SIMULATED CURRENT-DRIVEN INSTABILITIES IN AGN JETS

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In collaboration with:
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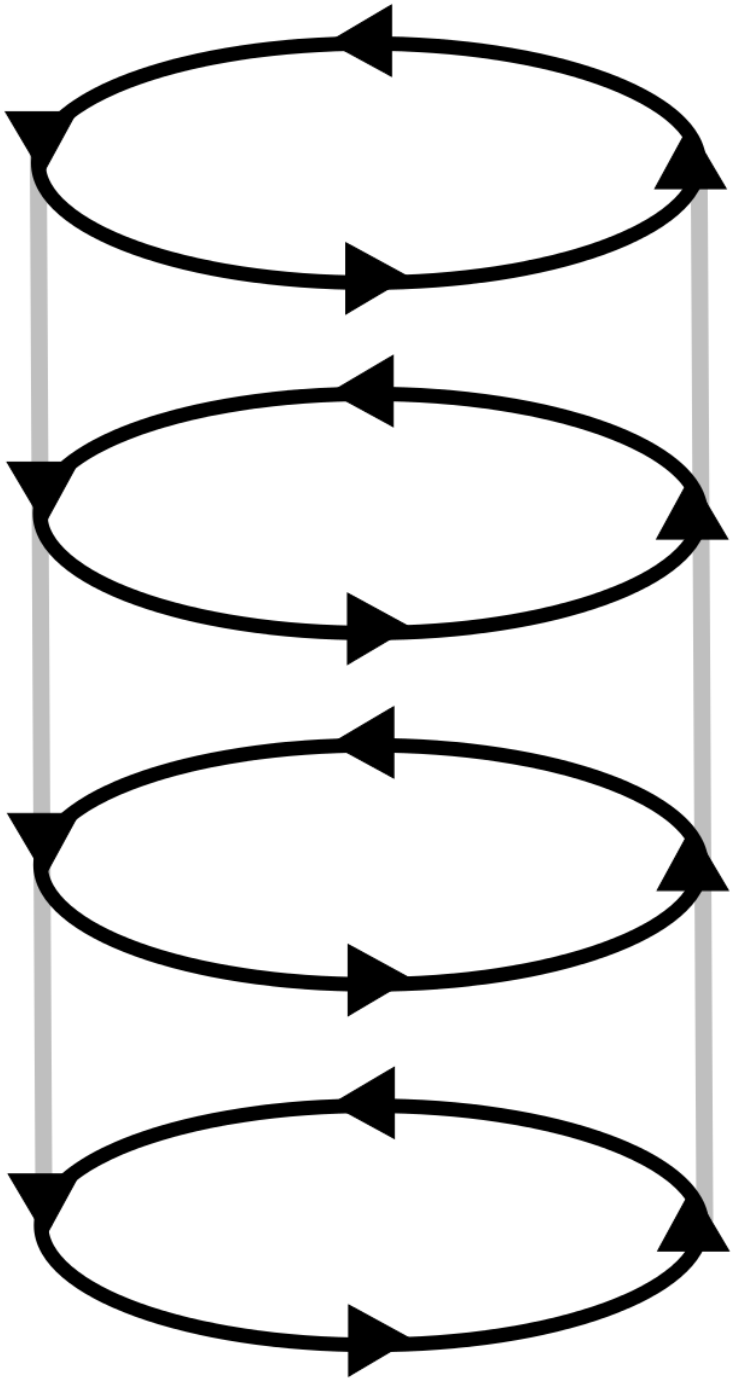
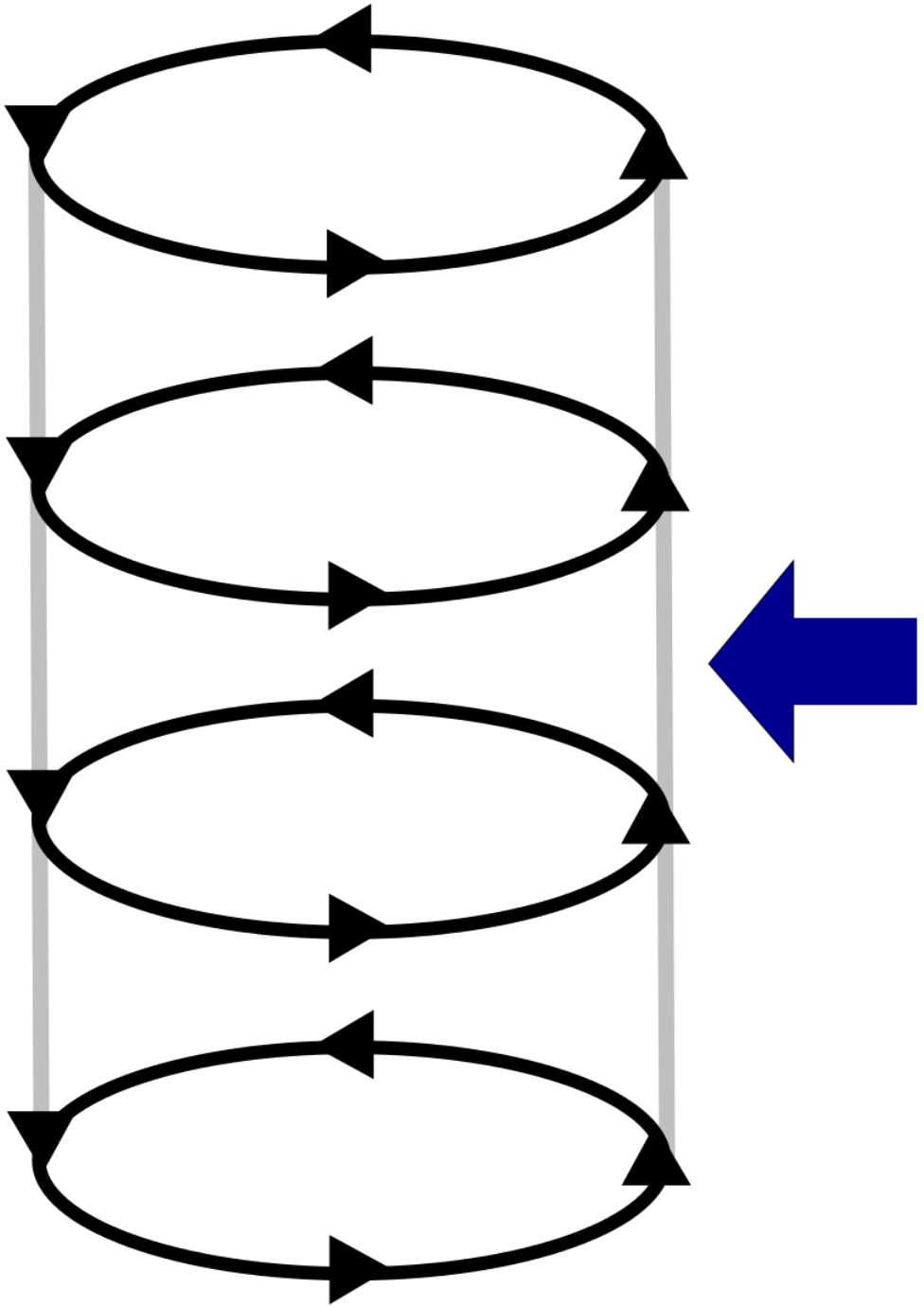
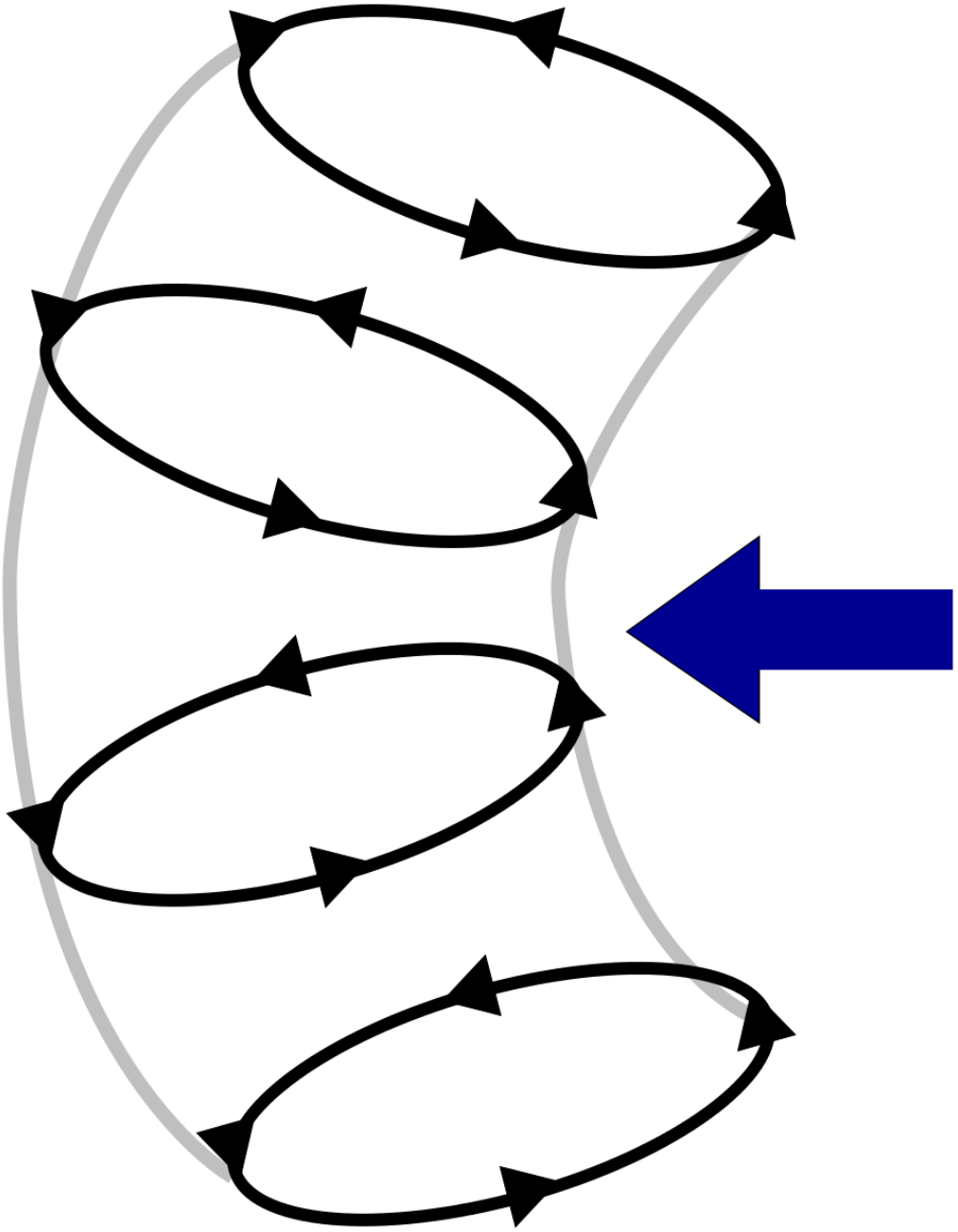
Greg Salvesen (JILA/APS)

Based on O'Neill, Beckwith, & Begelman (2012)

What Are Current-Driven Instabilities?

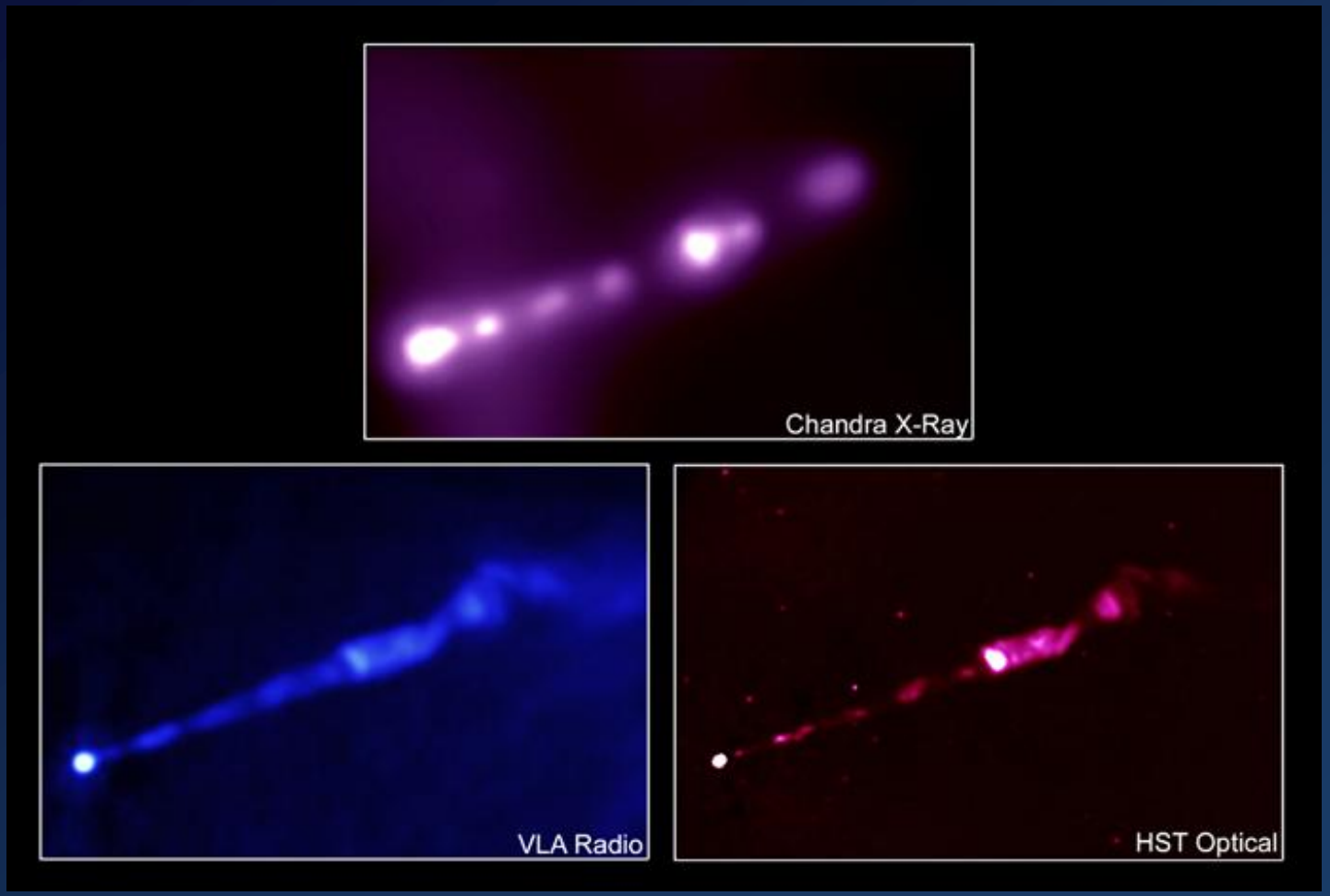






Why Are Current-Driven Instabilities Relevant?

M87/Virgo A/Virgo X-1



Credit: X-ray: H. Marshall (MIT), et al., CXC, NASA
Radio: F. Zhou, F. Owen (NRAO), J. Biretta (STScI)
Optical: E. Perlman (UMBC), et al., STScI, NASA

Connections With AGN

Jets dominated by Poynting flux near source but kinetic energy at greater distances (Sikora et al. 2005).

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How do jet magnetic fields cross shear layer?

How do jets remain collimated over many orders of magnitude in physical scale (sub-pc to Mpc)?

How to Model Current-Driven Instabilities?

Linear Analysis

Physics: Lundquist (1951), Kruskal & Schwarzschild (1954), Tayler (1957), Kadomtsev (1966)

Astrophysics: Non-relativistic limit

Cohn (1983), Pietrini & Torricelli-Ciamponi (1989), Corbelli & Torricelli-Ciamponi (1990), Appl & Camenzind (1992), Appl (1996), Appl et al. (2000), Kersalé et al. (2000), Bonanno & Urpin (2011)

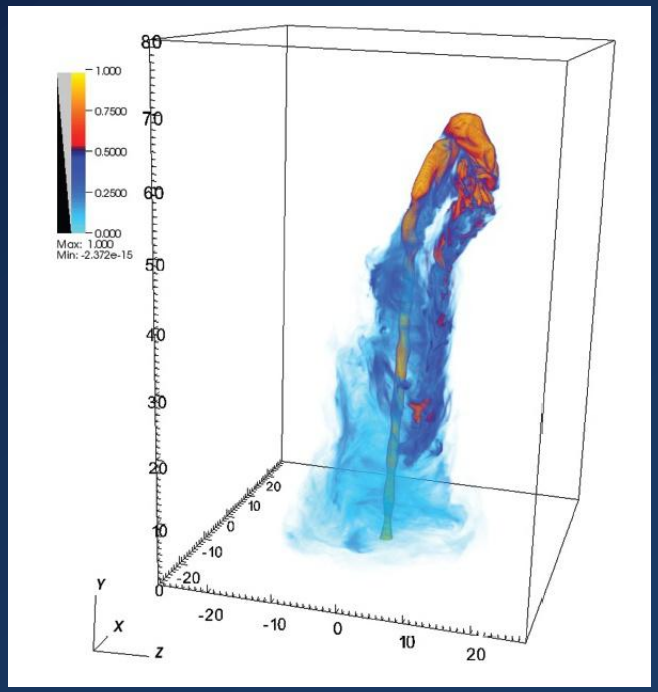
Astrophysics: Relativistic limit

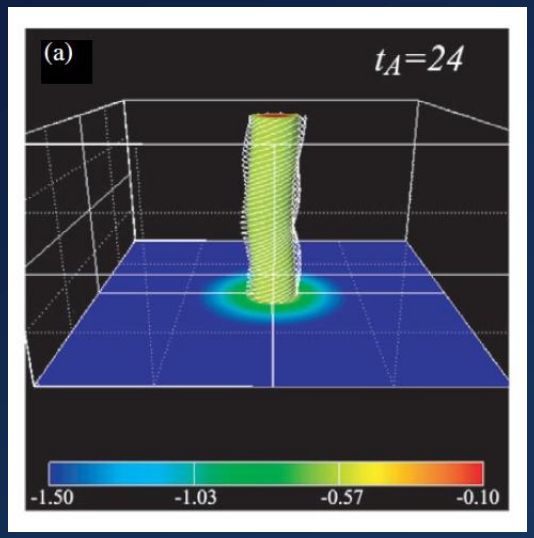
Istomin & Pariev (1994, 1996), Begelman (1998), Lyubarskii (1999), Tomimatsu et al. (2001), Narayan et al. (2009), Nalewajko & Begelman (2012)

Numerical Modeling

Relativistic simulations:

Global models (full jet propagation)
McKinney & Blandford (2009),
Mignone et al. (2010)





Local models (small section of jet)
Mizuno et al. (2009) and
Mizuno et al. (2011, 2012)

Our Approach

Local simulations co-moving with jet

Away from shear layer, jet origin

Athena code (Gardiner & Stone 2005, 2008, Stone et al. 2008, Stone & Gardiner 2009, Beckwith & Stone 2011)

- Special relativistic MHD (Beckwith & Stone 2011)
- Conservative, second-order accurate
- Well-tested, publicly available
- Diverse set of physics and algorithmic options

Initial Force Equilibrium

$$-\frac{v_\phi^2}{r}\hat{\mathbf{r}} = -\frac{1}{\rho}\nabla p + \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B})$$

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CASE 1: $v_\phi = 0$ $\frac{1}{\rho}\nabla p = 0$ $\frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B}) = 0$

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CASE 3: $-\frac{v_\phi^2}{r}\hat{\mathbf{r}} = -\frac{1}{\rho}\nabla p + \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B})$

Initial Force Equilibrium

$$-\frac{v_\phi^2}{r}\hat{\mathbf{r}} = -\frac{1}{\rho}\nabla p + \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B})$$

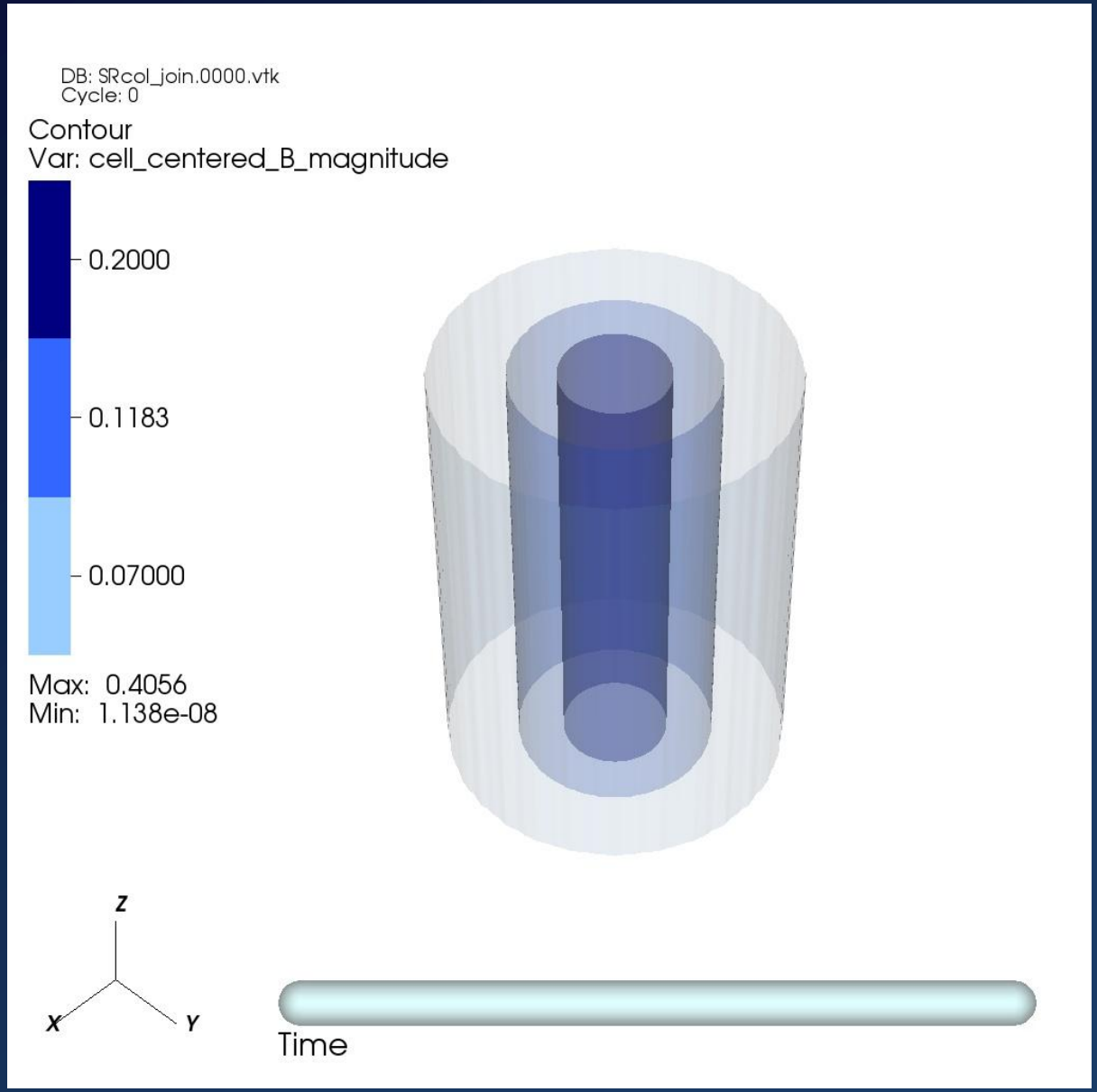
Force-free: $v_\phi = 0$ $\quad \frac{1}{\rho}\nabla p = 0$ $\quad \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B}) = 0$

P/B-supported: $v_\phi = 0$ $\quad \frac{1}{\rho}\nabla p = \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B})$

Rot/P/B-supported $-\frac{v_\phi^2}{r}\hat{\mathbf{r}} = -\frac{1}{\rho}\nabla p + \frac{1}{4\pi\rho}(\mathbf{J}\times\mathbf{B})$

Simulated Column Morphology

Force-Free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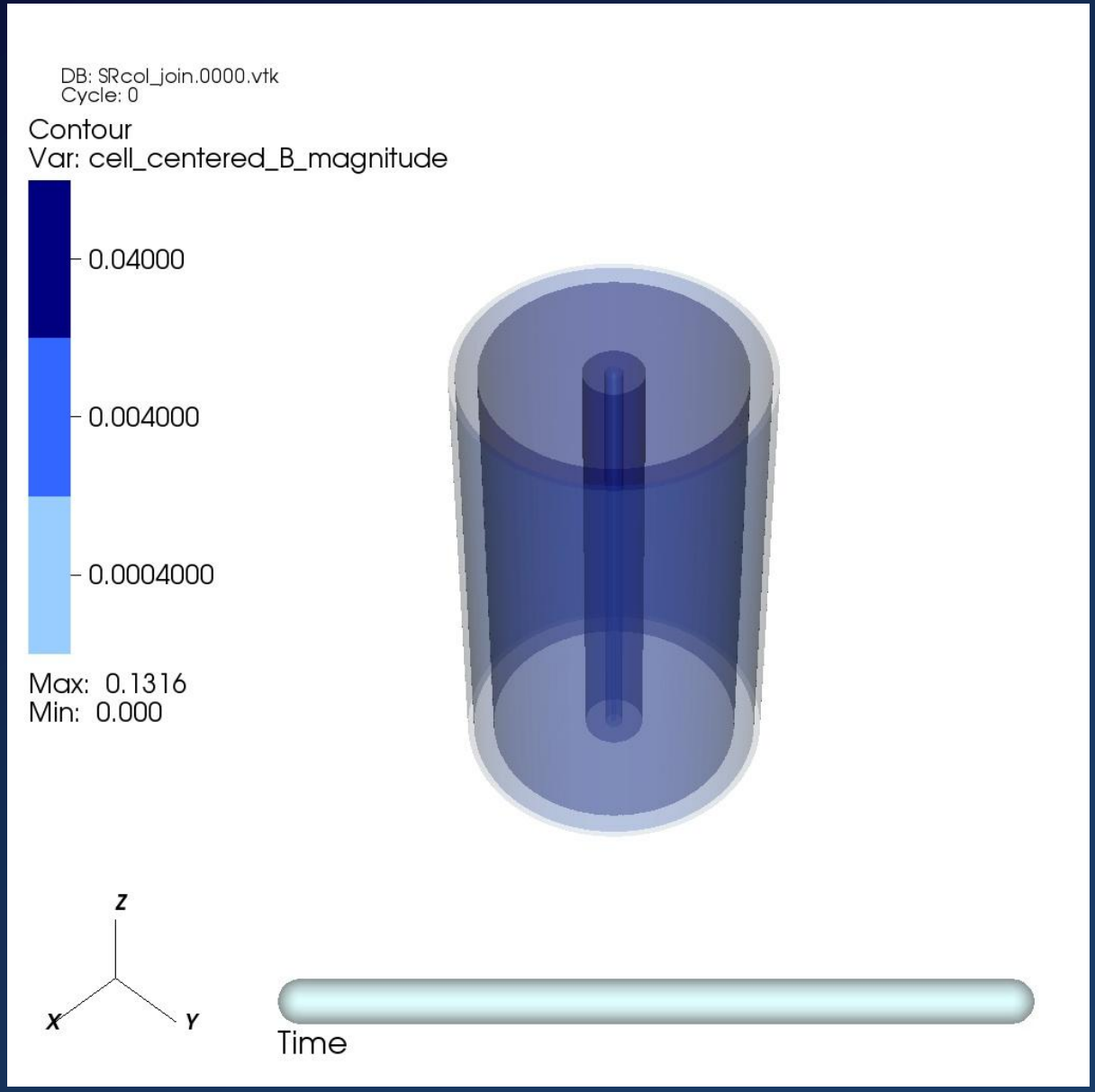
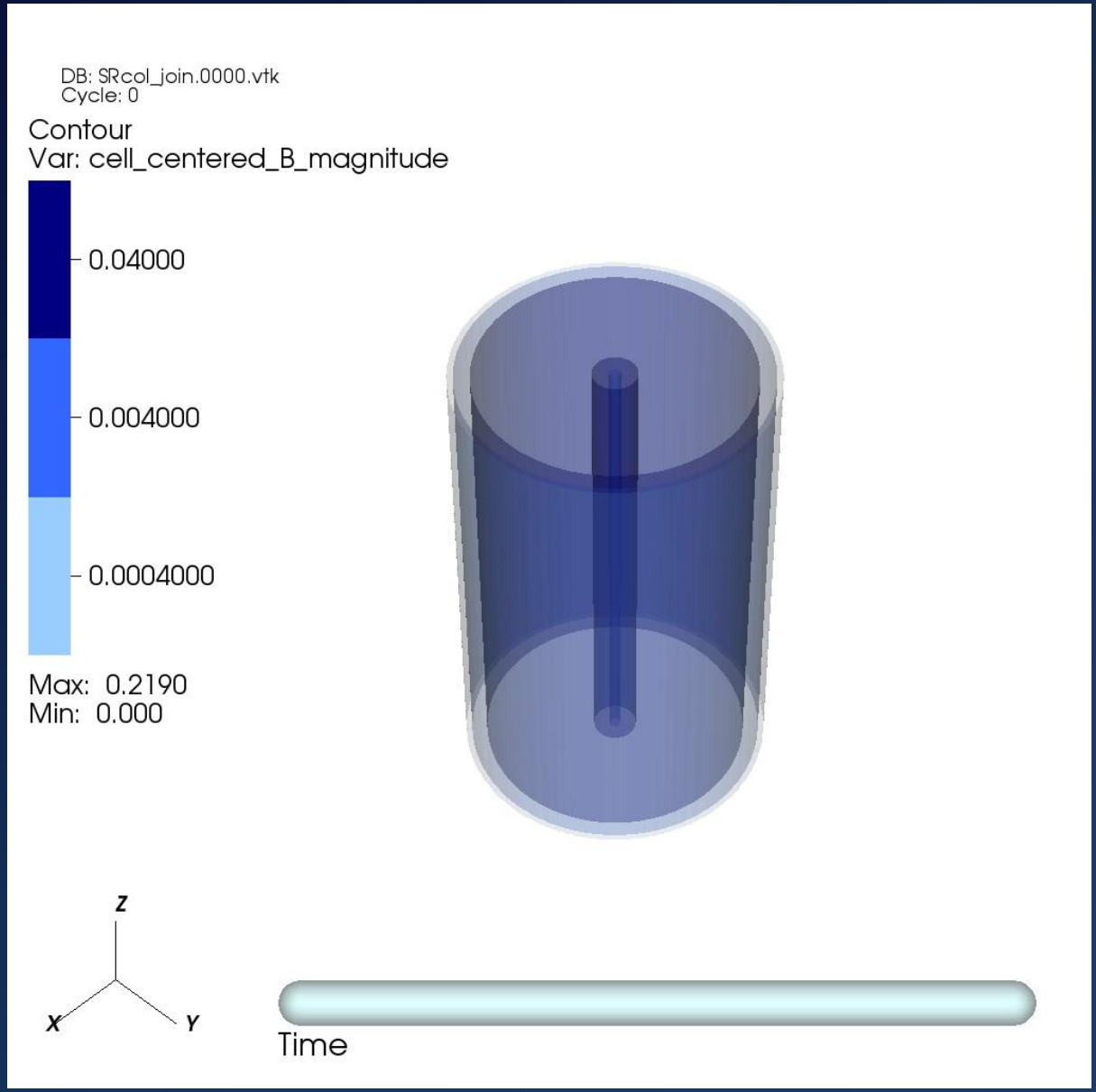
Min: 1.138e-08
Z
X
Y
Time

P/B-supported



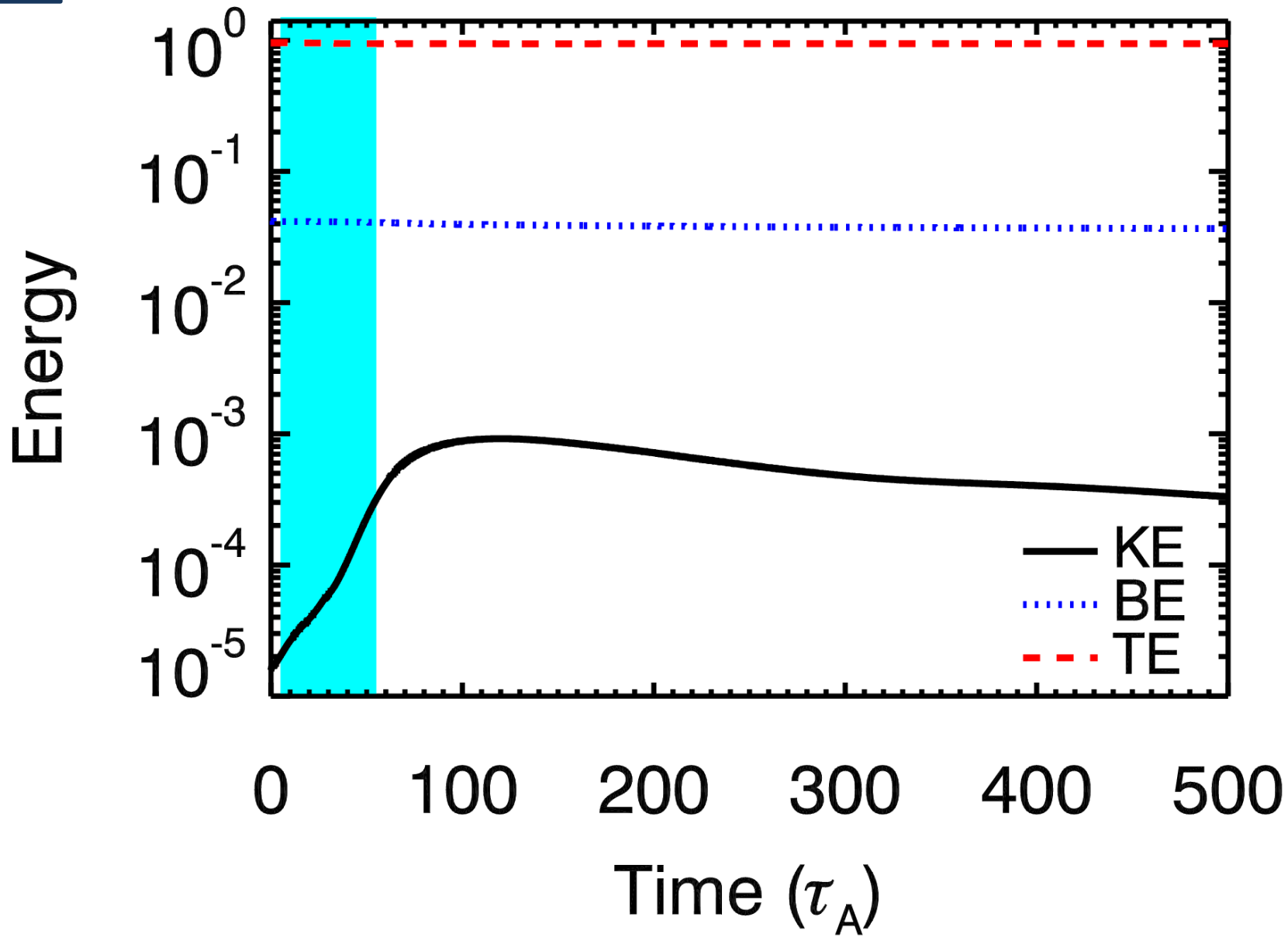
Rot/P/B-supported



Simulated Column Energetics

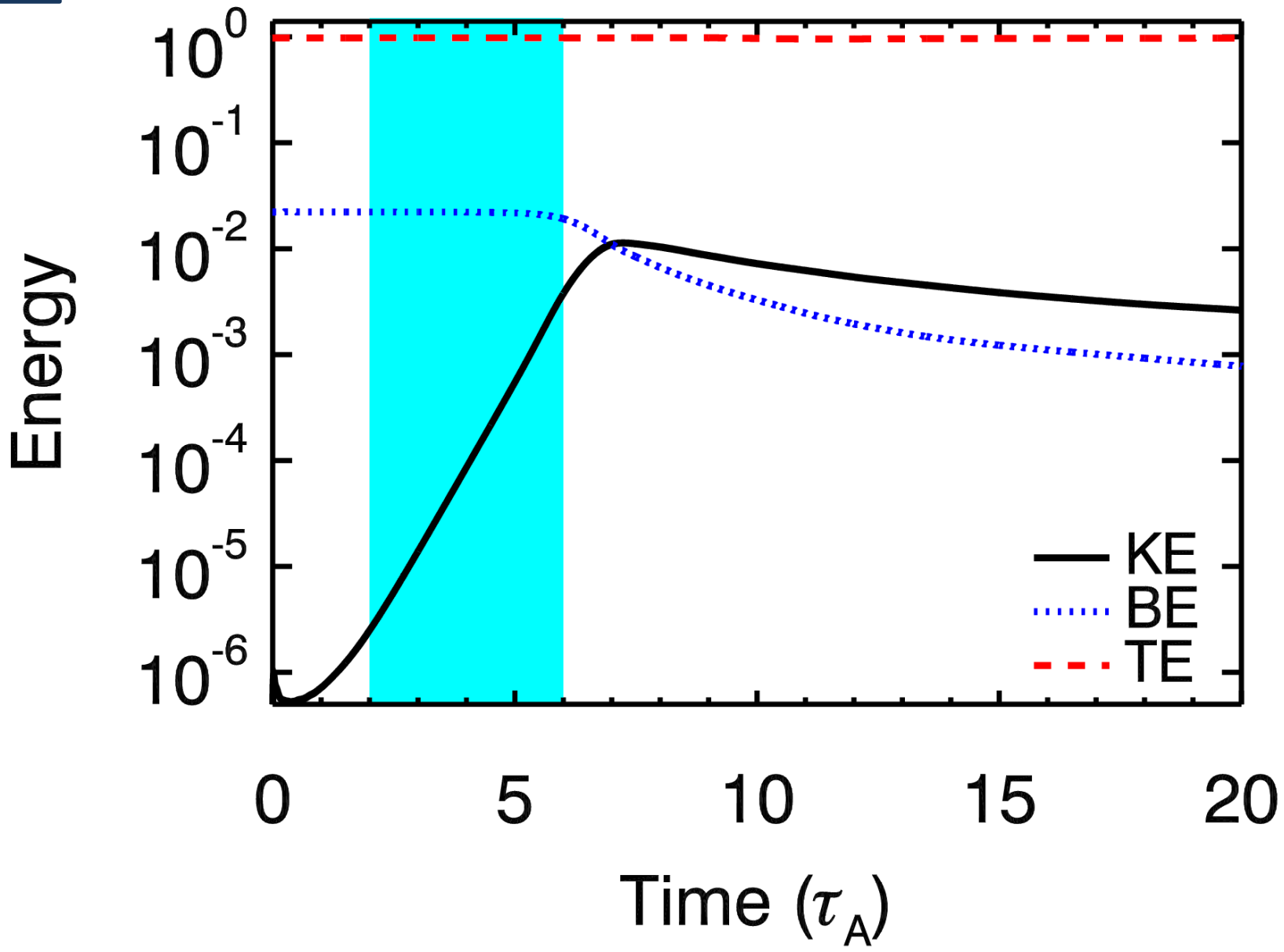
FF

Force-Free



PB

P/B-Supported



Next Steps

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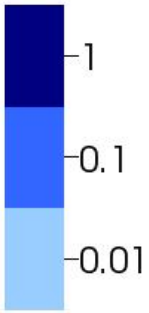
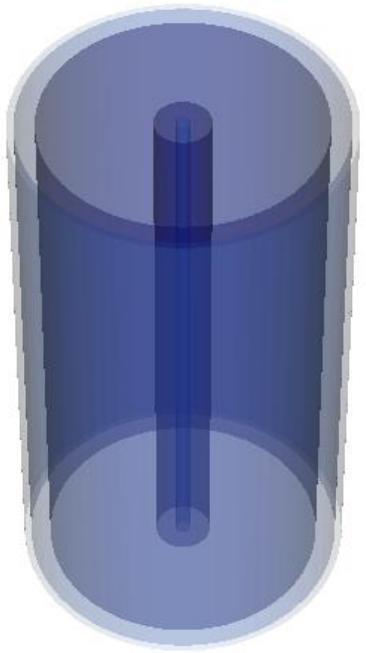
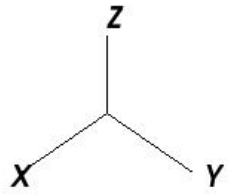
Cycle: 0

Contour
Var: cell_centered_B_magnitude



Max: 3.931
Min: 0.000





Time

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Contour
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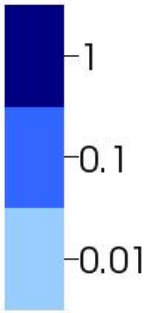

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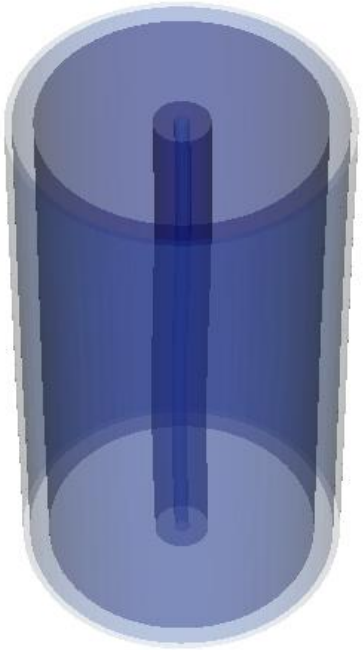

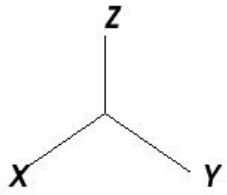

Time

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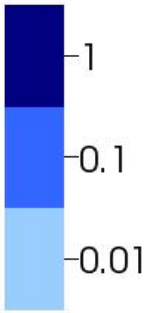
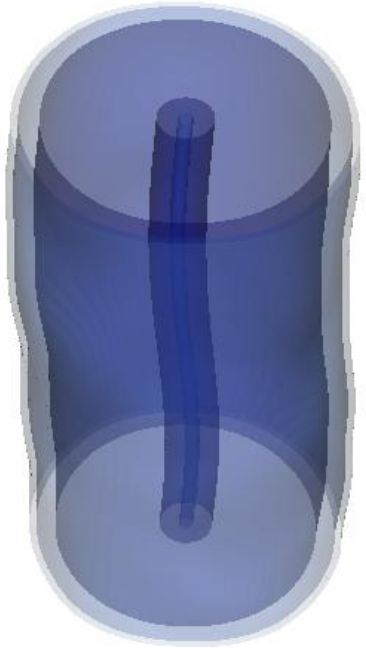
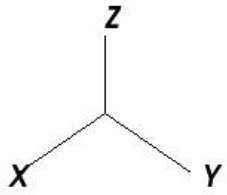
Contour
Var: cell_centered_B_magnitude



Max: 3.983
Min: 0.000





Time

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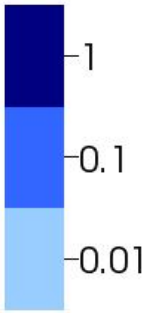
Cycle: 150

Contour
Var: cell_centered_B_magnitude



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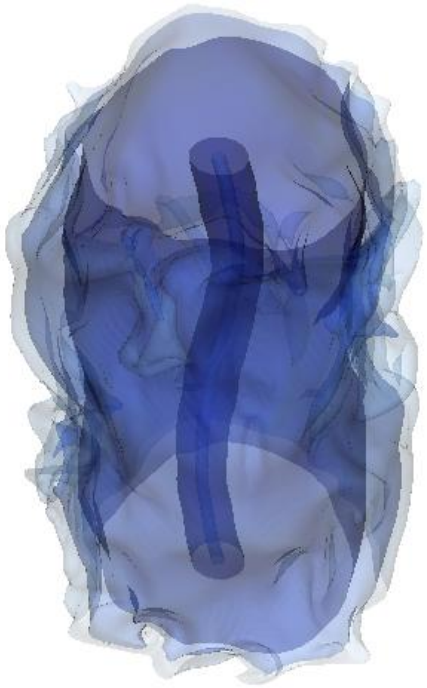
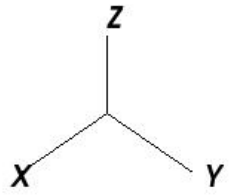
Min: 0.000





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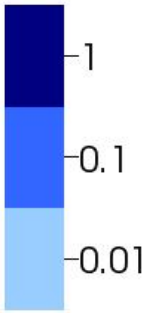
Cycle: 200

Contour
Var: cell_centered_B_magnitude



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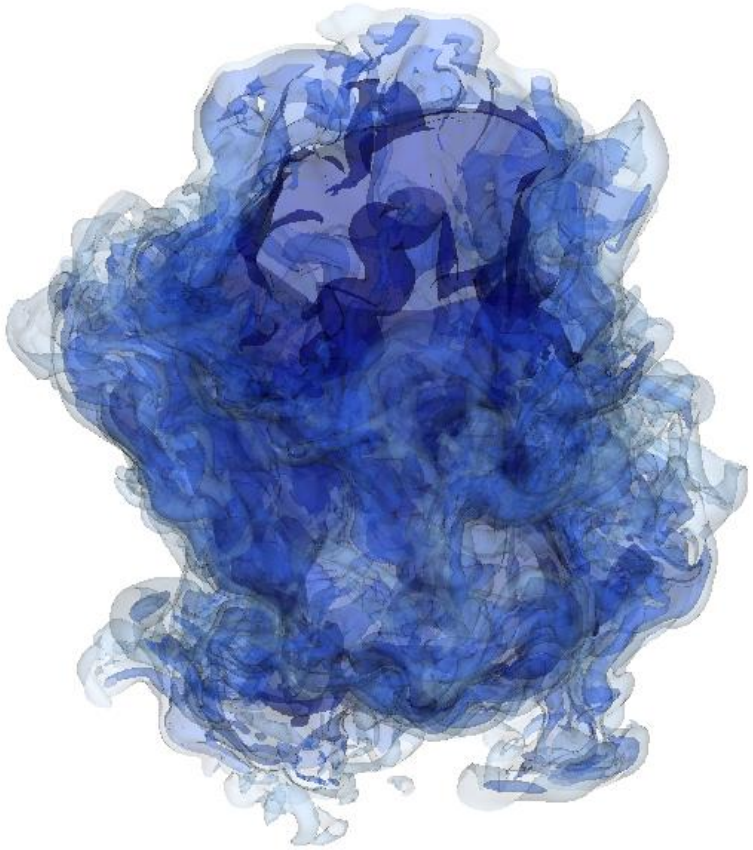
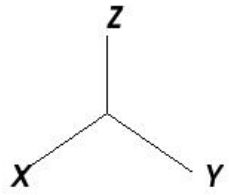
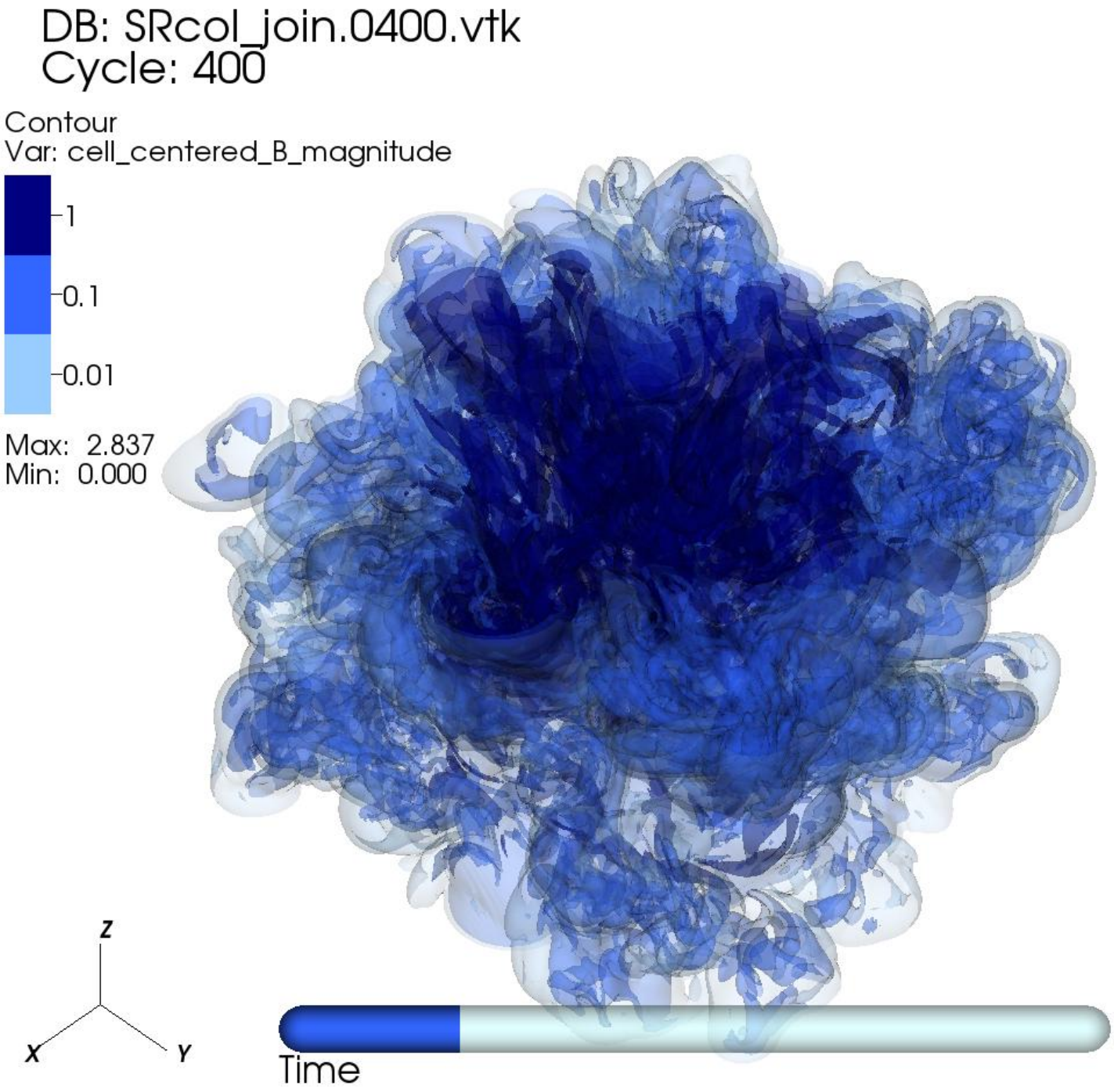




Time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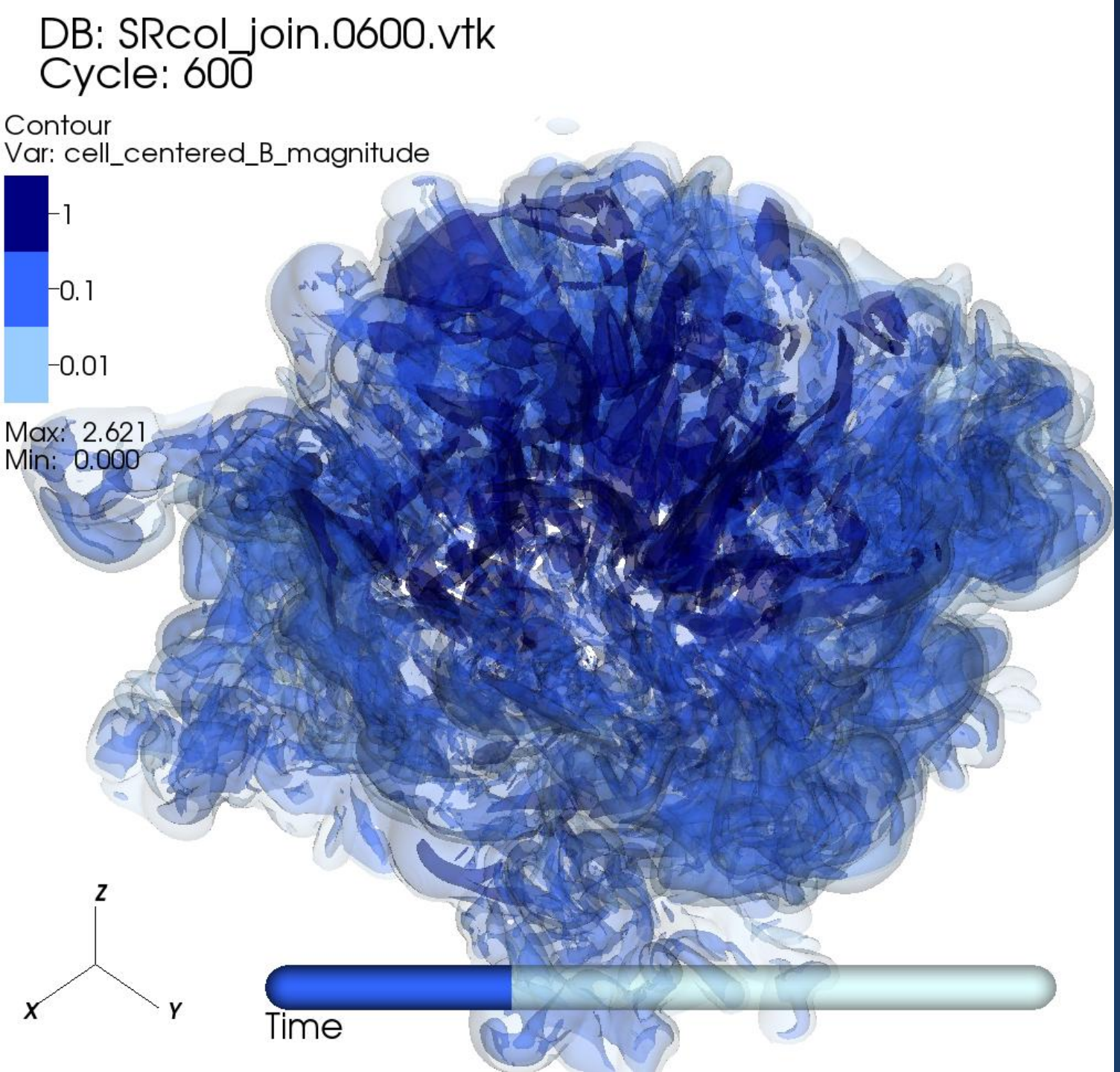
Min: 0.000
Z
X
Y
Time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Cycle: 600
Contour
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0.01
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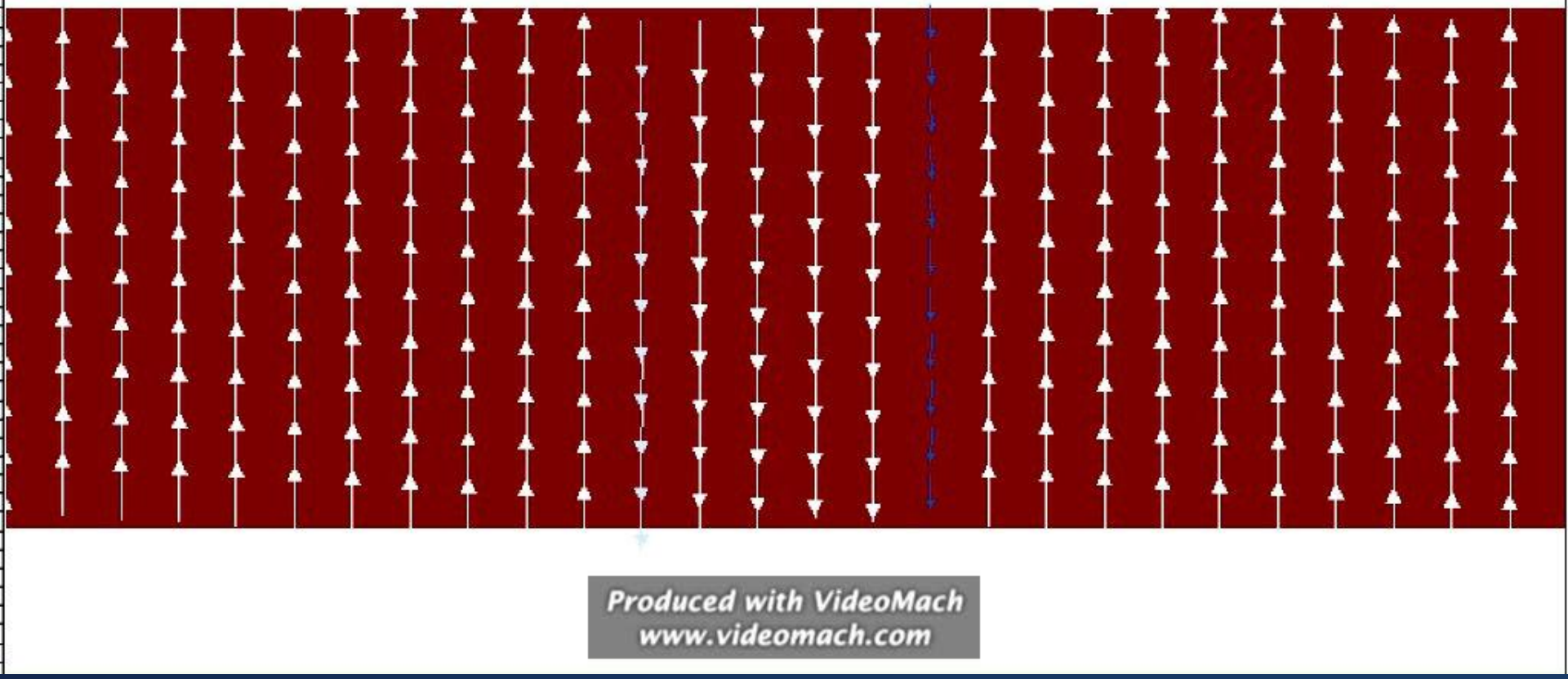
Min: 0.000
Z
X
Y
Time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- NSF AST-0907872
- Computations supported by NSF through XSEDE resources at the Texas Advanced Computing Center (TG-AST090106) and the University of Colorado's Janus supercomputer (CNS-0821794).
- Simulations run using Athena (https://trac.princeton.edu/Athena/)
- Visualizations accomplished using VisIt (Lawrence Livermore National Lab).