The Role of Outflow Feedback on Accretion of Compact Objects in Accretion Disk of Active Galactic Nuclei [1]

Ken Chen[1], Jia Ren[1] and Zi-Gao Dai[2,1]

[1] School of Astronomy and Space Science, Nanjing University, Nanjing 210023, People's Republic of China; [2] Department of Astronomy, School of Physical Sciences, University of Science and Technology of China, Hefei 230026, People's Republic of China.

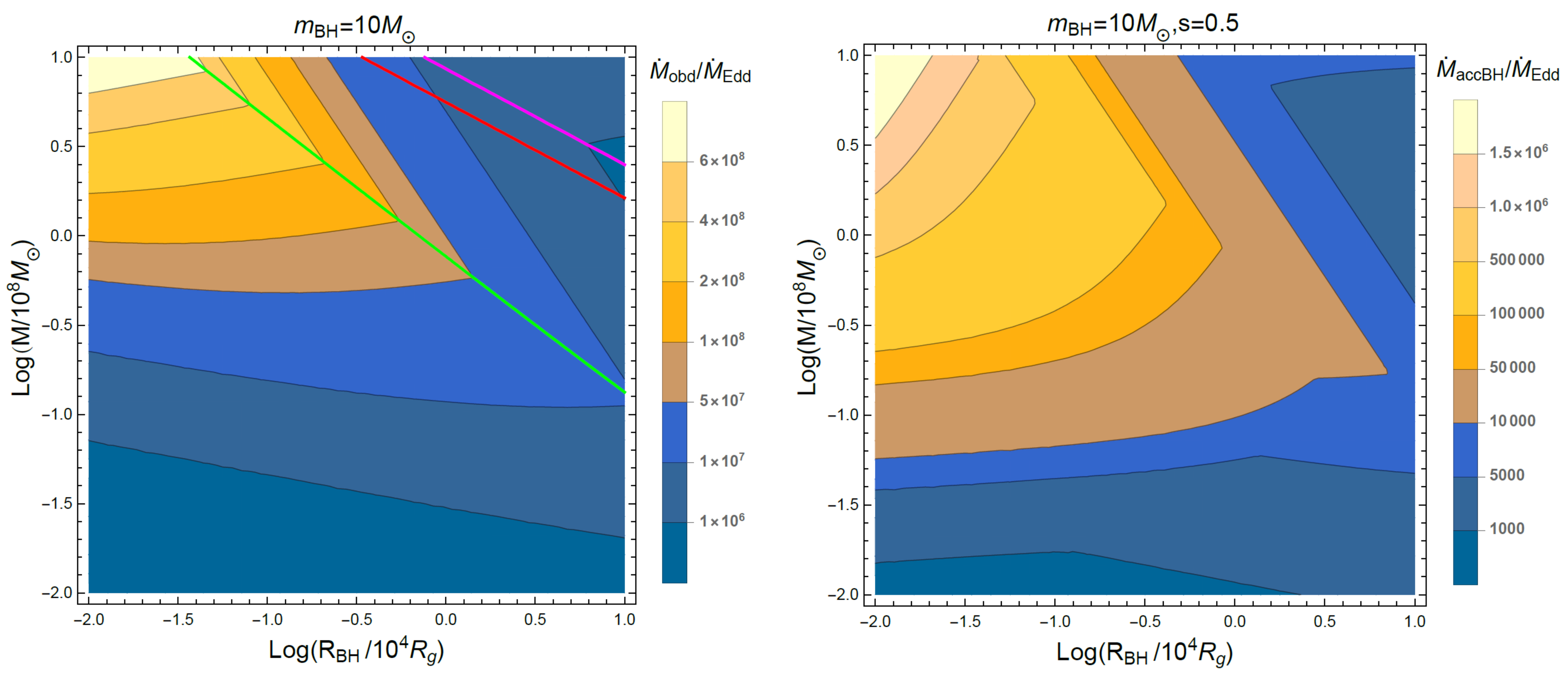
Correspondence to: daizg@ustc.edu.cn; Authors' addresses: ck@smail.nju.edu.cn, jia@smail.nju.edu.cn

Ken's Wechat QR code

Abstract Compact objects (COs) can exist and evolve in an active galactic nuclei (AGN) disk, triggering a series of attractive CO-related multi-messenger events around a supermassive black hole, e.g. [2]-[3]. To better understand the nature of an embedded CO and its surroundings and to investigate CO-related events more accurately, in this work, we study the specific accretion process of a CO in an AGN disk and explore the role of outflow feedback. We show that the CO hyper-Eddington accretion generated outflow results in recurrent formation and refilling of an outflow cavity to intermittently stop the accretion. We find that the averaged mass rate accreted onto a CO is dramatically reduced compared with the initial gas captured rate. We demonstrate that although outflow feedback itself may be unobservable, it remarkably alters the CO evolution via reducing its mass growth rate, and the AGN disk can survive from the otherwise drastic CO accretion.

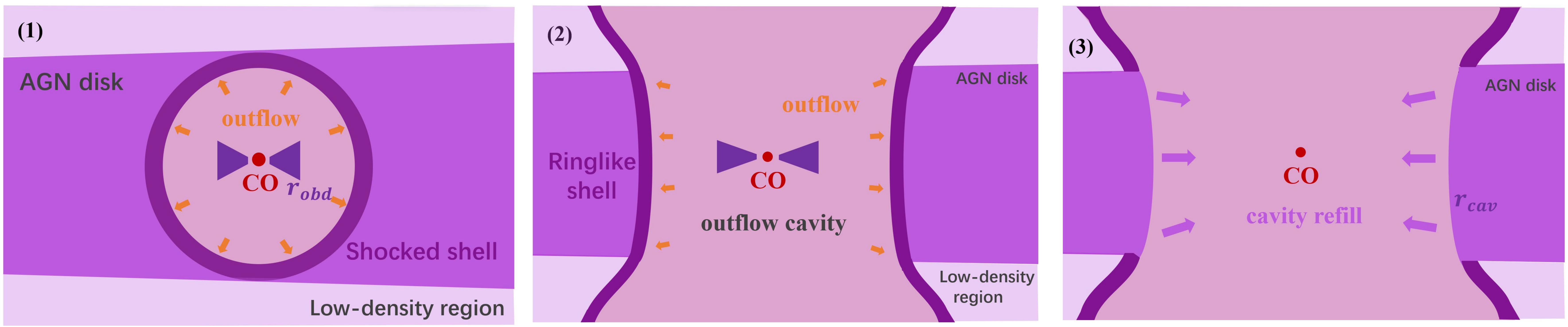
Compact object accretion in AGN disk

Embedded in an extremely dense and differentially rotating AGN disk, a compact object captures the ambient gas under Hyper-Eddington mass rate (described by the Bondi-Holye-Lyttleton formulation[4]), and a circum-CO disk would form, of which the mass inflow rate decreases with radius as $\dot{M}_{in} \propto r^{s}$[5] on account of the continuous generation of disk wind. When propagating within the optical thick environment, the Hyper-Eddington outflow becomes asymptotically isotropic.



Mass captured rate of a $10M_\odot$ black hole in an AGN disk; mass accretion rate of the black hole setting the power-law index $s = 0.5$. Though taking into account the reduction of the circum-BH disk mass inflow rate due to disk wind, the accretion rate of BH is still hyper-Eddington, i.e., $\gg \dot{M}_{Edd}$.

Accretion feedback of an embedded compact object



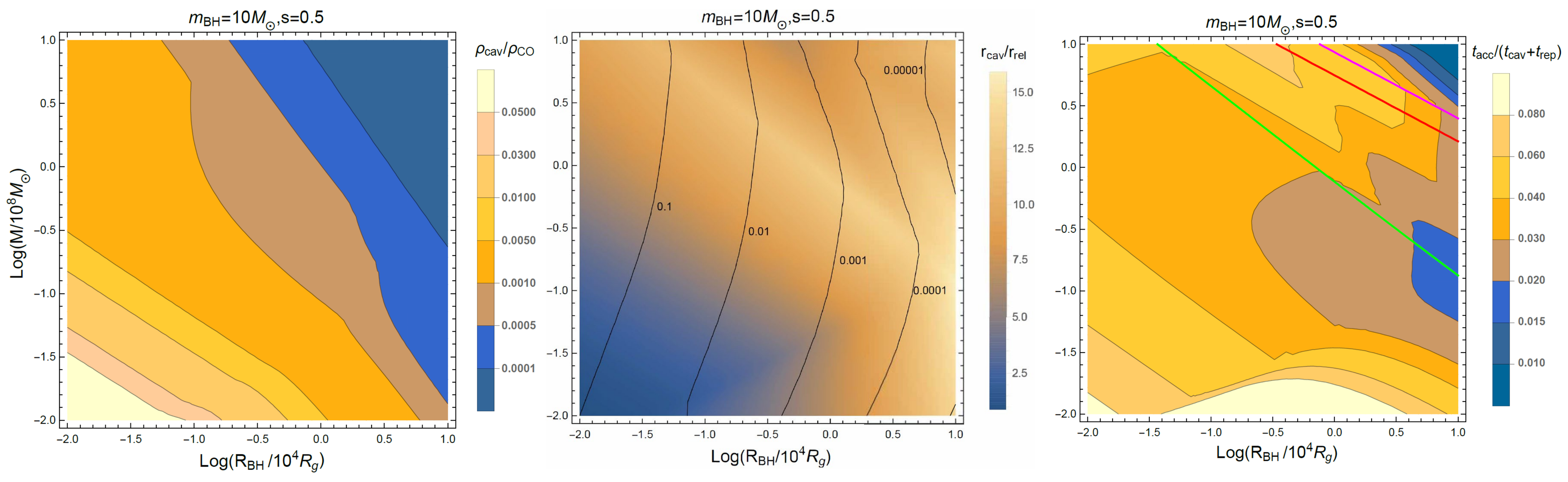
Evolution of the circum-CO disk outflow in the AGN disk.

(1) The asymptotically isotropic outflow interacts with the AGN disk gas to form a shocked shell; the shell expands to break the AGN disk and punches a cavity.
(2) Outflow persistently pushes the ringlike shell along the AGN disk on CO accretion timescale, then the shell undergoes a momentum conservation snowplow phase.
(3) After the shell becomes transonic, the surrounding gas instead resumes refilling the low-density cavity. The whole evolution processes proceed circularly.

Cavity surrounding compact object

1. The density of the outflow-produced cavity is significantly diluted compared to the initial unperturbed AGN disk environment;
2. The cavity size is much larger than the Bondi-Holye-Lyttleton radius and the Hill radius of the compact object;
3. The accretion timescale of compact object is much shorter than the duration of the cavity evolution;

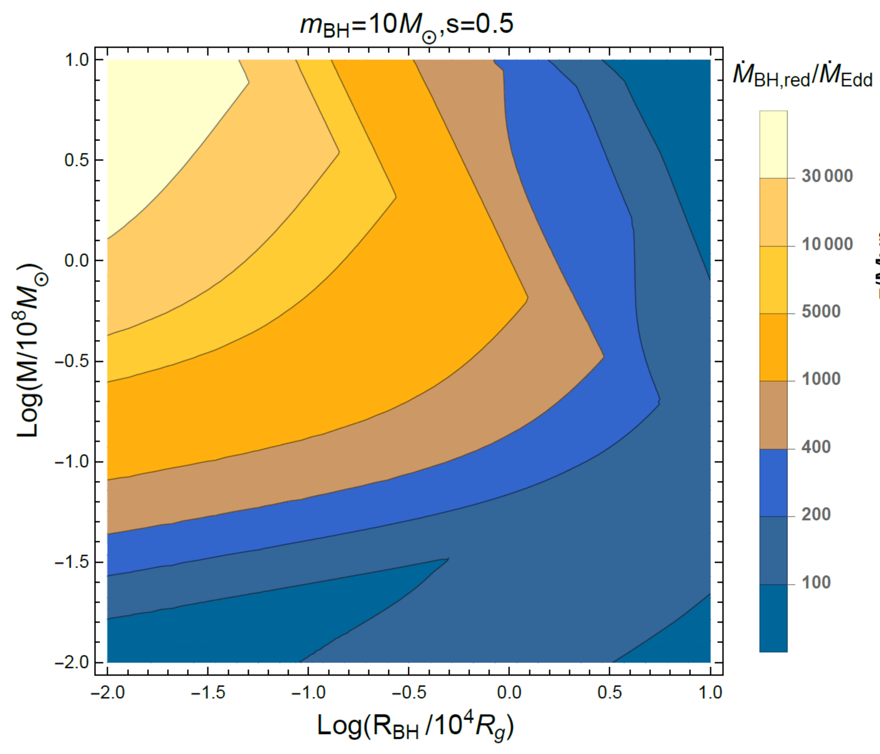
So, a compact object is generally harbored in the low density cavity rather than the AGN disk environment.

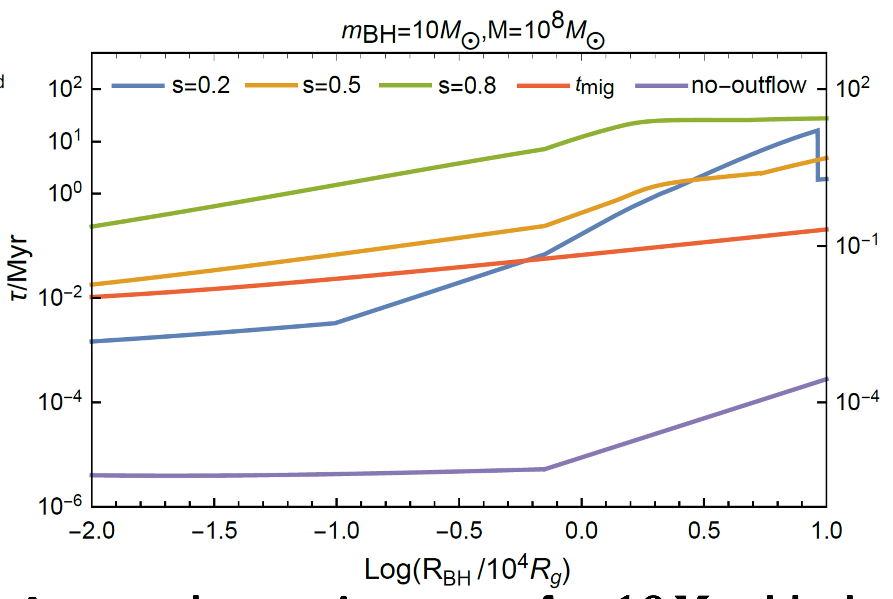


The density and the size of the outflow-produced cavity; and comparison between the compact object accretion timescale and the cavity evolution timescale.

Reduced mass accretion rate and accordingly mass growth

The averaged mass accretion rate of compact object receives a markedly reduction by $\sim O(10^4)$ order of magnitude. Compared to the case overlooking outflow feedback, the compact object would not experience violent mass growth, and can observably migrate before significantly being heavier.





Averaged accretion rate of a $10M_\odot$ black hole within one cyclic process; timescales of mass growth and migration in AGN disk.

References

[1] Chen, K., Ren, J., & Dai, Z.-G., The Role of Outflow Feedback on Accretion of Compact Objects in Accretion Disk of Active Galactic Nuclei, 2023, ApJ, 948, 136.

[2] Ren, J., Chen, K., Wang, Y., et al., Interacting Kilonovae: Long-lasting Electromagnetic Counterparts to Binary Mergers in the Accretion Disks of Active Galactic Nuclei, 2022, ApJL, 940, L44.

[3] Chen, K. & Dai, Z.-G., Electromagnetic Counterparts Powered by Kicked Remnants of Black Hole Binary Mergers in AGN Disks,2023, arXiv:2311.10518.

[4] Edgar, R., A review of Bondi-Hoyle-Lyttleton accretion, 2004, NewAR, 48, 843

[5] Blandford, R. D., & Begelman, M. C., On the fate of gas accreting at a low rate on to a black hole, 1999, MNRAS, 303, L1