Optical and X-ray variability of Seyfert galaxies NGC 5548, NGC 7469, NGC 3227, NGC 4051, NGC 4151, Mrk 509, Mrk 79, Akn 564.

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At the work we present the results of study of the variability properties of 8 Seyfert galaxies using optical light curves, obtained at the Crimean Astrophysical Observatory (CrAO) and X-ray from RXTE public database.

Software

For our calculations we use package SPE for work with spectrums developed by Sergeev S.G.

Optical light curves

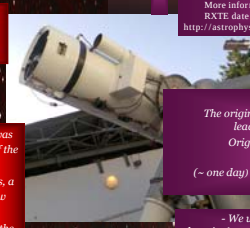
Optical light curves were obtained at the Crimean Astrophysical Observatory with the 70-cm telescope (AZT-8)

CCD camera

We use CCD camera AP7p, which was mounted at the prime focus (f=282 cm) of the telescope.

The CCD camera has 512×512 pixels, a scale of 1",755 pixel-1 and a field of view 15'×15'.

There are a set of B-V-R-I filters at the camera.



X-ray light curves

We used RXTE light curves for studying X-ray properties of AGNs, available on the public archive of RXTE data.

About RXTE

The RXTE (Rossi X-ray Timing Explorer) was launch on December 30, 1995 from NASA's Kennedy Space Center to obtain high quality long-time light curves.

- spectral range from 2 to 250 keV
- time scales from microseconds to months are covered

More information about how to work with RXTE date you can find at http://astrophysics.gsfc.nasa.gov/xrays/programs/rxte/pca/

RXTE Sampling

Rebinning

The original observations were made with a wide variety of science goals, leading to a variety of sampling patterns and durations.

Originally RXTE light curves were binned at 64 s time-interval.

We rebinned its to 15 satellite orbits (~ one day) to exclude short variations of flux (short-time variability component) and to study the long-term X-ray variability.

- We used parts of light curves without long gaps (> 1/3 of the total duration) because gaps reduce the statistical significance of parameters derived over the full duration, and interpolating across such large gaps would result in an underestimate of the true variability amplitude.
- Bad quality light curves with only fewer points were discarded.
- Light curves with poor signal-to-noise ratio were discarded.

The final light curves have contain at least about 30 points to obtain an accurate estimate of the variability amplitude.

ANALYSIS

Structure function

As a first approximation SF can be defined as:

$$SF = M[F(t+dt) - F(t)]^2$$

It was entered by Kolmogorov in 1941 (Rytov 1976) for turbulence theory. In application to AGN structure, this function was discussed by Hufnagel et al. 1992; Hughes et al 1992; Lainela and Valtaoja 1993; Smith et al. 1993.

We calculated the structure function by binning the time interval into equally spaced parts on a logarithmic scale and determined pairs of the times of observations

$t_j > t_i$

for each bin in such a way that their difference

$dt = t_j - t_i$

was within a given bin;

we then calculated:

$$SF(dt_k) = \sum_{i,j} [F(t_j) - F(t_i)]^2 / n_k,$$

where n_k is the number of pairs in the k-th bin

Logarithmic slope of the structure function

$$b = dlog(SF)/dlog(dt).$$

It characterizes the nature of the process :
b = 0 corresponds to flicker noise and
b = 1 to shot noise.
The logarithmic slope of structure function varies with shift and takes value from 0 to 2 for shot noise processes.

Variability amplitudes

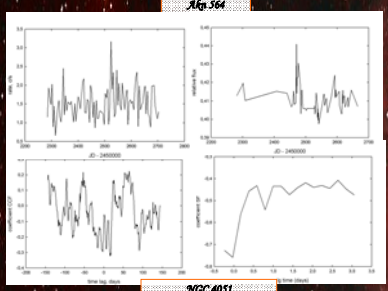
Fractional variability amplitudes (F_{var} ; e.g., Vaughan et al. 2003a; Edelson et al. 2002) were measured for each light curve to quantify the intrinsic variability amplitude relative to the mean count rate and in excess of the measurement noise.

$$F_{\rm var} = \sqrt{\frac{S^2 - \langle \sigma_{\rm err}^2 \rangle}{\langle X \rangle^2}},$$

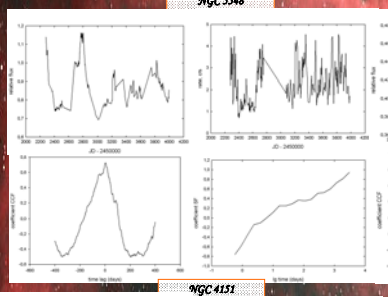
where S^2 is the total variance of the light curve, $<\sigma^2_{err}>$ is the root-mean square error, and $<X>$ is the mean count rate of N total points.

Graphics

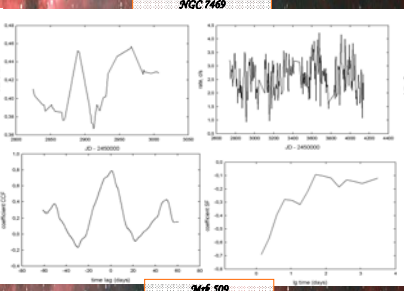
Akn 564



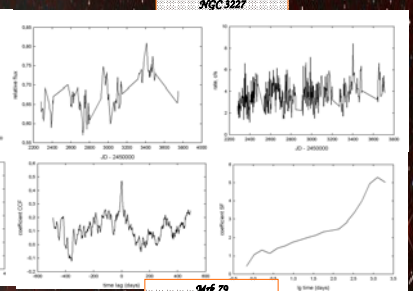
NGC 5548



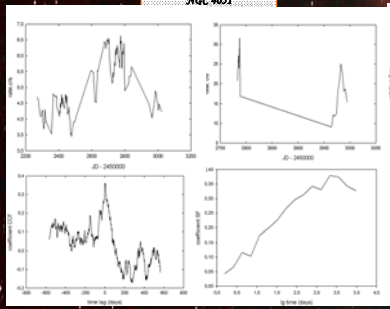
NGC 7469



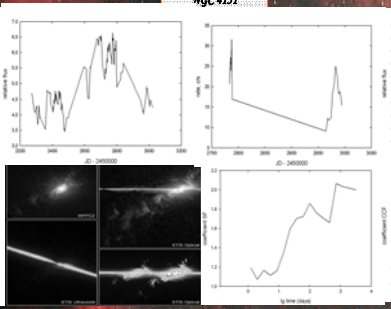
NGC 3227



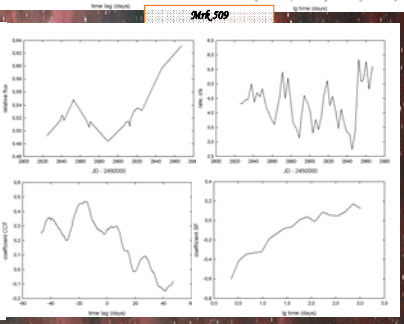
NGC 4051



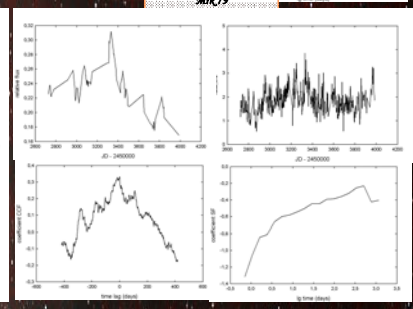
NGC 4151



Mrk 509



Mrk 79



Tables

Cross-correlation analysis

Object's name	τ_{peak}	τ_{cent}	r_{max}	period JD−2,450,000	$P(r_{peak} > 0)$,%
NGC 5548	$2.8^{+2.7}_{-2.3}$	$4.3^{+4.2}_{-3.2}$	0.73	2279...3995	96.8
NGC 7469	$0.6^{+2.4}_{-2.3}$	$-0.9^{+2.3}_{-1.3}$	0.79	2824...3007	54.6
NGC 4051	$2.1^{+1.0}_{-1.1}$	$4.3^{+3.3}_{-2.2}$	0.36	2271...3065	97.4
NGC 3227	$1.5^{+0.6}_{-0.6}$	$0.6^{+0.6}_{-0.6}$	0.474	2281...3708	75.9
Mrk 79 *	$-15.5^{+1.8}_{-1.1}$	$-15.1^{+1.8}_{-1.1}$	0.33	2727...3988	17.2
Mrk 509	$-16.1^{+16.6}_{-5.7}$	$-17.0^{+17.5}_{-5.1}$	0.47	2824...2967	18.3

Cross-correlation analysis has been performed using an interpolation cross-correlation function (Gaskell and Sparke 1986; White and Peterson 1994).

Errors

The uncertainties in the column τpeak and τcent were computed for ±1σ confidence level and they were evaluated using the model-independent Monte Carlo flux randomization/random subset selection (FR/RSS) technique of (Peterson et al. 1998).

For each object we performed 4000 random simulations in the range of error of observation.

The slope of structure function (b)

Object's name	linear site in X-ray lg days	b_{optic}	b_{X-ray}	linear site in optic lg days	b_{optic}	b_{X-ray}
NGC 5548	0.06...3.49	0.87	0.35	0.52...2.49	1.18	0.29
NGC 7469	0.18...1.74 *	1.16	0.28	0.51...2.55	0.68	0.14
NGC 4051	0.34...3.15	0.35	0.12	0.62...3.02	0.31	0.12
NGC 3227	0.02...2.91	0.58	0.20	0.52...2.96	0.43	0.20
Mrk 79	0.02...2.70	1.08	0.25	0.52...3.15	0.77	0.13
Mrk 509	0.51...3.01	0.73	0.22	0.59...2.31	1.08	0.29
Ark 564 b	–	–	–	0.52...3.01	0.29	0.02
NGC 4151	0.87...2.98	0.46	0.32	0.59...2.51	0.60	0.42

The Table 2 has two parts. On the right half we listed the slope of structure function (b) for linear site in X-ray, on the left half we listed the slope of structure function (b) for linear site in optic. For all objects the slope of SF is bigger in optic light curve.

Characteristics of X-ray variability

Object's name	Flux c/s	F_{var} (%)	(ACF)	period JD−2,450,000
NGC 5548	3.37	46.6	430	0208...4144
NGC 7469	2.63	23.0	9	2737...4140
NGC 4051	1.96	53.7	10	0196...4145
NGC 3227	3.36	44.6	96	1260...3709
Mrk 79	1.83	26.7	11	2720...4145
Mrk 509	4.10	19.6	28	2726...3946
Ark 564	1.51	23.8	5	1265...2703
NGC 4151	13.81	50.7	50	0102...4134

The data from Table 3 characterize X-ray variability. Average meaning of flux is given in second column in c/s. Fractional variability amplitudes Fvar (Vaughan et al. 2003; Edelson et al. 2002) were measured for each light curve to quantify the intrinsic variability amplitude relative to the mean count rate and in excess of the measurement noise.

Characteristics of optical variability

Object's name	B_{abs}	F_{var} (%)	(ACF)	period JD−2,450,000
NGC 5548	-19.56	13.82	163	2279...3995
NGC 7469	-20.27	6.92	30	2472...3007
NGC 4051	-15.67	4.95	75	2270...3965
NGC 3227	-16.84	6.94	185	2280...3897
Mrk 79	-20.05	15.36	155	2283...3987
Mrk 509	-22.13	7.23	64	2417...2967
Ark 564	-20.04	2.77	95	2281...4118
NGC 4151	-18.28	18.47	233	2270...3022

The data from Table 4 characterize optical variability. Average meaning of flux is given in second column in absolute stellar magnitude (Babs). It was computed by assuming a value of the Hubble constant of 75 km s^{-1} Mpc^{-1}. Fractional variability amplitudes Fvar (Vaughan et al. 2003; Edelson et al. 2002) were measured for each light curve to quantify the intrinsic variability amplitude relative to the mean count rate and in excess of the measurement noise.

Conclusion

(i) objects with high correlation in optical and X-ray pass band:
NGC 5548 (rmax = 0,73 at the τpeak = 2,8 days) and
NGC 7469 (rmax = 0,79 at the τpeak = 0,6 days).
No strong evidence to exist positive time lag between optical and X-ray flux is in the case of NGC 7469. Conclusion: the short-term X-ray and optical flux can be correlated and the time lag is small in this case.

(ii) objects with similar behavior of the cross-correlation function as in (i), but in this case correlation isn't so strong:
NGC 3227 (rmax = 0,47 at the τpeak = 1,5 days) and
NGC 4051 (rmax = 0,36 at the τpeak = 2,1 days).

(iii) objects with negative and longer time lag: Mrk 509 (rmax = 0,47 at the τpeak = -16,1 days) Mrk 79 (rmax = 0,33 at the τpeak = -15,5 days).
It means that variations appear in optic and then transform into X-ray.
Conclusion: the long-term optical and X-ray flux can be correlated and the time lag is for aboul 10 times bigger in comparison with (i) case.

(iiii) objects which has no evidence for any correlations: Ark 564.
Conclusion: there are objects which has no correlation between optical and X-ray pass band.

So, some Seyfert galaxies in our sample demonstrate strong flux correlation in optic and X-ray, when X-ray variations are leading.

Question which is remaining to be discussed: there are objects when optical variations are leading. What is the AGN's mechanism in these rarely cases?

Amplitude analysis

We have made the assumption that long-term optical variability can arise due to the Compton upscattering transformed into X-ray in hot corona. In these cases the amplitude of optical variability must be greater. This don't contradict with our results because of we didn't separate the amplitude of X-ray variability on the short-term and long-term analysing light curves.