ASTROMETRY AND NUMERICAL METHODS FOR THE SOLAR HELIOMETER AT OBSERVATÓRIO NACIONAL IN BRASIL

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ABSTRACT. Started its regular, daily operational phase in 2011, the results so far obtained show that the Heliometer from Observatorio Nacional (O.N.) fulfilled its planed performance of single measurement to the level of few tens of mas, freely pivoting around the heliolatitudes without systematic deviations or error enhancement. Such fruition led to evaluate high order terms that are commonly neglected in other solar astrometric observations. Namely, these are: the constancy of the basic heliometric angle, the dependence to meteorological and pointing conditions, the second order terms for diurnal aberration and parallax, the accounting of the Earth's ellipticity of the orbit, and the second order atmospheric refraction. We present and discuss these astrometric additions that are seldom required on ground base astronomic programs.

1. THE HELIOMETER OF O.N. — MAIN CONCEPTS

The heliometric method is one of the most successful techniques to measure small variations of angles. Its principle has been used for the latest space borne astrometric missions, aiming to milliarcsecond precision. The angle to be measured is small (the variation of the solar diameter) confronted with the corresponding linear displacement at the focal plane, thus an error on the linear measurement is smaller by orders of magnitude over the angular variation that is being measured.

At Observatorio Nacional a primary parabolic mirror was bissected to form an angular heliometer. The displacement of the images is produced by rotating the two half-mirrors along a line perpendicular to the line of cut. The heliometric mirror is all made of CCZ-HS, a ceramic material with very low thermal expansion coefficient ($0.2 \times 10^{-7}/°C$). The two half mirrors are immobilized, in relation to each other, by means of an external ring, all resting over an optical plate. Its cell guarantees the mechanical and geometrical stability for the entire set. This niche is also made in CCZ. The surface quality of the optical plate and the mirrors is better than $\lambda/12$ and $\lambda/20$, respectively. A mask at the top of the cell has been designed to keep the two half mirrors blocked in place and also to assure that the entrance pupil has a symmetric shape, regularizing the PSF. The tube of the telescope is made of carbon fiber. This material, as well as extremely rigid, has very low coefficient of thermal expansion. It is mounted inside a stainless steel truss support and can rotate around its axis. In order to eliminate the secondary mirror the CCD chip was removed apart from the camera electronics and installed directly in the focal plane. Each half-mirror is tilted of an angle slightly greater than 0.135° in order to displace the images relatively to each other by one solar diameter approximately. In this way we will have the opposite limbs of the Sun almost in tangency in the focal plane at the perihelion (D'Ávila et al., 2010).

The plate scale can be instantaneously known by timing the solar movement over the detector, removing the out-of-focus dependence for the linear distance between two points. No dependence to meteorogical conditions was found examining the results during the first full year of observations (2011), against troposphere and upper atmosphere temperature, pressure, and wind (Andrei et al., 2013a).

The general view of the heliometer and the hemi-mirrors are shown in Fig. 1.

Figure 1: The Heliometer developed at Observatório Nacional/MCTI. The hemi-mirrors and containing cell are shown in the side detail.

2. ASTROMETRIC CORRECTIONS

The corrections for Refraction and Annual Parallax follow what is usually done for precision astrometry. And in particular for the treatment of the Solar Astrolabe observations. Their effects are large (∼arcsec) but taken care of. However there are smaller terms which are usually discarded. But that had to be considered for the $\sim 0.01''$ Heliometer precision.

Aberration. Annual and diurnal effects are opposite for Solar observations. The net effect owes more to the translation velocity. It is given by the difference of two opposite points on the equatorial limb, that is $30'$. The maximum correction is $0.04''$.

Diurnal Parallax. Maximum effect is when for the Sun in perihelion and observed at lowest (in our case z=50°). The difference between the geometric and observing distance amounts to a correction of $0.02''$.

Diurnal Parallax Hourly Variation. The variation of the Solar diameter between aphelion and perihelion is of $16.01''$, with a quasi-sinusoidal modulation. It hence translates to a maximum hourly correction of $0.05''$/hour.

Refraction second order terms. Taking into account the third order terms in the tan expansion of the refraction series, and deriving the maximum difference, which refers to a vertical diameter, the correction attains to $0.02''$.

All these corrections are fully implemented in the program of treatment of the Heliometer mean results (Andrei et al., 2013b).

3. REFERENCES

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