UPGRADED GRIS MANUAL

Collados, Quintero & Trelles

April 2025

1. INTRODUCTION

The GREGOR Infrared Spectrograph (GRIS, Collados et al. 2012) installed on the GREGOR (Schmidt et al. 2012) solar telescope was first upgraded in 2018, adding to the standard long-slit mode an Integral Field Unit (IFU). See Dominguez-Tagle et al. (2022) and references therein for more information. The IFU unit uses an image slicer to observe a 2D field of view (FOV) and the spectral range of interest strictly simultaneously; see the publications of Calcines et al. (2013, 2014) as a reference. This upgrade made GRIS the first IFU system based on image slicers offered to the community (since 2019) in solar physics.

The next upgrade of GRIS was presented in Quintero Noda et al. (2022), where two additional spectral channels have been added to allow observing multiple spectral regions of interest strictly simultaneously. The new optical design can be found in Quintero Noda et al. (2022) and Regalado Olivares et al. (2022). The baseline operations are to observe the spectral windows at 770, 854, and 1083 nm in each spectral channel, respectively. More information about the potential of those windows can be found in Quintero Noda et al. (2016, 2017a,b, 2022). Finally, a detailed description of the most recent updates the instrument has undertaken can be found in the recent proceedings of the 2024 SPIE astronomical telescopes meeting (see Regalado Olivares et al. 2024; Quintero Noda et al. 2024a) as well as a summary of the first light observations from the commissioning phase started in early 2024 can be found in Quintero Noda et al. (2024b).

2. GRIS OPERATIONS

In the following, we detail most of the elements that constitute GRIS. In particular, we highlight the new elements added in the latest upgrades. Also, at the end of the document, in Section 5, we include two short manuals (for slit and IFU modes) with the basic steps to operate the instrument.

2.1. *Configurations*

The upgraded GRIS is a spectrograph with three sensors. Two new sensors can operate in the visible range up to around 900 nm. The third (the original one) is an infrared sensor that operates from 1000-2300 nm. Hence, if an appropriate narrow-band filter is available, the instrument can tune any wavelength spectral region in that spectral range to perform spectroscopic measurements. In addition, the instrument has a Polarization Modulation Unit (PMU) based on Liquid Crystal Variable Retarders (LCVRs). Two pairs of LVCRs are optimized to work in wavelength regions centered at 1083 and 1565 nm, respectively. The first pair of LVCRs was recently modified to expand the wavelength range of operations from 770 to 1083 nm (Quintero Noda et al. 2024a).

The transition between spectroscopic and spectropolarimetric modes can be carried out carefully by the observer (with the help of the telescope assistant) in just a few minutes. It involves, among other things, manually moving the polarimeter and switching the control program to POLAR. For detailed instructions, see Appendix 4 in the full GRIS manual. If you plan to make this change, it is advisable to contact the GRIS team in advance.

Concerning changing the desired wavelength range, the operation has to be done by the GRIS team and requires a certain amount of time for calibration. Additionally, the change from long-slit mode to IFU and vice versa will take around a day. Thus, it is recommended that the user choose one system as input for the spectrograph and one spectral configuration for the entire campaign.

2.2. *Operation programs*

The different sub-systems of GRIS are controlled by the following three programs:

- POLAR: Main program to operate the instruments. It includes commands to run an observation, and calibration operations like a flatfield. It runs on the computer named Arm1 (accessible from the observers room) by default.
- PEGASO: This program controls physical systems of the instrument, like the spectrograph, and other moving elements. It is run on the Ulises3 computer and is mainly used by the GRIS team.
- POLEA: The last program on the list is related to the old polarimetric calibration unit. It also runs on Ulises3. NOTE: Observers do not need to use it.

2.3. *Starting the programs*

If you are on-site, start the program TigerVNC on one of the observer room computers. If you are observing remotely, you can run TigerVNC on your own computer (download it here: https://tigervnc.org/), but you must first be connected to the GREGOR network via VPN. Please, contact KIS staff in advance to arrange access. Once the TigerVNC window is open, enter the IP address 161.72.22.76:2 to connect to the GRIS control computer (Arm1). The telescope assistant can provide the password, which is written on the whiteboard or in the checklist document. TigerVNC remotely opens a window from the Arm1 computer, allowing you to operate GRIS.

The most common option to start any of the programs mentioned above is the following.

- In the open window, look for the terminal connected to computer Ulises3.
- If it is not open, connect to the Ulises3 computer by typing the following command in a terminal: `ssh -X tip@ulises3`
  (requires the same password as before)
- In the terminal connected to Ulises3, you can run
  - `pegaso &`
- In a different terminal on Arm1, move to the directory `/scratch/tip/` and create a new directory with the observation date with the format YYYYMMDD. Also, create a subdirectory inside the new one called `level0`.
- After that, move to the directory `level0` and run `polar` without the & symbol.
- NOTES:
  - If you observe remotely, you will need a large, high-resolution screen for optimal performance.
  - If the directory `/scratch/tip/` is full you can use `/scratch1/tip/` instead
  - Please, confirm with the telescope assistant that the **Telescope control** system is running, the AO GUI (specific for GRIS) is open and inside the AO Run menu and that the specific de-rotator GUI (specific for GRIS) is opened, before starting POLAR.

2.4. *Operation notes*

Creating a file containing the description of the main tasks performed during each observing day is recommended. The file should be created in the main folder of each day, that is, `/scratch/tip/YYYYMMDD/`, with the following name and extension: `YYYYMMDD.txt`. Please, add notes about the configuration setup and any relevant information that could help during data analysis. For instance, you may include notes about the observing conditions, such as the presence of clouds or any issues/errors encountered during the observation. Reference log file examples for Slit and IFU observations can be found in `/scratch/tip/examples/`. You can copy one of them to your observation directory (`/scratch/tip/YYYYMMDD/`) and modify it as needed.

2.4.1. *Long-slit operation mode*

The long slit is mounted on the old slit-scan unit. The Slitscanner GUI needs to be running before POLAR runs. It can be started in the instrument control system. This GUI can also be used to manually move the slit. POLAR takes control while doing the scan. The POLAR 2.0 window is shown in Figure 1.

The main commands in the POLAR window are the following:

- **operation**: Clicking on it will open a pop-up panel like the one shown in Figure 1 with the following options:
  - **scanning**: Main observing mode for science.
  - **flat field**: Mode in which the instrument takes flat field observations for calibrating the data.
  - **instrumen. cal.**: Instrument calibration tasks. Not used by default.
  - **telescope cal.**: Observing mode aimed to obtain the telescope polarisation matrix. It is better to run it at the end of the observation, and it is not affected by the atmospheric seeing although it is important to avoid clouds.

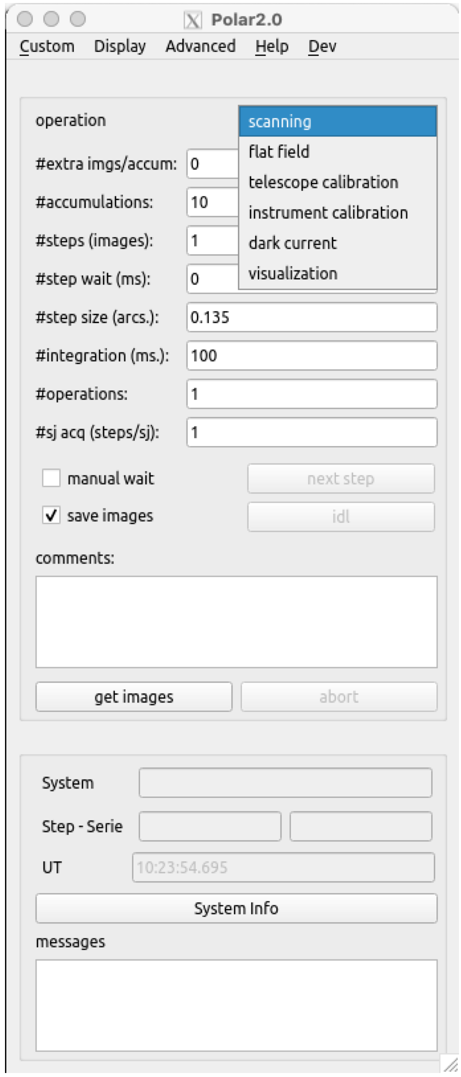

Figure 1: Reference snapshot of the POLAR 2.0 program when using the long-slit as input for the spectrograph. We show the pop-up panel that appears when clicking the option `operation`.

  - **dark current**: Mode for taking sensor images without illumination. It is not currently used as the scanning mode will take the dark current measurements when initiated.
  - **visualization**: Observing mode where images taken by the sensor are displayed on the screen but not saved on disk.

- **#extraimg/accum**: Number of extra images to be taken between slit scanning positions. Usually, 0 extra images is the default value.
- **#accumulations**: Number of images to be added (accumulated) for a specific scan position. By default, we can set it to 10 accumulations to get a signal-to-noise of 10^{-3} of the continuum intensity (I_c) for the polarisation signals at 1083 nm.
- **#scanning steps**: Number of steps we scan the surface of the Sun with the long-slit.
- **step wait (ms)**: waiting time between the scanning steps mentioned above. If the user wants to have a time delay between one scan and the next, we should add positive values here. Otherwise, the default is 0 ms.
- **step size (arcsec)**: Size of the slit step. Usually, it can be set to half of the slit width, i.e., 0.135 arcsec.

- **integration (ms)**: Integration time for each accumulation. Standard integration times are 100 ms for spectropolarimetric observations at 854.2 and 1083 nm, and 30 ms for spectropolarimetric observations at 1565 nm.
- **#operations**: This global value will indicate how many times we repeat the above instructions. For instance, if the observer aims to perform repeated maps of 18 scanning steps, will include the number of desired maps here. Otherwise, leave it as 1 operation, that will correspond to the total number of scanning steps defined above.
- **sj acq (steps/sj)**: The user can specify whether slit-jaw images are taken and at which rate. For example, 1 will mean that every time a scan step is performed, a slit-jaw image will be taken as a reference.
- **manual wait**: The observer can indicate the instrument to wait before moving on to the next scanning step. This is helpful mainly for instrument development activities.
- **save images**: Activate it to record the observations on disk. Deactivate it in case of performing tests that will not be saved and analyzed later.
- **idl**: Available for visualization mode. It runs the IDL programming language and loads the latest recorded images as input variables. The POLAR program will wait for the user to close IDL before continuing operations. Finally, in order to use this option, we need to run POLAR without the `&` symbol.
- **comments**: The user can add comments about the observation here. They will be added to the data header. See also the following option.
- **get images**: Clicking this button will run the operation defined before. At the end of the operation, a pop-up window will appear and require comments on the observation and to select the type of solar feature observed, e.g., quiet Sun, spot, filament, etc.
- **abort**: This option stops the running operation. The images acquired so far will be saved on disk.

2.5. *A reference example of single slit sequence*

The general operation should be to take a flat field, run the observation program, take a flat field at the end of the operation (or around every hour), scan the USAF target once per day, and finally run the telescope calibration at the end of the day. A reference set of parameters for each case is described in the following.

Flat field:

- Check the sky and confirm that there are no clouds
- Select the item “flat field” in the operation field.
- Set **#accumulations**: 10
- The integration time should match that of the observing program. By default, the integration times are 100 ms for spectropolarimetric observations at 854.2 and 1083 nm, and 30 ms for spectropolarimetric observations at 1565 nm.
- The number of steps is recommended to be 50.
- The number of operations is 1.
- Update the log file `YYYYMMDD.txt` including when this operation corresponds to a flat-field.
- In addition, check with the telescope assistant that:
  - The AO is not running (no correction).
  - The telescope is in flat-field mode.
  - By default the telescope should point to disk centre. However, no Active Region should be included in the telescope FOV.
  - The image de-rotator must be in, and stopped.

Observations in long-slit mode

- Select the item "scanning" in the operation field.
- Set #**accumulations**: 10
- By default the integration times are 100 ms for spectropolarimetric observations at 854.2 and 1083 nm, and 30 ms for spectropolarimetric observations at 1565 nm.
- Update the log file `YYYYMMDD.txt` including when this operation corresponds to a scan
- In addition, check with the telescope assistant that:
  - The AO is running
  - The image de-rotator must be in and tracking.

Scan of the USAF target

- Select the item "scanning" in the operation field.
- Set #**accumulations**: 2
- By default the integration times are 100 ms for spectropolarimetric observations at 854.2 and 1083 nm, and 30 ms for spectropolarimetric observations at 1565 nm.
- Update the log file `YYYYMMDD.txt` including when this operation corresponds to a scan of the USAF target.
- The number of steps is recommended to be 200.
- The number of operations is 1.
- In addition, check with the telescope assistant that:
  - The AO is running, and the user can see the USAF target on the slitjaw images.
  - The image de-rotator must be in and tracking.

Telescope calibration:

- Check the sky and confirm that there are no clouds
- Select the item "telescope calibration" in the operation field.
- Set #**accumulations**: 10
- The integration time should match that of the observing program. By default, the integration times are 100 ms for spectropolarimetric observations at 854.2 and 1083 nm, and 30 ms for spectropolarimetric observations at 1565 nm.
- The number of steps is set automatically to 74.
- The number of operations is 1.
- Update the log file `YYYYMMDD.txt` including when this operation corresponds to a telescope calibration.
- In addition, check with the telescope assistant that:
  - The AO is not running (no correction). And deselect the box of `M11 pupil control`
  - The telescope pointing should be at the disk centre
  - The beam tracker must be stopped.
  - The image derotator must be in and stopped.
  - At the end of the calibration, we need to restart the beam tracker and the derotator (with "rel" not checked to return to the previous orientation).

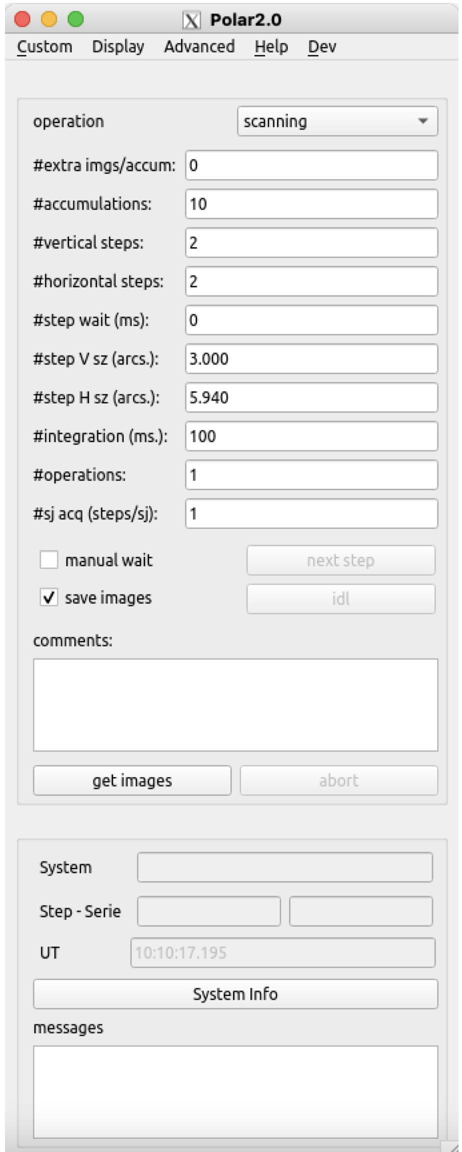

Figure 2: Reference snapshot of the POLAR program when using the IFU system as input for the spectrograph.

2.5.1. *Integral Field Unit mode*

The user can select the long-slit or the IFU system as input to the GRIS spectrograph. Both systems behave similarly, scanning a specific solar region in a set of scan steps. However, in the case of the IFU unit, the scanning can be done by moving the 2D IFU FOV in the horizontal (with respect to a reference location) and vertical directions. This adds two additional options to the observing program, but the rest of the configurable parameters remain the same as in the case of the long-slit. Finally, check Appendices 2 and 5 in the long GRIS manual for further information regarding the type of scans that can be done and the GUI that controls the IFU in the telescope Instrument Control System (ICS).

The POLAR 2.0 window for the IFU mode is shown in Figure 2

The main operations are the same as described in Section 2.4.1. We only have a few additions that are:

- #**Vertical steps**: This instruction indicates the number of steps performed in the vertical direction. Please note that the IFU system covers an FOV of $6{\times}3$ arcsec^2. So, for example, a scan with 2 vertical steps and 1 horizontal step will end up producing a total FOV of $6{\times}6$ arcsec^2.

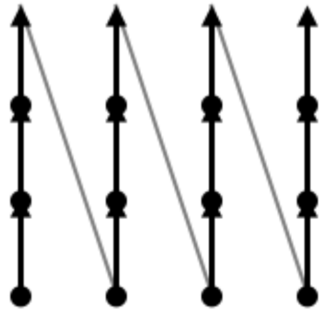

Figure 3: Scanning pattern by default. It simulates a scanning configuration where #**Vertical steps** = 4, and #**Horizontal steps** = 4.

- #**Horizontal steps**: The number of steps performed in the horizontal direction. Please note that the IFU system covers a FOV of 6×3 arcsec^2. So, for example, a scan with 2 horizontal steps and 1 vertical step will produce a total FOV of 12×3 arcsec^2.
- **step V size (arcs.)**: Size of the scanning step in the vertical direction. If the observer aims to have continuity between the different scans, the step should have the same size as the IFU FOV, that is, 3 arcsec.
- **step H size (arcs.)**: Size of the scanning step in the horizontal direction. If the observer aims to have continuity between the different scans, the step should have the same size as the IFU FOV, that is, 5.940 arcsec.

2.5.2. *Reference IFU program*

As the operation is almost identical between the long-slit and the IFU mode, we refer the reader to Section 2.5. The recommended exposure time for the 854.2 and 1083.0 nm spectral ranges is 70 ms in the IFU mode. To estimate the time required to complete a scan, it is necessary to consider the exposure of each tile times the number of steps in the horizontal and vertical directions. In the next section, we explain how to compute that time.

2.5.3. *IFU Scan time and pattern*

The default option is called RasterV. We show how it works for a reference case where #**Vertical steps** = 4, and #**Horizontal steps** = 4 in Figure 3. The scanning system will move half of the steps to the left from the center and half of the steps to the bottom from the center of the pointing. Then, it will start scanning in the vertical dimension (the shortest one of the 6×3 arcsec^2 FOV) and complete all the vertical steps. Then, it will take one horizontal step and move the initial vertical step to start moving in the vertical direction, and so on. Additional scanning patterns will be available in the future.

The total scanning time is given by:

$$\mathrm{t} = \mathrm{Scan_{time}} \cdot \mathrm{IFU_{sampling}} \cdot \mathrm{N_V} \cdot \mathrm{N_H}$$

with

- $\mathrm{IFU_{sampling}}$: 1 for single (default), 2 for double. It has to be changed in custom, see Appendix 5 in the long GRIS manual.
- $\mathrm{N_V}$: Vertical scanning steps
- $\mathrm{N_H}$: Horizontal scanning steps

and

$$\mathrm{Scan_{time}} = \mathrm{PMU_{state}} \cdot \mathrm{N_{acc}} \cdot (\mathrm{t_{int}} + \mathrm{t_{readout}}) + \mathrm{t_{move}}$$

with $\mathrm{PMU_{state}} = 4$, $\mathrm{t_{readout}} = 30$ ms, and $\mathrm{t_{move}} = 1000$ ms.

3. DATA REDUCTION

Observers are encouraged to reduce the data on the same day of the observation when operations have been completed. In this regard, the data will be ready to be used at the end of the campaign. For this purpose, create two IDL procedures (one for each sensor with the current instrument set-up) with the name `calDDmonthYYarm1.pro` and `calDDmonthYYarm2.pro`, for instance, `cal28jun24arm1.pro` and `cal28jun24arm2.pro` in the same directory `YYYYMMDD` (20240628, in this example) where the data have been stored

An example of what options need to be specified can be found below for arm1 data:

```
pro cal28jun24arm1

; Specify the name of the target USAF scan file.
target = '28Jun24ARM1.004'
data = limits_fov(target)
Note: The two lines above are used only in slit mode. In IFU mode, you should remove them.

; Set the observing wavelength in angstroms. 10830 and 8542 for ARM1 and ARM2, respectively.
lambda = 10830.

; Specify the name of the Flatfield files. Usually, we provide the two fields taken before and after the observation.
fileff = ['28jun24ARM1.000','28jun24ARM1.002']

; Specify the name of the polarimetric calibration file, recorded using the TELESCOPE CALIBRATION operation mode.
filecal = ['28jun24ARM1.003']

; Provide the name of the science scan. Note that multiple submaps (i.e., 28jun24.001-number) may exist. The reduction routine only needs the stem of the file name and will look for additional files with the same stem in the same level0 directory.
map = ['28jun24ARM1.001']

; Call the reduction program (V9 in 2024 and 2025) with the parameters defined.
gris_v9,map,fileff,filecal,lambda=lambda,fts=1,data=data,newgrating=1,/xtalki

return
end
```

Repeat the same steps for all the science scans done in the day. Be careful to select the flatfield files that are closest in time to the observation.

4. DATA ARCHIVE AND DOWNLOAD

The user can copy all the useful data from the `YYYYMMDD` directory to the /gris_archive/ directory using the command rsync -rav.

For example, at the directory `/scratch/tip/` type:

```
rsync -rav 20240628 /gris_archive/.
```

Note that there is no space between "/" and the "."

The Slit-Jaw images are automatically saved in Gregor file storage (see the configuration in Section 6.1). These images are in the directories `/instruments/gsjc/gsjc1/` and `/instruments/gsjc/gsjc2/` for camera 1 and 2, respectively. They can be downloaded directly from there. Please be careful not to delete them!

5. SHORT MANUALS TO RUN OBSERVATIONS

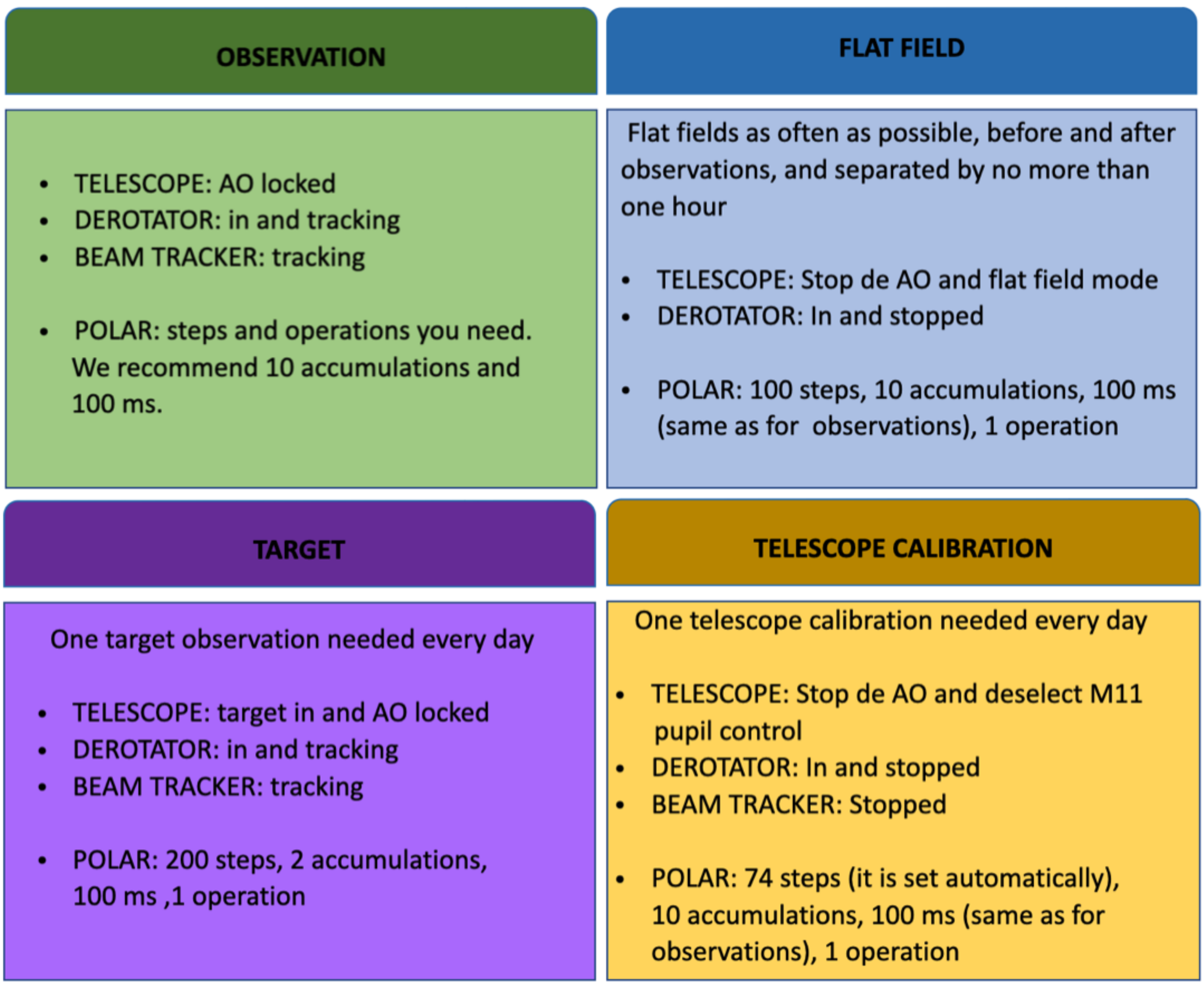

Figure 4: Short guide to running observations in slit mode.

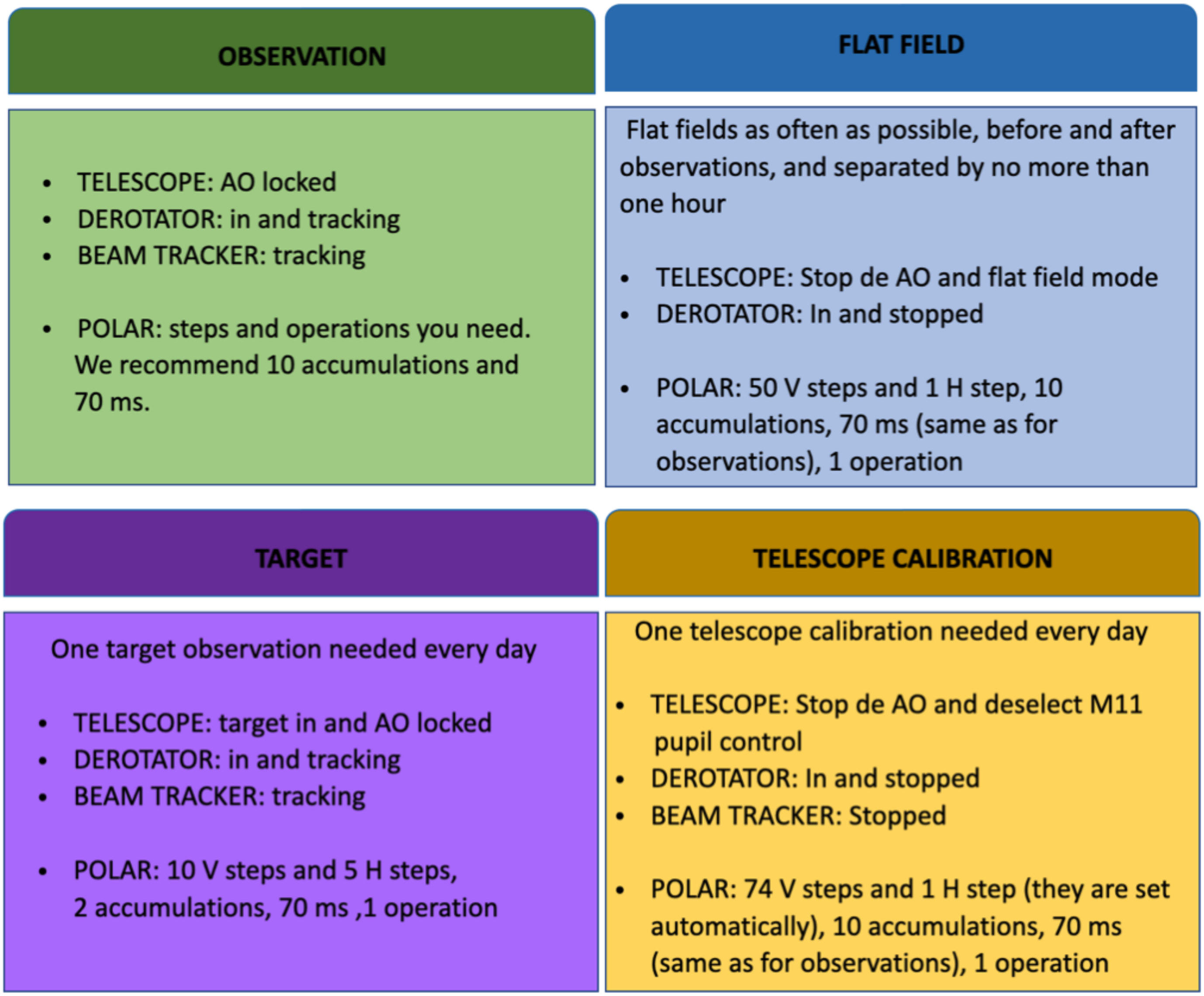

Figure 5: Short guide to running observations in IFU mode.

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