

Metal Mixing near Spiral Arms

Chao-Chin Yang

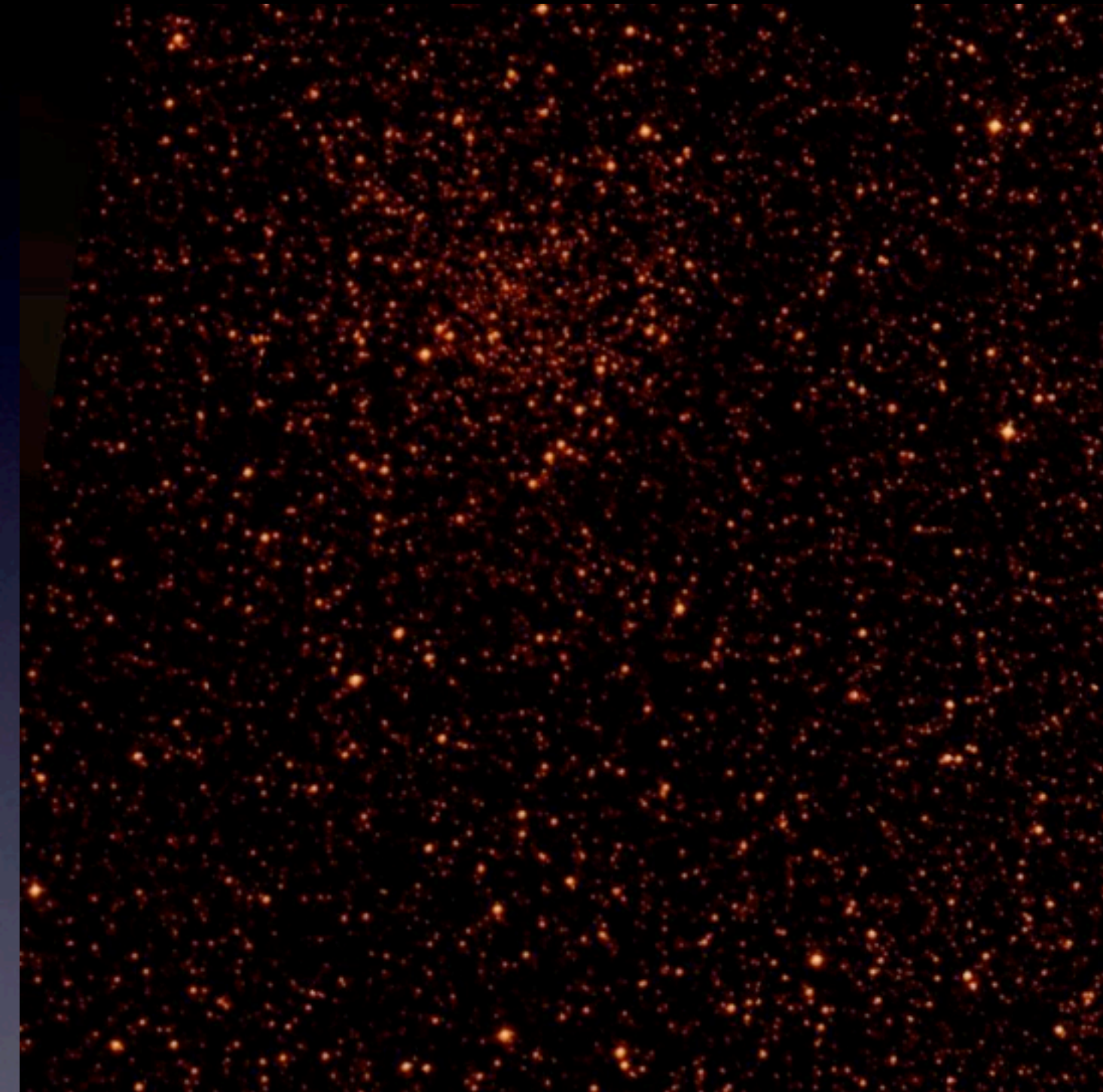
Mark Krumholz

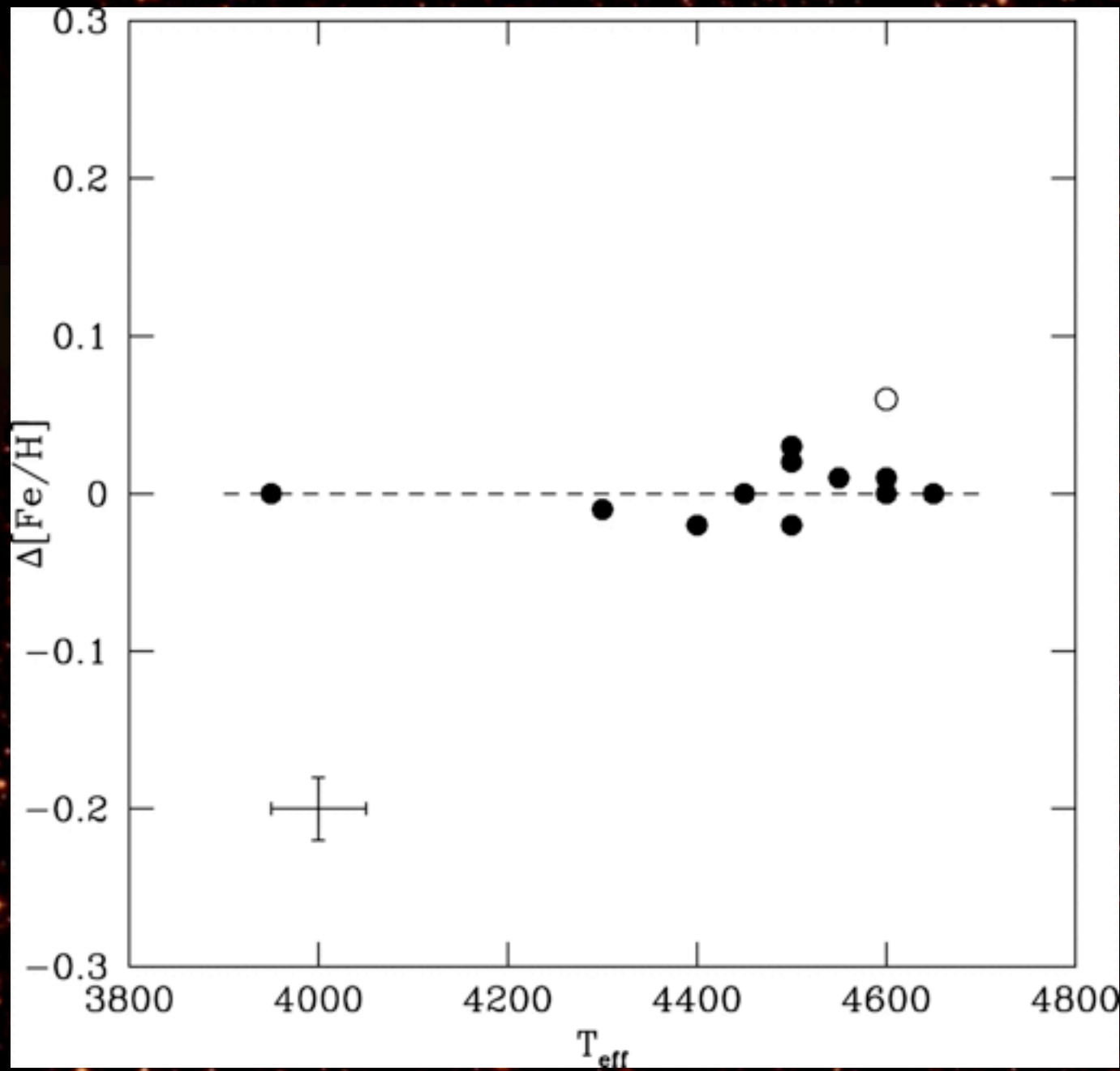
University of California, Santa Cruz

Collinder 261

- old open star cluster
- distance ~ 2.4 kpc
- age $\sim 5\text{--}11$ Gyr
- **chemically homogeneous**

(Carretta et al. 2005; De Silva et al. 2007b)





Collinder 261

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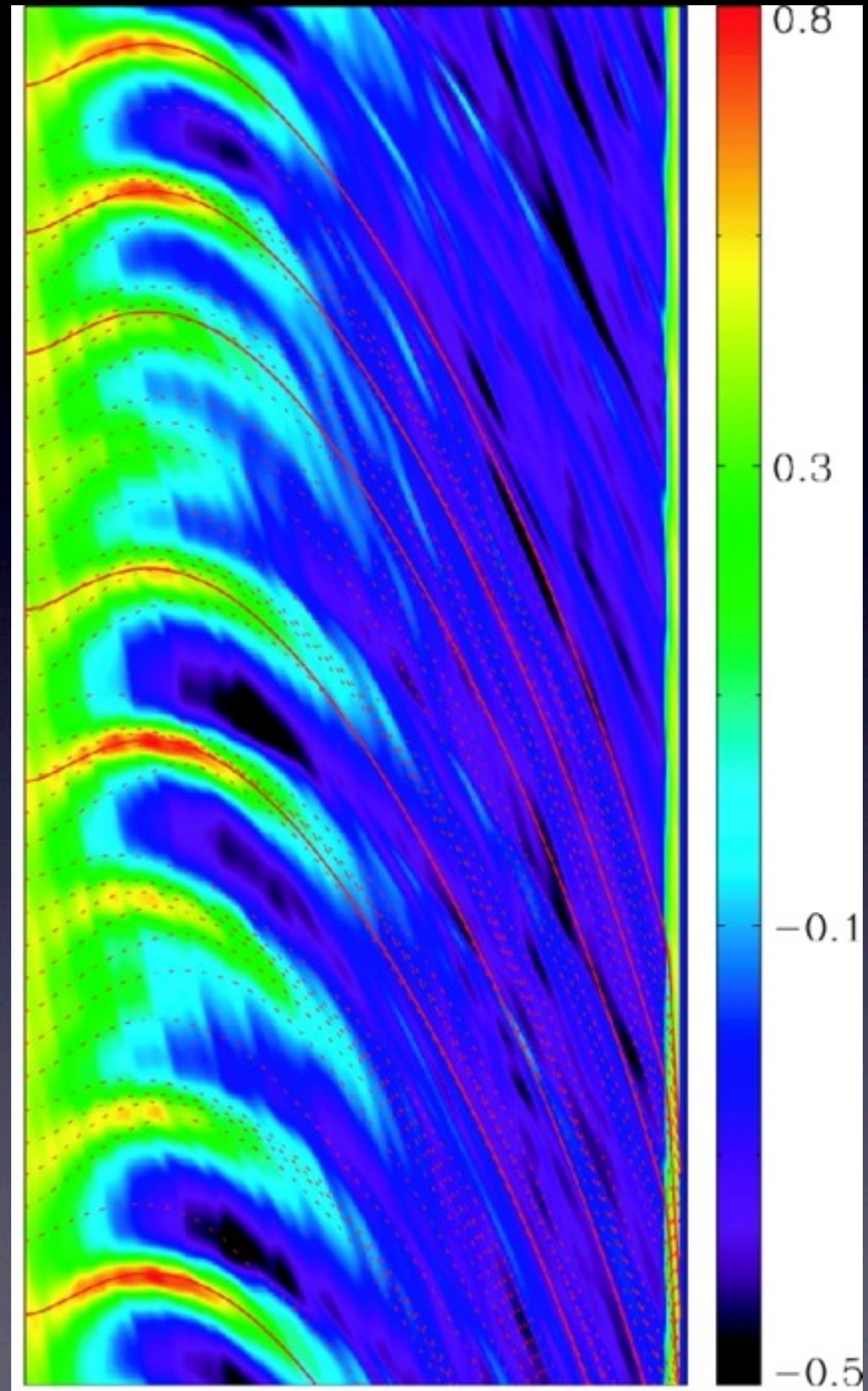
(Carretta et al. 2005; De Silva et al. 2007b)

Chemical Homogeneity

- Found in many open clusters
(Gonzalez & Wallerstein 2000; Tautvaišiene et al. 2000; Friel et al. 2003; Schuler et al. 2003; De Silva et al. 2007b)
- Also found in moving groups
(Castro et al. 1999; De Silva et al. 2007a)
- Observationally: favors chemical tagging
(Freeman & Bland-Hawthorn 2002; Bland-Hawthorn, Krumholz, & Freeman 2010)
- Theoretically: *why* homogeneous?



M51 (nasaimages.org)

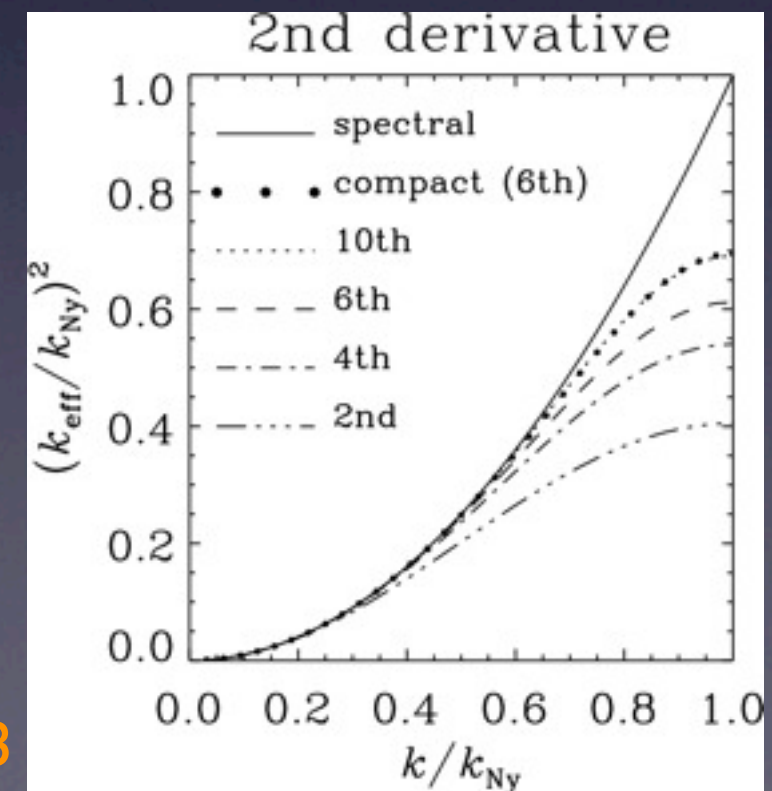
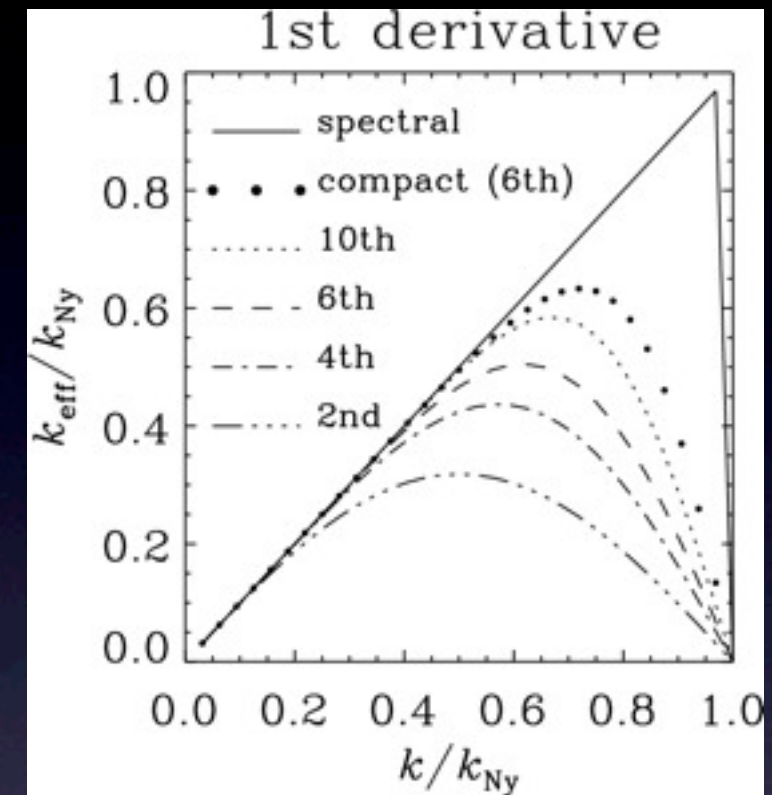


Kim & Ostriker 2002



The Pencil Code

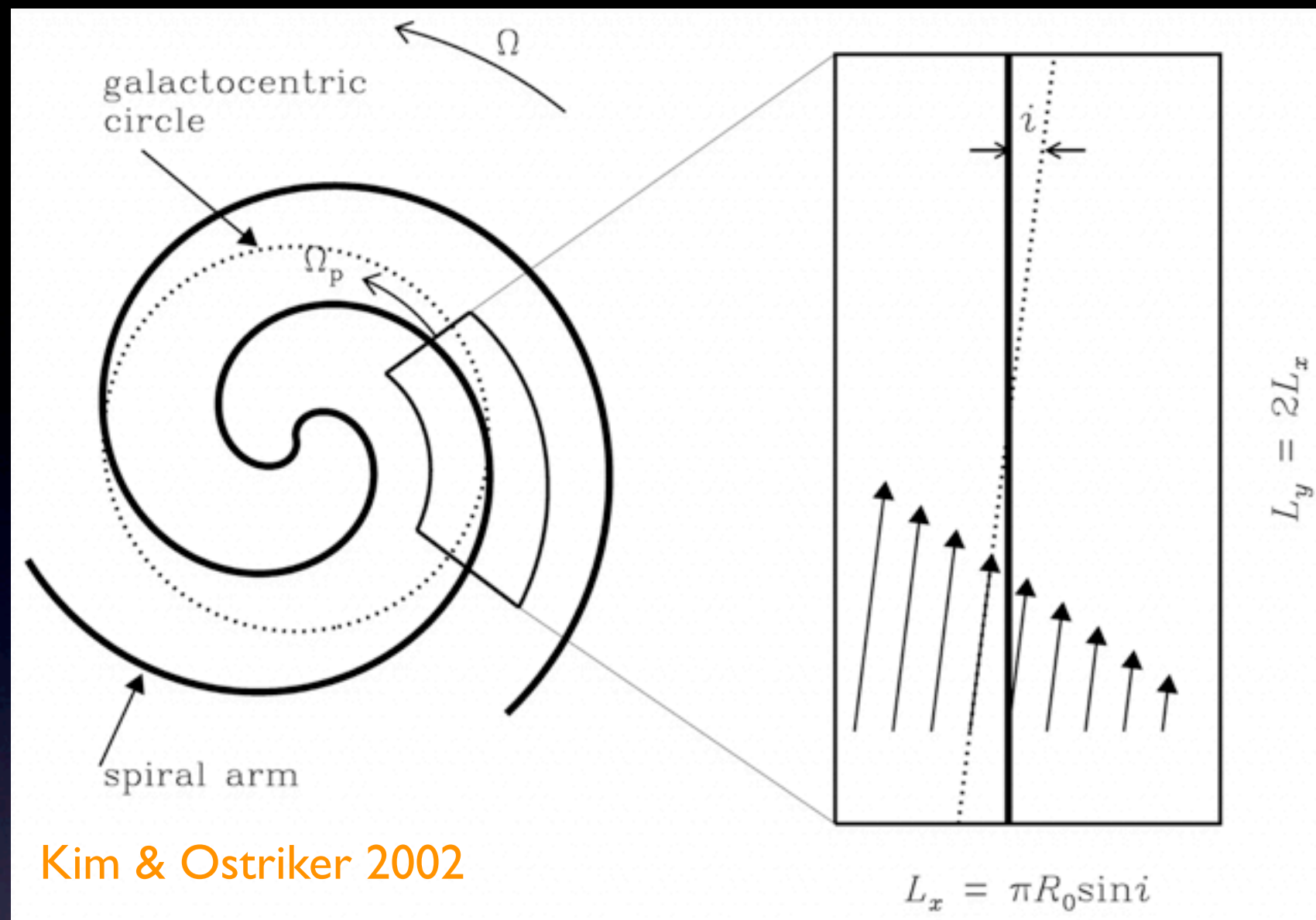
- High-order finite differences
 - Sixth order in space
 - Third-order Runge-Kutta steps in time
- MHD (optionally with particles, chemistry, radiative transfers, etc.)
- Advantages
 - High fidelity at high wavenumbers
 - Computationally cheap
 - Easy to add and modify terms and equations



Brandenburg 2003

Numerical Models

- MHD + self-gravity
- Isothermal thin disk
- Local shearing sheet approximation
- Background spiral potential
 - pitch angle $i \sim 6^\circ$
 - No assumption on m
- Background azimuthal magnetic field
- Dimensionless parameters
- Passive scalar fields tracing metals



$$\delta \equiv \frac{c_s}{v_c}$$

$$Q_0 \equiv \frac{\kappa c_s}{\pi G \Sigma_0}$$

$$\beta_0 \equiv \frac{\Sigma c_s^2}{B_0^2 / 2\mu_0}$$

$$F \equiv \frac{|\Phi_0|}{v_c^2 \sin i}$$

“Low” Resolution

Surface Density

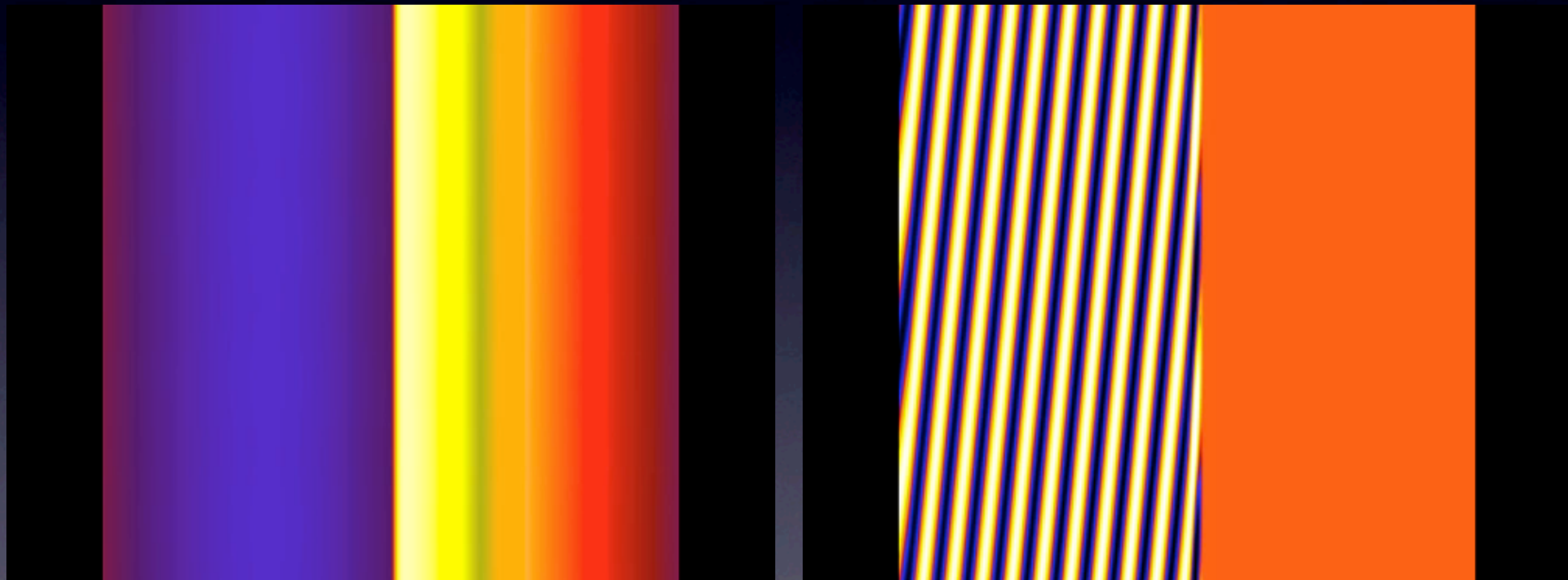
Passive Scalar

$$\delta = 0.027, Q_0 = 1.5, \beta_0 = 2, F = 3\%$$

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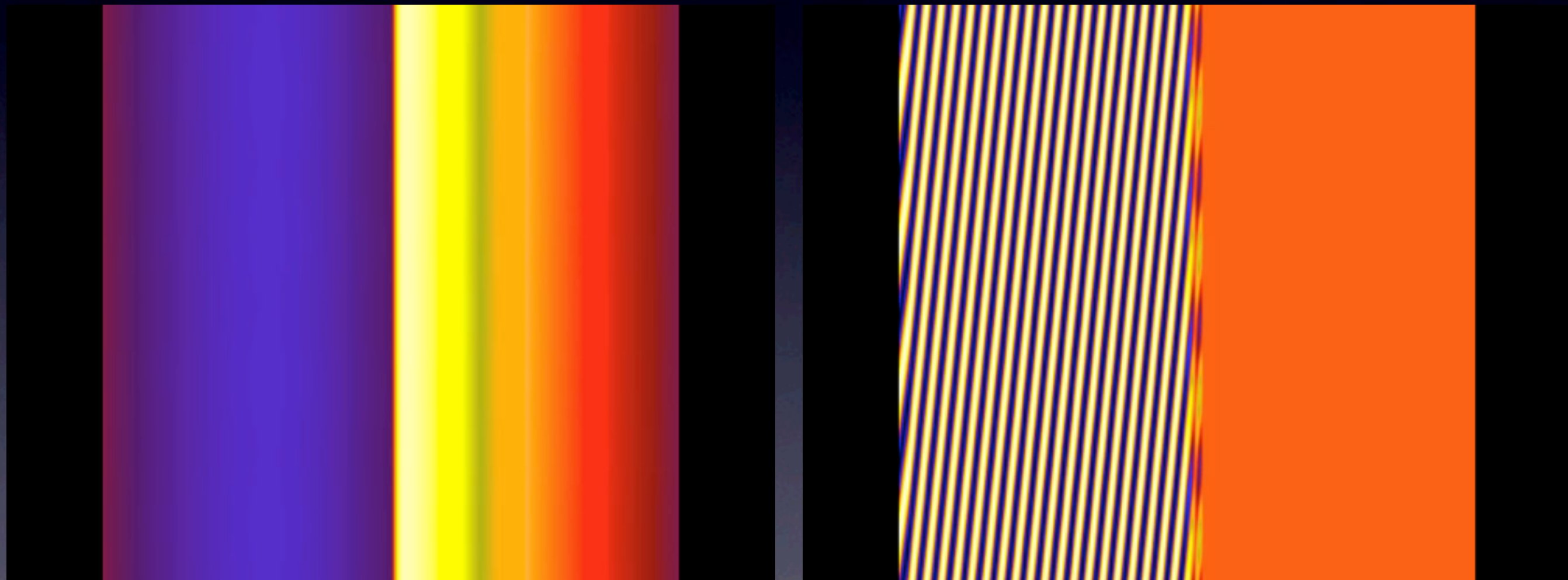
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“High” Resolution

Surface Density

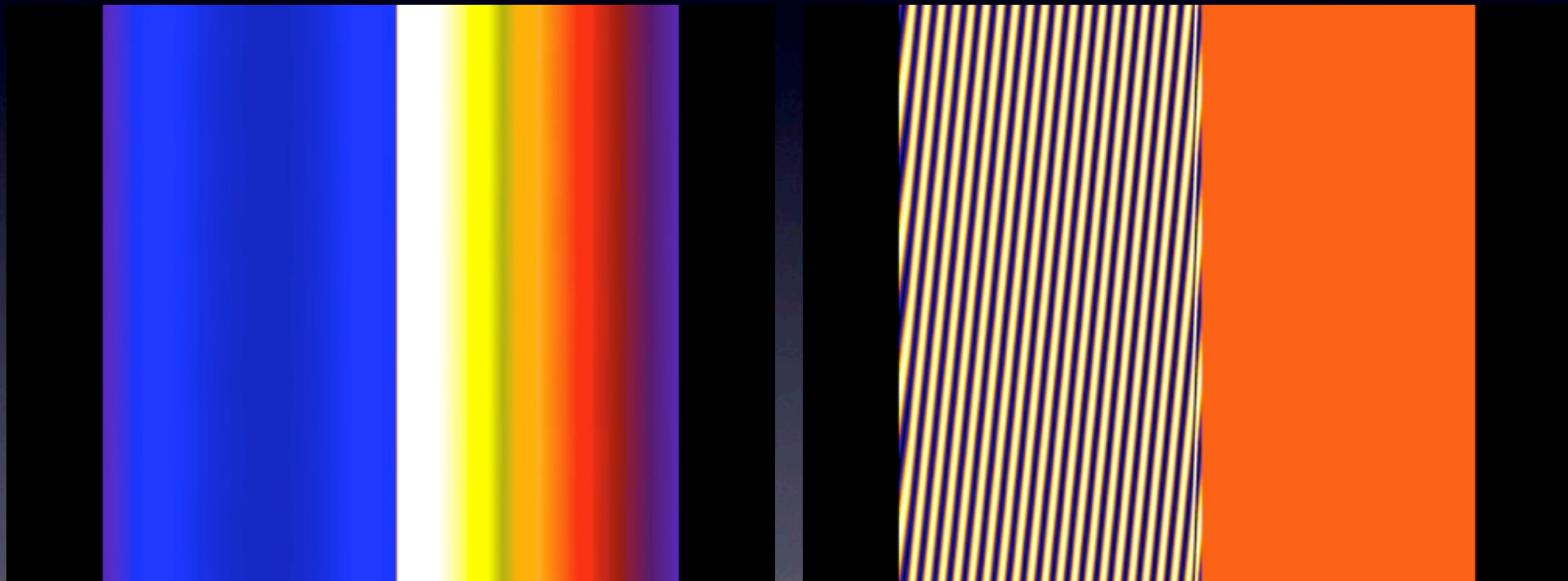
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“High” Resolution

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The Other Mode

Surface Density

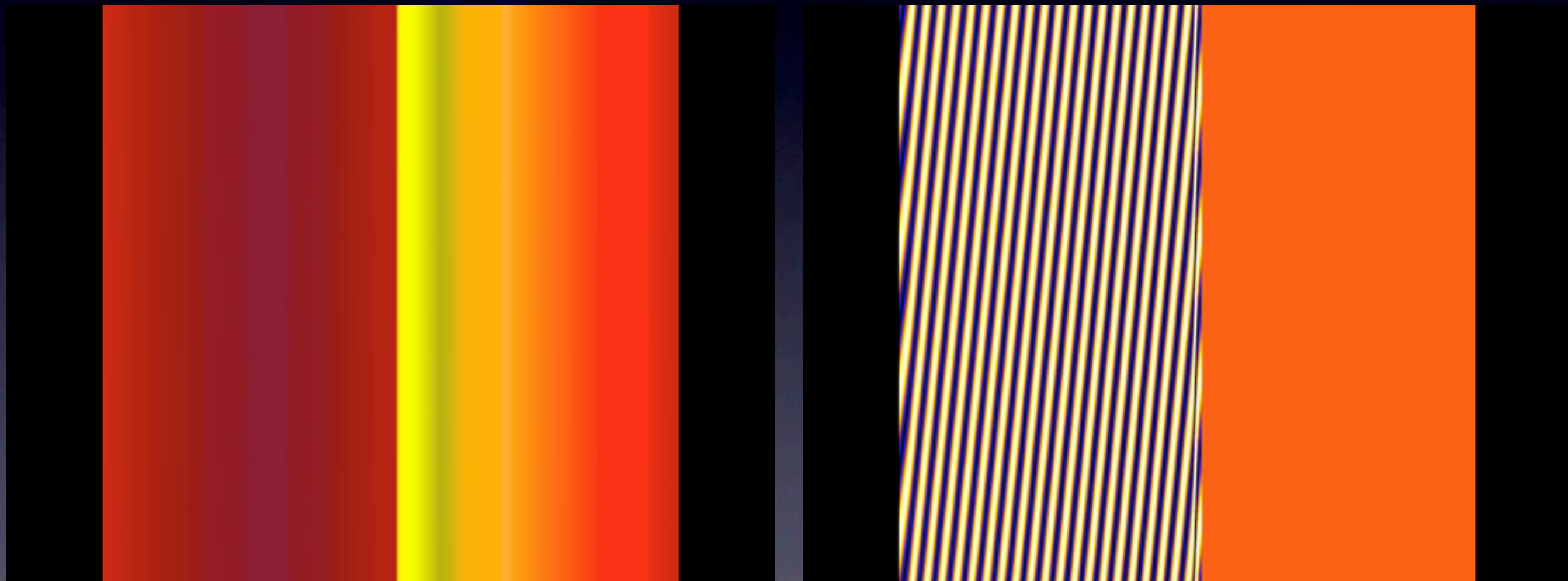
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The Other Mode

Surface Density

Passive Scalar

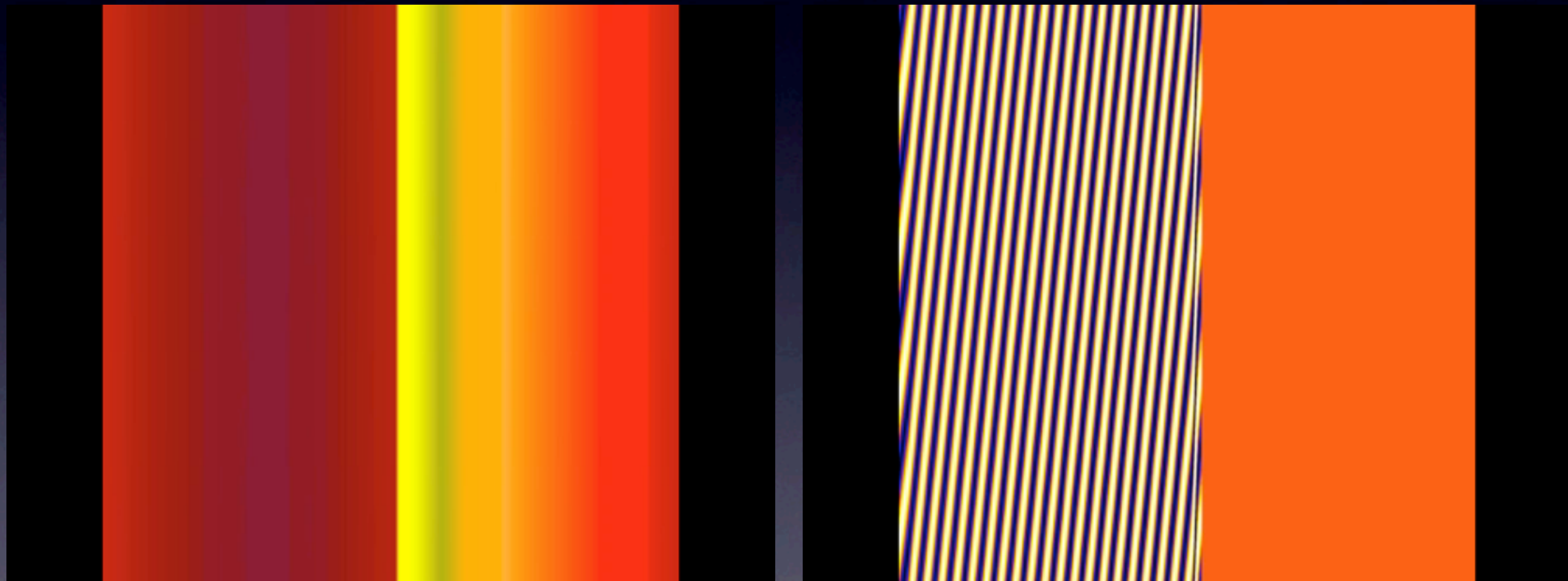


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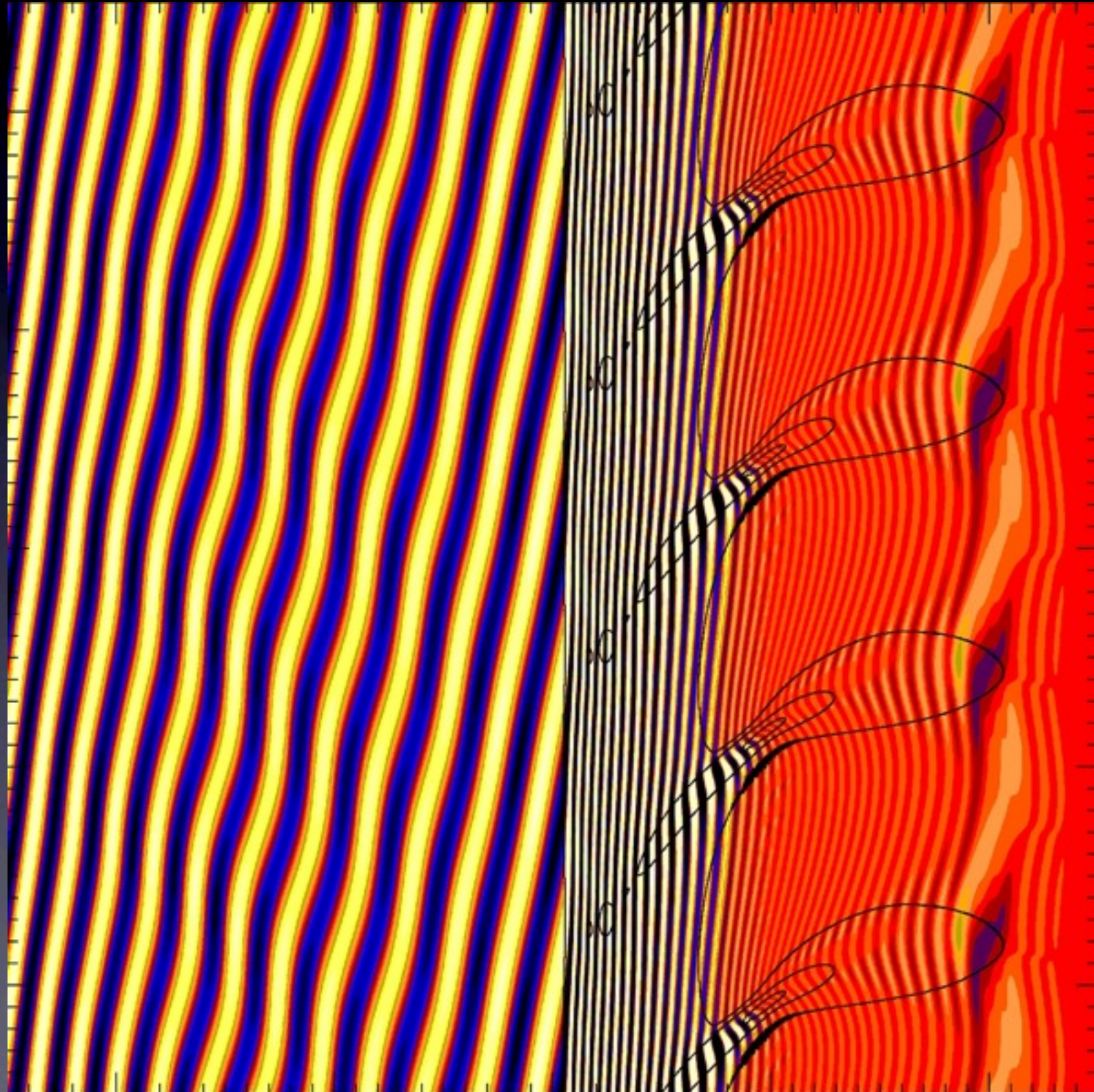
Surface Density

Passive Scalar



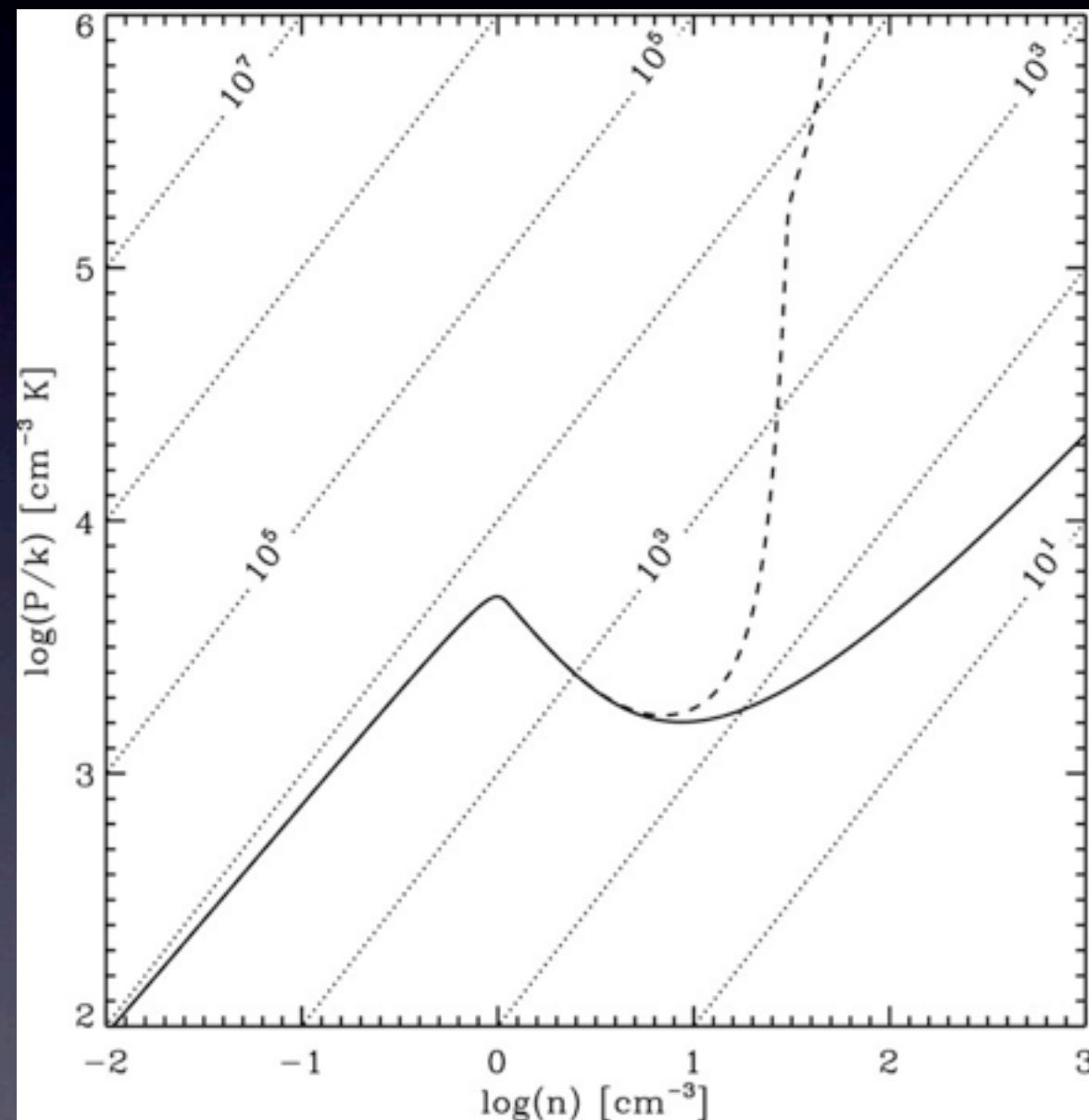
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Molecular Diffusion?



Thermodynamics

- Koyama & Inutsuka (2002) recipe
(see also Vázquez-Semadeni et al. 2007)
 - Heating: photoelectric, cosmic ray, x ray, H₂ chemistry
 - Cooling: line, collisional
- Thermal instability
 - ⇒ multi-phase ISM
 - ⇒ turbulent convective motions

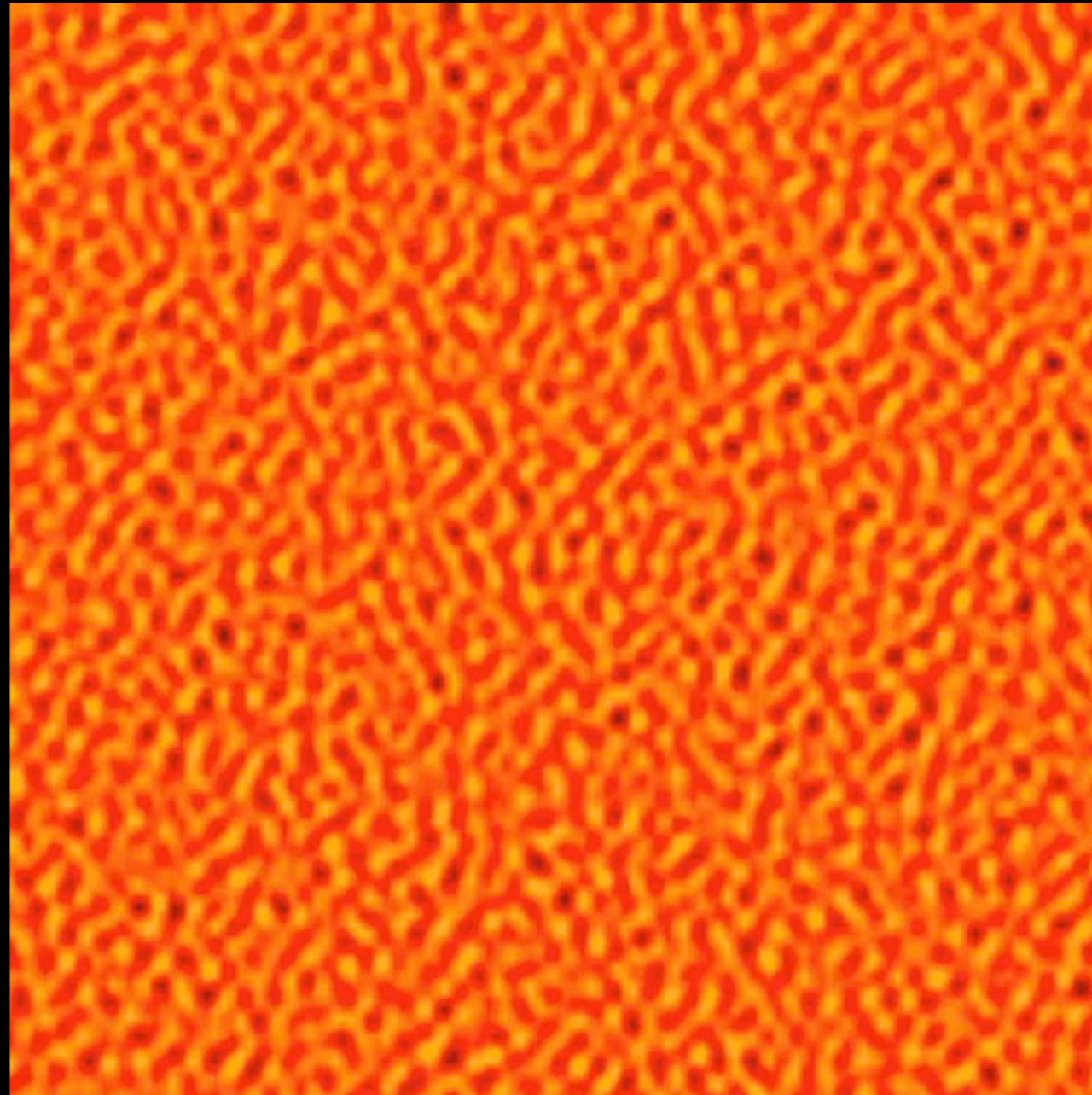


Kim, Kim, & Ostriker 2010

Work in Progress

$$\delta_0 = 0.022, Q_0 = 1.5, \beta_0 = \infty, F = 3\%$$

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