WFI Focus analysis

TABLE OF CONTENTS

1) Introduction

The whole process of focusing the telescope is transparent to the user. Nevertheless, it was felt important to explain some of the details of this critical procedure aspect for an imaging instrument. As with the guiding subsystem, the focusing subsystem is both part of the instrument and of the TCS, and will be described here.

Focusing is accomplished by moving the secondary mirror of the telescope. A focus sequence can be invoked via BOB. It consists of a number of exposures with different focal positions between which the charges on the CCD are shifted by a constant amount. The CCD is read out only at the end of the sequence. It is recommended to use at least 8 focus positions with a step size of 40-50 M2 encoder units and to shift the subimages by 50 CCD pixels.

The central focus position of the sequence is automatically chosen using the formula (in M2 encoder units, valid near the zenith)

$$focus(T) = 25283 + filterOffset + grismOffset - 66 \times T$$

where the filter offset is a number that depends on the filter, and ranges between approximately 0 and -230; the grism offset is approximately 861 eu for the R50 grism; and where T is the temperature (in degrees centigrade) of the telescope's long Serrurier struts. It is displayed and continually updated in the TCS control panel. The focus value is expressed in units of steps of the M2 encoder, one encoder step corresponding to 1.25 µm. The proportionality
factor is negative because M2 has to move towards M1 in order to compensate a thermal expansion of the Serrurier. There is an additional dependency of the focus on telescope position.

Under good seeing conditions, a dedicated focus exposure should be done if the zenith distance between the science exposure and the last focus differ by more than 30 .
A MIDAS procedure, called from a focus Observation Block is used by the operator to fit a parabola to the variation of the FWHM of point sources with focus position in order to determine the best focus. Since also the peak flux values are displayed, it is possible to check that no subimage was saturated, i.e. reached a value of 65,535. When the autoguider has been used, the focus curves displayed for both x and y should coincide extremely well.

Under reasonable observing conditions, the focus values returned for different stars in the same exposure should not scatter by more than 3-5 encoder units.
The depth of focus is about 50 M2 encoder units. Remember that the residual tilt of the CCD mosaic with respect to the focal plane amounts to less than 15 encoder units to which up to 20 encoder units need to be added for the position-dependent instrument flexure.

The focus needs to be checked (or adjusted according to the above formula) whenever the change in temperature since the last setting of the focus exceeds half a degree. This is done automatically by the observing software.

Because the filters are in the converging beam, they have some optical power. Each filter is characterized by a focus offset with respect to the B/99 filter. The system automatically considers Serrurier temperature, telescope position, and filter offset, to determine the best focus before each science exposure. Nevertheless, the system can not refocus the telescope during a single integration, therefore observers are advised to keep individual exposure integration time short.

2) Summary

This document is to study the actual focusing algorithm implemented in 2.2 Telescope in relation to the results of each focus sequence OB executed.

The job is based in a log file with data of different focus sequences taken between 2005-05-18 to 2007-06-09 (615 logs) using different filters, telescope positions and temperatures.

The variables that define the equations are:

Variable	Description
Ha	Hour angle coordinate
Dec	Declination coordinate
ZenithD	Zenith distance
SerrTº	Serrurier Temperature
M1Tº	Mirror 1 temperature
filteroffset	Fixed offset settings to different filters
grismoffset	Offset by grism
Focus	Focus estimation from data logged.
FocusLog	Focus logged in data file (real focus logged after focus OB execution)
Dfocus	differential focus between Focus Log and Focus
EU	Encoder units.

Table 1: Variables definition and description

The WFI focus (wide field imager) actually used is the following equation:

$$FocusTheory = -66 * SerrT^{o} + 2 * ZenithD + 25283 + filteroffset \qquad (1)$$

In order to simplifier this analysis, we leave the variable “grismOffset” indicated in the introduction out of this analisys, also because his value is equal to 0.

This is the base to confirm the precision of the actual equation and the possibility to find a more accurate one.

3) Data Logged interpretation

In w2p2ins machine we save a logfile with information of focusing results between 2005-05-18 and 2006-09-18. This log file is created by the TIO when a focus sequence is executed successfully. The file shows the information as follows:

2005-05-18T04:20:52.141 BB#Rc/162_ESO84 1.53 1.58 5.39 5.29 12749.257405 -453615.185779 23.75261 24935.0
2005-05-29T23:21:37.308 BB#Rc/162_ESO84 0.82 0.71 15.66 15.39 11911.446443 -1902.686948 34.554517 24282.0
2005-07-27T08:45:54.560 BB#I/203_ESO879 1.03 0.93 10.05 9.95 2708.360132 -295041.50154 5.930912 24478.0
.....
.....

Where:

Date	Sideral Time	Filter name	Seeing X [arcsec]	Seeing Y [arcsec]	Serrurier Tº [ºC]	Main Mirror Tº [ºC]	Right Ascension	Declination	Zenital Distance	Focus Log
2005-05-18	04:20:52.141	BB#Rc/162_ESO84	1.53	1.58	5.39	5.29	12749.257405	-453615.185779	23.75261	24935.0
2005-05-29	23:21:37.308	BB#Rc/162_ESO84	0.82	0.71	15.66	15.39	11911.446443	-1902.686948	34.554517	24282.0
2005-07-27	08:45:54.560	BB#I/203_ESO879	1.03	0.93	10.05	9.95	2708.360132	-295041.50154	5.930912	24478.0

Table 2: Saved data n focus logfile

After checking the info saved in this file use, to get the new focus equation, we decided to the focus logged of **BB#Rc/162_ESO84** filter because it is he one which have more data saved (135 log dates).

The first analysis plotted the data of this file in function of different variables to find a focus pattern.

The first test was to check the focus log values in function of telescope position, this is a function of (hour angle, declination) variables (in degrees). The plotted results are:

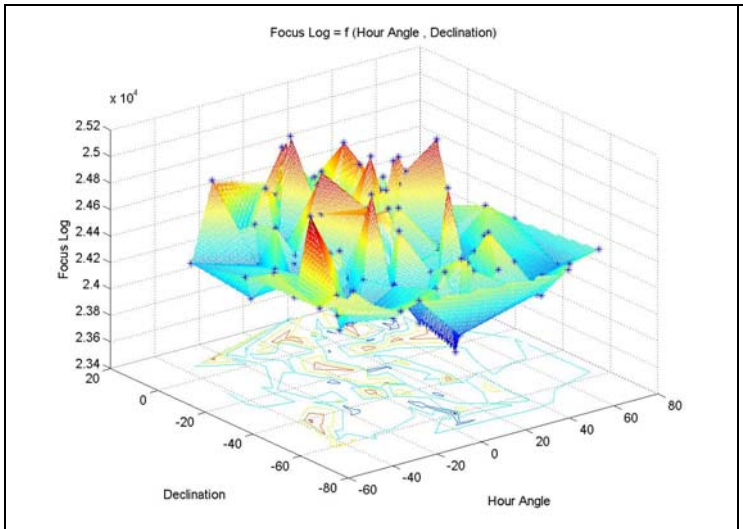


Figure 1a :Focus Logged v/s Hour Angle & Declination

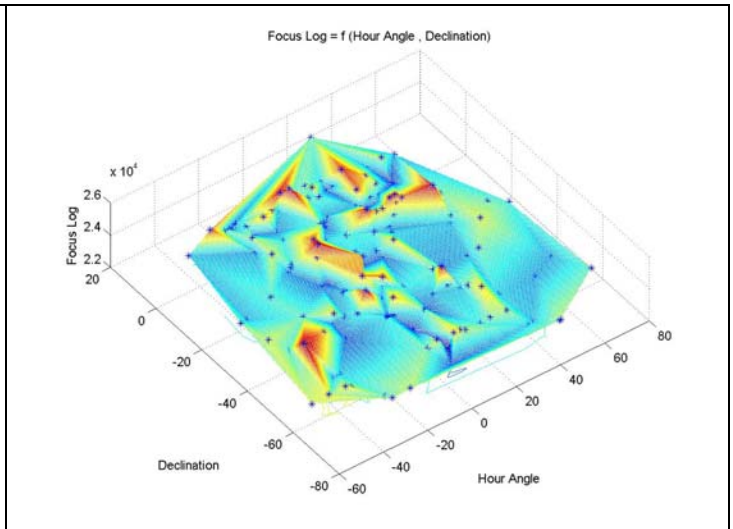


Figure 1b: Focus Logged v/s Hour Angle & Declination

We can see no clear relation between these variables, but we will see some analysis after.

Likewise we review other possibilities with all variables in combination of two, this is:

$$FocusLog = f(x, y)$$

where x and/or y can be : Dec, HA, Tº Serrurier, Tº M1, Zenith Distance, mean (seeing X, seeing Y).

And only one function displayed good results (a pattern), this one is the know function

$$FocusLog = f(T^{o}\,Serrurier, ZenithDis\tan ce)$$

This plot is displayed in the following figures:

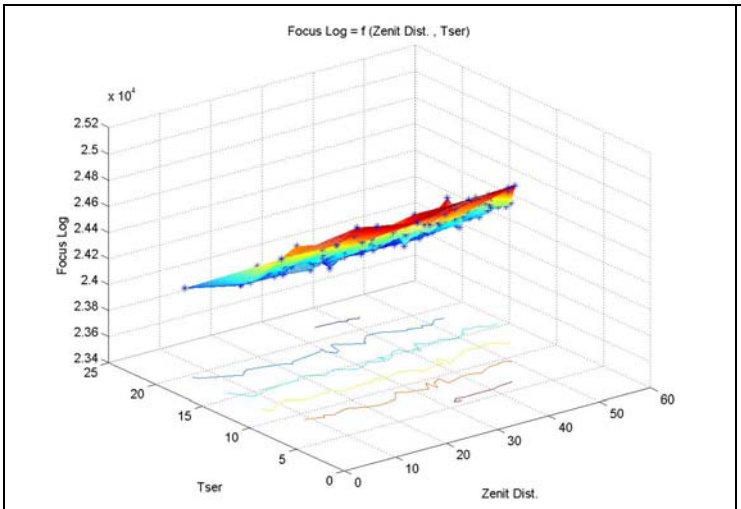


Figure 2a :Focus Logged v/s Serrurier Tº & Zenith Distance

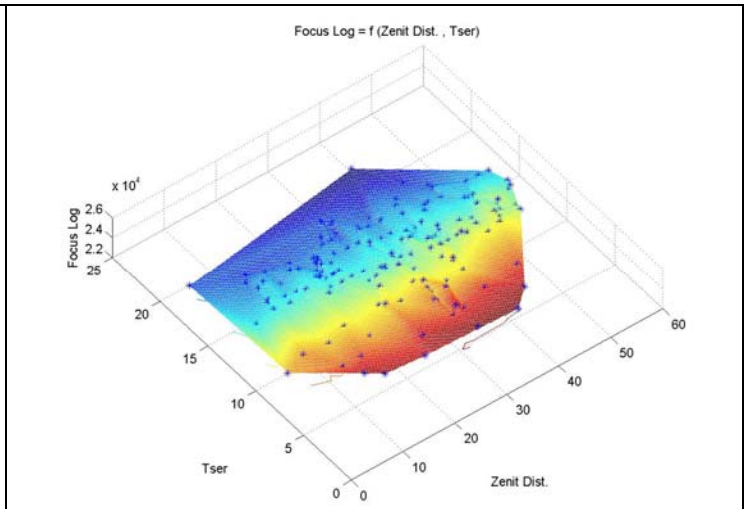


Figure 2a :Focus Logged v/s Serrurier Tº & Zenith Distance

Clearly we can see a pattern to focusLog function to Serrurier Tº and Zenith Distance. In first instance we can do some observations:

1) The plot is similar to a plane, then, we can say a good approximation is a linear equation of this two variables.
2) The biggest inclination of the plane in the figure 1 and the color gradient in figure 2 indicate a high negative coefficient to Tº Serrurier variable.
3) In the figure 2a, the lines displayed in the plane (Serrurier Tº, Zenith Distance) are the relations between focus and zenith distance but we must find a meaning of all linear fitting.
4) The most important variable in focus value is the Serrurier Tº.

These comments reaffirm the original theory focus equation (equation (1))

Now we check the plot of theoretical focus, if we replace the logfile data into the equation, this is:

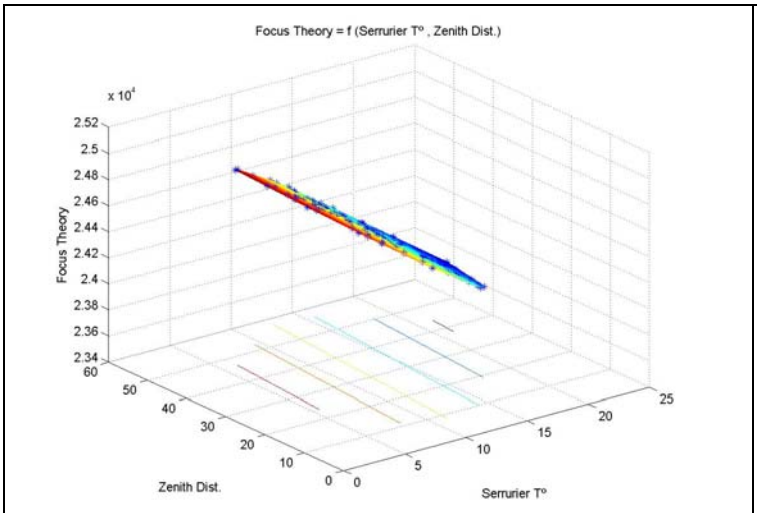


Figure 3a :Focus Theory v/s Serrurier Tº & Zenith Distance

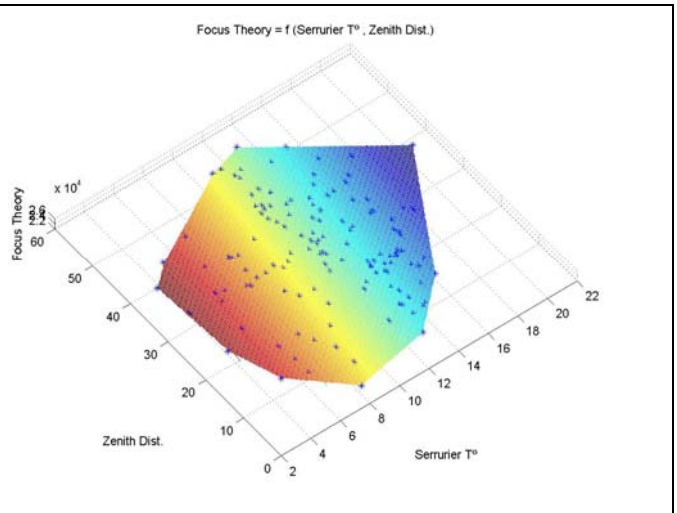


Figure 3b :Focus Theory v/s Serrurier Tº & Zenith Distance

In this figures, we see a perfect plane (obviously because it is a linear function of 2 variables) with inclination and focus values some how similar to focusLog plot displayed in figure 2a/b.

Because the Zenith Distance and Serrurier Temperature are independent variables between each other , for the next steps we can find the relations between each of these variables with the focus log without aproximation errors.

4) Linear Approximations

Now, with this input, we can get a new focus equation in function of Serrurier Tº and Zenith Distance, the first step is to plot the real focus $FocusLog = f(SerrurierT^{o})$ only to get a linear fitted linear curve and compare this results with $FocusTheory = f(SerrurierT^{o})$ as:

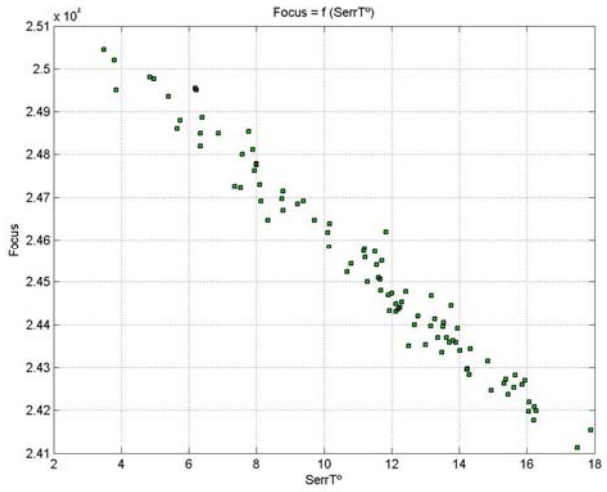


Figure 4a :Focus Log v/s Serrurier Tº

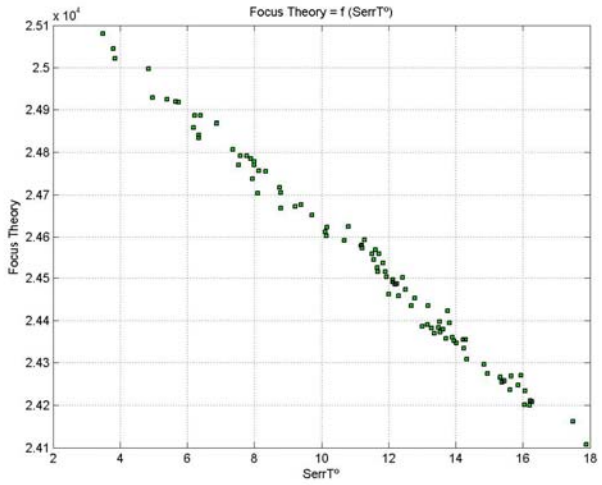


Figure 4b :Focus Theory v/s Serrurier Tº (Zenith Distance)

The 4a/b figures show the data focus points logged (real) and theoretic (from equation 1) respectively, now, we can remark that:

- It exists a similar point distribution showing clearly that, if the Serrurier Temperature is high, the focus position in EU is lower and vice versa.
- The distribution of points to the Figure 4b is narrower; obviously, the plot is FocusTheory v/s Serrurier Tº but actually with Zenith distance compensation included as results of equation (1).

For these points plotted we can get a linear approximation as:

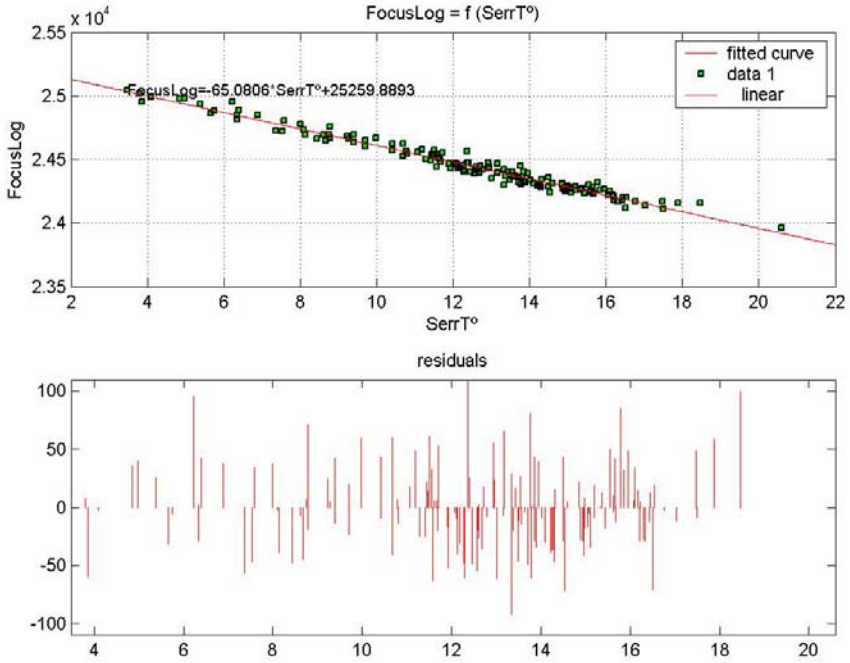


Figure 5a: Focus Log v/s Serrurier Tº and linear fitted curve.

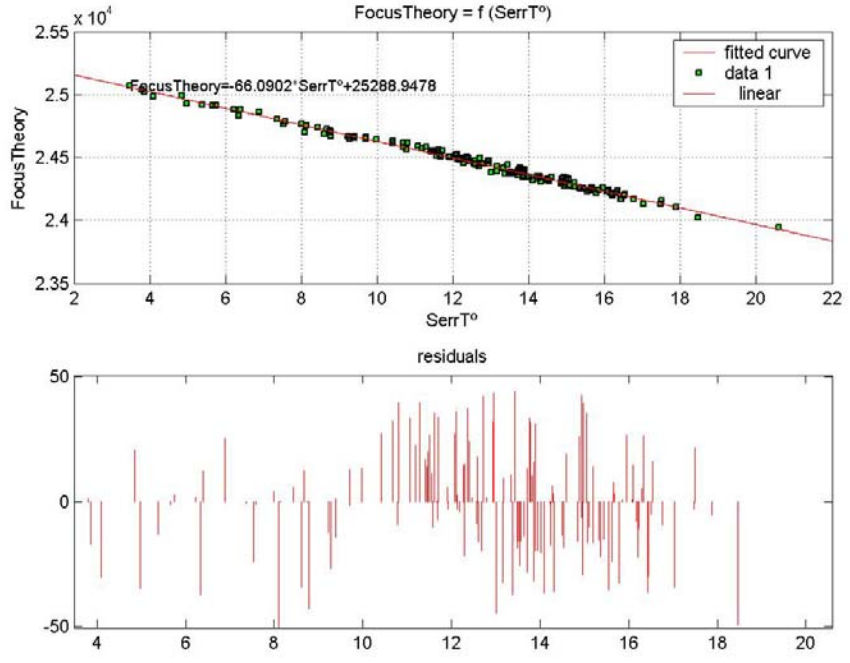


Figure 5b: Focus Theory v/s Serrurier Tº (& Zenith Distance) and linear fitted curve.

The Figure 5a/b display 2 plots, the above ones show the straight line to that point distribution and the equation representative and the down ones show the respective residual, the difference between the point and the straight line.

If we look in more details, the linear approximations are the same but we can see an important difference of points distributions. Now we have the first approximation focus equation from the figure 5a as:

$$Focus = FocusLog(SerrT^{o}) = -65{,}08 * SerrT^{o} + 25260 \qquad (2)$$

To add to the equation the filter offset parameters we must consider the base offset to Rc filter= -50, then the first linear approximation finishes as:

$$Focus = -65{,}08 * SerrT^{o} + 25310 + filteroffset \qquad (3)$$

Continuing the analysis, the differences between each points and the straight line is the residual value and is the error in the linear approximation as we can see in the figures 5a/b (up). In our first linear approx. (figure 5a) we can calculate errors of +-100 EU and the theoretical Focus (figure 5b) shows +-50 EU residuals, less because we have included the zenith position compensation. Then, for now it is important to correct these errors with in a second linear approximation.

In order to do this second linear approximation we can create a new variable:

$$Dfocus = FocusLog - Focus \qquad (4)$$

As we know, the zenith distance (ZenithD) is the trigonometric result of hour angle (Ha) and the declination (Dec) telescope coordinates (dependency variables), so we can analyze separately (case 1 and case 2) as follow.

Case 1: Focus approximation function of Serrurier temperature and Zenith Distance

And now we plot $Dfocus = f(ZenithD)$ and we get the best straight line as:

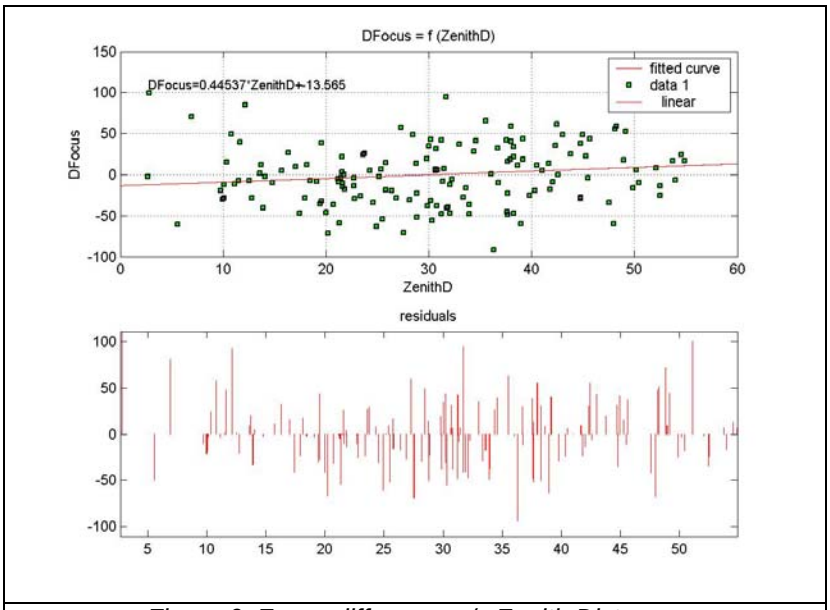


Figure 6: Focus difference v/s Zenith Distance.

Then

$$DFocus = 0{,}45 * ZenithD - 14 \qquad (5)$$

This not is a really good approximation but the rank is important, between -30 and 30 encoder units (EU) if we consider a focus error tolerance of -+ 20 EU.

If we add the equations (3) and (5) we have:

$$Focus = -65{,}08 * SerrT^{o} + 0{,}45 * ZenithD + 25296 + filteroffset \qquad (6)$$

This equation correspond to the second linear approximation

With this new focus function we get news values to DFocus, then we continue to analyses the plot:

$DFocus = f(x)$ where x take different variables as:

x = Mirror 1 Temperature (M1T), seeing x, seeing y.

But the results were not convergent, so the final function in this case it is (6):

Important note: After some code analysis we found that M1 temperature logged into the focus log file was not correct, so it is not a valid variable (please see LPRS about it)

Case 2: Focus approximation function of Serrurier temperature, hour angle (degrees) and declination (degrees)

The plots were:

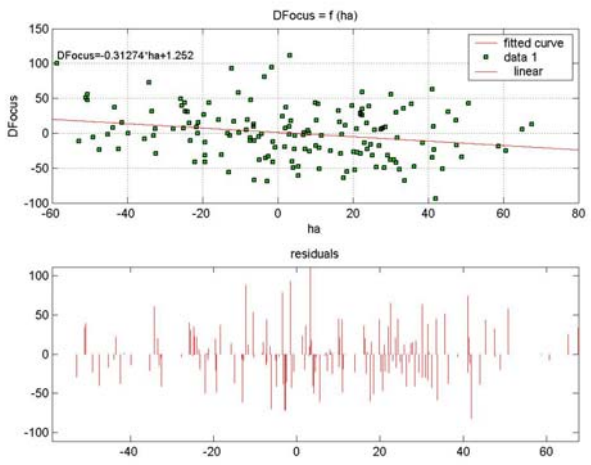


Figure 7: Focus difference v/s Hour Angle

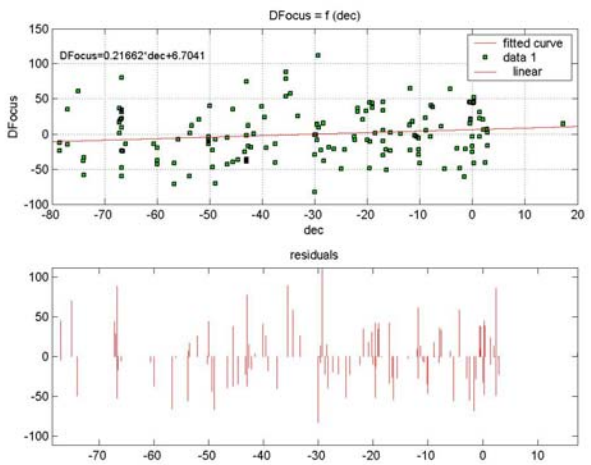


Figure 8: Focus difference v/s Declination

Then

$$DFocus = 0{,}32 * ha + 0{,}22 * dec + 8 \qquad (7)$$

Where we can see that the focus value decrease if we pointing the telescope from the east to the west and it is increase if we point the telescope from the south to the north.

If we add the equations (3) and (8) we have:

$$Focus = -65{,}08 * SerrT^{o} + 0{,}31 * ha + 0{,}22 * dec + 25268 + filteroffset \qquad (8)$$

We did the same exercise as the case 1 testing Dfocus variable in function to other variables without results, so the final focus function is (8).

5) Results Analysis

Finally to check the differences between all linear approximations we calculate statistic variables of DFocus equation in every case as:

Case 1:

Equation	Description	DFocus				
		Maxim	Minimal	Mean	Standard Deviation	Variance
Focus Theory=-66*SerrTº+2*ZenithD+25283+filteroffset	Original eq.	138	-118	-16,49	40,77	1662
Focus=-65,08* SerrTº +25310+filteroffset	Linear Approx. 1	109	-92	0	37,35	1394
Focus=-65,08* SerrTº +0.45* ZenithD+25296+filteroffset	Linear Approx. 2	111	-94	0	36,93	1363

Table 3: Statistic of different approximations for case 1

Equation	Description	DFocus				
		Maxim	Minimal	Mean	Standard Deviation	Variance
Focus Theory=-66*SerrTº+2*ZenithD+25283+filteroffset	Original eq.	138	-118	-16,49	40,77	1662
Focus=-65,08* SerrTº +25310+filteroffset	Linear Approx. 1	109	-92	0	37,35	1394
Focus=-=-65,08* SerrTº - 0,29*Ha +25311+filteroffset	Linear Approx. 2	99	-81	0	36,46	1329
Focus=-=-65,08* SerrTº - 0,29*Ha + 0,17* Dec + 25316 + filteroffset	Linear Approx. 3	99	-81	0	36,22	1311

Table 4: Statistic of different approximations for case 2

Some comments about this statistics:

Case 1:

- The second linear approximation for case 1 fixes the offset error to 0 and the standard deviation is 36.93, better that the original equation and the first approximation.

Case 2:

- The second linear approximation for case 2 fixes the offset error to 0 and the standard deviation is 36.46, better that the original equation and the first approximation.

- The third linear approximation for case 2 fixes the offset error to 0 and the standard deviation is 36.22, better that the original equation and the first approximation

General:

- Minimal and maxim DFocus values are not a good precision representation because we are not sure if always the focus value was logged as result of a good focus sequence.
- Mean value is really a constant error of filter offset value.
- The first equation (the original equation) displays minimal – maxim range of 254 EU with a constant error of -16 EU (filter offset error) and a standard deviation of 40,77 EU.
- The first linear approximation (both cases) fixes the offset error to 0 and the standard deviation is 37.35 better than the original equation and only function of SerrTº.

Now, with these approximations for only one filter (Rc) we can define the offset parameters for each filter so that each one gets an offset error 0.

Filter Name	Equation		
	original	Linear Approximation Case 1	Linear Approximation Case 2
	f (SerrTº, ZenithD)	f (SerrTº, ZenithD)	f (SerrTº, HA, Dec)
BB#Rc/162_ESO84	-50	-50	-50
BB#V/89_ESO843	-100	-103	-105
BB#I/203_ESO879	-230	-160	-163
BB#B/123_ESO878	-60	-34	-32
BB#B/99_ESO842	0	5	0

Table 5: Filter offset constants to each equation

We now see some bigger offset differences in the rows displayed in red, some differences include until 25 EU errors between the original and the estimated offset. This parameter is important to consider depending whether we select one linear approximation or another one, but is not a definitive conclusion because it depends of the number of point saved in the log file.

6) Comments and conclusions

- In this analysis we can confirm the actual algorithm (equation 1) to focus calculation in relation to Serrurier Tº and Zenith Distance but with different constants values.
- The filter offset value of the equation can change if we change the original equation, but this point requires more analysis because this depends of the number of logfiles saved for the specific filter.
- Finally I recommend 2 actions:

1) Make corrections in the parameters of the original equation (1) according to the results of the linear approximation 2. With this action we get a small improvement in the focus representation like the table 3 show in the deviation standard parameter. The equation must be:

$$Focus = -65{,}08 * SerrT^{o} + 0{,}45 * ZenithD + 25296 + filteroffset \quad (9)$$

2) Consider in the focus estimation with Ha and Dec coordinates, the figure 7 & 8 show that a pattern exists in the focus values and, if we review the statistics results (table 3), we decrease the standard deviation. In this case the new focus equation should be:

$$Focus = -65{,}08 * SerrT^{o} + 0{,}31 * ha + 0{,}22 * dec + 25268 + filteroffset \quad (10)$$

The problem is that to implement this new formula we have to include some extra function in the code to convert HA and Dec in degrees.

Whatever be the taken decision, we must consider the filteroffset corrections.

TODAY

Today we really have implemented a new formula:

$$Focus = -64{,}98 * SerrT^{o} + 0{,}49 * ZenithD + 25294 + filteroffset$$

This formula must be change to (9):

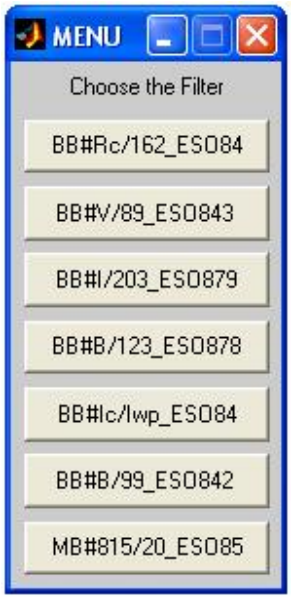
$$Focus = -65{,}08 * SerrT^{o} + 0{,}45 * ZenithD + 25296 + filteroffset$$

It is a small difference but can help

Appendix: Software program.

The software was development in MATLAB MATHWORKS 6.5 for Windows.

The analyze software was do it flexible to processing different filter data because it looks and save by separate the corresponding data. The filter menu to start the analysis is:



After analysis init the results are displayed in the command window as:

NEWfocusTH = -65.0806*SerrTº+0.44537*ZenithD+0*ha+0*dec+25296.3243+filteroffset

maxvalue = 111.4
minvalue = -94.3
meann = 0
Standard_desviation = 36.9
Variance = 1.3638e+003

The analysis is in base to a log file with all focus sequence data.