DEEP SPACE ASTROPHOTOGRAPHY TUTORIAL

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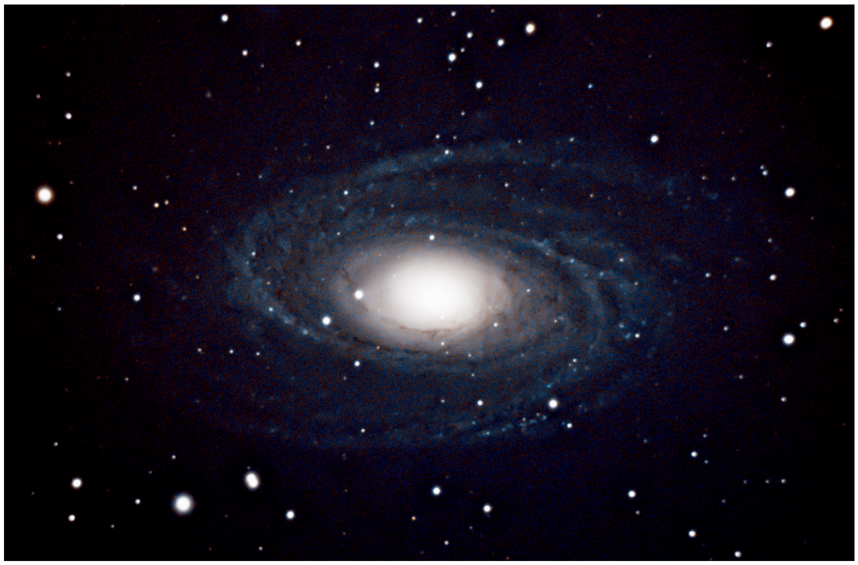

ABSTRACT

The purpose of this tutorial is to serve as an introduction to a set of specific methods for deep space astrophotography that enable straightforward imaging of distant galaxies (10-30 million light years or more). Hardware equipment, software, and exact processes are described in detail in the hopes of enabling efficient reproduction by individuals interested in gaining early skills in this field. This tutorial leverages the Celestron NexStar 8SE schmidt cassegrain telescope, which offers a great deal of support to streamline alignment, navigation, and tracking, making imaging sessions time efficient and easy, while providing flexibility to explore many stellar phenomena inaccessible to the unaided eye. For image capture, the Sony Alpha 7R III Mirrorless Camera is chosen. Examples are carried out using M81 Bode's Galaxy as the target of acquisition. Subjective comparisons are made to an image capture from the Hubble Space Telescope to validate the quality and accuracy of the resulting image. Finally, an image of M104 Sombrero Galaxy captured using similar procedures is included in the Appendix.

1 INTRODUCTION

Astronomy compels the soul to look upwards and leads us from this world to another.

- Plato

A common dream among many is having the ability to explore outer space and learn more about the universe in which we reside. Indeed, such is the subject of a vast quantity of science fiction and science fact literature. While transporting one's body to space is challenging and costly given current technology, what is often overlooked is that our planet is itself a "spacecraft" with a large view-port directly overhead – all that is necessary to explore the cosmos is having the right imaging equipment that enables one to view distant destinations.

Fortunately there is a multitude of equipment and information available for astrophotography: the art, science, and engineering of taking photographs of distant objects in space, making the inaccessible cosmos suddenly accessible and familiar. Many resources exist to educate interested individuals, including online written guides [2; 10; 11; 6], YouTube videos [7], product purchasing guides [5; 3], and more. Certainly, there are more resources online than are practical or possible to summarize in this single document.

Instead, the goal of this tutorial is to complement the collection of existing online educational resources by providing a comprehensive yet succinct explanation of how to reproduce a particular image, and in so doing, enable individuals to quickly gain equipment and skills that can generalize to a wide array of other stellar objects. The intended audience are individuals who have an interest in astrophotography but may have limited time to dedicate to the hobby, and want to take an efficient but flexible approach. Specifically, the characteristics of this tutorial are as follows:

- **End-to-End Image-Focused**: Rather than provide the reader with a comprehensive assessment of the plethora of imaging options at their disposal, this tutorial focuses on a single image acquisition and provides exact details regarding hardware, software, and steps involved, to recreate the photograph. Similar procedures can then be applied to many other deep space objects the individual may be interested in capturing.
- **Based on Efficient, Capable, and Lightweight Equipment**: The tutorial is based on the Celestron line of telescope equipment, which offers a great deal of support to streamline alignment, navigation, and tracking, to make imaging sessions time efficient, easy, and provide flexibility to explore many stellar phenomena inaccessible to the unaided eye. The particular model chosen provides a wide aperture enabling imaging of even faint and distant stellar objects. An Altitude-Azimuth mount is selected to minimize telescope weight (not requiring a counter-weight as with equitorial mounts, for example) while maximizing flexibility of navigation.
- **Leverages a Consumer Grade Camera:** Many dedicated imaging devices for astrophotography are available that provide excellent image quality and yield capabilities beyond standard cameras. However, this guide limits itself to using a standard consumer grade camera for two reasons: 1) the camera can be used for other tasks, and 2) the photographer is not required to connect a laptop computer to the telescope/camera combination, avoiding the possible need of additional outdoor furniture or managing a device not physically and structurally linked to the telescope. Where a laptop or other computing device is required for post processing, these steps occur indoors after the initial data capture with the telescope and camera outdoors.

Please enjoy this tutorial. Feel free to contact the author with suggestions. And most importantly, enjoy your adventure in exploring the cosmos.

2 METHODS

In this section, the resources required for the exercise are described. Section 2.1 specifies the deep space object to be imaged. Section 2.2 covers both the telescope (2.2.1) and camera (Section 2.2.2) equipment necessary. Finally, section 2.3 describes the software and computing system used for image reconstruction.

2.1 TARGETS

This effort focuses on M81 Bode's Galaxy [9], which is a spiral galaxy located approximately 11.6 million light years from Earth, visible from the northern hemisphere. The size of the galaxy in the sky is roughly 20x10 arcmins [8] (60 arcmins = 1 degree), fitting well within the telescope's field-of-view (See section 2.2.1). The apparent magnitude [1] is 6.9, also fitting within the capabilities of the telescope.

2.2 EQUIPMENT

The following section lists the telescope and camera equipment used for data capture.

2.2.1 Telescope

For this effort, the **Celestron NexStar 8SE** schmidt cassegrain telescope is used, which provides a field of view of approximately 60 arcmins and a limiting stellar magnitude of 14 [4]. In addition, the following series of components are useful to further improve convenience, image quality, physical stability, and flexibility:

- **StarSense Auto-align**: for automating and accelerating telescope alignment to support "Go To" operation, which enables the telescope to automatically aim at and track objects selected by the operator.
- **Celestron SkySync GPS Telescope Accessory**: for accelerating telescope localization and acquisition of time of day.
- **Celestron Focus Motor for SCT and EdgeHD (94155-A)**: this device electronically operates the focusing dial on the telescope and is configured via the telescope controller. This enables exact recording and recall of specific focus settings, enabling the photographer to swap equipment such as Barlow lenses, without needing to re-measure focus using manual assessments or a Bahtinov mask.
- **Celestron - PowerTank Lithium LT Telescope Battery**: to provide telescope mobility for positioning and reliability of power supply.
- **Celestron - Aluminum Telescope Dew Shield with Cover Cap**: to prevent condensate from forming on light path surfaces.
- **2 x Celestron Aux Port Splitter, Black (93919)**: to enable multiple peripheral devices to connect to telescope computer system.
- **Celestron Vibration Suppression Pads**: these devices sit under the feet of the telescope and absorb vibration noise from wind or ground movement that can disrupt image quality.
- **Farpoint Bahtinov Focus Masks**: to assist in achieving optimal telescope focus.
- **Celestron Universal Piggyback Mount**: useful when wanting to take wide field photographs without the telescope, but also useful to wrap camera shoulder strap around for extra security should the camera loosen from the visual back, which is attached only with thumb screws.
- **(Not used) 3X and 5X TeleVue Barlow Lenses**: while not used in this exercise for deep space astrophotography, these lenses are helpful for expanding into planetary imaging or exploring details of the lunar surface.
- **(Not used) Celestron – EclipSmart Safe Solar Eclipse Telescope Filter**: not used in this exercise, but helpful for solar imaging (see Appendix).

2.2.2 Camera

To capture and store image data, the **Sony Alpha 7R III Mirrorless Camera with 42.4MP Full-Frame High Resolution Sensor (ILCE-7RM3A)** was used, in addition to the following peripherals:

- **Celestron Sony E-Mount T-Ring**: this item attaches to the camera lens receptacle and has a connector to link with the T-adapter (below).
- **Celestron T-Adapter with SCT 5, 6, 8 with 9.25, 11, 14, Black (93633-A)**: this item connects to the camera mount T-Ring, and will connect to the Visual Back of the telescope.
- **Sony Wireless Remote Commander**: to enable shutter operation without touching any of the imaging equipment and introducing vibrations that can contaminate the image quality.
- **SanDisk 1TB Extreme microSDXC UHS-I Memory Card (SDSQXA1-1T00-GN6MA)**: providing a large storage capacity to eliminate any planning around data capture limitations other than time.

The following camera setup options were configured prior to imaging:

- **Silent Shooting (ON)**: this disables the physical shutter, which can introduce vibration that may degrade image quality (see Fig. 1).

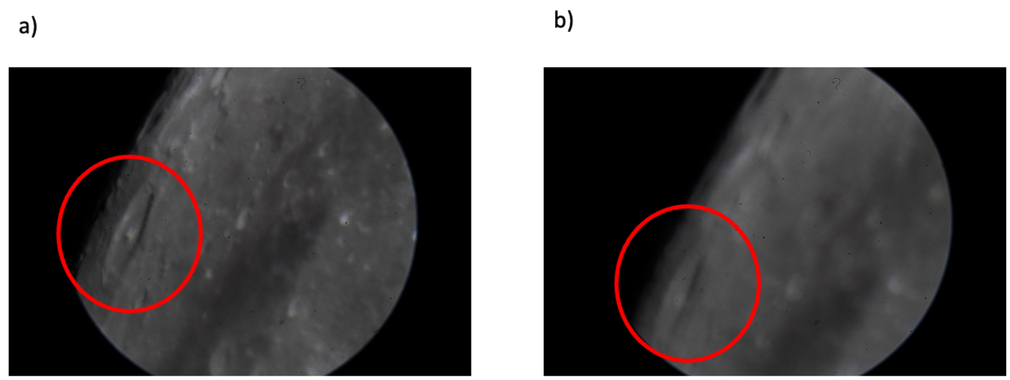

Figure 1: Example of motion artifacts introduced by camera shutter during bracket shooting, using the lunar surface as a subject. Images were acquired with the support of 5X and 3X TeleVue barlow lenses in series. a) Single image of lunar surface. b) Motion blur due to shutter during bracket shots.

- **SteadyShot (OFF)**: this disables the physical shake mitigation mechanisms in the camera, which when fixed on a stationary mount may only serve to introduce additional unwanted vibration, leading to similar artifacts observed from shutter motion.

2.3 Software and Computer System

For image stacking, Siril 1.2 was used [12], and for post-processing the stacked results, Adobe Photoshop 2024 was used (Releases 25.5.0 and 25.7.0). All computation was performed on a Macbook Pro 16-inch 2023 model, with the Apple M2 Max CPU, 64 GB of RAM, and running Ventura 13.6.5.

The Siril script "OSC_Preprocessing_WithoutFlat.ssf" was downloaded from the official repository on GitLab [1]. Line 39 of the script to align the sky images was modified to change the number of required star pairs to 4 and limit the alignment methods to affine transformations:

```
# Align lights
register pp_light -minpairs=4 -transf=affine
```

The script was placed in a dedicated folder on the host machine and referenced within the "Settings" menu, under subsection "Scripts", enabling its access from the blue "Scripts" button menu on the main screen (Fig. 4).

3 Results

This section describes the process to capture data, stack images, and post-process resulting images. Section 3.1 describes the setup of the telescope and camera equipment. Section 3.2 details the image data acquisition process. Section 3.3 outlines the image stacking process in the Siril software environment. Finally, section 3.4 describes the post-processing steps undertaken in Photoshop.

3.1 Telescope Setup

The telescope was placed on an asphalt surface, and made level using the supplied leveling device supplied by Celestron. Moon phase was near full, but images were acquired prior to moon rise to help limit light pollution. Vibration suppression pads were placed under the feet. The aluminum

[1] https://gitlab.com/free-astro/siril-scripts/-/blob/main/preprocessing/OSC_Preprocessing_WithoutFlat.ssf?ref_type=heads

Figure 2: Capella as imaged through the Bahnitov mask at 5 second exposure with ISO 1000. Image has been cropped to the region around the star for illustration purposes. The vertical line crosses directly through the middle of the "X" indicating nearly ideal focus settings.

dew shield was fixed to the end of the telescope to reduce the risk of moisture accumulation during imaging. For additional physical security, the camera shoulder straps were wrapped around the piggyback mount attached to the telescope tube.

StarSense AutoAlign was leveraged to calibrate the telescope, which enables the imaging target to be selected from the control unit. The camera equipment was attached to the visual back.

The telescope was first aimed toward Capella in the constellation Auriga for the purposes of optimizing visual focus. This was accomplished by placing the Bahtinov mask over the open telescope dew shield and acquiring photographs at 5 second exposure with ISO 1000 (Fig. 2). If the bisecting line of the diffraction patterns did not intersect the center of the X, focus was adjusted until this was achieved. The resulting focus setting was noted and recorded for later re-use, and the mask removed from the telescope.

3.2 Image Capture

Table 1 the total number of images and the parameters of data capture. A total of 335 5-second exposures, 208 10-second captuers, and 4 30-second captures were acquired. A representative single image capture is shown in Fig. 3. The camera interval function was leveraged to automate image capture, in batches of about 5-10 minutes worth of captures, after which the accuracy of the telescope tracking was monitored and corrections were made as necessary to maintain Bode's Galaxy near the center of the field-of-view. Ambient temperatures were approximately 40 degrees Fahrenheit.

Table 1: The capture parameters and number of each type of shot acquisition

Number of Shots	Exposure Time (s)	ISO
335*	5	10000
208*	10	5000
3	30	5000
1	30	10000

* Shots automatically acquired through camera interval shooting function.

While ideally "dark images" (images acquired with the protective cap on the telescope leading to black images used for background subtraction) would be captured in the same settings as the ac-

Figure 3: A single image capture of Bode's Galaxy at 10 second exposure with ISO 5000. The galaxy center is subtly visible near the center of the photograph.

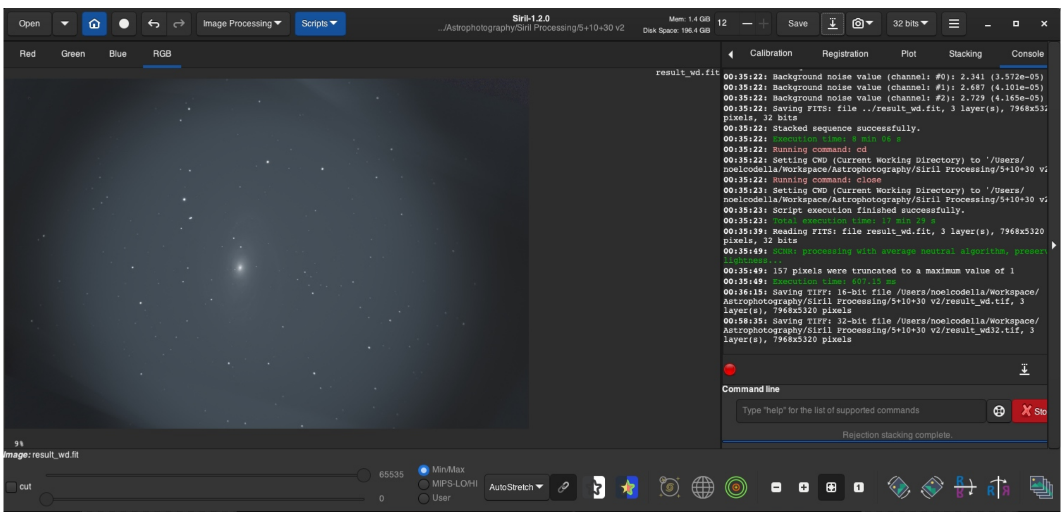

Figure 4: The Siril graphical user interface, with a completed result log output visible on right.

quired images outdoors, for this effort 30 5-second dark images were acquired indoors at room temperature after the initial data capture.

3.3 Siril Processing

All captured sky images were placed in a subfolder named "Lights" within a dedicated parent folder. The dark images were placed within a subfolder named "Darks".

The Siril graphical user interface is depicted in Fig. 4. The input folder was selected by clicking the blue "Home" icon, and navigating to the dedicated parent folder holding the subfolders with images for processing. Execution was started by clicking on the blue "Scripts" button and selecting the downloaded and modified script "OSC_Preprocessing_WithoutFlat".

Execution took 17 minutes and 29 seconds. Of note, this is running on the Macbook Pro's main SSD HD. If instead input data for processing is moved to an external drive (i.e. in particular Crucial X10

Pro 4TB Portable SSD with 2GB r/w speeds was attempted), execution time can lengthen to over 2 hours.

Once execution was completed, "Remove Green Noise" was applied from within the grey "Image Processing" button menu to mitigate the green haze apparent from the camera digital sensor containing twice as many green channels as red and blue.

Finally, the down arrow to the right of the "Save" button was pressed to save the result to a TIFF image leveraging 32-bits floating points per sample.

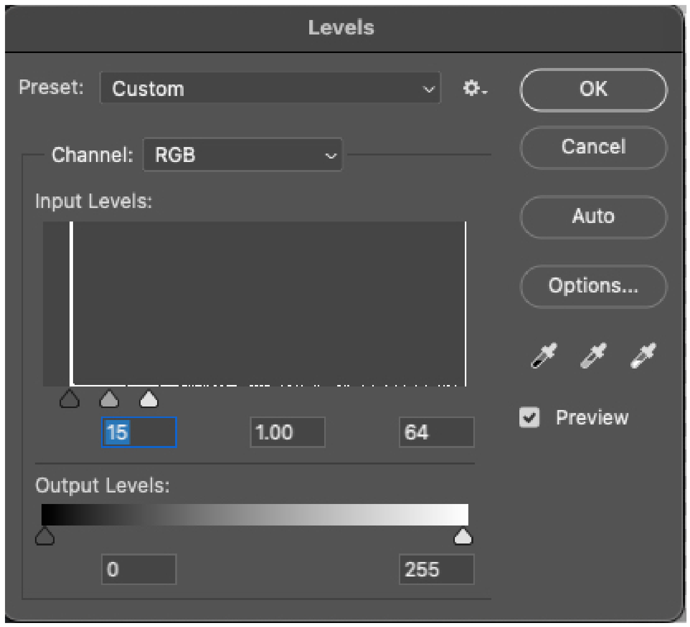

Figure 5: Window leveling panel in Photoshop, with chosen levels entered.

3.4 Photoshop Processing

The output file from Siril was "right-clicked" and opened in Photoshop. Fig. 6a depicts the appearance of the image data after import. Once loaded, Photoshop processing was broken down into the following steps:

- **Convert layer to smart object**: right-click the layer and select "Convert to Smart Object". This enables all subsequent actions and filters to be applied as processing layers which can be easily undone or toggled on/off. This provides maximum flexiblity as one may wish to experiment with different options and settings in processing.
- **Window Leveling**: From the menu, "Image" →"Adjustments" →"Levels..." was selected to bring up the window leveling tool (Fig. 5). Values of 15, 1.0, and 64 were entered to achieve a subjectively good balance between dynamic range and visibility, without introducing an excessive amount of overexposure of stars. Fig. 6b depicts the appearance of the image data after window leveling.
- **Camera Raw Filtering, Phase 1**: From the menu, "Filter" →"Camera Raw Filter" was selected to bring up the filtering window. Under the "Effects" sub-panel the "Dehaze" operator was applied at 100%. Under the "Light" sub-panel, "Exposure", "Whites", and "Blacks" were adjusted to improve visualization. Specifically values of +4.25, -60, and -95 were applied respectively, to optimize visualization. Next, within the "Color" sub-panel, "Temperature" and "Tint" were adjusted so that RGB values of background space would yield similar intensities. Specifically, values of +12 and +10 were chosen. Fig. 6c depicts the appearance of the image data after this filtering step.
- **Camera Raw Filtering, Phase 2**: In order to make final touches on visual appearance, one more camera raw filter layer was applied. Specifically, "Exposure" was raised +1.7 and

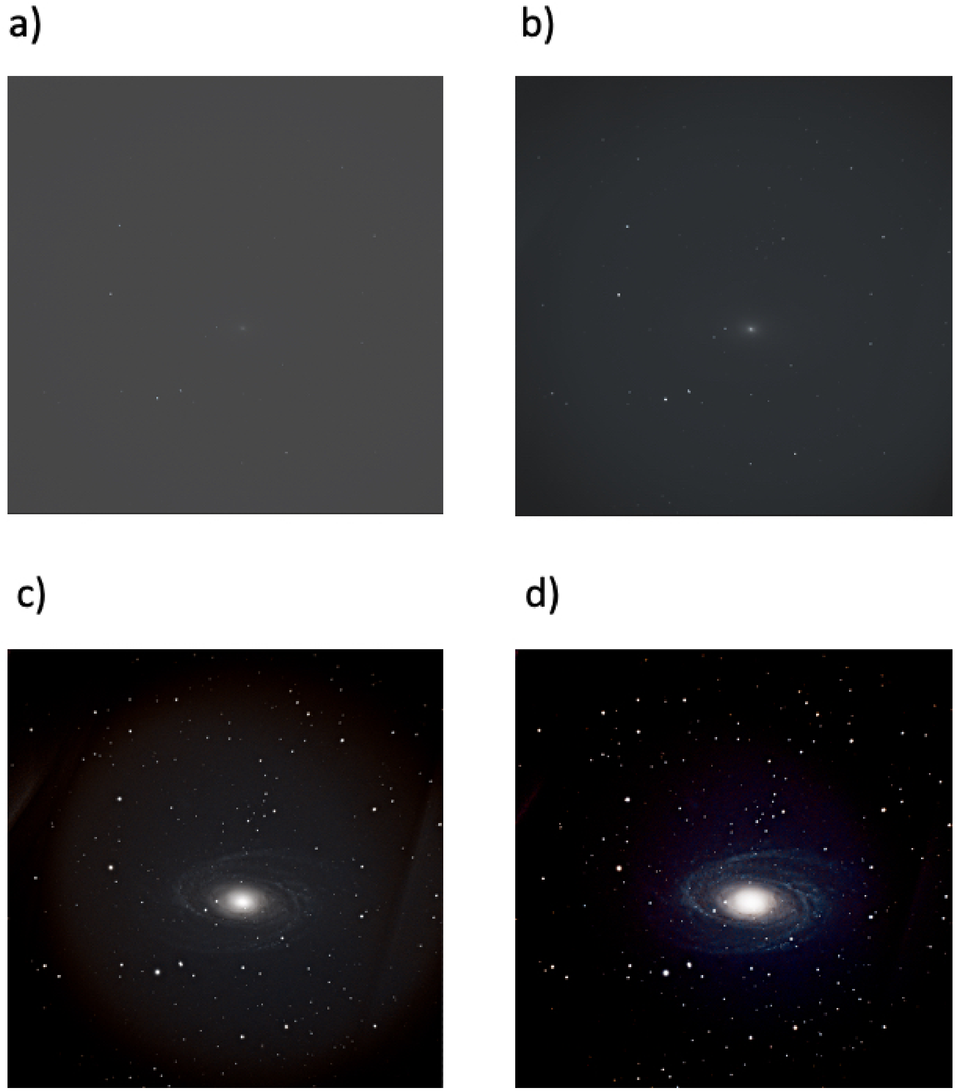

Figure 6: Intermediate and final results in Photoshop processing pipeline. a) Original image as imported from Siril output. b) Intermediate result after window leveling. c) Intermediate result from first pass of camera raw filtering. d) Final result after second pass of camera raw filtering.

"Blacks" were decreased by -100 to improve contrast and visualization clarity. Finally, in "Color" sub-panel, "Saturation" was increased by +100. Fig. 6d depicts the appearance of the image data after this final filtering step. Fig. 7 displays the same result after cropping closer to the galaxy features.

4 Discussion

This tutorial outlines the steps taken by an amateur astrophotographer to acquire deep space photographs of M81 Bode's galaxy. The intent is to describe the process in sufficient enough detail, unified under a single document, as to enable anyone interested in astrophotography to purchase the same or similar equipment and follow the same or similar steps to achieve comparable photographic results.

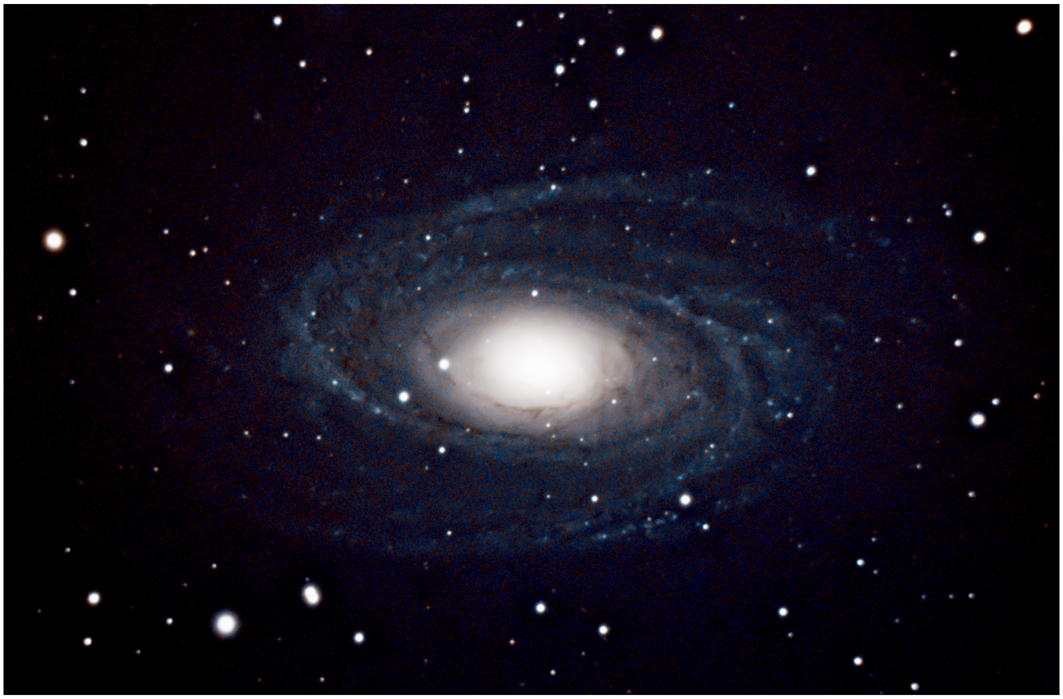

Figure 7: M81 Bode's Galaxy final result, cropped region around galaxy center. This image can be compared to the Hubble Space Telescope's capture, included in the appendix for validation.

As the author is by no means an expert in this field, there remains much opportunity for improvement. For example, ideally, images of the same exposure length should be acquired, and matched with dark images of equal exposure length. This was not done in this exercise as the author sought to experiment with various imaging parameters to get a feel for effects on image quality. As is evidenced by this effort, however, even exposures of mixed settings can be stacked together to form fairly decent image quality.

5 Conclusion

This tutorial describes a process that can be followed to obtain an image of M81 Bode's Galaxy that enables one to observe the spiral features and color of the object. The equipment and methods described here can be used to image other deep space objects as well (see Appendix Fig. 9).

References

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[12] Siril image stacking software. https://siril.readthedocs.io/en/stable/. Accessed: 2024-04-30.

A Appendix

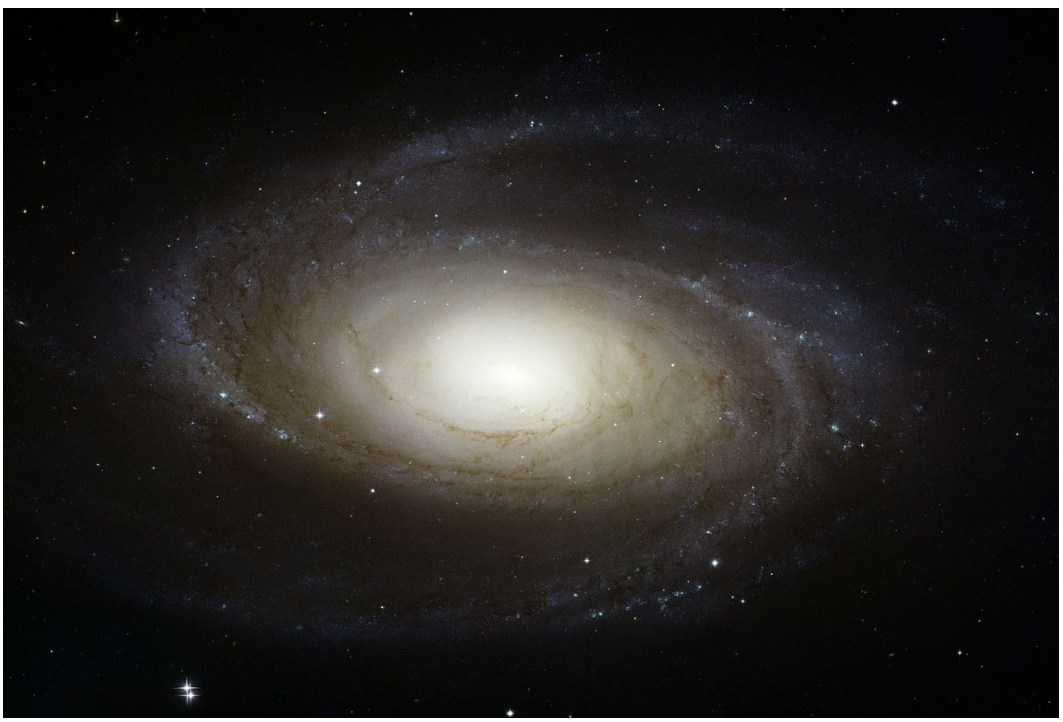

Figure 8: M81 Bode's Galaxy, captured from the Hubble Space Telescope in 2007: https://esahubble.org/images/heic0710a/

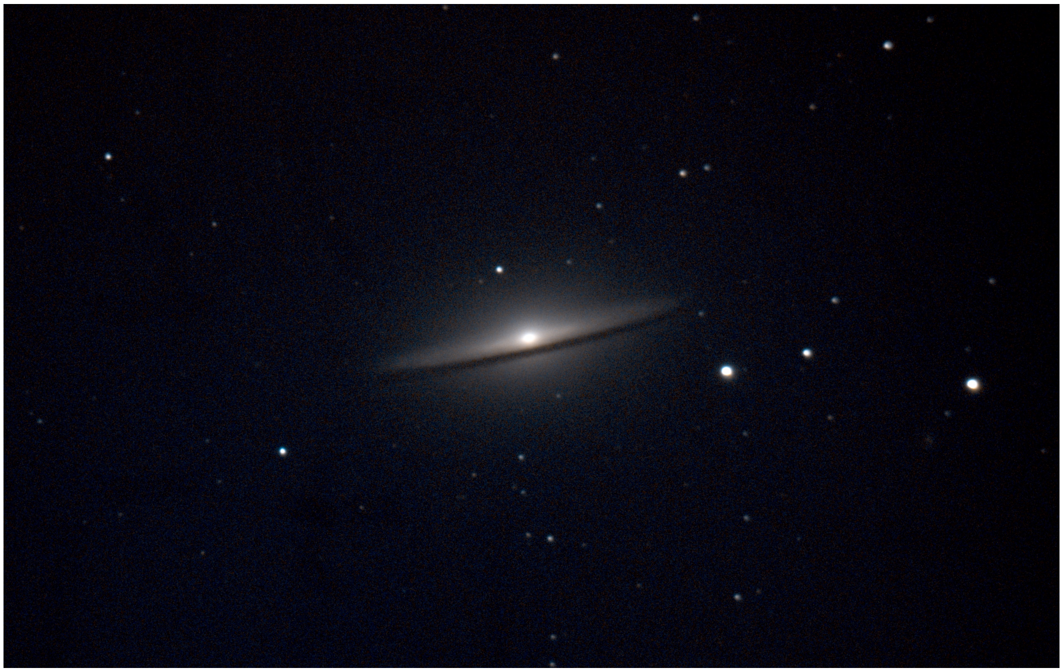

Figure 9: M104 Sombrero Galaxy, 31.1 million light years away, captured using similar methods described in this tutorial

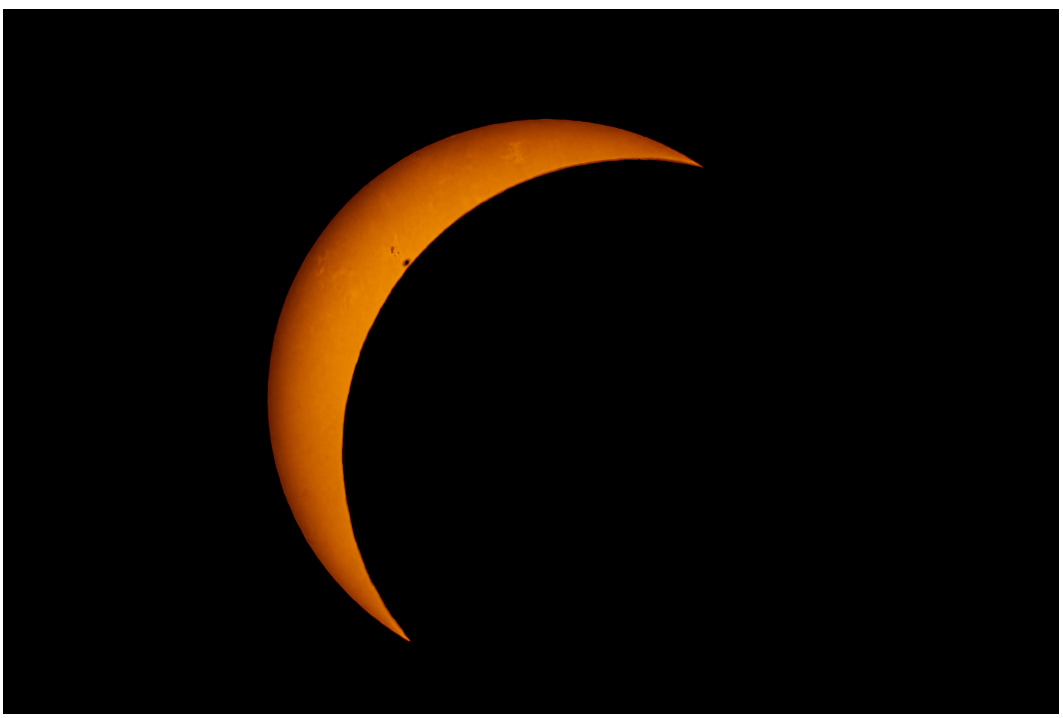

Figure 10: Eclipse of 2024, using optional solar filter, single image. Sunspot visible near lunar profile. Faculae visible near periphery.

Figure 11: Half moon visible in 2024, single image.

Figure 12: Full moon with colors enhanced, visualizing the variations in composition of lunar regolith. Single image. Blue areas designate regions of higher titanium.

Figure 13: Region around Vega, imaged with Celestron Focal Reducer. Stacked and processed image of 120 5-second exposures.

Figure 14: Lunar surface details visible using the 5X TeleVue Barlow lens

Figure 15: Lunar surface details visible using the 5X and 3X TeleVue Barlow lens in series. Landing regions for Apollo 11, 16, and 17 missions visible in the FOV.