IIA Summer School 2022

Proper Motion of Barnard's Star

Background:

Even if the stars are called “fixed stars” sometimes, they are not really fixed. This word was chosen in ancient times, when one did not know much about the real nature of the celestial bodies. To distinguish them from the “moving stars”, that change their position every night. Today we know that those are planets and that also the “fixed” stars do move – although their motion is very small and it took some time for the astronomers to measure it. There are different reasons why a star changes its position in the sky. There are apparent changes, due to the motion of the Earth around the Sun (parallax) and due to the finite velocity of light (aberration). And there is also a real change of position, due to the proper motion of the star. A star, moving on the sky, is changing its right ascension and declination. The following formula gives the change during a certain time:

$$\mu_\delta = \mu \cos(\Theta)$$

$$\mu_\alpha = \mu \sin(\Theta) / \cos(\Theta)$$

The total proper motion per unit time is called μ. Θ is the angle, in which the star is moving (North = 0°).

The star with the fastest proper motion measured so far is Barnard's Star. **Barnard's Star**, also known occasionally as ***Barnard's "***Runaway***" Star***, is a very low-mass red dwarf star approximately six light-years away from Earth in the constellation of Ophiuchus (the Snake-holder). In 1916, the American astronomer E.E. Barnard measured its proper motion, which remains the largest-known proper motion of any star relative to the Sun. How fast it really is, can be found out with Aladin tool.

Procedure:

1. We start this exercise by downloading Aladin tool from following location --

   https://aladin.u-strasbg.fr/

   Download the Aladin desktop on your machine. It is a widely-used java tool capable of addressing challenges such as locating data of interest, accessing and exploring distributed datasets, visualizing multi-wavelength data.

2. We start Aladin.Click on the Aladin icon on the desktop of the PC/laptop and then with File → Open → the server selector. Enter "Barnard's Star" in the "target" field and hit "submit".
3. The available images of Barnard's Star are listed. To investigate the proper motion, we chose two images that were observed at different times. The longer in between, the better. Let's choose two images from the POSSII-Catalogue (13' x 13'). The column "date" shows when the image were observed. We take the images from 1991 and 1988. Click on the submit to load the images in Aladin.
4. We now can combine the two images to a movie and see, if the star has moved. Therefore we use the "blink" button from the toolbar on the right. We specify the images we want to use and hit "create". The movie now starts playing and we can see that the star is moving.
5. To measure how far the star has moved, we use the "rgb" button from the toolbar. This function is meant to be used for the combination of images in different wavelengths to obtain a color picture. But we can also use it for our case.
6. In the "rgb" window, we chose one of the images for the red channel and one for the green. Clicking "create" gives a new image. The two images are now superomposed. Where the stars have not moved, they appear white. But Barnard's Star has moved and thus we see two images: one in green and one in red.
7. We now magnify the part of the image around the Barnard Star ("zoom") and use the "dist" tool to measure the distance between the red and the green image. The result will be approx. 32 arc seconds, that is the apparent distance that the star has moved. But during what time?

8. With a right-click on the images in the Aladin-stack, we can view the properties of the image. There we find the exact time, when the pictures were made.
9. The relevant information can be found at the label “epoch”. In our case, the pictures were taken on May, 12th 1988, 09:54:00 and June, 16th 1991, 07:47:59. Or written in decimals : 1988,36115674196 and 1991.45468856947.
10. We can now easily calculate the time that has passed during the two exposures: 3.09353182751 years.Thus, the proper motion per year for Barnard's star is distance/time (answer - 10.35 arcseconds/year).
11. If the star moves 10.35 arcseconds per year along the celestial sphere, what is its real velocity through space? To calculate that value, we have to know the distance of Barnard's Star. To obtain this information, we load a catalogue: File → Load catalogue → Simbad Database.
12. The catalogues symbol is now displayed in the stack on the right side. With the “mark” tool we select the objects of the catalogue in the image and the database entries are shown in the measurement window.
13. Barnards Star is here listed under its other name: “V* V2500 Oph” (“V” means “variable” since Barnard's Star is a variable star). Clicking on its name opens the Simbad-Database in the web browser where one can find all relevant data.
14. “Parallaxes mas” indicates the parallax of the star in milliarcseconds (mas). It is given as 0.549 arcseconds We now can calculate easily the distance r to Barnard's Star:

$$r = 1 / 0.549 = 1.82 \text{ pc}$$

15. We now know that Barnard's Star is 1.82 parsecs away and shows an apparent motion of 10.35 arcseconds per year. Simple trigonometry gives the real distance that Barnard's Star covers in a year.
16. The distance that the star moves during a year is 0.0000912 parsec or. 2813000000 km. That corresponds to a tangential velocity of 90 km/s or 321000 km/h.

Motion on the celestial sphere

17. The visible motion of Barnard's Star on the sky is also influenced by other factors. The motion of the earth around the sun; the influence of the moon on the motion of the earth, etc.
18. The APFS-toll of the german virtual observatory (GAVO) allows a visualization of the real motion of a star on the celestial sphere. It can be accessed at http://dc.zah.uni-heidelberg.de/apfs/res/apfs_new/hipquery/form.

19. Enter “Barnard Star” in the “Object” field and specify the timescale. Lets look at the motion between June 1st 2009 and June 1st 2014. The output interval (“interval of generation”) should be 24 hours. As “output format“ we choose a graphical representation and select “VOPlot“.
20. Clicking “Go” starts the calculation and the graphical user-interface. There we have to adjust the correct columns for “x” and “y“. We want to have the right ascension (“raCIO”) at “x“ and the declination (“dec“) at “y“. A click on “plot“ draws the new image. We can now see how the position of the star is changing during time. There are five loops that correspond to the five years from 2009 to 2014 and are due to the motion of the earth around the sun. The superimposed linear motion from the lower left to the upper right is the real proper motion of the star: That gets more clear, if we change the output interval from 24 hours to 8766 hours (one year). The motion of the earth is now filtered out and we can see the linear proper motion of Barnards Star.
21. Write a report on the above analysis with figures and diagrams and answer the questions asked in various steps. If you have any doubt or would like to know more, please write to **Sudhanshu Barway** at **sudhanshu.barway@iiap.res.in**.