The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
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International Atomic
Energy Agency

SMR.1771 - 17

Conference and Euromech Colloquium #480

on

High Rayleigh Number Convection

4 - 8 Sept., 2006, ICTP, Trieste, Italy

Ruminations in convection

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Trieste
Italy

These are preliminary lecture notes, intended only for distribution to participants

F.H. Busse

Almost certainly the most versatile person in thermal convection

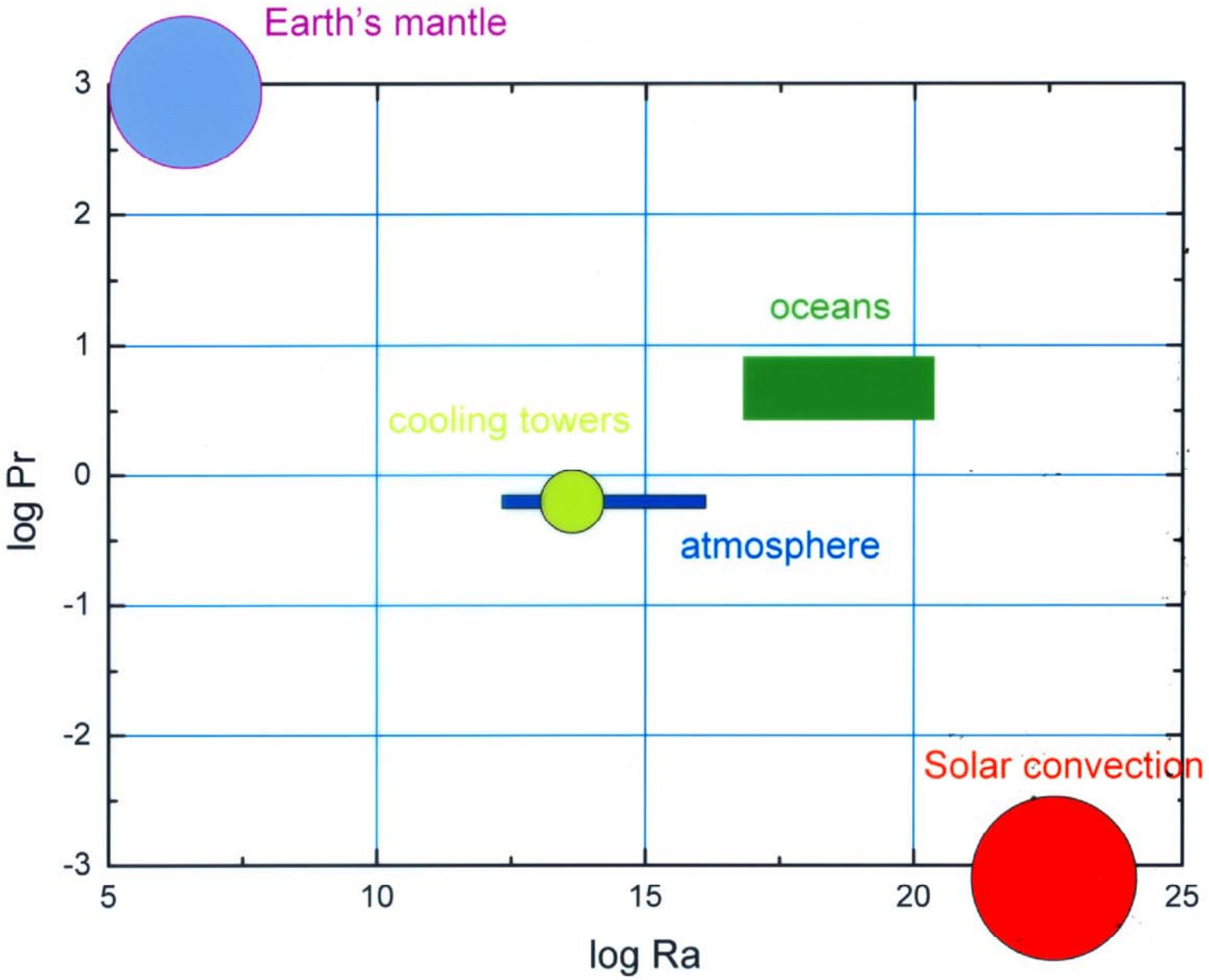
70 papers in *J. Fluid Mech.* dealing with convection

- Rotation
- Magnetic effects
- Prandtl number effects
- Geometry effects
- Phase changes
- Pattern formation
- Non-Boussinesq effects

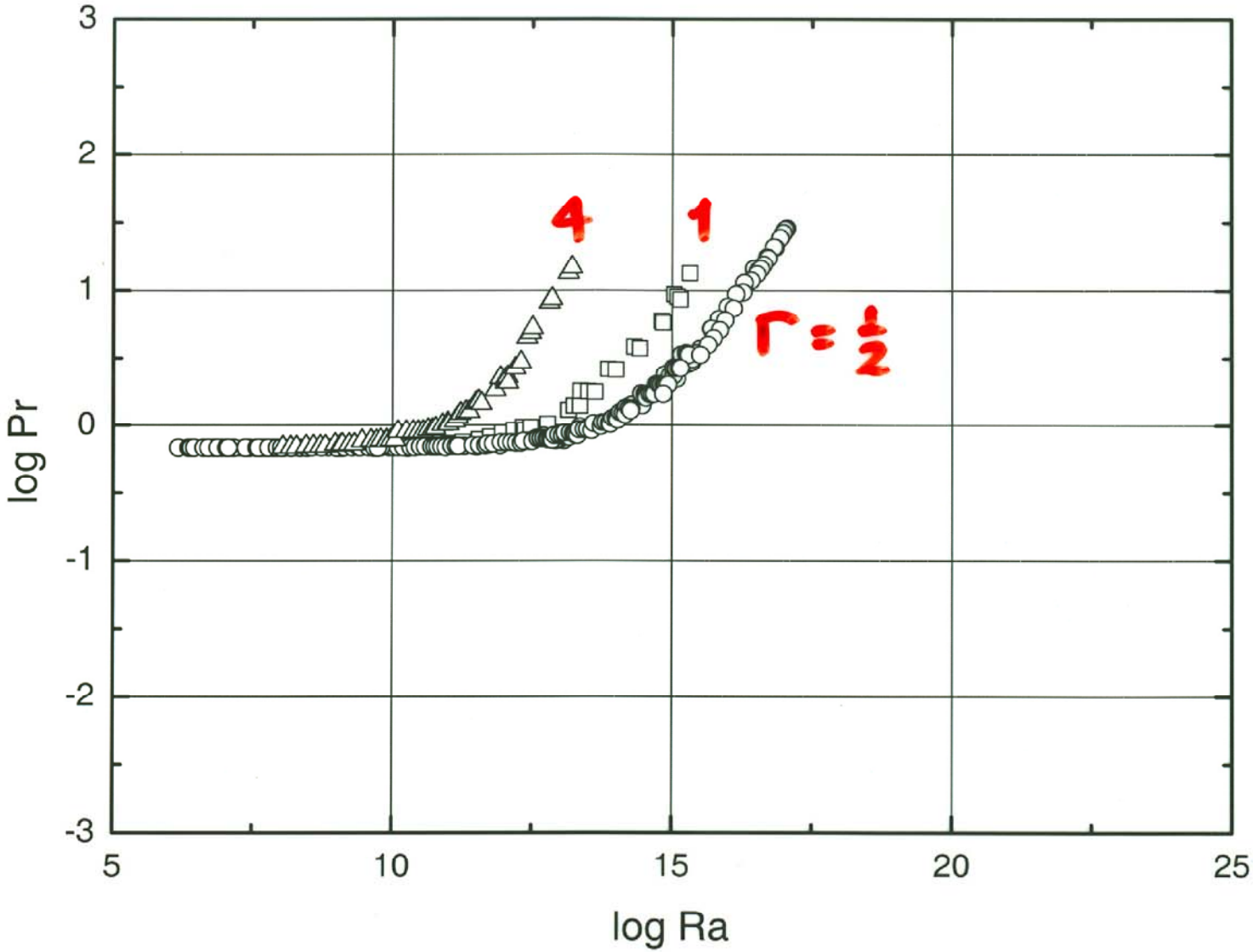
All are non-trivial papers.

Ruminations on convection

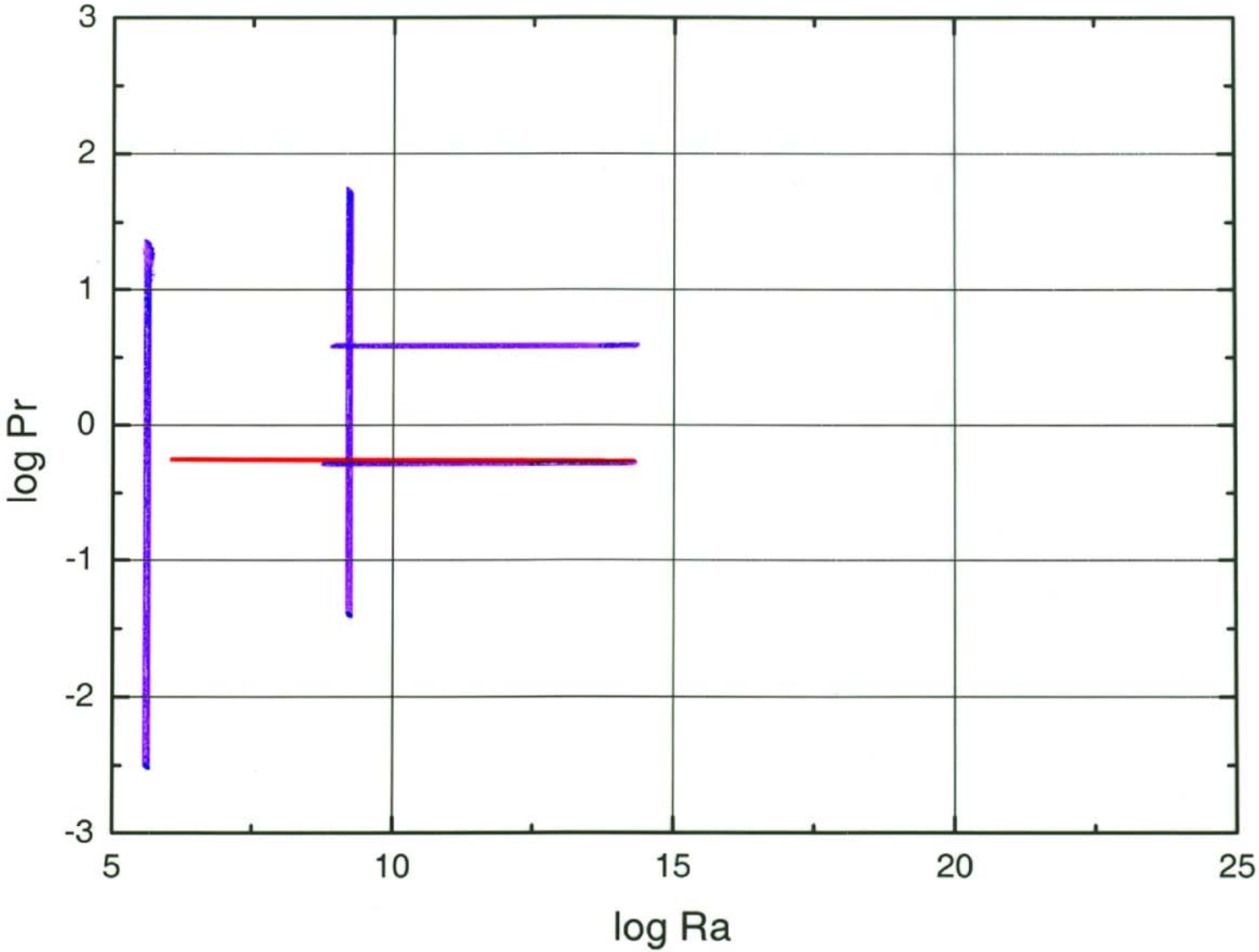
Ruminate = chew again what has been chewed slightly and swallowed



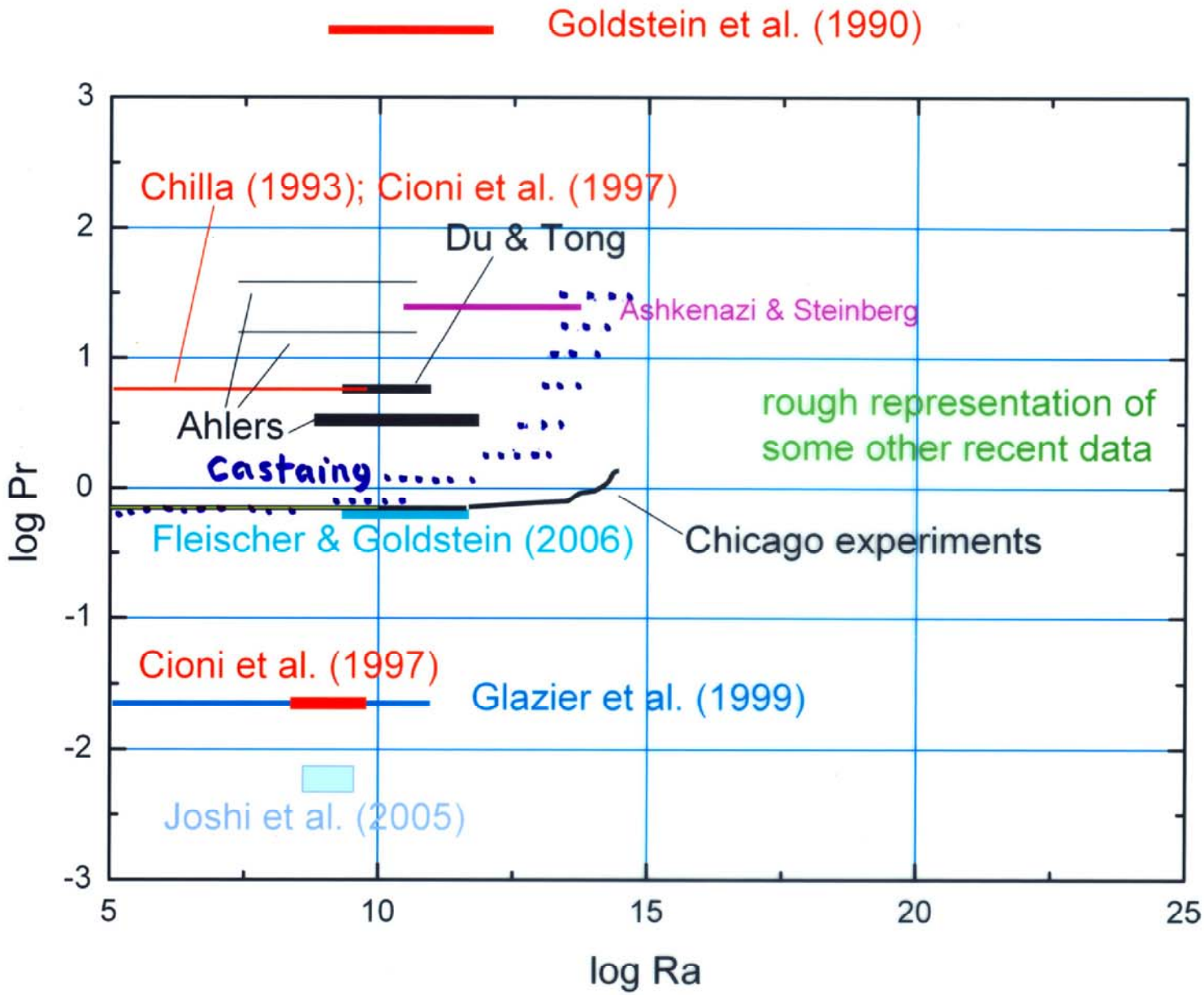
SOME PARADIGMS OF CONVECTION

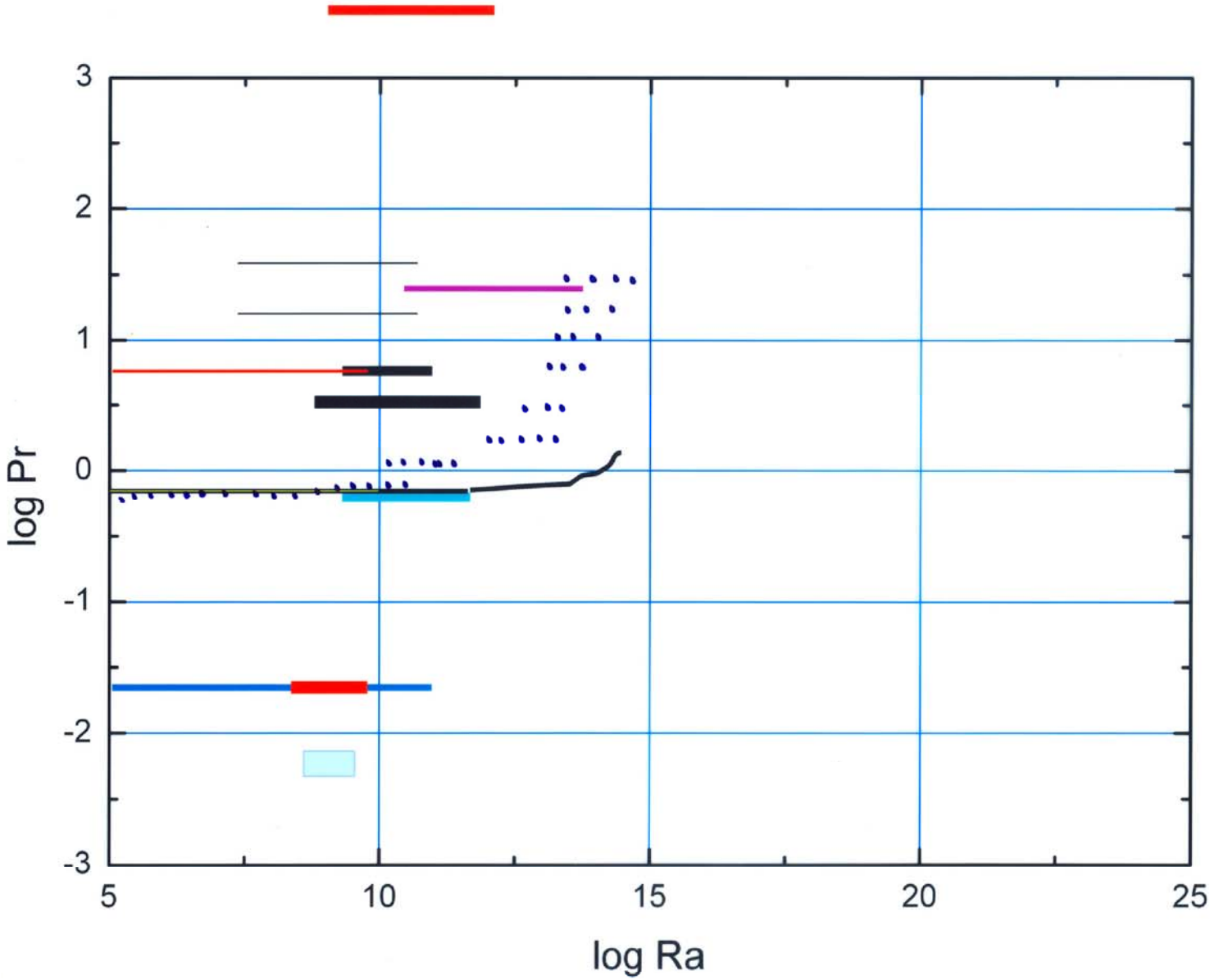


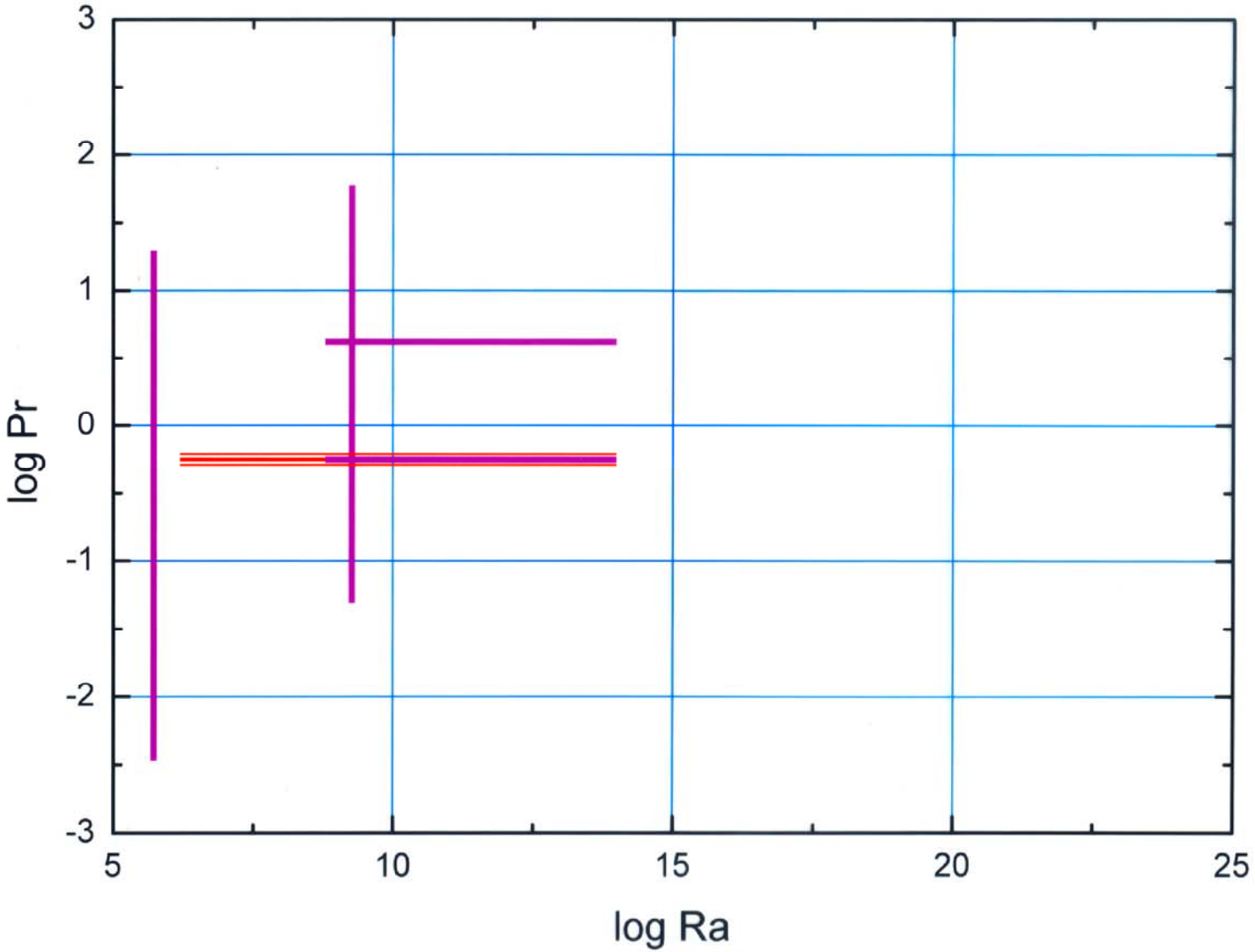
Experiments with J.J. Niemela ...

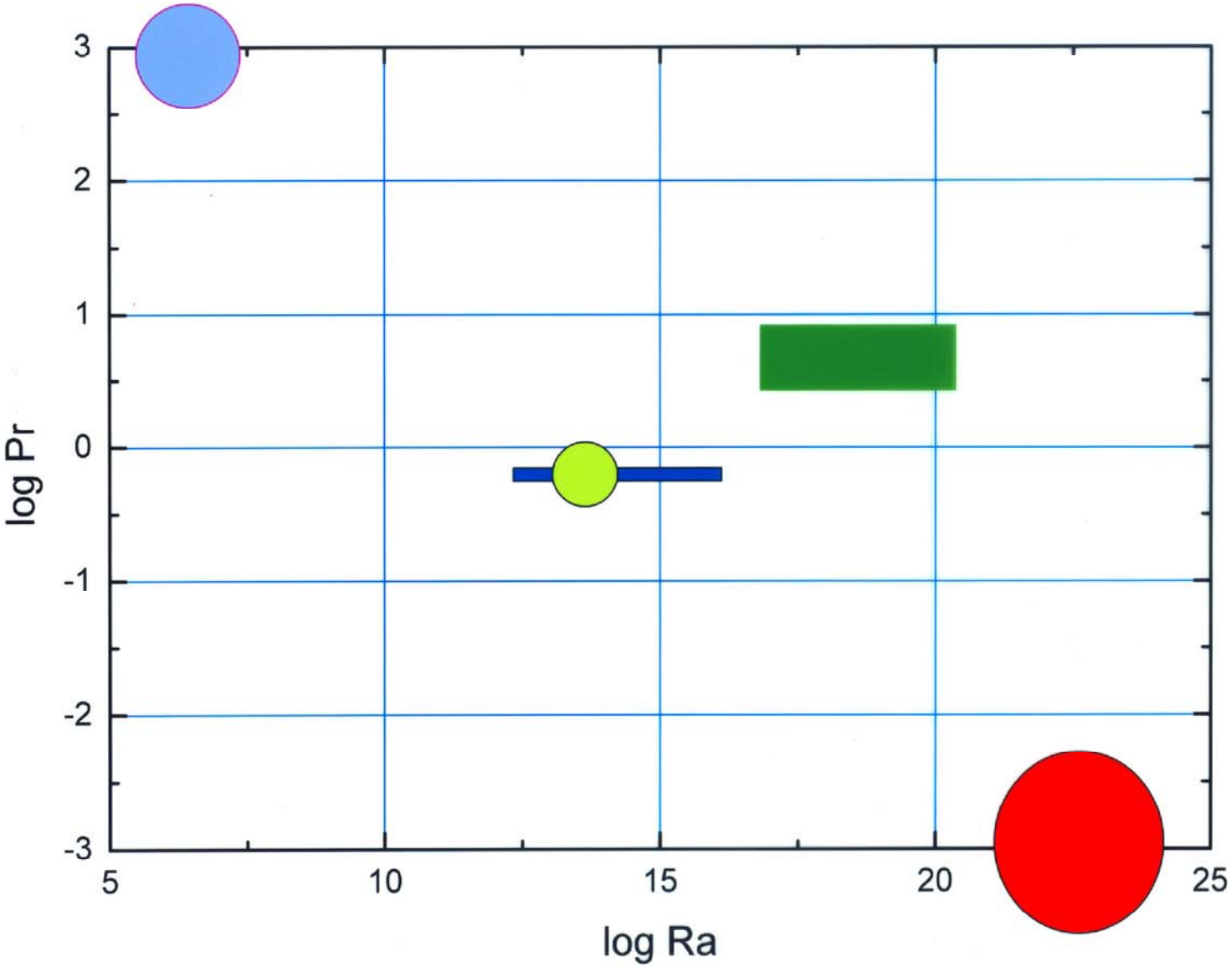


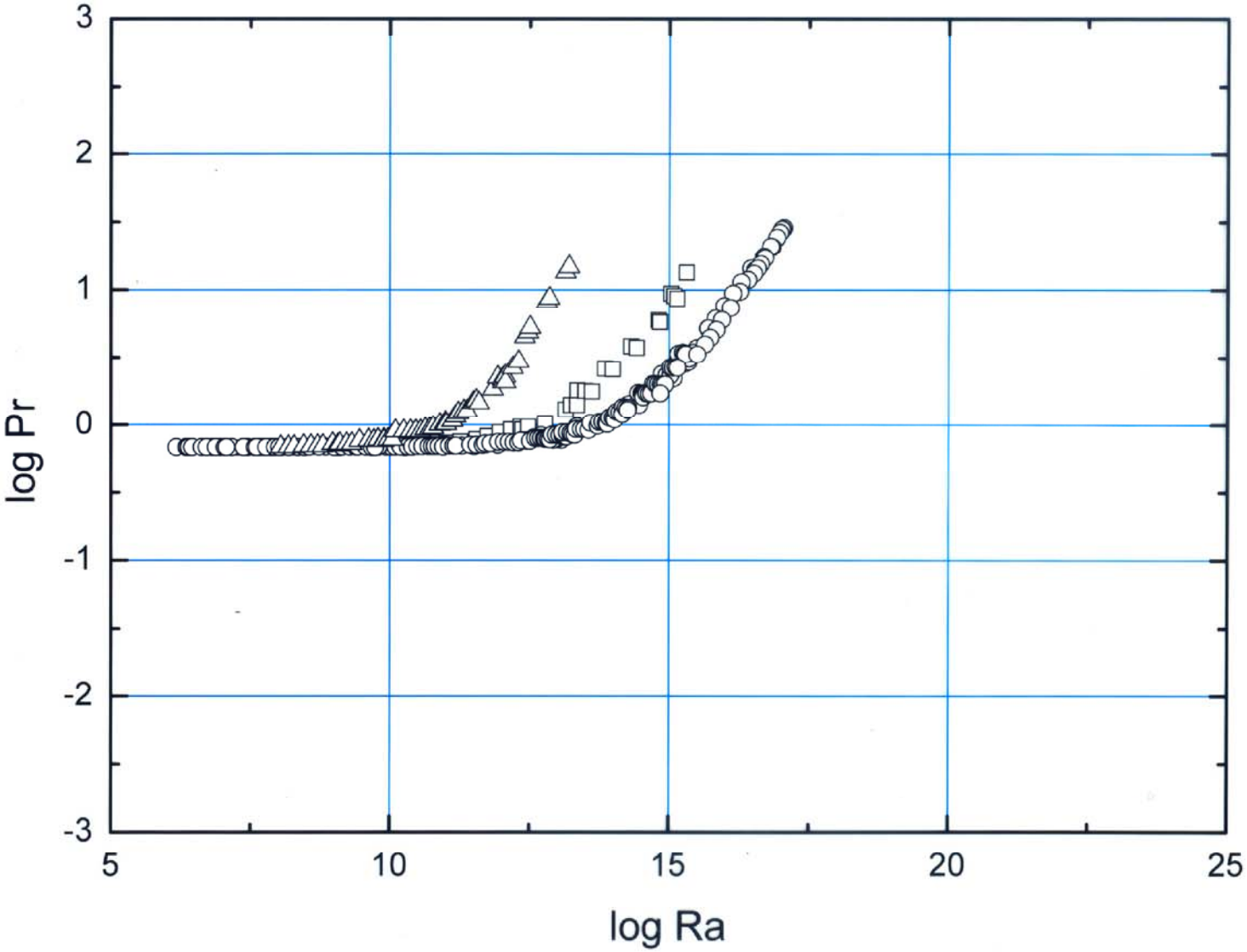
VERZICCO'S SIMULATIONS

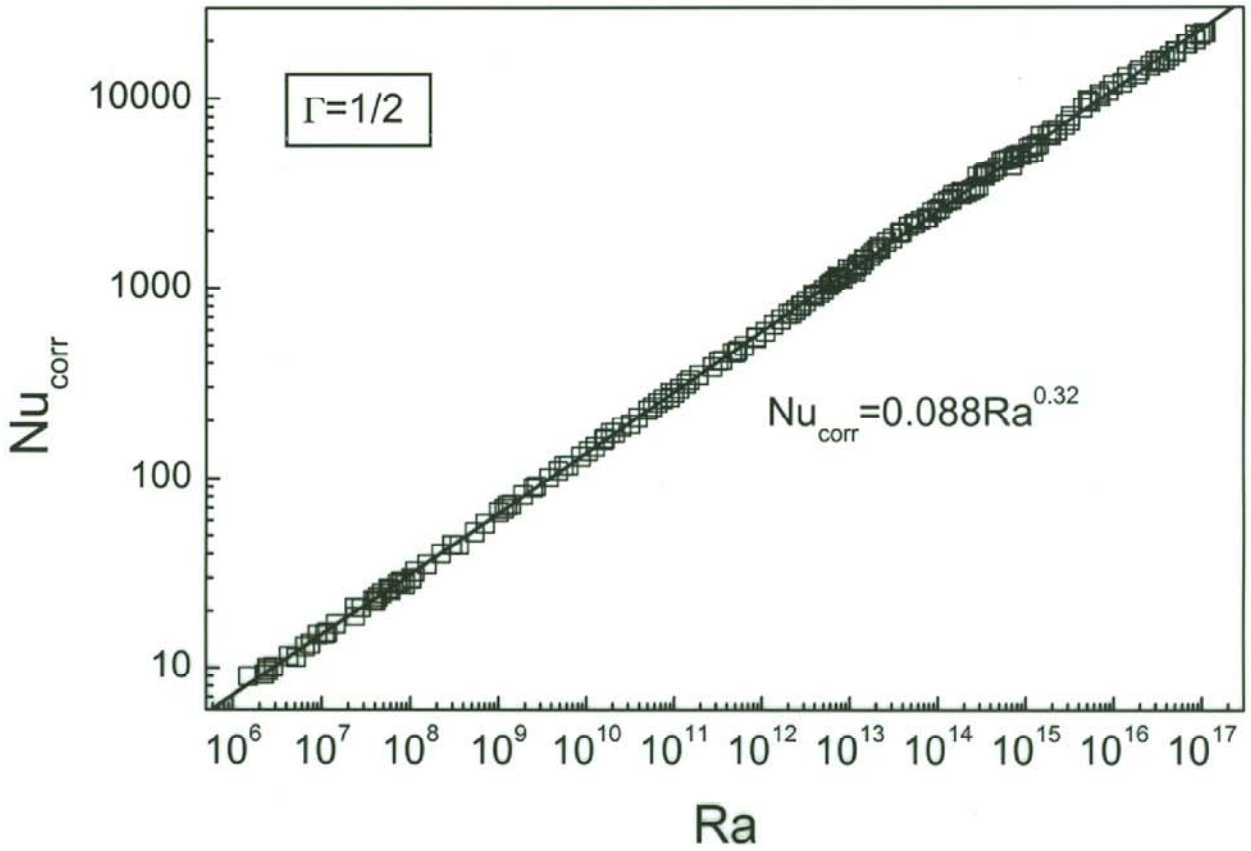

Goldstein et al. (1990)
Chilla (1993); Cioni et al. (1997)
Du & Tong
Ashkenazi & Steinberg
rough representation of
some other recent data
Ahlers
Castaing
Fleischer & Goldstein (2006)
Chicago experiments
Cioni et al. (1997)
Glazier et al. (1999)
Joshi et al. (2005)
log Pr
log Ra
3
2
1
0
-1
-2
-3
5
10
15
20
25

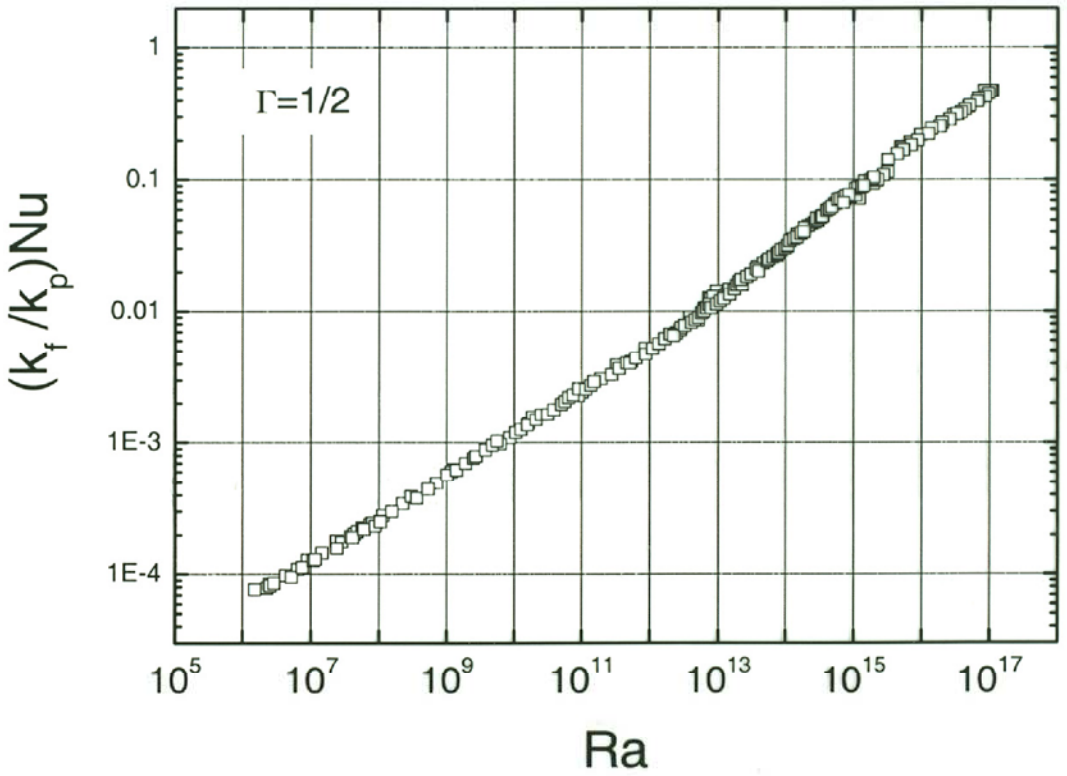

3
2
1
0
-1
-2
-3
log Pr
5
10
15
20
25
log Ra


3
2
1
0
-1
-2
-3
log Pr
5
10
15
20
25
log Ra

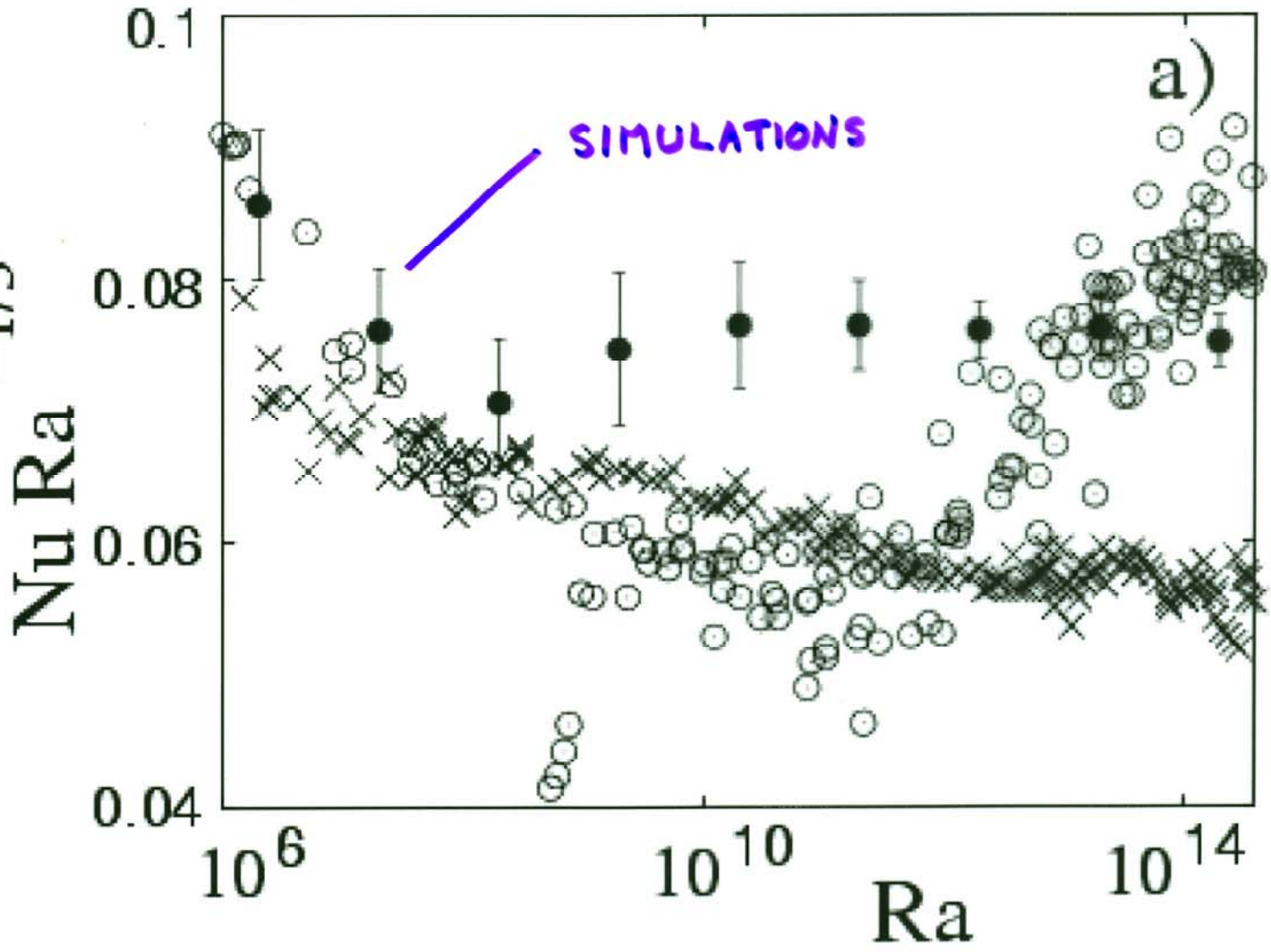

3
2
1
0
-1
-2
-3
log Pr
5
10
15
20
25
log Ra

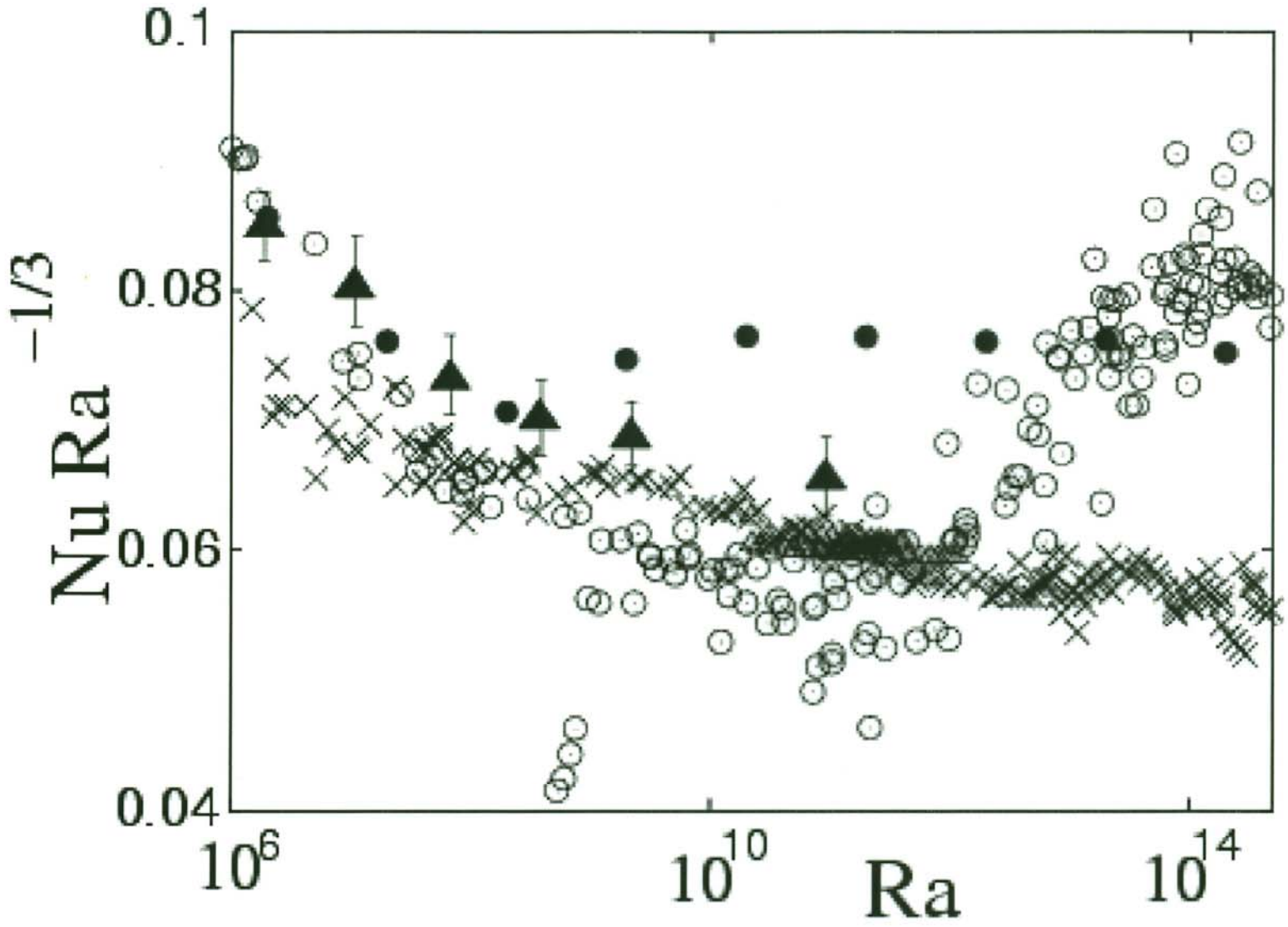

3
2
1
0
-1
-2
-3
log Pr
5
10
15
20
25
log Ra


Γ=1/2
Nu_corr=0.088Ra^0.32
Nu_corr
Ra
10000
1000
100
10
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17

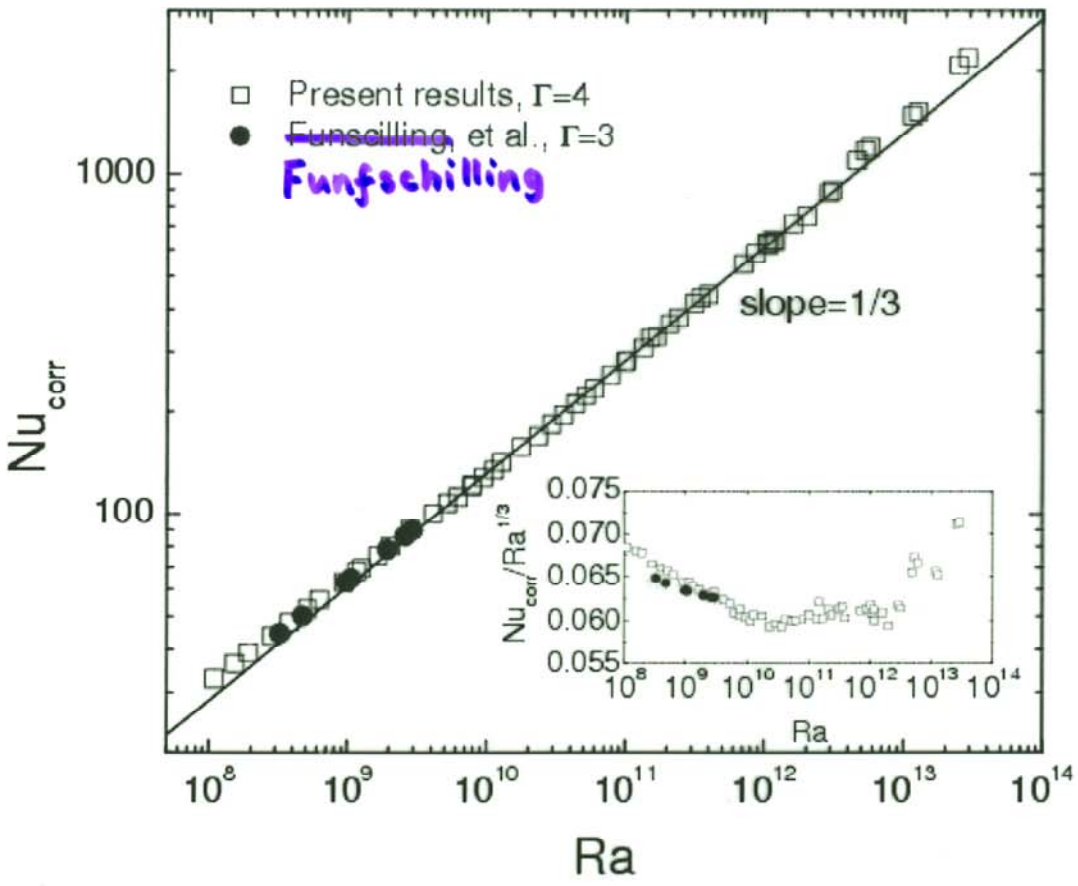


Niemela et al. (2000)


a)
SIMULATIONS
0.1
0.08
0.06
0.04
Nu Ra −1/3
10^6
10^10
10^14
Ra

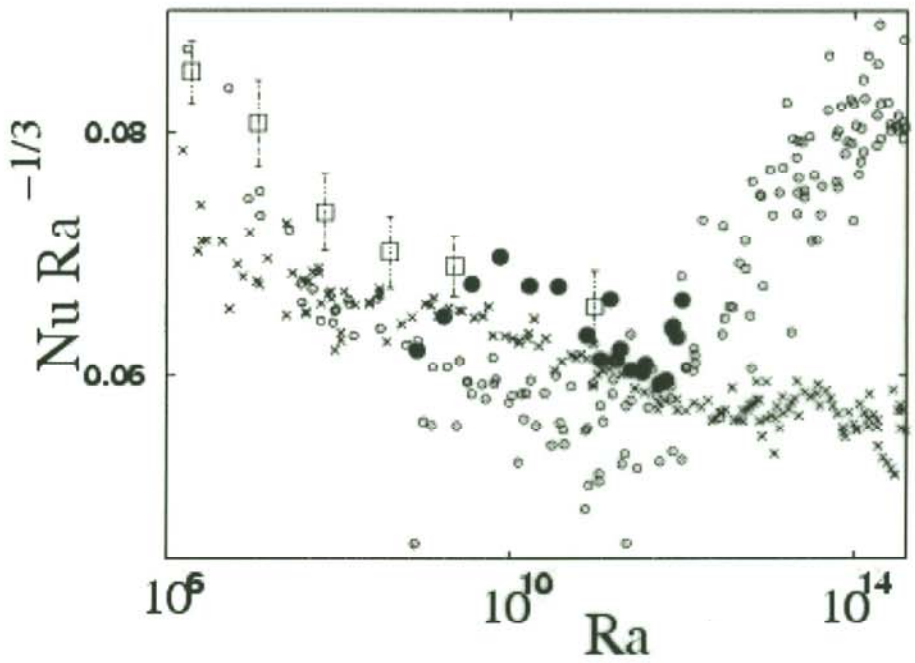


▲ CONSTANT HEAT FLUX



Niemela & Sreenivasan

J. Fluid Mech 557, 411 (2006)

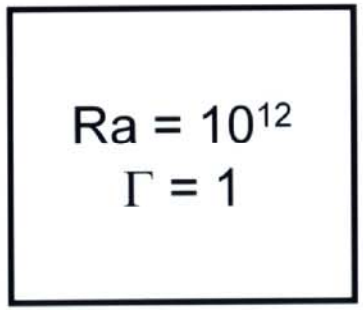


- du Puits et al. (2006) to appear

From these studies, it appears reasonable to state that the 1/3 is most likely power for Boussinesq convection for Prandtl numbers = O(1) and $\Gamma = O(1)$.

- What about Pr effects?
- What about Γ effects?
- What about $Ra > 10^{14}$?
- What about n-B effects?

- More experiments are under way
- For now, I will use results from simulations



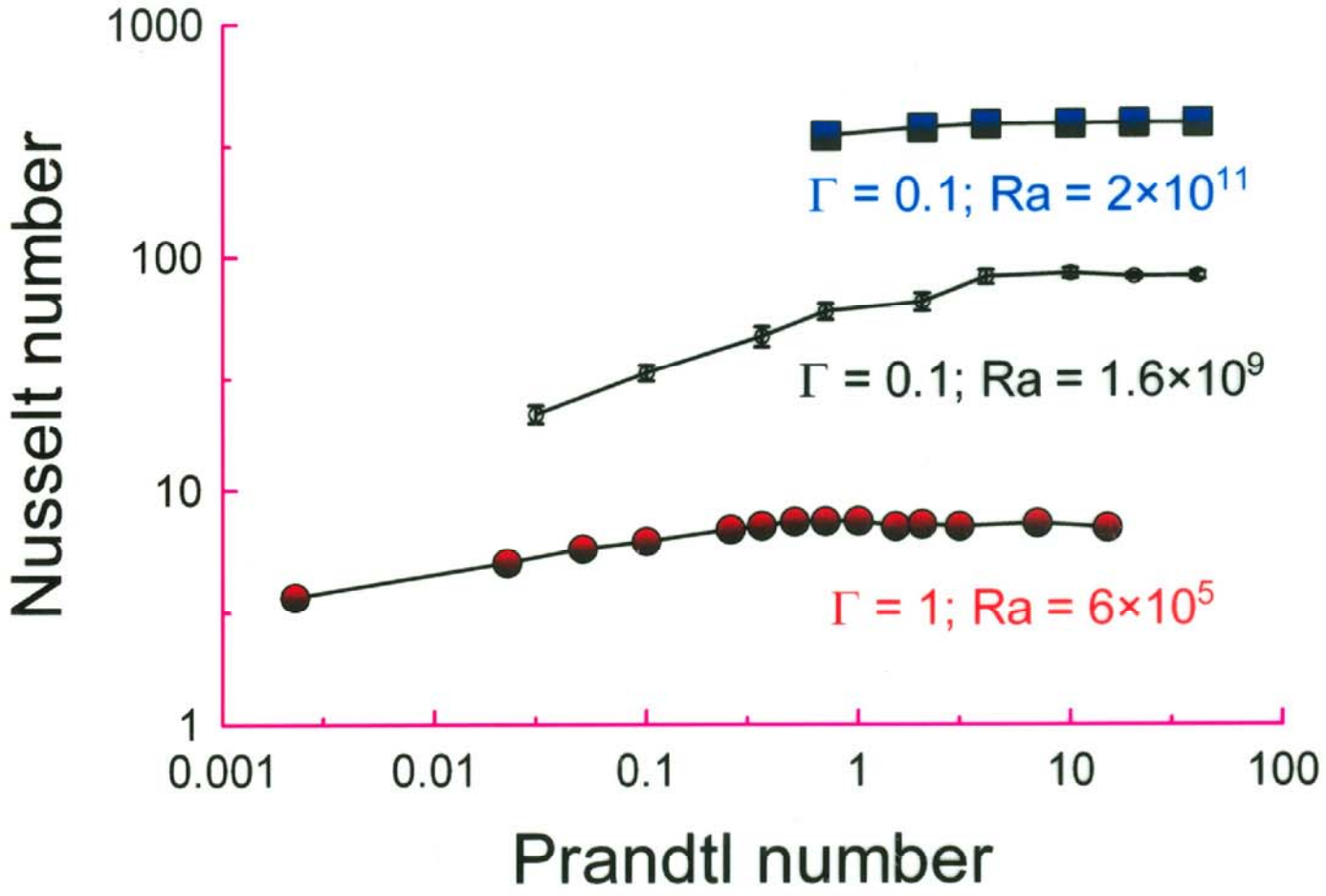
slender

$Ra_{0.1} = Ra_1\Gamma^2$

~10^{14} or so

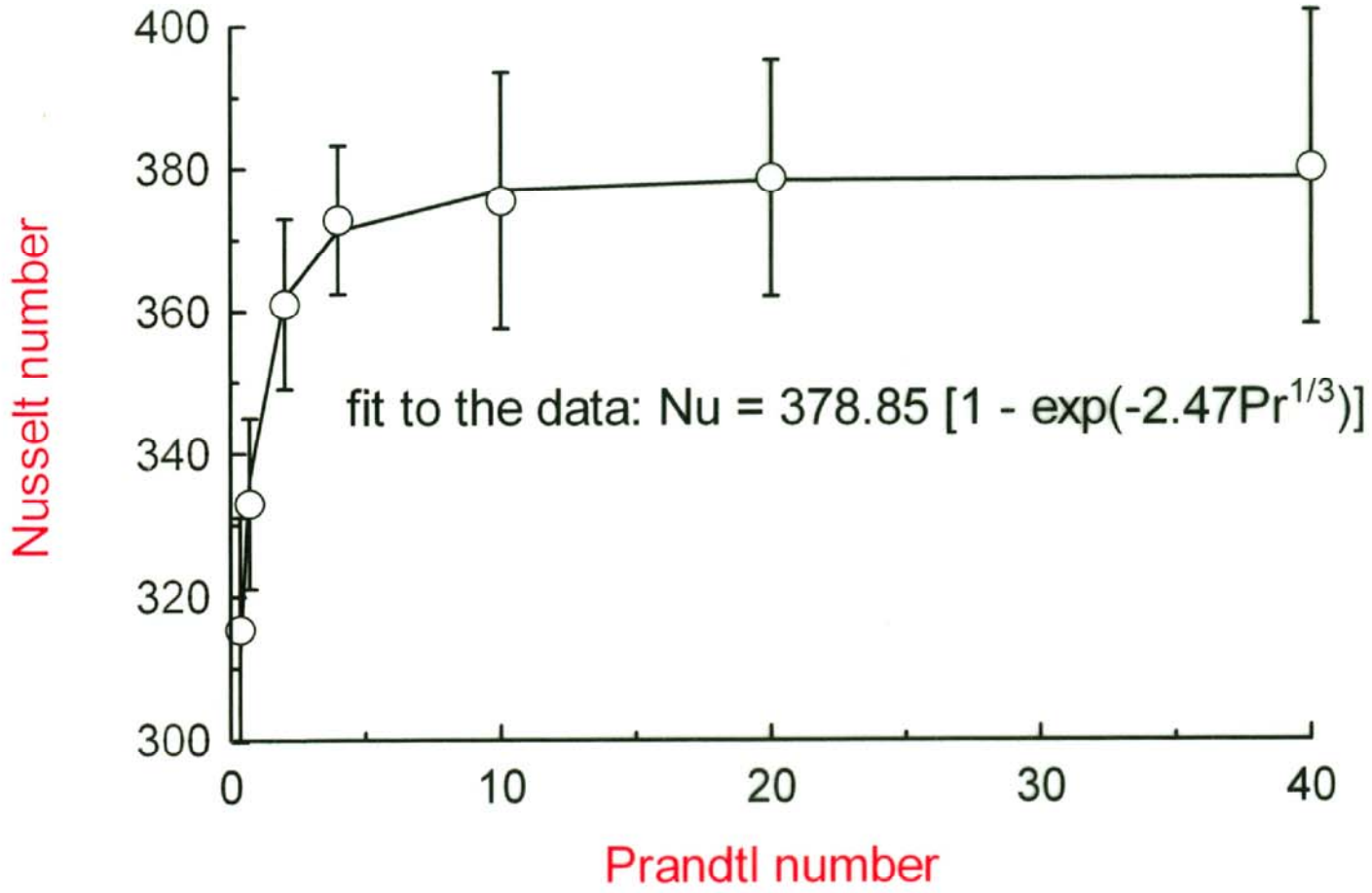
cigar

Prandtl number effects on heat transport



Nusselt number variation with Prandtl number

Rayleigh number = 2×10^{11}, aspect ratio = 0.1



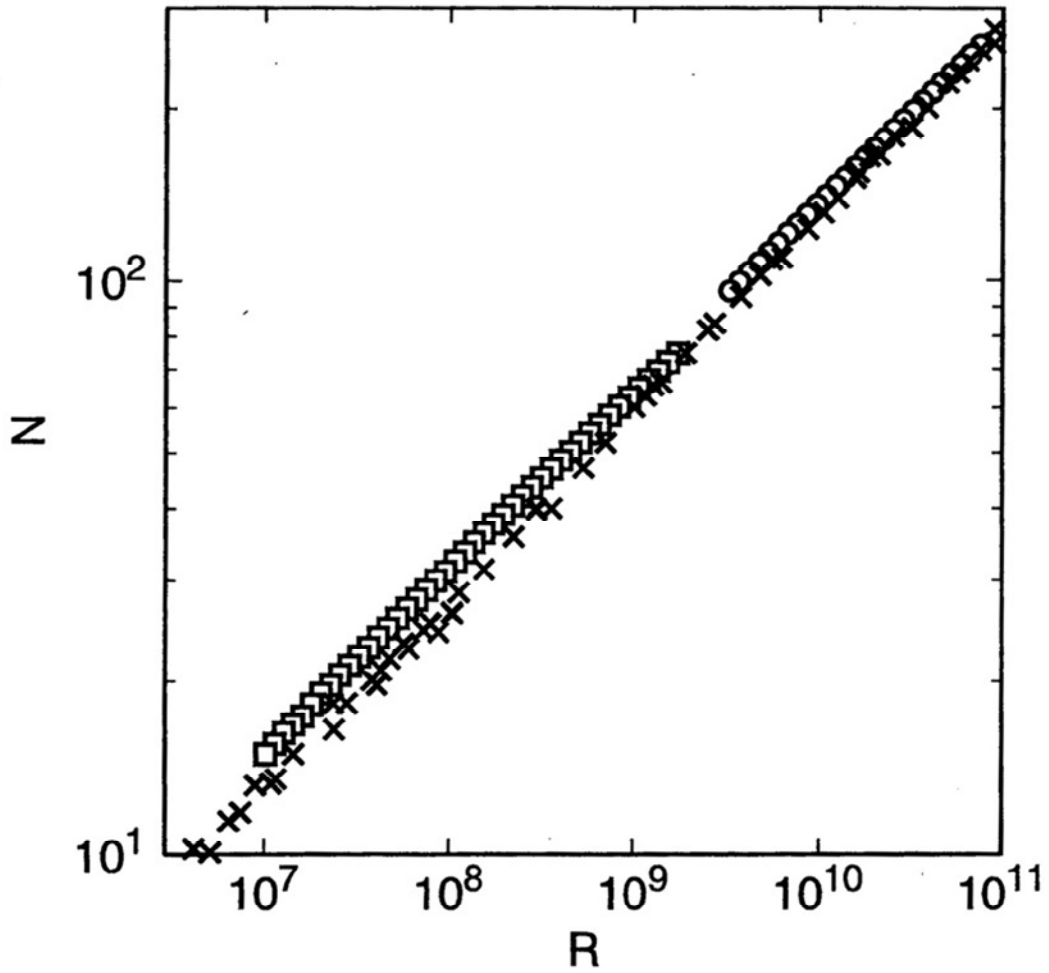
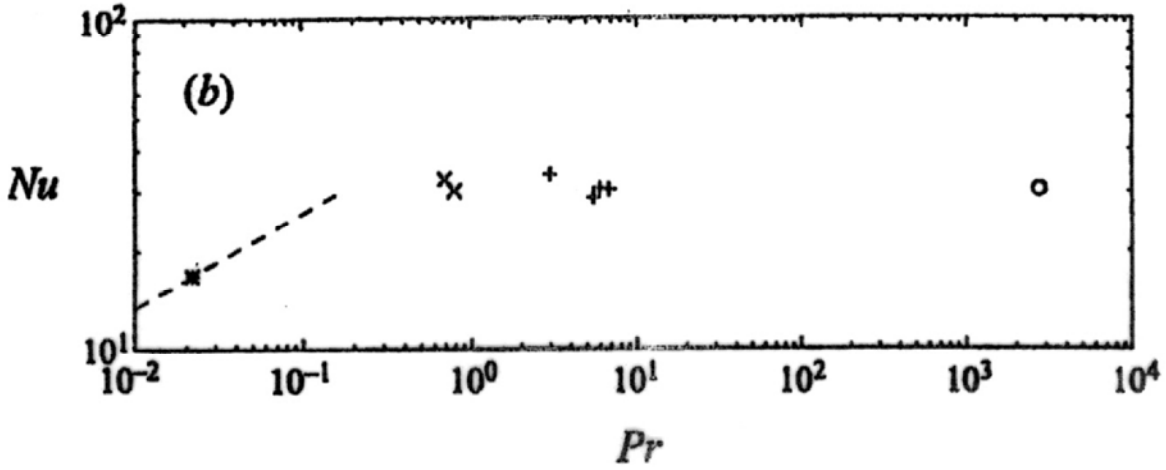
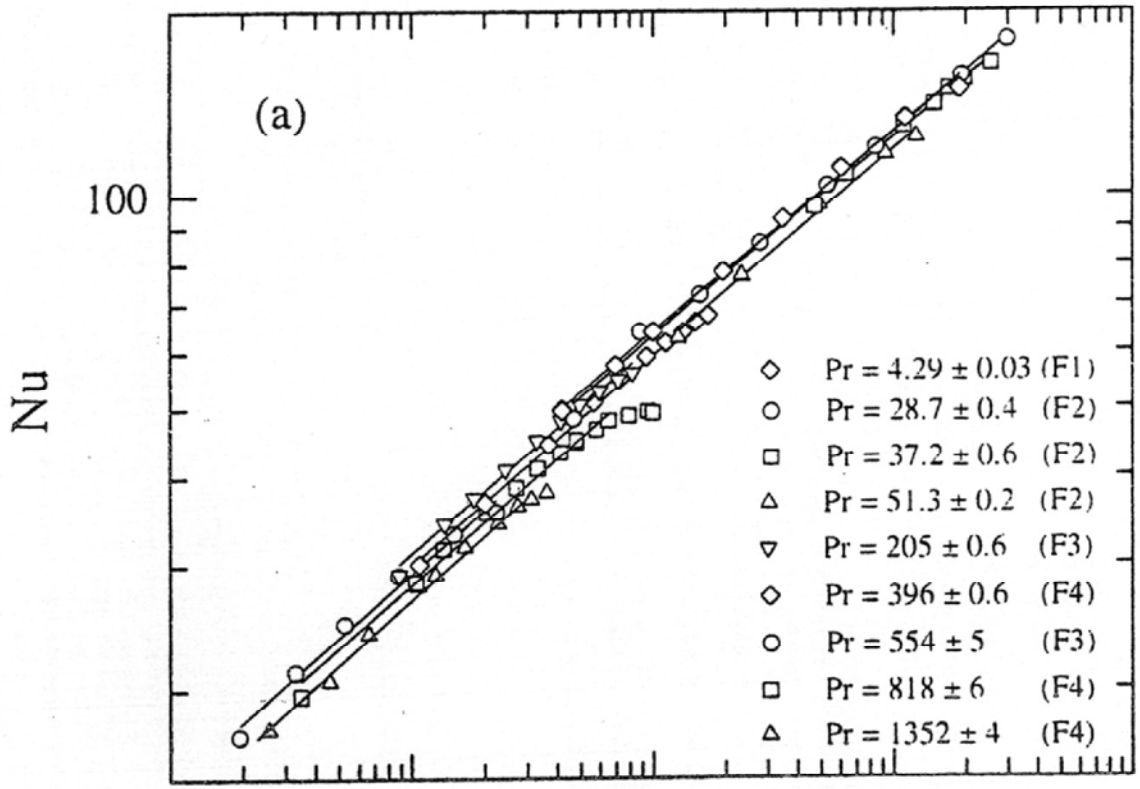


FIG. 2. The Nusselt number as a function of R on logarithmic scales for acetone ($\sigma = 3.94$) and $\Gamma = 0.5$ (open circles), and for 2-propanol ($\sigma = 34.1$) and $\Gamma = 1.0$ (open squares). The crosses are the data of Ref. [3]. A correction for the wall conduction based on model 2 of Ref. [6] was applied to all data.

G. Ahlers & X. Xu
(Phys. Rev. Lett. 86, 3320, 2001)



Results collected by S. Cioni, S. Ciliberto & J. Sommeria (J. Fluid Mech. **335**, 111-140, 1997), from experiments on thermal convection in mercury, air, helium and water, and electro-chemical convection. Ra = 10^8. The dashed line to the left corresponds to $Pr^{2/7}$.



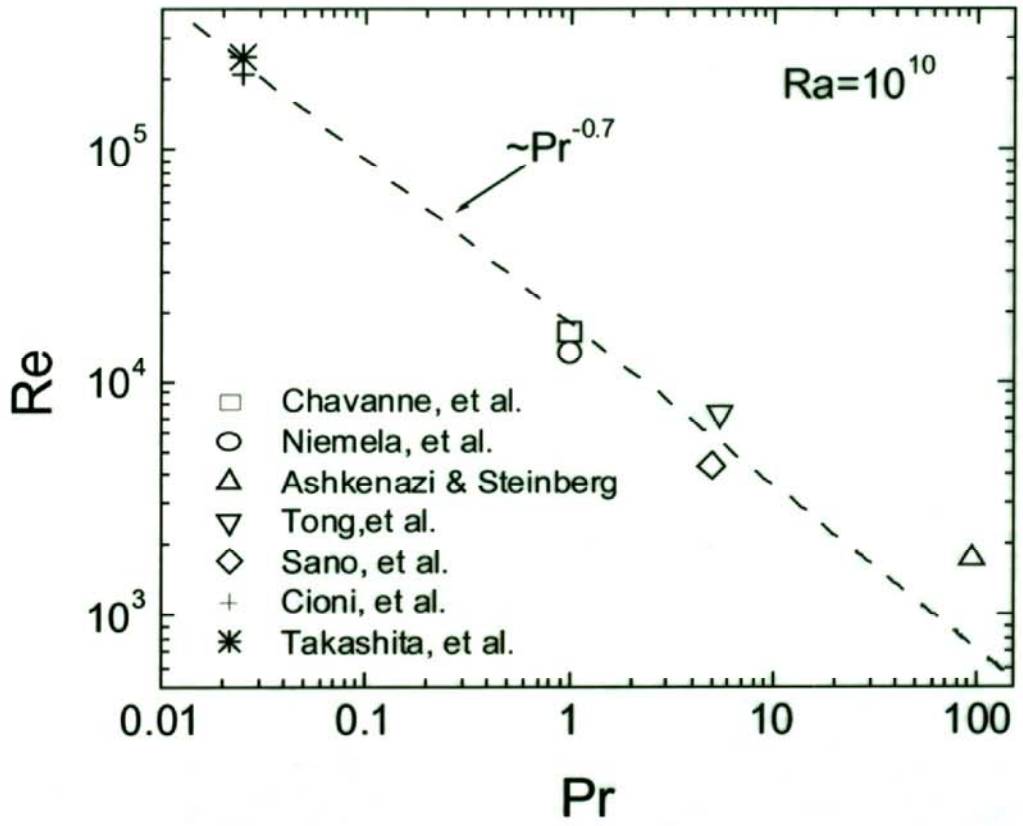
Data from K-Q. Xia, S. Lam & S-Q. Zhou
(Phys. Rev. Lett. **88**, 064501, 2002)

and all subsequent analyses. For the high-Pr fluids, we find that after taking into account all the heat leakage the exponent β in general is increased by 0.04 as compared to that for the uncorrected data. Of this, roughly 0.025 to 0.02 can be attributed to corrections for leakage through the bottom plate, with the rest due to sidewall conduction. For water, the overall correction to β is less than 0.01. Note

By the way

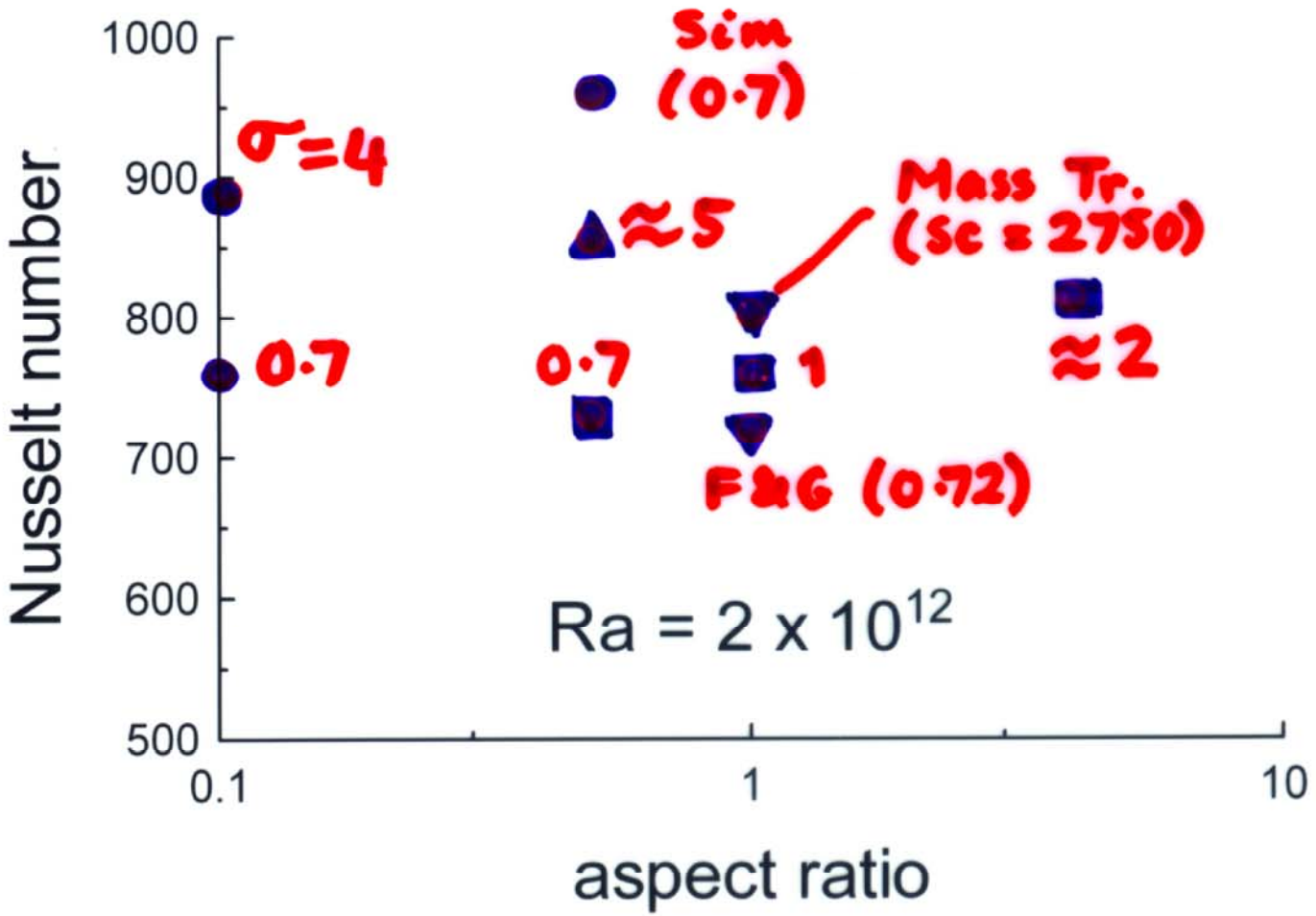
The formula found in the literature on free convection at high Rayleigh numbers

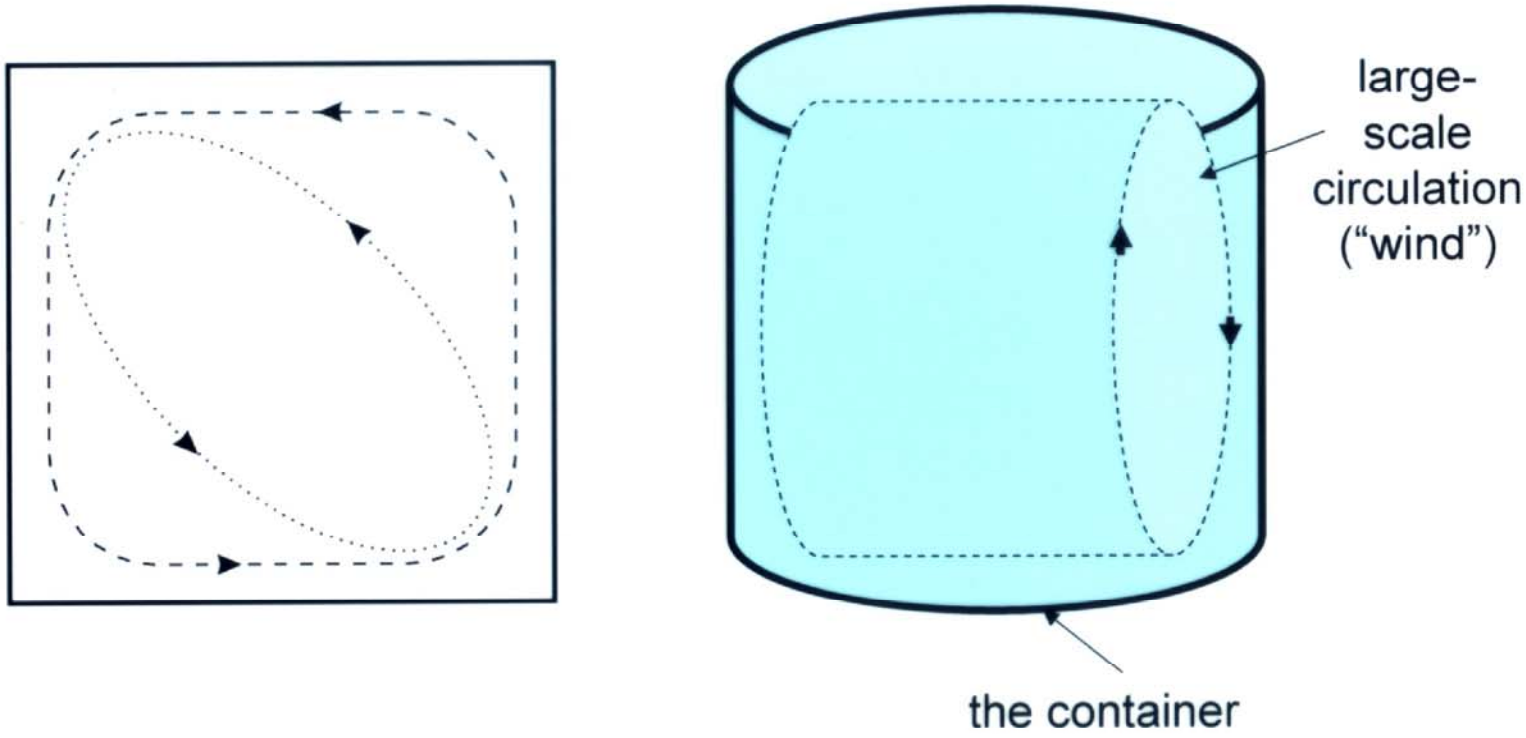
$$Nu = 0.067\ Ra^{1/3}\ Pr^{-0.04}$$



$$Re = 0.2\ Ra^{0.49}\ Pr^{-0.7}$$

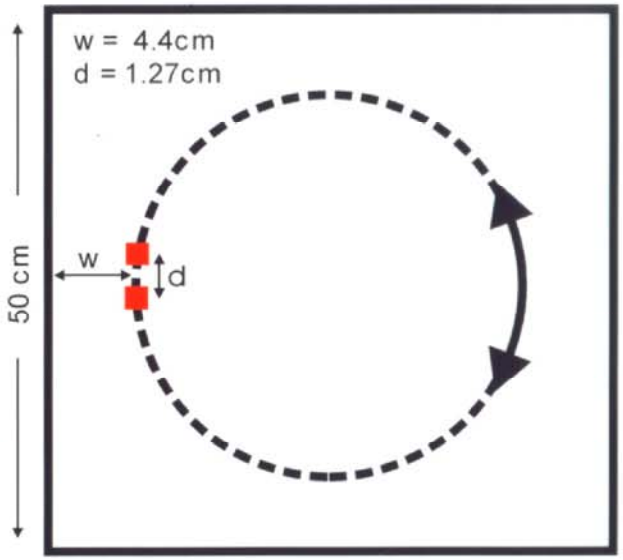
aspect ratio effects



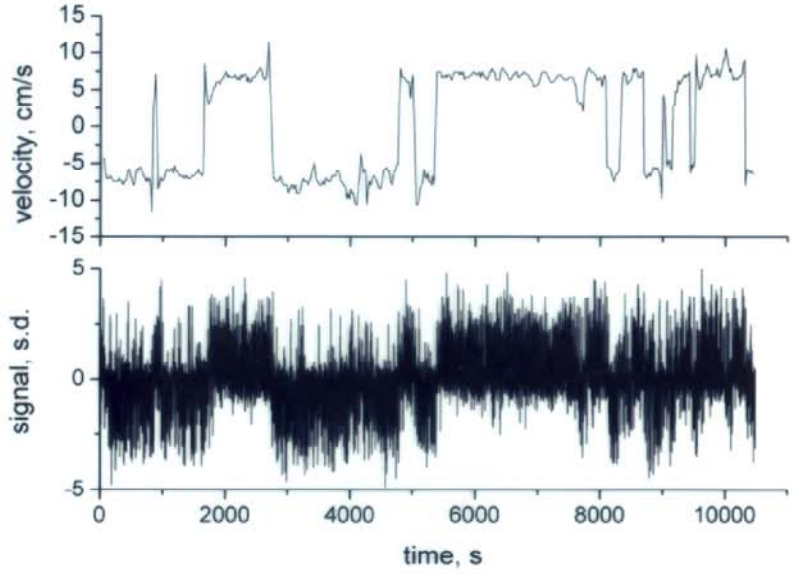


The wind breaks the symmetry, with important consequences

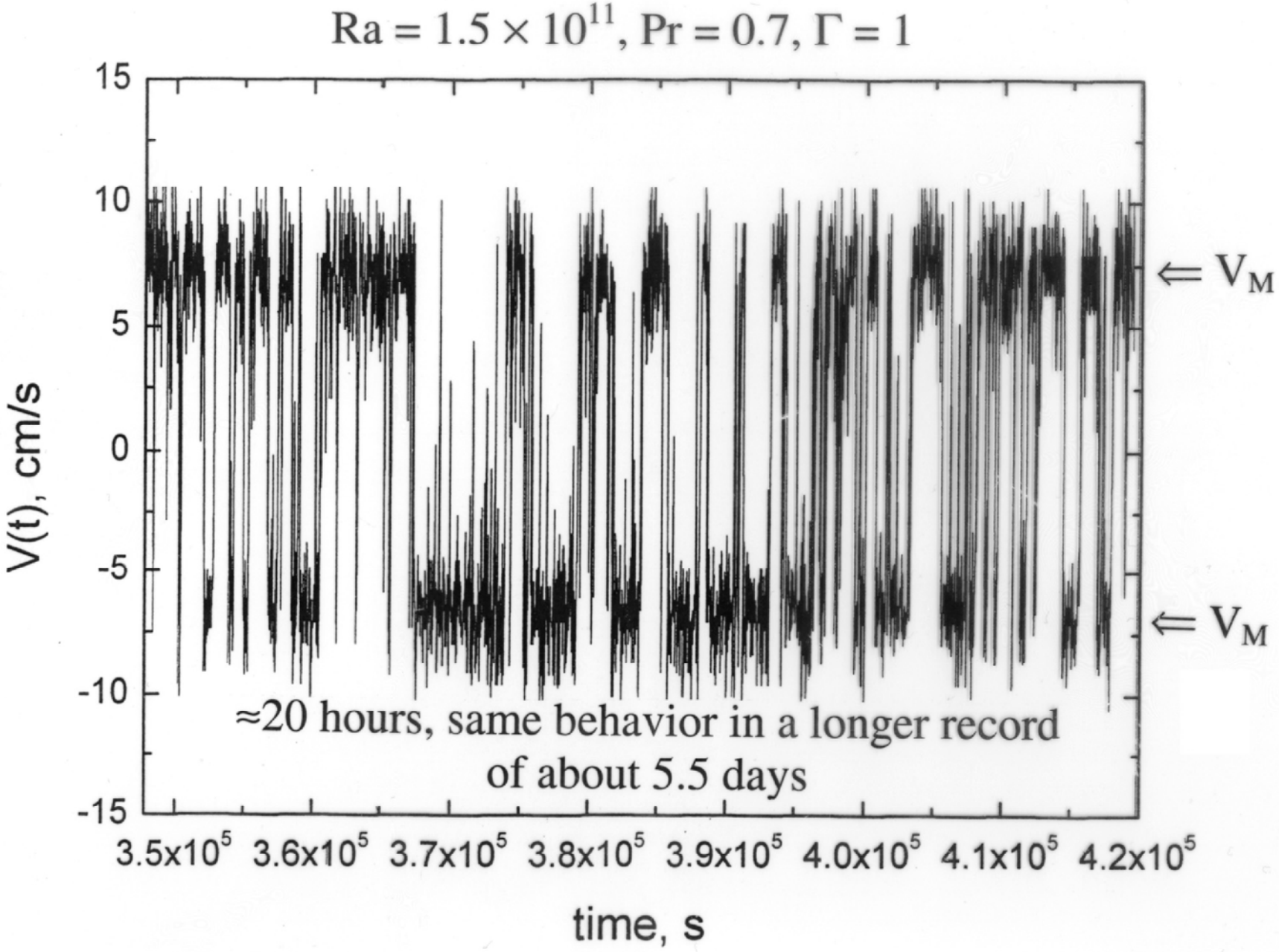
The reversal of the mean wind

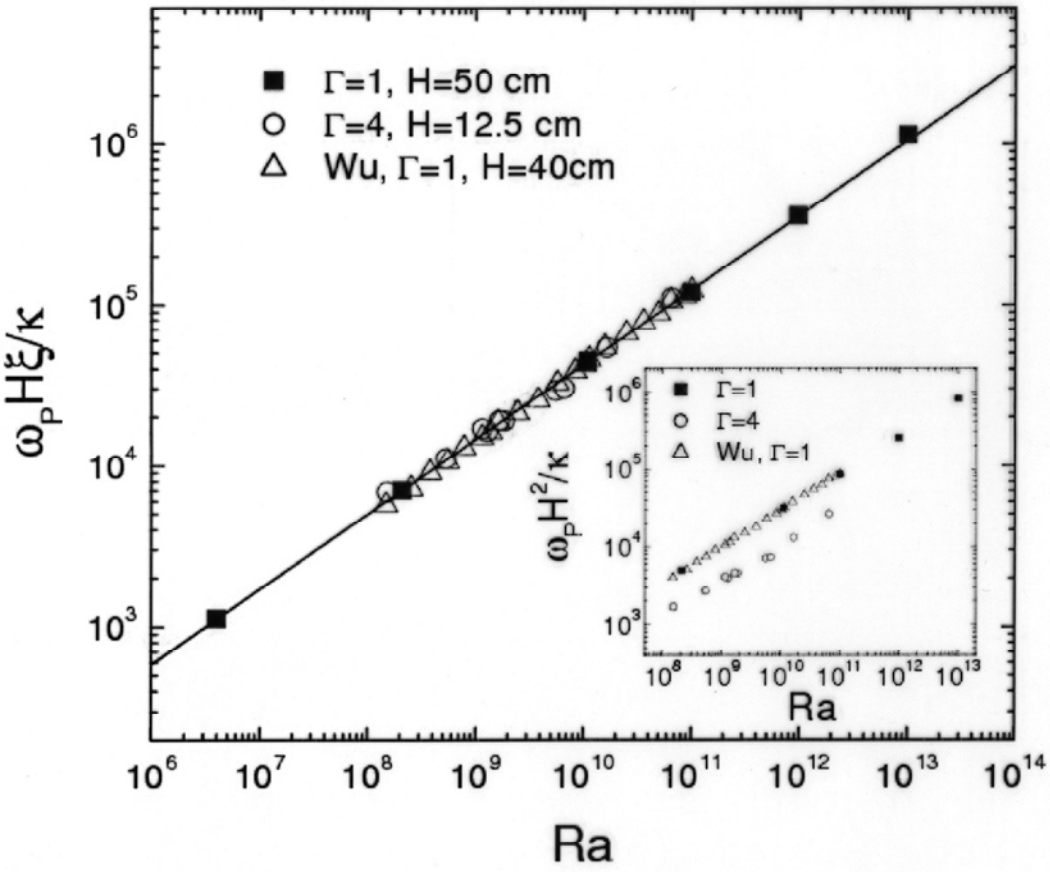


250-micrometer NTD-doped Ge sensors are placed in various positions in the flow.



Maximizing the correlation between temperature signals gives the magnitude and direction of a large scale circulation.


Ra = 1.5 × 10^11, Pr = 0.7, Γ = 1
15
10
5
0
-5
-10
-15
V(t), cm/s
⇐ V_M
⇐ V_M
≈20 hours, same behavior in a longer record
of about 5.5 days
3.5x10^5
3.6x10^5
3.7x10^5
3.8x10^5
3.9x10^5
4.0x10^5
4.1x10^5
4.2x10^5
time, s


Γ=1, H=50 cm
Γ=4, H=12.5 cm
Wu, Γ=1, H=40cm
$\omega_p H\xi/\kappa$
Ra
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
10^{13}
10^{14}
Γ=1
Γ=4
Wu, Γ=1
$\omega_p H^2/\kappa$
Ra

How are the reversals distributed?

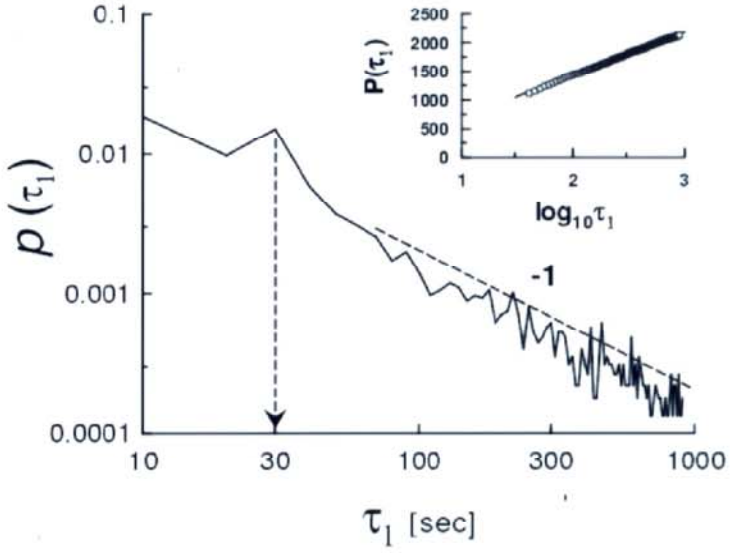
τ_1 = time between subsequent switches in the velocity signal

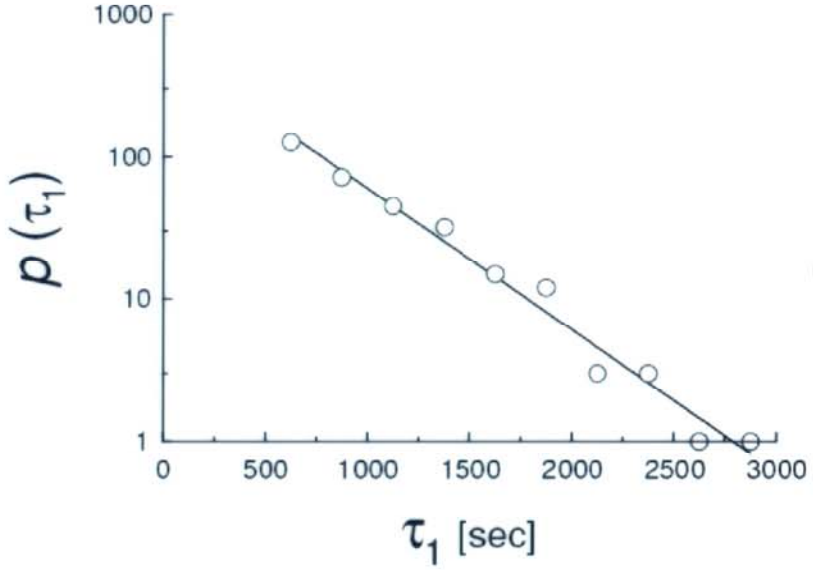
$$\tau_1 \equiv T_{n+1} - T_n$$

Power-law scaling of the probability density function

For large τ_1: $p(\tau_1)$: $\exp[-(\tau_1 / \tau_m)]$

τ_m ; 400s





Sreenivasan, Bershadskii & Niemela, Phys. Rev. E 65, 056306 (2002)

-1 power law scaling characteristic of SOC systems

Summary remarks

- Fritz Busse is one of the greatest convection experts.

- Best research avenues to expand into are:
  - High-Ra--Pr = O(1)
  - High-Ra--low Pr
  - Moderate Ra--high Pr
- 1/3 power most likely correct
- Pr-effects are probably weak at high Ra
- Aspect ratio effects not too large
- We don't understand how to model non-B effects well.
- Reversals are qualitatively different from modest changes in direction or orientation. Full change of orientation appears quite unlikely.
- We have begun to understand how to model the dynamics of the mean wind.