Pulsar Astronomy — 2000 and Beyond
ASP Conference Series, Vol. 202, 2000
M. Kramer, N. Wex, and R. Wielebinski, eds.

The interaction of pulsar winds with old supernova remnants

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1. Introduction

Shock waves in young supernova remnants (SNR) are generally considered to be the places where production and acceleration of charged particles (relativistic electrons and cosmic rays) take place. Older remnants can be re-energised if an active pulsar catches up with the shell of the remnant (Shull, Fesen, & Saken 1989). In that case a pulsar-driven wind can inject energetic particles into the shell, resulting into a rejuvenation of the radio emission of the old remnant due to the presence of additional relativistic electrons.

Radio observations of CTB80 (Angerhofer et al. 1981) and G5.4-1.2 (Frail & Kulkarni 1991) give evidence for the importance of the presence of an active pulsar close to the old shell of the remnants. In the first case the pulsar is believed to be inside the SNR. In the second case the pulsar is thought to have penetrated the shell of the SNR, and resides in the interstellar medium (ISM). We intend to investigate the physics which are connected with these kind of systems. One expects new effects resulting from the interaction of the three different shocks; the SNR shock, the bowshock bounding the pulsar wind nebula (PWN) and the (pulsar) wind termination shock. The dynamics of the system is described by a hydrodynamics code. We use the results from the hydrodynamics code to investigate the process of acceleration and transport of particles which are advected by the flow and diffuse with respect to the flow. We have applied the latter to a simple problem, the case of a spherically expanding SNR.

2. Modelling systems like CTB80 and G5.4-1.2

An evolutionary scenario can be summarised as follows: a supernova explosion results in an expanding SNR plus a high-velocity pulsar. The SNR is decelerated by the surrounding ISM. The pulsar has a constant kick velocity and will overtake the shell of the remnant. By the time the pulsar overtakes the shell of the remnant the velocity of the pulsar is supersonic with respect to the interior of the SNR: the PWN will be bounded by a bowshock. The lenght scale of the PWN at this stage is $\sim$ 0.1 parsec to be compared with the SNR radius of $\sim$ 30 parsec. Because of this large scale difference we model the interaction of the PWN bowshock and the forward SNR shock as the crossing of a plane-parallel shock. We use the Versatile Advection Code, a hydrodynamics code, developed by Gabor Tóth (Toth & Odstrčil 1996). The left picture of figure 1 shows the result of a numerical simulation: the pulsar has penetrated the shock of the

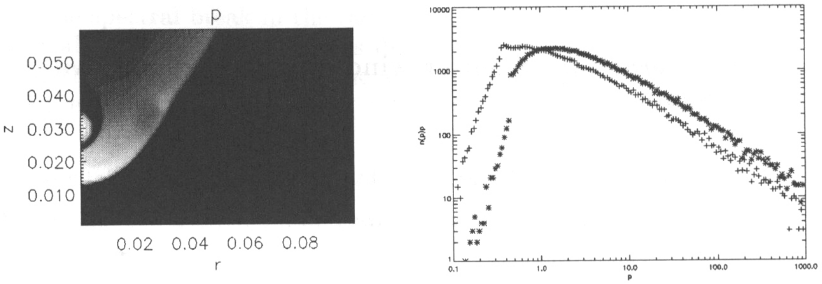

Figure 1. *Left picture* : Pressure profile of a pulsar bowshock. The configuration is axially symmetric. The pulsar is located at (0,0.03). The simulation is performed in the pulsar rest frame. *Right picture:* Momentum-distribution of the accelerated particles. The points indicated by a cross represent results using analytical expressions for the flow. The points indicated by a star represent results which used the flow as obtained from hydrodynamical simulations.

SNR. A termination shock, bowshock and the (plane-parallel) SNR shock (at $z \simeq 0.04$) are visible.

We describe the physics of the transport and acceleration of particles with Itô stochastic differential equation (SDE), which is based on the correspondence with the Fokker-Planck equation (Achterberg & Krülls 1994). As a test for the implementation of this method into the hydrodynamics code we solved a well-known problem, that of particles accelerated in an expanding SNR. We find a spectral index for the momentum distribution $n(p) \propto p^{-s}$ with $s = 2$, which one expects from shock acceleration at a strong shock. Furthermore there is a comparison by using an analytical expression for the flow using the results of McKee & Truelove (1994).

3. Conclusions

We have shown first results of hydrodynamical simulations for systems like CTB80 and G5.4-1.2. The next step is to use the flow of these calculations to describe the process of particle acceleration in the test-particle approximation where the particles do not influence the dynamics of the system.

References

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