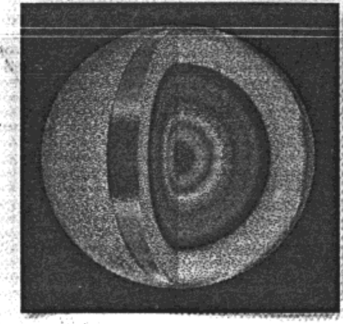
Solar Neutrino Puzzle

- Less neutrinos detected on earth than emitted by the Sun (30% à 2.5)

  Verification of the number of emitted neutrinos, variation with time?

- Transport of neutrinos from central Sun
- Distribution of energy of the neutrinos
- Interaction cross sections between neutrinos and detectors

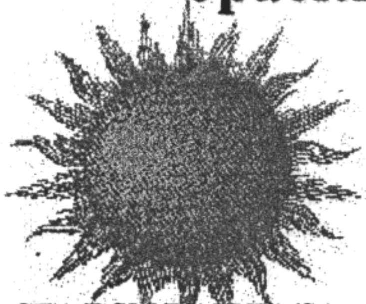


THE HISTORY OF BORON 8 FLUX

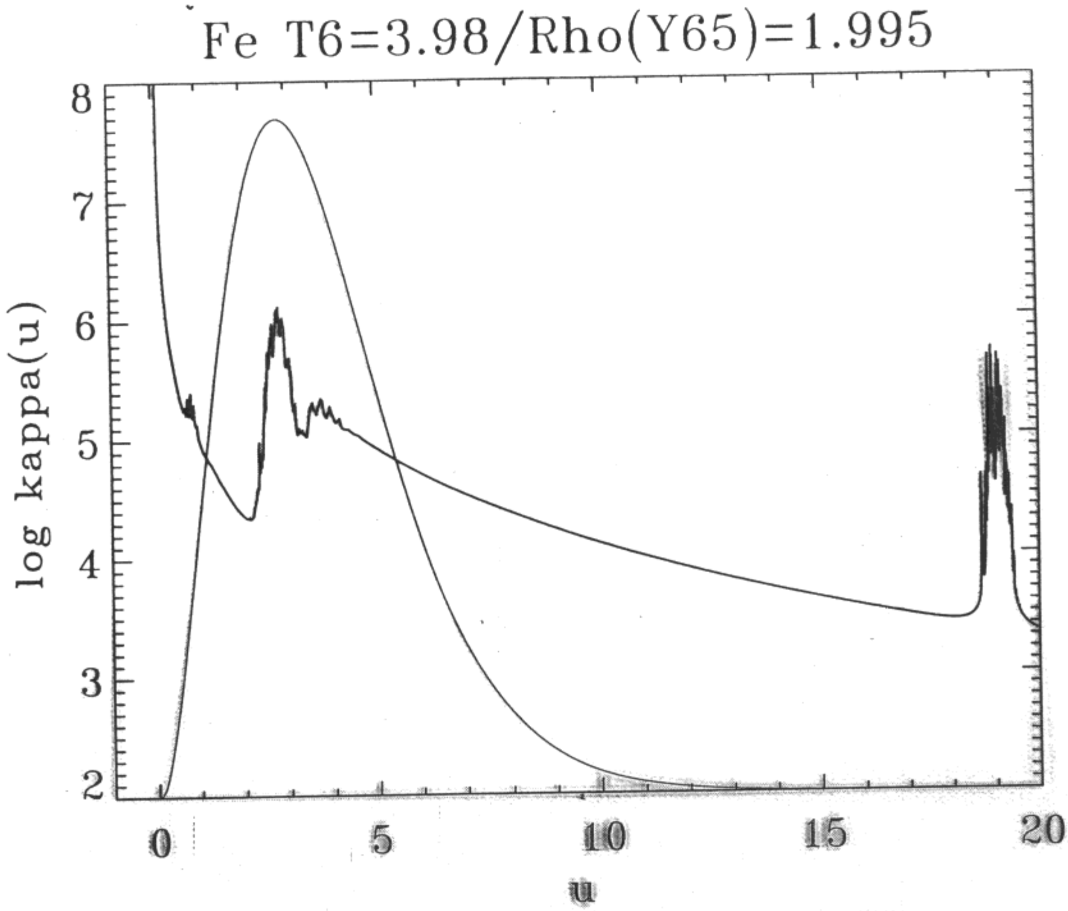
- This flux is not dependent on the solar luminosity

- It is mainly dependent on the pp chain III : ^{7}Be (p, γ)

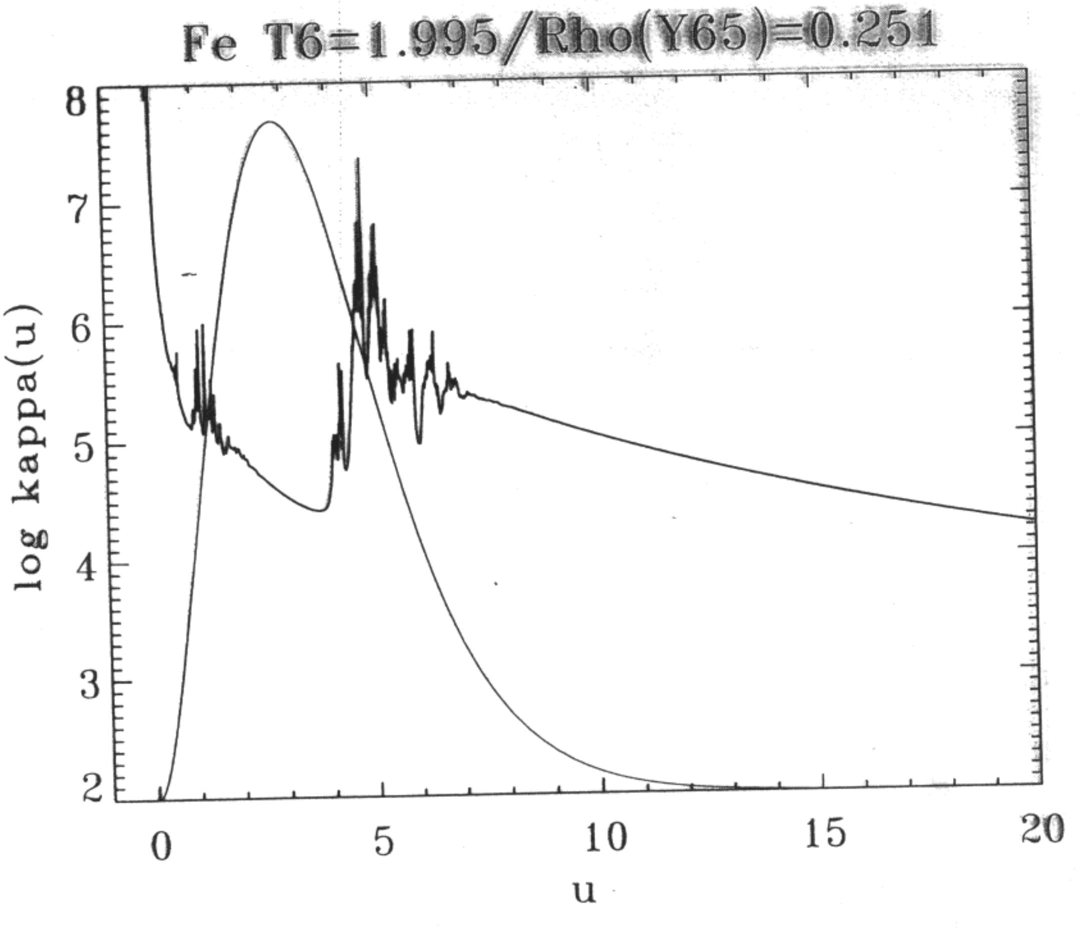
- It is extremely dependent on the temperature (T ^{20}), so on the central thermodynamical quantities: composition, opacities..



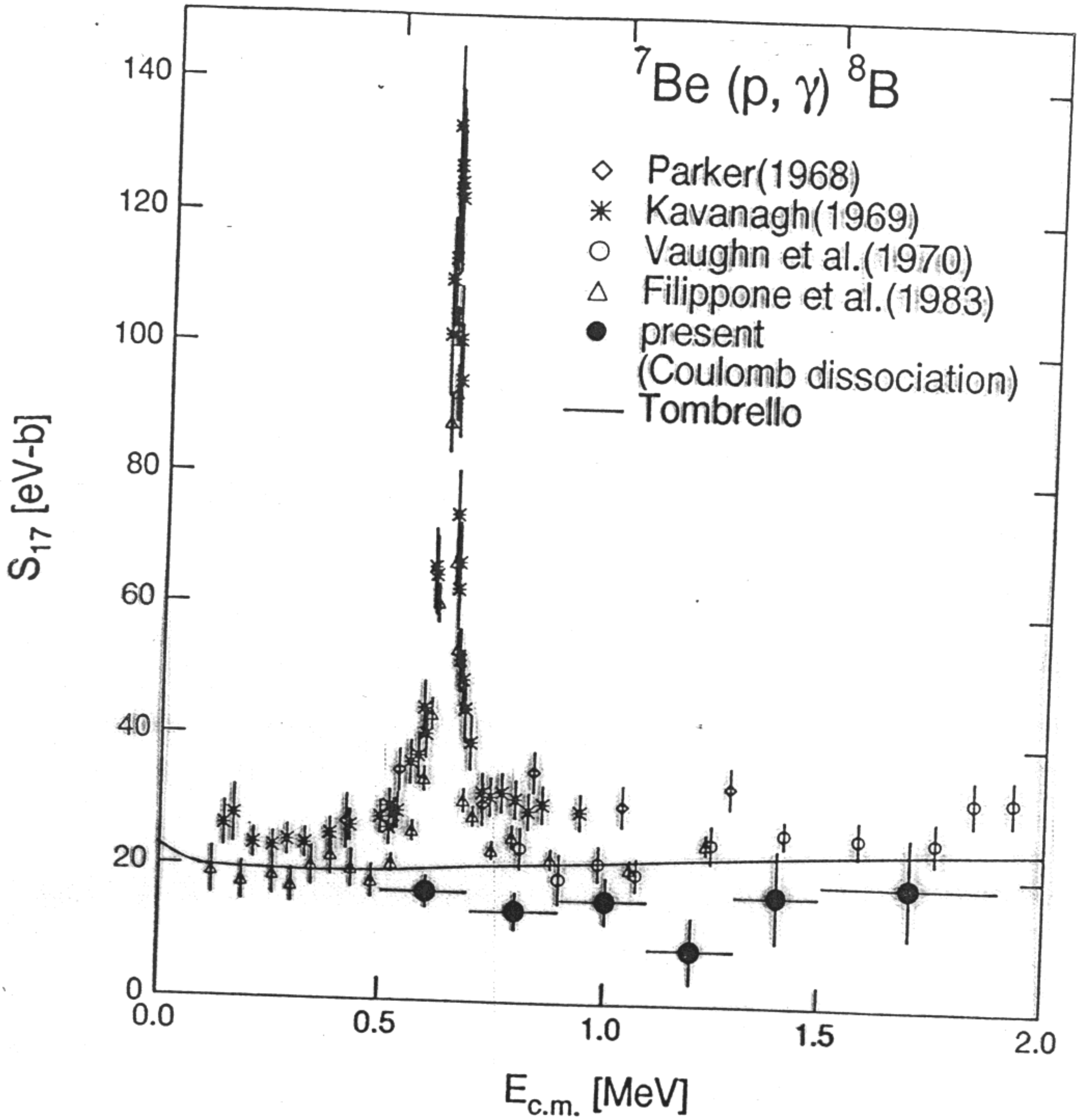
NEED OF LABORATORY EXPERIMENTS,
IMPROVED NUCLEAR, ATOMIC PHYSICS,
HELIOSEISMOLOGY



Fe T6=3.98/Rho(Y65)=1.995
log kappa(u)
u



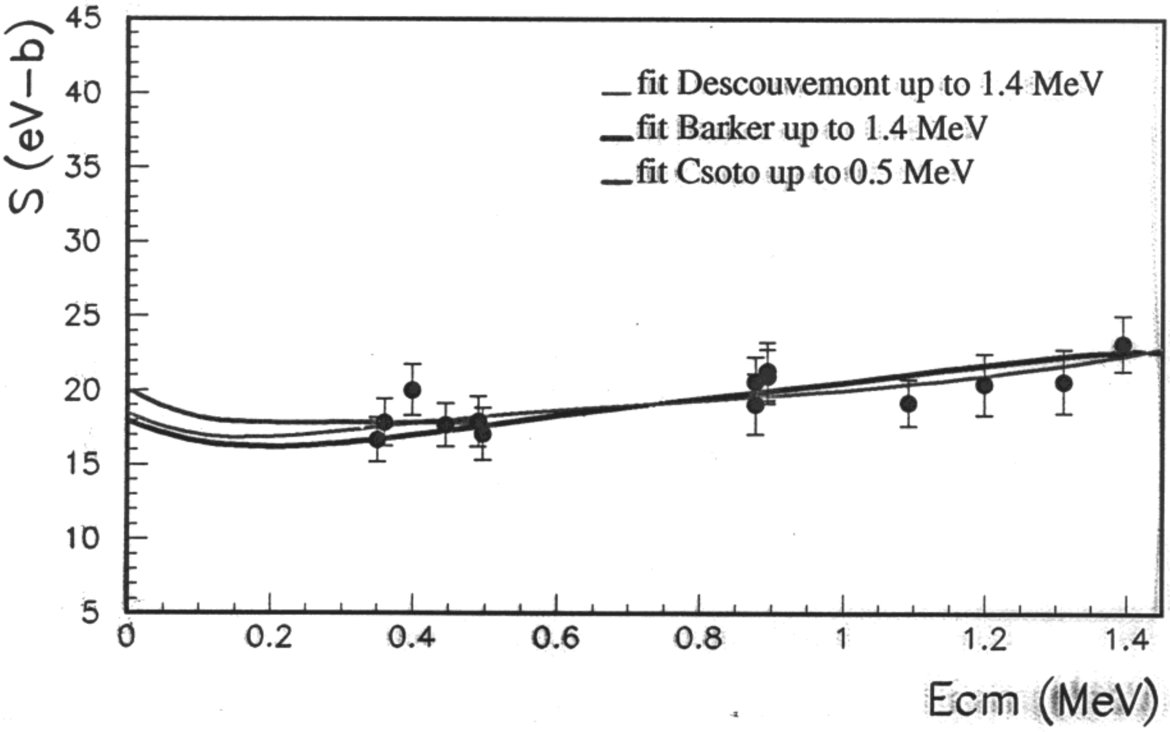
Fe T6=1.995/Rho(Y65)=0.251
log kappa(u)
u



^{7}Be (p, γ) ^{8}B
Parker(1968)
Kavanagh(1969)
Vaughn et al.(1970)
Filippone et al.(1983)
present
(Coulomb dissociation)
Tombrello
S_{17} [eV-b]
$E_{c.m.}$ [MeV]
0
20
40
60
80
100
120
140
0.0
0.5
1.0
1.5
2.0

Fig. 5

$^{7}Be(p,\gamma)^{8}B$



from Hammache et al. 1999

S(0) = 19.2 +- 1.3 keV.b

S(18 keV) = 18.8 keV.b

Extrapolation must be constrained by the quadrupole moment measurement

Screening effect

Dzitko, Turck-Chiege, Delbourgo, Lagrange
ApJ 447, (1995), 428

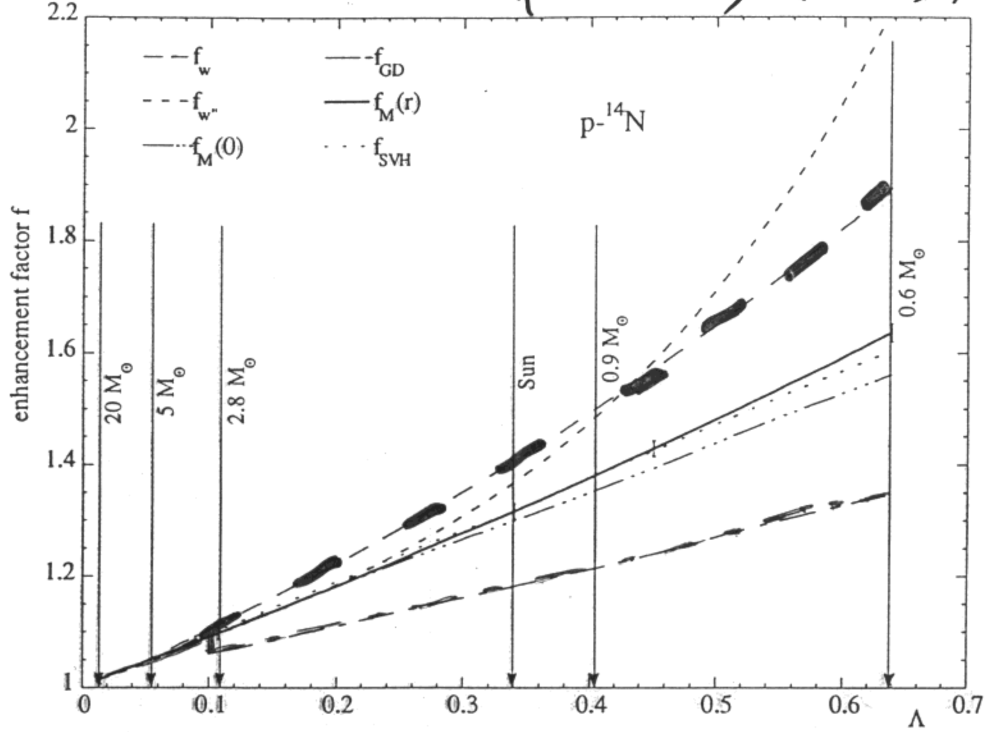


FIG. 3.—Comparison of the screening factors given by the various formalisms for the (p, ^{14}N) reaction, in central stellar conditions, vs. the screening strei parameter Λ; f_w is S54 WS, $f_{w''}$ is the extended WS, $f_M(0)$ is Mitler's prescription, f_{SVH} and f_{GD} are respectively SVH and GDGC screening, and $f_M(r)$ is enhancement factor obtained with radial-dependent formalism.

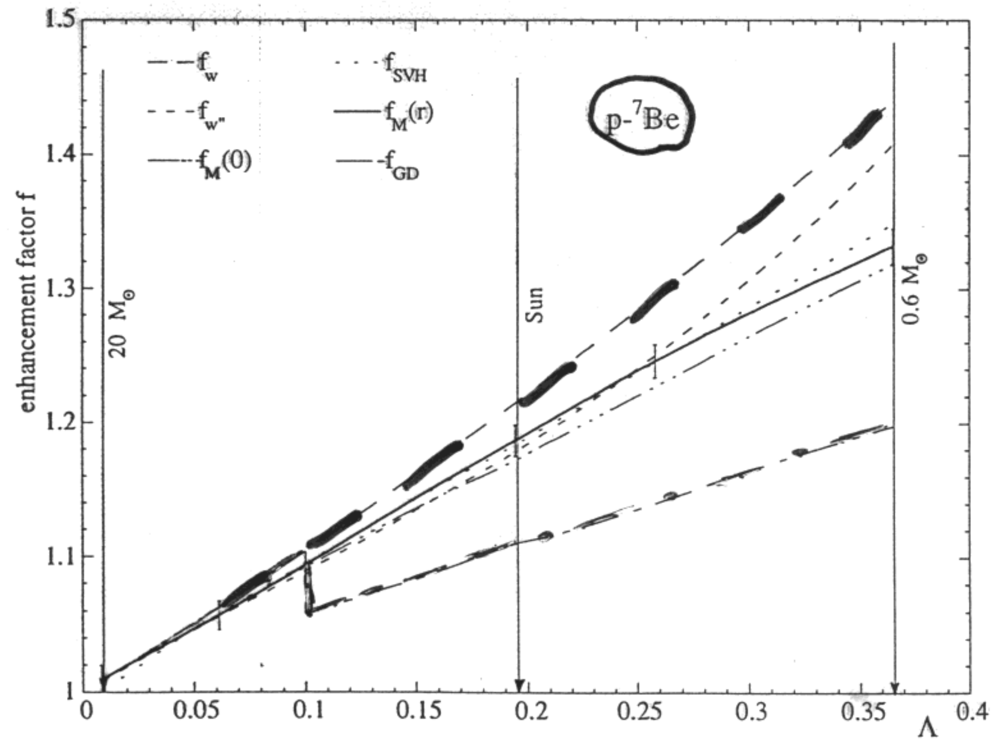


FIG. 4.—Same representation as in Fig. 3, for the (p, ^{7}Be) reaction.

Table 13

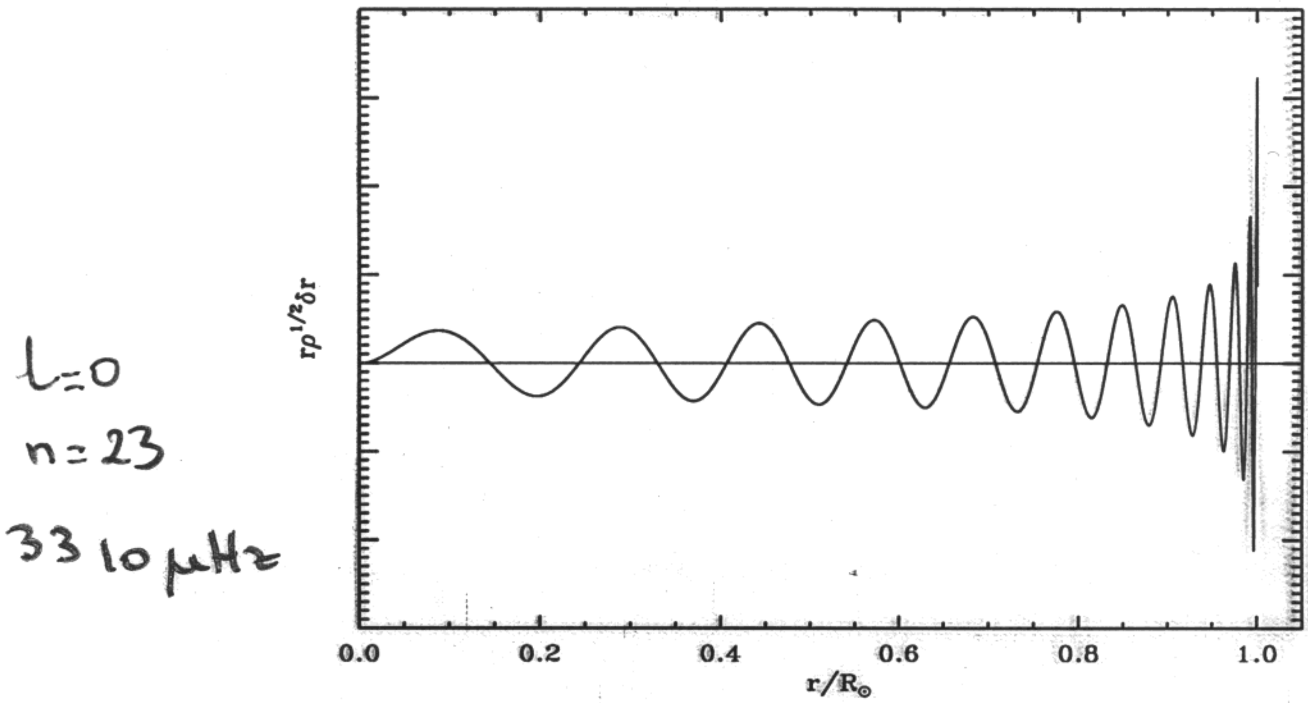
Upper part: Theoretical predictions for the neutrino fluxes coming from the different sources. *Lower part:* The most recent theoretical predictions for the neutrino flux. The second model of Bahcall and Pinsonneault includes part of the microscopic diffusion (see section 6).

	Neutrino fluxes (10^{10} cm^{-2} s^{-1})			
Neutrino sources	Bahcall and Ulrich [53] 3σ error 1988	Turck-Chièze et al. [74] 1σ error 1989	Sackman et al. [175]	
pp	6.0 (1 ± 0.02)	5.98 (1 ± 0.03)	6.00	
pep	1.4×10^{-2} (1 ± 0.05)	1.30×10^{-2}	1.29×10^{-2}	
^{7}Be	4.7×10^{-1} (1 ± 0.15)	4.18×10^{-1}	4.23×10^{-1}	
^{8}B	5.8×10^{-4} (1 ± 0.37)	3.83×10^{-4} $(1^{+0.18}_{-0.27})$	5.8×10^{-4}	
^{13}N	6.1×10^{-2} (1 ± 0.5)	6.27×10^{-2}	$3.99\ 10^{-2}$	
^{15}O	5.2×10^{-2} (1 ± 0.58)	5.60×10^{-2}	3.09×10^{-2}	
^{17}F	5.2×10^{-4} (1 ± 0.46)		4.23×10^{-4}	
	Bahcall and Pinsonneault [62]		Berthomieu et al. [199]	Turck-Chièze and Lopes [183] 1993
pp	6.04	6.00	5.93	6.02
pep	1.43×10^{-2}	1.43×10^{-2}	1.40×10^{-2}	1.3×10^{-2}
^{7}Be	4.61×10^{-1}	4.89×10^{-1}	4.47×10^{-1}	4.33×10^{-1}
^{8}B	5.06×10^{-4}	5.69×10^{-4} (MD)	5.4×10^{-4}	4.43×10^{-4}
^{13}N	4.35×10^{-2}	4.92×10^{-2}	5.71×10^{-2}	3.83×10^{-2}
^{15}O	3.72×10^{-2}	4.26×10^{-2}	4.81×10^{-2}	3.15×10^{-2}

Sensitivity of the modes to the solar structure

Turck~ - (

Acoustic modes: sensitivity to the surface, 5% to the nuclear core



Gravity modes: sensitivity to the nuclear core, 75% from the nuclear core

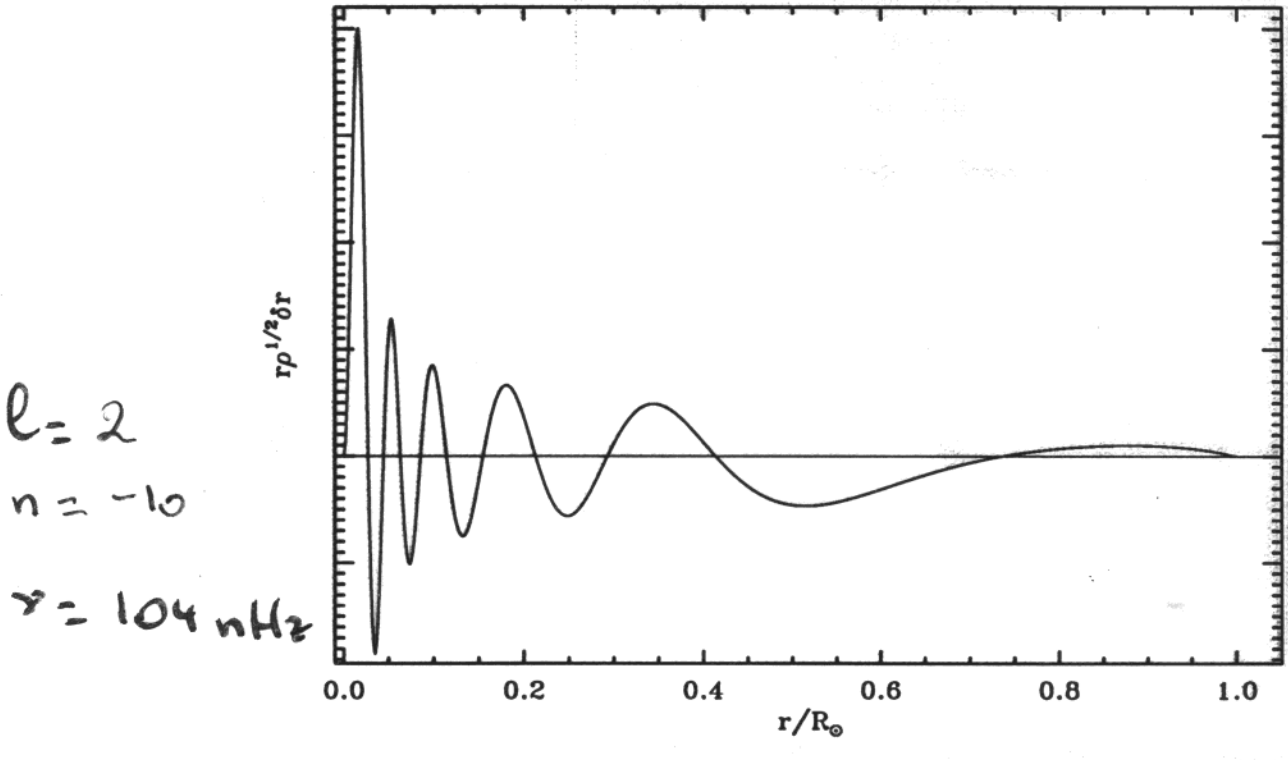
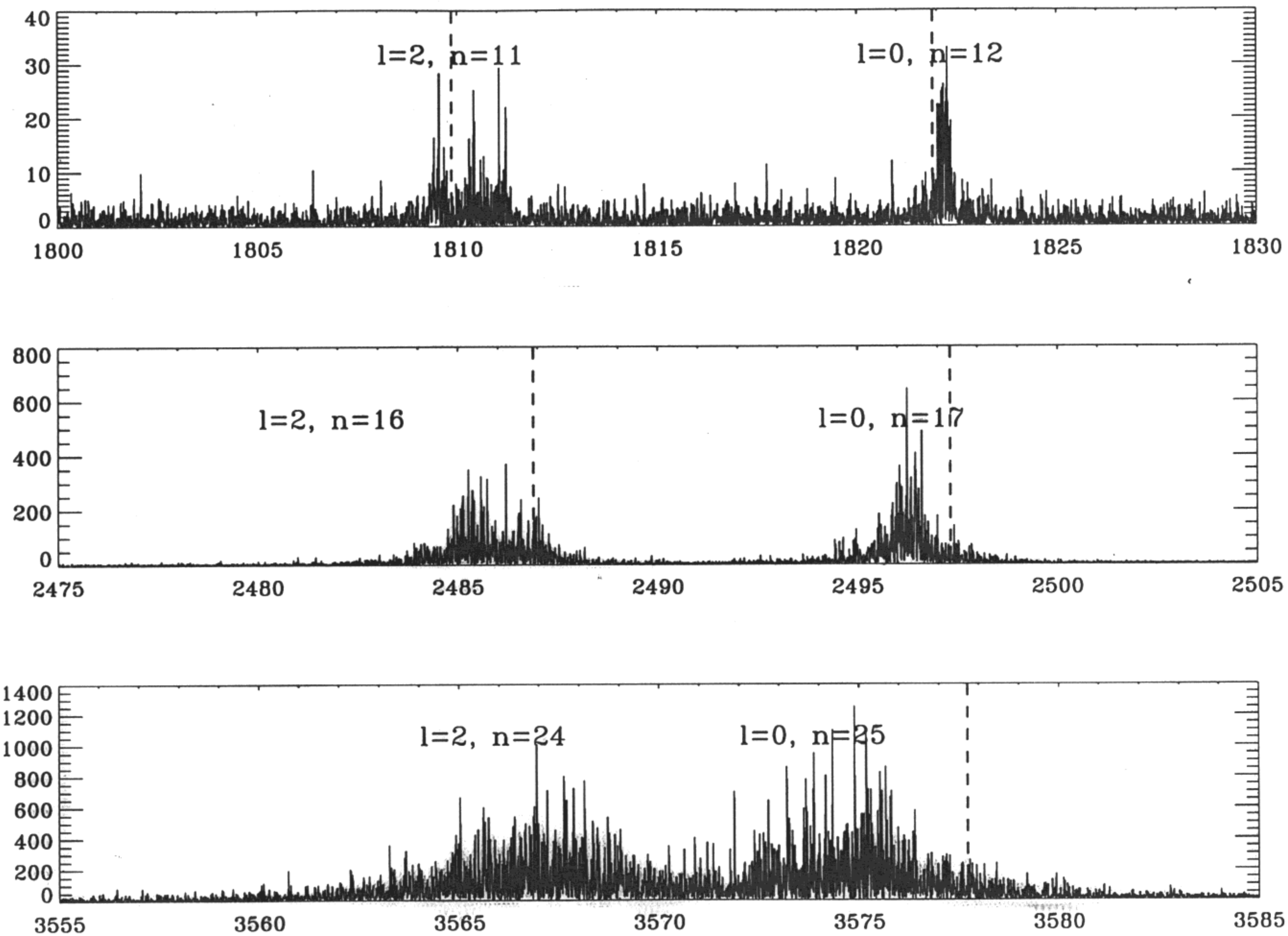


Table I. Sensitivity of the sound speed to the physical processes

Quantity	variation	$\Delta c^2/c^2$ variation
T	1 %	1%
κ	1 %	0.1 %
$X_c\,{}^{56}Fe$	4 %	0.1 %
$X\,{}^{3}He$	25%	0.1 %
(p,p) reaction rate	1%	± 0.1%
(^{3}He, ^{3}He) reaction rate	- 25 %	- 0.1 %
(^{3}He, ^{4}He) reaction rate	-25%	+0.2%
(p, ^{7}Be) reaction rate	10%	none
(p, ^{16}O) reaction rate	-50%	- 0.1-0.2 % just at the center

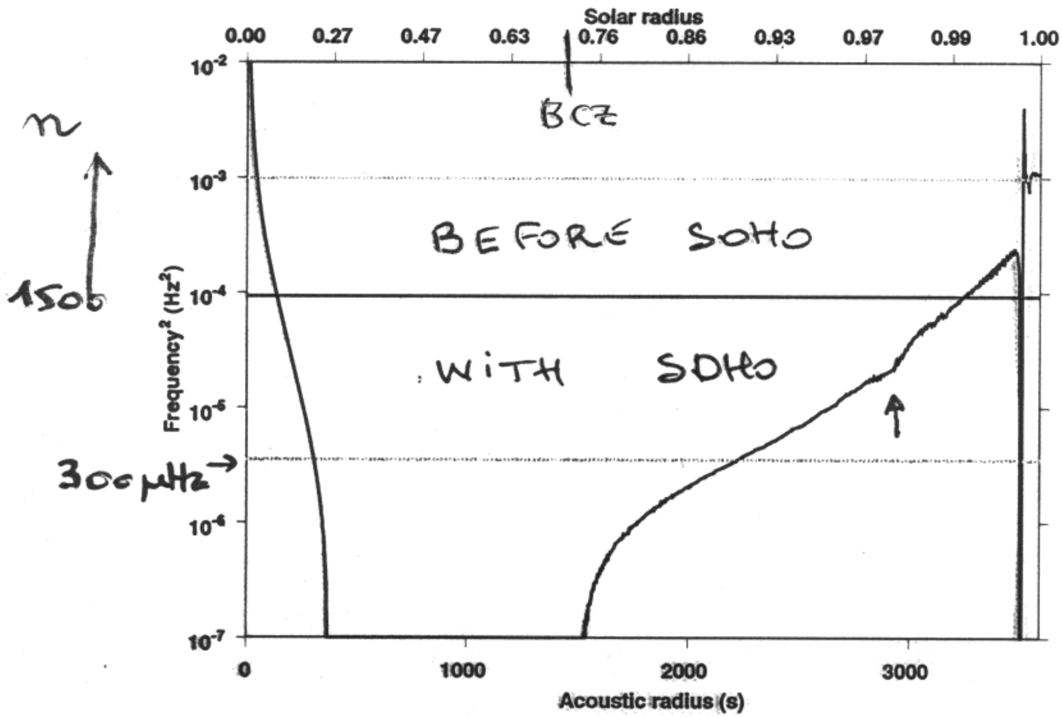
Turck - Chièze et al, 2001,

Sol. Phys 200, 323.

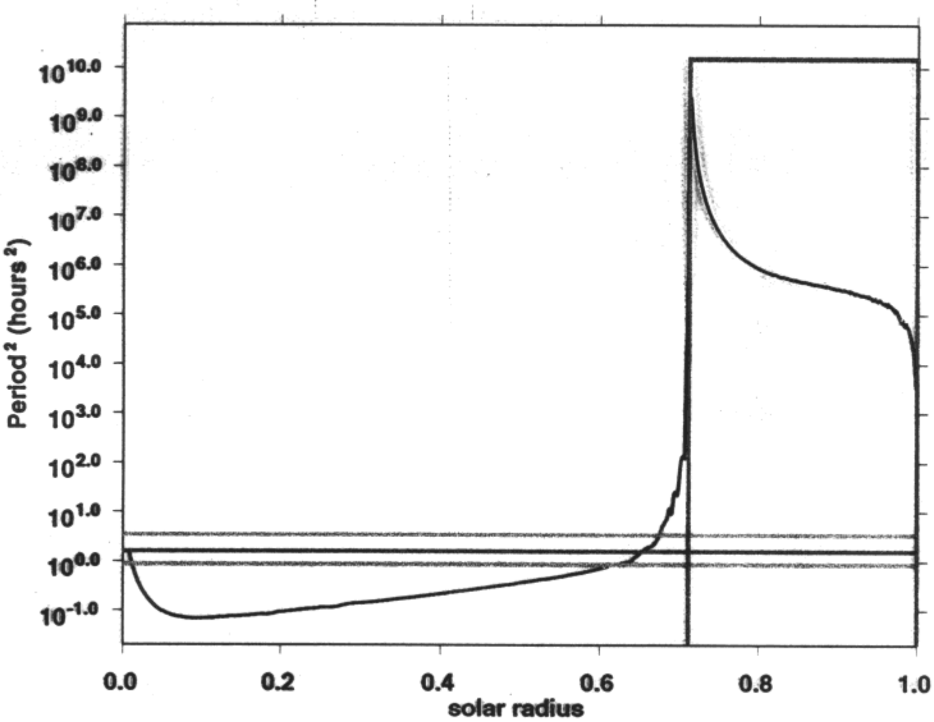


l=2, n=11
l=0, n=12
l=2, n=16
l=0, n=17
l=2, n=24
l=0, n=25

Solar cavity



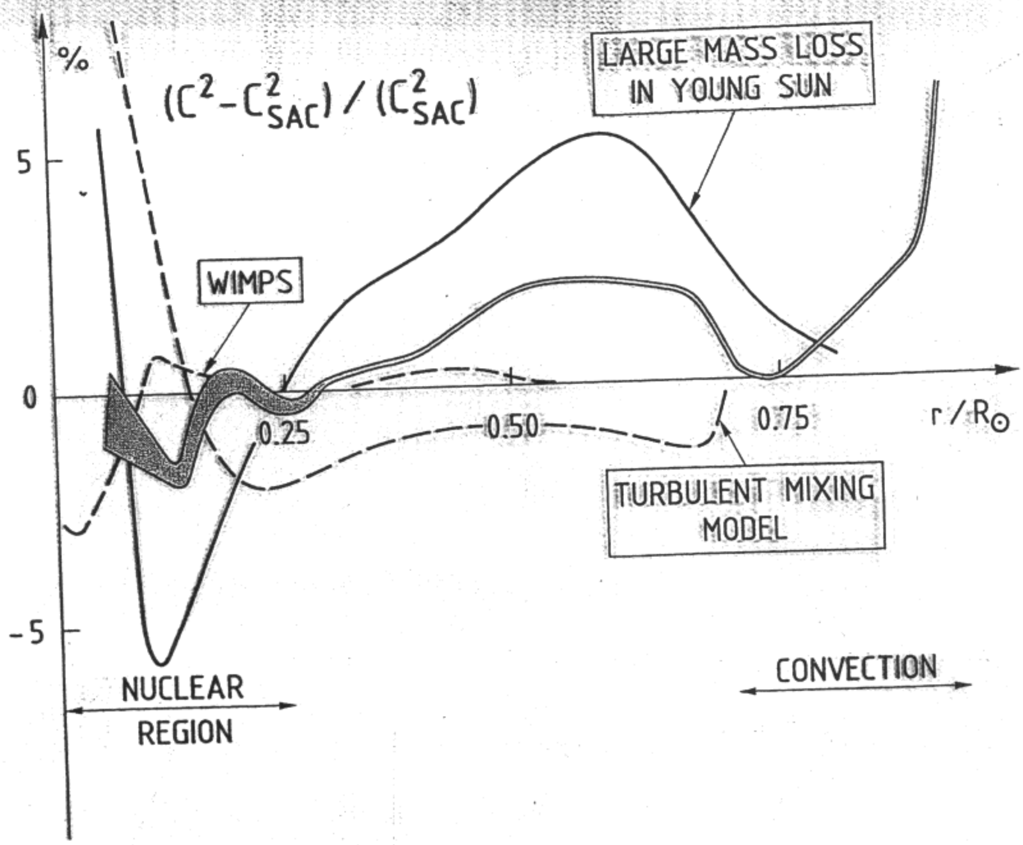
Acoustic cavity for $l = 1$



Gravity cavity

$l = 2$
$n = -3$

from Turck-Chièze, et al 2000
Lopes 1999, 2000



Gain of factor 20

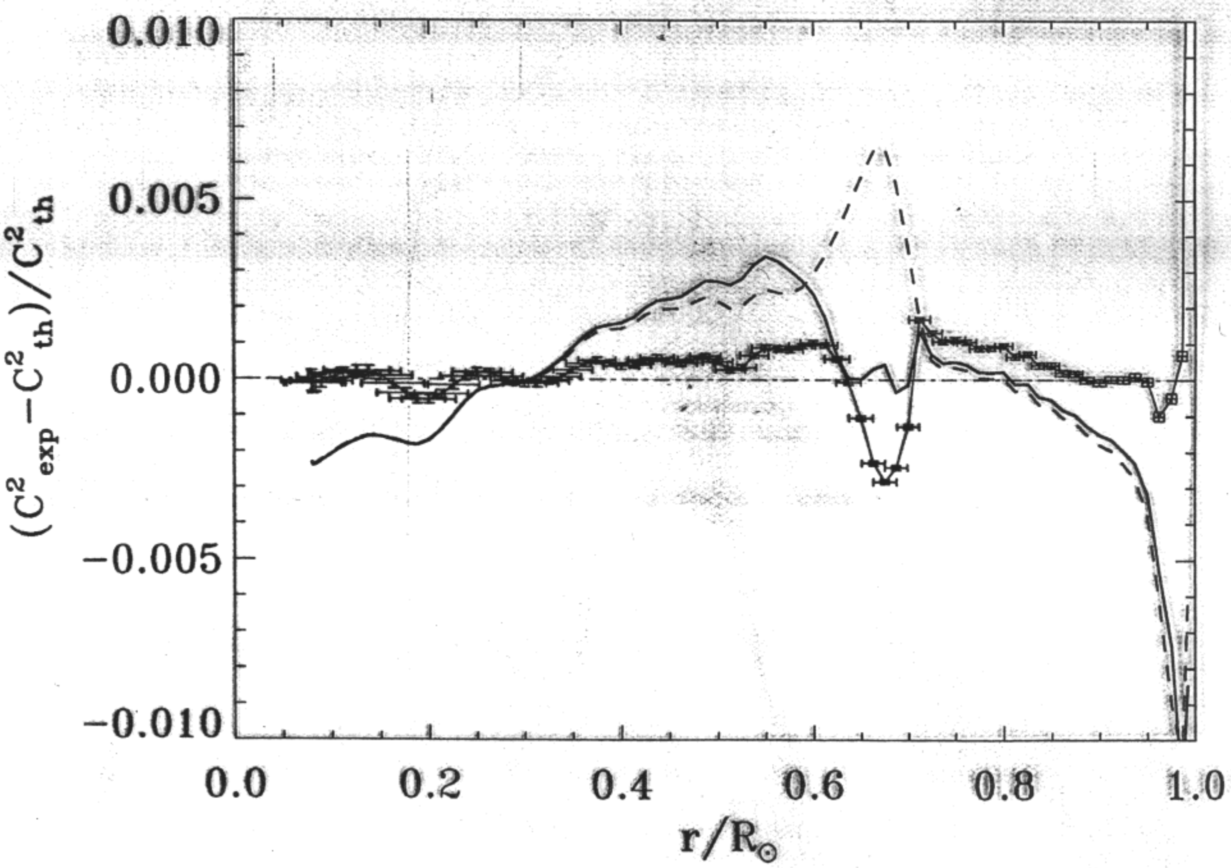


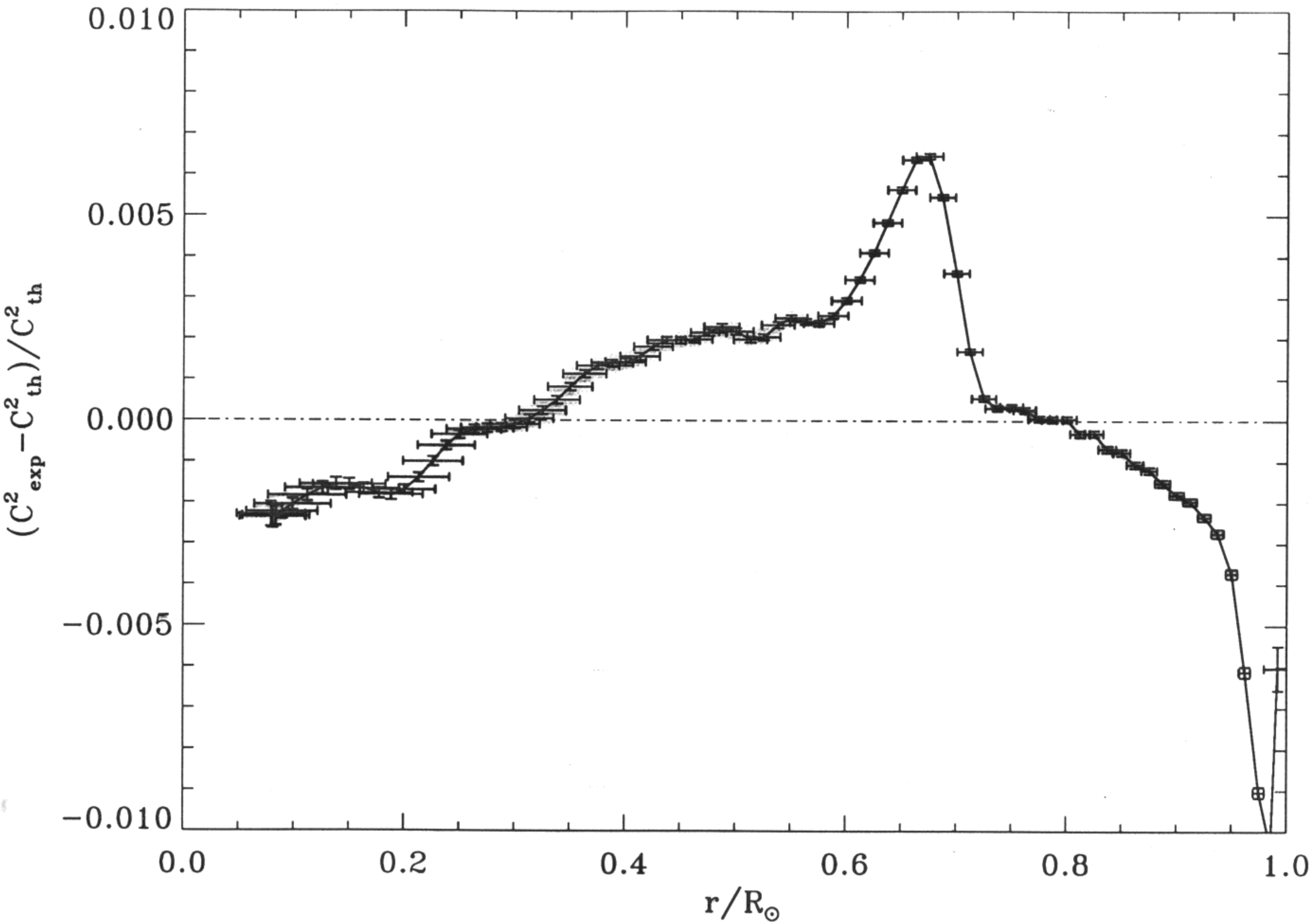
Table 2
Confrontation of observed neutrino detections and respective neutrino predictions for the chlorine, gallium and water detectors in the case of the reference model and two other models which suppose variation of the cross sections in the present error bars or a reduction of the ^7Be abundance in the Sun to respect the SuperKamiokande result. $1SNU = 10^{-36}$ capture/atom s.

		Observations		
Experiments	Chlorine exp.	SuperK exp. (10^6/cm^2/s)	Gallium GALLEX	experiments SAGE
	2.55 ± 0.25 SNU	2.44 ± 0.26	76 ± 8 SNU	70 ± 8 SNU
calibration			0.91 ± 0.08	0.95 ± 0.12
		Predictions		
Reference model	7 ± 1.7 SNU	5 ± 1.25	127 ± 8 SNU	127 ± 8 SNU
Nuclear model	5.2 SNU	3.21	119 SNU	119 SNU
^7Be model	3.87 SNU	2.4	105 SNU	105 SNU

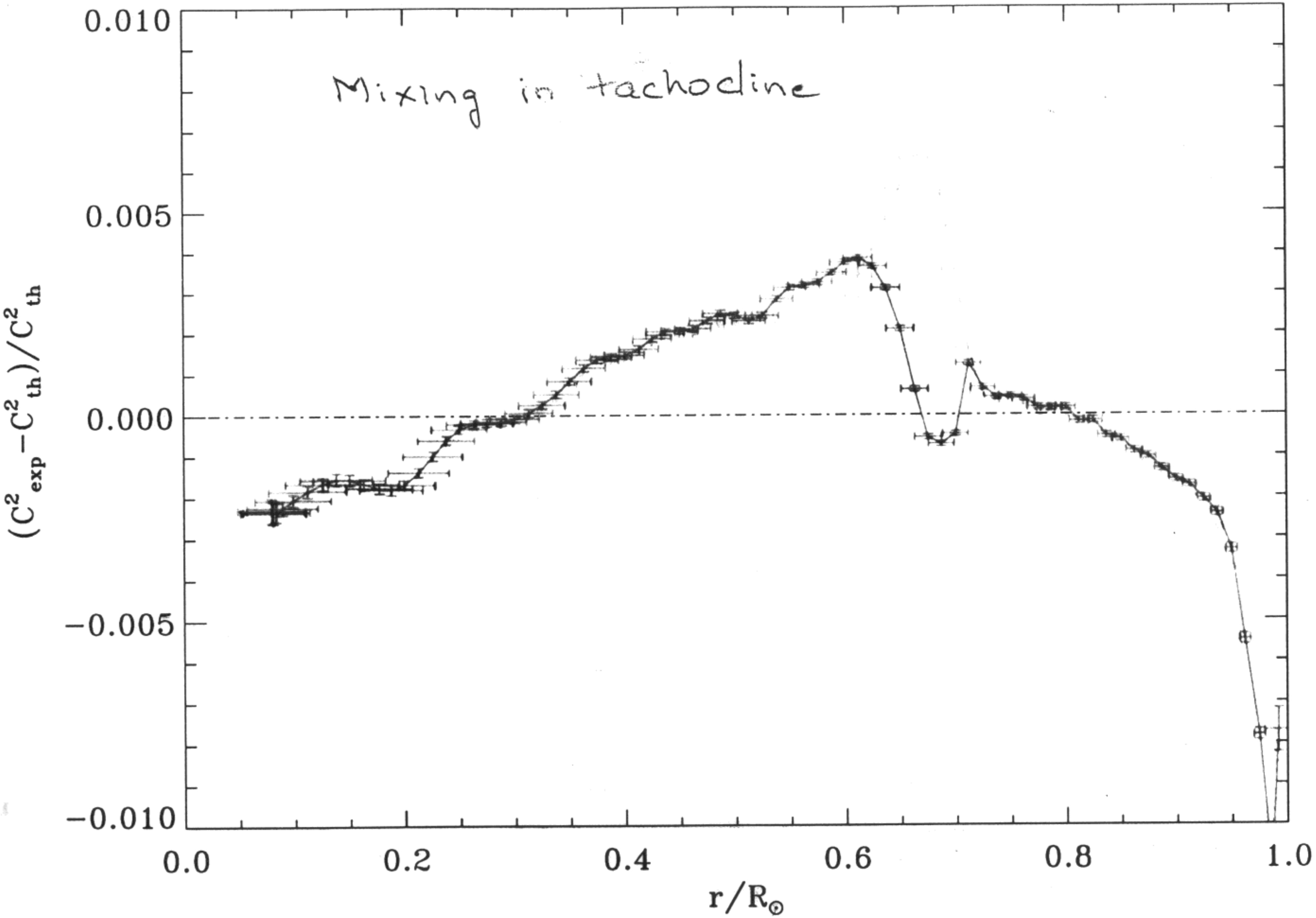
rejected by Turck-Chièze et al. Sol Phys 200, 323 (2001

tion of the central part of the Sun from acoustic modes: perturbation due to the solar cycle [25], the asymmetry of the line [26,17] or the treatment

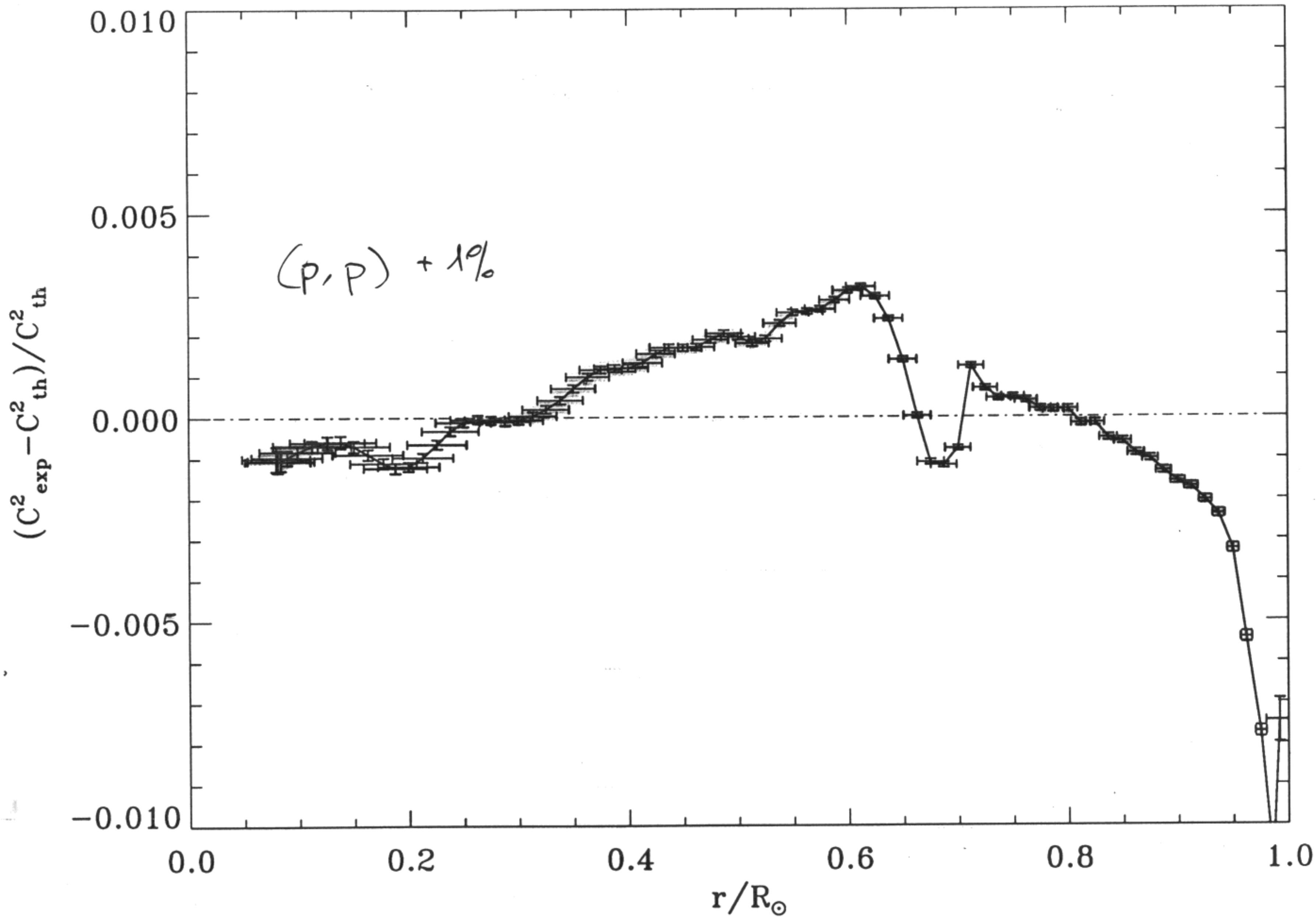
10% variation of the opacity coefficients along the solar radius has a negligible effect on the sound speed but a 1% variation of the central



0.010
0.005
0.000
−0.005
−0.010
$(C^2_{exp} - C^2_{th})/C^2_{th}$
0.0
0.2
0.4
0.6
0.8
1.0
$r/R_\odot$

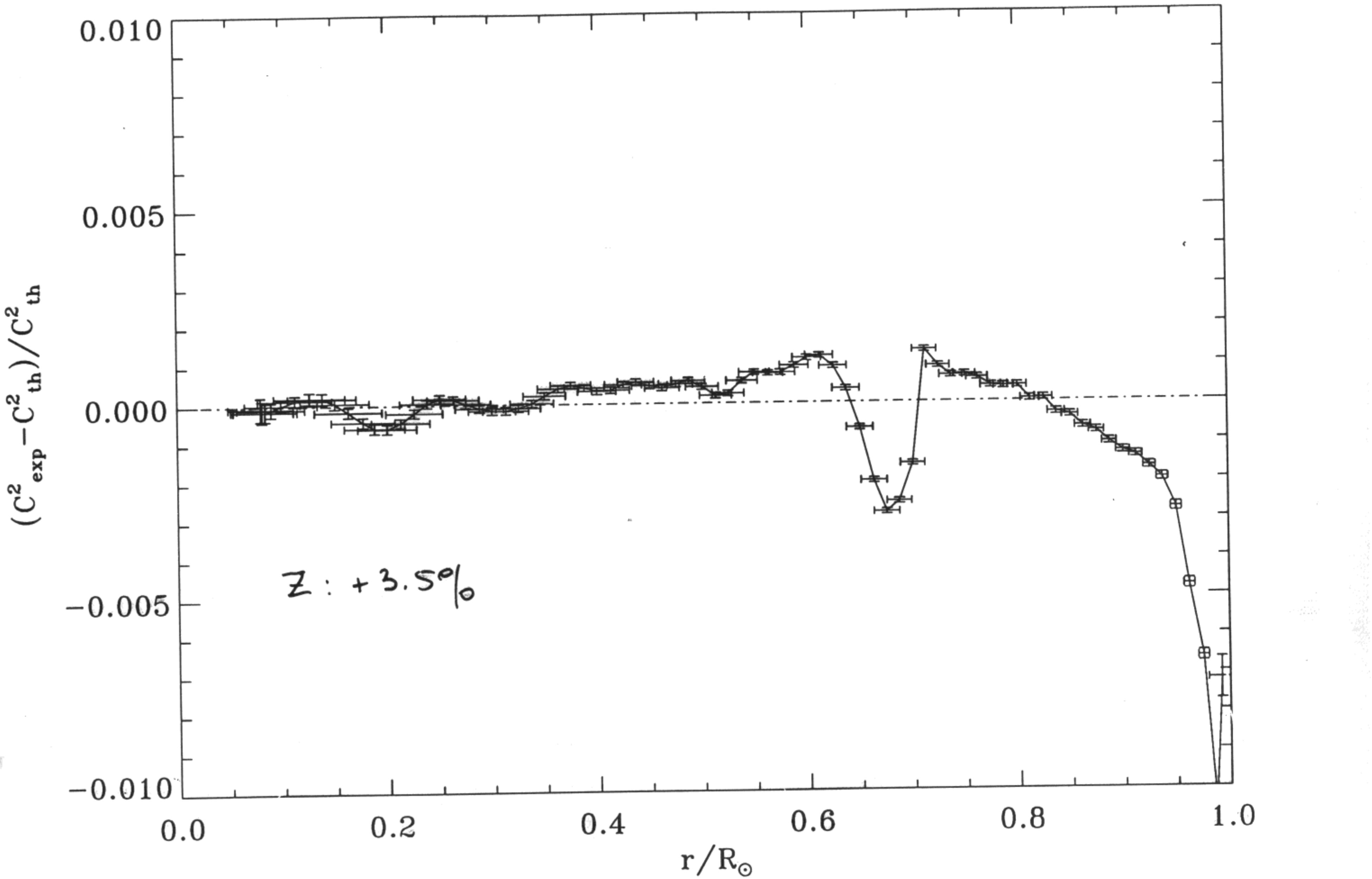


Mixing in tachocline
0.010
0.005
0.000
−0.005
−0.010
$(C^2_{exp} - C^2_{th})/C^2_{th}$
0.0
0.2
0.4
0.6
0.8
1.0
$r/R_\odot$



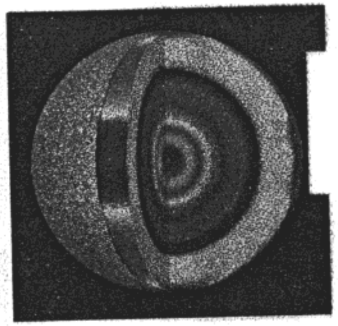
0.010
0.005
0.000
−0.005
−0.010
(p, p) + 1%
$(C^2_{exp} - C^2_{th})/C^2_{th}$
0.0
0.2
0.4
0.6
0.8
1.0
$r/R_\odot$

Seismic Model

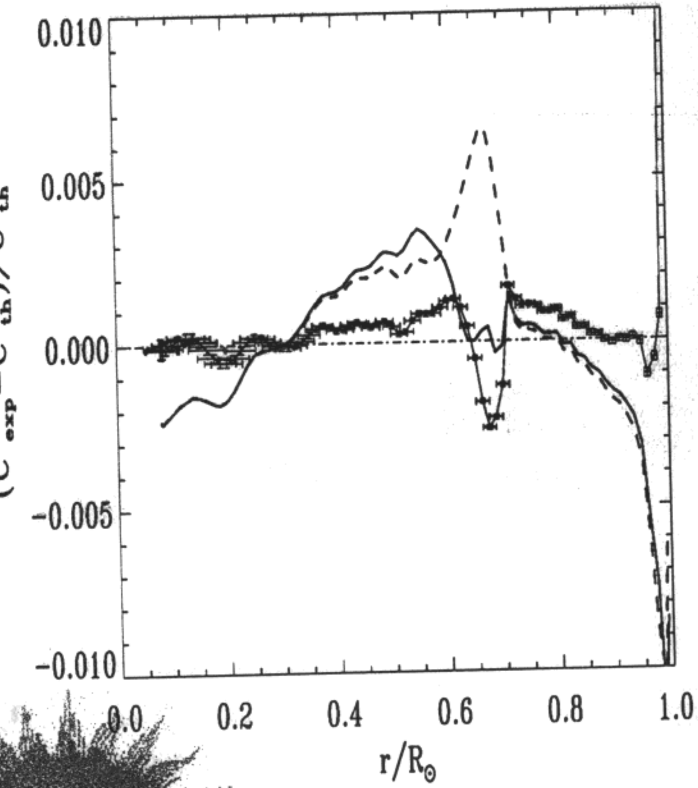


Turck-Chieze, Couvidat, Kosovichev et al ApJ lett

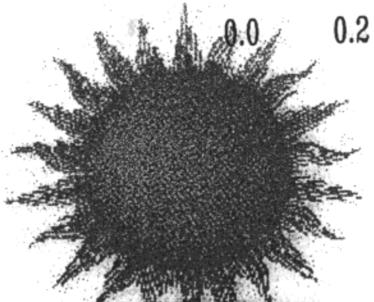
CEA DSM - DAPNIA SAp

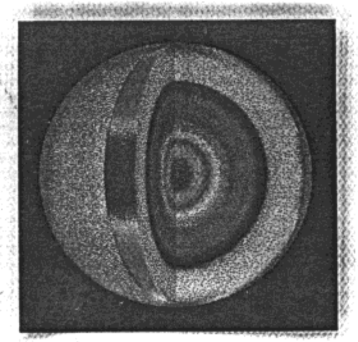


Seismic model



- microscopic diffusion
- turbulent term at the base of the convective zone
- minimal modification: pp reaction rate increased by 1%
- Z increased by 3.5%
- Neutrino fluxes:
- SUPERK: 4.95 ± 0.72 2.44±0.08 SNO ↓ 2.39±0.34 (+0.16 −0.14)
- HOMESTAKE: 7.44±0.96 2.55±0.25
- GALLIUM: 128.3±8.6 76±8 SNU
- Initial helium: 0.272
- Photospheric helium: 0.248
- $^7Li_{init}/^7Li$ photos.: 90-130





Uncertainties on neutrino fluxes

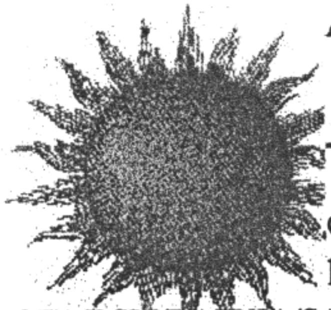
ApJ Turck-Chièze et al. (2001), 555, L69

TABLE 2

UNCERTAINTIES AND NEUTRINO FLUX PREDICTIONS OF THE SEISMIC MODEL COMPARED WITH THE OBSERVATIONS

Sources S	$\delta S/S$ (%)	^{71}Ga (%)	^{37}Cl (%)	Water (%)
(p, p)	1	0.9	−1.9	−2.4
(^{3}He, ^{3}He)	10	Negligible	3	4
(^{3}He, ^{4}He)	10	2.5	7.5	8.2
(^{7}Be, p)	7	<1	5.5	7
(CNO, p)	25	1.1	1.6	2.9
$L_\odot$	0.05	0.3	1.6	2
Z/X	5	0.9	4.5	4.9
Age	2	<1	2	2.5
Central κ	2	<1	5	6
Absorption cross section		6	4	...
Predicted Earth detection		127.8 ± 8.6	7.44 ± 0.96	4.95 ± 0.72
Detections		74.7 ± 5	2.56 ± 0.23	2.4 ± 0.08

NOTE.—The Superkamiokande neutrino flux (water) is given in 10^6 cm^{-2} s^{-1}. Gallium and chlorine detections are in SNU; 1 SNU = 10^{-36} captures atom^{-1} s^{-1}. Central κ is central opacity; predicted Earth detection is for fluxes emitted by the seismic model.



Emitted Neutrino [illegible]

➔ Neutrino fluxes (in $cm^{-2}.s^{-1}$)

	ν_{pp}	ν_{pep}	$\nu_{^7Be}$	$\nu_{^8B}$	$\nu_{^{13}N}$	$\nu_{^{15}O}$	$\nu_{^{17}F}$
production	$1,67.10^{38}$	$3,94.10^{35}$	$1,37.10^{37}$	1,40.10[illegible]	1,62.10[illegible]	1,39.10[illegible]	8,62.10[illegible]
on earth	$5,92.10^{10}$	$1,39.10^{8}$	$4,84.10^{9}$	$4,94.10^{6}$	$5,72.10^{8}$	$4,92.10^{8}$	3,05.10[illegible]
^{71}Ga	69,35	2,84	34,67	11,86	3,45	5,59	$3,47.10^{-2}$
^{37}Cl	0,0	0,223	1,15	5,63	$9,48.10^{-2}$	0,325	2,03.10[illegible]

➔ Neutrino capture predictions

^{71}Ga : 127.8±8.6 SNU (detection : 74.7±5)

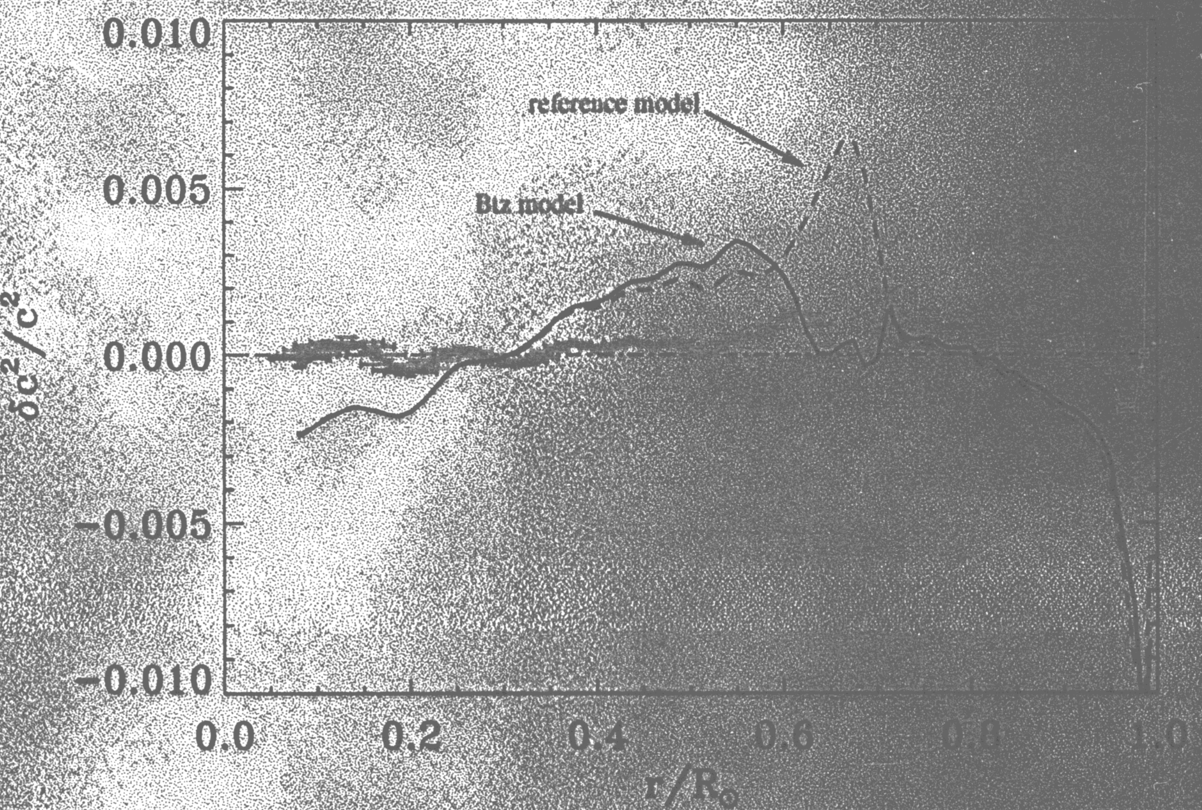
^{37}Cl : 7.44±0.96 SNU (detection : 2.56±0.23)

^{8}B : 4.95±0.72 $cm^{-2}.s^{-1}$ (detection 2.4±0.08)

|| 10^6

5.44 ± 0.99 10^6 cm^{-2} s^{-1} deduced from SK+SNO

Second Seismic



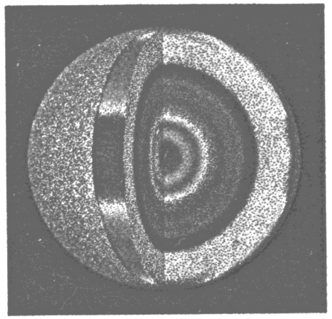
^{71}Ga = 125.97±8.47 SNU

^{37}Cl = 7.11±0.92 SNU

^{8}B = 4.72±0.69 $cm^{-2}.s^{-1}$

p–p reaction rate

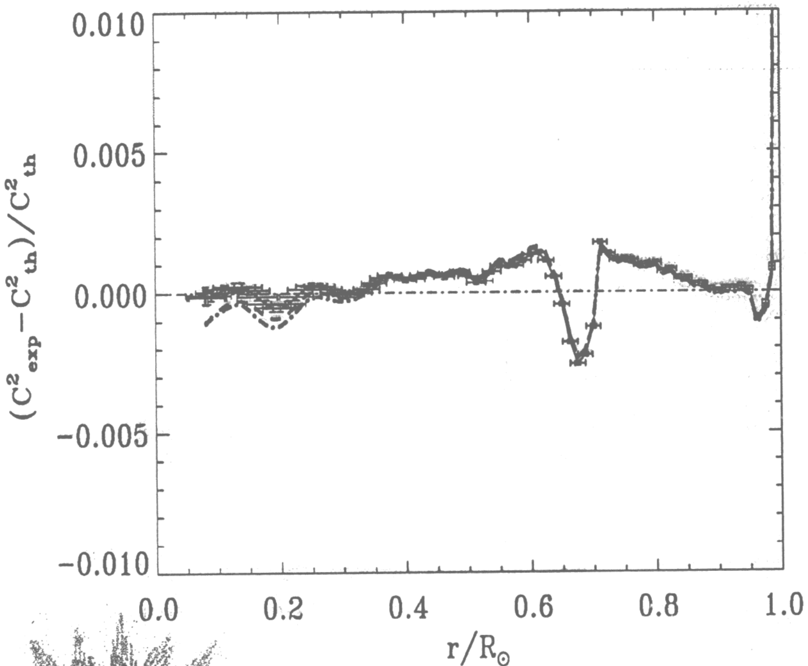
opacities modified from the core (~+1.5%) to the tachocline (~+5%) in a way simulating an increase of the opacities of the heavy elements

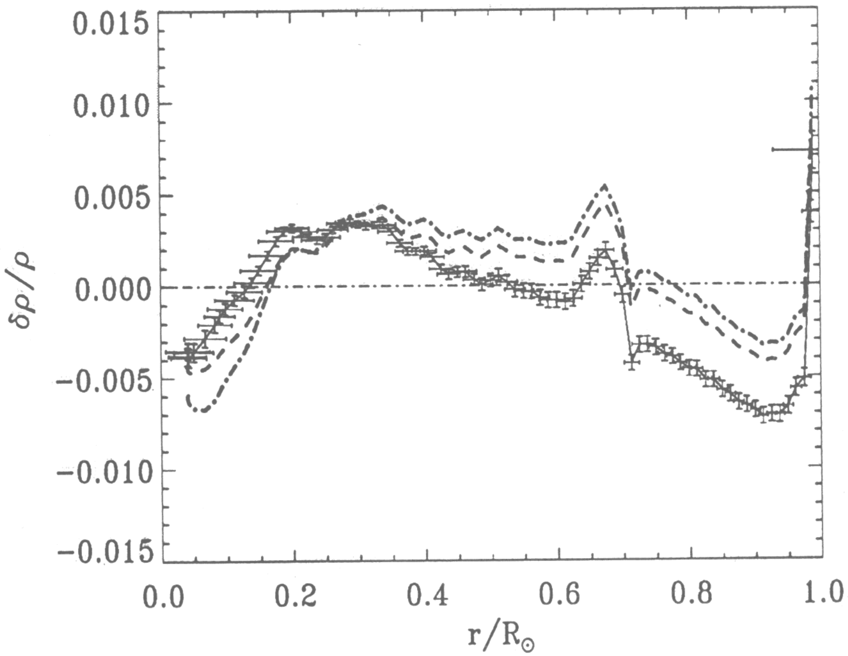


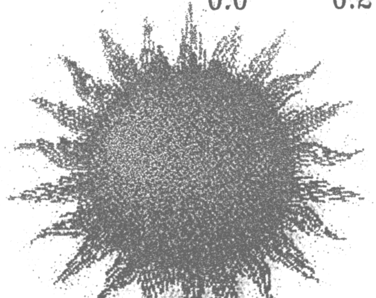
CEA DSM - DAPNIA SAp

Impact of reaction rates on the sound speed and the density

(^3He,^4He) -10%; CNO -70%

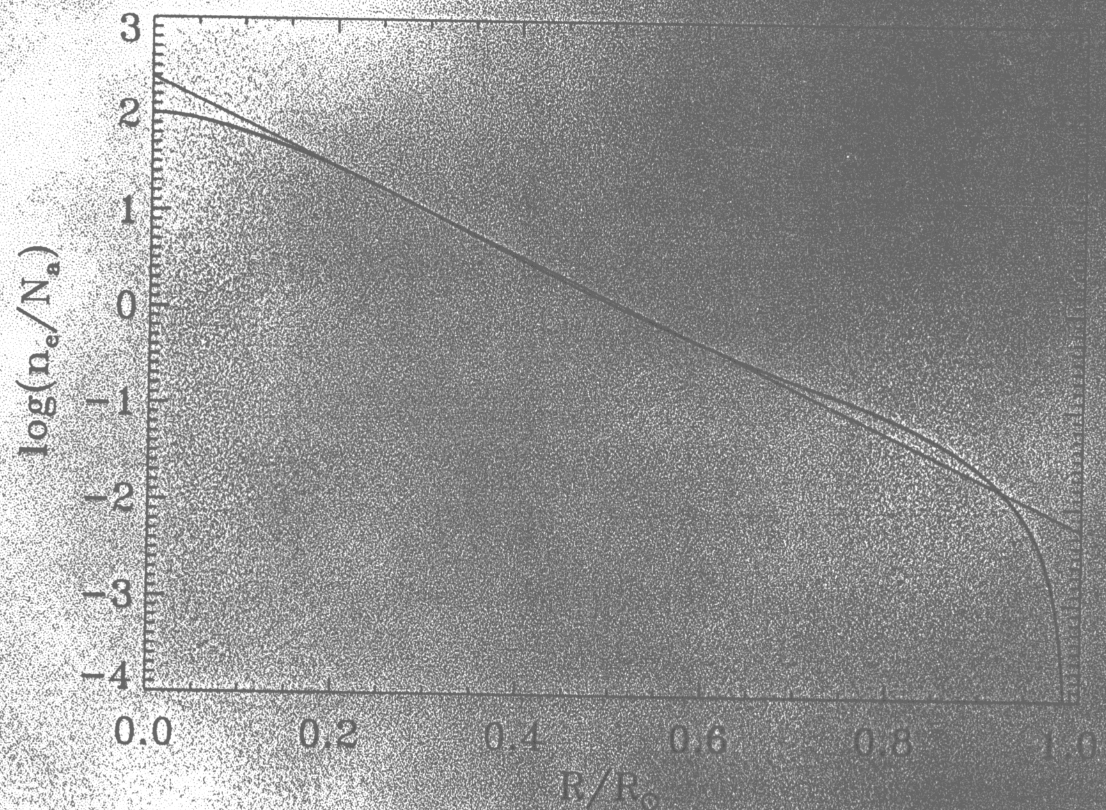


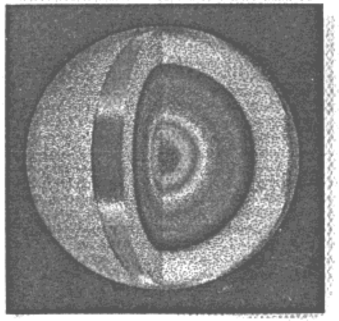




Electron Density Number

for the first seismic model





CONCLUSION

- Accuracy on the core sound speed profile is improving with time due to the detection of low order radial modes

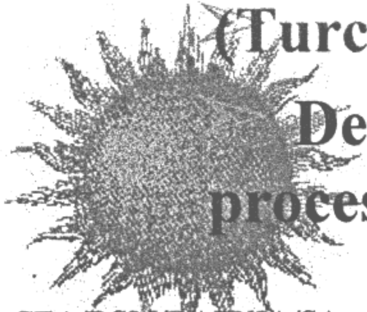
(Bertello et al. ApJ 2000, Garcia et al. Sol. Phys. 2001)

- With a static vision of the solar core, fundamental physics is validate and pp reaction rate is verified within 2% (Turck-Chièze et al. ApJ, 2001, 555, L69)

- Turbulence in the central region is not supported by the present study and screening effect on pp chain seems valid, CNO screening is not yet accessible by the sound speed

(Turck-Chièze et al. , 2001, Sol. Phys. 200, 323)

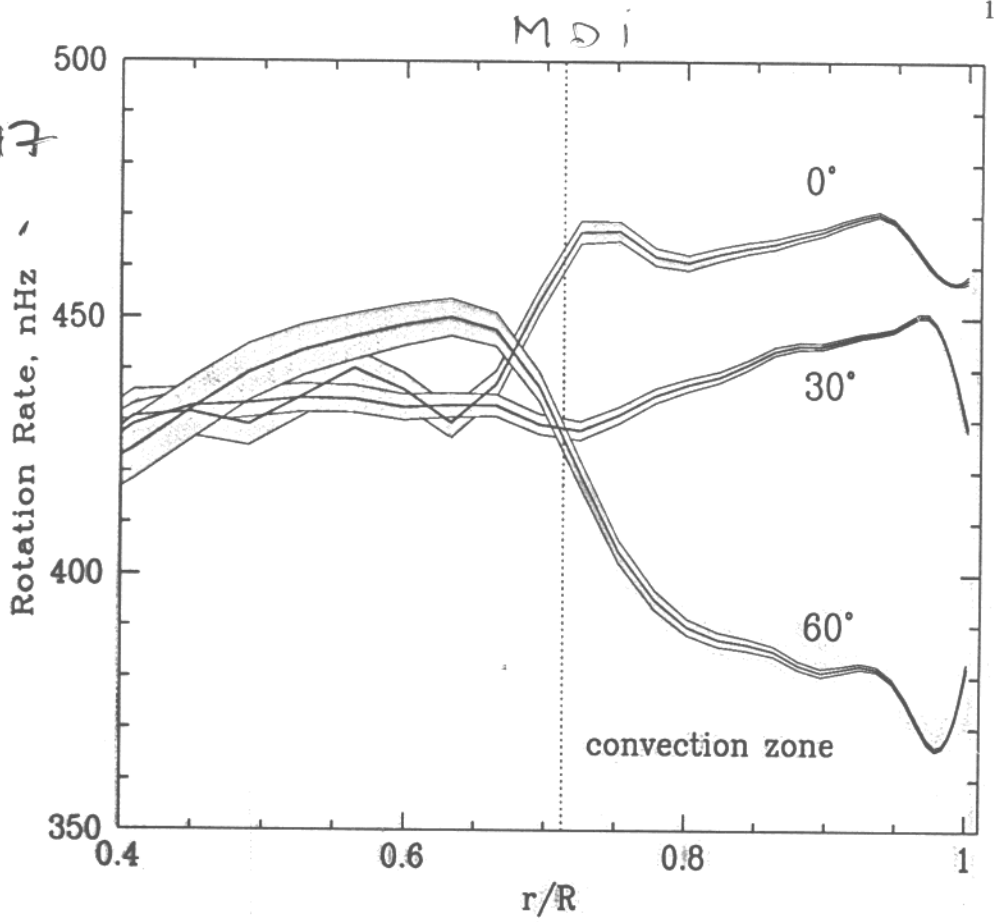
- Density profile must be used now to constrain physical processes.



Brun, Turck-Chieze, Zahn
ApJ (1999) 525, 1032

Turck~-

Kosovichev et al 1997 Sol. Phys.,



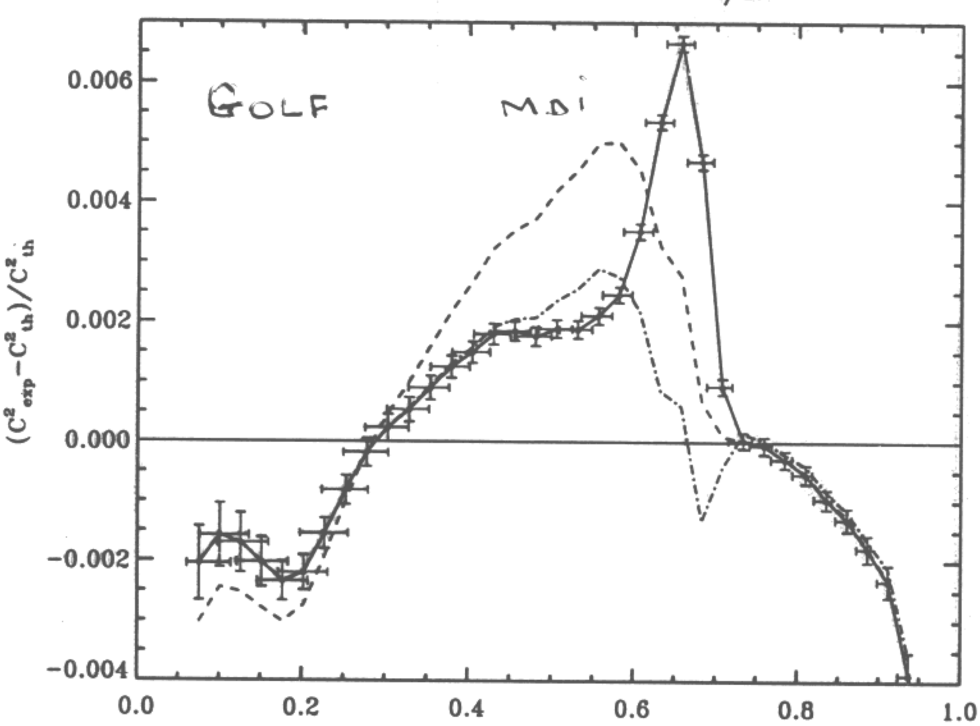
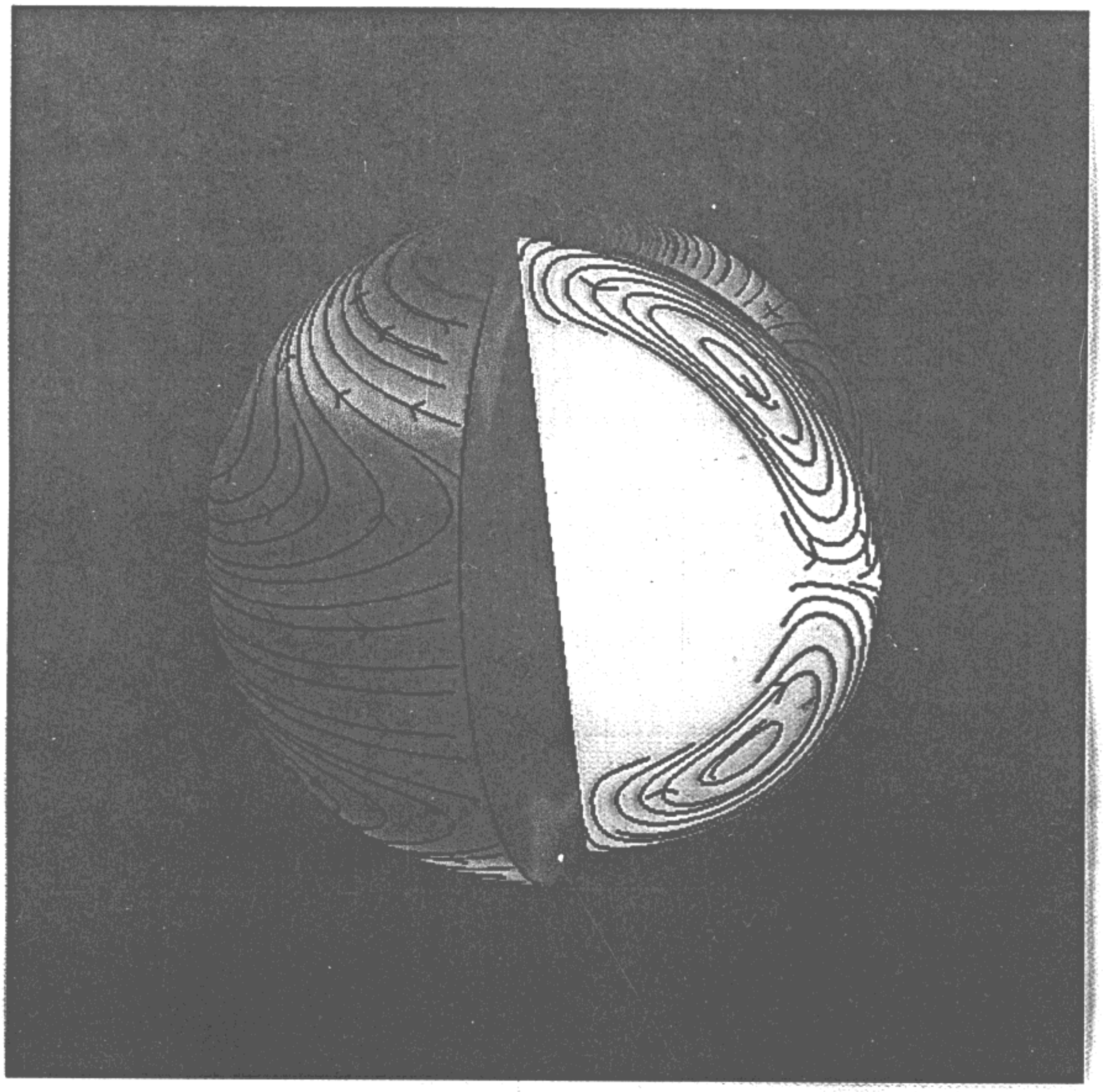
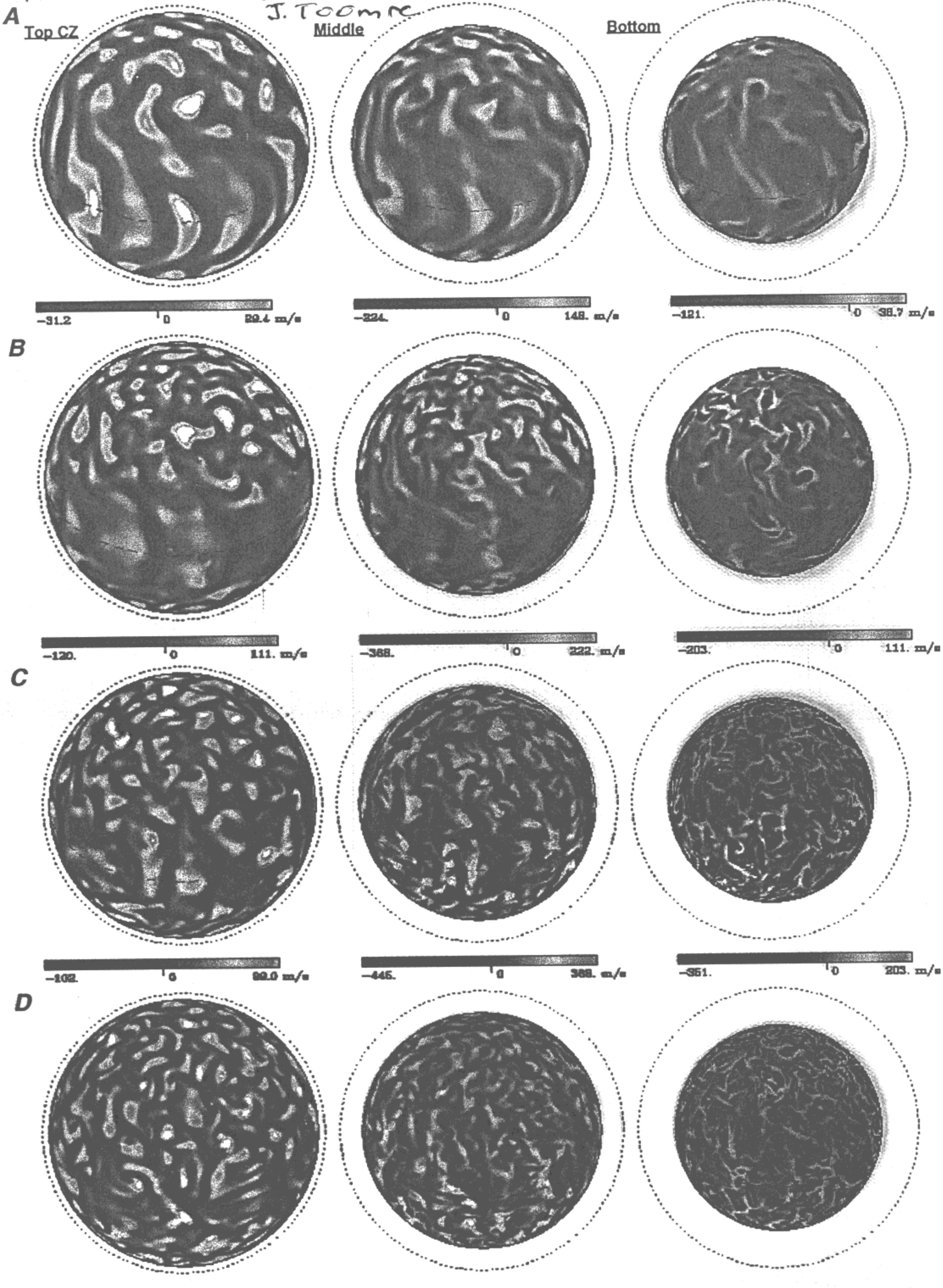


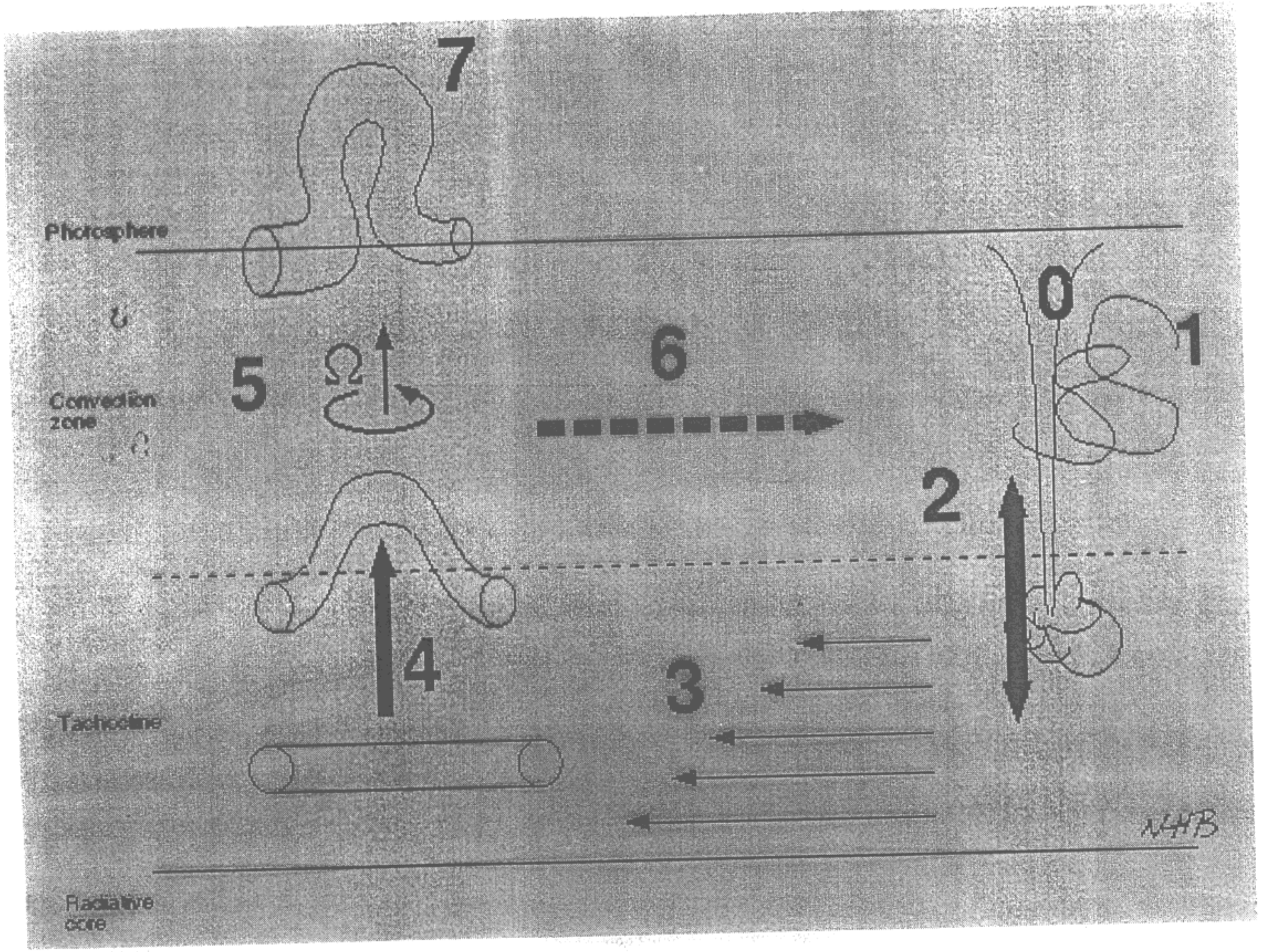
Figure 1. a) Internal rotation profile from MDI (from Kosovishev et al. 1997). b) Sound speed square difference between the Sun seen by GOLF + MDI instruments aboard SOHO and solar models. The full line corresponds to a reference model where the microscopic diffusion is included, the other models include also turbulent terms, the dashed line corresponds to a model where the photospheric Z/X=0.0245



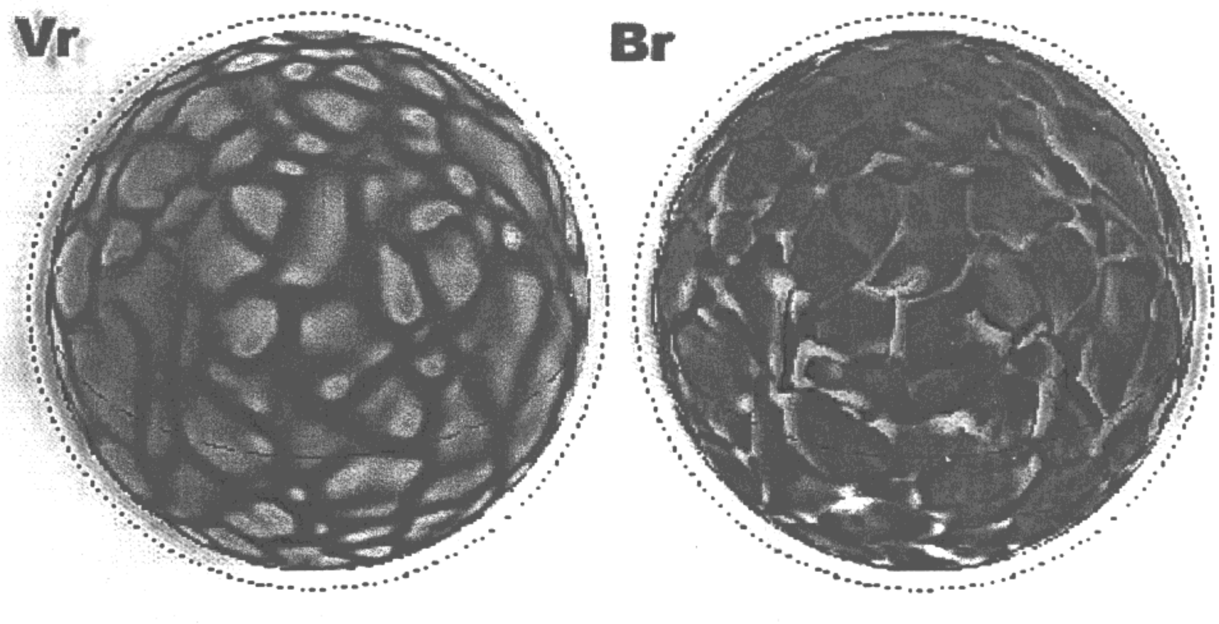
Turbulent Convection in Rotating Spherical Shells
(A.S. Brun, University of Colorado)

J. Toomre





7
Photosphere
0
1
5
6
Convection zone
2
4
3
Tachocline
Radiative core



Code MHD Toomre

Brun .... to be publishe

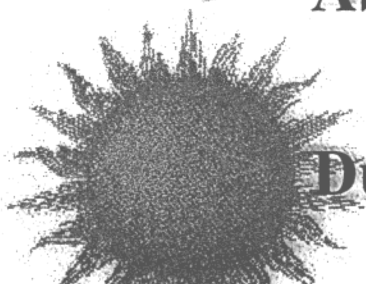
Impact of magnetic field on neutrinos ?

- Measurement of the magnetic field : 20 kG just below the phostosphere

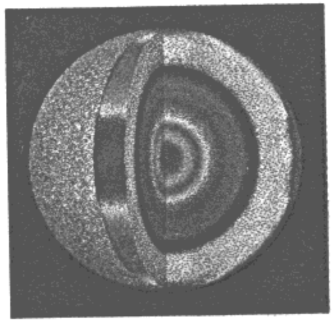
- Base of the convective zone : < 10^5 G

- Tubes of fluxes on the limits of the supergranulation cells: about 4kG, everywhere at the surface

- Above the magnetic field spreads everywhere



During activities: CME idem, but more localized



CONCLUSION II

- Emitted boron neutrino fluxes are now verified with a high accuracy
- The value obtained in Astrophysics is in agreement with the combined SNO+Superkamiokande results This is the first time !
- This proves the oscillation of the solar neutrinos for the first time
- Are we detecting ne, nm, nt or ne, nm, nt and vm, nt ?
- How to check if there is an influence of the internal magnetic field of the Sun ?