

A search for rapid optical variability in low-mass Seyfert galaxies: NGC 4395

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Abstract. We present first results of a program to monitor active galactic nuclei with intermediate mass black holes. The monitoring aims to search for rapid (intranight) optical variations in these objects, most of which are known to show significant X-ray variability on minutes-to-hours timescales. Finding optical counterpart of the higher energy variations might be of importance for the modeling of the innermost regions of these objects. This paper presents the results for NGC 4395 – the lowest mass AGN known so far.

Key words: active galactic nuclei, quasars, variability; individual - NGC 4395

Търсене на бърза фотометрична променливост при сийфертови галактики с малки маси: NGC 4395

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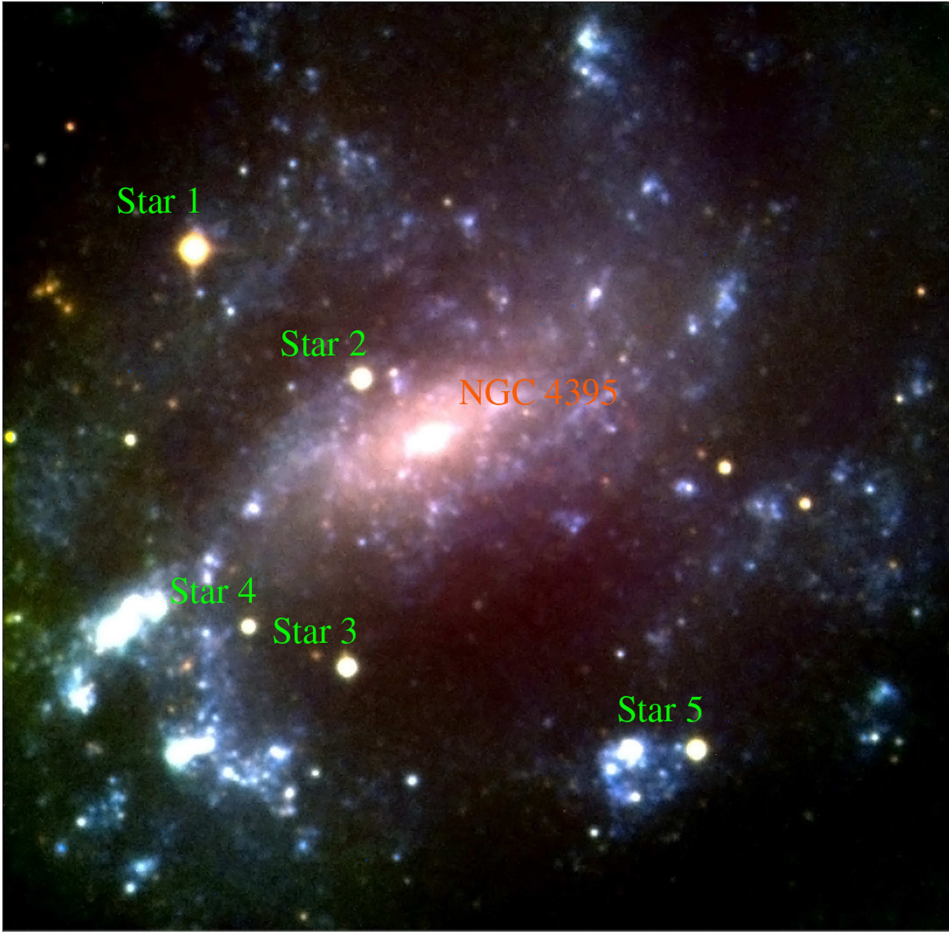
В статията са представени първите резултати от програма за наблюдения на активни галактични ядра със средна по големина маса на черните дупки. Нашата цел е търсене на бързи оптични промени (рамките на една нощ) в тези обекти, за повечето от които е известно, че е наблюдавана значителна променливост в рентгеновия диапазон за време от минути до часове. Намирането на оптични аналози на промените в областта на високите енергии може да бъде от значение за моделиране на най-вътрешните области на тези обекти. Тази статия представя резултатите за NGC 4395 - галактика с активно ядро с най-малка маса от известните досега.

1 Introduction

Brightness variability is an intrinsic feature of all accreting objects, from interacting binaries with a compact component (cataclysmic variables, dwarf novae, Galactic black holes, etc.) to supermassive accreting systems (quasars, Seyfert nuclei). The cause of the variability is not yet fully understood, but should somehow be related to some instability processes associated with the accretion itself. Therefore studying variability might help to better understand accretion, which appears to be one of the most important processes for energy generation and all-scale structure building in the Universe.

Time scales of accretion-driven optical variability are very different and perhaps depend on many unknowns, but as a first approximation they appear to scale with the mass of the compact object. Thus stellar-mass compact accretors may vary significantly within minutes or seconds (optical band), while a $10^9 M_{\odot}$ (radio-quiet) quasar typically needs weeks or months for such a brightness change. The gap between them is partially filled by the IMBH

(intermediate mass black holes, $\sim 10^3 M_\odot$), whose observational appearance is mostly in the X-ray bands, and LLAGN (low-luminosity/mass active galactic nuclei, $\sim 10^{5-6} M_\odot$), which can successfully be studied in optical bands as well.



Фиг. 1. NGC 4395 field with standard stars indicated. North is up, East is to the left. The field is approximately 5x5 arcmin. The image is obtained with the 2-m RCC telescope of NAO Rozhen (VersArray CCD camera + *B*, *V* and *R* filters)

We selected a sample of such low-mass AGN (Seyferts) to probe the characteristics (time scales, amplitudes, color dependences, etc.) of their short-term optical variability. All objects are radio-quiet, e.g. no relativistic jet contribution is present to alter the characteristics of the accretion-attributed variability. Here we present our first results for the dwarf Seyfert galaxy NGC 4395.

2 NGC 4395 notes

NGC 4395 is a nearby ($z=0.001$) Sd-type active galaxy (activity discovered 1989) with broad optical emission lines and a point-like hard X-ray source. It is often referred to as the nearest and the least luminous Seyfert 1 type AGN. Its central black hole mass and Eddington ratio, measured through the reverberation-mapping technique, are found to be $M_{BH} \sim 4.10^5 M_{\odot}$ and $L/L_{Edd} \sim 0.001$ (Peterson et al. 2005). The X-rays continuum of this object shows very rapid variations on seconds-to-minutes time scale (Leighly 1999; Vaughan et al. 2005)

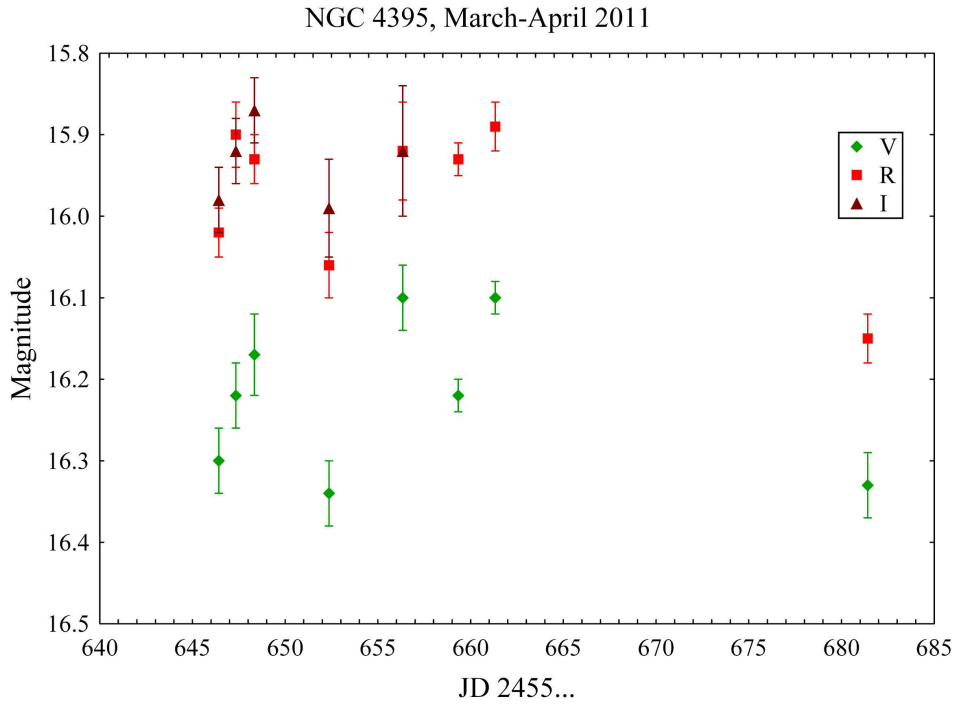


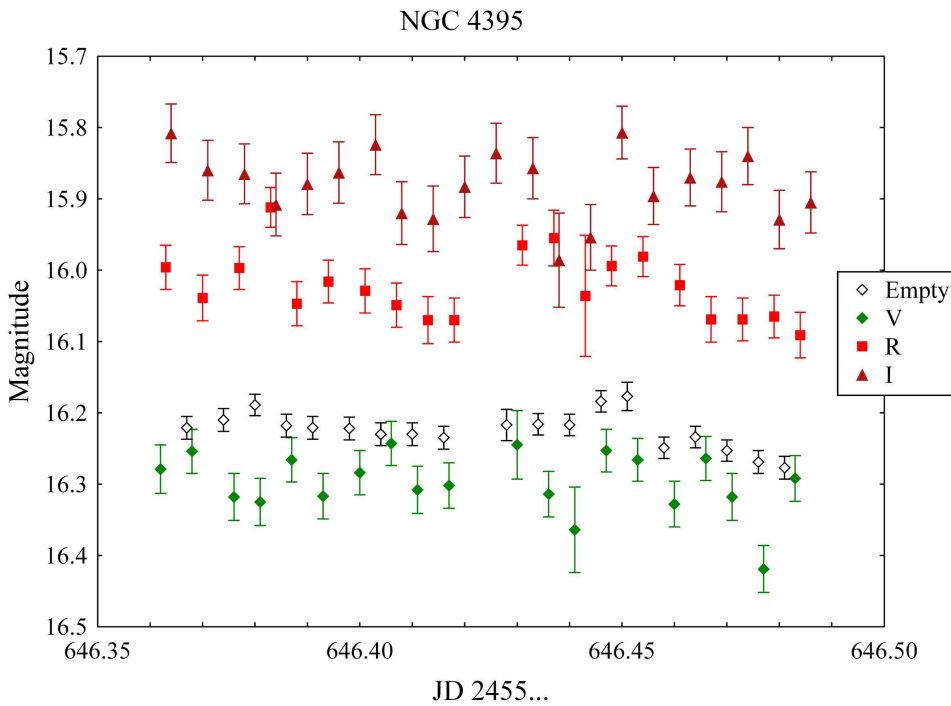
Fig. 2. Short-term variability of NGC 4395 during the observational period. All magnitudes are measured with respect to Star 1.

On the other hand, rapid (intranight) optical variations have been previously reported by Lira et al. (1999) and Desroches et al. (2006) who, during a low activity state, also found a lag of optical bands behind the UV (~ 25 min) and X-rays (~ 45 min), consistent with the idea of a hard radiation reprocessing within the accretion disk into softer wavelengths. Similarly, for this object variations are found in the optical and near IR bands by Minezaki et al. (2006) and Skelton et al. (2005).

3 Observations and reductions

We monitored NGC 4395 for 2-5 hours each observing night for several nights during the period March - April, 2011. The object was observed with the 2-m RCC and 50/70-cm Schmidt telescopes of the National Astronomical Observatory Rozhen, and the 60-cm telescope of the Astronomical Observatory Belogradchik, Bulgaria. All telescopes are equipped with CCD detectors and standard *UBVRI* filter sets. To improve the signal-to-noise ratio, the smaller 60-cm telescope observed without filter on some occasions.

All frames were properly corrected for bias/dark current and flat field. Photometry was performed with an aperture radius of 4 and 6 arcsec, which is typically two times the seeing. During some nights the atmospheric conditions were rather unstable, which lead to increased photometric uncertainty. Variable atmospheric conditions (seeing, transparency), combined with a rich stellar field and underlying host galaxy make aperture photometry quite difficult and the results should be interpreted with care (e.g. Fig. 5).



Фиг. 3. Intra-night variability in three colors as well as in unfiltered light during the night of 25.03.2011. No significant variations are seen. Measured with respect to Star 1. 60-cm telescope of Belogradchik Observatory

4 Results

Table 1 gives the log of the observations and measured magnitudes. All magnitudes are measured with 6 arcsec aperture radius, with respect to Star 1 (see below) with no other color corrections. Background is subtracted from an annulus just outside the diaphragm. No host galaxy contribution is removed.

Таблица 1. Log of observations and measured *VRI* magnitudes of NGC 4395

JD 2455...	<i>V</i>	err	<i>R</i>	err	<i>I</i>	err	Telescope
646.42	16.30	0.03	16.02	0.03	15.98	0.04	AOB60
647.34	16.22	0.04	15.90	0.04	15.92	0.05	AOB60
648.34	16.17	0.05	15.93	0.03	15.87	0.04	AOB60
652.36	16.34	0.05	16.06	0.04	15.99	0.05	AOB60
656.34	16.10	0.04	15.92	0.06	15.92	0.08	R50/70
659.33	16.22	0.02	15.93	0.02			R2m
661.33	16.10	0.02	15.89	0.02			R2m
681.41	16.33	0.04	16.15	0.03			R2m

4.1 Secondary standards in the NGC 4395 field

In order to facilitate future monitoring, we calibrated secondary standard stars in the field of NGC 4395. For that purpose we observed in a photometric night calibrated standards in the field of M67 (Chevalier & Ilovaisky, 1991). The *VRI* calibrated magnitudes of stars shown in Fig. 1 are presented in Table 2. The errors are mostly due to the calibration. As this result is based on single-night observations, it should be considered preliminary.

Таблица 2. Log of observations and measured *VRI* magnitudes of NGC 4395

Stars	<i>V</i>	err	<i>R</i>	err	<i>I</i>	err
St1	14.45	0.04	13.57	0.05	12.53	0.06
St2	15.88	0.04	15.42	0.05	14.98	0.06
St3	15.89	0.04	15.50	0.05	15.09	0.06
St4	17.24	0.08	16.64	0.07	16.10	0.08
St5	15.86	0.04	15.25	0.05	14.75	0.06

4.2 Short-term light curve

The short-term variations (*VRI* bands) of NGC 4395 on a day-to-day scale are shown in Fig. 2. Despite the mostly unstable weather conditions, we see

good indications of variability amplitudes of 0.2 - 0.3 mag for the period of monitoring. The object appears to be on average ~ 0.4 mag brighter than it was the last time it was observed by us (May 04, 2006) and should perhaps be considered in a high state. Unfortunately, the lack of systematic photometric data prevents drawing a firm conclusion about its brightness state.

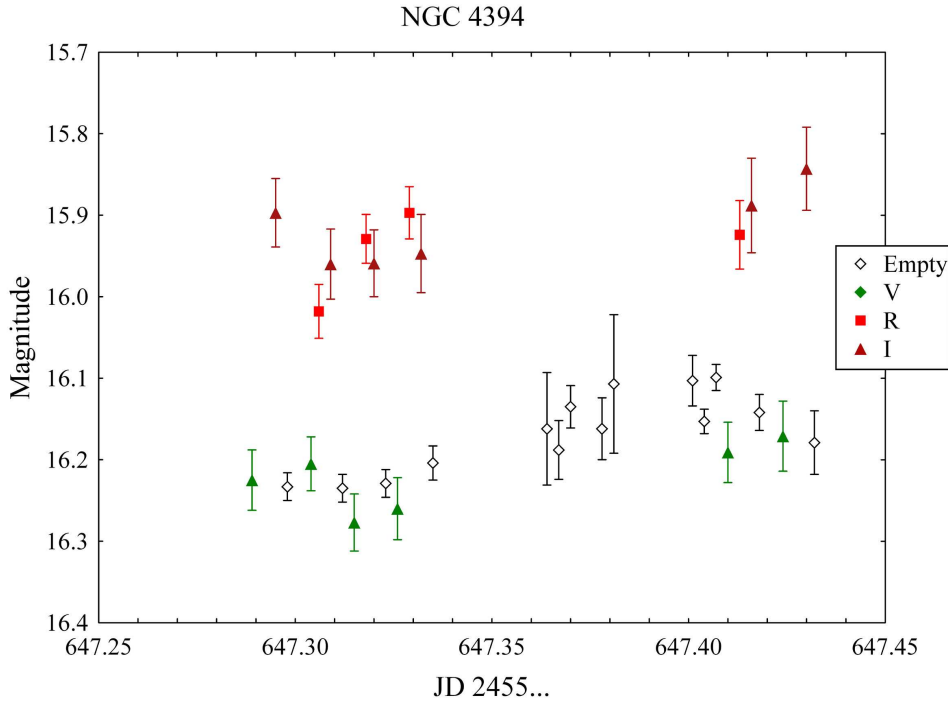


FIG. 4. The same as in Fig. 3 for the night of 26.03.2011.

4.3 Intra-night variability

Fig. 3 - 5 show examples of intra-night variations. In spite of the previous reports, no significant variations, exceeding the errors, are seen there as well as during the other nights of monitoring (not shown here). One sees (Fig. 5) a slow trend of the check star due either to some slow variability of the check or to slowly deteriorating atmospheric conditions, combined with the rich stellar field. It is not clear how the conditions affect the NGC 4395 measurements, but the wobbles seen of amplitude up to 0.05 mag are perhaps real.

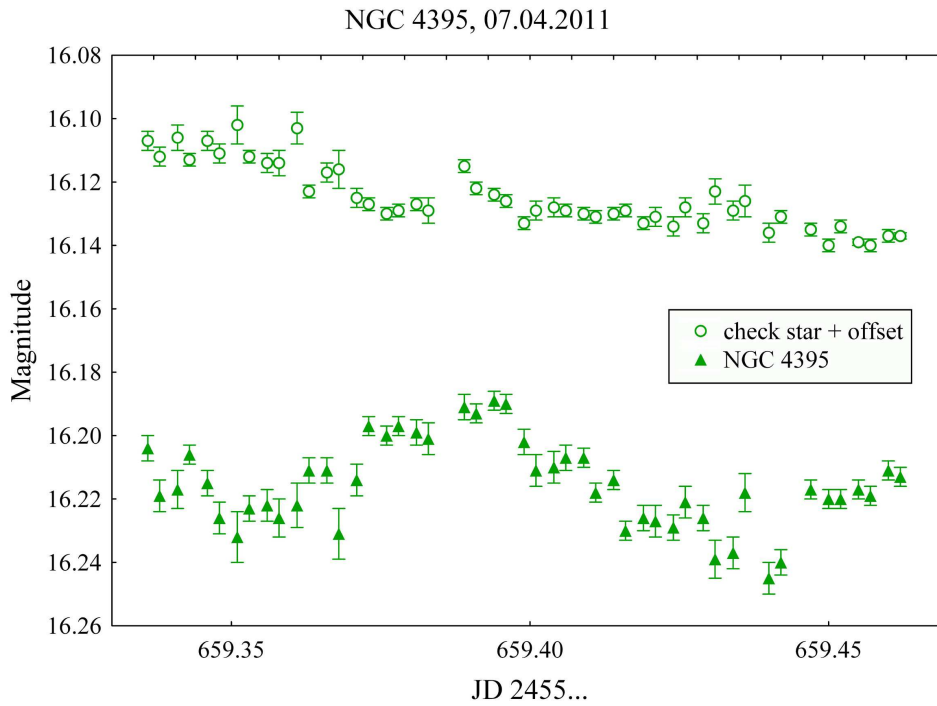
5 Discussion and conclusions

During seven nights and a total of ~ 16 hours of monitoring with two telescopes, NGC 4395 showed some variability on a day scale but no significant

intra-night variations. The later, if present at all, can be described as slow, small-amplitude wobbles or trends. This result is in a stark contrast with the X-ray variability picture; however is not surprising, considering the probably different regions producing these two wavebands.

While the X-rays are produced very near the center or in compact regions in the corona above the accretion disk (hot spots), the optical emission arises in a much geometrically larger region in the accretion disk. Obviously, only a small fraction of the optical emission is due to X-ray reprocessing; otherwise even light-travel effects (smearing) cannot prevent optical variations of up to a magnitude to be observed on an hour timescale (taken into account the time lags, mentioned in Sect. 2).

On the other hand, the X-ray monitoring was performed a few years ago, during perhaps a lower brightness state. There is no way to know if the X-ray variations are of such violent nature during the time of our observations.



Фиг. 5. V-band variability of NGC 4395 and a check star (Star 3), all measured with respect to Star 1. 2-m RCC telescope of Rozhen NAO

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