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優勝作品專輯

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作品名稱	Sunprints in the sky
得獎獎項	大會獎 三等獎

國　　家	South Africa
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作者照片

Introduction

Revealing fascinating and educating concepts in a field of astronomy usually requires expensive equipment. Therefore, most schools have very little practical equipment to teach astronomy. I wanted to investigate the Sun's track using a simple apparatus that can be afforded by many schools instead of using an expensive one.

Purpose

To investigate the movement of the track of the Sun over a period of 5 months compared to the movement of the track of three specific stars.

Focus questions

How do the tracks of the movement of the Sun and stars through the sky differ?

How does the position of the track of the Sun and the stars change over a period, in relation to fixed terrestrial landmarks?

Literature Review (Theory)

Sun

The Sun is a huge ball of gas that burns up hydrogen and converts it to helium by fusion, to release energy in the form of heat and light. In simple astronomical terms, the Sun is a star. There are billions of stars in outer space in different galaxies. The Sun is in the Milky Way galaxy. Amongst billions of stars in the Milky Way galaxy, the Sun is positioned about two thirds of the way out, between the center and the outer edge of the Milky Way (H.A.Rey, 2008). The Sun is at the center of our solar system. The celestial objects (planets) that are part of the solar system are, in order of closeness the Sun, are: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune.

Models of the Solar System

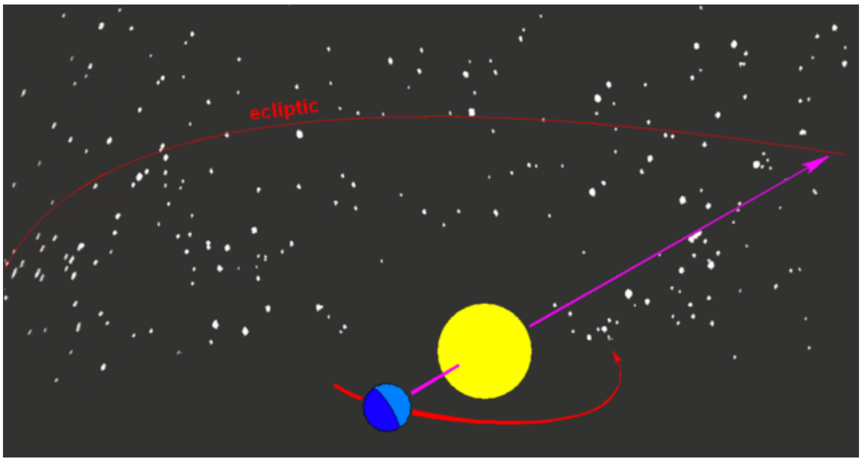
According to the **Geocentric** model of the solar system, described by the Alexandrian Greek scholar, Ptolemy, in 150 B.C, the Earth was considered to be the centre of the universe and all of the celestial bodies in the universe, including the Sun, orbited around the Earth. Nicholas Copernicus argued that this model was wrong in 1545. He proposed the Heliocentric model. The **Heliocentric** model considers the Sun to be the centre of the solar system and all the planets, including the Earth, to orbit around it. However, Aristarchus, two thousand years before, had already initiated the idea that one should regard the Earth, and the other planets, to be orbiting around the Sun. Johannes Kepler between 1609 and 1619 published the Laws of Planetary Motion which supported the Heliocentric model. The heliocentric model is the most popular model used at school today. (Kelly, 2014).

Rotation of the Earth

Since our observations of the movements of celestial bodies through the sky are made from the Earth, the Sun appears to rise above the Eastern horizon and appears to set below the Western horizon. The Sun repeats this relative motion every day 365.25 times a year. In reality, apparent movement of the Sun is caused by the rotation of the Earth around its own axis. The Earth also completes one revolution (in a clockwise direction, when observed from far above the Southern celestial pole) around the Sun in a period of 365.25 days in an elliptical orbit.

Ecliptic

The Ecliptic is an imaginary line that shows the path along which the Sun travels in a course of a year against the background stars. The Ecliptic is actually the projection of the plane of the Earth's orbit around the Sun onto the celestial sphere in the background (P.Stern, 2004). When the Ecliptic is drawn on a flat star chart, it appears to oscillate above and below the Celestial Equator in different seasons of the year (H.A.Rey, 2008).

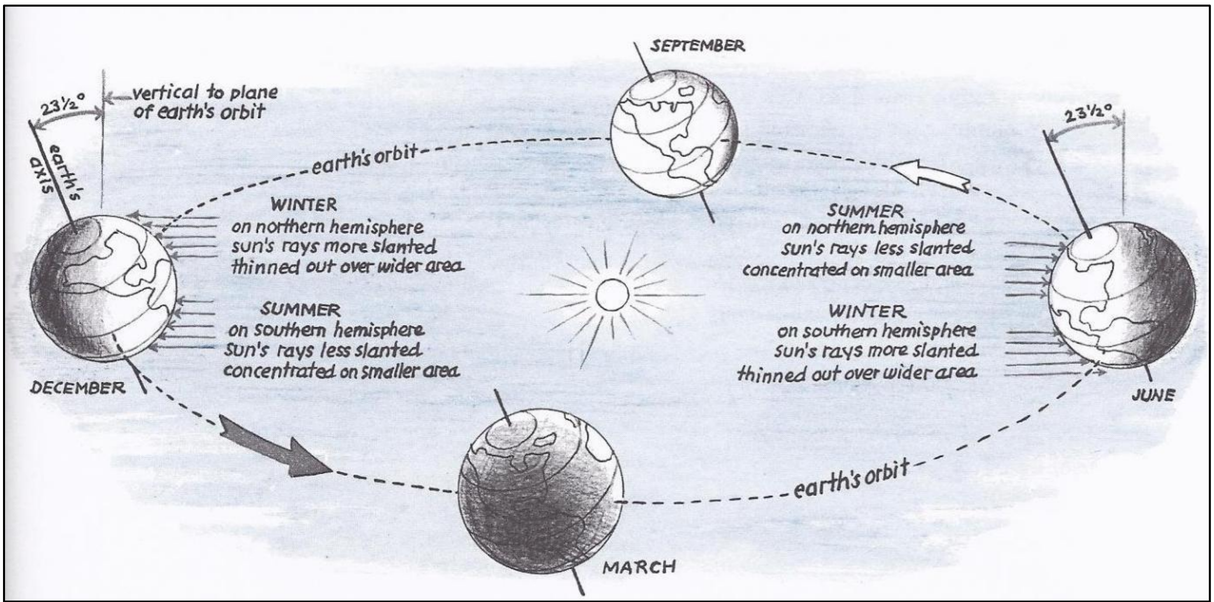


https://www-spof.gsfc.nasa.gov/stargaze/Secliptc.htm

Inclination of the Earth's axis

The main factor that causes the oscillation of the Ecliptic line is the 23.5° inclination (tilt) of the Earth's axis relative to the plane of the Earth's orbit around the sun. (H.A.Rey, 2008).

Although the angle of inclination is constant, as the Earth orbits around the Sun during the course of a year, the part of the Earth that is perpendicular to the Sun's rays changes from the northern to the southern hemisphere and back again. This is the reason for the Earth's four seasons of the year.



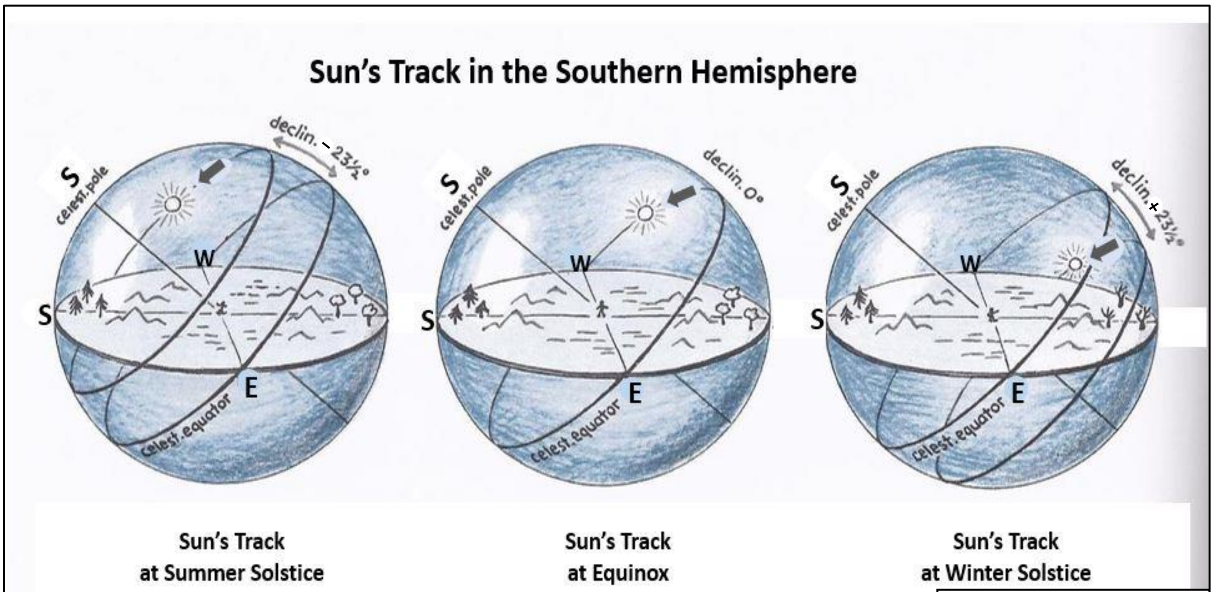
Inclination of Earth's Axis as it orbits around the Sun(H.A.Rey, 2008)

Celestial Equator, Meridian & Zenith

The position of the **Celestial Equator** is directly above the Earth's equator. Therefore, the observed position of the Celestial Equator varies according to the latitude of the observer. My observing position was from Bloemfontein, South Africa, which is situated at latitude 29° south of the Equator. Therefore, in Bloemfontein, the Celestial Equator crosses the Meridian 29° north of the zenith, or 61° above the northern horizon. The **Meridian** is the line joining the northern and southern celestial poles, running directly above the observer. The **Zenith** is the point in the sky vertically above the observer. (H.A.Rey, 2008).

Solstice

The height of the midday Sun above the horizon varies according to the seasons of the year. When viewed from the southern hemisphere, the height of the midday Sun above the northern horizon is the greatest during summer and the lowest during winter. The Celestial Equator is at the half-way line between these positions. In astronomical terms, these maximal deviations to the north and south of the Celestial Equator are referred to as the Solstices. On 21 June the Sun is at maximum declination north of the celestial equator. On 21 December the Sun is at maximum declination south of the celestial equator. Thus a Solstice occurs twice a year (H.A.Rey, 2008).



(H.A.Rey, 2008)

Equinox

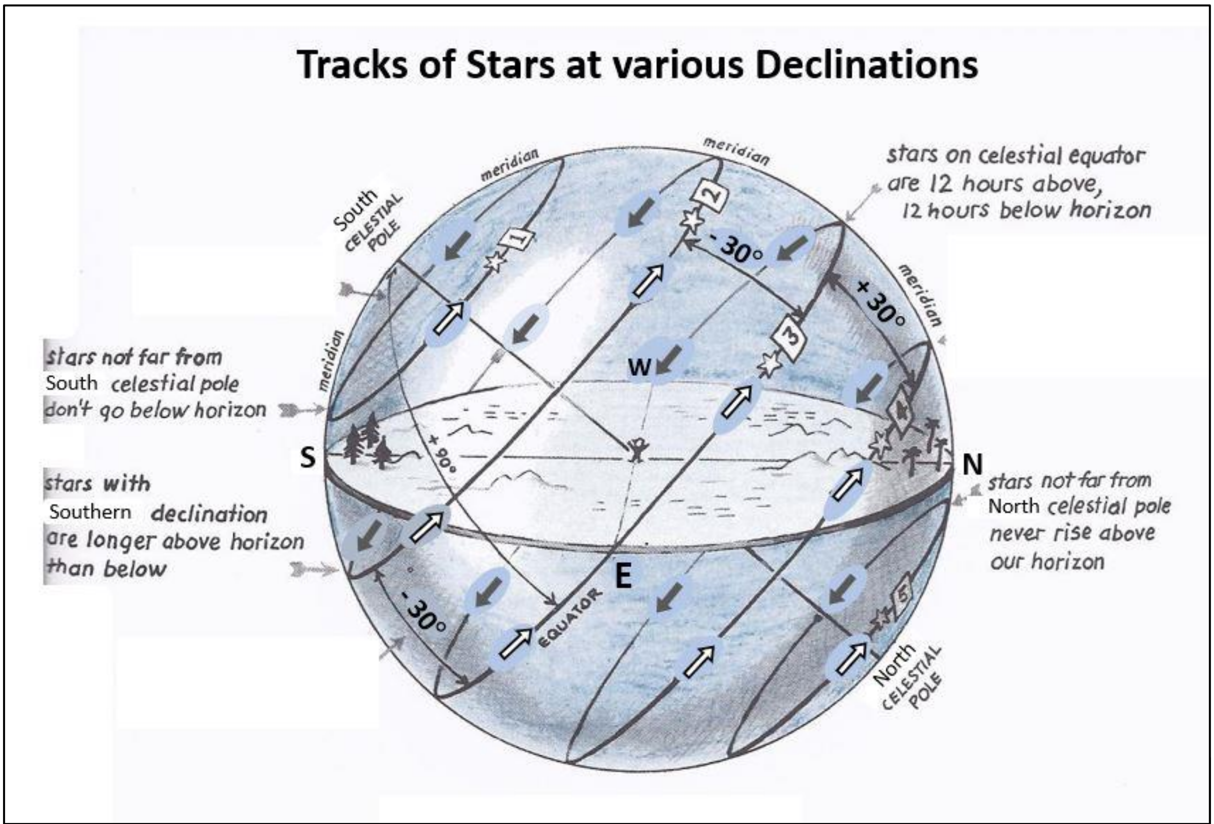
During spring and autumn, the path of the Sun (Ecliptic) crosses the Celestial Equator. The astronomical term for this phenomenon is the Equinox. An Equinox occurs twice a year. The Vernal (spring) Equinox occurs when the Sun crosses into the northern celestial hemisphere on 21 March every year. The Autumnal Equinox occurs when the Sun crosses into the southern celestial hemisphere on 23 September every year. (P.Stern, "From Stargazers to starships"--Site Map, 2005).

Track of the Stars

The track along which the Sun moves circling around the Earth in different seasons varies greatly. In contrast, the track along which each star moves is unchanging. Stars other than the Sun never change their tracks as they move across the sky, regardless of the season. They have constant declinations (the angular distance of a celestial body north or south of the Celestial Equator). Simply stated, they do not deviate from their fixed positions in the celestial sphere. However, because of the Earth's rotation around the Sun, the Earth's position relative to the Sun is constantly changing. For this reason, the celestial sphere appears to rotate westward around the celestial axis (between the northern and southern celestial poles) by nearly 1° each day. And for the same reason each star rises nearly 4 minutes earlier above the eastern horizon every day. The reason is that the celestial sphere takes 4 minutes to rotate 1° westwards.

Stars

Three stars were selected for tracking because of their convenient declinations for the purpose of my project. Altair lies close to the Celestial Equator. Arcturus lies close to the declination of the Solstice on 21 June. Antares lies close to the declination of the Solstice on 21 December.



Altair

Altair (alpha Aquilae/αAql) is the brightest star in the constellation Aquila (the Eagle) and the twelfth brightest (luminous) star in the night sky. It is 1,201 billion years old and 16.73 light years away from the Earth. Altair is an A-type main sequence star with an apparent visual magnitude of +0.74 and is one of the vertices of the summer Triangle. Altair is a white dwarf star. The declination of Altair is +8°55’14”.

Antares

Antares (alpha Scorpi/ αScorpi) is a red super giant star in the Milky Way Galaxy in the constellation Scorpius (the scorpion) and is the sixteenth brightest star in the night sky (sometimes listed the fifteenth of the brightest if the two brighter components of the Capella quadruple star system are counted as one star). Antares is 11.01 million years old, close to its death, and 619.7 light years away from the Earth. Along with Aldebaran, Spica and Regulus, it is one of the four brightest stars near the Ecliptic. Antares is a slow variable star with an average magnitude of +0.89. The declination of Antares is -26°28’24”.

Arcturus

Arcturus (alpha Bootes/α Boo) is the brightest star in the constellation Bootes (Herdsman). Arcturus is 7.105 billion years old and is 36,67 light years away from the earth. With a visual magnitude of -0.06, it is also the third brightest star in the night sky, after Sirius and Canopus. It is, however, fainter than the combined light of the two main components of Alpha Centauri, which are too close together for the eye to resolve as separate sources of light, making Arcturus appear to be the fourth brightest. It is the second brightest star in the Northern latitudes and the brightest star in the Northern celestial hemisphere. The star is in the local Interstellar Cloud. The declination of Arcturus is +19°04’54”.

Julian Day (JD)

To measure recurring events over long periods in astronomy such as the cycle of the sunspot variations, scientists use the Julian Day System. The Julian Day System numbers days continuously, without division into months and years since noon GMT on 1 January 4713 BC, which is defined as day zero. The Julian day number for a specific date, is the number of days that have elapsed since day zero. The usefulness of the Julian day system is that it avoids the confusion caused by the transition from BC to AD. In historical usage the year 1 BC is followed immediately by the year 1 AD, whereas in astronomical usage the year 1 BC is followed by the year 0 which is in turn followed by the year 1 AD.

Hypothesis

1. The shape of the Sun's track over the period of a year (Ecliptic) projected onto a flat star chart of the background stars appears to have the shape of a sine-wave. Therefore, the displacement of the Sun's track from the Celestial Equator over time should follow the equation of a sine-wave.
2. The rate at which the position of the Sun's track changes, is maximal at the time of the Equinox and decreases to zero at the time of the Solstices.

Method

a) Variables

<u>Independent variables:</u>

- Date of Observation

<u>Dependent variables:</u>

- Change of position of the Sun's track over time
- Change of the position of the stars' track over time

<u>Controlled variables</u>

- The position and direction of the observational apparatus during the times of plotting
- The period for doing each series of plots
- The terrestrial reference points
- The direction the observational apparatus faces

b) Measurements

A ruler was used to measure the distance between the plots.

c) Apparatus

- Observational apparatus
- Spirit-level
- Ruler
- Transparency sheets
- Colored marker pens
- File clips
- Stopwatch
- 30°/60°Set-square

d) Procedure

1. An observational apparatus was constructed by mounting a transparent acrylic screen could be mounted onto a photographic tripod. An eyepiece was positioned perpendicular to the center of the screen at a distance of exactly 110mm. This would make possible a total viewing angle of 60 degrees. (30 degrees in any direction from the center of the screen.)

2. The observational apparatus was set every day of plotting facing the direction of the two beacon poles that served as my terrestrial reference points.

3. Using a spirit level, the centre-pole of the tripod was ensured to be vertical, by adjusting the length of the tripod legs.

4. The eyepiece of the observational apparatus was adjusted to be perpendicular to the centre of the screen at a distance of 110mm.

5. Looking through the eyepiece, the screen of the observational apparatus was turned so that the tops of the two beacon poles were equidistant from the vertical midline of the screen. They had to appear in the lowest quarter of the screen.

Photo taken by Thabo Maliea. 19/01/2019

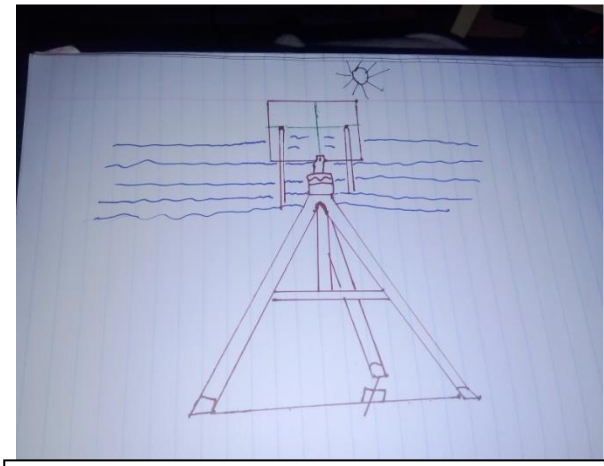


Photo taken by Thabo Maliea. Date:19/01/2019

6. Transparency film was mounted onto the apparatus screen with clips.

7. The positions of the Beacon poles and the edges of the vertical and horizontal midlines were marked on the transparency film. The date was written in the upper right-hand corner.

8. The position of the sun and stars were plotted five times at 30-minute intervals starting from exactly 4 hours before their expected Meridian Crossing Time (MCT–calculated using *Stellarium*).

9. Plotting of the Sun was done at intervals of 2 weeks. Each series of five plots was made on a new transparency film.

10. Plotting of the three stars had to be done three times at intervals of 4 weeks. Each series of five plots had to be done on a new transparency film.

11. The period of plotting commenced 4 weeks before the 21 March Equinox and continued until just after the June 21 Solstice.

Test of hypothesis

The hypothesis will be confirmed as correct if the displacement of the Sun's track from the Celestial Equator over a time follows the equation of a sine wave.

The hypothesis will be confirmed as correct if the maximal rate of displacement of the Sun's track is measured at an Equinox and declines to zero at a Solstice.

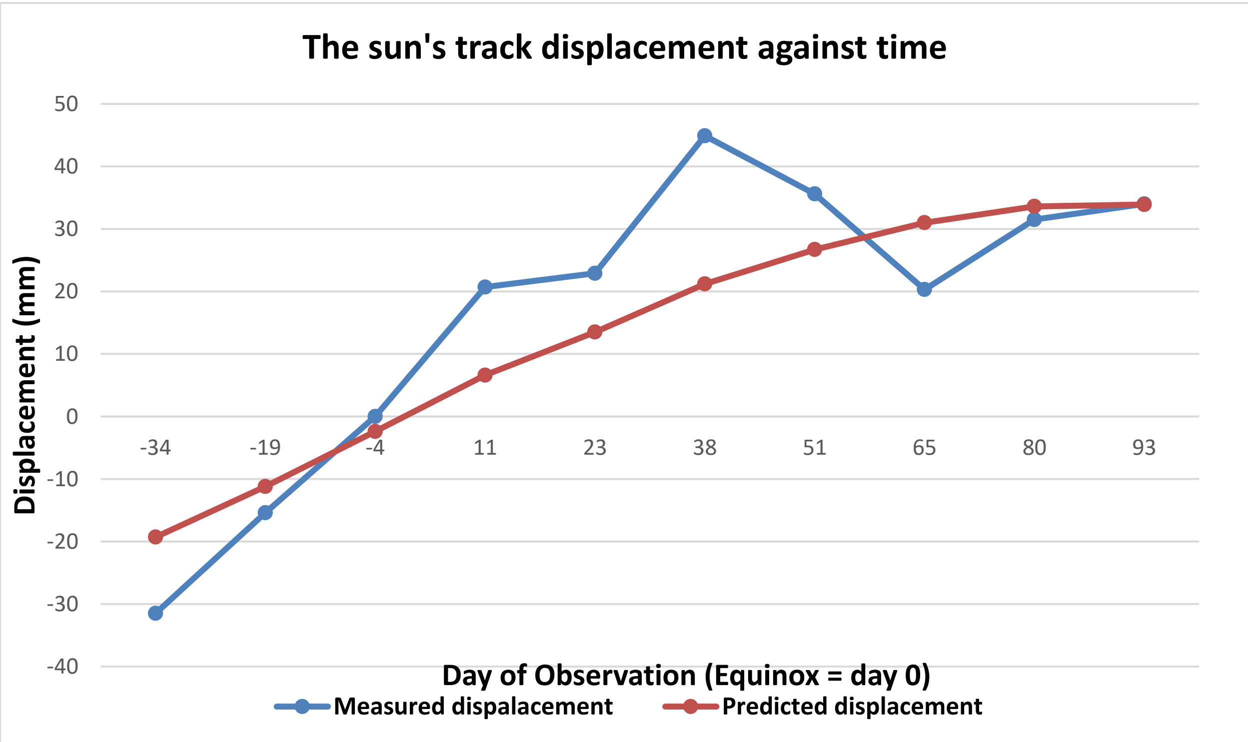
Results

a) Sun’s track

1. Displacement of the Sun’s Track over Time

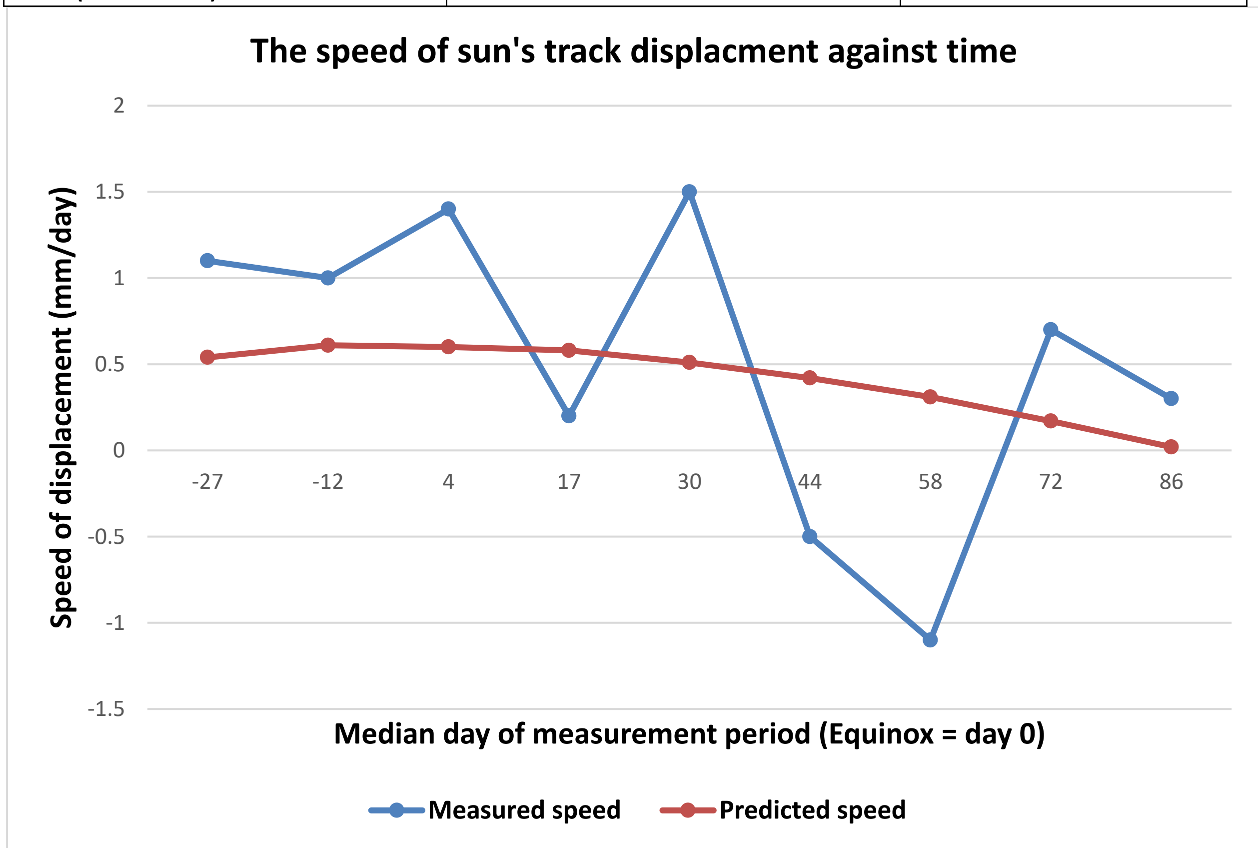
Day of Observation Equinox = Day 0	Measured displacement of the sun’s track (mm)	Predicted displacement of the sun’s track(mm)
-34	-31.5	-19.3
-19	-15.4	-11.2
-4	0	-2.4
11	20.7	6.6
23	22.9	13.5
38	44.9	21.2
51	35.6	26.7
65	20.3	31.0
80	31.5	33.6
93	34.0	33.9

2. Speed of Displacement of the Sun’s Track



Speed of Displacement of the Sun's Track

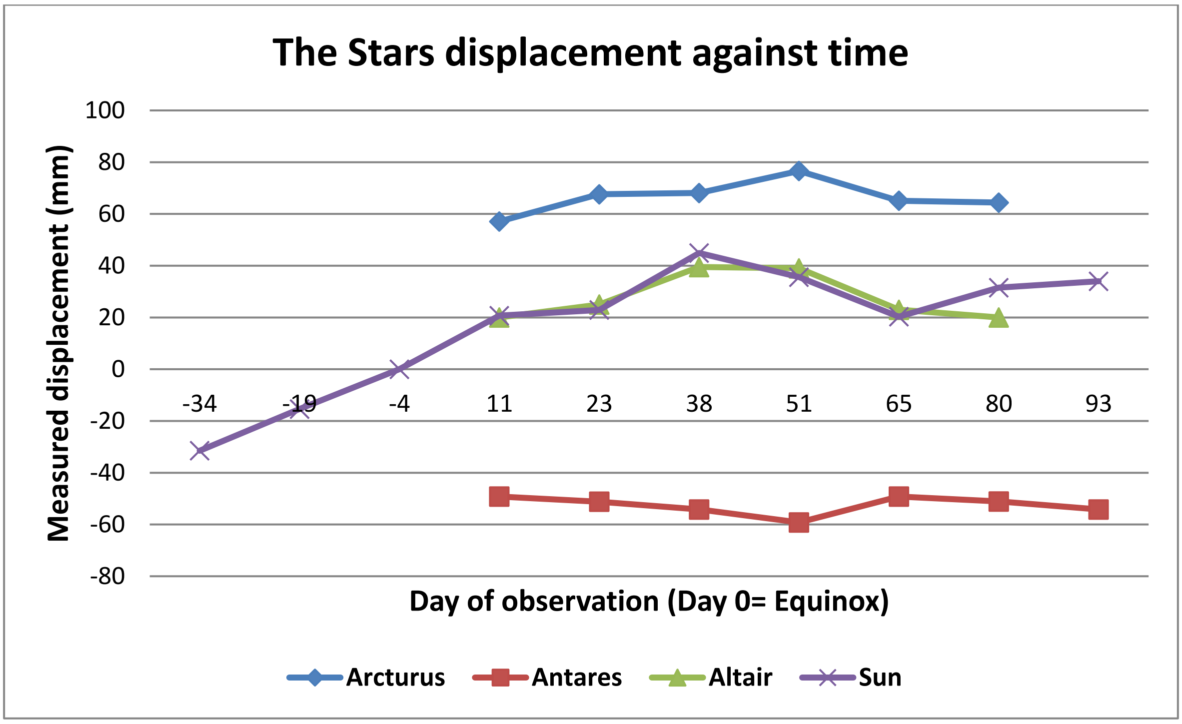
Median day of observation period in relation to the Equinox	Measured Speed of the sun's track (mm/day)	Predicted speed of the sun's track (mm/day)
-27 (-34 to -19)	1.1	0.54
-12 (-19 to -4)	1.0	0.61
4 (-4 to 11)	1.4	0.60
17 (11 to 23)	0.2	0.58
30 (23 to 38)	1.5	0.51
44 (38 to 51)	-0.7	0.42
58 (51 to 65)	-1.1	0.31
72 (65 to 80)	0.7	0.17
86 (80 to 93)	0.3	0.02



b) Star Tracks

Displacement was measured relative to the Sun's track on Day -4 (17 March).

	Day of observation (Day 0= Equinox)	Arcturus	Altair	Antares	Sun
Measured displacement (mm)	-34				-31.5
	-19				-15.4
	-4				0
	11	57.1	20.0	-49.2	20.7
	23	67.6	25.0	-51.2	22.9
	38	68.1	39.5	-54.2	44.9
	51	76.6	39.0	-59.2	35.6
	65	65.1	23.0	-49.2	20.3
	80	64.4	20.0	-51.1	31.5
	93			-54.2	34.0



Discussion

Displacement of the Sun’s Track

The shape of the curve of the predicted displacement was an upward slope that gradually levelled out. The predicted values were calculated using the equation for a sine-wave. My measured plots of the Sun’s track varied around the predicted values. The variability of the measured values can be attributed to measurement inaccuracies. Nevertheless, my measured values followed the general direction of the predicted values, confirming that the displacement of the Sun’s track does indeed follow the pattern of a sine-wave.

Close to the period of Equinox the gradient of the graph of displacement of the Sun’s track is the steepest. At this point the Ecliptic crosses the Equator. The displacement was measured relative to the Sun’s track plotted closest to the time of Equinox, because at this time the Sun is on the Celestial Equator and therefore it was used as our reference point. Close to the period of Solstice the gradient of the graph of displacement of the Sun’s track was close to zero. The reason is because the Sun is at the maximum displacement from the Equator during the period of Solstice and the change in the Sun’s position declines to zero. After the Solstice the Sun’s track changes the direction and begins to move back towards the Celestial Equator.

Speed of Displacement of the Sun’s Track

Close to the period of Equinox the speed of the Sun’s track displacement was at its greatest. Close to the period of Solstice the speed of the Sun’s track displacement was the lowest. This pattern is clearly indicated in the graph of predicted speed of displacement. My measured speeds varied greatly, once again due to measurement inaccuracies. However, the general trend followed the predicted values and confirms my hypothesis.

Displacement of the Stars’ Tracks

The displacement of the stars’ tracks varied much less than the Sun’s track. The predicted displacement for the stars is zero. The reason is because the stars have the fixed declinations on the celestial sphere. The variations in my measurements must once again be attributed to measurement inaccuracies. Both Arcturus and Altair showed a track displacement just less than 20mm from the baseline in the same direction during the middle of the observation period.

However, there was almost no displacement at the beginning and the end of the observation period for both stars. The track displacement of Antares was never more than 10mm from baseline and was erratic in different directions. The variations can be attributed to measurement inaccuracies. These observations indicate that the tracks of the stars do not change, also confirming my hypothesis.

Deviation of the Reference Track

The reference-track of the Sun (plotted on 17 March) lies 2.4mm higher than the predicted plot. Therefore, for perfect comparison, all the measured displacements should be decreased by 2.4mm. However, because the deviation of the reference track is negligible, I decided not to correct the measured displacements.

Conclusion

1. The changes in the position of the Sun's track are maximal close to the Equinox and decline to zero at the Solstice.
2. The speed of the Sun's track displacement is maximal during the period of Equinox and declines to zero during the Solstice period.
3. The changes in the position of the tracks of the stars were relatively small and did not show a consistent pattern.
4. The findings of my investigation are consistent with both of my hypothesis statements.

Significance

- I have confirmed by personal observation that the Sun's track changes over time but the track of the stars does not.
- The use of this apparatus has enormously enhanced my understanding of the apparent movement of the Sun and the stars.
- The use of a simple apparatus has been able to reveal fascinating patterns of celestial mechanics (movement of the Sun, stars and other celestial bodies).
- There are many other applications for which the apparatus can be used. Examples are: demonstrating the changes in the length of the solar day; plotting the change in positions of the planets against the background stars and deviations of the moon's position around the ecliptic.
- The apparatus can be used in school to enhance learners' understanding of astronomy (please invite me to your science class!).

Limitations

- I used a flat surface to plot the movements of celestial bodies on a spherical surface (the celestial sphere).
- I could only plot the movement of the Sun over a 2-hour period due to small screen size of the apparatus.
- I could only plot the movement of the track of the Sun and stars over a limited period of 5 months.
- Mist (water condensation) frequently formed on the screen during the very cold nights of plotting.
- I could not plot the track of the stars from the beginning because they only appeared above the horizon in the night sky later during the observation period.
- Rain and clouds obscured my view of the Sun on some days, resulting in some lost data-collection opportunities.
- Light pollution and smoke interfered with taking highly accurate plots.
- I had to remount the observational apparatus every day of plotting and this decreased the accuracy of data collected.

Ways to Overcome Limitations

- Plotting the tracks of the Sun and stars using hemispherical plastic dome instead of a flat surface, would greatly improve accuracy.
- A supporting frame for the plastic dome mounted in concrete, would also greatly improve accuracy.

Further Research and Expansion

- Doing measurements over a period of 12 months instead of 5 would give me the opportunity to fully record the sine-wave pattern of sun-track movement.

Acknowledgements

Dr Johannes Cronje: For guiding the researcher during the investigation and giving him the apparatus he needed.

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Appendix

Raw data tables

Altair

1. Measured displacement of Altair’s track against time relative to the track of the Sun on day -4 (17 March).

Day of observation (Day 0 = Equinox)	Measured displacement (mm)
-4	Not measured
12	20.0
24	25.0
38	39.5
52	39.0
66	23.0
79	20.0

Antares

2. Measured displacement of Antares track against time relative to the track of the Sun on day -4 (17 March).

Day of observation (Day 0 = Equinox)	Measured displacement (mm)
-4	Not measured
12	-49.2
24	-51.2
38	-54.2
51	-59.2
65	-49.2
79	-51.1
93	-54.2

Arcturus

3. Measured displacement of Arcturus track against time relative to the track of the Sun on day -4 (17 March).

Day of observation (Day 0 = Equinox)	Measured displacement (mm)
-4	Not measured
11	57.1
23	67.6
37	68.1
51	76.6
66	65.1
80	64.4

Sun

Formula for calculating predicted displacement: y=Asin(t×365,25÷360)

y = displacement from Equinox on day "t"

A = amplitude (maximum displacement as measured on 21 June)

t = number of days before or after Equinox.

1. Measured Speed of Displacement of the Sun's Track

Median day of observation period in relation to the Equinox	Number of days	Difference in measured displacement (mm)	Measured Speed (mm/day)
-27 (-34 to -19)	15	16.1	1.1
-12 (-19 to -4)	15	15.4	1.0
4 (-4 to 11)	15	-20.7	1.4
17 (11 to 23)	12	-2.2	0.2
30 (23 to 38)	15	-22.0	1.5
44 (38 to 51)	13	+9.3	-0.7
58 (51 to 65)	14	+15.3	-1.1
72 (65 to 80)	15	-11.2	0.7
86 (80 to 93)	13	-3.5	0.3

2. Predicted Speed of Displacement of the Sun's Track

Median day of observation period in relation to the Equinox	Number of days	Difference in predicted displacement (mm)	Predicted speed (mm/day)
-27 (-34 to -19)	15	8.1	0.54
-12 (-19 to -4)	15	9.2	0.61
4 (-4 to 11)	15	9.0	0.60
17 (11 to 23)	12	6.9	0.58
30 (23 to 38)	15	7.7	0.51
44 (38 to 51)	13	5.5	0.42
58 (51to 65)	14	4.3	0.31
72 (65 to 80)	15	2.6	0.17
86 (80 to 93)	13	0.3	0.02

3. Displacement of the Sun's Track over Time

Day of observation	Displacement measured (mm)	Predicted displacement(mm)
-34	-31.5	-19.3
-19	-15.4	-11.2
-4	0	-2.4
11	20.7	6.6
23	22.9	13.5
38	44.9	21.2
51	35.6	26.7
65	20.3	31.0
80	31.5	33.6
93	34.0	33.9

Pictures

Photo taken by Thabo Maliea. 12/05/2019

Photo taken by Thabo Maliea. 12/05/2019

Photo taken by Tshepang Maliea. 12/05/2019

【評語】160049

The author has investigated the Sun's track using a simple apparatus that can be afforded by many schools. For countries with less resources or lack of access, developing inexpensive and practical tools/methodologies is crucial to educate concepts in the field of astronomy, which usually requires expensive facilities nowadays. An observational apparatus is constructed by mounting a transparent acrylic screen, which can be mounted onto a photographic tripod. An eyepiece is positioned perpendicular to the center of the screen at a distance of 110 mm, which makes possible a total viewing angle of 60 degrees. Using this simple apparatus, the author has recorded the change of position of the Sun's track over time for over five months, revealing some fascinating patterns of celestial mechanics.