HOW TO OBSERVE WITH THEMIS-MTR in 2010

This document is a revision of the equivalent document for 2006. It contains instructions for observations done using the new Acquisition System with the iXon cameras and the new IO software. As in 2006 this document also includes instructions to handle the tiptilt and to have a catch on polarimetric sensibilities beyond 10^{-4}.

The reader of this document is supposed to have some experience at THEMIS, but otherwise any missing help can be asked to the operator. Furthermore, this document is the result of my own experience and is therefore biased toward my observing protocoles and uses (*qu'on se le disse!*).

In what follows there is a list of 20 points to perform a successful operation at THEMIS. In page 3 you will have some information on the *coulisses,* and in page 4 on the cospatiality problem. In page 5 we give some hints on the scanning techniques. In page 6 we talk about the T3 tiptilt system usage. Finally in pages 7 and 8 we go into some detailed instructions and hints to reach the 10^{-5} level in polarimetric sensitivity.

How to observe:

1. Make sure the iXon cameras are available to the IO and the "master": Go the "Cameras" tag and see if the available cameras are in the list, do "Update" if not. Select each camera and fill in the by-default acquisition times and gains. Also fill the wavelength assigned to that camera. Make sure to correct the data if you change wavelengths.
2. Create a new Scan target in the IO: In the "Target" tag, select "Scan" in the drop menu to the left and press "Create". If nothing happens, make sure you have the right "model".
3. Using the tracking ball place yourself over the region you want to observe. For example go the limb at the angular position you selected
4. Using the IO, place the slit at the correct position angle, for instance "tangential". Remember that because of the implementation of the slit motor controls a tangent slit at both limbs at the solar equator has the same end pointing upwards. Therefore when you approach the solar poles from one or the other side (east or west) you will end up with two slits turned 180 degrees one respect to the other. The changing point is at exactly 0 and 180 degrees of heliospheric position angle. A telescope placed at exactly 0 degrees of PA with a tangent slit may rotate 180 degrees without warning if a small perturbation in the solar position takes the telescope at say 359.9 degrees. To avoid this problem I place myself 1 or 2 degrees off the singular points.

5. After the slit has reached its correct angle, wait until the *coulisses* have stabilised and then use the tracking ball to improve the fine positioning of your observation. At this point you may want to use simultaneously the slit-jaw camera (on the upper shelf) and the MTR cameras in Quick-Look mode. Remember to do "Config Cam" before asking for a Quick Look if you changed the exposure times recently. The position of the slit may have been drawn over the slit jaw image, but errors in its

position are possible, that is the reason for the check with the MTR cameras.

6. Use the "Get" button in the "Center Position" box of the Target tag at the IO to freeze your choice. You are ready to turn on the tiptilt (T3) at this point although it is not yet needed.
7. Configure the iXon cameras if you did not before or if there has been changes in the observing conditions. This may require an iterative process of trial and error. See the appendix on this subject for further info.
8. Verify your scan parameters at the "target" tag of the IO: how many steps and how many modulation cycles per step. For limb observations there are 0 steps (remember that these are steps, implying movement!) and 100-500 modulation cycles.
9. Check your modulation cycle. Although always recommended, it is compulsory for a correct demodulation that if you are away from the wavelengths at which the retarders are quarter-waves (look at the instrumentation page at www.themis.iac.es) you request a full modulation: +Q-Q+U-U+V-V
10. If you are trying a scan, see below before continuing here...
11. Check the FITS header keywords: kind of object, NOAA number etc. Name the target you have just created with a mnemotechnic name. Once you are done, remember to press the green + button to add the recently created Scan target to the list of targets. If you change tag in the IO before pressing the green + button you will loose your target configuration!!
12. Stop the Quick-Look on the target screen if it was still running. A Quick-Look can only be stopped from the target it was launched. If you happened to delete such target, the only way to stop the Quick-Look will be to exit from the IO altogether.
13. Create a FlatField target, by selecting them in the drop menu and pressing "Create". The flat fielding is made as a random-varying elliptical movement at disk center. You can modify the parameters of the movement at the target definition, although this is usually unneeded. However it is very convenient that you choose a correct slit angle at this point for the flat. If you chose a tangent slit for your observation and forgot to indicate a slit for the flat field, the slit will try to place itself tangent to the limb at each moment during the flat field: you can imagine the result when it crosses disk-center. Pick therefore a slit-angle which is fixed and that it is not two different from what you picked for your observation. For example, if you where at the north limb with a tangent slit, you may want to pick a "solar equator" slit for your flat.
14. 20 flat field images are usually enough in my experience (if you had a modulation cycle of 6 that translates into 120 images!). Give an appropriate name to your Flat target, probably something that describes for what kind of Scans it can be used. Do not forget to add the newly created target to the list by pressing the green + button.
15. Create a dark current in a similar manner to the flat: 10 exposures is a correct number. Do not forget to add the newly created target to the list by pressing the green + button!!
16. Select the "Observation" tag. First of all you should create a Sequence of targets. Insert as many targets as you want to do in the same sequence tree. But my advise is that you pick a Scan, then a Flat Field, then a Dark Current (that is called a SQUV sequence). You can select "All" in the top drop menu and then you will find the list of all your targets (Scans, flats and darks confounded) in the bottom drop

menu. If you chose good mnemotechnic names for them you should have no trouble in finding the targets you need for your sequence.
Every time you pick a target from the drop menu you need to press the green + button to add it to the list on the left. On this list you should have selected the basis Sequence first so that the tree of targets is correctly build

17. You are ready to go and press the "Start Observation" button, but WAIT! Check that everything is working:
    - is the telescope at the correct place?
    - Is the slit already in its correct angle?
    - Are the *coulisses* stabilised?
    - Have you sent the "Config Cam" order from the appropriate target?
    - Ask the operator if everything is "Go" for him.
18. Check the time estimate made for your operation. Make sure you are not launching an operation into coffee time, lunch time or sunset!
19. Now "Start Observation" and cross fingers. The telescope will go into position and turn the slit first. If you did things in order it should do nothing since you placed both right before starting, did you? The T3 tiptilt will turn on now if you forgot about it. Two seconds later the acquisition will start. This is critical. From now on you can relax to the end of the observation.
20. In the "Observation" tag you will see, on top, the operation number (no need to change it) and the comment button. I strongly advise you to use it. You can place there comments on the present operation or on any previous one. Write about seeing, on why you did this particular observation, on the angle of the slit and the PA of the telescope (this info is deep into the FITS header and not easy to verify later on), if there are clouds or dust or if you saw something unusual during the scan. The comments, altogether with a summary of your scan go into the logbook webpage that you can print out at the end of the day. It is the most helpful tool for data reduction ever conceived so use it at full.

What is the matter with the *coulisses*?

The *coulisses* are a servomechanism that controls the position of the F1-spar. The F1 spar is a metal plate on which the grid mask has been punched, placed right before the polarimeter at F1. Since THEMIS is an altazimutal telescope the solar image turns during the day. The polarimeter should be aligned with the turning image, and therefore the F1 spar turns following the sun. But the polarimeter and the grid mask (or any other pre-slit) should be fixed respect to the spectrograph slit at the F2 focus. There is therefore an image derotator device which also turns (in the opposite sense) to keep the image fixed. For this to work the axes of rotation of the F1 spar and the derotator should be strictly parallel. In the real world they are not and the image of the sun appears to drift on the F2 focus (in fact it draws a cardioid curve).
To prevent this movement THEMIS has a servomechanism informally called the *coulisses*. In the F1 pre-slit there is a pinhole to the side of the grid mask. The solar light passing through the pinhole (and the polarimeter) is collected by a video camera. You can see the image on a monitor high above the operator table. It looks like two

bright eyes (sometimes a smiley is drawn on the screen for fun). The servo computes the position of the eyes every 10 seconds or so and corrects it by moving the F1 spar. This is controlled by the operator and you will see that in one of the screens close to him there is a big green/red button that turns on/off the *coulisses.*

Keep an eye over this mechanism at all times. It is one of the most critical subsystems at THEMIS and the reason for many scan aborts. After turning the slit and after turning on/off the T3 tiptilt, or before launching a scan, check that it has stabilized. Ask the operator!

If you are observing off limb you may find yourself in a situation in which the pinholes are out of the sun. If there is no light the servo does not work and often that translates into the *coulisses* drifting away quite fast. You have two options:

1. If you are not too far from the limb (less than 30 arc seconds) with a tangent slit, it may just happen that the pinhole is on the wrong side. Manually turn the slit 180 degrees and, if you are lucky, the pinhole will see light again and you are back in business. The manual position of the slit of course translates into the fact that if you move over the limb you should turn the slit yourself.
2. Turn off the *coulisses* before start observing. The F1 will drift but probably slow enough that you can still demodulate safely (there is a risk of crosstalks of course!). Good luck!

Cospatiality issues

One of the tradeoffs of a polarimeter placed at the F1 focus is that you enter the slit of the spectrograph with two solar images. If the splitting direction of your analyzer does not coincide strictly with the slit direction you will be sampling different pieces of the sun in one and the other beam. The result will be what we call "slit-induced crosstalk" or "cospatility problem".

If you are using the grid mask (*grille* in French) you are lucky. The split is made in the longitudinal direction and you just need to turn the polarimeter respect to the spectrograph slit to get a perfect alignment. You do so by introducing an offset to the derotator angle. The support astronomer will usually do this for you, but you may feel like testing yourself (with the help of the operator).

1. Pick one of your MTR cameras in Quick Look mode
2. Using the IO displace the pre-slit in the Z direction (ask the operator for instructions and remember the original position!), until the edge of the mask shadows the spectrograph slit. You will quickly notice it in the MTR camera which will only show scattered light (measure it by the same time). Go back and forth until you are sure you are right at the edge. If there is some cospatility problem, the mask bands will not be illuminated identically (the top will be brighter than the bottom one for example).
3. Using the tracking ball introduce an offset to the derotator trying to illuminate as identically as possible all the mask bands. Correct the position of the F1 pre-slit if by turning you have displaced from the edge and iterate until happiness or desperation is reached.

Usually you only need to do this once per campaign.

Scanning the sun.

If you intend to do a scan a few tips may help you do what you intend to do and understand what THEMIS is doing.
Start by placing the number of steps in the IO target window. Remember that 1 step means 2 raster positions and that the place at which you point at the beginning is the **center** of the scan. You may want to check the limits of your scan before launching the observation. There are tools to do this in the IO target window: ask for assistance.
In which sense is the scan going to proceed? This is a difficult question to answer because of the multiple coordinate modes at THEMIS. The best thing to do is to try it and, if it goes in the wrong sense then use a negative step.
In which direction? X always means across the slit. So start by placing your slit angle and then you will know in which direction it is going to go.
What coordinate system should I use? Most often the coordinate system will be automatically chosen for you as a function of your slit orientation. So if you are positive about the orientation of the slit, you do not need to worry about the reference system. This is mostly so if you choose to scan in arcseconds over the solar disc and then the Equatorial (referred to the earth's north direction) or Heliocentric (referred to the sun's north direction) systems will be used as a function of your slit angle.

If you choose to scan over the solar spherical surface in degrees of local longitude and latitude you need to select the Heliographic reference system. Coordinate systems in latitude and longitude are easier to remember and do not change with solar rotation (if you choose so). Watch out: the step is given there in degrees!! 180 steps of 1 degree each go all the way over the disk. Also 1 degree at disk center is bigger than 1 degree at the limb if you understand what I mean. And obviously you will never reach the solar limb nor the regions off limb.

If you are using the grid mask you may be tempted also to perform a scan along the slit to *fill he holes*. This is done by introducing a scan in the Y direction. It mostly works like the usual one in the X direction but:

- You will need to choose between X-first and Y-first: should the telescope complete a scan in X before making a step in Y? Think about timing issues and coherence of the final scan. But also think on the consequences respect to the tiptilt (see below).
- How big should the steps be? Your mask band is 15.5 arcsec long and the separation between bands is of 17 arcsec. In order to correctly fill the hole with enough intersection for an acceptable reconstruction of the map I recommend 3 steps of 8 arcsec each. Time issues may advise you otherwise.

The T3 tiptilt at work.

The T3 subsystem should be mostly transparent to you. Often the only apparent effect of the working T3 is an slit jaw image with a fixed sun and a vibrating mask grid.

There are some interactions with other subsystems that you should nevertheless remember:

- Since the T3 sends orders to the *coulisse* subsystem, remember to turn on the T3 only when you have turned the slit into its correct and final angle and after the *coulisse* system itself has stabilized.
- Using the T3 systems when the seeing is bad will only drive you to a mask getting out of your MTR cameras. The data will not be reduced without the mask edges so you will just have screwed up your observation. If for some unknown reason you observe with bad seeing do not turn on the T3. Your data will be useless either way but at least you will not blame the T3 system but your own stupidity.
- The previous point does not apply to limb observations. The T3 will catch on the limb as long as you can see the sun yourself. It is the only observation that can make some sense with bad seeing.
- If you are scanning remember that the T3 will take care of your scan in X (for step sizes of the order of the arcsec) but not in Y. Before a step in the Y direction T3 will stop, let the step take place and try to take over the new region. This means that you cannot expect field correlation in an Y-first scan like you woul do in an X-first scan.

Going to 10^{-5} in polarimetry at the limb (or elsewhere)

A few hints on top of what has already been said will help you in reaching the 10^{-5} level in your observations. You are asking for quite difficult observations so the smallest mistake will result in signals much bigger than the required precision. Don't be scared if you don't get results and do not know why, just delete them and start all over again.

- Follow the previous instructions double-checking every step
- You most probably do not need scanning so place a 0 in the X and Y boxes at the corresponding scan target .

- Now you will need to make some numbers about the number of photons you will need. To get the photon noise down to 10^{-5} yo need 10^{10} photons at least. If you use the provided codes just 30% of the photons are considered free of errors and therefore you will need of the order of 10^{11} photons. You will need now to go over your iXon camera and adjust the exposure time, the number of accumulations and the two amplifiers to make sure that 10^6 photons are detected per acquisition. See the iXon appendix for help.
- Next select the number of modulation cycles. 100 will easily take you to better than 10^{-4} . Put 300 exposures and you are approaching 10^{-5}. You can get to 10^{-5} and beyond by adding up the slit (a factor 10 in noise)
- Take extra time to place the telescope over the limb at the desired position. Iterate moving in and out of the limb so you can be sure of your distance to the sun.
- Check that the slit is at place and that the *coulisses* receive light and are stable. Verify that the T3 tiptilt is catching on the limb (ask the operator) and you are ready to go.
- Reduce data as soon as you can. For a first data reduction use the provided tools, either SQUV or the specific code for high sensitivity.
- By now you will have discovered fringes. These are not actual fringes, but a combination of spectral fringes, channels and only in polarized light (one author has called them *chinpols* because of that). Their amplitude is extremely small but what you are measuring is ridiculously small so they bother you. We do not provide you with any defringing algorithm. Defringing is an extremely dangerous business in which you end up introducing some information on the data. Since we do not concur with the concept "*the support astronomer said it was right and I believed him*" we do no defringing. Under some circumstances we can nevertheless provide you with trial codes that you may use at your own risk.
- With or without fringes you have now reached the 10^{-5} level. Are all those signals true? I cannot tell you. You need to do a very carfeul analysis of hidden sources of errors before accepting the data:
    - do telluric lines show signal? Yes, you are screwed
    - do all lines show an antisymmetric signal? Yes, you are screwed
    - do all lines look like the intensity profile? Yes, you are most probably screwed
    - do Q looks like -U everywhere? A high chance you screwed up.
    - do you see signal amplitudes above 10^{-3} in lines that you are not aware of? You are most probably screwed
- A number of mistakes spring from the data reduction process. For example, antisymmetric signals in all the lines reveal errors in the deslanting process (ask the code author for help or do it yourself). Another usual mistake is to forget telling the demodulation algorithms the true wavelength you are observing (quite often the case if you changed lines recently).
- "*The signals in my lines are correct and I do see a polarized continuum, should I believe it?*" I have not the slightest idea. THEMIS measurement technique can only guarantee relative polarizations, but not absolute polarizations. In consequence the continuum should be put to zero. But in many cases it comes up non-zero and the value appears to be quite correct. If there is a big variation of the continuum polarization in your spectral domain (like between the Na D1 and D2 lines) I

would believe the result. In other cases I am just tempted to say that the non-zero value of the continuum is a measure of the residual instrumental polarization at THEMIS

- "*Can we trust these signals without a telescope calibration?*" No, you shouldn't. But there is no telescope calibration at this level and therefore you should trust yourself and our experience. Other than the continuum polarization level we have never seen any unexpected signal at the level of $2\ .10^{-5}$ what makes us say that we have no instrumental polarization at that level, at least in the tested spectral ranges.

Finding your way with the iXon cameras

The iXon cameras were tested during the second half of the 2006 campaign. Six of them are now available as the standard detectors of the MTR mode and have substituted the old THEMIS cameras. Documentation on the characteristics of each camera is available at the web documentation server and also at the Control Room of the telescope.

The 3 newest cameras (iXon 4 through 6) have received a more sophisticated optical coating that allows them to observe in the near-IR in better conditions than the iXon 1 through 3. Remember that before you place the wrong wavelength on the wrong detector.

The cameras are 512x512 pixels in size. Each pixel is 16µm squared. They have been depleted for use in back-illumination so their potential well is around 155000 electrons (the actual number varies with the cameras and you should write down that value for each one of the cameras you observed with.

Each camera has a pre-amplifier with 3 possible values (1, 2.5 and 4.7, actual figures varying with the camera) acting on the signal before digitalization. This means that the actual number of electrons per ADU changes with the value of pre-amplification. The pre-amplification value is recorded in a FITS keyword so that one can always recompute how many electrons per ADU were used for a given data set if you were careful enough to keep a record for the potential well of every used camera.

Usually the relationship between electrons and photons is given by the quantum efficiency of the camera at your present wavelength (I skip here the Poissonian distribution that applies to the interaction of the photon with matter). With the iXon cameras you can make use of an electron-multiplying device that can multiply the number of electrons per photon up to 1000. This is the so-called EM-gain.
In normal conditions you should not use the EM-gain, since it will quickly saturate the converter and contribute to the accelerated ageing of the camera. The use of the EM-gain should be reserved to the cases where the photon noise is too close to the readout noise. The EM-gain will amplify the number of photo-electrons before readout and therefore will effectively reduce the apparent readout noise. Notice that the effect is not free of problems: a noise factor of up to 1.40 will be applied to your photon noise, and you should therefore consider the situation before selecting an EM-gain.

In what follows there is a 6-step procedure to find an appropriate set of parameters to configure your iXon camera for a given observation. These are just guidelines that you are free to follow or not at your own risk.

1. Place yourself at maximum foreseeable photon flux for your spectral domain
2. Set the Pre-Gain to High on the IO and the EM-Gain to 1. Set the exposure to Single Image (not accumulate). Send the “Config Cam” order from any target of the IO and then a Quick Look
3. Try to see if there is a exposure time below 1 second that appropriately fills the potential well of the pixel. To make the numbers self-explaining I am going to use the iXon#5 as example. Its potential well is of 151062 electrons, and with a high setting for the pre-amplifier (5.0x foe the iXon#5) we find 12.21 e/ADU. This translates into the camera saturating at 12372 ADU.
4. To reach 10^{-3} you need about 10^{6} electrons or roughly 6 acquisitions at full-well. Once you have set you appropriate exposure-time, you may want to put therefore 6 accumulations over the default settings of the camera (use the IO for this).
5. The new saturation level will therefore be $12372 \times 6 = 74232$ ADU. Set this value on the “Color Map” of the iXon#5 display for future reference (I usually pick a 1% non-linear buffeting for safety from this value) and you are ready to go.

My photon noise level is around 60 electrons. Why do I need to set the pre-amplifier to High if it would be enough to set it to Low and let 1 ADU be roughly equal to photon noise?

Your photon noise should be the dominant statistical noise. The numerization of the measured electrons of each pixel is a measurement and has an associated noise often forgot. At best you can think of this noise as a gaussian noise over the number of ADU's measured (probably the situation is much worst). You want this noise to be small compared to photon noise, and therefore you want the number of electrons per ADU to be as small as possible. Set the pre-amplifier to HIGH as long as possible.

Is any use to the Low settings of the pre-amplifier?

The digitizer is used at 14 bits, enough to handle the potential well of the camera at the highest amplification available with the fastest readout available. It would seem that there is no use, after the previous response, to the lower settings of the pre-amplifier. Its use comes with the setting of an EM-gain. If the number of electrons N_e times the EM-gain times the pre-amplifier gain, divided by the number of electrons per ADU is bigger than 2^{14}, you will saturate the digitizer, even if the pixel is not saturated. You may have in this case to pick a lower pre-amplifier setting.

To give an example of this with the iXon#5, let us take N_e = 4000 electrons, with the pre-amplifier set to high (5.0x) and the EM-gain set to 10:

N_e x5 x10 / 12.21= 16380 ADU which is bigger than 2^{14}, and you have just saturated the digitizer with just 4000 electrons.

When should I use the EM-gain?

The EM-gain does NOT increase your signal-to-noise ratio. It actually worsens it by an undetermined noise factor which lays between 1.2 and √2.

It comes to use when the number of electrons detected during your acquisition is smaller than the readout noise. The EM-gain can then be used to reduce the readout-noise under the photon noise, by amplifying the number of electrons before read-out.

One should use it if the spectral region or the object observed provide us with very low fluxes and exposure times bigger than 1 or 2 seconds.

Why not use a very short exposure time with the EM-gain?

This may be an acceptable setup if one is seeking high spatial resolution, but does not care much about S/N ratio. The reason is that there is an unavoidable 35 ms lag for reading the CCD. During those 35 ms there is no photon detection and the duty cycle, the final efficiency drops. A 30msec exposure implies a duty cycle of 30/(30+35) = 46%. Furthermore if a modulation cycle is in effect one should add 250 msec per polarimeter position. A setup with 5 accumulations and a cycle of 6 with exposure time of 30 msec will yield a duty cycle of (30x5x6)/[((30+35)x5)+250)x6]=26%.

Increasing the exposure time to 60 msec yields, on the other hand 52%. Obviously, the higher the duty cycle the better S/N attained in the same time.