POWERING THE TRANSIENT SKY

Powering the Transient Sky: Extreme Efficiency Jet Production in BH Accretion

BLACK HOLES AT DIFFERENT FLAVOURS · WARSAW · 21–25 SEPTEMBER 2026

SELECT AN ENGINE TO DIVE IN

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TDE OUTFLOWS

What the flow needs to launch them

2

THE CENTRAL ENGINE

Jet power vs. accretion rate

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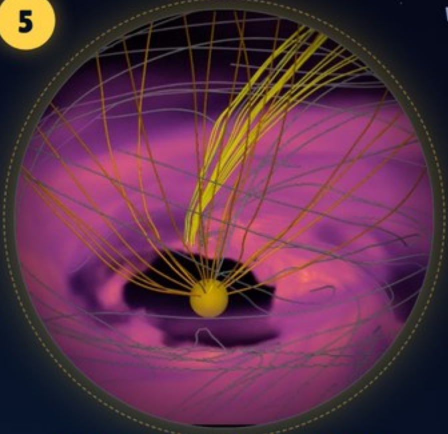

THE SUPER–MAD STATE

When magnetic pressure wins outright

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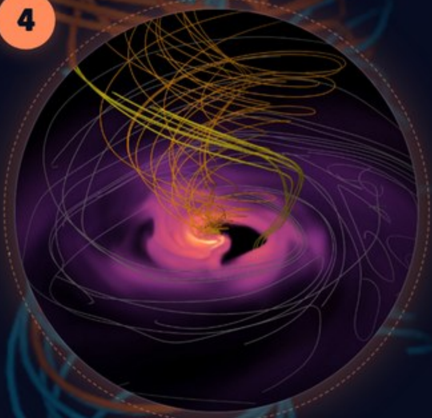
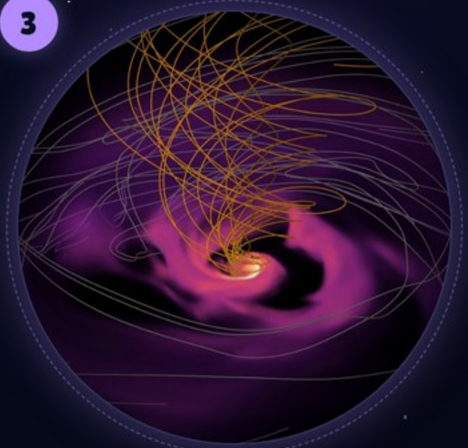


RESISTIVE MAD

Where reconnection actually happens

3



MAD ACCRETION

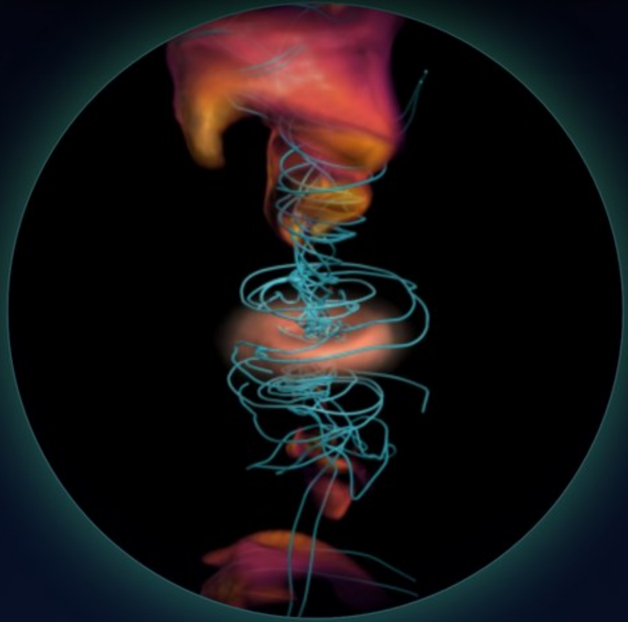
When the flow chokes on its own field

Antonios Nathanail

RCAAM · Academy of Athens

Funded by the European Union

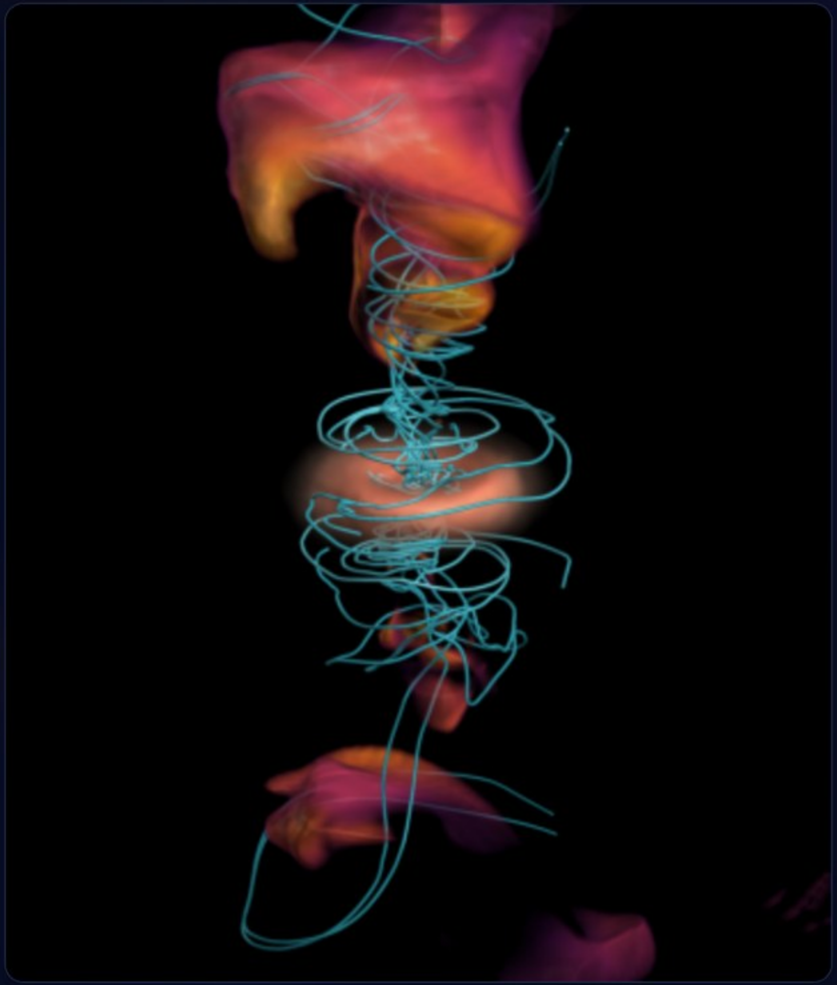
Not a jet: discrete ejections along the funnel wall



3D GRMHD, MULTI-LOOP, THREE SPINS

TDE Outflows

Sub-relativistic · episodic · late



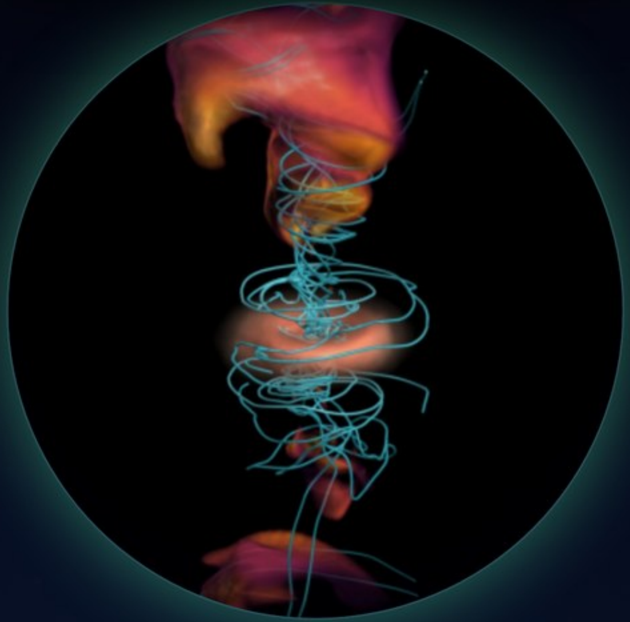
3D GRMHD, a = 0.5, t = 4990 M.

Cream: density torus. Magenta–orange: unbound gas, coloured by v/c up to 0.22. Cyan: field lines, which close back through the disc.

Overdensities are expelled one by one. Nothing collimates into a steady jet.

> Nathanail & Matsumoto 2026, *What a black-hole accretion flow needs in order to launch a sub-relativistic outflow in TDEs: the case of AT2020vwl*, to be submitted

σ < 1 wherever there is mass: no relativistic jet



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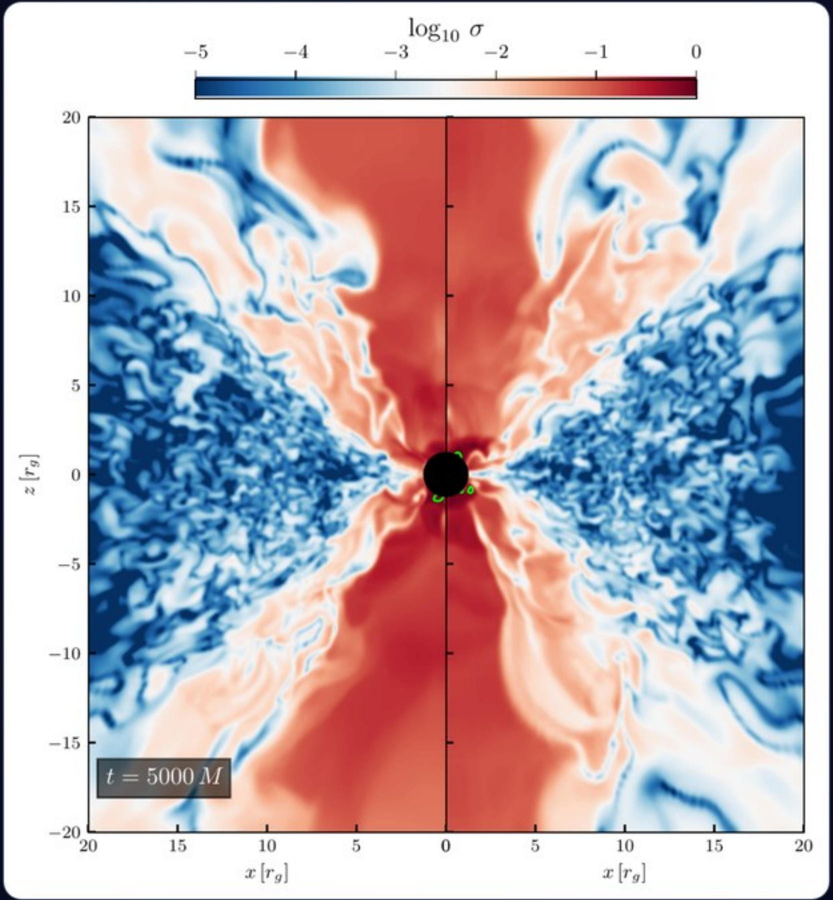

Magnetization $\sigma = b^2/\rho$ in two meridional cuts at t = 5000 M.

Only a narrow polar funnel is magnetized, and even there σ stays below unity.

Loops of alternating polarity keep the horizon flux from ever saturating.

> **Nathanail & Matsumoto 2026**, ***What a black-hole accretion flow needs in order to launch a sub-relativistic outflow in TDEs: the case of AT2020vwl***, **to be submitted**

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Spin is necessary

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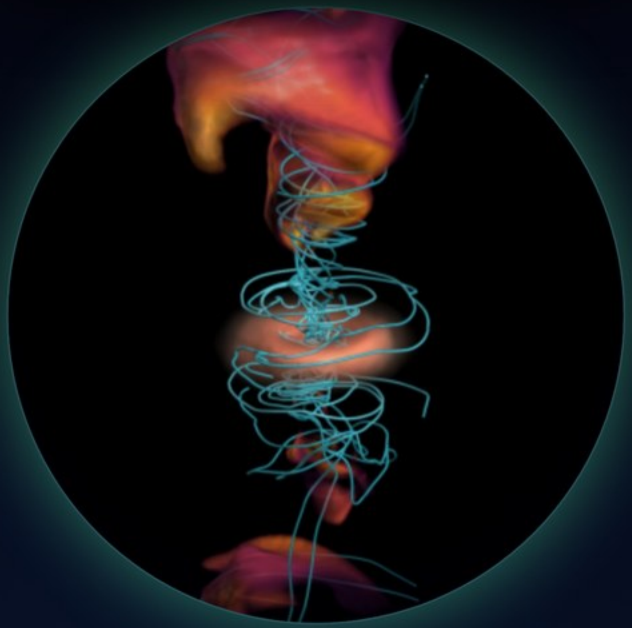
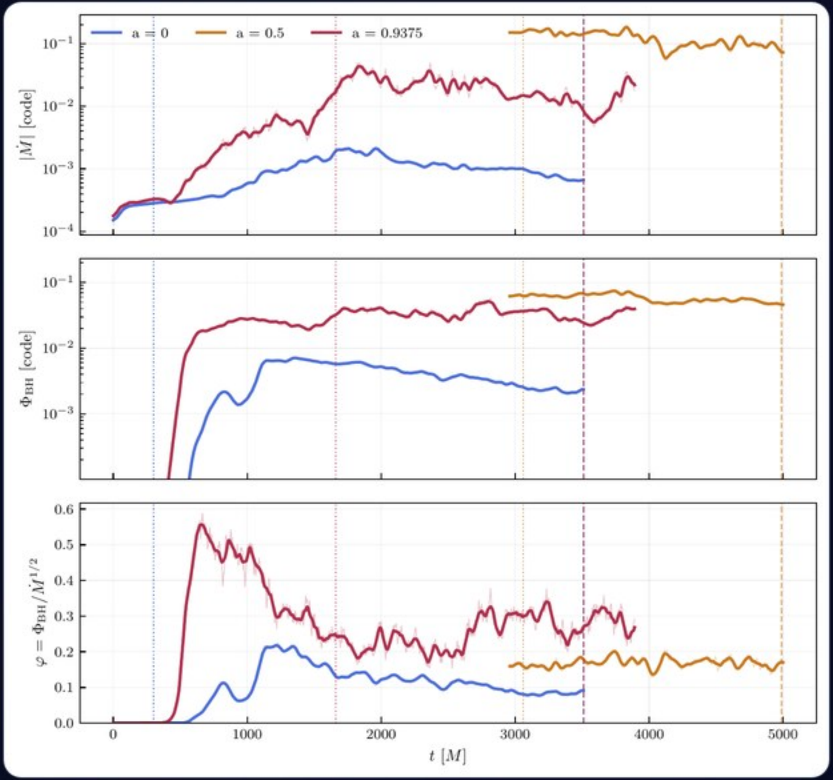


3D GRMHD, MULTI-LOOP, THREE SPINS

TDE Outflows

Sub-relativistic · episodic · late

RETURN TO OVERVIEW



$\dot{M}$, horizon flux Φ_{BH} and $\varphi = \Phi_{BH}/\sqrt{\dot{M}}$ for a = 0, 0.5, 0.94.

a = 0: no unbound outflow at all.
a = 0.5, 0.94: discrete ejections cross 50 r_g every ~500 M.

The horizon flux plateaus far below MAD: the multi-loop field cancels itself.

> Nathanail & Matsumoto 2026, ***What a black-hole accretion flow needs in order to launch a sub-relativistic outflow in TDEs: the case of AT2020vwl*, to be submitted**

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What the ejecta look like, against spin

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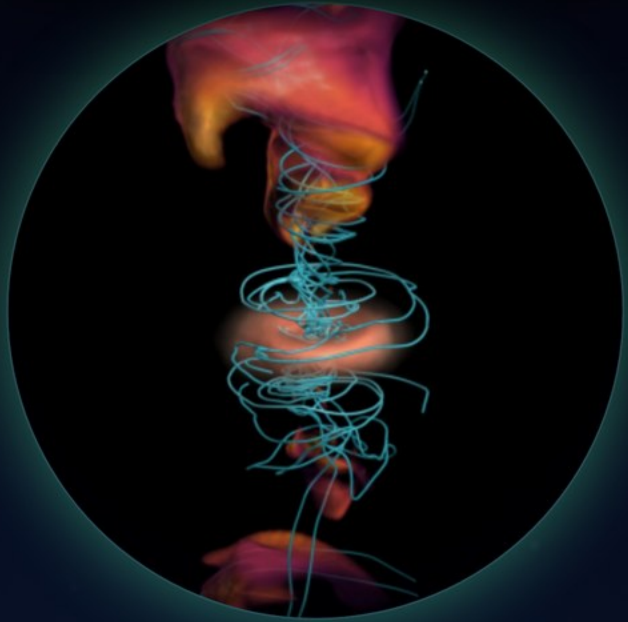

3D GRMHD, MULTI-LOOP, THREE SPINS

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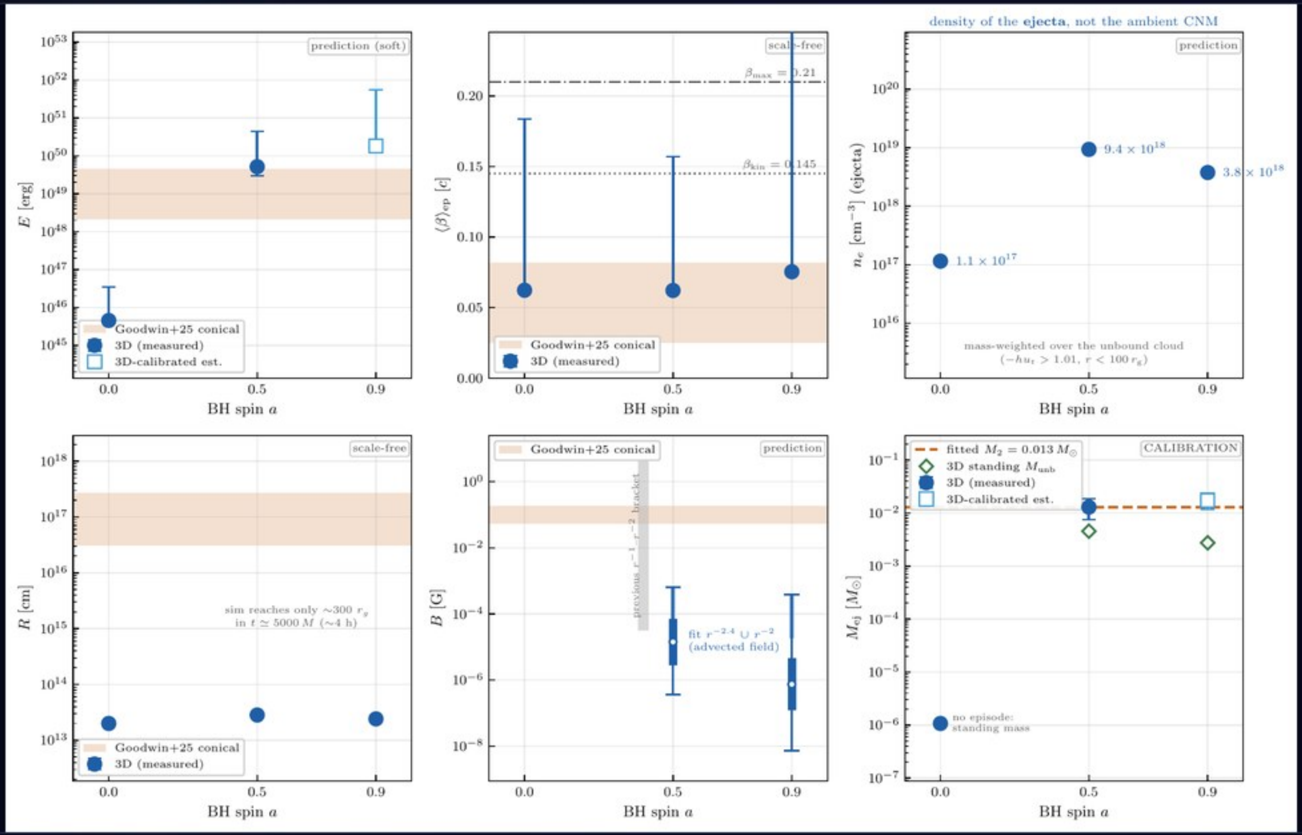


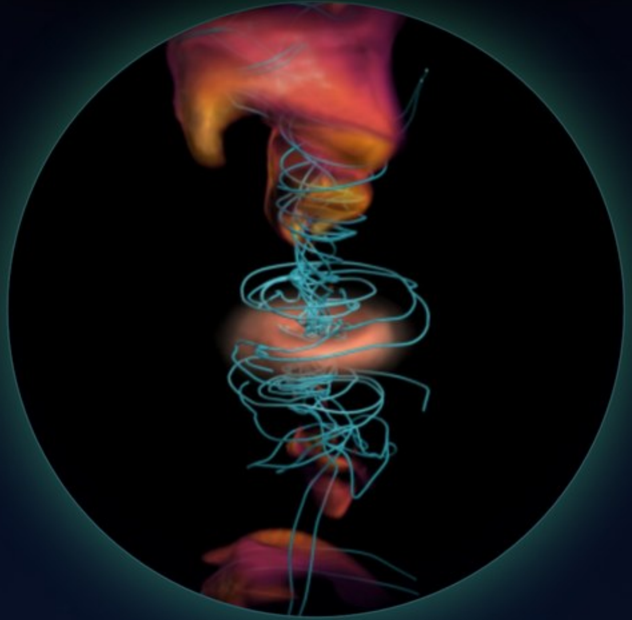
Thermally and kinetically driven ($\mu_{EM} \sim 10^{-5}$), so **$\beta \leq 0.21$**. Lightly loaded: 0.1–2% of the mass crossing 50 r_g.

$E = 5 \times 10^{49}$ erg at a = 0.5, **2×10^{50} erg** at a = 0.9. Shaded bands: AT2020vwl from the radio.

> **Goodwin et al. 2025, ApJ 981, 122 · Nathanail & Matsumoto 2026, *What a black-hole accretion flow needs in order to launch a sub-relativistic outflow in TDEs: the case of AT2020vwl*, to be submitted**

↗ RETURN TO OVERVIEW

AT2020vwl: two ejections, not a collision



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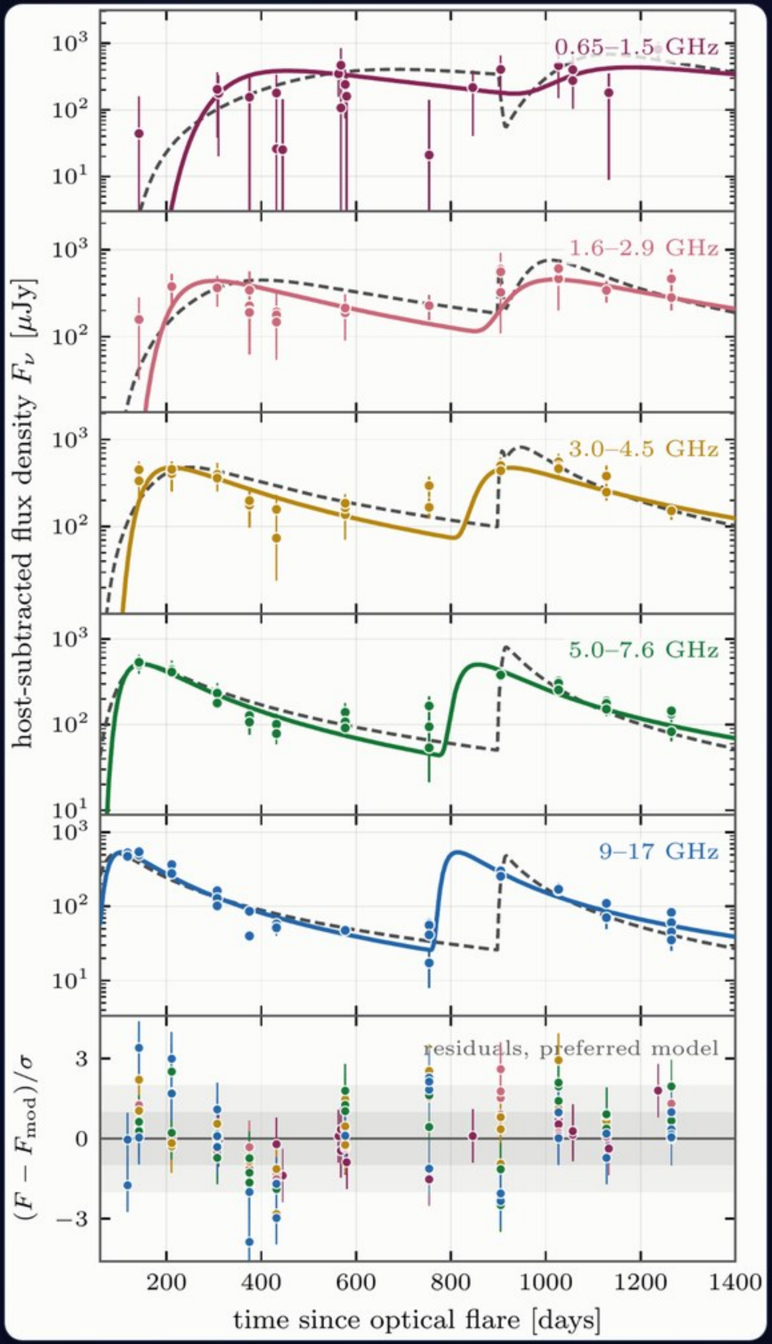

129 host-subtracted flux densities, 0.65–17 GHz, days 118–1265.

Solid: two independent ejections, **β_1 = 0.082** prompt, **β_2 = 0.151** launched at **day 722**.
Dashed: the best collision, which free-free absorbs its own low-frequency flux.

ΔAIC = 93 against the collision, 1258 against a single ejection.

Data: Goodwin et al. 2025, ApJ 981, 122 · Fit: Nathanail & Matsumoto 2026, *What a black-hole accretion flow needs in order to launch a sub-relativistic outflow in TDEs: the case of AT2020vwl*, to be submitted

Magnetically arrested disks

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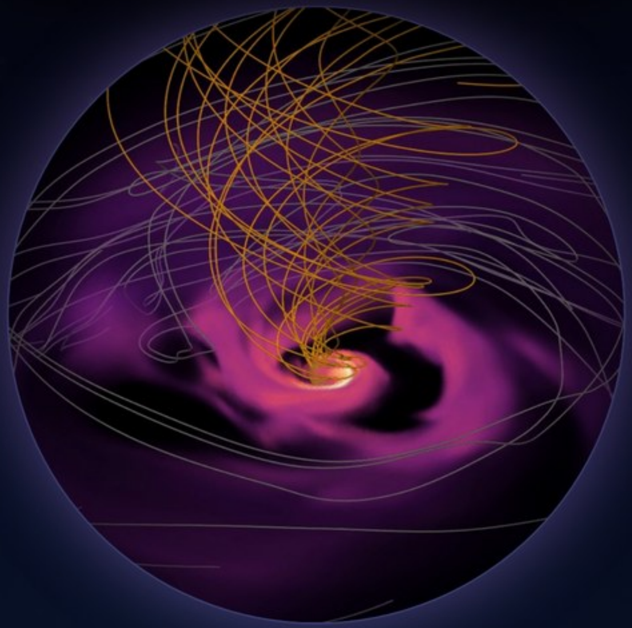

MAGNETICALLY ARRESTED DISKS

MAD Accretion

When the flow chokes on its own field

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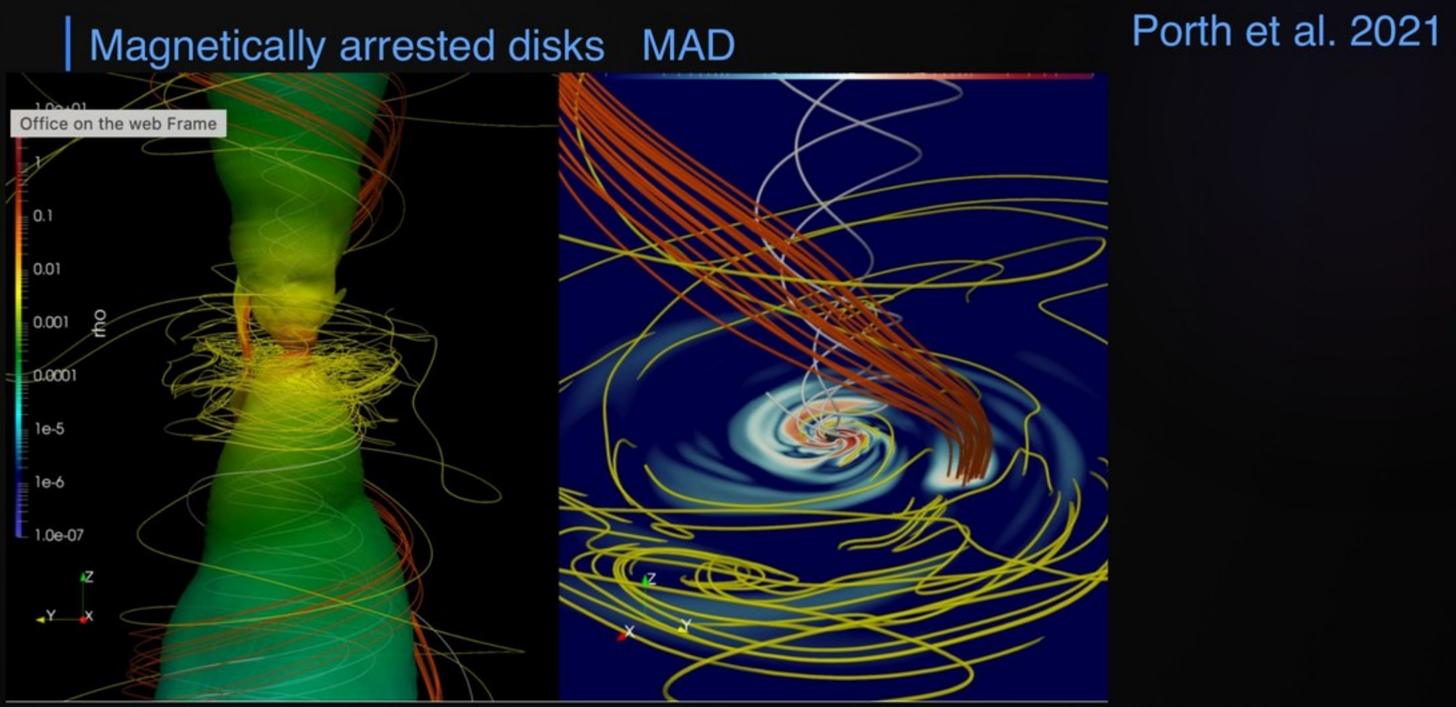
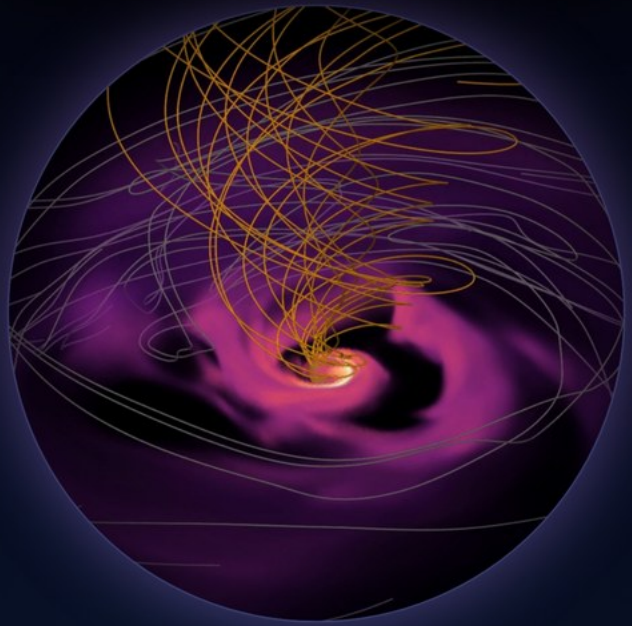


See also Dexter et al. 2020, Nathanail et al. 2020,Ripperda et al. 2020, Chatterjee et a. 2021, Ripperda et al. 2022, Antonopoulou et al. 2025 …..

Push poloidal flux inward until it pushes back.

Flux piles up on the horizon, magnetic pressure balances the ram pressure of the infall, and gas can only leak through in discrete clumps.

What the MAD state buys you



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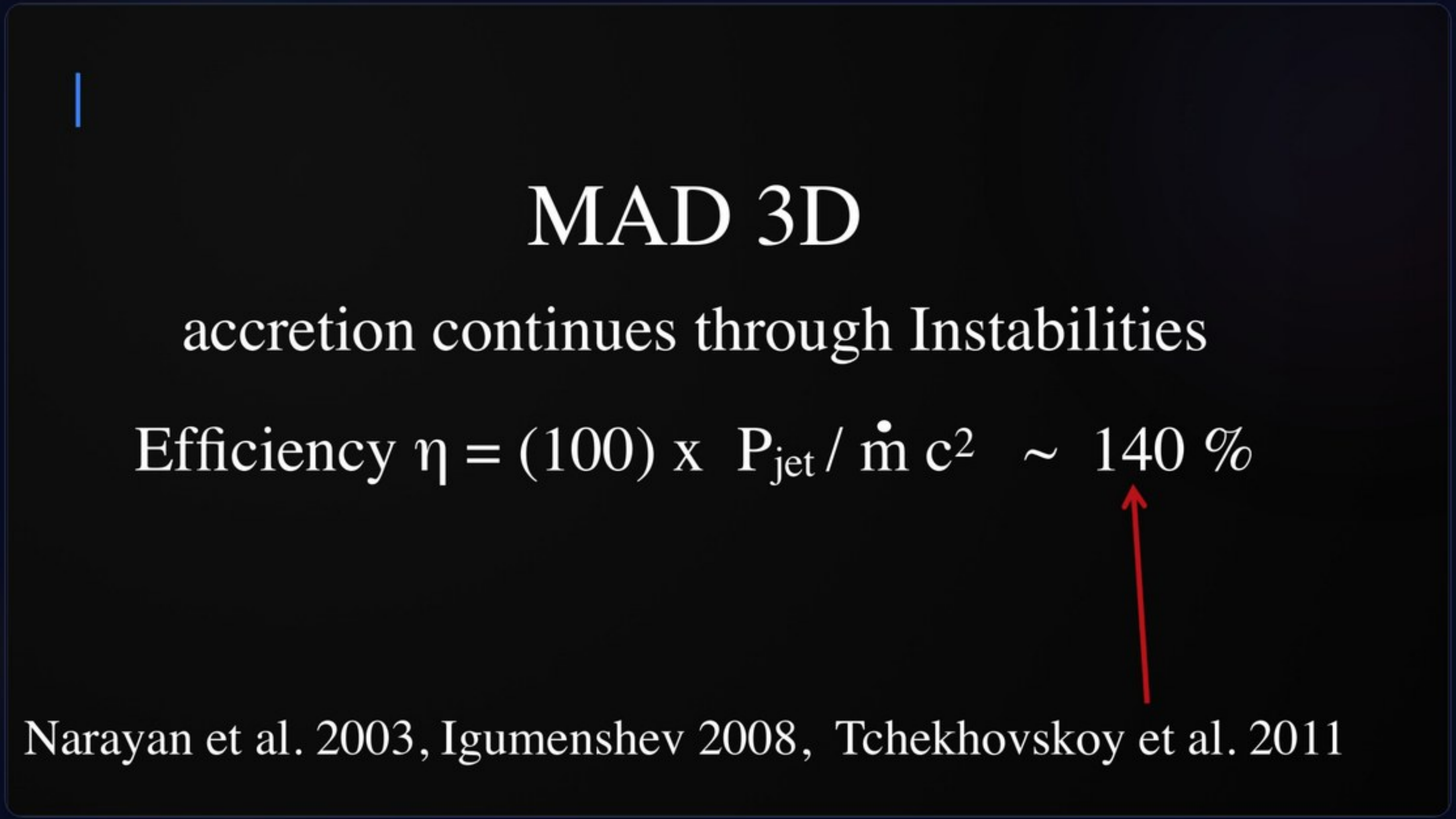

MAD maximizes Φ, and $P_{BZ} \propto \Phi^2$.

In 3D the flow never fully arrests: interchange instabilities let gas in from other directions.

Result: a persistent jet at **$\eta \approx 140\%$**, fed by an already intermittent flow.

Multi-loop accretion: MAD transitions

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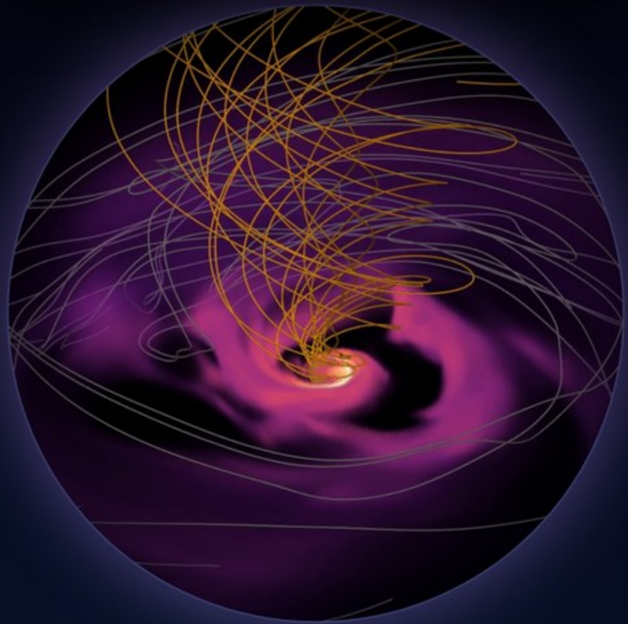

MAGNETICALLY ARRESTED DISKS

MAD Accretion

When the flow chokes on its own field

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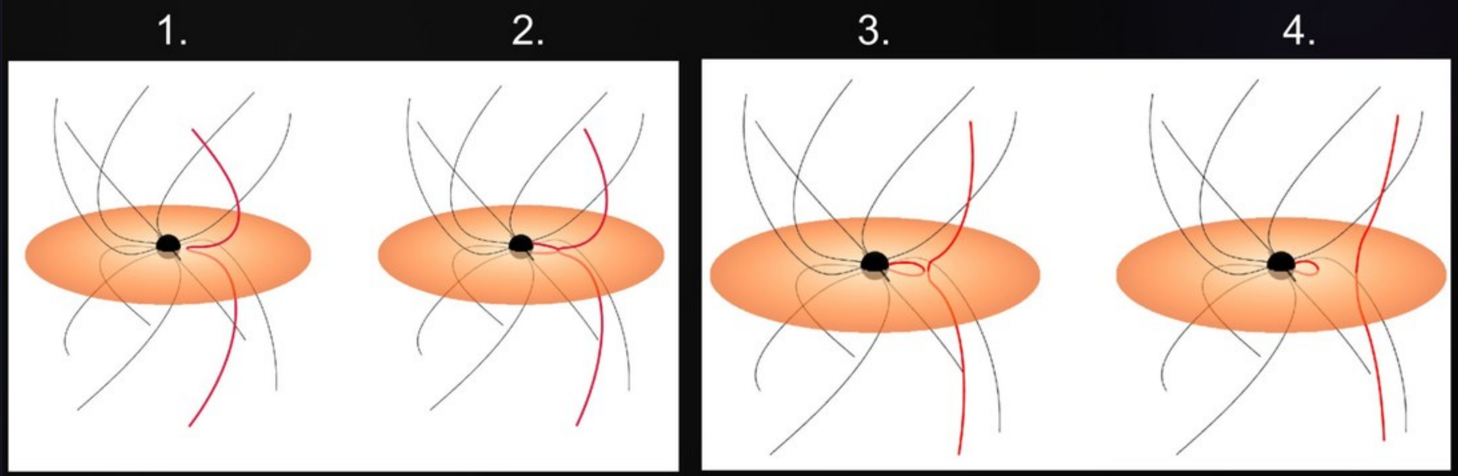
MAD TRANSITIONS



Loules, Nathanail & Contopoulos 2026

Real accretion rarely delivers one clean flux bundle.

Feed loops of alternating polarity and the disc hops between distinct arrested states as the loops reconnect near the horizon.

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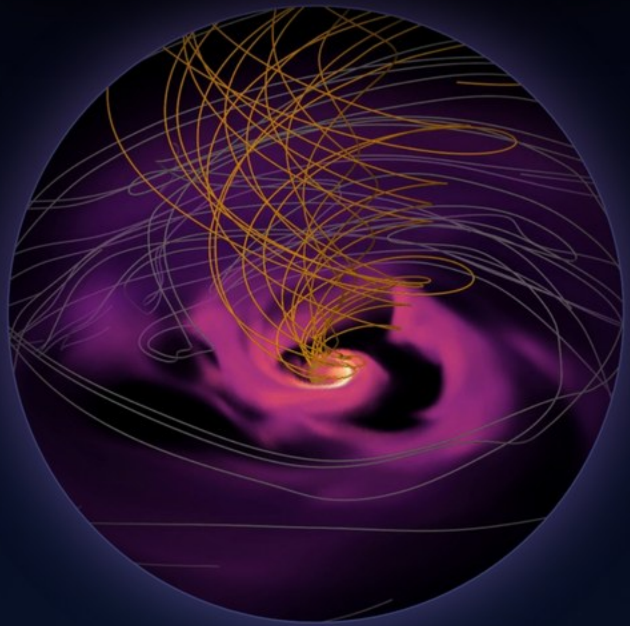
The MAD state is not static

‹ PREV CONTINUE → RESISTIVE MAD

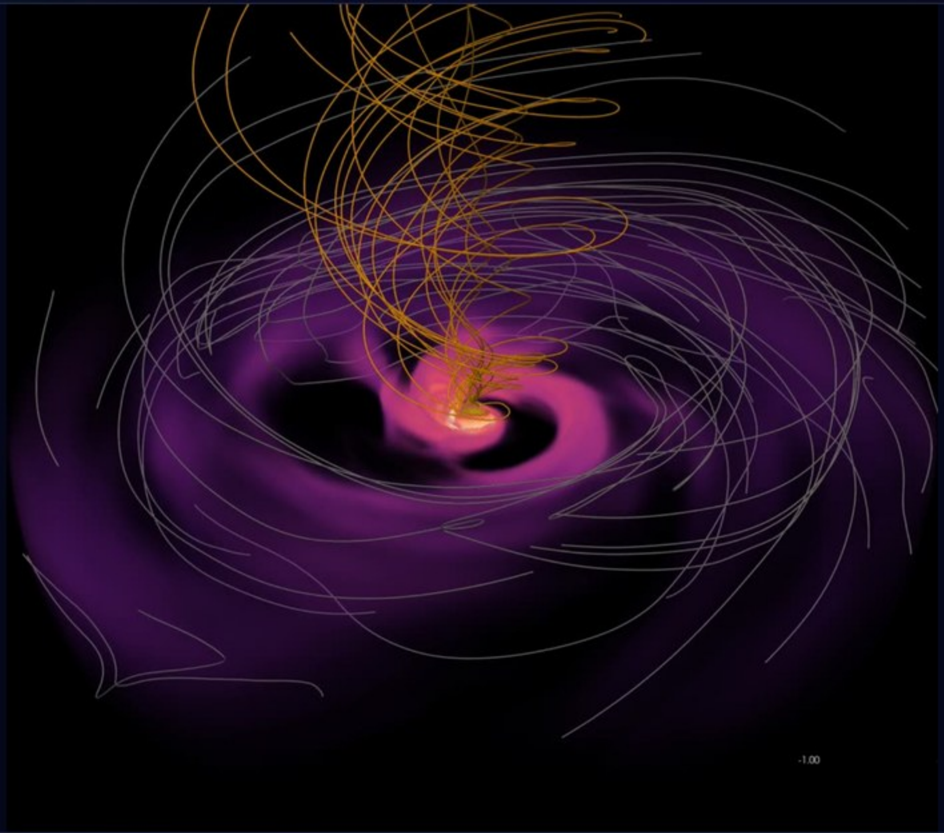


MAGNETICALLY ARRESTED DISKS

MAD Accretion

When the flow chokes on its own field

↗ RETURN TO OVERVIEW



Flux keeps building until it reorganizes in a burst.

Matter floods back in, the jet stutters, a fresh bundle takes over. **That burst is the opening act of the next circle.**

> Nathanail et al. 2026, to be submitted

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Resistivity only where the current is

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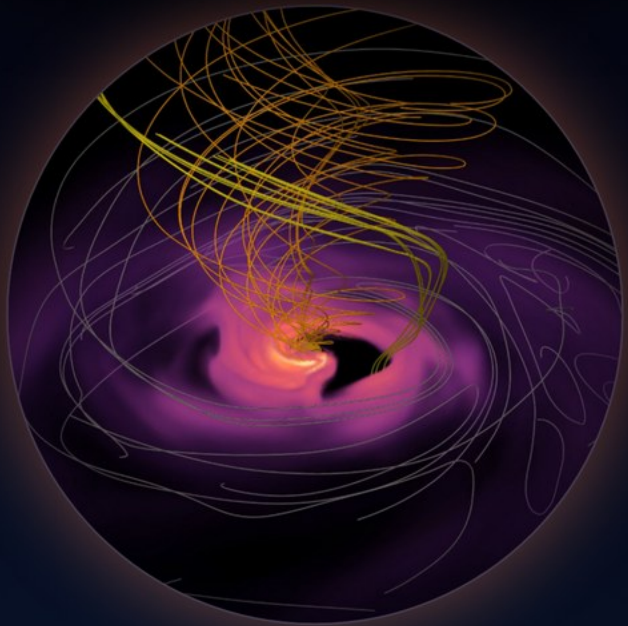
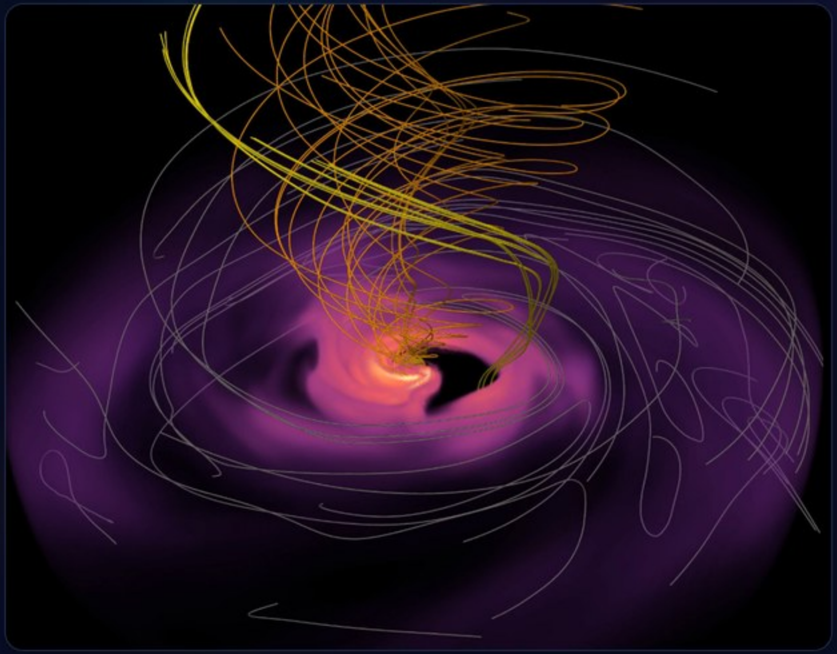


ANOMALOUS RESISTIVITY & DISSIPATION

Resistive MAD

Where the flow stops being ideal

RETURN TO OVERVIEW



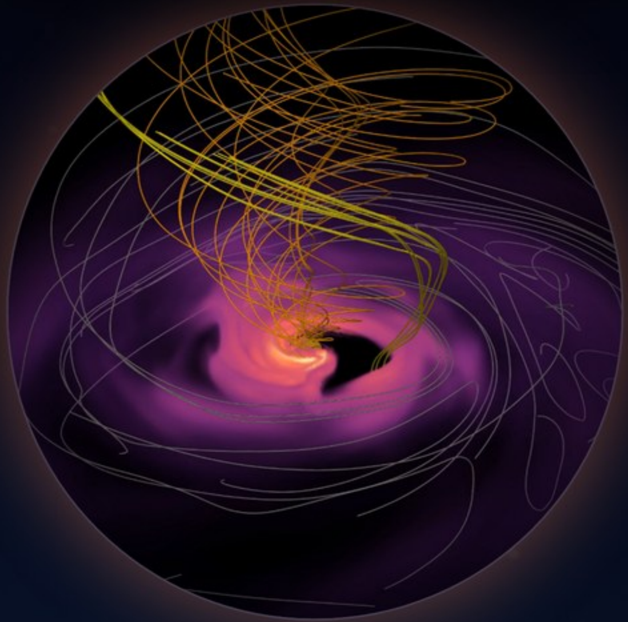
3D GRMHD of a MAD with an **anomalous resistivity**: the background stays effectively ideal and η switches on **only inside strong-current sheets**, where reconnection physically operates.

The switch is anchored to kinetic physics: PIC reconnection saturates at $|E_{\|}|/|B| = 0.26$–0.37, the fast rate $\beta_{rec} \simeq 0.1$.

Same torus, three prescriptions: ideal, uniform η, anomalous η.

> **Nathanail, Meringolo, Fromm, Mizuno, Cruz-Osorio & Rezzolla 2026**, ***Anomalous resistivity and energy dissipation during flux eruptions in 3D magnetically arrested disks***, **to be submitted**

The MAD survives — a uniform η does not



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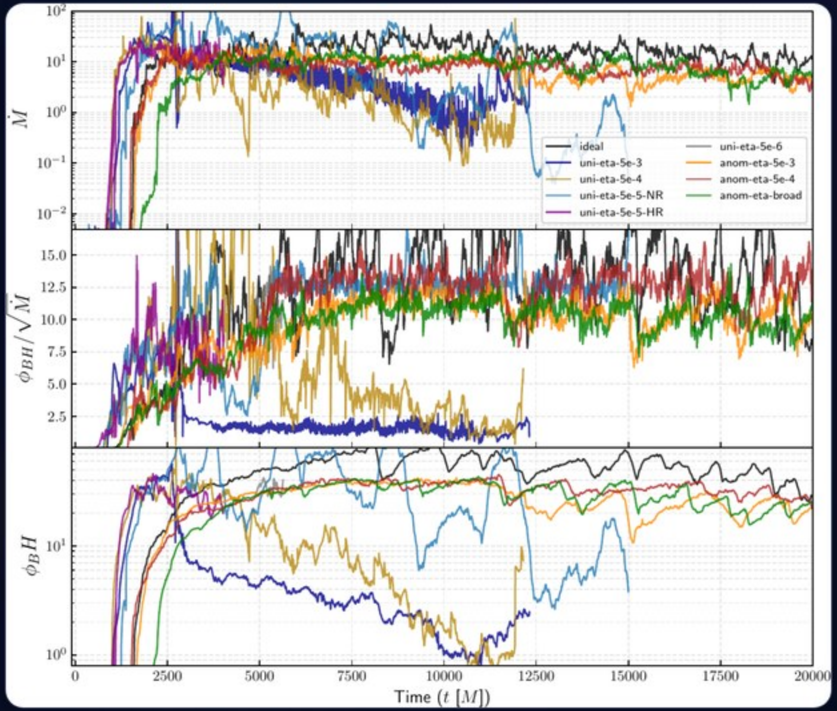


$\dot{M}$, $\varphi_{BH} = \Phi_{BH}/\sqrt{\dot{M}}$ and Φ_{BH} for every run.

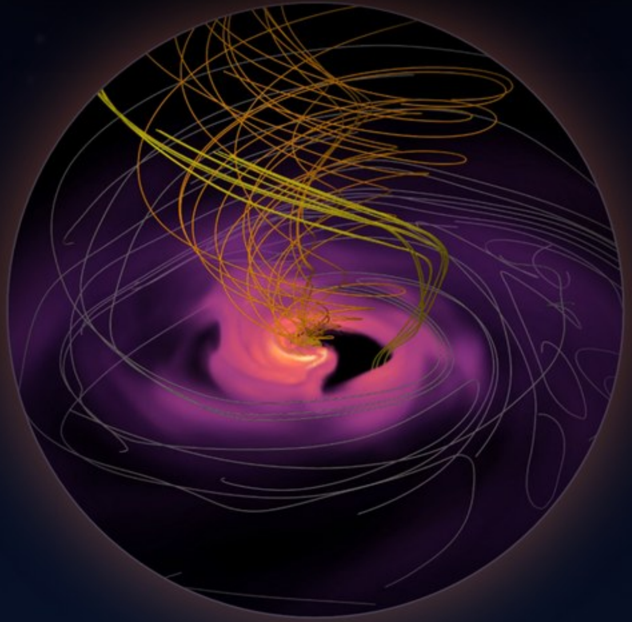
$\langle\varphi_{BH}\rangle$ = 13.4 ± 0.5 ideal → **12.6 / 10.5 / 10.3** anomalous: still firmly MAD, the plateau only drops by 6–23% and it orders with η_{max}.

At **uniform** $\eta = 5\times10^{-3}$ the flux never accumulates at all — global, unphysical diffusion dissolves the accretion stream.

And the clock is untouched: eruptions recur every **1–2 × 10^3 M** in *all* models.

> Nathanail, Meringolo, Fromm, Mizuno, Cruz-Osorio & Rezzolla 2026, to be submitted

Two dissipation channels, two places



ANOMALOUS RESISTIVITY & DISSIPATION

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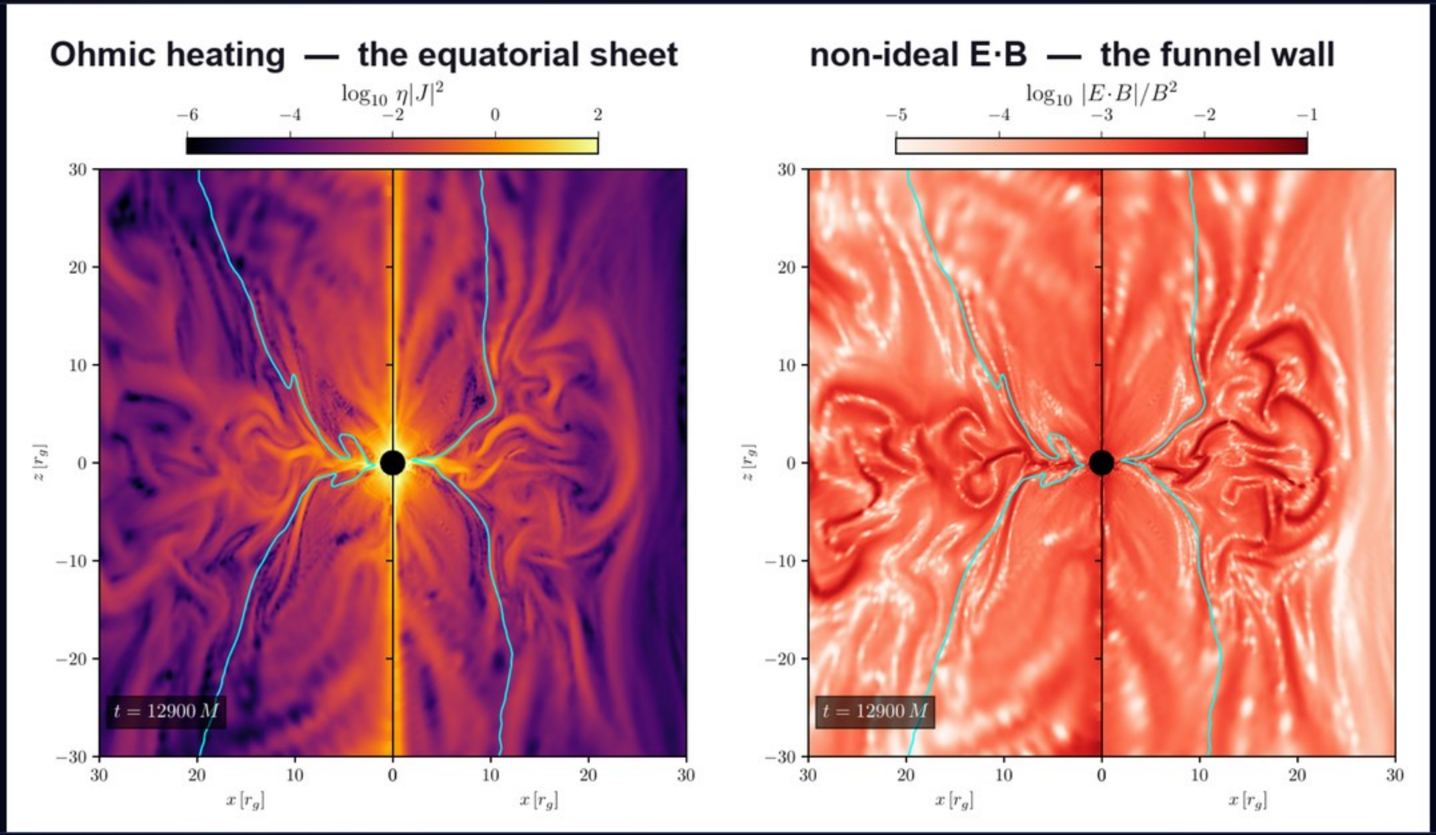
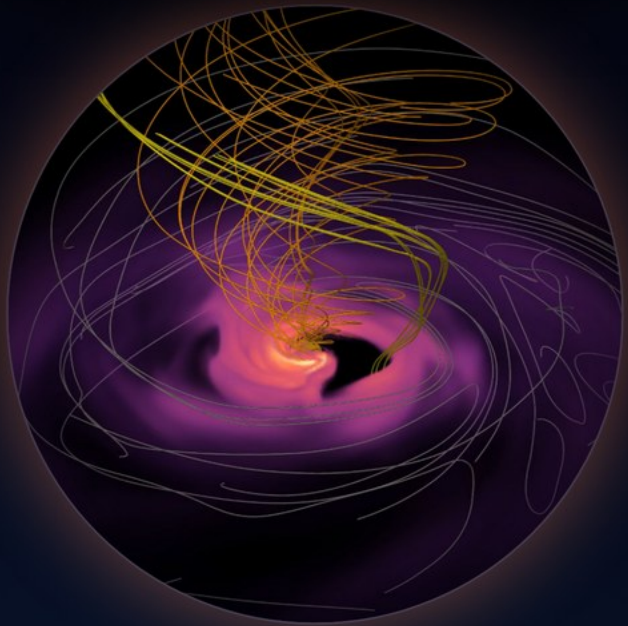


Equatorial sheet → Ohmic. $\eta|J|^2$ peaks there and thermalizes the plasma.

Funnel wall → non-ideal. $E{\cdot}B \neq 0$ along the fragmented jet boundary — the prerequisite for **non-thermal particle acceleration**, exactly where imaging and flare models have been *assuming* it.

Nathanail, Meringolo, Fromm, Mizuno, Cruz-Osorio & Rezzolla 2026, to be submitted

How fast the sheets go — and how many



ANOMALOUS RESISTIVITY & DISSIPATION

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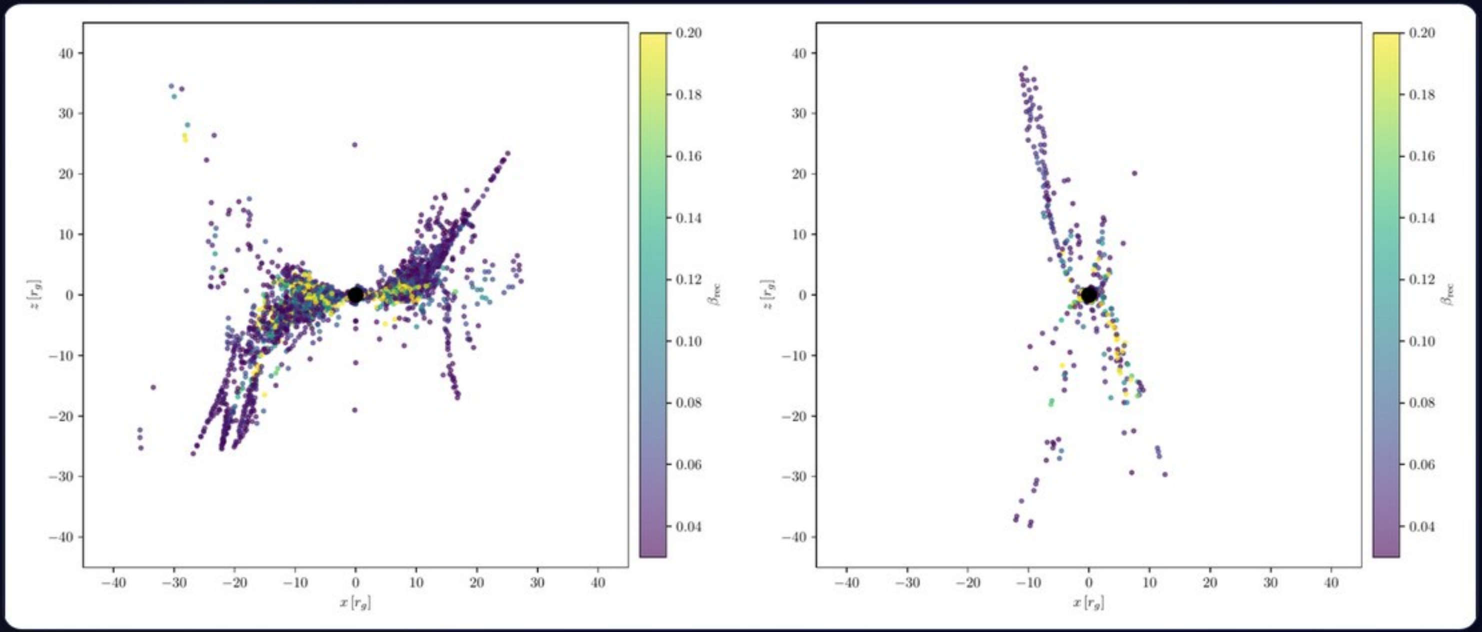
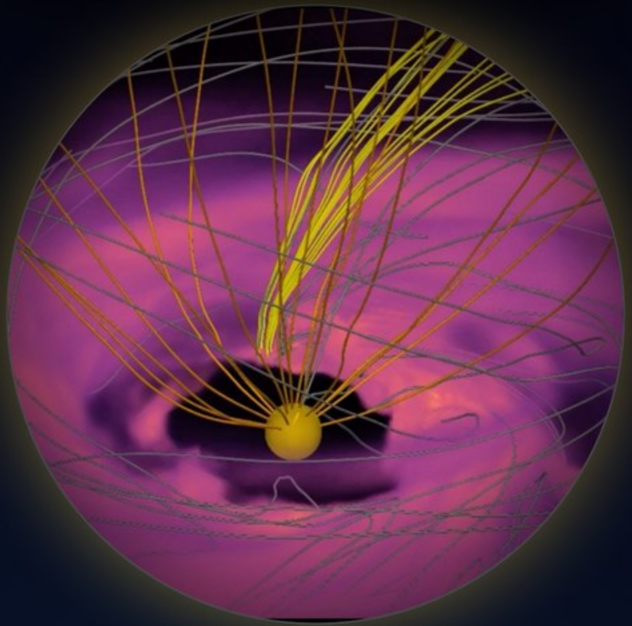


Fast sheets reconnect at $\beta_{rec} \simeq 0.05$–0.2 — in the uniform and the anomalous run **alike**. The rate is set by large-scale force balance, not by η.

What η changes is **how many sheets go fast, and where**: both funnel walls and the whole equatorial sheet, instead of one patchy, transient layer. Quantitative inside **$r < 20\ r_g$**.

> Nathanail, Meringolo, Fromm, Mizuno, Cruz-Osorio & Rezzolla 2026, to be submitted · ceiling: Liu et al. 2017

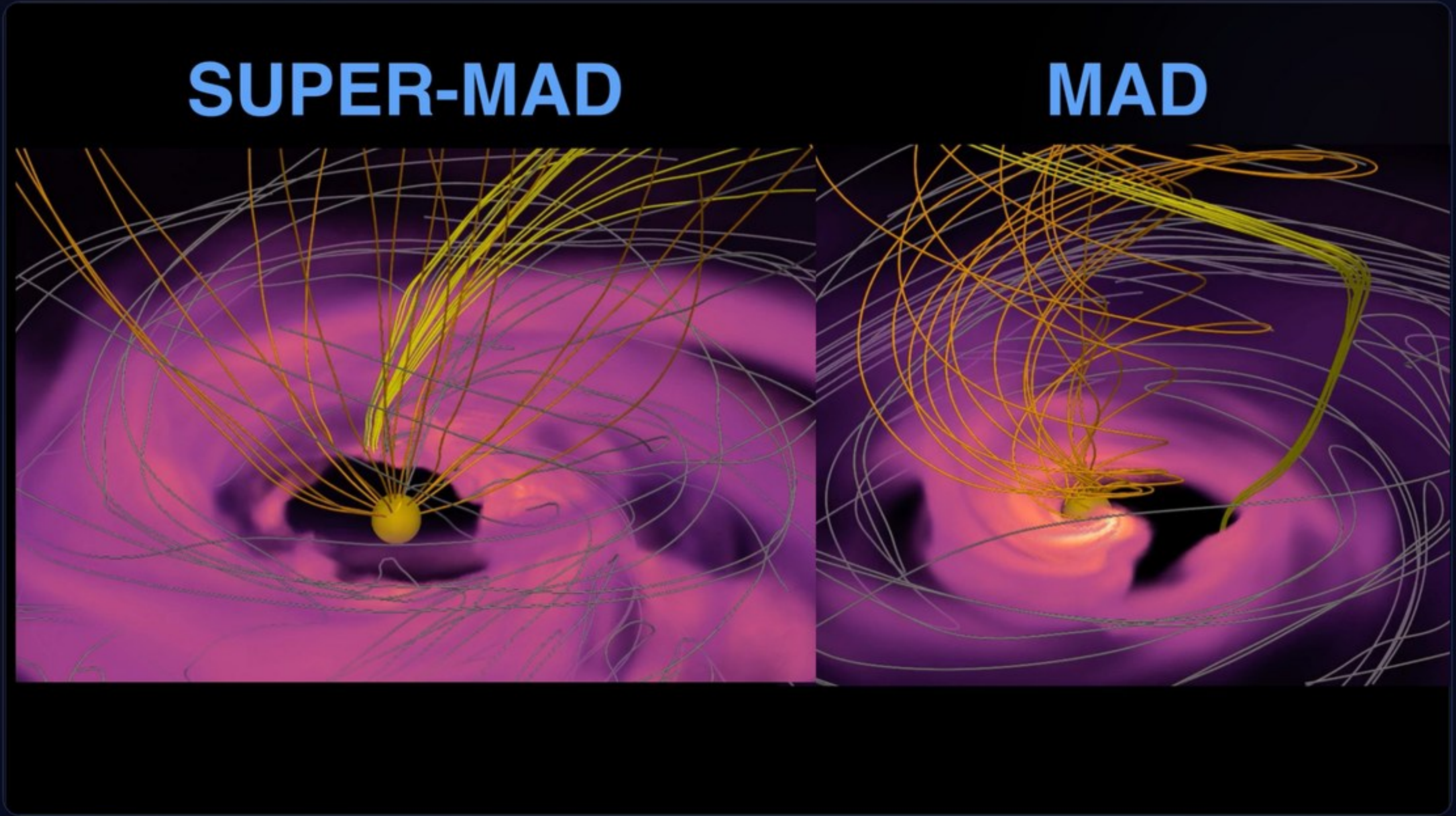


EXTREME TRANSIENTS

The SUPER-MAD State

When magnetic pressure wins outright

RETURN TO OVERVIEW



Drive more flux through the funnel than a MAD can hold and the flow goes **SUPER-MAD**.

Magnetic pressure no longer arrests accretion in patches. It governs the whole inner flow, disc and jet alike.

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Accretion stops

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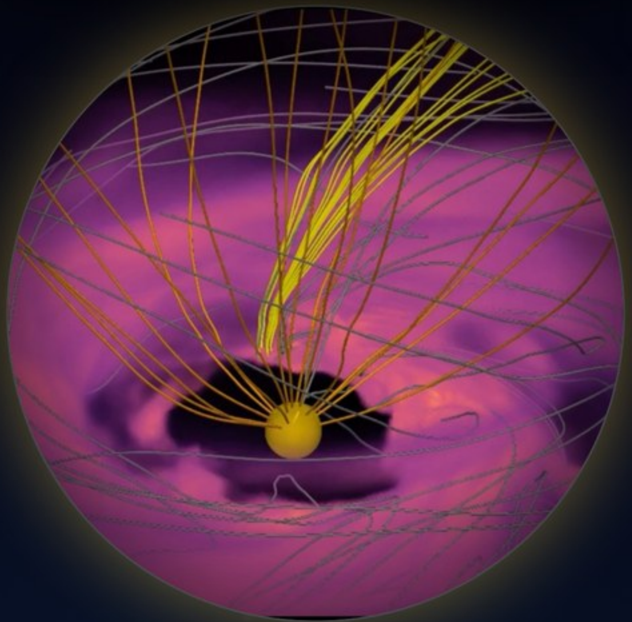

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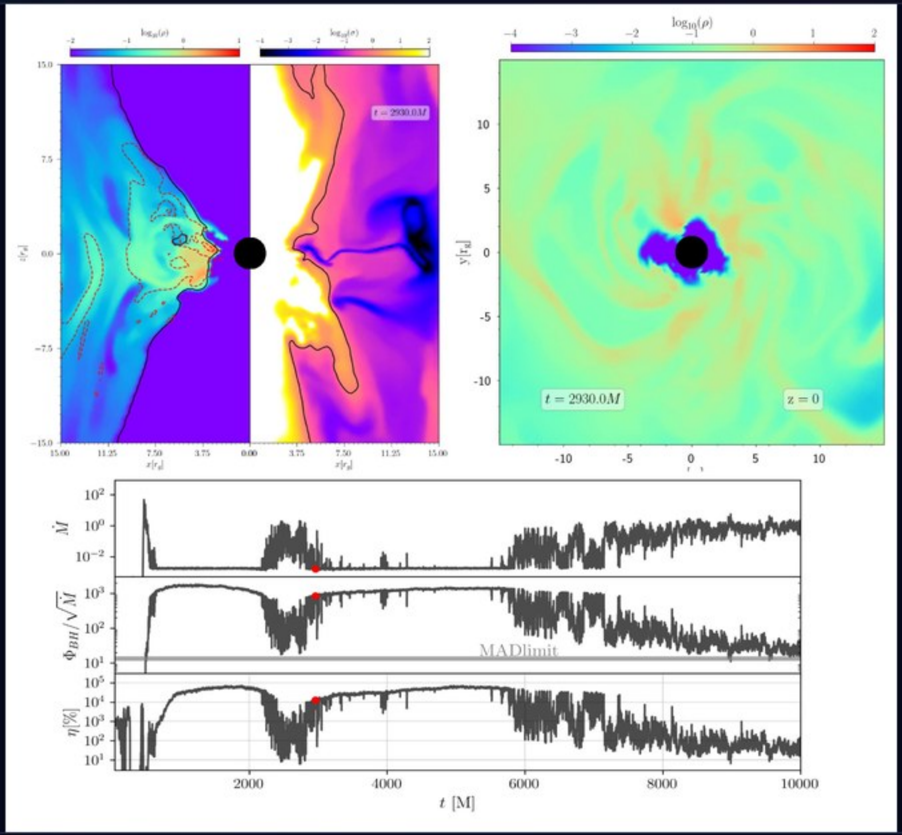

$\dot{M}$ onto the horizon collapses by orders of magnitude. The jet power barely moves.

η ~ 17,000%

Essentially all the liberated energy is electromagnetic, not gravitational.

Nathanail 2026

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The same shutdown, in KHARMA

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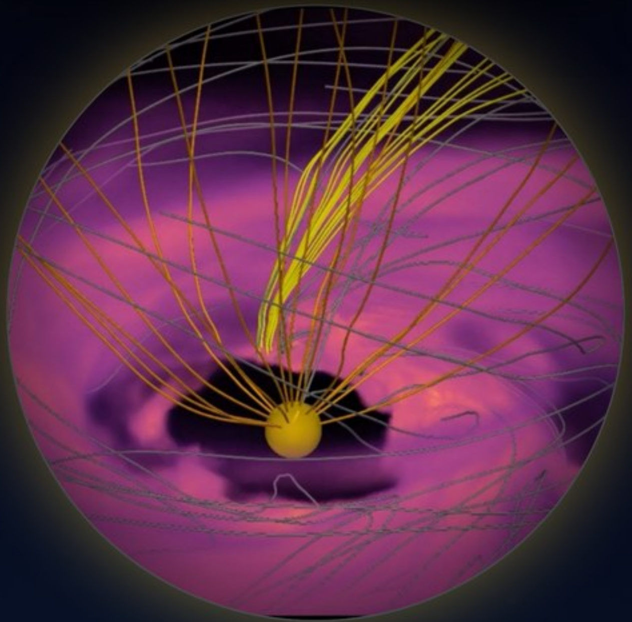

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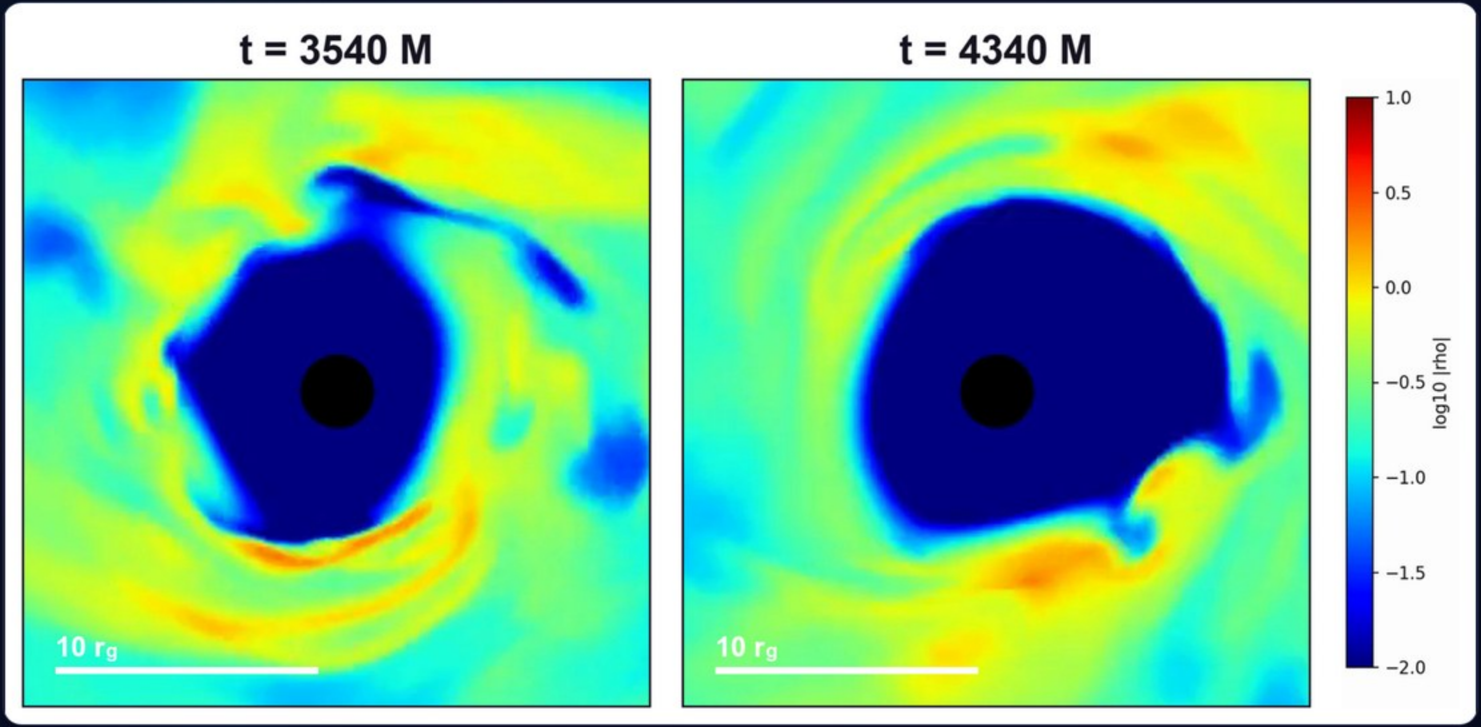
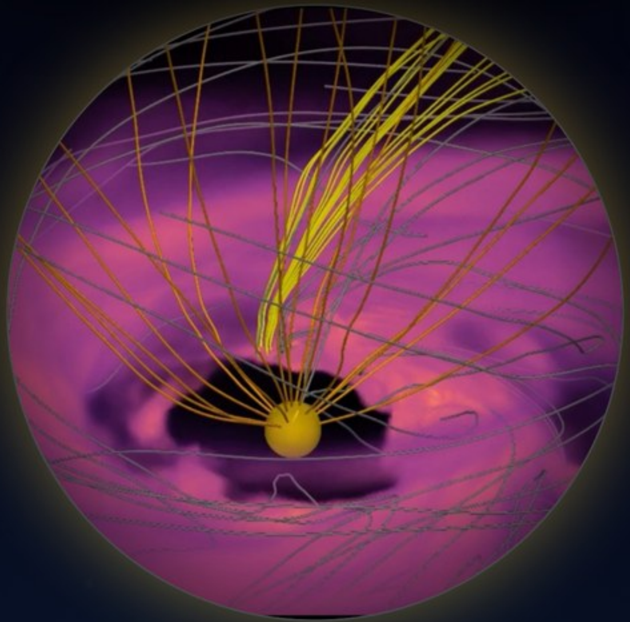


Midplane density, inner 12 r_g, from the **KHARMA** code.

BHAC (Porth et al. 2017) & KHARMA

RETURN TO OVERVIEW

One accretion flow, many transients



EXTREME TRANSIENTS

The SUPER-MAD State

When magnetic pressure wins outright

RETURN TO OVERVIEW

Five circles, one axis: **how much magnetic flux sits on the horizon.**

Accretion is not a smooth supply curve. It can be erratic, arrested, or SUPER-MAD, and each leaves its own signature in the light we detect.