Journey to the binary stars with AIDA
By Unisféra, Silesian University in Opava

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Ernest: “Hmm..? What’s happening, what’s that sound?”

Aida: “Ernest, wake up! We are approaching our destination.”

Ernest: “What on earth are you talking about?”

Aida: “You are currently on a spaceship, Ernest. Don't you remember?”

Ernest: “Barely.”

Aida: “Well, do you recognize me at least? I am Aida, the Astronomical Information Transport Assistant.”

Ernest: “What?”

Aida: “I am an artificial intelligence who ensures safe journeys across the universe. Rest assured that I am also great company.”

Ernest: (sighs tiredly) “Well, if you say so... I have got such a horrible headache though!”

Aida: “Don't worry, it will pass soon, but try to concentrate now. We are currently 4.23 light years from Earth.”

Ernest: “If you would be so kind, explain to me what we are doing here?”

Aida: “We are currently located in the nearest star system to our Solar System. We are in a system called Alpha Centauri which consists of three stars. Two main sequence stars: Alpha Centauri A and B form a binary system. The third star is the red dwarf called Alpha Centauri C, but you probably know it under its more common name Proxima. Our mission is to detect asteroids crossing the orbit of Earth and to examine any exoplanets around the red dwarf itself. Do you remember now? “

Ernest: “Hmm, not really... would you elaborate further to refresh my memory?”

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Aida: Our mission is a part of a project officially named “Breakthrough Starshot” founded by Milner, Hawking and Zuckerberg back in 2016.”

Ernest: “That Facebook guy has his hands on literally everything these days... So, anyway, you were saying it's a system of three stars. That is quite unusual, is it not?”

Aida: “When it comes to space it actually is not. Up to 85.00001% of stars make up a binary star system and a few of them exist in a trinary or more complex stellar system.”

Ernest: “How did you come up with that exact number?”

Aida: “Must be an error in my numeric formatting system…”

Ernest: “I am not awake enough to deal with this. Go on: why are there so many binary stars?”

Aida: “Such a high number is most likely related to the stars’ evolution itself. The whole process starts in the coldest and densest bits of space’s enormous dust &

gas clouds. There, all the molecules are pulled towards each other by gravity’s power until they get too close and stick togerher in clusters. Not only does it hold the masses together and attract more, but the temperature increases due to the collisions of molecules and their interactions. When it forms a big ball like our Solar System’s sun we call it protostar, the fetus of a future star.”

Ernest: “I’m still not sure if my headache has more to do with the stasis sickness or you... So, Alpha Centauri is a trinary star system in the end?”

Aida: “Some scientists do say that, yes. But some claim that it is a binary star system instead, since Proxima is too far away to be strongly gravitationally connected to Alpha Centauri A and B. There is another group of people who claim it is simply a collection of stars.”

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Ernest: So you can't simply give me a clear answer, then? To sum up and correct me if I am wrong: the point is that in a multi-stellar system each star is influenced by the others' gravitational forces."

Aida: Excellent, you are slowly waking up, though I must disappoint you. Should we define multi-stellar systems solely based on gravity, it would force us to define any two stars in the universe as binary systems. As gravity is a universal interaction with long (indeed, infinite) range. Additionally, we need to address the difference between optical and physical binary stars. When observed through a telescope it is very easy to think that optical binary stars are true binary systems due to their apparent closeness, but that can be very far from the truth. In fact, they might be very far from each other. A physical binary star is where both stars' gravity attracts the other and both orbit around a common center of gravity or mass."

Ernest: "Could you draw it for me, please?"

Aida: "Just imagine a universe with only two stars of masses M_1 and M_2 . Let's connect these points with an imaginary line and find the point where their gravitational influences are equal. We will call this the centre of gravity. It is around this center of gravity, generally called the barycentre, that all binary stars and multi-star systems orbit. We can observe their orbits in their first approach thanks to Kepler's law."

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Ernest: “Ah, Kepler's law...that is something I’ve heard of before. So, if something can behave like a binary star, but does not have to be a physical binary system, how are we supposed to differentiate them?”

Aida: “We can reveal an optical binary star by measuring its radial speed or its angular motion in the sky. It’s also possible to measure the distances between the stars over the course of a year, in order to determine their stellar parallax. In truth, we have not yet studied many famous binary stars to the point where we can speculate whether they are a part of a gravitationally bound system.”

Ernest: “And we’re sure Alpha Centauri A and B are a binary system?”

Aida: “Yes, we are certain. We have been observing Alpha Centauri for a very long time. The first mention was noted in Ptolemy’s star catalog in the 2nd Century CE. Despite that, its binary characteristics were confirmed later by Jean Richaud in 1689 while he observed a comet flight. It became the 2nd confirmed binary system after the binary stars of Acrux - the brightest star-system of the South Cross constellation. The other monumental discovery was by Robert T.A. Innes in 1915 when he found the third member of the group Proxima Centauri based on the observation of its movement relative to Alpha Centauri. He also suggested a gravitational connection between the visual binary stars Alpha Centauri A and B.”

Ernest: “Wait, wait, wait! What do you mean “visual binary star”? Is that an optical binary star? We’ve got optical and physical binary stars, right?”

Aida: “I understand your confusion. This is just another category of binary stars. We sort them by the method of their observation and trajectories. One of the observation methods includes directly monitoring the stars with telescopes for example. If, for example, we see two stars or the star broadening and narrowing, we can determine there are two stars. This type of binary system we refer to as visual binary stars. Other types are spectroscopic, astrometric and eclipsing variable stars.”

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Aida continues: Visual binary stars are able to be distinguished with the help of either telescopes or binoculars and it is for this reason that these binary stars were the first we discovered. When Galileo Galilei observed Big Dipper using his telescope in 1617, he discovered that the star Mizar is actually a binary star. However, the term "binary star" was first introduced by Wiliam Herschel around 1802. He also compiled a catalog with around 700 pairs of binary stars. Nowadays, there is a prevailing opinion among astronomers that around 5% of all visible stars are actually binary stars. We usually denote a binary star's brightest first component by the suffix A, and the second by suffix B. . When we fix the heavier star's position and work out their The heavier star is in center - namely in relative trajectory, long term observation of these trajectories can be plotted on a graph which can reveal an elliptical trajectory of the lighter star orbiting the heavier star. In order to calculate the weight of the stars involved we use Kepler's law. Based on their connection we use this formula m_1 + m_2= a**3/T**2. m_1 and m2 are the masses of each body, *a* is the semi-major elliptical axis s of the trajectory and *T* is the period of revolution."
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Aida continues on: Returning to Mizar, the star I mentioned, it was first observed to be a spectroscopic binary system by Antonia Mauri in 1889. The close proximity and similar relative brightness of the stars of this system do not allow us to distinguish them visually, even with a telescope. However, if we observe the spectra of possible binary stars, the Doppler effect can cause deviations in the spectral lines, we can determine that particular system is a spectroscopic binary star . As the star moves away from us (or we from it) it appears redder and when it comes towards us its motion makes it appear more blue. Based on the movement of the spectral lines with respect to time we are able to determine orbital speed of the second constituent part."
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Aida: One of the other binary star categories is eclipsing binary stars. These systems undergo periodic changes of brightness due to the eclipsing of its component stars relative to observers on Earth. In particular, they are binary stars whose orbit is almost parallel to the observer. Eclipsing binary stars have a distinctive pattern to their brightness, i.e the amount of light reaching us oscillates over time . We can observe each eclipse since and in doing so, we can determine the nature of the binary star system. To date, we have discovered several hundred thousand systems like this. One of the most famous eclipsing binary stars is called Algol in the constellation of Perseus.”
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Aida: The last category of binary stars is that of the astrometric binary stars. In short, it is a visual binary star where optically we can see only one star. Our astronomical measurement of its position reveals the periodic changes of the star. It is caused by the presence of a second component which gravitationally affects the first star. This method was only successful in locating a few binary stars. Firstly, there is inaccuracy in the process of measuring the movement of stars themselves and secondly, we have to measure them over a long period. The best known astrometric binary star is Sirius which was discovered in 1844.
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Ernest: Oh dear, astronometry was never a favorite subject of mine…"

Aida: "Among other subjects… (Aida laughs out loud and continues). We can also classify binary stars by their mutual distance and proportional size. So, let's take two points (in our case two stars) and highlight the areas around them where each star's gravitational field is strong enough to bind passing matter - in a binary system we get a figure-eight, consisting of two teardrop-shaped regions which meet at one single point. These two surfaces are called Roche lobes. Czech-born astronomer Zdeněk Kopal introduced the evolutionary classification of binary stars with respect to the Roche area in 1995 which is still used today. He defined three possible cases:

- Detached binaries where in the representation, the two systems' volumes are fully contained within their respective Roche lobes.
- A semi-detached system where one of the volumes fills its Roche lobe .
- A contact system where both volumes fill their whole Roche lobes."

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Ernest: “I think that I must’ve passed out again at some point…”

Aida: (ignores what Ernest said and goes on) “Binary systems ,like others, evolve and can be accelerated or influenced by the presence of a companion.”

Ernest: “Finally, this is starting to sound exciting! What’s the most dramatic thing that could possibly happen to the binary star though?”

Aida: “Should both parts of the binary be main sequence stars it can develop over time into a red giant instead. The process starts when the Roche lobe fills and massive amounts of material transfer between the stars resulting in cataclysmic catastrophe, a huge explosion releasing a massive surge of energy. This can spell the end for the binary system, leaving only fragments behind.”

Ernest: “Wow! What if one member of the system is not part of the main sequence? What would happen then?”

Aida: Ah, you’re finally waking up! This case makes it all the more interesting actually. Should one component be either a neutron star or black hole it would form an x-ray binary star. What happens here is as the flow of material to the more massive body accelerates, the temperature increases and when it collides with the surface of the neutron star, it results in a thermonuclear explosion accompanied by x-ray bursts. These x-ray bursts are very visible thanks to the space telescopes in orbit around the Earth. These x-ray jets can occur quite frequently, that is unless the explosions destabilise the binary system and blow it apart.”

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Ernest: Well done! You've managed to completely terrify me! So, could something like that happen on our mission to Alpha Centauri then?"

Aida: "That is something we do not have to worry about for now. The evolution of stars takes hundreds of millions of years."

Ernest: "Alright, but any life on an exoplanet near a neutron star wouldn't survive, right?"

Aida: "In my opinion, any life on the exoplanet would not be able to survive the birth of a neutron star in the system. However, it is one of our objectives to find out whether any exoplanet would be suitable for life in the Alpha Centauri system, so let's get to work. Any further questions can wait until we finish our measurement process "

Ernest: "If you say so... but due to your "explanations" I haven't even had any coffee yet!"

Aida: "Oh dear! That is definitive proof of the weakness of carbon intelligence…(laughs)"