Measurements of apparent viscosity in rapidly rotating fluids :

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- Turbulent diffusivities are broadly used in many *numerical* simulations under various asumptions… oftentimes quite difficult to physically justify.

- In-situ *measurements* of these turbulent properties in deep planets are out of reach… (as opposed to turbulent viscosity *measured* in oceans and used successfully in modelisation).

Can we gain information on turbulent properties in rotating fluids with experiments?

FIRST run experiments in configurations where the laminar flow is theoretically known (using molecular diffusivity properties) .

SECOND run the same kind of experiment in a turbulent regime and possibly infer scaling laws for turbulent diffusive properties.

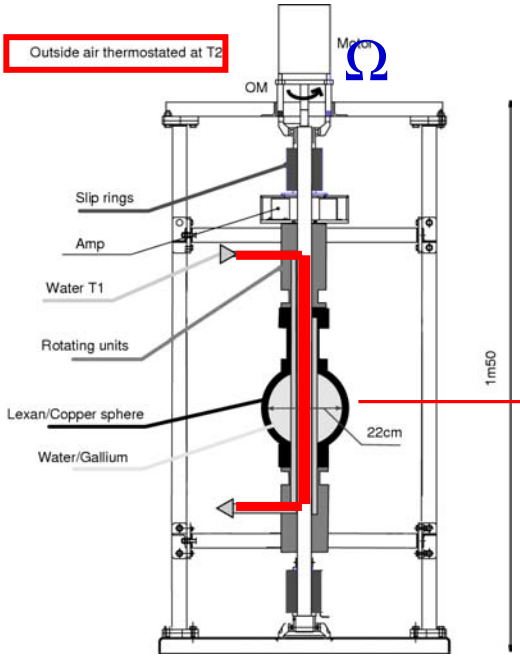
Three experiments

1) Rotating spherical shell in WATER (Grenoble).

2) Rotating spherical shell in GALLIUM (Grenoble).

3) Rotating cylinder (Oxford, UK).

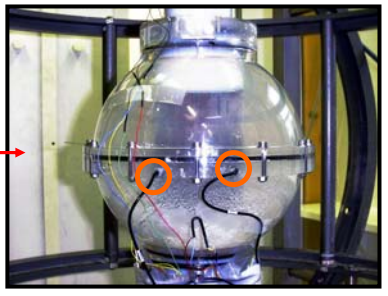
I) Rapidly rotating spherical shell in WATER.



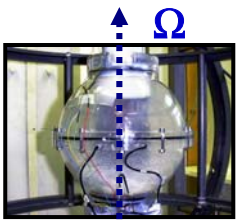
WATER

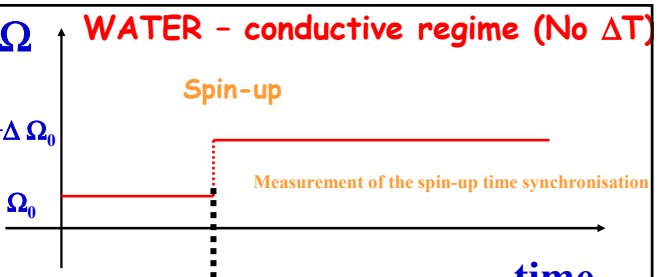
$P=\nu/\kappa=7$

$E\approx 10^{-6}$



(Aubert et al., 2001,2003)

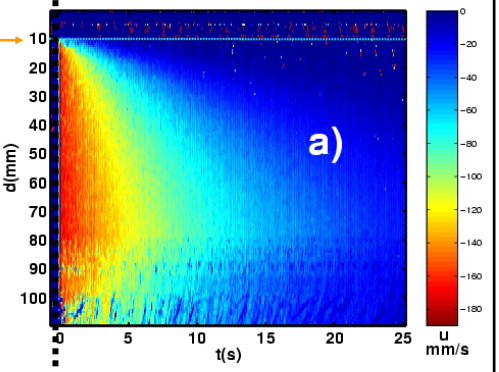




Outer radius

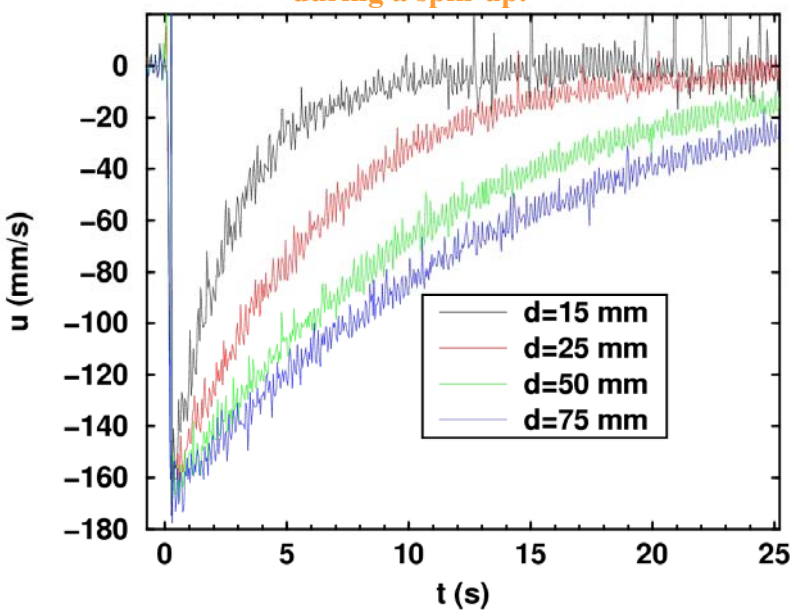
at t=0

Ω =300 rpm→ Ω=340 rpm

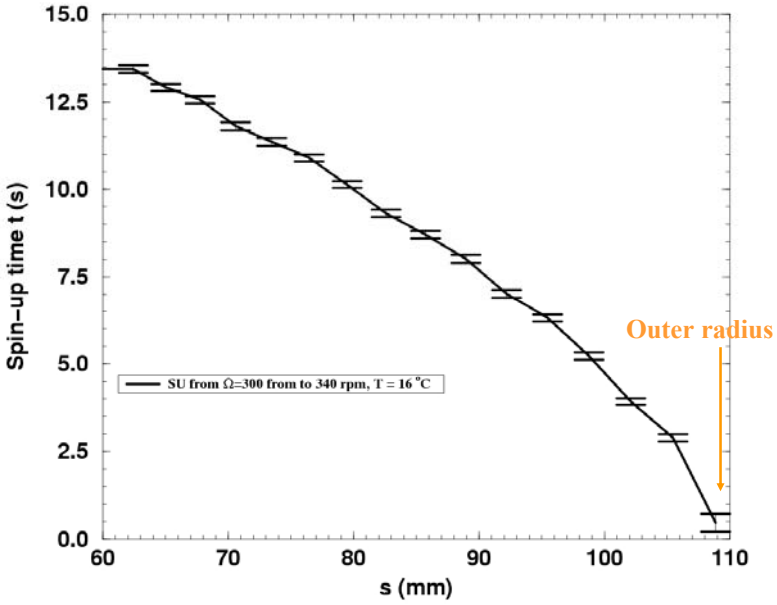


(Brito et al., 2004)

Exponential decay-time of the velocity at various radii during a spin-up.



Spin-up τ of the velocity at various radii s.



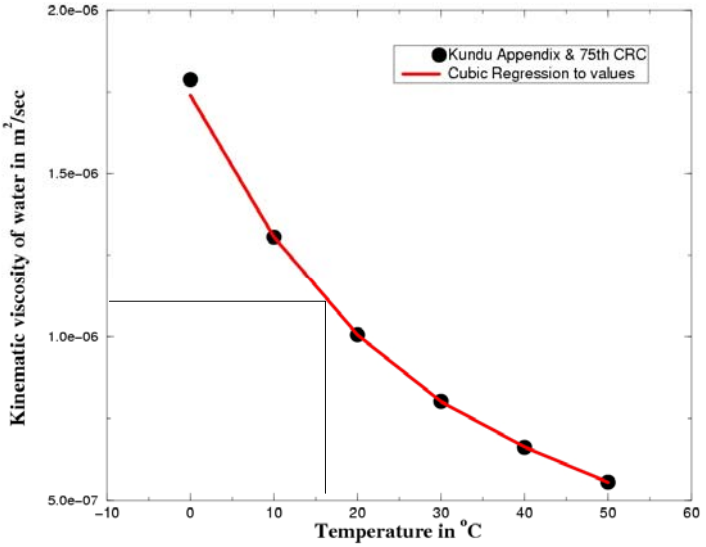
- Azimuthal velocity u_ϕ as a function of *t*, *s*, after a spin-up: (Greenspan, 1968)

$$u_\phi(s,t) = s\,\Delta\Omega\,\exp\left(-\frac{t}{\tau}\right)$$

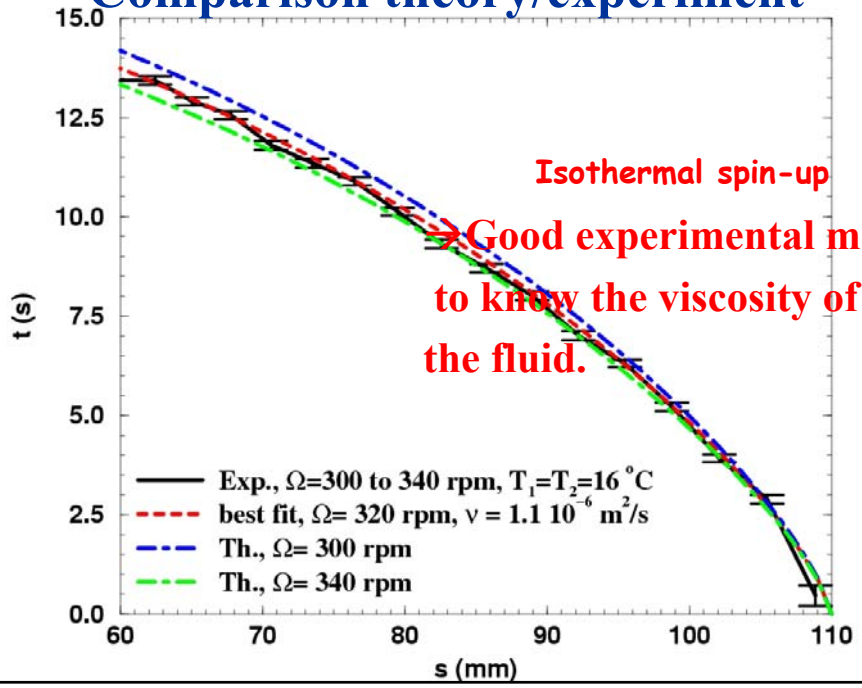
$$\tau = \frac{(1-s^2/R^2)^{3/4}}{E^{1/2}\Omega}$$

$$\tau \;\alpha\; E^{-1/2} \quad \text{for} \quad \frac{\Delta\Omega}{\Omega} \ll 1 \text{ (linear theory)}$$

ν(T) for water



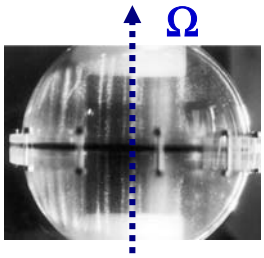
Comparison theory/experiment

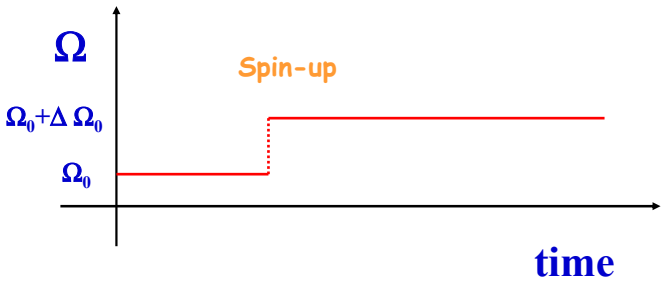


Isothermal spin-up

⇒Good experimental mean to know the viscosity of the fluid.

WATER – CONVECTIVE regime ($\Delta T \approx 10$-20-$30°C$)

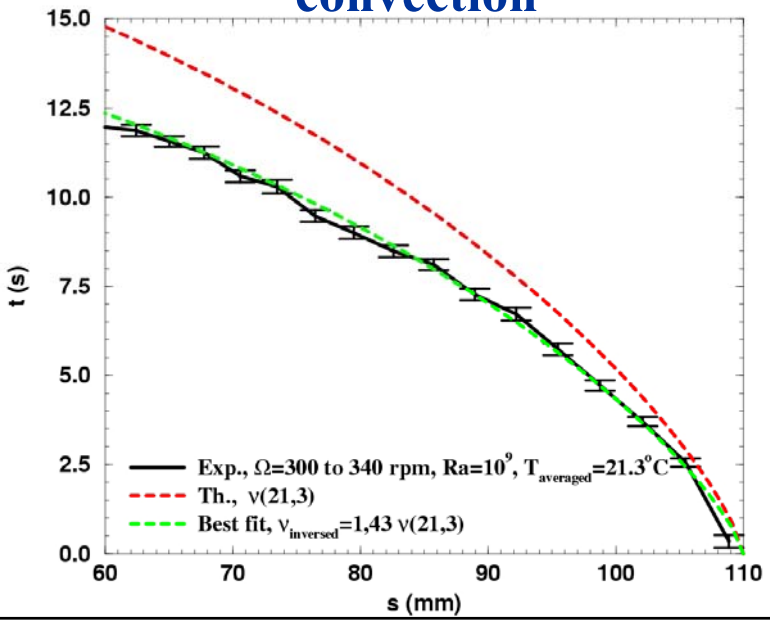




$Ra < 80\ Ra_C$

$Re_l < 200$

Spin-up in presence of thermal convection

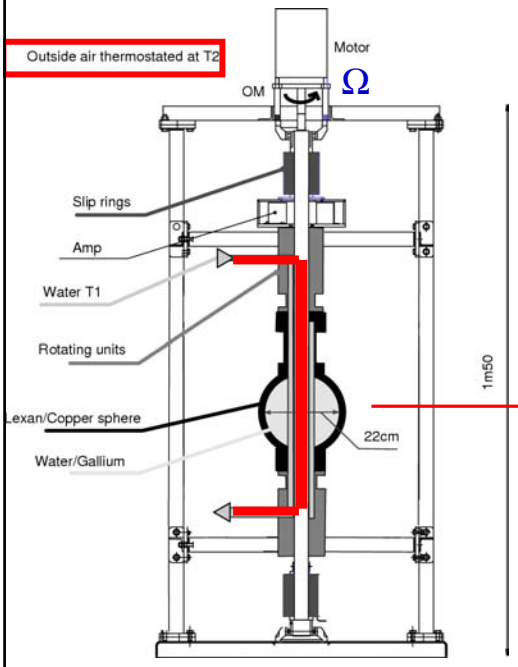


Ω (rpm)	$(\Omega + \Delta\Omega)$ (rpm)	Ra/Ra_c	ν_{eff}/ν
300	340	24.1	1.16
300	340	40.9	1.36
* 300	340	50.7	1.43
360	400	29.2	1.18
360	400	52.0	1.35
360	400	73.4	1.54
500	540	40.8	1.19
500	540	68.1	1.40
500	540	78.2	1.49

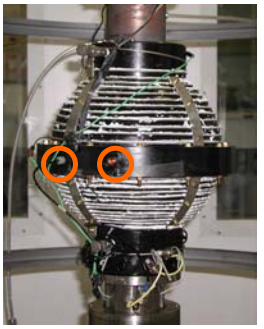
As the forcing increases (Ra/Rac), the apparent viscosity increases as well.

(Brito et al.,PEPI, 2004)

II) Rapidly rotating spherical shell in GALLIUM



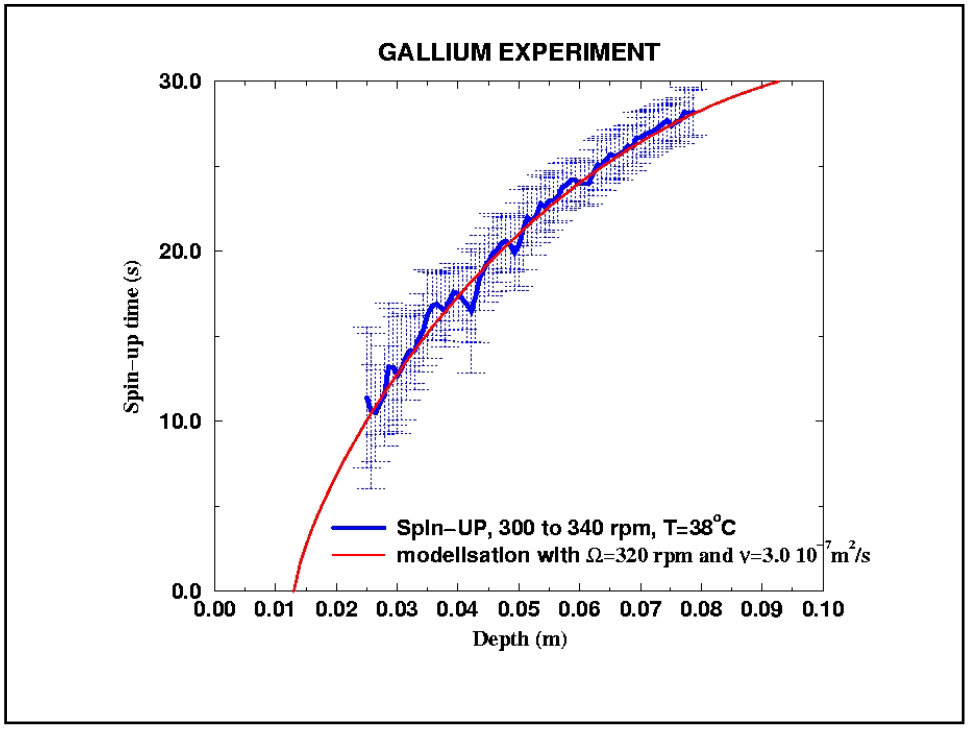
GALLIUM

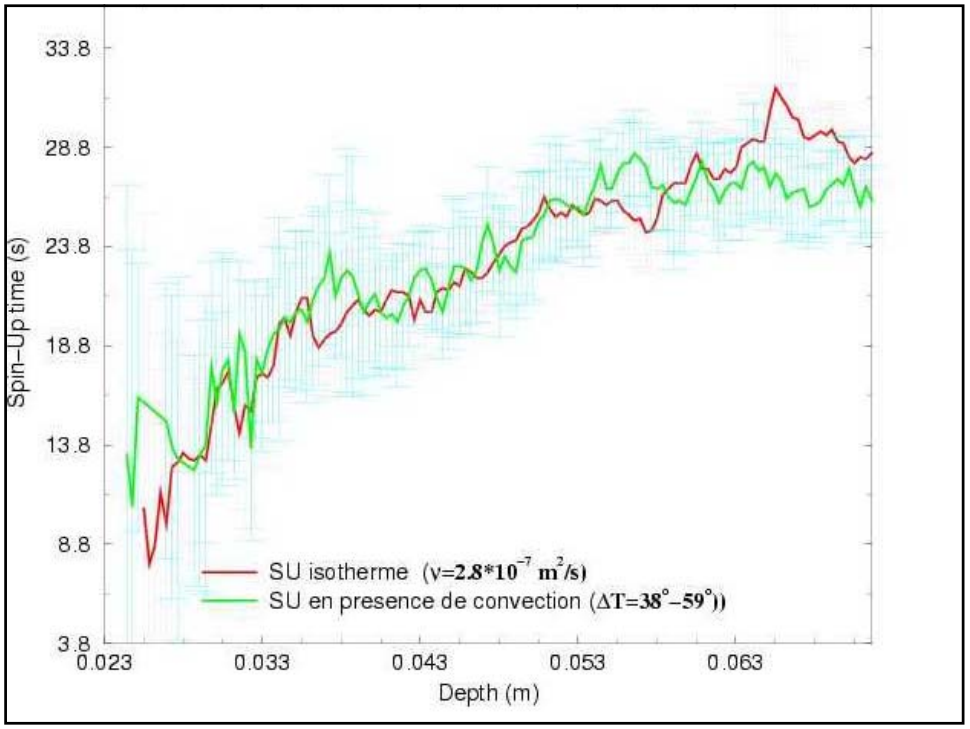


(Aubert et al., 2001,2003)

Comparison between experiments

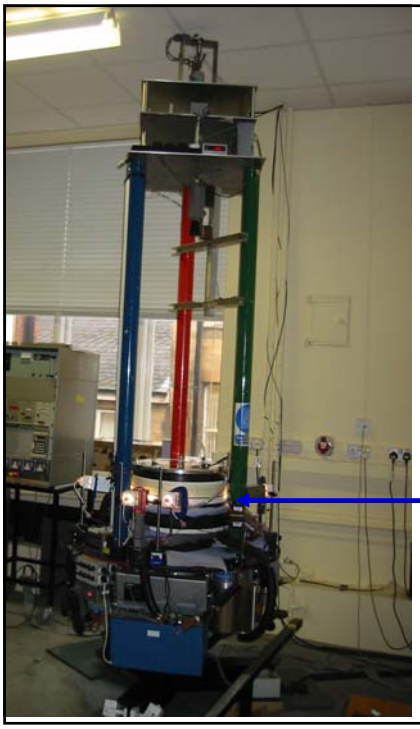
	Thermal convection Water experiments.	Thermal convection Gallium experiments.
Ra	3 Ra_c-80 Ra_c	Ra_c-4 Ra_c
P	7	0.02
E	10^{-5} -10^{-6}	10^{-6} -10^{-7}
Re	10^2	10^3


GALLIUM EXPERIMENT
30.0
20.0
10.0
0.0
Spin–up time (s)
0.00 0.01 0.02 0.03 0.04 0.05 0.06 0.07 0.08 0.09 0.10
Depth (m)
Spin–UP, 300 to 340 rpm, T=38°C
modellsation with Ω=320 rpm and ν=3.0 10⁻⁷m²/s

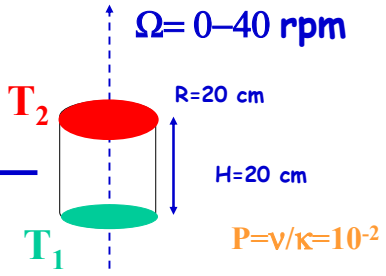

33.8
28.8
23.8
18.8
13.8
8.8
3.8
Spin–Up time (s)
0.023 0.033 0.043 0.053 0.063
Depth (m)
SU isotherme (ν=2.8*10⁻⁷ m²/s)
SU en presence de convection (ΔT=38°–59°))

III) Rotating cylinder in WATER

Oxford, UK, Peter Read.



Rotating cylinder with temperature control between top and bottom. WATER

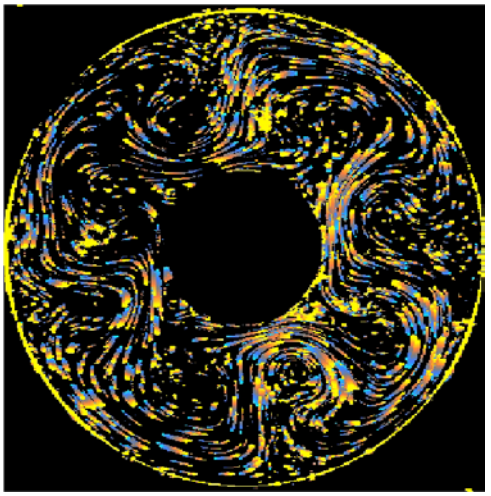


$P=\nu/\kappa=10^{-2}$

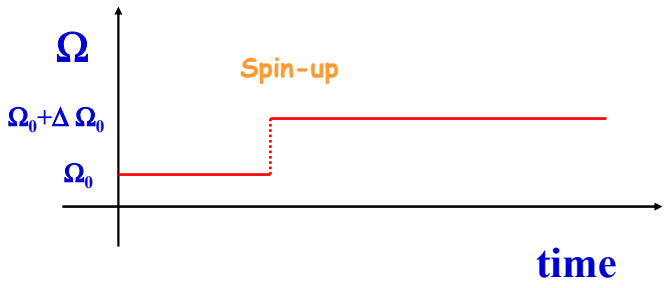
$E\approx10^{-4}$

$Ra<20\ Ra_C$

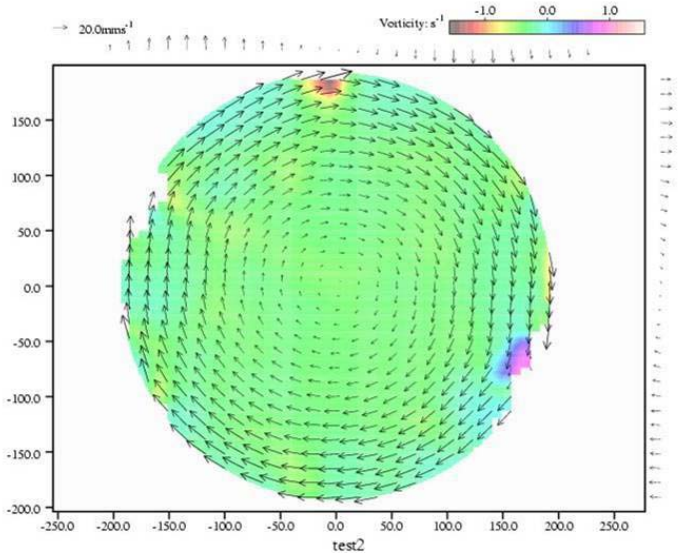
Particle Imaging Velocimetry measurements



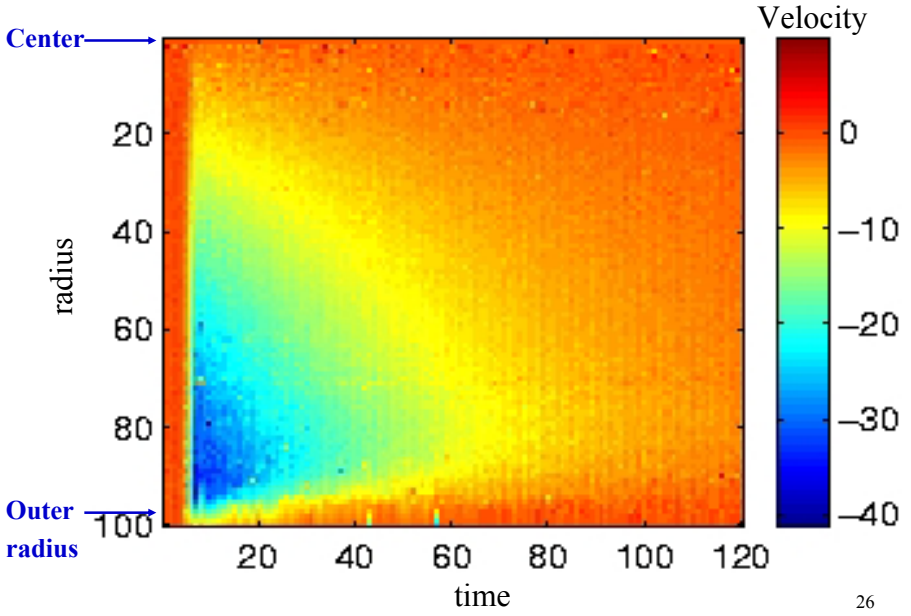
Spin-up velocity measurements

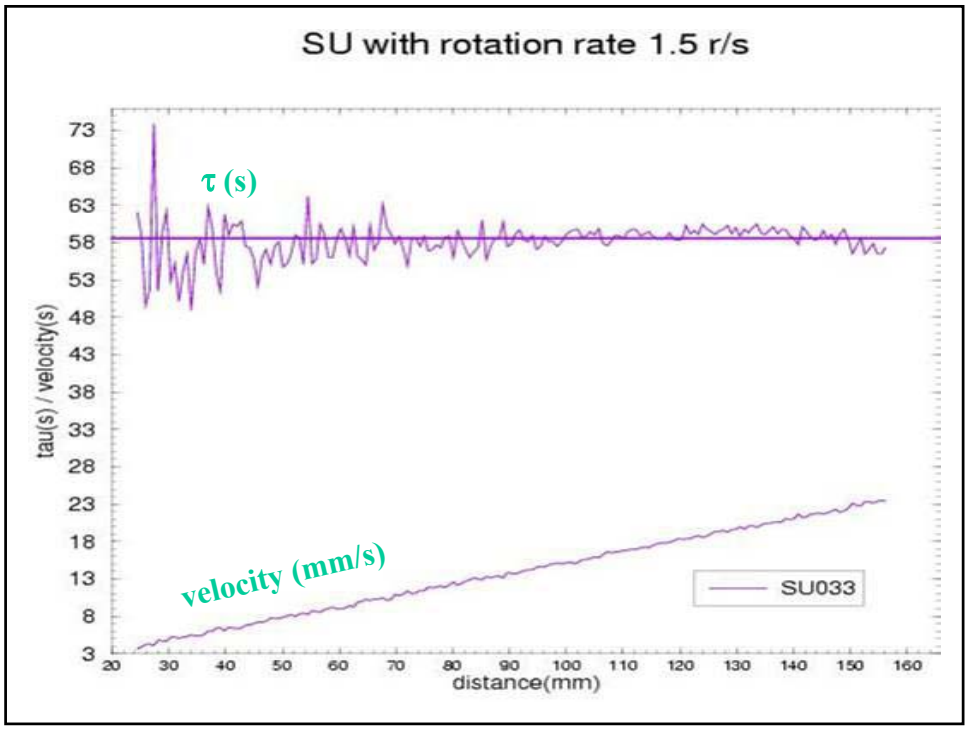


Spin-up velocity measurements



Spin-up velocity measurements





Conclusions

1) Sphere of water, geophysical implication:
Core-mantle coupling may be greater than previously believed (geodynamo session, B. Deleplace).

2) Sphere of water vs Sphere of gallium: The apparent measured viscosity is not only a function of Re…. but also a function of P.