DE LA RECHERCHE À L'INDUSTRIE

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THE ACTIVE SUN

Why new solar measurements and Which?

Solar Metrology, Paris , October 7-9 th 2014

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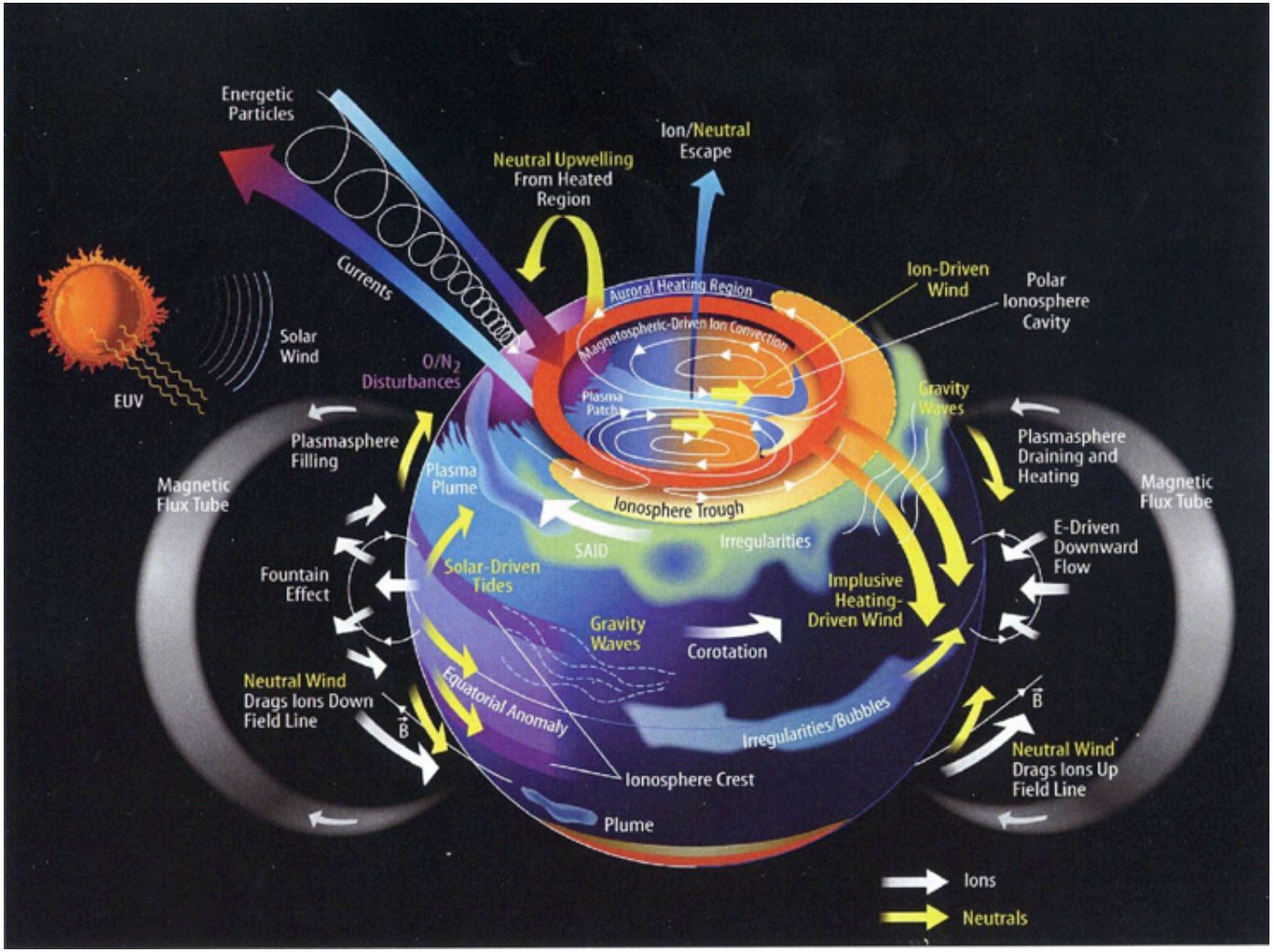
OCTOBER 9TH 2014

SOLAR METROLOGY
SPACE WEATHER….. SPACE CLIMATE



These questions are more and more important to find answers

TIMESCALES

Million of years: pure theoretical work SSM

Millenia: indirect measurements ^{14}C ^{10}Be
reconstructions reliability?

Long term : 300 years

Intermediate term 30 - 40 years SoHO, Ground networks
Impact on Earth Not yet clear but real progress has been done

Short term: s, days, seasons

ACTIVITY INDICATORS

sunspot relative numbers	1917
sunspot areas	1956
chromospheric eruptions	1935
coronal intensities	1947
radio emission	1947
synoptic magnetic maps	1969
(changed to color version in	1977)

Acoustic modes : 1985 on ground with BiSON and GONG
1996 in space with SOHO GOLF/ MDI

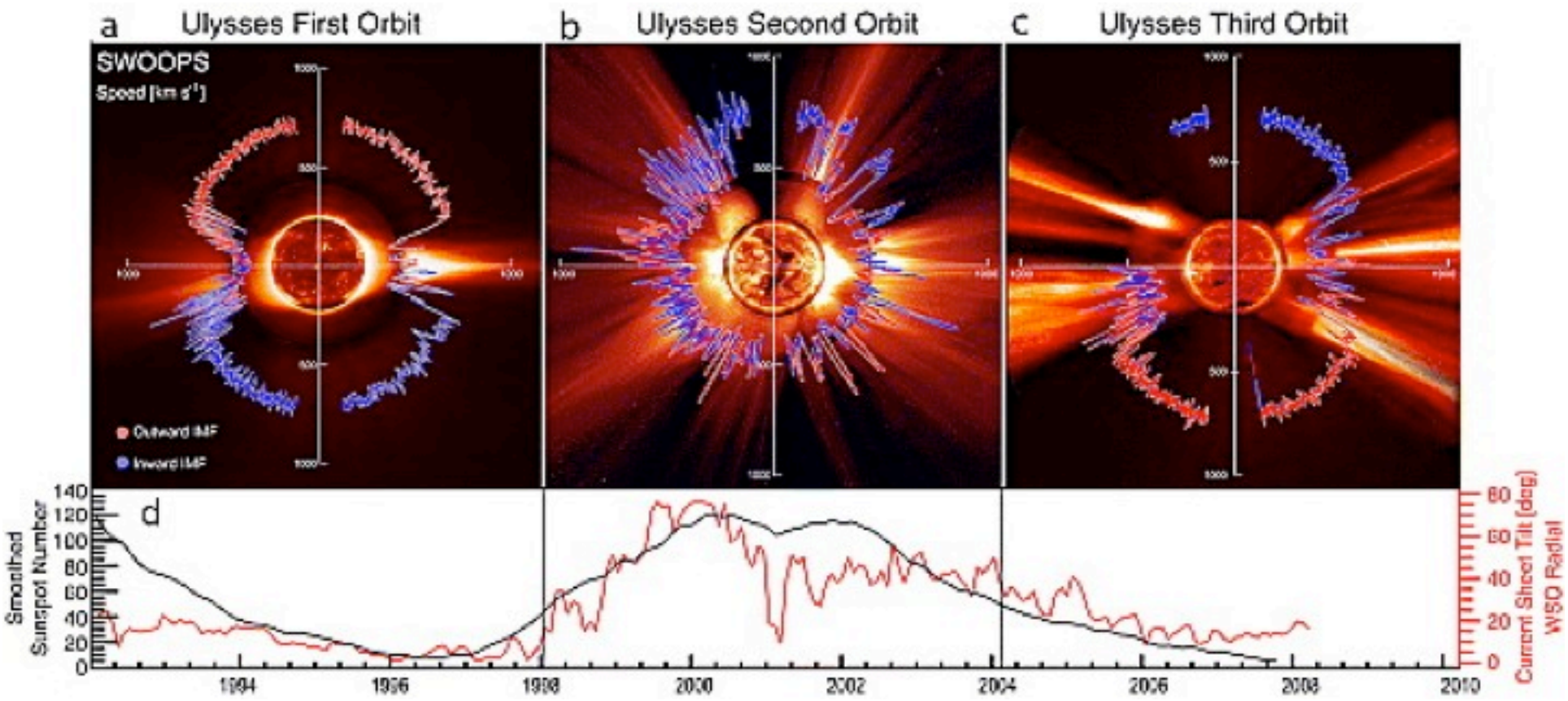
SOLAR METROLOGY TOWARD SPACE WEATHER….. SPACE CLIMATE

What have we learned ?

What would we like to learn ?

What have we learned during the last 3 decades?

SPACE WEATHER….. SPACE CLIMATE

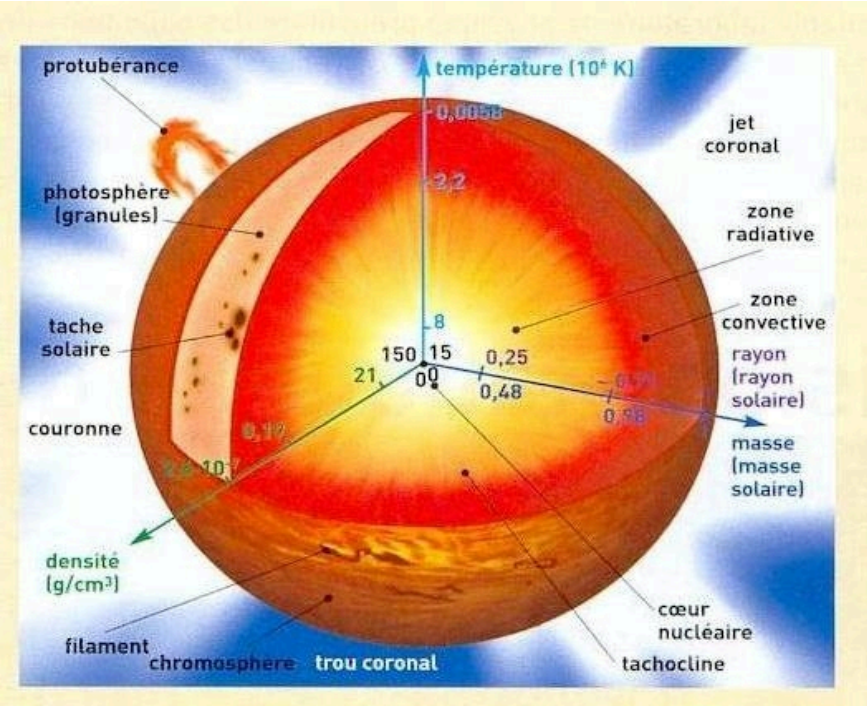


McComas et al. 2008

THE INTERNAL PHYSICS IS FUNDAMENTAL
THE SUN AS A REFERENCE FOR STARS

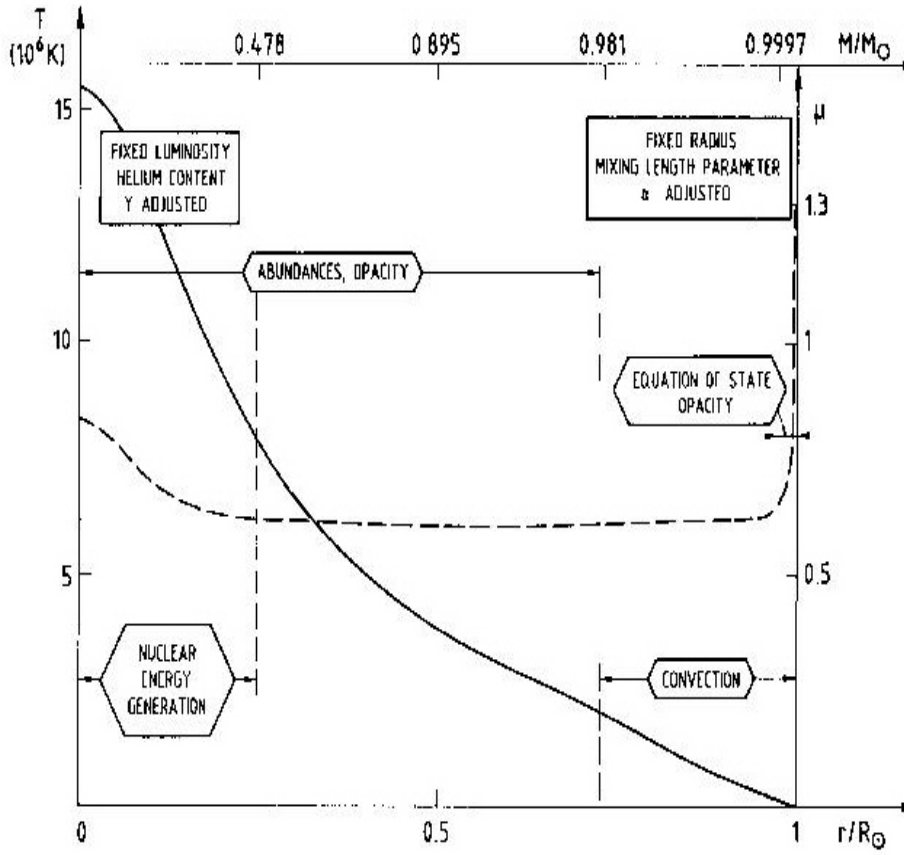
There no reason to think that the external activity is not coming from internal phenomena but as $P_{gas} >> P_{mag}$ **in the solar interior, it is difficult to put in evidence its evolution**

Is the static Sun of SSM contradicted by helioseismology ?



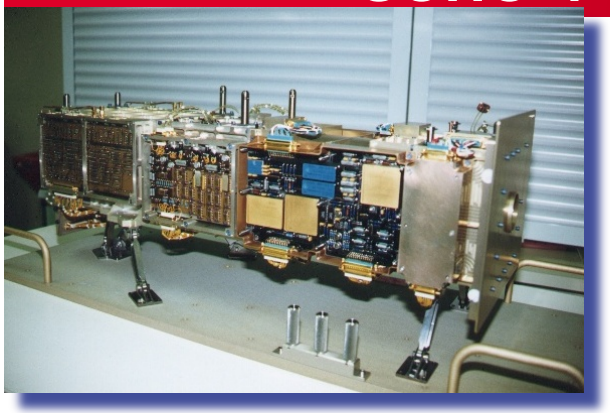
THE SUN AS A REFERENCE FOR STARS
CHECKING THE STELLAR EQUATIONS OF STRUCTURE

He photospheric: 0.25, BZC: 0.713 R sol

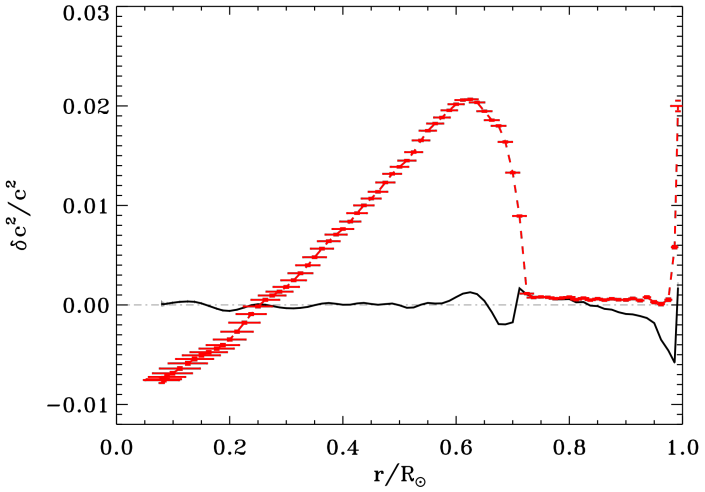


Vorontsov 1989, 1992, Basu 1995, Christensen-Dalsgaard et al. 1991

THE SUN AS A REFERENCE FOR STARS: SOHO : GOLF+ MDI

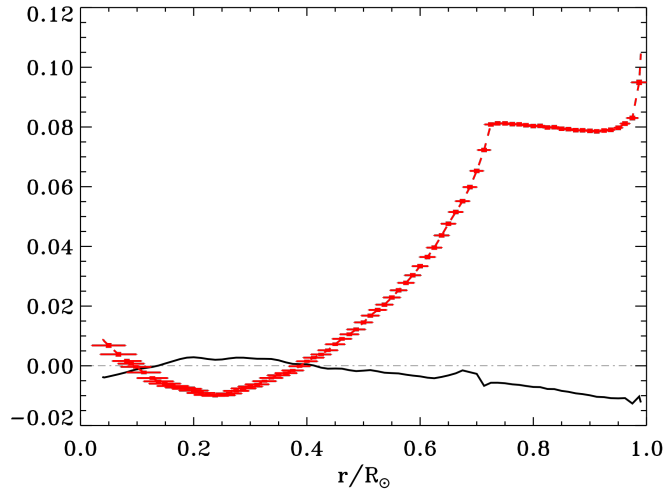


GOLF:IAS-CEA-IAC collaboration
18 years of observation already



$c^2 = \gamma P/\rho$ and prop to T/μ

$\delta c^2/c^2 = (c^2_{exp} - c^2_{model})/ c^2_{model}$

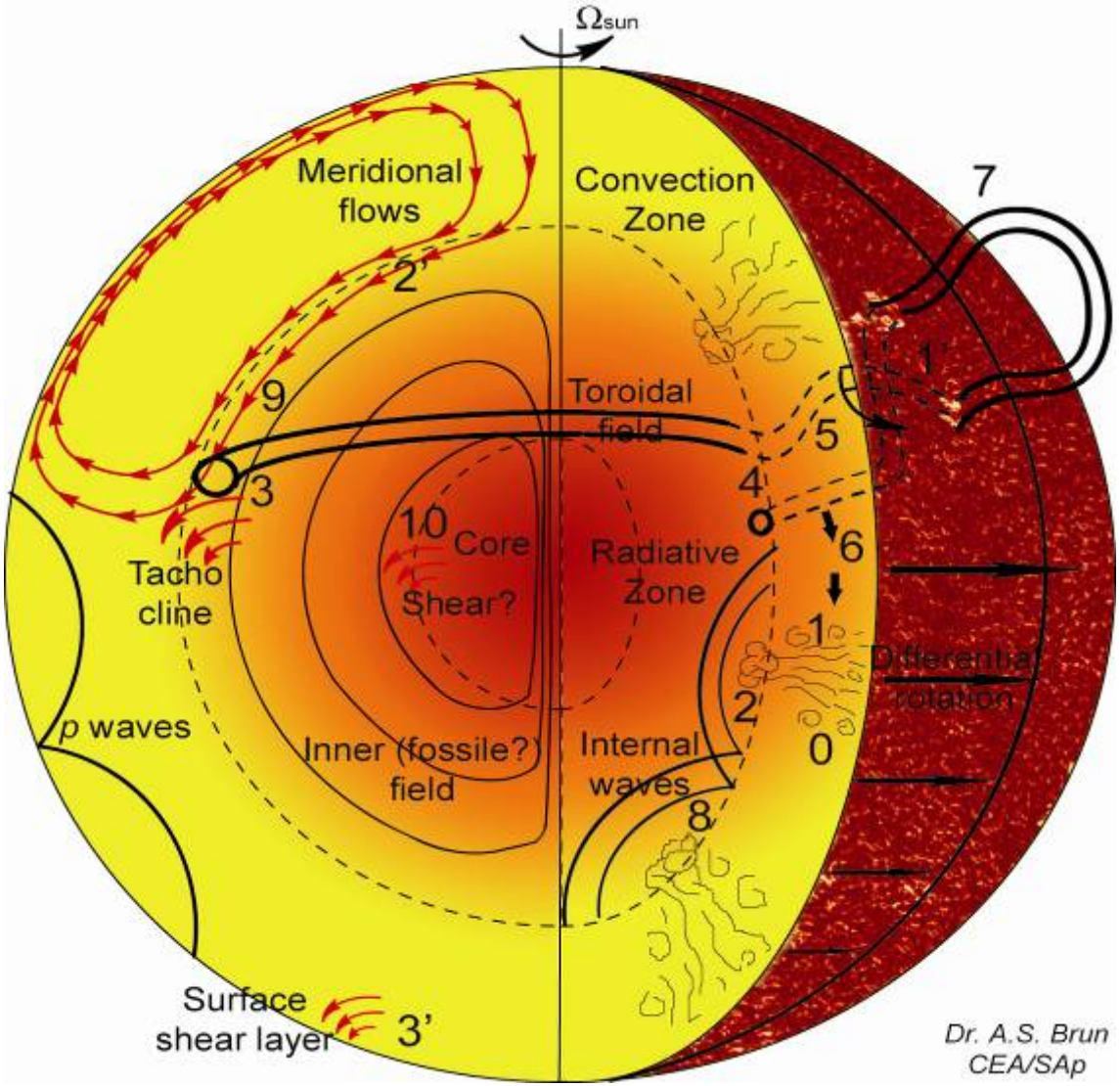


Significant differences: Two solutions

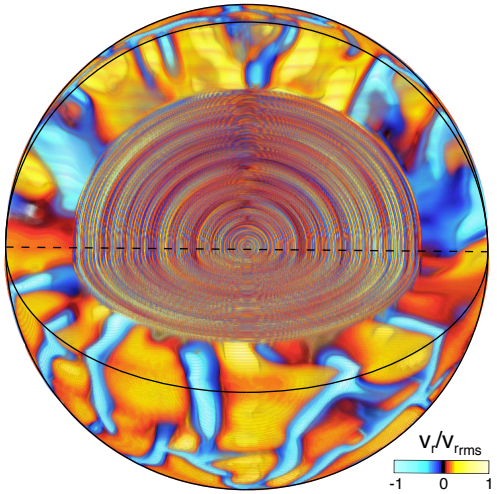
- Production of energy different from energy released at the surface ? Now quantified ΔE <5%: sismo + neutrinos => verification: precise pp or pep neutrinos flux today Borexino 10%
- Incorrect transport of energy by photons ? verification of kappa by new calculations + experiments on large laser facilities

Turck-Chièze et al. ApJ 2001, Phys. Rev 2004, ApJ 2010, Basu et al. 2009, 2014; T-C and Couvidat, Rep. Prog. Phys 2011, T-C, Piau, Couvidat, ApJ lett 2011; Turck-Chièze & Lopes 2012, 2014

THE SUN AS A REFERENCE FOR STARS: THE SUN IS A DYNAMICAL STAR



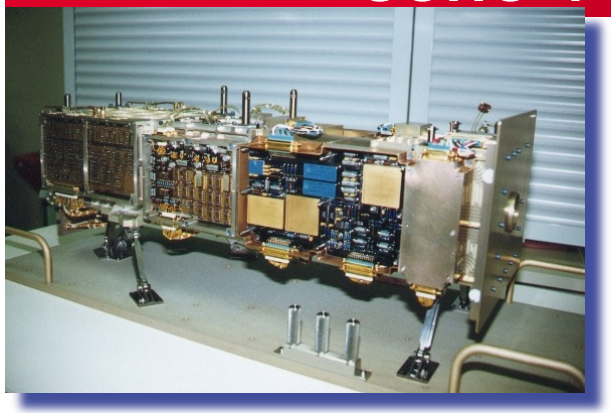
3D ASH simulation



Brun et al. 2004
Alvan et al. 2013, 2014

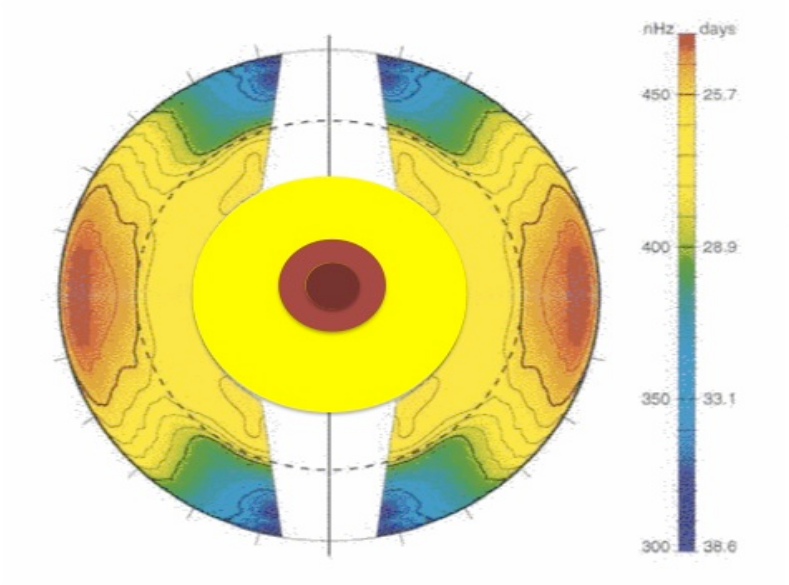
Excitation of the gravity waves by the convection and the turbulence of the tachocline. Order of magnitude ?

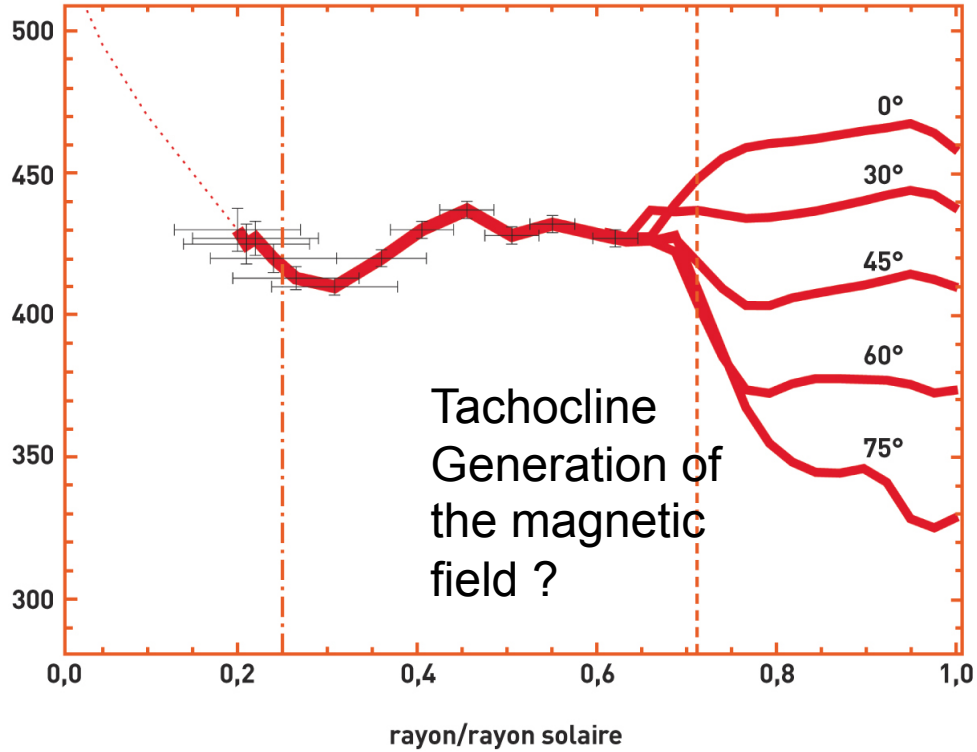
THE SUN AS A REFERENCE FOR STARS: SOHO : GOLF+ MDI



GOLF:IAS-CEA-IAC
Collaboration 18 years of observation already

Couvidat et al. 2003, Garcia et al. 2007, T-C et al. 2010….





Impact on the formation of the solar system
Impact on the oblateness
Initial deep dynamo: persistance ??

SOLAR OBLATENESS: PICARD, SDO

$$\varepsilon = \frac{r_E - r_P}{r_E} = \varepsilon_G + \varepsilon_S = \frac{3}{2} J_2 + \frac{1}{2} \frac{\Omega^2 R^3}{GM}$$

If ε < 8.3-8.4 mas

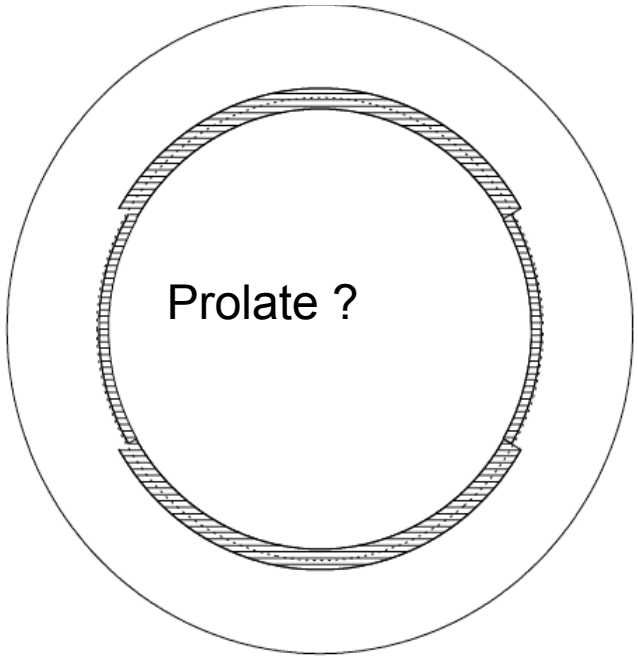
$\varepsilon_s = 8.45\ 10^{-6}$ for $\Omega_s = 2.58$ μrad/s

ε_G is influenced by the rotation of the core and by a fossil magnetic field if any

Flat internal rotation J2= 2.2 10^{-7}
Paterno et al 1996, Roxburgh 2001

$$2.21 \times 10^{-7} < J_2 < 2.94 \times 10^{-7}$$

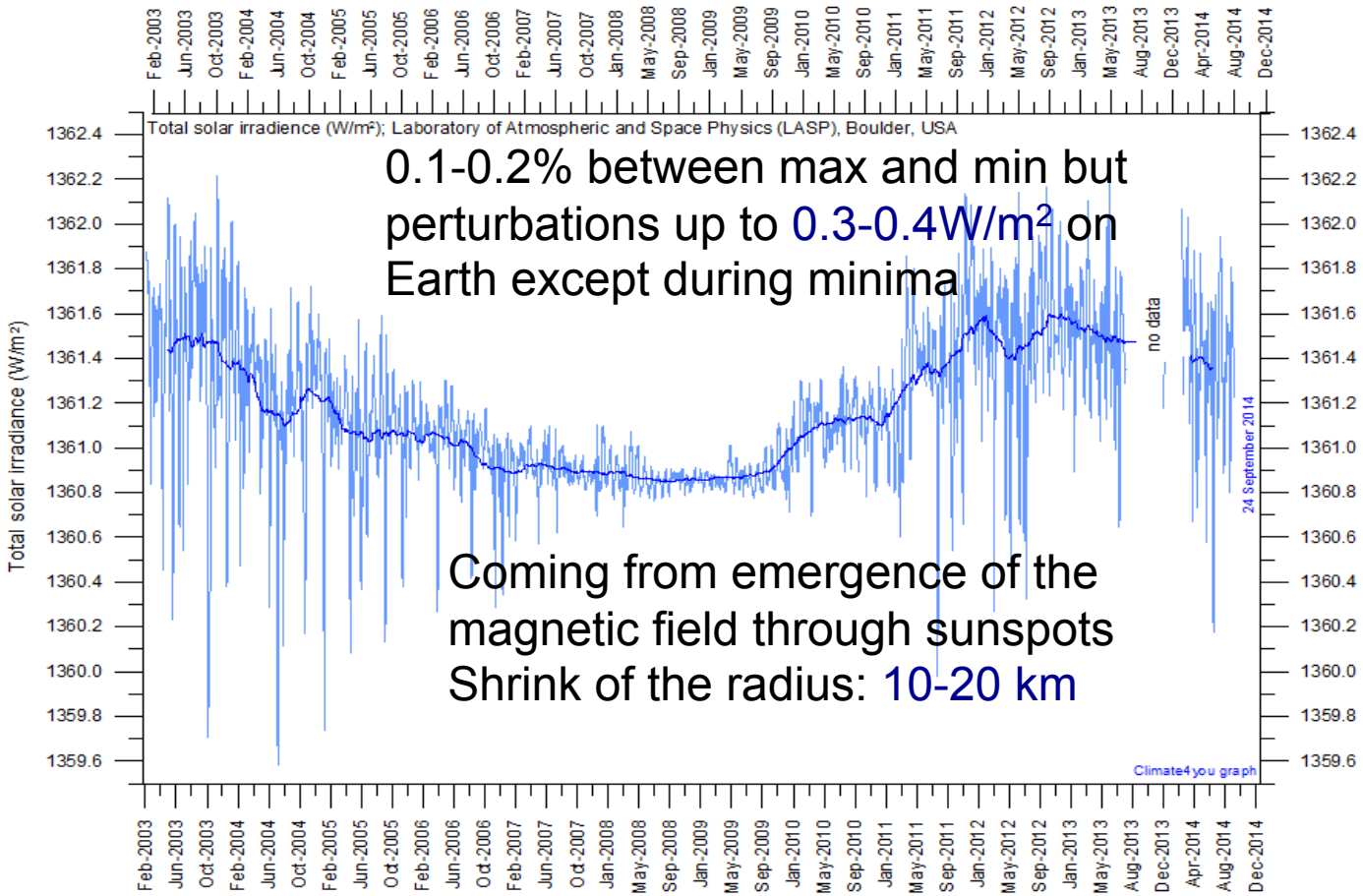
So 8.5 mas compatible with such approach about 6-7 km !! No influence of internal magnetic field ? To be improved…



Basu & Antia 2003

LUMINOSITY AND RADIUS CONSTRAINTS FOR SOLAR MODEL

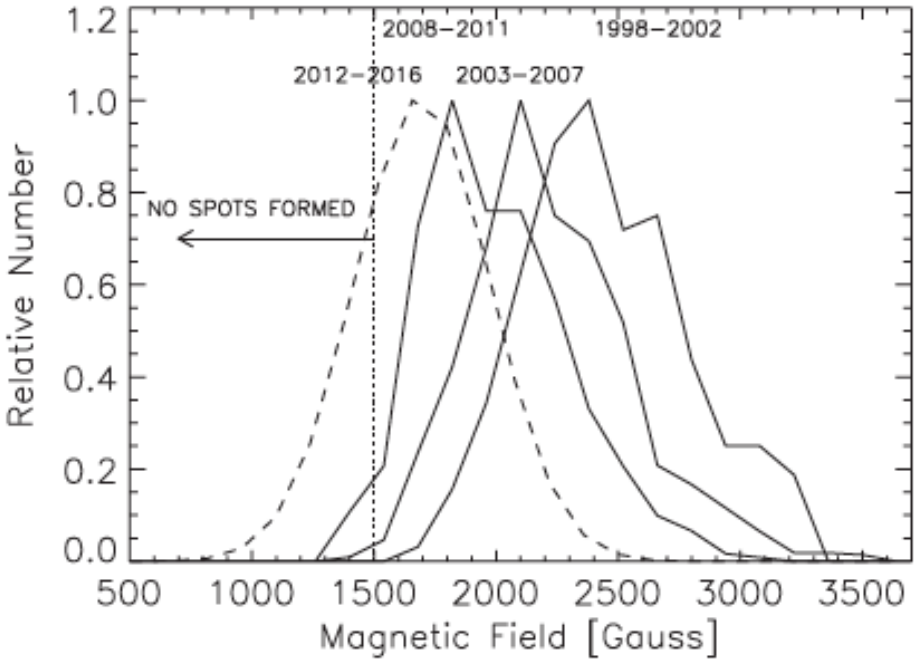
Absolute value under control

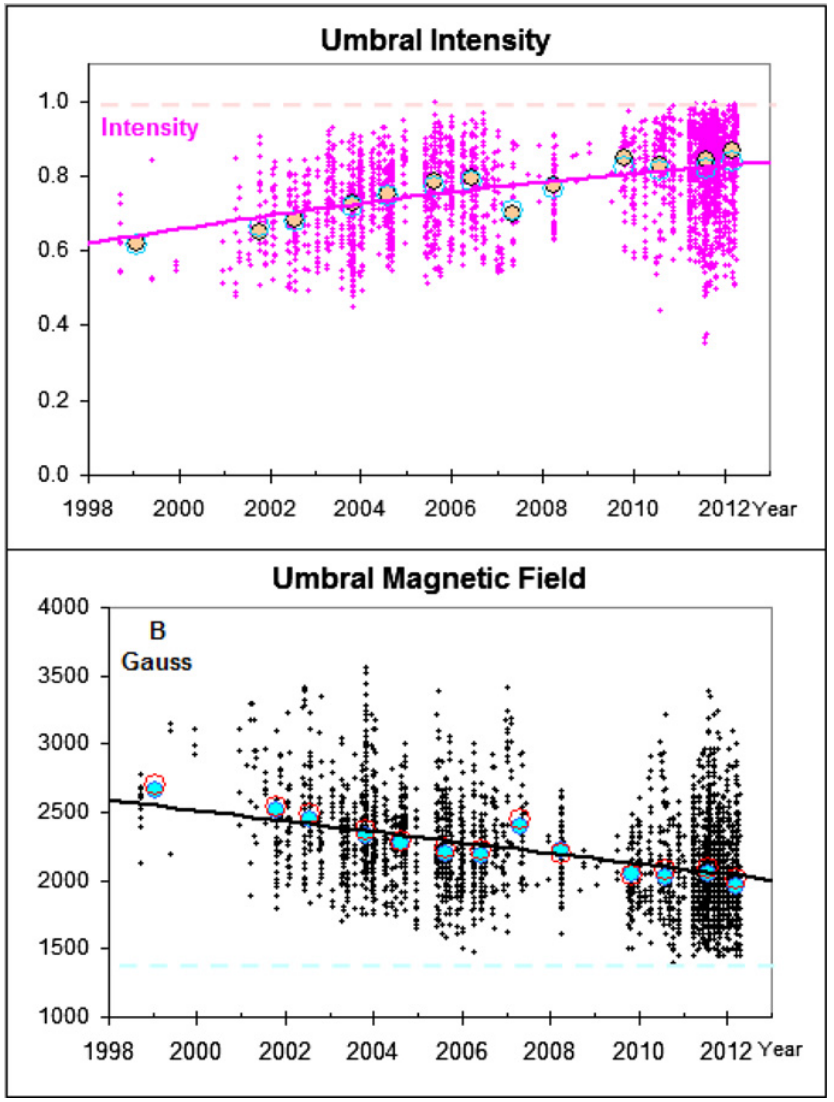


40 years of measurements
But the magnetic field at the surface is extremely low
Not really a tracer of the magnetic field configuration that impact on wind, eruptions… and earth magnetosphere

Livingston, Penn, Svalgaard 2012

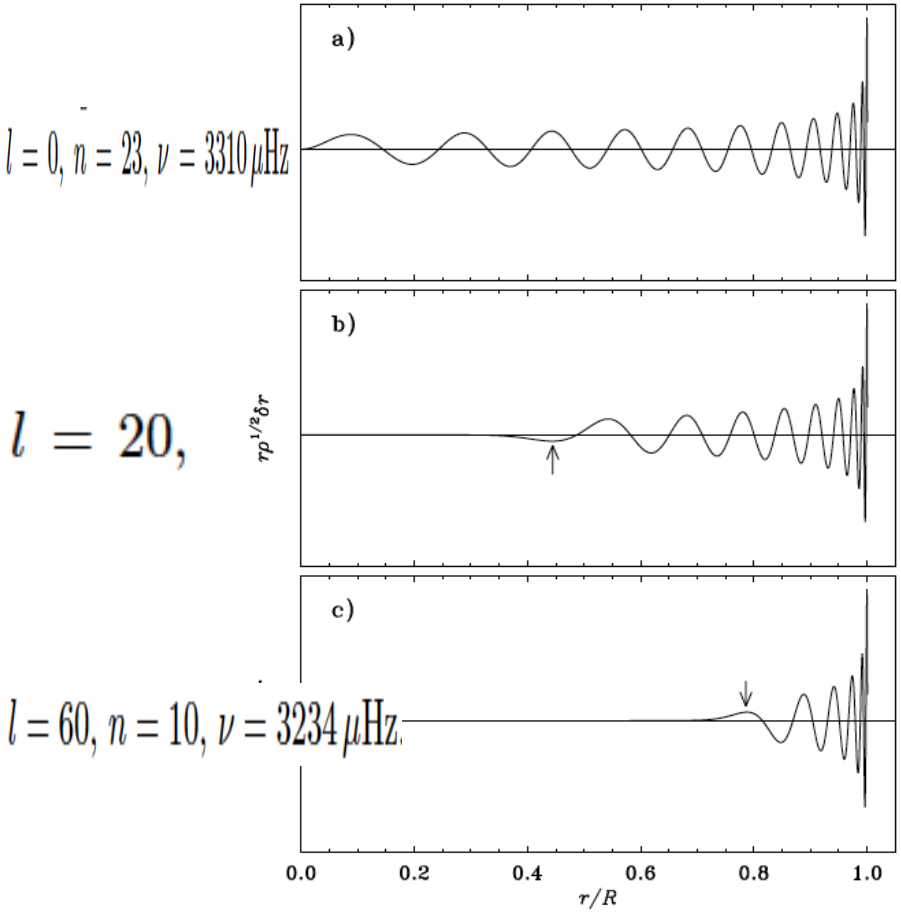
Sunspots emerge when the magnetic field > 1500 G

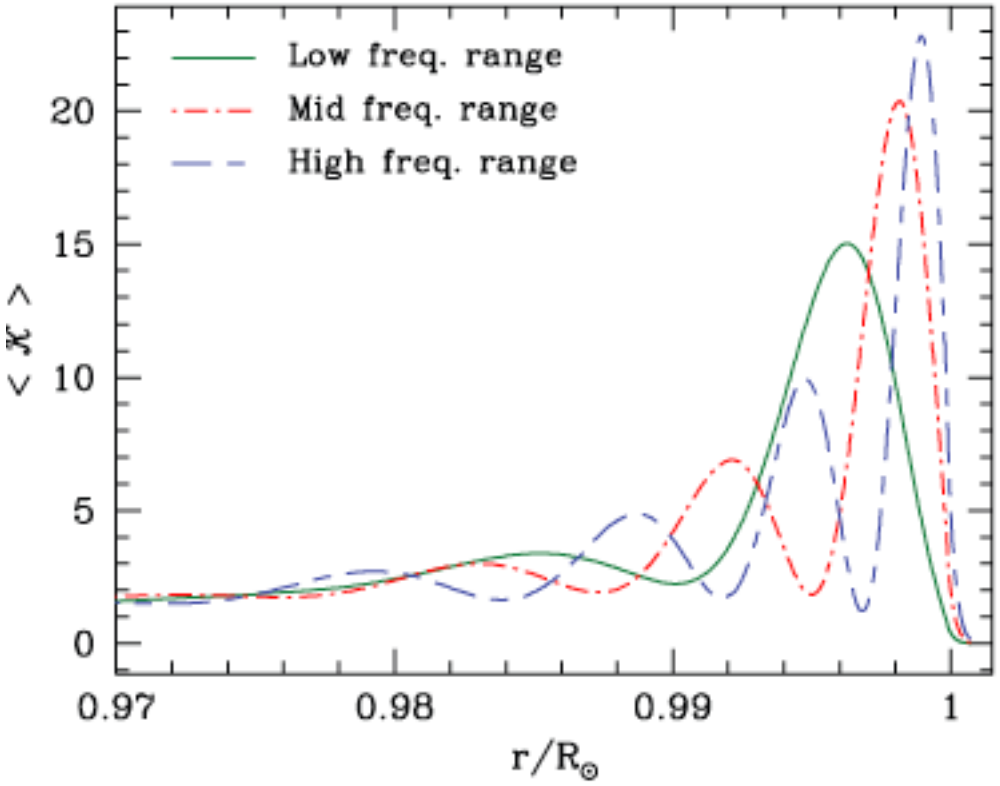




WHAT HAVE WE LEARNED FROM LOW DEGREE ACOUSTIC MODES ON INTERNAL MAGNETIC FIELD ?

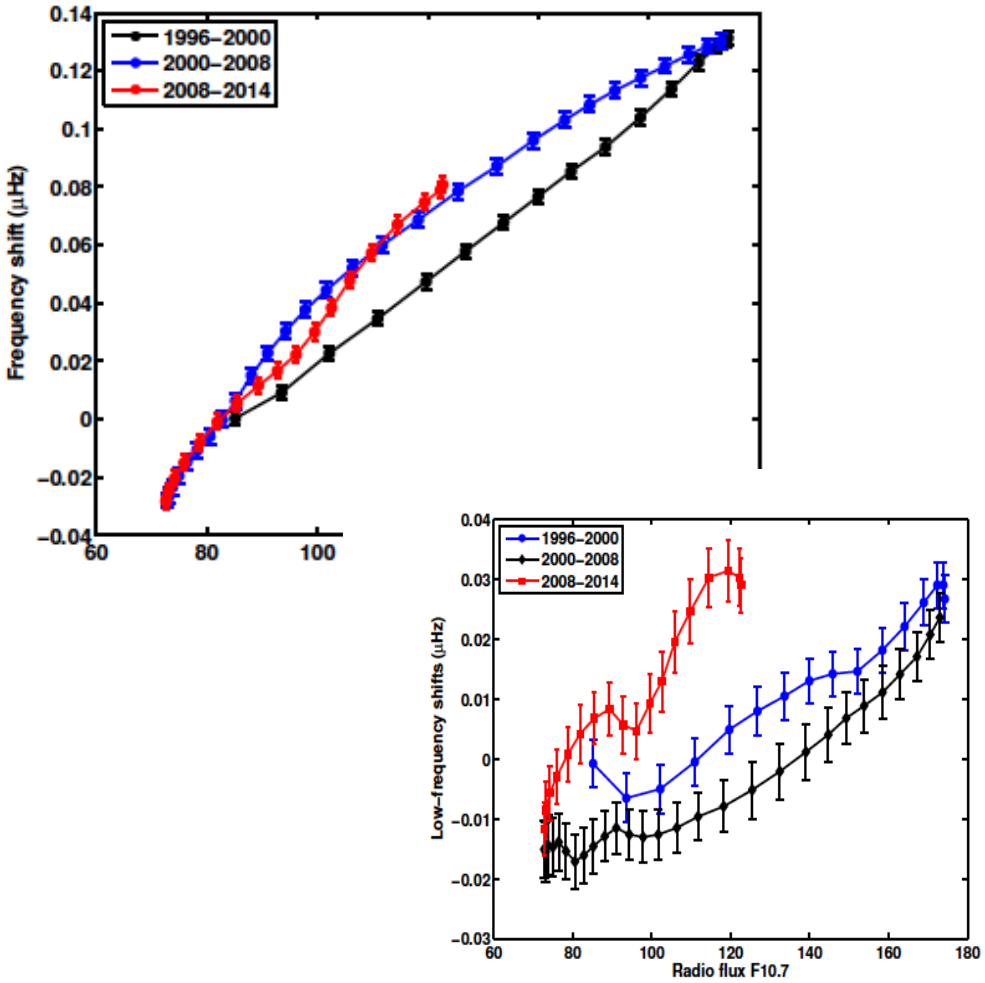
Salabert et al. 2009, Basu et al. 2012





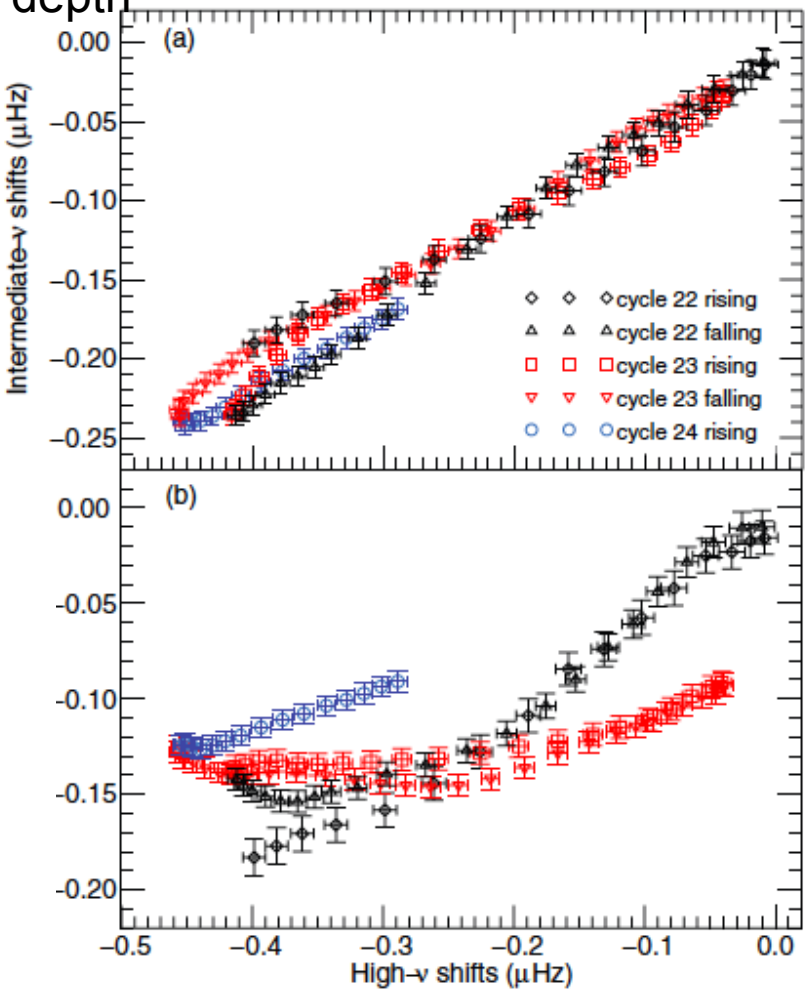
WHAT WE LEARN FROM SEISMOLOGY ?

Change of Magnetic hysteresis between cycles



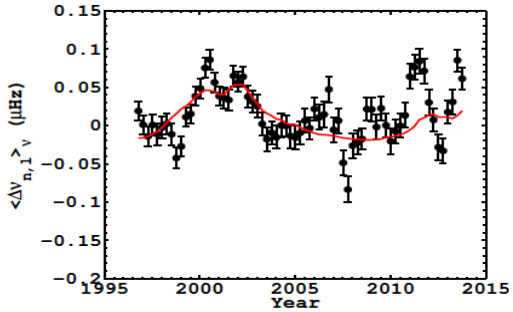
GOLF: Salabert, Garcia, Turck-Chièze 2014

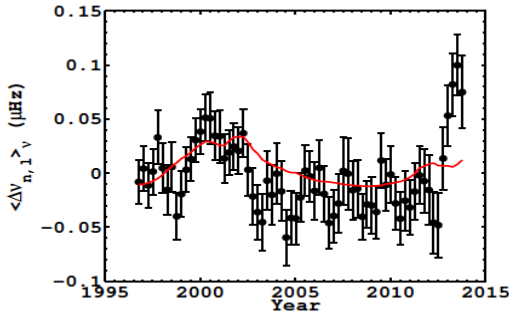
Change of Magnetic hysteresis with depth

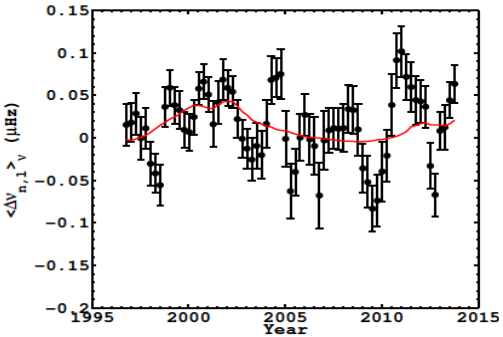


BiSon Basu et al. 2012

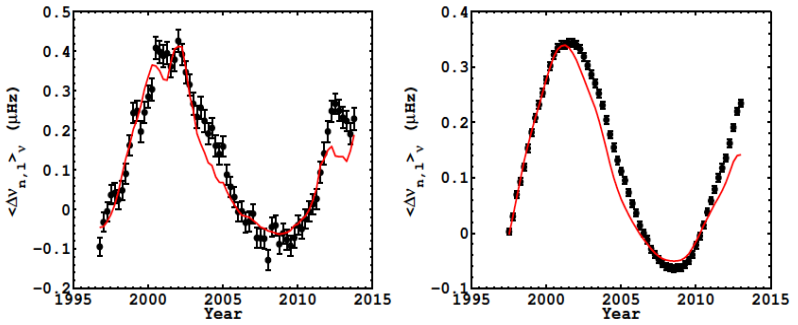
QUASI BIENNAL OSCILLATION INCREASES IN PARTICULAR FOR THE QUADRUPOLE COMPONENTS

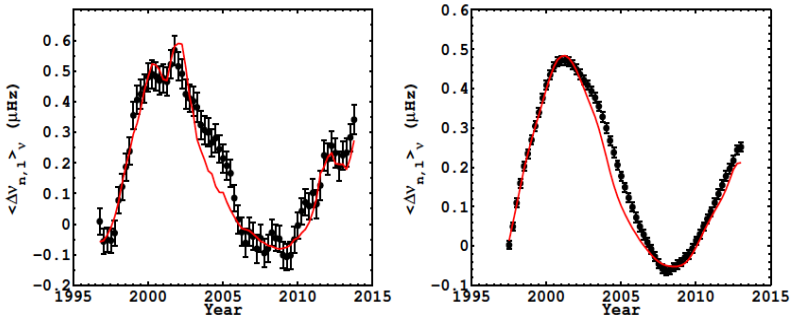


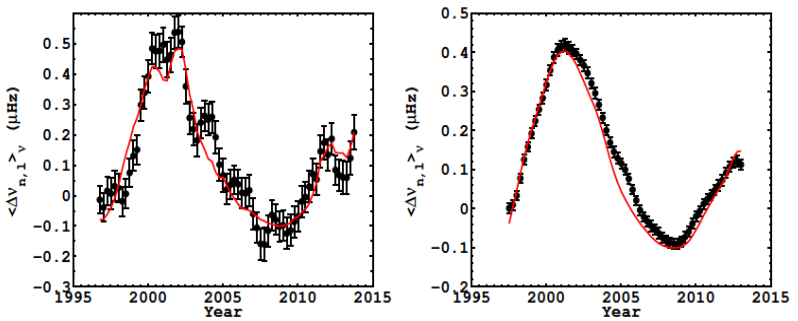




l =0, 1, 2 between 1800-2450 μHz





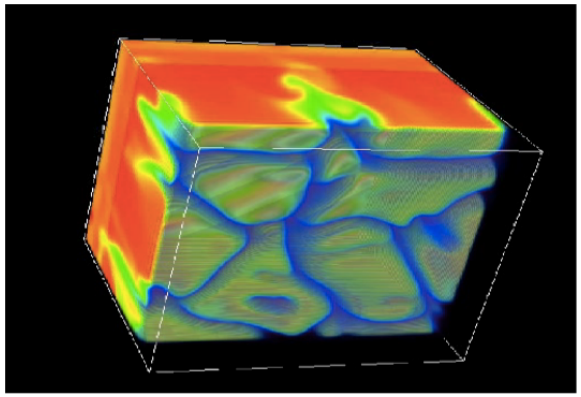


l =0, 1, 2 between 3110-3790 μHz

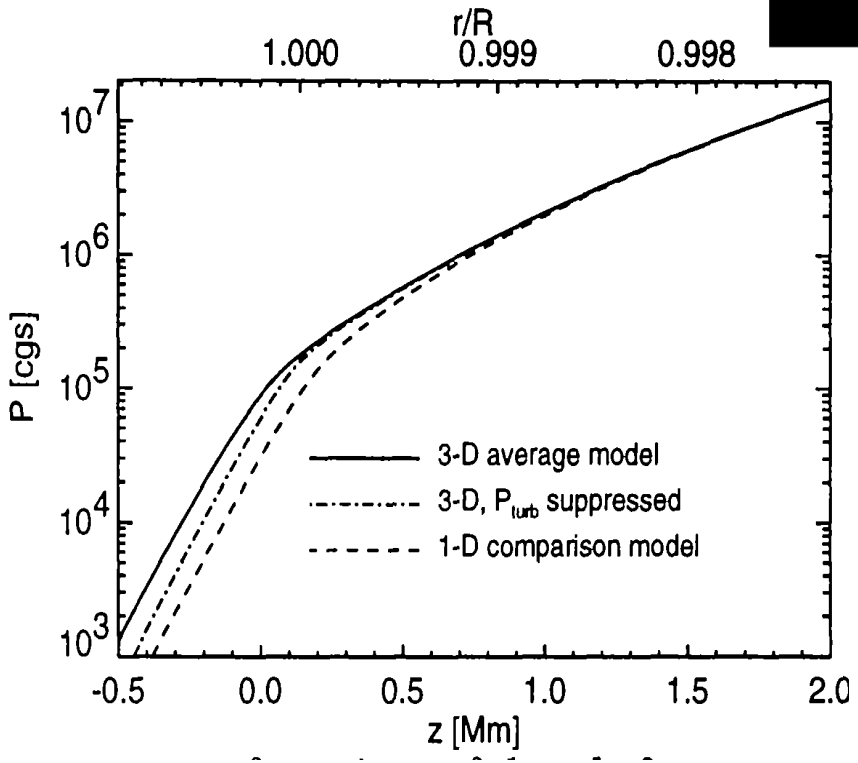
Salabert, Garcia & Turck-Chièze 2014

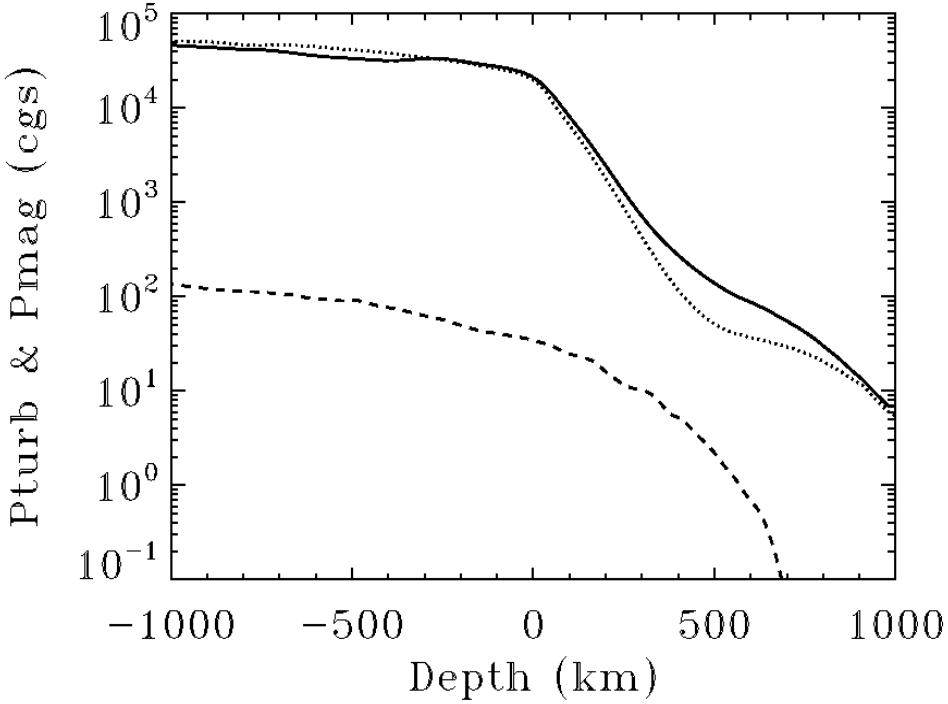
3D STAGGER SIMULATIONS Nordlund and Stein 2001

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



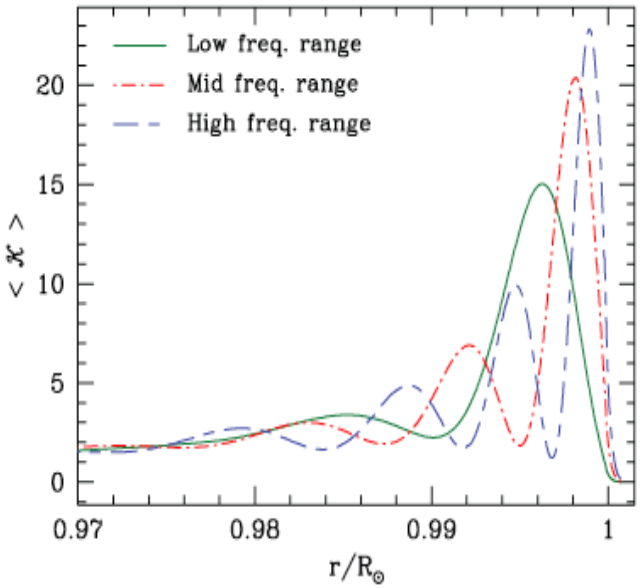
Piau et al. 2012

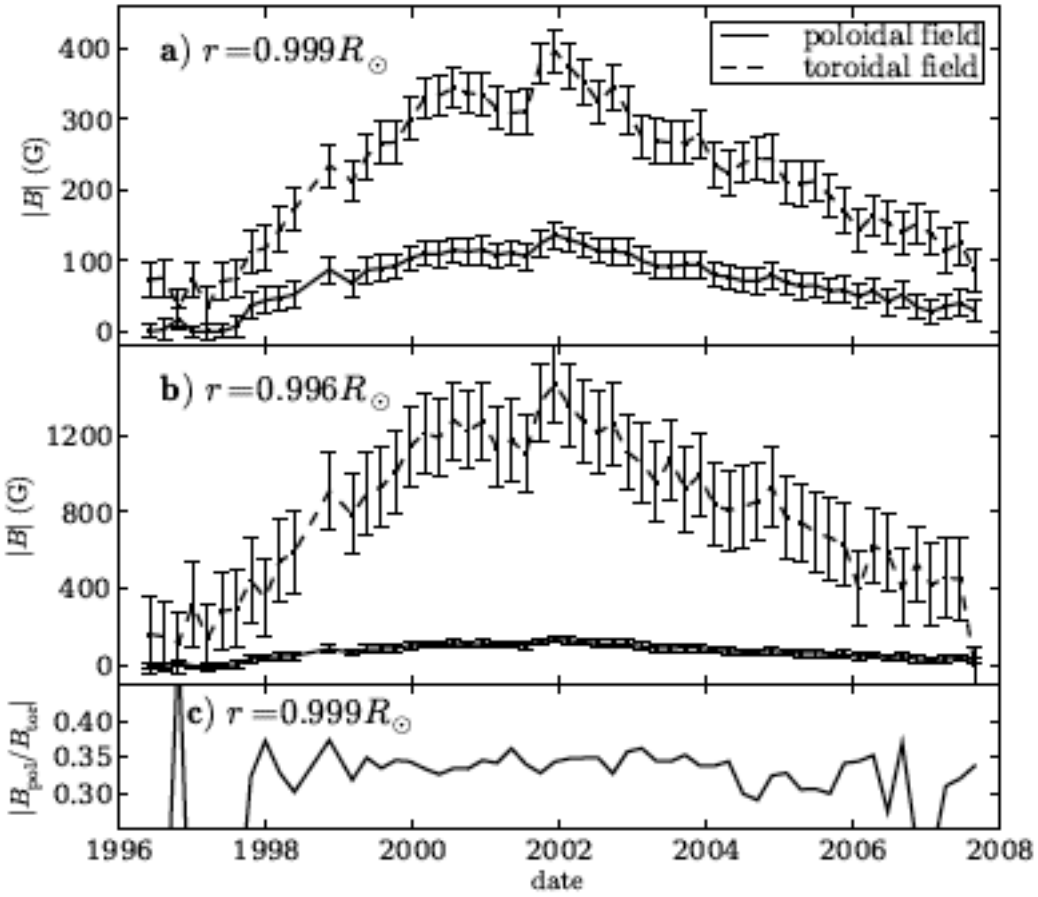




One hope to extract the evolution of the poloidal and toroidal field below the surface from 20-30 years measurements of low degree acoustic modes

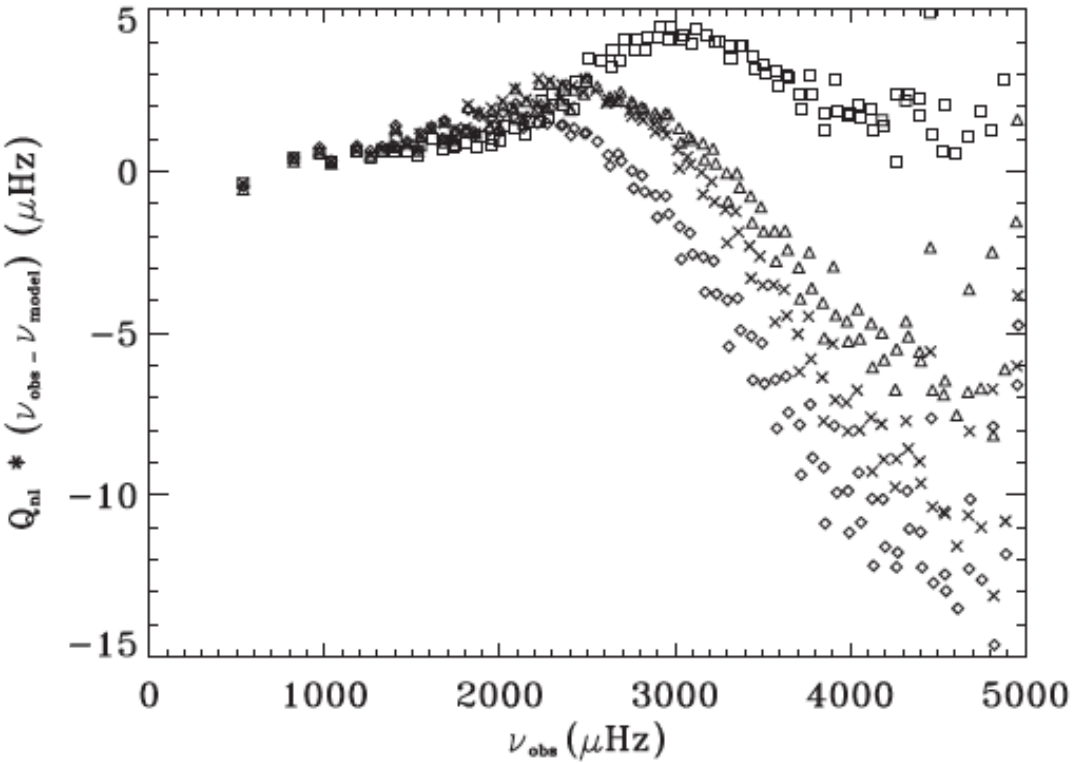
Baldner et al. 2009

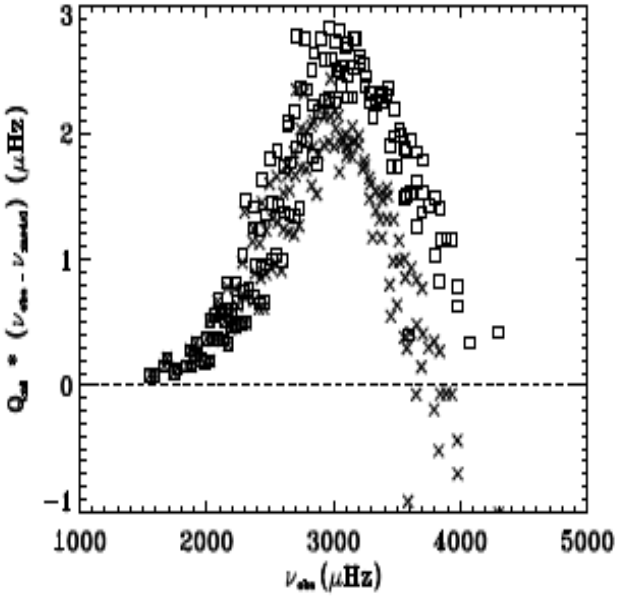




Impact on the acoustic modes frequencies: GOLF MDI

Coupling 3D simulations to 1D model are used for a better understanding of the absolute values of the frequencies and for the radius variation along the 11 yr solar cycle Piau et al. 2012, 2013, T-C & Lopes 2012





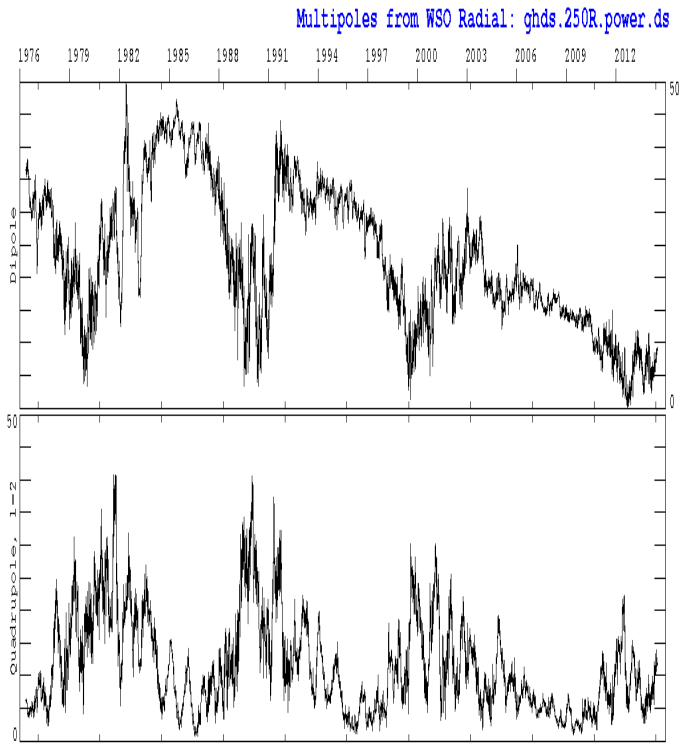
Difference between pure hydrodynamical model and magnetohydrodynamical model using the MDI toroidal value1.2 kG at the base of the computation leads to

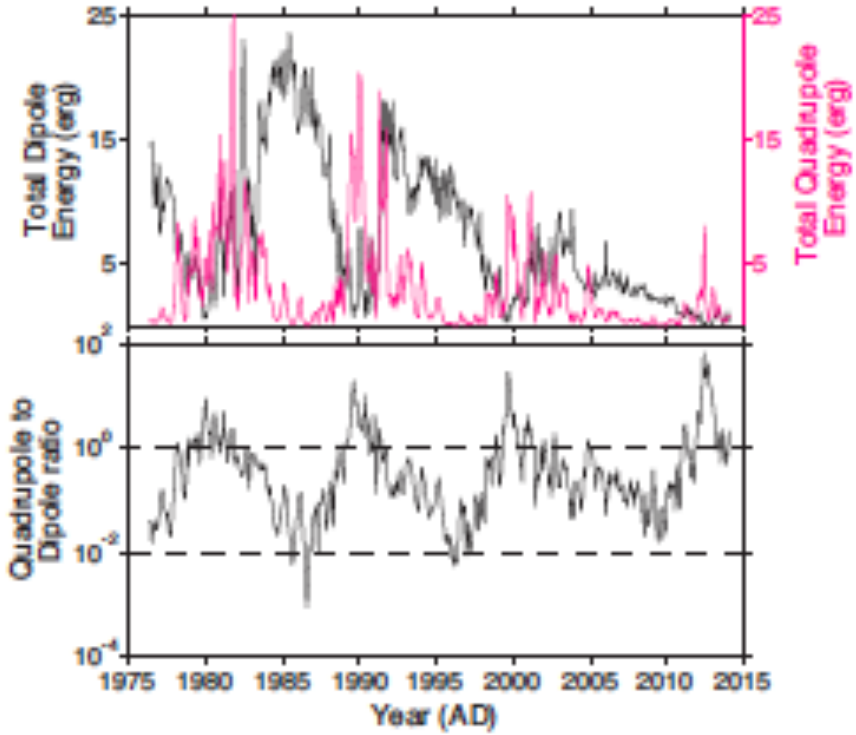
a shrink of the radius of 14 mas for the solar cycle 23

SOLAR RADIAL FIELD STRENGTH

Wilcox Solar Observatory since May 1975

Courtesy Hoaksema + analysis Inceoglu, Simoniello et al. 2014

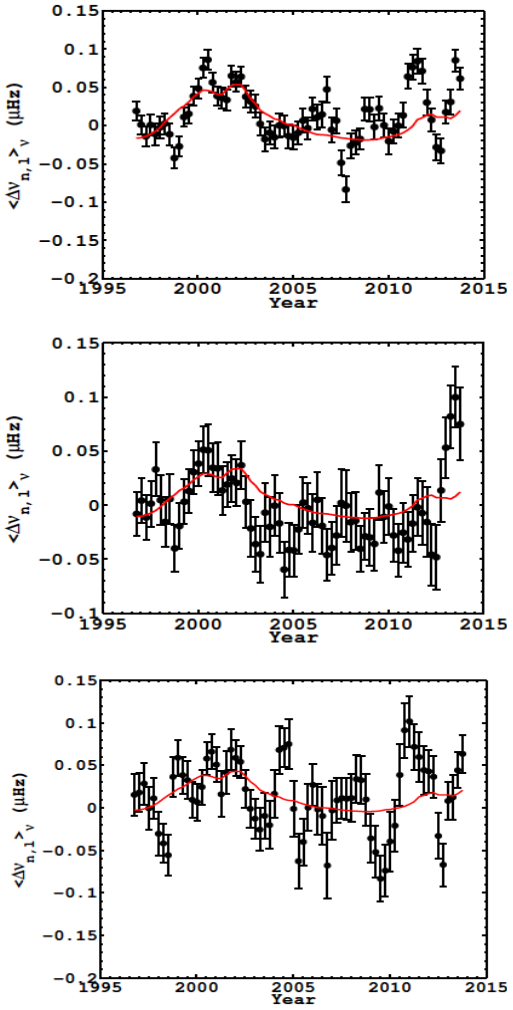




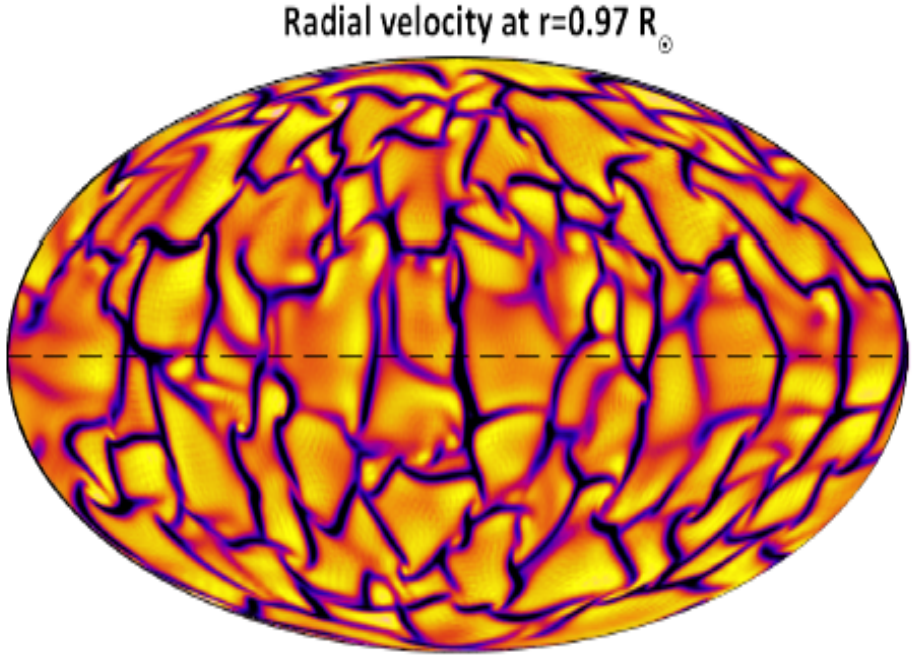
Decrease of the dipole component
Relative Increase of the quadrupole component

What would we like to learn more and how ?

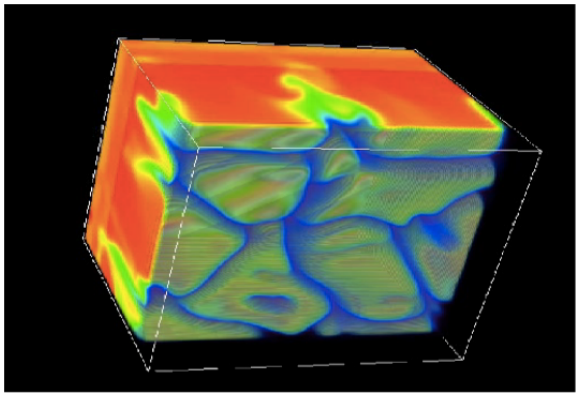
EXTRACTION OF THE VARIABILITY OF THE COMPONENTS OF THE MAGNETIC FIELD DOWN TO 0.995 R ALONG TWO OR THREE CYCLES



3D simulations spherical: ASH-EULAG cartesian STAGGER

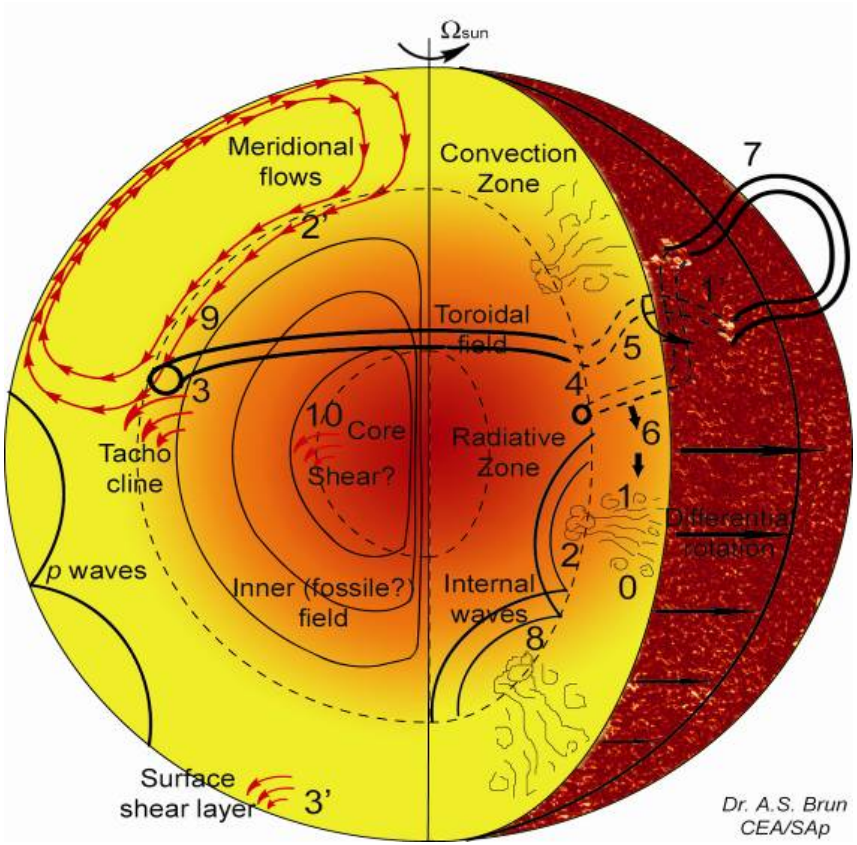


From 0.985 to 1.02 Rsol



It would be nice to extract from long time simulations of Passos & Charbonneau some magnetic topology as the seed of the evolution of the magnetic field configurations in the STAGGER code

SPACE WEATHER….. SPACE CLIMATE: NEXT OBSERVATIONS



Better knowledge of the tachocline

Improvement of the detection of g-modes: GOLF-NG

Pursuit of the detection of acoustic modes for near sub surface magnetic field configuration

Pursuit of the spectral and total irradiance

….

All the external manifestations altogether

SPACE WEATHER….. SPACE CLIMATE: PREDICTIONS

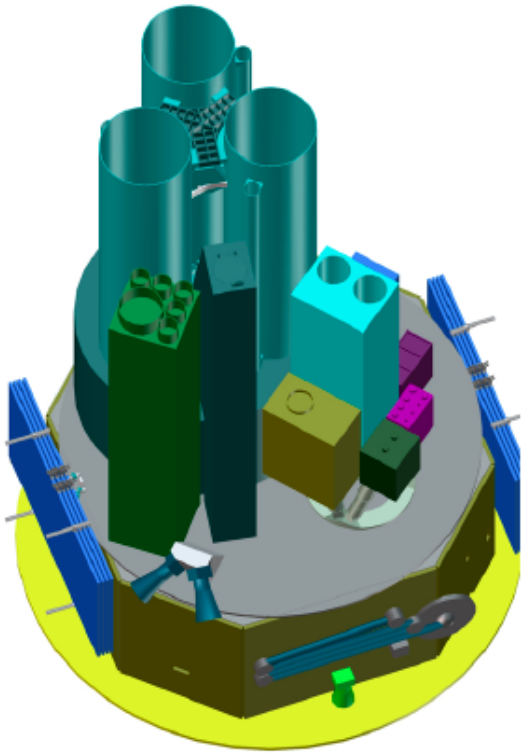
The formation flying project DynaMICCS: first satellite internal and metrology
second satellite external part,
coronography, study of the transition region, low chromosphere

Turck-Chièze et al. 2009

Proposed to ESA M4 call

HiRISE/NEOCE

High Resolution Imaging and Spectroscopy Explorer/ New External Occulting Coronagraph Experiment



A new generation, ultrahigh resolution, interferometric and coronagraphic, Solar Physics mission