DARK ENERGY
SURVEY

DES Guider
Software Manual

(Draft)

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1 Introduction

The main task of the guide software is to analyze the images taken with the Guide CCDs, compute the offsets of the telescope pointing with respect to the required position on the sky and relay this information to the telescope control system (TCS) to ensure precision telescope tracking.

The main guider features are:

- Provide guide error signals to de TCS with accurate precision
- Use the information of the 4 CCDs or a combination of any of them to determine the tracking error
- Self and User mode for guide star selection (independent for each Guide CCD)
- Visualize any of the active Guide CCD images or 4 at same time
- Identify & highlight the stars on the CCD image
- Show a list ordered by quality (Signal to Noise Ratio) of all the available stars with its main characteristics
- Plot display with the Output Offset (error signal to the TCS)
- Different image view modes with adjustable contrast parameters

2 Overview

Here it is presented some information that can be useful for the Observer to understand how the Guider works and how to make it work.

2.1 Guide Algorithm

The guide algorithm is the core of the guide software. It delivers error corrections to the TCS, ultimately providing reliable information for stabilization of the image. Following this objective the guide algorithm development has been focused on optimizing the next stages:

- *Acquisition*. Set the best reference star for guiding (once).
- *Tracking*. Find the reference star with the most precision and sureness.
- *Compute offset*. Provide the most reliable offset to the TCS.

The star position and its characteristics are extracted from the Guide CCDs images using SExtractor code.

The following **operation modes** are supported:

- *Auto*: This is the main loop mode and is in charge of the acquisition and continuous tracking of the guide stars for delivering the correction signal to the TCS. It expects already pre-computed Region Of Interest (ROI) images with at least one star in it. Thus, the guider does not attempt to optimize nor configure the ROI in this mode. The guider continuously reads new images, tracks guide stars and sends correction signals until stop_guiding signal is sent.
- *Self*: This mode only executes the Acquisition stage once to automatically set the guide star and configure the ROI. In this mode the guide analyzes the next (first) image and finds the best guide star for each CCD. ROI information is extracted and sent to the Guide Control System (GCS). The GCS then issues another start_guider call with the mode changed from 'self' to 'auto'. stop_guiding is called after the first image.
- *User*: This mode carries out the same task as “Self” mode, with the difference that the guide star selection is made manually by the Observer rather than by itself. Then it executes the Acquisition stage only to manually set the guide star. In this mode a single image is taken, analyzed and presented to the observer. The observer selects the guide star(s) and the guider determines the ROI information, which it forwards to the GCS. The internal mode is then changed from 'user' to 'auto'. The (PML) function 'manual_selection' can be used to load ROI settings for the selected star(s) into the GCS. stop_guiding is called after the first image.

2.1.1 Acquisition

Acquisition is carried out in the initialization phase of the guiding process. As said, the target is to select the best star for guiding from the ones available in the Guide CCD image. On average, SExtractor provides more accurate stellar positions with stars that have a higher signal-to-noise (SN). This is fairly simple to achieve as the only thing to do is order the stars found in the image by SN. However SExtractor provides objects that must be discarded as candidates for guiding since they could cause serious problems while tracking. These are:

- Stars with at least one pixel saturated in the CCD
- Stars truncated in the border of the image or close to it
- Stars with neighbors, bright and close enough to significantly bias its flux
- Galaxies

Also, the algorithm looks for isolated stars within a range defined by the user, to avoid mismatching the guide star at the tracking stage.

To sum up, the guider will:

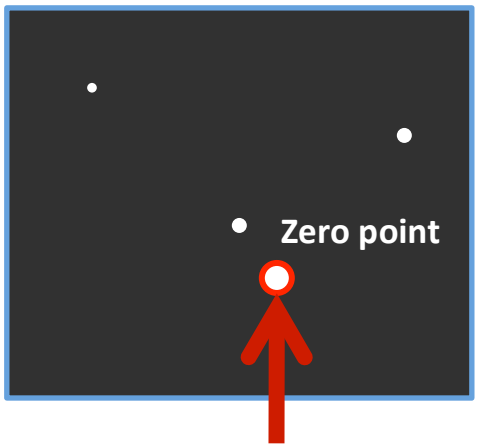
- Create a list with all the objects found
- Discard the objects not suited for guiding
- Select the star with best SN from the remaining list (except in User mode)
- Establish a zero point at the guide star position for the whole exposure

In User mode, the observer will be able to select any object from the list to be the reference guide star.

2.1.2 Tracking

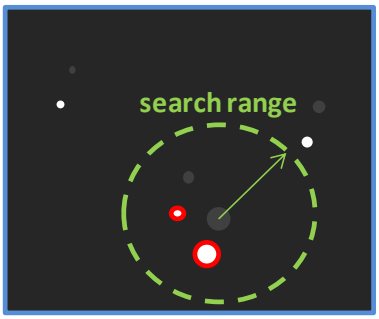
At this stage the Guider task is to find which is the reference guide star from the sources detected in each iteration image. SExtractor is in charge of extracting sources from the input image (determines guiding precision). The Guider is responsible for finding which of these sources corresponds to our initially set guide star (determines guiding confidence). It is extremely important to avoid the situation of loosing or mismatching the reference guide star; hence the guider follows the next algorithm:

Acquisition - only in first iteration

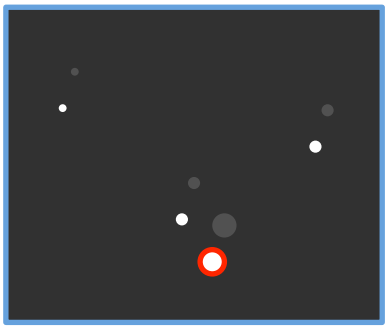


0. Select a guide star and establish the **zero point** at its position. As said in the previous section, if mode is 'self' the reference star will be the one with highest SN. On the other hand, if mode 'user' the user selects a custom star.

Tracking - next iterations



1. Set the stars found inside the **search range** (surrounding the **zero point** position) as original reference guide star candidates. The search range is large enough to have the guide star inside (larger than the maximum tracking error) and small enough to cover just few stars from the several available in the entire CCD image (ideally only the reference guide star will be within the search range as non-isolated stars are discarded at the Acquisition stage)



2. Choose the star with **most similar flux** to the reference guide star flux (guide star flux is updated every iteration to safeguard changing sky conditions during the exposure).

In general, only the reference star is located in the search range but in case we find more than one star, step 2 identifies easily the guide star.

2.1.3 Compute Offset

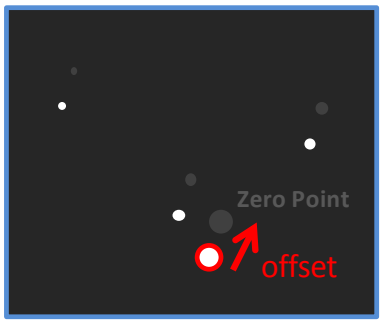
Computing the offset from a single CCD is as simple as measuring the distance from the position of the new guide star found and the zero point. However, the technique lies in managing multiple offsets when more than one Guide CCD is active.

The simplest way to combine the information from the multiple CCDs is by averaging the offsets. But as it is known that the position accuracy of SExtractor is higher in high SN stars, the offset will be averaged by weighting the mean with the corresponding guide star SN. The expression for the output offset is shown below:

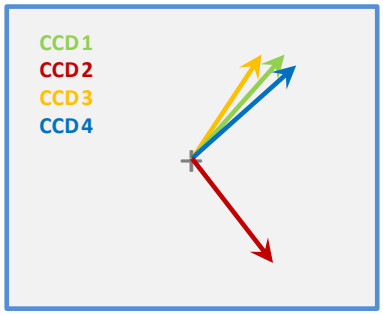
$$OutputOffset = \frac{\sum_{iCCD}^{activeCCDs} offset_{iCCD} \cdot GuideStarSN_{iCCD}}{\prod_{iCCD}^{activeCCD} GuideStarSN_{iCCD}}$$

By using the weighted mean, the more reliable stars have more importance in the final offset. Even so, having 4 Guide CCDs provide us more advantages. The second measure is involved with the agreement/discordance among the tracking error information given by the different CCDs. This means that if three CCDs say the same thing and the remaining one says a

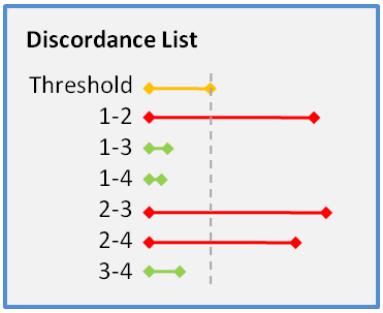
completely different thing, we probably should discard the disaccording one and do not take it into account for the output offset average.



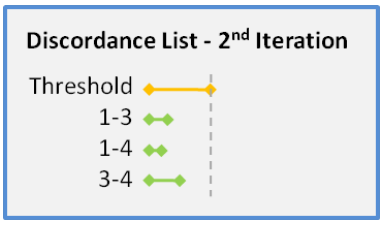
3. The offset for each CCD is calculated measuring the distance between found guide star and the zero point



4. Obtain the offset for all active Guide CCDs.

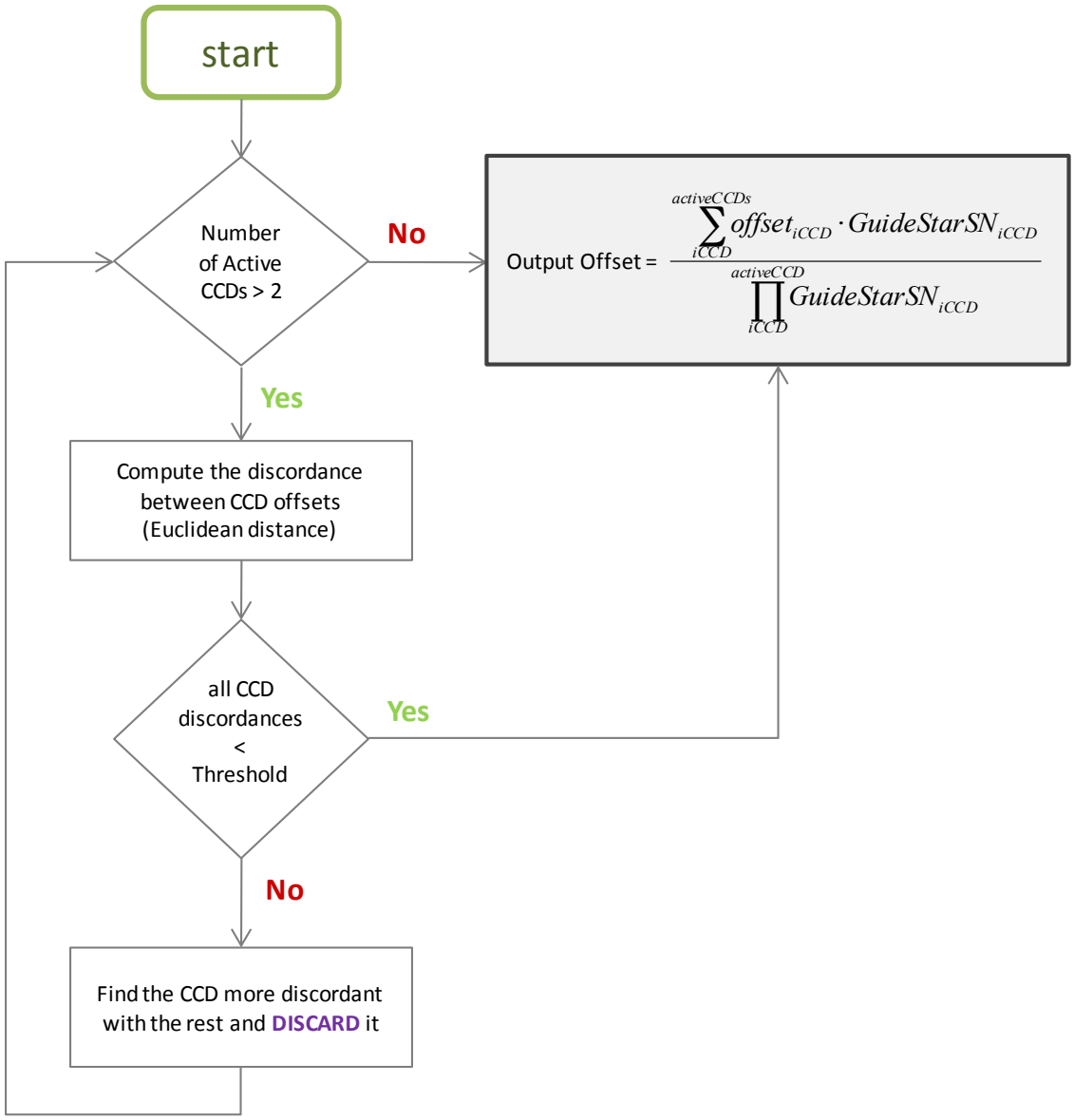


5. Compute the discordance (Euclidean distance) between offsets for all CCDs. If the discordance is over a threshold discard the most discordant (in this example it is obvious that CCD 2 must be discarded).



6. The discordance between the remaining offsets must be minimum (In this case and after discarding CCD2, all distances stay under the threshold so no more CCDs will be discarded). At this moment or when the number of CCDs is less than 3, the remaining offsets are averaged.

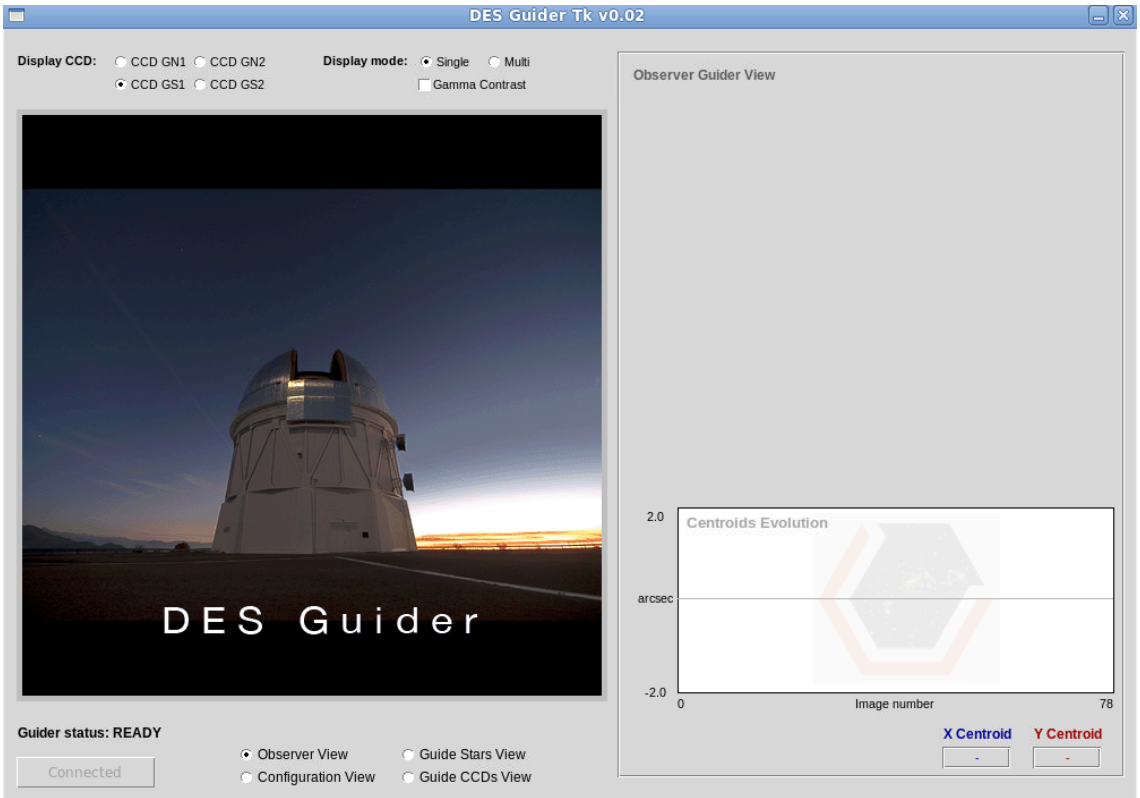
The next flowchart represents the discard CCDs algorithm:



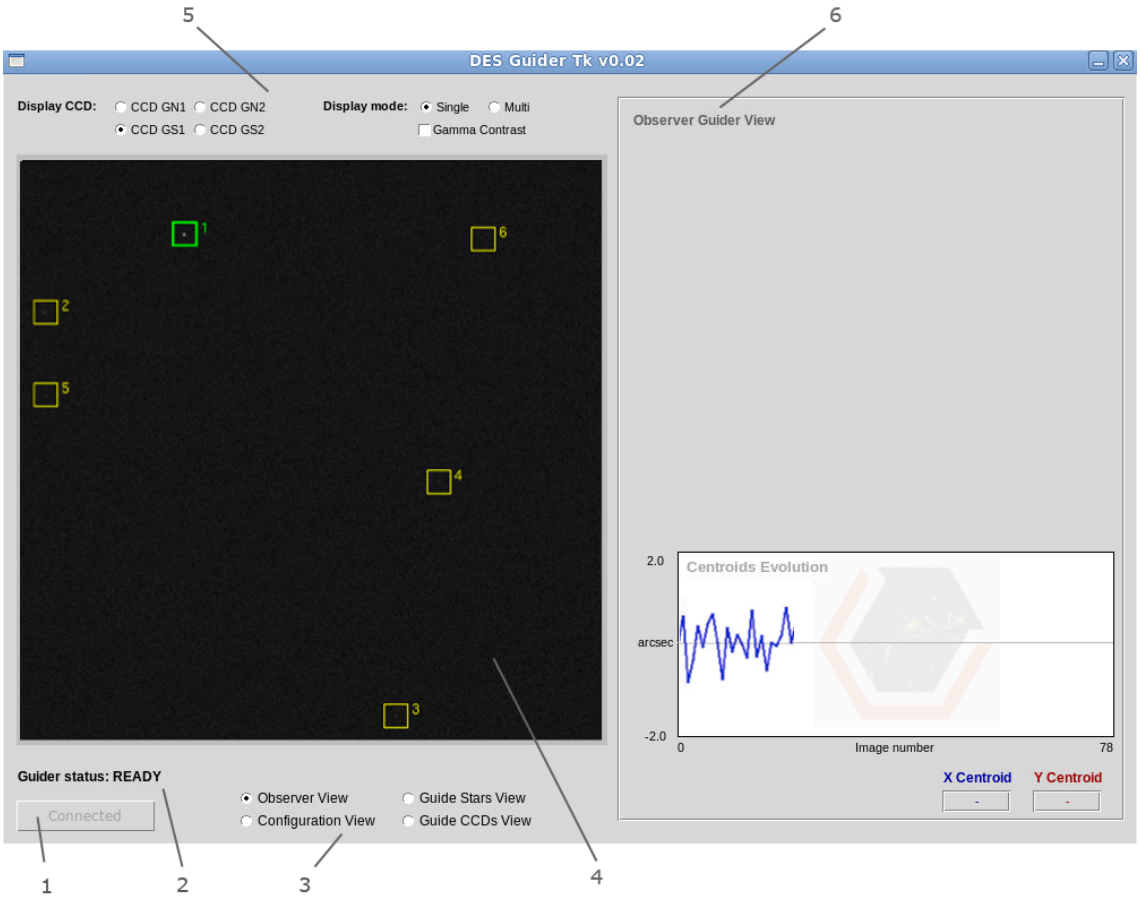
2.2 Running the guider

2.2.1 GUI Main Screen and Views

The Main view screen appears after the Guider GUI application starts:



The next figure represents the guider running after several iterations. Here is a brief explanation of the Main Screen parts:



1. *Connection Button*: Press this button at start to connect the GUI to the SISPI Guider.
2. *Guider Status*: Displays the current status of the Guider.
3. *View Selection*: Selects which view is displayed in the right part of the window.
4. *Image Screen*: Displays the FITS images of the Guide CCDs. The detected objects in the guide image are highlighted with a box. It also displays error messages (i.e. a reference star is lost). The guider differentiates 3 types of stars:

Green Box
Guide Star

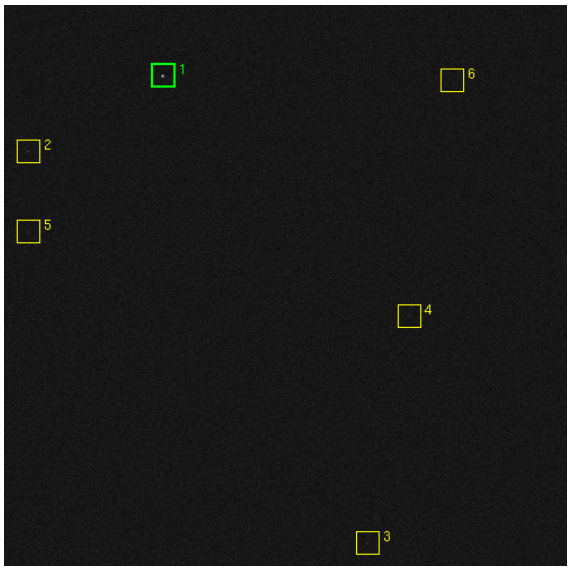
Yellow Box
Available Star

Red Box
Object not recommended for guiding

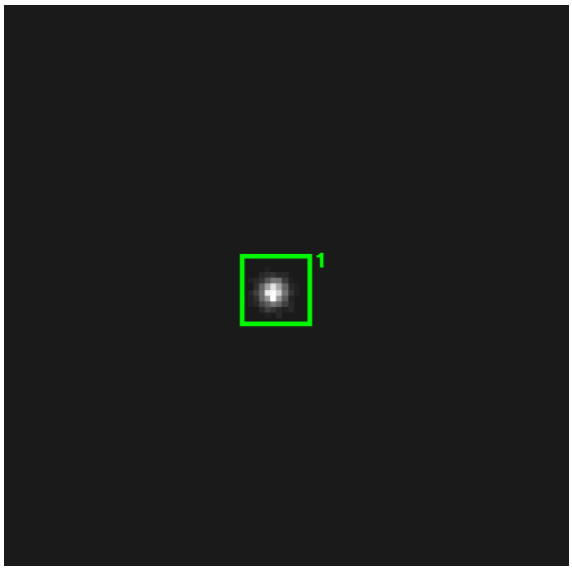
The objects not recommended for guiding correspond to:

- Stars close to the edge of the CCD image (most common)
- Stars with at least one pixel saturated in the CCD
- Stars truncated in the border of the image
- Stars with neighbors, bright and close enough to significantly bias its flux
- Galaxies

If the Guider is receiving ROI fits files, it automatically zooms in the image:



Guide with full Image



Guide with ROI

5. *Display Control*: Choose between Single display (One CCD Image in the screen) or Multi display (All 4 CCD Images in screen) in **Display Mode**. When Display Mode is Single, indicate which CCD want to display in **Display CCD**. Gamma Contrast can be turned on to increase the contrast at the image displayed (useful when guiding with low SN guide stars).
6. *View*: The frame in the right side of the window can display different information.
    a. Observer View: Plots the evolution of the output offset (also named as correction or error signal) that has been sent to the TCS. The **blue** line corresponds to the offset in the X axis of the CCD and the **red** line corresponds to the Y axis.
    b. Guide Stars View: Prints an updated list of the stars found in the CCD image (for the CCD displayed in the *Image Screen*). Each star is listed with the following characteristics:
        i. *Star*: The star number. Matches with the number close to the star in the Image Screen. As the stars are listed in S/N order, the lower the number is, the better is its quality.
        ii. *S/N*: Signal to noise ratio.
        iii. *Flux: Number of counts received*
        iv. *Mag*: Apparent Magnitude (Uncalibrated)
        v. FWHM: Full Width at Half Maximum (Seeing)
    c. Configuration View:
        i. Operation Mode: Displays Operation mode (auto, self, user).
        ii. CCD Configuration: Allows enable/disable any Guide CCD (note: it just skips the information, it does no interaction with the electronics nor the readout system). Auto or Manual selection can be adjusted when mode is User.

iii. TCS Correction signal: Enables/Disables the delivery of correction signals to the TCS. The percentage of the correction signal can be adjusted.

d. CCDs View: N/A yet.

2.2.2 Internal Settings

Here are listed some configuration available only in the header of the main guider code:

- *enable_simulation*: Enable simulated images, overwriting acquired images (Default is False)
- remove_temp_files: Remove processed .fits and .USED/.ERROR files after the guiding loop (Default is True)
- remove_old_files: Remove already existing .fits and .DONE before the guiding loop. Renamed .MISSED if False. (Default is True)
- safe_edge: Distance from the edge of the image where stars are considered safe for guiding (Default is 10 pixels)
- search_range: Radius range where the guide algorithm searches the reference (Default is 5")
- flag_cut: SExtractor flag limit to discard detections (Default is 0)
- max_ccd_errors: Maximum number of ccd errors in a row (guide star not found) before disabling it (Default is 3)
- max_null_centroids: Maximum number of void centroids in a row before stopping the guider (Default is 2)
- centroid_combination_type: As it has been explained in the *Compute Offset* section, the output offset is calculated weighting the mean with the corresponding guide star SN value.

$$OutputOffset = \frac{\sum_{iCCD}^{activeCCDs} offset_{iCCD} \cdot GuideStarSN_{iCCD}}{\prod_{iCCD}^{activeCCD} GuideStarSN_{iCCD}}$$

The offset will be then computed using an arithmetic mean (same as if all weights were the same).

$$OutputOffset_{weight_disabled} = \frac{1}{\#activeCCDs} \sum_{iCCD}^{activeCCDs} offset_{iCCD}$$

[Mean, WeightedMean, Median] (Default is WeightedMean)

- discard_options: # Discard CCD centroids mode [Disabled/Fix/Adaptive] (Default mode is Adaptive, Default threshold is 4).

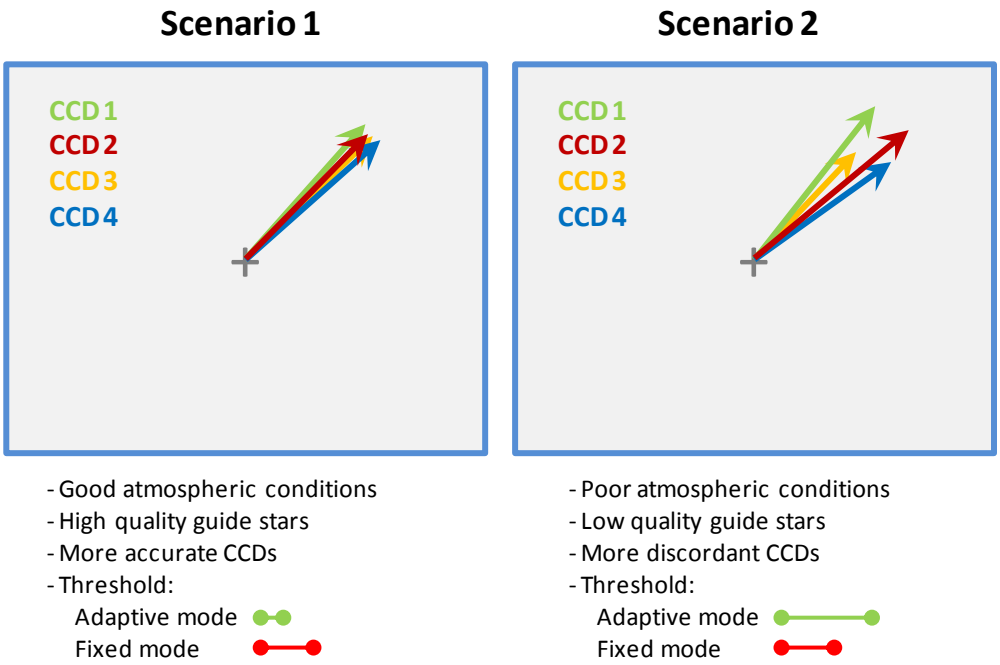
  This is another technique made to maximize the quality and veracity of the output correction signal. Basically the technique relies in discard CCD offsets that disagree with the rest (more information about the Discard CCDs option

in the *Compute Offset* section). If this option is disabled no CCD will be discarded. The default value is ON.

To discard CCDs we need to establish a limit (threshold) of maximum discordance accepted. Offsets found over that limit will be discarded and offsets under the limit will be averaged for the final correction signal. There are two ways of settle on this constraint:

- **Adaptive:** The threshold is adjusted every iteration depending on the correction signal differences found among the available CCDs. In other words, more discordant CCD offsets will have a more tolerant threshold than very accurate CCDs.
- **Fixed:** The threshold is set to a fix value given by the user.

The following example illustrates the advantage of the *Adaptive* mode against the *Fixed* mode.



Differences between CCDs can differ significantly depending on the quality of the guide star or due to different atmospheric conditions.

Using the *fixed* mode to establish the threshold has a risk. In scenario 1, fixed mode will probably never discard a CCD (even if it is clear that one CCD is saying something different than the rest) and in scenario 2 almost certainly it will discard 2 CCDs every iteration. It has been tested that *Adaptive* mode performs better in all conditions. For this reason it is recommended to use *Adaptive* mode (set by default).

2.2.3 Error cases

Due to different reasons such as clouds, poor guide star SN, CCD acquisition failure, etc. the guide star can be lost. Depending on the state of the guider a different action will be carried out:

Error ID	Cause	Effect
1	Guide star lost in CCD X	Error message
2	Guide star lost in CCD X for 3 consecutive iterations	Error message and stop guiding with CCD X
3	No available stars in any CCD	Error message and short alarm
4	All CCDs stopped due to Error 2	Error message, stop Guider and intense alarm

3 Technical Information

The guider software has been developed with the aim of creating a stable guider with the most useful features together with a user-friendly interface. It has around 3200 lines of code written in Python and Tkinter (Tcl/Tk).

3.1 System requirements

The program has been designed to run under *Linux-Unix* system. The following the specifications detailed below are just indicative but necessary to reach the performance described on the next section.

- Processor speed: 2.0GHz
- Memory: 1GB
- Graphics Memory: 256MB
- Screen Resolution: 1024×768 pixels

3.2 Installation

There is a list of programs that must be installed **before** running the guider software as they are called during the guiding execution. The programs are:

- *SExtractor* - Builds a catalogue of objects from an astronomical image.
  - Download it from: http://terapix.iap.fr/rubrique.php?id_rubrique=91
- *Tkinter* - Python's standard Graphical User Interface
  - Using (K)Ubuntu -> Open "Adept Manager" -> Install "idle" and "python-tk"
- *GraphicsMagick* - Software to create, edit, convert and compose bitmap images.
  - Using (K)Ubuntu -> Open Terminal -> `> sudo apt-get install graphicsmagick`
- *cfitsio* - Library needed to run the simulation package
  - Download from: http://heasarc.gsfc.nasa.gov/docs/software/fitsio/fitsio.html

3.3 Folder structure

The program is organized under a folder structure. This structure cannot be modified as the code has been made to run under this folder configuration.

Here is a brief description of each folder contents:

bin: Contains two python links to Guider and GuiderGUI and the image simulator binary.

config: Contains Guider and SExtractor configuration files.

external: Contains the image simulation source code (in C language). ImageSim is the image simulator to be run at real time with the guider under simulation mode and SequenceSim is used to generate sequence of guide images that are fed later to the readout system. In the last case the guider should not be configured in simulation mode. Also contains images and sound files required for the guiders GUI.

python/Guider: Contains the python code both for the Guider (guider.py) and its GUI (guidergui.py).

ups: Contains guider software requirements to be used within the SISPI framework.

4 Testing & Validation

4.1 Simulation Package

In order to test the guide software a guide image simulation package has been developed. It is fully written in C and makes use of the CFITSIO library and C Numerical Recipes to carry out specific tasks.

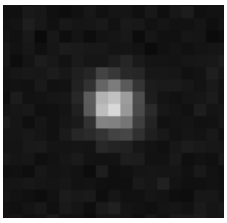
Once compiled, the package consists of an executable together with a parameter file. To create guide images the executable must be called with a set of arguments. The images created will depend on the arguments passed and on the parameter file. Next it will be explained only the parameter file as its parameters are the ones that can be interesting for testing and the executable arguments are automatically set inside the guide code.

Parameter File

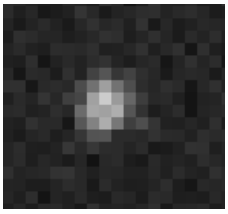
The following table lists the customizable parameters available in the Parameter file.

Parameter name	Typical Value	Unit (Description)
gain	1.0	e^-/ADU
readout_noise	10.0	e^-
scale	0.27	arcsec/pix (pixel scale)
zeropoint	26.5	e^-/s_to_mag (conversion)
seeing	0.9	arcsec (FWHM)
exptime	1.0	s (exposure time)
sky	0.5	mag/arcsec^2 (sky brightness)
stars_mag_bright	12.0	mag (min magnitude of stars to simulate)
stars_mag_faint	23.0	mag (max magnitude of stars to simulate)
stars_seed	10	- (seed for stars magnitude & position)
turbulence_sigma	0.50	arcsec (gauss sigma for image movement)
sample_freq	1500	samples/s/star (*)

*The sample frequency determines the number of samples per second used to represent a star in the CCD. Setting sample_freq to 1500, exposures longer than 1 second will represent stars with a similar Gaussian/Moffat PSF shape. On the other hand exposures shorter than 1 second will be drawn in a different PSF shape, more accurate to a real CCD image.



1 sec exposure star



0.5 sec exposure star

As we expect exposures from 0.5 to 10 seconds this feature provides more realistic guide images for testing.

4.2 Testing & Performance

In terms of performance, the parameters to take into account are the correction signal accuracy and the process time (we understand process time as the time elapsed from the reception of the Guide Images to the consignment conclusion of the correction signals).

The precision on the tracking error basically depends on the quality of the stars and on the number of Guide CDDs used. The following table shows the measures obtained using the DES Guider software with simulated data:

Star Magnitude	1 Guide CCD	4 Guide CCDs
15	0.044 pix	0.038 pix
16	0.074 pix	0.049 pix
17	0.103 pix	0.056 pix
18	0.143 pix	0.082 pix
19	0.220 pix	0.095 pix

This guide precision was obtained with the following simulation parameters:

- Readout Noise = 10.0 e^-
- Pixel Scale = 0.27 arcsec/pixel
- Zeropoint = 26.5 e^-/s_to_mag
- Seeing = 0.9 arcsec
- Exposure = 1 sec
- Sky = 20.5 mag/arcsec^2
- Turbulence Sigma = 0.5 arcsec

Concerning to the process time it is basically influenced by the size of the image that has to be analyzed. Initially the image size is always the Guide CCD size (2k×2k). However, if it is not specified the contrary, the image will be only analyzed in the Region of Interest (ROI) which is much smaller than the full CCD image and consequently, the process time will decrease significantly. The values measured using the 4 guide CCDs are the following:

Image Size	Process Time
Full CCD (2k×2k)	1.300 s
ROI (500×500)	0.140 s
ROI (200×200)	0.070 s
ROI (100×100)	0.060 s
ROI (50×50)	0.060 s

By default, the ROI Size is 50x50 pixels. With this size the guider can analyze images with the minimum process time and follow the guide star with no risk of losing it.

5 APPENDIX

5.1 Output files

The 3 programs present in the Guiding Package (Guider, SExtractor and Simulation Package) store their output files in the *outfiles* folder. They are all are written in ASCII code and have the following format:

GUIDER OUTPUT - *output.dat*

```
#GUIDING OUTPUT
#1.Iteration
#2.X offset (in pixels)
#3.Y offset (in pixels)
#4.Seeing
#5.Transparency
#6.CCDs used for offset average
0      0.000       0.000      0.938 1.000 [1, 2, 3, 4]
1     -0.835       1.263      0.933 0.999 [1, 4]
2      0.834       0.681      0.911 1.000 [1, 2, 3, 4]
3      0.652       0.167      0.948 0.999 [1, 2, 4]
4      2.138       1.735      0.919 0.999 [1, 2, 3, 4]
5     -1.886      -0.163      0.919 1.000 [1, 2, 3, 4]
6      0.118      -0.048      0.911 1.000 [1, 2, 3, 4]
7     -0.003      -1.719      0.904 0.999 [1, 2, 3, 4]
8     -1.711       0.211      0.951 0.999 [1, 2, 3, 4]
9     -0.986       0.399      0.935 1.000 [1, 2, 3, 4]
10    -0.119      -1.024      0.925 1.000 [1, 2, 3, 4]
11     0.383       0.570      0.902 1.000 [1, 2, 3, 4]
12    -0.010      -0.017      0.941 1.000 [1, 2, 3, 4]
13     0.310      -0.902      0.954 0.999 [1, 2, 4]
14     0.360      -0.046      0.934 1.000 [1, 2, 4]
15    -0.706       0.187      0.923 0.999 [1, 2, 3, 4]
16    -0.341      -0.892      0.945 1.001 [1, 3, 4]
...
```

GUIDER LOG file - *autologfileDMY_HM.log* *(D=Day, M=Month, Y=Year, H=Hour, M=Minute)*

```
> 12:59:25.669ms - Start guiding
> 12:59:25.675ms - Initializing guider...
> 12:59:25.692ms - Guide Image number 1
> 12:59:25.699ms - Simulating guide image for CCD 1
> 12:59:27.354ms - Simulation for CCD 1 image finished successfully
> 12:59:27.357ms - Simulating guide image for CCD 2
> 12:59:28.871ms - Simulation for CCD 2 image finished successfully
> 12:59:28.874ms - Simulating guide image for CCD 3
> 12:59:30.220ms - Simulation for CCD 3 image finished successfully
> 12:59:30.223ms - Simulating guide image for CCD 4
> 12:59:31.579ms - Simulation for CCD 4 image finished successfully
> 12:59:31.601ms - Guide image simulation finished successfully
> 12:59:31.604ms - Running SExtractor for CCD 1 image
> 12:59:32.288ms - SExtractor finished
> 12:59:32.294ms - Running SExtractor for CCD 2 image
> 12:59:32.447ms - SExtractor finished
> 12:59:32.452ms - Running SExtractor for CCD 3 image
> 12:59:32.587ms - SExtractor finished
> 12:59:32.598ms - Running SExtractor for CCD 4 image
> 12:59:32.758ms - SExtractor finished
> 12:59:32.764ms - Starting FITS image conversion
> 12:59:33.325ms - FITS image conversion finished
> 12:59:33.340ms - Number of objects found in CCD 1: 5
> 12:59:33.343ms - Number of objects found usefull for guiding in CCD 1: 5
> 12:59:33.346ms - Number of objects found in CCD 2: 7
> 12:59:33.348ms - Number of objects found usefull for guiding in CCD 2: 6
> 12:59:33.351ms - Number of objects found in CCD 3: 5
> 12:59:33.354ms - Number of objects found usefull for guiding in CCD 3: 5
```

```
> 12:59:33.357ms - Number of objects found in CCD 4: 4
> 12:59:33.359ms - Number of objects found usefull for guiding in CCD 4: 4
> 12:59:33.362ms - Reference star SET in CCD 1 (Auto mode)
> 12:59:33.365ms - Reference star Position in CCD 1: [290.674,889.641]
> 12:59:33.367ms - Reference star Flux in CCD 1: 6913.397
> 12:59:33.370ms - Reference star Seeing in CCD 1: 0.915
> 12:59:33.374ms - Reference star SET in CCD 2 (Auto mode)
> 12:59:33.377ms - Reference star Position in CCD 2: [726.396,613.422]
> 12:59:33.379ms - Reference star Flux in CCD 2: 32741.340
> 12:59:33.382ms - Reference star Seeing in CCD 2: 0.972
> 12:59:33.384ms - Reference star SET in CCD 3 (Auto mode)
> 12:59:33.387ms - Reference star Position in CCD 3: [813.664,435.502]
> 12:59:33.389ms - Reference star Flux in CCD 3: 2235.581
> 12:59:33.393ms - Reference star Seeing in CCD 3: 1.085
> 12:59:33.397ms - Reference star SET in CCD 4 (Auto mode)
> 12:59:33.402ms - Reference star Position in CCD 4: [855.675,774.075]
> 12:59:33.406ms - Reference star Flux in CCD 4: 3742.896
> 12:59:33.411ms - Reference star Seeing in CCD 4: 0.902
> 12:59:33.416ms - The CCDs to be averaged for final offset are: [1, 2, 3, 4]
> 12:59:33.475ms - Iteration time: 7.785 sec
> 12:59:33.495ms - Guide Image number 2
> 12:59:33.500ms - Simulating guide image for CCD 1
> 12:59:33.590ms - Simulation for CCD 1 image finished successfully
> 12:59:33.593ms - Simulating guide image for CCD 2
> 12:59:33.660ms - Simulation for CCD 2 image finished successfully
> 12:59:33.665ms - Simulating guide image for CCD 3
> 12:59:33.802ms - Simulation for CCD 3 image finished successfully
> 12:59:33.805ms - Simulating guide image for CCD 4
> 12:59:33.859ms - Simulation for CCD 4 image finished successfully
> 12:59:33.886ms - Guide image simulation finished successfully
> 12:59:33.889ms - Running SExtractor for CCD 1 image
> 12:59:33.900ms - SExtractor finished
> 12:59:33.906ms - Running SExtractor for CCD 2 image
> 12:59:33.917ms - SExtractor finished
> 12:59:33.923ms - Running SExtractor for CCD 3 image
> 12:59:33.934ms - SExtractor finished
> 12:59:33.940ms - Running SExtractor for CCD 4 image
> 12:59:33.951ms - SExtractor finished
> 12:59:33.958ms - Starting FITS image conversion
> 12:59:34.003ms - FITS image conversion finished
> 12:59:34.014ms - Number of objects found in CCD 1: 1
> 12:59:34.018ms - Number of objects found usefull for guiding in CCD 1: 1
> 12:59:34.021ms - Number of objects found in CCD 2: 1
> 12:59:34.025ms - Number of objects found usefull for guiding in CCD 2: 1
> 12:59:34.028ms - Number of objects found in CCD 3: 1
> 12:59:34.031ms - Number of objects found usefull for guiding in CCD 3: 1
> 12:59:34.036ms - Number of objects found in CCD 4: 1
> 12:59:34.041ms - Number of objects found usefull for guiding in CCD 4: 1
> 12:59:34.045ms - Searching reference star
> 12:59:34.051ms - Stars found near to the reference in CCD 1 [ID]: [0]
> 12:59:34.055ms - Reference star found in CCD 1
> 12:59:34.060ms - Guide Star details:
> 12:59:34.065ms - SNR: 55.3
> 12:59:34.069ms - Position: [292.031,887.601]
> 12:59:34.074ms - Flux: 7389.5
> 12:59:34.078ms - Seeing: 1.002
> 12:59:34.083ms - Measured Offset in CCD 1: [1.357,-2.040]
> 12:59:34.089ms - Searching reference star
> 12:59:34.093ms - Stars found near to the reference in CCD 2 [ID]: [0]
> 12:59:34.098ms - Reference star found in CCD 2
> 12:59:34.103ms - Guide Star details:
> 12:59:34.107ms - SNR: 156.2
> 12:59:34.112ms - Position: [727.684,611.372]
> 12:59:34.117ms - Flux: 32717.7
> 12:59:34.121ms - Seeing: 0.942
> 12:59:34.126ms - Measured Offset in CCD 2: [1.288,-2.050]
> 12:59:34.131ms - Searching reference star
> 12:59:34.135ms - Stars found near to the reference in CCD 3 [ID]: [0]
> 12:59:34.140ms - Reference star found in CCD 3
> 12:59:34.144ms - Guide Star details:
> 12:59:34.149ms - SNR: 23.3
> 12:59:34.154ms - Position: [814.958,433.589]
> 12:59:34.158ms - Flux: 2402.0
> 12:59:34.163ms - Seeing: 1.026
> 12:59:34.168ms - Measured Offset in CCD 3: [1.294,-1.913]
> 12:59:34.172ms - Searching reference star
> 12:59:34.177ms - Stars found near to the reference in CCD 4 [ID]: [0]
```

```
> 12:59:34.181ms - Reference star found in CCD 4
> 12:59:34.186ms - Guide Star details:
> 12:59:34.190ms - SNR: 34.4
> 12:59:34.195ms - Position: [856.897,771.971]
> 12:59:34.199ms - Flux: 3987.2
> 12:59:34.204ms - Seeing: 0.953
> 12:59:34.209ms - Measured Offset in CCD 4: [1.222,-2.104]
> 12:59:34.214ms - CCD number 3 has been discarded
> 12:59:34.218ms - CCD number 4 has been discarded
> 12:59:34.223ms - The CCDs to be averaged for final offset are: [1, 2]
> 12:59:34.240ms - Guiding error : 0.066 (pixels) in CCD 1 with star sn = 55.3
> 12:59:34.244ms - Guiding error : 0.085 (pixels) in CCD 2 with star sn = 156.2
> 12:59:34.249ms - Guiding error : 0.077 (pixels) in CCD 3 with star sn = 23.3
> 12:59:34.254ms - Guiding error : 0.168 (pixels) in CCD 4 with star sn = 34.4
> 12:59:34.258ms - FINAL Guiding error : 0.074 (pixels) using CCDs number [1, 2]
> 12:59:34.263ms - FINAL Guiding error (MEAN) : 0.074 (pixels)
> 12:59:34.267ms - Error standard deviation is 0.000000
> 12:59:34.278ms - Iteration time: 0.783 sec
> 12:59:34.283ms - Sleeping for 1.217s... zzZz...
> 12:59:35.931ms - Wake up!
> 12:59:35.967ms - Guide Image number 3
...
```

SIMULATION PACKAGE OUTPUT - *guideNs_CCDX.dat* *(N=CCD pixels size, X=CCD number)*

Format:

Iteration - Star Number - X & Y CCD pixel position - X & Y Offset - Magnitude - Flux

```
    0     0 1462.157  423.112     0.000     0.000     21.16     1.367e+02
    0     1 1352.327 1431.410     0.000     0.000     22.95     2.626e+01
    0     2  699.287 1300.950     0.000     0.000     22.90     2.761e+01
    0     3  593.038   39.469     0.000     0.000     19.22     8.140e+02
    0     4  363.929 1001.039     0.000     0.000     22.12     5.644e+01
    0     5 1778.099  843.911     0.000     0.000     21.38     1.112e+02
    0     6 1796.853 1120.807     0.000     0.000     15.21     3.273e+04
    0     7 1774.688  473.967     0.000     0.000     17.70     3.299e+03
    0     8 1025.006 1619.696     0.000     0.000     19.33     7.361e+02
    0     9  865.298 1859.654     0.000     0.000     22.47     4.089e+01
    0    10  458.431 1116.537     0.000     0.000     20.40     2.764e+02
    0    11 1846.575  521.872     0.000     0.000     22.91     2.721e+01
    0    12  918.741 1610.807     0.000     0.000     17.98     2.551e+03
    0    13 1577.278 1621.784     0.000     0.000     19.04     9.601e+02
    0    14 1239.561  917.194     0.000     0.000     22.32     4.692e+01
    0    15 1947.045 1404.353     0.000     0.000     21.80     7.557e+01
    0    16 1669.464 1918.328     0.000     0.000     22.96     2.613e+01
    0    17 1819.649 1338.272     0.000     0.000     18.77     1.232e+03
    0    18  911.658 2014.435     0.000     0.000     17.14     5.532e+03
    0    19 1209.891 1828.582     0.000     0.000     20.07     3.750e+02
    0    20  537.443  917.480     0.000     0.000     20.75     2.004e+02
    0    21  596.778 1530.496     0.000     0.000     19.92     4.281e+02
    0    22  440.493  857.856     0.000     0.000     21.32     1.185e+02
    0    23 1539.469 2040.156     0.000     0.000     21.64     8.827e+01
    0    24 1594.412 1734.006     0.000     0.000     21.85     7.234e+01
    0    25  914.382  443.754     0.000     0.000     22.30     4.808e+01
    0    26 1510.892 1679.950     0.000     0.000     22.26     4.975e+01
    0    27   85.633  164.620     0.000     0.000     20.76     1.985e+02
    0    28 1226.915 1838.306     0.000     0.000     18.75     1.264e+03
    0    29 1891.909  838.047     0.000     0.000     21.27     1.231e+02
    0    30 1584.769  488.927     0.000     0.000     20.53     2.436e+02
    0    31  416.520  525.014     0.000     0.000     21.33     1.173e+02
    0    32 1512.551  129.426     0.000     0.000     18.89     1.111e+03
    0    33 1917.593  640.353     0.000     0.000     14.02     9.791e+04
    0    34  940.179 1883.071     0.000     0.000     21.13     1.400e+02
    0    35  924.140  892.601     0.000     0.000     22.84     2.911e+01
    0    36 1413.527 1571.928     0.000     0.000     22.49     4.003e+01
    0    37  445.260 1340.128     0.000     0.000     20.57     2.356e+02
    0    38  865.667 1692.060     0.000     0.000     21.77     7.827e+01
    0    39 1679.058  131.351     0.000     0.000     17.10     5.773e+03
    0    40  997.642 2043.116     0.000     0.000     19.44     6.675e+02
```

0	41	943.368	144.645	0.000	0.000	19.50	6.283e+02
0	42	1137.504	318.319	0.000	0.000	22.88	2.801e+01
0	43	1689.165	140.105	0.000	0.000	16.94	6.672e+03
0	44	165.555	86.092	0.000	0.000	16.24	1.267e+04
0	45	1554.959	218.497	0.000	0.000	21.78	7.724e+01
0	46	704.894	931.005	0.000	0.000	22.56	3.781e+01
0	47	1045.590	1700.339	0.000	0.000	21.64	8.818e+01
0	48	1163.426	195.263	0.000	0.000	19.46	6.537e+02
0	49	1594.557	1896.252	0.000	0.000	19.45	6.617e+02
0	50	551.301	2019.320	0.000	0.000	20.16	3.448e+02
0	51	118.895	1709.161	0.000	0.000	20.89	1.747e+02
0	52	1072.040	60.229	0.000	0.000	22.47	4.099e+01
0	53	386.937	1129.361	0.000	0.000	21.89	6.988e+01
0	54	718.045	1273.974	0.000	0.000	21.62	8.927e+01
0	55	1284.663	1817.053	0.000	0.000	21.68	8.504e+01
0	56	981.200	1506.114	0.000	0.000	19.66	5.451e+02
0	57	532.939	948.702	0.000	0.000	20.24	3.181e+02
0	58	632.237	152.657	0.000	0.000	21.14	1.390e+02
0	59	52.891	176.710	0.000	0.000	20.25	3.165e+02
0	60	740.480	1328.656	0.000	0.000	21.99	6.384e+01
0	61	1695.600	1432.828	0.000	0.000	20.34	2.918e+02
0	62	557.352	950.646	0.000	0.000	21.56	9.495e+01
0	63	862.095	271.026	0.000	0.000	22.03	6.160e+01
1	0	1462.157	423.112	-0.861	1.277	21.16	1.367e+02
1	1	1352.327	1431.410	-0.861	1.277	22.95	2.626e+01
1	2	699.287	1300.950	-0.861	1.277	22.90	2.761e+01
1	3	593.038	39.469	-0.861	1.277	19.22	8.140e+02
1	4	363.929	1001.039	-0.861	1.277	22.12	5.644e+01
1	5	1778.099	843.911	-0.861	1.277	21.38	1.112e+02
1	6	1796.853	1120.807	-0.861	1.277	15.21	3.273e+04
1	7	1774.688	473.967	-0.861	1.277	17.70	3.299e+03
1	8	1025.006	1619.696	-0.861	1.277	19.33	7.361e+02
1	9	865.298	1859.654	-0.861	1.277	22.47	4.089e+01
1	10	458.431	1116.537	-0.861	1.277	20.40	2.764e+02
1	11	1846.575	521.872	-0.861	1.277	22.91	2.721e+01
1	12	918.741	1610.807	-0.861	1.277	17.98	2.551e+03
1	13	1577.278	1621.784	-0.861	1.277	19.04	9.601e+02
1	14	1239.561	917.194	-0.861	1.277	22.32	4.692e+01
1	15	1947.045	1404.353	-0.861	1.277	21.80	7.557e+01
1	16	1669.464	1918.328	-0.861	1.277	22.96	2.613e+01
1	17	1819.649	1338.272	-0.861	1.277	18.77	1.232e+03
1	18	911.658	2014.435	-0.861	1.277	17.14	5.532e+03
1	19	1209.891	1828.582	-0.861	1.277	20.07	3.750e+02
1	20	537.443	917.480	-0.861	1.277	20.75	2.004e+02
1	21	596.778	1530.496	-0.861	1.277	19.92	4.281e+02
1	22	440.493	857.856	-0.861	1.277	21.32	1.185e+02
1	23	1539.469	2040.156	-0.861	1.277	21.64	8.827e+01
1	24	1594.412	1734.006	-0.861	1.277	21.85	7.234e+01
1	25	914.382	443.754	-0.861	1.277	22.30	4.808e+01
1	26	1510.892	1679.950	-0.861	1.277	22.26	4.975e+01
1	27	85.633	164.620	-0.861	1.277	20.76	1.985e+02
1	28	1226.915	1838.306	-0.861	1.277	18.75	1.264e+03
1	29	1891.909	838.047	-0.861	1.277	21.27	1.231e+02
1	30	1584.769	488.927	-0.861	1.277	20.53	2.436e+02
1	31	416.520	525.014	-0.861	1.277	21.33	1.173e+02
1	32	1512.551	129.426	-0.861	1.277	18.89	1.111e+03
1	33	1917.593	640.353	-0.861	1.277	14.02	9.791e+04
1	34	940.179	1883.071	-0.861	1.277	21.13	1.400e+02
1	35	924.140	892.601	-0.861	1.277	22.84	2.911e+01
1	36	1413.527	1571.928	-0.861	1.277	22.49	4.003e+01
1	37	445.260	1340.128	-0.861	1.277	20.57	2.356e+02
1	38	865.667	1692.060	-0.861	1.277	21.77	7.827e+01
1	39	1679.058	131.351	-0.861	1.277	17.10	5.773e+03
1	40	997.642	2043.116	-0.861	1.277	19.44	6.675e+02
1	41	943.368	144.645	-0.861	1.277	19.50	6.283e+02
1	42	1137.504	318.319	-0.861	1.277	22.88	2.801e+01
1	43	1689.165	140.105	-0.861	1.277	16.94	6.672e+03
1	44	165.555	86.092	-0.861	1.277	16.24	1.267e+04

```
   1   45 1554.959  218.497   -0.861    1.277    21.78    7.724e+01
   1   46  704.894  931.005   -0.861    1.277    22.56    3.781e+01
   1   47 1045.590 1700.339   -0.861    1.277    21.64    8.818e+01
   1   48 1163.426  195.263   -0.861    1.277    19.46    6.537e+02
   1   49 1594.557 1896.252   -0.861    1.277    19.45    6.617e+02
   1   50  551.301 2019.320   -0.861    1.277    20.16    3.448e+02
   1   51  118.895 1709.161   -0.861    1.277    20.89    1.747e+02
   1   52 1072.040   60.229   -0.861    1.277    22.47    4.099e+01
   1   53  386.937 1129.361   -0.861    1.277    21.89    6.988e+01
   1   54  718.045 1273.974   -0.861    1.277    21.62    8.927e+01
   1   55 1284.663 1817.053   -0.861    1.277    21.68    8.504e+01
   1   56  981.200 1506.114   -0.861    1.277    19.66    5.451e+02
   1   57  532.939  948.702   -0.861    1.277    20.24    3.181e+02
   1   58  632.237  152.657   -0.861    1.277    21.14    1.390e+02
   1   59   52.891  176.710   -0.861    1.277    20.25    3.165e+02
   1   60  740.480 1328.656   -0.861    1.277    21.99    6.384e+01
   1   61 1695.600 1432.828   -0.861    1.277    20.34    2.918e+02
   1   62  557.352  950.646   -0.861    1.277    21.56    9.495e+01
   1   63  862.095  271.026   -0.861    1.277    22.03    6.160e+01
   2    0 1462.157  423.112    0.822    0.751    21.16    1.367e+02
   2    1 1352.327 1431.410    0.822    0.751    22.95    2.626e+01
   2    2  699.287 1300.950    0.822    0.751    22.90    2.761e+01
   2    3  593.038   39.469    0.822    0.751    19.22    8.140e+02
   2    4  363.929 1001.039    0.822    0.751    22.12    5.644e+01
   2    5 1778.099  843.911    0.822    0.751    21.38    1.112e+02
   2    6 1796.853 1120.807    0.822    0.751    15.21    3.273e+04
   2    7 1774.688  473.967    0.822    0.751    17.70    3.299e+03
   2    8 1025.006 1619.696    0.822    0.751    19.33    7.361e+02
   2    9  865.298 1859.654    0.822    0.751    22.47    4.089e+01
   2   10  458.431 1116.537    0.822    0.751    20.40    2.764e+02
   2   11 1846.575  521.872    0.822    0.751    22.91    2.721e+01
   2   12  918.741 1610.807    0.822    0.751    17.98    2.551e+03
   2   13 1577.278 1621.784    0.822    0.751    19.04    9.601e+02
   2   14 1239.561  917.194    0.822    0.751    22.32    4.692e+01
   2   15 1947.045 1404.353    0.822    0.751    21.80    7.557e+01
   2   16 1669.464 1918.328    0.822    0.751    22.96    2.613e+01
   2   17 1819.649 1338.272    0.822    0.751    18.77    1.232e+03
   2   18  911.658 2014.435    0.822    0.751    17.14    5.532e+03
   2   19 1209.891 1828.582    0.822    0.751    20.07    3.750e+02
   2   20  537.443  917.480    0.822    0.751    20.75    2.004e+02
   2   21  596.778 1530.496    0.822    0.751    19.92    4.281e+02
   2   22  440.493  857.856    0.822    0.751    21.32    1.185e+02
   2   23 1539.469 2040.156    0.822    0.751    21.64    8.827e+01
   2   24 1594.412 1734.006    0.822    0.751    21.85    7.234e+01
   2   25  914.382  443.754    0.822    0.751    22.30    4.808e+01
   2   26 1510.892 1679.950    0.822    0.751    22.26    4.975e+01
   2   27   85.633  164.620    0.822    0.751    20.76    1.985e+02
...
```

SExtractor OUTPUT - *guide_CCDX.cat (X=CCD number)*

```
#   1 NUMBER           Running object number
#   2 FLUX_APER        Flux vector within fixed circular aperture(s)   [count]
#   3 FLUXERR_APER     RMS error vector for aperture flux(es)          [count]
#   4 MAG_APER         Fixed aperture magnitude vector                 [mag]
#   5 MAGERR_APER      RMS error vector for fixed aperture mag.        [mag]
#   6 FLUX_AUTO        Flux within a Kron-like elliptical aperture     [count]
#   7 FLUXERR_AUTO     RMS error for AUTO flux                         [count]
#   8 MAG_AUTO         Kron-like elliptical aperture magnitude         [mag]
#   9 MAGERR_AUTO      RMS error for AUTO magnitude                    [mag]
#  10 KRON_RADIUS      Kron apertures in units of A or B
#  11 BACKGROUND       Background at centroid position                 [count]
#  12 FLUX_MAX         Peak flux above background                      [count]
#  13 X_IMAGE          Object position along x                         [pixel]
#  14 Y_IMAGE          Object position along y                         [pixel]
#  15 ELONGATION       A_IMAGE/B_IMAGE
#  16 ELLIPTICITY      1 - B_IMAGE/A_IMAGE
#  17 FWHM_IMAGE       FWHM assuming a gaussian core                   [pixel]
#  18 FWHM_WORLD       FWHM assuming a gaussian core                   [deg]
#  19 FLAGS            Extraction flags
```

```
#  20 CLASS_STAR      S/G classifier output
         1     98110.97     340.2325  14.0207   0.0038     98031.16     330.0103
14.0216   0.0037  3.50      5.68345     6906.708     51.985     49.592    1.018
0.018     3.47 0.0002602816   0  1.00
...
```