Pseudo-Maxwellian and Ring Velocity Distributions in Magnetic Reconnection

Shunsuke Usami[1,2], Ritoku Horiuchi[1]
[1] National Institute for Fusion Science, National Institutes of Natural Sciences,
[2] The University of Tokyo
e-mail (speaker): usami.shunsuke@nifs.ac.jp

Magnetic reconnection is a fundamental phenomenon which contains a wide variety of research topics. In order to investigate various processes associated with magnetic reconnection, velocity distributions are analyzed in satellite observations and simulation studies.

Among various types of velocity distributions, ring-shaped velocity distributions are focused on. Ring velocity distributions are created because of the gyromotion of seed charged particles [1-5]. Let us consider that seed particles are continuously supplied to a region in which there exist an electric field $\boldsymbol{E}$ and a magnetic field $\boldsymbol{B}$ causing the $E \times B$ drift with a velocity $\boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}}$. In our previous works [3,4], we have assumed that seed particles have the same initial velocity. In a velocity space, the orbit of the seed particles is a circle whose center is $\boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}}$ so that a ring velocity distribution with no width is formed.

In this work, we consider that seed particles initially have velocity variations [5]. As a plausible case of the seed particles, we postulate a shifted Maxwellian velocity distribution $(1/2\pi v_{T0}^2)\exp[-(\boldsymbol{v}-\boldsymbol{v}_0)^2/2v_{T0}^2]$. In a velocity space, the orbits of the seed particles are concentric circles whose center is $\boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}}$, and hence a ring velocity distribution with a width is created. We formulate a function G which expresses a ring distribution with a width as follows [5]:

$$G(\boldsymbol{v}) = \frac{1}{2\pi v_{T0}^2} \exp\left[-\frac{V^2 + v_R^2}{2v_{T0}^2}\right] I_0\left(\frac{V v_R}{v_{T0}^2}\right), \qquad (1)$$

where $v_R = |\boldsymbol{v}_0 - \boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}}|$ (the circle radius), $V = |\boldsymbol{v} - \boldsymbol{v}_{\boldsymbol{E}\times\boldsymbol{B}}|$, and I_n is the modified Bessel function of the first kind. The shape of G significantly depends on v_R and v_{T0}. Figure 1 shows a bird's eye view of G. We set $v_{T0} = 0.3$, 0.5, 0.7, and 1.0 in the panels (a)-(d), respectively, while $v_R = 1.0$ in all the panels. In the panels (a) and (b), each shape has a dip in the center, and ring-shape holds. In the panel (c), there is not a dip, but a plateau in the center. The panel (d) shows that the shape becomes a mountain structure. From Eq. (1), we analytically derive that if $v_{T0} > v_R/\sqrt{2}$, the local minimum of the ring center changes into the maximum, and consequently the shape is transformed into maintain structure. We name it "a pseudo-Maxwellian distribution," because it is almost indistinguishable in shape from a genuine Maxwellian distribution.

By using our code "PASMO," we carry out particle simulation runs of magnetic reconnection in the presence of a guide magnetic field. In cases of the guide field ratio $B_g = 2$, we find ring-shaped ion velocity distributions which have a finite width. Next we simulate cases of $B_g = 1$, in which ions as the seed particles have a larger thermal speed, because compressional heating in the upstream region is stronger than the cases of $B_g = 2$. Actually, we observe that mountain-shaped ion velocity distributions are formed in the downstream. They are too similar to a Maxwellian distribution to be distinguishable in shape, and thus we almost conclude that they are pseudo-Maxwellian distributions.

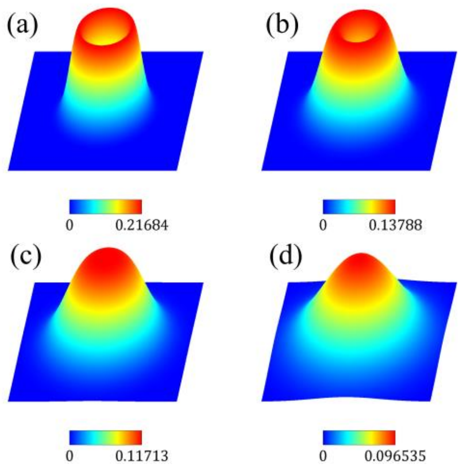

Figure 1: Brid's eve view of the function G expressed by Eq. 1, (a) for $v_{T0} = 0.3$, (b) for v_{T0} =0.5, (c) for $v_{T0} = 0.7$, and (d) for $v_{T0} = 1.0$.

To completely prove that they are pseudo-Maxwellian distributions, we show two types of evidence. One is to analyze the dependence of the distribution shape on the guide magnetic field. The other is to observe velocity distributions under a hypothetical condition of an artificial zero temperature in the upstream by utilizing a test particle simulation. From the two types of evidence, it is definitely confirmed that the mountain-shaped distributions found in the particle simulations are pseudo-Maxwellian distributions. These results imply that pseudo-Maxwellian distributions would be created for various cases of guide field magnetic reconnection. For detail, see Ref. [5].

References

[1] E. Möbius *et al.*, Nature **318**, 426 (1985).
[2] J. F. Drake and M. Swisdak, Phys. Plasmas **21**, 072903 (2014).
[3] S. Usami, R. Horiuchi, and H. Ohtani, Phys. Plasmas **24**, 092101 (2017).
[4] S. Usami, R. Horiuchi, H. Ohtani, Y. Ono, M. Inomoto, and H. Tanabe, Phys. Plasmas **26**, 102103 (2019).
[5] S. Usami and R. Horiuchi, Front. Astron. Space Sci. **9**, 846395 (2022).