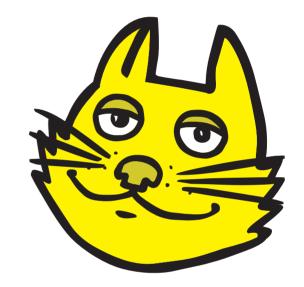
Introduction to TOPCAT

Mark Taylor (University of Bristol)



NADC New Year Lecture Series Online

11 January 2021





\$Id: topcat.tex,v 1.7 2021/01/10 10:15:52 mbt Exp \$

Outline

TOPCAT

- What is it?
- What can it do?

Demos with Gaia EDR3

- Pleiades proper motions using Cone Search
- Hyades in 3D velocity space using TAP

Questions & Answers

Overview

TOPCAT = Tool for OPerations on Catalogues And Tables

"Does what you want with tables"

Suitable for:

- Interactive exploration
- Quick look at unfamilar data
- In-depth analysis

Overall aim:

• Makes table manipulation easy, so users can concentrate on doing science

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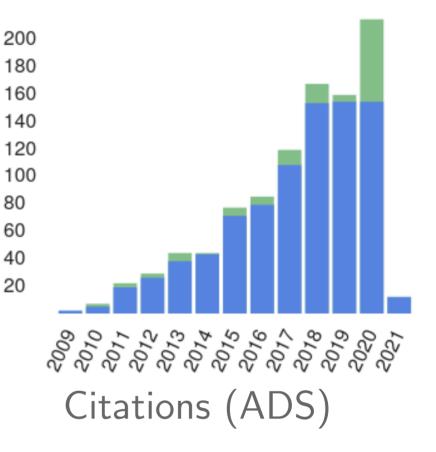
- Developed more or less continuously since ${\sim}2003$
- Funded by numerous agencies/projects
 - ▷ STFC/PPARC, Starlink, AstroGrid, Euro-VO, ESA, Gaia, Heidelberg
- Associated with (but not tied to) Virtual Observatory

Usage

- Cited by \sim 1000 papers (2005ASPC..347...29T)
- Run from ${\sim}700$ unique IP numbers per day

Development

- Platform: desktop pure Java (easy deployment)
- Open source, currently (L)GPL: https://github.com/Starlink/starjava/
- Development team: just me (easy project management)
- Issue management: github, mailing list, personal emails etc
 - ▷ Try to work out/guess what features most users want
 - \triangleright Do easy things first
 - ▷ Try not to break/get in the way of existing functionality
- Short development cycle, encourage user involvement



Characteristics

Aims:

- User-friendly
 - ▷ Easy to install and run (pure Java one download file, no library issues)
 - ▷ Easy to get started
 - Simple things fairly obvious
 - Complicated things at least well-documented
 - ... this does get harder as more functionality is added
- High Performance
 - ▷ Most things are fast
 - ▷ Handles quite large tables: millions of rows, hundreds of columns easily (can be much more)
 - \triangleright ... even on modest hardware
 - ▷ Recent/upcoming versions: better use of multi-core machines
- Do the things that astronomers need
 - ▷ Development is led by community input (mailing list, personal emails, tutorials, feature requests, bug reports...)
 - Feedback always welcome!

Capabilities

It can do:

- Read/write tables in various formats (FITS, VOTable, CSV, ...)
- View data
- View metadata
- Calculations and simple statistics (expression language)
- Visualisation (many options, interactive)
- Make/combine/display row selections in various ways (linked views)
- Crossmatching (many options)
- Access external data services (VO and others)
- Talk to other astro tools (SAMP)
- Trigger some event when a row is selected

It can't do:

- Images, spectra (it's only for tables)
- Scripting (but see STILTS)
- Very large tables (but see STILTS)
- All possible file formats
- Do astronomy for you

Table Data and Metadata

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Column Metadata view

Row Selections

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File Subsets Help

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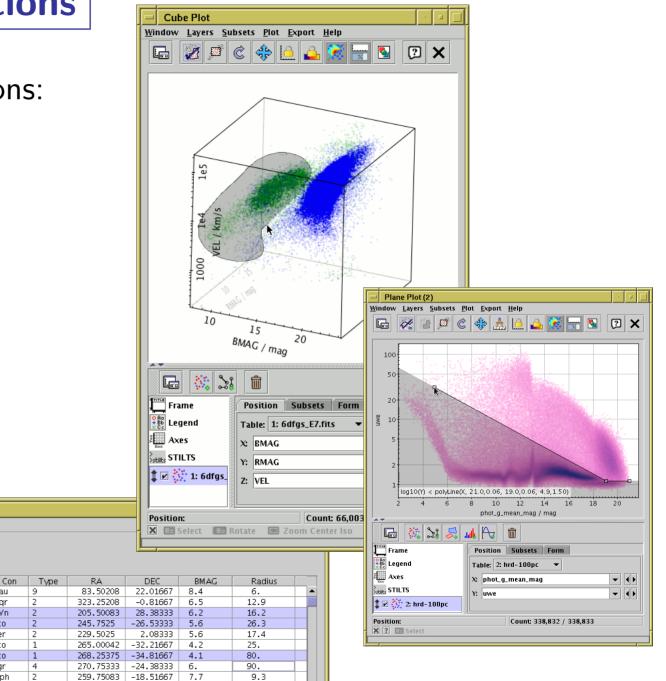
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Different ways to make single or multiple row selections:

- Select points graphically from a plot (freehand or polygon)
- Select rows from the table view
- Use an algebraic expression
- Combine existing subsets
- Receive from an external application (SAMP)

Linked views mean a selection made one way is visible in other ways

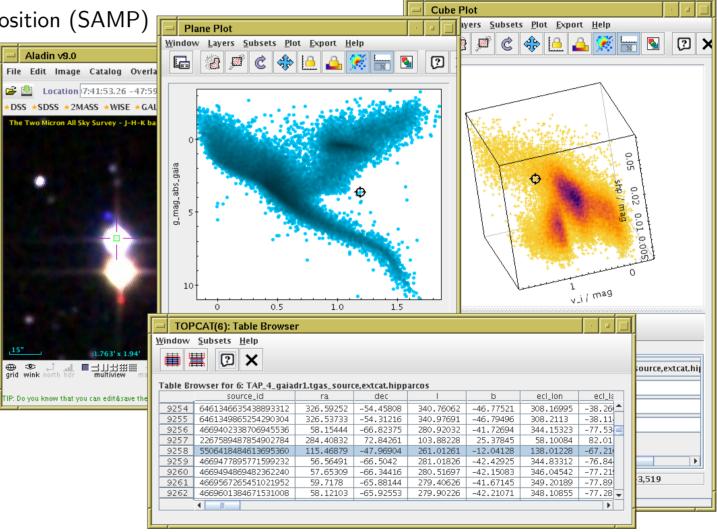
- Perform crossmatch only on items in red giant branch
- Where on the sky is this colour cut?
- Spot outliers
- Identify objects on ds9 image display



Row Highlighting

Row selection is coordinated between linked views:

- Click on row in table browser or plot
- Same row is highlighted in other plots & table browser
- Can configure external tools to highlight same object/position (SAMP)



Calculations

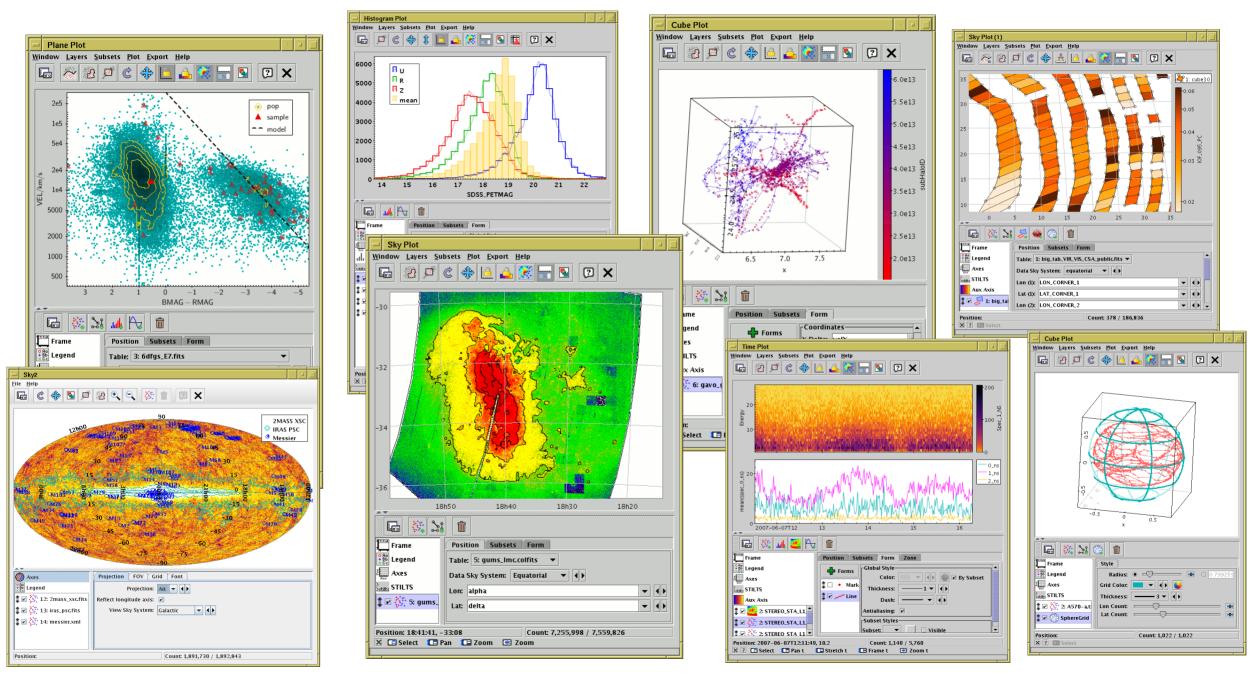
- Expression language used for creating columns, defining selections, making plots etc:
 - Straightforward arithmetic syntax (C-like)
 - Use column names as variables
 - Standard arithmetic operators (+, -, /, *)
 - Standard mathematical functions (abs, max, round, sin, cos, pow, ...)
 - Conditional expressions (q?a:b)
 - Sky coordinates (degrees, sexagesimal, sky distances)
 - Astrometry (epoch propagation with/without errors, ...)
 - Cosmological distances (redshift, luminosity dist, lookback time, ...)
 - Fluxes (Johnson AB Magnitudes, Jansky)
 - Time conversions (ISO8601, MJD, Julian, Besselian)
 - ... and more (and it's extensible)
- Examples:
 - mag_u mag_g
 - janskyToAb(flux)
 - skyDistanceDegrees(ra, dec, 14.1, -72.9) < 1.2

Visualisation

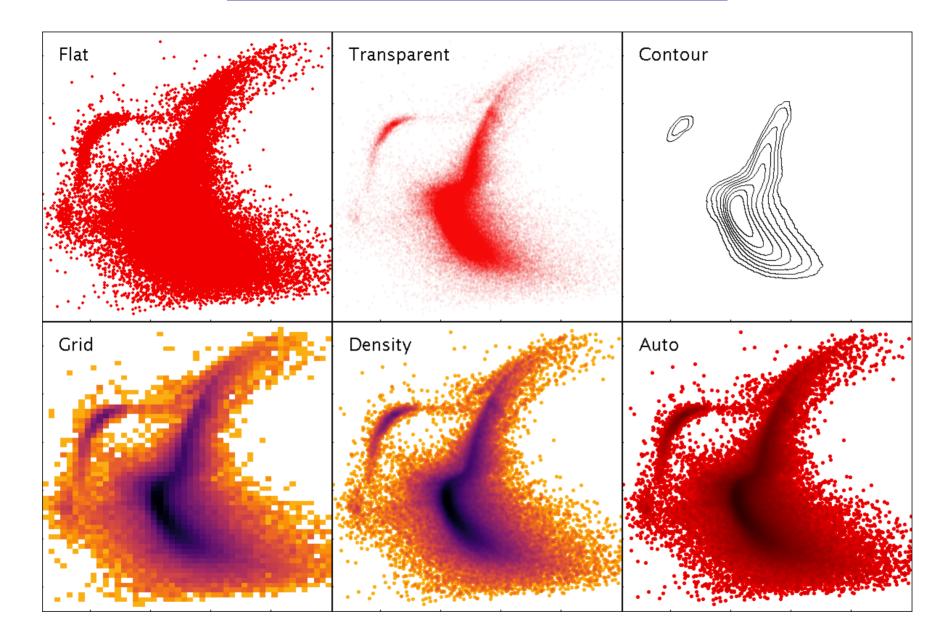
Very good for interactive exploration of large (or small) datasets:

- Many plot types!
 - 2d/3d scatter plots, histograms, HEALPix, density maps, error bars/ellipses, vectors, lines, quantiles, text labels, contours, KDEs, analytic functions, spectrograms, ...
- Many options!
 - Colour, colour maps, shading mode, weighting, marker shape/size line style, sky projection, sky system, coordinate grid, axis labelling, smoothing, binning, ...
- Highly responsive
 - ▷ Interactive changes to options update plot immediately
- Special attention to large data sets
 - Plot arbitrarily large datasets in fixed memory
 - ▷ Represent very dense plots in comprehensible ways
 - Many options for high-dimensional visualisation
- Publication-quality output?
 - ▷ Export to PDF, EPS, PNG, SVG (coming soon), ...
 - ▷ Optional LaTeX annotation
 - ▷ Script output (STILTS) for reproducibility
 - $\triangleright \ \ldots$ but not quite as good as Matplotlib/IDL/R

Visualisation: Plot Types



Visualisation: Dense plots



Different options for shading scatter-plot data.

Crossmatching

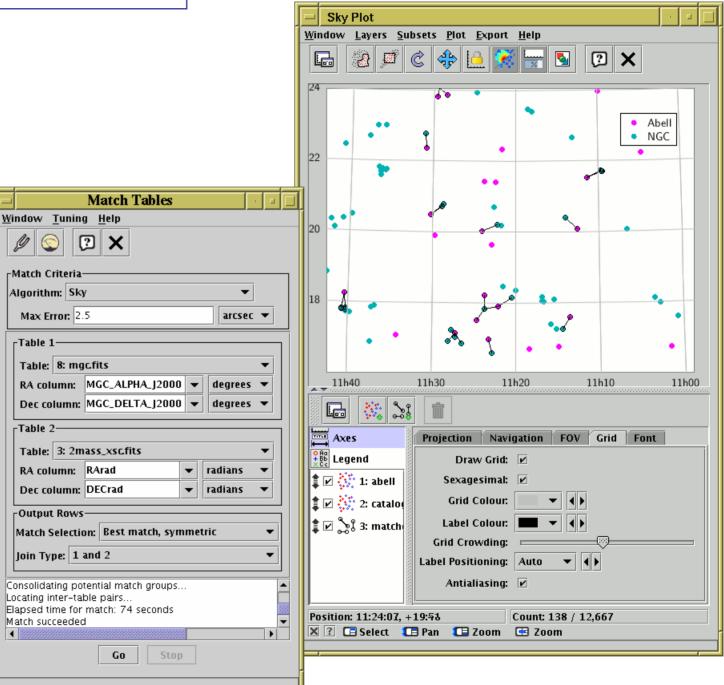
Internal

- Both/all files loaded into TOPCAT
- Works well up to ${\sim}1$ million rows each
- Pretty fast (<couple of minutes)
- Very flexible (sky, Cartesian, exact, 3D, ellipses, errors, combinations...)

External

- One or both tables too big to download
- Several options, with different pros and cons:
 - CDS X-Match (any VizieR table, sky match, fast, easy)
 - Multiple cone search (many tables available, sky match, slow)
 - ⊳ TAP

(few tables available, flexible, tricky)



Virtual Observatory



What is the Virtual Observatory (VO)?

- "All astro archives in your computer"
- A set of protocols that allows software clients to talk to external data services in a uniform way
- In most cases you (the software user) don't need to understand the details, but it's under the hood making data access work

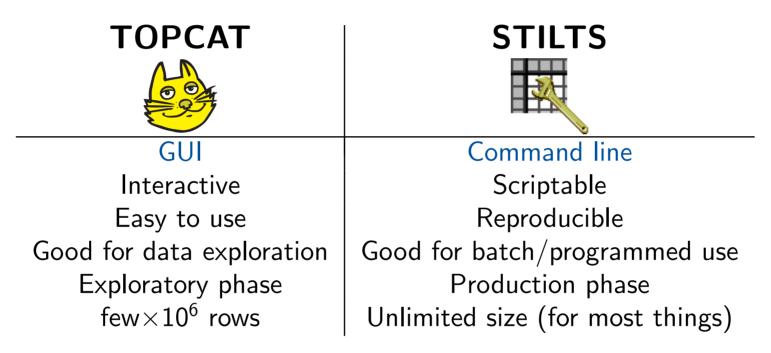
External data access from TOPCAT:

- Cone Search: positional query of remote catalogue
- Table Access Protocol (TAP): SQL-like queries against remote databases
- Simple Image Access/Simple Spectral Access: positional query of image/spectrum archives
- CDS services: Simbad, VizieR cone/all-sky, X-Match, Hips2fits
- Registry: service discovery
- SAMP: communication with other desktop/web applications



STIL Tool Set (STIL = Starlink Tables Infrastructure Library)

- Has pretty much the same capabilities as TOPCAT
- but works from the command line (also JyStilts from Jython)



Typical usage:

- start off with TOPCAT
- maybe move on to STILTS for more specialised requirements
- TOPCAT STILTS control helps constructing plot commands

Further Information

TO <u>File</u><u>H</u>e

Find: S • 20 • 11

- There are things I haven't mentioned!
- Full tutorial and reference documentation:
 - ▷ HTML/PDF manual on web page

http://www.starlink.ac.uk/topcat/ (or search for "topca

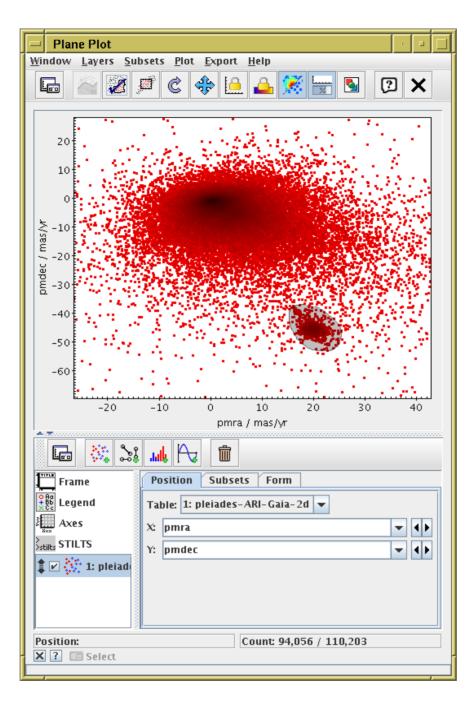
- ▶ **Help for Window** button **(?)** on every window
- Help browser includes search tool \triangleright
- More options in Help Menu (including Help for Window in Browser \triangleright
- ▷ Or print out the 500-page manual
- Support by email:
 - ▷ on list: topcat-user@jiscmail.ac.uk
 - > in person: m.b.taylor@bristol.ac.uk
 - All feedback and questions welcome!

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	Next Previous Up Contents Next: <u>Supported Input Formats</u> Up: <u>Table I/O</u> Previous: <u>Table I/O</u>	
	4.1 Table Formats	
	TOPCAT supports a wide variety of tabular data formats. In most cases these are file formats for tables stored single files on a disk or at the end of a URL, but there are other possibilities, for instance a table you have op could be the result of an SQL query on a database.	
	Since you can load a table from one format and save it in a different one, TOPCAT can be used to convert a ta from one format to another. If this is all you want to do however, you may find it more convenient to use the t command line utility in the <u>STILTS</u> package.	
pcat")	The format handling is extensible, so new formats can be added fairly easily. All the table input/output is hand by STIL, the Starlink Tables Infrastructure Library; more detailed descriptions of the I/O capabilities can be fou its <u>documentation</u> .	
	The following subsections describe the available formats for reading and writing tables. The two operations a separate, so not all the supported input formats have matching output formats and vice versa.	are
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• 7 TOPCAT Command-line A	Control Window SAMP Panel	
• 7 Activation Window	If TOPCAT is running in SAMP mode, the SAMP panel at the bottom of the	
7 Messages Received	Control Window gives a quick view of the current status of SAMP	
 6 System properties 3 Control Window 	communications. For a discussion of the whats and whys of SAMP, see	
3 Toolbar Buttons	Section 9. Note that if not running in SAMP mode (e.g. if in PLASTIC or no-server mode) this panel will not appear. SAMP mode is the default	
2 TOPCAT Windows	under normal circumstances.	
• 1 Other Windows		
 1 Subsets Window 1 Current Table Properties g 	The panel is made up of the following main parts:	
• 1 Session	Message View	
 1 Virtual Observatory Access 	This shows a graphical representation of any messages which have 👻	
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Demo 1: Pleiades in Gaia and 2MASS

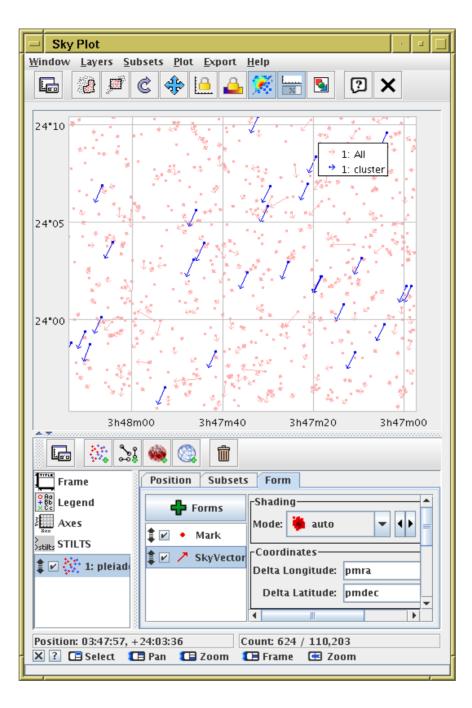
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Acquire Gaia DR2 data in the region of the Pleiades using the Cone Search window

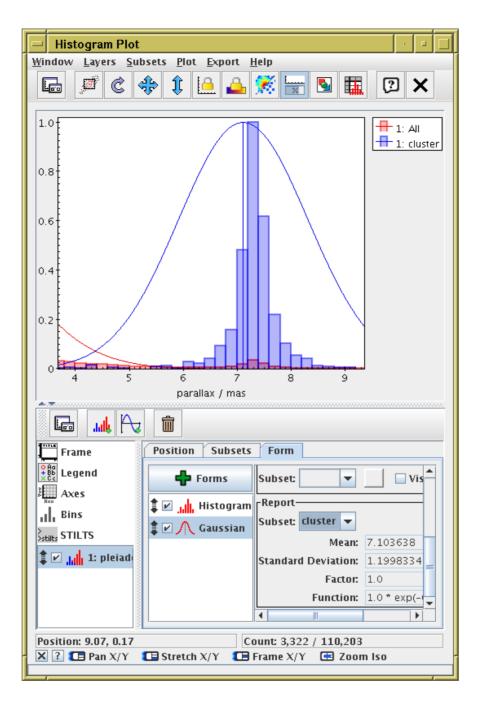


Plot the points in proper motion space,

and select the comoving sub-population graphically to create a new subset

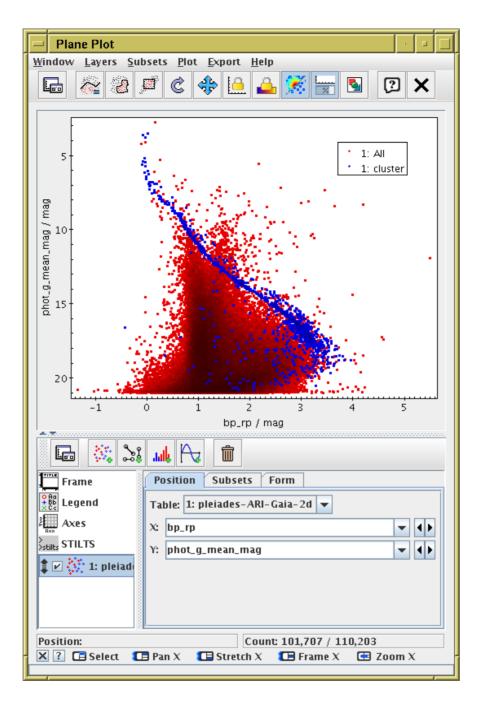


Plot the background and cluster objects on the sky with their proper motion vectors



Plot a histogram of the background and cluster objects.

Fit a Gaussian to calculate mean parallax hence distance of cluster objects: $1000/7.1 \, {
m mas} \simeq 140 \, {
m pc}$.



Plot colour-magnitude diagram using Gaia photometry for cluster and background objects

CDS Upload X-Match	· • 🗆					
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Find 2MASS associations for cluster objects using CDS X-Match window

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ļ.		Window Rows Help		Send Sky Coordinates	Hips2Fits service provided by CDS.	
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Plot colour–colour diagram using Gaia and 2MASS photometry (Gaia bp_rp vs. 2MASS Jmag - Kmag) and investigate outliers. Colour points using distance from mean cluster parallax; darker ones are PM interlopers.

Set up Activation Action **Display HiPS Cutout**; use survey 2MASS/color.

Click on point of interest for linked view: in table display and 2MASS imagery in image window.

Demo 2: Hyades in 3D using TAP

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	FROM gaiaedr3.gaia_source			
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	AND parallax_over_error > 5	NULL I		
	AND dr2_radial_velocity IS NOT	NULL		
				17
	Examples ()			Info

Use ESA Gaia TAP service Investigate metadata Load position and velocity information for nearby sources:

SELECT ra, dec, pmra, pmdec, parallax, dr2_radial_velocity, bp_rp, phot_g_mean_mag + 5*log10(parallax/100) as g_abs FROM gaiaedr3.gaia_source WHERE parallax > 15 AND parallax_over_error > 5 AND dr2_radial_velocity IS NOT NULL

Define Synthet	ic Column
<u>W</u> indow <u>H</u> elp	
f(x) 🖓 🗙	
? Name:	uw
Expression:	icrsToGal(astromUVW(array(ra, dec, parallax, pmra,
Units:	km/s
Description:	
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	OK Cancel

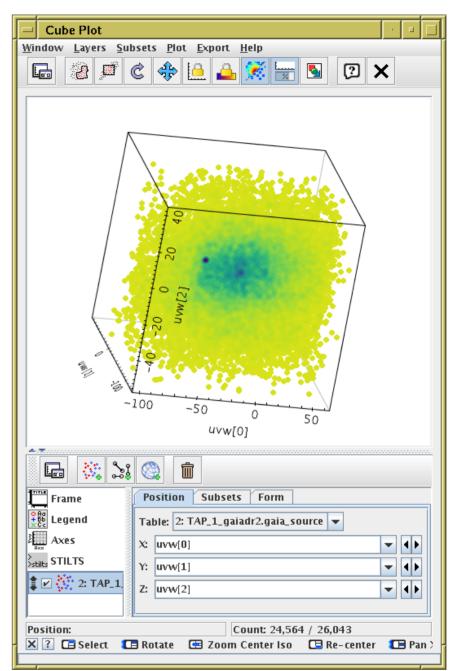
Define a new column uvw giving *Cartesian* velocity components:

astromUVW(array(ra, dec, parallax, pmra, pmdec, dr2_radial_velocity))

Plot in 3D velocity space

Navigate to overdense region - it's the Hyades.

Make a subset and plot it on the sky or a colour-magnitude diagram.



Do It Yourself!

Work through the tutorial at

https://github.com/mbtaylor/tctuto/releases/download/asterics-vo-school-4/tctuto.pdf

- ▷ The first part is what I've demonstrated today
- ▷ Later parts contain other examples and functionality
- Do whichever parts you like!

Downloads and full documentation available online (or in topcat):

http://www.starlink.ac.uk/topcat/

http://www.starlink.ac.uk/stilts/

Support by email:

- on list: topcat-user@jiscmail.ac.uk
- in person: m.b.taylor@bristol.ac.uk
- All feedback and questions welcome!