THE ACCRETION DISK AND IONIZED ABSORBER OF THE 9.7 hr DIPPING BLACK HOLE BINARY MAXI J1305−704

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ABSTRACT

We report the results from X-ray studies of the newly discovered black hole candidate MAXI J1305−704 based on Suzaku and Swift observations in the low/hard and high/soft states, respectively. The long Suzaku observation shows two types of clear absorption dips, both of which recur on a dip interval of 9.74 ± 0.04 hr, which we identify with the orbital period. There is also partially ionized absorption in the nondip (persistent) emission in both the high/soft state and, very unusually, the low/hard state. However, this absorption (in both states) has substantially lower ionization than that seen in other high inclination systems, where the material forms a homogeneous disk wind. Here instead the absorption is most likely associated with clumpy, compact structures associated with the dipping material, which we see uniquely in this source likely because we view it at a very large inclination angle. A large inclination angle is also favored, together with a low black hole mass, to explain the high disk temperature seen in the fairly low luminosity high/soft state, as Doppler boosting enhances the disk temperature at high inclination. The disk radius inferred from these data is significantly smaller than that of the soft component seen in the low/hard state, supporting models where the disk is truncated at low luminosities. We find, however, that the lack of variability power on timescales of ~50 s in the Suzaku low/hard state data is difficult to explain, even with a low-mass black hole.

Key words: accretion, accretion disks – black hole physics – line: profiles – X-rays: binaries – X-rays: individual (MAXI J1305−704)

Online-only material: color figures

1. INTRODUCTION

Transient black hole X-ray binaries (BHXBs) are the best laboratories to study the physics of the accretion flow in a wide range of mass accretion rates. They make drastic changes in spectral properties during their outburst while exhibiting orders of magnitude increase and decrease in their X-ray luminosity, suggesting that the geometry of the inner disk differs significantly according to the mass accretion rate (e.g., McClintock & Remillard 2006; Done et al. 2007, and references therein). In low X-ray luminosity phases, they show a relatively hard, power-law-shaped spectrum with a photon index of less than 2.0 and an exponential cutoff at \( \approx 100 \) keV, which is generally interpreted as the disk emission Comptonized by thermal electrons in the surrounding corona. This state is called the “low/hard state,” in which the inner part of the standard disk (Shakura & Sunyaev 1973) is thought to be truncated. Following the rapid increase of the X-ray luminosity in outbursts, they undergo a state transition to the so-called “high/soft state” typically at a mass accretion rate of \( \approx 0.1 \) \( L_{\text{Edd}} \) (\( L_{\text{Edd}} \) is the Eddington luminosity: \( 4\pi Gm_0 c M_{BH}/\sigma_T \), where \( G, m_0, c, M_{BH}, \) and \( \sigma_T \) represent the gravitational constant, proton mass, speed of light, black hole mass, and Thomson scattering cross-section, respectively), in which the soft X-ray flux is dominated by thermal emission from the standard accretion disk.

Many previous studies showed that the inner disk radius remains constant during the high/soft state (see, e.g., Ebisawa et al. 1993). This suggests that the disk extends down to the innermost stable circular orbit (hereafter ISCO) in the high/soft state. The properties of fast-time variabilities are also remarkably different between the low/hard state and the high/soft state. In the low/hard state, BHXBs show noisy light curves on timescales of up to a hundred seconds. Their power density spectra (PDSs) are roughly characterized with the so-called band-limited noise with a flat profile in the \( v \nu \) spectrum \( (v \nu \propto \nu^0) \) within the low- and high-frequency break, below and above which the power declines as \( v \nu \propto \nu^0 \) and \( v \nu \propto \nu^{-1} \), respectively. This noise profile is better described as a superposition of multiple Lorentzians (Belloni et al. 1990, 2002; Nowak 2000). Negoro et al. (2001) reported that these structures are reproduced by the superposition of “shots” (flare-like events) seen in the low-/hard-state light curve, which are thought to be related to density fluctuation of advection-dominated accretion flow inside the inner edge of the standard disk (e.g., Manmoto...
et al. 1996). In contrast, rapid variability is typically weak in the high/soft state, where the constant standard disk emission dominates the X-ray flux (e.g., Homan et al. 2001). The low-frequency break of the band-limited noise seen in the low/hard state moves toward higher frequencies as the X-ray luminosity increases, and the profile of PDS is smoothly connected to those in the high/soft state through the intermediate or very high state (van der Klis 2004; Axelsson et al. 2005). These characteristics support the idea that the standard disk is truncated and the inner edge moves inward to reach ISCO as the luminosity increases (Ingram & Done 2012).

BHXBs with a relatively high inclination angle are particularly interesting objects because they give us key information to uncover the structure of the outer accretion disk. In the high/soft state, these sources often exhibit highly ionized blue-shifted absorption lines that originate in the “disk wind” outflowing from the outer region of the accretion disk (e.g., Ueda et al. 1998; Kotani et al. 2000; Miller et al. 2006a; Kubota et al. 2007; Ponti et al. 2012). Importantly, the mass-loss rate of a disk wind is comparable with, or even several to a few dozens times larger than, the mass accretion rate (Ueda et al. 2004; Neilsen et al. 2011), which suggests that the disk wind would also affect the properties of the inner region of the disk and play a critical role in accretion disk physics.

High inclination X-ray binary systems often show quasiperiodic dips accompanied by spectral hardening in their light curves. It is generally believed that the dips are caused by absorption of the X-ray emission from the central source with a dense structure in outer disks such as the “bulge,” which is formed by the accretion stream from the companion star impacting the rim of the disk (see, e.g., White & Swank 1982). Previous studies showed that dipping spectra are well reproduced by a partial absorption by neutral material (e.g., Marshall et al. 1993). While this approach was successfully applied in many sources including both neutron star and BHXBs, another explanation has recently been proposed: Boirin et al. (2005) and Díaz Trigo et al. (2006) successfully described both nondipping and dipping spectra of neutron star low-mass X-ray binaries, using a single photoionized absorption model with different column densities and ionization parameters. It is suggested that absorption dips are generally caused by ionized gas of a lower ionization state and a higher column density than the disk winds (see Section 5.2).

MAXI J1305−704 is an X-ray transient discovered on 2012 April 9 (Sato et al. 2012) with Monitor of All-sky X-ray Image/Gas Slit Camera (MAXI/GSC; Matsuoka et al. 2009). The monitoring results with the GSC suggest that the source is likely a BHXB, as its hardness–intensity diagram showed a q-shaped hysteresis over the whole outburst, and the spectrum during the soft phase is well modeled with thermal emission from the standard disk like those of typical BHXBs in the high/soft state (Morihana et al. 2013). Many of follow-up observations were triggered in the X-ray and other wavelengths. However, multiple Swift X-ray telescope (XRT) observations discovered dips in the X-ray light curves whose interval has still been controversial: 1.5 hr and 2.7 hr were suggested by Kennea et al. (2012). Swift/XRT also detected strong ionized absorption lines, likely originated in the disk wind (Miller et al. 2012a). Chandra HETGS discovered a complex absorption feature around 1 keV, which can be reproduced by ionized iron-L absorption lines (Miller et al. 2012b). Those dips and absorption profiles strongly indicate that the source has a large inclination angle, although the precise value is not yet determined. The optical and near-infrared counterparts were also detected in the observations performed about a few days after the start of the outburst (Greiner et al. 2012).

In this paper, we present the results of a Suzaku Target of Opportunity (TOO) observation of MAXI J1305−704 performed during the low/hard state to investigate the detailed properties of the accretion flow, dips, and ionized absorbers in a low-mass accretion rate. The data obtained from a Swift/XRT observation during the high/soft state are also analyzed to be compared with the Suzaku results. In addition, we report the near-infrared observations with the 1.4 m telescope of Infrared Survey Facility (IRSF) performed quasi-simultaneously with the Suzaku observation and in an earlier epoch when MAXI J1305−704 was in the high/soft state. Errors represent the 90% confidence range for a single parameter in the following sections. Throughout the paper, we refer to the table by Anders & Grevesse (1989) as the solar abundances.

2. X-RAY OBSERVATION AND DATA REDUCTION

2.1. Suzaku Observation in the Low/Hard State

We observed MAXI J1305−704 with Suzaku (Mitsuda et al. 2007) from 2012 July 20 18:10:29 (UT) to 22 00:30:23 for a net exposure of ≈40 ks. This was carried out as a TOO observation based on the monitoring by MAXI/GSC. Suzaku carries an X-ray CCD camera called the X-ray Imaging Spectrometer (XIS), operated in the energy range of 0.2–12 keV, and a non-imaging collimated instrument called the Hard X-ray Detector (HXD), which consists of PIN silicon diodes sensitive to 10–70 keV and gadolinium silicon oxide (GSO) crystal scintillators covering 40–600 keV. The XIS consists of two frontside-illuminated (FI) chips (XIS-0 and XIS-3) and a backside-illuminated (BI) chip (XIS-1), which has a larger effective area than the FI chips below ≈1.5 keV and a higher sensitivity to low-energy X-rays. In this observation, the 1/4 window option was employed for the XIS. The actual observed count rate was ≈5 counts s⁻¹ on average, which is low enough that we can ignore any effects by pileup. The Suzaku observation (MJD 56128–55130) corresponds to the period after the spectral hardening at the end of the outburst in 2012 June (Morihana et al. 2013), suggesting that the source was in the low/hard state in our observation.

We utilized the cleaned event data produced by the pipeline processing version 2.7.16.33 and reduced them with HEASOFT version 6.12 and Calibration Database (CALDB) released on 2012 October 5. The source events of the XIS were extracted from a circular region centered on the source position with a radius of 1.9. The background was taken from a circular region with the same radius in a source-free area. For the non-X-ray background of the HXD, we used the modeled background files provided by the Suzaku team. The modeled spectrum of the cosmic X-ray background was subtracted from the PIN data, but not from the GSO data, because its contribution is less than 0.1% of the total background rate of the GSO. The PIN and GSO data were corrected for dead time with hxdtdcor. The XIS response matrix and ancillary response files were created with the xisrmfgen and xissimarfgen, respectively, to be used in our spectral analysis. We utilized ae_hxd_pinxinom11_20110601.rsp as the response file for PIN, and ae_hxd_gsoxinom_20100524.rsp

12 http://www.astro.isas.ac.jp/suzaku/analysis/hxd/gsonxb/
and ae_hxd_gsoxinom_crab_20100526.arf\textsuperscript{13} for GSO. We combined the spectra and response files of the FI-XISs (XIS-0 and XIS-3) to improve statistics. The data in the 1.7–1.9 keV band were always ignored in the spectral fits due to the systematic uncertainties in the instrumental Si-K edge. A 1% systematic error was included in each bin of the XIS and HXD spectra to account for possible calibration uncertainties.

The spectra of the FI-XISs, BI-XIS, and HXD were simultaneously fitted in the spectral analysis. The cross-normalization of the HXD with respect to the FI-XISs was fixed at 1.16.\textsuperscript{14} We corrected for cross-calibration errors in the energy responses between the FI-XISs and BI-XIS, as we found that our FI-XIS data resulted in significantly harder spectra than the BI-XIS data from the individual spectral analysis, probably due to uncertainties in modeling the contamination on the XIS window filters. To examine these uncertainties in the period near our observation, we analyzed two Suzaku archival data of the blazar PKS 2155–304 observed on 2012 April 27–29 and October 30 and 31, both of which were operated with the same (1/4) window option. We created time-averaged FI-XIS and BI-XIS spectra separately for the two epochs, using the same versions of HEASOFT and CALDB as those applied in the analysis of the MAXI J1305–704 data. The spectra were fitted with an absorbed power-law model, in which the photon indices were linked between the FI-XIS and BI-XIS data. We found that the FI-XIS spectra show larger $N_{\text{H}}$ than the BI-XIS spectra by $\Delta N_{\text{H}} = 1.2 \times 10^{20} \text{ cm}^{-2}$ and $\Delta N_{\text{H}} = 2.0 \times 10^{20} \text{ cm}^{-2}$ in the April and October observations, respectively. Similarly, for the case of MAXI J1305–704, we estimated difference of $\Delta N_{\text{H}} = 3 \times 10^{20} \text{ cm}^{-2}$. To account for this offset, we unlinked the column density of the neutral absorption along with the flux normalization between the FI-XIS and BI-XIS spectra in the simultaneous fit. In the following section we show the column density obtained from the BI-XIS spectrum as the best estimated value. The inclusion of this correction is found to significantly improve the quality of the fit, although it does not affect the conclusion of this paper.

MAXI J1305–704 is located near a bright source 4U 1254–690 with a separation angle of 1°41, and the GSO flux can be contaminated by the emission from this nearby source (Takahashi et al. 2007). However, we confirmed that the contamination is completely negligible by considering the previous spectral study of 4U 1254–690 (Díaz Trigo et al. 2009)—the source is more than several orders of magnitude fainter than our target above 50 keV.

### 2.2. Swift/XRT Observations in the High/Soft State

Since its discovery, MAXI J1305–704 was observed with Swift/XRT many times. In order to compare the Suzaku data in the low/hard state with Swift ones in the high/soft state, we analyzed the data of Swift/XRT obtained from 2012 April 19 13:19:53 to 21 17:03:00 (UT). This is one of the longest ($\approx 10$ ks) Swift/XRT observations for this source in the high/soft state. Using this dataset, Miller et al. (2012a) reported the existence of a strong iron-K absorption line around 6.6 keV. In this observation, XRT was operated with the one-dimensional window timing mode. The data are not affected by pileup because the averaged count rate ($\approx 30$ counts s$^{-1}$) is much lower than the maximum pileup-free count rate (100 counts s$^{-1}$; Romano et al. 2006).

We used Swift/XRT archival data and performed the standard reduction with xrtpipeline. The source events were extracted from a box region of 40 pixels $\times$ 30 pixels along with the X- and Y-axis in the detector coordinates, respectively, with the center located at the target position. The background region was defined as two boxes of 40 pixels $\times$ 30 pixels in the source-free area at the same distance from the target position. We included 3% systematic error in each spectral bin to absorb possible calibration uncertainty.\textsuperscript{15} We utilized a response matrix file, ae_hxd_gsoxinom_crab_20100526.arf, taken from the Swift CALDB provided on 2012 October 5. The ancillary response file is created by using xrtpmkarf with the exposure file produced in the pipeline tool.

### 3. ANALYSIS AND RESULTS

#### 3.1. Suzaku Light Curve and Dip Feature

Figure 1 shows the Suzaku XIS-3 light curves in the soft (0.7–2 keV) and hard (2–10 keV) bands, together with their hardness ratio in 128 s binning. The light curve is highly variable, particularly in the soft band, suggesting that the variability is mainly caused by absorption. We can see two dipping features with different mean hardness ratios ($\approx 5$–10 for the softer ones and $\approx 20$–30 for the harder ones), in which more than 80% of the averaged flux is lost in the soft band, and those dips with similar mean hardness ratios are observed almost periodically. Here we define the start and end times of the dips as the points at which the hardness ratio crosses a value to 2.6 upward and downward in Figure 1. We then call the dips whose peak hardness ratios reach 20 in 128 s binning as “deep dips” and the other softer ones as “shallow dips.” In shorter timescales, the shallow dips have small variabilities with a typical timescale of a few minutes, while this behavior is not significant in the deep dips (Figure 2).

We find each dip recurrently occurs with a period of 9.74 ± 0.04 hr, which is calculated from the intervals of the start times

\textsuperscript{13} http://www.astro.isas.ac.jp/suzaku/analysis/hxd/gsoarf2/  
\textsuperscript{14} http://www.astro.isas.ac.jp/suzaku/doc/suzakumemo/suzakumemo-2008-06.pdf  
\textsuperscript{15} http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/swift/docs/xrt/SWIFT-XRT-CALDB-09_v16.pdf
of deep dips obtained in the XIS-3 hardness ratio with 64 s bin. The error is estimated by propagating the uncertainty of each measured start time, which is assumed as half width of time bins in the light curve (32 s). This interval, instead of the 1.5 or 2.7 hr suggested by Swift/XRT observations with shorter exposure (Kennea et al. 2012), likely corresponds to the orbital period. The light curves have data gaps with durations of 0.8–1.1 hr, which are not exactly periodic. The durations of the deep and shallow dips (1.0–1.7 hr) are comparable or larger than those of the data gaps. Because the hardness ratio never exceeds 2.6 outside of the dip phases we identified, it is unlikely that the actual period is shorter than 9.74 hr and we miss other dip events in these data gaps. We also note that dips do not always appear precisely in the same orbital phase, and the interval between the first and second deep dips is actually 50 s longer than that of second and third deep dips when we measure them from the light curve with shorter time bins. The interval from a deep dip to the next shallow dip is derived to be 6.38 ± 0.04 hr, which is obtained by averaging the intervals between the beginning of deep dips and those of the following shallow dips. However, the durations of the deep and shallow dips are not precisely constant, and consequently their intervals are slightly different event by event.

Figure 3 shows the normalized PDSs in the nondip phases in the 0.7–1 keV, 1–5 keV, and 5–10 keV bands, calculated from the combined light curve of all three XISs with 8 s bins. We find that the softer energy band has much larger power than those of the harder bands in the frequency range of $10^{-3}$ to $5 \times 10^{-2}$ Hz. This suggests that the power is likely dominated by the residual variability of absorption that exists even outside the dips. The source has only small intrinsic power ($\approx 1 \times 10^{-3}$ rms$^2$/mean$^2$) in the 5–10 keV band, where the flux variabilities are little affected by absorption. Thus, this frequency region is likely below the low-frequency break of the band-limited noise observed from BHXBs in the low/hard state.

3.2. Modeling Time-averaged Nondip Spectrum

We extract the time-averaged XIS and HXD spectra in the deep dip, shallow dip, and nondip phases and analyze them separately. In this subsection we concentrate on the nondip spectra. We utilize the energy bands of 0.7–9.0 keV, 0.7–8.0 keV, 12–70 keV, and 50–130 keV for FI-XISs, BI-XIS, HXD/PIN, and HXD/GSO, respectively, where the signal-to-noise ratios are sufficiently good and the calibration is the most reliable.

The nondip spectrum is roughly characterized by a power-law component extended up to 130 keV with a photon index of $\approx 1.591 \pm 0.005$ ($\chi^2$/dof = 1472/1171), although we find broad depressions around 0.75 keV and 0.9 keV. These structures likely correspond to the photoelectronic absorption lines and/or edges of highly ionized oxygen-K and iron-L shells, which are similar to "warm absorbers" seen in many active galactic nuclei such as MCG–6–30–15 (e.g., Nandra & Pounds 1992; Fabian et al. 1994) and NGC 4051 (e.g., Pounds et al. 1994; Mihara et al. 1994). The hard spectral shape suggests that the source stayed in the low/hard state during our observation. The exponential cutoff is not detected within the energy band of the non-dip spectrum ($<130$ keV), and therefore in the following analysis, we fix the cutoff energy at 300 keV, which is within the typical value observed from BHXBs in the low/hard state ($\lesssim 300$ keV; see, e.g., Tanaka & Shibazaki 1996).

To investigate the detailed properties of the accretion flow and the ionized absorber, we next analyze the nondip spectrum with a more sophisticated model. Following the general description of the X-ray spectrum in the low/hard state (e.g., Gierliński et al. 1997), we adopt a model composed of the multicolor disk (MCD) emission and its thermal Comptonization. The
ninthcomp model (Zdziarski et al. 1996; Zycki et al. 1999) and the diskbb model (Mitsuda et al. 1984) are employed to represent the Comptonization and direct emission from the disk, respectively. We assume that all the seed photons for the Comptonized component are produced by the disk and link the seed temperature of the ninthcomp model to the inner disk temperature of the MCD component. We add phabs as interstellar absorption, assuming the solar abundance. To consider reflection of Comptonized photons on the disk, we convolve the ninthcomp component with the reflect model. This model calculates a reflected spectrum from neutral material (Magdziarz & Zdziarski 1995). The reflect model does not contain the iron Kα emission line, whose equivalent width is ≈1 keV with respect to the reflected continuum, as suggested by numerical calculations (e.g., Matt et al. 1991). Hence, we add a Gaussian component as the iron-Kα emission line and fix the line energy and the line width at 6.4 keV and 10 eV, respectively.

The normalization of Gaussian component is linked to the equivalent width with respect to a reflection continuum (Ω). We first adopt a sin-2 power-law model with a photon index of 1.6 as the input spectrum calculated with XSTAR depend on the spectral shape of the incident radiation on the absorber, respectively, and the Doppler shift. The absorption spectra calculated with XSTAR depend on the spectral shape of the incident radiation on the absorber. We first adopt a single-power-law model with a photon index of 1.6 as the input spectrum for XSTAR and fit the resulting model to the nondip spectrum. Next, we re-create an XSTAR absorption model using the best-fit unabsorbed continuum model and then re-fit the spectrum with the newly obtained absorption model. These steps are performed in an iterative manner, until the parameters of the continuum model become identical to those obtained in the previous iteration within the ranges of 90% errors. In the following, we show the final best-fit results after the iteration.

To analyze the ionized absorption features, we create a photoionized absorption model with the spectral synthesis code XSTAR version 2.2.1bk, assuming that the ionized absorber has the solar abundances and that its turbulent velocity is 300 km s⁻¹. This model can be used in XSPEC as a multiplicative component with free parameters of the equivalent hydrogen column density (N_H), ionization parameter (ξ = L_X/n_H R^2), where L_X, n_H, and R represent the ionizing flux in the energy range of 1–1000 Ry [Rydberg unit; 1 Ry = 13.6 eV], the number density of hydrogen nuclei, and the distance from the X-ray source to absorber, respectively, and the Doppler shift. The absorption spectra calculated with XSTAR depend on the spectral shape of the incident radiation on the absorber. We first adopt a single-power-law model with a photon index of 1.6 as the input spectrum for XSTAR and fit the resulting model to the nondip spectrum. Next, we re-create an XSTAR absorption model using the best-fit unabsorbed continuum model and then re-fit the spectrum with the newly obtained absorption model. These steps are performed in an iterative manner, until the parameters of the continuum model become identical to those obtained in the previous iteration within the ranges of 90% errors. In the following, we show the final best-fit results after the iteration.

The final fitting model is thus expressed as phabs*xsabs*(diskbb+kdblur*(gaussian+reflect*ninthcomp)), where xsabs represents the XSTAR ionized absorption model. The spectra and the best-fit model are shown in Figures 4 and 5, and the resulting parameters are given in Table 1. We find that this model describes the Suzaku spectra reasonably well, with χ^2/dof = 1269/1165. The fit quality is improved from that of the power-law model with an F-test probability of 1 × 10⁻³⁴. The ionization parameter and column density are estimated as log ξ = 2.19 ± 0.04 and \( N_H = (6.1^{+1.0}_{-0.9}) \times 10^{21} \) cm⁻² for the ionized absorber, respectively. The Doppler shift is not detected with an upper limit of <2300 km s⁻¹. A small inner disk temperature (0.168±0.008 keV) and a large normalization of the MCD model (6.0^{+3.4}_{-2.4} × 10³) are obtained, which suggest that the standard disk is truncated (see Section 5.3) during the Suzaku observation. The hydrogen column density of neutral absorption, (1.2 ± 0.3) × 10²¹ cm⁻², is comparable to the total Galactic column in the direction of MAXI J1305–704 (≈1.8 × 10²¹ cm⁻²), estimated from the H I all-sky map by Kalberla et al. (2005) by utilizing the nh ftool.
Table 1
The Best-fit Parameters of Suzaku Spectra in the Deep Dip, Shallow Dip, and Nondip Periods

| Component | Parameter | Nondip | Deep Dip | Shallow Dip |
|-----------|-----------|--------|----------|-------------|
| phabs     | $N_H$ ($10^{22}$ cm$^{-2}$) | 0.12 ± 0.03 | 0.23$^{+0.04}_{-0.00}$ | 0.17 ± 0.02 |
| xsabs     | $N_H$ ($10^{22}$ cm$^{-2}$) | 0.61$^{+0.10}_{-0.09}$ | 14.4 ± 0.6 | 6.6$^{+0.5}_{-0.4}$ |
|           | log $\xi$  | 2.19 ± 0.04 | 1.90 ± 0.07 | 1.79 ± 0.07 |
|           | Blue shift (km)$^a$ | <2300 | <2700 | <5800 |
|           | Covering fraction | 1 (fix) | 0.91 ± 0.01 | 0.72$^{+0.10}_{-0.04}$ |
| diskbb    | $kT_{in}$ (keV) | 0.168$^{+0.008}_{-0.006}$ | 6.0$^{+3.4}_{-1.0}$ × 10$^3$ |
|           | Norm       | 1.70$^{+0.03}_{-0.02}$ |
| nthcomp   | $E_{cut}$ (keV) | 300 (fix) | 2.46$^{+0.05}_{-0.03}$ × 10$^{-2}$ |
|           | Norm       | 75 (fix) | 6.4 (fix) |
| reflect   | $\Omega/2\pi$ | 0.4 ± 0.2 |
|           | $i$ (deg)  | 75 (fix) |
| gauss$^b$ | $E_{cut}$ (keV) | 10 (fix) |
|           | $\sigma$ (eV) | 1.3 × 10$^{-10}$ | 7.1 × 10$^{-11}$ | 1.0 × 10$^{-10}$ |

$\chi^2$/dof = 1269/1165, 540/535, 1070/994, flux$^c$ = 1.3 × 10$^{-10}$ s$^{-1}$.

Notes. The nondip spectrum is fitted with phabs*xsabs*(diskbb+kdblur+reflect*nthcomp+gauss), where xsabs is an ionized absorption model created with XSTAR. In fitting the two dip spectra, all the parameters except for those of the neutral and ionized absorption components are fixed at the best-fit values of the nondip spectrum. The blank columns in the table of the dip spectra are the fixed parameters. Partial covering of the ionized absorber is included in the model of dipping spectra.

$^a$ Positive values represent blue shifts.

$^b$ The normalization of Gaussian component is linked to the reflection strength $\Omega/2\pi$ of the reflect model so that the equivalent width with respect to the reflection continuum is $\approx$1.0 keV.

$^c$ Absorbed 1–10 keV flux (erg cm$^{-2}$ s$^{-1}$).

Recent Suzaku observation of BHXBs in the low/hard state have revealed that the Comptonized plasmas are more complex than a single-zone homogeneous structure. Takahashi et al. (2008), Makishima et al. (2008), and Shidatsu et al. (2011) reproduced the time-averaged spectra with double Comptonization components that have different optical depths. Furthermore, Yamada et al. (2013) successfully separated the second variable component from the Suzaku spectra of Cyg X-1 in the low/hard state by considering timing information. Here we investigate whether or not these complex structures are also detected in MAXJ1305−704. We add another nthcomp component to the single nthcomp model to consider the double Comptonization corona. The seed temperatures of the two nthcomp models are linked to the inner disk temperature of the MCD component. We find, however, that this “double nthcomp” model does not improve the fit.

3.3. Analysis of Dip Spectra

We analyze the deep and shallow dip spectra with the same model that used for the nondip spectrum. Figure 6 compares the XIS and HXD spectra in the deep dip, shallow dip, and nondip phases. We obtain the HXD/PIN spectrum up to 60 keV for the shallow dip and up to 50 keV for the deep dip. However, the HXD/GSO data in the dips are not usable due to the limited photon statistics. We employ the final results described in the previous section and fix all the parameter at the best-fit value of the nondip spectrum, except for those of the neutral and ionized absorption components. Considering that dipping spectra are often modeled with partial absorbers, we introduce a covering fraction of the ionized absorber. The total fitting model for the dip spectra is described as phabs*(f*xsabs*(1-f)*

\( \text{diskbb+kdblur(} \text{gaussian+reflect*nthcomp}\)), where f corresponds to the covering fraction.

This model successfully reproduce the dip spectra, yielding $\chi^2$/dof = 540/535 and 1070/994 for the deep and shallow dips, respectively. We find that the two dip spectra can be described with more than one order of magnitude larger column densities and about a factor of two smaller ionization parameters than those of the nondip spectrum. The column density of the deep dip is twice as much as that of the shallow dip. The covering fraction f is estimated as 0.72$^{+0.03}_{-0.04}$ for the shallow dip, while the deep dip spectrum is almost totally absorbed, with f = 0.91 ± 0.01. The resulting parameters are listed in Table 1, and the best-fit spectra are plotted in Figure 7.

The xsabs model do not include the Comptonization in the ionized absorber itself. This might affect the fits, particularly for the deep dip spectrum in which the ionized absorber has a relatively large column density ($N_H \sim 10^{23}$ cm$^{-2}$). To account for the possible effects of Compton scattering, we add the cabs model to the final model with its column density linked to that of the ionized absorber and refit the deep dip spectrum. We find, however, that the effects are negligible and all the parameters remain unchanged within their 90% confidence ranges. We confirm that the energy dependence of the scattering cross section which is not included in cabs, is also negligible in our energy range. The column density of the deep dip corresponds to an optical depth of $\tau \approx 0.1$ in Thomson scattering, which only reduces to $\tau \approx 0.08$ at 50 keV.

3.4. Swift/XRT Spectrum in the High/Soft State

To compare the Suzaku nondip spectrum in the low/hard state with spectra in the high/soft state, we analyze a Swift/XRT spectrum of MAXI J1305−704 obtained from 2012 April 19 to 21 during the high/soft state. As described in Miller et al. (2012a), these XRT data also show dipping behaviors. We create a time-averaged nondip spectrum by extracting the events when the count rate exceeds 20 counts s$^{-1}$ in the 1–10 keV light curve with 16 s bins. Following the release note for the Swift XRT...
First we fit the XRT spectrum using an MCD model with a neutral absorption. A \texttt{simpl} model (Steiner et al. 2009) is also incorporated to account for Comptonization, with a fixed photon index of 2.2, a typical value in the high/soft state of BHXBs (e.g., Ebisawa et al. 1994; Done et al. 2007; Kolehmainen et al. 2011). We extend the energy range to 0.01–100 keV for the model calculation as \texttt{simpl} is a convolution model. We find that this model, \texttt{phabs*simpl*diskbb}, roughly describes the XRT spectrum with an inner disk temperature ($\approx$1.0 keV) and a small scattering fraction ($<2.6\%$ of the total disk emission), although the fit is far from acceptable ($\chi^2$/dof = 1749/370) mainly due to the broad absorption- (and/or emission-) like structures in the soft band below $\approx$1 keV. These large residuals are probably a composition of the iron-L absorption lines, which are detected in the \textit{Chandra} HETGS observation 10 days after the \textit{Swift} observation, as reported by Miller et al. (2012b). The XRT spectrum also has a narrow absorption line at about 6.6 keV, which likely corresponds to K lines of highly ionized iron ions. By fitting the line with a negative Gaussian, its center energy, line flux, and equivalent width are estimated to be $6.57^{+0.08}_{-0.07}$ keV, $2.7^{+4}_{-1.1} \times 10^{-4}$ erg cm$^{-2}$ s$^{-1}$ and $49^{+62}_{-35}$ eV, respectively.

We find that the unabsorbed flux in the 0.01–100 keV band, $1.4 \times 10^{-5}$ erg cm$^{-2}$ s$^{-1}$, is only $\approx$2.3 times larger than that of the \textit{Suzaku} nondip spectrum ($6.1 \times 10^{-10}$ erg cm$^{-2}$ s$^{-1}$). This suggests that MAXI J1305–704 was in a relatively faint high/soft state and that the bolometric luminosity in the \textit{Swift} observation was comparable with that in the soft-to-hard transition, typically $\approx 0.02L_{\text{Edd}}$ (Maccarone 2003). However, the inner disk temperature is too high to be expected for such a faint high/soft state with a low accretion rate. This could be understood in the way that the strong relativistic beaming effects due to a high inclination angle and/or a high black hole spin significantly modify the disk spectrum, and consequently we obtain an apparently higher inner temperature than the intrinsic one. We therefore replace \texttt{diskbb} with \texttt{bhspec} (Davis et al. 2005), a relativistic disk emission model, to fit the spectra (i.e., \texttt{phabs*simpl*bhspec}; Model 1 in Table 2). The \texttt{bhspec} model calculates the radiation transfer in the accretion disk around a black hole by self-consistently considering its vertical structure. The model parameters are the black hole mass ($M_{\text{BH}}$), spin parameter ($\alpha = cJ/GM_{\text{BH}}^2$, where $J$ represents angular momentum of the black hole), distance, inclination angle, disk luminosity, and the $\alpha$ parameter, which we fix at 0.01. Here we assume a black hole mass of $M_{\text{BH}} = 3 M_{\odot}$, a high inclination, $i = 75^\circ$ (see Section 5.1), and a disk luminosity corresponding to 0.05 $L_{\text{Edd}}$, and leave $\alpha$ and the normalization $K$, which is related to the distance $d$ via $K = (10 \text{ kpc}/d)^2$, as free parameters. We find that the \textit{Swift}/XRT spectrum favors this \texttt{bhspec} model better than the \texttt{diskbb} model with a smaller reduced chi-squared value ($\chi^2$/dof = 1687/370). A moderate spin parameter ($\alpha \approx 0.7$) is obtained.

To investigate the properties of the ionized absorber responsible for the structures at 6.6 keV and below $\approx$1 keV, we create a multiplicative photoionized absorption model by utilizing \texttt{XSSTAR} to fit the nondip XRT spectrum. We adopt an MCD with an inner temperature of 1.0 keV as the incident spectrum in the energy range of 1–1000 Ry. The ionized absorber is assumed to have the solar abundances and a turbulent velocity of 300 km s$^{-1}$. The fit is much improved ($\chi^2$/dof = 1018/367) by using this model, \texttt{phabs*xsabs*simpl*bhspec} (Model 2 in Table 2), where the \texttt{xsabs} represents the photoionized absorption. We obtain an ionization parameter of $\log \xi \approx 2.6$ and an equivalent hydrogen column density of $\approx 8 \times 10^{22}$ cm$^{-2}$.

CALDB,\footnote{http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/swift/docs/xrt/SWIFT-XRT-CALDB-09_v16.pdf} we use the data down to 0.3 keV for the following spectral fit, where the calibration of the energy response is reliable.

\begin{figure}[h!]
\centering
\includegraphics[width=\textwidth]{figure7.png}
\caption{The spectra, best-fit models, and data vs. model ratios in the dipping and nondip phases. The top, middle, and bottom panels show the results in the deep dip, shallow dip, and nondip phases, respectively. The dipping spectra are fitted with the best-fit model of the nondip spectrum. The XIS-1 and HXD spectra are ignored in all panels for illustrating purposes. (A color version of this figure is available in the online journal.)}
\end{figure}
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The fit is still far from acceptable, however, due to the large residuals at around 0.7 keV and 1.2 keV, which cannot be explained by calibration uncertainties of the response. The iron-K absorption line is not well modeled either, likely because these structures at around 1 keV lead to wrong constraints on the parameters of the ionized absorption component. Moreover, the residuals are not originated from the uncertainties of bhspec in modeling absorption edges. We confirm that the quality of the fit is not improved by replacing the bhspec component with another relativistic disk emission model, kerrbb, which does not consider the vertical structure of the disk and has no absorption edges. Furthermore, they are neither reproduced by ionized O and Ne edges of additional absorption components nor by a superposition of emission lines created by the ionized absorber, which can never produce huge equivalent widths to fit the structures. We also change the oxygen, neon, and iron abundances in the model, which could produce artificial emission and/or absorption-like structures around 0.5–1.0 keV if not appropriate. While the fit is not improved by varying the iron abundance, a better fit is obtained with a smaller oxygen abundance: $\chi^2/dof = 734/367$ for an oxygen abundance of 0.5 in the solar unit both for neutral and ionized absorbers. Nevertheless, we find that huge residuals still remain at $\approx 0.7$ keV even in the extreme case of no oxygen. A larger neon abundance also gives a better fit, but the improvement of $\chi^2$ value is not as significant as the oxygen abundance (at best $\chi^2/dof = 930/366$ for a neon abundance of 9.0 in the solar unit). Thus, the oxygen and neon abundances in the absorbers cannot entirely explain the differences between the data and model in the soft energy band. We find that the structures below $\approx 1$ keV are well reproduced by empirically adding two broad Gaussian components at 0.75 keV and 1.2 keV with line widths of $\approx 100$ eV and 140 eV, and equivalent widths of $\approx 160$ eV and 60 eV, respectively. The fit is significantly improved and becomes acceptable ($\chi^2/dof = 313/361$) with this model $\text{phabs*}(\text{xabs2}*\text{xabs1})*\text{bhspec+gauss+gauss}$ where the solar abundances are assumed for both the ionized and neutral absorbers. For the ionized absorber, the resulting ionization parameter is $\log \xi = 1.7 \pm 0.1$ and the column density is $(1.4^{+0.4}_{-0.3}) \times 10^{22} \text{ cm}^{-2}$. However, the equivalent width of the iron-K absorption line estimated from this model is somewhat smaller than what is actually seen in the Swift/XRT spectrum. We therefore add another ionized absorption component and fit the spectrum with the model expressed as $\text{phabs*}(\text{xabs2}*\text{xabs1})*\text{bhspec+gauss+gauss}$

| Component | Parameter | Model 1a | Model 2b | Model 3c | Model 4d |
|-----------|-----------|----------|----------|----------|----------|
| phabs     | $N_H (10^{22} \text{ cm}^{-2})$ | 0.097 ± 0.002 | 0.123 ± 0.004 | 0.097 ± 0.020 | 0.098 ± 0.006 |
| xsabs1    | $N_H (10^{22} \text{ cm}^{-2})$ | $7.81^{+1.4}_{-1.3}$ | 5.1 ± 3.8 | 5.8 ± 3.4 |
|           | log $\xi$ | $2.64 \pm 0.06$ | $2.86 \pm 0.52$ | $2.86 \pm 0.18$ |
|           | Blue shift (km) | $1700^{1000}_{-1200}$ | <4800 | <3400 |
| xsabs2    | $N_H (10^{22} \text{ cm}^{-2})$ | ... | 1.0 ± 0.4 | 1.5 ± 0.6 |
|           | log $\xi$ | ... | 1.2 ± 0.2 | 1.7 ± 0.1 |
|           | Blue shift (km) | ... | 0 (fix) | 0 (fix) |
| diskbb    | $T_a$ (keV) | ... | ... | 0.85 ± 0.03 |
|           | Norm       | ... | ... | 139 ± 26 |
| bhspec    | $\alpha$   | 0.69 ± 0.01 | 0.56 ± 0.02 | 0.46 ± 0.06 |
|           | Norm       | 1.77 ± 0.01 | 2.35 ± 0.06 | 2.5 ± 0.3 |
| simpl     | $\Gamma$   | 2.2 (fix) | 2.2 (fix) | 2.2 (fix) |
| gaussian  | Line energy (keV) | <0.003 | 0.02 ± 0.01 | 0.03 ± 0.01 | 0.04 ± 0.01 |
|           | $\sigma$   | ... | 1.17 ± 0.03 | 1.19 ± 0.06 |
|           | Norm       | ... | 0.14 ± 0.3 | 0.15 ± 0.04 |
|           | EW (eV)    | ... | 0.022 ± 0.009 | 0.017 ± 0.008 |
| gaussian  | Line energy (keV) | ... | 0.74 ± 0.01 | 0.75 ± 0.01 |
|           | $\sigma$   | ... | 0.10 ± 0.01 | 0.10 ± 0.01 |
|           | Norm       | ... | 0.11 ± 0.01 | 0.10 ± 0.01 |
|           | EW (eV)    | ... | 159 ± 22 | 183 ± 18 |

$\chi^2/dof$: 1687/370, 1018/367, 294/359, 292/359

Notes.

1. $\text{phabs*}\text{bhspec}$.
2. $\text{phabs*}\text{xabs1*gauss}$.
3. $\text{phabs*}(\text{xabs2}*\text{xabs1})*\text{bhspec+gauss+gauss}$.
4. $\text{phabs*}(\text{xabs2}*\text{xabs1})*\text{diskbb+gauss+gauss}$, for direct comparison with the disk flux obtained from the Suzaku non-dip spectrum.
5. Ionized absorption model created with XSTAR. Incident spectrum is defined as the diskbb model with a inner temperature of 1.0 keV. We assume a turbulent velocity of 300 km s$^{-1}$.
6. Positive values represent blue shifts.
7. We assume $i = 75^\circ$, $M_{BH} = 3 M_\odot$, luminosity = 0.05 $L_{Edd}$, and $\alpha = 0.8$, where $\alpha$ represents the viscosity parameter in the Shakura & Sunyaev (1973) prescription for the stress $\tau_{r\phi} = \alpha \times P$ ($P$ is the total pressure).
Model 1

0.01

0.1

1

keV² (Photons cm⁻² s⁻¹ keV⁻¹)

Model 2

10.5

2

5

0.5

1

1.5

ratio

Energ (keV) Ener (keV)

Model

10.5

2

5

0.5

1

1.5

ratio

Energ (keV) Energ (keV)

Figure 8. The time-averaged spectrum of the XRT spectrum fitted with various models. The lower panel represents the data vs. model ratios in each bin. Top left: phabs*simpl*bhspec. Top right: phabs*xsabs1*simpl*bhspec. Bottom left: phabs*(xsabs1*xsabs2*simpl*bhspec+gauss+gauss). Bottom right: phabs*(xsabs1*xsabs2*simpl*diskbb+gauss+gauss), where “xsabs” is the ionized absorption model created with XSTAR.

(A color version of this figure is available in the online journal.)

gauss) (Model 3 in Table 2). This model excellently describes the overall spectrum and further decreases the reduced $\chi^2$ value ($\chi^2$/dof = 294/359). The resulting model is plotted in Figure 8, and the best-fit parameters are given in Table 2. The ionization parameter and column density are $\log \xi = 2.86^{+0.32}_{-0.18}$ and $5.1^{+3.8}_{-1.5} \times 10^{22}$ cm⁻² for one ionized absorber responsible for the iron Kα absorption line, and $\log \xi = 1.2 \pm 0.2$ and $1.0^{+0.4}_{-0.2} \times 10^{22}$ cm⁻² for the other. The spin parameter is estimated as $a = 0.46 \pm 0.06$.

For direct comparison of the disk emission between the low/hard state (Suzaku) and the high/soft state (Swift), we replace bhspec in the final model with diskbb (phabs*(xsabs1*xsabs2*simpl*diskbb+gauss+gauss); Model 4 in Table 2) and fit the Swift/XRT spectrum. The fit is again acceptable ($\chi^2$/dof = 292/359), and the inner disk temperature and normalization of diskbb are estimated to be $0.89^{+0.03}_{-0.04}$ keV and $139^{+26}_{-45}$, respectively. The normalization is about 35 times smaller than that of the direct MCD component obtained from the Suzaku best-fit model. This indicates that the inner disk radius is smaller during the Swift observation in the high/soft state than during the Suzaku observation in the low/hard state. These Swift/XRT results are summarized in Table 2 and Figure 8.

4. NEAR-INFRARED OBSERVATIONS AND RESULTS

Photometric observations of MAXI J1305–704 in the J (1.25 μm), H (1.63 μm), and Ks (2.14 μm) bands were carried out over six nights by using the SIRIUS camera (Nagayama et al. 2003) on the 1.4 m IRSF telescope at the South African Astronomical Observatory. The first three nights (2012 April 27, 28, and 29) were about 20 days after the beginning of outburst; the source remained in the high/soft state, while it was in the low/hard state on the last three nights (2012 July 22, 23, and 24). The July observations with IRSF/SIRIUS were made only one day after the end of the Suzaku X-ray observation. The typical seeing in full width at half maximum was ≈1′.5–2′.0 (3.5–4.5 pixels) in the J band. The observation log is given in Table 3.

We performed the standard data reduction (i.e., dark subtraction, flat-fielding, sky subtraction, and combining dithered images) with IRSF pipeline software on Image Reduction and Analysis Facility, version 2.16 (distributed by the National...
IRSF fluxes are in the J noise ratio. We found the most probable near-infrared counterpart frames obtained in one night to maximize the signal-to-optical Astronomy Observatory). We combined all the optical and near-infrared fluxes obtained from the GROND observation on April 11 are also shown in the left panel (red cross).

(A color version of this figure is available in the online journal.)

Table 3
Log of IRSF Observations

| Date     | Number of Observations<sup>a</sup> | Integration Time in Each Frame (s) | J         | H         | K<sub>S</sub> |
|----------|-------------------------------------|------------------------------------|-----------|-----------|--------------|
| Apr 27   | 1                                   | 30                                 | 15.95 ± 0.53 | 15.69 ± 0.57 | 14.99 ± 0.59 |
| Apr 28   | 1                                   | 30                                 | 15.84 ± 0.51 | 15.49 ± 0.49 | 15.32 ± 0.59 |
| Apr 29   | 54                                  | 30                                 | 15.74 ± 0.47 | 15.43 ± 0.47 | 15.19 ± 0.47 |
| Jul 22   | 1                                   | 15                                 | 16.63 ± 0.10 | 16.20 ± 0.05 | 15.86 ± 0.09 |
| Jul 23   | 1                                   | 15                                 | 16.46 ± 0.04 | 16.08 ± 0.04 | 15.88 ± 0.08 |
| Jul 24   | 1                                   | 15                                 | 16.66 ± 0.05 | 16.24 ± 0.03 | 16.03 ± 0.08 |

Notes.
<sup>a</sup> Ten and fifteen dithered frames are combined for each observation at the first and last three nights, respectively.
<sup>b</sup> All the object frames are added for each night separately to measure the magnitudes.
<sup>c</sup> Systematic errors due to the installation of the polarizer (3% of the observed magnitude at the maximum) are included in the data of the April observations.

Optical Astronomy Observatory). We combined all the object frames obtained in one night to maximize the signal-to-noise ratio. We found the most probable near-infrared counterpart of MAXI J1305−704 at R.A. = 13°06′55.3 ± 0.1 and decl. = −70°27′05.1 ± 0.1 (J2000), which is located in the Swift/XRT 90% error circle (Kennea et al. 2012) and is consistent with the position of the optical/near-infrared counterpart discovered on April 11 by Greiner et al. (2012) with the GROND instrument mounted on the 2.2 m telescope in the MPI/ESO La Silla observatory. The IRSF/SIRIUS position is also consistent with those estimated in the Swift/UVOT (Ultraviolet/Optical Telescope) and Chandra HETGS observations (Greiner et al. 2012; Miller et al. 2012b) performed on April 10 and 29, respectively. The magnitudes in the three bands on each night are listed in Table 3. These were obtained by performing aperture photometry calibrated with the Two Micron All Sky Survey (Skrutskie et al. 2006) photometric data of the stars in the field of view.

Figure 9 shows the IRSF fluxes on April 29 in the high/soft state (left panel) and on July 22 in the low/hard state (right panel). These fluxes were corrected for Galactic extinction. Considering the Suzaku and Swift results, we assumed the hydrogen column density of interstellar absorption as \( N_H = 1 \times 10^{21} \) cm\(^{-2}\) and derived the extinction in each band as \( A_J = 0.15, A_H = 0.09, \) and \( A_K = 0.06 \) by combining the conversion factors given by Predehl & Schmitt (1995) and Rieke & Lebofsky (1985).

In Figure 9, the quasi-simultaneous X-ray data obtained in the Swift and Suzaku observations are plotted in the left and right panels, respectively. The best-fit intrinsic disk components are separately shown. The X-ray spectra are corrected for both neutral and ionized absorptions. The GROND data in the optical and near-infrared bands (\( g', i', r', z', J, \) and \( H; \) Greiner et al. 2012) are also plotted in Figure 9 together with our IRSF data obtained in the high/soft state. As noticed from the figure, these fluxes in the high/soft and low/hard states are \( \approx 10 \) times larger than those of the intrinsic disk components estimated from the X-ray data. The flux levels in the optical and near-infrared bands were decreased by \( \approx 50\% \) from the high/soft state to the low/hard state. These results suggest that in addition to the direct disk emission and the constant blackbody radiation from the companion star, another component (probably irradiation in the outer disk region) significantly contributes to the optical and near-infrared fluxes (see also Section 5.1). The IRSF fluxes on
July 24, which are the weakest ones of the six nights, correspond to the absolute magnitudes of 2.8, 2.4, and 2.1 in the J, H, and K$_s$ bands (where the distance of MAXI J1305$-$704 is assumed as 6 kpc), respectively. If the companion is a main-sequence star, these magnitudes indicate that it is a late F-type or smaller mass star (Wainscoat et al. 1992).

5. DISCUSSION

5.1. Implications for the System Parameters

It is likely that the compact object of MAXI J1305$-$704 is a black hole because the behavior of spectral evolution in the outburst is quite similar to those of typical BHXBs (Morihana et al. 2013). However, no constraint has been obtained so far on the black hole mass of this source, as well as its distance and the mass of the companion star. Here we summarize what we find about these system parameters from the Suzaku and Swift results.

The power spectrum obtained with the XIS light curve shows very weak intrinsic variability with a fractional rms$^2$ of $\sim10^{-3}$ Hz$^{-1}$ from $1 \times 10^{-3}$ Hz to $5 \times 10^{-2}$ Hz. This result suggests that the low-frequency break of the band-limited noise is located above the frequency range. Normally, BHXBs have an order of magnitude stronger power, and the break frequency is much lower when they are in the low/hard state, although weaker variability is sometimes observed from low-mass black holes like GRO J1655$-$40 ($5 \sim$ M$_o$; Remillard et al. 1999) in that state. This might suggest that MAXI J1305$-$704 also have a relatively small mass black hole. However, even with a low-mass black hole it is difficult to explain the lack of the variability power for such a very hard spectrum with a photon index of $\approx1.6$.

Since the source shows dips but no eclipse, its inclination angle $i$ is estimated to be $\approx60^\circ$--$75^\circ$ (Frank et al. 1987). The dips seen in MAXI J1305$-$704 are more complex than those in GRO J1655$-$40, whose inclination angle is 69:50 $\pm$ 0:08 (Orosz & Bailyn 1997). This suggests that MAXI J1305$-$704 has a larger inclination angle than GRO J1655$-$40, likely $\sim75^\circ$, and that the complex dips originate in absorbing structures with small-scale heights above the disk crossing the line of sight. From the Suzaku XIS light curve, the dip interval is estimated as 9.74 $\pm$ 0.04, which likely corresponds to the orbital period of MAXI J1305$-$704. We derive the binary size as $\approx3 \times 10^6 M_{\odot}^{1/3}$ km from Kepler’s third law, where $M_{\text{tot}}$ represents the total mass of the companion star and the black hole in the unit of 4 M$_o$. Combining Kepler’s third law and the relation between the radius and mass of the Roche lobe in a semidetached binary system (Equation (4) in Paczyński 1971), we have

$$\rho_c = 30.375 \frac{\pi}{G P^2} (0 < M_c/M_{\text{BH}} < 0.8),$$

(1)

where $\rho_c$, $M_c$, and $P$ represent the averaged density and mass of the companion star, which fills its Roche lobe, and the orbital period. From this equation, we derive the averaged density of the companion star as $\approx1.2$ g cm$^{-3}$, which is smaller than that of the Sun ($\approx1.4$ g cm$^{-3}$). If the companion is a main-sequence star, it has a slightly larger mass than the Sun. This is consistent with the near-infrared absolute magnitudes observed with IRSF in the low/hard state. However, an upper limit of the stellar radius is imposed by the inclination angle and binary size, $\approx7 \times 10^2 \left(\cos i/\cos 75^\circ\right) M_{\text{tot}}^{1/3}$ km, or $\approx1 \left(\cos i/\cos 75^\circ\right)$ $M_{\text{tot}}^{1/3} R_{\odot}$, by considering that the source has no eclipses. This radius and the averaged density of the Roche lobe give a somewhat smaller mass of the companion star than that of the Sun, $<0.9 \left(\cos i/\cos 75^\circ\right)^3 M_{\text{tot}} M_{\odot}$, although this limit strongly depends on the assumed inclination angle and the total mass of the binary system. Thus, it is also possible that the companion is an evolved star with a mass of $\lesssim1 M_{\odot}$, instead of an earlier-type main-sequence star than the Sun.

As presented in Figure 9, the near-infrared and optical fluxes of MAXI J1305$-$704 in the high/soft state is $\approx10$ times higher than the flux level of the MCD component, suggesting that the fluxes are dominated by other components, likely reprocessed emission from the irradiated outer disk and the black-body emission from the companion star. To estimate the contributions of these two components to the optical and near-infrared spectral energy distribution (SED), we fit the Swift/XRT (X-ray), GROND (optical and near-infrared), and IRSF (near-infrared) data in the high/soft state using the diskir (Gierliński et al. 2008, 2009) plus bbodyrad model, which represent the direct and reprocessed emission from the disk and the blackbody component from the companion star, respectively. The diskir model calculates the total spectrum of the disk emission and its Comptonization, including the reprocessed emission from the irradiated outer disk, by using the inner disk temperature ($kT_{\text{in}}$), photon index and electron temperature of the Comptonized component ($\Gamma$ and $kT_e$, respectively), the ratio of the luminosity of the Compton tail to disk luminosity ($L_c/L_d$), the fraction of luminosity of the Comptonized component that is thermalized in the inner disk ($f_{\text{in}}$), the fraction of bolometric flux that illuminates the outer disk ($f_{\text{out}}$), the radius of the Compton illuminated disk ($r_{\text{irr}}$), and the outer disk radius ($R_{\text{out}}$). The bbodyrad model produces a blackbody spectrum from a temperature ($kT_{\text{BB}}$) and a normalization ($K_{\text{BB}}$), which is related to the source radius $R_{\text{BB}}$ (km) and distance through $K_{\text{BB}} = (R_{\text{BB}}/D_{10})^2$, where $D_{10}$ is the distance in units of 10 kpc.

We replace diskir of the best-fit results of Model 4 in the Swift/XRT fit (Section 3.4) with diskir and add bbodyrad to fit the multicolour spectrum SED. Here we set $f_{\text{in}} = 0.1$ and $r_{\text{irr}} = 1.1 R_{\odot}$ following Gierliński et al. (2009). The photon index of the Compton tail and the inner disk temperature are fixed at the same values of Model 4, $\Gamma = 2.2$, and $kT_{\text{in}} = 0.88$ keV. The electron temperature of the Compton component is set to 300 keV in order not to have an exponential cutoff in the energy range of the Swift/XRT. After some trials of the spectral fit, we find that the black-body component favors a small temperature and a large normalization. Considering the maximum radius constrained from the absence of eclipse, we vary the normalization of the bbodyrad component within $R_{\text{BB}} < 1.0 D_{10} R_{\odot}$.

The best-fit parameters of the diskir and bbodyrad models are listed in Table 4. The optical and near-infrared SED in the high/soft state is reproduced reasonably well with the dominant irradiated disk component and the weak black-body component from the companion star (Figure 10). The irradiation fraction ($f_{\text{out}} \approx 4 \times 10^{-3}$) is $\approx10$ times larger than those of GX 339$-$4 and GRS 1915$+$105 during the high/soft state (Rahoui et al. 2010, 2012), but $\approx5$ times larger than those of XTE J1817$-$330 in that state (Gierliński et al. 2009). The radius of the companion star is estimated as $R_{\text{BB}} > 0.8 D_{10} R_{\odot}$, and the temperature is found to be smaller than that of the Sun (3000 K $< T_{\text{BB}}$ $< 5600$ K). These results and the averaged density estimated from Equation (1) suggest that the companion is likely an evolved star at an early stage that has a smaller mass than $\approx1 M_{\odot}$. 

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We find that the nondip spectra in the Swift and Suzaku observations have comparable bolometric luminosities within a factor of 3. This suggests that they are likely to be only a few times more and less than that in the soft-to-hard transition, $\approx 0.02 L_{\text{edd}}$, respectively, by considering the results of Maccarone (2003). However, the inner disk temperature of the diskbb component obtained from the Swift spectrum ($\approx 1.0$ keV) is much higher than what we expect from a faint high/soft state for normal BHXBs. This suggests that the disk spectrum is significantly modified by the Doppler effects due to a very high inclination angle, probably $\approx 75^\circ$. Indeed, assuming a black hole mass of $3 M_\odot$, a bolometric luminosity of $0.05 L_{\text{edd}}$, and an inclination angle of $75^\circ$, we successfully reproduce the Swift spectrum with a relativistic disk emission model (hbbpec) and obtain a moderate spin ($a = 0.46 \pm 0.06$) and a distance of $6.3^{+0.3}_{-0.3}$ kpc calculated from the normalization ($2.5^{+0.2}_{-0.2}$). We note that there is strong coupling between the spin, luminosity, and black hole mass in the hbbpec fit, and a smaller spin parameter is obtained when a larger luminosity and/or a lower black hole mass is assumed. For instance, in the cases of $L_X = 0.1 L_{\text{edd}}$ and $0.01 L_{\text{edd}}$, we have $a < 0.16$ and $0.90 \pm 0.02$, while $M_{\text{BH}} = 5 M_\odot$ and $10 M_\odot$ give $a = 0.63^{+0.05}_{-0.04}$ and $0.80 \pm 0.03$, respectively.

5.2. Dipping Behavior

The Suzaku observation revealed that MAXI J1305$-$704 have two separate periodic dips with different column densities, ionization parameters, and covering fractions of the absorbers. We find that these dips have the same recurrence period of $9.74 \pm 0.04$ hr, and the harder dip (deep dip) is followed by the softer dip (shallow dip) in $6.38$ hr. Such strong, softer “secondary dips” are occasionally seen in dipping X-ray binaries (a few neutron star binaries like XB 1916$-$053; Smale et al. 1992, and a black hole candidate MAXI J1659$-$152; Kuulkers et al. 2013). Dips are generally interpreted as the absorption by the “bulge” formed in a region where the accretion stream from the companion star impacts the outer boundary of the disk, but what is the origin of a secondary dip? It may be the result of the accretion stream hitting the disk again and splashing at its circularization radius, which is smaller than the outer disk radius (Frank et al. 1987, 1992). Frank et al. (1987) suggest that the stream causes ionization instabilities at the second impact and creates patchy cold clouds within a hot medium. This is consistent with the behavior of the shallow dip, in which significant time variabilities can be seen in the XIS light curve. The shallow dip occurs at the orbital phase of $\approx 0.64$ (if the start of the deep dip is assumed to be phase 0), which is also consistent with the picture of Frank et al. (1987).

The properties of time variabilities and absorption profiles in the dipping spectra provide us with key information on the two dips. The shallow dip exhibits significant fast variabilities on the timescale of a few minutes in the XIS light curve, suggesting that the absorber is not a single continuous structure but is composed of clumps. If the absorber of the shallow dip is created at the circularization radius of $10^6$ km and rotates with the Keplerian velocity, one minute corresponds to a typical blob size of $\approx 10^4 M_\odot^{1/2}$ km, where $M_1$ is defined as $M_{\text{BH}}/3 M_\odot$. The covering fraction $0.72^{+0.03}_{-0.04}$ in the shallow dip can be understood as the filling factor of blobs in the dipping zone. Interestingly, similar short-time variability was also found in the neutron star X0 1254$-$690 (Díaz Trigo et al. 2009), suggesting that shallow dips in dipping X-ray binaries may generally consist of clumps. By contrast, in the deep dip, short-time variabilities are not significant and the covering fraction is larger than 90%, suggesting that the absorber of the deep dip has more continuous structure or is filled with much smaller blobs than those of the shallow dip.

We have shown that both nondip and dip spectra of MAXI J1305$-$704 obtained with Suzaku are successfully modeled by ionized absorbers with different column densities and ionization parameters. The dip spectra have orders of magnitude larger hydrogen column densities and smaller ionization parameters than those of the nondip spectrum. These results are very similar to those reported by Boirin et al. (2005) and Díaz Trigo et al. (2006) for neutron star low-mass X-ray binaries. Thus, it may be a general picture in low-mass X-ray binaries that dips are created by ionized absorbers with much larger column densities and in lower ionization states than those observed in nondips.

### Table 4

Best-fit Results from the Simultaneous Fit of the X-ray, Optical, and Near-infrared Data of the Swift/XRT, GROND, and IRSF

| Component | Parameter | Value |
|-----------|-----------|-------|
| diskir    | $kT_{in}$ (keV) | 0.88 (fix) |
|           | $T_f$      | 2.2 (fix) |
|           | $kT_e$ (keV) | 300 (fix) |
|           | $L_C/L_d$  | 0.10 $\pm$ 0.02 |
|           | $f_{in}$   | 0.1 (fix) |
|           | $r_{in}$ (R$_{in}$) | 1.1 (fix) |
|           | $f_{out}$  | $4.4^{+0.05}_{-0.04} \times 10^{-3}$ |
|           | log$_{10}$($R_{out}/R_{in}$) | 5.15$^{+0.4}_{-0.5}$ |
|           | Norm       | 137 $\pm$ 1 |
| bbodyrad  | $T_{BB}$ (K) | 4200$^{+1100}_{-1200}$ |
|           | $R_{BB}$ (R$_{\odot}$/6 kpc) | $1.0^{+0.1}_{-0.2}$ pegged |

$x^2$/dof 415/377

Notes. The model is phabs*(xsabs*xsabs*diskir+bbodyrad+gau**s+gauss). The parameters of neutral and ionized absorptions (phabs and xsabs, respectively) and two Gaussians are set to the best-fit values of Model 4 in the Swift/XRT spectral fit (Table 2).

![Figure 10](image-url)
5.3. Structure of Accretion Disk and Comptonized Corona

The Suzaku nondip spectrum of MAXI J1305−704 is approximated by a power-law extending up to 130 keV with a photon index of ≈1.6. This hard spectrum indicates that the source was in the low/hard state. By more detailed modeling, we find that the spectrum can be described with a general model in the low/hard state of BHXBs (e.g., Gierliński et al. 1997), an MCD and its Comptonization with a reflection component from the disk. Although recent Suzaku studies on other BHXBs report that two Comptonization components with different optical depths are needed to reproduce their spectra in the low/hard state (Takahashi et al. 2008; Makishima et al. 2008; Shidatsu et al. 2011; Yamada et al. 2013), our data do not require the second component. The reason is unclear, but it may be because the large inclination of MAXI J1305−704 makes it difficult to detect the softer component (i.e., with a small optical depth) than the other systems, although it may be partially due to the poor statistics of our data. The smooth spectral profile below 5 × 10−2 Hz (see Section 5.1), are unusual and interesting properties for a BHXB in the low/hard state.

We obtained a much larger normalization (6.0±3.4 × 105) and smaller temperature (0.168±0.006 keV) of the direct MCD component than those obtained with the Swift/XRT spectrum in the high/soft state. Assuming that the Comptonized corona is isotropic and that the total number of photons from the disk is conserved after reprocessed by Comptonization, we obtain the following equation (Kubota & Makishima 2004):

\[ F_{\text{disk}}^p + F_{\text{thc}}^p 2 \cos i = 0.0165 \left( \frac{r_{\text{in}}^2 \cos i}{(D/10\text{kpc})^2} \right) \left( \frac{T_{\text{in}}}{1\text{keV}} \right)^3 \text{photons s}^{-1}\text{cm}^{-2}, \]

where \( F_{\text{disk}}^p \) and \( F_{\text{thc}}^p \) are the 0.01–100 keV photon flux from the disk and thermal Comptonized component, respectively. We estimate the flux of the nthcomp component as 0.180 photons cm−2 s−1 and that of diskbb component as 0.394 photons cm−2 s−1. Using Equation (2), we estimate the innermost disk radius of \( r_{\text{in}} = 93_{-49}^{+72} D_0 (\cos i / \cos 75^\circ)^{-1/2} \) km, (where \( D_0 \) is the distance in unit of 6 kpc). The actual radius is derived to be \( R_{\text{in}} = 111_{-58}^{+67} D_0 (\cos i / \cos 75^\circ)^{-1/2} \) km, by multiplying 1.19, a correction factor of the boundary condition and spectral hardening (Kubota et al. 1998).

We compare the inner disk radius in the Suzaku and Swift observations, using the intrinsic flux of the MCD component. Although the absolute radius obtained from the Swift result may be affected by the strong beaming effects, we are able to discuss the relative difference of the radius between the two epochs. Using the diskbb normalization obtained with the XRT spectrum (139±26) and multiplying the correction factor 1.19 (Kubota et al. 1998), we derive the inner disk radius as 6.5±2.7 D_0 (\cos i / \cos 75^\circ)^{-1/2} km. Thus, the inner radius obtained from the best-fit model of Suzaku data, \( 111_{-58}^{+67} D_0 (\cos i / \cos 75^\circ)^{-1/2} \) km, is 5.8–8.8 times larger than that from the XRT result. Thus, we robustly conclude that the inner radius increased in the Suzaku observation, giving strong evidence for disk truncation in the low/hard state.

We find significant broad emission-line-like residuals at ≈0.7 keV and ≈1.2 keV in the Swift/XRT spectrum, which cannot be reduced by multiple ionized absorptions, partial covering, or emission components from the absorber itself. Also, these residuals are not completely explained by changing the elemental abundances in the neutral and ionized absorbers. It is difficult to know what makes these structures. Because they are not seen in the Suzaku spectra in the low/hard state, their origin would be associated with the geometry of the accretion disk and/or the ionized absorbers in the high/soft state.

Similar features at ≈1.0 keV were reported in some neutron star binaries such as Cyg X-2 (Kuulkers et al. 1997 and references therein) and features at ≈0.7 keV were reported in several ultracompact low-mass X-ray binaries (UCXBs; e.g., Juett et al. 2001), which have very short orbital periods (less than about 80 minutes). Madej et al. (2010) and Madej & Jonker (2011) recently suggested that the structures seen in UCXBs are the relativistically broadened O viii Lyα line created by reflection on the disk in the vicinity of the accretor with an ionization parameter of log \( \xi \approx 2.3 \). Likewise, the residuals in MAXI J1305−704 might originate from reflection on an ionized accretion disk in the strong gravitational field created by the central black hole. Indeed, we find that a relativistic emission line model 1αor instead of a Gaussian model can also give an acceptable fit (\( \chi^2 / \text{dof} = 297 / 360 \)) by assuming an inclination of 75°, an inner radius of \( 4 R_g \) (corresponding to \( a \approx 0.5 \)), an outer radius of 400 \( R_g \), and an emissivity index (\( \beta \)). The resulting line energy and equivalent width of the 1αor model are 0.66 ± 0.01 keV and 194 eV for the lower energy feature and 1.03 ± 0.02 keV and 83 eV for the higher energy feature (here we vary the emissivity index within 2 \( \leq \beta \leq 3 \) and obtain the best-fit value of \( \beta = 2.4 ± 0.1 \)). These line energies are consistent with the Kα line from H-like oxygen ions and L lines from ionized iron ions. The photons to illuminate the disk would be produced from the Comptonizing corona, or from the disk itself whose emission could be partially incident on the disk because of gravitational light bending. If these photons could strongly illuminate the disk, huge emission lines might arise through a temperature inversion region of the irradiated disk atmosphere. The large equivalent width of the emission lines with respect to the continuum emission would be expected for a very high inclination source because of a large optical depth of the disk atmosphere. However, we have no model to accurately evaluate these effects at present. Radiative transfer calculation, including all these possible effects, is left for future studies.

5.4. Ionized Absorbers

We find that not only the Swift/XRT spectrum in the high/soft state but also the Suzaku spectrum in the low/hard state exhibit ionized absorption features. Blue shifts are not significantly detected with upper limits of 2300–5800 km s−1. The absorber of the Suzaku nondip spectrum has a column density of \( N_H = 6.1_{-1.0}^{+1.1} \times 10^{21} \text{cm}^{-2} \) and an ionization parameter of \( \log \xi = 2.19 ± 0.04 \), while the Swift/XRT spectrum requires two ionized absorbers with different parameters, \( N_H = 5.1_{-2.3}^{+3.8} \times 10^{22} \text{cm}^{-2} \) and \( \log \xi = 2.86_{-0.18}^{+0.20} \) for one, and \( N_H = (1.0_{-0.3}^{+0.4}) \times 10^{22} \text{cm}^{-2} \) and \( \log \xi = 1.2 ± 0.2 \) for the other. As discussed in Section 5.2, the dip spectra of Suzaku are also described with ionized absorbers but with much larger column densities and lower ionization parameters, \( N_H = (1.44 ± 0.06) \times 10^{23} \text{cm}^{-2} \) and \( \log \xi = 1.90 ± 0.07 \) for the deep dip, and \( N_H = 6.6_{-0.4}^{+0.5} \times 10^{22} \text{cm}^{-2} \) and \( \log \xi = 1.79 ± 0.07 \) for the shallow dip.

To investigate the origin of the ionized absorbers, we estimate their distances from the X-ray source (\( R \)) from the definition of
the ionization parameter,

$$\xi = \frac{L_X}{n_H R^2} = \frac{L_X}{N_{H}\Delta R} \frac{\Delta R}{R},$$

where \(n_H\) and \(\Delta R\) represent the hydrogen number density and the length of the absorber, respectively. Here \(L_X\) is the incident luminosity, whose energy range is 1–1000 Ry in the definition of XSTAR. \(L_X\) is estimated as \(1.3 \times 10^{38} D_6^2 \text{ erg s}^{-1}\) for the Suzaku observation and \(8.1 \times 10^{36} D_6^2 \text{ erg s}^{-1}\) for the Swift observation. Assuming \(\Delta R/R = 1\), we obtain \(R \approx 1.4 \times 10^3 \text{ km}\) for the absorber seen in the Suzaku non-dip spectrum. For the Swift/XRT data, we estimate \(R \approx 2.2 \times 10^5 \text{ km}\) for the absorber with a higher ionization state and \(R \approx 5.1 \times 10^8 \text{ km}\) for the absorber with a lower ionization state. All these radii are more than an order of magnitude larger than predicted values for thermally driven disk winds in BHXBs \((R \sim 10^7 \text{ km}; \text{e.g., Begelman et al. 1983; Woods et al. 1996; also see below})\).

Furthermore, they are comparable to or even larger than the binary size (see Section 5.1). Hence, if the ionized absorbers of MAXI J1305−704 are located on the disk, \(\Delta R/R\) should be much less than 1. This suggests that the absorbers are originated from rather compact structures and do not largely extend in the radial direction. The absorbers in the deep and shallow dips are calculated to be \(R \approx 1.1 \times 10^6 \text{ km}\) and \(R \approx 3.2 \times 10^8 \text{ km}\), respectively, which are comparable to those seen in the Suzaku and Swift/XRT non-dip spectra.

Table 5 summarizes the physical properties of ionized absorbers reported in previous studies of black hole or neutron star X-ray binaries. The ionization parameter, column density, Doppler velocity, and luminosity taken from the literature are listed. We then calculate the apparent distance \(R\) by assuming \(\Delta R/R = 1\) for each set of parameters. Although there is considerable variety in each parameter, almost all of the absorbers in the BHXBs are found to be outflowing with a velocity of 100–1000 km s\(^{-1}\). Typically, they are located at \(R \sim 10^4–10^5 \text{ km}\) when \(\Delta R \sim R\) is assumed. They are interpreted as thermally (e.g., Kubota et al. 2007), radiatively (Kotani et al. 2000), or magnetically driven disk winds (Miller et al. 2008). By contrast, ionized absorbers in neutron star low-mass X-ray binaries do not often exhibit significant blue shifts, except for some sources such as GX 13+1 (Ueda et al. 2004) and Cir X-1 (Schulz et al. 2008), which are known to have powerful outflows. This implies that the photoionized plasma on neutron star dimmers remain gravitationally bound to the system as disk atmosphere and is not outflowing due to a small system size and a low luminosity of the central X-ray source (see Díaz Trigo & Boirin 2012).

From comparison, we find that MAXI J1305−704 has somewhat lower ionization parameters (log \(\xi < 3\)) and consequently larger \(R\) than those of typical disk winds observed in other BHXBs. By contrast, absorbers in neutron star dippers sometimes have similar \(R\) values (see the table of XB 1916−053 and EXO 0748−676) and exhibit complex and deep dips like MAXI J1305−704. Although the BHXB GRO J1655−40 shows a similar value of \(R\) (4 \(\times\) 10^6 km and 1.3 \(\times\) 10^7 km) based on the results by Díaz Trigo et al. (2007), the turbulent velocity \((v_{\text{turb}})\) adopted there is much higher than that assumed for MAXI J1305−704 in our paper. We have to note that a larger \(v_{\text{turb}}\) value gives a smaller column density; in the case of 4U 1630−47, about 10 times larger values of \(N_H\) was obtained with \(v_{\text{turb}} \approx 2000 \text{ km s}^{-1}\) than that with \(v_{\text{turb}} = 100 \text{ km s}^{-1}\) (Kubota et al. 2007). If we assumed \(v_{\text{turb}} \sim 5000 \text{ km s}^{-1}\), the \(R\) values of the MAXI J1305−704 would become much larger than those of GRO J1655−40. The BHXB GRS 1915+105 also shows a large apparent distance \((R \sim 10^6 \text{ km})\), but its binary size is very large \((\sim 10^8 \text{ km})\) as the source has a very long (33.5 ± 1.5 days; Greiner et al. 2001) orbital period and contains a massive black hole \((\sim 15 M_\odot)\). Thus, the distance of the ionized absorber in GRS 1915+105 would be well within the size of accretion disk, even if \(R \sim \Delta R\) is assumed. Figure 11 plots the values of \(N_H\) and \(R\) for the ionized absorbers in MAXI J1305−704 and those in other BHXBs that exhibit dips and have turbulent velocities less than 1000 km s\(^{-1}\), except for GRS 1915+105. The absorbers in MAXI J1305−704 have large \(R\) values and comparable or smaller \(N_H\) values compared to those in the other sources.

These properties suggest that the absorbers in MAXI J1305−704 are originated from compact structures like those responsible for the dips, rather than a typical disk wind, which would be widely extended in the radial direction (i.e., \(\Delta R/R \sim 1\)). The Suzaku light curve in the soft band exhibits significant time variability even in the nondip phases on the shorter timescale than the orbital period. We find these small variabilities occur almost recurrently as well as the deep and shallow dips by folding the Suzaku light curve with the orbital period. This fact would support the idea that the ionized absorbers in MAXI J1305−704 are associated with the disk and composed of compact clouds, unlike disk winds observed in other BHXBs that distribute quite homogeneously over the orbital phase (Yamaoka et al. 2001). Miller et al. (2013) have recently obtained a very large number density \((n_H \sim 10^{17} \text{ cm}^{-3})\) from density-sensitive absorption lines seen in the high-resolution Chandra/HETG spectrum of the source in the high/soft state and derived the actual distance of the absorber as \(\approx 4 \times 10^3 \text{ km}\) utilizing the density without any assumption of \(\Delta R/R\). From the distance and density, we can estimate the size of ionized absorber as \(\Delta R \approx 1 \text{ km}\). This strongly indicates that the absorbers are composed of small clumps.

A possibility is that a fraction of the absorbing gas responsible for the dips is spread to the nondip phases. MAXI J1305−704 is likely to be a high inclination system even compared with other dipping BHXBs, and we may see many complex structures.
### Table 5

Properties of Ionized Absorbers in X-ray Binaries

| Source Name | Photon Index or State | Distance (kpc) | Orbital Period (h) | $N_H$ \(\times 10^{22}\) cm\(^{-2}\) | $\log \xi$ | $L_X$ \(\text{erg s}^{-1}\) | Energy Band of $L_X$ (keV) | $R$ \(\text{10}^{13}\) km | $v_{\text{outflow}}$ \(\text{km s}^{-1}\) | $v_{\text{inh}}$ \(\text{km s}^{-1}\) | Reference |
|-------------|----------------------|----------------|-------------------|-----------------|---------|-----------------|-----------------|----------------|-----------------|---------------|----------------|
| XB 1916−053 | $\pm 0.03$           | 9.3            | 0.8 h             | $4.2 \pm 0.5$   | 3.05 ± 0.04 | $4.4 \times 10^{36}$ | $0.6−10$        | 9.3             | $\cdots \pm 1$ | $2300_{1800}^{2300}$ | Díaz Trigo et al. (2006) |
| 4U 1254−690 | $\pm 0.02$           | 10             | 5.8 h             | $8.4 \pm 0.3$   | $4.3 \pm 0.1$ | $1.04 \times 10^{37}$ | $0.6−10$        | 0.62            | $\cdots \pm 1$ | $2800_{1600}^{2600}$ | Díaz Trigo et al. (2006) |
| MXB 1659−L  | $\pm 0.03$           | 15             | 7.1 h             | $11.1 \pm 0.6$  | $3.8 \pm 0.1$ | $3.44 \times 10^{37}$ | $0.6−10$        | 4.9             | $\cdots \pm 1$ | $700_{400}^{700}$  | Díaz Trigo et al. (2006) |
| EXO 0748−676| $\pm 0.05$           | 10             | 3.8 h             | $3.5 \pm 0.2$   | $2.45 \pm 0.02$ | $3.4 \times 10^{36}$ | $0.6−10$        | 34              | $\cdots \pm 1$ | $13 \pm 6$       | Díaz Trigo et al. (2006) |
| XB 1523−619 | $0.90_{0.51}^{+0.10}$| 10             | 2.9 h             | $3.6_{-0.9}^{+0.7}$ | $3.90_{-0.09}^{+0.08}$ | $5.2 \times 10^{36}$ | $0.6−10$        | 1.8             | $\cdots \pm 1$ | $1700_{1000}^{1700}$ | Borin et al. (2005) |
| X 1624−490  | $2.25$               | $15_{-0.6}^{+0.6}$ | 21 h              | $20 \pm 10$    | $4.3 \pm 0.4$ | $4.9 \times 10^{37}$ | $1−10$          | 1.2             | $607_{540}^{607}$ | $280_{180}^{280}$ | Xiang et al. (2009) |
| GRO J1655−47| High/soft state      | 10             | Unknown           | 5−19            | 4.38−4.88      | $2.8 \times 10^{38}$ | full            | 0.1−1           | $\cdots \pm 1$ | $2100_{1800}^{2100}$ | Cubilla et al. (2018) |
| H 1743−32a  | High/soft state      | 8.5            | Unknown           | $\approx 5$    | 5.7            | $6.8 \times 10^{38}$ | $0.5\sim10$     | 0.01−1          | 670±170        | $1800_{400}^{2000}$| Miller et al. (2006b) |
| GRO J1655−40| High/soft state      | 3              | 2.6 day           | 30−100          | 3              | $1 \times 10^{36}$ | 9−$\sim$10      | 0.1−0.3         | $\cdots \pm 1$ | $<130_{400}^{130}$ | Ueda et al. (1998) |
| GRO J1655−40| High/soft state      | 3.2            | 1.5±1.2          | 3.0±0.04        | 4×$10^{37}$    | $130$           | 5900±1200       | 3500±900        | Diaz Trigo et al. (2007) |
| GRS 1915+105| “Low/hard” state     | 20             | 33.5±1.5 day     | $\approx 1$     | $\approx 3.8$  | $4 \times 10^{38}$ | 2−10            | $\approx 10$    | $\approx 1000$ | 740±400 (fixed) | Kotani et al. (2000) |
| GRS 1915+105| “Low/hard” state     | 5              | $\approx 3$     | $\leq 4.15$     | $6.4 \times 10^{38}$ | 2−10          | $\approx 10$    | $\approx 1000$ | 740±400 (fixed) | Kotani et al. (2000) |
| GRS 1915+105| High/soft state      | 12             | $\approx 10$    | $4.2−4.3$       | $(6.6−8.8) \times 10^{38}$ | 2−10        | 2−6            | 90±560         | 70−200         | Ueda et al. (2009) |
| GRS 1915+105| Intermediate state   | 5              | $\approx 10$    | $1.76$ day      | $\approx 10$ | $10^{37}$ | 5.5−10 | 20\footnote{b} | 510\footnote{b} | 400\footnote{b} | Miller et al. (2004) |
| MAXI J1305−704| High/soft state     | 6              | 9.74±0.04 h     | $5.1_{-0.3}^{+1.3}$ | $2.86_{-0.34}^{+0.52}$ | $8.1 \times 10^{36}$ | 0.0136−13.6 | 22 | 8600 (fixed) | 300 (fixed) |
| MAXI J1305−704| High/soft state     | 1.0±0.2        | $\pm 0.2$     | $5.1 \times 10^{37}$ | 0 (fixed) | 300 (fixed) |
| MAXI J1305−704| Low/hard state      | (Nondip)       | $0.61_{-0.10}^{+0.09}$ | 2.18 ± 0.04 | $1.3 \times 10^{36}$ | 140 | $<2300$ | 300 (fixed) |
| MAXI J1305−704| (Deep dip)          | 14.4±0.6       | 1.90±0.07       | $<2700$ | 300 (fixed) |
| MAXI J1305−704| (Shallow dip)       | 6.6±0.4        | 1.79±0.07       | $<5800$ | 300 (fixed) |

**Notes:**
- $R$ is calculated from $L_X/N_H$ by assuming $\Delta R = R$, unless otherwise stated. The positive values of $v_{\text{outflow}}$ indicate blue shifts. The distances represent the assumed values that are used to estimate $L_X$. 4U 1630−47 and the following sources are BHXBs. The results in the nondip phases are shown for the top six sources (dippers).
- $^a$ Observation 1 in Miller et al. (2006b).
- $^b$ In the soft-to-hard transition.
- $^c$ Corbet et al. (2010).
- $^d$ Papitto et al. (2013).
- $^e$ Greiner et al. (2001).
- $^f$ Hynes et al. (2003).
- $^g$ Estimated from the Fe XXV absorption line.
- $^h$ Estimated from the Fe XXVI absorption line.
- $^i$ Bolometric luminosity.
- $^j$ $\Delta R/R = 0.1$.
- $^k$ Calculated by assuming the thickness and number density of the absorber as 20 km and $8 \times 10^{33}$ cm$^{-3}$, respectively.
- $^l$ Not constrained.
- $^m$ The line width when the Gaussian model is applied.
- $^n$ The results of the Ne ii line at 14.631 Å, from which the largest blue shift is obtained.
of the absorbing gas with a small-scale height on the surface of the accretion disk. As described in Frank et al. (1987), the short orbital period of MAXI J1305−704 may maintain the clumpy absorbers and produce the similarity in the properties of the ionized absorbers seen in neutron star binaries. Also, like neutron star dippers, the disk size of MAXI J1305−704 (\(\lesssim 10^6 M_\odot\)) estimated from the binary size, is comparable with or maybe smaller than the Compton radius (\(\sim 4 \times 10^7 T_{\rm{CCS}}^{-1} M_\odot\) km, where \(T_{\rm{CCS}}\) is the Compton temperature in units of \(10^8\) K) and would not be sufficiently large to power a thermal-driven disk wind (see Díaz Trigo & Boirin 2012). However, there remains a possibility that we are seeing the launching site of the disk wind near the outer edge of the disk, which may be less homogeneous than in its outer parts and can be compact (\(\Delta R/R < 1\)). If this were the case, our Suzaku result would imply that such a disk wind exists in the low/hard state of a BHXB and that the accretion states do not always determine the presence of disk winds. Future studies using high quality BHXB and that the accretion states do not always determine

6. SUMMARY
The Suzaku, Swift, and IRSF observations of the newly discovered black hole candidate MAXI J1305−704 provide us with the following results.

1. The source clearly shows two absorption dips with different mean hardness ratios. They have the same interval (9.74 \pm 0.04 hr), which likely corresponds to the orbital period.
2. The Suzaku nondip spectrum in the low/hard state can be described with a model composed of a MCD emission, its Comptonization, and a reflection component, absorbed by an ionized gas.
3. The Swift/XRT spectrum in the high/soft state is well reproduced with a relativistic disk emission model with a moderate spin parameter (\(\approx 0.5\)) for an assumed inclination angle of 75°, a black hole mass of 3\(M_\odot\), and a luminosity of 0.05 \(L_{\rm{Edd}}\). The inner disk radius obtained in the Swift/XRT spectrum is much smaller than that in the Suzaku spectrum, indicating that the inner edge of the standard disk was receded during the state transition from the high/soft state to the low/hard state.
4. The ionized absorbers in the dip spectra of Suzaku have smaller ionization parameters and larger hydrogen column densities than those of the nondip spectrum. Similar trends are observed from dipping neutron star X-ray binaries.
5. We find that the ionized absorbers have much smaller ionized parameters and column densities than those of typical disk winds seen in other BHXBs. The properties of the absorbing gas are rather similar to the deeply dipping neutron star X-ray binaries. These results suggest that the absorbers have compact and clumpy structures (like those responsible for the dips) rather than a homogeneous disk wind. However, the possibility that we are seeing the launching site of a disk wind is not ruled out.
6. Near-infrared observations in the \(J\), \(H\), and \(K_s\) bands were also performed with IRSF both in the high/soft state and low/hard state. The fluxes in the three bands are about an order of magnitude larger than the disk emission estimated from the reprocessed thermal emission from the irradiated outer disk and the black-body emission from the companion star.

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