

# An Analysis of Field Rotation Associated with Altitude-Azimuth Mounted Telescopes: the Potential Effect on Position Angle Measurements of Double Stars

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**Abstract:** The phenomenon of field rotation observed with altitude-azimuth mounted telescopes is discussed. The mathematical concepts behind field rotation are presented. Azimuth and altitude values are obtained from a telescope computer and a software program for five stars and compared. The values are then used to calculate rates of rotation for the five stars. Calculated rates of rotation are then compared to observed rotation. The results are discussed and possible implications on double star position angle measurements presented.

## Introduction

### *Alt-Az and Equatorial Mounts:*

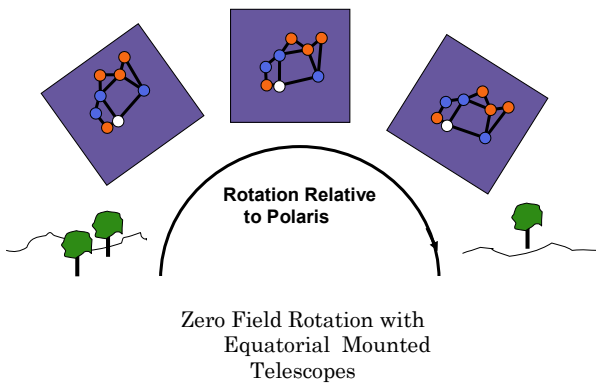
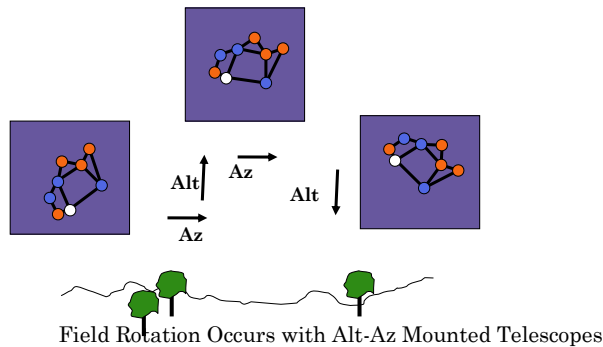
Comparisons are continually made between the equatorial mount and the altitude-azimuth (or simply alt-az) mount regarding astrophotography. Alt-az mounts are to be avoided due to a phenomenon known as field rotation. Field rotation occurs due to the design of the alt-az mount. One axis, the azimuth axis, rotates around a vertical line passing from the center of the telescope to the zenith (left to right). The altitude axis rotates about a horizontal axis (up and down). Both axes must rotate at different rates to maintain the object in the field of view (FOV). As the Earth rotates about its axis, the central object in the field of view will remain centered but other objects in the FOV will appear to rotate with elapsed time. Thus long exposure photographs are not allowed. But with the equatorial mounted telescope, the right ascension axis is oriented toward the north celestial pole. As the stars rise in the east, the telescope only has to rotate about the right ascension axis to follow the stars so that the position of the ob-

ject in the FOV remains static and long exposure photographs are possible. These movements can be seen in Figure 1.

Let the FOV of the telescope be represented by a square and follow the motion of Sagittarius as it rises in the east. Because the alt-az mount can only move around the azimuth axis and the up and down on the altitude axis, the FOV remains fixed with the bottom parallel to the horizon. The objects in the sky, however, are rotating around the celestial pole star, Polaris. So asterisms and binary stars appear to rotate in the FOV. An equatorially mounted telescope does not suffer field rotation because the telescope is polar aligned and the FOV does not remain horizontal as it tracks; the telescope rotates. So the FOV matches the rotation of the object and it remains in the same fixed position.

Position angle measurements of double stars with alt-az mounted telescopes can suffer the same fate as long exposure astrophotos. The field rotation that occurs during the drift time could change the actual value of the position angle. So how severe is it?

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**Figure 1:** Field Rotation: Alt-Az and Equatorial Mounts

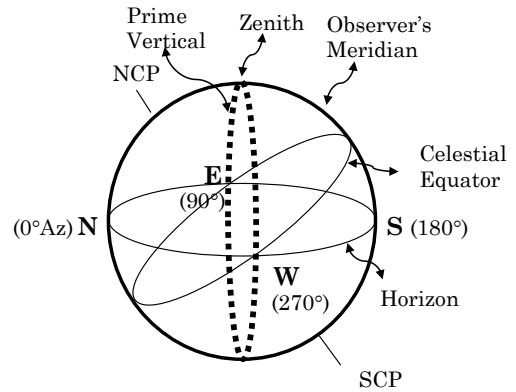
How much will it affect the measured position angle? This study will attempt to answer these questions. Due to the increasing numbers of alt-az telescopes being used by astronomers, methods designed to deal with field rotation would be helpful, especially when these instruments are being used for scientific research.

The amount of field rotation depends on several factors. The Earth's rate of rotation, the location of the double star in the sky (altitude and azimuth values), the latitude of the observing site, and the drift time required for the primary to pass from the center of the astrometric eyepiece to the outer protractor scale all affect the amount of field rotation.

This article will describe the simple trigonometric phenomenon behind the effect, discuss an equation that will enable one to calculate the rate of rotation, and then present actual data comparing the theoretical and observed field rotation for five different stars in various parts of the sky.

**Terminology**

The terms used in describing field rotation need to be defined prior to discussing the mathematical implications. See Figure 2.



**Figure 2:** The Celestial Sphere

The four terrestrial directions north, east, south, and west are indicated on the horizon. The celestial equator, with declination equal to zero, is tilted with respect to the horizon and lies in the same plane as the terrestrial equator, only projected on the celestial sphere. It is tilted at an angle of 23.4°; the obliquity of the ecliptic. The north and south celestial poles are indicated by NCP and SCP. The zenith is the point in the sky directly overhead, 90° to the horizon. The line connecting the NCP, the zenith, moving directly south toward the SCP is the observer's (or local) meridian. The arc passing from east, through the zenith, toward the west is the prime vertical.

Stars located on the celestial sphere can be described by giving their right ascension and declination or from a terrestrial point of view. The latter involves citing the altitude above the horizon (horizon=0° and the zenith=90°), the azimuth (N=0°, E=90°, S=180°, and W=270°), and the latitude of the observation site.

**Mathematical Concepts Behind Field Rotation**

Stars appear to rise in the east and set in the west, rotating about the north celestial pole star, Polaris. Rising stars will reach their highest elevation in the sky as they cross the local meridian, due south of the line between Polaris and the zenith.

The altitude indicates the vertical position of the star with 0° at the horizon and 90° at the zenith.

From direct observation, the following aspects are known about rate of rotation.

1. The maximum rate of field rotation occurs as the star passes through the zenith.
2. The rate of field rotation is minimal when a star passes through the prime vertical at the horizon.

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3. Considering the azimuth only, the rate of field rotation is highest when the star passes through 0° (N) and 180° (S), and lowest when the star passes through 90° (E) and 270° (W).
4. Regarding latitude, field rotation is highest at the Earth's equator and non-existent at the NCP and SCP.

Let's now see why this is the case. The Earth's rotation can be expressed as 15.041 degrees/hour, 2.507 x 10<sup>-1</sup> degrees/minute, or 4.178 x 10<sup>-3</sup> degrees/second. Equation 1, as noted by Keicher<sup>(Ref. 4)</sup>, expresses the rate of rotation (often referred to herein as RoR) in terms of the Earth's rotation and the cosine functions of latitude, azimuth, and altitude.

$$\text{Rotation Rate} = \frac{W * \cos(\text{Latitude}) * \cos(\text{Azimuth})}{\cos(\text{Altitude})} \quad (1)$$

where W=4.178 x 10<sup>-3</sup> degrees/second; Earth's rotation.

The cosine function of the azimuth can be graphed with respect to the four terrestrial directions and the 360° of a circle. The azimuth angle is measured clockwise from the north going eastward. See Figure 3.

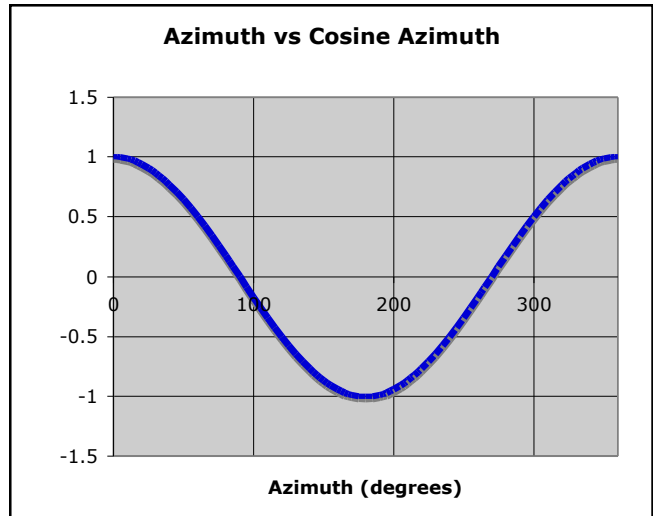
If we only consider changing the values of the azimuth in Equation 1, the least amount of field rotation (zero) is along the prime vertical (due east or west) because east is 90° from north (cos 90°=0) and west is 270° from north (cos 270°=0). Looking toward the other directions, the maximum rate of field rotation is when the star is due south (180° from north; cos 180°=1) or directly north where cos 0°=1.

$$\text{Least RoR}_{E,W} = \frac{W * \cos(\text{Lat}) * 0}{\cos(\text{Alt})} = 0 \quad (\text{Az} = 90^\circ \text{ or } 270^\circ)$$

$$\text{Max RoR}_{N,S} = \frac{W * \cos(\text{Lat}) * 1}{\cos(\text{Alt})} \quad (\text{Az} = 0^\circ \text{ or } 180^\circ)$$

The altitude function deals with values between the horizon (0°) and the zenith (90°), so only considering changes to the values of the altitude in Equation 1 and using the trig values given above we get to following.

$$\text{RoR}_{\text{Horizon}} = \frac{W * \cos(\text{Lat}) * \cos(\text{Az})}{1} \quad (\text{Alt} = 0^\circ)$$



Direction	North	East	South	West	North
Degrees	0	90	180	270	360
Cosine Value	1	0	-1	0	1

Figure 3: Cosine Function of Azimuth

so the rate depends solely on the latitude and azimuth.

$$\text{RoR}_{\text{Zenith}} = \frac{W * \cos(\text{Lat}) * \cos(\text{Az})}{0} \quad (\text{Alt} = 90^\circ)$$

which is an undefined quantity and not allowed.

The rapid change in the field rotation in various parts of the sky can be represented graphically. In Figure 4a, the altitude vs the rate of rotation is plotted where the azimuth is held constant and the altitude is changed from 0° to 90° in 1° increments. This will show just the effect of the change in altitude on the RoR. The following data are entered into Equation 1 and the results shown in Figure 4a:

W = 0.2507 degs/m Azimuth = 30° (held constant)  
 Latitude=35.449° Altitude = 0° to 90°

(Note: the Excel program is used for computations with Equation 1. The default value for angles in Excel is the radian, so all angles expressed in degrees are divided by 57.2958 degs/radian. The final answer is converted back to degrees.)

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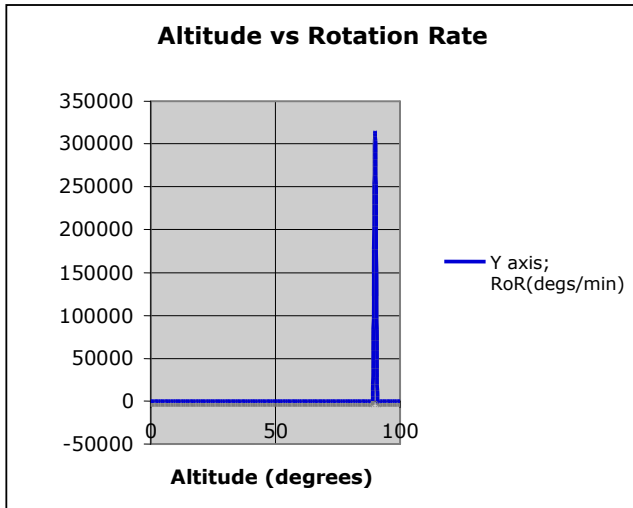


Figure 4a: Altitude vs Rotation Rate

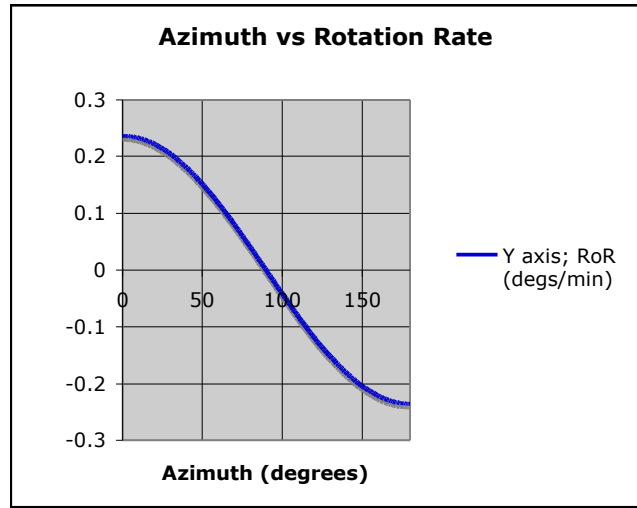


Figure 4b: Azimuth vs Rotation Rate

Table 1a: Altitude vs Rotation Rate

Altitude (degs)	RoR
10	0.1796
20	0.1882
50	0.2752
80	1.0185
88	5.0678
89	10.1339
90	314,900.2*

\*actual result is ∞

Table 1b: Azimuth vs Rotation Rate

Azimuth	Rotation Rate
10	0.2322
20	0.2216
50	0.1780
80	0.0410
88	0.0082
89	0.0041
90	1.32E-07*

\*actual result is 0.0000

Figure 4a shows the asymptotic increase in the rate as the altitude value approaches the zenith. Table 1a shows several examples of the RoR data from Figure 4a and how rapidly the rate changes at 90°. (At 90° the actual value of the RoR is infinity, but due to the fact that the graph is generated in 1° increments, the scaling and internal floating point generated by Excel shows a definite ending point (314,900.2 degs/min) rather than infinity.)

Just as the RoR takes a dramatic jump in value as the altitude value approaches the zenith at 90°, we see a similar dramatic drop in the RoR as the azimuth value approaches the prime vertical at 90°. (Again, considering the 90° azimuth value (due east), the actual value of RoR is zero. The graph is generated in 1° increments, so the scaling and internal

floating point generated by Excel shows a minimum RoR of  $1.32 \times 10^{-7}$  degs/min, where the value is actually zero. This is graphically shown in Figure 4b.) A similar effect is noted near 270°, or due west. Although the graph cannot accurately represent the asymptotic change in values, the computed values in the region near the azimuth of 90° are shown in Table 1b. As with the altitude vs rotation rate the values for W and latitude are the same. But here the altitude is held constant at 30° and the azimuth values are changed from 0° to 180° in 1° increments.

Again this demonstrates the advantage of making double star measurements along the prime vertical at 90° and/or 270° where the RoR is very small when using an alt-az mounted telescope.

In summary, the minimum RoR is observed at the

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horizon on the prime vertical (due east or due west); the maximum RoR is observed at the zenith.

The cosine value for the latitude in Equation 1 corresponds to the latitude of the observing site. At  $0^\circ$  latitude, the observation site is at the equator. So  $\cos 0^\circ = 1$  and  $W \times (1) = W$ , the Earth's rotation rate, and so the RoR of the star is governed by the cosine ratios of the azimuth and the altitude. As the latitude becomes greater, the cosine value decreases. At the NCP,  $\cos 90^\circ = 0$ , so

$$\text{RoR NCP} = (W \times (0) \times \cos \text{Az} / \cos \text{Alt}) = 0$$

### Goals

The purpose of this study is to compare theoretical rates of rotation obtained using Equation 1 with actual observed rates of rotation measured with the alt-az mounted telescope. If the comparison of values obtained using the two methods agree closely enough, then rates of rotation of double stars in subsequent studies could be calculated from altitude/azimuth/latitude measurements and the rate of rotation used to adjust the observed position angle to compensate for the rotation using the primary star as the fixed  $x=0$ ,  $y=0$  reference point.

### Locale and Instrumentation

Observations were conducted at the Coombs' Observatory in Atascadero, California on February 8, 2011 (Besselian epoch: 2011.10487). This site has been used for previous double star studies (Frey and Coombs, 2010). It is surrounded by large oak trees which shield the site from local city lights. The air was dry and a slight breeze would blow occasionally. The transparency was good, a slight amount of scintillation was present, and the temperature was in the middle 40's°F.

An 18" f/4.5 Obsession reflector on a Dobsonian mount equipped with a 12.5 mm Celestron Micro Guide astrometric eyepiece and an Orion "Shorty" 2x Barlow was used for all observations. Wildcat's Argo Navis computer was used to determine observed azimuth and altitude values on the Obsession telescope.

### Procedure

The 12.5 mm astrometric eyepiece was attached to the 2x Barlow lens. This assembly was inserted into the barrel of the focusing tube and all set-screws securely tightened. Astronomer Thomas Smith of Dark Ridge Observatory posed that any readjustment

of the eyepiece in the focusing tube during the observing session could result in a misalignment that could cause erroneous readings, especially when the observed rotations are quite small. As a result of this suggestion, the astrometric eyepiece-Barlow combo was not moved or readjusted during the session. No attempt was made to align the drift cycles to pass, say, through the  $0^\circ$  mark on the protractor scale.

The Obsession telescope was two-star aligned. The tracking motors WERE NOT ENGAGED throughout the observing session. All slewing and star-centering in the eyepiece was done manually.

The field rotation for each of five different stars was observed over the course of the evening. The telescope was manually moved so each individual star would pass through the central 30-division mark on the linear scale of the Celestron eyepiece and allowed to drift to the inner protractor scale. The initial alignment allowing the star to drift through the 30-division mark usually took 5-10 attempts. Once the successful drift has been initiated, the drift time to the inner scale was recorded. The observed drift time and change of angle was converted to an observed rate of rotation and compared to the rates of rotation obtained from Equation 1 for the same star, at that time and on that date.

### Data

#### *Theoretical Rates of Rotation for Hypothetical Alt-Az Values*

It would be helpful to know the approximate values of the RoR expected. Using Equation 1, RoR were calculated for a hypothetical star at four different altitudes, in each of the four directions. In this example, the Earth's rotation,  $W$ , used the value of  $2.507 \times 10^{-1}$  degrees/minute so the answers would be neither too large nor too small for comparison. The latitude used was that of the Coombs' Observatory,  $35^\circ 26' 56''$ . The data listed in Table 2 for altitudes 5, 45, 75, and 85 degrees altitude in all four directions are graphed in Figure 5.

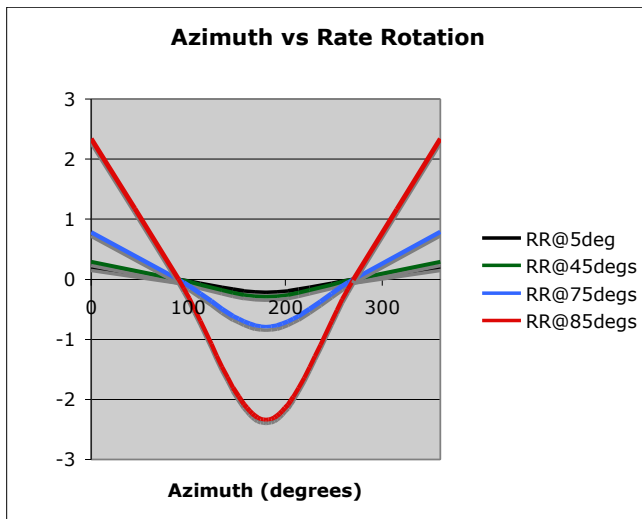
Values range from extremes of  $\pm 2.34$  degrees/minute when the star is N or S at the highest altitude of  $85^\circ$  to lowest values of  $-3.5 \times 10^{-7}$  degrees/minute when the star is in the west near the horizon at  $5^\circ$ . Also notice how the change in rotation is much more rapid as the altitude value approaches the zenith as noted in Figure 4a. The  $\pm$  values of the rates of rotation indicate either the clockwise (-) or counter clockwise (+) rotation as it appears in the eyepiece. This change in direction occurs as the star passes across

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**Table 2:** Azimuth Values Compared to Rates of Rotation (deg/min) for Four Different Altitudes

Alt (degs)	RoR@5deg	RoR@45deg	RoR@75deg	RoR@85deg
Az (degs)				
0	0.2050	0.2888	0.7891	2.3433
90	1.15148E-07	1.62224E-07	4.43204E-07	1.31614E-06
180	-0.2050	-0.2888	-0.7891	-2.3433
270	-3.45444E-07	-4.86672E-07	-1.32961E-06	-3.94842E-06
360	0.2050	0.2888	0.7891	2.3433

(Gamma Orionis), Pollux (Beta Geminorum), Dubhe (Alpha Ursae Majoris), Navi (Gamma Cassiopeiae), and Aldebaran (Alpha Tauri). All observations occurred on February 8, 2011, beginning at 6:27 PM and ending at 10:35 PM. The Argo Navis computer time clock was set to local time (Greenwich time, -8:00 hours) and the locale locked into the Coombs' Observatory (Latitude, 35° 26' 56.5"N, and Longitude, 120° 37' 09.6"W).



**Figure 5:** Azimuth Values Compared to Rates of Rotation (deg/min) for Four Different Altitudes

the prime vertical (due east or due west) where the sign of the cosine of the azimuth changes at zero rotation. The RoR values for azimuth 90° and 270°, which should be the same except for the minus sign, differ due to the internal floating point math utilized by Excel.

**Polaris Alignment Check; Measured and Computed Altitude-Azimuth Values Compared**

Five stars were involved in this study: Belletrix

**Table 3:** Argo Navis and SkyX Coordinate Changes in Polaris' Az-Alt Values

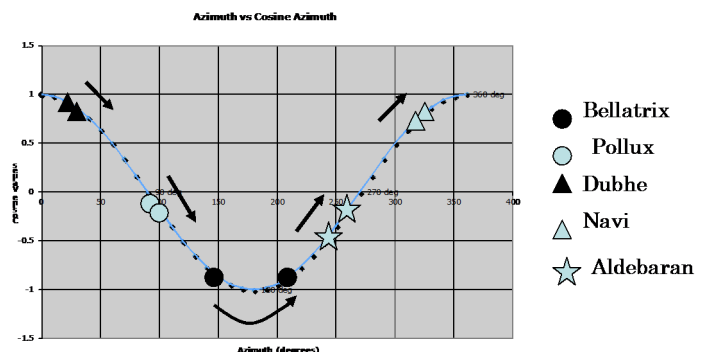
Time	Argo Navis Computer		SkyX Software	
	Az Value	Alt Value	Az Value	Alt Value
6:27PM	359° 41'	36° 01'	359° 48'	36° 07'
10:38PM	359° 01'	35° 35'	359° 11'	35° 36'
<b>Overall Change</b>	40'	26'	37'	31'

The telescope was two-star aligned. Eight checks on azimuth and altitude alignments with Polaris were carried out throughout the evening. Table 3 shows measured azimuth and altitude changes at the beginning and end of the session along with the SkyX computed values as an additional check.

A typical drift trial was carried out as follows: the telescope was manually moved so the star drifted through the 30-division mark of the linear scale of the Celestron eyepiece. At contact with the 30-mark, the stopwatch was started and the initial local clock time was recorded (i.e. 7:28 PM) to the nearest half minute. When the star made contact with the inner protractor scale, the stopwatch was turned off, the drift time recorded, and the angle on the inner scale recorded. This was repeated 7-8 times for each star.

**Experimental and Software Azimuth and Altitude Values for Five Stars**

Each of the five stars were examined for changes in azimuth and altitude using the Argo Navis computer over a period ranging from about 1 to 2.25 hours per star. The different stars were chosen for their magnitude and position in the sky. Attempts were made to observe stars on various segments of the cosine curve and measure their change in azimuth and altitude over time. These values were then used in Equation 1 to calculate the rates of rotation



**Figure 6:** Azimuth Cosine Value Changes for Five Stars

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**Table 4:** Experimental and Software Azimuth and Altitude Position Values For Five Stars

Star	Time	Argo Navis	Argo Navis	Argo Navis	SkyX	SkyX	% Difference	
		cosAz	Az	Alt	Az	Alt	Az	Alt
Bellatrix	7:28	-0.9324	158.817	59.367	157.942	59.15	0.554	0.367
	9:44	-0.7390	222.35	53.75	221.292	54.088	0.478	-0.625
Pollux	7:45.5	-0.0084	90.483	54.783	89.903	53.9	0.645	1.638
	8:35	-0.1504	98.65	64.467	98.325	63.977	0.331	0.766
Dubhe	8:05	0.8284	34.067	32.433	34.045	32.253	0.065	0.558
	10:03	0.8203	34.883	46.483	35.035	46.142	-0.434	0.739
Navi	9:05	0.8087	323.967	34.633	324.63	34.652	-0.204	-0.055
	10:11	0.8368	326.8	26.917	327.555	27.105	-0.230	-0.694
Aldebaran	9:28	-0.4271	244.717	55.883	243.857	56.41	0.353	-0.934
	10:35	-0.1857	259.3	42.967	258.863	43.442	0.169	-1.093

and eventually compared with the observed rates of rotation.

Figure 6 shows the approximate changes in cosine azimuth values for each of the five stars just to give the general indication of celestial location. The arrows by each set of data points indicate all positive changes in azimuth. Negative cosine values all correspond to clockwise rotations as seen through the eyepiece; positive cosine values correspond to counterclockwise rotations.

Error bars are not shown on Figure 6 because even a difference of only 0.1° in the azimuth value from the Argo Navis computer would only account for a difference in the cosine value of 0.001.

Comparisons were made between the azimuth and altitude readings obtained from the Argo Navis computer on the telescope and the software generated azimuth and altitude on TheSkyX set for the same locale, date, and time for the five stars illustrated in Figure 6. The data are shown in Table 4. Column 3 in Table 4 lists the cosine of the azimuth reading from the Argo Navis and is plotted in Figure 6. The last columns in Table 4 list the percent difference between the Argo Navis values and TheSkyX values. The formula used was

$$\% \text{ Difference} = \left( \frac{\text{experimental} - \text{The SkyX value}}{\text{The SkyX value}} \right) * 100\%$$

where experimental values are taken from the Argo Navis and TheSkyX values are obtained from TheSkyX program. All azimuth and altitude values in Table 4 are given in degrees.

**Calculated Rates of Rotation Compared to Observed Rates of Rotation for Five Stars**

It has been shown above that the experimental values for azimuth and altitude obtained from the Argo Navis computer on the Obsession telescope closely compares to those values generated from TheSkyX software program. Percentage differences ranges from absolute values of 0.055 to 1.093 percent. Given these comparisons, rates of rotation are calculated from Equation 1 using azimuth and altitude values from the Argo Navis computer and the SkyX program. The rates of rotation are then compared to those observed using the Obsession telescope, the astrometric eyepiece, and the 2x Barlow lens. The latitude is that of the Coombs' Observatory. All rates of rotation in Table 5 are given in degrees/minute.

Here's an example of how the observed rate of rotation was carried out using the Obsession telescope, Celestron eyepiece, and Barlow lens. Let's use Bellatrix as a model. At 7:32 PM the star drifted from the 30-mark on the linear scale to the inner protractor scale at 292°. At 7:44 the same procedure was used and the star crossed at 285°. The elapsed time was 12 minutes. The change in angle was 7°. The observed rate of rotation for this period was 7°/12 minutes = 0.58°/minute. This was repeated several times for each star. The results are shown in Table 5.

**Amount of Rotation Occurring During Drift Cycles**

The main reason this study was performed was to eventually determine if significant field rotation would occur during position angle measurements of

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**Table 5:** Calculated Rates of Rotation (Argo Navis and SkyX) Compared to Observed Rates of Rotation (Obsession/Astrometric Eyepiece) for Five Stars

Star	Time (PST)	Rates of Rotation (Calculated)		Observed Rates of Rotation (Obsession)					
		Argo Navis	The SkyX	Time Duration	Angles (deg)	Rate (deg/min)			
Bellatrix	7:28	-0.3741	-0.3695	7:32	292	0.583			
	9:44	-0.2555	-0.2619	7:44	285				
				7:44	285	0.367			
				8:27.5	269				
						8:27.5	269	0.344	
							9:43	243	
Pollux	7:45.5	-0.0030	-0.0006	7:50	343	0.100			
	8:35	-0.0713	-0.0675	8:00	342				
				8:00	342	Undef.			
				8:43	342				
						8:43	342	0.360	
						9:58	315		
Dubhe	8:05	0.2006	0.2003	8:12	352	0.286			
	10:03	0.2436	0.2416	8:19	354				
				8:19	354	0.146			
				8:43	357.5				
						8:43	357.5	0.253	
						10:02	17.5		
Navi	9:05	0.2009	0.2026	9:07	198	0.231			
	10:11	0.1918	0.19323	9:20	201				
				9:20	201	0.180			
				10:10	210				
Aldebaran	9:28	-0.1557	-0.1628	9:32	227	0.250			
	10:35	-0.0519	-0.0544	9:40	225				
				9:40	225	0.152			
				10:13	220				
						10:13	220	0.048	
						10:34	219		

**Table 6:** Observed Rotation During Drift Times for Three Stars

Star	Time	Angle	RoR (°/min)	No. Drift Trials	Ave Drift Time	Amount of Rotation
Bellatrix	7:32	292				
	7:44	285	0.583	7	11.63 sec	0.113°
Dubhe	8:12	352				
	8:19	354	0.286	8	24.55 sec	0.117°
Aldebaran	9:40	225				
	10:13	220	0.152	8	12.32 sec	0.031°



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double stars. Would there be enough rotation to significantly alter the experimentally determined position angle? Drift times are usually quite short. The range of drift times for the five stars studied was about 12 to 25 seconds. Three examples are given in Table 6 that show the amount of rotation that occurred for the star during the drift time. Seven to eight trials were carried out for each star and the average drift time determined. Using an observed RoR (degs/minute) from Table 5 and applying the average drift time to these values, the amount of rotation during the drift time was determined. For example, the RoR for Belletrix from 7:32 to 7:44 was 0.583 °/min. So

$$\begin{aligned} \text{rotation during drift} &= \left( \frac{0.583^\circ}{1 \text{ min}} \right) \left( \frac{1 \text{ min}}{60 \text{ sec}} \right) (11.63 \text{ sec}) \\ &= 0.113^\circ \end{aligned}$$

This is the key data showing that the RoR associated with short time intervals and the instrumentation used for empirical data collection in this study has a fairly large inaccuracy in measurement precision.

As can be seen from these few instances, the amount of field rotation is on the order of 0.1° or less during the drift. Since the Celestron Micro Guide eyepiece is calibrated to the nearest 5°, these changes would not be detectable with the astrometric eyepiece assembly used in this study.

**Discussion**

The azimuth and altitude values obtained from both the Argo Navis computer and from TheSkyX program were fairly close indicating the telescope was properly aligned and the computer had the correct input for location and local time. All percent differences between the Argo Navis and TheSkyX azimuth and altitude values were less than ±1.1% except for Pollux where the percent difference between altitude measurements at 7:45.5 PM was 1.64%. This could be an anomalous Argo Navis reading or due to the fact that Pollux was just emerging from the prime vertical where the rate of rotation is essentially zero due to the dramatic change at 90°.

When the azimuth and altitude values obtained from both sources were used to calculate the rates of rotation in degrees per minute, most of the values, when compared, were very close as seen in Table 7. The percent agreement is given by:

**Table 7:** Comparison of RoR Values Obtained from Argo Navis and SkyX Azimuth and Altitude Data

Star	Time	RoR AN	RoR SkyX	% Agreement
Bellatrix	7:28	0.374	0.370	101.1
	9:44	0.256	0.262	97.7
Pollux	7:45.5	0.003	0.001	300.0
	8:35	0.071	0.068	104.4
Dubhe	8:05	0.201	0.200	100.5
	10:03	0.244	0.242	100.8
Navi	9:05	0.201	0.203	99.0
	10:11	0.192	0.193	99.5
Aldebaran	9:28	0.156	0.163	95.7
	10:35	0.052	0.054	96.3

$$\text{percent agreement, RoR}_{AN, SkyX} = \left( \frac{\text{RoR}_{AN}}{\text{RoR}_{SkyX}} \right) \times 100\%$$

where absolute values of the rates of rotation from Table 5 were used in the calculation.

Values greater than 100% imply the RoR determined from Argo Navis had a greater value than that of TheSkyX. Nine of the ten percent agreements ranged from 95.7% to 104.4%; about a 9% difference. The anomaly was the data for Pollux at 7:45.5 PM where the percent agreement was 300%, indicating a much larger RoR from the telescope measurements. This might be explained by the fact that Pollux is just passing through the prime vertical, so the RoR will be very low and the altitude values of approximately 54° will also contribute to a fairly low RoR. Slight changes in such low values of RoR could lead to substantially large changes in the percentage. For example, if TheSkyX RoR were only 0.001 greater (0.002 instead of 0.001), the percent agreement would change from 300% to 150%. Data from Table 1b verifies the dramatic change in RoR over a 1-2° range.

When calculated values of RoR were determined from Argo Navis or TheSkyX, only single azimuth and altitude readings were used. This is a case of putting all of your eggs in one basket. Experimental measurements should always be carried out in multiple trials, and averages used in computations. In the present

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**Table 8a:** Calculated and Observed Rates Compared

Star	Time	Rate of Rotation Calculated		Observed Rotation		
		ArgoNavis	SkyX	Times	Angles	Rate
Bellatrix	7:28	-0.374	-0.370	7:44	285	
				8:27.5	269	-0.367
Aldebaran	9:28	-0.156	-0.163	9:40	225	
				10:13	220	-0.152

**Table 8b:** Calculated and Observed Rates Compared

Star	Time	Rate of Rotation Calculated		Observed Rotation		
		ArgoNavis	SkyX	Times	Angles	Rate
Pollux	7:45.5	-0.003	-0.0006	7:50	343	
				8:00	342	0.100
Bellatrix	7:28	-0.374	-0.370	7:32	292	
				7:44	285	0.538

study, as time elapses, azimuth and altitude values continually change resulting in different values for RoR. This makes it difficult to compare calculated values with observed RoR obtained with the Obsession, where a definite elapsed time is required. This elapsed time could be as short as the drift time from the center of the reticle eyepiece to the protractor scale (~0.1 to 1.0 minutes) or greater than a minute if the star is close to the prime vertical and/or at the horizon.

Examples of observed RoR are given in Table 5. In many cases the observed RoR is fairly close to the calculated values from the Argo Navis or the SkyX. See Table 8a. Other observed RoR are greatly different from the calculated values. See Table 8b.

To be sure the experimental values represent the actual data, a series of readings should be taken. The

telescope should be centered on a star, the reading of azimuth and altitude recorded, the telescope moved off center, re-centered, and another set recorded. This technique should be done a minimum of 3-4 times, as close together in time as possible, since the values will be constantly changing. Averages should then be used to determine the azimuth and altitude and in turn used to calculate the RoR.

A similar technique should be used for direct observation of RoR. This, again, has the inherent problem of low resolution of the Celestron Micro Guide eyepiece that is only graduated in 5° increments. Extensive estimation is required for these measurements and only crude estimates are possible when small changes occur in rotation. So a reading of 242° might also be read as 241° or 243° due to the presence of some parallax. This is especially true in regions near the prime vertical, at the horizon, where RoRs are small or near the zenith where RoRs are large.

**Conclusion**

The purpose of this study was to become acquainted with the phenomenon of field rotation observed in az-alt mounted telescopes. Attempts have been made to compare the calculated values of rates of rotation of stars at different sky positions using computer data with observed rates of rotation using an astrometric eyepiece. To ensure the validity of the results, the following steps were conducted on the five stars Bellatrix, Pollux, Dubhe, Navi, and Aldebaran.

1. Azimuth and altitude values from an Argo Navis computer on the Obsession telescope were compared with azimuth and altitude values generated from TheSkyX software, the latter being set for the correct latitude, date, and time. The percentage differences between the two methods never exceeded 1.09% as seen in Table 4.
2. The telescope was manually slewed to Polaris

**Table 9:** Calculated and Observed Rates of Rotation Compared and % Difference

Star	Time (PST)	Argo Navis RoR (deg/min)	Time Duration (min)	Observed RoR (deg/min)	%Difference
Bellatrix	7:28	-0.374	43.5	-0.367	-1.87
Aldebaran	9:28	-0.156	33	-0.152	-2.56
Pollux	07:45.5	-0.003	10	0.1	-3433.33
Bellatrix	7:28	-0.374	12	0.538	-243.85

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eleven times during the study. The azimuth and altitude values from the Argo Navis computer were recorded. TheSkyX values for azimuth and altitude for each of the eleven time slots were recorded. The differences in their values never exceeded 40 minutes of arc as seen in Table 3, indicating the telescope had a good alignment throughout the study.

3. Rates of rotation were calculated with Equation 1 for the five stars using the azimuth and altitude data collected from both the Argo Navis computer and values obtained from TheSkyX database. These are shown in Table 5. The percentage agreement between the two calculated rates of rotation are shown in Table 7. Nine of the ten calculated percentage agreements were within a range of about 9%.
4. The calculated rates of rotation were compared to some of the observed rates of rotation. Some of the rates were very close; others had large differences as seen in Table 9. The percent difference formula used was

$$\% \text{ Difference} = ((\text{observed} - \text{Argo Navis value}) / \text{Argo Navis value}) \times 100$$

Many of the differences between calculated and observed rates of rotation can be traced to a time duration problem. For calculated rates of rotation, a specific time exists for specific azimuth and altitude values. For observed rates of rotation, the azimuth and altitude values are constantly changing and, therefore the rate itself is changing. Slower rotation results for stars close to the horizon and/or close to the prime vertical (east or west). Faster rotation results for stars close to the zenith and/or close to northern or southern directions. But to determine an observed rate, a specific amount of time must pass between angle measurements using the astrometric eyepiece. An additional limitation to accuracy is the 5° graduations along the protractor scale, meaning estimated measurements would be in the 1° range.

This study was done as a prequel to double star measurements where field rotation is posited to adversely affect position angle measurements. The next step is to carry out a number of position angle meas-

urements of double stars, in various sky locations, with well known, fixed position angles. This should then be compared with measured position angles with the most recent literature values. If they differ, calculate the rate of rotation for the double star using data from the telescope computer or TheSkyX. Apply this rate of rotation to the drift time of the double star and see how much it changes the measured position angle. That is, does the modified position angle more closely approach the accepted literature? If it does, then this might be a tool that can be used to improve az-alt determined measurements. However, examples shown in Table 5 indicate these changes will probably be too small to detect with the instruments used in this study. Yet, the study needs to be carried out.

## References

- Argyle, Robert, *Observing and Measuring Visual Double Stars*, Springer, London, 2004.
- Covington, Michael A., Piggyback Astroimaging, Astronomy, March, 2011.
- Frey, Thomas G., Coombs, Lee C., Fall 2010, *Journal of Double Star Observations*, 6(4), p. 261.
- Keicher, Bill, Mathematics of Field Rotation in an Altitude over Azimuth Mount, AstroPhoto Insight, September, 2005.
- TheSkyX software: <http://www.bisque.u-strasbg.fr/simbad/>
- Schmidt, Gary D., Pointing/Derotator Coalignment for Alt-Az Telescopes, Internal Technical Memorandum #04-1, MMT Observatory, May, 2004.
- Smith, Thomas, personal communication, 2010.

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