# Solar System and Celestial Mechanics Practical Report

Conducted by:

**SA Department**


| *Team Members* | *Email* |
|---|---|
| HUYNH Quoc Thang | thanghq.bi12-400@st.usth.edu.vn |
| NGUYEN Thi Yen Binh | binhnty.bi12-060@st.usth.edu.vn |


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# 1 Introduction

The celestial wonders that adorn our night sky never cease to amaze and inspire us. Among these captivating objects, Venus and Mars, our neighboring planets in the Solar System, offer a fascinating opportunity for observation and study. This practical report focuses on understanding the movement of Venus and Mars in relation to the celestial background, shedding light on their dynamics within the Solar System.

Venus and Mars, though distinct in their characteristics, share a common trait: their motion within the Solar System. By observing their movement against the backdrop of stars and other celestial objects, we can uncover valuable insights into their orbital paths and the forces that govern their motion.

The movement of Venus and Mars is intricately linked to their respective orbits around the Sun. As Venus and Mars orbit the Sun, their positions relative to Earth change over time, resulting in apparent movement against the starry background. This movement, known as their apparent motion, can be observed and recorded to trace the paths they follow in the night sky.

Besides, the phases of Venus are captivating phenomena that unveil the intricate dance between itself, the Sun, and Earth. Venus exhibits a range of phases similar to those of our Moon. As Venus orbits the Sun, the varying angles between the Sun, Venus, and Earth result in different illuminated portions of the planet being visible from Earth. The phases of Venus transition from a slender crescent to a fully illuminated disk, offering a unique insight into its orbital motion and its relationship with the Sun and Earth.

To study the movement of Venus and Mars, we rely on practical observations using telescopes and appropriate equipment. By capturing images at regular intervals, we can document their positions in relation to the stars and record their trajectory over time. This data allows us to visualize their movement and analyze the patterns they exhibit.

One aspect of their movement that warrants attention is their retrograde motion. However, for the purpose of this report, we will focus solely on the general movement of Venus and Mars without delving into the intricacies of retrograde motion. By observing their motion without the complexities of retrograde periods, we can gain a clearer understanding of their overall paths and behaviors.

Comparing the movement of Venus and Mars, we can discern their unique characteristics and differences. Venus, often referred to as the "Evening Star" or "Morning Star," exhibits a relatively swift movement across the sky. Its bright and distinct presence is hard to miss, making it an ideal subject for observing and tracking its journey through the celestial sphere. Mars, on the other hand, appears as a reddish dot, moving at a slower pace compared to Venus. Its unique coloration and distinctive position make it a fascinating object to observe as it traverses the night sky.

By studying the movement of Venus and Mars, we contribute to our understanding of celestial mechanics. These observations enable us to analyze their orbital parameters, such as their distances from the Sun and their periods of revolution. By linking these parameters to their observed movement, we can deepen our comprehension of the laws that govern planetary motion in the Solar System.

Additionally, the movement of Venus and Mars allows us to appreciate the vastness of our cosmic neighborhood. As we observe their paths against the backdrop of stars, we gain a sense of the immense distances that separate these celestial objects. The vastness of space becomes tangible, emphasizing the awe-inspiring nature of our universe.

In conclusion, observing the movement of Venus and Mars against the celestial background provides a valuable opportunity to study their dynamics within the Solar System. By capturing images, tracing their paths, and analyzing their overall motion, we gain insights into the complexities of planetary orbits and celestial mechanics. Through these observations, we deepen our understanding of our neighboring planets and their place in the vast expanse of the universe.

# 2 Experimental Set-up and Methodology

## 2.1 Location

The practical sessions were all conducted in front of USTH, A21 building, 18 Hoang Quoc Viet Rd., Cau Giay Dist., Hanoi, Vietnam.

Time: From 19h30-20h30, 19/05 and 23/05/2023

## 2.2 Instruments

- ZWO ASI178MC Camera

Table 1: Specification of ZWO ASI178MC

| **ZWO ASI178MC Camera** | |
|---|---|
| **Sensor** | 1/1.8" CMOS IMX178 |
| **Resolution** | 6.4 Mega Pixels 3096*2080 |
| **Pixel Size** | 2.4 $\mu$m |
| **Sensor Size** | 7.4 mm * 5 mm |
| **Diagonal** | 8.92 mm |
| **Exposure Range** | 32$\mu$s - 1000s |
| **Interface** | USB3.0/USB2.0 |
| **Focus Distance to Sensor** | 12.5 mm |
| **Shutter Type:** | Rolling Shutter |
| **Adaptor** | 2" / 1.25" / M42X0.75 |
| **Dimension** | $\phi$62 mm x 36 mm |
| **Weight** | 120g or 4.2 ounces (without lens) |
| **Working Temperature** | -5°C - 45°C |
| **Working Relative Humidity** | 20% - 80% |

- Celestron NexStar 127 SLT
- Celestron Travel Scope 70
- Sky-Watcher Evostar 72ED
- Eyepieces: 23mm, 20mm, 10mm
- Software: Stellarium, ASIStudio
- Mobile app: SkyPortal, SkySafari, ASIStudio (for tablet)

In addition, the images of Mars are captured by the Quy Nhon Observatory which include:

- PlaneWave CDK 600
- QHYCCD-Cameras-Capture

## 2.3 Alignment method and eyepieces

### 2.3.1 Which method is suitable for tracking Venus and Mars? Which one is the best?

There are two suitable alignment methods for tracking planet: Auto Two Star Align and Solar System Align. Although Auto Two Star Align would be more precise, due to time limited, we used the Solar System Align instead.

To align the telescope with planets, we used the NexStar+ Control in the following manner:

- Turn on the telescope's power switch.
- Wait for the controller to be ready.
- To begin the alignment process, press the ENTER key.
- A menu will appear, displaying the various alignment methods. Roll and select Solar System Align, then press ENTER to proceed.
- Opt for Standard Time.
- Choose time zone 7, then enter the date.
- Press ENTER, and the display will now prompt you to "Select Object" from the controller's displayed list. Roll and select Venus and Mars, respectively, press ENTER.
- When the telescope's view gets close to the Moon, use the Red Dot Finder to center the red dot directly on the Moon.
- Finally, using the eyepiece, center the planet and press ALIGN.
- Allow the controller to complete the alignment calculation. The telescope should be aligned after a few seconds.

### 2.3.2 Which eyepieces can be used to observe Venus and Mars?

We can observe these planets through various eyepieces depending on our objectives. In this case, we use 23mm eyepiece to observe the phases of Venus, 20mm for observing Mars and Venus displacement.

## 2.4 Methodology

### 2.4.1 Angular Seperation

Angular separation refers to the measurement of the apparent angular distance between two celestial objects in the sky. In order to determine the angular separation in units of arcminutes, we multiply the image scale per pixel by the number of pixels. This multiplication yields the angular distance between the objects represented by the given image data.

$$\text{Image Scale per Pixel} = \left(\frac{\text{Pixel Size}}{\text{Focal Length}}\right) \times 206.265 \tag{1}$$

where

Image scale per pixel is in the unit of arcseconds
Pixel Size is determined by the camera in the unit of microns
Focal length is determined by the telescope in the unit of millimeters
206.265 converts to arcseconds

$$\text{Number of pixel} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{2}$$

where

$(x_1, y_1)$ is the coordinate of the first object.
$(x_2, y_2)$ is the coordinate of the second object.

Thus,

$$\text{Angular seperation} = \text{Number of pixel} \times \text{Image Scale per Pixel} \tag{3}$$

```python
def angular_seperation(obj1_x, obj1_y, obj2_x, obj2_y, pixel ,focallen):
    pixel_dist = np.sqrt((obj1_x - obj2_x)**2 + (obj1_y - obj2_y)**2)
    return 206.265 * pixel_dist * pixel / (focallen * 60)
```

Listing 1: Python function for calculating the angular seperation in unit of arcminute

#### 2.4.2 Displacement of the Planet over time

We assume that the background stars exhibit negligible relative motion among themselves, we calculate the displacement of the corresponding Planet at two different time on the sky using the law of cosine. Given the value of $x_1$, $x_2$ are the distance from two stars to the planet at the time $t_1$, the value of $y_1$, $y_2$ are the distance from two stars to the planet at the time $t_2$ and $a$ is the the distance between 2 stars, we can calculate the angle $\alpha$ between ($x_1$, $a$) and $\beta$ between ($x_2$, $a$) by the expression below:

$$y_1^2 = x_1^2 + a^2 - 2x_1 acos(\alpha) \tag{4}$$

$$y_2^2 = x_2^2 + a^2 - 2x_2 acos(\beta) \tag{5}$$

Therefore, the angle can be calculated as:

$$\alpha = arccos(\frac{x_1^2 + a^2 - y_1^2}{2x_1 a}) \tag{6}$$

$$\beta = arccos(\frac{x_2^2 + a^2 - y_2^2}{2x_2 a}) \tag{7}$$

The displacement of the planet from point 1 (time $t_1$) to point 2 (time $t_2$):

$$disp = \sqrt{x_1^2 + x_2^2 - 2x_1 x_2 cos(\alpha - \beta)} \tag{8}$$

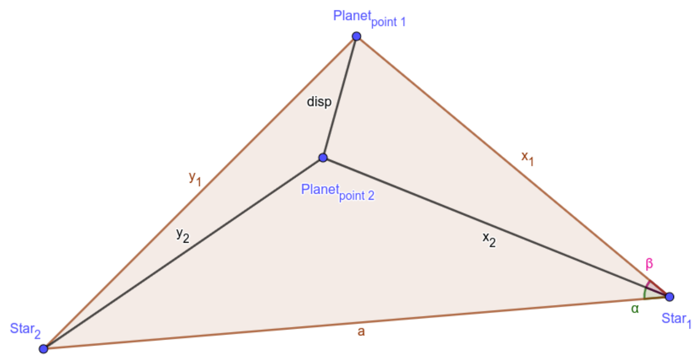
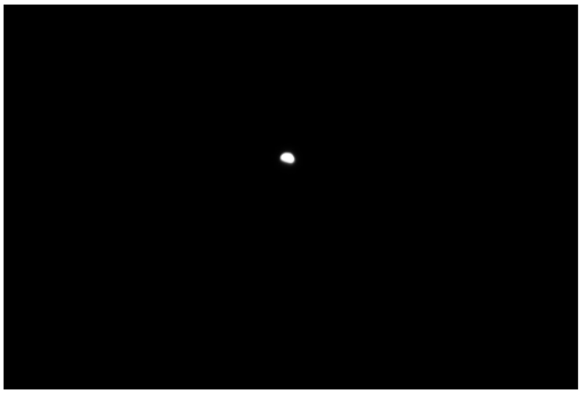


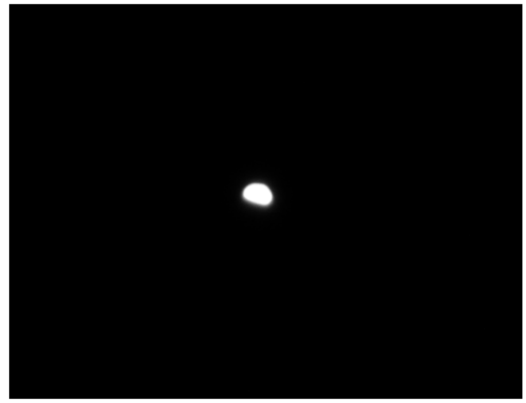

Figure 1: Illustration for calculation of displacement of the planet from point 1 and point 2

# 3 Outcome

## 3.1 Phase of Venus



(a) Phase of Venus



(b) Phase of Venus - Zoom In

The code below is used to plot the image as well as zoom in for better view of the Venus' phase:

```
import matplotlib.image as im
import matplotlib.pyplot as plt

image = im.imread('2023-05-18-0552_7-CapObj_0000.PNG')

fig, ax = plt.subplots(1,2, figsize=(20,20))

ax[0].imshow(image, cmap="gray")
ax[0].set_title("Phase of Venus")
ax[0].axis('off')

ax[1].imshow(image, cmap='gray')
ax[1].axis('off')
ax[1].set_title("Phase of Venus - Zoom in")
ax[1].set_xlim(900, 2200)  # Adjust the x-axis limits
ax[1].set_ylim(1350, 350)  # Adjust the y-axis limits

plt.show()
```

Listing 2: Python code

We then used Stellarium to have a closer look to Venus and the insights of its properties at that time, e.g. phase's illumination, position, distance from Earth, etc.

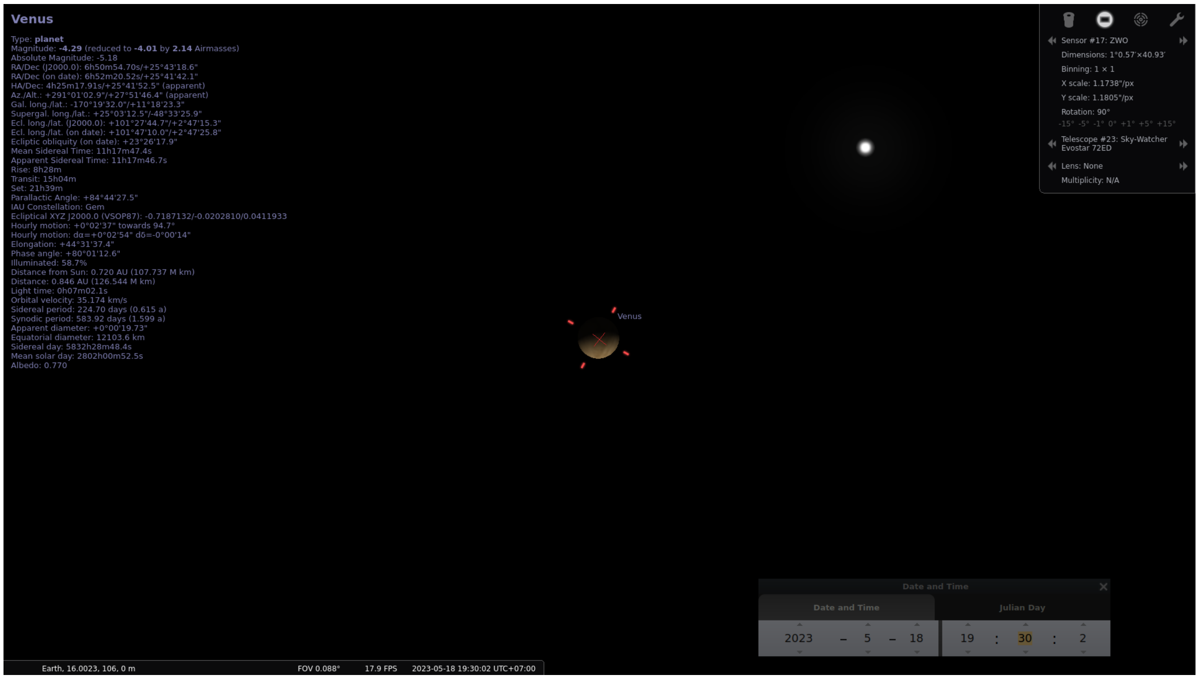



Figure 3: Venus - Using Stellarium

### Discussion

The images we have captured of Venus using the Celestron NexStar 127 SLT telescope and the Allsky Camera ZWO178MC provides a remarkable opportunity to observe and study the phases of this enigmatic planet. The first is the original one while the second one was zoomed-in for a clearer sight.

Upon closer examination, we observe that Venus exhibits a gibbous-like shape, with illuminated was about 59% and phase angle was +80°01'12.6", akin to a miniature Moon. In this phase, Venus unveils a substantial portion of its illuminated disk, captivating observers with its radiant presence against the backdrop of the night sky. .

In the gibbous phase, Venus appears as a convex shape. Its brilliance and apparent size increase as a greater portion of its disk becomes visible. The precise appearance of the gibbous phase can vary depending on factors such as Venus' distance from Earth, atmospheric conditions, and the angle at which sunlight illuminates its surface.

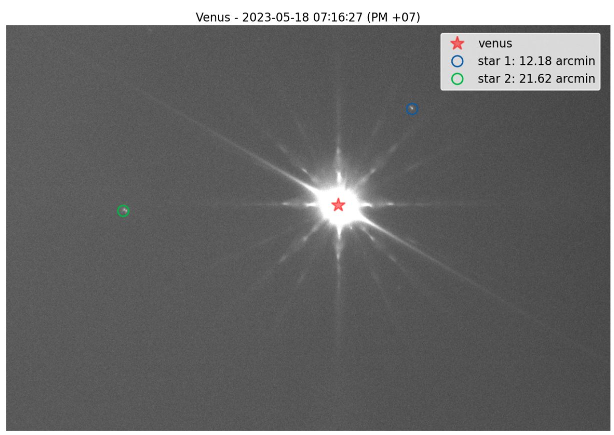
One of the most notable features of the gibbous phase is its symmetry. As Venus approaches its greatest elongation from the Sun, the illuminated portion of its disk appears almost perfectly symmetrical. This symmetry is a consequence of Venus' spherical shape and the even distribution of sunlight across its surface.

The gibbous phase of Venus is an exciting phase for astronomers and stargazers alike. Observing this phase allows astronomers to make important measurements and calculations that contribute to our understanding of Venus' orbital dynamics and physical characteristics. By carefully studying the changing appearance of Venus during the gibbous phase, astronomers can refine measurements of its size, shape, and axial tilt.

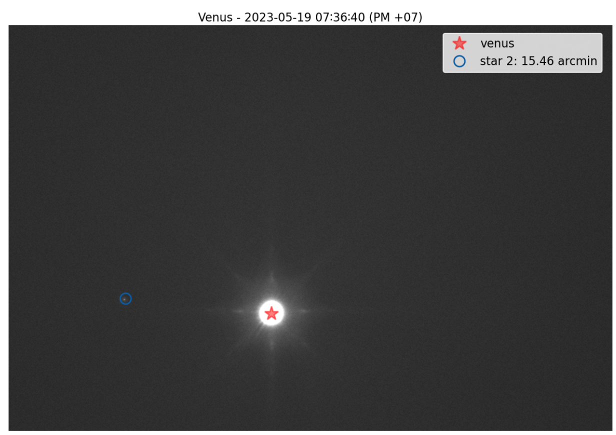
Furthermore, the gibbous phase of Venus holds significant cultural and historical significance. Throughout history, Venus has been associated with various mythological and cultural beliefs. Its striking presence in the night sky, particularly in the gibbous phase, has inspired poets, artists, and astronomers for centuries. The ethereal beauty and luminosity of Venus in the gibbous phase continue to captivate and inspire a sense of wonder and awe in those fortunate enough to witness it.

## 3.2 Displacement of Venus

The image of Venus captured by the telescopes and All-sky Camera on 18-19/05/2023 are processed in order to find the distance between objects. The planet Venus is marked by the star, the visible stars are marked with the circle with their distances to Venus are shown in the label.




(a) Venus - 18/05/2023




(b) Venus - 19/05/2023

Figure 4: Venus and background stars relative position in the sky. The angular distance between Venus and stars are shown in the legend.

The code below shows the way we used to mark Venus and background stars using module `io` and `measure` from the package `skimage` as well as angular separation calculation following the method introduced in section 2.4.1 by taking the pixel size of 2.4 $\mu$m in the specification of ASI178MC Camera and the focal length of the telescope of 420 mm and 400 mm in the first day and second day respectively. The threshold for brightness is set at 95% of the maximum value, the contour surrounding the celestial objects are taken at 90%, we take the mean value of the coordinate of all the pixels in the contours to find the center of the objects and mark them. The results are shown by the figure 4a and 4b:

```python
from skimage import io, measure
from PIL import Image
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.patches import Circle
import os

```

```python
venus = io.imread('2023-05-18-0616_4-CapObj_0000.PNG', as_gray=True)  # Read the image file of Venus

# Set the threshold at 95% of the maximum pixel value
threshold = venus > np.max(venus) * 0.95

# Find contours in the thresholded image above a threshold of 0.9
contours = measure.find_contours(threshold, 0.9)

# Sort the contours based on their length in descending order
contours = sorted(contours, key=len, reverse=True)

venus_contours = contours[0]  # Select the contour with the largest length as Venus
venus_center = np.mean(venus_contours, axis=0)
venus_y, venus_x = venus_center

f = plt.figure(figsize=(15, 12))
plt.imshow(venus, cmap='gray')  # Display the grayscale image of Venus
plt.plot(venus_x, venus_y, 'r*', markersize=20, markeredgewidth=2, alpha=0.5, label='venus')

for i in range(1, 20):
    star_contours = contours[i]  # Select contours of other objects as stars
    star_center = np.mean(star_contours, axis=0)
    star_y, star_x = star_center
    ang_sep = angular_separation(venus_x, venus_y, star_x, star_y, 2.4, 420)  # Calculate the angular separation
    if ang_sep > 5:  # Check if the angular separation is greater than 5 arcminutes
        plt.plot(star_x, star_y, 'o', markersize=15, alpha=1, markerfacecolor='none', markeredgewidth=2,
                 label=f'star 1: {ang_sep:.2f} arcmin')

ang_sep = angular_separation(venus_x, venus_y, 600, 950, 2.4, 420)
plt.plot(600, 950, 'o', markersize=15, alpha=1, markerfacecolor='none', markeredgewidth=2,
         label=f'star 2: {ang_sep:.2f} arcmin')

# Create a legend box for the plotted objects
legend_box = plt.legend(bbox_to_anchor=(0.72, 0.98), loc='upper left', borderaxespad=0., frameon=True)
frame = legend_box.get_frame()
frame.set_edgecolor('white')
frame.set_linewidth(1.5)

plt.axis('off')
plt.title("Venus - 2023-05-18 07:16:27 (PM +07)")  # Set the title of the plot
plt.show()  # Display the plot
```

Listing 3: Python code for defining the center position of Venus and background stars in 18/05/2023 in the image and calculate the angular distance between them.

```python
venus = io.imread('2023-05-19-1236_6-CapObj_0000.PNG', as_gray = True)

threshold = venus > np.max(venus)*0.95 #Set the threshold at 95% of the maximum value.

contours = measure.find_contours(threshold, 0.9)

contours = sorted(contours, key = len, reverse = True)

venus_contours = contours[0]
venus_center = np.mean(venus_contours,axis =0)
venus_y, venus_x = venus_center #Position of vanus

# Plot figure
f = plt.figure(figsize=(15,12))
plt.imshow(venus, cmap='gray')

# Angular seperation of venus and background stars
ang_sep = angular_seperation(venus_x, venus_y, 600,1400, 400)

plt.plot(venus_x, venus_y, 'r*', markersize=20, markeredgewidth=2, alpha = 0.5, label = 'venus')
plt.plot(600,1400, 'o', markersize=15, alpha = 1, markerfacecolor='none', markeredgewidth=2, label = f'star 2: {ang_sep:.2f} arcmin')

# Create a legend box
legend_box = plt.legend(bbox_to_anchor=(0.72, 0.98), loc='upper left', borderaxespad=0., frameon=True)
frame = legend_box.get_frame()
frame.set_edgecolor('white')
frame.set_linewidth(1.5)
plt.axis('off')

# Create a title
plt.title("Venus - 2023-05-19 07:36:40 (PM +07)")

plt.savefig("venus_1905")
```

Listing 4: Python code for defining the center position of Venus and background stars in 19/05/2023 in the image and calculate the angular distance between them.

We also use Stellarium with relevant Field of View (FOV) to track as well as check for the angular separation, then compare to our results and determine which stars were. In addition, due to some technical limitations, for the image on 19/05, the FOV of our instrument could not take photo of Venus with its same background stars as be done on 18/05; hence, we use Stellarium as an alternative way to find the angular distance from Venus to other star, then use the obtained data to find the displacement of Venus after a day.

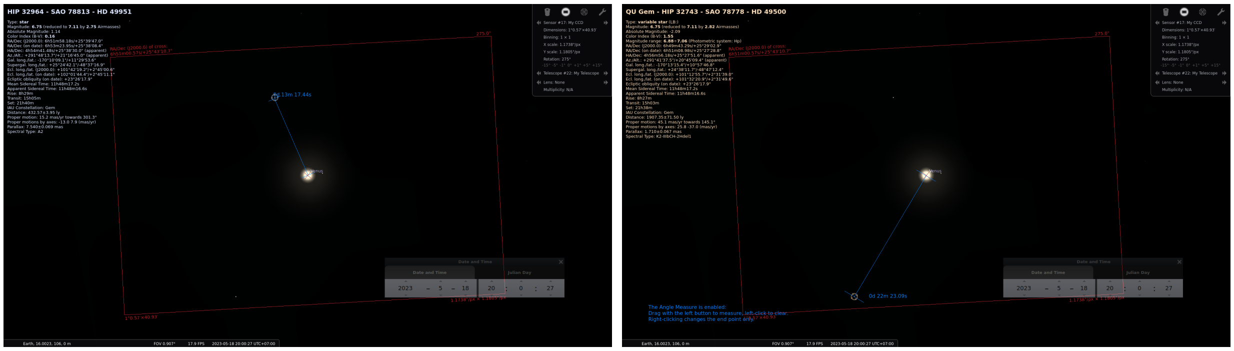


Figure 5: Venus - 18/05 - Using Stellarium

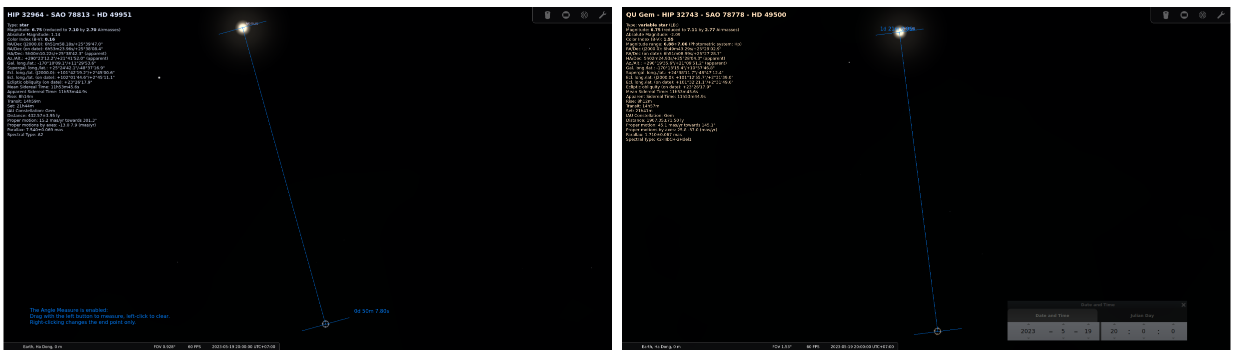


Figure 6: Venus - 19/05 - Using Stellarium

### Discussion

The Venus images captured on the 18th and 19th of May are different in the framing, background stars, and, unfortunately, on the night of the 19th, only one background star was present. Consequently, due to these data limitations, it is not feasible to calculate the displacement of Venus accurately.

To address this limitation, we utilized additional information from the software Stellarium for the position of star in 19/05. Combining with the data from our image taken in 18/05, we found the displacement of Venus relative to the background stars after one day is about 58.6 arcmin following the method presented in section 2.4.2.

```
dis_star_12 = angular_separation(star_X[0], star_Y[0], star_X[1], star_Y
    [1], 2.4, 420)
x1 = AP_1[0]; y1 = AP_1[1]  # Data from the image processing of Venus on
    18/05
x2 = 50; y2 = 80  # Data taken from Stellarium

# Calculate the cosine of theta for the first point
c_theta_1 = (x1**2 + dis_star_12**2 - y1**2) / (2 * x1 * dis_star_12)

# Calculate the cosine of theta for the second point
c_theta_2 = (x2**2 + dis_star_12**2 - y2**2) / (2 * x2 * dis_star_12)

```

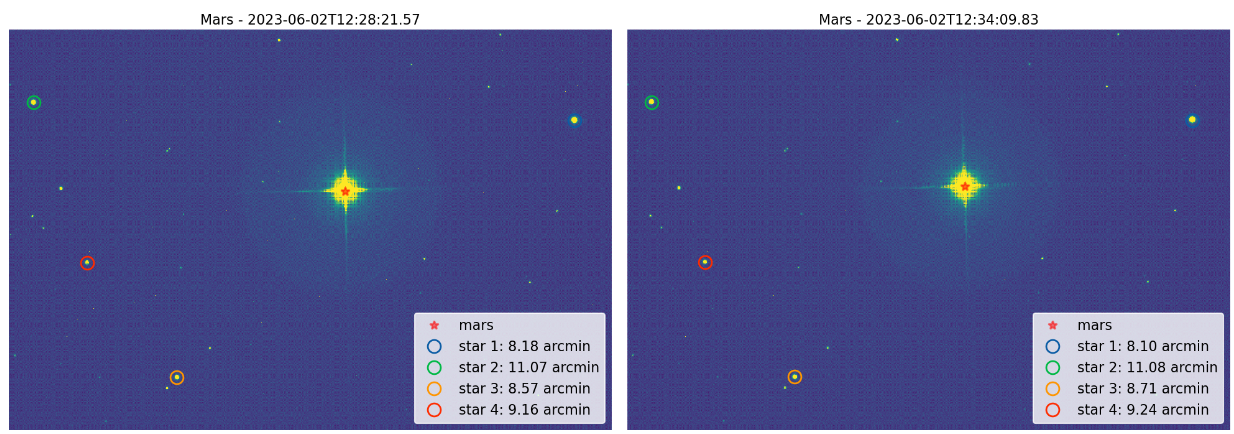
```python
# Calculate the angles theta
theta_1 = np.arccos(c_theta_1)
theta_2 = np.arccos(c_theta_2)

# Calculate the absolute difference in angles
delta_theta = np.abs(theta_1 - theta_2)

# Calculate the displacement using the law of cosines and convert it to
    arcminutes
disp = np.sqrt(x1**2 + x2**2 - 2 * x1 * x2 * np.cos(delta_theta)) * u.
    arcmin

print(disp)
```

```
58.59792858358075 arcmin
```

It is important to note that what we tried to calculate is not the real trajectory of Venus which actually made a rotation over a course of one day, it is just merely the displacement of Venus in comparison with background stars which are considered to be fixed with each other.

## 3.3 Displacement of Mars

The images of Mars captured by the telescope and camera from the Quy Nhon Observatory in 02/06/2023 are processed in order to find the distance between objects. The objects under consideration are marked by a circle with their distances to Venus are shown in the label.




(a) Mars - 02/06/2023 - 19:28 (UTC-7) (b) Mars - 02/06/2023 - 19:34 (UTC-7)

Figure 7: Mars and background stars relative position in the sky. The angular distance between Mars and stars are shown in the legend

The code below shows the way we used to mark Venus and background stars using module `io` and `measure` from the package `skimage` as well as angular separation calculation following the method introduced in section 2.4.1 by taking the pixel size of 4.8 $\mu$m and the focal length of the telescope in Quy Nhon Observator is 3962 mm giving in the header of the images. The results is shown in the figure 7a and 7b.

```
import aplpy

# Create an APLpy FITSFigure
f = aplpy.FITSFigure(mars_path + 'Mars-30.fit')

# Open the FITS file and extract data and header
file_path = os.path.join(mars_path, 'Mars-30.fit')
hdul = fits.open(file_path)
mars = hdul[0].data
header = hdul[0].header
hdul.close()

# Thresholding and contour extraction
threshold = mars > np.max(mars) * 0.95
contours = measure.find_contours(threshold, 0.9)
contours = sorted(contours, key=len, reverse=True)
mars_contours = contours[0]
mars_center = np.mean(mars_contours, axis=0)
mars_y, mars_x = mars_center

# Plot Mars with a red star marker
plt.plot(mars_x, mars_y, 'r*', markersize=10, markeredgewidth=2, alpha
    =0.5, label='mars')

# Plot the stars and calculate their angular separation
AP_1 = []
star_X = []
star_Y = []
for i in range(1, 5):
    star_contours = contours[i]
    star_center = np.mean(star_contours, axis=0)
    star_y, star_x = star_center
    ang_sep = angular_separation(mars_x, mars_y, star_x, star_y, header['
    XPIXSZ'], header['FOCALLEN'])
    if ang_sep > 5:
        plt.plot(star_x, star_y, 'o', markersize=15, alpha=1,
    markerfacecolor='none', markeredgewidth=2,
                 label=f'star {i}: {ang_sep:.2f} arcmin')
    AP_1.append(ang_sep)
    star_X.append(star_x)
    star_Y.append(star_y)
# Customize the legend
legend_box = plt.legend(frameon=True)
frame = legend_box.get_frame()
frame.set_edgecolor('white')
frame.set_linewidth(1.5)

# Remove axes and ticks
plt.axis('off')
```

```python
# Set the title
plt.title("Mars - " + header['DATE-OBS'])

# Show the APLpy colorscale image
f.show_colorscale()

# Adjust the figure size and spacing
plt.subplots_adjust(left=0, right=1, bottom=0, top=1)
plt.tight_layout()

# Save the figure
plt.savefig("mars_aplpy_30")
```

Listing 5: Python code for defining the center position of Mars and background stars in 02/06/2023 at 19:28 (UTC-7) in the image and calculate the angular distance between them.

```python
# Create an APLpy FITSFigure using the FITS file 'Mars-30-1.fit'
f = aplpy.FITSFigure(mars_path + 'Mars-30-1.fit')

# Open the FITS file and extract the data and header information
file_path = os.path.join(mars_path, 'Mars-30-1.fit')
hdul = fits.open(file_path)
mars = hdul[0].data
header = hdul[0].header
hdul.close()

# Apply thresholding to the Mars image to obtain a binary mask
threshold = mars > np.max(mars) * 0.95

# Find contours in the binary mask, sort them by length in descending
    order
contours = measure.find_contours(threshold, 0.9)
contours = sorted(contours, key=len, reverse=True)

# Get the contour and center of the largest contour (Mars)
mars_contours = contours[0]
mars_center = np.mean(mars_contours, axis=0)
mars_y, mars_x = mars_center

# Plot the center of Mars as a red star marker
plt.plot(mars_x, mars_y, 'r*', markersize=10, markeredgewidth=2, alpha
    =0.5, label='mars')

AP_2 = []
# Process the remaining star contours
for i in range(1, 5):
    star_contours = contours[i]
    star_center = np.mean(star_contours, axis=0)
    star_y, star_x = star_center

    # Calculate the angular separation between Mars and each star
    ang_sep = angular_separation(mars_x, mars_y, star_x, star_y, header['
    XPIXSZ'], header['FOCALLEN'])

```

```python
    # Plot stars with an angular separation greater than 5 arcminutes as circles
    if ang_sep > 5:
        plt.plot(star_x, star_y, 'o', markersize=15, alpha=1, markerfacecolor='none', markeredgewidth=2,
                 label=f'star {i}: {ang_sep:.2f} arcmin')
    AP_2.append(ang_sep)

# Customize the legend with a white frame
legend_box = plt.legend(frameon=True)
frame = legend_box.get_frame()
frame.set_edgecolor('white')
frame.set_linewidth(1.5)

# Remove axes and ticks
plt.axis('off')

# Set the title using the observation date from the FITS header
plt.title("Mars - " + header['DATE-OBS'])

# Display the APLpy colorscale image
f.show_colorscale()

# Adjust the figure size and spacing to remove empty space at the bottom
plt.subplots_adjust(left=0, right=1, bottom=-1, top=1)

# Save the figure as "mars_aplpy_30_1.png"
plt.savefig("mars_aplpy_30_1")
```

Listing 6: Python code for defining the center position of Mars and background stars in 02/06/2023 at 19:34 (UTC-7) in the image and calculate the angular distance between them.

Similar to Venus, we also used Stellarium in order to find the angular separation of Mars and its background stars for comparison purposes; also, to figure out which stars were.

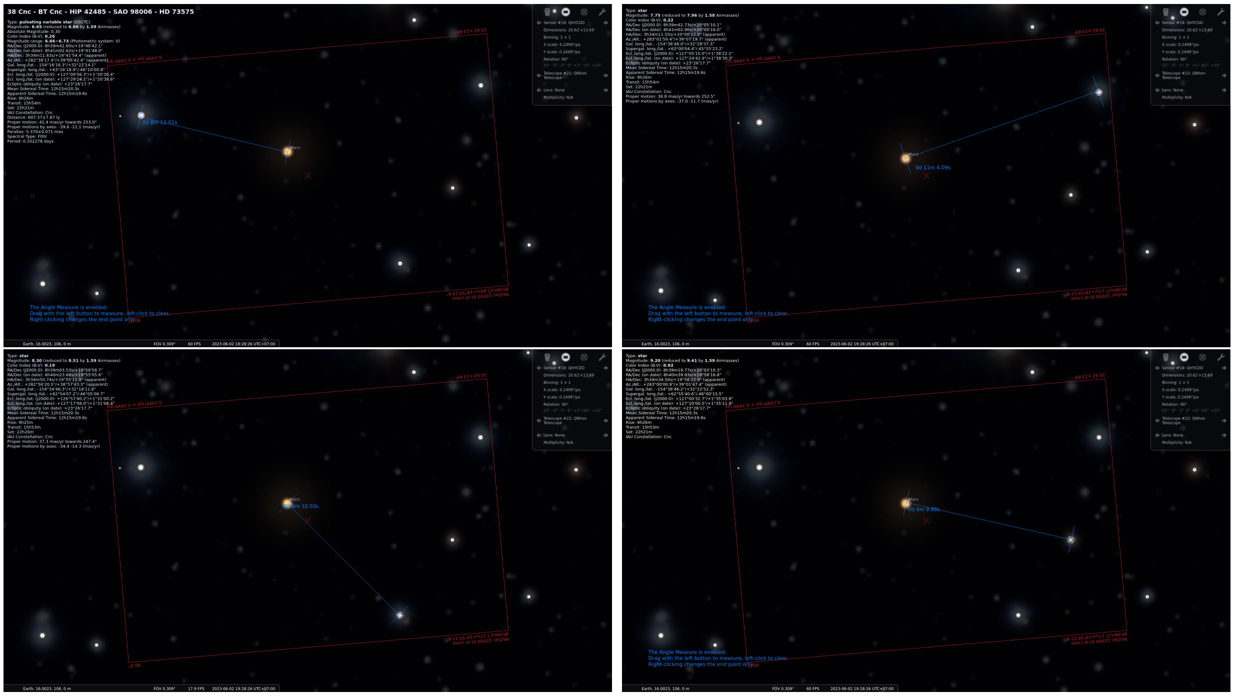


Figure 8: Mars - 02/06 - Using Stellarium

**Discussion:**

Following the method introduced in the section 2.4.2 and the value that we obtained at the beginning of this section, we can calculate the angular displacement of Mars relative to the background stars from 19:28 to 19:34 in the same day only using two star, which can be referred as star 1 and star 2 circled in blue and green in the figure 7a and 7b. The code is showing below:

```
dis_star_12 = angular_separation(star_X[0], star_Y[0], star_X[1], star_Y
    [1], header['XPIXSZ'], header['FOCALLEN'])

# Calculate coordinates and distances for convenience
x1 = AP_1[0]
y1 = AP_1[1]
x2 = AP_2[0]
y2 = AP_2[1]

# Calculate cosine of angles using the law of cosines
c_theta_1 = (x1**2 + dis_star_12**2 - y1**2) / (2 * x1 * dis_star_12)
c_theta_2 = (x2**2 + dis_star_12**2 - y2**2) / (2 * x2 * dis_star_12)

# Calculate the angles using arccosine
theta_1 = np.arccos(c_theta_1)
theta_2 = np.arccos(c_theta_2)

# Calculate the absolute difference between the angles
delta_theta = np.abs(theta_1 - theta_2)

```

```
# Calculate the displacement using the law of cosines and convert to
    arcminutes
disp = np.sqrt(x1**2 + x2**2 - 2 * x1 * x2 * np.cos(delta_theta)) * u.
    arcmin

# Show the result
print(disp)
```

```
0.14546949 arcmin
```

The result provides that in about 6 minutes, Mars displaced by the amount of 0.145 arcminutes relative to the background stars. The interval between two shots is very short leading to a very small displacement in the position of Mars relative to the background stars.

# 4 Conclusion

In conclusion, the observation and study of Venus and Mars have offered a remarkable journey into the intricacies of our neighboring planets within the Solar System. Through the analysis of their movement against the celestial background, we have gained valuable insights into their dynamics, orbital paths, and the laws that govern their motion.

By observing the apparent motion of Venus and Mars, we have witnessed the beauty of their journey through the night sky. The diligent capture of images, tracing their paths, and analyzing their movement have provided a deeper understanding of their orbits and the forces that shape their motion. We have come to appreciate the uniqueness of each planet's trajectory and the variations in their speeds as they navigate their way around the Sun.

The comparison between Venus and Mars has further enriched our understanding of these planetary bodies. Venus, with its brilliant appearance and swift movement, has captivated observers for centuries. Its phases and distinctive behavior have provided valuable insights into its position in relation to the Sun and Earth. On the other hand, Mars, with its rusty hue and slower motion, has intrigued astronomers with its subtle changes in apparent shape. Through the comparative analysis, we have recognized the diversity of planetary dynamics and the intricate dance of celestial bodies within the Solar System.

The practical observations conducted throughout this study have enabled us to connect the dots between theoretical knowledge and real-world applications. By utilizing telescopes and appropriate equipment, we have captured the essence of Venus and Mars' movements, transforming abstract concepts into tangible visual representations. These observations have allowed us to witness firsthand the vastness of the universe and the grandeur of our cosmic neighborhood.

Moreover, studying the movement of Venus and Mars has provided us with a deeper understanding of celestial mechanics. By analyzing their orbital parameters and linking them to their observed motion, we have unraveled the fundamental principles that govern planetary motion within the Solar System. These observations have affirmed the laws of gravity and planetary dynamics proposed by visionaries such as Johannes Kepler and Sir Isaac Newton, reinforcing the foundations of modern astrophysics.

Beyond the scientific realm, the observation of Venus and Mars serves to inspire awe and wonder. The exploration of their movement against the celestial backdrop has awakened a sense of curiosity and imagination within us. It reminds us of our place in the universe and the vastness of the cosmos that lies beyond our own world. By peering into the night sky and studying the motion of these celestial bodies, we connect with the age-old tradition of stargazing and pondering the mysteries of the universe.

In conclusion, the observation of Venus and Mars, with their movement within the Solar System, has provided us with a deeper appreciation of the intricacies of our planetary neighbors. By tracing their paths, comparing their behaviors, and studying their movement against the celestial background, we have expanded our knowledge of celestial mechanics and the dynamic nature of our cosmic environment. These observations have not only contributed to the scientific understanding of Venus and Mars but have also kindled a sense of wonder and exploration, inspiring us to continue our quest for knowledge and further exploration of the universe.