POSSIBILITY OF A WHITE DWARF AS THE ACCRETING COMPACT STAR IN CI CAMELOPARDALIS (=XTE J0421+560)

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ABSTRACT

We present results from ASCA observations of the binary CI Cam both in quiescence and in outburst in order to identify its central accreting object. The quiescence spectrum of CI Cam consists of soft and hard components, which are separated clearly at around 2–3 keV. A large equivalent width of an iron Kα emission line prefers an optically thin thermal plasma emission model to a nonthermal power-law model for the hard component, which favors a white dwarf as the accreting object, since optically thin thermal hard X-ray emission is a common characteristic among cataclysmic variables (binaries including an accreting white dwarf). However, since the power-law model, which represents the X-ray spectrum of the soft X-ray transients in quiescence, provides an equally good fit to the hard component statistically, we cannot exclude the possibility of a neutron star or a black hole from the quiescence data. The outburst spectrum, on the other hand, is composed of a hard component represented by multitemperature optically thin thermal plasma emission and an independent soft X-ray component that appears below 1 keV intermittently on a decaying light curve of the hard component. The spectrum of the soft component is represented well by a blackbody with the temperature of 0.07–0.12 keV overlaid with several K edges associated with highly ionized oxygen. This, together with the luminosity as high as \( \sim 1 \times 10^{39} \) ergs s\(^{-1}\), is similar to a supersoft source. The outburst in the hard X-ray band followed by the appearance of the soft blackbody component reminds us of recent observations of novae in outburst. We thus assume that the outburst of CI Cam is that of a nova and obtain the distance to CI Cam of 5–17 kpc by means of the relation between the optical decay time and the absolute magnitude. This agrees well with a recent estimate of the distance of 5–9 kpc in the optical band. All of these results from the outburst data prefer a white dwarf for the central object of CI Cam.

Subject headings: novae, cataclysmic variables — stars: individual (CI Camelopardalis, XTE J0421+560) — white dwarfs — X-rays: binaries — X-rays: stars

1. INTRODUCTION

On 1998 Mar 31 Smith et al. (1998) discovered the new X-ray transient XTE J0421+560 with the All-Sky Monitor (ASM; Levine et al. 1996) on board Rossi X-Ray Timing Explorer (RXTE). Follow-up observations of the ASM and the Proportional Counter Array (PCA) showed that XTE J0421+560 reached its peak intensity of \( \sim 2 \) crab on April 1.04, well within a day of the onset of the outburst. On April 2.63, Hjellming \\& Mioduszewski (1998a) found a variable radio source within the PCA error circle (Marshall, Strohmayer, \\& Lewin 1998). The position of the radio source coincides with that of the optical variable star CI Cam (Wagner \\& Starrfield 1998), which establishes CI Cam as the optical counterpart of XTE J0421+560.

Observations of BeppoSAX on April 3 and 9 and of ASCA on April 3 and 4 revealed that unlike other X-ray transients that harbor a black hole (BH) or a neutron star (NS) (Tanaka \\& Shibazaki 1996), the X-ray spectra up to 10 keV have an optically thin thermal nature with a plenitude of K-shell emission lines from highly ionized O, Ne, Si, S, and Fe (Frontera et al. 1998; Orr et al. 1998; Ueda et al. 1998). The spectra can be represented well by a two-temperature optically thin thermal plasma emission model with temperatures of \( \gtrsim 1 \) and 3–6 keV. Significant cooling of the plasma and the intensity declination were found both between the two BeppoSAX observations and within the single ASCA observation. A detailed X-ray temporal analysis based on the PCA data from during the outburst found no rapid random variability (Belloni et al. 1999), which is remarkably different from the NS and BH transients. The X-ray to radio light curves (Frontera et al. 1998) clearly show that the burst peak occurs later for longer wavelengths and that the e-folding decay time is shorter for shorter wavelengths. The Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory (CGRO) recorded the shortest timescales among all of the wavebands, the intensity arriving at the peak within only \( \sim 0.1 \) days and its e-folding decay time being \( \sim 0.56 \) days (Harmon, Fishman, \\& Paciesas 1998). The hard X-ray spectrum in the 20–100 keV band obtained with BATSE between April 1.0 and 2.0 is represented by a power law with a photon index of 3.9 \( \pm 0.3 \). The flux is compatible with that of the contemporaneous RXTE PCA observations in the 2–25 keV band (Belloni et al. 1999). In the optical spectra, a broad blue wing with a velocity of more than 2500 km s\(^{-1}\) was detected from hydrogen Balmer emission lines only during the outburst (Robinson, Ivans, \\& Welsh 2002; Hynes et al. 2002). By comparing the radio data from April 2.63 and 3.83, Hjellming \\& Mioduszewski (1998b) found that the radio spectra showed a transition from optically thick to thin emission. The results described above indicate that the radiation from radio to \( \gamma \)-ray during the outburst originates from an expanding gas ejected by a sort of eruptive event.
Observations of XTE J0421+560 in the quiescent state, on the other hand, were carried out by *BeppoSAX* in 1998 September (Orlandini et al. 2000), 1999 September, and 2000 February (Parmar et al. 2000), and by *XMM-Newton* in 2001 August (Boirin et al. 2002). Except for the third *BeppoSAX* observation, which gives only an upper limit to the absorption-corrected 1–10 keV luminosity of less than $2.5 \times 10^{32}$ ergs s$^{-1}$, the other three observations positively detected XTE J0421+560 at the luminosities in the range $(1.4–23) \times 10^{33}$ ergs s$^{-1}$. The X-ray spectrum obtained by *XMM-Newton* is composed of two components; one dominates in the band below ~4 keV with little absorption, and the other, undergoing heavy photoelectric absorption with $N_H = 5^{+3}_{-5} \times 10^{23}$ cm$^{-2}$, is conspicuous above ~5 keV. It seems that the spectrum of the first *BeppoSAX* observation is dominated by the former component, whereas that of the second is dominated by the latter. It is worth noting that a strong iron emission line component, whereas that of the second is dominated by the prodigious mass-loss rate of greater than $10^{-5} M_\odot$ yr$^{-1}$. Belloni et al. (1999) argued against this on the basis of their infrared-to-optical spectrum and classified it as a B[e] star. Taking into account the high bolometric luminosity and composition of the optical emission lines, Robinson et al. (2002) finally categorized CI Cam as a supergiant B[e] (sgB[e]) star that has a high bolometric luminosity and composition of the optical emission lines.

The optical nature of CI Cam has been a matter of debate until recently. It was originally designated as MWC 84 in a list of Be stars with infrared excess (Allen & Swings 1976) that were later recognized as B[e] stars. Although a symbiotic characteristic is reported (Bergner et al. 1995), Belloni et al. (1999) argued against this on the basis of their infrared-to-optical spectrum and classified it as a B[e] star. Taking into account the high bolometric luminosity and composition of the optical emission lines, Robinson et al. (2002) finally categorized CI Cam as a supergiant B[e] (sgB[e]) star that has a prodigious mass-loss rate of greater than $10^{-5} M_\odot$ yr$^{-1}$ (de Freitas Pacheco et al. 1998) and high bolometric luminosity of $10^5 < L_{bol}/L_\odot < 10^6$ (Zickgraf 1998). The distance to CI Cam had been estimated to be 1–2 kpc on the basis of the luminosity and the extinction-distance relation (Zorec 1998; Belloni et al. 1999; Clark et al. 2000; Orlandini et al. 2000). Robinson et al. (2002), however, pointed out that the extinction-distance relation is unreliable in the direction of CI Cam, because the interstellar matter is patchy. With the aid of the Galactic rotation model (Burton 1988a), distribution of matter in the Galactic disk (Burton 1988b), and distances to the known H ii region (Blitz, Fich, & Stark 1982; Chan & Fich 1995), they proposed a new distance estimate based on the velocity of optical emission lines. Hynes et al. (2002) also estimated the distance by making use of a velocity structure of the interstellar Na D absorption line. The authors of these two papers arrived at almost the same conclusion that the distance to CI Cam is in the range 5–9 kpc. We hereafter adopt the distance of 5 kpc as a default according to recent convention.

One of the most controversial issues as yet unsettled for CI Cam is the identification of the accreting compact object. There are, of course, three possibilities: a BH, an NS, or a white dwarf (WD). Orlandini et al. (2000) pointed out that the outburst behavior of CI Cam is similar to that of a nova outburst and that the compact object might be a WD. Belloni et al. (1999) argued for an NS since the overall outburst behavior is similar to that of the 69 ms X-ray pulsar A0538–66 in the LMC (Corbet et al. 1997). Robinson et al. (2002) obtained an X-ray luminosity of $L(2–25 \text{ keV}) = 3 \times 10^{38}$ ergs s$^{-1}$ based on their revised distance of 5 kpc, making CI Cam one of the most luminous X-ray transients. Comparing the outburst luminosity with that during quiescence, they concluded that the compact object is most likely a BH.

In this paper we present results from *ASCA* observations of CI Cam in quiescence and those from a more detailed analysis of the soft X-ray component in outburst dominating below ~1 keV (Ueda et al. 1998), which is probably identical with that detected in one of the 1998 April observations by *BeppoSAX* (Orr et al. 1998). Overall X-ray behavior revealed by the *ASCA* observations is consistent with the picture that the compact object in CI Cam is a WD, and the eruptive event that triggers the hard X-ray outburst can be identified with a nova outburst (=thermonuclear flash on the surface of the WD). We note that the errors quoted throughout this paper are at the 90% confidence level unless otherwise mentioned.

2. OBSERVATIONS

The *ASCA* observation of CI Cam in quiescence was performed during 1999 September 19.415–20.445, which was between the first (1998 September 3–4) and second (1999 September 23–35) *BeppoSAX* observations of CI Cam in quiescence (Orlandini et al. 2000; Parmar et al. 2000). Throughout the observation, the Solid-State Imaging Spectrometer (SIS; Burke et al. 1994; Yamashita et al. 1999) was operated in PH mode with default telemetry bit assignment. We retrieved the data from the Data Archive and Transmission System (DARTS) operated by the Institute of Space and Astronautical Science (ISAS).

We applied the following selection criteria to both the SIS and GIS data. We did not use the data obtained while the spacecraft was located within 60 s from the South Atlantic Anomaly. We also discarded data obtained while the pointing direction of the telescope was within 5° of the Earth limb. In addition to these, we further adopted the following criterion only for the SIS. We discarded data obtained while the pointing direction of the telescope was within 20° of the bright Earth limb illuminated by the Sun. After these criteria were applied, some 37.4 and 43.8 ks remained as good time intervals for the SIS and the GIS, respectively. For source photon integration regions, we adopted circles with radii of 2' and 3' centered on CI Cam for the SIS and the GIS, respectively. For background regions, we used the residual area of the same CCD chip employed for the CI Cam observation that is out of the source integration region for the SIS, while for the GIS we adopted a circle with a radius of 6' whose center is located opposite to the source integration region with respect to the optical axis of the telescope, in order to take vignetting of the telescope into account. After background subtraction, the average count rates throughout the observation are $0.054 \pm 0.003$ and $0.058 \pm 0.004$ counts s$^{-1}$ per detector for the SIS in the 0.5–10 keV band and the GIS in the 0.7–10 keV band, respectively.

The *ASCA* observation of CI Cam in outburst was carried out from 1998 April 3.31 to 4.14, which was only 3 days after the onset of the outburst and only 2 days after the X-ray peak (Smith et al. 1998). A detailed observation journal is presented in Ueda et al. (1998). The spectrum was represented by a two-temperature optically thin thermal emission model with temperatures of 1.1 and 5.7 keV and with relative abundances of Si, S, and the other metals of $1.25 \pm 0.04$, $1.03 \pm 0.13$, and $0.98 \pm 0.12$.

1 See http://www.darts.isas.ac.jp.
0.36 ± 0.02, respectively, relative to the cosmic composition (Anders & Grevesse 1989). A neutral iron emission line at 6.41 keV was found with an equivalent width of 90 eV. The entire spectrum was covered by neutral absorber with $N_{\text{HI}} = (4.6 ± 0.3) \times 10^{21} \text{ cm}^{-2}$. In addition to this hard X-ray component, they also discovered another spectral component, which appears and flickers in the latter half of the observation. Its spectrum has a sharp cutoff at \( \sim 0.8 \) keV, and it is detected only below 0.9 keV (Ueda et al. 1998). They could fit the spectrum with a blackbody model with \( kT = 0.12 ± 0.02 \) keV with K edges of hydrogenic and He-like oxygen at \( \sim 0.77 \) and \( \sim 0.84 \) keV. We are interested in this soft component, which is not analyzed in full detail by Ueda et al. (1998). Accordingly, we concentrate on the SIS when analyzing the outburst data, because the SIS has higher sensitivity below 1 keV than the GIS. The same selection criteria as those for the quiescence data are applied, except that the radius of the source photon integration region is taken to be 3\'.

3. ANALYSIS AND RESULTS

3.1. Light Curve in Quiescence

We have first made light curves of CI Cam in quiescence, in order to see whether there is any variability during the ASCA observation. According to the data selection criteria (\S 2), we have extracted source and background photons for each detector (SIS0, SIS1, GIS2, and GIS3) separately. With a bin width of 6400 s, we have created SIS light curves by adding up the photons from the two SIS detectors after background subtraction. The same procedure is applied for the GIS. A large bin size of 6400 s is adopted because of statistical limitations. As shown in the next subsection, in quiescence the ASCA (Fig. 1) and XMM-Newton spectra (Boirin et al. 2002) both obviously consist of two spectral components separated at around a few keV. Accordingly, we have attempted to fit them with soft and hard components undergoing independent photoelectric absorptions. For spectral fitting, we use XSPEC version 11.2 (Arnaud 1996). Throughout this subsection, the GIS and SIS spectra are always fitted contemporaneously.

First of all, we attempt to fix spectral models for both emission components from a purely statistical point of view. We have tried optically thin thermal plasma emission (MEKAL), power law, and blackbody models for the soft component, and MEKAL, power law, and thermal bremsstrahlung models for the hard component. As noticed from Figure 1, the ASCA spectra suggest presence of an iron K\( \alpha \) emission line feature around 6–7 keV. The iron K\( \alpha \) emission lines have also been detected from the BeppoSAX and XMM-Newton observations (Parmar et al. 2000; Boirin et al. 2002). We thus have added a narrow Gaussian, with its central energy free to vary, when either the power law or the thermal bremsstrahlung is adopted for the hard component. To check

![CI Cam spectrum](image-url)
the validity of adding the Gaussian line, we tried a model composed of a soft MEKAL and a hard power law, and by including a Gaussian, we found that the resultant $\chi^2$ value is improved from 38.23 (44 dof) to 31.78 (42 dof), implying $\Delta \chi^2 = 6.46$ for 2 dof. According to an $F$-test, the inclusion of the iron line in the ASCA spectra is justified at the 98.0% confidence level.

The best-fit $\chi^2$ matrix for the fits with the trial models is summarized in Table 1. There is no reason to prefer any particular model statistically for both soft and hard components. We thus need some physical reason for choosing a particular pair of the models. It has been suggested that the soft component probably originates from the sgB[e] star (Robinson et al. 2002). A temperature of $\sim 0.22$ keV (Orlandini et al. 2000) and a $0.5-2.0$ keV luminosity of $2 \times 10^{39}$ ergs s$^{-1}$ are consistent with the X-ray emission from the sgB[e] star (Robinson et al. 2002). A power-law fit to the soft-band spectrum of the current ASCA data results in a photon index of $5.3^{+1.1}_{-1.0}$. Such a steep spectrum probably corresponds to the high-energy end of a thermal spectrum. Accordingly, we hereafter adopt the MEKAL model for the soft component.

For the hard component, on the other hand, since the MEKAL model and the thermal bremsstrahlung plus Gaussian model are essentially the same, we compare the power-law model (plus Gaussian) with the MEKAL model. The results of the fits in the $0.5-10$ keV band, including the soft MEKAL below $\sim 2$ keV, are summarized in Table 2. For the MEKAL components, we first tried to set their abundances free to vary independently ("2 MEKAL I" model in Table 2) and found that they are consistent within the errors. We thus have constrained the two abundances to be the same ("2 MEKAL II" model). The fit with this model results in an abundance of $0.26^{+0.54}_{-0.26}$ times the cosmic value (Anders & Grevesse 1989). The error is, however, large owing to statistical limitation. We thus have fixed the abundance at the value 0.36 times the cosmic value obtained from the outburst observation by Ueda et al. (1998) ("2 MEKAL III" model). As can be seen from Table 2, all three MEKAL fits are acceptable at the 90% confidence level, and the fit with the "2 MEKAL I" model is formally the best. As described above, however, the soft component can be interpreted as coronal emission from the sgB[e] star, and since the hard-component emission is probably a result of mass accretion from the sgB[e] star, there is no reason that the abundance of the hard MEKAL component would be different from that of the soft component. Accordingly, we believe the last "2 MEKAL III" model is physically the most reasonable. On the basis of this model, the best-fit temperatures of the soft and hard components are $kT_1 = 0.45^{+0.17}_{-0.14}$ and $kT_2 = 5.5^{+7.7}_{-2.9}$ keV, respectively. Bolometric luminosities of the hard MEKAL component are calculated from the emissivity of thermal bremsstrahlung (Rybicki & Lightman 1979) at the observed temperature and the emission measure. Those of the soft MEKAL, on the other hand, are calculated from the emissivity of the optically thin thermal plasma (Gaetz & Salpeter 1983).

### Table 1

| Soft Component | MEKAL | Power Law+Gaussian | Thermal Bremsstrahlung+Gaussian |
|----------------|-------|-------------------|-------------------------------|
| MEKAL.......... | 0.78 (43) | 0.76 (42) | 0.76 (42) |
| Power law...... | 0.77 (44) | 0.75 (43) | 0.75 (43) |
| Blackbody...... | 0.80 (44) | 0.76 (43) | 0.76 (43) |

Note.—Values in parentheses are the dof.

### Table 2

| Parameter | MEKAL+Power Law+Gaussian | 2 MEKAL I | 2 MEKAL II | 2 MEKAL III |
|-----------|--------------------------|-----------|------------|-------------|
| $N_{HI}$ (10$^{21}$ cm$^{-2}$) | $2.8^{+2.4}_{-1.3}$ | $2.8^{+4.2}_{-2.9}$ | $7.9^{+14}_{-8.9}$ | $8.3^{+18}_{-9.0}$ |
| $N_{H2}$ (10$^{23}$ cm$^{-3}$) | $1.9^{+0.5}_{-0.4}$ | $2.0^{+0.5}_{-0.4}$ | $2.0^{+0.5}_{-0.4}$ | $1.9^{+0.5}_{-0.4}$ |
| Photon index | $2.2^{+0.5}_{-0.3}$ | $2.2^{+0.5}_{-0.3}$ | $2.2^{+0.5}_{-0.3}$ | $2.2^{+0.5}_{-0.3}$ |
| $kT_1$ (keV) | $0.5^{+0.1}_{-0.1}$ | $0.5^{+0.1}_{-0.1}$ | $0.5^{+0.1}_{-0.1}$ | $0.5^{+0.1}_{-0.1}$ |
| $kT_2$ (keV) | $5.9^{+9.1}_{-4.2}$ | $5.5^{+7.7}_{-2.9}$ | $5.2^{+7.4}_{-2.9}$ | $5.5^{+7.4}_{-2.9}$ |
| $E_{M1}$ (10$^{56}$ ergs cm$^{-3}$) | 4.64 | 4.53 | 4.53 | 3.91 |
| $E_{M2}$ (10$^{56}$ ergs cm$^{-3}$) | 4.92 | 5.66 | 4.98 |
| $Z_{Fe}/Z_{e}$ | $0.01^{+0.01}_{-0.01}$ | $0.01^{+0.01}_{-0.01}$ | $0.01^{+0.01}_{-0.01}$ | $0.01^{+0.01}_{-0.01}$ |
| $Z_{C}/Z_{e}$ | $0.38^{+0.20}_{-0.20}$ | $0.26^{+0.24}_{-0.26}$ | $0.26^{+0.24}_{-0.26}$ | $0.36$ (fix) |
| Line center (keV) | 6.51 $\pm$ 0.23 | ... | ... | ... |
| Line normalization (10$^{-6}$ photons cm$^{-2}$ s$^{-1}$) | 8.5 $\pm$ 2.6 | ... | ... | ... |
| Equivalent width (eV) | 624 $\pm$ 410 | ... | ... | ... |
| $L_{5300}^{soft}$ (10$^{37}$ ergs s$^{-1}$) | ... | ... | 6.0 | ... |
| $L_{5300}^{hard}$ (10$^{37}$ ergs s$^{-1}$) | ... | ... | 9.4 | ... |
| $\chi^2$ (dof) | 0.76 (42) | 0.78 (43) | 0.86 (44) | 0.84 (45) |

a Two abundances free to vary independently.

b Two abundances free to vary but constrained to be the same.
c Both abundances fixed at the outburst value (Ueda et al. 1998).
d $Z_{e}$ implies the cosmic abundance (Anders & Grevesse 1989).
e Bolometric luminosity for the soft component at the distance of 5 kpc.
f Bolometric luminosity for the hard component at the distance of 5 kpc.
Around the plasma temperature of 0.4–0.5 keV observed, the emissivity of the plasma is dominated by the iron L line emissions. Accordingly, we have taken the observed iron abundance into account in the luminosity calculation. As a result, the bolometric luminosities of the soft and hard components obtained with the “2 MEKAL III” model are $6.0 \times 10^{33}$ and $9.4 \times 10^{33}$ ergs s$^{-1}$, respectively.

The power-law model, on the other hand, can fit the spectra as well as the MEKAL models. We thus next consider the nonthermal power law as the continuum emission model of CI Cam in quiescence. In this case, the observed iron emission line should be of fluorescent origin. We assume that the line originates from matter surrounding the hard-component emitter uniformly with the $4\pi$ solid angle. The thickness of the matter is then equal to the line-of-sight photoelectric absorption $N_{\text{H2}} = 1.9_{-0.0}^{+0.3} \times 10^{23}$ cm$^{-2}$ (Table 2). From this hydrogen column density, the equivalent width of the iron K$\alpha$ emission line is expected to be $190_{-40}^{+40}$ eV under the condition that the intrinsic photon index of a power-law emission is 1.1 and that the fluorescing matter has the cosmic composition (Inoue 1985). In the case of CI Cam, there are two factors that reduce the expected equivalent width; one is the iron abundance, which is $0.36 \pm 0.02$ times the cosmic value (Ueda et al. 1998), which reduces the equivalent width proportionally; the other is the larger photon index of 2.28 (Table 2), which also reduces the equivalent width according to the following scaling relation:

$$\text{EW}(\gamma) \propto \frac{1}{f(E_{\text{K}\alpha}, \gamma)} \int_{E_{\text{edge}}}^{\infty} f(E, \gamma) \sigma(E) dE$$

(Ezuka & Ishida 1999), where $f(E_{\text{K}\alpha}, \gamma)$ represents the intrinsic X-ray photon flux density of the power law with the photon index $\gamma$ at the energy $E_{\text{K}\alpha}$; $E_{\text{K}\alpha}$ and $E_{\text{edge}}$ are the energies of the K$\alpha$ line and the K edge of the neutral iron, which are 6.40 and 7.11 keV, respectively, and $\sigma$ is the cross section of the iron K-edge photoelectric absorption. In the case of $\gamma = 2.28$, we have obtained an EW scaling factor from the $\gamma = 1.1$ case of 0.64, assuming $\sigma(E) \propto E^{-3}$ for $E > E_{\text{edge}}$. As a result, the expected equivalent width from CI Cam is only $\sim 40$ eV with a 90% upper limit of 80 eV within the errors of the related parameters. This is not compatible with the observed equivalent width of $624_{-1033}^{+9}$ eV (Table 2). It is difficult to explain the observed iron K$\alpha$ emission line solely by the fluorescence. The underlying continuum is thus likely to be optically thin thermal plasma emission, supplying additional iron K$\alpha$ line emission. In Figure 1 we show the best-fit “2 MEKAL III” model by histograms, which we put forward as the best representation of the CI Cam spectra. We note, however, that this conclusion is derived under the hypothesis that fluorescing matter surrounds the central object uniformly. This may, however, not be true, because there is a dense circumstellar disk around the sGB[e] star out of the line of sight. Also, the absorber is assumed to be neutral, but this may not be true either. Both these effects provide us with a larger equivalent width at a given line-of-sight column density estimated with cross section of neutral matter. Hence, we cannot rule out the power-law model for the hard spectral component of CI Cam in quiescence.

Note also that although we have shown that the thermal iron K$\alpha$ line is preferred, a partial contribution form a fluorescent component is not ruled out. In the XMM-Newton observation (Boirin et al. 2002), the iron line is detected at the energy 6.43 ± 0.09 keV with the equivalent width of $940_{-460}^{+53}$ eV, which is greater than that obtained with ASCA. Since the line-of-sight hydrogen column density from the XMM-Newton observation is also greater than that of the ASCA observation, the greater equivalent width and the lower line central energy are probably brought about by an incremental contribution from a fluorescent component. The upper limit of the line width 0.28 keV obtained by XMM-Newton probably allows contribution from the thermal plasma component to the observed iron line. Hence, the iron K$\alpha$ emission line from CI Cam is probably a mixture of thermal plasma and fluorescent components. For the ASCA spectra in Figure 1, it is possible to insert an additional Gaussian representing the fluorescent iron line into the model, which we have, however, refrained from doing because of statistical limitation.

### 3.3. Reanalysis of the Soft Component in the Outburst Spectrum

#### 3.3.1. Light Curve

As described in § 1, the X-ray emission from CI Cam during the outburst is dominated by that from an optically thin thermal plasma with a temperature of several keV (Ueda et al. 1998), which is probably escaping from the binary system. In addition to this, a separate soft X-ray component that is detected only below 1 keV starts to appear in the middle of the ASCA observation. Although it once fades away, it brightens again near the end of the observation. We show the SIS0 light curve during the outburst in Figure 2. As noted by Ueda et al. (1998), the satellite telemetry is saturated after around April 4 2:40 because of the increasing intensity of the soft component, and the detection efficiency of the SIS at the image core is significantly reduced as a result of event pile-up. In drawing the light curve we have corrected for this effect by utilizing photons well outside the overflowed core and a saturated region.

In order to examine the nature of the soft component, in Figure 2 we divide the full data set into several pieces, designated “flares 1 and 2,” “nonflares 1 and 2,” and “flares 3–5,” which are delineated by the dashed vertical lines, and draw the average SIS spectra during those intervals separately in Figure 3. We corrected for the event pile-up effect for the spectrum during the flare 5 interval. As obviously seen from the spectral variation, what changes during the soft flare is not the line-of-sight absorption but the emission component itself; the spectrum extends to a higher energy band as the intensity increases. Owing to a very slow decay of the hard component, the flux levels of all of the data segments are similar above $\sim 1$ keV. Accordingly, we regard the average of the nonflare 1 and 2 spectra as background and simply subtract them from the flare spectra.

#### 3.3.2. Evaluation of the Spectra by a Power Law

We first tried to fit all five flare spectra after the background subtraction (Fig. 4) by a power law undergoing the photoelectric absorption. We used the spectral energy bins in the 0.5–0.7 keV band for flares 1 and 3 and the 0.5–0.9 keV band for the others. The fits are, however, generally poor. Ueda et al. (1998) point out that the high-energy cutoff starting at $\sim 0.8$ keV seen in the flare 5 spectrum is as steep as what can be realized by a sharp atomic edge alone. Accordingly, we overlaid the power law with two edges and tried to fit the spectra again. In doing this, we have fixed the hydrogen column density at $4.6 \times 10^{21}$ cm$^{-2}$, which is obtained by the fit.
to the hard X-ray component during outburst out of the soft flare (Ueda et al. 1998). The results are summarized in Table 3. The fits for all five spectra are markedly improved and are now acceptable at the 90% confidence level. Although the power-law model is acceptable as an underlying continuum, however, it is difficult to understand the large variation of the photon index ranging 0.5–5.3 over the five flare phases. No power-law X-ray source has been known so far whose photon index varies by such a wide range on the timescale of a day. The apparent large photon index variation thus probably represents a temperature variation of the continuum. We therefore examine a blackbody model in the following subsection.

3.3.3. Evaluation of the Spectra by a Blackbody

We have attempted to fit five flare spectra with a blackbody model in the same energy bands as in the previous subsection. As we already know, some absorption edges are necessary to fit the spectra. We thus introduce absorption edges one by one.
until we obtain acceptable $\chi^2$ values. The results are summarized in Table 4. As suggested by Figure 3, the blackbody temperature increases with the intensity whereas no $N_H$ decrease is found with increasing intensity. Two edges are necessary to fit the flare 2, 4, and 5 spectra, one edge for the flare 1 spectrum, and no edge for the flare 3 spectrum. The fit to the flare 3 spectrum is, however, further improved significantly if we overlay the blackbody with an edge at 0.67 keV, as listed in the last column of Table 4. Note that the obtained edge energies in the flare 1 and 3 spectra (0.62 and 0.67 keV, respectively) are somewhat apart from those of O vii and O viii K edges. Obviously we need a more systematic and sophisticated treatment for the oxygen edges, which is essential for determining the intrinsic spectral shape and the luminosity of the soft component.

**Fig. 4.**—Best-fit SIS0+SIS1 spectra of CI Cam from the flare 1–5 segments fitted by the blackbody with the five oxygen edges. The top panel shows the data and the models for the five flare spectra. The other five panels show the fit residuals for the five spectra separately. For the best-fit parameters, see Table 5.

**TABLE 3**

**Best-Fit Parameters of the Flare Spectra with a Power Law Overlaid with Dual Edges**

| Flare Phase | Flare 1 | Flare 2 | Flare 3 | Flare 4 | Flare 5 |
|-------------|--------|--------|--------|--------|--------|
| $N_H$ (10^{21} cm^{-2}) | 4.6 (fixed) | 4.6 (fixed) | 4.6 (fixed) | 4.6 (fixed) | 4.6 (fixed) |
| Photon index | 3 ± 2 | $3.6^{+0.2}_{-0.2}$ | $5.3^{+0.3}_{-0.3}$ | $2.34^{+0.13}_{-0.08}$ | $0.5^{+0.2}_{-0.1}$ |
| Normalization$^a$ | $1.4^{+2.3}_{-2.0}$ | $6^{+1}_{-2}$ | 0.47 ± 0.02 | 8.2 ± 0.1 | $27.7^{+0.4}_{-0.3}$ |
| $E_{edge1}$ (keV) | 0.6144 (fixed) | 0.66 ± 0.01 | 0.65 ± 0.05 | 0.67 ± 0.01 | 0.773 ± 0.002 |
| $\tau_1$ | < 3 | 1.3 ± 0.1 | < 1.4 | 1.06 ± 0.05 | 3.1 ± 0.1 |
| $E_{edge2}$ (keV) | 0.6 ± 0.1 | 0.76 ± 0.02 | 0.67 ± 0.03 | 0.767 ± 0.002 | 0.832 ± 0.004 |
| $\tau_2$ | < 78 | $12^{+2}_{-1}$ | < 7.8 | $12^{+2}_{-1}$ | 80 ± 10 |
| $\chi^2$ (dof) | 0.81 (51) | 0.92 (104) | 0.82 (50) | 0.80 (104) | 1.03 (104) |

$^a$ Power-law normalization in the unit of $10^{-3}$ photons s$^{-1}$cm$^{-2}$ at 1 keV.

$b$ Optical depth of the atomic edge at the energy $E_{edge1}$.

$c$ Optical depth of the atomic edge at the energy $E_{edge2}$.
In the second column of Table 5, we tabulate the energies of ionized oxygen edges above 0.60 keV (Verner & Yakovlev 1995). It is likely that the edges found in the flare 1 and 3 spectra are associated with O iv or O v. We thus introduce a model composed of a blackbody with five edges corresponding to O iv–O viii. If we allow all of their energies to vary independently, however, they never converge because of the limited energy resolution and the narrow energy bands available. We have therefore linked the energies of edge1 through edge5 to edge1 so that their ratios to edge1 are consistent with the theoretical values listed in the second column of Table 5. The results of the best-fit to each flare spectrum are shown in Figure 4; the parameters are listed from the third column in The results of the best-fit to each flare spectrum are shown in Table 4. The oxygen edges are significant for the middle-flux spectrum flare 2, and only the He-like and hydrogenic edges are significant for the high-flux spectra flares 4 and 5. Note that edge5 is beyond the upper boundary of the fitted energy range (0.5–0.9 keV) for some spectra. The edge is, however, still important to cut off the high-energy part of the spectra because of the finite energy resolution of the SIS. As a result, the blackbody temperature of the soft component varies in the range 0.07–0.12 keV. Although bolometric luminosities are not always well constrained, they include the Eddington luminosity of a 1 $M_\odot$ object for the assumed distance of 5 kpc.

4. DISCUSSION

4.1. Accreting Object Suggested from Data in Quiescence

We argued in § 3.2 that the hard component of the CI Cam spectra in quiescence is likely to be optically thin thermal plasma emission with a temperature of $kT_2 = 5.5–7.7$ keV, based on the discussion of the iron line equivalent width. This

| Flare Phase | Flare 1 | Flare 2 | Flare 3 | Flare 4 | Flare 5 |
|-------------|--------|--------|--------|--------|--------|
| $N_0$ (10$^{21}$ cm$^{-2}$) | 3.2 | 4.5 ± 0.3 | < 7.6 | 0.8 ± 0.3 | 7.3 ± 1 |
| $kT_{bb}$ (keV) | 0.10 ± 0.02 | 0.110 ± 0.002 | 0.07 ± 0.01 | 0.115 ± 0.003 | 0.113 ± 0.007 |
| $E_{edge1}$ (keV) | 0.6414 | 0.60 ± 0.03 | 0.641 ± 0.003 | 0.59 ± 0.01 | 0.64 ± 0.02 |
| $\tau_1$ | < 29 | 0.2 ± 0.1 | 1.7 | < 0.1 | 0.1 |
| $E_{edge2}$ (keV) | 0.6941 | 0.64 | 0.676 | 0.676 | 0.69 |
| $\tau_2$ | 5.28 | 0.9 ± 0.1 | 1.1 | 0.65 ± 0.06 | < 0.2 |
| $E_{edge3}$ (keV) | 0.6837 | 0.67 | 0.713 | 0.66 | 0.712 |
| $\tau_3$ | 1 | 0.25 ± 0.06 | > 2.3 | 0.22 ± 0.07 | 0.3 ± 0.2 |
| $E_{edge4}$ (keV) | 0.7393 | 0.73 | 0.771 | 0.72 | 0.770 |
| $\tau_4$ | 0.0 (fixed) | 4.3 ± 0.3 | 0.0 (fixed) | 4.3 ± 0.3 | 4.9 ± 0.3 |
| $E_{edge5}$ (keV) | 0.8714 | 0.860 | 0.908 | 0.84 | 0.907 |
| $\tau_5$ | 0.0 (fixed) | > 8.0 | 0.0 (fixed) | > 2.1 | 100 |
| $L_{rad}^{*}$ (10$^{36}$ ergs s$^{-1}$) | 0.3 ± 10 $^{17}$ | 2.2 ± 2.7 | 1.3 ± 18 $^{7}$ | 1.0 ± 1 | 9.0 ± 82.0 |
| $\chi^2$ (dof) | 0.85 (49) | 0.92 (101) | 0.83 (49) | 0.83 (101) | 0.85 (101) |

* A single edge is added although no edge model is acceptable.
* Optical depth of the atomic edge at the energy $E_{edge1}$.
* Optical depth of the atomic edge at the energy $E_{edge2}$.

a Theoretical ionized oxygen edge energies from O iv to O viii taken from Verner & Yakovlev 1995.
b Hydrogen column density in excess of 4.6 $\times$ 10$^{21}$ cm$^{-2}$.
c Linked to $E_{edge1}$ so as to be consistent with the theoretical value (Verner & Yakovlev 1995) listed in the second column.
d The depth is unbound within the range 0–200, and we fixed at the value tabulated.
e Distance is assumed to be 5 kpc.
type of spectrum reminds us of hard X-ray emission from accreting WDs (cataclysmic variables). Mukai & Shiozawa (1993) have summarized the EXOSAT observations of dwarf novae (DNe) and found that the spectra can be represented by a thermal bremsstrahlung with a temperature of several keV in general, plus an iron emission line at 6.7 keV. Their luminosities are, however, in the range $7 \times 10^{30} - 3 \times 10^{32}$ ergs s$^{-1}$, which is smaller than that of CI Cam in quiescence by more than an order of magnitude. Note, however, that the mass-donating companion stars in these DNe are low-mass main-sequence stars. In such systems, the mass accretion rate is in general lower than in systems that include an evolved companion. In comparing with CI Cam, we thus have to refer to an accreting WD binary that includes an evolved mass-donating star. One of the best such systems is the symbiotic star CH Cyg. Ezuka, Ishida, & Makino (1998) analyzed the ASCA data of CH Cyg, which is a binary composed of a WD and a Roche lobe–filling M6.5 giant star. We would like to stress, in particular, the remarkable similarity of the CH Cyg spectrum (see Fig. 2 of Ezuka et al. 1998) to that of CI Cam; it obviously consists of two components separated at 2 keV; the harder component is represented by an optically thin thermal spectrum with a temperature and metal abundance of $7.3 \pm 0.5$ keV and $0.43 \pm 0.05$ the cosmic value undergoing heavy photoelectric absorption with $N_H$ as large as $10^{23}$ cm$^{-2}$, which probably results from the huge amount of matter supplied by the evolved star, thereby surrounding the accreting object; the bolometric luminosity of the hard component is $1 \times 10^{33}$ ergs s$^{-1}$ (Ezuka et al. 1998). Because of all these similarities to the accreting white dwarf binaries, the most likely candidate for the accreting object in CI Cam is a WD.

The hard X-ray nature of the BH transients, on the other hand, has been revealed by recent Chandra observations. Their X-ray spectra are represented by a power law with a photon index of 1.7–2.3 (Kong et al. 2002), which covers that of CI Cam (=2.28; Table 2). Although the X-ray luminosities are found to be mostly in the range $10^{30} - 10^{32}$ ergs s$^{-1}$ (Garci a et al. 2001), which is significantly lower than that of CI Cam ($\approx 10^{34}$ ergs s$^{-1}$; Table 2), the longest orbital period system V404 Cyg (=GS 2023+338) is found to have a luminosity as high as $5 \times 10^{33}$ ergs s$^{-1}$ (Garci a et al. 2001; Asai et al. 1998a). A power law with the photon index of $\approx 2$ can thus be realized at a luminosity level of up to $\approx 10^{34}$ ergs s$^{-1}$ in BH transients that include an evolved mass donor. Since the power-law model can fit the hard component of CI Cam in quiescence as well as the MEKAL model (Table 2), as described in § 3.2, we cannot rule out a BH as a possible candidate for the accreting object of CI Cam from the analysis of the ASCA quiescence data.

For the same reason, we cannot exclude a possibility of an NS either. The X-ray spectra of the NS transients in quiescence are represented well by a blackbody model with a temperature of 0.1–0.3 keV (Asai et al. 1998a) or an NS atmosphere model (Rutledge et al. 2002), occasionally accompanied by the power law that has nearly the same photon index as that found in the BH transients. It is thus possible that the hard component of CI Cam in quiescence is the power-law emission often detected from NS transients. Narayan, McClintock, & Yi (1996) claim that the power-law component is emission from an advection-dominated accretion disk formed around the central object. In this case, the blackbody component from the NS surface in CI Cam should be obscured by the heavy photoelectric absorption ($N_H \approx 1.9 \times 10^{23}$ cm$^{-2}$; Table 2) and invisible. The soft component should thus be attributed to the coronal emission of the sgB[e] star, as described in § 3.2.

In summary, because of the similarities of the CI Cam spectra in quiescence to other mass-accreting WDs, we argue that the accreting object of CI Cam is most likely a WD. This argument depends mostly on the identification of the hard X-ray component with the optically thin thermal plasma emission; this has not, however, been completely established owing to statistical limitation. The spectral slope of the hard component is similar to that of the BH and NS transients in quiescence if we adopt the power law in evaluating the spectra. Hence, we cannot rule out an NS or a BH as candidates for the accreting object in CI Cam.

4.2. Accreting Object Suggested from Outburst Data

The updated distance of 5 kpc to CI Cam results in a hard X-ray luminosity at the burst peak of $L(2–25$ keV$)$ = $3 \times 10^{38}$ ergs s$^{-1}$, which exceeds the Eddington limit of a $1 M_\odot$ star. On the other hand, the peak luminosities so far obtained from other NS and BH transients are, in general, in the ranges $10^{37} - 10^{38}$ and $10^{38} - 10^{39}$ ergs s$^{-1}$, respectively (Tanaka & Shibazaki 1996; Chen, Shrader, & Livio 1997). The burst peak luminosity of CI Cam thus matches that of the BH transients. These are the main reasons to put forth a BH identification of CI Cam (see, e.g., Robinson et al. 2002).

As reported by Corbet et al. (1997), however, the luminosity of the transient X-ray pulsar A0538–66 in the LMC reaches as high as $\sim 10^{39}$ ergs s$^{-1}$ at the burst peak, which violates both the Eddington limit of an NS and the empirical source classification according to the burst peak luminosity. There are some pieces of evidence that the plasma emitting the hard X-rays during the CI Cam outburst is not the one accreting steadily onto the central object but rather escapes from the binary (see § 1). One thus has to be prudent enough to apply the Eddington-limit luminosity to the outburst of CI Cam. We believe we cannot exclude a WD from the candidates of the central object of CI Cam simply because the hard X-ray luminosity at the burst peak exceeds the Eddington luminosity of the typical $1 M_\odot$ object.

Although novae have been regarded as soft X-ray emitters, some have been found to show hard X-ray emission in an early phase of their outbursts. The earliest detection of hard X-ray emission from a nova was obtained from the ROSAT PSPC observation of V838 Her 5 days after the optical peak (Lloyd et al. 1992). ASCA detected hard X-ray emission from the fast nova V382 Vel 20 days after the optical peak. The ASCA spectrum of V382 Vel can be well fitted by a thermal bremsstrahlung model with the temperature of $\sim 10$ keV (Mukai & Ishida 2001). The optically thin nature and significant X-ray flux above 10 keV are similar to the ASCA spectrum of CI Cam obtained 3 days after the onset of the outburst (Ueda et al. 1998). We note that no soft X-ray transient that harbors an NS or a BH shows an optically thin thermal nature in the X-ray spectrum during its outburst.

In addition, the remarkable similarity of the soft component to that of the supersoft source (SSS) further strengthens the WD identification of CI Cam. The spectrum of one of the SSSs, CAL 87, obtained by ASCA is well represented by a blackbody model with $kT_{bb} = 75$ eV multiplied by the K edges of O vii and O viii, and the bolometric luminosity varies in the range $4 \times 10^{37}$ to $1.2 \times 10^{38}$ ergs s$^{-1}$ (Asai et al. 1998b; Ebisawa et al. 2001), which are both common to those of the
CI Cam soft component. It has been pointed out that novae can show the properties of an SSS, after the photosphere shrinks back onto the WD surface in the declining phase of the outburst. Starrfield et al. (2000) discovered a supersoft continuum underneath a line-rich spectrum of the nova V1494 Aql using the Chandra grating observations. A supersoft continuum was also found for V382 Vel by BeppoSAX after 6 months (Orio et al. 2002), and for V1974 Cyg (=Nova Cyg 1992) by the ROSAT PSPC after 8 months (Krautter et al. 1996) from their outbursts. The soft component of CI Cam detected by ASCA can thus be ascribed most naturally to the supersoft X-ray emission from the WD. It is possible to interpret the on-and-off behavior manifested in Figure 2 as the repeated bounces of the WD photosphere, which is subject to radiation pressure in the high-luminosity environment close to the Eddington limit.

4.3. Distance Estimate Based on the Nova Hypothesis

In the preceding two subsections, we have shown evidence based on the quiescence and outburst observations that indicates that the central object of CI Cam is a WD, and have proposed a nova outburst picture for the CI Cam outburst. It is well known that nova outbursts are good distance indicators, though the characteristics of the nova light curve could be significantly modified with the circumstellar environment of the WD. The relation between the absolute peak visual magnitude ($M_V^{\text{max}}$) and the speed class (Warner 1995), the latter of which is characterized by the time that must elapse for a nova to decline by 2 and 3 mag from its peak (conventionally denoted as $t_2$ and $t_3$, respectively). As described in §1, the distance to CI Cam is estimated to be 5–9 kpc. Although the characteristics of the nova light curve could be significantly modified with the circumstellar environment of CI Cam, it still seems worthwhile to estimate the distance to CI Cam under the assumption of a nova outburst.

The relation between $M_V^{\text{max}}$ and $t_2$ is calibrated by Cohen (1988) as

$$M_V^{\text{max}} = 2.41\,(\pm0.23)\log_{10}t_2 - 10.70(\pm0.30), \quad (1)$$

where the unit of $t_2$ is a day. In order to estimate $t_2$, we have retrieved the optical light curve between April 3 and May 20 from VSNET database,2 which is shown in Figure 5 together with some data points obtained in the earliest phase (Garcia et al. 1998; Hynes et al. 1998). We have attempted to fit the following model to this light curve:

$$m_V(t) = m_V^{\text{const}} - m_V^{\text{amp}}\exp\left(-\frac{t-t_{\text{max}}}{\tau_{\text{fold}}}\right), \quad (2)$$

where $t_{\text{max}}$ is the time of the peak magnitude, $m_V^{\text{const}}$ is the magnitude of the sgB[e] star, and $m_V^{\text{amp}}$ is the decrement of the magnitude at the burst peak. Unfortunately, the earliest optical observation was made on April 3.08–3.17 (Garcia et al. 1998), at which time the optical flux had probably already started to decline (Hynes et al. 1998). The multiwaveband light curves (Frontera et al. 1998), on the other hand, indicate that the burst peak occurs later for the longer wavelength. It is thus reasonable to assume that the optical peak occurs no earlier than that of the X-ray, which was April 1.04 (Smith et al. 1998). We thus need to take into account the contribution of optical flux from the sgB[e] star, which is completely negligible for ordinary novae. We thus first convert equation (2) to a flux, then subtract the flux of the sgB[e] star, and then calculate $t_2$ as the time at which the subtracted flux becomes $10^{-0.8}$ of the peak. The resulting $t_2$ is in the range 5.8–7.2 days, depending on the choice of $t_{\text{max}}$. Accordingly, CI Cam is classified as a very fast nova ($t_2 < 10$ days). The apparent $V$-magnitudes at the peak ($=m_V^{\text{const}} - m_V^{\text{amp}}$) are subject to the an extinction correction of $A_V = 2.0 - 4.4$ (Hynes et al. 2002), resulting in the distance modulus with $M_V^{\text{max}}$ obtained through equation (1) using $t_2$. It is obvious that most of the error in the distance originates from $A_V$. We thus neglect all of the other errors, such as those of the parameters in equation (2) and those of the data points in the light curve. As a result, the distance to CI Cam is estimated to be in the range 5–17 kpc, irrespective of the choice of $t_{\text{max}}$.

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2 See http://vsnet.kusastro.kyoto-u.ac.jp/vsnet/LCs/index/index.html.
between April 1.0 and 3.0. This result is consistent with an estimate of 5–9 kpc (Robinson et al. 2002; Hynes et al. 2002), which provides additional support to the picture that the central object of CI Cam is a WD and the outburst is a nova outburst.

4.4. A Few Remarks on the White Dwarf Interpretation

We have so far argued for the picture that the central object of CI Cam is a WD and that its outburst is consistently interpreted as a nova outburst. Novae, however, are in general brightened by 7–16 mag in the optical during outburst (Warner 1995). Compared with this, the optical brightening of CI Cam (Δm_V ≃ 2 – 3) is remarkably small. This apparent inconsistency is due to the high persistent optical flux from the sgB[e] companion star. According to Hynes et al. (2002), its optical luminosity can be greater than 10^{34} L☉, which implies that in quiescence the CI Cam system is more luminous than the standard nova by more than 13 mag. The apparent small brightening of CI Cam is thus caused by this high “background” level.

Finally, we confess our discomfort in proposing that CI Cam is a binary composed of a WD and an OB star, because the existence of such a binary has never been confirmed observationally, although one could be formed through mass exchange between the components or tidal capture of a WD by an OB star. We, however, point out that γ Cas has been proposed as a candidate for such a binary (Kubo et al. 1998; Owens et al. 1999). Based on the ROSAT all-sky survey, Motch et al. (1997) have found that some OB stars show X-ray emission in excess of the level expected from the empirical ratio L_X/L_,opt. They suggest that some of them may harbor a WD.

5. CONCLUSION

We have presented the results of ASCA observations of CI Cam both in quiescence and in outburst. The quiescent spectrum of CI Cam consists of two spectral components separated at ∼2–3 keV. Of these, the hard component, which undergoes photoelectric absorption with N_H = 1.9 × 10^{21} cm^{-2}, is likely to be optically thin thermal plasma emission, based on a quantititative discussion of the iron line equivalent width 624−495 eV. If this is so, the central accreting object of CI Cam is probably a WD, because the optically thin thermal nature of the hard X-ray emission is common among accreting white dwarf binaries such as cataclysmic variables, whereas no NS and BH transient in quiescence manifests this characteristic in its X-ray spectrum. The spectrum of the hard component. This is a common characteristic among soft X-ray transients in quiescence, can, however, also be fitted with a power law equally well. Consequently, the possibility of an NS or a BH cannot be ruled out solely on the basis of the ASCA data taken during quiescence.

The outburst data, on the other hand, obviously favor the picture that CI Cam hosts a WD for the following reasons:

1. The spectrum of the soft component intermittently visible in the ASCA observing window during the outburst can be represented well by the blackbody multiplied by the highly ionized oxygen edges. This, together with luminosity as high as 1 × 10^{38} ergs s^{-1}, reminds us of the SSS CAL 87, suggesting strongly that CI Cam harbors a WD. Since some novae are reported to mimic SSSs during the decline phase, it is possible that the outburst of CI Cam is a nova outburst.

2. Recent observations have revealed that in an early phase of its outburst a nova can emit hard X-ray emission above the energy of 10 keV in the form of optically thin thermal emission. This optically thin plasma emission has also been detected from CI Cam during its outburst, whereas so far it has not been found for any NS or BH transient during outburst.

3. By assuming the nova outburst, we can estimate the distance to CI Cam by means of the decay-time constant of the optical light curve. Within the uncertainty of the burst onset date, the resulting distance is in the range 5–17 kpc, which strengthens the identification of CI Cam as a nova because this range matches the updated distance to CI Cam of 5–9 kpc.

Synthesizing all the results obtained from the ASCA quiescence and outburst observations, we are led to conclude that the central accreting object of CI Cam is a WD and that its outburst can be regarded as a nova outburst.

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