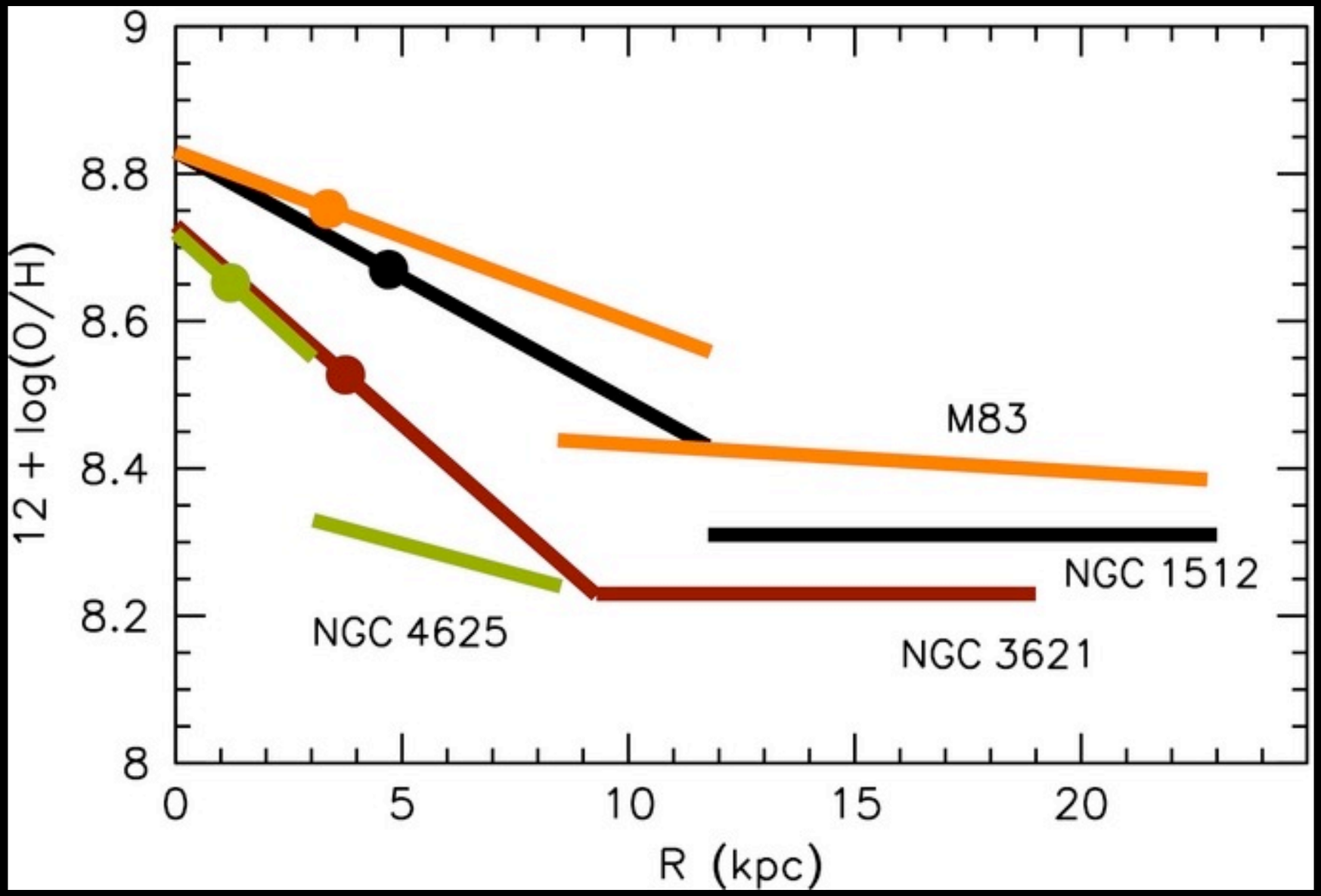
Thermal-Instability-Driven Turbulent Mixing in Galactic Disks

Chao-Chin Yang and Mark Krumholz
University of California, Santa Cruz

ApJ, submitted

Radial Metallicity Gradient

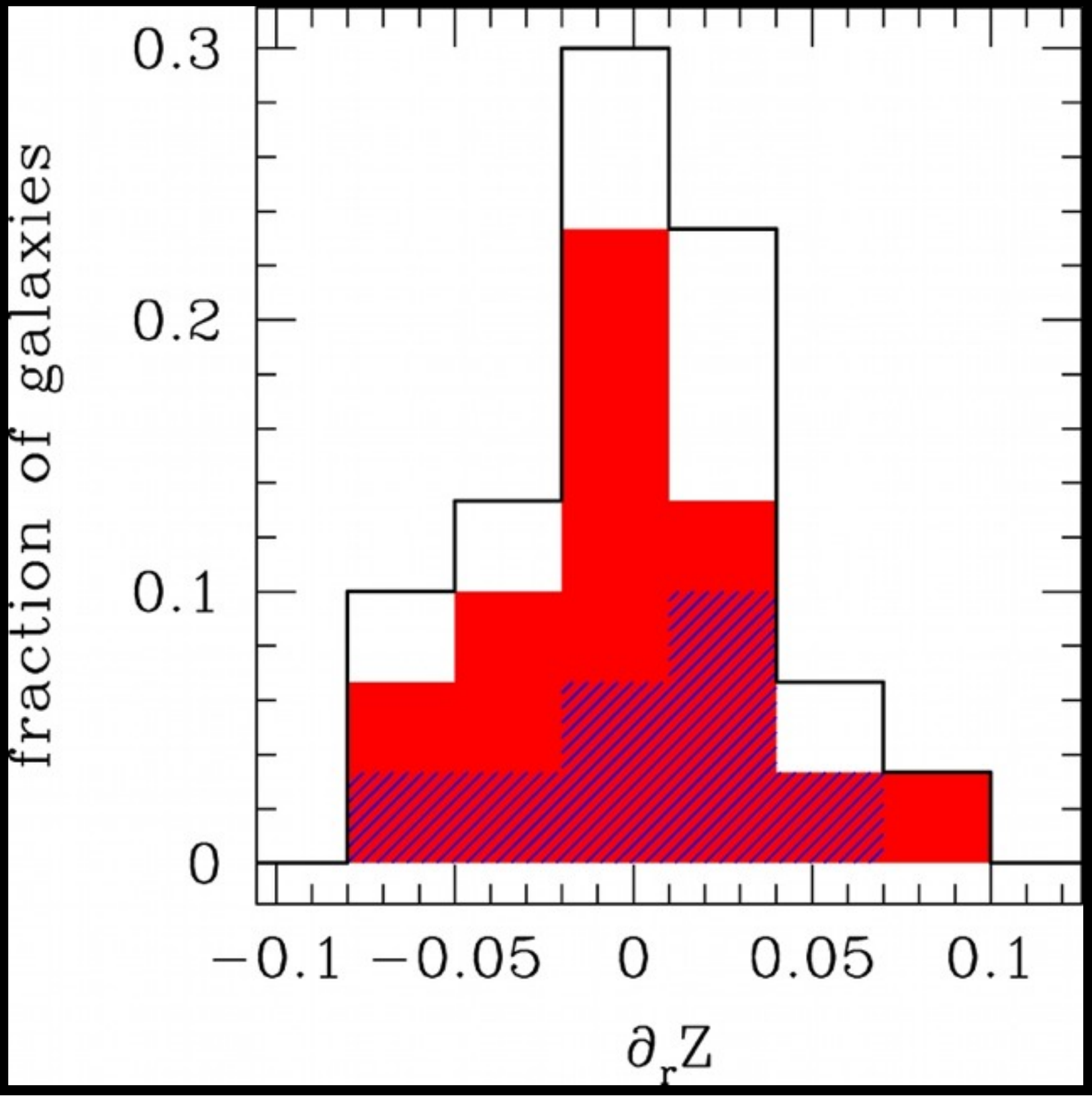
Nearby Disk Galaxies



Bresolin, Kennicutt, & Ryan-Weber 2012

Radial Metallicity Gradient

26 MASSIV Galaxies at $z \sim 1.2$



Queyrel et al. 2012

What Sets Radial Metallicity Gradients?

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- Supernova-driven galactic fountains (Spitoni, Recchi, & Matteucci 2008; Spitoni et al. 2009)
- Gas radial inflows within the disk (Mayor & Vigroux 1981; Lacey & Fall 1985; Pitts & Tayler 1989; G¨otz & K¨oppen 1992; Portinari & Chiosi 2000; Spitoni & Matteucci 2011; Bilitewski & Sch¨onrich 2012)
- Gas accretion/infall from halo/CGM (Tinsley & Larson 1978; Chiosi 1980; Matteucci & Fran¸cois 1989; Chiappini et al. 1997, 2001; Prantzos & Boissier 2000)
- Merger/interaction history (Perez et al. 2006, 2011; Kewley et al. 2010; Rupke, Kewley, & Barnes 2010; Rupke, Kewley, & Chien 2010; Torrey et al., in prep.)
- Stellar radial migration (Roškar et al. 2008a,b; Schönrich & Binney 2009)

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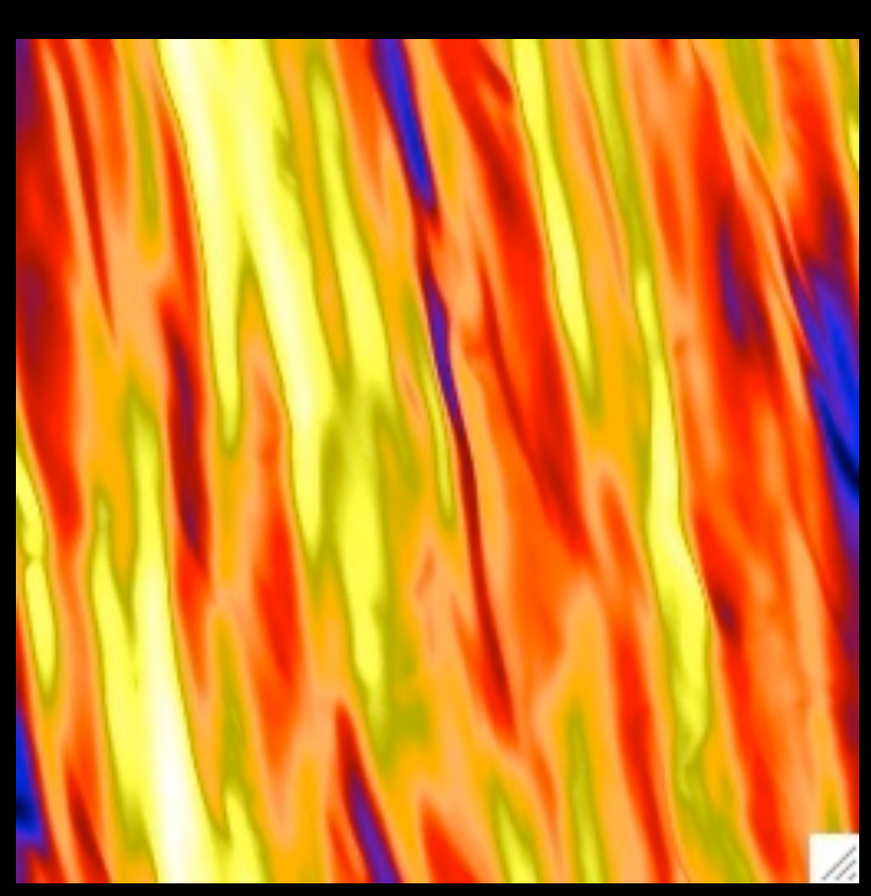
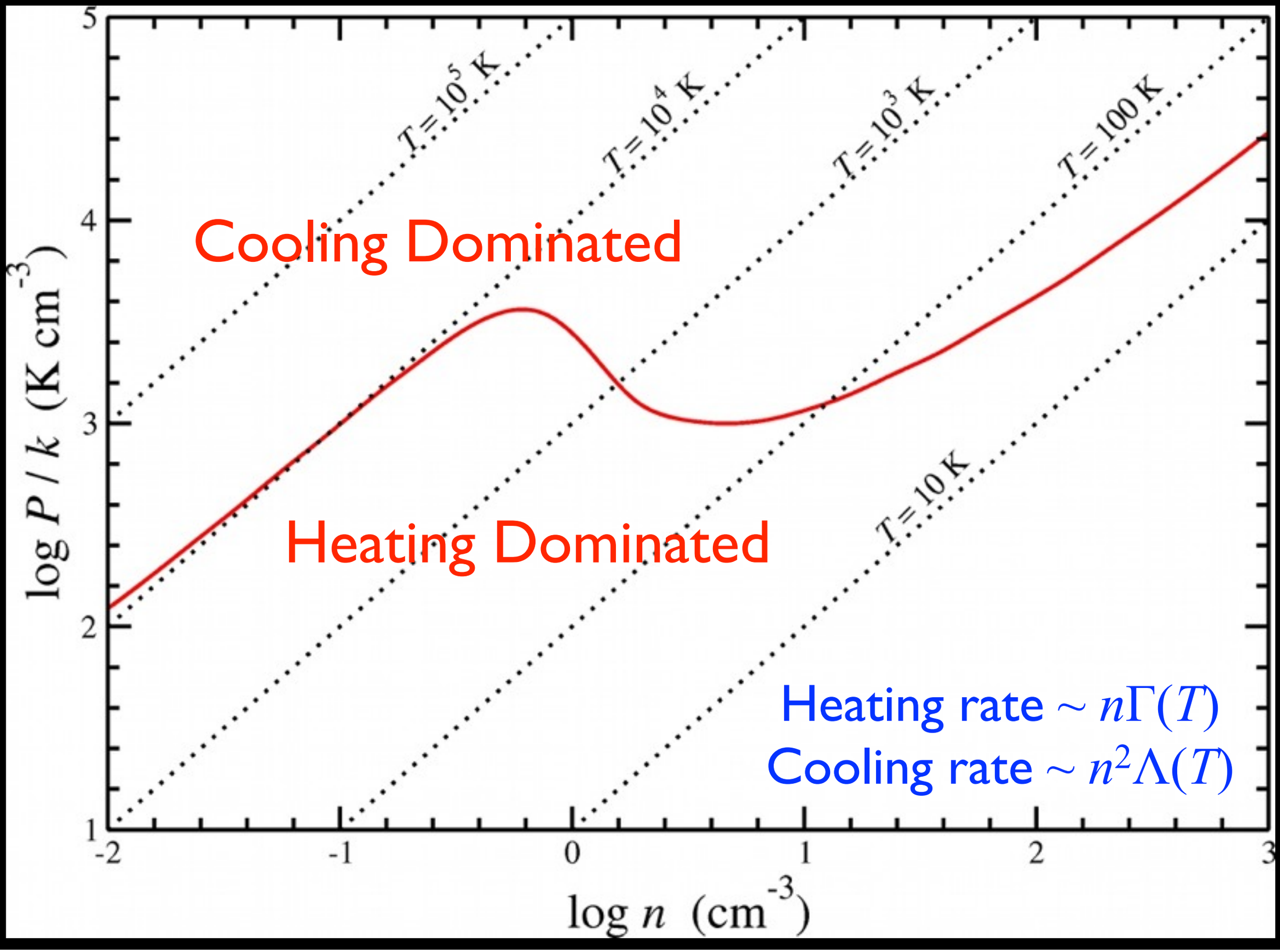
- Turbulent mixing (?)

Driving Turbulence in the Interstellar Medium

- Supernova explosions
  - Rayleigh-Taylor instability
- Gravitational instability
- Magneto-rotational instability
- *Thermal instability*



Two-phase Model for the ISM



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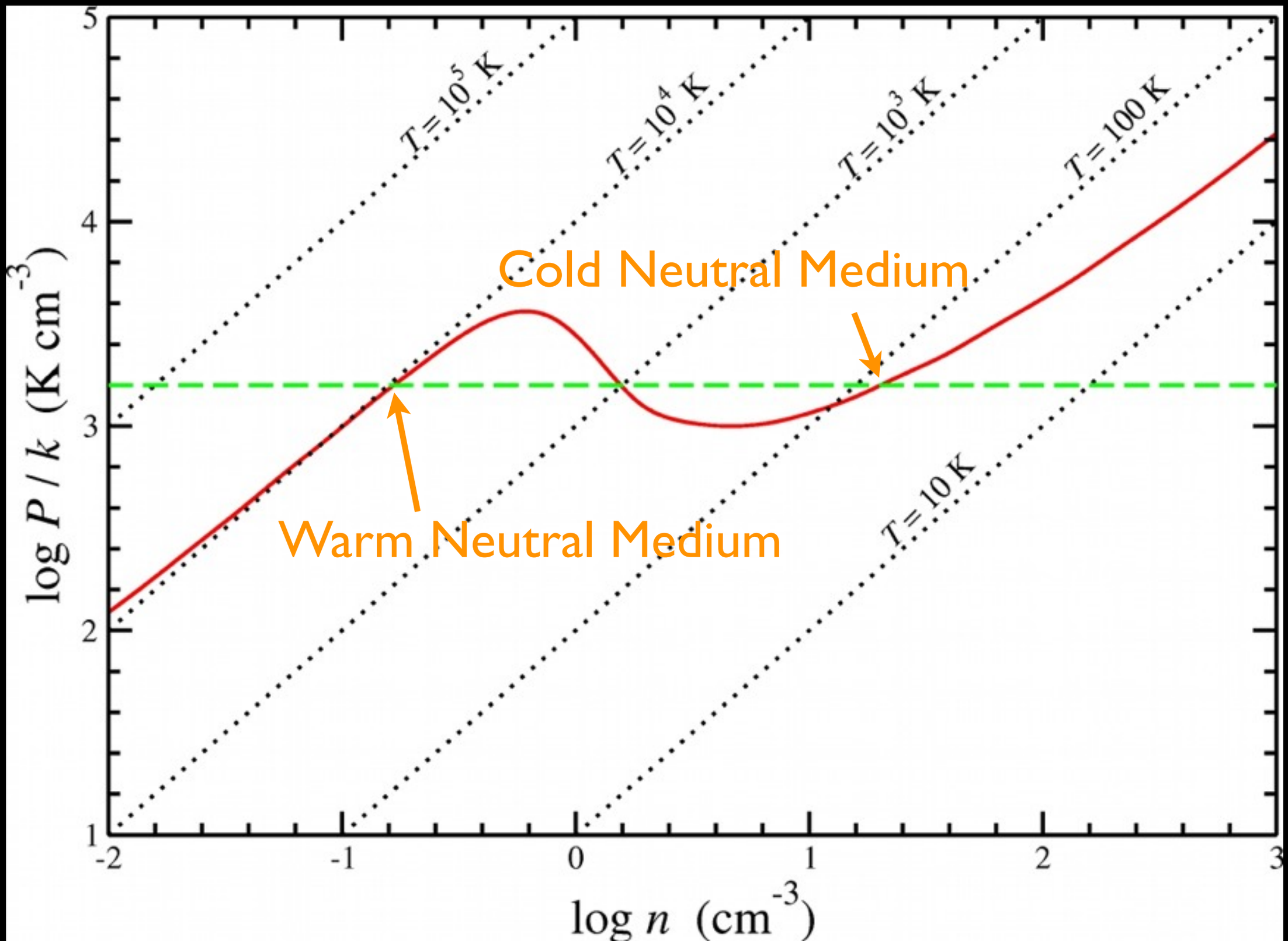

Setup

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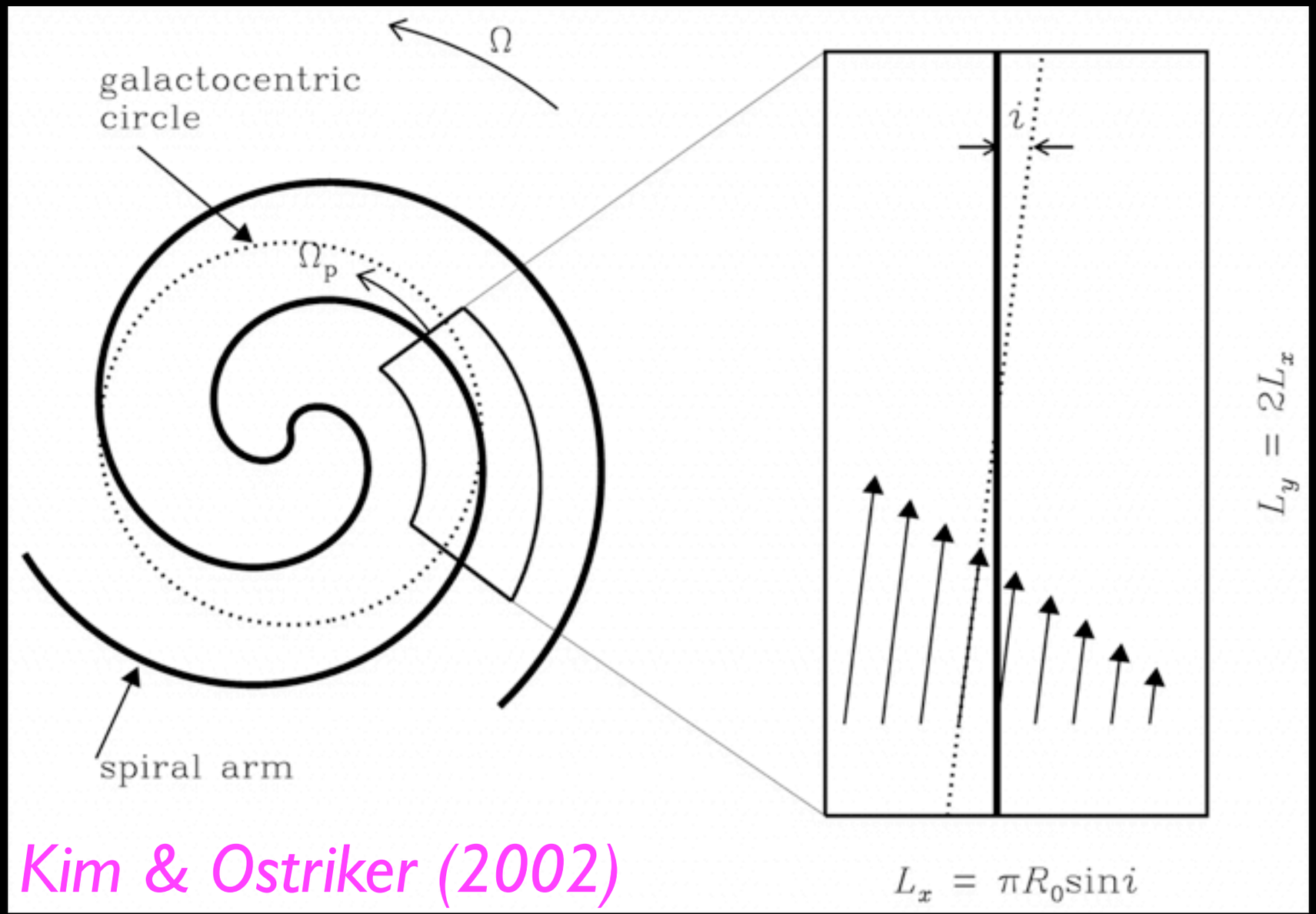

Kim & Ostriker (2002)

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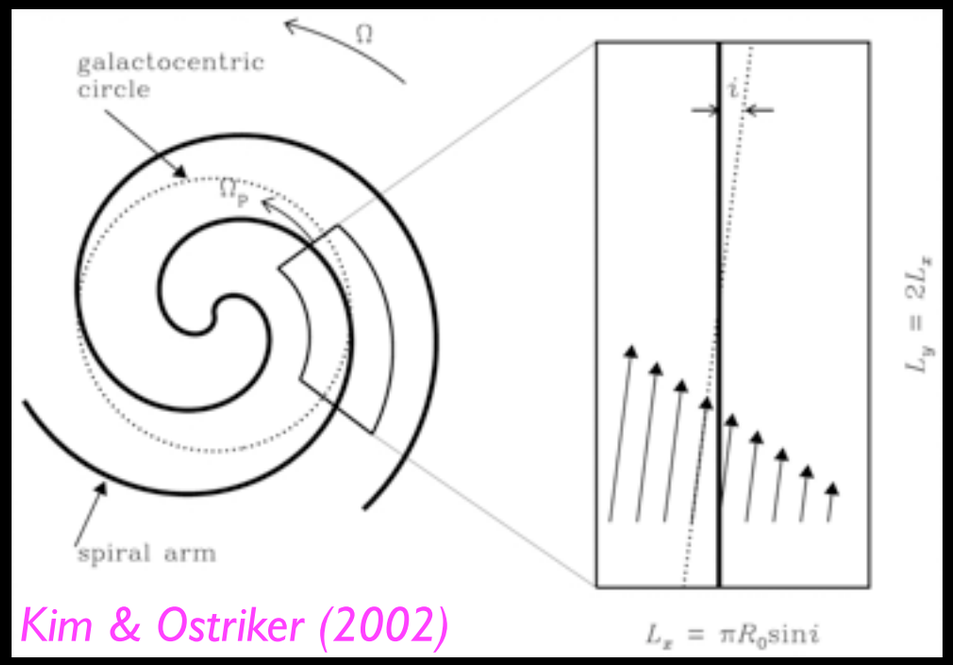

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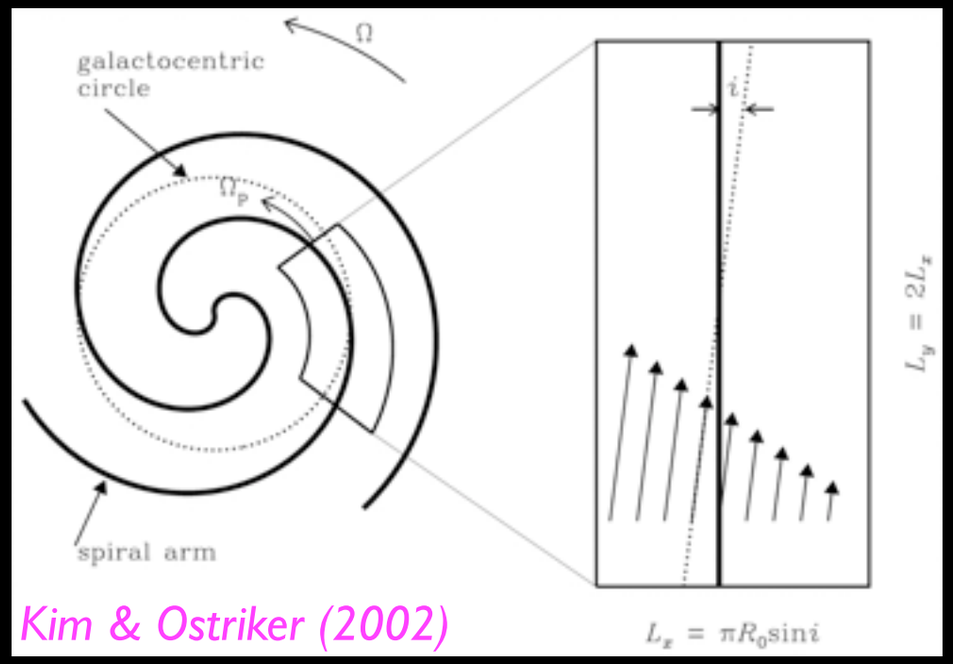

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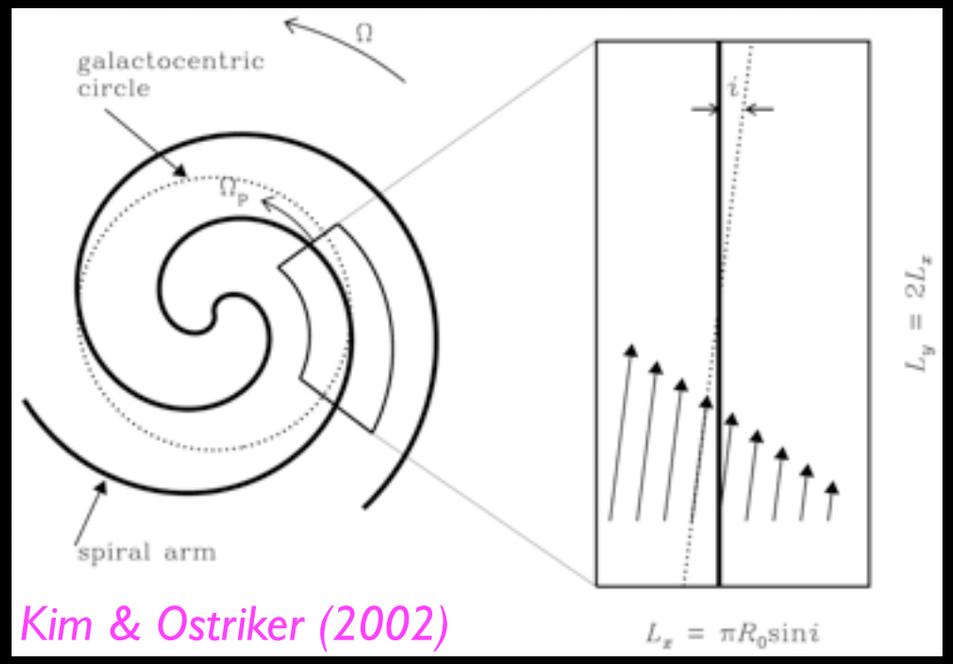

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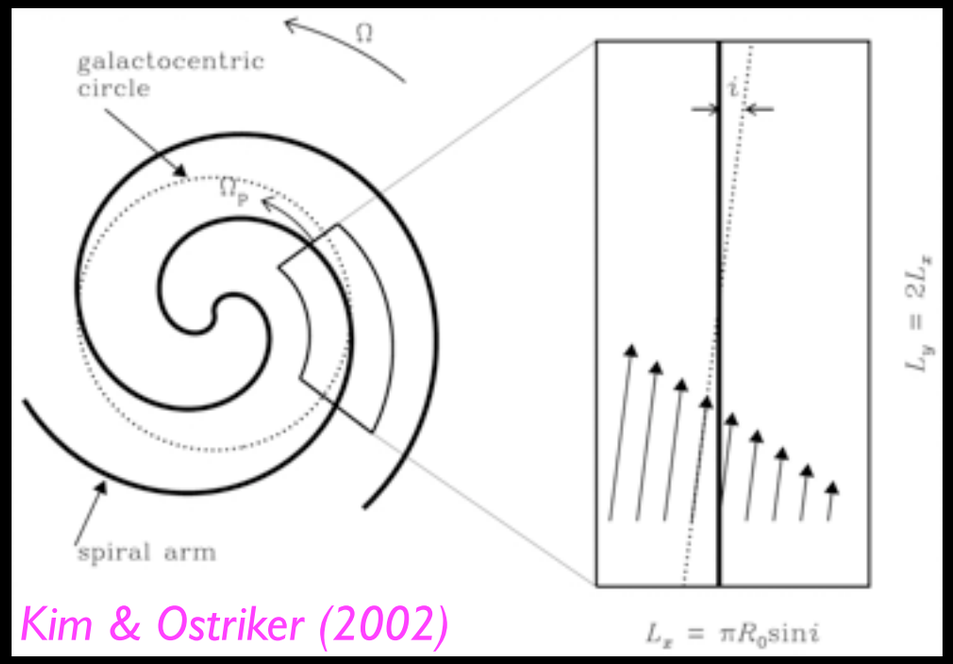

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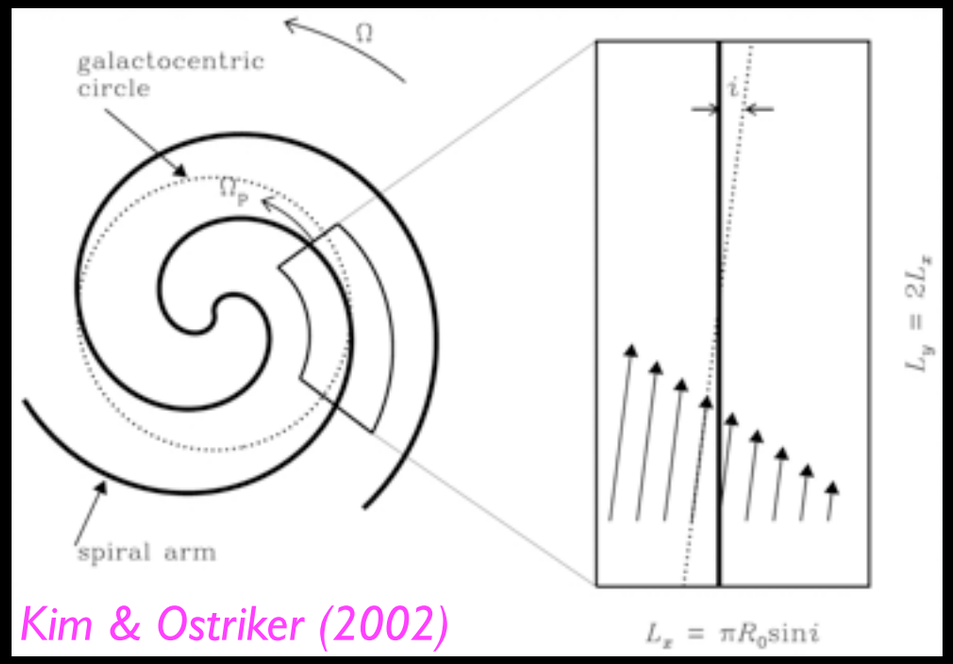

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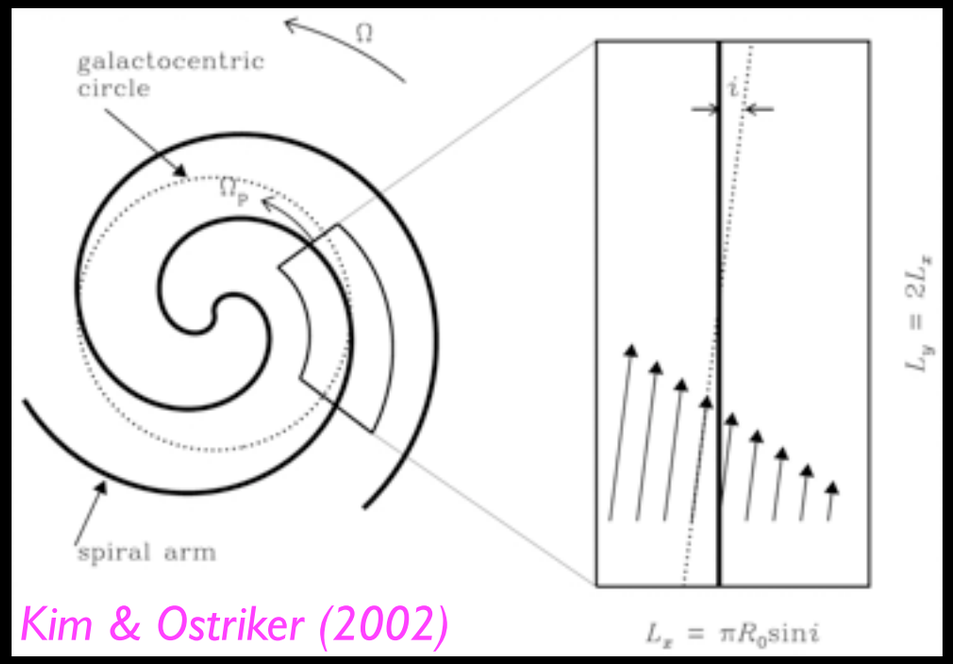

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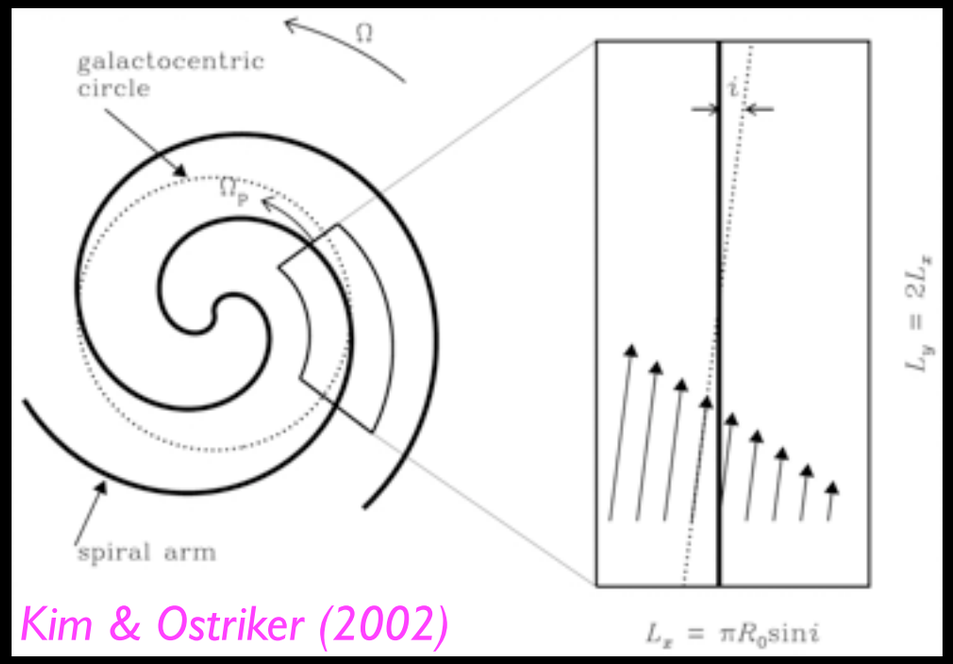

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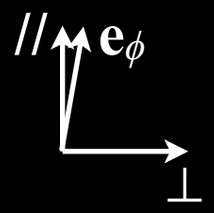
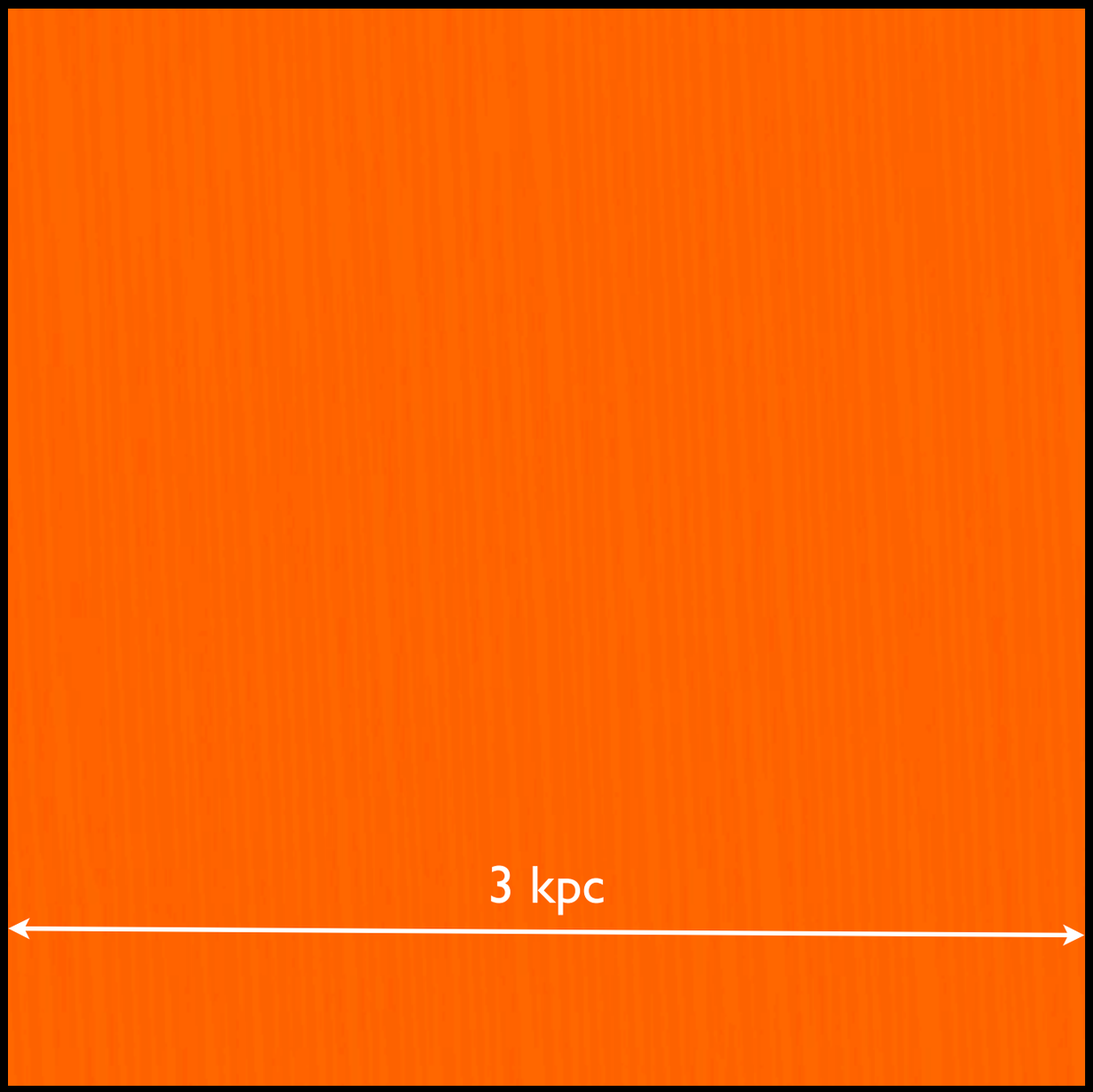
Turbulent Steady State

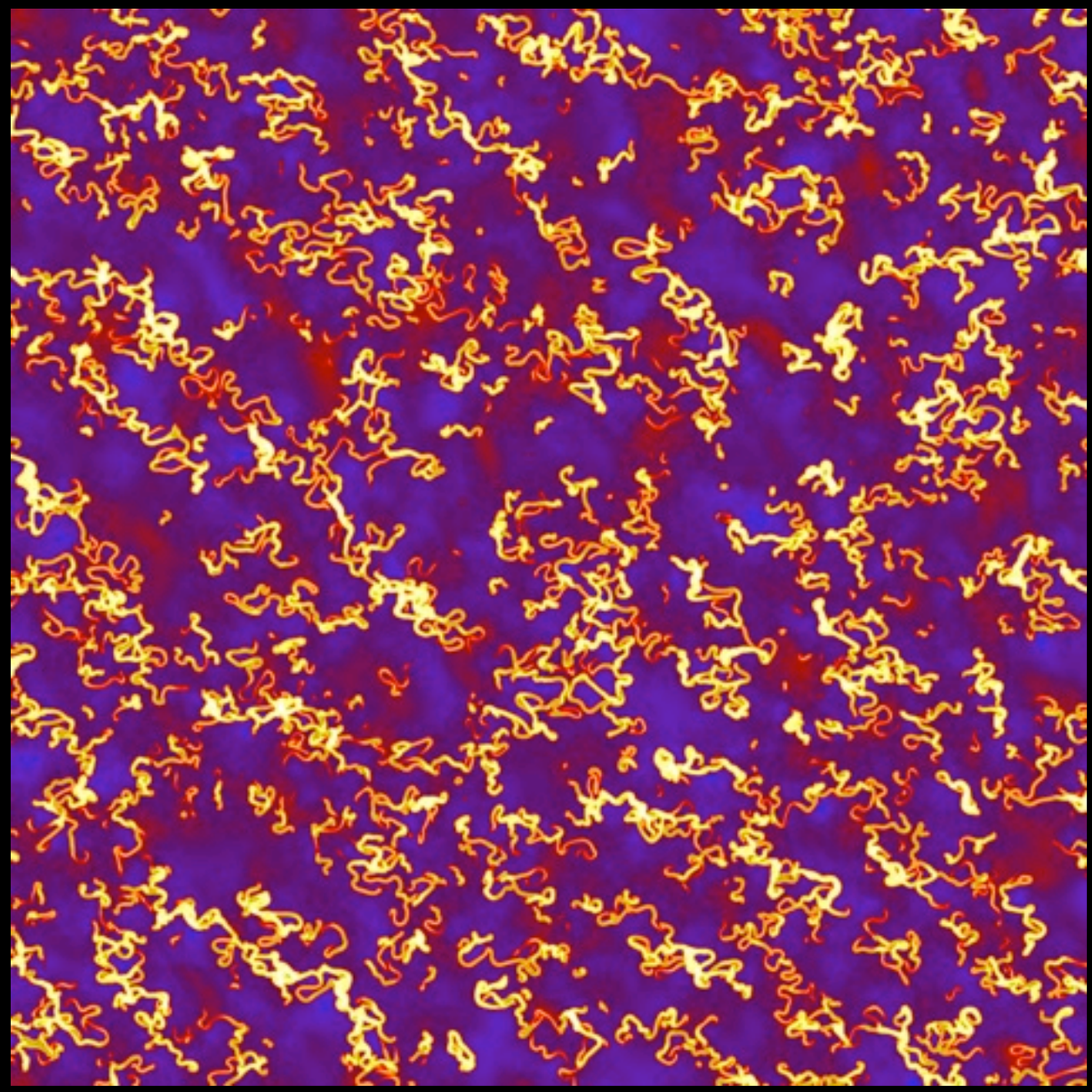
~~Spiral Forcing~~ ~~Magnetic Fields~~



Surface Density



Isothermal



Thermally Unstable

Turbulent Steady State

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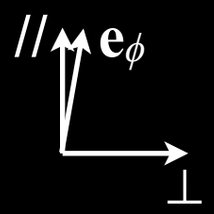
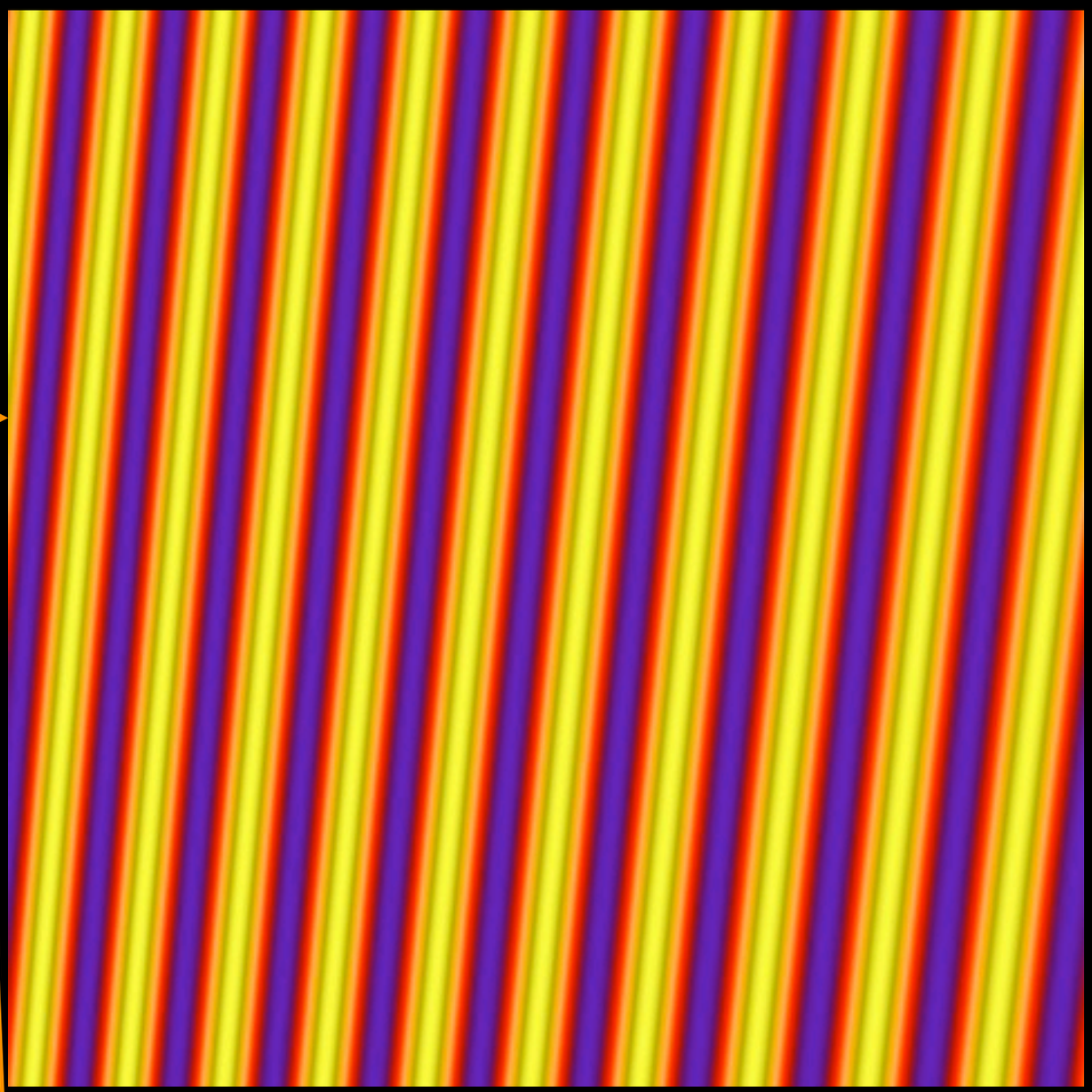


Metal Tracer Field



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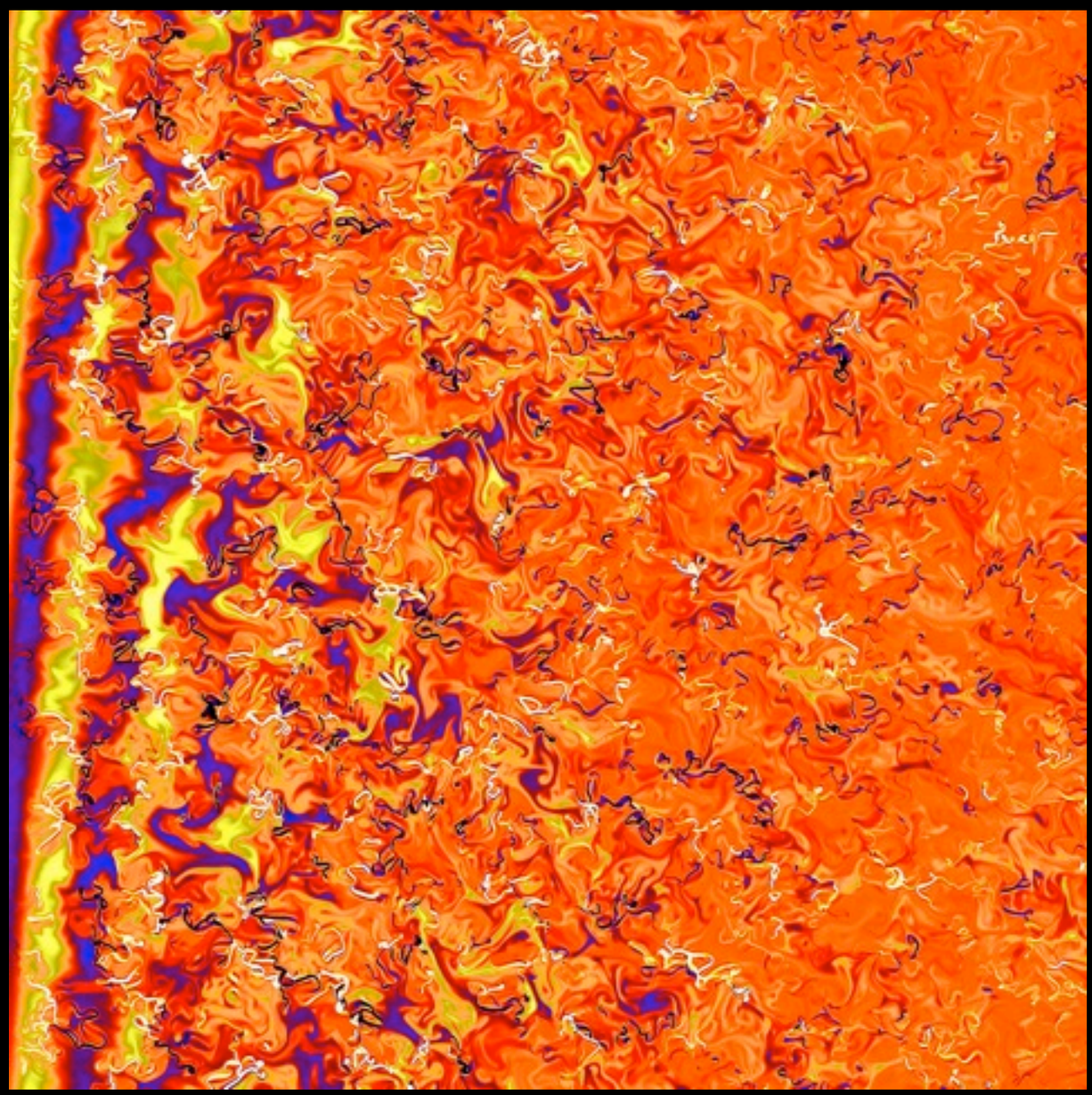


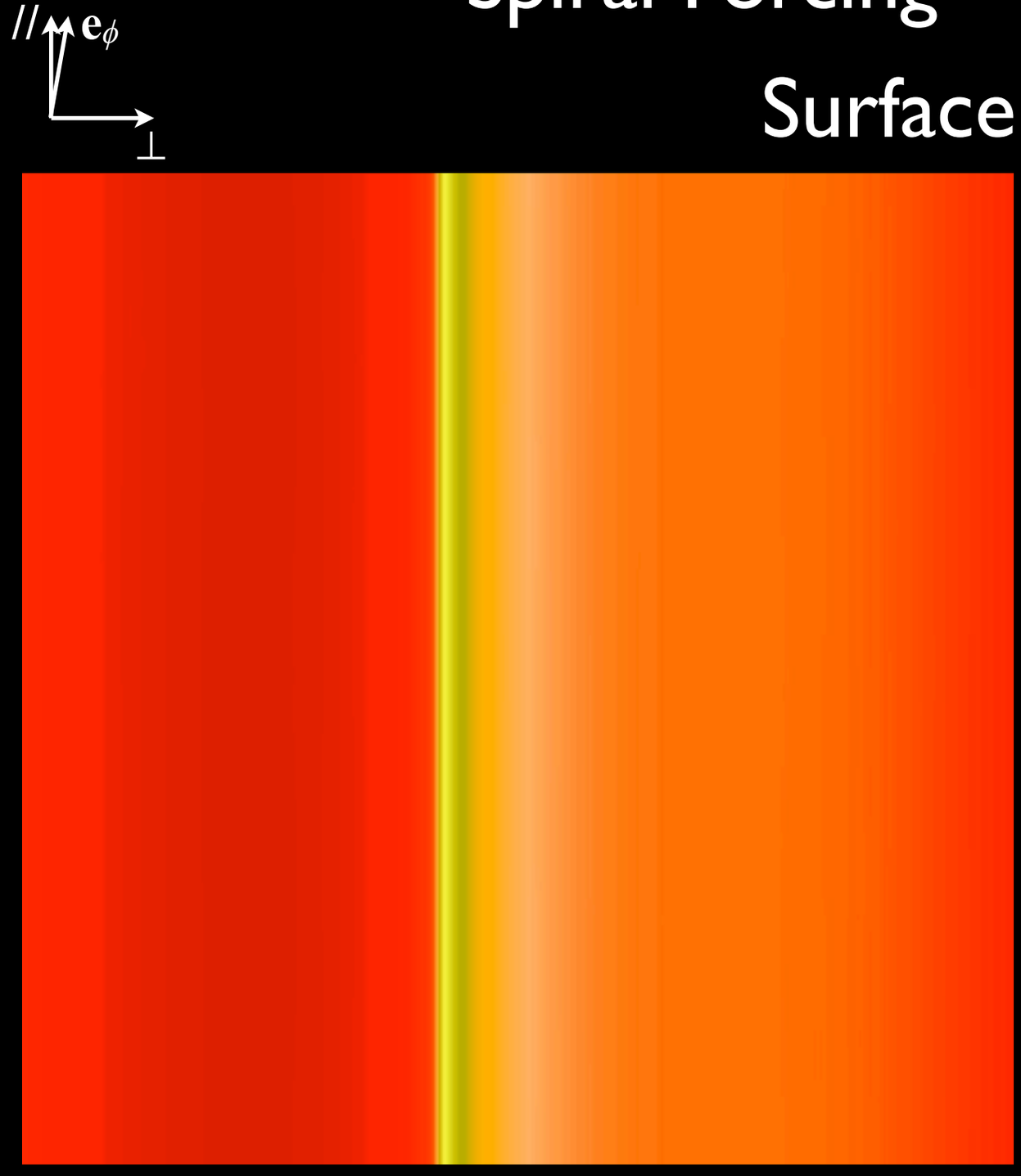
Thermally Unstable

Metal Injection Layer

Turbulent Steady State

Spiral Forcing ~~Magnetic Fields~~

Surface Density



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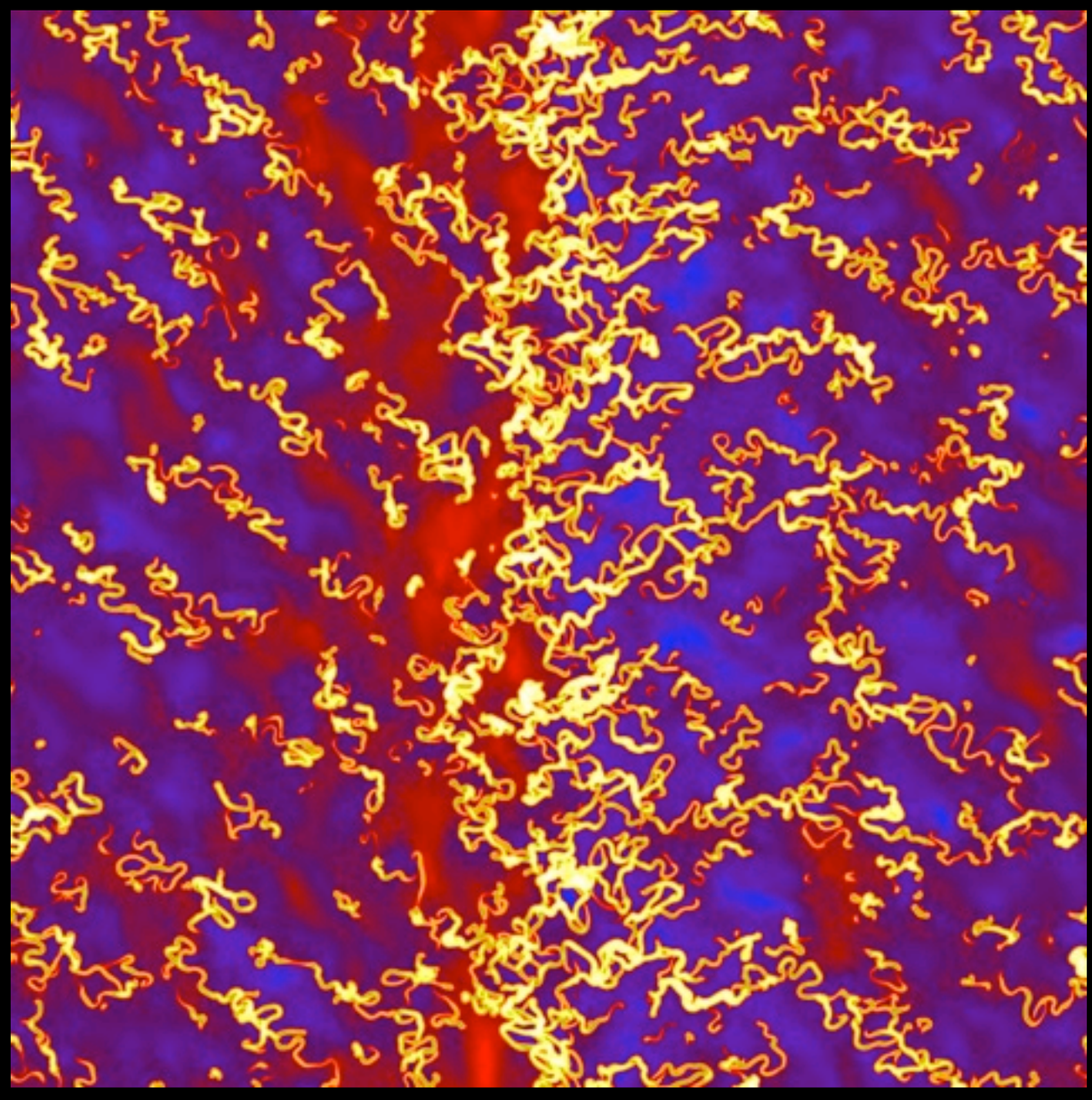

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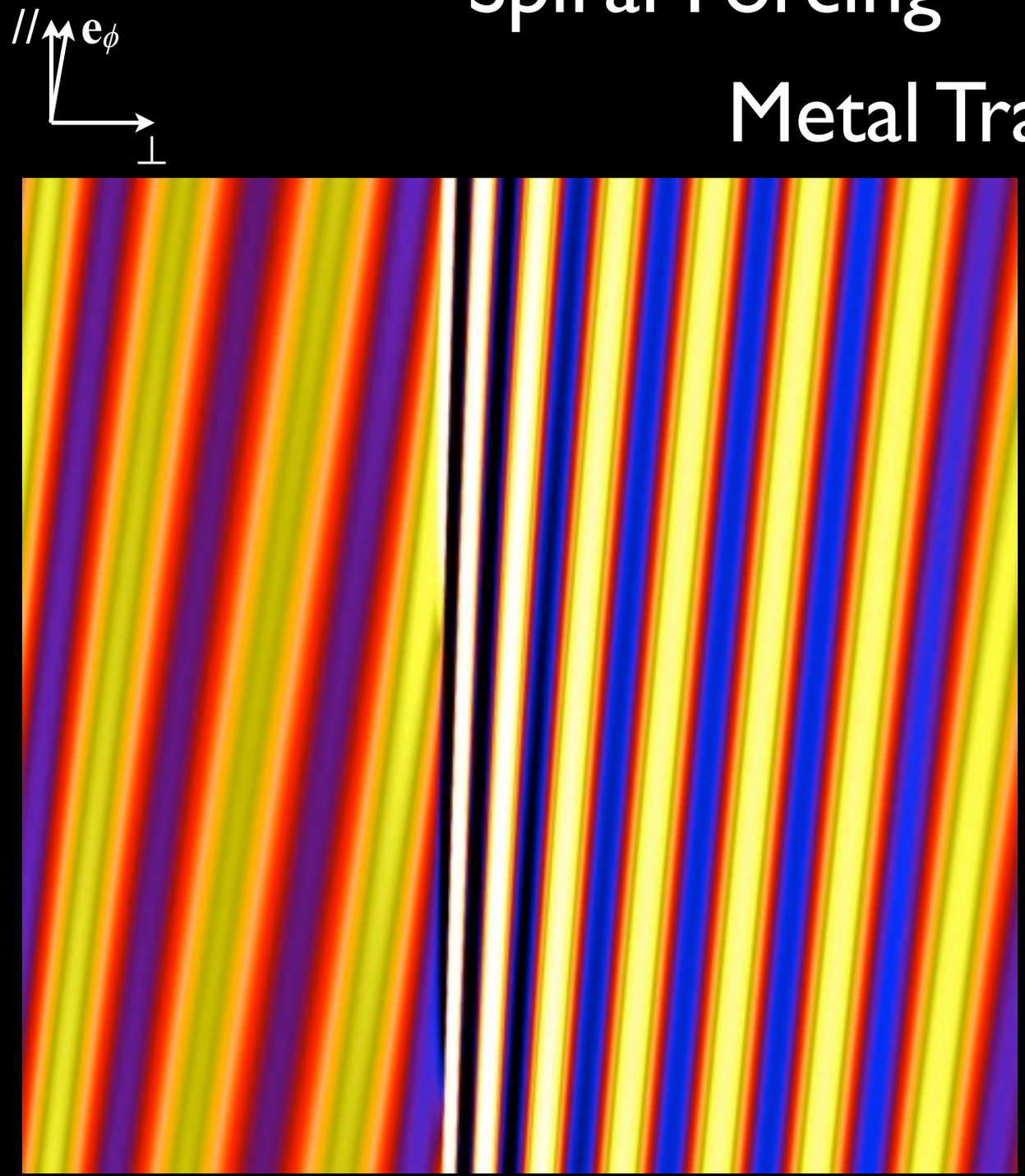

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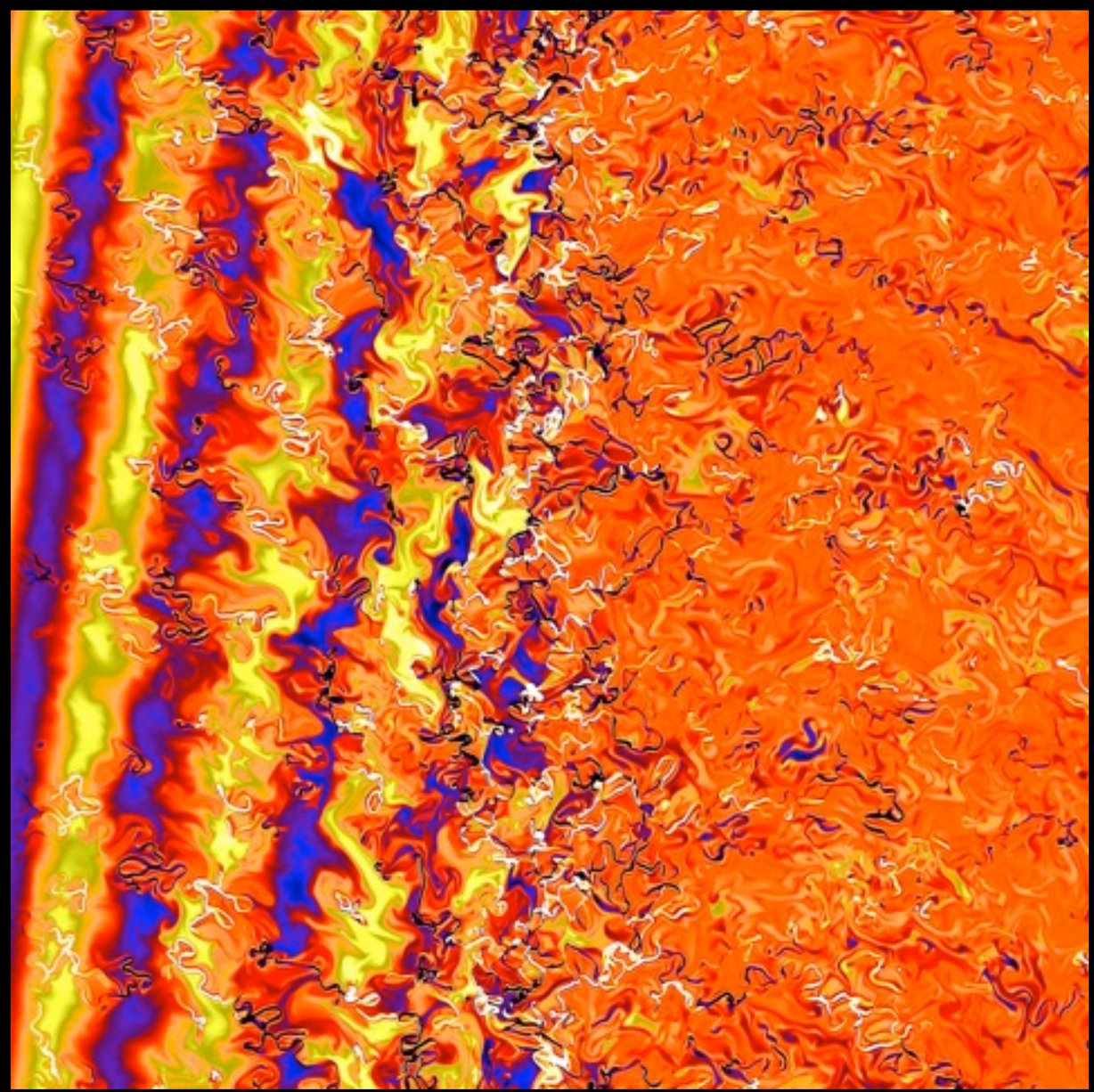

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Spiral Forcing Magnetic Fields

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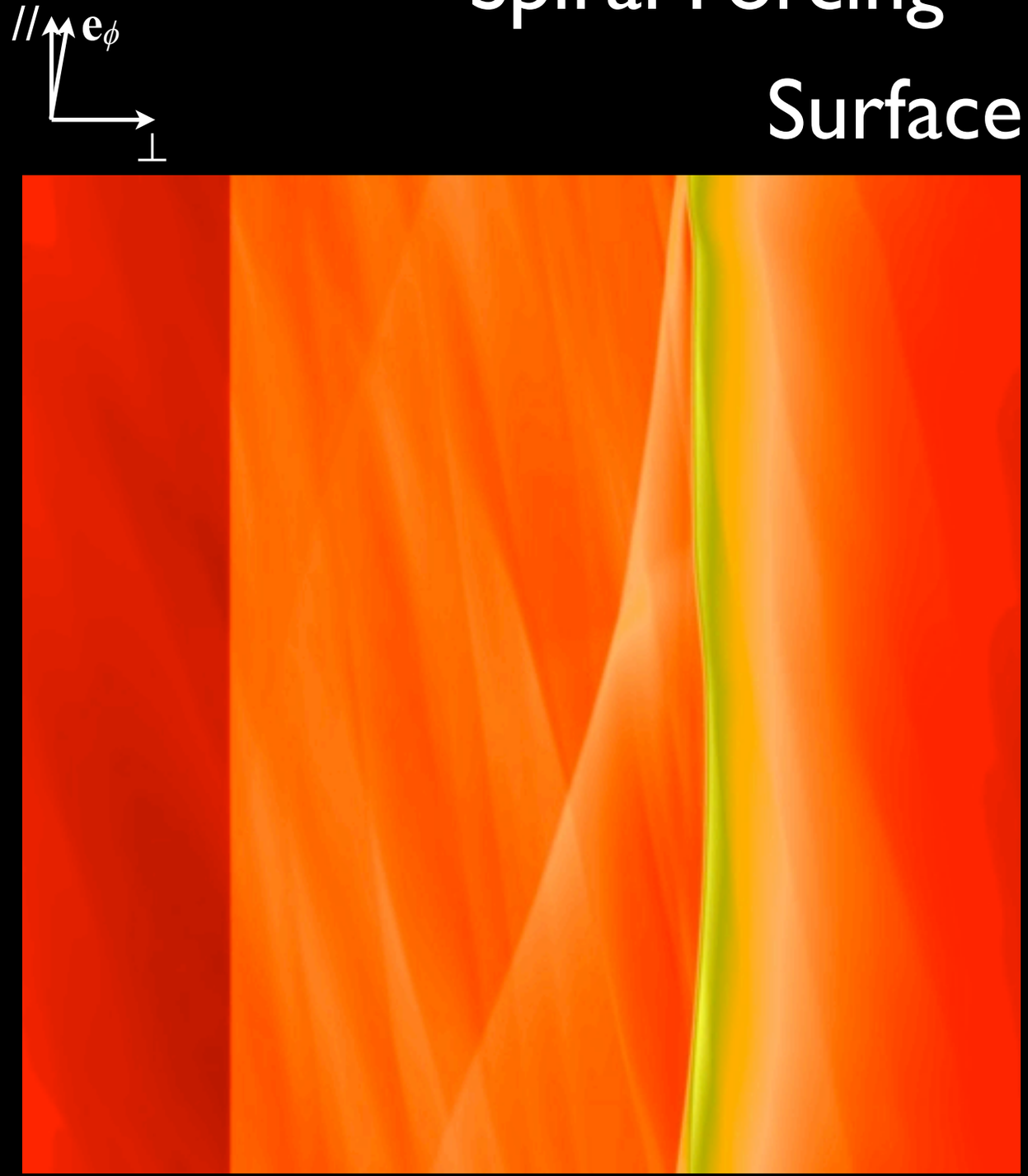

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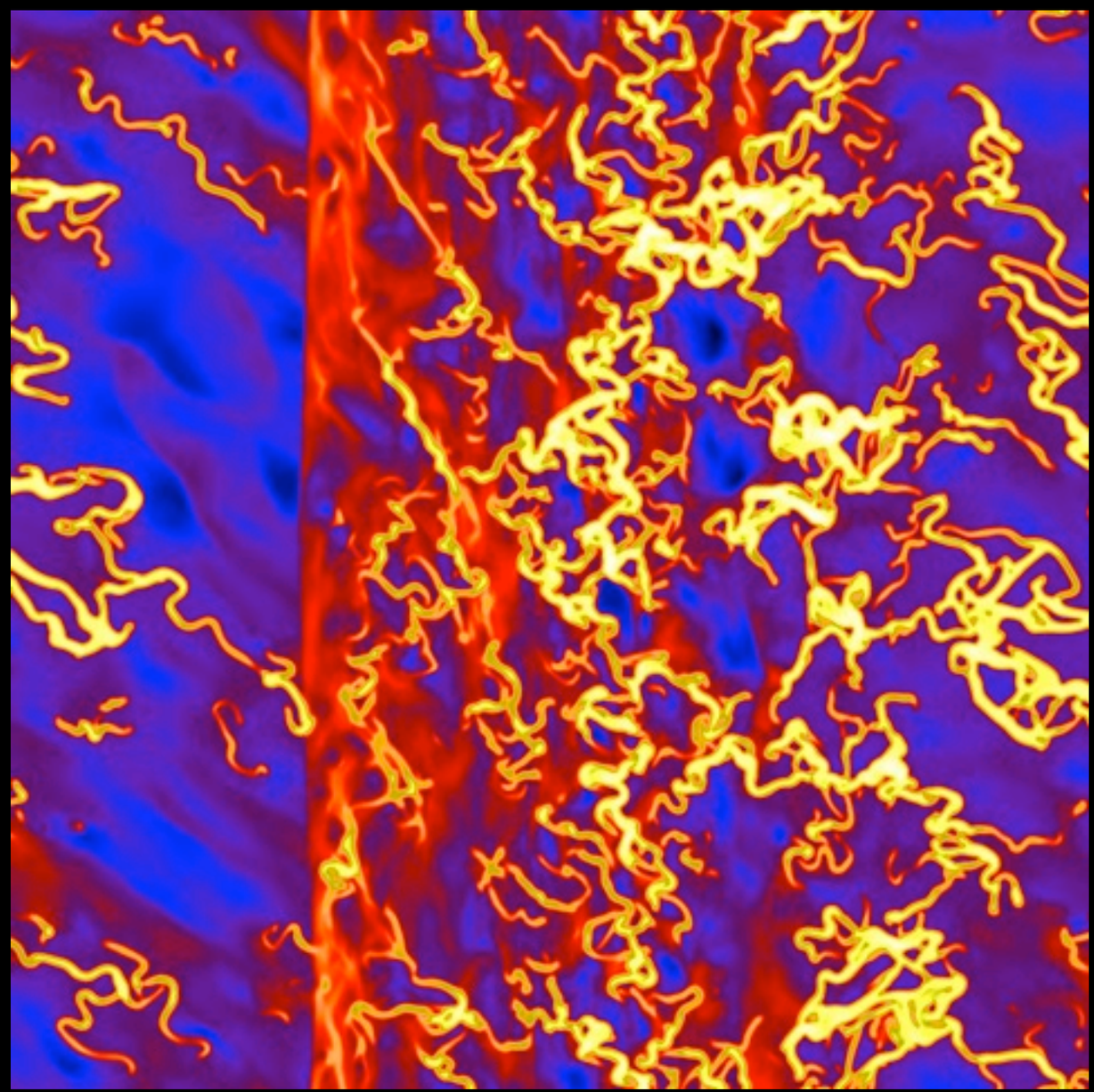

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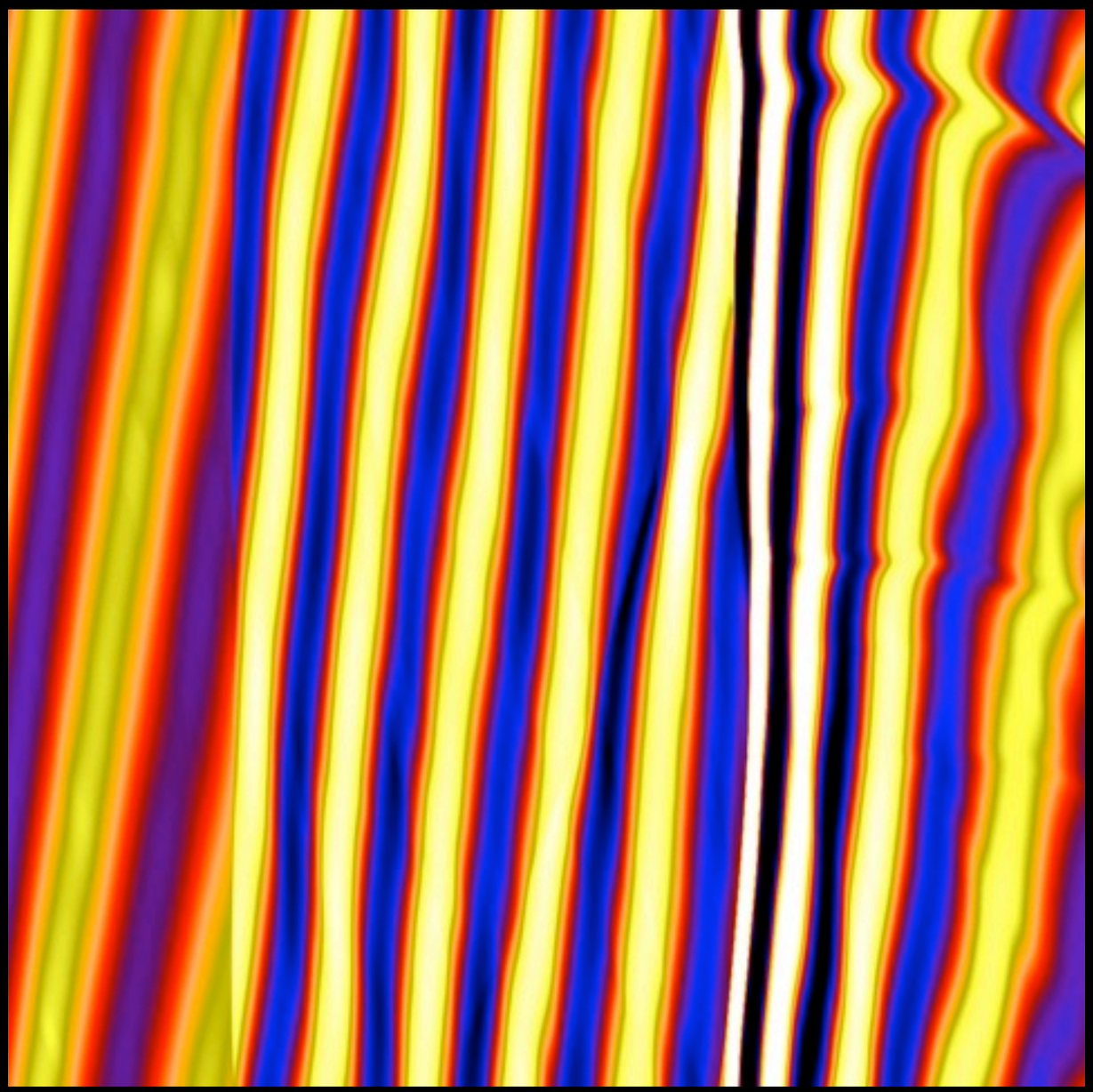

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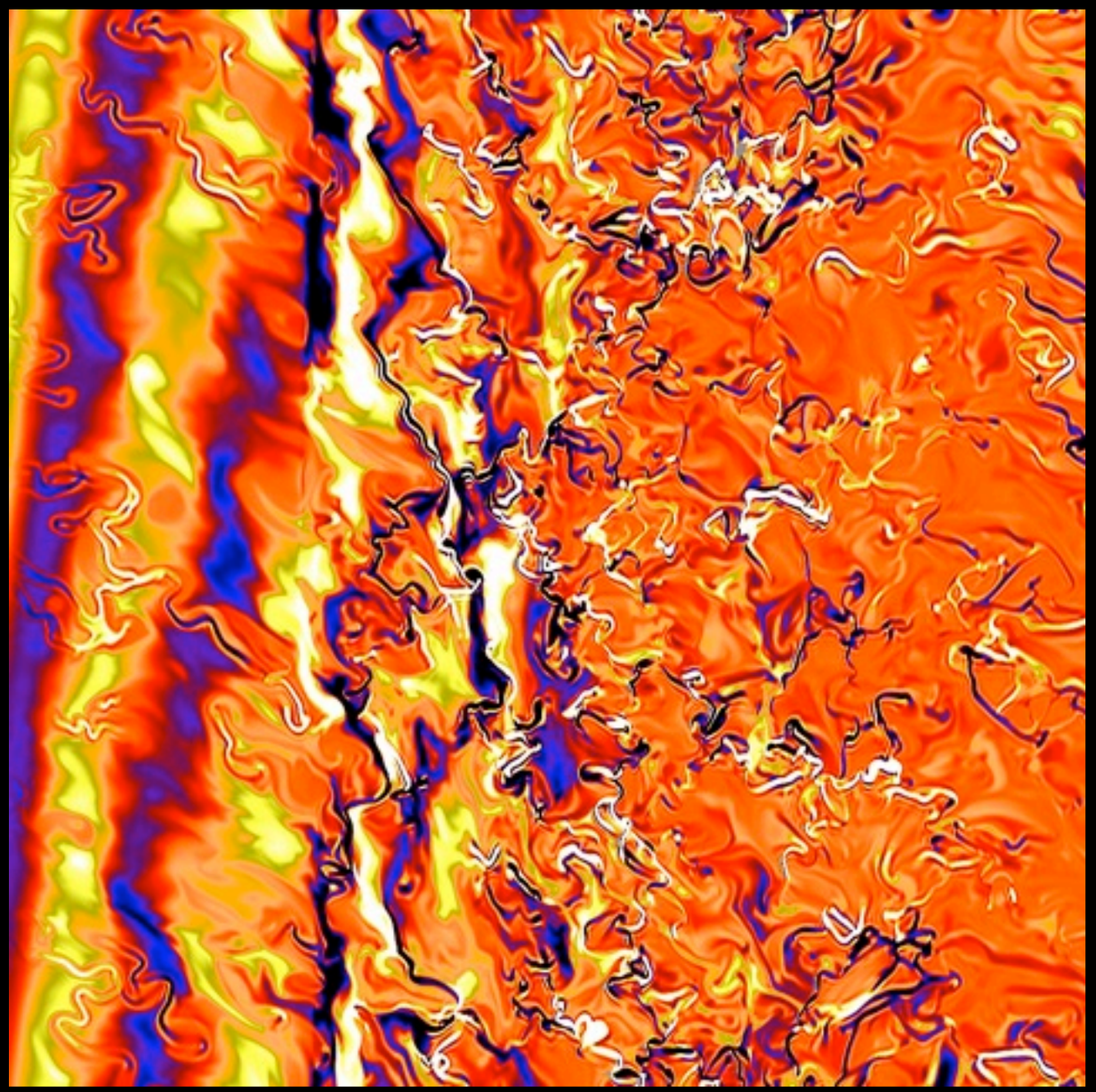
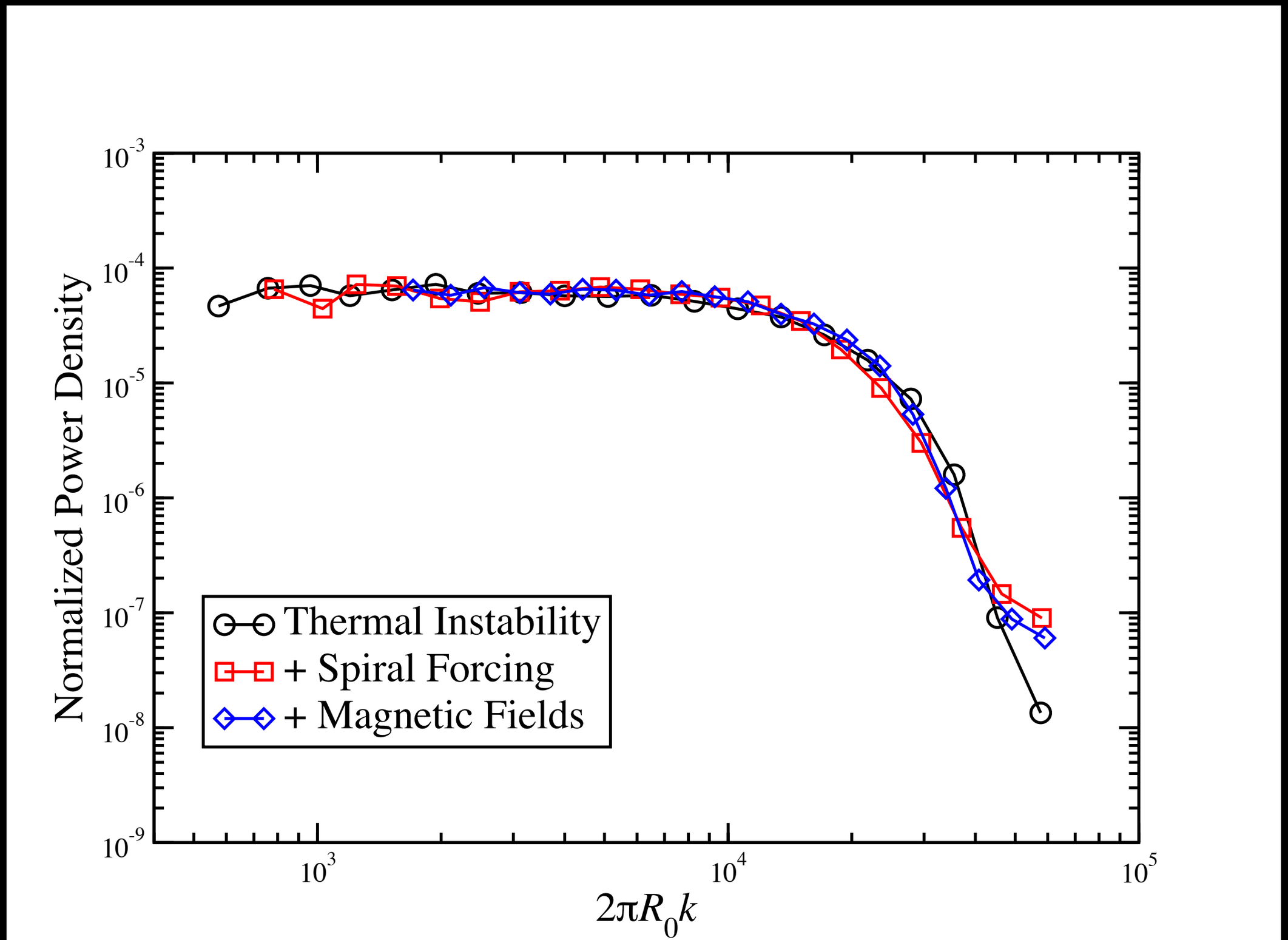


Thermally Unstable

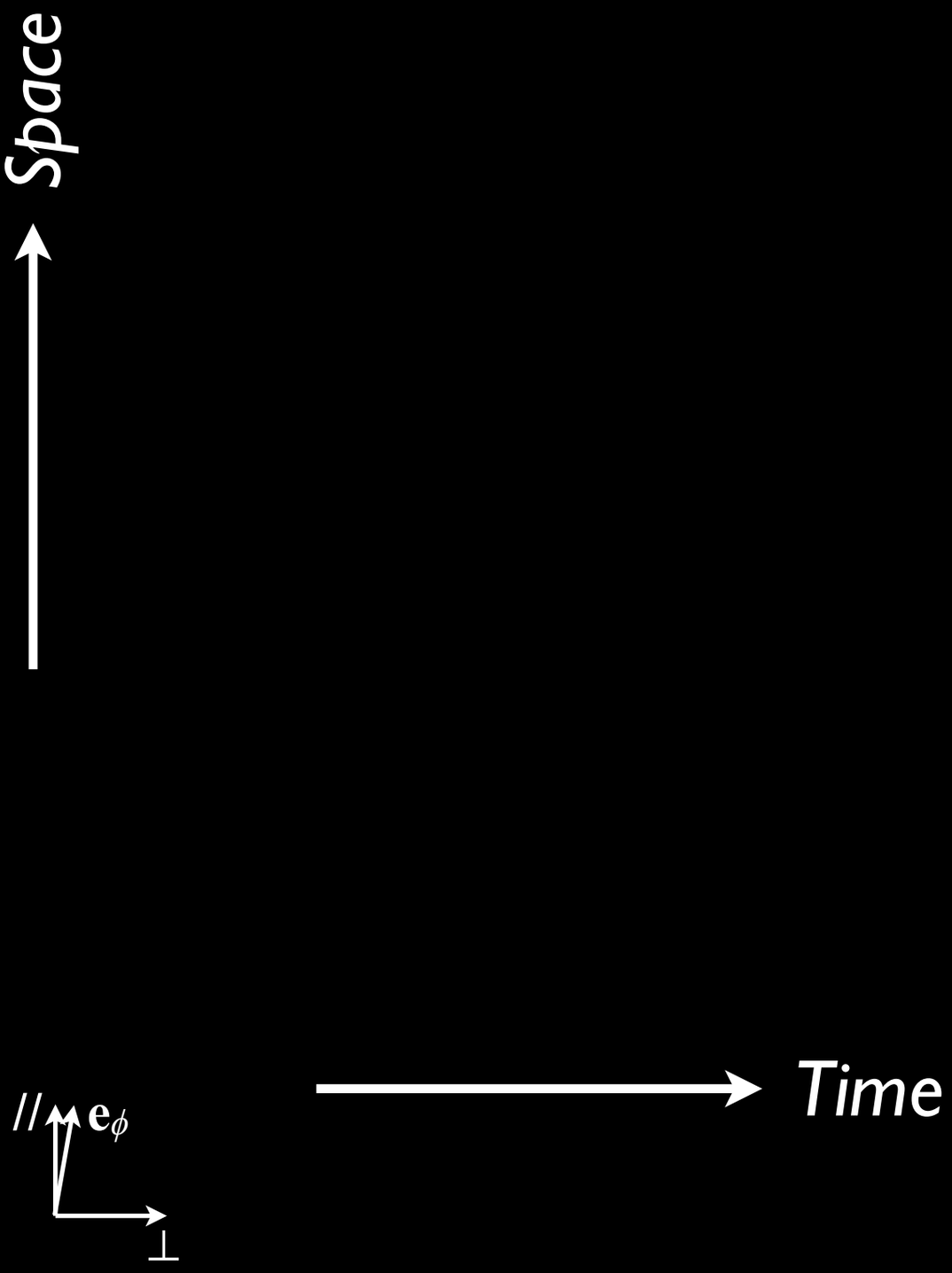
Power Spectrum of Mixed Metals



Following the Flow

Metal Tracer Field

Power in k_y



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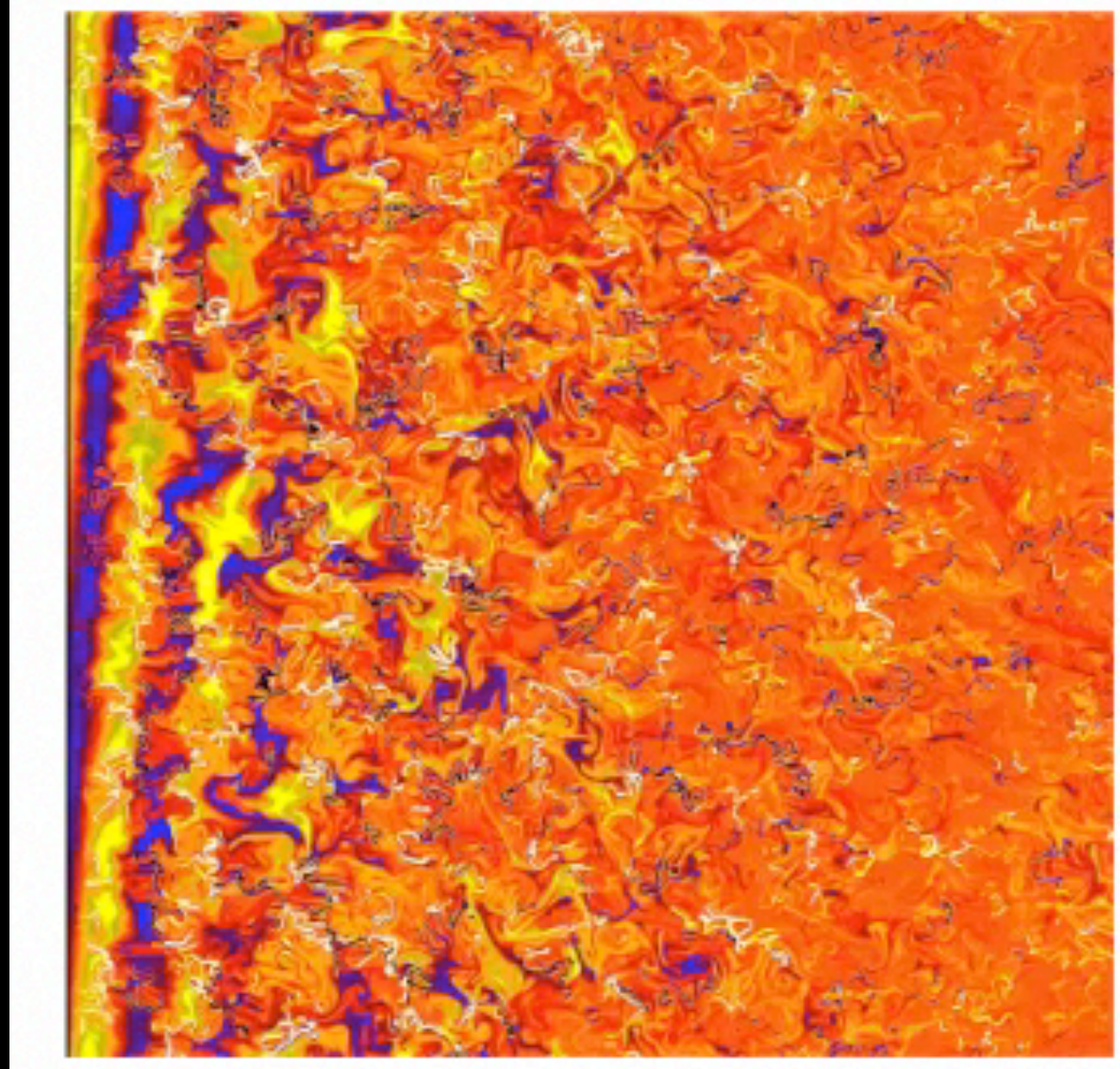
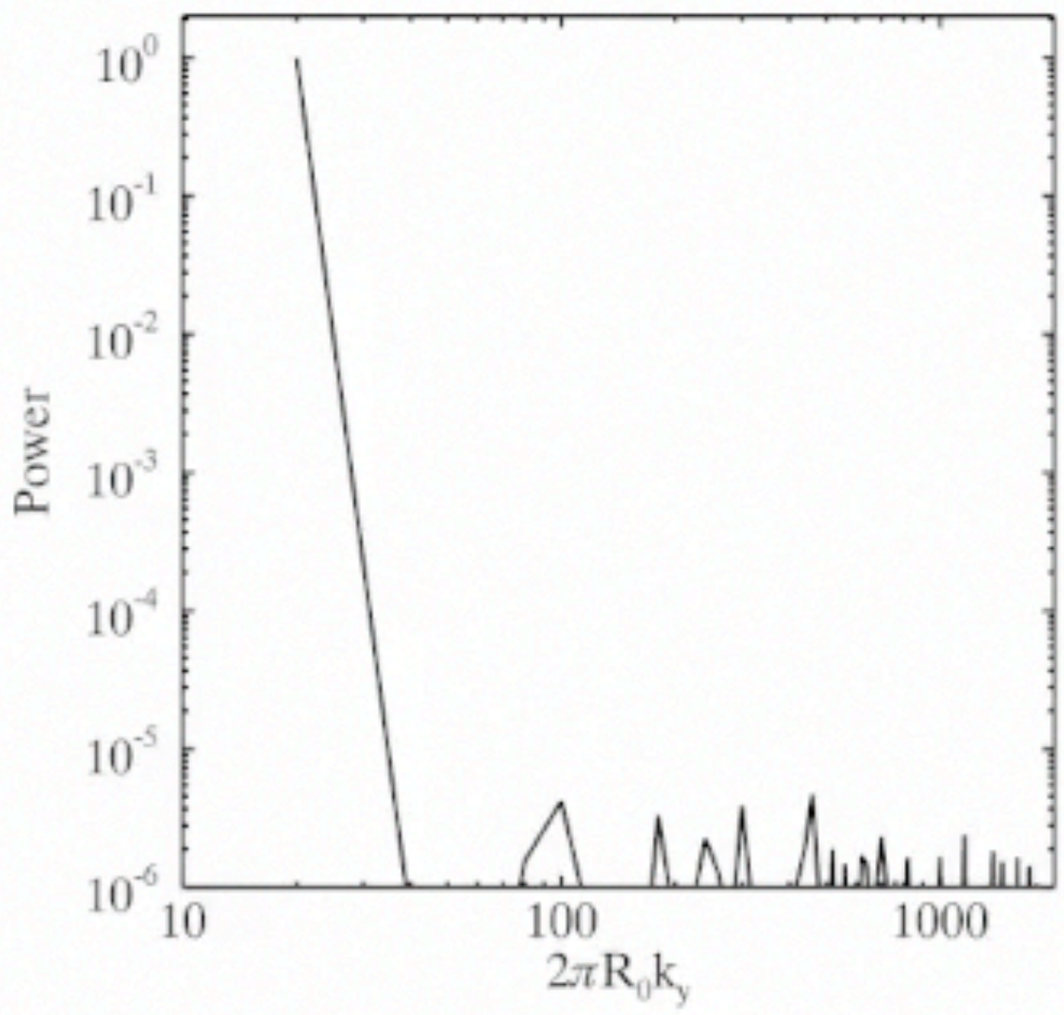




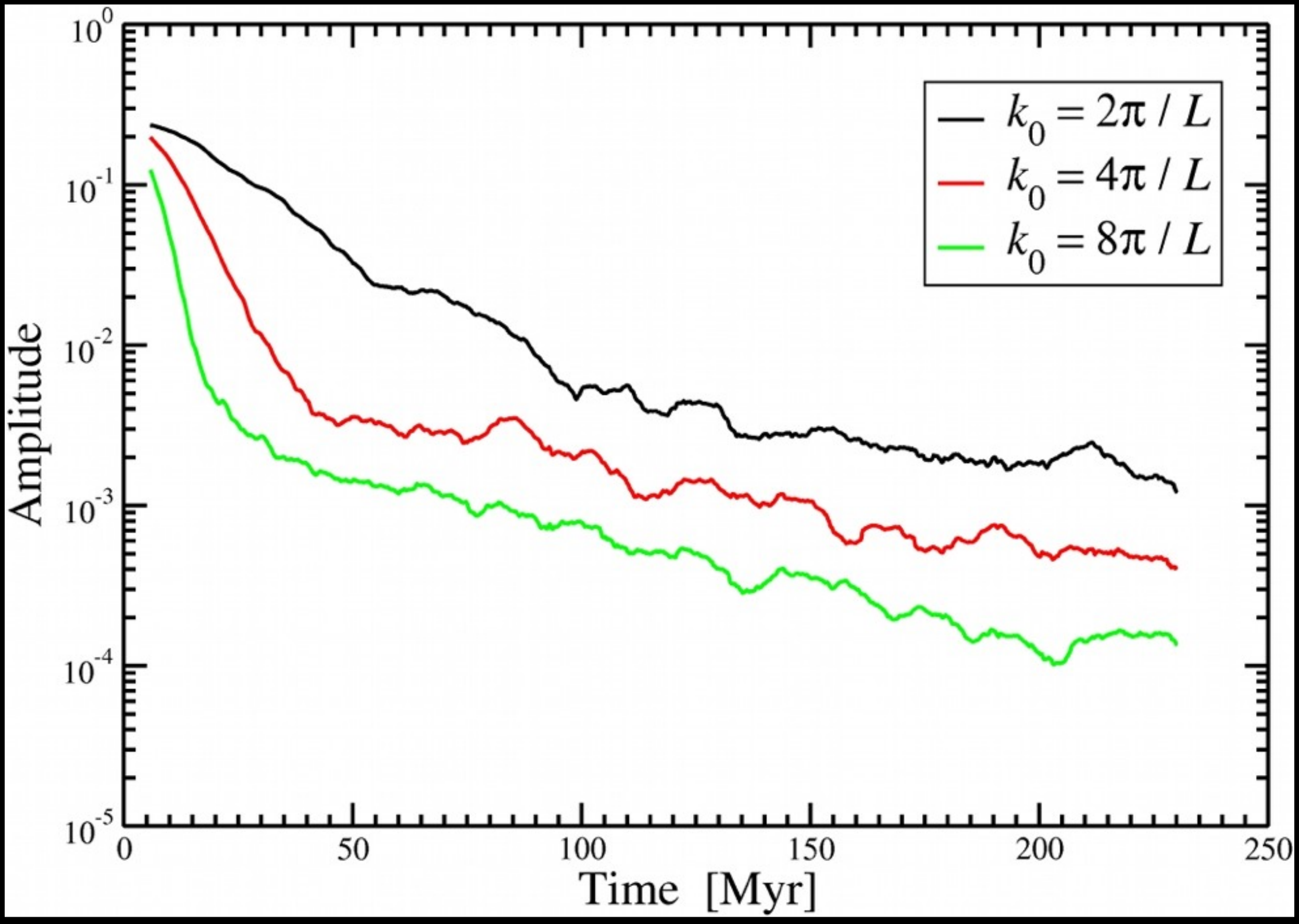
Space

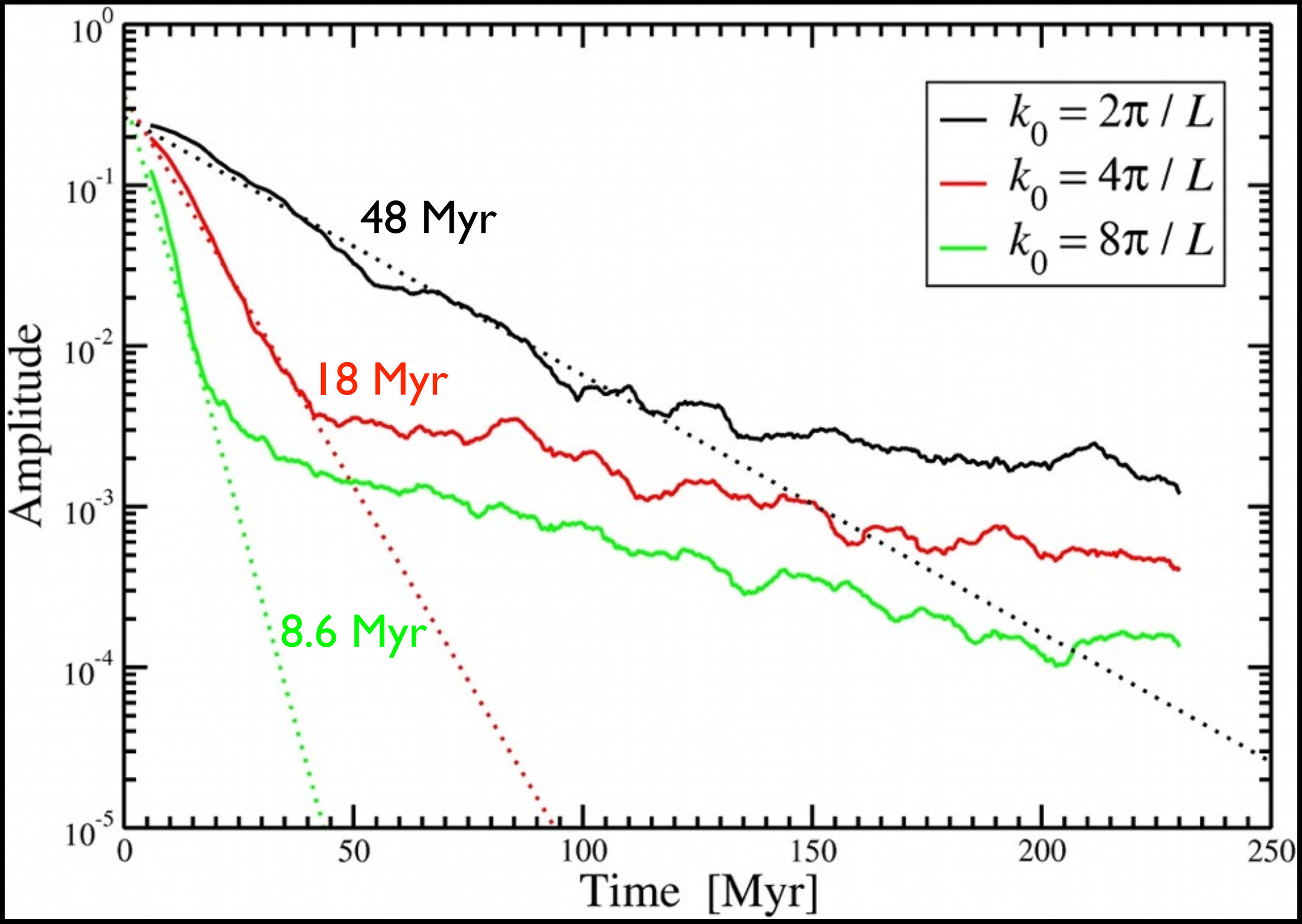
Time

$\mathbf{e}_\phi$

$//$

$\perp$


$k_0 = 2\pi / L$
$k_0 = 4\pi / L$
$k_0 = 8\pi / L$
Amplitude
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
50
100
150
200
250
Time [Myr]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48 Myr
18 Myr
8.6 Myr
Amplitude
Time [Myr]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
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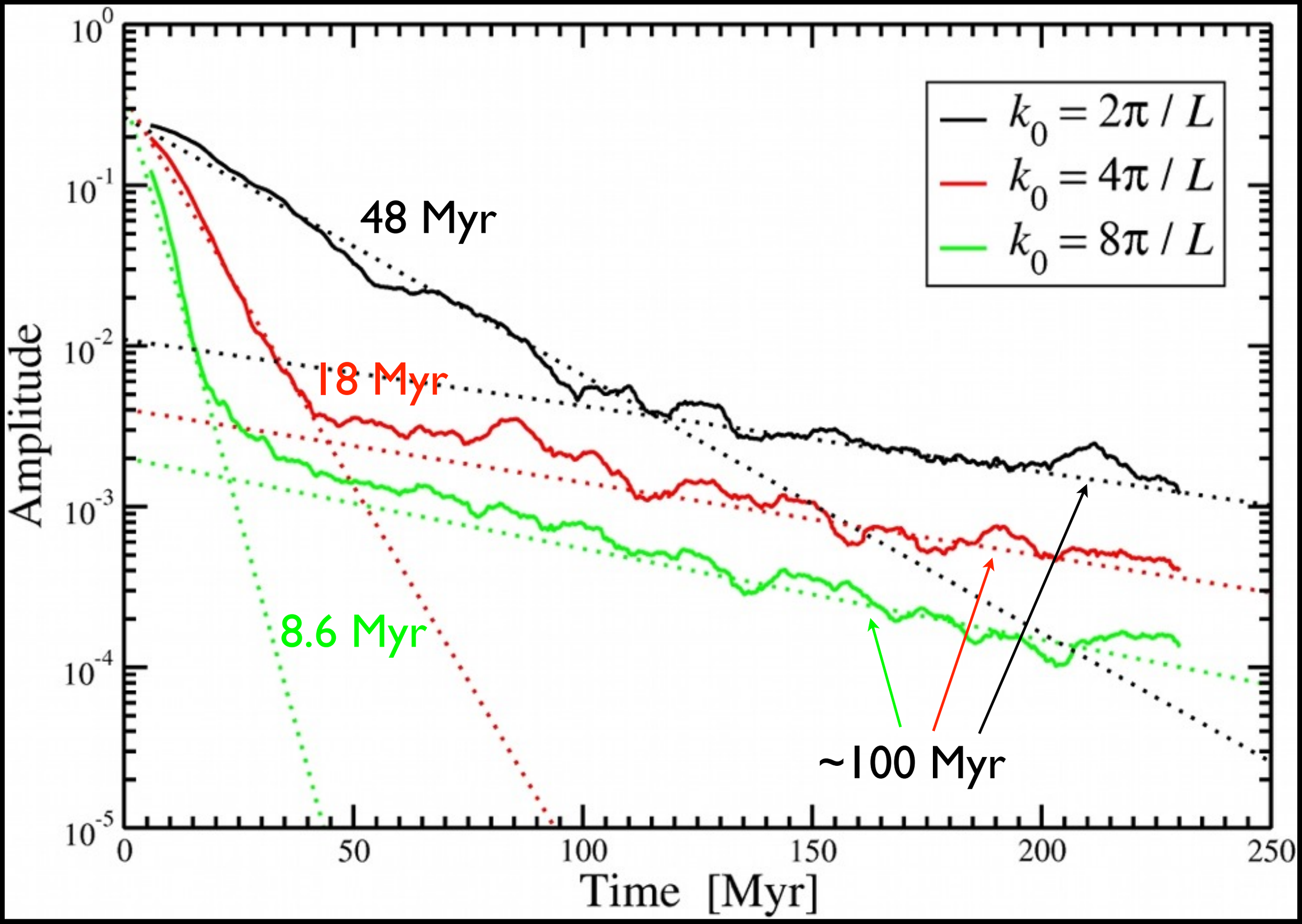
100
150
200
250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10^{-5}
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Conclusions

Turbulent mixing of metals is...

- efficient (timescale < orbital time).
- not the same as the viscous stress of the gas.
- important in setting metallicity gradients.