Numerical Simulations of GRB Afterglow Dynamics

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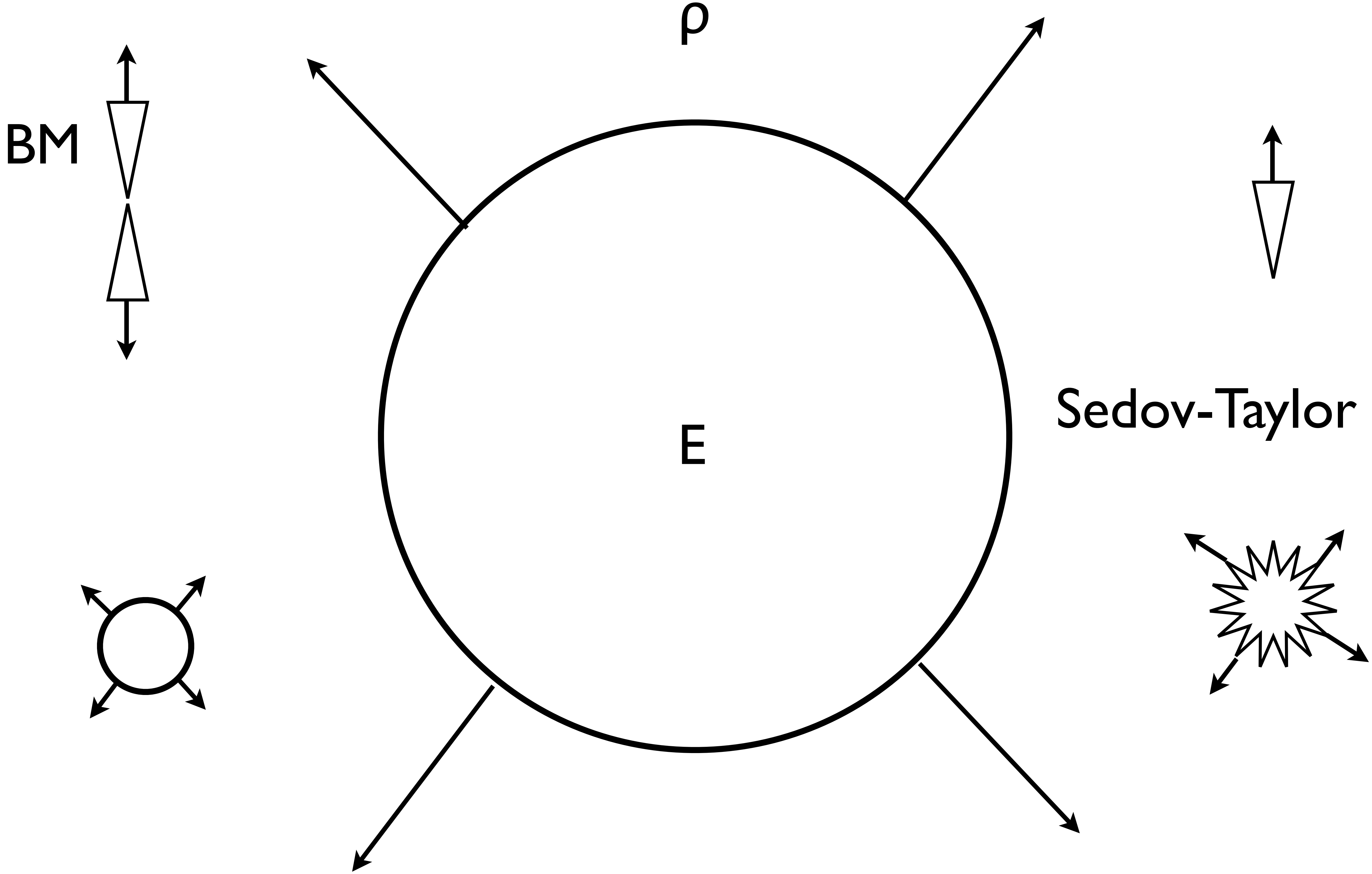
Outline

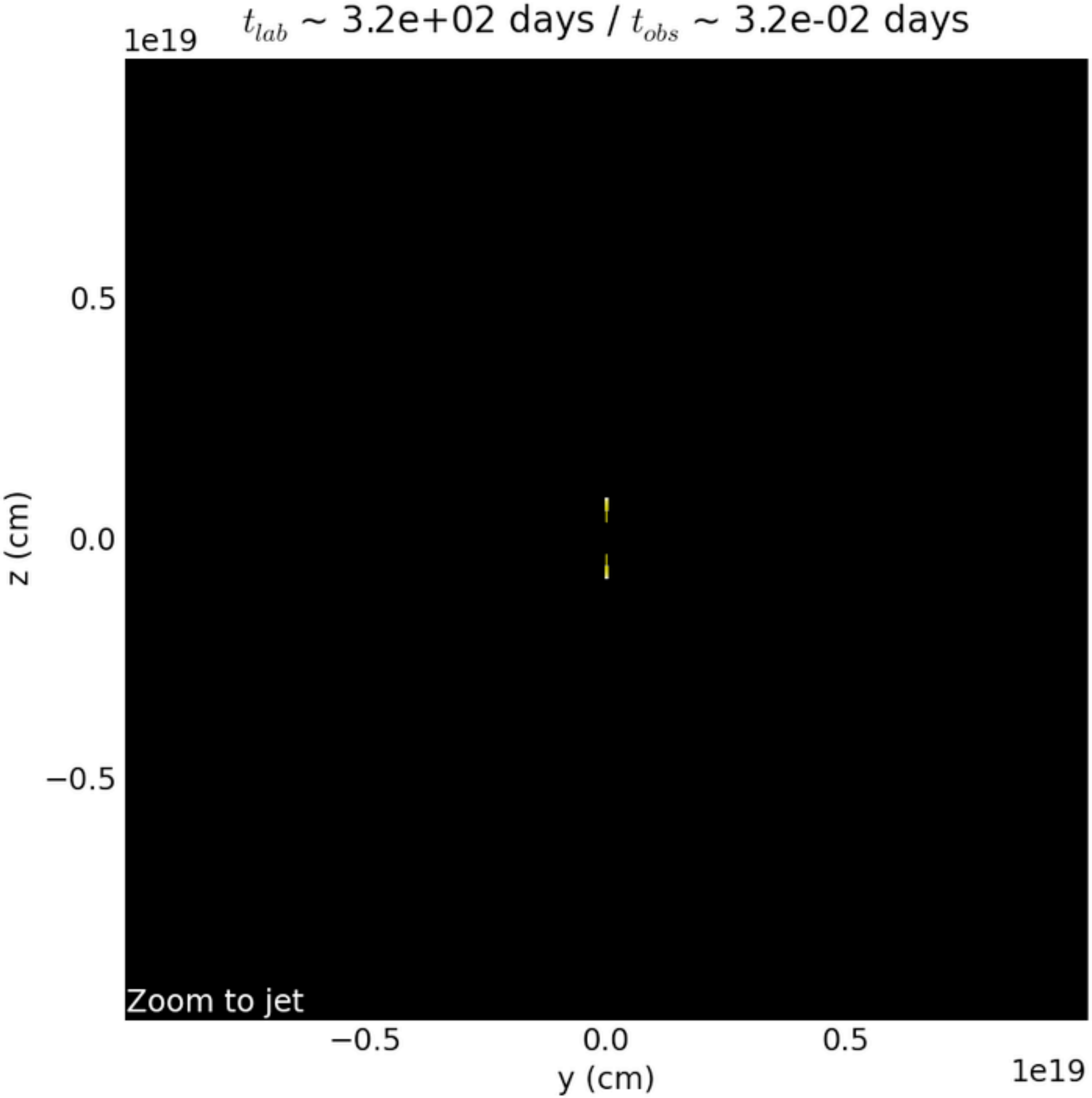
2D High Resolution AG Jets: Broadband Light Curves

Plasma Dynamics with accurate PIC code: $\Gamma=2$

Relativistic MHD Turbulence

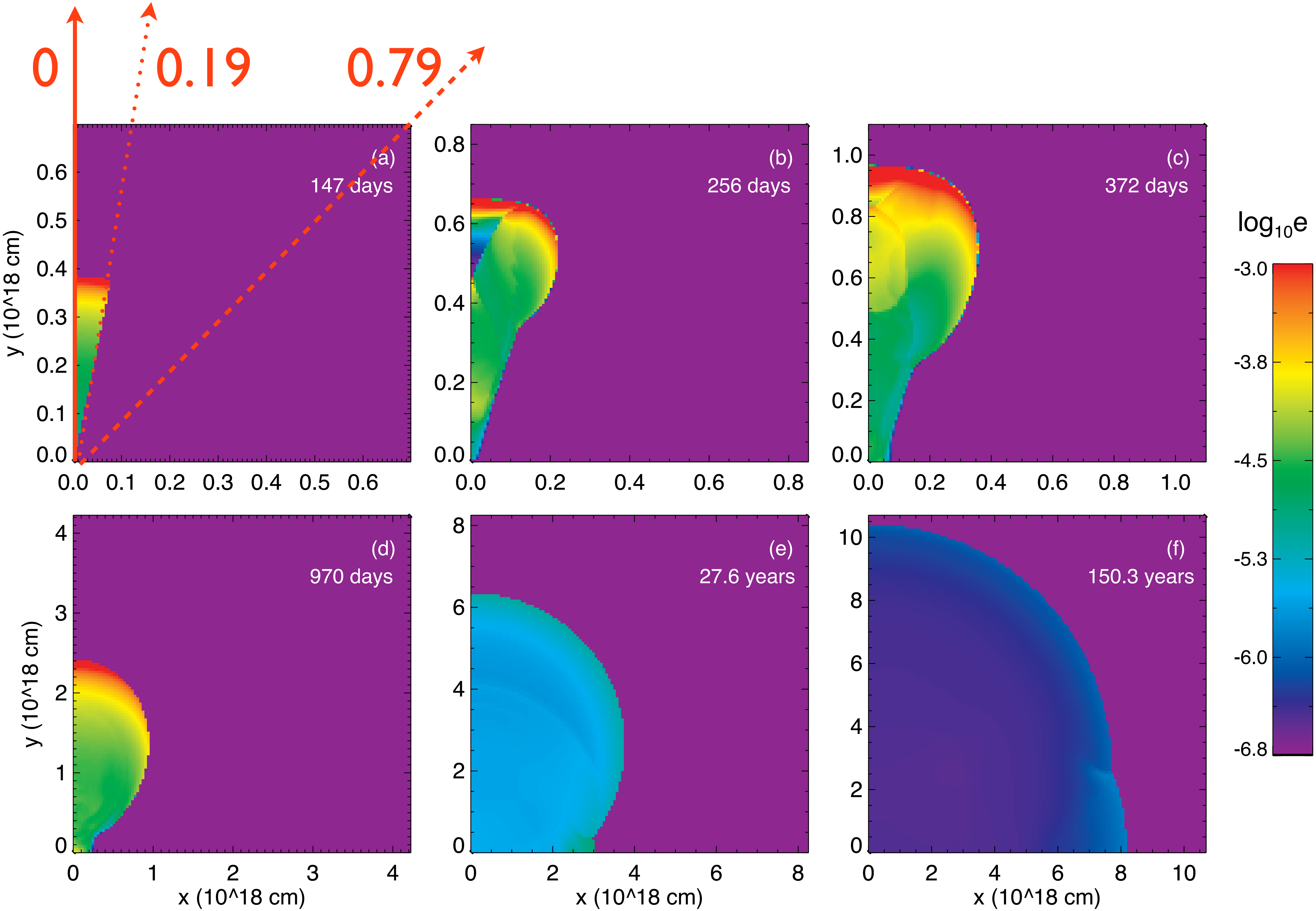
Spherical Attractor





Ej = 2e52
θj=0.05
n=1cm^-3

van Eerten & AM (in prep, 2010)



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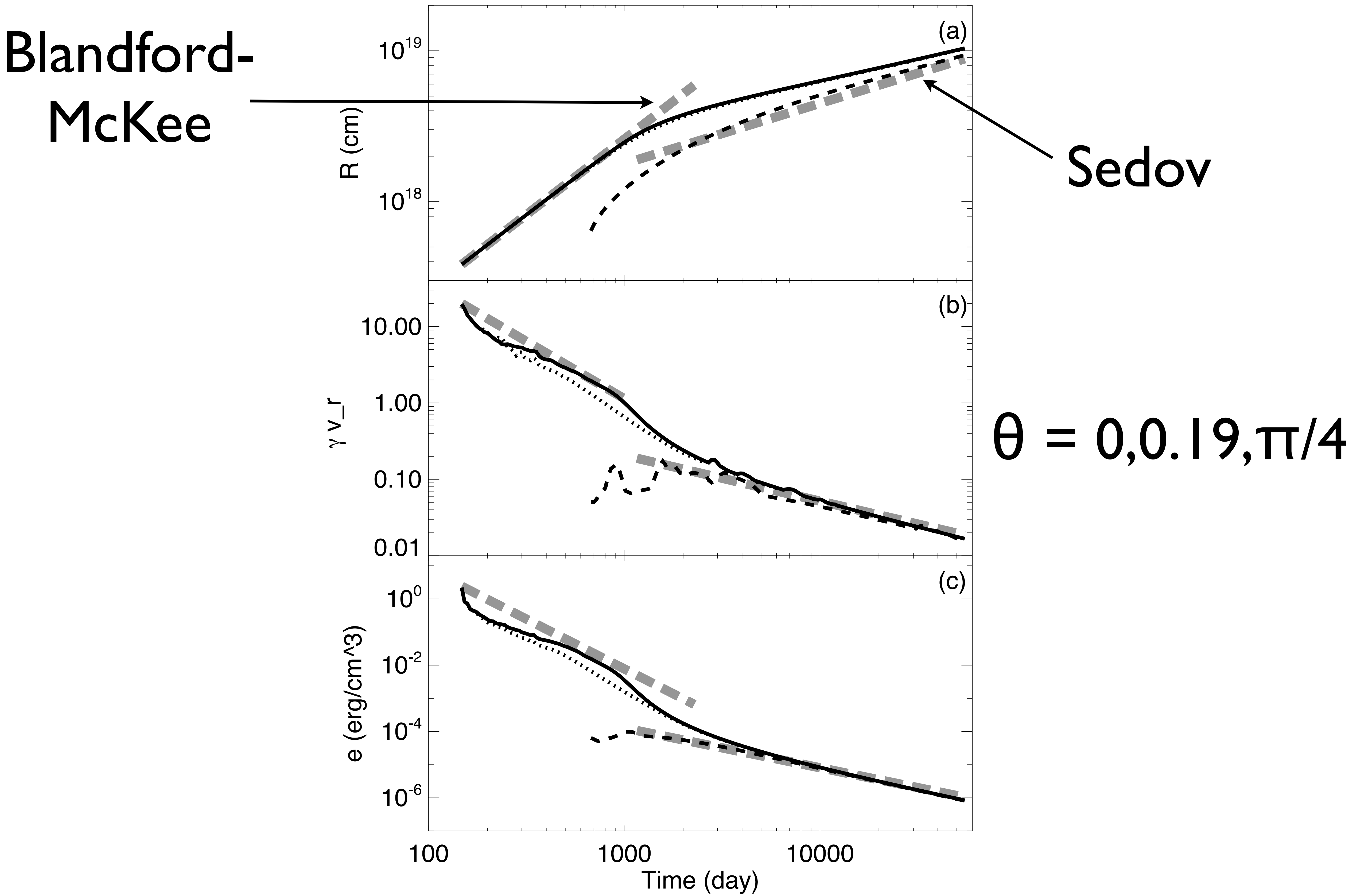
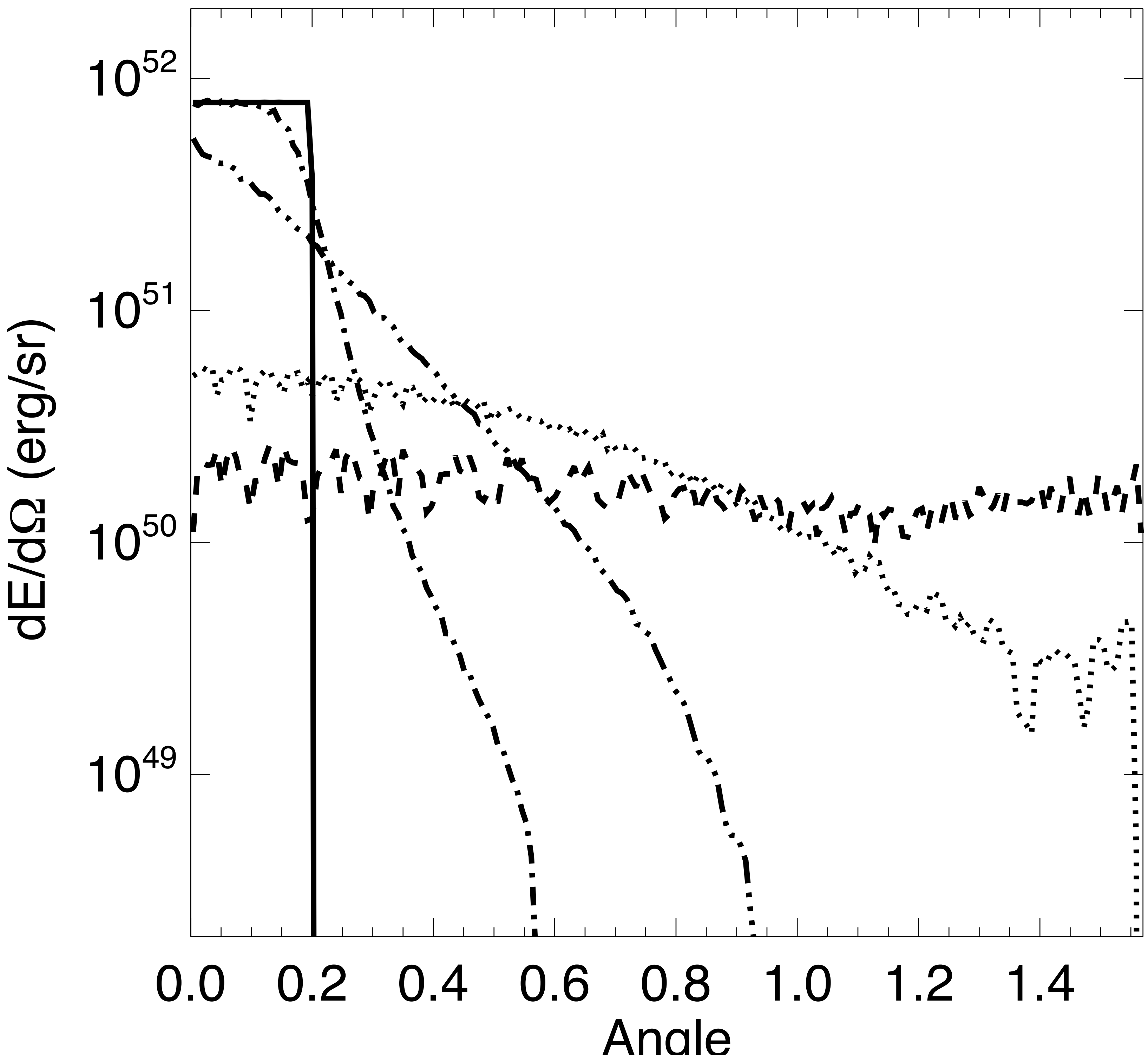


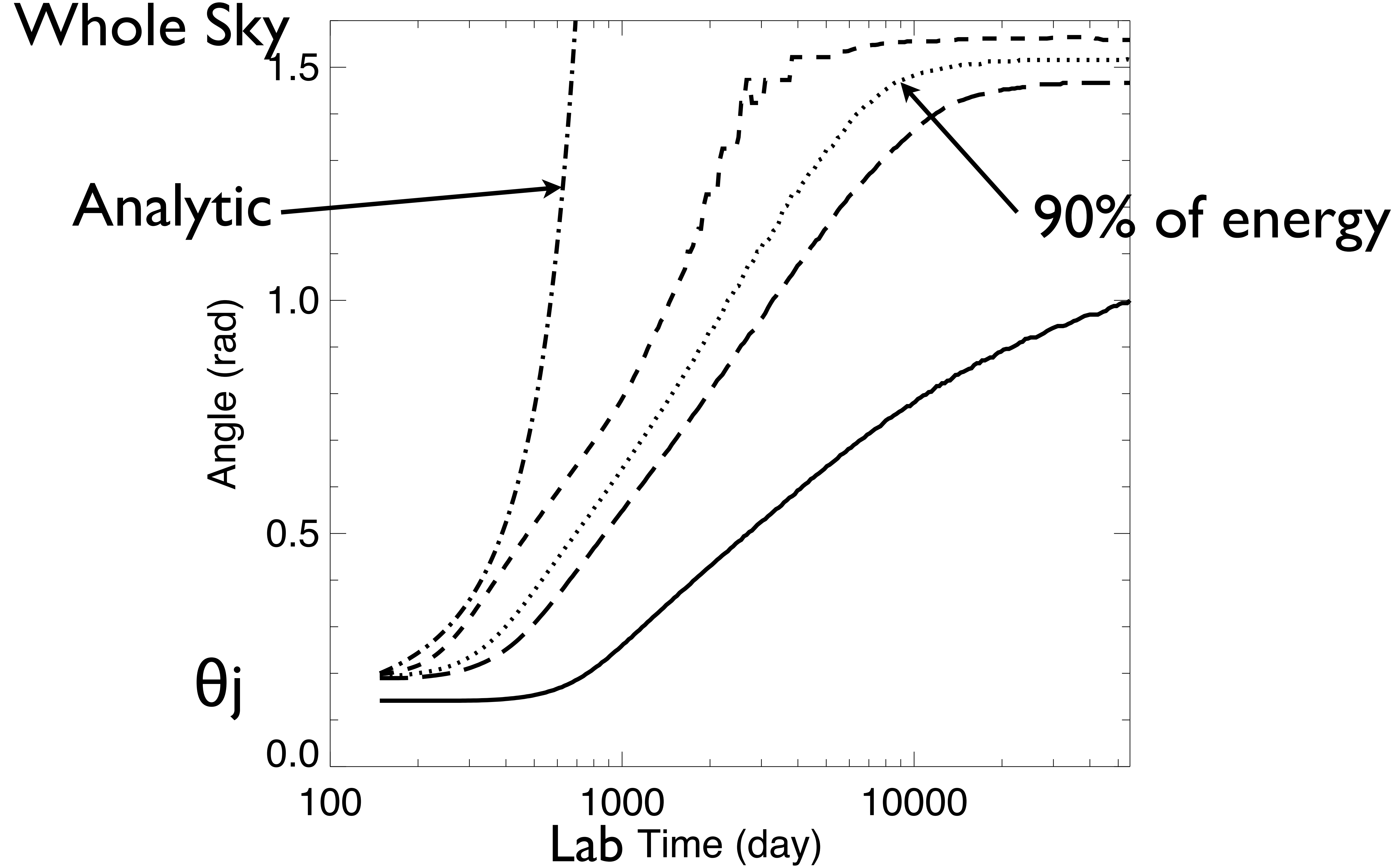
Blandford-McKee
Sedov
$\theta = 0, 0.19, \pi/4$
(a)
R (cm)
10^{19}
10^{18}
(b)
γ v_r
10.00
1.00
0.10
0.01
(c)
e (erg/cm^3)
10^{0}
10^{-2}
10^{-4}
10^{-6}
100
1000
10000
Time (day)



2d: Zhang & MacFadyen (2009)

1d: Kumar & Granot (2003)

SLOW SPREADING



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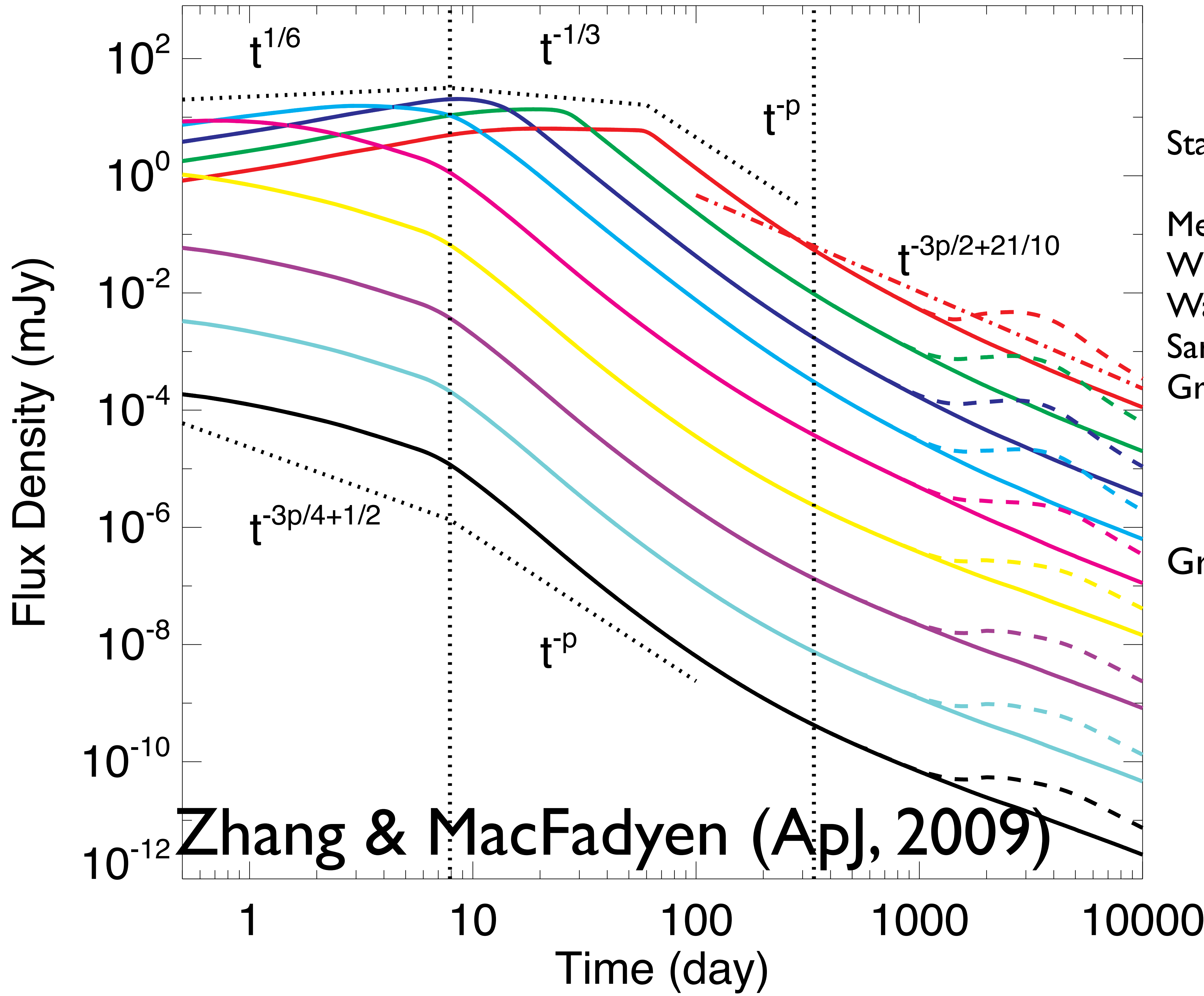
On Axis Light Curves



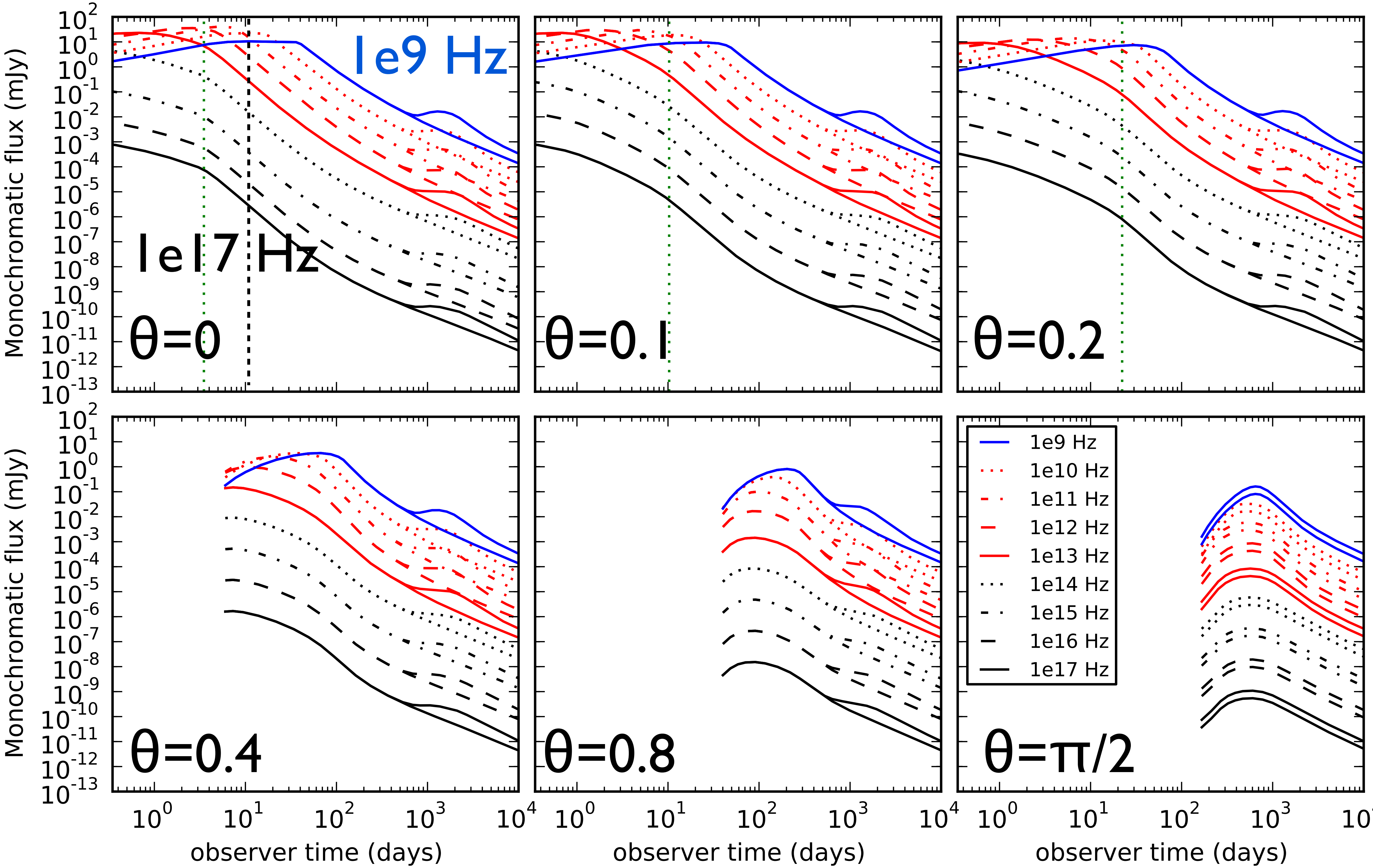
Standard radiation model:

Meszaros & Rees(1997),
Wijers et al (1997),
Waxman(1997),
Sari et al(1998),
Granot et al (1999)

Granot et al (2001)

Off-Axis Light Curves

van Eerten, Zhang & AM (ApJ, 2010)



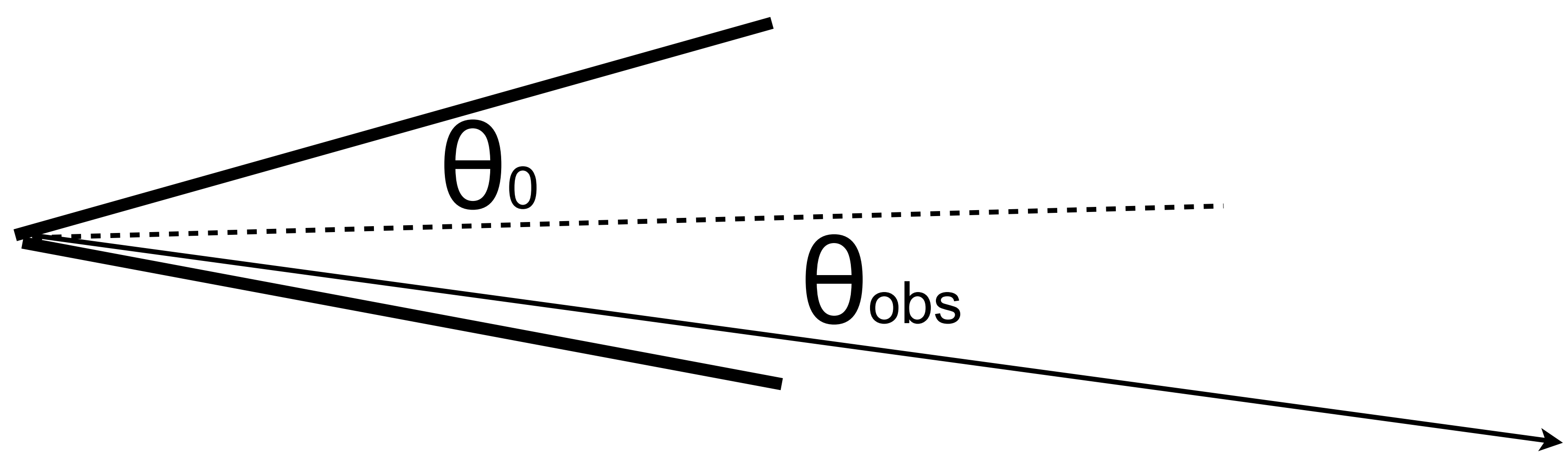
Poster 3.05

http://cosmo.nyu.edu/afterglowlibrary/

Supported by NASA 09-ATP-0190

Estimated Jet Break Time for Off-Axis Observer

$$t_j = 3.5(1+z)E_{iso,53}^{1/3} n_1^{-1/3} \left(\frac{\theta_0+\theta_{obs}}{0.2}\right)^{8/3} \text{ days},$$



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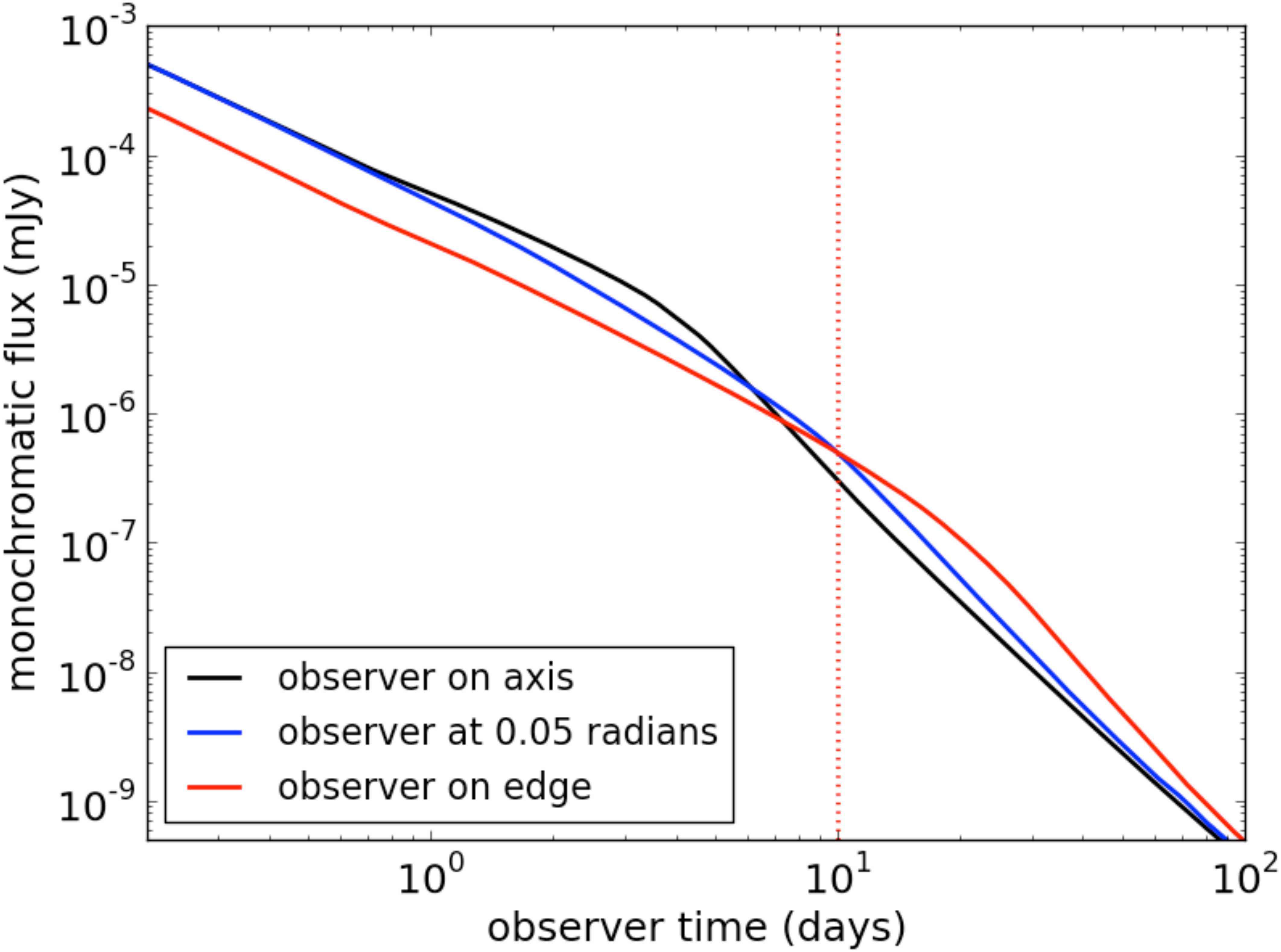
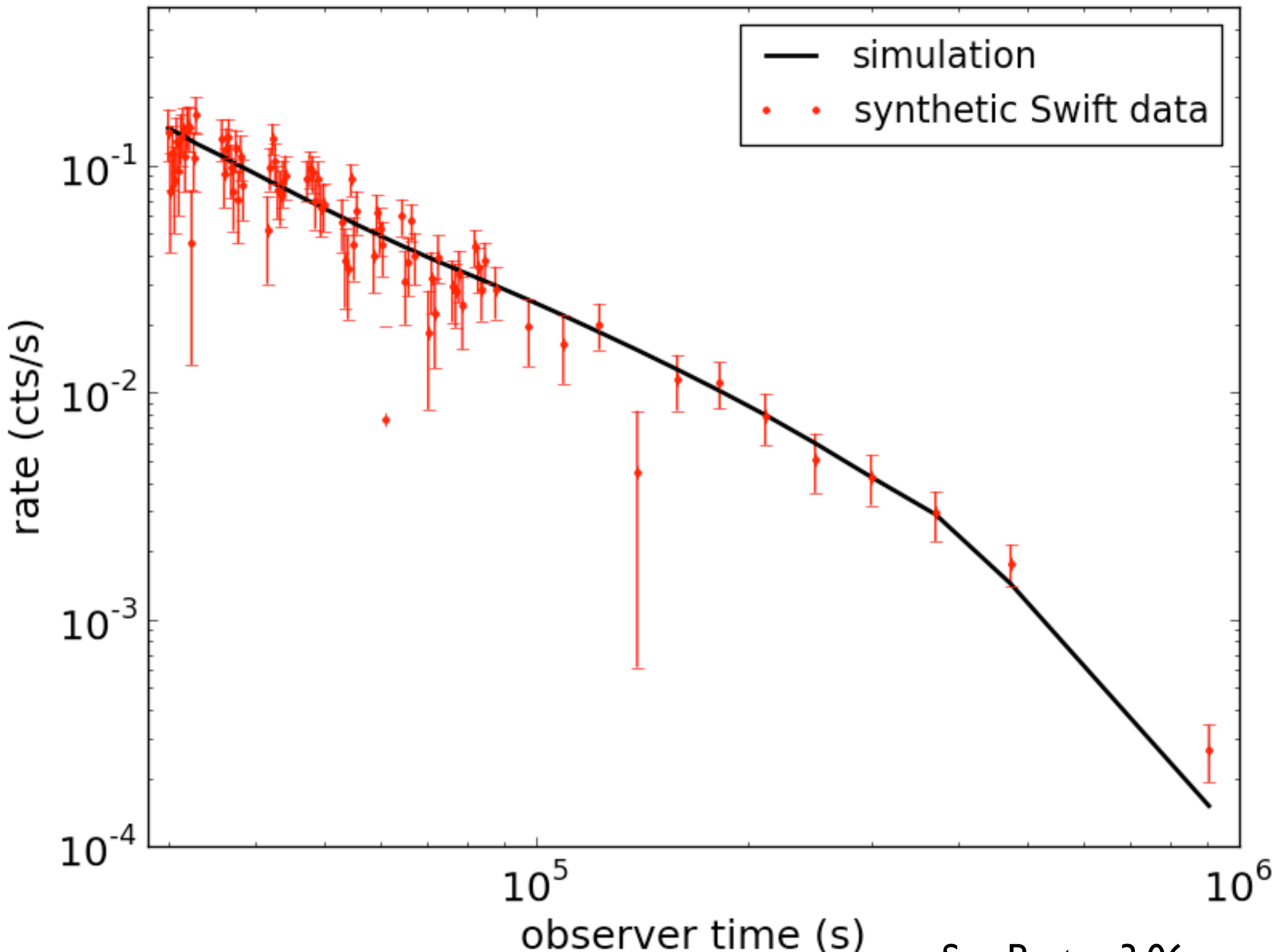


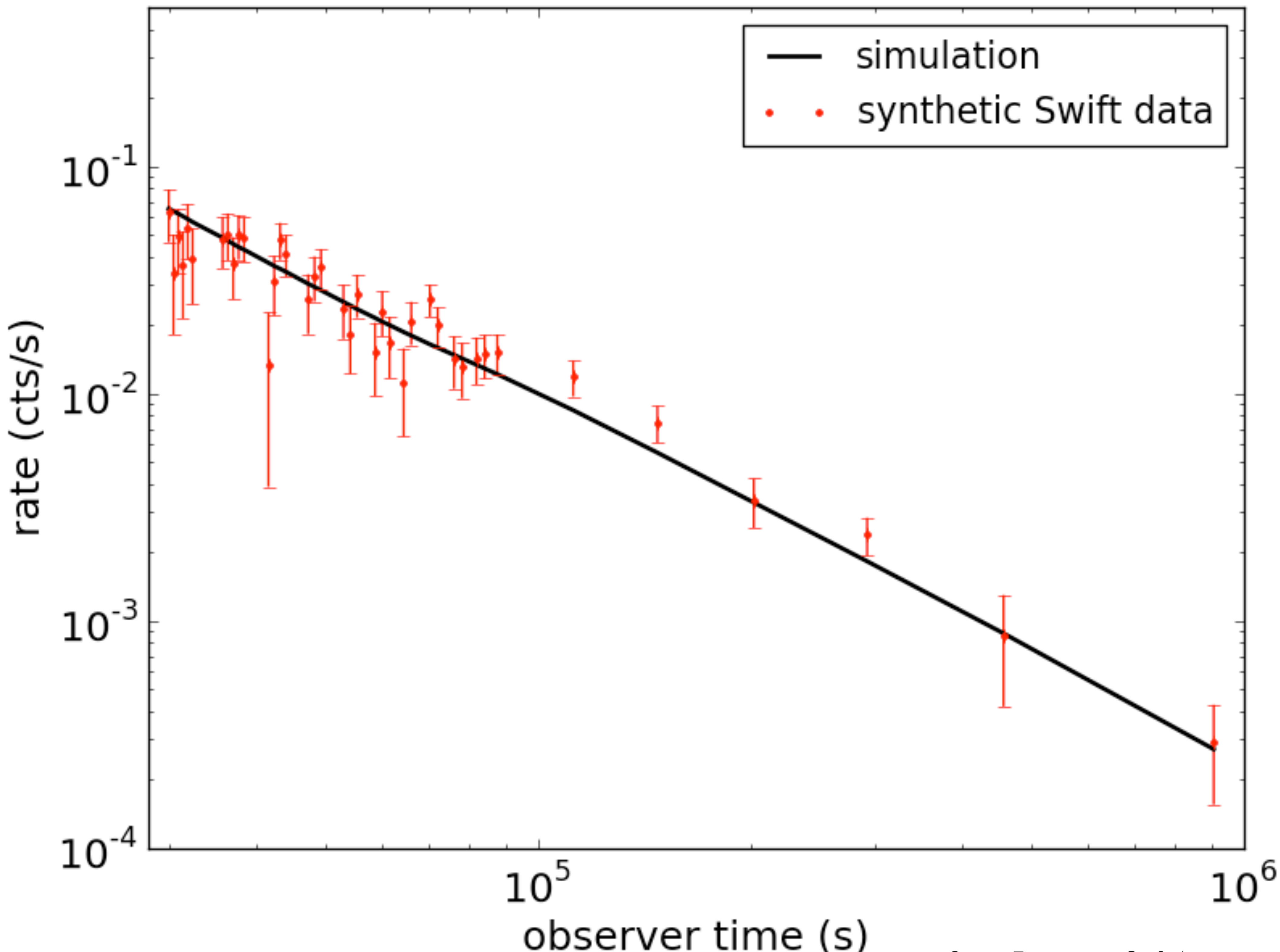
See Poster 3.06

On Axis

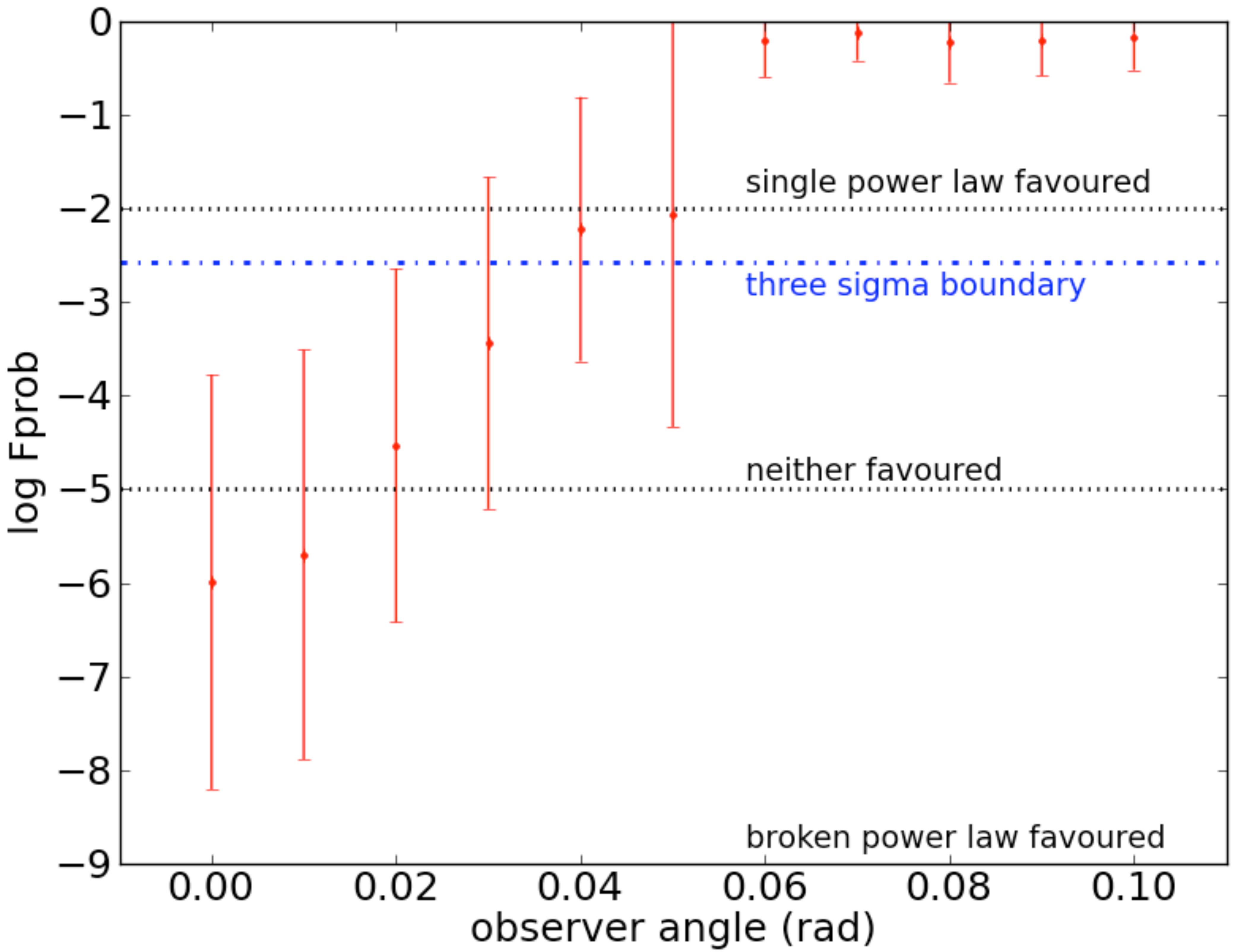


See Poster 3.06

On Edge



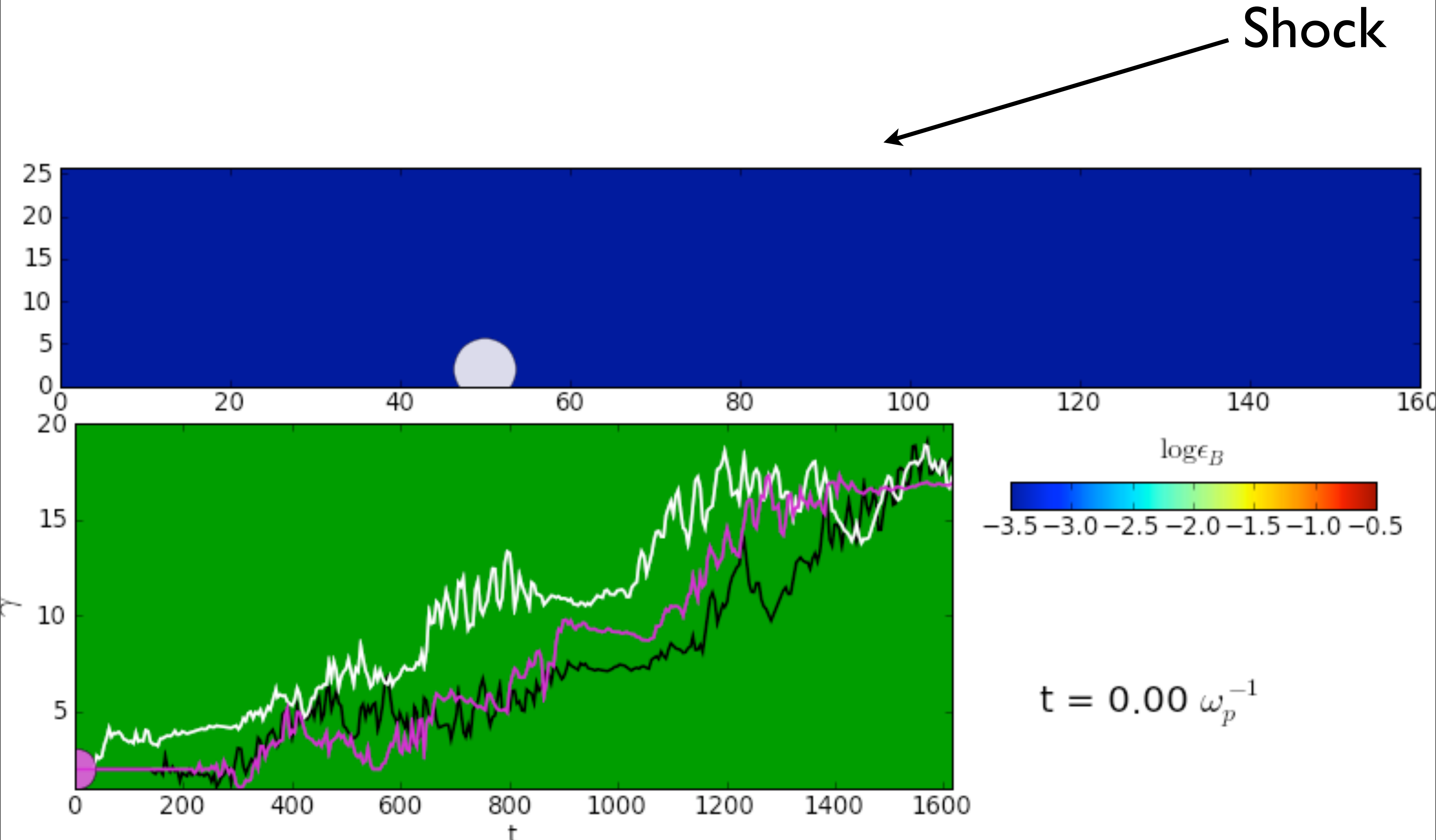
See Poster 3.06



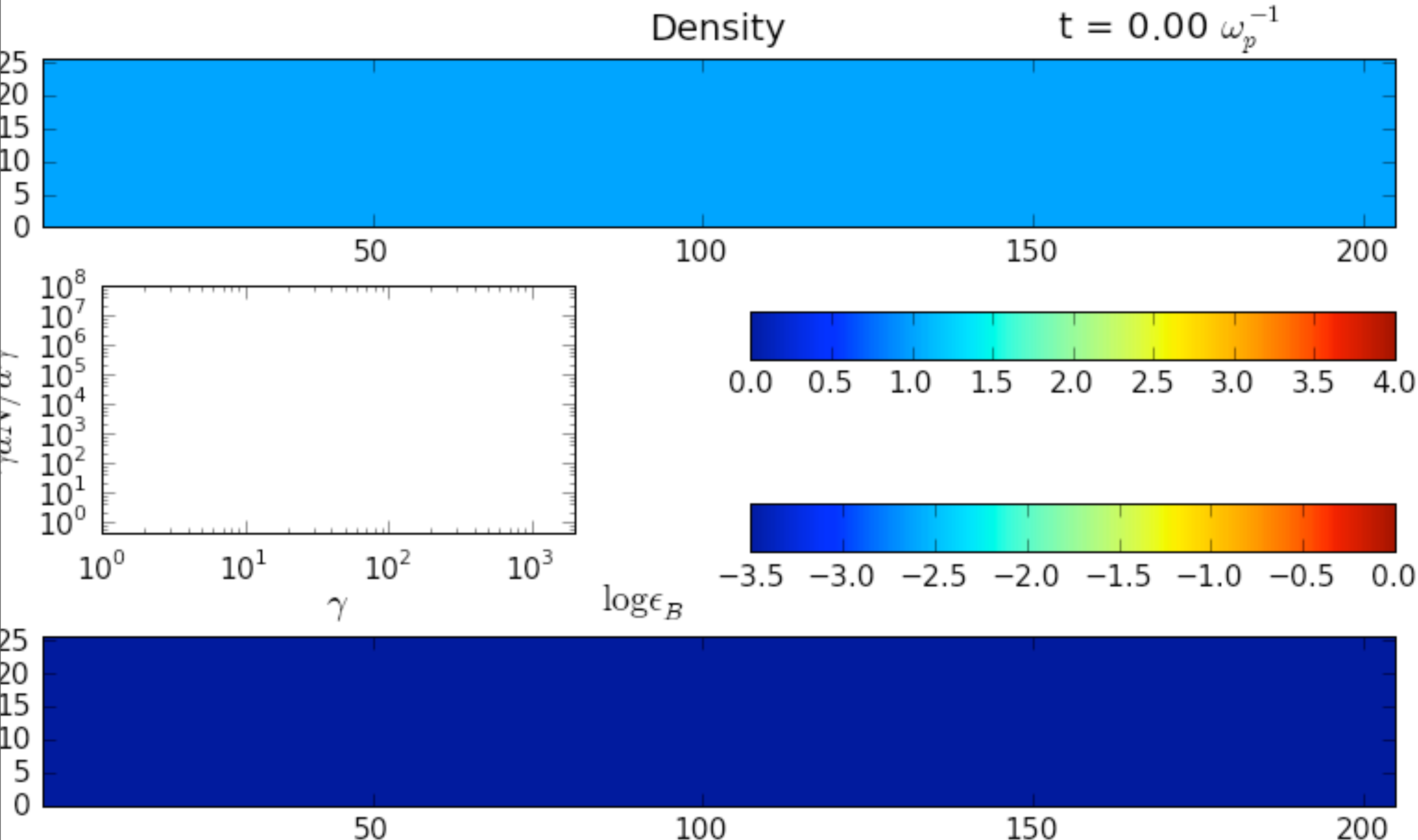
See Poster 3.06

Shock

Zhang, AM (in prep, 2010)

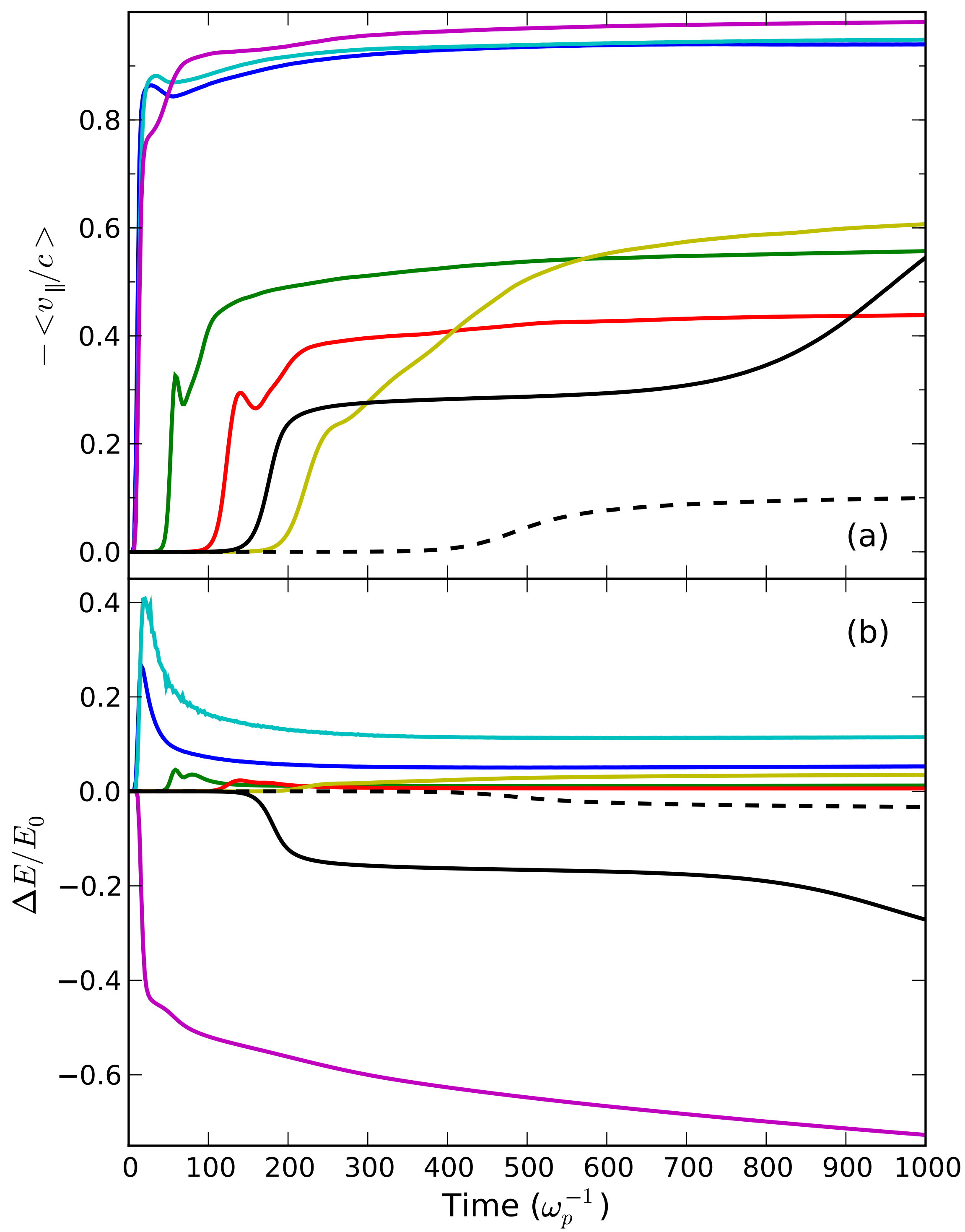


Zhang, AM (in prep, 2010)

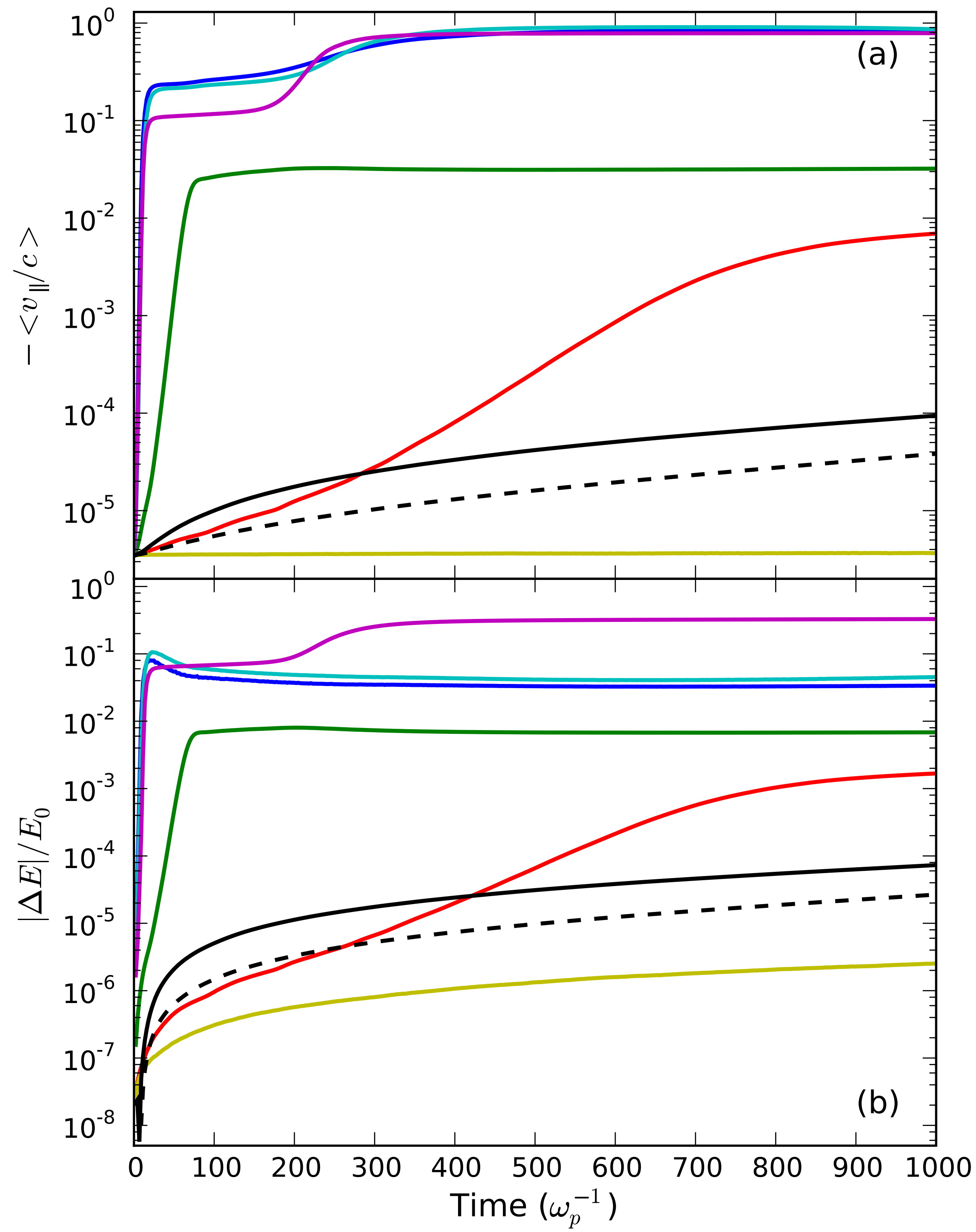


Zhang & AM (in prep, 2010)

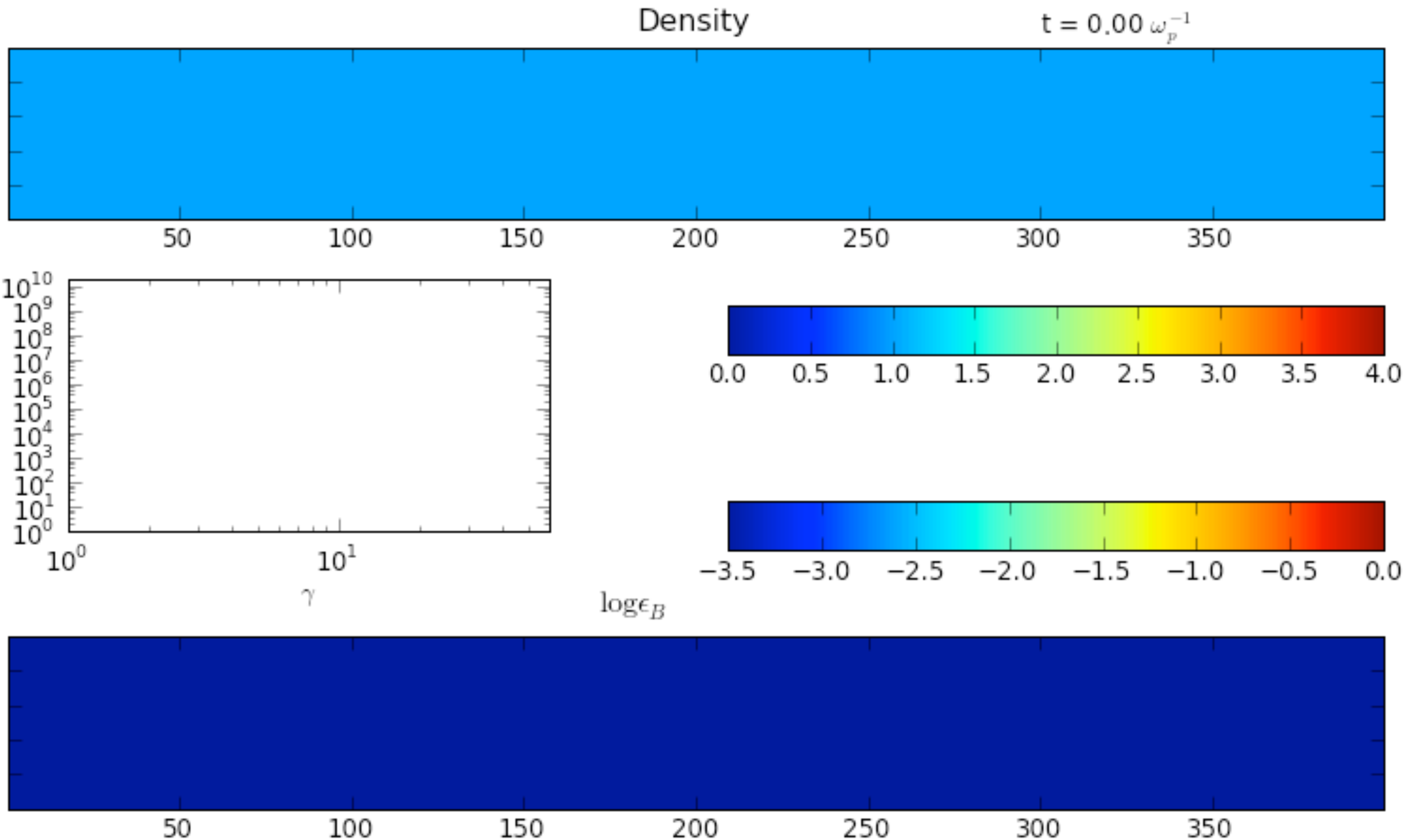
Γ = 15

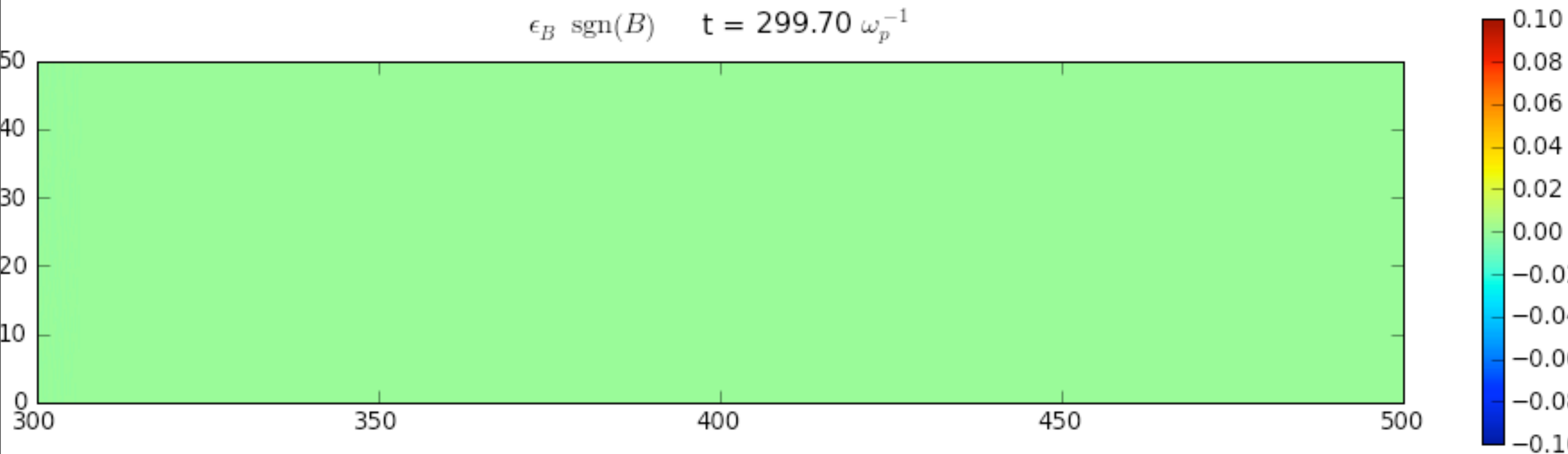


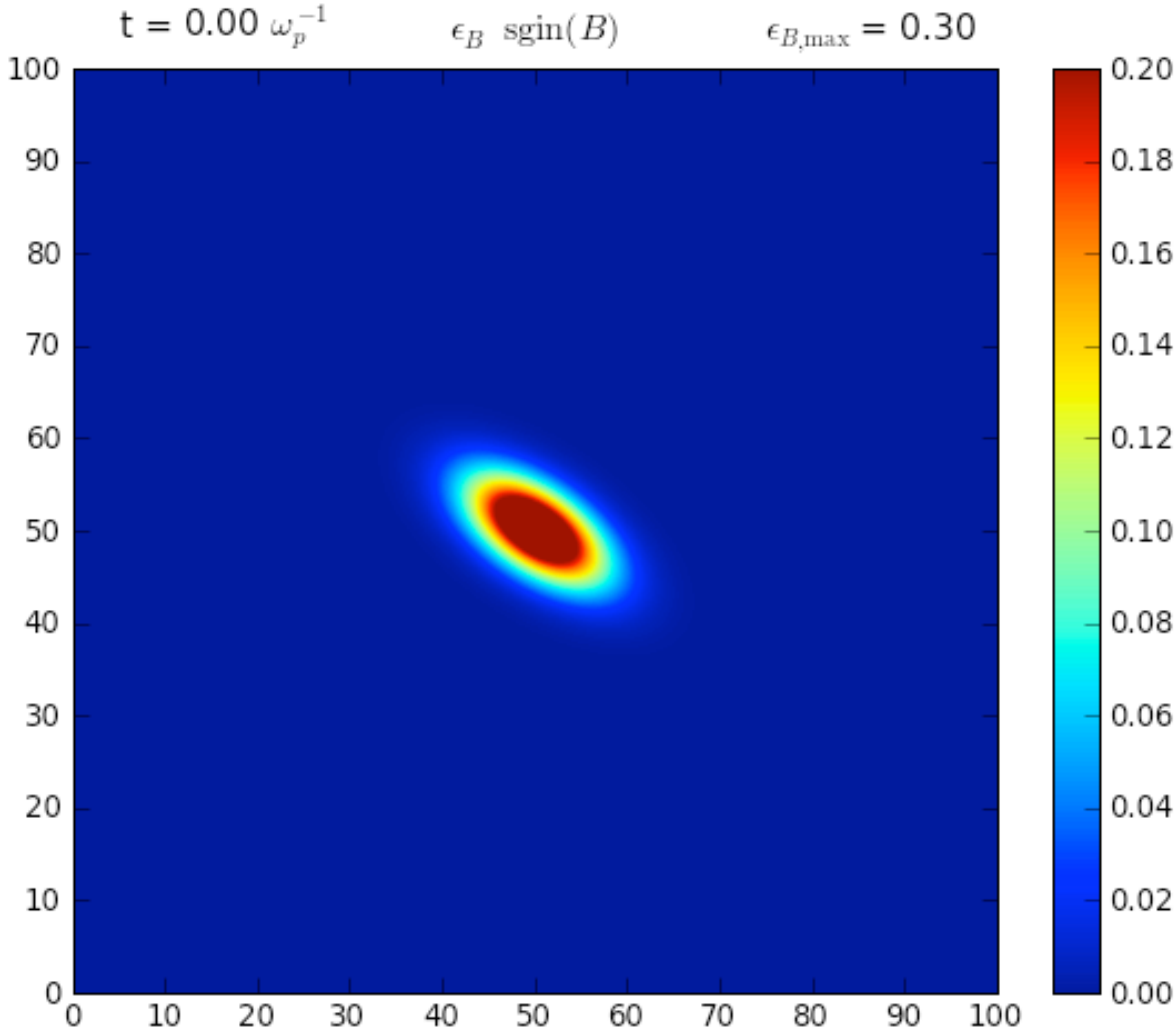
Γ = 2

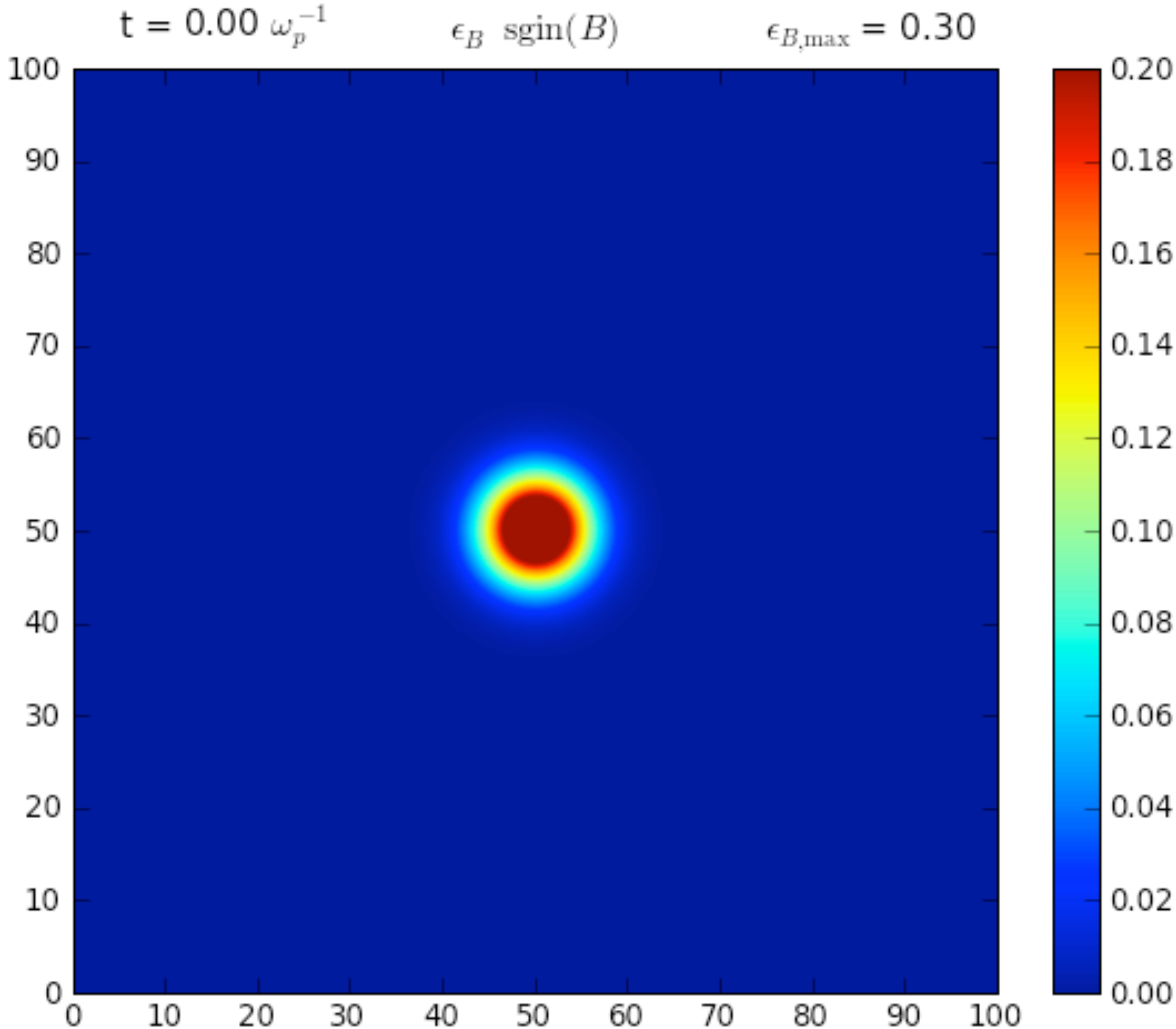


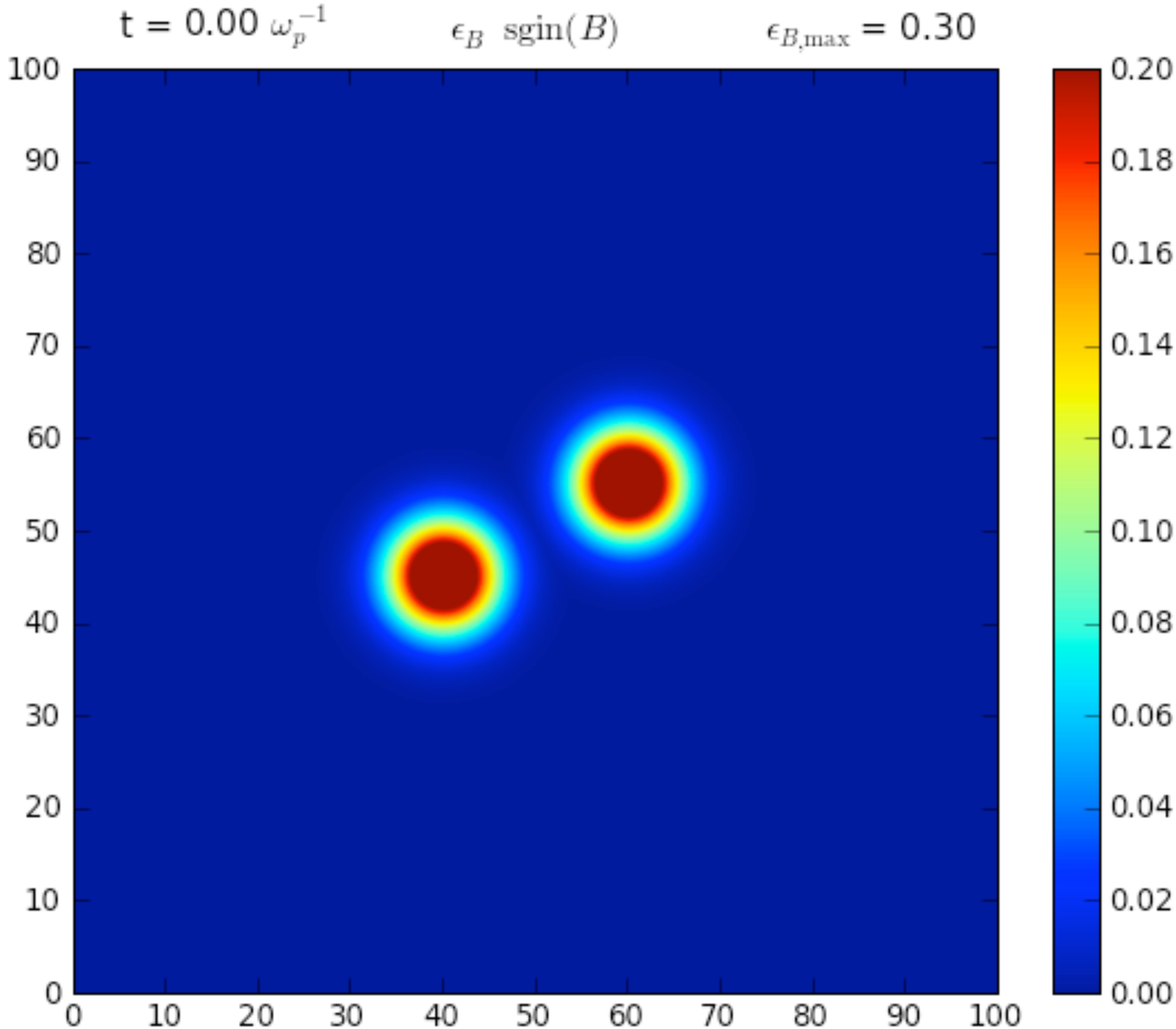
(a)
(b)
$-<v_{\parallel}/c>$
$|\Delta E|/E_0$
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0 100 200 300 400 500 600 700 800 900 1000
Time (ω_p^{-1})


Density
t = 0.00 ω_p^{-1}
50
100
150
200
250
300
350
10^{10}
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^0
10^1
γ
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
−3.5 −3.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0
$\log \epsilon_B$
50
100
150
200
250
300
350

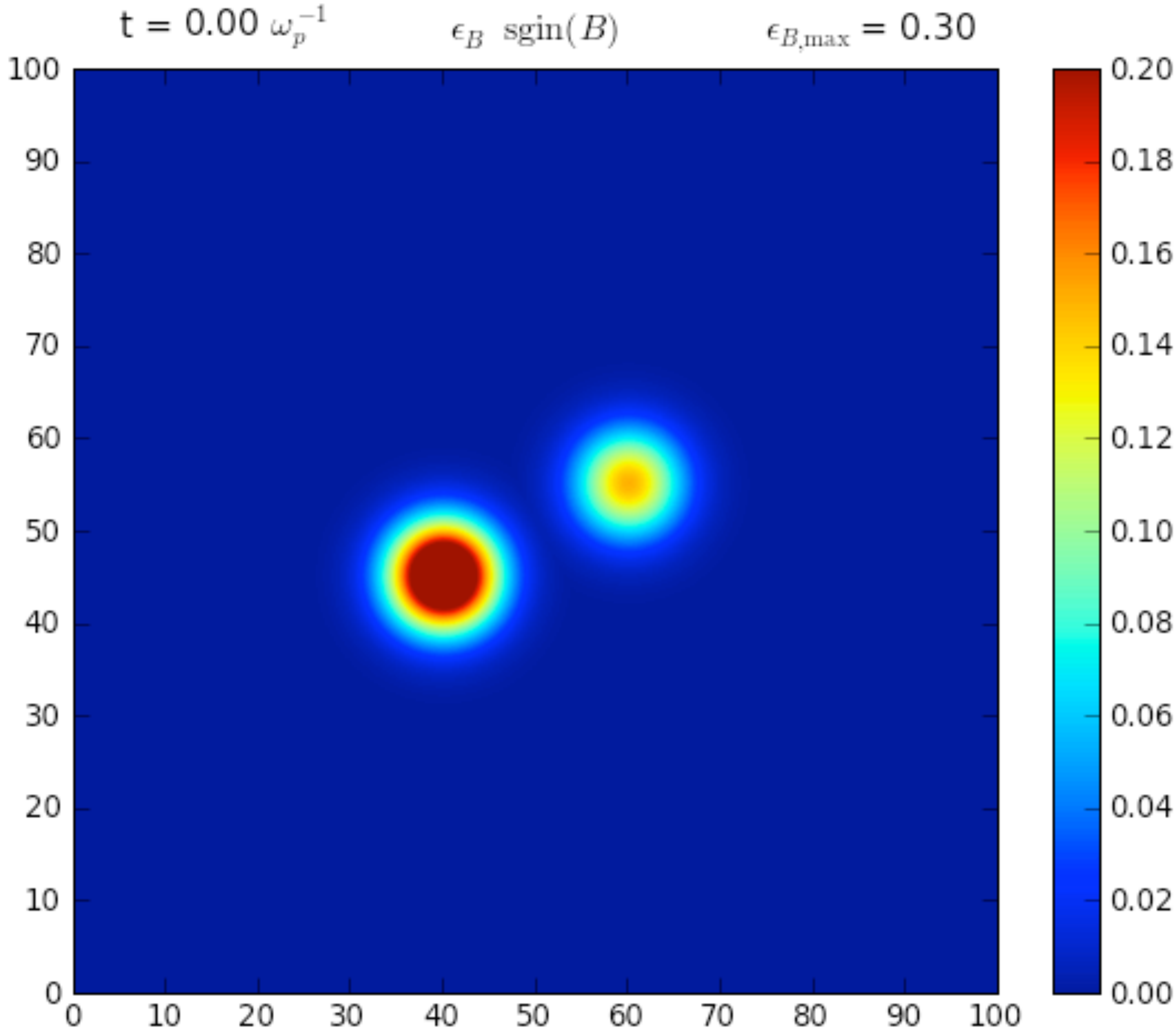

ϵ_B sgn(B) t = 299.70 ω_p^{-1}
50
40
30
20
10
0
300
350
400
450
500
0.10
0.08
0.06
0.04
0.02
0.00
−0.02
−0.04
−0.06
−0.08
−0.10


t = 0.00 ω_p^{-1}
ϵ_B sgin(B)
$\epsilon_{B,\max}$ = 0.30
0
10
20
30
40
50
60
70
80
90
100
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

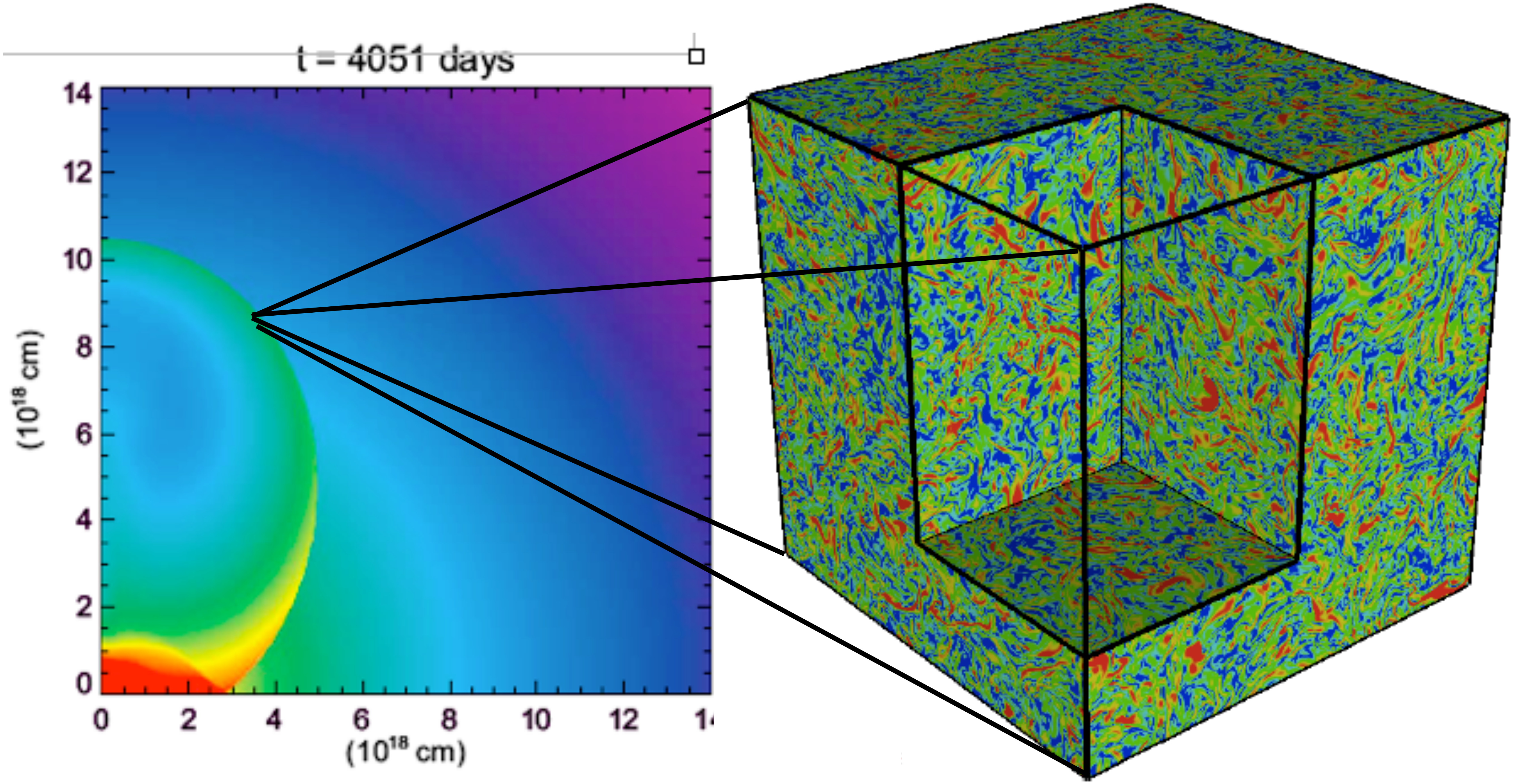

t = 0.00 ω_p^{-1}
ϵ_B sgin(B)
$\epsilon_{B,\max}$ = 0.30
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00



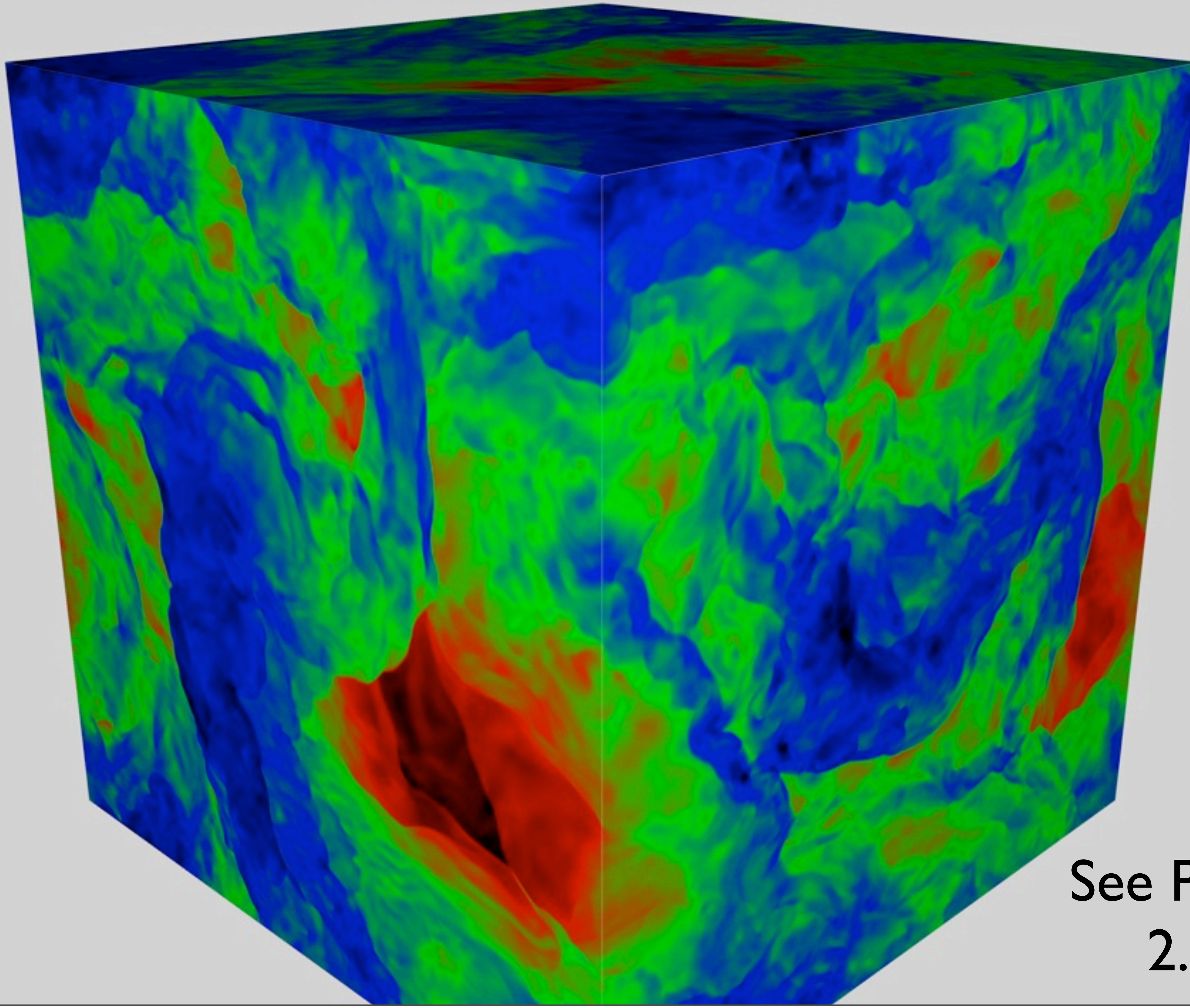
t = 0.00 ω_p^{-1}
ϵ_B sgin(B)
$\epsilon_{B,\max}$ = 0.30
0 10 20 30 40 50 60 70 80 90 100
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20


t = 0.00 ω_p^{-1}
ϵ_B sgin(B)
$\epsilon_{B,\max}$ = 0.30
0
10
20
30
40
50
60
70
80
90
100
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

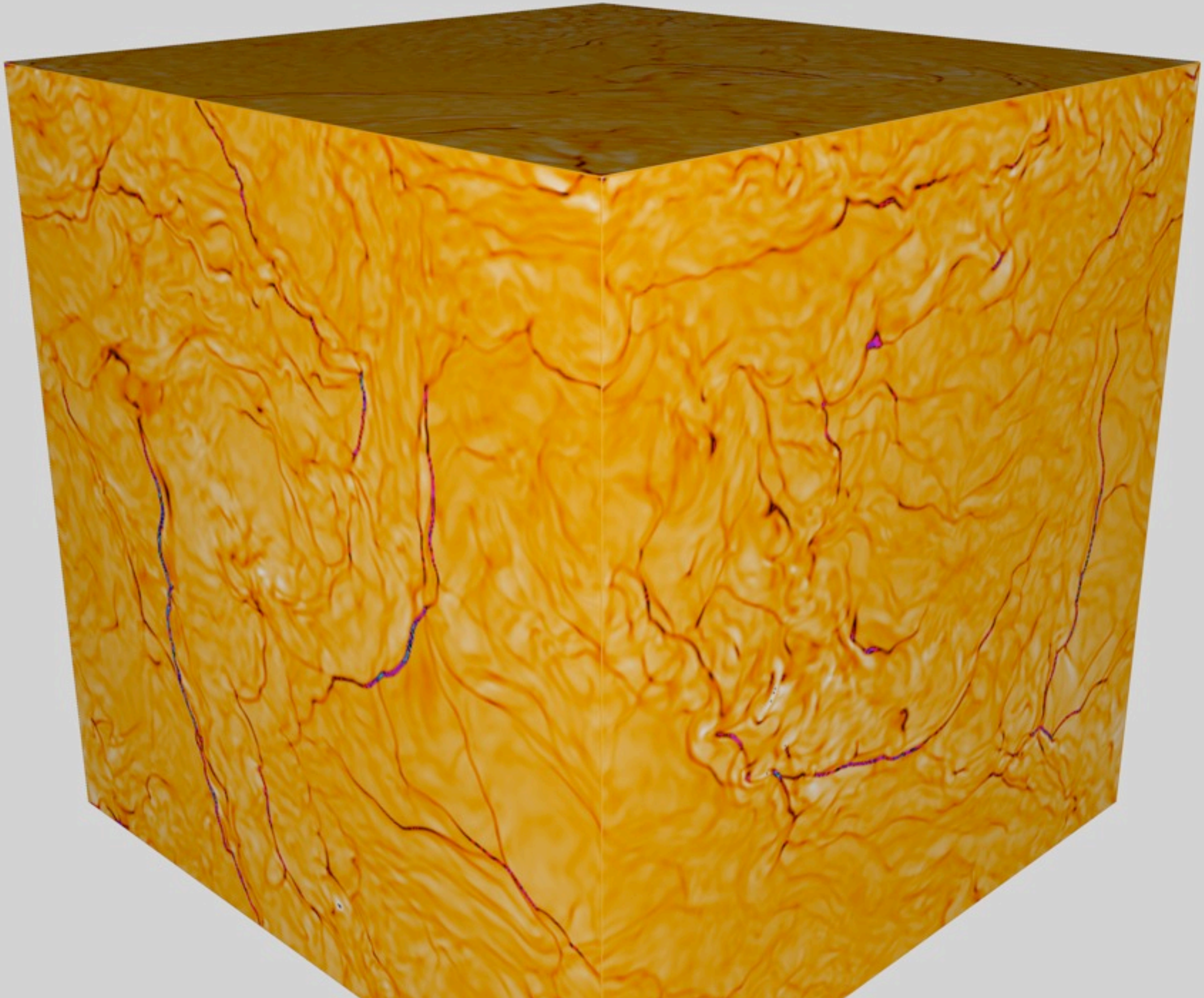
$\varepsilon_B = 0.005$

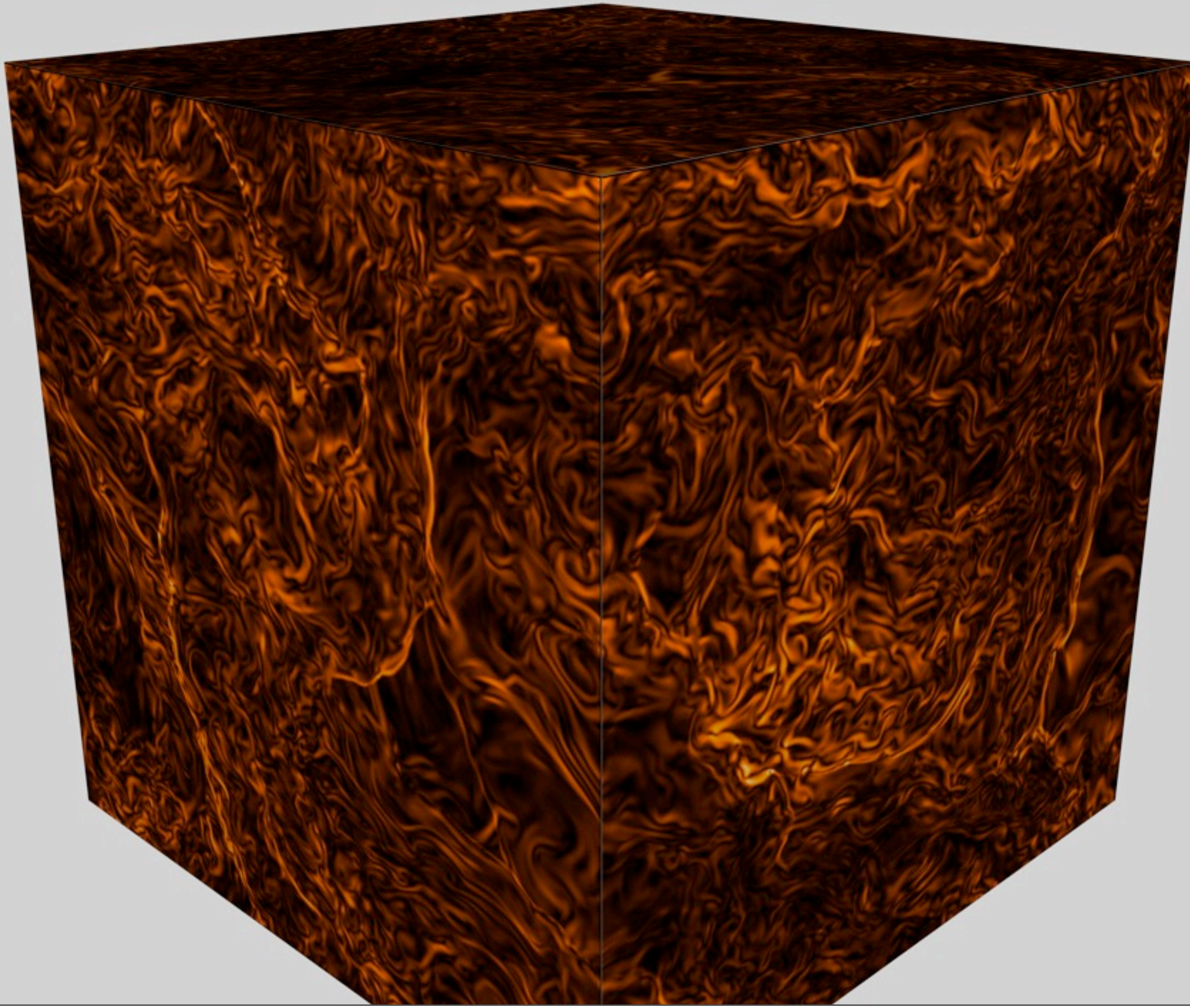


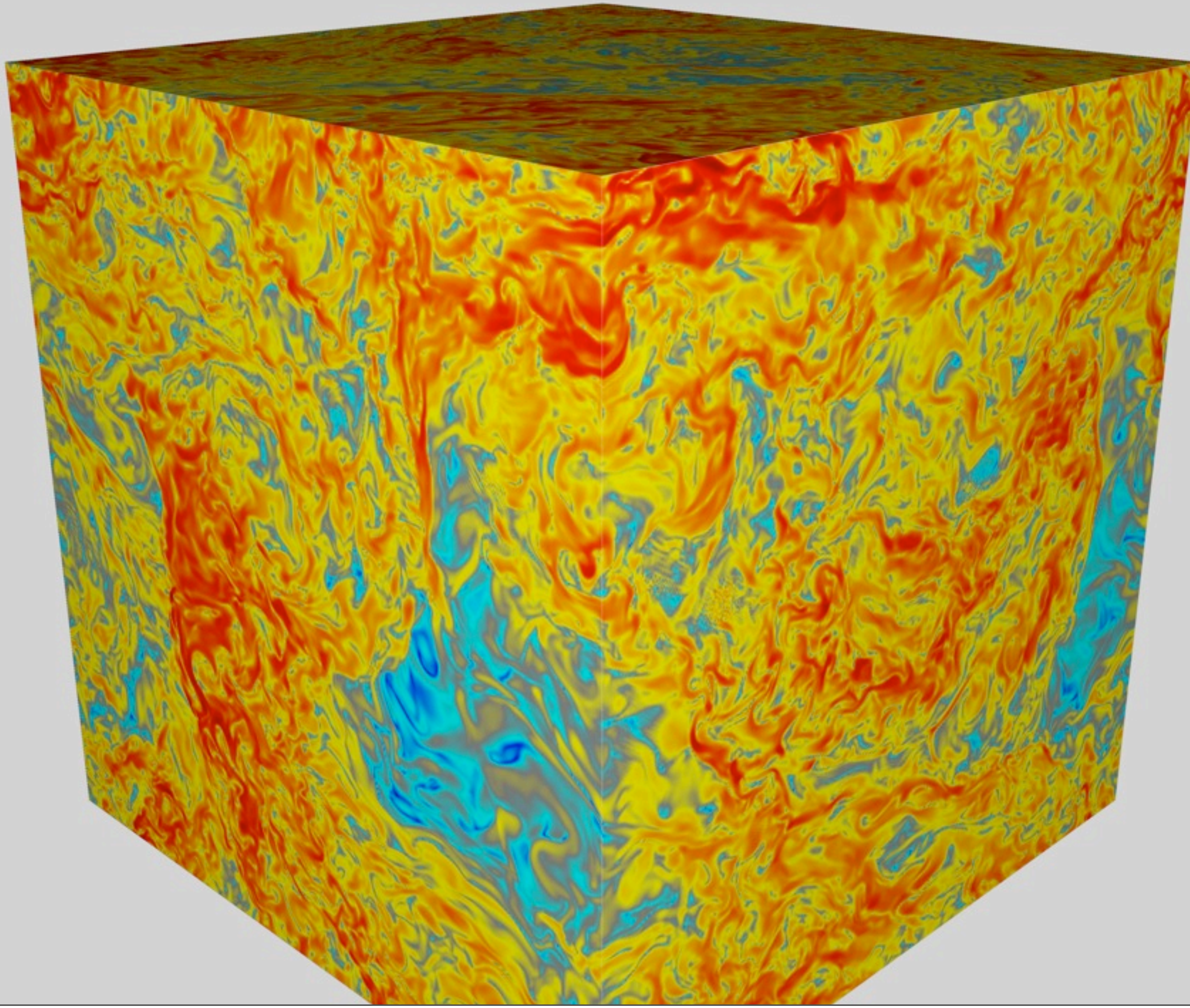
Zhang, AM&Wang, ApJL (2009)

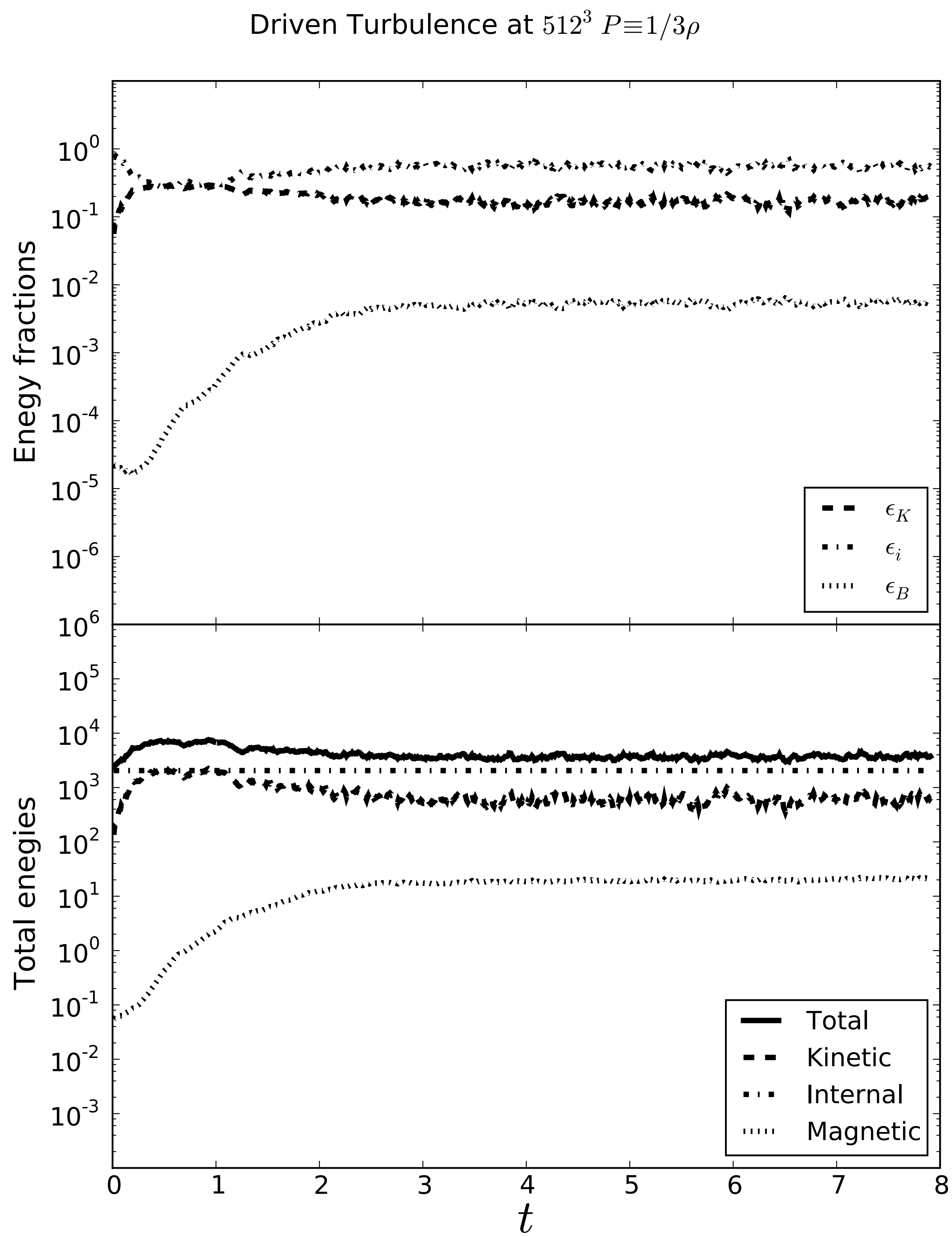


See Poster
2.15









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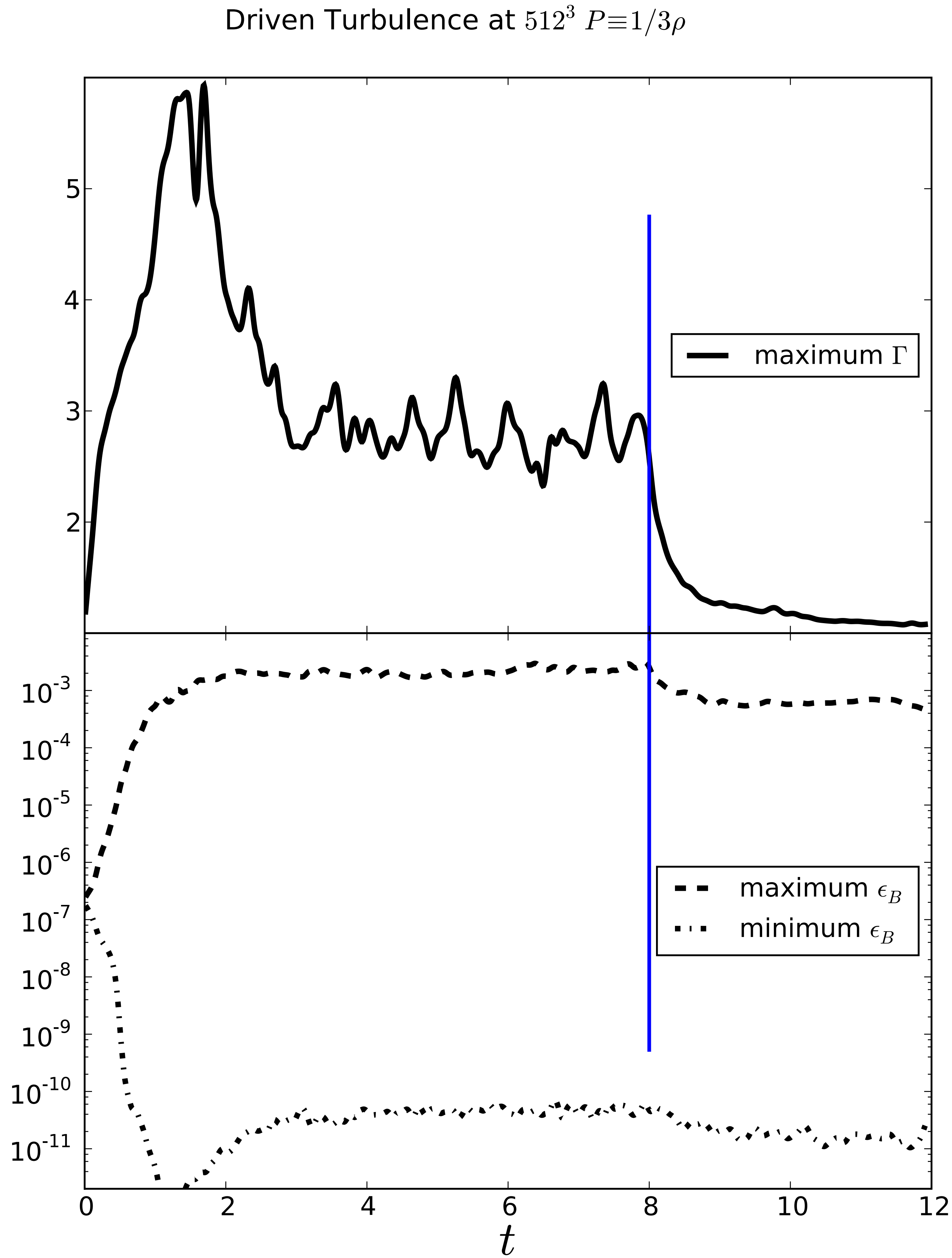

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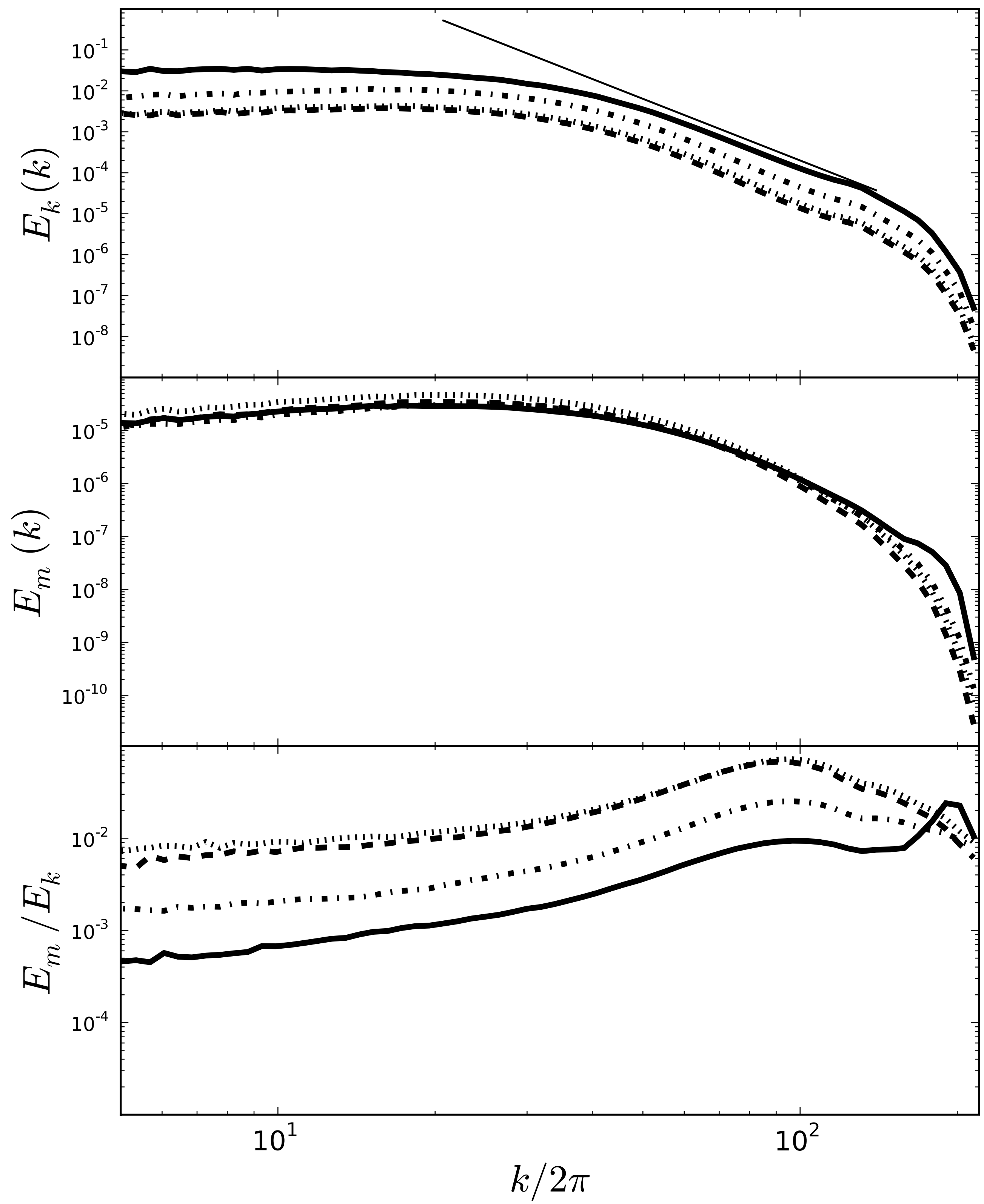
Power spectra of kinetic and magnetic energy



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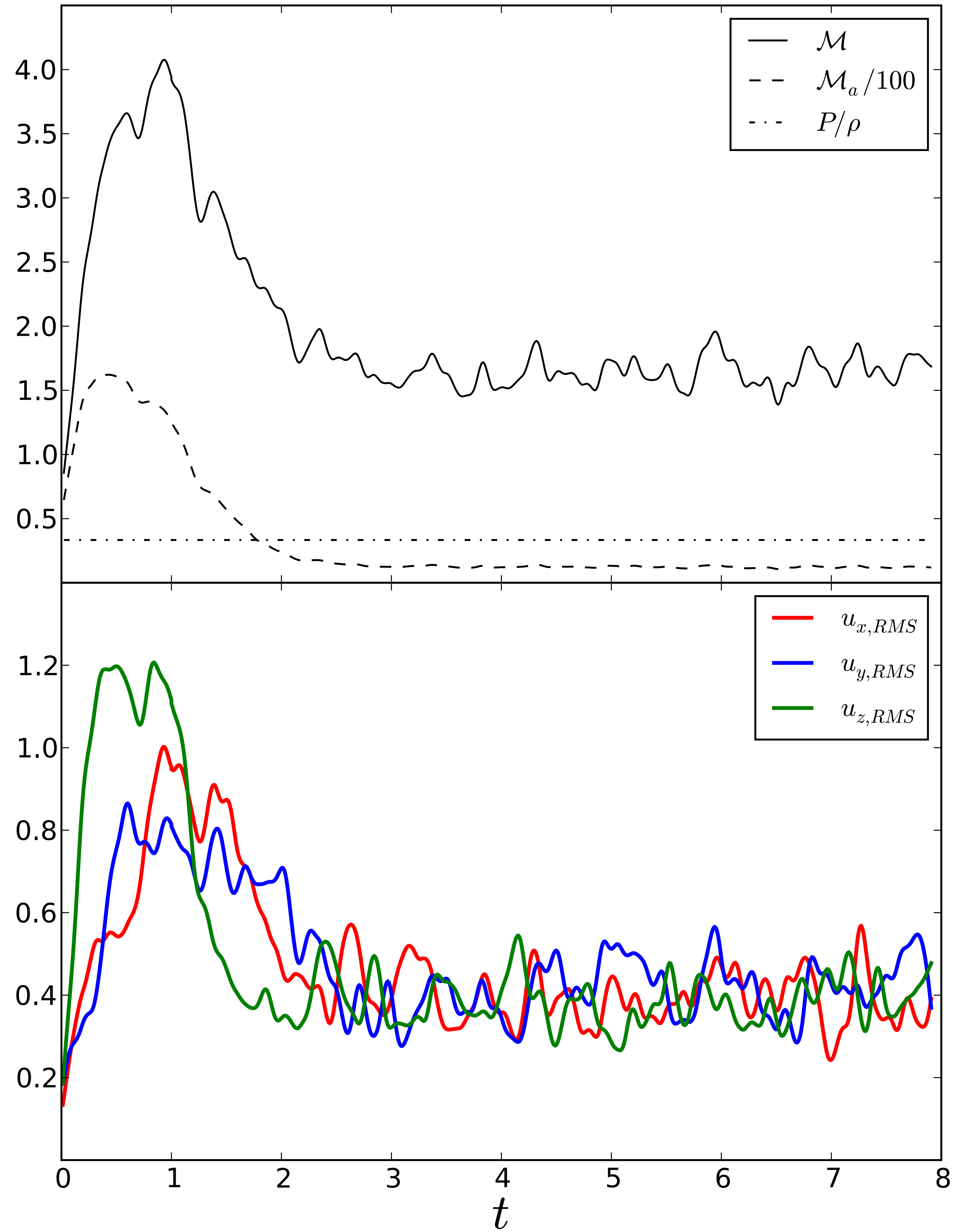
Driven Turbulence at 512^3 $P \equiv 1/3\rho$



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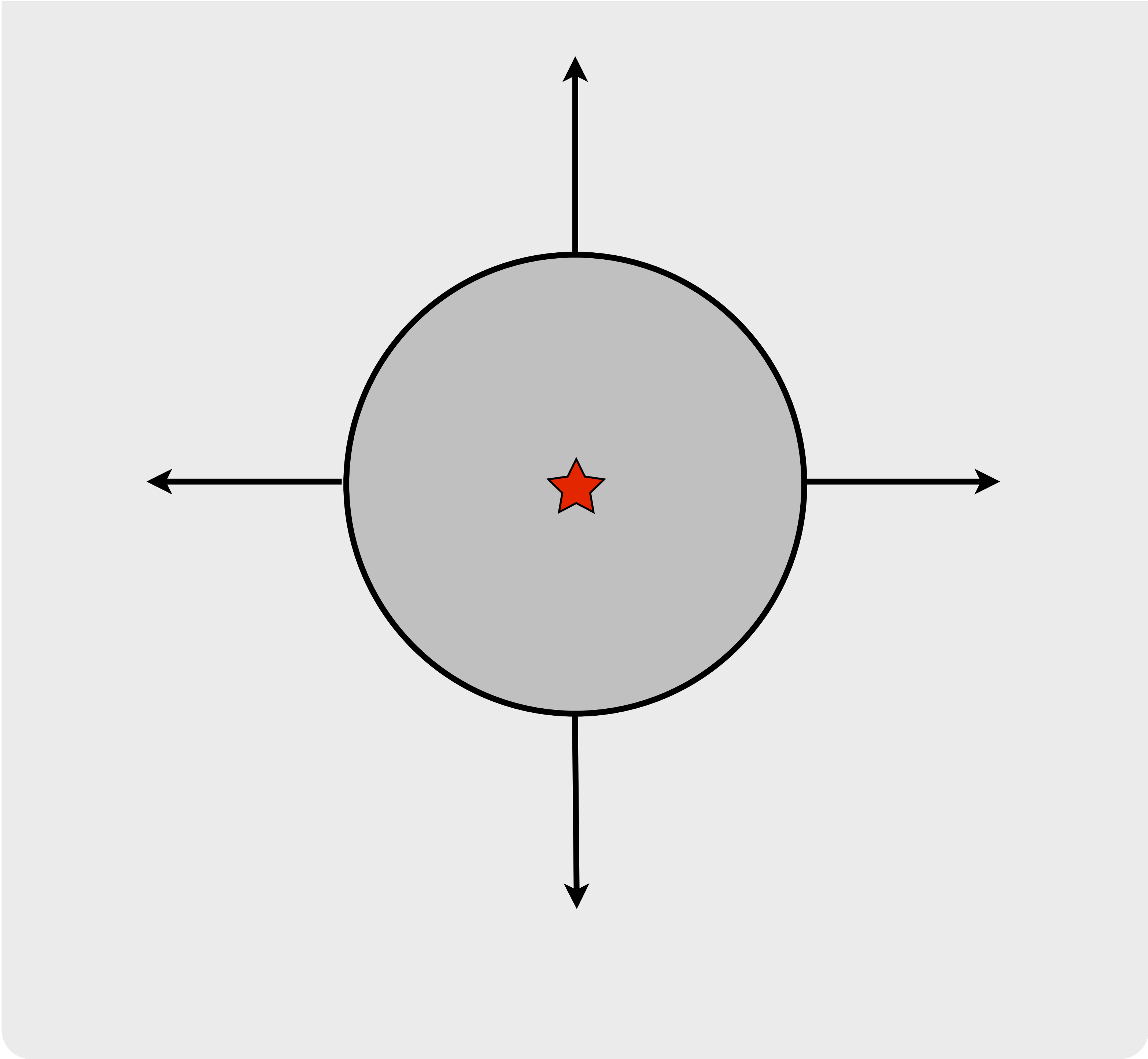
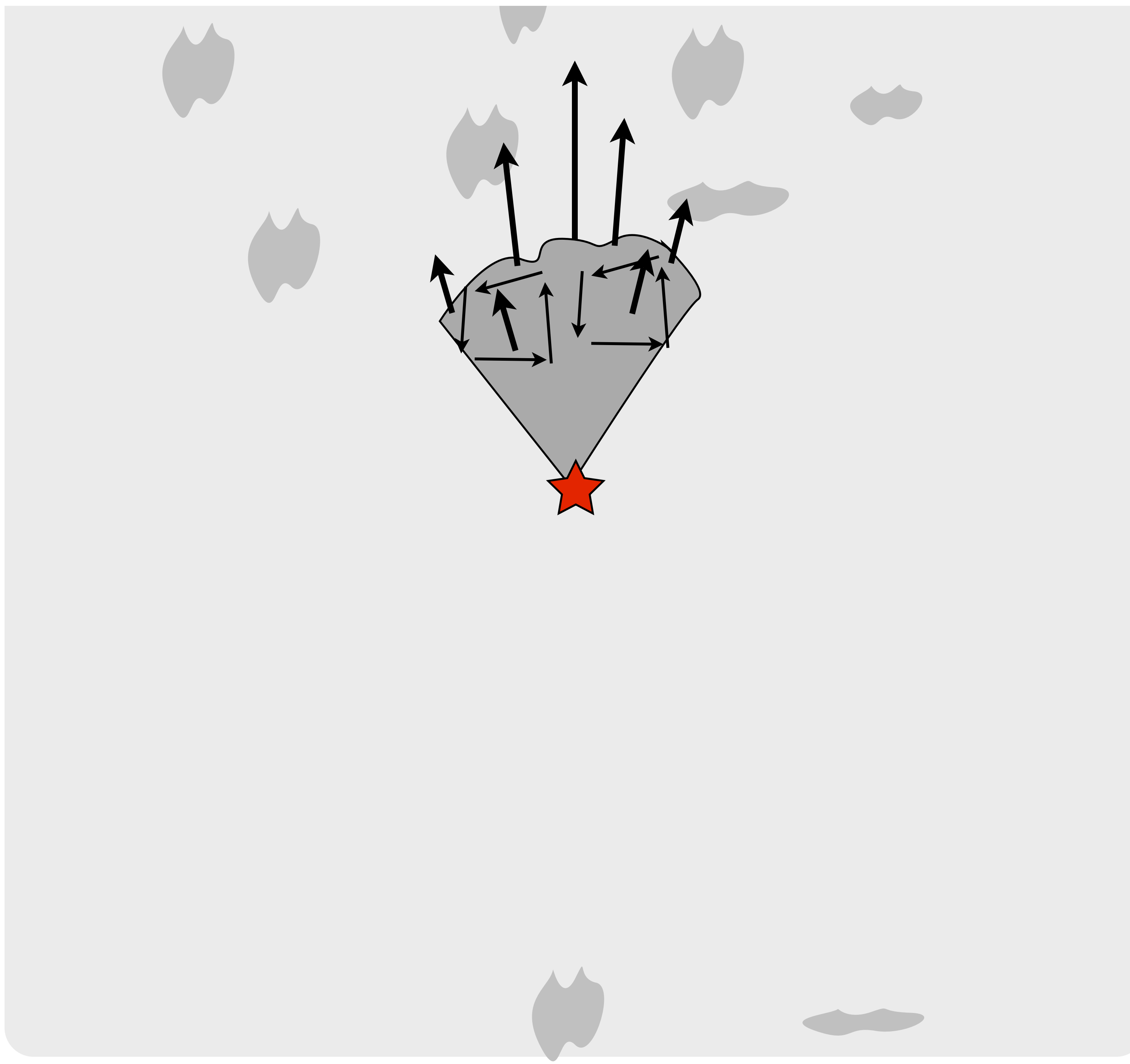
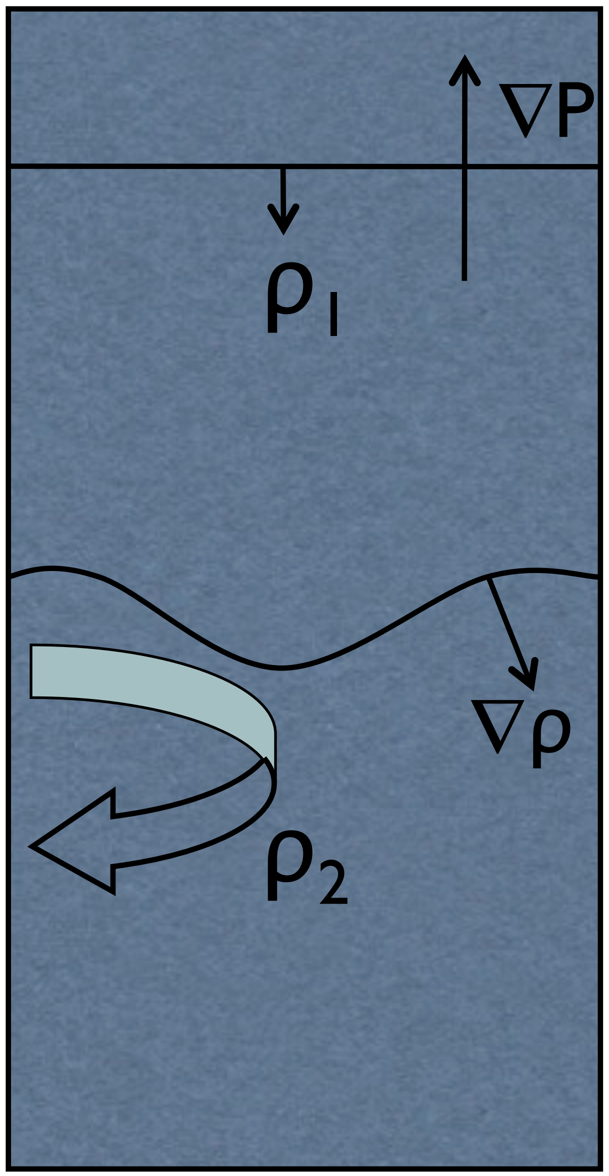
$$T^{\mu\nu} = (P + \rho)u^{\mu}u^{\nu} + Pg^{\mu\nu}$$

Smooth & Spherical



Jet & Clumps



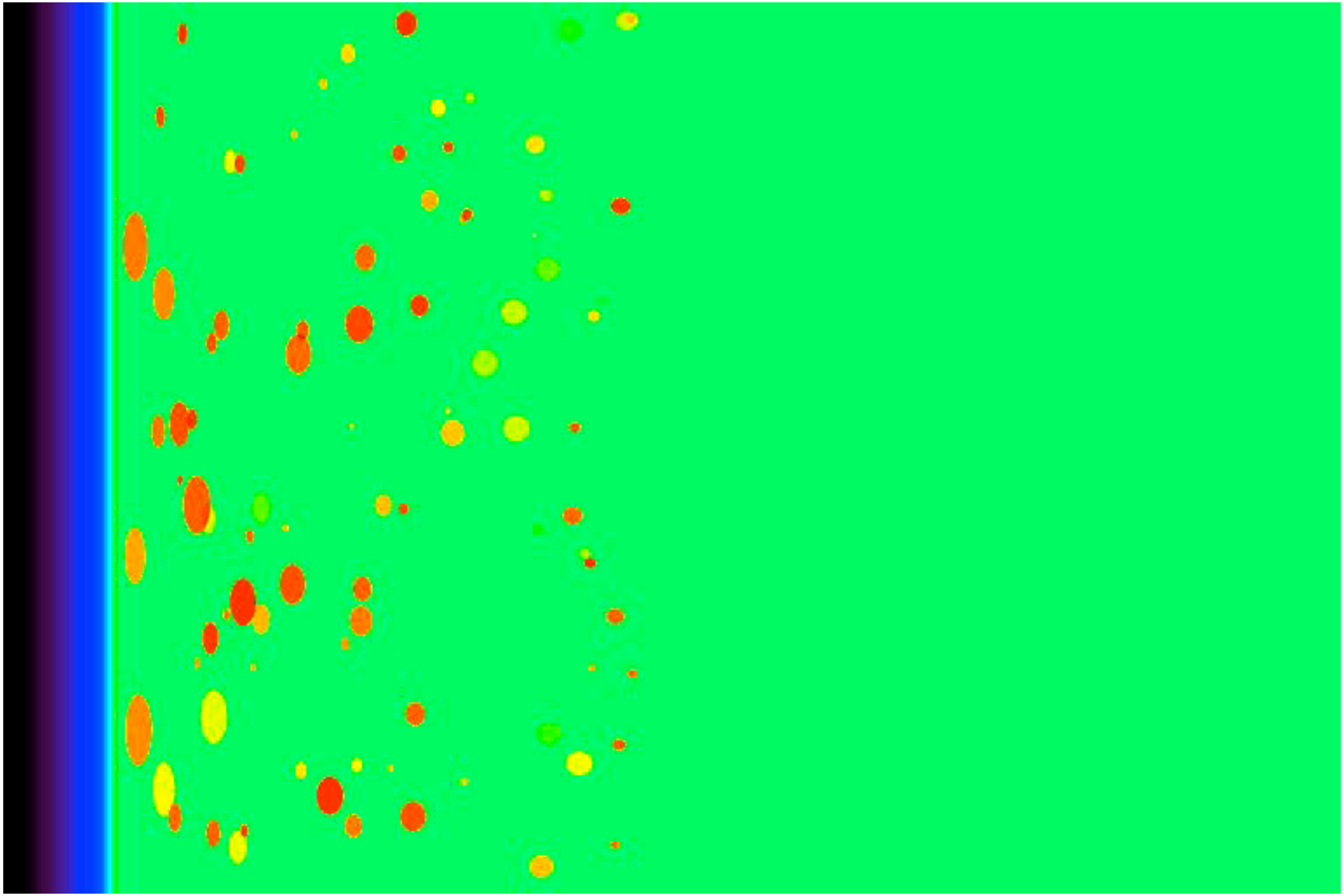


$\eta_t = k[u]A\eta$ $\quad$ $A \equiv (\rho_1 - \rho_2)/(\rho_1 + \rho_2)$

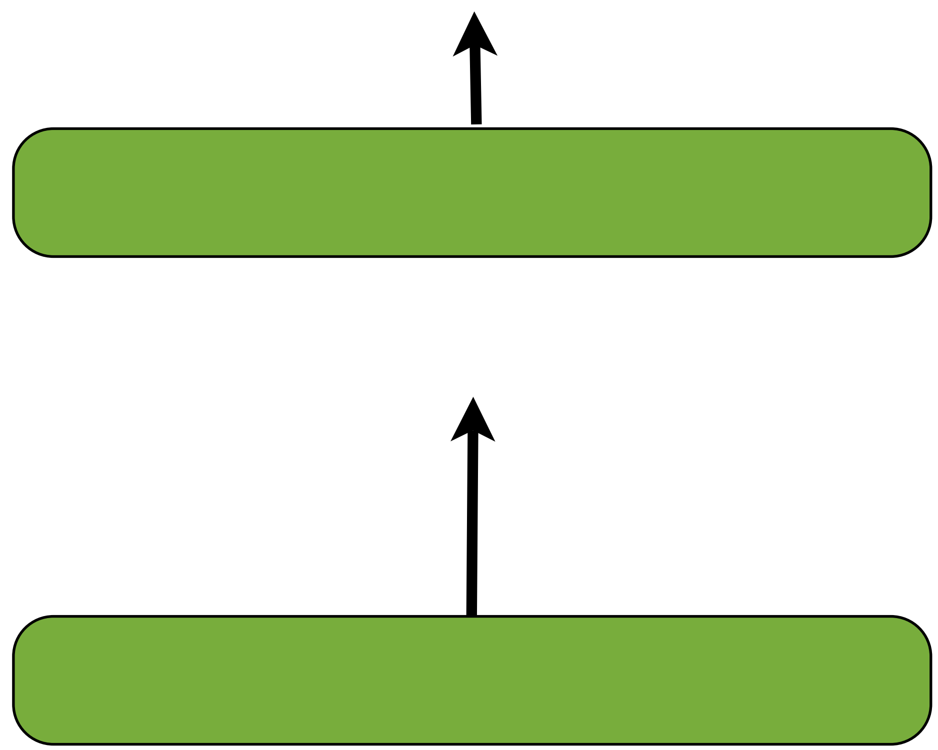
Ultra-relativistic Vorticity
and Shock Dynamics

Goodman & MacFadyen (2008)

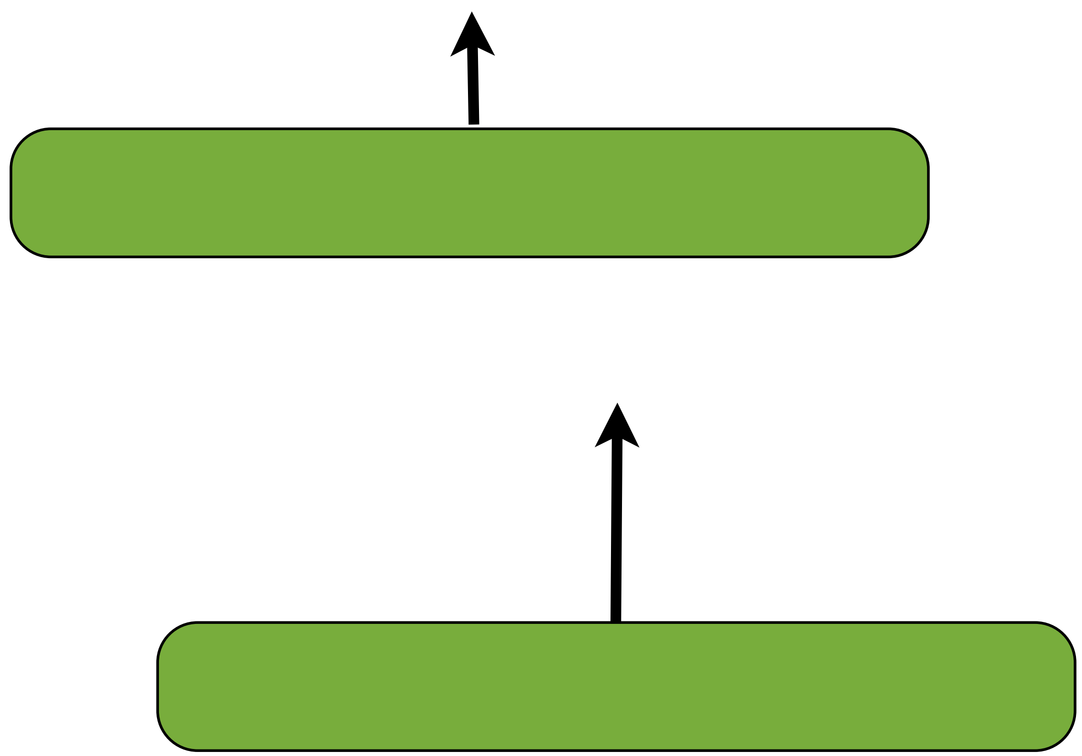
Clumpy Medium



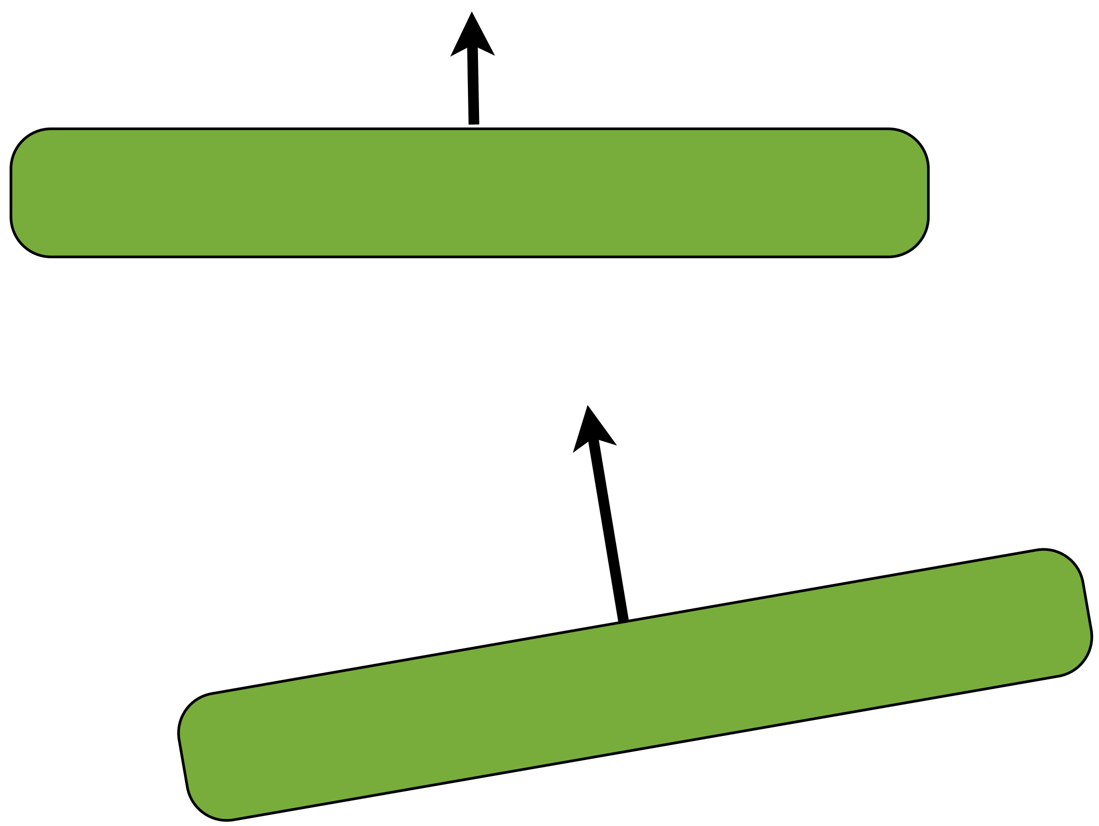
Flying Pancakes



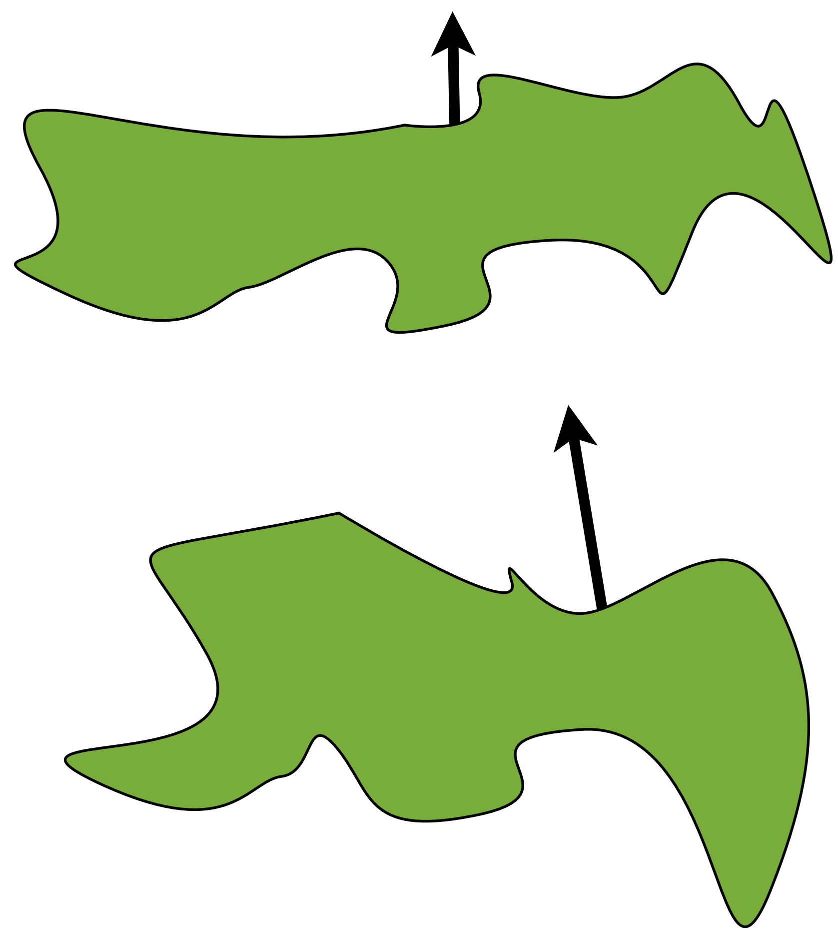
Misaligned



Oblique

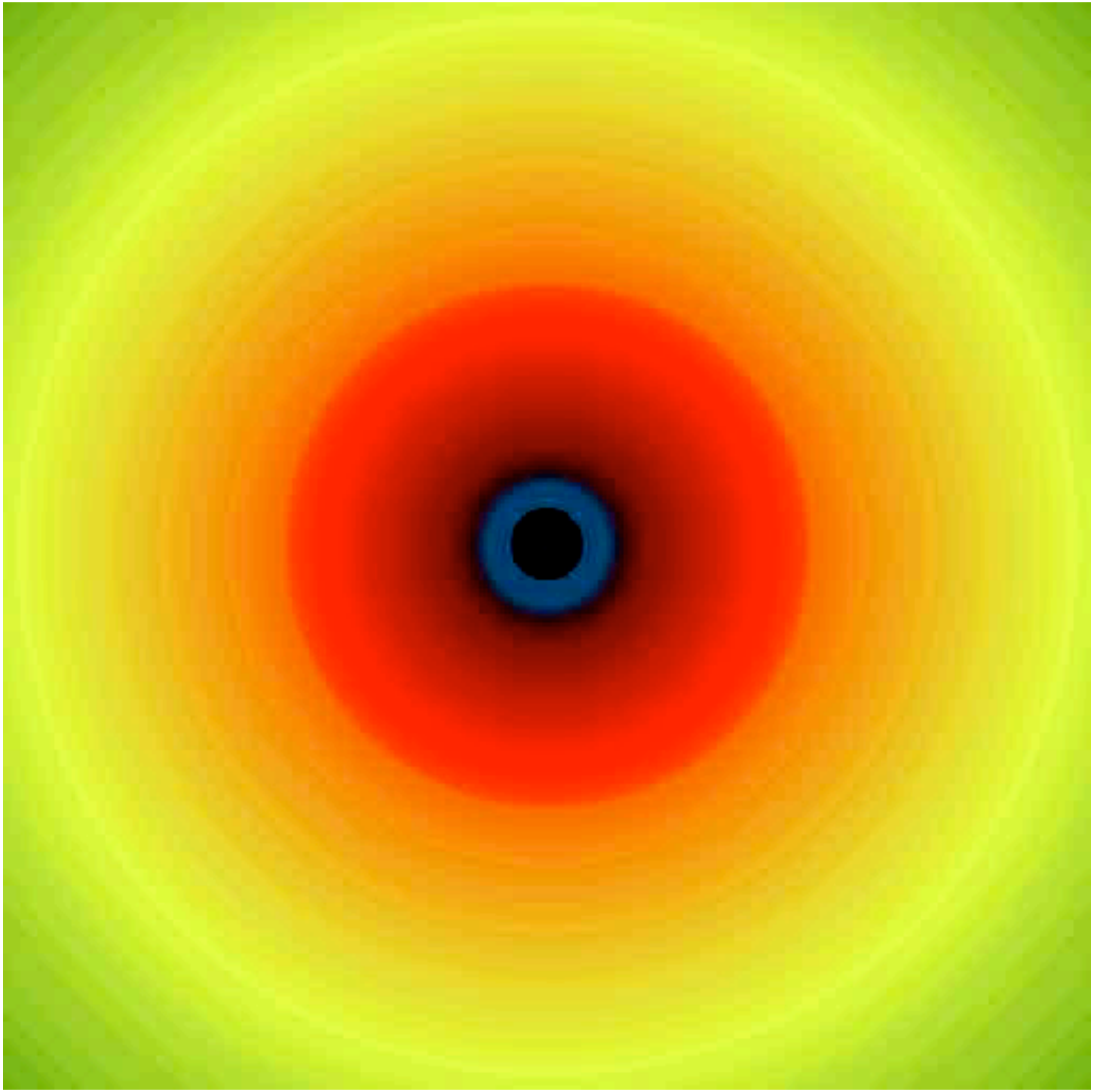


Colliding Clumps



AMR
jet
+wind

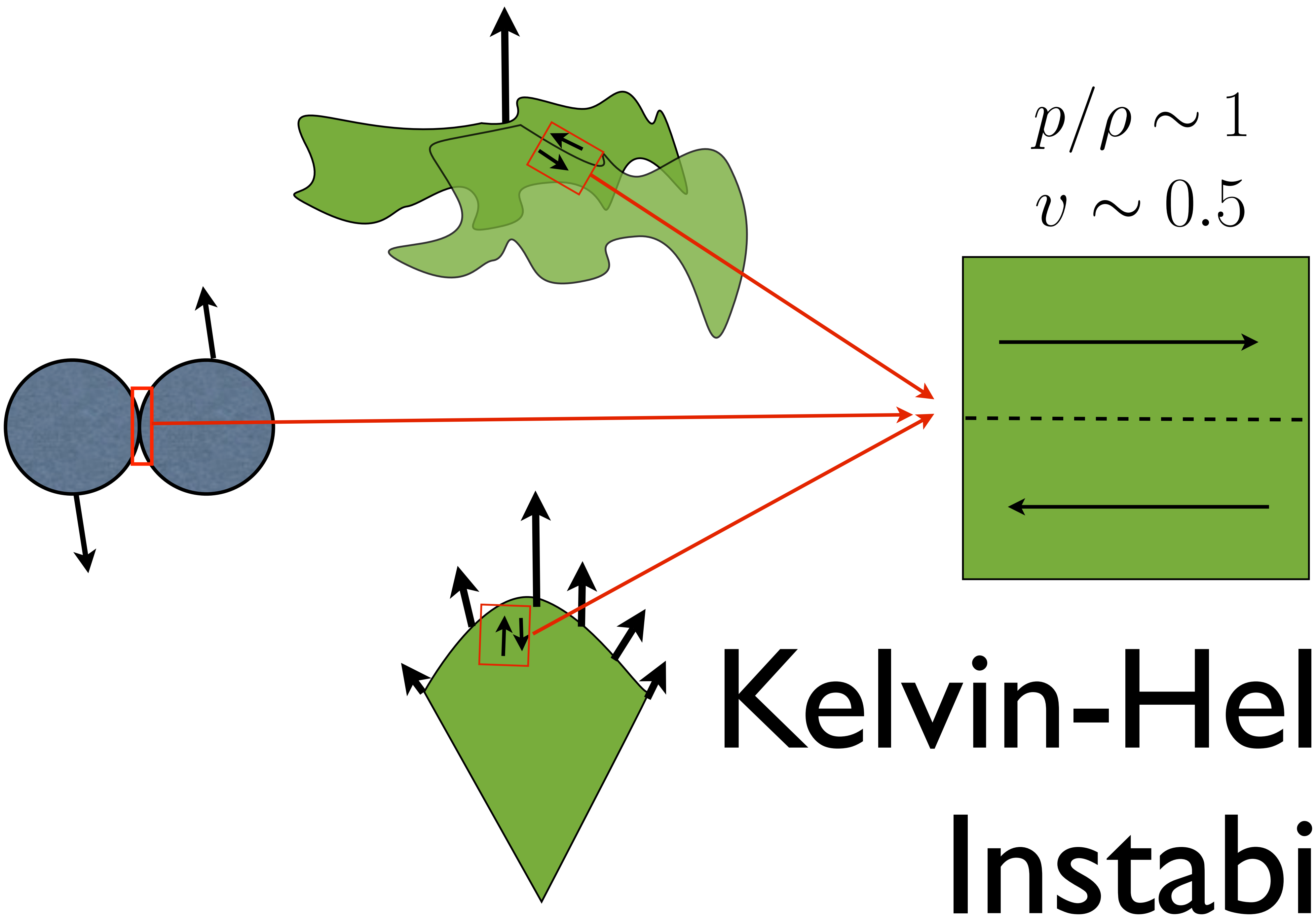
AM&Zhang
(2009)



AMR
jet
+wind

AM&Zhang
(2009)

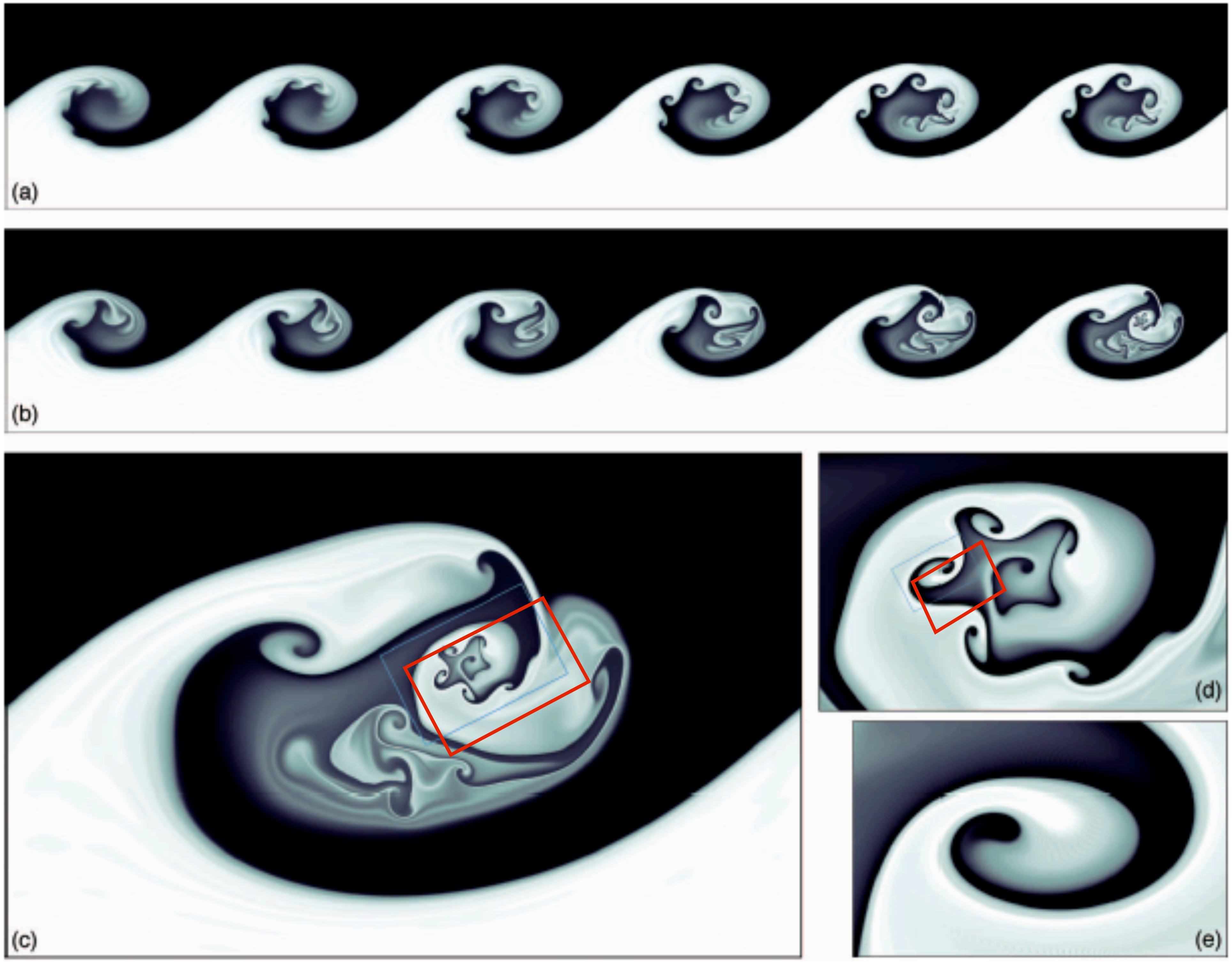
Shear Patches



Kelvin-Helmholtz Instability

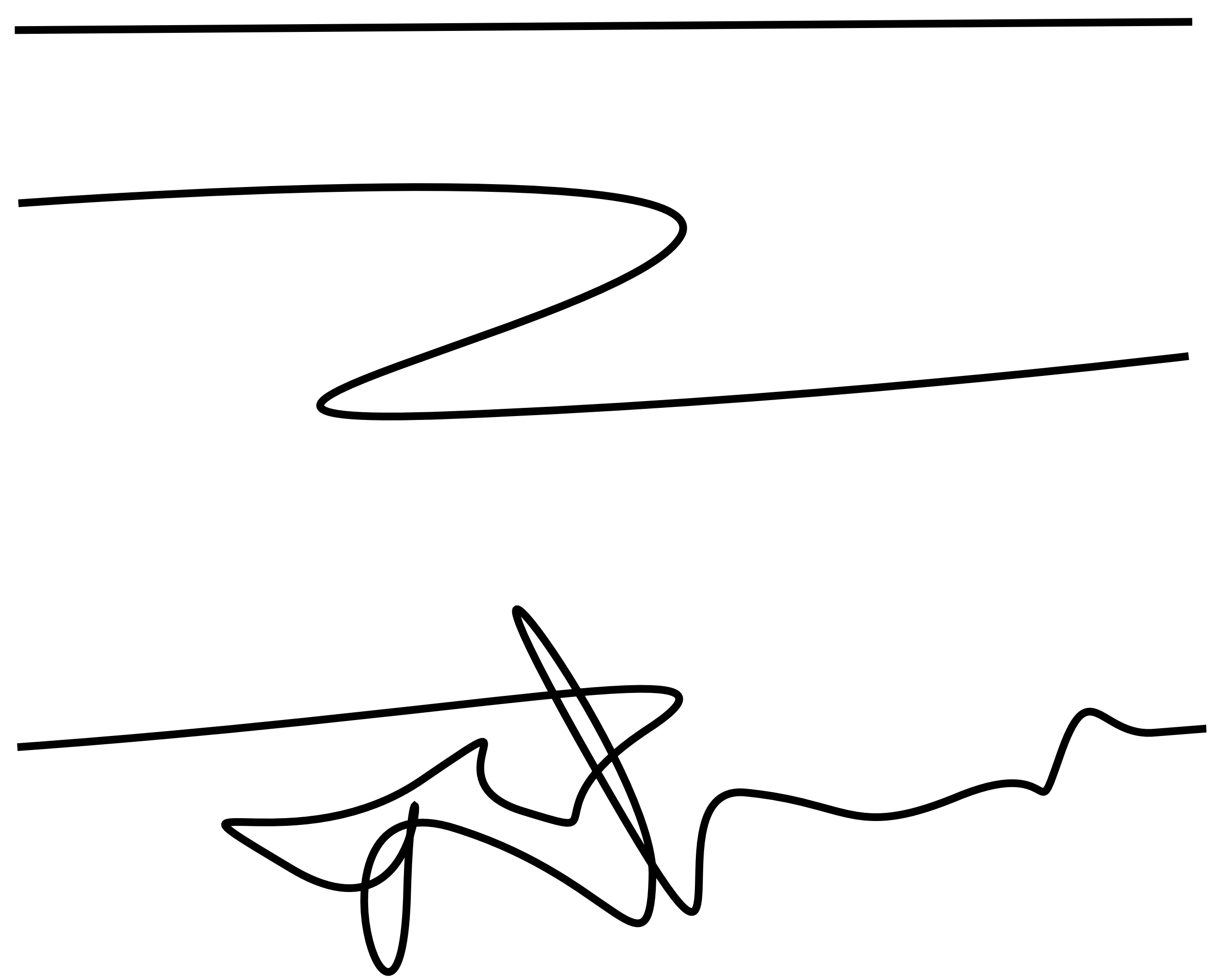
Kelvin Helmholtz Clouds

Big Whirls Have Little Whirls

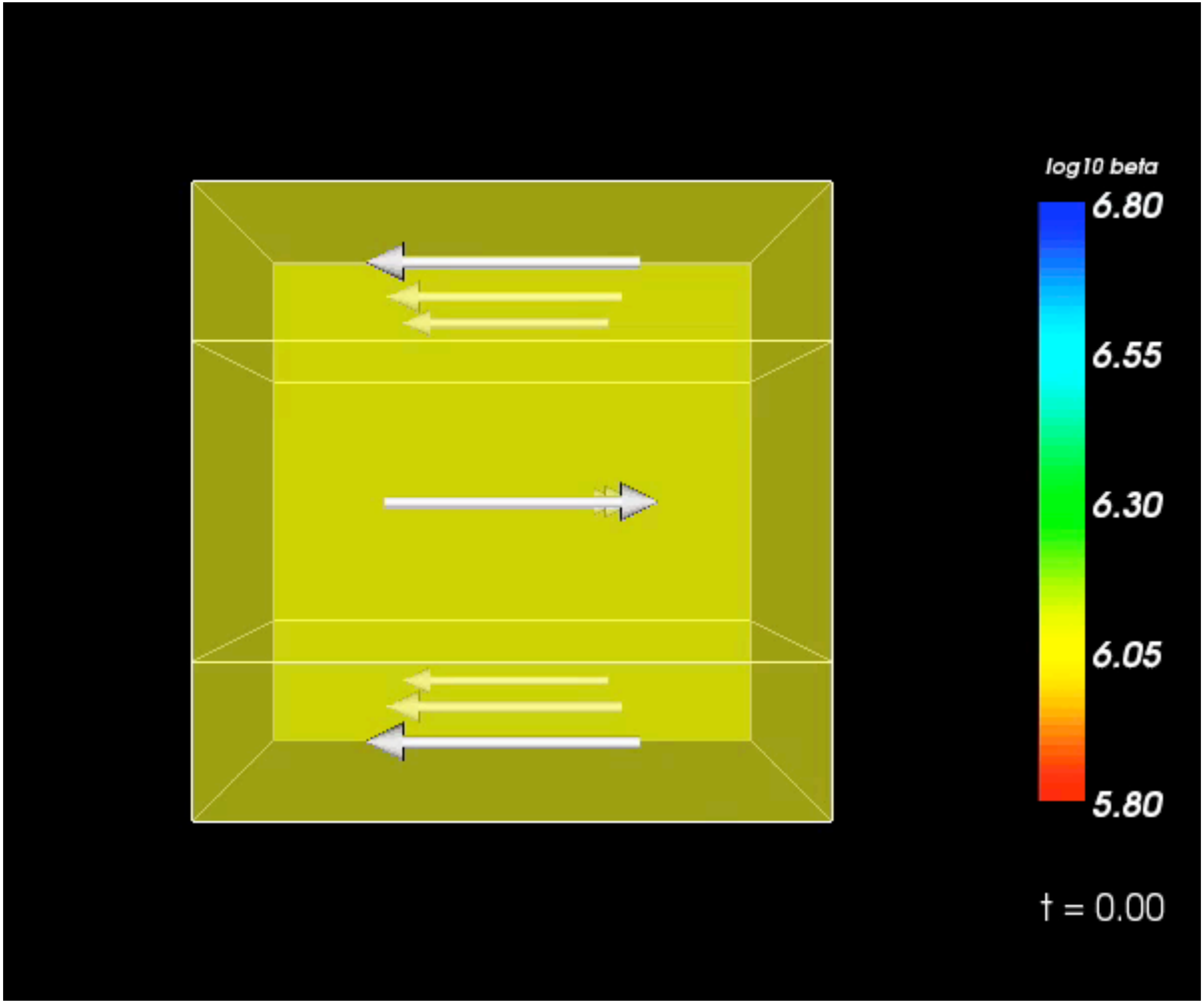


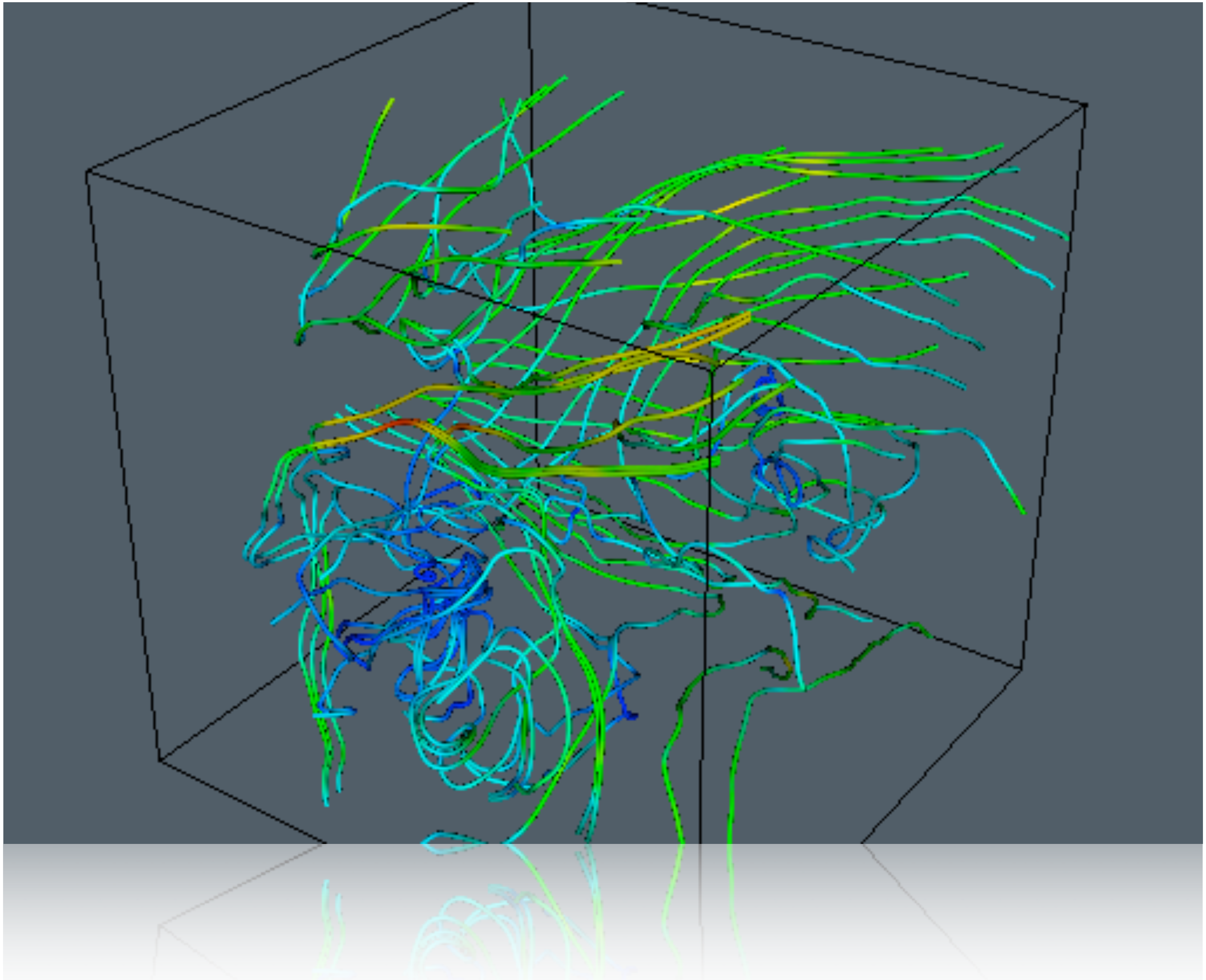
Joly et al (2008)

Twisting and Folding

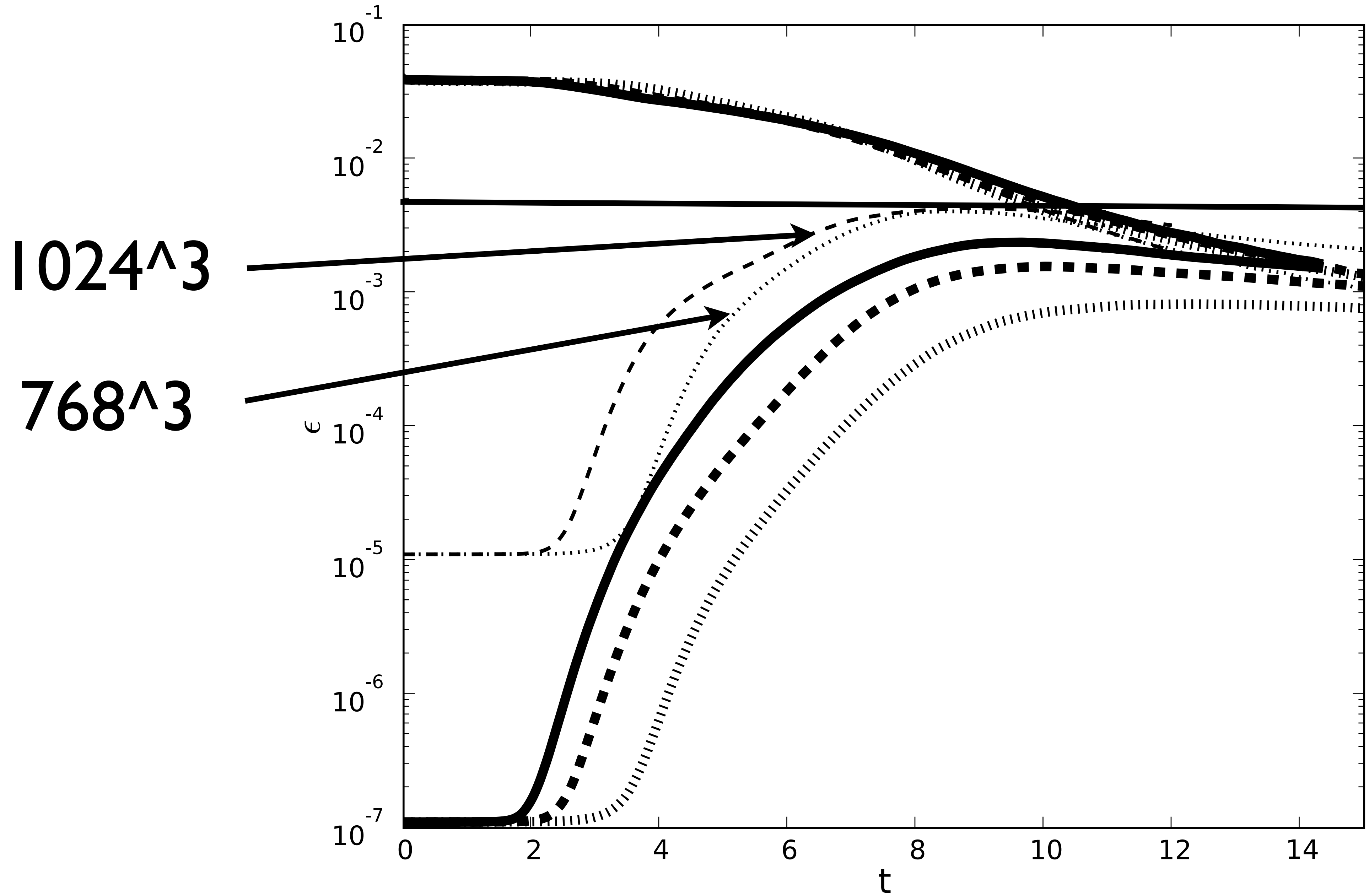


KH: 1024^3 Rel. MHD





Magnetic Energy Saturation



$$\epsilon_B = 5 \times 10^{-3}$$

Conclusions

- Hi Res 2D AG jet sims - On/Off-Axis LCs
  - Delayed or hidden jet break, E overestimate?
  - Slow spreading
  - Orphan AGs - SNIbcs result holds
  - New $\theta j = 0.05$ simulation
  - http://cosmo.nyu.edu/afterglowlibrary

Conclusions

- New Accurate PIC Code
- Γ=2 vs Γ=15
- Particle acceleration B-field (thin)
- Downstream field decay
- Bubble interactions

Conclusions

- Relativistic MHD sims of turbulence
- Mag Field Dynamo, $\varepsilon_B = 0.01$
- Supersonic relativistic turbulence decays quickly