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# Outflow from black hole accretion flows

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Black hole accretion is accompanied by wind and jet. In addition, episodic ejection is also observed. In this talk, I will review the current understanding of the wind from hot accretion flows and episodic ejection.
The study of wind can be traced back to the first global numerical simulation of black hole accretion where the mass inflow rate is found to decrease with decreasing radius (Fig. 1). This is surprising because people have been assuming that the inflow rate should be a constant of radius. Two models have been proposed to explain this result, with one being convection another being outflow (or wind). To study which model is correct, we have performed numerical simulations of black hole accretion. Using simulation data, we have analyzed the convective stability and found that the MHD accretion flow is convectively stable. We have also compared the velocity, angular momentum, and Bernoulli parameter of inflow and outflow and found that they are systematically different. This indicates that inflow and outflow are not due to convective turbulence. These results suggest that systematic outflow must exist and is the reason for the inward decrease of accretion flow.

The properties of wind such as their mass flux and velocity are crucial for the study of AGN feedback. The values of these two quantities are not easy to obtain since they are contaminated by MRI turbulence. In the literature many works do time-average to the simulation data to filter the turbulence. But this will also filter out wind since wind is instantaneous. Instead, we have tried to obtain the trajectories of virtual test particles in the accretion flow to judge whether the flow is wind or turbulence. In this way, we can loyally trace the wind and obtain their properties. Using this approach, we have successfully obtained the wind properties launched by hot accretion flow of different modes, i.e., MAD and SANE, around black holes with various spin values. The mass flux of wind as a function of radius is shown in Fig. 1. We have also compared the fluxes of energy and momentum of wind and jet. The observational evidences of wind and the comparison between theory and observations will also be briefly discussed.

The second topic we will discuss is episodic ejection from accretion flows. Such kind of ejection has been observed in more and more AGNs, such as Sgr A*, M81, and M87, and in some cases the velocity of the ejected blobs has been measured. By analogy with the coronal mass ejection in the Sun, we have proposed an MHD model for episodic ejection from accretion flows. In this scenario, flux ropes are formed in the coronal region of the accretion flow due to the magnetic reconnection driven by the turbulent and differential motion of the accretion flow where magnetic field lines are rooted. The flux rope will be further ejected out due to the magnetic pressure force. We have performed 3D GRMHD simulation and confirmed this scenario (Cemeljic et al. 2022). The trajectories of ejected flux rope are shown in Fig. 2. During the reconnection, electrons will be accelerated and they will emit strong radiation. This explains why ejection is associated with flares, as observed by GRAVITY in Sgr A* (Lin, Li & Yuan 2023).

References

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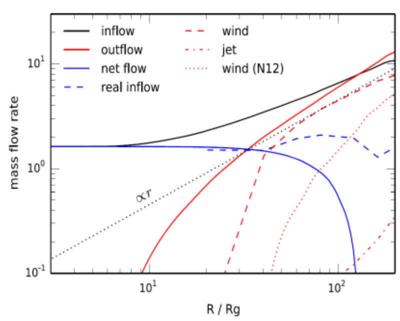


Fig. 1. The mass fluxes of inflow, outflow, wind, and jet as a function of radius. Taken from Yuan et al. (2015).

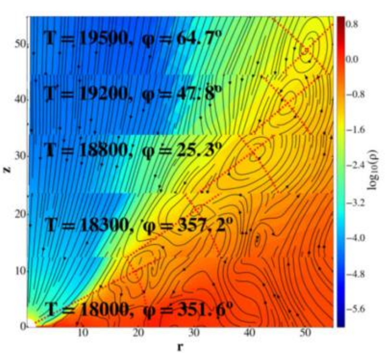


Fig. 2. The trajectories of ejected flux ropes. Taken from Cemeljic et al. (2022).