Heliophysics Summer School 2015

Planetary dynamos and their seasons

Part 1

Gary A Glatzmaier

University of California, Santa Cruz

Part 1: Basics of convection and magnetic field generation

Thermal convection and internal gravity waves

Effects of viscous and thermal diffusion, rotation, density stratification, geometry

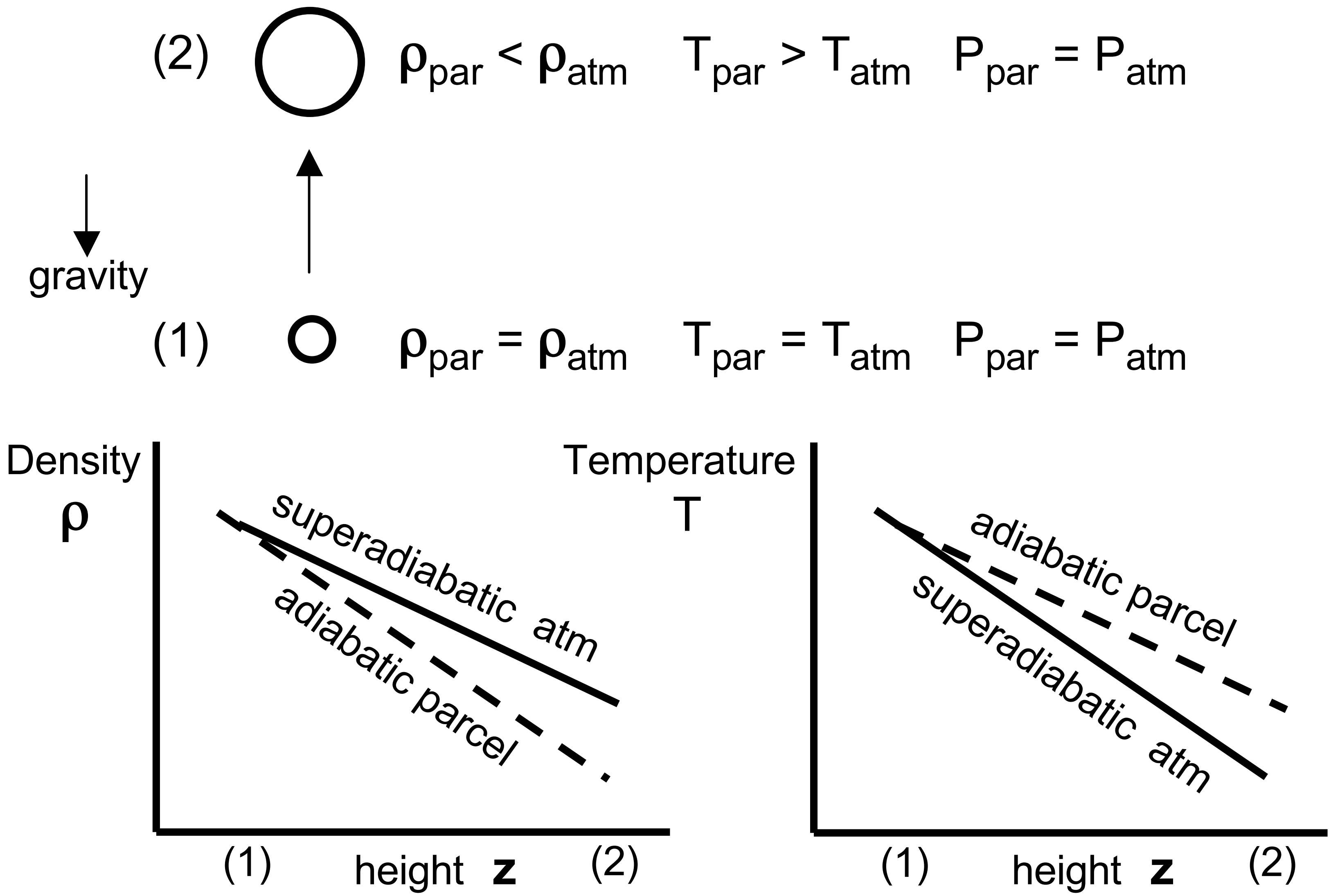
Part 2: Planetary dynamo simulations

Thermal convection

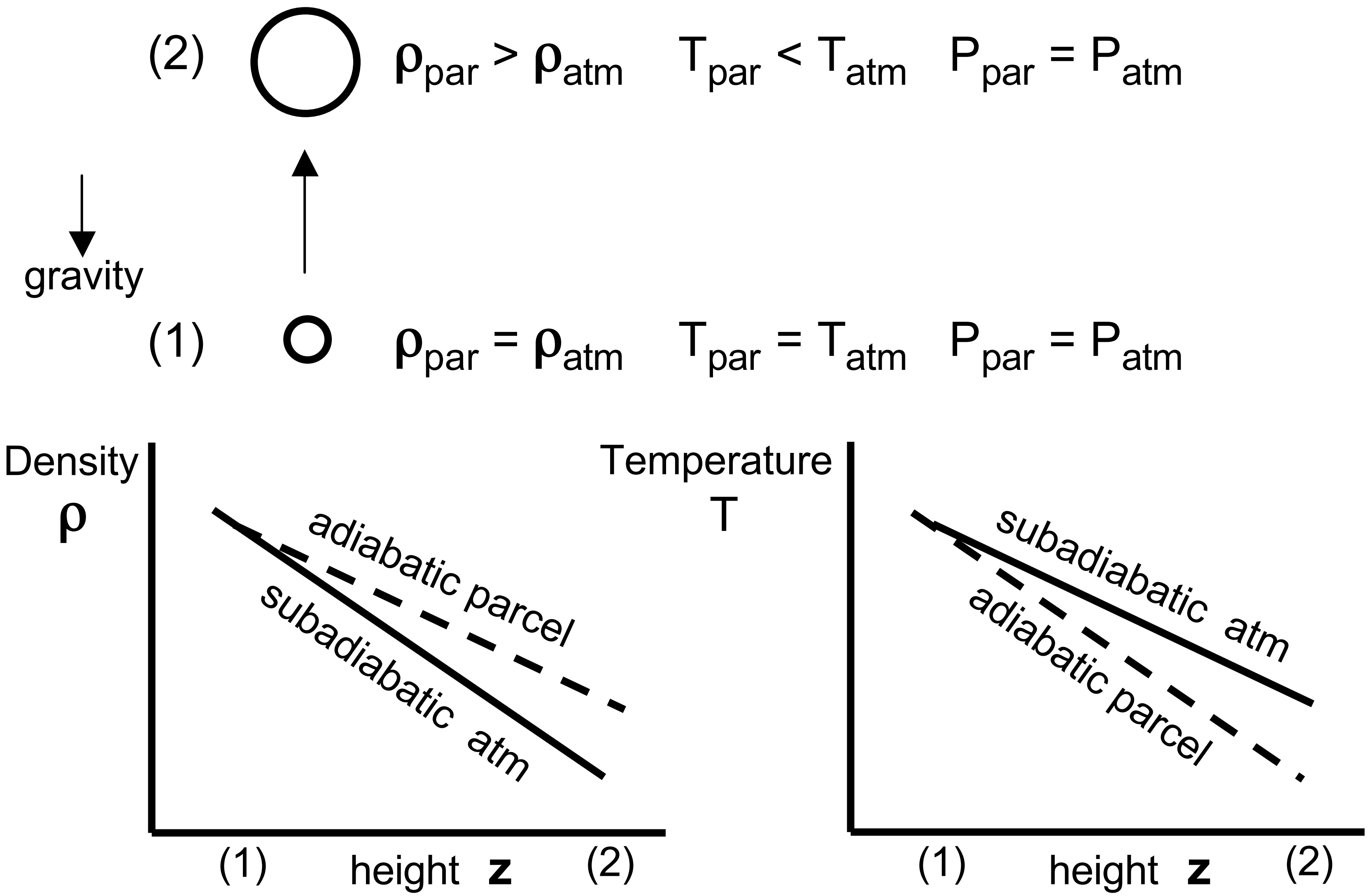
A parcel of fluid heats up, expands, becomes buoyant, and rises. It then cools off, contracts, becomes heavy, and sinks.

This process is an efficient method of transferring heat (internal energy) upwards when thermal conduction can not diffuse heat upwards fast enough and buoyancy forces are sufficient to overcome viscous drag.

Thermal convection in an unstable (superadiabatic) atmosphere



Internal gravity wave in a stable (subadiabatic) atmosphere

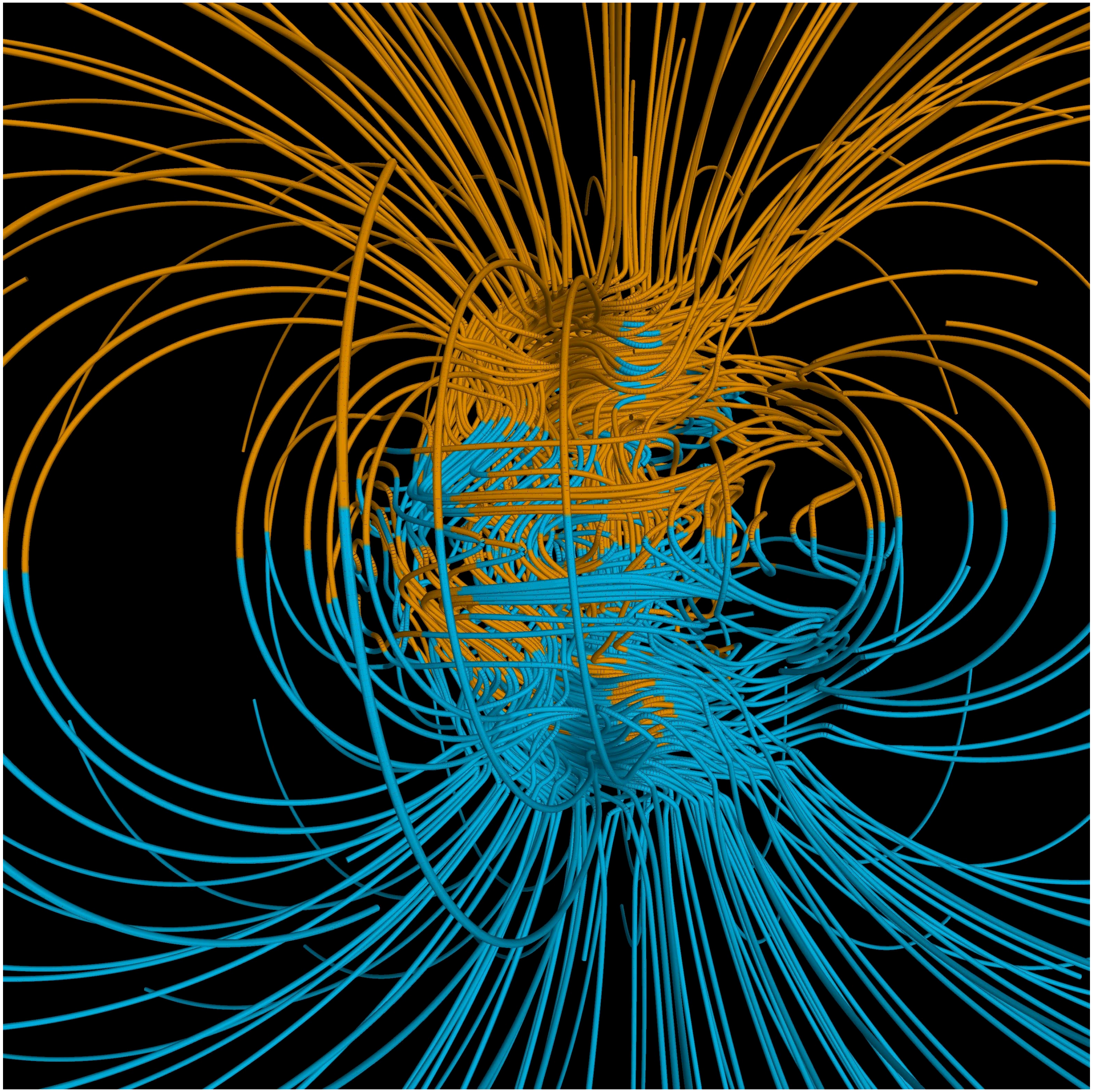


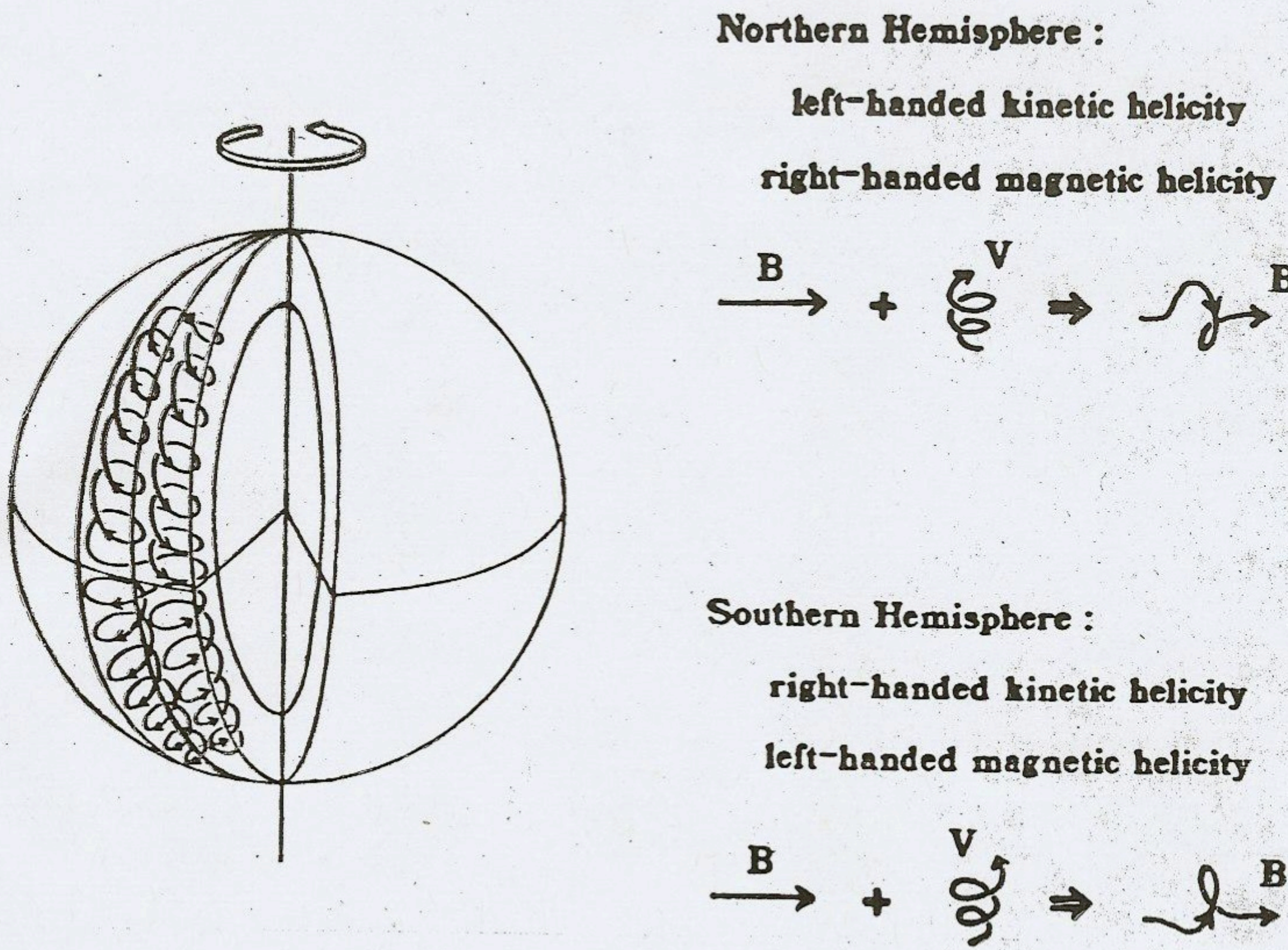
Dynamo mechanism in a rotating, convecting, electrically conducting, fluid:

Differential rotation shears poloidal magnetic field into toroidal magnetic field

and

helical fluid flow twists toroidal magnetic field into poloidal magnetic field.




Northern Hemisphere :
left–handed kinetic helicity
right–handed magnetic helicity
B
V
B
Southern Hemisphere :
right–handed kinetic helicity
left–handed magnetic helicity
B
V
B

Convective dynamo equations

Conservation of mass

Conservation of magnetic flux

Equation of state

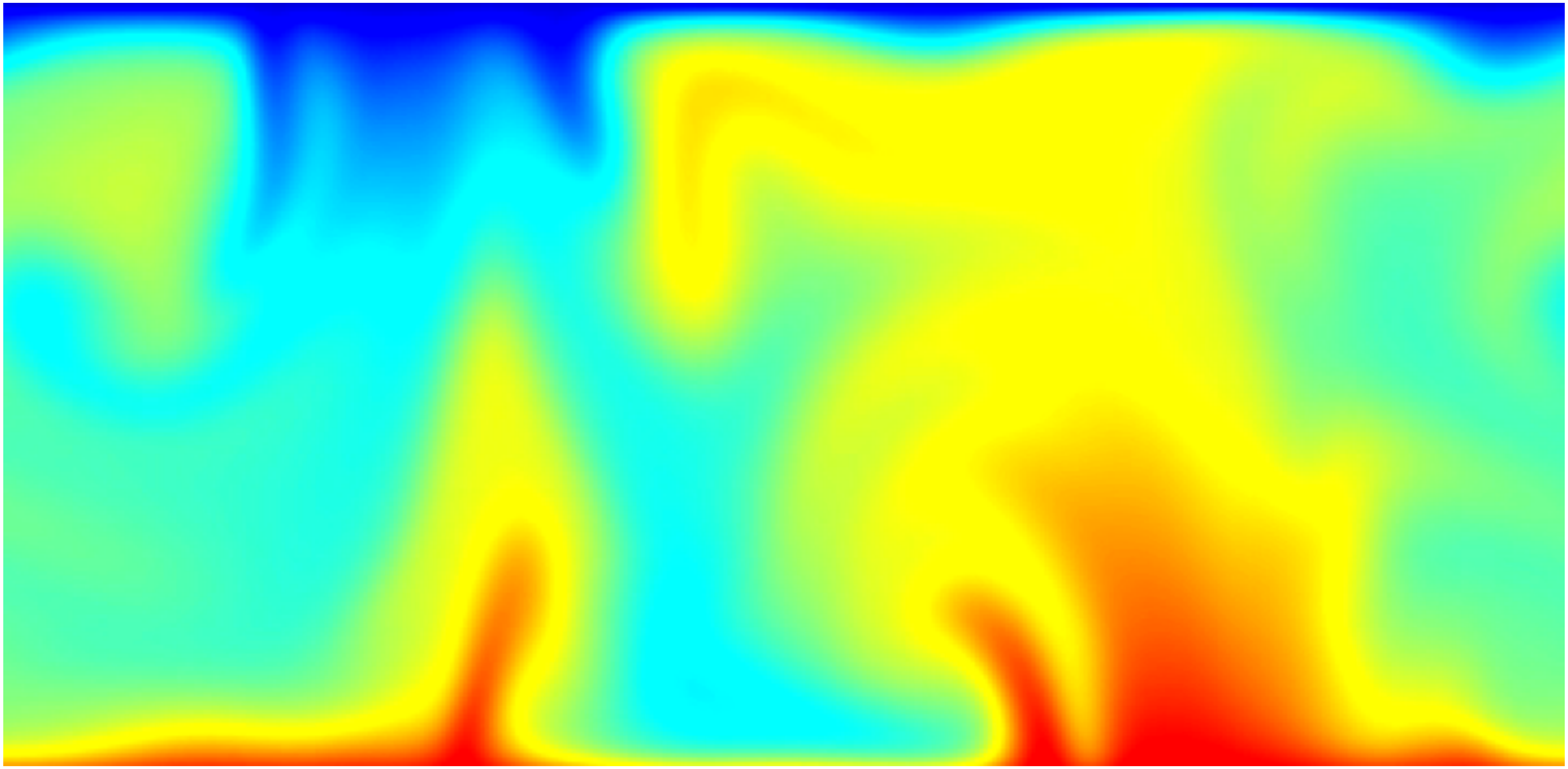
Rate of change of velocity = - pressure gradient + buoyancy
+ advection + diffusion
+ Coriolis + Centrifugal + Poincare
+ Lorentz

Rate of change of magnetic field = induction + diffusion

Rate of change of entropy = Joule heating + viscous heating
+ advection + diffusion

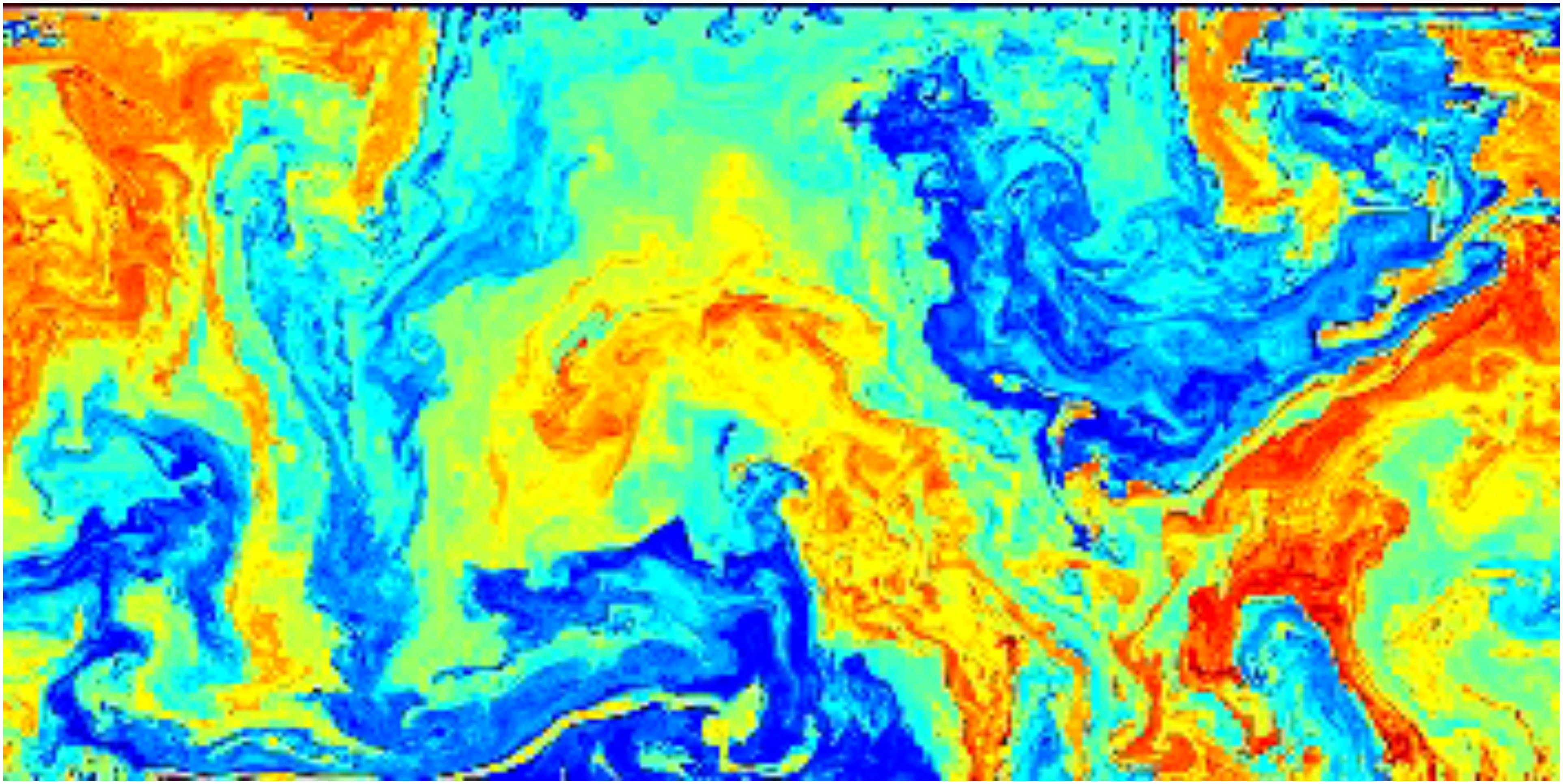
Rate of change of composition = advection + diffusion

Thermal convection



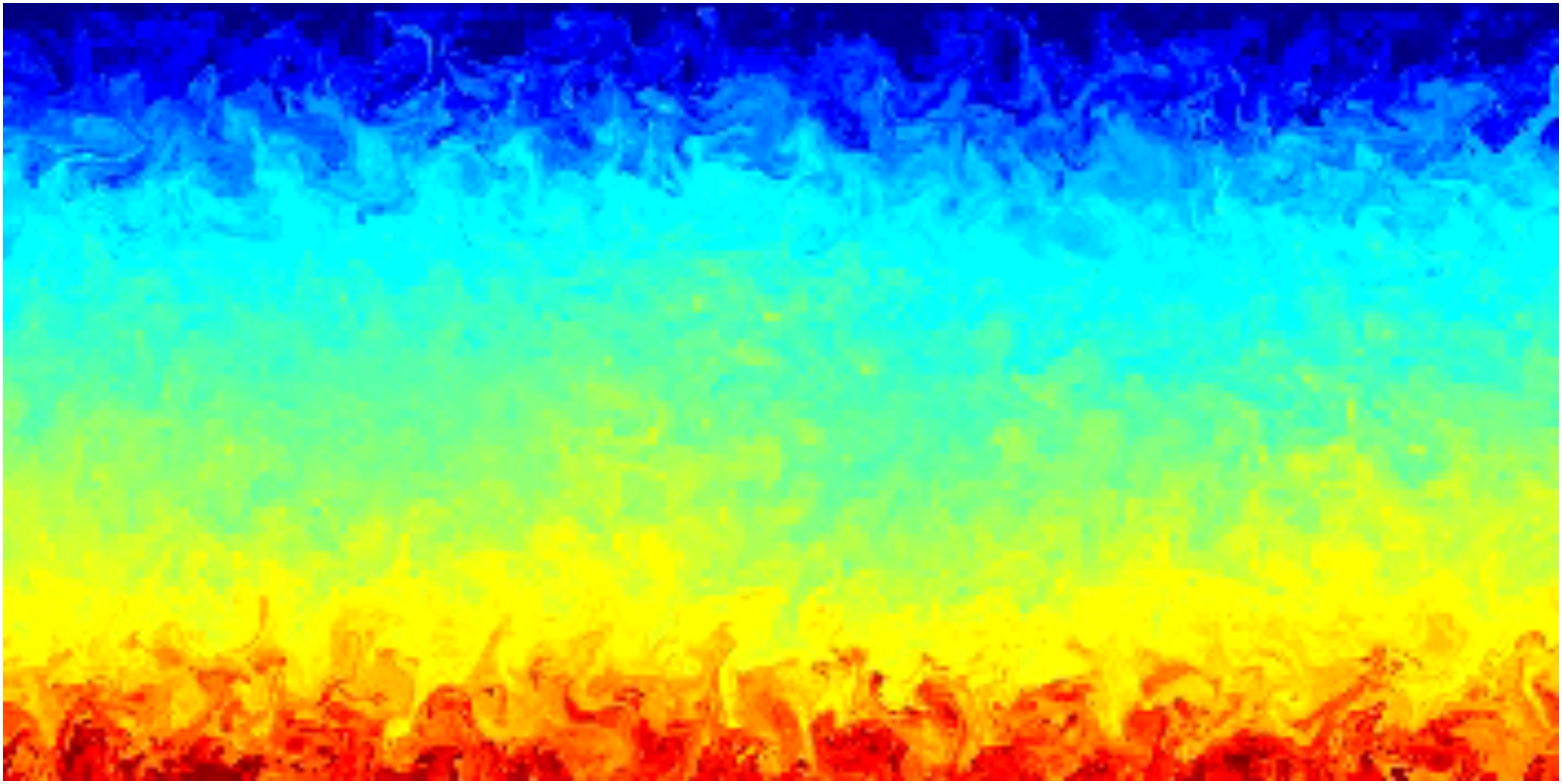
large viscous and thermal diffusivities

Thermal convection



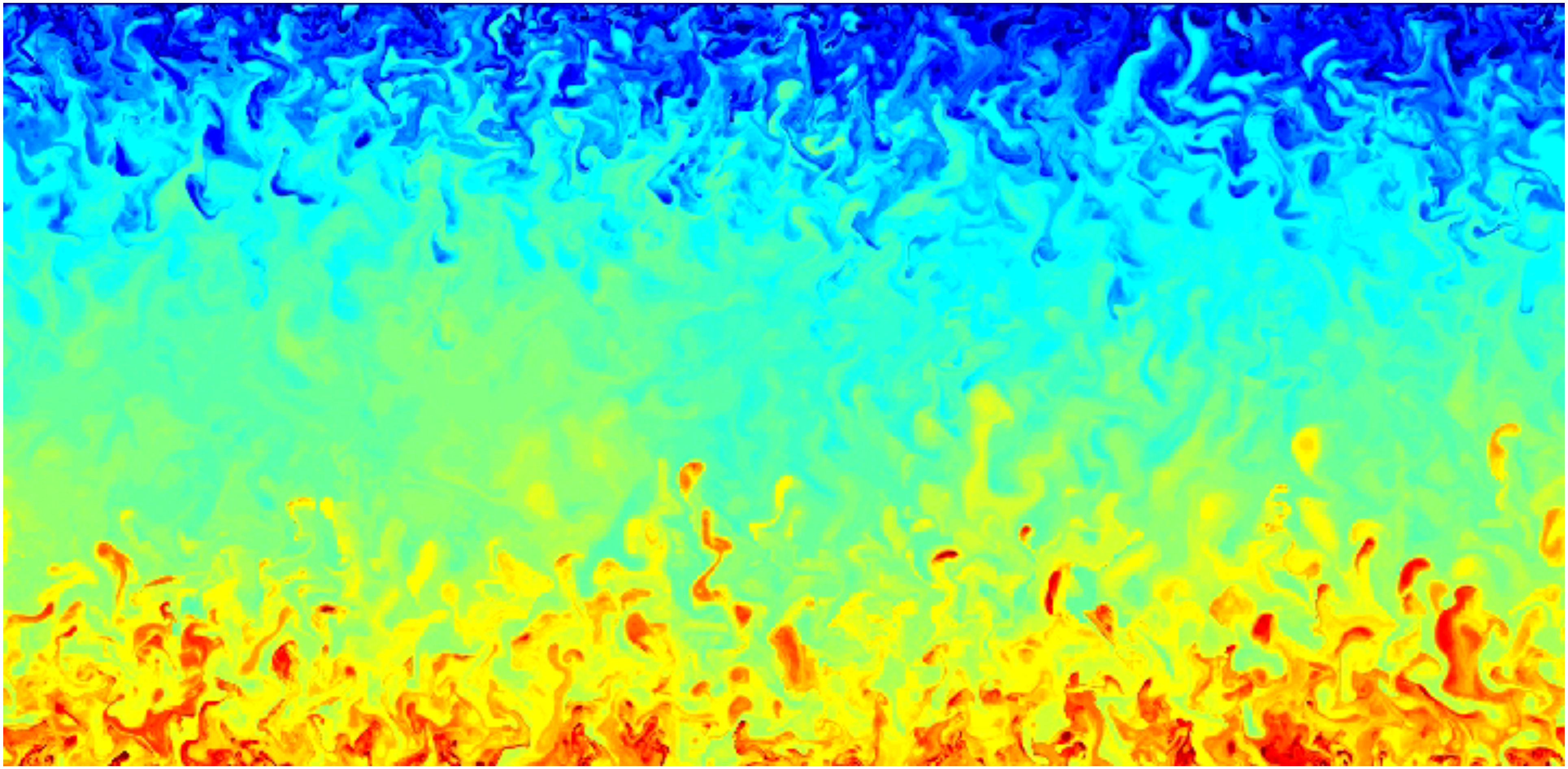
small viscous and thermal diffusivities

Rotating thermal convection

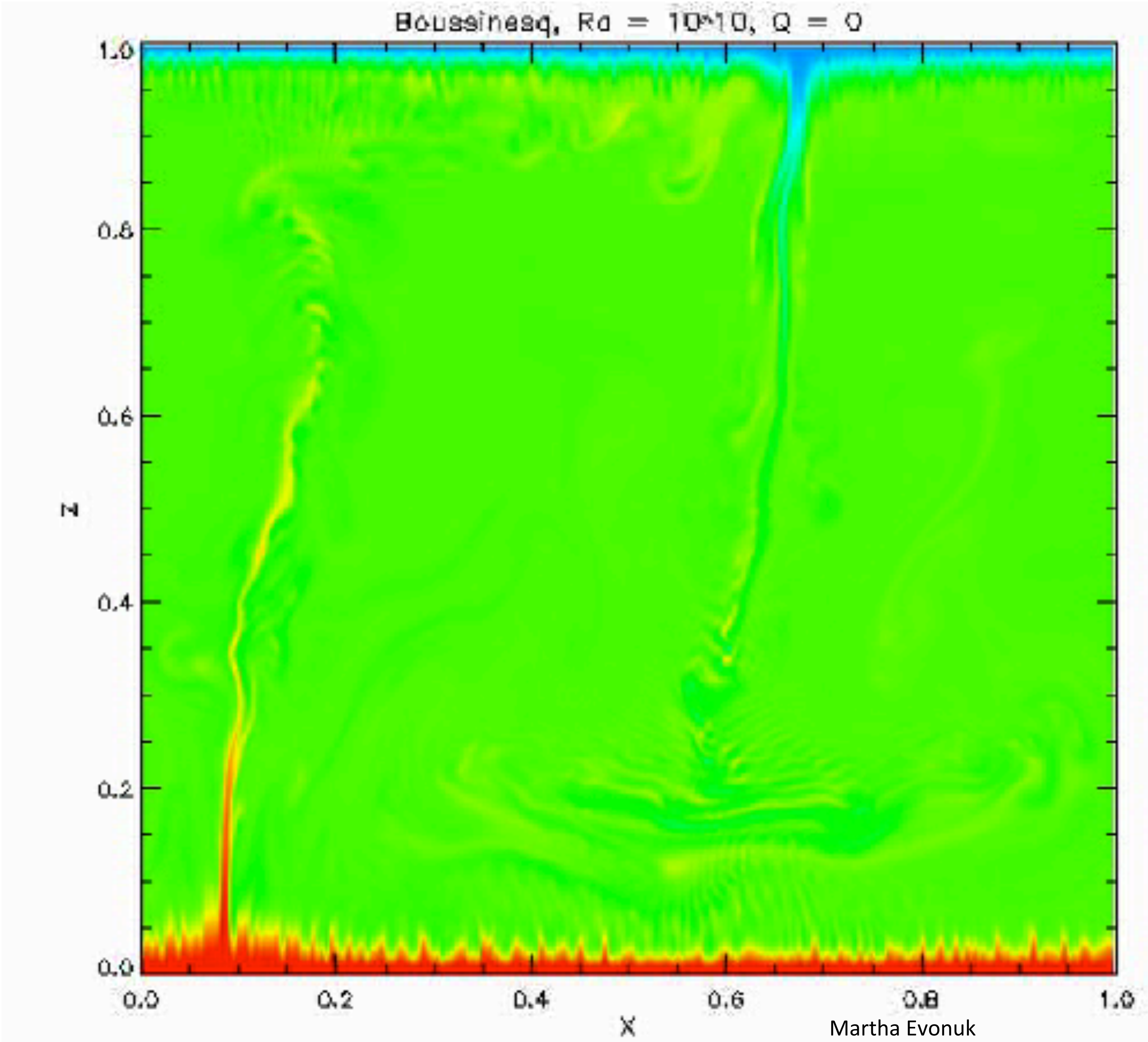


small viscous and thermal diffusivities

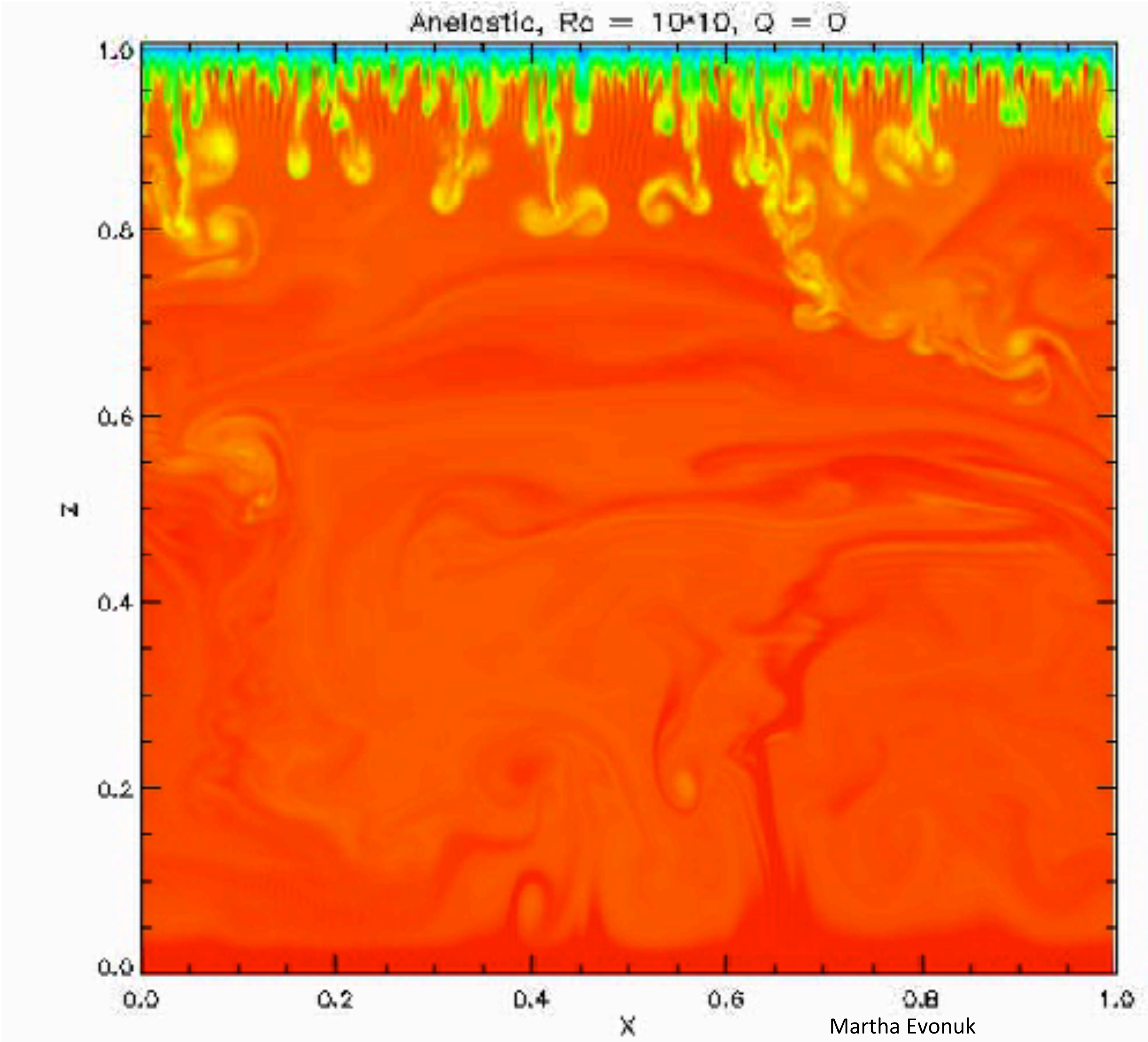
Rotating and magnetic thermal convection



small viscous and thermal diffusivities



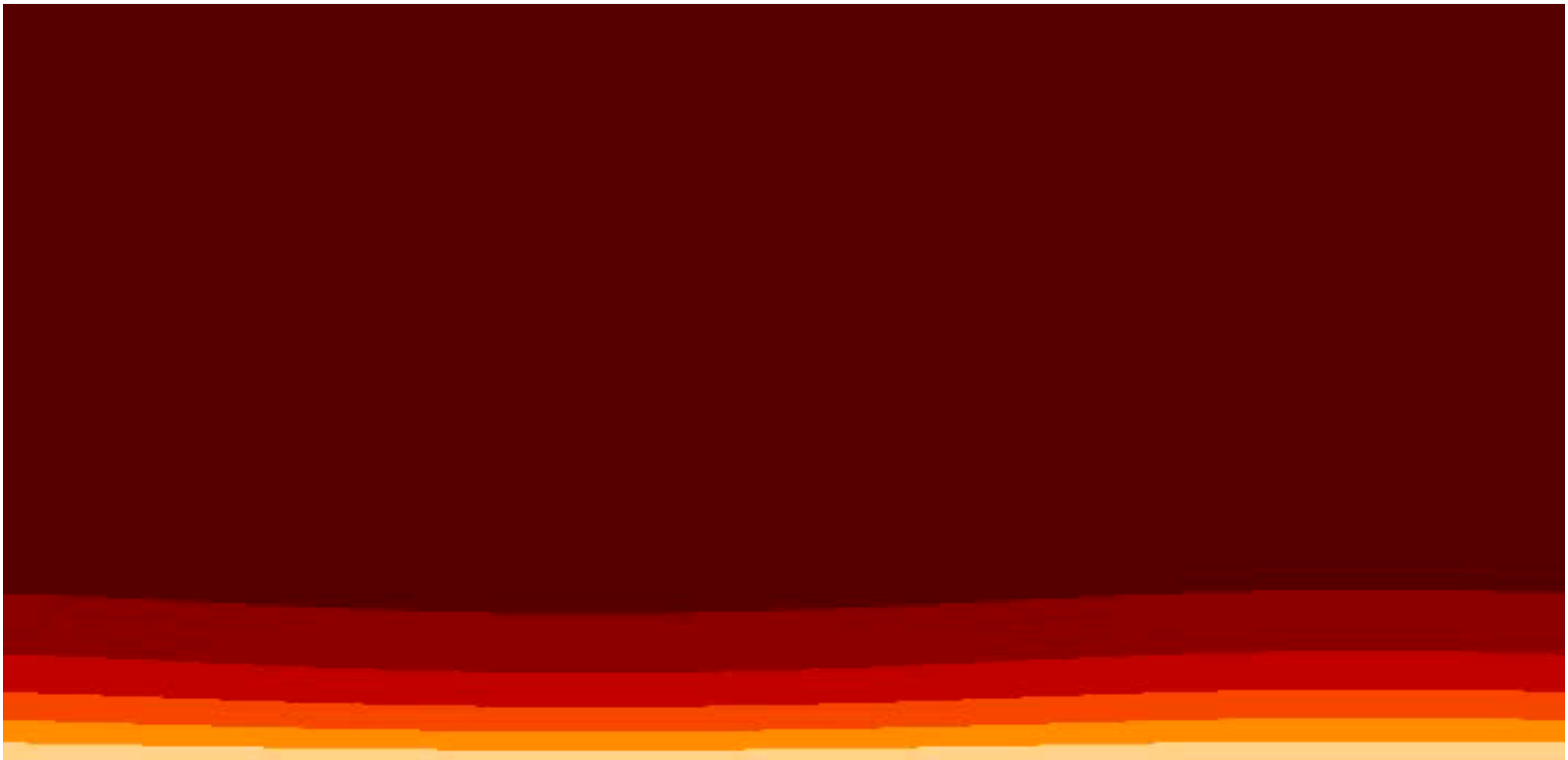
Boussinesq, Ra = 10^10, Q = 0
1.0
0.8
0.6
0.4
0.2
0.0
z
0.0
0.2
0.4
0.6
0.8
1.0
X
Martha Evonuk



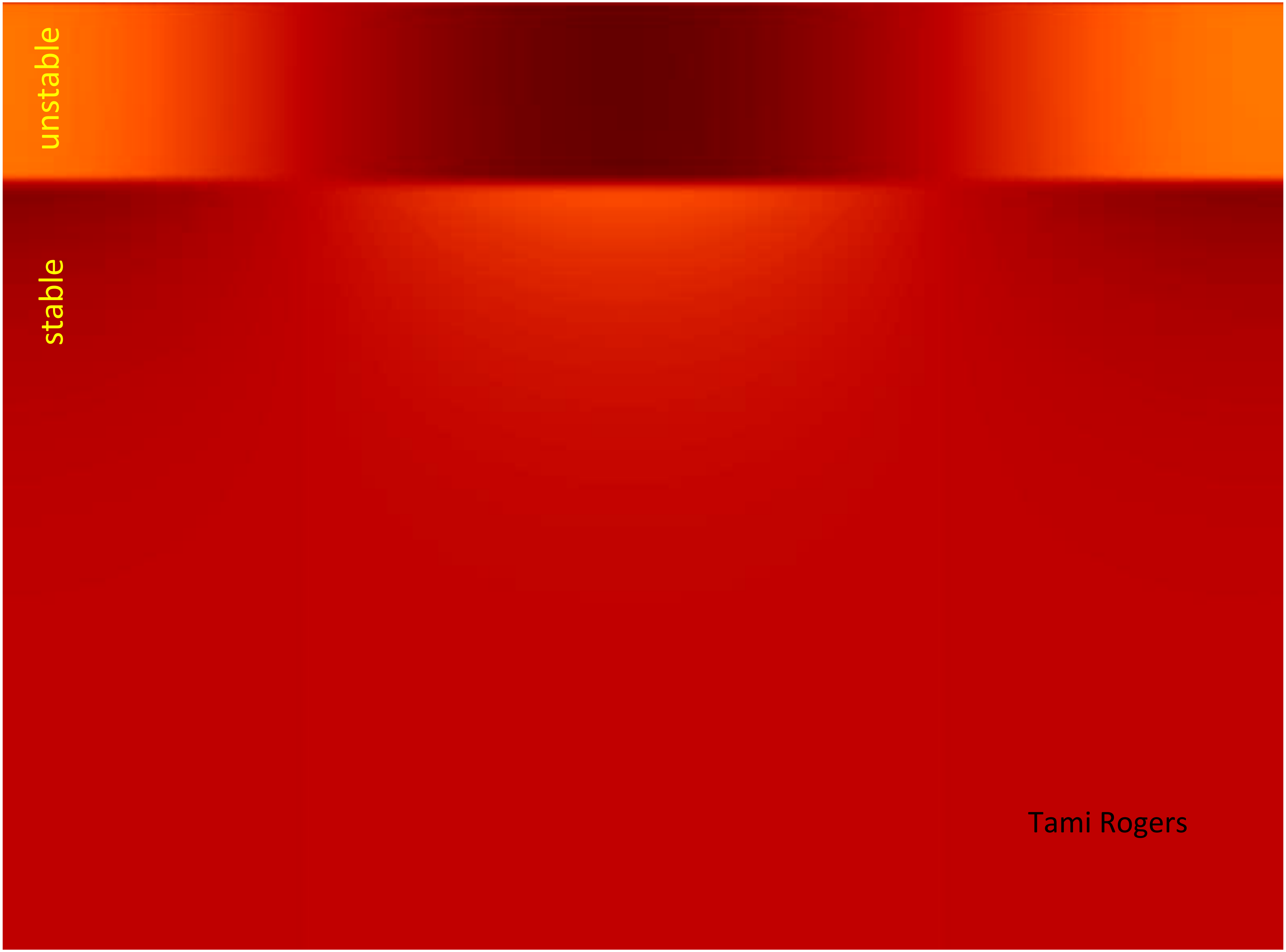
Martha Evonuk

Rotating thermal convection

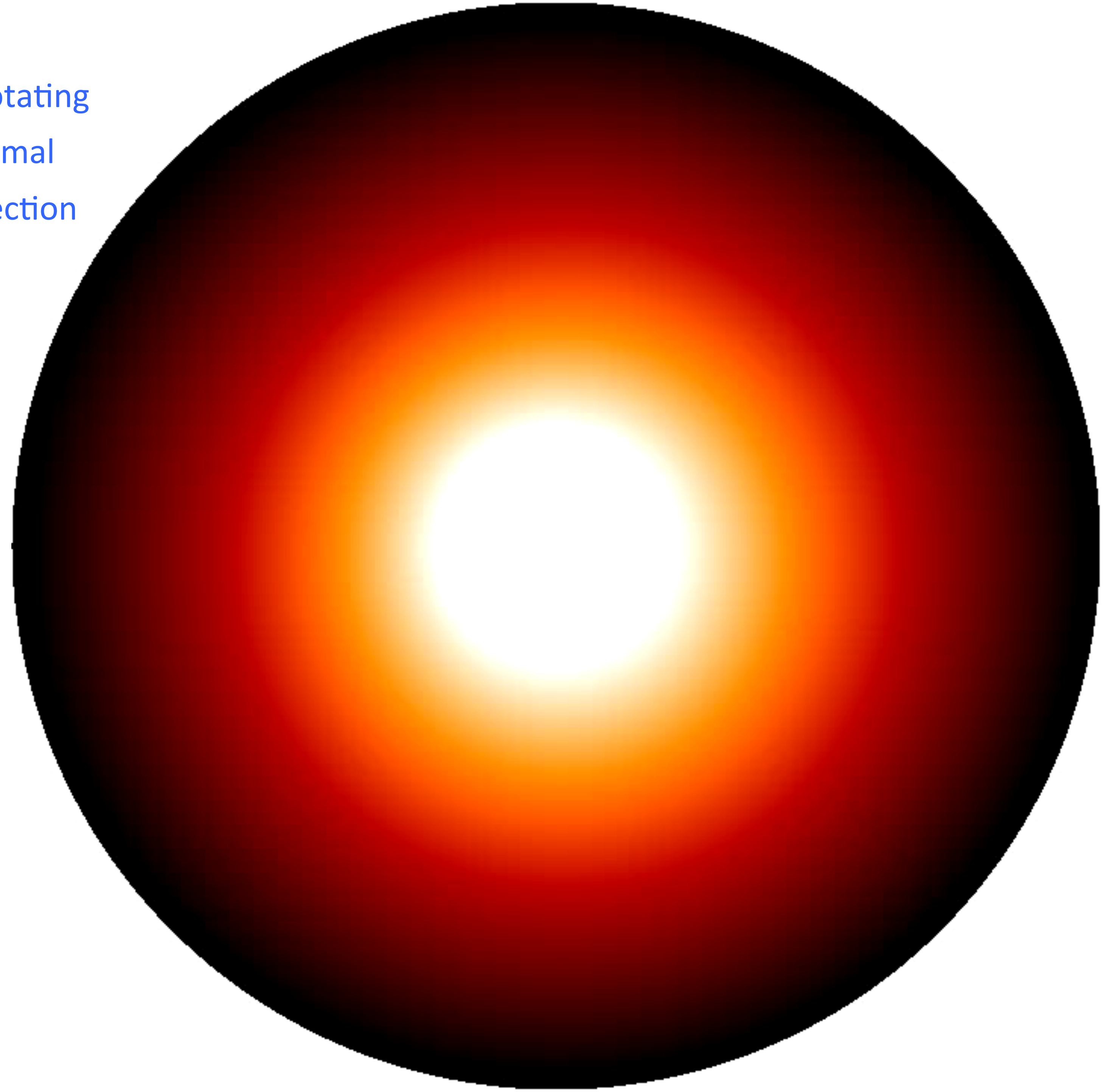
with large density stratification



small viscous and thermal diffusivities

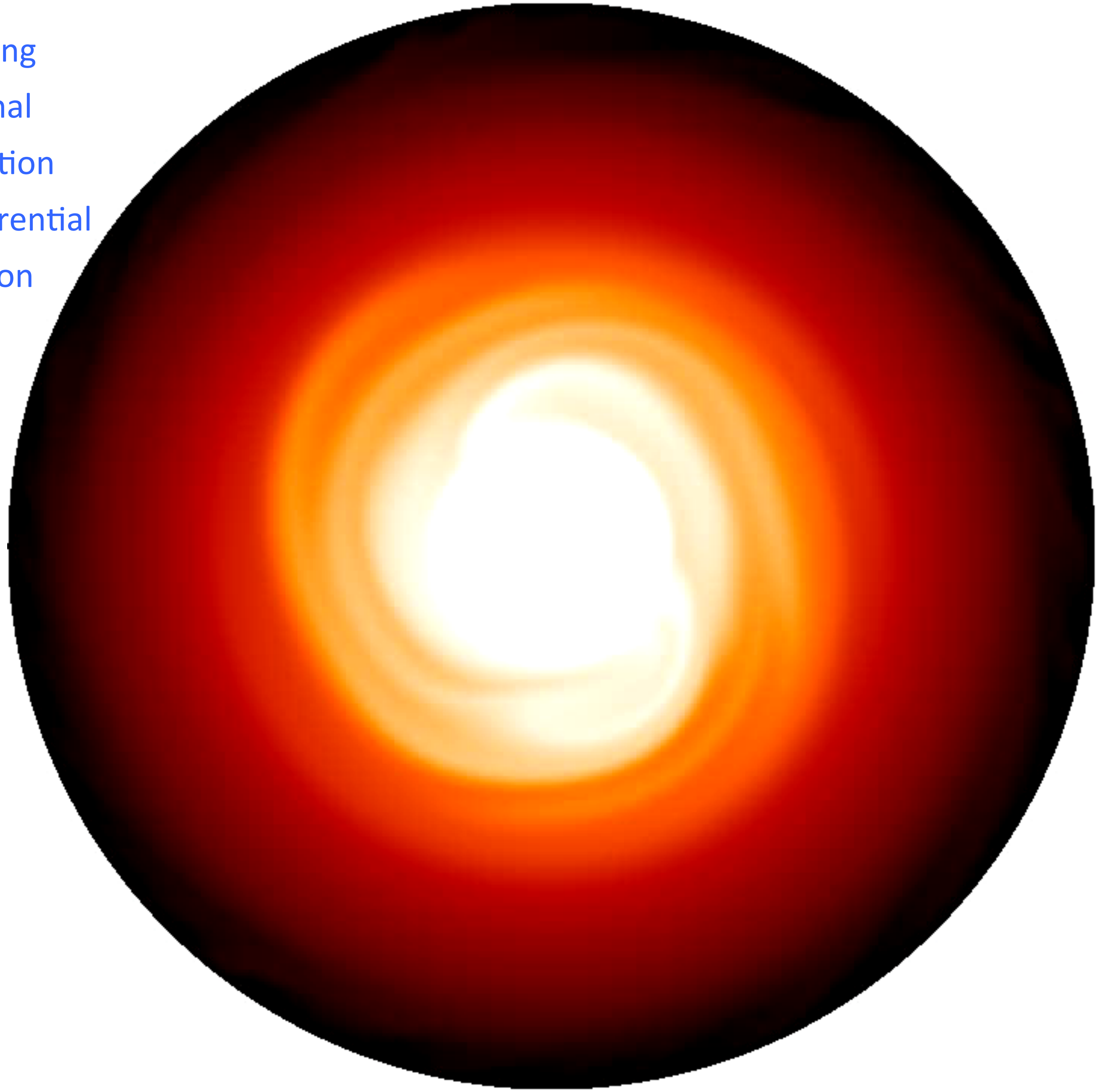

unstable
stable
Tami Rogers

non-rotating
thermal
convection



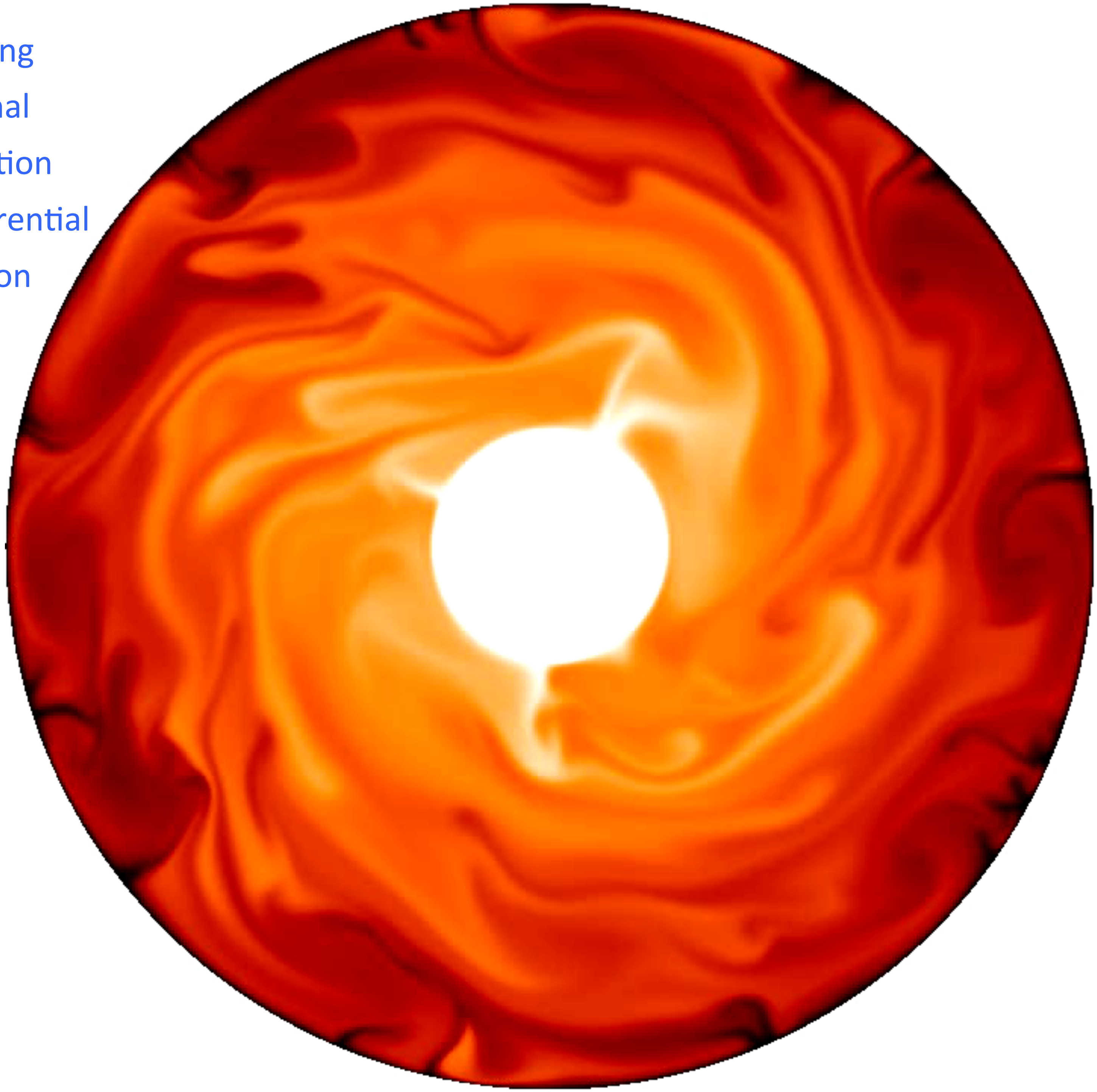

case 1
Convergence of prograde
angular momentum flux
near the inner boundary,
where the density stratification is greatest

Rotating thermal convection with differential rotation

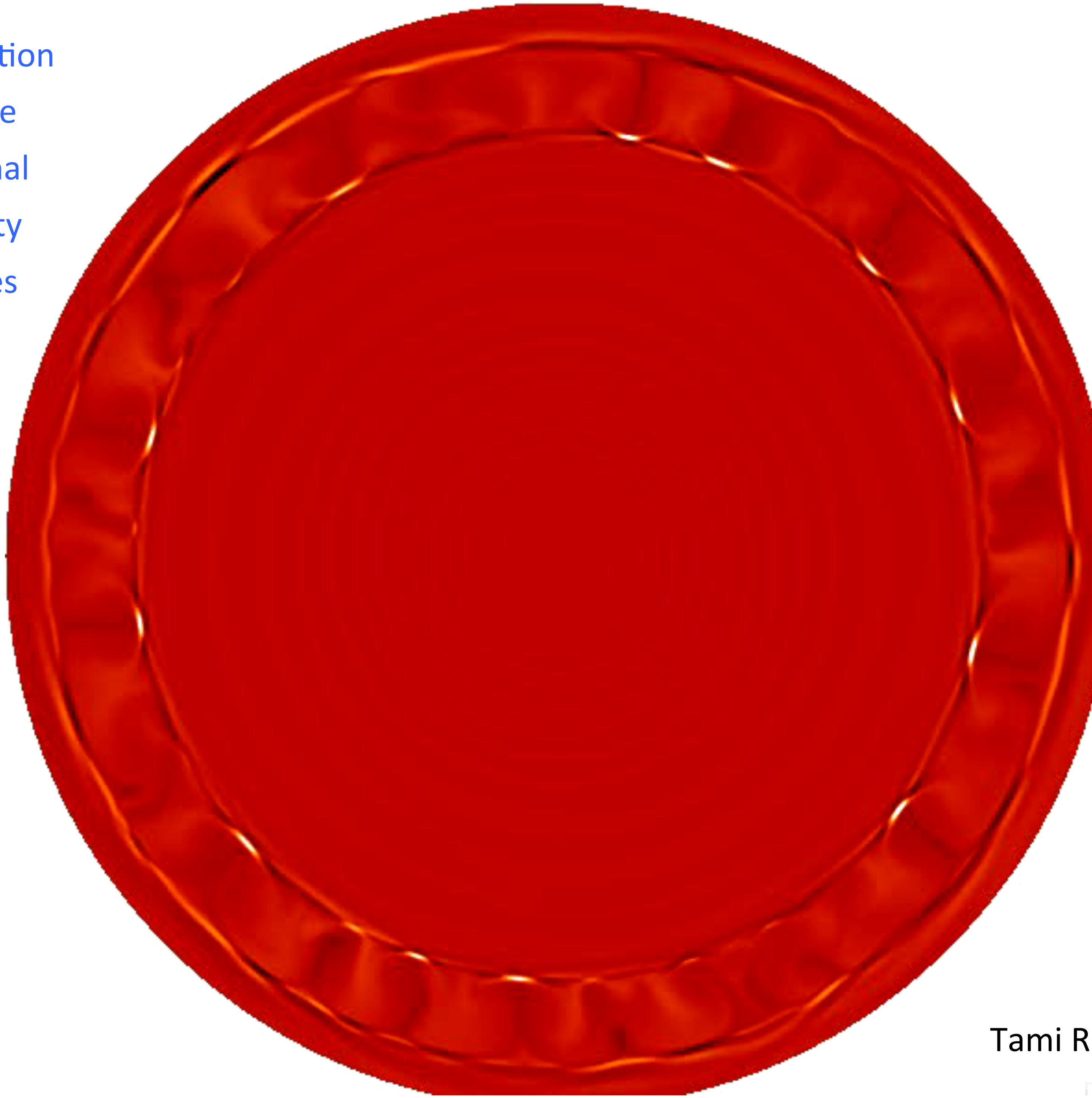



case 2
Convergence of prograde
angular momentum flux
near the outer boundary,
where the density stratification is greatest

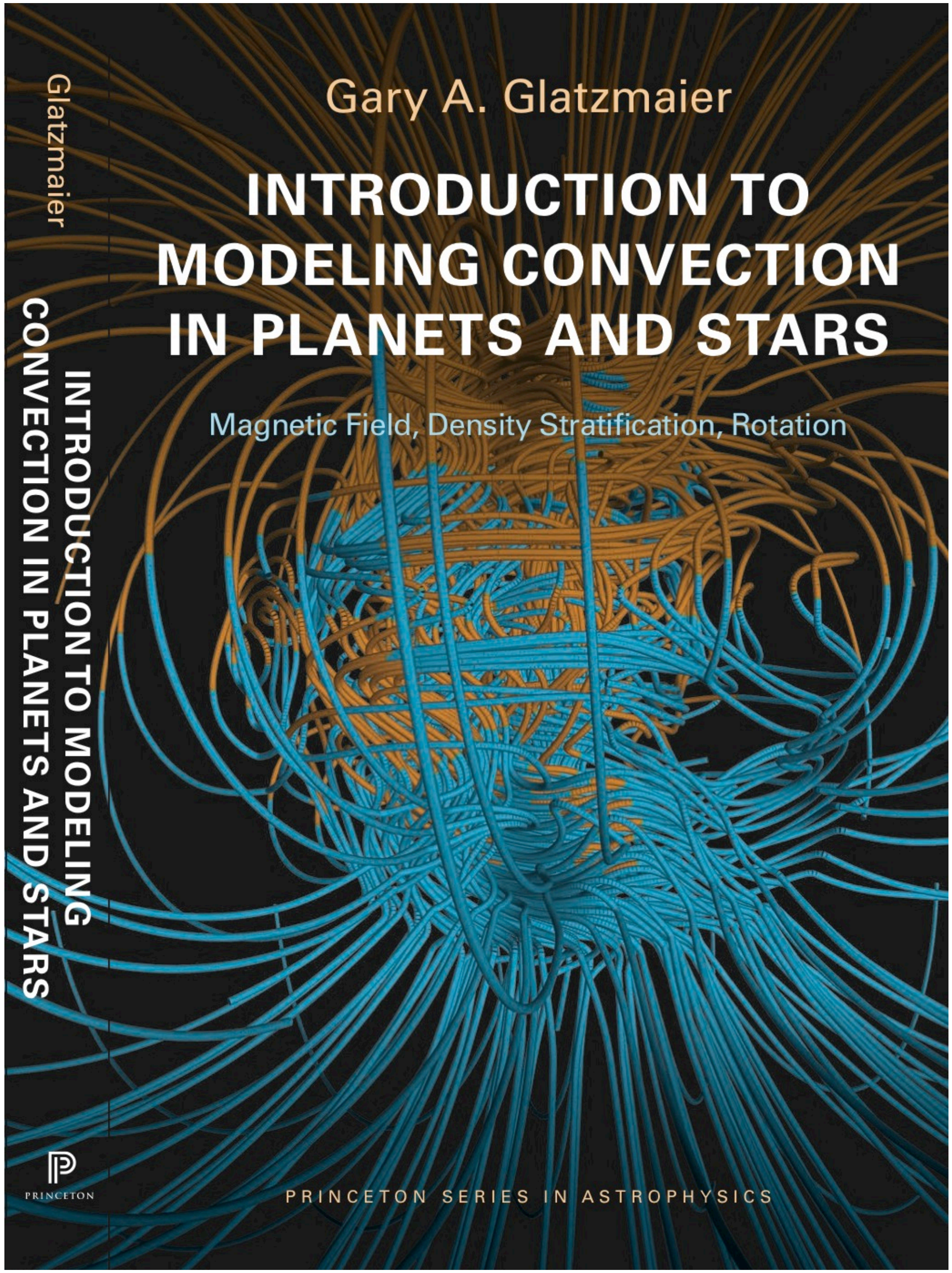
Rotating thermal convection with differential rotation



Convection
above
internal
gravity
waves



Tami Rogers



Gary A. Glatzmaier

INTRODUCTION TO MODELING CONVECTION IN PLANETS AND STARS

Magnetic Field, Density Stratification, Rotation

PRINCETON SERIES IN ASTROPHYSICS

Glatzmaier

INTRODUCTION TO MODELING CONVECTION IN PLANETS AND STARS

PRINCETON