

DiPol-UF Observer's manual

Basics

DiPol-UF is a high-precision three-bands polarimeter produced in collaboration between Tuorla Observatory (University of Turku, Finland) and Kiepenheuer Institute for Solar Physics (Germany). DiPol-UF consists of several parts:

- three nearly identical ANDOR iXon Ultra 897 EM CCD cameras, one per each of B, V, and R registration channels,
- three industrial grade computers, each controlling its own CCD camera; one of them works as a “master” or “main” PC. It is also used for remote control of the observation process,
- the polarimeter unit, which contains all necessary optical and mechanical elements, including retractable beam-splitter and rotatable retarder (half or quarter wave plate); both elements are moved by Trinamic stepper motors,
- the Mikrotik router that supports the intercommunication between DiPol-UF computers during observations,
- the remotely controlled **Power Distribution Unit (PDU)**, which can power on/off individual elements of the polarimeter. There are eight separate power units which are plugged into power following sockets:
 - CCD cameras (BVR) plugged to sockets #1, #2, #3
 - Main (master) PC plugged to socket #4
 - Secondary (slave) PCs – to sockets #5 and #6
 - Plate stepper motor – to socket #7
 - Retractor stepper motor – to socket #8

DiPol-UF can be operated either *remotely* (assuming that someone is operating telescope locally and remote observer has a communication channel with that person) or from the NOT control room. In both cases, observer is required to connect to the DiPol-UF's internal network using a VPN client. We support several protocols, including PPTP, OpenVPN, and optionally L2TP. DiPol-UF components can and should be controlled only from its internal network. This ensures all communications are secured and only DiPol-UF router is exposed to the outside world.

There is a spare (bigger) mini-PC which can be used at the NOT control room. We have also provided a mouse, keyboard, and display. This mini-PC must be switched on and connected to the network to be used for DiPol-UF control during observations at the NOT. **For support astronomer on cite:** Instruction on how to set up and use “**Florence**” computer for connection and polarimeter control is provided at the internal NOT webpage, see: <http://www.not.iac.es/intranot/dipol/remote-support.html>.

DiPol-UF observation routine

When observing *remotely* (note: this option is only possible when support astronomer is operating the telescope!)

Establish VPN connection to the instrument. Personalized credentials are provided for each remote observer, please **do not share** them with others. Detailed instruction on how to set up VPN is given on page 5.

- 1.1. Turn on power for computers and cameras. PDU login/password is provided in the credentials list and in the Power Manual. See the document “apc-power”, which is provided separately for details.

- 1.2. Connect to the main computer using VNC. Multiple simultaneous connections are possible, and several users can connect and operate polarimeter at the same time.

VNC credentials and main PC Windows credentials are provided in the credentials list as well. Normally you don't need to be connected to the slave PCs which are used for the control of the V and R – bands cameras. However, if necessary, they can be also accessed via the VNC. It is strongly recommended do not operate slave PCs when DiPol-UF control software is running. The folders with the images acquired with the V and R-band cameras can be accessed via shortcuts on the main control PC desktop (see also section 5, "Observations with DiPol-UF").

When observing at the NOT control room as a visitor:

- 1.1 Prepare DiPol-UF control mini-PC for work (if not ready). This small-sized computer is located on the table in the rightmost corner. You can recognize it by display that is covered by protective cover with "DiPol-UF" handwriting on it. Plug mini-PC and display power cables to the available power outlets. Plug keyboard and mouse to the corresponding USB2 sockets on the mini-PC front panel (if they are disconnected). PC must be powered automatically after plugging the power cable. If not, press power button on the mini-PC front panel once. Press power button on the display lower right corner to power it on.
 - 1.2 Log on as "Dipol-uf polarimeter" user with the password "1st.dipol-uf.polarimeter#Tuorla". Please, check the keyboard layout first!
 - 1.3 Check current Windows status. When computer was not in use for the long periods of time, installation of Windows updates may be required. It is strongly advisable to install all necessary updates in daytime before observations.
 - 1.4 Establish the VPN connection. You can do it by clicking on "action center" icon which is the rightmost on the Windows taskbar. Select "VPN" tile and then choose "Dipol-UF" option. Click "connect" and the required connection will be established.
 - 1.5 Start Firefox browser and connect to the **PDU** (browser has a bookmark for this connection).
 - 1.6 After powering on polarimeter (see "apc-power" document), double-click "VNC Viewer" icon on the Windows desktop and connect to "Dipol-4" computer by double-clicking on its icon.
 - 1.7 Log on as dipol-uf-01@outlook.com user. Password is the same as for the mini-PC in the control room.
2. Launch 'DiPol-UF' application from the desktop.
 - 2.1. Make sure all systems are responding, including other computers, all three cameras, and both stepper motors.
 - 2.2. Connect all cameras and prepare them for observations.
 - 2.3. For each camera, set desired detector temperature and start cooling. **Do not forget to turn on fans! It is not recommended to keep cameras powered with cooling switched off, as they may become overheated.** If this happens, the camera temperature doesn't change, and remains high after switching on cooling. In such case, switch off cooling and fans, switch off camera powers and power them on again. If you want to change cooling temperature, first switch cooling off, set up new value and switch cooling on again.
 - 2.4. Wait until all cameras are cooled down and temperatures have stabilized (and are not drifting).
 3. Start observations with DiPol-UF (See also "Working with 'DiPol-UF' application" section)
 - 3.1. Point telescope to the new target.
 - 3.2. Click on '**Job Settings**' and load template configuration file for your target, adjust settings if needed (e.g., change exposure time),

- 3.3. Start 'Video Mode' by clicking '**Start Video**' in *B* camera (or all three simultaneously) – video mode produces frames every *X* second, where *X* is the exposure time. This regime is recommended for telescope pointing and focusing.
 - 3.4. Adjust telescope position until both rays of the target are positioned reasonably close to the image center in all three image fields. Beware that the field view is smaller and image scale larger in the V and R – bands (by approximately 30%).
 - 3.5. Click '**Stop Video**'
 - 3.6. Ensure the configuration for this target is correct. Click on '**Job Settings**' and check parameters. Pay attention to 'Exposure Time' and 'Amplifier'. If all settings are correct, click '**Cancel**', otherwise click '**Modify**', adjust the settings, then click '**Submit**'.
 - 3.7. Once settings for the new target are saved and submitted, take one exposure in one or all cameras to ensure that the guiding is OK.
 - 3.8. Start cycle. Choose the number of cycles to observe for (bear in mind the exposure time set for the target). At the end of each cycle, you can take calibration images. In general, calibrations are taken only once per target (if the settings do not change). The displayed message will inform you if calibrations for this target have been already taken.
 - 3.9. Make an entry in the observation log while the cycle is running. You can find it on the desktop of the main PC.
 - 3.10. After the cycle is finished – either start new cycle to get more measurements (go to **3.8**) or change the target (go to **3.1**).
 - 3.10.1. If the observations have been interrupted, **you must first delete corrupted images on all computers**. This can be done by accessing each computer's folders on the desktop, navigating to the current night folder (folders are named as YYYYMMDD, that is year, month, date), then to the current target subfolder (has the target name), and then removing corrupted files. The last saved image name can be seen at the top of each camera's tab. After data cleanup has been finished, proceed to either **3.1** or **3.8**
4. Finish observations
 - 4.1. When the program is complete, make sure that no camera is taking any exposures. Interrupt cycle if it is still running.
 - 4.2. Disable cooling for each camera. Wait while temperature climbs back to +5 or so. Switch off the fans.
 - 4.3. Close 'DiPol-UF' App
 - 4.4. Power off computers
 - 4.4.1. Open **POWER** folder, select **SHUTDOWN ALL**
 - 4.4.2. Observe the Windows shutdown procedure on the main PC.
 - 4.5. Wait for 1 minute or so.
 - 4.6. Turn off power of all DiPol-UF components with the PDU.
 - 4.7. Disconnect your VPN connection. **If you forget to do this, all your traffic will be routed through the observatory no matter where you are. When using mini-PC in the control room: simply power it off.**

Establishing VPN connection (for remote user)

If this is your first time, please follow specific instructions on how to configure VPN client on your machine.

If you have done this before and you run Windows 10 OS – search VPN settings for DiPol-UF connection (using PPTP protocol). Otherwise, look for an OpenVPN application with the same configuration. When prompted – enter your **personal credentials**.

1) Power cycle

DiPol-UF equipment is kept powered off while it is not used. Only router and power distribution unit (PDU) are constantly powered. If your VPN connection is established, navigate to **192.168.88.101** in your browser and use PDU credentials to access its controls. Plug names give you hints of what components are connected to them. **Never power off computers if they are still running, issue a shutdown command from the main computer first!**

2) Establishing connection to the main computer

DiPol-UF is operated from its main computer – a Windows-based machine. It can be accessed using VNC (preferred way) and RDP (used rarely; backup solution). Launch VNC client of your choices (VNC Viewer is a good example) and connect to the computer located at **192.168.88.40** (address of the main computer in the DiPol's internal network). As usual, look for the appropriate credentials in the list provided to you.

3) Establishing connection to the slave computers (PC2 and PC3)

They are accessible at **192.168.88.20** and **192.168.88.30 addresses** (credentials are given to each remote observers). You don't need direct access to them during the observations, but such access may be necessary to update Windows before the observing run, restart them if the software hung, etc. Normally, there is no need to connect to the slave PCs neither for terminating polarimeter control software nor for shutting them down. Control software running on slave PCs is terminated automatically after its termination on the main PC. You can safely shutdown PC2 and PC3 via "POWER" button on the desktop of the main computer at any time when necessary (without being logged on them).

Working with 'DiPol-UF' application

On the desktop of the main PC, you will find several useful links. These links include data folders on each computer, to where DiPol-UF will store acquired images, scripts to reboot/shutdown computers, link to the Observations Log and the 'DiPol-UF' app link. **Make sure all cameras and stepper motors are powered on before launching 'DiPol-UF' app. If you have forgotten to do so, you will see the messages that they are not found. Quit the app, power on cameras and motors and start the 'DiPol-UF' app again.**

Launch 'DiPol-UF' by double-clicking it. Check the messages you are presented with – the app will report it has established connections to **2 out of 2** remote servers. Check buttons in the lower right corner – lower two should be green and show text '**Motor OK**' and '**Retractor OK**'. If one of these conditions is not met, exit the application, check power supply to DiPol-UF components and try again. If it does not help, refer to the Troubleshooting manual.

The main window of the App with DiPol-UF correctly connected is shown in Fig. 1. Click '**Connect**' button and wait for the cameras to be discovered. Make sure the app has found all **3 cameras** (Fig. 2). Refer to the Troubleshooting if this is not the case.

Select all cameras and click '**Connect**', or simply click '**Connect All**'. You will be returned to the main window. Rightmost panel will be updated with the status of each camera, such as its current temperature, cooling regime, and fan speed (Zone 2 in Fig. 3). The central panel contains information about each individual camera. Each camera has its own tab, which can be switched at any time (above Zone 1 in Fig. 3).

The next step is cooling down cameras. **Important: this should be done for each camera individually!** Using controls shown in Zone 3 of Fig. 3, set up target temperature (use either the input field or the slider). **Important: Never set the cooling temperature lower than -60°C!** EM CCDs can be cooled down to -120°C using liquid cooling system, which is not installed on DiPol-UF. Recommended temperatures are between -30°C and -50°C. Lower temperatures are better for faint targets observed in the electron-multiplication regime. Click on **'Start cooling'** to begin the cooling process. Use the right slider to switch on fan. It is recommended to use 'Full' speed. Proceed to the next phase when each camera has stabilized its temperature (Green **'Stabilized'** in Zone 2 of Fig. 3)

Note: Cameras can be heated up or cooled down between observational targets, but not during any acquisition process. If you feel like you need to cool cameras more for the next target, hit **'Stop cooling'**, adjust temperatures, and start cooling again.

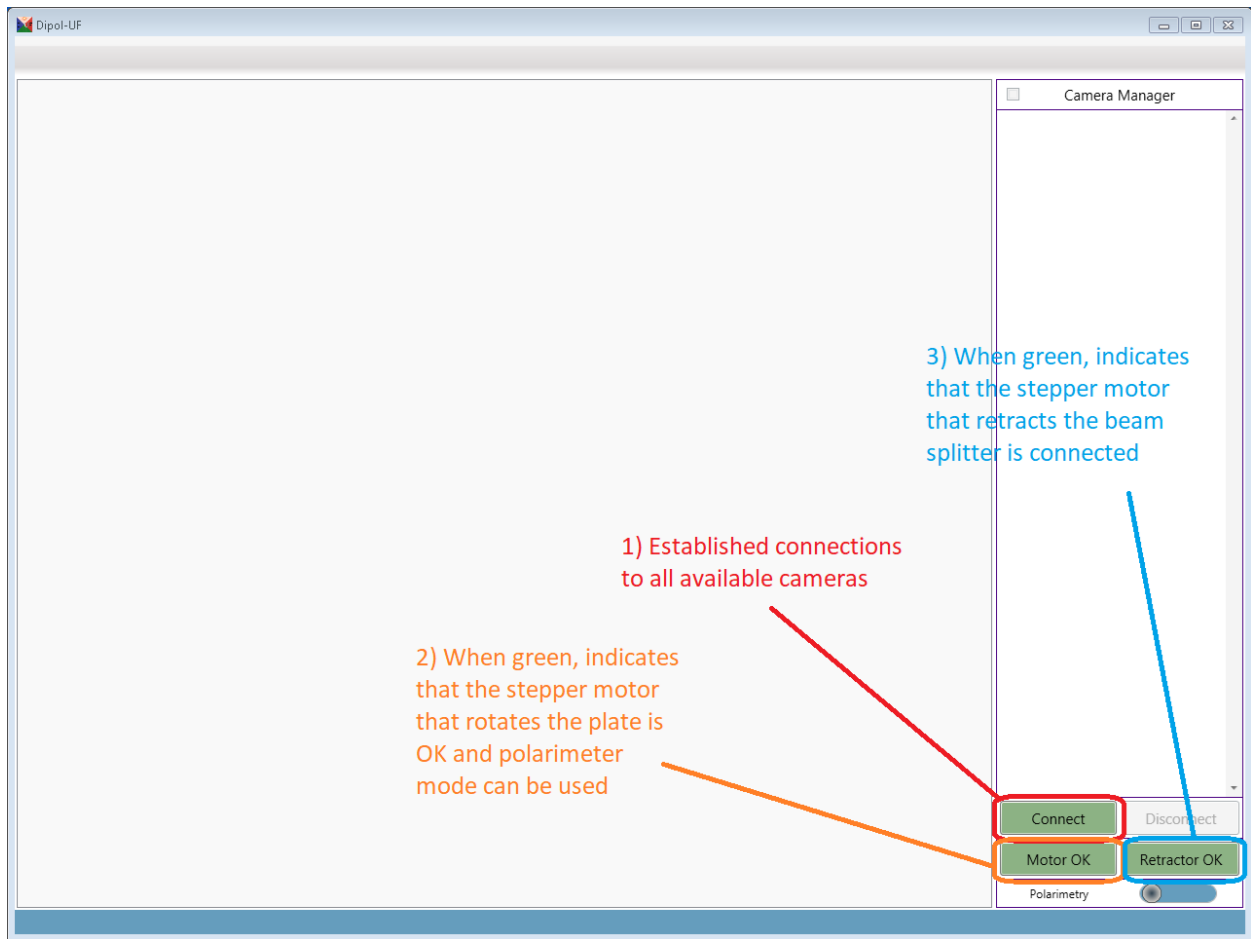


Figure 1

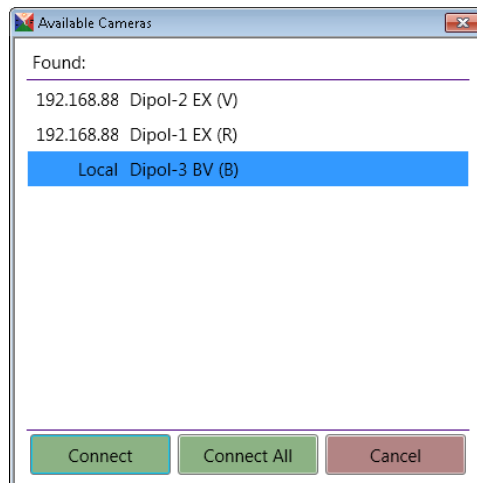


Figure 2

1. Polarimeter control

Important: Dipol-UF can observe either linear (with the HWP) or circular polarization (with the QWP). However, before switching polarimetry modes with the software, the proper waveplate must be installed / exchanged by staff member in daytime. Pay attention to the polarimetric mode that you select and do not change it during the night. You cannot damage the instrument by selecting an incorrect regime, but you will likely lose observing time. If you intend to observe linear polarization with the HWP installed and use circular polarization mode, you will not be able to use obtained data. All three Stokes parameters can be measured with the QWP in the linear polarization mode. However, the efficiency of the measurements will be reduced by factor of 1.4 for the circular polarization and by factor of 2 for the linear polarization components.

DiPol-UF operates using so-called 'jobs' - JSON-based (human- and machine-readable) configuration files that contain all necessary presets for a given targets. These files can be stored on disk between different observing runs, so the more you observe, the richer the library of jobs and the easier it is for the next observer to select an appropriate configuration. Zone 4 of Fig. 3 shows 'Acq. Settings' and 'Job Settings' buttons. 'Acq. Settings' allows you to fine-tune settings of the currently selected camera. This is rarely needed but can be used to e.g., assign different exposure times to different cameras (for e.g., bright red/blue targets, see Fig. 4, right).

To start observations of a new target, click 'Job Settings', then either 'Load' to reuse one of the existing configurations, or 'Modify' to modify settings by hand. Adjust camera settings to satisfy your observing conditions, brightness of your target and desired time resolution. Pay attention to 'Exposure Time' and 'Amplifier'. Give your target a meaningful name, add an optional description, and make sure you have selected 'Linear polarimetry' regime (or 'Circular polarimetry' if that is what you are observing). 'Submit' your new job. You will be prompted with a file save dialogue. **Please, save you**

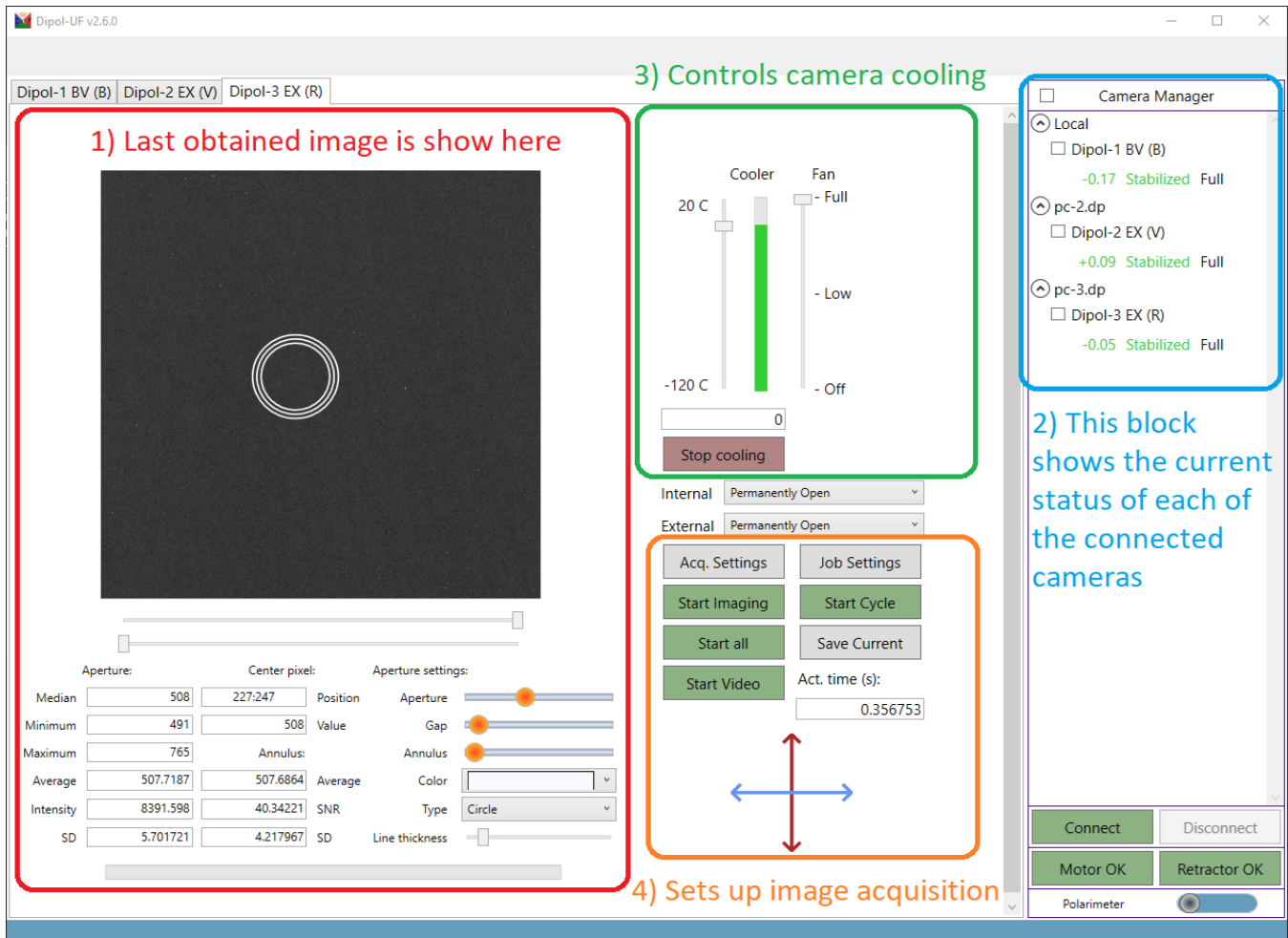


Figure 3

configuration to a new file if the target is new – it will make observations easier during next observational session. By loading and submitting job settings, the CCD parameters set for the job will be used automatically for the exposures taken with ‘Start Imaging’ and ‘Start All’ buttons.

Once the job is submitted, the acquisition time (exposure + image download) of each camera can be seen in Zone 4 of Fig. 3. The polarimetric regime, selected for the current target, is also displayed there. A blue-red cross denotes linear polarization, while a green circle marks circular polarization.

Andor CCDs have a specific regime called ‘Video mode’ – cameras essentially act as regular video cameras, displaying continuously images in the camera window. This regime is helpful for target acquisition & focusing. It can be enabled by clicking on ‘Start Video’ button. You can check the image size in pixels (FWHM) by positioning software aperture around the stellar image and clicking right mouse button once.

Once ‘Video mode’ is enabled, the image view (Fig. 3 Zone 1) will be constantly updated with the newly acquired frames, allowing you to adjust both focusing and telescope pointing. **Note:** for observations of bright targets, image defocusing is strongly recommended. This helps to avoid saturation, collect large number of ADUs and spend observing time efficiently. With defocusing, stars with m_V up to ~ 3.5 mag can be measured with the NOT. The calcite provides enough separation of the e and o-images for significant defocusing, but make sure that they are not touching each other and not overlaid. Use ‘Video Mode’ to test telescope guiding stability. When you have positioned both rays of you target in the center of each camera’s field, stop monitoring by clicking on ‘Stop Video’.

If you are satisfied with the star positioning / focus, proceed to observations. Take one test exposure in all filters with the ‘Start Imaging’ or ‘Start All’ buttons – to see how your target looks like. Note, that acquired images are not yet saved on disk, and if you wish to save an image, click “Save Current” button.

Start your polarimetric cycle when ready. Click ‘Start Cycle’ and input desired number of cycles. Each linear polarization cycle consists of 16 images taken at different half-wave plate position angles (incremented by 22.5°). If you observe circular polarization, one cycle consists of 4 images at quarter-wave plate position angles from 0° to 270° , incremented by 90° . **Important:** Every time you observe a new target, Dipol-UF will suggest making calibrations (bias & dark). If there are up to date calibrations, all subsequent cycles of the same target will produce no calibrations **unless** you modify camera settings using ‘Acq. Settings’ button (not recommended). Pay attention to the notifications displayed at the end of each cycle.

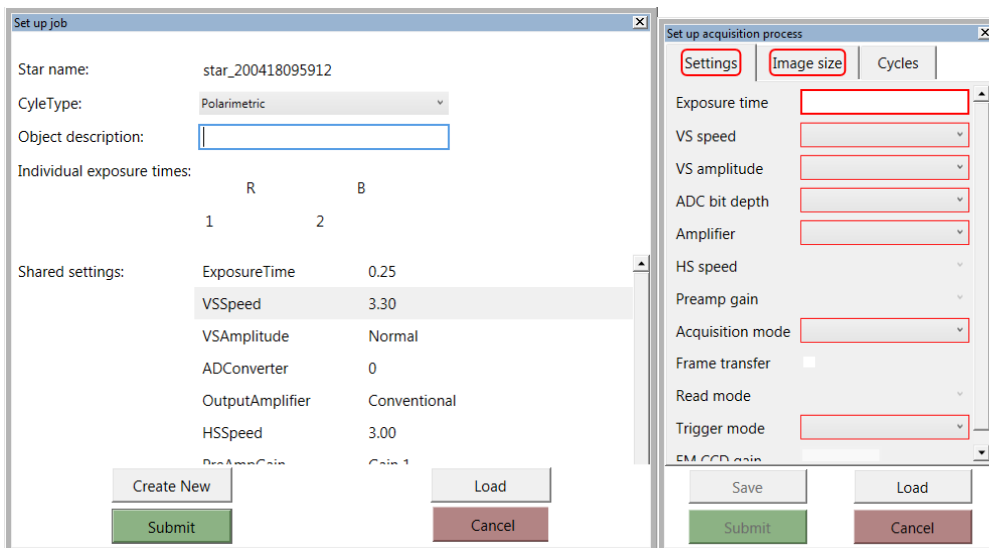


Figure 4

During polarimetric cycle, ‘DiPol-UF’ GUI switches to the observational regime (see Fig. 5). Zone 1 shows the number of images already acquired, the total number of images to be recorder, and the position angle of the half-/quarter-wave plate. Zone 2 allows you to interrupt the cycle if something goes wrong. **It should be avoided when possible.** Zone 3 shows progress bars – one for the current exposure, and one for the overall progress.

Important: If you interrupt the cycle, **you must clean up last images you obtained on ALL computers before continuing.**

There are three shortcuts on the desktop of the main PC, leading to the data folders for each camera. The software creates sub-folder where images are saved on each PC automatically, according to the date of the observations (in 'yyyymmdd' format). The scientific and calibration images acquired for each target are saved in the same folder and are post-fixed appropriately (e.g., '*_bias' for bias). All file names start with the name of the star specified in the Job file. The last image written by each camera is displayed in the main window above the last acquired image (at the top of Zone 1 of Fig. 3). Linear polarization images are processed in series of four, so **the index of the last image should be divisible by 4.** For example, if you have taken 131 exposures, then you need to delete 129, 130, and 131, as they are part of an incomplete polarimetric measurement cycle and they will complicate the procedure of follow up data reduction, if left in the folders. Circular polarization images are processed in series of two and you may need to delete only the last exposure if its number is odd. **Do not continue observations before cleaning up the redundant/corrupted images.**

During observational cycle

Do not forget to keep the record of your observations. Use a table called 'Observation Log' (or create one on the desktop if it is missing; use OpenOffice for that) found on the desktop of the main PC. Write down as much information as possible, including poor weather conditions, interruptions, and other issues.

It is possible to inspect the last acquired image using an 'Aperture tool'. You can change image brightness and contrast by moving two horizontal sliders found under the displayed image. You can explore the stellar image properties such as maximum and minimum pixel value, average value, S/N, etc. by setting parameters of the circular aperture (aperture radius, gap width and sky annulus thickness) and moving the aperture over the stellar image. Double-clicking on the aperture will pin it to the place, and image statistics will be updated as soon as new frame arrives. Double-clicking again releases aperture, so it starts to follow mouse pointer again. Single right click gives the image size in pixels (useful for finding and checking telescope focus best value).

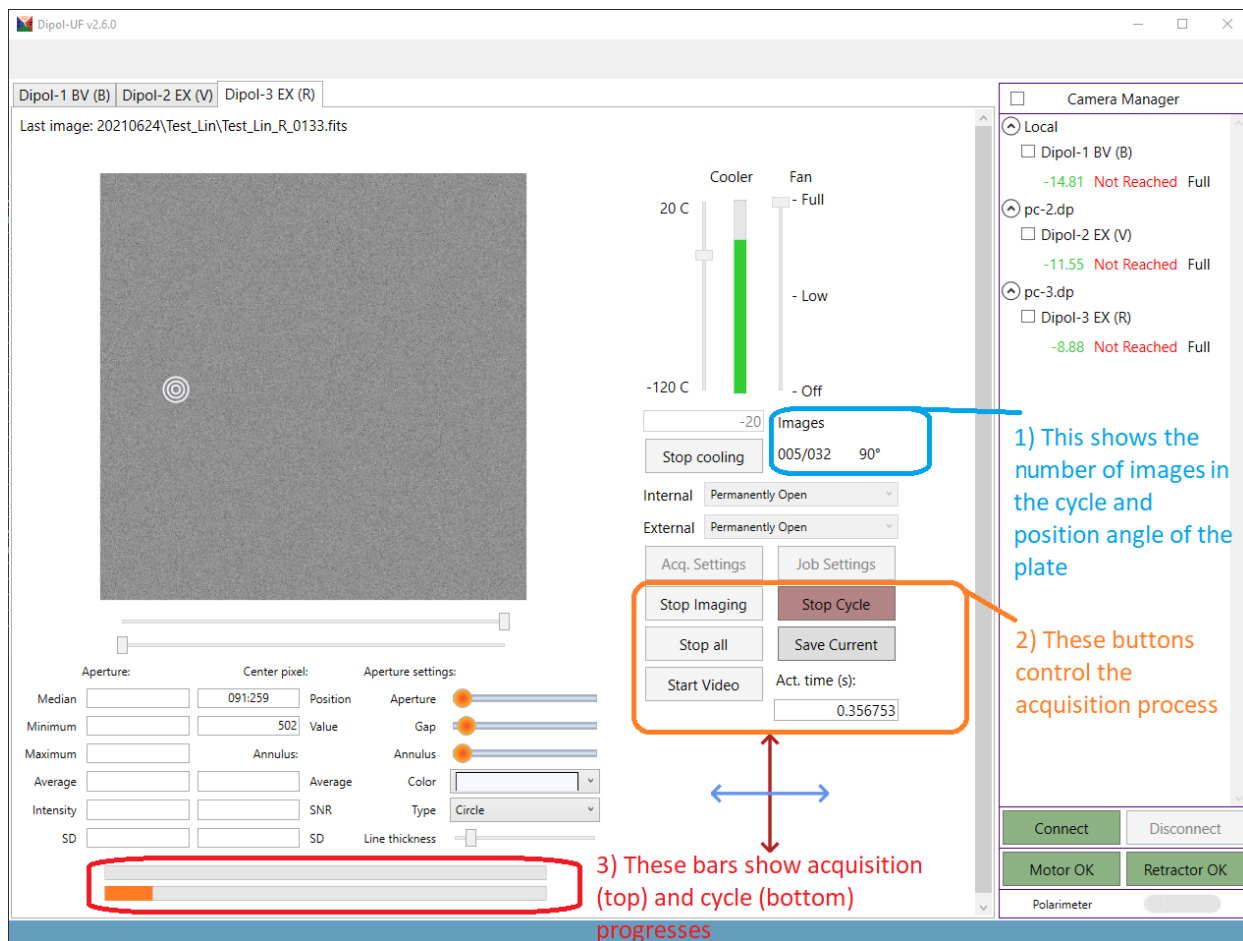


Figure 5

2. Photometry mode

DiPol-UF can be used as a convenient three-channel photometer. For this purpose, the calcite is retracted by the retractor motor. This can be done by moving a slider on the lower right corner from 'polarimetry' to 'photometry' mode. Switching to photometry mode during first-time target acquisition may be useful for polarimetry too, because when the calcite is retracted, the stellar images are not doubled. After identification of the target, switch polarimeter back to the 'polarimetry' mode for final centering and focusing. Moving calcite in one way takes approximately 15 seconds. Note, that when you start observing cycle, the software selects the observing mode according to the value set in the Job file. However, if you changed settings via '**Acq. Settings**' menu, they will override the values configured via 'Job Settings'. The best way is to proceed in the following order: 1) load or create a Job file; 2) test exposure time, adjust other settings; 3) use video mode to point and focus; 4) edit Job file, if necessary, making sure job settings are adequate; and 5) start the observing cycle. If you want to do both photometry and polarimetry for the same target, it is recommended to create two separate Job files for the same object and name them accordingly, e. g. 'star_name_polarimetry' and 'star_name_photometry'. Note that telescope focus values for polarimetry mode (calcite in) and photometry mode (calcite out) are different.

Important note: DiPol-UF photometric B', V' and R' passbands *are not identical* to those of the Johnson - Cousins system but are defined by the dichroic beam-splitters and additional sharp cut-off filters with high peak transmission. See details and transmission curves in Berdyugin et al., 2022, A&A, 657, 105.

Make sure that the type of the job matches instrument regime. If the job is 'Linear/Circular Polarimetry', instrument should be set in 'Polarimetry' regime. Same applies for the photometric regime.

3. Finishing observations

Once your program is finished, prepare DiPol-UF for shutting down. Make sure all observations have been finished and no cycles/video mode monitoring are running (if necessary, abort acquisition). Stop cooling of each camera (see Zone 3 of Fig. 3). Monitor temperatures (Zone 2 of Fig. 3), wait until cameras heat up to +5°C or so. After that – just hit the red cross at the top of the GUI window to close the program. **Make sure your Observational Log is filled in and saved.**

Navigate to the '**POWER**' folder located on the desktop. Find '**SHUTDOWN ALL**' script inside. Double-click on it. Your VNC connection will be terminated within a minute or so (you can close it earlier if you have seen the Windows shutting down process is in process). **Wait for 1 minute or so to give computers time to properly shut down.**

When you are sure that computers are off, go to the PDU control page (consult Section 2 of the present manual) and switch all plugs to 'Off' position. **Make sure they are indeed switched off, update the page once or twice to check plug statuses.**

Finally, disconnect your VPN connection (otherwise you will put unnecessary stress onto the NOT network system).

If you used DiPol-UF mini-PC in the control room, power it off. Do not forget to re-establish VPN connection before starting the observations with it on the next night.

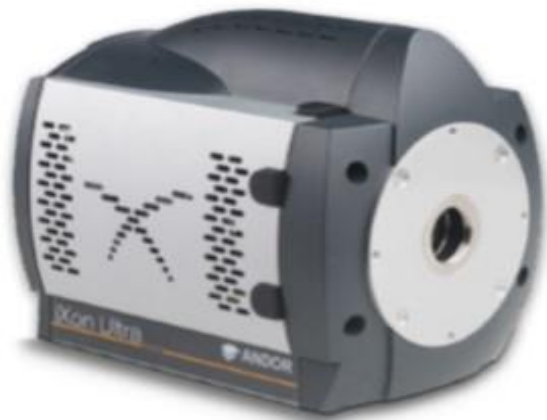
That's it, your observing run with DiPol-UF has been finished.

The DiPol-UF team

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Key Specifications

Active pixels (H x V)	512 x 512
Pixel size (W x H; μm)	16 x 16
Image area (mm)	8.2 x 8.2
Active Area Pixel Well Depth (e ⁻)	180,000
Max Readout Rate (MHz)	17
Frame rates (fps)	56 (full frame) - 11,074
Read noise (e ⁻)	<1 with EM gain
QE Max	>95%