Moon Surface

I. Exploring Topography, Shadows, and Data Reduction

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ABSTRACT

Context. This paper presents an overview of lunar observation project using the Celestron NexStar Evolution 8 telescope and ASI294MM Pro camera.
Aims. The project consist of three parts: theory, observation, and data reduction. The goal of the project is to study lunar surface features, collect the data, and apply data reduction techniques on the images of the Moon.
Methods. The data collection process consists of alignment of the telescope with a finder and star map, after which the ocular is replaced with monochromatic a camera. Calibration frames are captured using the ASI294MM Pro camera. The data reduction process consists of creating master bias frames, measuring and subtracting dark current frames, and capturing and normalizing flat field frames.
Results. The research project demonstrates application of telescope and camera in lunar observations by amateur astronomers. Despite some challenges, the project nevertheless provides valuable data and insights into the understanding of lunar surface.

Key words. moon shadows – lunar topography – data reduction

1. Introduction

The exploration of the Moon and its features has been a topic that intrigued humans since ancient times. Significant progress can be seen throughout history and significant milestones have been reached. As the Moon is the Earth's only natural satellite and the closest astronomical object it has been thoroughly researched.

NASA is currently planning Artemis mission, whose goal is to learn and gather information needed for sending the first astronauts to the Mars. They will land for the first-time woman and the person of color on the Moon. This mission is very important because they will explore lunar surface in greater detail thanks to advancements in technology since the previous human landing. They had already sent Artemis I which was uncrewed flight test and the next step, Artemis II, will be crew flight test, and lastly Artemis III which is the crew landing mission.[1]

Creating detailed lunar topographic map is very important for landing astronauts on the Moon and deploying rovers. These maps contain information about terrain, locations and depths of craters, heights of mountains, the presence of slopes, and more. So precise topographic maps are important to decide which landing sites are suitable for landing missions and astronauts will need them to navigate around the Moon. By analyzing lunar surface features, scientists can study the geological processes that have shaped the Moon's surface. Also, by making lunar topography maps potential resources on the Moon can be identified, such as water in the permanently shadowed regions.[2]

In this paper we are firstly focusing on the theoretical part, starting with historical background where the human fascination with the Moon can be seen. The next part is the Moon surface features where the Moon's diverse landscape is described. After that the main theoretical part is explained, which is the Moon shadows, how they are being casted and how can we measure heights and depths of lunar surface features using shadows. After theoretical part we are delving into data reduction. The crucial importance of data reduction is explained and the explanations of the codes is described. Lastly, the observational part is described, starting with the important things that you must consider before going on an observation. Then the process of collecting the data will be explained in the form of a tutorial for ASII studio software and observation process.

2. Historical Background

The exploration of the Moon and its surface characteristics has always been fascinating to humans. In prehistoric times they would link night sky objects to some Earth objects or living beings. For example, the parts of the Moon surface which appear darker were interpreted as human face, an old lady spinning etc. Some of the interpretations are shown in the Fig. 1. People were fascinated about a lot of things regarding the Moon, such as Moon phases, Moon surface, distance, and size of the Moon. Throughout history, different civilizations have interpreted the Moon and its surface in various ways, leading to the development of early theories, drawings, and derivations that eventually contributed to human exploration and eventual landing on the Moon.

In the early stages of history of Moon topography people relied only on naked eye viewing of the Moon, which is a lot constraining generally but in case of the Moon it still can provide some details because of its close distance to the Earth and ability

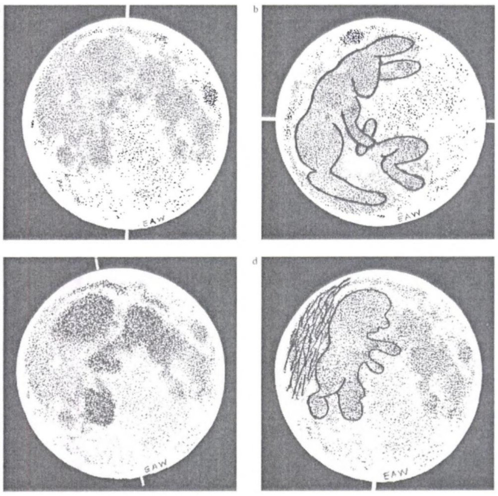

Fig. 1. Different shapes imagined on the Moon's surface in prehistoric times. (a) Full Moon with some details, (b) a rabbit pounding a heap of rice, (c) 'Man in the Moon' and (d) an old man carrying a bundle of sticks.[3]

to observe it through different illuminations. When observing the Moon with naked eye they have also noticed that the markings are more visible in twilight than against the black sky, so that the surrounding sky's light cancels some of the brightness. It was also widely believed that dark spots were seas (lat. 'Mare'), and they are still called maria today.

So, in the beginning they heavily relied on mythology, story-telling, and personification to explain natural phenomena.

In 1608, Hans Lippershey invented the first telescope, and as far as we know, just a year later Thomas Harriot made a first telescopic sketch of the Moon, and in 1611 he made a first telescopic map of the Moon which is shown in Fig. 2. Invention of the telescope was important milestone because it allowed the astronomers to observe its surface in much greater detail, revealing intricate features and enabling the creation of more detailed lunar surface maps.[3]

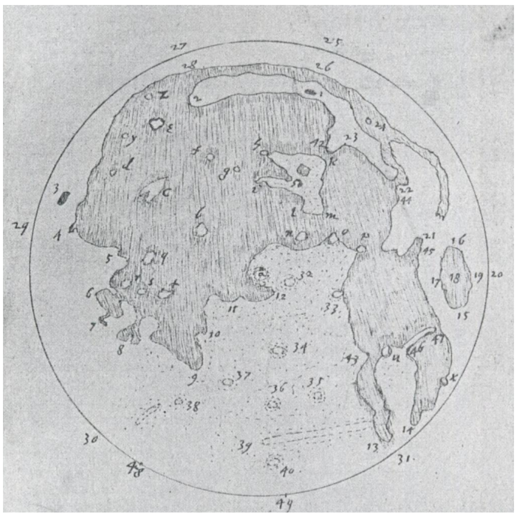

Fig. 2. Thomas Harriot's telescopic map of the Moon.[3]

Astronomer Johannes Hevelius made an atlas of the Moon called 'Selenographia', and he is thought to be a founder of lunar topography. During 17th, 18th, and 19th century a lot of astronomers studied the Moon and made lunar maps, some of them were Galileo Galilei who made detailed telescopic observations of the Moon, John Seller who made one of the first lunar maps, Tobias Mayer who developed improved methods for measuring lunar position, Maurice Loewy who produced high-quality lunar photographs using a camera, and many other astronomers.[4]

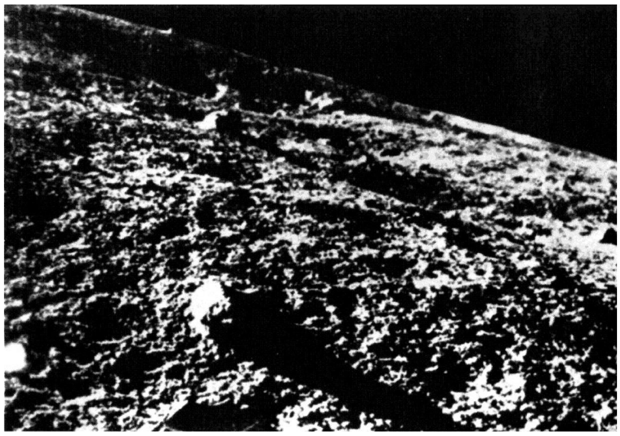

Fig. 3. First close-up picture of the Moon from the Luna 9 mission.[6]

In the mid-20th century, there was a significant improvement in the field of selenography with launching of spacecraft. For the first time humans were able to observe and collect data directly from the Moon's surface. For example, Soviet Union's Luna program and NASA's Ranger and Surveyor missions were the first three missions that provided close-up images of the Moon's surface (Fig. 3). One of the most significant missions were the Apollo missions, especially Apollo 11 mission in 1969 when the first humans landed on the Moon. These missions provided important data about topography of the Moon.[5]

3. Moon Surface Features

On the 'near' side of the Moon, which we always see, Maria occupies around 30% and Terrae 70% of the lunar surface. Maria (singular, mare) is the name for dark areas on the Moon and terrae (singular, terra) for bright, highland regions of the Moon. Most of the maria are circular, which will be important for latter approximations. The circular maria are boarded by surrounding features called terra rims which are typically annular or arcuate (meaning they form a ring or curve shape around maria), and the broader structure where they are located are called ringed basins. The rims surrounding the maria can have both bright and dark areas.

Latin name	Common name	Description
Mare (maria)	Sea (not used in this volume).	Dark, smooth plains.
Lacus, palus, sinus		Small mare.
Terra (terrae)[1]	Highlands, uplands, continents.	Rugged, relatively bright (high albedo) terrain.
Mons (montes)	Mount, mountain(s)	High massif(s), generally forming arcuate ranges.
Promontorium	Promontory	Mountains partly enclosed by mare.
Rupes	Scarp	Fault in mare or high arcuate scarp in terra.
Dorsum (dorsa)	Mare ridge, wrinkle ridge.	Narrow ridge, mostly in mare.
Rima (rimae)	Rille	Narrow, elongate depression (sinuous, arcuate, or straight).
Vallis (valles)	Valley	Wide, elongate depression, commonly consisting of inconspicuous craters.
Catena (catenae)	Chain	Chain of distinct craters.
	Crater	Circular or subcircular depression, generally bounded by a raised rim.[2]
	Basin, ringed basin	Large craterlike depression containing one or more rings in addition to a rim.[3]

Fig. 4. Typical names for lunar surface features.[7]

When observing the maria they appear generally level and smooth, which means that they lack roughness typically associated with highlands (terrae). But at closer inspection there are variations in elevation and surface features within the maria (local topographic relief).

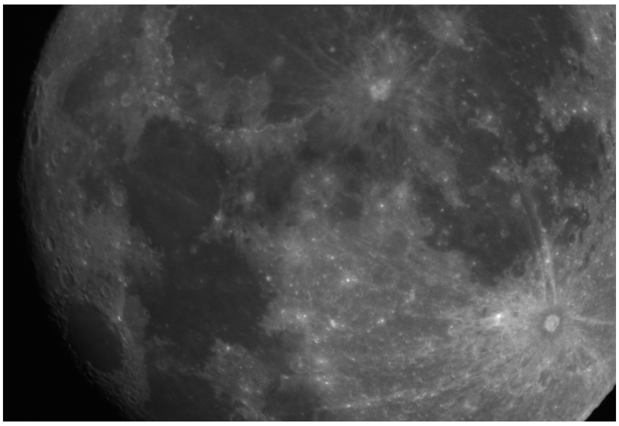

Fig. 5. Moon surface photography taken on May 6th, 2023.

Dark mantling materials are found both in the mare and terrae and they are darker than the surrounding terrain. That is the layer of darker substances that cover and follow the contours of the lunar landscape.

Craters are extremely common and can be found throughout the lunar surface, but there are generally more crates on the terrae than maria. They also widely range in size (diameter).[7]

Mare Imbrium (Sea of Showers) is a prominent feature and the largest maria on the Moon, and it can be seen on the map of the Moon in the Fig. 5. It is approximately circular with mountainous boarders, but it is important to note that not all maria have mountainous boarders. A lot of the major maria are connected to each other, forming a network of interconnected dark plains (you can see some in the Fig. 4.). The Mare Crisium (Sea of Crises) is detached and visible with naked eye. Some of the maria are so badly placed that they are hardly visible from the Earth, except when libration allows us to observe them.

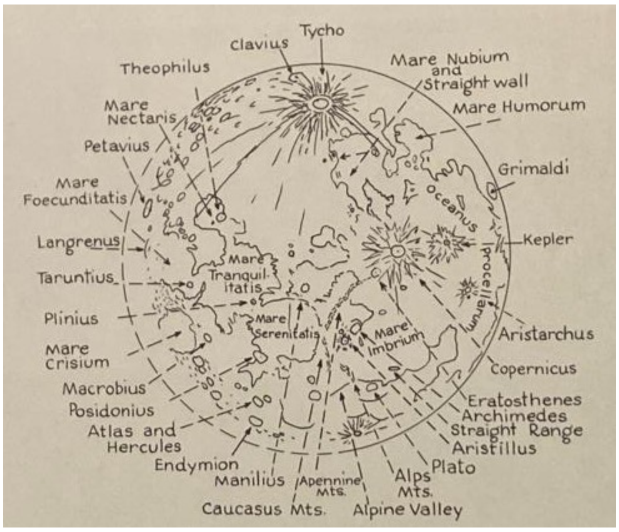

Fig. 6. Simple map of the Moon.[8]

The lunar mountains can be very high, for example Apennines is around 4,570 meters high. Lunar mountain heights are determined by measuring the length of their shadows during specific lighting conditions (more about this in the Moon Shadows chapter).

Some of the more notable craters are Tycho, Copernicus, Aristarchus, Kepler etc. Some of them have massive, terraced walls and sunken floors and generally they appear as “shallow saucer”. They (and maria) are formed through impacts of meteoroids, asteroids, and comets. The Moon was bombarded with meteoroids in the period from around 4.2 to 3.9 billion years ago.

Rills appear as cracks that extend for few to hundred kilometers, for example Ariadeus Rill near the Mare Vaporum.[9]

When the Moon is full (Fig. 5.), bright streaks that radiate outwards from certain impact craters called rays are clearly visible. They don’t cast shadow; they can’t be broken by any lunar features and are only noticeable by their lighter/brighter color.[8]

4. Moon Shadows

We can easily observe the Moon with a small telescope or binoculars and still obtain a lot of information about its surface, for example we can observe the shadows that craters and mountains cast, recognize them, and “move” around the Moon. Terminator is the line dividing illuminated and darkened parts of celestial body as seen from the observers point, and in this case we are observing the Moon surface from the Earth. Terminator line moves gradually across its surface as it orbits the Earth which results in lunar phases (Fig. 7.) in the line of sight of the observer.

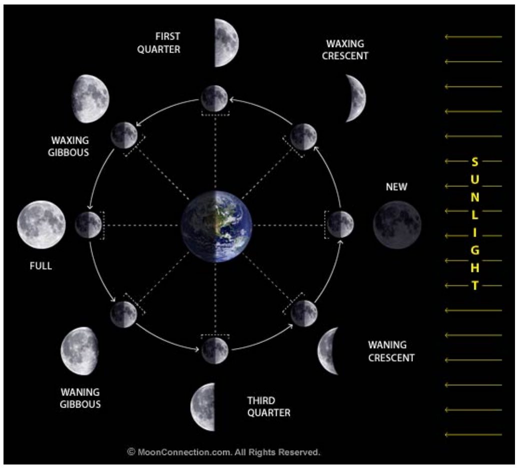

Fig. 7. Lunar phases.[10]

If the crater is near the terminator its shadow will be long and thus visible and prominent. As the terminator is moving, shadows of the observed crater will shrink making it harder to observe, unless it has very dark floor. Near and during the full Moon, there are basically no shadows because the Sun, the Earth, and the Moon are all aligned with each other (Fig. 7.). When the Sun is closer to the horizon, the shadows will appear longer. So, the Sun angle influences the length and direction of the shadows, if the Sun angle is lower the visibility of its surface features will be better.[8]

The best phases to observe Moon shadows near terminator is near the first or third quarter. The sunlight at terminator is approximately perpendicular to our line of sight. By observing shadows many irregularities can be recognized that are invisible when the Moon is full (or nearly full). So, during the full Moon the only thing that we can observe are the light and dark areas, and that is because the Sun is above horizon and then the lunar surface features appear relatively flat and uniform.[9]

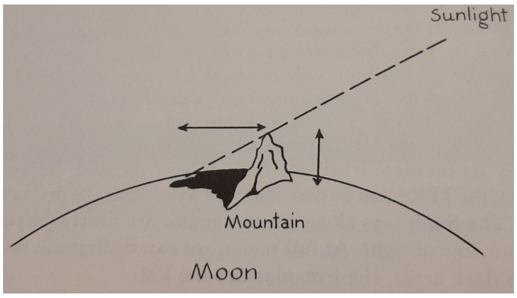

Fig. 8. Lunar mountain casting a shadow.[9]

By observing shadows, we can get accurate approximation of the heights and depths of the lunar surface features as following:

1. Choose a crater or a mountain or any prominent lunar surface feature that you want to observe and, in the end, calculate its height or depth.
2. Using a telescope, camera, and appropriate software for astronomy imaging (in our case it was ASIStudio) observe the shadows (Fig.9.) and take an image (explained in chapter 7).
3. Determine at which angle was the sunlight hitting lunar surface at the time of observation. You can find the information online, use an online sun angle calculator or calculate it yourself.
4. Measure the shadow length.
5. Calculate height or depth using trigonometric principle.
6. Compare your result with data provided online and keep in mind what can cause variations in the results (for example, Earth's atmosphere).

By looking at the Fig. 10. it is easy to derive the expression for calculating the lunar surface heights and depths. L is the length of the shadow that crater casts, H is depth or height of lunar feature, and θ is the Sun's angle of incidence. As it is shown in Fig. 10. you can form a triangle, and now using trigonometric function we easily obtain H.

$$\tan(\theta) = \frac{H}{L}, \tag{1}$$

and we just rearrange equation to get H

Fig. 9. Shadow that crater casts on lunar surface.[11]

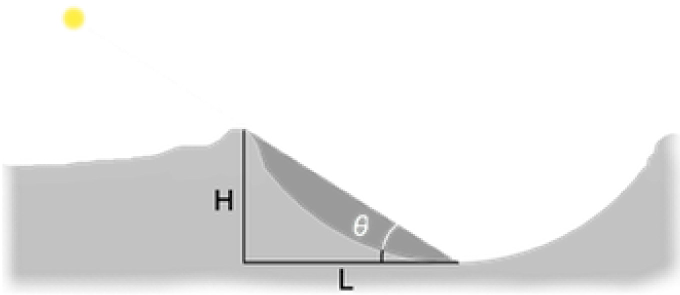

Fig. 10. Determinations of crater height using shadows.[12]

$$H = \tan(\theta) * L. \tag{2}$$

As simple as that we can calculate depths and heights of lunar surface features with 10% error.

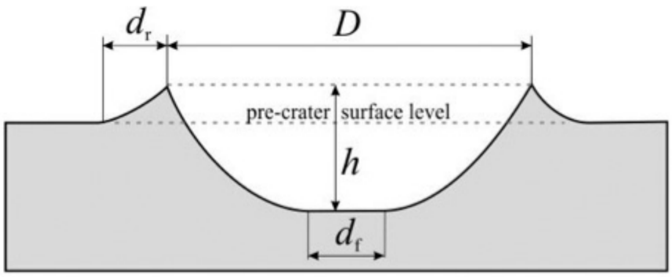

Fig. 11. Cross section of a crater.[13]

After you calculate the height or depth of some lunar feature, next thing that you want to determine is its diameter. The Fig. 11. shows a cross section of a crater, where D is rim diameter, h is crater height, d_r is rim width, and d_f is floor diameter. If you have a clear view of a crater or a mountain you can estimate its diameter from an image.[13]

Keep in mind that previously described method is the simplest one for amateur astronomers. Here we are making several approximations which can be potential causes of an error. Many more improved and generalized methods have been derived over the years with a lower error.

One interesting new approach was developed by Iris Fernandes and Klaus Mosegaard at Niels Bohr Institute. This new method has been developed that uses shadows to reveal the topography of the moon. By analyzing multiple shadowed images taken at different times and angles, along with elevation data, a 3D model of the terrain can be created without prior assumptions. This new technique is faster and produces high-resolution terrain maps, providing a better understanding of the Moon's surface features. The researchers tested the method using data from NASA's Lunar Reconnaissance Orbiter (LRO), which has been orbiting the Moon since 2009. The resulting high-resolution terrain model greatly improved elevation resolution, allowing the identification of small craters.[14]

Example of a lunar topography map is Fig. 12. It shows NASA's high resolution topographic map of the Moon, they used LRO's Wide Angle Camera and the Lunar Orbiter Laser Altimeter instrument.[15]

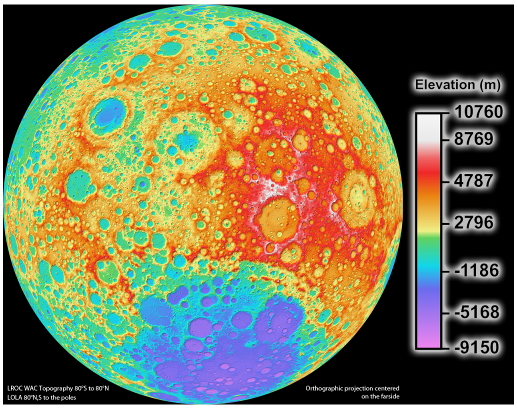

Fig. 12. Topographic map of the Moon.[15]

5. Data reduction

5.1. Master bias

In the field of data acquisition and image processing, bias frames play a crucial role in ensuring the accuracy and reliability of scientific or calibration data. Bias frames capture the inherent electronic noise present in an imaging system and are used to correct for this noise in subsequent frames. This introduction will explore why it is necessary to take bias frames and how they are related to dark current and flat field calibration.

Bias frames are typically captured by taking a series of images with the camera shutter closed in order to eliminate any incoming light. These frames record the constant electrical signal generated by the camera's sensor, including sources of noise such as thermal fluctuations, electronic offsets, and readout variations. By averaging multiple bias frames, a master bias frame is created, which represents the combined noise characteristics of the system. Here is the procedure to do so :

```
def master_bias(data):
    #Purpose: create Master Bias frame
    #Input: A list of images to combine
    #Output: Master bias
    (median of all the bias images)

    img_list = [] #create empty list of images
    for file in data: #loop over all files listed
    in data
        #read each file
        hdu = fits.open(path+file)
        im = hdu[0].data #this reads the image
        img_list.append(im)
        #append this image to the list

    cube = np.array(img_list)
    #transform the image list into an array
    print('Cube dimensions:', cube.shape)

    # Save the array as fits -
    it will save it as an image cube
    #Usefull for checking.
    #download this cube and inspect it in ds9
    fits.writeto(temp_path+'bias_cube.fits',
    cube, overwrite=True)

    #Calculate the master bias as
    ža median over the shortest axis of the cube
    master_bias = np.nanmedian(cube,0)
    print('Master bias dimensions:', master_bias.shape)
    return master_bias
```

One of the main reasons bias frames are so important is that they provide a baseline reference for correcting subsequent data frames. Each science or calibration frame, with the exception of the bias frame, must be corrected by the corresponding master bias frame from the same day. This correction ensures that noise or variations that occurred during image acquisition are properly accounted for and removed from the final data.

It is important that a master bias frame is created for each specific date. It is not advisable to combine bias frames taken on different days or even on the same day but several hours apart. This is because the characteristics of electronic noise can change over time due to factors such as temperature variations or changes in camera operating conditions. To maintain calibration accuracy, only one set of consecutive bias images, usually taken within a short period of time, should be combined.

In addition to bias frames, dark current frames and flat field frames are also important calibration elements in astrophotography and other imaging applications. Dark current frames capture the thermal signal generated by the camera sensor when exposed to extended periods without incoming light. Flat-field frames take into account variations in the system's response to different lighting levels across the entire image. All these calibration frames, including the bias frame, work together to guarantee the accuracy and quality of the final data.

5.2. Dark current

Dark current is a major source of noise that affects data quality. It refers to the thermal fluctuations of the charge that occur inside a charge-coupled device (CCD) detector, independent of any incoming light. These fluctuations are directly influenced by temperature and can be reduced by cooling the CCD. This part focuses on the measurement and reduction of dark current to improve the accuracy and reliability of astronomical data.

5.3. Measuring Dark Current

Our objective is to determine if the dark current in our telescope's CCD is negligible. We need to performed a series of tasks to investigate its behavior under various conditions.

We first ensured that no external light could enter the system by closing the telescope and if necessary, covering the camera with a black or dark cloth. This step was essential to isolate the CCD from any potential sources of light.

We conducted multiple dark frame exposures using different exposure times, such as 1s, 10s, and 100s. By varying the exposure time, we aimed to observe any variations in the dark current levels. If the dark current is negligible, we would expect to see consistent and minimal values across different exposure times.

To examine the influence of temperature on dark current, we tested also different cooling temperatures while capturing dark frames. By adjusting the CCD's cooling system, we can determine if lower temperatures effectively reduce dark current levels. We observed and compared the dark current behavior at different cooling settings to evaluate its impact. To gain further insights into the nature of dark current, we performed a comparison between the acquired dark frames and bias frames. Bias frames serve as a reference signal captured without any exposure. Under ideal conditions, dark current should be minimal and similar to the levels observed in the bias frames. However, the presence of dark current would lead to deviations from the bias frames. These dark frames were taken with the same exposure time (EXPTIME) as the science images or other calibration frames. By capturing multiple dark frames and averaging them, we generated a master dark frame that represents the typical dark current present in the CCD.

```
def master_dark(data):
img_list = [] #create empty list of images
hdu_bias =
fits.open(masterfile_path+"masterbias.fits")

for file in data: #loop over all files listed
in data
    #read each file
    hdu = fits.open(path+file)
    im = hdu[0].data #this reads the image
    #im_avg = np.average(im)
    img_list.append(im-hdu_bias[0].data)

cube = np.array(img_list) #transform the image
list into an array
print('Cube dimensions:', cube.shape)


# Save the array as fits -
it will save it as an image cube
#Usefull for checking. To make sure that
the program does exactly what you intend it to do,
you should #download this cube and inspect
it in ds9
#fits.writeto(temp_path+'masterdark_cube.fits',
cube, overwrite=True)

master_dark = np.nanmedian(cube,0)
#master dark as median of multiple images
scalar_master_dark = np.average(master_dark)
#master dark average value
dev_master_dark = np.std(master_dark)
#master dark standard deviation
print('Master dark dimensions:', master_dark.shape)
return master_dark, scalar_master_dark,
dev_master_dark
```

This comparison and measurement process allowed us to assess the nature of dark current and its relationship with the baseline bias signal. It served as a crucial step in understanding the behavior of our CCD and determining the extent to which dark current affects our science data. By carefully analyzing these frames, we could address any deviations from the bias frames and evaluate the need for additional calibration techniques to account for dark current in our observations.

5.4. Importance of Matching

When subtracting the master dark frame from the science data, it is crucial to "match" certain parameters to ensure accurate correction. While some factors require matching, others can differ without affecting the dark current subtraction process.

One parameter that must be matched is the exposure time. Dark current is directly proportional to time, meaning that longer exposure times result in higher levels of dark current. Therefore, using the same exposure time for both the science and dark frames allows for an accurate subtraction of the dark current.

On the other hand, the filter used in the observations does not affect dark current. Dark current arises solely from thermal fluctuations within the CCD and does not involve any light passing through the telescope or instrument optics. Thus, matching the filter between the science data and dark frames is not necessary for dark current subtraction.

In addition to exposure time, other camera settings such as binning and gain should be matched. Binning involves combining adjacent pixels to create larger "super pixels," reducing readout noise. Matching the binning configuration ensures that the dark current correction accurately accounts for the specific pixel grouping used during the science observations. Similarly, gain settings affect the conversion of charge to digital values, and matching them ensures proper dark current subtraction.

By carefully considering these matching requirements, we can effectively subtract the dark current from the science data, minimizing its impact on the final results. The accurate removal of dark current is vital for improving the quality and reliability of astronomical data, ultimately leading to more robust scientific conclusions.

5.5. Flat field

The process of measuring the flat field and applying it to the science data is very important for accurate and reliable analysis.

The measurement and application of the flat field in data analysis is essential to correct for systematic variations in the imaging system. In addition, the flat field plays a crucial role in eliminating imperfections such as dust particles and scratches on the camera sensor or optical elements.

Thanks to division by the flat field, these imperfections can be corrected, resulting in precise images that represent the underlying phenomena while guaranteeing an accurate representation of the response of each pixel.

Another essential aspect addressed by the flat field is the calibration of relative flux. By comparing the pixel values in the scientific data with the corresponding pixel values in the flat field, it becomes possible to determine the relative brightness of objects in the field of view. This calibration is essential for obtaining accurate photo metric measurements and for ensuring the consistency and comparability of data acquired at different times or with different instruments.

In summary, the measurement and use of the flat field plays an essential role in data analysis. By taking account of systematic variations, eliminating imperfections and enabling relative flux calibration. The flat field guarantees the accuracy and reliability of scientific investigations by producing high-quality, correctly calibrated data.

5.6. Measuring Flat Field

The first step is to subtract the master bias frame from each individual flat field frame. This helps to remove the bias or offset produced by the camera's sensor and electronics, ensuring that the subsequent flat field frames are free from this systematic noise.

We then need to separate the flat-field images by filter and date. It is important to group and organise the flat field images according to the filter used and the date they were taken. Flat field images should ideally be taken in sequence to allow for potential variations in light levels that may occur at different times.

Finally we have to normalized flat field frames that are stacked together, typically by taking the median at each pixel position. This stacking process helps to create a master flat field image that represents the average response of the imaging system to uniform illumination. Taking the median helps to mitigate the impact of any individual outlier frames and produces a more robust and representative master flat field.

In Python, the function np.nanmedian(image) can be used to calculate the median, taking into account possible missing or invalid values (represented as nan). Here it7s the same idea than with the master dark current.

```
 def master_ffield(data):

img_list = [] #create empty list of images
hdu_bias = fits.open("")
hdu_dark = fits.open("")
for file in data:
#loop over all files listed in data
    #read each file
    hdu = fits.open(path+file)
    im = hdu[0].data #this reads the image
    img_list.append
    ((im-hdu_bias[0].data-hdu_dark[0].data)
    /np.nanmedian
    (im-hdu_bias[0].data-hdu_dark[0].data))
    #append this image to the list

cube = np.array(img_list)
#transform the image list into an array
print('Cube dimensions:', cube.shape)


# Save the array as fits -
it will save it as an i
#download this cube and inspect it in ds9
fits.writeto(temp_path+'ffield_cube.fits', cube,
overwrite=True)

flat_field = np.nanmedian(cube,0)
print('Flat field dimensions:', flat_field.shape)
return flat_field
```

By following these steps, the master flat field is obtained, which can then be used to correct for systematic variations, remove imperfections, and calibrate the science data for accurate and reliable analysis.

Here is a sketch of all the precedure we need to do in order to obrain a correct science data images:

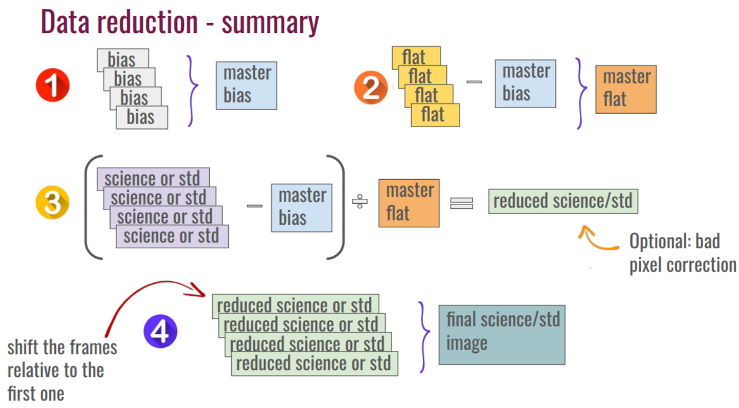

Fig. 13. All procedure for data reduction.

6. Before observations

Before making an observations it is important to consider a few important factors.

1. Optimal time for observations: in the case of observing lunar shadows, the best time to observe the Moon is during its first and third quarter. Of course, before you go you have to look online when is the moon rise and moon set that night.
2. Bias, dark current, and flat field: you must take them at the same night of the observations. You should capture flat field at dusk or dawn so plan it appropriately. For example, if the Moon rises at 3AM it may be more convenient to capture flat field at dawn.
3. Determine ideal exposure time: use online exposure time calculator. You need to know camera and telescope specifications.
4. Filters: from accessible filters, find out which ones may be helpful to you. In our case, we had BVR filters, but they are not usually used for lunar observations, they are primarily used for observing stars and galaxies. Moon is very close and bright object, so no filters are needed to enhance its appearance. Blue filter should enhance the visibility of lunar maria, and red filter should enhance the details in lunar highlands. Although we used them all and they did not affect Moon's appearance.
5. Calculate the Sun's angle of incidence: calculate it using online tools, but you can also do this after observations.
6. Test your equipment: it will be more time efficient if you test it out before you make an observation so any possible inconveniences are avoided.

7. Collecting the data

For the needs of our observations, we used Celestron NexStar Evolution 8 telescope with the aperture of 208 mm with its own motorized GoTo mount. Before starting the observation first challenge that we need to overcome is the alignment. There are few steps which need to be followed in this process. First after we install the telescope on the mount and put in the ocular, we need to align the telescope with the finder. We choose a relatively far object on Earth that we can easily recognize in the finder field with naked eye and focus it with our telescope. In the next step we put the telescope back in the starting position and we begin with the star map alignment. This alignment can be done in different ways. Generally, the best way is to choose multiple sky objects, but it can also be done with few of them as for example with two stars or even just one object from Solar System. The quality of this alignment is very important for the smooth tracking of celestial objects as for finding them. In our case Moon was easy to spot on the sky so we could choose the option to aligned it directly with the Moon.

As soon as our alignment is done successfully, we can replace the ocular with the camera. For this purpose, we used monochromatic ASI294MM Pro camera with attached motorized filter wheel in which we had stored B, V and R filters sorted in their available slots. Camera needs full-time power supply and that is why we used a portable battery on our observations. Next step is to connect the camera with the laptop and open the Asii studio.

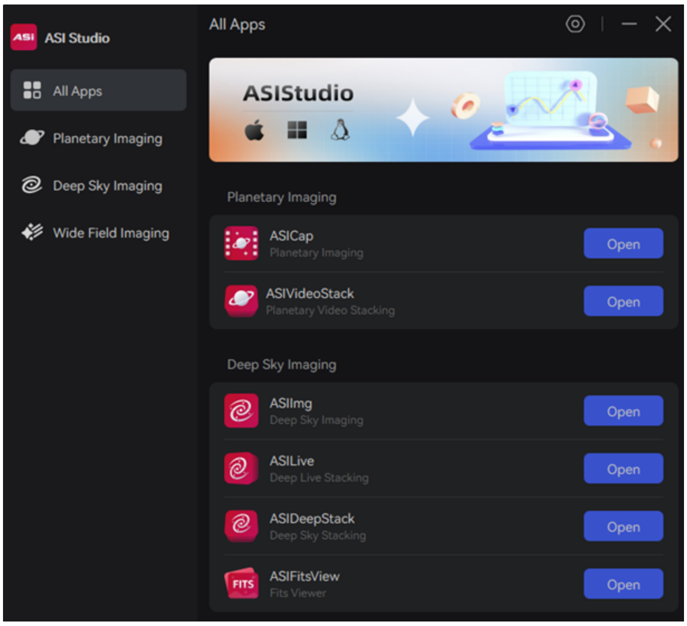

Fig. 14. Possible options and modes inside Asii studio program.

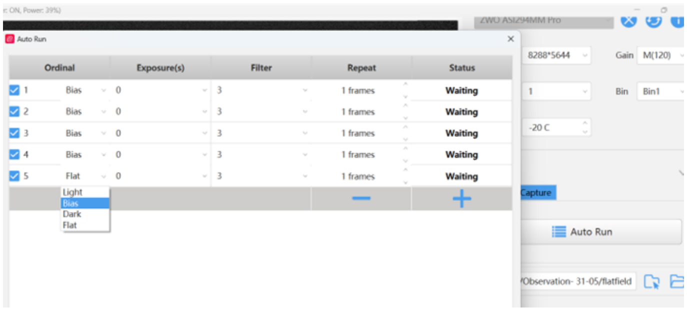

Fig. 15. Auto Run option inside ASIImg Deep Sky Imaging.

On the Fig.13. we see the main window in Asii studio with listed options for this camera. In our project we used the ASICap Planetary Imaging mode for taking images of the Moon surface and ASIImg Deep Sky Imaging for taking bias, dark current and flat field data.

Once we arrive on the place of observation, we start with taking the frames of flat field that are done by ASIImg Deep Sky Imaging option. On the Fig.14. we see an example of Auto Run option that we use for taking calibration frames. In first drop down we can choose Light option for normal frames, Bias, Dark for dark current and Flat for flat field. Using this option the program creates separate folder just for this session. It is very important to use same settings for our calibration frames as for taking the scientific data later. So in the options we always take gain to be M(120), the highest possible resolution and we try to maintain the same temperature of the camera. Depending on the weather, place and hour of observation our camera could cool down to -20°C.

All calibration frames we took are not stacked by the program but manually combined and processed later in the codes. It is required to separately take Flat fields for all filters that are planned to use. By changing the exposure time we are aiming to get average values in the filed around 20 000 counts.

On our observations we used to take bias and dark current after our observation firstly because it was darker and environment conditions as humidity would rapidly change after the Sun goes down. Also, we couldn't precisely determine the exposure time before taking the frames of the Moon which we need to know before taking the dark current. For taking the bias calibration frames as explained before we would put additional coverage on the telescope to prevent any external light coming in and choose the exposure time to be zero. For dark current it is required to use same exposure time as in our scientific data. In the later paragraph I will explain how we get to this exposure time.

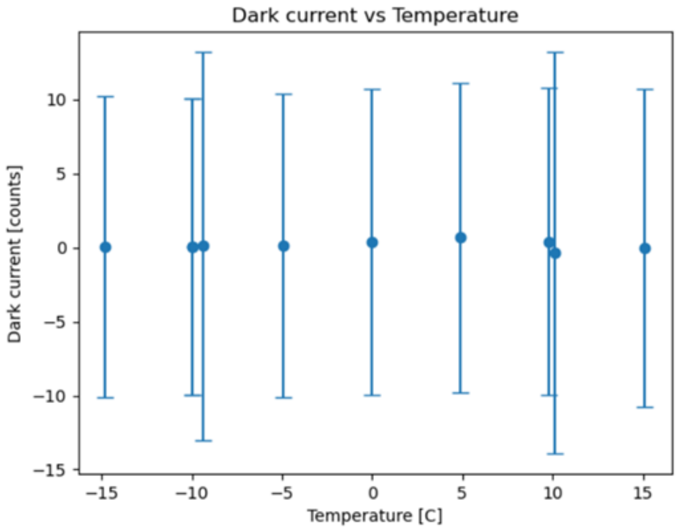

Fig. 16. Dark current in respect to the different temperature of camera.

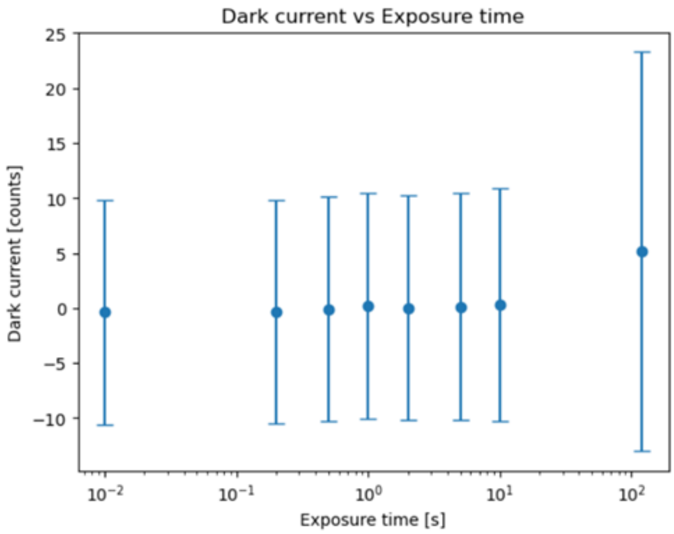

Fig. 17. Dark current in respect to the different exposure time.

In the early beginning of our project we took the measurements to check the values of dark current with our camera in the respect to the temperature and the exposure time. On Fig.14. and Fig.15. we presented our results. Even though the deviation in our measurements seems pretty high, average values are around zero which led us to the conclusion that dark current can be neglected.

As mentioned earlier for taking the frames of the Moon we used Planetary Imaging mode in which we are offered to choose any object of the Solar System. This option is providing us extended settings to easier focus our observing object. For example one of the useful options is the automatic choose of the exposure time to avoid the saturation of the image. We set the gain to 120

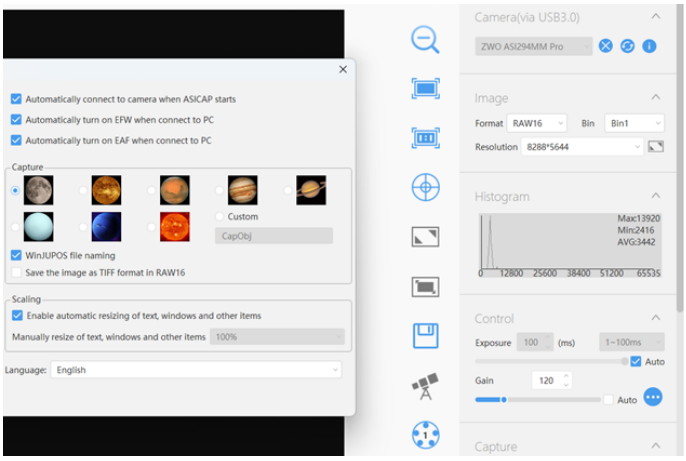

Fig. 18. Planetary imaging mode in Asii studio.

to match our calibration frames. Exposure time is changing accordingly to the resolution and the part of the Moon that we are focused on.

8. Conclusions

There are a few problems that can cause an issue when observing the Moon with telescope.

1. Earth's atmosphere: even the best telescopes used by professional observers are limited by the Earth's atmosphere, which is one of the reasons why the space program has been very popular.[9]
2. Light pollution: urban areas are light polluted which can reduce the visibility of the Moon by washing out details on the lunar surface.
3. Telescope or equipment issues:in our case we had a problem with aligning the telescope.
4. Weather conditions: unpredictable changes in weather conditions affected the ability to observe which led to cancellation of observations.

These are some problems that we have noticed that affected amateur observations. The problem of Earth's atmosphere was out of our hands, we tried to select observation sites away from bright lights, the problem of the alignment could not be solved, and how the weather in Split is often very unpredictable and it limited the days when we could go observing.

There are also a lot of approximations and possible causes of errors in description of height and depth measurements.

1. Approximation of shadow length: small errors in shadow length can cause significant errors in the calculations of heights and depths. This refers to, for example, accuracy of the telescope and camera, Earth's atmosphere can make an image appear blurry or shaky etc.
2. Assumption of uniform lighting: it is approximated that the lighting conditions on the Moon's surface are uniform, which does not always have to be the case. Uneven illumination can affect the accuracy of the measurement.
3. Idealized lunar surface: lunar surface (craters and mountains) is simplified in the terms of geometric shapes with well-defined shadows, which is not always a good approximation.
4. Precision of Sun's angle of incidence determination: even the online calculators have inaccuracies.
5. Estimation of diameter: manually measuring diameters with a scale reference is not precise enough, and image analysing precision can be affected by factors like image resolution, noise etc.
6. Accuracy of online data: online available data is sometimes incomplete and also is not 100% precise, and we wanted to compare our results with online data.

These are some of the factors that we would have kept in mind if we did data analysis.

In conclusion, our lunar observation project included the collection of data using the Celestron NexStar Evolution 8 telescope and ASI294MM Pro camera, and we had a problem with the alignment. Despite that limitation, we managed to collect the data needed for data reduction. We did not managed to do the observation when lunar shadows where present and pronounced, so we weren't able to map and measure topology of surface of the Moon. Despite these challenges, our project provided valuable insights into lunar surface features, lunar observations and the data reduction process.

9. Lunar Observation Log

Date	Illumination	Lunar Phase	Moonrise	Moonset
May 7th	98%	Waning Gibbous	06:24 AM	10:32 PM
May 31st	87.1%	Waxing Gibbous	04:27 PM	03:06 AM

Table 1. Lunar Observations Log

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