Astro2 Operator Guide (V0.7)

Michael Stewart

March 16 2022

1 Image Reduction

1.1 First Basic Calibration Run

Requirements:

- Dark Frames
- Flat Frames
- Non-calibrated Science Images

Optional:

- Bias Frames

Not Allowed:

- Dark Flats

The first step of the image processing pipeline is Image Reduction, also known as Image Calibration. To accomplish this task the user must select a directory which only includes uncalibrated "science" images: Images that have not had their bias or dark frames subtracted and divide by a flat frame. To check to see if an image has already been calibrated, open up the image in a .fits file viewer such as **MaximDL** or **AStroimageJ**. The *Image Folder* Directory in the GUI should point towards the non-calibrated images. Bias Frames (optional) [1], Dark Frames and Flat Frames directories should be selected below the Image Folder directory. If the user does not have Bias Frames, leave the Bias image Directory blank and deselect the Create Master Bias checkbox below. On the first run of the chosen dataset, deselect the *Use Existing Masters*.For Ground Based Data deselect the Space Based Checkbox.

The summation symbol in Figure 2 equates to producing the average of the frame collection to create a combined image.

1.2 Further Calibration

After the initial calibration round has been successfully completed, a folder called *master_frame _data* will be created. The user must then use the *Use Existing Masters* option and chose the aforementioned *master_frame _data* folder for all datasets which use the same bias,dark and flat data. In the GUI uncheck the *Create Master Bias*, *Create Master Dark* and *Create Master Flat* and leave the directories for the Bias,Dark and Flats empty. Fill the Image Folder Direcotry with the direcotry of images to be calibrated and Reduce.

If the user deems it acceptable to now correct outliers , they may check it and *master_frame_data* will be updated with corrected master frames .

[1] Not having bias frames will automatically turn off dark scaling

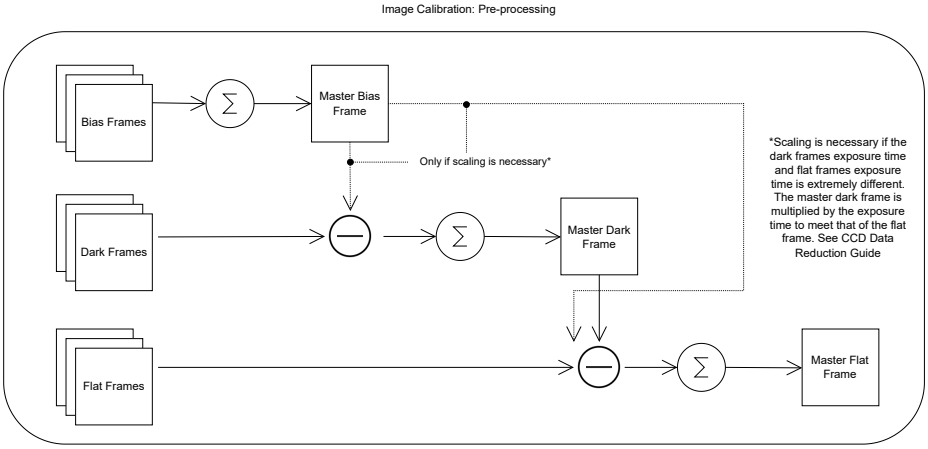

Figure 1: Image Calibration:Master Frame Combination

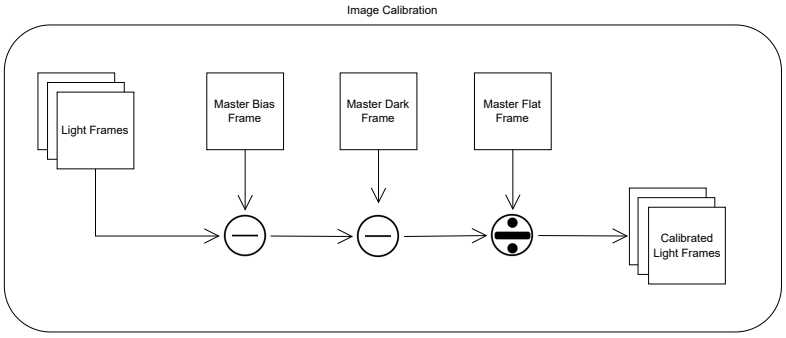

Figure 2: Image Calibration: Applying the Master Frames to an image

1.3 Correct Pixel Outliers

The program has the ability to correct for outliers such as Hot Pixels, Cosmic Rays and Flat Field differences (ccdmask). To identify the Hot Pixels the Master Dark pixels are analyzed while Flat Field difference are identified through the greatest difference between the Flats Frames or from the a Master Flat Frame. Cosmic Rays are identified from the reduced image after the calibration process is completed.

Correction for Pixel Outliers can be divided into two sections:

1. Identifying Faulty pixels with a Mask
2. Correct for Faulty pixels

1.3.1 Identifying Faulty Pixels with a Mask

By editing the options in the Correct Outlier Parameters section of the GUI, the user can chose which faulty pixels to mask. A brief description of them is provided below:

1. Hot Pixel: The first option is to identify hot pixels. This is done by calculation the dark current of the image and if the dark current for an individual pixel is **4 times** [2] the average dark current, the pixel is considered a hot pixel

2. The second option to identify pixels outside of the norm, is the dark frame threshold. This option is meant more for advanced users due to it's sensitivity. The default min of -50 and max of 100 threshold is great for dark scaled images due to it's bias subtraction but caution must be taken nonetheless.

3. Flat Field Masking: First a difference is found between the flat frames, if this difference isn't large (due to flat fields being captured inside the dome), the master flat frame is used to identify the faulty pixels instead. If the difference is large, then the difference between the maximum flat field and the minimum flat field is used.

4. Once the image has been reduced, cosmic ray removal can be added to the reduced images to get rid of the cosmic rays. The built in method used for Cosmic Ray Reduction also corrects the image automatically.

Identification of the bad pixels follows methods described in AstroPy CCD Data Reduction Guide [1]

1.3.2 Correcting for Faulty Pixels

In the frames where the faulty pixels have been identified, there are two different ways to fix the pixels. The Replace Mask Values must be enabled for the masked (faulty) pixels to be corrected. These are:

- Local Averaging: Local averaging takes in the Radius below the method selection as the radius of averaging. The radius must only be a positive integer. If an error occurs with the local averaging technique then the pixel will be replaced with the global average.

- Global Averaging. Global Averaging takes the average value of the non-masked pixels and replaces the mask pixels with the global average. Figure 4 shows the steps taken by the program to correct for outliers.

Multiple Flat Field Combination takes the masked pixels found in the flat field correction and corrects each flat frame in the flat frame data (usable only when combining multiple flats and not using previous master data). The option is present to save the new altered flats is available.

[2] Subject to Change

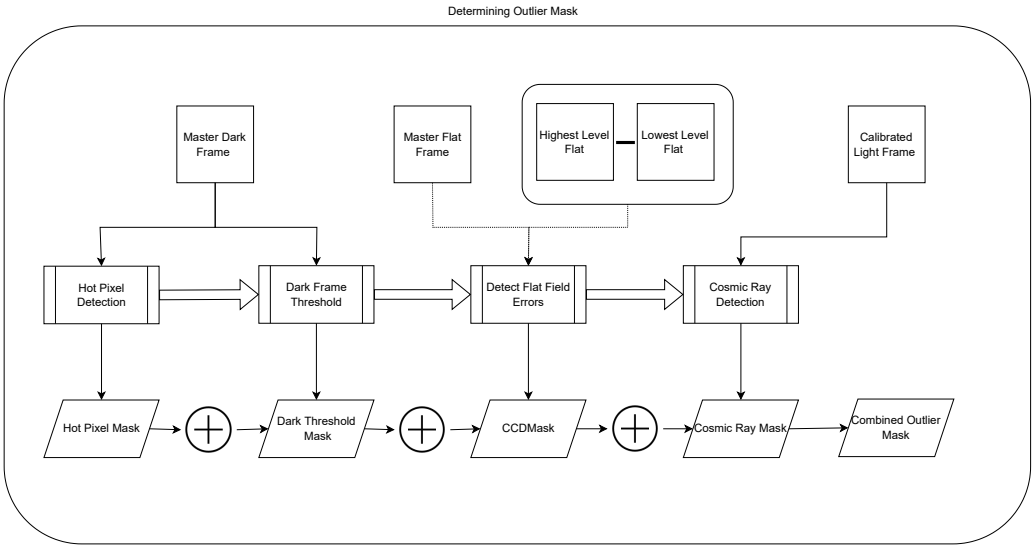

Figure 3: Determining the Outlier Mask

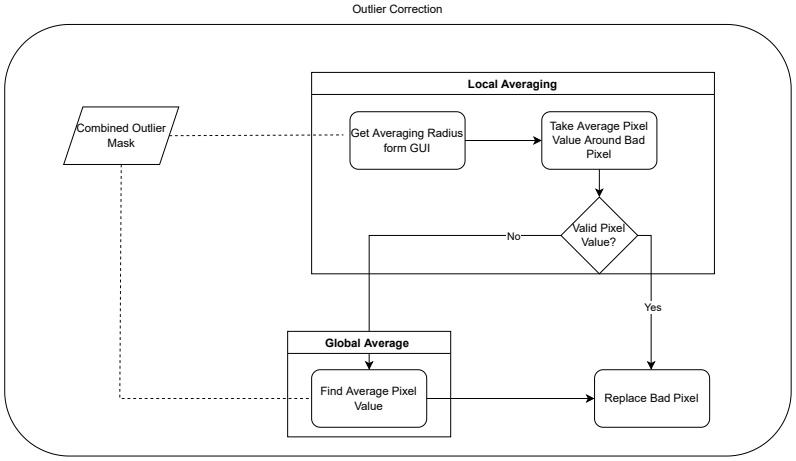

Figure 4: Outlier Correction

2 AstroSolver

2.1 General

In essence the AstroSovler tab follows a pipeline which takes in the images (preferably calibrated) identifies them, extracts the sources from them, matches them to known reference Landolt Stars and produced light curve data in the form of CSv Tables. Figure 5 briefly describes the processes which are undertaken.

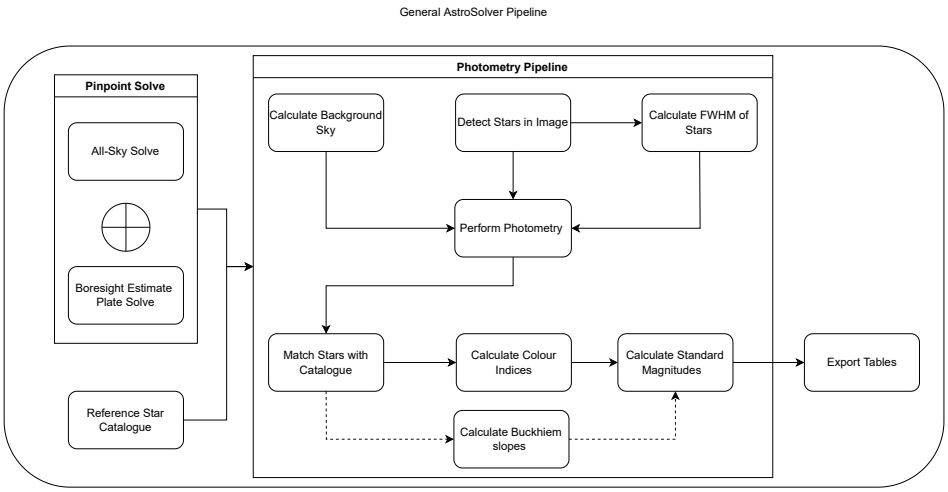

Figure 5: AstroSolver General Pipeline

2.1.1 Input Directories

1. **Image Folder:** Point to the direcotry of the image to be processed
2. **Catalogue Folder:** Point to UCAC 4 Folder
3. **Reference Stars:** Point to the Reference Stars file Used for photometry. Reference file are located in the Reference Files on Github

2.2 Star Stare Mode

The methods used for star stare mode will be much different than those of Track Rate Mode.

2.2.1 Plate Solve

If the image has not yet been plate solved, the user should check the box to attempt to do so. Plate Solving increases the accuracy of the Right Ascension and Declination used to determine the Reference Star in a given image. Pinpoint Solve only works for Star Stare Mode.

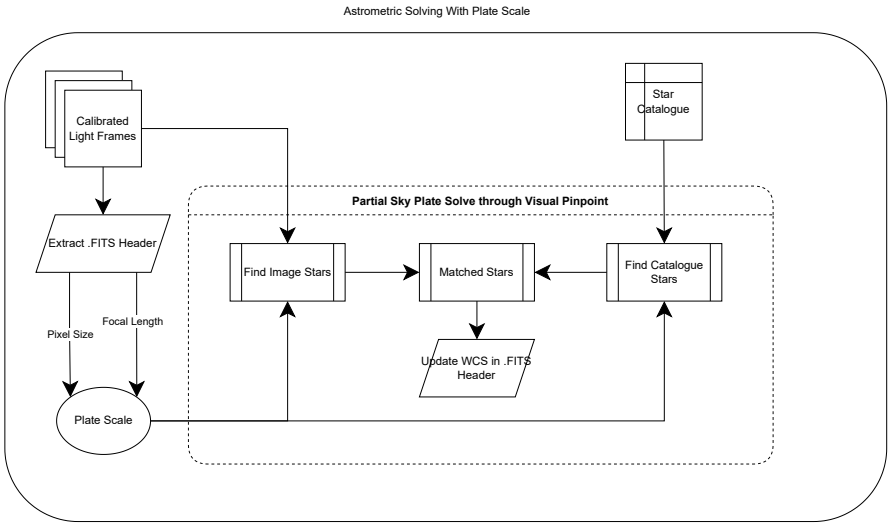

Figure 6: Plate Solve with Plate Scale

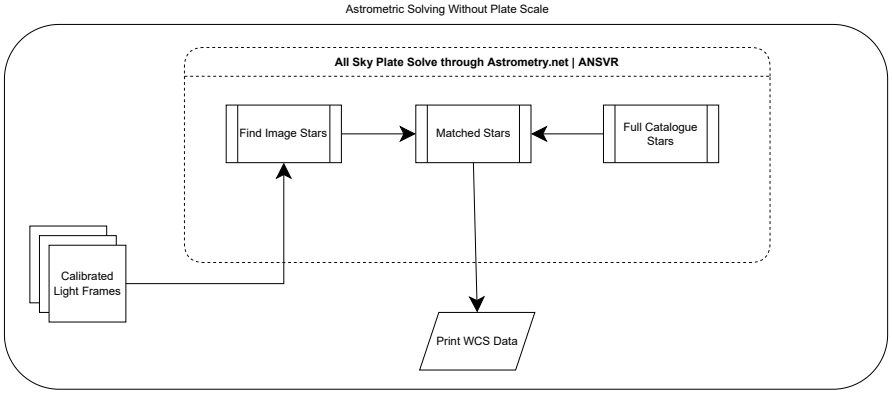

Figure 7: Plate Solve without Plate Scale

2.2.2 Plate Solve Parameters

The Plate Solve Parameters control the following inputs:

- Maximum Magnitude:The maximum (fainter) magnitude for selection in the reference catalogue
- Sigma Above Mean: Minimum brightness ratio (sigmas) above background) for a star to be detected
- Max Solve Time : The maximum time in seconds Pinpoint will spend on a solution

- Max Match Residual: The maximum positional error for matching images and catalogue stars.
- Catalogue Expansion: Expansion of catalogue search area outside the image dimension
- Catalogue: UCAC 4
- Use SExtractor?: Source Extractor is a higher fidelity Centroiding method that better distinguishes stars and extended objects.
- All Sky Solve?: This option tells Pinpoint to Sky Solve the image. Sky Solving is only recommended when sources are detected but cannot be matched to the reference catalogue.

Editing the Pinpoint Solve Parameters should be changed when detected light sources cannot match stars.

2.3 Track Rate Mode

Track Rate Mode can be used on images to acquire their light curves, FWHM and Light Curves. To start processing them the following parmameters will need to be set:

- **Image Directory:** Images to be used
- **Max Distance from Satellite:** Maximum number of pixels away from the satellite to contiue acknowledging the satellite
- **Size:** Aperature Size
- **Max number of nan**: The number of non- detections of the satellite for the program loop to break
- **Source Capture Mode:** Set to Track Rate Mode

Once the Solve button has been pressed the following actions will happen

1. An external window will pop up with displaying the images.
2. User needs to click on the desired Satellites in the image. Once all objects are clicked, the user must exit the window.
3. User will be asked to label satellites chosen in the previous step.
4. The program will now enter a loop of acquiring satellite sources and calculating light curve characteristics. A tally of the acquired sources will appear in the command prompt. If the max number of nan tally is reached (the max number of non-detections of the satellite) the loop will break.

5. When the loop breaks a window of the latest frame in that loop pop ups. The user is to re-click on the satellite sources again and relabel them (such as what's seen in Step 2 and 3. Exiting the window will "rewind" the max number of nans back and attempt to reacquire the source.

6. Repeat Step 4 and 5 until the dataset is complete.

7. The program will ask the user what they wish to display, at least two options will need to be checked for the plots to be displayed correctly.

3 Common Errors

3.1 Directory Errors

Several directories errors can occur. Listed below are a brief description of the one's encountered:

- **FileNameError**: File does not exists for imported/exported data.
  Recommendation: Navigate through Windows Explorer to find the File trying to be accessed. Check out the properties of such a file. If the directory listed in the properties is not that listed in windows explorer than the file name is too long. Without setting windows to allow Long Path names, the name of the path introduces weird characters in the name. To fix this, How-To-Geek has a tutorial on how to allow longer file path. [2]

3.2 Keyword Error

- **Image has no keyword ****.
  Possible Cause: There is no standard of FITS Header Keywords and will differ based on the hardware/software used to capture the images. **Recommendation**: Manually open up the image with a .fits image viewer such as **MaxImDL** or **AstroImageJ**. Using this program view the header information and investigate what property could not be found. Change the keyword in the Python Program to that of the dataset's key [3]

[3] Future work is planned on creating a keyword editor

References

[1] Matthew Craig. *CCD Reduction and Photometry Guide*. URL: https://www.astropy.org/ccd-reduction-and-photometry-guide/v/dev/notebooks/00-00-Preface.html. (accessed: 03.18.2022).

[2] Walter Glenn. *How to Make windows 10 Accept File Paths Over 260 Characters*. URL: https://www.howtogeek.com/266621/how-to-make-windows-10-accept-file-paths-over-260-characters/. (accessed: 03.18.2022).