**Tutorial #4: TOPCAT** 

Mark Taylor (University of Bristol)



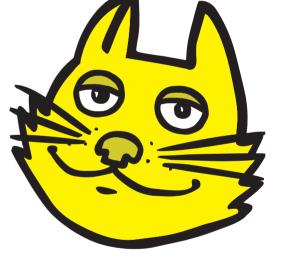
ESCAPE/SVO Science with interoperable data school Online

11 February 2021





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# Outline

#### TOPCAT

- What is it?
- What can it do?

Gaia mission overview

Questions?

Hands-on investigations using Gaia EDR3

- Cluster identification in velocity space
  - ▷ 2-d proper motions (M4 globular cluster)
  - ▷ 3-d velocities (NGC346 open cluster)
  - $\triangleright$  TOPCAT then STILTS
- Cross-match Gaia and HST observations
  - ▷ CDS X-Match service
  - Internal TOPCAT matching
- Gaia Herzsprung-Russell Diagram

# 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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# 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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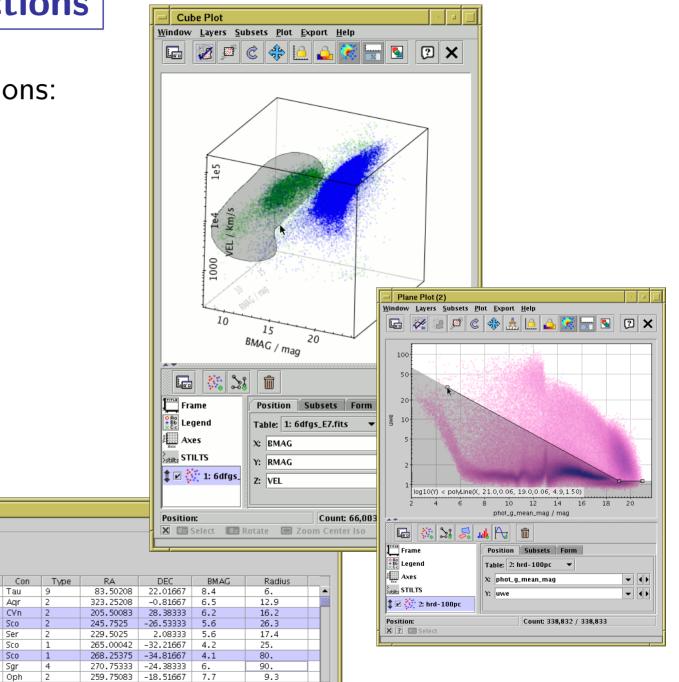
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Different ways to make single or multiple row selections:

- 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

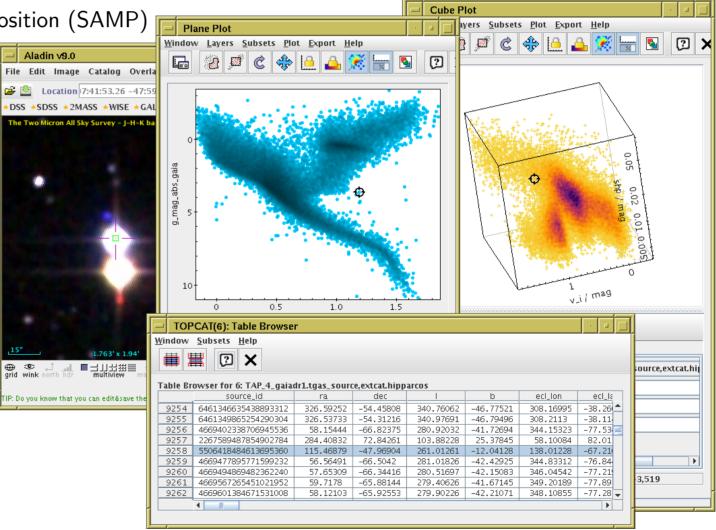
- Perform crossmatch only on items in red giant branch
- Where on the sky is this colour cut?
- Spot outliers
- Identify objects on ds9 image display



# **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

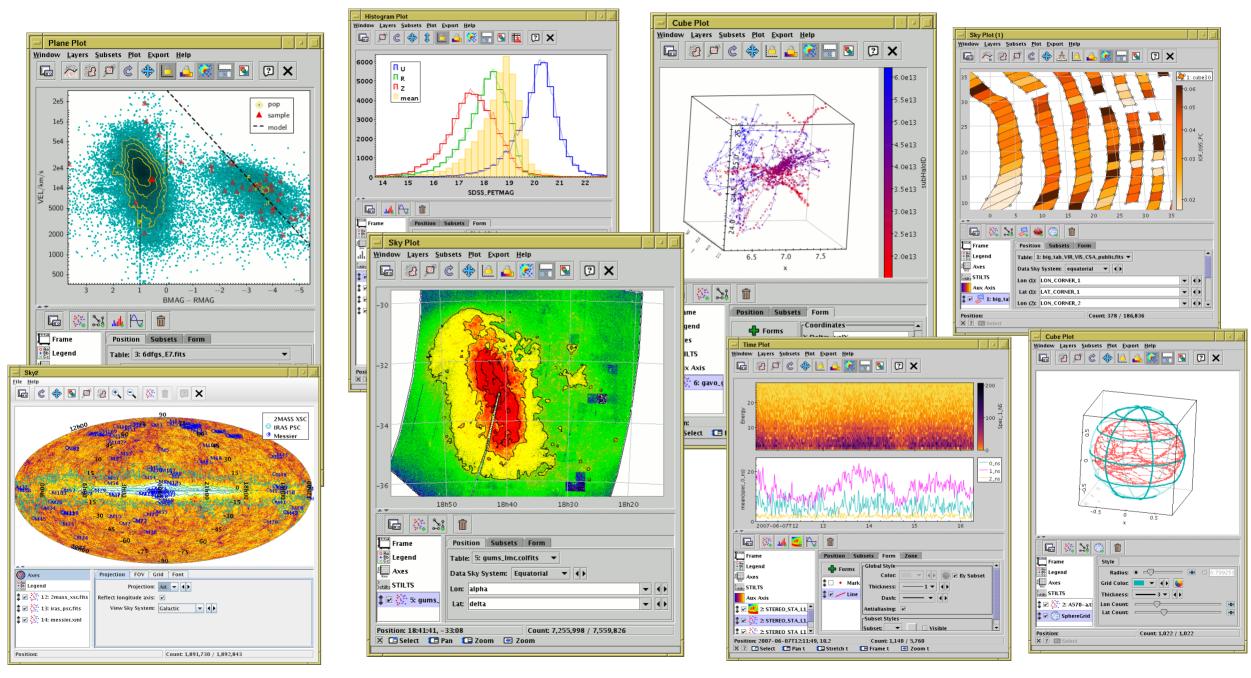
- Expression language used for creating columns, defining selections, making plots etc:
  - Straightforward arithmetic syntax (C-like)
  - Use column names as variables
  - Standard arithmetic operators (+, -, /, \*)
  - Standard mathematical functions (abs, max, round, sin, cos, pow, ...)
  - Conditional 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:

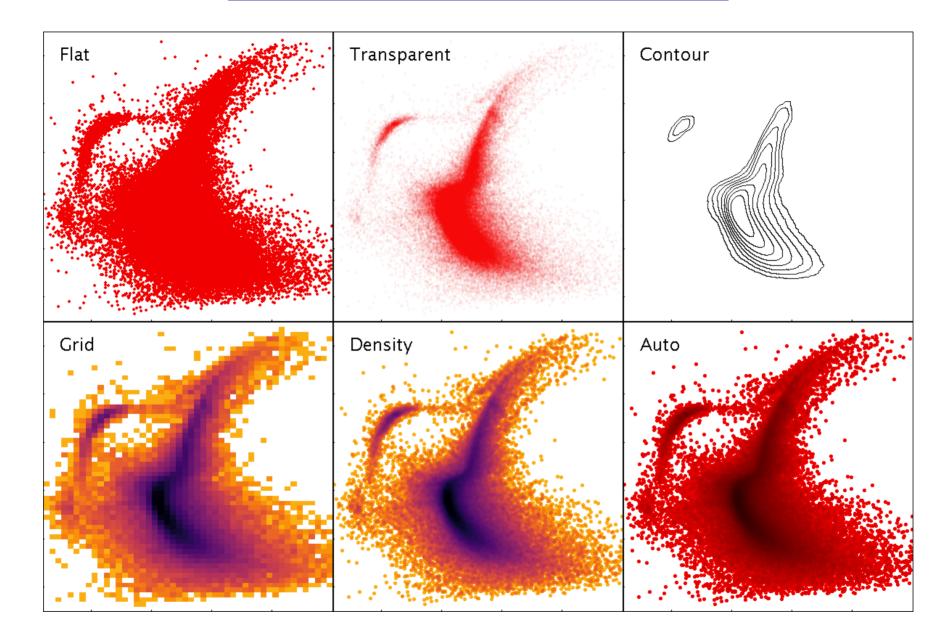
- Many plot types!
  - 2d/3d scatter plots, histograms, HEALPix, density maps, error bars/ellipses, vectors, lines, quantiles, text labels, contours, KDEs, analytic functions, spectrograms, ...
- Many options!
  - Colour, colour maps, shading mode, weighting, marker shape/size line style, sky projection, 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
  - $\,\triangleright\,$  ... but not quite as good as Matplotlib/IDL/R

### **Visualisation: Plot Types**



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### **Visualisation: Dense plots**



Different options for shading scatter-plot data.

# Crossmatching

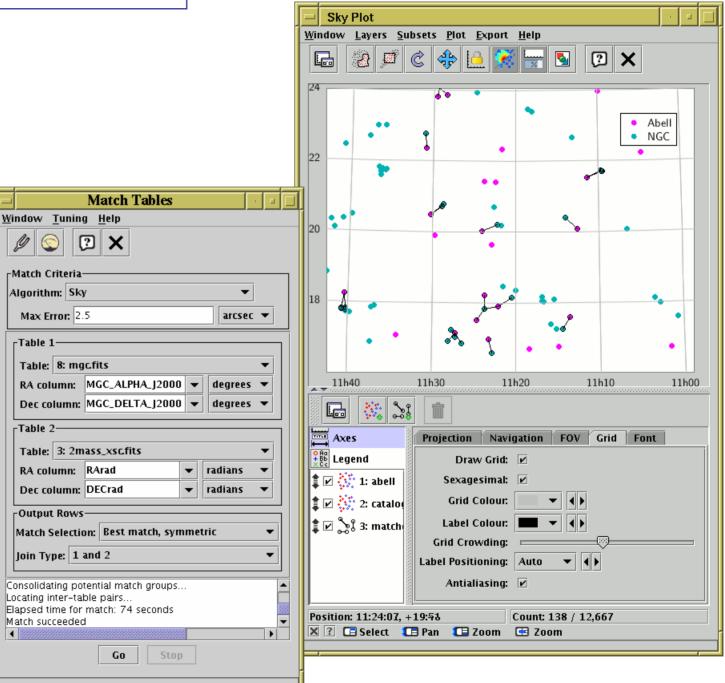
#### Internal

- 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

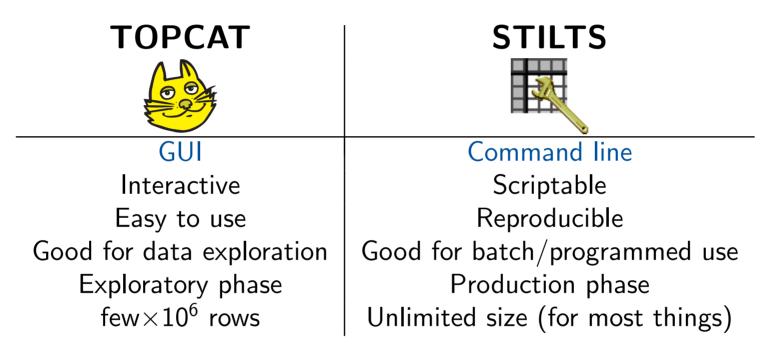
#### External data access from TOPCAT:

- 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**

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- 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 google it)

- ▶ **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:

- ▷ **Slack** (this school)
- mailing list: topcat-user@jiscmail.ac.uk
- personal email: m.b.taylor@bristol.ac.uk  $\triangleright$
- All feedback and questions welcome!  $\triangleright$

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	Next Previous Up Contents Next: Supported Input Formats Up: Table I/O Previous: Table I/O
	4.1 Table Formats
	TOPCAT supports a wide variety of tabular data formats. In most cases these are file formats for tables stored as single files on a disk or at the end of a URL, but there are other possibilities, for instance a table you have opened 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 table from one format to another. If this is all you want to do however, you may find it more convenient to use the tcopy command line utility in the <u>STILTS</u> package.
	The format handling is extensible, so new formats can be added fairly easily. All the table input/output is handled by STIL, the Starlink Tables Infrastructure Library; more detailed descriptions of the I/O capabilities can be found in its <u>documentation</u> .
	The following subsections describe the available formats for reading and writing tables. The two operations are separate, so not all the supported input formats have matching output formats and vice versa.
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# Gaia Mission

#### ESA astrometry satellite:

- Satellite at L2
- 5 year mission (+3–5 year extension), launched 19 Dec 2013

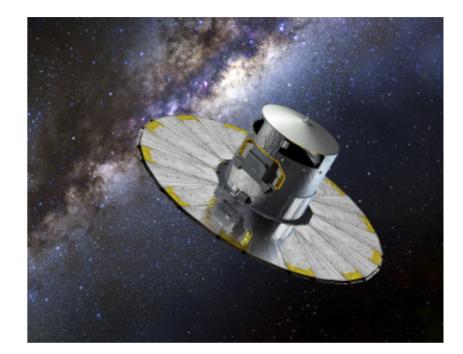
#### Aims

- Measure  $\sim\!2$  billion point sources, complete to  $G\!\approx\!20$ 
  - ▷ mostly milky way stars, also galaxies, QSOs, SSOs, ...
  - ▷ each source observed multiple times
- Astrometry: positions, parallaxes, proper motions  $(10^1 10^3 \mu \text{as accuracy})$
- Photometry: G, RP, BP bands (mmag accuracy)
- Spectrometry: radial velocities (1–15 km/s accuracy)
- Spectro-Photometry in range 330–1050 nm

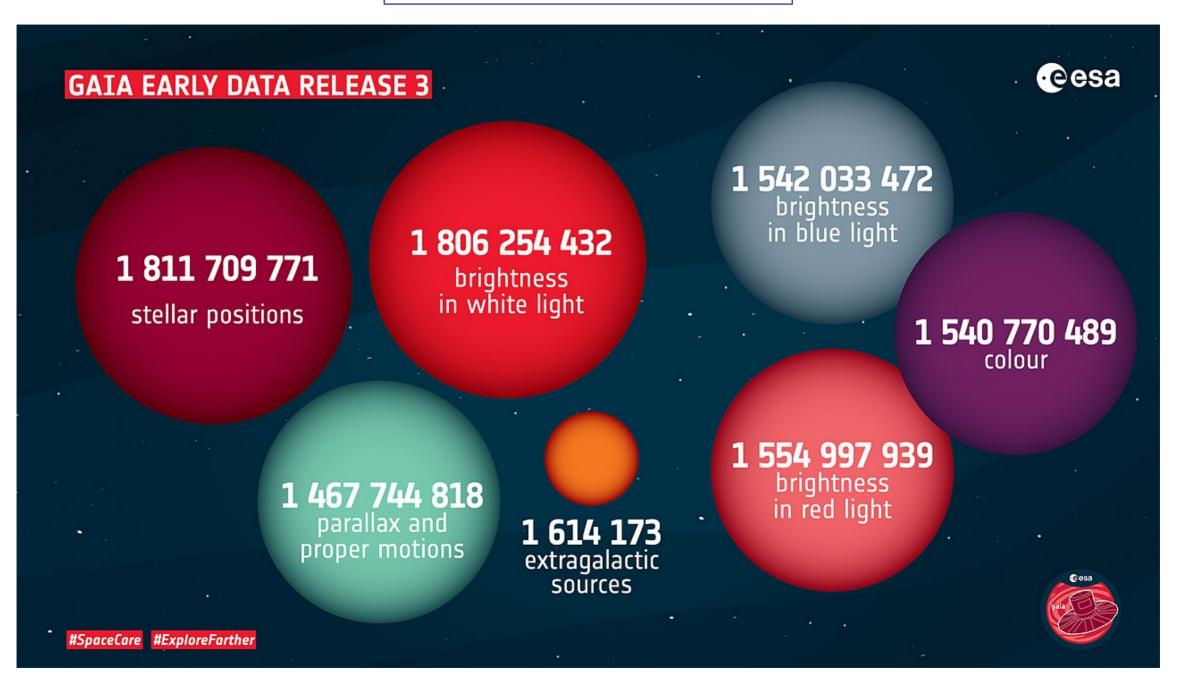
#### Data Releases:

- **DR1**: 14 Sept 2016 (2-parameter astrometry, G magnitude for >1 billion sources; 5-parameter astrometry for 2 million; ...)
- DR2: 25 April 2018 (5-parameter astrometry, G, RP and BP magnitudes for >1 billion sources;  $R_V$  for 7 million; ...)
- EDR3 (Early DR3): 3 December 2020 (DR2 + improved astrometry & photometry; ...)
- DR3: first half 2022 (DR3 + BP/RP/RVS spectra; object classification; non-single stars; Andromeda epoch photometry; ...)
  - $\rightarrow$  thousands of papers already

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### Gaia EDR3 Numbers



### Hands-On Exercises: Topics

1. Cluster Identification #1: Messier 4 in proper motion space

- Cone search, sky plot, subsets, histogram
- 2. Cluster Identification #2: Hyades in 3-D velocity space
  - TAP, expression language, 3D plot, linked views
- 3. Match Gaia and HST Observations for NGC346
  - VizieR download, CDS X-Match, multi-layer plots, pair match
- 4. Cluster Identification using STILTS
  - STILTS usage, pipelines, plotting
- 5. Local Herzsprung-Russell Diagram
  - Shading modes, polygon selection



### Hands-On Exercises: Instructions

Zoom ettiquette:

- Please, turn your microphone off
- Video sharing is optional

Exercises:

- Work through the script; instructions are quite detailed, especially for the earlier exercises
- If you have problems, use Raise Hand
- When you reach the end, please display the Yes 🗸 reaction
- If you finish before others, explore the software and data to see what else you can do; some exercises have optional/bonus parts at the end
- When most people have finished, I will talk through the example

You may ask questions at any time:

*Either* Post questions in the zoom chat, addressed to **Everyone** *Or* Use the **Raise Hand** button at the bottom of the participants window





#### Cluster identification #1: Messier 4 in proper motion space

- Locate Gaia EDR3 Cone Search service
- Query for sources in region of Messier 4
- Plot positions on sky
- Plot proper motions
- Create subset of comoving objects
- Create subset of background objects
- Plot proper motion vectors
- Histogram parallaxes of comoving and background objects
- Infer distance to Messier 4



#### Cluster identification #2: Hyades in 3-D velocity space

- Locate Gaia TAP service
- Explore Gaia TAP service
- Run toy TAP query
- Run TAP query giving 6-d phase space information for nearby sources (cut'n'paste)
- Create new columns with 3-d Cartesian velocity components
- Plot sources in 3-d velocity space
- Create subset of comoving sources (Hyades)
- Examine Hyades *vs.* background sources on the sky
- Plot colour-magnitude diagram of Hyades vs. background sources



#### Match Gaia and HST observations for NGC 346

- Download J/ApJS/166/549 catalogue from VizieR
- Crossmatch with Gaia EDR3 using CDS X-Match service
- Plot the crossmatch results
- Graphically find offset between HST and Gaia positions
- Use this to make sense of cross-match results
- Re-do crossmatch using TOPCAT internal match window



#### Use STILTS for Messier 4 cluster identification

- Run a simple STILTS command (calc)
- Download M4 data from a cone search service (cone)
- Get used to table pipeline processing (tpipe)
- Obtain mean parallax for comoving objects  $\rightarrow$  distance to M4
- Try some STILTS plotting (plot2sky)