Binary Stars

(Rob Horvat)

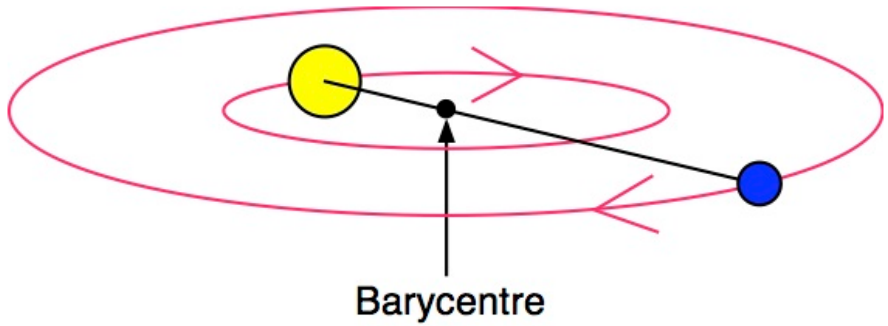
Almach (gam And)

Mesarthim (gam Ari)

Above images by Professor F. Ringwald, California State University, Fresno.
Taken as video with a Phillips Toucam II and processed with Registax.

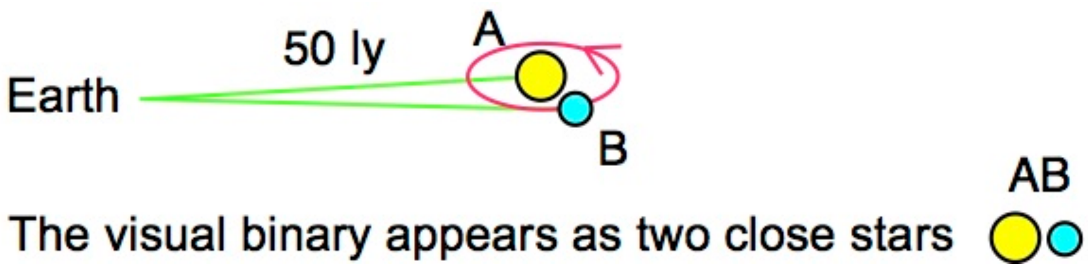
What is a Binary Star?

Conceptually, a **binary star** is a system of two stars orbiting around a common centre of mass. The term “binary” was first used in reference to stars by William Herschel in 1802.



By apparent magnitude, the brighter star is referred to as the primary component (A), the dimmer star as the secondary component (B). Binary stars that can be resolved (split) with a telescope are referred to as **visual binaries**.

Observations of the B component over time will describe an apparent elliptical orbit of B around the A star. For most of the known visual binaries the period of orbit is in hundreds or thousands of years and only a small arc of the orbit has been observed.



Some Better Known Binary Stars

Designation	Name	Spectral Types	Vmag1	Vmag2	Sep	Period
Alp Cen AB	Rigil Kent	G2/K1	0	1.3	5.1”	79.9
Alp 1,2 Cru	Acrux	B1/B1	1.3	1.8	4”	>1500
Alp Gem AB	Castor	A1/A2	2	2.9	4.5”	440
Alp Her AB	Rasalgethi	M5/G5	3.4	5.3	4.8”	~3600
Gam 1,2 And	Almach	K3/B8	2.3	5	9.5”	?
Gam 1,2 Ari	Mesarthim	B9/B9.5	3.9	3.9	8”	>5000
Gam 2,1 Del		K1/F7	4.4	5	12.1”	~3200
Gam 1,2 Leo	Algieba	K1/G7	2.2	3.4	4.4”	>500
Gam Vir AB	Porrima	F0/F0	3.5	3.6	1.9”	169
Rho Oph AB		B2/B2	4.6	5.3	3”	>2000
36 Oph AB		K0/K1	4.3	4.3	5”	470
61 Cyg AB		K5/K7	5.2	6	31”	650

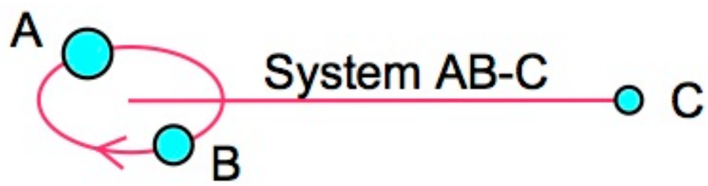
Note the similarities in spectral type for many of those listed in the table.
The period of orbit is in years.

Multiple Star Systems

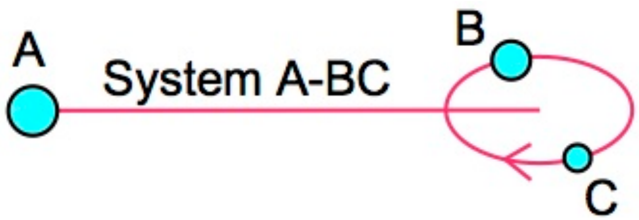
If three or more stars are close to each other in the sky they are referred to as a multiple star. If the stars are gravitationally bound to each other they become a **multiple star system**. The stars in a system should be moving through space together.

Larger systems (typically 12 to 20 light years across) would be referred to as star clusters.

A triple star system in which A and B orbit each other, with a more distant component C orbiting the AB pair, would be designated AB-C.



A triple star system in which B and C orbit each other, with BC orbiting a more distant component A, would be designated A-BC.



Close Binary Stars

Some stars are so close that they cannot be split visually.
They are detected **spectroscopically** (a doplar shift in the spectral lines of the stars is measured as they move towards or away from us in their orbits), **photometrically** (a periodic change is measured in the light curve of an eclipsing binary) or **astrometrically** (a periodic deviation or wobble in the primary's position is measured due to an unseen companion). The latter two methods can also be used to detect exoplanets.

The close components of the primary star A are labelled Aa and Ab. If the primary has a visual companion B that is also a spectroscopic binary then each component of B would be labelled Ba and Bb. The star Castor is such an example. It actually has 3 visual components, each of which is a spectroscopic binary. Castor C is an eclipsing binary.

Designation	Name	Spectral Types	Vmag	Distance Apart
Alp Gem AaAb	Castor A	A1/M5 dwarf	2	0.12 AU
Alp Gem BaBb	Castor B	A2/M2 dwarf	2.9	0.03 AU
Alp Gem CaCb	Castor C	M1/M1 dwarfs	9.1-9.6	0.018 AU

In comparison, the planet Mercury is about 0.4 AU from the Sun.

Semi-detached Binaries

Beta Lyrae is an example of a **semi-detached binary**. The primary A is a B7 type star and the secondary probably also a B-type star. The brighter less massive A component was once the more massive of the pair. As the star evolved into a giant, expanding beyond its Roche Lobe, it transferred much of its mass to its companion.

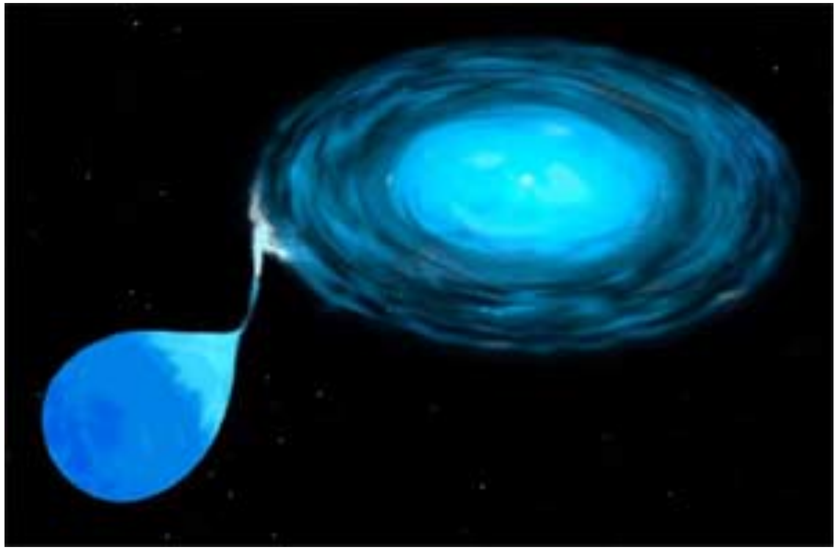


Image courtesy of NASA

The secondary, now the more massive of the two, is surrounded by an accretion disk and a perpendicular bipolar jet. Component A is about 2.8 solar masses, component B about 12.8 solar masses.

Wide Binaries

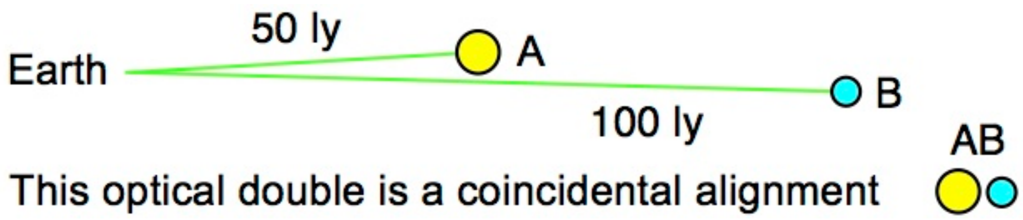
The descriptions **binary or multiple star** can also be given to stars where orbital rotation has not been detected. The stars are measured as being at similar distances and with having the same proper motion through space. The orbital period is calculated from their approximate masses and distances apart.

$T = 2\pi(a^3/(G(M_1+M_2)))^{1/2}$, where "a" is the mean distance between the two stars. M1 and M2 are the masses of each component star.

Designation	Name	Spectral Types	Vmag1	Vmag2	Sep	Period
Bet 1,2 Cap		K0/B9.5	3.1	6.2	205"	>700000
Bet 1,2 Tuc		B9/A2	4.3	4.5	27"	>155000
Eps 1,2 Lyr		A3/A7//A5/A5	5	5.9	208"	>100000

Double Stars

A double star may be a binary star or just an optical double. An **optical double** is a pair of stars that look close together in the sky but whose components are in fact too far apart to be in the same system.



Gamma Crucis (Gacrux) is an optical double. The A and B components are separated by 111”. The primary (A) is 88.6 light years away. The secondary (B) is believed to be roughly four times further away.

Designation	Name	Spectral Types	Vmag	Distance
Gam Cru A	Gacrux	M3.5	1.6	88.6 ly
Gam Cru B		A0	6.4	400 ly

The Washington Double Star Catalog (USNO) contains over 100,000 pairs of double stars. Orbits are only known for a few thousand of them. For most of the rest, it is not known whether they are true binary stars or just optical doubles.

Albireo (beta Cygni)

Photo: wikipedia

Albireo is one of the finest and best known doubles in the whole sky.
It has orange (K3) and blue (B8) stars of magnitudes 3.2 and 4.7.
The A and B components are separated by a wide 35 arcseconds.

At about 400 light years distance, it is not known whether the A and B components orbit each other. If they do, their period is more than 75000 years.

Number of Binaries

Surveys for binary stars have suggested that binary star frequency may be a function of spectral type (e.g., Fischer & Marcy 1992).

Charles Lada of the Harvard-Smithsonian Center for Astrophysics concluded from a study in 2006 that most stellar systems formed in the galaxy are likely single and not binary as previous believed.

Among very massive stars, known as O- and B-type stars, 80 percent of the systems are thought to be multiple, but these hot stars are comparatively rare.

Slightly more than half of all sun-like (G-Class) stars are multiples.

However, only about 25 percent of red dwarf stars have companions. Combined with the fact that about 85 percent of all stars that exist in the Milky Way are red dwarfs, one would have to conclude that upwards of two-thirds (75% of 85% ~ 64%) of all star systems in the Galaxy consist of single, red dwarf stars.

Reference- Stellar Multiplicity and the IMF: Most Stars Are Single. Paper by Charles J. Lada 13th Feb 2006.

Formation of Binaries

Theoretical simulations support the idea that the stars of a binary were formed at the same time from the same cloud of gas.

A rotating pre-stellar core is presumed to collapse and form rings that fragment to produce a number of protostars. Interactions between these protostars and the surrounding gas then determine the final masses of the stars and which ones end up in multiple star systems.
Reference: Binary star formation from ring fragmentation, D. A. Hubber and A. P. Whitworth, 18th March 2005.

Where two stars in a binary are of equal brightness, they tend to be of the same spectral type. It is likely that the stars were formed from the same gas cloud.

Where stars are of substantially different spectral type, it is possible that the secondary was a captured star or, perhaps, the primary absorbed mass from the secondary or another nearby star.

Distance between Components

Binary stars can orbit so closely that they are in contact with each other, while they can also be so far apart that their connection is deduced only through their common proper motion through space.

Most of the known binaries seem to be separated by a distance of less than 1000 Astronomical Units (AU). It is possible that there are more spectroscopic type binaries than visual binaries.

Alpha Centauri A and B vary in distance apart from 11.2 AU to 35.6 AU. In comparison, Neptune is 30 AU from the Sun. The alp Cen AB orbit has an eccentricity of e = 0.52 (a circle has eccentricity e = 0).

The rho Ophiuchi AB pair are separated by about 400 AU.

Beta 1,2 Tucanae are separated by around 1160 AU.

The doubles of epsilon Lyrae are separated by about 10,000 AU or 0.16 light years.

One of the widest known binaries, the Beta 1,2 Capricorni components are separated by around 21,000 AU or 0.34 light years.

It strikes me that it is highly unlikely that two stars orbit each other outside one light year's distance apart. For a system to be binary, the stars must not only be visually close but essentially the same distance from the Earth as measured by parallax.

Measuring Angular Separations

A 12mm Meade Astrometric Eyepiece can be used to measure the angular separations of the component stars in a double.
It has an illuminated etched glass reticle.

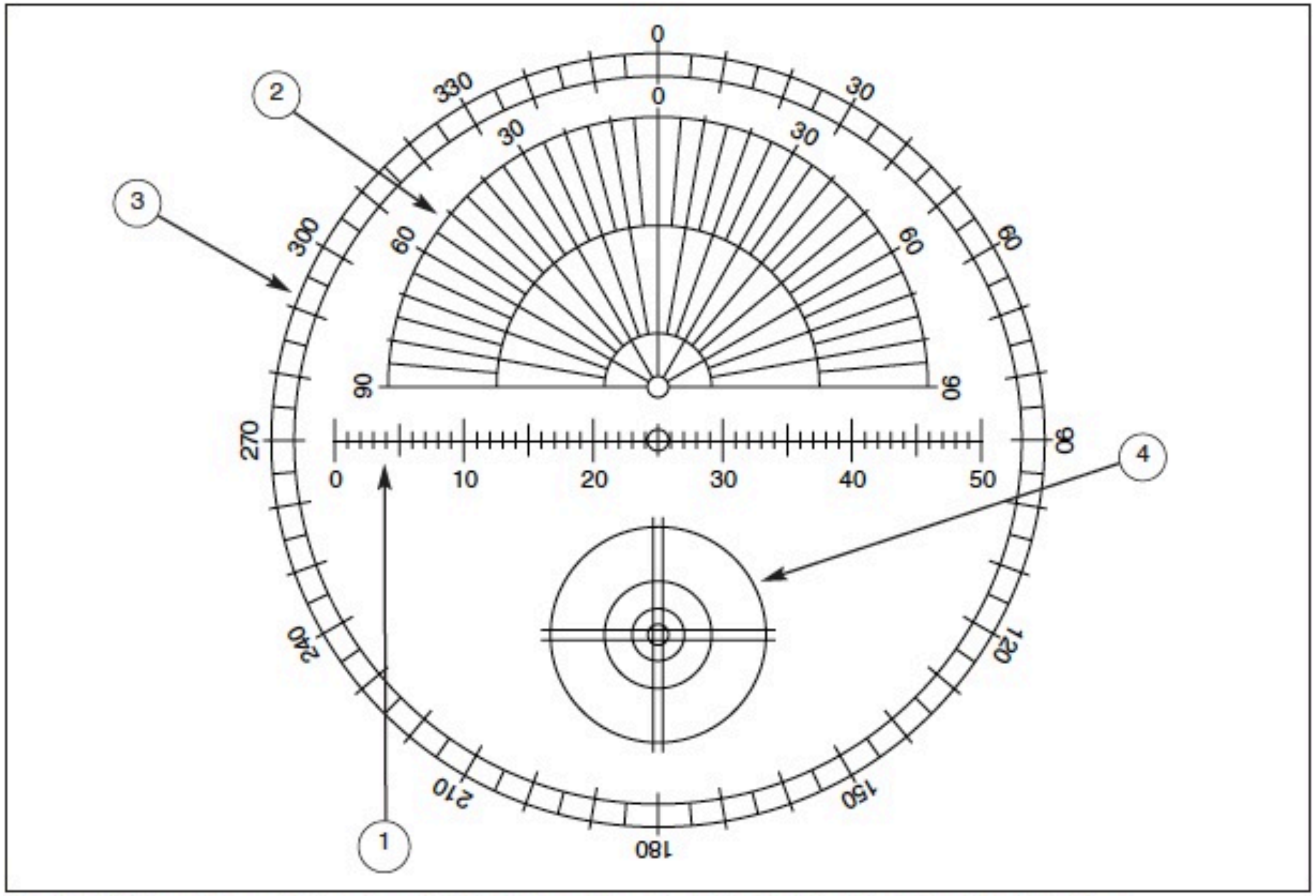


Fig. 2: MA 12mm Astrometric Eyepiece Reticle. (1) Linear Diameter Scale, (2) Semicircular Position Angle Scale; (3) 360° Position Angle Scale; (4) Double Crossline/Concentric Circle Guiding Scale.

The Drift Method

The angular separation of component stars can be measured using the linear diameter scale of 50 subdivisions.
However, the 50 subdivisions will be a different angular measure in telescopes of different focal length and will also change if you use a barlow.

To accurately measure the number of arcseconds per subdivision, the star drift method is used. This method can also be used to get the true FOV for an eyepiece.

1. Select a bright star.
2. Rotate the EP so the star drifts along the diameter of the reticle.
3. Measure the time in seconds it takes for the star to drift from the 0 to 50 points on the scale.
4. Number of arcseconds per unit = drift time in seconds x cos(declination) x 15 / 50

Note: the Earth rotates once every 24 hours (actually 23hrs 56m 04s).
On the Celestial Equator, a star will drift 360/24 = 15 degrees per hour.
This equates to an angular distance of 1 degree every 4 minutes of time.
Or, an angular distance of 3600 arcseconds every 240 seconds of time.
Or, an angular distance of 15 arcseconds every second of time.

The observed speed of drift depends on a star's declination.
A star near the South Celestial Pole (dec -90 degrees) will show hardly any drift at all.
Hence, the cos(declination) in the formula above. Note that cos(-90) = 0.

For example: I measure a time of 120 seconds for a star on the celestial equator to drift across the imaginary diameter of an eyepiece’s field of view.
Here cos(declination) = cos(0) = 1.

The true FOV of the eyepiece is
120 x 1 x 15 arcseconds = 1800 arcseconds
Or 1800 / 3600 = 0.5 degrees.

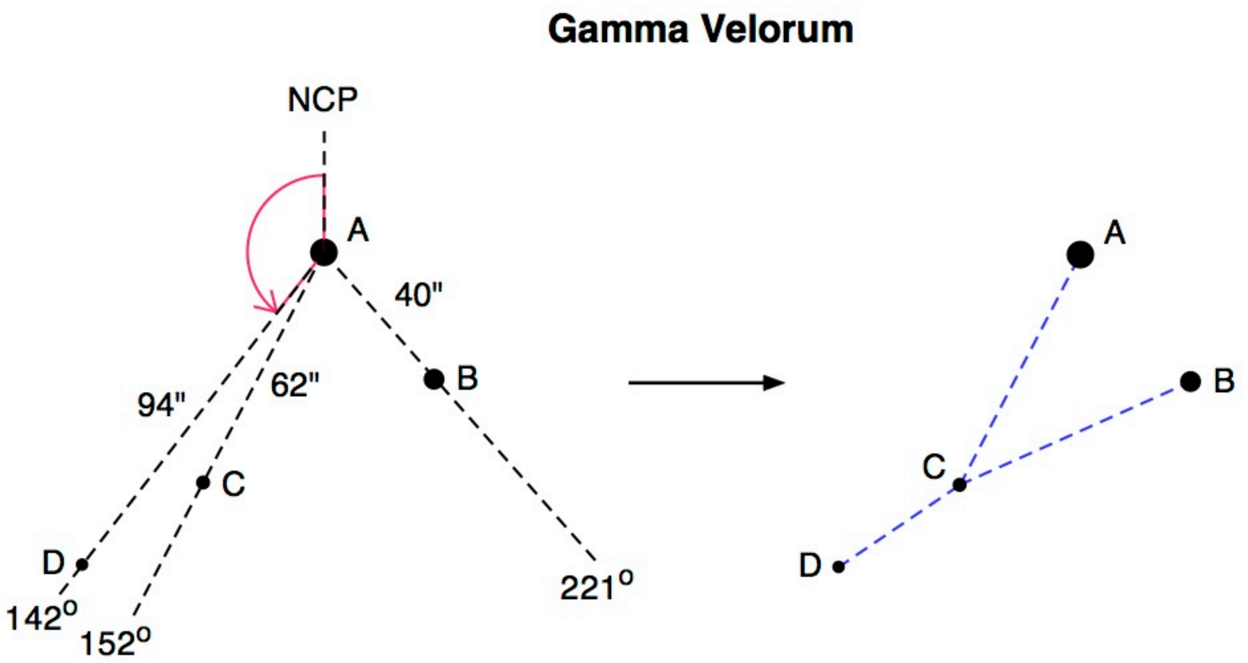
If this was the drift time from the 0 to 50 points on the astrometric eyepiece, then each subdivision would be 120 x 1 x 15 / 50 = 1800 / 50 = 36 arcseconds.

If you used a two times barlow,
the subdivisions should be about 36/2 = 18 arcseconds.

Calculating the Position Angle (PA)

The position angle gives the relative angular position from celestial north of the secondary star relative to the primary star. From the star's drift the E-W line can be determined (all stars drift east to west). The PA is measured from north towards the east first. For a refractor or cassegrain scope with a diagonal mirror, the PA is read clockwise on the semicircular scale, whilst for a newtonian reflector the PA is read anti-clockwise.

For gamma Velorum, the PA of component B is 221 degrees.



Importance of Binary Stars

The distance of a binary star system can be determined by parallax measurements. Recorded angular separations over time can lead to a description of the elliptical orbit and a determination of the period of orbit.
This provides empirical data from which the masses of the component stars can be calculated.

From the observed visual magnitude and distance, the luminosity of the component stars can be determined and a mass-luminosity relationship can be formed.
As a consequence, the mass of a star that is not in a system can be determined from its luminosity.

The diagram at right shows the mass-luminosity relationship for a main sequence star. (Diagram from Australia Telescope Outreach and Education).