ON THE VERIFICATION OF THE ACCURACY IN THE DETERMINATION OF THE ASTRONOMICAL NORTH ORIENTATION AT CHAJNANTOR

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Applicable documents:

AD1 Determinación del Norte Celeste en el Llano de Chajnantor, Instituto de Astronomía, Universidad Católica del Norte, Antofagasta-Chile, Octubre 2003.

AD2 Observaciones Astronómicas, ALMA Project, Sector Chajnantor, Ing. Emilio Pacheco, EP Servicio de Engenieria en Geomensura, Agosto 2005.

Summary
This document summarises the results of a geodetic campaign carried out to verify the accuracy in the determination of the orientation of the Astronomical North at Chajnantor. The astronomical local meridian is indicated as the line of sigth between two geodetic marks know as Master0 and the Astronomical North Monument (ANM).
The final results are included in this report on Table 5 and indicate that the accuracy of the orientation of the local meridian at Chajnantor is of -1'09". The negative sign indicates the existing marked local meridian is a slightly westward from the true astronomical meridian. Our geodetical observations give a 1 sigma of (1 σ= 44").
(*Warning note*: We found the ANM concrete monument is simply over the surface and not anchored to the rock-underground)

Introduction

During the night of August 11, 2005 (UT), with the assistance of the Survey Engineer Mr. Emilio Pacheco, we conducted astronomical observations at Chajnantor as to verify the accuracy of a previous determination of the astronomical north from the reference survey point named Master0. The original work included the installation of a monument located 100 m north from Master 0 with a plate on top indicating the orientation of the local meridian.

This verification was conducted because this orientation might be relevant in subsequent survey works at Chajnantor during the construction and proper orientation to the astronomical north of the ALMA antenna pads.

Applicable document AD1 cover the report on the astronomical observations performed to determine the local meridian and the installation of the monument to indicate the meridian orientation with reference to the geodetic point named to the ALMA project as Master0. This point corresponds to the monument installed by the Onsala Space

Observatory (OSO) in Collaboration with the European Southern Observatory (ESO) as a permanent GPS station.

Applicable document AD2 cover recent astronomical observations performed with the exclusive purpose to verify the accuracy in the position of the reference monument indicating, together with Master0, the orientation of the local astronomical meridian at the particular geographic longitude of Master0.

This report includes the result from the analysis of the geodetic measurements reported on AD2. Is important to notice the angular measurements in AD2 are in centesimal degrees (i.e. 400 degrees in a full circle). Centesimal degrees are standard for high angular resolution geodetic theodolites. In our particular case we used a Wild T-2 instrument with an angular resolution of 1/10 of a centesimal arc-second.

Data Analysis

The geographic coordinates of the point over the one the theodolite was installed (Master0), reported by OSO are include here in Table 1.

Table 1: Coordinates of Master0

Point	Geographic Coordinates
Master0	Latitude ϕ=23°01'21.7601" S Longitude λ=67°45'15.7063" W

The astronomical observations consisted on measuring the horizontal angle (azimuth) and vertical angle (elevation) to four stars with reference to the line conformed by Master0 (see Figure 2) and the Astronomical North Monument (see Figure 1). The stars were observed twice within 30 minutes time as to generate a total of eight observations. The four stars observed in this work are those included in Table 2 together with their equatorial coordinates with reference to the J2005.5 epoch.

Simultaneously with having the observed star centered in the objective of the theodolite we got the time of the measurement (UT) directly from a GPS receiver with a resolution of 1 second of time (this limits the angular resolution we can obtain in the determination of the azimuth and elevation of the star under observation).

Table 2: Astronomical objects observed

number	Star Name	Right Ascension (RA) (*)	Declination (δ) (*)
		hh:mm:ss	Deg:minutes:secs
1	α^2 Cen	14:39:33.30	-60:50:04.1
2	α Crux	12:26:54.5	-63:07:46.0
3	β Cen	14:04:13.0	-60:23:58.0
4	α Sco	16:29:44.8	-26:26:38

(*) Equatorial coordinates extracted from Astronomical Almanac 2005 (Epoch J2005.5)

The time of the observation and the geographic longitude were to calculate the hour-angle (h) of each star at the moment of the observation. The hour angle together with the latitude allowed us to calculate the azimuth and the elevation of the star at the moment of the observation. This azimuth is then compared to that determine with reference to the ANM point and help us to verify the accuracy of the local meridian as indicated at the site by the line ANM/Master0. The error in the elevation angle (corrected by atmospheric refraction) helps us to determine the accuracy of our own angular measurements.

Results

The results of our data analysis, based on the procedure mentioned in the previous section, are included here in Table 3, 4 and 5.

Table 3: Azimuth and Elevation calculated from the time of the measurements

Observation	**Star**	**LMST**	**Based on the hour angle**	
			Azimuth	**Elevation**
		h:m:s	**Deg.**	**deg**
1	α^2 Cen	19:35:19.8437	211.91827932	27.79387952
2	α^2 Cen	20:02:59.8763	211.86223583	24.42774122
3	α Crux	20:15:59.0036	204.00874819	09.10727646
4	α Crux	20:51:55.8928	201.49441236	05.90414411
5	β Cen	21:09:56.8442	208.99506604	12.20739255
6	β Cen	21:27:10.6669	208.00370823	10.31518707
7	α Sco	21:44:38.5279	248.75513462	19.59059956
8	α Sco	21:53:51.0366	248.11686197	17.62012612

Table 4: Azimuth and Elevation calculated with reference to the ANM/Master0 Line

Observation	**Star**	**LMST**	**Based on the hour angle**		
			Refraction Correction T=265 K P=560 mbar	Azimuth	Elevation Corrected by refraction
		h:m:s		Deg.	deg
1	α^2 Cen	19:35:19.8437	1’05”	211.94469	27.78159
2	α^2 Cen	20:02:59.8763	1’16”	211.58115	24.43860
3	α Crux	20:15:59.0036	3’33”	204.02397	09.09401
4	α Crux	20:51:55.8928	5’27”	201.50928	05.90839
5	β Cen	21:09:56.8442	2’38”	209.00844	12.19778
6	β Cen	21:27:10.6669	3’09”	208.02312	10.32522
7	α Sco	21:44:38.5279	1’37”	248.77575	19.58235
8	α Sco	21:53:51.0366	1’48”	248.13891	17.63151

Table 5: Differences between the observed and calculated positions of the stars (astronomical position subtracted from the geodetic observed position)

Observation	**Star**	**ΔAZ**	**ΔEL**
1	α^2 Cen	-1’35”	+0’44”
2	α^2 Cen	-1’08”	-0’39”
3	α Crux	-0’55”	+0’48”
4	α Crux	-0’54”	-0’15”
5	β Cen	-0’48”	+0’35”
6	β Cen	-1’10”	-0’36”
7	α Sco	-1’14”	+0’30”
8	α Sco	-1’29”	-0’41”
Error		**-1’09”±44”**	**+0’03”±34”**

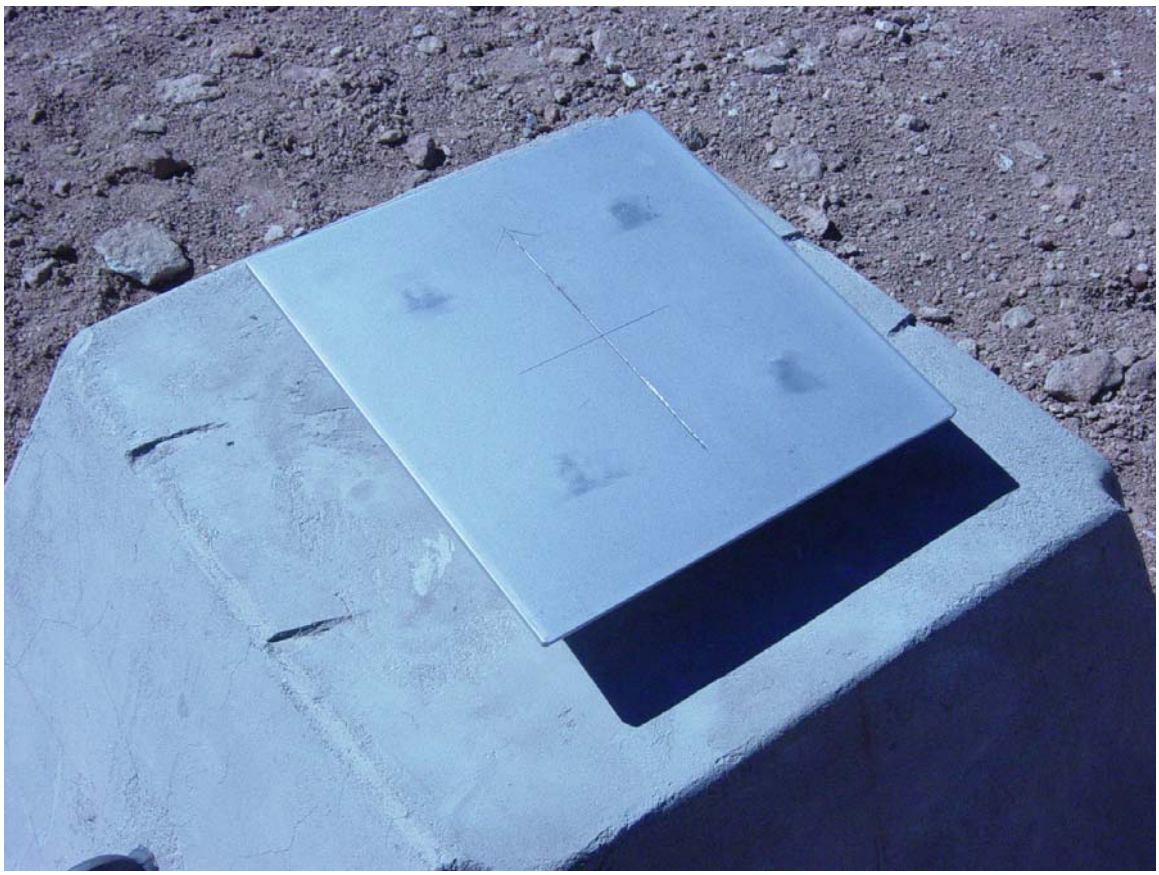

Figure 1: Astronomical North Monument (ANM)

Figure 2: Master0 monument (front), ANM (far back) - The Master0-ANM line defines the local astronomical meridian at this location.