CASTEL-FILTERS

Introduction

The rationale for observing the Sun from Antarctica has traditionally been the need for long, uninterrupted time-series of data (Fossat, Grec and Pomerantz 1981, Duvall et al. 1991), in the framework of studies of solar oscillations. State-of-the-art helioseismology, however, begun to take advantage of the deployment of networks of observing stations in more accessible sites around the globe (GONG, IRIS, BISON, TON), or of data from satellite experiments (SOHO). These experiments provide full-disk solar images whose best spatial resolution is 2”/pixel, and the fastest acquisition rate is typically one minute. The fact that the South Pole site, where most helioseismological campaigns have been carried out, is not exceptional in terms of quality and stability of the seeing, explains why Antarctica seems to have lost much of its appeal for high-quality solar research.

Very recently, other Antarctic sites have been suggested to be advantageous for astronomical research. In particular, the Dome C site, where an Italian-French base is being built, seems especially promising. Preliminary site test campaigns at Dome C demonstrate that the atmosphere there is very stable, due to a combination of several favourable conditions, including its high elevation (3280 m a.s.l.) and the near absence of wind (in average below 3 km/s) (Valenziano and Dall’Oglio 1999). Thus, Dome C is probably one of the best sites in the world, if not *the* best, for long-duration, high-resolution astronomy, especially in the infrared.

Several aspects of solar research could also take advantage of such characteristics. While high-resolution solar observations (down to subarcsecond values) are becoming increasingly common, especially through the use of adaptive optics techniques, telescopes providing very high resolution images guarantee their best performances only for (at most) a few hours per day. Thus, long-duration, *continuous* high-resolution observations, are currently impossible to attain from ground-based sites.

In principle, space-borne observatories could address such needs, over the full electromagnetic spectrum. Nevertheless, an Antarctic site, however remote, allows a much greater flexibility in managing, modifying, and upgrading telescopes and instrumentation, in comparison with any space project. Thus, the Dome C, with a combination of great stability and transparency of the atmosphere, could be now considered unique among ground-based sites for solar observations.

Primary Scientific Objective

The primary objective of the Concordiastro/Italy project is the verification of the expectations of excellent and stable *solar* seeing at Dome C.

The peculiar atmospheric characteristics observed at Dome C cannot be easily translated into excellent seeing conditions, specially for solar observations in Antarctica, where the Sun is rather low in the sky (being at most at $\approx 40°$ above the horizon at Dome C). Furthermore, in day-time observations, extreme care has to be devoted in suppressing heat sources (and dispersing the heat from Sun itself) in order to avoid introducing local turbolence. For this reason, meaningful *solar seeing estimates need to be carried out in the operative conditions for solar high-resolution observations*.

The solar group from the Capodimonte Observatory in Naples collaborates with the French group based in Nice (Observatory and University), which is already developing asteroseismology researches at Dome C (P.I.: E. Fossat). In the framework of this collaboration, the Concordiastro/Italy project proposed by the Capodimonte Observatory (P.I.: G. Severino), has been approved by the Italian Antarctic Agency (P.N.R.A.) and partially funded.

The aim of the project is to install a 40 cm telescope (named CASTEL, Capodimonte Antarctic Solar TELescope) on the same platform hosting the French stellar telescopes in order to obtain intensity images, whose analysis will describe the solar seeing quality and stability. The diffraction limit for the telescope at 400 nm is of the order of 0.25", close to the values obtained in the best sites on Earth (Atacama desert, Canary and Hawaii islands). A seeing of about 0.3" can be measured only if structures of the same size, or smaller, are present on the Sun. In white light, intergranular lanes fullfill this request throughout the solar activity cycle.

Measuring the seeing at longer wavelengths implies larger diffraction limits, which would require a larger telescope, with corresponding strong increase in costs and complexity of the project. On the other hand, at shorter wavelengths the sensitivity of standard sensors drops dramatically. Therefore, the wavelength range around 400 nm represents the best compromise for seeing measurements at Dome C, given the diameter of the telescope to be built.

Observations in solar lines can be simultaneously carried out for scientific purposes as that previously described. In the following, the motivations and description of the characteristics of the filters at the CaII K line are shown.

Additional Scientific Objectives

As mentioned above, the objective of the Concordiastro/Italy requires only broad-band measurements in the blue region of the spectrum with a relatively small telescope. However, if the expectations of an exceptional solar seeing are met, the same telescope could also be used to address additional scientific objectives with just a modest fractional increase in the budget of the project, by simply taking into account in the design phase the possibility of adding one or more filters.

Exploiting the transparency of the atmosphere at in Dome C in the infrared could also be an interesting possibility for solar research with the CASTEL telescope. However, this would require working at wavelengths far from the band for which the telescope is optimized. In particular, the resolution attainable by a 40 cm telescope in the infrared becomes a major limit. Also, observing in the infrared would require non-standard (with current technology) detectors, and a correspondingly higher cost of the project.

In order to avoid an excessive increase in the complexity of the system, mainly due to the need for temperature stabilization (see section "Temperature stabilization" below), only medium- or broad-band filters should be considered (FWHM > 0.1) . Near the working wavelength of the telescope, 400 nm, some interesting wavelengths could be explored:

- Ca II H and K lines at 396.8 and 393.4 nm respectively;
- The G band centered at 431 nm;
- The $H\beta$ line at 486.1 nm.

A medium-band filter around the latter line is probably useful only for off-limb measurements, such as in prominences, where the line is in emission. The G band has been successfully employed in some specific studies (such as Berger & Title 2001) of high-resolution structures in the solar photosphere. The Ca II K line is that used during the previous long duration antarctic observations with low spatial resolution intensity images (Duvall et al. 1991). Two networks (TON, Chou et al. 1985 and RISE-PSPT, Coulter and Kuhn 1994 and Ermolli et al. 1998) are currently providing full-disk intensity images in this line.

One specific objective the Capodimonte solar group is planning to pursue with CASTEL, concerns the source of solar oscillations.

Recently, the main trigger of the global pressure oscillations has been addressed to seismic events,

whose spatial scales are of the order of less than one arcsec and duration of about few minutes, Goode et al. 1998. these events have been associated to convective downflows whose global sun occurrence rate is of the order of 5000 s^{-1} (Strous, Goode and Rimmele 2000). The correlation between the seismic events and Ca II K bright points has been investigated (Hoekzema, Rimmele and Rutten 2002).
Another hypothesis for the source of the solar oscillations suggests the downflowing jets related to the chromospheric explosive events to be responsible of part of the excitation (Moretti et al. 2001). The penetration of such jets down to photospheric heights has been observed only for large flare energies (Kosovichev and Zharkova 1998, Moretti et al. 2003).
Until now, only a handful of these transients has been studied over small areas and limited durations and for both the mentioned mechanisms, the energy transfer to the global oscillations has to be demonstrated. For this reason high spatial resolution, long duration observations are needed.

We will therefore consider more in detail the possibility of adding a Ca II K filter to the instrumentation of CASTEL.

λ_0 393.4 nm (Ca II K line)

Figure 1 shows the solar spectrum around the Ca II K solar line from the Kurucz, Furenlid, Brault, and Testerman (1984) atlas of solar flux, calibrated according to data from the University of Utrecht (Oranje 1983).

The central wavelength (λ_0) of the filters is given by manufacturers with a tipical maximum error of 15% of the filter band width (FWHM). The (λ_0) depends on the working temperature (in summer at Dome C corresponding to about -35^{0}C, see figure 2 and mean values from Valenziano and Dall'Oglio 1999), and it has to be specified in the order. Temperature fluctuations during the observations introduce wavelength shifts, whose effects will be described in one of the next sessions.

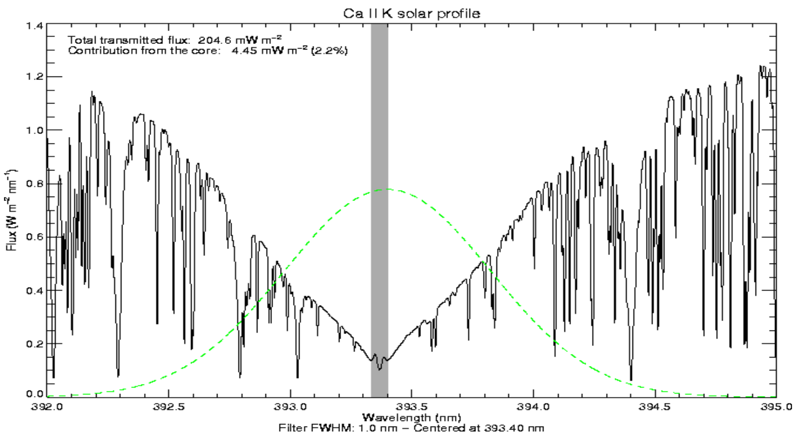

Figure 1: solar flux profile in the external atmosphere for the CaII K (solid line). In dashed the transmission profile for a 1 nm FWHM filter centered at 393.4 nm (with a peak transmission of 0.5). The flux has been derived from the solar atlas (Kurucz et al. 1984) and its calibration using the radiation temperature scaled at 1 AU (Vernazza, Avrett, Loeser, 1976). The grey region indicates the region where the K1V and K1R points are placed.

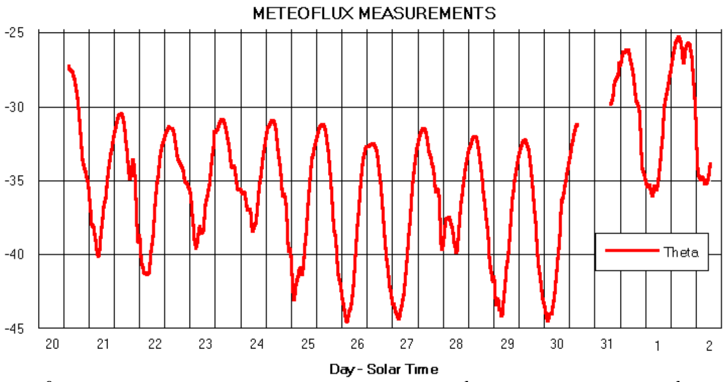

Figure 2: temperature (in ^{0}C) at Dome C from January 20th to February 2nd,1997 (data provided by S. Argentini and G. Dargaud).

FWHM (1 nm)

In the case the excellent seeing conditions will be confirmed, the search for the source of the solar oscillations implies additional constraints on the FWHM of the filters.
Very narrow passbands filters (less than 0.1 nm) are usually employed in studies of the dymanics of solar structures. Nevertheless, the stability of the (λ_0) has to be strictly maintained to permit a reliable interpretation of the data. This request implies a temperature control of the filter, with additional complexity, costs and heating of the system. The use of medium FWHM filters is less sensitive to temperature fluctuations, and permits a reasonable study of the dynamics and morphology of the solar atmosphere (as performed with 1 nm FWHM filters centered on the CaII line or in the G-band). The total flux through a 1 nm FWHM filter in the CaII line is mainly due to a photospheric contribution plus a small but very variable chromospheric contribution corresponding to the K1V and K1R points (see figure 1). The latter contribution spans from 1% in the quiet sun to much greater values (> 10%, Oranje 1983). Velocity field induce Doppler shifts of the order of 0.002 nm (Lites et al. 1993).

Temperature stabilization

The temperature coefficients for Barr and Andover filters are 0.002 nm/^{0}C and ten times larger respectively. An additional temperature control implies a cost of 2.5 k€ and a probable impact on the local heating of the telescope.
The maximum temperature excursion during a day at Dome C is of the order of 10 ºC (see figure 2), that is a spectral variation of the (λ_0) of 0.02 nm (either in case of Barr or 1 ºC stabilized Andover filters).
This wavelength shift introduces 2.7% and 0.5% intensity fluctuations with 0.3 and 1.0 nm FWHM filters (figure 3). These fluctuations have to be compared with the 10 % and 2 % changes due to the variability of the central emission of the chromospheric contribution, which is in practice not sensitive to the (λ_0) variations if the transmission profile of the filter is flat in the central core of the line (in 0.05 nm). In conclusion, 0.02 nm wavelength dayly variations introduce a maximum 25 % contribution to the solar intensity fluctuations.

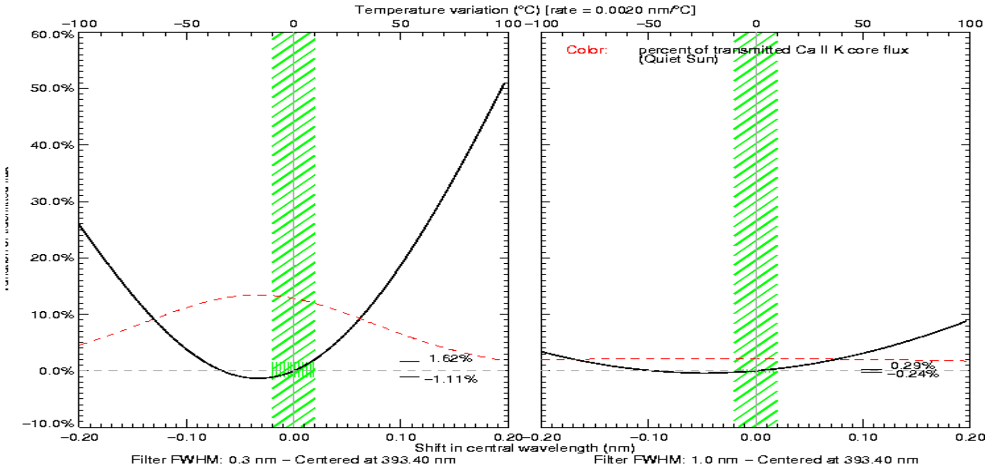

Figure 3: variation of flux transmitted by gaussian filters (FWHM= 0.3 nm left, FWHM = 1 nm right) as a function of the central wavelength shift. The percentage of flux variations due to the line core in the quiet sun is indicated with the dashed line. The dashed zone indicates the maximum dayly variations expected from the temperature variations at Dome C using a Barr filter.

Clear aperture (45 mm)

In practice, only two main filters diameters are avaliable on the market: 25 e 50 mm.
The advantage of the smaller diameter is only the reduced cost (about 1k€ less for a filter respect to the correspondent 50 mm diameter one).
Moreover, 50 mm diameter neutral density filters have already been purchased.
In the following we summarise the advantages in using the larger diameter:

- mechanical compatibility with the Barr filters used by the PSPT project now running at the Rome Astronomical Observatory, already involved in the CASTEL project;
- possible use of the filters in front of a full-disk facility;
- compatibility with large format sensors, possibly used to provide high resolution full-disk images. As an example, the 4096 x 4096 pix Kodak KAF-1680 is 37 mm x 37 mm wide.

Neutral density filters

Andover 50 mm diameter neutral density filter have been already purchased with optical densities of 0.3, 0.6, 1.0, 1.5, 2.0, 3.0 (that is transmission of 50, 25, 10, 3, 1, 0.1 %). Some examples of the transmission profiles from 300 to 1200 nm are shown in figure 4.

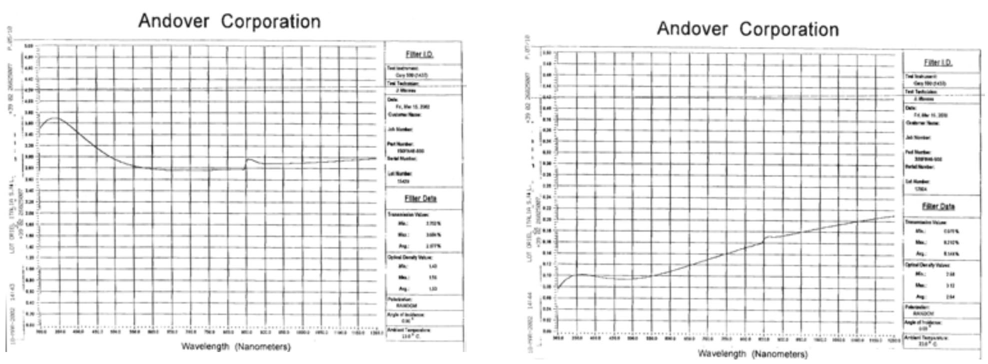

Figure 4: transmission profiles for Andover neutral density filter with ND = 1.5 and 3 respectively.

Choices

In the following, the choices with their motivations are indicated:

λ_0	393.4 nm @ -37^{0}C	Network support data
Thermal control	no	No maintainance. Minimum impact to local heating.
FWHM	?	λ_0 error
Diameter	50 mm	Future developments
Company	Barr	Lowest temperature coefficient. Compatible with PSPT Rome filters.

Filter	Andover	Barr	Daystar	Omega
Company	LOT-Oriel	Barr associates	Daystar	Crisel-instruments
λ_0	393.4 ±0.2 nm	393.4±0.15nm 393.4±0.05nm	393.37 nm	393.4±0.2nm
FWHM	1.0 ± 0.2 nm	1.0± 0.2 nm 0.3 ± 0.06 nm	1.0nm 0.2 nm	0.2 nm
Diameter	50 mm	50 mm	32 mm	50 mm
Optical quality (λ/4)	si	si	si	no
Temperature coefficient	0.02 nm/^{0}C	0.002 nm/^{0}C	-	-
Cost	4.2 k€	2.6 k€ 4.5 k€	4.2 k€ 7.0 k€	-

References

- Berger, T.E., Title, A.M., 2001, ApJ, 553, 449
- Chou, D. et al., 1995, Solar Physics, 160, 237
- Coulter, R.L. and Kuhn J.R., 1994 ASP 68, 37
- Duvall, T.L., Harvey, J.W., Jefferies, S.M. Pomerantz, !991, ApJ, 373, 308
- Ermolli, I., Fofi, M., Bernacchia, C., Berrilli, F., Caccin, B., Egidi, A., Florio, A.T., 1998, Solar Physics, 177, 1
- Fossat, E. grec, G., Pomerantz, M., 1981, Solar Physics, 74, 59
- Hoekzema, N.M., Rimmele, Th.R., Rutten, R.J., 2002, A&A, 390, 681
- Kosovichev, A.G., Zharkova, V.V., 1998, Nature, 383, 317
- Kurucz, R. L., Furenlid, I., Brault, J., Testerman, 1984, "Solar flux atlas from 296 to 1300 nm", National Solar Observatory
- Lites, B., Rutten, R., Kalkofen, W., 1993, ApJ, 414, 345L
- Moretti, P.F., Cacciani, A., Hanslmeier, A., Messerotti, M., Oliviero, M., Otruba, W., Severino, G., Warmuth, A., 2001, A&A, 372, 1038
- Moretti, P.F., Berrili, F., Sebastianelli, A., Briand, C., Pietropaolo, E., 2003, ApJ Letters, submitted
- Oranje, B.J., 1983, A&A, 124, 43
- Strous, L.H., Goode, P.R., Rimmele, Th.R., 2000, ApJ, 535, 1000
- Valenziano, S., Dall'Oglio, G., 1999, PASA, 16, 167
- Vernazza, J., Avrett, E. H., Loeser, R., 1976, ApJS, 30, 1