Determining True Flux and Magnitude of a Star From Deep-Sky Image of eQuinox Telescope by Performing Photometry on Python

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ABSTRACT

Aims. A course of study to estimate the true flux and the magnitude of an object from the deep-sky image of eQuinox telescope.
Methods. PSF Photometry is carried out on Python packages while noise and non-astronomical characteristics produced by the telescope are taken into account when preparing images.
Results. The final result is produced by evaluating the calibration factor using the photometric data of the Reference and Test star.

Key words. photometry – photutils

1. Image Preparation

Fig. 1. 5 minutes exposure of the Star Vega and its surroundings through eQuinox telescope.

The eQuinox telescope is a particular kind of telescope made especially for deep sky imaging, or taking pictures of celestial objects like star clusters, nebulae, and galaxies that are located beyond our solar system. Because these telescopes are designed with astrophotography in mind, both amateur and professional astronomers can take detailed, high-quality pictures of far-off celestial objects. It has on-board computer which helps the user to stack images over the time.

As we can see from the Fig.1, Vega appears to be a very bright object after stacking, thus we were only able to capture a maximum of 5 minutes of exposure for the frame we were observing at. To prepare the stacked image, it will now be essential to convert it to Grayscale. This conversion may be beneficial or necessary for a number of reasons:

Simplicity: When it comes to some kinds of analysis, grayscale photos are frequently easier to deal with than color ones. They are simpler to process and evaluate since each pixel just has one channel of intensity data.

Photometry: Converting to grayscale can make the analysis easier if the objective is to assess the brightness of the stars in the image or perform photometry. The main task of photometry is to measure the light intensity from stars, which is easier to do in grayscale.

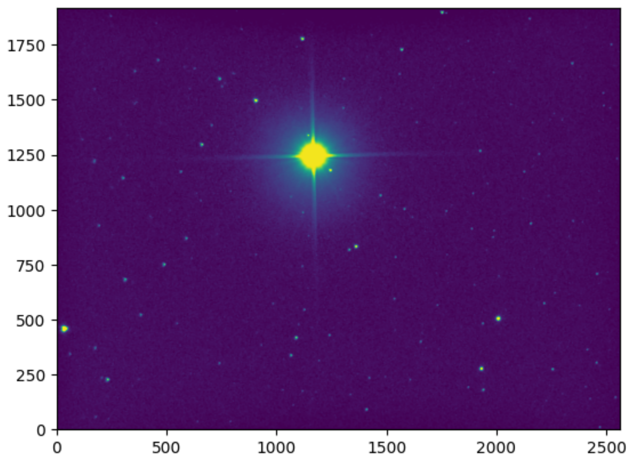

Fig. 2. Grayscale conversion Where all the values of x and y axis indicate the coordinates in pixel units.

Noise reduction: Changing the image's color channels to grayscale can assist lessen the effect of noise or artifacts. In many instances, noise may appear less noticeable in the grayscale form, which facilitates feature identification and analysis.

Representation: Grayscale images can be sufficient for visualizing needs, and may even be desired in some circumstances. They can enhance contrast and structure in an image without distracting from color information.

2. Background

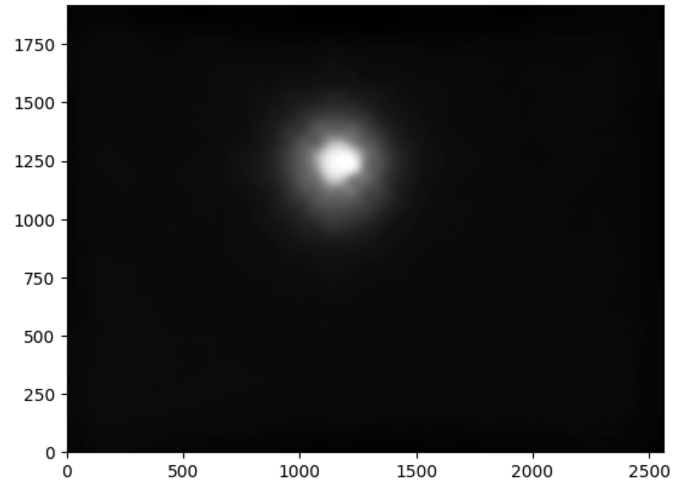

Fig. 3. Background signal image.

An astronomical image's background is estimated and visualized using the written computer program. Importing the required classes and functions from the Astropy and Photutils libraries is the first step. Pixel coordinates are represented using 2D arrays, and the image's dimensions are obtained. The picture data is then subjected to normalization via the square root scaling technique. To find outliers in the data, a sigma clipping method is then performed.

To measure the background signal in the picture, a median background estimator is applied. It uses parameters like the filter kernel and background box size to compute the background signal. Next, using Matplotlib, the estimated background signal is extracted and shown as a picture. The image is visualized using a reversed grayscale colormap with its origin set to the lower-left corner. Accurate analysis and interpretation of the astronomical image depend on the process's ability to detect and remove background noise.

3. Subtracting Background Image

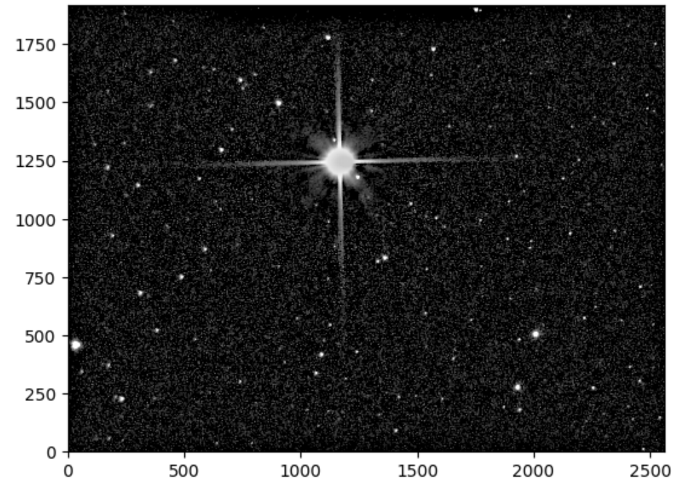

Fig. 4. Subtracted background image.

By subtracting the predicted background signal from the original image, the background-corrected image eliminates pixel intensity changes caused by non-astronomical sources. These sources could be sky glow, instrumental effects, or uneven illumination over the image.

This subtraction procedure produces an image in which the background signal has been efficiently removed, displaying more clearly the genuine astronomical characteristics present in the data. By reducing the foreground, the contrast between dim astronomical objects and background noise improves, making it easier to identify and examine these objects precisely.

4. PSF Photometry

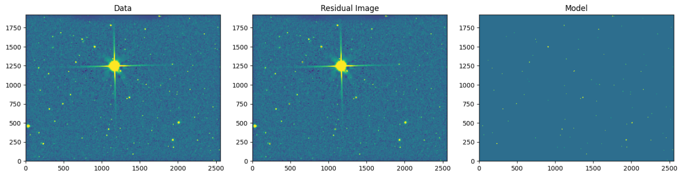

Fig. 5. Composite image of Data, Residual, and Model.

Point Spread Function (PSF) photometry is a technique used in astronomical image analysis to calculate the flux (brightness) of stars and other point-like sources in an image. It involves modeling the shape of the PSF, which represents how light from a point source spreads in an image as a result of atmospheric turbulence, optical flaws, and detector characteristics.

PSF photometry works by assigning a PSF model to every detected source in the image. The PSF model is often a mathematical function that depicts the distribution of light around a single point source. By convolving this PSF model with the image, we can create a model of how a point source should appear in the image while accounting for the telescope and detector system's features. After doing PSF Photometry, we receive the final images as:

- **Data Image**: This is the original background-corrected image containing the observed astronomical sources.

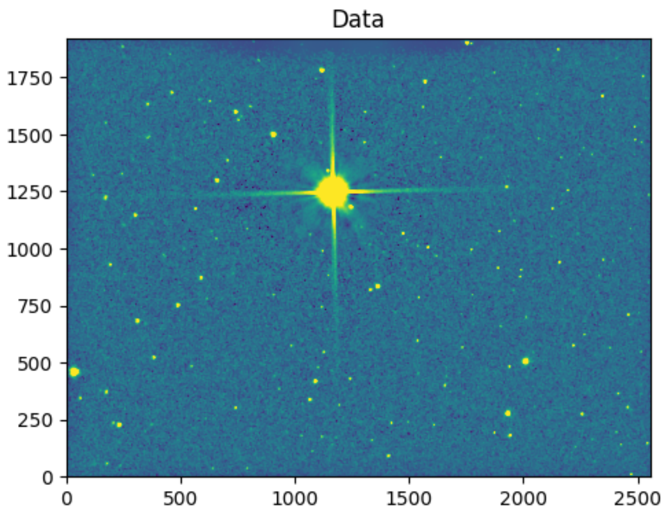

Fig. 6. Original background corrected image.

- **Residual Image**: This image depicts the residuals after removing the modeled sources from the original image. It illustrates any features or artifacts in the image that the PSF model could not account for. The residual image is the discrepancy between the observed image and the model of the sources.

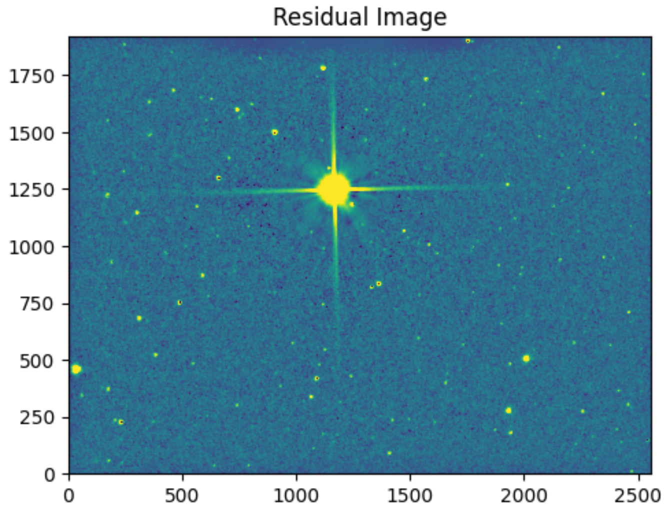

Fig. 7. Data minus Model image.

- **Model Image**: The below image represents the model of the sources produced by fitting the PSF model to the observed data. It provides a simulated image of how the sources should appear using the PSF model and the fitted parameters.

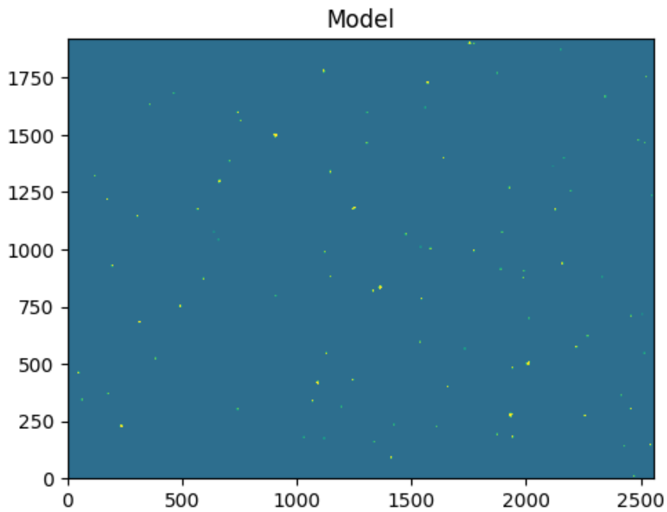

Fig. 8. Model image after performing PSF.

5. Calculating Flux and Magnitude

Now we will perform photometric calibration on **nearby two stars** of **Vega** from the computer generated image we have done so far.

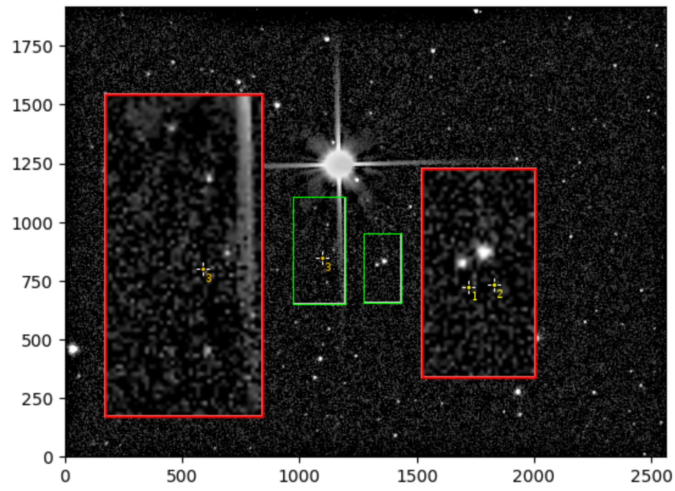

Fig. 9. The **Reference Star (Star A)** is represented by "**Number 1**" object in the right Red Box, while the **Test Star (Star B)** is represented by "**Number 3**" object in the left.

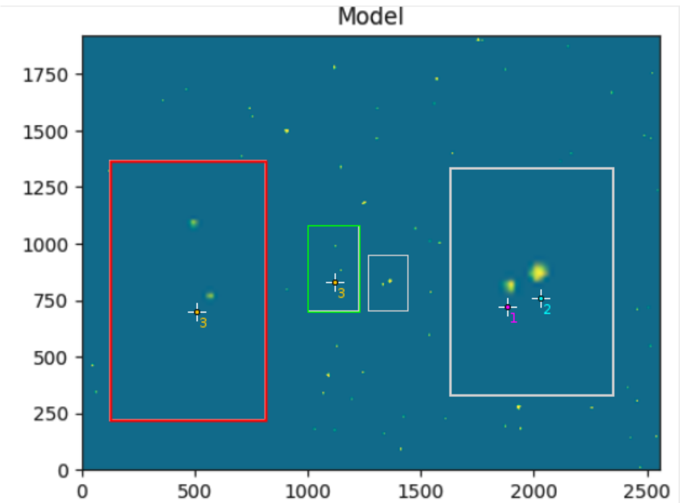

Fig. 10. Model-Image zoomed in, using the same **Reference** and **Test Star** as Fig 9.

The $x_{\mathbf{fit}}$ and $y_{\mathbf{fit}}$ in the photometry output represent the fitted centroid positions of the detected sources in the image. These values indicate the coordinates (in pixel units) of the source's positions relative to the origin of the image. And $y_{\mathbf{fit}}$, flux value as $\mathbf{flux_{fit}}$. We will take True "flux and Magnitude" data of reference star from GAIA Database.

Reference Star:

- Star A: Gaia DR2 2097891657798430848
- $x_{\text{fit}} = 1331$; $y_{\text{fit}} = 818$
- $\text{flux}_{\text{fit}} = 765.311$
- $\text{True flux}_A = 406590.8711472734$
- $\text{True magnitude}_A = 11.665472$

Test Star:

- Star B: Gaia DR2 2097939383475063296
- $x_{\text{fit}} = 1119$; $y_{\text{fit}} = 986$
- $\text{flux}_{\text{fit}} = 226.241$

To perform photometric calibration and calculate the actual magnitude of the test star, we can use the known information about the reference star. Here's a general outline of the steps to follow:

1. Obtain the Known Calibration Information:
   - We know the flux and magnitude of the reference star (Star A).
2. Calculate the Calibration Factor:

$$\text{calibration\_factor} = \frac{\text{True\_flux}}{\text{flux\_fit}}$$

3. Calculate the True Flux of the Test Star:

$$\text{True\_flux\_B} = \text{flux\_fit\_star\_B} \times \text{calibration\_factor}$$

4. Calculate the True Magnitude of the Test Star:

$$\text{True\_magnitude\_B} = \text{True\_magnitude\_A} - 2.5 \times \log_{10}\left(\frac{\text{True\_flux\_B}}{\text{True\_flux\_A}}\right)$$

6. Result

And finally, we get our desired result:

True Flux of the Test Star: **120196.266**98065268
True magnitude: **12.988**638609657132

True magnitude of the Test Star (Star B) is **12.69** (from **Stellarium**). After considering magnitude error bar from the **GAIA Database** which is **12.7386** ± **0.0002**, we can finally get the true magnitude of the test star.