Contrib. Astron. Obs. Skalnaté Pleso **49**, 377 – 379, (2019)

# Hydrodynamics of supernova remnants: interaction with interstellar medium

**P. Kostić, S. Knežević and B. Vukotić**

*Astronomical Observatory, Volgina 7, P.O.Box 74 11060 Belgrade, Serbia*

Received: October 27, 2018; Accepted: January 29, 2019

**Abstract.** We study the large scale interaction of the supernova remnants with clouds of interstellar gas. Optical proper motion measurements and H$\alpha$ emission in supernova remnants are discussed, especially for the 1.4 m telescope "Milanković" and astroclimate conditions at the Astronomical station Vidojevica near Prokuplje, Serbia. We present our hydrodynamical simulation that is used to estimate the observables. The simulation implements a fractal density structure of interstellar clouds. We analyse how such clouds influence the expansion of the remnants and shock properties in order to estimate the distance to the remnants. From distributions of density and temperature behind the shock we calculate the resulting H$\alpha$ emission and discuss how such emission can be used to probe the interstellar medium properties.

**Key words:** supernova remnants – numerical simulation

## 1. Introduction

Supernova remnants (SNRs) are a critical connection between stellar objects and interstellar medium (ISM). They disperse products of stellar evolution over a significant spatial scales while shaping the ISM and interacting with giant molecular clouds. The studies of such objects are crucial for understanding the evolution of galaxies.

A supernova remnant forms as a collisionless shock wave when supernova ejecta sweep the surrounding ISM. These magneto-hydrodynamic shocks accelerate charged particles to high speeds, which produces a very energetic radiation. Shock waves as well as SNR interiors are vastly observed from radio to X-ray parts of the electromagnetic spectrum. In addition, SNRs and their shocks are successfully modeled with hydrodynamical simulations.

A numerous empirical and theoretical studies of SNRs have indicated that ISM properties are of great significance for SNR evolution (e.g., see Pavlović et al., 2018). Dense ISM parts, such as molecular clouds, slow down the shock-wave changing the emission features and shape of the remnant. A lifetime of a typical SNR is of the order $10^4$ years. The observed features of such long-lived objects can only be put into the right evolutionary context using the data from numerical models. Contemporary SNR simulations model the ISM either as homogeneous medium or as assembly of the homogeneous clumps. However, ISM has a much more complex structure and ISM density distribution can be described as a fractal, turbulence driven medium.

This work discusses the possibility for observing the interactions between SNRs and clumpy ISM with small, meter-class telescopes, especially with the 1.4 m telescope "Milanković", recently commissioned at the Astronomical station Vidojevica, near the town of Prokuplje in southern Serbia. To comprehend the connection between the ISM structure and observables we present a numerical model of SNRs interaction with a fractal-structured medium.

## 2. Astronomical station Vidojevica

The largest instrument at the Astronomical station Vidojevica is a 1.4 m reflector "Milanković". Typical astro-climate conditions on the site give clear sky seeing median of 1.15 arcsec (Jovanovic et al., 2012). On a displayed figure of a numerical simulation of SNR evolution in a fractal ISM the SNR-cloud interaction features emerge on scales of up to 20 pc. With the telescope "Milanković" such features, in H$\alpha$, could be observed up to a 70 kpc distance if bright enough. If we consider that older remnants (older than $\sim 10^4$ years) are less bright than younger ones, the small telescopes can be used to observe remnants in the Milky Way. Apart from that, the long term projects of proper motion observations might be more feasible on smaller telescopes. Observed proper motions in combination with predicted shock speeds from simulations might give distance estimates to SNRs.

Our grid-based 2D hydrodynamical numerical simulation is based on the MUSCL-Hancock finite volume scheme with the HLLC Riemann solver (Toro, 2009). The ISM is modeled as a fractal cloud, ie. a cloud with fractal density distribution (Elmegreen, 1997).

## 3. Summary

- Fractal distribution of ISM density can influence the properties of SNRs.
- Such properties have a potential to be observed even with small, meter-class telescopes in the Milky Way.
- Numerical hydrodynamical simulations can link the SNR observables to ISM properties.

**Acknowledgements.** The authors acknowledge the financial support by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the project #176021 "Visible and invisible matter in nearby galaxies: theory and observations".

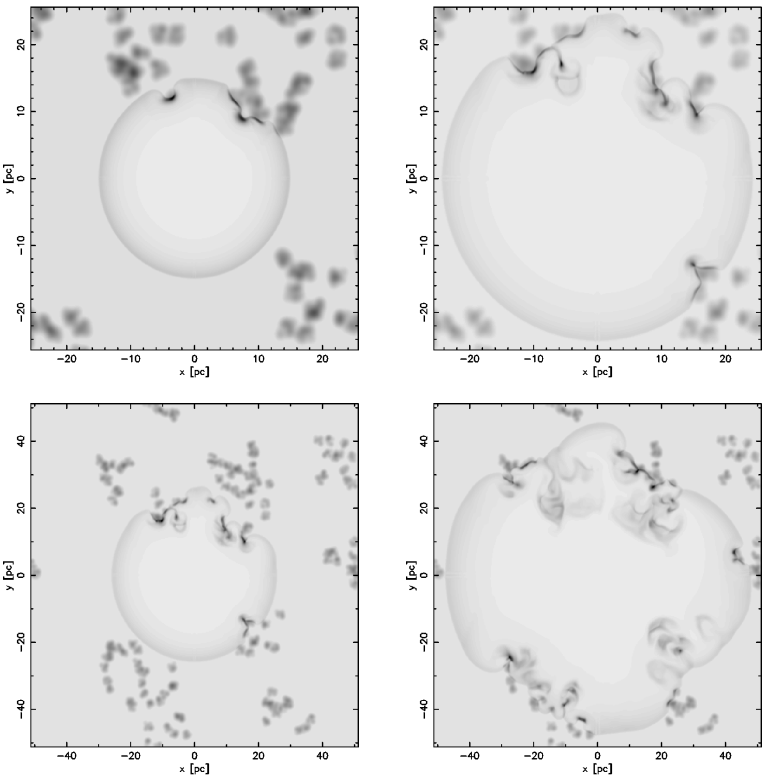


**Figure 1.** A simulation frame of density distribution for SNR expanding into the fractal ISM. A test simulation on a $400 \times 400$ grid, time instances after the supernova explosion are: 3000 yr (upper left), 8000 yr (upper right), 9000 yr (lower left) and 30000 yr (lower right).

## References


Elmegreen, B. G., Intercloud Structure in a Turbulent Fractal Interstellar Medium. 1997, *Astrophys. J.*, **477**, 196, DOI: 10.1086/303705

Jovanovic, M., Stojanovic, M., Martinovic, N., et al., Astronomical Station Vidojevica: Astro-Climate. 2012, *Publications de l'Observatoire Astronomique de Beograd*, **91**, 83

Pavlović, M. Z., Urošević, D., Arbutina, B., et al., Radio Evolution of Supernova Remnants Including Nonlinear Particle Acceleration: Insights from Hydrodynamic Simulations. 2018, *Astrophys. J.*, **852**, 84, DOI: 10.3847/1538-4357/aaa1e6

Toro, E. F. 2009, *Riemann Solvers and Numerical Methods for Fluid Dynamics: A Practical Introduction, 3rd edn.* (Berlin, Heidelberg: Springer-Verlag)