central radiation. A lower limit for the distance of this dust torus, R_{DT}, to the central source can be estimated in the following simple way: we set $L_D = 4\pi R_{DT}^2 \sigma T_D^4 (\Omega/4\pi)$, where L_D is the dust re-radiated luminosity and we assume that the dust temperature has the highest possible value before evaporation $T_D \sim 2\,000$ K (e.g., Barvainis 1992).

For the observed $\Delta L = 4.5 \times 10^{44}$ erg s $^{-1}$ we obtain $R_{DT} \geq 2 \times 10^{17}$ cm. This implies that any light fluctuation of internal origin (i.e., coming from the central source or inner parts of the accretion disc) could not be observed as re-processed IR radiation from the torus before one month (and we have not included here any calculation on the dust cooling timescales). Although this would "save" us from not observing a similar behaviour in the visible simultaneously, there are, unfortunately, strong inconsistencies with this scenario. We have considered isotropic ($\Omega/4\pi$ = 1) illumination (and thus re-radiation) of the dust torus. This implies taking into account light travel time through the whole torus and hence an original brightness fluctuation lasting about an hour would be observed as reprocessed IR light in timescales of about a month. Also the idea of eclipsing part of this outer dust torus has serious difficulties (apart from postulating some sort of opaque eclipsing cloud), since the cloud would have to occult 40% of the torus to produce the observed change. For an average inclination of the disk (which is actually unknown) of 45°, such an occultation would last about one month (certainly not a couple of hours!).

On the other hand, if we postulate an anisotropic illumination of only a small part of the outer disk (as small as 1.65 light hours) we require a central beamed radiation within a solid angle of only ~ 6 arcmin (for $R_{DT} \sim 2 \times 10^{17}$ cm), and if we maintain the dust temperature below the evaporation level, $T \sim 2000$ K, we can achieve an IR re-emitted luminosity of only $\sim 3.4 \times 10^{38}$ erg s^{-1} (six orders of magnitude below the observed one).

We are left with the possibility of a non-thermal component dominating the IR emission and the very *ad hoc* assumption that we missed the optical event by a couple of hours (or more), that is, it occurred before the beginning of the observing night. In any case it is important to repeat this kind of monitoring which is very rarely carried out at IR wavelengths.

4. FINAL REMARKS

1. The variability in the *H* band reported here is based on just a single point. It should, evidently, be taken with skepticism. Whatever the physical reason that might have caused the variation, if real, is highly transient. Wolstencroft et al. (1982) report that for the blazar OJ 287 "'variations of this type have been observed on only one occasion out of many tens of hours"... In any case, to confirm the existence of such rapid IR variations, many hours of better time resolution monitoring are clearly needed.

2. Considering all the precautions and error analysis (which include the underlying galaxy) discussed in the text, however, we are inclined to believe that the observation of IR variability with $\Delta H = 0.39$ mag in $\Delta t = 1.65$ hrs is real. Relativistic or anisotropy effects are not needed to explain the observed change in luminosity, although its physical cause remains obscure.

3. No significant variability is observed in optical light, the behaviour is similar to the last night of our first monitoring (paper 1), which again points out to the transient character of the phenomenon. It also casts doubt on the possibility of a non-thermal component being responsible for the variation in the *H* band (at least the same non-thermal component extending to the optical). The explanation for the IR variation of a comparatively cool outer region of an accretion disc (dust torus) which re-emits reprocessed central radiation principally in the near IR, is in contradiction with the observed luminosity change in the time interval in which this change occurs, and so does the explanation of an eclipse. There is of course a possibility that the IR emission is non-thermal and that we missed the optical counterpart of the event due to a lag of a couple of hours or more (before the beginning of the observation).

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Note added in manuscript.—Recently, H.R. Miller & J.C. Noble [(1993), preprint] found optical micro-variability for the Seyfert 1 nucleus Akn 120 from a CCD photometric monitoring.

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