

CHANGING LOOKS OF THE NUCLEUS OF THE SEYFERT GALAXY NGC 1566 COMPARED WITH OTHER CHANGING-LOOK AGNS

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We present results of a long-term optical, UV and X-ray study of variability of the nearby changing-look (CL) Seyfert NGC 1566 which was observed with the *Swift* Observatory from 2007 to 2020. We summarize our previously published spectroscopic and photometric results and present new observations. We reported on the alteration in the spectral type of NGC 1566 in 2018 (Paper I). Moreover, we focused on the exceptional postmaximum behavior after 2018 July, when all bands dropped with some fluctuations (Paper II). We observed four significant re-brightenings in the post-maximum period. We have found differences in X-ray and UV/Optical variability. The L_{UV}/L_X ratio was decreased during 2018-2020. New post-maximum spectra covering the period 2018 November 31 to 2019 September 23 show dramatic changes compared to 2018 August 2, with fading of the broad lines and [Fe X] $\lambda 6374$ until 2019 March (REF2). Effectively, two changing look (CL) states were observed for this object: changing to type 1.2 and then returning to the low state as a type 1.8 Sy. We suggest that the changes are mostly due to fluctuations in the energy generation.

Variability properties of NGC1566 are compared with our results for other CL active galactic nuclei (AGNs).

Keywords: galaxies – active – X-ray – UV -optical

1. INTRODUCTION

The NGC1566 was discovered in 1826 by James Dunlop but intensive investigations of it were triggered after discovery of the Seyfert phenomenon in this object in 1956 [1, 2] which was confirmed in 1962 [3]. These investigations of

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NGC 1566 have long history (see e.g. references at [4–7]). The NGC1566 is one of the brightest and nearest galaxies with AGN in the South Hemisphere. This object is also nearest Changing Look (CL) AGN [5, 8]. It is one of two (also NGC3516) firstly discovered (soon after discovery of variability of AGNs in continuum by [9]) CL AGNs [10, 11], however this designation came into common use only in the past decade. The CL AGNs are active nuclei of galaxies which undergo dramatic variability of the emission line profiles and classification type, which can change from type 1 (showing both broad and narrow lines) to type 1.9 (where the broad lines almost disappear) or vice versa within a short time interval (typically a few months). This dramatic spectral change in the NGC1566 was correlated with optical variability [12]. Due to the optical monitoring since 1954 about 20 years (first published optical light curve) the object was in bright state during few years till 1962 then it shortly dropped down and shortly moved up to the maximal level at 1963. Such re-brightenings after strong outbursts and CLs probably are typical property of CL AGNs and were fixed in several other ones of them [8, 13, 14]. After 1963 the NGC 1566 was mostly in low state what was a reason to note it as a “weak Seyfert”, however occasional recurrent brightenings of H and optical continuum (not as strong as the outbursts of 1962 and 2018) were observed in the period 1982-1991 [15–19].

The first multi-wavelength (X-ray, UV, optical and IR), UV/optical emission lines investigations of the variability of NGC 1566, as well as the first IR reverberation mapping, were published by [19]. It seems that found IR time delays (\sim several months) was significantly overestimated (see discussion of that in Paper II) and more realistic value for the IR time delay is less than 20 days [20].

NGC 1566 is a galaxy with a very well-studied variable active nucleus, however the spectral and photometric data have big gaps. The most intensive multiwave photometric observations were done during past years after discovery of a new reawakening [7, 21–24] and new CL phase (see [5, 6, 8] and references there). During these few years 2 CLs were discovered in the object: first happened in 2018 when object changed from Sy1.9 to Sy1.2 ([5] = Paper I) and second one in 2019 when object changed back to the low state ([6] = Paper II). This was happened about 60 years after previous CLs [11, 12], but, taking into account too long gaps in the spectral coverage, some other possible CLs could well have been missed. Meanwhile it is entirely possible that CLs of NGC 1566 such as in 1962 and 2018 (see [8] and Paper I) are recurrent events happening on time-scales of several decades.

The spectral transition during the CL events (during 2018-2020) of NGC 1566 not only manifested in dramatic intensity changes of the broad emission lines but also in significant strengthening of the UV Balmer continuum and high-ionisation coronal lines such as [FeX] λ 6374 (Papers I – II). Such variability of coronal lines

was observed also in some other CL AGNs: NGC 4151 [28–32] and NGC 3516 (in preparation). The H/H ratio (for broad components) changed from ~ 2.6 in high state to ~ 6.2 in the low state (see details in Paper II). The variability of the Balmer decrements is a typical property of a CL AGN (see e.g.) [28–32]. After maximum was reached in July 2018, fluxes in all bands declined, with some re-brightenings Event 1 in December 2018 [33], Event 2 in the end of May 2019 [34], Event 3 in August 2019 (Paper II) and Event 4 in May 2020 [34]. This decline was accompanied by a decrease of the $L_{\text{uv}}/L_{\text{x}}$ ratio (Paper II). The estimated Eddington ratios were about 0.055% for minimum in 2014 and 2.8% for maximum in 2018.

In [36] and in this paper we present results of the continuation of our multi-wavelength (optical, UV and X-ray) monitoring of NGC 1566 using the data obtained with *Neil Gehrels Swift Observatory* over the period 2007-2020 combined them with published before results in Paper I and Paper II, which include also spectral data obtained with the South African Astronomical Observatory 1.9-m telescope from 2018 August to 2019 September and photometry with the MASTER Global Robotic Network from 2014 to 2020 December. We compare these results with the revealed before facts for other CL AGNs to fix some common properties which can eventually help us to understand better physics of the CL phenomenon.

2. OBSERVATIONAL DATA AND RESULTS

NGC 1566 has been regularly observed by the *Neil Gehrels Swift Observatory* [37] for many years, starting in late 2007 and the results of the monitoring were published mostly by [5–7, 22, 23, 34, 35, 38]. In the present paper we have added to the analysis the most recent data (both from the XRT and UVOT telescopes), using the same methods as in Paper I and II, but we uniformly re-reduced all available data to ensure usage of the most recent versions of the software and calibration files. No significant variations were found between different versions of the reduced X-ray data. Meanwhile last update of the UVOT calibrations can give the difference up to almost 0.3 mag (see details here <http://www.swift.ac.uk/analysis/uvot/>). The new data include 28 dates for interval between 5th December 2019 and 20th October 2020. The data allows us to trace better the long and short term evolution of NGC 1566's behaviour including post maximum period.

We summarize a study of optical, UV and X-ray light curves of the nearby changing look active galactic nucleus in the galaxy NGC 1566 obtained with the Neil Gehrels Swift Observatory and the MASTER Global Robotic Network over the period 2007-2019 published before in Paper II and new data for the years 2019-

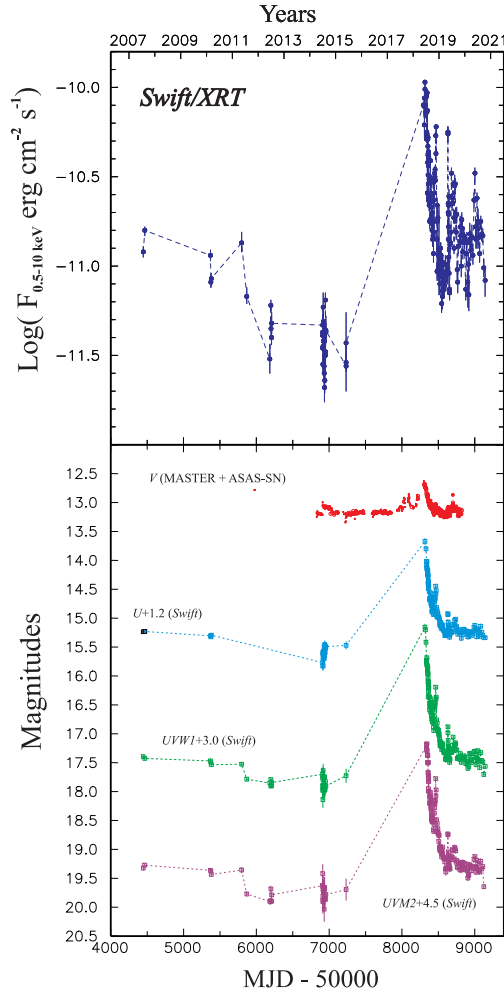


Fig. 1. Multi-wavelength observations of NGC 1566 spanning the period 2007 December 11 to 2020 October 21. *Top panel:* The *Swift*/XRT 0.5–10 keV X-ray flux (in $\text{erg cm}^{-2} \text{s}^{-1}$). *Bottom panel:* Optical–UV photometric observations. The large open circles represent MASTER unfiltered optical photometry reduced to the *V* system while the points are *V* ASAS-SN (nightly means) reduced to the *Swift* *V* system. The filled circles show MASTER *V*-band photometry. The small open boxes correspond to the *U*, *UVW1* and *UVM2* *Swift*/UVOT photometry.

2020 (see Figures 1– 2). The MASTER observations and results of the ASAS-SN (All-Sky Automated Survey for Supernovae) [39–41] *V*-band magnitudes reduced to the *V* *Swift*/UVOT system are presented in Figures 1 and 2 (till 2019 December 5) as were published before in Paper II. The light curves in the optical *UBV*, *UVW1*, *UVM2* and X-ray bands are well correlated as can be clearly seen in Figure 1 (bottom panel) for 2007–2020 and Figure 2 (bottom panel) for 2018–2020.

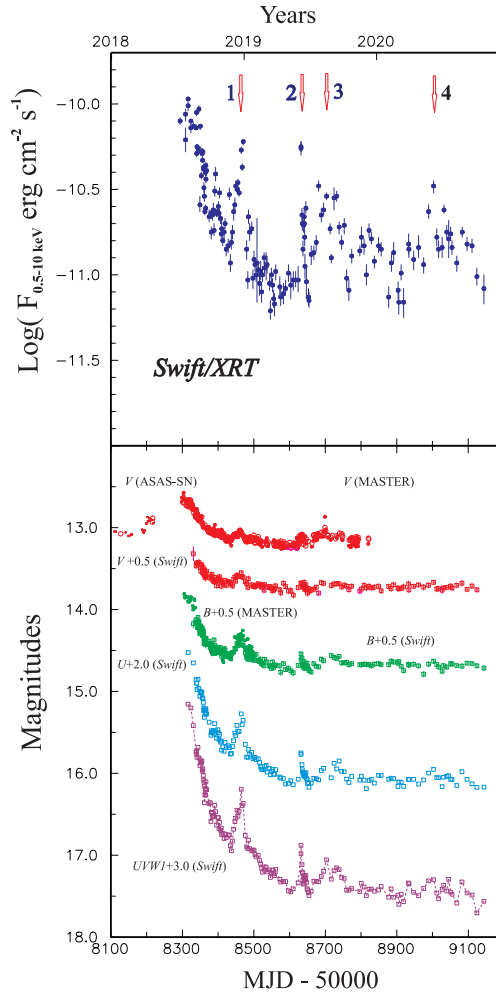


Fig. 2. Multi-wavelength observations of NGC 1566 shown just for 2018–2020. *Top panel:* The *Swift*/XRT 0.5–10 keV X-ray flux (in $\text{erg cm}^{-2} \text{s}^{-1}$). *Bottom panel:* The large open circles represent MASTER unfiltered optical photometry reduced to the *V* system while the points are *V*-band ASAS-SN (nightly means) reduced to the *Swift* *V* system. The filled circles show MASTER *BV* photometry results. The open boxes correspond to the *UVW1* and *UBV* data obtained by *Swift*. The arrows indicate the Events 1, 2, 3 and 4 (see text for the details).

The light curves till 2019 December 5 were discussed in details in the Paper II. There were considered 3 re-brightening Events 1–3. Here in new data we see one more Event 4 (2020 August), which was firstly noted by [35]. The Event 3 was most significant and it happened about one year after the main maxim but was seen mostly from the MASTER data since its maximum was missed by *Swift* observations. We didn't see any clear signature of periodicity of these events as

it was suspected by [35]. The event 2 and 3 were very fast and short and so some other such re-brightening could well have been missed. In the Paper II was firstly found a decrease of the $L_{\text{UV}}/L_{\text{X}}$ ratio at post-maxim decrease. Here that is seen more clear from the Figures 1 and 2: the X-ray flux was in mean grow up after the minimum in 2019 March but UV brightness had tendency to move down in mean. This effect for UV bands is significant, it is smaller for U and not seen for BV variations.

3. DISCUSSION

The properties of multi-wavelength variability of NGC 1566 is not unusual for a CL AGNs. The dramatic changes of factors few tens in the X-ray flux (see Paper I) along with correlated variations at UV and optical wavelengths is a typical property of CL AGNs. However, such a strong correlation of the X-ray and UV/Opt is not common among AGNs (see e.g.) [42, 43], there are exceptions for some other CL AGNs, viz. NGC 2617, NGC 4151, NGC 3516, and NGC 5548 (see e.g.) [13, 39, 44–46]. The UV/Optical variations are typically delayed relative to the X-ray fluctuations by about a few days. These delays correlate with the masses of the supermassive black holes (SMBH). From these results we can conclude that the variability across several wavebands in CL AGNs (spanning from X-rays to the UV/Optical) is driven by variable illumination of the accretion disc (AD) by soft X-rays. We have to determine the most significant common features of such variability. That can help us to find the most likely explanations for the CL phenomenon (see e.g. discussion and references in Papers I–II and below). There are several different possibilities that have been considered: variable obscuration, AD flares, tidal disruption events (TDEs), and supernova event (see e.g. more detailed discussion and references in Papers I – II and below) . In case of NGC 1566 the duration of the rise and decay times for the main brightening in 2018 was about the same (~ 9 months) and much longer than the recurrent brightenings (with lower amplitude) described by [16] (~ 20 days). A similar dramatic brightening was observed previously in 1962, with re-brightening about one year later [47]. Such re-brightenings soon after the main maximum may be common in the variability of CL AGNs. Whilst there is good evidence for obscuration in many of AGNs (see [30–32] and references therein), it is not the dominant variability mechanism. It is difficult to explain the dramatic rise of the X-ray and UV/optical flux by some variable obscuration. The main problem with the obscuration theory is that it would predict much longer time scales for the spectral changes than what is observed in CL AGNs (see e.g.) [48]. For NGC 1566 we expect timescales of more than a few years for a CL event in the obscuration scenario, which is much longer than what is observed. It does not exclude the

possibility of intervening clouds causing variable obscuration, but seems to exclude that as a dominant explanation for the CL mechanism. The more obvious explanation of this, and AGN variability in general, is that it is due to variation of the intrinsic energy-generation rate. These two leading possibilities – intrinsic variability and variable obscuration – do not need to be mutually exclusive. For example, a dramatic change in the energy generation could cause the sublimation of dust in clouds near the central source energy source [13,49]. If such sublimation occurs in some clouds along the line of sight, then the rise in the UV can be explained in part with the change in obscuration. The typical time for the recovery of dust clouds after the UV flux has abated can be several years [13,49,50], but it could be less for NGC 1566 if we take into account the significantly smaller mass of the SMBH compared with NGC 4151. So we could see some increase in obscuration during the time when the energy generation is falling. We do see some differences in variability in different wavelengths after Mar. 2019, which can be explained by variable obscuration since it must be most significant for the UV and less in optical bands, and with hardly any noticeable effect for X-ray flux. Similar decrease in UV/X-ray ratio at post maximum deeming was found by us for NGC 2617 and NGC 3516 (in preparation). That is in agreement with absorbing column variations (more than of a factor of 3 from during 2015 – 2018) found in the NGC 1566 by [35] (however the estimates are model-dependent and the variations can be due to dust sublimation). After the maximum in 2018 the estimated (by Jana et al.) hydrogen column density had tendency to grow up in correlation with variations of $H\alpha/H\beta$ ratio (found in Paper II). Meanwhile there are some other possible explanations for these variations and difference in X-ray and UV variability. For example, the strong change in the $L_{\text{uv}}/L_{\text{x}}$ flux ratio observed in the NGC 1566 after Mar. 2019 (see Paper II) can be connected with changing of the height of the X-ray source that can reduce the amount of UV/optical emission produced by reprocessing in the AD (see e.g.) [51]. Also a transition in accretion mode might explain the observed differences in properties of variability in high and low states (see e.g.) [52] The most intriguing question is what the mechanism would be for such dramatic switching on or off for the energy generation of CL AGNs. This has been explored in some firsts reports on CL events as well as in recent papers [14, 53–55]. See discussion of the possible mechanisms for CLs in [7, 52, 55–59] and Paper II. The TDE and supernova explanations can be rejected given the differences between expected and observed time scales for such events, as well as their spectral properties and evolution. An alternative theory proposes the tidal stripping of stars [60,61], which could lead to more frequent and recurrent events [62] if these stars have bound orbits similar to some known objects near the SMBH in the Milky Way. However, the mechanism has not been investigated in sufficient details yet. At present we are far from understanding

the CL phenomenon, and many questions remain still.

4. CONCLUSIONS

We summarize a study of the NGC 1566 published before in Papers I–II with new optical, UV and X-ray light curves with the Neil Gehrels Swift Observatory over the period 2007-2020 taking into account most recent versions of the software and calibration files. We found some common properties in variability of the NGC 1566 with other CL AGNs which can be useful for the future models intended to explain the CL phenomenon:

1. CLs are recurrent events [5, 6, 46, 63].
2. After the strong outbursts, as a rule some re-brightenings are happened [7, 13, 14, 36, 64].
3. The $L_{\text{uv}}/L_{\text{x}}$ flux ratio is significantly decreased at post maximum time [6, 36].
4. The UV/Optical variations are delayed to X-ray ones on few days [13, 39, 43, 46].
5. The UV and X-ray variations are correlated but some uncorrelated events or trends are typical [13, 46, 65].
6. During the strong outbursts dust sublimates in the clouds. The dust can be recovered if the object moves to a low state at least on few years. That can explain variations of obscuration [13, 50, 66].
7. The $H\alpha/H\beta$ is higher in low states (see e.g. [67] and Paper II) .
8. The time delays grow along $H\gamma$, $H\beta$, $H\alpha$ [46, 68]
9. Variability of coronal lines (which are broader than usual forbidden lines) might be common property of CL AGNs [36, 49, 69–72].
10. The significant strengthening of the UV Balmer continuum might be common for CL AGNs [6, 13, 39, 46].
11. CL AGNs have low accretion rate $\ll 1\%$ Edd in minimum and few % in maximum [6, 63] .

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