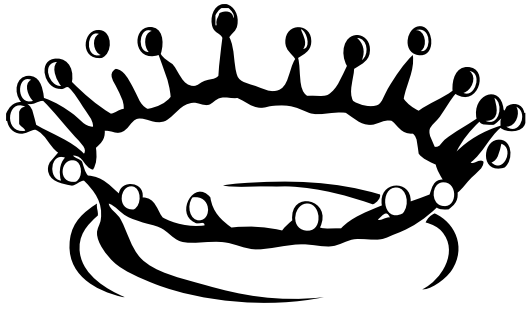
Towards the “ultimate” state of turbulence

R. Ostilla Mónico, E. P. van der Poel,
S. Grossmann, R. Verzicco & D. Lohse



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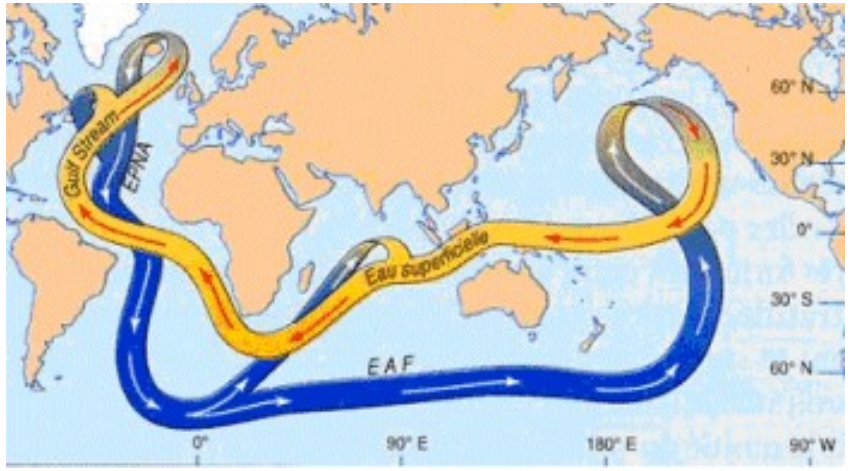
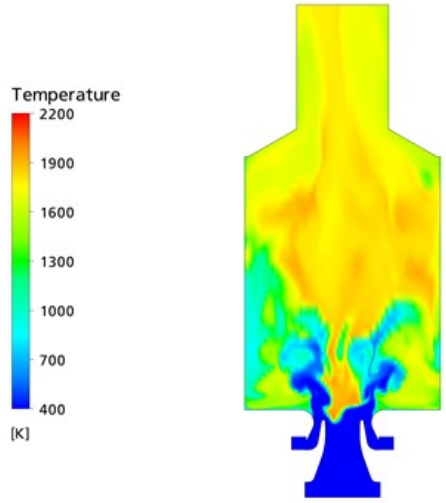
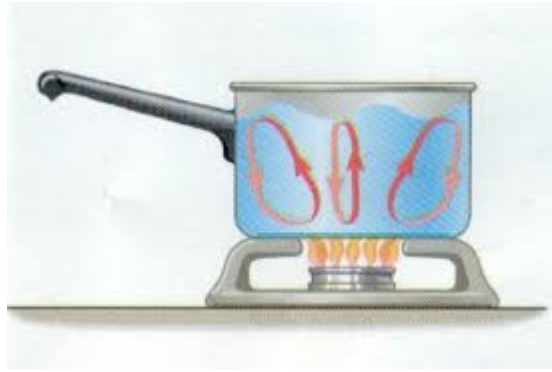
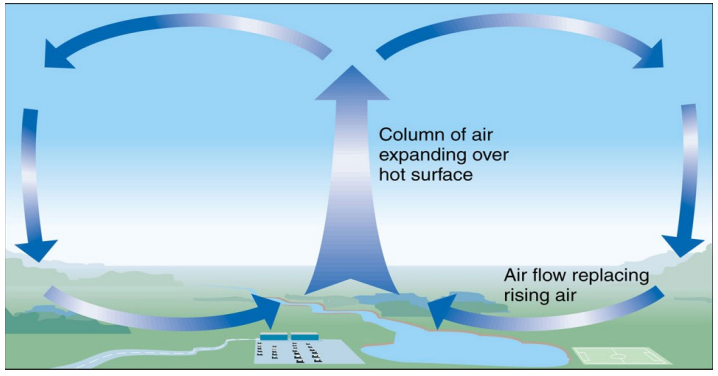
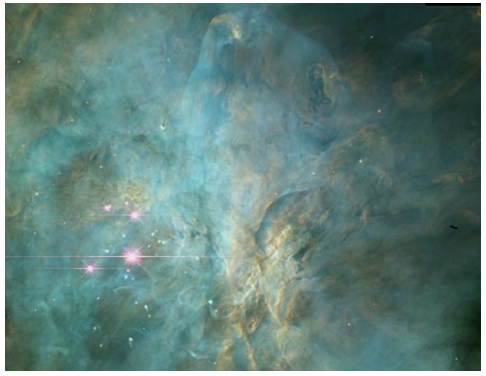
Turbulent flow matters!

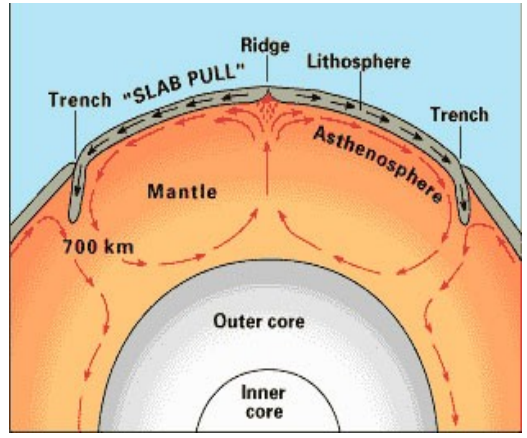




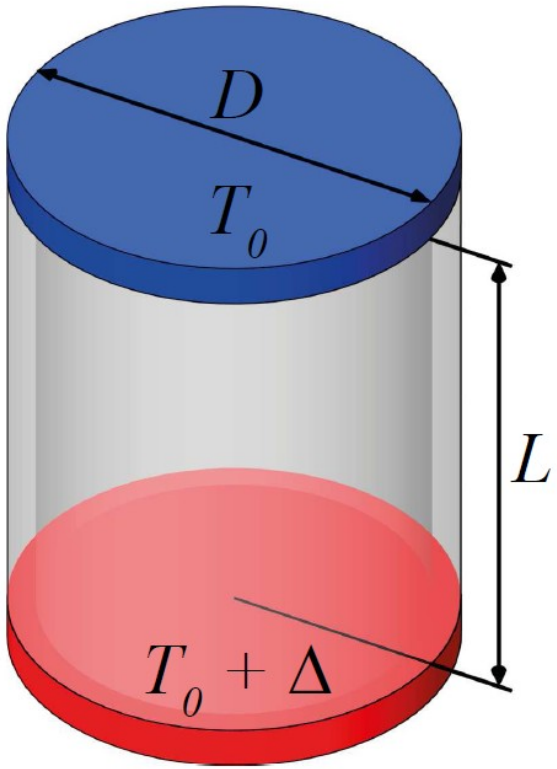




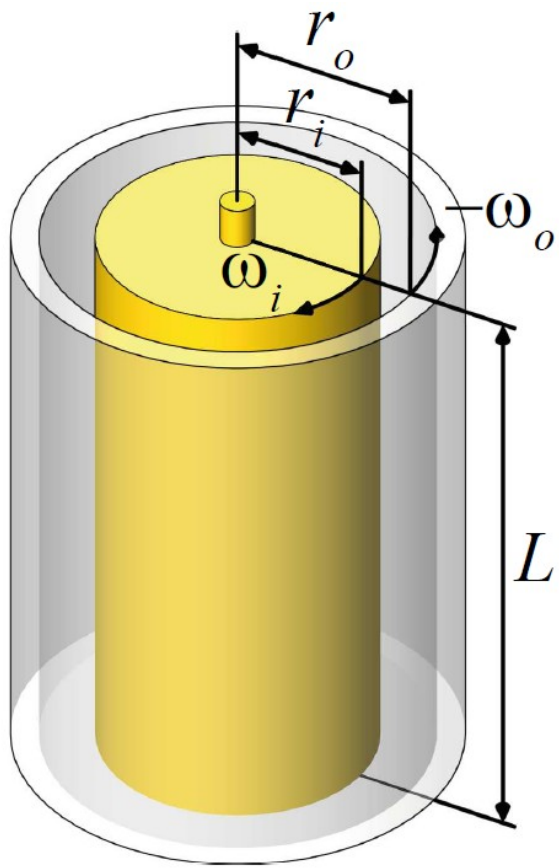




Model systems for studying turbulence

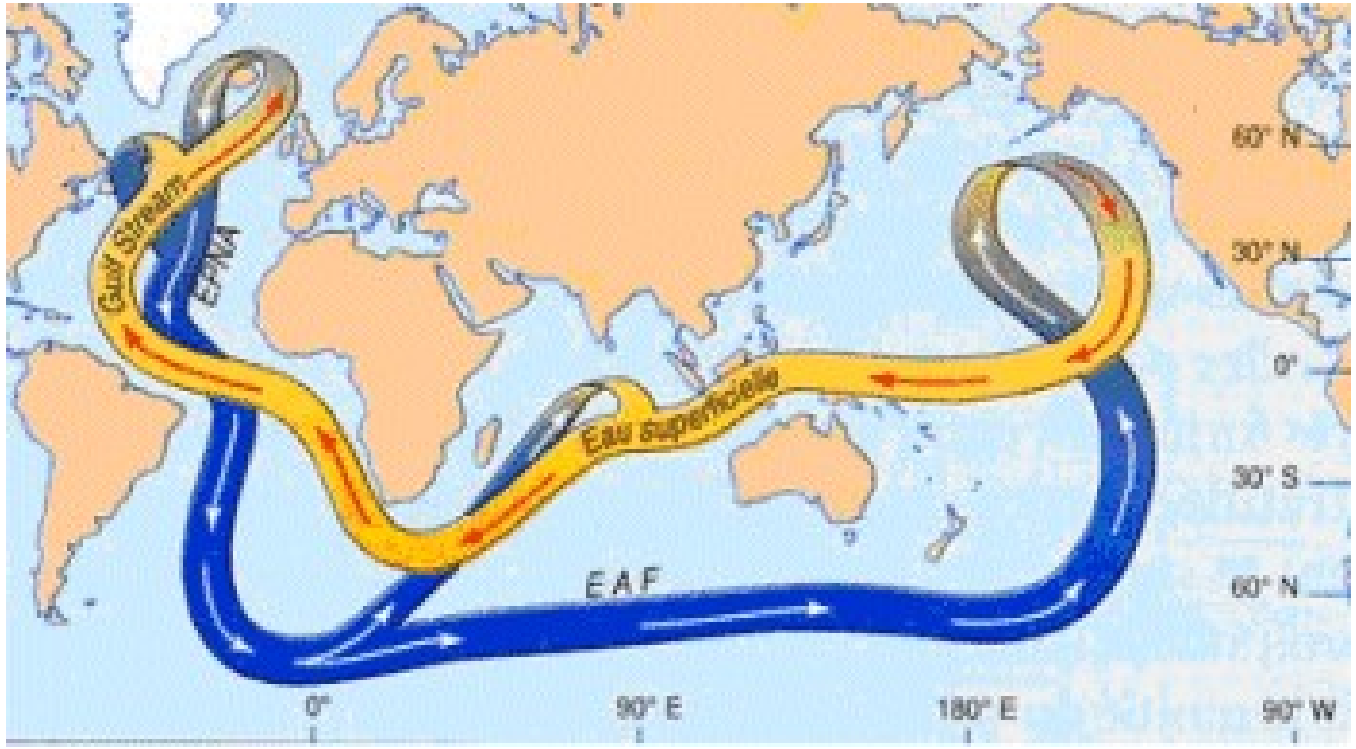


Rayleigh-Bénard: flow driven by buoyancy

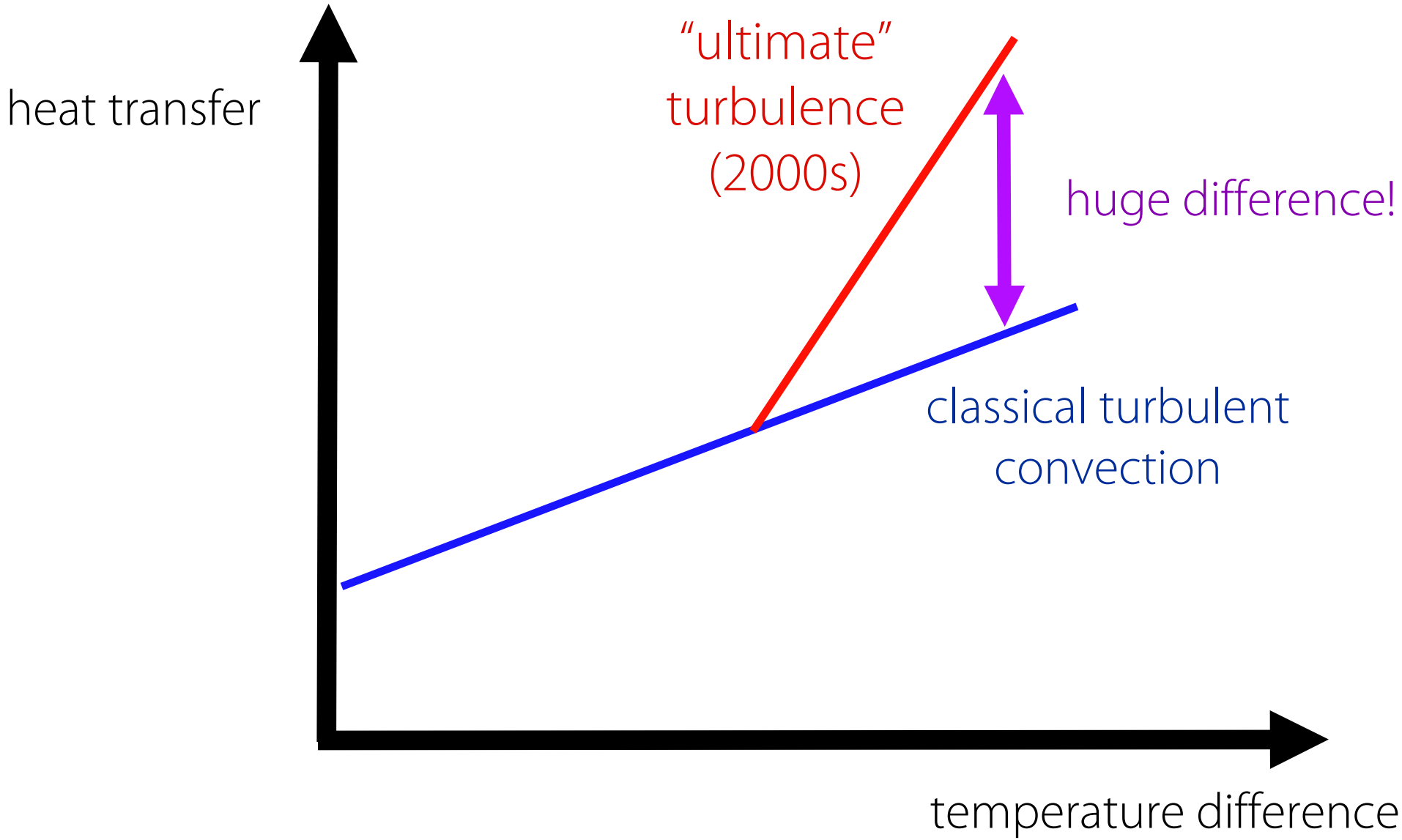


Taylor-Couette: flow driven by shear

Are there different turbulent states?



Is it possible that the Gulf Stream suddenly reverses tomorrow, changing the climate of the world?

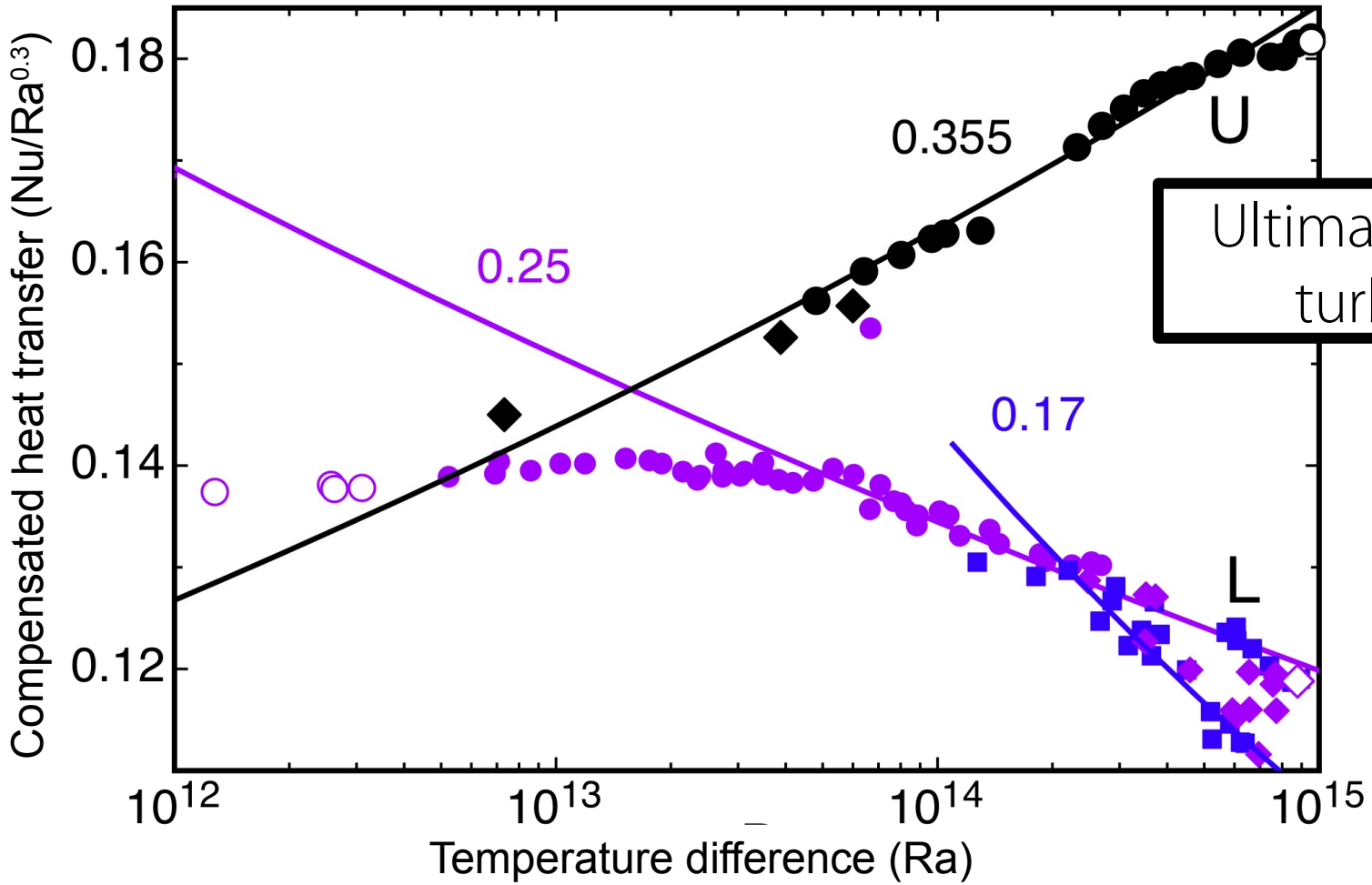

heat transfer
"ultimate"
turbulence
(2000s)
huge difference!
classical turbulent
convection
temperature difference

Large experiments were built to gain insight …

Opaque insulating walls - hard to look inside

Cost – millions of Euros

… that can't agree on what's happening



Ultimate state of RB turbulence??

Simulations are needed for better understanding

A Finite-Difference Scheme for Three-Dimensional Incompressible Flows in Cylindrical Coordinates

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Received January 31, 1995; revised July 6, 1995

$$\frac{d\phi}{dx} = \frac{\phi(x+\delta x) - \phi(x)}{\delta x}$$

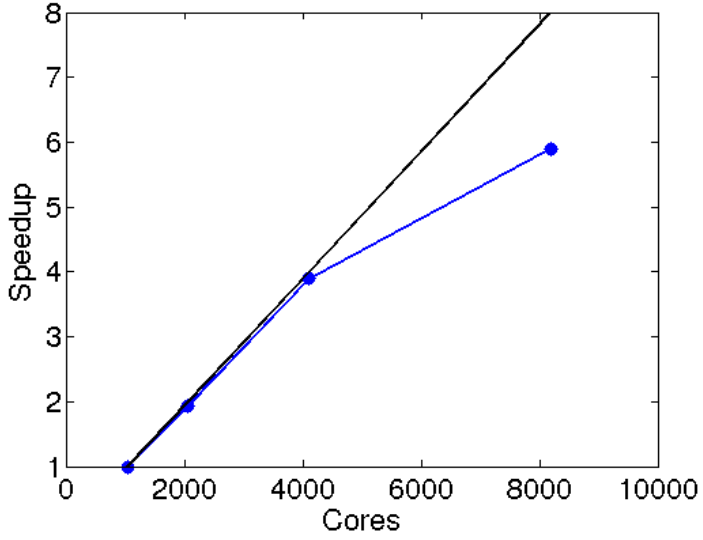
- Flexible grid distribution
- Energy conserving
- Easy to adapt and extend
- Fast (even with ~10^9-10^{10} grid points)

Bottleneck: Poisson equation (non-local) $\nabla^2\phi = \rho(x,y,z)$

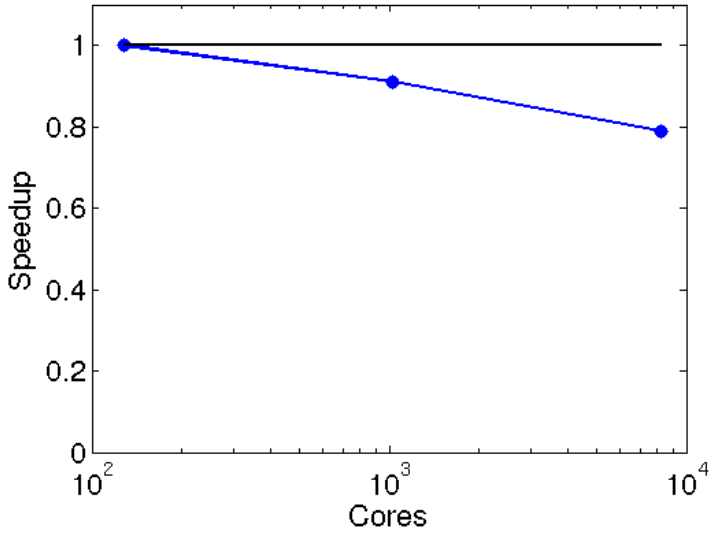
Large scale parallelization (OpenMP & MPI hybrid)

Curie Thin nodes, Genci@CEA, Paris, France

Strong Scaling



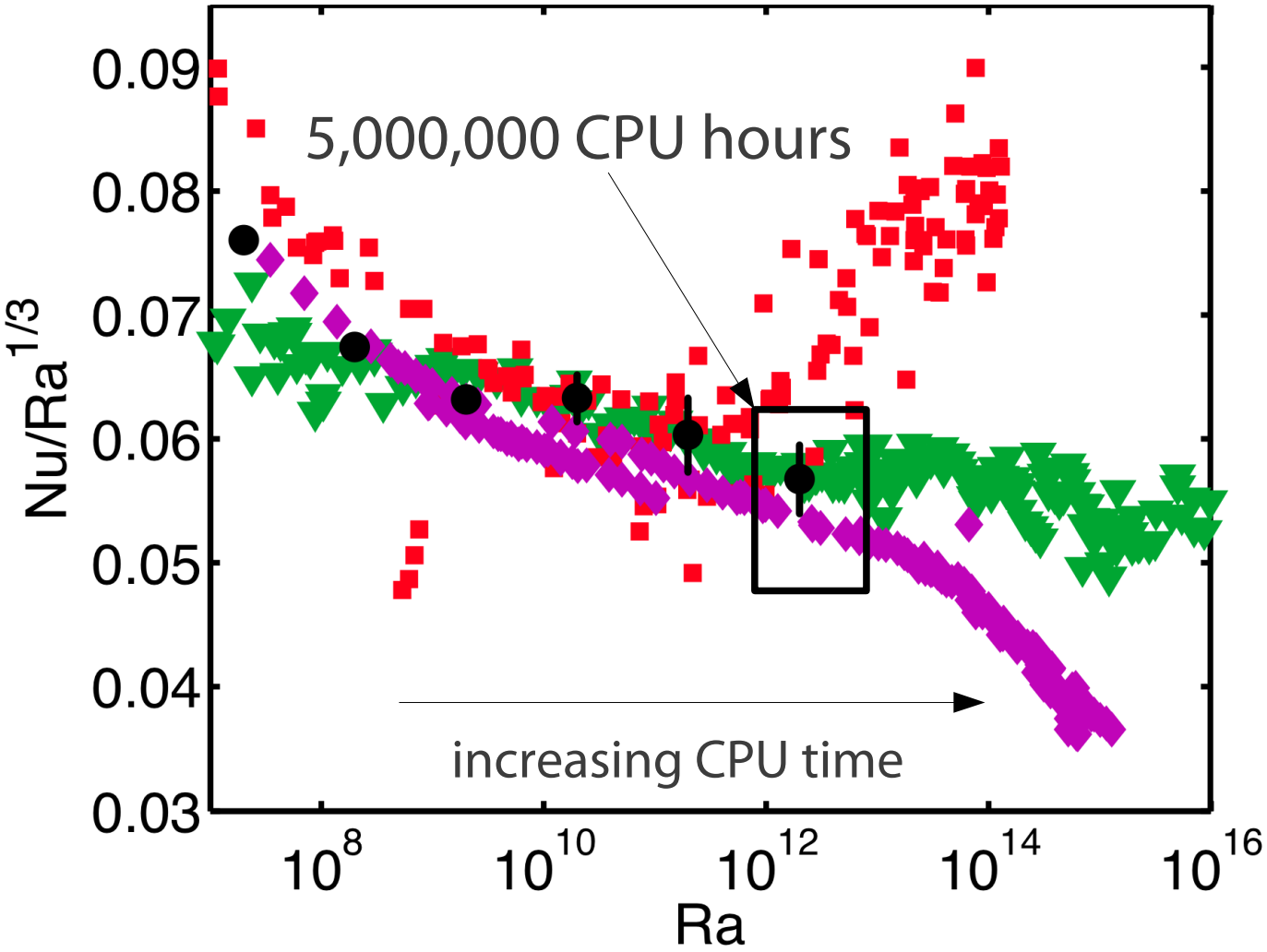
Weak Scaling



Similar scaling on Intel, Cray and IBM supercomputers

We can now look inside

…and help with the controversy



E Niemela et al. (2000)

E Chavanne et al. (2001)

E Funfschilling et al. (2010)

N Stevens et al. (2010-2011)

E=Experiments, N=Numerics

Just one more effort ...

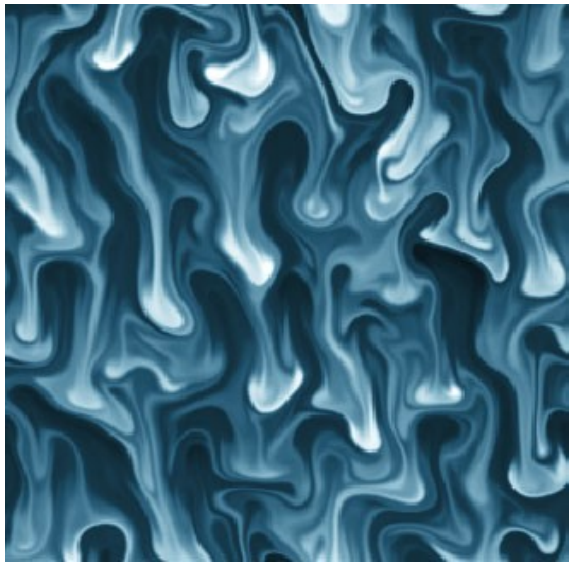
Ultimate regime:
in 5 years?

Present

… but there are always more mountains to climb

Rough boundaries

Boiling???



Convection with salinity & temperature
(double diffusion)

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