Broadband X-Ray Spectroscopy and Estimation of Spin of the Galactic Black Hole Candidate GRS 1758–258

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Abstract

We present the results of a broadband (0.5–78 keV) X-ray spectral study of the persistent Galactic black hole X-ray binary GRS 1758–258 observed simultaneously by Swift and NuSTAR. Fitting with an absorbed power-law model revealed a broad Fe line and reflection hump in the spectrum. We used different flavors of the relativistic reflection model for the spectral analysis. All models indicate the spin of the black hole in GRS 1758–258 is >0.92. The source was in the low hard state during the observation, with the hot electron temperature of the corona estimated to be $kT_e \sim 140$ keV. The black hole is found to be accreting at ~1.5% of the Eddington limit during the observation, assuming the black hole mass of 10 $M_\odot$ and distance of 8 kpc.

Unified Astronomy Thesaurus concepts: Astrophysical black holes (98); Accretion (14); Low-mass x-ray binary stars (939); Black hole physics (159); High energy astrophysics (739)

1. Introduction

Black hole X-ray binaries (BHXBs) are powered by the accretion process, where matter from the companion star gets accreted onto the central black hole (BH). The gravitational energy is converted to radiation emitted over the electromagnetic spectrum in the accretion process. Depending on the X-ray activity, a BHXB can be classified into a transient or a persistent source (Tetarenko et al. 2016). The transient source spends most of the time in a quiescent state with very low X-ray luminosity ($L_X < 10^{32}$ erg s$^{-1}$) and occasionally undergoes an outbursting phase when the X-ray luminosity increases to $L_X > 10^{35}$ erg s$^{-1}$. On the other hand, a persistent source is always found to be active in X-rays with the X-ray luminosity $L_X \sim 10^{35–37}$ erg s$^{-1}$ (e.g., Tetarenko et al. 2016).

A BH is characterized by its mass ($M_{\text{BH}}$) and spin ($a^*$). Estimation of the BH spin is harder compared to the estimation of BH mass. There exist various direct methods to estimate the BH mass, such as radial velocity measurement of the secondary, dips, and eclipses in the light curves (e.g., Kreidberg et al. 2012; Torres et al. 2019; Jana et al. 2022). The BH mass can also be estimated from the spectral modeling and timing analysis (e.g., Kubota et al. 1998; Shaposhnikov & Titarchuk 2007, 2009; Chatterjee et al. 2016; Jana et al. 2016, 2020, 2021a). The BH spin can be estimated from X-ray spectroscopy. In this method, the spin can be estimated in two processes: the continuum fitting (CF) method (e.g., Zhang et al. 1997; McClintock et al. 2006; Steiner et al. 2014), and the study of Fe line and reflection spectroscopy (e.g., Fabian et al. 1989; Miller et al. 2012; Reynolds 2021). Both methods require measuring the inner edge of the accretion disk that extends up to the inner most stable circular orbit (ISCO). It has also been suggested that the BH spin can affect the polarization state of X-ray emission (e.g., Schmittman & Krolik 2010; Dovčiak et al. 2011).

In the CF method, the inner radius of the accretion disk is measured by fitting the thermal disk continuum with a general relativistic model (e.g., Gierliński et al. 2001; McClintock et al. 2006; Shafee et al. 2006). In this process, one also needs to have prior knowledge of the BH mass, distance, and inclination angle. On the contrary, no knowledge of BH mass or distance is required to measure the spin in reflection spectroscopy. In this method, the reflection of the coronal emission at the inner disk is studied. The essential features of the reflection spectra are Fe fluorescent emission between 6.4 and 6.97 keV and a reflection hump around 15–40 keV. The accretion disk is optically thick and geometrically thin and extends up to the ISCO (Shakura & Sunyaev 1973). Due to the relativistic effect (Doppler shifts and gravitational redshift), the line profile of the Fe line originating from the inner accretion disk is blurred. As the ISCO depends on the spin, the study of the blurred spectra allows us to estimate the spin of the BH (Bardeen et al. 1972; Novikov & Thorne 1973).

The spin of the BH has been estimated using either the CF method, or reflection spectroscopy, or both. The CF method has been used to estimate spin for LMC X–1 (Mudambi et al. 2020), LMC X–3 (Bhuvana et al. 2021), and MAXI J1820 +070 (Zhao et al. 2021). The reflection spectroscopy is used to estimate spin for several BHs, e.g., MAXI J1535–571 (Miller et al. 2018), XTE J1908–094 (Draghici et al. 2021), Cygnus X–1 (Tomsick et al. 2018), MAXI J1631–479 (Xu et al. 2020), and GX 339–4 (García et al. 2019). Both reflection spectroscopy and CF have been used to measure the spin in a few BHs, e.g., GRS 1716–249 (Tao et al. 2019), LMC X–3 (Jana et al. 2021b), and GX 339–4 (Parker et al. 2016). The majority of the BHs are found to have prograde spin, i.e., the accretion flow rotates in the same direction as the BH. Only a few BHs are found to have retrograde spin, e.g., MAXI J1659–152 (Rout et al. 2020), Swift J1910.2–0546 (Reis et al. 2013), and GS 1124–683 (Morningstar et al. 2014). Nonetheless, the spin of the BH has been observed to have a wide range. Although, the spin has been measured for a substantial number of BHs, the spin of many BHs remains unknown.
GRS 1758–258 is a BH X-ray binary located in the close vicinity of the Galactic center. GRS 1758–258 was discovered by GRANAT/SIGMA in 1990 (Syunyaev et al. 1991). It is one of the few persistent BHXRBs in our Galaxy. The source has been observed in multiwavelengths over the years (e.g., Rodriguez et al. 1992; Mereghetti et al. 1994, 1997; Lin et al. 2000; Keck et al. 2001; Smith et al. 2001; Pottschmidt et al. 2006; Luque-Escamilla et al. 2014). It is considered to be a BH based on its spectral and timing properties (Sidoli & Mereghetti 2002). GRS 1758–258 is predominantly found to be in the low hard state (LHS; Soria et al. 2011). From the RXTE monitoring, Smith et al. (2002) reported a state transition to the soft state in 2001 with the 3–25 keV flux decreased by over an order of magnitude. GRS 1758–258 also shows two extended radio lobes, which makes the system a microquasar (Rodriguez et al. 1992). For a long time, the companion star was not identified due to the dense stellar population in the field. Recently, the spectroscopic study suggested that the companion is likely an A-type main-sequence star (Martí et al. 2016). The orbital period of GRS 1758–258 is reported to be 18.45 ± 0.10 days (Smith et al. 2002).

GRS 1758–258 is the least studied source among three persistent Galactic BH binaries. The mass and spin of the BH in GRS 1758–258 are not known yet. In this paper, we aim to estimate the spin of the BH in GRS 1758–258 from the broadband X-ray spectroscopy. The paper is organized in the following way. We present the observation and data reduction technique in Section 2. In Section 3, we present the analysis and result. Finally, we discuss our findings in Section 4.

2. Observations and Data Reduction

NuSTAR observed GRS 1758–258 on 2018 September 28, for a total exposure of 42 ks (see Table 1). NuSTAR is a hard X-ray focusing telescope, consisting of two identical modules: FPMA and FPMB (Harrison et al. 2013). The raw data were reprocessed with the NuSTAR data analysis software (NuSTARDAS, version 1.4.1). Cleaned event files were generated and calibrated by using the standard filtering criteria in the nupipeline task and the latest calibration data files available in the NuSTAR calibration database (CALDB). The source and background products were extracted by considering circular regions with radii 60′′ and 90′′, at the source coordinate and away from the source, respectively. The spectra and light curves were extracted using the nuproduct task. We rebinned the spectra with 30 counts per bin by using the grppha task.

Swift/XRT observed GRS 1758–258 simultaneously with NuSTAR for an exposure of 1.7 ks in window-timing (WT) mode. The XRT spectrum did not suffer from photon pileup. In general, the pileup occurs if the count rate is over 100 counts s⁻¹ in the WT mode (Romano et al. 2006).

| Instrument | Date (UT) | Obs ID | Exposure (ks) | Count (s⁻¹) |
|------------|-----------|--------|---------------|-------------|
| NuSTAR     | 2018-09-28| 30401030002 | 42           | 17.39 ± 0.02 |
| Swift/XRT  | 2018-09-28| 00088767001  | 1.7          | 7.88 ± 0.07  |

Figure 1 shows the 3–78 keV light curve of GRS 1758–258 from the NuSTAR observation. The light curve is binned at 100 s. Bottom panel: variation of the hardness ratio (HR). The HR is defined as the ratio of count rates in the 6–30 keV range to the 3–6 keV range.

0.5–10 keV spectrum was generated using the standard online tools provided by the UK Swift Science Data Centre (Evans et al. 2009). For the present study, we used simultaneous observations of Swift/XRT and NuSTAR in the 0.5–78 keV energy range.

3. Analysis and Result

Figure 1 shows the 3–78 keV light curve of GRS 1758–258 from the NuSTAR observation in the top panel. In the bottom panel of Figure 1, the variation of the hardness ratio (HR) is shown. We define the HR as the ratio of the count rate in the 6–30 keV to the 3–6 keV energy ranges. We did not observe any variation in the count rate or HR during the observation period. Hence, we carried out the spectral analysis using the time-averaged spectrum obtained from the observation. The spectral analysis was carried out in HEASARC’s spectral analysis package XSPEC version 12.8.2 (Arnaud 1996). For the analysis, we used the TBABS model for the interstellar absorption with the WILMS abundance (Wilms et al. 2000) and the cross section of Verner et al. (1996).

Generally, X-ray spectra of BHXRBs can be approximated by a multicolor disk blackbody (MCD) and power-law components. Additionally, reprocessed emission may be observed: a Fe K line at ~6.4 keV and a reflection hump at ~15–40 keV. We started our spectral analysis with the Swift/XRT+NuSTAR data in the 0.5–78 keV energy range. The MCD component may not be present in the LHS. Thus, we attempted to fit the data with the absorbed power-law model with an exponential high energy cutoff. This model did not give us an acceptable fit with clear signatures of the Fe K line, and a reflection hump in the 5–8 keV and 15–40 keV energy ranges, respectively. Figure 2 shows the 3–78 keV NuSTAR spectrum in the top panel. For clarity, we only show the NuSTAR spectrum. The bottom panel of Figure 2 shows the residuals in terms of data/model ratio. We added a Gaussian line to incorporate the Fe K line in the 5–8 keV energy range to improve the fit. Although, the fit improved with Δχ² = 91 for 3 degrees of freedom (dof), it was still unacceptable as the
corresponding reduced χ² is mentioned.

3.1. Relxill

The RELXILL model uses a cutoff power law as an incident primary emission. In this model, the reflection strength is measured in terms of reflection fraction \( R_{\text{cut}} \), which is defined as the ratio of reflected emission to the direct emission to the observer. A broken power-law emission profile is assumed in the RELXILL model with \( E(r) \sim R^{-\theta_{in}} \) for \( r > R_{\text{in}} \) and \( E(r) \sim R^{-\theta_{out}} \) for \( r < R_{\text{in}} \), where \( E(r) \), \( q_{\text{in}} \), \( q_{\text{out}} \), and \( R_{\text{in}} \) are emissivity, inner emissivity index, outer emissivity index, and break radius, respectively.

We used the RELXILL model in two assumptions: first by keeping the inner and outer emissivity indices fixed at the default value, i.e., \( q_{\text{in}} = q_{\text{out}} = 3 \) (hereafter Relxill-1); and second, allowing the inner and outer emissivity index to vary freely (hereafter Relxill-2). During our analysis, we fixed the outer disk at \( R_{\text{out}} = 1000 R_g \). Both models gave us a good fit with \( \chi^2/\text{dof} = 1718/1618 \) and 1691/1617 for Relxill-1 and Relxill-2, respectively. Although RELXILL-2 gave us a better fit. Both models indicated a high spinning BH with spin parameter, \( a^* > 0.94 \). The accretion disk is found to extend almost up to the ISCO, as we obtained \( R_{\text{in}} = 1.14_{-0.03}^{+0.02} R_{\text{ISCO}} \) and \( 1.13_{-0.02}^{+0.03} R_{\text{ISCO}} \) from Relxill-1 and Relxill-2, respectively. We could not constrain the cutoff energy \( E_{\text{cut}} \) from these two models, as the cutoff energy pegged at the upper limit of the model at 1000 keV. The reflection is found to be weak with \( R_{\text{out}} \approx 0.39 \) and \( \approx 0.21 \) from the RELXILL-1 and RELXILL-2 models, respectively. With RELXILL-2, we obtained a steep inner emissivity \( q_{\text{in}} = 6.78_{-0.09}^{+0.07} \) and a flat outer emissivity index \( q_{\text{out}} = 2.04_{-0.08}^{+0.09} \) with the break radius \( R_{\text{break}} = 4.8_{-0.2}^{+0.3} R_g \).

We also included a disk component in our spectral analysis to check if the disk is present. The thermal disk component was modeled with DISKBB (Makishima et al. 1986). We obtained the inner disk temperature, \( kT_{\text{in}} = 0.18 \pm 0.12 \) keV. The other spectral parameters remained the same. The addition of the disk component did not improve our fit for both the RELXILL-1 and RELXILL-2 models. We checked if the disk component is required with FTOOLS task FTEST. The FTEST returned with probability = 1, indicating the disk component was not required. As statistically, the disk component was not required, we did not add the disk component for further analysis.
### Table 2: Spectral Analysis Results

| CUTOFF | Relxill-1 | Relxill-2 | RelxillCp | RelxillD | RelxillP | RelxillPcP |
|--------|-----------|-----------|-----------|----------|----------|-----------|
| $N_H \times 10^{22}$ cm$^{-2}$ | 0.86$^{+0.18}_{-0.18}$ | 2.55$^{+0.01}_{-0.01}$ | 2.56$^{+0.02}_{-0.02}$ | 2.54$^{+0.02}_{-0.02}$ | 2.53$^{+0.02}_{-0.01}$ | 2.52$^{+0.03}_{-0.02}$ |
| $\Gamma$ | 1.56$^{+0.00}_{-0.01}$ | 1.54$^{+0.01}_{-0.01}$ | 1.53$^{+0.02}_{-0.02}$ | 1.56$^{+0.02}_{-0.02}$ | 1.54$^{+0.02}_{-0.01}$ | 1.57$^{+0.02}_{-0.01}$ |
| $E_{cut}/kT_c$ (keV) | 500$^{+8}_{-28}$ | >946 | >925 | 134$^{+2}_{-2}$ | 300$^{+2}_{-2}$ | 406$^{+2}_{-2}$ |
| $q_{in}$ | ... | $\delta$ | 6.78$^{+0.05}_{-0.05}$ | 6.51$^{+0.05}_{-0.06}$ | 7.09$^{+0.11}_{-0.07}$ | ... |
| $q_{out}$ | ... | $\delta$ | 2.04$^{+0.06}_{-0.06}$ | 1.99$^{+0.08}_{-0.07}$ | 2.10$^{+0.04}_{-0.06}$ | ... |
| $R_{in}/h$ ($R_g$) | 10.8$^{+2.5}_{-1.4}$ | 4.8$^{+1.5}_{-1.5}$ | 5.3$^{+1.7}_{-1.7}$ | 4.5$^{+0.8}_{-0.8}$ | 3.4$^{+0.6}_{-0.6}$ | 3.7$^{+0.6}_{-0.6}$ |
| $R_{in}$ ($R_{ISCO}$) | 1.14$^{+0.04}_{-0.03}$ | 1.13$^{+0.04}_{-0.03}$ | 1.13$^{+0.03}_{-0.03}$ | 1.15$^{+0.03}_{-0.03}$ | 1.04$^{+0.03}_{-0.03}$ | 1.04$^{+0.03}_{-0.03}$ |
| $a^\ast$ | ... | ... | 0.97$^{+0.02}_{-0.02}$ | 0.97$^{+0.02}_{-0.02}$ | 0.97$^{+0.02}_{-0.02}$ | 0.97$^{+0.02}_{-0.02}$ |
| $i$ (degree) | ... | 31$^{+2}_{-2}$ | 32$^{+2}_{-2}$ | 29$^{+2}_{-2}$ | 37$^{+2}_{-2}$ | 27$^{+2}_{-2}$ |
| log($n_c$) (log cm$^{-3}$) | ... | 15$^7$ | 15$^7$ | 15$^7$ | 15$^7$ | 15$^7$ |
| log($\xi$) (log erg cm s$^{-1}$) | ... | 3.68$^{+0.03}_{-0.07}$ | 3.61$^{+0.10}_{-0.10}$ | 3.71$^{+0.14}_{-0.11}$ | 3.90$^{+0.17}_{-0.11}$ | 3.62$^{+0.10}_{-0.12}$ | 3.72$^{+0.12}_{-0.13}$ |
| $\chi^2$/dof | ... | ... | ... | ... | ... | ... |
| $N_{PL}/N_{tot}$ (10$^{-3}$ ph cm$^{-2}$ s$^{-1}$) | 0.12$^{+0.01}_{-0.01}$ | 5.02$^{+0.05}_{-0.03}$ | 4.75$^{+0.05}_{-0.05}$ | 4.68$^{+0.05}_{-0.07}$ | 4.61$^{+0.05}_{-0.04}$ | 22.7$^{+0.7}_{-0.8}$ | 22.7$^{+0.7}_{-0.8}$ |
| $\chi^2$/dof | 1484/1165 | 1718/1618 | 1691/1617 | 1691/1617 | 1712/1617 | 1715/1619 | 1726/1619 |
| $F_{2-10 \text{ keV}}$ | 5.49$^{+0.04}_{-0.03}$ | 5.69$^{+0.04}_{-0.05}$ | 5.71$^{+0.04}_{-0.04}$ | 5.70$^{+0.02}_{-0.03}$ | 5.64$^{+0.06}_{-0.05}$ | 5.68$^{+0.04}_{-0.03}$ | 5.68$^{+0.04}_{-0.03}$ |

Note. The $F_{2-10 \text{ keV}}$ is in units of 10$^{-10}$ erg cm$^{-2}$ s$^{-1}$. Errors are quoted at 1.6$\sigma$. $^a$ Indicates fixed value in the model; $^b$ indicates the value is fixed during the analysis.

#### 3.2. RelxillCp

For further spectral analysis, we applied the RELXILLCp model for the spectral analysis. The RELXILLCp has an advantage over RELXILL, as the RELXILLCp directly estimates the coronal properties, namely, the hot electron plasma temperature ($kT_c$). In RELXILLCp, the primary incident spectrum is computed using the NTHCOMP (Zdziarski et al. 1996; Życki et al. 1999) model, replacing CUTOFFPL in the RELXILL model. The analysis with RELXILLCp returned with a good fit with $\chi^2 = 1691$ for 1617 dof. We obtained a similar fit with this model with the spin and inner disk radius were found to be, $a^\ast = 0.97^{+0.01}_{-0.02}$ and $R_{in} = 1.13^{+0.03}_{-0.03}$, respectively. We also obtained the temperature of the Compton corona as $kT_c = 134^{+5}_{-2}$ keV.

#### 3.3. High Density Model: RelxillD

The RELXILL and RELXILLCp models consider a fixed density of the accretion disk as $n = 10^{15}$ cm$^{-3}$, while RELXILLD allows the density to vary. In this model, the incident primary emission is a cutoff power law with cutoff energy fixed at 300 keV. The spectral analysis with the RELXILLD model returned with a high spin $a^\ast > 0.98$. We obtained a steeper emissivity with the RELXILLD model with $q_{in} = 7.09^{+0.07}_{-0.11}$, compared to the RELXILL and RELXILLCp models. The inclination angle of the inner disk is found to be higher with higher density, with $i = 37^{+2}_{-2}$. We obtained the disk density as $n < 2 \times 10^{15}$ cm$^{-3}$. The detailed spectral analysis result is tabulated in Table 2.

#### 3.4. Lamppost Geometry: RelxillP and RelxillPcP

In the RELXILL model, no particular geometry of the corona is assumed. In the lamppost model, the corona is assumed to be a point source, located above the BH (García & Kallman 2010; Dauser et al. 2016). RELXILLLP and RELXILLPCP flavors of the RELXILL family of models assumed the lamppost geometry. The incident primary emission is either CUTOFF (RELXILLLP) or NTHCOMP (RELXILLPCP). The height of the corona ($h$) is an input parameter in this model.

We obtained a good fit with both the RELXILLLP and RELXILLPCP models, with the fit returned as $\chi^2 = 1715$ and $\chi^2 = 1726$ for 1619 dof, respectively. The coronal height ($h$) is obtained to be $h = 3.4^{+1.2}_{-1.1} R_g$ and $h = 3.7^{+0.9}_{-0.8} R_g$ from the RELXILLLP and RELXILLPCP models, respectively. The spin of the BH is obtained to be $a^\ast < 0.92$ from the analysis with these models. The reflection is obtained to be stronger with $R_{off} \sim 0.46$, compared to the other models. Table 2 shows the detailed spectral analysis results with the RELXILLLP and RELXILLPCP models.

#### 3.5. Error Estimation

To calculate the uncertainty of the best-fitted spectral parameters, we ran Markov Chain Monte Carlo (MCMC) in XSPEC. The chains were run with eight walkers for a total of 10$^6$ steps using the Goodman–Weare algorithm. We discarded the first 10,000 steps of the chains, assuming them to be in the “burn-in” phase. The uncertainty is estimated with “error” command at 1.6$\sigma$ confidence level. In the paper, we used the error at 1.6$\sigma$ level (90% confidence), or mentioned otherwise. Figure 5 shows the posterior distribution of the spectral parameters and errors obtained with the RELXILLLP model. The errors are mentioned at 1$\sigma$ level in Figure 5. The following models like RELXILL, RELXILLCp, or RELXILLD do not assume any coronal geometry, while RELXILLLP assumes lamppost geometry. As RELXILLLP provides a physical picture of the coronal geometry compared to other models mentioned before, we used the RELXILLLP model for the MCMC analysis.

#### 4. Discussion and Concluding Remarks

We studied the spectral properties of GRS 1758–258 using the data obtained by NuSTAR and Swift observatories in the

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6 https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/node43.html
energy range of 0.5–78 keV. We used various spectral models to understand the inner accretion flow during the observation period.

Figure 5 shows the degeneracy between several parameters. The spin parameter ($a'$) is observed to be correlated with the reflection fraction ($R_{\text{rel}}$) and anticorrelated with the inner disk radius ($R_{\text{in}}$). These are expected as the high spin would bring the disk closer to the BH, and would make reprocessed emission strong. We also observed the photon index ($\Gamma$) is anticorrelated with the ionization parameter ($\xi$). This indicates if the photon index decreases, the ionization increases, which means the hard X-rays are more effective in ionizing the disk.

During our analysis, the hydrogen column density was obtained to be $N_H \sim 2.5 \times 10^{22}$ cm$^{-2}$. However, this is higher than the previously reported $N_H$. Soria et al. (2011) found that $N_H \sim 1.5 \times 10^{22}$ cm$^{-2}$. The discrepancy arises due to consideration of the different abundances during the spectral analysis. Soria et al. (2011) assumed the abundances to be ANGR (Anders & Grevesse 1989), while we assumed WILM abundances. We checked this by assuming ANGR abundances during the spectral fits. Using ANGR abundances, the column density was obtained to be $N_H \sim 1.5 \times 10^{22}$ cm$^{-2}$.

The unabsorbed flux was obtained to be $F_{2-10 \text{ keV}} \sim 5.7 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$ in the 2–10 keV energy range. The bolometric flux ($F_{\text{bol}}$; in the 0.1–500 keV energy band) is estimated to be $F_{\text{bol}} \sim 2.6 \times 10^{-8}$ erg cm$^{-2}$ s$^{-1}$. From this, we calculated the bolometric luminosity as $L_{\text{bol}} \sim 2 \times 10^{37}$ erg s$^{-1}$, assuming the source distance of 8 kpc (Soria et al. 2011). Considering the mass of the BH in GRS 1758–258 as 10 $M_\odot$ (Soria et al. 2011), the Eddington ratio is obtained as $L/L_{\text{Edd}} \sim 0.015$ or 1.5% of the Eddington limit during the NuSTAR observation. GRS 1758–258 is predominately observed in a similar accretion state with the X-ray luminosity $L_X \sim 0.01–0.03 L_{\text{Edd}}$ (Soria et al. 2011).

The spectral analysis indicated that the source was observed in the LHS. The spectrum was found to be hard, with the photon index $\Gamma \sim 1.53–1.57$ from different spectral models. We could not estimate the cutoff energy as it was not constrained. The spectral fits with RELXILLCP gave us the temperature of the corona as $kT_c = 134^{+92}_{-73}$ keV. Assuming lamppost geometry, we obtained the corona temperature as $kT_c = 146^{+58}_{-32}$ keV. For completeness, we calculate the optical depth ($\tau$) of the corona using,

$$\tau = \frac{3}{4} + \frac{m_e c^2}{kT_c} \left(\frac{1}{\Gamma^2 - 1}\right) \left(1 + \frac{1}{\Gamma^2 + 1}\right) \frac{3}{2}$$

(Zdziarski et al. 1996). The optical depth is obtained to be $\tau = 1.33^{+0.31}_{-0.54}$ for the RELXILLCP model. The lamppost geometry gave $\tau = 1.30^{+0.30}_{-0.37}$, which is consistent with the RELXILLCP model. The observed coronal parameters are consistent with other BHs in the LHS (Yan et al. 2020). The height of the corona is obtained as $h \sim 3.4 R_g$ and $h \sim 3.7 R_g$ from the lamppost models RELXILLF and RELXILLPCP, respectively. We did not detect any signature of the accretion disk in our analysis of the 0.5–78 keV Swift/XRT+NuSTAR spectra. We tested this by adding a disk component (DISKBB in...
RELXILLD model indicated a higher inclination with models. We obtained a steeper inner emissivity index and RELXILLD models, we allowed XSPEC The Astrophysical Journal, = n(Slow spin solution is possible for GRS 1758 ∼ 10^20 cm^−3). We reanalyzed the data by keeping RELXILL-2 and RELXILLD models, respectively. A different lamppost models, with the RELXILL and RELXILLCP models showed that the same spectra can be fit with Fe 1.2, 2.7–3.2 A_v. The high density RELXILLD model also indicated similar iron abundances with Fe 3.17±0.11 A_v and Fe 3.28±0.11 A_v, respectively. It is often observed that the fitting with a low density disk gives a high iron abundance (e.g., Tomick et al. 2018). Various studies of Cygnus X–1 with the constant low density model yield the iron abundance Fe > 9 A_v (e.g., Walton et al. 2016; Basak et al. 2017). Tomick et al. (2018) showed that the same spectra can be fitted with Fe = 1 A_v with the density of the disk as n ~ 4 × 10^{20} cm^{-3}. In RELXILL, RELXILLCP, and RELXILLP models, the disk density is considered as n = 10^{15} cm^{-3} while the density is a free parameter in the RELXILLD model. The spectral analysis of GRS 1758–258 with the RELXILLD model returned the disk density as n < 2 × 10^{15} cm^{-3}. We reanalyzed the data by keeping A_v fixed at one. The fit became significantly worse with ∆χ^2 > 500 for 1 dof with n ~ 10^{18} cm^{-3}. Hence, the high density solution is not required for GRS 1758–258.

The spin of the BH in GRS 1758–258 is estimated to be very high with a* > 0.93. RELXILL-1, RELXILL-2, and RELXILLP indicated the spin of the BH to be a* = 0.97±0.02, 0.96±0.02 and 0.97±0.02, respectively. The RELXILLD model even indicated a higher spin, with a* > 0.98. We obtained the spin of the BH as a* = 0.97±0.02 and 0.95±0.02 from the RELXILLP and RELXILLP models, respectively. We also checked if a low spin solution is possible for GRS 1758–258. We fixed the spin at zero, and reanalyzed the 0.5–78 keV XRT+NuSTAR data with all the models. All models returned with a significantly worse fit with ∆χ^2 > 60 for 1 dof. Hence, a high spin solution is preferred for GRS 1758–258.

In our analysis, we obtained a good fit from all reflection based models, with χ^2_{red} ~ 1.04–1.07. Statistically, RELXILL-2 and RELXILLCP returned a better fit than other variants of the model with ∆χ^2 ~ 20. Nonetheless, our analysis shows that GRS 1758–258 hosts a high spinning BH, with a* > 0.92. In future, high resolution spectroscopy missions, such as XRISM (Tashiro et al. 2018), ATHENA (Nandra et al. 2013), AXIS (Mushotzky 2018), Colibri (Heyl et al. 2019; Caiazzo et al. 2019), and HEX-P (Madsen et al. 2018) are expected to constrain or reconfirm the BH spin of GRS 1758–258 more accurately.

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Facilities: Swift, NuSTAR.
Software: XSPEC; NUSTARDAS; PYTHON; CORNER; PY; ASTROPY; SCIPY; MATPLOTLIB; GRACE.

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