

SRGA J2306+1556: an extremely X-ray luminous, heavily obscured, radio-loud quasar at $z = 0.44$ discovered by *SRG/ART-XC*

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ABSTRACT

We report on a detailed study of a luminous, heavily obscured ($N_{\text{H}} \sim 2 \times 10^{23} \text{ cm}^{-2}$), radio-loud quasar SRGA J230631.0+155633 discovered in the 4–12 keV energy band by the Mikhail Pavlinsky ART-XC telescope aboard the *SRG* observatory during the first two years of its all-sky X-ray survey in 2020–2021. The object is located at $z = 0.4389$ and is a type 2 AGN according to optical spectroscopy (SDSS, confirmed by DESI). Our analysis combines data from the radio to the X-ray energy range, including quasi-simultaneous pointed observations with the *SRG/ART-XC* and *Swift/XRT* telescopes, conducted in June 2023. During these follow-up observations, the source was found in a significantly fainter but still very luminous state ($L_{\text{X}} = 1.0^{+0.8}_{-0.3} \times 10^{45} \text{ erg s}^{-1}$, absorption corrected, 2–10 keV) compared to its discovery during the all-sky survey ($L_{\text{X}} = 6^{+6}_{-3} \times 10^{45} \text{ erg s}^{-1}$), which indicates significant intrinsic variability on a rest-frame time scale of ~ 1 year. The radio data show a complex morphology with a core and two extended radio lobes, indicating a giant FR II radio galaxy. Using multiwavelength photometry and the black hole–bulge mass scaling relation, we estimate the bolometric luminosity of the quasar at $\sim 6 \times 10^{46} \text{ erg s}^{-1}$ and the mass of its central black hole at $\sim 1.4 \times 10^9 M_{\odot}$. This implies that the black hole is accreting at $\sim 30\%$ of the Eddington limit. Overall, SRGA J230631.0+155633 proves to be one of the most luminous obscured quasars in the observable Universe out to $z = 0.5$ (i.e. over the last 5 billion years of cosmic time). As such, it can serve as a valuable testbed for in-depth exploration of the physics of such objects, which were much more abundant in the younger Universe.

Key words: black hole physics – (galaxies:) quasars: supermassive black holes

1 INTRODUCTION

Active galactic nuclei (AGN) range greatly in their luminosity, with the most powerful ones (excluding blazars) emitting more than $10^{47} \text{ erg s}^{-1}$ across the electromagnetic spectrum. Various types of extragalactic surveys indicate that luminous quasars were much more abundant in the past (at $z \gtrsim 1$) than at the present epoch (e.g. Ross et al. 2013; Ueda et al. 2014; Aird et al. 2015; Shen et al. 2020). This is usually interpreted in terms of strong evolution of supermassive black hole (SMBH) growth, namely that the most massive holes experienced their major episode(s) of accretion in the first few billion years after the Big Bang (e.g. Shankar et al. 2009; Hirschmann et al. 2014; Weinberger et al. 2018).

A significant fraction of the cosmic SMBH growth has been taking place in obscured AGN, for which the primary (ultraviolet) emission component, originating in the accretion disc, is hidden from our view (mainly due to orientation) by an optically thick layer of cold gas and dust, usually attributed to a so-called torus (see Hickox & Alexander 2018 for a review). The torus also absorbs the soft X-rays from the hot corona of the accretion disc. As a result, obscured AGN can only reveal themselves in the infrared (IR) and hard X-ray

bands, as well as in (relatively weak) narrow optical emission lines, which complicates their detection and exploration. One of the most important and still open questions is the relative fraction of obscured AGN. There are strong indications, especially in the (better studied) low-redshift Universe, that this fraction decreases with increasing luminosity and Eddington ratio (e.g. Hasinger 2008; Merloni et al. 2014; Ueda et al. 2014; Sazonov et al. 2015; Ricci et al. 2022).

Due to the combined effect of the steep AGN luminosity function and the decreasing fraction of obscured AGN with luminosity, luminous obscured AGN are extremely rare objects and are thus usually found only at large (cosmological) distances, which complicates their detailed studies. It is thus interesting to search for and explore the nearest of such obscured quasars, for which sufficient photon statistics can be collected by telescopes. In this paper, we describe such a rare case.

The object of our investigation is a heavily obscured quasar, SRGA J230631.0+155633 (hereafter, SRGA J2306+1556), which was discovered via blind search during the all-sky X-ray survey (Pavlinsky et al. 2022) by the Mikhail Pavlinsky ART-XC telescope (Pavlinsky et al. 2021) aboard the *SRG* observatory (Sunyaev et al. 2021). We have associated this bright ($\sim 5 \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$ in the 4–12 keV energy band) X-ray source with the optical object SDSS J230630.38+155620.4, for which an archival spectrum is avail-

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Table 1. Log of X-ray observations of SRGA J2306+1556.

Date	Observatory/Telescope/Mode	Exposure, s
2020-06-03	SRG/ART-XC/survey	23
2020-12-07	SRG/ART-XC/survey	22
2021-06-08	SRG/ART-XC/survey	25
2021-12-11	SRG/ART-XC/survey	24
2023-06-03	SRG/ART-XC/pointed	72900
2023-06-09	Swift/XRT/pointed	2300
2023-12-13	SRG/ART-XC/survey	26
2024-06-15	SRG/ART-XC/survey	26
2024-12-17	SRG/ART-XC/survey	26

able from the Sloan Digital Sky Survey (SDSS) DR16 data release (Ahumada et al. 2020) that clearly identifies it as a type 2 quasar (Pavlinisky et al. 2022; Sazonov et al. 2024) at a fairly low redshift of 0.4386. This implies that its intrinsic X-ray luminosity exceeded $4 \times 10^{45} \text{ erg s}^{-1}$ during the SRG/ART-XC all-sky survey. Furthermore, SRGA J230631.0+155633 proves to be radio-loud, based on archival radio data. To study this interesting quasar in detail, we organized its follow-up pointed X-ray observations with SRG/ART-XC and the XRT telescope (Burrows et al. 2005) aboard the Neil Gehrels Swift observatory (Gehrels et al. 2004), which revealed a strongly absorbed X-ray spectrum.

Below, we examine the physical properties of SRGA J2306+1556 using the available multi-wavelength information. To compute luminosities, we use a cosmological model with $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_\Lambda = 0.7$ and $\Omega_m = 0.3$.

2 X-RAY OBSERVATIONS AND DATA ANALYSIS

2.1 Discovery and observations during the SRG/ART-XC all-sky survey

The X-ray source was discovered in the 4–12 keV energy band by the ART-XC telescope during the first year of the SRG all-sky survey, on the summed map of the first two half-year scans (ARTSS1-2, Pavlinisky et al. 2022). Its existence was then confirmed in the updated source catalogue based on the data of the first four ART-XC scans (ARTSS1-5, Sazonov et al. 2024)¹. The source is listed as SRGA J230630.9+155637 and SRGA J230631.0+155633 in ARTSS1-2 and ARTSS1-5, respectively. To our knowledge, it is not present in any published X-ray source catalogues from other missions. The statistical positional uncertainty of the source in ARTSS1-5 is $R_{98} = 23.2''$ (the radius of the 98% confidence region), as shown in Fig 1.

In October 2023, ART-XC resumed the all-sky survey, and as of writing, SRGA J2306+1556 has been scanned three more times since then. Table 1 provides the dates and vignetting corrected exposures of all seven visits of SRGA J2306+1556 during the SRG/ART-XC all-sky survey.

2.2 SRG/ART-XC pointed observation

To obtain X-ray spectral information, pointed observations of SRGA J2306+1556 were performed in June 2023, first by SRG/ART-

XC in hard X-rays and six days later by Swift/XRT in soft X-rays. See Table 1 for more details.

During the ART-XC observation (ID 12310089001, PI: S. Sazonov), the telescope was pointed at the presumed optical counterpart SDSS J230630.38+155620.4. The telescope’s field of view (FoV) is 36 arcminutes in diameter, which provides a comprehensive picture of the surrounding region. All seven detector modules were operational during the observation. A few bad time intervals, amounting in total to nearly 300 seconds, were excised from the obtained data.

Using attitude data from the on-board inertial navigation system GYRO, we located the X-ray source at RA=23h06m30.4s, DEC=+15°56′17″, with a 98% statistical error $r_{98} = 2''$. We determined this confidence region based on likelihood fitting with the point-spread function (PSF). Given the current quality of the ART-XC PSF model, the likelihood was computed for sky maps with a $2''$ pixel size and the 98% confidence interval fell within the pixel. In addition, a $7''$ systematic uncertainty caused by the attitude precision must be included. Thus, the total position uncertainty of SRGA J2306+1556 can be estimated at $7.3''$.

We extracted the source and background spectra using the standard ART-XC software package, adapted to the goals of this study with the current version of the calibrations. We constructed the photon, exposure, and vignetting maps for individual energy intervals. The spectrum of SRGA J2306+1556 was extracted from a circle of $90''$ radius centered on the quasar’s optical coordinates. The background spectrum was estimated within an annular region with an inner and outer radius of $4'$ and $8'$, respectively (Fig. 1). The ART-XC background is strongly dominated by the particle contribution, with the cosmic (extragalactic) X-ray background contributing just $\sim 3\%$ in the 4–12 keV band and even less at higher energies (Sazonov et al. 2024). The particle background is actually weakly dependent on the position within the ART-XC FoV. Using background model maps obtained during the all-sky survey in ‘blank’ fields, we verified that the assumption of a flat background does not significantly affect the inferred source photon counts for SRGA J2306+1556 across the spectrum. We thus ignore this effect and use the background spectrum in our spectral analysis in the standard way, i.e. just taking into account the difference in the areas of the background and source regions.

At $9'$ from SRGA J2306+1556, ART-XC detected another source (23h06m44s, +15d48m11s) during the pointed observation.

Its observed flux in the 4–12 keV energy band is $\sim 2 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$ and the detection likelihood is 41.2. Due to its faintness and large offset, this source does not affect our estimation of the source and background spectra for SRGA J2306+1556.

We limited our spectral analysis to the 4–20 keV energy band, since the background dominates over the source signal above 20 keV.

To study the short-term variability of SRGA J2306+1556 during the pointed observation, we used several energy bands between 4 and 16 keV. To this end, the source counts were extracted from a circular region with a radius of $1'$ centered on SDSS J230630.38+155620.4. The background counts were not subtracted for this analysis.

2.3 Swift/XRT pointed observation

The source was observed by the Swift observatory (Target of Opportunity observation ID 18931, requested by I. Mereminskiy). We

¹ This catalogue also includes data of the fifth scan for $\sim 40\%$ of the sky, hence the name ARTSS1-5.

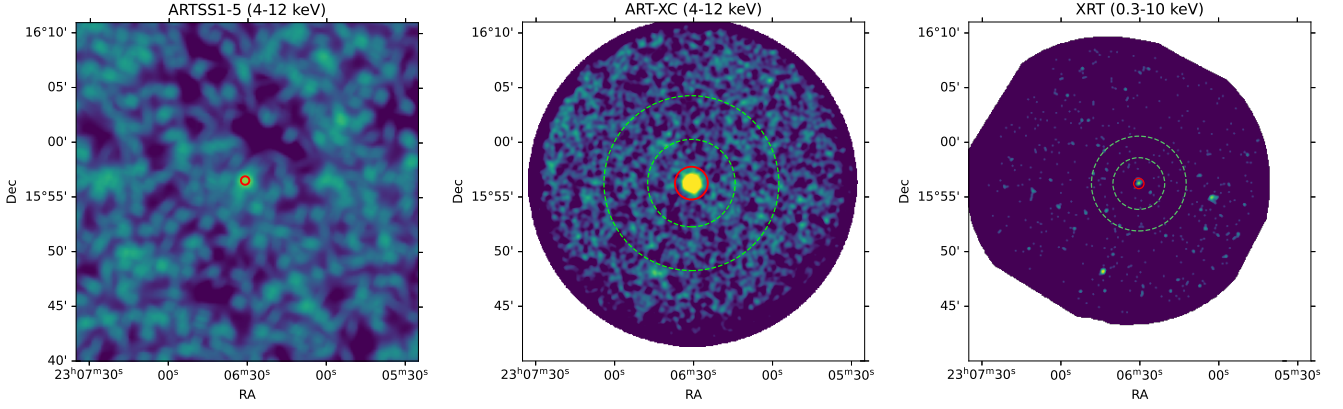


Figure 1. Smoothed X-ray images of SRGA J2306+1556. The left image is based on survey data from ARTSS1-5 (4–12 keV), while the middle and right images are based on pointed observations by *SRG*/ART-XC and *Swift*/XRT (see Table 1) in the 4–12 and 0.3–10 keV bands, respectively. In the left panel, the red circle indicates the 98% localization region, with a radius of $23.2''$; the circle is centered on the ARTSS1-5 coordinates. In the middle and right panels, the red solid circle marks the source spectrum extraction region, with a radius of $90''$ for ART-XC and $28.32''$ for XRT, respectively. The green dashed annuli represent the background extraction region, with an inner radius of $4'$ and outer radius of $8'$ for ART-XC, and $142''$ and $260''$ for XRT, respectively. The ART-XC source region is centered on the optical counterpart SDSS J230630.38+155620.4, while the XRT source region is centered on the X-ray source (these positions are different by just 6.5 arcseconds).

processed the *Swift*/XRT data (Target ID 00016070) using the University of Leicester’s service², which utilizes HEASOFT v6.32³.

The telescope was pointed at SDSS J230630.38+155620.4. The target source is confidently detected in the *Swift*/XRT image (see Fig. 1), with a position RA=23h06m30.4s, DEC=15°56′14″. The standard position error provided by the *Swift* pipeline software based on the star tracker is $6.3''$, which is composed of the 90% statistical uncertainty, $r_{90} = 5.2''$, and the systematic error of $3.5''$ added in quadrature. Unfortunately, it is not possible to derive an ‘enhanced position’ for the source, because *Swift* was in an anomaly state during the observation of SRGA J2306+1556 (Leicester Swift Helpdesk, private communication) due to problems with the attitude control system, which affected the data of the UVOT telescope (Roming et al. 2005). Assuming a Gaussian profile for the source, we can estimate the statistical position uncertainty at the 98% confidence level (as for ART-XC above) at $r_{98} \approx 1.3r_{90} = 6.8''$, and adding the aforementioned systematic error we obtain a conservative estimate of the total uncertainty in the source position of $7.6''$.

To extract spectra, we used grades 0–12 in Photon Counting (PC) mode. We set the centroid method to ‘single pass’ with a maximum of 10 attempts. The source spectrum was extracted from a circle of $28.3''$ radius centered on the position of the X-ray source. The background spectrum was extracted from an annulus between $142''$ and $260''$ from the source (Fig. 1). We restricted our spectral analysis to the 0.3–10 keV energy band, as recommended for XRT.

There are no other sources within the source and background extraction regions. The nearest source detectable by the standard pipeline is located at $6'$ from SRGA J2306+1556, which ensures that no external contamination affects the extracted spectra.

2.4 X-ray spectrum

We performed X-ray spectral modeling using *XSPEC* (version 12.12.0, Arnaud 1996). The *Swift*/XRT and *SRG*/ART-XC were analyzed jointly, using C-statistic to evaluate the quality of spectral

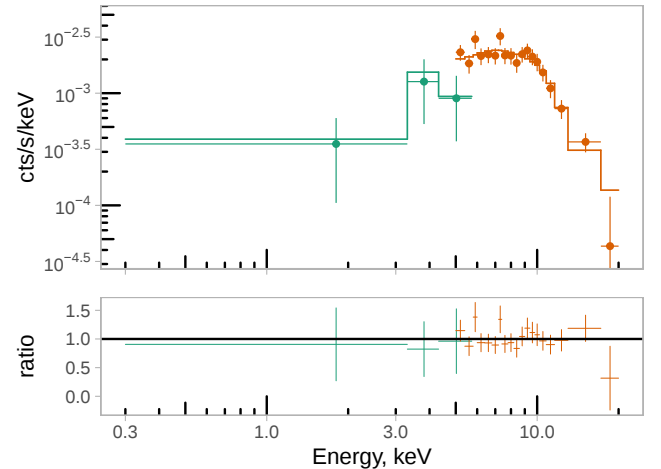


Figure 2. The upper panel shows the X-ray spectrum of SRGA J2306+1556 measured with *SRG*/ART-XC (orange) and *Swift*/XRT (green), and fitted by the absorbed power-law model. The ART-XC spectrum is re-binned in the plot for better clarity. The bottom panel shows the data-to-model ratio. The model parameters are listed in Table 2. The uncertainties are shown at 1σ confidence level.

modeling. We grouped the XRT data to ensure a minimum of three counts per energy bin in the source spectrum. The resulting XRT source spectrum covers the 0.3–5.73 keV energy band and contains a total of nine counts. The ART-XC data were grouped with a minimum of 20 counts per bin in the source spectrum. There are a total of 2701 counts in the ART-XC source spectrum over the 4–20 keV energy band.

According to the widely accepted AGN paradigm, Comptonization of the accretion disc’s photons in its hot corona leads to the formation of a power-law spectrum with a high-energy cutoff (Sunyaev & Titarchuk 1980; Haardt & Maraschi 1991), typically above ~ 100 keV (e.g. Malizia et al. 2020). Also a low-energy cutoff appears in the X-ray spectrum due to photoelectric absorption. Since

² www.swift.ac.uk/user_objects

³ www.heasarc.gsfc.nasa.gov/docs/software/heasoft

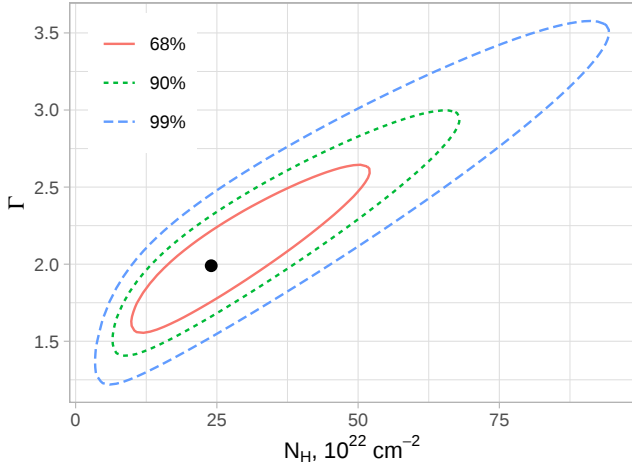


Figure 3. Joint confidence regions for the N_{H} and Γ parameters of the $\text{TBABS} \times \text{ZTBABS} \times \text{CFLUX} \times \text{ZPOWERLAW}$ model at the 68%, 90% and 99% levels.

the spectral range of the ART-XC data is limited in our analysis by a maximum energy of 20 keV (≈ 29 keV in the SRGA J2306+1556 rest frame), we do not consider a high-energy cutoff and use a simple power-law model modified by absorption in the Galaxy and within the quasar. Hence, we use the following spectral model (in the *XSPEC* terminology):

$$\text{TBABS} \times \text{ZTBABS} \times \text{CFLUX} \times \text{ZPOWERLAW}. \quad (1)$$

Here, TBABS is the Galactic interstellar absorption model (Wilms et al. 2000). We adopt the Galactic hydrogen column density in the direction of SRGA J2306+1556 from the HI4PI survey data (HI4PI Collaboration et al. 2016), $N_{\text{H}}^{\text{MW}} = 6 \times 10^{20} \text{ cm}^{-2}$, and the solar element abundances. To describe the intrinsic absorption in the object (N_{H}), we use the ZTBABS model, again assuming the standard chemical composition. The power-law continuum is characterized by the photon index Γ and the absorption-corrected flux in the observed 4–10 keV band (CFLUX) F_{4-10}^{PL} .

The XRT and ART-XC joint spectrum can be described by this model quite well, as shown in Fig. 2. The derived spectral parameters are presented in Table 2.

We confidently detect intrinsic absorption in the object, although the absorption column density is poorly constrained by the data because of the degeneracy with the photon index (see Fig. 3). Specifically, N_{H} can be anywhere between 10^{23} cm^{-2} and $6 \times 10^{23} \text{ cm}^{-2}$ (90% confidence).

The inferred slope of the power-law continuum, $\Gamma = 2.0_{-0.5}^{+0.7}$, is consistent with typical values found for AGN. Given the presence of the intrinsic absorption (presumably, due to a dusty torus), it is natural to expect also the presence of a Compton reflection component. Therefore, we added a PEXRAV (Magdziarz & Zdziarski 1995) reflection component to our model, i.e.:

$$\text{TBABS} (\text{ZTBABS} \times \text{CFLUX} \times \text{ZPOWERLAW} + \text{CFLUX} \times \text{PEXRAV}) \quad (2)$$

We fixed the photon index at 1.8 for both the ZPOWERLAW and PEXRAV components. To include only the reflected emission (without the direct emission continuum) in PEXRAV , we fixed the rel_refl parameter at a negative value. As before, the model does not include a high-energy cutoff. The cosine of the inclination angle was fixed at 0.5. The abundances of all elements heavier than He were fixed at 1.0 relative to the solar ones, adopted from Anders & Grevesse (1989).

The only free parameter of the reflection component is its flux in the observed 4–10 keV band corrected for Galactic absorption (CFLUX2), F_{4-10}^{PEXRAV} .

As shown in Table 2, reflection emission is not detected in the spectrum, and it adds less than 8% (90% confidence) to the intrinsic (i.e. corrected for intrinsic absorption) power-law continuum in the observed 4–10 keV energy band (5.8–14.4 keV in the quasar’s rest frame) or, equivalently, contributes less than 11% of the total observed emission in this band. For the adopted spectral slope $\Gamma = 1.8$, the absorption column is constrained fairly tightly between 1.0×10^{23} and $2.8 \times 10^{23} \text{ cm}^{-2}$. Within the AGN torus paradigm, one expects the reflected component to contribute less than 15% (the exact number depends on the line-of-sight and equatorial column densities as well as other parameters of the torus) to the total observed emission in the 5.8–14.4 keV energy band for such moderate (Compton thin) column densities (e.g. Melazzini & Sazonov 2023), which is consistent with the upper limit inferred for SRGA J2306+1556.

In the same scenario of reflection of X-rays from the torus, there must also arise a $\text{K}\alpha$ fluorescent line of iron at ~ 6.4 keV. We thus added a Gaussian component ZGAUSS at the rest-frame energy $E = 6.4$ keV with a free normalization or, equivalently, with a free equivalent width, EW :

$$\text{TBABS} (\text{ZTBABS} \times \text{CFLUX} \times \text{ZPOWERLAW} + \text{ZGAUSS}). \quad (3)$$

The photon index was fixed as before at $\Gamma = 1.8$.

The fit proves to be nearly insensitive to the width of the Gaussian for $\sigma_{\text{line}} < 0.5$ keV. We thus fixed it at 0.01 keV to present the results in Table 2. The line is not detected, and the 90% upper limit on its equivalent width is 1.3 keV. This is consistent with the expected strength of the 6.4 keV line $EW < 200$ eV for tori with $N_{\text{H}} \lesssim 3 \times 10^{23} \text{ cm}^{-2}$ and solar abundance of iron (Melazzini & Sazonov 2023).

2.5 Short-term X-ray variability

We next examine the short-term (intraday) X-ray variability of SRGA J2306+1556. To this end, we constructed light curves (count rate as a function of time, in 1-hour bins) during the ART-XC pointed observation in the main energy band of 4–12 keV and in two additional bands: 4–8 and 12–16 keV (Fig. 4). Because *Swift*/XRT detected just ten counts in the 0.3–10 keV energy band from the source region during its short (≈ 40 min) observation, we did not use these data for studying variability.

To investigate whether the X-ray flux is variable in a given energy band during the observation, we calculate a χ^2 statistic as follows:

$$\chi^2 = \sum_{i=1}^N \frac{(f_i - \bar{f})^2}{\sigma_i^2}, \quad (4)$$

where f_i is the count rate in the i -th time bin, σ_i is the corresponding error, $\bar{f}$ is the weighted mean count rate for the observation, and N is the total number of measurements. Accordingly, we determine $1 - p$ – the probability of obtaining by chance a χ^2 value greater than the measured one for $\text{dof} = N - 1$ degrees of freedom under the hypothesis that the count rate remained constant during the observation.

To estimate the amplitude of X-ray variability, we calculate the normalized excess variance, which is the variance normalized to the mean flux and corrected for the flux measurement errors (Vaughan et al. 2003):

$$\sigma_{\text{rms}}^2 = \frac{S^2 - \overline{\sigma_{\text{err}}^2}}{\langle f \rangle^2}, \quad (5)$$

Table 2. X-ray spectral parameters.

$N_{\mathrm{H}}^{\mathrm{MW}}$	N_{H}	F_{4-10}^{PL}	Γ	$F_{4-10}^{\mathrm{PEXRAV}}$	E	EW	σ_{line}	$Cstat$ (dof)
$10^{22} \mathrm{cm}^{-2}$	$10^{22} \mathrm{cm}^{-2}$	$10^{-13} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$		$10^{-13} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$	keV	keV	keV	
TBABS×ZTBABS×CFLUX×ZPOWERLAW								
0.06 (fixed)	24^{+31}_{-15}	8^{+5}_{-2}	$2.0^{+0.7}_{-0.5}$					57.4 (65)
TBABS(ZTBABS×CFLUX×ZPOWERLAW + CFLUX2×PEXRAV)								
0.06 (fixed)	18^{+10}_{-8}	$7.6^{+0.7}_{-1.5}$	1.80 (fixed)	< 0.6				57.8 (65)
TBABS(ZTBABS×CFLUX× ZPOWERLAW + ZGAUSS)								
0.06 (fixed)	19^{+11}_{-8}	$7.6^{+0.9}_{-0.8}$	1.80 (fixed)		6.4 (fixed)	< 1.3	0.01 (fixed)	57.4 (65)

The uncertainties and upper limits for the parameters are quoted at the 90% level of confidence.

Table 3. Characteristics of the short-term X-ray variability.

Band, keV	$\bar{R}$, cnt s ⁻¹	χ^2 (dof)	$1 - p$	σ_{RMS}^2
4–8	0.011	21.88 (20)	0.35	0.004 ± 0.008
4–12	0.019	11.39 (20)	0.94	-0.0063 ± 0.0022
12–16	0.004	23.98 (20)	0.24	0.02 ± 0.03

where

$$S^2 = \frac{1}{N-1} \sum_{i=1}^N (f_i - \langle f \rangle)^2 \quad (6)$$

and

$$\overline{\sigma_{\mathrm{err}}^2} = \frac{1}{N} \sum_i \sigma_i^2. \quad (7)$$

The error of σ_{rms}^2 can be estimated as follows (Turner et al. 1999):

$$\delta \sigma_{\mathrm{rms}}^2 = \frac{sD}{\langle f \rangle^2 \sqrt{N}}, \quad (8)$$

where

$$s_D^2 = \frac{1}{N-1} \sum_{i=1}^N \{[(f_i - \langle f \rangle)^2 - \sigma_i^2] - \sigma_{\mathrm{rms}}^2 \langle f \rangle^2\}^2. \quad (9)$$

Table 3 presents the derived mean flux rate $\bar{R}$, $\chi^2(\mathrm{dof})$, $1 - p$, and σ_{rms}^2 for each energy band. The X-ray flux did not exhibit any statistically significant variations (i.e., $1 - p > 0.05$) over the ~ 20 -hour period covered by the ART-XC observation.

2.6 Long-term X-ray variability

Using the available data of the all-sky survey and pointed ART-XC observations (Table 1), we can also study the X-ray variability of SRGA J2306+1556 on time scales of years. To this end, for the survey observations, we performed forced photometry in the circular region with a radius of $71''$ around the SDSS J230630.38+155620.4 position. We then converted the measured count rates to energy fluxes in the 4–12 keV energy band assuming a Crab-like spectrum⁴ and applying an aperture correction of 96%. The 90% upper limits were calculated using equation (7) from Gehrels (1986), with $S = 1.282$. The corresponding background was estimated using ART-XC measurements in the 30–70 keV energy band (see Sazonov et al. 2024 for details). The inferred fluxes are given in Table 4.

⁴ As discussed by Sazonov et al. (2024), the energy flux to count rate conversion factor only weakly depends on the spectral shape.

Table 4. Information on the detection of SRGA J2306+1556 in the individual ART-XC all-sky surveys.

ART-XC survey	S	B	$1 - p$	F_{4-12} , $10^{-12} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$
1	4	0.69	0.005361	8^{+7}_{-5}
2	6	0.65	0.000060	13^{+9}_{-6}
3	1	0.79	0.544614	< 8
4	3	0.71	0.035158	5^{+7}_{-4}
6	1	0.44	0.359156	< 8
7	1	0.49	0.384645	< 8
8	0	0.43	1.000000	< 5

S – number of observed counts; B – predicted background counts in the source region in the 4–12 keV energy band; $(1 - p)$ – probability of the null hypothesis (i.e. there is no source), assuming Poisson photon statistics: $Pr(N \geq S | \lambda = B)$; F_{4-12} – observed flux in the 4–12 keV energy band. Uncertainties are at the 1σ level, and upper limits at 90% confidence. Note that SRGA J2306+1556 was not scanned by ART-XC during the incomplete fifth sky survey in Dec. 2021–March 2022.

For the ART-XC pointing observation, we estimated the observed flux in the 4–12 keV energy band using our baseline spectral model CFLUX×TBABS×ZTBABS×ZPOWERLAW (see Table 2). It turns out to be $(7.6 \pm 0.3) \times 10^{-13} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$ at the 1σ confidence level.

The resulting light curve in the 4–12 keV energy band is shown in Fig. 5. We clearly see strong variability. The source was relatively bright during the ART-XC all-sky survey visits between June 3, 2020 and December 11, 2021. The maximum flux $13^{+9}_{-6} \times 10^{-12} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$ was reached in the second survey (on Dec. 7, 2020), although the variability between the first four surveys is statistically insignificant. Formally, the source was detected with high statistical significance in the second survey and less significantly in the first and fourth surveys (see Table 4). The detection of SRGA J2306+1556 on the summed map of the first four ART-XC all-sky surveys is also robust (maximum likelihood detection significance $S/N = 5.65$) and the corresponding average flux is $(4.6 \pm 1.6) \times 10^{-12} \mathrm{erg s}^{-1} \mathrm{cm}^{-2}$ (4–12 keV, Sazonov et al. 2024). Subsequently, during the pointed observation on June 3, 2024, the quasar was dimmer by a factor of 9–30 compared to the peak flux measured on Dec. 7, 2020. Afterwards, during the resumed all-sky survey, on Dec. 13, 2023, June 15, 2024, and Dec. 17, 2024, the source was not detected anymore, but the derived upper limits on its flux are not very restrictive.

We can thus conclude that SRGA J2306+1556 experienced an X-ray outburst in 2020–2021 and was in a ‘low’ state in June 2023. Given the absence of data before 2020 and the gaps in monitoring afterwards, the outburst could have lasted ~ 1 year or more in the

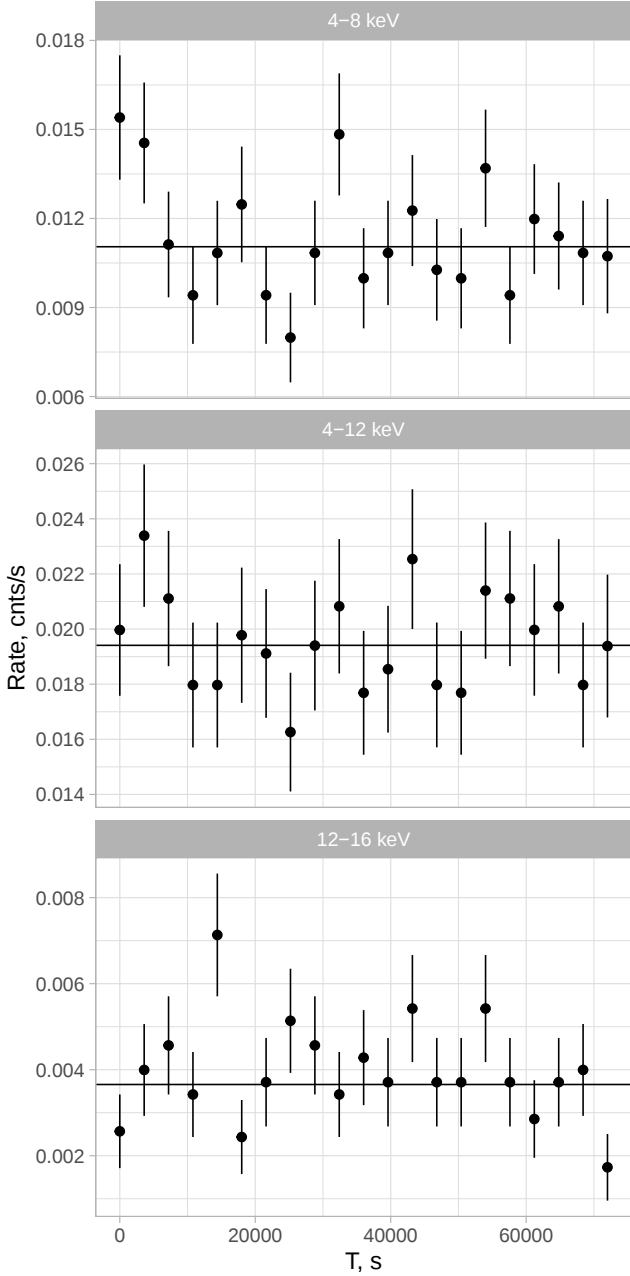


Figure 4. X-ray light curves of SRGA J2306+1556 in three energy bands obtained by the ART-XC telescope during the pointing observation, with a bin time of one hour. The error bars represent the 1σ uncertainty level.

quasar’s rest frame. Importantly, this variability cannot be explained by variable obscuration. Indeed, according to our X-ray spectral analysis in Section 2.4, intrinsic absorption, although substantial, suppressed the observed 4–12 keV flux by only a factor of 1.3 when the source was in its low X-ray state, much smaller than the observed drop in the flux relative to the ‘high’ state caught during the *SRG/ART-XC* all-sky survey. Therefore, the outburst was definitely caused by an increase in the intrinsic luminosity rather than by the disappearance of intervening cold gas.

It is also worth noting that such an X-ray outburst is expected to be followed by an ‘echo’ due to scattering in the surrounding torus.

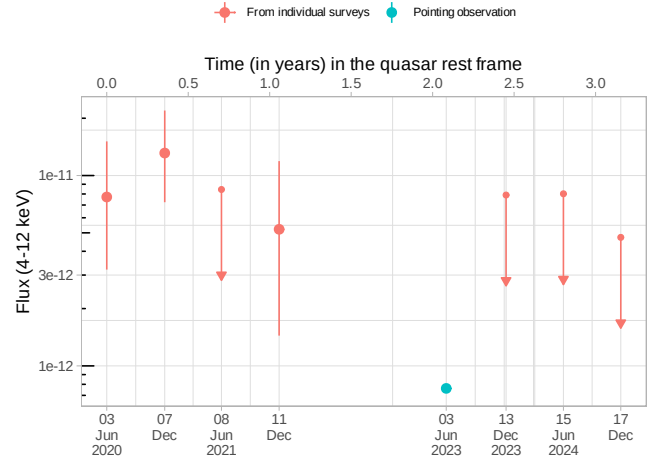


Figure 5. Long-term X-ray light curve of SRGA J2306+1556. Shown is the observed flux in the 4–12 keV energy band. The lower horizontal axis provides the dates of observations, while the upper axis shows the time passed since the first observation of the source in its rest frame. The error bars represent 1σ uncertainties, while the upper limits are shown at the 90% confidence level.

Although the result will strongly depend on the orientation and structure of the torus, the minimum duration of the reflected signal will be determined by the inner radius of the torus, R_{dust} . For an estimated bolometric luminosity of $L_{\text{bol}} \sim 6 \times 10^{46} \text{ erg s}^{-1}$ (see Sect. 4 below) of SRGA J2306+1556, one expects $R_{\text{dust}} \sim 2 \text{ pc}$ based on dust sublimation physics and reverberation mapping studies of AGN (e.g. Mandal et al. 2024). This corresponds to times scales longer than ~ 6 years. Therefore, the non-detection of a strong reflection feature in the X-ray spectrum of SRGA J2306+1556 in its low state does not seem surprising.

3 MULTIWAVELENGTH DATA

Figure 6 presents a $1' \times 1'$ optical image around SRGA J2306+1556 obtained in the r band by the DESI Legacy Surveys (LS, Dey et al. 2019). There are three optical/IR objects within the overlapping area of the *SRG/ART-XC* and *Swift/XRT* localizations regions. Table 5 presents photometric data from the LS Data Release 10 (DR10) and the UKIRT Hemisphere Survey Data Release 2 (UHS DR2, Dye et al. 2018).

Apart from optical photometry (g, r, z), LS DR10 provides mid-infrared (MIR) photometry from the *Wide-field Infrared Survey Explorer* (WISE). Namely, fluxes in the $W1$, $W2$, $W3$, and $W4$ bands have been measured using data from all WISE imaging through year 7 of NEOWISE-Reactivation via forced photometry at the locations of LS optical sources and adopting their brightness profiles determined from LS imaging. We retrieved these data from the web service⁵. We computed the g , r , z , $W1$, $W2$, $W3$, and $W4$ magnitudes in the AB system from the corresponding flux measurements reported (in nanomaggies) in the `ls_dr10.tractor` table, using the standard relation $m = 22.5 - 2.5 \log_{10} \text{flux}$; additionally converted the $W1$, $W2$, $W3$, and $W4$ magnitudes to the Vega system to facilitate comparison with standard MIR AGN diagnostics; and propagated the corresponding

⁵ <https://datalab.noirlab.edu>

Table 5. Optical/IR objects within the *SRG/ART-XC–Swift/XRT* X-ray localization region.

LS							UKIRT HS			LS–WISE			
Offset	RA	DEC	<i>g</i>	<i>r</i>	<i>z</i>	Type	<i>J</i>	<i>K</i>	Class	<i>W1</i>	<i>W2</i>	<i>W3</i>	<i>W4</i>
Object 1													
0.0	346.62658	15.93905	21.17 ± 0.02	19.861 ± 0.009	18.791 ± 0.015	SER	17.8 ± 0.2	15.77 ± 0.12	Gal.	14.606 ± 0.008	13.309 ± 0.009	9.28 ± 0.02	5.78 ± 0.06
Object 2													
6.3	346.62494	15.93828	24.14 ± 0.19	22.28 ± 0.05	21.37 ± 0.10	REX	–	–	–	18.09 ± 0.13	> 18.1	> 12.8	> 8.2
Object 3													
6.7	346.62603	15.93728	21.802 ± 0.018	19.900 ± 0.005	17.777 ± 0.003	PSF	16.19 ± 0.03	15.26 ± 0.04	Gal.	16.89 ± 0.05	15.76 ± 0.06	13.1 ± 0.8	> 8.2
7.3	346.62578	15.93717	23.84 ± 0.11	21.95 ± 0.03	19.727 ± 0.018	PSF				15.328 ± 0.012	15.67 ± 0.06	> 12.8	10 ± 3

The first seven columns provide information from LS DS10, namely: angular distance (in arcsec) from SDSS J230630.38+155620.4, ICRS coordinates, *g*, *r*, and *z* magnitudes (in the AB system), and morphological classification. The next three columns provide the *J*, *K* magnitudes (in the Vega system) and classification (Gal. for galaxy) from UHS DR2. The final four columns provide the *W1*, *W2*, *W3* and *W4* magnitudes (in the Vega system) obtained by *WISE* forced photometry at the LS DR10 positions.

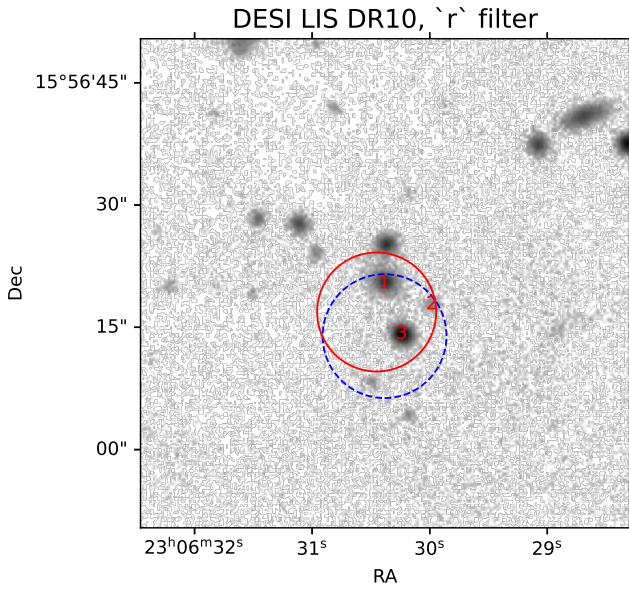


Figure 6. Optical *r*-band image from LS DR10. The red solid and blue dashed circles denote the 98% localization regions of the X-ray source based on the *SRG/ART-XC* and *Swift/XRT* pointed observations, with radii of 7.3'' and 7.6'', respectively. The numbers mark optical sources that are present in the overlapping area of these regions (see Table 5).

uncertainties ($1/\sqrt{\text{inverse variance of flux}}$) accordingly. For sources with negative fluxes in some bands, we estimated 2σ upper limits. The LS DR10 fluxes are based on the best-fitting profile model (see Table 5) for each source⁶. The possible morphological types are point source ('PSF'), round exponential galaxy ('REX'), de Vaucouleurs profile (elliptical galaxy, 'DEV'), exponential profile (spiral galaxy, 'EXP'), and Sersic profile ('SER').

UHS DR2 provides photometric data in two near-infrared (NIR) bands, *J* and *K*, with magnitudes calibrated to the Vega photometric system. We use the Petrosian magnitudes from this catalog, because this type of magnitudes is more appropriate for extended sources.

Object 1 is SDSS J230630.38+155620.4. It is extended in the optical image (Sersic brightness profile), and its optical spectrum is typ-

ical of type 2 AGN, as will be discussed in Section 3.1. Furthermore, it has a MIR color $W1 - W2 \approx 1.3$, which significantly exceeds the standard threshold of $W1 - W2 = 0.8$ for robust AGN identification (Stern et al. 2012). If this object is the true counterpart, we can further estimate the ratio of its intrinsic MIR (λL_λ at $12 \mu\text{m}$) and X-ray (2–10 keV) luminosities. Interpolating between the measurements in the *W3* and *W4* bands (virtually unaffected by Galactic absorption), we estimate $\lambda L_\lambda(12 \mu\text{m}) \approx 2.7 \times 10^{45} \text{ erg s}^{-1}$. For comparison, during the *SRG/ART-XC* all-sky survey, SRGA J2306+1556 exhibited an unabsorbed luminosity of $6_{-3}^{+6} \times 10^{45} \text{ erg s}^{-1}$ in the rest-frame 2–10 keV band, whereas during the ART-XC pointed observation its X-ray luminosity was significantly lower, $1.0_{-0.3}^{+0.8} \times 10^{45} \text{ erg s}^{-1}$. This implies $\lambda L_\lambda(12 \mu\text{m})/L(2 - 10 \text{ keV}) = 0.3 \div 0.9$ and $1.5 \div 3.9$ for the 'high' and 'low' X-ray state, respectively (neglecting possible variability in the MIR). Here, we have corrected the observed X-ray fluxes for intrinsic absorption using $N_{\text{H}} \sim 2 \times 10^{23} \text{ cm}^{-2}$, as inferred from our X-ray spectral analysis, and taken into account the corresponding uncertainty. The derived values are close to the typical $12 \mu\text{m}$ to 2–10 keV luminosity ratio of ~ 2 for AGN (Gandhi et al. 2009; Sazonov et al. 2012; Asmus et al. 2015). Therefore, object 1 is certainly an AGN and is very likely the counterpart of the X-ray source SRGA J2306+1556.

Object 2 is very faint. There is an indication from LS imaging that it is extended (see Table 5) and thus could be a galaxy. The object is not detected in UHS in either the *J* or *K* filter. It has no reported optical spectroscopy and is barely detected by *WISE*. Its MIR color $W1 - W2 \lesssim 0.1$ strongly points against an AGN origin. If we nevertheless further consider the hypothesis that it is the counterpart of SRGA J2306+1556 and is an AGN, then we can estimate the ratio of its intrinsic MIR and X-ray luminosities, similarly to our analysis for object 1 above. Specifically, based on the *W1* measurement and the upper limits on the *W2*, *W3*, and *W4* fluxes, and assuming a power-law MIR spectrum (as is typical for AGN, e.g. Mullaney et al. 2011), we obtain an upper limit on the λF_λ (rest-frame $12 \mu\text{m}$) flux of $3 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$ for redshifts $z < 1$, whereas the unabsorbed flux in the rest-frame 2–10 keV band is $(3 \div 14) \times 10^{-12}$ and $(1.0 \div 1.6) \times 10^{-12} \text{ erg s}^{-1} \text{ cm}^{-2}$ for the high and low X-ray state, respectively (taking into account the uncertainty in the intrinsic X-ray absorption as a function of redshift). Thus, the ratio $\lambda L_\lambda(12 \mu\text{m})/L(2 - 10 \text{ keV})$ is less than 3×10^{-3} , much smaller than expected for AGN. We can thus rule out that object 2 is related to SRGA J2306+1556.

Object 3 is a star at a distance of $660 \pm 300 \text{ pc}$, with a significant proper motion of $20.5 \pm 1.0 \text{ mas yr}^{-1}$, according to *Gaia* astrometry (*Gaia* Data Release 3, Gaia Collaboration et al. 2023). However,

⁶ <https://www.legacysurvey.org/dr10/description>

there are strong indications that this is not a single object. First, it is actually listed in LS DR10 as a pair of stellar-like (PSF morphology) objects at an angular distance of $0.95''$ from each other. Secondly, UHS DR2 classifies this source as a single object of morphological type ‘galaxy’. Thirdly, the *Gaia* astrometric solution is characterized by a Renormalized Unit Weight Error (RUWE) of 1.85, which significantly exceeds the threshold ~ 1.3 for single stars (Castro-Ginard et al. 2024). Therefore, we might be dealing with a wide binary system. If it were related to SRGA J2306+1556, its unabsorbed X-ray luminosity would be $\sim 10^{32} \text{ erg s}^{-1}$ (2–10 keV). Such luminosity could correspond to a cataclysmic variable (CV), which would require the presence of a third (indiscernible) component, namely a white dwarf. However, fitting the joint ART-XC–XRT spectrum by a power-law model absorbed at $z = 0$, we find $N_{\text{H}} = 7^{+9}_{-4} \times 10^{22}$ (at the 90% confidence level), whereas CVs never exhibit such strongly absorbed X-ray spectra. Moreover, object 3 is several magnitudes fainter in the optical than typical CVs with such high X-ray fluxes (e.g. Sazonov et al. 2006).

We conclude that SDSS J230630.38+155620.4 (object 1) is the true counterpart of the X-ray source SRGA J2306+1556. It is also worth noting that no optical outbursts have been detected from SDSS J230630.38+155620.4 or any other object within $30''$ of SRGA J2306+1556 over the period 2019–2025 according to the Automatic Learning for the Rapid Classification of Events (ALeRCE) light curve classifier (Sánchez-Sáez et al. 2021) of the Zwicky Transient Facility (ZTF) alert stream⁷.

3.1 Optical spectrum

On November 13, 2012 (MJD 56244), a spectrum of SDSS J230630.38+155620.4 was obtained by the 2.5-m telescope at the Apache Point Observatory (New Mexico, US) during the Baryon Oscillation Spectroscopic Survey (BOSS, Dawson et al. 2013), part of SDSS. The BOSS spectrograph (Smeed et al. 2013) covers a wavelength range of 3560–10400 Å with a variable spectral resolution of 2–5 Å. The mean full width at half maximum $\text{FWHM}_{\text{res}} = 3.2 \text{ Å}$, combining both the red and blue channels. During the observation, Plate 6134 was mounted in the telescope’s focal plane, with Fiber 337 targeting the object.

Figure 7 shows the spectrum of SDSS J230630.38+155620.4, retrieved from the SDSS Science Archive Server⁸. We did not apply any additional processing steps to this spectrum. However, the automatic SDSS pipeline (v5_13_2) had incorrectly classified the source as ‘QSO BROADLINE’ due to poor spectral line fitting. Therefore, we recondacted the spectral line analysis to obtain correct line measurements.

We first corrected the spectrum for the Galactic absorption of $E(B - V) = 0.1962$ in the direction of the object (Schlafly & Finkbeiner 2011), assuming $R_V = 3.1$ and using the extinction curve from Cardelli et al. (1989). We then fitted Gaussian functions to all identified lines to calculate the redshift. The spectral continuum was fitted by a polynomial function. For convenience, we split the spectrum into several parts: $6200 \text{ Å} < \lambda < 7000 \text{ Å}$ (near $H\alpha$), $4200 \text{ Å} < \lambda < 5100 \text{ Å}$ (near $H\beta$), and $3317 \text{ Å} < \lambda < 4000 \text{ Å}$ excluding the range $\lambda = 3860\text{--}3880 \text{ Å}$. In each segment, we simultaneously fitted the lines and continuum. After measuring the line centers, we calculated the barycentric-corrected redshift $z = 0.43891 \pm 0.00008$ (1σ uncertainty). The confidence interval for the redshift was determined

Table 6. Spectral line characteristics of SDSS J230630.38+155620.4.

Line	Wavelength, Å	Flux, $10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$	EW, Å	FWHM, 10^2 km s^{-1}
[NeV] λ 3346	4814.0 ± 0.3	0.269 ± 0.018	-17.8 ± 1.1	6.1 ± 0.7
[NeVI] λ 3426	4930.83 ± 0.12	0.601 ± 0.017	-37.2 ± 1.0	5.1 ± 0.2
[OII] λ 3726	5364.33 ± 0.08	1.100 ± 0.019	-61.4 ± 1.0	5.45 ± 0.15
H ϵ	5710.4 ± 0.5	0.29 ± 0.02	-17.3 ± 1.3	6.3 ± 0.8
H γ	6246.0 ± 0.3	0.302 ± 0.019	-13.2 ± 0.8	4.0 ± 0.4
HeII	6743.9 ± 0.3	0.251 ± 0.014	-9.5 ± 0.5	4.4 ± 0.4
H β	6996.02 ± 0.12	0.812 ± 0.017	-28.6 ± 0.5	5.01 ± 0.17
[OIII] λ 4959	7136.57 ± 0.04	3.10 ± 0.02	-105.5 ± 0.8	4.90 ± 0.06
[OIII] λ 5007	7205.33 ± 0.02	9.40 ± 0.05	-314.4 ± 1.6	4.78 ± 0.03
[OI] λ 6300	9068.6 ± 0.8	0.154 ± 0.019	-4.9 ± 0.5	4.2 ± 0.9
[NII] λ 6548	9421.3 ± 1.0	0.41 ± 0.05	-12.8 ± 1.6	4.4 ± 1.0
H α	9443.90 ± 0.19	4.11 ± 0.10	-124 ± 3	5.4 ± 0.2
[NII] λ 6584	9474.5 ± 0.4	1.22 ± 0.06	-36.9 ± 1.6	4.8 ± 0.4
[SII] λ 6716	9664.5 ± 1.2	0.47 ± 0.07	-13.8 ± 1.9	4.8 ± 1.0
[SII] λ 6731	9686.5 ± 1.6	0.40 ± 0.09	-12 ± 3	5.1 ± 1.8

The wavelengths are presented in the observer’s frame, while the equivalent widths in the source rest frame. The uncertainties are given at the 1σ confidence level.

using the Student’s t -distribution. This redshift corresponds to a luminosity distance of $2426.32 \pm 0.5 \text{ Mpc}$ for the adopted cosmology.

3.1.1 Emission lines

The identified lines, along with their observed wavelengths, fluxes, equivalent widths (EW), and physical widths (FWHM) are presented in Table 6. The FWHM values (converted to velocities) were calculated as:

$$\text{FWHM} = \frac{\sqrt{\text{FWHM}_{\text{mes}}^2 - \text{FWHM}_{\text{res}}^2(\lambda)}}{1 + z}, \quad (10)$$

where FWHM_{mes} is the measured line width and $\text{FWHM}_{\text{res}}(\lambda)$ is the spectral resolution at the observed central wavelength λ . The confidence intervals for EW were obtained using Monte Carlo simulations. Specifically, assuming that the flux errors obey a normal distribution, we generated 1,000 spectral realizations and estimated EW for each of them. The confidence intervals were then estimated from the derived EW distribution.

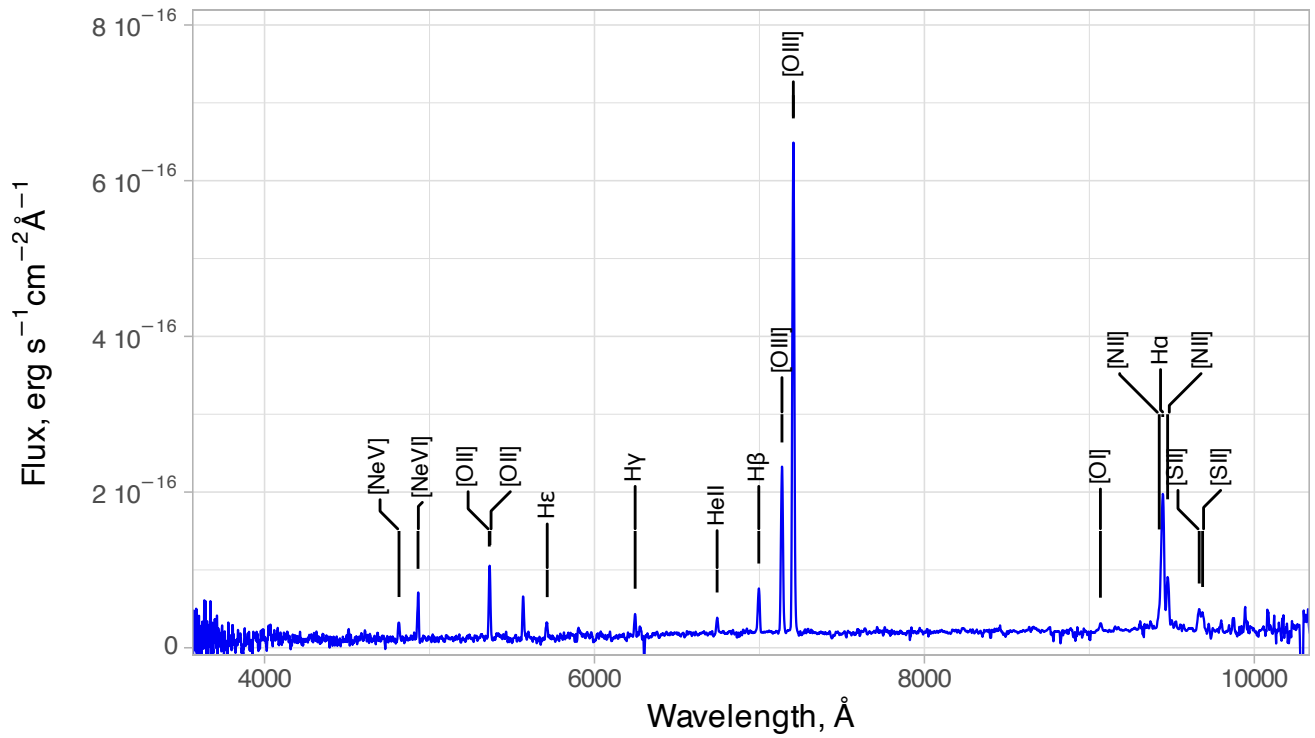
All the emission lines detected in the spectrum, namely those of the Balmer series and many forbidden lines, have Doppler widths of approximately 500 km s^{-1} , which is typical of type 2 AGN. The flux ratios of the key pairs of lines are $\log([\text{OIII}]\lambda 5007/\text{H}\beta) = 1.064 \pm 0.009$ and $\log([\text{NII}]\lambda 6584/\text{H}\alpha) = -0.53 \pm 0.02$, thus the source falls within the Seyfert region of the Baldwin, Phillips & Terlevich (BPT) diagram (Fig. 8).

Based on the measured fluxes of the Balmer lines, we can estimate the Balmer decrement in the direction of the narrow-line region (NLR): $(\text{H}\alpha/\text{H}\beta)_{\text{measured}} = 5.1 \pm 0.2$. This value falls into the 1σ region (3.5–5.5) of the distribution of NLR Balmer decrements found by Lu et al. (2019) for a large sample of AGN from the SDSS survey and implies the presence of dust in the NLR and/or the surrounding medium. If there were no dust, the intrinsic NLR Balmer decrement is expected to be $\text{H}\alpha/\text{H}\beta \approx 3.1$, i.e. slightly higher than the value 2.85 corresponding to case B recombination, which is attributed to collisional excitation of $\text{H}\alpha$ (Osterbrock & Ferland 2006). We can then estimate the intrinsic extinction in the direction of SRGA J2306+1556’s NLR (again assum-

⁷ <https://alerce.online>

⁸ <https://dr16.sdss.org/optical>

SDSS, 2012-11-13



DESI, 2021-11-03

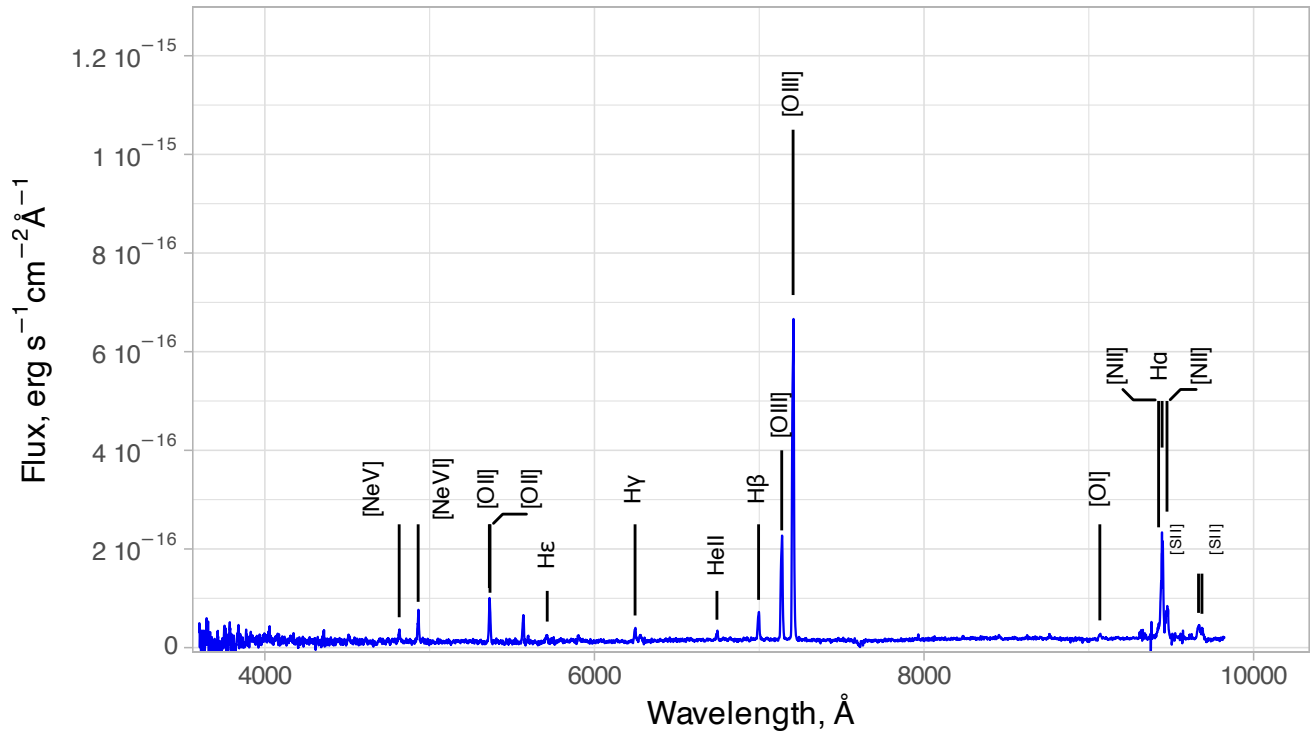


Figure 7. Top panel: SDSS spectrum. Bottom panel: DESI spectrum. Both spectra corrected for Galactic absorption, with emission lines annotated. For visualization purposes, the spectra were smoothed using a moving average algorithm with a window size of five bins.

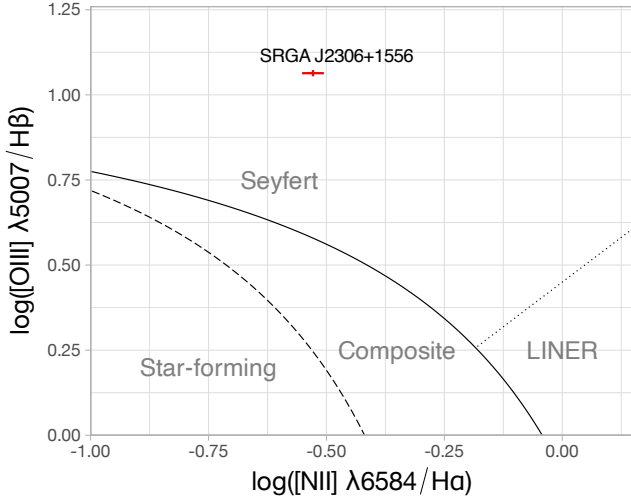


Figure 8. Location of SRGA J2306+1556 on the BPT diagram (Baldwin et al. 1981) and the corresponding 1σ error bars (in red). The boundaries separating different types of galaxies are adopted from: Kauffmann et al. (2003), solid line; Kewley et al. (2001), dashed line; and Schawinski et al. (2007), dotted line.

ing $R_V = 3.1$ and the extinction curve of Cardelli et al. (1989): $A_V = 7.202[\log(H\alpha/H\beta)_{\text{measured}} - \log 3.1] = 1.5 \pm 0.1$ mag, or $E(B - V) = 0.50 \pm 0.03$ (here, the B and V bands are defined in the object's rest frame). Accordingly, the extinction in the $O[III]\lambda 5007$ emission line, which will be discussed below, can be estimated as $A(O[III]) = 3.475 A_V / R_V = 1.7 \pm 0.1$ mag.

3.1.2 Continuum

The spectrum exhibits a weak but significant optical continuum. The $[\text{NeV}]\lambda 3346$, $[\text{NeVI}]\lambda 3426$, and $[\text{OII}]\lambda 3726$ emission lines contribute $(1.97 \pm 0.03) \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$, or 10% of the total emission in the g band of the Dark Energy Camera (DECam). The HeI , $\text{H}\gamma$, HeII , $\text{H}\beta$, $[\text{OIII}]\lambda 4959$, and $[\text{OIII}]\lambda 5007$ lines contribute $(1.415 \pm 0.007) \times 10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2}$, or 40% to the r band. The $[\text{OI}]\lambda 6300$, $[\text{NII}]\lambda 6548$, $\text{H}\alpha$, $[\text{NII}]\lambda 6584$, $[\text{SII}]\lambda 6716$, and $[\text{SII}]\lambda 6731$ lines contribute $(6.8 \pm 0.2) \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$, or 14% to the z band.

Correcting the visual/IR photometric magnitudes quoted in Table 6 for the Galactic extinction in the direction of SDSS J230630.38+155620.4 following the standard procedure described in the LS DR10 documentation, we obtain total extinction-corrected magnitudes of $g = 20.43 \pm 0.02$, $r = 19.358 \pm 0.009$, $z = 18.510 \pm 0.015$, $J = 17.6 \pm 0.2$ and $K = 15.77 \pm 0.12$, $W1 = 14.563 \pm 0.008$, $W2 = 13.284 \pm 0.009$, $W3 = 9.27 \pm 0.02$, and $W4 = 5.78 \pm 0.06$. If we now assume that line emission does not contribute significantly outside the SDSS J230630.38+155620.4 central region of $\sim 1''$, or ~ 6 kpc radius that corresponds to the SDSS/BOSS spectroscopy aperture, then subtracting the line fluxes estimated from spectrophotometry above, we derive Galactic extinction-corrected magnitudes of $g = 20.54 \pm 0.02$, $r = 19.918 \pm 0.018$, and $z = 18.67 \pm 0.02$ for the optical continuum emission. We will use these values, as well as the J and K magnitudes quoted above, to estimate the mass of the SDSS J230630.38+155620.4 host galaxy (in Sect. 5).

The continuum luminosity at rest-frame 5100Å (a quantity often used in studies of galaxies and AGN), averaged over five spectral

bins around this wavelength, is $\lambda L_\lambda = (9.9 \pm 0.7) \times 10^{43} \text{ erg s}^{-1}$. In summary, based on the totality of optical line and continuum properties, in combination with the high bolometric luminosity of SRGA J2306+1556=SDSS J230630.38+155620.4 (see below), we can confidently classify it as a type 2 quasar.

When we were completing this paper, the first release of data from the Dark Energy Spectroscopic Instrument (DESI DR1) came out (DESI Collaboration et al. 2025). It provided a new spectrum of SDSS J230630.38+155620.4, which was taken on November 3, 2021 (with an exposure time of 1360 seconds), i.e. about nine years after the SDSS observation. This new spectrum is shown in the lower panel of Fig. 7. DESI (DESI Collaboration et al. 2022) is installed on a 4-m telescope and employs three spectral cameras that operate in the B , R , and Z bands and cover the wavelength range from 3600 to 9800 Å; the spectral resolution ($\lambda/\Delta\lambda$) varies from approximately 2000 to 9800 depending on the wavelength. The DESI spectrum of SDSS J230630.38+155620.4 proves to be very similar to the SDSS one but is systematically fainter by $\sim 15\%$. This suggests that the difference arises from absolute flux calibration uncertainties rather than intrinsic variability of the source. The absence of substantial spectral variability in the optical band on a rest-frame time scale of ~ 6 years is unsurprising, given that SDSS J230630.38+155620.4 is a type 2 quasar.

3.2 Radio data

It turns out that SRGA J2306+1556 = SDSS J230630.38+155620.4 has been known as a radio source for a long time (see Table 7 for key characteristics of the surveys discussed below). The source, roughly located at $156''$ from the quasar's optical position, was first detected in the 4C survey at 178 MHz (Gower et al. 1967). Its measured flux density was 2.2 Jy. Later observations with better angular resolution revealed a double radio source near SRGA J2306+1556 at 74 MHz (VLSSr survey, Lane et al. 2014, see Fig. 9, top panel⁹) and 150 MHz (TGSS survey, Intema et al. 2017). The bright components have almost equal flux density: 3.02 ± 0.41 and 2.79 ± 0.39 Jy at 74 MHz; 1.51 ± 0.15 and 1.32 ± 0.13 Jy at 150 MHz for the northern and southern components, respectively. The corresponding spectral indices of these components $\alpha_{74-150} = -0.98 \pm 0.24$ and -1.06 ± 0.24 , which implies optically thin, aged synchrotron emission. The RACS survey (887.5 MHz) also reveals a double radio structure, with the total flux density of about 640 mJy and two brightest Gaussian components of 137 and 120 mJy (Hale et al. 2021).

The NVSS morphology at 1400 MHz shows two bright components (Fig. 9, bottom panel¹⁰) with approximately equal flux density for the northern and southern components: 215 ± 8 and 193 ± 7 mJy, respectively (Condon et al. 1998). However, there is also a weak central component (14 ± 1 mJy) at $5''$ from SDSS J230630.38+155620.4. The triple morphology with a central component (≈ 5 mJy) is confirmed at 3000 MHz by the Very Large Array Sky Survey (VLASS) (Fig. 10, Lacy et al. 2020). This central component coincides with the optical position of the quasar within $0.3''$. The central component does not show variability according to VLASS data: 4.81 ± 0.28 mJy (Epoch 1, October 2017) and 4.64 ± 0.39 mJy (Epoch 2, August 2020). The northern component (N) has a flux density of 20.47 ± 0.69 mJy in Epoch 1 and 25.90 ± 1.12 mJy in Epoch 2. The southern component

⁹ The radio map is taken from <https://www.cv.nrao.edu/vlss/vlsspostage.shtml>

¹⁰ The radio map is taken from <https://www.cv.nrao.edu/nvss/postage.shtml>

Survey	Frequency, MHz	Angular resolution	Period of observations	Reference
VLSSr	74	80''	2001–07	Lane et al. (2014)
TGSS	150	25''	2010–12	Intema et al. (2017)
4C	178	3.5'	1960–65	Gower et al. (1967)
TXS	365	20''	1974–83	Douglas et al. (1996)
MRC	408	3'	1968–78	Large et al. (1991)
RACS	887.5	15''	2019	Hale et al. (2021)
NVSS	1400	45''	1993–97	Condon et al. (1998)
VLASS	3000	2.5''	2017–23	Lacy et al. (2020)
87GB	4850	3.5'	1987	Gregory & Condon (1991)
GB6	4850	3.5'	1986–87	Gregory et al. (1996)

Table 7. Radio surveys discussed in the text.

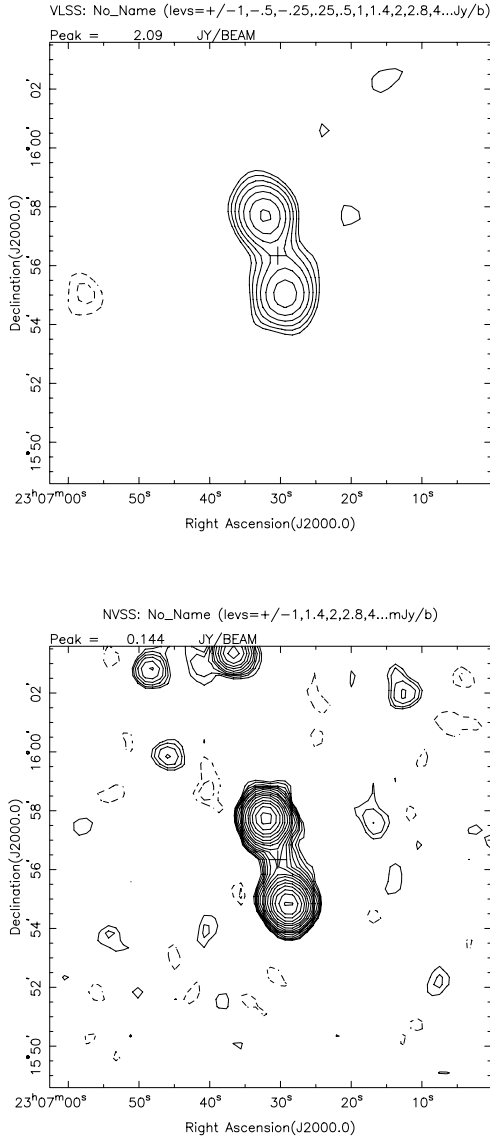


Figure 9. Radio maps of SRGA J2306+1556 at 74 MHz (VLSSr, top panel) and 1400 MHz (NVSS, bottom panel). The cross indicates the position of the optical counterpart of SRGA J2306+1556.

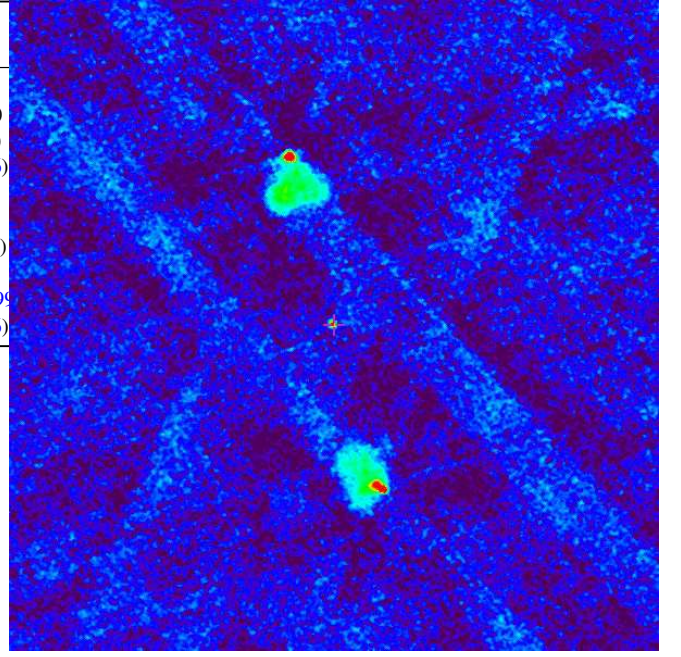


Figure 10. Radio image (6.5' on a side) of SRGA J2306+1556 at 3000 MHz based on median stacks of the Quick Look images from the three VLASS epochs. The red cross indicates the position of the optical counterpart of SRGA J2306+1556. The northern (red point at the top of the image) and southern (two red points at the bottom of the image) components are hotspots in extended radio lobes (denoted with green colors).

(S) appears as double: 13.00 ± 0.26 mJy (S_a) and 11.88 ± 0.66 mJy (S_b) in Epoch 1 (the separation between these subcomponents is 4.7''); 12.81 ± 0.36 mJy (S_a) and 9.69 ± 0.82 mJy (S_b) in Epoch 2. The region near SRGA J2306+1556 was also observed during Epoch 3 of the VLASS survey in January 2023, but a catalog of radio sources for Epoch 3 is not yet available.

At yet higher frequencies, there are only individual measurements at 4.85 GHz with the Green-Bank 91m radio telescope in 1986–87 (Gregory & Condon 1991; Becker et al. 1991; Gregory et al. 1996). However, these observations were made with 3.5' angular resolution and the radio source was not resolved, with the total flux density of about 110 mJy.

Figure 11 presents the spectra of the northern, southern and central components as well as the total spectrum of the radio counterpart of SRGA J2306+1556. The total spectrum can be well described by a steep power law, $F_\nu \sim \nu^\alpha$ with $\alpha \approx -1$, despite the fact that measurements were made over a period of 55 years. This indicates that the source is not strongly variable in the radio band.

One exception to this power law is the total measured flux density of 50–55 mJy at 3 GHz: this is much less than the expected flux density of about 200 mJy based on the steep power-law spectrum inferred from measurements at lower and higher frequencies. This problem can be solved by accounting for the presence of diffuse radio emission at 3 GHz. VLASS has the highest angular resolution among the radio surveys discussed here and detects only the brightest components with high signal-to-noise ratio. A significant fraction of radio emission at 3 GHz is spread over an area that is bigger than the VLASS beam size. Let us roughly estimate the potential contribution of the diffuse emission to the total flux density. The RMS sensitivity per epoch is about 0.12 mJy/beam for VLASS and the beam size is about 3''. The separation between the VLASS N and

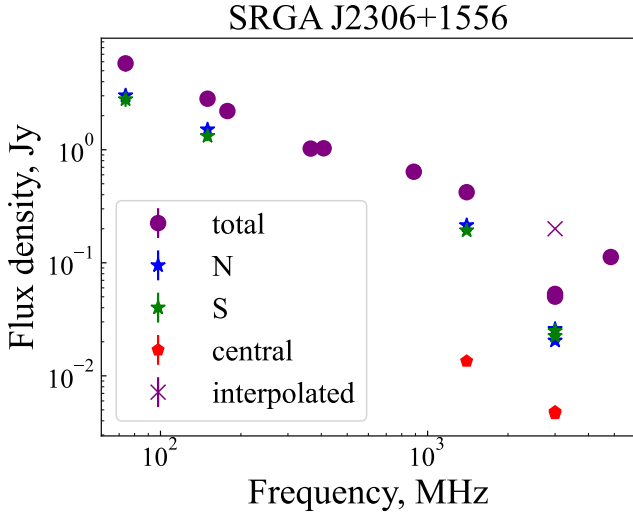


Figure 11. Broadband spectrum of the radio counterpart of SRGA J2306+1556. The purple symbols denote the total flux density of all components; the blue and green stars denote the flux density of the northern and southern components, respectively; the red symbols show the flux density of the central component. The purple cross indicates the interpolated flux density at 3000 MHz from the measurements at 888–4850 MHz.

S components is about $210''$, and the RMS is 147 mJy per circle of $105''$ radius. We thus obtain an upper limit of about 200 mJy for the total flux density at 3 GHz by summing the flux density of the three VLASS components and this RMS value. We can further assume that the extended morphology at 3 GHz is dumbbell-shaped like that at 1.4 GHz. Then we can consider the N and S components as circles of radius $r = xR$, where $R = 105''$ is the angular separation between each of these components and the central one. It is likely that $x = 0.6$ – 0.8 , thus $r = 63$ – $84''$. The RMS is about 53 mJy per circle of $63''$ radius, whereas the RMS for the bridge between the N and S circles is about 24 mJy for $r = 63''$. In total we get an RMS of about 130 mJy for the area of the radio source. Hence, the upper limit for the total flux density in the considered case is about 180 mJy, in satisfactory agreement with the power-law spectrum shown in Fig. 11.

We suppose that the VLASS N and S components are hotspots. This is confirmed by the interactive radio image based on median stacks of the Quick Look images from all three VLASS epochs¹¹ of the region centered on SDSS J230630.38+155620.4 (Fig. 10). This stacked image demonstrates the presence of radio lobes that are not detected in individual epochs.

The radio core contribution can be characterized as the ratio of the flux density of the central component and the total one: $C_\nu = S_{\nu,c}/S_{\nu,\text{total}}$. We estimate $C_{1.4\text{GHz}} = 0.032 \pm 0.04$ and $C_{3.0\text{GHz}} = 0.025 \pm 0.001$ (if we take $S_{3.0,\text{total}} = 180 \div 200$ mJy), thus the contribution of the radio core does not become more important at higher frequencies.

The projected distance between the centers of the symmetric components is about 0.9 Mpc according to the VLSSr and TGSS data, and 1.0 Mpc according to NVSS (at redshift $z = 0.4389$). The projected distance between the VLASS components is 1.2 Mpc, confirming that these are hotspots. The central VLASS compo-

nent has the deconvolved size $\leq 0.9 \times 0.5''$ (the projected size is $\leq 5 \times 3$ kpc), which suggests its association with the central region of the quasar's host galaxy. These estimates imply that the radio counterpart of SRGA J2306+1556 is a giant radio galaxy. Its radio power is $P_{1400\text{MHz}} = 2.86 \times 10^{26} \text{ W Hz}^{-1}$, which is equivalent to $\nu L_\nu = 4 \times 10^{42} \text{ erg s}^{-1}$. This high radio power and the morphological features at 3 GHz discussed above mean that this giant radio galaxy belongs to FR II type. Our conclusion about the nature of the radio counterpart of SRGA J230631.0+155633 confirms the findings of Bhukta et al. (2024) who reported the discovery of J2306+1556 as a giant radio quasar among 34 new giant radio sources based on TGSS data.

4 SPECTRAL ENERGY DISTRIBUTION

We constructed the broadband spectral energy distribution (SED) of SRGA J2306+1556 from radio to X-ray energies (Fig. 12). In the radio band, we used the total flux measurements in the observed range of 74.0–4850 MHz, excluding the 3 GHz high-angular-resolution measurement by VLASS because it underestimates the diffuse radio emission, as was discussed in Section 3.2. For the optical and infrared bands, we used the photometry from DESI LS DR10 (*grz*, *W1*, *W2*, *W3*, *W4*) and UKIRT HS DR2 (*JK*), corrected for Galactic extinction (see Sect. 3.1.2). The emission-line contribution was not subtracted. In the X-ray band (0.3–20 keV in the observed frame, corresponding to 0.4–29 keV in the rest frame), for the source's low state we used the power-law spectral model with a free slope (see Table 2), corrected for Galactic and intrinsic absorption, and evaluated the corresponding confidence intervals using a Markov chain Monte Carlo technique (the Goodman-Weare algorithm) with 30 walkers and a total of 600,000 steps. For the high state (for which we do not have X-ray spectral information), we assumed the same spectral shape as for the low state and additionally took the flux measurement uncertainty into account.

It is interesting to compare the SED of SRGA J2306+1556 with the composite SEDs of radio-loud and radio-quiet type 1 quasars from Shang et al. (2011), which span a range from rest-frame 2.45 m (radio) to 11.6 keV (X-ray). These templates have been obtained by averaging the SEDs of many objects and are thus representative of the corresponding populations (although there is a significant scatter from object to object). The object of our study is a type 2 quasar, whose intrinsic emission from the NIR through the soft X-ray band is expected to be nearly totally obscured from us by the dusty torus. We thus normalize the Shang et al. (2011) templates to the luminosity density of SRGA J2306+1556 in the W4 band, i.e. at a rest-frame wavelength of $15 \mu\text{m}$, where the torus is likely to be optically thin to its own radiation so that the observed luminosity should not depend strongly on the viewing angle. We can clearly see from Fig. 12 that SRGA J2306+1556 is a radio-loud quasar, since the contribution of radio emission to its total radiative output is much closer to the radio-loud template than to the radio-quiet one.

We can estimate the intrinsic bolometric luminosity of SRGA J2306+1556 by integrating the radio-loud type 1 SED template. Since the IR ‘bump’ (centered at around $15 \mu\text{m}$) is presumed to be reprocessed optical–ultraviolet (UV) emission from the accretion disk and soft X-ray emission from its hot corona, it is reasonable to integrate the SED only at wavelengths shorter than $1 \mu\text{m}$. The dominant contribution is provided by the ‘Big Blue Bump’ ($1 \mu\text{m} - 1 \text{ keV}$): $L_{\text{BBB}} = 5 \times 10^{46} \text{ erg s}^{-1}$ (including the significant contribution of emission lines), and the X-ray (1–11.6 keV) component provides an additional minor contribution of $2.6 \times 10^{45} \text{ erg s}^{-1}$.

¹¹ Taken from https://archive-new.nrao.edu/vlass/HIPS/All_VLASS/Quicklook

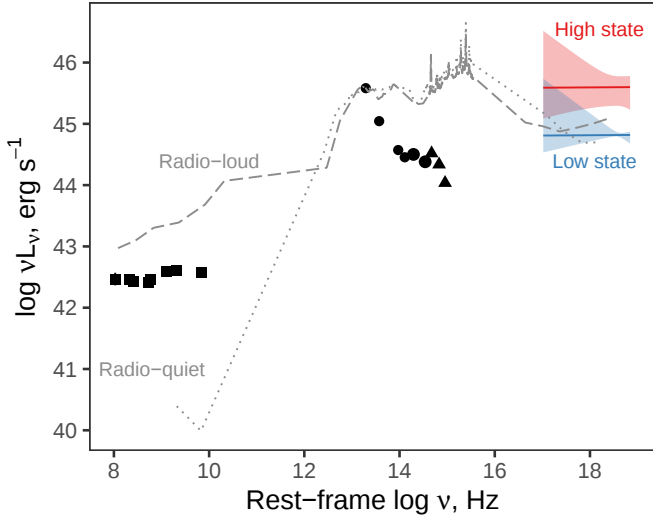


Figure 12. Spectral energy distribution of SRGA J2306+1556. The squares, circles, and triangles show the radio (74.0–4850 MHz), IR (*W1*, *W2*, *W3*, *W4*, *J*, *K*), and optical (*grz*) measurements, respectively, corrected for Galactic extinction and converted to intrinsic luminosity densities. In the X-ray band (rest-frame 0.4–29 keV), the blue and red solid lines show the intrinsic power-law component for the ‘low’ and ‘high’ source states, while the surrounding shaded regions provide the 1σ confidence intervals. The dotted and dashed lines show the radio-quiet and radio-loud type 1 quasar templates from [Shang et al. \(2011\)](#), each normalized to the *W4* measurement.

For comparison, the integration of the radio-loud template over the IR band, namely over the wavelengths longer than $1\mu\text{m}$, yields: $L_{>1\mu\text{m}} = 2.1 \times 10^{46} \text{ erg s}^{-1}$, i.e. $\sim 40\%$ of the BBB luminosity, which probably reflects the covering fraction of the obscuring torus as seen from the accretion disk.

The actually measured unabsorbed luminosity of SRGA J2306+1556 in the 2–10 keV band is $L_X = 1.0^{+0.8}_{-0.3} \times 10^{45}$ and $6^{+6}_{-3} \times 10^{45} \text{ erg s}^{-1}$ in its low and high X-ray state, respectively.

Assuming a power law with $\Gamma = 1.8$ and an exponential-cutoff energy $E_{\text{cut}} = 150 \text{ keV}$, as typical of AGN ([Malizia et al. 2014](#); [Ricci et al. 2017](#)), we can estimate the total luminosity of the X-ray continuum between 1 and 1000 keV (L_{HX}) at $\sim 4 \times 10^{45}$ and $\sim 2 \times 10^{46} \text{ erg s}^{-1}$ for the low and high state, respectively. Consequently, a more realistic estimate of the quasar’s bolometric luminosity is $L_{\text{bol}} = L_{\text{BBB}} + L_{\text{HX}} \sim 5.4 \times 10^{46}$ and $\sim 7 \times 10^{46} \text{ erg s}^{-1}$ for the low and high state, respectively, and the corresponding ratios $L_{\text{HX}}/L_{\text{bol}} \sim 0.07$ and ~ 0.3 . For comparison, the summed emission of all quasars in the Universe is characterized by an average value $L_{\text{HX}}/L_{\text{bol}} \sim 0.13$ ([Sazonov et al. 2004](#)). Neglecting the uncertainties, we can thus regard the low and high states of SRGA J2306+1556 as ‘X-ray dim’ and ‘X-ray bright’, respectively. However, there is of course a possibility that the UV luminosity, about which we have no direct information, also increased during the X-ray outburst.

While the X-ray observations presented here have revealed that SRGA J2306+1556 is significantly variable on time scales of a few years, its typical level of activity on much longer time scales can be inferred from observations of emission from the (kpc-scale) NLR. Using the measured flux in the [OIII] $\lambda 5007$ line and the corresponding intrinsic absorption correction determined in Section 3.1.1, we can estimate the luminosity in this line at $L_{\text{O[III]}} = (3.2 \pm 0.3) \times 10^{43} \text{ erg s}^{-1}$. The corresponding ratio to the 2–10 keV luminosity $L_{\text{O[III]}}/L_X \approx 0.03 \pm 0.02$ and $L_{\text{O[III]}}/L_X \approx 0.005 \pm 0.004$

Table 8. Host galaxy properties inferred with SED fitting.

$\log M_{\text{gal}},$ $M_{\odot}$	$u-r$ mag	τ_{SFH} Gyr	t_{age} Gyr	$\log Z$ $Z_{\odot}$	$E(B-V)$ mag
$11.39^{+0.03}_{-0.02}$	$1.61^{+0.06}_{-0.06}$	$5.78^{+1.16}_{-0.88}$	$13.18^{+0.47}_{-1.08}$	$0.48^{+0.02}_{-0.04}$	$0.19^{+0.03}_{-0.07}$

The uncertainties of the parameters are quoted at the 1σ level of confidence.

for the low and high X-ray state, respectively. This can be compared with a typical value ~ 0.01 for AGN (e.g. [Ueda et al. 2015](#)). This suggests that SRGA J2306+1556 has spent most of the past several thousand years at similar levels of activity as found during our X-ray observations.

Finally, we can estimate the luminosity of SRGA J2306+1556 in the radio band (rest-frame 106–6980 MHz) from the available measurements over the observed band of 74–4850 MHz: $L_{\text{radio}} \approx 2.3 \times 10^{43} \text{ erg s}^{-1}$, so that $L_{\text{radio}}/L_{\text{bol}} \approx 4 \times 10^{-4}$.

For comparison, for the [Shang et al. \(2011\)](#) radio-loud and radio-quiet composite SEDs, which start at frequencies of 122 MHz and 2100 MHz respectively, we find $L_{\text{radio}}/L_{\text{bol}} \approx 4 \times 10^{-3}$ and 8×10^{-7} (we estimated the corresponding bolometric luminosities as $5\lambda L_{\lambda}$ (3000Å), following [Shang et al. 2011](#)). This again attests that SRGA J2306+1556 is a radio-loud quasar. We finally note that giant radio lobes that are observed around FR II galaxies have estimated characteristic ages $\sim 100 \text{ Myr}$ (e.g. [Machalski et al. 2009](#)), thus the presence of similar structures in SRGA J2306+1556 indicates that substantial AGN activity in this object has maintained on at least a similar timescale.

5 HOST GALAXY AND THE CENTRAL BLACK HOLE

Since SRGA J2306+1556 is a type 2 quasar, it is reasonable to assume that its SED in the optical and, perhaps, NIR bands is dominated by the emission of the host galaxy. This allows us to estimate its stellar mass. To this end we followed the methodologies outlined by [Mendel et al. \(2014\)](#). Specifically, we modeled the SED using the Bayesian inference code Prospector ([Johnson et al. 2021](#)), which incorporates the Flexible Stellar Population Synthesis (FSPS) library ([Conroy & Wechsler 2009](#)) to generate synthetic stellar population models. We used the optical photometry from DESI LS DR 10, from which the contribution of emission lines (presumably emitted by the active nucleus) had been subtracted, and the NIR photometry from UHS DR2, all corrected for Galactic extinction, as was described in Section 3.1.2.

The best-fit parameters are summarized in Table 8, where M_{gal} is the total stellar mass of the host galaxy, $u-r$ is the synthetic rest-frame color corrected for Galactic extinction, τ_{SFH} is the characteristic e-folding timescale of the star formation history, t_{age} is the mean stellar age, Z is the stellar metallicity, and $E(B-V)$ is the dust attenuation within the host galaxy. As can be seen from Fig. 13, the optical–NIR data are well described by this model, while the MIR part of the SED, not used in the analysis, rises dramatically above the extrapolation of the best-fit model. This excess emission can clearly be attributed to the AGN dusty torus.

We find that the stellar population is very old, with the mean star age, $13.2^{+0.5}_{-1.1} \text{ Gyr}$, formally being larger than the age of the Universe (9.1 Gyr) at $z = 0.4389$. This probably indicates a more sophisticated history of star formation in the galaxy than is assumed in our (exponential) model. Also, perhaps, the NIR photometry is slightly affected by the AGN emission reprocessed by molecular gas and hot dust. Nevertheless, it is unlikely that our estimate of the

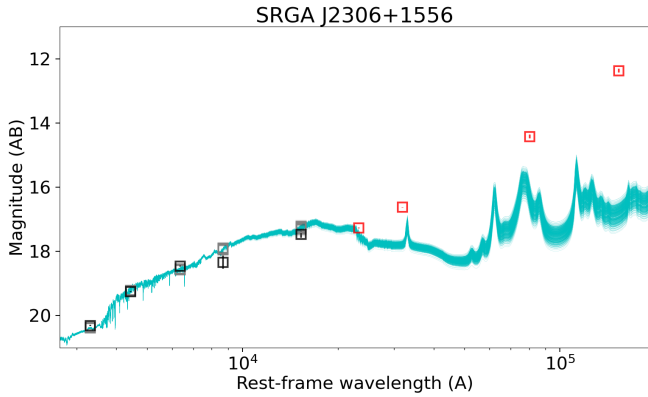


Figure 13. Modeling of the SED of SRGA J2306+1556's host galaxy. The black squares are the measured optical (*grz*) and NIR (*JK*) photometry corrected for Galactic extinction and with the contribution of optical emission lines having been subtracted. The gray squares show the best fit to these data, and the blue region shows 100 walkers of a Markov chain Monte Carlo analysis. The red squares are the MIR (*W1*, *W2*, *W3*, and *W4*) WISE photometry, which was not used in the modeling, since it is presumably dominated by the emission from the AGN dusty torus.

total stellar mass is strongly affected by these systematic effects. We also note that the intrinsic reddening inferred for the host galaxy is significantly smaller than the value that we found for the NLR based on the Balmer decrement (see Sect. 3.1.1), which suggests that the NLR is more dusty than the rest of the galaxy.

The inferred parameters of the galaxy, namely its large mass and old stellar population, suggest that it is an elliptical or at least bulge-dominated one. We can then estimate the mass of the central black hole, M_{BH} , using the correlation between M_{BH} and the mass of the bulge, M_{bulge} , in the local Universe (Kormendy & Ho 2013):

$$\frac{M_{\text{BH}}}{10^9 M_{\odot}} = \left(0.49^{+0.06}_{-0.05}\right) \left(\frac{M_{\text{bulge}}}{10^{11} M_{\odot}}\right)^{1.17 \pm 0.08}, \quad (11)$$

Substituting the M_{gal} value from Table 8 for M_{bulge} in this formula, we find $M_{\text{BH}} \sim 1.4 \times 10^9 M_{\odot}$ with a factor of ~ 2 uncertainty, mainly due to the intrinsic scatter in the $M_{\text{BH}}-M_{\text{bulge}}$ correlation (0.28 dex, Kormendy & Ho 2013).

Finally, using our estimate of the bolometric luminosity of $L_{\text{bol}} \sim (6 \pm 1) \times 10^{46} \text{ erg s}^{-1}$, we find that it constitutes $\sim 30\%$ of the object's Eddington luminosity for the derived black hole mass. Therefore, the quasar accretes mass at a high rate.

6 SRGA J2306+1556 IN THE AGN POPULATION CONTEXT AND CONCLUSIONS

SRGA J2306+1556 proves to be a fairly exceptional AGN for the $z < 0.5$ Universe. First, its unabsorbed X-ray luminosity ranged between $L_X = 1.0^{+0.8}_{-0.3} \times 10^{45}$ and $6^{+6}_{-3} \times 10^{45} \text{ erg s}^{-1}$ (2–10 keV) in our observations, and it exhibited a strongly absorbed X-ray spectrum, with $N_{\text{H}} \sim 2 \times 10^{23} \text{ cm}^{-2}$. Such X-ray luminous obscured AGN are extremely rare in the low-redshift Universe.

We can best judge about this based on the serendipitous all-sky surveys that have been conducted over the past two decades in hard X-rays (at energies above 15 keV), where absorption bias is minimal, by the BAT instrument aboard the *Swift* observatory (e.g. Oh et al. 2018) and the IBIS instrument aboard *INTEGRAL* (e.g. Krivonos et al. 2022). Thanks to follow-up X-ray and optical identification

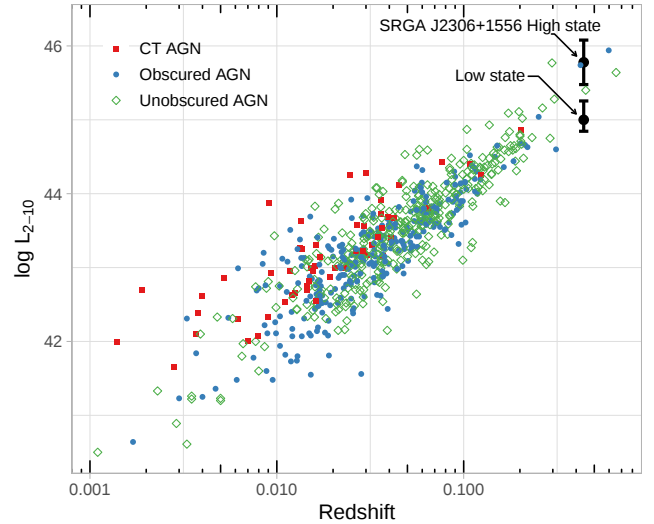


Figure 14. Intrinsic 2–10 keV luminosity vs. redshift for the AGN from the 70-month *Swift*/BAT catalog, excluding blazars. The sources are classified as unobscured ($N_{\text{H}} < 10^{22} \text{ cm}^{-2}$), obscured ($10^{22} < N_{\text{H}} < 10^{24} \text{ cm}^{-2}$), and Compton-thick ($N_{\text{H}} > 10^{24} \text{ cm}^{-2}$). The corresponding uncertainties are not shown. For comparison, we show SRGA J2306+1556 in its low and high luminosity states, respectively, and the corresponding uncertainties (see the legend).

programs, these surveys have provided highly complete catalogs of hard X-ray selected AGN with information on their redshifts, optical types, and X-ray spectral properties. Figure 14 shows the location of objects from the *Swift*/BAT 70-month AGN catalog (Ricci et al. 2017) on a diagram of redshift vs. intrinsic luminosity in the 2–10 keV band. Here, the blazars have been excluded and a distinction is made between unobscured ($N_{\text{H}} < 10^{22} \text{ cm}^{-2}$), obscured ($10^{22} < N_{\text{H}} < 10^{24} \text{ cm}^{-2}$), and Compton-thick ($N_{\text{H}} > 10^{24} \text{ cm}^{-2}$) AGN. The intrinsic luminosities in this catalog were determined from broadband X-ray spectral analysis of data from various X-ray telescopes, using the same cosmology as ours and more accurate distances for the nearest AGN. For comparison, we placed SRGA J2306+1556 on the same diagram, using its redshift $z = 0.4389$ and our luminosity estimates for the low and high states.

There are just 11 non-blazar AGN with $L_X > 10^{45} \text{ erg s}^{-1}$ in the *Swift*/BAT catalog. They are located at $z = 0.1735\text{--}0.6540$ and only three of them are obscured: Swift J0952.3–6234 ($z = 0.252$, $L_X \approx 1.1 \times 10^{45} \text{ erg s}^{-1}$, $N_{\text{H}} \approx 1.2 \times 10^{23} \text{ cm}^{-2}$), Swift J0216.3+5128 ($z = 0.422$, $L_X \approx 5.5 \times 10^{45} \text{ erg s}^{-1}$, $N_{\text{H}} \approx 2.8 \times 10^{22} \text{ cm}^{-2}$), and Swift J2344.6–4246 ($z = 0.5975$, $L_X \approx 8.7 \times 10^{45} \text{ erg s}^{-1}$, $N_{\text{H}} \approx 3.3 \times 10^{23} \text{ cm}^{-2}$).

Of course, the *Swift*/BAT all-sky survey is a fairly shallow one, with a sensitivity of $1.3 \times 10^{-11} \text{ erg s}^{-1}$ or better in the 14–195 keV energy band over 90% of the sky for the 70-month survey (Baumgartner et al. 2013). This, assuming a power-law spectrum with $\Gamma = 1.8$ and a $E_{\text{cut}} = 150 \text{ keV}$, implies that quasars with $L_X > 3 \times 10^{45} \text{ erg s}^{-1}$ (such as SRGA J2306+1556 in its high state) are robustly detectable by *Swift*/BAT out to $z = 0.336$. Therefore, the presence of just one such high-luminosity AGN up to this redshift in the *Swift*/BAT catalog (Swift J1822.0+6421, $z = 0.297$, $L_X \approx 5.9 \times 10^{45} \text{ erg s}^{-1}$, unobscured) means that it is indeed alone in the entire low-redshift Universe.

Apart from being X-ray luminous, SRGA J2306+1556 is also radio-loud. We can classify it as a giant FR II radio galaxy based

on its aforementioned morphological features and radio power. SRGA J2306+1556 well fits into the theoretical framework of evolution of double extragalactic radio sources (e.g. An & Baan 2012). We observe this source in the stage of Large Symmetric Objects (LSO) nowadays, during which the radio spectrum is steep with an index $\alpha \sim -1$. Inverse Compton losses resulting from the interaction with the Cosmic microwave background presumably prevail over synchrotron losses at this stage.

In fact, apart from X-ray surveys, luminous obscured quasars can also be discovered in low-frequency radio surveys, which are virtually unaffected by intrinsic absorption. A large sample of FR II galaxies selected from the 3CRR catalog (Laing et al. 1983) up to $z \sim 2.5$ has been observed with modern soft X-ray telescopes (see, e.g. Masaro et al. 2015; Jimenez-Gallardo et al. 2020). Utilizing data from this sample Kuraszewicz et al. (2021) have shown that luminous narrow-line radio galaxies (NLRGs), resembling SRGA J2306+1556, are fairly frequent at $0.5 < z < 1$. This is consistent with AGN statistics inferred from deep (pencil-beam) X-ray surveys, which probe the high-redshift Universe. The measured AGN X-ray luminosity function (XLF) shows that the number density of luminous ($L_X \gtrsim 10^{45} \text{ erg s}^{-1}$) quasars increases rapidly with redshift up to $z \sim 2$ and that $\sim 20\%$ (this fraction tends to decrease with increasing luminosity) of them are obscured (e.g. Ueda et al. 2014).

Therefore, our discovery of a powerful obscured quasar (or, equivalently, a NLRG) at $z \approx 0.44$ has evidently become possible due to a combination of two factors: i) strong cosmological evolution of the XLF and ii) higher sensitivity (for moderately obscured AGN, $N_H \lesssim 2 \times 10^{23} \text{ cm}^{-2}$) of the SRG/ART-XC all-sky survey compared to the *Swift*/BAT and *INTEGRAL*/IBIS all-sky surveys. The latter allowed us to reach further out into the Universe and thus probe a significantly larger comoving volume, which resulted in detecting one of only few luminous obscured quasars that have existed over the last 5 billion years.

In conclusion, SRGA J2306+1556 is one of the nearest luminous obscured quasars, similar in its intrinsic properties to powerful quasars and NLRGs that become abundant at significantly higher redshifts. As such, it can serve as a valuable testbed for in-depth exploration of the physics of such objects. Further studies of SRGA J2306+1556 could include its broader band X-ray spectroscopy to better constrain the spectral shape (in particular, to measure a high energy cutoff due to Compton recoil), low-frequency radio mapping to better expose the large-scale structures, and continued monitoring in X-ray, optical, IR, and radio bands to reveal luminosity and spectral variability.

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This work also made use of data supplied by the UK Swift Science Data Centre at the University of Leicester; data of the Sloan Digital Sky Survey IV, provided by the Alfred P. Sloan Foundation, the U.S. Department of Energy Office of Science, and the Participating Institutions; data obtained with the Dark Energy Spectroscopic Instrument (DESI), whose construction and operations is managed

by the Lawrence Berkeley National Laboratory; and data of the Very Large Array Sky Survey (VLASS) provided by the National Radio Astronomy Observatory and the Canadian Initiative for Radio Astronomy Data Analysis.

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DATA AVAILABILITY

The *Swift*/XRT, SDSS, DESI, and VLASS data used in this article are accessible through the corresponding web pages. At the time of writing, the SRG/ART-XC data and the corresponding data analysis software have a private status. We plan to provide public access to the ART-XC scientific archive in the future.

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