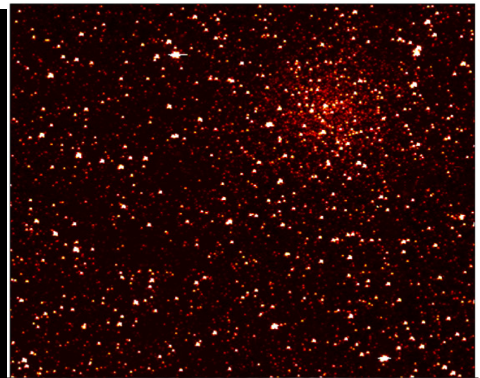


Macroscopic and Microscopic processes for solar-like stars

From Sun to Stars

Sylvaine TURCK-CHIEZE, CEA Saclay Santa Barbara October 2011

Agenda

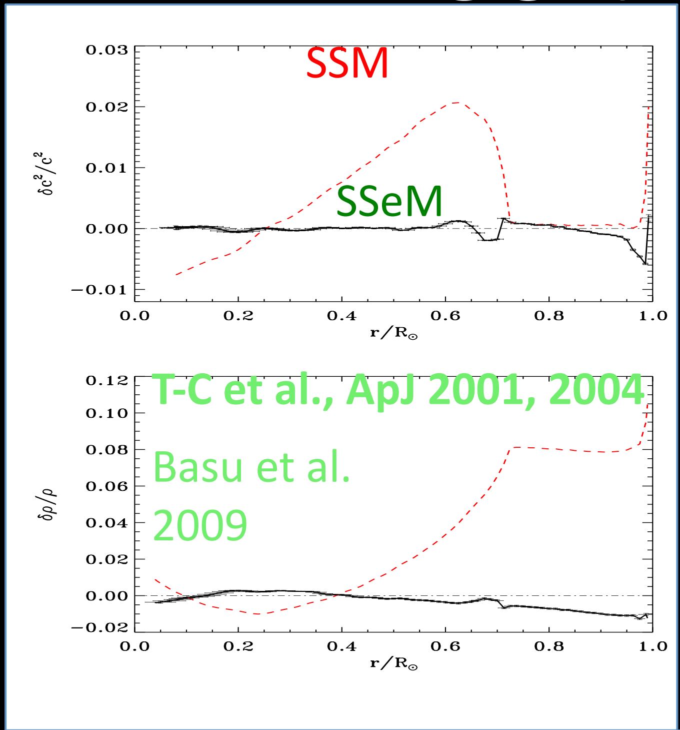
What we have learned from SoHO
useful for solar like stars

Near Surface treatment

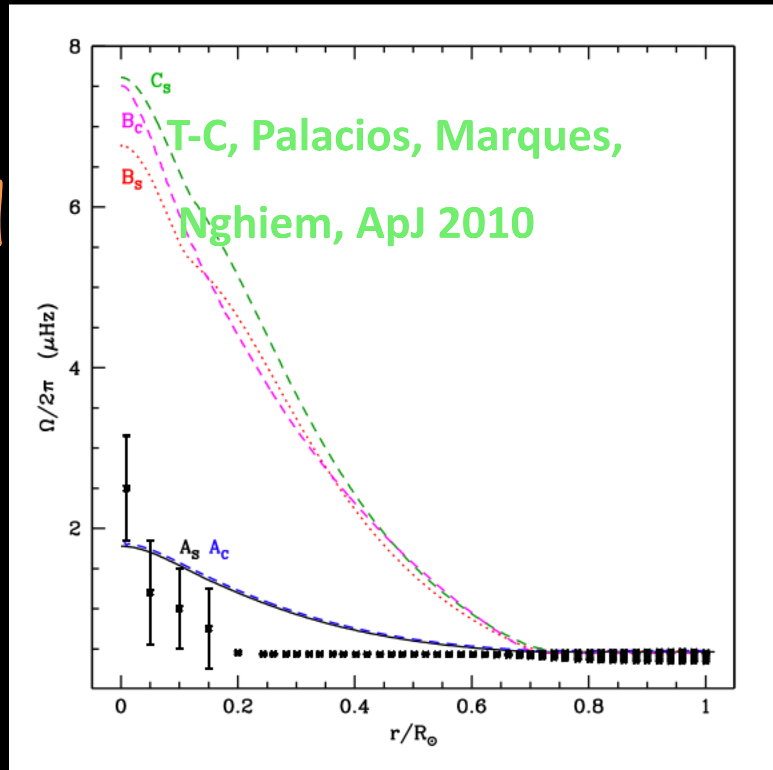
Rotation, Young Sun and activity

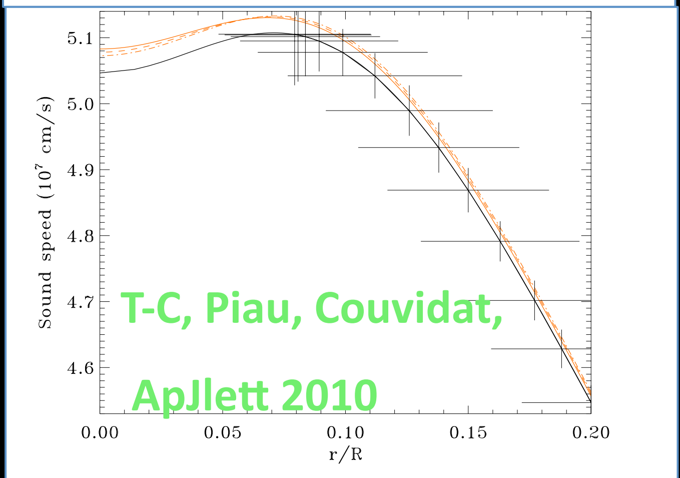
Microscopic effects

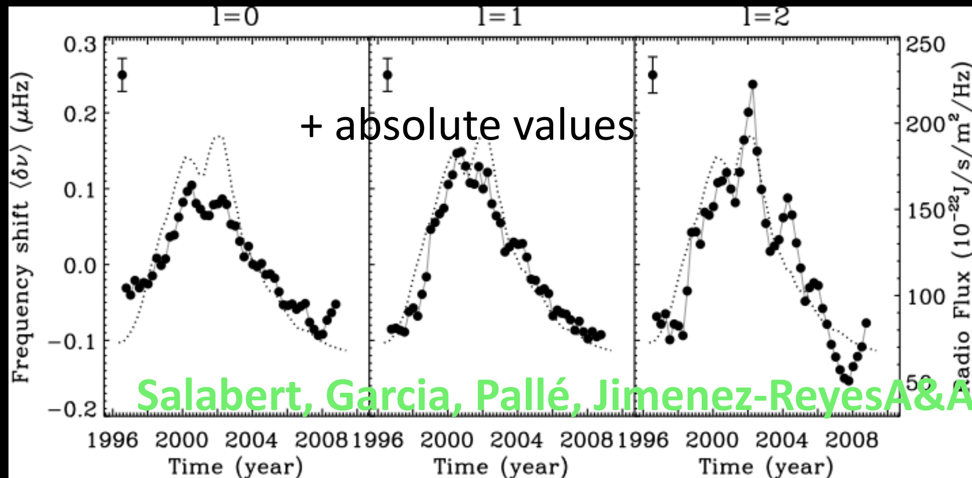
Main results from SOHO useful to KEPLER GOLF+ MDI



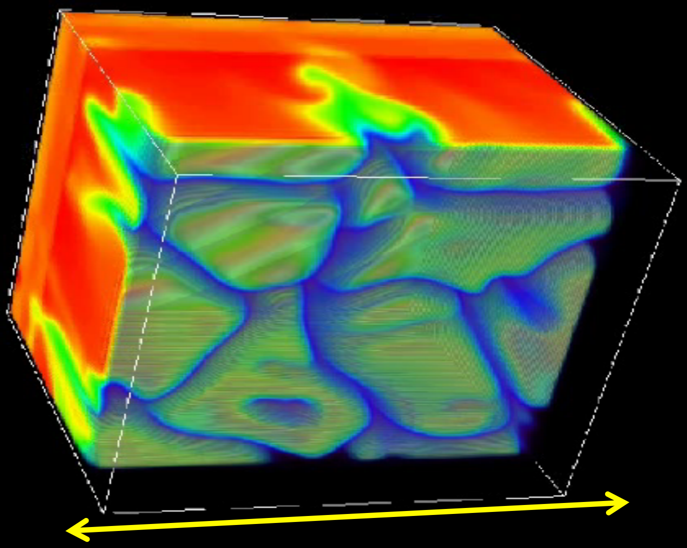
How could we improve stellar modelling ?







Surface effects

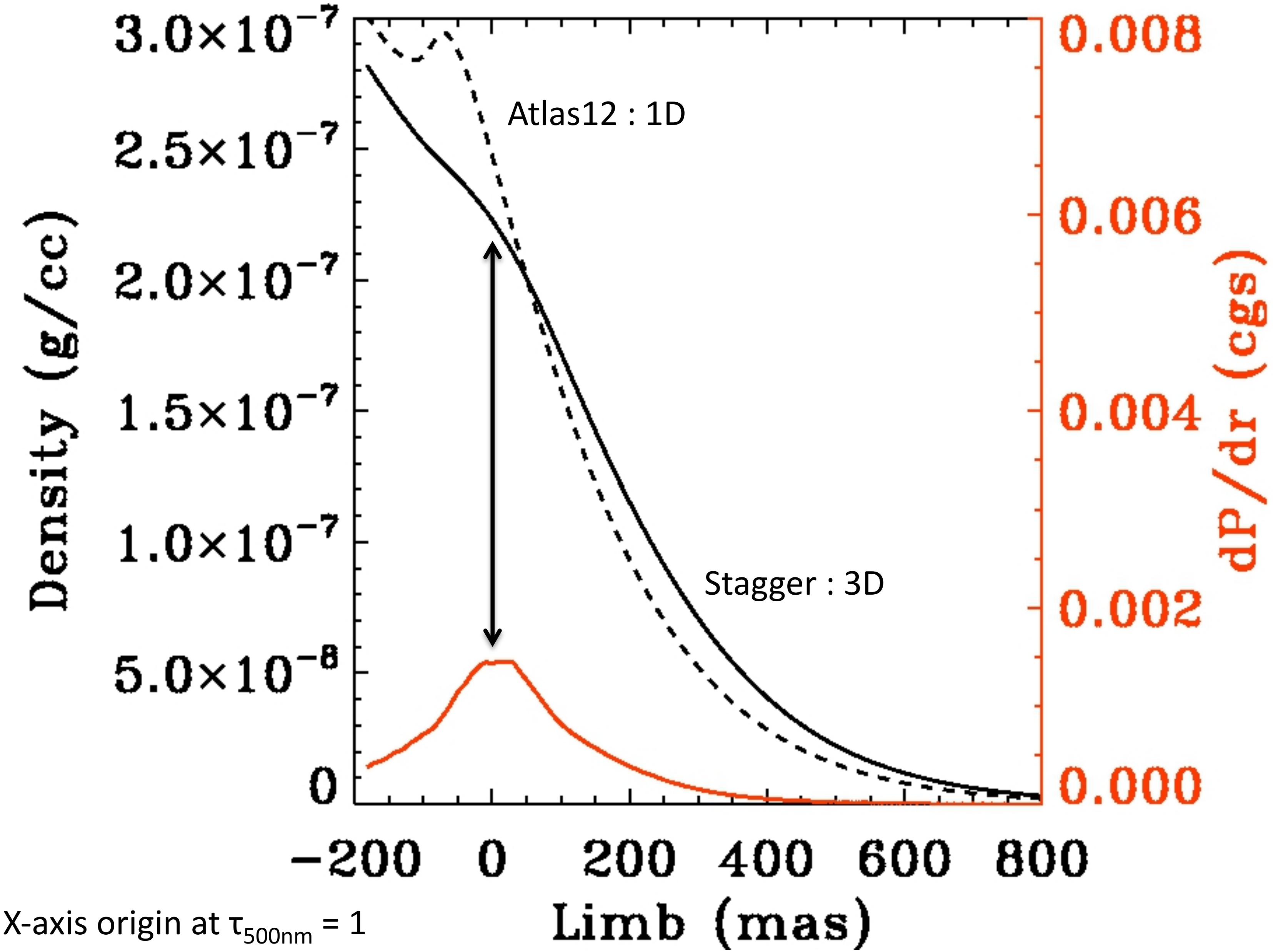


STAGGER 3D code

Collaboration : L. Piau, R. Stein, S. Turck-Chièze,
N. Mein, A. Hauchecorne, J-F Hochedez, G. Thuillier

Density profiles and P_{turb}

Piau, Stein, T-C et al. 2011

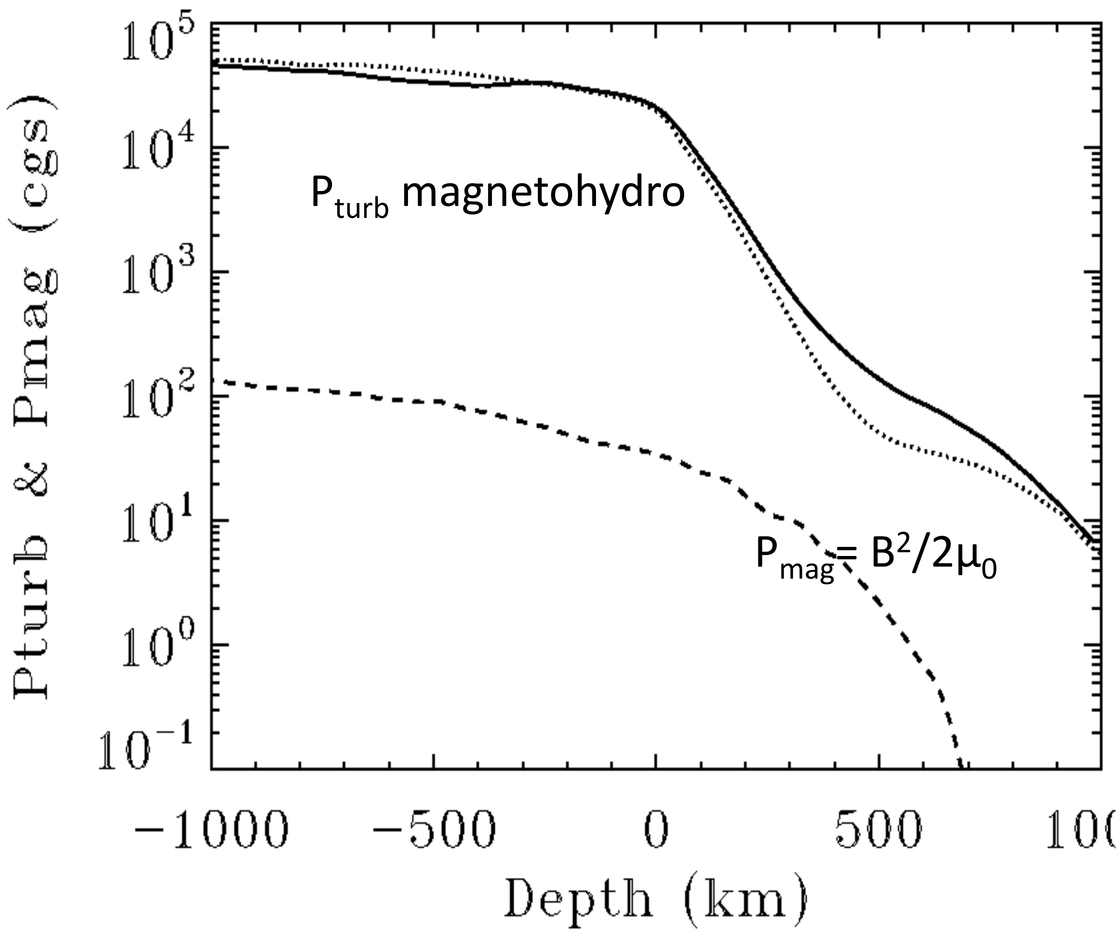


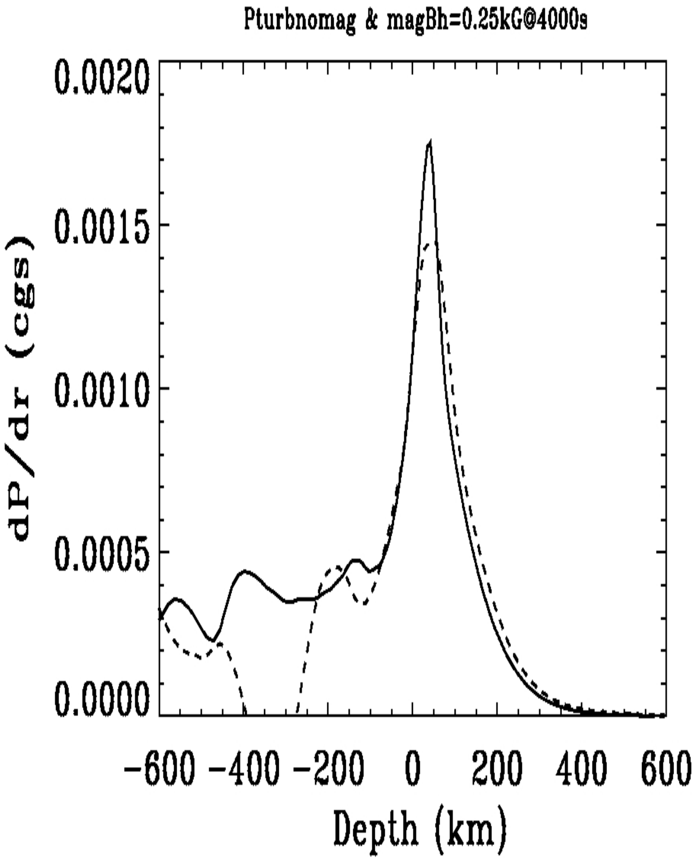
X-axis origin at $\tau_{500nm} = 1$

Effect of activity for B h= 0.25 kG

Piau et al. 2011

$$P_{turb} = \rho(\bar{v_z^2} - \bar{v_z}^2)$$



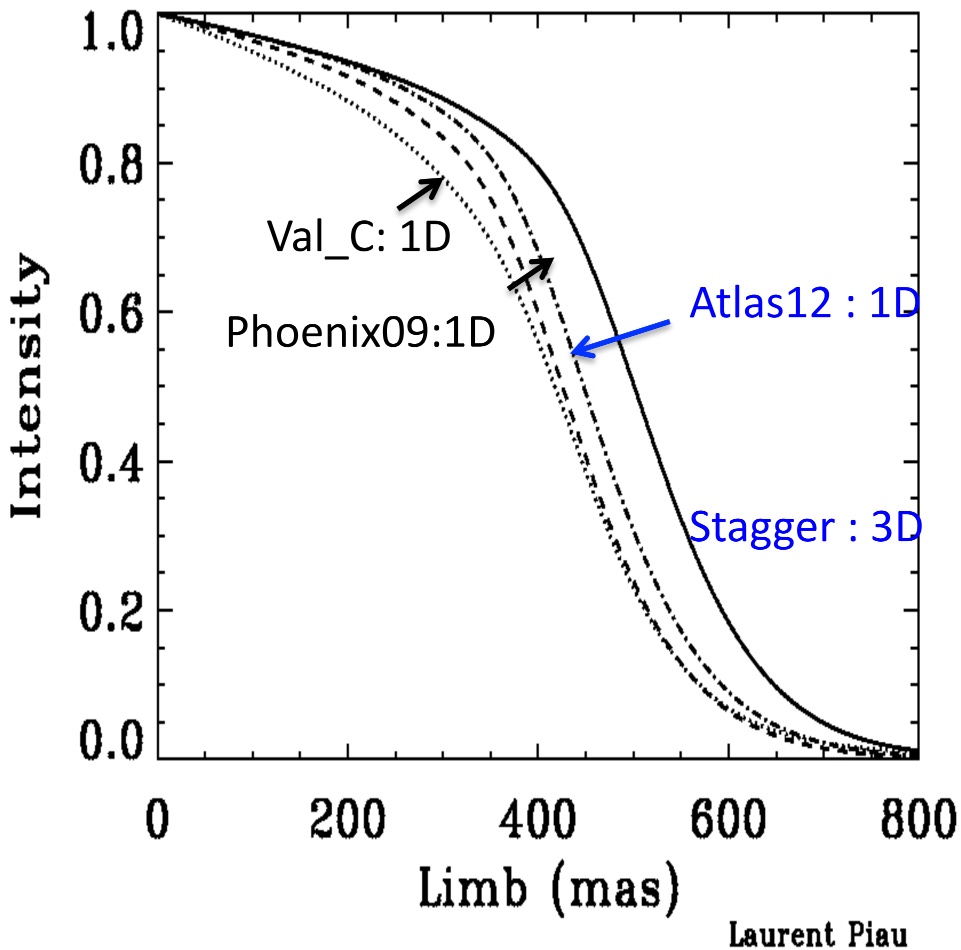


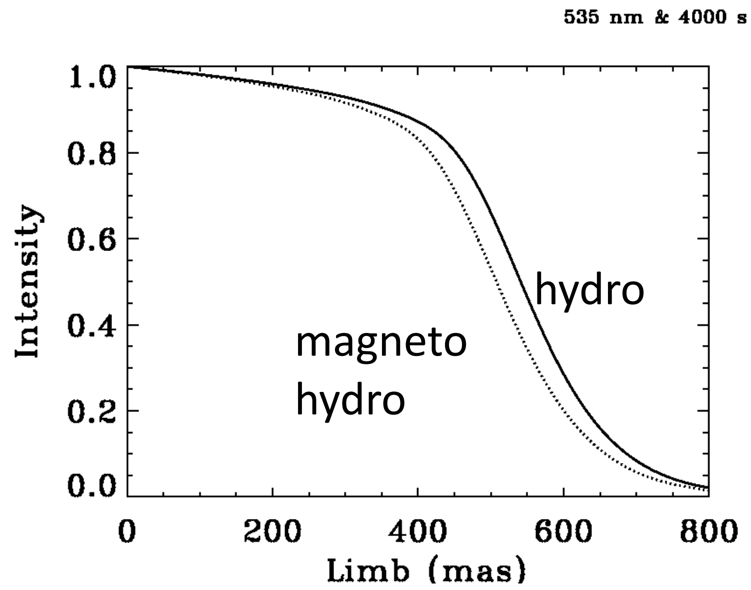
PICARD and SDO

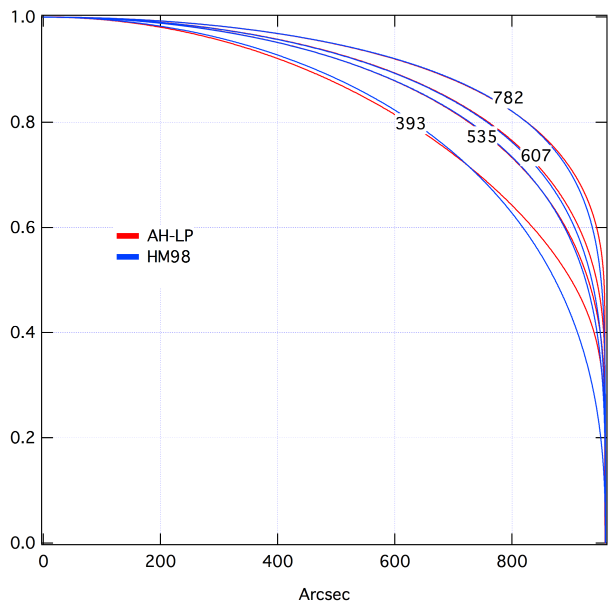
$$I(cos\theta) = \int_0^\infty \frac{S(\tau_\lambda)}{cos\theta} e^{-\frac{\tau_\lambda}{cos(\theta)}} d\tau_\lambda$$

Compared limbs at λ=393.3 nm

1D/3D atmosphere models & 1D radiative transfer :





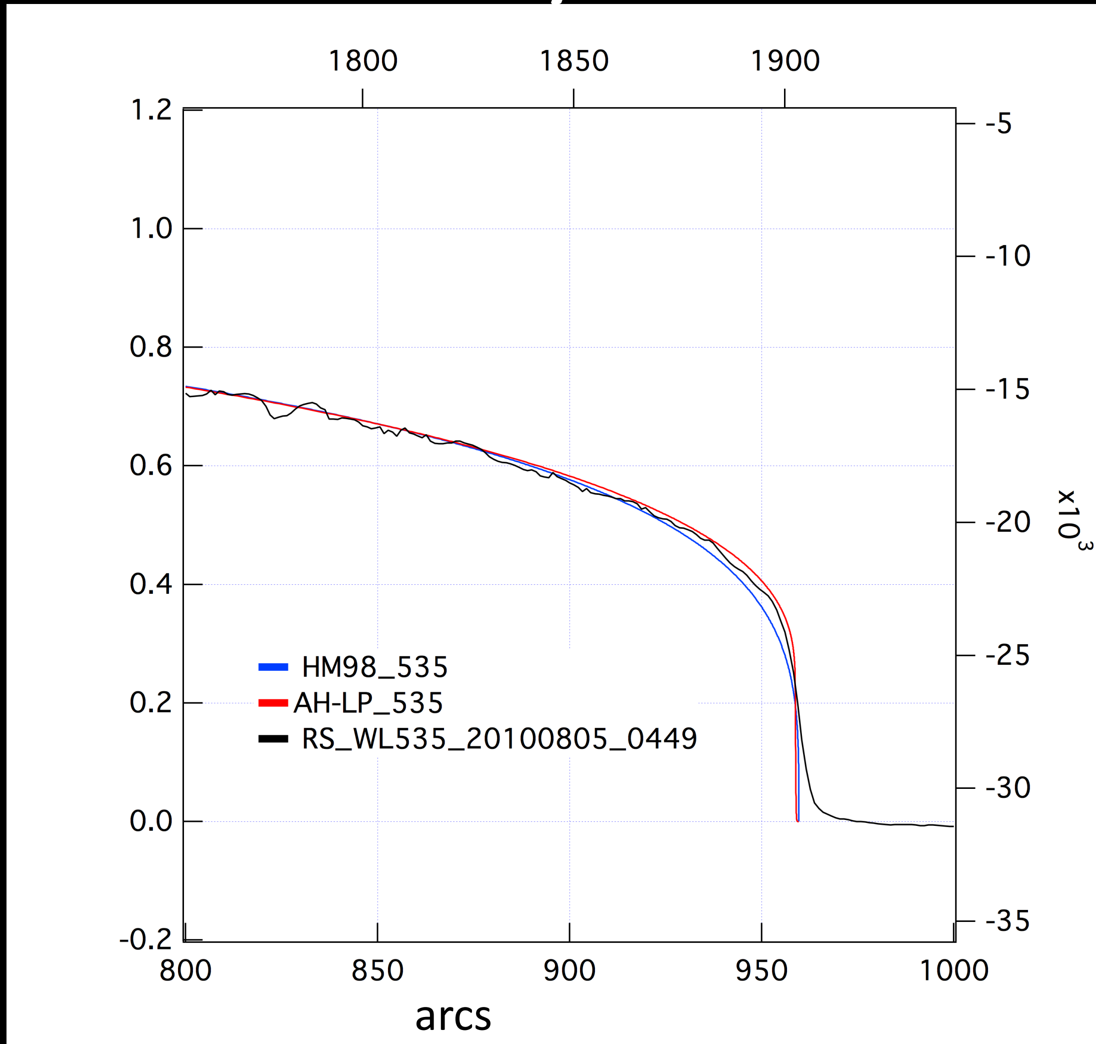


X-axis origin at $\tau_{500nm} = 1$ &

Intensities normalized to 1 at the origin

What is the reality ?

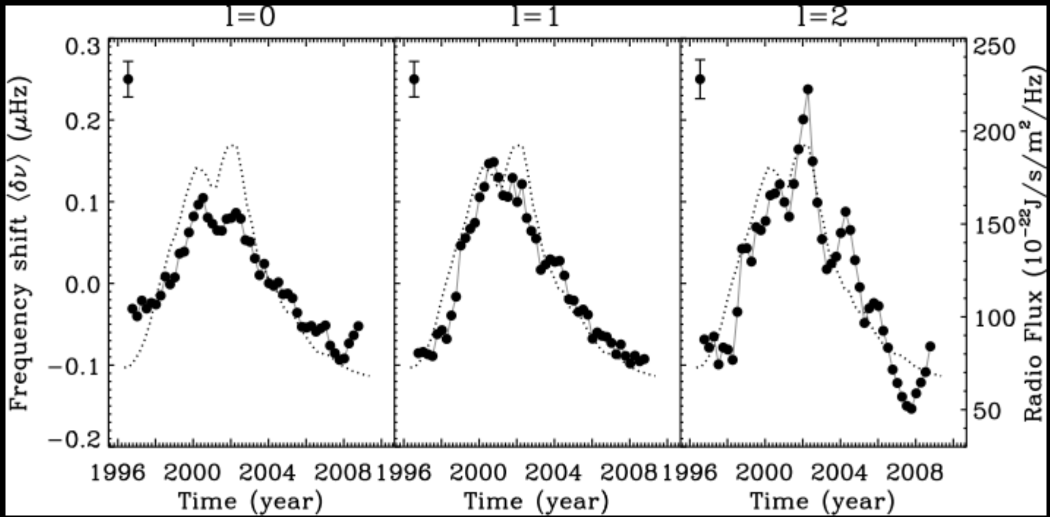
Preliminary results from PICARD that must be confirmed



Objectives

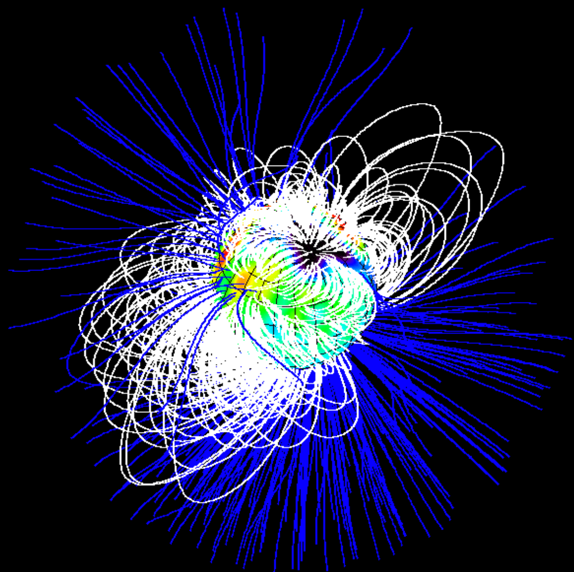
Perform grids of 3D atmosphere models for different magnetic activity levels and insert them in 1D solar model

It will contribute to better interpret what we get with SOHO GOLF/BiSON, PICARD and KEPLER on the variability of the solar cycle and probably improves the absolute frequencies



Rotation

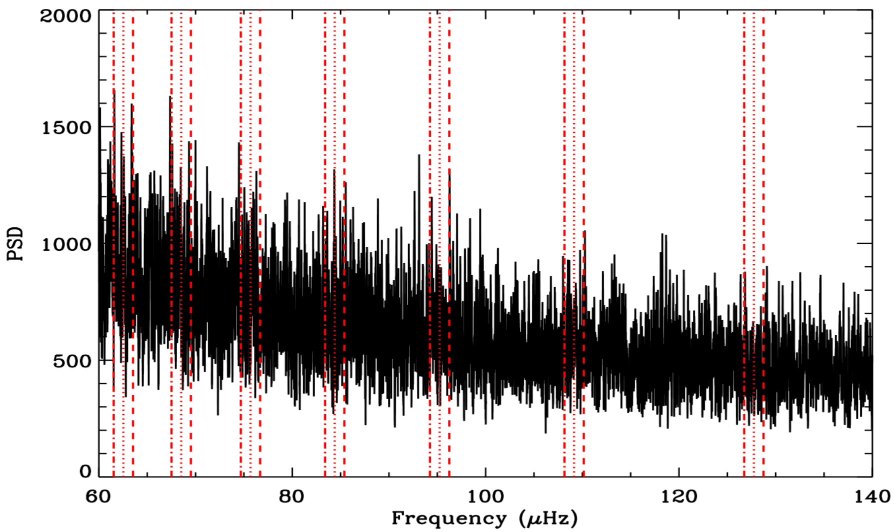
Young stars and activity

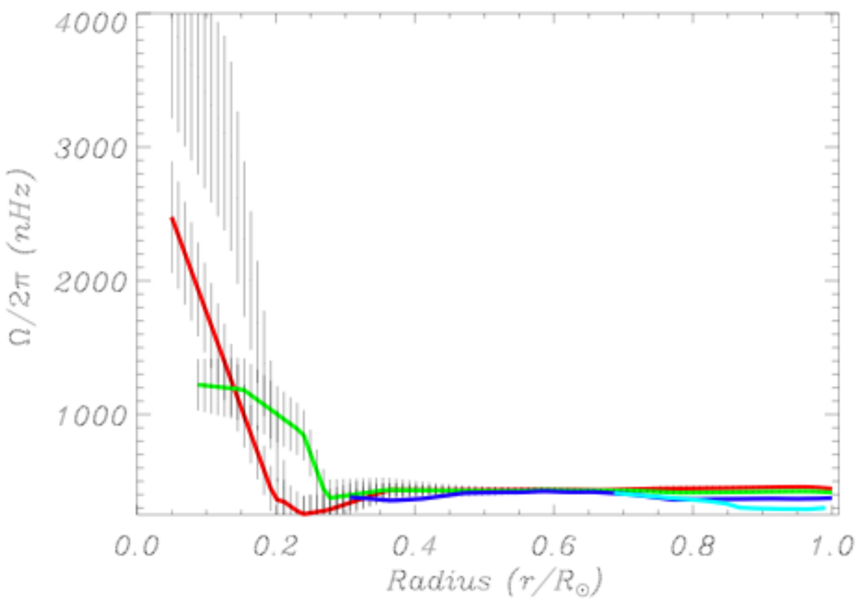


Collaboration : V. Duez, L. Piau, S. Couvidat, J. Marques, S. Mathis, P. Nghiem, A. Palacios, S. Turck-Chièze

Dipolar gravity modes integrated on more than 10 years: m=±1

Garcia et al. 2007, Turck-Chièze et al. 2010, Garcia et al. 2011





6 detected modes in integrating the signal on at least 10 years: velocity of several mm/s

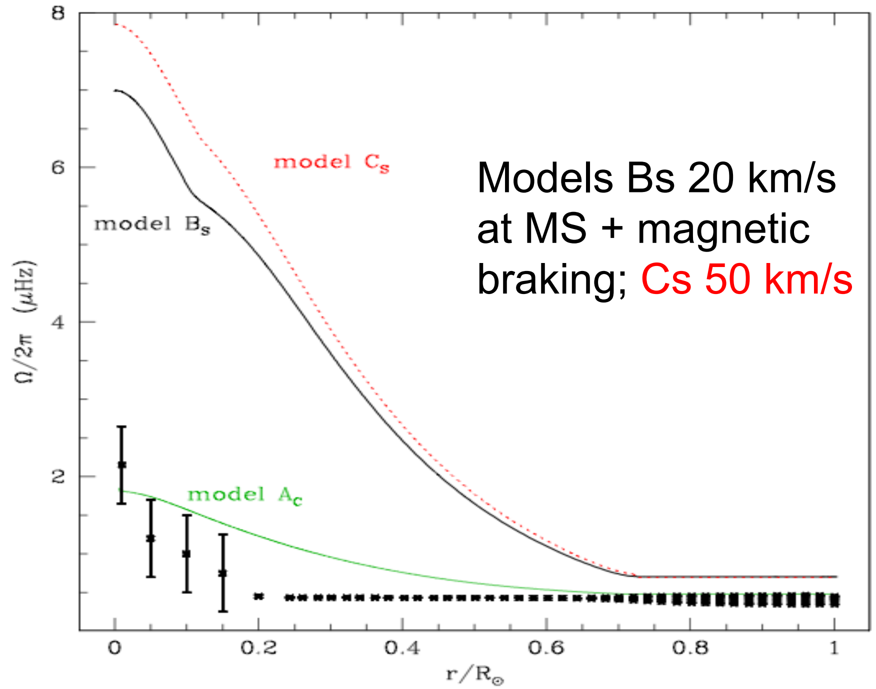
Solar models including transport of momentum by rotation

Turck-Chièze, Palacios, Marques, Nghiem ApJ 2010

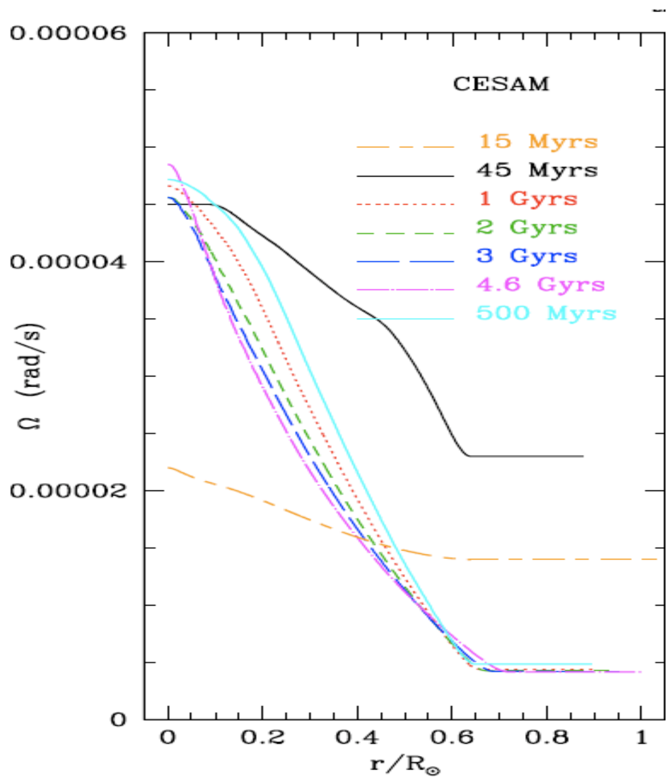
$$\rho \frac{d}{dt}\left(r^2\overline{\Omega}\right) = \frac{1}{5r^2}\frac{\partial}{\partial r}\left(\rho r^4 \overline{\Omega} U_2\right) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(\rho \nu_v r^4 \frac{\partial \overline{\Omega}}{\partial r}\right)$$

Zahn, 1992, Mathis & Zahn 2005

Solar rotation from GOLF+MDI



Models Bs 20 km/s at MS + magnetic braking; Cs 50 km/s



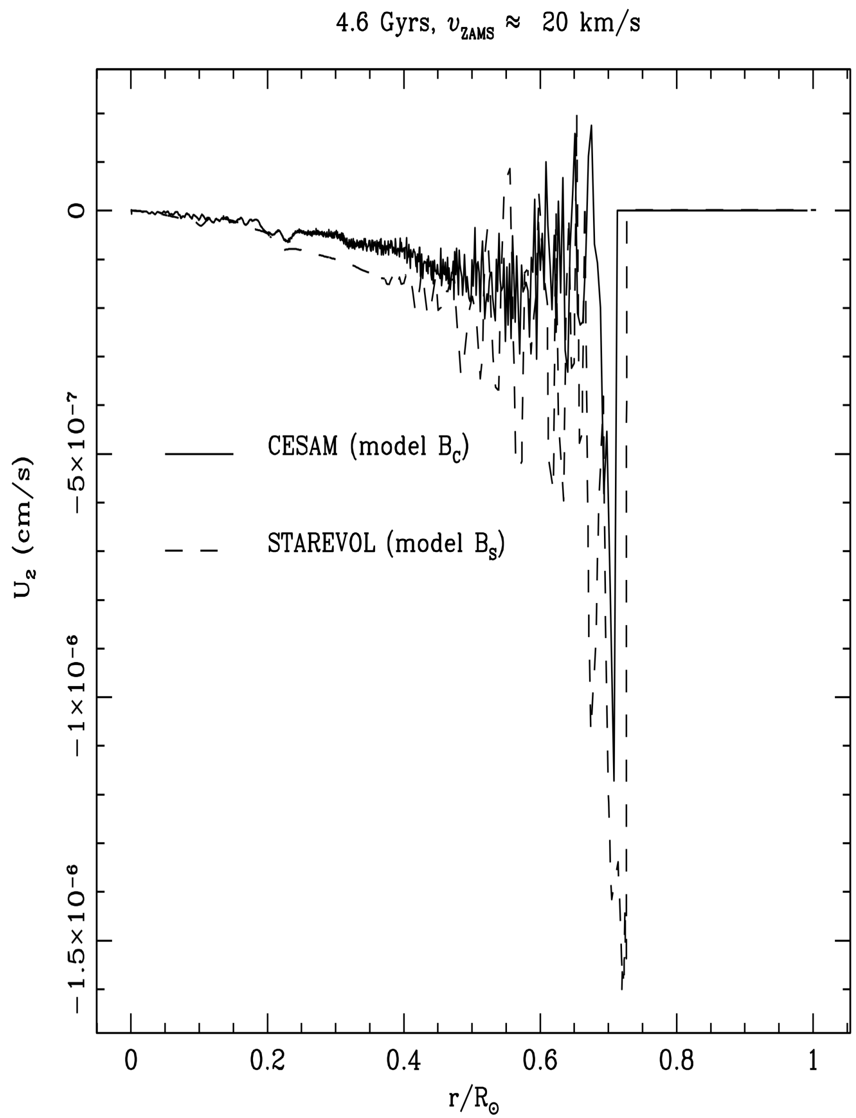
Model Ac: Weak initial rotation no magnetic braking:

The core rotation is induced during the contraction phase: first 10^6 yrs

The comparison with models suggests an initial rotation around 10 km/s

One needs other stars to confirm the fundamental role of the contraction and another process to explain the rotation rigidity between 0.2 to 0.65

Natural tachocline

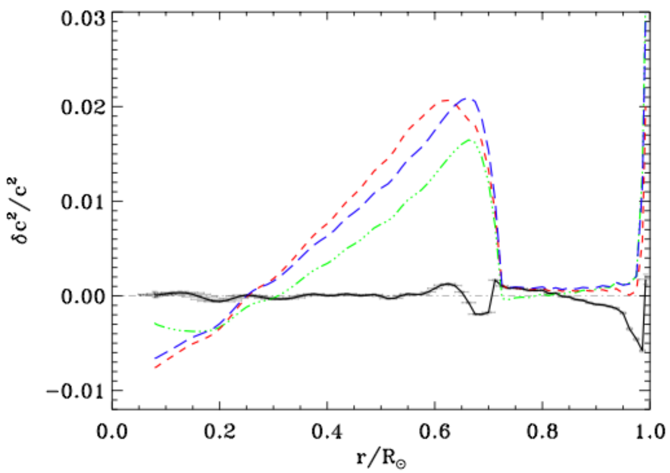


The present meridional circulation velocity in the RZ is extremely small (some 10^{-6}cm/s) in comparison with the convective zone meridional circulation (m/s)

In young Sun analogous, X and XUV are amplified by a factor 1000, they are more active with associated mass loss

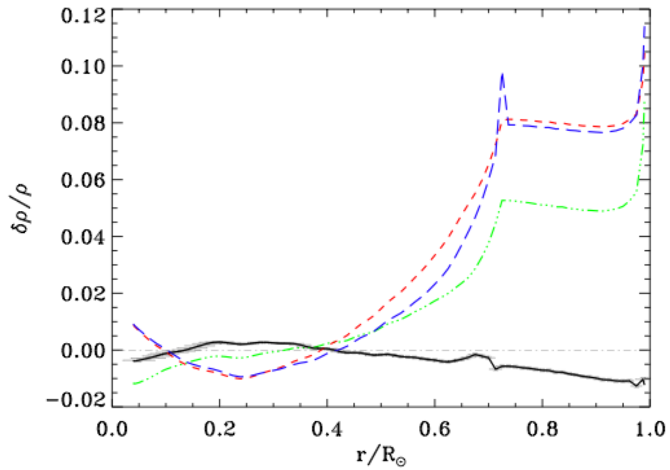
T-C, Piau, Couvidat 2011, ApJ lett

$$\dot{M}_W = 9\ 10^{-12} \tau(Gyrs)^{-2.23}$$



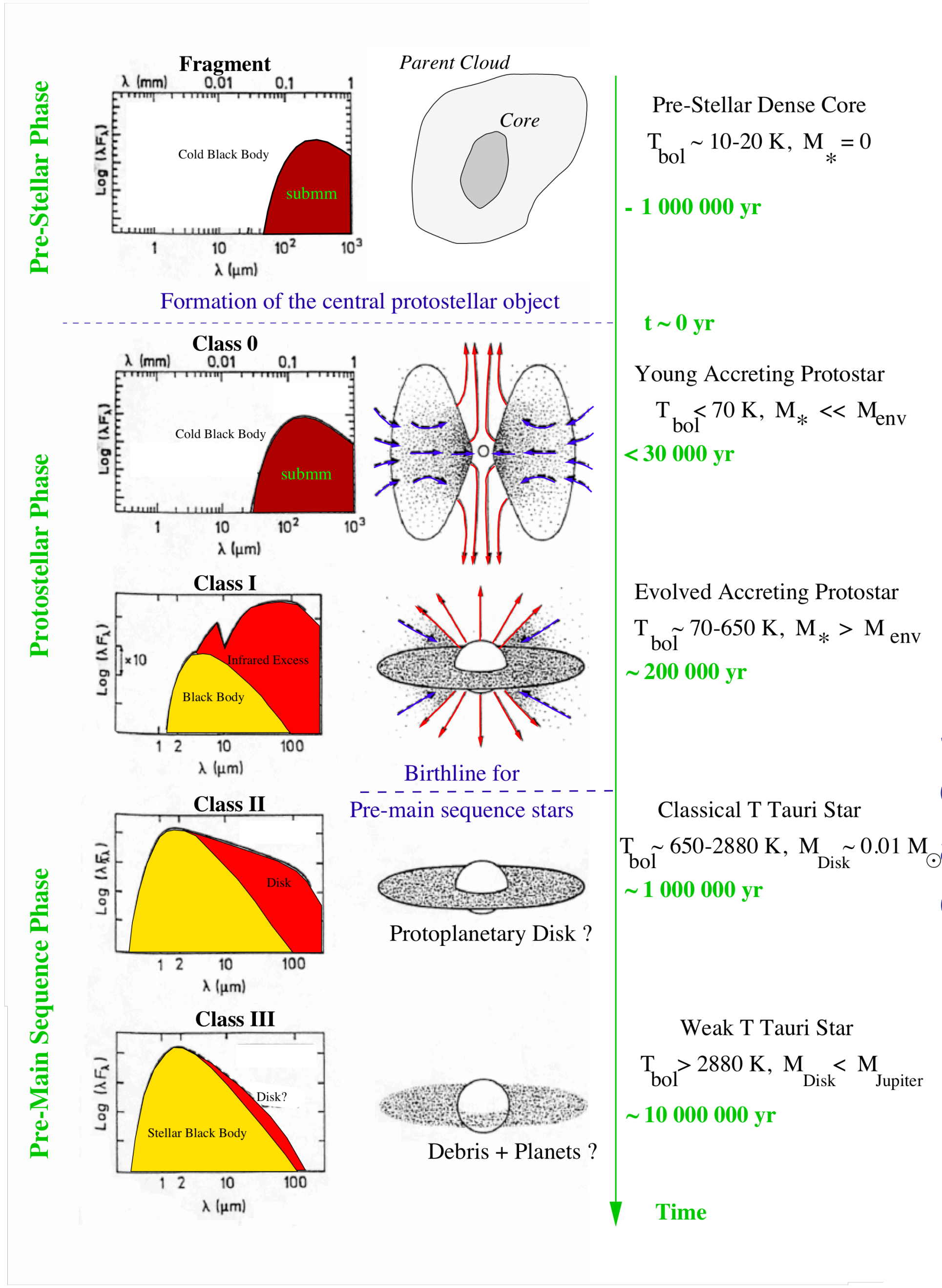
We get

- M initial 1.33 M_{sol} L_{init} = 1.5 Lsol
- If the initial mass is larger, the discrepancy with observation of the sound speed is reduced



The introduction of mass loss helps to solve the « solar paradox » that the initial luminosity is too small to explain the initial conditions of Mars formation

Following the first stages



Andre 1998, 2000, 2008

In phase 0 accretion dominates

Solar analog of 2Myrs: mass loss dominates by an order of magnitude the accretion rate (Donati et al 2009) and complex MF configuration is observed

The presequence modelling must be largely improved and stellar models must be enriched by dynamical effects

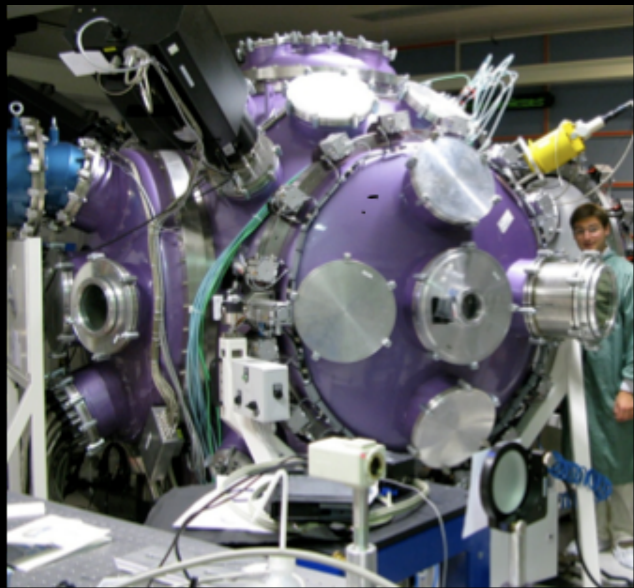
The early Sun (solar –like stars) was probably more active and have experienced mass loss that modifies the evolution of its luminosity at the beginning of its evolution.
If the mass loss is sufficient, it could modify the present sound speed.

Up to 150 Myrs, the Sun was totally convective and could have experienced a dynamo in its interior that has relaxed as a non force free mixed magnetic field

The developed magnetic field then diffuses in the radiative zone and might stay present with some interaction with the dynamo field of the CZ

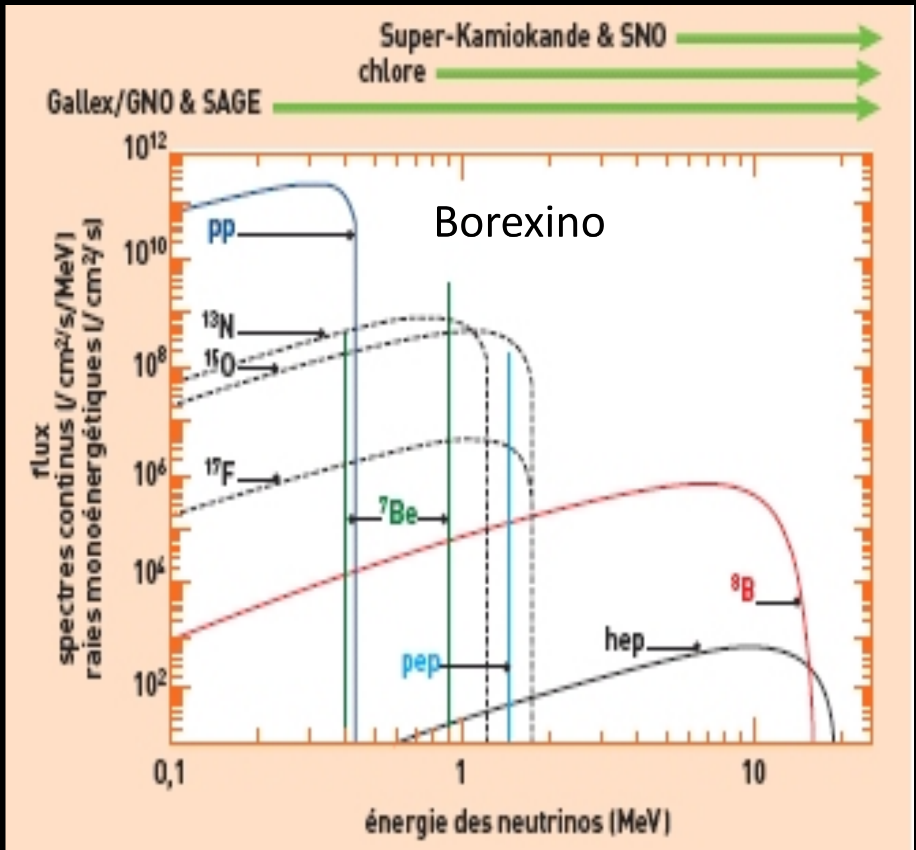
Observational evidence is looked for !!
And also numerical simulations

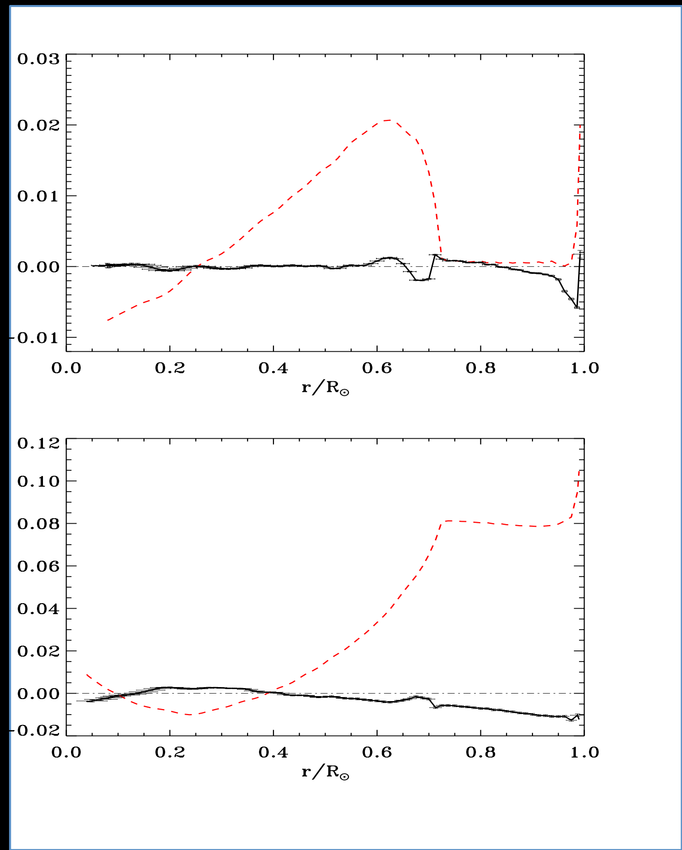
Microscopic physics



Collaboration : L. Piau, S. Couvidat, J. E. Ducret, D. Gilles, S. Turck-Chièze + internal collaboration on opacities 30 persons

Microscopic Physics of the central region: predictions of the seismic model



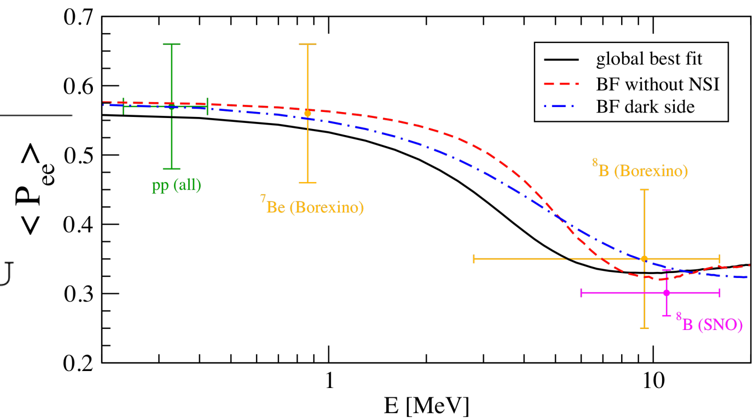


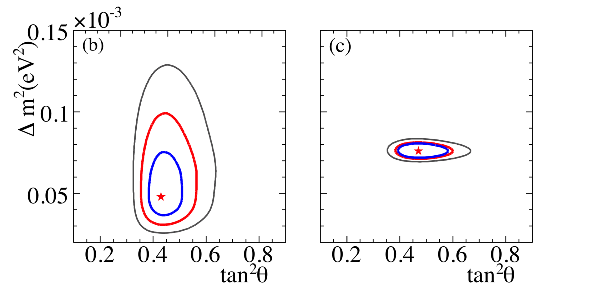
SSeM neutrino predictions agree with all the neutrino detections

it is not the case for the SSM predictions

	Predictions without neutrino oscillation	Predictions with neutrino oscillation
HOMESTAKE		**2.56 ± 0.23 SNU**
Standard model 2009	6.315 SNU	2.24 SNU
Seismic model	7.67 ± 1.1 SNU	**2.76±0.4 SNU**
GALLIUM detectors	GALLEX	73.4 ± 7.2 SNU
	GNO	62.9 ± 5.4 ± 2.5 SNU
	GALLEX + GNO	**67.6 ± 3.2 SNU**
	SAGE	**65.4 ± 3.3 ± 2.7 SNU**
	GALLEX+GNO+SAGE	**66.1 ± 3. SNU**
Standard model 2009	120.9 SNU	64.1 SNU
Seismic model	123.4 ± 8.2 SNU	**67.1 ± 4.4 SNU**
BOREXINO ^{7}Be		**3.36 ± 0.36 $10^9 cm^{-2} s^{-1}$**
Standard model		
Seismic model	4.72 $10^9 cm^{-2} s^{-1}$	**3.045 ± 0.35 $10^9 cm^{-2} s^{-1}$**

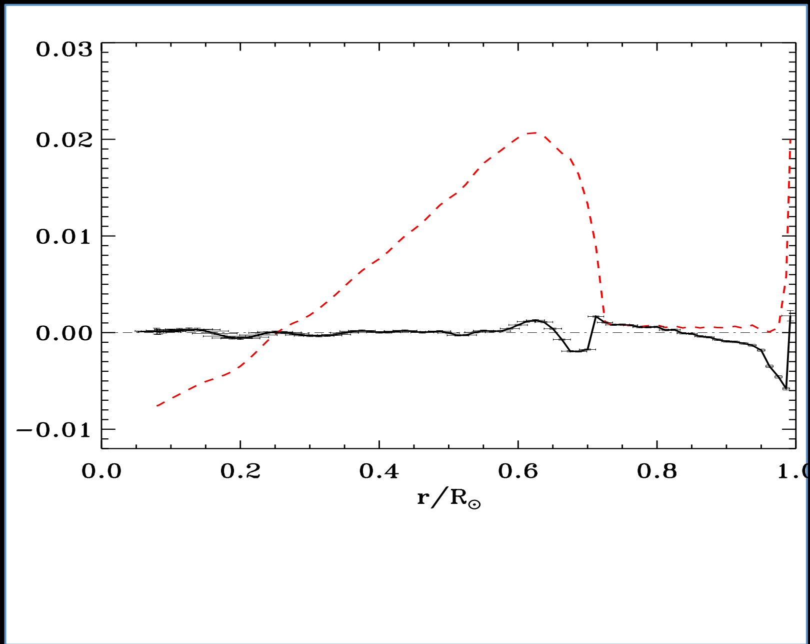
Water detectors	Predictions or Detections B^8 electronic neutrino flux
SNO	**5.045 ± 0.13 (stat)± 0.13 (syst) $10^6 cm^{-2} s^{-1}$**
SNO +SK	**5.27 ± 0.27 (stat)± 0.38 (syst) $10^6 cm^{-2} s^{-1}$**
Standard model 2009	4.21 ± 1.2 $10^6 cm^{-2} s^{-1}$
Seismic model	**5.31 ± 0.6 $10^6 cm^{-2} s^{-1}$**





Turck-Chièze and Couvidat, 2011 Report in progress in Physics, 74

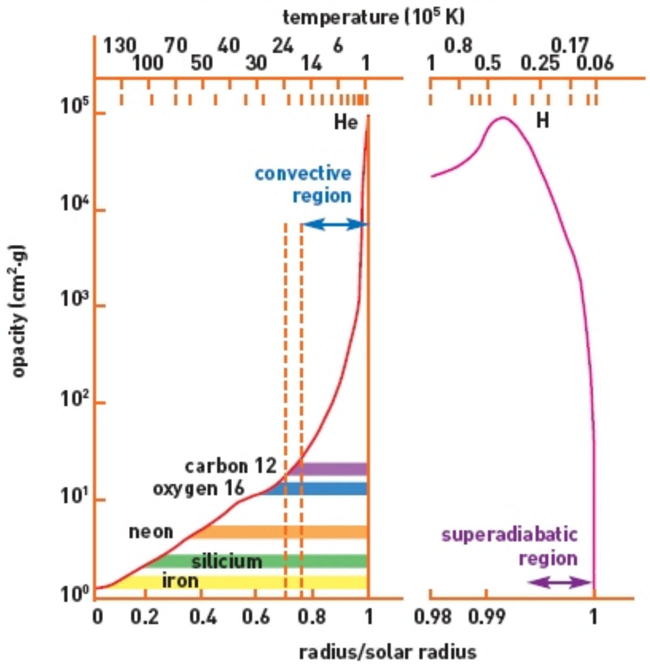
CNO neutrinos /predictions < 1.5
Bellini et al. 2011

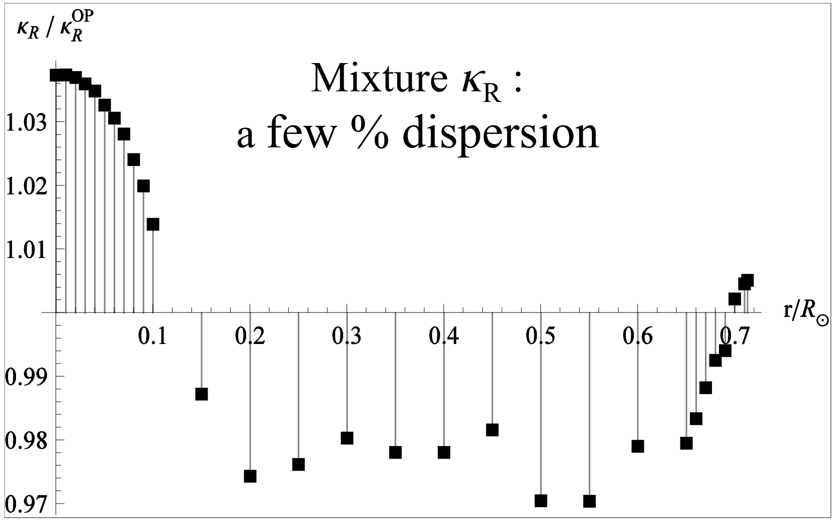


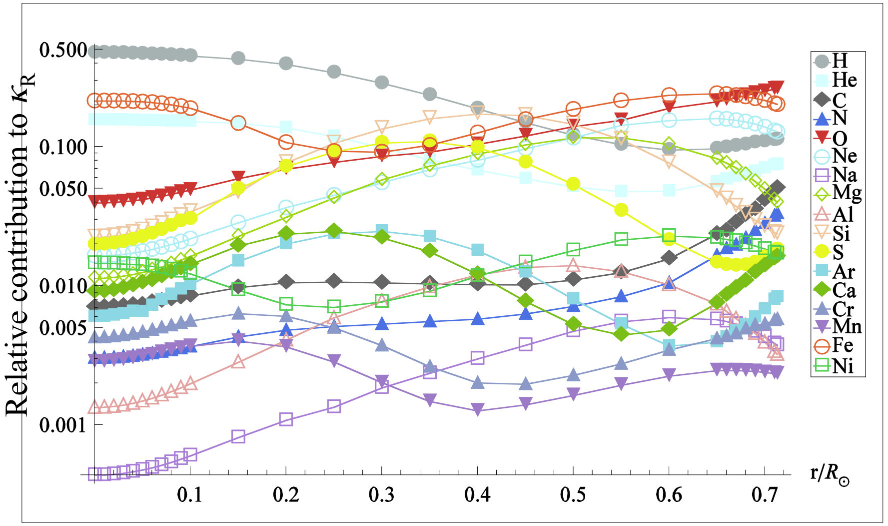
Opacity ?

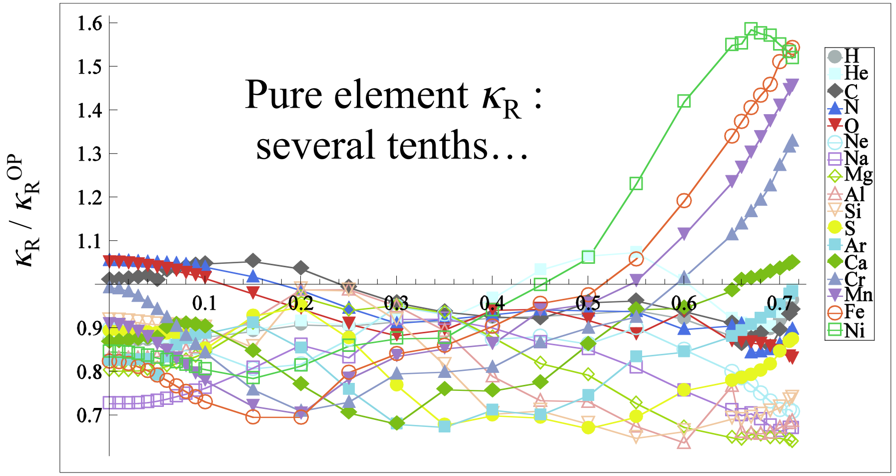
Microscopic diffusion ?

Opacity: OPAS vs OP Blancard, Cosse and Faussurier ApJ 2011 in press

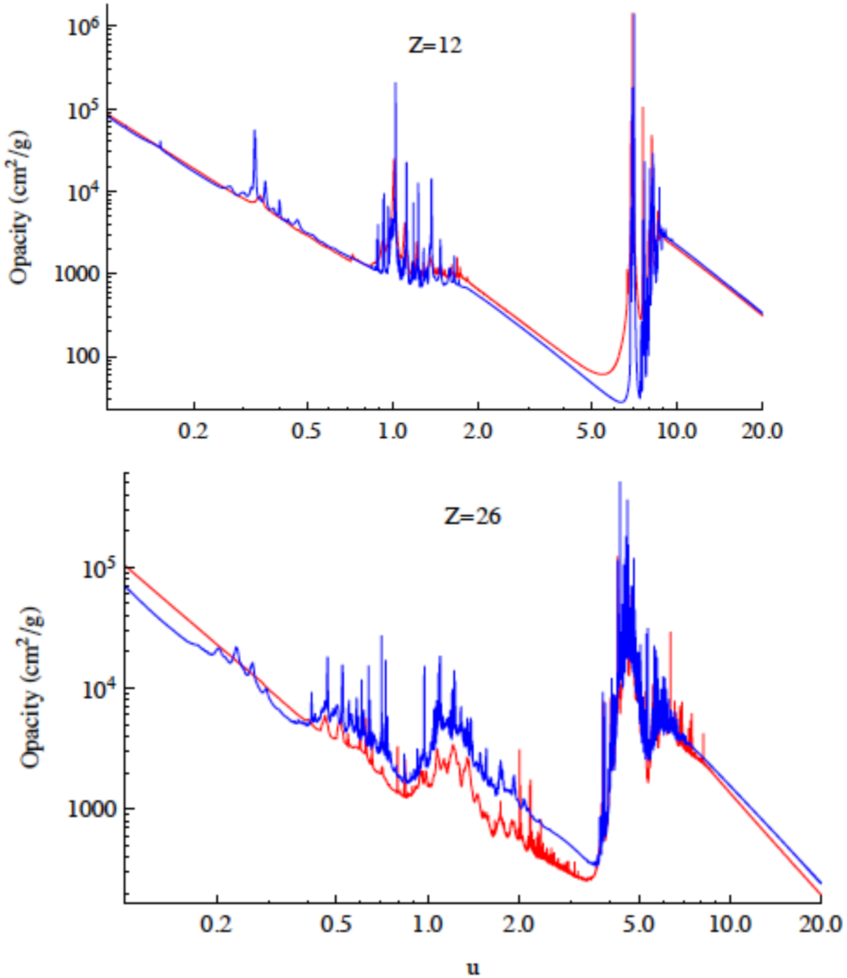








Origin of the differences



Broadening of the lines

Ionic fraction distribution

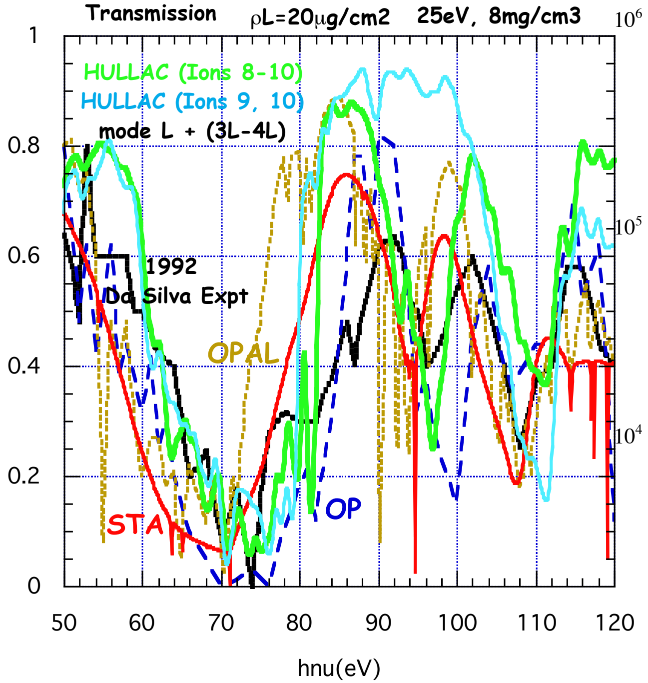
Blue: OPAS   Red: OP

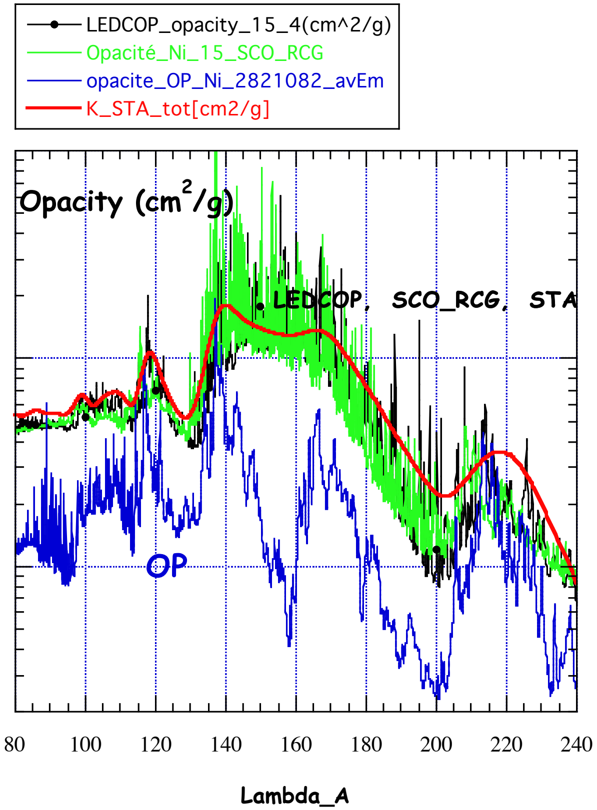
There exists good agreement between OPAL, OPAS and OP mean Rosseland values in the solar radiative zone.

But a compensating effect between elements (Z around 12 and Z around 24) is possible that leads to large discrepancies between delivery calculations (up to 60% for iron) that could lead to more important effect.

Some progress can still exist (direct effect or indirect effect) which impact on the sound speed profile, other stars of different composition

Opacity of iron peak for envelops





We have performed measurements for Ni, Fe, Cr and Cu last September and we have engaged a large comparison between calculations: OPAS, SCO-RCG HULLAC + Los Alamos and Livermore

In these conditions, the interaction between configuration is important and OP seems to reproduce better the experiment for Fe than OPAL but some spectra for Ni seem underestimated

We shall organize a second meeting on opacity next spring

Conclusion

Different activities have been developed to better understand the helioseismic results. They must be useful for solar-like stars: 3D atmosphere, transport by rotation, role of magnetic field ?

They lead to some hints that could be believed only if one finds a coherent picture between Sun and other stars on both rotation (origin of the rotation contrast) and magnetic field

This progress could require the introduction of a third actor: the gravity waves