PROCEEDINGS OF SCIENCE

PoS(MQW7)093

Hydrodynamic Simulations of the SS 433-W50 Complex.

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The compelling evidence for a connection between SS 433 and W50 has provoked much imagination for decades. There are still many unanswered questions: What was the nature of the progenitor of the compact object in SS 433? What causes the evident re-collimation in SS 433's jets? How recent is SS 433's current precession state? What mass and energy contributions from a possible supernova explosion are required to produce W50? Here we comment on two of our 53 models: (i) featuring the SNR evolution alone, and (ii) the SNR combined with a simple jet model.

VII Microquasar Workshop: Microquasars and Beyond
September 1-5 2008
Foca, Izmir, Turkey

1. INTRODUCTION

SS 433 and the conch-shaped W50 nebula are located approximately 2° from the plane of the Milky Way disc (Fig.1), and together they form an intriguingly complex and turbulent environment. W50 spans over 200pc in length and features a circular bubble-like region, which is centred upon SS 433's coordinates to within $\sim$5 arcmins (Lockman et al. 2007). Additionally, the nebular axis of symmetry is coincident with SS 433's mean jet axis. Finally, radio observations confirm that the distances to both objects are approximately 5.5 kpc (Blundell & Bowler 2004, Lockman et al. 2007). Thus it is important to investigate the possibility that these two objects share a mutual evolution. It is feasible that the circular region in W50 has formed through mass ejection from a supernova explosion, or even through a strong stellar wind from SS 433's companion star or a wind from its disc. The East-West lobes of W50 may have formed via interaction between the jets and this ejecta. Under certain conditions, it is also possible for jets alone to produce the morphology displayed in W50. The East-West asymmetry of the lobes can be attributed to the gradient in the density of the ISM towards the Galactic plane (Fig.1). We have developed comprehensive models of these scenarios using the latest observational parameters for SS 433 and W50, and we implement these hydrodynamically using FLASH[1].

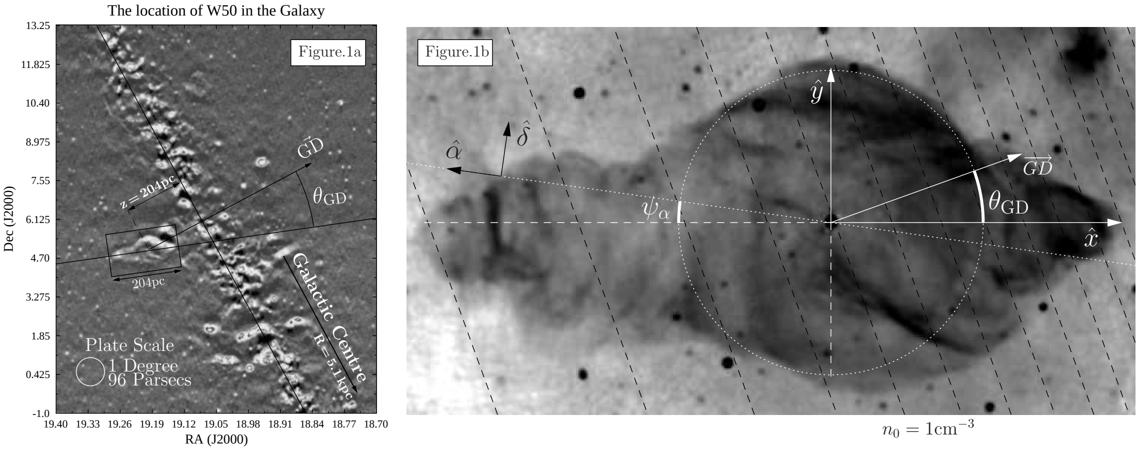

Figure.1 - (a) The location of W50 within the Milky Way, created using archival data from the GBT6 survey. (b) The orientation of W50 in our model as transformed from Dubner et al, (1998). An example of the Galactic density profile used in our model is indicated by the dashed black contour lines, with adjacent lines corresponding to changes in density of 0.25 particles cm^{-3}, and normalised to 1 particle cm^{-3} at SS 433.

2. METHOD

The field-of-view of our simulation has been chosen carefully to match that of the Dubner et al., (1998) image (see Fig.1), and we achieve a maximum spatial resolution $\Delta x = 0.014$pc on the

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[1] Courtesy of the University of Chicago Center for Astrophysical Thermonuclear Flashes: http://flash.uchicago.edu/website/home/

AMR grid. We create the local background environment of SS 433 and W50, using the Galactic density profile adapted from Dehnen & Binney (1998), according to:

$$\rho_{\rm ISM}(R,z) = \rho_{o_{\rm (ISM)}} \exp\left[-\frac{R_{\rm m}}{R_{\rm d}} - \frac{R}{R_{\rm d}} - \frac{z}{Z_{\rm d}}\right] \tag{2.1}$$

where the constant $R_{\rm m}$ = 4 kpc, $R_{\rm d}$ = 5.4 kpc is the scale length of the stellar disc, and $Z_{\rm d}$ = 40 pc is the scale height above the Galaxy disc. The temperature estimates across this region are taken from the observations of Lockman et al., (2007), and the temperature profile is adjusted to maintain hydrostatic equilibrium of the unperturbed background medium.

We then introduce a pre-Sedov supernova explosion within a radius $R_0 = f_{\rm r} R_{\rm Sedov}$ of the epicentre of the explosion (x_0, y_0), by adding an ejecta mass $M_{\rm ej}$ to this region, where $R_{\rm Sedov} = \left[\frac{3M_{\rm ej}}{4\pi\rho_0}\right]^{1/3}$ and $f_{\rm r} < 1$. We allow the SNR to evolve until it reaches $\sim$45 pc (the approximate size of W50's shell) as shown in Fig. 2 below:

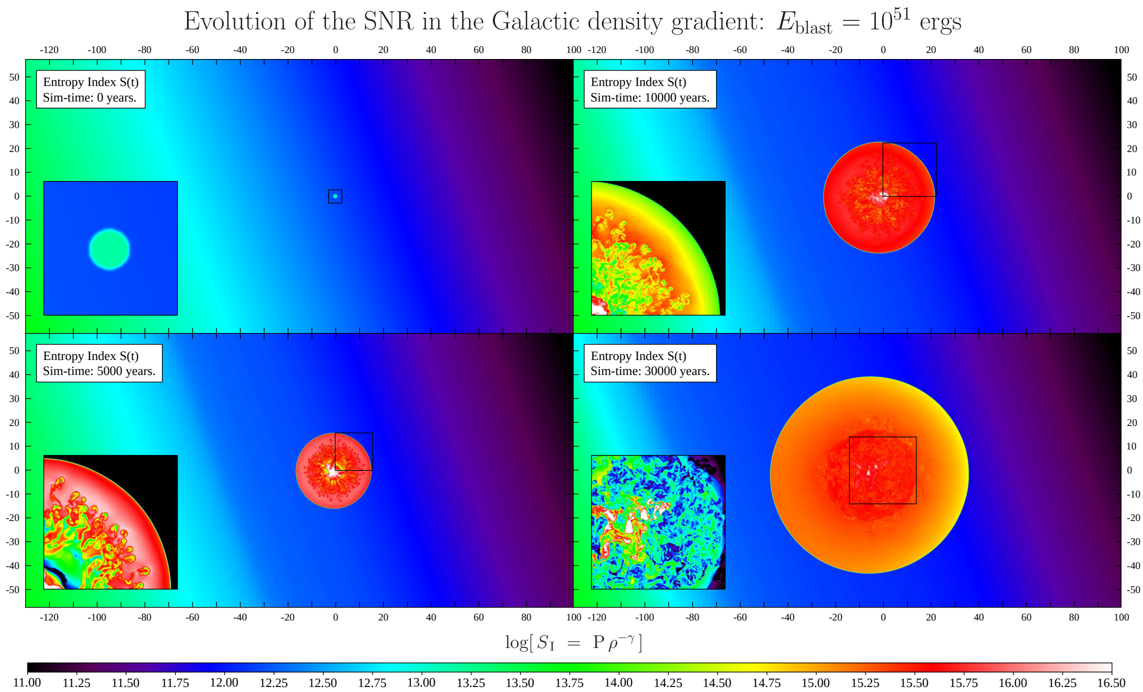

Figure.2 - Snapshots of the SN evolution with $E_0 = 10^{51}$ ergs, $f_{\rm r} = 0.25$ and $M_{\rm ej} = 5M_\odot$

This particular jet model consists of a simple cylindrical jet with a mass ejection rate of $10^{-4} M_\odot\,{\rm yr}^{-1}$. The jet temperature, density, energy and pressure are initialised for the jet injection-zone cells, which are set to the maximum resolution of the grid. This jet model does not include precession or orbital motion, and the jets have a velocity only along the x-axis, thus $v_{\rm x} = v_{\rm jet} = 0.26c$. The evolution of the jets and SNR are monitored within the simulation domain until the Eastern jet reaches approximately 120 pc. The results of this simulation (SNR+jets) are shown in Fig. 3.

3. RESULTS

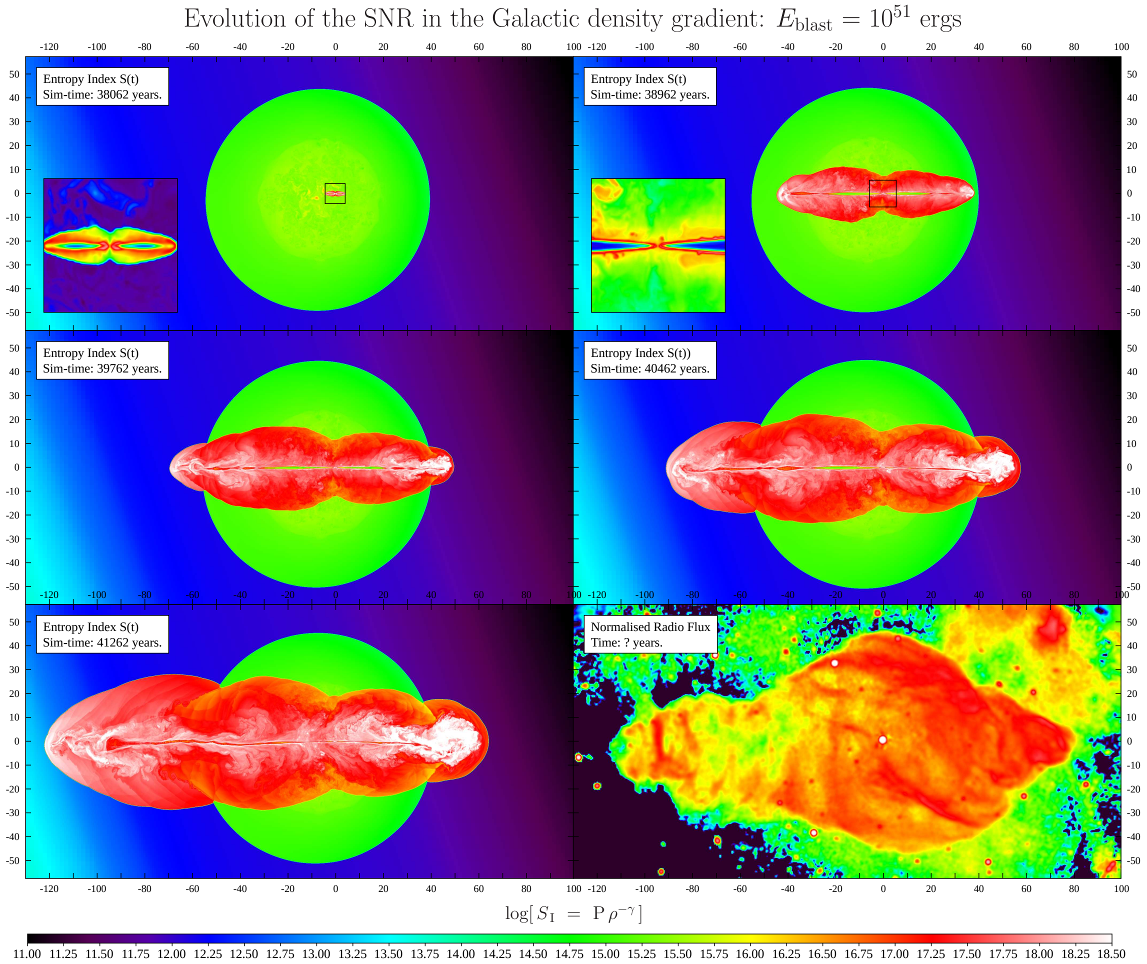

Figure.3 - Evolution of a 10^{51} erg supernova blast with non-precessing cylindrical jets, as described in the text.

4. SUMMARY

We present the results from two of our simulations. The first simulation involves a supernova remnant with blast energy 10^{51} ergs evolved to the characteristic size of W50's central circular shell. The second simulation features our most primitive jet model (no precession) in conjunction with the SNR from the previous simulation. For the SNR evolution alone, we observe a small increase in ellipticity due to the hydrodynamic evolution of the SNR in the Galactic exponential density profile. The SNR bubble also experiences a buoyancy effect, by which the focus of the SNR shell displaces from the origin of the explosion (x_0, y_0) as the SNR evolves. Although no precession is included in the jet model presented here, the resultant nebula from the SNR+jets simulation has dimensions and a morphology comparable to that of W50 from the Dubner et al., (1998) image as shown in Fig.3, and shows evidence of recollimation of the jet-shock upon exiting the SNR shell. Further work will include a full description of the jet precession and of the accretion disc wind.

References

[1] Abell, G. O., & Margon, B. 1979, Nature, 279, 701

[2] Begelman, M. C., Sarazin, C. L., Hatchet, S. P., McKee, C. F., Arons, J., 1980, ApJ, 238, 722-730,

[3] Dehnen, W., & Binney, J., 1998, MNRAS, 294, 429,

[4] Blundell, K. M., et al, 2001, ApJL, 562, L79,

[5] Blundell, K. M., & Bowler, M. G., 2004, ApJL, 616, L159

[6] Blundell, K. M., & Bowler, M. G., Schmidtobreick, L., 2007, A&A, 474, 903B

[7] Blundell, K. M., & Bowler, M. G., Schmidtobreick, L., 2008, ApJ, 678, L47-L50

[8] Brinkmann, W., Aschenbach, B., Kawai, N., 1996, A&A, 312, 306

[9] Brinkmann, W., Kotani, T., & Kawai, N., 2005, AAP, 431, 575

[10] Chevalier, R. A., & Gardner, J., 1974, ApJ, 192, 457

[11] Colella, P., Woodward, P., , 1984, J. Comp. Phys., 54, 115-173

[12] Collins, G W., Scher R, W., 2002, MNRAS, 336, 1011

[13] Crampton, D., Hutchings, J. B., 1981, ApJ, 251, 604

[14] D’Odorico, S., Oosterloo, T., Zwitter, T., Calvani, M., „ 1991, Nature, 353, 329

[15] Downes, A. J. B., Pauls, T., & Salter, C. J., 1986, MNRAS, 218, 393

[16] Dubner, G. M., Holdaway, M., Goss, W. M., & Mirabel, I. F., 1998, ApJ, 116, 1842

[17] Eikenberry, S. S., et al., 2001, ApJ, 561, 1027

[18] Elston, R., & Baum, S., 1987, ApJ, 94, 1633

[19] Fabian, A. C., Rees, M. J., 1979, MNRAS, 187, 13

[20] Fabrika, S., 2004, Astro. & Space Phys. Rev., 12, 1-99

[21] Fuchs, Y., Miramond., L, K., Ábrahám, P., 2006, A&A, 578, 1041

[22] Fryxell, B., Olson, K., Ricker, P., Timmes, F. X., Zingale, M., Lamb, D. Q., MacNeice, P., Rosner, R., Truran, J. W., Tufo, H., 2000, ApJ, 131, 273-334

[23] Gies, D R., Huang, W., McSwain, M. V., 2002, ApJ, 578, L67

[24] Goranskii, V. P., Esipov, V. F., & Cherepashchuk,A. M., 1998, Astronomy Reports, 42, 209

[25] Hillwig, T. C., et al , 2004, ApJ, 615, 422

[26] King, A. R., Taam, R. E., & Begelman, M. C., 2000, ApJ, 530, L25

[27] Kochanek, C. S., & Hawley, J. F., 1990, ApJ, 350, 561

[28] Lockman, C. S., Blundell, K. M., & Goss, W. M., 2007, ArXiv Astrophysics e-prints, arXiv:astro-ph/0707.0506v1,

[29] Lopez, L. A., Marshall, H. L., Canizares, C. R., Shulz, N. S., Kane, J. F., 2006, ApJ, 650,338-349

[30] Margon, B., Ford, H. C., Grandi, S., & Stone, R. P. S., 1979, ApJ, 230, L41

[31] Margon, B., & Anderson, S. F., 1989, ApJ, 347, 448

[32] Mazeh, T., Aguilar, L. A., Treffers, R. R., Konigl, A., & Sparke, L. S., 1983, ApJ, 265, 235

[33] Milgrom, M., 1979, A&A, 76, L3

[34] Mioduszewski, A. J., Rupen, M. P., Walker, R. C., Schillemat, K. M., & Taylor, G. B., 2004, AAS, 36, 967

[35] Mirabel, I. F., & Rodríguez, L. F., 1999, ARAA, 37, 409

[36] Mirabel, I. F., & Rodríiguez, L. F., 1994, Nature, 371, 46

[37] Murata, K., & Shibazaki, N., 1996, PASJ, 48, 819

[38] Paragi, Z., Vermeulen, R. C., Fejes, I., Schilizzi R. T., Spencer, R. E., Stirling, A. M., 1999, New. Ast. Rev., 43, 553-557

[39] Safi-Harb, S., & Öegelman, H., 1997, ApJ, 483, 868

[40] Velázquez, P. F., Raga, A. C., 2000, A&A, 362, 780

[41] Zavala, J., Velázquez, P. F., Cerqueira, A. H., Dubner, G. M., 2008, ArXiv Astrophysics e-prints, arXiv:astro-ph/0804.0491v1,

[42] Vermeulen, R. C., Schilizzi, R. T., Icke, V., Fejes, I., Spencer, R. E., 1987, Nature, 328, 309-313

[43] Woodward, P., Colella, P., 1984, J. Comp. Phys., 54, 174-201

[44] Zealey, W. J., Dopita, M. A., & Malin, D. F., 1980, MNRAS, 192, 731