Astron. Nachr. / AN **000**, No. 00, 1 – 797 (0000) / **DOI** ***please set DOI!***

Laboratory performances of the solar multichannel resonant scattering spectrometer prototype of the GOLF-New Generation instrument

S. Turck-Chièze, P.H. Carton, S. Mathur, J.-C. Barrière, P. Daniel-Thomas, C. Lahonde-Hamdoun, R. Granelli, D. Loiseau, F. Nunio, Y. Piret[⋆] and **J.M. Robillot**[⋆⋆]

DSM/IRFU/SAp, CEA/Saclay, 91191 Gif-sur-Yvette Cedex, France and Laboratoire AIM, CEA/DSM – CNRS - Université Paris Diderot – DAPNIA/SAp, 91191 Gif-sur-Yvette Cedex, France

Received 3 Dec 2007, accepted 17 Dec 2007

Key words solar resonant spectrometer, solar oscillation measurements, solar gravity modes

This article quickly summarizes the performances and results of the GOLF/SoHO resonant spectrometer, thus justifying to go a step further. We then recall the characteristics of the multichannel resonant GOLF-NG spectrometer and present the first successful performances of the laboratory tests on the prototype and also the limitations of this first technological instrument. Scientific questions and an observation strategy are discussed.

1 Introduction

The SoHO satellite first milestone of the ESA Horizon 2000 programme, is a real success due to the simultaneous presence of internal and external solar probes. It enriches the present transition period between a classical view of stars and a dynamical view that we are beginning to constrain. The success is partly due to helioseismology which reveals the properties of millions of modes not yet within reach for any other type of stars. This fact enables a strong scientific return with some problems being solved and totally new questions emerging.

Seismology of the Sun and stars will be pursued during the next decade with a strong impact in Astronomy. The successors of SoHO are SDO in the United States (launch in 2009) and Solar Orbiter in Europe (launch in 2014-2015). But these missions have not been designed to probe the deep solar interior.

After more than a solar cycle of continuous observation with SoHO and three decades with the BiSON ground network, it is time to critically review the results obtained by the European community to highlight the advantages and the limitations of the resonant spectrometer instrument and to deduce which directions will lead to improvements. In section 2, we recall the characteristics of the GOLF instrument and its results. The third section deals with the objectives of the GOLF-NG instrument, successor of GOLF, the performances obtained in the laboratory and the necessary improvements to get a scientifically relevant instrument. The last section will be devoted to (1) the questions that we need to solve in the future, (2) the solar proposal at the ESA Cosmic Vision level and (3) the way we might observe during the next decade.

2 Probing the nuclear core

Three instruments from the SoHO satellite (GOLF, VIRGO and MDI, Domingo 1995) have now been observing the Sun down to the core for more than ten years and two ground networks (GONG and BiSON) have accompanied this effort, as they have been operating for the last two or three decades. This redundancy allows us to compare the quality of the observations and to study possible progress. We note that GOLF has been the most successful for the exploration of the solar nuclear core which contains practically half the solar mass and for which the dynamics was totally ignored before the SoHO launch. Moreover, despite the observing conditions of BiSON which are more difficult than around the L1 Lagrangian point, such a network is extremely useful and reaches very good performances for the low degree acoustic modes due to the fact that we can integrate the information for a long period of time (Brookes et al. 1978). In the two cases resonant spectrometers are used.

2.1 Comparison of the techniques used aboard SoHO

GOLF measures the variability of the Doppler velocity by the resonant spectrometer technique on three sodium lines: D1, D2a and D2b (Gabriel et al. 1995). The name of this instrument, Global Oscillations at Low Frequency, was given because it has been designed to measure very small velocities (down to 1mm/s) in order to get the low-degree low-frequency modes, *i.e.* the modes which penetrate deeply in the radiative zone down to the core. The method has been invented by Brookes, Isaak and van der Raay (1978) and is

---

[⋆] Corresponding author: e-mail: cturck@cea.fr, pcarton@cea.fr

[⋆⋆] from the Bordeaux Observatory in France, presently retired used in the IRIS and BiSON ground networks. The GOLF instrument filters the solar light at wavelengths corresponding to the mentioned lines. The corresponding photons, left or right polarised, are absorbed by the atoms of a hot sodium cell and re-emitted in a narrow band, shifted thanks to the presence of a permanent magnet which produces a Zeeman effect. The Doppler velocity is theoretically deduced from the comparison of the left and right circularly polarized photons. Its time variation is measured every 10s. The power spectrum obtained by Fourier transform of the velocity signal is shown in Figures 1 and 2. Despite the malfunction of the quarter wave plate motor, this measurement has been done on one wing (left or right depending on the period of observation) during the 12 years of the SoHO mission (García et al. 2005) thanks to the presence of a small modulation of the magnetic field. Several comparisons have been made between GOLF performances in this configuration and the BiSON and GONG networks and also between GOLF, VIRGO and MDI.

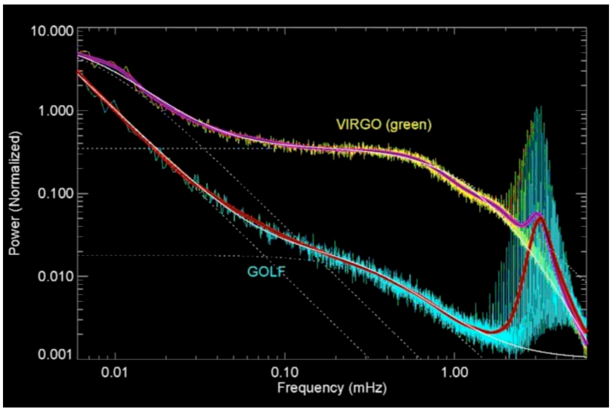


Fig. 1 Comparison of the power spectrum of GOLF and VIRGO which look at the Sun as a star from SoHO. GOLF uses the Doppler velocity technique and VIRGO the variability of the luminosity at different wavelengths. The first technique is largely better at low frequency where acoustic modes are not perturbed by the solar cycle (below 1.6 mHz) and where gravity modes are expected (below 0.4 mHz). From Bedding and Kjeldsen (2006).

Figure 1 shows the superiority of the Doppler velocity technique over measurements of luminosity variations through two instruments located aboard SoHO. During the first two years of observation, one could notice a difference of up to a factor 10 to 30 in the Fourier transform at low frequencies in the range of gravity modes located between 10 to 400 μHz. This is due to two factors. First the GOLF velocity is extracted from the solar atmosphere at a height of 300 to 500 km and this region is less turbulent than the photosphere. Secondly, the GOLF instrument has been specifically designed to detect very low amplitude signal at low frequency down to 1 mm/s in the range of the first gravity modes. This performance is obtained by using photomultipliers and a counting rate of 1.2×10^7 photons/s associated to very stable electronics. Consequently the instrumental noise was significantly smaller than the statistical noise which was chosen as low as possible in relative value (at least during the first years). So, this noise contribution was reasonably flat at low frequencies in the range of gravity modes without any atmospheric perturbation (see Figure 2).

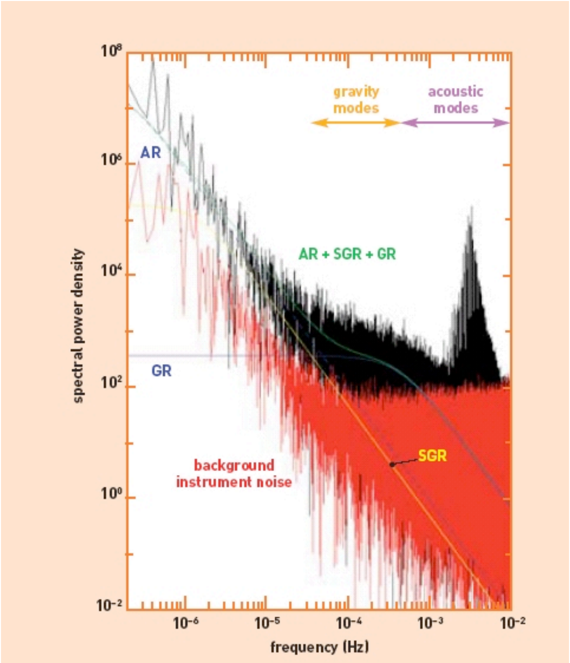


Fig. 2 GOLF velocity measurement power spectrum. We have shown explicitly where acoustic and gravity modes are located together with the different contributions which form the solar noise. The instrumental noise is superimposed in red. From Turck-Chièze et al. (2004a).

2.2 Scientific results

The GOLF instrument has been successful in answering the different questions for which it has been designed. There are three domains where it has given very positive answers:

- the description of the solar core and the prediction of the emitted neutrinos thanks to the detection of previously unknown low-degree low-frequency acoustic modes not polluted by the variability of the external layers during the solar cycle. The sound speed is precisely determined down to 6% $R_\odot$ and the deduced neutrinos in agreement with detections (Turck-Chièze et al. 2001, 2004b, Turck-Chièze & Talon 2008).
- a better understanding of the impact of the solar cycle on subsurface layers by low degree acoustic mode variations above 1.6 mHz (Gelly et al. 2002, García et al. 2008a). The evolution of these modes during the Hale 11 year solar cycle also benefit from the three decades of observations with the BiSON network (Chaplin et al. 2007). They allow us to put some constraints on the lo-

cal and varying subsurface magnetic field (Nghiem et al. 2006).
- the ability to detect gravity modes. We have mentioned that the GOLF instrument has been specifically designed to detect some gravity modes. But the publication of Kumar et al. (1996), after the SoHO launch, on very low surface velocities coupled to the malfunction of the polarizers have put some doubts as to GOLF's ability to detect any signal. Nevertheless, a search strategy (among others) has been defined: first to look for multiplets (it improves the ability to detect gravity mode signal) in the region above 150 μHz where velocities are greatest and then to examine the low frequency region if the first search was successful. In both cases, signals have been detected with more than a 98% of confidence level (Turck-Chièze et al. 2004a, Turck-Chièze 2006, Mathur et al. 2007) and even at low frequency at more than a 99.7% of confidence level (García et al. 2007).

2.3 Limitations of present observations

We are today confident that GOLF has detected the signature of dipolar solar gravity modes. Nevertheless the information on the rotation profile in the nuclear core remains rather poor due to some uncertainties on the identification of the observed components or to the fact that it is difficult to extract the splitting of the modes located in the lower part of the spectrum (García et al. 2007, Mathur et al. 2008). It is interesting to note that the two analyses seem compatible only if the core of the Sun turns quicker than the rest of the radiative zone and is an oblique rotator; this idea was already discussed a long time ago (Isaak 1982). Clearly this conclusion needs to be confirmed by improved observations because the scientific consequences of such a behaviour have a high level of interest. Presently, the analysis of the other instruments (MDI, VIRGO, BiSON and GONG networks) has shown the superiority of space instruments in the gravity mode range: one component of the GOLF gravity mode candidate appears continuously in the VIRGO data (García et al. 2008b). Unfortunately the BiSON data has not yet revealed any signal in this range (Broomhall et al. 2007).

Considering present observing conditions of GOLF, we know since 1998 that we need to go further. The CNES microsatellite PICARD mission selected at that time, will be launched in 2009. It will explore the potential increase of gravity mode sensitivity at the solar limb. An enhancement by a factor of 4 or 5 has been measured with MDI in the range of acoustic modes but it is not evident that such an effect would be sufficient to detect gravity modes with a photometric instrument when considering Figure 1. So it is natural to also push the development of a new instrument using the Doppler velocity technique which derives from our expertise in Europe. The first pollution to limit a good signal/noise ratio in the gravity mode range comes from the Sun itself, so the idea for decreasing this noise is to measure the velocity at different heights in the atmosphere which do not experience the same granulation noise (Espagnet et al. 1995). Trying to do so supposes the exploration of a line sufficiently broad to examine the total range between the photosphere and the chromosphere (see Simoniello et al. 2008, this volume). In that sense, the D1 sodium line is well justified for this purpose. This is the reason why we are pushing the performances of a sodium resonant spectrometer to its limits. The GOLF-NG instrument will be described in the next section. The main objective of this instrument is to reduce both the solar noise and the instrumental noise by a factor of 5 to 10.

3 The GOLF-NG prototype

3.1 A multichannel resonant scattering spectrometer

Like GOLF, the GOLF-NG (Global Oscillation at Low Frequency New Generation) instrument measures global Doppler velocity variations. It is being developed in the CEA/France in collaboration with the IAC/Spain. It results from 30 years of expertise on resonant scattering spectrometers used on the ground (IRIS and BiSON networks) and in space (GOLF/SoHO). The characteristics of this instrument are described in Turck-Chièze et al. (2006). The objectives in space (or possibly on the ground) are to lower the mode detection threshold by about a factor of 5, to detect easier acoustic modes, to identify different components of several individual gravity modes and to pursue the analysis of the asymptotic behaviour of the modes at low frequency for at least $\ell = 1, 2, 3$ and maybe 4 and 5. The improvements are the following:

- we measure simultaneously the velocity at 8 positions between the photosphere and the chromosphere to reduce the noise due to solar granulation in the range of g-modes. As the granulation patterns change with altitude (Espagnet et al. 1995), we will benefit from the lack of coherence in the solar noise to improve the signal to noise ratio in the range of gravity modes; this point has been already shown with GOLF data (García 2004),
- we increase the number of photons detected to also reduce the relative instrumental noise. This relative noise increases with time in the GOLF instrument so we will try to avoid degradation with time to have long observation periods in the best conditions. For this purpose, we have multiplied by 2 the number of detectors per height in the atmosphere: 4 detectors instead of 2, and we must use a stable detector with a higher quantum efficiency (60-75 % instead 5%). Altogether we get 32 outputs (in fact 31 for mechanical reasons) from the cell (instead of 2 in GOLF),
- the gravity mode spectrum is very dense so the identification of components in the observed pattern requires the use of some masks at the entrance of the instrument. Detection and identification of degrees up to 5 for gravity modes is an objective for the coming decade and might allow a precise determination of the rotation profile in the whole solar core,

- adding an entrance polarizer could help measure the mean magnetic field and its time evolution, like in the nominal operation of GOLF. It has been used in space during the first month (Gabriel et al. 1995, García et al. 1999, Chaplin et al. 2003).

This instrument measures the Doppler shift of the D1 sodium solar line alone (in contrast to GOLF which was using the 3 lines D1, D2a, D2b only knowing their mean position). The associated photons are compared to those of an absolute standard given by the sodium vapour cell, the heart of the instrument. A small portion of the line is measured by the resonant photons which escape from the vapour cell. It is split into its Zeeman components by means of a longitudinal magnetic field, the strength of which varies linearly along the axis of the magnet to explore different heights in the atmosphere located between 300 and 1000 km (Jiménez-Reyes et al. 2007). One selects simultaneously 8 points on the right wing of the line or 8 points on the left wing, including one fixed point at the center of the line (supposing no shift of the line, see Figure 3) by changing the circular polarization of the incoming flux thanks to liquid crystals. It avoids the change of polarisation by a motor and it reduces the weight of this instrumental part. The instrument must measure a flux high enough to reduce the instrumental noise or (and) to allow consecutive measurements of portions of the Sun with a good statistics and no saturation. A second liquid crystals polariser could be installed at the entrance to get a spectrum of the mean magnetic field.

A second objective of this instrument is to put some constraints on the influence of the magnetic field on the solar atmosphere. In measuring the sodium line in 15 points every 2 seconds, we will probably be able to check atmospheric models and their evolution with solar activity.

3.2 The subsystem level

During the last 3 years, time has been devoted to solving the critical technical problems (Carton et al. 2008) we need to face to succeed measuring the 31 resonances along the cell (Figure 4). The sub-systems have been studied separately to estimate the performances of the prototype (magnetic field linearity, response of the photodiode matrix detector, dark current, optical design, thermal equilibrium of the cell, reflection of light ...). GOLF-NG is an extremely complex instrument to construct because it needs to achieve very good performances to be able to detect signals corresponding to velocities as small as a fraction of mm/s. It needs (1) a permanent magnet of small size varying linearly between 0 and 12 kG, (2) good thermal conditions of the cell heated presently to around 170°C and located inside a magnet maintained at a temperature around 25°C thanks to (3) an heavy insert piece (see Figure 4). The long but small cell (8 mm* 60 mm) is filled with pure sodium and must be used with caution to prevent any deterioration of the glass properties and (4) to keep a good thermal equilibrium of the cell bulk despite the 31 outputs with a temperature homogeneity within only several °C and a stem heated to a temperature lower by 10-15 degrees. The difficulties are to limit the reflection of light in the cell, a loss of counting rate between the cell and the detector. (5) The chosen detector for the prototype is able to measure a high flux (up to 1.5 10^8ph/s) per photodiode without saturation. Unfortunately, the electronic noise is too high (see Mathur 2007). In fact this electronic noise needs to be about 1/10 of the statistical uncertainty to get an instrumental white noise in the range of gravity modes instead of an instrumental noise increase below 10^{-3} Hz.

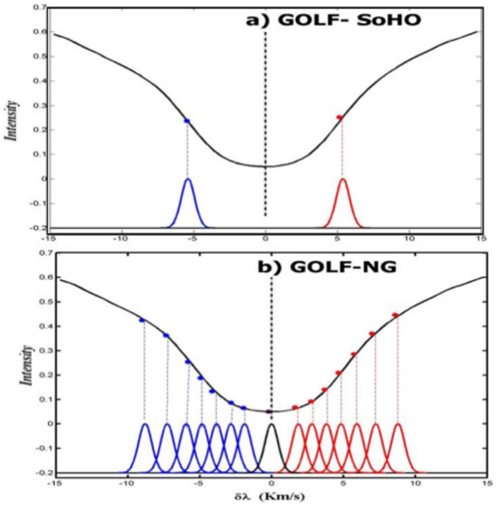


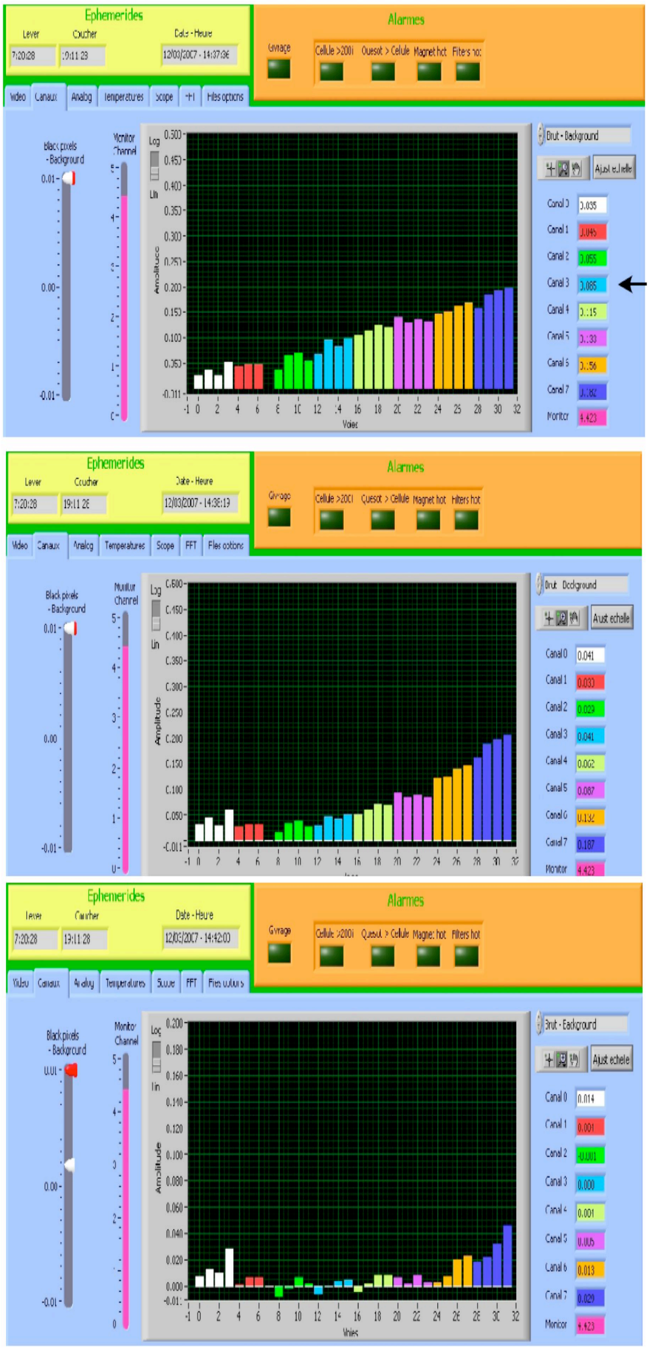
Fig. 3 Solar resonant spectrometer GOLF-NG principle: an alternating measurement of 8 points along the blue wing and then 8 points along the red wing ensures a measurement of 15 points along the line in 2s (or less) to extract the velocity at different heights in the atmosphere. These different points are obtained by putting the cell inside a permanent magnet delivering a magnetic field varying quasi linearly from 2 to 8 kG.

3.3 Laboratory tests

Most of the hard points have been solved at the sub-system level and a complete prototype equipped with Hamamatsu photodiodes has been studied during the year 2007.

The laboratory tests are done in space conditions. It is useful to study the critical thermal conditions i.e. in a vacuum tank (see Figure 4c) to prepare this instrument for space measurements.

Different tests, which we briefly summarize here, have been performed, first with a LED and then with the Sun. At the entrance of the instrument, two filters can be used: the first one is located around the NaD1 line (∼589.6 nm) with a width of 0.6 nm, the second one is centered on the continuum (∼591 nm) with a larger width. These filters enable us to distinguish the luminosity variation (if we look directly at the corresponding photons without looking through the cell) from the velocity variation (measurement of the photons absorbed and re-emitted by the sodium cell) during solar observations. When we use a lamp at the entrance of the



Lever 7:20:28
Coucher 19:11:23
Date - Heure 12/03/2007 - 14:37:36
Brut - Background
Canal 0 0.035
Canal 1 0.045
Canal 2 0.055
Canal 3 0.085
Canal 4 0.115
Canal 5 0.133
Canal 6 0.156
Canal 7 0.182
Monitor 4.423

Lever 7:20:28
Coucher 19:11:28
Date - Heure 12/03/2007 - 14:38:19
Brut - Background
Canal 0 0.041
Canal 1 0.033
Canal 2 0.029
Canal 3 0.041
Canal 4 0.062
Canal 5 0.087
Canal 6 0.132
Canal 7 0.187
Monitor 4.423

Lever 7:20:28
Coucher 19:11:28
Date - Heure 12/03/2007 - 14:42:00
Brut - Background
Canal 0 0.014
Canal 1 0.001
Canal 2 -0.001
Canal 3 0.000
Canal 4 0.001
Canal 5 0.005
Canal 6 0.013
Canal 7 0.029
Monitor 4.423

Fig. 6 A quick look at solar measurements done in March 2007 at Saclay during half an hour. One observes the resonance on the 31 channels for the NaD1 filter in the two polarity measurements (left and right of the line on the first two figures) and the absence of resonance (last figure) when the second filter is chosen (corresponding to a continuum region where we have no sodium line), in which case we measure the scattered light. In the different measurements, the subtraction of the detector background is already applied.

instrument or when we look at the Sun, the continuum measurement through the cell allows us to measure scattered light inside the cell.

The resonance has been obtained for each channel with a LED and Figure 5 shows how the resonance flux evolves with the temperature. One notes that the behaviour is similar for the 8 positions and that the dispersion between the channels, which is not so large and results from the dispersion between the photodiodes, can be corrected.

A rapid measurement with the Sun has been performed in March 2007. Figure 6 shows that the resonance appears clearly for the two polarizations and the shape of the photon flux along the cell corresponds reasonably well with what is expected from the different points along the line. Complementary measurements have also been done with a laser

Fig. 4 a) View of the long cell equipped with the heaters and prepared with its 31 outputs (8*4-1). b) The same cell inside an insert piece designed in Saclay and constructed at the IAC. It ensures the cell's mechanical position and the thermal difference between the cell's high temperature and the low temperature of the magnet. c) A view of the GOLF-NG prototype functioning in a vacuum to respect the thermal conditions in space.

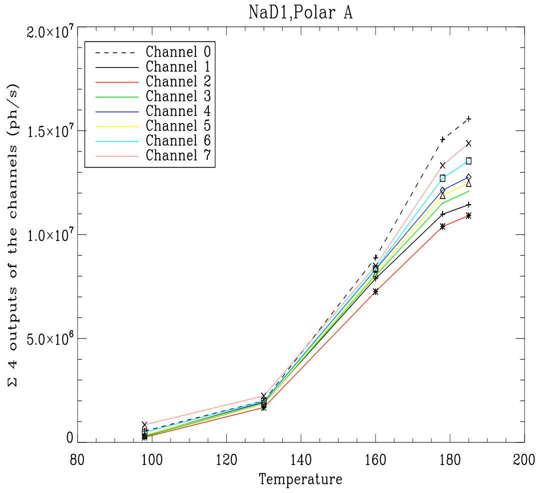


Fig. 5 Mean value of the resonant photon response of each channel as a function of the temperature of the cell using a calibrated LED at the entrance of the instrument.

to properly estimate the wavelength width of the different channels (typically 25 mAngstrom) illustrated in Figure 3.

Several corrections are taken into account: the dark current including the electronic noise and the reflection light (measured at low temperature) or the scattering light measured with the continuum option. These corrections seem much more severe for the extreme channels with the Sun, in particular for the channels at the bottom of the line, and must be improved in the scientific instrument.

We have deduced from the first series of measurements the response of the whole system. Complementary measurements have been done during the year and a new campaign of measurements with the Sun in Saclay has been done in March 2008 which show nearly nominal fluxes. The resonant flux is presently nearly nominal. A campaign of tests is scheduled at Tenerife to study the interest of this multichannel resonant scattering spectrometer, even though the nominal performances have not yet been reached with this prototype and only allow a first estimate of the measurement of the solar noise at different heights in the atmosphere.

3.4 Towards a scientific instrument

Several problems must be solved before producing an instrument scientifically representative of a new generation resonant spectrometer for space observations:

- we cannot avoid having the sodium vapour attack the pyrex cell at high temperature (the GOLF instrument was equipped with a galeniet glass). This problem limits the resonance temperature and consequently the lifetime of the cell. The prototype must be used at a lower temperature than the nominal one (165 instead of 190 degrees) with a reduction of the flux by practically a factor of 2. So we are investigating manufacturing another cell for the scientific instrument to avoid this problem which is only a limitation in the final flux (which may also be compensated by other actions). We will also estimate the cell lifetime with pyrex at a reasonable temperature.
- we need to use a detector which delivers 2.5×10^7ph/s per channel at mid height of the line with an intrinsic noise significantly smaller than the statistical one. It is not the case today for arrays of Hamamatsu photodiodes containing an integrated electronic which produces an electronic noise at the same level as the statistical noise for an optimal temperature of 6 degrees. Such limitations have a direct impact on the behavior of the instrument at low frequency leading to an increase

of the instrument background below 1 mHz which competes with the solar background. We hope to use a CCD detector and add together the pixels corresponding to a spot of about 1.3*1.3 mm^2. This detector will be cooled to the appropriate temperature (-40 or -50 degrees) to get a low instrumental noise largely dominated by the statistical noise (by about a factor of 10),
- for an optimal response of the whole instrument, we could slightly increase the entrance pupil, the response of the filters or the quantum efficiency of the detector. We will estimate this need after the determination of the flux response of the prototype to sunlight in the laboratory (partly done already) and in Tenerife,
- we need to study some masks at the entrance of the instrument. This will be useful in order to take advantage of the amplification of the signal at the limb or to identify without ambiguity the observed patterns when the first g-modes will appear.

So after the first tests in a helioseismic station, the next step will be the building of a scientific instrument hopefully more compact and having improved performances that we could put in different sites. It seems today that Tenerife is a good site to analyze the behavior of the solar noise at different levels in the acoustic range and then in the gravity mode range when the detector will be sufficiently good to avoid any instrumental perturbation. Then a measurement in Dome C could be determinant to try to observe g-modes on ground during 1 or 2 campaigns of several months. If such a step demonstrates the potential of the GOLF-NG concept, it will be easy to extrapolate it to a space version very quickly. We note that the development of an operational multichannel resonant scattering spectrometer needs a very dedicated effort during several years if we want to detect properly gravity modes in a reasonable period of time (at least one or two months for real constraints on the rotational splittings and then several months for some magnetic field displacement of these splittings).

4 Perspective for the next decade

The success of SoHO invites the European community to pursue its investigation of the Sun as a whole because it is the only star which can deliver an internal information on all the processes in action in stars. SoHO and CLUSTER have also revealed a strong interaction between the Sun and the Earth. Knowing the different origins of solar activity justifies a continuous and permanent observation of our star from the core to the corona. SDO and Solar Orbiter will only partly cover this objective. This is the reason why we have described new scientific perspectives during the Cosmic Vision meeting at ESA in 2005 and prepared the DynaMICCS formation flying mission which is one way to answer the questions through a dedicated unique mission (Turck-Chièze et al. 2005, 2006, 2008). It is interesting to note that the origins of the Maunder minimum or of the historical maxima must be connected to the understanding of the dynamical processes of the solar machine including the dynamics of the radiative zone. We need such information for a proper prediction of solar variabilities during the next century.

4.1 The new scientific objectives

A lot of questions remain unsolved and will not be solved by the already confirmed missions. They correspond to the knowledge of the dynamics of the radiative zone which represents 98% $M_\odot$ and more specifically of the core with more than 50% $M_\odot$ and require gravity mode detections and associated theoretical efforts. They can be summarized here:

- What is the dynamical influence of the central rotation and of the magnetic field on external activity?
- Which processes are at the origin of the solid body rotation observed in the radiative zone down to 0.2 solar radius? What is the respective role of the agents responsible for the redistribution of the angular momentum: rotation, gravity waves, magnetic field? What are the consequences of a rapidly rotating core? Is there another dynamo in the core?
- What is the topology, strength and influence of a fossil field? How do progressive internal waves modify the overall internal dynamics? Could we determine the nature of the nonlinear interactions between the convective dynamo and the fossil field if it exists?
- How do we check the presence of large scale flows, their amplitude and their mixing properties in the radiative zone? Could we put some constraints on the presence of magnetohydrodynamical instabilities in the radiative zone and their coupling with the convection zone?

These questions show the need to understand deep solar magnetism and deep solar motions in their different forms.

The mission called DynaMICCS for *Dynamics and Magnetism from the Core to the Corona of the Sun* is conceived to measure the observables which must identify the different sources of the solar cyclic variabilities. To reach this objective, crucial regions of the Sun must be scrutinized simultaneously: (1) the previously unexplored dynamics of the inner core thanks to gravity modes, (2) the time evolution of the radiative/convective zone interface layer thanks to a large number of acoustic modes, (3) the emergence of the flows from the photosphere to the chromosphere layers thanks to the study of different lines and different heights in the atmosphere, (4) the evolution of the low corona never explored continuously thanks to a permanent eclipse, (5) the total and spectral irradiance and (6) in-situ measurements of plasma/energetic particles/magnetic fields of the solar wind.

The complementary instruments are well identified but unfortunately this mission will not be scheduled in ESA before 2020 due to the delay of the Solar Orbiter mission.

Among them, GOLF-NG has a crucial place if its performances are in accordance with its objectives.

4.2 Progressing on the solar core dynamics during the next decade

It seems very important to estimate the potential of the new technique of GOLF-NG in comparison with GOLF, the BiSON network or the SODISM instrument aboard PICARD. While building the Solar Dynamical Model (SDM) instead of the Standard Solar Model (SSM) (Turck-Chièze 2008) and developing more and more realistic 3D solar simulations (Brun & Zahn 2006), it is important to find a way to constrain these models with a scientific instrument like GOLF-NG during the coming decade, to add constraints on the solar core dynamics and to explore convective dynamics with SDO and PICARD.

We hope to accomplish the following steps: first, a campaign with the prototype in Tenerife to see how the acoustic modes behave at different heights, and what we learn from the line and the atmosphere, if the present detector allows these measurements; then we hope to develop a scientific instrument for GOLF-NG that would have the characteristics of a space version, in terms of weight and size. With this instrument, we will estimate the interest of this new multichannel spectrometer at very low frequency (the gravity-mode range) in comparison with the instruments of the BiSON network, HMI aboard SDO and SODISM aboard PICARD. We would like to check its performances at Dome C through one or two rather long and continuous observation campaigns of at least 1 month to be able to really quantify the performances and see if one needs to improve them. The polar location and the data continuity of Dome C would be crucial for validating the performances and we hope to detect the already seen g-modes. The important periods for the observations of GOLF-NG will be the years 2009-2012 where SoHO observations will be finished or difficult with GOLF. During this period, PICARD and SDO will be operational. The schedule is tight and assumes a good organization.

If the performances of GOLF-NG are satisfactory, it will be integrated in a space mission as soon as possible. The best would be to overlap in time with the SDO mission. GOLF-NG could be also included in a ground network.

Helioseismology in Europe constitutes a long and dedicated effort for the last three decades, in which it is at the origin of a lot of discoveries and the transition to a multiscale stellar physics. The present project benefits from a French culture developed in the IAS, Nice, Saclay and Meudon with some interaction with Themis. Moreover, the expertise of British and Spanish teams are important. Thus, such effort must be pursued at low cost for at least one decade continuously.

This discipline largely contributes to the understanding of the dynamics of stars and will play, in the future, an important role on the long term Sun-Earth relationship. It will enrich the development of dynamical stellar evolution. Finally, it will indirectly contribute to the knowledge of how planets evolve with their stellar environment, a new direction of very promising improvements with KEPLER, GAIA and PLATO.

Acknowledgments

The GOLF-NG instrument is developed under the responsibility of S. Turck-Chièze and P.H. Carton by an international consortium joining the CEA/Saclay team and the IAC team directed by P. Pallé in Spain. The whole consortium will publish detailed analysis of the GOLF-NG prototype and wishes to thank the GOLF and IRIS teams for transmitting their useful expertise for this instrument. The DynaMICCS mission proposed to ESA has evolved through the DynaMICCS/HIRISE consortium. This collaboration is supported by scientists coming from 30 institutes from Europe, India and the United States.

References

Bedding T. R. and Kjeldsen H.: 2006, *Mem. Della Soc. Astron. Ital.* **77**, 384

Bertello L., Henney C. J. and Ulrich R. K.: 2000, *ApJ* **537**, L143

Broomhall, A. M., Chaplin, W.J., Elsworth, Y.: 2007, *MNRAS* **379**, 2

Brookes J. R., Isaak G. R. and van der Raay H. B. :1978, *MNRAS* **185**, 1-17

Brun, A. S. & Zahn, J.P.: 2006, *ApJ* **457** , 665

Carton P. H., Turck-Chièze S et al.: 2008, *to appear in Experimental Astronomy*

Chaplin, W. J., Dumbill, A. M., Elsworth, Y. et al.: 2003, *MNRAS* **343**, 813

Chaplin, W. J., Elsworth, Y., Miller, B.A. et al.: 2007, *ApJ* **659**, 1749

Domingo V., Fleck B. and Poland A. I.: 1995, *Sol. Phys.* **162**, 1

Espagnet O., Muller R., Roudier, Th., Mein, N., Mein, P.: 1995, *A&A Suppl. Ser.* **109**, 79

Gabriel A., Grec G., Charra J. et al.: 1995, *Sol. Phys.* **162**, 61

García R. A., Boumier P., Charra, J. et al.: 1999, *A&A* **346**, 626

García R. A., Regulo C., Turck-Chièze S. et al.: 2001, *Sol. Phys.* **200**, 361

García R. A., Jiménez-Reyes S. J., Turck-Chièze S., Mathur S.: 2004, ESA-SP **559**, 432

García R. A., Turck-Chièze S., Boumier P. et al.: 2005, *A&A* **442**, 385

García R. A., Turck-Chièze S., Jiménez-Reyes S. et al.: 2007, *Science* **316**, 1537

arcía R. A., Mathur S., Ballot J. et al.: 2008a, *Sol Phys* in press

arcía R. A., Jiménez-Reyes S., Mathur S. et al.: 2008b, *Astron. Nachr.*, in press

Gelly B., Lazrek M., Grec G. et al.: 2002, *A&A* **394**, 285

Isaak, G.: 1982, *Nature* **296**, 130

Jiménez-Reyes S. J., Chaplin W. J., Elsworth Y. et al.: 2007, *ApJ* **654**, 1135

Kumar P., Quataert E. J. and Bahcall J.: 1996, *ApJ* **458**, L83

Mathur S.: 2007, Thèse de doctorat, Paris XI

Mathur S., Turck-Chièze S., Couvidat S. and Garcia R. A.: 2007, *ApJ* **668**, 594

Mathur S., Eff-Darwich, A., García R. A. and Turck-Chièze S.: 2008, *A&A* accepted

Nghiem P. A. P., García R. A. and Jiménez-Reyes S.: 2006, *ESA-SP 624* 70
Turck-Chièze S.: 2006, *Adv. Space Res.* **37**, 1569
Turck-Chièze S.: 2008, JPCS, Proceedings of the HELAS II International Conferenceheld in Göttingen : Helioseismology, Asteroseismology and MHD connections, ed by L. Gizon
Turck-Chièze S., Couvidat S., Kosovichev A. et al.: 2001, *ApJ* **555**, L69
Turck-Chièze S., García R. A., Couvidat S. et al.: 2004a, *ApJ* **604**, 455
Turck-Chièze S., Couvidat S., Piau L. and Ferguson, E.: 2004b, *Phys. Rev Lett.* **211102**
Turck-Chièze S et al. : 2005, *ESA-SP 588* **39th ESLAB symposium** p 193
Turck-Chièze S., Carton, P. H., Ballot, J. et al.: 2006, *Adv. Space Res.* **38**, 1812
Turck-Chièze S. & Talon, S.: 2008, *Adv. Space Res.* **41**, 855
Turck-Chièze S et al.: 2008, *Experimental Astronomy* , in press