9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Instability of current sheet in low-density plasma around the anchor region of relativistic jets of AGNs

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Understanding of the structure of active galactic nuclei is rapidly progressing thanks to high-resolution observations by very long baseline interferometer, general relativistic magnetohydrodynamics (GRMHD), and general relativistic radiative transport. Currently, it is suggested that the accretion disks of Sgr A* and the central nucleus of the giant galaxy M87 (M87*) are most consistent with the model, in which accretion is inhibited by a strong magnetic field, called a Magnetically Arrested Disk (MAD) model [1,2]. In the GRMHD numerical calculations on the MAD model, the relativistic jet observed from M87* is formed by the rotational energy of the black hole extracted by the very strong magnetic field across the black hole. However, the source of the plasma for the jet remains unclear because the plasma from the accretion disk cannot cross the strong magnetic field because of the frozen-in condition. At present, it is generally believed that plasma near the black hole is composed of pair plasma (electron-positron plasma) generated by the pair creation in strong magnetic field and strong radiation from the accretion disk, such as flares (e.g. [3]). However, it is hard to believe that strong radiation from the accretion disk exists to supply the jet plasma through pair production continuously.

The strong magnetic field around the black hole originates from the turbulent magnetic field in the accretion disk, so there should be no special direction and it is thought to contain many antiparallel magnetic fields (Fig. 1). When the density of the current layer in the antiparallel magnetic fields decreases, two-stream instability occurs. This instability causes the current layer to collapse, the magnetic field to disappear, and plasma is supplied from the disk.

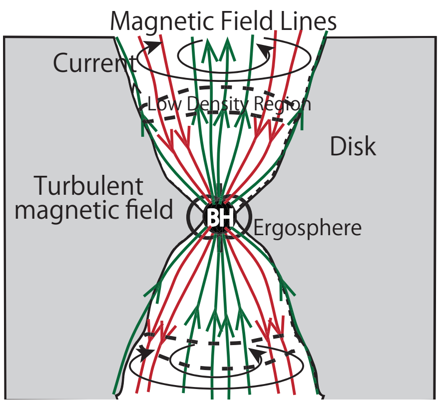

Figure 1. A schematic picture of low density region in the jet forming footpoint area around a spinning black hole (BH) of AGN. The magnetic field in the low density region may contain thin current sheet supporting the anti-parallel magnetic field of MAD model.

Primary numerical calculations using the criteria for two-stream instability [4] showed that the annihilation of the magnetic field occurs much faster than magnetic reconnection. However, in the simulations, an artificial model was used to calculate the disappearance of the magnetic field. In this study, we performed a direct (first-principle) numerical 2D calculations of the instabilities using the two-fluid equation of the current sheet, and investigated the physical process in which the current layer collapses and the antiparallel magnetic field disappears (Fig. 2). Unexpectedly, the simulations show that the two-stream instability is inhibited slightly by the effect of finite width of current sheet and rapid kink instability occurs. The two-steam kink instability would destroy the current sheet and the anti-parallel magnetic field disappears. The kind instability shown in Fig. 2 decreases the vertical component of magnetic field only near the current sheet at $t = 11$. Longer simulations with lower density is required to confirm the annihilation of the magnetic field due to the instability in the low density region.

References

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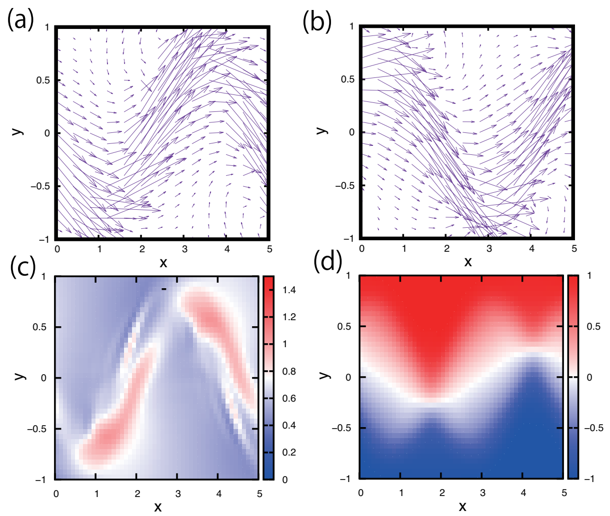

Figure 2. The snapshot of the 2D simulation of two-fluid plasma at $t = 11$. (a) Current density of positively charged fluid $\boldsymbol{J}_+$. (b) Current density of negatively charged fluid $\boldsymbol{J}_-$. (c) Density of positively charged fluid. (d) Vertical component of magnetic field B_z.