

Probing Anisotropic Particle Acceleration and Limb Brightening in Centaurus A's Jet

Felix Glaser

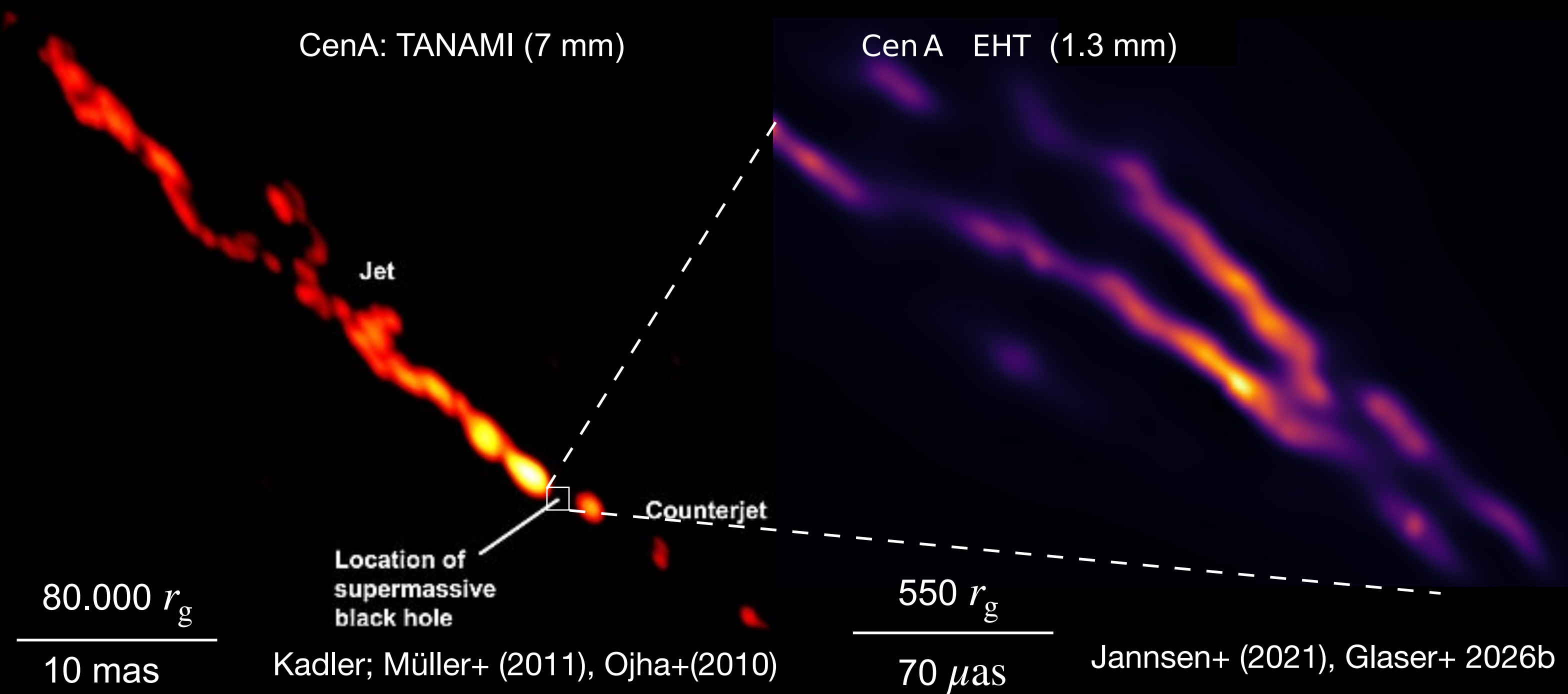
MSc Thesis
& Pilot Study:

F. Glaser, C. Fromm, L. Ricci, Y. Mizuno,
M. Kadler, K. Mannheim & M. Janssen,
2026b, Accepted by A&A

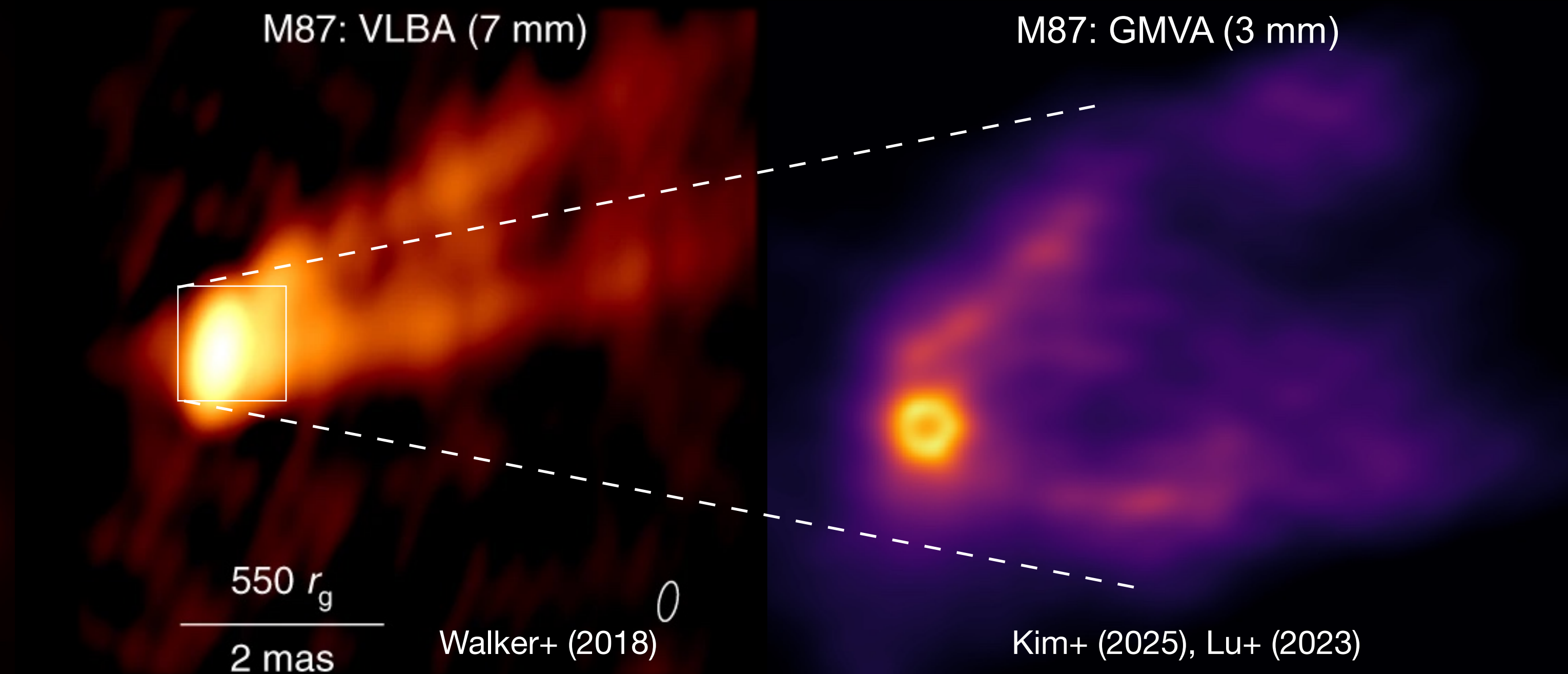
AG Fromm: Christian Fromm,
Aihara Saiz-Perez, Raoul Kinadeter

Annual meeting of the
German Astronomical Society
8th of September 2026

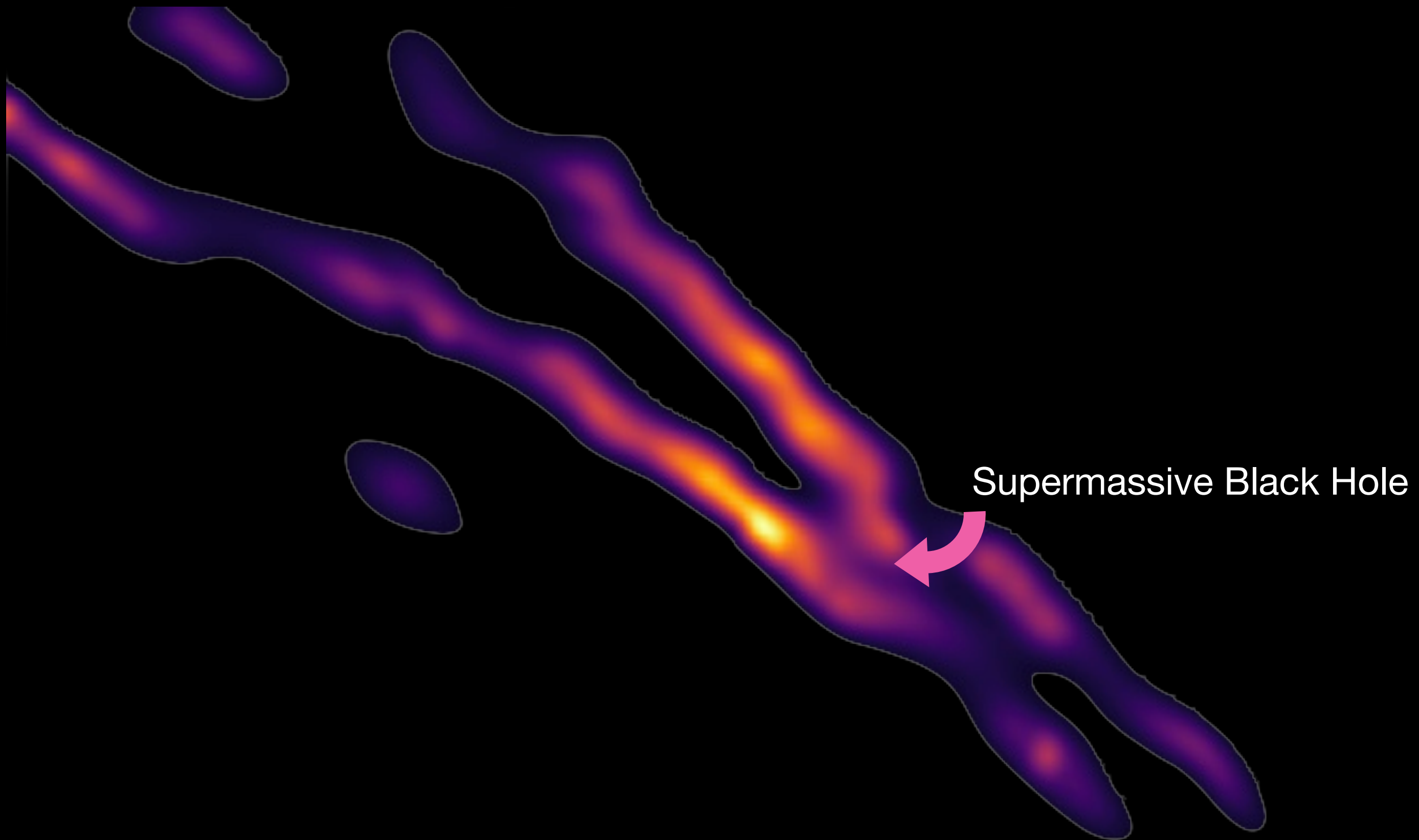
Limb-brightened Jets



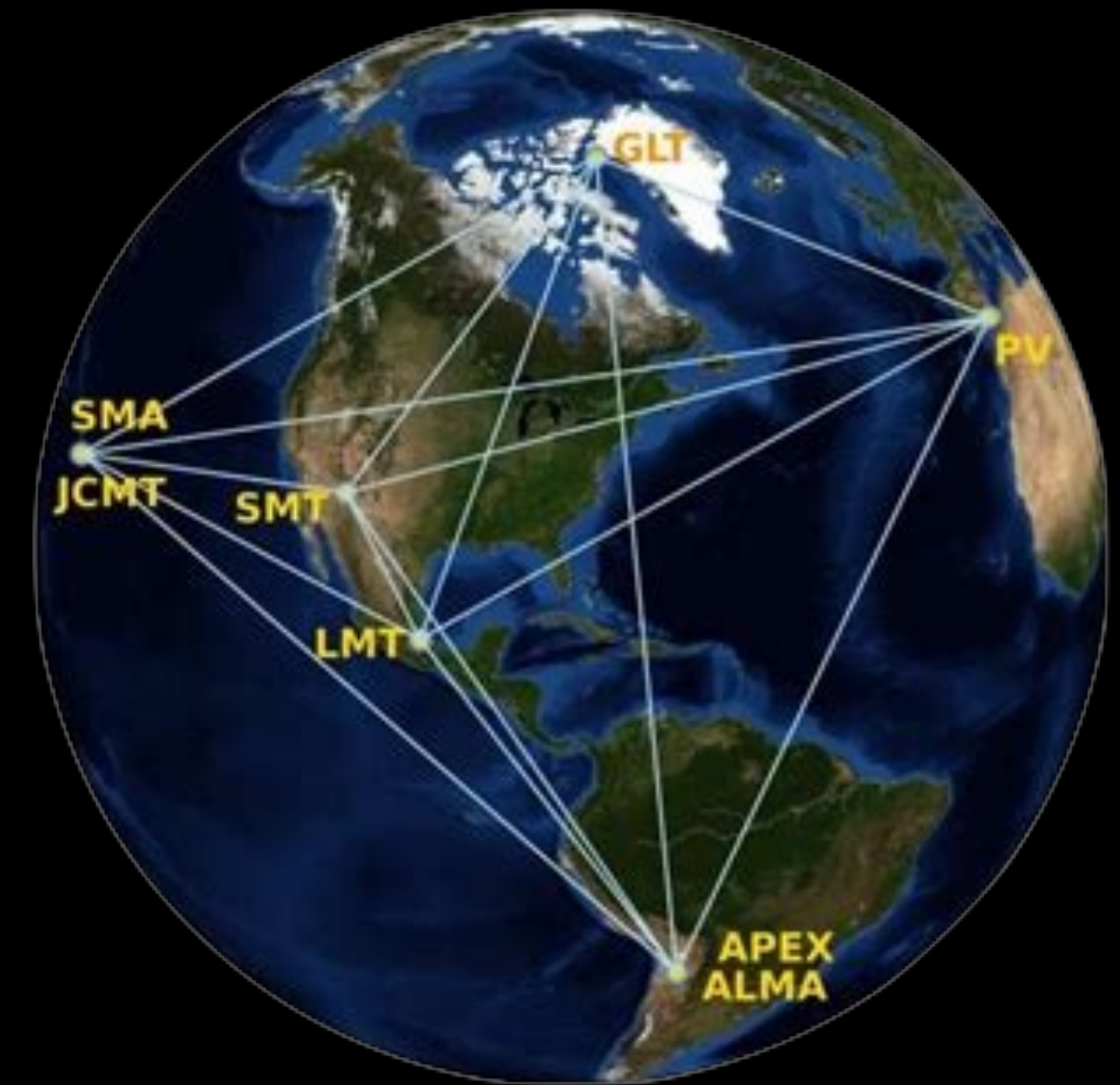
Universal Scaling of Accretion and Jet-Launching Physics?



The EHT observation of Centaurus A (CenA)



Event Horizon Telescope (EHT)



The EHT observation of Centaurus A (CenA)

Simulation: Nonthermal Jet-Emission
from ~~ISOTROPIC~~ Electron-Momentum Distribution

=
NO Limb Brightening

ANISOTROPIC
w.r.t. the **Magnetic Field**

Why Anisotropic Particle Distributions?

- Conservation of magnetic moment:

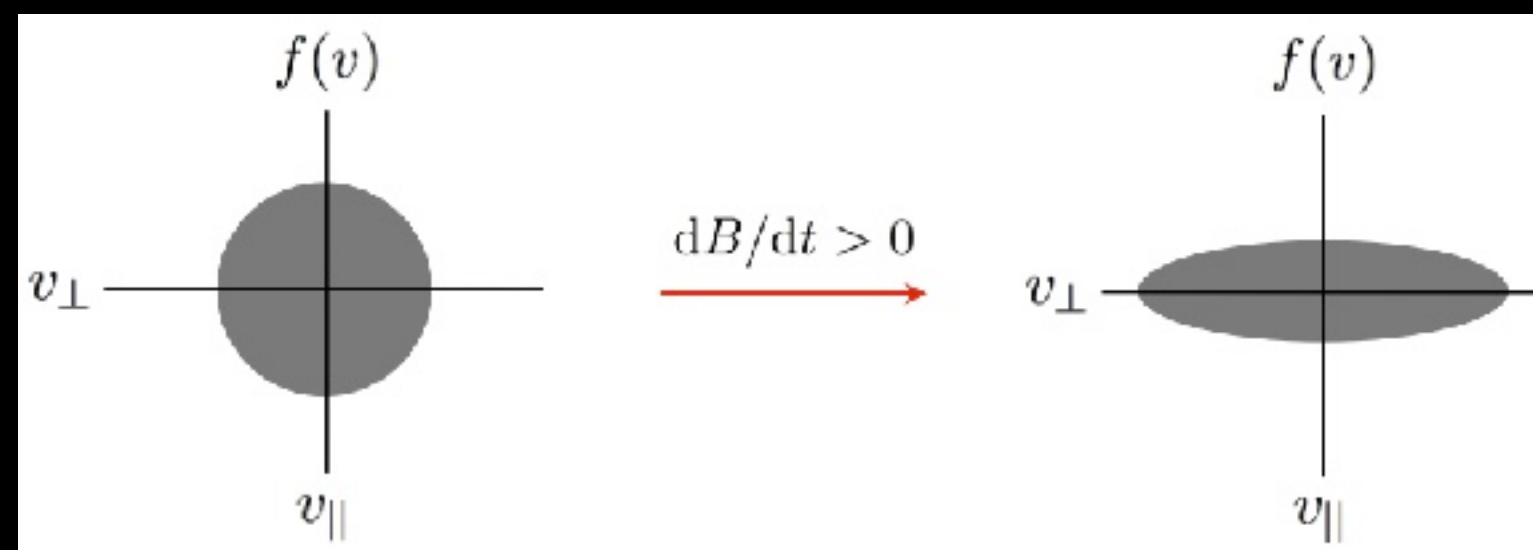
$$\mu \equiv \frac{mv_{\perp}^2}{2B} \sim \text{const.} \rightarrow V \int dv \mu f = \boxed{\frac{p_{\perp}}{nB} \sim \text{const.}}$$

- Conservation of linear momentum:

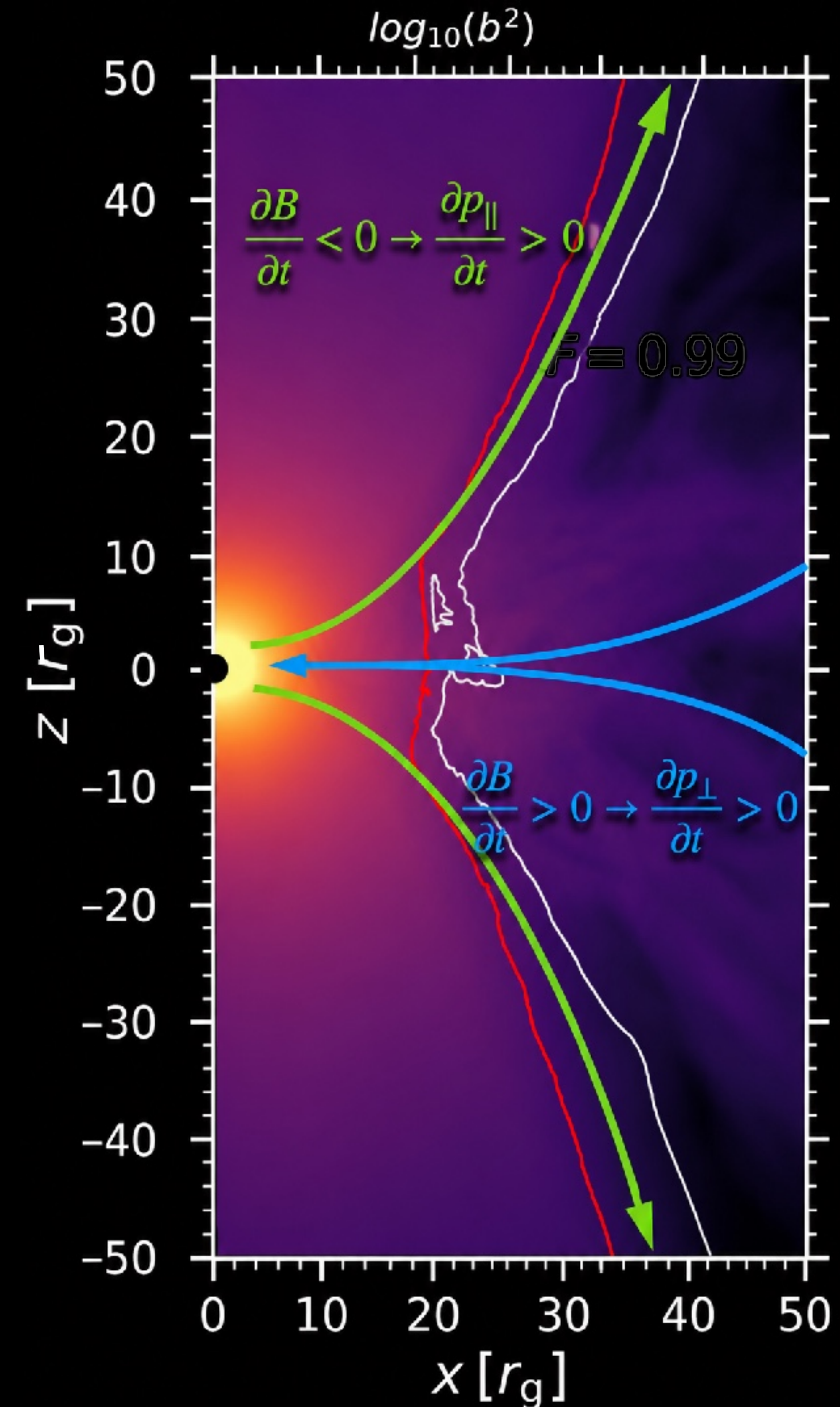
$$J = \int mv_{\parallel} dl \sim \text{const.} \rightarrow V \int dv \mathbf{J} f = \boxed{\frac{p_{\parallel} B^2}{n^3} \sim \text{const.}}$$

⊥ / ∥ w.r.t. Magnetic Field

Adiabatic evolution:

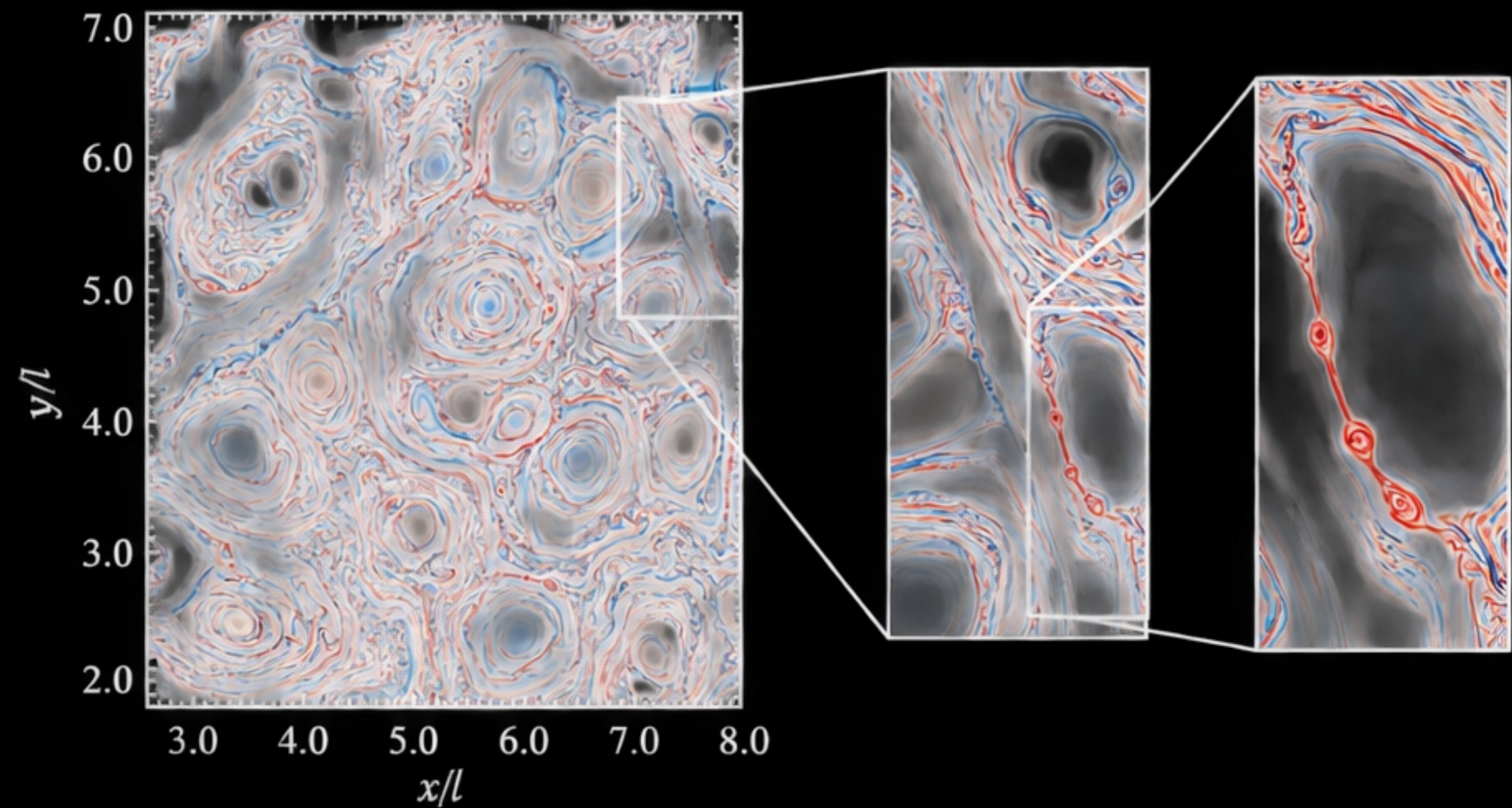
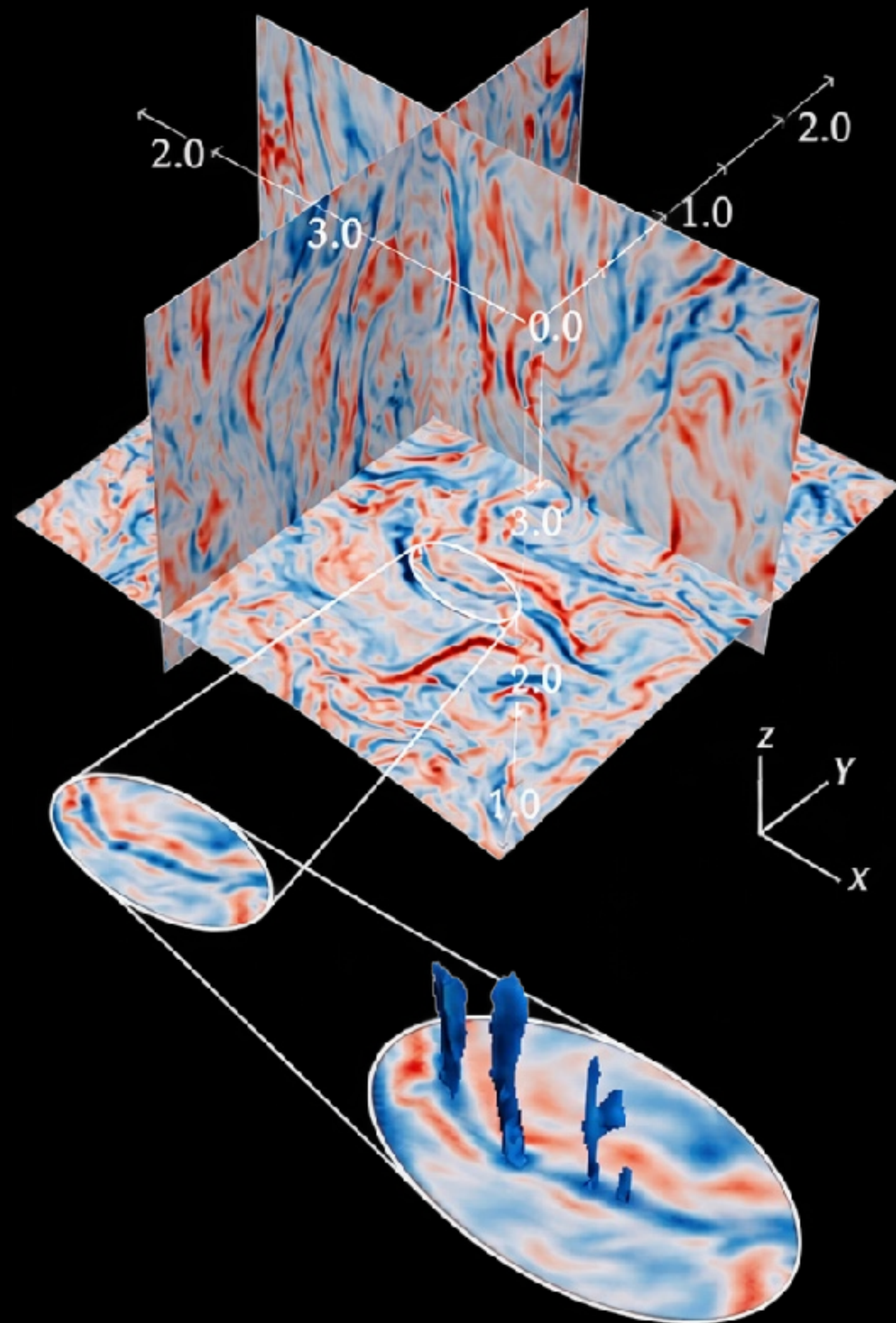


$$p \propto n^{\frac{5}{3}} \rightarrow p_{\perp} \propto nB \text{ \& \; } p_{\parallel} \propto \frac{n^3}{B^2}$$



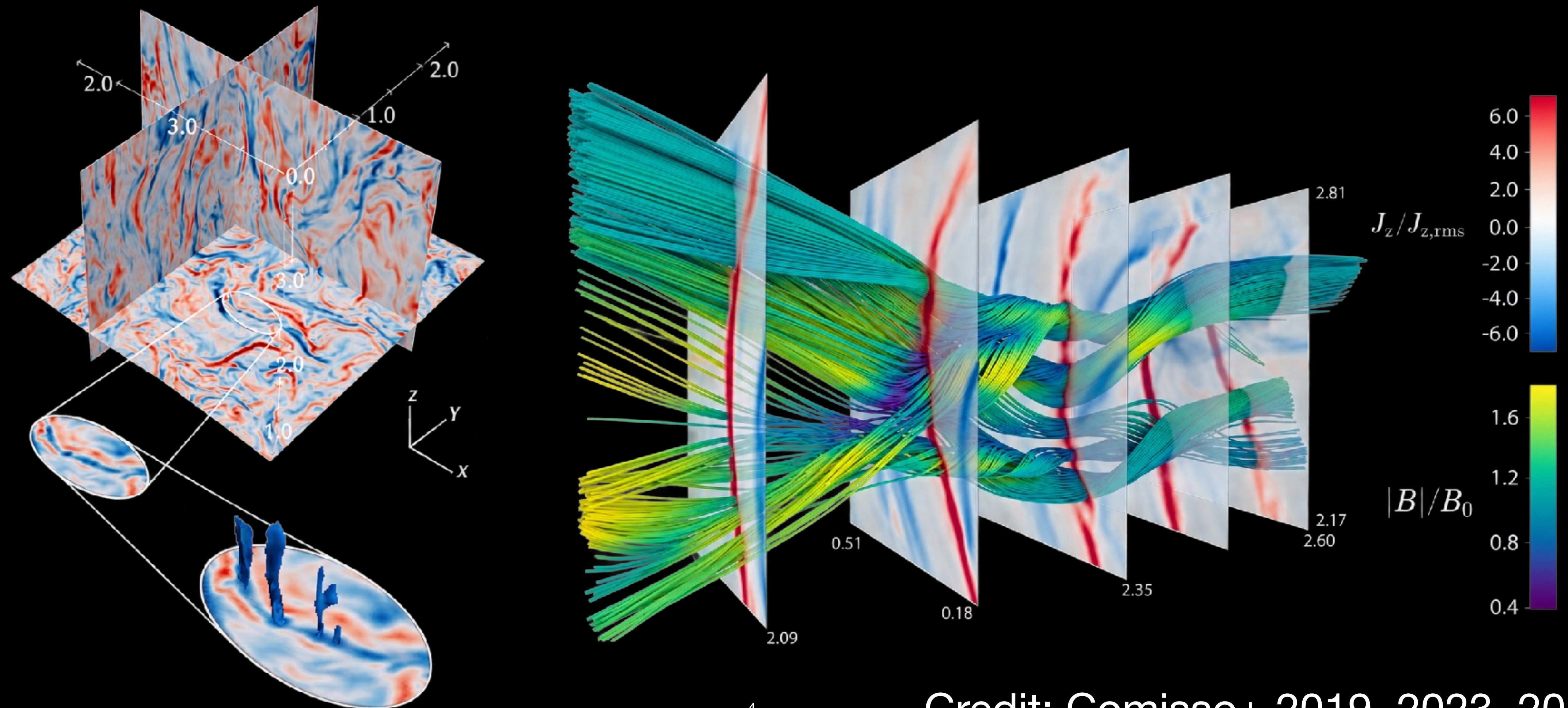
2D/3D Particle-In-Cell (PIC) Simulations

Pitch-Angle Anisotropy from Magnetic Reconnection in Alfvénic Turbulence



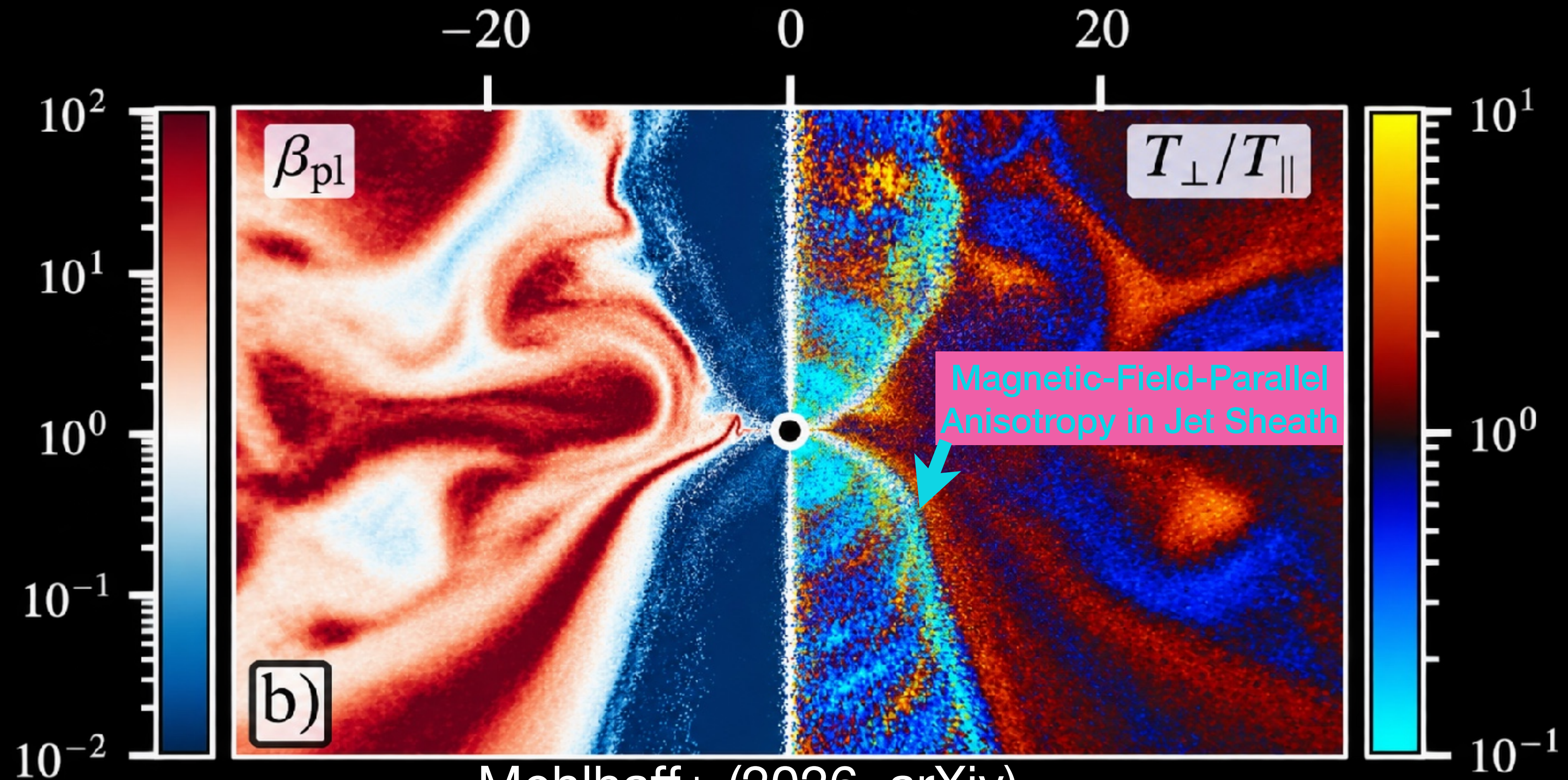
2D/3D Particle-In-Cell (PIC) Simulations

Pitch-Angle Anisotropy from Magnetic Reconnection in Alfvénic Turbulence



Anisotropy in Jet-Launching SMBHs

From the First-Principle General-Relativistic PIC (GRPIC) Approach



Mehlhaff+ (2026, arXiv)

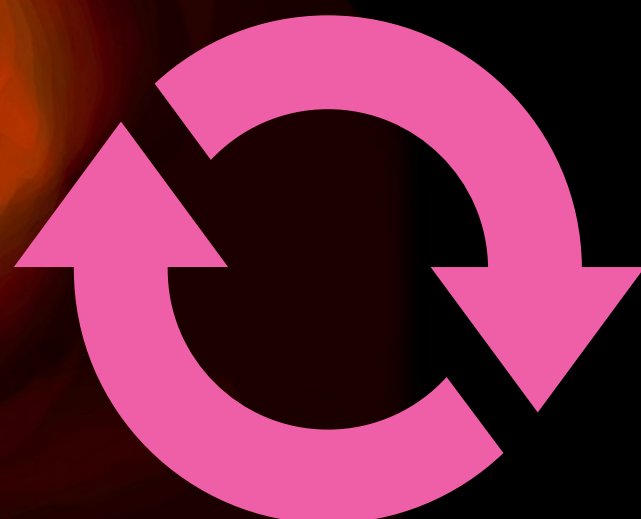
Bayesian Fitting Pipeline: Markov-Chain Monte Carlo (MCMC) Simulations

GRMHD Simulation

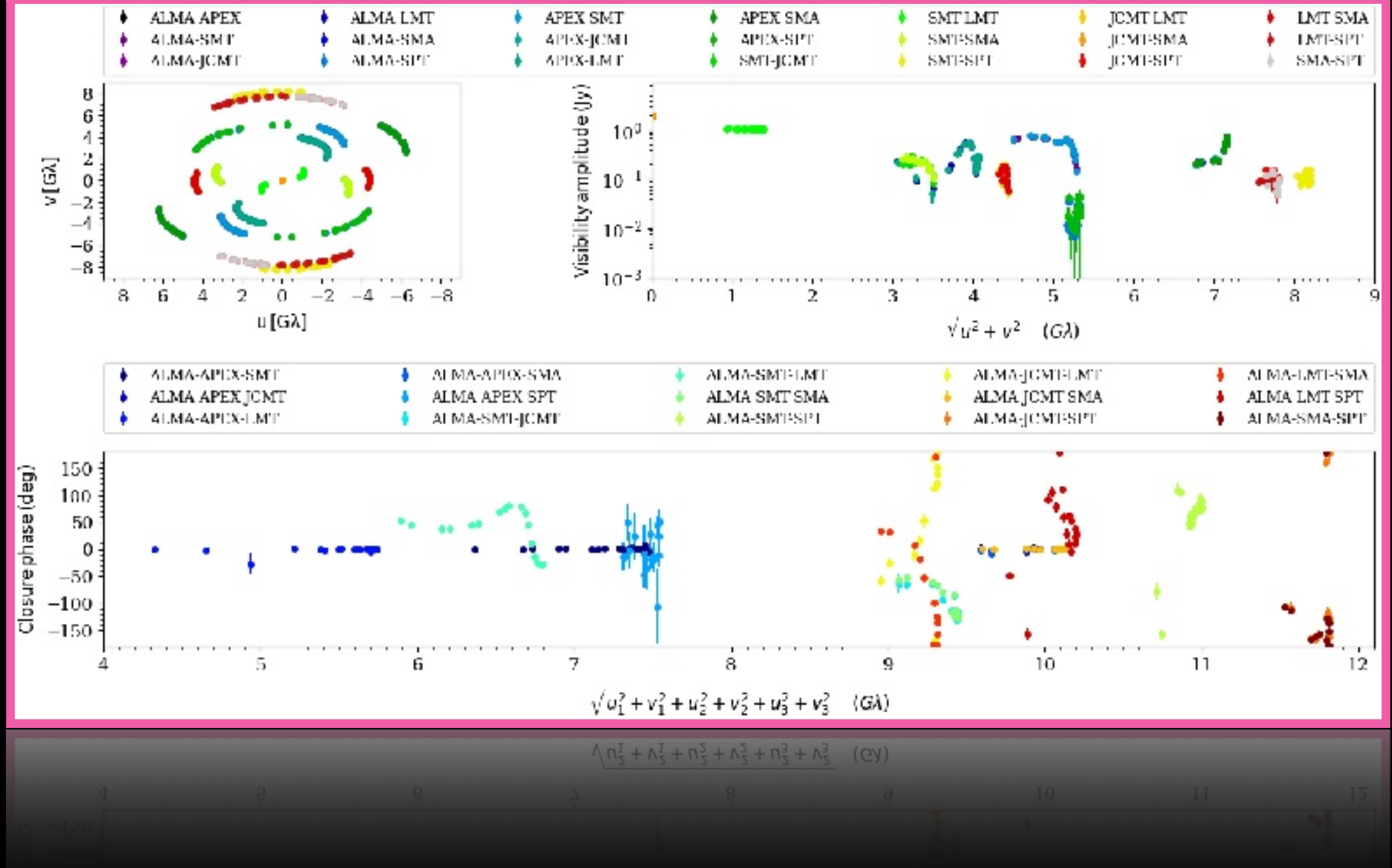
Rays

Screen

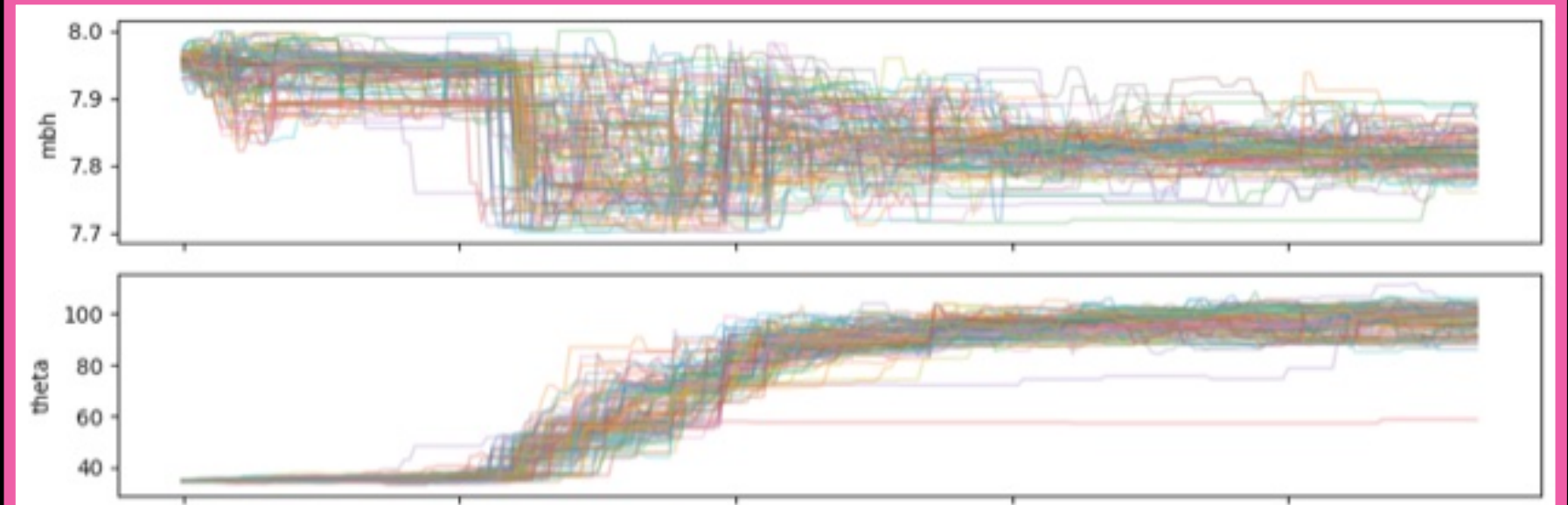
Simulate Synchrotron-Image
of Nonthermal/Thermal Emission



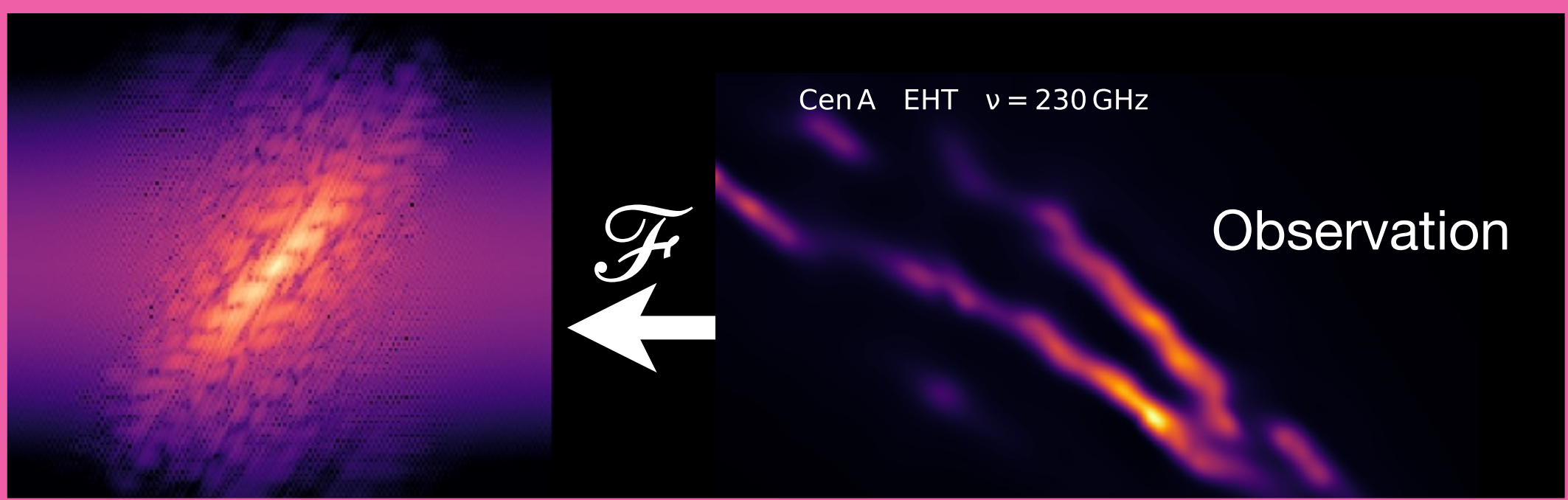
Simulate Synthetic Observation with the EHT Array



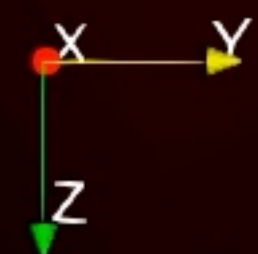
Initialize next Walker in MCMC
until Converged to Observational Visibilities



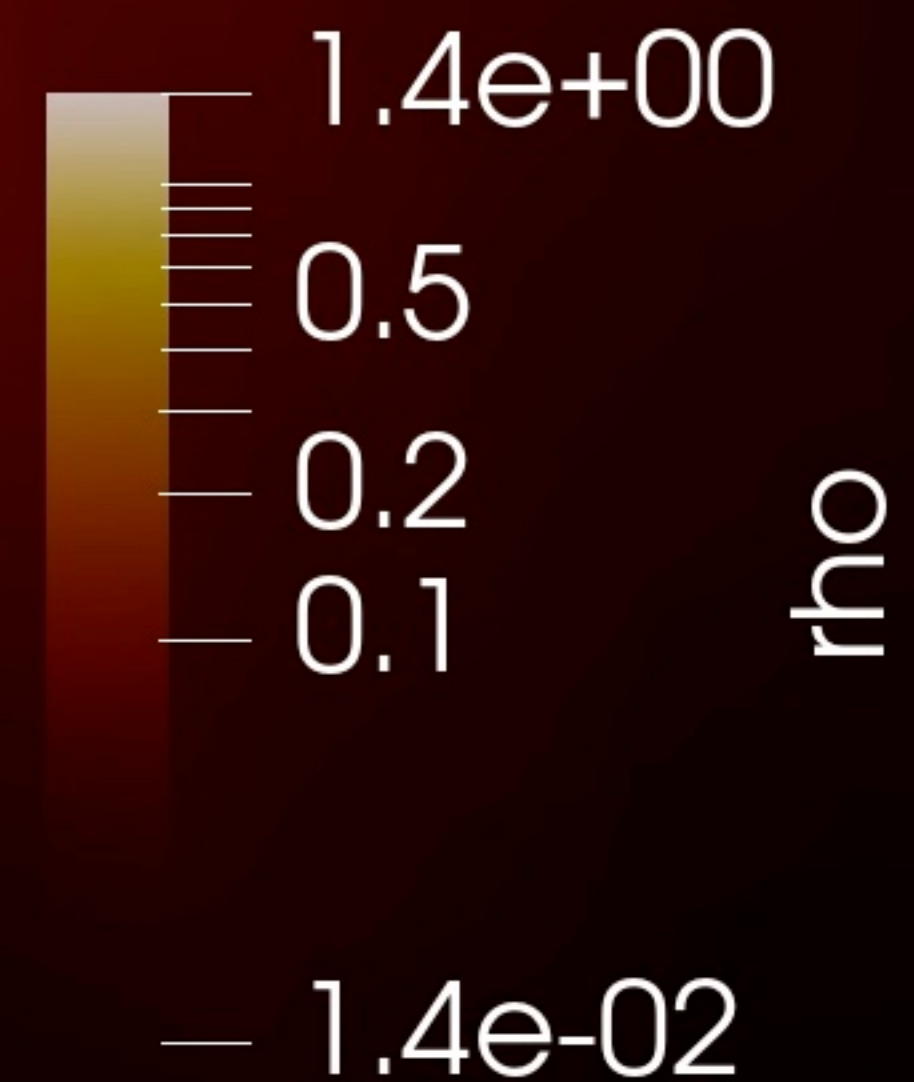
Fit directly to Interferometric Data in Fourier Space



GR Magnetohydrodynamics (GRMHD) Magnetically Arrested Disk (MAD) Simulation



Accretion-Disk Density-Rendering
(Code: KHARMA, Jet not rendered)

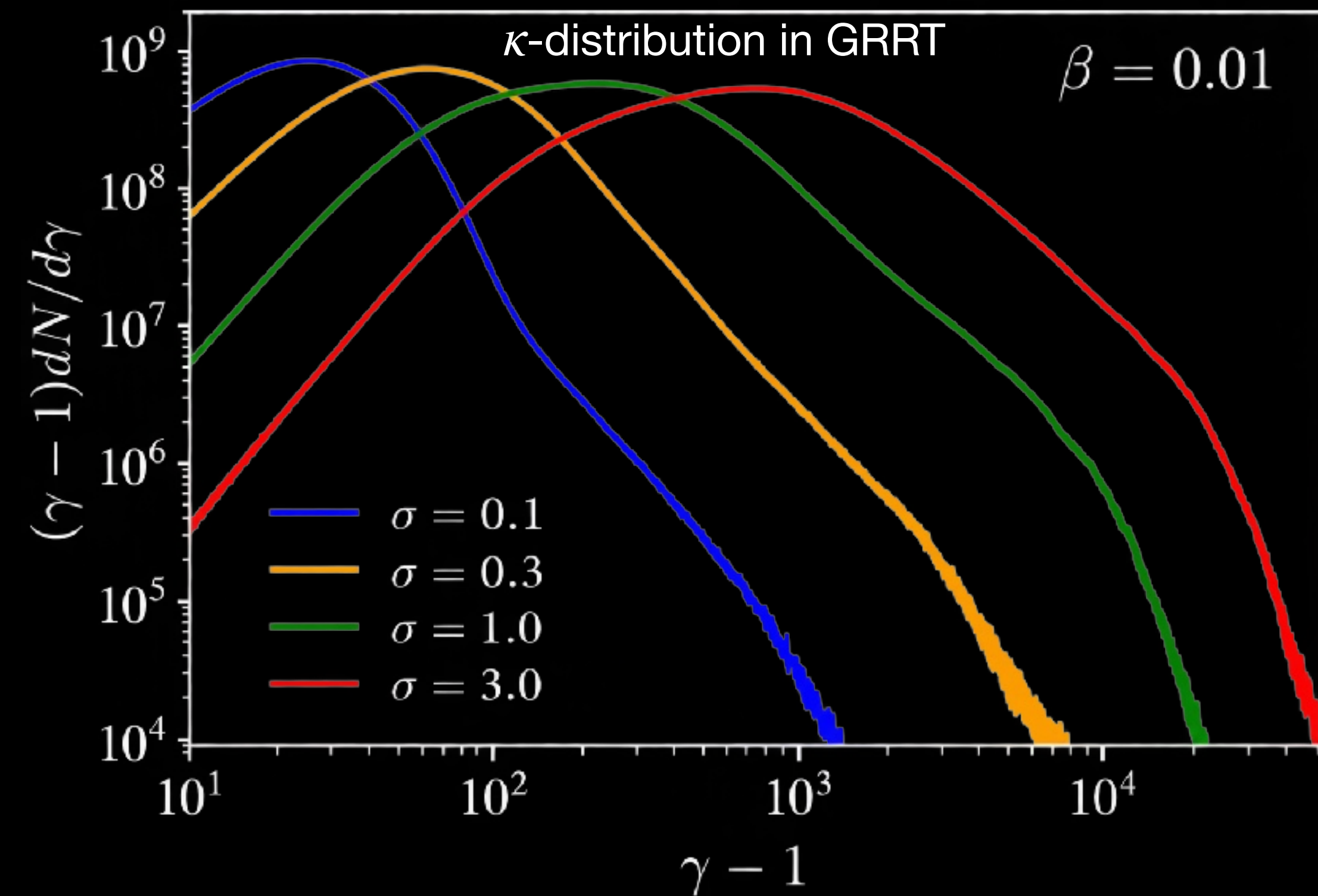


GR Radiative Transfer (GRRT)

Novel Nonthermal GRRT Simulations: Bridging Micro- & Macro-Physics

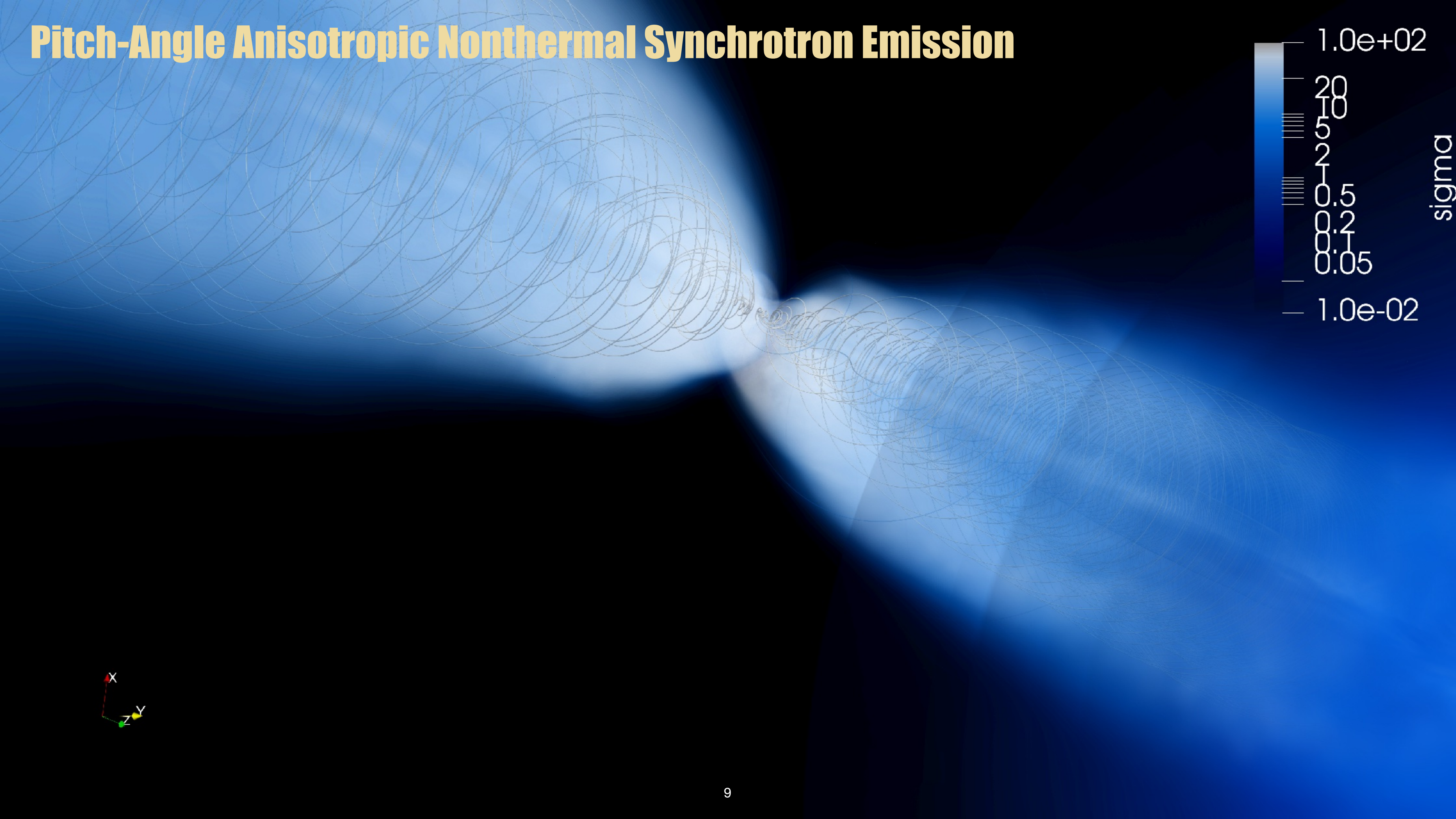
GRMHD provides Large-Scale Fluid-Description of Plasma; No Micro-Physics

- ➔ Infer **Nonthermal** Synchrotron-Emission from relativistic **PIC Sub-Grid Model** (implemented in `ipole`)
- ➔ Transition between Thermal and Nonthermal Emission informed by PIC
- ➔ Modeled **Synchrotron Cooling** for dim Jet Base

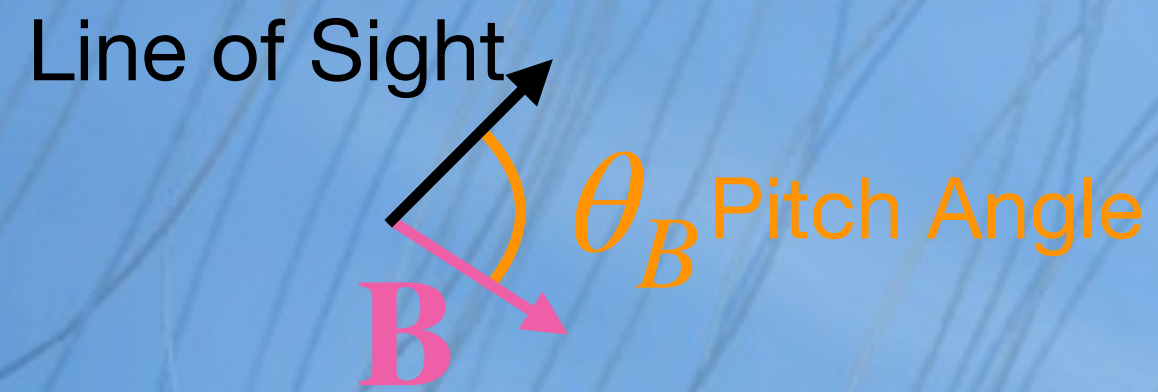


Meringolo+ (2023)

Pitch-Angle Anisotropic Nonthermal Synchrotron Emission



Pitch-Angle Anisotropic Nonthermal Synchrotron Emission



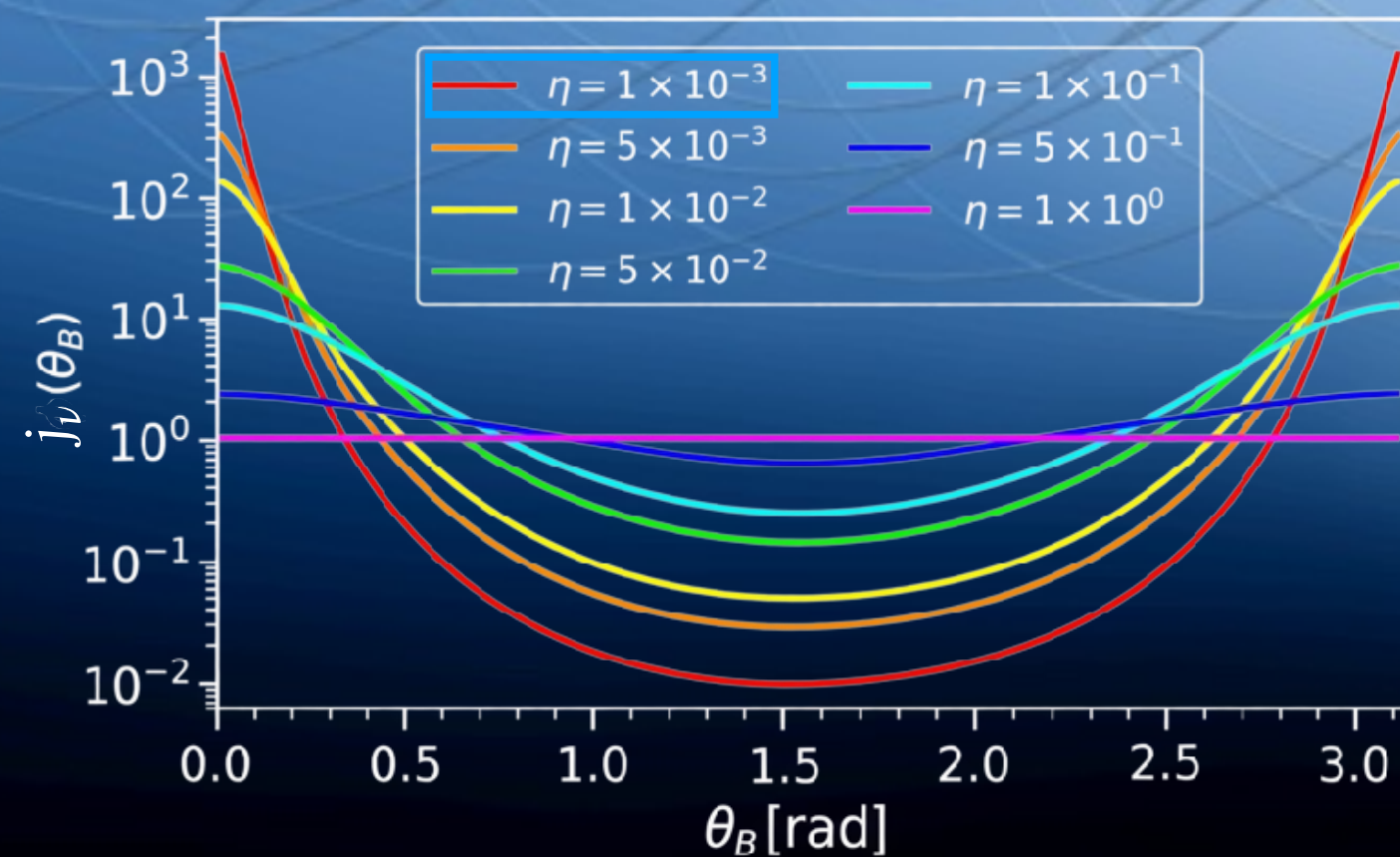
$$j_\nu \sim (1 - \cos^2(\theta_B))^{-p/2}$$

↑ $\eta \rightarrow 0$

Parallel/Anti-Parallel to **B**

$\hat{=}$

Maximal Emissivity



⊙ Line of Sight

Projected **B**

θ_B Closer to 180° in Jet Sheath

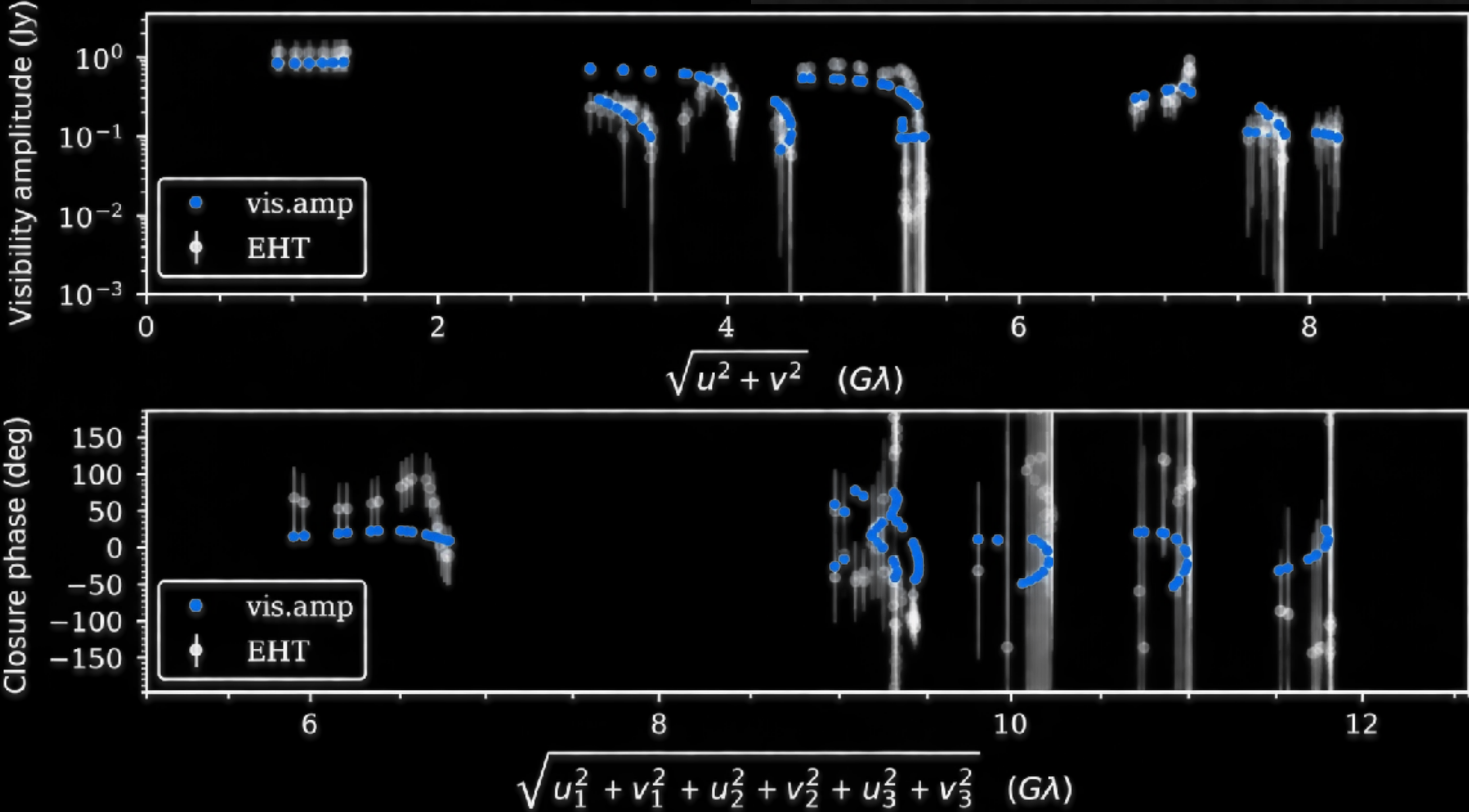
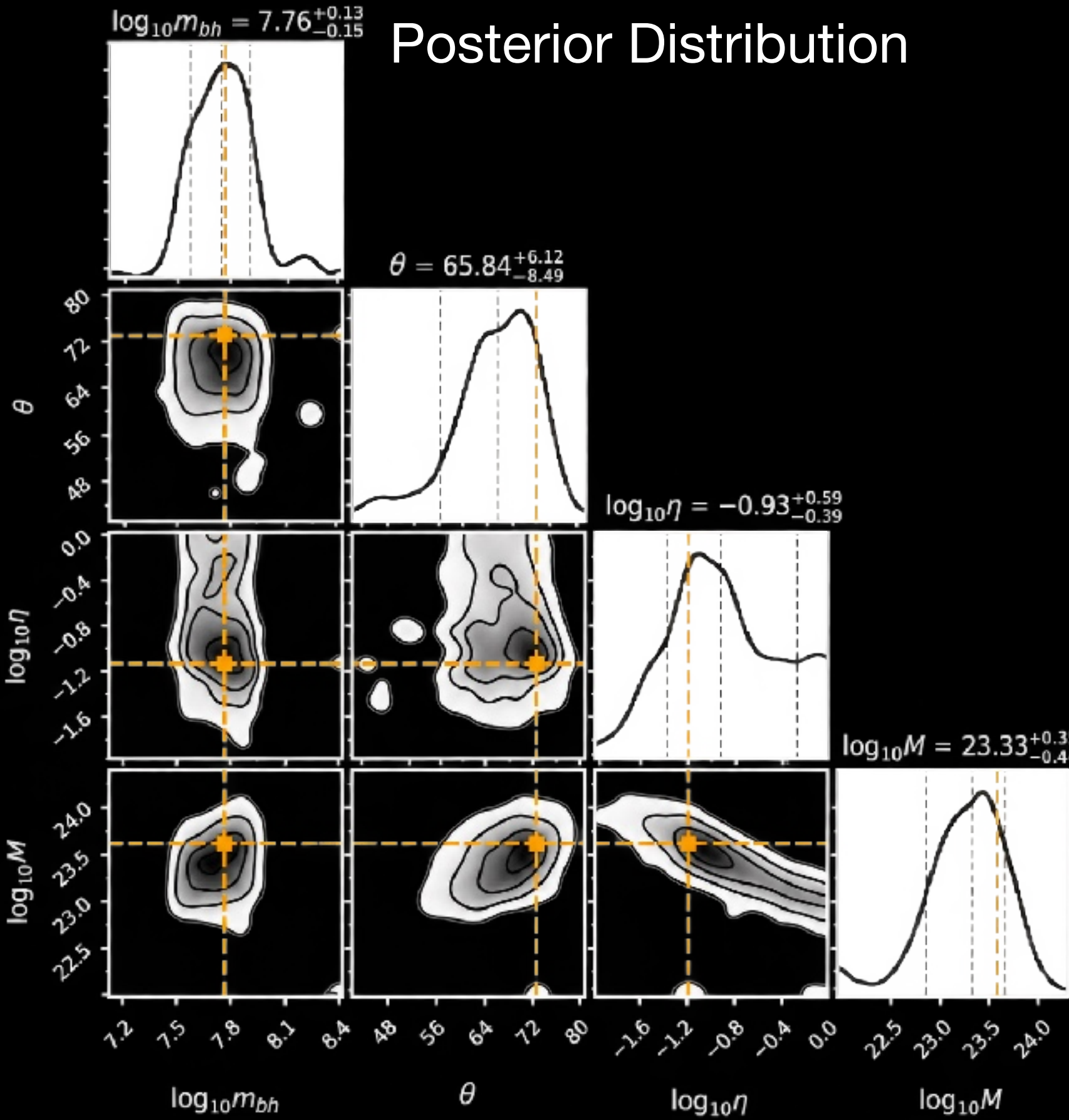
θ_B Close to 90° in Jet Spine

θ_B Closer to 0°

Results: Final Parameters from the MCMC

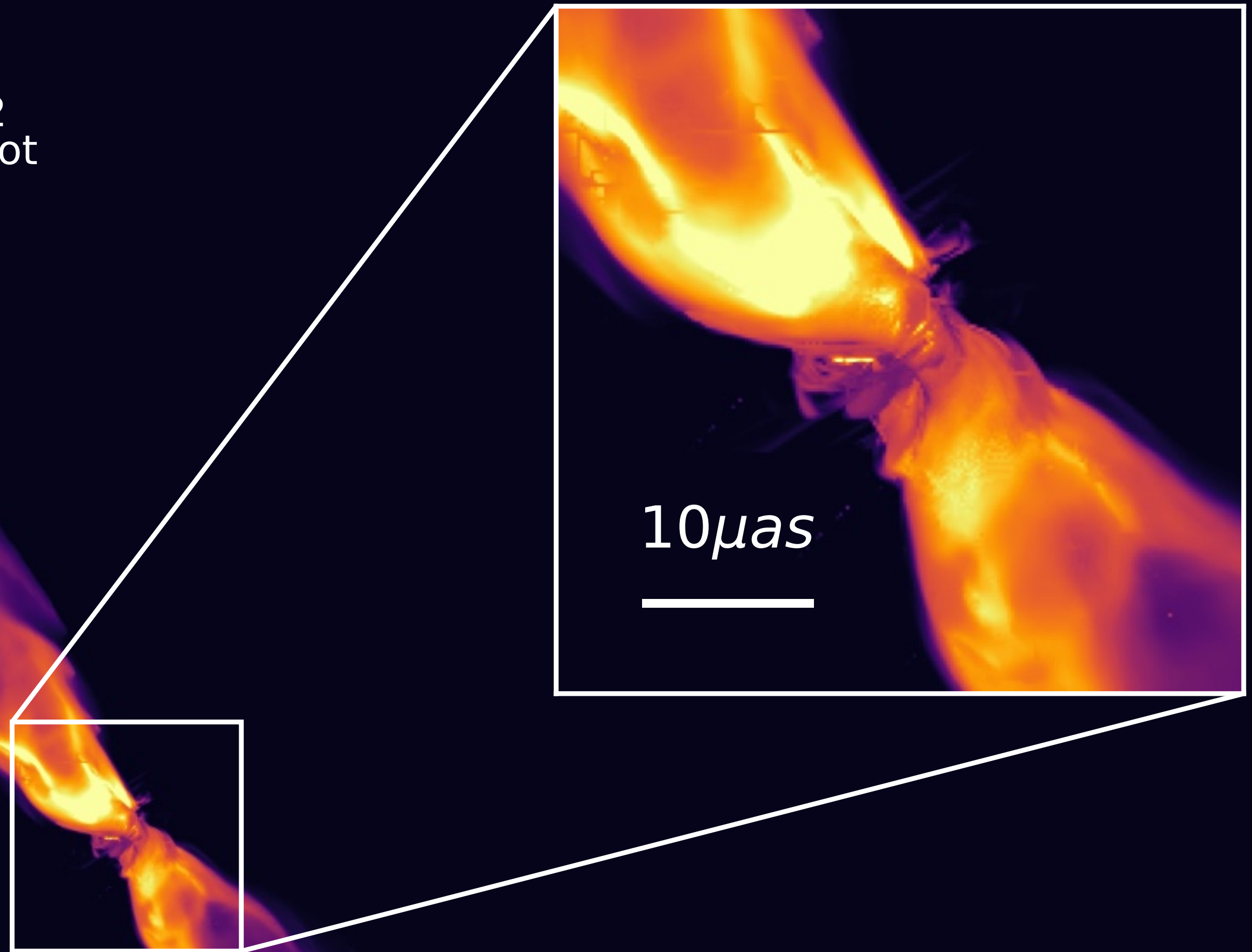
Model of Highest Likelihood

parameter	highest likelihood
M_{bh} (black hole mass)	$6.01 \times 10^7 M_{\odot}$
ϑ (viewing angle)	72.4°
M (mass unit)	$4.12 \times 10^{23} \text{ g/cm}^3$
η (eDF anisotropy)	0.07
t (time GRMHD file)	64.7 kM
$\chi^2_{\text{vis.amp}}, \chi^2_{\text{cphase}}$	2.0, 1.8

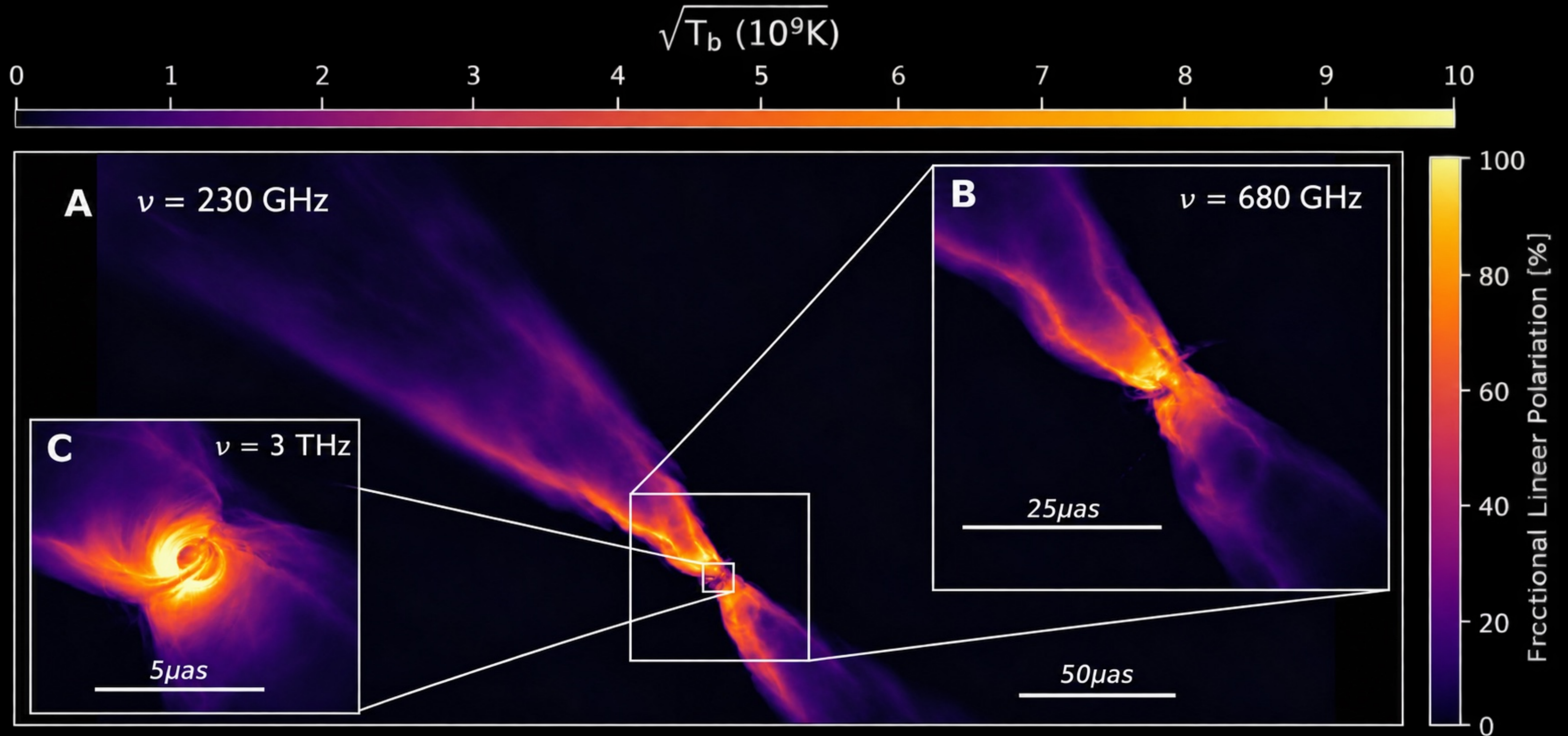


GRMHD $\nu = 230$ GHz best χ^2_{tot}

The First Simulation of Cen A[★]

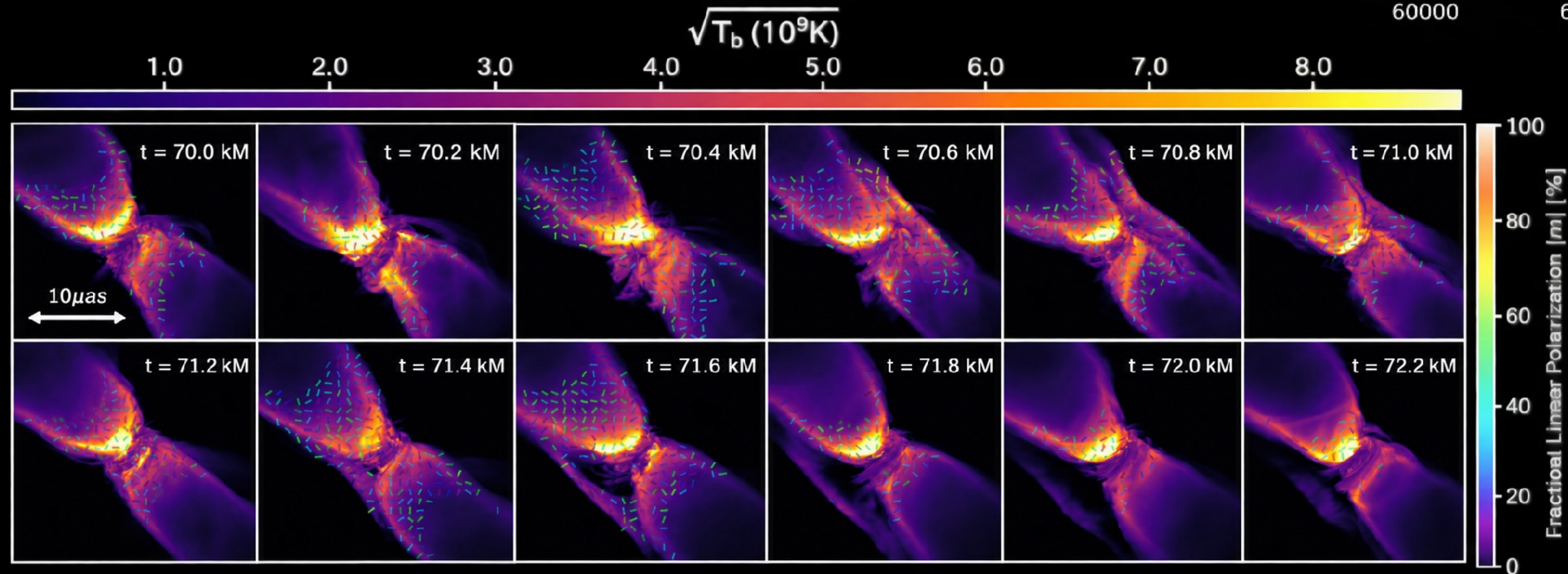
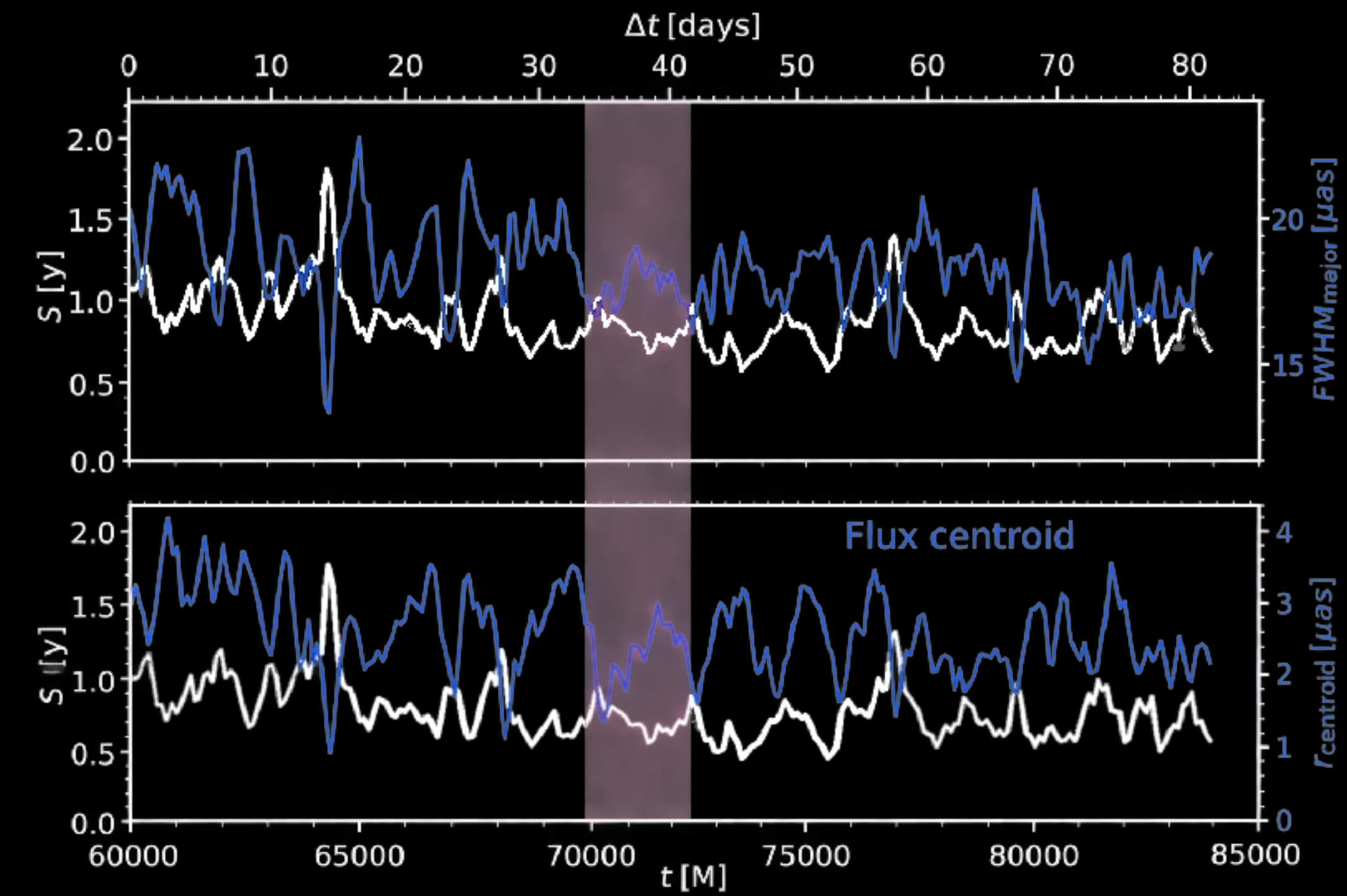


Results: Multi-Frequency Imaging Reveiling the Black-Hole Shadow in Cen A



Results: 680 GHz Signatures

MAD-States == Orbiting Flux Tubes



Summary

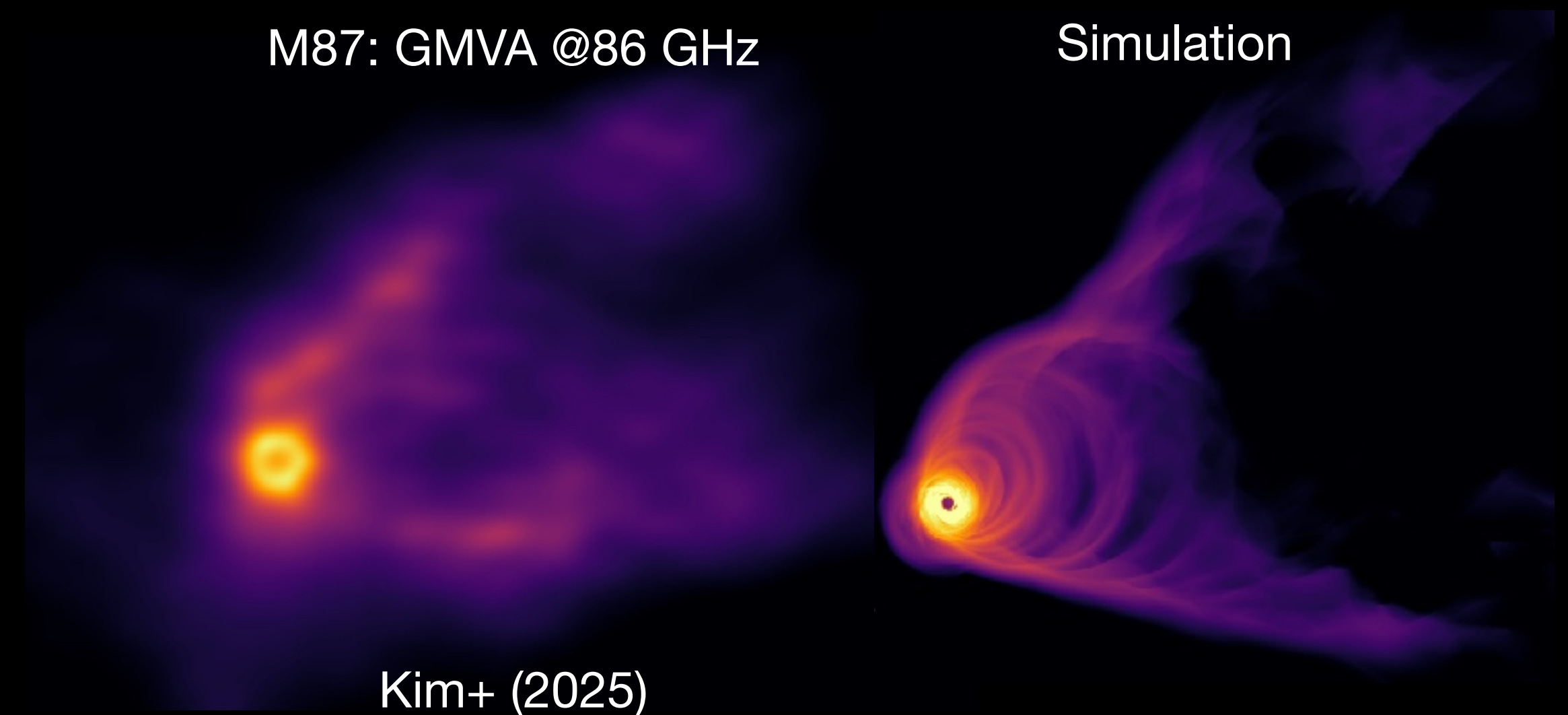
Simulating the Core of Cen A for the First Time

- State-of-the-art Numerical Simulations and **Anisotropic Particle Acceleration** consistent with observed **Limb-Brightened** Morphology in Cen A
- Model provides a Variety of Spectro-Polarimetric Signatures testable with the Next Generation of Telescopes

Outlook

- Model applied to **M87** shows very good Fit to Limb-Brightened Jet
- Also improved Fit to Horizon-Scale Polarization

(preliminary)



Thanks for your attention!



Meanwhile, enjoy this wormhole!

