Ecliptic cut Angles from GCS for ELEvoHI (EAGEL) Manual

Jürgen Hinterreiter

August 3, 2020

Introduction

EAGEL is an IDL tool to create an ecliptic cut from the GCS wire frame. It provides the download and pre-processing routines for the coronagraph images and incorporates the GCS tool. Furthermore, EAGEL calculates the half width and the propagation direction of the CME based on the ecliptic cut from the GCS wire frame and the values obtained are saved and can used by ELEvoHI.

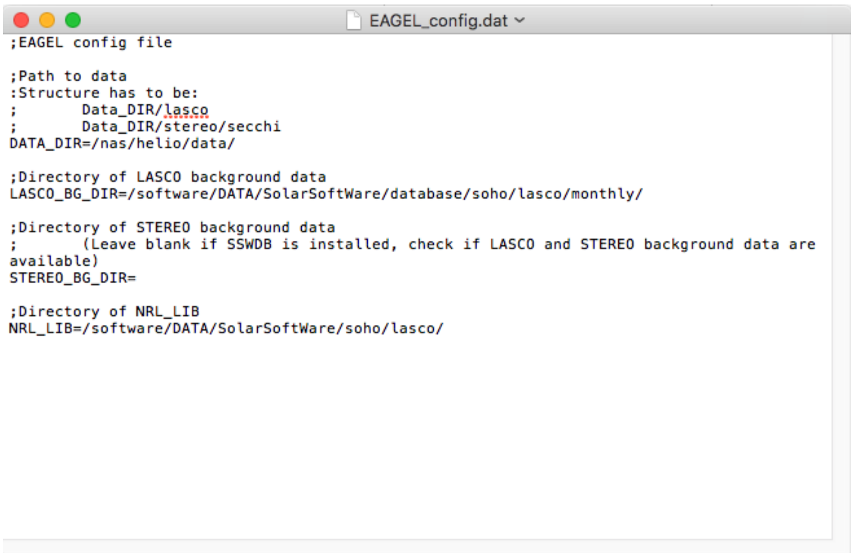
Contents

1 EAGEL overview

EAGEL is an acronym and stands for *E*cliptic cut *A*ngles from *G*CS for *EL*EvoHI. It is implemented in Implemented Data Language (IDL) version 8.4 and combines the needed routines to download and pre-process data and further to perform GCS (Graduated Cylindrical Shell [THV06; TVH09]) reconstruction, using the IDL built-in procedure *rtsccguicloud*. Additionally, EAGEL helps to perform an ecliptic cut of the hallow croissant shape wire frame which is an idealized shape for a CME. Based on the ecliptic cut the maximum half width of the CME is found and the predicted propagation direction is calculated and saved. The propagation direction and the half width are two important parameters for the CME arrival prediction model ELEvoHI [Rol+16; Ame+18]

2 Using EAGEL

2.1 Requirements



```
;EAGEL config file

;Path to data
:Structure has to be:
;        Data_DIR/lasco
;        Data_DIR/stereo/secchi
DATA_DIR=/nas/helio/data/

;Directory of LASCO background data
LASCO_BG_DIR=/software/DATA/SolarSoftWare/database/soho/lasco/monthly/

;Directory of STEREO background data
;        (Leave blank if SSWDB is installed, check if LASCO and STEREO background data are
available)
STEREO_BG_DIR=

;Directory of NRL_LIB
NRL_LIB=/software/DATA/SolarSoftWare/soho/lasco/
```

Figure 1: Example *EAGEL_config.dat*

EAGEL is implemented and tested with the IDL version 8.4 and it is recommended that the SSWDB is installed in your IDL configuration. Before first running EAGEL, the config file (*EAGEL/Code/EAGEL_config.dat*) has to be updated. This file contains the paths to the needed data directories. An example config-file is shown in Figure 1. *DATA_DIR* defines the path to the STEREO and LASCO coronagraph data. The structure of the data directory must be as following: *DATA_DIR/lasco* and *DATA_DIR/stereo/secchi*. Also the path to the LASCO background images (*LASCO_BG_DIR*) and to the NRL library (*NRL_LIB*) must be set. In the EAGEL directory there is the *Code* and a *results* folder. In *Code* all the needed routines and the config file are found. *results* contains the EAGEL outputs.

2.2 Starting EAGEL

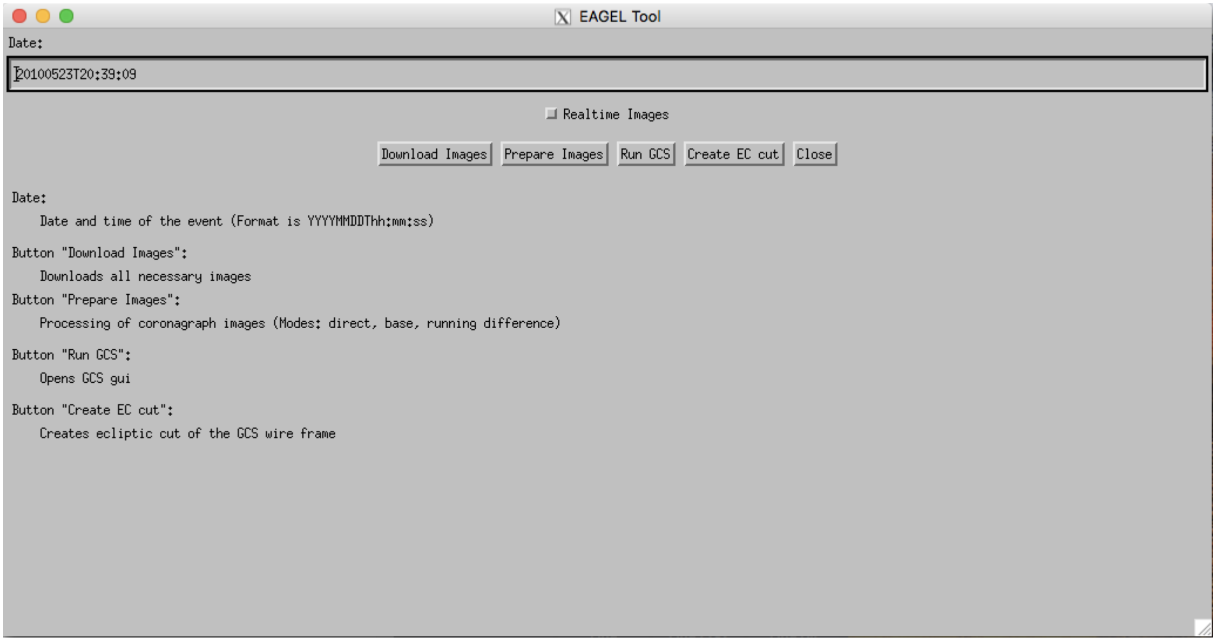


Figure 2: EAGEL main panel

EAGEL is started by typing *EAGEL, '20100523'* in the IDL command line. Here *'20100523'* denotes to the date of the CME event but can be any other string. It is the name of the sub-directory that is created in the *results* directory and contains the .sav-files created when pre-processing the images and performing GCS reconstruction. Alternatively, EAGEL can be started with an additional keyword *datetime* (*EAGEL, '20100523', datetime='20100523T20:39:09'*). When EAGEL is started with the *datetime* keyword it will already show the given date and time in the application. Otherwise, a pre-defined date is used. Figure 2 shows the main panel of EAGEL. *Date* is the given date and time for an event and has a fixed format: YYYYMMDDThh:mm:ss. It is recommended to use the LEVEL 2 science data for GCS reconstruction. This data is usually downloaded using the Virtual Solar Observatory (*vso_search* and *vso_get*). However, sometimes GCS reconstruciton is required for recent events where only LEVEL 0.5 data is available. This data can be obtained by selecting the checkbox *Realtime Images*. How to download (*Download Images*) and pre-process (*Prepare Images*) the data as well as performing GCS fits (*Run GCS*) and creating an ecliptic cut (*Create EC cut*) is shown in the next sections.

2.3 Download Images

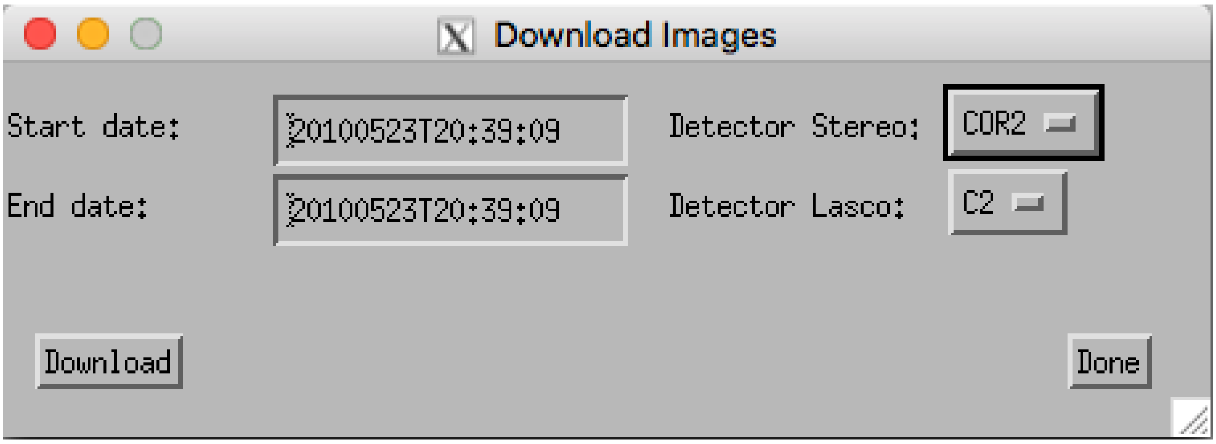


Figure 3: Download dialog

By clicking on *Download Images* a dialog is opened (Figure 3). The user can set the start and end date and also select the coronagraph detectors. For STEREO *COR1* and *COR2* and for LASCO *C2* and *C3* are available. However, when *Realtime Images* is selected only STEREO *COR2* data download is implemented. Depending on the internet connection, the download may take some time. EAGEL checks whether the data is already downloaded and does not overwrite existing files. The files are saved to the *DATA_DIR* directory where a couple of sub-directories are created.

2.4 Pre-process Images

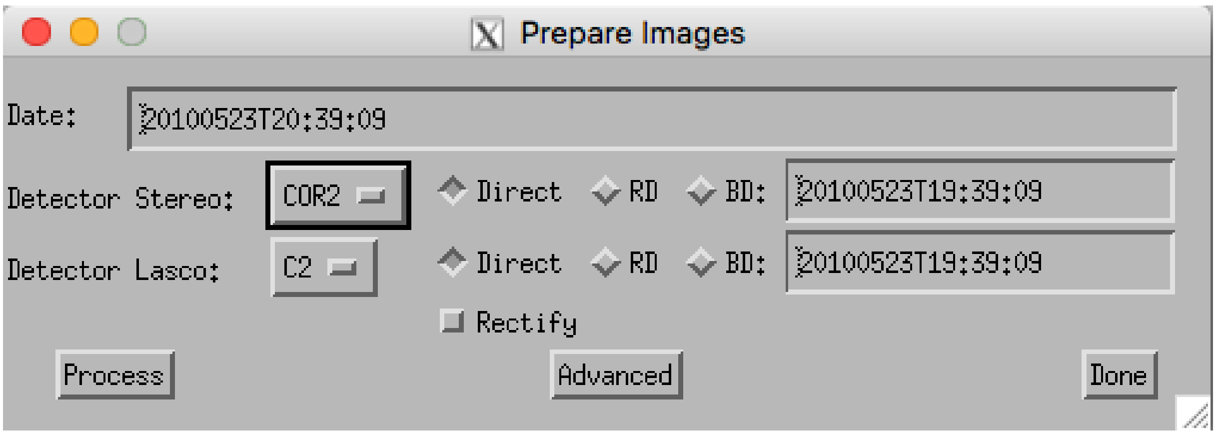


Figure 4: Prepare dialog

Pre-processing coronagraph images is an essential requirement for GCS reconstruction. It is needed to clearly see the CME structures in the images. Figure 4 show the *Prepare Images* dialog. *Date* sets the date and the time for which the image pre-processing is done and EAGEL selects the image which is closest in time. The user can select between the

STEREO (*COR1*, *COR2*) and LASCO (*C2*, *C3*) detectors, but only *COR2* is available when *Realtime-Images* is set. EAGEL provides three different ways to prepare the images:

1. Direct images,
2. Running difference (RD) images,
3. and Base difference (BD) images.

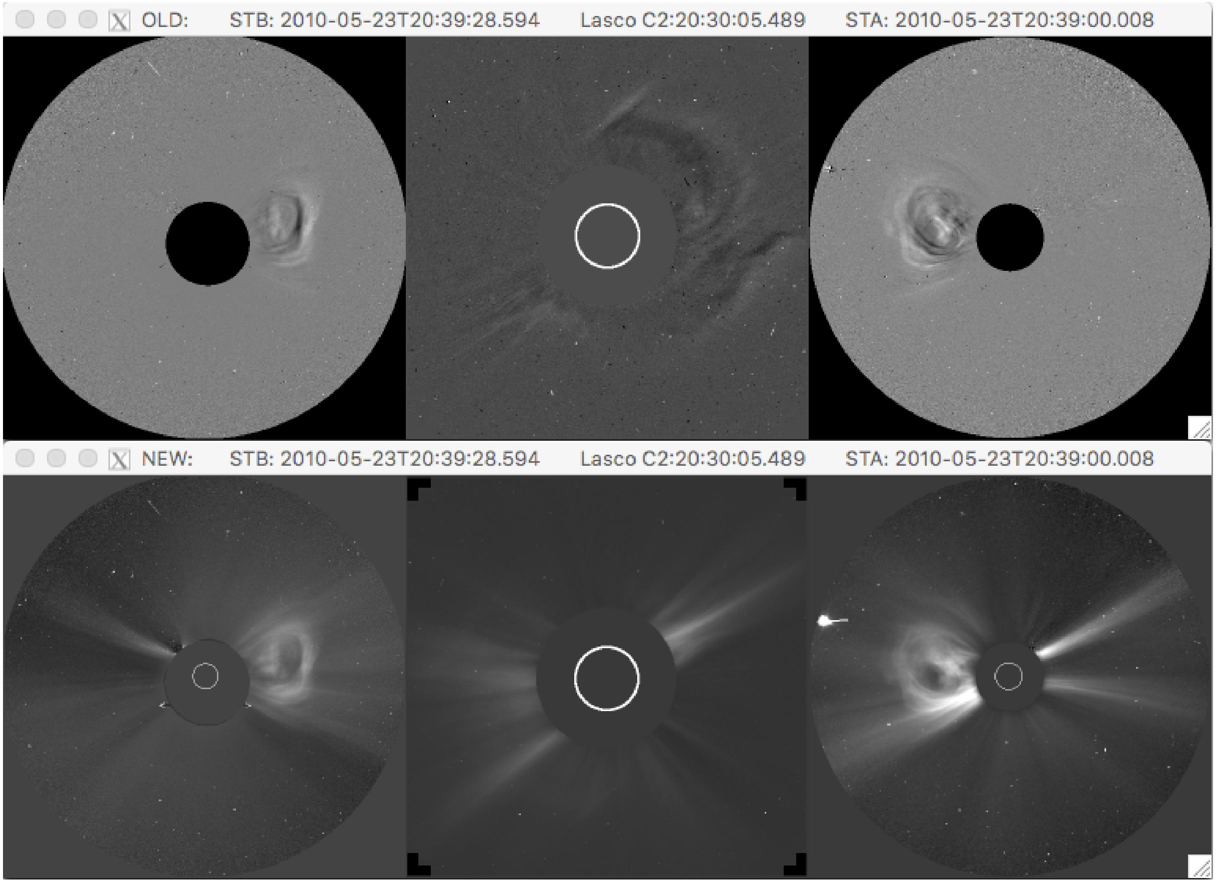


Figure 5: Processed coronagraph images with two different settings. Top row: running difference, bottom row: direct images

When selecting *Direct* the standard pre-processing steps are performed (*scc_mk_image*, *secchi_prep*, *bytscl*) with pre-defined values that have turned out to lead to the best contrast in the images. For running difference (RD) image processing, in addition to the image closest to *Date* also the latest image before that is loaded. This image is then subtracted and again the pre-processing is preformed. The same is done for base difference (BD), but there the user has to set the date and time of the image that is defined as the 'base'.

Sometimes the LASCO images are mirrored. This can be solved by setting the check-box *Rectify*. The orientation of the coronagraph images should always be double checked by using for example https://helioviewer.org or https://cdaw.gsfc.nasa.gov/CME_list/. The image pre-processing is started when clicking on *Process* button. If, for the given time, the images were already processed the user is asked whether the pre-processing steps should be redone. When the preparation of the images is completed, the old and new images are displayed on the screen and the user can decide to stick to the old images or to save the new ones. Figure 5 shows two different ways to prepare the coronagraph images. In the top row 'RD' is selected while in the bottom row the processing is done using direct images.

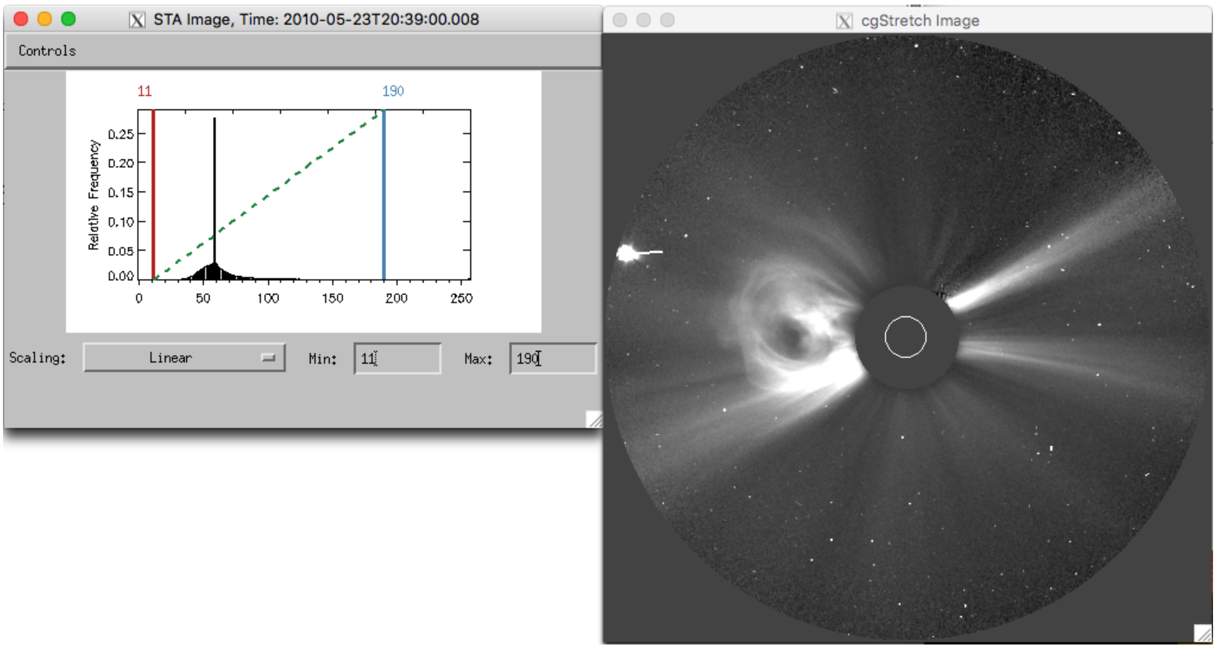


Figure 6: *cgStretch* from the 'coyote' library to pre-process the coronagraph images. The image contrast can be changed by moving the red and blue vertical lines.

In some cases the implemented standard pre-processing routines applied by EAGEL may not give the desired results, or the user is interested in specific features in the image. Therefore, the *Advanced* option to prepare the images is provided by EAGEL. *Advanced* is only available when the 'coyote' library by David Fanning is installed. The library can be downloaded here: http://www.idlcoyote.com/documents/programs.php. With the *Advanced* option the *cgScretch* function is called (Figure 6). It allows the user to change the constrast of the coronagraph images by moving the red and blue vertical lines. Also the scaling can be adjusted. This can be done for *Direct*, *RD* and *BD* images. By closing the dialog, the image with the current setting is saved and the next coronagraph images is shown.

All the coronagraph images are saved in the *results* directory. An sub-directory is created with the name, corresponding to the input parameter when starting EAGEL, e.g *results/20100523/*. It contains an IDL .sav-file with all the pre-processed coronagraph images. The file is named according to the date and time, e.g. *20100523_203909.sav*

2.5 GCS reconstruction

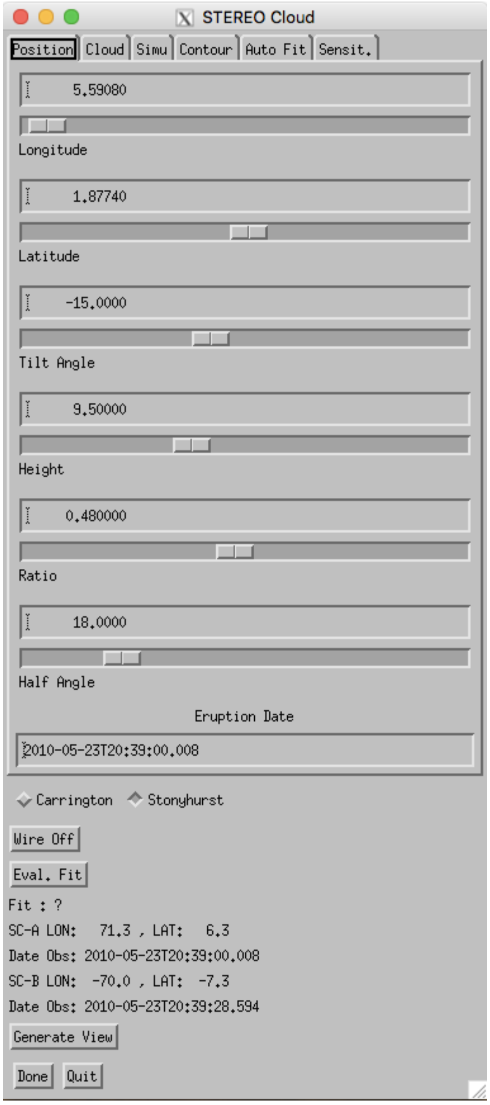


Figure 7: GCS tool implemented in IDL (*rtsccguicloud*)

On of the main parts of EAGEL is the GCS reconstruction. This is implemented using the IDL built-in procedure *rtsccguicloud* (Figure 7). Additional information and a tutorial can be found here: `http://secchi.nrl.navy.mil/synomaps/scraytrace/dobo/examples.html#tutrtsccguicloud`. The GCS model is an empirically-defined density model designed to reproduce the large-scale flux-rope morphology of CMEs. Its geometry is often referred to as a hollow croissant and consists of a half-torus main body with two conical legs connected back to the Sun. It can be parameterized with six parameters:

1. Longitude ϕ [deg],
2. Latitude θ [deg],
3. Tilt angle γ [deg],
4. Height h_{front} $[R_{Sun}]$,

5. Half angle $\alpha/2$ [deg],

6. Aspect ratio κ.

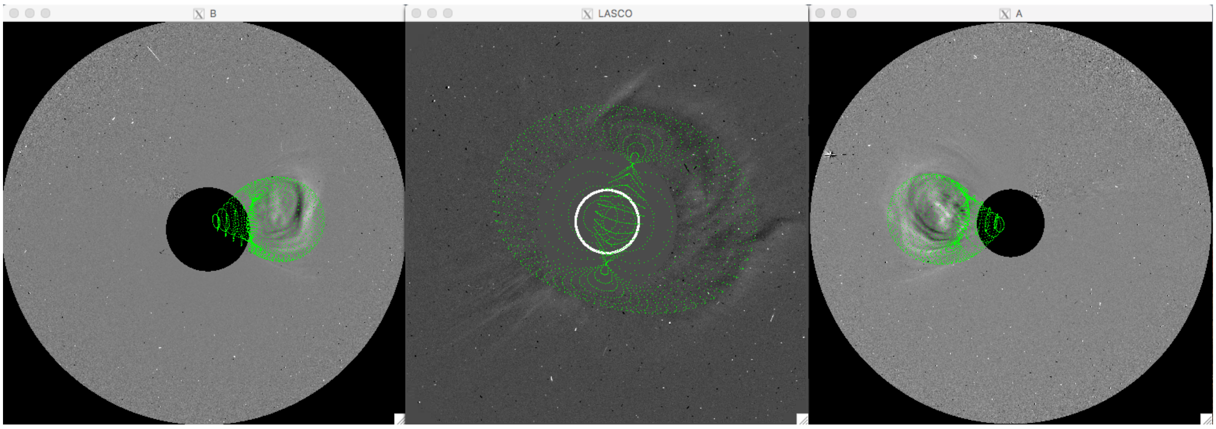


Figure 8: Three coronagraph images with the GCS wire frame (green).

The six GCS parameters can be changed in such a way that the hallow croissant shape best fits the coronagraph images. An example can be seen in Figure 8. It shows the two STEREO and the LASCO (middle) coronagraph images with the GCS wire frame in green. All the parameters are saved when the user clicks the *Done*-button in the GCS tool. The IDL .sav-file can be found in the *results* directory (e.g. *results/20100523/*) and is named according to the date and time with an additional *params*, e.g. *20100523_203909params.sav*.

2.6 Ecliptic cut and ELEvoHI input parameters

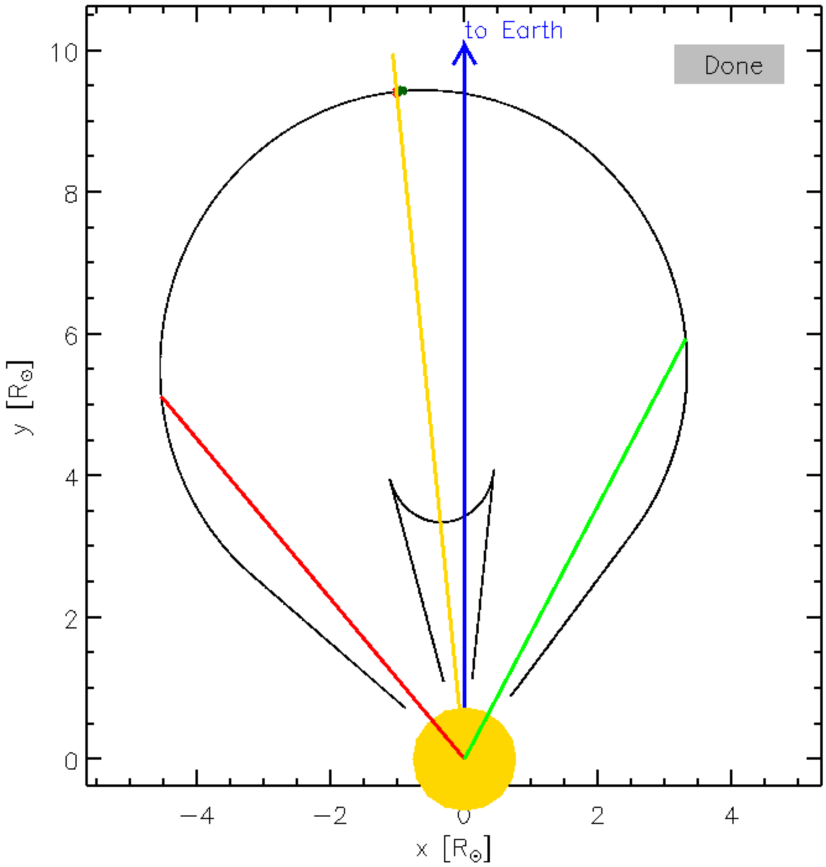


Figure 9: Ecliptic cut of the GCS wire frame (black). Red and green lines show the boundaries selected by the user. The yellow line defines the propagation direction, ϕ, of the CME. The half angle, λ is the angle between one boundaries and ϕ. The red asterisks defines the point of the cutout that is farthest away from the Sun, while the green asterisks is the propagation direction of the GCS reconstruction projected to the ecliptic plane. The blue arrow indicates the direction to Earth.

In order to get to the input parameters that are needed by ELEvoHI, EAGEL creates an ecliptic cut of the GCS wire frame. This is done in such a way, that the points of the GCS wire frame are increased and only those points are taken into account that lie in the ecliptic plane with a limited margin. Figure 9 shows the ecliptic cut of the CME (black points) with the boundaries selected by EAGEL (red and green lines, defined as the points of the ecliptic cut that are farthest out, according to the x-axis). The blue arrow represents the direction to Earth. The user can change the right and left boundary (selected by EAGEL) by using the right and left mouse button, respectively. By clicking on the *Done*-button, the user confirms the selection. EAGEL then calculates the propagation direction (yellow line in Figure 9), which is defined to be right in the middle of the two boundaries. Shown are additionally the propagation direction from the GCS reconstruction projected to the ecliptic plane (green asterisks) and the point of the ecliptic cut that is farthest away from the Sun (red asterisks).

Based on the user selection, EAGEL calculates the half angle and the angle of the propagation direction with respect to Earth, STEREO-A and STEREO-B. Those values are saved in a .dat- and .sav-file (e.g. *EAGEL_results_20100523T203909.sav*) and serve as input for ELEvoHI. The files can be found in e.g. *results/EAGEL4ELEvoHI/20100523/* where *20100523* is again the input parameter when EAGEL is started.

References

[THV06] A. F. R. Thernisien, R. A. Howard, and A. Vourlidas. "Modeling of Flux Rope Coronal Mass Ejections". In: *Astrophys. J.* 652.1 (Nov. 2006), pp. 763–773. DOI: `10.1086/508254`.

[TVH09] A. Thernisien, A. Vourlidas, and R. A. Howard. "Forward Modeling of Coronal Mass Ejections Using STEREO/SECCHI Data". In: *Solar Phys.* 256.1-2 (May 2009), pp. 111–130. DOI: `10.1007/s11207-009-9346-5`.

[Rol+16] T. Rollett et al. "ElEvoHI: A Novel CME Prediction Tool for Heliospheric Imaging Combining an Elliptical Front with Drag-based Model Fitting". In: *Astrophys. J.* 824.2, 131 (June 2016), p. 131. DOI: `10.3847/0004-637X/824/2/131`. arXiv: `1605.00510 [astro-ph.SR]`.

[Ame+18] T. Amerstorfer et al. "Ensemble Prediction of a Halo Coronal Mass Ejection Using Heliospheric Imagers". In: *Space Weather* 16.7 (July 2018), pp. 784–801. DOI: `10.1029/2017SW001786`. arXiv: `1712.00218 [astro-ph.SR]`.