1. INTRODUCTION

The dwarf starburst galaxy IC 10 provides a unique setting to study X-ray binaries containing youngest and most massive stars. According to Massey et al. (2007b) the IC 10 starburst peaked $\sim 7 \times 10^9$ yr ago and the galaxy is filled with diffuse H ii regions, wind-bubbles, and an unusually high space-density of Wolf–Rayet stars (Bauer & Brandt 2004). Young stellar populations such as those in IC 10 host massive stars that are rapidly approaching the end of their main sequence lifetimes. Binary systems containing recent post-supernova relics are known to form in such environments, where they can provide an important probe of massive-star evolution. IC 10 contains $\sim 100$ X-ray point sources, whose combined spectrum is indicative of a population of high-mass X-ray binaries (Wang et al. 2005).

High mass X-ray binaries (HMXBs; see, e.g., Liu et al. 2005; Reig 2011 for reviews of the field) are binary stars containing a neutron star (NS) or black hole (BH) and a massive star as the mass donor. In the majority (upward of 80%) of known systems in the Milky Way (MW) and Magellanic Clouds, the primary is a Be star (McBride et al. 2008). In the remaining systems, it is an O or B supergiant whose wind provides the fuel for accretion-powered X-ray emission. Supergiant (SG)-HMXBs emit X-rays continuously at a $10^{35} \text{erg s}^{-1}$ level, with eclipses being relatively common as a consequence of the small orbital separations on the order of a few stellar radii. Tidal interactions rapidly circularize the orbits leading to little variation in the wind density and velocity encountered by the compact object. Be-HMXBs are transient due to a complex interaction between the wide (many AU) elliptical orbit and the circumstellar disk surrounding the Be star (Okazaki & Negueruela 2001). Frequent outbursts reach $>10^{37}$ erg s$^{-1}$ for days at a time and generally recur with the orbital period of the system, taking place at or close to the time of periastron passage. Much rarer "giant" outbursts last for weeks to months, exceed $10^{37}$ erg s$^{-1}$, and generally begin around periastron but otherwise show little correlation with orbital parameters. A small number of BH-HMXBs are known, and all have supergiant primaries, in line with population modeling predictions (Belczynski & Ziolkowski 2009).

In recent years, a small subset of HMXBs have been discovered that do not fit the picture described above. These are the supergiant fast X-ray transients (SFXTs; Negueruela et al. 2006; Sguera et al. 2005), which share the following properties: very short duration X-ray flares of $\sim$hours with $L_X$ reaching $10^{37}$ erg s$^{-1}$; variability within these flares; hard X-ray spectra; supergiant companions; and a location in young, heavily dust-obscured star-forming regions in the plane of the MW (all but two are in the Sagittarius–Scutum Arm at R.A. = $16^h$–$19^h$). In between outbursts, SFXTs continue to accrete matter at a much lower level, with an average luminosity of $10^{33} \text{–} 10^{34}$ erg s$^{-1}$, occasionally reaching a true quiescent state at $10^{32}$ erg s$^{-1}$ (Sidoli et al. 2008). It is difficult to explain the abrupt luminous flares since this requires that either the mass transfer rate from the donor changes by a factor of $10^2$–$10^3$ on short timescales (for example by clumpy stellar wind) or that the accretion onto the NS is somehow gated, perhaps by a magnetic process (Sidoli 2009). A recent survey by Romano et al. (2014) lists 12 confirmed SFXTs; their orbital periods ranging from 3 days (IGR J16479-4514; Jain et al. 2009) to 164 days (IGR J11215-5952; Romano et al. 2009), with most at the shorter end of this range (Half are below 10 days, e.g., AX J1845; Goossens et al. 2013).

X-ray surveys of nearby galaxies have revealed populations of HMXBs in all star-forming galaxies, with their number scaling with star-formation rate (Grimm et al. 2003). There is growing evidence that HMXBs with B-type primaries (the most common type) are strongly associated with stellar populations aged 40–80 million years (Antoniou et al. 2010; Williams et al. 2013). The lifetime of an O supergiant is only few My (depending on...
the initial mass and chemical composition). On this basis, we expect IC 10 to contain SG-HMXBs, including SFXTs, which share the same 3.2 s frame time.

In this paper, we adopt $D_{\text{IC10}} = 660$ kpc (Wilson et al. 1996) as the distance to IC 10, which implies a distance modulus $\mu_{\text{IC10}} = 24.1$. The foreground extinction to sources in IC 10 is $E_{B-V}$ = 0.85 (e.g., Gonçalves et al. 2008; Sanna et al. 2008), implying $A_V = 3.1$.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Chandra X-Ray Data

We discovered a transient X-ray point-source in a series of 10 Chandra ACIS-S observations of IC 10 spanning from 2003–2010 as detailed in Table 1, which include three deep observations from the archive and a year-long monitoring campaign of seven 15 ks observations at roughly 6 week intervals (Laycock et al. 2010). Data were taken in very faint (VF) or faint (F) mode with the maximum efficiency 3.2 s CCD frame time.

The optical diameter of IC 10 is ~7 arcmin, so essentially the whole galaxy fits within the ACIS-S3 chip, where the point-spread function, sensitivity, and spectral resolution are maximized. Chandra’s aim point and roll angle were varied among the observations, to best position IC 10 within the field of view given scheduling constraints.

Data reduction was carried out in CIAO 4.3\(^1\) following the standard processing threads and referring to Hong et al. (2005) for consistent selection of energy bands, error circles, and extraction regions. A check of the CIAO release notes indicates that subsequent CIAO versions will not lead to different results. Source detection was accomplished using wavdetect at wavelet scales of 2, 4, 8, and 16 pixels. Exposure maps generated for 1.5 keV were used to correct for sensitivity variations and to isolate an equal region of continuum emission immediately adjacent to the Chandra aim point and to the coordinates of the star identified above; its profile is consistent with a point source. Additional images from the Hubble Space Telescope (HST; 2002), Mayall 4 m at KPNO (2000), and Gemini (2006–2009) were examined to check for proper motion (which would indicate a foreground object) and variability.

We used MOS to obtain a spectrum of this optical counterpart (as part of a 25 object mask). Our MOS mask setup was observed six times over two different nights (2010 September 2 and 7). Each exposure was 45 minutes, for a total integration time of 4 hr in dark, photometric conditions with good seeing (FWHM = 0.5). The resulting optical spectrum shows strong Hα and He II features, absorption features, and a single prominent emission feature is seen at the coordinates of the star identified above; its profile is consistent with a point source.

2.2. Gemini: Optical Imaging and Spectra

Narrow band Hα and HαC Gemini Multi-Object Spectrograph (GMOS) images from the Gemini Science Archive (GSA)\(^6\) show the counterpart as a strong Hα emitter. Figure 2 shows the direct and difference images, with the Chandra error circle for comparison. The GMOS images were astrometrically calibrated using the catalog of Massey et al. (2007b) and differenced in IRAF 2.14.\(^4\) The Gemini HαC filter is designed to isolate an equal region of continuum emission immediately adjacent to the Hα line. The off- and on-line images were obtained minutes apart, with the same exposure time (1800 s), under excellent seeing (FWHM = 0.5). In the difference image Hα line emission appears as positive (white) features, while absorption is negative (black). A single prominent emission feature is seen at the coordinates of the star identified above; its profile is consistent with a point source. Additional images from the Gemini Multi-Object Spectrograph (GMOS) images were carried out using CIAO, R\(^3\), XSPEC 12.7,\(^4\) and SAOImage DS9.\(^5\)

We then bore-sighted the source catalogs from each individual Chandra observation onto this calibration using the X-ray coordinates of IC 10 X-1 (which has by far the smallest positional uncertainty owing to its high count rate). We then bore-sighted the source catalogs from each individual Chandra observation onto this calibration using the X-ray coordinates of IC 10 X-1 (which has by far the smallest positional uncertainty owing to its high count rate). The final rms scatter between X-ray and optical coordinates (after rejecting the 3σ outliers) is 0.5.

Subsequent analysis of events, light curves, spectra, and images were carried out using CIAO, R\(^3\), XSPEC 12.7,\(^4\) and SAOImage DS9.\(^5\)

\(^5\) The R-Project for Statistical Computing, http://www.r-project.org.

\(^4\) http://heasarc.nasa.gov/xanadu/xspec

\(^3\) http://iraf.noao.edu

\(^6\) http://iraf.noao.edu

\(^1\) http://cxc.harvard.edu/ciao

\(^2\) http://hopper.si.edu/wiki/mmti/Starbase

\(^7\) See the Gemini or GSA webpages for observing condition definitions.

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Table 1: X-ray Observations of IC 10 X-2

| MJD   | Date      | ObsID | Offset (arcmin) | Exposure (ks) | Mode |
|-------|-----------|-------|-----------------|---------------|------|
| 52710.7 | 2003 Mar 12 | 03953 | 1.21            | 28.9          | VF   |
| 54041.8 | 2006 Nov 2   | 07082 | 2.48            | 40.1          | F    |
| 54044.2 | 2006 Nov 5   | 08458 | 2.48            | 40.5          | F    |
| 55140.7 | 2009 Nov 5   | 11080 | 0.52            | 14.6          | VF   |
| 55190.2 | 2009 Dec 25  | 11081 | 0.25            | 8.1           | VF   |
| 55238.5 | 2010 Feb 11  | 11082 | 0.87            | 14.7          | VF   |
| 55290.6 | 2010 Apr 4   | 11083 | 1.97            | 14.7          | VF   |
| 55337.8 | 2010 May 21  | 11084 | 2.33            | 14.2          | VF   |
| 55397.5 | 2010 Jul 20  | 11085 | 1.75            | 14.5          | VF   |
| 55444.6 | 2010 Sep 5   | 11086 | 0.78            | 14.7          | VF   |

Note. \(^4\) Chandra ACIS-S observations in faint (F) and very faint (VF) mode share the same 3.2 s frame time.

We then bore-sighted the source catalogs from each individual Chandra observation onto this calibration using the X-ray coordinates of IC 10 X-1 (which has by far the smallest positional uncertainty owing to its high count rate). The final rms scatter between X-ray and optical coordinates (after rejecting the 3σ outliers) is 0.5.

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Figure 1. Chandra 2003–2010 X-ray light curve. Points with statistical error bars show net ACIS-S count rates in broad (0.3–8 keV), soft (0.3–2.5 keV), and hard (2.5–8) energy bands. Upper limits for non-detection in the B band are shown as arrows.

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

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We used MOS to obtain a spectrum of this optical counterpart (as part of a 25 object mask). Our MOS mask setup was observed six times over two different nights (2010 September 2 and 7). Each exposure was 45 minutes, for a total integration time of 4 hr in dark, photometric conditions with good seeing (CC50/1Q70/SB20).\(^8\) We used the B600 grating centered at 6000 Å and 6050 Å with 0\(^7\)5 slitlets, and the detector binned 2 × 2 to provide spectral resolution of 0.9 Å pixel\(^-1\) (equivalent to 3 Å/km s\(^-1\)).
to 45 km s\(^{-1}\)). The central wavelength was carefully chosen so as to observe the H\(\alpha\) line in all 25 objects, while reaching blueward of H\(\beta\) for as many stars as possible. Two closely spaced wavelength settings were used in order to cover the CCD gaps in the GMOS focal plane. Due to the properties of GMOS, it is not possible to obtain the same wavelength coverage for objects in different parts of the focal plane.

GMOS spectra were reduced using the Gemini-IRAF package. Processing consisted of flat-field correction, cosmic-ray rejection, wavelength calibration using GCAL CuAr exposures, rectification to a linear wavelength versus spatial coordinate system, two-dimensional (2D) sky subtraction, and extraction to one-dimensional spectra. We analyzed the spectrum of each object using IRAF's splot and \textit{R}.

3. RESULTS

3.1. The X-Ray Properties of IC 10 X-2 (\(=\)CXOU J002020.99+591758.6, \(=\)W05[XA-11])

The aspect-corrected \textit{Chandra} coordinates for IC 10 X-2 are R.A. 00\(^h\)20\(^m\)20\(^s\):94, and decl. 59\(^\circ\)17\('\)59\('\):0, with a 95\% confidence region of radius (statistical plus systematic) \(\sqrt{0.31^2 + 0.52^2} = 0.6\). The object was detected in outburst during the 2003 \textit{Chandra} ACIS-S observation (30 ks integration) and appears as object XA-11 in Wang et al. (2005) and as IC 10 X-2 in Liu (2011); however, its true nature was not recognizable from a single observation. The long-term light curve is presented in Figure 1, showing that we detected X-2 on three occasions, and placed upper limits on its quiescent luminosity on a further seven occasions.

During the initial 2003 \textit{Chandra} observation, X-2 was the second brightest X-ray object in IC 10, after the massive BH binary X-1 (Prestwich et al. 2007). The net broadband count rate of \(1.18 \times 10^{-2}\) count s\(^{-1}\) corresponds to an X-ray luminosity of \(1.8 \times 10^{37}\) erg s\(^{-1}\) for the best fitting power-law spectral model (\(\Gamma = 0.3, N_H = 6.3 \times 10^{21}\) atom cm\(^{-2}\)) shown in Figure 3. We tested several spectral models using XSPEC as summarized in Table 2. These were a simple power law appropriate for X-ray binaries, a blackbody and thermal bremsstrahlung (TB) models (both widely applicable to stellar coronae, LMXBs, and BH systems), and non-equilibrium ionization (NEI) plasma which is descriptive of supernova remnants. All fits included the \textit{phabs} component for foreground absorption. All models were able to reasonably represent the data (reduced \(\chi^2 \sim 1\)), but examination of the parameter values definitively rules out the TB and NEI models, which required unrealistically high temperatures (\(kT \gtrsim 100\) keV).

By 2006 November, the source was barely detectable in the pair of 45 ks observations (separated by 2 days). It was detected by wavdetect only in the first of the two pointings, and in the hard band only. Stacking the two exposures to 90 ks allowed a 3.8\(\sigma\) flux measurement in the broad band of \(1.65 \times 10^{-4}\) count s\(^{-1}\). Subsequent observations were shallower (15 ks integrations) and provide six null detections (none of which is more constraining than \(3 \times 10^{-4}\) count s\(^{-1}\)) and one...
positive detection at $2.16 \times 10^{-3}$ count s$^{-1}$. Taking the ratio of the peak to the lowest $B$-band count rate provides a variability factor of $f_{\text{max}}/f_{\text{min}} = 71$. We note that if we did not stack the data, then our conservative (five counts) upper limit estimate for non-detection in 45 ks would impose an upper limit of $f_{\text{max}}/f_{\text{lim}} = 117$. Thus the result for either method agrees within a factor of $<2$. Applying the same spectral model as observed at peak brightness to the faint 2006 detection gives a luminosity of $1.8 \times 10^{35}$ erg s$^{-1}$. This could represent the quiescent luminosity of a faint HMXB transient. Alternatively, it could be that the source was in transition to or from an active state. From the 2009–2010 monitoring series, we can only constrain the overall duration of the 2010 May outburst (MJD 55337.5) to be less than 107 days. The source was not yet detectable on MJD 55290 and had faded from view by MJD 55397.

The median photon energies for the three positive detections, are $3.3 \pm 0.1$ keV, $6.2 \pm 0.5$ keV, and $3.4 \pm 0.3$ keV, respectively. A K-S test confirms that the photon energy distribution during the 2010 May detection is consistent with the 2003 outburst ($p = 0.58$) and supports the faint 2003 spectrum being harder ($p = 0.0012$); despite the small number of counts.

For the bright outburst of 2003, the broadband (0.3–8.0 keV) light curve is shown in Figure 4. Events are binned to 1000 s resolution, giving an average of $\sim 10$ events per bin. The light curve reveals variability at $>3\sigma$ level (assuming $\sqrt{N}$ Poisson errors). A K–S test performed on 326 ACIS event arrival times returns $D = 0.068$, $p = 0.1$ compared to a uniform distribution of arrival times. Thus variability is likely present, but we refrain from reading too much into the shape of the light curve. We searched for periodicity using the Lomb–Scargle periodogram (range $= 6.5$–10,000 s). No features rise to the 90% significance level for a blind search using the method of (Press et al. 1996).

### Table 2

| Model          | Parameters | $\chi^2$/dof | $ disc (2–10 \text{ keV})$ |
|----------------|------------|-------------|-----------------------------|
| Powerlaw       | $\Gamma = 0.3$ | 21/20       | $3.5 \times 10^{-13}$ |
|                | $N_H = 6.3 \times 10^{21}$ |             |                             |
| Blackbody      | $kT = 2.2$ keV | 17/20       | $3.1 \times 10^{-13}$ |
|                | $N_H = 2 \times 10^{21}$ |             |                             |
| Thermal brems. | $kT = 200$ keV | 27/20       | $2.3 \times 10^{-13}$ |
|                | $N_H = 1.6 \times 10^{22}$ |             |                             |
| NEI plasma     | $kT = 80$ keV | 24/19       | $2.4 \times 10^{-13}$ |
|                | $\tau = 5 \times 10^{11}$ |             |                             |
|                | $N_H = 1.6 \times 10^{22}$ |             |                             |

**Notes.**

* Values of spectral model parameters are rounded to appropriate significant figures.
* Fits are for 228 net counts, 0.3–8 keV, grouped into 23 bins.

3.2. Optical Counterpart: [LGGS]J002020.94+591759.3, [2MASS] J002020.90+591759.0

IC 10 X-2 is positionally coincident with the star [LGGS]J002020.94+591759.3 in the catalog of Massey et al. (2007b). The distance between the X-ray and optical coordinates is 0.28 which is within the 95% error circle. There is a Two Micron All Sky Survey (2MASS) point source catalog (Skrutskie et al. 2006) counterpart [2MASS] J002020.90+591759.0, which lies 0.31 away from our X-ray position. The association with this 2MASS star was noted by Wang et al. (2005) and our result moves the X-ray coordinates closer toward it. The star appears in the Massey et al. (2007a) catalog of emission line objects, based upon narrow-band photometry, it does not appear in the Crowther et al. (2003) catalog of WR stars in IC 10.

The optical spectrum (Figure 5) resembles a Be star with its prominent hydrogen–Balmer emission lines and smooth continuum. The average blueshift of the Balmer lines gives a radial velocity of $-337$ km s$^{-1}$, which places the object in IC 10. In Table 3, we show the observed and de-reddened colors using extinction values from the literature and derived by us from the X-ray spectrum. The apparent magnitude is $V = 19.95$, which applying $\mu = 24.1, A_V = 3.1$ results in absolute magnitude $M_V = -7.2$. This is in the upper range of luminosity for supergiants. The de-reddened optical colors are too red for a normal OB spectral type (Drilling & Landolt 2000), with the exception of the $U – B$ color, which indicates a hot star. We speculate that the colors could be affected by circumstellar material and the large equivalent width of Hα that contributes significantly to the R-band luminosity.
The velocity profiles of the Hα and Hβ lines, which are blueshifted by the −340 km s\(^{-1}\) radial velocity of their host galaxy (IC 10). The spectrum is not flux calibrated and the instrumental flux units are ADU per binned detector pixel.

The first star later than O8 to show He\(\alpha\)\(\lambda\)4686 in emission was HD 226868 (the primary in the BH HMXB Cyg X-1). The current practice forgoes the OBC designation as being a normal OB star, but recognizes the unusual abundance pattern of OB stars. In this scheme (e.g., Massey et al. 2009; Gray & Corbally 2009), the combination of N\(\text{iii}\) and He\(\text{ii}\) 4686 in emission identify the \textquotedblleft f\textquotedblright \ subclass.

The star shows selective emission and absorption effects in the He\(\alpha\) lines; with He\(\alpha\)\(\lambda\)5865 in emission and He\(\alpha\)\(\lambda\)6675 in absorption (see Figure 5). The physical conditions leading to the appearance of emission lines from certain energy levels while other transitions in the same ion species remain in absorption is not well understood. However, the phenomenon is a well-established feature of the O-type stars (Walborn 2001), and the selective-emission lines are believed to originate in the stellar photosphere.

According to the classification system of Walborn (1976), supergiant O and B stars are divided into the OBN and OBC subtypes. By analogy to the classification protocol for WR stars, the OBN/C subtypes denote nitrogen or carbon enrichment. Stars of this class show He lines, but usually in absorption except at the highest luminosities. The identification of the N\(\text{iii}\) triplet puts the star in the OBN class of nitrogen-enriched B supergiants. According to Walborn (1977) the \textquotedblleft f\textquotedblright \ subclass corresponds to N\(\text{iv}\) 4058, stronger than the N\(\text{iii}\) 4634–4640–4642 triplet; our spectrum does not reach shortward of 4500 Å. The current practice forgoes the OBC designation as being a normal OB star, but recognizes the unusual abundance pattern of OB stars. In this scheme (e.g., Massey et al. 2009; Gray & Corbally 2009), the combination of N\(\text{iii}\) and He\(\text{ii}\) 4686 in emission identify the \textquotedblleft f\textquotedblright \ subclass.

The Balmer lines are strongly in emission with EW[H\(\alpha\), \(\beta\)] = −110 Å, −25 Å. At the blue end of our GMOS spectral range, we detect the combination of N\(\text{iii}\) (4634–4640–4650) and He\(\text{ii}\) (4686) emission lines that constitute the primary characteristic of spectral class Of. According to Gray & Corbally (2009), the Of stars are regarded as supergiant analogs of Be stars, having significant outflows.

The star also shows the complex of Fe lines that characterize the B[e] spectral class. In Figure 6, we identify both permitted and forbidden lines of Fe. The Hα and Hβ lines both show broad wings indicative of high-velocity bulk flows, but there is no double peak that would indicate an inclined circumstellar disk.

### Table 3

| Parameter | Observed \(M_V\) | \(A_{opt}\) \(b\) | \(A_x\) \(c\) |
|-----------|-----------------|-----------------|-----------------|
| \(M_V\)   | 19.954 ± 0.005  | −6.78           | −7.51           |
| \(U - B\) | −0.259 ± 0.011  | −0.87           | −1.04           |
| \(B - V\) | 1.211 ± 0.005   | 0.32            | 0.07            |
| \(V - R\) | 1.043 ± 0.005   | 0.39            | 0.20            |
| \(R - I\) | 0.820 ± 0.005   | 0.10            | −0.095          |
| \(V - K\) | 4.454           | 2.11            | 1.47            |
| \(J - H\) | 1.0             | 0.76            | 0.69            |
| \(J - K\) | 0.9             | 0.45            | 0.33            |
| \(H\alpha\)−R | −1.16           | d               | d               |

**Notes.**

\(a\) References: \(UBVRI\), Massey et al. (2007b); \(JHK\), 2MASS; \(H\alpha\), Massey et al. (2007a).

\(b\) De-reddened values using optically derived \(E(B-V) = 0.85\) (Sanna et al. 2008).

\(c\) X-ray derived \(E(B-V) = 1.09\) (this study).

\(d\) No straightforward correction of \(H\alpha\)-R for extinction.

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The star also shows the complex of Fe lines that characterize the B[e] spectral class. In Figure 6, we identify both permitted and forbidden lines of Fe. The Hα and Hβ lines both show broad wings indicative of high-velocity bulk flows, but there is no double peak that would indicate an inclined circumstellar disk.
Massey et al. (2009) finds that lower metallicity (in the Small Magellanic Cloud, or SMC) results in stars that are outluminous (by a whole luminosity class or more) compared to what their spectral classifications would imply. This is consistent with the observation of Walborn (1977) that supergiants in the LMC are more luminous than those of the same spectral type in the MW. Lower metallicity results in weaker stellar winds, thus for a metal-poor star to exhibit the “usual” luminosity indicators requires a much larger luminosity than if it had “normal” (galactic) metallicity. For example, the SMC star AzV 83 has both H i in 4638–42 and He ii 4686 strongly in emission, leading to an Of or even Ofa luminosity class, given the strength of emission (Massey et al. 2009). This argument would apply to a lesser extent in IC 10, as the metallicity is intermediate between the SMC and the MW.

In the Walborn & Fitzpatrick (2000) atlas of peculiar OB spectra, the WN stars appear similar to our object in displaying He ii, H α, and Hβ emission. Unfortunately, Walborn’s atlas does not go longward of Hβ, so we cannot compare the complex Fe lines.

4. DISCUSSION AND CONCLUSIONS

The bright X-ray transient IC 10 X-2 is located close to the center of IC 10. A positional optical counterpart lies within the 0′.31 error radius. This counterpart shows prominent Balmer lines in emission Doppler-shifted to a radial velocity of −340 km s⁻¹, matching the established value for IC 10. Analysis of the X-ray light curve reveals a factor of ∼100 variability and a hard power-law spectrum, with absorption consistent with IC 10. The peak X-ray luminosity implied by \( P_{\text{IC10}} = 660 \) kpc is \( 1.8 \times 10^{37} \) erg s⁻¹. The apparent magnitude, distance, and reddening imply a supergiant primary with absolute magnitude in the range of \( M_V = -6.8 \) to \( -7.5 \) depending on the extinction model used. The optical spectrum is dominated by Balmer emission lines, a faint continuum is seen, and the photospheric emission lines N iii[4634–4640–4642] triplet and He ii[4686] are present, which is indicative of spectral type Of I–II. The star may be outluminous for its spectral type due to the low metallicity of IC 10.

The very large equivalent width of the optical emission lines and the IR excess provides abundant evidence for an enhanced stellar outflow, as is typically seen in HMXB primaries (e.g., Wilson et al. 2008). Thus the star’s mass-loss is sufficient to provide the required accretion rate onto the NS. In order for the circumstellar material to form strong optical emission lines without raising the X-ray absorption above \( 10^{22} \) atom cm⁻², it must lie out of the line of sight to the X-ray source. A circumstellar disk could provide the required geometry if it were oriented close to face-on. Galactic OBN stars are preferentially found in close binaries, where the enrichment of nitrogen is due to tidal dredge-up of CNO cycle products from the core. Rotational mixing is now recognized as a key factor in the formation of massive binaries (de Mink et al. 2013). According to Bolton & Rogers (1978) between 50% and 100% of the OBN stars appear to be short-period binaries \((P \sim 1–100 \) days), while none of the OBC stars fall into this category. The counterpart to X-2 fits this pattern, as the measured X-ray luminosity requires an XRB interpretation, which in turn implies a close binary. The binary must be close in order for the wind density (Chlebowski & Garmany 1991) encountered by the compact object to deliver a sufficient mass accretion rate. The range of binary separations for supergiant HMXBs in the MW is 0.04–0.8 AU (typically a few \( R_\odot \)), corresponding orbital periods are 1–200 days (see table in Lewin 1995).

Our formation scenario for this system is that the precursor was a close OBN+O star binary, whose orbit was both widened and made elliptical by the supernova kick. This could be a similar system to HD 235679, a supergiant Be star in a spectroscopic binary \((P = 225 \) days) with an invisible companion (Bolton & Hurkens 2001). Difficulty remains in reconciling the transient X-ray outbursts with a powerful wind, which must be supplying a large mass transfer rate at all times. SG-HMXBs are usually continuous wind accretors; the same paradox applies to SFXTs (Romano et al. 2013). Plausible solutions include a highly eccentric orbit to modulate the mass transfer rate, as in Be-HMXBs, or a rapidly spinning young NS that does not accrete because it is evolving through the so-called propellor regime. Supergiant+NS binary systems where the primary overflows its Roche lobe yet accretion is centrifugally inhibited are explicitly predicted by the theoretical work of Urpin et al. (1998). The duration of this “disk-propellor” phase is expected to be \( \sim 10^4 \) yr, followed by onset of a “standard” SG-HMXB phase if the NS spin is spun-down sufficiently. Assuming the primary to be a 30 \( M_\odot \) supergiant with \( M_V = -7.5 \) and applying the standard approximation for main sequence lifetime \( T_{\text{MS}} \sim (M/L) \times 10^{10} \) yr gives an age of 3.5 Myr. Thus it is possible that in IC 10 X-2, a very young NS is spinning at a rate that puts it in the centrifugal inhibition regime. If this is true, then the spin period is probably \(< 1 \) s and the orbital period should be a few days, at most.

An alternative explanation for IC 10 X-2 is that the optical counterpart is not a single star, but an association buried in a compact H ii region. A Be-NS HMXB could then explain the transient X-ray emission, although the X-ray spectrum would then be much harder than is usual for such systems. The supernova impostor SN2010da (Binder et al. 2011) is similar in this regard. Attempts to explain the large equivalent widths as a supernova remnant, planetary nebula, or H ii region are inconsistent with the absolute magnitude of \( -7 \) and compact dimensions. Images from the HST Advanced Camera for Surveys (ACS) show an optical point source with no extended nebulosity. At 660 kpc, the projected size of the HST FWHM \((\sim 0.1 \) arcsec) is 0.32 pc. This is smaller than typical H ii regions (Hodge & Lee 1990). A foreground galactic star is ruled out by the radial velocity value.

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