Strongly magnetized quasars

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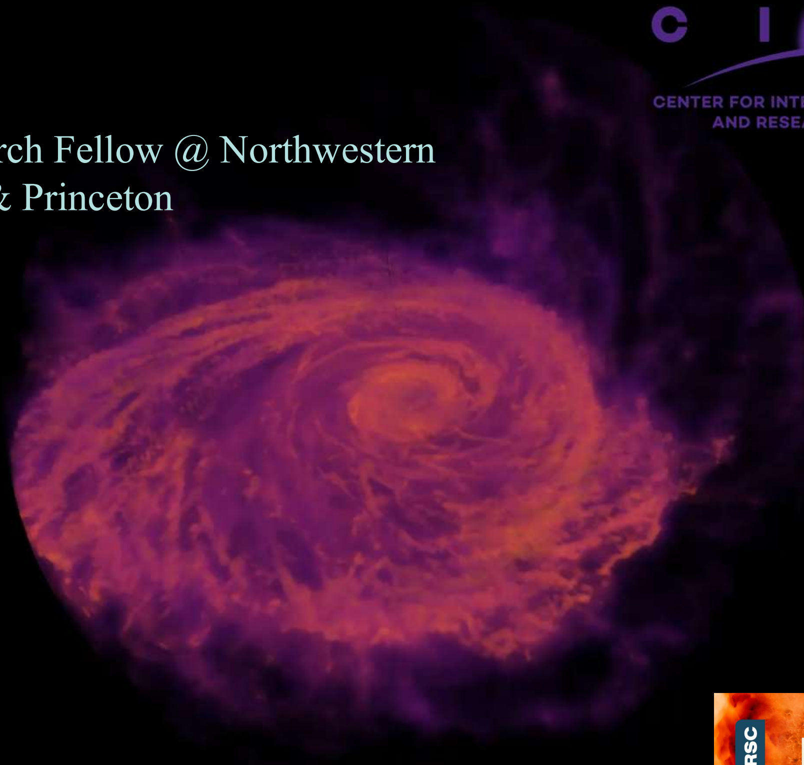
REFCO2025



main collaborators:

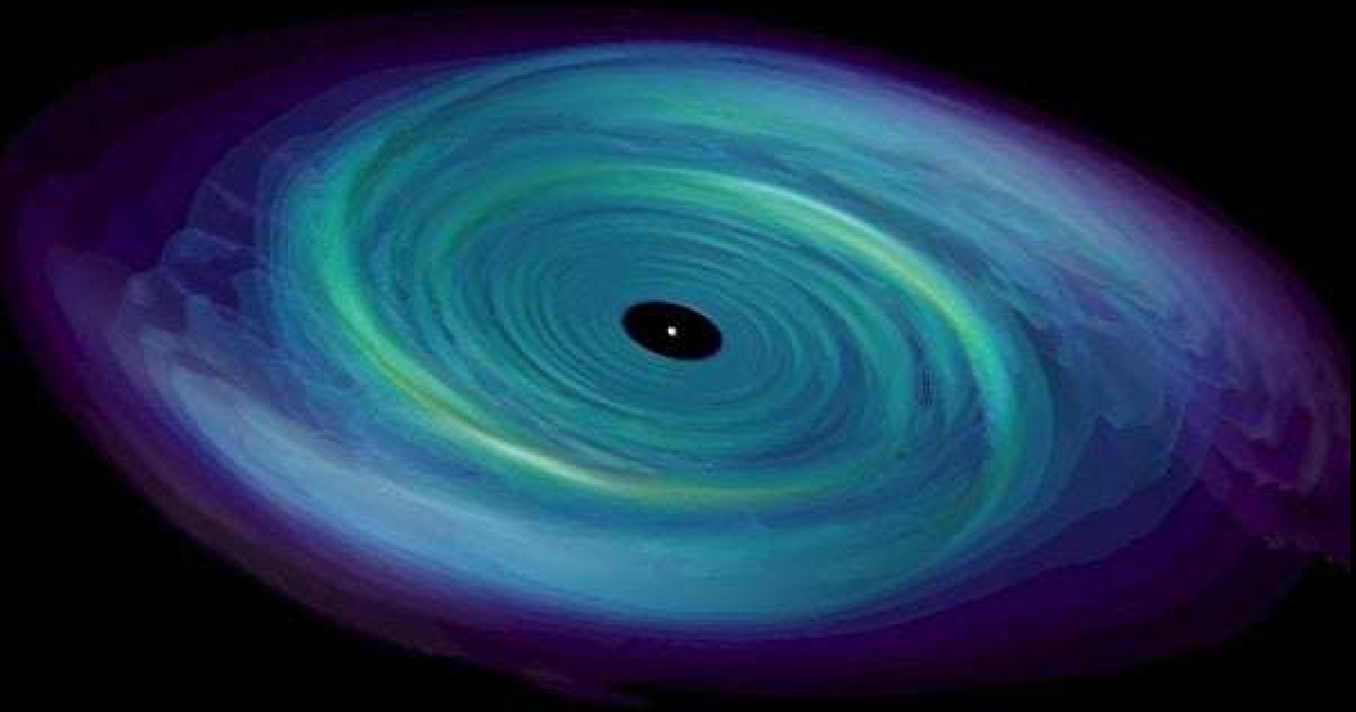
Matthew Liska

Sasha Tchekhovskoy

Phil Hopkins

Standard Thin Accretion Disks

("shakura-sunyaev disks", "α-disks", "Novikov-Thorne" disks, etc)



- Razor-thin
- Efficiently cooling
- Powered by effective viscosity
- Subdominant magnetic fields

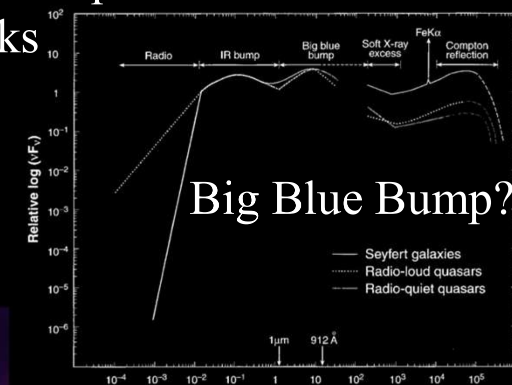
Struggles for classical disk models?

Shakura+Sunyaev 1973
Novikov+Thorne 1973
also slim disks, eg Abramowicz 1988

Quasar microlensing predicts huge disks

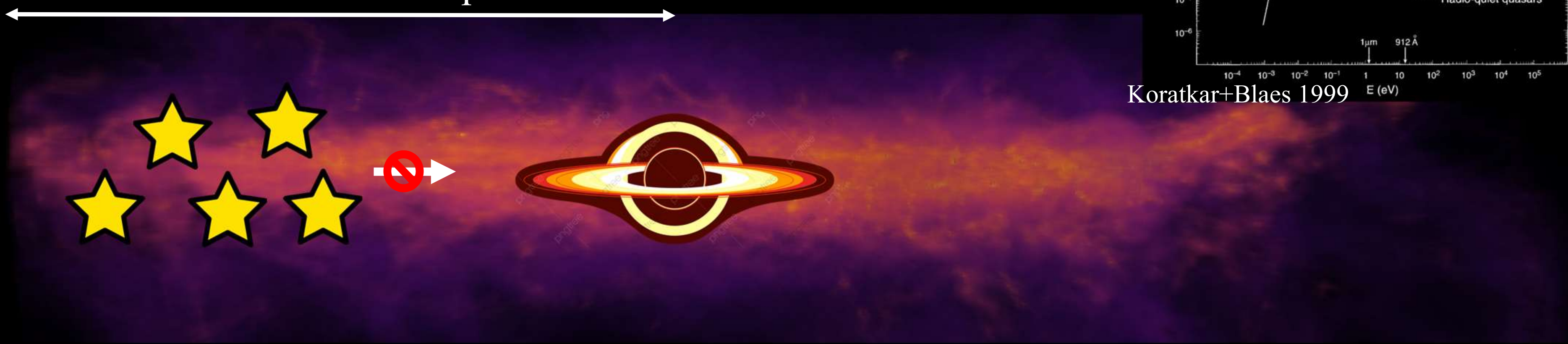
Morgan et al 2010

AGN SEDs problematic for thin disks



Koratkar+Blaes 1999

~ Few hundreds of a parsec



- Gas pressure dominated
- Unstable to star formation

Toomre 1964

- Rad pressure dominated
- Thermally+viscously unstable
- (little to no obs. evidence)

Gierlinski+Done 2004

The list goes on!

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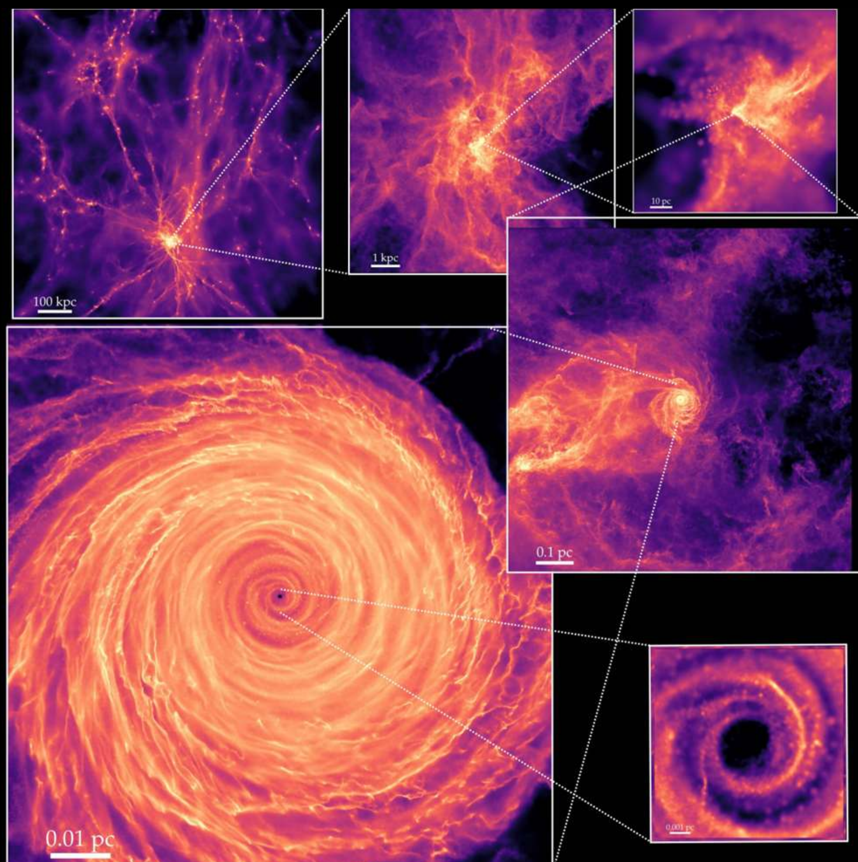
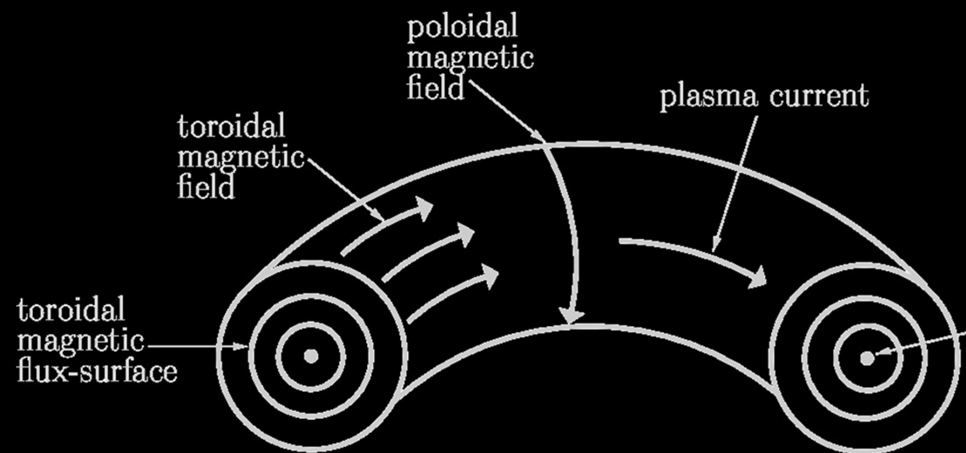
Galaxies assemble strongly magnetized disks?

Tidal disruptions of giant molecular cloud complexes lead to magnetically dominated disks accreting at very high rates

e,g. Gaburov et al 2012

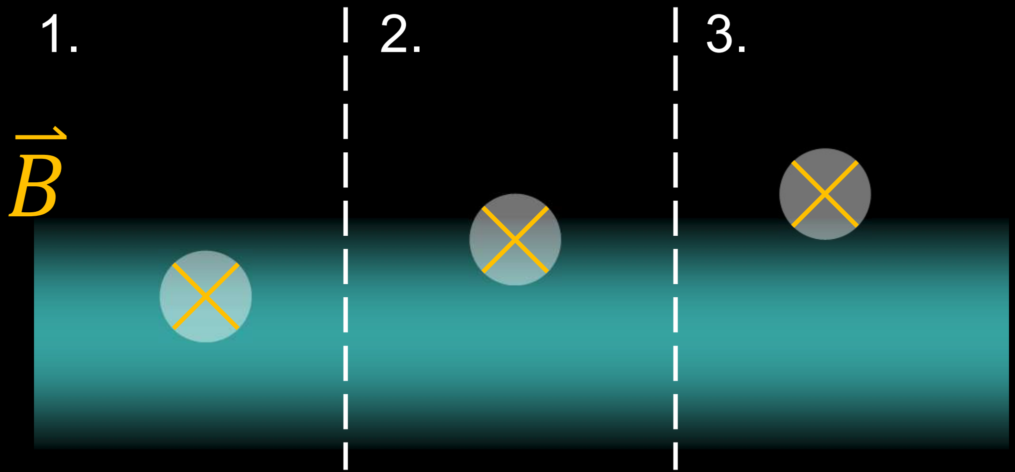


Hopkins et al 2024

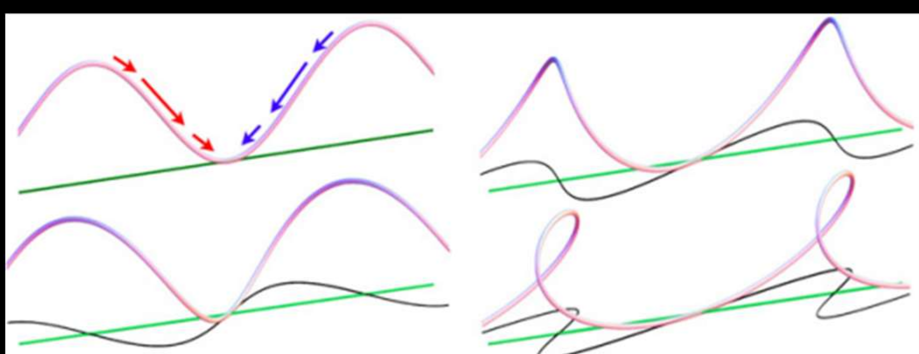


Disk has strong *toroidal* magnetic fields

Toroidal magnetic fields in thin disks: buoyantly unstable?

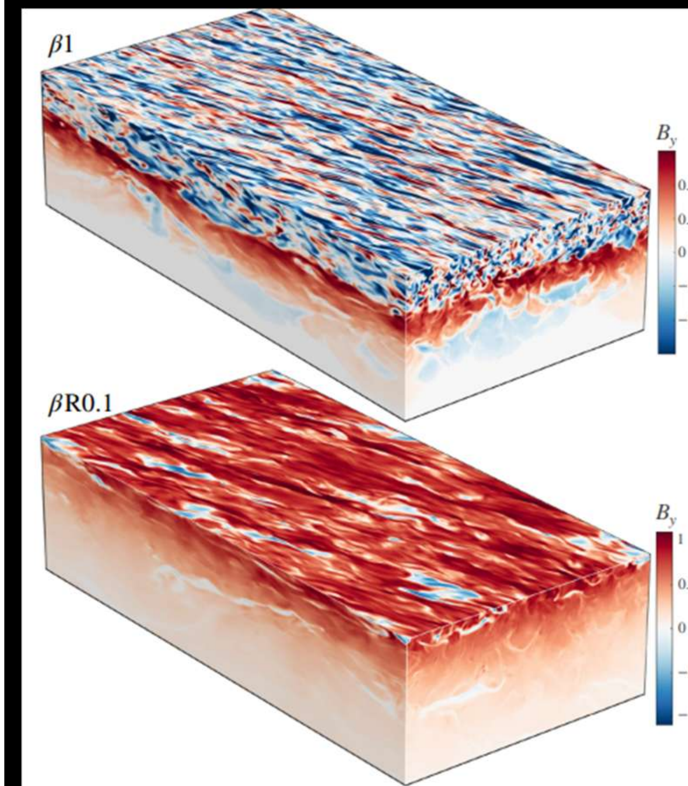


Saved by Coriolis force?



Gaburov et al 2012

Bimodal disks?



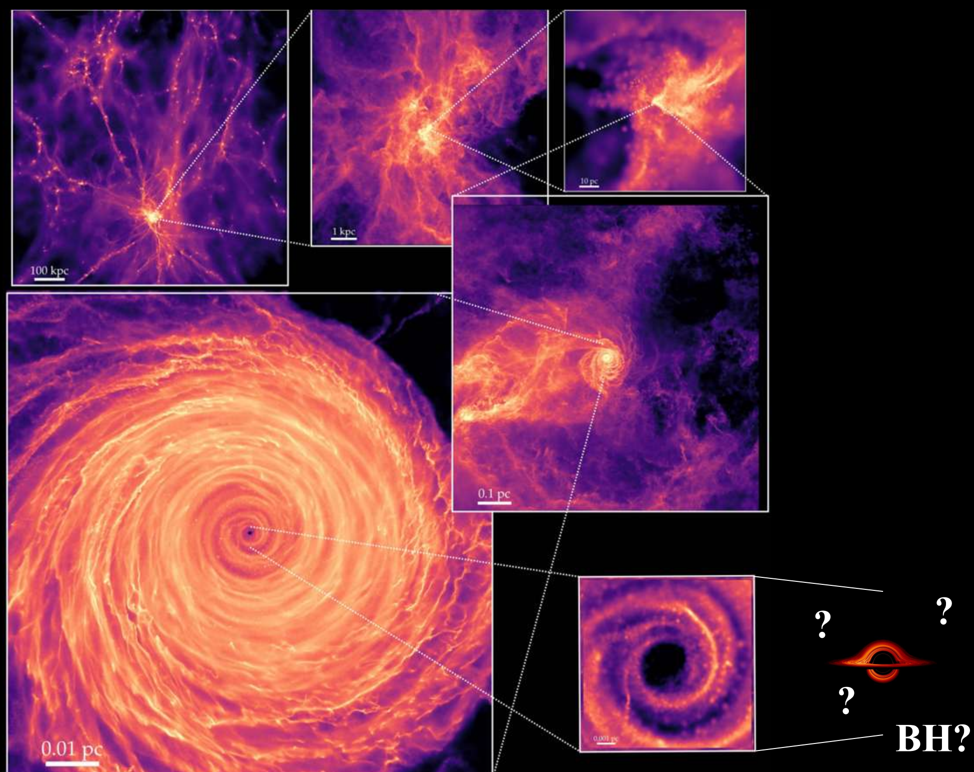
Squire et al 2024

a H-AMR FORGE'd in FIRE

Tidal disruptions of giant molecular cloud complexes lead to magnetically dominated disks accreting at very high rates

e,g. Gaburov et al 2012

see also Guo et al 2024, Cho et al 2024 for recent related works



Hopkins et al 2023, "FORGE'd in FIRE II"

FIRE w/ STARFORGE: Cosmo., galaxy to sub-pc scales, provides us initial conditions

Remap

H-AMR: Horizon scales, can study jet launching, frame dragging, etc

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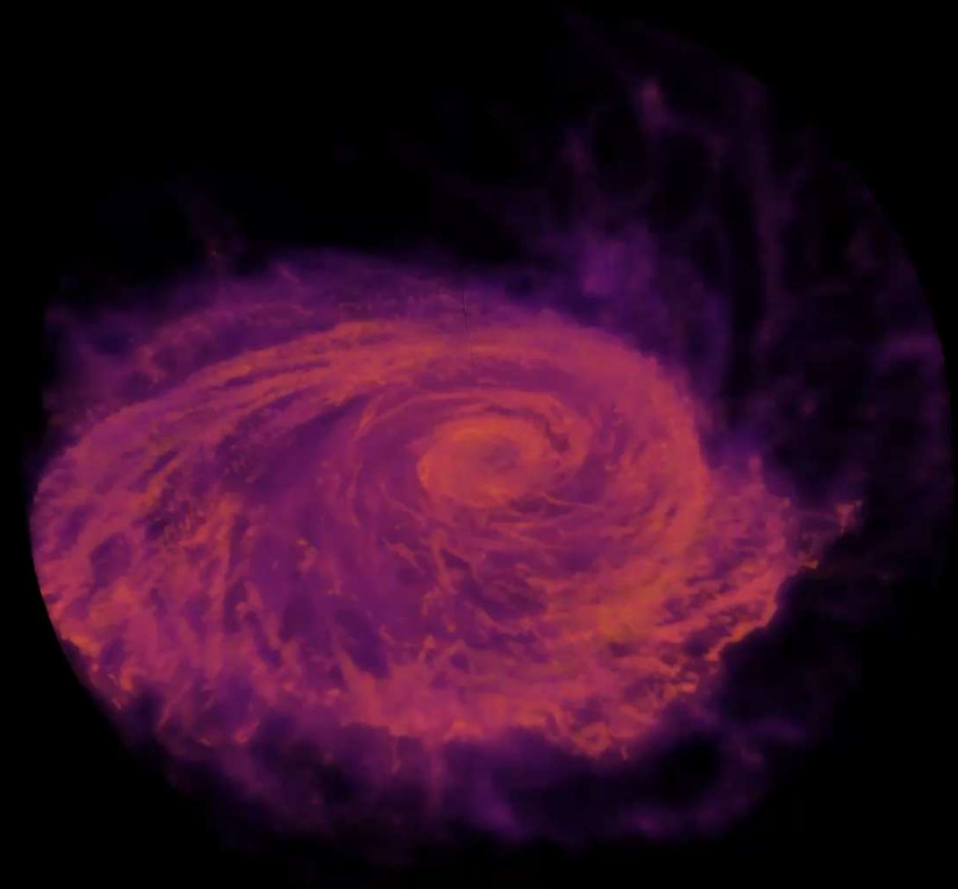
Interpolation from FIRE to H-AMR



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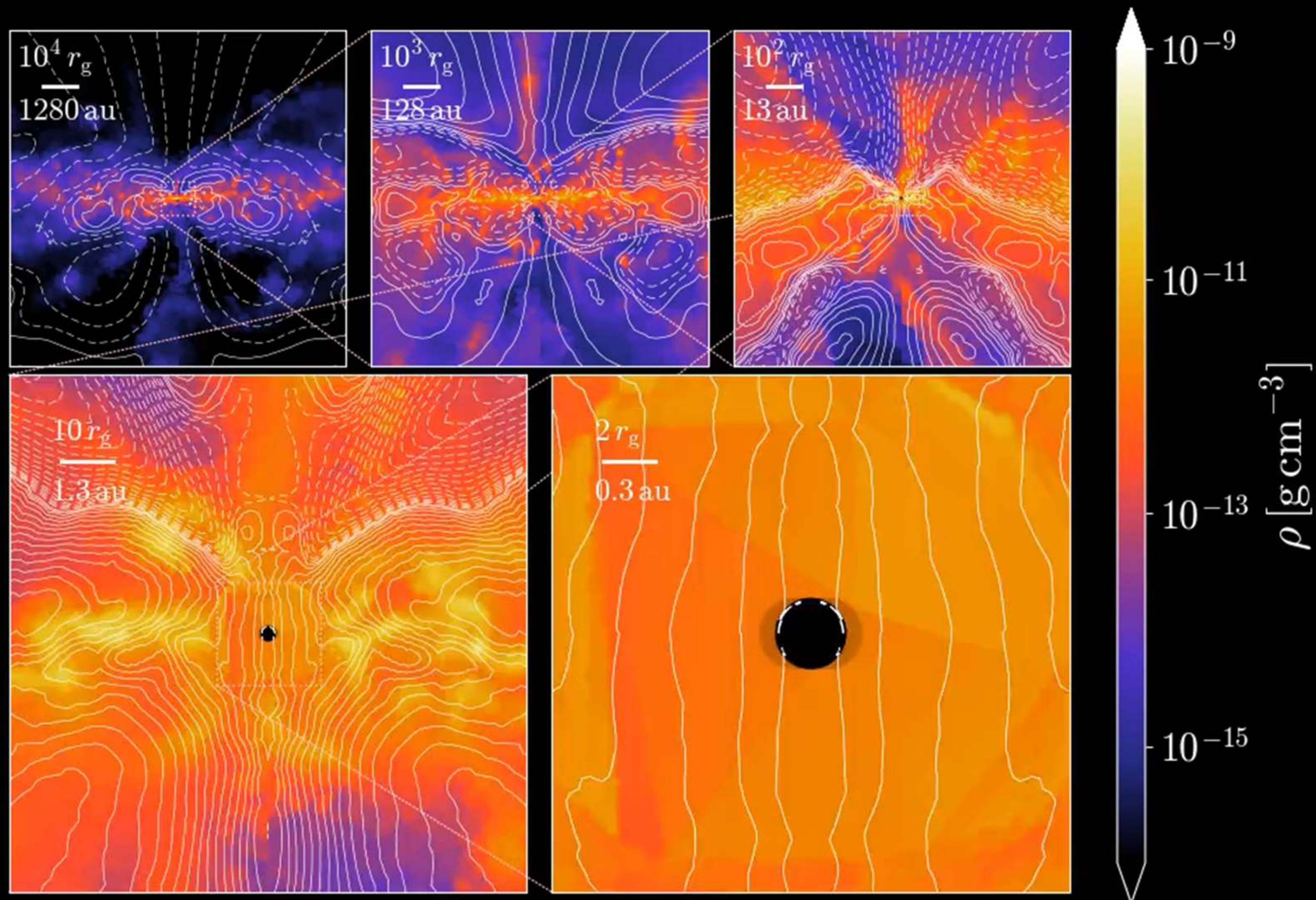
- 3D GRMHD simulation + restarted with live radiation (M1) later
- 4-5 orders of magnitude in scale separation
- ~200 million cells (~20-60 cells / scale height)
- 1.3e7 Solar Mass SMBH
- ~11e4 rg/c or ~80 days runtime



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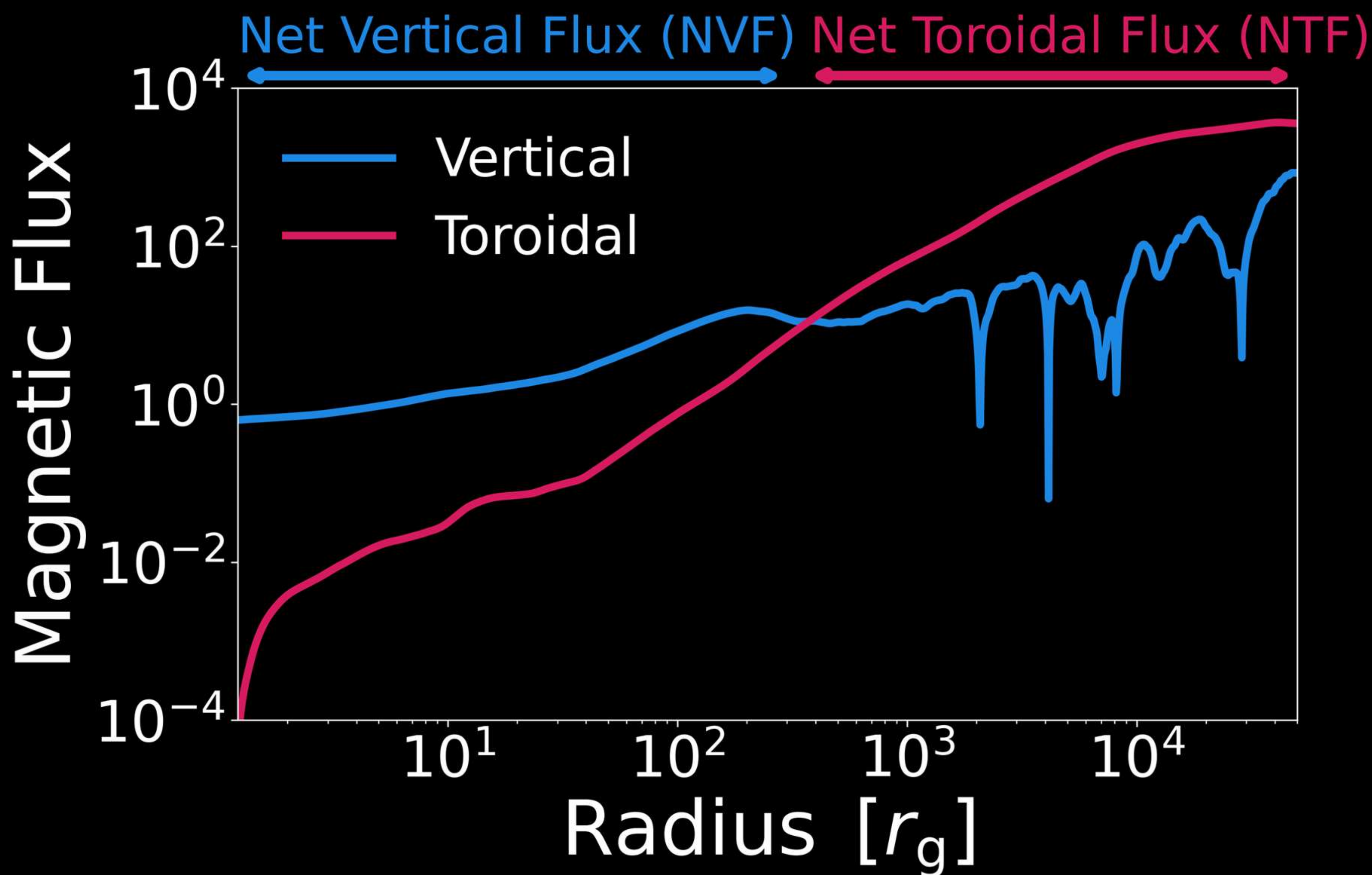
What happens to the magnetic field?



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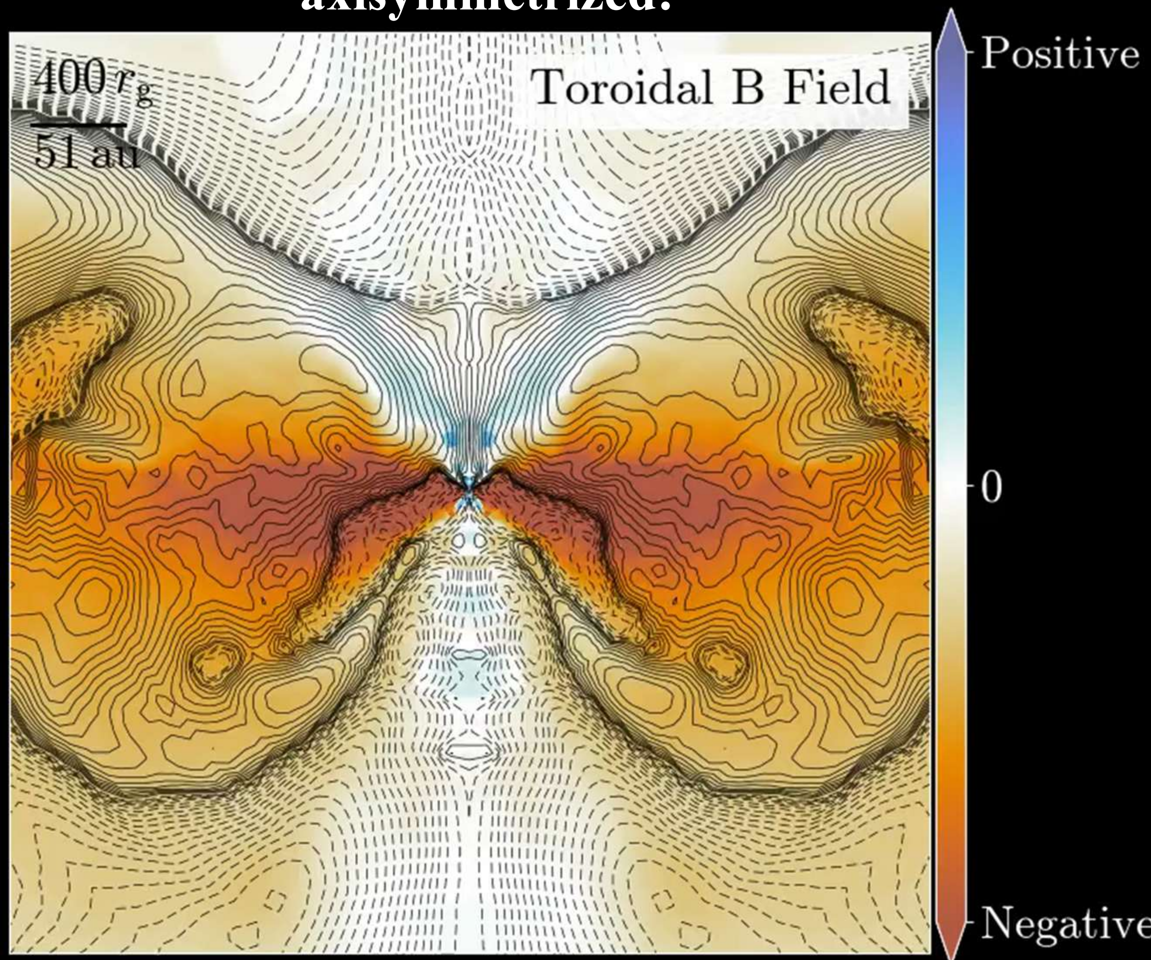
What happens to the magnetic field?

axisymmetrized:



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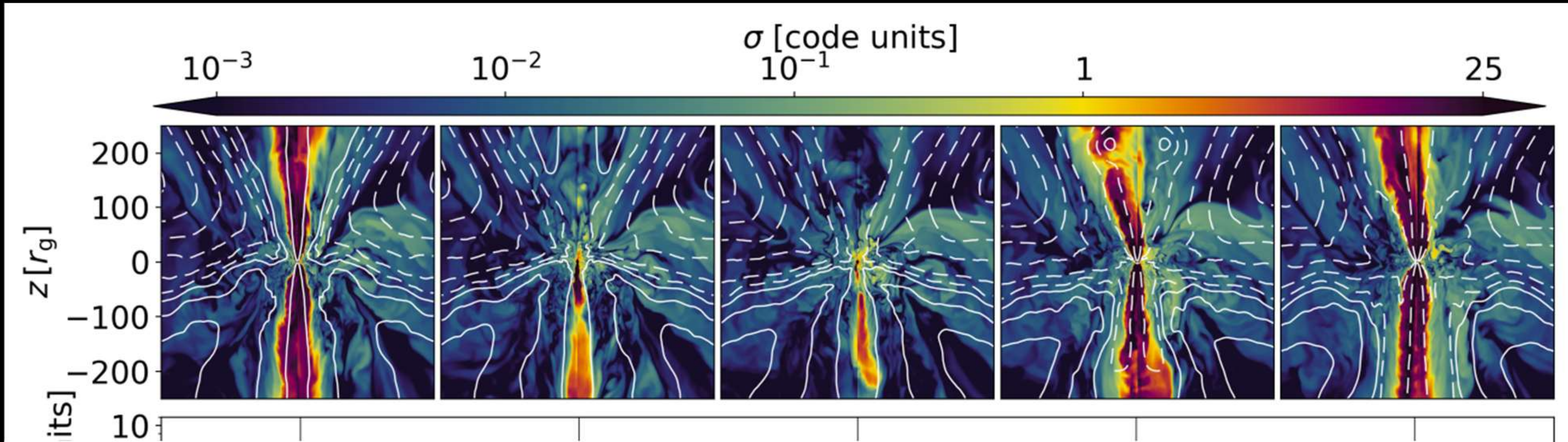
Flux inversions = Extreme quasar variability?



Multi-wavelength observations of a jet launch in real time from the post-changing-look Active Galaxy 1ES 1927+654

Sibasish Laha,[1,2,3] Eileen T. Meyer,[4] Dev R. Sadaula,[5,2,3] Ritesh Ghosh,[2,5,3,6] Dhrubojyoti Sengupta,[2]
Megan
Alexander
Ehud Beh
Susanna Biso
Matt N
J. A.

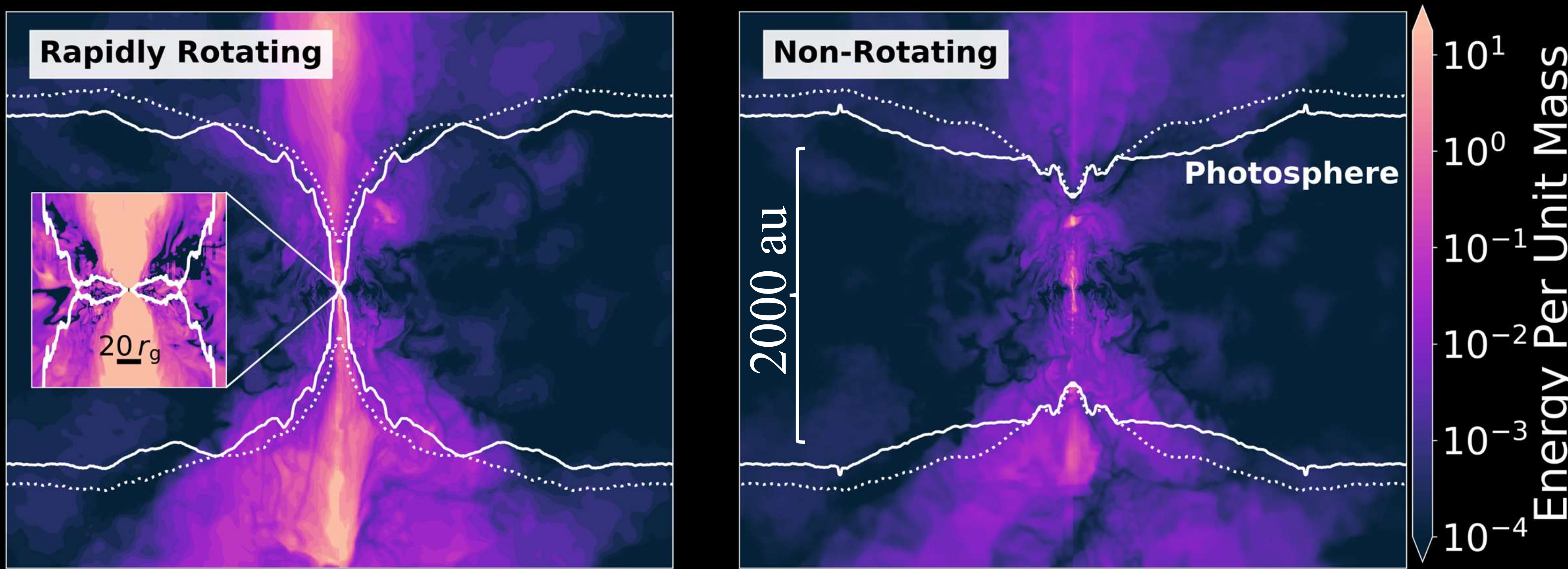
Late-time radio brightening and emergence of a radio jet in the changing-look AGN 1ES 1927+654

Eileen T. Meyer,[1]
Lauren Rhodes,[7] A
Mitchell C. Begelman,[1
Matteo Guainazzi,[1
Mark A. Gurw
Emmanuel K. Bem
Fabio La Franca,[22] Erin

Magnetic flux inversion in a peculiar changing look AGN

Nicolas Scepi[1★] Mitchell C. Begelman,[1,2] and Jason Dexter[1,2]
[1]*JILA, University of Colorado and National Institute of Standards and Technology, 440 UCB, Boulder, CO 80309-0440, USA*
[2]*Department of Astrophysial and Planetary Sciences, University of Colorado, 391 UCB, Boulder, CO 80309-0391, USA*

Jets open up the photosphere



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Strongly magnetized quasars

- Quasar disk from the galaxy to the event horizon
- Accretion disks sometimes sustain extremely strong toroidal magnetic fields
- Magnetic state transitions transforms net toroidal flux dominated disk into one dominated by net vertical flux
- Flux inversions may lead to extreme quasar variability such as in the CLAGN 1ES 1927

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Initial interpolation via tetrahedral mesh

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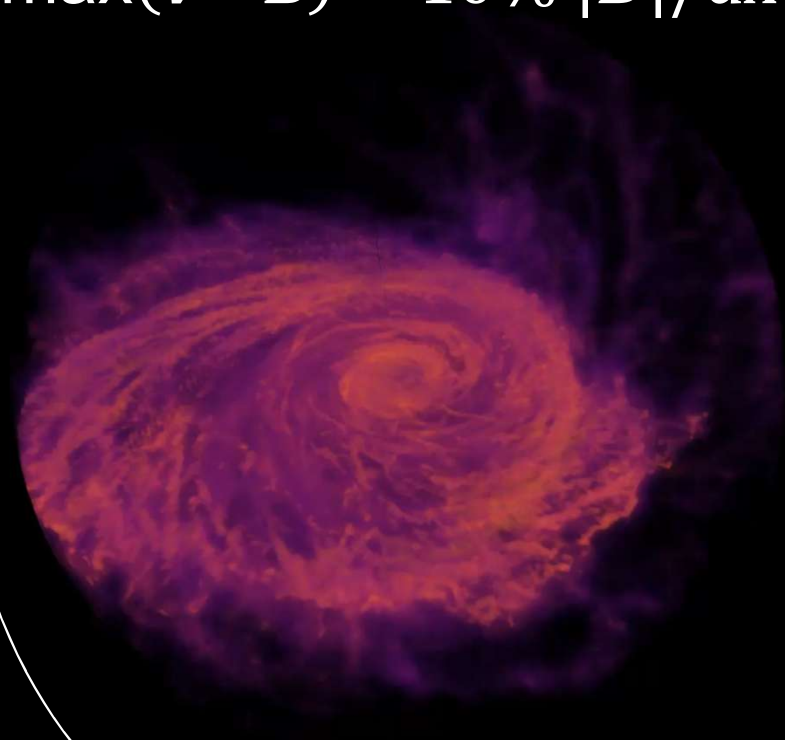
Cleaning Magnetic Field Divergence

$\max(\nabla \cdot \mathbf{B}) \sim 10\% \, |\boldsymbol{B}|/\mathrm{dx}$



Morally deficient):

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Cleaning Magnetic Field Divergence

→ **Scalar Divergence Cleaning**

If $\boldsymbol{\nabla} \cdot \boldsymbol{B} \neq \mathbf{0}$,

$$\boldsymbol{B} = \boldsymbol{\nabla} P + \boldsymbol{\nabla} \times \mathbf{A}$$

Scalar Potential

$$\boldsymbol{\nabla} \cdot \boldsymbol{B} = \boldsymbol{\nabla}^2 P$$

Solve for P, and you can clean **B**!

Small, Uniform, Cartesian Grids

Small, Uniform, **Spherical** Grids

Big, Uniform, Spherical Grids

Big, **AMR,** Spherical Grids

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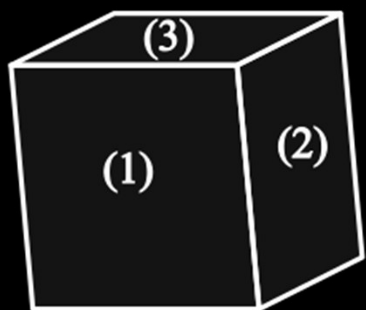
Cleaning Magnetic Field Divergence

Break a hard problem into a bunch of easy problems?



$$\sum_n^6 \Phi_n \neq 0$$

$$\sum_n^6 (1 + c_n)\Phi_n = 0$$

Φ_n uncleaned magnetic flux leaving block face

c_n adjustable coefficient for each block

We can clean block-by-block if blocks have clean boundaries

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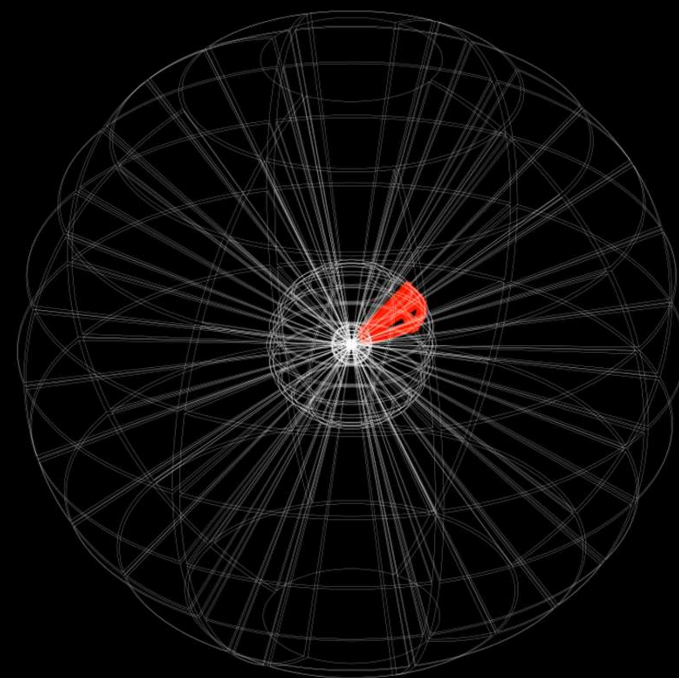
Cleaning Magnetic Field Divergence

We "walk" through the grid, cleaning block boundaries as we go



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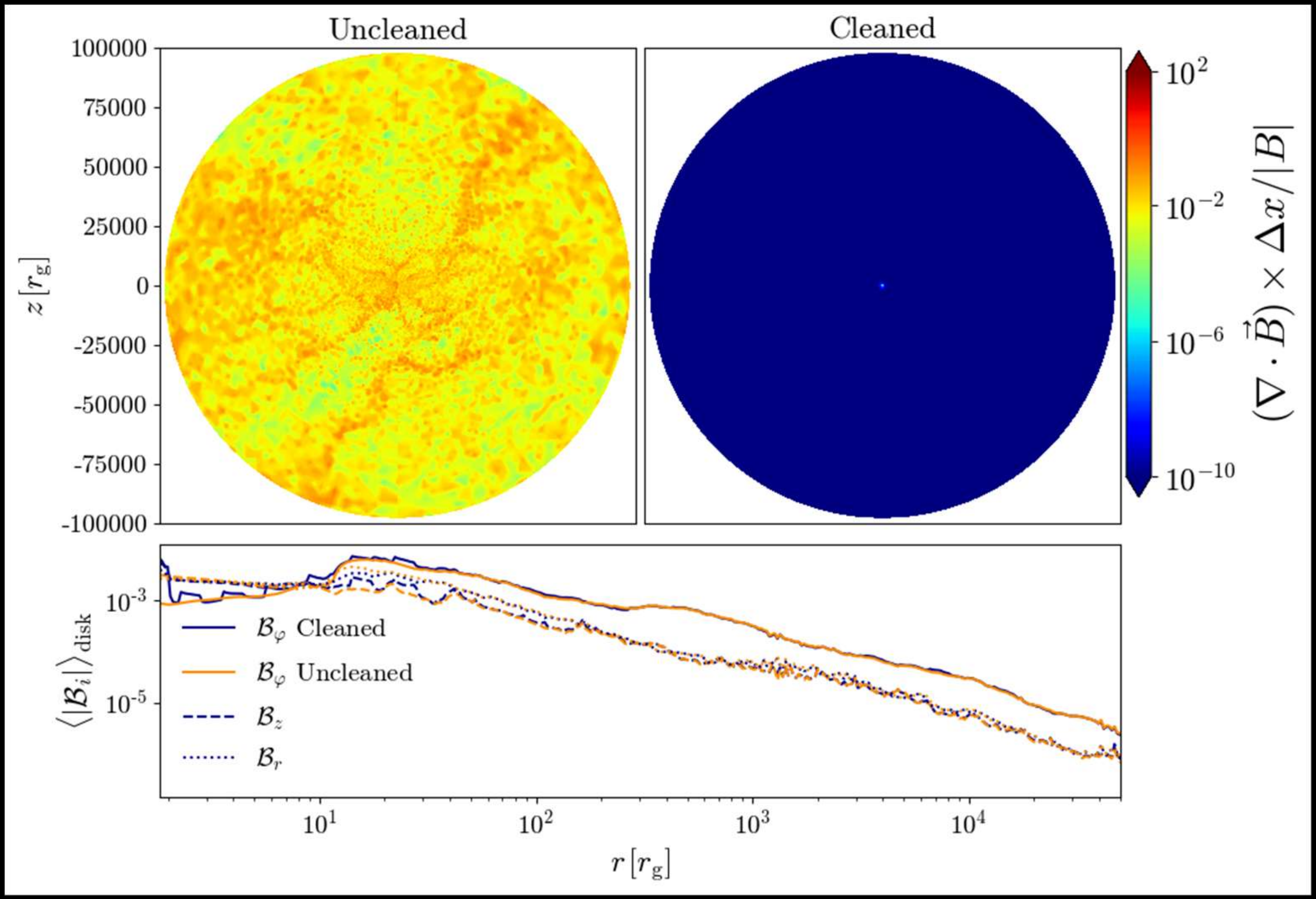
Cleaning Magnetic Field Divergence



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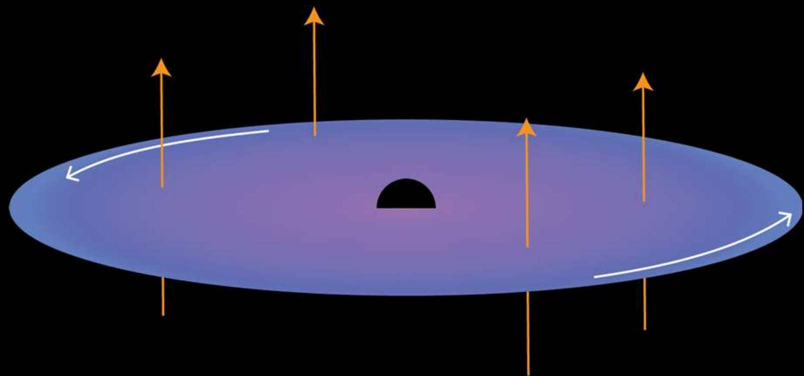
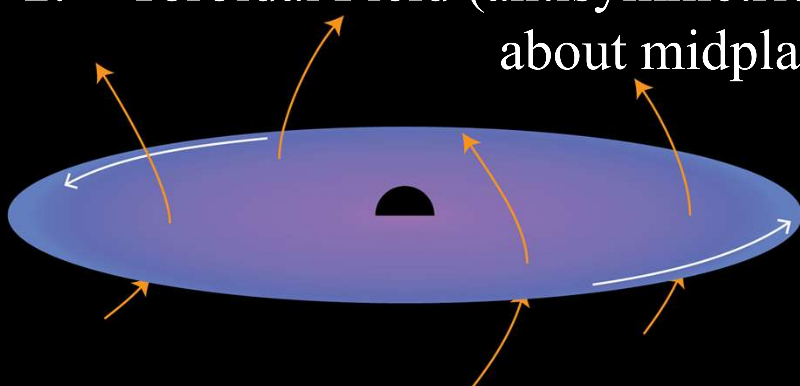
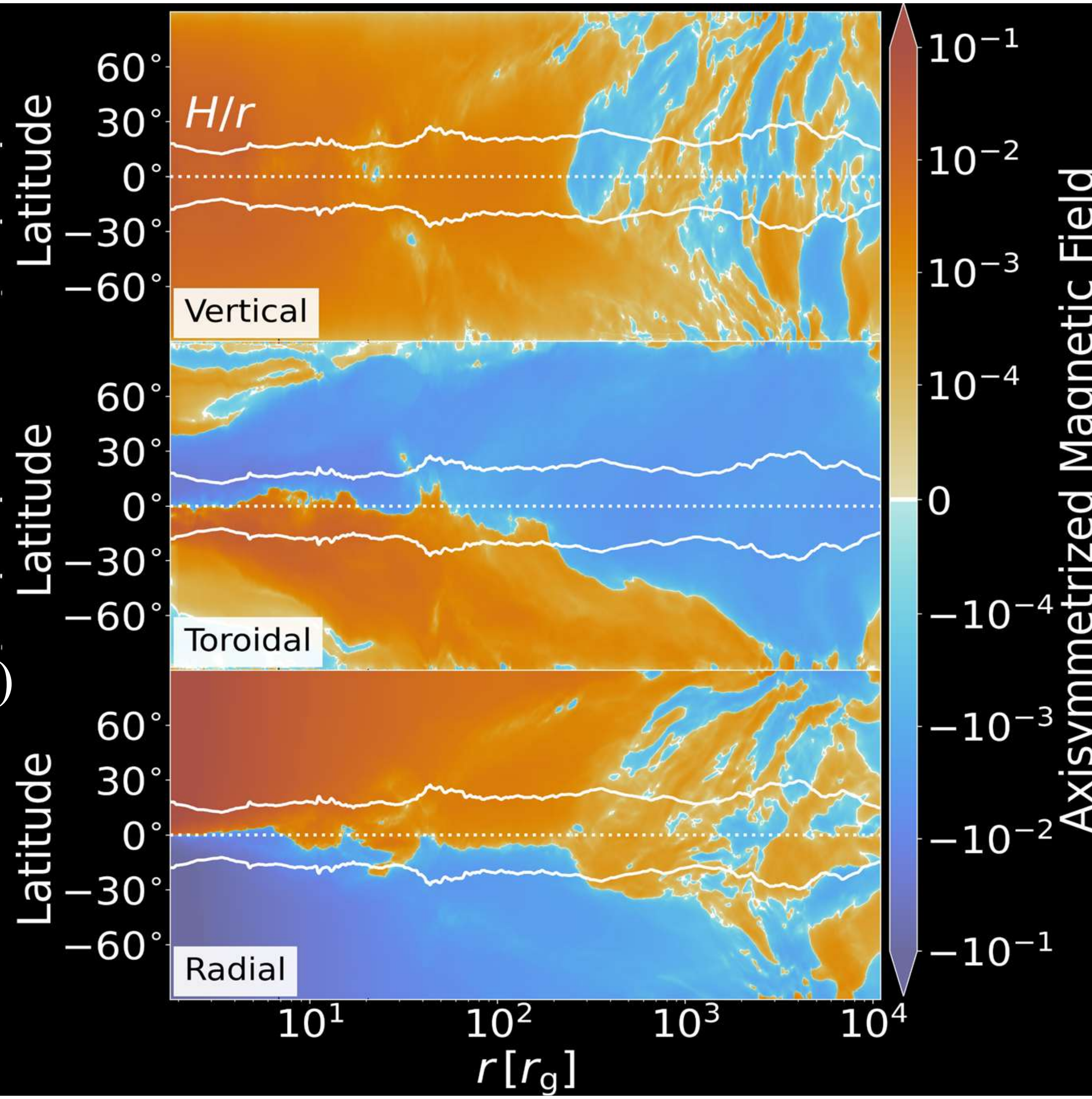
What happens to the magnetic field?

1. Vertical Field + Rotation



2. = Toroidal Field (antisymmetric about midplane)





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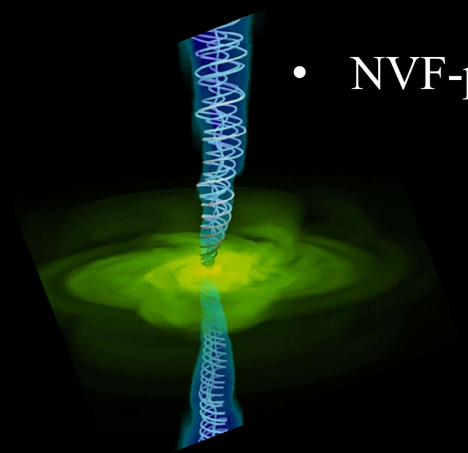
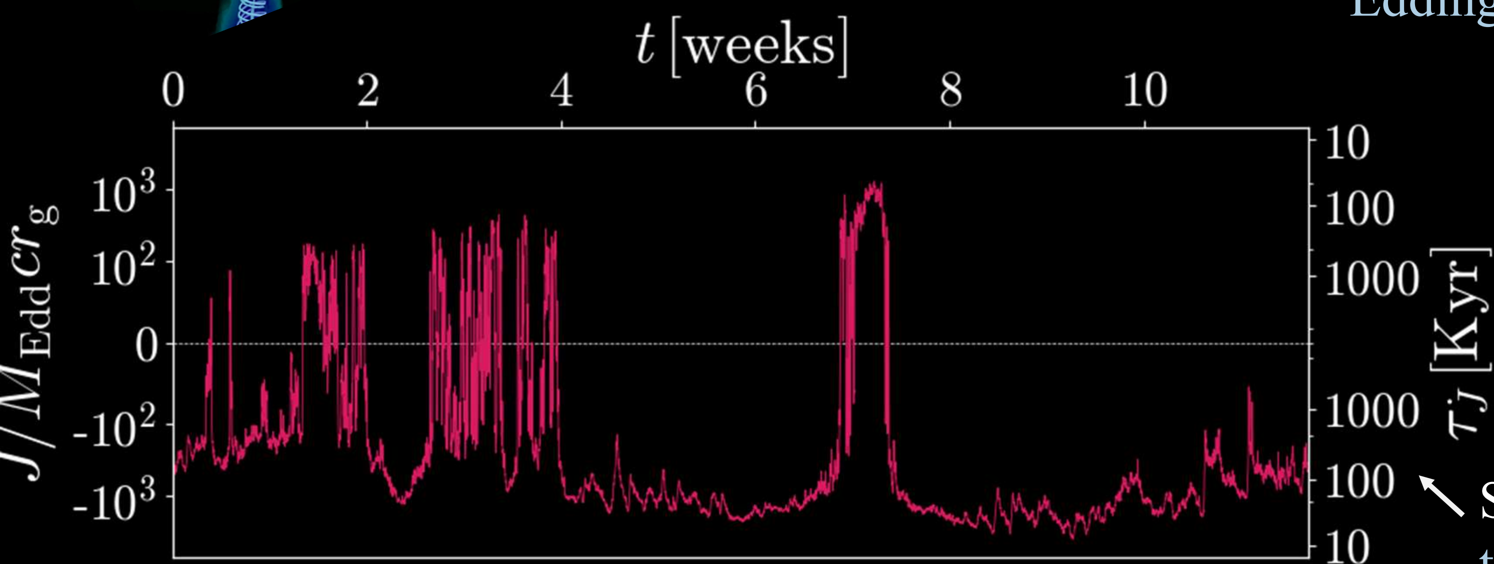
Jets lead to black hole spin down



- NVF-powered "Blandford-Znajek" jets extract rotational energy from the BH

Short timescales enabled by accretion at ~5-10x Eddington limit



Spin-down on Myr timescales! (short for a SMBH)

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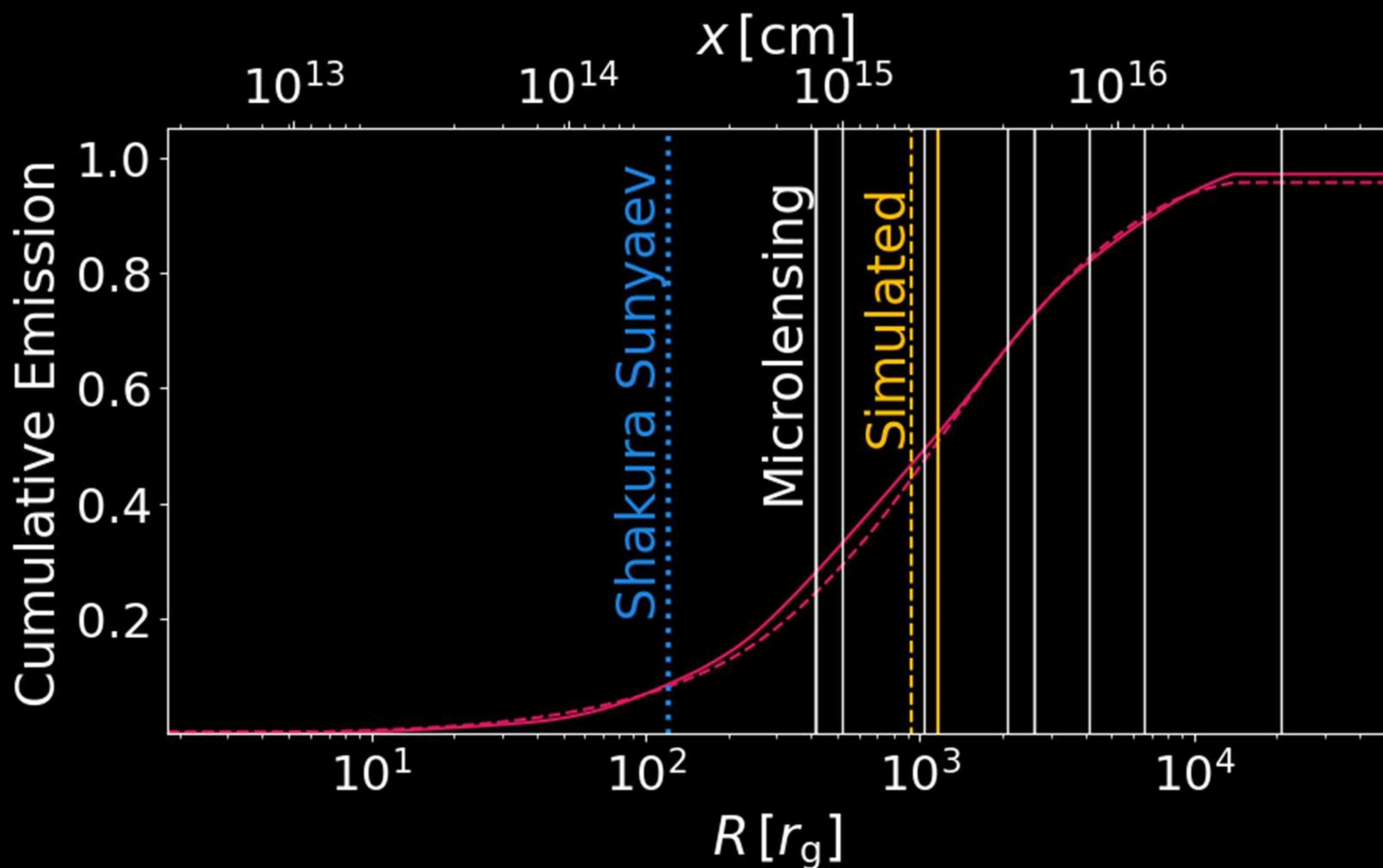
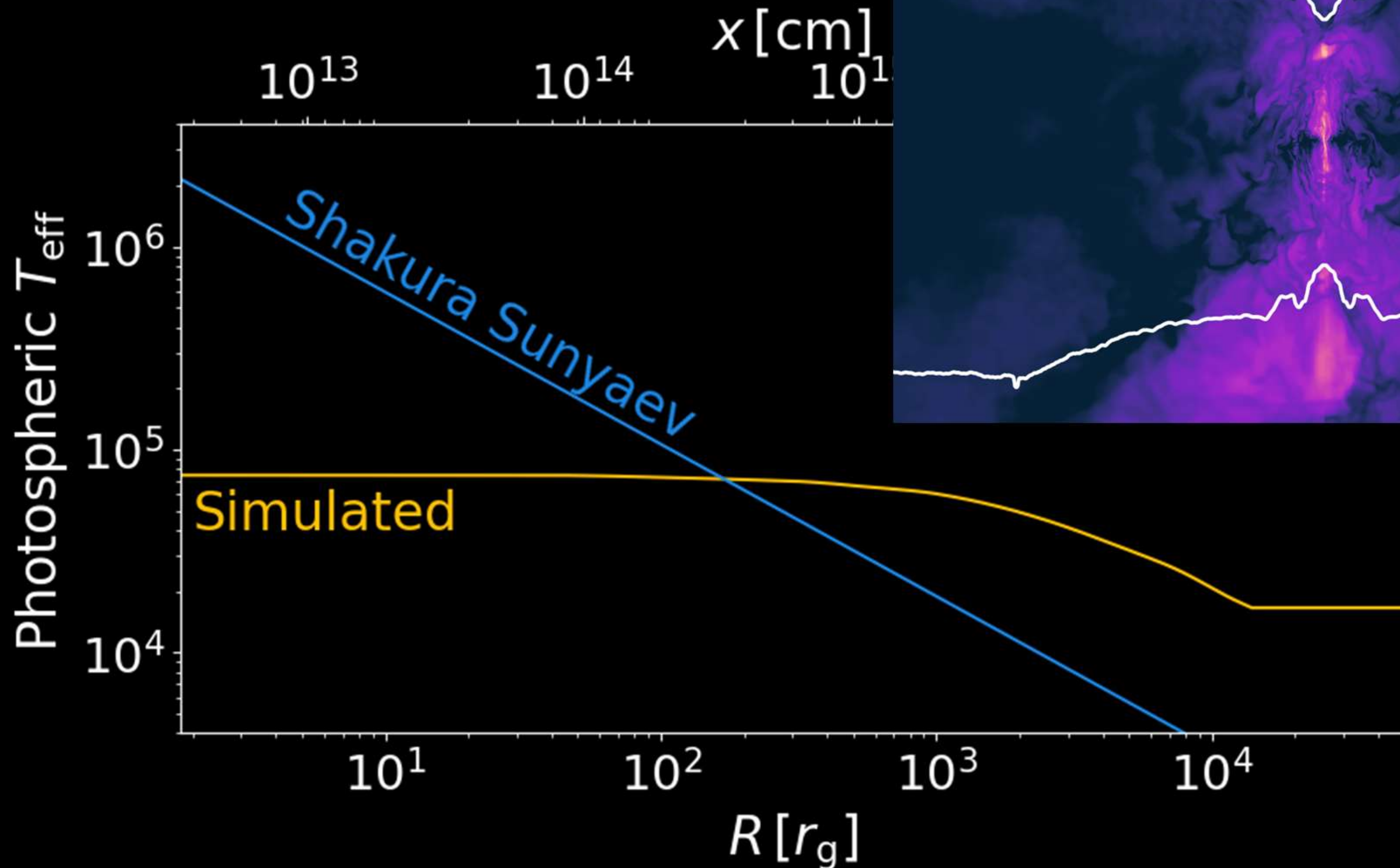
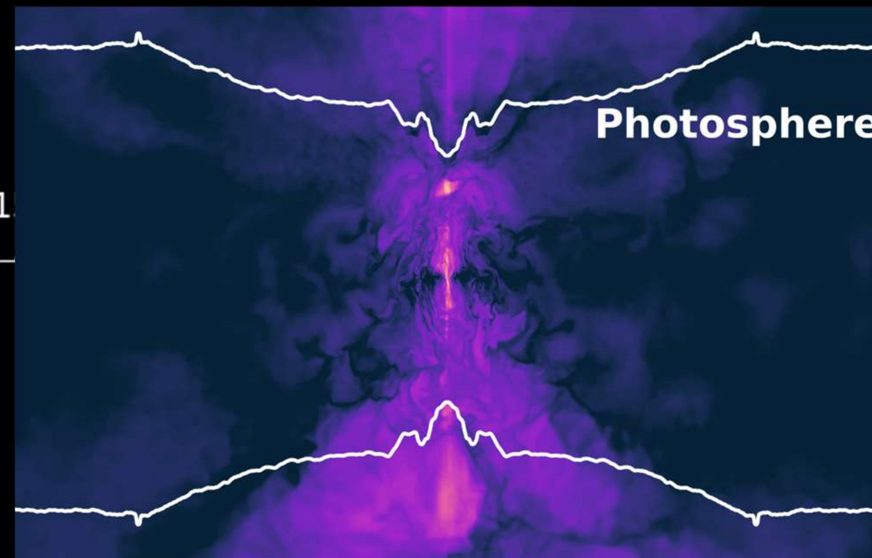


Morgan et al 2010





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