

STAR CLUSTERS

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Within this use case you learn about the difference between intrinsic linear size and apparent angular size, a difference that is frequently at the center of astronomical problems. Star clusters are the objects used to illustrate this difference. You also learn some basic facts about star clusters, whose distribution in space has helped us to understand the structure of our Milky Way. Thanks to Aladin, you will be able to explore their distribution on the sky on your own.

If used in the classroom this intermediate use case requires a very basic knowledge of the relations between angles and sides of triangles. However, even if relatively easy from a technical point of view, the arguments are quite long and require guidance from teachers.

1. Introduction

When observing the sky, even with just a small telescope or binocular, it is possible to discover groups of very close stars. Detailed observations made by professional astronomers have demonstrated that these groups are made of stars that are physically close together in space, rather than just a projection effect along the line of sight. The common origin of these stars is an interstellar cloud of gas and dust where an over-dense region starts growing denser because of gravitational attraction, eventually fragmenting into stars. If stars are only about thousand or fewer, they

can remain together for a few hundred million years, but then their relatively weak gravitational field is not enough to keep them together. These groups are called open clusters. If instead stars are plentiful, hundreds of thousands, they remain together linked by gravity in a stable system with a regular shape. This is a real new celestial body that astronomers call globular cluster. The age of globular clusters exceeds 10 billion years and their formation process is not yet clearly understood. Several theories on their formation have still to be verified with observations. In this use case we discover some of the main properties of star clusters.



Fig. 1: Core of the globular cluster M13 and the Pleiades open cluster (credits: ESA/ Hubble e NASA/AURA/Caltech).

2. Cluster sizes

Examples of open clusters are the Pleiades (M45), M41 and M67. Examples of globular clusters are M4, M13 and M15. All these clusters are observable with a binocular or with a small telescope, M45 can be clearly seen also by naked eye. When we look at these clusters on the sky, we observe a variety of densities and sizes, but it is important to remember that these differences may be only apparent since they depend on the different distances from us of the objects. This is a common situation in astronomy: we measure apparent properties (in this case the angular size), but in order to understand the nature of celestial bodies we need to know their intrinsic properties (in this case their linear size). Intrinsic and apparent properties of objects are related through their distance from us. In order to understand this fact we can describe a similar situation in our everyday life. Imagine to observe a person in front of us and then the same person 500m far from us: we see the distant person very small compared with the near one, but in the reality they have the same height. The two persons have the same intrinsic dimension and different angular dimensions due to different distances from us.

Otherwise we can see two persons that appear with the same height, but in the reality we are observing a child near to us

and an adult distant from us. In this case they have the same angular dimensions and different intrinsic dimensions.

The quantity that relates intrinsic and angular (apparent) sizes is the distance. Since we are dealing with star clusters, that are celestial objects with very small angular dimensions, it is possible to compute the linear (intrinsic) size of the clusters from the simple relation:

$$R = \alpha_{(\text{rad})} \times D \quad [1]$$

where $\alpha_{(\text{rad})}$ is the angular size measured in radians, D is the distance and R is the linear size of the cluster in the same units as D . In this use case we measure D in light years. A light year is the distance light travels in a year at the speed of 300000 km/s. In kilometers it is a huge number: 9460 trillions.

Note that $\alpha_{(\text{rad})}$ can be computed from $\alpha_{(^\circ)}$ with the following formula:

$$\alpha_{(\text{rad})} = \alpha_{(^\circ)} \times \pi / 180 \quad [2]$$

Figure 2 shows the geometry of angular dimensions of two clusters that have the same linear dimensions but are at different distances from us. Figure 3 shows how these two clusters appear on an astronomical image.

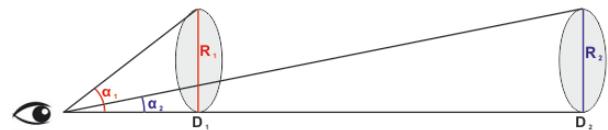


Fig. 2: Geometry of angular dimensions of two clusters that have the same linear dimensions but are at different distances from us.

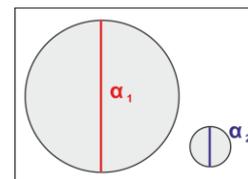


Fig. 3: How the two clusters of figure 2 appear on an astronomical image.

3. Aladin

Aladin is an interactive sky atlas developed and maintained by the Centre de Données astronomiques de Strasbourg (CDS) that can be used to identify and study astronomical sources via visual analysis of professional images. It is available for download here:

<https://aladin.u-strasbg.fr/java/Aladin9.0.jar>.

Aladin connects to databases and services of CDS (e.g. the SIMBAD database or the VizieR catalogs). Aladin has been designed in order to be used by professional astronomers as well as by amateur astronomers, students and the general public.

Aladin allows users to visualize astronomical digital (or digitized) images of the sky in any direction and to associate to these images table data and CDS online catalogs.

In this Use Case we use Aladin in the *undergraduate* configuration that has been developed in the framework of the European project EuroVO-AIDA.

Start Aladin and select the option "undergraduate" from the menu

Modify -> user preferences -> profile -> undergraduate.

Restart Aladin in order to activate the option undergraduate.

4. Visualize star clusters in Aladin

First we compare between each other the three open clusters (Pleiades, M41 and M67). We then discuss their angular and linear sizes given their known distances from us.

We begin by loading the images of the three open clusters. We open the panel of the server selector (fig. 4):

File -> Load astronomical image -> Aladin image server

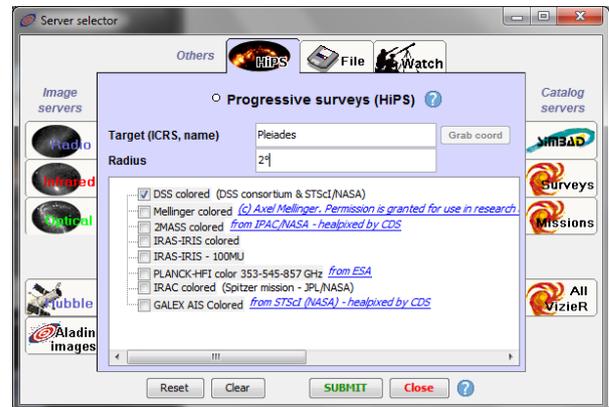


Fig. 4: The server selector window of Aladin

and select the tab "HiPS" at the top of the window.

HiPS -> DSS colored

We then insert the name of the first cluster, "Pleiades", in the field "object" and click "submit".

Aladin displays an image of the whole sky centered on the Pleiades open cluster. In order to compare the Pleiades to the other two open clusters, we split the main window into 4 panels by clicking the multiple window icon  under the main window of Aladin.

We select the second panel and repeat the same steps for M41. Finally, we select the third panel and repeat once more the same procedure in order to load the image of M67.

Now we need to find a zoom factor that fills the display with the main cluster members. The solution is to experiment in each window with the zoom slider just under the Aladin stack of planes until we are satisfied. The field of view corresponding to each zoom factor is written at the bottom of the display

window. It may also be useful to measure the field of view, or parts of it, using the “dist” tool to draw a vector from one side to the other of the window (fig. 5).

We find that the apertures of the windows that work best are 2° (or $120'$) for the Pleiades (M45), $20'$ for M41, and $15'$ for M67 (fig. 6). We take these apertures as diameters of the clusters, so using formula [2] we have $\alpha_{(\text{rad})M45} = 0.035$ and $\alpha_{(\text{rad})M41} = 0.006$.

The window for the Pleiades is 6 times wider than that for M41. Does it mean that the Pleiades are also intrinsically bigger? In order to find out, we need to know the distances. According to the Kharchenko* catalog the Pleiades are at 424 light years from us while M41 is at 2260 light years.

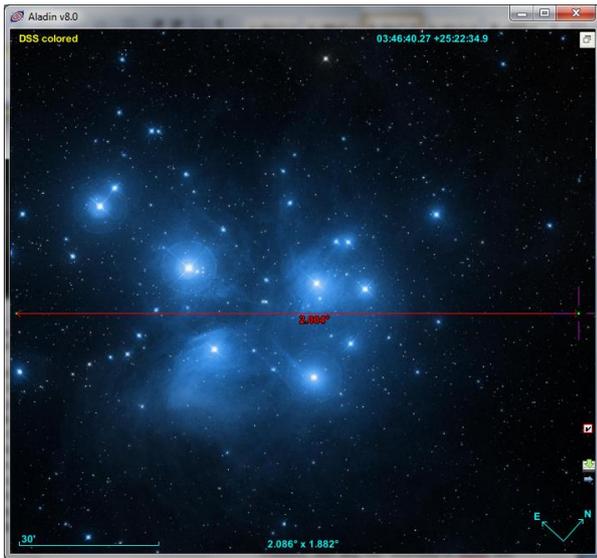


Fig. 5: Distance vector drawn on the image of the Hyades in order to measure the angular size of the field of view.

Therefore, M41 is 5 times more distant than the Pleiades.

By substituting in the formula [1] the values $D_{M45} = 424$ light years and $\alpha_{(\text{rad})M45} = 0.035$ we calculate the linear diameter of the Pleiades $R_{M45} = 14.8$ light years. For M41, $D_{M41} = 2260$ light years and $\alpha_{(\text{rad})M41} = 0.006$, we obtain $R_{M41} = 13.6$

light years. The diameters we obtained are very close to those computed without approximations, $R_{M45} = 14.8$ light years and $R_{M41} = 12.0$ light year. We find that the Pleiades and M41 have a similar linear (or intrinsic) size in spite of the very different angular size.

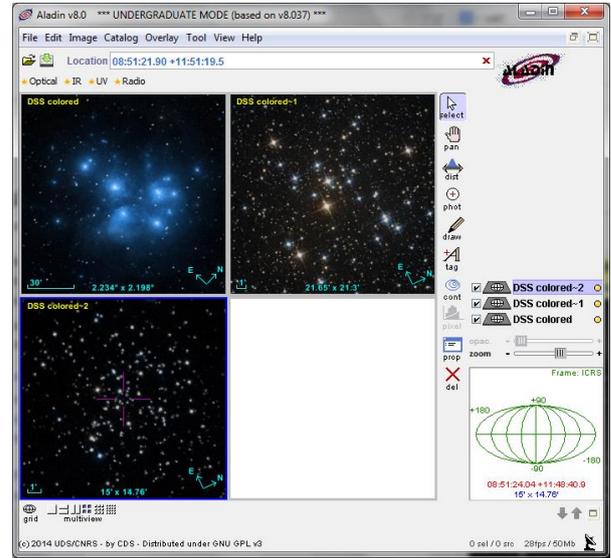


Fig. 6: The images of the three open clusters Pleiades, M41 and M67 displayed in Aladin with appropriate zoom levels.

Finally, M67 is at $D_{M67} = 2961$ light years from us. Using $\alpha_{(\text{rad})M67} = 0.004$, the diameter of M67 turns out to be $R_{M67} = 12.0$ light years.

In conclusion, the Pleiades, M41 and M67 have all very similar intrinsic sizes, notwithstanding their different angular size on the sky.

We now consider the three globular clusters and repeat the same procedure we followed for the open cluster in order to load the images of M4, M13 e M15 (fig. 7).

As before, the best visualization of the clusters requires the selection of a proper zoom factor. We select a field of view of $30'$ for all three panels. According to the Monella* catalog the angular sizes of the three globular clusters are comparable. M4 and M13 have a diameter of $22.8'$

and 23.2', while the diameter of M15 is 12.3'.

Even if the angular sizes of the clusters are similar, they have very different distances: 6850 light years M4, 23150 light years M13 and 31600 light years M15. The resulting intrinsic sizes are 45 light years, 156 light years and 113 light years respectively. From these numbers we see that globular clusters are up to 20 times bigger than the three open clusters.

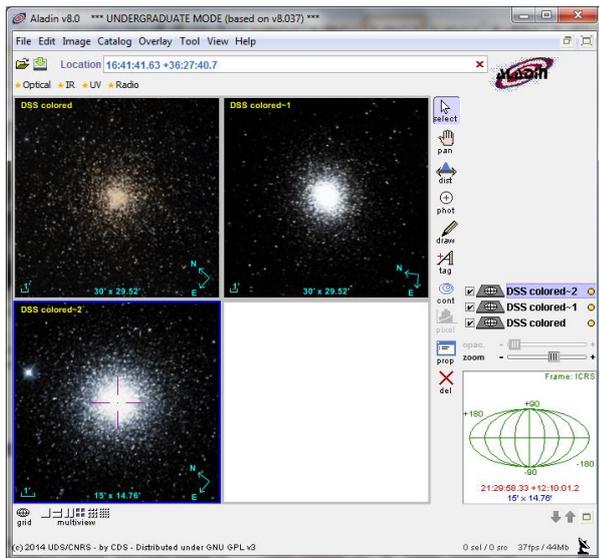


Fig. 7: The images of the three globular clusters M4, M13 e M15 displayed in Aladin with appropriate zoom levels.

5. The distribution in space

We know about a thousand open clusters, but there could be up to 10 times more in our Milky Way. The Messier* catalog (see use case n. 15) lists 29 open clusters. The number of globular clusters is much smaller, about 150 have been observed and the total population could reach about 200. The Messier catalog lists 29 globular clusters. Because globular clusters are very luminous we can see them in other galaxies. For example, we see about 400 globular clusters in the Andromeda galaxy (see use case n. 7) and estimate a population

of 12000 globular clusters in M87, based on detailed observations of the 8m class Subaru telescope.

Not only the populations of open and globular clusters are numerically very different, but also their distribution on the sky is very different. In order to appreciate this fact, we represent the whole sky in Aladin with a sphere where we display the radio image map provided by the Planck satellite. The radio image of the sky allows us to immediately identify the white region produced by the Hydrogen gas of the galactic disc.

We proceed as follows: open Aladin and select "Radio" in order to load the whole sky image in the radio band (fig. 8). We tweak the zoom level in order to visualize the whole celestial sphere on the display.

In the panel server selector we click on "All VizieR"  on the right hand column of tabs. Then we select "Open_Cluster" in the object list of the "astronomy" column and click submit (fig. 9).

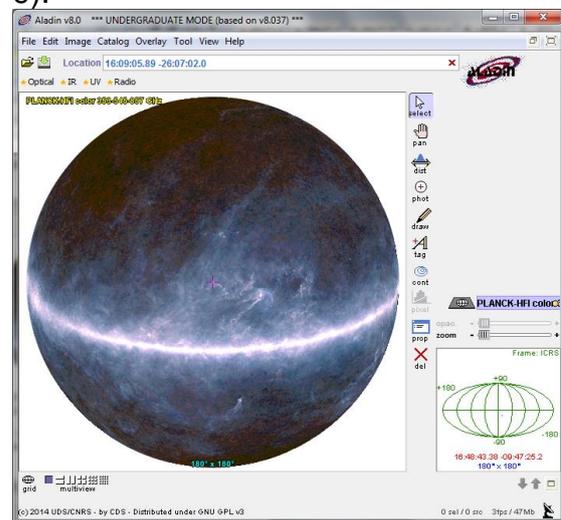


Fig. 8: Representation of the whole sky (AllSky) in the radio band.

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Fig. 9: Selection of open clusters (Open_Clusters) among available objects to search for in the catalogs.

A window pops up with the list of available catalogs (fig. 10): we check the Kharchenko catalog (J/A+A/438/1163) and submit. We repeat the same steps for globular clusters (“Globular_Clusters” in the astronomy window) and load the Monella catalog (VII/103).

For clarity, if needed, we can change the color of the symbols (in the stack on the right side of Aladin select the desired catalog -> click on the right button of the mouse -> properties).

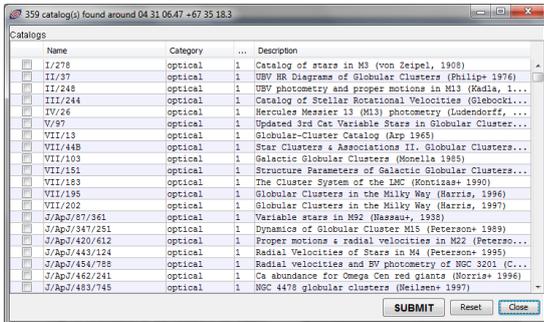


Fig. 10: List of available catalogs.

From the image in Aladin it is clear that open clusters (red crosses in fig. 11) closely follow the disc of the Milky Way while globular clusters are more uniformly distributed on the sky (blue diamonds in fig. 11)

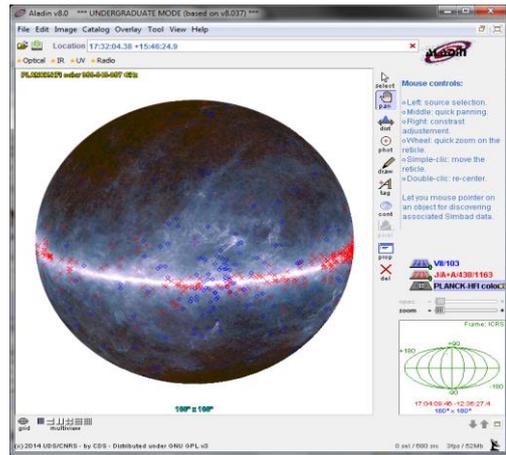


Fig. 11: Distribution of star clusters in our Galaxy. Red crosses are open clusters, blue diamonds are globular clusters.

Furthermore, by rotating the celestial sphere, we note that open clusters are less numerous toward the center of the Galaxy. This is a consequence of the absorption of light by the clouds of gas and dust that form the galactic disc. In order to center the view from Aladin’s window on the center of our Galaxy we can center the red dot on the grid in the small window under the stack (fig. 12). On the contrary, globular clusters are more numerous toward the center of the Milky Way where they form a spherical halo.

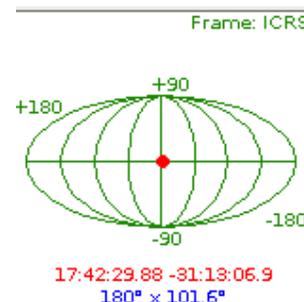


Fig. 12: Navigator window: the red dot represents the direction of the center of the image displayed in Aladin with respect to the Galaxy.

The properties of star clusters that we discovered in this use case are only a few of those that astronomers investigate. Together with color, luminosity, mass,

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velocities of both individual stars and clusters give fundamental clues for the understanding of stellar evolution and galaxy structure.

* these catalogs are mentioned for information, there is no need to search for or load them in Aladin.

References:

Kharchenko *et al.*, 2005, Catalogue of Open Cluster Data (COCD), *Astron. Astrophys.*, 438, 1163-1173.

Monella, 1985, *Galactic Globular Clusters*.



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