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SEP PHOTOMETRY

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1. INTRODUCTION TO SEP

SEP, or Source Extraction and Photometry (Barbary 2016), is a Python library that makes use of the Source Extractor (Bertin & Arnouts 1996) algorithms to perform background subtractions, source detections and photometry on FITS images. Here is a brief description of the functions that SEP performs.

1.1. *Background Estimation*

The background estimation is found by SEP using the SExtractor algorithm. To summarize, an image background is estimated by SEP by first finding local backgrounds of a user-defined window (in pixels). Histograms of these local backgrounds are then constructed. Values that are in the far tails of the distribution are thrown out, and this process is repeated until all values are within 3σ of the histogram mean. The local background is then determined by the mean (for crowded fields) or $2.5 * \text{median} - 1.5 * \text{mean}$ (for non-crowded fields). An area is crowded if a histogram's σ is changed by more than 20% during each iteration. The local background estimation is repeated across the entire field, and the local background values are spatially interpolated to create a background field.

1.2. *Object Detection*

Several user inputs are required and/or available for SEP object detection. The user must give the pixel detection threshold either as an absolute threshold (surface brightness) or a relative background rms threshold to the user provided σ. The user may also define a pixel mask that excludes pixels from the detection process. A filter can be provided to smooth an image to better detect faint, extended objects.

Deblending is useful to differentiate nearby objects, and is done by SEP if there is a "saddle" in the light profile between two sources. The user defines the deblending threshold in units of detection thresholds, as well as the minimum contrast ratio (which is usually small). The process in which SEP (and SExtractor) deblends begins by generating a 2D light profile model with a "tree structure" (see Figure 1). Branches are generated when pixels are larger than the deblending threshold below the initial pixel. This process is repeated until all branches are found. SEP then begins with the top of the "tree" and locates the first branch. If that branch has a fraction (contrast ratio) of counts above the total counts of the not yet deblended object and there is another branch similarly above this fraction, then two objects can be distinguished. In Figure 1 branches A and B are both above the contrast ratio and are separated by the deblending threshold.

1.3. *Photometry*

SEP allows for circular and elliptical aperture photometry (as well as circular and elliptical annular apertures). The SExtractor MAG_AUTO option can be replicated with SEP using a three step process. First, the Kron radius containing an estimated 90% of an object's flux is calculated (Kron 1980). SExtractor (and SEP) define the Kron radius as

$$R = \frac{\sum r_i I(r_i)}{\sum I(r_i)}, \tag{1}$$

where I is the intensity and r_i is the distance to pixel i. This definition, which is slightly different from Kron's original definition, sums over a 2D aperture rather than a light profile. Next, elliptical aperture photometry is performed within $2.5 * R$ (arbitrarily set by SEP) for each object.

Finally, for objects that satisfy the following criterion

$$R\sqrt{a * b} < r_{min}, \tag{2}$$

where a & b are the semi-major and semi-minor axes and r_{min} is a user defined minimum aperture radius, circular aperture photometry will be performed.

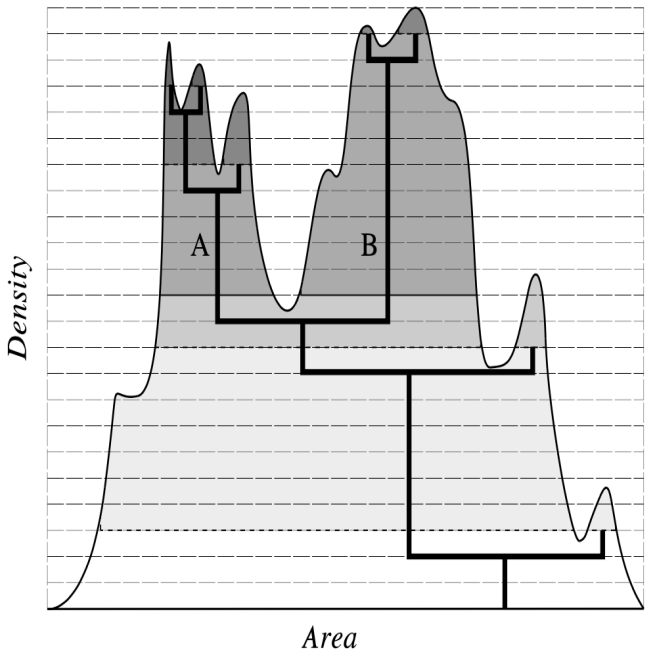

Figure 1. SExtractor deblending tree model example (see Bertin & Arnouts 1996).

2. POINT SOURCE IMAGE

I have performed photometry on a F090W exposure generated by Christopher Willmer (see Figure 2) using these SEP functions. This exposure consists of 100 point sources uniformly distributed spatially and in magnitude (ranging from AB Magnitudes 17.2-21.2). Object detection was performed using a threshold of five times the global background rms value σ. Circular aperture photometry was performed using four separate radii.[1] Figure 3 shows the final magnitude discrepancies between the extracted and catalog sources, where

$$\Delta M = M_{extracted} - M_{catalog}. \tag{3}$$

The use of a masked background subtracted image can be useful for photometry. In SEP this is done by an iterative background estimation process. First, the background of an image is found and is subtracted from the image. Then object detection is performed to produce a segmentation map. A new background is then estimated by masking pixels associated with objects by using this segmentation map. Finally, object detection is done using the new background subtracted image. Figure 4 shows the source magnitude discrepancies by performing photometry on a masked background subtracted image. All object detection and photometry user inputs are the same as those used to find magnitudes in Figure 3. For this point source example, the masked-background subtracted image SEP photometry process gives the same magnitude values as the non-masked background case.

The magnitudes given in Figures 3 and 4 account for aperture corrections. These correction are found by integrating the PSF flux within the designated aperture size. A plot of all aperture corrections can be seen in Figure 5, and the corrections for each aperture in Figures 3 and 4 are given in Table 1.

[1] The pixel scale is 0.003962”/pixel.

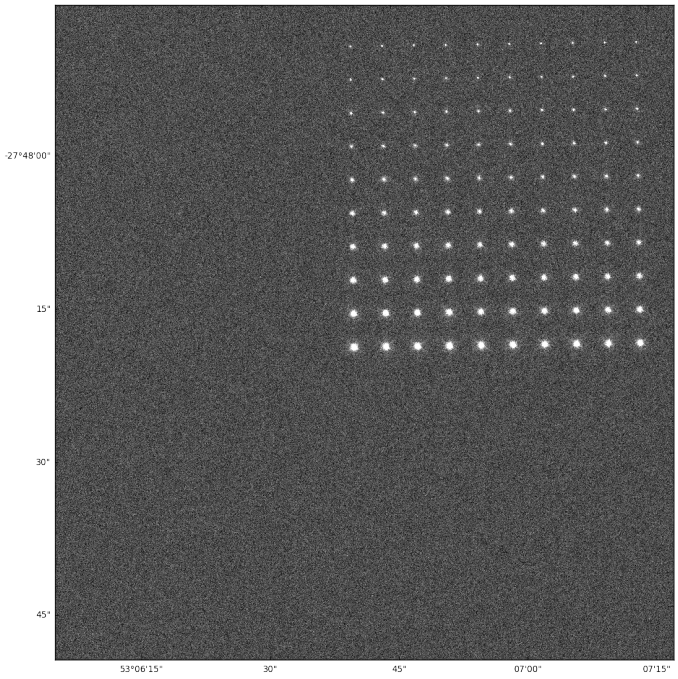

Figure 2. F090W point source exposure

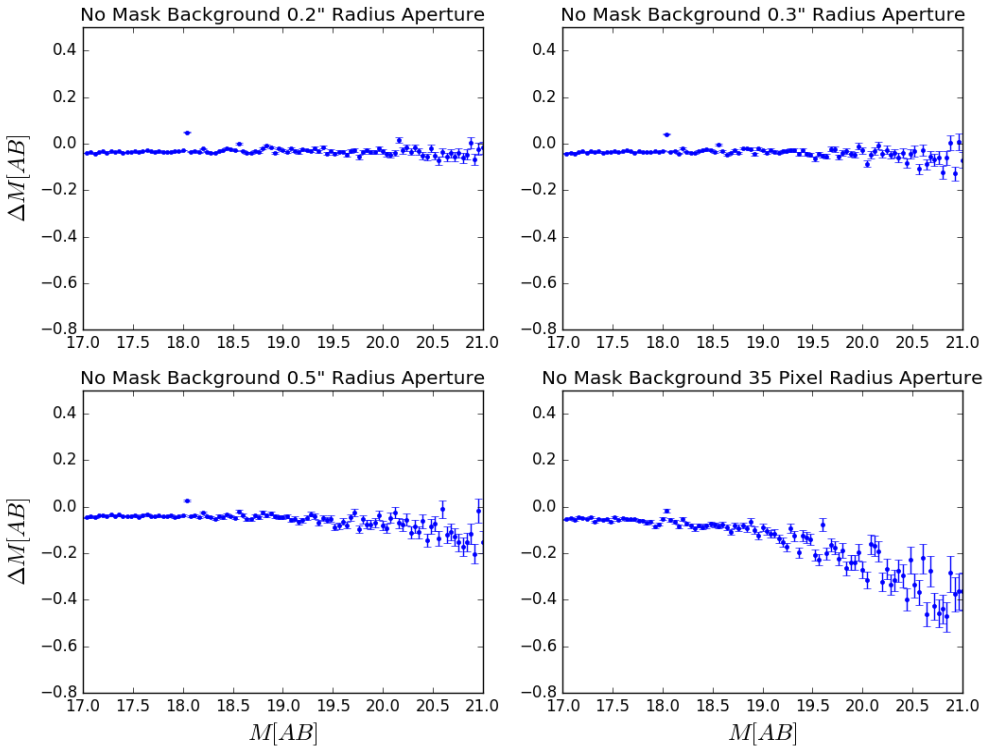

Figure 3. Point source exposure SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for four circular aperture radii. Background masking was not used in object detection.

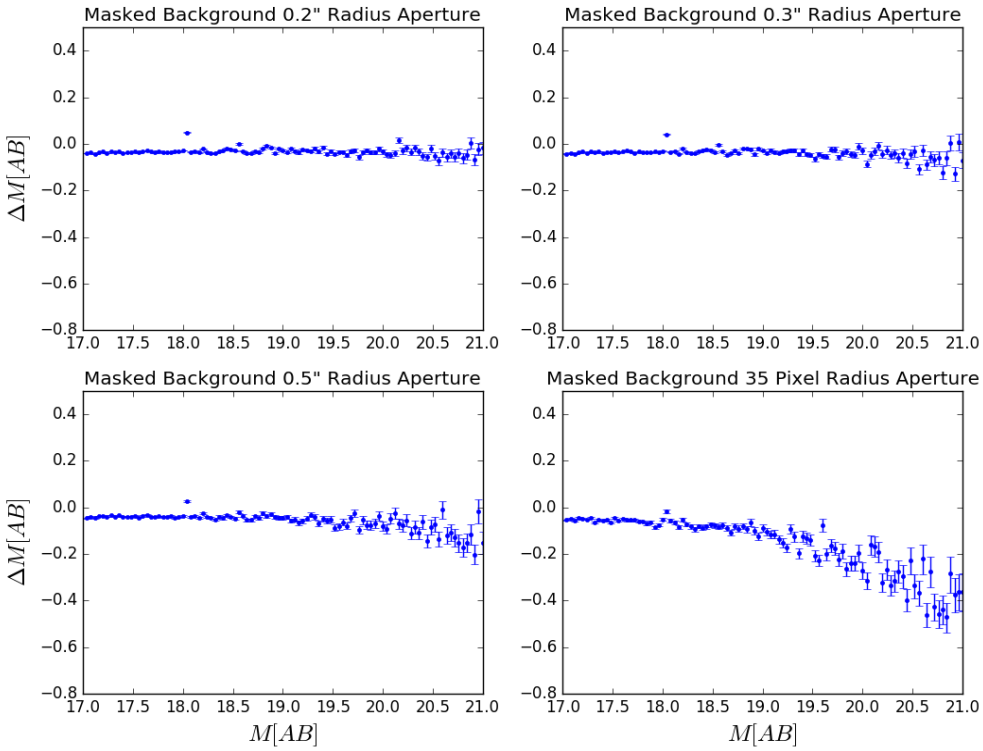

Figure 4. Point source exposure SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for four circular aperture radii. Photometry was performed on a masked background subtracted image.

Table 1. Circular Aperture Corrections for Point Source Mosaic Photometry

Aperture Radius	Correction (AB Mag)
0.2”	0.320210235177
0.3”	0.204462939361
0.5”	0.114377680748
35 pixels	0.0274911626418

For completeness Figure 6 shows magnitude discrepancies for masked-background subtracted images without aperture corrections applied.

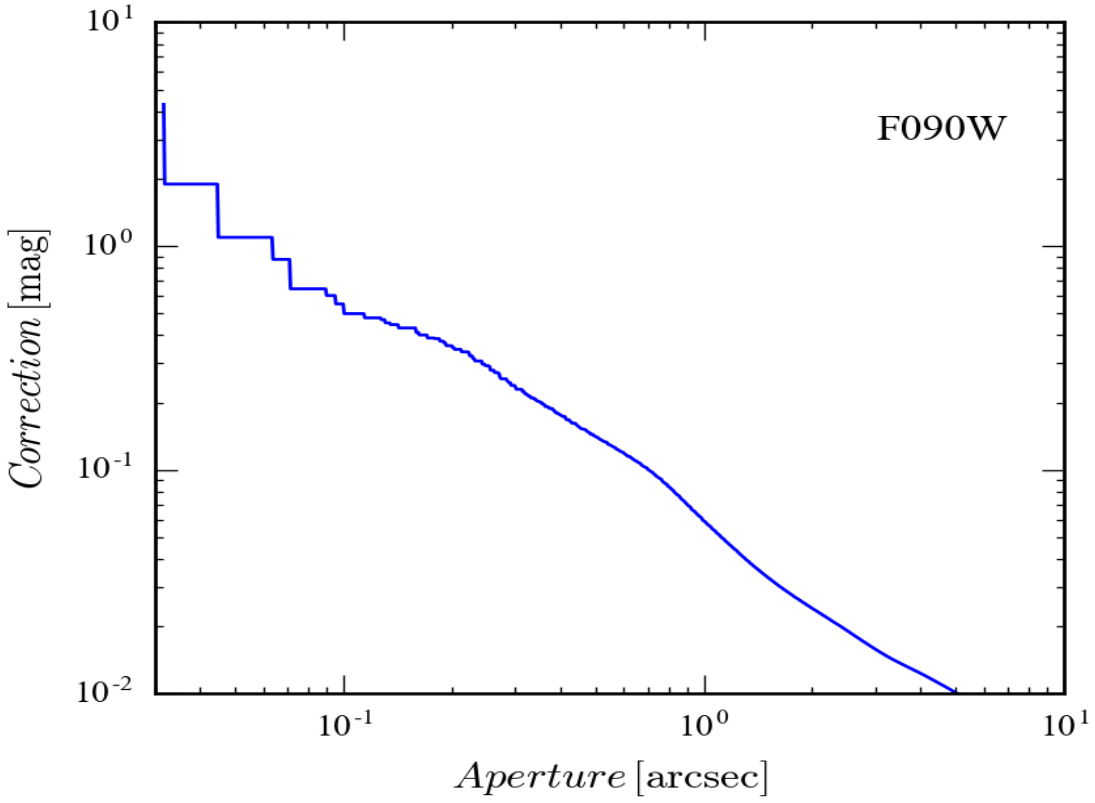

Figure 5. F090W circular aperture corrections as a function of radius.

3. EXTENDED SOURCE IMAGE

Figure 7 shows a Montage mosaic generated from eight F090W exposures provided by Christopher. One may notice a square artifact in the mosaic. This is likely due to a border surrounding each exposure with a 0.1 count difference over a five pixel width.

SEP object detection was performed on this image with a detection threshold of 5σ where σ is the global background rms, and the image was masked-background subtracted. The SEP equivalent to the SExtractor, MAG_AUTO, photometry was used, where sources that require circular aperture photometry use a $r_{min} = 0.3''$ circular aperture. Figure 8 shows the magnitude discrepancies for extracted sources. Aperture correction is not applied.

There are a few sources in the plot with $\Delta M = 1 - 2$ discrepancies. To test whether these discrepancies owe to mosaicing process I run the first exposure through the same SEP process. This exposure is shown in Figure 10, and the magnitude discrepancies are shown in Figure 11. There are still some $\Delta M = 1 - 2$ values, and it appears that these discrepancies do not owe to the mosaicing process.

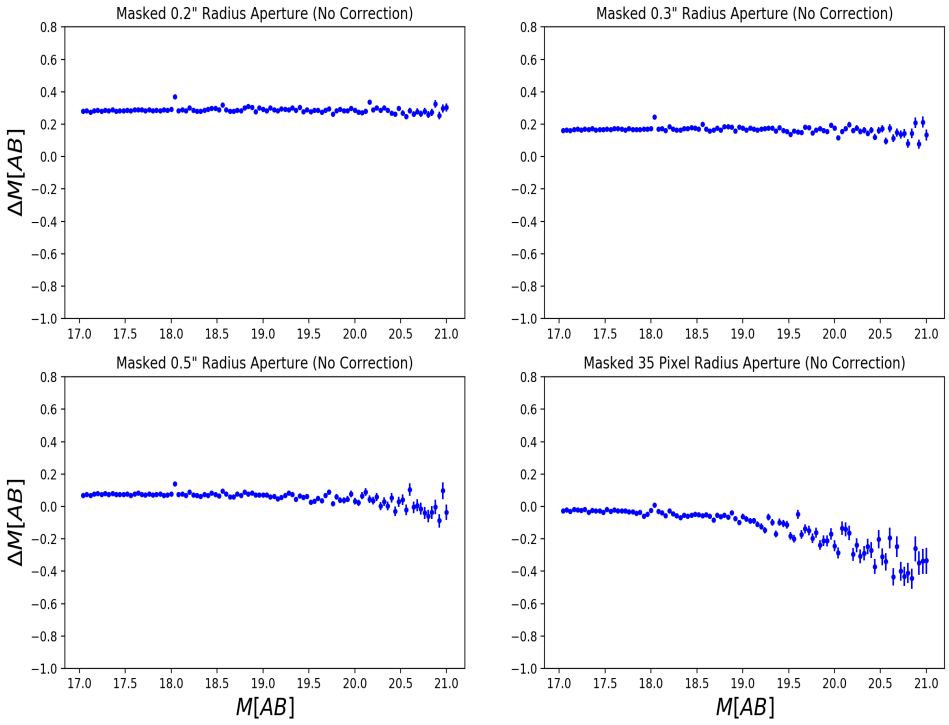

Figure 6. Point source exposure SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for four circular aperture radii. Photometry was performed on a masked background subtracted image. Aperture corrections were not applied.

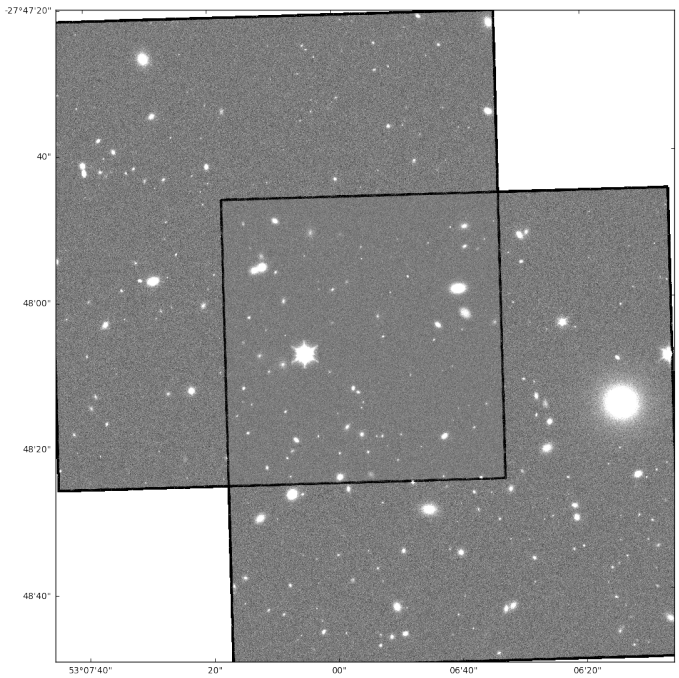

Figure 7. F090W extended source Mosaic

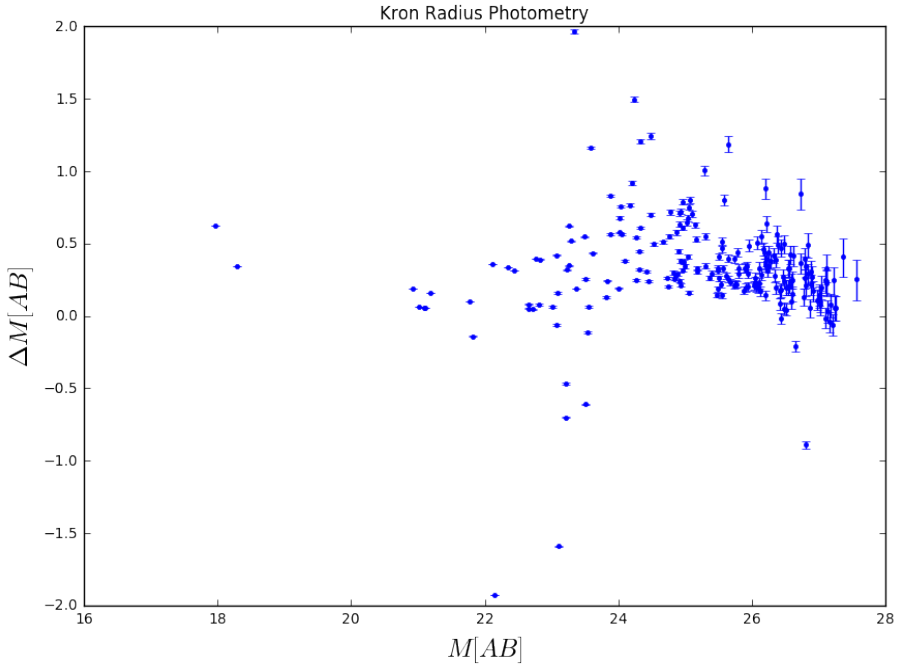

Figure 8. SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for the F090W extended source Montage mosaic. Aperture correction is not applied.

4. UDF

I have also performed SEP photometry on the AstroDrizzle HST UDF i-band mosaic (see Figure 12). I use the Beckwithet al. (2006) catalog as a comparison, restricting to the brightest 100 extracted sources. For object detection I use parameters described in Beckwithet al. (2006). They are

- Detection threshold, 0.61 * background rms
- Minimum number of pixels to be considered an object, minarea=9
- Number of thresholds used for deblending, deblend_nthresh=32 (default)
- Deblending contrast ratio, deblend_cont=0.33
- FWHM for filter kernel = 0.09”

Photometry was performed on a masked-background subtracted image. The “MAG_AUTO” option is used, with $r_{min} = 0.3''$ for circular aperture photometry. Figure 13 shows the extracted and catalog source magnitude discrepancies. SEP tends to extract faint sources with a brighter than expected flux, which I am currently investigating.

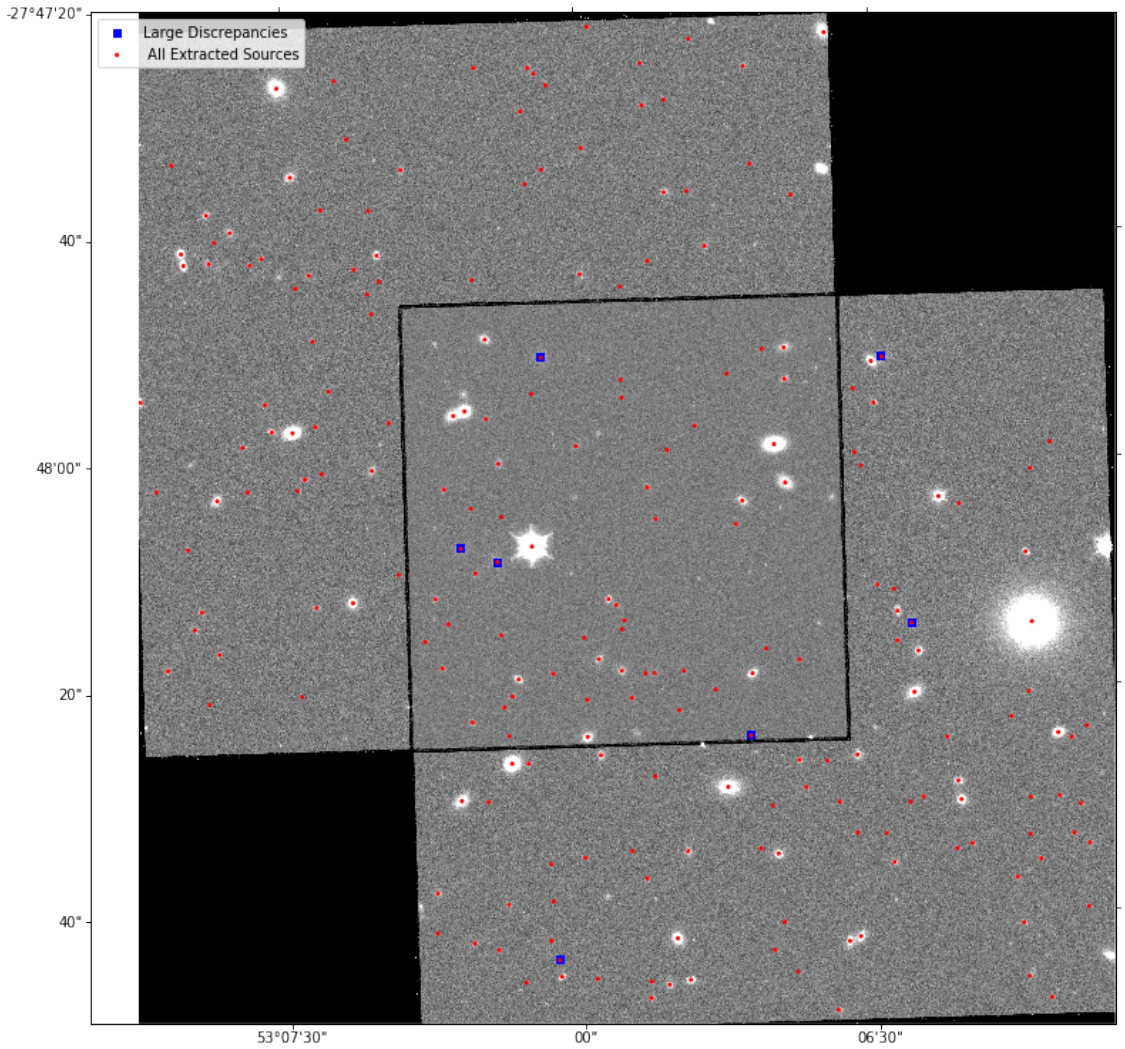

Figure 9. F090W extended source Mosaic. Red dots indicate all extracted sources and blue squares indicated extracted and catalog source discrepancies with $\Delta M >= 1.0$.

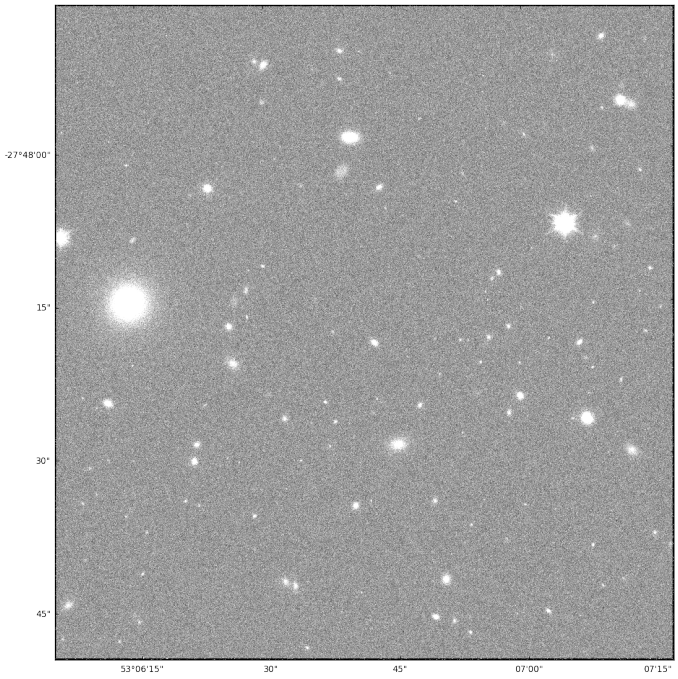

Figure 10. F090W extended source exposure

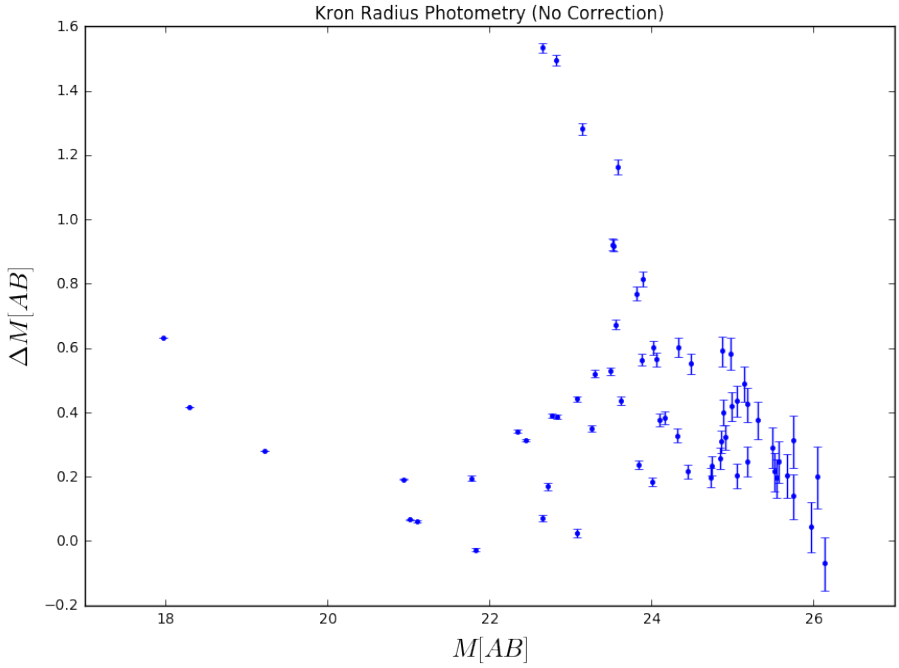

Figure 11. SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for the F090W extended source exposure. No aperture correction is applied.

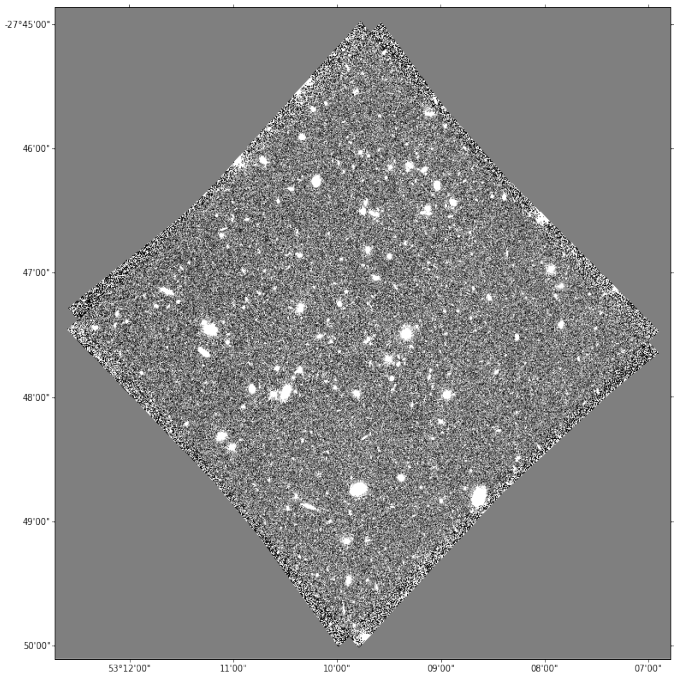

Figure 12. UDF AstroDrizzle mosaic

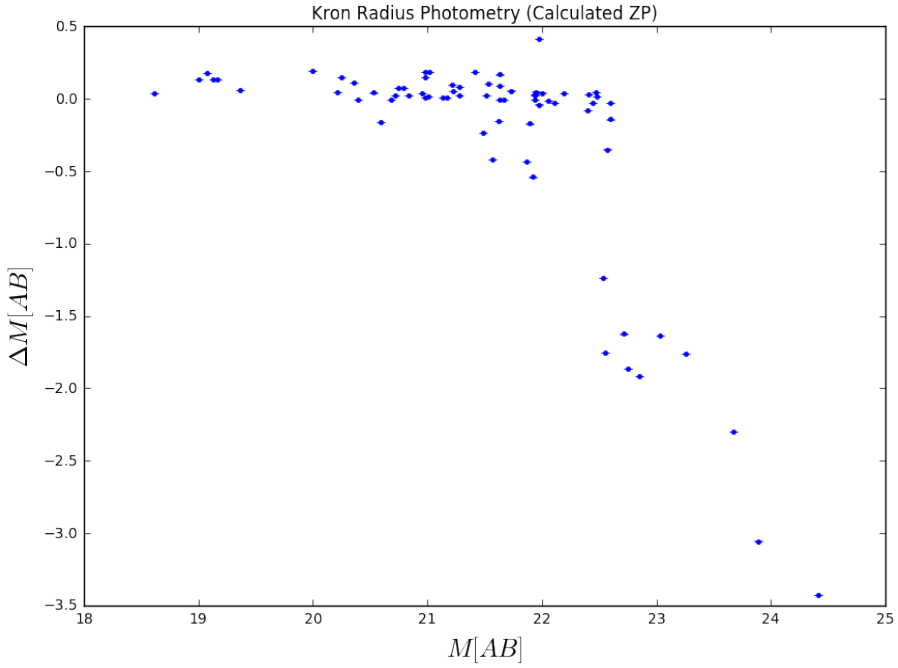

Figure 13. SEP extracted and catalog magnitude discrepancies as a function of catalog magnitude for the UDF i-band mosaic. Aperture correction is not applied.

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