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The Fate of Solar Observations from Space

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Abstract. In the past 10 years, observations from space have generated a genuine revolution in our understanding of the Sun. Its interior is now "observed" down to a few % of the solar radius, its internal dynamics, its rotation and the large scale flows that are found to exist under its "surface" are studied continuously for over nearly a complete solar cycle. The mechanisms that underlie solar activity are better understood as well as their effects on the heliosphere and on the planets of the Solar System, in particular on the Earth.

However, there are still opened questions that deserve to be answered through a new generation of space instruments, requiring the best experts in the world and an extended fleet of space missions that no single country is able today to undertake alone. In this context, the International Living with a Star programme is a key element that must be pursued with full strength. At the same time, new missions that are not part of that programme should begin to be studied. They will provide the ultimate resolution and accuracy that are necessary to go a step further in the knowledge of the Sun and of its effects on our planet.

1. Introduction

The interest of studying solar physics is twofold. First, the Sun is the closest star to the Earth. It offers a unique possibility for observation, in particular its atmosphere can be studied in great detail, and spatially resolved observations of its disk can be performed. Understanding the structure and the physical processes at play inside the Sun is mandatory for any kind of study of star formation, galaxy evolution or cosmological models. The Sun is a unique laboratory for fundamental research in particle and atomic physics, magnetism, plasma physics and their mutual interplay. It is a reference star.

Second, in recent years, the Sun's interaction with the Earth's atmosphere has gained more and more attention. Various studies have been performed of the impact on the climate of the variations of the solar radiative and particle flux and of the solar irradiance. The extreme ultraviolet radiation has direct effects on the Earth's middle and upper atmosphere. In addition, both the interplanetary medium and the Earth's magnetosphere and ionosphere are directly influenced by the solar wind. During unusually high particle flux conditions, terrestrial systems like communication networks, power grids, and satellites, can suffer deleterious effects. Since such systems are more and more indispensable for our modern way of living, it becomes necessary to understand better the processes through which the Sun influences the Earth, and possibly to predict the manifestations of its activity.

These two aspects of solar physics determine the future evolution of that discipline and the trend in the instruments that are required for observations.

2. The Recent Progress in Ground Based Capabilities

Numerous high-standard solar observatories are presently operated all over the world. Ground-based astronomical observations are certainly cheaper than those obtained from space. They have nevertheless always been compromised by cloudy weather or turbulence in the Earth's atmosphere, disturbing the seeing, limiting the angular resolution to one arc-second. The seeing problem, however, has recently been overcome by new correction techniques leading to spectacular improvements in the spectral bands that are capable of penetrating the Earth's atmosphere (Scharmer et al., 2002).

Detectors of neutrinos have provided unique tools to probe the interior of the Sun by comparing the emitted flux with the standard models predictions. In 2001 and 2002, the Sudbury Neutrino Observatory (SNO) was able to measure the ratio of the electron neutrino flux to the total neutrino flux (all flavors) confirming that the total count is in excellent agreement with the standard solar model and with the results of helioseismology, putting the long-standing solar neutrino enigma to a rest (SNO collaboration, 2001, 2002).

3. The Unique Advantages of Solar Observations From Space

In spite of their relatively high cost, solar space missions offer unique advantages, such as the capability to operate outside the Earth's atmosphere and to use all wavelengths of the electromagnetic spectrum. That capability has been fully exploited to probe the atmosphere of the Sun, since each different regime corresponds to light emitted in different temperature layers. Multi-spectral tomography is a powerful diagnostic tool for the investigation of phenomena in three dimensions. In addition, space observatories are not affected by the Earth's atmospheric perturbations, thereby permitting perfect seeing conditions and making it possible to use telescopes at their diffraction limit.

Space also permits the exploitation of unique observing sites such as the sun-synchronous orbits (TRACE) or the halo orbits around Lagrange point L1 (SOHO), allowing uninterrupted solar observations. Ulysses' orbit, perpendicular to the ecliptic plane, is also unique and has allowed the first observations ever of the magnetic properties of the Sun above the poles and of the distribution of the solar wind velocity and density with heliographic latitude.

Table 1 lists the eight space missions that have led to a genuine revolution in solar physics (Bonnet & Pauluhn, 2004).

4. What Have We Learnt?

The availability of these new facilities has led to major progress in our understanding of the Sun. We briefly describe some of these most important findings.

4.1. *The Sun's Interior and Solar Internal Rotation*

Helioseismology observations from ground-based networks and from SOHO, in combination with the results from neutrino measurements, supplied corroborating evidence that the standard solar model is basically correct with a precision of a few parts per thousands. However, we do not yet reach the deep core below a few percent of the solar radius, and our present knowledge of the deep interior is poor.

SOHO-MDI data (Schou et al.,1998) have also yielded the variation of solar rotation in the convection zone and in the outer part of the radiative core with unprecedented accuracy. Figure 1 shows a combination of results from MDI and ground-based data. The rotation of the core at distances less than 0.05 Rs is still uncertain because of the unavailability of modes penetrating deep enough and in particular the g-modes. The present techniques (GOLF instrument on SOHO), have not allowed yet an unambiguous detection (Turck-Chièze et al., 2004). At high latitudes, the results differ significantly, due to the difficulty of measuring mode splitting near the poles.

[H]

Missions	Years of operation	Origin
Yohkoh	1991/2001	Japan
Ulysses	1990/....	ESA/NASA
CGRO	1991/2000	NASA
SOHO	1995/....	ESA/NASA
TRACE	1998/....	NASA
ACE	1997/....	NASA
CORONAS	2001/....	Russia
RHESSI	2002/....	NASA

Table 1. The space missions that created a true revolution in solar physics

At the base of the convection zone, small oscillations (6 to 8 nHz peak-to-peak) have been observed showing a periodicity of about 1.3 years. The cause of these variations near the transition between the radiative core and the convective zone (tachocline) is not yet understood and their relationship with the solar cycle is not clear.

4.2. *Solar Wind Acceleration and CME's*

The structure of the solar wind was studied by Yohkoh, SOHO and Ulysses. Ulysses in particular has unambiguously proven the existence of two types of wind that differ in speed, elemental composition, and charge-state composition (Geiss et al., 1995). The fast steady wind is associated to the coronal holes and the coronal streamers are the sources of the slow wind (Hassler et al., 1999), (Wilhelm et al., 1998).

Most probably, the fast wind is to a large part sustained through high-frequency wave dissipation, already in the lower solar corona (Marsch et al., 2003). Data from more than 2000 ion species measured by SOHO show that the acceleration mechanism can be attributed to ion-cyclotron dissipation of Alfvén waves (Cranmer, 2000). The high-frequency waves are damped already very efficiently when they resonate with ions of relatively small charge-to-mass ratios in the lower corona.

The slow solar wind is by far more irregular and filamentary than the fast wind. Roughly 80 to 90 % of the slow wind connects to variable fields in the magnetic network and originate in the streamer belt. The other fraction of the slow wind has no connection to the coronal base. It comes in the form of small plasmoids or bubbles (Sheeley et al., 1997), and seems to originate from bursty reconnection processes, mostly at points of field reversals at the top of coronal streamers.

The Coronal Mass Ejections or CME's, (Crooker et al., 1997) are playing the most important role in solar-terrestrial relations. They are due to the disruption of closed magnetic structures along a huge part of the solar surface. Their mass ranges generally

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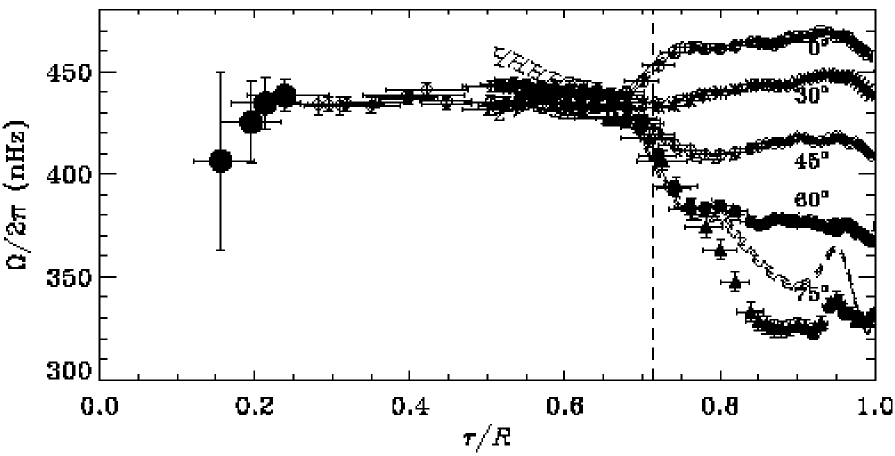

Figure 1. Rotation rate, as a function of fractional radius at different latitudes within the Sun. The results in the outer part (for $r > 0.5$ Rs) were obtained with MDI (Schou et al., 1998), the results for $r < 0.45$ Rs were obtained from a combination of BISON and LOWL data (Chaplin et al., 1999). (Courtesy, M. Thompson.)

from 10^{15} to 10^{16} g. Their fronts propagate through interplanetary space with speeds between 100 and 1000 km/s, the average being 400 km/s (Brueckner et al., 1995).

4.3. *Atmospheric Heating*

The space revolution has also cast new light on the long-standing problem of chromospheric and coronal heating. While the base of the chromosphere is heated by pure acoustic shock waves, the lower and middle parts, where the relative importance of the magnetic flux tubes increases, are heated by longitudinal MHD shock waves propagating in the vertically oriented flux tubes which spread with height and eventually fill the entire available space. In the upper parts of the chromosphere non-wave magnetic processes like micro- or nanoflares may also contribute to the heating (Ulmschneider and Kalkofen, 2003).

In the transition region, observations from SOHO and TRACE have revealed a finely structured, highly dynamic and extremely time variable plasma region, at time scales of minutes (Kjeldseth-Moe, 2003), structured by numerous magnetic loops. Flaring events caused by magnetic reconnection are observed on a scale from large flares to nanoflares, spanning several orders of magnitude in the energy spectrum. There are many indications that significant variations occur on spatial and temporal scales that are smaller than can be resolved by today's instruments. Observing these transition region phenomena poses the highest demands on spatial and temporal resolution for future instrumentation.

5. What's Left For The Future?

Our Sun is clearly a magnetic star, and further progress must address in priority the mechanisms underlying the generation of the field through the dynamo process in the interior, how it varies with time and how it dissipates its energy to the upper layers, in the solar wind, the interplanetary medium and the environment of the Earth. Therefore, what's left for the future is:

(*a*) To better understand the deep and lower interior through better helioseismology measurements, requiring higher sensitivity and resolution and above all, observations at high latitudes.

(*b*) To have access to better magnetic field observations & measurements, both in the interior and in the upper atmosphere, and to investigate the internal circulation and the dynamo mechanism(s).

(*c*) To measure or infer the value of the field below and above the surface. This is particularly difficult because the classical technique of Zeemann splitting is not applicable in the case of the chromospheric and coronal weak fields. The use of the Hanlé effect (Raouafi et al. 1999) has not been yet systematically exploited due to intrinsic experimental difficulties, in particular the measurement of linear polarization.

(*d*) To refine the studies of the solar wind structures and acceleration mechanisms as well as of the CME mechanism(s).

The corresponding specifications for future instruments and satellites can easily be derived from these requirements and be summarized as follows:

- Better sensitivity
- Better angular resolution (at least one order of magnitude above present, i.e. better than 0.1 arc-second)
- Tomography through multi-spectral observations
- Observations above the poles
- Observations in three dimensions
- Continuous observations over more than one solar cycle
- In situ observations

5.1. *Future Needs of Helioseismology*

Future progress will come from any one of these areas or any combination of them. The detection of gravitational modes will not be possible in a reasonable time frame without new techniques being able to increase the sensitivity of the velocity oscillations up to a fraction of 1mm/s, or the detection of limb oscillations at the 10^{-6}arc-second level (Appourchaux, 2003).

A successor of the GOLF, instrument on SOHO, would derive radial velocities through 15 points in the wing of the sodium D line (Turck-Chièze et al., 2001), with an expected accuracy of 0.1 mm/s, solar noise permitting. At Nice University, a Mach-Zender interferometer is being developed (Jacob, 2002).

Amplification of the p-modes at the limb as observed in the SOHO-MDI data (Appourchaux and Toutain, 1998 and Toner et al., 1999), could be used for detecting g-modes by measuring the fluctuations of the limb at the 10^{-6}arc-second level, and the solar irradiance with a precision better than a few parts per million. This is proposed in the PICARD micro-satellite of the French space agency CNES (Damé et al., 1999). A similar technique is used in the Helioseismic and Magnetic Imager of Stanford University, foreseen to fly on board NASA's Solar Dynamics Observatory (http://hmi.stanford.edu).

A more revolutionary approach would be to detect the tidal perturbations of the gravitational field produced by the g-modes of order $\geqslant$2. Such measurements might be possible with the ESA/NASA Laser Interferometer Space Antenna (LISA) to be launched around 2013, with a detection level equivalent to a few mm/s, probably at the limit of clear detection. A more sensitive mission, ASTROD (http://gravity5.phys.nthu.edu.tw/~ASTROD), using laser ranging of two satellites located on the far side of the Sun on an Earth orbit, would reach beyond the theoretical amplitude of the g-modes (Kumar et al., 1996), and appears today as the ultimate concept. Figure 2 (Appourchaux, 2003) presents a summary of the limits reached by these various techniques.

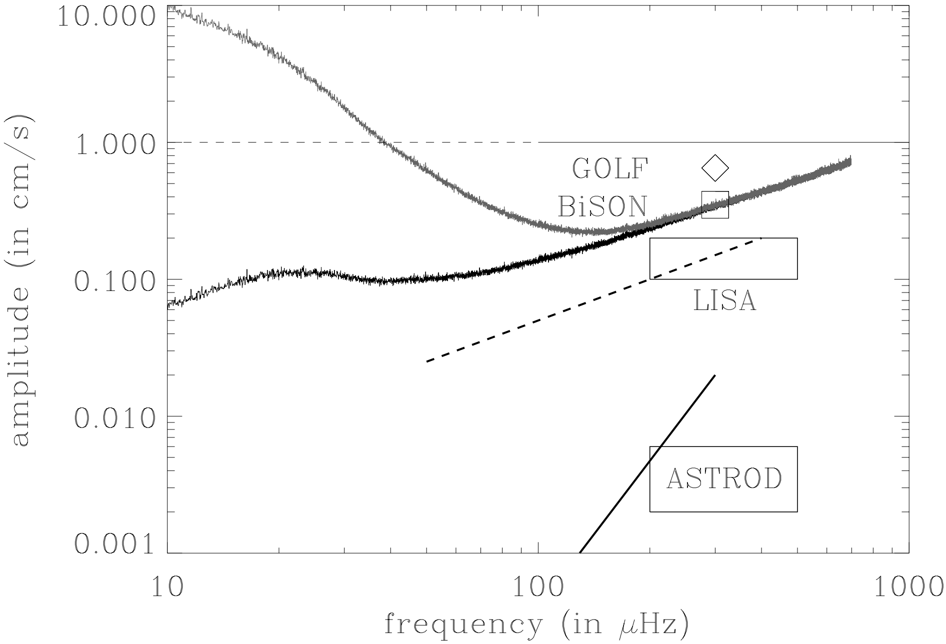

Figure 2. Predicted upper detection limit of gravitational modes for various existing and planned missions. (From Appourchaux, 2003).

5.2. *Observing at High Latitudes*

All helioseismology observations have up to now been conducted from the ecliptic plane be it from the ground or from space. As far as the probing of the convection zone and the dynamo/tachocline region is concerned, it is imperative to improve the accuracy of measurements at high latitudes. Indeed, observations of high-degree modes ($l \geqslant 250$) are questionable near the poles (Howe, 2003).

The only mission which could observe the poles, Ulysses, was deprived of its imaging capability when NASA decided to abandon the second satellite of the original mission. ESA's Solar Orbiter (http://www.rssd.esa.int/SH-general/Projects/SolarOrbiter/), which is able to reach latitudes some 38° above the ecliptic plane at a distance of 45 Rs, with a record equivalent resolution of 0.05 arc-second from Earth, corresponding to 35 km per pixel, would go a long way in improving the present situation.

An ideal mission would be a repeat of the original Out-of-Ecliptic Mission (Figure 3). In this twin-spacecraft mission, each satellite should be equipped with exactly the same set of instruments, in particular the most modern version of the SDO-HMI. The simultaneity of observations would add a tremendous power to the study of the solar interior. It would also provide a unique tool for the forecast of solar activity by being able to observe both sides of the Sun at the same time.

5.3. *The Need For High Angular Resolution*

The heating process is dominated by small scale phenomena at the limit of the present set of space and ground based instruments. To go further in the comprehension of these processes, one must have access to higher-resolution and to three-dimensional observations as well. Two new satellites carry great promises in this respect and would improve substantially the present status.

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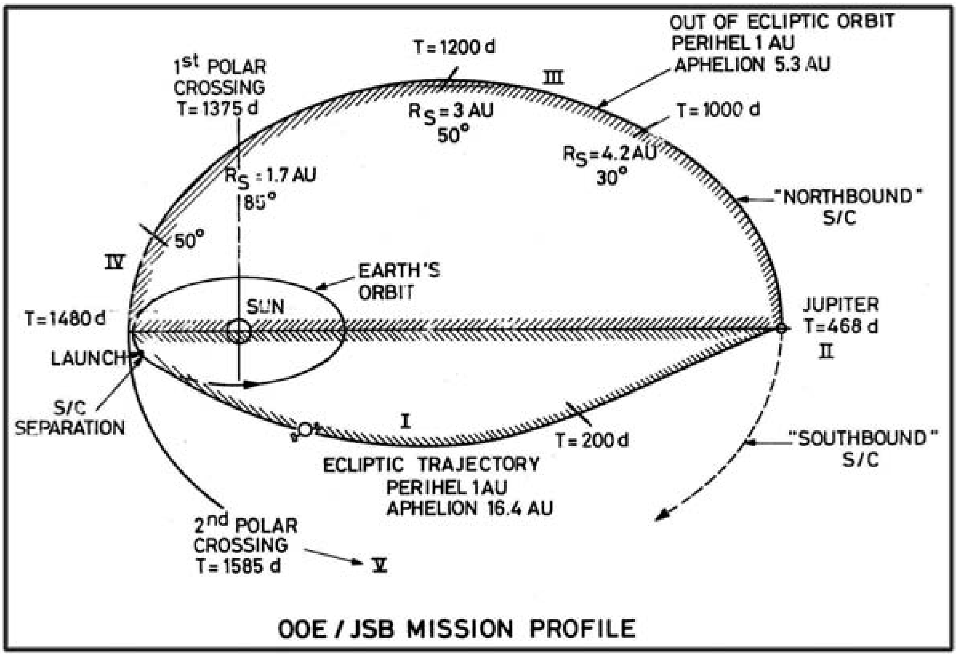

Figure 3. Concept of the twin satellite out-of-ecliptic mission, from the original design of the Out of Ecliptic mission.

SOLAR-B, a Japanese mission with US and UK participation (http://www.jaxa.jp/missions/projects/sat/astronomy/solar_b/index_e.html), a successor to Yohkoh, is planned to be launched in 2006, Fleck (2002). Its scientific payload comprises a diffraction limited 50-cm telescope, capable of sub-arc-second resolution ($\leqslant$0.1 arc-second) in the spectral range 388 to 660 nm. Its grazing incidence X-ray telescope would provide full Sun coronal images at wavelengths from 0.2 to 6 nm with one arc-second resolution. SDO, already mentioned, will also strongly contribute to this domain.

The Space Solar Telescope (http://ilws.gsfc.nasa.gov/Space_Solar_Telescope.pdf), is being developed by the National Astronomical Observatories of the Chinese Academy of Sciences (NAOC). It is foreseen to be launched in 2005 into a Sun-synchronous orbit at a height of 735 km and an inclination of 98.3°. It is likely, however, that super-high resolution might be necessary to fully understand the small-scale processes. This could be the domain of projects like SIMURIS (Damé, 1998), or of the Reconnection and Micro-scale Probe, RAM, a candidate mission in NASA's Sun Earth Connection roadmap (Fleck, 2002).With expected performances of a few 0.001 arc-second and high time resolution these projects may address the fundamental processes at play in magnetic reconnection, micro-scale instabilities and particle acceleration. However, the capability of accessing super high resolution observations with enough light flux is still to be demonstrated.

5.4. *In Situ and 3-Dimensional Measurements*

Further progress in our understanding of the acceleration mechanisms of the solar wind will require 1) refined imagery and spectrometry and 2) in-situ measurements at close distances to the Sun as well as 3-D observations, in particular of the CME's.

In the first category, it is expected to extend the SOHO-UVCS type measurements over several spectral lines such as He I Lyβ, the OVI doublet at 103.0 nm or the He II 30.4 nm resonance line. The light flux from these lines is rather weak and the sensitivity of the respective instruments will have to be at least one order of magnitude higher than that of UVCS. Advanced coronagraphs of the LASCO type, capable of observing closer to the Sun (1.1 Rs) and with polarimetric capabilities, will help observing the acceleration processes at the very base of the corona. This is the objective of the Advanced Spectroscopic and Coronographic Explorer of NASA (Fleck, 2002). The already mentioned twin-satellites Out-of-Ecliptic mission would prove to be invaluable in the understanding of the fast component of the solar wind. Similarly, ESA's Solar Orbiter will analyze the slow component.

Much more demanding, and certainly at the limit of today's technological capabilities of NASA and ESA, is the in-situ Solar Probe (Habbal et al., 1998), (http://science.msfc.nasa.gov/sol/pad/solar/suess/SolarProbe/SolarProbe.htm). The concept has been studied for more than 30 years and has still not yet been materialized! Obviously, the thermal environment very close to the Sun with a perihelion at 4 Rs, is one of the main technological difficulties to overcome for building such an ambitious and revolutionary mission. The proposed orbit is extremely interesting for the study of the acceleration regions of the fast and slow solar wind. The payload would incorporate both in-situ and remote-sensing instruments: a magnetometer, spectrometers to measure solar wind electrons and energetic particles, X-ray telescopes, coronagraphs, etc. Due to the rapidity of the probe's transit into the corona, such local measurements need to be complemented by observations and more continuous sets of data such as those permitted by ESA's Solar Orbiter, in order to reconstruct the structures and the environment in which the acceleration and heating processes take place. Because of the importance of the heliospheric latitude dependence of the acceleration mechanisms, the Solar Probe should be placed in a polar orbit.

The old technique of stereoscopic observations, used in the 1970's in the radio range is soon to be applied in the visible and UV part of the spectrum. The main objectives of NASA's STEREO mission (http://stp.gsfc.nasa. gov/missions/stereo/stereo.htm) to be launched in 2006, is to understand the origin and the effects in the heliosphere of the CME phenomenon. It will use two identical satellites with exactly the same payload, one drifting ahead of the Earth, the other one behind, providing a stereoscopic view of the coronal structures and of the CMEs, as well as of their propagation throughout the heliosphere and their effects at Earth.

6. Conclusion

Space observations have yielded tremendous progress, from the study of the solar interior, to the role of the magnetic field in the heating of the chromosphere and of the corona and identifying the sources and acceleration mechanisms of the solar wind and understanding the perturbations caused by the Coronal Mass Ejections.

Nevertheless, several key questions still need to be analyzed in greater depth. This is the case for the generation of the magnetic field and of the role of differential rotation and its interplay with convection in creating the dynamo effect. This is also the case of the coronal heating process, in particular the roles and the details of the small-scale processes. Magnetic reconnection seems to be omni-present, also in the manifestation of the CME's, but we are far from being in the position to forecast them accurately.

New generations of instruments and new observations are needed. Higher spatial resolution will provide better insight in the small-scale processes intervening in the heating of the corona and in the acceleration of the solar wind. Stereoscopic observations are crucial to understand the larger-scale processes which affect the changes in the configuration of the magnetic field and result in the CME phenomenon. Up to now, the Sun has been observed at all wavelength ranges only from the ecliptic plane. This is limiting the accuracy of the measurements in particular of solar differential rotation and of our understanding of the processes which occur at the poles. This illustrates the need for a new solar-polar mission able to observe the poles from above the ecliptic plane, with two spacecraft equipped with a set of the most modern visible and EUV telescopes, magnetometers and coronagraphs. Finally, it is clear that in situ measurements will prove invaluable in analyzing and understanding the processes at play inside the corona itself. In that respect, the long awaited Solar Probe should cast new light on the physics of the extended atmosphere of the Sun.

These observations should provide the necessary tool for the forecast of the solar influence on our planet, on its climate and on the systems of our modern civilization. This requires a large number of missions operated in a coordinated way. The International Living with a Star program (http://ilws.gsfc.nasa.gov), appears today one of the most promising approach in that respect. It assembles in a unique system, the missions of a large number of space faring nations or agencies. International cooperation appears to be an absolute necessity in attempting to better understand and evaluate what kind of positive or negative effects our Sun can have on our daily life.

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References

Appourchaux, T.: 2003, 'The Search for g-Modes', ESA SP-517, ed.: H. Sawaya-Lacoste, ESA Publications Division, Noordwijk, The Netherlands, 131–138.

Appourchaux, T. and Toutain, T.: 1998, in J. Provost and F.-X. Schmider (eds.), Sounding Solar and Stellar Interiors, IAU Symp. 181, Poster volume, 5, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bonnet, R. M. and Pauluhn, A.,: 2004, 'Recent progress and future prospects in solar physics', Surveys in Geophysics, Kluwer Academic Publishers, Dordrecht, The Netherlands, In Print.

Brueckner, G. E., Howard, R. A., Koomen, M. J., et al.: 1995, 'The Large Angle Spectroscopic Coronagraph (LASCO)', *Solar Phys.* **162**, 357–402.

Chaplin, W. J., Christensen-Dalsgaard, J., Elsworth, Y., et al.: 1999, 'Rotation of the solar core from BiSON and LOWL frequency observations', *Mon. Not. Roy. Astronom. Soc.* **308**, 405–414.

Cranmer, S. R.: 2000, 'Ion Cyclotron Wave Dissipation in the Solar Corona: The Summed Effect of More Than 2000 Ion Species', *Astrophys. J.* **532**, 1197–1208.

Crooker, N., Joselyn, J. A., and Feynman, J. (eds.): 1997, 'Coronal Mass Ejections', American Geophysical Union, Washington DC, US.

Damé, L.: 1998, 'Low Orbit High Resolution Solar Physics with the Solar Interferometer', *Adv. in Space Res.* **21**, 295–304.

Damé, L., Hersé, M., Thuillier, G., et al.: 1999, 'PICARD: Simultaneous Measurements of the Solar Diameter, Differential Rotation, Solar Constant and their Variations' *Adv. in Space Res.* **24**, 205–214.

Fleck, B.: 2002, 'Prospects of Future Solar Space Missions', ESA SP-505, ed.: H. Sawaya-Lacoste, ESA Publication Division, Noordwijck, The Netherlands, 311-318.

Geiss, J., Gloeckler, G., and von Steiger, R.: 1995, 'Origin of the Solar Wind From Composition Data', *Space Sci. Rev.* **72**, 49–60.

Habbal, S. R., Gloeckler, G., McNutt, R. L., Jr., and Tsurutani, B. T.: 1998, 'The Solar Probe Mission: A Search for the Origin of the Solar Wind and an Unprecedented View of the Solar Surface', ESA SP-417, 83–90.

Hassler, D. M., Dammasch, I. E., Lemaire, P., et al.: 1999, 'Solar Wind Outflow and the Chromospheric Magnetic Network', *Science* **283**, 810–813.

Howe, R.: 2003, 'The Internal Rotation of the Sun', ESA SP-517, ed.: H. Sawaya-Lacoste, ESA Publications Division, Noordwijk, The Netherlands, 81–86.

Jacob, C.: 2002, in F. Combes and D. Barret (eds.), SF2A-2002, Semaine de l'Astrophysique Française, Editions de Physique, Les Ulis, France.

Kjeldseth-Moe, O.: 2003, 'The Solar Transition Region', in B. N. Dwivedi (ed.), *Dynamic Sun*, Cambridge University Press, 196–216.

Kumar, P., Quataert, E. J., and Bahcall, J. N.: 1996, 'Observational Searches for Solar g-Modes: Some Theoretical Considerations', *Astrophys. J. Lett.* **458**, L83–L85.

Marsch, E., Axford, W. I., and McKenzie, J. F.: 2003, 'Solar Wind', in B. N. Dwivedi (ed.), *Dynamic Sun*, Cambridge University Press, 374-402.

Raouafi, N.-E.: 2002, 386, 721–731.

Raouafi, N.-E., Lemaine, P., Sahal-Bréchot, S.: 1999, *Astron and Astrop.*, **345**, 999–1005.

Schou, J., Antia, H. M., Basu, S., et al.: Helioseismic Studies of Differential Rotation in the Solar Envelope by the Solar, Oscillations Investigation Using the Michelson Doppler Imager, Astrophys. J. **505**, 390–417.

Scharmer, G. B., Gudiksen, B.V., Kiselman, D., et al.: 2002, 'Dark Cores in Sunspot Penumbral filaments', *Nature* **420**, 151–153.

Sheeley, N. R.,Jr.,Wang, Y.-M., Hawley, S. H., et al.: 1997, 'Measurements of Flow Speeds in the Corona between 2 and 30 $R_{\_}$', *Astrophys. J.* **484**, 472–478.

SNO collaboration: 2001, 'Measurement of the Rate of ν_e + d $\rightarrow$ p + p + e- Interactions Produced by ^{8}B Solar Neutrinos at the Sudbury Neutrino Observatory' *Phys. Rev. Lett.***87**, 071301.

SNO collaboration: 2002, 'Measurement of Day and Night Neutrino Energy Spectra at SNO and Constraints on Neutrino Mixing Parameters', *Phys. Rev. Lett.* **89**, 011302.

Toner, C. G., Jefferies, S. M., and Toutain, T.: 1999, 'Increasing the Visibility of Solar Oscillations', *Astrophys. J.* **518**, L127–L130.

Turck-Chièze, S., Robillot, J. M., Dzitko, H., et al: 2001, 'G-Mode: a New Generation of Helioseismic Instrument', ESA SP-464, ed.: A. Wilson, ESA Publications Division, Noordwijk, The Netherlands, 331–335.

Turck-Chièze, S., Garcia, R. A., Couvidat, S., et al.: 2004, 'Looking for Gravity-Mode Multiplets with the GOLF Experiment aboard SOHO', *Astrophys. J.* **604**, 455–468.

Ulmschneider, P. and Kalkofen, W.: 2003, 'Heating of the Solar Chromosphere', in B. N. Dviwedi (ed.), *Dynamic Sun*, Cambridge University Press, 181–195.

Wilhelm, K., Marsch, E., Dwivedi, B. N., et al.: 1998, 'The Solar Corona Above Polar Coronal Holes as Seen by SUMER on SOHO', *Astrophys. J.* **500**, 1023–1038.