3-D Simulations of Magnetized Super Bubbles

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Abstract

We present 3-dimensional simulations of magnetized super bubbles with ZEUS MP. These models provide quantitative predictions of density, temperature, magnetic field strength and velocity of the gas in the bubble, which can be compared with high-resolution observations of the neutral gas, ionized gas, and Faraday rotation from the International Galactic Plane Survey. These new models incorporate important physics not previously included in the analysis of observed super bubbles. The simulations will improve our understanding of the age, kinematics and morphology of super bubbles in the Galaxy, the ionization of the Galactic halo, and the structure and kinematics of neutral gas clouds at large distances from the Galactic plane.

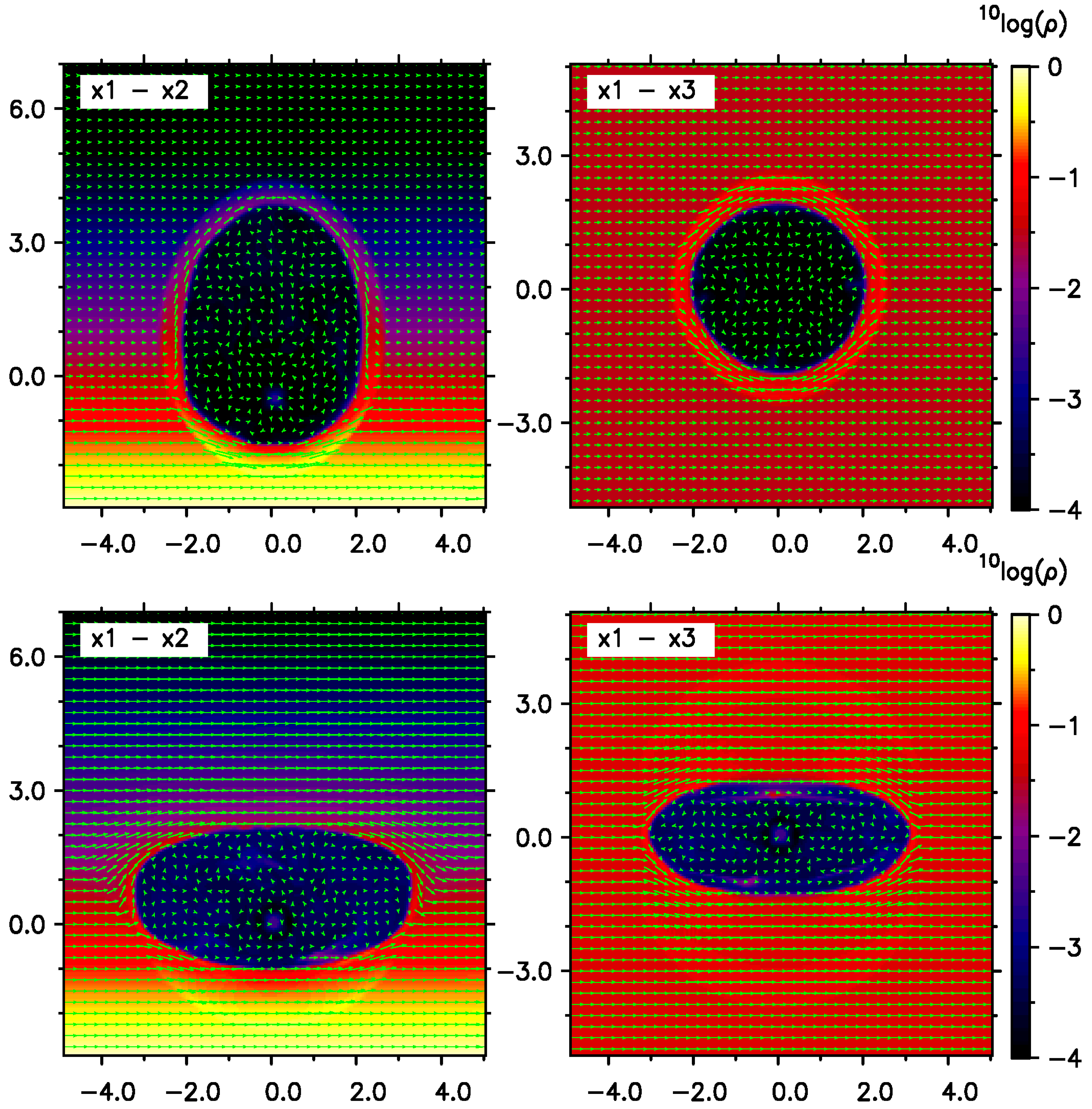

Figure 1: Simulated super bubbles in an isothermal atmosphere with constant β (top row) and constant magnetic field (bottom row). The exponential density gradient of the atmosphere is along the x2 axis. The undisturbed magnetic field is oriented along the x1 axis. Colour indicates density on a logarithmic scale. The vector fields indicate strength and direction of the magnetic field components in the plane of the figure. Left panels: x1 – x2 plane through the source. Right panels: x1 – x3 plane through the source. The x1 – x3 plane is parallel to the Galactic plane. The coordinates are expressed in units of the exponential scale height of the atmosphere.

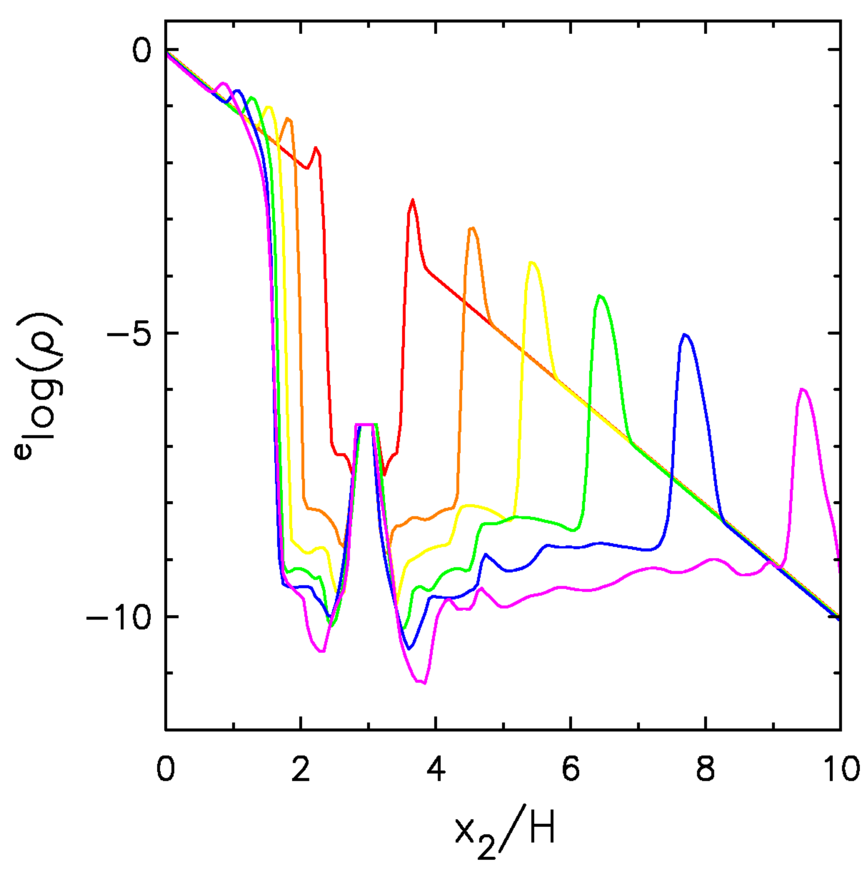

Figure 2: Time evolution of a weakly magnetized (β=3) super bubble. Profiles give the density on a logarithmic scale in the vertical direction (x2).

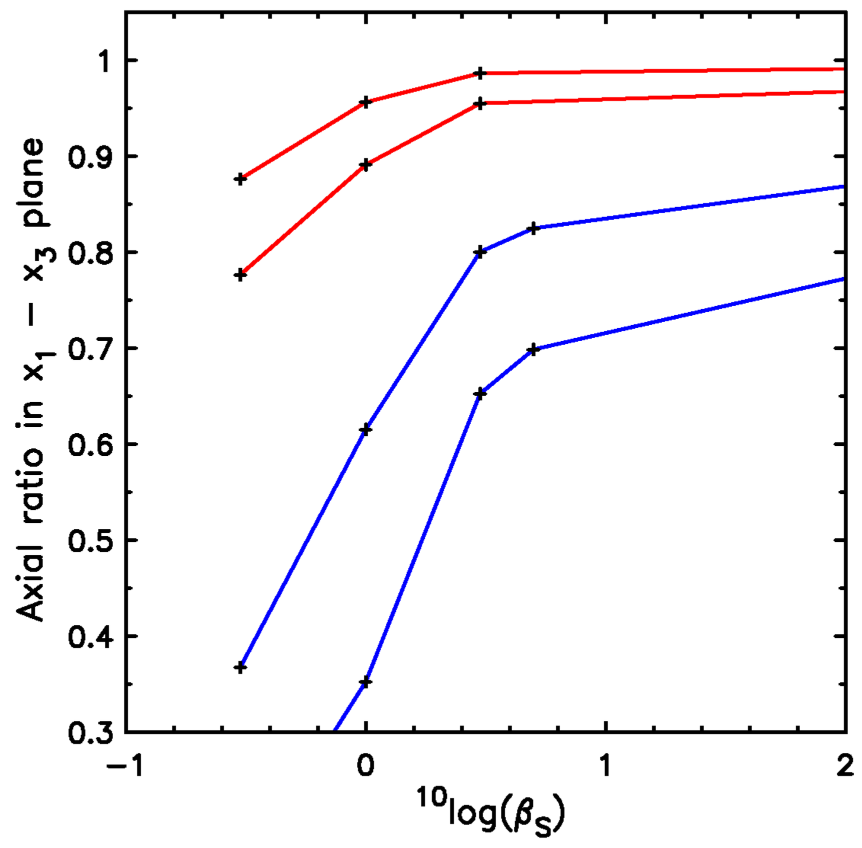

Figure 3: Axial ratio of the cavity in the x1 – x3 plane as a function of β at the level of the source and time. Red curves: constant β; Blue curves: constant magnetic field. Upper red/blue curve: dimensionless time 0.25. Lower red/blue curve: dimensionless time 0.5

Introduction

Large bubbles blown in the interstellar medium by the stellar wind and supernova explosions of clusters of O and B stars can grow larger than the scale height of the Galactic gas disk and burst out of the disk into the halo. Such events are observed in the form of Galactic "worms" (Heiles 1984) or "chimneys" (e.g. Normandeau et al. 1996). The International Galactic Plane Survey (IGPS) provides images of the neutral atomic gas, and radio continuum brightness and polarization which allow us to study these structures in unprecedented detail. Large super bubbles play an important role in the mass exchange between the Galactic disk and the halo and the dynamics of the interstellar medium. Observations of large super bubbles are often interpreted by means of analytic models which do not do include the important effect of the Galactic magnetic field. The first study of the 3-dimensional evolution of super bubbles in the Galaxy was done by Tomisaka (1998), who considered the conditions for a super bubble to break out of the Galactic plane. Our simulations aim to improve our understanding of super bubbles detected in the IGPS by incorporating the important effect of the Galactic magnetic field.

3-D Magneto-hydrodynamic simulations

We present initial 3-D MHD simulations of stellar wind bubbles with ZEUS-MP. A source with a constant mass loss rate is placed in an isothermal atmosphere with a vertical exponential density profile and a magnetic field. The strength of the magnetic field is parameterized with the parameter β, the ratio of gas pressure to magnetic pressure. We assume either a constant β, or a constant magnetic field. Initially, the magnetic field is directed along the Galactic plane. The resolution of the simulations presented here is 200^3 with $(5\ pc)^3$ voxels.

The axes of the simulated volume are labeled x1, x2, and x3. The initial magnetic field is along the x1 axis, the atmospheric density gradient is along the x2 axis.

Figure 1 shows the density and magnetic field of a bubble for β = 1, and for a constant magnetic field. The different morphology between bubbles in these magnetic field geometries is a result of different confinement by the magnetic field, as described before by Tomisaka (1998). Note the magnetic field wrapping around the hot low-density cavity an a weak disordered magnetic field inside the cavity. The top views (x1-x3) in Figure 1 show that Faraday rotation of the Galactic synchrotron background by these magnetized bubbles depends strongly on the direction of the line of sight through the bubble.

Figure 2 shows profiles of the density along the vertical (x2) axis for a simulation with constant β = 3 at equal intervals in time. Note the accelerating upper cap of the bubble. The density in the upper cap appears to decrease exponentially with a scale height larger than that of the atmosphere. The density is approximately the same everywhere inside the cavity, but the average density inside the cavity decreases as the bubble expands.

Figure 3 shows the shape of a super bubble as a function of β at two different times for the two magnetic field geometries. As time progresses, the bubble becomes more elongated along the magnetic field lines (x1 axis). Bubbles in the constant magnetic field case are more elongated because of the strong confinement by the magnetic field.

Application to observations

The International Galactic Plane Survey is an international effort to map the Galactic plane with the unprecedented resolution of 1'. Large parts of the Galaxy have been mapped in the 21-cm line of atomic hydrogen, 21-cm radio continuum and multi-frequency polarization measurements. Our simulations will allow us to exploit the full potential of the IGPS dataset, by combining observations of the morphology kinematics and polarization structure of Galactic super bubbles.

Future work

The simulations presented here are initial results of a study of 3-D MHD effects in the evolution of a super bubble in the interstellar medium. In the future, we plan to include more realistic density profiles for the atmosphere, other magnetic field geometries and more complex source geometries, and cooling in the simulations. This will allow us to incorporate physics which was not considered before in the study observed super bubbles.

References

Normandeau, M., Taylor, A. R., Dewdney, P. E. 1996, Nat, 380, 687
Tomisaka, K. 1998, MNRAS, 298, 797
Heiles, C. 1984, ApJS, 55, 585

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