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Hydrodynamic Simulations of Radiation-driven Sub-parsec Scale Multiphase Outflows in Active Galactic Nuclei

Yuki Kudoh[1], Keiichi Wada[2], Nozomu Kawakatu[3], Mariko Nomura[4]
[1] Tohoku University, [2] Kagoshima University,
[3] National Institute of Technology (KOSEN), Kure College, [4] Hirosaki University
e-mail (speaker): yuki.kudoh@astr.tohoku.ac.jp

Active Galactic Nuclei (AGN) are located in the central regions of galaxies and are significantly brighter than the entire galaxy. The gas structure of AGN is thought to explain the statistical properties of objects with varying ionizing emission line intensities in a unified manner through the presence of a dust torus that obscures the central region.[1] Outflowing gas, on the other hand, has recently been revealed by multi-wavelength observations ranging from X-ray to radio bands.[2] The brightness of AGN can be attributed to the release of gravitational energy through gas accretion. However, the relationship between this brightness and gas outflow/accretion is not well understood.[3]

Wada (2012, 2015)[4,5] showed by radiation hydrodynamics simulations that AGN outflow driven by dust radiation force accumulate in a fountain-like structure on scales of tens of parsecs. This gas structure successfully explains the observed molecular gas in radio wavelengths [6] and thermal dust in infrared [7].

We have carried out the simulations of dust-driven outflows on sub-parsec scales, spatially resolving the sublimation radius where dust is destroyed by radiation. We found that a steady AGN source irradiating a geometrically thin dust disk causes time-varying outflows with shock-induced shells (Figure 1). [8]

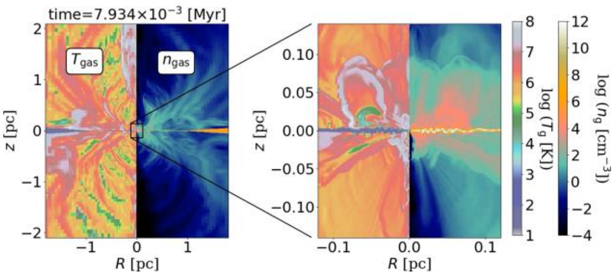

Figure 1. In each panel, the temperature (left side) and density (right side) of the gas are shown. Left panel is the parsec-scale distribution. Right panel is zoomed into the sub-parsec scale of the left panel.

The sub-parsec-scale outflow plays a crucial role in understanding the dynamics of dust-free and dusty gases, contributing to the obscured structure covering the central nuclei. We also studied the dependence of the Eddington ratio, which is the bolometric luminosity divided by the Eddington luminosity proportional to the SMBH mass. When the Eddington ratio is larger than 10^{-3}, the radiation force overcame the gas pressure. This resulted in the stronger outflow and larger dust sublimation radius. The time averaged temperature and number density of outflows were almost independent of the Eddington ratio. However, the density within 0.1 parsec and outflow velocity outside the dust sublimation radius were dependent on the angle because of the gas acceleration of the gas pressure or the dust-radiation force. The dusty and dust-free gases covering the nucleus were essentially determined by the dust sublimation radius independent on the Eddington ratio.

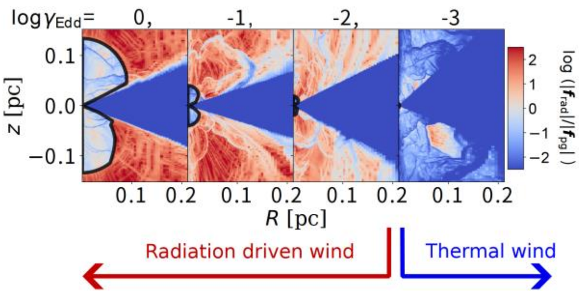

Figure 2. The spatial distributions denote the ratio of the radiation force to gas pressure force for four models with different Eddington ratios, $\log(\gamma_{\mathrm{Edd}}) = 0, -1, -2$, and -3, respectively. Red regions indicate where radiation force dominates, while blue regions indicate the dominance of gas pressure. In the model with $\log(\gamma_{\mathrm{Edd}}) = -3$, the thermal wind is primarily driven by gas pressure, contrasting with the radiation-driven wind observed in the other three models. Black contours are dust sublimation radius.

References

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