Discovery and Interpretation of an X-ray Period in the Galactic Center Source CXOGC J174536.1-285638

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Abstract. We present X-ray and infrared observations of the X-ray source CXOGC J174536.1-285638 (hereafter, Edd-1). The spectrum of the X-ray source has a very prominent Fe 6.7keV emission feature and the infrared counterpart has strong Brackett series and HeI emission. The presence of CIII, NIII, and HeII in the infrared spectrum indicates a binary system. Analysis of the combined *Chandra* and XMM light curves suggests a possible period of 189 ± 6 days; if we interpret this as an orbital period, we can place constraints on the nature of the primary star and the mass ratio of the system. We compare the source to several massive star systems including both known colliding wind binaries and high-mass X-ray binaries. The X-ray and infrared luminosities are consistent with these types of systems, however, Edd-1 cannot be definitively classified by color alone.

1. Introduction

In 2005, we identified Edd-1 as the first spectroscopically confirmed infrared (IR) counterpart to a low luminosity *Chandra* source (Mikles et al. 2006, hereafter Paper I). IR spectroscopy with IRTF has revealed a source rich in emission features signifying the presence of a hard radiation field consistent with an associated IR and X-ray source. We combine a long-term *Chandra* monitoring campaign with archival *XMM* data to search for periodicity in the X-ray light curve and find a period of 189 ± 6 days.

2. Observations and Analysis

2.1. Infrared

On 2006 July 1 UT we obtained J, H, and K band (1.1-2.4 μm) spectra of Edd-1 using SpeX on IRTF (Rayner et al. 2003) and on 2006 Aug 02-04 we obtained follow-up spectra to search for radial velocity variations. The infrared spectra are dominated by strong hydrogen emission lines, including Paschen-β, Brackett-γ, and Brackett series lines Br10 - Br14. The Br13 line is not distinguishable in our spectrum. We observe two neutral Helium lines (λ 1.701 and 2.113 μm) and six HeII transitions (λ 1.163, 1.736, 1.772, 2.189, 2.038, and 2.348 μm). The HeII λ 1.736 is blended with the Br10 line. In the K-band we also observe

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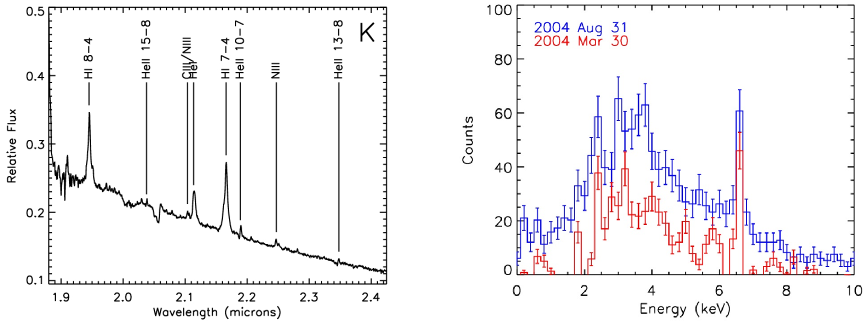

(a) (b)

Figure 1. (*a*) The K-band spectrum of Edd-1 shows strong Brγ, Brδ, and HeI emission. P Cygni profiles are seen in several of the Helium lines suggesting a Helium wind around a massive star. (*b*) The X-ray spectrum of Edd-1 taken with XMM. The source displays prominent line emission at 6.7 keV.

metal lines from CIII and NIII, consistent with an accretion signature or a colliding wind system. We give the line centers, equivalent widths, and full-width velocity in Paper I. Most of the emission lines are broad with a full-width velocity above 300 km/s. The Brγ line is strongest and has a full-width velocity of 710 km/s. Three HeII lines in Edd-1 show P Cygni profiles at 2.034 μm, 2.189 μm, and 2.348 μm. We calculate the differential velocity from the line center to the blue edge and get an average v = 170 km/s. Error due to pixel size and peak location is $\sim$70km/s. Figure 1(a) shows the K-band spectrum for Edd-1 dereddened by A_V= 29 mag. We find no radial velocity variations, nor do we find significant flux variations in the lines. We checked for IR variability on 1-year, 3 day, 3 hours, 1 hour, and 30 minute baselines and found no evidence of periodic variability or flaring in this sample.

2.2. X-ray

Muno et al. (2004a) examined the spectrum and variability of the X-ray emission from Edd-1 as part of a study of $\approx$2000 X-ray sources detected toward the Galactic Center. The analysis is described in detail in Muno et al. (2004b). The most prominent feature is line emission centered at 6.7 keV from the n=2–1 transition of He-like Fe with and equivalent width of 2.2keV (see Fig. 1(b)). We model the X-ray spectrum with a two-component plasma model, fixing the extinction toward the X-ray source at $N_{\rm H} = 5.2 \times 10^{22}$ cm^{-2} (by Predehl & Schmitt 1995, $A_V = 29$). This gives an inferred X-ray luminosity of $(1.1 \pm 0.3) \times 10^{35}$ ergs. This would make Edd-1 either one of the most luminous known colliding wind binaries, or a moderately bright accreting black hole or neutron star. Our X-ray spectral analysis is described in detail in Paper I.

We supplement our *Chandra* observations with a series of XMM archival data giving us a baseline of almost six years. We describe the XMM reduction in detail in a forthcoming paper (see Mikles et al. 2008, hereafter Paper II). Using one-hour resolution XMM light-curves we perform a period analysis, searching for periodicities in the range of 0.1-40 hours, but find no significant periods in this range. We find that the XMM X-ray flux is constant within Poisson errors during a single observation (as long as 40 hours), though we do find a four-sigma variation in consecutive observations separated by five months (see Fig. 1(b)). We calculate a single flux value for each observation epoch and combine these measurements with the *Chandra* light curve in Figure 2. Using the combined light curve, we can test for the presence or absence of periodic flux variations on a variety of timescales.

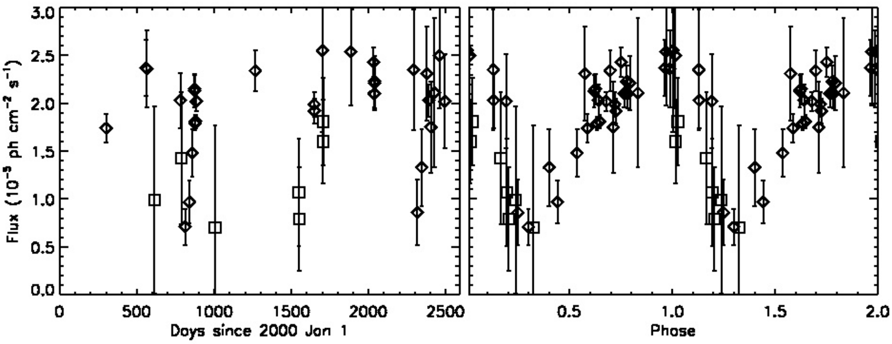

Figure 2. The X-ray light curve (left) and folded light curve (right) of Edd-1. The light curve is folded on a 189 d period. The squares are XMM data; the diamonds are *Chandra* data.

Using the method of Horne & Baliunas (1986), we perform a periodogram analysis of the combined light curve and find a period of 189 ± 6 days (details in Paper II). In Figure 2, we plot the X-ray light curve folded on the 189 d period. Analytically estimating the significance of a signal in non-uniformly sampled data is non-trivial. Thus, in order to estimate the confidence of this detection, we perform a Monte Carlo simulation as follows. We take the existing data set and maintain the same sampling intervals throughout. For each Monte Carlo realization, we randomly reassign the observed flux values to the time samples, effectively scrambling the light curve. In 30,000 trials, we do not achieve a peak power approaching the power of our original periodogram, implying that the 189-day period is not due to random noise with a confidence level greater than 99.997%.

The previous test accounts for white noise variability; however, red noise is a significant source of false peaks in X-ray power spectra of X-ray binaries (Titarchuk et al. 2007). Red noise is a flux variation in the power spectrum that can be parameterized with a frequency dependence $f^{-\beta}$. A white noise process will generate a flat power spectrum such that $\beta \sim 0$; a value of $\beta \sim 2$ describes random walk noise (Timmer & Koenig 1995). A $\beta \sim 1$ dependence has been noted in stellar-mass black hole candidates and may be strongly related to accretion physics in the system (Mineshige et al. 1994; Timmer & Koenig 1995; Titarchuk et al. 2007). Following the method of Timmer & Koenig (1995), we test the possibility of red noise creating a false signal matching the strength of our periodogram. Simulating a number of red noise dominated light curves of varying power law slope, β, we find that as β increases, more noise gets shunted near the period frequency, and the significance of our detection decreases. We find the significance of our period detection remains above 3σ for values of $\beta \leq 1.0$ and above 2.5σ for $\beta \leq 1.5$ showing that the significance decreases slowly as red noise is increased.

3. Discussion

In Paper I, we discuss in detail the spectral and photometric characteristics of Edd-1, comparing it more thoroughly to isolated stars, HMXBs, and CWBs (Mikles et al. 2006). To summarize, Edd-1 shares qualities with a variety of high mass systems. While an isolated star scenario is supported by the IR emission spectrum, it is not consistent with the high X-ray luminosity. Edd-1's X-ray luminosity is fairly common for an HMXB but in general, CWBs are not as X-ray luminous as Edd-1.

For both the CWB and HMXB cases, X-ray periodicity can trace an orbital period. CWBs have periods of days to years while HMXBs have shorter periods ranging from hours to days (Vanbeveren et al. 1998; Lewin & van der Klis 2006). Edd-1's light-curve shows flux variation by a factor of 5 over the course of the 189 d period. If we assume that the X-ray emitting source is being obscured by a windy counterpart, we can show that for the N_H range expected for Edd-1, the mass-loss rate will be between $(1-3)\times 10^{-5} M_{\odot}/yr$ which is fairly common for massive stars (details to be presented in Paper II).

By assuming that the low-flux portion of the dip is caused by an eclipse of the X-ray region, we can use this to estimate a transit time and thus an orbital velocity for the primary star. We estimate a transit time of 50-80 d for the putative eclipse, limited by adjacent observations in the high-flux stage. Assuming general parameters for a massive primary, the mass ratio of the system is $M_2/M_1 < 0.3$, meaning that in the eclipsing binary scenario the companion star cannot be a massive star ($M_2 < 12 M_{\odot}$). We find that adjusting the inclination does not significantly alter this result because 'eclipsing' scenarios do not exist at low inclination. Recognizing that both the X-ray and IR spectra are indicative of a high-energy process, and acknowledging the stringent inclination requirements for a CWB if the periodicity is caused by an eclipse, in this scenario Edd-1 is likely an HMXB.

4. Summary

Edd-1 is a reddened source with an estimated extinction $A_V = 29$ mag. We have identified Edd-1 as having prominent emission lines in the X-ray and IR. The HeII lines show P Cygni profiles consistent with a 170 km/s wind. In addition, Edd-1 has very strong Fe-XXV emission in the X-ray, the line having an equivalent width of 2.2keV. We have identified an apparent 189 ± 6 d period in the Edd-1 X-ray light curve that we speculate may be associated with an orbital period. Using a Monte Carlo simulation, we test the significance of the 189 d period detection; despite our fairly sparse time sampling, we find a confidence level greater than 99.997%.

While it is difficult to positively classify Edd-1 based on the X-ray and IR characteristics observed to date, Edd-1's spectral features indicate the presence of a high mass star. We have compared Edd-1 to OB stars, LBVs, HMXBs, and CWBs – all of which are types of systems containing a massive star. Further study of the variability and spectral features in Edd-1 is necessary to solidify such a classification.

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