Identifying kinematical members of the Pleiades cluster

A step-by-step Virtual Observatory tutorial using ESASky and TOPCAT

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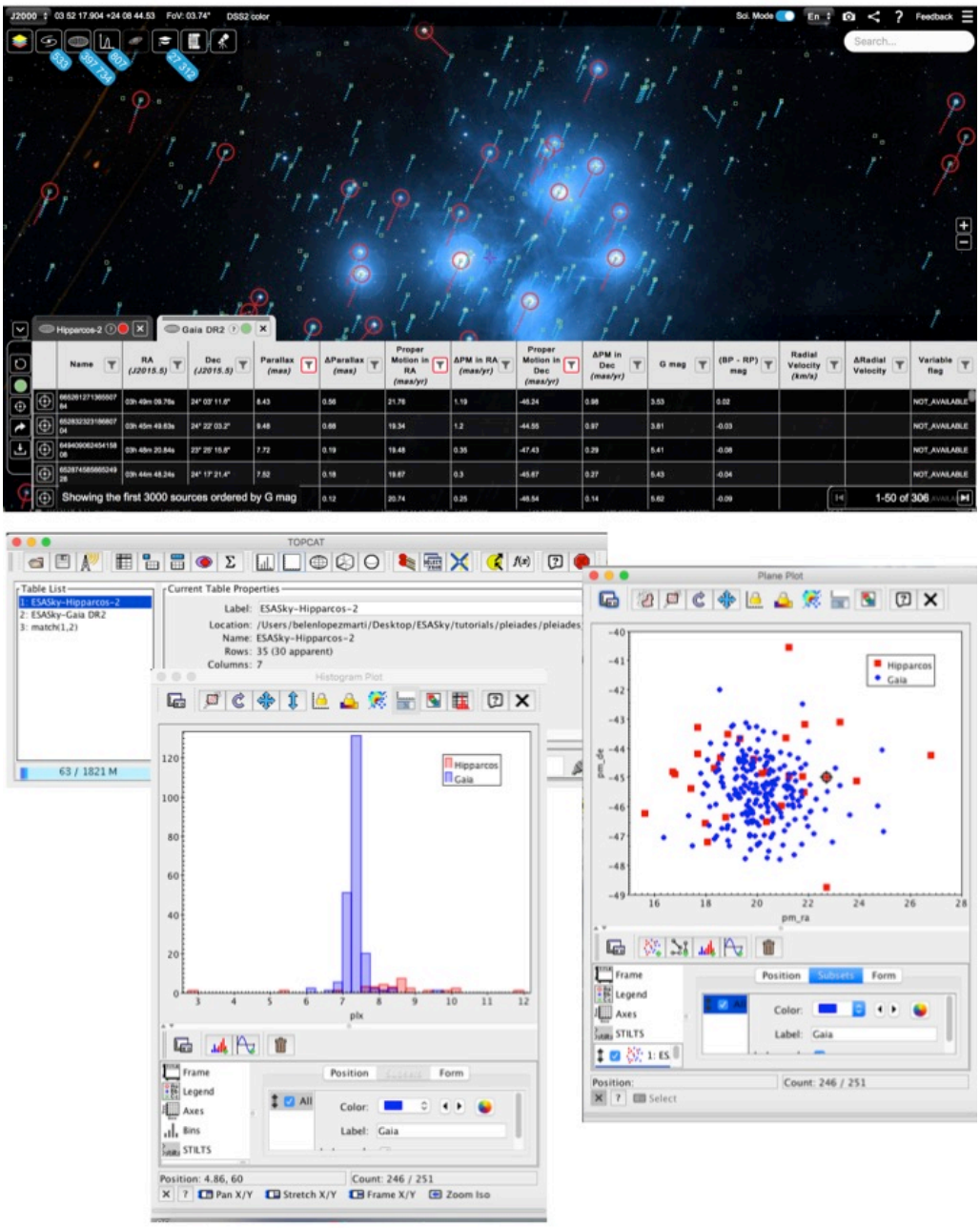

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Description

The goal of this tutorial is to use ESASky and TOPCAT to identify members of the Pleiades cluster based on parallaxes and proper motions from the Hipparcos-2 and Gaia DR2 catalogues. First, the Hipparcos data for the brightest and best-known stars in the Pleiades are used to determine the average parallax and proper motion expected for the cluster members. Then, this information is used to identify more members using the deeper Gaia data.

The tutorial makes use of the data visualisation and filtering functionalities of ESASky, and of the data selection and plotting functionalities of TOPCAT.

For the screenshots, ESASky v3.1 on Safari v12.0 and TOPCAT v4.5 were used, running on Mac OS High Sierra v10.13.6.

Requirements

To successfully carry out the activity, you will need to install TOPCAT in your computer. You can download the tool from:

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

Alternatively, you can use the WebStart version that is provided in the very same page. To access the TOPCAT documentation, go to:

http://www.star.bris.ac.uk/~mbt/topcat/#docs

No installation is required for ESASky. Just open your browser and enter:

https://sky.esa.int

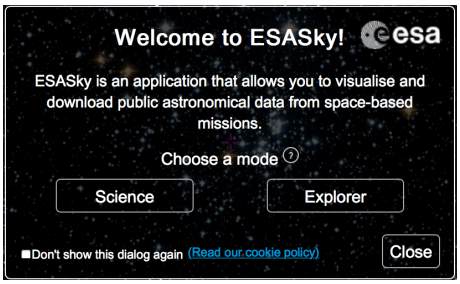
For more information on ESASky, visit:

https://www.cosmos.esa.int/web/esdc/esasky-how-to

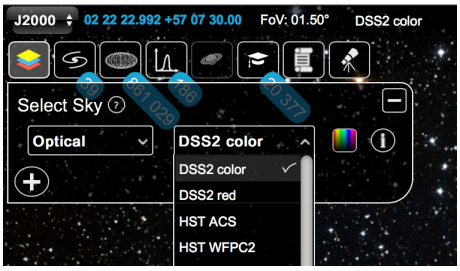
Workflow

STEP 1: VISUALISING THE PLEIADES IN ESASKY

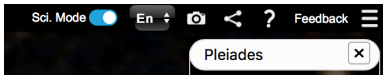
1. Load ESASky by entering the following URL in your browser: https://sky.esa.int/
2. When prompted, choose “Science Mode”.



3. The application will show a random object in an optical sky map. The left side of the top bar displays basic information on the visualised region, including the coordinates and coordinate system (equatorial J2000 or galactic), the size of the field-of-view (FoV) and the displayed sky. If necessary, use the colourful Skies button  on the top left (below the bar) to change the displayed sky to “optical/DSS 2 color”.



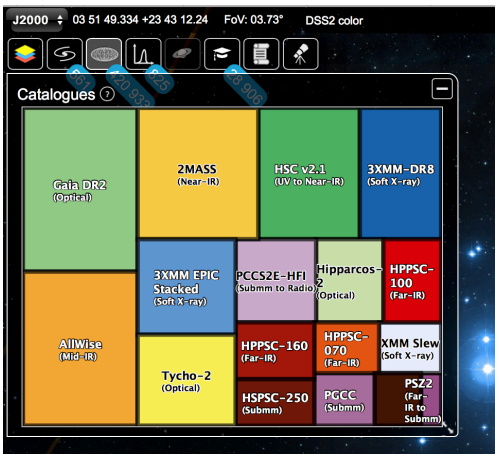
4. Search for the Pleiades by entering “Pleiades” or “M45” in the search box on the top right corner (below the top bar). The region will be displayed.



5. Set the field of view to about 3.7° using the mouse, the trackpad, or the “+/-“ buttons on the right. You should be able to see all the bright members of the “Seven Sisters” asterism.
6. You can explore the region in different wavelengths using the Skies menu. (Note that not all missions have covered the full sky, and therefore, the Pleiades won’t be visible in all maps)

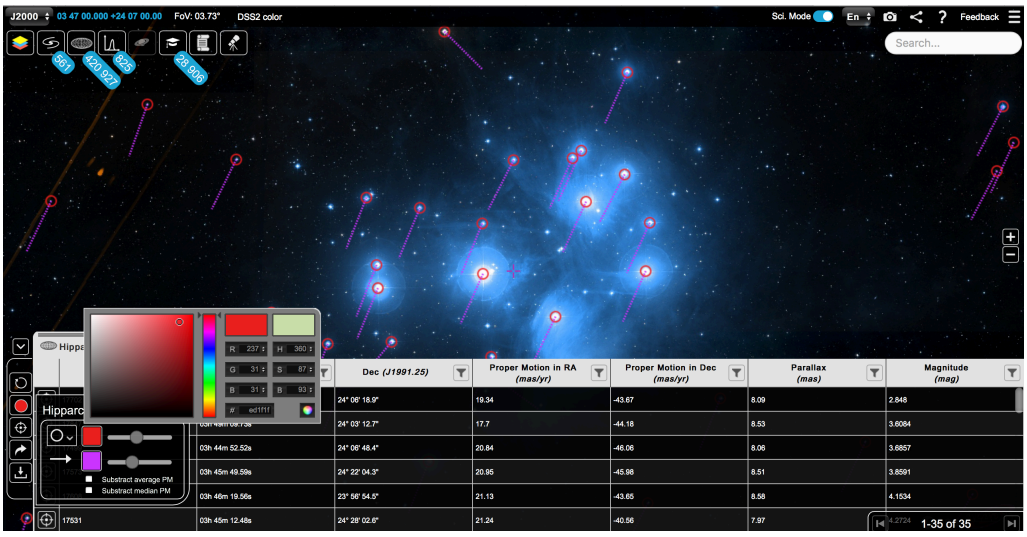
STEP 2: RETRIEVING HIPPARCOS ASTROMETRY FOR THE BRIGHTEST MEMBERS

7. Click on the Catalogues button (below the top bar, the third button from the left). A window will open showing a treemap that summarises the catalogue data available in the visualised region. The size of the box is an indication of the number of sources available.



8. Click on “Hipparcos-2”. A table will open in the bottom part of the window displaying the catalogue information. The position of all sources in the sky will be displayed, with lines indicating the direction of their proper motions.

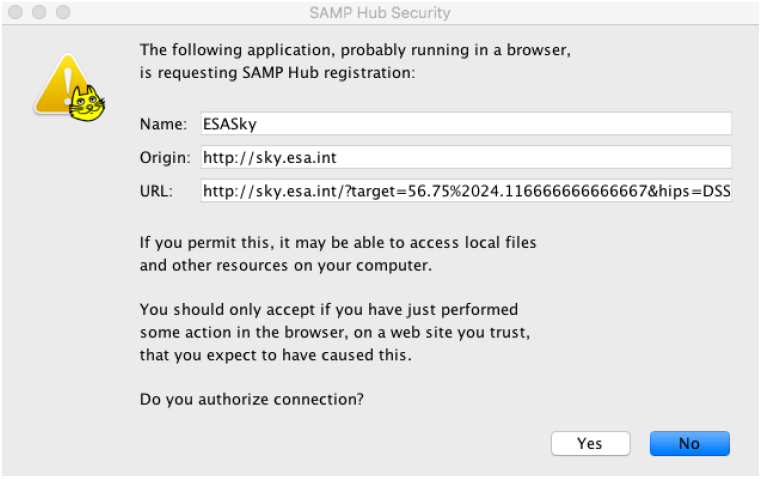
9. Visually inspect the displayed proper motions. If you want, you can customise the shape, size and colours of the symbols and the length and colour of the lines. To do so, click on the button with the coloured circle on the left of the table or, alternatively, on the table tab. Can you recognise the cluster members?



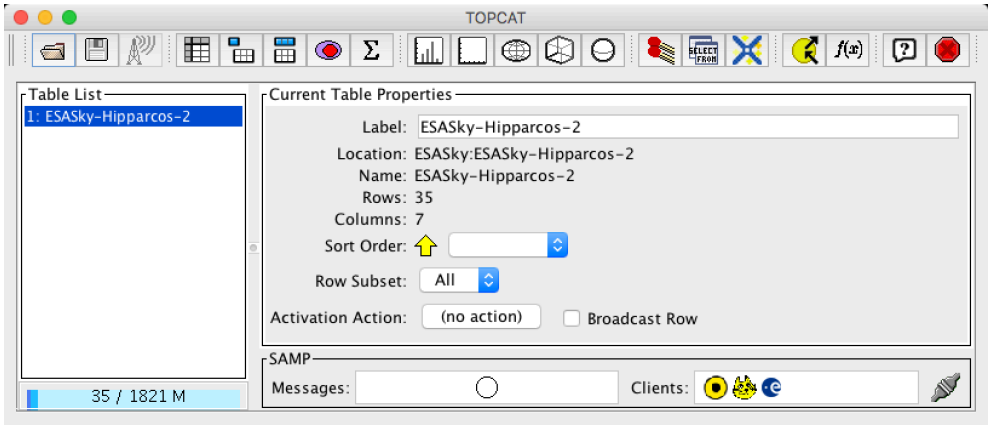
10. You can sort the columns by clicking on the column header, and filter them using the Funnel button . Playing with these functionalities, you can get a first idea of the range of proper motion and parallaxes of the Pleiades members. (Note that you can minimise the table to visualise the complete FoV)

STEP 3: IDENTIFYING THE CLUSTER MEMBERS IN THE HIPPARCOS SAMPLE

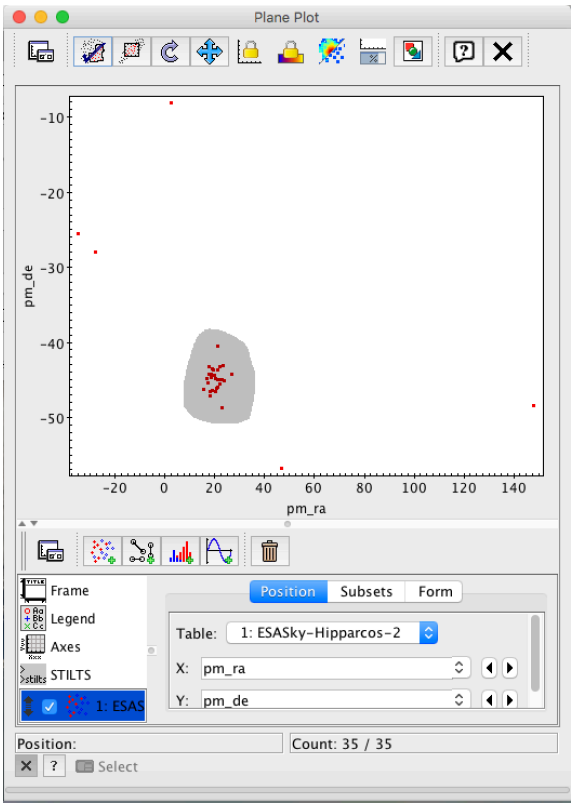
11. Open TOPCAT.
12. In ESASky, click on the Arrow button on the left of the table to send the table to TOPCAT via Simple Application Messaging Protocol (SAMP). A window will pop up asking you to authorise the connection. When accepted, the table will be loaded on TOPCAT.



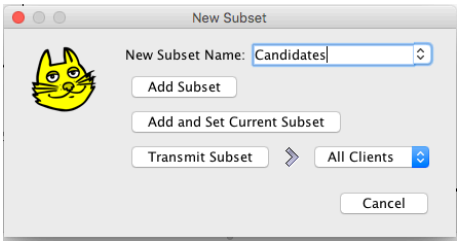
13. The table name will appear in the "Table list" field in the TOPCAT main window. You can view the table content by clicking on the "Display table cell data" button .



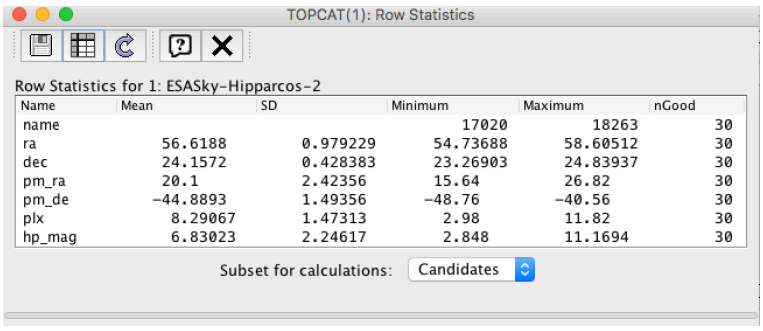
14. In TOPCAT, click on the "Plane plotting window" button . A new window will open.
15. Create a scatter plot of the proper motion in the declination direction (column name: pm_de) versus the proper motion in the right ascension direction (column name: pm_ra). Where are the cluster members in this plot?
16. In the plot, manually select the cluster members: Click on the button "Define subset from drawn region" on the top of the plotting window, and encircle the members with the mouse.



17. Click on the same button again to save the subset. In the pop-up window, enter the name “Candidates” and click on “Add and set current subset”.

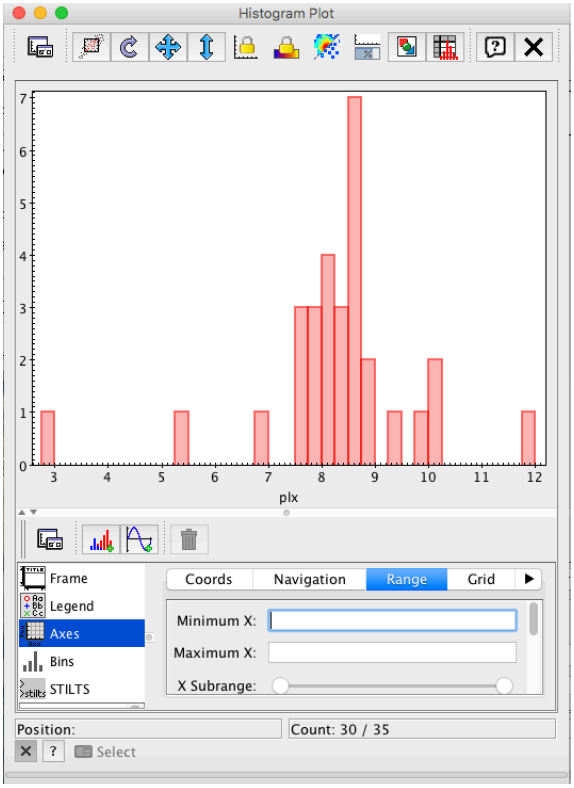


18. Check the statistics for the Candidates subset by clicking on the Σ button of the main window. What are the mean proper motion values in right ascension and declination?

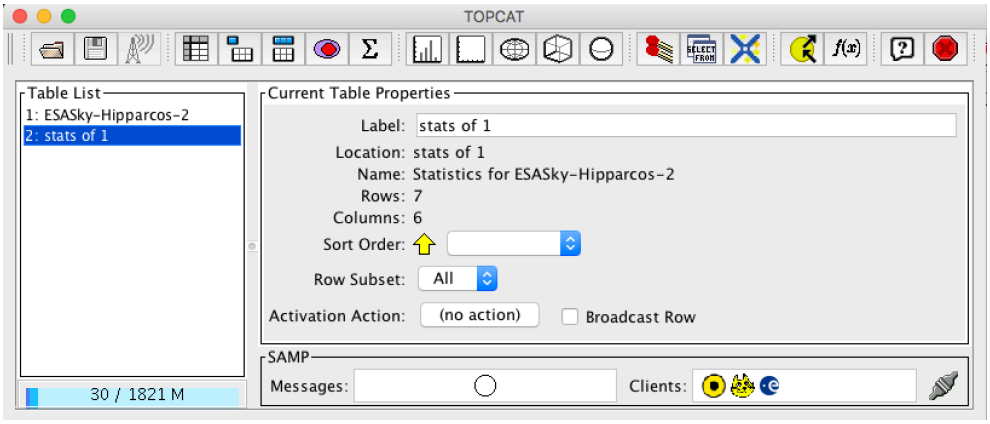


19. Refine the sample by looking at the parallax: Click on the “Histogram” button and create a histogram of the parallax (column name: plx) values for the Candidates subset.

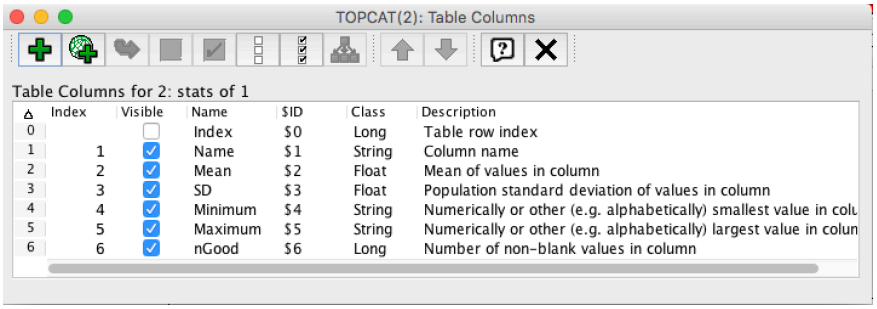
20. Inspect the histogram, and adjust the range to the mean value ± 2σ (as given by the stats window). To do so, select “Axes > Range” and manually enter the minimum and maximum X values.



21. Click on the “Define a new subset” button  and save the visualised subset as “Pleiades”.
22. Check the statistics for the Pleiades sample. What are now the mean values of parallax and proper motions?
23. You can import the statistics into TOPCAT as a new table by clicking on the  button in the statistics window. The table will be listed in the main window below the Hipparcos table as “stats of 1” (if the Hipparcos table is table #1 in your list).



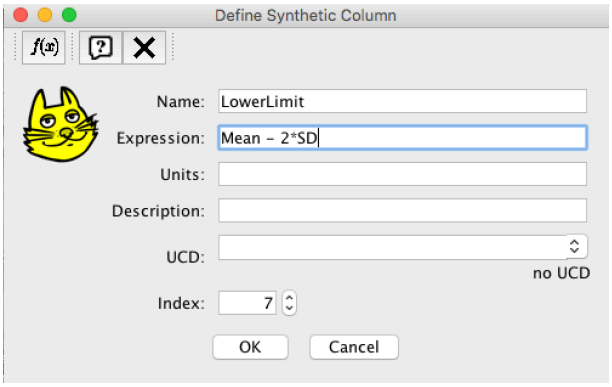
24. For future reference, create two new columns in the statistics table that contain the mean values of the different columns in the original table ± 2σ; these are going to be the limits for the selection of candidates. To do so, select the statistics table in the table list and click on the button "Display column metadata"  . A new window will open listing the column names and properties.



	Index	Visible	Name	$ID	Class	Description
0		☐	Index	$0	Long	Table row index
1	1	☑	Name	$1	String	Column name
2	2	☑	Mean	$2	Float	Mean of values in column
3	3	☑	SD	$3	Float	Population standard deviation of values in column
4	4	☑	Minimum	$4	String	Numerically or other (e.g. alphabetically) smallest value in colu
5	5	☑	Maximum	$5	String	Numerically or other (e.g. alphabetically) largest value in colun
6	6	☑	nGood	$6	Long	Number of non-blank values in column

25. Click on the  button to add a new column. In the pop-up window, enter the name of the new column (for example: "LowerLimit") and the expression:

```
Mean - 2*SD
```



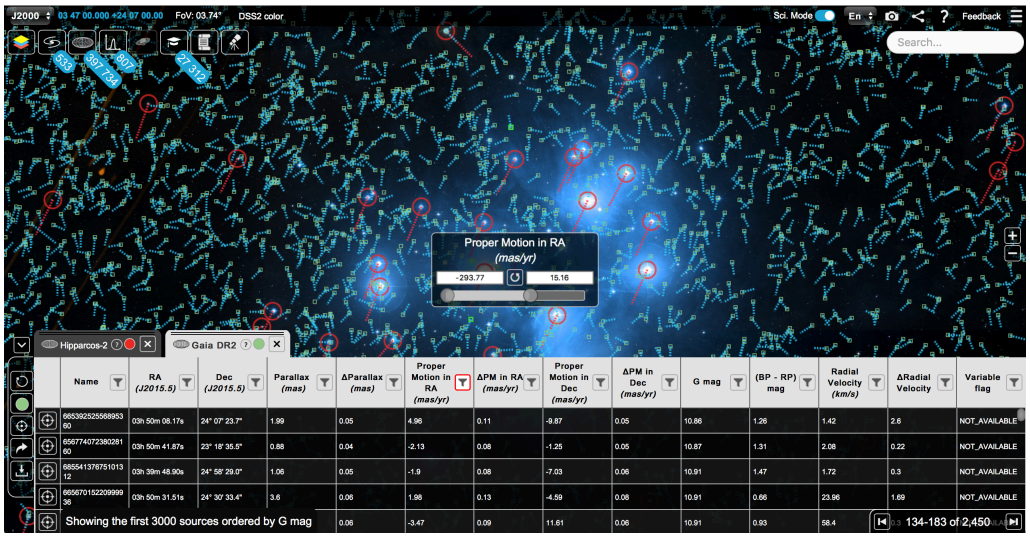
26. Repeat the process to create a column containing the upper limits of the original table columns (you can call this column "UpperLimit"). This time, enter the expression:

```
Mean + 2*SD
```

27. If you want, you can use the new statistics to filter the columns in the original ESASky table and visualise the members of the Pleiades you have just identified.

Step 4: Enlarging the sample with Gaia data

28. In ESASky, open the Catalogues treemap and click on "Gaia DR2". A new table will open.
29. Visually inspect the proper motions of the stars in this catalogue. Filter the proper motion and parallax columns to values around the mean values of the Pleiades sample. Can you identify new candidate members of the cluster?

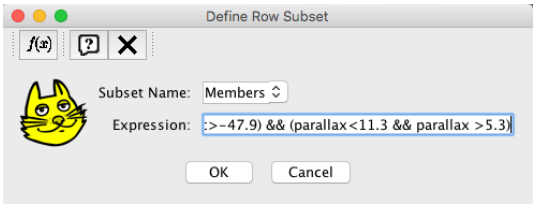


30. Send the Gaia table to TOPCAT via SAMP.

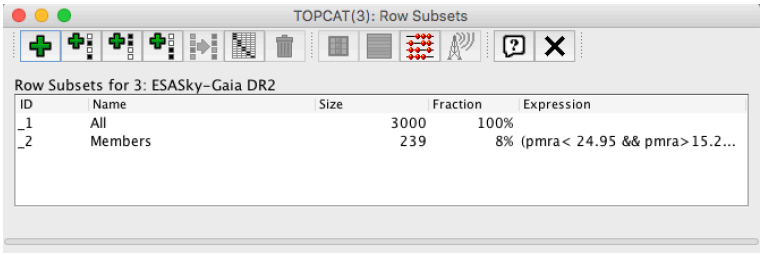
31. In TOPCAT, click on the “Display row subsets” button  of the main window and define a subset of the Gaia sample that contains all sources with proper motions and parallaxes compatible with the Hipparcos Pleiades subset. To do so, click on the  button of the emerging dialogue window and enter the following expression:

```
(pmra < pmra_max && pmra > pmra_min) && (pmdec < pmdec_max && pmdec > pmdec_min)
                && (parallax < plx_max && parallax > plx_min)
```

where pmra_max, pmra_min, pmdec_max, pmdec_min, plx_max and plx_min are the upper and lower limits you calculated for the Hipparcos Pleiades subset in steps 24-26.

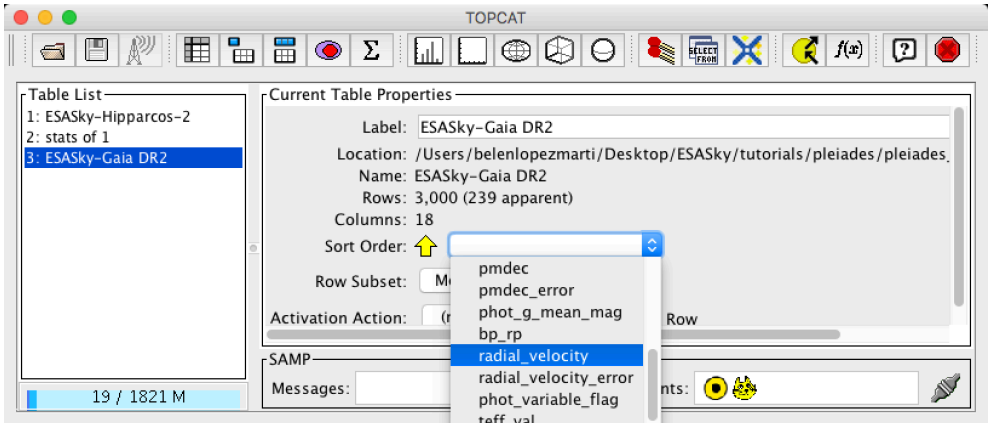


Save this subset with the name “Members”; it will be listed in the row subset window.



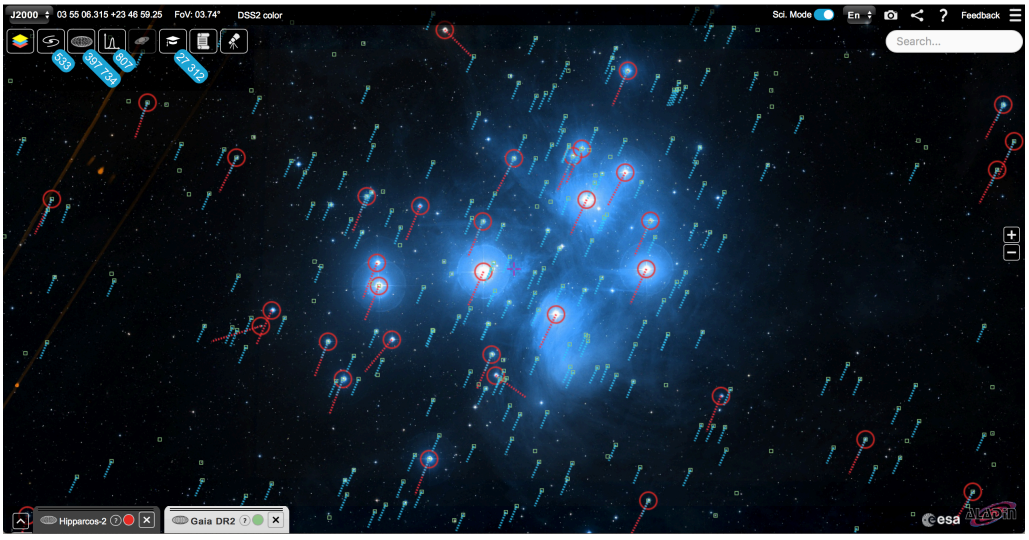
32. Some of the Gaia sources have radial velocity measurements. Plot a histogram of the radial velocities (when available) of the Members subset (column name: radial_velocity). Do you see any clearly discrepant radial velocity value?

33. If you found discrepant radio velocities in the previous step, go back to the TOPCAT main window and make sure that the selected “Row subset” is “Members”. Use the “Sort order” drop-down menu in the main window to sort the table according to radial velocity.



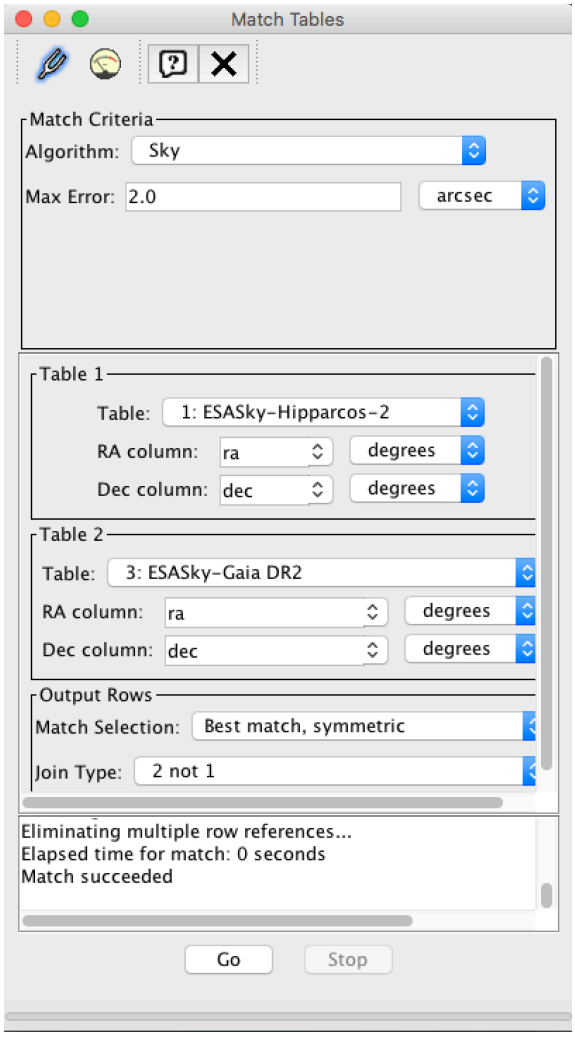
34. Click on the “Display table cell data” button  to display the actual table in a separate window (only the rows from the selected subset will be displayed). Manually select the rows with discrepant radio velocities and click on the button “Define a row subset containing all visible unselected rows”  . You can save this new subset as “Members”, overriding the previous subset.

35. If you want, you can reproduce the filtering from items 31-34 in the columns in the original ESASky table to visualise the members of the Pleiades you have just identified. You will notice that some of the Gaia members are also included in the Hipparcos-2 catalogue.



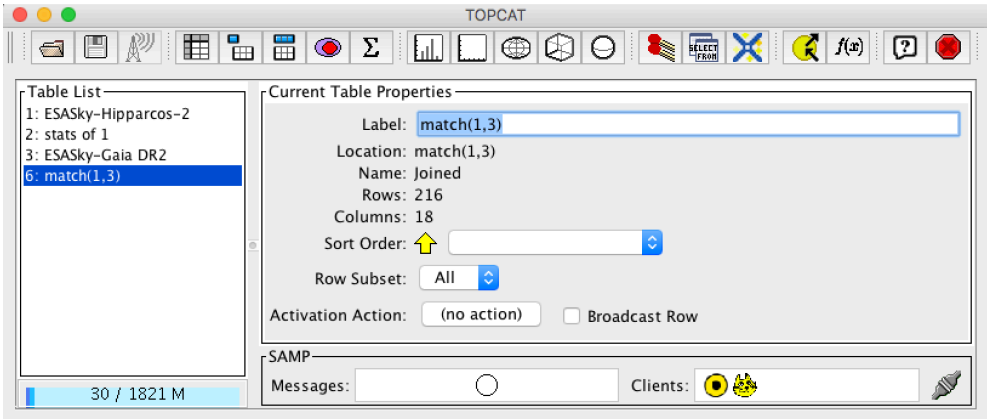
STEP 5: IDENTIFYING THE NEW MEMBERS IN THE GAIA SAMPLE

36. In TOPCAT, click on the Match button  . The table cross-match window will open.
37. Set “Table 1” to the Hipparcos table and “Table 2” to the Gaia table. Make sure that the correct subsets (Pleiades and Members, respectively) are selected in the main window. The coordinate columns will be automatically selected.
38. Set Algorithm to “Sky” (the default) and “Max error” to 2.0 arcsec.
39. Set “Match selection” to “Best match, symmetric” (the default) and “Join type” to “2 not 1”. This option will select all rows in the Gaia Member subset that are not in the Hipparcos Pleiades subset.



40. Click on “Go”. This will create a new table that contains all members from the Gaia Members sample that are not in the Hipparcos sample. In the main window, you can change the name of this table (to e.g. “New members”) by typing the new name in the “Label” field.

41. You can save all tables in the format of your choice by clicking on the “Save” button  (note that, if a subset is selected, only that subset will be saved). Alternatively, you can also save the full session in case you want to resume your work at some other time.



STEP 6: INSPECTING THE PROPERTIES OF THE PLEIADES MEMBERS

42. Plot the Hipparcos Pleiades subset in a proper motion graph like the one you created in items 14-15. Click on the “Add a new positional plot” button  in the plotting window to plot the Gaia Members sample in the same graph. Repeat the process with the New Members sample. How do the proper motions of the new members compare to the old members?
43. Plot the Hipparcos Pleiades sample in a parallax histogram graph like the one you created in item 19. Click on the “Add a new histogram” button  in the plotting window to plot the Gaia Members sample in the same graph. Repeat the process with the New Members sample. How do the parallaxes of the new members compare to the old members?
44. Create a new histogram plot to compare the G-magnitudes (column name: phot_g_mean_mag) of the full Gaia Members sample with those of the New Member sample. How do the magnitudes of the new members compare to the old members?
45. Open a new plotting window and create a (BP-RP, G) colour-magnitude diagram (CMD) for the full Gaia Members sample and the New Member sample (column names: bp_rp and phot_g_mean_mag. Can you see any trend in this diagram?

Other things you can do

- Query other catalogues in ESASky, then use TOPCAT to cross-match the tables and retrieve photometry for your sources. You can plot and compare different CMD to learn more about the properties of the cluster members.
- Use the TOPCAT “VO” functionalities to perform a cross-match of the New Members sample with SIMBAD using the CDS X-match service and check if you have some truly new members in the sample. Later, you can upload the list of SIMBAD names to ESASky (by clicking on the Parchment button  and then on “Upload Target List”) and use the Publications functionality (accessed by clicking on the Academic Hat button ) to scan the available publications for each object.
- Use the TOPCAT “VO” functionalities to make a multicone search of literature catalogues (by entering the keyword “Pleiades”) and get more data for your sources.