A GLIMPSE of Possible Mid-Infrared Bowshocks Using the Spitzer Space Telescope

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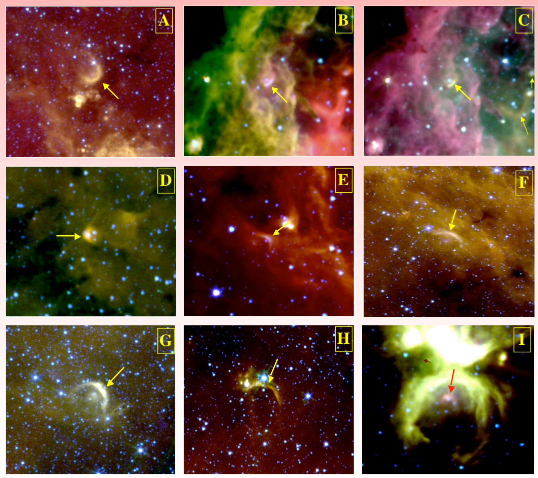
Abstract: We present images of several bowshock-shaped structures discovered as part of GLIMPSE, a Spitzer Legacy project using IRAC to map the inner Galactic plane. Analysis is presented of the first two objects discovered in the vicinity of RCW49. These objects are coincident with IRAS point sources: IRAS 10205-5729 and IRAS 10227-5730. MSX observations indicated that these sources were extended; the high angular resolution afforded by Spitzer Space Telescope show that the emission arises from bowshock shaped structure. 2MASS, Spitzer, MSX and IRAS observations are used to obtain the spectral energy distribution of these objects. We discuss how the morphology of these structures can be used constrain the density and velocity of both the stellar wind and the ambient interstellar medium. The discovery of several bowshock candidates using IRAC/Spitzer, and the recent Gemini discovery of a similar structure in the H and K bands towards the Galactic center source IRS 8, suggest that there may be many more detections of infrared stellar bowshocks yet to come.

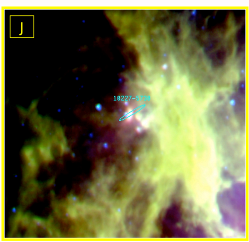
GLIMPSE and Serendipity

GLIMPSE (*Galactic Legacy Infra-Red Midplane Survey Extraordinaire*) is a Spitzer Space Telescope Legacy Project to map the inner Galactic plane from |*l*|= 10-65° and |b|<1° using IRAC. A point source catalog, point source archive, and mosaicked image are being produced by the GLIMPSE team, and will be released through the *Spitzer Science Center*. The two principal goals of GLIMPSE are to study the stellar structure of our Galaxy and to characterize star formation in the inner Galaxy. However, given the large amount of extinction in the Galactic plane, it was expected that GLIMPSE would turn up unexpected sources. So far this has included a new globular cluster candidate (Kobulnicky et al. 2004) and new planetary nebulae (Cohen et al. 2005). Here, we report a new class of unexpected sources: infrared bowshocks.

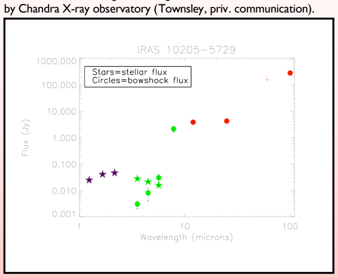
We have searched 40 square degrees of the GLIMPSE region for diffuse emission with bowshock morphology and have identified 16 candidate bowshocks. Eleven of the candidates are shown here.

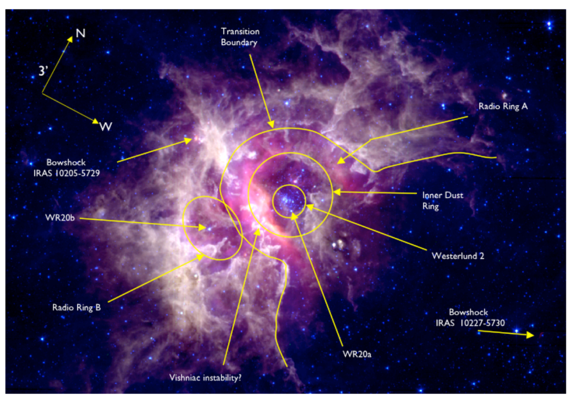


A subset of bowshock candidates identified using the *GLIMPSE* survey. All images are made with blue=4.8 μm, green=5.6 μm, and red=8.0 μm, with a difering bias and constrast levels set to highlight the bowshock structures.



IRAC image of bowshock associated with IRAS 10205-5729 (above) and spectral energy distribution (below). The location of the bowshock with respect to RCW 49 is shown in the image to the right. The associated star has also been detected by Chandra X-ray observatory (Townsley, priv. communication).





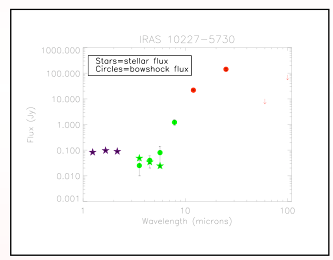
Spitzer/IRAC image of RCW49 from Churchwell et al. 2004. Radio continuum studies and a lack of Br α emission (in the IRAC [4.5 μm] band) indicate that over-pressured gas in the star formation region has broken out to the west (lower right). This outflow mass may be interacting with the stellar wind associated with IRAS 10227-5730.

Comments about bowshock candidates

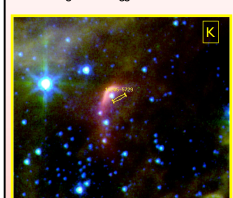
• Many (but not all) bowshocks seem to be located near large star formation regions (SFR), particular the smallest and brightest sources. The associated star formation regions are shown in the table below.

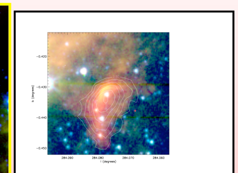
• All but one of the bowshock candidates not associated with large star formation regions are associated with IRAS point sources. We suspect that these may be bowshocks associated with ultracompact HII regions.

Figure	l	b	Assoc SFR	Associated sources
A	10.620	-0.320	—	IRAS18072-1954
B	15.081	-0.657	M17	—
C	15.103	-0.649	M17	—
D	25.628	-0.107	—	IRAS18357-0635
not shown	30.641	-0.114	W43	—
K	284.077	-0.432	RCW49	IRAS10205-5729
not shown	284.301	-0.371	RCW49	—
J	284.340	-0.283	RCW49	IRAS10227-5730
E	311.042	0.373	RCW82	—
F	312.387	-0.057	—	IRAS14081-6112
not shown	313.586	-0.050	—	—
G	313.600	-0.514	—	IRAS14189-6115
H	321.113	-0.270	—	—
I	328.574	-0.550	RCW99	—



IRAC image of bowshock associated with IRAS 10227-5730 (below) and spectral energy distribution (above). Countour overlay of the MSX 20μm emission from this source indicate that the bowshock morphology can be seen out to longer wavelengths and suggest that the IRAS flux also comes from this structure.





Stellar Bowshocks in Star Formation Regions: Probes of Momentum flux

The two bowshocks in RCW49 shown above, IRAS 10205-5729 and IRAS 10227-5730, seem very likely to be individual stellar bowshocks, similar to the stellar bowshocks detected in optical line emission around stars like LL Ori in the Orion Nebula (Bally et al. 2000). The standoff distance between the star and the bowshock are d_s=0.11 ± 0.01 pc (IRAS 10205-5729) and d_s=0.12 ± 0.01 pc (IRAS 10227-5730) assuming they are at the distance of RCW49 (assumed to be 4.2 kpc, see Churchwell et al 2004). Analytical models of "thin" stellar bowshocks have been calculated both for a symmetric stellar wind (Wilkin 1996) and an asymmetric wind (Wilkin 2000), and a comparison of these models to our data will allow us to estimate the inclination of the position vector connecting the star to the apex of the bowshock to our line of sight. Here, we assume that this position vector is in the plane of the sky.

The standoff distance is determined by balancing the momentum flux of the stellar wind with the momentum flux of the ambient medium with respect to the star. If we assume an isotropic stellar wind and the cluster flow covering a solid angle, Ω, are interacting, we can write

$$\dot{M}_{cl} v_{cl} = \left(\frac{\Omega}{4\pi}\right)\left(\frac{d_{cl}}{d_w}\right)^2 \dot{M}_w v_w$$

The IRAS 10227-5730 bowshock is located 5" from the star, and 540" from the center of the Westerlund 2 cluster (located at the center of RCW49), yielding d_d/d_s=110. If we assume that the outflow velocity from the cluster is v_{cl}=100 km/s (approximately the sound speed of a 10^6 K gas), we can relate the cluster mass loss rate to the stellar parameters. Typical stellar products of stellar ($M_{dot}v$) range from 10^{-6} (cool stars) to 10^{-4} (M_o/yr)·(km/s) (hot O stars), yielding a range for the cluster mass loss rate of 1.2 x 10^{-4} to 1.2 x 10^{-2} M_o/yr. Unfortunately, we currently do not have spectrum that constrains the outflow velocity and mass loss rate of the bowshock stars. With this additional information, these stellar bowshocks will become a powerful probe of the velocity structure of the ISM in star formation regions.

Energetics and Emission mechanism for Infrared Bowshocks

Near infrared (JHK) studies of far IR sources near Galactic center using the Gemini 8m telescope (Geballe et al. 2004) and the Keck 10m telescope (Tanner et al. 2005) have recently shown that some of these sources also have a bowshock morphology. K-band spectra of IRS8 by Geballe *et al.* show a featureless continuum climbing steeply with increasing wavelength, reminiscent of the SED we find for our bowshocks. On the other hand, on the basis of near infrared polarization, Tanner *et al.* argue that reflected stellar continuum could significantly contribute to the 2.2 micron K band emission. An examination of the emission mechanism for our mid-IR, and the use of these bowshocks as a "calorimeter" for the energy flux of the two colliding flows will be presented in an upcoming paper.

ACKNOWLEDGEMENTS

We are grateful to support to RAB at UW-Whitewater through NASA contract 1224653, as part of the Spitzer Space Telescope Legacy Program, and the work of Stephan Jansen to maintain the GLIMPSE computer network. This research has made use of the SIMBAD database (operated at CDS, Strasbourg, France), the NASA/IPAC Infrared Science Archive(operated by the Jet Propulsion Laboratory, California Institute of Technology under contract with NASA), ds9 (developed at the Harvard-Smithsonian Center for Astrophysics), and has made use of data products from the Midcourse Space Experiment (processing funded by the Ballistic Missile Defense Organization with additional support from NASA Office of Space Science).

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