MAD Jets Induce RADs through Misaligned Angular Momentum

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M87 Shocks

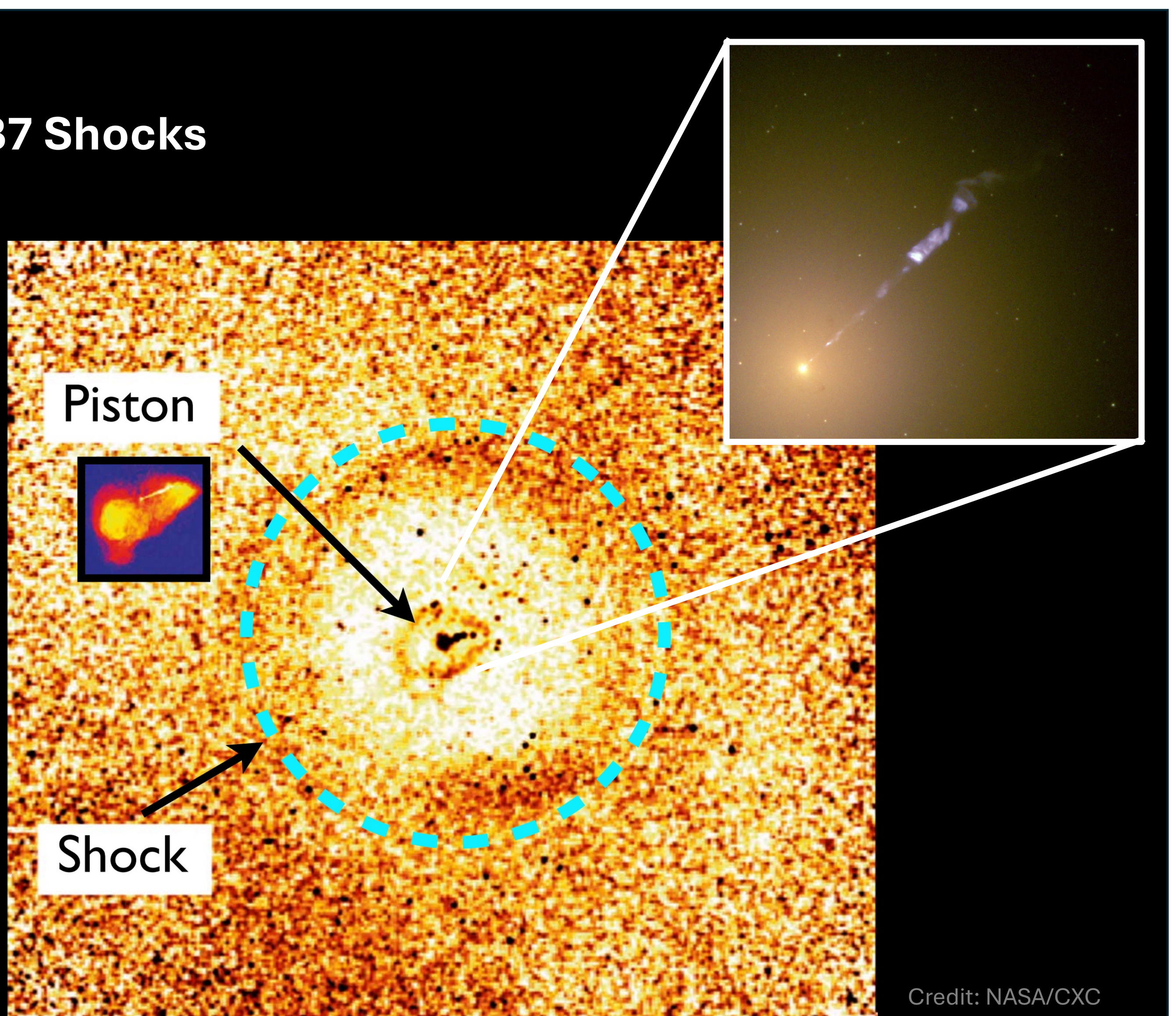

Figure 1. X-ray emission observed from the galaxy M87, which hosts a supermassive black hole (SMBH) at its center. The blue-dashed ring labels the outer edge of a shock, evidence of outbursts produced by the "piston", a jet-inflated cavity, 12Myr ago. The outburst lasted 2Myr. [1]

Whodunnit?

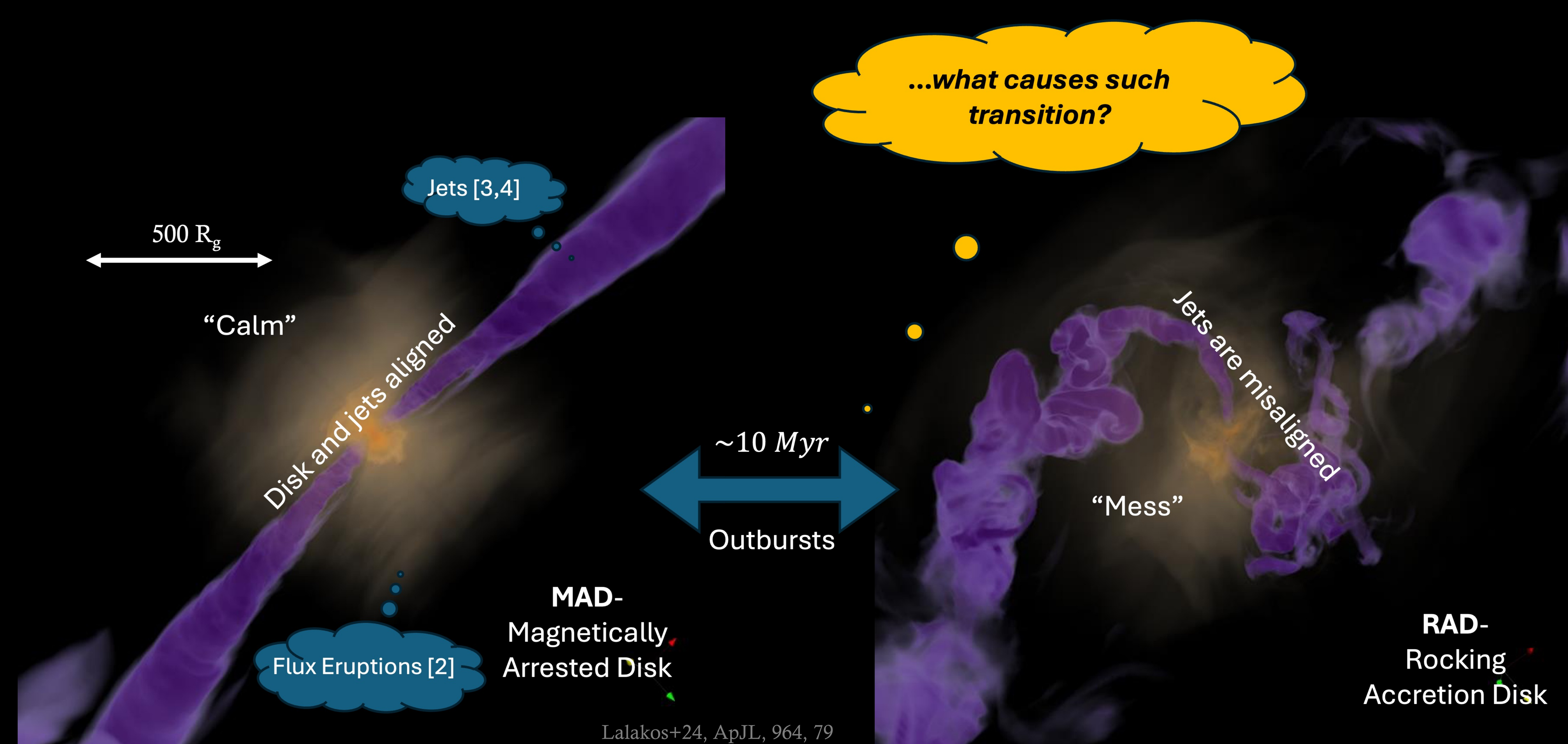

Figure 2. Magnetically arrested disk (MAD) messes up ambient medium that disrupts subsequent jet formation. While MAD produces the most powerful and stable jets, the accretion disk becomes unstable as the system evolves toward the rocking accretion disk (RAD) state, disrupting jet formation and eventually creating chaos in the ambient medium[3].

Understanding the "Mess" through "Misalignment"

The radial angular momentum flux from the ideal-GRMHD stress–energy tensor:

$$\mathcal{L}_z = T^r{}_\varphi = (\rho c^2 + u_g + p_g + b^2)u^{\mathrm{r}}u_\varphi - b^{\mathrm{r}}b_\varphi + \left(p_g + \frac{b^2}{2}\right)\delta^{\mathrm{r}}{}_\varphi$$

where,

ρ : rest-mass density
u_g : internal energy density,
u^μ : fluid four-velocity,
b^μ : magnetic-field four-vector measured in the fluid frame, $b^2 = b^\mu b_\mu$,
p_g : ideal-gas pressure, where $p_g = (\Gamma - 1)u_g$, with adiabatic index $\Gamma = 5/3$.

To calculate x, y direction angular momentum flux, create coordinate system via mapping respectively:

$$\begin{cases} S': \; x' = -z, & y' = y, & z' = x, \\ S'': \; x'' = x, & y'' = -z, & z'' = y. \end{cases}$$

Transform stress-energy tensor:

$$\begin{cases} T^r{}_{\varphi'} = T^r{}_\lambda \dfrac{\partial x^\lambda}{\partial \varphi'} = T^r{}_r \dfrac{\partial r}{\partial \varphi'} + T^r{}_\theta \dfrac{\partial \theta}{\partial \varphi'} + T^r{}_\varphi \dfrac{\partial \varphi}{\partial \varphi'} \\ T^r{}_{\varphi''} = T^r{}_\lambda \dfrac{\partial x^\lambda}{\partial \varphi''} = T^r{}_r \dfrac{\partial r}{\partial \varphi''} + T^r{}_\theta \dfrac{\partial \theta}{\partial \varphi''} + T^r{}_\varphi \dfrac{\partial \varphi}{\partial \varphi''} \end{cases}$$

Radial angular-momentum fluxes about the Cartesian axes :

$$\begin{cases} \mathcal{L}_x = T^r{}_{\varphi'} = -T^r{}_\theta \sin\varphi - T^r{}_\varphi \cos\varphi \cot\theta, \\ \mathcal{L}_y = T^r{}_{\varphi''} = T^r{}_\theta \cos\varphi - T^r{}_\varphi \sin\varphi \cot\theta. \end{cases}$$

Figure 3. Calculating the misaligned angular momentum in the $x-$ and $y-$ directions, provides us with a tool for understanding which factors tangle up the ambient medium in MADs.

Results

Flux eruption events do not directly generate misaligned angular momentum; instead, ***jets*** reshape the ambient medium and ***drive black hole MAD to RAD transitions***.

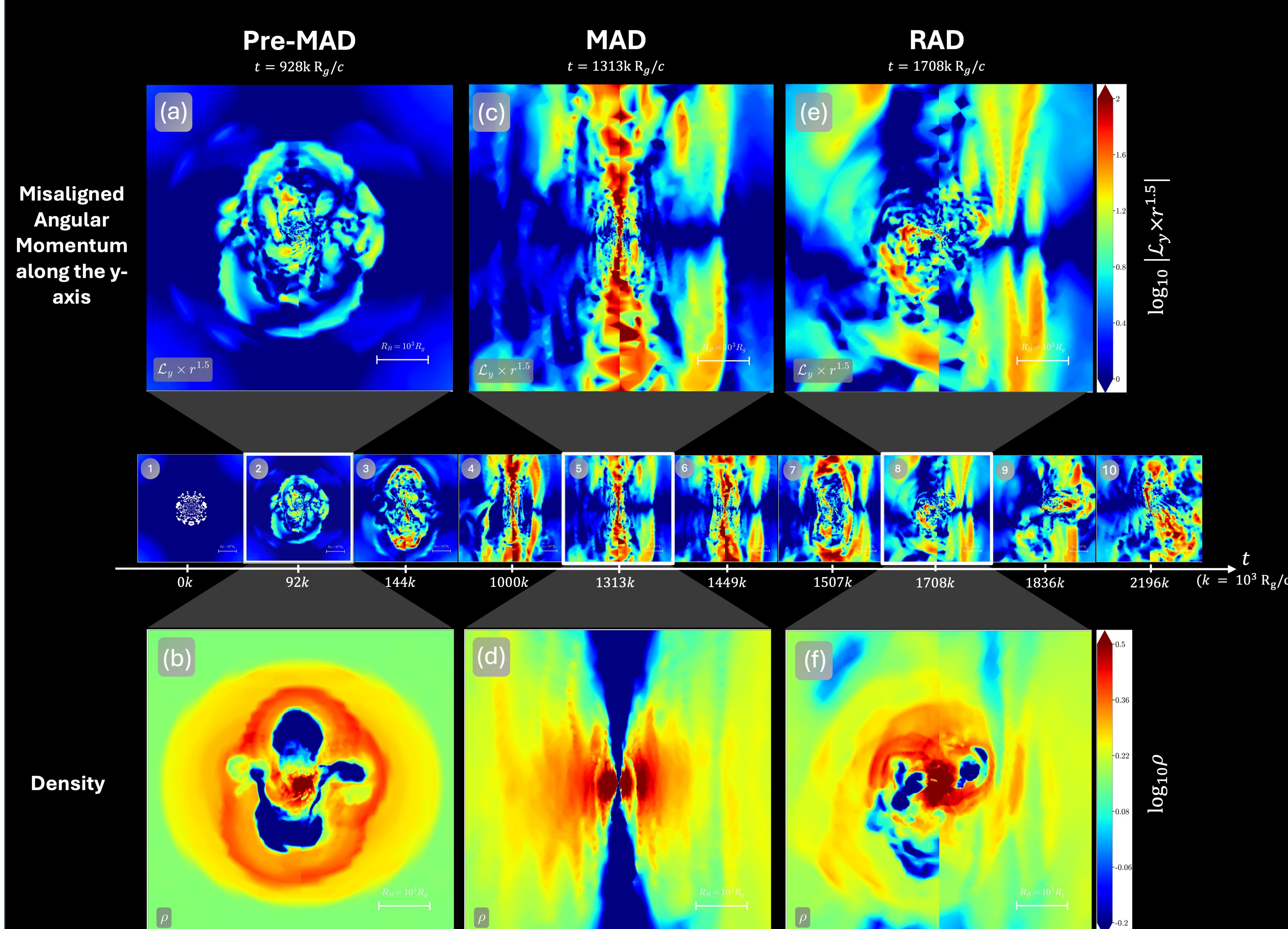

Figure 4. The ambient medium remains calm before MAD (panels a and b). The jets then disrupt its surrounding rotation (panels c and d), resulting in a tangled RAD state (panels e and f). When the bright magnetic filaments in panel c are traced through frames 4–6, they do not lose intensity as they travel away from the black hole. Therefore, these magnetic filaments, or flux-eruption events, are not the direct source of the misaligned angular momentum. Instead, the jets eject a large amount of angular momentum into the surroundings, driving the accretion flow from MAD to RAD and creating chaos in the ambient medium.

Figure 5. QR Code for full movie.

References & Acknowledgements

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