The Evolving ISM in the Milky Way & Nearby Galaxies

A Large Infrared Shell Structure Associated with the Symbiotic Star BI Crucis

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ABSTRACT

Spitzer IRAC and MIPS images reveal a large dust emission feature ∼6 arcmin in diameter which appears to be a shell in close proximity to, and perhaps physically related to, the D-type Mira symbiotic BI Cru. Smaller optical lobes are already known to be emanating from some symbiotics including BI Cru. However, this is the first extended structure found in the IR which is associated with a symbiotic Mira system. The IR shell of BI Cru is more than five times larger in arc size than the star's optical lobe. Published distance estimates imply that the IR shell is ∼4 to ∼8 pc in diameter, which is larger than the largest optical lobe known to be associated with any Mira symbiotic system. The large disparity between its IR and optical shell sizes, along with what appear to be multiple intersecting arcs, suggest that BI Cru has undergone multiple mass-loss episodes. A trend of rapidly increasing brightness toward longer wavelengths, along with a much more diffuse structure at 70μm than at shorter wavelengths, and suggests a greater abundance of relatively colder and older dust which may be the remnant of earlier mass outflows.

Subject headings: stars: symbiotic — stars: individual[BI Crucis] — infrared: ISM — ISM: dust — ISM: structure

1. Introduction

BI Crucis is a symbiotic star (Henize & Carlson 1980) with strong Hα emission (Henize 1976), consisting of a Mira variable (Allen 1974) and a hot compact object, classed as a D-

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type (dusty) symbiotic (Rossi et al. (1988)). Schwarz & Corradi (1992) discovered a large, clumpy, optical bipolar nebula associated with BI Cru which extends to ∼80 arc seconds from the star in [N II] (Corradi & Schwarz (1995)) and in [O III] (Schwarz & Corradi 1992). Optical nebulae around symbiotic Miras are common. A literature survey by Corradi et al. (1999a) found that about 40% of Mira symbiotics have extended ionized nebulae which range in size from a few arcsec in diameter to 150 arcsec, the largest known so far being that of BI Cru, and which have a variety of morphologies. However, before now, no structured, extended IR emission has been detected associated with a symbiotic Mira.

2. Observations

We used *Spitzer* (Werner et al. 2004) archival data from two Spitzer Legacy surveys: GLIMPSE (Benjamin et al. 2003), which utilized IRAC (Fazio et al. 2004), and MIPSGAL (Carey et al. (2005), which used the MIPS detector (Rieke et al. 2004). The IRAC obtains images at bandpasses centered on 3.6, 4.5, 5.8, and 8.0μm with a field of view of 5.21×5.21 arcmin^2 in each image. Additional processing by the GLIMPSE team produced final image mosaics with pixel sizes of 0.6×0.6 arcsec^2. In addition, we obtained MIPS 24μm and 70μm images as part of our own guest observer study of symbiotic stars.

3. Characteristics of the IR Emission

The IRAC and MIPSGAL images all reveal arcs of IR emission delineating a slightly ovoidal shell ∼6 arcmin in diameter. The main shell falls directly across BI Cru, with smaller partial arcs visible in some places (Figure 1).

Churchwell et al. (2006, 2007) reported detailed *Spitzer* imaging of almost 600 partial and closed "bubbles" in the galactic plane. Upon examining the archival data, we discovered that the edge of one such shell spatially overlaps BI Cru. Churchwell et al. (2006, 2007) report this shell as having an unknown origin, and do not note its proximity to BI Cru. The IRAC shell adjacent to BI Cru is listed as S174 in the catalog of Churchwell et al. (2006, 2007). Churchwell et al. (2006) do not discuss this shell specifically apart from its catalog notation, and no MIPS image has been published.

Relatively little extended emission is apparent at 3.6μm and 4.5μm, but part of a ring is visible connecting with BI Cru. In the 5μm and 8μm bands, complex IR-emitting structures are seen including multiple intersecting arcs. The IRAC resolution is about four times higher than that at 24μm and nine times higher than that at 70μm, but emission of the same diameter and roughly the same structure is seen in both MIPS and IRAC images. The longer-wavelength emission is more irregular but remains within the outer boundary of the shell which is delineated in the IRAC wavelengths. The location to the southwest of BI Cru is consistent with the axis of the small-scale optical bi-polar ejecta at P.A = -149^{o} shown by Schwarz & Corradi (1992). A comparison of optical and IR features within 10 arcsec of BI Cru is not possible because Schwarz & Corradi (1992) used a 20 arcsec occulting disk to cut out light contamination from BI Cru. Some fainter, more diffuse emission is seen north and east of BI Cru at 8μm, but any IRAC images near the Galactic plane are typically contaminated by emission from interstellar clouds (Benjamin et al. 2003), so the faint emission northward, because it is not clearly structured or strikingly brighter than the ISM nearby, cannot confidently be attributed to something besides the ISM.

The 24μm emission (Fig. 2) is clumpier and more diffuse than at the IRAC wavelengths, but it still matches fairly well the overall spatial extent and location of the IRAC features including the outer boundary. A fainter, diffuse, somewhat rounded and lobe-like region of extended 24μm emission is visible on the northeast side of BI Cru where an opposing lobe might be expected, but it is uncertain whether this is the other part of a bipolar lobe or whether it is merely a bright patch of the ISM. As part of our own *Spitzer* program to observe symbiotic stars and search for smaller-scale ejecta from symbiotic stars, we obtained deeper 24μm and 70μm exposures on the north side of BI Cru, but those images revealed no extended emission which conclusively appears to be associated with BI Cru.

The 70μm MIPSGAL images (not shown) reveal emission which is both brighter and more diffuse than at shorter wavelengths. The 70μm emission falls within the outer boundary seen at shorter wavelengths, with a greater concentration of bright emission in the central parts than that seen in the IRAC images.

The 70μm flux densities of the extended material are mostly a few to several times greater than the 24μm flux densities, suggesting that there is larger quantity of colder and presumably older material. Flux densities of the brightest parts of the material increase from a few MJy/sr at IRAC wavelengths to over 200 MJy/sr at 70μm after rough estimates of the complex ISM background are subtracted. The extended material is typically a factor of a few brighter than the nearby ISM at all wavelengths. Because the spatially complex ISM background cannot be distinguished from IR-shell emission where the two sources overlap, our estimated IR-shell flux densities must be considered only approximate upper limits.

Although we refer to the overall BI Cru extended emission as a shell, it is seen that the emission becomes much more diffuse at 24μm and especially at 70μm, although it remains within the boundaries outlined by the short-wavelength shell. The fact that the interior of the shell tends to be filled in with substantial emission at 24μm and 70μm is difficult to reconcile with a simple shell-like distribution of dust.

4. Evidence for a Physical Association with BI Cru

There are several indirect and circumstantial reasons for thinking that this shell comes from material ejected from BI Cru. First, BI Cru is already known from its optical lobes to be a mass-ejecting system. Second, the axis of the optical lobes passes almost exactly through what appears to be the center of the IR shell, and rather closely matches the shell's semimajor axis if one accepts the estimate of Churchwell et al. that the shell is somewhat elliptical. Third, a literature and catalog search produces no reason to think that any other object in or on the shell is the sort of object which which could create such a shell, the other IR-bright objects on or near the shell in the *Spitzer* images being optically very faint and unstudied. Fourth, a chance association between a symbiotic Mira and a shell of $\sim$6 arc minutes in diameter is improbable, because Churchwell et all. (2006) find an average of about 1.5 shells per square degree in the region of the galactic plane surveyed and there are only a few hundred symbiotic systems known in the entire sky.

5. Age and Size of the Shell

Rossi et al. (1988), using IRAS fluxes, estimated the distance to BI Cru to be $\sim$2000 pc. However, the bright extended emission we have found near the star at scales much smaller than the IRAS resolution implies that there may have been a large non-stellar contribution to flux in the IRAS 12μm bandpass ($\sim$8 - 15μm; Neugebauer et al. (1983). This would not have been properly taken into account in the distance scaling from IR brightness or in the IR SED modeling of the system. Whitelock et al. (1983) estimated its distance to be $\sim$4400 pc using the Mira period-luminosity relationship, which may be a more accurate distance value because the IR luminosity used would not have been affected by unresolved emission from the shell. A distance of 4400 pc would imply that the BI Cru IR arc is $\sim$8 pc in diameter. The largest optical ionized nebula known around a symbiotic is $\sim$1 pc in diameter.

Although bipolar PNe are different in origin from the observationally similar bipolar nebulae associated with symbiotic systems (e.g. Corradi et al. 1999b), the possible connections between bipolar PNe and symbiotics are still being studied (e.g. Balick (2003)), so we note that the estimated optical diameters of 43 known bipolar PNe are roughly similar ($\sim$0.5-1.8 pc) to that of the BI Cru shell (Corradi & Schwarz (1995). Corradi & Schwarz (1995) attributed the large sizes of the PNe to the high expansion velocities in those systems.

Optical images (e.g. Schwarz & Corradi (1992)) show large, clumpy emission condensations at several wavelengths, where radial velocities from nebular emission indicate rapid expansion, $v_{exp} \sim$ -210 km s^{-1}. Henize & Carlson (1980) found that the BI Cru optical ejecta have a velocity of ∼461km s^{-1}. These are among the highest known expansion velocities of such nebulae (Corradi 1993). If we assume the expansion velocity of the the IR shell has consistently been ∼461km s^{-1}, then we would infer a lower limit to its age of of $t_{dyn} \geq 15 \times 10^3$ yrs. In comparison, Corradi et al. (1999b) estimate the age of the optical nebula of BI Cru to be 2000 yr.

Our estimated lower limit of the age of the IR shell assumes that the region interior to the shell was already empty of gas and dust so that the observed IR shell material has not been slowed by interactions. In reality, the region through which the shell has passed might already have contained some material from previous outbursts, or instead might have been swept clear of material because of a previous mass ejection. Several symbiotics have been found to have jets having velocities of hundreds of km s^{-1} to well over 1000 km s^{-1}, (Brocksopp et al. 2004 and references therein). However, the cause of outbursts in classical symbiotics is not well understood. It is not known whether all outbursts from the same object should have the same initial velocity, whether high-velocity jets result in significant mass loss, how much mass loss results from symbiotic mass outflows over the lifetime of a system, or whether they they all at some point produce large extended structures.

6. Summary

Spitzer IRAC and MIPS images reveal a bright, slightly elongated, shell-like region of dust ∼6 arcmin in diameter which apparently connects with BI Cru and which probably originates from that system. The shell extends more than five times farther from the star than does the optical lobe. The two published distance estimates of BI Cru imply that the shell, if those estimates are correct, has a physical diameter of ∼4 pc or ∼8 pc. Although optical mass ejection features are known to exist with a large fraction of D-type symbiotic systems, this is the first extended IR structure to be discovered associated with any symbiotic. The estimated distance of BI Cru implies that the outer edge of the IR lobe is slightly larger than the largest optical lobe known with a symbiotic. The expansion velocity of the IR shell is unknown, but if its velocity is assumed to be the same as smaller optical lobes presently being ejected from BI Cru, then the shell's dynamical age is $\geq 15 \times 10^3$ yrs, which is ∼8 times longer than the estimated age of the optical lobes. The structure's brightness increases from shorter to longer wavelengths, by a factor of ∼10-20 from 3.6μm to 70μm, which suggests that there is substantially more cold dust than warm dust present.

This work is based on observations made with the *Spitzer Space Telescope*, which is operated by the Jet Propulsion Laboratory (JPL), California Institute of Technology under NASA contract 1407. Support for this work was provided by NASA and through JPL Contract 1255094.

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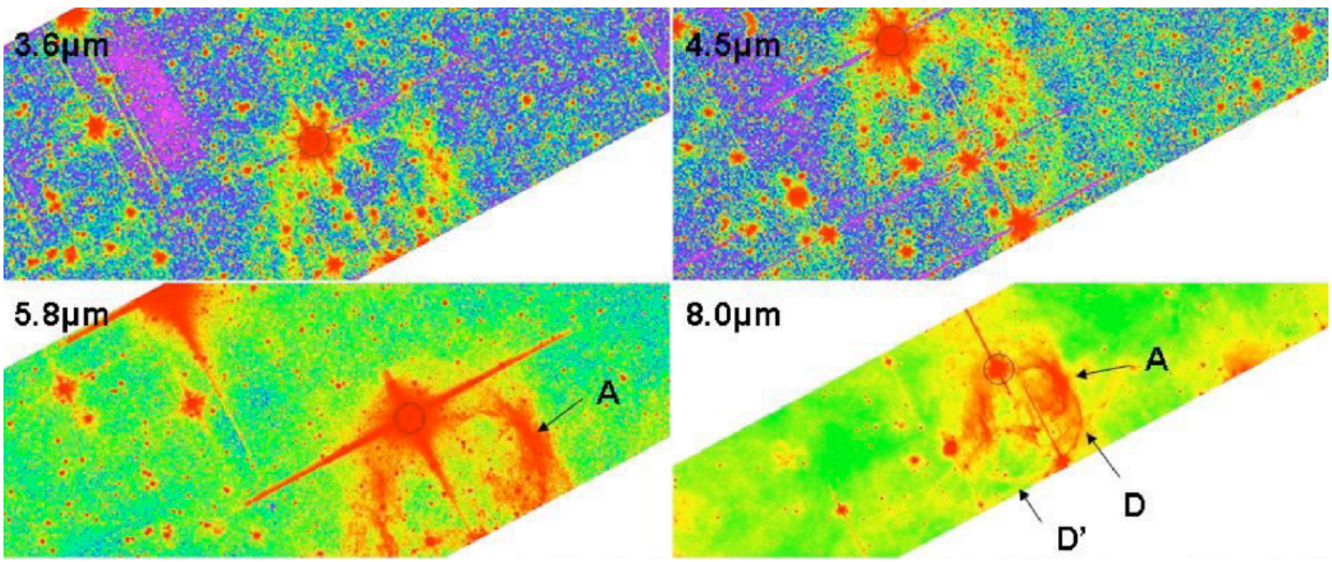

Fig. 1.— BI Cru shell in IRAC images. North is up, east is left. Feature A indicates overlapping arcs which form the brightest part of the shell and which suggest a history of multiple mass ejections. Features D and D' indicate the outer boundaries of the shell. In the 8μm image, a somewhat symmetric region of enhanced brightness is seen on the opposite side of BI Cru from the main shell which is possibly a fainter counter-lobe, although there is little evidence of such an opposing structure on this side of the star visible at other *Spitzer* wavelengths except possibly at 24μm. The shell is $\sim$6 arc minutes across in all images.

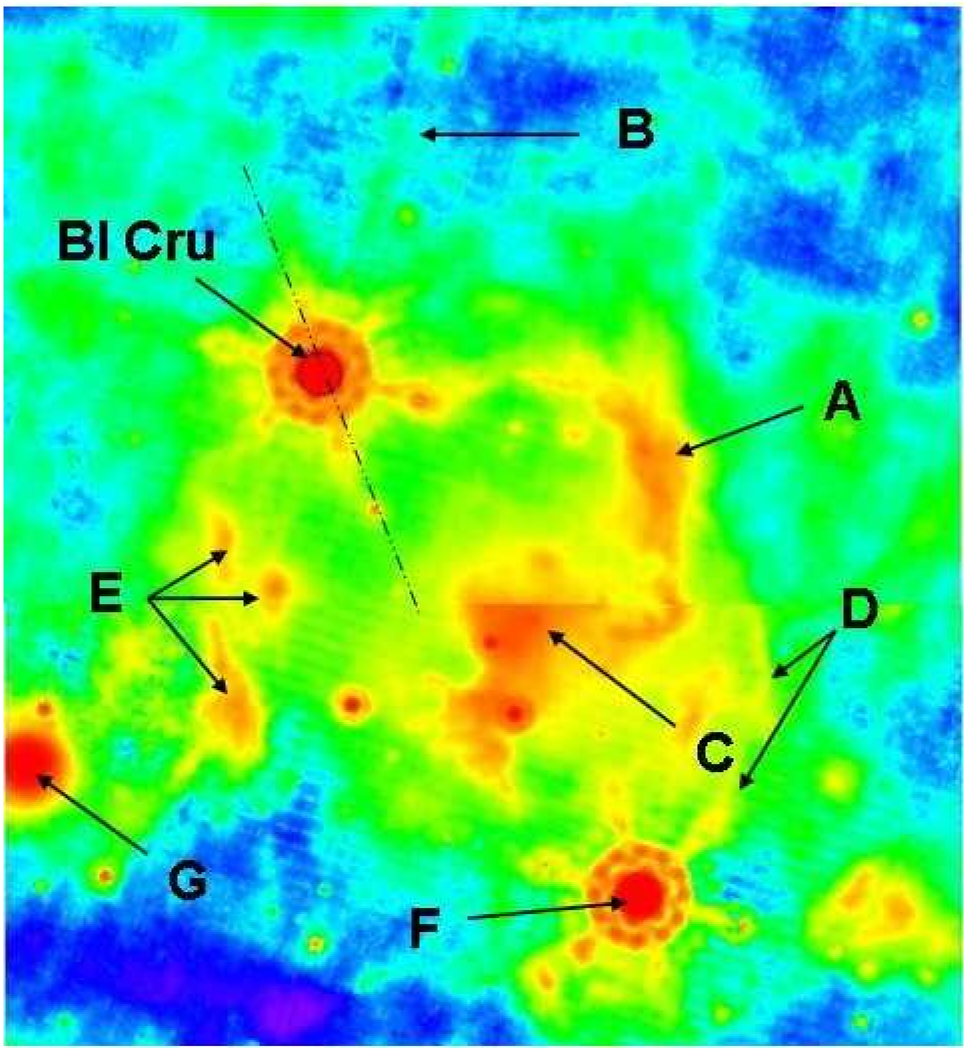

Fig. 2.— 24μm image of BI Cru shell. Features A, D, and E mark bright parts of the outer shell boundary. G and F are unrelated IR-bright but optically faint objects. C marks bright region near the center of the shell, where a similar bright region is visible at 70μm (not shown). B indicates an area of faint, somewhat arc-like emission on the opposite side of the main shell, which could be parts of a fainter shell but which is much more difficult to distinguish from what could be unrelated emission from the ISM background. The dashed line shows the position angle of the smaller optical lobes of BI Cru.