CD-I3 AAPPS-DPP2019

3rd Asia-Pacific Conference on Plasma Physics, 4-8,11.2019, Hefei, China

Rapid black hole formation and growth

Kohei Inayoshi[1]

[1] Kavli Institute for Astronomy and Astrophysics, Peking University

inayoshi@pku.edu.cn:

Supermassive black holes (SMBHs) with the order of millions to billions of solar masses ($M_\odot$) are among the most interesting objects in the universe. In galaxies, where SMBHs almost ubiquitously exist and are fed with gas, a large amount of energy is released as radiation and/or in outflows. The outputs of energy associated with BH feeding affect star formation on galactic scales, and prevent gas supply onto the BH itself. Therefore, SMBHs are one of the most essential components of galaxies and are believed to coevolve with their host galaxies over the cosmic time [1]. Nevertheless, the origin of these massive BHs remains one of the most intriguing and longest-standing unsolved puzzles in astrophysics. In particular, recent observations of bright quasars have revealed that giant SMBHs with ~billions $M_\odot$ are already formed within 1 Gyr after the beginning of the universe [2, 3]. This observational fact strongly constrains the origin and formation pathway of such monster SMBHs, since the time required to form such massive objects naively exceeds a Hubble time. Their quick assembly has been attributed to mechanisms such as rapid collapse of gas into the nuclei of protogalaxies, formation of massive heavy seed BHs [4, 5] and their subsequent growth by gas accretion up to SMBHs.

The nature of BH feeding and feedback is essentially determined by the global response of the inflowing gas since most of radiation is produced in the nuclear region and gas supply begins to occur from large galactic scales. In fact, if the treatment of gas dynamics and feedback was not self-consistent at both small and large scales, the conclusion could be contradictory. However, previous studies with numerical simulations of BH accretion have focused on the gas/radiation dynamics at either small or large scales. Therefore, it is required to construct the global structure of accretion flows onto a BH at higher rates exceeding the Eddington value $\dot{M}_{\rm Edd}$, which is the critical rate above which outward force due to emergent radiation dominates gravitational force of the BH.

For this purpose, we have performed multi-frequency radiation hydrodynamical simulations including BH feedback processes, radiative cooling and chemical reactions of gas. In the specially symmetric case [6, 7], we have found that a global and steady inflow solution can be realized when a large amount of gas at a rate of $> 500\ \dot{M}_{\rm Edd}$ is supplied from the BH gravitational influence radius. In this solution, emergent radiation is efficiently trapped within the fast inflow near the BH and thus an ionized region cannot expand to the influence radius due to recombination by the ambient neutral gas. As a result, inflowing gas from larger scales is not prevented by radiative feedback associated with BH feeding, but rather leads to collapse of the ionized region. Through the transition, a steady and high-accretion-rate solution is achieved. We further extended the 1D global solutions to 2D cases, and investigated two non-spherical effects; anisotropic radiation [8] and angular momentum of the accretion flow [9], considering realistic radiation spectra which depends on the properties of the nuclear accretion disk and determines the strength of radiative feedback. In summary of those studies, we have concluded that a global and steady accretion solution from the BH gravitational influence radius down to the BH can be realized as long as the gas supplying rate exceeds $10^3\ \dot{M}_{\rm Edd}$ without depending on the detailed properties of non-spherical effects.

We apply those results to SMBHs embedded at the centers of protogalaxies and discuss their subsequent growth. We also find that the rapid BH growth model can nicely explain the recent observational results of BH mass function and luminosity function of high-redshift quasars obtained by the Hyper Suprime-Cam Subaru strategic survey program.

References:

[1] Kormendy, J., and Ho, L. C., Annu. Rev. Astron. Astrophys, 51, 511 (2013)

[2] Mortlock, D. J., Warren, S. J. and Venemans, B. P. et al., Nature, 474, 616 (2011)

[3] Wu, X.-B., Wang, F. and Fan, X., et al., Nature, 518, 512 (2015)

[4] Inayoshi, K., and Omukai, K., Mon. Not. R. Astron. Soc, 422, 2539 (2012)

[5] Inayoshi, K., Omukai, K., and Taker, E., Mon. Not. R. Astron. Soc, 445, L109 (2014)

[6] Inayoshi, K., Haiman, Z., and Ostriker, J. P., Mon. Not. R. Astron. Soc, 459, 3738 (2016)

[7] Sakurai, Y., Inayoshi, K., and Haiman, Z., Mon. Not. R. Astron. Soc, 461, 4496 (2016)

[8] Takeo, E., Inayoshi, K., Ohsuga, K., Takahashi, H. R. and Mineshige, S., Mon. Not. R. Astron. Soc, 476, 673 (2018)

[9] Sugimura, K., Hosokawa, T., Yajima, H., Inayoshi, K. and Omukai, K., Mon. Not. R. Astron. Soc, 478, 3961 (2018)