Radiative cooling changes the dynamics of disks in MAD state

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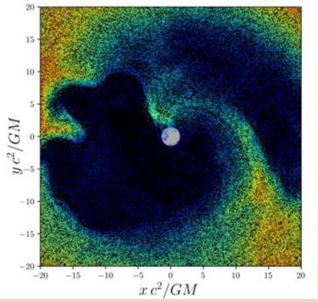
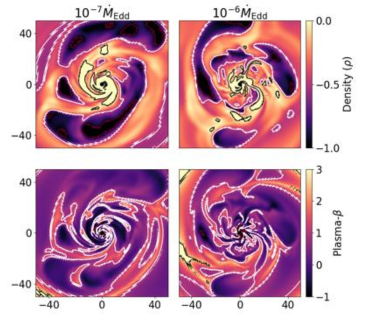
Radiative cooling can strongly influence the structure and dynamics of black hole accretion disks. Considering synchrotron and bremsstrahlung emission, we quantify how radiative losses modify the disk structure and the accretion dynamics. We introduce a critical value of the mass accretion rate, ~10^{-5.5} Eddington, above which the cooling by the synchrotron process efficiently radiates the thermal energy of the disk. We show that at higher accretion rates, the disk undergoes a structural transition: cooling substantially reduces the gas thermal pressure, leading to considerably thinner and denser accretion filaments, and a substantial increase in radiative efficiency, relative to lower accretion rates. This lead us to propose a new definition to the disk height. We numerically observe that the jet efficiency vary by a factor of ~2 as the mass accretion rate increases above the critical accretion rate. Our results thus have important observational consequences on the observed signals from both the disk and jets in accreting systems.

Background: Magnetically Arrested Disks

- Magnetic fields generated in the disk are amplified by Magneto-rotational Instability (MRI) reaching ~ equipartition values in the inner-most disk regions.
- Pending on the initial cinfiguration, they may accumulate near the BH, forming 'magnetic islands' that prevent smooth accretion. This is called "Magneticallty Arrested Disk" (MAD) state.



The inner disk becomes filamented.



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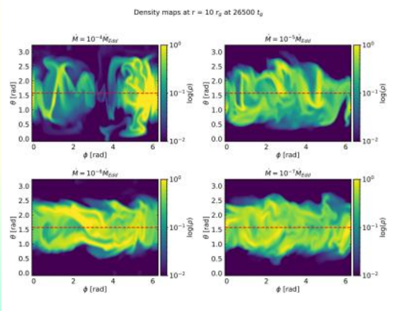
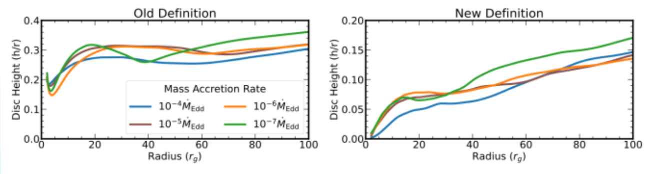
This state is ideal for strong jet formation.

Disk Filamentation & implication



Disk density as seen in θ–ϕ plane: filaments are more pronounced at high acc. rate.

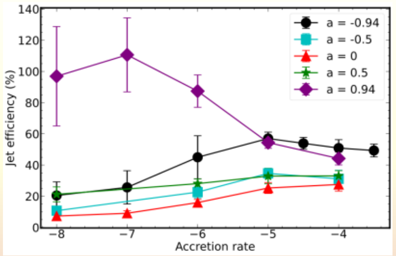
- Gas pressure loss & MAD state causes the inner disk to become filamented.
- Higher accretion rate = more filamented disk



Need a revision in the definition of the disk height: Rather than equatorial-centered, must use filament-centered.

Cooling effect on the jet efficiency

- We consider the effects of Synch. & Brem. cooling on the disk structure and the resulting jet efficiency, η.
- At low accretion rate, positive BH spin – η>100% i.e., more energy is released than enters the BH. This is the Blandford-Znajek process.



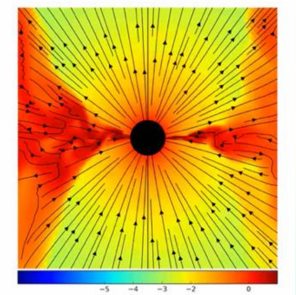
$$\eta(r = r_H) = 1 + \frac{\dot{E}(r = r_H)}{\dot{M}(r = r_H)}$$

- We identified a critical accretion rate: ~$10^{-5.5}\ \dot{M}_{Edd}$ above which grav. energy gain ~ rad energy losses.
- We derived an analytical expression for $\dot{M}_{crit}$
- Above $\dot{M}_{crit}$ the jet efficiency converges to ~50%, for all spins

Jet efficiency depends on (1) spin (2) accr. rate !

Conclusions

- The inner disk regions are not steady, but continuously evolving.
- They are highly magnetized, at near equipartition vales.
- Their structure depends on the magnetic field configuration.
- In MAD state, they are filamented. **This means that the classical measure of the disk height is invalid.**
- **The jet efficiency is a strong function of the BH spin and accretion rate.**
- We identified a critical mass accretion rate, $\dot{M}_{crit}$ ~$10^{-5.5}\ \dot{M}_{Edd}$ at which the gained grav. energy = rad. energy losses. At lower acc. rates, cooling is unimportant; At higher accretion rates, the jet efficiency (& other properties, such as structure) converges.



For full details: Singh, Bégué, Pe'er, 2025, Ap.J 98, L11; 2026a (arXiv:2605.09326); 2026b (in prep.)