

Observations of Sy2 galaxy NGC 3281 by XMM-Newton and INTEGRAL satellites

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We present the results of the analysis of X-ray properties of the Seyfert 2 galaxy NGC 3281, based on the observational data obtained by XMM-Newton and INTEGRAL within the energy ranges 0.2–12 keV and 20–150 keV, respectively. The XMM-Newton spectrum of this object is presented for the first time. We show that fitting the X-ray spectrum of this galaxy with models based on the reflection from the disc with infinite column density yields non-physical results. A more appropriate fit takes into account both transmitted and reflected emission, passed through a gas-dust torus-like structure. Keeping this in mind, to model the inhomogeneous clumpy torus, we used the *MYTorus* model. Hence, we conclude that the torus of NGC 3281 is not a continuous structure, but rather consists of separate clouds, which is in a good agreement with the results of near-IR observations. Using this assumption, we found that the torus inclination angle and the hydrogen column density are $66.98_{-1.34}^{+2.63}$ degrees and $2.08_{-0.18}^{+0.35} \times 10^{24} \text{ cm}^{-2}$, respectively. Also, emissions of hot diffuse gases with temperature $\sim 590 \text{ eV}$, and warm absorption, were detected.

Key words: galaxies: Seyfert: individual: NGC3281 – galaxies: nuclei – X-rays: galaxies

INTRODUCTION

Dusty tori play a significant role in the Active Galactic Nuclei (AGN) Unification scheme [1], constituting the main differences among various types of Seyfert galaxies. In obscured AGNs (Sy2), the nuclear emission is partially absorbed by a torus (depending on energy and column density, N_H , values). That is why the X-ray spectra of such objects are usually considered to contain two components: emission reprocessed (scattered) by the dusty torus and direct (unscattered) emission, which dominates at energies $\approx 3 - 10 \text{ keV}$ and $> 10 - 12 \text{ keV}$, respectively. Thus the broad-band X-ray observations are often used to determine the AGN geometry and physical conditions of matter around a supermassive black hole (SMBH). A recent increase of the number of physical models based on Monte Carlo simulations provided us with powerful tools for studying various properties of tori, such as geometry, column density, inclination and opening angles. The NGC 3281 galaxy is a very interesting object in this regard, because it is a candidate for a Compton-thick source. It is a near-by, low-redshifted ($z \approx 0.010674$) X-ray bright radio quiet, Sab spiral galaxy with type 2 AGN (Sy2). ASCA observations of this object revealed a relatively high value of hydrogen column density $N_H \approx 7 - 9 \cdot 10^{23} \text{ cm}^{-2}$ [11], taking into ac-

count that in the mid-infrared (mid-IR) amplitude $A_V \approx 22^m$. Thus, following [11], N_H/A_V is a value of the order of magnitude significantly larger than the one determined along the line of sight in the Milky Way [2]. That fact can be considered as a proof of the presence of an optically-thick absorber of both X-ray and IR emission here, possibly with partial covering. Vignali & Comastri [14] studied NGC 3281 galaxy in X-ray, treating the BeppoSAX data, and had shown that NGC 3281 is a Compton-thick source with $N_H \approx 1.5 - 2 \cdot 10^{24} \text{ cm}^{-2}$. Their N_H/A_V value is two times higher than that obtained by Simpson from ASCA observations. They also showed the presence of reflection dominated continuum at 3–10 keV, with a relatively strong (EW $\approx 0.5 - 1.2 \text{ keV}$) Fe K α emission line. Afterwards, NGC 3281 is one of 153 galaxies of the Swift/BAT 9-month catalogue, and the Swift/BAT survey revealed here the hydrogen column density $N_H \approx 8.6 \cdot 10^{23} \text{ cm}^{-2}$ and the central black hole mass $\approx 4 \cdot 10^8 M_\odot$ [15].

Sales et al. [10] studied NGC 3281 with mid-IR spectra obtained with the Gemini-South telescope. They found a very deep silicate absorption and confirmed the Compton-thick nature of NGC 3281. For an explanation of spectroscopic properties they suggest that NGC 3281 has a dusty clumpy torus with number of clouds in equatorial radius equal to 14 and an inclination angle of approximately $i = 60^\circ$.

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Finally, De Rosa et al. [4] obtained the value of $N_H \approx 1.5 \cdot 10^{24} \text{ cm}^{-2}$ using BeppoSAX and INTEGRAL data.

In the present work, we use one of the new models of AGN torus, the MYTorus model by Murphy and Yaqoob [8], to describe the combined spectrum of the NGC 3281 nucleus from INTEGRAL/ISGRI and recent XMM-Newton/EPIC data. Compared with models which include a partial covering absorption with additional reflection component describing reflection for Compton-thick torus [4, 14], this model should give us more physically reasonable parameters of the dusty torus.

OBSERVATIONS AND DATA REDUCTION

To study X-ray emission of NGC 3281 galaxy we used the 1 May 2011 XMM-Newton observations (ID0650591001, PI name: L. Bassani) during the exposure time of 23715 s. Data from EPIC cameras were reprocessed using XMM SAS v.11.0 **emproc** and **epproc** standard procedures. To obtain the XMM-Newton spectrum we collected the photons from the source and background areas on the same CCD chip (see Fig. 1). After filtering the EPIC data set we used the M. Guainazzi script¹ to combine spectra from 3 EPIC cameras into one single spectrum in the 0.2–12.0 keV range.

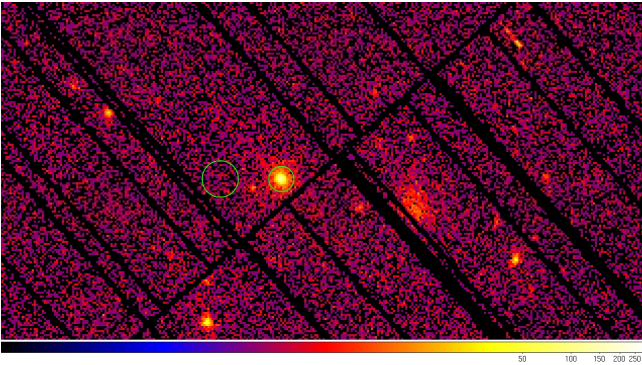


Fig. 1: The X-ray image of NGC 3281, obtained by XMM-Newton EPIC PN camera (0.2–15 keV).

Following this, the effective duration of observations was 21848 s with count-rate of 0.24 cts/s. Spectra are rebinned to have at least 20 counts in each spectral channel. The analysis of the reflection grating spectrometer (RGS) spectrum is not reported here. We also analysed all 186 pointed public observations (on February 2013) by INTEGRAL/ISGRI for NGC 3281 with effective exposure time 341 ks with count-rate 0.9 cts/s. ISGRI data analysis was performed using standard procedures of OSA 9.0, the metatask `ibis_science_analysis`. For fitting procedure we used the IBIS/ISGRI stan-

dard response matrix with 13 spectral channels. Thus, we obtained the good quality broad band spectrum in the range of 0.2–150 keV. All spectral fits were performed using XSPEC v.12.6.0. The value of the intercalibration constant used in our simultaneous modelling of XMM-Newton/EPIC and INTEGRAL/ISGRI spectrum was in the range 1.2–0.9, i. e., within the typical range of values 2.0–0.5 [3].

SPECTRAL ANALYSIS

To reproduce the spectrum we applied two spectral models. The first model (model A hereafter) is based on exponentially cut-off power-law spectrum reflected from neutral material (**pexrav** [7]). The second one (model B) is based on the toroidal model of the Compton-thick X-ray reprocessor (**MYTorus**² [8]). For our modelling we used the frozen value of the Galactic absorption, taken from Dickey & Lockmann’s work [5], i. e. $6.42 \cdot 10^{20} \text{ cm}^{-2}$. We assumed a cosmological framework with $H_0 = 70 \text{ km/s Mpc}^{-1}$, $\Omega_\Lambda = 0.73$, $\Omega_M = 0.27$.

SPECTRAL FITS WITH MODEL A

The model A includes the following components: Galactic absorption (modelled by **phabs** model in XSpec), intrinsic partially covered absorption with power law (**po×zpcfabs**), thermal emission at soft X-rays and exponentially cut-off power-law spectrum reflected from neutral material of infinite cold slab (**pexrav** [7]), plus the Gaussian FeK α and NiK α emission lines. The redshifted partial covering model (**zpcfabs**) is a multiplicative model defined as $M(E) = f \times \exp[-N_H \sigma(E[1+z])] + (1-f)$. Here, f is the covering fraction, N_H is the neutral hydrogen column density, and $\sigma(E)$ is the photo-electric cross-section. A fully covering model (with $f = 1$) corresponds to direct emission. The absorbed power-law model characterizes the nuclear component transmitted through a medium with column density N_H . A_{refl} is the normalization of the reflected component.

Model A demonstrates quite a good quality of fit with $\chi^2/\nu = 1.08$. The fitting parameters of the model A are shown in Table 1, and in Fig. 2 the spectrum is shown. It should be noted that the obtained column density $N_H = 5.38 \cdot 10^{23} \text{ cm}^{-2}$ indicates that the galaxy is probably mildly obscured Sy2 [9], but not a Compton-thick Sy2. Our N_H value is close to the value obtained by Winter et al. [15]. It should also be noted that the value of relative reflection $R \approx 166$ is unphysical if related only to the geometry $R = \Omega/2\pi$. Here, Ω is a solid angle. So, in this interpretation, R lies between 0 and 1. Another explanation of a high value of R is the fact that part of the direct emission is blocked by

¹http://xmm.esac.esa.int/sas/current/documentation/threads/epic_merging.shtml

²<http://mytorus.com/mytorus-manual-v0p0.pdf>

partially-covered material with a transmission efficiency of $\sim 1/R$ [13]. Particularly, reflected material is represented as a dusty torus. Additionally, note that a torus should be distributed in a clumpy structure, because a torus with smooth uniform distribution cannot survive close to the AGN [6]. Besides, we also found thermal emission from hot diffuse gas described by the `mekal` model with $kT = 590$ eV, and warm absorber described by the `wndabs` model.

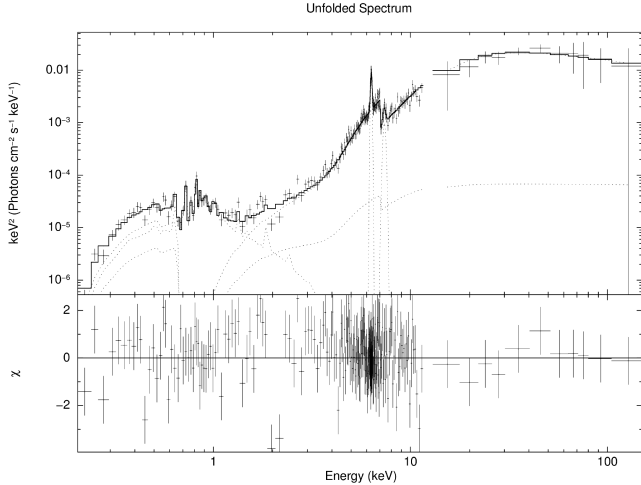


Fig. 2: NGC 3281 unfolded broad-band spectrum with disk-reflection continuum.

Table 1: Parameters of spectrum with `pexrav` continuum model, for which $L_{2-10\text{keV}}^{\text{intr}} = 1.84 \cdot 10^{42}$ ergs/s, $L_{20-100\text{keV}}^{\text{intr}} = 1.27 \cdot 10^{43}$ ergs/s, $\chi^2/\text{d.o.f} = 232/214$

Component	Parameter	Unit	Value
mekal	kT	keV	$(5.90^{+0.43}_{-0.42}) \cdot 10^{-1}$
	abund		$(1.27^{+0.13}_{-0.12}) \cdot 10^{-1}$
	norm		$(9.62 \pm 0.62) \cdot 10^{-5}$
wndabs	nH	10^{22} cm^{-2}	$1.34^{+0.28}_{-0.19}$
	WindowE	keV	$(6.58^{+0.36}_{-0.46}) \cdot 10^{-1}$
zpcfabs	nH	10^{22} cm^{-2}	$53.76^{+1.75}_{-1.63}$
	CvrFract		$(93.0^{+0.5}_{-0.4}) \cdot 10^{-2}$
zpowerlw	PhoIndex		$2.040^{+0.016}_{-0.014}$
	norm ^a		$(8.86 \pm 0.26) \cdot 10^{-5}$
Arefl			2.87 ± 0.08
pexrav	foldE	keV	$1 \cdot 10^4$ (fixed)
	Rel_refl		166.39 ± 5.67
zgauss	Line E	keV	$6.398^{+0.011}_{-0.012}$
	Sigma	keV	$(5.03^{+1.25}_{-1.99}) \cdot 10^{-2}$
	norm		$(5.62 \pm 0.56) \cdot 10^{-5}$
zgauss	Line E	keV	$7.449^{+0.041}_{-0.094}$
	Sigma	keV	$(1.06^{+0.58}_{-0.81}) \cdot 10^{-1}$
	norm		$(1.62 \pm 0.55) \cdot 10^{-5}$

^a norm=[photons $\text{cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$].

In the energy range 6–8 keV we found two emission features with centroid energies 6.39 keV and 7.45 keV, which we interpreted as Fe K_{α} and Ni K_{α} emission lines, respectively. The FWHM value for these lines are ~ 5500 km/s for Fe K_{α} and ~ 11000 km/s for Ni K_{α} , and the equivalent widths EW are 526 ± 4 eV and 251 ± 130 eV for the same lines, respectively. This leads us to the idea that Fe K_{α} line originated a far distance away from the central black hole, e.g. in the gaseous/dusty torus, and that the location of the emission Ni K_{α} line source is closer to the centre, i.e., near the inner torus wall.

Despite of the good statistics of the model A, we keep in mind that physically it is not an adequate model, because `pexrav` is not appropriate to describe the torus reflection in S2 type AGNs. This model supposes that the reflecting material is absolutely opaque (optically thick) and has a disk-like geometry, but the torus can be clumpy and inhomogeneous with more or less transparent parts. Moreover, the torus geometry is also not known. Thus, the `pexrav` fit parameters, despite good statistics, could not be considered as physical characteristics of the torus in AGNs, like the one considered here [16].

SPECTRAL FITS WITH MODEL B

The second model (model B), instead of `pexrav`, has another primary continuum component: a toroidal model of the Compton-thick X-ray reprocessor (`MYTorus` [8, 16]), which describes reflected emission from a dusty torus with different geometry. Our case of `MYTorus` model includes zero-order (intrinsic) continuum (source emission) and a dual Compton-scattered continuum. The spectrum from the back-side reflection, which reaches the observer without further interception by any absorbing matter, is approximated using a 0° MYTS component, and scattered emission, which is not from the back-side reflection, is approximated using a 90° MYTS component. To describe the intrinsic continuum we have chosen `compTT`, which is an analytic model describing Comptonization of soft photons in a hot plasma, developed by Titarchuk [12]. Such a continuum is characterized by the temperature and optical depth of the comptonizing plasma (kT and τ , respectively). We also replaced partially-covered absorption with simple absorption `phabs`.

The fitting parameters of the model B are presented in Table 2, and in Fig. 3 the spectrum is shown.

COLUMN DENSITIES

We obtained the value of the column density along the line of sight $N_H = 2.08 \cdot 10^{24} \text{ cm}^{-2}$. This value indicates that NGC 3281 is a Compton-thick source, and it is comparable with the value obtained by Vignali & Comastri [14]. The obtained hydrogen column densities for `MYTorus` model are: $N_H = 5.73 \cdot 10^{22} \text{ cm}^{-2}$ for 0° MYTS and $N_H = 5.99 \cdot 10^{23} \text{ cm}^{-2}$ for 90° MYTS. Taking into account the meaning of

these models, we can conclude that the parameters of model B properly define the spatial structure of the absorber. If we suppose that the X-ray source irradiates the torus isotropically, the hydrogen column density can be expressed in terms of Thompson optical depth [18], which is $\tau_T = (11/9)N_H\sigma_T \approx 0.81N_{24}$, thus in our case we have $\tau_T \approx 2.08 \cdot 0.81 \approx 1.7$ along the line of sight.

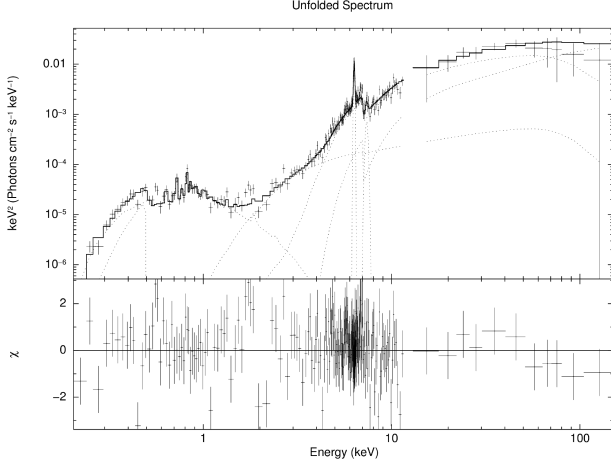


Fig. 3: NGC 3281 unfolded broad-band spectrum with toroidal reprocessor model of continuum.

Table 2: Parameters of spectrum with MYTorus continuum model, for which $L_{2-10\text{keV}}^{\text{intr}} = 5.56 \cdot 10^{41}$ ergs/s, $L_{20-100\text{keV}}^{\text{intr}} = 1.44 \cdot 10^{43}$ ergs/s, $\chi^2/\text{d.o.f} = 246/214$.

Component	Parameter	Unit	Value
mekal	kT	keV	$(5.8 \pm 0.3) \cdot 10^{-1}$
	abund		$(4.0 \pm 0.6) \cdot 10^{-2}$
	norm		$(2.00 \pm 0.12) \cdot 10^{-4}$
wndabs	nH	10^{22} cm^{-2}	$(5.4^{+0.4}_{-0.3}) \cdot 10^{-1}$
	WindowE	keV	$(6.58 \pm 1.12) \cdot 10^{-1}$
compTT	Tau		$2.56^{+0.56}_{-0.63}$
	kT	keV	40(fixed)
	norm ^a		$(9.63^{+0.28}_{-0.31}) \cdot 10^{-5}$
MYTorusZ	nH	10^{24} cm^{-2}	$2.08^{+0.35}_{-0.18}$
	Incl	deg	$66.98^{+2.63}_{-1.34}$
Const			33.17 ± 2.73
MYTorusS	nH	10^{24} cm^{-2}	$(5.73^{+0.48}_{-0.49}) \cdot 10^{-2}$
	Incl	deg	0.0(fixed)
Const			92.61 ± 3.97
MYTorusS	nH	10^{24} cm^{-2}	$(5.99^{+0.30}_{-0.27}) \cdot 10^{-1}$
	Incl	deg	90(fixed)
zgauss	Line E	keV	$6.399^{+0.012}_{-0.011}$
	sigma	keV	$(4.24^{+1.2}_{-1.9}) \cdot 10^{-2}$
	norm		$(2.42 \pm 0.24) \cdot 10^{-5}$
zgauss	Line E	keV	$7.449^{+0.104}_{-0.132}$
	sigma	keV	$(1.06^{+1.46}_{-0.91}) \cdot 10^{-1}$
	norm		$(3.6 \pm 1.62) \cdot 10^{-6}$

^a norm=[photons $\text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$].

INTRINSIC AND SCATTERED CONTINUA

Using the **compTT** model for the intrinsic continua, we can determine the plasma temperature and optical depth, i. e. in our case $kT = 40 \text{ keV}$ and $\tau \approx 2.5$. Unfortunately, we cannot apply the models to the reflected spectrum of the accretion disc as intrinsic continua, due to parameters degeneration for the model B. However, it should be noted that the model B describes the spectrum above $\sim 70 \text{ keV}$ worse than the model A does. This can be due to the dominance of the disk reflection over the torus reflection on these energies. In support of this assumption, the zeroth order continuum seen in Fig. 4 dominates in the spectrum over the back-side reflection above $\sim 10 \text{ keV}$. Taking also into account that the spectrum from the back-side reflection dominates over the inner torus wall emission below $\sim 4 \text{ keV}$, we can conclude that we can observe the appearance of a clumpy dusty torus, and not a ‘‘classical’’ homogeneous one.

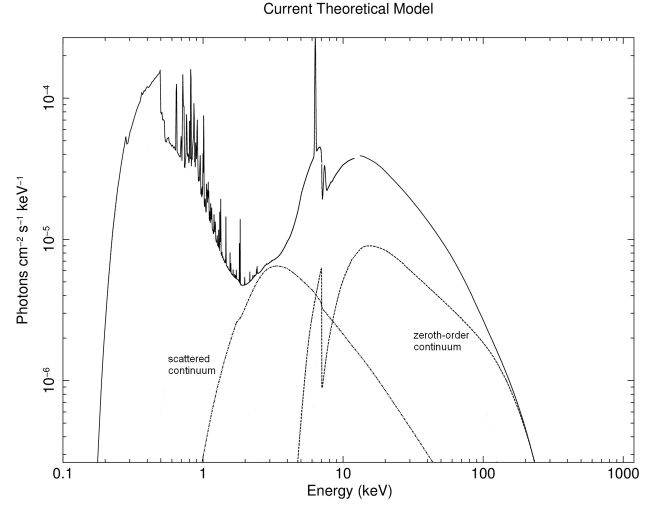


Fig. 4: The main components of the NGC 3281 model of broad-band spectrum with the toroidal X-ray reprocessor model of continuum. In addition to the total spectrum (solid line), the zero-order continuum (dashed line) and the Compton-thick scattered spectrum from back-side reflection (0° MYTS component, dash-dotted line) are shown.

FE AND NI LINES

The MyTorus model is consistent with the line emission in the Compton-thick medium. Thus within the model B the line parameters were being varied independently, despite the continuum model. So, we obtained the EW and FWHM values for Fe K_α line EW = $589 \pm 54 \text{ eV}$. This is slightly higher than the values obtained within the model A, but it is in a good agreement with the result of [8]. The FWHM value is $\approx 4600 \text{ km/s}$, which is also higher than the one obtained within the model A. At the same time for the Ni K_α line, the normalization con-

stant in this model is almost ten times higher and equivalent width is $EW = 176 \pm 73$ eV. This value is in a good agreement with the models of $Ni K_{\alpha}$ line emission for our value of the hydrogen column density along the line of sight, described in [17]. We would like to stress that our discrepancy with the value of ~ 2.3 keV obtained by Vignali & Comastri [14] can be induced by the fact that they neglected the influence of absorption on $Fe K_{\alpha}$ line profile and intensity (see e. g. [13]).

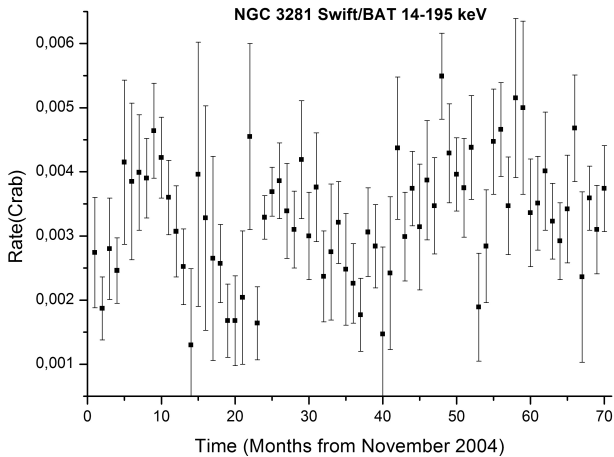


Fig. 5: NGC 3281 Swift/BAT 70-month lightcurve in the 14–195 keV. Each time bin corresponds to one month time interval, the first bin corresponding to 2004, November. The rate is given in “Crab” units.

DISCUSSION

As we have mentioned in the introduction, in 1998, using the ASCA observations, Simpson [11] found the ratio $N_H/A_V \approx 3.2 \cdot 10^{22} \text{ cm}^{-2} \text{ mag}^{-1}$ for NGC 3281, which was large as compared to the Galaxy [2]. Having considered the possible explanations of the near-IR emission, he rejected the compact star formation areas and optically thin clouds in the wide emission lines area. The best hypothesis he proposed was the optically-thin medium containing thick clouds. Thus, the torus surrounding the nucleus can be essentially inhomogeneous. Afterwards, Sales et. al. [10] confirmed the conclusions of Simpson, and additionally determined the inclination of the torus $i = 60^\circ$. Note that this value is close to the one obtained in our work, $i \approx 67^\circ$. Sales et. al. also determined the relation between the inner and the outer radii of the torus, $R_0/R_d = 20$, where $R_0 \sim 11$ pc. Additionally, in Fig. 5 we show the 70-month Swift/BAT crab-weighted lightcurve for NGC 3281 in 14–195 keV energy range. As we can see, the 14–195 keV count rate is strongly variable on time-scales from months to years, showing a dynamic range of about a factor of ~ 5 between the highest and the lowest count rate states. Thus, our results, along with the results of the previous works,

confirm the existence of the Compton-thick clumpy dusty torus in this AGN.

SUMMARY AND CONCLUSIONS

We have analysed the broad-band 0.2–150 keV X-ray properties of the active galactic nucleus of Sy2 galaxy NGC 3281. The observational data from XMM-Newton and INTEGRAL satellites give us a possibility to study the absorption features, continuum components, as well as the iron and nickel fluorescent lines $Fe K_{\alpha}$ and $Ni K_{\alpha}$. The main results of this study can be summarized as follows:

- the obtained value of the hydrogen column density along the line of sight, $N_H = 2.08 \cdot 10^{24} \text{ cm}^{-2}$, confirms the Compton-thick nature of the NGC 3281 galaxy;
- the continuum contains a reflected component, possibly originated from the back-side reflection, and the zero-order continuum dominates over it in the spectrum above ~ 10 keV;
- the fluorescent $Fe K_{\alpha}$ line demonstrates the stable flux level, as was the case in the previous works [4, 11, 12, 15].

At the same time, the 70-month Swift/BAT lightcurve of this object demonstrates an irregular variability above 15 keV, with an amplitude of ~ 5 . This can be considered as an evidence for a dusty clumpy torus. The spectral features in the mid-IR range also confirm the presence of a torus-like structure with Compton-thick clouds [10, 11].

We also found the inclination angle between the torus polar axis and the observer’s line of sight $i \approx 67^\circ$. This result is in a good agreement with the value obtained from the mid-IR observations [10].

Let us note that the continuum above ~ 70 keV can not be described only by toroidal reprocessor model plus comptonized spectrum. In the same time the ~ 15 – 50 keV spectrum can not only be described by the disk-reflected model. Thus it would be very desirable to use the method containing both models.

The mild broadening of the $Fe K_{\alpha}$ ($\sigma \approx 2$ – 50 eV) and $Ni K_{\alpha}$ ($\sigma \approx 106$ eV) emission lines corresponds to their origin inside the gas/dust torus, either in its inner part, or in the outer part of the broad-line region. The values of EW for each line agree with our N_H value, according to the results of modelling of line production from [8, 17].

Within the energy range 0.2–2 keV the soft excess explained by the thermal emission from the hot diffuse gases with $kT = 590$ eV, was disclosed. Warm absorption is also present in the spectrum.

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