Tracking errors at the 40 m radiotelescope

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Revision history

Version	Date	Author	Updates
1.0	14-08-2013	P. de Vicente	First draft

Contents

1 Introduction

We have investigated tracking errors with the 40 m radiotelescope. Some systematic effects have been discovered and corrected.

2 The problem: offsets errors

Tracking errors were spotted when doing spectral OnOff scans. CLASS displays non zero offsets in the list of observations which ammount a maximum of 12 arcsecs and vary with time. This is a large error which at 3 mm is crucial since it is very close to the HPBW of the antenna. Figs. 1, 2 and 3 show a summary of some observations between September and December 2012 which demonstrate the problem.

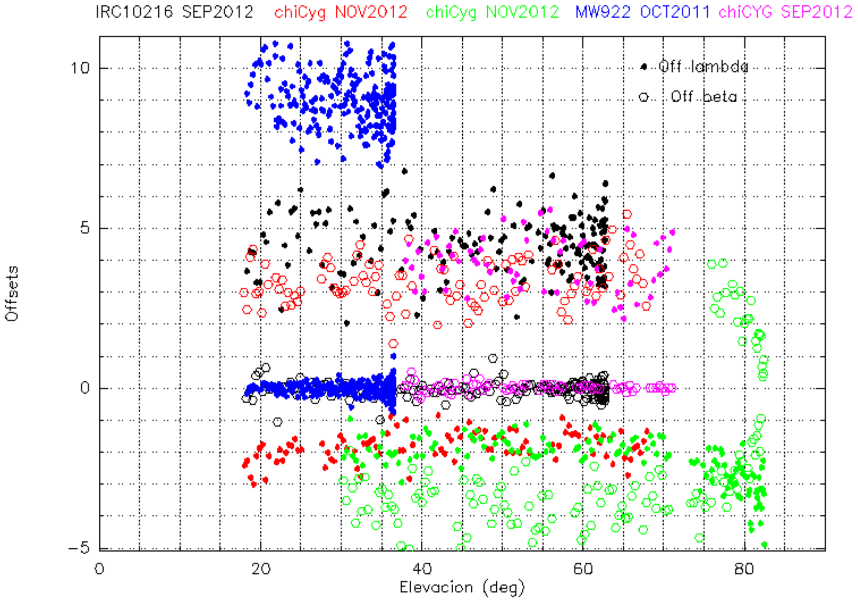

Figure 1: *Offsets in longitude (lambda) and latitude (beta) versus elevation as displayed by CLASS for several sources. Units for offsets are arcsecs*

Fig. 1 shows longitude and latitude offsets, in CLASS syntax lambda and beta, as a function of elevation for different sources and epochs. This figure demonstrates the problem which triggered the study of this report. Errors range from 8 to -5 arcsecs in both coordinates. Offsets keep constant as a function of elevation for the same source, except in the beta coordinates for ChiCyg source. Some offsets stay very close to zero.

Offsets are computed by substracting the theoretical position of the antenna from the current position of the antenna. The theoretical position is obtained from the equatorial coordinates of the tracking source. Two kind of offsets are computed depending on how the On Off scan was performed. That means that offsets in CLASS may have a different meaning. If the OFF subscan was done in equatorial coordinates the offsets will mean right ascention (lambda) and declination (beta) offsets, if the Off subscan was done in horizontal coordinates it will mean azimuth and elevation offsets. Usually the latter is the most common mode at high frequencies where the atmopshere has a non-negligible emission. In this case the offset is usually an azimuth offset, keeping the elevation the same as in the ON subscan.

If the offsets are horizontal (azimuth and elevation) the theoretical offsets are obtained from the equatorial position, the time and the geographic position of the radiotelescope. If the offsets are equatorial, the current position of the antenna is transformed to an equatorial position, using the time and the geographic position of the radiotelescope, and the substraction is done in the equatorial system.

Fig. 1 contains a mixture of offsets, both horizontal and equatorial, which prevents a simple analysis of the data. Fig. 2 demonstrates this mixture of reference systems for the previous data: two kind of behaviours can easily be spotted.

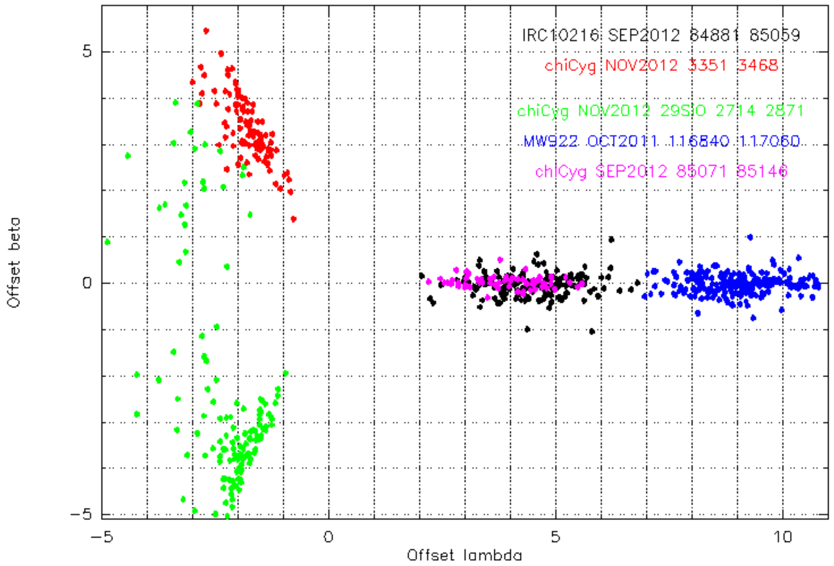

Figure 2: *Offsets in latitude (beta) versus offsets in longitude (lambda) as displayed by CLASS for several sources. Units for offsets are arcsecs*

Sources MW922, IRC10216 and Chi Cyg on september 2012 show zero errors in the beta coordinate and errors ranging between +2 and +11 arcsecs in the lambda coordinate. Offsets for Chi Cyg in November show a completely different behaviour in which the beta offset depends linearly on the lambda offset. As we will discuss below, a lack of errors in declination immediately points towards an error in the timing of the data.

Fig. 3 shows offsets for Chi Cyg as a function of elevation, separated by scans and according to the movement of the antenna as it tracked the source from horizon to culmination (upwards) and back to the horizon (downwards). Offsets were in the horizontal reference system.

Scans show that the beta (elevation) offset moves from -4 arcsecs to +4 arcsecs when going from upwards to downwards with respect to the culmination. The errors keep constant until the source reaches culmination, where they reverse the sign. The lambda (azimuth) offset also keeps constant at -2 arcsecs and slowly shifts towards -5 arcsecs close to culmination. At culmination

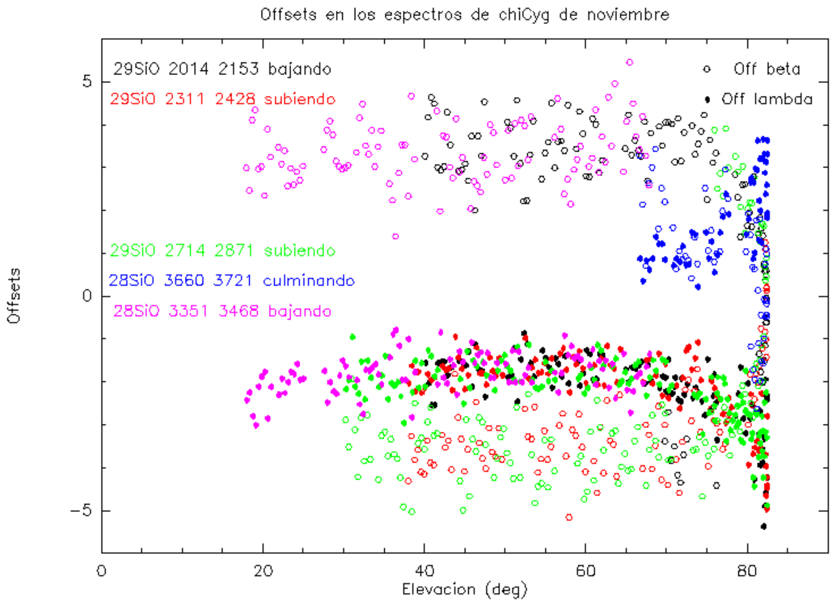

Figure 3: *Offsets in longitude (lambda) and latitude (beta) versus elevation for Chi Cyg. Units for offsets are arcsecs. Data have been splitted in scan intervals and upwards (red and green) and downwards (magenta and black) movements with respect to culmination, and during culmination (blue)*

it suddenly jumps to +1 arcsecs and after culmination it goes back to the position it had while moving upwards.

2.1 Discussion

The lack of errors in the declination offsets and the existence of those in the right ascention ones, points towards a timing issue. If the time with which the data are tagged is wrong the computed right ascention for the antenna will also be wrong. An error of 1 second in time ammounts 15 arcsecs in right ascention. If the time tag is larger than the real one, the computed right ascention will be larger than expected as seen in the data. By the time of the observations summarized in Fig. 1, the software that tags the data was obtaining the time from the computer that writes the FITS file. This computer is always synchronized with UTC (Coordinated Universal Time) using NTP (Network Timing Protocol), with an error of the order one millisecond at most. The time was obtained making an average between the time before and after the data acquisition and therefore it corresponds to the middle of the acquisition time interval. We believed this procedure was correct and no error should stem from here.

A source of error could arise from the DUT1 value which is automatically obtained by the control system from the IERS bulletin using the USNO FTP site (*http://maia.usno.navy.mil/ser7/ser7.dat*) or the Observatoire de Paris site (*ftp://hpiers.obspm.fr/iers/bul/buld/bulletind.dat*). The DUT1 used for the tracking and for tagging of data should be the same but a software error was preventing it and some differences may have arisen in some occasions.

Finally another error may arise from a difference in the time used by the Antenna Control

Unit (hereafer ACU) and the one from the computer that tags and writes the data. We have investigated this issue which is described in next section.

A timing error causes azimuth and elevation offset errors. This is very easy to understand using Fig. 4, where we have represented the trajectory of a source (red line) and the trajectory it would have if time runs 59 seconds later (green line), sampled every one minute for two short intervals. According to that figure, if the source's declination is below the latitude of the site, its culmination happens at 180 degrees azimuth. If the time runs behind the real one the error in elevation will be negative upwards and reverses to positive downwards. As for azimuth the error will be negative upwards, close to zero during culmination and again negative downwards. However if the source's declination is larger than the latitude's site, the error will be negative upwards, close to zero during culmination and then positive downwards. The sign for the errors derives from the definition: the error is the position of the antenna (green line) minus the position where the source really is (red line).

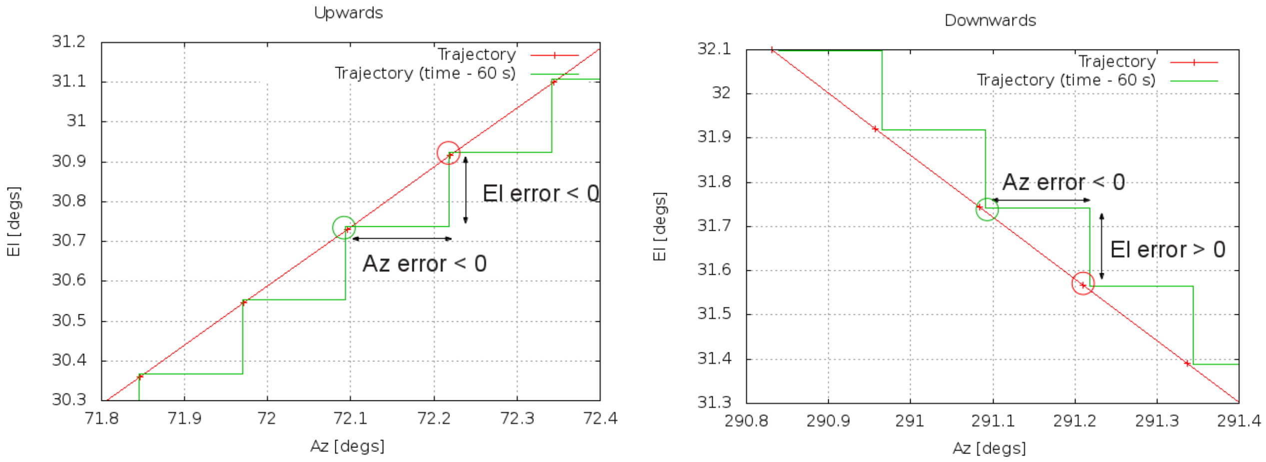

Figure 4: *Comparison of the trajectory of a source (red line) that culminates towards the south sampled every minute with the trajectory it would have if time runs 59 seconds behind (green line with steps) for two small intervals*

3 Antenna Control Unit Timing

The ACU runs an embedded Windows XP operative system with a real time extension from Beckhoff which allows to control the servo system of the antenna. The time is set with an IRIG B signal and the command set allows to configure a DUT1 value. We do not know how the real time extension locks the clock but we can monitor time differences between the data acquisition computer and the ACU from the status message delivered every 200 ms. The IRIG-B signal is generated in a GPS receiver which also acts as NTP stratum 1 server for all the Local Area Network in the observatory. Therefore, any time difference between NTP and IRIG-B should arise from the cable length and connectors of the latter, since the NTP corrects for delays in the network. The ACU time broadcasted in the status message is UTC.

The control software reads the ACU time (UTC) delivered by the status message every 200 ms and retransmits it, once the DUT1 correction is applied, as a Julian day variable using a notification channel. The antenna notification channel is started once, when the oanAntenna component is initialized, and runs until the component is stopped. This channel outputs periodically some important variables from the ACU. The periodicity has been chosen to match the ACU status message one, 200 ms, since the values are not updated until a new status message is delivered. In the current version of the software, the notification channel can start at any time, which means that there may be a lag which ranges from 0 to 200 ms after the ACU status message. This is depicted in Fig. 5. In the plot, the red squares represent the moment when the antenna notification channel is published. This publishing can happen any time between two status messages, and this is graphically explained with the light red squares. Therefore the difference between the ACU time from the status message and the ACU time from the notification channel should always be constant and can only take two values: DUT1 or DUT1 + 200 ms, but the publishing of the latter varies between, 0 and 200 ms.

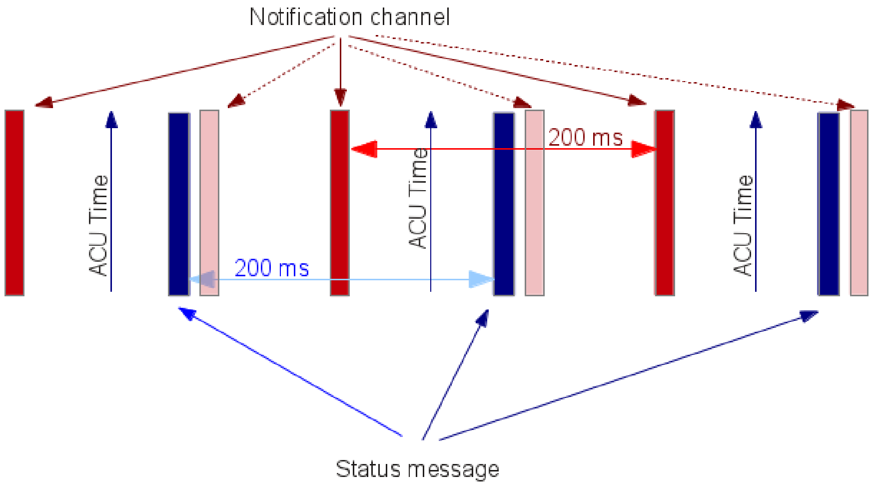

Figure 5: *Scheme that depicts the timing of the status message and the antenna notification channel*

On the other hand the status message publishes the ACU time, which is represented with a blue vertical arrow that can also happen any time between 0 and 200 ms before the status message. This is in the internals of the ACU code. We believe that a good aproach would be to choose the mean value, that is 100 ms, since it is the most representative time value for the interval. This value has been measured with an external computer synchronized with NTP.

Fig. 6 shows the comparison between one of the control computers synchronized with NTP and the ACU time from the status message sampled every 10 milliseconds for 2 seconds. We also represent the ACU time from the status message which changes following a step function. Internally in the ACU, the time runs smoothly, but the status message is broadcasted every 200 ms. The sawtooth dependency that we see in the previous figure is due to the NTP time running versus the ACU time, frozen in every status message. Immediately after the status message is delivered the time difference between the NTP and the ACU varies between 110 and 120 ms. This difference is the distance between the ”blue arrow” in the Fig. 5 and the status message. Therefore it seems that the ACU time in the status message is the mean time of the previous interval and hence it corresponds to $\simeq$ 100 ms before it is published.

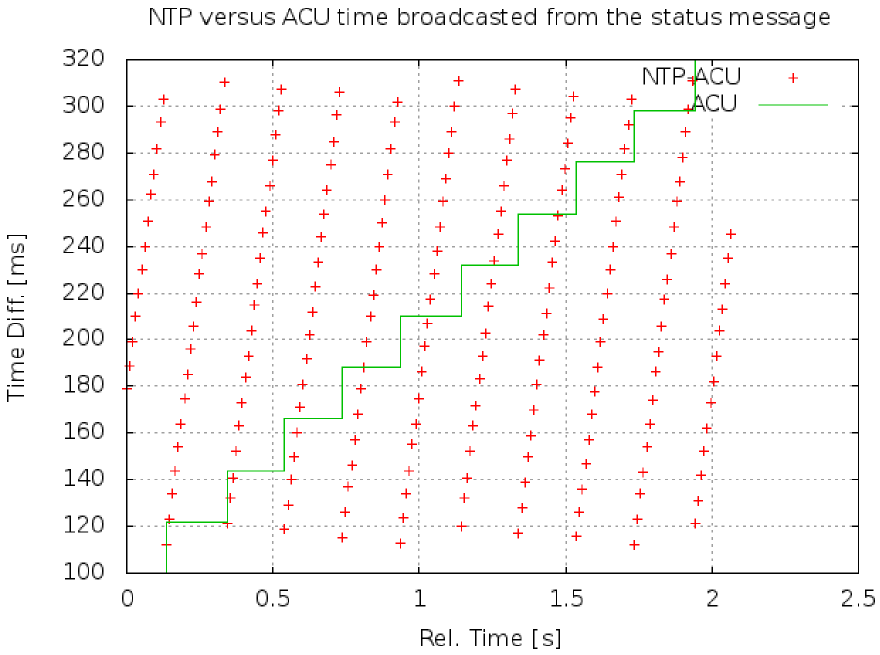

Figure 6: *Time difference between the NTP and the ACU time broadcasted every 200 ms in the status message. Green line is the ACU time (it uses a different scale for the Y axis). Internaly the ACU time runs smoothly.*

We have repeated the comparison in Fig. 6 but with a longer time and sampling every time the notification channel publishes the value. The result is in Fig. 7 where the two panels show the comparison between the time from one or two control computers of the radiotelescope and the time of the ACU computer. The right panel shows the comparison between the ACU time as provided by the status message and the NTP time in the two computers. In principle the difference between NTP and ACU should remain constant, since both are delivered with the same periodicity. However this is not the case, since we see again the sawtooth behaviour of Fig. 6 but on a longer time interval. This effect arises because the period for the status message and for the notification channel, unexpectedly, differ.

Fig. 7 also shows that there is a delay of $\sim$ 100 ms between the status message and the notification channel, and in some cases this difference ”jumps” to 300 ms.

To check the difference of periods between the status message and the notificacion channel, we have plotted the ACU time from the status message and from the notification channel sampled every 10 ms, compared them and with the NTP time. Results are in Fig. 8. The time period for the ACU status message differs from that of the notification channel slightly. This explains the behaviour seen in Fig. 6. The difference between both time scales is 100 ms or 300 ms and the slope we see in that figure for NTP-ACU comes from the lower envelope of the curve in Fig. 8.

The code that controls the timing of the notification channel has been modified to make its period match that of the status message and be published immediately after. The maximum delay between both times is 20 ns.

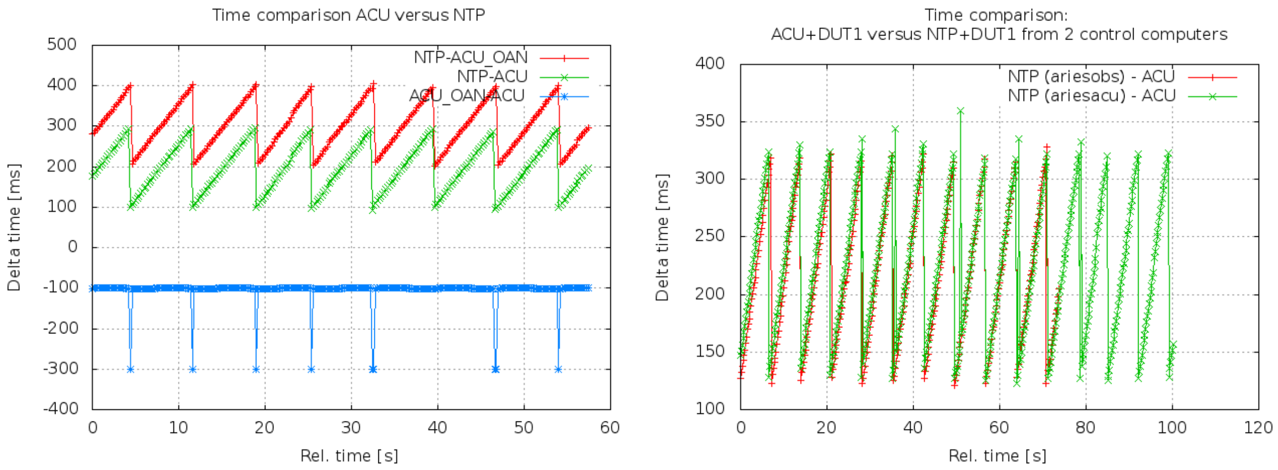

Figure 7: *Time comparison between the ACU and two control computers of the 40 m radiotelescope. The ACU is synched using an IRIG-B signal and a real time Windows extension from Beckhoff. The control computers run Linux and are synchronized with NTP. ACU_OAN means the ACU time broadcasted by the antenna notification channel and therefore delayed by DUT1 (or 200 ms + DUT1). DUT1 was -100 ms in this case.*

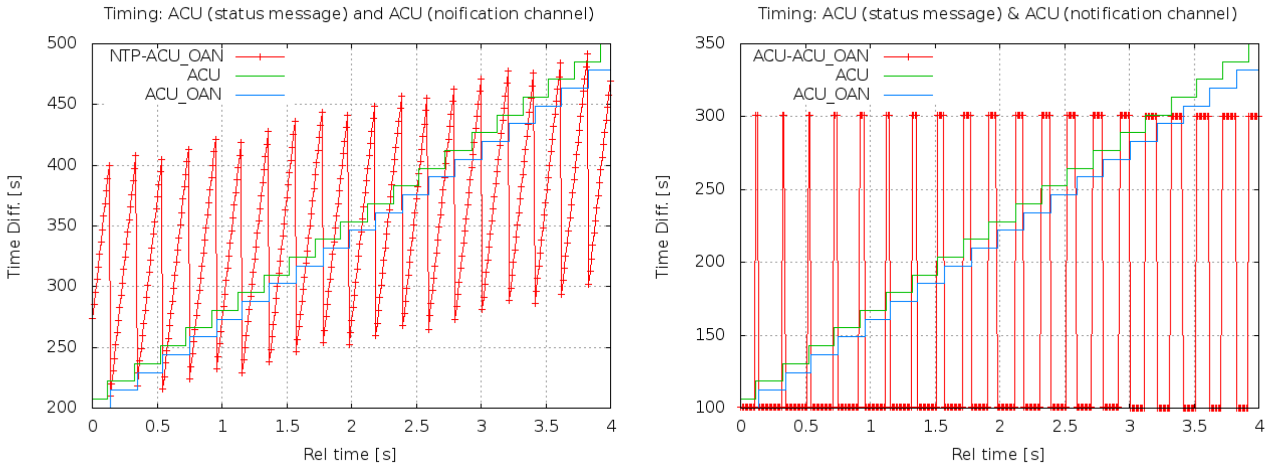

Figure 8: *Time comparison between the ACU time from the status message and from the notification channel (ACU + DUT1). On the left panel NTP - ACU time is plotted. On the right the difference between both ACU times is plotted. The two step functions with continuous lines (AXU and ACU_OAN) are depicted in a different scale in the Y axis. Each step in Y is 200 ms*

4 Short time scale tracking errors: wind, DUT1 and ACU offset effects

We have investigated the tracking errors of the antenna sampled at the rate of the status message (5 Hz) for 60 seconds. Results are shown below.

Fig. 9 shows the tracking errors: elevation errors versus azimuth ones (on the sky), towards chiCyg. The position accuracy is always below 0.6 arcsecs. This figure was created using the time from the ACU to compute the position of the source and comparing this result with the position of the antenna. The azimuth error is collimation, that is distances on the sky. The dispersion in the values seems to be random and it probably comes from mechanical effects from the antenna and the effect of the wind.

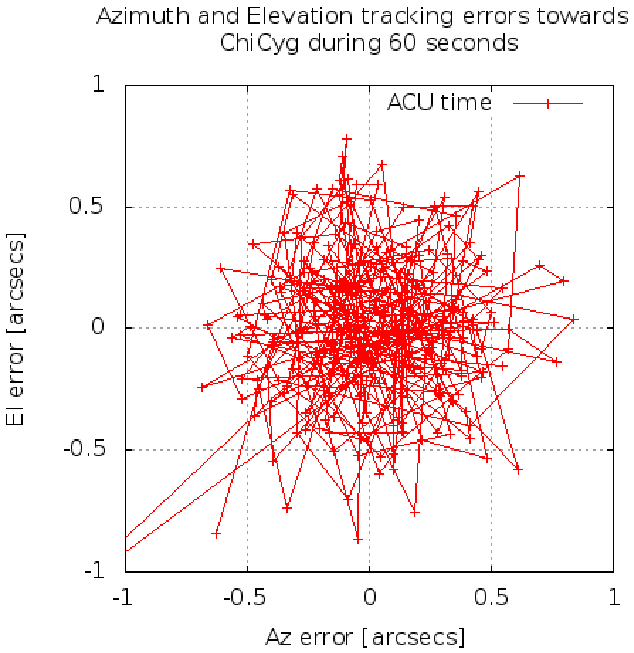

Figure 9: *Antenna tracking errors towards chiCyg for 60s seconds and with low wind speeds ($\simeq$ 2 m/s) at an elevation of $\simeq$ 30 degrees. Time reference system: ACU*

The effect of the wind is shown in Fig. 10 which shows the azimuth and elevation errors in two different cases with a wind of 2 m/s and 5 m/s.

Tracking is not reliable for winds above 10 m/s and observations at frequencies higher than 22 GHz should be avoided under these circumstances.

5 Conclusions

The systematic errors described in this report regarding the position of the antenna while tracking have been solved by using the ACU time system to tag the data and DUT1 in all steps (antenna tracking **and** in the pipeline). This value is automatically retrieved from the USNO or

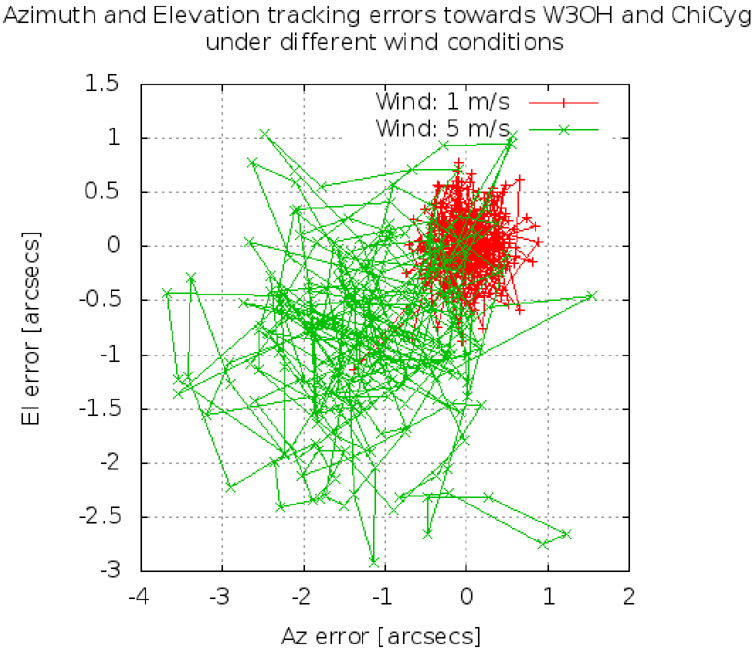

Figure 10: *Antenna tracking errors in azimuth and elevation for different wind conditions. There is an offset in the average position for W3OH data because these data were not using the ACU time.*

OBSPM FTP servers and applied. If we wanted to use NTP from the control computers to tag the data, two corrections should be applied: DUT1 and the delay in the broadcast of the position of the antenna, which ammounts 100 ms. The antenna notification channel is now published at most 20 ns after the ACU delivers its status message. With these corrections current offsets are below 1 arcsec in almost all cases.

The wind has an important impact on observations leading to a peak to peak error of 2 arcsecs approximately when the wind is 5 m/s.