Visualization of magnetic field structure in shock wave blasts

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We explore the formation of a dense shell of gas from a shock wave blast explosion and the resultant effects on the surrounding magnetic field. This project focuses on modeling the gas density and magnetic field evolution in both 2 and 3 dimensions to better understand supernovae expansions and their impact on interstellar gas.

I. INTRODUCTION

The rapid expansion of gas caused by a stellar explosion forces the formation of a dense shell. The expansion of this shock wave blast impacts the magnetic field around it; this project explores the evolution of the magnetic field due to a spherical blast wave by plotting simulation data in both 2 and 3 dimensions to better understand the impact of supernovae expansions on their environment.

II. THEORETICAL BACKGROUND

We focus on the equation describing the expansion of a spherical shock wave, as presented in Taylor 1950:

$$R = S(\gamma) t^{2/5} E^{1/5} \rho_0^{-1/5}, \tag{1}$$

where R is the radius, S is a function of γ, γ is the ratio of the specific heats of air, t is time, E is the energy released, and ρ_0 is the atmospheric density.

III. METHODS

Eq. 1 was first graphed and analyzed to understand the nature of the shock wave blast expansion. Various 2D plots were generated using existing code to create cross-sectional and surface maps of the gas density and velocity vectors.

Various packages in the Matplotlib library were used to create a 3D visualization of the gas density and velocity and magnetic field lines, specifically using the voxel function to plot the gas density and the quiver function to plot the velocity vector field. Finally, a streamline function was created to model the bending of magnetic field lines using nearest-neighbor interpolation and a Runge-Kutta integration method.

The 2D visualization of the gas density and magnetic field vectors was modeled using the HEALPix library. Using data from Athena++ magnetohydrodynamics simulations, the gas density and magnetic field vectors were integrated over radial lines at equal area distributions across the surface of the shock wave blast sphere as calculated by the HEALPix software. These radial column densities and vectors were then compiled into a HEALPix map to be plotted via various projections.

IV. RESULTS

Mollweide projection models were produced for the standard simulation data at $t = 0$ and $t = 31$ in addition to a model of perturbed simulation data at $t = 30$, shown below.

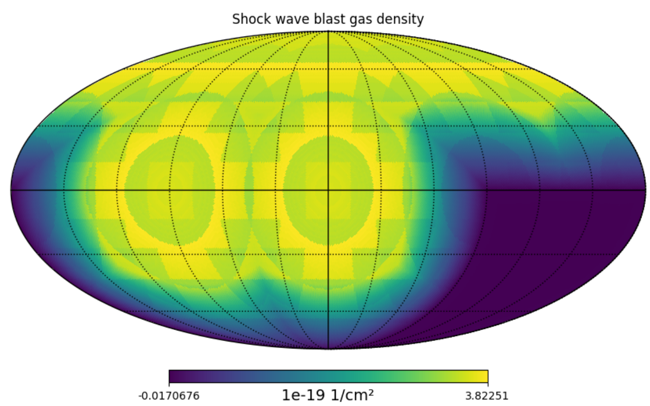

FIG. 1: Shock wave blast density for a standard model at $t = 0$

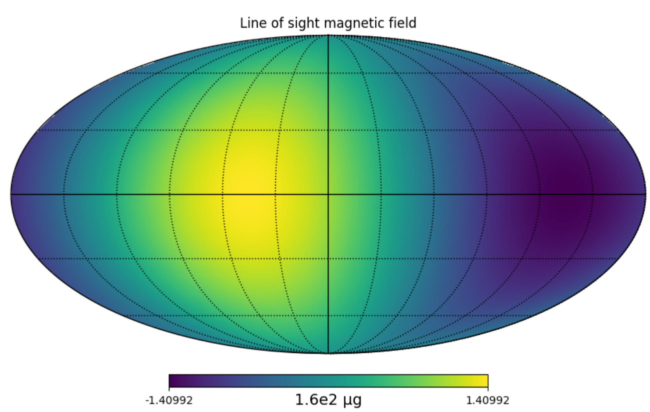

FIG. 2: Line of sight magnetic field for a standard model at $t = 0$

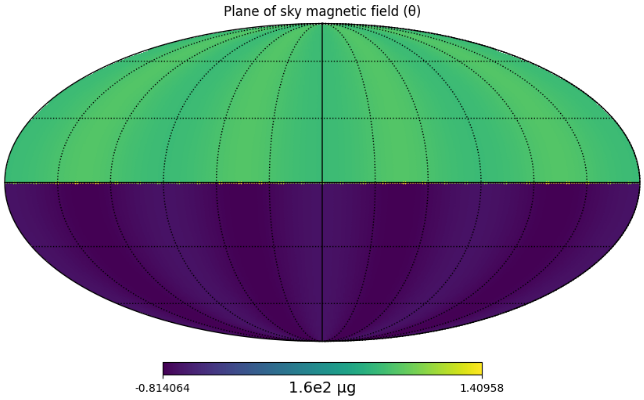

FIG. 3: Plane of sky θ component for a standard model at $t = 0$

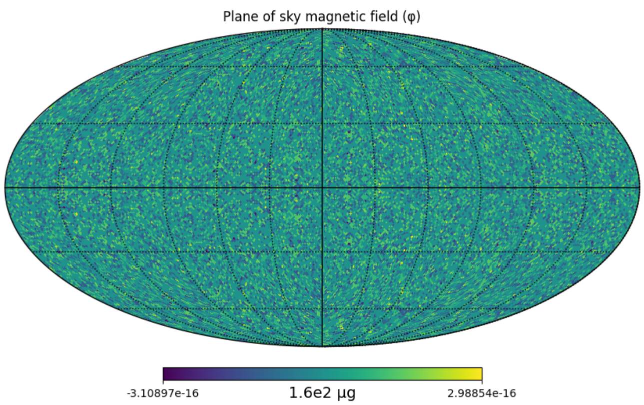

FIG. 4: Plane of sky ϕ component for a standard model at $t = 0$

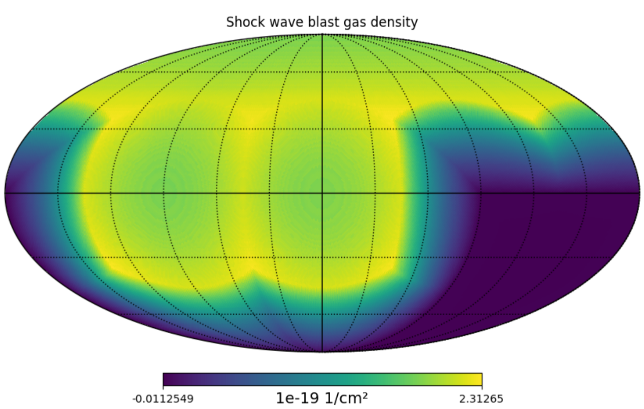

FIG. 5: Shock wave blast density for a standard model at $t = 31$

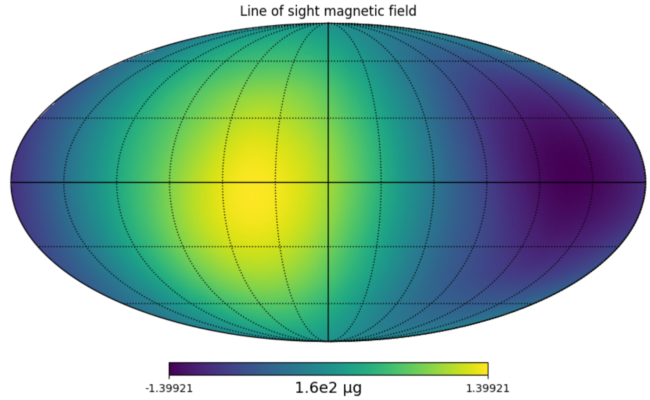

FIG. 6: Line of sight magnetic field for a standard model at $t = 31$

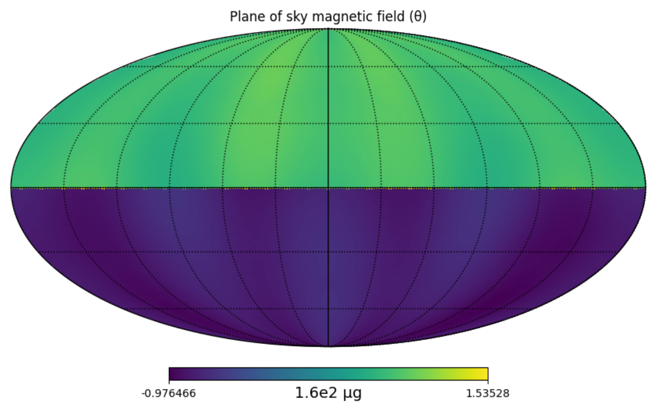

FIG. 7: Plane of sky θ component for a standard model at $t = 31$

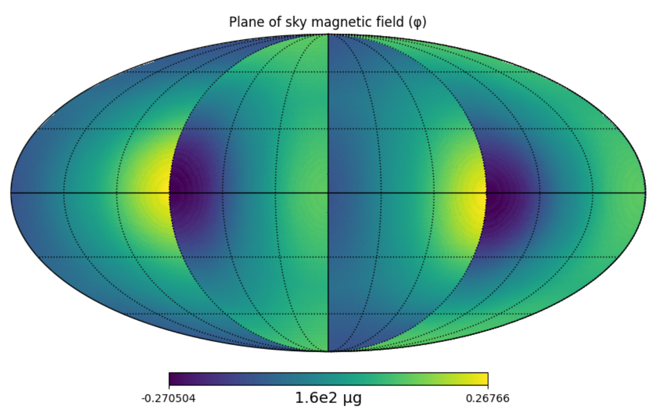

FIG. 8: Plane of sky ϕ component for a standard model at $t = 31$

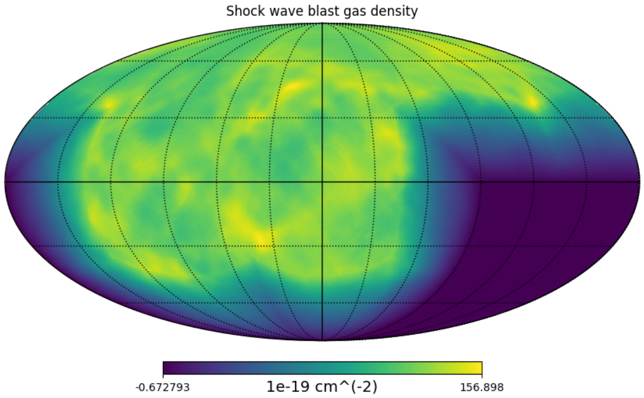

FIG. 9: Shock wave blast density for a perturbed model at $t = 30$

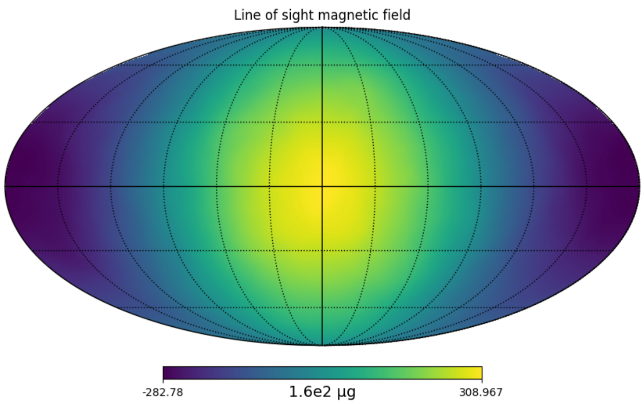

FIG. 10: Line of sight magnetic field for a perturbed model at $t = 30$

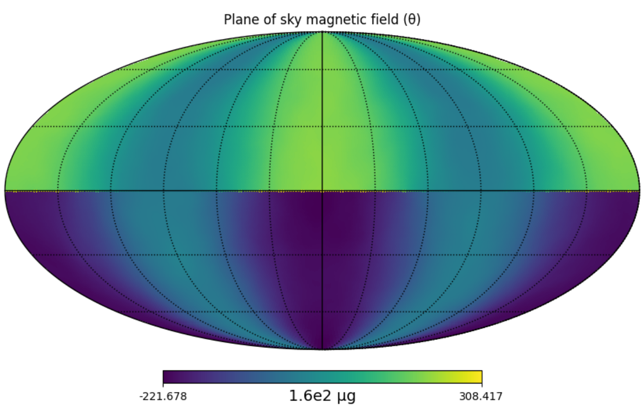

FIG. 11: Plane of sky θ component for a perturbed model at $t = 30$

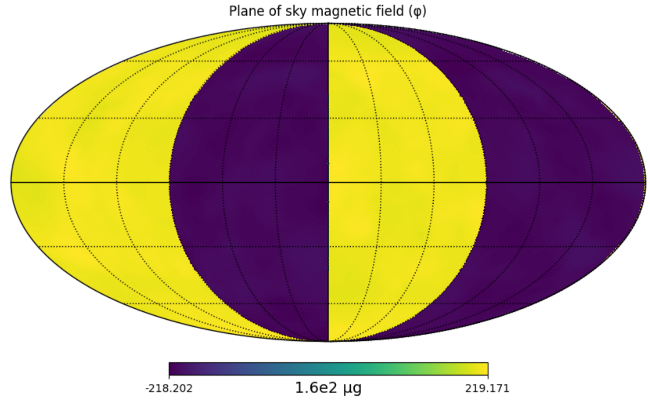

FIG. 12: Plane of sky ϕ component for a perturbed model at $t = 30$

V. DISCUSSION AND CONCLUSIONS

The results demonstrate the expected effects by the magnetic field on the flow of interstellar material and potential cloud formation; the expansion of the shock wave blast shell causes magnetic field bending, forcing material against the inside of a shell surface that expands laterally. The method of visualization presented in this paper can be used to visualize and analyze simulations of expanding supernova shells and investigate the potential formation of clouds. Specifically, the line of sight maps allow observation of Zeeman effect, while the plane of sky maps illustrate polarization effects.

VI. ACKNOWLEDGMENTS

This project was conducted under the guidance of Dr. Fabian Heitsch. Some of the results in this paper have been derived using the healpy and HEALPix package.

VII. REFERENCES

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