Determination of the distance to the Pleiades using TOPCAT

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In this tutorial we will explore how to use TOPCAT (Tool for Operations on Catalogues And Tables) in a realistic science case to access catalogues, cross-match tables, filter sources, create subsets, and represent the results using different kinds of plots.

This tutorial is based on TOPCAT v4.7-3, running on a Mac. You can download the tool from:

http://www.star.bristol.ac.uk/~mbt/topcat/#install

SCIENCE CASE

We will use data from the Tycho-Gaia Astrometric Solution (TGAS) catalogue to determine the mean parallax of the stars in the Pleiades open star cluster, thus obtaining its distance.

SCIENTIFIC BACKGROUND

Stars do not form isolated in the space. They form in large groups from the same interstellar cloud. We call them star clusters. Thus, star clusters are large groups of stars that have the same age, similar chemistry, and that keep the same kinematics than the parent interstellar cloud.

The Pleiades (M45) is one of the nearest Earth star clusters. It is visible by the naked eye and contains thousands of stars.

WORKFLOW

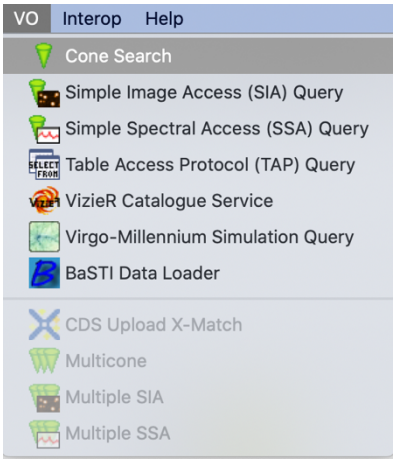
Step 0: Launch TOPCAT

1. Open a terminal and go to the directory where topcat-full.jar was saved.
2. Type: **java -jar topcat-full.jar &**
   (On a Mac, click on the TOPCAT icon)

Step 1: Discover

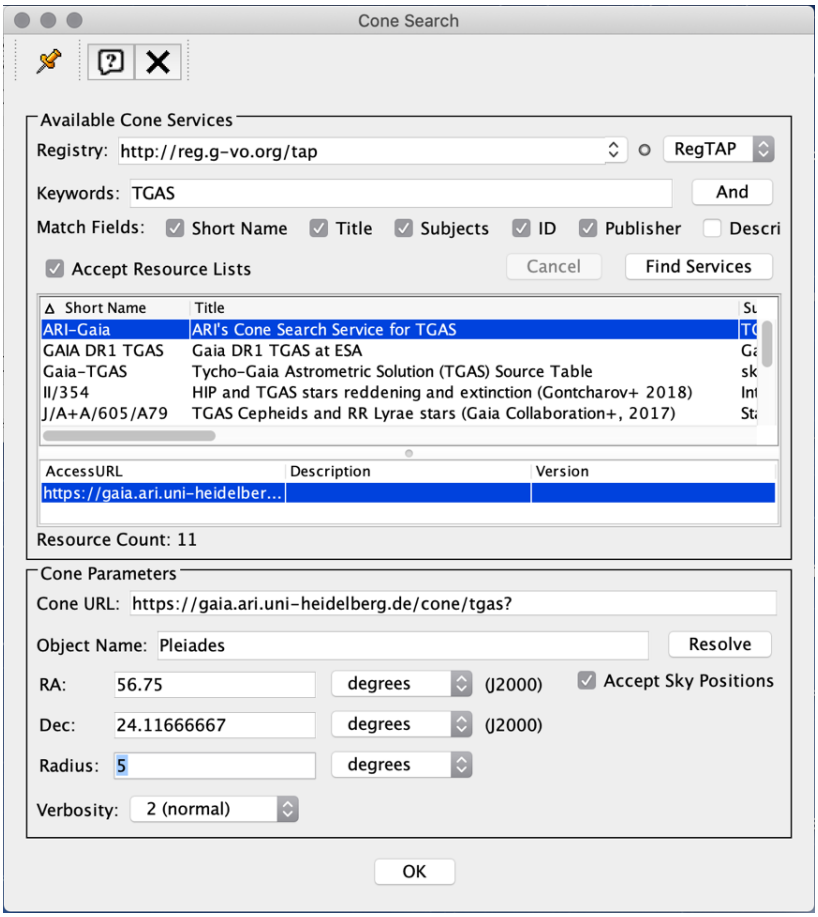
Let's begin by acquiring TGAS data in the Pleiades region.

3. In the TOPCAT main menu, follow: *VO → Cone Search*

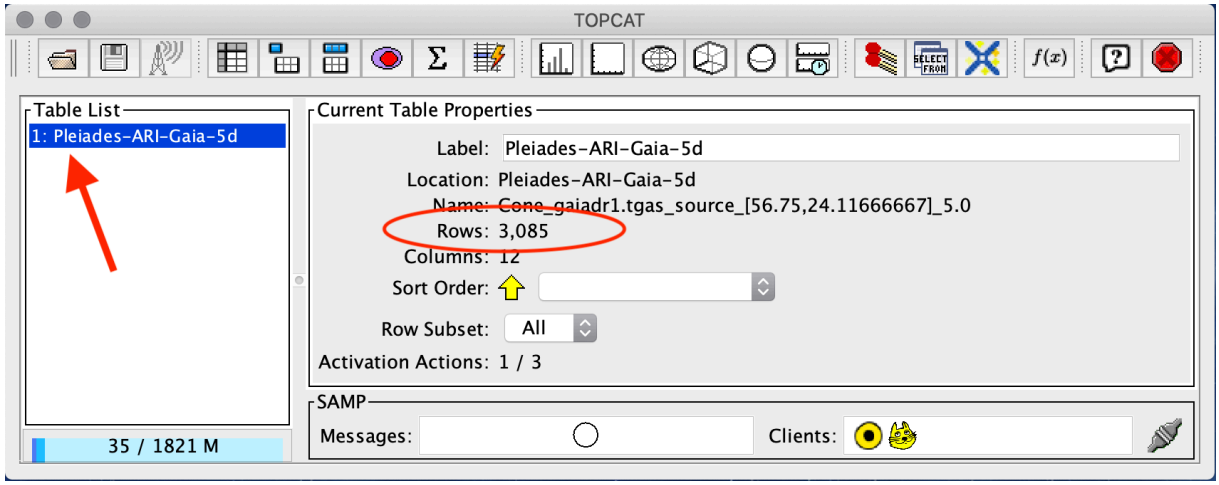


4. The *Cone Search* window opens. In the *Available Cone Services* box of this window:
   - In the *Keywords* field, enter: **TGAS**
   - Click *Find Services*.
5. When the list of services is displayed, select ***ARI-Gaia***. The partial URL of the service appears in the *Cone URL* field in the *Cone Parameters* box.
6. In the *Cone Parameters* box:
   - Enter *Object Name*: **Pleiades**
   - Click *Resolve* to fill in sky position fields.
   - Set *Radius* to **5 degrees**.

   and click *OK.*



7. A table with 3,085 entries called *Pleiades-ARI-GAIA-5d* is loaded in the TOPCAT main window.

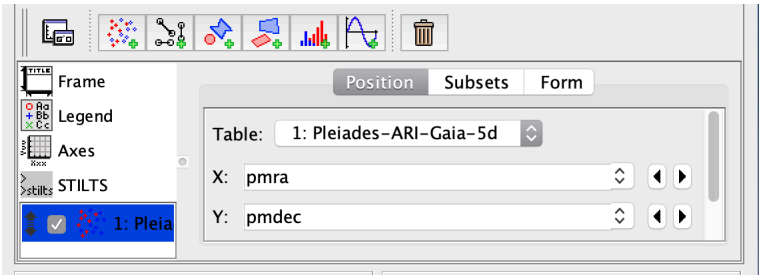


Step 2: Select comoving sources

Now let's explore the proper motion diagram of this sky region to separate probable Pleiades members from the field stars.

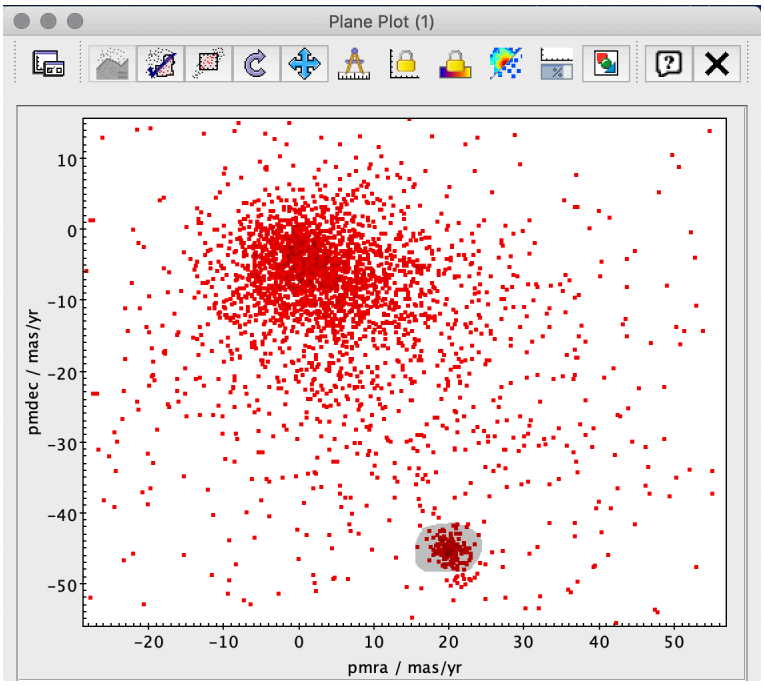
8. In the TOPCAT main menu, follow: *Graphics → Plane Plot*
   (Alternatively: Click on the *Plane plotting window* button of the top panel in the main window)

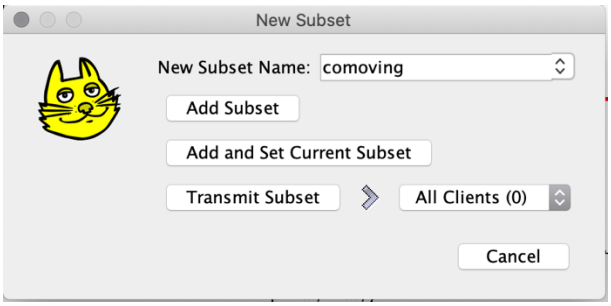
9. In the *Plane Plot* window, go to the *Position* tag at the bottom of the window, and select the columns to be plotted:
   - *X*: ***pmra***
   - *Y*: ***pmdec***



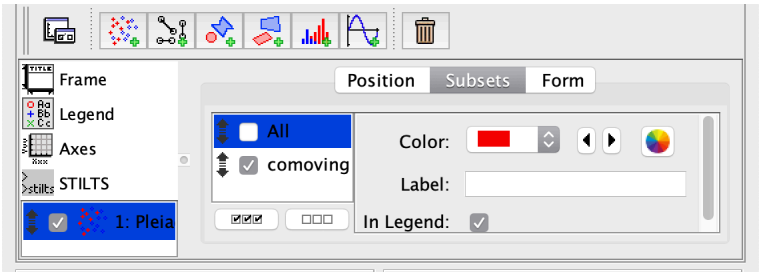
10. In the plot, note the overdensity around (20,−45). Use the mouse to navigate.
11. Graphically select this comoving cluster as a new subset:
    - In the TOPCAT main window, follow: *Subsets → Draw Blob Subset*
      (Alternatively: Click on the *Draw Freehand Region* button on the top of the *Plane Plot* window)

    - Drag the mouse around the cluster on the plot, and click same button again. The *New Subset* window pops up.
    - In the *New Subset* window, enter the *New Subset Name*: **comoving**. Click on *Add Subset*.

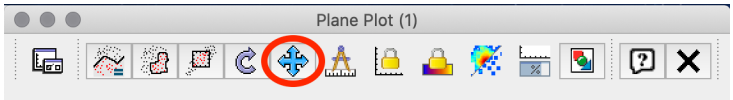




12. Go to the *Subsets* tab at the bottom of the *Plane Plot* window. Turn "All" off and ***comoving*** on. Now only the "comoving" subset will be displayed.



13. You can click on the *Rescale Plot* button on the top of the *Plane Plot* window to rescale the plot.



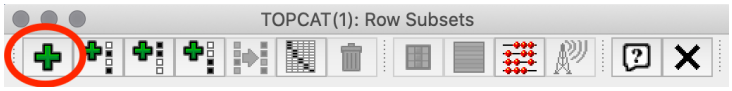
Step 3: Identify Pleiades members

We will now use the parallax to refine the selection and identify the Pleiades members.

14. In the TOPCAT main menu, follow: *Graphics → Histogram Plot.*
    (Alternatively: Click on the *Histogram* button of the upper panel in the main window)

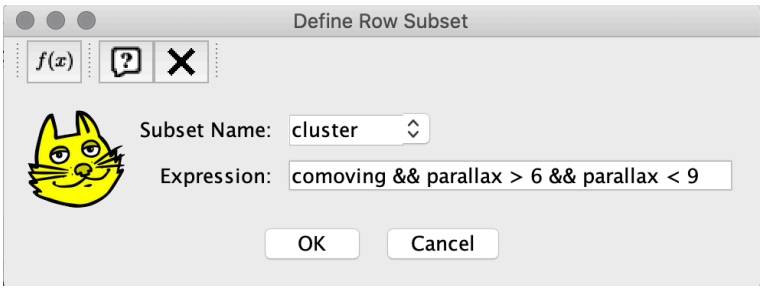
15. In the *Histogram Plot* window, go to the *Position* tag on the bottom of the window, and select the column to be plotted:
    - *X*: ***parallax***
16. In the *Subsets* tab, make sure that only the subset ***comoving*** (and not "All") is plotted.
17. Rescale the plot by clicking on the *Rescale Plot* button on the top panel, or navigate with mouse. There are some outliers visible, probably not cluster members. We want to create a new subset excluding those parallax outliers.
18. In the TOPCAT main menu, follow: *Views → Row Subsets*.
    (Alternatively: Click on the *Display Row Subsets* button of the top panel in the main window)

19. In the *Row Subsets* window, click on the *New Subsets* button. The *Define New Subset* window will pop up.
    (Alternatively: In the TOPCAT main window, follow: *Subsets → New Subset*)

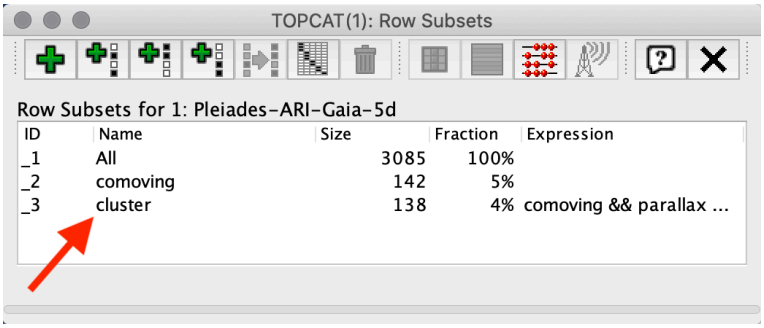


20. In the *Define Row Subset* window, enter:
    - *Subset Name*: **cluster**
    - *Expression*: **comoving && parallax > 6 && parallax < 9**

    and click *OK.*



21. The new subset will be listed in the *Row Subsets* window.



22. Plot only the ***cluster*** subset using the *Subsets* tab in the *Histogram Plot* window.

Step 4: Estimate the mean parallax

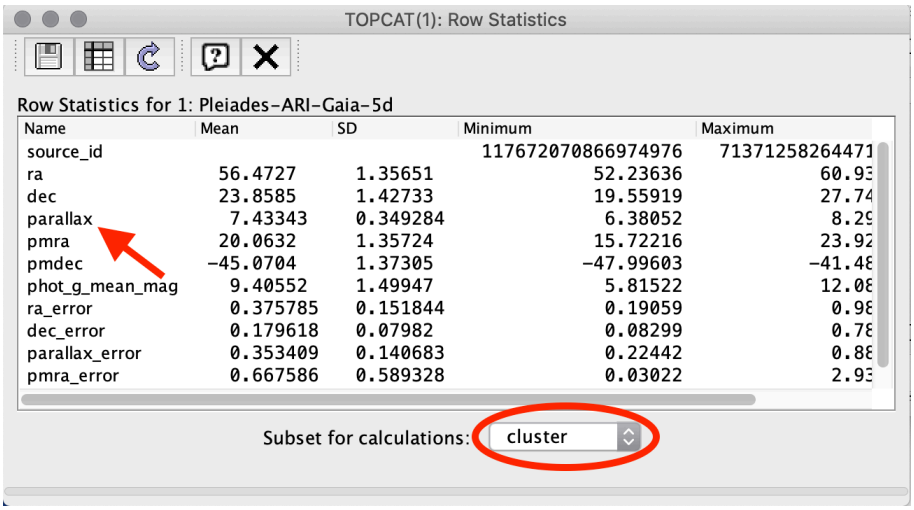
Next, we will use TOPCAT to do some statistics and find the mean parallax of the cluster members. This will provide us with the distance to the cluster.

23. In the TOPCAT main menu, follow: *Views → Column Statistics*

    (Alternatively: click on the *Display Statistics* button of the upper panel in the main window)

24. In the *Row Statistics* window, select ***cluster*** as *Subset for calculations*.
25. Read off the *Mean* and *SD* (standard deviation) of the *parallax* column. How far away are the Pleiades?

Distance in parsec is the reciprocal of parallax in arcsec. However, inverting parallax to get distance is problematic if parallax errors are large, say > 10%. Let's select only sources with good parallax.



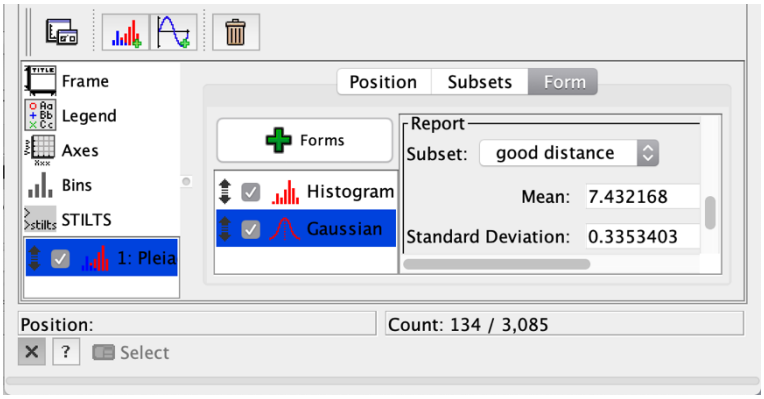
26. Create a new subset as we did in steps 18-21, using:

    - Subset Name: **good distance**
    - *Expression*: **cluster && parallax_error/parallax < 0.1**

27. Plot only the "good distance" subset using the *Subsets* tab in the *Histogram Plot* window.

28. Let's fit a Gaussian to the parallax distribution:

    - In the *Histogram Plot* window, click on the *Forms* tag.
    - Click on the *Forms* button and select *Add Gaussian* in the menu.
    - Scroll down the bottom-right panel to find the *Report* box. Note the *Mean* and the *SD*.



Step 5: Find the distance

Now we can estimate the mean distance to the cluster.

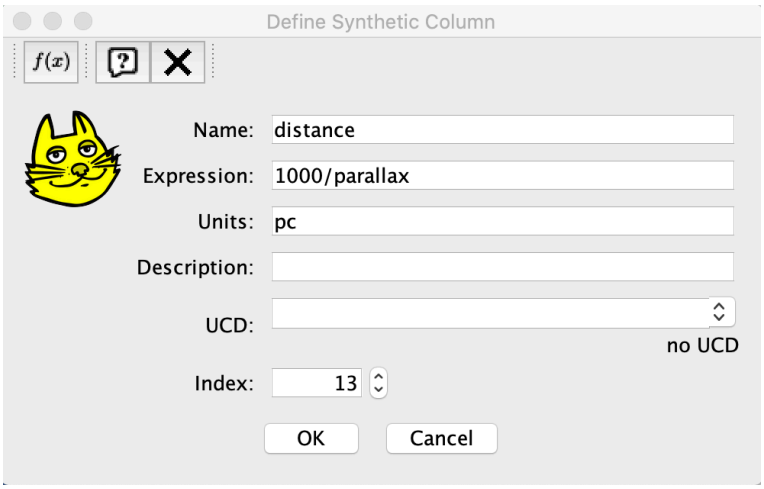
29. In the TOPCAT main menu, follow: *Views → Column Info*
    (Alternatively: Click on the *Display Column Metadata* button of the upper panel in the main window)

30. In the *Table Columns* window, follow: *Columns → New Synthetic Column*
    (Alternatively: Click on the *Add Column* button of the upper panel in this window)

31. In the *Define Synthetic Column* window, enter:

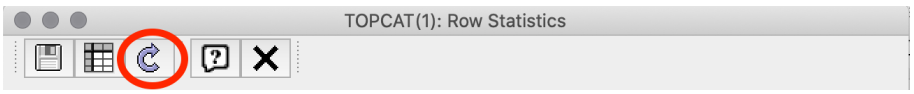
    - *Name*: **distance**
    - *Expression*: **1000/parallax**
    - *Units*: **pc**

    and click *OK.*



32. Go back to the *Row Statistics* window (step 23):

    - Set *Subset for calculations*: **good distance**.
    - Click on the *Recalculate* button on the top panel of the window.

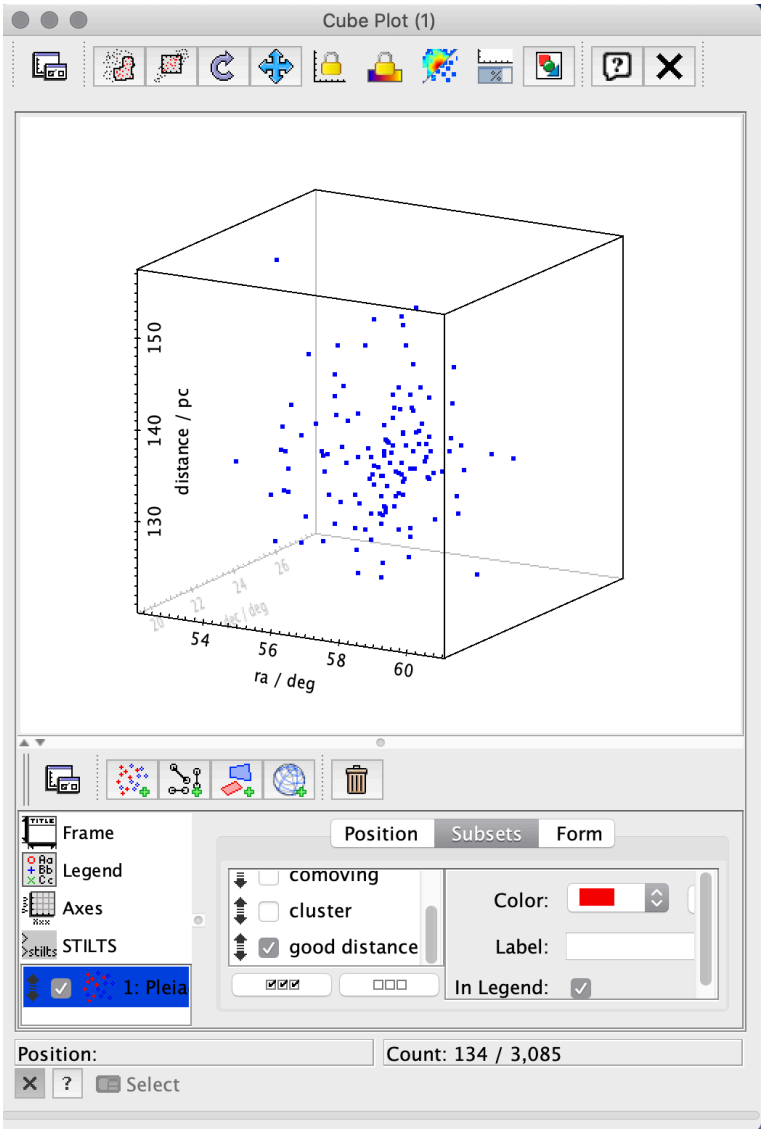


33. Read off the *Mean* and *SD* (standard deviation) of the *distance* column. How far away are the Pleiades? (You should have got something close to 134 ± 7 pc)

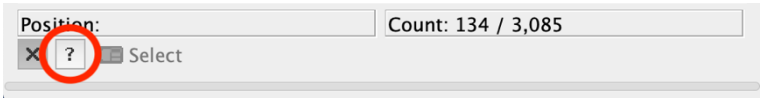
Step 6: Analyze

Let's study the space distribution of the stars.

34. In the TOPCAT main menu, follow: *Graphics → Cube Plot*
(Alternatively: Click on the *Cube Plot* button of the upper panel in this window)



35. In the *Cube Plot* window, go to the *Position* tag and select the columns to be displayed:
    - *X*: ***ra***
    - *Y*: ***dec***
    - *Z*: ***distance***
36. In the *Subsets* tab of the *Cube Plot* window, make sure that only the subset ***good distance*** is plotted.
37. Rescale the plot by clicking on the *Rescale* button on the top window panel.
38. Use the mouse to navigate. Note that 3D navigation is a bit hard. You may use the click the *Help* button at the bottom left of the *Cube Plot* window for help.



Extras

Note: Before trying these actions, make sure that the subset ***good distance*** is selected in the *Row Subset* field of the TOPCAT main window.

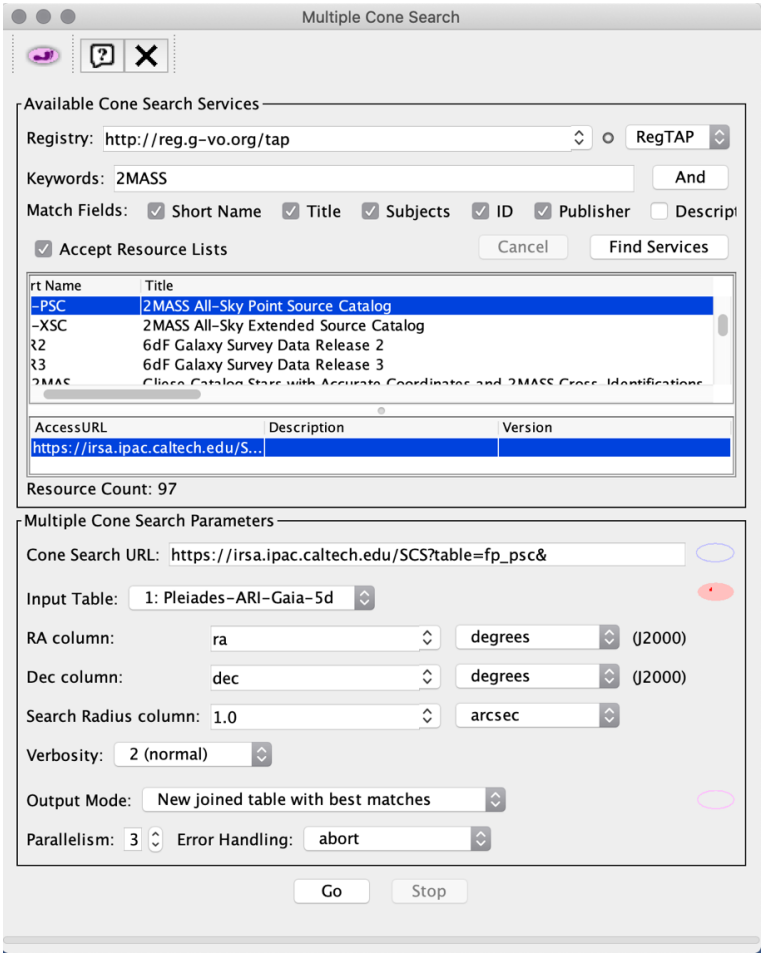
How many stars have 2MASS photometry?

We can query the 2MASS catalogue for each one of the stars in the cluster.

39. In the TOPCAT main menu, follow: *VO →Multicone*
40. The *Multiple Cone Search* window opens. In the *Available Cone Service*s box of this window, enter:
    - *Keywords*: **2MASS**

    and click *Find Services*.
41. When the list of services is displayed, select ***2MASS-PSC***. The partial URL of the service appears in the *Cone URL* field in the *Multiple Cone Parameters* box.
42. In the *Multiple Cone Parameters* box:
    - Select the table name and the input coordinates column.
    - Select Output Mode: New joined table with best matches.

    and click *Go.* The cross-matched table will be loaded to the TOPCAT main window (it may take some time).
43. You can now explore the new data creating, for example, a colour-colour plot with the *Plane Plot* functionality (see steps 8-9).



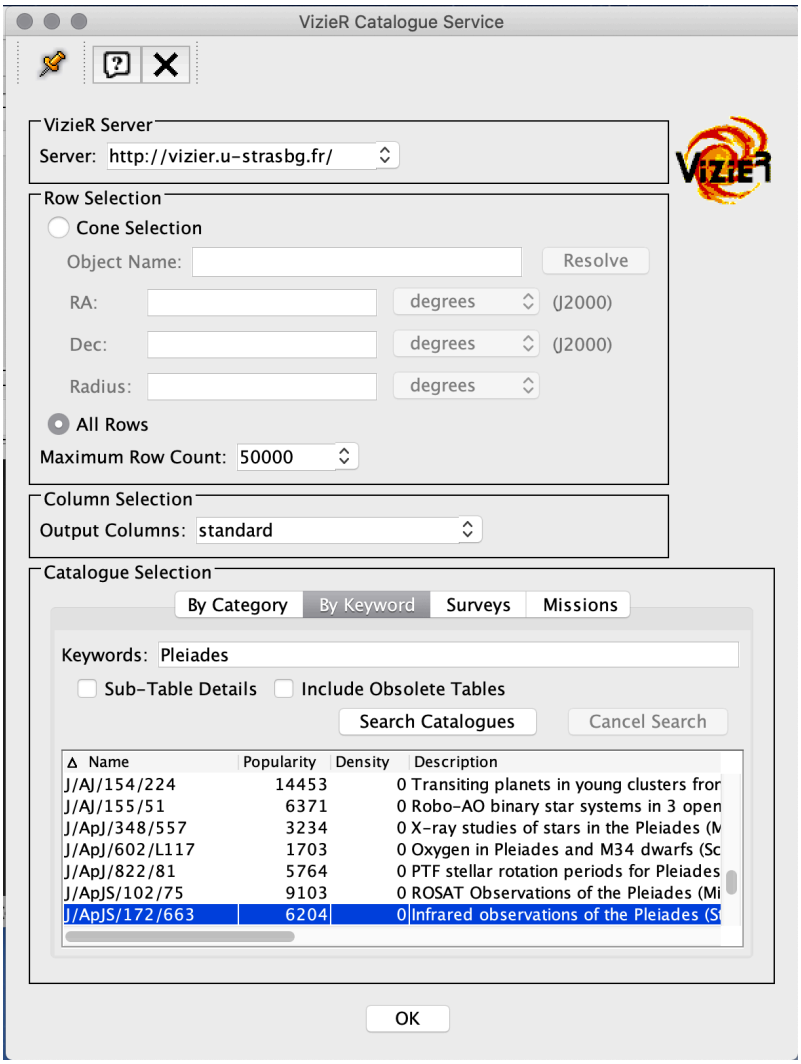
Alternatively, we can perform the cross-match with the 2MASS catalogue following: *VO → CDS Upload XMatch* (or using the corresponding button from the upper panel of the TOPCAT main window). This procedure is more efficient than the multicone, but it only provides a selection of the columns in the catalogue, and is restricted to those catalogues available in VizieR.

Compare with another study

We can also compare our resulting member list with another census of Pleiades members to see how many objects they have in common. As an example, we will cross-match our table with a catalogue from VizieR.

44. In the TOPCAT main menu, follow: *VO → VizieR Catalogue Service*
45. In the *Row Selection* box of the *VizieR Catalogue Service* window, tick ***All Rows***.
46. In the *Catalogue Selection* box:
    - Click on the ***By Keyword*** tag.
    - In the *Keywords* field, enter: **Pleiades**
    - Click on *Search Catalogues.* A list of catalogues will be displayed.
    - Select catalogue ***J/ApJS/172/663*** (Stauffer+ 2007).

    and click *OK.* Several tables will be loaded. We are interested in Table 2.



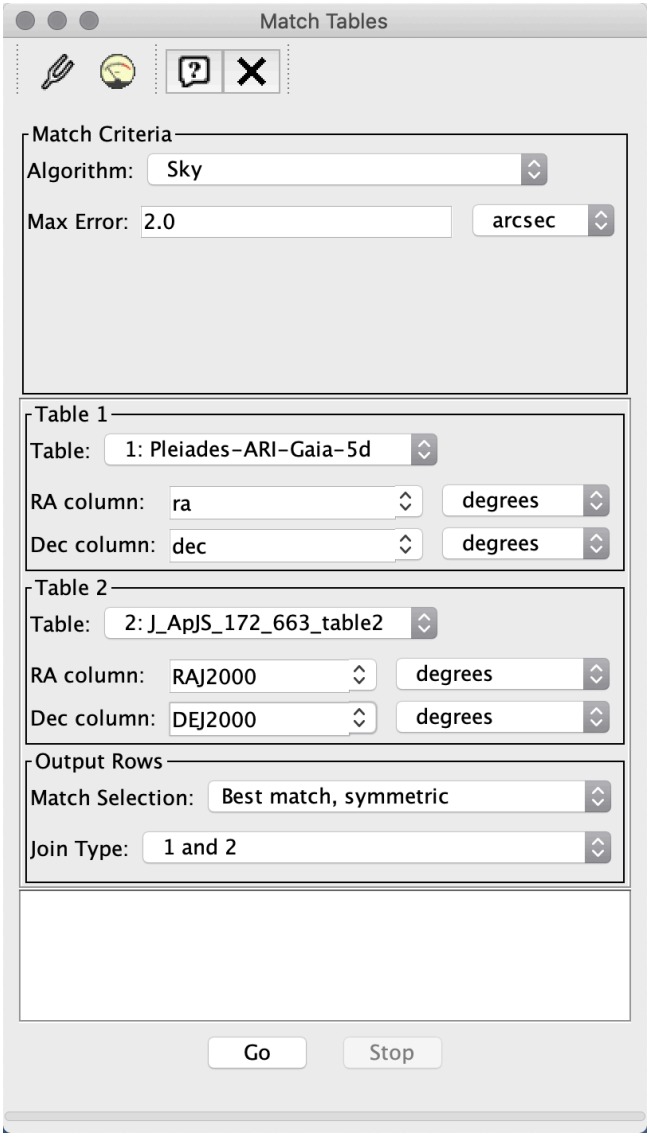
47. Let's now perform the cross-match. In the TOPCAT main menu, follow: *Joins → Pair Match*
(Alternatively: Use the *Pair Match* button of the upper panel in the main window)

48. In the *Match Tables* window:

- Select the *Algorithm*: ***Sky***
- Set the *Max Error* to ***2.0 arcsec***.
- In the *Table 1* and *Table 2* boxes, select the tables to cross-match and the coordinate columns to compare.
- Set *Join Type* to ***1 and 2***.

and click *Go*.

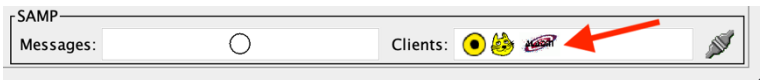
49. The cross-matched table will be loaded to the TOPCAT main window. How many objects from the second table are confirmed as kinematical members of the Pleiades?



How do these stars look like?

You can send your table (or the selected subsample) to Aladin for visualization and further analysis.

50. Launch Aladin. The Aladin icon will appear in the *Clients* field of the TOPCAT main window.



51. Load a sky map (HiPS) in Aladin, for example: Collections → Images → Optical → DSS colored
52. In the TOPCAT main menu, follow: *Interop → Send table to… →* ***Aladin***
53. The position of the stars will be displayed in the Aladin main panel. Now you can explore them further with this tool.

TO KNOW MORE

Many other functionalities are available in TOPCAT: concatenate tables, cross-match multiple tables, save tables in LaTeX format, and many more…. For further information in these and many more functionalities, we refer the user to the TOPCAT manual web page:

http://www.star.bristol.ac.uk/~mbt/topcat/sun253/sun253.html