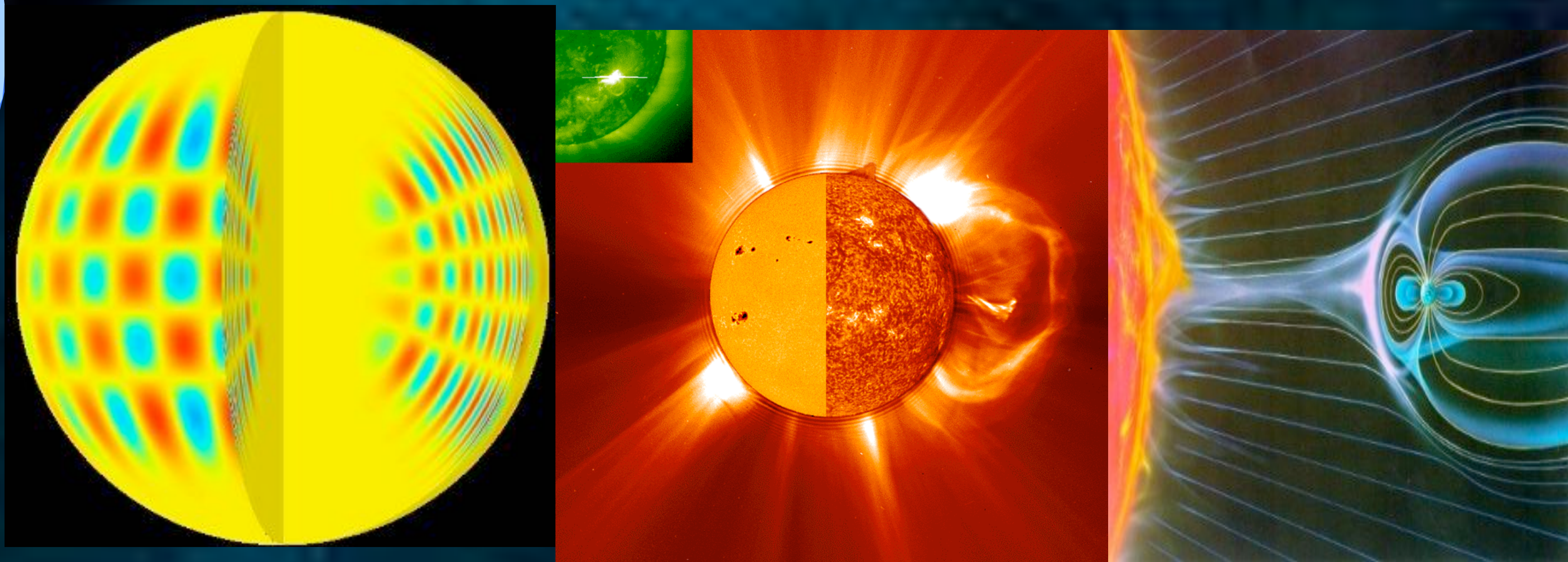
HELAS

cea
COMMISSARIAT À L'ÉNERGIE ATOMIQUE

DSM - DAPNIA
Service d'Astrophysique

The DynaMICCS perspective

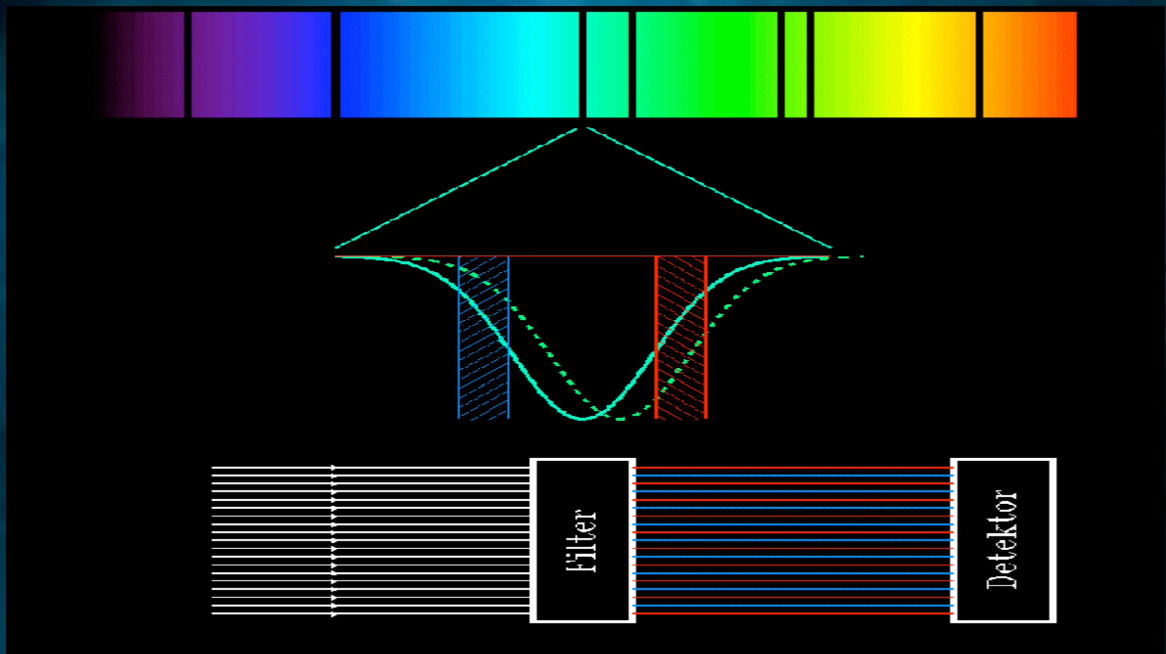
The internal magnetism, could we get it ?



Ecole de la Rochelle Sylvaine Turck-Chièze, 28 Septembre 2007

Quick history of the field

Periodic Motions P ~ 5 min
of the absorption lines of the photospheric spectrum
(Leighton et al. 1962)

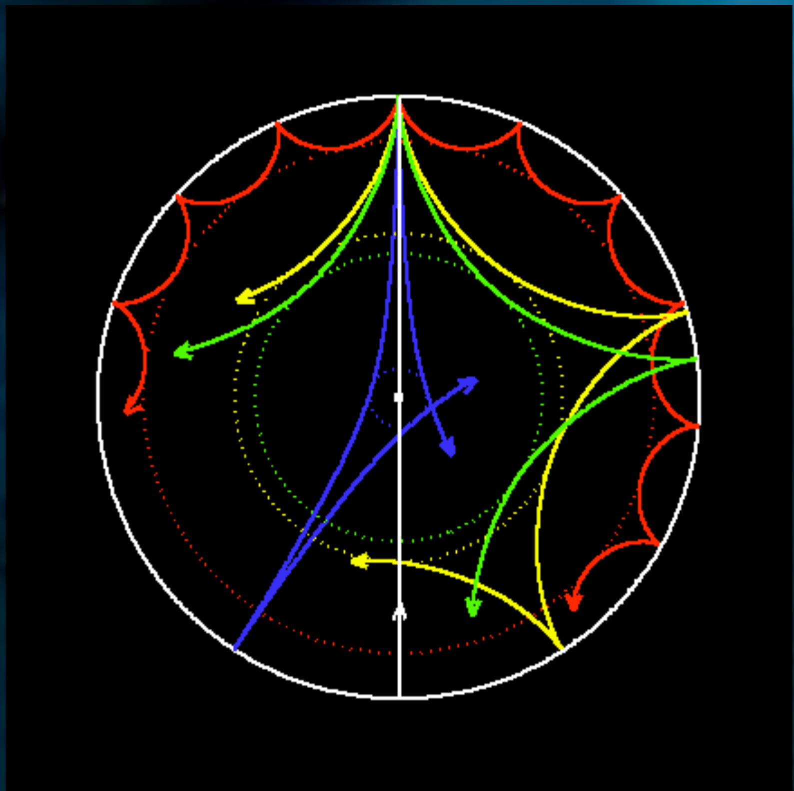


PULSATIONS OF THE PHOTOSPHERE!!!

Normal Modes

Acoustic waves trapped in resonant cavities ➔ p modes

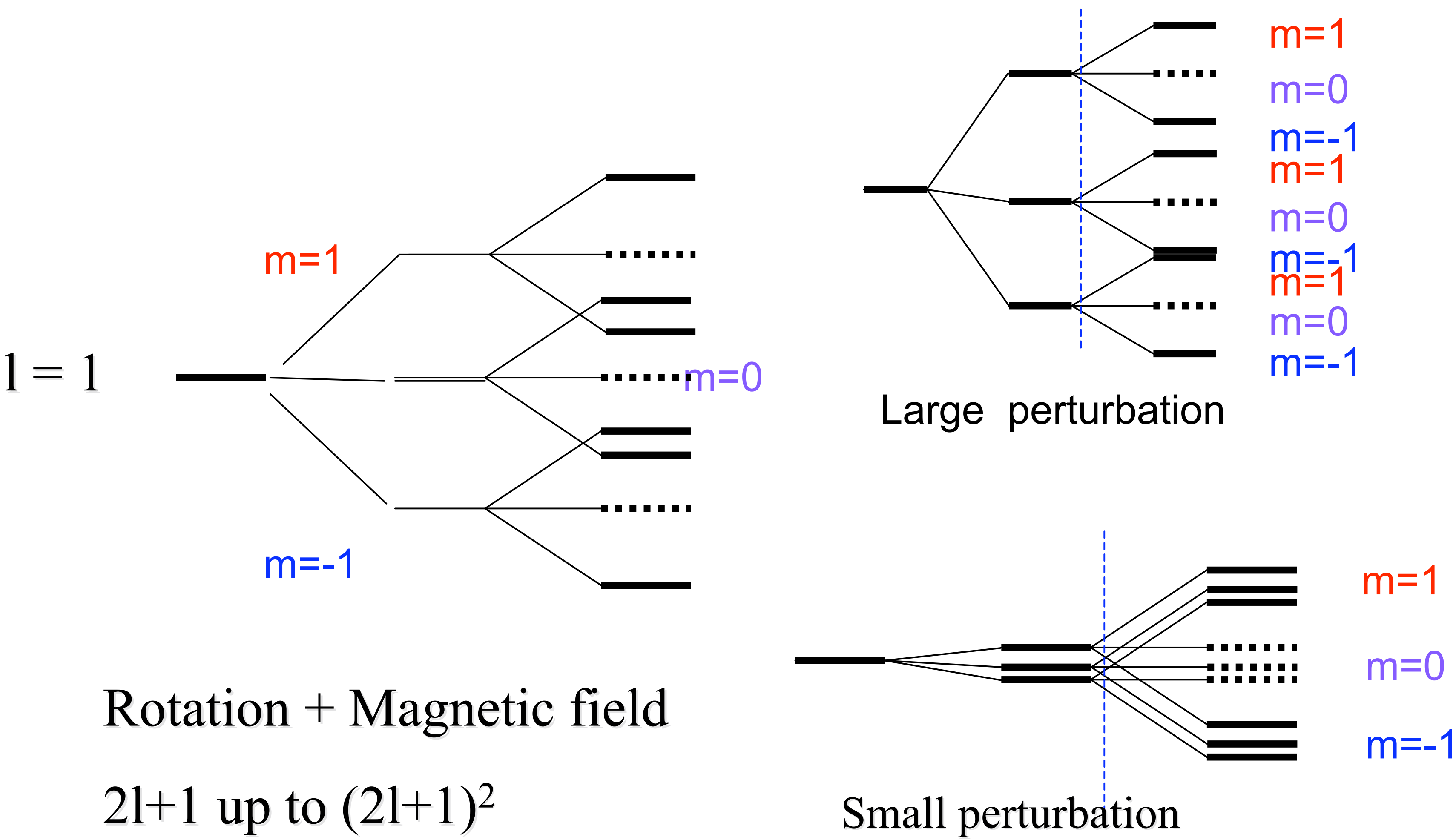
(Ulrich 1971, Leibacher & Stein 1972)



Normal modes

n ➔radial order
l ➔harmonic degree
m➔azimuthal order: 2l+1
Connected to the rotation and the magnetic field

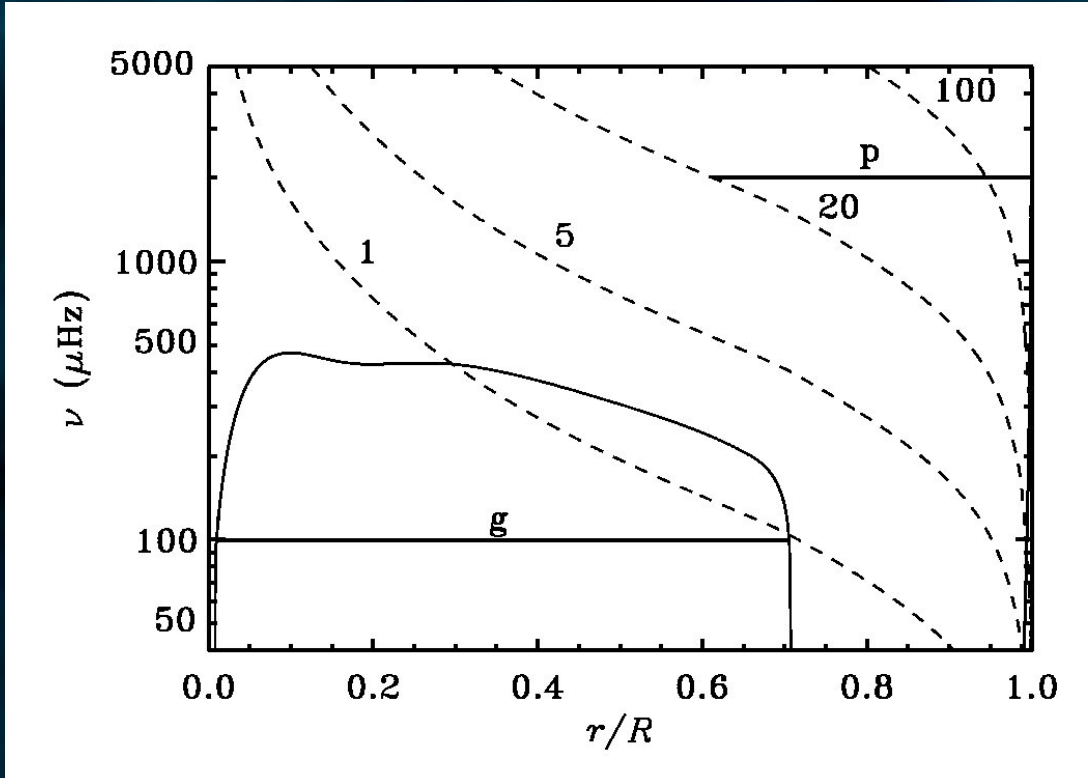
Hyperfine structure: dipole mode l=1

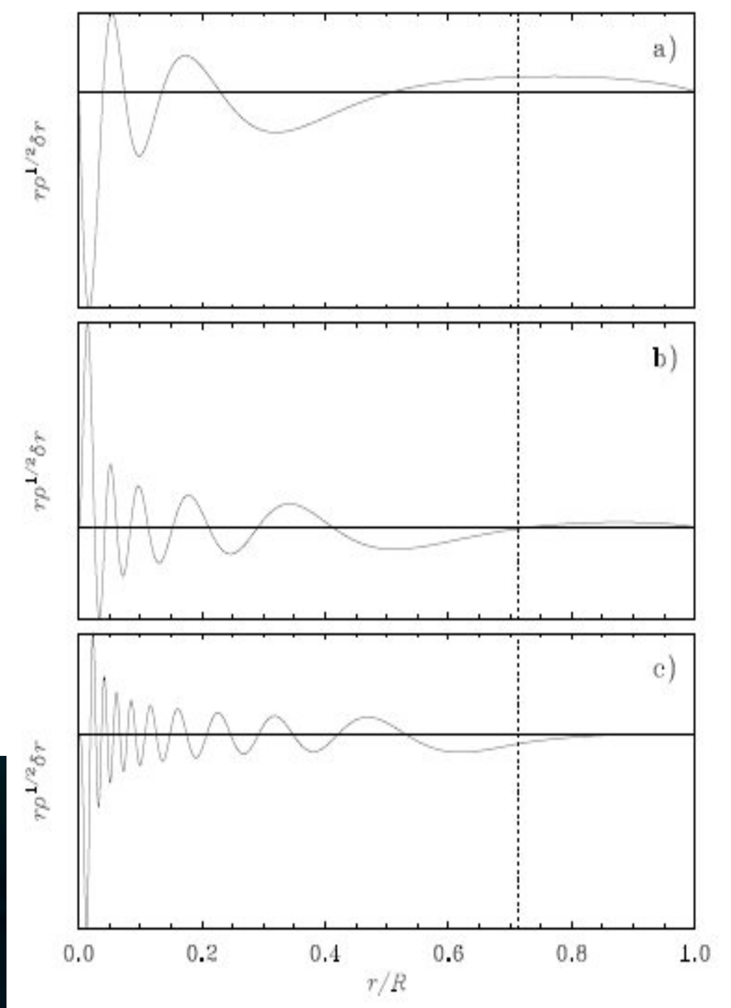


Rotation + Magnetic field

2l+1 up to $(2l+1)^2$

Mode trapping





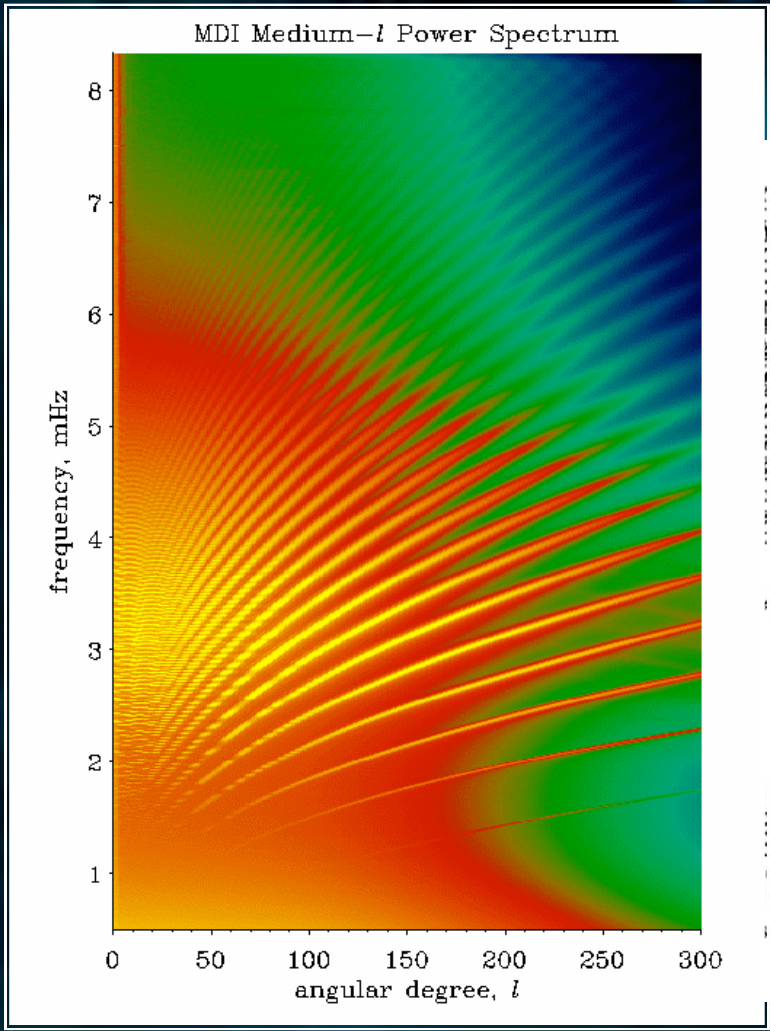
Eigenfunction oscillates in function of *r* when

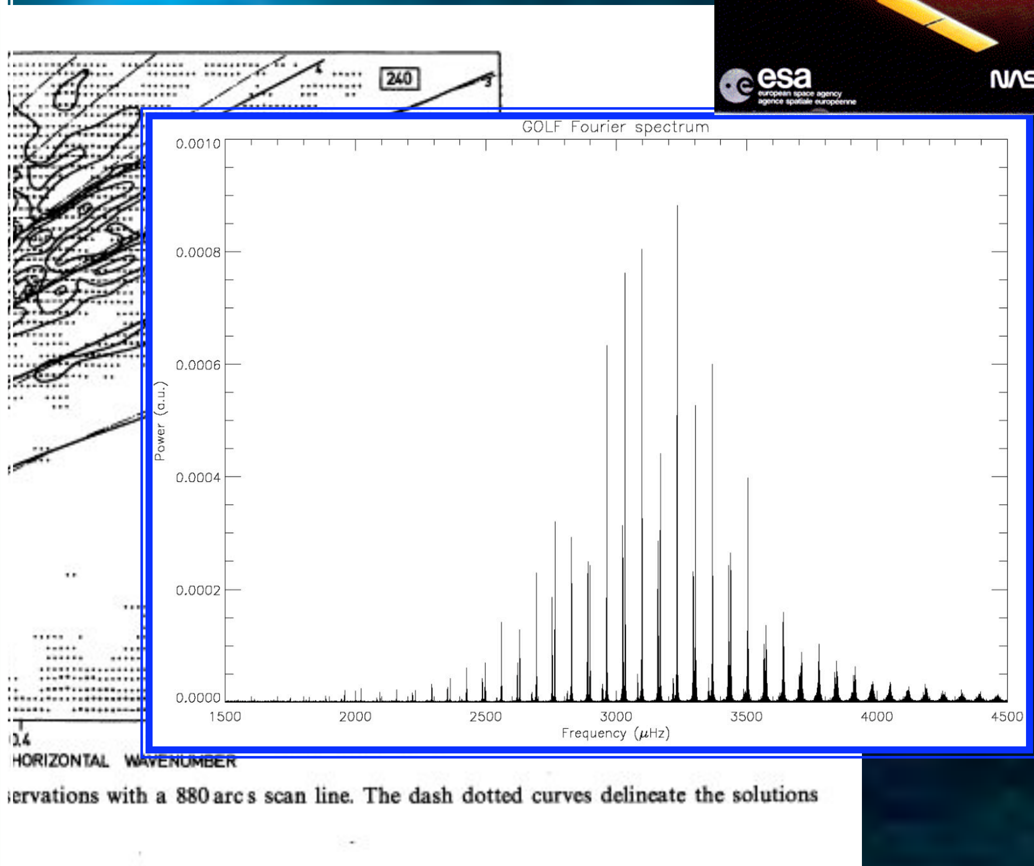
$\omega^2 > S_l^2, N^2$ **p modes**

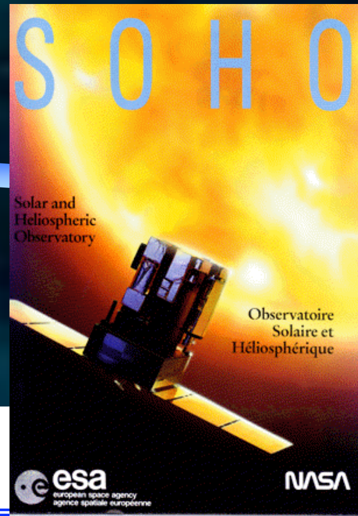
$\omega^2 < S_l^2, N^2$ **g modes**

The proof

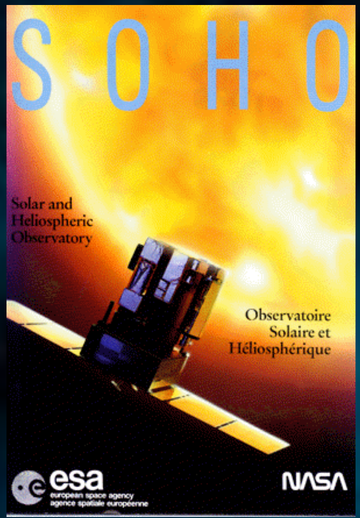
Deubner 1975

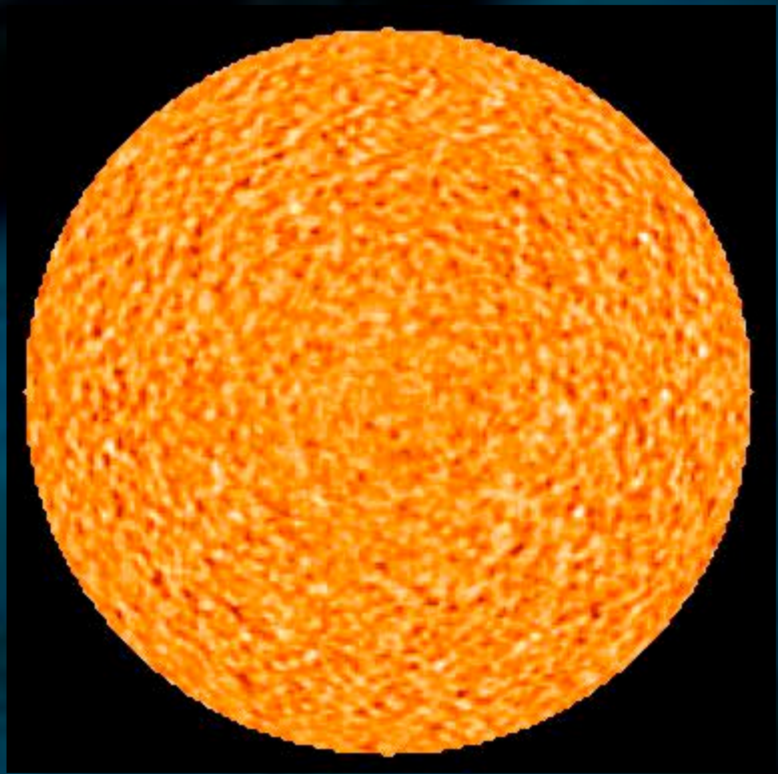






Patches of the solar surface oscillate up and down





These data from the SOI/MDI instrument on board the SOHO satellite

1024x1024 points over visible disk

1-minute cadence or better

One Million of independent modes excited.
Each mode with a different tone!!

Properties of solar oscillations

- Modes are excited stochastically by convection

- Periods $\ll \tau_{th}$ ➔ adiabatic approximation

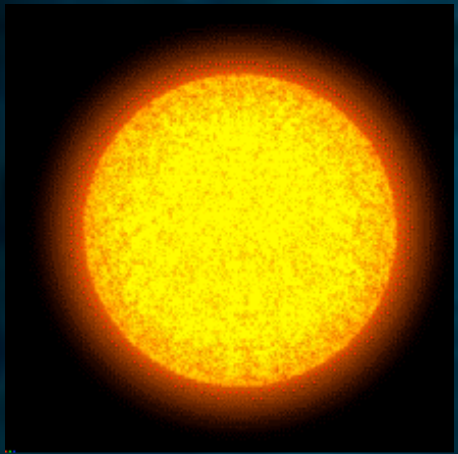
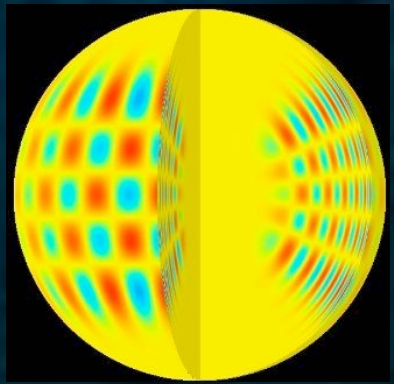
- Modes are damped by convective flux and turbulent pressure perturbations

- Amplitude ➔ low

  $v_r \cong 15$ cm/s $\delta\lambda/\lambda < 10^{-9}$ $\delta I/I \cong 10^{-6}$

Helio- Astero seismology

- Study of the solar (stellar) oscillations observed at the surface to probe the structure and the dynamics
- Study of oscillations in the Sun in a similar way as geoseismology is the study of earthquakes
- The technique is very similar to trying to determine the shape of musical instruments from the sound they make.


The interest of helioseismology

- **Frequencies depend on the structure of the star**

$$\rho(r)\ ,\ p(r)\ ,\ \Gamma_1(r)\ ,\ c(r)$$

- **Frequencies can be measured with accuracy (10^{-5})**
- **Microscopic physics addressed**

  -Equation of state, opacities, neutrinos, general relativity, fluid dynamics, Stellar evolution

- Macroscopic **physics through splittings and asymetry between them**

  Differential rotation, origin of solar magnetism, nature of spatial and temporal inhomogeneities

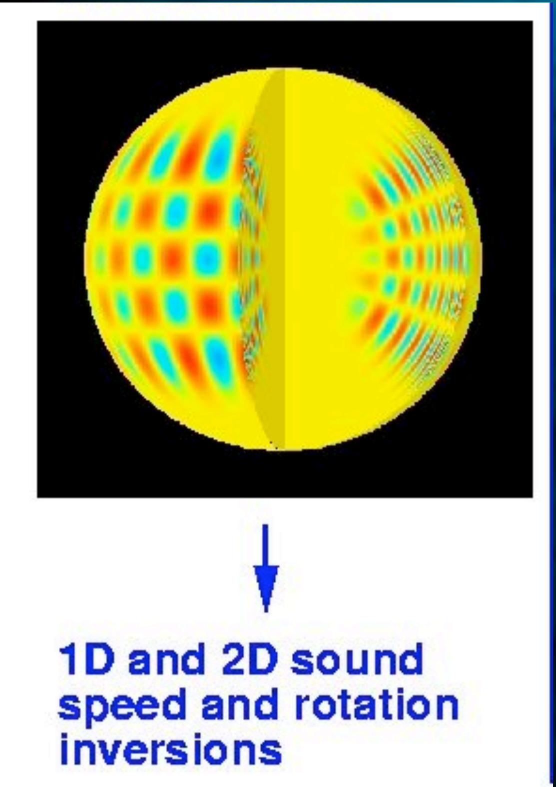
- **Solar-terrestrial physics addressed**

  -Origin of magnetic storms

Helioseismic Methods

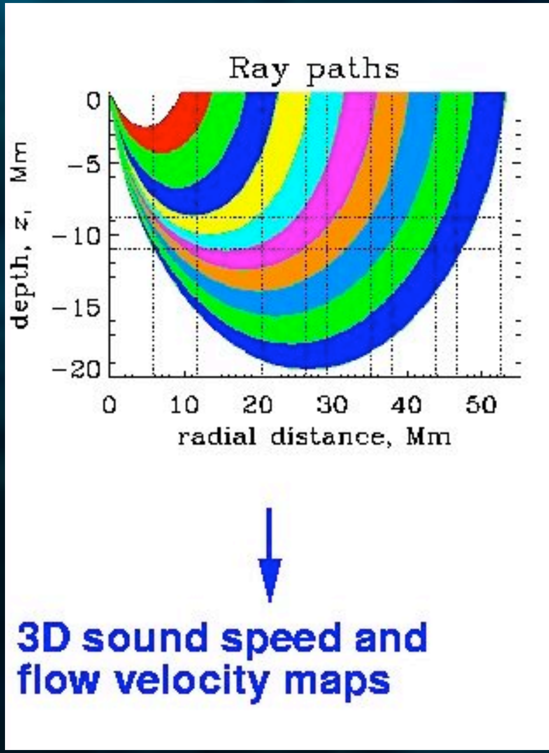
Global Helioseismology

- Structure & dynamics of the longitudinally averaged solar interior & changes with time
- Frequencies of p modes



Local Helioseismology

- Structure and dynamics of pieces of the solar interior & changes with time
- Travel time of running sound waves



Notable Successes of Helioseismology

- Depth of the solar convection zone (Christensen-Dalsgaard 1985)
- Helium abundance (Vorontsov 1992)
- Diffusion of helium and heavy elements (Michaud and Proffit 1993, Basu et al. 1996)
- Improvements in Opacity (Iglesias & Rogers, 1996, 2000)
- Neutrino Problem (Turck-Chièze et al. 2001, 2004)
- Relativistic effect in the core (Elliot & Kosovichev 1998)
- Rotation in the core thanks to gravity mode detection (Turck-Chièze et al. 2004, Garcia et al. 2007)
- Internal Dynamics

HELIOSEISMIC APPROACHES

Forward approach

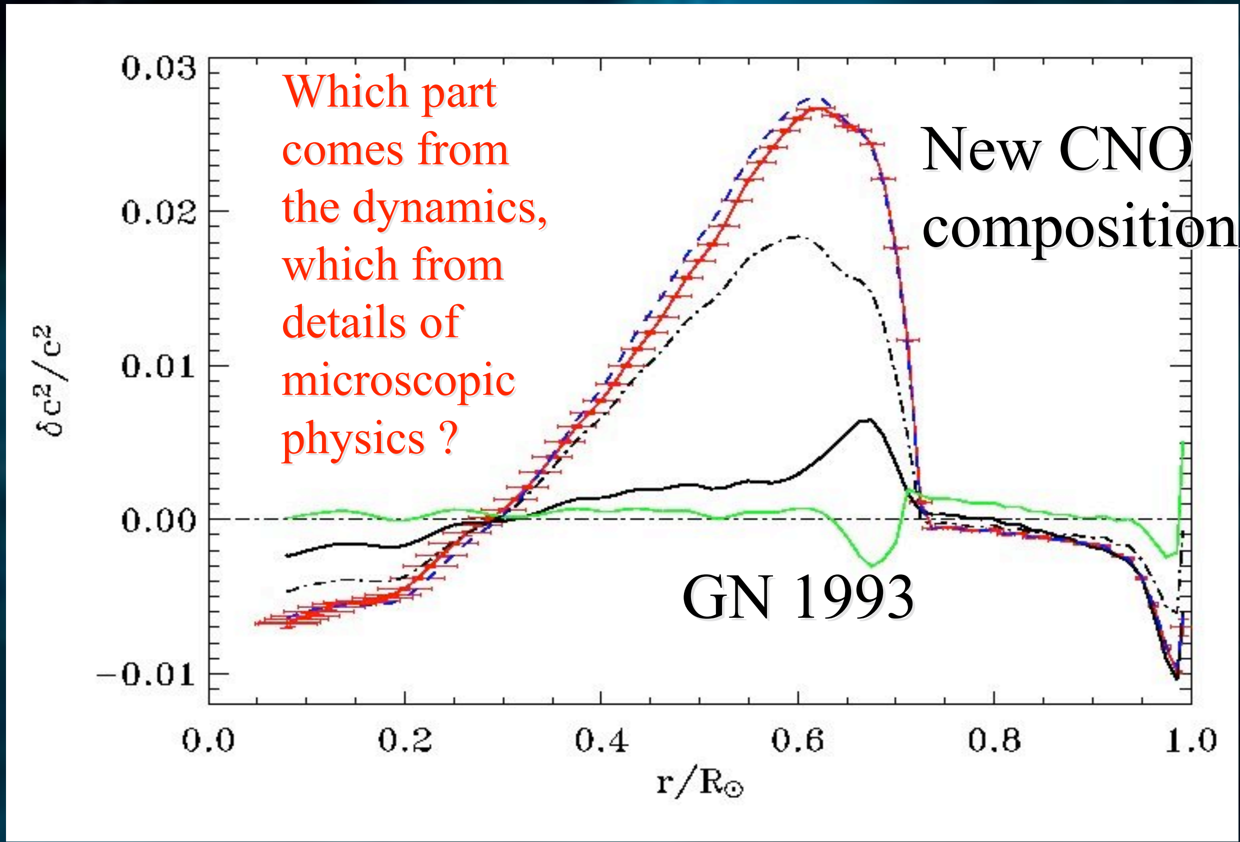
Model → Observables

Model ← Observables

Inverse approach

Aim of inversion: to make inferences about localized properties of the solar interior

ACTUAL SOUND-SPEED DIFFERENCE



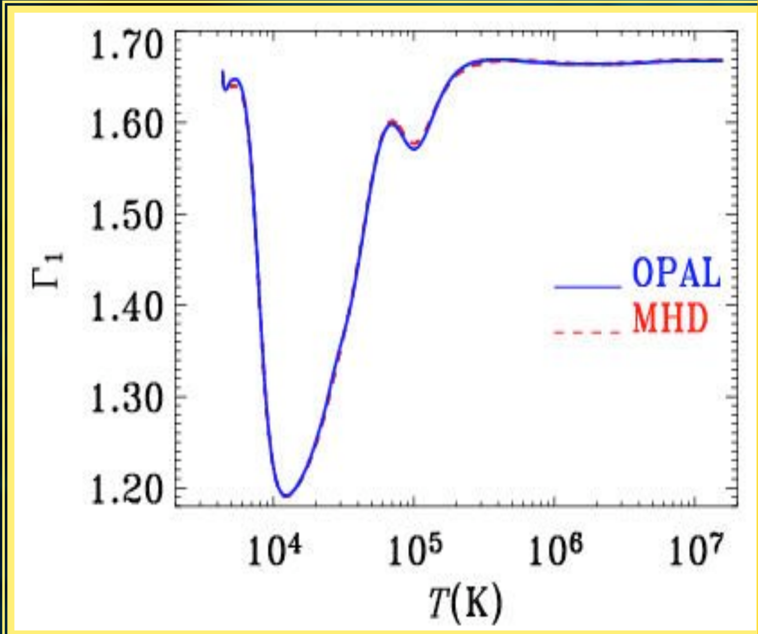
Turck-Chièze et al. 2004

EQUATION OF STATE

First adiabatic exponent

Γ_1~ 5/3 in the interior except in the H and He ionization zones

$$\Gamma_1 = \left(\frac{\partial \ln p}{\partial \ln \rho}\right)_{ad}$$

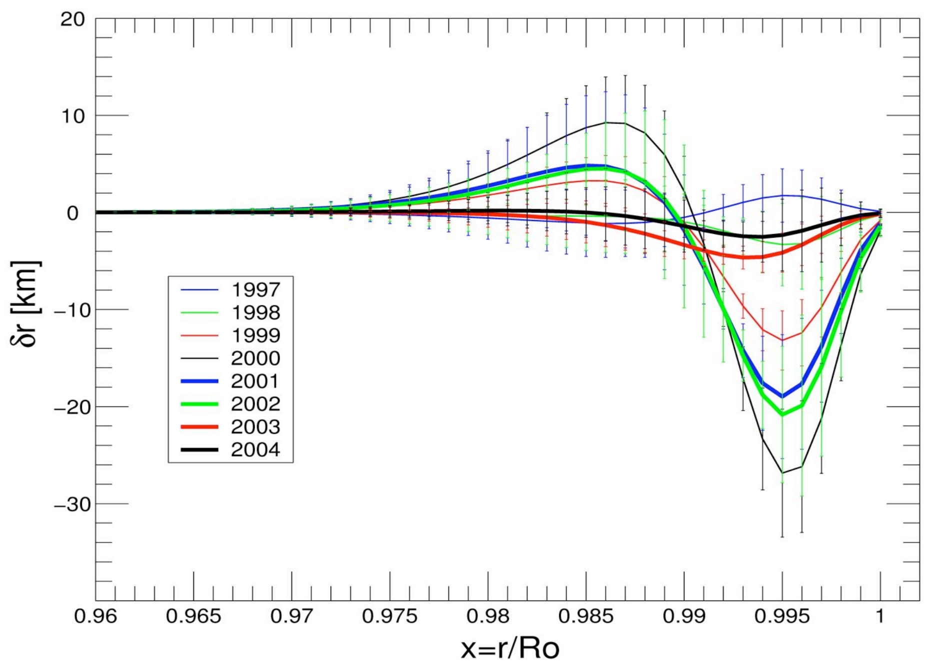


Reference	DATA	Y MHD	Y OPAL
Basu & Antia (1995)	HLH 100 ≤l ≤1200	0.2456± 0.007	0.2489± 0.0028
Kosovichev (1996)	BBSO 4≤ l≤140	0.232± 0.006	0.248± 0.006
Richard et al. (1998)	MDI 0≤ l≤140	0.242± 0.002	0.248± 0.002
Basu (1998)	MDI l≤194	0.2524± 0.0001	0.2488± 0.0001

f-modes probe the subsurface layers

Complexity due to turbulence, magnetic field

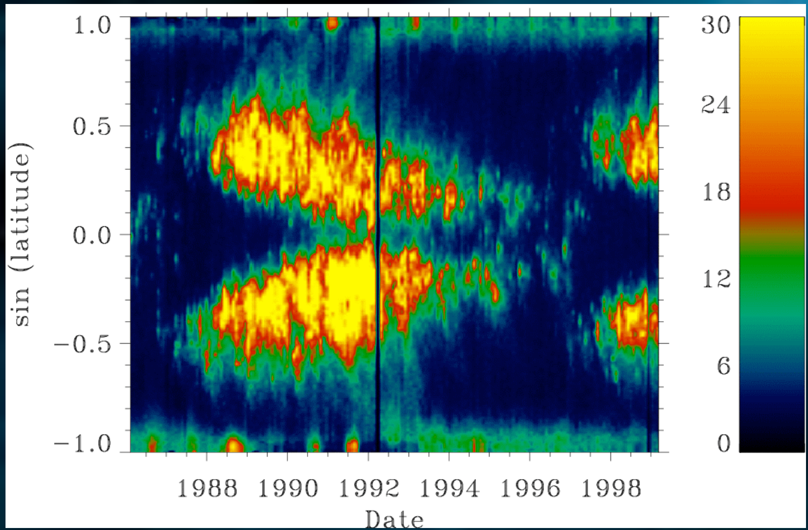
Lefebvre, Kosovishev 2005



Extraction of mean magnetic field : <10 kG from low degree acoustic modes Nghiem 2006

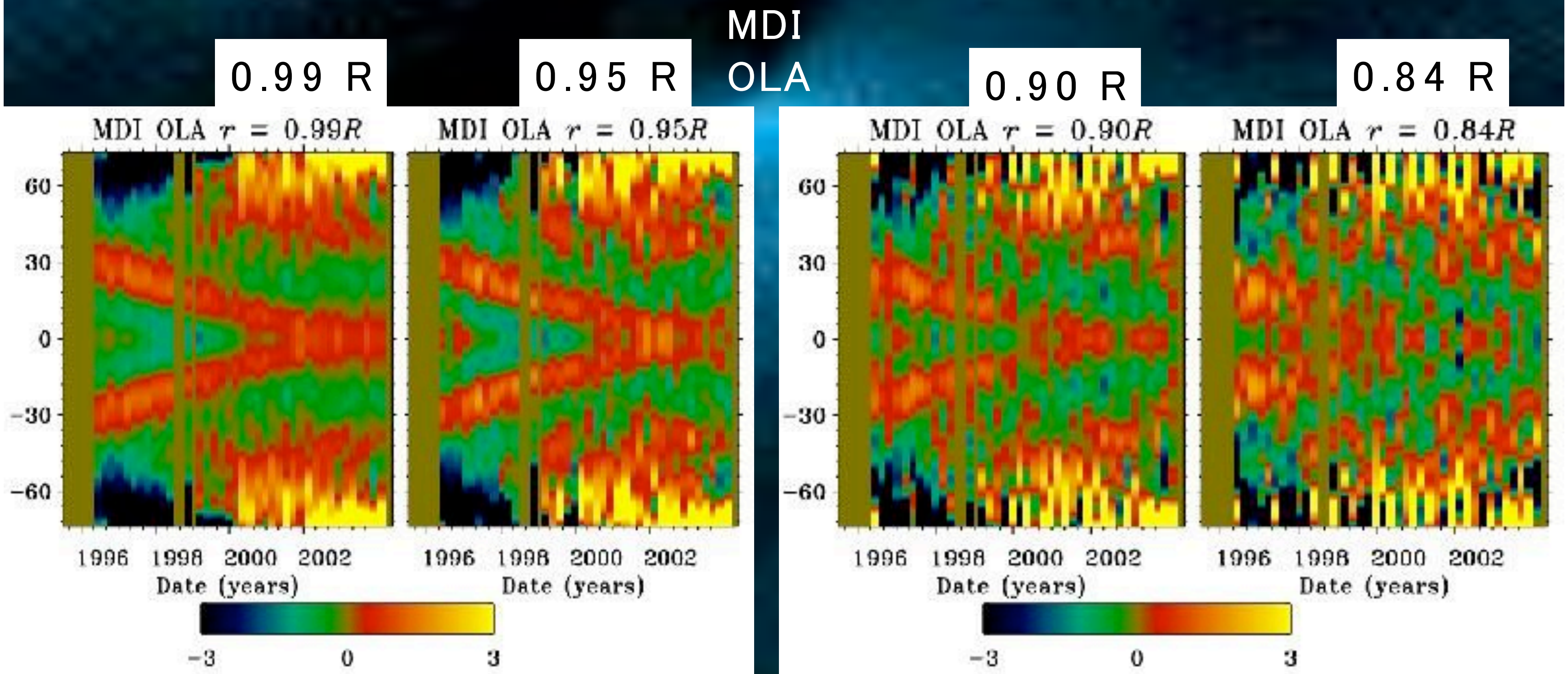
Radius and solar surface deformation along the solar cycle

The Solar Cycle



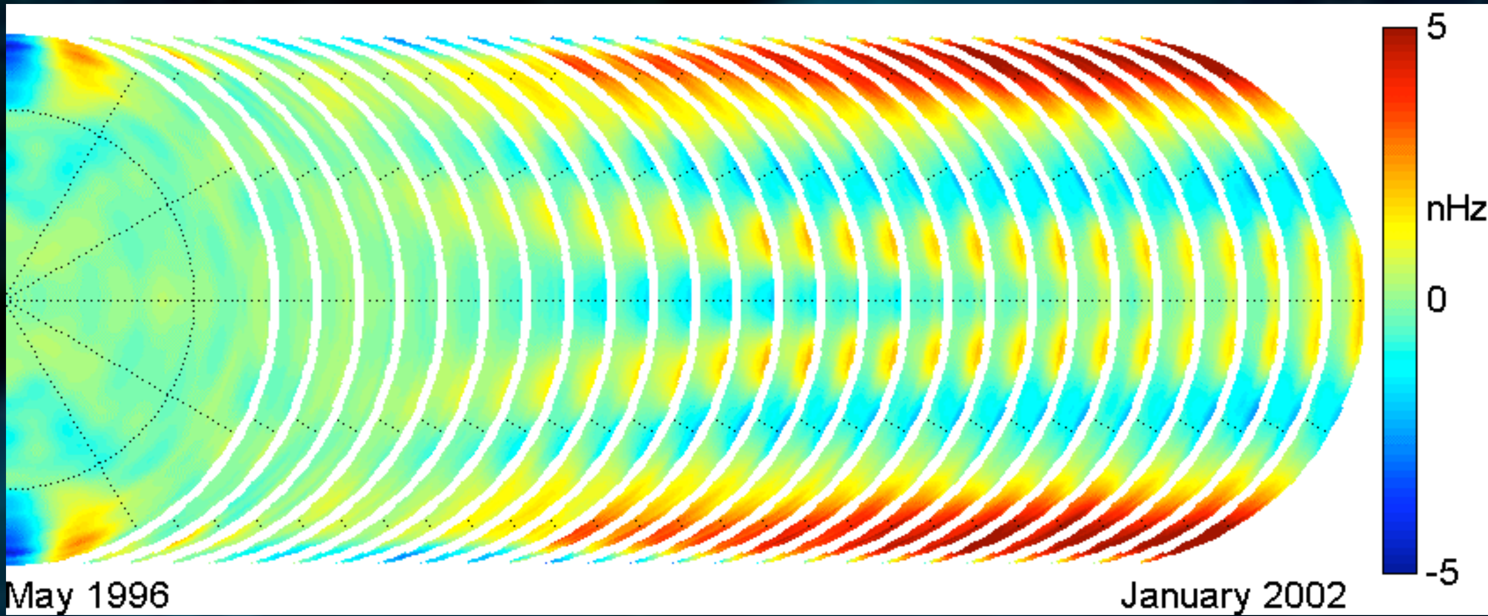
- Activity grows and decays over 11 years
- Zones of magnetic activity move towards the equator
- Bands of slower and faster rotation also migrate, ahead of the magnetic bands

TORSIONAL OSCILLATIONS



Differences between inversions of data taken at successive times reveal the "torsional oscillation"

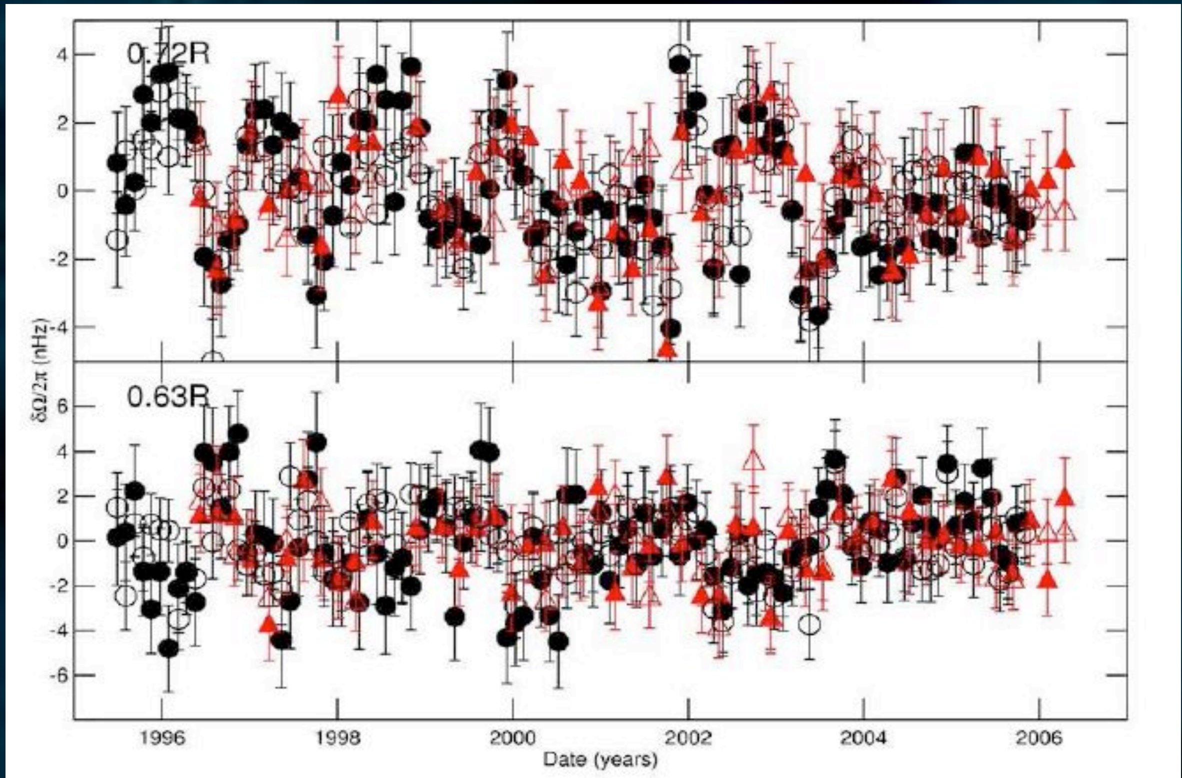
Torsional oscillations of whole CZ



Differencing rotation inversions at successive 72-day epochs relative to solar minimum (1996) shows equatorward and poleward migration of torsional oscillations

Vorontsov et al. 2002 Science

Tachocline Oscillations ??



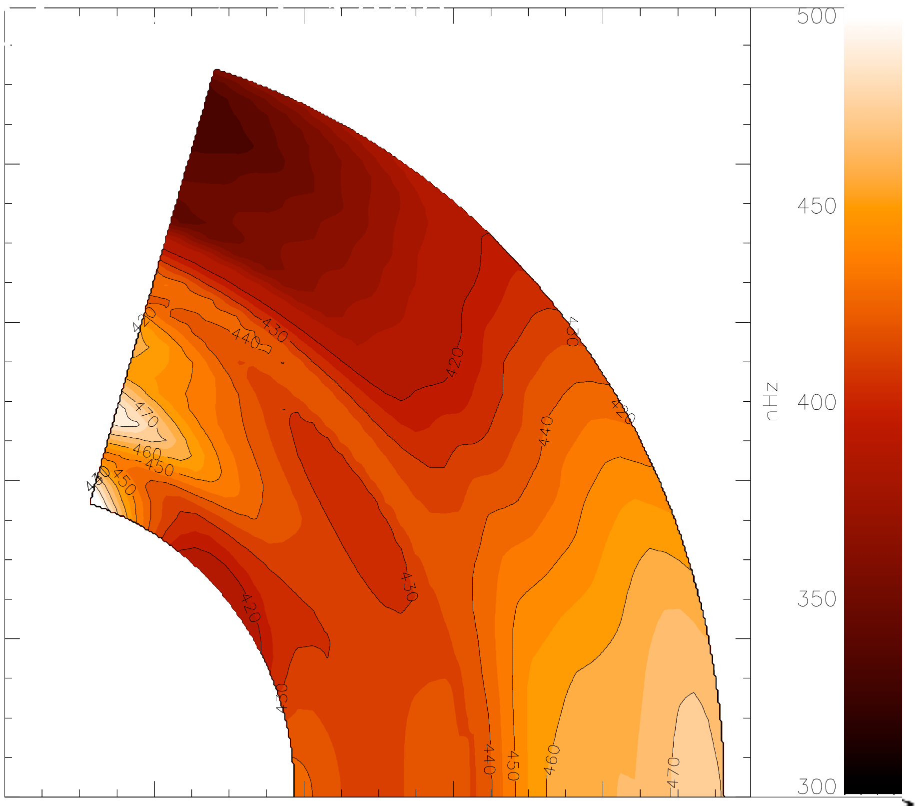
Howe 2006

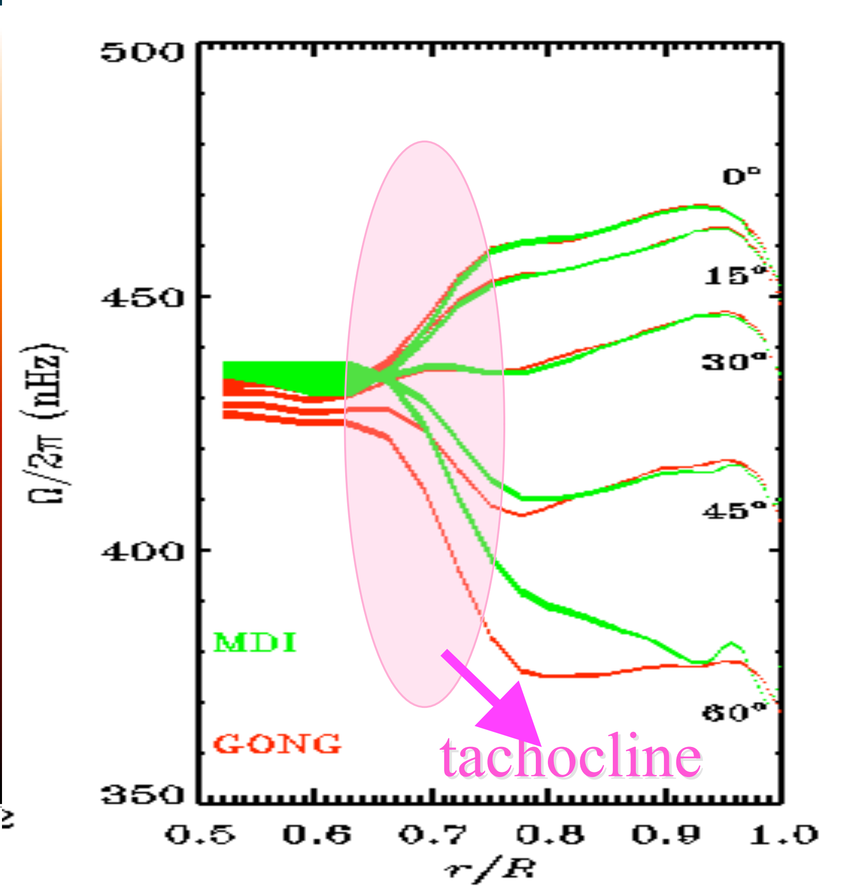
The rotation rate appears to show quasi-periodic oscillations of 1.3 year period near the base of the convection zone at mid-latitudes

Convective Internal Rotation

Corbard 1998, DiMauro

Howe et al. 2000



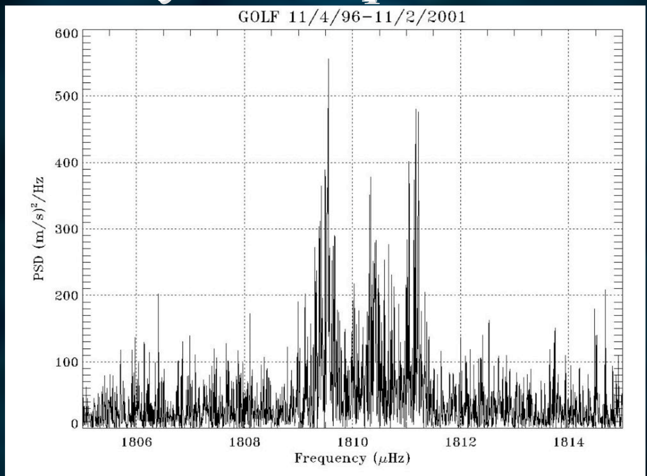


$r_c/R = 0.67 +/- 0.05$ (Di Mauro et al 1997)

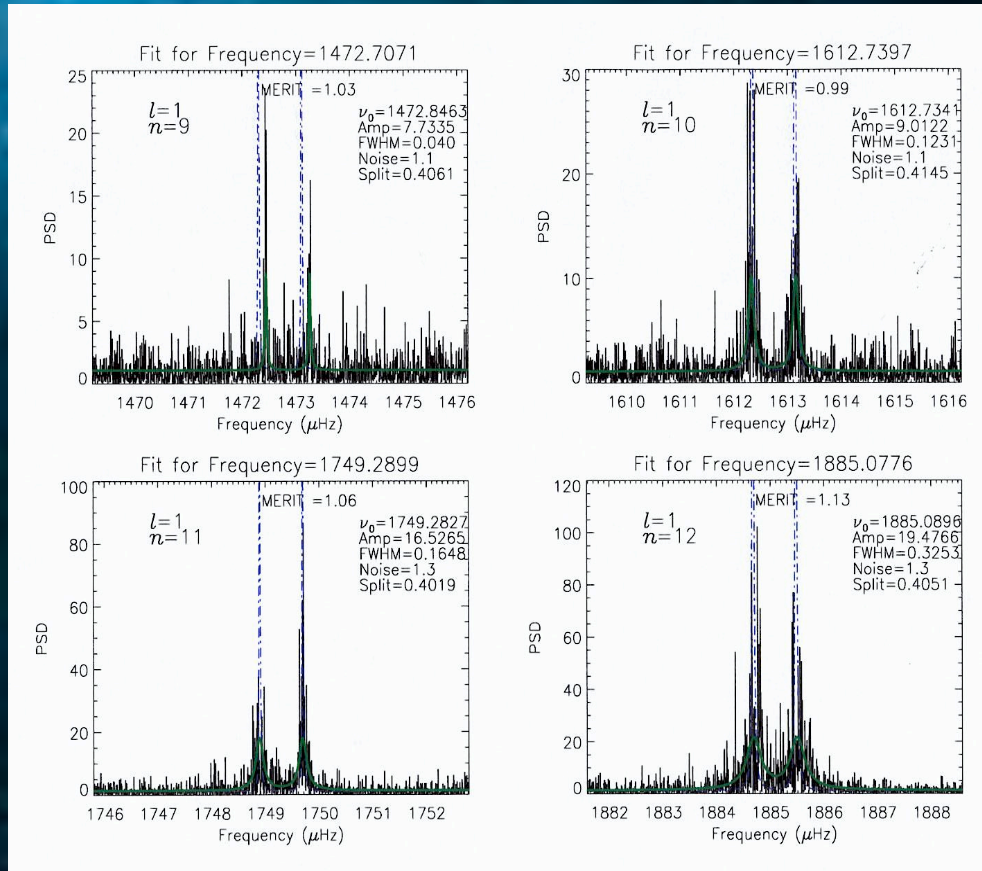
Radiative Internal Rotation : 98% mass, core 65%

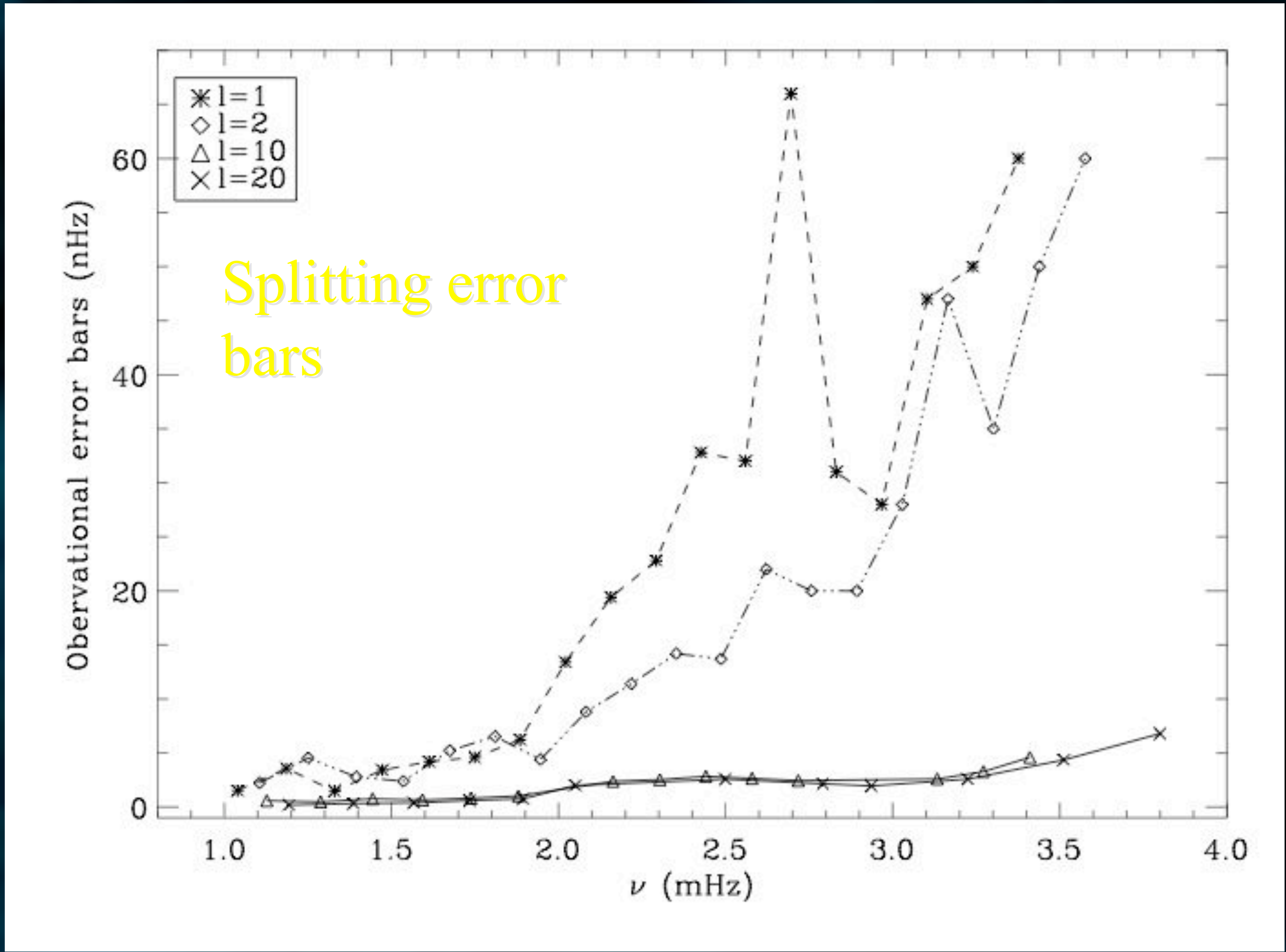
Rotation breaks spherical symmetry of the Sun and splits the frequency of oscillations

l = 2: from a global view of the Sun, only 3 components

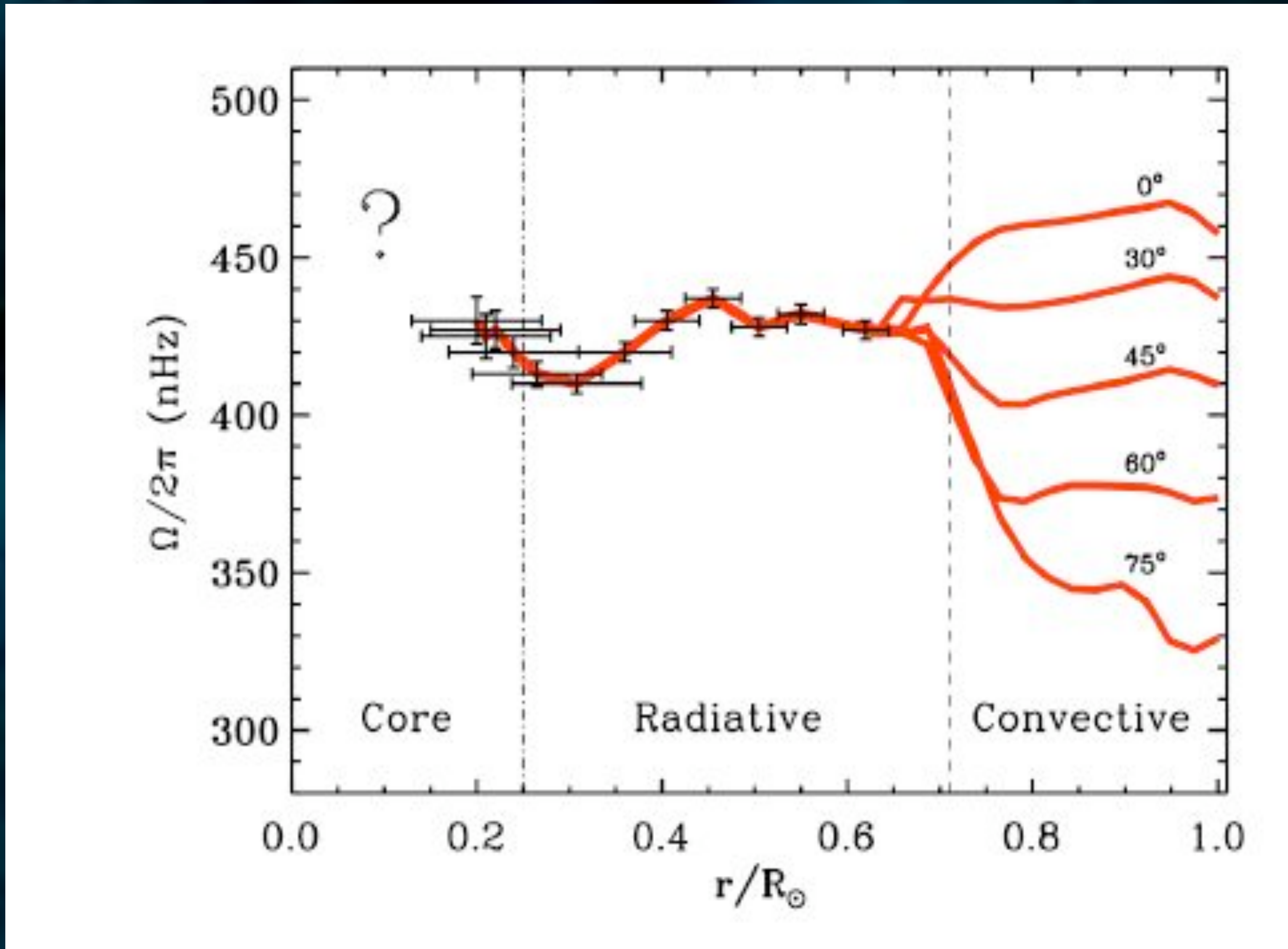


l = 1



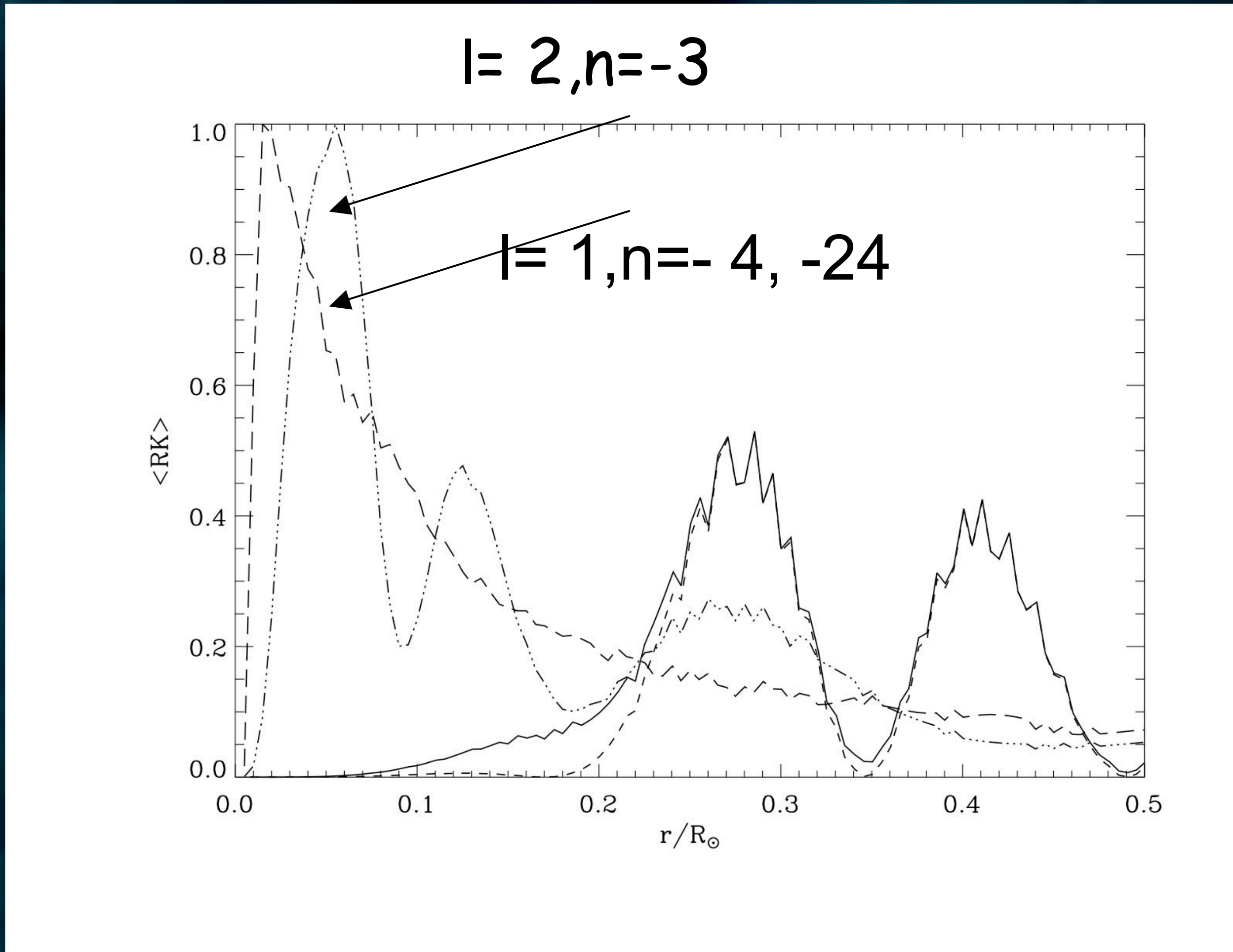


l=1
l=2
l=10
l=20
Splitting error bars
Obervational error bars (nHz)
0
20
40
60
1.0
1.5
2.0
2.5
3.0
3.5
4.0
ν (mHz)



500
450
400
350
300
Ω/2π (nHz)
0.0
0.2
0.4
0.6
0.8
1.0
r/R⊙
?
0°
30°
45°
60°
75°
Core
Radiative
Convective

Need for gravity modes

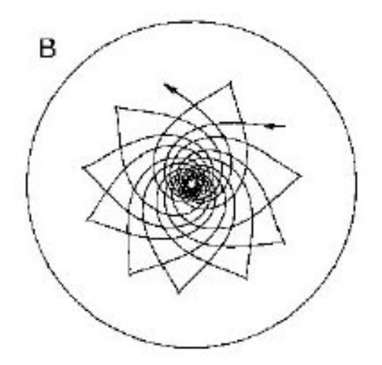


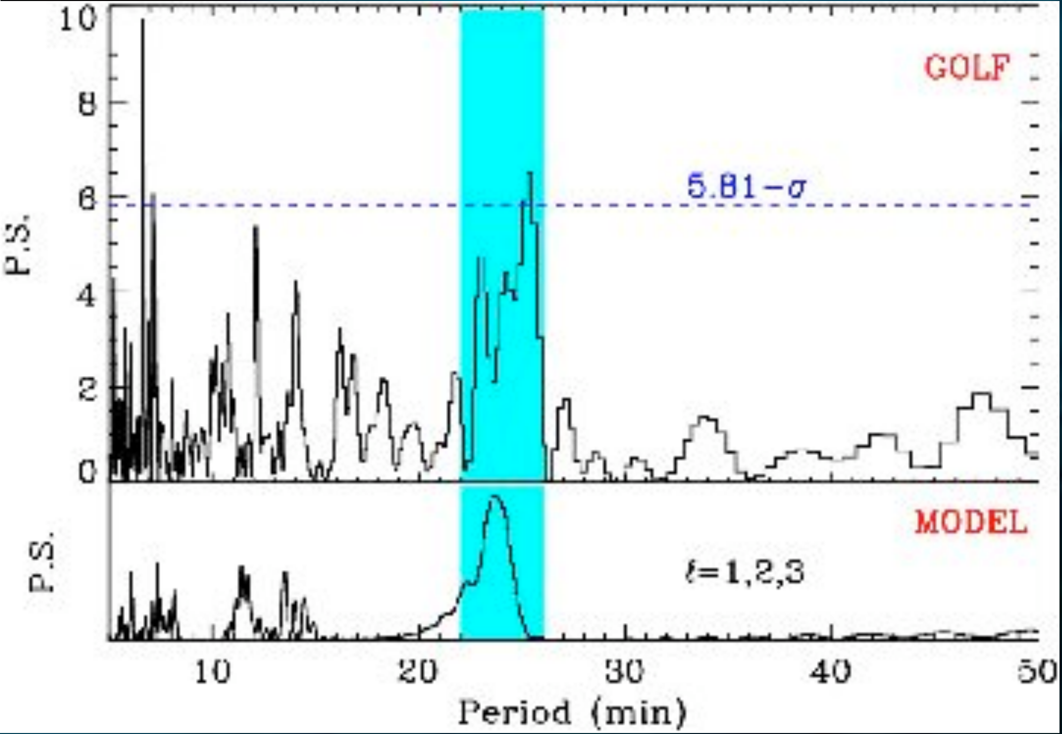
Interest of the gravity modes to investigate the rotation of the solar core

News!!!

Solar Gravity dipole Modes detected with GOLF!!!

Garcia, Turck-Chièze et al. 2007 Science





10 years of observations from GOLF

With more than 99.7% CL

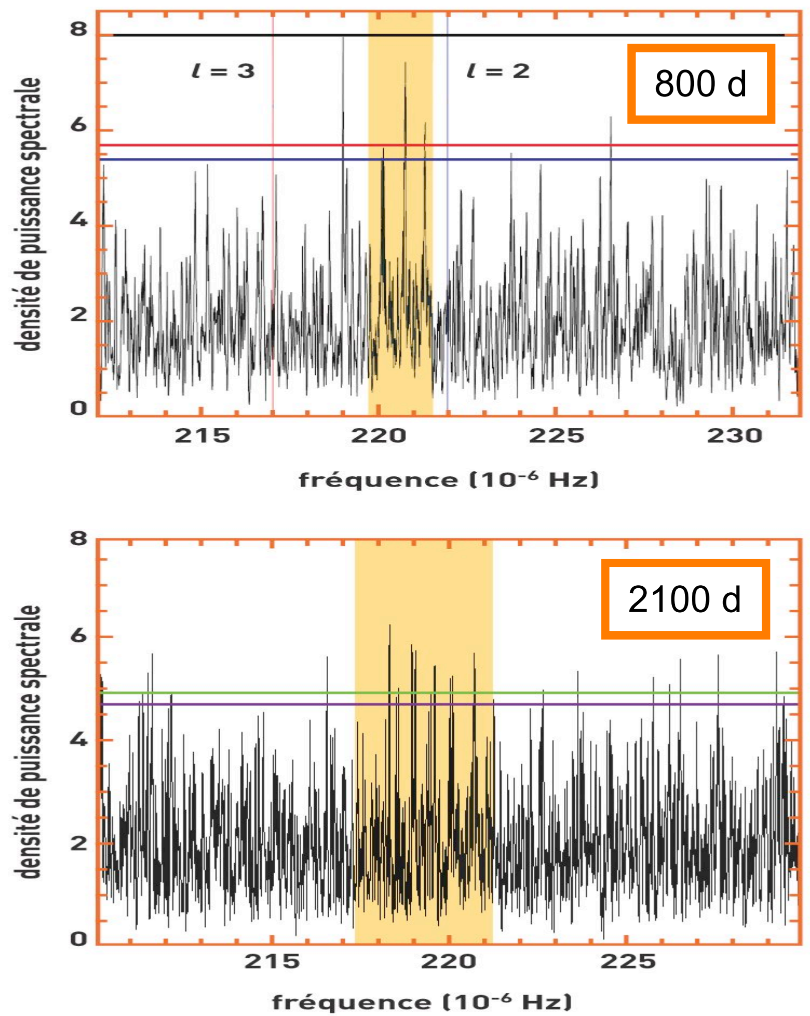
This pattern has a higher coherence with a model including a rotation rate 3 or 5 times higher than the rest of the radiative interior

Individual g-mode research

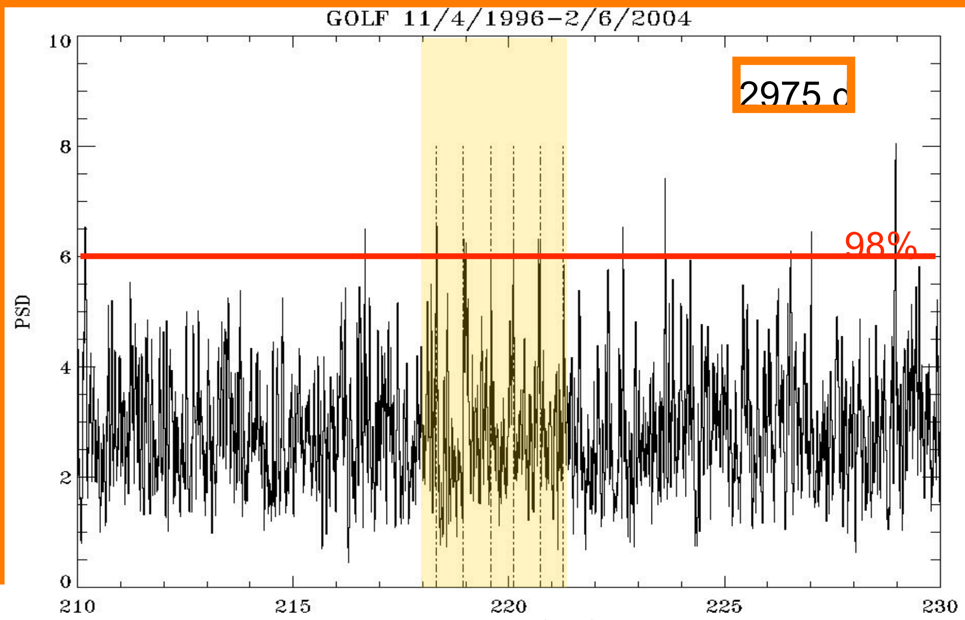
- Above 150 μHz:
  - Higher expected amplitudes
  - Multiplets: GOLF candidates > 90%, > 98%

Candidate at 220 μHz:

- Evolving with time in GOLF
- Quintuplet ?: l=2, n=-3 rotation double
- different axis
- Highest predicted amplitudes
- 1 component also visible in VIRGO at the same frequency

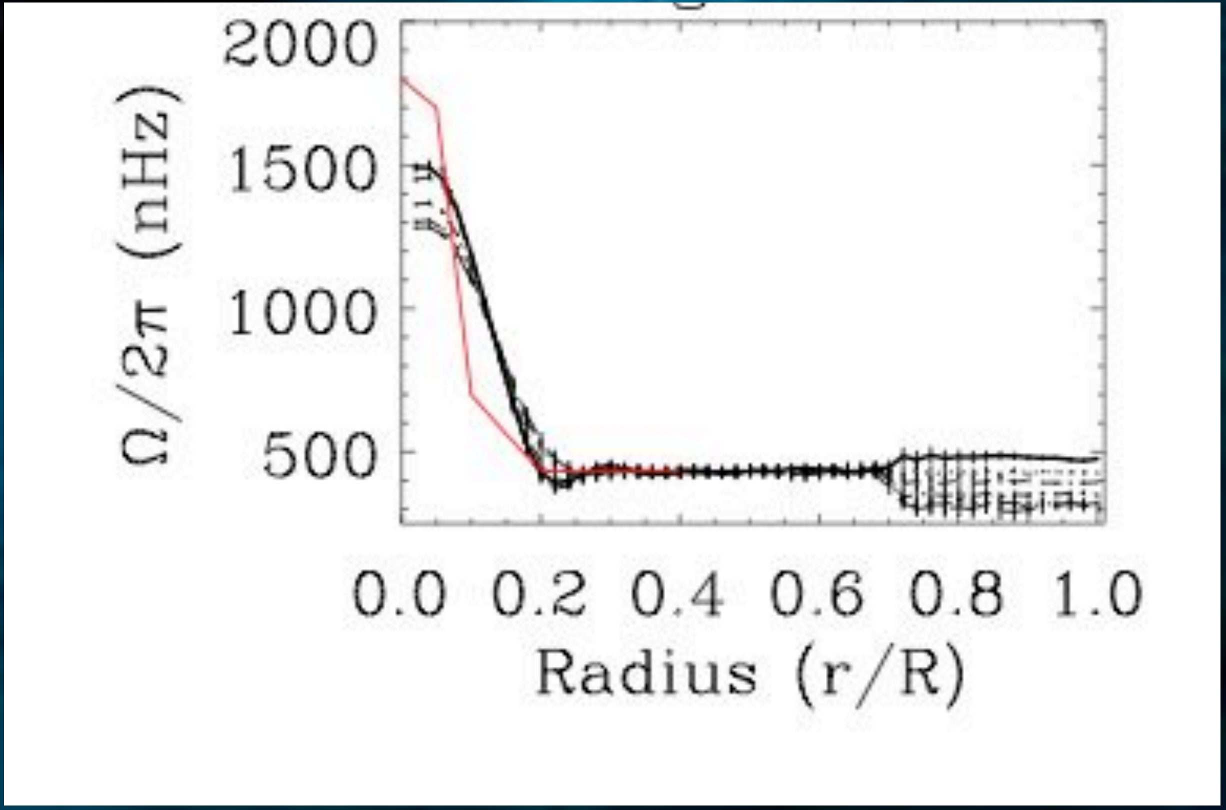


[Turck-Chièze, et al., ApJ, 604, 2004]



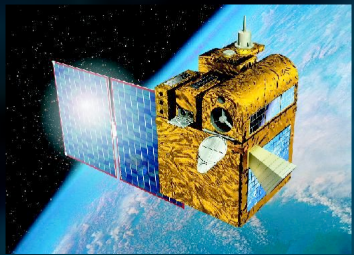
[Turck-Chièze, et al., SoHO 14, 2005; Mathur, T-C et al. 2007]

Mathur et al. 2007

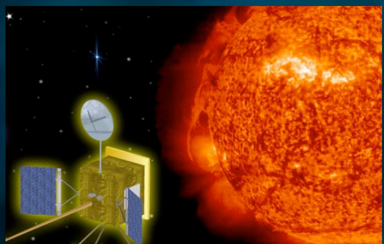


The future…

SDO Solar Dynamics Observatory, HMI (local helioseismology) NASA launch: 2008 to understand variation of magnetic fields in the convective zone and its impact on Earth



PICARD CNES Launch: 2009 PREMOS (low l and g modes) to study of the Earth climate and Sun variability relationship



Solar Orbiter ESA Launch: 2014 VIM (local helioseismology at high latitude) to study, by approaching as close as 45 solar radii, the polar regions and the side of the Sun not visible from Earth

DYNAMICCS Dynamics and Magnetism from the Internal core to the Corona of the Sun, ESA Cosmic Vision Turck-Chieze et al. , 30 institutes

The new questions of the DynaMICCS perspective

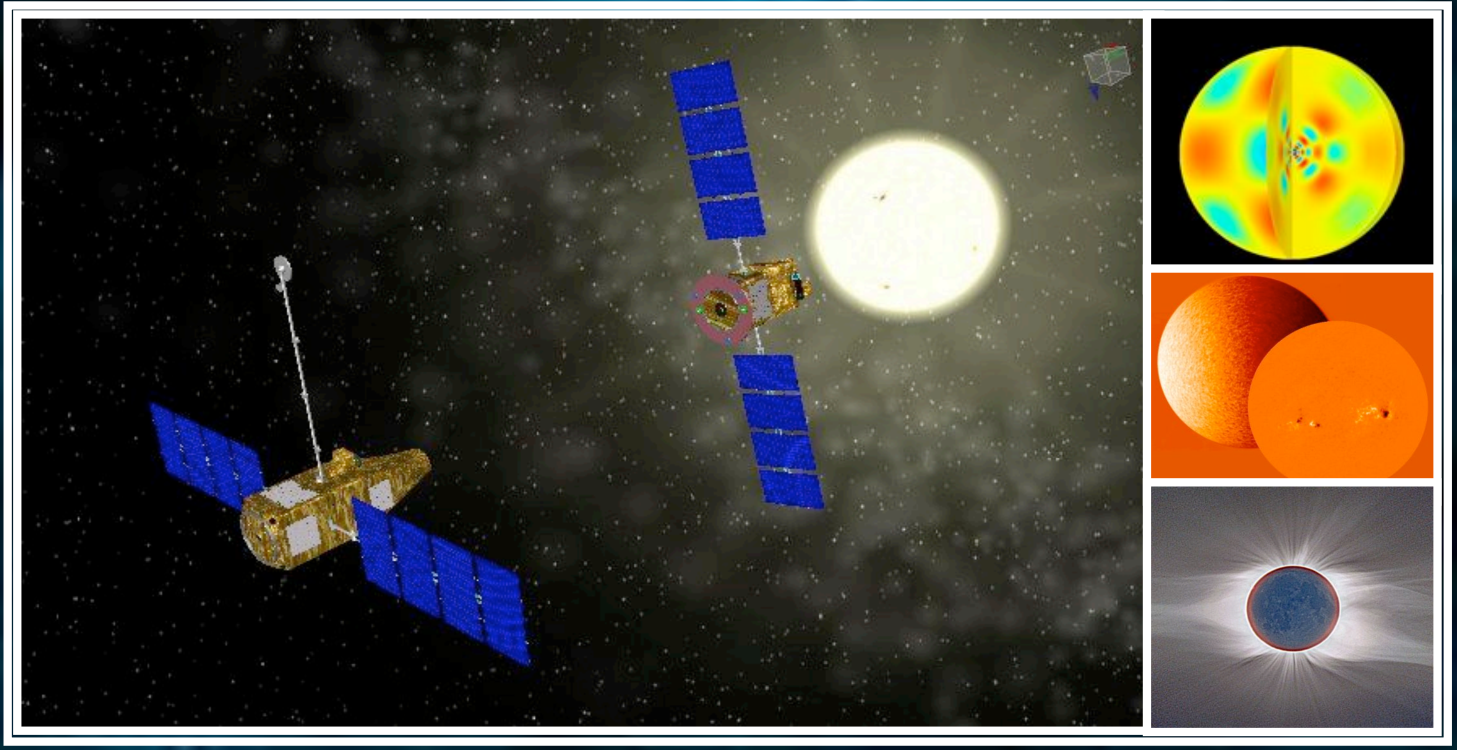
Defining properly the rotation in the core and at the limit of the core

Defining the interaction between the magnetic field of the radiative zone and of the convective zone

Understanding propoerly the great minima: only one type of dynamo, or another dynamo in the core

Predicting the activity of the next century
Study the real impact of the Sun on Earth

DynaMICCS: A mission for a complete and continuous view of the Sun dedicated to magnetism, space weather and space climate



Ecole de la Rochelle   Sylvaine Turck-Chièze, 28 Septembre 2007

DynaMICCS *

The DynaMICCS project is proposed by the core team

S. Turck-Chièze, CEA, **France**; P. H. Carton, CEA, **France**; I. Dandouras, CESR, **France**; S. Dewitte, RMIB, **Belgium**; T. Dudok de Wit, LPCE, **France**; J-F. Hochedez , ROB, **Belgium**; P. Lamy, LAM,**France**; N. Murphy, JPL, **USA**; P. L. Pallé, IAC, **Spain**; P. Rochus, CSL, **Belgium**; A. Ruzmaikin, JPL, **USA**; W. Schmutz, PMOD/WRC, **Switzerland**; G. Thuillier, SA, **France**, S. Vives, LAM, **France**

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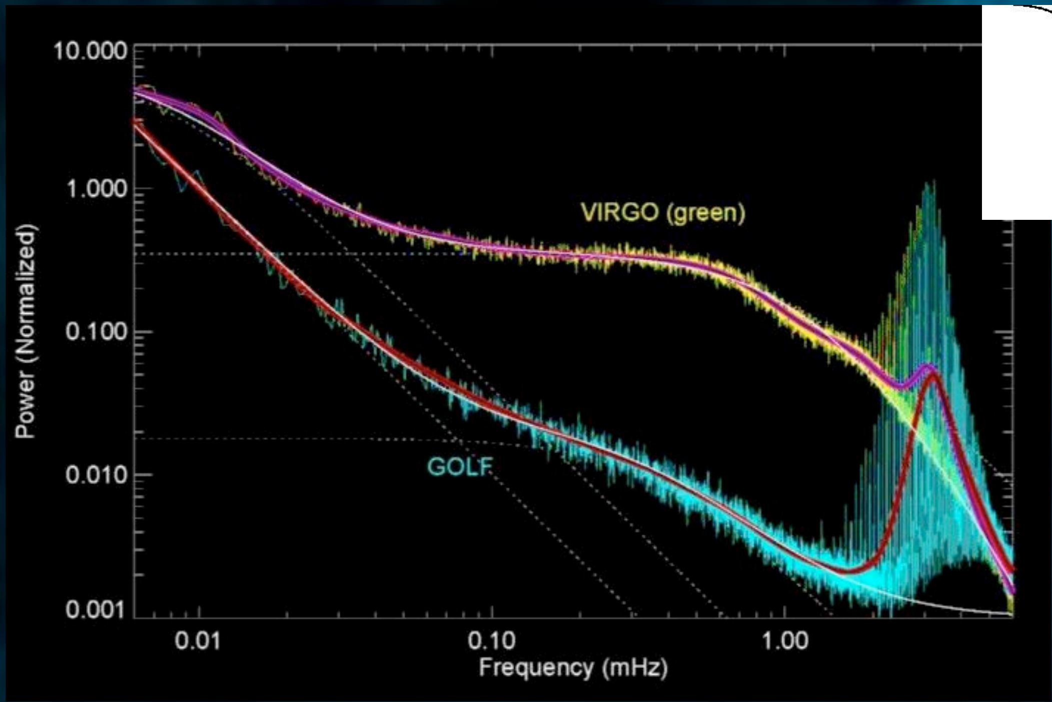
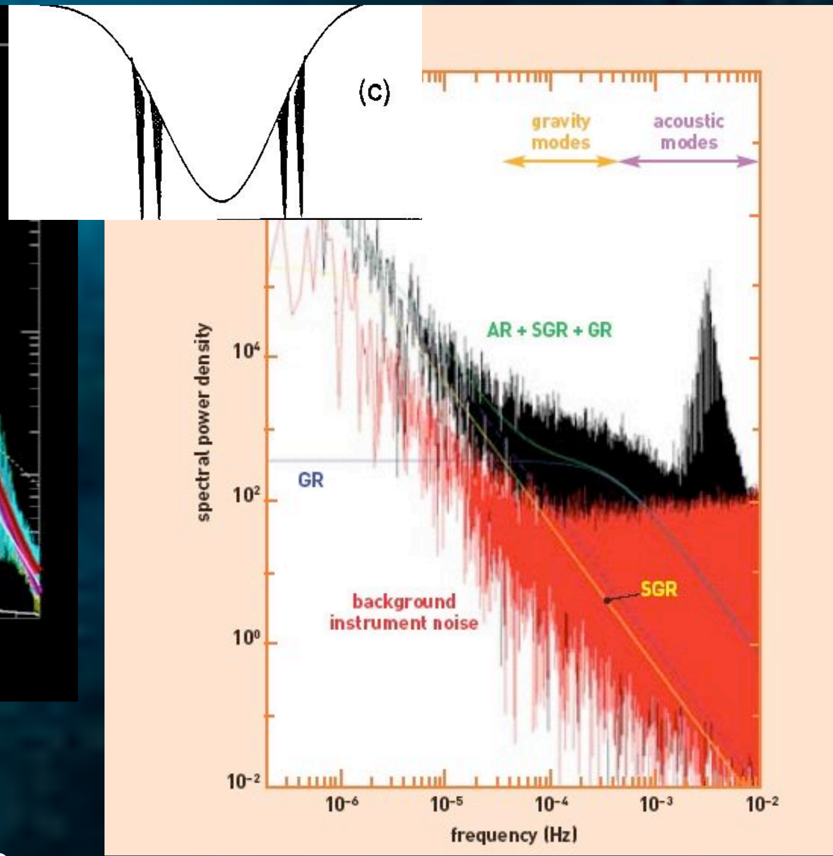
and the participation of Thales Alenia Space

Lesson from SoHO

Doppler velocity is the most promising to detect gravity mode.





Factor 10-30 in the range of gravity modes

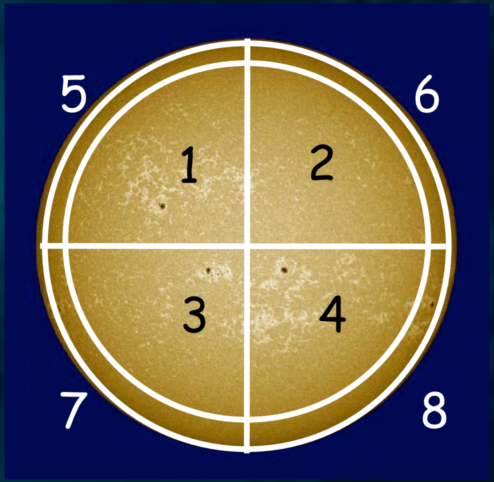
New instrument is necessary in parallel to the development of PICARD

a factor 4- 5 of amplification at the limb

What we need to do

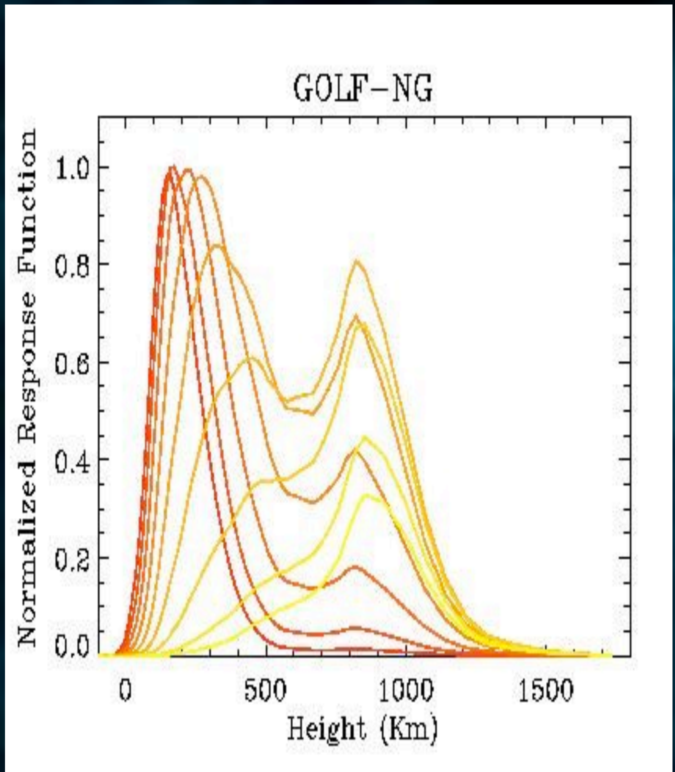
- Reduction of the influence of the granulation

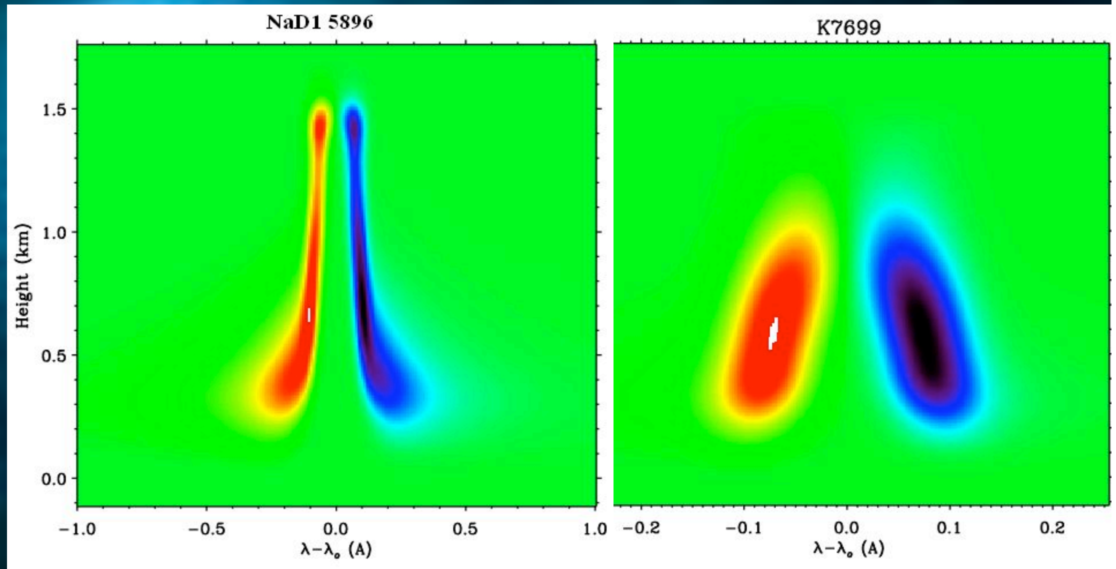
- Label the g- mode patterns: masks



- Better understand the excitation of the gravity modes and regularly measuring the mean magnetic field along different cycles

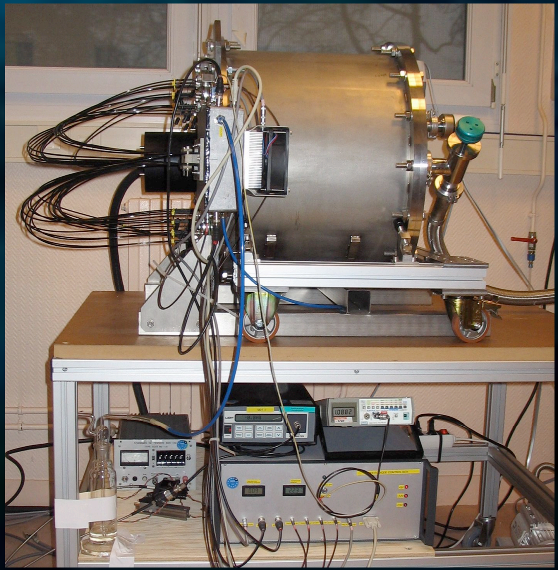
GOLFNG + MOF (SDM)





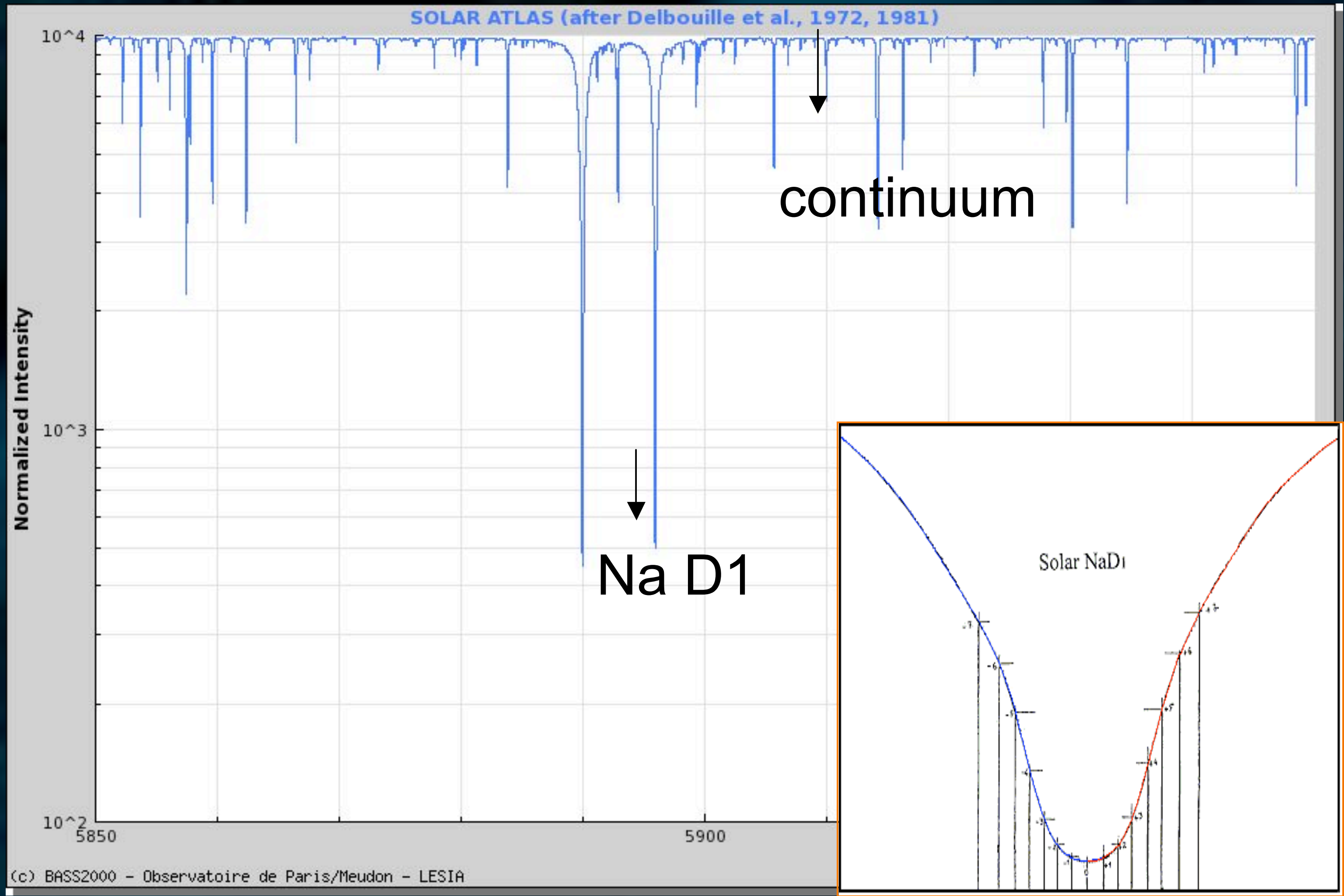
GOLF -New Generation (french-spanish team) for ESA Cosmic Vision

- Technological Prototype
- Perspective on ground
- Extension to Space Mission ..



GOLF-NG prototype in test in Saclay/CEA

GOLFNG is a resonant spectrometer



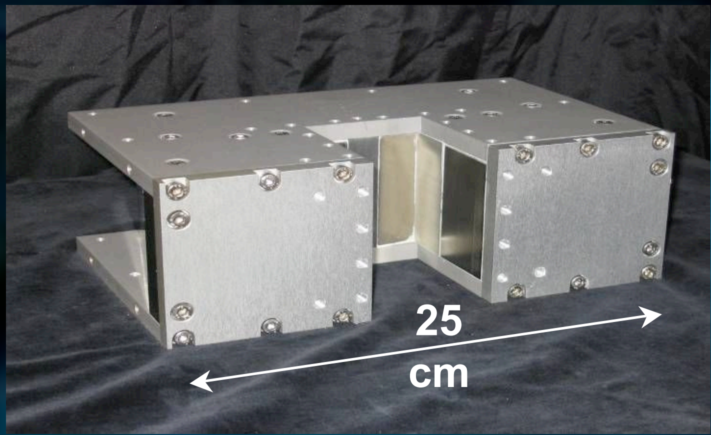
Permanent Magnet with quasi linear variation of B

➢ **Magnetic field for Zeeman effect spectrometry :**

compact magnet with progressive field

Sizes :

- **25 x 15 x 9 cm**
- **15 Kg**

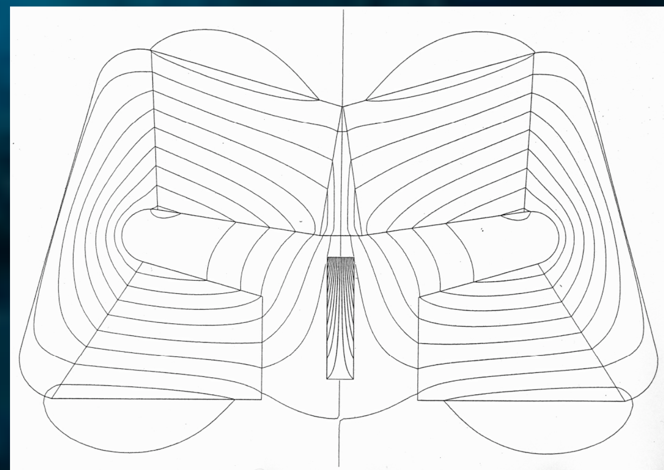


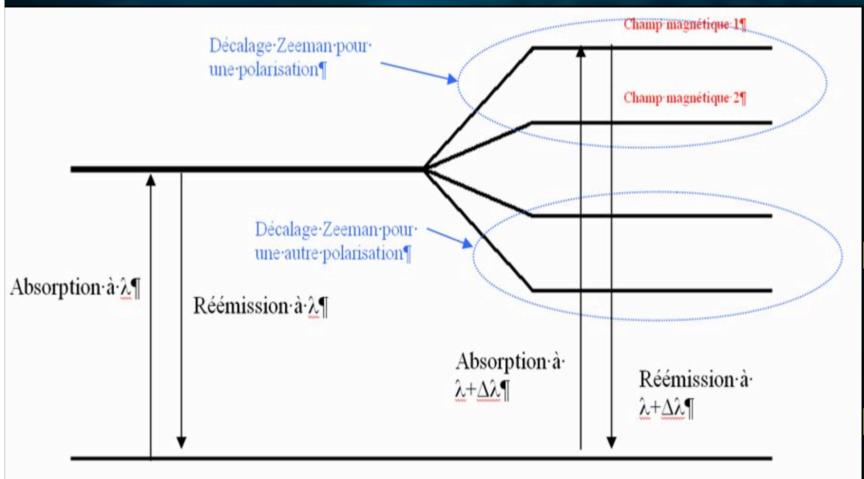
Field range : de 0 à 12 K Gauss

Cell area : 0 - 8 K Gauss

Leakages : axial ≤ 500 Gauss@50mm, ≤ 150 Gauss@100mm

latéral ≤ 150 Gauss @50mm

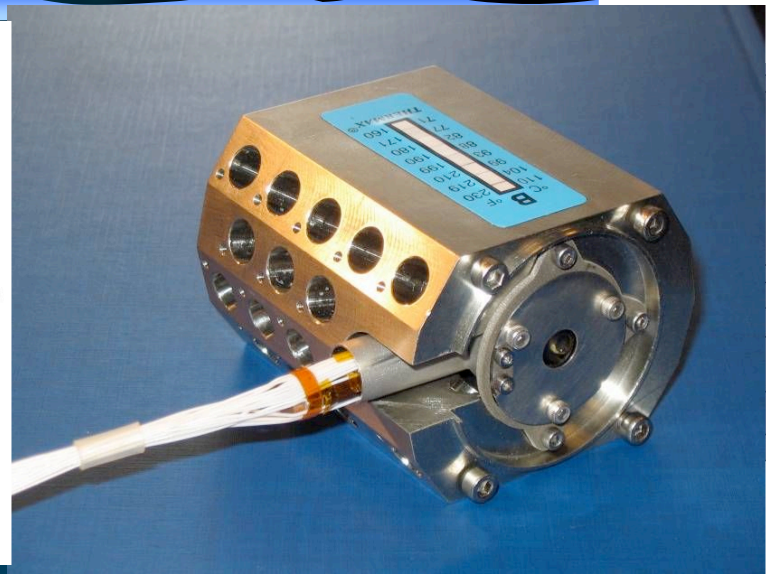


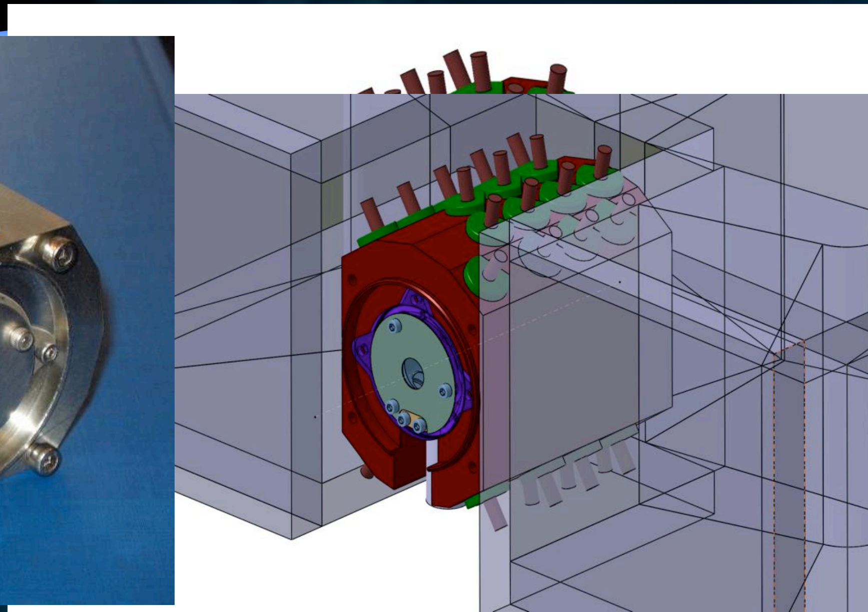


Transverse homogeneity of B better than 93%
in 8mm diameter along the 60mm cell

Sampling pitch : 25 mAngtröms
Absorption width of a channel : about 20 mAngströ

The cell and the magnet environment

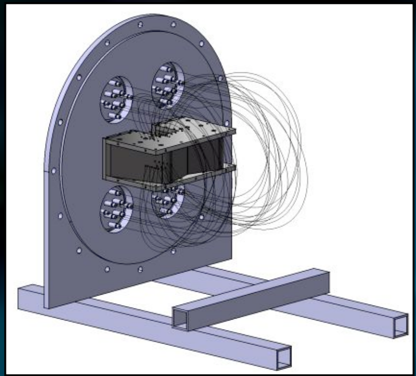




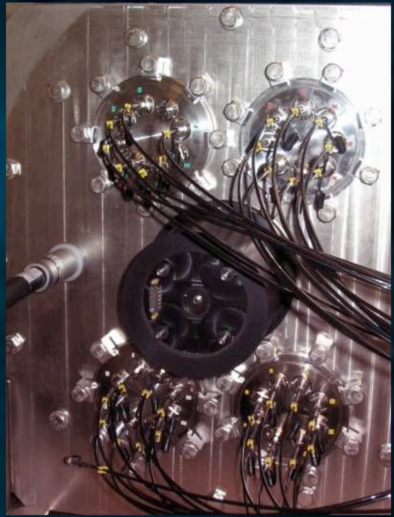
- to integrate heater system (170-190°C) and thermal insulation
- to integrate cell carriage system and optical alignment system along the cell
- to integrate relay optics for resonant light coupling to photodetectors

Resonant Spectrometer design

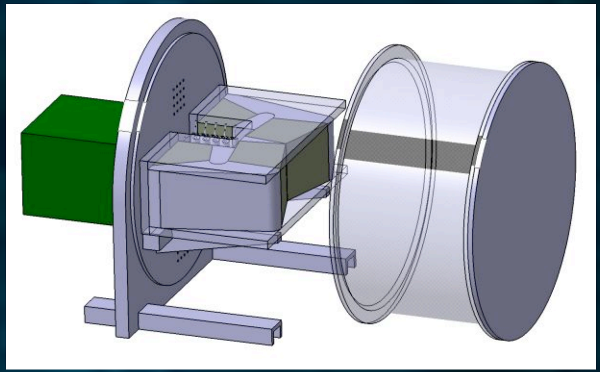
- vacuum vessel for space environment conditions
  - » thermal tests validated

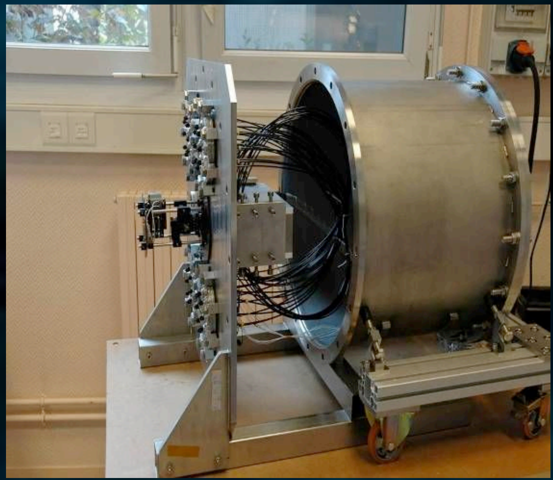


Front tapes with sealed optical throughoutputs



Spectrometer integration

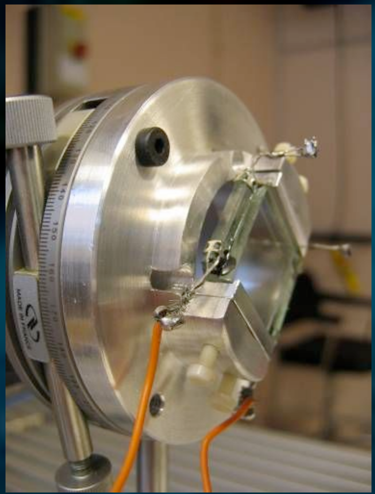




Entrance Optics : beam polarization

- incident light polarization for activation of Zeeman resonant process

Choice of fast response system with no motor control



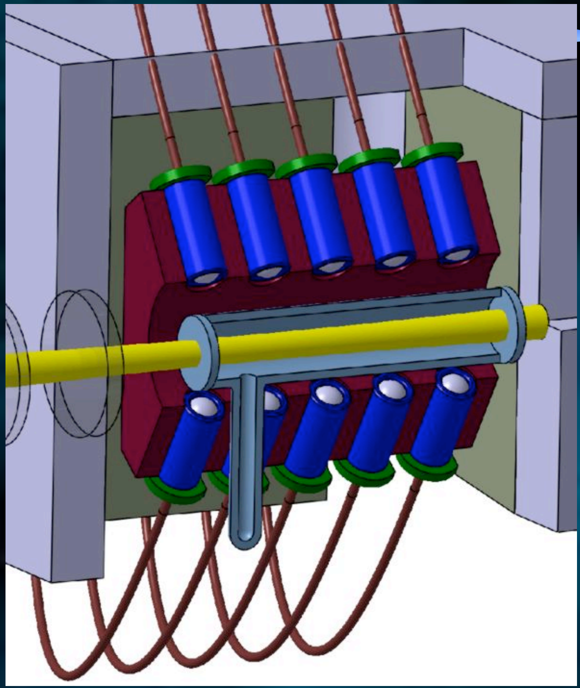
- validation in labs with high purity polarisation analysis system

✓ circular polarisation degree at 99,5% min

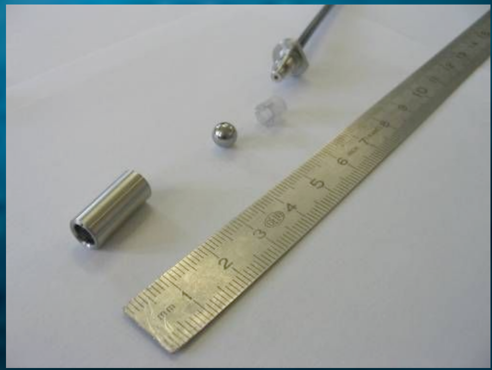
(spécification of 10^{-2})

✓ validation of pulses control system

Readout system (1) : coupling optics



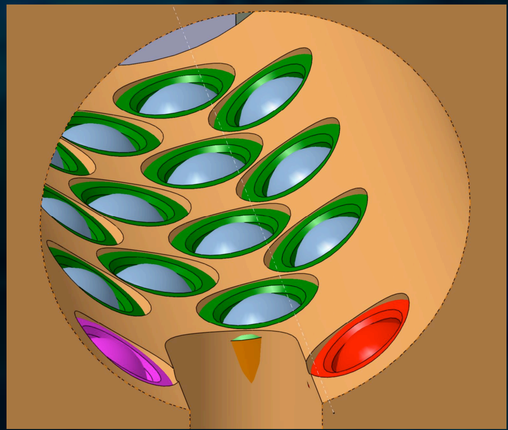
4 measurement channels for each spetrometer point in order to increase SNR and redundancies !



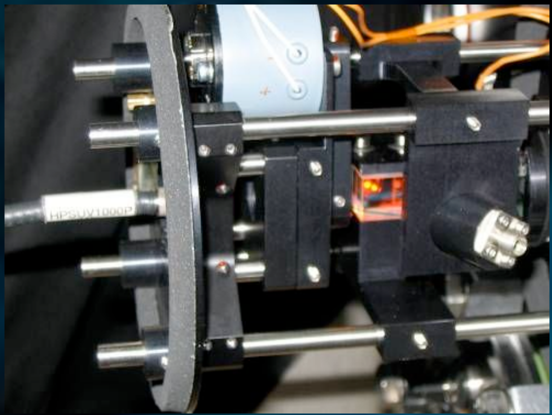
numerical studies are used for

- **light coupling optimization:**
  - ✓ use of ball lenses , better than direct coupling in optical fiber.
  - ✓ ghost rays ≤ **5%**

- mechanical design : **study and simple**
  - ✓ **low misalignments**
  - ✓ **fiber and lenses changing possibilities**
  - ✓ **easy integration in the insert**
  - ✓ **up to 80°C without pertubations**

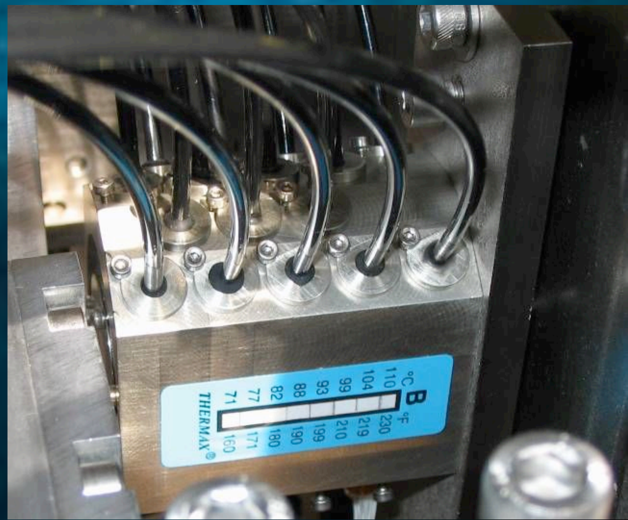


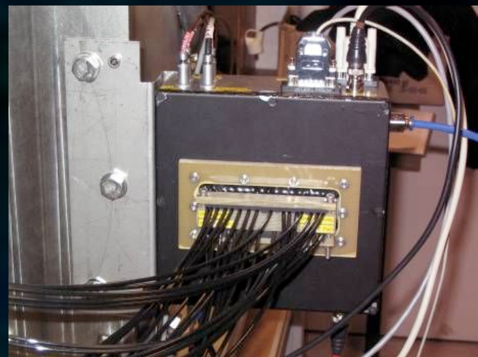
R&D present status



Complex instrument

➔ Most of the hard points already solved



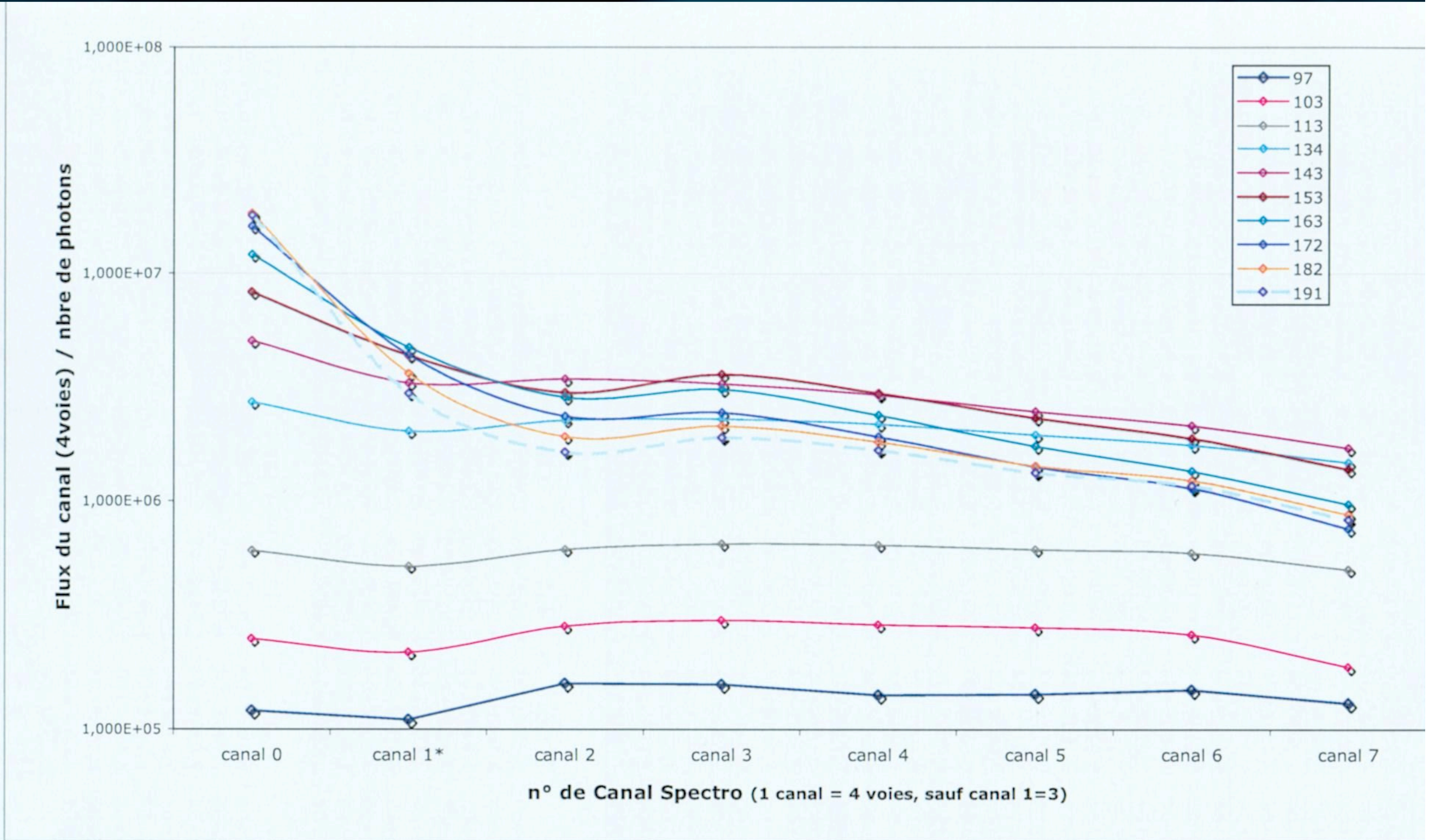


Tests & Calibration :

➔1st quarter of 2007: laboratory tests CEA

(functionning tests, small tests with Sun)

First test with a led sensitive to sodium photons: resonance on first channel only !



Sun exposure:

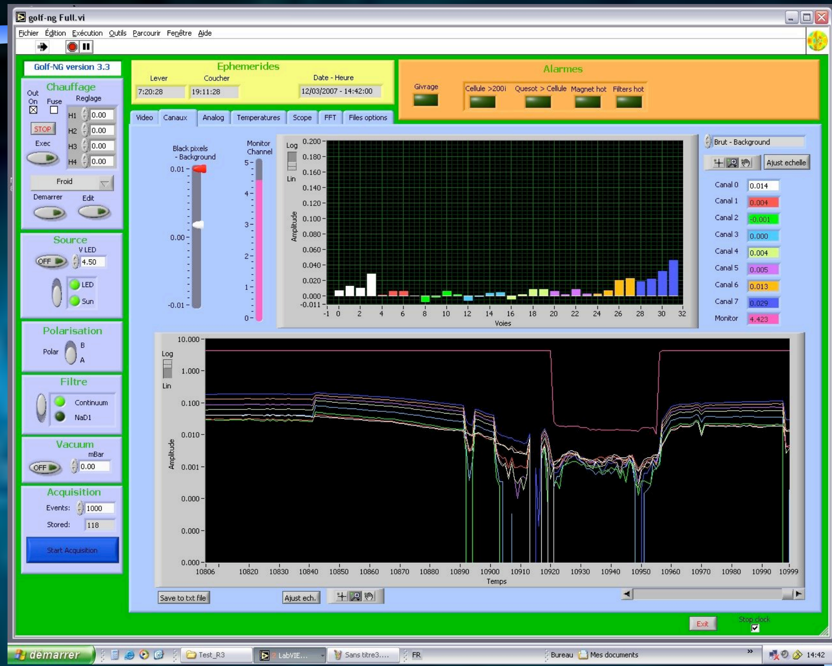
Continuum, polar A, polar B

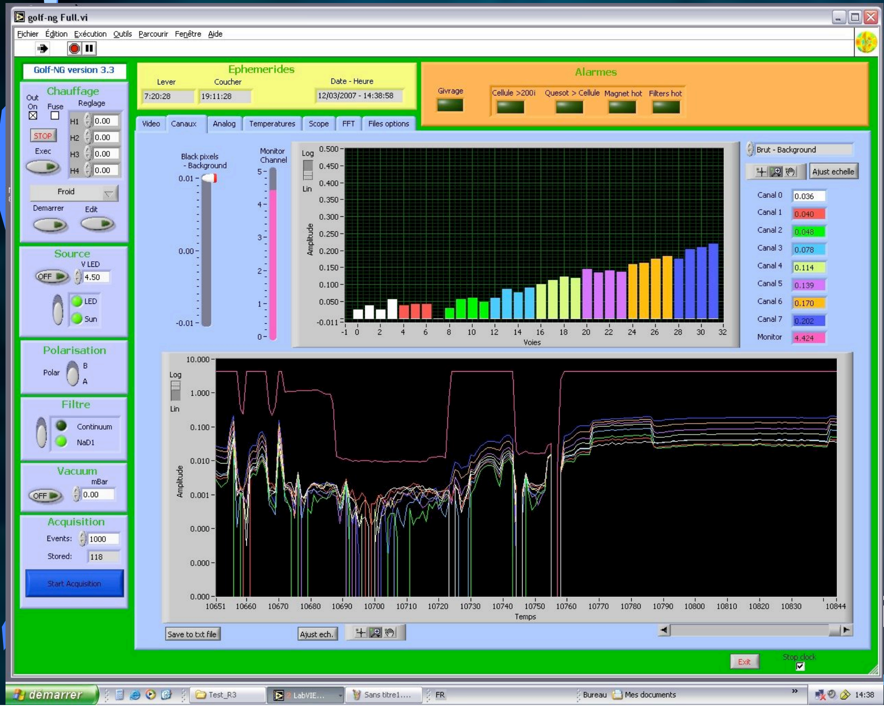
12 March

First light

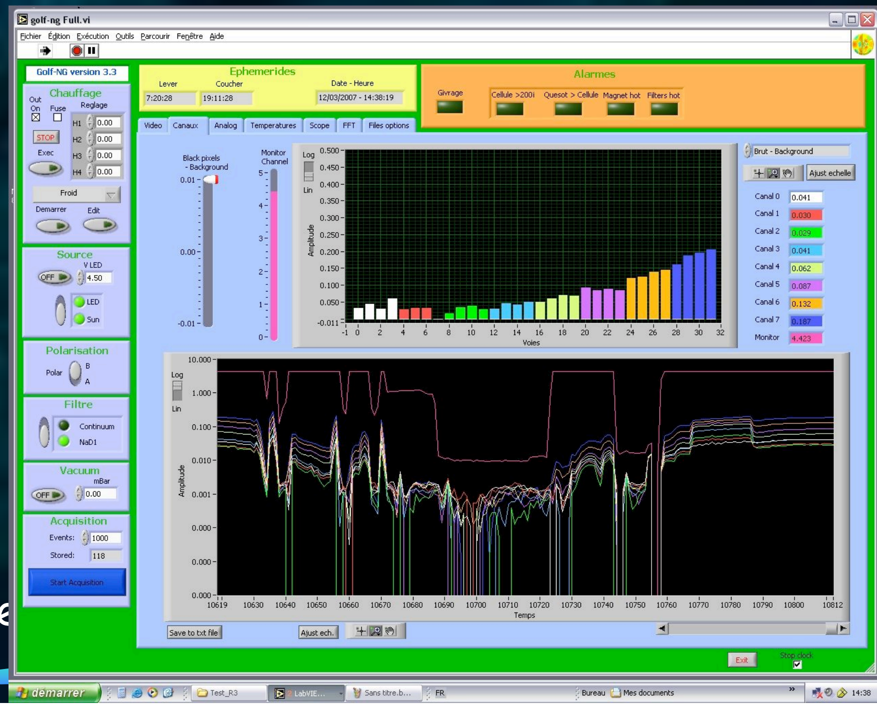
this method is working

Turck-Chièze et al. 2008



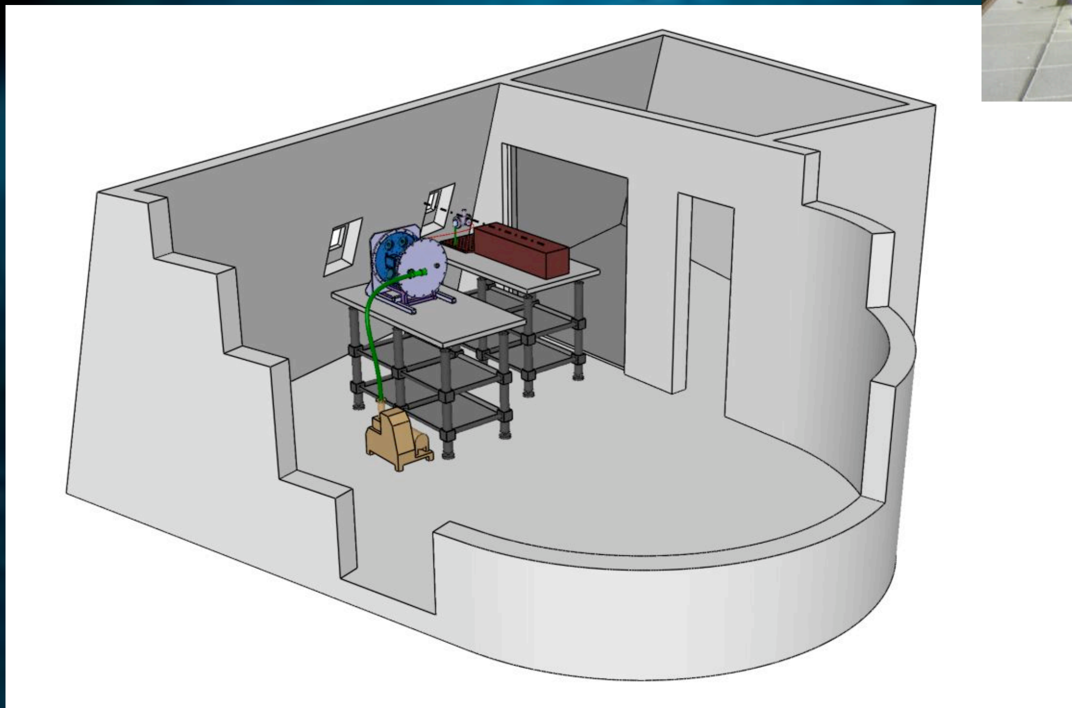


ièze

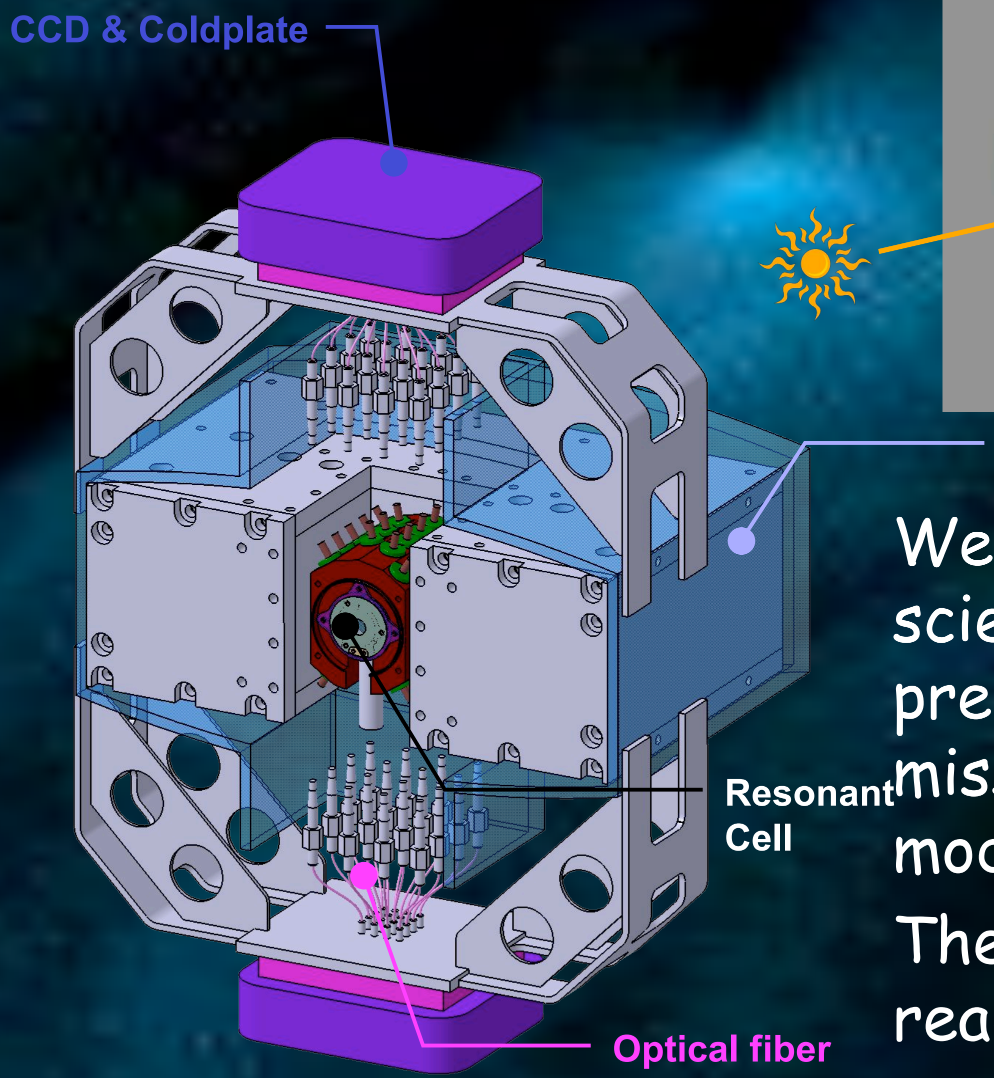


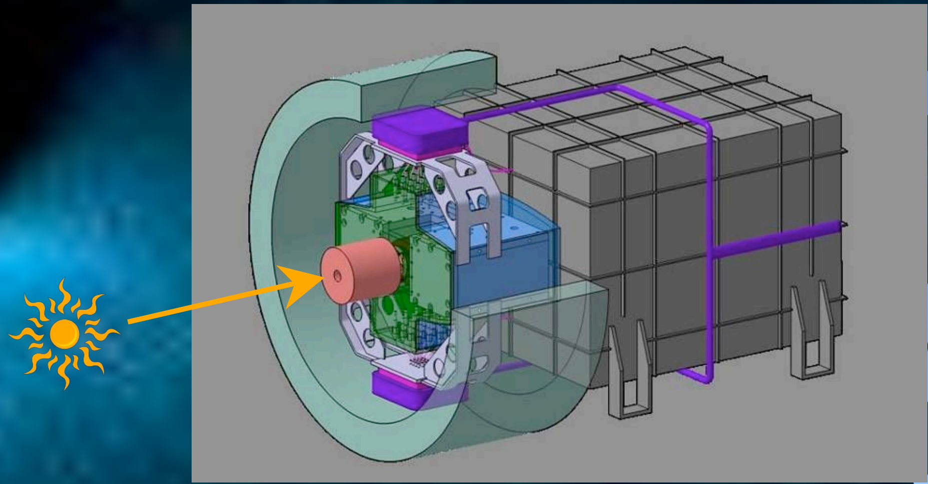
Study of the solar line during several months in Tenerife

at the End of 2007



Possible Space design of GOLFNG





We will build a compact scientific instrument prepared for future space missions: a qualification model

The instrument must be ready mean 2009

Ph. Daniel-Thomas / F. Nunio

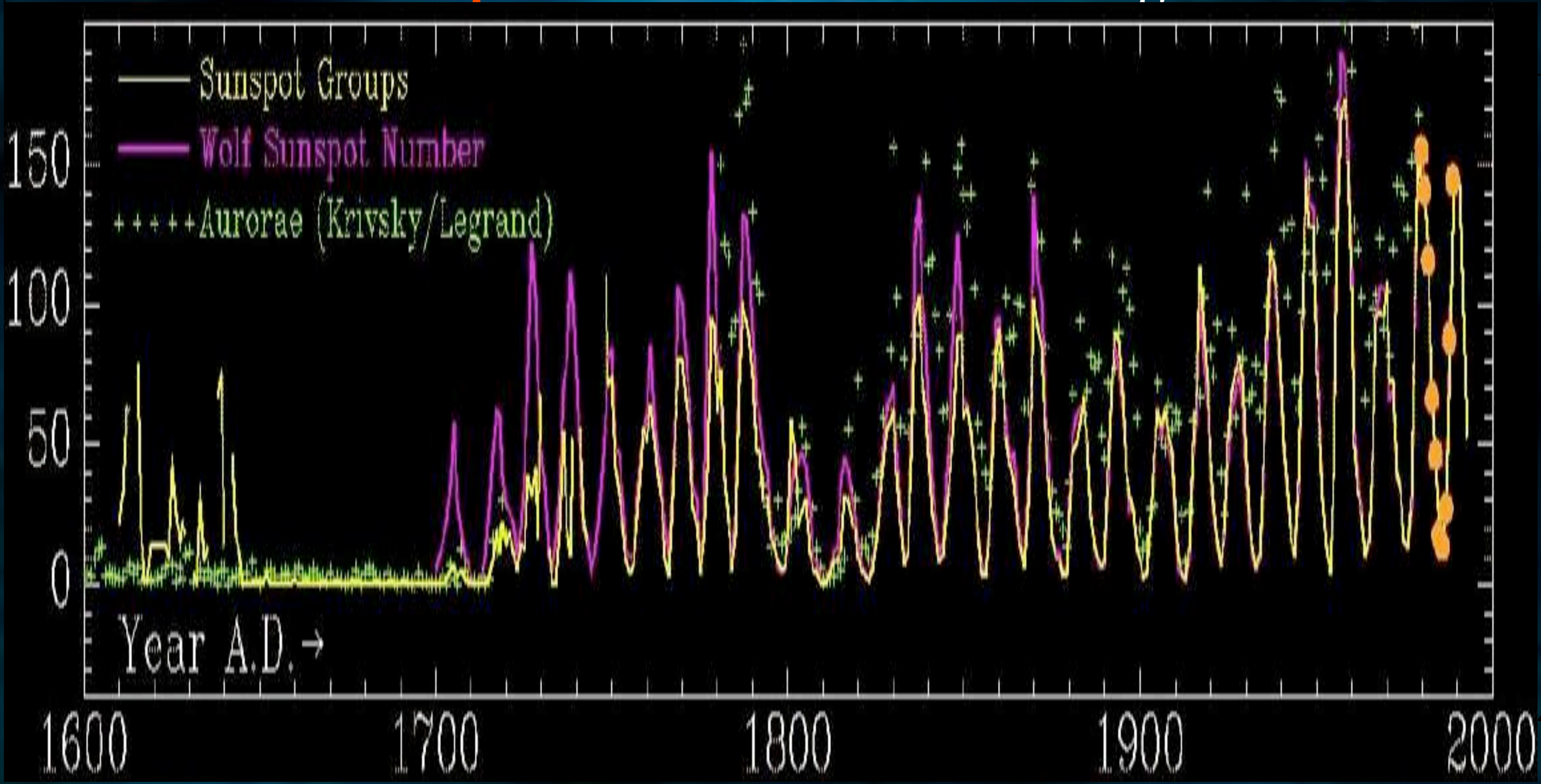
Continuous observations in Tenerife summer !! and for 3 months in Dome C in December 2009 with 2 weeks of excellent seeing 2 campaigns: qualification of the scientific objectives splitting of g-mode: 30 nHz !

New detector,

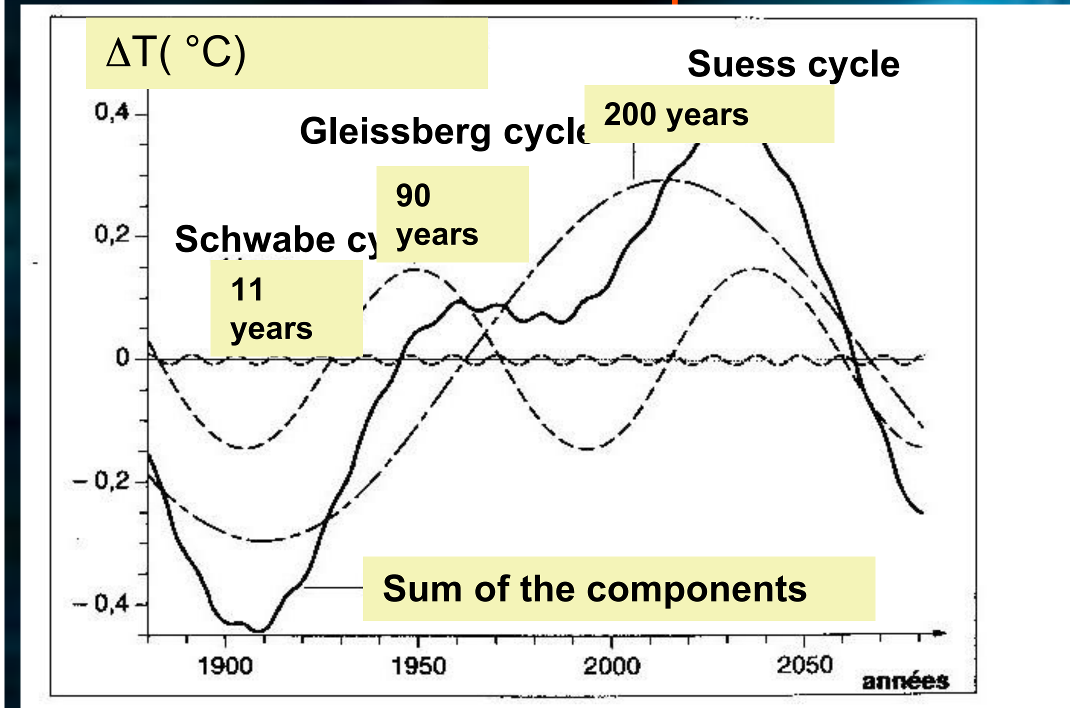
New cell

DynaMICCS leads to a better knowledge of the transition region between photosphere and chromosphere, and of the deep interior.

It must result an improved understanding of the solar activity cycles, including large minima and maxima with predictions for the next century and a better description of the Sun's potential impact on earth's climate change.



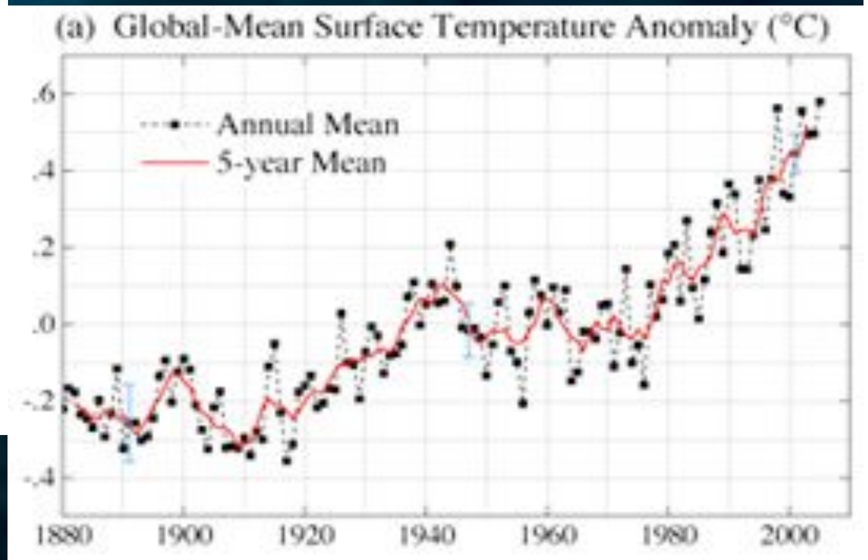
We must put constraints on the origin of the different cycles and predict



Damon & Jirikowic, 1992; Turck-Chièze & Lambert 2007

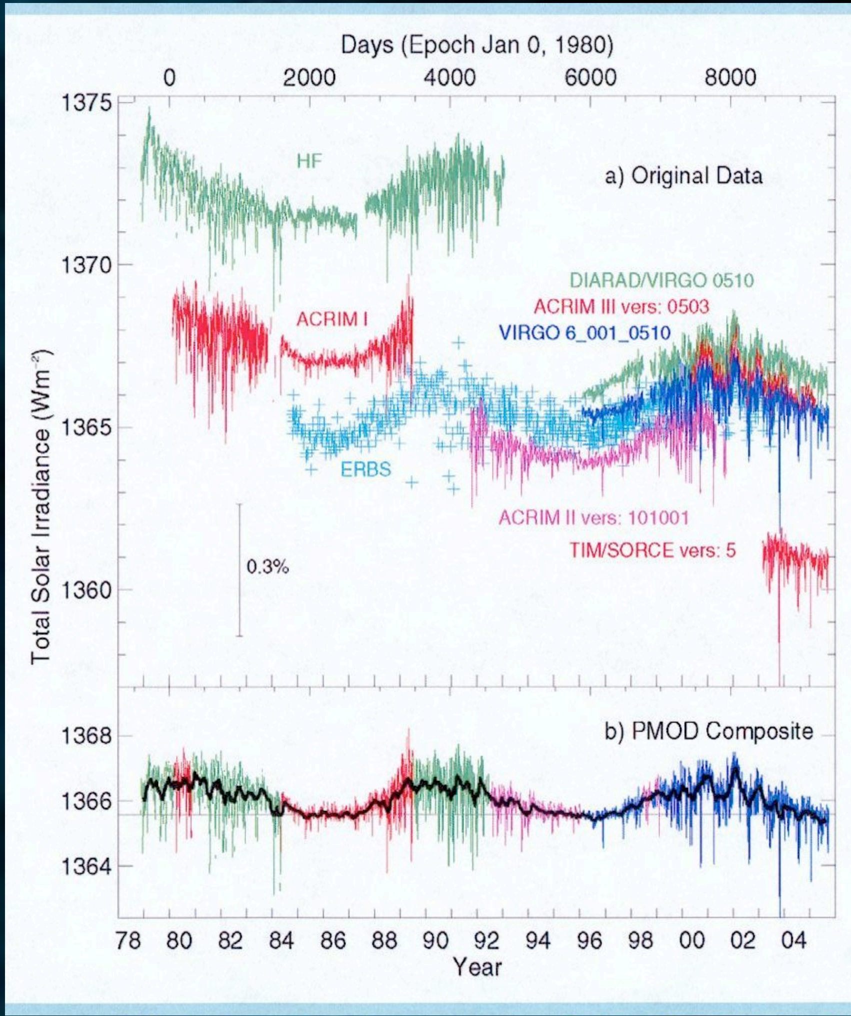
30% of the total effect ???

Indirect effect not estimated ?



Only magnetic effects or impact of gravity waves

Comparison of internal motions with DynaMICCS and SoHO-SDO: 20-30 years



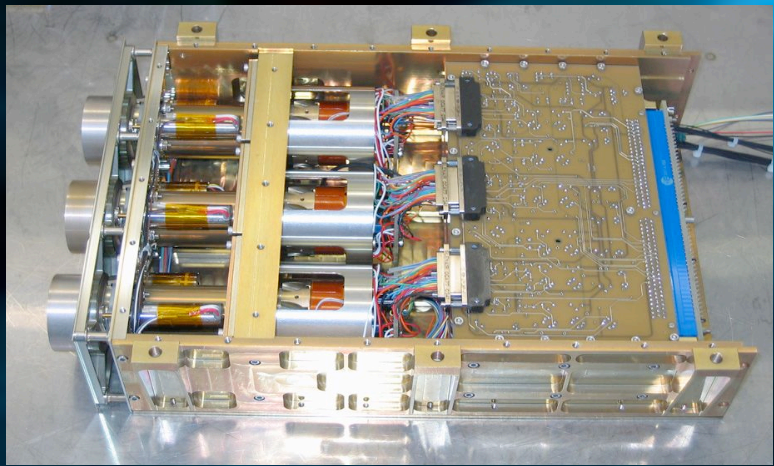
Total irradiance and infrared spectrum

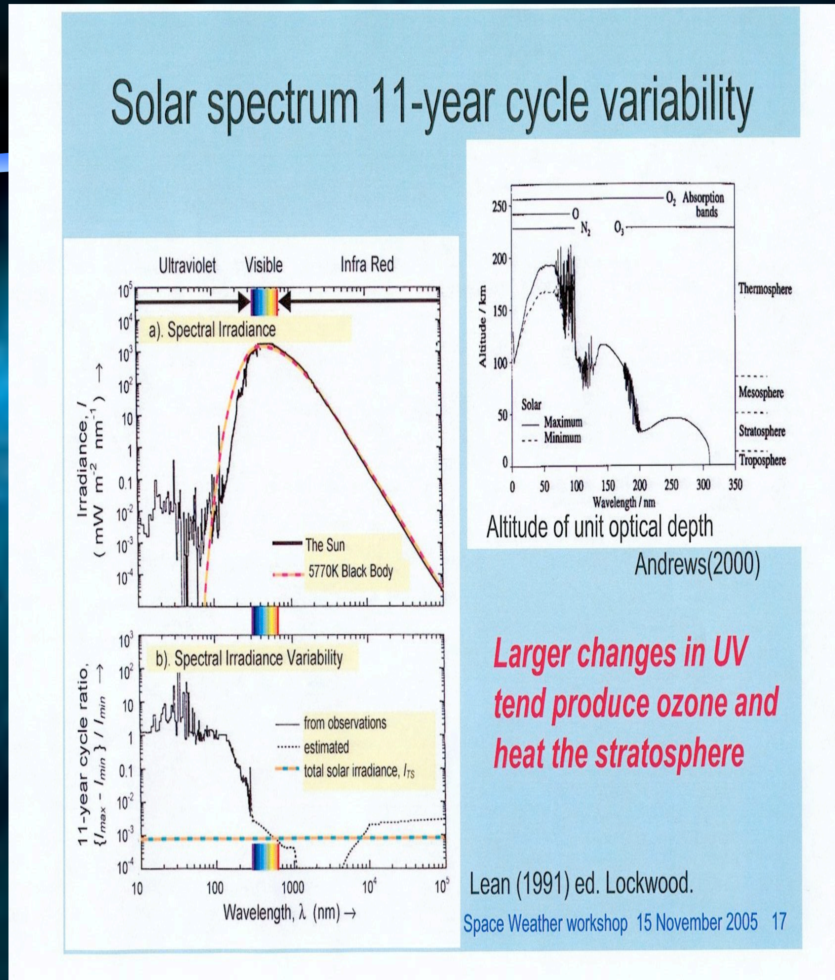
PRE +STIP

Fröhlich & Lean 2004

TSI variation 0.1% through 11 year cycle, longer trend ?? Impact of shorter and greater variations (0.6W) on climatic models ??

LYRA for UV to

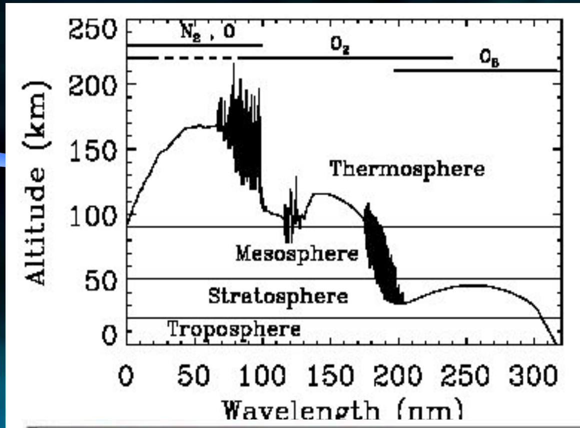




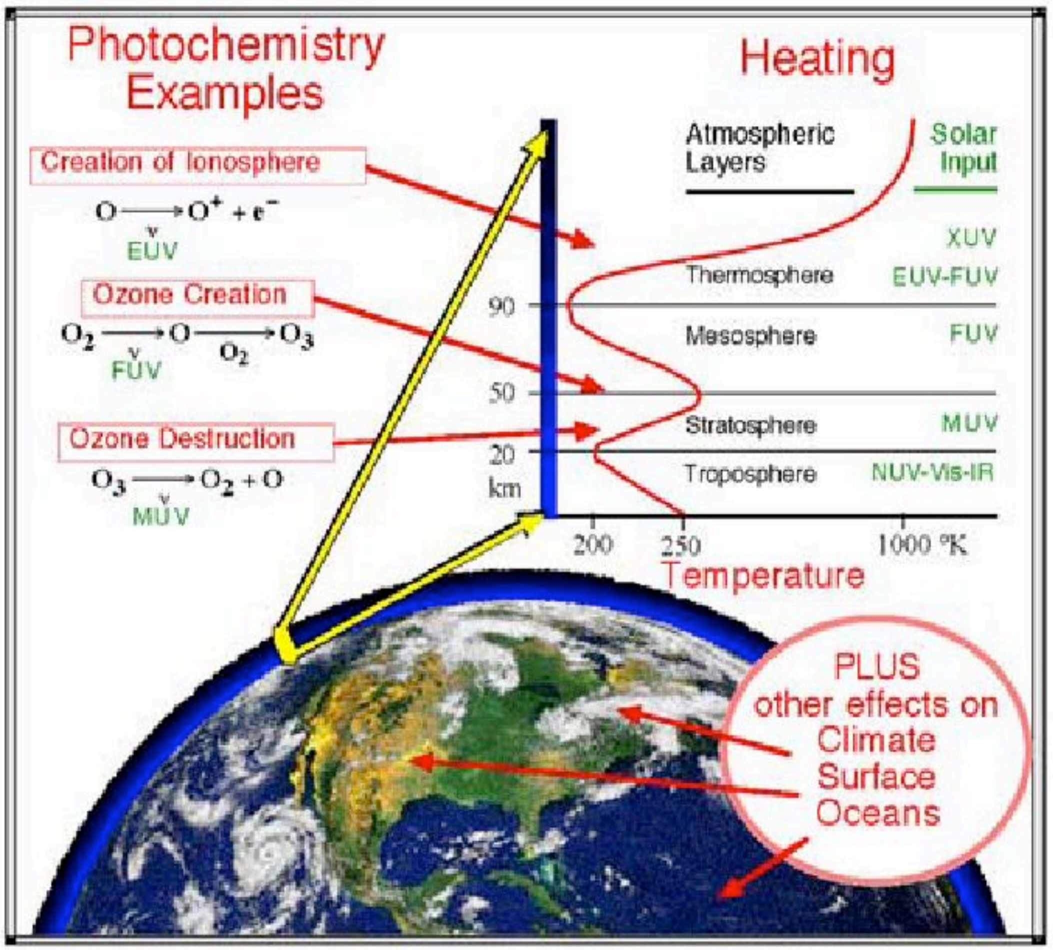
- 4 channels covering a wide temperature range
  1. 200-220 nm Herzberg continuum range (interference filter)
  2. Lyman-alpha (121.6 nm, interference filter)
  3. Aluminium filter channel (17-70 nm) incl. He II at 30.4 nm
  4. Zirconium filter XUV channel (1-20 nm)
     - rejects strongly He II

Aeronomy

- UV irradiance governs
  - The thermal structure of the Earth atmosphere,
  - Its dynamics,
  - Its chemistry:
    - Photodissociation, photoionization
    - Cf. Ozone

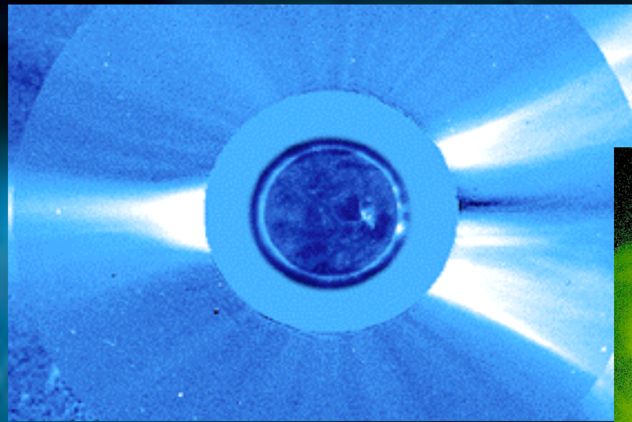


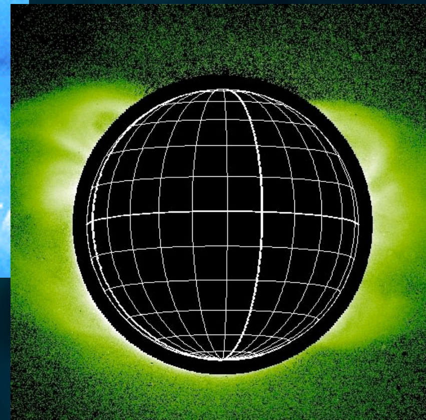
Woods Rottman 2002

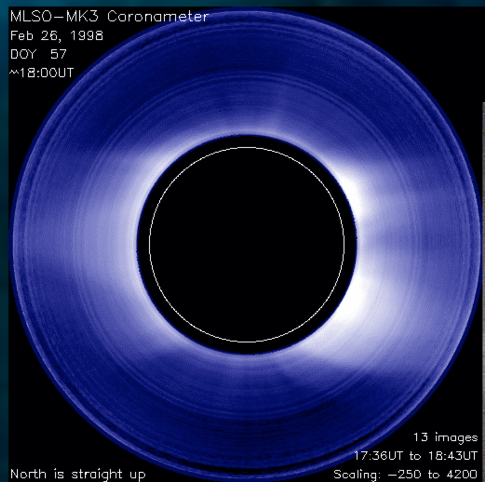


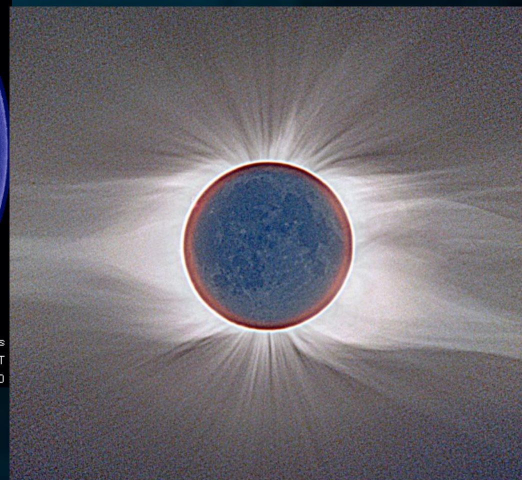
Observing the inner corona

- After 40 years of space coronagraphy, the lower corona (<2.5Rsol) remains practically unobserved
  - SOHO/LASCO-C1: high level of instrumental straylight
  - STEREO/SECCHI-COR1: performances to be seen
  - Ground-based coronagraphs: affected by seeing and atmospheric conditions, FOV<1.5Rsol
  - Total solar eclipses: very rare!!!



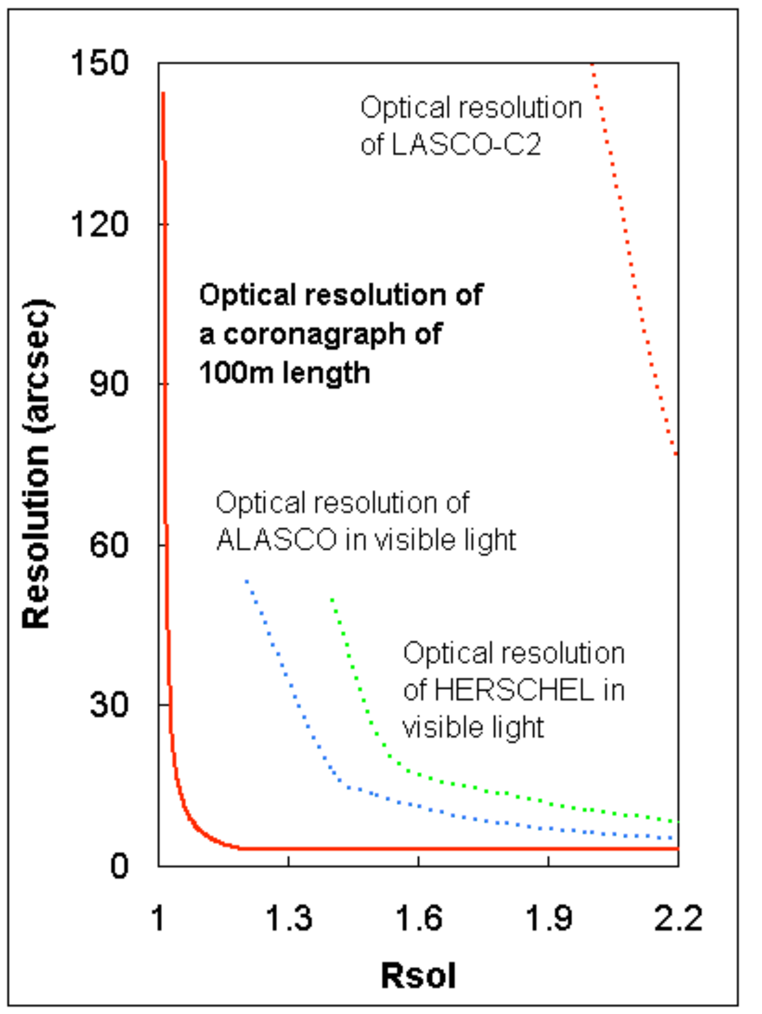


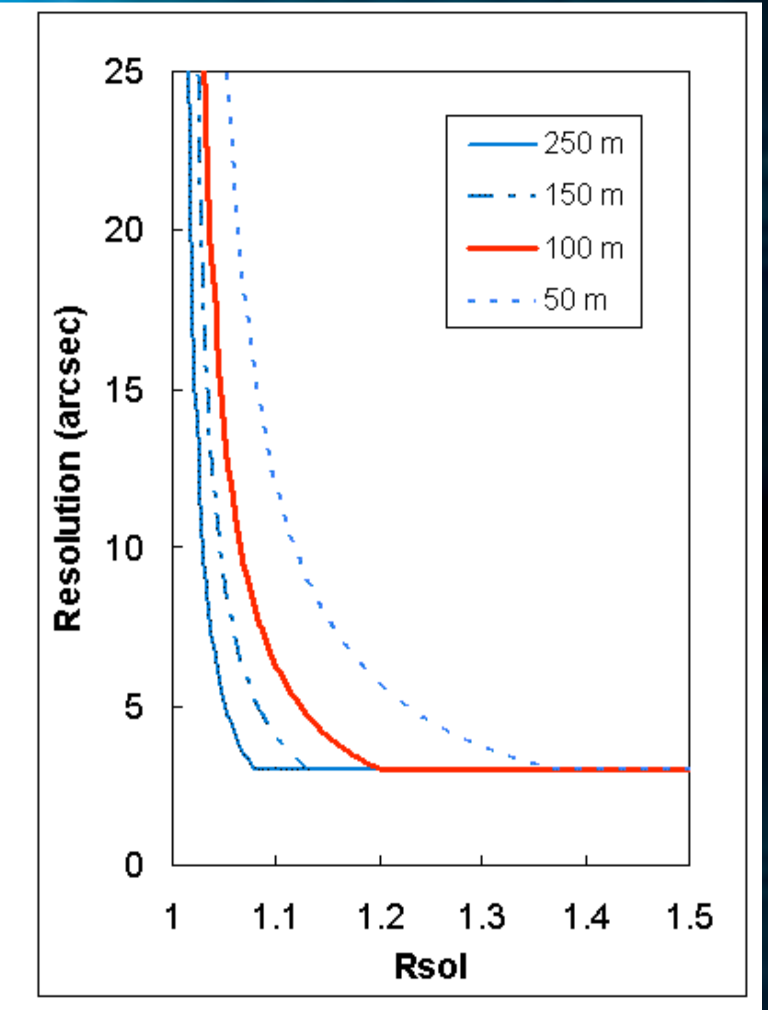




Ground-based observation of total solar eclipse of 19 March 2006

DynaMICCS offers unprecedented spatial resolution



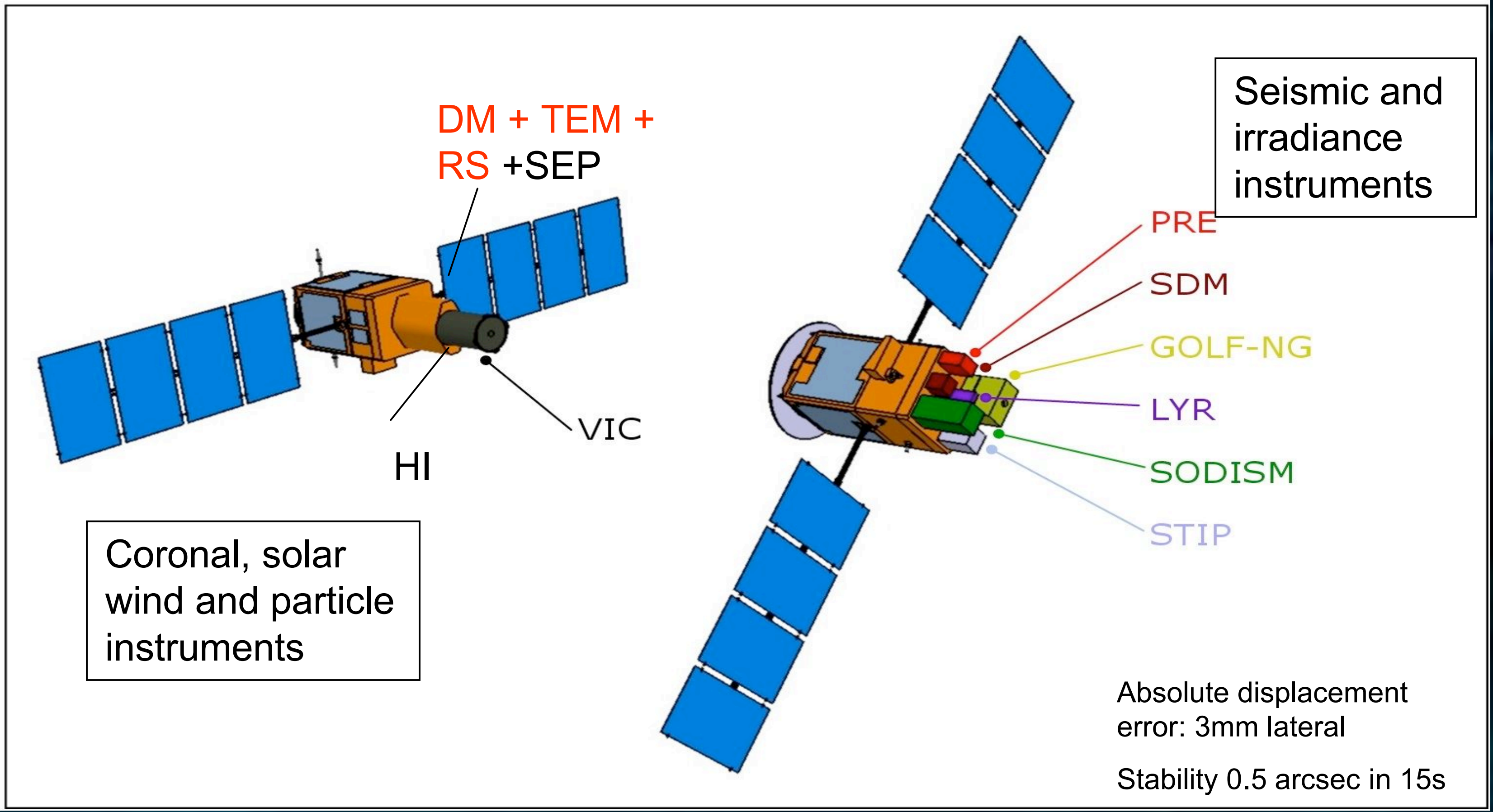


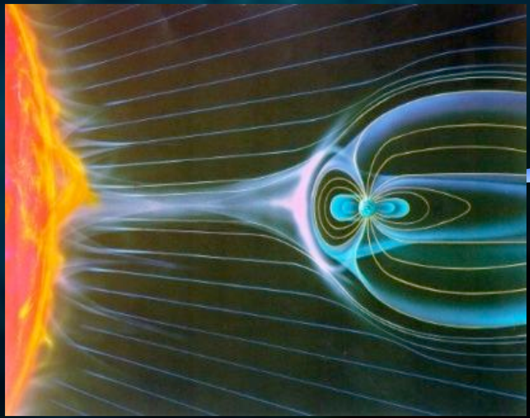
D= 150 m

Sylvaine T

Formation Flying Mission

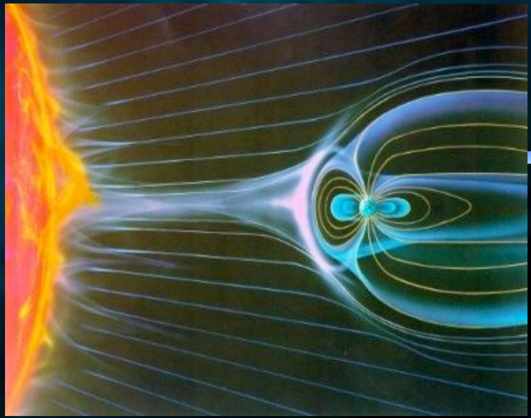
2 S/C separated by 150 m realize a giant coronagraph
and will achieve conditions close to a total solar eclipse





DynaMICCS Scientific objectives

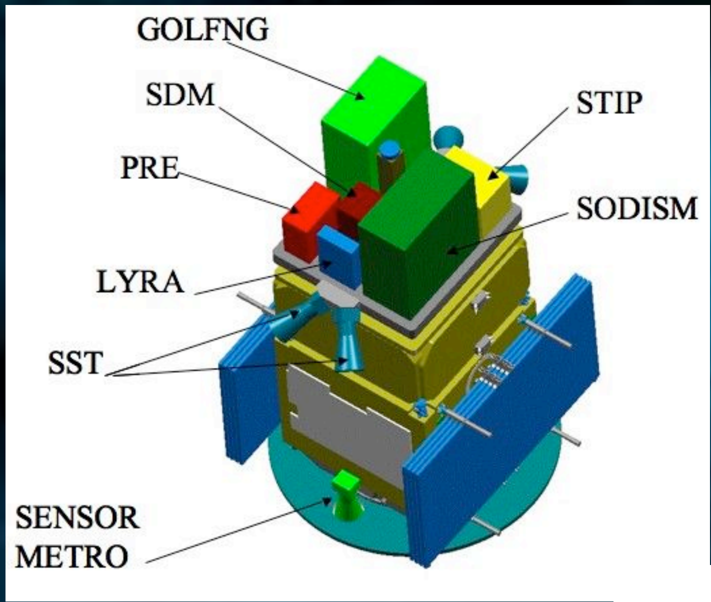
- In looking to the 3 New regions of Investigation
  - The dynamics of the solar core
  - The transition region between sublayers and chromosphere
  - The low corona
- DynaMICCS will attack totally new questions:
  - **Central rotation, central magnetic field**
  - **Origin of different solar cycles**
  - **Source of emergence of coronal mass ejection**
  - **Pursuit of space weather**
  - **Development of the real Solar-Earth connection (space climate) and prediction for the next century …**

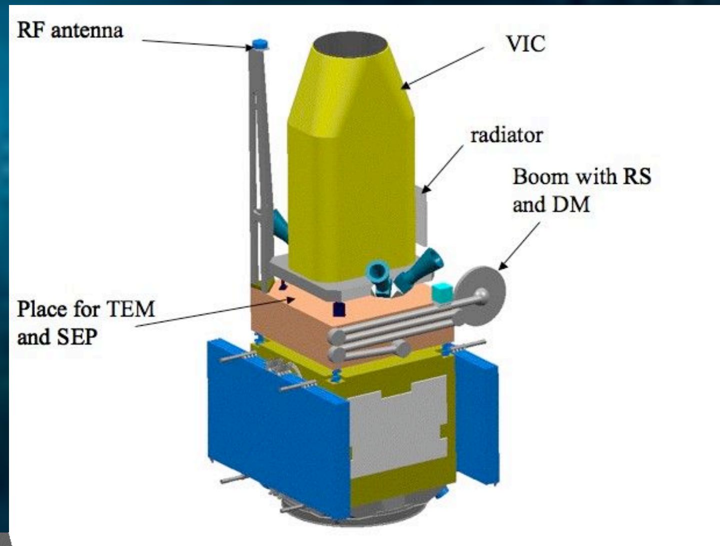


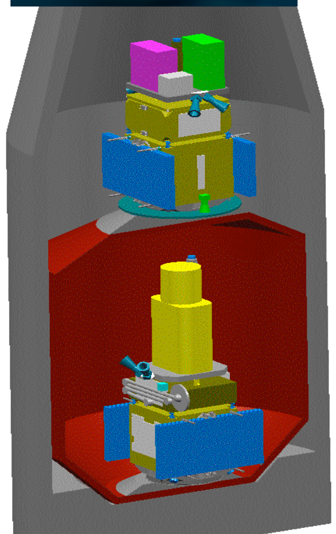
DynaMICCS observables

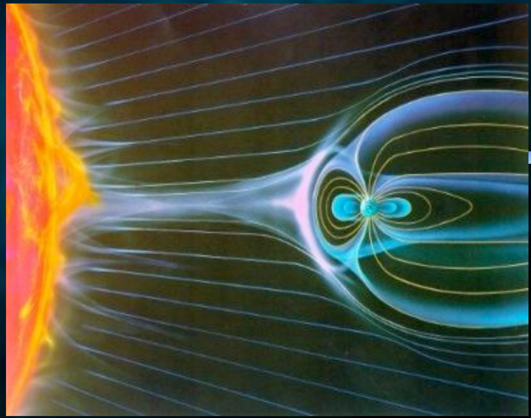
- gravity modes to improve the core and the tachocline dynamics : NEW
- acoustic modes to follow the variability of the rotation in the convective zone and below the tachocline and the latitudinal dependence
- time evolution of radius
- shape deformations NEW
- solar irradiance at different wavelengths from visible to far UV simultaneously
- global magnetic field evolution from the photosphere up to chromosphere or above through lines deformations NEW
- low corona emergence of the flows =>formation flying + IR coronograph NEW
- solar wind quantities

• The objectives require continuity and stability to measure low signals and small variability of important global quantities => Lagrangian point L1


GOLFNG
SDM
STIP
PRE
SODISM
LYRA
SST
SENSOR
METRO


RF antenna
VIC
radiator
Boom with RS
and DM
Place for TEM
and SEP





Summary

DynaMICCS carries all the instruments for understanding the solar magnetism and will contribute the space climate determination

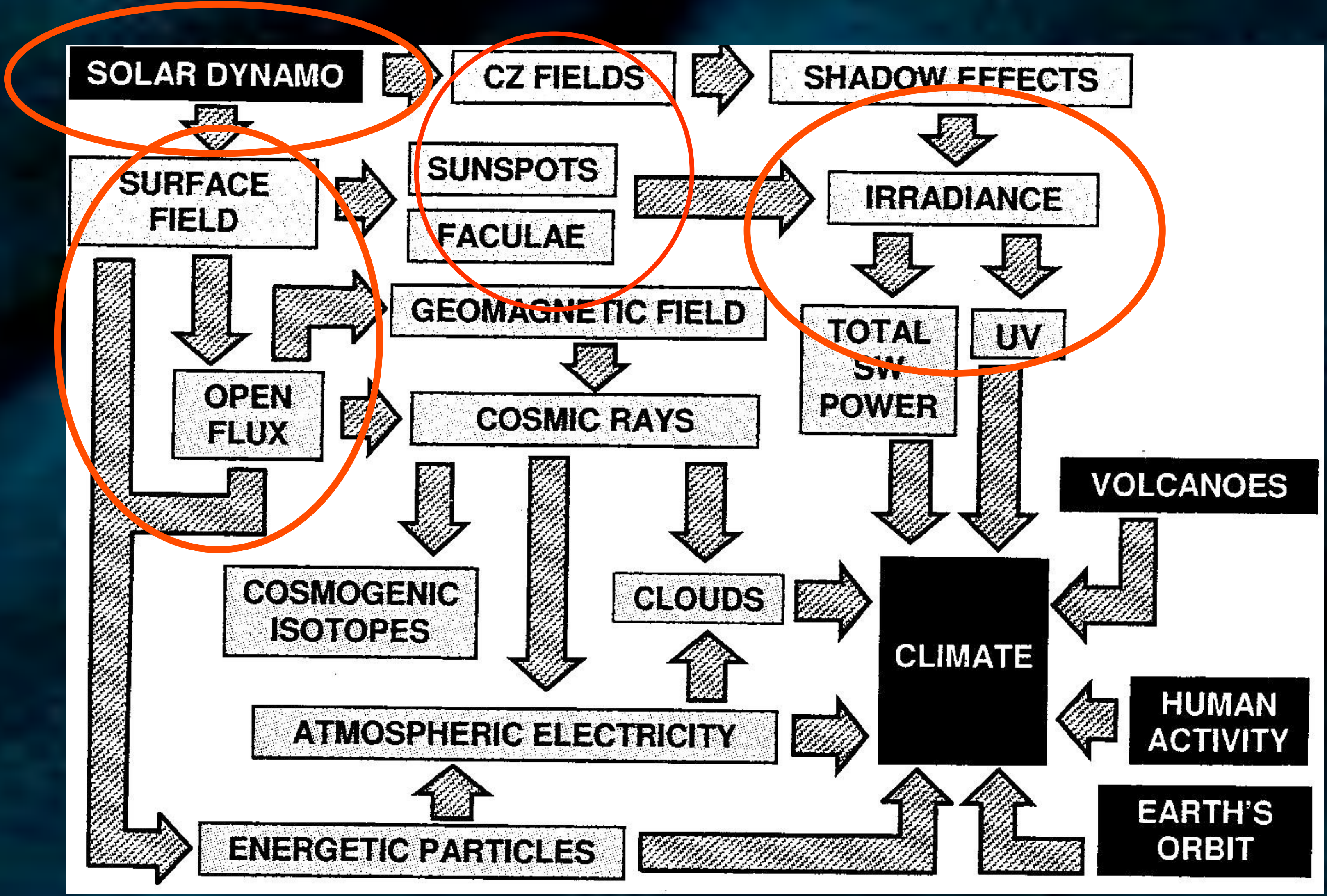
DynaMICCS is an heritage of space and industrial agency efforts: PROTEUS platform and FF on PROBA3?

=> category M for ESA

An heritage of laboratory expertises GOLF-NG, SODISM on PICARD, total irradiance, LYRA on PROBA3, coronograph

DynaMICCS is a scientific and societal mission at L1 ESA, NASA + other space agencies (India ?) + other institutions

DynaMICCS will put constraints on the energetic balance first milestone to improve the earth climate modelling



Lockwood 2004

COSMIC VISION: last news

- 5 solar missions proposed: PHOIBOS, POLARIS, DynaMICCS, Compass, HIRISE
- The last 3: Formation flying, L1, 2 satellites following our study; Compass only dedicated to the corona
- 3 seismic instruments, irradiance, corona and solar wind instruments
- 2 selected at the first stage inside 8: PHOIBOS and HIRISE
- HIRISE: idem than DynaMICCS for scientific objectives but bigger, in using HERSCHEL platform one can put also an interferometer leading to good resolution 30-40 km to study the corona and transmit a large number of data
- Joint efforts between DynaMICCS and HIRISE presentation at ESA level in October for the second selection

Summary

- SoHO has been a success to put constraints on the dynamics of the internal Sun,
- Efforts must be pursue for determining the respective role of magnetic field and gravity waves
- We need to prepare the next big european solar mission horizon 2017 and increase the theoretical , modelling and simulation parts
- GOLFNG performances must be estimated in advance: 2009 is an important year

Real work begins in 2003

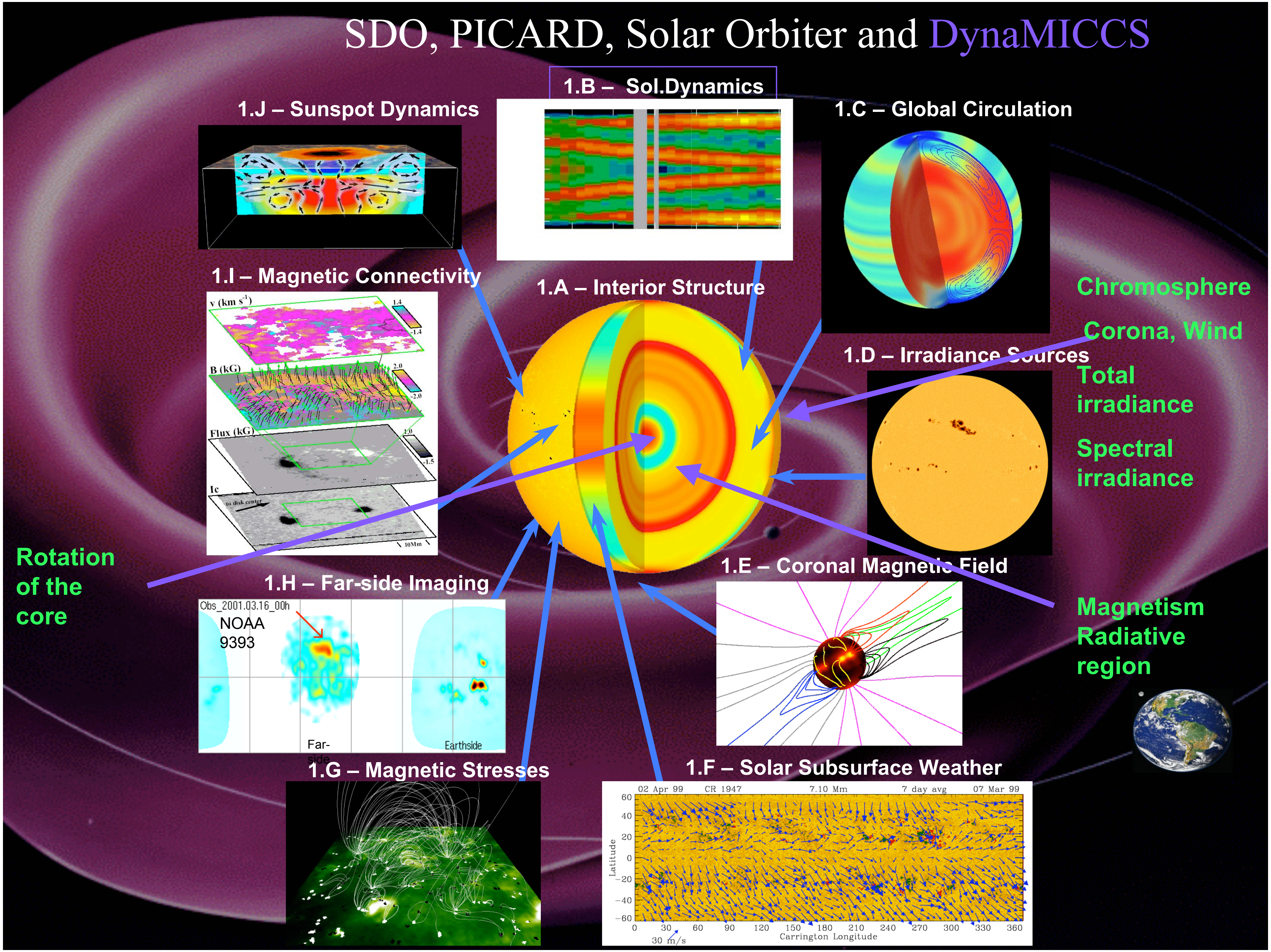
List of GOLF-NG members

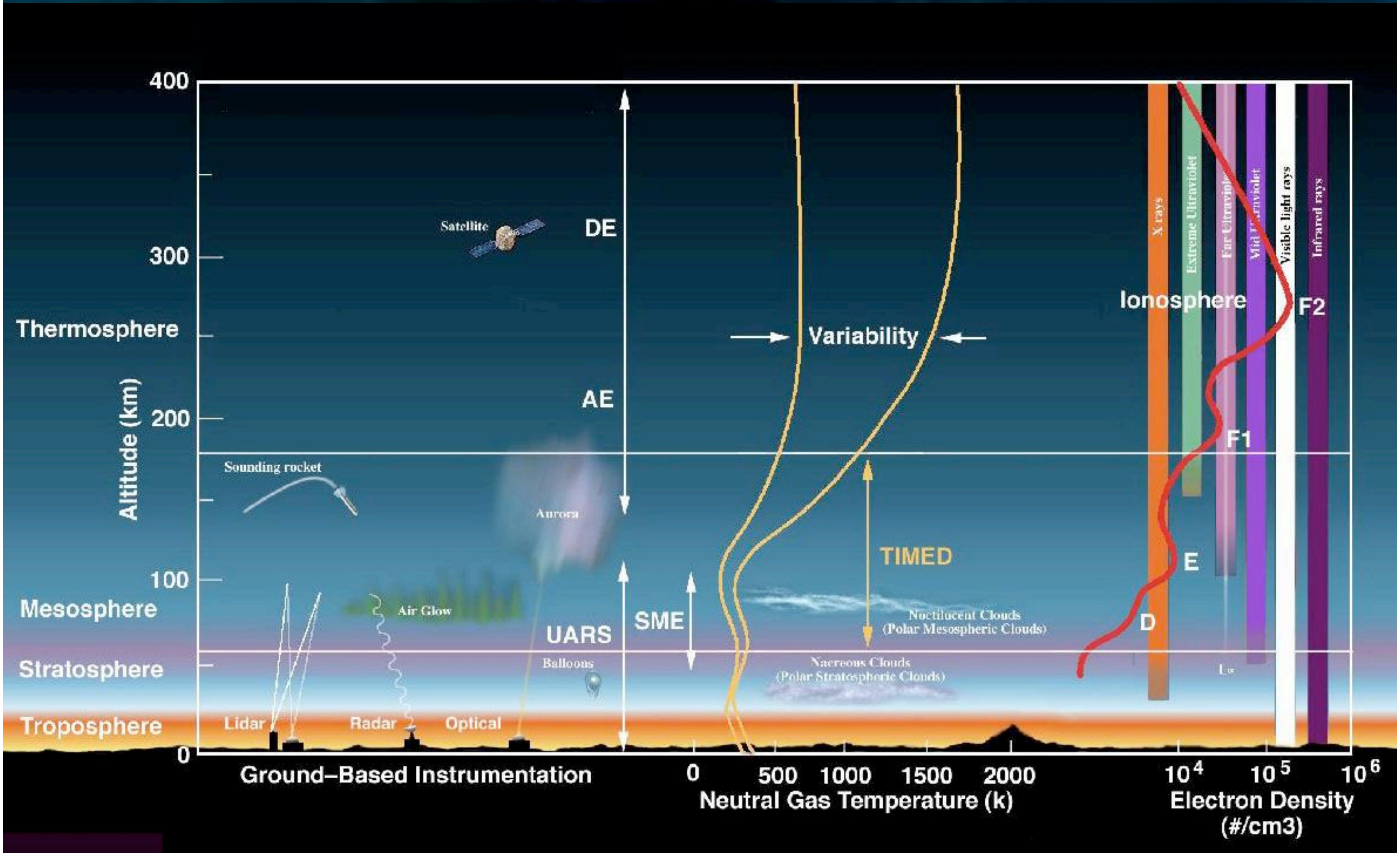
S. Turck-Chièze, P-H. Carton, A. Delbart, R. Granelli, Y. Piret, J-C. Barrière, P. Daniel-Thomas, C. Lahonde-Hamdoun, D. Loiseau,F. Nunio, R. Garcia, J. Ballot, S. Mathur,
DAPNIA, CE Saclay, CEA, 91191 Gif sur Yvette Cedex, France

P. L. Pallé Manzano, A. J. Jiménez Mancebo, S. J. Jiménez Reyes, A. M. Eff-Darwich Pena, S. Korzennik, R. Simoniello
IAC, Calle Via Lactea s/n, la Laguna, Ténérife, Spain

J. M. Robillot, Observatoire de Bordeaux, Bordeaux 1, France

… collaboration is open !


SDO, PICARD, Solar Orbiter and DynaMICCS
1.B – Sol.Dynamics
1.J – Sunspot Dynamics
1.C – Global Circulation
1.I – Magnetic Connectivity
1.A – Interior Structure
Chromosphere
Corona, Wind
1.D – Irradiance Sources
Total irradiance
Spectral irradiance
Rotation of the core
1.H – Far-side Imaging
Obs_2001.03.16_00h
NOAA 9393
Far-side
Earthside
1.E – Coronal Magnetic Field
Magnetism
Radiative region
1.G – Magnetic Stresses
1.F – Solar Subsurface Weather
02 Apr 99
CR 1947
7.10 Mm
7 day avg
07 Mar 99
Latitude
Carrington Longitude
30 m/s


400
300
200
100
0
Altitude (km)
Thermosphere
Mesosphere
Stratosphere
Troposphere
Satellite
DE
AE
Sounding rocket
Aurora
Air Glow
UARS
SME
Balloons
Lidar
Radar
Optical
Ground–Based Instrumentation
Variability
TIMED
Noctilucent Clouds
(Polar Mesospheric Clouds)
Nacreous Clouds
(Polar Stratospheric Clouds)
0 500 1000 1500 2000
Neutral Gas Temperature (k)
X rays
Extreme Ultraviolet
Visible light rays
Infrared rays
Ionosphere
F2
F1
E
D
10^4 10^5 10^6
Electron Density
(#/cm3)