Cosmic Magnetic Fields: From Planets, to Stars and Galaxies
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Accretion and magnetic field submergence in neutron star surface

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Abstract. We study the effects of hypercritical accretion onto a neutron star surface. The magnetic field submergence in the neutron star crust and the possible rediffusion is investigated.

Keywords. Stars: neutron – SN 1987A – methods: numerical – accretion – magnetic fields

1. Introduction

Supernova 1987A in the Large Magellanic Cloud was the first nearby supernova in over 400 years. Fortunately, the LMC has been well studied, and the precursor star has been identified: SK–69 202 was a 19-$M_\odot$ B3I supergiant star with a helium core mass of 6 $M_\odot$, an iron core mass of 1.45 $M_\odot$ that resulted in a 1.40 $M_\odot$ neutron star. Nevertheless, the compact remnant is not detected yet.

We present HD and MHD simulations of hypercritical accretion onto the compact object in SN 1987A. The submergence of the field by any amount of accreted matter can easily explain the absence of PSR activity in recent SNe, but the very existence of PSRs leads to the conclusion that in some fraction of SNe the fall-back accretion is weak enough that it allows a re-diffusion of the field in $10^3 - 10^4$ years. Stellar ejecta at the center of the SNR might still be optically thick in X-rays. Compare the observed 3-8 keV band images before and after adding simulated point sources (with various count rates) at the center of the SNR in order to determine an upper limit (90 %) to point source contribution. Point source spectrum: $\Gamma = 1.7 - 3.0$, $N_H = 2 \times 10^{21} - 10^{24}$ cm^{-2} are assumed. Based on the image taken on July 22, 2004, a point source upper limit at 3-10 keV is $L_x \approx 5 \times 10^{33} - 3 \times 10^{35}$ erg s^{-1} (Park *et al.* 2005). A numerical approximation of MHD hypercritical accretion in SN1987A can help us to resolve this mystery.

2. Hypercritical accretion onto SN1987A core

Analytical. In the hypercritical accretion onto compact objects scenarios, Chevalier (1989) argued that if the accretion mass rate ($\dot{M}$) exceeds the Eddington $\dot{M}_{\rm Eddington}$, then some of the accretion energy must be removed by means other than photons. In this case, the accretion is called hypercritical. Chevalier (1989) took in account that neutrinos can carry away accretion energy and developed self-consistent solutions for hypercritical accretion.

When $\dot{M} > 2 \times 10^{22}$ g s^{-1}, the ram pressure at the neutron star surface is larger than the pressure of a 10^{12} G magnetic field, which means that the accretion flow is purely hydrodynamical. This critical $\dot{M}$ is also the accretion rate at which hypercritical accretion is stopped by radiation pressure and becomes unstable, at which time about 0.1 $M_\odot$ has been accreted in the case of SN1987A. The analytical solution of envelope structure is: $P = P_{sh}(\frac{r}{R_{sh}})^{-4}$, $\rho = \rho_{sh}(\frac{r}{R_{sh}})^{-3}$, and $v = v_{sh}(\frac{r}{R_{sh}})$, where $R_{sh}, P_{sh}, \rho_{sh}, v_{sh}$ are

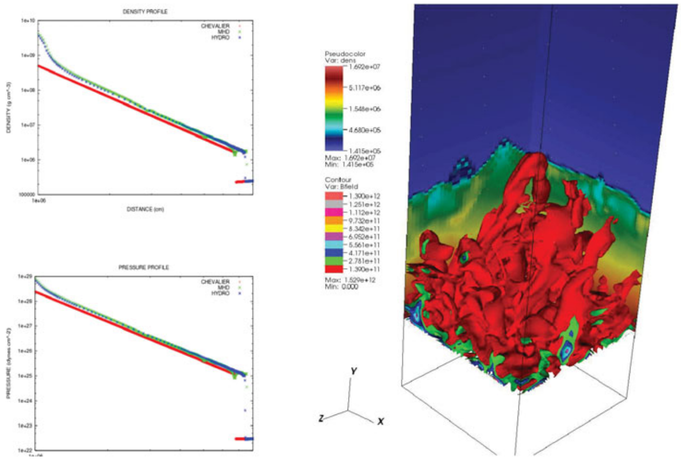

Figure 1. Left: The radial density (top) and pressure profiles (bottom). Right: Submergence and re-diffusion of the magnetic field in the SN-1987A scenario.

the values in the accretion shock. For the SN1987A scenario the values are: $v_0 = \sqrt{\frac{2GM}{R_{sh}}} \simeq 2.1 \times 10^9 \ \mathrm{cm\,s^{-1}}$, $\rho_0 = \frac{\dot{M}}{4\pi R_{sh}^2 v_0} \simeq 108.75 \ \mathrm{g\,cm^{-3}}$, $\rho_{sh} = 7\rho_0 \simeq 761.75 \ \mathrm{g\,cm^{-3}}$, $v_{sh} = -\frac{1}{7}v_0 \simeq -3 \times 10^8 \ \mathrm{cm\,s^{-1}}$, $P_{sh} = \frac{7}{8}\rho_0 v_0^2 \simeq 4.17 \times 10^{20} \ \mathrm{dyn\,cm^{-2}}$.

Numerical: Above analytical approximation does not take into account the magnetic field nor the piling up from material in the neutron star surface. We used the AMR FLASH2.5 code. The absence of PSR activity in recent SNe unfortunately depends on the poorly understood late evolution of the envelope of massive stars, but the nature of the progenitor of SN1987A shows that this fraction is not vanishingly small (Muslimov & Page 1995).

The radial profiles match very good with the Chevalier (1989) profiles, and the magnetic field onto the neutron star surface is submerged in the crust. This does not depend on the magnetic field configuration but on the intensity and the accretion rate. Good agreement between the analytical solution and numerical approach is achieved but we have gained the crust of the neutron star. The 3D simulation show the submergence and the possible re-diffusion of the magnetic field.

3. Conclusions

The accretion onto object compact in SN1987A is hypercritical ($\dot{M} \gg \dot{M}_{\mathrm{Eddington}}$). The diffusion of radiation from central region causes the later accretion to be ballistic, if the luminosity of the central source can be neglected. Steady state accretion envelopes are plausible for the mass accretion rates of SN1987A. The submergence of the magnetic field can be hiding the pulsar in SN1987A. The numerical simulations with FLASH2.5 code in KANBALAM cluster (128 processors), support this hypothesis.

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References

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