Criteria to Determine the Nature of Double Stars: the Stellar Masses

Francisco Rica Romero

Astronomical Society of Mérida, Spain
Coordinator of LIADA's Double Star Section, Argentina

Email: frica0@gmail.com

Abstract: In this article several works that relate projected separations (in AU) and stellar masses of double stars are reviewed. The plots made in this work could be used to detect optical pairs, especially when there is no other way to determine the nature of a pair of stars.

Some astrophysicists are investigating the evolution and stellar processes of low mass stellar systems (mainly stellar systems consisting of red and brown dwarfs). In these studies, astrophysicists often use diagrams that relate the stellar masses of the primary or of the stellar system with the projected separation in Astronomical Units (AU, 1 AU = 150 x 10^6 km). In this article, I comment in detail these diagrams and their possible use in detecting optical pairs.

The astronomer Abt (1988) determined a relation between maximum projected separation (in AU) with stellar masses or spectral types of the primary. He plotted the data and obtained the graph shown in Figure 1, which allows one to reach conclusions about occasional encounters of these stellar systems and other stars or galactic molecular clouds. The relation obtained is valid for main sequence stars with spectral types from B5 to K0, members of binary systems, trapezia and hierarchical systems. The mathematical expression is:

$$d_{\lim}(AU) = 2500 * M_{pri}^{1.54}$$

where $d_{\lim}$ is the limit distance (in AU) for a stellar system with a primary mass M_{pri} (in solar masses).

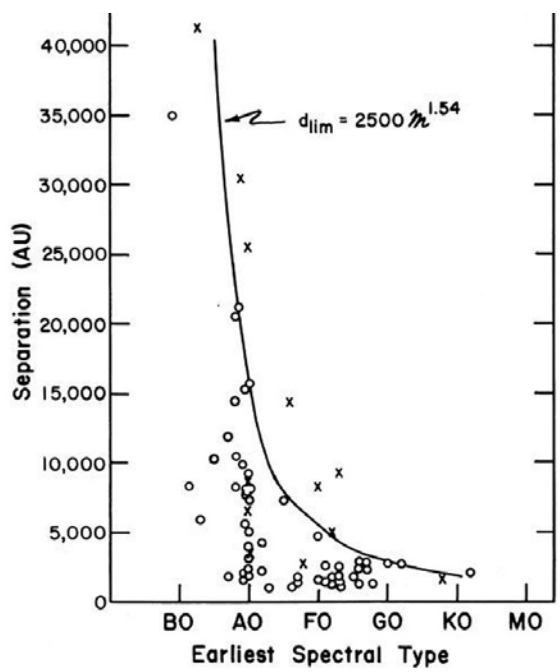

Figure 1: The diagram shows the relation of projected separation with the spectral types (or with the stellar masses). Only pairs with projected separation greater than 1,000 AU were plotted. The physical pairs are plotted with empty circle and the optical pairs with the "x" symbol. The curve represents the boundary between physical and optical pairs. (Abt 1988)

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Neil Reid, *et al.* published a work in 2001 (searching for new L dwarfs) where they plotted in a graph the total mass of several low mass stellar systems against the projected separation (in AU) of the components. This plot showed with great clarity a dependence of projected separation with the total stellar masses of the system (the greater the total stellar mass, the greater the possible maximum projected separation). The dependence is defined by the mathematical expression:

$$\log(a_{\max}) = 3.33 * M_{tot} + 1.1$$

where M_{tot} is the total stellar mass of the system (in solar masses) and a_{max} is the possible maximum projected separation (in AU).

The three M-dwarf binaries located below the dotted line in Figure 2 are Gl 412 AB, RHY 240 AB and MT 3AB. These very wide binaries are composed of two stars, weakly bound. We can expect a linear scale for the disruption of the stellar system by encounters of point sources. It seems unlikely that the strong decrease in a_{max} with M_{tot} is due only to the dynamic evolution. Reid *et al.* (2001) noted that the common proper motion binaries, plotted in the graph, have dimensions larger than typical protoplanetary disks. The last studies have suggested that the properties of short and large period binaries are significantly different, maybe reflecting different formation history. The individual components of wide systems could have formed independently.

L. M. Close, *et al.* (2003) published an article in which a graph showed the total mass of the systems vs projected separation for very low mass binaries (VLM) known at that moment (about 34 binaries). This graph is reproduced in Figure 3. It seems that all VLM binaries and brown dwarf binaries (symbols not filled) are much closer than M0-M4 binaries (filled symbols). The A0-M0 binaries closer than 25 pc came from the work of Close, *et al.* (1990) and were plotted as solid filled triangles. They concluded that these wide binaries have maximum projected separations (in AU) that fits the relationship:

$$a_{max} = 1000 * (M_{\text{tot}} / 0.185)$$

In Figure 3, we can see that the stellar systems with $\rho = a_{max}$ will be unbound with a "kick" that produces a differential velocity Vesc > 0.57 km/s (see the upper solid line in the figure). But when they fitted the projected separation of the VLM binaries and brown dwarf binaries (defined in Close et al. (2003) as systems with Mtot < 0.185 M☉) they found that the

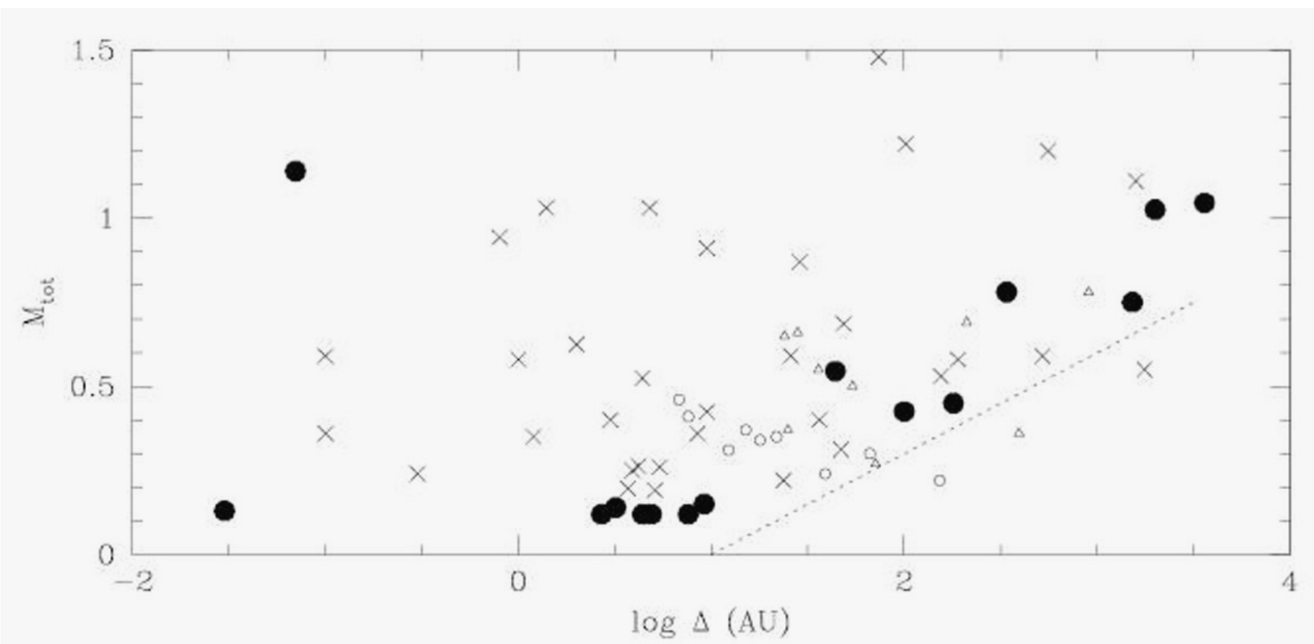

Figure 2. Relationship again projected separation (in AU) and the total mass of the system. Filled circle are brown dwarf binaries; the "x" symbol are M dwarf binaries. (Reid et al. 2001)

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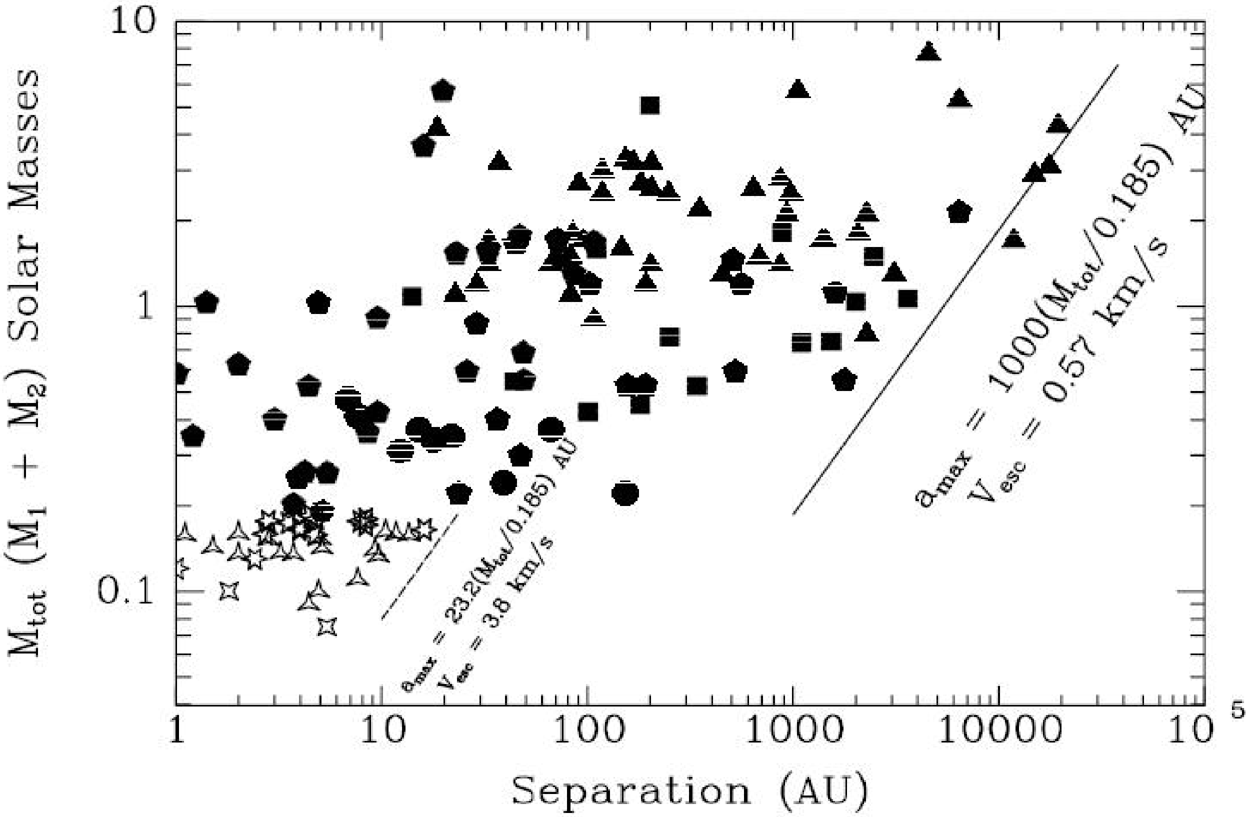

Figure 3. Relationship of projected separation (in AU) and the total mass of the systems. Different types of binaries are plotted as differents symbols. In the graph, the lineal relation are plotted. (from Close, *et al.* 2003)

maximum projected separation (in AU) is

$$a_{max}(VLM) = 23.2 * (M_{tot} / 0.185)$$

Since these systems have smaller separations, the systems with rho = a_{max}(VLM), need an escape velocity greater than 3.8 km/s to gravitationally separate the components.

Using the Mass-Separation Diagrams to Detect Optical Pairs

These diagrams show the relationship of maximum projected separation vs. stellar masses of the components. The plots determine the maximum separation (in AU), using linear fits, for stellar systems of determined masses. So we can use these mathematical formulae as a necessary condition, but not a sufficient condition, of the binarity of a pair of stars.

Example 1

The stellar system KUI 96 AB (= WDS 08426+4106) was observed by the LIADA Double Star Section. It is composed of stars of magnitudes 10.31 and 10.95 at about 378.8" in direction 168.9º. According to our study, the primary star could be a F5V (dwarf) or a F5III (giant) star. If it is a giant star, then its stellar mass could be about 4.3 solar masses. The secondary star could be a G7V star of 0.92 solar masses. At the mean distance of the members of KUI 96 AB, the angular separation of 378.8" corresponds to a projected separation of about 138,300 AU. This is an incredibly large separation! The mathematical expression used in Abt (1988), determined that a stellar system with a primary star of 4.3 solar masses could have a maximum separation of about 23,631 AU. Using Close, *et al.* (2003), for a stellar system with a total mass of 4.3 + 0.92 solar masses the maximum separation was of about 28,216 AU. The projected separation for KUI 96 AB is much larger than these limits determined by Abt (1988) and Close, *et al.* (2003) expressions. So KUI 96 AB is an optical pair. The proper motion of the members are incompatible, confirming the optical nature for this pair.

Example 2

The double star STF 1999 AB = WDS 1604427 is composed of stars of 7.55 and 7.96 magnitudes, separated by about 11.8" in direction 99º. The components are at 26.5 pc and the angular separation corresponds to a projected real separation of about 310 AU. A previous detailed study published by the author in the Spanish journal ***AstronomiA*** of November 2009 (II Epoch, number 125), concluded that the components are G6V and G9V stars with stellar masses of about 0.9 and 0.8 solar masses. The mathematical expression used in Abt (1988) gave a maximum projected separation of 2,126 AU, while Close *et al.* (2003) gave a value of 9,189 AU. It was then concluded that there are binary systems of similar masses to those of STF 1999 AB much wider than the projected separation of STF 1999 AB (310 AU), so STF 1999 AB obeys a necessary, but not sufficient, condition to be physical pair.

Example of Use

We can use this criteria to search for physical companions to a star. The mathematical expressions detailed in this article allow us to determine the area of the sky where we must search for bound companions to a star. As an example, we will use the expression of Close *et al.* (2003). The star Vega is located at 7.76 pc of distance and its mass is 2.11 solar masses. For a bound companion of a stellar mass less or equal to 2.11 we expect widest separation of 22,811 AU. At a distance of 7.76 pc correspond to an angular separation of 49.0 minutes of arc (2,941 arcseconds). So we must search for a bound companion in an area of the sky within 49.0 arcminutes of Vega.

References

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