The Sun-Earth System: Observed Variations of the Photospheric Diameter

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Este texto foi preparado para a apresentação no III Simpósio Brasileiro de Geofísica, Belém, 26 a 28 de novembro de 2008. Seu conteúdo foi revisado pelo Comitê Técnico do III SimBGf, mas não necessariamente representa a opinião da SBGf ou de seus associados. É proibida a reprodução total ou parcial deste material para propósitos comerciais sem prévia autorização da SBGf.

Abstract

Here we derive a formulation connecting the observed variations of the solar diameter to the heliophysics of the photosphere, in particular in connection to the granulation pattern and morphology. The results from the measurements are next used to correlate the variations of the semi-diameter and of estimators of the solar activity along the solar cycle 23. The values obtained strongly support a broader physical description of the photosphere entwining the diameter variations with the irradiance, the sunspots, the 10.7cm radio emission, and to a lesser degree with the integrated magnetic field and with the flares count. Finally the solar oblatness can be derived thanks to capacity of the CCD astrolabe to make measurements across the full range of heliolatitudes. In the conclusion the next steps of instrumental development are briefly described.

Introduction

The bulk of solar light and heat received by the Earth is released from the solar photosphere. Though virtually all the energy is produced in the solar core through the proton-proton fusion chain, it undergoes a lengthy pathway, across the radiation zone and up to the convective zone, during a million years process, to finally reach what is purposely called the solar photosphere (Mursula, 2005).

The solar constant S expresses the total irradiance, *i.e.*, the total power of solar radiation over the full frequency spectrum per perpendicular area at the mean distance of the Earth. S can be measured directly and is usually given as

$$S = 1367 \pm 3\ Wm^{-2}. \qquad (1)$$

The accurate determination of S requires that it is observed above the dense atmosphere that absorbs most of the radiation in ultraviolet and infrared wavelengths. S is related to the luminosity L by $L = 4\pi(AU)^2$, to give

$$L = 3.844 \pm 0.010 \times 10^{26}\ W \qquad (2)$$

This is quite a typical value of luminosity for a G2 star. The absolute magnitude of the Sun is $M = 4.8$.

Note that the solar constant is not constant. The luminosity of the newly-born Sun was about 72% of its present value. Furthermore, the present "solar constant" varies by a factor of

- 10^{-6} over minutes. (These are related to pressure variations called solar oscillations).
- 10^{-3} over several days. (These are related to sunspots and other active regions).
- 10^{-3} over solar cycle (exact value uncertain).

The solar energy is one of the major driving inputs for terrestrial climate. Some evidences of correlations exist between surface temperature changes and solar activity. It is then important to know on what time scale the solar irradiance and other fundamental solar parameters, like the diameter, vary in order to better understand and assess the origin and mechanisms of the terrestrial climate changes.

Global effects, such as diameter changes, large convective cells, the differential rotation of the Sun's interior and the solar dynamo at the base of the convective zone, can probably produce variations in the total irradiance or, at least, correlate with these variations associated, during maximum, with the changing emission of bright faculae and the magnetic network (Damé et al., 2000).

Since 1981 the Observatório Nacional/MCT (ON) group makes daily solar observations, in particular, since 1997, aiming to record and study the diameter variations (Jilinski et al., 1998). In 2002 an international network (Réseau de Suivi au Sol du Rayon Solaire – R2S3) was formed to combine the similar work pursued in five countries worldwide (Andrei ewt al., 2002). In 2006 the ON associated to the SCOSTEP/CAWSES project for the investigation of Space Weather and the Earth-Sun System issues (Andrei et al., 2006). The goal of the work done at ON is therefore multiple: to record lengthy, coherent series of digitized solar diameter observations; to use this series and those from the R2S3 and other groups to investigate the physics of the photosphere and convection zone; to contribute to the understanding of the Earth-Sun relationship as driven by the heliosphere, with emphasis on short term, geographically local effects; and finally to upgrade and develop data acquisition and treatment methods and apparatus.

The Convective Zone and the Solar Photosphere – and Diving into the Earth Magnetosphere

Convection becomes the dominant energy transport process at some distance from the center of the Sun., where the radiative transport becomes less efficient because opacity increases outwards with decreasing temperature. In a lower temperature, more and more ions recombine, and only partially ionized and neutral atoms absorb radiation much more efficiently than fully ionized plasma (Schussler & Vogler, 2003).

At the base of the convection zone it is found the solar tachocline, a thin layer containing the strong radial differential rotation, which has proven to be important for several mechanisms surfacing to the photosphere. In the tachocline, radial shear generates the strong toroidal fields, which eventually erupt as bipolar spots at the surface. The tachocline provides also a good location for magnetic flux-storage (Lefebvre et al., 2005).

In the convection zone radiation can no longer remove all energy coming from inside. This starts to heat the gas and it becomes convectively unstable. In recent models this begins at the distance of r = 0.71–0.72 r (*i.e.*, some 200000 km below the solar surface). On the other hand, once convection is initiated, it is a very efficient mechanism for distributing heat.

The convection zone is unstable, horizontally nonuniform (while the radiation zone is stably stratified, horizontally uniform). Hot gas parcels move up, dissolve, and finally cool gas returns back downward around the upward moving gas parcels. So, opposed to oscillatory motion where parcels of gas move back and forth, the convective motion is overturning. The whole convection zone is continuously mixed which makes it chemically homogeneous. Still, this does not mean that the mean molecular mass μ is constant since the degree of ionization drops rapidly, in particular close to the surface. However, within most of the convection zone $\mu \approx 0.61$ (Giorgobiani, 2003).

At the top of the convection zone starts the photosphere, the apparent, visible surface of the Sun. It is a gaseous atmospheric layer less than 500km deep, with an average temperature of approximately 5800K. In the photosphere the optical depth becomes one for a photon of wavelength equal to 5000 angstroms. Thus, the radiation emitted from the photosphere accounts for most of the solar energy flux at the Earth (Durney and Roxburgh, 1971).

Convective cells give the photosphere a granular appearance with bright cells (hot rising gas) surrounded by dark intergranular lanes (cool descending gas). A typical granule is approximately 1000km in diameter. Measurements of horizontal velocity reveal a larger convective pattern, the supergranulation; and the horizontal motion of individual granules reveals intermediate-scale convective flows (Muller et al., 2007).

Other prominent features of the photosphere are sunspots and faculae. Sunspots appear as dark spots on the surface of the Sun. Temperatures in the dark centers of sunspots drop to about 3700K. They typically last for several days, although very large ones may live for several weeks. Sunspots are magnetic regions on the Sun, with magnetic field strengths thousands of times stronger than the Earth's magnetic field. Sunspots usually come in groups with two sets of spots. One set will have positive or north magnetic field while the other set will have negative or south magnetic field. The field is strongest in the darker parts of the sunspots - the umbra. It is weaker and more horizontal in the lighter part - the penumbra.

Faculae are bright areas that are usually most easily seen near the limb, or edge, of the solar disk. These are also magnetic areas but the magnetic field is concentrated in much smaller bundles than in sunspots. While the sunspots tend to make the Sun look darker, the faculae make it look brighter. During a sunspot cycle the faculae actually win out over the sunspots and make the Sun appear slightly (about 0.1%) brighter at sunspot maximum that at sunspot minimum.

The sunspots, progressively appearing from mid-latitudes to the equator, mark the solar activity cycle, for short the 11-year solar cycle. The period is not constant, but varies between about 9.5 and 12.5 years. During the cycle, changes occur in the Sun's internal magnetic field, in the photosphere, and in next upper level, the chromosphere. At the beginning of a cycle the solar magnetic field resembles a dipole which axis is aligned with the Sun's rotation axis. In this configuration the helmet streamers form a continuous belt about the Sun's equator, and coronal holes are found near the poles. During the following 5-6 years towards the maximum this configuration is totally destroyed, leaving the Sun, magnetically, in a disorganized state with streamers and holes scattered all over different latitudes.

During the latter part of the cycle the dipole field is restored. At the beginning the dipole tilt can be large, but as the minimum epoch approaches and the dipole grows in strength, it also orients itself more with the Sun's rotation axis. When a new dipole is reformed, it has an opposite polarity than the old one: this creates a 22-year cycle for the Sun, the so-called double-solar-cycle (Callebaut et al., 2002).

As the solar cycle unfolds towards its maximum, the associated energy and particle outbursts (e.g., flares and coronal mass ejections) occur in larger number and intensity. Both the regular and explosive variations affect the state of the heliosphere, of the solar wind, and ultimately of the Earth’s magnetosphere, ionosphere, and atmosphere (Thuiller et al., 2005).

The solar wind streams off of the Sun in all directions at speeds of several hundred km/s, only becoming subsonic beyond the orbit of Pluto. It consists of particles, ionized atoms from the solar corona, and fields, in particular magnetic fields.

As the Sun rotates once in about 27 days, the magnetic field transported by the solar wind gets wrapped into a spiral. Variations in the Sun's magnetic field are carried outward by the solar wind and can produce magnetic storms in the Earth's own magnetosphere. Furthermore, regions on the surface of the Sun often flare and give off ultraviolet light and x-rays that heat up the Earth's upper atmosphere. This Space Weather can change the orbits of satellites and shorten mission lifetimes. The excess radiation can physically damage satellites and pose a threat to astronauts. Shaking the Earth's magnetic field can also cause current surges in power lines that destroy equipment and knock out power over large areas.

Finally, the Sun is a source of light and heat for life on Earth. Some of those cycle variations, as well as other at longer terms, most certainly affect our climate though in uncertain ways.

Solar Diameter Variations

Observatório Nacional and R2S3 measures have been consistently obtaining variations of the observed diameter on the order of 100mas/solar cycle. Past and current independent experiments from different groups find (at least) likewise. However, from gravitational energy variation considerations only, a radius variation gives rise to

$$\Delta E = \Delta R \times (3GM^2/5R^2) \qquad (3)$$

Therefore, to vary the Sun stellar radius by 5exp(-5) along the 11y solar cycle, the required energy variation is about 75 times the total solar output (Durney, 1972). Yet, if just the irradiating surface is considered, and assuming that the flux per unit area is kept, a radius variation gives rise to

$$\Delta I = \Delta R \times 2/R^{-1} \qquad (4)$$

That is, the observed 0.1% radius variation would explain half of the irradiance variation along the solar cycle. Now, if the radius variation is assumed confined to the convective zone (for which in turn an adiabatic regimen is granted), the same 0.1% variation becomes inexpensive in gravitational energy terms (0.01% in the solar cycle). At the same time, a variation on the convective zone height scale would be quite effective to produce a change of the radius defined by hydrostatic equilibrium, at no expense of gravitational energy and very little change of irradiance.

$$dI \propto d\rho = dh_0 \times \rho \ \exp[h/h_0^2] \qquad (5)$$

Heliosismology holds that "results from f-mode oscillations that the solar radius only changes by about 1 km/year do not preclude the less-sensitive efforts to measure variations of the solar radius at the photosphere by limb observations since the latter are likely to be much larger than the former." (Sofia et al., 2006) (and similar quotations can be extracted from other authors). So, prevented gravitational or irradiance catastrophes by keeping the physics confined to the convection zone, or better to the photosphere, the massive vault of observations reporting radius variations can be exploited just as the experimental evidence they are.

Some hypothesis to explain the diameter variations have been put forward: localized variations depending of heliolatitude (in special by the equatorial bulge, by the boundary of the royal zone, and at 60° heliolatitude) - following the magnetic network evolution along the cycle; shear in the differential rotation in the convective zone; self-refraction in the solar atmosphere.

On the other hand, disturbances of the troposphere were for quite a while used as an alternative explanation for the observed variations. Quantitative results were obtained for non-linear quasi-zenith distance dependencies in the case of non-varying prism astrolabes, while an analytic description relates the coherency window (Fried's parameter) and the placement of the inflection point defining the solar limb effective stop. The episode analysis and the compound R2S3 series, bringing together multi-site results from widely separate stations, enforce limits on the effectiveness of those mechanisms (Andrei et al., 2004). Either way, they before all produce strong yearly signals that are not verified, and if prevalent should smear the multi-site signal.

More recently, attention was drawn to the stratosphere modulation with the solar cycle. Such would imprint both a mark on multi-site observations (in special from alike instruments, leading to alike biases), due to the effective horizontal mixing, and at the same time as a solar activity related signature. However, it should be considered that the QBO and the yearly stratosphere variations are stronger than the 11 years one, respectively by factors of 2 and 10. On the contrary, for the R2S3 series the 11 year signal is much more evident than one or two year periods. In support to the amplitudes mismatch, it can be also remarked that the 11 year stratospheric modulation befalls on the upward structure, while the solar astrolabe observations are, at least to first order, insensitive to small amplitude refraction and focusing variations.

Combining the self-refraction and height scale variation principles, a more likely mechanism surfaces. The observed solar radius is just the level beyond which the optical depth reaches unity ($\tau = 1$). The optical depth can be expressed by

$$\tau = \kappa\rho \times (KT/mg) \qquad (6)$$

Thus, the optical depth can vary – and in so making vary the observed radius – in different ways. Either of them will leave a signature on the appearance of the photosphere. We propose that such a signature must by necessity modify the granulation structure. In what follows we bring evidence to these statements.

Though granulation forms the very face of sun's photosphere, there are no long term registers of it. Observational and computational hardships to define and follow such highly variable "face" have so far prevented the realization of those registers (but see Roudier & Reardon, 1998) – even much they are useful for solar physicists. However, in recent years a large, coherent body of white light images became available (Hirzberger et al., 1997). The resolution of the images is at the level of 1 arcsec, thus enabling to perceive granulation structures and individual grains. We retrieved the full solar disk white light images from the Big Bear Solar Observatory (BBSO), at California/USA. Only FITS standard images were retrieved, aiming to standardized IRAF treatment. These images cover the raising, peaking, and pos-peak periods of the solar cycle 23. They are unevenly but densely distributed from the years 2000 to 2006. Two kind of images were retrieved, and will be treated separately for measure of control: full disk image dark subtracted and flat field corrected (*Fl*, 1261 images), and full disk image limb darkening subtracted (*Fr*, 1341 images). The images are 1364×1035 pxs. The exposure time varies between 50 and 80ms, what modulates the effective size of the well imaged Sun.

To avoid the contamination of the limb darkening on the images treatment, only the central part of the Sun's disk is retained for treatment. To that, the center of the Sun is found, and around it only a sector of relative radius of 0.35 is cut in. With this, the intensity variation is maintained below 2% even for the *Fl* images. The internal sector is next divided into a net of 10×10 contiguous subsectors. Each subsector contains 30×30 pxs. All statistics are performed independently for each sector, and the ones which results deviate from the average by 3σ are removed from the final analysis. This strategy seeks to discard the presence of sunspots upon the graining description.

Three estimators are here used as first assessment to the granulation state. For each estimator the average of the subsectors is calculated (after removing the deviating ones).
- standard deviation of counts (*S*) – as probe of the grains' mean size.
- difference between the uppest and lowest counts tenths (*Q*) – as probe of the grains' brightness.
- degree of the better adjusted polynomial along lines and columns (*N*) – as probe of the grains' number.

The model then assumes a patch of grains formed by bright centers and dark intergrain contours. Through large number statistics the balance between the two structures along the solar cycle is assessed. After all *Fl* and *Fr* images have been treated, and the three statistics obtained for each one, a final filter was applied removing within each year the images for which all three statistics mean value were afar more than 3*σ* from the yearly average.

The number of used images is 1104 *Fl* and 1245 *Fr*. The average number of subregions used (that is, not suspected of containing spots or faculae) per image is very similar, being 94.1 (*σ* 2.6) for *Fl* and 94.6 (*σ* 2.4) for *Fr*.

The autocorrelation S, Q, and N statistics, for both the *Fl* and *Fr* images, extends up to about two months. The exception is *N*(*Fr*), for which it extends beyond half a year (this feature is better understood when of the analysis of the statistics itself). In agreement to the autocorrelation distributions, the Run's test indicates statistically significant presence of signal for all the statistics.

The time series for the *S* and *Q* statistics, for both types of images, shows anti-phase correlation larger than 0.99 to the solar cycle evolution. The position of the minimum of the time series fitted to the *S* and *Q* statistics always. They are: *S*(*Fr*)*min* = 2003.15; *Q*(*Fr*)*min* = 2003.29; *S*(*Fl*)*min* = 2002.83; *Q*(*Fl*)*min* = 2002.89

On the other hand, there is no significantly variation for the *N* statistics. That is, according to the *N* statistics, there is no significant variation in the number of grains.

In conclusion, the grains sizes are the largest by the solar maximum, in excellent agreement with the maximum of the measured diameter. The grains brightness, on the contrary, is minimum at the solar maximum, and again an excellent agreement is verified with the maximum of the measured diameter. Accordingly, the granulation variation varies the photosphere density, mixing, and eventually its height scale, therefore providing a mechanism to vary the optical depth, and hence the measured diameter.

At the Observatório Nacional/MCT in Rio de Janeiro (Ψ = -22^o 53' 42" , Ω = +2^h 52^m 53^s.5 , *h* = 33m) the series of solar semi-diameter measurements started in 1997. The original Danjon Astrolabe was specially re-designed for this type of observations. The most important features were the installation of a variable angle front prism enabling the continuous observations between the zenith distance of 26^o and 56^o, the concurrent installation of a moving density filter, and the installation of a CCD camera, which allowed the observations to become fully freed of personal equations Jilinski et al., 1999).

The principle of the measurements uses two images of the Sun: one is said direct while the other follows a path that reflects on a horizontal basin of mercury. To each image, parables are adjusted to produce the solar edge. The raw data were corrected from effects related to the observation conditions: the air temperature, its first derivative, the Fried factor and the standard deviation of the adjusted parable to the directly observed solar edge. The Fried factor was obtained from the observation data. Further, it was inspected whether the data could also be corrected from the detected effect caused by the lacking of stability of the objective prism, and from the detected effect caused by the lacking of leveling of the astrolabe that causes errors as function of the observed azimuth. Finally, systematic errors of unknown origin were modeled by a statistical approach. The treated results present standard deviation around of 0".567, this evidentiates that all applied corrections are small, and thus are not apt to introduce any spurious long term modulation upon the final results (Penna et al., 2002) .

The solar semi-diameter series treated here was observed with the CCD Astrolabe from March 2nd 1998 to November 27th 2003. It comprises more than 18,000 observations, with mean internal error of 0".20 and standard deviation of 0."596. The observations are made daily, to an average of 20 observations (actually observing days considered), and even distribution of the measurements all year around. A major gap is verified on the series between September 21th 2001 and December 19th 2001 due to apparatus problems. The observations are taken on before and after meridian sessions. As a rule, there is no significant difference between the measurements from the two sessions. The heliolatitude coverage covers the whole solar figure in a semi-annual cycle (Boscardin, 2004).

From an analysis on heliolatitude bins, the solar oblateness can be derived. A conservative approach was chosen, and an ellipsoid of revolution was directly adjusted to the data, in view of the errors involved in the measurements as well as possible systematic effects due to brightness variations on the observed limb. All data considered, we obtain an equatorial radius (*Re*) equal to 959".113±0."007 and a polar radius (*Rp*) equal to 959".100±0".011. These values are in good agreement with other determinations of the solar oblateness. In order to improve on the precision of the determination, and taking advantage of the large number of independent measurements and their normal distribution, the series was sampled by progressively removing the more discrepant points (relatively to an ellipsoid adjustment). We took steps of 0.1 units of standard deviation, removing from 2σ up to 3σ. In the first case, the strictest, 7556 measurements are used, while in the more relaxed case 9047 measurements are used. By this method the robustness of the solution was tested, by bootstrapping. The final equatorial and polar radii are given by the average of the values at each step. The final errors are calculated by the root mean square of the squared error at each step plus the covariance of adjacent steps. The covariance was always assumed as unity, to keep the most conservative stand. The final value obtained for the oblateness is 13 ± 4 mas, corresponding to slightly smaller radii *Re* = 959".110 ± 0".002 and *Rp* = 959".097 ± 0".003. Adopting the component of the oblateness due to surface rotation alone as δr = 7.8 mas, the gravitational quadrupole moment of the Sun, is obtained as $|J_2| = 3.61 \pm 2.90 \times 10^{-6}$ (Reis Neto et al., 2003).

The data file here concerned comprises the rise, crest and beginning of the subduing of the solar cycle 23. Combined to large quantity and even spreading of the observations, this offers the conditions to statistically compare the observed solar semi-diameter (SD) variations against estimators of the solar activity, which also could be expressed as continuous daily series. The estimators were the sunspot count number (SS) and its proxy, the 10.7cm radio flux (RF), both sensing the photosphere state; the total solar irradiance (IR) and the strength of the integrated solar magnetic field (MF), sensing directly the solar cycle age, and finally the flare index (FI) to assess the major solar outbursts. All estimator data were retrieved from the National Geophysica lData Center - NGDC. The hypothesis that the variation of the solar semi-diameter could be linked to the solar activity was checked by calculating the correlations between the solar semi-diameter series against each one of those estimators. Afterwards, the correlations were re-calculated, taking pairs of correlated series and allowing variable time delays between them. This may points to interconnected phenomena, either with some time delay between them, or even a causal relationship. In order to get a broader picture, the correlations among the estimators were likewise calculated (Boscardin et al., 2008).

Table 1:Pearson Linear Correlation between the Time Variations of the Semi-Diameter and Estimators of the Solar Activity (1998-2003)

Pair	SD-SS	SD-RF	SD-IR	SD-MF	SD-FI
Correl.	0.80	0.88	0.78	0.62	0.66

In particular, when the periods where have occurred peaks of solar activities are removed from the solar semi-diameter and from the total solar irradiance series, the time delay for the largest correlations between them changes prominently. As it was already noticed that, taking the complete, no-removal series, the semi-diameter versus irradiance correlation shows two maxima, one close to zero and one close to -380 days. Lets now chose the periods of most intense soar activity, between the Julian modified dates 1709.0 and 1919.0 and between 2213.0 and 2378.0, and remove them from the series. In this case the maximum close to zero disappears. This suggests two modes of response of the semi diameter relatively to the solar irradiance. Along the solar activity cycle the semi-diameter variation trails behind the cycle. However when peaks of activity occur, it also occurs a rapid variation on the measured semi diameter. In these cases the semi diameter variation actually acts as a predictor of intense solar activity.

Conclusions and Perspectives

The physics of the photosphere is important for the understanding of the solar flux, from the convection zone to the violent outbursts that emerge from the solar outer layers. It is also all relevant to understand the space weather and relationships to the Earth's magnetosphere, ionosphere, and atmosphere.

In this work we briefly review the present status of the knowledge about the physics of the photosphere. In this way a model is forwarded by which the variations observed on the solar diameter are explained by the variation on the size and brightness of the solar granules along the solar cycle. Those lead both to variations on the optical depth and on the photosphere scale height.

The ON series enables to obtain a broader description of the photosphere physical processes, including the relationships between the variations of the diameter and of the main estimators of the solar activity. The correlations between the variations along the solar cycle attain 0.78 for the pair of diameter and total solar irradiance, 0.80 for the pair of diameter and sunspot number, and 0.88 for the pair of diameter and 10.7cm radio flux.

Also, from the analysis grouping the results in heliolatitude bins, the solar oblatness is derived to a precision of -3 dex.

The CCD Astrolabe is presently the main instrument for the continuous surveying of the solar-diameter. Around the word, research centers from five countries (Brasil, France, Turkey, Spain, and Argelia) use basically the same equipment, data acquisition, and data treatment methods to contribute solar measurements to the R2S3 network.

The major next steps are the PICARD satellite to be launched by the French Space Agency in 2009/2010 and the instrumental development made by the Rio de Janeiro Group.

The ON group is developing a state-of-the-art heliometer, dedicated to highly accurate measurements of the solar diameter (Reis Neto et al., this meeting). A prototype, a functional reflector, has already generated hundreds of double images of the Sun. About 700 of these have been analyzed and the results show an accuracy of 0."09 on the solar diameter. Based on these results the specifications for the project have been established in order to obtain the highest performance of the instrument. The stability of the focal length will be achieved by using rods of extremely low thermal expansion materials as carbon fiber. These rods will take part in tubular structure of the telescope to ensure the mechanic stability of the instrument. A CCZ mirror will ensure the stability of the optical configuration, keeping the images of the solar disks fixed in relation to each other.

For the construction of the second prototype reflector we established the best technique for the manufacture of the dihedron between the halves of the cut parabolic mirror along the diameter. The stabilization of this dihedron was done by polishing of the rear surfaces of mirrors against a base of optical glass for the perfect lodging between the pieces. The perfect lodging between the mirrors and this base define the angular instrumental separation. The collimation is a key feature of the instrument to certify the stability of the measurements. It is done through the placement of a back illuminated disk on the collimation mirror focal plane. Such scheme fully duplicates the actual observation geometry and can be undertaken as often as desired. The program developed for the image treatment is likewise compliant to the collimation task. All optical design is been done using CAD-3D.

Acknowledgements

The authors acknowledge partial financial support from the Brazilian Science Funding Agencies FAPERJ, CNPq, and FINEP. We also acknowledge the use of solar data from the BBSO and from the NGDC. We register the fruitful relationship between the national institutions belonging in the R2S3 solar network and in the SCOSTEP/CAWSES project.

References

Andrei, A. H., Boscardin, S. C., Chollet, F., Delmas, C., Golbasi, O., Jilinski, E. G., Kiliç, H., Laclare, F., Morand, F., Penna, J. L. and Reis Neto, E., 2004, Comparison of CCD astrolabe multi-site solar diameter observations, Astronomy & Astrophysics, 427, 717-723.

Andrei, A.H., Penna, J.L., Reis Neto, E., D'Ávila, V.A., de Almeida, W.G. and Jilinski, E.G., 2001, What are the astrolabe observations of the Sun measuring?, First Annual Meeting of the R2S3, Calern, France.

Andrei, A. H., Boscardin, S. C., Reis Neto, E., Penna, J.L., D'Ávila, V.A., 2006, Variations of the solar radius in solar cycle 23, SCOSTEP-CAWSES Meeting, 1, 43-44.

Boscardin, S.C., Andrei, A.H., Penna, J.L., Reis Neto, E. and D'Ávila, V.A., 2008, Solar Diameter and Activity – Correlation Analysis, 1998-2003, submitted to Astronomy and Astrophysics.

Boscardin, S.C., 2004, Diameter observations analysis in the solar activity context, MSc Thesis, UFRJ, Observatório do Valongo.

Callebaut, D.K., Makarov, V.I. and Tlatov, A.G., 2002, Gravitational Energy, solar radius and solar cycle, The 2nd Cycle and Space Weather Euroconference, 24-29.

Damé, L., Brun, J.-F., Cugnet, D., Derrien, M., Leroy, C., Meftah, M., Meissonnier and M., Porteneuve, J., 2000, A solar diameter metrology measurement : the PICCARD microsatellite program, ICSO 2000.

Durney, B.R. and Roxburgh, I.W., 1971, Inhomogeneous convection and the equatorial acceleration of the Sun, Solar Physics, 16, 3-11.

Durney, B., 1972, The Sun's differential rotation and pole equator temperature difference, Solar Physivs, 26, 3-7.

Giorgobiani, D., 2003, Numerical simulations of solar and stellar convection and oscillations, PhD Thesis, Michigan State University.

Hirzberger, J., Vázquez, M., Bonet, J.A., Hansmeier, A. And Sobotka, M., 1997, The series of solar granulation inages. I. Differences between small and large granules in quiet regions, The Astrophysical Journal, 480, 406-419.

Jilinski, E.G., Puliaev, S.P., Penna, J.K., Andrei, A.H., Sinceac, V., Chollet, F. and Delmas, C., 1998, Solar diameter observations with the astrolabe at Observatório Nacional – Rio de Janeiro, Astronomy & Astrophysics Supplement Series, 130, 317-321.

Jilinski, E.G., Puliaev, S.P., Penna, J.K., Andrei, A.H. and Laclare, F., 1999, Solar diameter observations with the astrolabe at ON in 1997–1998, Astronomy & Astrophysics Supplement Series, 135, 227-229.

Lefebvre, S., Rozelot, J.P., Pireaux, S., Ajabshirizadeh, A. and Fazel, Z., 2005, Global properties of the Sun and stars: what can we learn from irradiance and shape?,

Memorie de la Societa Astronomica Italiana, 76, 994-997 Mullder, R., Hanslmeier, A. and Saldaña-Muñoz, M., 2007, Space and time variation of the solar granulation, Memorie de la Societa Astronomica Italiana, 78, 71-76.

Mursula, K., 2005, Sun and Heliosphere, University of Oulu.

Penna, J.L., Jilinski, E.G., Andrei, A.H., Puliaev, S.P. and Reis Neto, E., 2002, Astronomy and Astrophysics Supplement Series, 384, 650-653.

Schussler, M. and Vogler, A., 2003: The Sun and its restless magnetic field, Astron. Nachr 324, 399, 81-89.

Reis Neto, E., Andrei, A.H., Pennal, J.L., Jilinski, E.G. and Puliaev, S.P., 2003, Solar Physics, 212, 7-16.

Roudier, Th. and Reardon, K., 1998, Variations of the solar granulation over the cycle: previous results and future observations, Synoptic Solar Physics, 140, 455-466.

Thuiller, G., Sofia, S. and Haberreiter, M., 2005, Past, present and future measurements of the solar diameter, Advances in Space Research, 35, 329-340.