SPITZER OBSERVATIONS OF BOW SHOCKS AND OUTFLOWS IN RCW 38

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ABSTRACT

We report Spitzer observations of five newly identified bow shocks in the massive star-forming region RCW 38. Four are visible at Infrared Array Camera (IRAC) wavelengths, the fifth is only visible at 24 μm. Chandra X-ray emission indicates that winds from the central O5.5 binary, IRS 2, have caused an outflow to the northeast and southwest of the central subcluster. The southern lobe of hot ionized gas is detected in X-rays; shocked gas and heated dust from the shock front are detected with Spitzer at 4.5 and 24 μm. The northern outflow may have initiated the present generation of star formation, based on the filamentary distribution of the protostars in the central subcluster. Further, the bow-shock driving star, YSO 129, is photo-evaporating a pillar of gas and dust. No point sources are identified within this region at near- to mid-IR wavelengths. We also report on IRAC 3.6 and 5.8 μm observations of the cluster DBS2003-124, northeast of RCW 38, where 33 candidate young stellar objects (YSOs) are identified. One star associated with the cluster drives a parsec-scale jet. Two Herbig–Haro objects associated with the jet are visible at IRAC and Multiband Imaging Photometer for Spitzer (MIPS) wavelengths. The jet extends over a distance of ~3 pc. Assuming a velocity of 100 km s−1 for the jet material gives an age of 3 × 104 yr, indicating that the star (and cluster) are likely to be very young, with a similar or possibly younger age than RCW 38, and that star formation is ongoing in the extended RCW 38 region.

Key words: circumstellar matter – infrared: stars – ISM: jets and outflows – stars: pre-main sequence – stars: winds, outflows – X-rays: ISM – X-rays: stars

1. INTRODUCTION

Young stars are not only shaped by their natal environments but shape it in return. They are responsible for triggering further generations of star formation, ablating the circumstellar disks of their lower mass neighbors, clearing gas and dust in parsec-scale cavities surrounding them, and altering the processing of dust grains in the intercluster medium. Observations of young clusters in the infrared (IR) and X-ray have been combined to allow the identification of the stellar population in these regions from the most massive down to the substellar (Preibisch et al. 2004). Our own Sun is thought to have formed in a massive cluster and have assimilated material (such as 60Fe and other short-lived elements) from a nearby supernova (Hester et al. 2004). The study of the effects of high mass stars in star-forming regions is thus of great importance in the understanding of both the large-scale development of clusters and of the smaller scale evolution of planetary systems around lower mass Sun-like stars. Such studies indicate that the sub-structure within these sites of star formation is complex and this can have an impact on the natal environment of individual stars.

Nearby regions of high mass star formation have recently been shown to exhibit varying spatial morphologies, such as the compact spherical structure of Tr 15 (Wang et al. 2011) or the subclustered Tr 16 (Wolk et al. 2011), where the clusters are contiguous and show no sign of mass segregation. RCW 38 itself shows evidence for at least four subclusters which are more loosely associated than those of Tr 16 and show indications of mass segregation in the central subcluster but not in the surrounding subclusters. By studying a number of high mass clusters we can better understand how the spatial distribution of young stars and their exposure to photo-ionizing radiation can affect the formation and evolution of young stars and their planets.

One way that massive stars interact with their environment is through strong stellar winds. These winds can clear gas from their environs and in so doing generate shocks where the high velocity outflowing gas intersects with the ambient interstellar/cluster medium or with the winds from other local massive stars (Draine & McKee 1993). Termination shocks arise where the stellar wind terminates as it is balanced by the ram pressure from the interstellar medium (ISM) or the wind from a local massive star. If the relative velocities of the star and ISM/wind are large the shocked material is swept backward around the star forming a “bow shock.” The orientation of the bow shock and its “stand-off” distance, the distance from the generating star to shock, are determined mainly by the velocity of the driving star and its wind, and the flow of the ISM or massive star wind.

Parsec-scale collimated outflows (jets) from young protostars entrain surrounding gas and dust and can disrupt their parent clouds, perhaps triggering star formation in regions where overdensities are generated or bringing it to an end by removing the gas from which young stars form. Massive stars with their strong stellar winds are particularly effective in this regard, but Herbig Ae/Be and T Tauri stars are also known to drive outflows. Such outflows are usually identified in the visible and near-IR as Herbig-Haro (HH) objects or knots of roughly symmetric emission around a young stellar object (YSO; Bally et al. 1995; Bally & Devine 1994). X-ray emission from jets has also been observed, e.g., in DG Tau (Güdel et al. 2008) and L1551 IRS 5 (Schneider et al. 2011). The lifetimes of these jets are short,
typically $\sim 10^5$ yr. They are typically most active during the high accretion protostellar phase, but can continue into the class II phase. The knots of emission may be linked to episodic accretion (Bally et al. 1995; Reipurth 1991).

Recently, observations of cluster populations in the mid-IR with Spitzer have identified emission from outflows, HH objects, and bow shocks in star-forming regions. Povich et al. (2008) report the identification using the Spitzer GLIMPSE survey data, of six bow shocks in two massive star-forming regions, M17 and RCW 49. Takami et al. (2010) have modeled survey data, of six bow shocks in two massive star-forming regions, M17 and RCW 49. Takami et al. (2010) have modeled emission from six HH objects over the Infrared Array Camera (IRAC) bands and have found that the emission is mainly due to H$_2$, and unlikely to have significant contributions from H I, [Fe ii], fluorescent H$_2$, or polycyclic aromatic hydrocarbon (PAH) emission. The HH objects HH 54 and HH 7-11 have been the subject of a recent study by Neufeld et al. (2006) with Spitzer Infrared Spectrograph (IRS) that mapped emission from rotational lines of molecular hydrogen (associated with the IRAC bandpasses) and fine structure transitions of ions such as Fe$^+$ (associated with the Multiband Imaging Photometer for Spitzer (MIPS) 24 $\mu$m bandpass). The authors found that the H$_2$ emission was consistent with nondissociative shocks with velocities of $\sim$10–20 km s$^{-1}$ and the fine structure emission with faster shocks with velocities of $\sim$35–90 km s$^{-1}$ offset from the slower shocks, indicating that shocks detected at 24 $\mu$m may be faster dissociative shocks than those detected in the IRAC bandpasses only.

Bow shocks have also been considered as indicators for runaway O stars in young massive clusters (Gvaramadze et al. 2011). The orientation of their bow shocks relative to the cluster, pointing away from its center, implies that the star has a velocity which is taking it out of the cluster. Such observations indicate that the O stars in question form centrally and their current trajectories arise from dynamical interactions in the cluster center (Kroupa 2004).

The RCW 38 cluster is a region of high mass star formation, lying at a distance of about 1.7 kpc from Earth. The region is one of the closest high mass star-forming regions known and contains an estimated 10$^3$–10$^4$ members, including more than 30 O-star candidates (Wolk et al. 2006; Winston et al. 2011). An extensive overview of the previous studies of RCW 38 is to be found in the Handbook of Star Formation article on the cluster (Wolk et al. 2008). The massive star candidates are spatially distributed throughout the observed region but are concentrated in four subclusters. The central subcluster of RCW 38 is dominated by two bright mid-IR sources: the O5.5 binary IRS 2 and the bright emission ridge IRS 1 (Frogel & Persson 1974; Smith et al. 1999; DeRose et al. 2009). Smith et al. (1999) suggest that the central region is a cavity blown by the wind from the IRS 2 binary and that IRS 1 is a ridge of material swept into a shell around IRS 2.

In our previous paper on the RCW 38 region, Winston et al. (2011, hereafter Paper 1), we presented mid-IR observations taken with Spitzer IRAC and MIPS combined with Chandra archival data. In this paper, we will report on the identification of five bow shocks surrounding YSOs in the RCW 38 star-forming region. We will then discuss the larger scale evolution of the cluster due to the winds and/or novae of massive stars in the central subcluster. Lastly, we will discuss the embedded cluster to the northeast (NE) of RCW 38: DBS2003-124, first identified in a survey for new IR clusters in Two Micron All Sky Survey (2MASS) by Dutra et al. (2003), and a newly identified protostellar jet associated with a young star in that cluster.

2. OBSERVATIONS AND DATA REDUCTION

The observations and data reduction for the Spitzer and Chandra data were presented in Paper 1 and Wolk et al. (2006). A brief summary of that work is presented here. We obtained observations of the RCW 38 region with the Spitzer IRAC (Fazio et al. 2004) in four wavelength bands: 3.6, 4.5, 5.8, and 8.0 $\mu$m and with the MIPS (Rieke et al. 2004). This photometry was supplemented by J-, H-, and K-band photometry from the 2MASS point-source catalog (Skrutskie et al. 2006). The infrared observations were further combined with Chandra Advanced CCD Imaging Spectrometer (ACIS; Weisskopf et al. 2002) X-ray data.

In Paper 1, we identified 624 YSOs in RCW 38, of which, 226 were detected in X-rays with Chandra. The YSOs were of the following evolutionary classes (Lada & Wilking 1984; Winston et al. 2007): 23 class I, 90 flat spectrum, 437 class II, and 74 class III. Of the YSOs, 9 class I, 18 flat spectrum, 125 class II, and 74 class III were also detected in the Chandra X-ray observation. The spatial distribution was studied using YSO density maps and minimum spanning-tree techniques and found to show evidence of three subclusters surrounding the central IRS2 subcluster. One of these subclusters is Obj-36 (Dutra et al. 2003) associated with the reflection nebula vdBH-RN43 (van de Bergh & Herbst 1975) and has now been identified as a subcluster of the RCW 38 complex. We found that the observed relationship of $N_{\text{H}}/A_K$ was consistent with the Vuong et al. (2003) ratio of $1.6 \times 10^{22}$ for the local ISM and nearby molecular clouds. An examination of photometric variance identified 72 variable sources, with variables in each of the subclusters and in the dispersed population. Using near-IR color–magnitude criteria, 29 candidate O stars were identified. These were also distributed across the extended RCW 38 region, with massive stars associated with each of the subclusters.

The bow shocks identified in this paper have an extended geometry such that their fluxes could not be obtained using the point-source extraction methods applied to the stellar sources in Paper 1. The flux apertures were constructed manually to most accurately enclose the shock on the image. The area of each bow shock was estimated using an irregular polygonal aperture in ds9 (Joye & Mandel 2003) and the flux estimated using funtools (Mandel et al. 2001). The same aperture was used at each IRC band, being defined in the band where emission in that shock was strongest and best defined, and then replicated at each wavelength. The background sky emission was estimated and removed by taking the flux in an adjacent rectangular aperture and scaling to the area of the shock aperture. The 24 $\mu$m bow-shock fluxes were estimated using funtools, similarly to the IRC fluxes, using the same irregular polygonal aperture used in the IRC bands where the shock was detected.

3. DISCUSSION

3.1. The Bow Shocks

In RCW 38 we identify five bow shocks in highly differing environments. The coordinates and photometry for the five driving stars are given in Table 1. Their individual identifiers correspond to the Spitzer IDs listed in Table 2 of Paper 1, where their evolutionary classification and variability over our two epochs of IRAC observations were determined. The coordinates of the apexes of the bow shocks and their estimated fluxes are listed in Table 2. Figure 1 presents an IRAC false-color image of the RCW 38 cluster with the locations of the five identified shocks highlighted. The bow shocks are clearly visible
Three-band false-color image of the RCW 38 cluster using the IRAC bands $3.6 \mu m$ in blue, $4.5 \mu m$ in green, and $8.0 \mu m$ in red. The positions of the five identified bow shocks are indicated.

Table 1

| Sp. a | R.A. | Decl. | $J$ | $H$ | $K$ | 3.6 $\mu m$ | 4.5 $\mu m$ | 5.8 $\mu m$ | 8.0 $\mu m$ |
|-------|------|-------|----|----|----|-------------|-------------|-------------|-------------|
|       | J2000 | J2000 | (mag) | (mag) | (mag) | (mag) | (mag) | (mag) | (mag) |
| 293   | 8:59:26.70 | $-47:33:10.14$ | 11.696 ± 0.024 | 10.967 ± 0.027 | 10.503 ± 0.030 | 10.082 ± 0.061 | 9.716 ± 0.101 | 9.168 ± 0.210 | ... |
| 49    | 8:59:18.44 | $-47:35:51.89$ | 11.104 ± 0.023 | 10.438 ± 0.026 | 10.016 ± 0.025 | 9.781 ± 0.024 | 9.555 ± 0.035 | 9.125 ± 0.083 | 7.944 ± 0.132 |
| 129   | 8:59:56.06 | $-47:33:04.4$ | 8.587 ± 0.021 | 8.254 ± 0.038 | 8.073 ± 0.021 | 7.999 ± 0.009 | 8.169 ± 0.012 | 7.978 ± 0.014 | 8.029 ± 0.031 |
| 581   | 8:59:02.94 | $-47:30:54.1$ | 11.002 ± 0.021 | 10.130 ± 0.021 | 9.607 ± 0.019 | 7.966 ± 0.038 | 6.772 ± 0.032 | 5.544 ± 0.072 | ... |
| 803   | 8:59:41.98 | $-47:41:22.8$ | 9.035 ± 0.025 | 8.434 ± 0.042 | 8.186 ± 0.030 | 8.879 ± 0.015 | 8.175 ± 0.012 | 7.970 ± 0.014 | 8.027 ± 0.021 |

Note. a See Winston et al. (2011, Paper 1) for further details.

Table 2

| Sp. | R.A._apex | Decl._apex | 3.6 $\mu m$ (mJy) | 4.5 $\mu m$ (mJy) | 5.8 $\mu m$ (mJy) | 8.0 $\mu m$ (mJy) | 24 $\mu m$ (mJy) |
|-----|-----------|-----------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 293_s | 8:59:27.31 | $-47:33:09.0$ | 16.3 ± 1.8 | 38.2 ± 2.1 | 28.9 ± 3.8 | 43.1 ± 6.2 | <3598 |
| 49_s  | 8:59:18.62 | $-47:35:45.8$ | 21.6 ± 1.3 | 38.9 ± 1.6 | 36.3 ± 2.7 | 68.6 ± 4.8 | <4013 |
| 129_s | 08:59:57.36 | $-47:32:45.7$ | <0.8 | <1.4 | 5.4 ± 5.0 | 62.7 ± 25.4 | 1251 ± 14 |
| 581_s | 08:59:02.94 | $-47:30:54.1$ | <366 | <869 | <1127 | <6950 | ... |
| 803_s | 08:59:43.07 | $-47:41:28.6$ | ... | ... | 6.3 ± 2.6 | 45.8 ± 3.0 | 813 ± 16 |

in shocked hydrogen emission, seen predominantly at 4.5 $\mu m$ (in green). PAH emission from heated dust is visible at 8.0 $\mu m$. The region of bright yellow emission to the west of center in the image is the central subcluster of RCW 38 where IRS 1 and 2 are located. Figure 2 provides IRAC and MIPS false-color enlarged images of each of the five identified shocks and their driving stars. The upper two plots (YSO 293 and YSO 49) show the bow shocks clearly visible in shocked hydrogen at 4.5 $\mu m$. The shocks in the central plots (YSO 129 and YSO 803) emit predominantly at 24 $\mu m$, indicating perhaps faster dissociative shocks (Neufeld et al. 2006). The lower plot shows YSO 581, which is seen as a faint emission feature against IRS 1, the bright X-shaped emission feature to the NE of the shock in the center of the image. IRS 2 is the bright blue source to the east of IRS 1.
Figure 2. Enlarged view in three-band false-color IRAC/MIPS images of the five bow shocks in RCW 38. Top left: the bow shock around YSO 293 in IRAC bands $3.6 \, \mu m$, $4.5 \, \mu m$, and $8.0 \, \mu m$. Top right: the YSO 49 and bow shock in IRAC bands $3.6 \, \mu m$, $4.5 \, \mu m$, and $8.0 \, \mu m$. Middle left: the YSO 129 in IRAC bands $4.5 \, \mu m$ and $8.0 \, \mu m$ and MIPS $24 \, \mu m$, with the bow shock only faintly visible in bands other than the $24 \, \mu m$. The evaporating pillars are also bright at $8.0$ and $24 \, \mu m$. Middle right: the fainter shock from YSO 803 to the SE in IRAC $4.5 \, \mu m$ and $8.0 \, \mu m$ and MIPS $24 \, \mu m$. It is only visible at $24 \, \mu m$. Bottom: the central shock from YSO 581 is shown in a three color image of IRAC $3.6 \, \mu m$, $4.5 \, \mu m$, and $8.0 \, \mu m$. IRS 1 glows brightly to the east of the bow shock, which is likely interacting with the strong winds from IRS 2 further to the east in the image.
Figure 3. Spectral energy distributions of the five driving stars (star symbols) and their shocks (square symbols). The 24 μm fluxes of YSOs 293 and 49 are contaminated by stellar emission. All fluxes for the YSO 581 shock are heavily contaminated by variable background and the relative location of 581 behind the shock. YSO 129 and source YSO 803 have only weak mid-IR fluxes and are identified at 24 μm.

Details on the individual driving stars and bow shocks can be found in the Appendix.

The near- and mid-IR fluxes were used to construct spectral energy distributions (SEDs) for the five driving stars and bow shocks, with the plots of the SEDs given in Figure 3. The star symbols show the stellar fluxes while the squares indicate the fluxes of the shocks. The shock fluxes of YSO 803 and YSO 129 are very faint shortward of 24 μm and so the IRAC fluxes are not greatly in excess of the background and are more uncertain. Both the stellar and shock fluxes from YSO 581 are contaminated by the superposition of the shock and star due to the line of sight. The objects YSO 581, YSO 293, and YSO 49 were classified as C0/I and II sources as their stellar SEDs exhibit excess emission above that of a stellar photosphere. The SEDs of the bow shocks are consistent with emission from a blackbody. These findings are consistent with those of shocks in RCW 49 and M17 presented by Povich et al. (2008) and by Bally et al. (2000) in the Orion Nebular Cluster (ONC). The ONC is relatively nearby at a distance of 145 pc, M17 lies at a similar distance (1.5 kpc) to RCW 38, while the distance to RCW 49 is given as 4.2 or 6 kpc in Povich et al. (2008). The five RCW 38 shocks increase the number of known mid-IR shocks by ~40% and more than double the known sample at 1–2 kpc.

3.1.1. Dynamical Implications

Consideration of the stand-off distance of the bow shock (the distance from the star to the apex of the shock) and the mass loss rate of the driving star can lead to an estimation of the relative velocity of the stellar winds or ISM in the region. From Povich et al. (2008), following the normalization of van Buren & McCray (1988), we have an equation relating the velocity (v_o) and hydrogen particle density (n_H,3 = 10^3 cm^{-3}) of the ambient medium to the mass loss rate (M_w, -6 = 10^{-6} M_☉ yr^{-1}) and relative velocity (v_{w,8} = 10^8 cm s^{-1}) of the driving star and the bow-shock stand-off distance (d_w):

\[ v_o n_H^{-1/2} = 1.5 \left( \frac{d_w}{\text{pc}} \right)^{-1} (M_w, -6 v_{w,8})^{1/2}. \]

The stand-off distance must incorporate a cos(i) term since we cannot ascertain the angle of the shock with respect to the plane of the sky. However, cos(i) has a mean value of 0.9 for angles between 0° and 45° so this will affect the resulting velocity measurement at the 10% level. The density of the ISM is assumed to be approximately 10^3 cm^{-3}, and hence equal to unity in the equation. The mass loss rates and stellar wind velocities from young massive stars are highly variable and strongly dependent on stellar spectral type (Fullerton et al. 2006). This uncertainty is further complicated by the estimation of the spectral type, which is calculated from the near-IR colors and not spectroscopy. In this case a value of \(<0.2 M_{w,-6}\) is applied to all stars with spectral type later than O9 applicable to all five objects in this case. This value is based on estimates taken from Vink et al. (2001) and Fullerton et al. (2006). A thorough description of the assumptions made in this calculation is presented in Povich et al. (2008).

The offset in pixels from the coordinates of the star to the apex of the bow shock was measured on the 8 μm mosaic and converted to distance in parsecs assuming a distance to RCW 38 of 1.7 kpc. The spectral types of the driving stars were estimated from their positions on the K versus J – K color–magnitude diagram (CMD). The spectral types, stand-off distances, and estimates of the relative velocity for the shocks are given in Table 3, except YSO 581, the geometry of which precludes the measurement of the stand-off distance. With the caveat that the values of \(v_o n_H^{-1/2}\) are highly uncertain we can say that in the cases of the four shocks with measurements the velocities span a small range, from 4 to 12 km s^{-1}. The velocities calculated for sources 129 and 803, those only visible at longer wavelengths,
are somewhat lower than those of the sources with shocks clearly visible in the IRAC bands. This would not agree with their emission arising from fast dissociative shocks and is perhaps an indication that these more outlying sources are located in a lower density medium. It may also be linked to evolutionary classification: both are class III sources. It may also be related to their being shocked by the ISM and not due to interaction with wind from high mass stars.

The orientations of all five bow shocks in RCW 38 appear to be aligned with O-star candidates identified in their vicinity. None of the five shocks are oriented such that their driving stars would appear to be following a trajectory away from IRS 2. This allows us to rule out the possibility that the stars driving the bow shocks are runaway O stars that are being ejected from the central subcluster. YSOs 293 and 49 are aligned to o15-v13 (see Table 11 in Paper 1), while the apex of the central bow shock is clearly pointing toward the central O5.5 binary IRS 2. This orientation indicates that the shock is ∼60º southwest (SW) of the binary and also perhaps ∼15º−45º behind the O stars. This would imply that the O-star binary is not clearing out a cylindrical structure as this is a projection effect and these walls lie behind the massive stars. Their winds are likely compressing and illuminating the posterior wall of the H2 blister bubble. In the case of YSO 129 and YSO 803 the source of the interaction is less clear; it may be the candidate O-star NE20, associated with the new subcluster, cf. Section 3.3. However, it is more likely that they trace the direction of the flow of the ISM material in their vicinity, implying that this material is moving in a roughly east to west direction across the face of the cluster.

### 3.2. Outflows and Winds: Influence of the Massive Stars

Discussion of the central O stars of IRS 2 leads to an examination of the overall structure of RCW 38 and the effect of the massive stars and their winds on the evolution of the cluster. In planetary nebulae, complex X-ray emission structures have been observed which show both evidence of axial symmetry and an anticorrelation between the X-ray diffuse emission and the infrared extinction, indicating that the X-ray outflows can in part be shaped by the material into which they expand (cf. Kastner et al. 2002; Chu et al. 2004). Similar features have also been observed in the center of RCW 38. The two O5.5 stars of IRS 2 have an estimated combined luminosity log($L_{\odot}$) of 5.71 and hydrogen ionizing photon flux log($Q_H$) of 49.4 (DeRose et al. 2009; Smith 2006; Martins et al. 2005) and are considered likely to be the main drivers of the outflows from the central subcluster. Wolk et al. (2002) modeled the diffuse X-ray emission and found it was best fit by synchrotron emission. We infer from the orientation of the central bow shock of YSO 581 that the central O stars of IRS 2 are not hemmed in by the dense dust and gas structures of IRS 1 and surrounding rim of material. Rather, they may be some distance in front of the face of the molecular cloud, perhaps ∼0.3 pc (the radius of a sphere centered on IRS 2 and defined by the rim of emission at 8 μm at the assumed distance to RCW 38 of 1.7 kpc). The outflows and stellar winds from these stars have been funneled outward in three outflows along an NE–SW axis and to the northwest (NW), evacuating the region and heating the gas and dust along the path as they are swept up in the moving shock front.

Further, the orientation of the outflow is possibly tilted with respect to the plane of the sky, with the SW lobe projecting out of the plane by a few degrees, while the NE lobe is projected into the molecular cloud in front of which the cluster sits. The southern lobe has met with less dense material at the border of the molecular cloud and ISM. This material is being shocked where the hot ionized gas of the expanding shell collides with it, as can be seen in Figure 5. The hot gas can be observed in the X-ray contours shown in Figure 5, filling the expanding cavity cleared by the outflow. The leading shock front is visible at 4.5 μm as shocked hydrogen emission and also via the heated dust visible at 24 μm, cf. Figures 4 and 5. The expanding flow of hot ionized gas to the NW visible in the X-ray data has caused shocked emission in the IR as it collides with and flows around the dust and gas. The third outflow, expanding to the NE, appears to be moving into a region of higher dust density and appears to be partially obscured by a ridge of dense dust. These outflows may have triggered the latest generation of star formation in the central subcluster, as can be traced by the filament of protostars, illustrated in Figure 5. The YSOs shown in Figure 5, identified in Paper 1, are the class 0/I (circles) and flat spectrum sources (triangles). While the class 0/I protostars are located throughout the region, they are notably concentrated in discreet groups in the three outer subclusters and within the central IRS 2 subcluster where they form a filament or arc-shaped distribution. The protostars in this filament are also spatially coincident with a ridge of dust emission observed at 1.2 mm (Vigil 2004).

Outside of the central subcluster, the molecular cloud is also being shaped by other massive stars. A dense pillar of dust is being carved away by the photo-evaporating winds of YSO 129 (one of the bow-shock driving stars) and possibly the O-star candidate ov15-v13, cf. Figure 1 and for an expanded view Figure 2. These two stars lie at projected distances from the top of the pillar of 1.37 and 4.94 arcmin (0.68 and 2.44 pc) for YSO 129 and ov15-v13, respectively. The pillar has a finger of dense material extending from it in the SW direction and two illuminated faces to SW and W. The faces and finger of the pillar show very bright emission at 4.5, 8.0, and 24 μm implying both heating of the dust and shocked gas emission. No point sources are detected in the pillar. This is perhaps because the density is currently too low to promote star formation or because any protostars within are as yet too young to be detected in the near- to mid-IR and would require observations at longer wavelengths, such as are available with Herschel or with ground-based submillimeter instruments.

Six of the candidate O stars are located on the periphery of the central subcluster. If these stars are early-type members, then the surrounding low to intermediate mass YSOs that have some shielding from the IRS 2 binary would be exposed to higher fluxes of ionizing photons than might otherwise have been expected. This may have an impact on the X-ray calculated YSO disk fraction (the ratio of X-ray detected class II to class III) which was found to be constant with radial distance beyond ∼0.5 pc from the central IRS 2 binary. Within a radial distance of IRS 2 of 0.5 pc the ratio is 40% ± 28%; this rises to

| Sp. ID | Est. Spectral Type | $d_{o}$ cos $i$ (pc) | $\rho_{\text{mic}}$ (cos $i$)$^{-1}$ (km s$^{-1}$) |
|--------|------------------|---------------------|------------------|
| 293    | B2-B3           | 0.079               | <8.41            |
| 49     | B1.5-B2         | 0.055               | <12.19           |
| 129    | B0              | 0.177               | <3.79            |
| 581    | B0.5-B1         | ...                 | ...              |
| 803    | B0              | 0.125               | <5.37            |

**Table 3**

Stand-off Distances and Estimated Stellar Wind Properties

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Figure 4. Three-band false-color image of RCW 38, with the smoothed ACIS-I 0.5–8 keV in blue, IRAC 4.5 μm in green, and 8.0 μm in red. Hot ionized gas outflows can be seen in the ACIS-I data. In the IRAC bands, ridges of emission from warm dust (8.0 μm) and shocked hydrogen (4.5 μm) coincide with the boundaries of the ionized gas outflows. Two of the stars with bow shocks, YSO 129 and YSO 293 (labeled a and b, respectively), also lie in regions of ionized gas, driven by winds from local massive stars, YSO 129 itself and two candidate O stars identified in Paper 1: oc15-v13 (c) and YSO 244 (d).

67% ± 5% beyond a radius of 0.5 pc and is approximately constant from 0.5 to 3 pc from the center of the subcluster. While the uncertainties do overlap (due to the small sample in the central region), there is an indication that the disk fraction is decreased in the vicinity of IRS 2. The three other subclusters each contain a candidate massive star, and while not as early as IRS 2 they are still capable of affecting the circumstellar disks of their subcluster members. The majority of the candidates are strewn throughout the distributed population and thus it may be difficult to identify any significant fraction of the population of the extended RCW 38 region that is isolated from the effects of a massive star.

3.3. DBS2003-124 and Protostellar Jet

The embedded stellar cluster DBS2003-124 was identified by Dutra et al. (2003) in a survey of the 2MASS catalog designed to identify new IR clusters. Located at coordinates 09h00m41.5s, −47d26m02.3, 169 NE of IRS 2, it lies close to edge of the IRAC image and was only observed in the 3.6 and 5.8 μm bands due to the offset in the fields of view of the IRAC channels. The cluster was also observed in the MIPS 24 μm image, cf. Figure 6. Visually, the region appears to be contiguous with the main 24 μm source and the 24 μm sources themselves were considered to be members of the cluster and their coordinates and photometry are included in Table 4. This method identified 14 possible members from the 3.6 and 5.8 μm photometry, with the five at 24 μm. The second method involved searching for sources with excess emission on the [3.6] versus [3.6–5.8] CMD in the region surrounding the cluster and 24 μm filament. With this method, we identify 17 objects, including 11 new possible cluster members. The coordinates and photometry of the sources identified using the CMD are presented in one very bright 24 μm detection in the center of the grouping and another 24 μm source on the NE of the central group. A string of five 24 μm point sources is observed, two within the ridge of dust emission and a tail of three sources extending to the SW, one of which appears to be the origin of the protostellar jet. The projected separations of these five objects are semi-regular from the northernmost source to the south: 0.26 pc, 0.43 pc, 0.27 pc, and 0.42 pc. The southernmost of the five 24 μm sources, NE20, is a candidate high mass star, and it is located 1.16 pc from the subcluster center. This would make DBS2003-124 the only one of the five identified subclusters without an O star at its center. Unlike Obj 36, the NW subcluster identified in Paper 1, there is no bright mid-IR emission nebula associated with this small cluster of stars. The region also exhibits faint extended emission at 24 μm and is the only subcluster where 24 μm point sources are identified (though both the central subcluster and Obj 36 are saturated in the 24 μm mosaic).

Two methods were used to identify candidate members of the cluster. In the first method, those sources within the ridge of dust surrounding the main 24 μm source and the 24 μm sources themselves were considered to be members of the cluster and their coordinates and photometry are included in Table 4. This method identified 14 possible members from the 3.6 and 5.8 μm photometry, with the five at 24 μm. The second method involved searching for sources with excess emission on the [3.6] versus [3.6–5.8] CMD in the region surrounding the cluster and 24 μm filament. With this method, we identify 17 objects, including 11 new possible cluster members. The coordinates and photometry of the sources identified using the CMD are presented in
Figure 5. Grayscale of the difference between the 4.5 and 5.8 $\mu$m IRAC image showing the central subcluster with ACIS-I data overlaid in contours. The subtracted image highlights the shocked hydrogen emission in the 4.5 $\mu$m band in white. Three outflows can be observed, extending to the SW, NE, and NW in the ACIS-I contours. The class 0/I (circles) and flat spectrum (inverted triangles) protostars in the central core are overlaid showing the filament of possibly triggered star formation by the NW lobe of the outflow. Labels a–d as in Figure 4.

Table 4
Coordinates and Photometry for the Candidate Members of NE Subcluster

| Sp. ID | R.A. J2000 | Decl. J2000 | $J$ (mag) | $H$ (mag) | $K_s$ (mag) | 3.6 $\mu$m (mag) | 5.8 $\mu$m (mag) |
|--------|------------|-------------|-----------|-----------|-------------|-----------------|-----------------|
| 1      | 9:00:42.92 | -47:25:52.30 | ...       | 15.22 ± 0.11 | 13.98 ± 0.08 | 12.48 ± 0.09 | 11.24 ± 0.11 |
| 2      | 9:00:42.04 | -47:26:22.32 | 16.06 ± 0.10 | 14.55 ± 0.05 | 13.84 ± 0.05 | 13.16 ± 0.11 | 12.91 ± 0.39 |
| 3      | 9:00:43.04 | -47:26:07.38 | ...       | 16.14 ± 0.19 | 14.81 ± 0.14 | 13.01 ± 0.09 | 11.85 ± 0.18 |
| 4      | 9:00:41.42 | -47:26:05.00 | 16.38 ± 0.13 | 13.59 ± 0.06 | 11.75 ± 0.04 | 9.78 ± 0.04 | ...            |
| 5      | 9:00:39.22 | -47:26:34.58 | ...       | 14.65 ± 0.06 | 12.78 ± 0.03 | 11.54 ± 0.05 | 11.02 ± 0.12 |
| 6      | 9:00:43.09 | -47:25:39.47 | 13.82 ± 0.03 | 12.12 ± 0.03 | 11.00 ± 0.02 | 9.37 ± 0.02 | 7.97 ± 0.01 |
| 7      | 9:00:42.09 | -47:25:53.74 | ...       | 13.84 ± 0.19 | 11.99 ± 0.06 | 10.55 ± 0.08 | ...            |
| 8      | 9:00:41.24 | -47:25:54.26 | ...       | 13.11 ± 0.15 | 11.04 ± 0.12 | 9.08 ± 0.04 | ...            |
| 9      | 9:00:42.01 | -47:26:00.25 | ...       | 11.43 ± 0.05 | 9.98 ± 0.05 | 8.72 ± 0.05 | ...            |
| 10     | 9:00:39.62 | -47:26:20.94 | ...       | ...         | 14.82 ± 0.39 | ...            | ...            |
| 11     | 9:00:40.88 | -47:26:14.79 | ...       | ...         | 12.00 ± 0.13 | ...            | ...            |
| 12     | 9:00:40.86 | -47:25:59.36 | ...       | ...         | 10.29 ± 0.07 | ...            | ...            |
| 13     | 9:00:41.43 | -47:25:45.97 | ...       | ...         | 13.29 ± 0.15 | ...            | ...            |
| 14     | 9:00:39.29 | -47:25:42.83 | ...       | ...         | 14.76 ± 0.26 | ...            | ...            |
| 15     | 9:00:41.94 | -47:25:33.31 | ...       | ...         | 14.19 ± 0.21 | ...            | ...            |
| 16     | 9:00:39.90 | -47:25:35.15 | ...       | ...         | 14.90 ± 0.38 | ...            | ...            |
| 17     | 9:00:39.31 | -47:25:36.05 | ...       | ...         | 14.85 ± 0.26 | ...            | ...            |
| 18     | 9:00:40.77 | -47:26:14.78 | ...       | ...         | ...           | 10.47 ± 0.12   | ...            |
| 19     | 9:00:41.42 | -47:26:06.34 | ...       | ...         | ...           | 8.00 ± 0.04    | ...            |
| 20     | 9:00:33.80 | -47:27:58.17 | 8.40 ± 0.02 | 6.60 ± 0.03 | 5.76 ± 0.02 | ...            | 6.28 ± 0.01 |
| 21     | 9:00:36.96 | -47:27:19.10 | ...       | 15.77 ± 0.15 | 12.99 ± 0.03 | 8.93 ± 0.01 | 6.44 ± 0.01 |
| 22     | 9:00:38.62 | -47:26:48.98 | ...       | 15.64 ± 0.13 | 13.51 ± 0.07 | 11.04 ± 0.04 | 8.91 ± 0.03 |
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Figure 6. Top: grayscale of the 3.6 μm IRAC image showing the location of DBS2003-124 with respect to the center of RCW 38. Bottom: three-band false-color image of the newly identified NE subcluster in RCW 38, DBS2003-124, and the YSO-driven jet, with IRAC 3.6 μm in blue, 5.8 μm in green, and MIPS 24 μm in red. The subcluster, in the upper left of the image, contains one source with bright 24 μm emission, which is surrounded by tens of IRAC sources. Two candidate infrared HH objects associated with the jet are visible in the center and center right of the image. The star powering the jet, NE21, lies NE of the brightest blue star in the image (OB candidate NE20).

Table 5. This gives an estimated membership of 33 objects in DBS2003-124. High-resolution imaging of the cluster in the near-IR would allow for a better estimate of the total population of this young cluster.

3.3.1. The Protostellar Jet

Figure 6 also reveals two aligned shells of MIR emission, which appear to be shocked emission from two infrared candidate HH objects in a westward moving protostellar jet. Tracing the outflow backward leads to the young star NE21, one of the 24 μm sources in the filament extending from DBS2003-124. This star also may have an extended emission feature at 5.8 μm, which might trace the beginnings of the protostellar jet and indicating that the jet remains active, though this feature may also be a data processing artifact. The coordinates of the apexes of the two shells are 09h00m13.94, −47d27m39.05 and 08h59m58.93, −47d27m54.28. These are found at distances from NE21 of 1.85 pc and 3.16 pc, respectively, assuming a distance of 1.7 kpc. By considering a range of velocities for the material in the jet, we can estimate the age of the jet from the two identified shells. In Table 6, we list the ages of the jet assuming velocities of 10, 100, and 500 km s⁻¹ (Bally et al. 1995; Bally & Devine 1994). We estimate the age of the jet to be ~6 × 10⁵ to 3 × 10⁹ yr. This would imply a very young age for this star and the subcluster as a whole. It is possible that this subcluster is younger than RCW 38 itself and that star formation is progressing through the molecular cloud.

4. CONCLUSION

We have examined the RCW 38 cluster using mid-IR observations taken with the Spitzer Space Telescope’s IRAC and MIPS instruments and discovered five bow shocks in the region. We have combined these data with 2MASS photometry and
from a YSO within this subcluster. The main results from our
its star formation history. We have also identified DBS2003-124
− its effects on the evolution of the cluster as a whole, in particular
ined the large-scale outflow from the central subcluster to study
driving stars and to estimate their spectral type. We have exam-
observations to classify the evolutionary stage of the
Chandra.

500 105 3.
.10 0.21 1

Velocity Velocity First Shell Second Shell
1)( A U y r (yr) (yr)

Table 5
Coordinates and Photometry for the Candidate Members of NE Subcluster from 3.6 μm Versus 3.6 μm–5.8 μm Color–Color Diagram

| Sp. ID | R.A. J2000 | Decl. J2000 | J (mag) | H (mag) | Ks (mag) | 3.6 μm (mag) | 5.8 μm (mag) |
|-------|------------|-------------|---------|---------|----------|--------------|--------------|
| 22    | 9:00:38.62 | −47:26:48.98| ...     | 15.64 ± 0.13 | 13.51 ± 0.07 | 11.04 ± 0.04 | 8.91 ± 0.03 |
| 23    | 9:00:26.47 | −47:26:27.64| 16.05 ± 0.08 | 14.52 ± 0.05 | 13.93 ± 0.05 | 13.46 ± 0.12 | 12.74 ± 0.23 |
| 24    | 9:00:26.76 | −47:26:57.52| ...     | 13.89 ± 0.03 | 12.00 ± 0.04 | 12.79 ± 0.08 | 12.19 ± 0.16 |
| 25    | 9:00:29.65 | −47:27:31.30| 13.19 ± 0.03 | 13.02 ± 0.11 | 13.98 ± 0.08 | 12.48 ± 0.09 | 11.24 ± 0.11 |
| 1     | 9:00:42.92 | −47:25:52.30| ...     | 15.22 ± 0.11 | 13.98 ± 0.08 | 12.48 ± 0.09 | 11.24 ± 0.11 |
| 26    | 9:00:44.90 | −47:25:20.41| ...     | ...         | 15.07 ± 0.15 | 12.56 ± 0.08 | 11.08 ± 0.07 |
| 3     | 9:00:43.04 | −47:26:07.38| 16.14 ± 0.19 | 14.81 ± 0.14 | 13.01 ± 0.09 | 11.85 ± 0.18 |
| 27    | 9:00:34.01 | −47:25:53.45| ...     | 14.66 ± 0.05 | 13.75 ± 0.06 | 12.57 ± 0.07 | 10.80 ± 0.06 |
| 28    | 9:00:36.25 | −47:25:52.88| 16.11 ± 0.10 | 14.41 ± 0.05 | 13.57 ± 0.06 | 12.57 ± 0.07 | 10.80 ± 0.06 |
| 29    | 9:00:38.98 | −47:26:19.35| ...     | 14.82 ± 0.13 | 11.90 ± 0.06 | 10.26 ± 0.06 |
| 30    | 9:00:43.83 | −47:24:04.82| ...     | 15.87 ± 0.16 | 14.11 ± 0.06 | 12.47 ± 0.07 | 11.30 ± 0.10 |
| 31    | 9:00:35.82 | −47:24:46.60| 15.37 ± 0.06 | 13.82 ± 0.04 | 12.98 ± 0.03 | 12.04 ± 0.06 | 11.14 ± 0.08 |
| 6     | 9:00:43.09 | −47:25:39.47| 13.82 ± 0.03 | 12.12 ± 0.03 | 11.00 ± 0.02 | 9.37 ± 0.02 | 7.79 ± 0.01 |
| 32    | 9:00:43.79 | −47:24:38.94| 15.22 ± 0.05 | 12.99 ± 0.03 | 11.77 ± 0.03 | 10.43 ± 0.03 | 9.32 ± 0.03 |
| 7     | 9:00:42.09 | −47:25:53.74| ...     | 13.84 ± 0.19 | 11.99 ± 0.06 | 10.55 ± 0.08 | 9.72 ± 0.05 |
| 9     | 9:00:42.01 | −47:26:00.25| ...     | 11.43 ± 0.05 | 9.98 ± 0.05 | 8.72 ± 0.05 |
| 33    | 9:00:26.97 | −47:25:08.63| ...     | ...         | ...         | ...         | ...         |

Chandra observations to classify the evolutionary stage of the
driving stars and to estimate their spectral type. We have exam-
ined the large-scale outflow from the central subcluster to study
its effects on the evolution of the cluster as a whole, in particular
its star formation history. We have also identified DBS2003-124
as an embedded mid-IR subcluster most likely associated with
RCW 38 and two candidate HH objects from a jet originating
from a YSO within this subcluster. The main results from our
study are as follows.

1. Five bow shocks were detected by their mid-IR emission in
the IRAC and MIPS bandpasses. The shocks are associated
with driving stars with estimated spectral types from
O9-B3, based on their near-IR magnitudes and colors. Four
of the driving stars are previously identified YSOs, with
one class I, two class II, and one class III objects. The fifth
driving star was classified as being class III. Three of the
bow shocks are clearly visible in the IRAC images, two are
only clearly detected at 24 μm.

2. The relative velocities of the shocks were estimated from
the stand-off distance of the shocks to their associated
stars and their estimated mass loss rates and stellar wind
velocities. Though with large uncertainties, the values of
v, n/(1/2) were all found to be on the order of 10 km s⁻¹.
Those shocks likely interacting with the ISM, YSO 129
and 803, and only detected in the longer wavelengths, had
slightly lower values.

3. The central O-star binary, IRS 2, is driving a powerful stellar
wind that is shaping the cluster environment. The outflow
of hot ionized gas, traced by diffuse X-ray emission, is carving
a cavity out of the molecular cloud, opening the region to
the SW and NW where hot ionized gas flows outward.

Outflowing material to the NE has possibly triggered a new
generation of star formation in the region.

4. A dense pillar of gas and dust has been observed that is
being photo-evaporated by the winds from the bow-shock
driving star YSO 129 and the O-star candidate o15v13. No
point sources are identified in the pillar at near- to mid-IR
wavelengths.

5. We report on the identification in IRAC bands 3.6 and
5.8 μm of DBS2003-124, an IR cluster to the NE of
RCW 38, as a subcluster of the RCW 38 complex. Using
association with the ridge of bright 5.8 μm emission and
color–magnitude criteria, we have identified 33 sources as
likely members of this cluster.

6. Two infrared candidate HH objects from a protostellar
jet, associated with NE21 in DBS2003-124, have been
identified. Two shocked emission lobes are visible to the
west of NE21, at distances of 1.86 and 3.16 pc from NE21.
Estimating the velocity of the jet material gives an age of
3 × 10⁵ to 3 × 10⁶ yr for the jet.

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ology. Montage is maintained by the NASA/IPAC Infrared

Table 6
Jet Velocities and Ages for the Two Shells

| Velocity (km s⁻¹) | Velocity (AU yr⁻¹) | First Shell (yr) | Second Shell (yr) |
|------------------|-------------------|-----------------|------------------|
| 10               | 0.21              | 1.8 × 10³       | 3.1 × 10³        |
| 100              | 21                | 1.8 × 10⁴       | 3.1 × 10⁴        |
| 500              | 105               | 3.6 × 10³       | 6.2 × 10³        |
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APPENDIX

DETAILS OF INDIVIDUAL BOW-SHOCK SOURCES

YSO 581. The bow shock associated with YSO 581 is located in the central subcluster of the RCW 38 cluster and likely arises from interaction with the strong winds emanating from the O5.5 binary IRS 2. The probable driving star (YSO 581) is classified as being of evolutionary class 0/I. It was not detected as an X-ray source in the Chandra observation and is not a candidate IR variable source. The bow shock is observed in all four IRAC bands but due to the high background and source density in the central cluster it was difficult to extract accurate values of the flux. It does not have a MIPS detection due to the saturation of the 24 μm mosaic in the central subcluster. From the image, the bow shock appears to lie partially in front of the driving star, which would lead to the measured fluxes of both objects being contaminated; thus it is possible that the identification of this object as having an envelope is inaccurate and that this “envelope” is in fact emission from the shock. Likewise the fluxes for the shock are contaminated by the stellar flux, though the aperture used to measure the shock flux excluded a circular aperture covering the star itself. Spectroscopic data of the star showing absorption features would help to clarify if this is the case. Smith et al. (1999) have identified YSO 581 as source “D” in their near-IR maps, where they mention the possibility of a cavity and ridge of emission to the west of IRS 1 likely corresponding to emission from the bow shock.

YSO 293. The bow shock associated with YSO 293 was found to the east of IRS 2 in an area not immediately affected by the winds from the central massive stars. The young star YSO 293 was classified as a class II member of the cluster. It is not a variable candidate, but was detected as an X-ray source in the Chandra observation. The source was detected with 10 counts in the ACIS data, with \(N_{\text{H}} = 1.91 \pm 0.81 \times 10^{22} \text{ cm}^{-2}\) and \(kT = 1.14 \pm 0.59 \text{ keV}\). The star is detected in the 2MASS bands, and in the three shortest wavelength IRAC bands, but not as a point source at 8.0 μm. The bow shock was detected at all four IRAC bands and at 24 μm. The bow shock and star are clearly separated on the sky in the shorter IRAC bands, though there is possibly some contamination at 8.0 μm and likely a larger degree of contamination at 24 μm. The shock likely arises at the interface of the stellar wind with that of the O-star candidate ov15-v13 (cf. Paper 1, Table 12). This star lies 0.88 to the east, or 0.45 pc at the assumed distance to RCW 38 of 1.7 kpc. The star is located in a region of elevated emission from hot ionized gas in the Chandra data where two candidate O stars (ov15-v13 and y244) are also found, as shown in Figure 4.

YSO 49. The next bow shock is associated with YSO 49 and displays similar properties to YSO 293. This star is also to the east of IRS 2 and to the SW of YSO 293. The driving star, YSO 49, was classified as being class II. This classification is not affected by the emission from the shock. It was not detected in X-rays, though it does lie within the field of view of the observation. This star did not show any indication of variability over the two epochs of IRAC observations. The star is detected in all 2MASS and IRAC bandpasses, where its stellarSED indicates excess emission in the IR. The shock is detected in the four IRAC bands and also in MIPS 24 μm. This star appears to be deeply enshrouded in the surrounding molecular cloud. This shock also likely arises at the interface of the stellar winds from ov15-v13 and YSO 49. YSO 49 lies at a distance of 3.4 or 1.68 pc from ov15-v13.

YSO 129. The fourth bow shock is located further east of IRS 2 than YSOs 293 and 49. The driving star is YSO 129, which has an evolutionary classification of class III, indicating that it does not have an optically thick circumstellar disk, consistent with its SED in Figure 3. This object was identified as a YSO from its detection in the Chandra observation. The source was detected with 143 counts in the ACIS data, with \(N_{\text{H}} = 0.23 \pm 0.08 \times 10^{22} \text{ cm}^{-2}\) and \(kT = 1.27 \pm 0.16 \text{ keV}\). It is not a variable candidate. The star is detected at all 2MASS and IRAC wavelengths, but not at 24 μm. The bow shock is visible only at 8.0 μm and 24 μm—indicating that it is perhaps more evolved than the others or is located in a less dense medium where the shocked dust is not heated to as high a temperature. It may also indicate fine structure emission from a faster shock (Neufeld et al. 2006). Measurements of the fluxes at 3.6, 4.5, and 5.8 μm were also obtained but are comparatively very faint. This star’s bow shock is possibly interacting with NE20, a new candidate O star detected in the newly identified NE subcluster (cf. Section 3.3). However, while the projected two-dimensional orientation of the shock is consistent, the large distance, 3.96 pc, and the topography of the dust structures surrounding YSO 129 would imply that the shock may be due to interactions with the local ISM. The star is located in a region of diffuse X-ray emission, which appears to show extended jet-like emission at the star, see Figure 5. YSO 129 also illuminates a dense pillar of dust, which appears to be photo-evaporating, cf. Section 3.2.

YSO 803. The last of the five bow shocks is visible only at 24 μm and is located further to the southeast (SE) of the central RCW 38 cluster than the other shocks, in a region at the edge of the illuminated cloud. The driving star was not identified as a YSO in Paper 1; its SED does not show any indication of excess emission in the mid-IR bands indicating that it could be a class III diskless member. It is outside the field of view of the Chandra observation hence its X-ray flux could not be measured. The star YSO 803 is detected in 2MASS and the three shorter IRAC bands, the emission at 8.0 μm was extended. Measurements of the flux of the bow shock were obtained at 5.8, 8.0, and 24 μm, though the flux at 5.8 μm is very faint. The detection only at longer wavelengths may suggest that this shock has a higher velocity than the other four, as evidenced by fine structure emission at 24 μm (Neufeld et al. 2006). This bow shock may also be interacting with the winds from the candidate O-star NE20, though the distance of 16’ or 8 pc means that even a small difference to the orientation of the bow shock will miss the star, we therefore conclude that this star is also interacting with the ISM or ambient cluster medium.

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