Determination of the distance to Pleiades using TOPCAT

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We will explore the use TOPCAT (Tool for Operations on Catalogues And Tables) in a real science case. We will therefore access catalogues, cross-match tables, filter sources, create subsets, and represent the results using different kind of plots.

This tutorial is based on TOPCAT v4.9, running on a linux PC with Debian distribution and also tested on a MacBook (chip M1) running on macOS Sonoma 14.1.1. TOPCAT can be downloaded 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 space. They are born in large groups from the same natal interstellar cloud. We call them star clusters. Because all the stars in a given open cluster have the same origin, they share important properties, and have the same age, similar chemistry, and the same kinematics.

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

WORKFLOW

Block 0: Launch TOPCAT

Step 1:   Open a terminal and go to the directory where topcat-full.jar was saved.

Step 2:   Type: **java -jar topcat-full.jar.**
On a Mac, click on the TOPCAT icon. Under Windows, double-click the downloaded file.
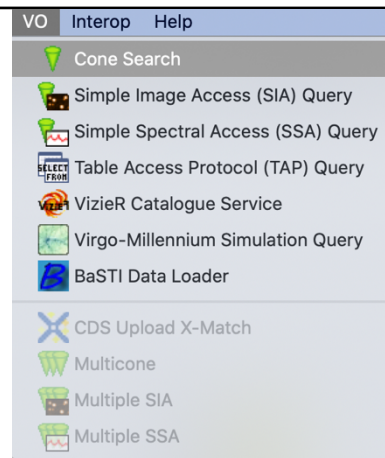
Block 1: Data discovery

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

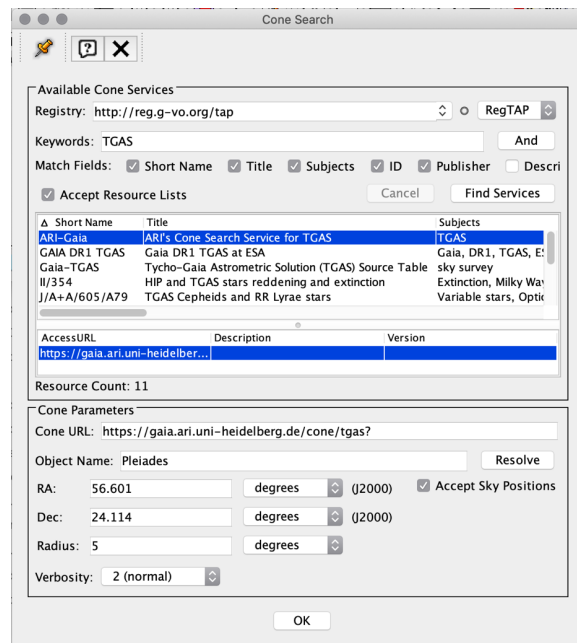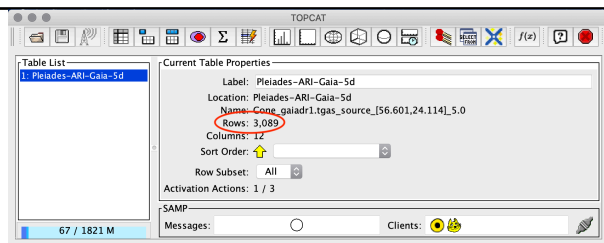|	
Step 3: In the TOPCAT main menu, select: • *VO → Cone Search*	**VO Interop Help** ◊ Cone Search Simple Image Access (SIA) Query Simple Spectral Access (SSA) Query Table Access Protocol (TAP) Query VizieR Catalogue Service Virgo-Millennium Simulation Query BaSTI Data Loader CDS Upload X-Match Multicone Multiple SIA Multiple SSA
Step 4: The *Cone Search* window opens. In the *Available Cone Service*s panel: • In the *Keywords* field, enter: **TGAS** • Click *Find Services*. Step 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. Step 6: In *Cone Parameters* panel: • Enter *Object Nam*e: **Pleiades** • Click *Resolve* to fill in sky position fields. • Set *Radius* to **5 degrees**. • Click OK	*(Cone Search window screenshot: Available Cone Services, Registry: http://reg.g-vo.org/tap, Keywords: TGAS, Match Fields, service list including ARI-Gaia, GAIA DR1 TGAS, Gaia-TGAS, II/354, J/A+A/605/A79, Resource Count: 11. Cone Parameters: Cone URL: https://gaia.ari.uni-heidelberg.de/cone/tgas?, Object Name: Pleiades, RA: 56.601 degrees (J2000), Dec: 24.114 degrees (J2000), Radius: 5 degrees, Verbosity: 2 (normal), OK)*
Step 7: A table with 3,089 entries called *Pleiades-ARI-GAIA-5d* is loaded in the TOPCAT main window.	*(TOPCAT main window screenshot: Table List: 1: Pleiades-ARI-Gaia-5d. Current Table Properties: Label: Pleiades-ARI-Gaia-5d, Location: Pleiades-ARI-Gaia-5d, Name: Cone_gaiadr1.tgas_source_[56.601,24.114]_5.0, Rows: 3,089, Columns: 12, Sort Order, Row Subset: All, Activation Actions: 1/3)*

Block 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.

Step 8:
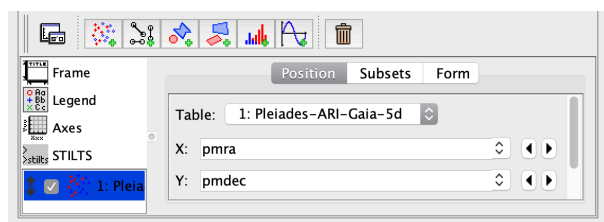In the TOPCAT main menu, select: *Graphics → Plane Plot*
As an alternative, click on the *Plane plotting window* button of the top panel in the main window

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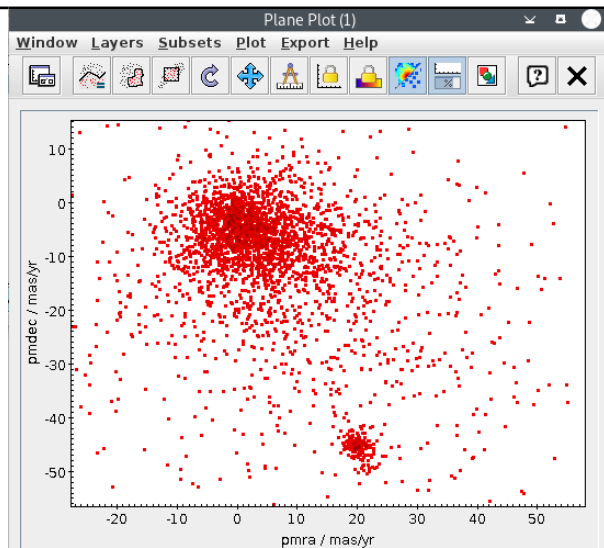- *X*: **pmra**
- *Y*: **pmdec**

Step 10:
A *Plane Plot* pops up. Note the overdensity around (20,−45).

Use the mouse to navigate. The wheel may be used to zoom in both axes, or just in one of them if it is pressed outside the plot.

Zoom is centered at the cursor position.

Step 11:

Graphically select this comoving cluster as a new subset:

- In the TOPCAT main window, follow: *Subsets → Draw Blob Subset*
As an alternative, 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.
This operation may be repeated several times if you want.
- In the *New Subset* window, enter the *New Subset Name*: **comoving**. Click on *Add Subset*.
- Note that the new subset *comoving* is now overplotted onto the *All* subset, probably in blue.
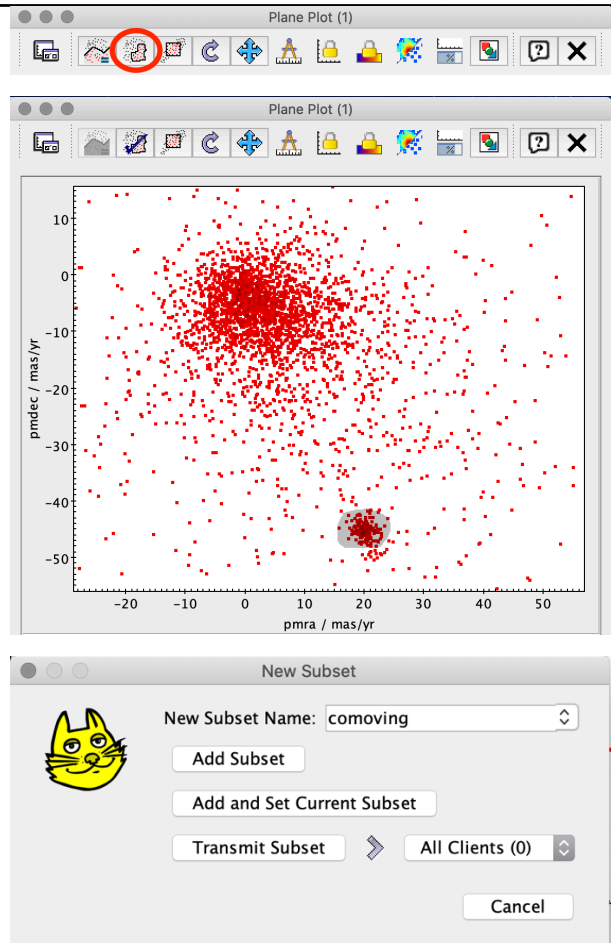
Step 12:

Go to the *Subsets* tab at the bottom of the *Plane Plot* window. De-select "All" and " Activated" tick boxes. Select **comoving** tick box. Now only the "comoving" subset will be displayed.
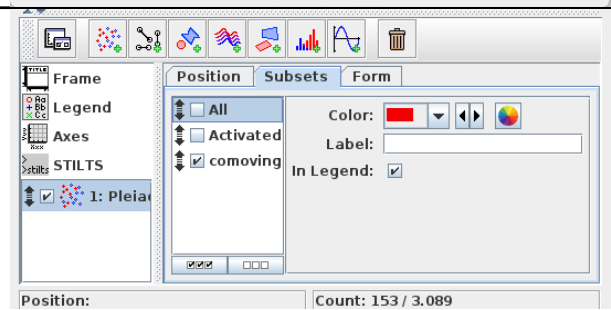
Step 13:

Click on the *Rescale Plot* button on top of the *Plane Plot* window to rescale the plot. Try different options to be familiar with them.
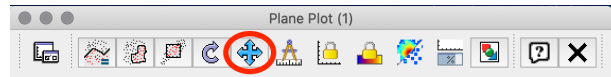
Block 3: Identification of Pleiades members

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

Step 14:

In the TOPCAT main menu, follow: *Graphics → Histogram Plot.*
As an alternative, click on the *Histogram* button of the upper panel in the main window

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Step 15:

In the *Histogram Plot* window, go to the *Position* tab on the bottom right panel, and select the column to be plotted:

- *X*: **parallax**

Step 16:

In the *Subsets* tab, make sure that only the subset **comoving** (and not "All" or "Activated") is plotted.

Step 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, and limited to parallaxes between 6 and 9.
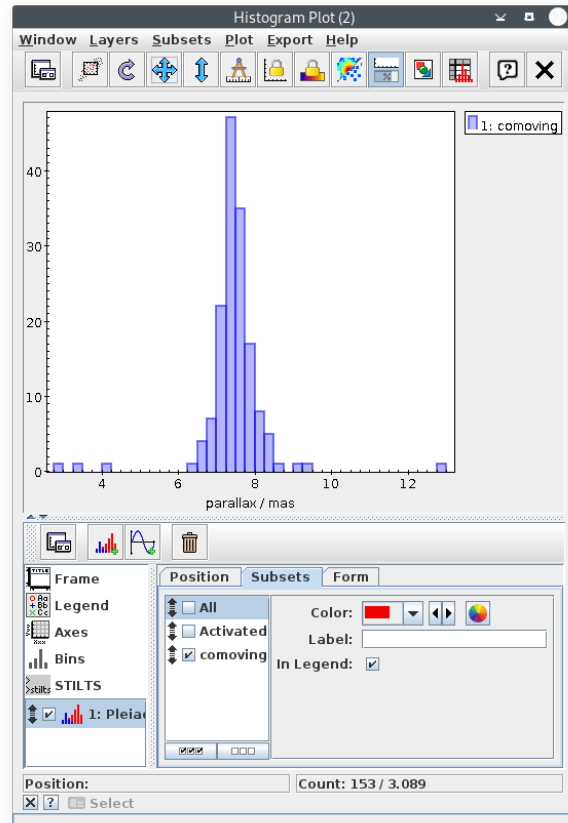
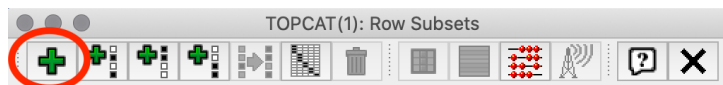**Step 18:**

In the TOPCAT main menu, follow: *Views → Row Subsets*.
As an alternative, click on the *Display Row Subsets* button of the top panel in the main window.
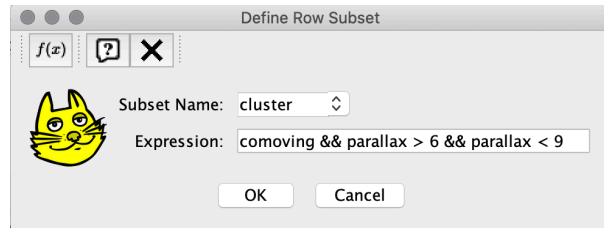

Step 19:

In the *Row Subsets* window, click on the *New Subsets* button. The *Define New Subset* window will pop up. As an alternatively, go to: *Subsets → New Subset i*n the TOPCAT main window,
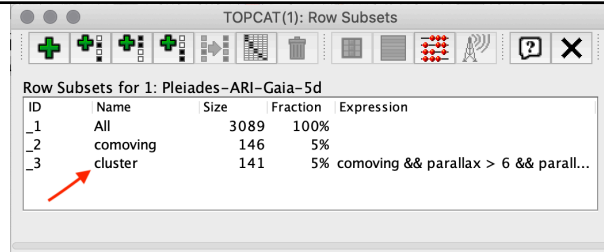
Step 20:

In the *Define Row Subset* window, type:

- *Subset Name*: **cluster**
- *Expression*:
  comoving && parallax > 6 && parallax < 9
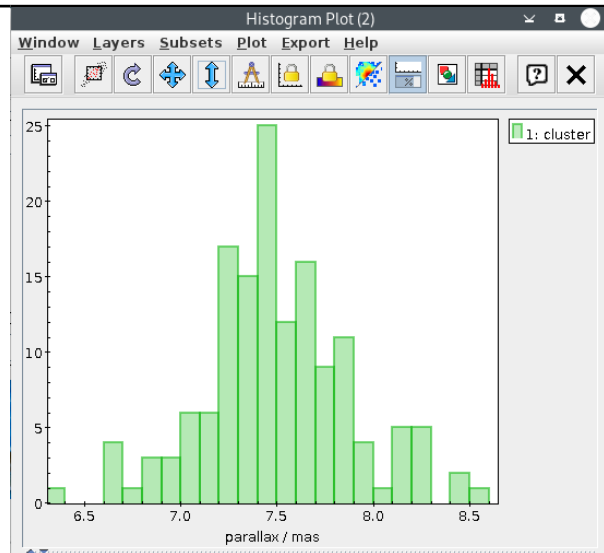- Click *OK.*

Step 21:

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

Step 22:

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

Rescale the histogram to display it conveniently. You can use the *Rescale Plot* button, the mouse wheel or the double-arrow button.

Block 4: Estimate mean parallax and mean distance

Now 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.

Step 23:

In the TOPCAT main menu, follow: *Views → Column Statistics*
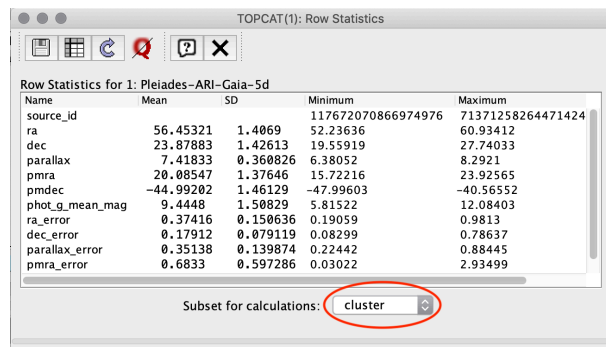As al alternative, click on the *Display Statistics* button of the upper panel in the main window.

Step 24:

In the *Row Statistics* window, select **cluster** as *Subset for calculations*.

Step 25:

Read off the *Mean* and *SD* (standard deviation) of the *parallax* column. How far away is the Pleiades open cluster?

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


Row Statistics for 1: Pleiades-ARI-Gaia-5d

Name	Mean	SD	Minimum	Maximum
source_id			117672070866974976	71371258264471424
ra	56.45321	1.4069	52.23636	60.93412
dec	23.87883	1.42613	19.55919	27.74033
parallax	7.41833	0.360826	6.38052	8.2921
pmra	20.08547	1.37646	15.72216	23.92565
pmdec	-44.99202	1.46129	-47.99603	-40.56552
phot_g_mean_mag	9.4448	1.50829	5.81522	12.08403
ra_error	0.37416	0.150636	0.19059	0.9813
dec_error	0.17912	0.079119	0.08299	0.78637
parallax_error	0.35138	0.139874	0.22442	0.88445
pmra_error	0.6833	0.597286	0.03022	2.93499

Subset for calculations: cluster

Step 26:

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

- Subset Name: **good distance**
- *Expression*:

  cluster && parallax_error/parallax < 0.1

Row Subsets for 1: Pleiades-ARI-Gaia-5d

| ID	Name	Size	Fraction	Expression
1	All	3089	100%	
2	Activated	0	0%	
3	comoving	153	5%	
4	cluster	147	5%	comoving && parallax> 6 && parallax < 9
6	good distance	143	5%	cluster && parallax_error/parallax < 0.1

Step 27:

Look at the histogram. Now the two subsets "cluster" and "good distance" are depicted. You may select only *"good distance"* in the *Subsets* tab of the *Histogram Plot* window.
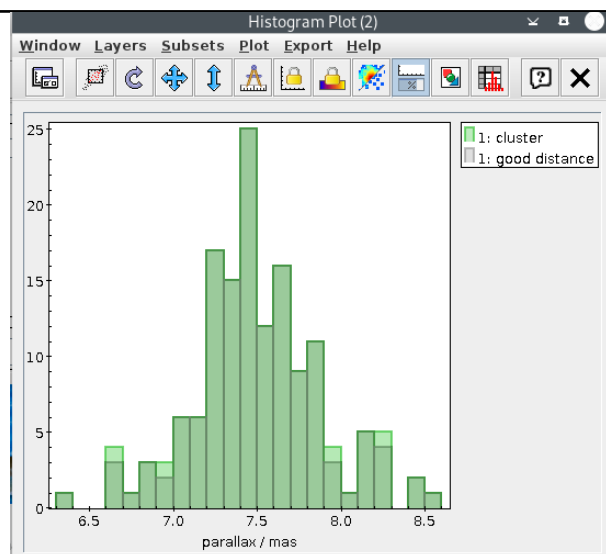
Step 28:

Let's do a Gaussian fit to the parallax distribution:

- In the *Histogram Plot* window, click on the *Subsets* tab. Select only "good distance" subset.
- Click on the *Form* tab.
- 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 *Standard Deviation*. They should be similar (but not equal) to the values obtained in Step 25.
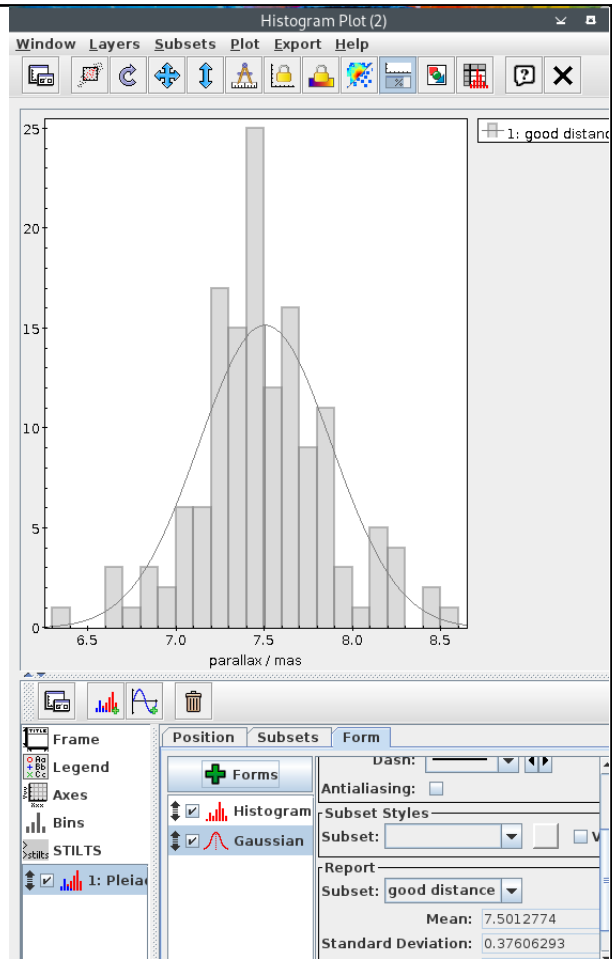
Step 29:

In the TOPCAT main menu, follow: *Views → Column Info.* As alternative, click on the *Display Column Metadata* button of the upper panel in the main window.

Step 30:

In the *Table Columns* window, follow: *Columns → New Synthetic Column.* Optionally, click on the *Add Column* button of the upper panel in this window.

Step 31:

In the *Define Synthetic Column* window, type:

- *Name*: **distance**
- *Expression*: **1000/parallax**
- *Units*: **pc**
- Click *OK.*

Step 32:

Go back to the *Row Statistics* window (like in step 23):
- Set *Subset for calculations*: **good distance**.
- Click on the *Recalculate* button on the top panel of the window.
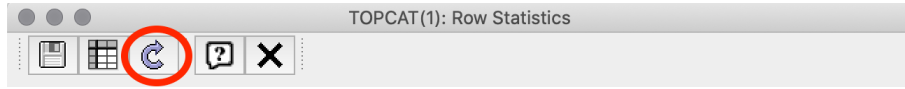
Step 33:

Read off the *Mean* and *SD* (standard deviation) of the *distance* column.

How far away is the cluster? You should have got something close to 134 ± 7 pc.

Step 34:

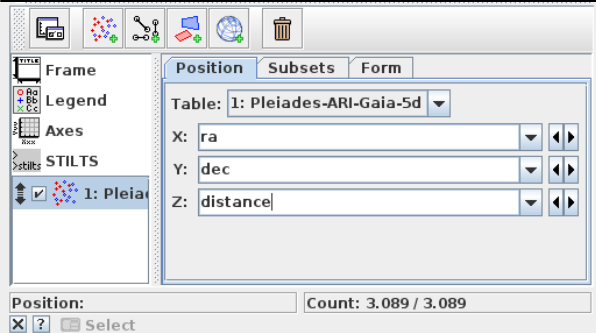In the TOPCAT main menu, follow: *Graphics → Cube Plot.*

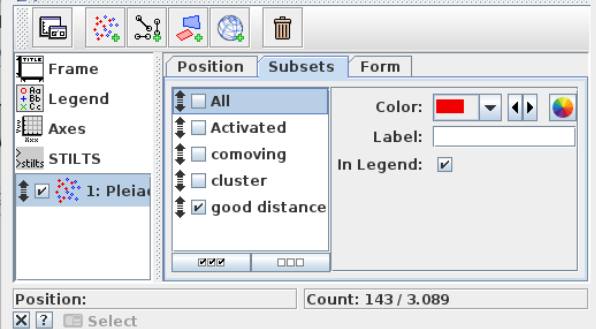Optionally, click on the *Cube Plot* button of the upper panel in this window.

Step 35:

In the *Cube Plot* window, go to the *Position* tab and select the columns to be displayed:
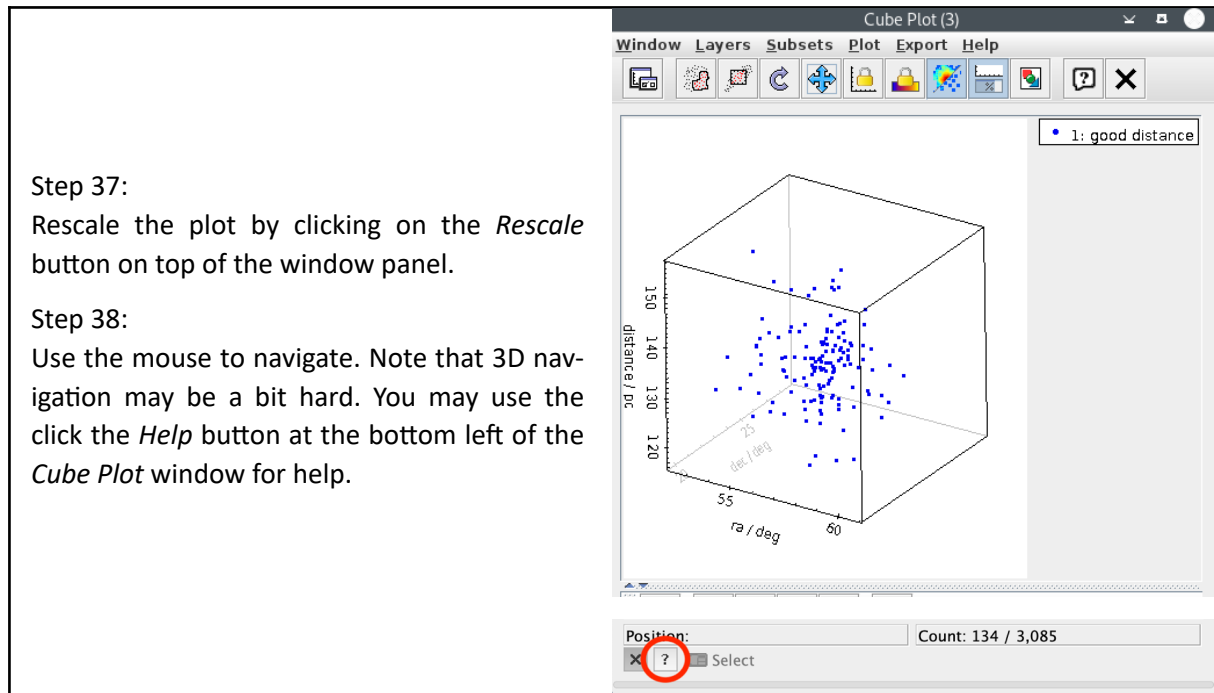- *X*: **ra**
- *Y*: **dec**
- *Z*: **distance**

Step 36:

In the *Subsets* tab of the *Cube Plot* window, make sure that only the subset **good distance** is plotted.

Step 37:

Rescale the plot by clicking on the *Rescale* button on top of the window panel.

Step 38:

Use the mouse to navigate. Note that 3D navigation may be a bit hard. You may use the click the *Help* button at the bottom left of the *Cube Plot* window for help.

*** *end of the tutorial* ***

BONUS

Important 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 Search Parameters* frame:

    - 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).
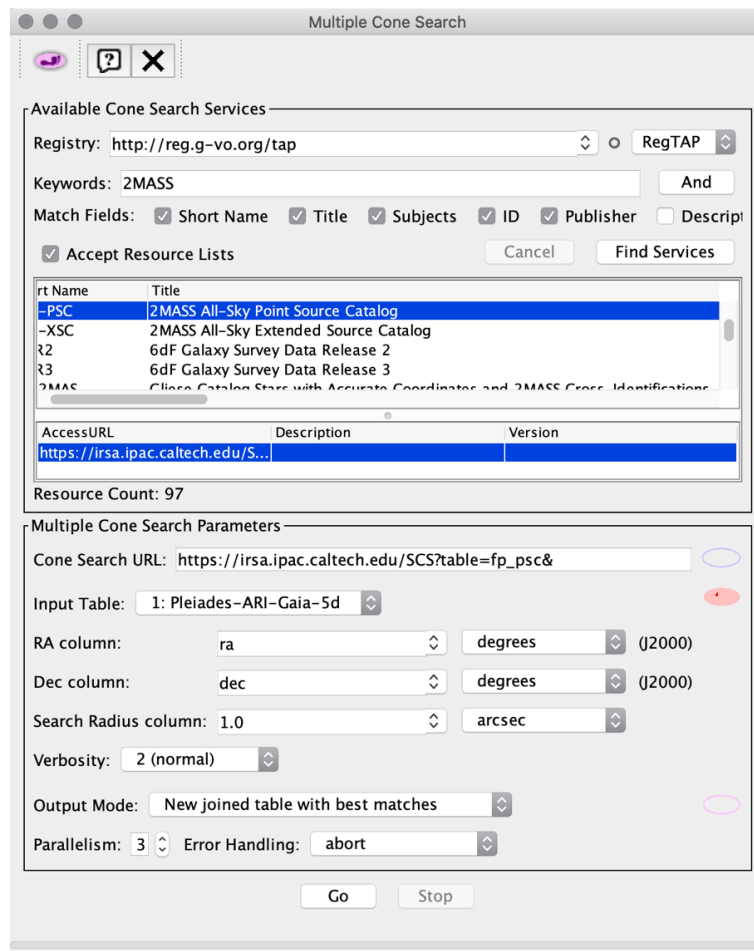
Alternatively, we can perform the cross-match with the 2MASS catalogue following: *VO → CDS Upload XMatch* (or using the corresponding button from the upper panel of the TOPCAT main window). This procedure is more efficient than the multicone, but it only provides a selection of the columns in the catalogue, 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.
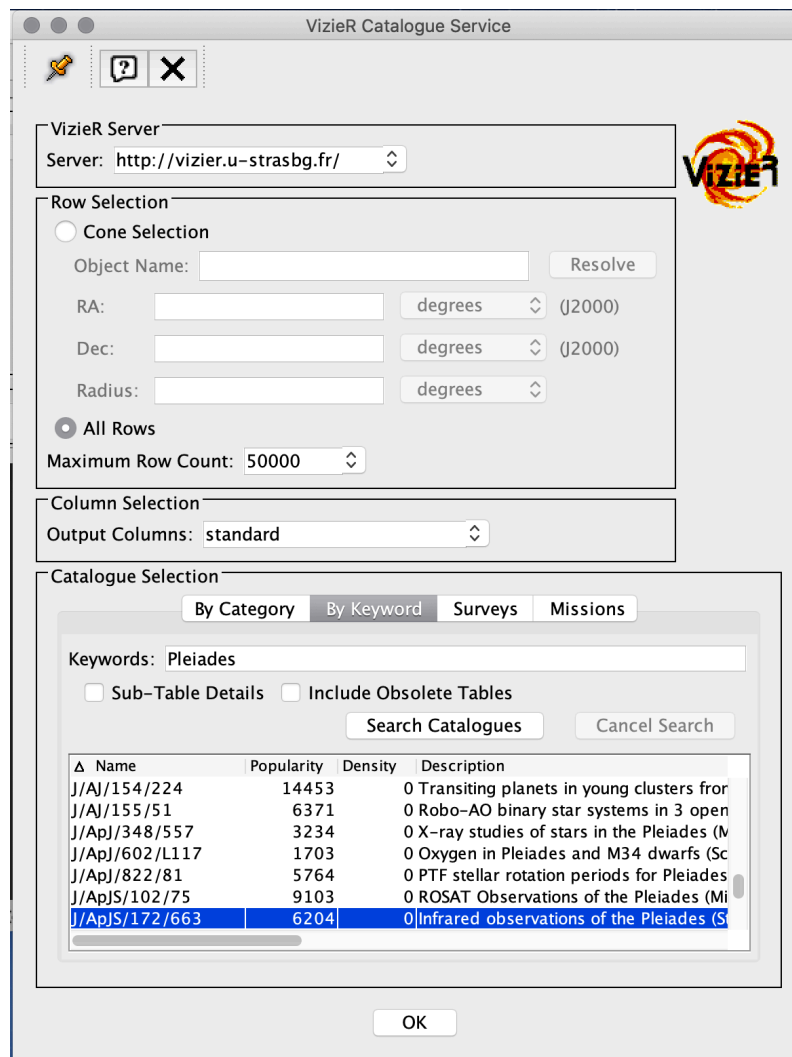
47. Let's now perform the cross-match. In the TOPCAT main menu, follow: *Joins → Pair Match*

(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?
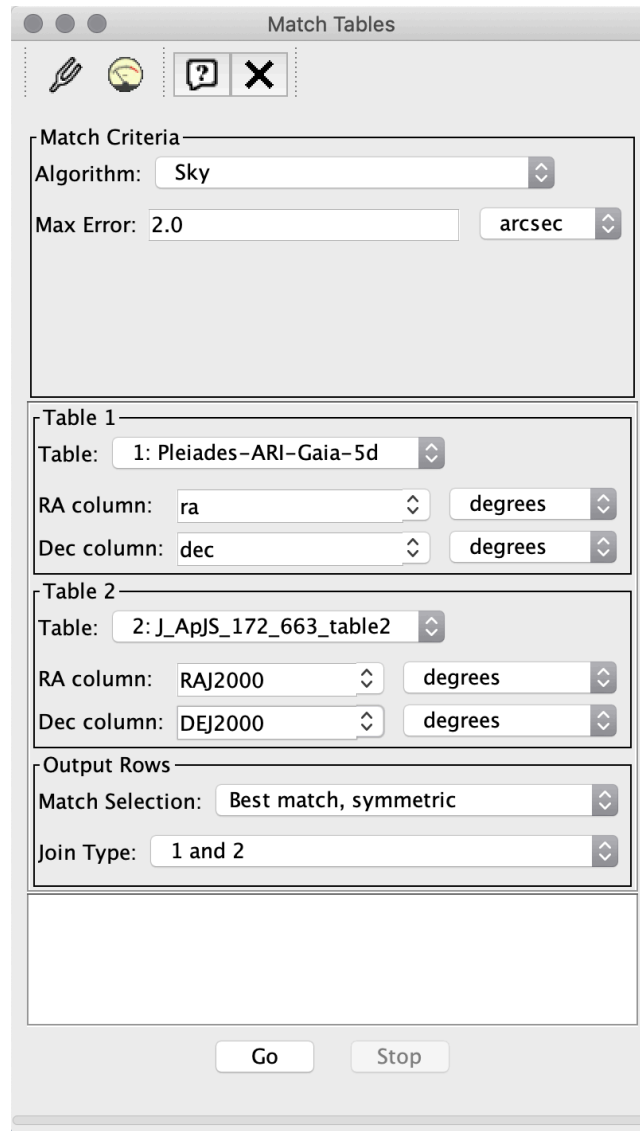
How do these stars look like?

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.
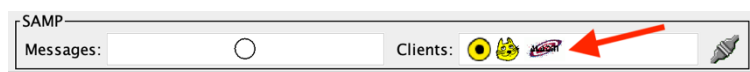
51. Load a sky map (HiPS) in Aladin, for example: Collections → Images → Optical → DSS colored

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.

EVEN 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/