UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI FISICA

SUPERNOVA REMNANTS III
AN ODYSSEY IN SPACE AFTER STELLAR DEATH
9-15 June 2024, Chania, Crete, Greece

Interaction of a Supernova Remnant with background interstellar turbulence

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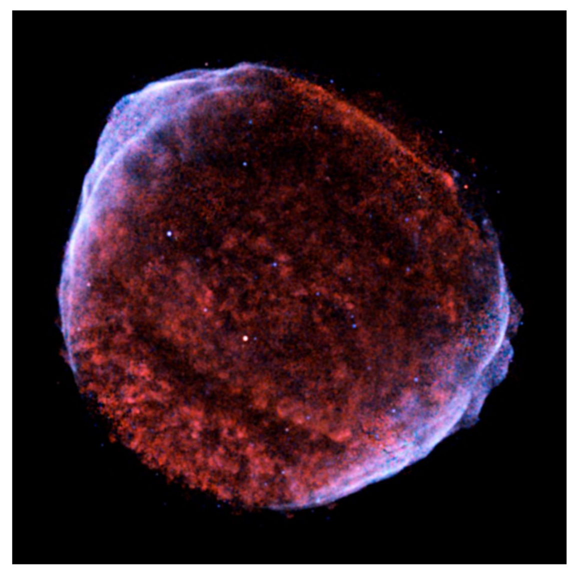
Introduction

Particle acceleration in SNR shocks is testified by the presence of enhanced synchrotron emission from relativistic electrons detected at shock fronts, where magnetic fields are amplified . One of the common SNR that shows this kind of emission is **SN1006**. SN1006 is a Type Ia supernova (see Figure on the right), which has a bilateral morphology consisting of two bright limbs located in the north-eastern part (NE) and in the south-western part (SW), that present knots and filaments along the boundary of the remnant (**Bamba et al., 2003**).

In this work we will try to reproduce the evolution of SN1006 by means of the MagnetoHydroDynamic (MHD) PLUTO code (**Mignone et al., 2007**). We will simulate the expansion of the blast wave in a turbulent environment, following the idea of **Guo et al., 2012**. We perform a parametric study of the expansion of the SN in different turbulence conditions. A comparison with Chandra data has been performed.



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Numerical model

MHD PLUTO code (**Mignone et al., 2007**) is used to reproduce the evolution of a SNR. The ideal MHD equations are

$$\begin{cases} \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}) = 0 \\ \frac{\partial (\rho \boldsymbol{v})}{\partial t} + \nabla \cdot (\rho \boldsymbol{v}\boldsymbol{v} - \boldsymbol{B}\boldsymbol{B}) + \nabla P_t = 0 \\ \frac{\partial \varepsilon}{\partial t} + \nabla \cdot \left[(\varepsilon + P_t)\boldsymbol{v} - (\boldsymbol{v}\cdot\boldsymbol{B})\boldsymbol{B} \right] = 0 \\ \frac{\partial \boldsymbol{B}}{\partial t} - \nabla \times (\boldsymbol{v} \times \boldsymbol{B}) = 0. \end{cases}$$

$$\varepsilon = \frac{P}{\gamma - 1} + \frac{1}{2}\rho v^2 + \frac{B^2}{2}$$

MHD equations must satisfy divergence free condition

$$\nabla \cdot \boldsymbol{B} = 0$$

2

Numerical set up

3

Typical initial conditions for a SNR: **2D Cartesian (x, y) uniform grids**

$L = 30$ pc $R_{SN,0} = 0.4$ pc $L_z = 0.8$pc $M_{ej} = 1.4\ M_\odot$

$E_{ej} = 1.5\times10^{51}$ erg $\gamma = 5/3$ $t_0 = 10$ years

$n_{inj} = 13.3\ cm^{-3}$ $n_{out} = 0.1\ cm^{-3}$

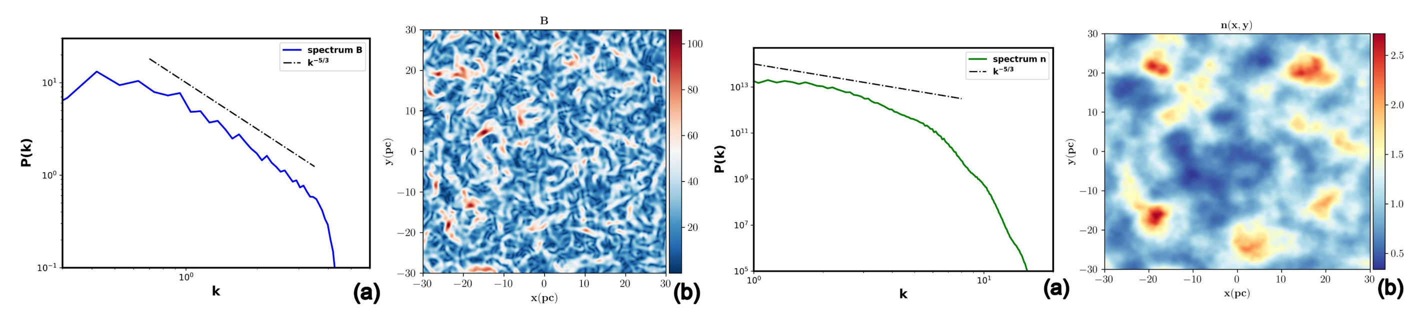
$t_{fin} = 10^3$ years Sedov-Taylor phase, energy is conserved

$B_0 = 3\ \mu G$ and its direction in spherical coordinates

$$\begin{cases} B_x = B_0 cos(\phi) sin(\tilde{\theta}) \\ B_y = B_0 sin(\phi) sin(\tilde{\theta}) \\ B_z = B_0 cos(\tilde{\theta}). \end{cases}$$

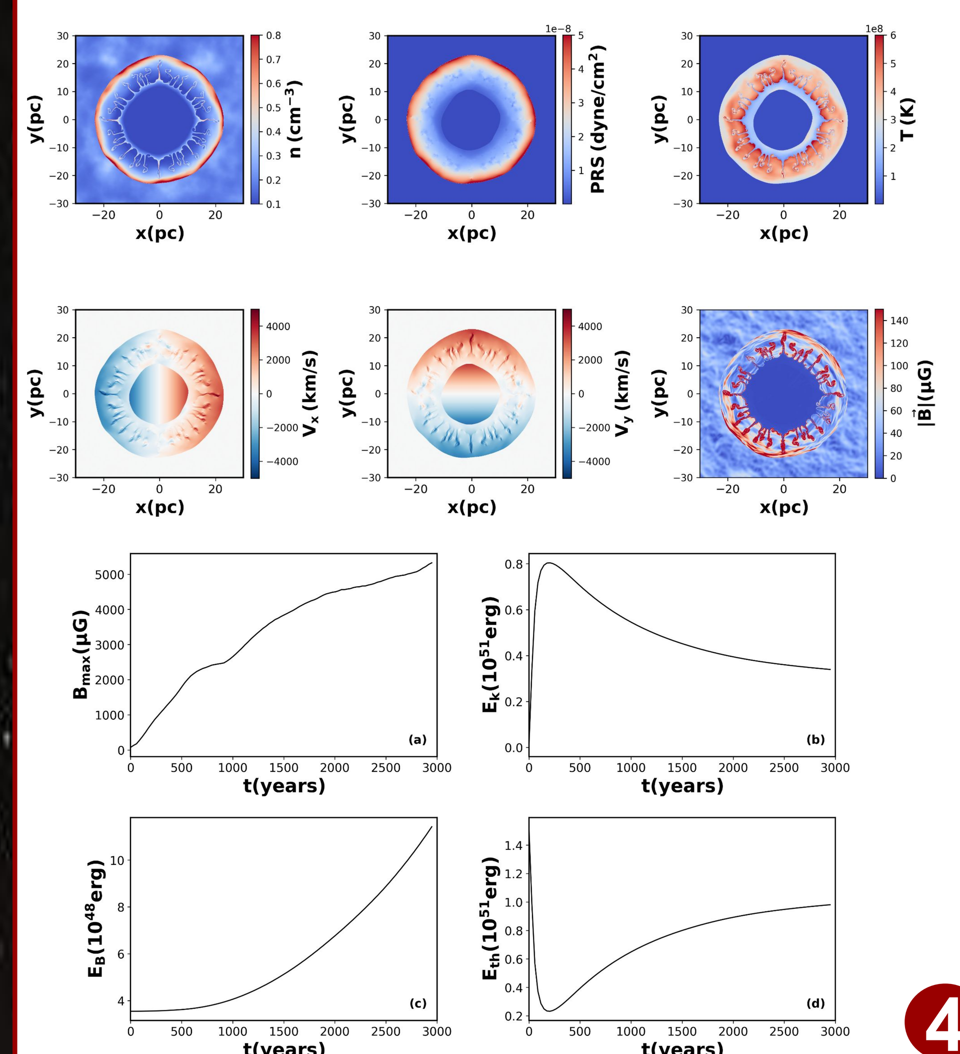
$\theta = 90°$, $\phi = 150°$ from **Reynoso et al., 2013**

Initial condition: in-plane mean magnetic field overimposed to a synthetic 2D isotropic turbulence (**Servidio et al., 2012, Giacalone & Jokipii 2007).**



Numerical results

Final time of the simulation obtained setting δ**B/B**=0.5 and δn/n = 1.



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Parametric study

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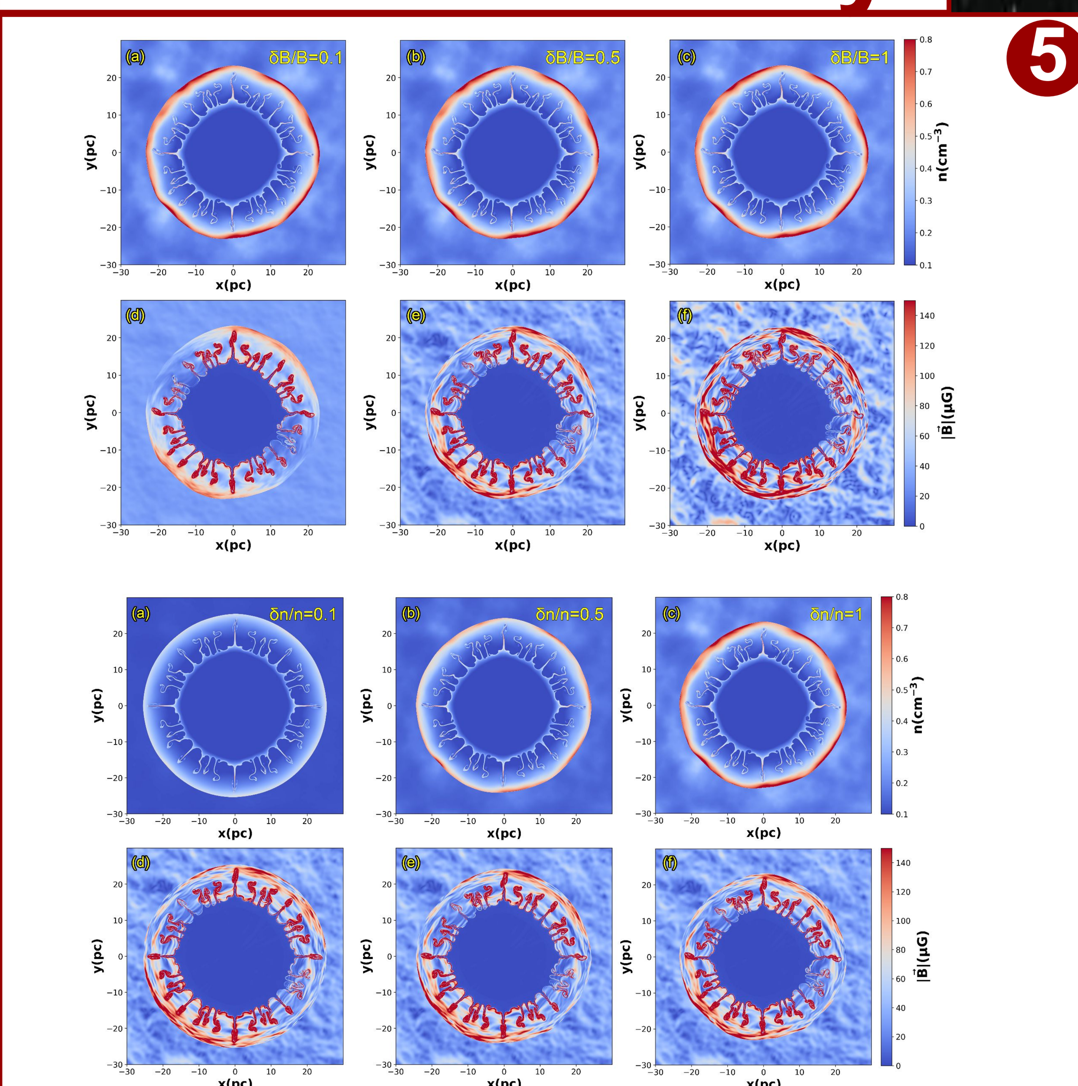
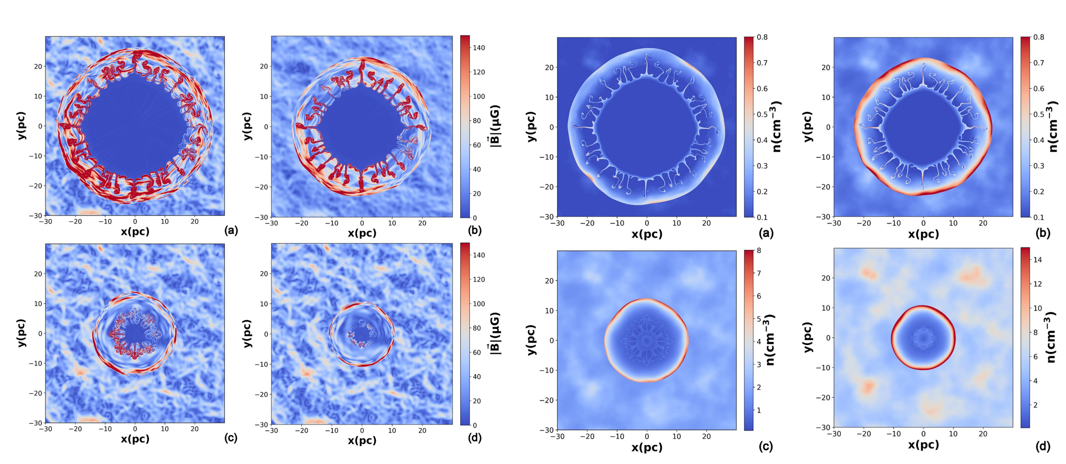


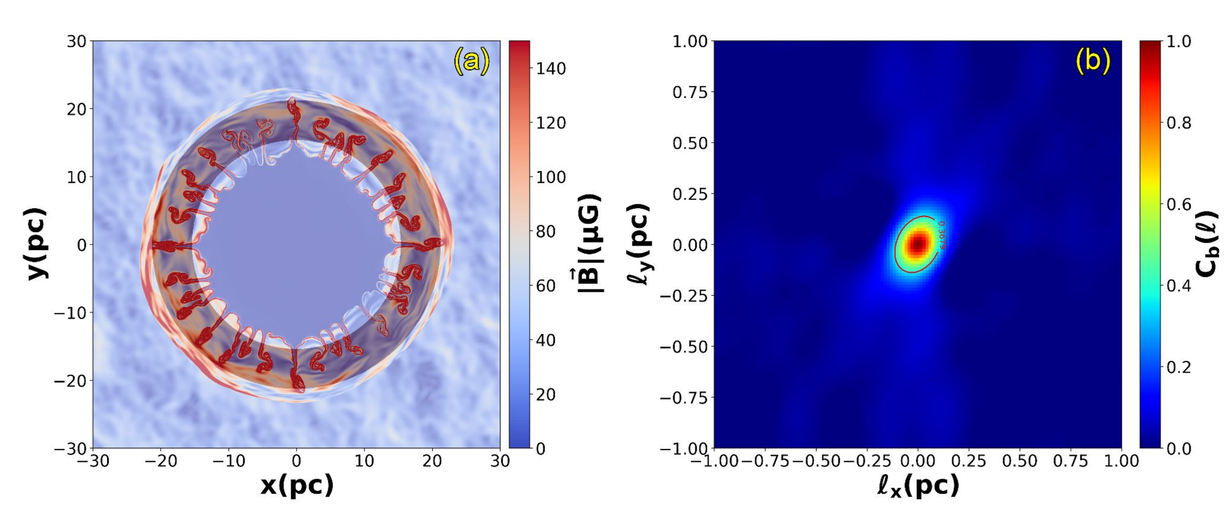
Variation of background density: n_{out} = 0.05 cm^{-3}, 0.1 cm^{-3}, 1 cm^{-3}, 3 cm^{-3} .

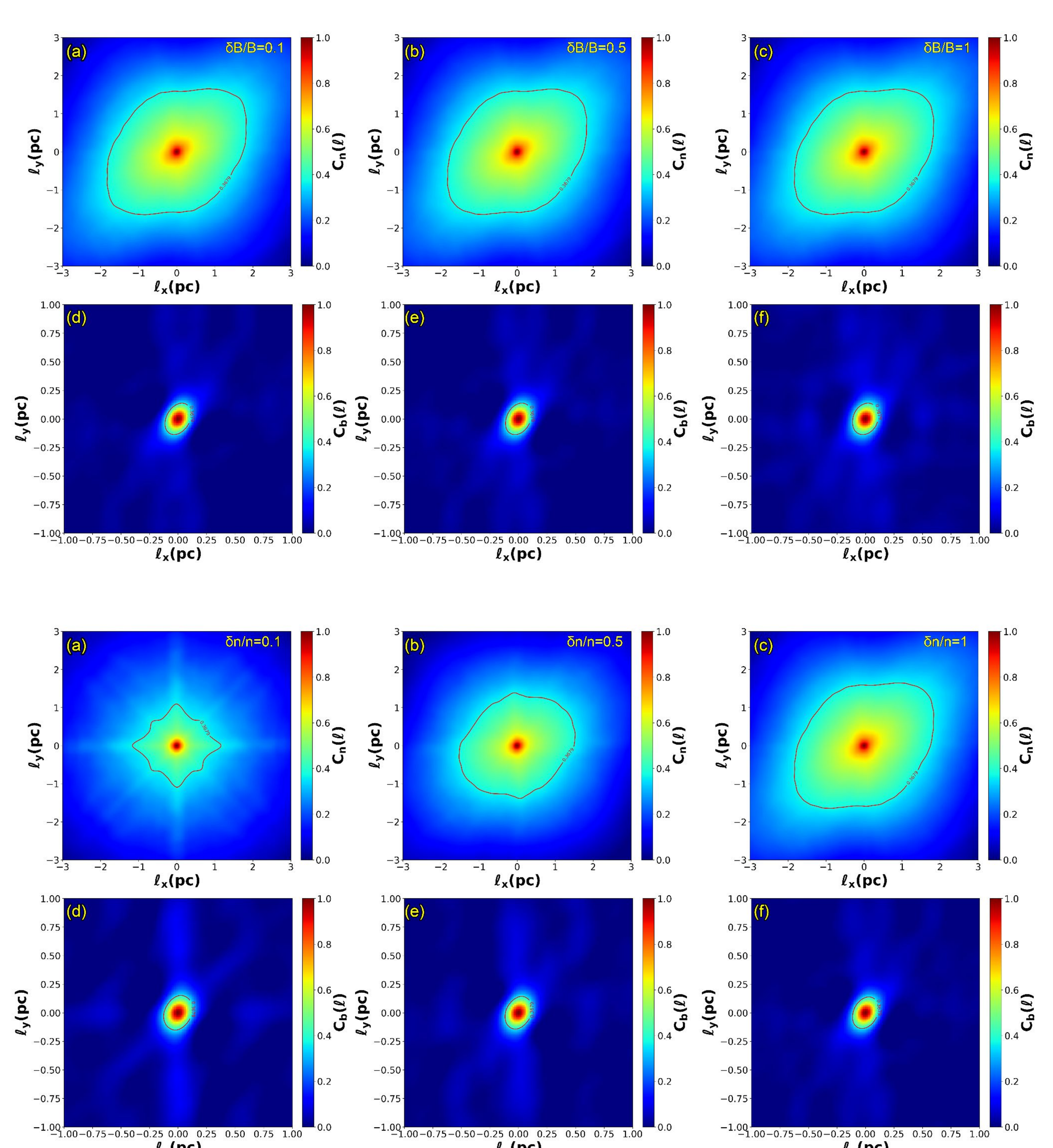


Autocorrelation functions

Autocorrelation function to probe plasma anisotropies on a Heavyside ring mask

$$C_b(\ell) = < \frac{b(\ell + \mathbf{r}) \cdot b(\mathbf{r})}{C_b(0)} >$$





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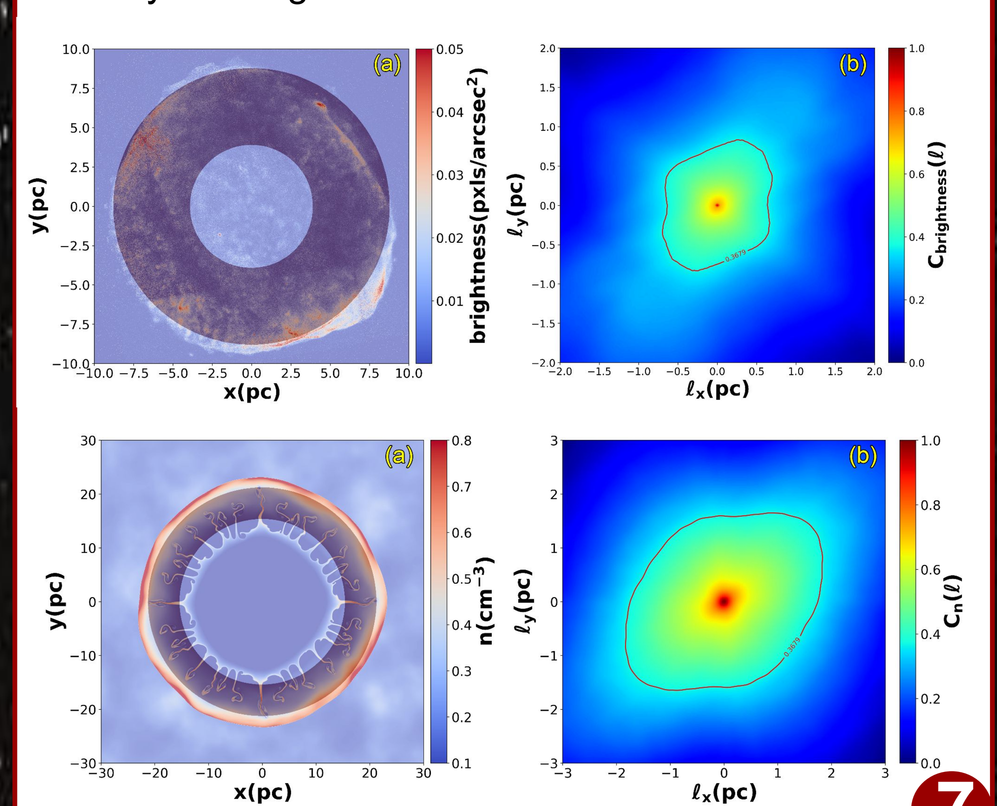
Chandra observations

Autocorrelation function to probe plasma anisotropies on a Heavyside ring mask



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Conclusions

- **We studied the evolution of a shock wave associated to a SNR by means of MHD-PLUTO code simulations, coupled with synthetic turbulence.**
- **The autocorrelation maps suggest, in most of the cases, that the correlation scale of turbulence is larger in the direction quasi perpendicular to B and shorter along it.**
- **We found a preliminary good agreement between numerical results and Chandra spacecraft data in the behavior of the autocorrelation function.**

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References

[1] Helder, E. A., Vink, J., Bykov, A. M., et al. 2012, Space430 Science Reviews, 173, 369,431
[2] Guo, F., Li, S., Li, H., et al. 2012, The Astrophysical Journal, 747, 98
[3] Servidio, S., Valentini, F., Califano, F., & Veltri, P. 2012, Physical review letters, 108, 045001
[4] Bamba, A., Yamazaki, R., Ueno, M., & Koyama, K. 2003, The Astrophysical Journal, 589, 827
[5] Bell, A. 1978a, Monthly Notices of the Royal Astronomical Society, 182, 443
[6] Reynoso, E. M., Hughes, J. P., & Moffett, D. A. 2013, The Astronomical Journal, 145, 104