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Astrometric observations of the Sun at Santiago: 1998–2000

F. Noël*

Departamento de Astronomía, Universidad de Chile, Casilla 36-D, Santiago, Chile

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Abstract. A program of solar astrometry with a modified Danjon astrolabe has been in progress since 1990 at the National Astronomical Observatory at Cerro Calán, Santiago, Chile. More than 3200 homogeneous observations have been made visually by a single observer at 30° and 60° zenith distances. Here we present and discuss the results in right ascension, parameter Y and apparent solar radius obtained during the period 1998–2000. These results and those obtained in former years are available in electronic form**. After almost 11 years of continuous observations, the most interesting aspect of the solar results of the Santiago astrolabe is a significant and positive correlation between variations in time of the apparent semidiameter of the Sun and solar activity.

Key words. astrometry – Sun: activity – Sun: fundamental parameters

1. Introduction

Within the frame work of joint collaborative research in astrometry between the European Southern Observatory (ESO) and Universidad de Chile, a Danjon astrolabe is in operation at the National Astronomical Observatory at Santiago (Blaauw 1991). This collaboration commenced in 1965 and since then it has made solid contributions to astrometry in the Southern Hemisphere (Fricke 1972; Blaauw 1991; Noël 2001).

The prismatic astrolabe of Danjon (1960) works according to the method of equal altitudes (Débarbat & Guinot 1970) which consists of timing the transit of a star through a small circle of fixed altitude or almucantar defined by means of a prism and a mercury mirror in front of the objective. Over many years the astrolabe produced high quality results on the rotation of the Earth, in stellar astrometry (Eichhorn 1974) and specially in the research of systematic errors in star catalogues (Anguita & Noël 1969; Fricke 1972).

The pioneer work of Laclare (1983) at the Centre d'Études et de Recherches Géodynamiques et Astronomiques (CERGA), France, has shown that after prior modifications, the astrolabe also can give good results in solar astrometry. Following this, the Santiago astrolabe was modified in 1989 to start a program of solar astrometry. The transparent prism of the classical Danjon astrolabe was replaced by two reflecting prisms made of CERVIT that allow observations at 30° and 60° zenith distances. The rather low thermal coefficient of CERVIT provides a far more stable instrumental reference than that defined by the primitive quartz prism. Solar observations are made possible by means of a filter made of transparent CERVIT installed in front of the objective in a fixed position, independent of the observing zenith distance. The bandwith of the solar filter plus the astrolabe optics is 200 nm centered at approximately 550 nm.

The observations of the Sun with the modified Danjon astrolabe of Santiago commenced in April 1990 as a contribution to the research of the orbital parameters of the Earth-Moon system and of an eventual difference between the dynamical and stellar equinox (Hohenkerk et al. 1992). More than 3200 homogeneous visual observations have been made so far by a single observer. The most interesting aspects of the results concern the apparent solar radius. There is a positive and significant correlation between variations in time of the apparent radius and solar activity (Noël 1997, 2001). A heliographic latitude dependence of the solar radius also has been disclosed (Noël 1999).

The individual results of the observations made since the beginning of the program in 1990 have been published elsewhere and are available in electronic form (Noël 1993, 1994, 1995, 1998). With this paper the data set of solar observations with the Santiago astrolabe will be updated with the results obtained during the period 1998–2000.

2. Observations and reductions

The observations consist of timing the east and west transits of the upper and lower border of the Sun through the

* e-mail: fnoel@das.uchile.cl

** Tables 3 and 4 are only available in electronic form via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via
http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/375/614

almucantars of 30° and 60° zenith distances. According to the latitude of Santiago ($-33\overset{\circ}{.}4$), the Sun can be observed all year round at 60° and from October 7th until March 7th at 30°. Since the prisms that define the almucantars can be interchanged in a few minutes, observations at both zenith distances are possible during the same day.

The computed transit times of the Sun are derived from the DE200/LE200 solar ephemeris. The instantaneous coordinates of the astrolabe are calculated with the Earth orientation parameters, polar coordinates and UT1-UTC, provided by the International Earth Rotation Service. The observed equatorial coordinates of the Sun, but not the semidiameter, are sensible to the adopted values of the Earth orientation parameters. A least square solution gives directly the right ascension and the radius of the Sun, and the parameter $Y = \Delta\delta \cos\eta + \Delta z$. This parameter includes the solution in declination, $\Delta\delta$ (observed-ephemeris), and in zenith distance, Δz (observed-adopted). It is not possible to separate both solutions, since there is insufficient variation of the Sun's parallactic angle η, between the east and west solar transits through the almucantars. A detailed description of the solar observations at Santiago and its reduction method is given by Noël (2001).

3. Results and discussion

The mean values of the solar radius obtained during 1990–2000 are given in Table 1 according to the observing zenith distance and according to east or west observations. There are no significant differences in the mean results depending on the zenith distance of observation. This is an important point when considering systematic effects of instrumental origin. Since the angle of the prism of an astrolabe is the only instrumental constant whose variation would affect the accuracy of the observations (Danjon 1960), results obtained at different zenith distances can be considered as being obtained with different instrumental systems. Therefore, eventual systematic effects of instrumental origin in the results of Santiago should be small, or they may affect the results obtained at different zenith distances in a similar way. This last eventuality is, in our view, quite improbable.

With respect to the mean results based on east or west observations, the values of Table 1 show a small but slightly significant difference. However, this difference has the same sense at 30° and 60°. The dispersion is also slightly different, beeing higher for the east observations, especially at the 60° zenith distance. Probably this difference comes from atmospheric effects due to the local topography. The high mountains of Los Andes range lie to the east and are close to Cerro Calán Observatory.

The mean annual values of the differences in right ascension in the sense astrolabe-ephemeris, and of the observed Sun semidiameter reduced to the astronomical unit, obtained during the period 1998–2000 and during former years, are given in Table 2. The n individual values involved in the annual means of Table 2 were obtained by means of a least square solution (Noël 2001). Each individual value is equivalent to the average of an east and a west observation.

Table 1. Mean values of the solar radius ($R_\odot$) according to to the zenith distance ($z_\odot$) and according to east and west observations with the Santiago astrolabe. The individual values involved in the mean results were deduced from the difference between the zenith distance residuals given by the upper and lower border observation of the Sun (Noël 2001).

$z_\odot$	$R_\odot$		σ	n
30° East:	$960\overset{''}{.}36 \pm$	$0\overset{''}{.}02$	$0\overset{''}{.}49$	563
30° West:	960.39	0.02	0.45	509
30° E&W:	960.37	0.02	0.47	1072
60° East:	960.33	0.02	0.59	1094
60° West:	960.40	0.02	0.50	915
60° E&W:	960.36	0.01	0.59	2009
TOTAL:	**960.36**	**0.01**	**0.53**	**3081**

Table 2. Annual mean values of solar right ascension(observed-ephemeris) and of semidiameter with their mean errors, derived from astrolabe observations at Santiago. n is the number of individual measurements involved. Each one was obtained by a least square solution and is equivalent to the average of an east and a west observation (Noël 2001).

Year	Alpha(O-E)		Semidiameter		n
1990	$0\overset{s}{.}043 \pm$	$0\overset{s}{.}009$	$961\overset{''}{.}05 \pm$	$0\overset{''}{.}07$	62
1991	0.024	0.006	960.78	0.06	52
1992	0.018	0.005	960.62	0.06	80
1993	0.029	0.003	960.49	0.03	146
1994	0.042	0.004	960.24	0.03	124
1995	0.063	0.004	960.08	0.03	115
1996	0.080	0.004	959.85	0.03	123
1997	0.052	0.004	960.00	0.03	120
1998	0.057	0.007	960.27	0.03	158
1999	0.043	0.004	960.47	0.03	200
2000	0.051	0.004	960.60	0.03	227
Mean	**0.048**	**0.002**	**960.37**	**0.01**	**1407**

The individuals results of the observations at 30° and 60° for the period 1998–2000 are reported in Tables 3 and 4 (accessible only in electronic form) with results of former observational periods. The following information is available from these tables:

– Year, month, day of the observation;
– The modified julian date;
– Zenith distance residual given by the observation of the Sun's east upper border, east lower border, west lower border and west upper border;
– Right ascension (observed-ephemeris) with its standard deviation;
– Y = dz+dδcos$S$, where dz = zenith distance (observed-computed), dδ = declination (observed-ephemeris) and S is the Sun's paralactic angle;

- Sun's apparent semidiameter (observed-ephemeris) with its standard deviation;
- Sun's apparent semidiameter reduced to the geocenter and to the astronomical unit.

4. Conclusions

The annual mean right ascension differences for the period reported in this paper, 1998–2000, that are presented in Table 2, confirm the general trend that these differences have shown in former years. As stated above, the local reference frame of the astrolabe is defined by the Earth rotation parameters provided by IERS, which are related to the International Celestial Reference System (ICRS) (Arias et al. 1995). Therefore, besides eventual instrumental or observer effects, the systematic differences in right ascension of Table 2 could be due to a positive offset of the ICRS equinox with respect to the dynamical equinox of the DE200/LE200 solar ephemeris. A positive difference in the sense catalogue-ephemeris, has been found also from solar observations made in the FK5 system and also using also the DE200/LE200 ephemeris of the Sun (Kolesnik 1995). Thus, our results should be in agreement with those of Kolesnik, considering that the ICRS and FK5 equinoxes according to Arias et al. (1995) should be equivalent. On the other hand, an effort was made to make the equinox of DE200/LE200 ephemerides agree with that of the FK5. However, it was recognized that there is some difference, which should be determined more accurately with time (Hohenkerk et al. 1992).

With respect to the observed solar radius, the annual means for the period 1998–2000 reported in this paper confirm, as can be seen in Table 2, that the apparent solar radius observed with the Santiago astrolabe varies in phase with solar activity. The first report of the solar radius variations observed at Santiago included only the results obtained until 1995 (Noël 1997). Later results, especially those obtained after the solar minimum of 1996, largely confirm our provisory conclusions of 1997. On the other hand, the results from Santiago are in agreement with other results obtained during the last years which also show positive correlations between solar radius variation and solar activity (Ulrich & Bertello 1995; Basu 1998; Costa et al. 1999; Emilio et al. 2000; see also Gough 2001).

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