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HW 07: LAB TECHNIQUES AND OBSERVATION PLANNING

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1. NOISE

- Thermal Noise (Darks) - Noise contributed mainly by components (electronics) within the imager itself. Even with no light, pixels produce current and adds to the ambient flux.
- Background - Ambient regions that also include darks. Flux not from the target and intense regions, analogous to contamination not in the regions.
- Flats - Normalized field that accounts for pixel variation. Subtract darks and divide by median of the remainder.
- Other sources of deviation - Chosen wavelengths/filters, exposure time, bias (mainly only if exposure times are not identical)

2. USEFUL NUMPY FUNCTIONS

np.mean() – mean value
np.max() – maximum value
np.min() – minimum value
np.indices() – indices of set parameters (can be (rows,columns))
np.log10() – log base 10
np.shape() – dimensions and shape of object
np.std() – standard deviation
np.sum() – total sum of defined
np.sqrt() – square root

3. PHOTOMETRY

Photometry is the measurement of an object brightness. Collecting measurements over a period shows the variation over time through magnitudes and subsequent light curves.
1) Obtain data and header information from .fits files. Print statements are very important, use exit(0) to debug issues and to end code at that specific line. The header is first loaded with (hdulist = fits.open('filename.fits')). The header is then invoked by (hdulist.info()—header = hdulist[0].header—print header). Main data input reader is np.genfromtxt, refer to https://docs.scipy.org/doc/numpy/reference/generated/numpy.genfromtxt.html.
2) Determine darks and backgrounds. This information is usually under the header, note that there may be multiple header inputs and specify with [0] or [1]. Useful information from the header includes read noise, background, gain, exposure time, etc. Note some headers do not include these information segments and must be derived. When using aperture photometry using a log10 of the background and color contours of the image allows for a first order approximation of the target/reference/background, for example (showIm = np.log10(background)—cbkg = plt.contourf(showIm,256)). A color bar can be added to the contour by (plt.colorbar(cbkg).set_label(label='Contour Levels',size=16) #,weight='bold').
3) Aperture photometry, the scipy package (from astropy.coordinates import Angle) is useful for RA/Dec conversions. RA: Angle('##h##m##.##s').deg and Dec: Angle('±##d##m##.##s').deg in degrees. A useful method included pinpointing a target and creating a box around it, for example (background_aperture = image[dec_conv_bk-30:dec_conv_bk+30, ra_conv_bk-30:ra_conv_bk+30]). It is imperative to note that the coordinates may not be precise and a pinpoint location could be many pixels off. Therefore, using this technique, a check is to increase the aperture size to view objects near the literature coordinates.

4. RELEVANT EQUATIONS

4.1. *Image correction*

If corrected image isn't provided, the image must be normalized. The exposure times for each, equations 1 and 2, must be the same respectively or a gain must be applied. The exposure time of equation 2 isn't import when plugging into the corrected image equation because it is a ratio at that point.

$$\text{Corrected Image} = \frac{\text{Science Observation Image - Dark (same exp. time)}}{\text{Normalized Flat}} \tag{1}$$

$$\text{Normalized Flat} = \frac{\text{flat - dark}}{\text{mean(flat - dark)}} \tag{2}$$

4.2. *Aperture photometry*

Pixel variance (s^2) is noted in equation 3. The equation includes the number of electrons (n) in the pixel (counts×gain), the background (b) which again is (countsgain), dark level (d), and the read noise squared (r^2). There are cases where d and r^2 can be assumed to be zero.

$$s^2 = n + b + d + r \tag{3}$$

For bright sources n>d and the signal-to-noise ratio will be the square root of n (basically Poisson). The signal to noise ratio determines the total number of counts, which depends on stellar flux (N_{rate}) and integration time (t).

$$\text{SNR} = \sqrt{N_{rate}}\sqrt{t} \tag{4}$$

The zero point is found through equation 5. The respective flux and magnitudes are used for identical filters.

$$\text{Zero Point} = Magnitude\,[Band] + 2.5\log(Flux\,[Band]) - 2.5\log(exposuretime) \tag{5}$$

The flux of both J-star ($F_\star$) and J-standard ($F_\dagger$), provided in equation 6, were obtained with background subtraction, while also taking the gain (ξ) into account. The total counts of photons ($N_{\star,\dagger}$) from the star apertures were subtracted with the total background photon counts (B). B was determined by finding the sum of counts within the background aperture.

$$F_{\star,\dagger} = (N_{\star,\dagger} \times \xi) - B\xi \tag{6}$$

The error associated with the flux required the same inputs as the flux, with a few additional parameters. The new parameters included the number of pixels within the aperture (N_{px}), read noise (R), and the standard deviation of the mean $B\xi$ component ($\sigma_{\overline{B\xi}}$).

$$\sigma_{F_{\star,\dagger}} = \sqrt{N_{\star,\dagger} + N_{px}(B\xi + R^2_{DN}) + N^2_{px}\sigma^2_{\overline{B\xi}}} \tag{7}$$

The *magnitude difference*, provided in equation 8, shows the magnitude and flux relationship between two stars. The apparent magnitude of J-star ($m_\star$) and the known magnitude of J-standard ($m_\dagger$) were both utilized. The equation also includes the flux ratio of both the photon fluxes $F_\star$ and $F_\dagger$. The error associated with the magnitude difference is provided in equation 9.

$$m_\star = -2.5\log_{10}\left(\frac{F_\star}{F_\dagger}\right) + m_\dagger \tag{8}$$

$$\delta m_\star = \sqrt{\left(\frac{\partial m_\star}{\partial F_\star}\delta F_\star\right)^2 + \left(\frac{\partial m_\dagger}{\partial F_\dagger}\delta F_\dagger\right)^2} \tag{9}$$

4.3. *Altitude and Azimuth*

Equations 10 and 11 can also be represented in elevation (e) or azimuth (a) by taking the inverse sine of both sides. Included variables consists of declination (d), latitude (B), hour angle (HA).

$$\sin e = \sin d \sin B + \cos d \cos B \cos HA \tag{10}$$

$$\sin a = -\frac{(\cos d \sin HA)}{\cos e} \tag{11}$$

The elevation is dependent on the hour angle which is found by taking into account the local sidereal time (LST). It is imperative to note that creating "delta_midnight" in equation 12 is a component in [hours]. This must be converted to radians/degrees to make units match. Equations 13 and 14 are both found using the information of our generated delta midnight and the local sidereal time at midnight of the detector. Note that this will change for each day, cataloged by the US Naval Observatory, and can be found at (http://aa.usno.navy.mil/data/docs/siderealtime.php).

$$delta\_midnight = np.linspace(-6, 6, 1000)/24 * 360 \tag{12}$$

$$LST = delta\_midnight + LST\_at\_midnight \tag{13}$$

$$HA = LST - RA \tag{14}$$

5. THINGS TO CHECK

1) Exposure times need to be equivalent for flux and darks (gains must be considered if not). This is known since flats will be normalized.
2) Consider which filter was used for observations
3) Background regions should be picked with low standard deviations to ensure extra brightness and stars do not affect the flux calculations. Ensure that darks are included in the background information.
4) Cosmic rays must be removed. An effective technique is to take the mean flux of the image or replace the peak that will be observed with the surrounding background pixels.
5) Compare to the flux from the already corrected photometry flux from the same sample if provided in literature.

6. IMAGE CORRECTIONS

Image corrections were done using equations 1 and 2. Normalized flats were created using flats and darks of the same exposure time, using equation 2. Additionally, using equation 1, the same exposure times were used. The since the normalized flats were "normalized", the exposure times were not considered for that section. Aperture photometry was used again on the corrected image and J-star and J-standard generated a magnitude of 13.22. All fluxes and information gathered from image corrections are provided in table 1.

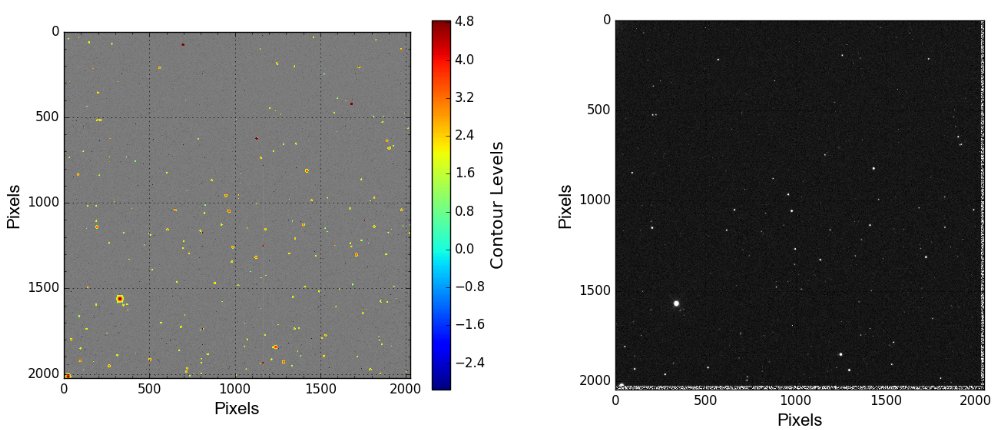

Figure 1. **Left:** Full reduced image that was provided. **Right:** Full corrected image. The corrected image was generated using a science image, darks, and flats. Both images were provided to show that image correction yielded the same full sky image that was already reduced.

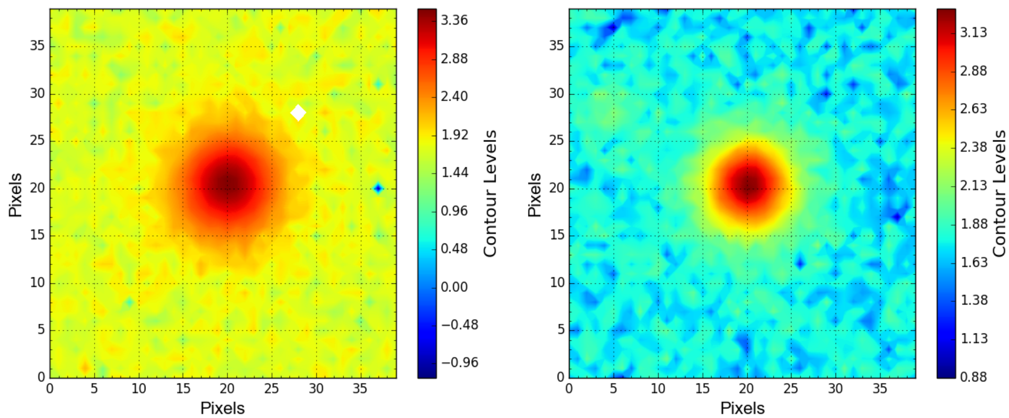

Figure 2. **Left:** The target, J-star, of the corrected image. **Right:** The reference/background star, J-standard, of the corrected image.

Table 1. Corrected Image Data

Object	Date	Start Time	Full Sky Flux	Background Flux	Background Standard Deviation	$J_\star$ Flux	$J_\dagger$ Flux	Aperture Size	Magnitude
J1614-1906	2014-06-07	14:51:40.337	65535.0	499885.161	19.00	171422.18	131921.58	40x40	13.22

Note—Aperture photometry was done to generate the above data. Object, date, and start times were collected from the header information. Fluxes were collected by taking the sum of aperture regions and magnitudes were found using equation 8.

Table 2. Signal-to-noise table

Star	B [u]	R [r]	I [i]	Flux/zp [R]	Flux/zp [B]	Flux/zp [I]	Exposure Time [s]
16:41:15.8, +36:33:18	15.17	14.27	13.84	491.46/21.00	492.85/21.90	997.79/21.34	43.002

Note—The flux for each RBI filter, normalized to 1 second. The calculated zero points are also included in the table.

7. OBSERVATION PLANNING

7.1. *Signal to Noise*

The signal-to-noise is found for the star 16:41:15.8, +36:33:18, which has an R-mag of 14.27 and an I-mag of 13.84. Equation 4 is used with the resulting electron flux from aperture photometry of the centroid and reference star. The reference used is the star located at 16:41:23.587, +36:30:17.65. The reference star has an R-mag of 10.43 and an I-mag of 10.55. The star was observed with an exposure time of 43.002 seconds and RBI zero-points 21.00, 21.90, and 21.34, respectively. The signal-to-noise using equation 4 for a 43.002 second exposure time and bands RBI are 1102.06, 1010.02, and 1456.56, respectively. The flux is normalized to a second by dividing the photometry flux by the total exposure time, 43.002 seconds. The normalized signal to noise ratio, found by equation 4, and the normalized flux yields ratios of 22.17, 22.20, and 31.59 for RBI filters, respectively. To reach a signal to noise ratio of 100, the exposure time required is 21 seconds. The resulting signal to noise ratios of each RBI filters with a 21 second exposure time are 101.59, 101.73, and 144.75, respectively.

Table 3. Finder Chart

Cluster	RA	Dec	RA (3rd)	Dec (3rd)	B (u)	V (g)	R (r)	I (i)	Catalog
Perseus*	03:18:36.930	41:30:34.44	03:18:41.245	$41:31:00.93$	17.52(16.14)	-	16.59(15.08)	16.35(14.86)	USNO-B 1.0
Train Wreck*	04:54:22.576	02:57:10:01	04:54:23.212	$02:56:29.58$	18.68(15.75)	-	18.32(14.86)	(13.87)	USNO-B 1.0
Abell 569*	07:09:10.138	+48:37:14.45	07:09:03.906	$48:36:54.44$	18.68(15.11)	-	18.32(14.64)	(14.27)	GSC 2.2
Hydra*	10:36:50.193	-27:30:46.88	10:36:42.120	$-27:30:44.26$	16.17(16.21)	-	16.14(15.51)	16.85(14.67)	USNO-B 1.0
Coma*	12:59:46.936	27:59:30.87	12:59:43.718	$27:59:40.75$	16.05(11.62)	-	15.19(10.95)	14.87(11.05)	USNO-B 1.0
Abell 1689*	13:11:30.0	-01:20:17.0	13:11:22.862	$-01:17:36.08$	17.32(17.47)	-	16.11(15.69)	15.75(15.69)	USNO-B 1.0

Note—The data of these cluster members are found using the USNO-B 1.0 and GSC 2.2 catalogs. Both are found using the VizieR search tool (http://vizier.u-strasbg.fr/viz-bin/VizieR-4). The clusters denoted with () were found by confirming with Aladin. The Aladin clusters also include measurements for a near bright objects. The BVRI magnitudes of the bright objects (3rd) are denoted after the cluster magnitude in the parenthesis.

7.2. *Finder chart*

Table 3 was generated using the VizieR catalog. For the USNO-B 1.0 catalog the filter magnitudes are denoted with [2].

Both figures 3 and 4 were generated with the above photometry techniques. The image corrections and aperture photometry techniques specifically were used. To find the reference star, the Aladin full sky atlas was invoked (http://aladin.u-strasbg.fr/AladinLite/). The Aladin site allows for a quick look at bright objects and provides coordinate that can be plugged into VizieR for more accurate coordinates.

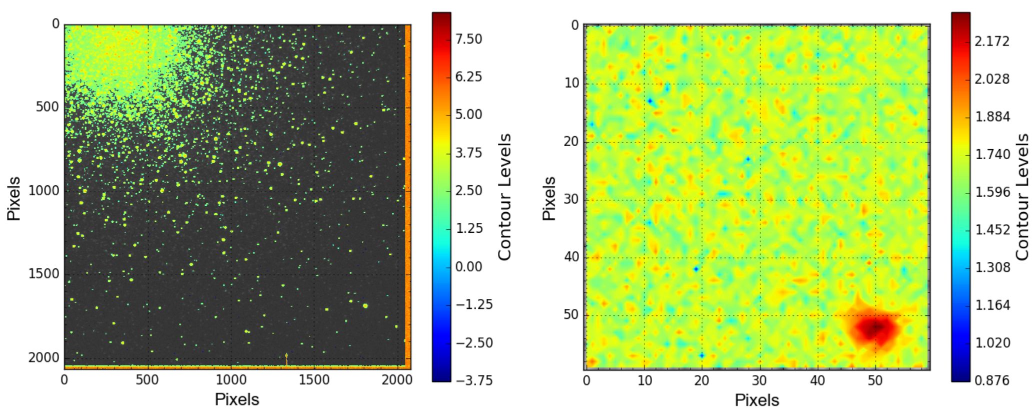

Figure 3. **Left:** Full image after corrections. **Right:** Background selection, note a slight intense region in the aperture, but it does not raise the standard deviation over the set threshold.

7.3. *Target availability*

The target availability for each cluster from table 3. Each cluster is observed from Mauna Kea, which is located at 19.8261 °N (latitude), -155.4708 °E (azimuth). The rest of the needed parameters arise from target coordinates (RA/Dec) and the LST of the optimal transit period. The cluster is in a prime location higher than 30° above the horizon. The TEK detector on the UH 2.2 m telescope is a 2048x2048 array of 0.22" pixels. The available filters are BVRI, although observation times are variable. The optimal observation time ranges are provided in table 4. Target availability curves were generated through equation 10 with the corresponding parameters outlined in table 5. The elevation in degrees is plotted against the LST relative to midnight on LST.

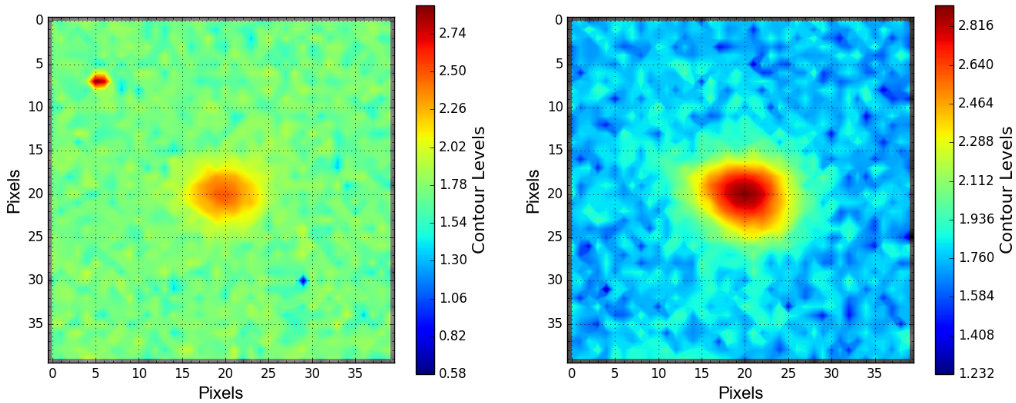

Figure 4. **Left:** The target. **Right:** The reference/background star.

Table 4. Target availability pointing times

Cluster	Start Time [hours off midnight]	Start Time [hh:mm:ss]	End Time [hours off midnight]	End Time [hh:mm:ss]
Perseus	-6*	18:00:00*	0.24	00:14:24
Train Wreck	-6*	18:00:00*	1.31	01:18:36
Abell 569	-4.84*	20:50:24*	4	04:00:00
Hydra	0.53	00:31:48	5.59	05:35:24
Coma	1.06	01:03:36	6	06:00:00
Abell 1689	1.81	01:48:36	6	06:00:00

Note—Observation times when the elevation is above 30° on Jan 18. The (*) and negative signs indicate times for the previous day (Jan 17).

Table 5. Target availability parameters

Date [mm-dd]	LST (midnight) [hhmmsss]	Elevation	Azimuth [0°-360°]	RA [hh:mm:ss]	Dec [dd:mm:ss]	Latitude [-90° - 90°]	Hour Angle [Hours]
01-18	07h34m05.33s	eqn 10	-155.4708	13 : 11 : 30	-01:20:17	19.8261	eqn 14

Note—Negative azimuth angles are subtracted from 360 to result in a positive angle.

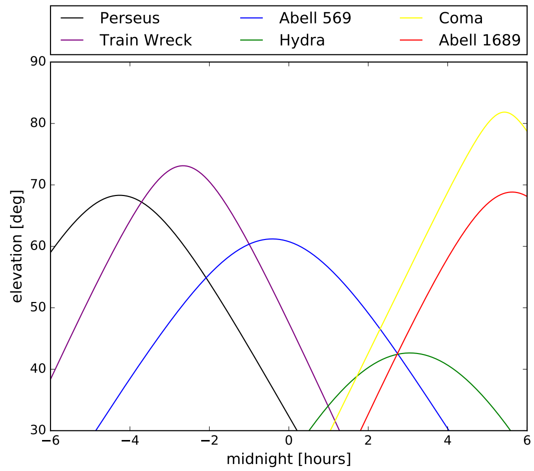

Figure 5. Target availabilities for all six clusters mentioned in table 3. The elevation starts at 30° from delta_midnight hours from -6 to 6.

7.4. *Field of view*

The field of view is shown for the Abell 1689 region, represented in figure 6. The objects within the field of view with the coordinates based off of the purple cross. Bright points were chosen based off of the field of view and confirmed with the VizieR catalog.

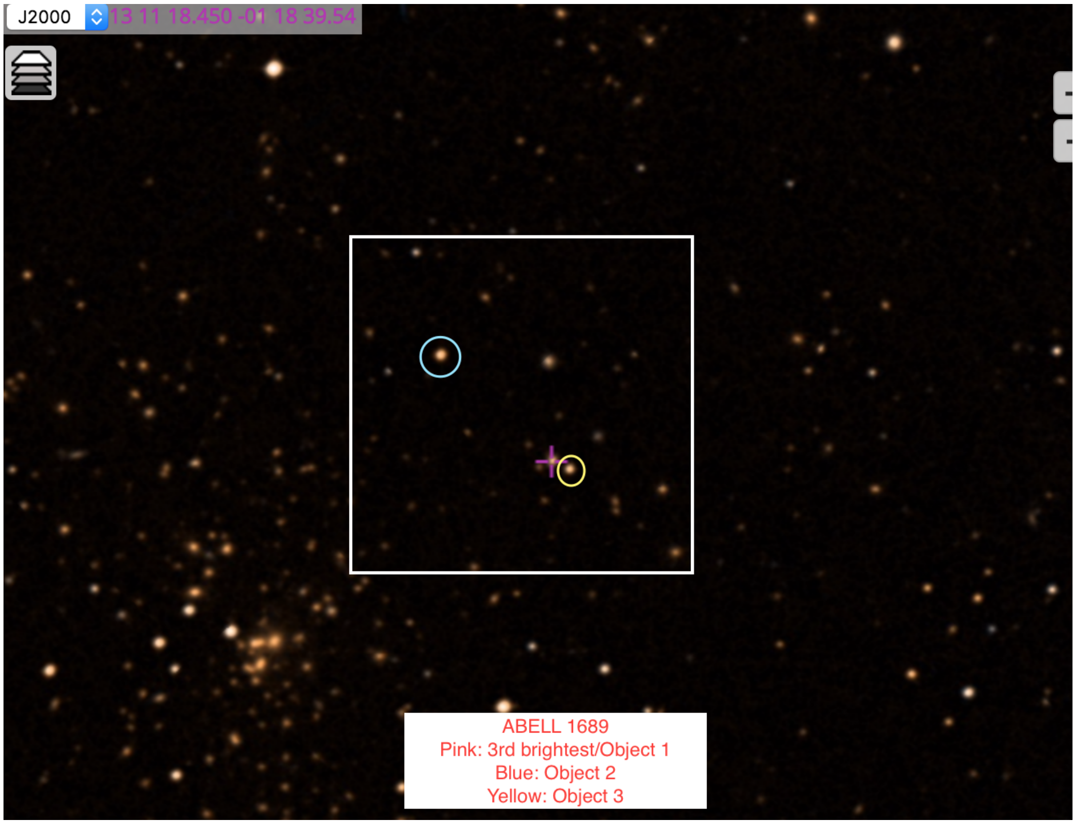

Figure 6. A sample magnified field of view from the Aladin full sky atlas. This field of view is of Abell 1689, where the coordinates are as labeled.

8. APPENDIX

Source code of the python scripts to conduct photometry and to generate target availabilities are included.
1) azimuth.py - Generates elevation plots regarding target availability.
2) decgalax.py - Photometry script, produces flux and magnitudes of aperture photometry.
3) dark.py - Image correction script, to generate corrected images using flats, darks, and corrected images.