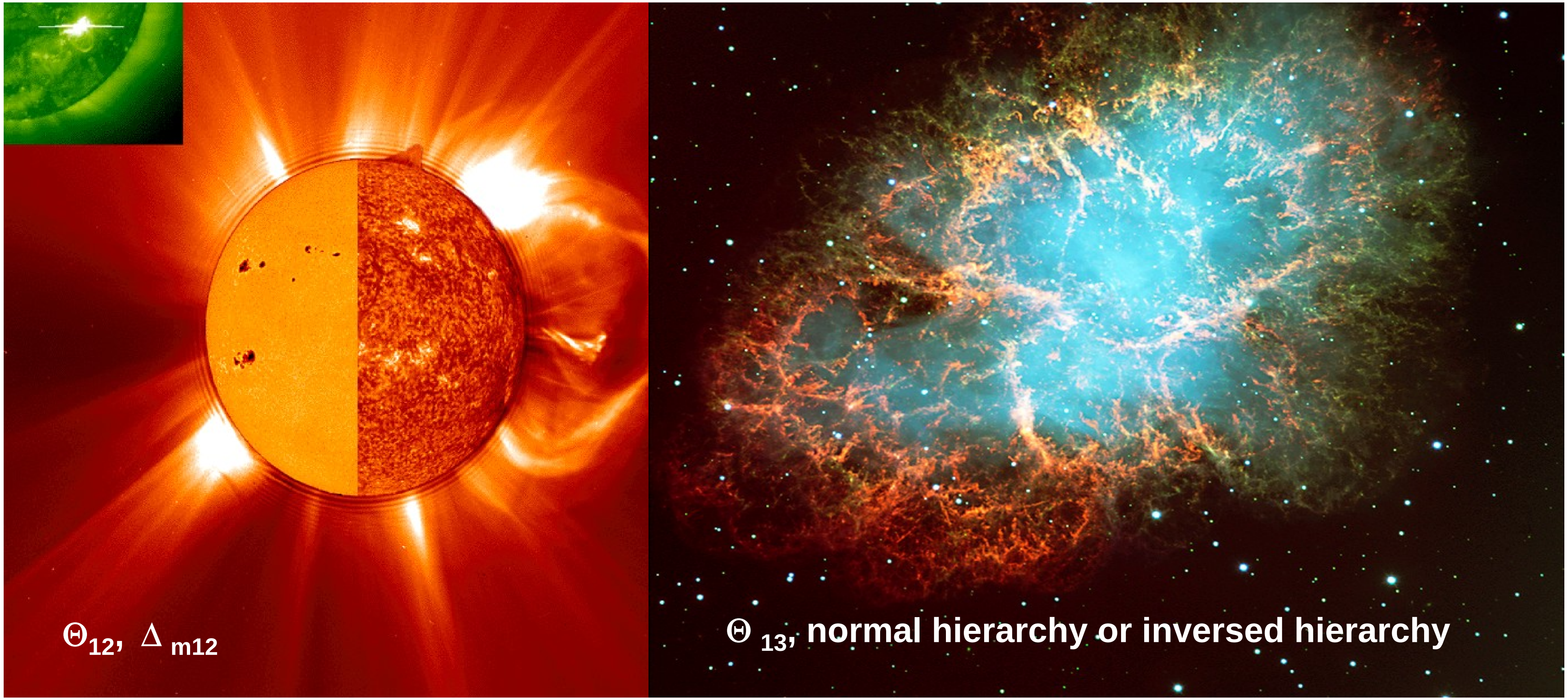


What we know and don't know about Neutrino production in stars ?

Sylvaine TURCK-CHIEZE Santa Fe June 15th 2006

Outline

– The solar neutrinos
  - The present status: what we know, what we do not know ?
  - Open questions and the low energy spectrum

– The other stars toward supernovae type II
  - What we know and do not know ?
  - Open questions: Toward a better determination of the presupernovae

– What are the directions for neutrino physics

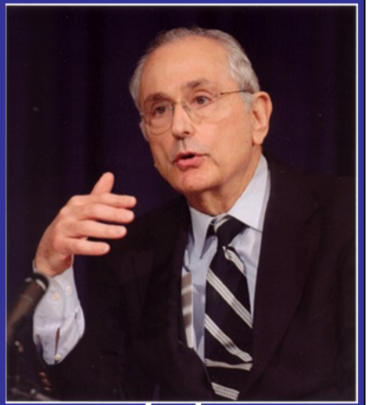
Neutrino properties **and** Neutrino astronomy

The motivations to improve the detections …

Neutrino productions in stars

Production of neutrino fluxes

- Reaction rates (NP)
- Number of interacting species (A)
- Profile of temperature and density in the region where neutrinos are emitted (A)

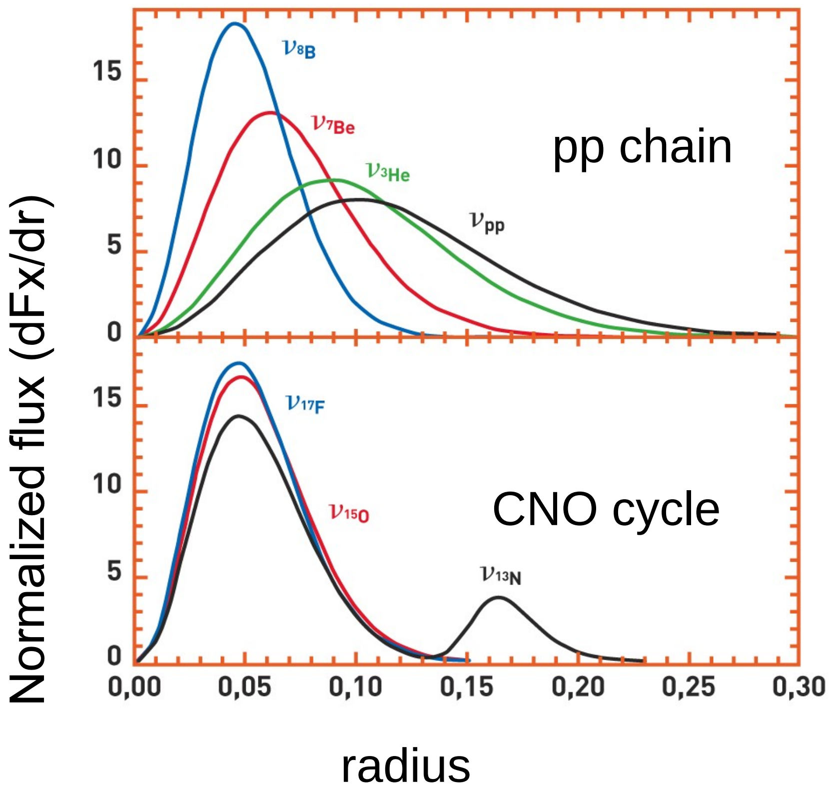


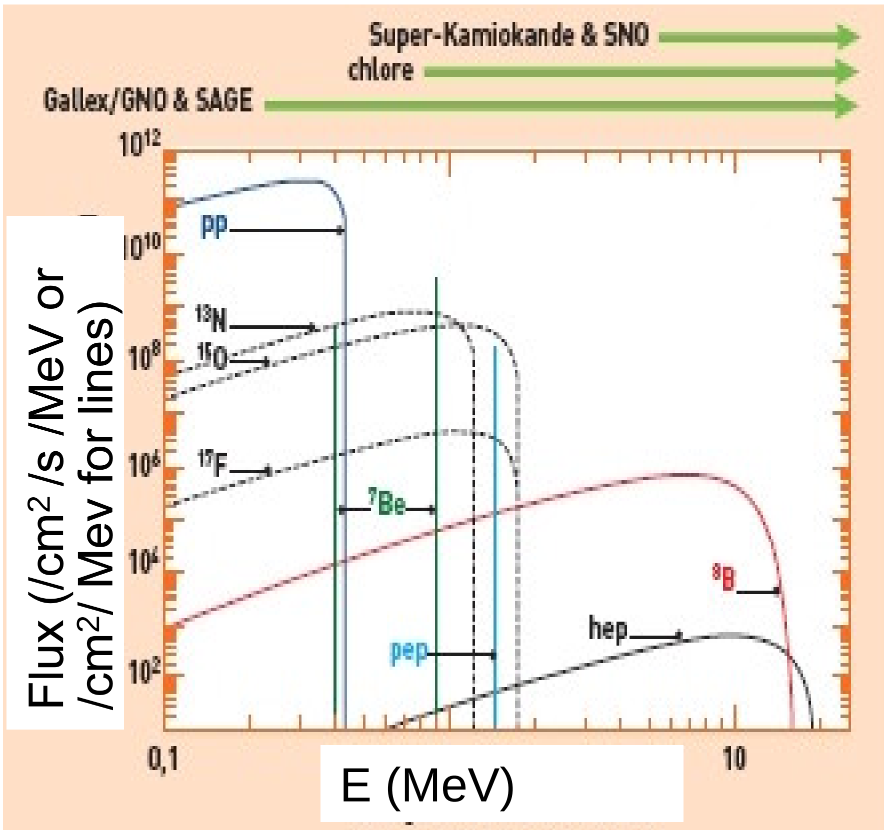
For comparison with detections

- Cross sections neutrinos - detectors (NP-PP)
- Profiles of electron and neutron densities for determining oscillation parameters (A)

The Solar Neutrinos

$4p \rightarrow {}^4He + 2e^+ + 2\,\nu_e + E$





What we know ?

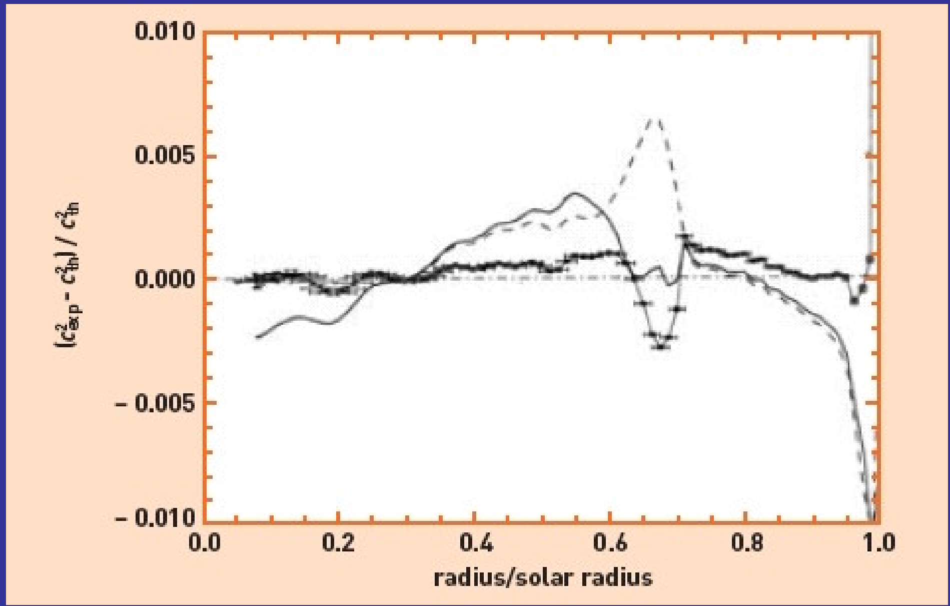
- **Laboratory cross sections** (^3He, ^3He; ^{12}C, p)
- **Opacity calculations**
- **Acoustic modes=>**

Sound speed profile: photospheric ^4He,
pp reaction rate,
energy transfer

- **Seismic model**

compatible with observed sound speed for determining neutrino fluxes compatible with acoustic modes

Turck-Chièze et al. 2001;
Couvidat et al. 2003



Direct comparison for ^8B neutrinos

great sensitivity to the temperature so to the detailed physics

	Flux	Tc		Y initial	Problem solved
1988	3.8 ± 1.1	15.6	SM	0.276	CNO opacity, 7Be(p,g)
1993	4.4 ± 1.1	15.43	SM	0.271	Fe opacity, screening
1998	4.82	15.67	SM	0.273	Microscopic diffusion
1999	4.82	15.71	SM	0.272	Turbulence in tachocline
2001	4.98 ± 0.73	15.74		0.276	Seismic model
2003	5.07 ±0.76	15.75		0.277	Seismic model +magnetic field
2004	3.98. ± 1.1	15.54	SM	0.262	- 30% in CNO composition
2004	5.31 ±0.6	15.75		0.277	Seismic model +magnetic field+ updated ingredients

SNO results

- 5.44 ± 0.99 (CC+ES 2001)
- 5.09 ±0.44 ±0.45 (NC 2002)   5.27 ±0.27 ±0.38 (2003)
- 4.94 ±0.06 ±0.34 active neutrinos   ***Aharmim et al, 2005***

Prediction for the other detectors without or with Neutrino Oscillation parameters

Chlorine detector	Seismic model 2001		Detected neutrinos	Detect. Seismic 2004
pep	0.228		0.13	0.13
^{7}Be	1.155	57%	0.66	0.66
^{8}B	5.676	31%	1.76	1.88
^{13}N	0.096	57%	0.054	0.022
^{15}O	0.328	57%	0.187	0.112
total	7.44 SNU (1.1)		2.79 SNU (0.36)	2.76 (0.4) SNU

Measurement 2.56 (0.23) SNU

Gallium detector	Seismic model		Detected neutrinos	Detect. Seismic 2004
pp	69.4	57%	39.6	39.6
pep	2.84	57%	1.62	1.62
^{7}Be	34.79	57 %	19.83	19.83
^{8}B	11.95	31%	3.70	3.95
^{13}N	3.48	57%	1.98	0.79
^{15}O	5.648	57%	3.22	1.29
total	128.2 SNU (8)		69.95 SNU	67.08 (4.4) SNU

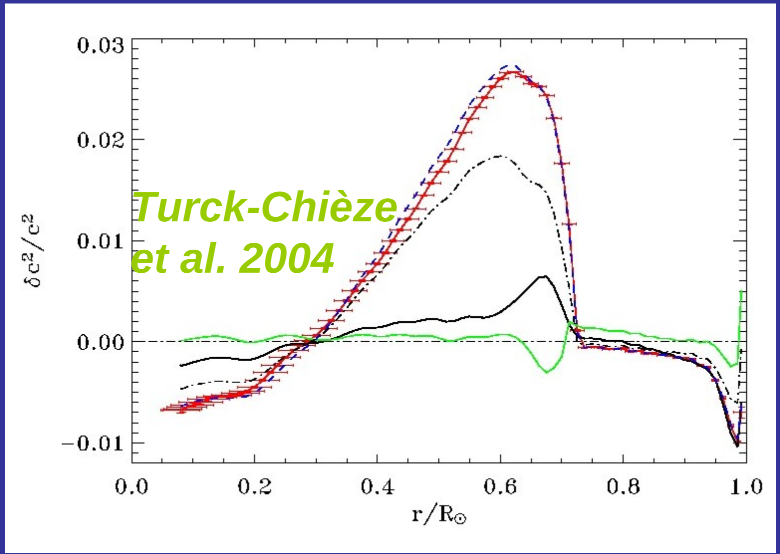
Measurement 68.1 SNU (3.75)

LMA solution $\Delta m^2 = 7\ 10^{-5}\ eV^2\ (8+0.6-0.4)\ tg^2\theta_{12}=0.45$ BPG2003

What we don't know ?

On the astrophysics part

- **CNO abundances ?? 30% uncertainty, opacities**



- **Internal dynamical phenomena**

On the neutrino part

- **agreement with chlorine experiment is not complete**
- **Comparison of mean values, fluctuations variation with time?**
- **Subleading properties: sterile neutrino, magnetic moment ??**

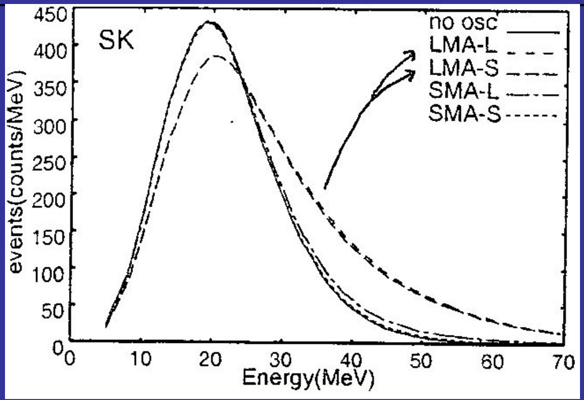
Toward Supernovae II neutrinos

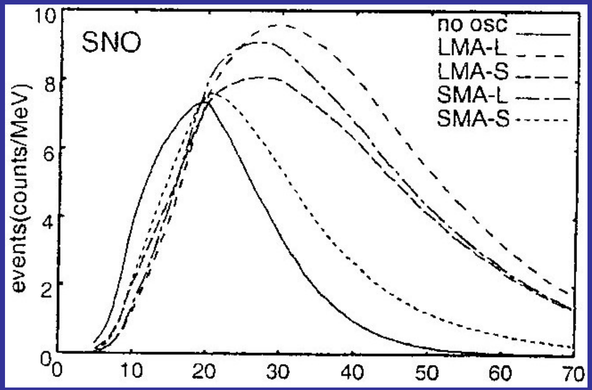
- Same range of energy

- 99% of energy is transported by neutrinos but the explosion is not yet well understood

- Role of the asymmetric explosion and of acoustic instabilities
- New neutrino properties

- Role of the dynamical effects of the progenitors



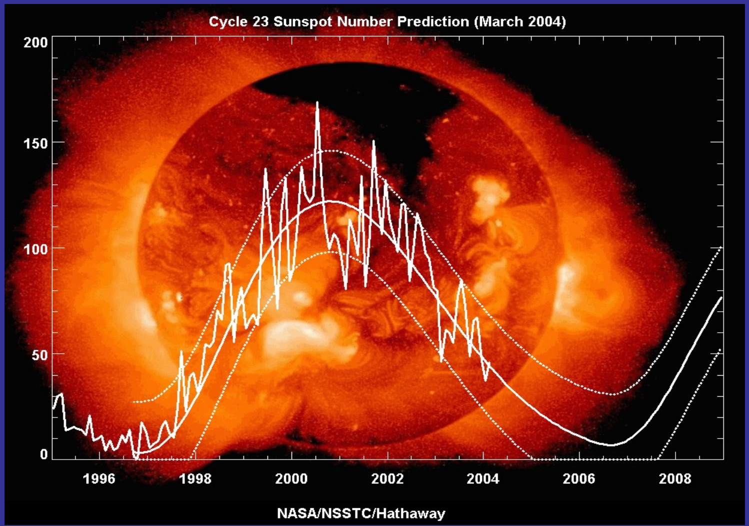


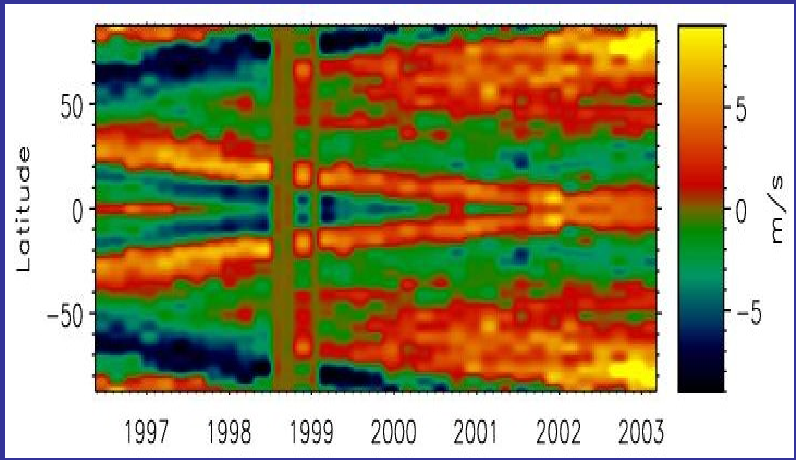
What don't we know yet properly : role of rotation and magnetic field?

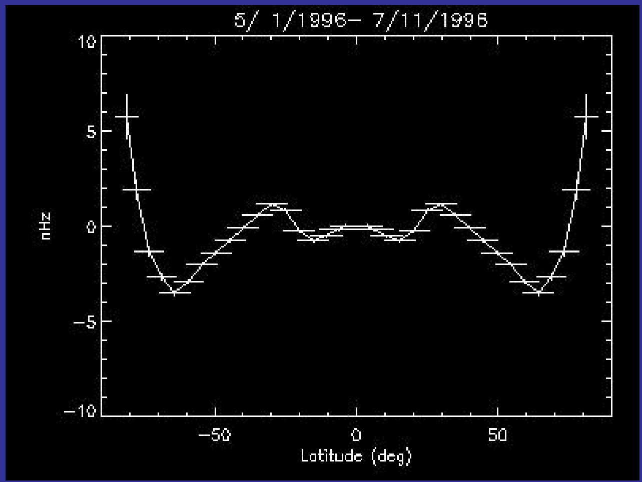
A more complete description of the Sun and stars

After the verification of the great time scales dominated by the nuclear processes,
we are looking to the small time scales dominated by turbulence convection, rotation and magnetic field

More and more evidence that the 11 year magnetic solar cycle has an internal origin

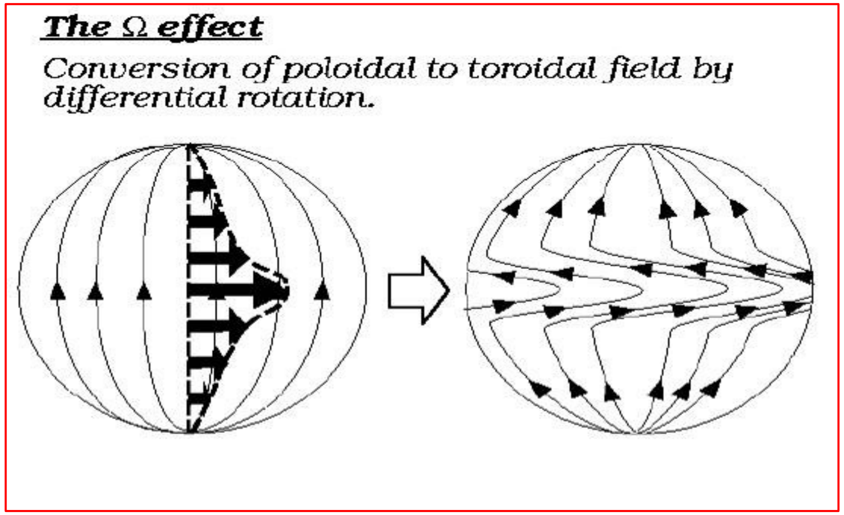


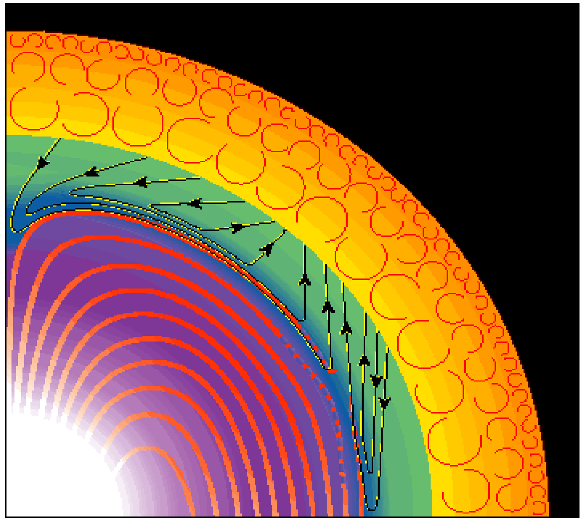




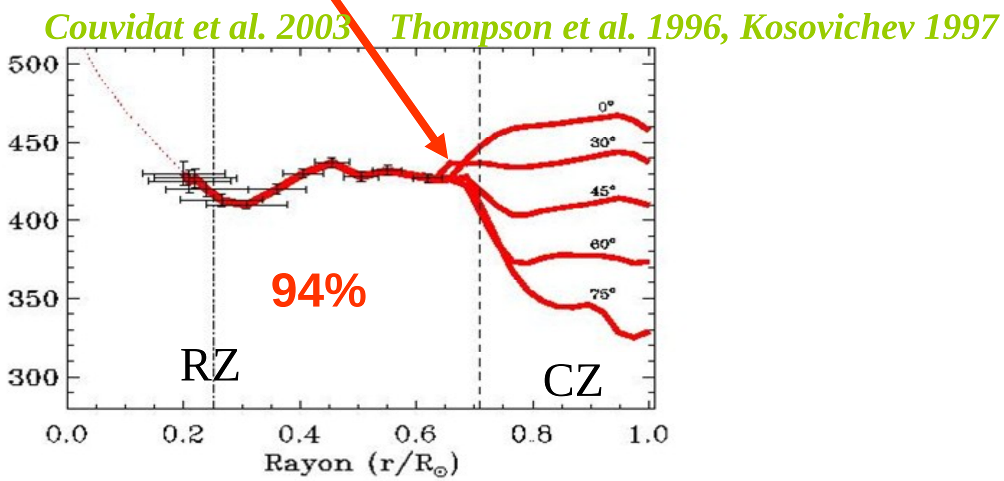
Howe et al. 2000

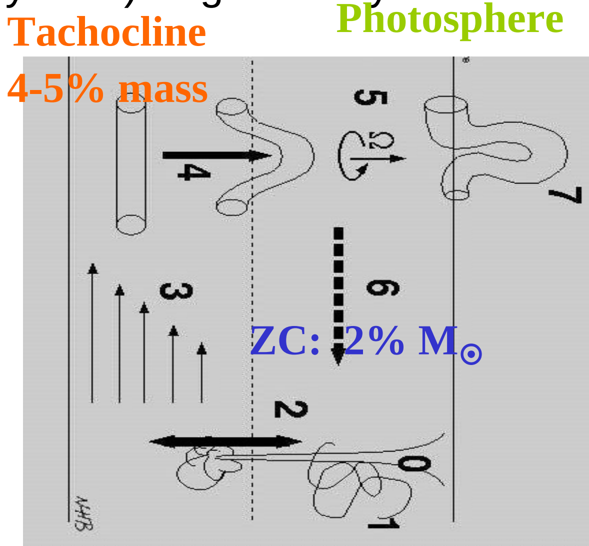
Magnetic field and Evolution of stellar modelling





The **tachocline** plays an important role in the **stockage and amplification of the toroidal magnetic field** for the **Schwabe cycle** 22 ans, one would like to know what phenomena can justify the possible existence of the **Gleissberg** cycle (90 year ?) or greater cycles ??





Development of 3D MHD simulations to understand the internal observations

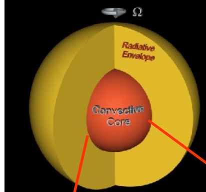
Understanding the dynamics of the stars

On all scales

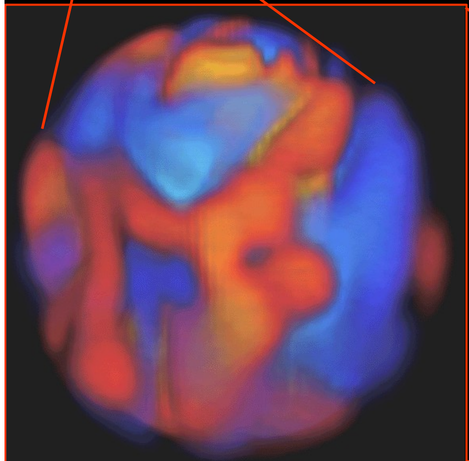
Asteroseismology/Magnetism

Corot/Espadon/XMM

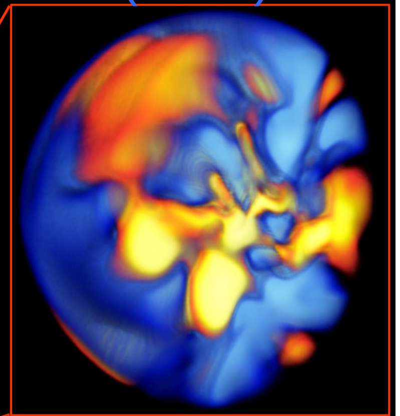
(Ballot et al. 2004, Brun et al. 2004, 2005, 2006)

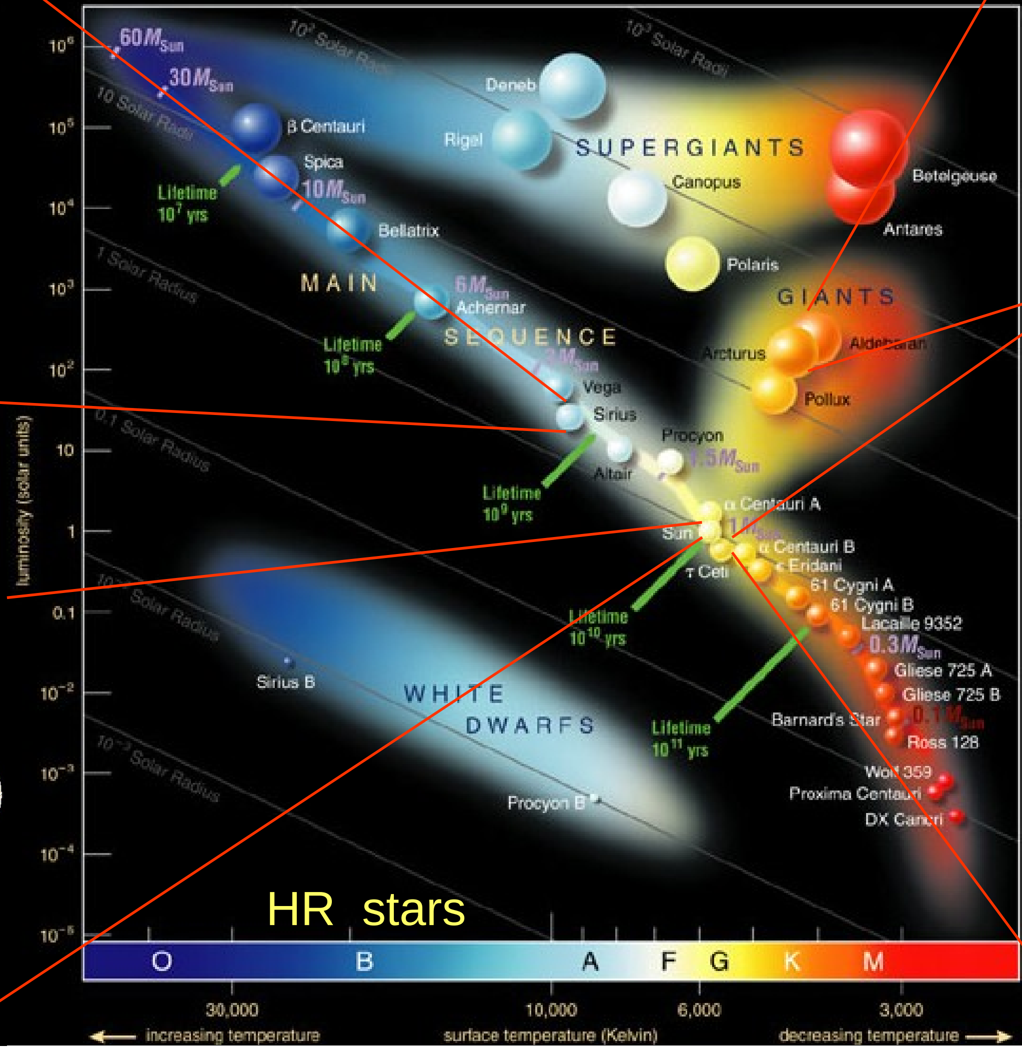


Massive Stars

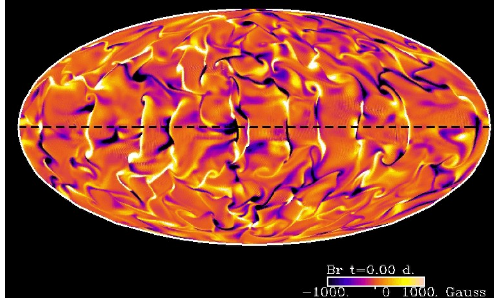


Evolved Stars (RGB)

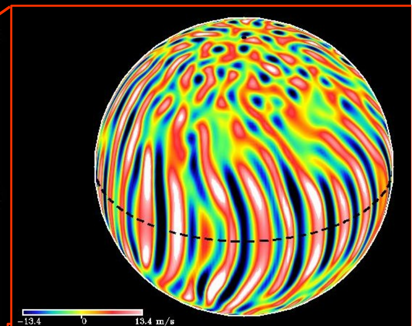


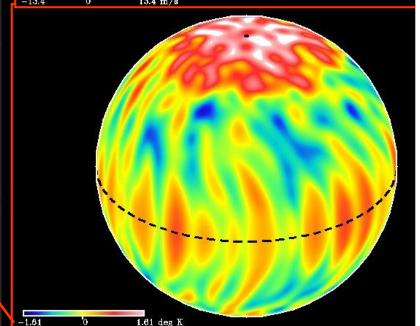


Sun



HR stars



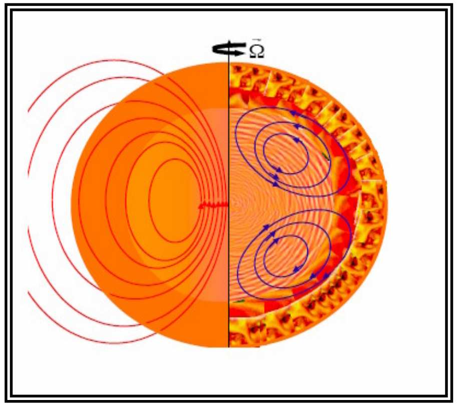


Young stars

Transport processes in radiation zones

Meridional circulation **(diff. rot. and A. M. transport)** **(ADVECTION)**
(Busse 1981, Zahn 1992, Maeder & Zahn 1998, Garaud 2002, Rieutord 2004)

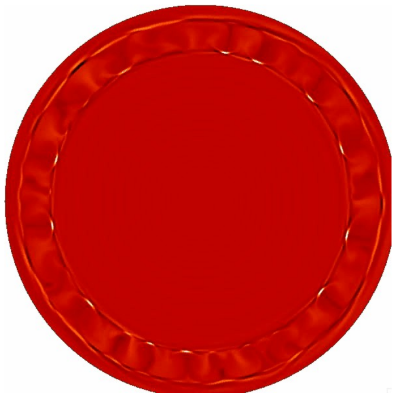
Turbulence **(shear of the diff. rot.)** **(DIFFUSION)**
(Talon & Zahn 1997, Garaud 2001, Maeder 2003)



Magnetic field

Secular torque
(Charbonneau & Mac Gregor 1993, Garaud 2002)

Instabilities
(Maeder & Meynet 2004, Braithwaite & Spruit 2005, Brun & Zahn 2006)



Internal waves
(Talon et al. 2002, Talon & Charbonnel 2003-2004-2005, Rogers et al. 2005)

excited at the borders with C. Z.

propagating inside R. Z.

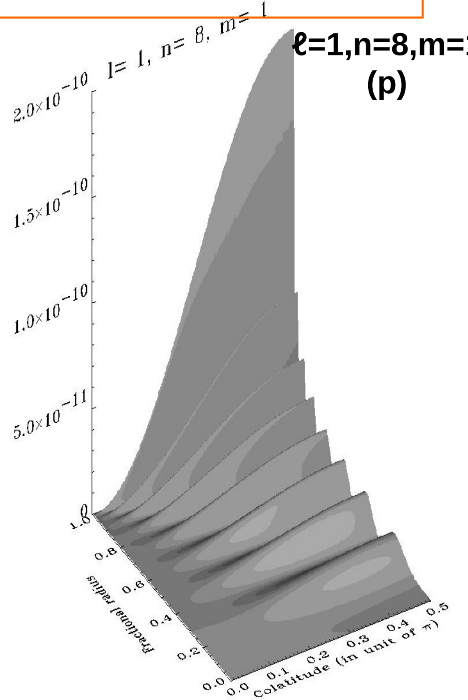
A. M. settled where they are damped
(Goldreich & Nicholson 1989)

Acoustic modes

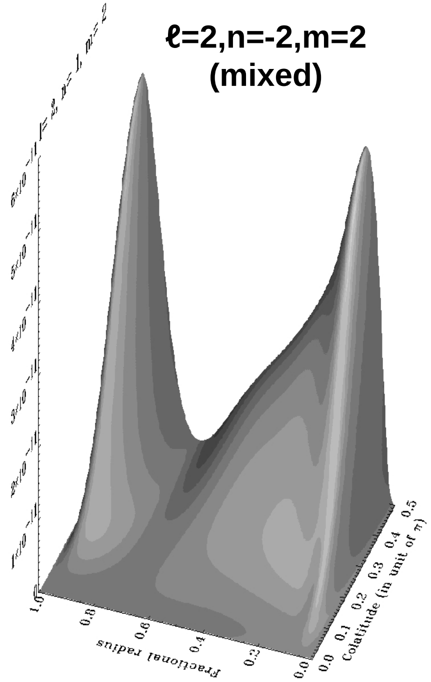
Mixed modes

Gravity modes

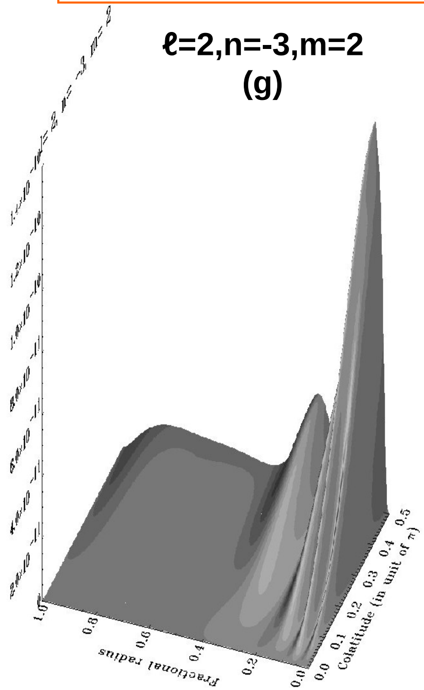
ℓ=1,n=8,m=1
(p)



ℓ=2,n=-2,m=2
(mixed)



ℓ=2,n=-3,m=2
(g)



Sound speed down to the core

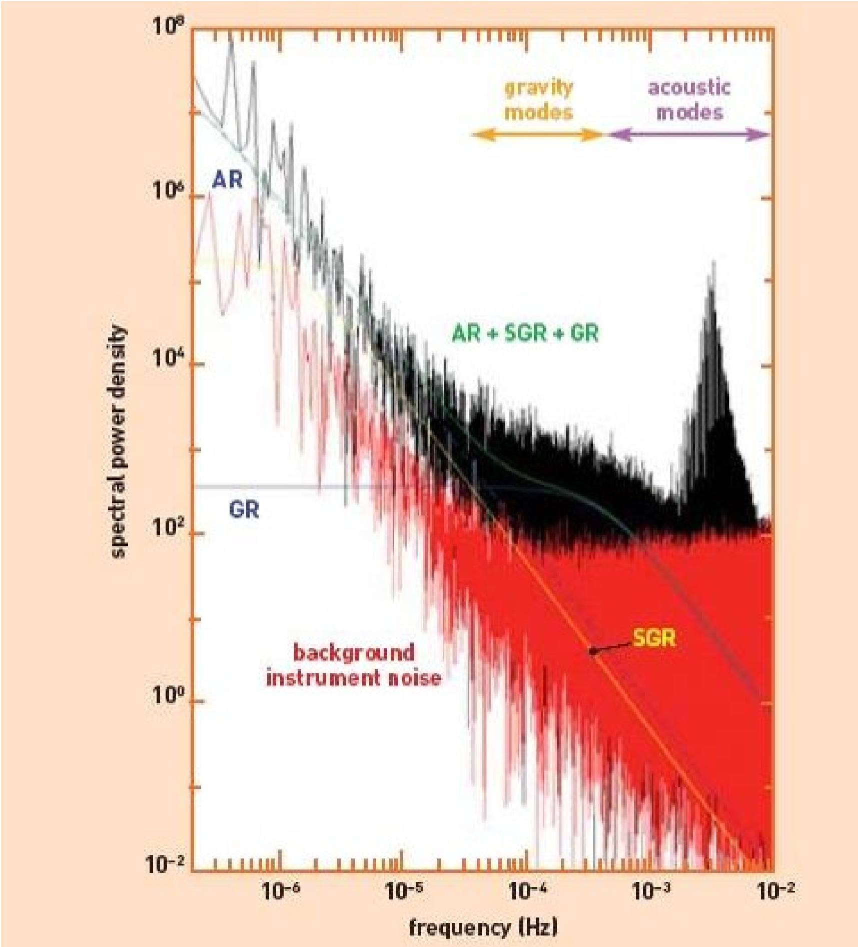
Rotation down to the limit of the nuclear core: 0.2 $R_{\odot}$

Dynamics of the convective zone

Rotation down to the core,
Influence of internal magnetic field
Dynamics of the radiative zone

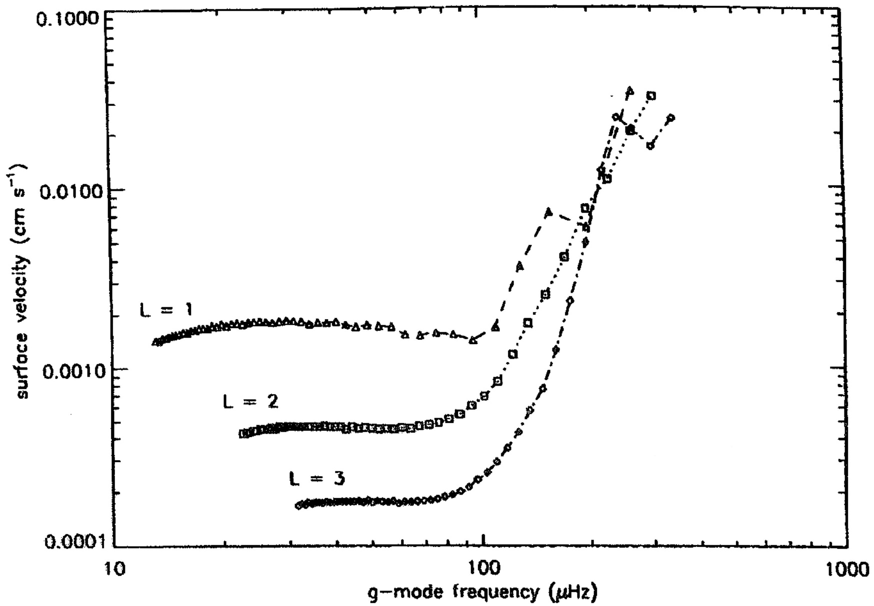
Sylvaine Turck-Chièze, Vienna 3 April 2006

Gravity modes with SoHO



GOLF spectrum:
Turck-Chièze et al., ApJ 2004, 604, 455

They are very informative on the core dynamics but their surface velocity is small…



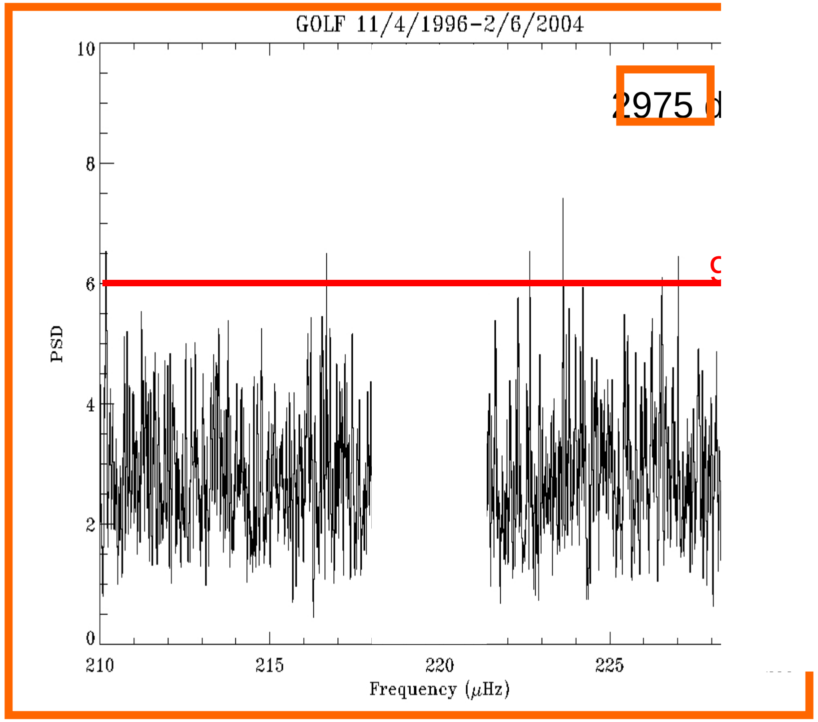
Lifetime of the modes: hyperfine structure, complex patterns ??

Two complementary searches

- **Individual modes: 150-450 μHz**
- **Research of multiplets for l=2,3 and follow the patterns with time**

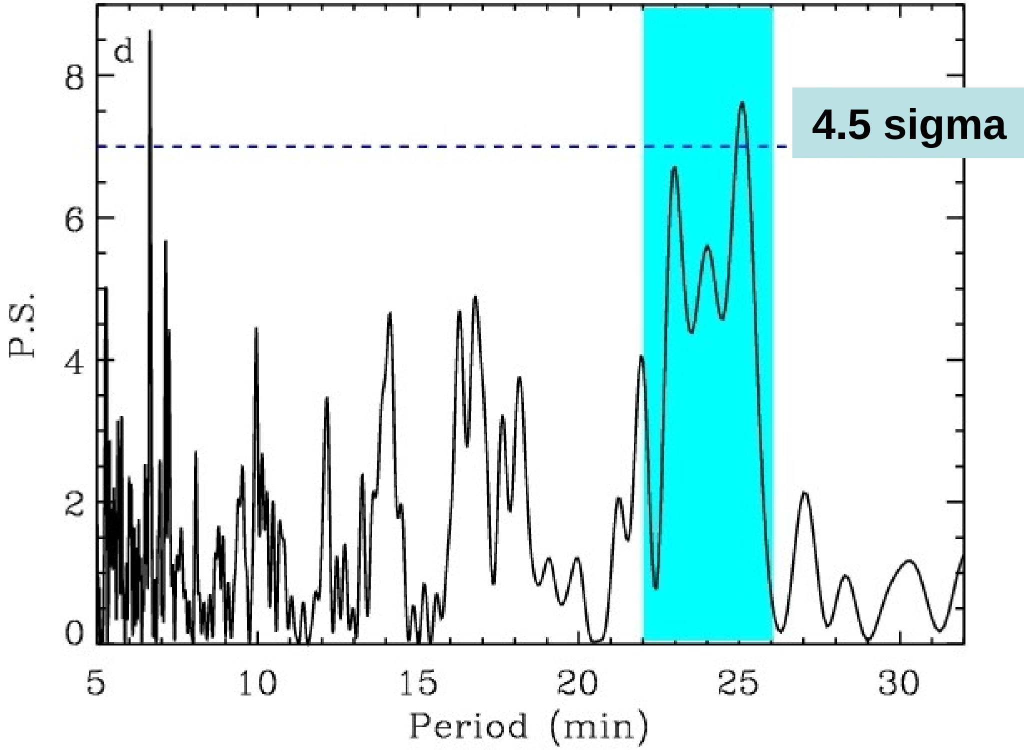
ℓ = 2 ? *Cox & Guzik 2004*

Turck-Chièze et al. ApJ 2004 & SoHO1



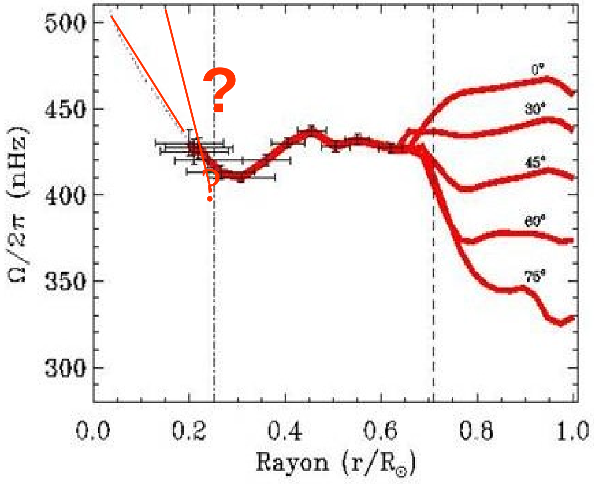
- **Global gravity mode asymptotic behaviour <150 μHz : 20-150 μHz**
- **ℓ = 1**

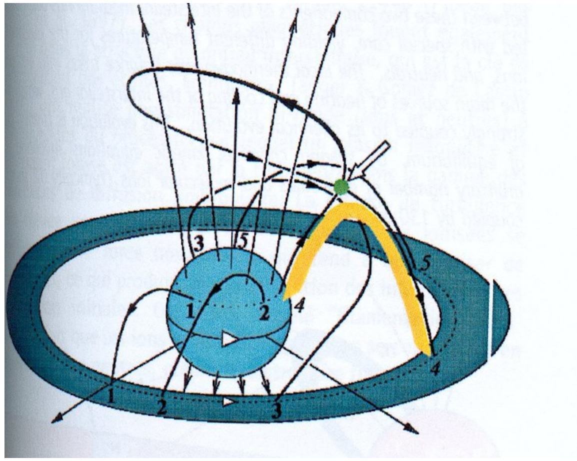
Garcia, T-C et al. 2006



Two independent methods lead to signals at the waited place with less than 2-8% to be pure noise

Rotation profile constructed with GOLF+MDI / SOHO acoustic modes and gravity modes





Montmerle 2000

What we would like to know ?

- The latitudinal rotation of the inner radiative zone
- Is there a relic of the formation of the solar system which justifies an higher central rotation profile ?
- Could we get real constraints on the magnetic configurations in the radiative zone and convective zone
- Is there a dynamo in the core ?…

A new vision of Sun and stars

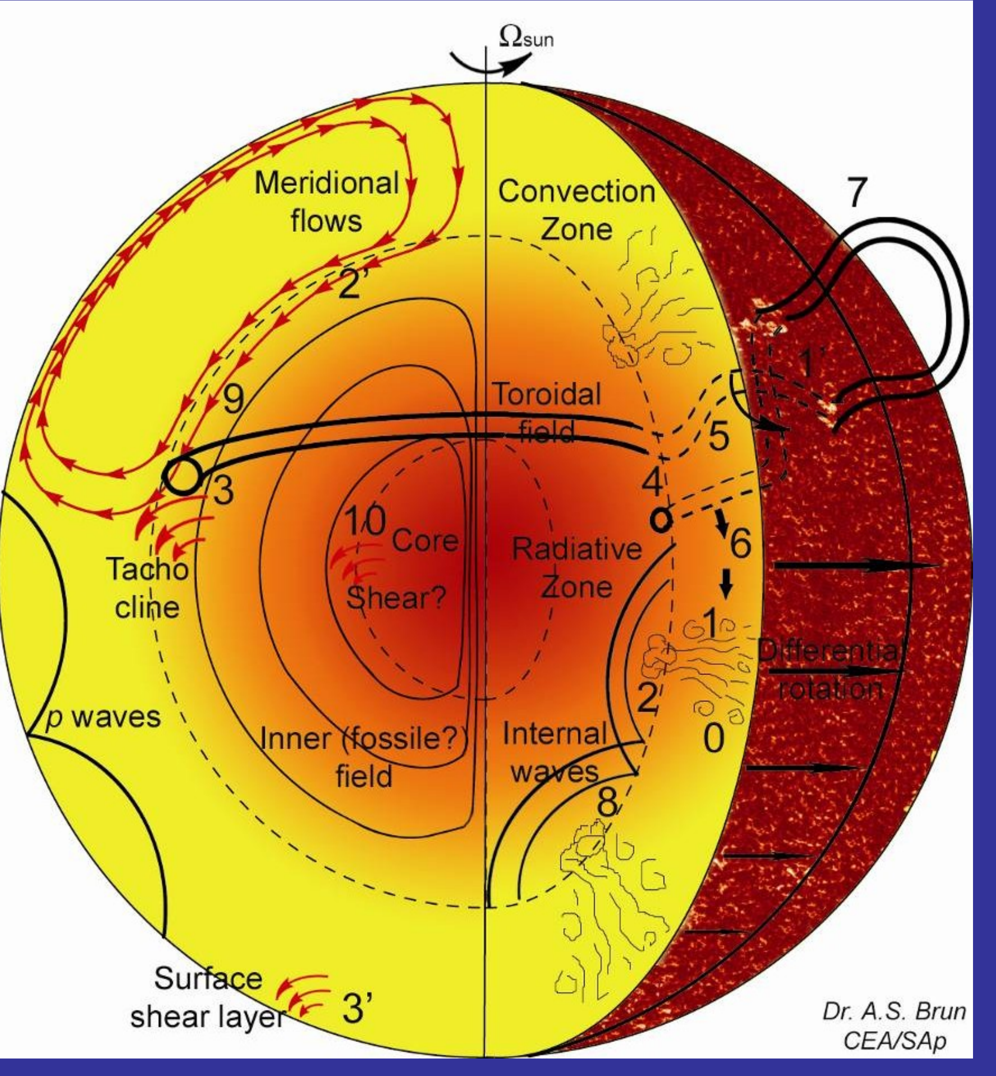
1D and 3D modelling

where

4 structure equations will be

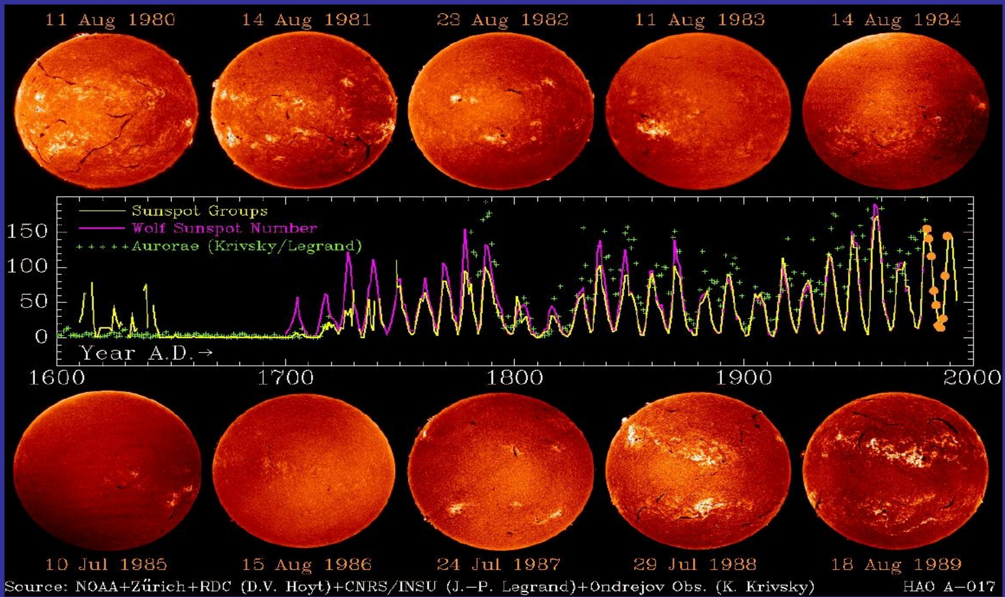
replaced by

16 equations

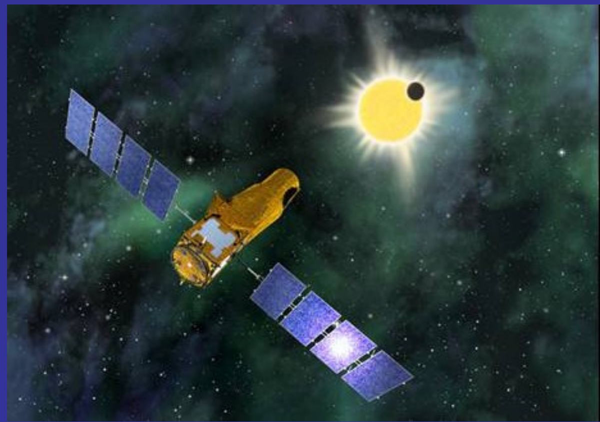


Solar and stellar Perspectives

We are preparing a new step in solar (stellar) modelling where effects of rotation and magnetic fields will be introduced



Space Projects PICARD 2008 then DynaMICS to study the real influence of the Sun on the Earth



COROT launch October 2006, development of asteroseismology,

Then KEPLER

Solar(stellar) neutrino Perspectives

- **This step opens the route to new neutrino properties that we need to search**
- **Is there central temperature fluctuations ? SNO has a great sensitivity to tell us some thing**
- **Can we separate the different neutrino sources at low energy**
- **BOREXINO results**
- **We would like to put constraints on**
- **CNO central compositions**
- **RSFP, sterile neutrinos**
- **spatial scales of hundred kms as gravity modes spatial scales of thousand kms**

Can we establish definitively if there is time variations of low energy solar neutrinos ???

Solar(stellar) neutrino Perspectives

- **We have still a lot of questions without answers**

- **We need to continue to detect solar neutrinos down to the lower energy that we can**

- **We need also to develop the capability of detecting supernovae detection which is the natural successor of such field with even more exciting physics**