Asociación Argentina de Astronomía
BAAA, Vol. 55, 2012
A.C. Rovero, G.E. Romero, L. Pellizza & M. Lares, eds.

PRESENTACIÓN MURAL

Energetics of nearby stellar bow shocks

Paula Benaglia[1,2]

(1) Instituto Argentino de Radioastronomía (CCT-La Plata, CONICET)
(2) Facultad de Ciencias Astronómicas y Geofísicas (FCAG, UNLP)

Abstract. The latest survey of stellar bow shocks (Peri et al. 2012, A&A, 538, 108) lists 28 candidates detected at IR wavelengths, associated with massive, early-type stars up to 3 kpc, along with the geometrical parameters of the structures found. I present here some considerations on the energetics involved, after the estimation of stellar wind power, infrared flux, stellar bolometric luminosity and radio flux limits for each source. The best candidates for relativistic particle acceleration are highlighted.

Resumen. Se consideran los candidatos a *bowshocks* listados en el relevamiento E-BOSS.v1 (Peri et al. 2012, A&A, 538, 108). Tomando como base los datos allí publicados, se calcula la luminosidad del viento, la luminosidad bolometrica de la estrella, la luminosidad correspondiente al flujo WISE medido, y la luminosidad a 1.4 GHz. Se discute la posibilidad de que alguno de los candidatos a bowshocks sea un sitio de aceleración de partículas a velocidades relativistas, con la consiguiente eventual emisión a altas energías.

1. Introduction

Runaway stars move with a speed larger than that of the average of the surrounding media, and tend to sweep the material found in the direction of motion. Ideally, the piled-up matter resembles a bow shock, larger for stars with strong winds. The first systematic search for bow shocks was carried out using the 1988 IRAS database (see Noriega-Crespo et al. 1997 and references therein). The authors listed $\sim$ 60 nebulosity sources around early-type stars, some arcmins in size. The advenement of new IR missions like Spitzer or WISE (2011) produced images at the arcsec resolution, and allowed not only to check former results but to address a much deeper search for stellar bow shocks.

With the help of the Tetzlaff et al. (2010) catalogue of runaway stars up to 3 kpc, we carried out a study to look for signatures of WISE emission (Wright et al. 2010) towards all nearby O-B2 stars. The results were compiled in the Extensive stellar BOw Shock Survey, version 1 (E-BOSS.v1, Peri et al. 2012), that lists and describes $\sim$ 30 bow shocks.

Very recently, Benaglia et al. (2010) analyzed the possibility that stellar bow shocks can give rise to high-energy emission, by studying the surroundings of the O supergiant BD+43°3654. We thus seeked for low-frequency radio emission from E-BOSS.v1 candidates, that could be indicative of synchrotron radiation from the stellar bowshocks, with the New VLA Sky Survey (Condon et al. 1998, 1.4 GHz). We found three new radio sources possible associated with E-BOSS candidates (Peri et al. 2012). Some comments on how common and under which conditions stellar bow shocks could be high energy emitters are presented here.

2. Bow shocks as acceleration sites

The bow shock of BD+43°3654 is the prototype of the non-thermal runaway stars. It has been observed with the VLA at two frequencies (L and C band), and the spectral index distribution showed average values $\alpha \sim -0{,}4$ ($S \propto \nu^{\alpha}$), characteristic of synchrotron radiation. Benaglia et al. (2010) proposed for the first time that a stellar bow shock can host relativistic particles also involved in high-energy emission processes, and built a zero-order SED that fits the radio emission and predicts the detectability at shorter wavelengths.

The powerful stellar winds of the early-type stars interact with the ambient medium creating two shocks, separated by a discontinuity: a forward shock with a velocity near the stellar one, and a reverse one fast as the stellar wind (see Benaglia et al., these Proceedings).

Del Valle and Romero (2012) improved the basic model, and applied it to the case of ζ Oph, concluding that the gamma-ray emission would be weak –if compared with other non-thermal emitters- but still detectable by forthcoming instruments like the Cherenkov Telescope Array.

The luminosities involved in the phenomenon can be estimated if the main variables of the star+bow shock systems are known. The E-BOSS.v1 database comprises stellar and bow shock parameters, like the stellar distance d, the wind terminal velocity $v_{\rm wind}$, the stellar mass loss rate $\dot{M}$, the tangential and radial stellar velocities, the stand-off distance R_0 and the original ambient density $n_{\rm ISM}$ at the position of the star, of each candidate.

3. Luminosities

Table 1 lists information on the stellar bow-shock candidates compiled in E-BOSS.v1, related with 28 OB stars. References on spectral types, distances - including error bars- and wind terminal velocities are given in Peri et al. (2012). Stellar velocities were computed from radial and tangential velocities. Distance values derived from parallax measurements, and stellar velocities computed from radial velocity information and proper motions are flagged. The large uncertainties in some stellar distances introduce important errors in v_*, R_0 and $n_{\rm ISM}$. The stellar luminosities are from Martins et al. (2005) and Benaglia et al. (2007).

The luminosity of the stellar wind is $L_{\rm wind} = 0{,}5\dot{M}(v_{\rm wind})^2$, and represents the available kinetic power. To ensure that the flow is compressible and shocks can develop, the magnetic energy density must be in subequipartition with respect to the kinetic energy $L_{\rm wind}$. In this case, the value of the magnetic field intensity in the flow can be expressed as $B^2/8\pi = L_{\rm wind}/(v_{\rm wind}4\pi R_0)$ (del Valle & Romero 2012). The authors considered that only a small fraction of the kinetic power available goes into relativistic particles $L_{\rm rel}$, and adopted a 10 % factor.

The infrared luminosity was estimated by measuring the WISE flux averaged over the extension of the bow shock, subtracting the background contribution, and applying the conversion factors (see wise2.ipac.caltech.edu).

The bow-shock candidates that correlate with NVSS emission are HIP 11891, HIP 38430, HIP 88652 and BD+43°3654. Their radio luminosity was derived by measuring the corresponding flux. For the rest of the candidates, an upper limit of $3\sigma = 3$ rms for the NVSS radio flux density was assumed.

Both $L_{\rm WISE}$ and $L_{\rm NVSS}$ will also be affected by large distance uncertainties. Distance errors of 50 %, for instance, corresponds to a factor 5 in luminosities.

4. Discussion

The results presented in Table 1 allow to draw some conclusions in regards with the emission mechanisms acting at the different bow shocks. The Hipparcos stars # 24575, 97796 and 114990 stand out with larger stellar velocities. The first one was studied at X-rays by López Santiago et al. (2012), who proposed the stellar bow shock as the first X-ray non-thermal emitter.

The faster stellar winds will be more efficient accelerators of relativistic particles, since the acceleration efficiency $\eta \propto (v_{\rm shock}/c)^2 \sim (v_{\rm wind}/c)^2 \leq 10^{-4}$.

IC scattering will be favoured wherever the infrared photon field is strong, i.e., for stars with larger $L_{\rm WISE}$. In the stellar bow-shock scenario, the stellar UV photon field is not relevant to IC, due of the large separation from the star.

According to Del Valle & Romero (2012), electron synchrotron losses dominate above relativistic Bremsstrahlung. Convection governs proton losses.

A crucial factor for high-energy emission detection is the distance to the star+bow shock system, as the luminosity decays with d^2.

Finally, the presence of significant radio emission at low frequencies (like 1.4 Ghz) is a very strong hint to look for relativistic particles. For those objects, observing campaigns at two or more radio frequencies should be implemented, in full polarization mode if possible, to study the radiation regime. If evidence of synchrotron emission is found, the conditions mentioned above can help to disentangle the importance of the different contributions to high energy emission.

Acknowledgments. P.B. is always grateful to G.E. Romero for useful discussions, and thanks C.S. Peri for comments, and PICT 00848-2007, ANPCyT.

Referencias

Benaglia, P., Vink, J. S., Martí, et al. 2007, A&A, 467, 1265

Benaglia, P., Romero, G. E., Martí, et al. 2010, A&A Lett, 517, 10

Condon, J. J., Cotton, W. D., Greisen, E. W., et al. 1998, AJ, 115, 1693

Del Valle, M. V. & Romero, G. E. 2012, A&A, 543, 56

López-Santiago, J. Miceli, M., del Valle, M. V., et al. 2012, ApJ Lett, 757, 6

Noriega-Crespo, A., van Buren, D., Dgani, R. 1997, AJ, 113, 780

Peri, C. S., Benaglia, P., Brookes, D., et al. 2012, A&A, 538, 108

Tetzlaff, N., Neuhausser, R., Hohle, M. M. 2010, MNRAS, 410, 190

Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al. 2010, AJ, 140, 1868

Star	Sp.type	d (kpc)	$n_{\rm ISM}$ (cm^{-3})	R_0 (pc)	v_* (km/s)	$v_{\rm wind}$ (km/s)	L_* log	L_w (erg	$L_{\rm WISE}$ /	$L_{\rm NVSS}$ s)
HIP 2036	O9.5III+...	0.76±0,16	130	0.22	16.0	1200	38.7	35.3	36.6	<27.5
HIP 2599	B1 Iae	1.50±0,30	0.4	1.27	26.3	1105	39.0	34.7	37.5	<28.0
HIP 11891†	O5 V((f))	0.40±0,15 (1)	17	0.12	49.5	2810	38.1	36.4	34.9	30.3
HIP 16518	B1 V	0.65±0,16 (1)	0.2	0.13	53.5	500	39.1	32.7	37.2	<27.3
HIP 17358	B5 III	0.15±0,10 (1)	600	0.04	(2) 35.2	500	38.0	31.9	35.5	<26.1
HIP 22783	O9.5 Ia	1.60±0,30	0.02	4.67	(2) 52.4	1590	39.2	35.3	37.1	<28.1
HIP 24575	O9.5 V	0.55±0,07	3	0.06	152.0	1200	38.3	34.7	35.0	<27.2
HIP 25923	B0 V	0.90±0,20 (1)	1	0.39	24.2	1000	38.1	34.3	35.8	<27.6
HIP 26397	B0.5 V	0.35±0,15 (1)	2	0.10	22.4	750	38.1	33.4	34.6	<26.8
HIP 28881	O8 Vn	1.5 :	0.3	1.85	(2) 17.7	2070	38.5	34.6	36.2	<28.1
HIP 29276	B1/2 III	0.40±0,03 (1)	0.003	0.23	32.0	600	37.8	32.1	35.6	<26.9
HIP 31766	O9.7 Ib	1.40±0,03	0.03	0.82	58.8	1590	39.1	35.9	37.2	<28.0
HIP 32067	O5.5V((f))+...	2.10±0,40	0.1	1.85	38.8	2960	39.0	35.6	37.3	<28.4
HIP 34536	O6.5V((f))+...	1.30±0,20	0.01	1.5	59.7	2456	38.8	35.6	37.7	<27.9
HIP 38430†	O6Vn+...	0.9 : (1)	60	0.13	(2) 30.9	2570	38.9	36.2	35.7	31.3
HIP 62322	B2.5 V	0.11±0,004 (1)	0.04	0.03	42.2	300	37.9	32.2	33.8	<25.4
HIP 72510	O6.5III(n)(f)	0.35±0,18 (1)	0.2	0.15	74.4	2545	39.1	35.7	34.2	<26.8
HIP 75095	B1Iab/Ib	0.80±0,50 (1)	40	0.12	28.9	1065	39.0	34.7	35.8	<27.5
HIP 77391	O9 I	0.8 : (1)	30	0.23	(2) 24.2	1990	39.2	35.5	37.3	<27.5
HIP 78401	B0.2 IVe	0.22±0,02	2	0.39	(2) 38.6	1100	37.8	34.7	36.8	<26.4
HIP 81377	O9.5 Vnn	0.22±0,02	1	0.32	28.6	1500	38.3	34.2	35.3	<26.4
HIP 82171	B0.5 Ia	0.85±0,12	1	0.17	84.6	1345	39.1	34.7	37.1	<27.6
HIP 88652†	B0 Ia	0.65±0,30 (1)	2	0.28	31.1	1535	39.0	35.6	35.9	30.1
HIP 92865	O8 Vnn	0.35±0,12 (1)	0.003	0.31	(2) 41.2	1755	38.5	33.6	34.6	<26.3
HIP 97796	O7.5 Iabf	2.2 :	0.02	3.84	(2) 110.4	1980	39.3	35.8	38.8	<26.8
HIP 101186	O9.7 Ia	1.50±0,40	0.1	1.73	35.8	1735	39.1	35.3	38.5	<28.4
BD+43 3654	O4 If	1.45± 0.05	0.2	1.48	(2) 67.7	2325	39.5	37.1	35.7	31.2
HIP 114990	B0 II	1.4 :	0.05	0.61	(2) 135.7	1400	39.0	35.6	35.2	<28.0

†: Potential gamma-ray emitters. They were chosen by IR luminosity, wind terminal velocity and NVSS flux.
(1): Stellar distances derived from parallaxes. (2): Stellar velocities derived from radial velocities and proper motions.
':': errors larger than 50 %.

Tabla 1. Stellar, wind and bow-shock luminosities of the 28 bow-shock candidates of Peri et al. 2012.