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Development of magnetically driven outflow from circumnuclear disk and its impact on the surroundings

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Supermassive black holes (SMBHs) are believed to grow rapidly in active galactic nuclei (AGN). AGN show jets and winds at different scales, a fraction of which seems to be powered (at least partly) by magnetic fields [1]. The magnetic driving of jets requires a large-scale poloidal field, and a "large"-scale field needs to be generated in the disks or carried from a large scale, possibly from the galactic scale in the form of accretion flows. However, how the mass and magnetic fields are transported toward SMBHs from the galactic scale remains unresolved. Solving this problem is challenging because of the huge scale gap between the two.

Theoretical and observational studies suggest the presence of circumnuclear disks (CNDs), which are objects at intermediate scales (~1-100 pc) between the small-scale accretion disks of SMBH and the galactic scale. Revealing the transport process of the mass and magnetic fields from the galactic scale to CNDs will therefore be important to understand the scale connection.

Recently, a collimated bipolar outflow in a Compton-thick AGN, NGC1377 is found by the Atacama Large Millimeter/submillimeter Array (ALMA) [2]. This AGN is extremely radio-quiet and has no radio jet. The Doppler velocity of the outflow is consistent with the picture of either a rotating or precessing outflow. The luminosity is found to be insufficient to power the outflow. For these reasons, the outflow is considered to be a magnetically driven outflow. As the launching region seems to be in the CND, this object is a great example to investigate the mass and magnetic field transport at the intermediate scale.

Motivated by the ALMA observation, we study the accretion of a magnetized flow and the development of a magnetically driven outflow at the intermediate scale. In this study, we particularly aim to investigate the connection between the galactic and CND scales using a simplified model.

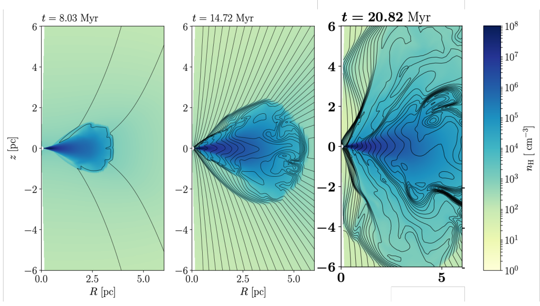

Figure 1. Formation process of outflows. Surrounding gases accrete to form a disk (left panel). A magnetic field is transported and accumulates above the disk (middle panel). Finally, a thinly squeezed magnetically driven outflow is emitted from both poles (right panel)

We conducted axisymmetric magnetohydrodynamic (MHD) simulations of the accretion of a rotating, magnetized gas in a galactic center. The numerical domain covers the scale ranging from 0.1 pc to 300 pc and resolves the Bondi radius. A magnetized CND is formed as a result of the accretion, as shown in Figure 1. The disk size grows in time, and the poloidal field is accumulated in the disk. The field strength is determined by the balance between advection and magnetic diffusion [3].

At some point, CND suddenly starts to blow a bipolar MHD outflow. We found that the outflow can reach the Bondi scale, without being stopped by the accretion flow. The outflow is surrounded by shock waves, which can heat the surrounding gas. These results imply that the outflow may have a dynamical feedback to the galactic scale. We will discuss the overall scenario of the mass and magnetic field transport and possible feedback of the outflow.

Reference

[1] Laha et al. 2021, Nat. Astron.,5,13

[2] Aalto et al. 2020, A&A, 640, p. A104

[3] Shinsuke Takasao et al. 2022, ApJ 926 5

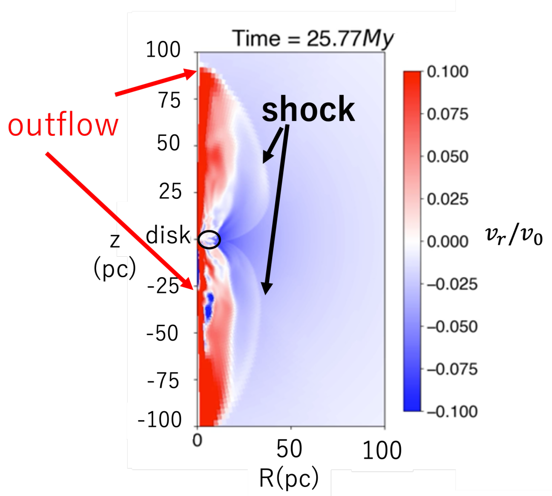

Figure 2. Development of outflow to Bondi scale. The magnetically driven outflow is developed and ejected in a thin and narrowly focused manner. It can also be seen that shock waves are generated at the same time. This outflow reaches the Bondi radius (~100 pc) that characterizes the connection to the galaxy.