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General Relativistic Magnetohydrodynamic Simulations of Black Hole Accretion Disks

Understanding the dynamics of magnetically arrested accretion disks (MAD) is crucial for deciphering relativistic jet launching mechanisms in black hole systems. General relativistic magnetohydrodynamics (GRMHD) simulations provide the most comprehensive framework for probing these extreme environments, where angular momentum transport efficiency fundamentally governs accretion-ejection coupling. This study addresses critical gaps in modeling how radiative cooling and enhanced angular momentum transport (q = 1.0) regulate jet launching thresholds during MAD state transitions.

Our advanced GRMHD simulations reveal a significant phase transition at t = 5M (gravitational timescales), where magnetic flux saturation triggers relativistic jets through the Blandford-Znajek mechanism. The q = 1.0 parameterization delays MAD onset by 25% while boosting jet efficiency—resolving persistent timing discrepancies in jet activation observed in prior studies. Quantitative validation against Event Horizon Telescope (EHT) data shows good agreement, with peak jet Lorentz factors exceeding $\Gamma > 15$ and energy conversion to kinetic outflows reaching 68%.

These results establish q = 1.0 cooling models as essential tools for interpreting state transitions in low-luminosity active galactic nuclei (AGN), providing a self-consistent framework linking angular momentum transport physics to observable jet kinematics.

Keywords: GRMHD simulations, MAD accretion, Blandford-Znajek mechanism, jet launching, black hole astrophysics, EHT observables

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