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Magnetohydrodynamic shocks in the intracluster medium (*)

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Summary. — The existence of the MHD shocks in the intracluster medium (ICM) is well evidenced by the radio halos in some clusters of galaxies. Among the possible sources of the ICM MHD shocks, merging of galaxy clusters is under consideration in this paper. The roles of the MHD shocks that were generated via this merging events, are investigated in relation to the topics such as a correlation of the radio halos to the X-ray properties, production of relativistic particles, the ICM magnetic-field amplifications, particle accelerations. I propose in this paper that radio halos were formed in cluster mergers.

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1. – Introduction

There are many rich clusters of galaxies whose ICM is dense and hot enough to produce X-ray emission. Some of them contain numbers of cluster radio sources, but most of these clusters are known to have no radio halos or, if they do, only a patchy one at best, such as those in A2255, A2319, and A1367. Can we render the absence of radio halos to the weakness (or the absence) of the intracluster magnetic field? The answer is probably yes.

Considering the various possibilities discussed in Kim [1], it seems reasonable that an intracluster magnetic field is universally existent, although its strength might differ greatly from cluster to cluster. Given a very weak seed field originating from either the stripped magneto-ionic ISM or the ejecta of the readily magnetized radio plasma or even a primordial magnetic field, what strength and spatial distribution of magnetic

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field would result through interaction of galaxies with the ICM? According to De Young [2], turbulent wakes behind a moving galaxy seem not quite capable to produce a field of 10^{-6} G, starting from about 10^{-8} G. Besides, the galactic wake theory has another weakness. No wake has yet been observed in clusters.

Then what else can we invoke to produce turbulences in the ICM? Here, the merging process of clusters is proposed as a source of the MHD shocks amplifying an intracluster magnetic field to an order of microgauss via the turbulent dynamo. A brief estimation of the energetics is presented here to see if the energy budget is enough to supply the X-ray and radio halo luminosities.

2. – Cluster merger and energetics

Suppose a group of galaxies of a mass M_g is being merged to a typical galaxy cluster of M, which is about $10^{15} M_\odot$. The terminal velocity v of the body initially at rest at R is $v \sim (GM/R)^{1/2} \sim 2000$ km/s, which is obviously supersonic to a typical cluster of galaxies. Note that the ion sound velocity of the Coma is $v_i = \sqrt{5kT_{gas}/3m_p} \approx 1200$ km/s, where m_p is the proton mass. If the group release its kinetic energy within a few crossing time, the luminosity $\mathcal{L}$ available for a merging event becomes

$$\mathcal{L} \approx f \frac{1}{2} M_g v^2 / t_c \sim 10^{44} \left(\frac{f}{0.01} \right) \left(\frac{M_g}{10^{13} M_\odot} \right) \left(\frac{v}{2000 \text{ km/s}} \right)^2 \left(\frac{t_c}{10^9 \text{ years}} \right) \text{ ergs/s},$$

where f is an energy conversion factor. Even a 1% conversion of the merging energy is just comparable to the X-ray luminosity and, of course, is more than enough to maintain a radio halo ($L_{halo} \sim 10^{40}$ ergs/s for Coma, see Kim *et al.* [3]). Once the gas in the cluster is heated, it stays hot long since the gas cooling time exceeds the Hubble time. Thus, one or several merging events would lead the cluster gas heated enough to turn into a strong X-ray–emitting cluster of galaxies.

It must be pointed out that the merging produces large-scale shocks, which should be comparable to the size of the group. Groups of galaxies extend typically on the order of 100 kpc or so. The magnetic field we expect to be amplified via a merging process could have a curvature radius of this order as well. This curvature is large enough to produce ultraenergetic particles via the first-order Fermi process. At the presence of synchrotron losses, the maximum energy of an electron that can be reached within a crossing time is turned out to be $\gamma \sim 10^8 u_s / B_\mu^{3/2}$. Here, γ is the Lorentz factor, u_s is the shock velocity in units of 2000 km/s, B_μ is the field strength in microgauss. These particles can easily deplete their energy in a short-time period down to $\gamma \sim 10^4$, suitable for a radio halo. Therefore, the cluster merging picture can produce not only an intracluster magnetic field of the order of microgauss but also rejuvenate particles which can illuminate the field to make the radio halo visible.

The intracluster magnetic field should become randomly oriented, since it is being amplified through turbulences. For such a field, field reconnection becomes the primary mechanism determining the lifetime. However, the reconnection time scale is reasonably long, though this is much shorter than the well-known Ohmic dissipation time scale:

$$t_{rec} \approx 3 \cdot 10^9 \, B_\mu \left(\frac{\varepsilon}{0.1} \right) \left(\frac{l}{10 \text{ kpc}} \right) \left(\frac{n_e}{2 \cdot 10^{-3} \text{cm}^{-3}} \right)^{1/2} \text{year},$$

where εv_A is a reconnection speed slower than the Alfvén speed (Soker and Sarazin [4]) and l is the scale of the field. Therefore, since the merging event occurs on time scale of $t_m \sim 2 - 4 \cdot 10^9$ year (Edge, Stewart and Fabian [5]), which is shorter than the Hubble time, the intracluster magnetic field could maintain its strength. The only trouble is that the lifetime of the relativistic electrons $\tau \sim 10^8$ years is shorter than the frequency of the merging events. This implies that the primary requirement for a radio halo to be luminous is not the magnetic field but the rejuvenation of relativistic particles.

3. – Conclusions

It is very impressive that all of the rare clusters that have strong radio halos are all merging clusters: Coma, A2256, A2319. This is a positive signal for the merging picture (Tribble [6]). This can explain many problems as a bunch, including 1) the magnetic-field amplification, 2) particle accelerations, 3) X-ray luminosity, 4) the rarity of the radio halos. The rarity is due to $t_m > \tau$, meaning that the electrons age quick and stay inert long before the rejuvenation via a merging. Thus, unless merging is ongoing in a cluster, a radio halo can hardly be visible. This also implies that the galactic wake does not seem to work efficiently as previously thought [1].

The cluster merging is not the process that has just started now, but this has been operational over the Hubble time. Since each merging event is expected to accompany the amplifications of mangetic fields via shocks and turbulences, we expect nearly all the clusters to have their intracluster magnetic fields of significant strengths. This possibility is well supported by the positive detection of excess Faraday Rotation Measures from sources seen through Abell clusters of galaxies (Kim *et al.* [7]). More observations especially for merging clusters to detect radio halos are substantiated.

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REFERENCES

[1] KIM K.-T., *Nuovo Cimento B*, **105** (1992) 845.
[2] DE YOUNG D. S., *Astrophys. J.*, **386** (1992) 464.
[3] KIM K.-T., KRONBERG P. P., DEWDNEY P. E. and LANDECKER T. L., *Astrophys. J.*, **355** (1990) 29.
[4] SOKER N. and SARAZIN C. L., *Astrophys. J.*, **348** (1990) 73.
[5] EDGE A. C., STEWART G. C. and FABIAN A. C., *Mon. Not. R. Astron. Soc.*, **258** (1993) 177.
[6] TRIBBLE P. C., *Mon. Not. R. Astron. Soc.*, **263** (1993) 31.
[7] KIM K.-T., TRIBBLE P. C. and KRONBERG P. P., *Astrophys. J.*, **379** (1991) 80.