

# Astrometric Measurements of Five Double Stars

Joseph M. Carro

Cuesta College  
San Luis Obispo, California

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**Abstract:** From my home in Paso Robles, California, measurements of the separation and position angle of five double stars were made. The five double stars were Eta Cassiopeiae, Gamma Andromedae, Lambda Arietis, Psi 1 Piscium, and Zeta Piscium. The two goals of this project were to 1) measure the position angle and separation of the aforementioned double stars, and 2) learn the necessary techniques to conduct this research.

## Methodology

My observations were made from my home in Paso Robles, California (located at approximately 35°37'36" N and 120°41'24" W) using a Celestron model CPC 1100 telescope. The telescope is computerized, motorized, and was fitted with a Celestron MicroGuide 12.5mm astrometric eyepiece. The telescope is of Schmidt-Cassegrain design, with aperture of 11 inches on an alt-azimuth mount. The manufacturer reports a focal length of 2,800 mm.

The Micro Guide eyepiece was oriented with the celestial coordinate system using the primary star of the double star under study or a bright star. The primary star was positioned on the mark 30, the drive was disabled, and the star was permitted to drift to the outer circle. The scale was rotated until the star lay on the 270 degree mark. The accuracy of this setting was verified by positioning the primary star on the 90 degree mark of the outer circular scale, and allowing the star to drift to the 270 degree mark.

Following the orientation, drift times were measured by placing the primary star on the 0 mark of the linear scale, and measuring the drift time from the 0 to the 60 mark using a stop watch precise to +/- 0.01 seconds. Measurements were made, and the average drift time was calculated. That average was used to calculate the scale constant Z, using the for-

mula (Frey 2008)

$$Z = \frac{(15.0411)T_{ave} \cos(\delta)}{D}$$

where  $D$  is the number of reticle divisions

Separation measurements were made by placing the pair of stars on the linear scale at the zero mark, and then counting the number of scale divisions between the stars. Because the scale has 60 divisions, it was only possible to estimate to the nearest  $\frac{1}{4}$  division. After each measurement, the double star was repositioned to the next major division. Measurements were made, and an average and standard deviation were calculated.

The position angle measurements were made by aligning both stars on the linear scale with the primary star at the 30 division, disabling the tracking feature, and then allowing the stars to drift to the circular scales. The crossing of the primary star at the outer scale was approximated to the nearest degree as the scale has divisions of 5°. Following each measurement, the tracking feature was enabled and the process was repeated. As recommended by Frey (2008), the eyepiece was rotated 180° every other measurement to help reduce bias.

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### Eta Cassiopeiae - Introduction

Eta Cassiopeiae was first determined to be a double star by William Herschel in the year 1799<sup>27</sup>. This double star consists of a primary star, Eta Cas  $\alpha$ , a yellow-orange star of magnitude 3.4, and Eta Cas  $\beta$ , an orange dwarf of magnitude 7.5. The right ascension of the double star is 00h 49m 06s, and its declination is +57° 48' 54"<sup>27</sup>. The proximity of this double star and the resemblance of Eta Cas A to our Sun (yellow-orange primary G3 V, 110 percent of Sun's mass, equal diameter, 1.2 times the luminosity) made it an interesting object for study (Popper 1980). Eta Cassiopeiae has been included in a study conducted by NASA in which a search for planets will be conducted (Terrestrial Planet Finder Project, 2010). It has catalog designations of 24 Cas, BD +57 150,  $\eta$  Cas, HD 4614, HIP 3821, HR 219, SAO 21732, and WDS 00491+5749A. It is also known by its traditional name of Achird.

### Eta Cassiopeiae - Observations

The measurements were made on 7 December 2010 (Bessell date 2010.934) beginning at 9:40 pm Pacific Standard Time. The night was clear and calm, and there was no moon.

The linear scale of the Micro Guide eyepiece was oriented with the celestial coordinate system using the star Alderamin. Once the orientation was completed, 18 drift time measurements were made, with an average value of 52.09 seconds, a standard deviation of 0.99 seconds, and a standard error of the mean of 0.23 seconds. The result was a scale constant of 6.9 arc seconds per division.

The primary star was placed on the linear scale, and 15 separation measurements were taken. The primary star was relocated and advanced on the linear scale prior to each measurement. The average value was 1.9 divisions with a standard deviation of 0.138 divisions, and a standard error of the mean of 0.04 divisions. The calculated separation was 13.1 arc seconds, which corresponded well with the value reported by Frey (2008) of 12.9° +/- 1.93° with an SEM of 0.97°.

The position angle measurements were made by aligning both stars on the linear scale with the primary star at the 30° division, disabling the tracking feature, and then allowing the stars to drift to the circular scales. The crossing of the primary star at the outer scale was approximated to the nearest degree as the scale has divisions of 5°. Following each measurement, the tracking feature was enabled and the process was repeated. Twelve position angle measurements were taken with an average value of 319°, a standard deviation of 2.0°, and a standard error of the mean of 0.17°.

A summary of recent measurements of  $\eta$  Cass is presented in Table 1.

### Gamma Andromedae - Introduction

Known since ancient times, the constellation Andromeda is a large constellation with an area of 722 square degrees, and is the location of the Andromeda Galaxy, the most distant object visible without the use of instruments.

Gamma Andromedae was first determined to be a double star by Johann Mayer in the year 1778 (Worley, 2006). This double star consists of a primary

**Table 1:** Separation (in arc seconds) and Position angle (in degrees) for Eta Cassiopeae

Reference name	Sep	PA
The Bright Star Catalogue (Hoffleit 1991)	11.6"	315°
Smithsonian Astrophysical Observatory (Staff 1996)	12.2"	315°
Sky Master 2000 Catalog (Meyers, 2002)	12.2"	315°
Kochab Observatory* (Koch 2005)	12.6"	317.3°
Washington Double Star Catalog* (Worley 2006)	12.6"	318.8°
Journal of Double Star Observations (Daley 2006)	12.9"	318.9°
<i>Measurements by the author 2011</i>	13.1"	319°

\* For the years 2003 through 2006, the position angles and separations reported in the Washington Double Star Catalog were 318.7°, 320.3°, 318.9°, and 317.3° (mean = 318.8°, st.dev. = 1.23°), and 13.0, 12.8, 12.9 and 12.6 (mean = 12.8; st.dev. = 0.17) arc seconds, respectively. The values from Kochab Observatory are the average of 16 measurements made during the year 2005.

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star, Gamma Andromedae A, a golden yellow star of magnitude 2.3, and Gamma Andromedae B, a blue star of magnitude 5.5. They are located about 350 light years from Earth. In 1842 Otto Struve discovered that Gamma Andromeda B is a triple star, and thus what appears to be a double star is actually a quadruple system (Maestre, 1960).

The right ascension of the double star is  $2^{\text{h}} 3^{\text{m}} 54^{\text{s}}$ , and its declination is  $+42^{\circ} 19' 47''$  (Worley, 2006). Gamma Andromedae has catalog designations of ADS 1630A, BD+41°395, CCDM J02039+4220A, HD 12533, HIP 9640, SAO 37734, STF 205, and WDS 02039+4220A. Gamma Andromedae is also known by its common name Almach, the Arabic word for the desert lynx.

### Gamma Andromedae - Observations

The measurements were made on 11 February 2011 (Bessell date 2011.115) beginning at 7:10 pm and ending at 9:4 pm PST. The night was clear and calm, and the temperature was 52-45 °F. The moon was 1/2 full.

Once the MicroGuide eyepiece orientation was completed, 12 drift time measurements were made, with an average value of 36.94 seconds, a standard deviation of 0.58 seconds, and a standard error of the mean of 0.17. The result was a scale constant of 6.8 arc seconds per division.

The primary star was placed on the linear scale, and 12 separation measurements were taken. The primary star was relocated and advanced on the linear scale prior to each measurement. The average value was 1.4 marks with a standard deviation of 0.2 marks and a standard error of the mean of 0.27. The

average value was used to calculate the separation, which was 9.5 arc seconds. This value corresponded well with the published separation angle of 9.6 arc seconds reported in the WDS (Worley 1996).

Twenty-four position angle measurements were taken with an average value of  $63^{\circ}$ , a standard deviation of  $1.5^{\circ}$ , and a standard error of the mean of  $0.28^{\circ}$ . (The Bright Star Catalog lists only the separation of 9.6 arc seconds.) (Cvetkovic, 2007)

Table 2 shows recent measurements of  $\gamma$  Andromedae.

### Lambda Arietis - Introduction

Lambda Arietis was first determined to be a double star by William Herschel in the year 1799<sup>27</sup>. This double star consists of a primary star, Lambda Arietis A, a yellow-white star of magnitude 4.9, and Lambda Arietis B, a blue-white star of magnitude 7.4. They are located about 133 light years from Earth. The right ascension of the double star is  $01^{\text{h}} 57^{\text{m}} 56^{\text{s}}$ , and its declination is  $+23^{\circ} 35' 46''$ <sup>27</sup>.

Lambda Arietis is located in the constellation Aries which has an area of 441 square degrees and which has at least four stars with planets. This double star has catalog designations of 9 Arietis, ADS1563, BD22°228, CCDM 01580+2336, HD 11973, HIP 9153, HR 569, SAO 75051, and WDS 01579+2336A.

### Lambda Arietis - Observations

The night of 16 January 2011 (Bessell date 2011.044) was clear with no wind and the temperature was 55-50 °F. Moon rise occurred at 7:54pm so there was little impact even though the moon was 2/3

**Table 2:** Separation (in arc seconds) and position angle (in degrees) for  $\gamma$  Andromedae

Reference name	Sep	PA
Sky Master 2000 Catalog (Meyers, 1997)	9.6"	63°
Journal of Double Star Observations (Arnold 2006)	9.88"	63.5°
Washington Double Star Catalog (Worley, 2006)	9.6"	63°
Journal of Double Star Observations (Schlimmer 2007)	9.45"	62.9°
Journal of Double Star Observations (Martín 2009)	9.11"	62.5°
Journal of Double Star Observations (Anton 2010)	9.48"	62.8°
Coldfield Observatory 2011	9.8"	63°
Hipparcos/Tycho Catalogue 2011	9.6"	63°
Measurements by the author 2011	9.5"	63°

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full. The session began at 6:40pm and ended at 9:50pm Pacific Standard Time.

Once the MicroGuide eyepiece orientation was completed, 12 drift time measurements were made, with an average value of 30.66 seconds, a standard deviation of 0.19 seconds and a standard error of the mean of 1.05. The result was a scale constant of 7.06 arc seconds per division.

The primary star was placed on the linear scale, and 10 separation measurements were taken. The average value was 5.4 marks with a standard deviation of 0.105 marks and a standard error of the mean of 0.03. The average value was used to calculate the separation, which was 38.1 arc seconds. This value corresponded well with the published separation angle of 38.5 arc seconds reported in the WDS (Worley 2006).

Thirty position angle measurements were taken with an average value of 48°, a standard deviation of 2.2°, and a standard error of the mean of 0.40°. The position angle and separation correspond well with the respective values of 47° and 38.5 arc seconds with the published values.

Recent measurements of  $\lambda$  Arietis are given in Table 3.

#### Psi Piscium - Introduction

The constellation Pisces (meaning *fishes*; Latin plural of the third declension noun *piscium*) has been known since ancient times, and it is one of the constellations of the Zodiac (the circle of animals). The constellation is large (889 square degrees) but dim, having no star with a magnitude greater than 3.7. Pisces is visible from both the northern and southern

hemispheres. The double star Psi 1 Piscium consists of a pair of blue-white stars having reported magnitudes of 5.3 - 5.6 and 5.5 - 5.8 (Worley 2006). The double star has catalog designations of 74 Psc, HD 6456, HIP 5131, HR 310, SAO 74482, STF 88, and WDS 01057+2128A.

#### Psi Piscium - Observations

These measurements were made on 26 December 2010 (Bessell date 2010.985), beginning at 8:40 pm and ending at 10:40 pm Pacific Standard time. The night was clear and calm. Moonrise occurred at 11:20 pm so there was no impact though the moon was 2/3 full.

Once the MicroGuide eyepiece orientation was completed, 18 drift time measurements were made, with an average value of 29.91 seconds, a standard deviation of 0.29 seconds and a standard error of the mean of 0.07. The result was a scale constant of 6.95 arc seconds per division.

The primary star was placed on the linear scale, and 10 separation measurements were taken. The primary star was relocated and advanced on the linear scale prior to each measurement. The average value was 4.4 divisions with a standard deviation of 0.1 divisions and a standard error of the mean of 0.31. The average value was used to calculate the separation, which was 30.6 arc seconds.

Twenty-five position angle measurements were taken with an average value of 159°, a standard deviation of 1.5°, and a standard error of the mean of 0.3°. The average value of 159° corresponds well with the published values.

Table 4 gives recent measurements of  $\psi$  Piscium.

**Table 3:** Separation (in arc seconds) and Position angle (in degrees) for Lambda Arietis

Reference name	Sep	PA
Bright Star Catalog (Hoffleit, 1991)	37.4"	-
Sky Master 2000 Catalog (Meyers, 1997)	38.5"	47 °
Saguaro Astronomy Club 2001	38.5"	47 °
Journal of Double Star Observations(Vollmann 2006)	36.7"	47 °
Washington Double Star Catalog (Worley, 2006)	38.5"	47 °
American Association of Variable Star Observers 2011	37"	46°
Measurements by the author 2011	38.1"	48 °

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**Table 4:** Separation (in arc seconds) and Position angle (in degrees) for Psi Piscium

Reference name	Sep	PA
Bright Star Catalog (Hoffleit 1991)	29.9"	-°
SKY Master 2000 Catalog (Meyers 1997)	30"	159°
Washington Double Star Catalog (Worley 2006)	30"	159°
Journal of Double Star Observations (Arnold 2008)	29.6"	159.3°
Journal of Double Star Observations (Anton 2010)	29.7"	159.3°
<i>Measurements by the author 2010</i>	30.6"	159°

### Zeta Piscium - Introduction

This double star consists of a primary star, Zeta Piscium A, a blue-white star of magnitude 5.2, and Zeta Piscium B, a white star of magnitude 6.2. They are located about 200 light years from Earth. The right ascension of the double star is 1<sup>h</sup> 13<sup>m</sup> 44<sup>s</sup>, and its declination is +07° 34' 31" (Worley, 2006). Zeta Piscium is located in the constellation Pisces and has catalog designations of ADS996, BD+06°174, CCDM J01137+0735, HD 7344, HIP 5737, HR 361, SAO 109739, and WDS 01137+0735.

### Zeta Piscium - Observations

These measurements were made on 23 January 2011 (Bessellian 2011.063) beginning at 7:04 pm and ending at 8:30 pm Pacific Standard Time. The night was clear and calm with temperatures from 55 – 45°F. Although the moon was full, moonrise (10:18 pm) occurred after the measurements were taken.

Once the MicroGuide eyepiece orientation was completed, 11 drift time measurements were made,

with an average value of 27.27 seconds, a standard deviation of 0.64 seconds and a standard error of the mean of 0.19 seconds. The result was a scale constant of 6.76 arc seconds per division.

The primary star was placed on the linear scale, and 12 separation measurements were taken. The primary star was relocated and advanced on the linear scale prior to each measurement. The average value was 3.5 divisions with a standard deviation of 0.21 divisions and a standard error of the mean of 0.06 divisions. The average value was used to calculate the separation, which was 23.7 arc seconds. This value corresponded well with the published separation angle of 23.6 arc seconds reported in the WDS (Worley 2006).

Twenty-four position angle measurements were taken with an average value of 62°, a standard deviation of 1.1°, and a standard error of the mean of 0.20°. The position angle value corresponds well with published values, see Table 5.

**Table 5:** Separation (in arc seconds) and Position angle (in degrees) for Zeta Piscium

Reference name	Sep	PA
SKY Master 2000 Catalog (Meyers 1997)	22.9"	63°
Saguaro Astronomy Club 2001	23.0"	63°
Washington Double Star Catalog (Worley 2006)	23.6"	63°
Hipparcos Catalog (van Leeuwen 2007)	23"	63°
Serbian Astronomical Journal (Cvetkovic 2007)	22.5"	63°
<i>Measurements by the author 2011</i>	23.7 "	62°

Curiously, two references gave different values for the position angle, namely the Internet Astronomer Catalog (2011) where the value was 60 degrees and the International Variable Star Index (2011) where the value was 65 degrees.

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*Joseph Carro (BS, MBA) is an instructor at Cuesta College where he teaches a variety of subjects. He lives in Paso Robles, California, and works with Dr. Russell Genet on the measurement of double stars. His interest in Astronomy began in 2003, and his current project is to measure "neglected stars".*