Perseus in Sicily: From Black Hole to Cluster Outskirts
Proceedings IAU Symposium No. 342, 2018
K. Asada, E. de Gouveia Dal Pino, M. Giroletti,
H. Nagai & R. Nemmen, eds.

doi:10.1017/S1743921318005951

Simulations of the W50-SS433 system

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Abstract. Supernovae and astrophysical jets are two of the most energetic and intriguing objects in the universe. We examine an interesting scenario that involves the interaction of these two extreme phenomena, motivated by observations of the W50-SS433 system: a jet launched from the microquasar SS433 (an X-ray binary) located inside a supernova remnant, W50. These observations revealed a unique morphology of the remnant, attributed to the presence of the jet. We performed full 3D relativistic hydrodynamic simulations to better capture the interaction between the remnant and the jet and post-processed the data with a radiative transfer code to create emission maps.

Keywords. hydrodynamics, methods: numerical, (stars:) supernovae: general, ISM: jets and outflows, (ISM:) supernova remnants

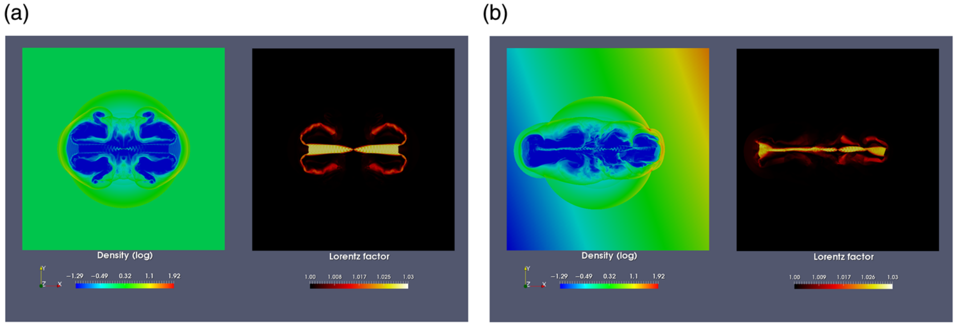
1. Introduction

W50 is a quite peculiar supernova remnant (SNR), well known for its characteristic "manatee" shape, with a profound "east - west" asymmetry. SS433 is an X-ray binary, know to host a precessing, relativistic jet (Dubner *et al.* 1998; Monceau-Baroux *et al.* 2014, 2015), with its mean axis almost parallel to the elongated part of the SNR. This elongated shape of the remnant is often associated with the presence of the jet and its interaction with the shell and has been examined in 2D simulations, e.g. Goodall *et al.* 2011. We now performed full 3D relativistic hydrodynamic simulations, aiming to capture the interaction between the SNR and the jet.

2. Simulations & Results

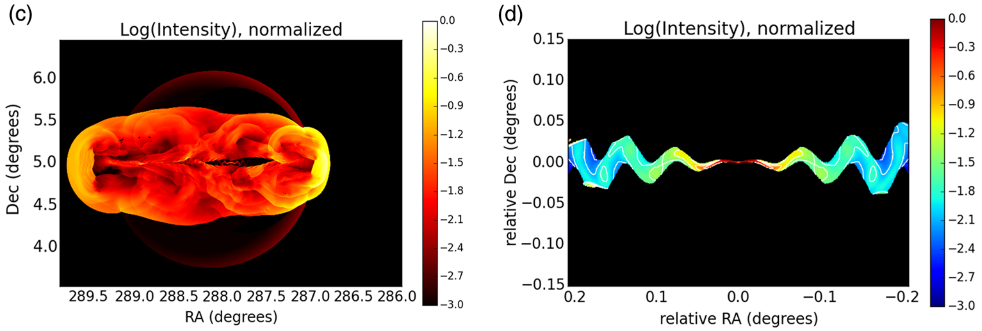
For the simulations we used the relativistic hydrodynamic module from the open source, parallel, grid adaptive, MPI-AMRVAC code (Keppens *et al.* 2012, Porth *et al.* 2014). The domain is a Cartesian grid with dimensions $-100pc \leq x, y, z \leq 100pc$, a base resolution 200^3 and 5 adaptive mesh levels (AMR), leading to an effective resolution of 3200^3. This feature is necessary to capture the initial supernova blast and the injection of the jet at a later time (treated as an internal boundary), while keeping the computational cost as low as possible. This is partially achieved by scaling-up the injection region of the jet. The mean jet axis is considered to be parallel to $\hat{x}$.

Following Goodall *et al.* 2011, we first model the supernova as a sphere of high density and velocity, against a static interstellar medium (ISM). During the free expansion phase, the velocity is self-consistently determined if we assume an energy of $10^{51} ergs$ for the SN blast and a mass of $6M_{\odot}$ for the ejected material; this results in a velocity of $v_{SN} \sim 10^4 km/s$. The jet is injected with a velocity of $v_j \simeq 0.25c$ (or Lorentz factor of $\gamma \sim 1.03$).



Uniform density ISM

Exponential density ISM



Emission (20cm)

Jet emission (0.4keV)

Figure 1. *Top:* Slice of a 3D run: uniform (left) vs exponential (right) density profile for the ISM. For each case we present the density (in log scale) and the Lorentz factor. *Bottom:* Emission map of the full system in radio, at the approximate location of W50-SS433 ($\sim 5.5kpc$) (left) and a zoomed image of the jet in X-rays (right).

The density is calculated via the kinetic luminosity of the jet, $L_{kin} = 10^{39} erg/s$ and the injection radius.

For the ISM we examine two different scenarios: (i) a uniform and (ii) an exponential density profile. In both scenarios, the number density in the center of the domain is fixed to n=1 particle/cm^3. The exponential profile for the ISM can be described as follows:

$$\rho(r,z) = \rho_o \exp(-R_m/R_d - r/R_d - z/Z_d) \tag{2.1}$$

where r is the distance from the galactic centre, z is the distance from the galactic disk and $R_m = 4kpc$, $R_d = 5.4kpc$, $Z_d = 40pc$ are constants determining the relevant scalelengths.

In Figs. 1a,1b we present a slice from the 3D output, perpendicular to the $\hat{z}$ axis, with the density and the Lorentz factor for the two cases. We verify that in order to obtain the observed asymmetry of the SNR, the density gradient is necessary. Synchrotron emission assuming equipartition, i.e. substituting the magnetic field energy density with a fraction of the internal energy density of the fluid (Fromm *et al.* (2016)), has been calculated by post-processing the output. For the exponential case, the emission map from the full simulation is shown in Fig. 1c and a zoomed image of the jet in Fig. 1d.

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