EM27/SUN spectrometer

Operating Manual

June 25, 2013

BRUKER

Contents

1 Safety Notes

Please note the following information to ensure the safety of the operators, to obtain the full performance of the system as well as to reach a long lifetime of the system:

- The system must only be operated by trained personnel.
- All system components must only be used for the designated use.
- The instruction manual must be studied carefully before using the device and follow the directions given in the instruction manual.
- Do not touch the spectrometer or the solar tracker while the device is on. The tracker head can turn any time in particular while the device is operating and during system initialization. The drive can cause injuries when touching the device.
- **Do not touch any optical parts of the device.** Remove dust and dirt from these parts only by carefully blowing at with clean air. Never treat the optical surfaces with cleaning agents or cleaning tissues because it will affect the reflectivity in infrared range. Do not use compressed air for cleaning, because it may contain small amounts of oil.
- Remove obstinate dirt or spatter on the housing (exterior) with a damp cloth. Do not use any aggressive solvents (benzene, acetone, lacquer thinner etc.).
- During usage and transportation the device must be protected against impacts.
- Do not open the spectrometer.
- Protect the device against splash water.
- The system must be inspected once every 12 months. In particular in order to warrant the reliability required for applications that involve risks for personnel, residents, and the environment, regular inspections including the replacement of consumables and a realignment of the optical parts are necessary.

2 Overview of the EM27/SUN spectrometer

The EM27/SUN spectrometer is intended to measure direct solar radiation in the near infrared (NIR) spectral range. The recorded spectra contain signatures of atmospheric constituents (H_2O, CO_2, CH_4, O_2), which can be evaluated to retrieve the total columns. Detailed information about measuring CO_2 in the atmosphere with a prototype of the EM27/SUN, can be found in the publication:

M. Gisi, F. Hase, S. Dohe, T. Blumenstock, A. Simon and A. Keens: XCO_2-measurements with a tabletop FTS using solar absorption spectroscopy, Atmos. Meas. Tech. Discuss., 5, 5691-5724, doi:10.5194/amtd-5-5691-2012, 2012.

It is available at:

http://www.atmos-meas-tech.net/5/2969/2012/amt-5-2969-2012.pdf

The EM27/SUN contains a solar tracker (see Figure 1), which is used to reflect the solar radiation onto the detector. A very high precision of the tracker is reached by using a camera and image processing software to detect the actual line of sight of the spectrometer and to correct the solar tracker angles if necessary. This system was first described in the publication:

M. Gisi, F. Hase, S. Dohe and T. Blumenstock: Camtracker: a new camera controlled high precision solar tracker system for FTIR-spectrometers, Atmos. Meas. Tech., 4, 47-54, doi:10.5194/amt-4-47-2011, 2011

Download: http://www.atmos-meas-tech.net/4/47/2011/amt-4-47-2011.pdf

Bruker has applied for a patent of this camera-based optical tracking feedback.

Figure 1: The solar tracker of the EM27/SUN

A sample spectrum recorded by the EM27/SUN spectrometer can be seen in Figure 2

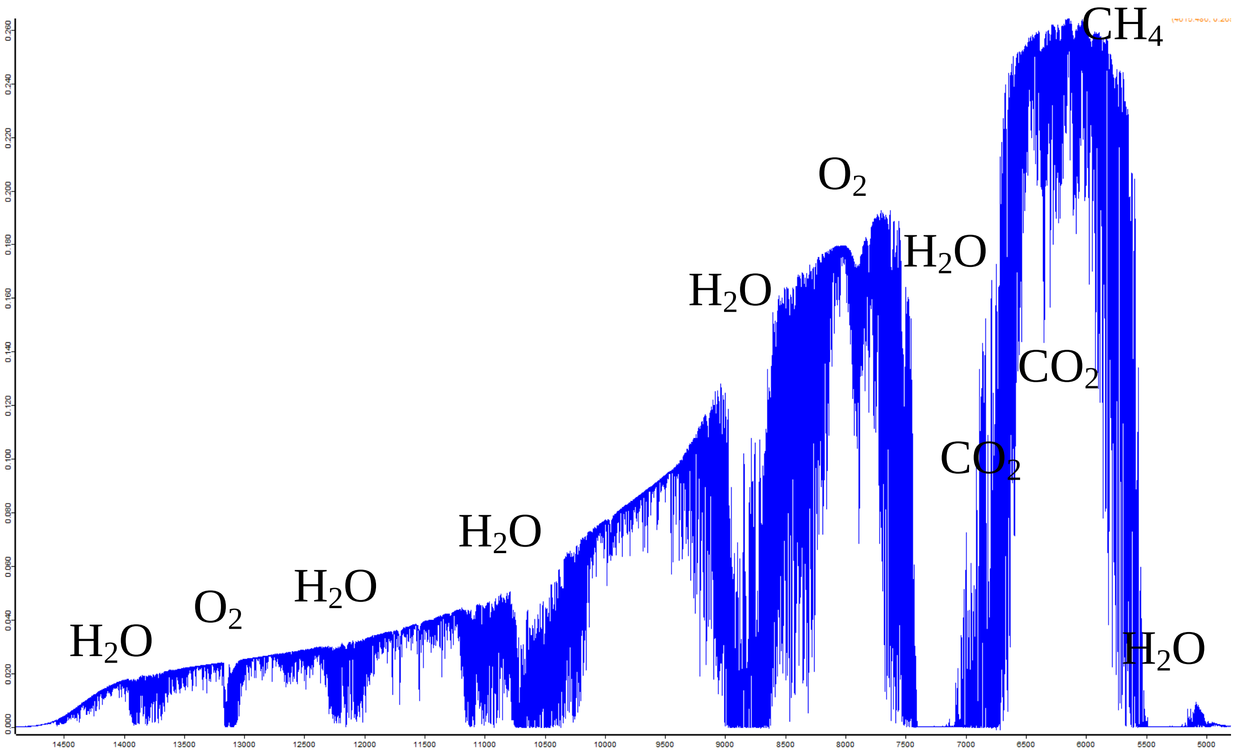

Figure 2: Solar spectrum recorded by the EM27/SUN. The main absorption lines are labeled with the respective gas.

An evaluation of these spectra to retrieve the gas abundance is not supplied by Bruker.

Commonly used atmospheric trace gas retrieval programs are:

- **PROFFIT:** widely used in the Network for the Detection of Atmospheric Composition Change (NDACC). The spectra recorded by the prototype EM27/SUN by Gisi et al. were evaluated using PROFFIT. More information: http://www.imk-asf.kit.edu/english/898.php

- **SFIT2**: widely used in the NDACC. More information; http://mysite.du.edu/~agoldman/publications/Hase-Intercomparison%20of%20retrieval%20codes.pdf

- **GFIT:** used as the official analysis code for the Total Carbon Column Observing Network (TCCON). More information: http://rsta.royalsocietypublishing.org/content/369/1943/2087.full.pdf

3 Quick set-up

The following list gives a very short overview to quickly getting started with measurements. More detailed information can be found in the following chapters.

1. Place the spectrometer on a horizontal surface.
2. Connect all cables (Power, TCP/IP, USB) to the spectrometer and the computer, and switch it on.
3. Make sure, the spectrometer is ready and connected, by entering its IP-address, which is 10.10.0.1 by default. The IP-address of the computer has to be 10.10.0.2 to 10.10.0.255.
4. In OPUS, select “External Image” in the measurement menu, and click on “Check signal”, activate the external input. Close the measurement menu.
5. In the CamTrackerConfig.txt the spectrometer’s IP-address has to be entered in the section $3.
6. Enter the tracker orientation:
   $2
   -50.5
   -180 (enter 0 if located on the southern hemisphere)
   0
   0
7. Start the CamTracker_3_8.exe and click on “Initialize Tracker”.
8. Orientate the spectrometer so that the tracker “looks” to the North on the northern hemisphere or to the South on the southern hemisphere.
9. Click on “Sun” in the “Image Processing”-tab.
10. Manually move the tracker orientation with the + and – sign buttons on the “Tracker”-tab in order to lead the solar radiation onto the 45 degrees mirror in front of the entrance window of the spectrometer. Alternatively rotate the whole spectrometer by hand.
11. If the solar image is visible and outlined by a blue ellipse, activate the check box “Camera” in the “Image Processing” tab. Here “Big ellipse” or “Circle” should have a green circle behind.
12. If the blue circle is not visible or no green circle is displayed, click on “Recalculate sun-pixels”.

13. The solar image should be moved onto the field stop opening, and the tracking is ready.
14. Start measurements in OPUS.

4 Setup of the spectrometer and tracker

The spectrometer can be set-up at any dry place where the tracker is reached by direct solar radiation. At places where particles, such as sand, are blown extensively, precautions should be made to protect the optics of the tracker.

For simplicity the instrument is placed horizontally. The best orientation is shown in Figure 6.

The EM27/SUN has three connectors at the rear side as shown in Figure 3:

USB: This connects the internal camera with the controlling computer. This camera ensures the precision of the tracking.

Power: A power supply with 24V and 4A should be connected

Ethernet: A network cable is used to connect the spectrometer with the computer. The tracker is controlled via this connection as well.

Figure 3: Connectors of the EM27/SUN

4.1 Orientation of the spectrometer

4.1.1 General remarks

The coarse orientation of the spectrometer has to be supplied to the tracker program. Using this, the location on earth and astronomical calculations, the program is able to orientate the tracker mirrors towards the sun. As it is not possible to perform the tracking with these values only (it would require a huge effort to determine all the involved orientations and angles of the spectrometer and the optics), this astronomically calculated position is used as a starting position for the highly precise camera-based tracking system.

The tracker consists of two rotation stages. The small one on the top of the tracker moves only one mirror and permits to set a desired elevation of the tracking direction. An elevation of 0 degrees corresponds to a horizontal direction. The large rotation stage moves both mirrors and allows setting the azimuthal direction of the tracker. In this document and the tracker program, an azimuth of zero degrees means a southern direction, 90° means West, 180° North and -90° East.

4.1.2 Constraints of the tracking angles

The connection cables of the elevation motor constrain the possible maximum rotation angles of the azimuth motor. Therefore, two switches are used to detect whether the azimuthal motor of the tracker moves into the minimum and maximum positions, which then leads to an immediate stop of the motors. The possible rotation range is about 360 degrees. Advantageously, the tracker (and with it the whole spectrometer), should be orientated in a way, that the solar position can be followed by the tracker over the day without moving into the maximum or minimum position. On the northern hemisphere, an orientation of the minimum position towards the north, on the southern hemisphere towards the south is advantageous. An illustration is shown in Figure 4.

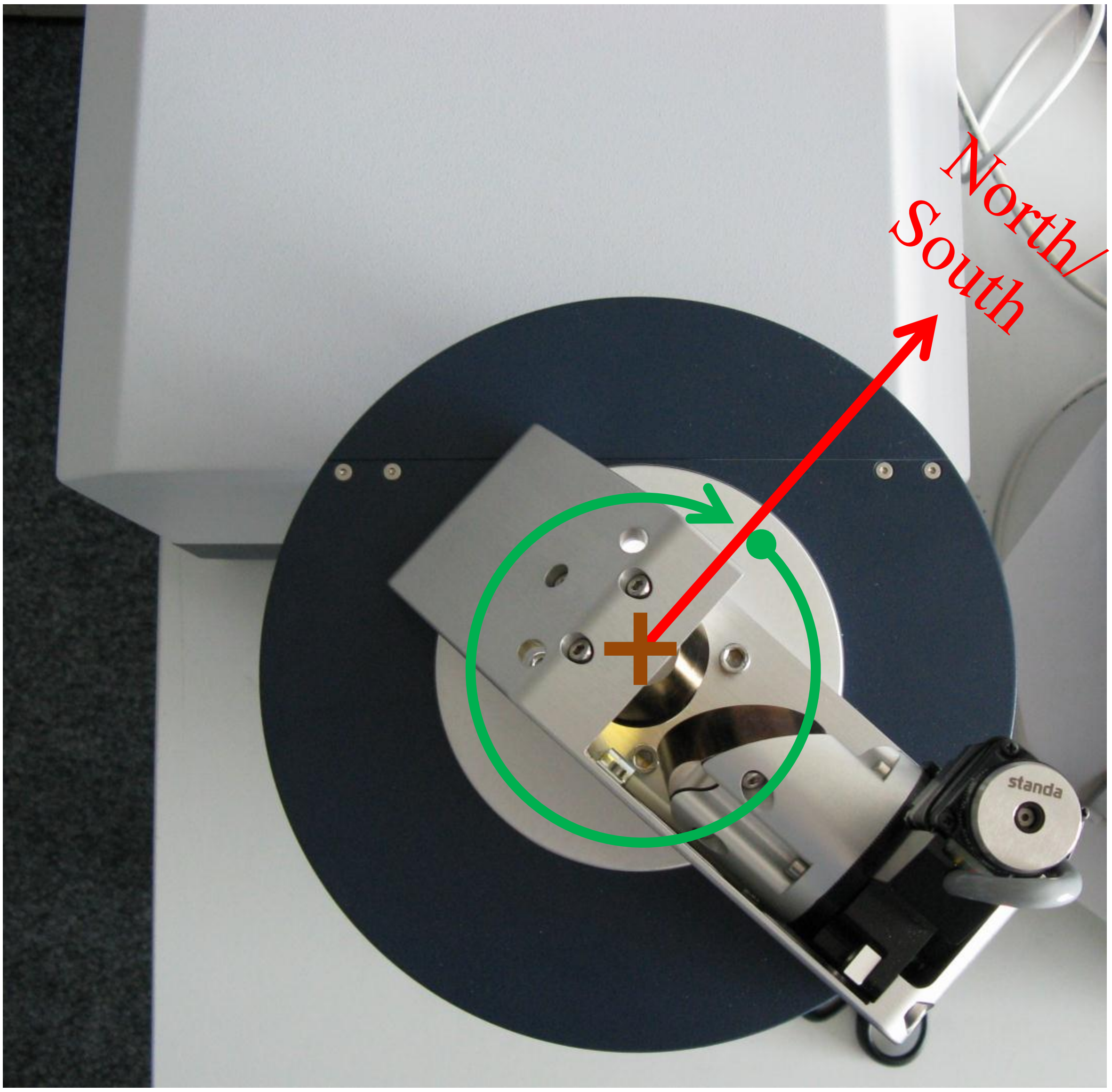

Figure 4: Tracker at its minimum azimuthal angle. In the initialization procedure of the tracker, it moves into this position. The allowed rotation range is about 360° in clockwise direction, so that the maximum direction is about the same as the minimum direction. In order to follow the sun in the course of the day, the red arrow (which indicates the observing direction) should point north (northern hemisphere) or south (southern hemisphere).

To move the tracker into the minimum position, the tracker has to be initialized by clicking on the respective button in the CamTracker program (see Figure 14). In the initialization procedure, the tracker moves counterclockwise until the minimum position is reached and stops at this position.

4.1.3 Orientation angles

As mentioned previously, some coarse orientation angles have to be provided to the tracker program, in order to initially “find” the sun before the camera-based tracking can take over.

The CamTracker program requires 4 angles:

- **Elevation mirror offset:** The observation angle offset of the elevation mirror above (or below) the plane defined by the blue plate of the tracker, after the initialization sequence has finished. An example is shown in Figure 5.

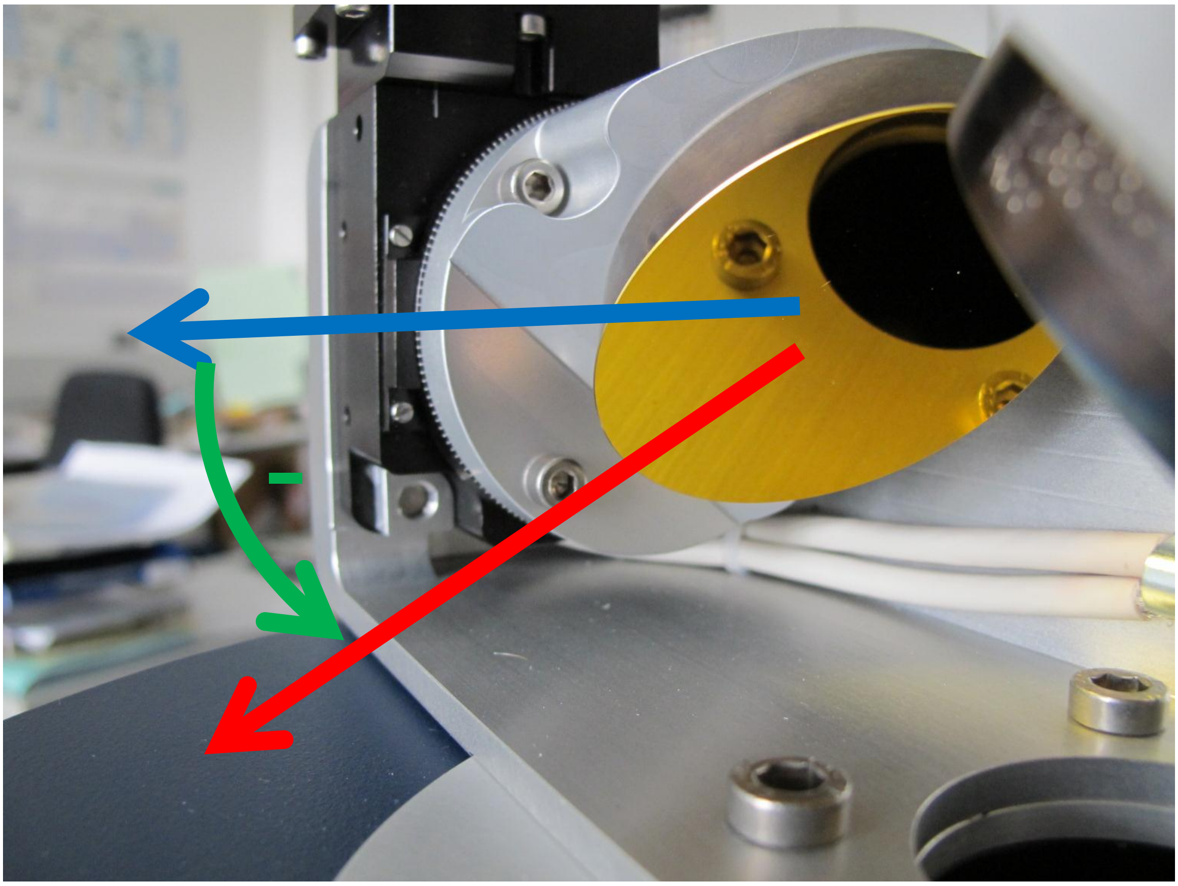

Figure 5: In this example, the orientation of the elevation mirror (red arrow) after the initialization procedure is lower than the plane defined by the blue plate of the tracker (blue arrow) as indicated by the green arrow. This angle is the “Elevation mirror offset”, which has to be provided to the CamTracker program. If the elevation mirror direction is lower, then the angle has to be negative, which is the case on this picture. For a typical tracker this value is about -50.5 degrees.

- **Azimuthal direction offset:** This is the angle between the southern direction (azimuth = 0) and the azimuthal observing direction after initialization. If seen from top, counter-clockwise angles are negative. If the spectrometer is oriented as mentioned above: observing direction towards the north after initialization (recommended for the northern hemisphere), then the azimuthal offset is 180 degrees as shown in Figure 6. Figure 7 shows an example, where the tracker is not orientated towards the North.

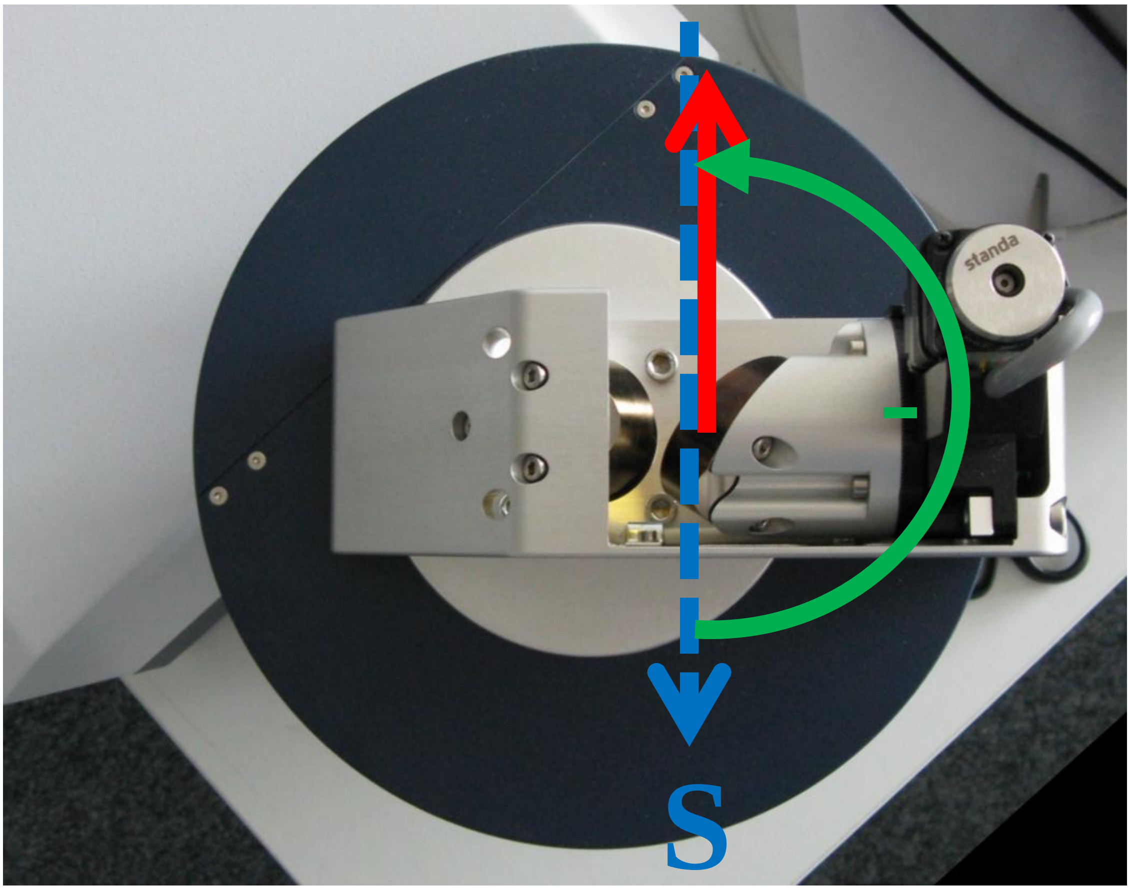

Figure 6: Recommended orientation on the northern hemisphere. The azimuthal direction offset is -180 degrees.

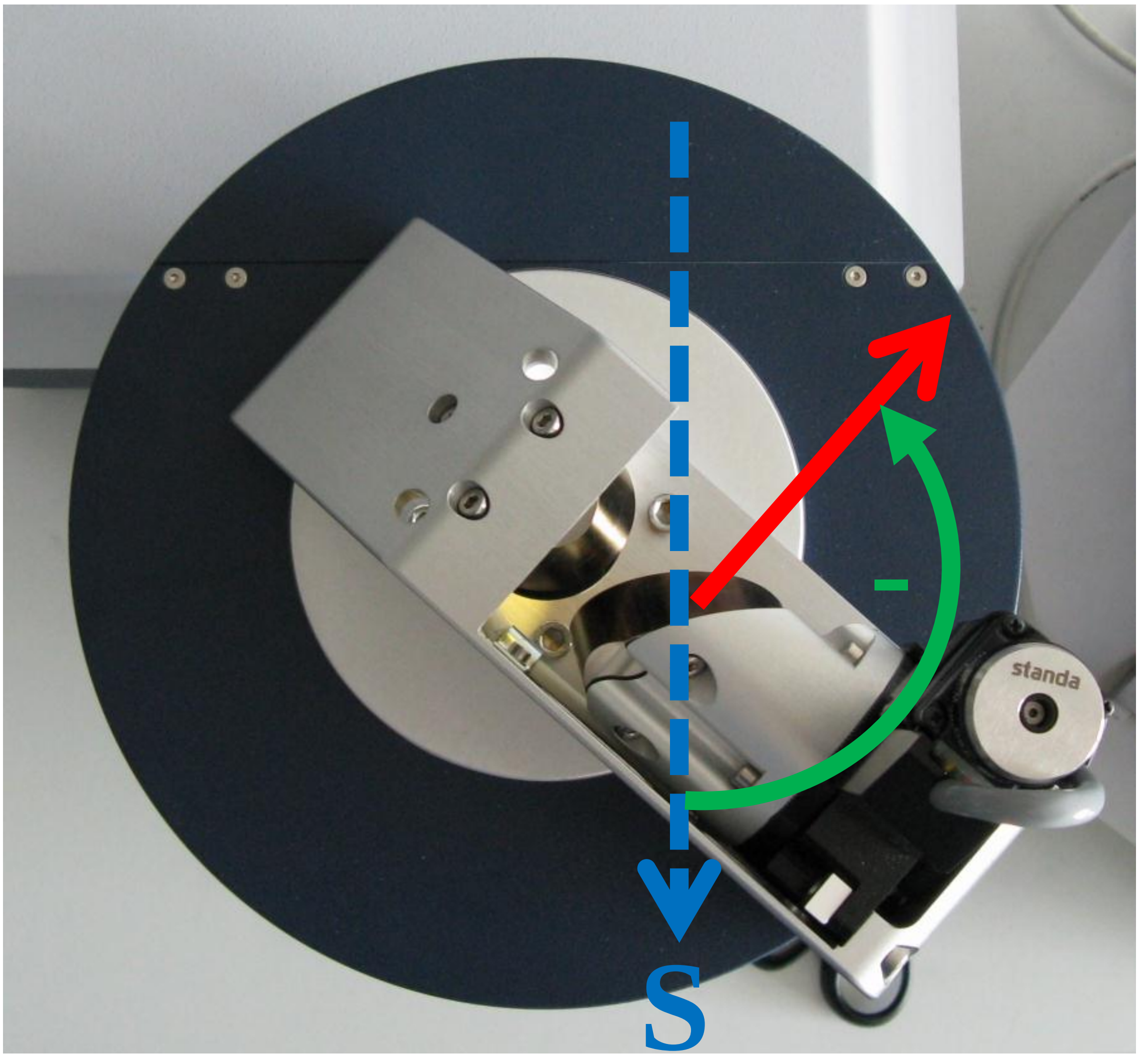

Figure 7: In this case, the „Azimuthal direction offset“ is -135 degrees. This is the angle between the southern direction and the azimuthal observing direction after initialization. Counterclockwise rotations have a negative sign.

- **Tilt of the tracker: North (-) / South (+) and East (-) / West (+).** Two values are needed describing the tilt of the blue base plate of the tracker in Northern/Southern and Eastern/Western direction. For North and Eastern tilts, negative values have to be used. In the ideal case, where the spectrometer is placed horizontally, these values are 0.

4.2 Observer's location

In order to calculate the solar position, the tracker program needs, besides the spectrometer's orientation and the precise time, the location of the spectrometer on Earth. For this three values have to be provided:

- **Latitude** (-90° to +90°): South Pole is -90°, Equator is 0° and North pole +90°.
- **Longitude** (-180° to +180°): Greenwich is 0°, East of Greenwich is counted positive and west of Greenwich negative.
- **Height:** The height of the spectrometer above sea level.

5 The CamTracker program

5.1 General principle

The tracking mechanism is based on astronomical calculations for a coarse tracking and an optical feedback provided by a camera.

It is based on the publication:

M. Gisi, F. Hase, S. Dohe and T. Blumenstock: Camtracker: a new camera controlled high precision solar tracker system for FTIR-spectrometers, Atmos. Meas. Tech., 4, 47-54, doi:10.5194/amt-4-47-2011, 2011.

Download: http://www.atmos-meas-tech.net/4/47/2011/amt-4-47-2011.pdf

Bruker Optics also applied a patent for this principle.

In the ideal case, the solar image is centered on the field stop opening of the spectrometer. For this reason, a camera is built into the spectrometer, recording the field stop. A sample image can be seen in Figure 8.

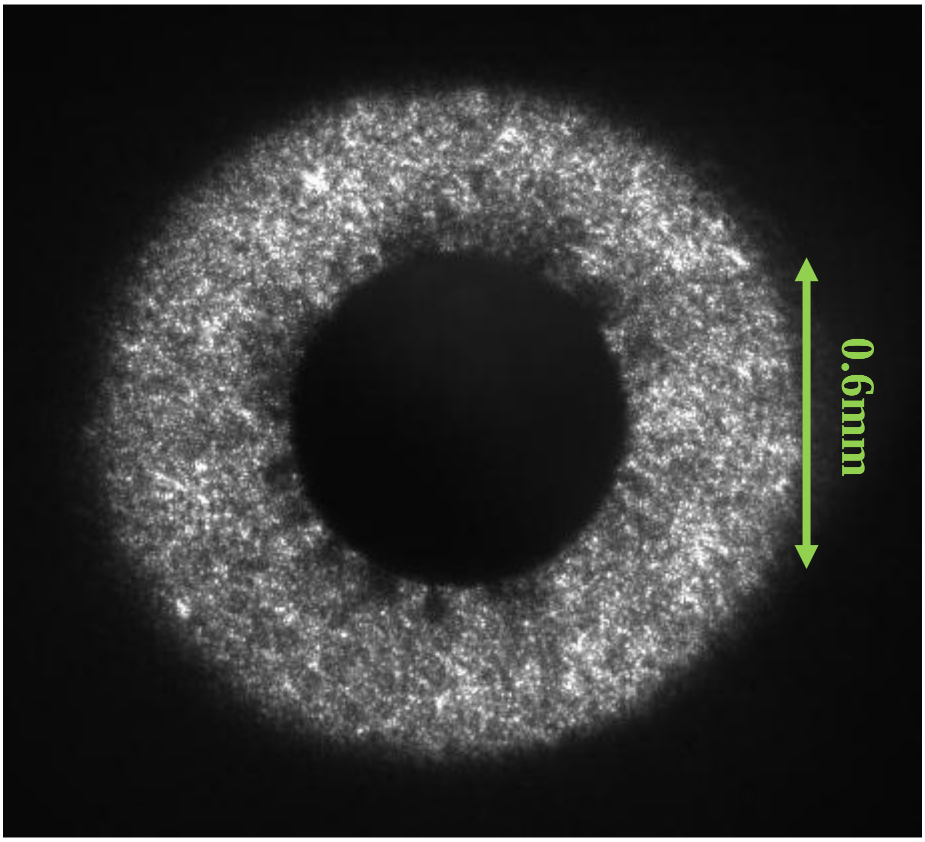

Figure 8: Image of the camera recording the field stop.

The CamTracker program detects the rim of the solar image as well as the field stop opening at the same time, which, by principle, minimizes misalignments significantly.

The rim of the sun is detected by setting a brightness threshold to the image using the brightness histogram (Figure 9) to separate the illuminated and non-illuminated areas.

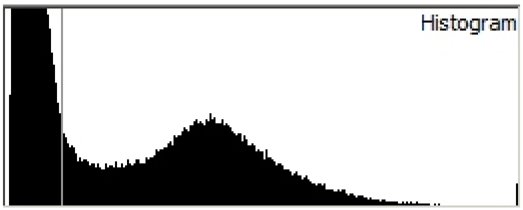

Figure 9: Brightness histogram of the camera image. The huge number on low illuminated pixels on the left side corresponds to the non-illuminated field stop regions (field stop opening and area around the solar image). The horizontal line marks a selected threshold.

A resulting image (with some additional modifications) is shown in Figure 10.

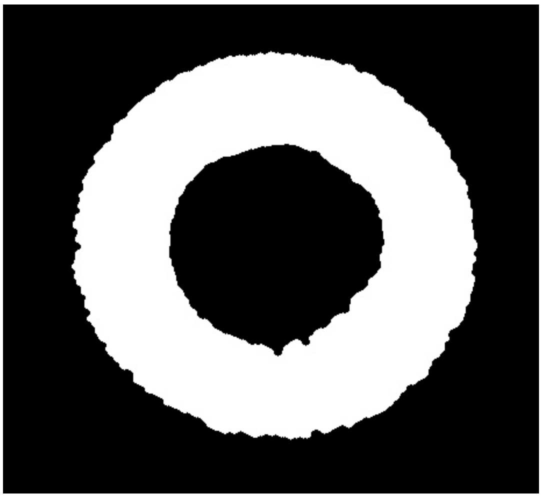

Figure 10: Solar image after conversion to a binary image. The black areas correspond to intensity values below a threshold value.

In a last step, 2 ellipses are fitted. A large one to the outer rim of the solar image and a smaller one to the rim of the aperture. The centers of these are then taken as the centers of the solar image and the field stop opening. The tracking position is modified so that the distance of the centers is and stays as small as possible. One reason that ellipses are fitted instead of circle is, that the camera observes the solar image from an angled position resulting in an non-round rim of the solar image.

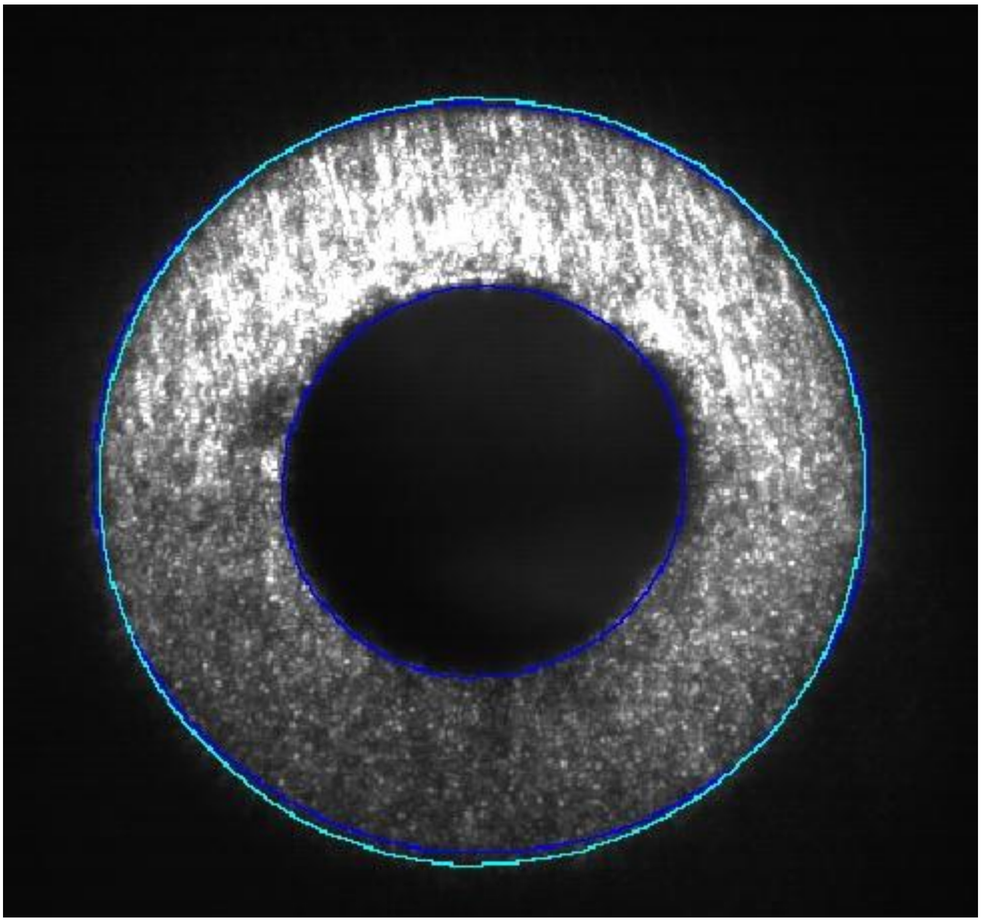

Figure 11: Overlay of original image together with the detected ellipses (blue) from the image processing. The white object is a circle, which is always fitted as well.

The advantage of this system is, that the image processing can detect the rim of the solar image even if a part of is not visible, e.g. due to obstructions (trees, clouds,…), leading to a high tracking precision.

Examples are shown in Figure 12 and Figure 13.

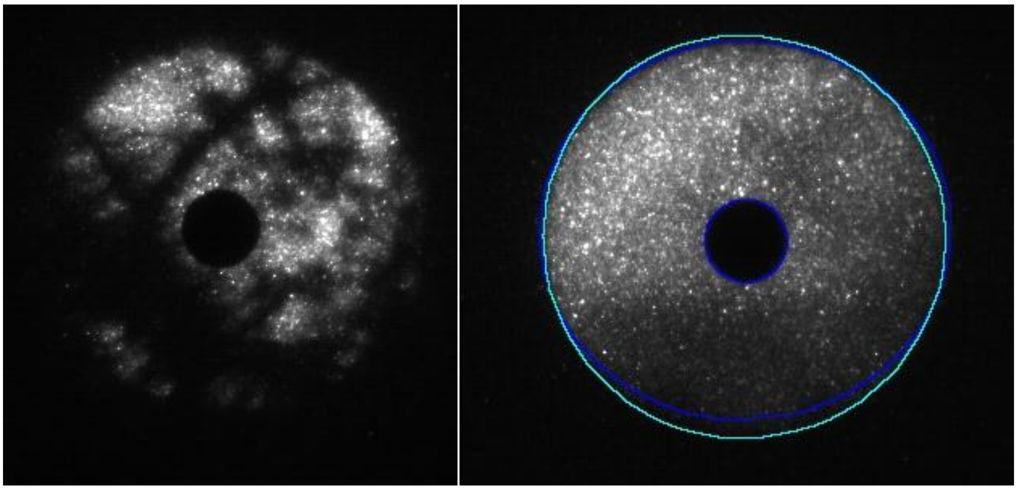

Figure 12: Left: A tree is obstructing the view of the sun. Right: The rim of the sun which is darkened by clouds still is detected correctly by the circle. Note: These images were recorded at a different spectrometer.

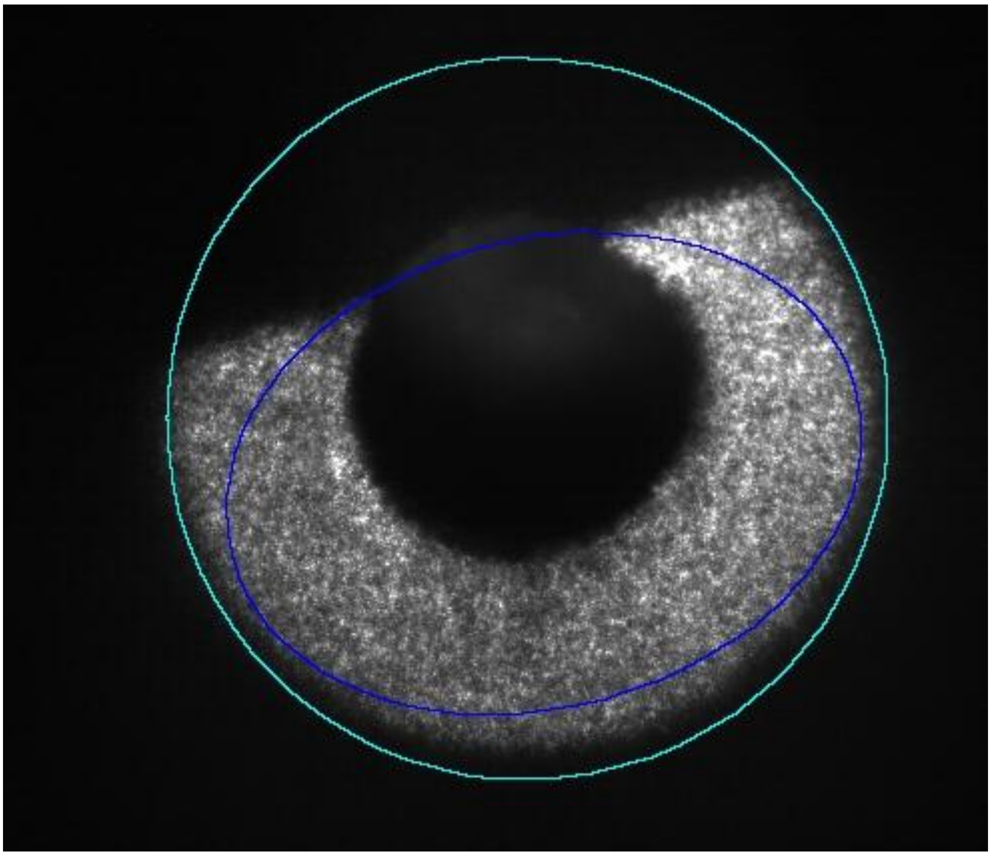

Figure 13: The sun is blocked by a large object. Nevertheless the circle fit approximately is able to detect the rim of the solar image..

To prevent the tracker program to use the blue ellipse in Figure 13 as the rim of the sun, several quality parameters have to be provided. These are minimum and

maximum radii of the ellipses and ellipticity values. As an example, in Figure 13 the ellipse will be marked with a bad quality, both as its radius is much smaller as would be correct for the radius of the solar image and it is too elliptic.
Some default values are set by Bruker. More information can be found in sec. 5.6.

5.2 Configuration file

Before the CamTracker program (CamTracker_3_8.exe) can work properly, a configuration file has to be set-up containing the tracker's orientation and location, and information for the camera-based tracking.

The settings which have to be set-up by the user are stored in the file "CamTrackerConfig-txt", which is located in the same folder as the actual tracker program.
The general structure is as follows:
There are 4 sections which are read by the program. These sections contain several parameters, one per line, and start after a $-sign ($1 to $4). Above the $-signs, a description of the parameters is given.
<u>Example:</u>

```
Tracker position:
- latitude [-90 to +90]
- longitude [-180 to +180] !! East is Positive
- height of observer [in km]

$1
49.10
08.44
0.1
```

The four parameters in section $2 correspond to the tracker orientation angle values described in Section 4.1.3
Section $3 describes additional settings for the tracker. The type of the tracker (EM27_SUN) and IP-address of the spectrometer has to be specified. When the tracker program is closed, the tracker is moved to a park position, which can be

specified as well. In addition, a maximum speed of the tracker can be stated. This should not exceed a certain speed.

Example:

```
Tracker Settings:
- Type of tracker used:   EM27_EWS
- IP-Address  e.g. 192.168.21.253
- Park angle Elevation Mirror
- Park angle Azimuth  Mirror
- Maximum Speed of Tracker (°/second) (recommended: 14)

$3
EM27_EWS
10.10.0.1
0
0
14
```

The parameters in section $4 are quality parameters of the solar image needed for the camera-based tracking. In short, they describe in which limits (radii, ellipticity, …) the ellipses that are fitted to the solar image and the aperture stop should be used for the optical feedback. These values are set to default values, and, in general; do not need to be modified. For more information about the ellipse which are fitted and how they are used as the optical feedback of the tracker see sec 5.1.

Example:

```
Solar image parameters:
- minimum Radius of Sun ellipse and circle / px
- maximum Radius of Sun ellipse and circle / px
- minimum Radius of Aperture ellipse / px
- maximum Radius of Aperture ellipse / px
- maximum deviation in big Ellipse-half-axis / px
- maximum deviation of centers from big ellipse and circle /px
          (if bigger, circle will be used for correction)
$4
160
175
75
```

85
15
15

5.3 Start of the tracking program

Before starting the tracker program (CamTracker_3_8.exe), the camera and the spectrometer should be connected to the computer. The user interface then looks like shown in Figure 14.

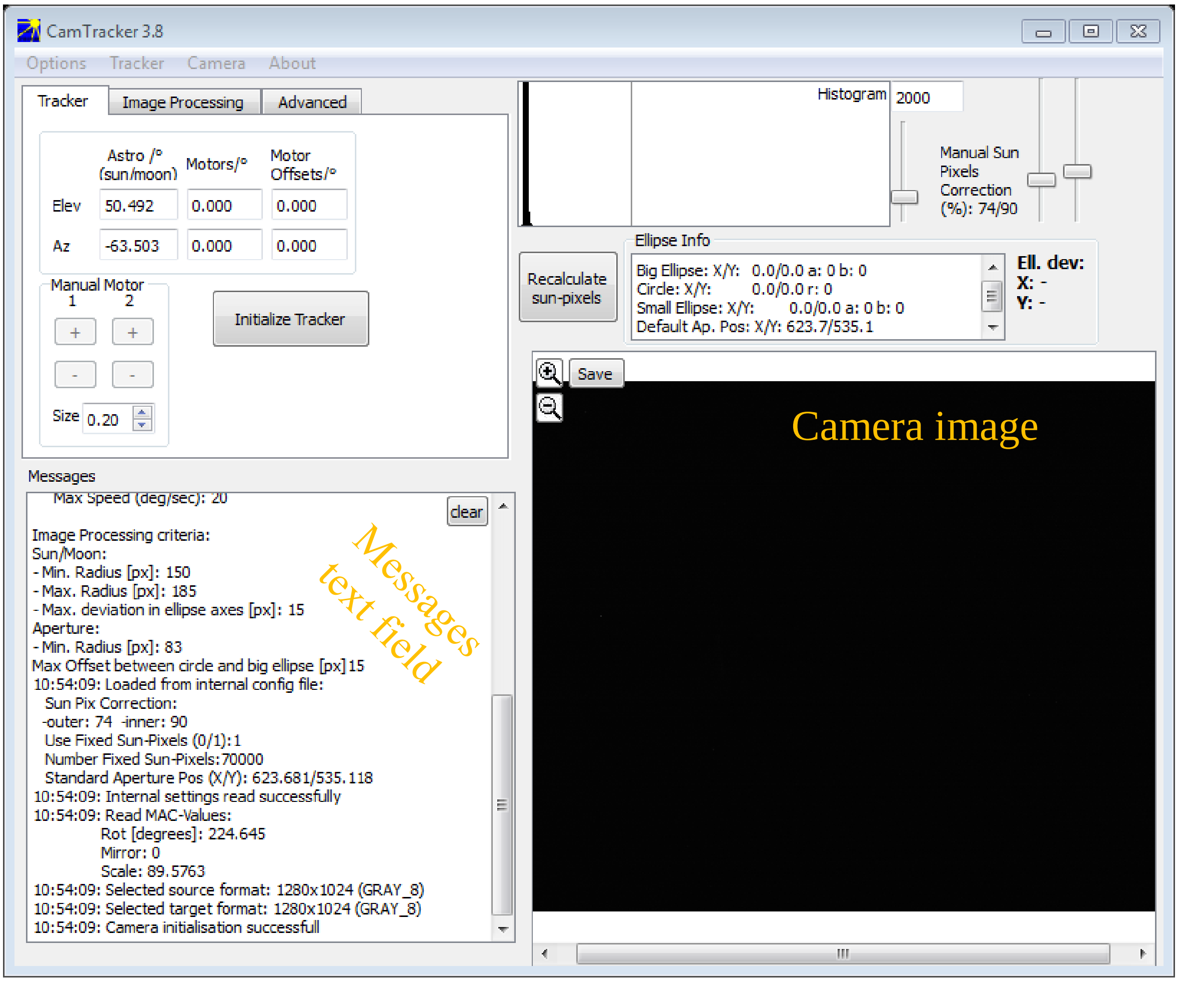

Figure 14: The CamTracker program after startup. As the tracking has not yet started, the camera image (bottom right) is all black. The messages text area on the bottom left side shows the information read from the configuration file. The current solar position is shown on the top left side, as derived from astronomical calculations.

When clicking on the “**Initialize Tracker**” button, the tracker motors move to their initial positions. This is the position relevant for determining the orientation angle of the tracker (see section 4.1.3). If this procedure is successful, the text on the button changes to ”**Move Tracker to park pos**”, and in the messages window on the bottom left side “Tracker successfully initialized!” occurs.

Now the tracker is ready to be moved, so that the relevant control panels become active as shown in the following images:

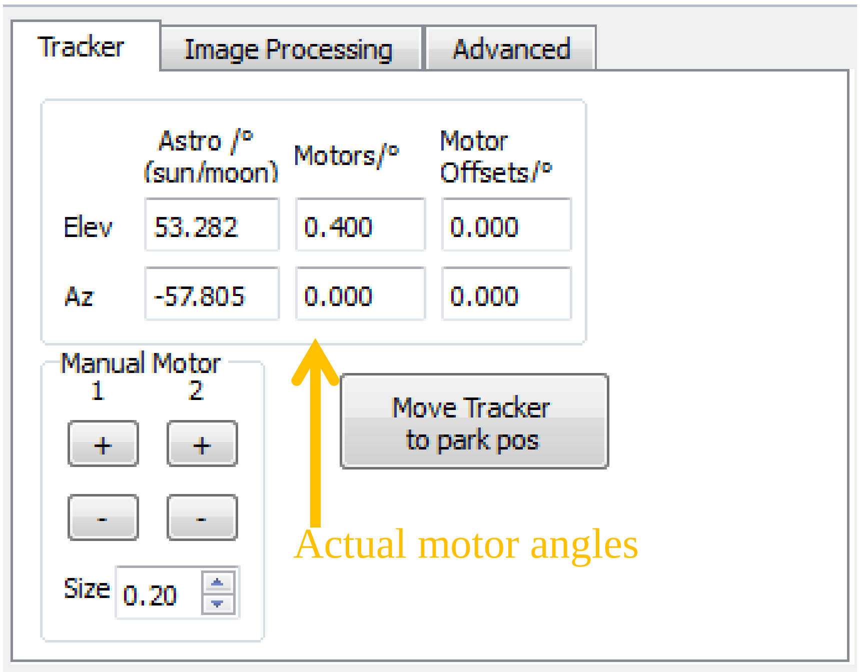

Figure 15: The motors can be moved by user-selected steps using the buttons with the + and – signs. Motor 1 corresponds to the elevation motor, motor 2 to the azimuthal motor. After the tracking has started, clicking these buttons will add an manual offset to the current tracking angles. The motor angles are set to 0 after initialization, and shown in the column right of the astronomically calculated angles.

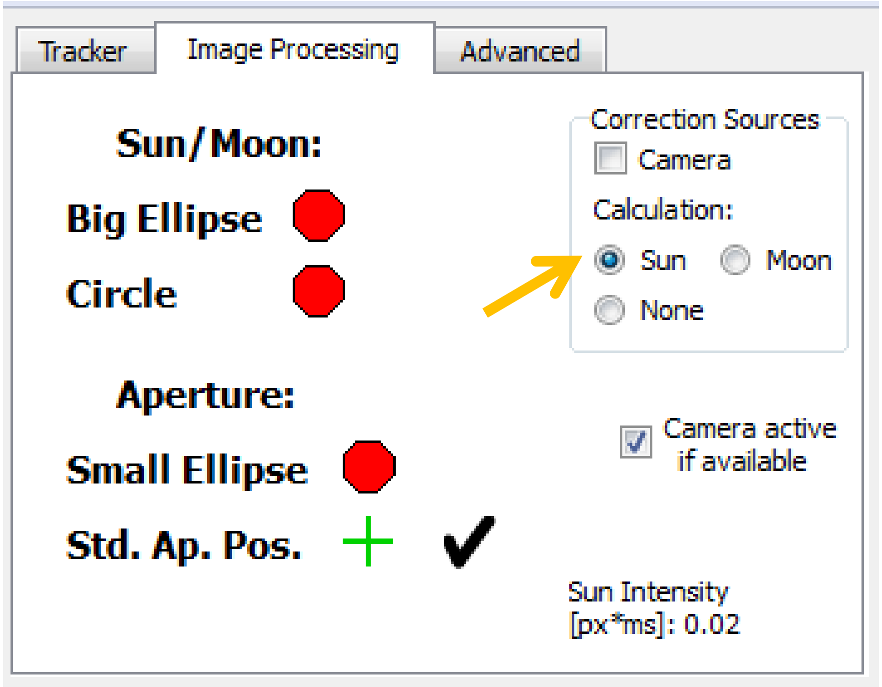

Figure 16: In the „Image Processing"-tab, the quality of the ellipses that are fitted is shown. After startup, there is no sun at all, so the quality is marked as bad with a red hexagon. In the field "Correction Sources", it is possible to select "Sun" as an input for the tracker. When clicking this, the motors move to initial positions derived from astronomical calculations and the tracking is performed astronomically.

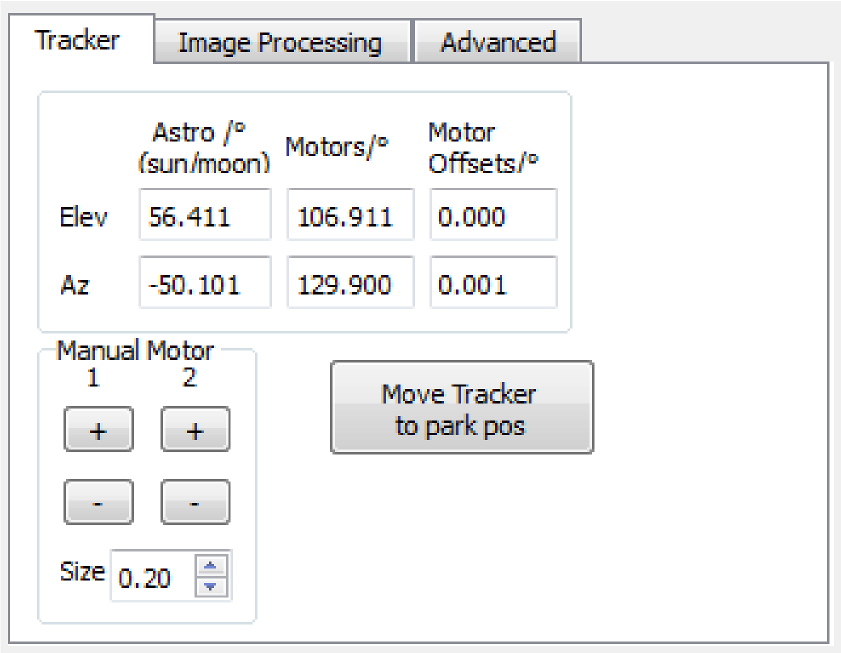

Figure 17: Tracker-tab after activating the sun for tracking. The tracker is guided by astronomical calculations only. As can be seen, the astronomical elevation and azimuth values differ from the values of the motors. This is due to the tracker orientation angles given in the CamTrackerConfig.txt-file as described in sec. 5.2. In this example, the elevation offset is -50.5°, the azimuth offset is -180°, as would be correct when the spectrometer is set-up as in Figure 6.

5.4 Start camera-based tracking

If the tracker orientation angles are correct, and the recording channel of the spectrometer is set to “external input” (see Figure 29), the camera should show an image of the sun when the tracker tracks astronomically (radio-button “Sun” is checked in the “Image Processing”-tab. If this is not the case, the orientation angles most probably are not correct.

To fix that, look at the tracker whether the solar beam correctly enters the vertical tube of the tracker, or if a part of it hits the tracker as shown in Figure 18.

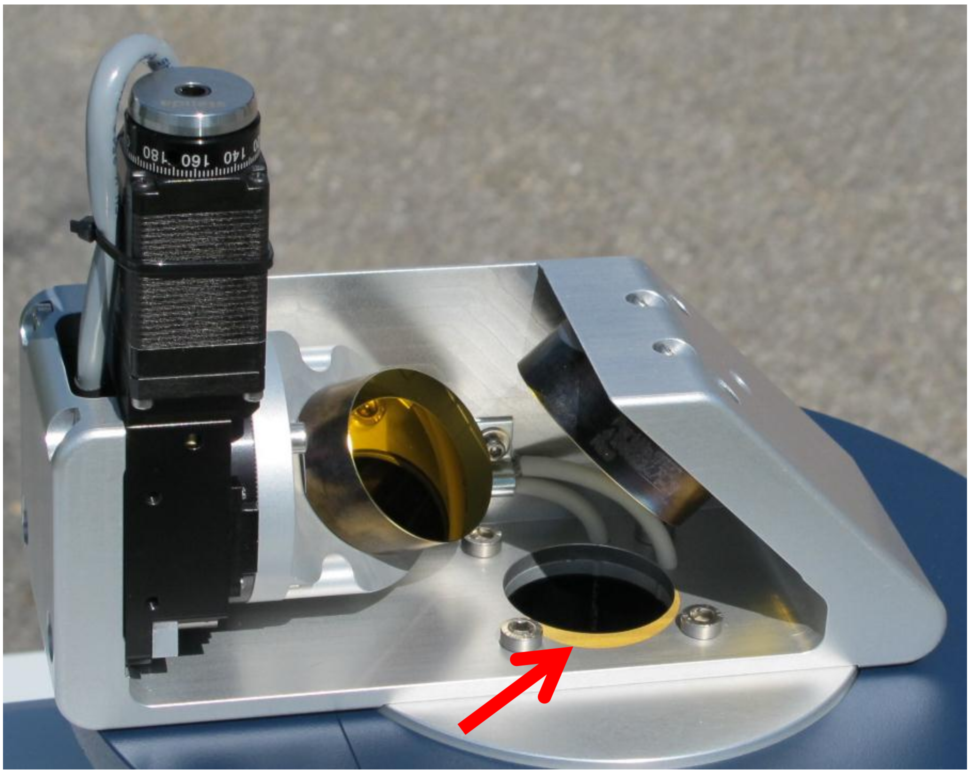

Figure 18: The solar does not enter the tracker correctly. Some part of it hits the rim of the opening.

By clicking on the buttons with the + and – signs (see Figure 15), a manual offsets can be added to avoid the light hitting the tracker as in Figure 18. If still no solar image is visible by the camera, it should be checked whether the radiation hits the 45 degrees mirror in front of the spectrometer's entrance window as shown in Figure 19.

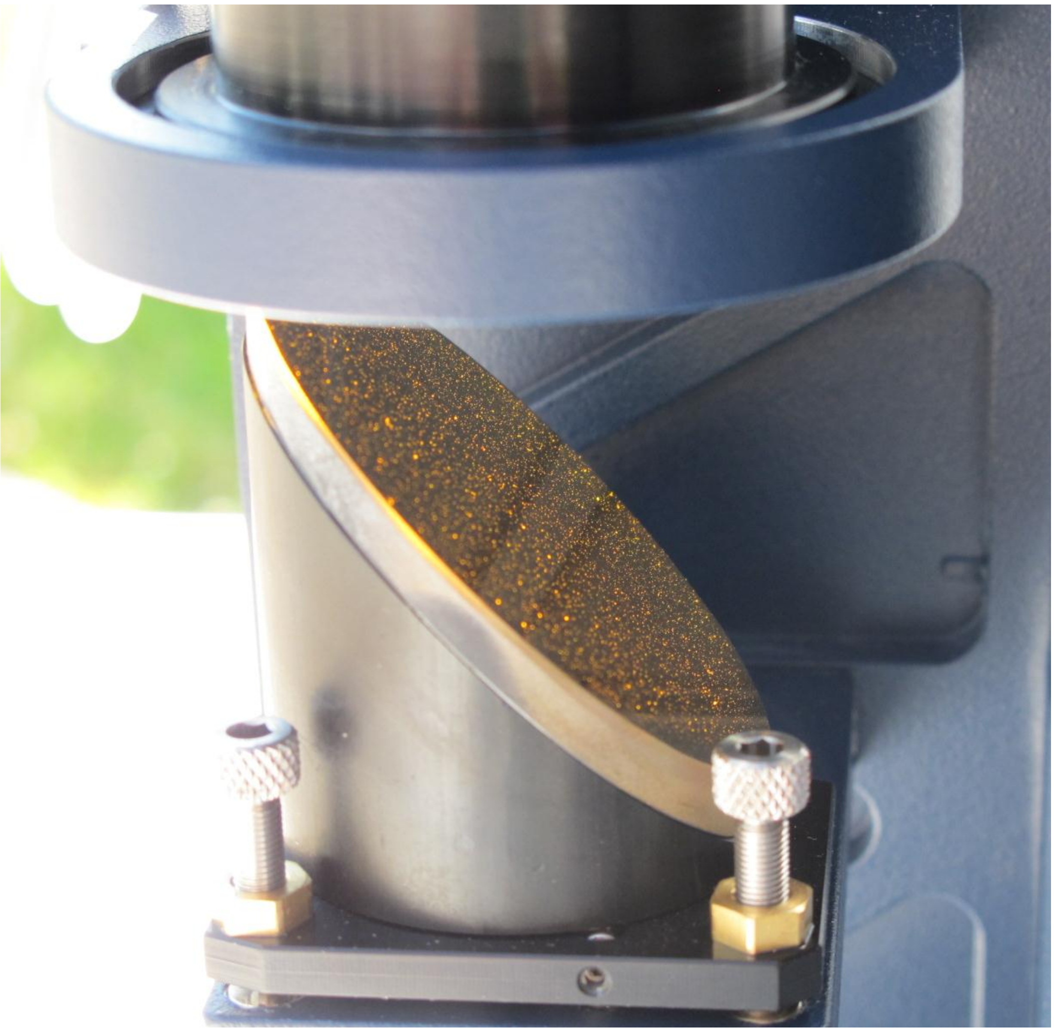

Figure 19: The radiation reflected downwards should hit the full area of the 45 degrees mirror.

Note: Instead of moving the motor 2, it also is possible to rotate the whole spectrometer.

Note: The offsets induced by rotating the tracker with the + and – buttons are shown in the third column on the in the Tracker-tab (see Figure 17). These offsets should advantageously be taken into the orientation parameter section in the CamTrackerConfig.txt, so that the Sun can be seen directly after starting up the system the next time. This can be done while the program is running as well, by modifying and saving the file and clicking on the line “Load configuration file” in the Options pull-down menu. By clicking on “None” and then again on “Sun” in the “Image processing tab”, the motors move to the astronomically calculated position.

At some stage, the sun should be visible by the camera, as shown in Figure 20.

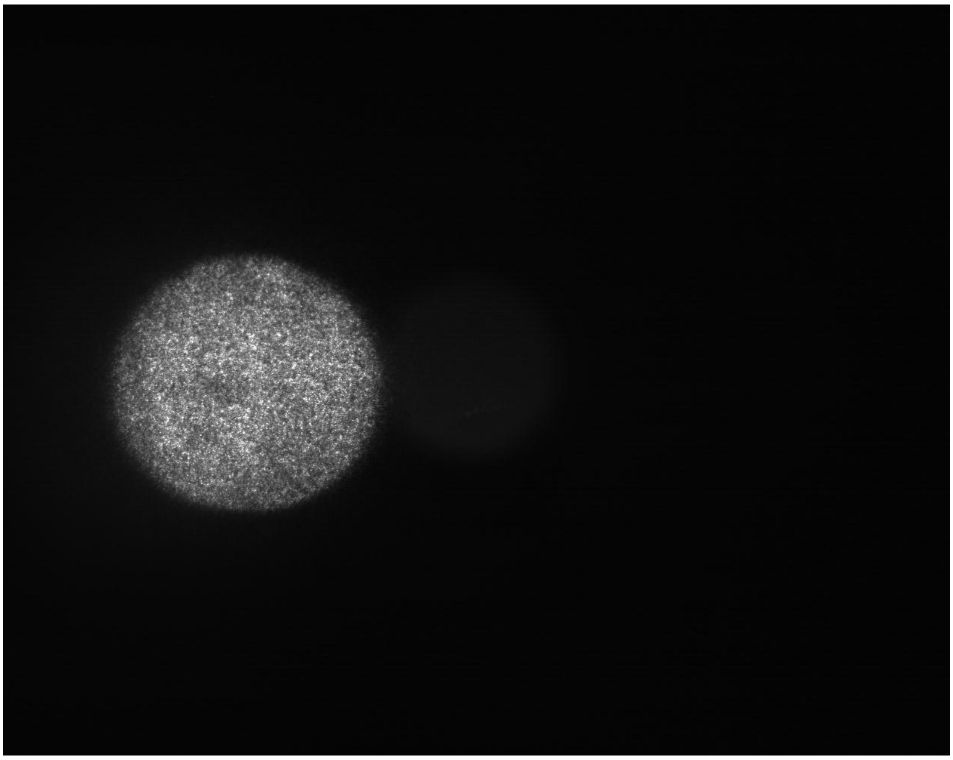

Figure 20: Image of the sun as seen by the camera. The area of the field stop position cannot be observed as the sun is not illuminating it.

When the solar disk becomes visible, the exposure time is adapted to the brightness of the solar image to avoid over-illumination. Then the image processing is detecting the rim of the sun, marking this with a blue ellipse. If this meets the quality specifications given in the CamTrackerConfig.txt (Radius and Ellipticity lie in a reasonable range), the Quality-Indicator on the "Image Processing" tab should turn green. This ellipse (more precisely its center) then is used as the actual position of the solar image (Figure 21).

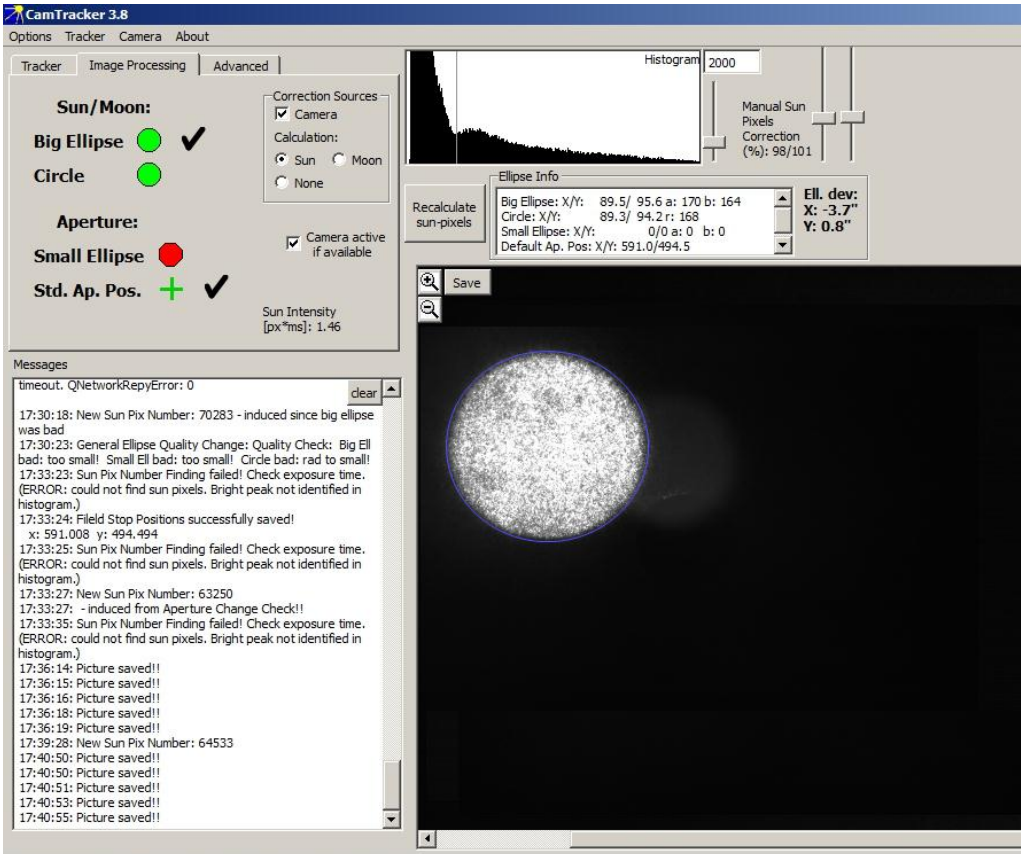

Figure 21: Solar image is visible, in contrast to the aperture. The rim of the solar image was detected (blue ellipse). This ellipse meets the quality requirements, so the quality marker becomes green. In this case, for camera-based tracking, the big ellipse is used as the solar position, and a standard-aperture position as the target central position is used, which is indicated by the two checkmarks.

As the next step, the camera (and with it the image processing) should be activated as a source for the tracking on the “Image Processing” tab, as done in Figure 21.

As the position of the aperture cannot be detected as it is not illuminated, the camera will “move” the solar image to a pre-defined pixel-position, which should be at the position of the field stop. This position is denoted as “Standard Aperture Position” (Std. Ap. Pos.). If everything works fine, the solar image is moved to the aperture. As soon as this is fully inside the solar image, a second ellipse denoting the rim of the aperture, will be fitted. Subsequently the center of this ellipse will be used as the target central position of the solar image instead of the standard aperture position, as long as its quality is good (minimum and maximum radii as defined in the CamTrackerConfig.txt-file.)

This normal mode of operation is shown in Figure 22.

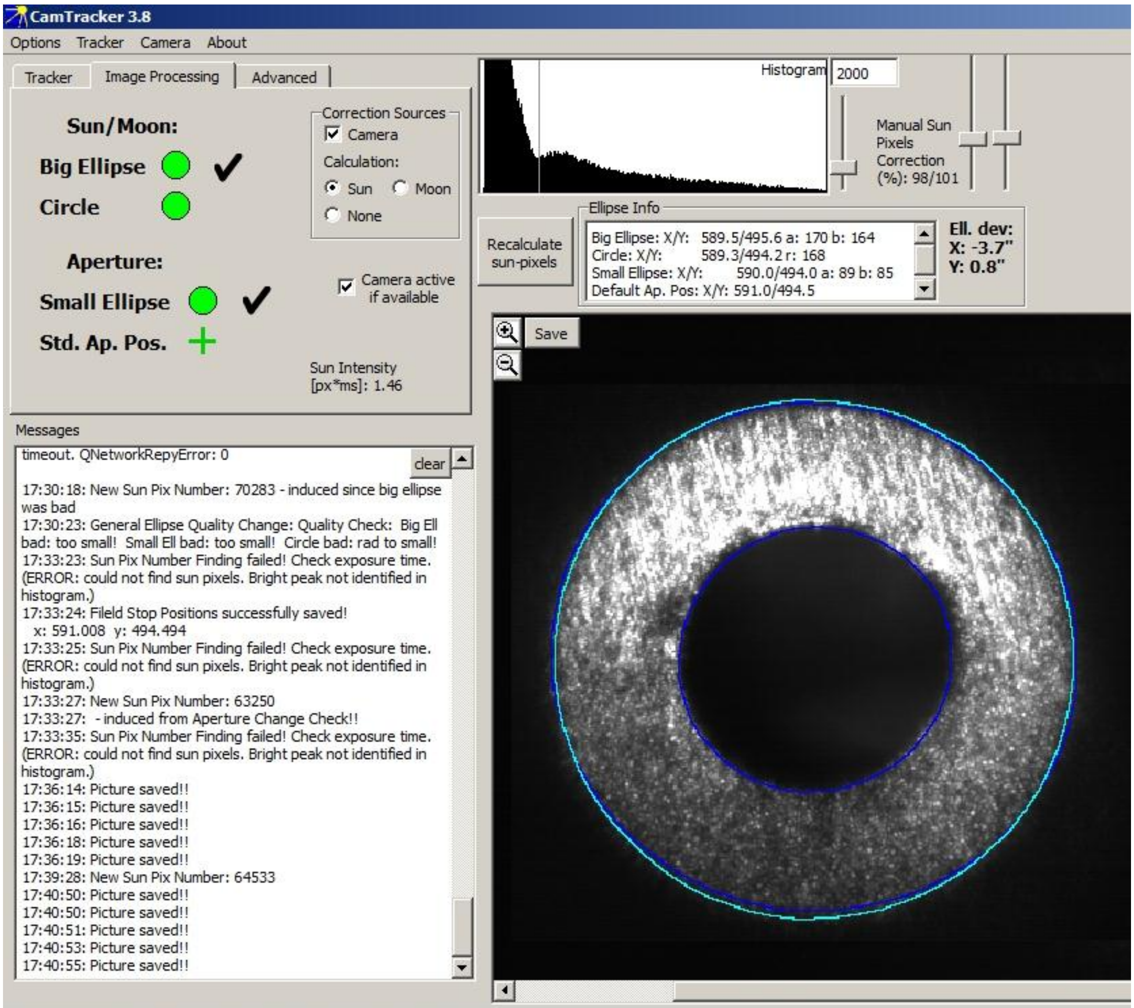

Figure 22: Normal mode of operation: Both the big and small ellipse corresponding to the rim of the solar image and the aperture have a good quality. Therefore their centers are used for the tracking.
The offset of the centers of the ellipses is measured, transformed to tracking offsets in arc seconds and displayed right above the solar image as "Ell. Dev". This transformation is done by assuming the big ellipse diameter corresponds to the apparent solar diameter of 30 arc minutes

Note: The standard aperture position can be set, when the true aperture was detected by the image processing (second blue ellipse, see Figure 22) and the line "Save current field stop position as standard" is clicked in the "Camera"-pull down menu.

If in the normal mode of operation the solar image can't be detected, e.g. due to clouds, the tracker continues using astronomical values only, until the solar image appears again.

5.5 Manual adaption of the circles

A crucial step in the image processing is finding the threshold used to separate the area illuminated from the Sun from the rest. This is done by finding a minimum value in the brightness histogram (e.g. see Figure 9), which is always shown above the image of the camera. The maximum left of the minimum corresponds to the non-illuminated pixels, the maximum right of it correspond to the illuminated region. In general, this automatically found minimum is not the best for all types of field stop surfaces. Therefore, one manually can change this value using the 2 sliders at the very top right of the tracker's user interface: "Manual Sun Pixels Correction (%)". The left one affects both the big and the small ellipse (the movement of the threshold in the brightness histogram can be seen), the right slider affects the small ellipse only.

These two values have to be set-up the first time only, as they are stored when the program is closed and re-loaded when it is started again.

Note: The minimum-finding can manually be activated by clicking on the button "Recalculate sun-pixels". Besides that, it is performed as soon as the big ellipse is marked with a bad quality.

5.6 Quality parameters for the image processing

As described above, the program always tries to fit 2 ellipses and one circle.

In the ideal case, the centers of the 2 ellipses are used and its distance is minimized. If the big ellipse is detected as having a bad quality, the center of the circle is used instead, as long as it has a good quality.

If the small ellipse has a bad quality (this also is the case if there was no second ellipse found as the field stop aperture is not illuminated by the sun at all), then the standard aperture position is used as the target to where the solar image is moved to.

The criteria which are used to determine whether a quality is good or bad, are located in the section $4 in the CamTrackerConfig.txt-file:

```
Solar image parameters:
- minimum Radius of Sun ellipse and circle / px
- maximum Radius of Sun ellipse and circle / px
- minimum Radius of Aperture ellipse / px
- maximum Radius of Aperture ellipse / px
- maximum deviation in big Ellipse-half-axis / px
- maximum deviation of centers from big ellipse and circle /px
           (if bigger, circle will be used for correction)
$4
160
175
75
85
15
15
```

The first 4 values describe ranges for the radii, in which the ellipses and the circles have to be in order to be able to be marked with a good quality. For the ellipses, the means of the big and small half axes are used.
The 5th number is a measure for the ellipticity of the big ellipse which is allowed.
The last number gives a deviation between the centers of the big ellipse and the circle, which must not be exceeded. If it is exceeded, then the big ellipse is marked as bad and the circle is taken if this has a good quality.

The values of the ellipses and the circle can be seen while the tracking is performed on the user interface, as can be seen on Figure 23.

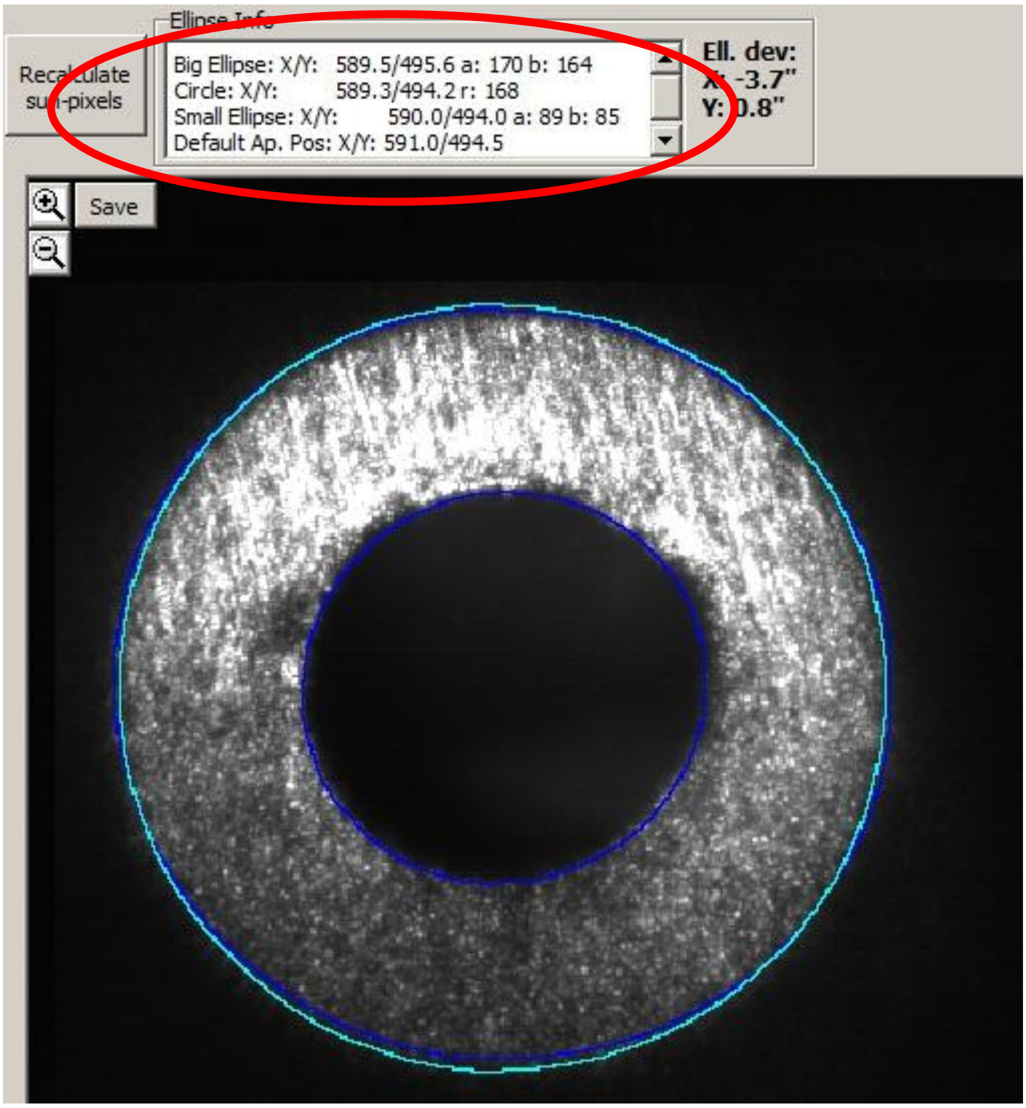

Figure 23: The central positions of the 2 ellipses and the circles, the large and small half axes of the ellipses and the radius of the circle resulting from the fit are displayed.

From the values displayed while the tracking is active and the ellipses correspond well to the rim of the solar image, the values in the configuration file can be derived, where the range for the minimum and maximum radii should be about 10%.

Note: When changing the values in the CamTrackerConfig.txt, these values can be load into the tracker program by clicking on the line “Read configuration file” in the Options pull-down menu.

5.7 Advanced tab

In the advanced tab (see Figure 24) it is possible to manually change the sensor gain and the exposure time. In normal operation it should be left at “Auto”.

In addition, it is possible to tell the program to use a specific object for tracking. If auto is activated, then the ellipses are used as long as they have a good quality. In case of a bad quality, the circle or the default position is used.

By unchecking the “Auto” check box, one can manually allow only one of the correction objects to be used as tracking. E.g. if “Def Pos” is activated, then the solar image will be centered on the default position, even if there is a small ellipse found with a good quality.

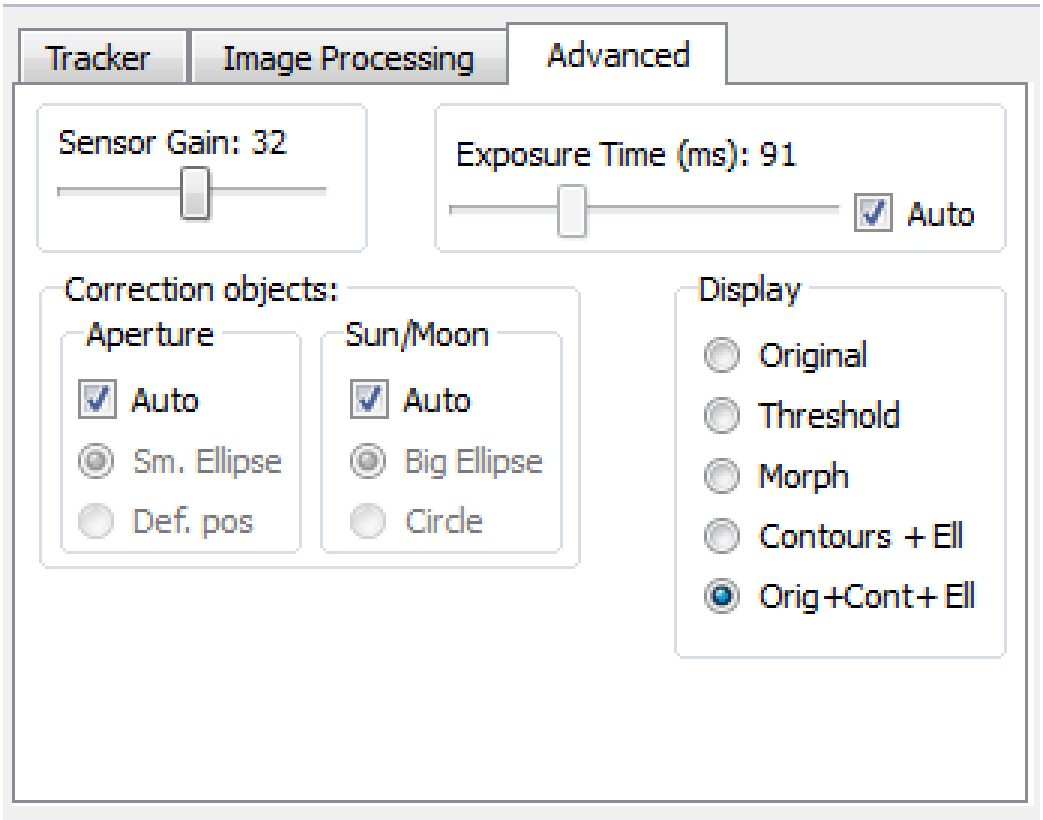

Figure 24: Advanced tab

5.8 Mirror image correlation

6 Recording spectra

The spectra can be recorded using OPUS.

6.1 Installation and configuring OPUS

OPUS has to be installed and registered.

Note: If you are running windows 7, you have to right-click on the setup button and select “Run as administrator”. It is not sufficient to be logged in as an administrator.

In the installation of OPUS, select “Tensor27” as the instrument that has to be controlled.

After the installation of OPUS, copy the file “EM27SUN.xpm” provided on the CD delivered with your instrument into the XPM-directory of OPUS (e.g. C:\OPUS_7.2.139.1294\XPM)

In addition copy the “EM27.ows” to the OPUS directory.

When starting OPUS, one has to enter a password which is OPUS. On the same input window, select EM27 as the working environment.

Note: If you do not want to enter the password every time you start opus, add the command line “/directloginpassword=OPUS” in the desktop symbol you use to start OPUS.

When starting OPUS the first time, you should register using the information which was supplied with the software.

Next click on “Measurement”->”Optic setup and service”. Here deactivate the checkbox “Enforce predefined Measurement Parameters” as shown in Figure 25

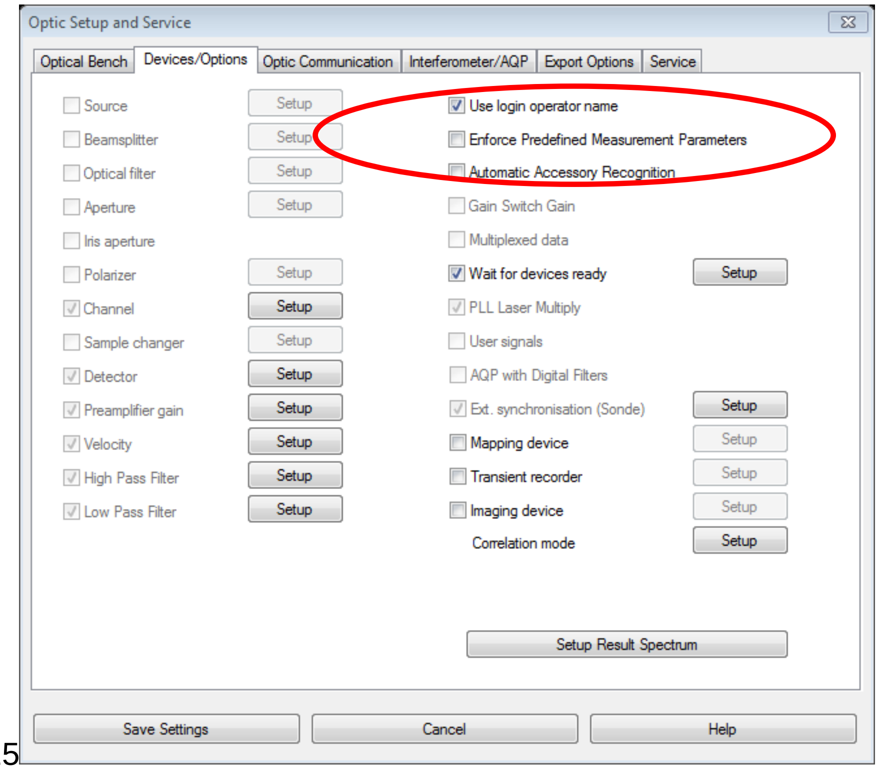

Figure 25: Uncheck „Enforce predefined Measurement Parameters”.

Click on “Setup”->”User settings”, and deactivate “Work in validated environment” in the “Rights” tab (see Figure 26)

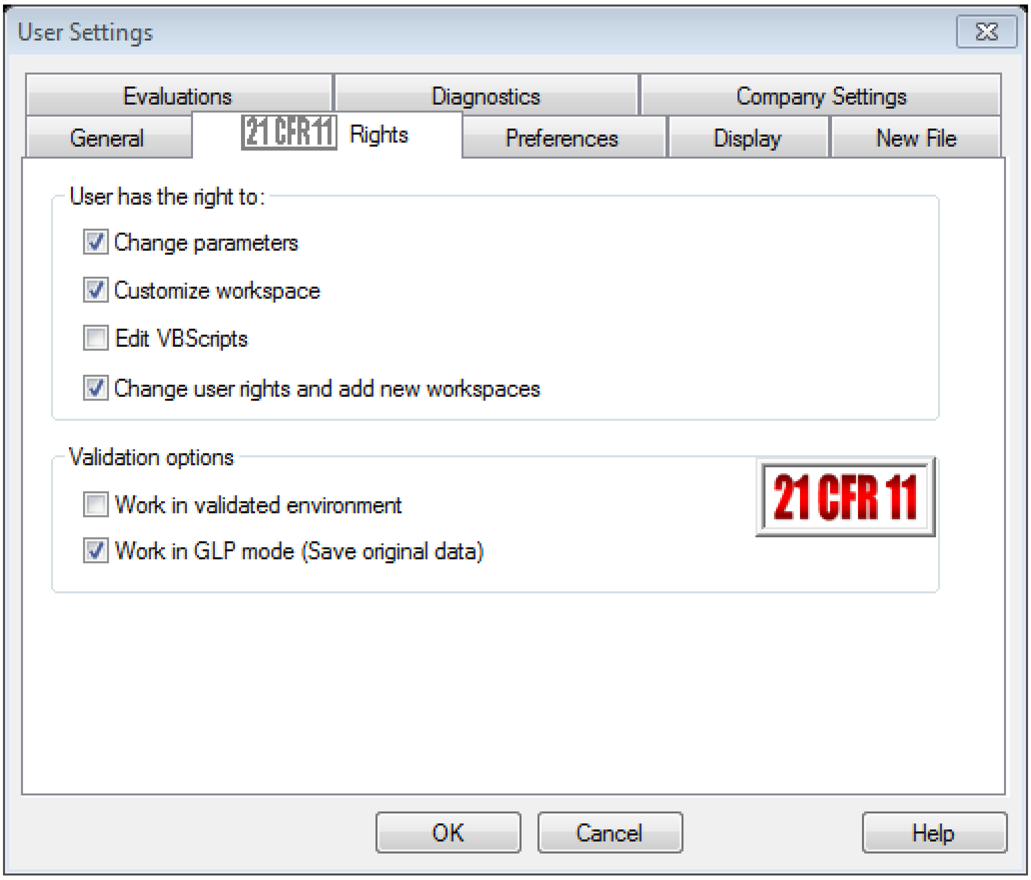

Figure 26: Deactivate „Work in validated environment“

6.2 Setting up measurements

To set up measurement parameters click on “Measure” -> ”Advanced Measurement”. In the appearing window it is possible to set all parameters for the measurements, and to load and save these in a .xpm file. For a first start, load the EM27SUN.xpm which you copied to the XPM-Folder. This contains the standard parameters recommended for solar EM27 measurements.

In the following the settings will be explained:

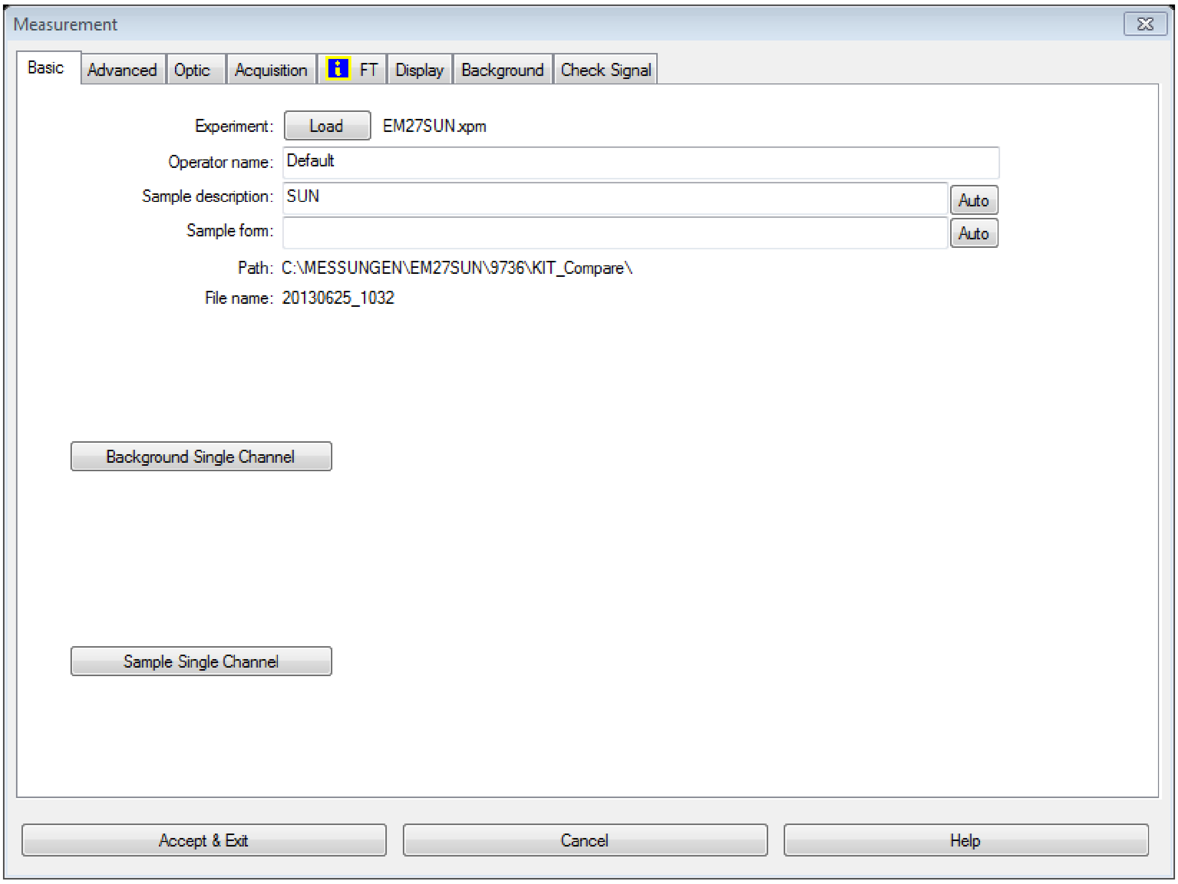

Figure 27: Basic: In this tab the measurement parameters can be loaded and a measurement can be started using the button „Sample Single Channel“.

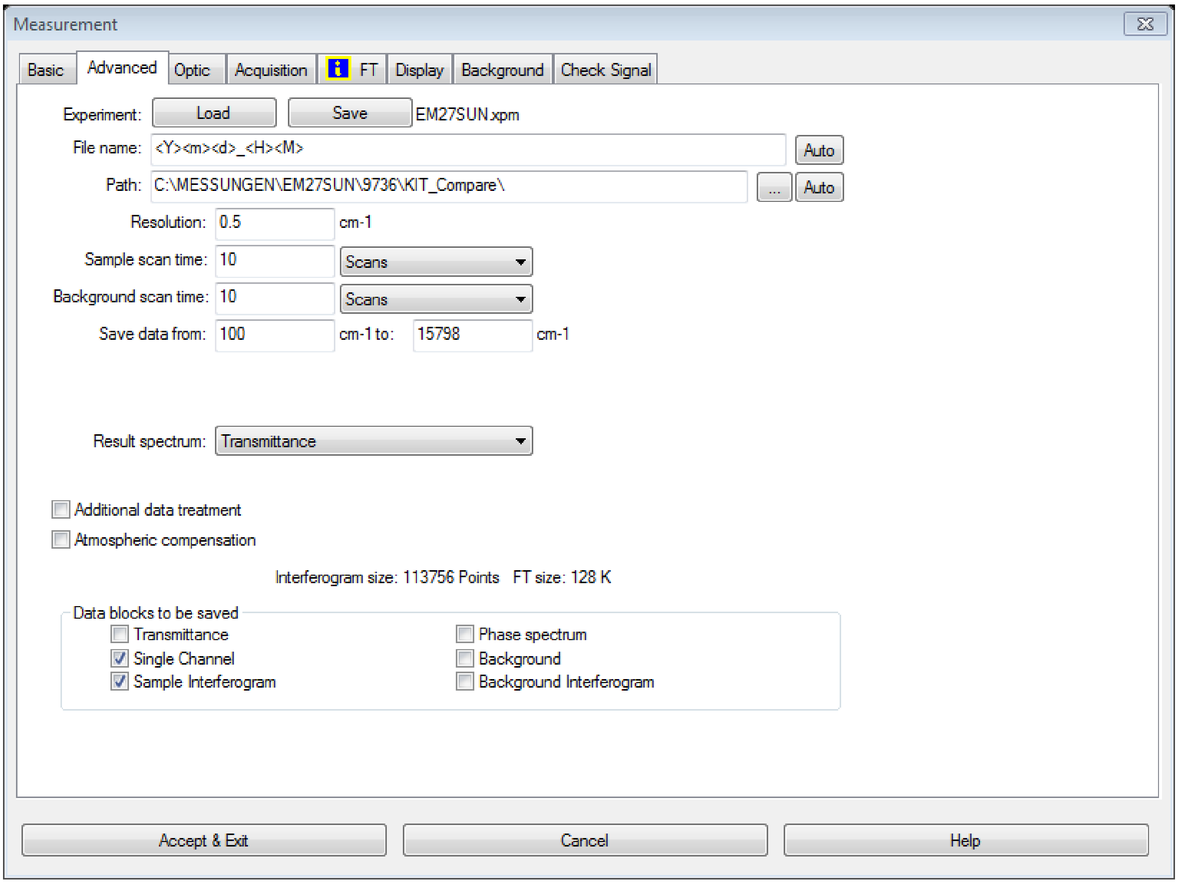

Figure 28: Advanced tab: Here the file name of the measured spectra can be set, together with the folder. In addition the resolution and the number of scans can be set. The maximum resolution of the EM27/SUN is $0.5cm^{-1}$. The range set by "Save Data" is saved directly after the measurement. Any other available range can still be calculated from the interferograms afterwards, as long as "Sample Interferogram" is checked at the bottom of the window.

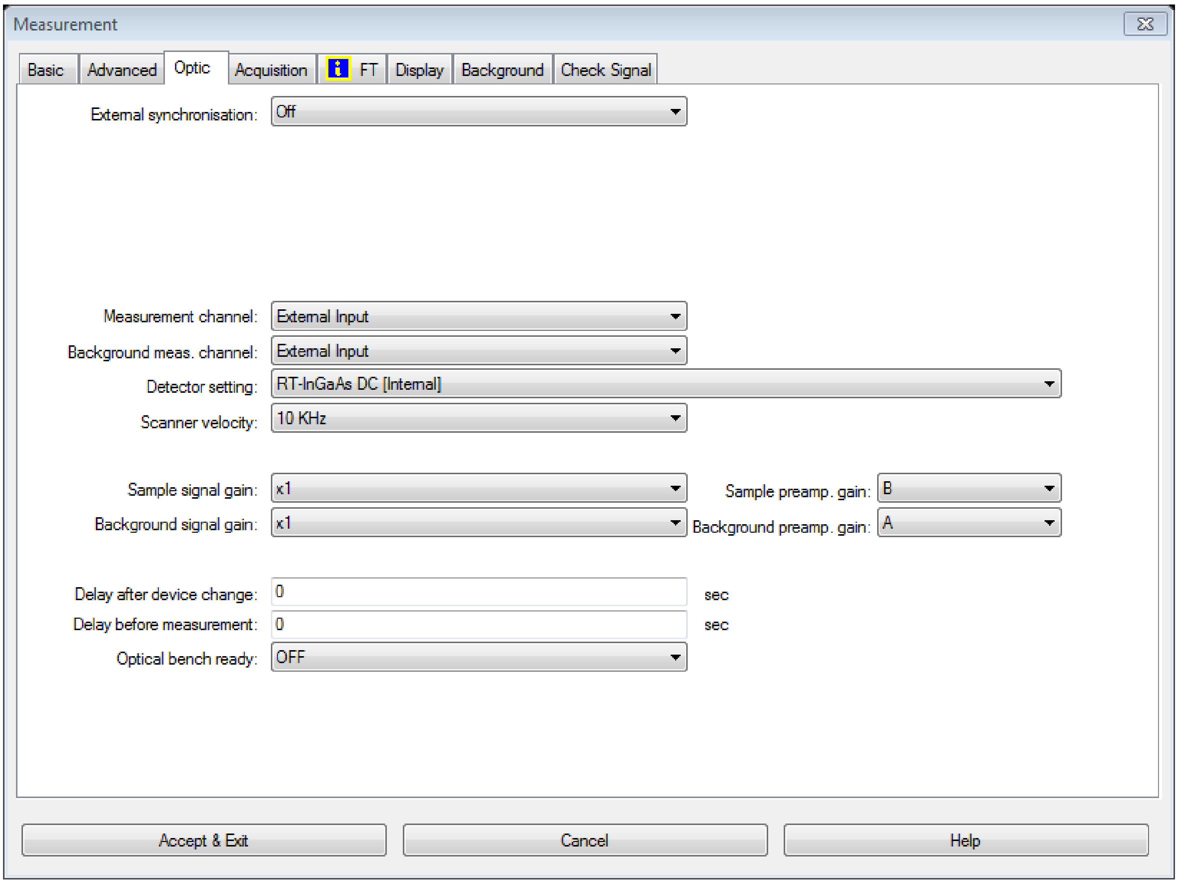

Figure 29: In the Optic tab, the source channel can be selected. The options are "External Input", which is used to measure the solar radiation, and "Reference", which activates and uses an internal NIR source. Note: In order to activate the changes, click on the "Check Signal" tab!.
The detector is able to measure the signal in AC and DC coupled mode. To correct the interferograms for solar brightness variations (e.g. clouds), DC mode is recommended for solar measurements. The scanner velocity can be set as well to 5, 10, 20 and 40 kHz. 10 or 20 kHz is recommended. The detector has four selectable preamplifier gains, denoted as A, B, C and Ref. These amplify the analog signal before digitalization. The amplification steps are approximately: 1 : 3.1 : 10 : 67. For solar measurements, the setting B is a good choice, for the internal radiation source Ref gives good values. These pregain settings should be chosen such that the ADC of the detector is used best. The currently used range can be seen in the "Check Signal" tab (Figure 33).

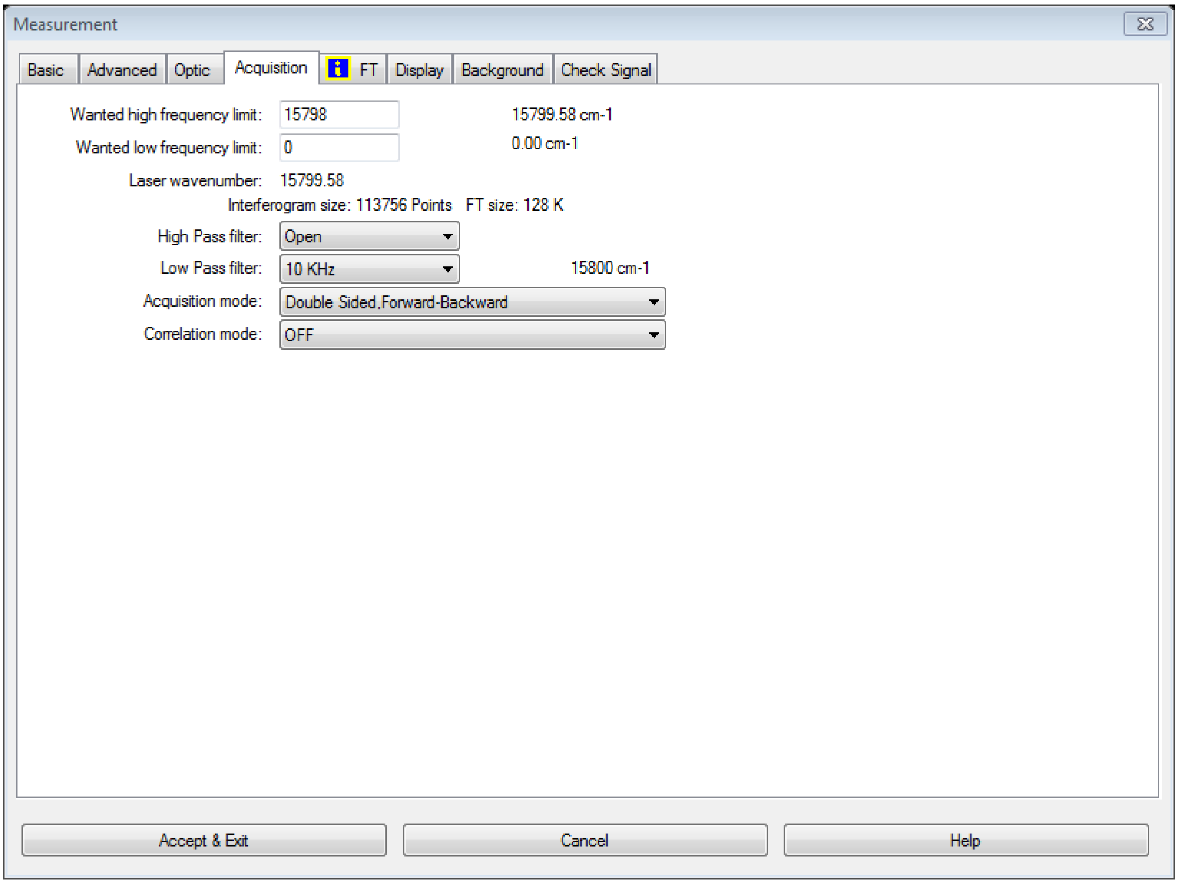

Figure 30: In the acquisition tab, the spectral range the detector detects radiation can be set. The "High Pass Filter" should be switched off (OPEN) when DC coupled measurements are done. Otherwise the DC component is lost. The "Low Pass Filter" should be set to the scanner velocity (see Optic tab). This prevents distortions which may be induced by the electronics above the recorded spectral range. The EM27/SUN allows for double sided measurements with 0.5 cm^{-1} resolution.

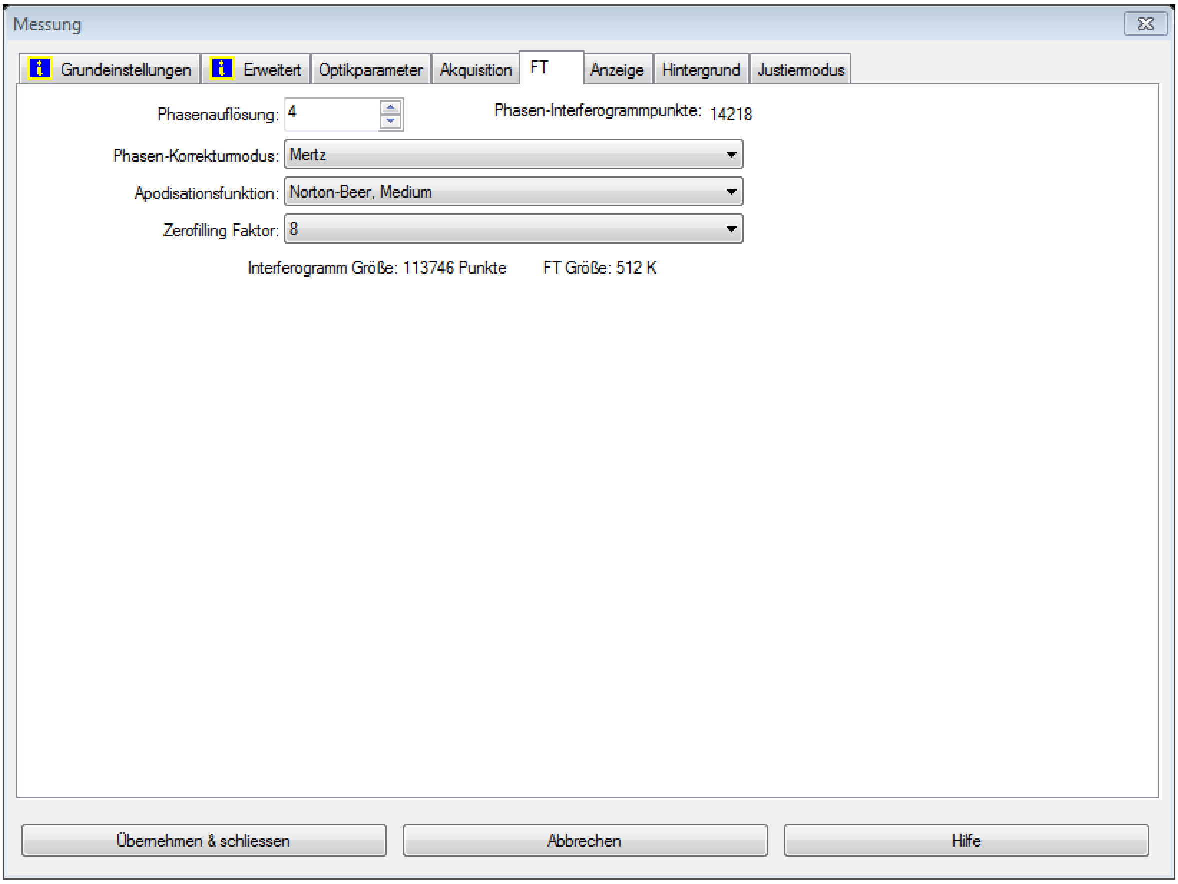

Figure 31: In the FT tab, the phase resolution that shall be recorded can be set, together with the FT-parameters for the Fourier Transformation performed directly after the measurement.

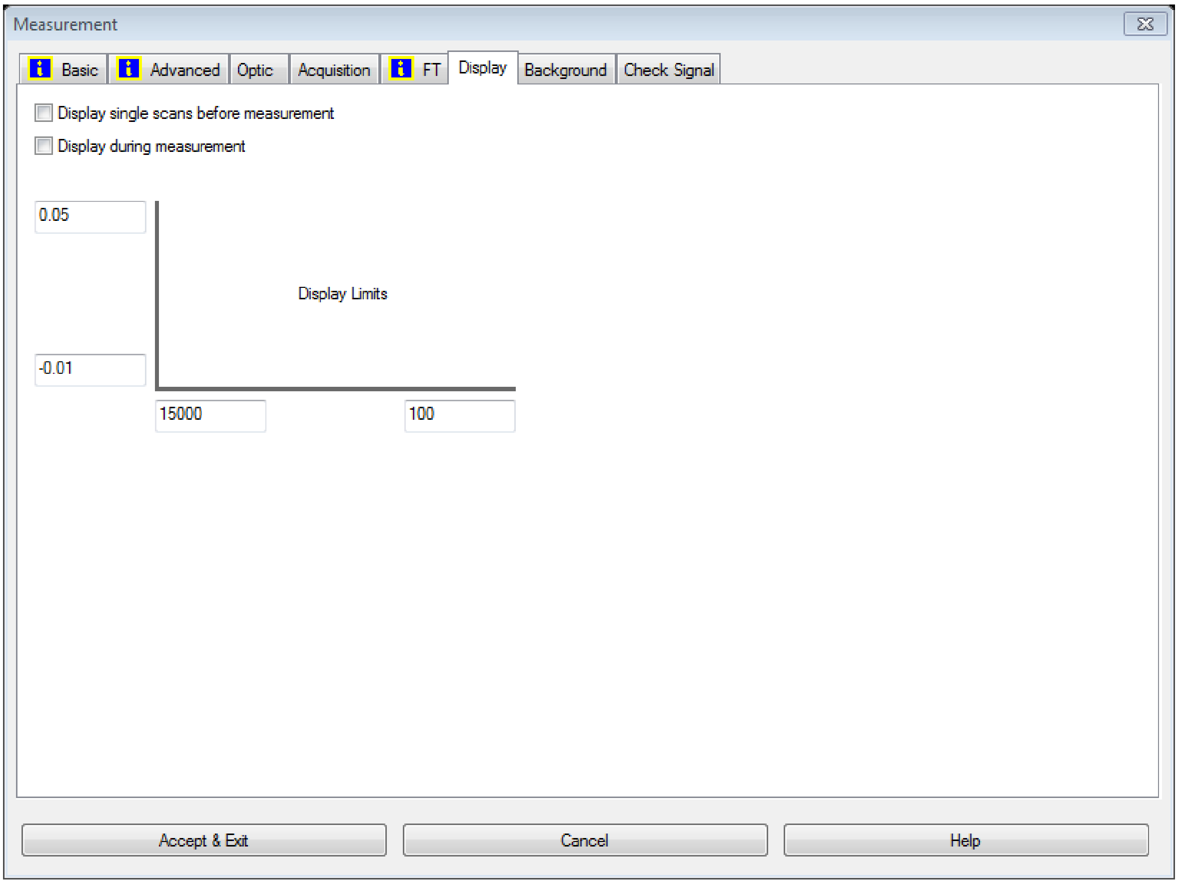

Figure 32: In the Display tab, the spectral range for the „Check Signal“ tab can be set. Important: make sure the check box “Display single scans before measurement” is unchecked.

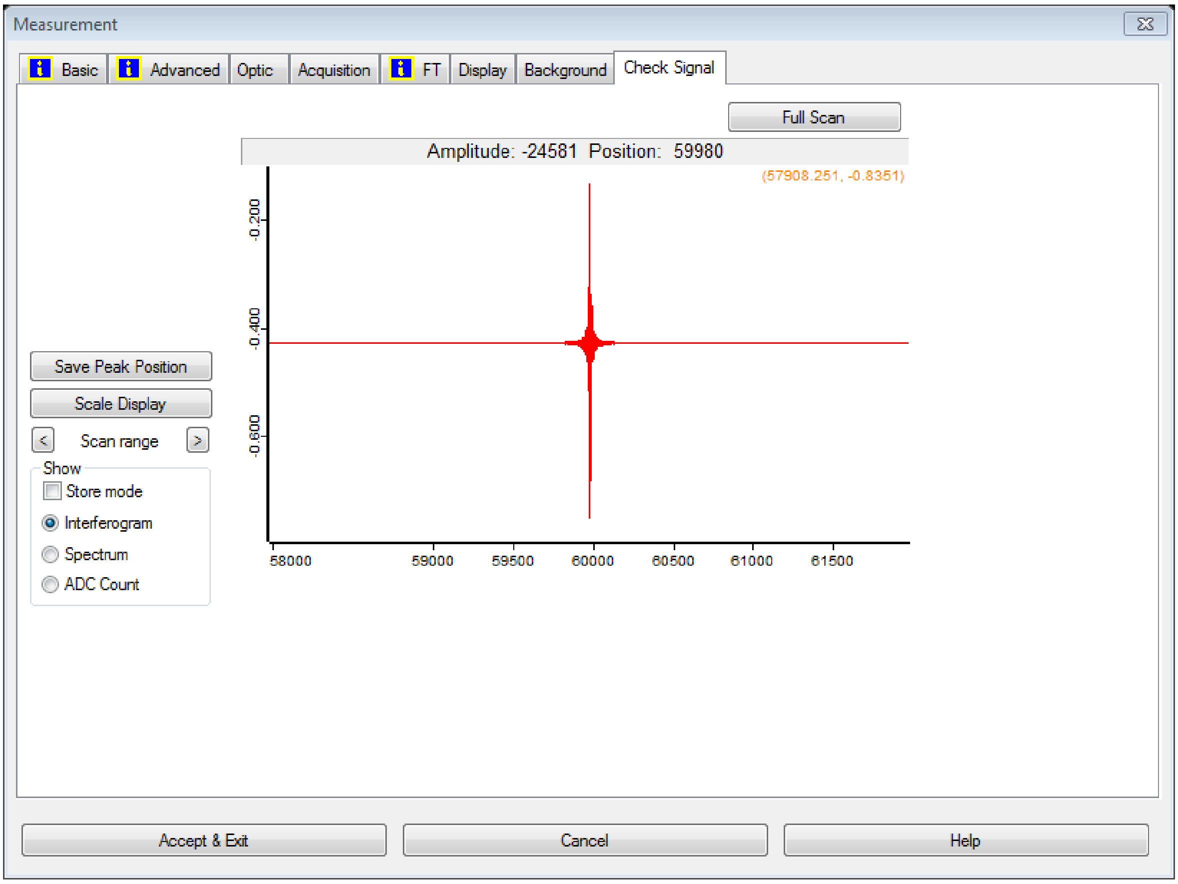

Figure 33: In the „Check Signal“ tab, an interferogram is shown which is recorded repeatedly. In the EM27/SUN, the value is inverted, so that high intensities on the detector result in a lower value (note the minus sign at the Y axis). The amplitude should not exceed 32000, as this is the maximum range of the ADC. Therefore the pre-amplifier gain on the Optic tab should be set such that the signal is as high as possible, but does not exceed the 32000 value.

Note: All the settings that can be selected in the shown tab are activated by starting a measurement or clicking on the “Check Signal” tab. Changing a value and clicking on “Accept & Exit” does not lead to an immediate change of the spectrometer’s setting.

6.3 Time of spectra

For solar measurements it is very important, that the time which is saved together with the spectral data is correct. The time which is used is taken from the spectrometer internal time reference, which is set when OPUS connects to the spectrometer.

The time which is saved is the start of the measurement, e.g. 13:34:09.727 (GMT+2).

6.4 Repeated measurements

One way to perform a series of measurements is by using the OPUS-function "Repeated measurements".

Another way is using a user defined OPUS-macro, which consists of a loop which repeatedly performs a measurement. This method gives more flexibility.

As an example, the following code performs measurements with 2 alternating measurement parameters (e.g. resolution). In addition, every hour a reconnect of OPUS to the Spectrometer is performed, which causes the time of the spectrometer to be synchronized with the time of the controlling PC:

```
VARIABLES SECTION

FILE <$ResultFile 1> = ScSm;
FILE <$ResultFile 2> = ScSm;
NUMERIC <LoopCount> = 0;
NUMERIC <year> = 0;
NUMERIC <month> = 0;
NUMERIC <day> = 0;
NUMERIC <hour> = 0;
NUMERIC <minute> = 0;
NUMERIC <second> = 0;
NUMERIC <hourAtLastTimeSync> = 0;

PROGRAM SECTION

UserDialog (0, STANDARD, EDIT:'<LoopCount>', BLANK, BLANK, BLANK,
BLANK, BLANK, BLANK, BLANK, BLANK, BLANK, BLANK, BLANK, BLANK,
BLANK);
GetTime (<year>, <month>, <day>, <hour>, <minute>, <second>);
<hourAtLastTimeSync>=<hour>;
StartLoop (<LoopCount>, 0);
```

```
  <$ResultFile 1> = MeasureSample (0, {EXP='RT-InGaAs_Res05.xpm',
  XPP='C:\OPUS_7.0.122\XPM'});
  <$ResultFile 2> = MeasureSample (0, {EXP='RT-InGaAs_Res1.xpm',
  XPP='C:\OPUS_7.0.122\XPM'});
  GetTime (<year>, <month>, <day>, <hour>, <minute>, <second>);
  If (<hourAtLastTimeSync>, .LT., <hour>);
    SendCommand (0, {UNI='RECONNECT'});
    Message ('Doing RECONNECT to re-sync time...', ON_SCREEN, 25);
    <hourAtLastTimeSync>=<hour>;
  Endif ();
EndLoop (0);

PARAMETER SECTION
```

6.5 Advanced options

6.5.1 Auto-save options

In the “Tracker” and “Camera” pull down menus, it is possible to activate the periodically saving of several values. The interval in seconds can be set as well.

6.5.1.1 Auto save motor offsets from astro:

If this line is activated, the program saves the offsets between the astronomically calculated angles and the actual motor angle. These offsets are induced from the camera information to center the solar image on the field stop. This data is saved in the folder of the tracker program in the file “LEARN_Az_Elev.dat”. The content looks like the following:

```
Julian Date, Tracker Elevation, Tracker Azimuth, Elev Offset from Astro, Az
Offset from Astro, Ellipse distance/px
2456462.008958,114.130600,147.685600,1.030589,-0.634910,2.132468
2456462.009016,114.126000,147.728400,1.031390,-0.632211,1.192406
2456462.009074,114.120400,147.771400,1.031199,-0.629298,1.427157
2456462.009132,114.116600,147.814200,1.032817,-0.626573,1.207216
2456462.009190,114.112800,147.857400,1.034444,-0.623434,1.710452
2456462.009259,114.107000,147.900200,1.035167,-0.628683,3.564279
2456462.009317,114.103800,147.943800,1.037413,-0.625116,2.494514
```

The first column is the Julian Date (http://en.wikipedia.org/wiki/Julian_day, http://aa.usno.navy.mil/data/docs/JulianDate.php). The second and third are the motor angles as calculated from astronomically calculations, including the tracker orientation. The 4th and 5th are the offsets induced from the camera. The last column is the distance of the ellipses as retrieved from the image processing.

6.5.1.2 Auto Save Pictures

The camera images are saved (as jpg-files) in a folder called "Bilder", and a subfolder derived from the date in pre-defined intervals, with the date and time as the name of the file. In contrast, using the "Save" button on the top left of the camera image saves the image which currently is shown (e.g. including ellipses and circles).

6.5.1.3 Auto Save Ellipse Deviations

Activating this option results in saving the offsets of the ellipses as derived from the image processing in a file called "SunPosOffsets.dat". The content looks like the following:

```
Julian Date, BigX-SmallX/px, BigY-SmallY/px
2456461.940347, -2.567871, -1.350403
 2456461.940370, -1.072449, -0.170349
 2456461.940405, -0.976379, -1.309448
 2456461.940428, -1.584595, -2.155823
 2456461.940451, -0.810181, -2.086426
 2456461.940486, -0.578674, -1.164917
 2456461.940509, 0.616882, 0.077515
 2456461.940532, 0.365479, 0.409790
 2456461.940567, -0.387024, -0.902283
```

6.5.1.4 Sun Intensity

In the current version, the intensity of the sun is saved to a file called "SunPixIntensity.dat" in intervals of about 5 seconds. This solar intensity is calculated as the average intensity of the pixels between the small and the big ellipse (the irradiated area), divided by the exposure time for normalization. This value can be used as an approximate measure for checking the intensity of the sun and is also shown on the “Image Processing” tab as “Sun Intensity [px*ms]”. The content of the file looks like this:

```
Julian Date, Sun Pix Intensiy /(ms+px)
2456462.015382,     2.85
2456462.015440,     2.83
2456462.015509,     2.81
2456462.015567,     2.84
2456462.015625,     2.80
2456462.015683,     2.79
```

6.5.2 Mirror Image Correlation

One parameter set the program has to know depends on the orientation of the camera relative to the tracker. This is called “Mirror Image Correlation” (MIC) and stays constant; therefore it is pre-set by Bruker. To retrieve new parameters, in the pull down menu “Tracker”, a line named “Retrieve Mirror Image Correlation (MIC)” exists. When the solar image is visible, then this activates a routine which moves the solar image in a predefined way, from which the MIC-parameters are retrieved. Using the option “Save MIC” in the Tracker pull down menu, these values are saved to a file named “CamTrackerInternalSettings.txt”.

7 Miscellaneous

This manual was created to explain the steps necessary to operate the Bruker EM27/SUN spectrometer and the evaluation software Opus RS.

For questions about the program, technical details, bugs, … please contact Bruker Optics GmbH.