UPGRADED GRIS MANUAL

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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 the wavelength regions centered at 1083 and 1565 nm, respectively. The first pair of LVCRs was recently upgraded 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 removing the polarimeter from the light path and switching the control program to POLAR. For detailed instructions, see Appendix 4 in the full GRIS manual. If the user plans 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 MASTER**: Main control program of the instrument. It provides commands to run observations as well as calibration procedures (e.g., flat-field acquisition). By default, it runs on the computer *itaca12*, which is accessible from the observers' room.
- **POLAR SLAVE**: Control program dedicated to the third arm of the instrument. Its sole purpose is to operate the third arm and manage its data display. By default, it runs on the computer *itaca3*. Access to this computer from *itaca12* is typically established via `ssh -l tip itaca3 -X`. This program is only required when operating the instrument in three-arm mode; for standard two-arm observations, only the **POLAR MASTER** is used.

- **PEGASO**: Program that controls the physical subsystems of the instrument, including the spectrograph and other movable components. It runs on the *Ulises3* computer and is primarily used by the GRIS team.
- **POLEA**: Program associated with the secondary polarimetric calibration unit. It also runs on *Ulises3*. This software is not intended for regular observer use.

2.3. *Starting the programs*

If you are on-site, open the TigerVNC application on one of the observer room computers. If you are observing remotely, you can run TigerVNC on your own computer (download it from `https://tigervnc.org/`), but you must first connect to the GREGOR network via VPN. Please contact the 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 (*itaca12*). The telescope assistant can provide the password, which is usually written on the whiteboard or included in the checklist document. This will open a remote desktop session on *itaca12*, from which GRIS can be operated.

All remote connections should be established using X11 forwarding (i.e., `ssh -X`).

The most common procedure to start the required programs is the following:

- In the remote session, locate a terminal connected to the computer *Ulises3*.
- If no such terminal is open, connect to *Ulises3* by running:

  ```
  ssh -l tip ulises3 -X
  ```

  (using the same password as before).
- In the terminal connected to *Ulises3*, start the instrument control software:

  ```
  pegaso &
  ```

- All observations are stored under the directory `/scratch2/tip/`, which is the default location for GRIS data.
- In a different terminal on *itaca12*, navigate to `/scratch2/tip/` and create a new directory with the observation date in the format `YYYYMMDD`. Inside this directory, create a subdirectory named `level0`.
- Move to the `level0` directory and run:

  ```
  polar_m
  ```

  to start **POLAR MASTER**.

Third arm operation (optional)

If the third arm is required, perform the following additional steps:

- Connect to the computer *itaca3* from *itaca12*:

  ```
  ssh -l tip itaca3 -X
  ```

  (using the same password as before).
- Navigate to `/scratch2/tip/` and create a directory for the observation date (`YYYYMMDD`), including a `level0` subdirectory.
- Move to the `level0` directory and run:

  ```
  polar_s
  ```

  to start **POLAR SLAVE**.

Additional Notes—

- Remote observations require a large, high-resolution display for optimal performance.
- The directory `/scratch2/tip/` in each computer provides increased storage capacity compared to previous systems and should be used as the default location for all observations.
- If the directory `/scratch2/tip/` is full in any of the itaca computers, you may use `/scratch1/tip/` instead.
- Before starting POLAR, confirm with the telescope assistant that:
  - the telescope control system is running,
  - the AO GUI (configured for GRIS) is open and in the AO Run menu,
  - the GRIS-specific de-rotator GUI is open.

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 on *itaca12*, that is, `/scratch2/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 the 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 (`/scratch2/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 MASTER and POLAR SLAVE windows are shown in Figure 1.

The main commands in the POLAR MASTER window are the following:

- **operation**: Clicking on it will open a pop-up panel (Figure 1, left) 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.
  - **instrument calibration**: Instrument calibration tasks. Not used by default.
  - **telescope calibration**: 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 crucial to avoid clouds.
  - **dark current**: Mode for taking sensor images without illumination. It is not currently used as the all other modes will take the dark current measurements when initiated.
  - **visualization**: Visualization mode where images taken by the sensor are displayed on the screen but not saved on disk. The slit or IFU does not move in this mode.
- **#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 step and the next, we should add positive values here. Otherwise, the default is 0 ms.

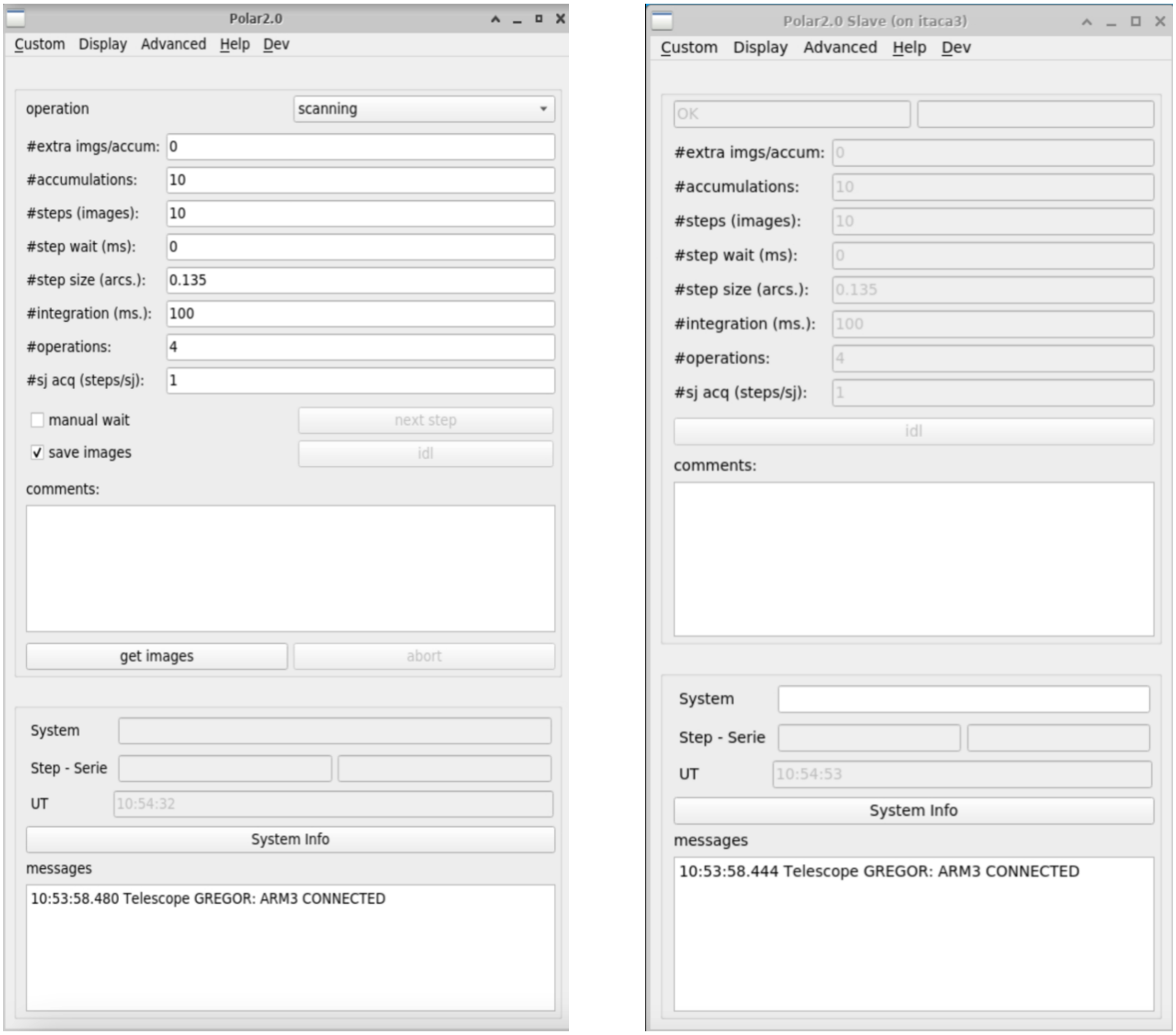

Figure 1: Reference snapshots of the POLAR MASTER (left) and POLAR SLAVE (right) programs in long-slit operation mode.

- **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 individual image. 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 indicates how many times we repeat the above instructions.
- **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. If the number is set to 2 it will mean that every time a scanning step is performed, two slit-jaw images will be taken as a reference, and so on.
- **manual wait**: The observer can indicate the instrument to wait before moving on to the next scanning step. The scan will resume when the next step button is clicked. 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 (accum1, accum2, accum3, and accum4). 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.

2.4.2. *Long-slit operation mode (three arms)*

If the third arm is required, the POLAR SLAVE program must be running. On the *itaca3* computer, navigate to the directory:

`/scratch2/tip/YYYYMMDD/level0/`

and execute:

`polar_s`

The POLAR SLAVE window will then open (Figure 1, right). This program is used to operate the third arm and control its display. Please, remember to execute first POLAR MASTER on *itaca12* as it will be the one providing the input parameters to POLAR SLAVE.

All observational parameters defined in POLAR MASTER (e.g., number of accumulations, integration time, scanning configuration) are automatically synchronized with POLAR SLAVE. Therefore, no additional configuration is required for the third arm.

2.5. *A reference example of single slit sequence*

The general operation should be to take a flat field, run the observation program (using the scanning operation mode), 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, the derotator (with “rel” not checked to return to the previous orientation), and the M11 pupil control.

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 extended 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 approximately 6×3 arcsec^2. So, for example, a scan with 2 vertical steps and 1 horizontal step will end up producing a total FOV of 6×6 arcsec^2.
- #**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, 6 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** = 2 in Figure 3. The scanning system will move half of the steps to the right from the center and half of the steps to the top from the center of the pointing by default. 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:

$$\mathrm{Scan_{time}} = \mathrm{Step_{time}} \cdot \mathrm{IFU_{sampling}} \cdot \mathrm{N_V} \cdot \mathrm{N_H} \cdot \mathrm{N_{operations}}$$

with

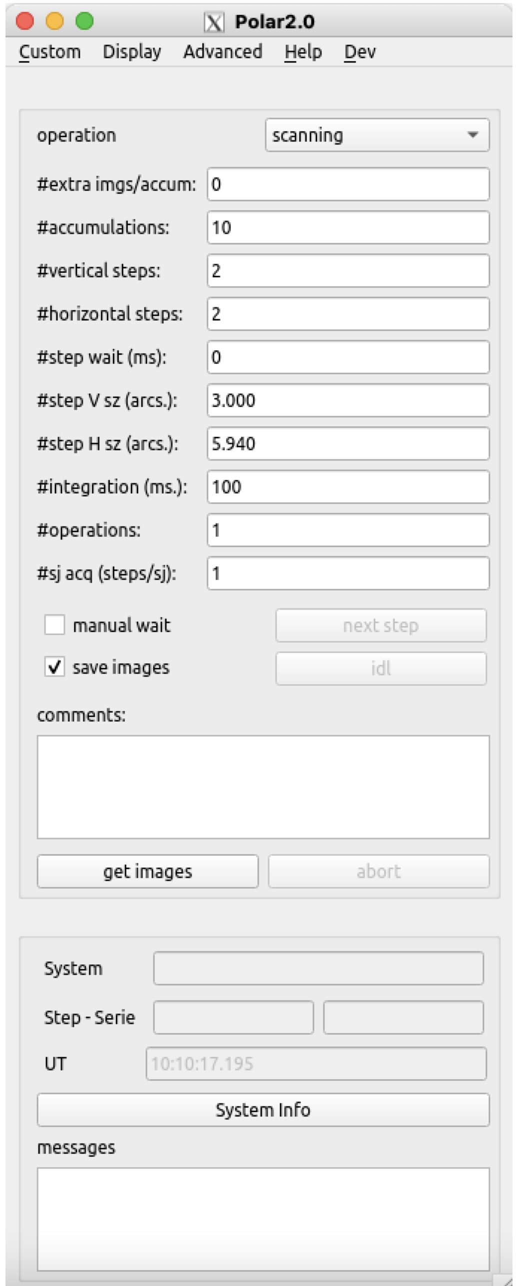

Figure 2: Reference snapshot of the POLAR program when using the IFU system as input for the spectrograph.

- $\mathrm{IFU_{sampling}}$: 1 for single (default), 2 for double sampling. It has to be changed in the GUI (under the option "Custom"), see Appendix 5 in the extended GRIS manual.
- $\mathrm{N_V}$: Vertical scanning steps
- $\mathrm{N_H}$: Horizontal scanning steps
- $\mathrm{N_{operations}}$: Number of repetitions of each scan.

and

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

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

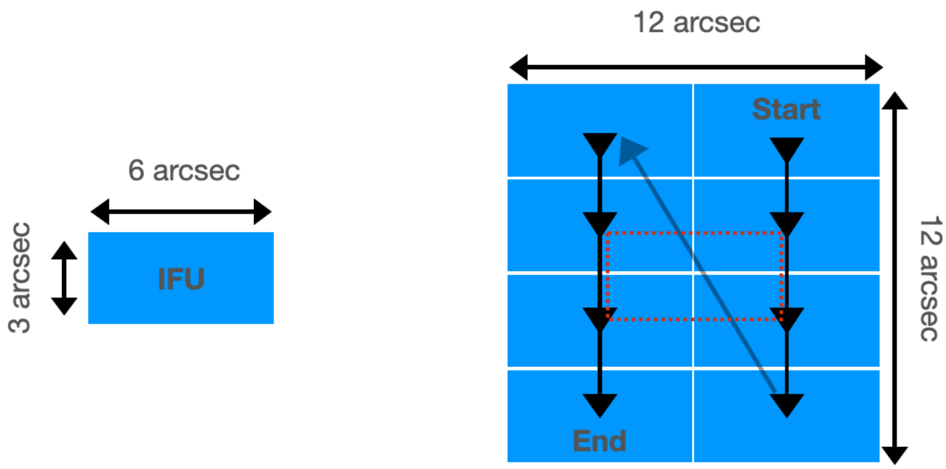

Figure 3: Left: Dimensions of the Integral Field Unit (IFU), which covers a field of view of 6×3 arcsec^2 on the Sun. Right: Default scanning pattern used with the IFU. The example shows a configuration with 4 vertical steps and 2 horizontal steps, resulting in a total scanned field of view of 12×12 arcsec^2. The red box indicates the initial position of the IFU (center of the full scan).

3. DATA REDUCTION

Observers are encouraged to reduce the data on the same day once the observations have been completed. This ensures that the data products are ready for scientific use by the end of the observing campaign.

To perform the data reduction, create one IDL procedure per arm (i.e., per detector) corresponding to the current instrument configuration. These procedures should be named following the convention:

`calDDmonthYYarmX.pro`

where `X` indicates the arm number.
For example:

- `cal28jun24arm1.pro`
- `cal28jun24arm2.pro`

These files should be created in the directory `YYYYMMDD` (e.g., `20240628`), where the data are stored.
In the case of third-arm observations, an additional procedure must be created:

- `cal28jun24arm3.pro`

This file should be placed in the corresponding `YYYYMMDD` directory on the *itaca3* computer.

An example of the required configuration options for arm 1 data is provided below:

```
pro cal28jun24arm1

; Specify the name of the target USAF scan file.
target = '28Jun24ARM1.004'
data = limits_fov2(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 scans one at a time. 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_v10,map,fileff,filecal,lambda=lambda,fts=1,data=data,newgrating=1,/xtalki
```
Note: In IFU mode, you should remove above data=data.
Note: If the new diffraction grating is used, then the keyword `newgrating=1` should be used. If the old diffraction grating is used, then the keyword `newgrating=0` should be used.
```
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 (before and after).

4. DATA ARCHIVE AND DOWNLOAD

Users can copy the observation data from the `YYYYMMDD` directory to the archive directory `/gris_archive/` using the `rsync` command.

For example, on *itaca12*, run:

```
DATE=YYYYMMDD
rsync -rtvh /scratch2/tip/${DATE}/ /gris_archive/${DATE}/
```

Third-arm data

For observations including the third arm, the same command must also be executed on *itaca3*:

```
DATE=YYYYMMDD
rsync -rtvh /scratch2/tip/${DATE}/ /gris_archive/${DATE}/
```

The commands can be executed simultaneously on both servers. The contents of the directories are merged automatically in `/gris_archive/YYYYMMDD`, resulting in a single archive containing the data from all GRIS arms.

The Slit-Jaw images are automatically stored in the GREGOR file system (see configuration in Section 6.1). These images are located in the directories:

- `/instruments/gsjc/gsjc1/` (camera 1)
- `/instruments/gsjc/gsjc2/` (camera 2)

They can be downloaded directly from these locations. Please ensure that these files are not deleted.

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

OBSERVATION

- TELESCOPE: AO locked
- DEROTATOR: in and tracking
- BEAM TRACKER: tracking

- POLAR: steps and operations you need. We recommend 10 accumulations and 70 ms.

FLAT FIELD (5 mins)

Flat fields as often as possible, before and after observations, and separated by no more than one hour.

- TELESCOPE: Stop the AO and flat field mode
- DEROTATOR: In and stopped
- BEAM TRACKER: tracking

- POLAR: 50 V steps and 1 H step, 10 accumulations, 70 ms (same as for observations), 1 operation

TARGET

One target observation needed every day

- TELESCOPE: target in and AO locked
- DEROTATOR: in and tracking
- BEAM TRACKER: tracking

- POLAR: 10 V steps and 5 H steps, 2 accumulations, 70 ms, 1 operation

TELESCOPE CALIBRATION (12 mins)

One telescope calibration needed every day

- TELESCOPE: Stop the AO and deselect M11 pupil control
- DEROTATOR: In and stopped
- BEAM TRACKER: Stopped

- POLAR: 74 V steps and 1 H step (they are set automatically), 10 accumulations, 70 ms (same as for observations), 1 operation

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

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