Convective flow velocity measurements in a rapidly rotating sphere

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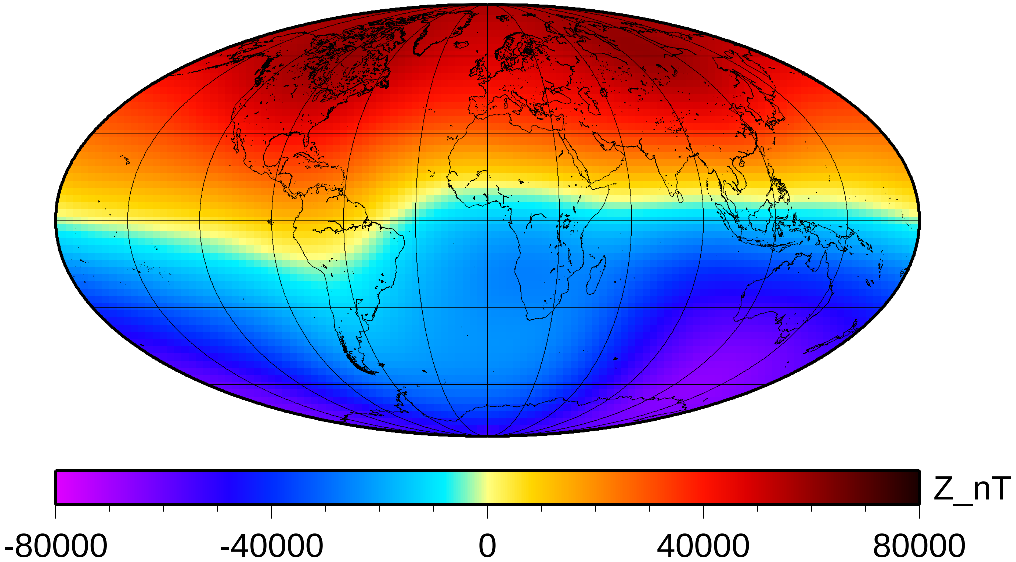
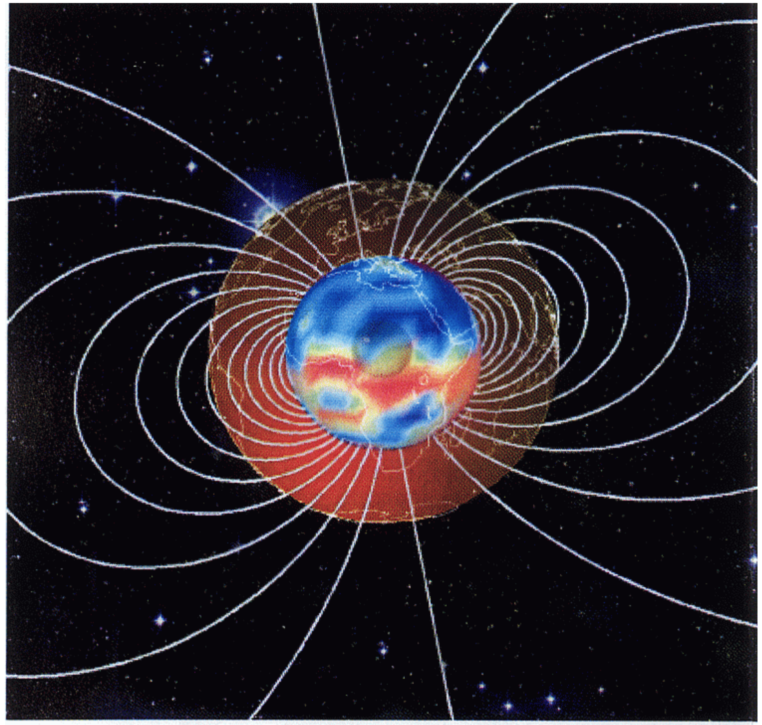
PAMIR, 4^{th} International Conference
MHD at dawn of 3^{rd} Millennium

Presqu'île de Giens - France
September 18-22, 2000

Observed Earth's magnetic field

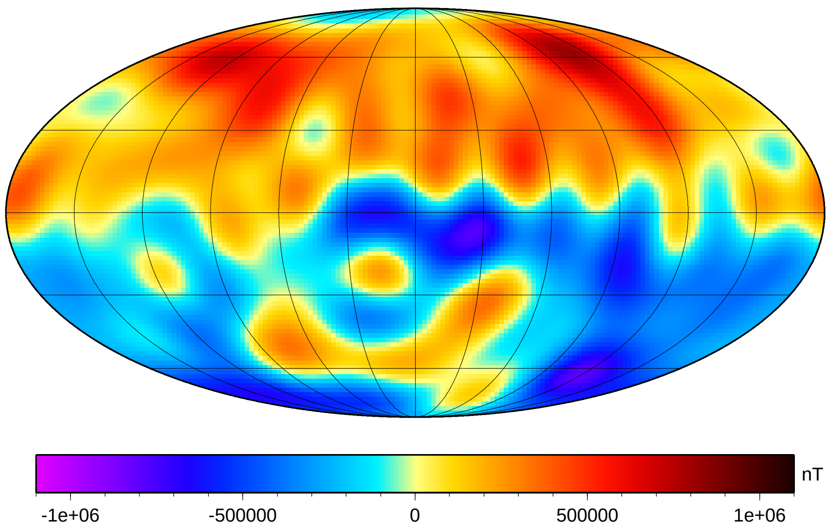


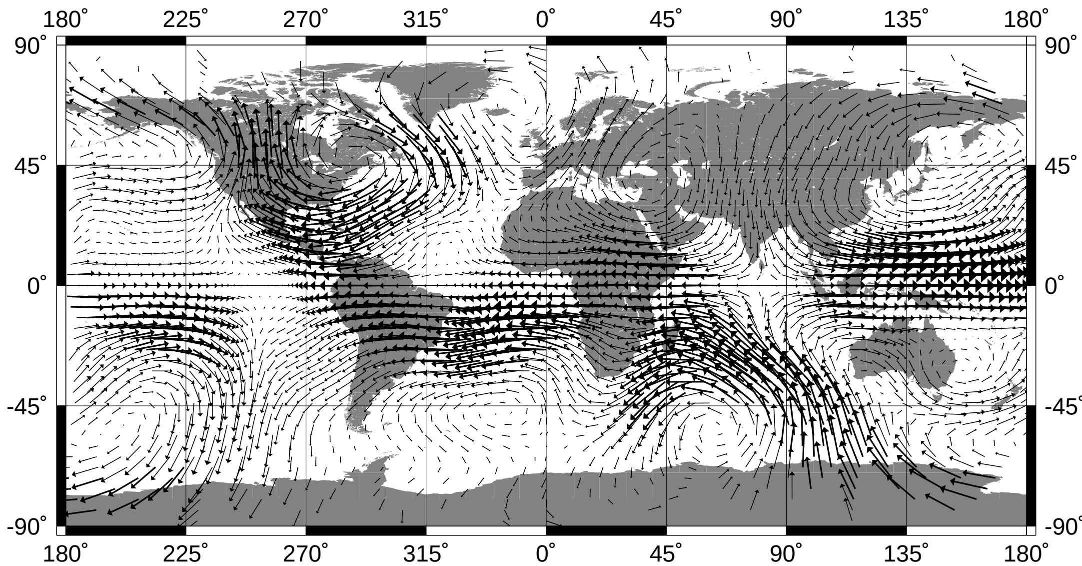
Oersted 2000



Dipolar magnetic field

Earth's magnetic field at the Core-Mantle Boundary

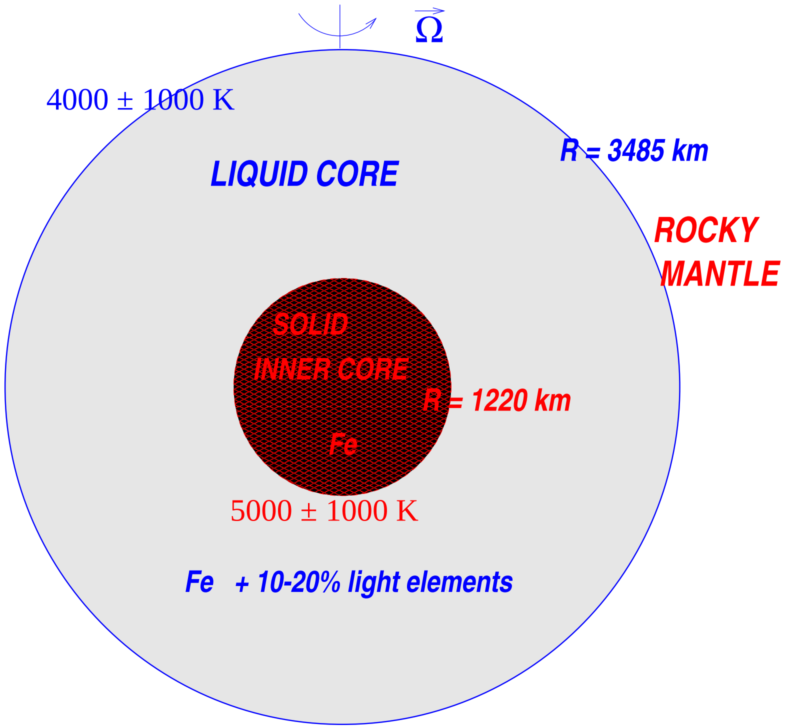




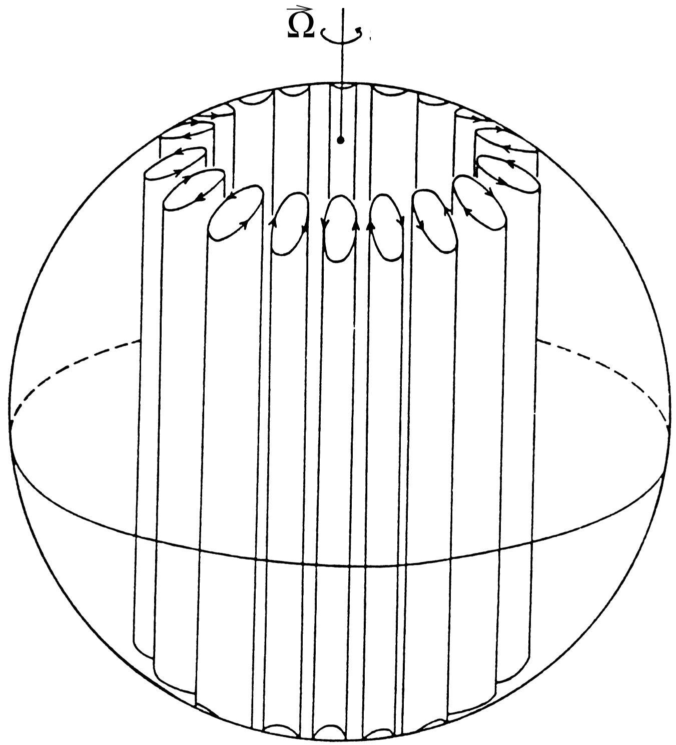
Oersted 2000, at the CMB

Velocity Field at the CMB

The Earth's Core

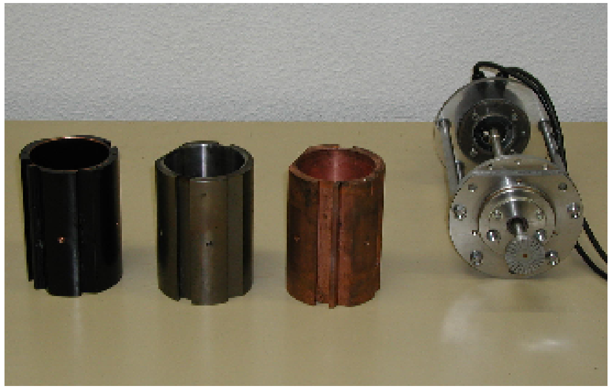


Structure and composition of the Earth's Core

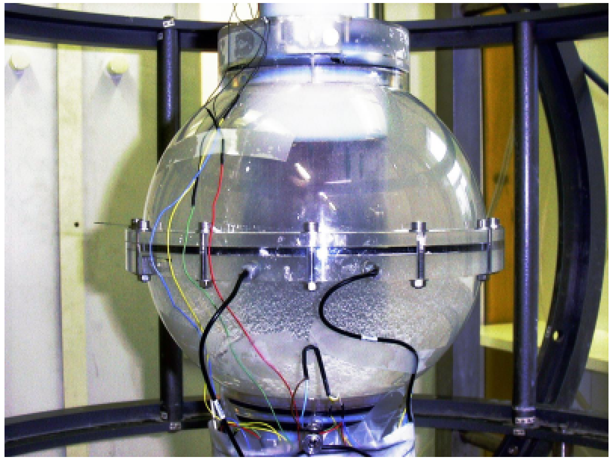


Flow at the onset of convection in a rapidly rotating sphere

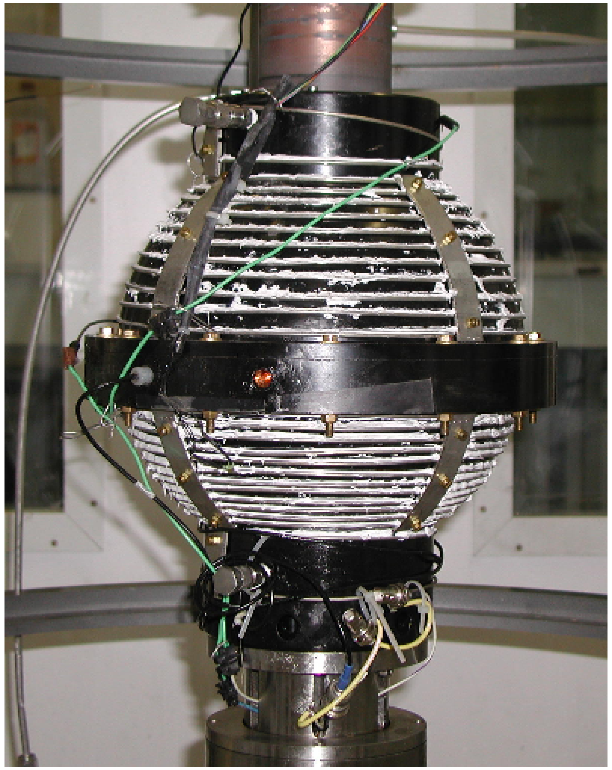
Our experimental approach of the dynamical flow of the Earth's Core



Vortex of Water, Gallium, Sodium

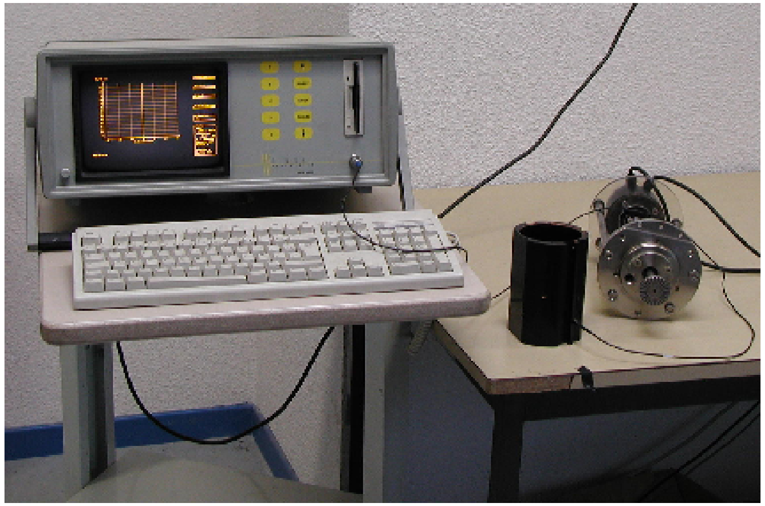


Thermal convection in Water

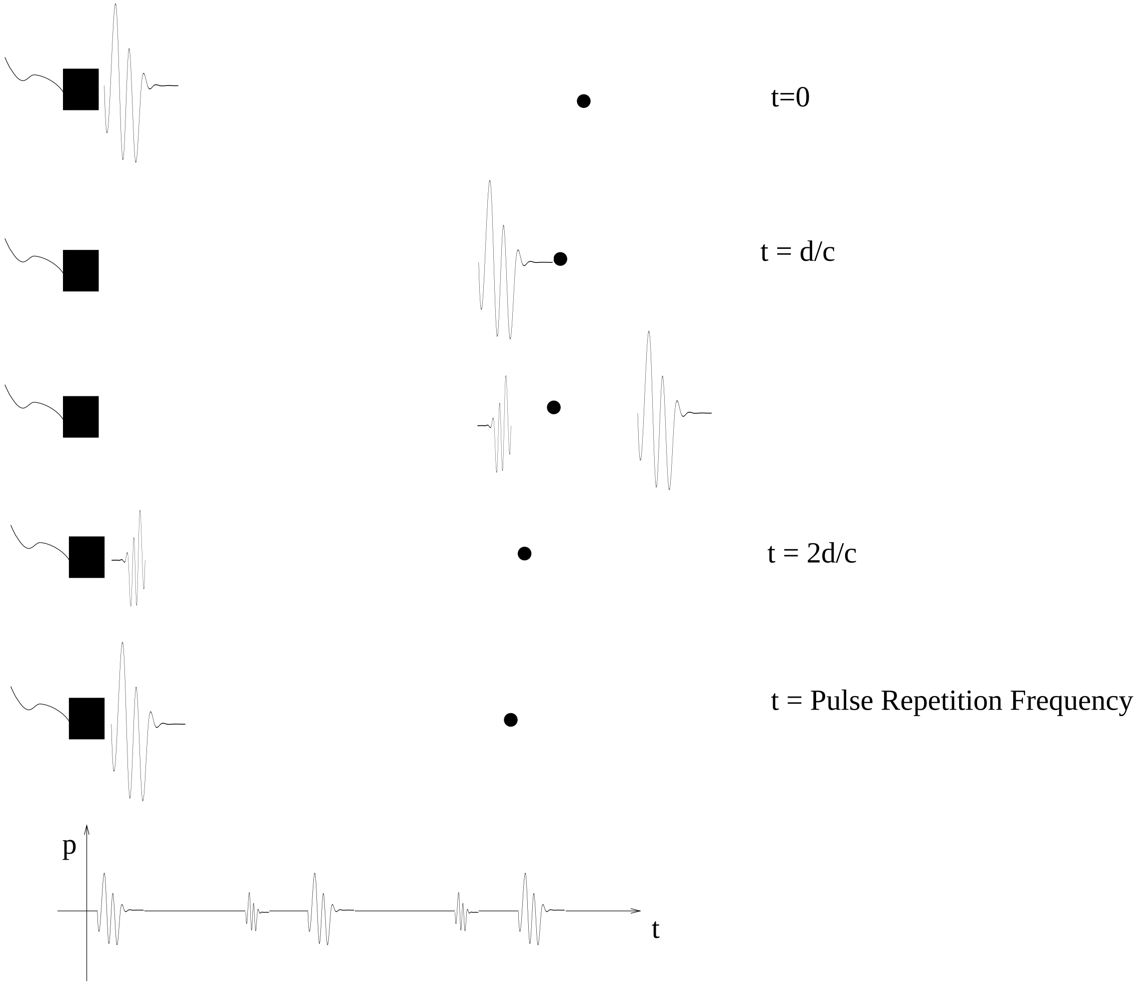


Thermal convection in Gallium

MEASUREMENTS OF $V(t)$

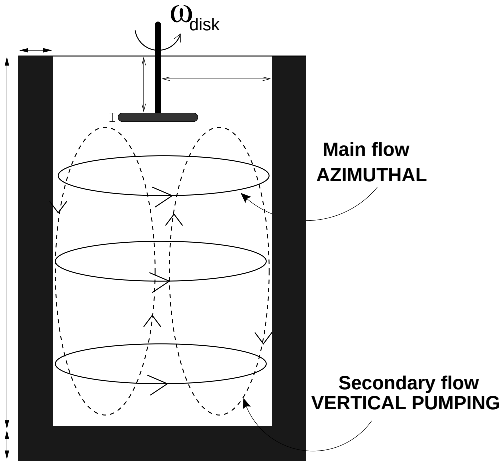


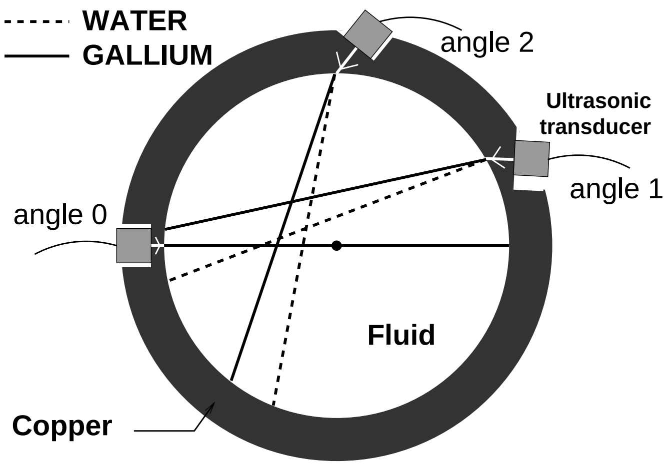
Doppler apparatus

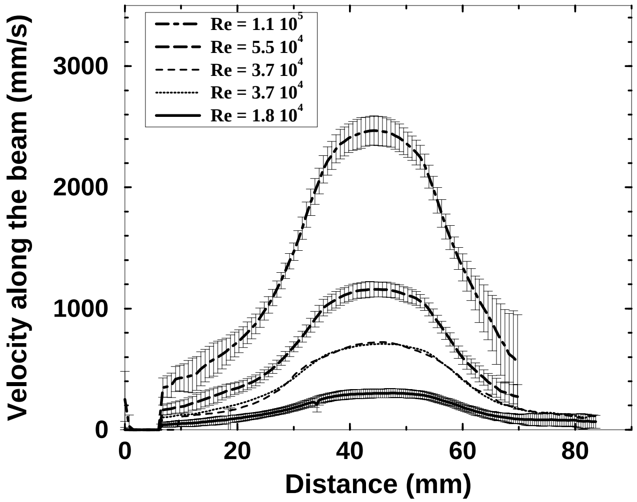


Doppler effect principle

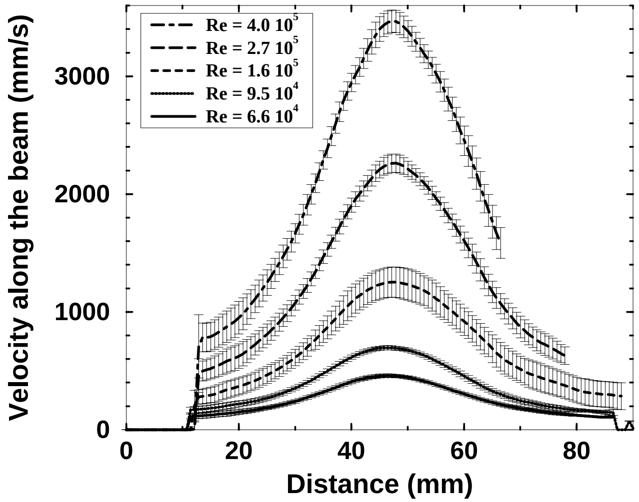
Velocity measurements in vortices of water, gallium, sodium



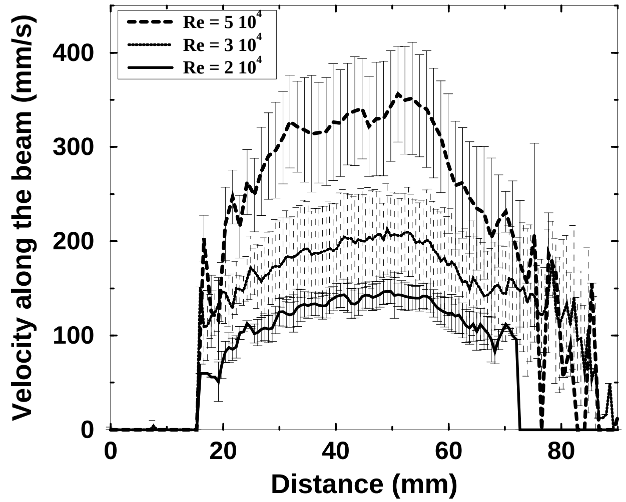




WATER

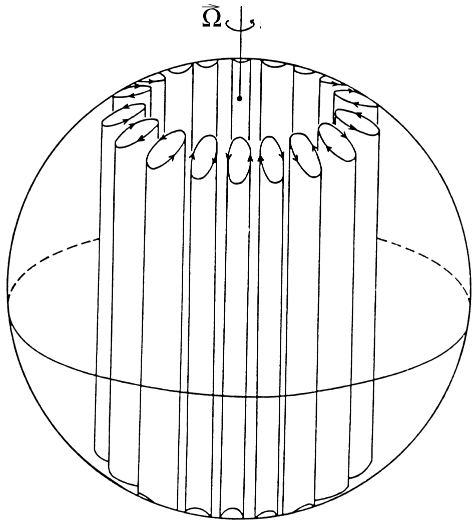


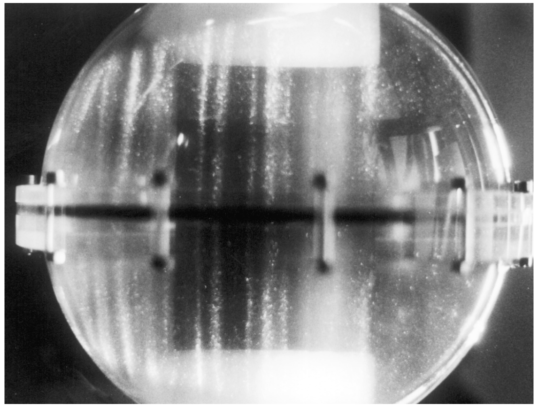
GALLIUM



SODIUM

Thermal convection in a rapidly rotating sphere: flow visualisation



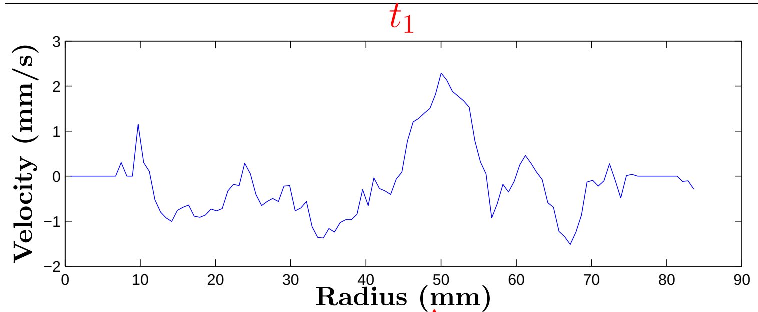


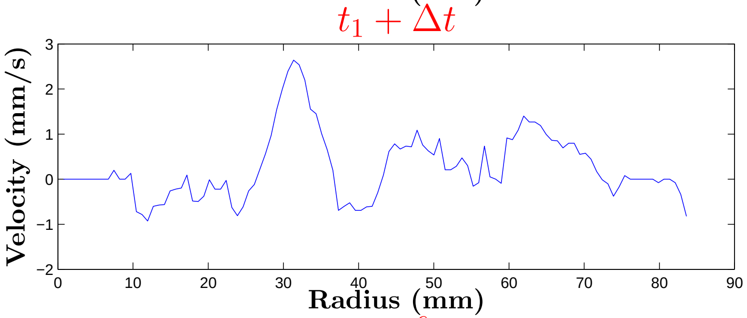
Coriolis Force $\Longrightarrow$

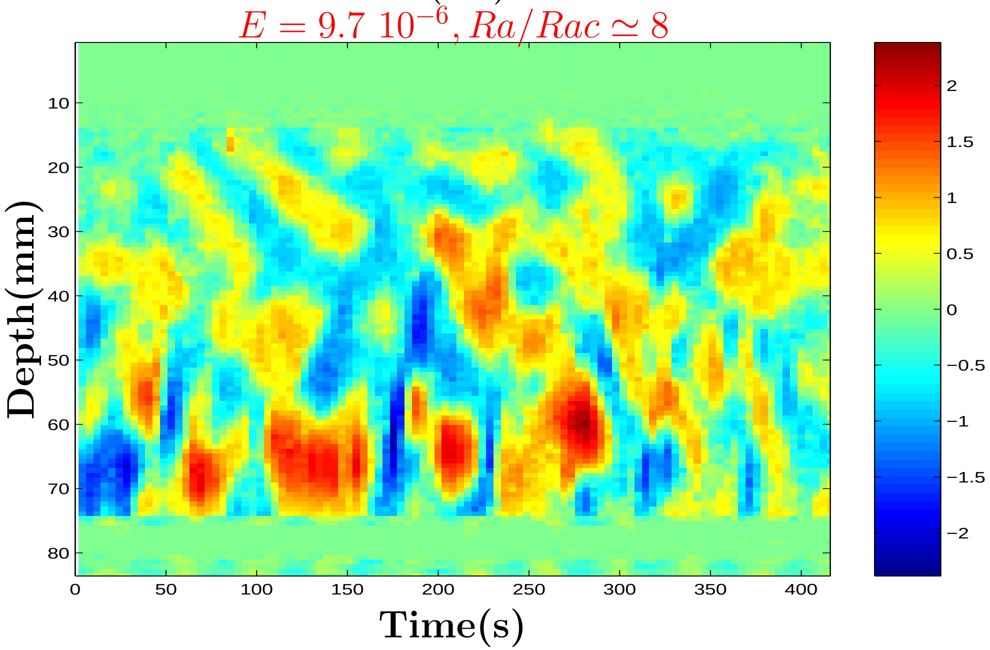
– **Geostrophic flow**

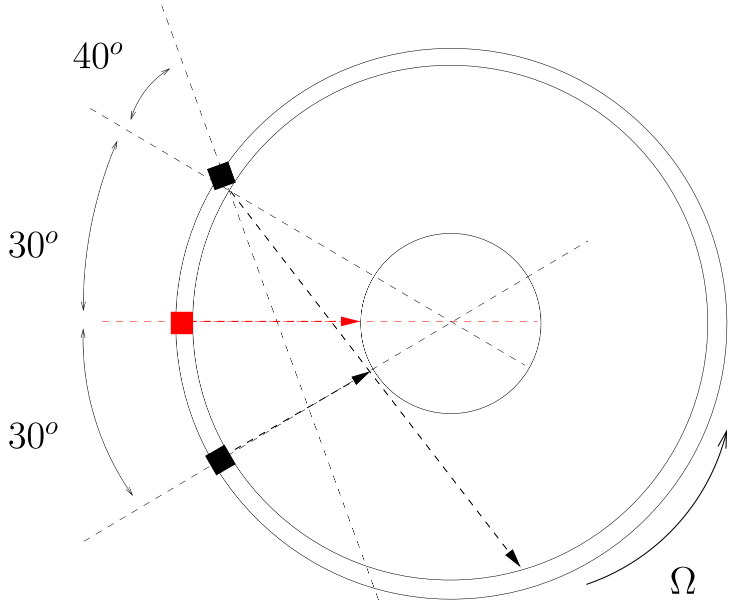
+ ...

Velocity measurements in a rapidly rotating sphere of water: radial velocities

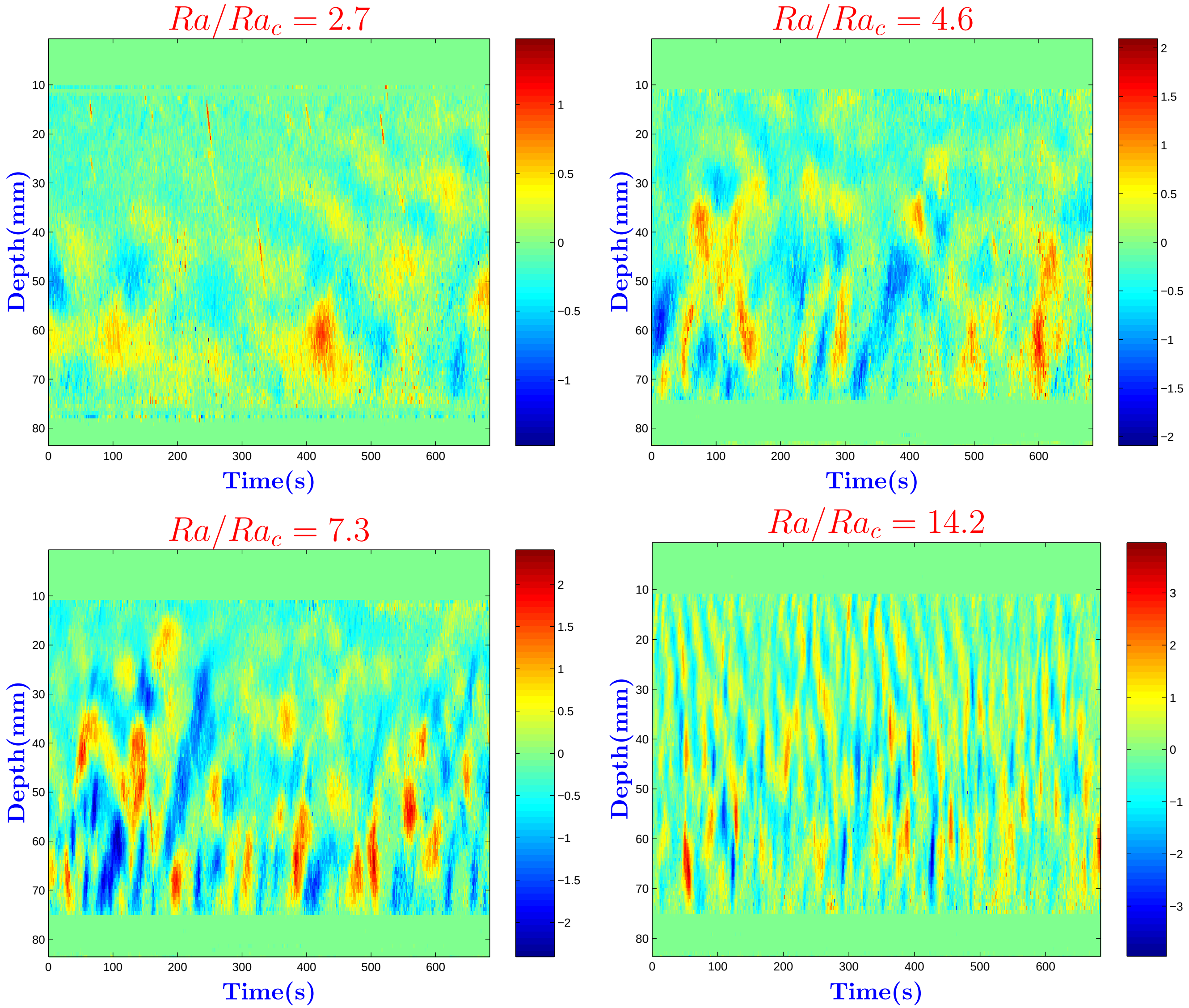






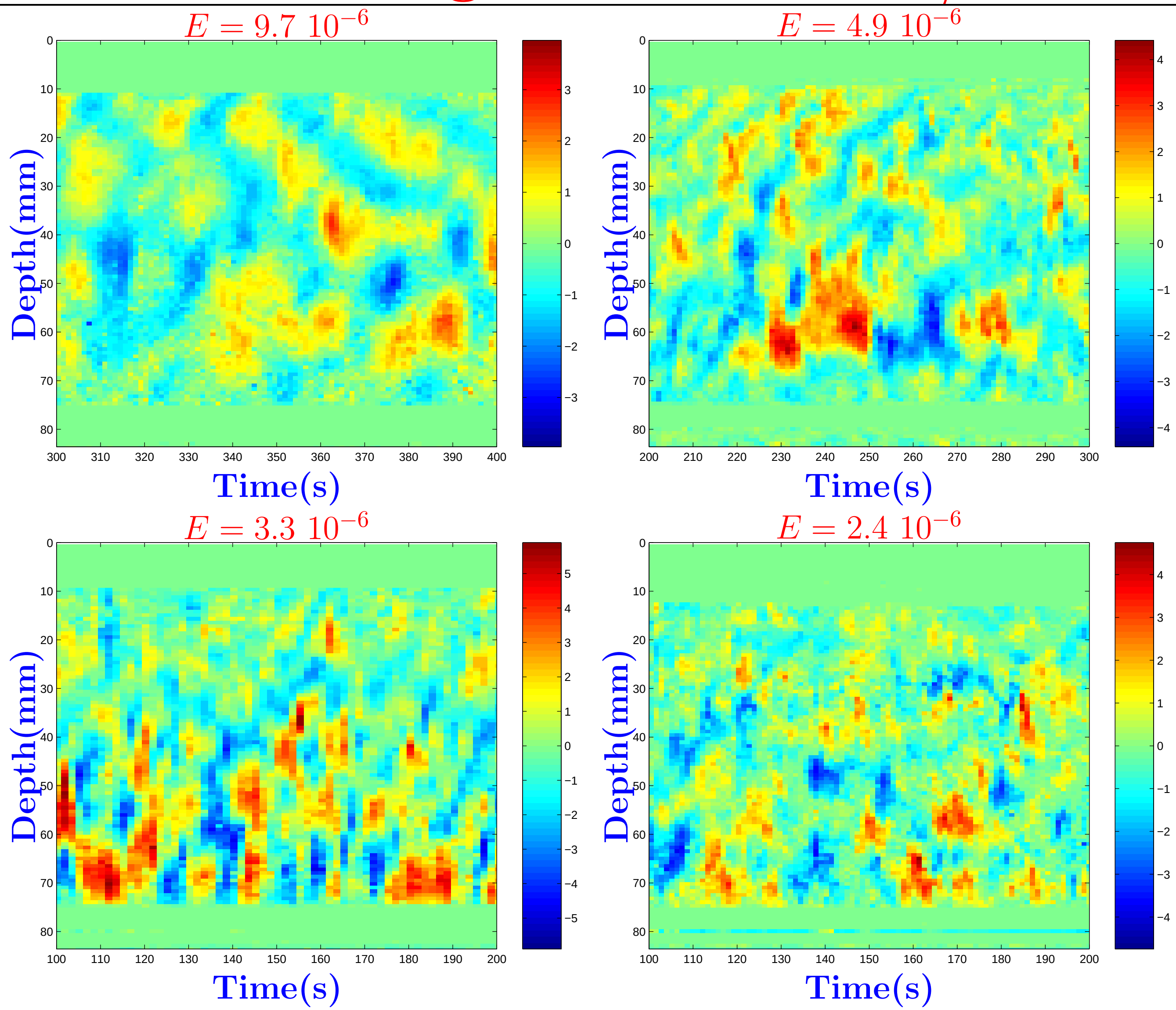


Velocity measurements in a rapidly rotating sphere of water : different dynamical regimes at fixed rotation rate



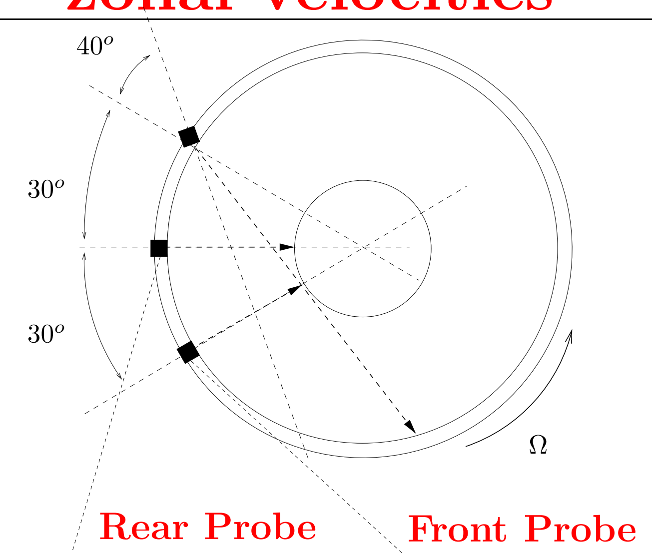
Evolution of time-depth radial patterns with Ra at $E = 9.7\ 10^{-6}$

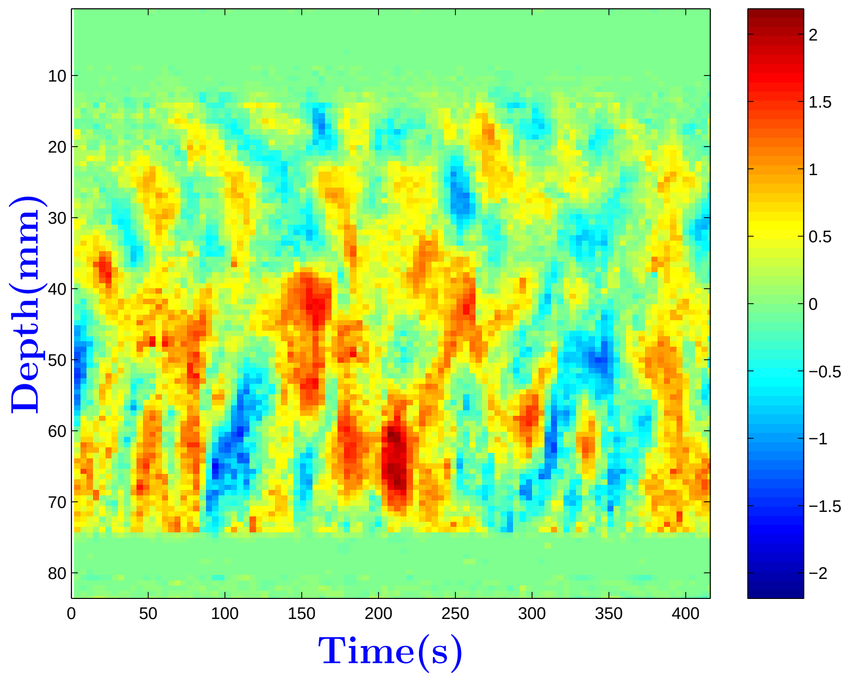
Velocity measurements in a rapidly rotating sphere of water : different regimes at fixed Ra/Ra_c

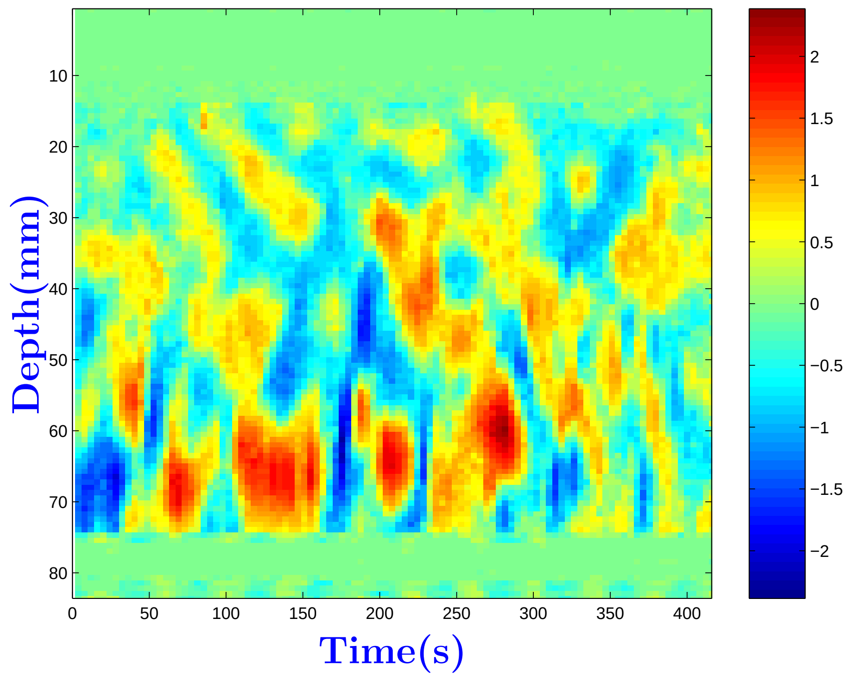


Evolution of time-depth radial patterns with E at $Ra/Ra_c = 14$.

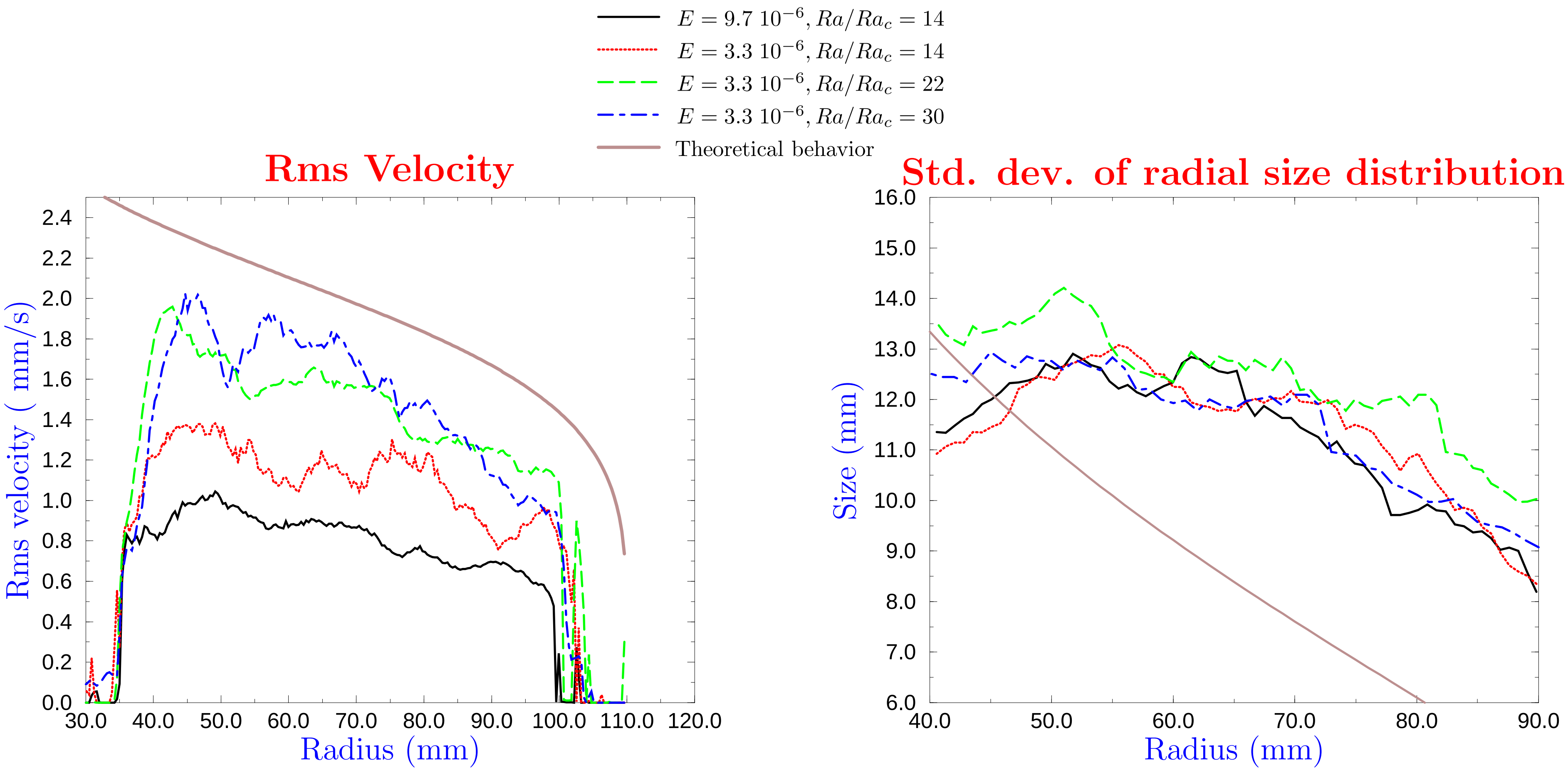
Velocity measurements in a rapidly rotating sphere of water : zonal velocities



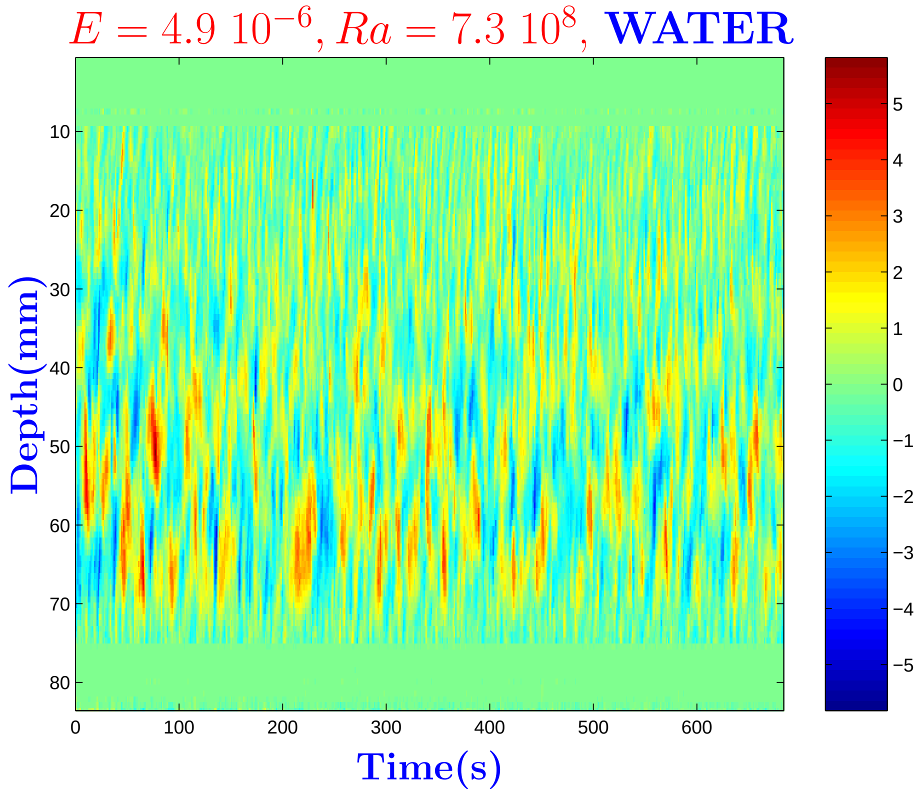


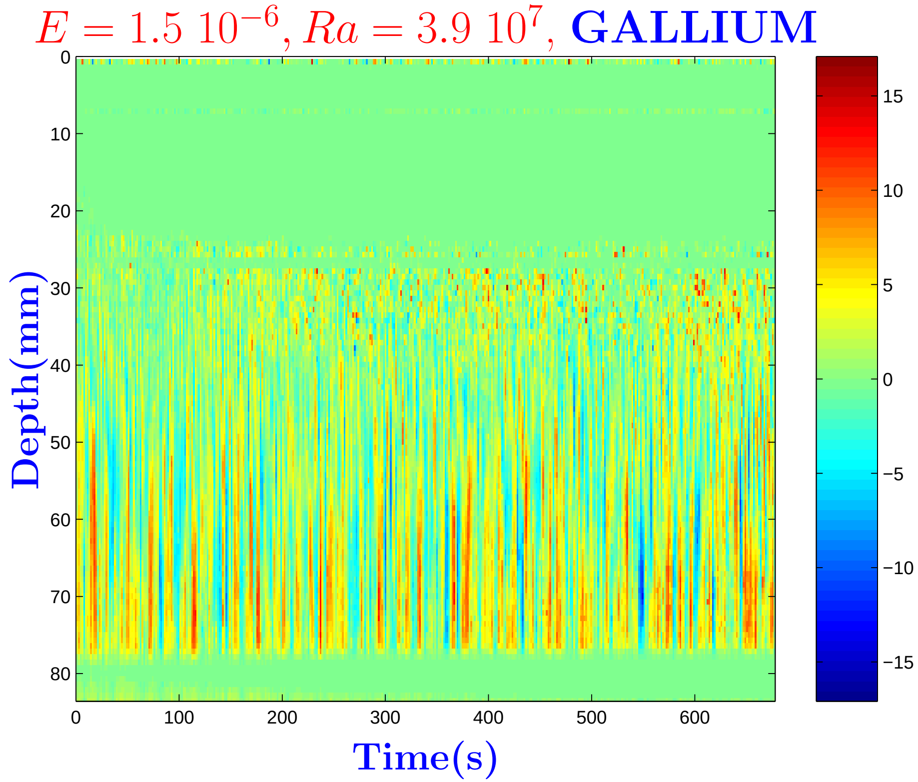


Mean Radial Properties of the flow.



Comparison of profiles obtained in Water and liquid Gallium.

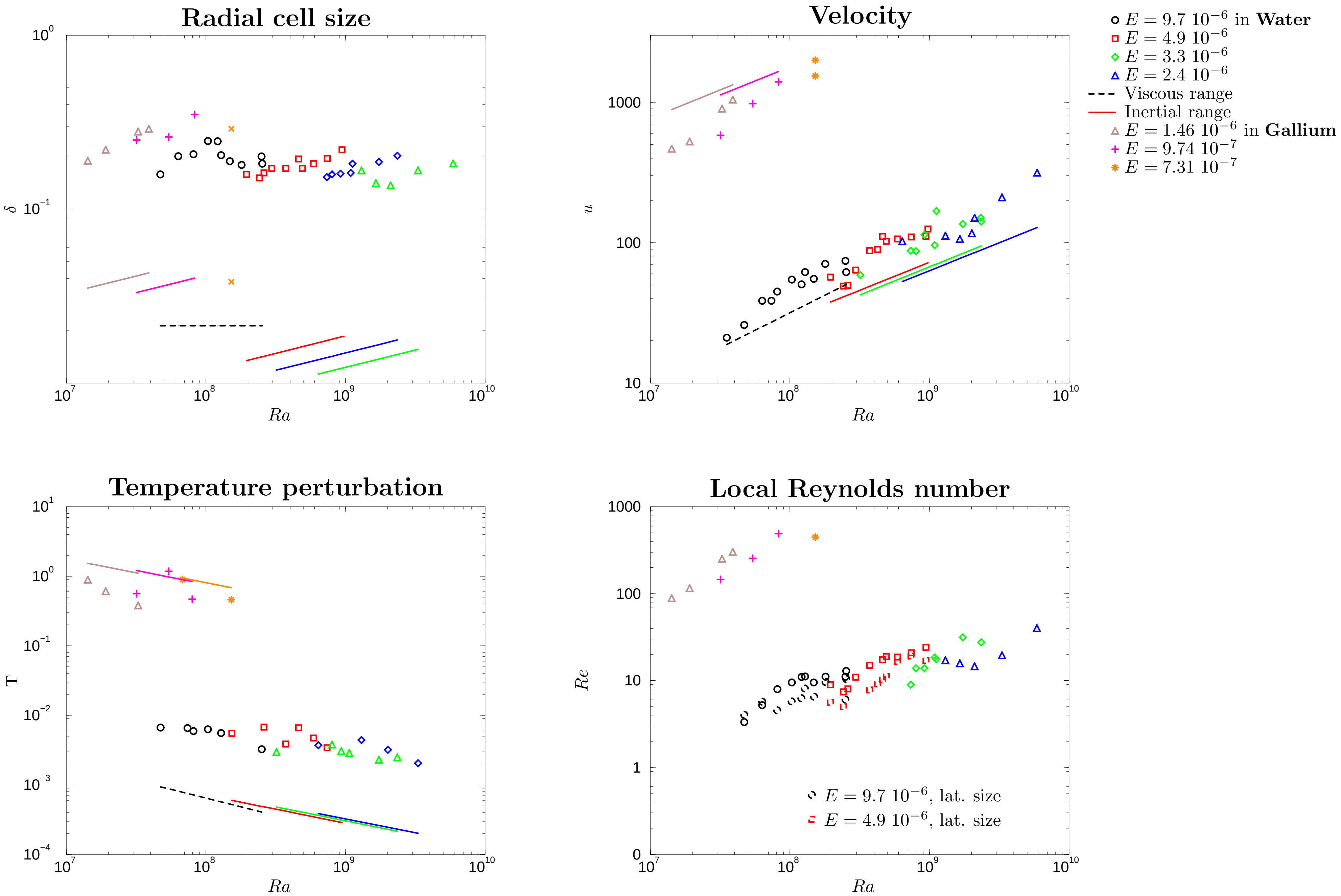




Non-dimensional numbers for the convection flow.

Number	Name	Meaning	Water	Gallium	Earth's core
$Ra = \frac{\alpha \Delta T g_D D^3}{\kappa \nu}$	Rayleigh number	$\frac{\text{buoyancy}}{\text{viscosity}}$	$10^7 - 10^9$	$10^7 - 10^8$	?
$E = \frac{\nu}{\Omega D^2}$	Ekman number	$\frac{\text{viscosity}}{\text{Coriolis}}$	$10^{-5} - 10^{-6}$	$10^{-6} - 10^{-7}$	$10^{-15} - 10^{-13}$
$P = \frac{\nu}{\kappa}$	Prandtl number	$\frac{\text{viscous diffusivity}}{\text{thermal diffusivity}}$	7	0.025	$0.1 - 10$

Non–dimensional mean properties of the flow.



CONCLUSIONS

Velocity fields are accessible in MHD experiments using the Doppler ultrasonic technique.

We have established power scaling laws for the explored parameter regime (Pr, E, Ra).

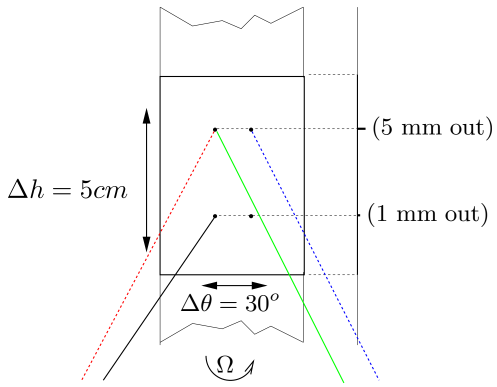
If the results are extrapolated to the core, they give structures which are too thin. Influence of the magnetic field...?

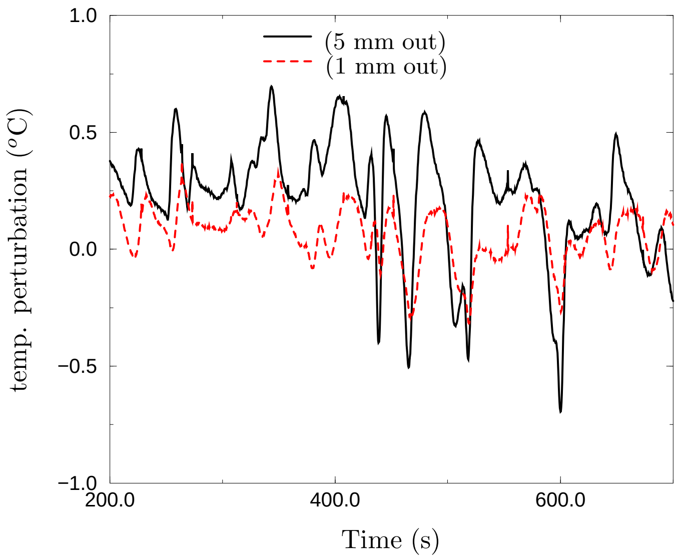
FUTURE:

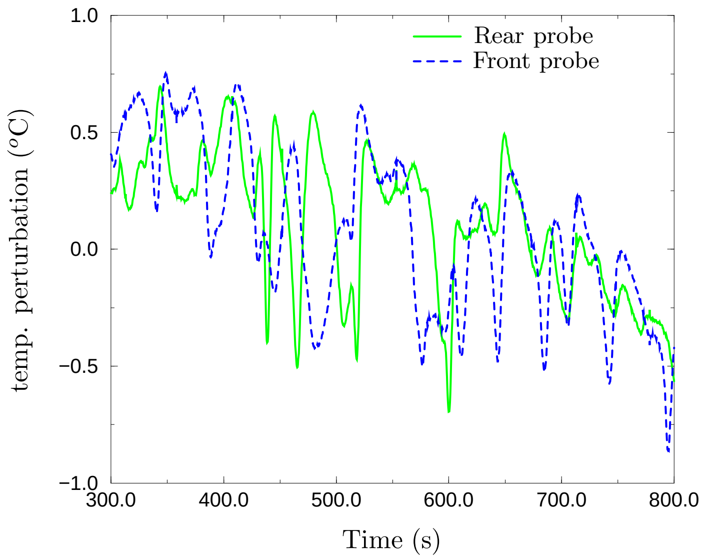
Magneto-convection in a rapidly rotating sphere of gallium.

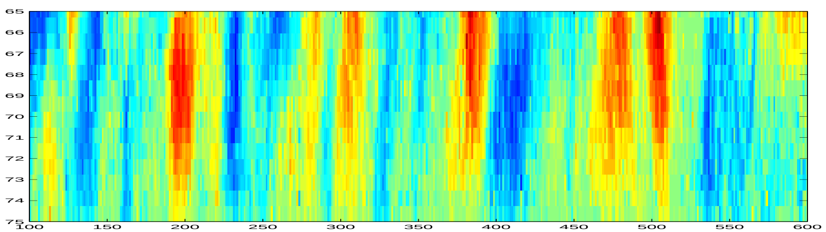
Moderate R_m experiments in Grenoble with liquid sodium under rotation and strong imposed magnetic field in a spherical geometry.

Temperature measurements.

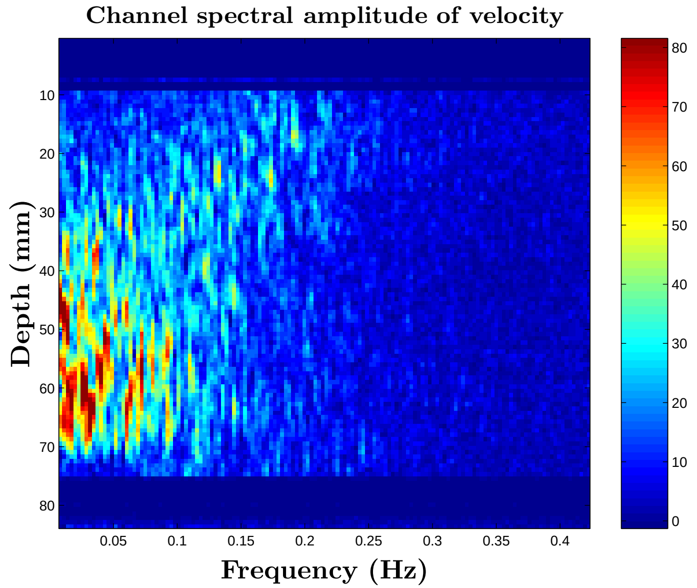


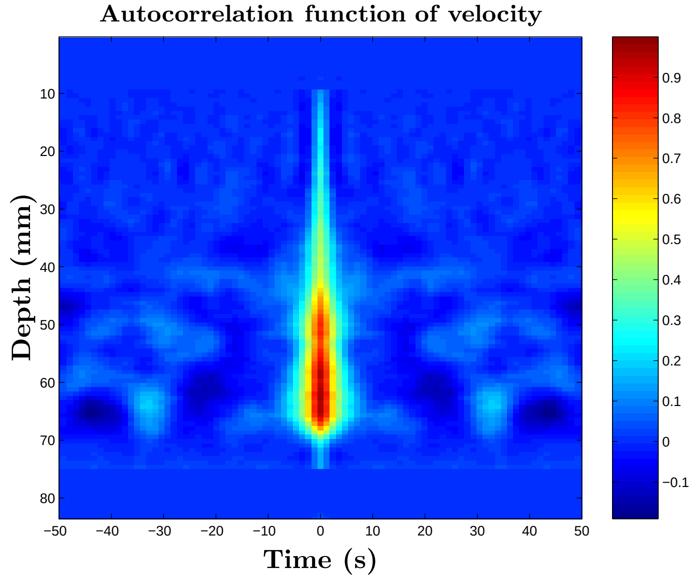


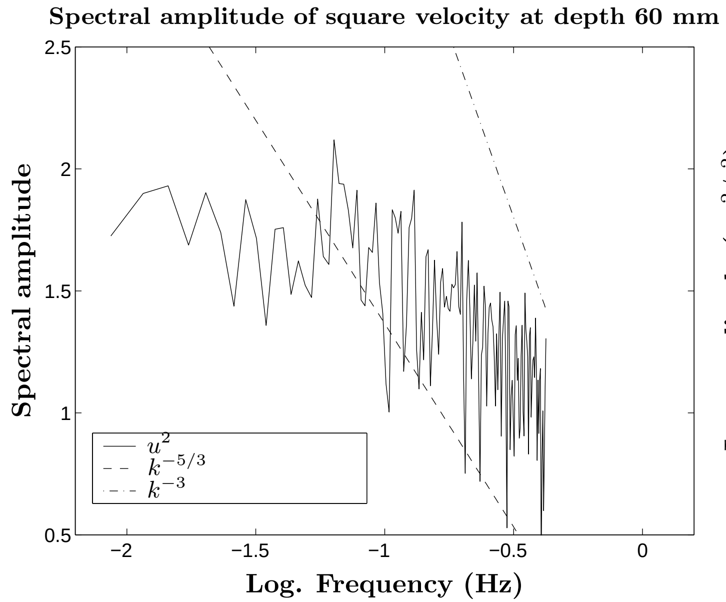


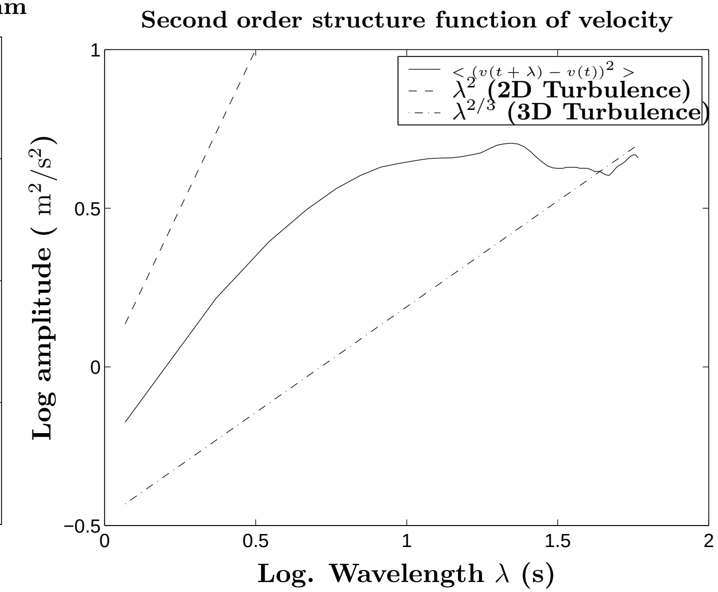


Time dependancy and quasigeostrophic turbulence.









Scaling relations for mean properties.

Let u, δ, T be scales for equatorial velocity, cell size and temperature perturbation. From convective heat flow over a sphere we get

$$T = 4\pi \frac{Nu}{uP^2},$$

Inertial balance: we equate Vortex stretching, Inertia, and buoyancy.

$$u = \left[(4\pi Nu)^{2/5} \left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{-1/5} \right] \left(\frac{Ra}{P^2} \right)^{2/5} E^{1/5}$$

$$\delta = \left[(4\pi Nu)^{1/5} \left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{-3/5} \right] \left(\frac{Ra}{P^2} \right)^{1/5} E^{3/5}$$

$$T = \left[(4\pi Nu)^{3/5} \left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{1/5} \right] \left(RaP^3 \right)^{-2/5} E^{-1/5}$$

Viscous balance: we equate Vortex stretching, viscosity, and buoyancy.

$$u = \left[(4\pi Nu)^{1/2} \left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{-1/3} \right] \left(\frac{Ra}{P^2} \right)^{1/2} E^{1/3}$$

$$\delta = \left[\left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{-1/3} \right] E^{1/3}$$

$$T = \left[(4\pi Nu)^{1/2} \left(\frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} \right)^{1/3} \right] \left(RaP^2 \right)^{-1/2} E^{-1/3}.$$

Governing equation of the flow

Vorticity $\boldsymbol{\omega}$ reduces to its z component ω, and the resulting equation writes:

$$\frac{\partial \omega}{\partial t} + \mathbf{u} \cdot \nabla \omega - \beta \mathbf{u} \cdot \mathbf{e}_r = \nabla^2 \omega + \frac{Ra}{r} \frac{\partial T}{\partial \theta}, \tag{1}$$

with

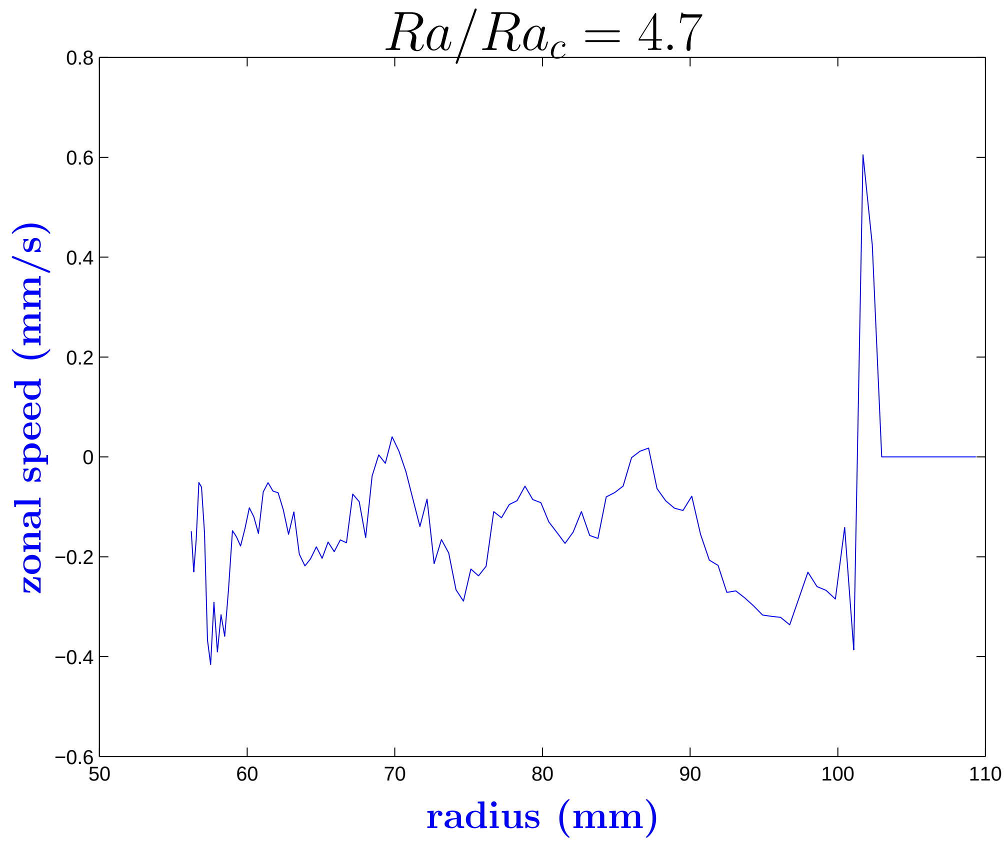
$$\beta = \frac{2}{L} \frac{\mathrm{d}L}{\mathrm{d}r} E^{-1},$$

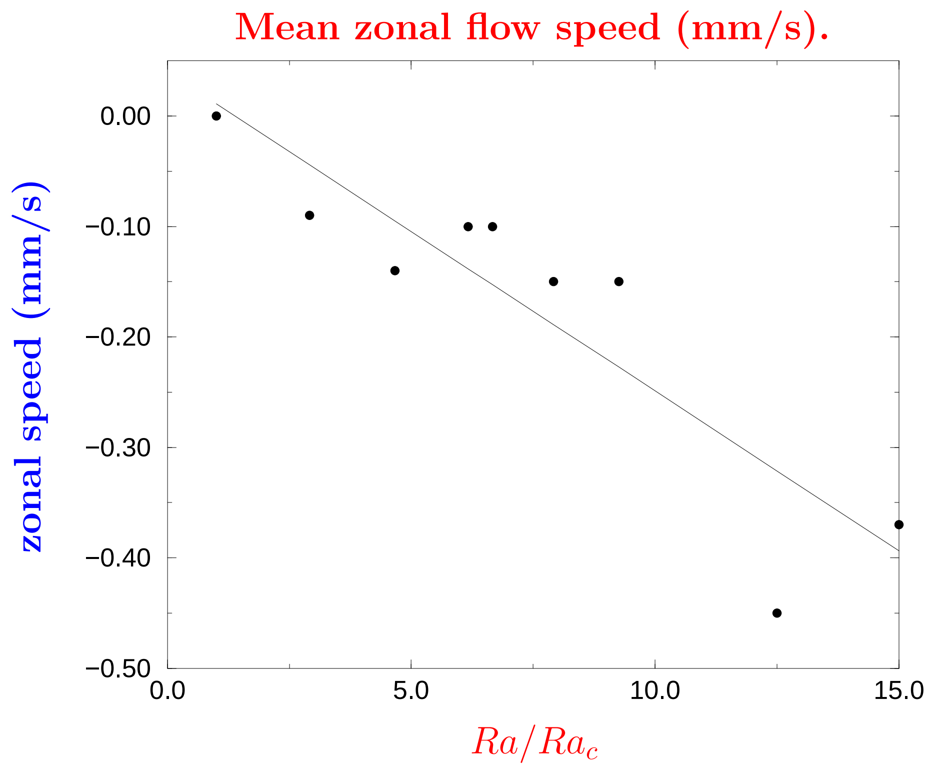
and

$$L = \sqrt{1 - \left(\frac{r}{r_e}\right)^2}.$$

L is half the height of a vertical fluid column between the upper and lower boundaries.

Velocity measurements in a rapidly rotating sphere of water





Time averaged zonal flow speed measured along radius **Radius-averaged zonal speed against** Ra

$$E = 9.8\ 10^{-6}$$