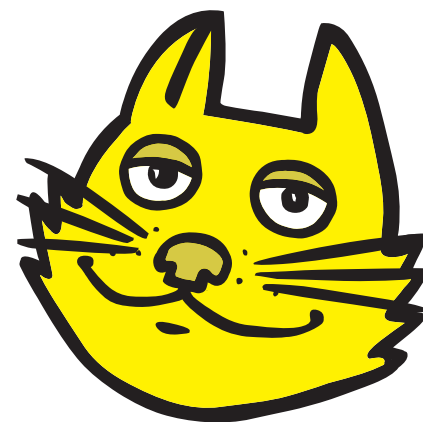


TOPCAT and how to use it for Gaia

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Gaia DR1 Workshop
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\$Id: tcgaia_ari.tex,v 1.4 2016/11/20 22:41:14 mbt Exp \$

TOPCAT

- very short intro

Accessing Gaia-DR1 Data from TOPCAT

- Cone Search
- CDS XMatch client
- TOPCAT TAP window
- TGAS FITS file download
- *(others)*

Examples

- Pleiades in TGAS
- Match local catalogue with Gaia sources
- TGAS-Hipparcos colour-magnitude diagram
- TGAS All-sky density maps

STILTS *(if there is time)*

TOPCAT

TOPCAT = Tool for OPerations on Catalogues And Tables

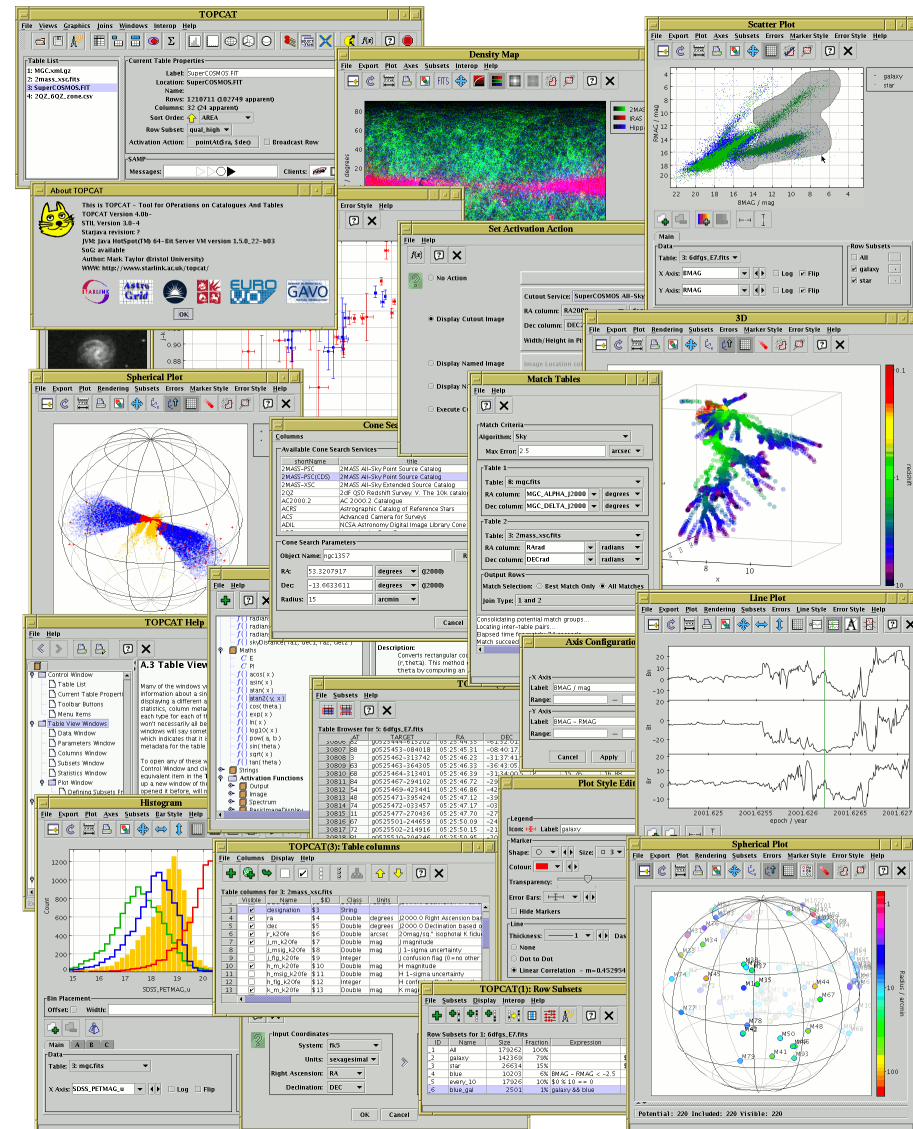
Aims:

- Works with tables
- Talks to the *Virtual Observatory*

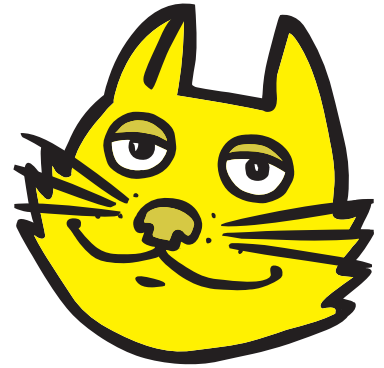
Help is available:

- Comprehensive [HTML](#) / [PDF](#) user manual
- **Help for Window**  button on every window
- Email support:
 - ▷ on list: topcat-user@bristol.ac.uk
 - ▷ in person: m.b.taylor@bristol.ac.uk
- Acknowledgement: 2005ASPC..347...29T

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



TOPCAT Capabilities



TOPCAT can:

- Read/write tables in multiple formats
- View/edit data
- View/edit metadata
- Calculations and statistics
- Visualisation
- Make/combine/display row selections in various ways (linked views)
- Crossmatching — efficient and very flexible
- Access external data services (VO and others)
- Trigger some event when a row is selected
- Talk to other astro tools (SAMP)

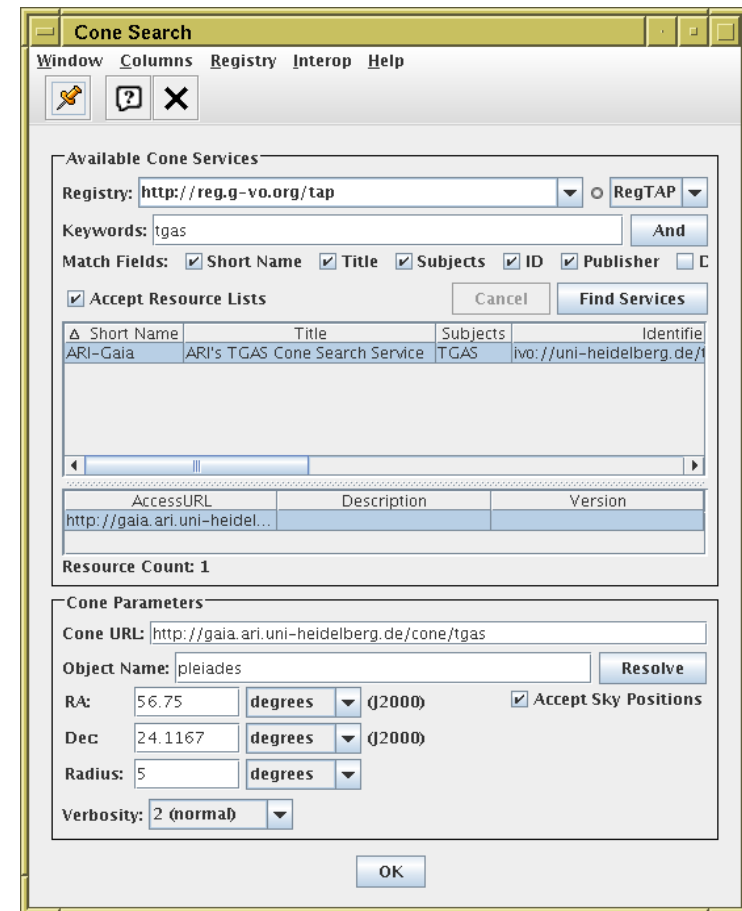
Scalability:

- Millions of rows, hundreds of columns (on modest hardware)

Data Access: Cone Search

Use TOPCAT's Cone Search window

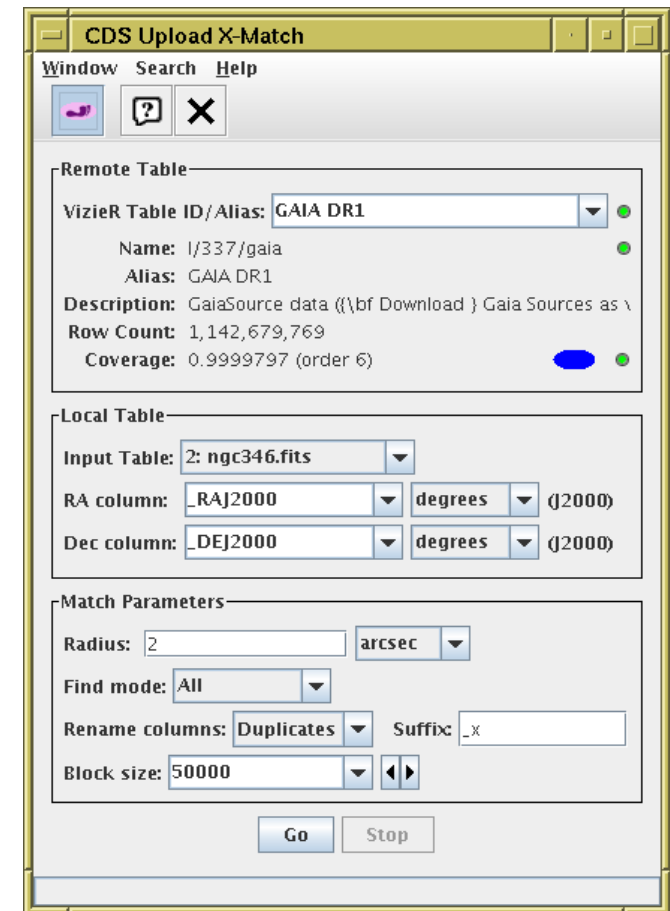
- Details:
 - ▶ Retrieves all Gaia/TGAS sources within a given radius of a given sky position
- Suitability:
 - ▶ If you want all Gaia sources in given sky region
 - ▶ Only selects on position (but can restrict further in TOPCAT)
 - ▶ Limit: 10 million rows
- Usage:
 - ▶  **VO|Cone Search** menu item
 - ▶ **Keywords:** “gaia” → **Find Services**
 - ▶ Select service **ARI-Gaia**
 - ▶ Fill in **Object Name** or **RA/Dec** and **Radius**, and hit **OK**
 - ▶ **Verbosity** selector controls which columns are included
 - ▶ Documentation:
<http://www.starlink.ac.uk/topcat/sun253/ConeSearchDialog.html>



Data Access: CDS X-Match

Use TOPCAT's CDS Upload X-Match window

- Details:
 - ▶ Fast, scalable service for crossmatching VizieR tables
 - ▶ TOPCAT can use it for crossmatch of loaded table against Gaia
- Suitability:
 - ▶ Nearest/all nearby Gaia sources for each row of local table
 - ▶ Scales to millions (or more) of rows
 - ▶ Not all columns returned
 - ▶ Only selects on position (but can restrict results further in TOPCAT)
- Usage:
 - ▶ Load local table into TOPCAT (or get it from VizieR, or TAP, or ...)
 - ▶  **VO|CDS Upload X-Match** menu item or toolbar button
 - ▶ Select **VizieR Table ID/Alias: "GAIA DR1"**
 - ▶ Docs: <http://www.starlink.ac.uk/topcat/sun253/CdsUploadMatchWindow.html>
 - ▶ Ack: *"This research made use of the cross-match service provided by CDS, Strasbourg."*



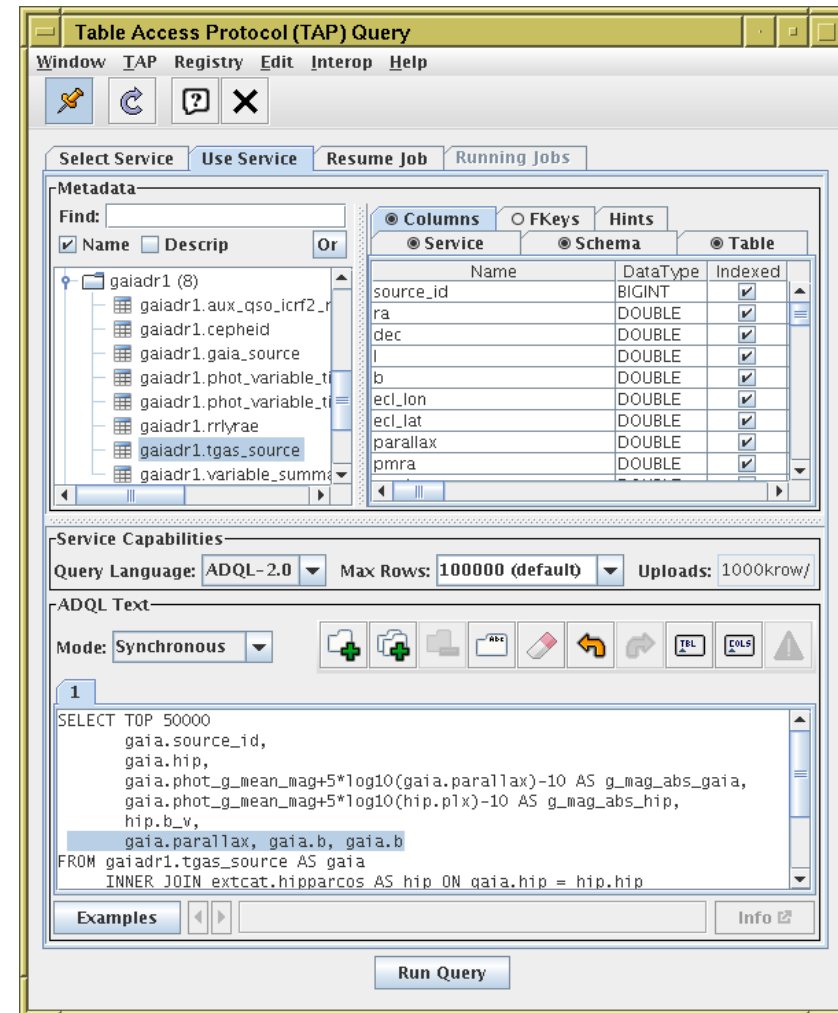
Data Access: TOPCAT TAP Window

Use TOPCAT's TAP (Table Access Protocol) client window

- Details:
 - ▶ Execute queries, view service metadata:
 - ESA: all Gaia DR1 tables
 - ARI: most Gaia DR1 tables
 - + many others (non-Gaia and Gaia)
- Suitability:
 - ▶ Suitable for ADQL queries
 - ▶ Better integrated into TOPCAT than ESA web interface
 - results load directly into TOPCAT
 - can upload tables from TOPCAT
 - ▶ Table/column metadata browsing different
 - ▶ ADQL editing features (multi-tab, validation, undo/redo, ...)
 - ▶ Limits: 10^5 rows (ESA), 10^7 rows (ARI)

- Usage:

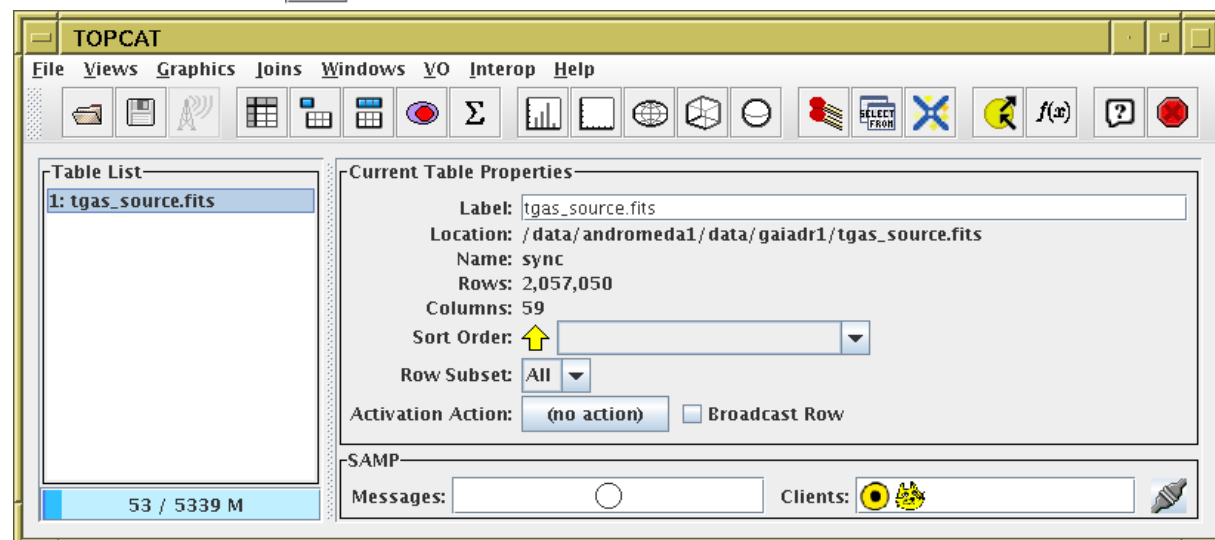
- ▶  **VO|Table Access Protocol (TAP) Query** menu item or toolbar button
- ▶ Select Service **Keywords**: “gaia” → [ARI-Gaia](#) or [\[ESA\] GAIA](#)
- ▶ Docs: <http://www.starlink.ac.uk/topcat/sun253/TapTableLoadDialog.html>



Data Access: TGAS Download

Use monolithic TGAS FITS file

- Details:
 - ▷ Various options to get it:
 - http://cdn.gea.esac.esa.int/Gaia/tgas_source/fits/ (16 files)
 - `SELECT * FROM gaiadr1.tgas_source`
 - http://andromeda.star.bristol.ac.uk/data/tgas_source.fits
 - ▷ Size: 2 057 050 rows × 60 columns, ~660 Mb
- Suitability:
 - ▷ Good size for TOPCAT (unlike `gaia_source`, ~325 Gb)
 - ▷ If you want *all* TGAS data, this may be the easiest way to use it in TOPCAT
- Usage
 - ▷ Load into TOPCAT using  **Load** window or from command line (instantaneous)



Data Access: Others

Other ways to get Gaia DR1 data into TOPCAT:

- ESA Gaia archive web interface (“TAP+”) (<http://gea.esac.esa.int/archive>)
 - ▷ persistent uploads, result table management, share results with collaborators
 - ▷ all DR1 tables (incl. pre-calculated crossmatch tables)
 - ▷ higher resource limits than anonymous (TOPCAT) TAP access
- ARI-Gaia web page (<http://gaia.ari.uni-heidelberg.de/>)
 - ▷ nice GUI
 - ▷ precalculated statistics, single source search + TAP, Cone Search, more to come
- CDS X-Match web page (<http://cdsxmatch.u-strasbg.fr/xmatch>)
 - ▷ allows VizieR/Gaia crossmatch as well as local/Gaia crossmatch
- VizieR (<http://vizier.u-strasbg.fr>)
 - ▷ Standard CDS interface + API (including access from TOPCAT)
- Gaia@AIP (<https://gaia.aip.de/>)
 - ▷ Scriptable multi-threaded MySQL queries (*beta*)
- And more ...

Example A: Pleiades in TGAS

Identify and view Pleiades cluster members

- Cone search TGAS within 5° of Pleiades
- 3D plot `pmra` vs. `pmdec` vs. `parallax`
- Identify cluster in (μ, ϖ) space, create subset graphically
- View proper motion vectors on the sky
- Plot histogram of σ_ϖ / ϖ for cluster members
- 3D plot of cluster members in real space

A.1: TGAS Cone Search

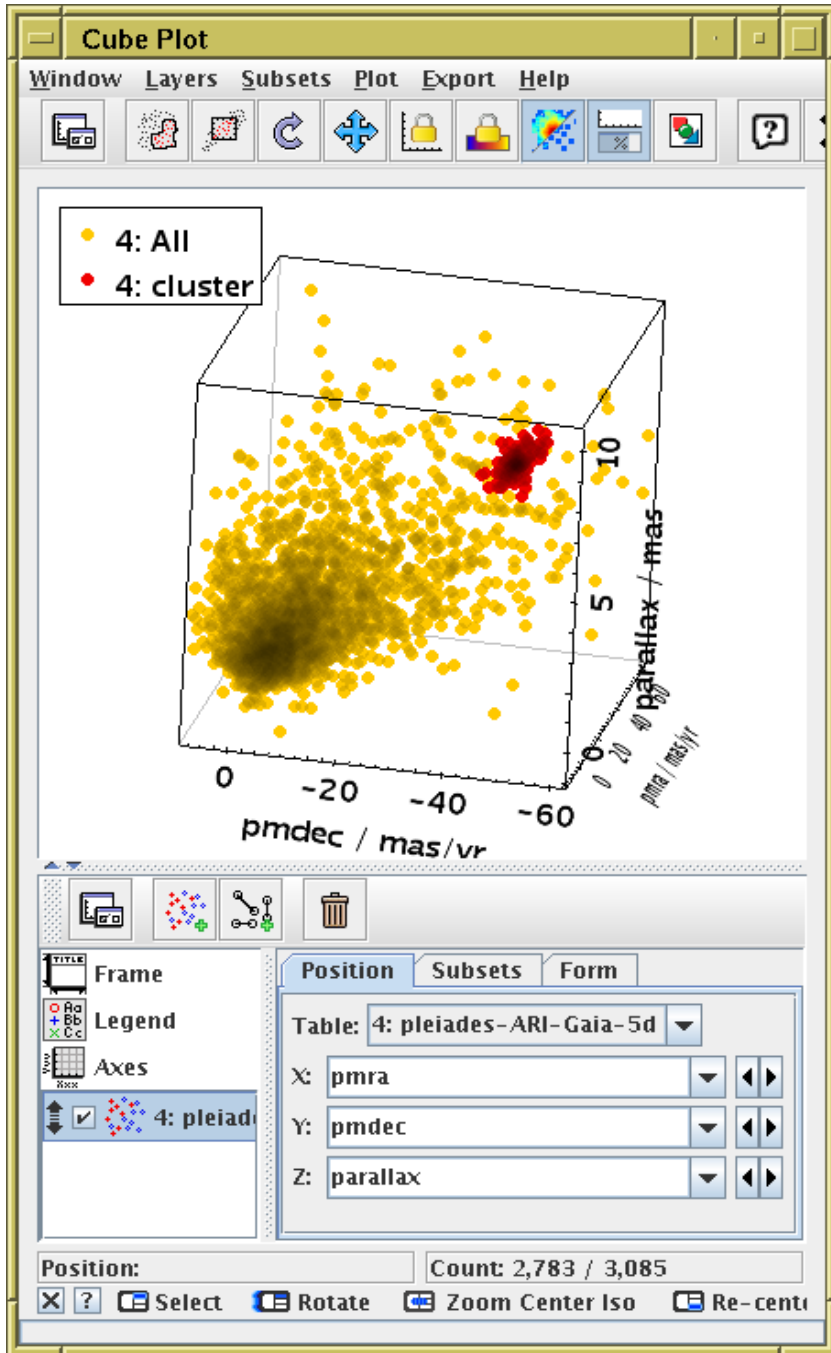
The screenshot shows the TOPCAT Cone Search window with the following configuration:

- Available Cone Services:**
 - Registry: `http://reg.g-vo.org/tap`
 - Keywords: `tgas`
 - Match Fields: ☒ Short Name, ☒ Title, ☒ Subjects, ☒ ID, ☒ Publisher, ☐ C
 - ☒ Accept Resource Lists
 - Buttons: Cancel, Find Services
 - Table:

Short Name	Title	Subjects	Identifie
ARI-Gaia	ARI's TGAS Cone Search Service	TGAS	ivo://uni-heidelberg.de/t
 - Buttons: AccessURL, Description, Version
 - Resource Count: 1
- Cone Parameters:**
 - Cone URL: `http://gaia.ari.uni-heidelberg.de/cone/tgas`
 - Object Name: `pleiades`
 - Buttons: Resolve
 - RA: `56.75` degrees (J2000) ☒ Accept Sky Positions
 - Dec: `24.1167` degrees (J2000)
 - Radius: `5` degrees
 - Verbosity: `2 (normal)`
 - Button: OK

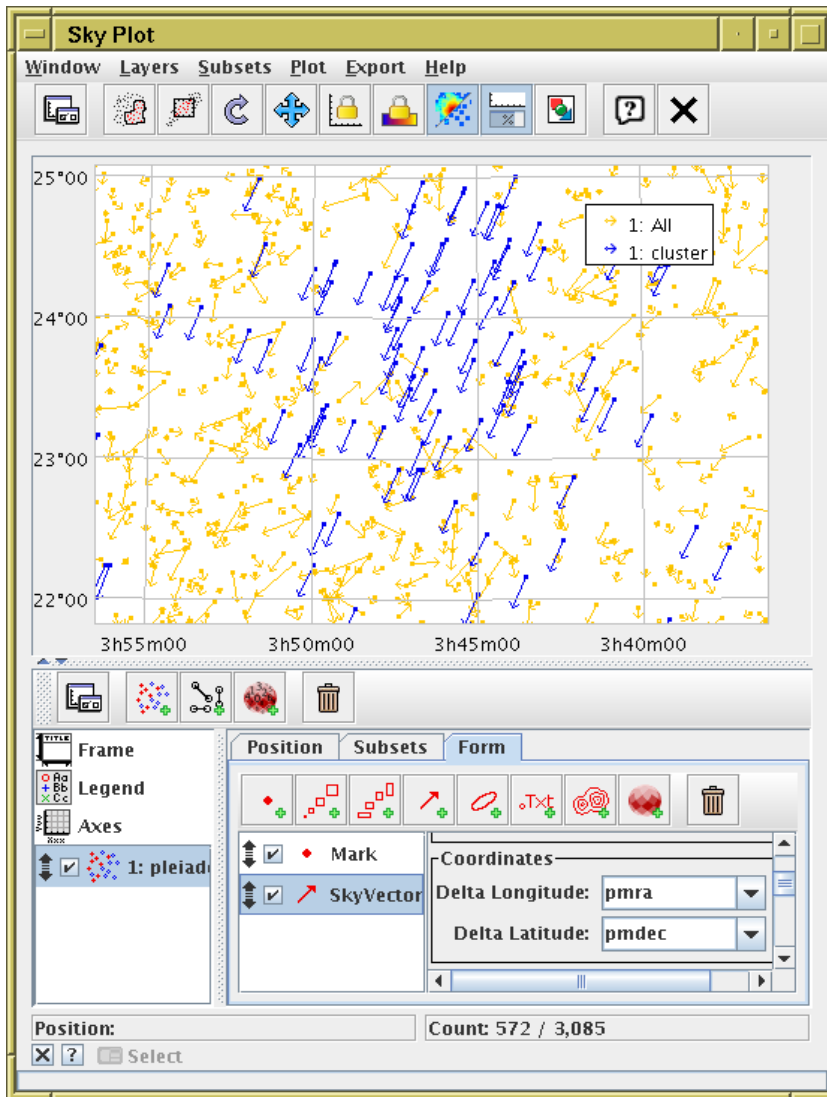
- Want to query TGAS sources within 5° of Pleiades
- Use TOPCAT Cone Search window:
 - ▷  **VO|Cone Search** menu item
 - ▷ **Keywords:** `"tgas"`
 - ▷ **Object Name:** `"pleiades"` + **Resolve**
 - ▷ **Radius:** `"5"`
- ... there are other ways to do it

A.2: Cluster Identification



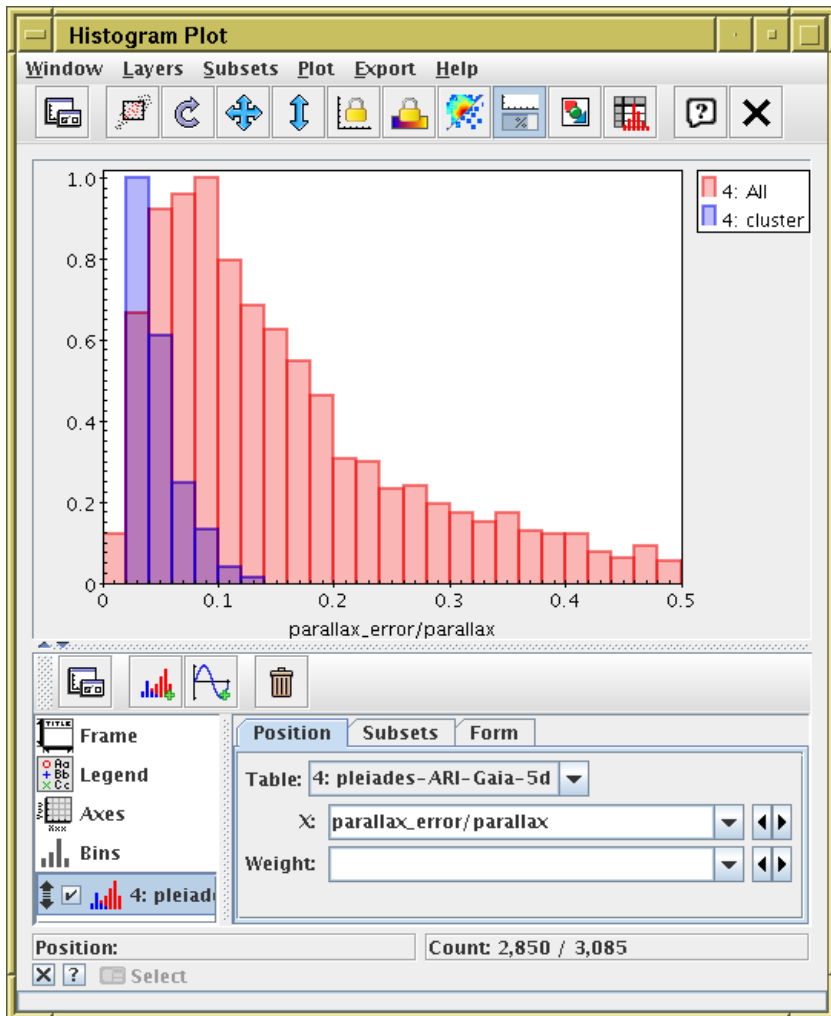
- Plot sources in 3d (μ , ϖ) space:
 - ▷  **Graphics|Cube Plot** menu item or toolbar button
 - ▷ **X:** “pmra”
 - ▷ **Y:** “pmdec”
 - ▷ **Z:** “parallax”
- Graphically select the visible overdense cluster as a new *Row Subset*
 - ▷ Navigate so cluster fills the visible cube (mouse wheel to zoom in/out, **right-click** (or **Ctrl-click**) to re-center)
 - ▷  button to define subset from visible
 - ▷ **New Subset Name:** “cluster”
+ **Add Subset**
- Zoom out again to see both cluster and non-cluster members

A.3: Visualise proper motions



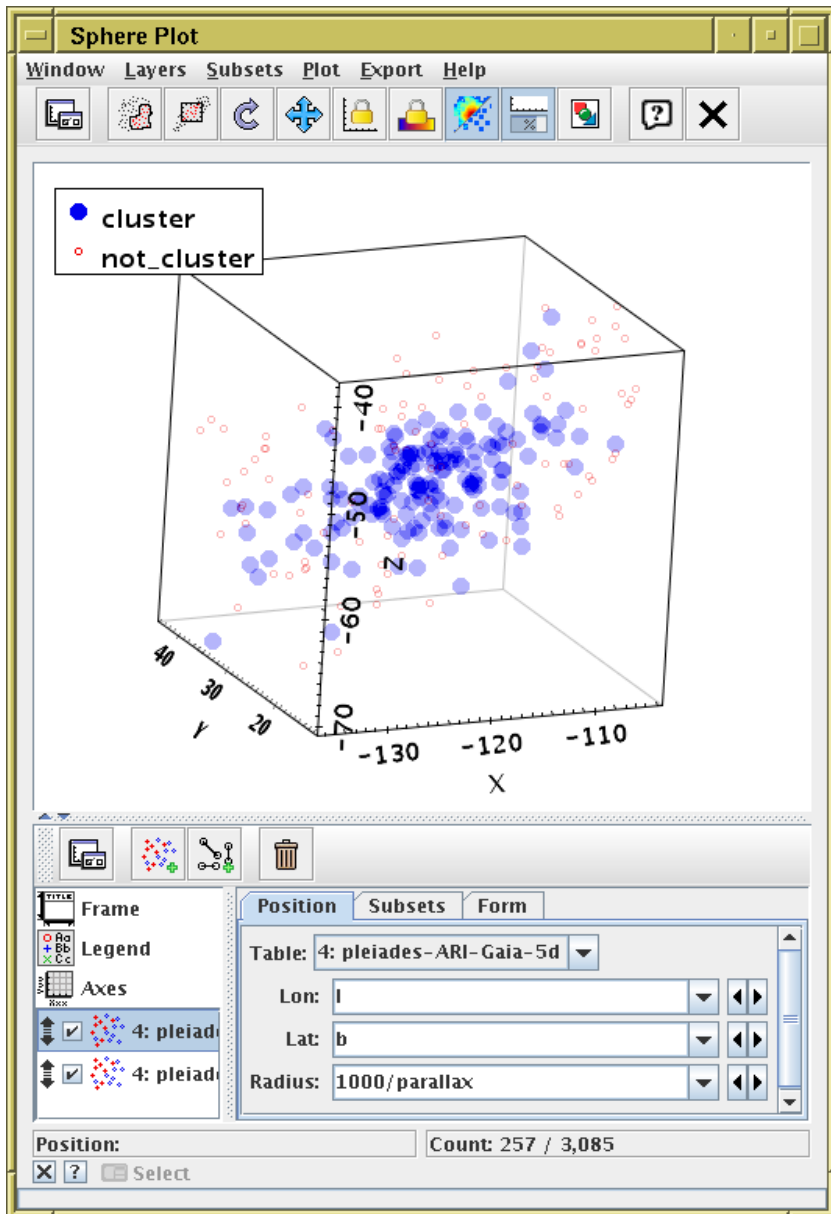
-  **Graphics|Sky Plot**
menu item or toolbar button
-  Add new **SkyVector** form in **Form** tab
- **Delta Longitude:** “*pmra*”
- **Delta Latitude:** “*pmdec*”
- See the little arrows showing proper motion

A.4: Assess Cluster Proper Motion Errors



- Plot relative parallax error σ_{ϖ}/ϖ
 - ▶ **Graphics|Histogram plot** menu item or toolbar button
 - ▶ **X:** "`parallax_error/parallax`"
 - ▶ **Subsets** tab: plot **All** & **cluster** subsets
 - ▶ **Axes** control, **Range** tab:
Minimum X: "`0`",
Maximum X: "`0.5`"
 - ▶ **Bins** control, **General** tab:
Normalise: "`maximum`"
- Cluster members have $\sigma_{\varpi}/\varpi < 15\%$
 - ▶ ... so it's probably OK to use $r = 1/\varpi$

A.5: 3d cluster positions



- Plot points in real space
 - ▶  **Graphics|Sphere Plot** menu item or toolbar button
 - ▶ **Subsets** tab: select **cluster** subset only
 - ▶ **Lon:** "l"
 - ▶ **Lat:** "b"
 - ▶ **Radius:** "1000/parallax"
 - ▶ Cluster positions are visible in 3d space (units of parsec, X/Y plane is galactic)
 - ▶ You can turn on **All** subset too

Example B: Crossmatch local catalogue with Gaia

Match with Gouliermis et al. 2006 (NGC 346 HST/ACS photometry)
([2006ApJS..166..549G](#))

- Find and download J/ApJS/166/549/table2 from VizieR load window
 - ▷ ... or any other way to load a positional catalogue in topcat
- Use CDS XMatch window to match with **GAIA DR1** (**Find mode: All**)
- Sky plot of Gouliermis and Gouliermis/Gaia matched pairs (many counterparts)
- Plot histogram of **angDist** (spike near 0.3)
- Plot _RAJ2000-ra vs. _DEJ2000-dec
- Identify modal ($\Delta\alpha$, $\Delta\delta$)
- Trace new subset to identify probable matches
- Now you have:
 - ▷ NGC 346 proper motion estimate (maybe)
 - ▷ G magnitudes for Gouliermis sub-sample ($\sim 1\,800/99\,000$ sources)

B.1: Acquire NGC 346 catalogue

The screenshot shows the VizieR Catalogue Service window. The 'VizieR Server' is set to 'http://vizier.u-strasbg.fr/'. Under 'Row Selection', 'Cone Selection' is chosen with 'Object Name' 'ngc346', 'RA' '14.771207', 'Dec' '-72.1759', and 'Radius' '1'. 'All Rows' is also an option. 'Maximum Row Count' is set to '100000'. Under 'Column Selection', 'Output Columns' is set to 'standard'. The 'Catalogue Selection' section has tabs for 'By Category', 'By Keyword', 'Surveys', and 'Missions'. The 'By Keyword' tab is active with 'Keywords' set to 'Gouliermis'. There are checkboxes for 'Sub-Table Details' and 'Include Obsolete Tables', and buttons for 'Search Catalogues' and 'Cancel Search'. A table of search results is displayed at the bottom.

Δ Name	Popularity	Density	Description
J/A+A/515/A56	721	66	NGC 346/N66 JHKs photometry (Gouliermis et al. 2006)
J/ApJ/672/914	1048	10	HST photometry in NGC 346 (Hennekemp et al. 2006)
J/ApJ/762/123	1368	1	PHAT. IV. Initial Mass Function (Weisz+, 2006)
J/ApJS/166/549	583	271	HST/ACS observations of NGC 346 (Gouliermis et al. 2006)

- Load catalogue from VizieR:
 - ▶  **VO|VizieR Catalogue Service** menu item
 - ▶ **All Rows** check box
 - ▶ **Maximum Row Count:** 100 000
 - ▶ Locate and load *Gouliermis et al. 2006* (J/ApJS/166/549)
- Or grab it from CDS VizieR web page

B.2: Crossmatch with Gaia

CDS Upload X-Match

Window Search Help

Remote Table

VizieR Table ID/Alias: GAIA DR1

Name: I/337/gaia

Alias: GAIA DR1

Description: GaiaSource data ({\bf Download } Gaia Sources as \

Row Count: 1,142,679,769

Coverage: 0.9999797 (order 6)

Local Table

Input Table: 2: ngc346.fits

RA column: _RAJ2000 degrees J2000

Dec column: _DEJ2000 degrees J2000

Match Parameters

Radius: 2 arcsec

Find mode: All

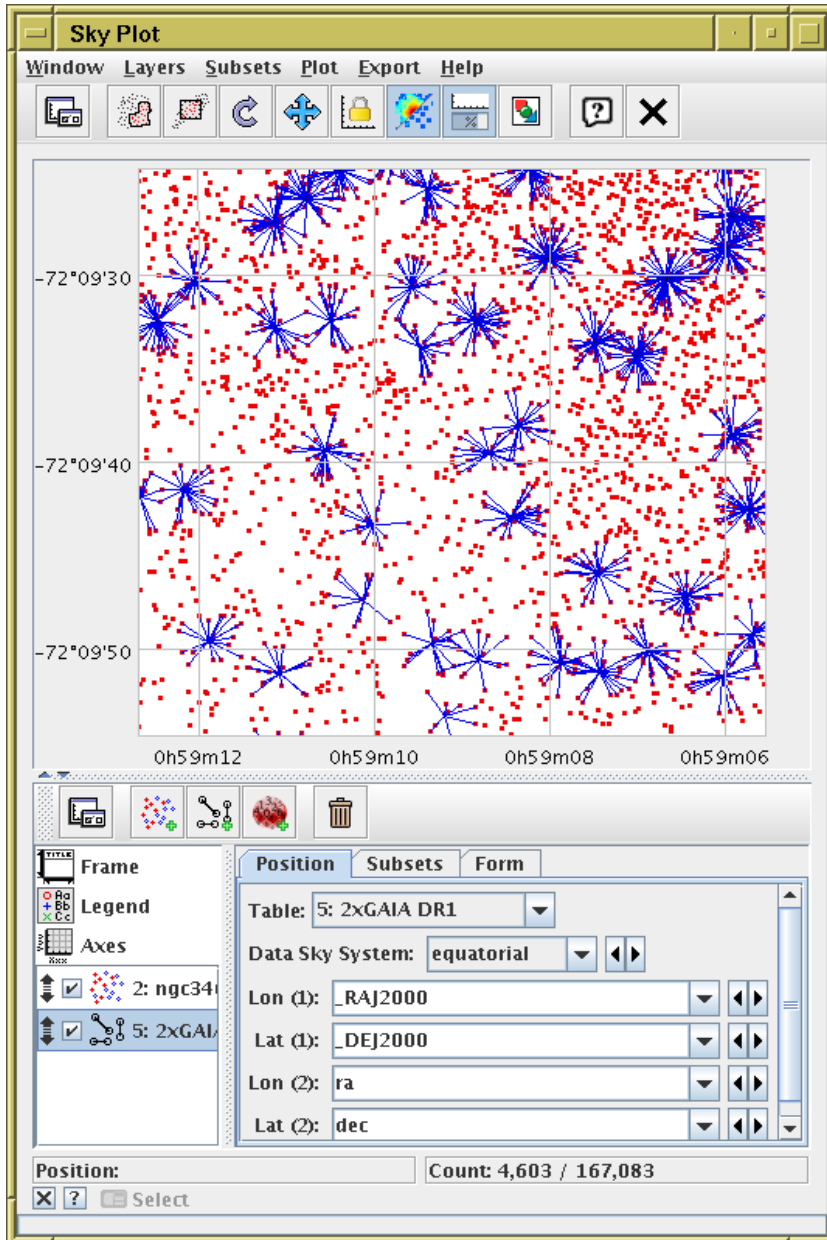
Rename columns: Duplicates Suffix: _x

Block size: 50000

Go Stop

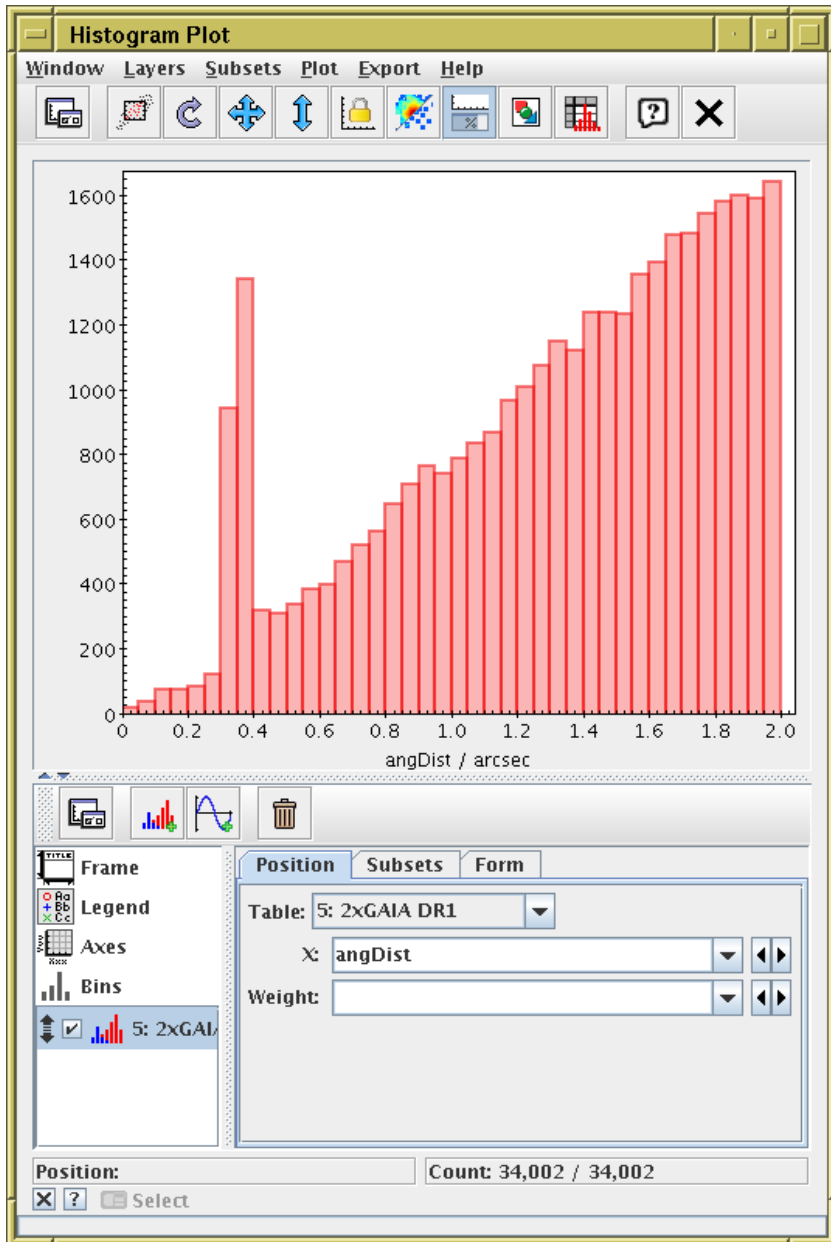
-  **VO|CDS Upload X-Match**
menu item or toolbar button
- **VizieR Table ID:** “GAIA DR1”
- **Radius:** “1” (arcsec)
- **Find mode:** All

B.3: Plot crossmatch results



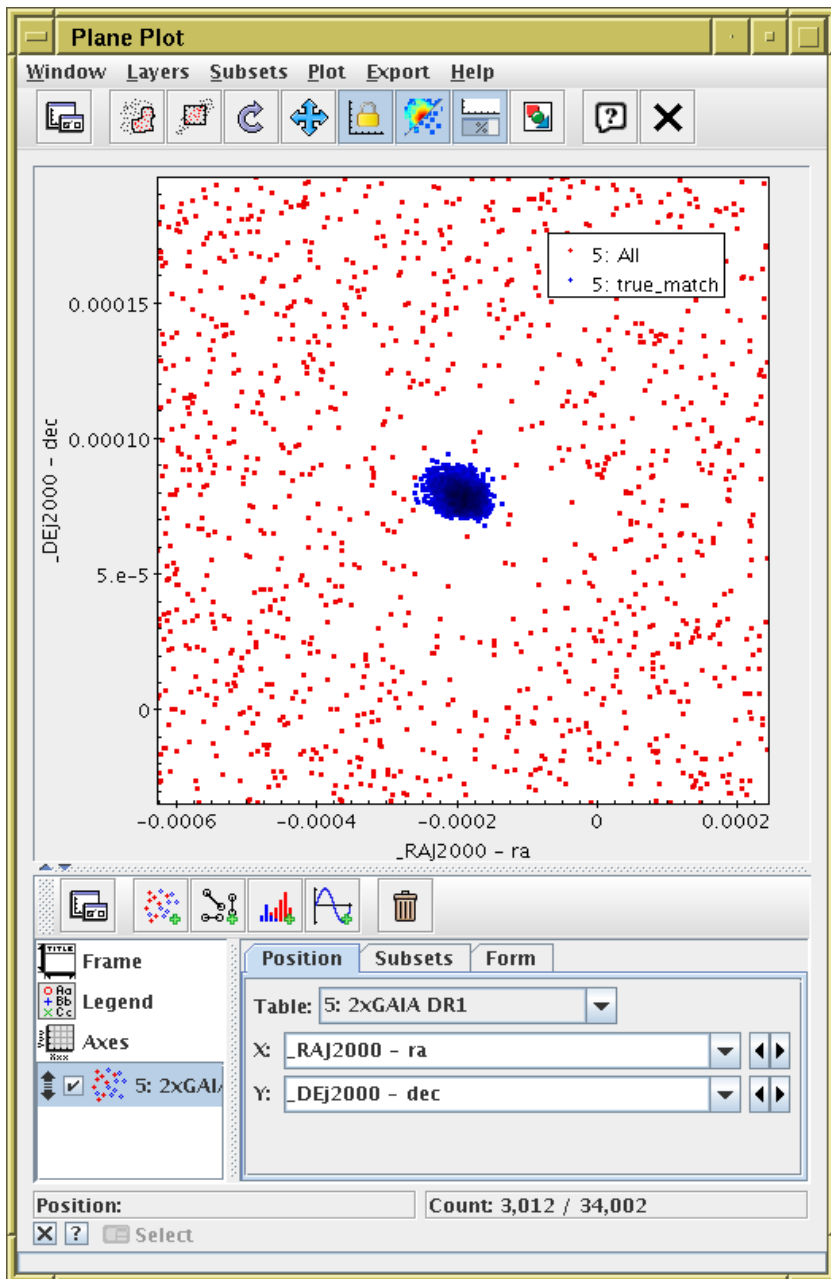
-  **Graphics|Sky Plot**
menu item or toolbar button
-  Plot NGC 364 points
-  Plot Gaia ↔ Gouliermis associations
(*[Goul]* _RAJ2000, _DEJ2000, *[Gaia]* ra, dec)
- ... too many

B.4: Plot crossmatch offsets



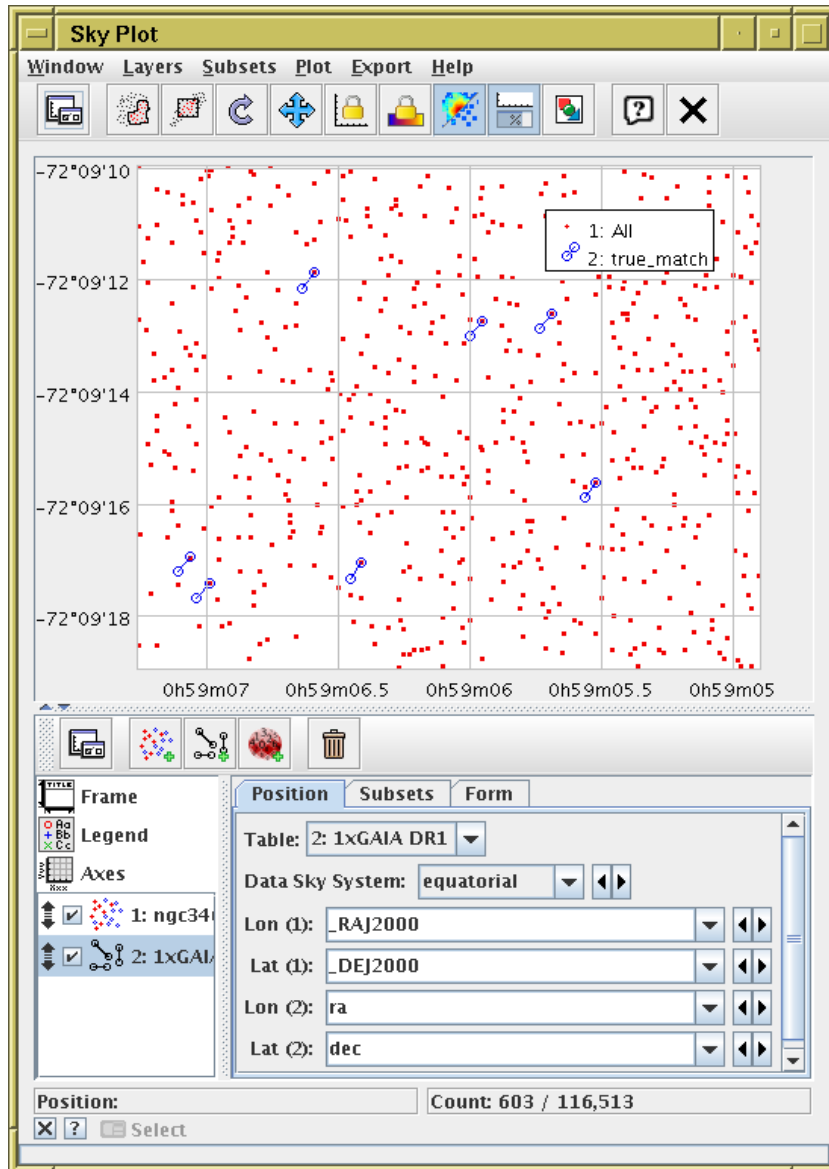
-  **Graphics|Histogram plot**
menu item or toolbar button
- **X:** “*angDist*”
(Gaia—Gouliermis association distance)
- (some) true associations near 0.35 arcsec

B.5: Identify true matches



- Plot matches in xmatch offset space:
 - ▶ **Graphics|Plane Plot** menu item or toolbar button
 - ▶ **X:** “_RAJ2000 - ra”
 - ▶ **Y:** “_DEJ2000 - dec”
- Obvious overdensity — corresponds to true offset
- Select new subset **true_match** graphically

B.6: Visualise true matches



- Return to sky plot
- **Subsets** tab: select `true_match` only
- Common association vector, $= (\overline{\Delta\alpha}, \overline{\Delta\delta})$ in `true_match` subset, is displacement between Gouliermis (2004.6) and Gaia (2015.0) observations:

$$\overline{\cos \delta \Delta\alpha} \approx +210 \pm 20 \text{ mas}$$

$$\overline{\Delta\delta} \approx -284 \pm 15 \text{ mas}$$

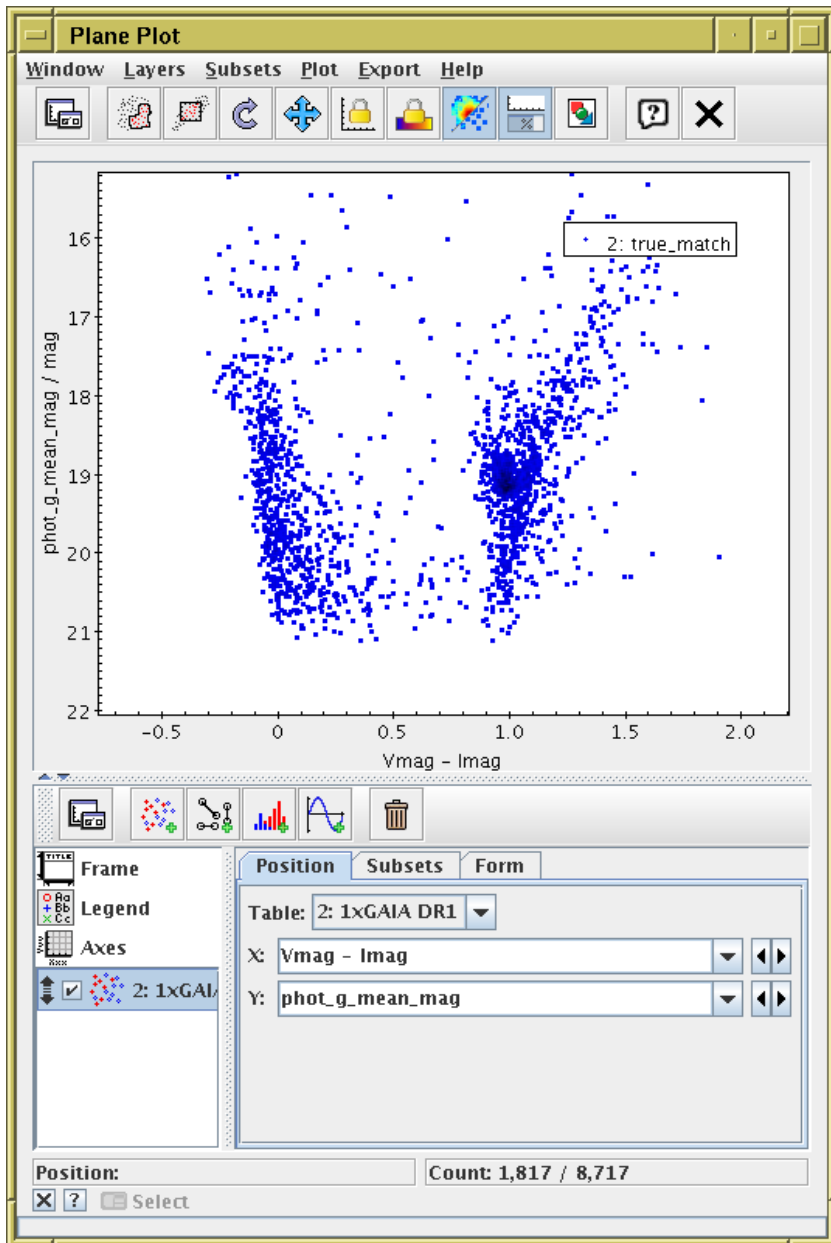
so proper motion:

$$\mu_{\alpha^*} \approx +20.2 \pm 2 \text{ mas.yr}^{-1}$$

$$\mu_{\delta} \approx -27.3 \pm 1 \text{ mas.yr}^{-1}$$

(or maybe not ... HST absolute astrometry?)

B.7: Combine HST and Gaia photometry



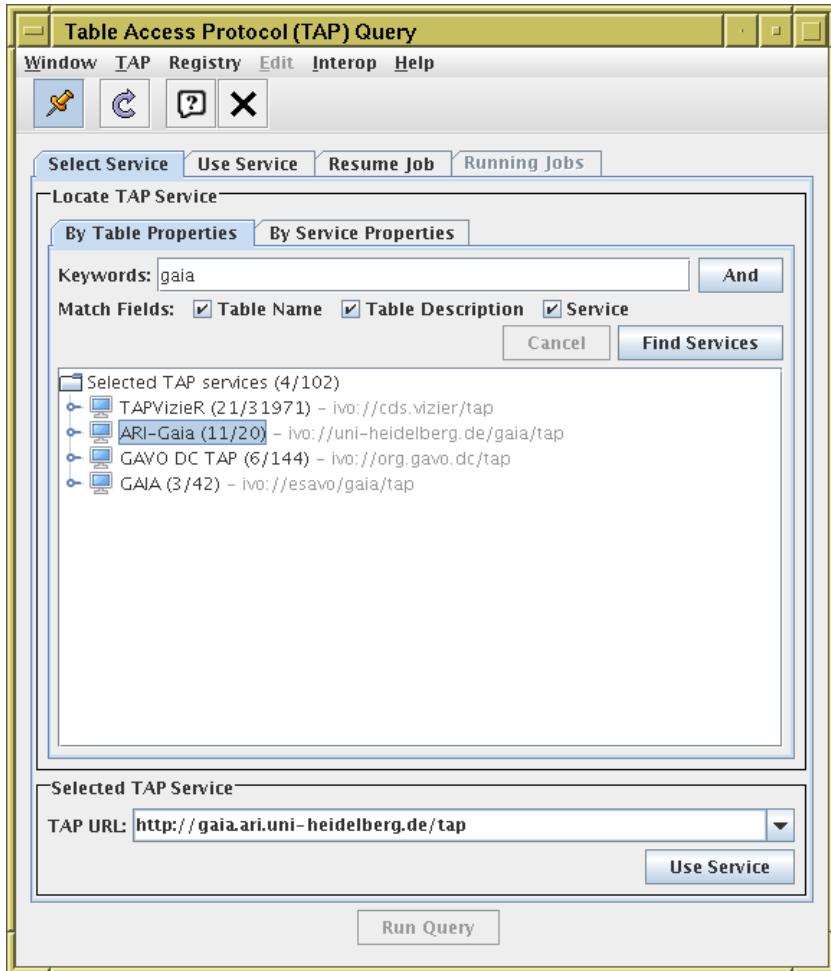
- Joined table now has Gaia G-band photometry alongside HST V/I-band photometry

Example C: TGAS-Hipparcos CMD

Use ARI **Example** query to generate fig 3 of Gaia DR1 paper

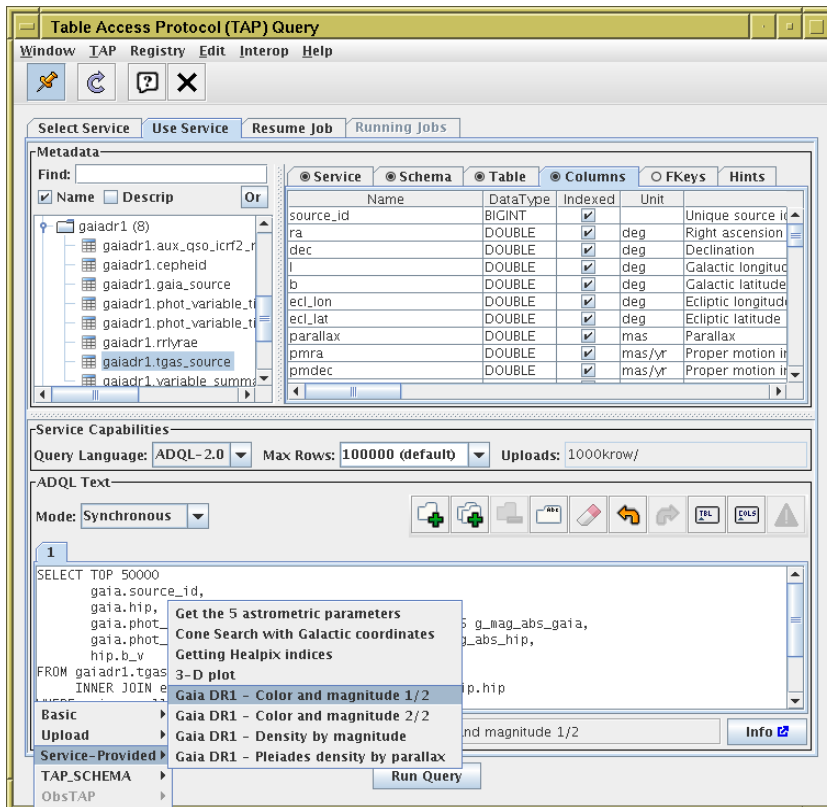
- Point TOPCAT TAP client at ARI-Gaia service
- Use **Examples|Service-Provided|Gaia DR1 Color and Magnitude** menu
- Plot Hipparcos $B - V$ vs absolute Gaia G
- Adjust TAP query to get more columns
- Colour-code points in CMD by parallax? galactic latitude?

C.1: Locate Gaia TAP service



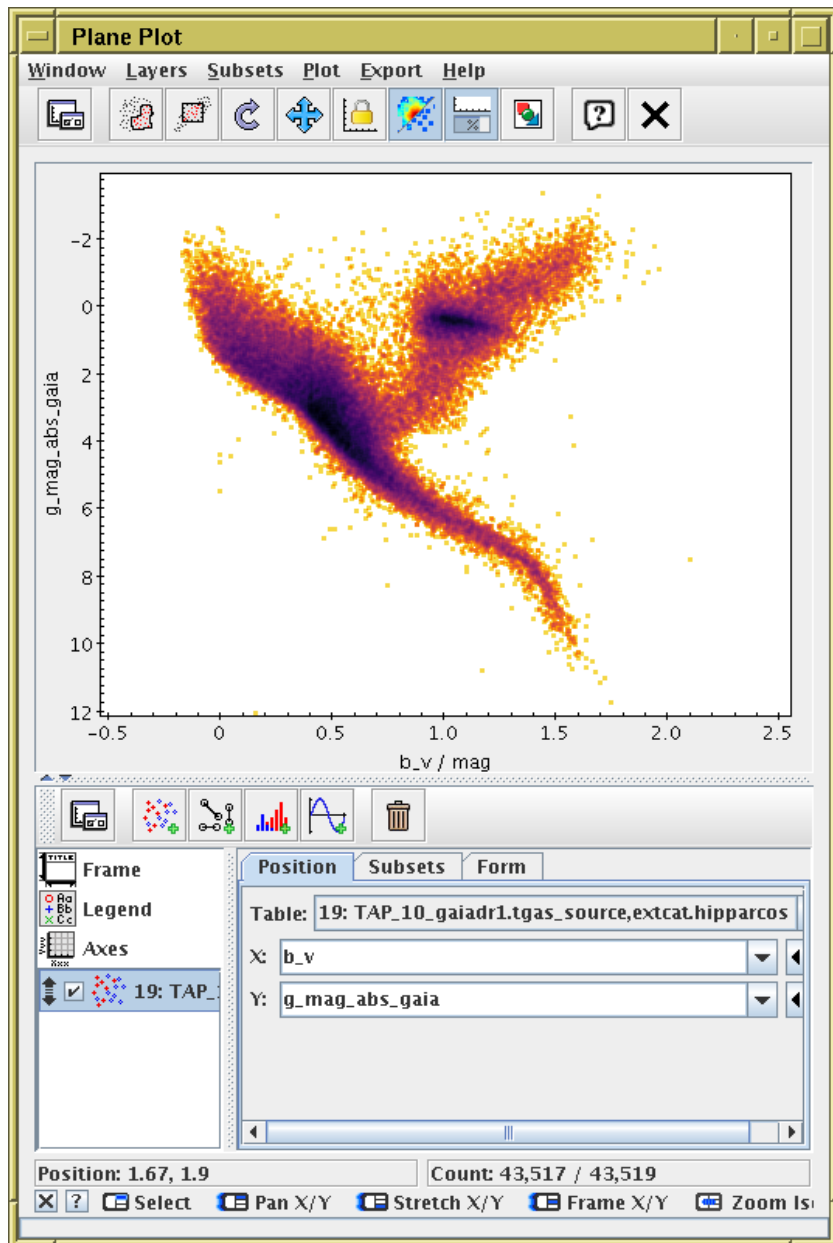
-  **VO|Table Access Protocol (TAP) Query** menu item or toolbar button
- **Select Service** tab, **Keywords:** “**gaia**”
- Select **ARI-Gaia**
- Hit **Use Service** button/tab

C.2: Execute Example CMD query



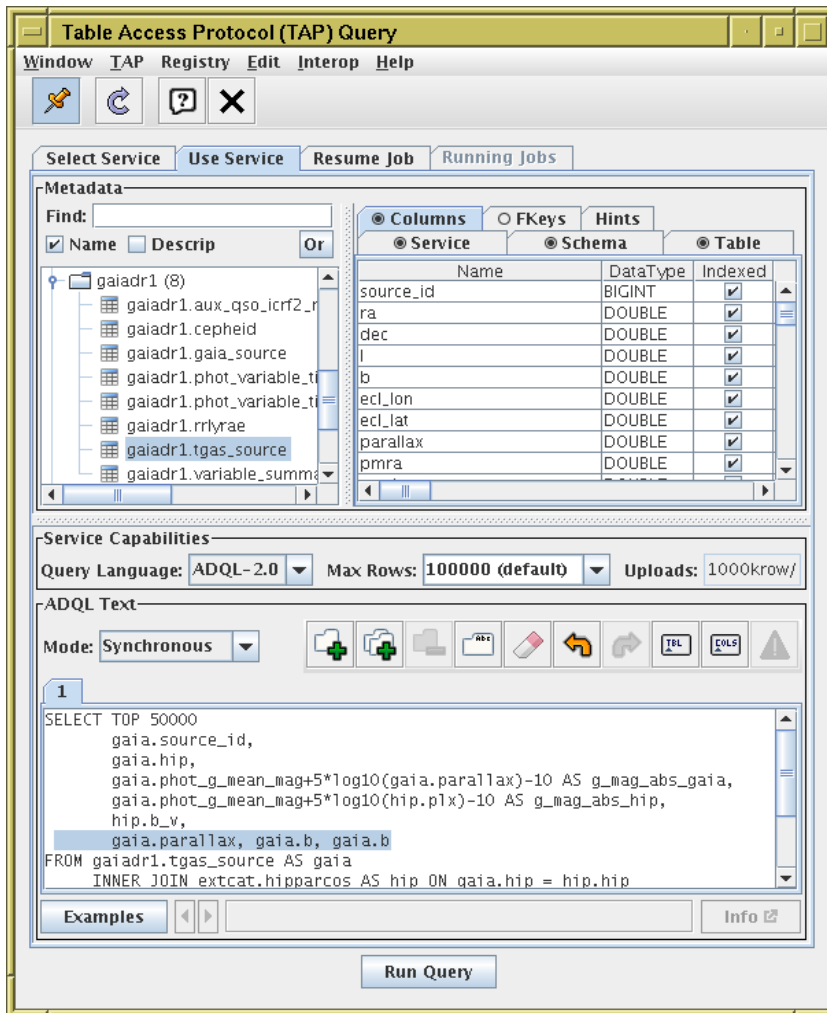
- Use **Examples** menu near bottom of window
- Select **Service-provided—Gaia DR1 - Color and magnitude**
- See ADQL is entered in window
- Hit **Run Query** to execute it

C.3: Plot CMD



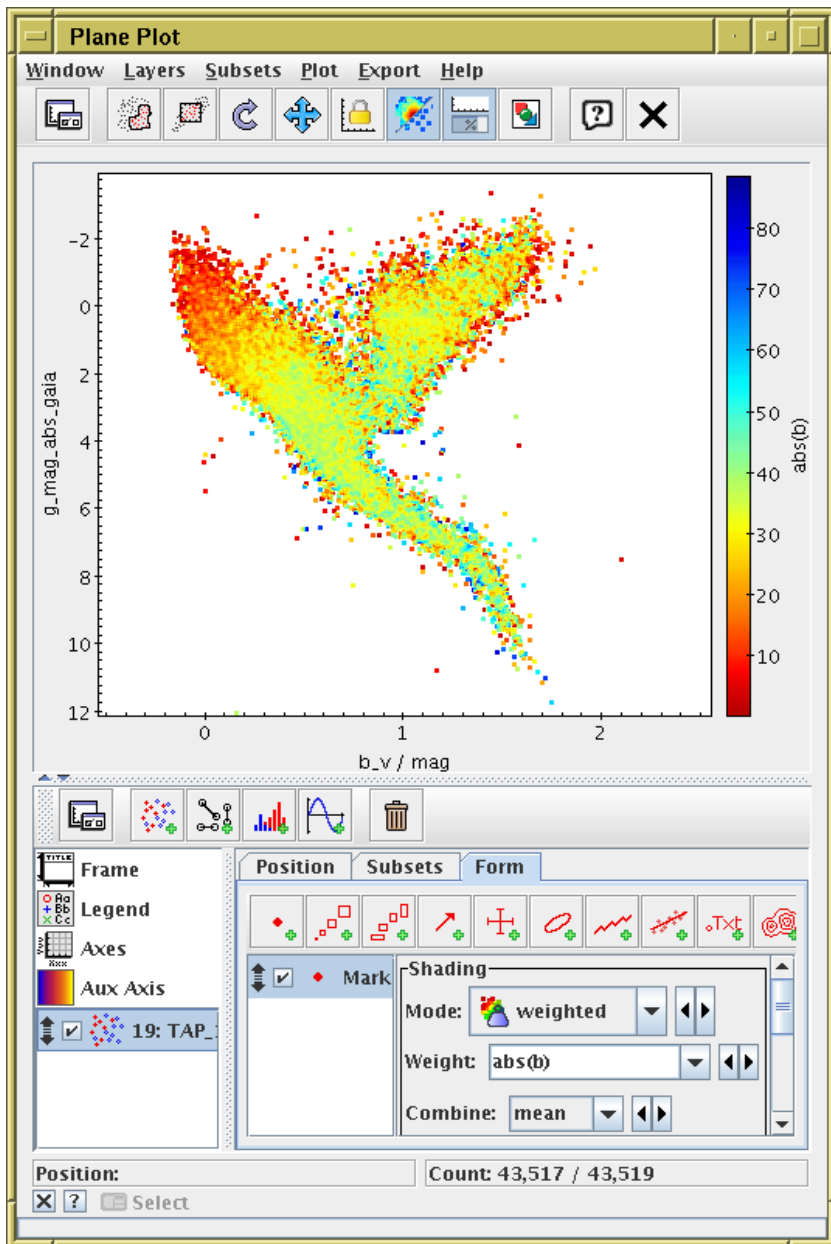
-  **Graphics|Plane Plot**
menu item or toolbar button
 - **X:** “b_v”
 - **Y:** “g_mag_abs_gaia”
 -  **Axes** control, use **Y Flip** checkbox
- ... it's almost too easy.

C.4: Customise ADQL and re-execute



- Back to TAP window, customise the query
- Request also `gaia.parallax`, `gaia.l`, `gaia.b`, more?
- Query again

C.5: Use customised query results



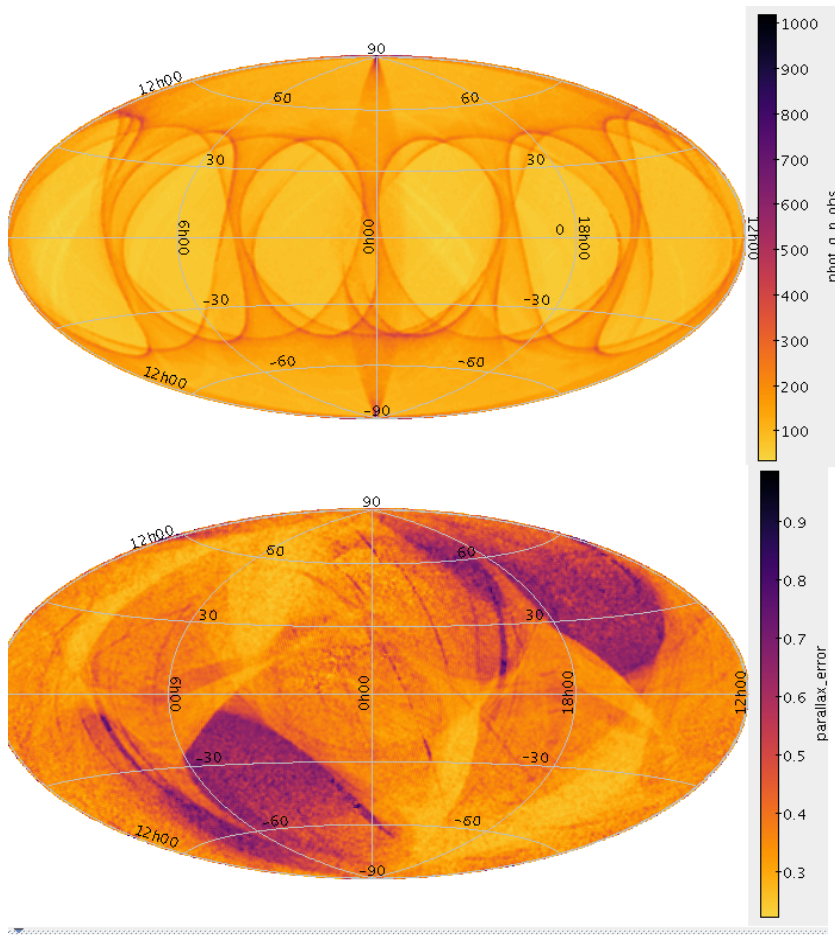
- Adjust the plot
- Use Weighted or Aux mode to colour points
- Find anything interesting? Try weightings:
 - ▶ distance from galactic plane
 $\text{abs}(b)$
 - ▶ transverse velocity
 $4.74 * \text{hypot}(\text{pmra}, \text{pmdec}) / \text{parallax}$

Example D: TGAS All-sky density maps

Statistical/density maps of all TGAS/gaia sources

- Load `tgas_source.fits`
- Sky marker plot: tweak projection, view sky-system etc
- Source densities using shading modes: flat, auto, density
- Statistical plots of `parallax_error`, `phot_g_n_obs`, `hypot(pmra_error, pmde_error)`, ... using shading modes `aux`, `weighted`

D.1: Display weighted TGAS all-sky plots



- Weighted `phot_g_n_obs` in ecliptic coords
- Weighted `parallax_error` in galactic coords
- Plot interactive 2Mrow density map in a few seconds

STILTS

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)

TOPCAT	STILTS
	
GUI	Command line
Interactive	Scriptable
Easy to use	Reproducible
Good for data exploration	Good for batch/programmed use
Exploratory phase	Production phase
few $\times 10^6$ rows	Unlimited size (for most things)

Typical usage:

- start off with TOPCAT
- maybe move on to STILTS for more specialised requirements

Examples: <http://www.star.bristol.ac.uk/~mbt/gaia/tutorial.html>

Summary

- Lots of ways to get Gaia data into TOPCAT
 - Different ones most suitable for different situations
- Lots of things you can do with it once it's there
 - Play around with plots
 - Use documentation
 - Support on mailing list, email me, ...
- Scriptable access/manipulation available using STILTS or JyStilts
- Materials: <http://www.star.bristol.ac.uk/~mbt/gaia/tutorial.html>