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COSMIC SHOCK WAVES ON LARGE SCALES OF THE UNIVERSE

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ABSTRACT

In the standard theory of the large scale structure formation, matter accretes onto high density perturbations via gravitational instability. Collisionless dark matter forms caustics around such structures, while collisional baryonic matter forms accretion shocks which then halt and heat the infalling gas. Here we discuss the characteristics, roles, and observational consequences of these accretion shocks.

The simulations of large scale structure in the universe, which include the evolution of baryonic matter as well as that of dark matter, have shown the formation of accretion shocks around the nonlinear structures such as supergalactic sheets, filaments, and clusters of galaxies (see, for example, Kang *et al.* 1994). Figure 1 shows the contours of baryonic density in a simulation performed with the cosmological hydrodynamic code described in Ryu *et al.* (1993). It is for a standard cold dark matter model universe in a box with $(32h^{-1}\mathrm{Mpc})^3$ volume using 128^3 cells and 64^3 particles. Solid lines indicate the regions with density larger than the mean baryon density while dotted lines indicate those with lower density. Shocks exits around the high density structures where density increases sharply.

The properties of the shocks and the accreting matter outside the shocks depend upon the power spectrum of the initial perturbations on a given scale as well as the background expansion in a given cosmological model. To study them, we calculated the accretion of dark matter particles around clusters in one-dimensional spherical geometry under various cosmological models (Ryu & Kang 1996). The velocity of the accreting matter around clusters of a given temperature is smaller in a universe with smaller Ω_o, but only by up to $\sim 24\%$ in the models with $0.1 \leq \Omega_o \leq 1$. It is given as $v_{acc} \approx 0.9 - 1.1 \times 10^3 \mathrm{km\ s}^{-1}[(M_{cl}/R_{cl})/(4 \times 10^{14}\mathrm{M}_\odot/\mathrm{Mpc})]^{1/2}$. However, the accretion velocity around clusters of a given mass or a given radius depends more sensitively on the cosmological models. It is smaller in a universe with smaller Ω_o by up to $\sim 41\%$ and $\sim 65\%$, respectively, in the models with $0.1 \leq \Omega_o \leq 1$.

Considering that these accretion shocks are very big with a typical size $\gtrsim$ a few Mpc and very strong with a typical velocity jump $\gtrsim$ a few 1000 km s^{-1}, they could serve as possible sites for the acceleration of ultra high energy cosmic rays by the first-order Fermi process (Kang, Ryu, & Jones 1996; Kang, Rachen, & Biermann 1996). With Jokipii diffusion, the observed cosmic ray spectrum near 10^{19}eV could be explained with reasonable parameters if about 10^{-4} of the infalling kinetic energy can be injected into the intergalactic space as the high energy particles. This problem was discussed by H. Kang in details at this meeting.

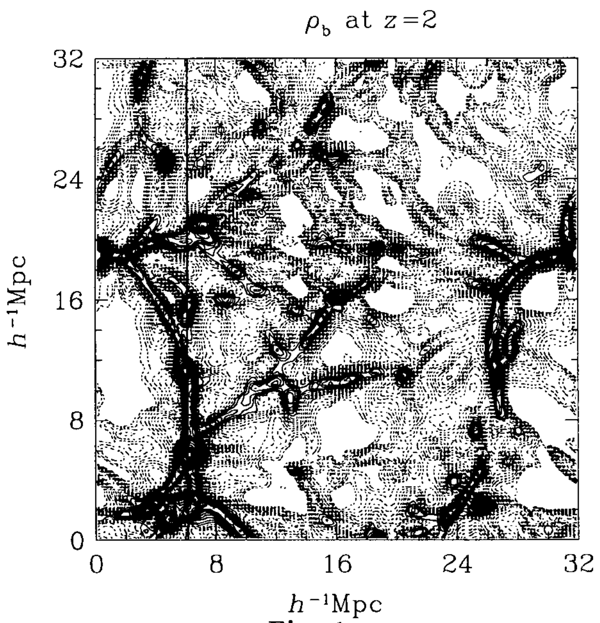

Fig. 1.

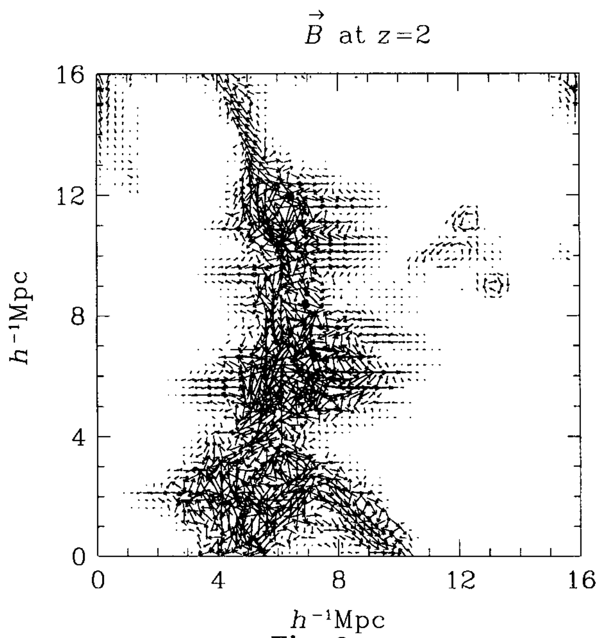

Fig. 2.

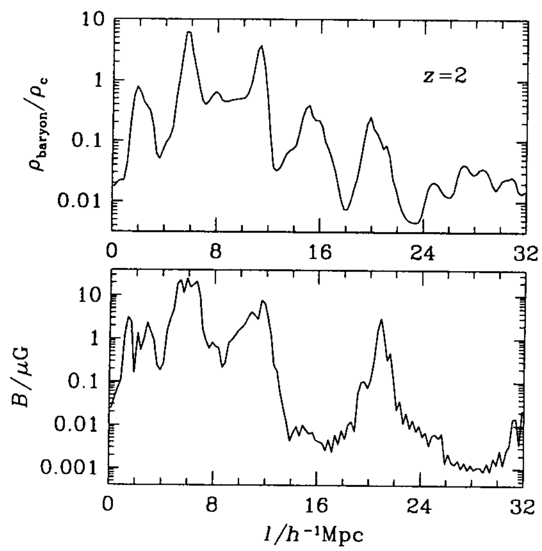

Fig. 3.

The shocks could serve also as sites for the generation of weak seeds of cosmic magnetic field by the Biermann battery mechanism. Then, these seeds could be amplified to strong (up to a few μG) and coherent (up to the galaxy scale) magnetic field by the Kolmogoroff turbulence endemic to gravitational structure formation of galaxies(Kulsrud *et al.* 1996). Figure 2 shows the vectors of seed magnetic field generated by the Biermann mechanism in a simulation which follows the evolution of magnetic field as well as that of matter. It shows the same slice as that in Figure 1 but is magnified for clarity. The size of arrows is proportional to the log of magnetic field strength. In the highest density regions of clusters, the magnetic field is chaotic since the flow motion is turbulent. However, in the regions which are identified as filaments or sheets, the magnetic field is aligned with the structures due to the streaming flow motion along the structures.

If there is aligned magnetic field in filaments and sheets, this would induce the Faraday rotation in polarized radio waves from extra-galactic sources. Then, an upper limit in its strength can be placed by comparing the expected rotational measure with the observed limit of rotational measure RM = 5 rad m^{-2} at $z = 2.5$ (Kronberg 1994) due to the intergalactic magnetic field. We performed this calculation using the data from the same simulation as that for Figure 2 (Ryu, Kang, & Biermann 1996). Figure 3 shows the resulting distributions of density and magnetic field strength along the line drawn in Figure 1. The result indicates that, with the present value of the observed limit in rotational measure, the existence of magnetic field of $0.1 - 1\mu$G in filaments and sheets can not be ruled out.

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