Cosmic-ray driven dynamo in spiral galaxies

Dominik Wóltański[(1)], Michał Hanasz[(1)], Kacper Kowalik[(1)], Hanna Kotarba[(2)]

[(1)] Toruń Centre for Astronomy, Nicolaus Copernicus University, Toruń, Poland

[(2)] University Observatory Munich, Germany

Abstract

We present our results of numerical simulations of the Cosmic-Ray driven dynamo in global galactic disks with spiral structure. We consider interstellar medium, composed of gas, magnetic field and cosmic-ray components. The simulations of disks dynamo have been performed by means of PIERNIK MHD code. The gravitational potential is derived from a live galactic disk composed of stars and dark matter particles, by means of N-body simulations performed with VINE code. Our results show that the Cosmic-Ray driven dynamo amplifies efficiently large scale magnetic fields in galaxies with evolving spiral arms. The amplification process is associated with efficient conversion of small-scale magnetic fields of SN-remnants into the galactic-scale magnetic fields. We find that: (1) synthetic synchrotron radio-images of polarized intensity exhibit the structure closely resembling the spiral pattern in gas distribution, (2) magnetic vectors in polarization maps appear parallel to spiral arms, (3) strong external perturbations of the gravitational potential, due to an interacting companion galaxy disorders the magnetic field structure. The magnetic field structure of the simulated spiral galaxy seems to be with the observed magnetic structure of M51, deduced from polarization maps and Faraday rotation measurements by Fletcher et al 2011.

Dynamo model

We construct a numerical global model of CR-driven dynamo (Hanasz et al 2004, 2009b) consisting of: (1.) The cosmic ray component – a relativistic gas described by the diffusion-advection transport equation, supplemented to the standard set of resistive MHD equations. (2.) The cosmic ray input of SNe, assumed at 10% efficiency of the typical SN kinetic energy output ($= 10^{51}$ erg), while the thermal energy output from supernovae is neglected. (3.) CRs diffusing anisotropically along magnetic field lines. (4.) Finite resistivity of the ISM, responsible for dissipation of small-scale magnetic fields (5.) Differential rotation of the interstellar gas. (6.) no magnetic field in the initial configuration, and weak, randomly oriented, dipolar magnetic field supplied in 10% of supernova remnants.

We assume:

⊙ Stars and dark matter particles forming the galactic disk, bulge and halo, while the gravitational potential is computed with the N-body algorithm

⊙ Interstellar medium composed of gas, magnetic field and cosmic ray component. The initial setup for the gaseous disk based on the Milky Way ISM model by (Ferriere 1998).

⊙ Supernova rate proportional to the temporal, evolving local gas density.

Simulation setup

We perform N-body simulations of the stellar galactic disk with the aid of VINE code ((Wetzsteine et al. 2008; Nelson et al. 2008)), and then CR+MHD simulations of thermal gas, magnetic field and CR components, with PIERNIK code (see Hanasz et al. 2008, 2009a, 2010a,b), which relies on the Relaxing TVD (RTVD) scheme by (Jin & Xin 1995) and (Pen et al. 2003).

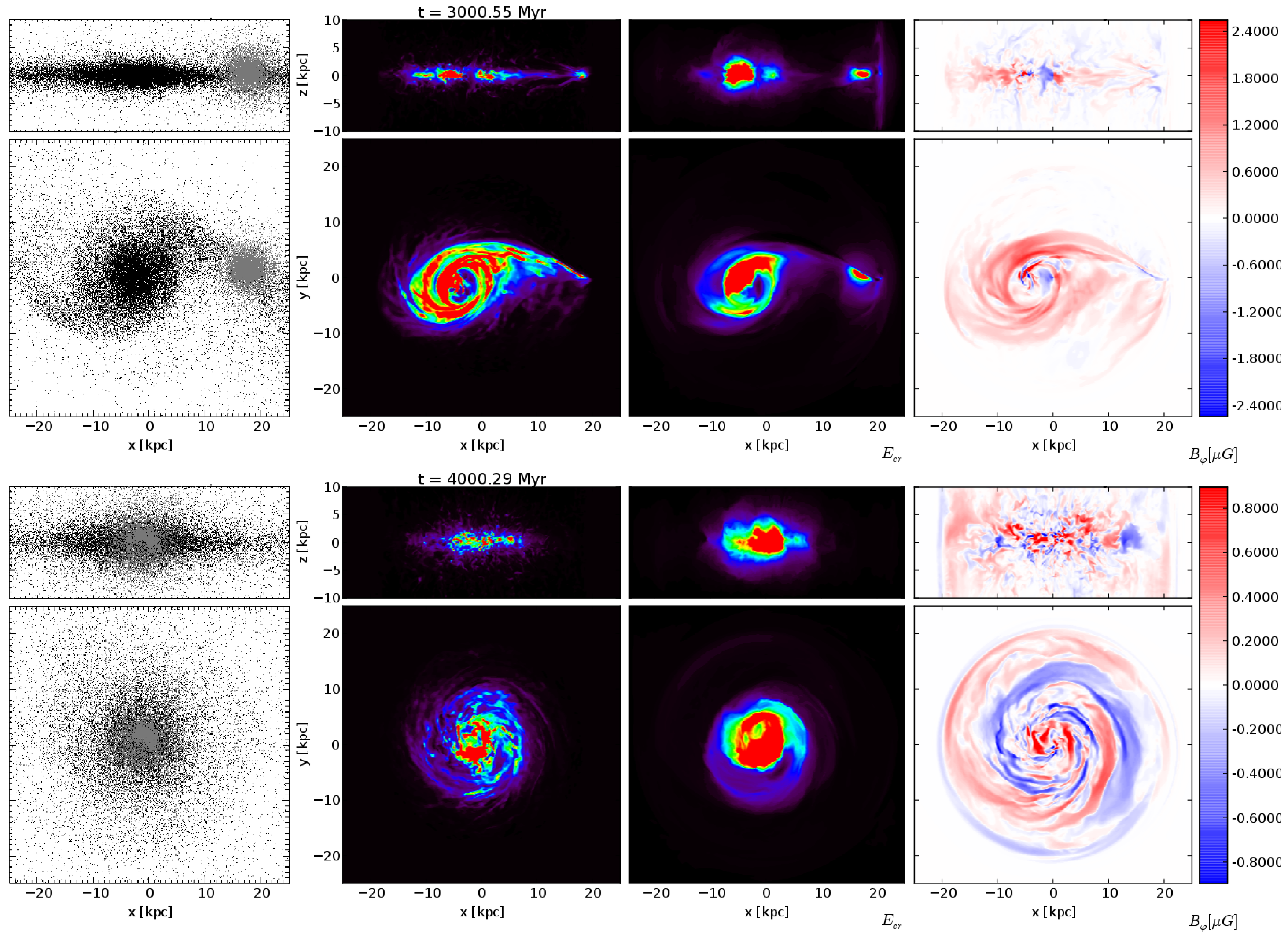
Resolution:

⊙ system 6×10^5 particles (30% of disk, 10% of bulge and 60% of halo) used in N-body simulations, ⊙ mesh of $500 \times 500 \times 200$ grid cells covering the Cartesian volume of $50 \times 50 \times 20$ kpc^3 adopted for CR-MHD simulations.

Simulation case:

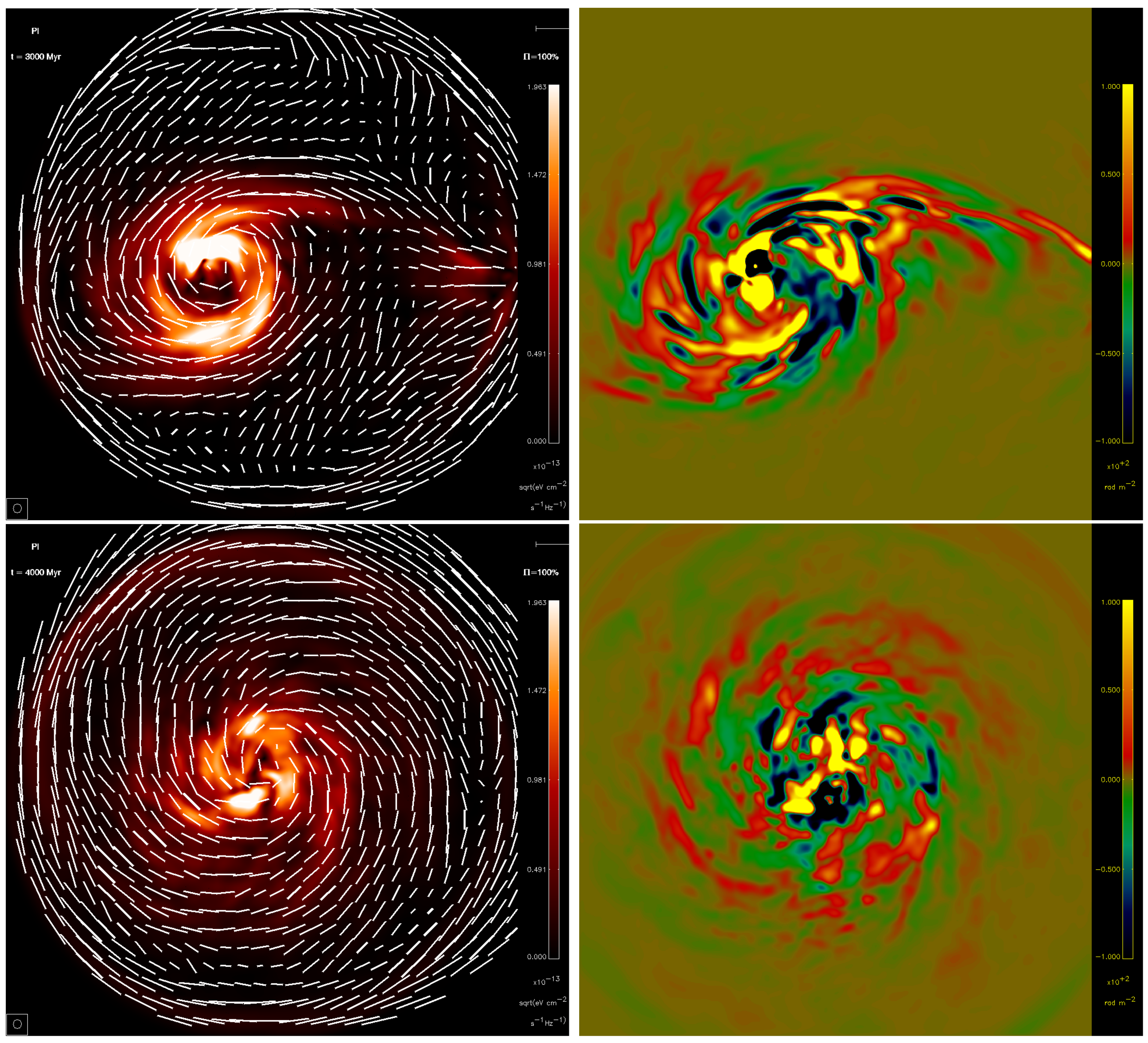
The galaxy forms spiral arms due to the gravitational interaction with a small companion galaxy. Magnetic field is efficiently amplified in the galactic disk. At $t \simeq 3$ Gyr the galaxies start to merge and the regular magnetic field component becomes disordered (see slices through the computational domain at $t = 4$ Gyr).

Simulaton results



From left to right panel: distribution of stars, gas density, cosmic-ray energy density and toroidal magnetic field component, respectively, at two stages: before and after the merger.

Synthetic radio maps of polarized intensity and rotation measure



Synthetic radio maps of the square root of polarized intensity of synchrotron emision (left) and rotation measure (right) before and after the merger. Polarization vectors direction resembles electric vectors rotated by 90°, and their lengths is proportional to the degree of polarization.

Acknowledgements

This work was supported in part by Polish Ministry of Science and Higher Education through the grants 92/N–ASTROSIM/2008/0 and N N203 511038. The computations have been performed on the GALERA supercomputer in TASK Academic Computer Centre in Gdańsk. This work was conducted within POWIEW project supported by the European Regional Development Fund in Innovative Economy Programme (POIG.02.03.00-00-018/08).

References

Ferriere, K. 1998 *Astrophys. J. 497, 759*

Fletcher, A., Beck, R., Shukurov, A., Berkhuijsen, E. M. and Horellou, C. 2011 *Mon. Not. Astron. Soc. 412, 2396*

Hanasz, M., Kowal, G., Otmianowska-Mazur, K., and Lesch, H. 2004 *2004, ApJ 605, L33*

Hanasz, M. and Kowalik, K. and Wóltański, D. and Pawłaszek, R. 2010 *EAS Publ. Series, 42, 275,*

Hanasz, M., Kowalik, K., Wóltański, D., Pawłaszek, R. and Kornet, K. 2010 *EAS Publ. Series, 42, 281,*

Hanasz, M., Kowalik, K., Wóltański, D. and Pawłaszek, R. 2008 *arXiv:0812.4839,*

Hanasz, M., Kowalik, K., Wóltański, D. and Pawłaszek, R. 2009 *arXiv:0901.0104*

Hanasz, M., Wóltański, D. and Kowalik, K. 2009 *Astrophys. J. Let. 706, L155*

Jin, S. and Xin, Z. 1995 *Comm. Pure Appl. Math., 48, 235*

Nelson, A. F., Wetzstein, M. and Naab, T. and . 2008, *arXiv:0802.4253*

Pen, U.-L., Arras, P. and Wong, S. 2003 *AStrophys. J. Supp. 149, 447*

Wetzstein, M., Nelson, A. F., Naab, T. and Burkert, A. 2008, *arXiv:0802.4245*