Proper Motion of Mars

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Abstract

The proper motion of Mars was determine in this lab using 14” telescope located at the University of Waterloo. Three main images were discussed in this report but only two were analyzed in producing the results. No background stars was determined in the images by our group thus the analysis focuses on the images taken by Stephen and Aiden’s group and also Dinindu and Daniel’s group. The angular distance and difference in times were used determine the motion of Mars between January 13,2019 to January 21, 2019. The results yield a proper motion of $(1149228 \pm 5\frac{deg}{hours})x10^{-8}$.

Introduction

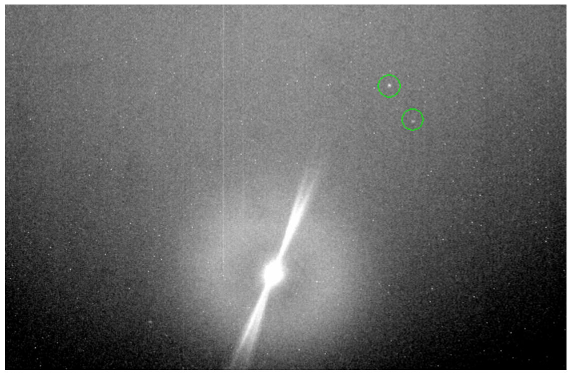
Historically humans have been engrossed in the idea of understanding the heavens. People realized that there are object that seemed to be glued to the sky while there are wanderers changed position in the skies and were called planeta by the Greeks. In astronomy, the proper motion of a celestial object describes the angular velocity of the object across the skies. For the most part these objects that are being observed are stars. However in this lab we would analyze and discuss the proper motion of Mars. The theory behind measuring the proper motion is quite simple: just find how far an object travelled and divided by the time it took to travel that distance. Distances between two objects in the skies are usually described in arc seconds where an arcsec is equivalent to $\frac{1}{3600}$. Therefore in this lab we will determine the proper motion of Mars in $\frac{arcsec}{day}$ and also the direction that it is travelling. To find the proper motion of Mars we used the observatory located on top of the Physics building of The University of Waterloo. The Observatory consist a 14" Celestron Telescope with 3.91m focal length.

Observational Method

The observatory is located at longitude: -80.541^o and latitude: 43.4706 North with elevation: 340m (Fich 2016). The target for the lab was Mars. The logic behind picking Mars was since it was the closest planet to Earth the proper motion can be easily observed within a small time frame. The observation was taken place on January 16,2019. On the night of observation the skies were clear and temperature outside was -11.8^o Celsius. Using theSkyX program on the telescope we were able to locate Mars without a finding chart. Once Mars was located we pointed the CCD camera in that direction and started taking images. We tested out the different binning on the camera to see which one gave the best picture of Mars. The best picture came from the 3x3 bin with an exposure length of 0.5s anything more than it becomes hard to pin point where the center of Mars is. Once Mars is taken obtaining the background stars alongside Mars was the new objective. Doing so will help astrometry.net determine the exact location of the picture. Alongside our data in the analysis images were from Stephen and Aidan and also the group Dinindu and Daniel. For Stephen's group the imaged used was 1x1 binning with exposure length of 4s taken on January 13, 2019. Likewise for Dinidu's group the image taken had 3x3 bin with exposure length of 0.5s taken on January 21, 2019.

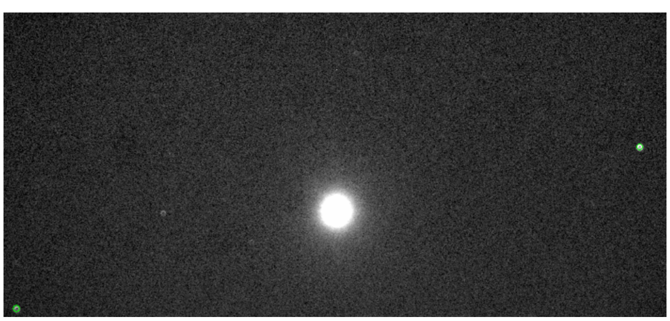
Analysis

The analysis would first begin with the data that we have taken. However the main bulk of calculations would be using the images from two other groups. The best image taken by our group where Mars is visible and also two other stars can be seen below:



Only two stars were clearly visible on the night of our observation. Even when the image was uploaded to astrometry.net the program couldn't find the location of this image on WCS. All the other images we've taken this night, astrometry.net failed to find any known stars. As a result a secondary purpose of this lab would be also to determine the right ascension and declination of this image. Since the date of the image is know the location of Mars can be found and can be compared to the location calculated using the images from the two other groups. Once the proper motion of Mars is determined then we can approximate the path that it takes and compare it to the actual location on Stellarium . Therefore once the analysis is done I would circle back to our groups image to check how good proper motion calculated was.

To start the two images taken for analysis can be seen below:



Starting with the image on the left is the image from Stephen's group under the file name ”mars_01_13_2019_2136_4sec_1x1.fits”. Once this image was plugged into astrometry.net they were able to find the WCS for this image. On the bottom left is the star HD 2879 while the star on the middle right is HD 2690. Now with for the image on the right it is from Dinindu's group with the file name "Mars_012119_1915_0_500sec.fits". When plugged into astrometry.net only one star HD 4888 was located which is the one at the bottom. For the star on the top left, it was determined using Aladin Lite. From the website I used two piece of information: first is the right ascension and declination from astronomy.net and second looking at the pattern of the stars around Mars. Resulting in the star being identified as TYC 18-985-1.

Now to find the plate scale of the two images. The method used was drawing a line between the stars on DS9 and finding what pixel distance is and also the distance in arcsec using WCS. The error for each measurement will be determined by how well the line is on the center of the star. If the star is blurry there would be a higher uncertainty associated with it. To begin the plate scale for Stephen's group would be determined. For both stars HD 2879 and HD 2690 both stars were fairly resolved and the centres were easy to determine. As a result the line from both centres measured a pixel of 3334 ± 3 pixels and arcseconds of $1629.92 \pm 3''$ from this the plate scale can be found by:

$$platescale = \frac{pixels}{distance(arcsec)} \tag{1}$$

Plugging in the values, the plate scale for this image is $0.4889 \pm 0.0001 \frac{pixel}{arcsec}$. The error was calculated using the formula (Arora[date unknown]):

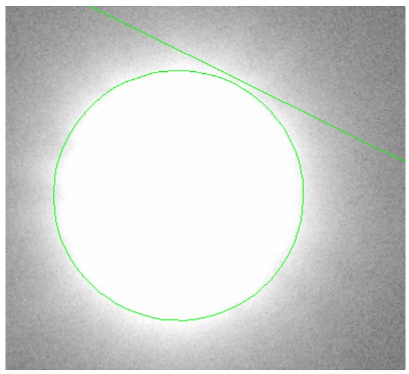
$$e_a\% = \sqrt[2]{(e_b\%)^2 + (e_c\%)^2} \tag{2}$$

The $(e_b\%$ and $(e_c\%$ can be found by dividing the error by the value. Doing so I get $e_a\%$ and when multiplied by $0.4889 \frac{pixel}{arcsec}$ the error comes out as $0.0001002 \frac{pixel}{arcsec}$ and round down as $0.0001 \frac{pixel}{arcsec}$. The value from astrometry.net was $0.489 \frac{pixel}{arcsec}$.

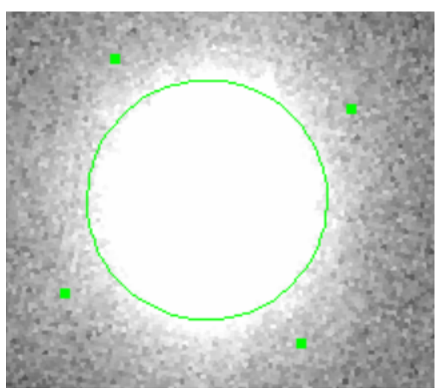
The exact same procedure can be done for Dinindu's group. But in their case the error was higher for the line drawn between the star HD 4888 and TYC 18-985-1. However the error for this image would be higher since the two stars weren't as resolved compared to Stephen's image. The stars are irregular shaped so finding the centre would be more difficult thus a higher uncertainty. With this in mind the line drawn had a length of 394 ± 5 pixels and arcseconds of $578.66 \pm 5''$. Then using equation (1) the plate scale comes out as $1.47 \pm 0.02 \frac{pixel}{arcsec}$ where the error was calculated using equation (2). When compared to astrometry.net they had $1.46 \frac{pixel}{arcsec}$.

The main purpose of finding the plate scale would be to measure the distance between Mars in one frame then in another after some time. But the main problem with using these two images is that the difference in time between them is relatively large with 8 days between them. Since Mars proper motion is high within the 8 days the planet moved quite a significant amount. As a result the stars in one image is completely different from the stars in the other. As a result it is extremely difficult to use the plate scales of both images to determine how far Mars went. In this case the method of determining the distance will be solely on the difference in right ascension and declination. The right ascension (α) and declination(δ). Similarly for calculating the plate scale the uncertainty in the position of Mars' center will be determined by how resolved it is.

Again starting with Stephen's group. The right ascension of Mars is 0:31:19.23 $\pm 0.5^s$ or in arcsec 1879.23 $\pm 0.5^s$ and the declination is +3:21:26.23 $\pm 1''$ again in arcsec its 12086.23 $\pm 1''$. The object was quite resolved so finding it's absolute position was easy. The image below shows Mars with a region encircling it, this helps me find the α and δ since it is just a matter of centering the circle.



Next the same procedure can be done for Dinindu's image. However their image was less resolved and the shape is a little more ellipsoid. As a result there would be a higher uncertainty associated with the declination. The center of the circle has right ascension of 0:50:51.13 $\pm 0.5^s$ or 3051.13 $\pm 0.5^s$ and a declination of +5:35:08.08 $\pm 3''$ or 20108.08 $\pm 3''$.



To find the angular distance between the two stars this equation would be used(Bruun 2010):

$$cos(D) = sin(dec1)sin(dec2) + cos(dec1)cos(dec2)cos(ra2 - ra1) \tag{3}$$

where dec are the declination of stars and ra is the right ascension. Both declination and right ascension are in degrees. Then from here finding the angular distance D would just be taking the arccos of the RHS. Plugging in the values into the equation gives (217951 $\pm 9^o) x10^{-6}$. The error was found by taking the upper and lower limit of the uncertainty and plugging the upper and lower bound into equation (3). For finding the upper bound the uncertainty would be added to the right ascension and declination of star 1 and 2. Likewise the lower bound would be subtracting the uncertainty. Finally plug the values into equation (3), then there would be a lower limit and upper limit from there take the difference and divide by two. The time difference between Stephen's and Dinindu is 189.65 hours. Therefore the proper motion can calculated as $\frac{2.17951}{189.65h}$ which is equal to $(1149228 \pm 5 \frac{deg}{hours}) x10^{-8}$

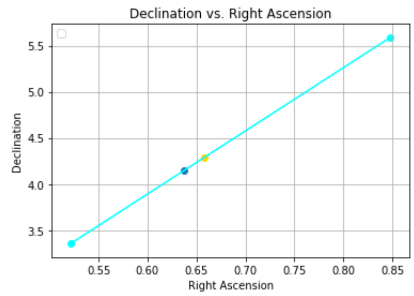
Now to circle back to the image our group has taken. The following analysis is use as a way to check our proper motion value as a result the numbers will not have an uncertainty associated with them. First we have the proper motion of Mars in terms of $\frac{deg}{h}$ but to find the position of Mars when our image was taken we also need to find the slope. To find the slope I treated right ascension like the x coordinate and declination like the y coordinate. By doing so we have two points on a graph one is from Stephen's group and the other Dinindu's. From this the slope of the graph can be obtain and in this case it yields 6.84. Now we will call Mars position on our image (RA2,Dec2) and Stephen's group (RA1,Dec1). The line that goes through the two points would have length (Proper motion of Mars) x (Time Difference). By doing so the length of the line is 0.803^o. Next a right angle triangle can be formed from the two points where the hypotenuse is 0.803^o. We now have two equations and two unknown:

$$0.803^2 = (Ra2 - Ra1)^2 + (Dec2 - Dec1)^2 \tag{4}$$

$$6.84 = \frac{(Dec2 - Dec1)}{(Ra2 - Ra1)} \tag{5}$$

Solving for both equations Ra2 = 0.6373^o and Dec2 = 4.146^o. Or in other words Ra2 = $0^o 38' 14.19''$and Dec2 = $4^o 8' 44.53''$. Checking the actual position on Stellarium yields Ra2 = $0^o 39' 27.87''$ and Dec2 = $4^o 17' 3.6''$.

The figure above shows the motion of Mars from the two data points. The dark blue shows the theoretical position of Mars for our image while the gold point shows the actual position from Stellarium.



Conclusion

The main purpose of this lab was to determine the proper motion of Mars on the nights sky. The images were taken from the observatory located on top of the Physics building of University of Waterloo. The images taken with our group were no used in the analysis however it was used as a check on whether the proper motion obtained was reasonable. The main analysis was done on two data sets: One taken from Stephen and Aiden and the other by Dinindu and Daniel. To determine the WCS of the images, they were uploaded to astrometry.net. Since the time difference between images were too large, the background stars were different and thus using the plate scale to find change in Mars' position was too difficult. As a result the absolute position using the right ascension and declination was used to find the distance Mars travelled. Finally the proper motion was determined to be $(1149228 \pm 5\frac{deg}{hours})x10^{-8}$.

References

Bruun SG. 2010. How to Calculate the Angular Distance Between Two Stars.Online. Available from: http://www.gyes.eu/calculator/calculator_page1.htm

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