

TOPCAT and how to use it for Gaia

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Outline

TOPCAT

- very short intro

Accessing Gaia-DR1 Data from TOPCAT

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

Examples

- Pleiades distance determination
- Match with local catalogue
- TGAS-Hipparcos colour-magnitude diagram
- All-sky density maps


TOPCAT

TOPCAT = Tool for OPerations on Catalogues And Tables

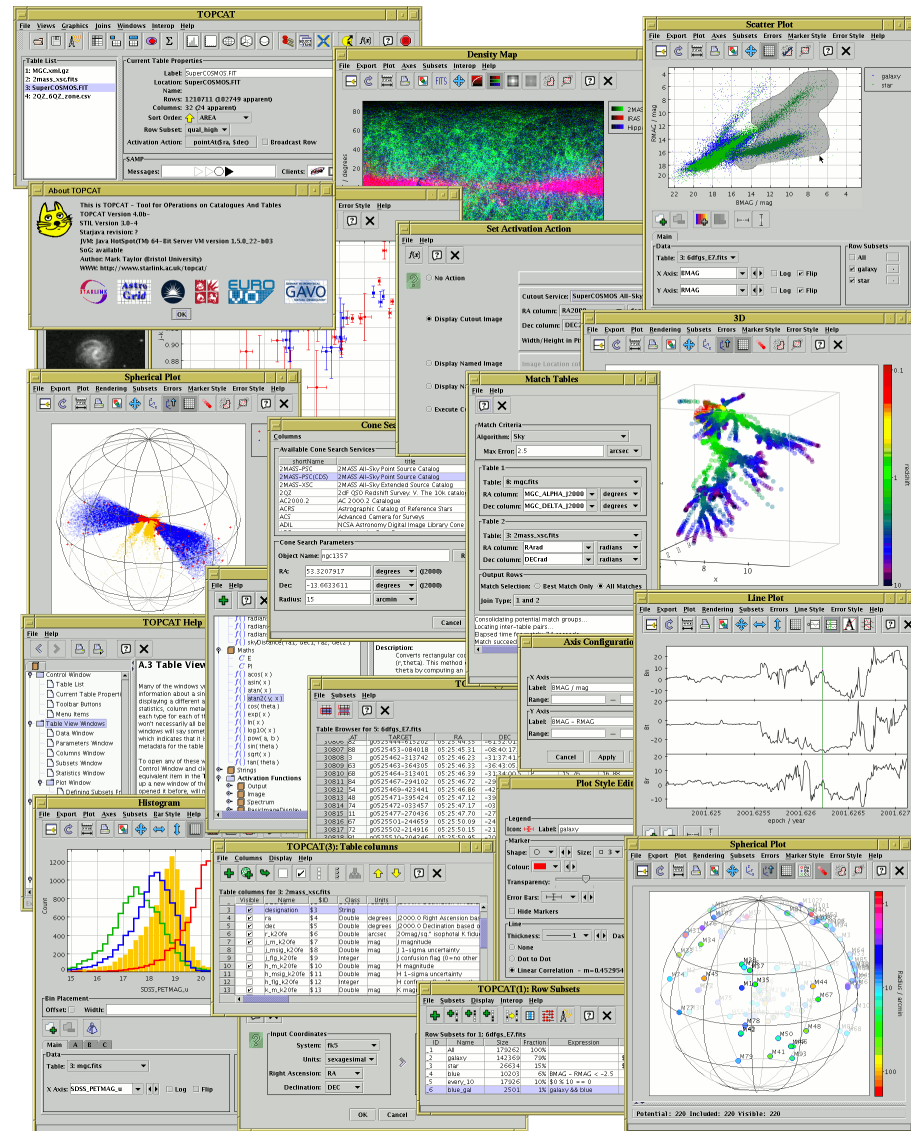
Capabilities:

- Does stuff 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

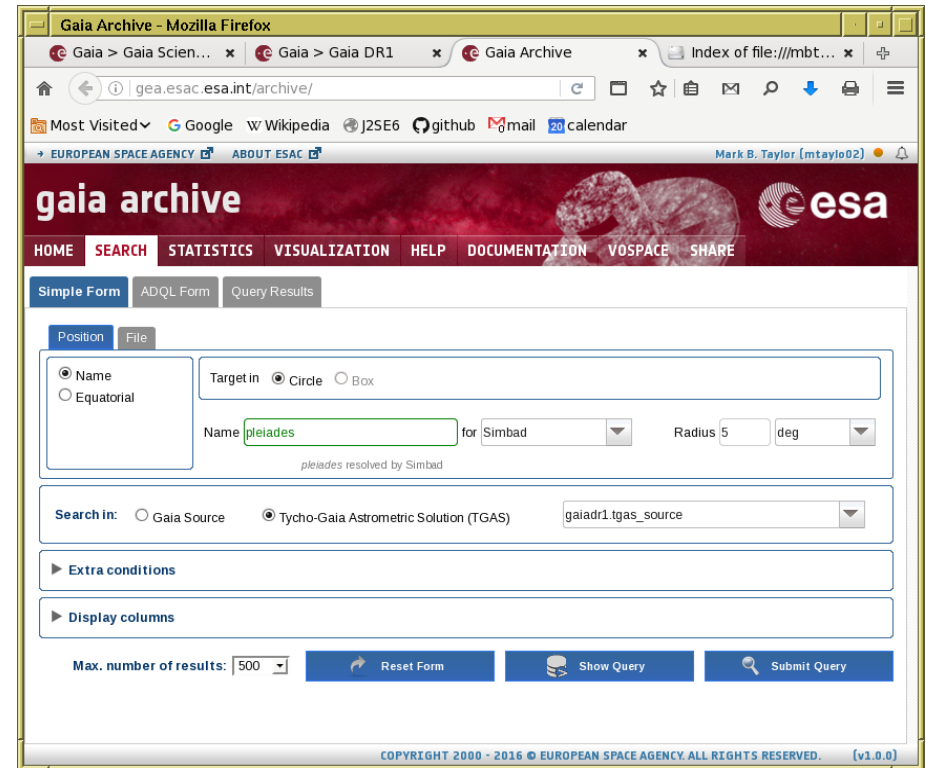
<http://www.starlink.ac.uk/topcat/>



Data Access: GACS


GACS Web interface

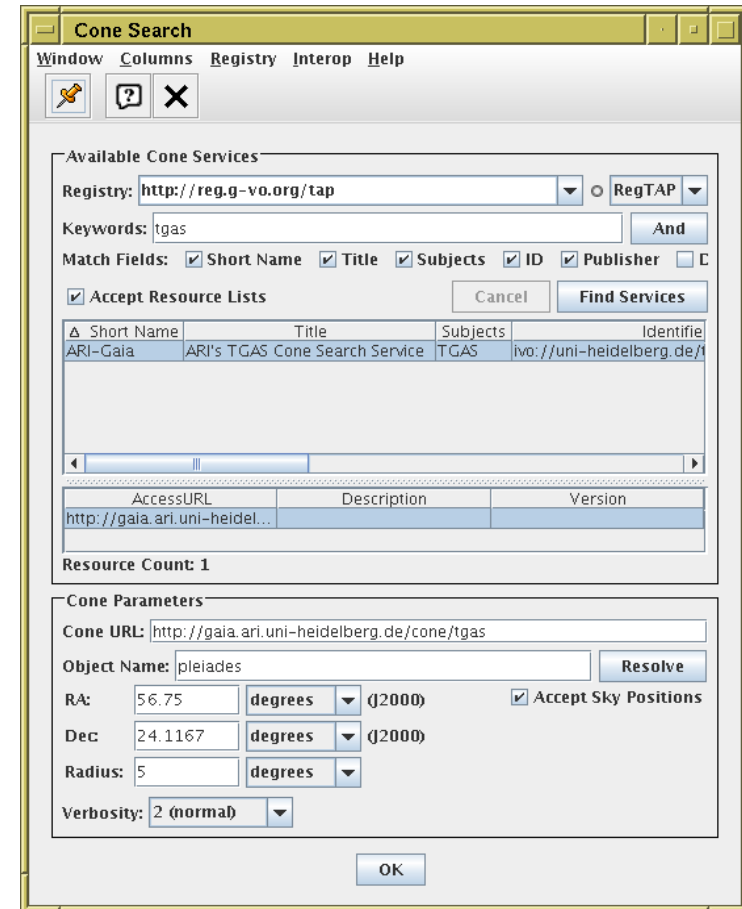
- Details
 - ▷ <http://gea.esac.esa.int/archive>
- Suitability:
 - ▷ large or complex queries
 - ▷ has all Gaia DR tables
 - ▷ persistent uploads
 - ▷ result table management
 - ▷ precalculated neighbour tables
 - ▷ large compute resources
 - ▷ ...
- Usage:
 - ▷ Download  result table to local disk and  **Load** into TOPCAT
 - ▷ Or use SAMP button  to transmit directly to TOPCAT
(requires GACS access using HTTP not HTTPS)



Data Access: Cone Search


Use TOPCAT's Cone Search window

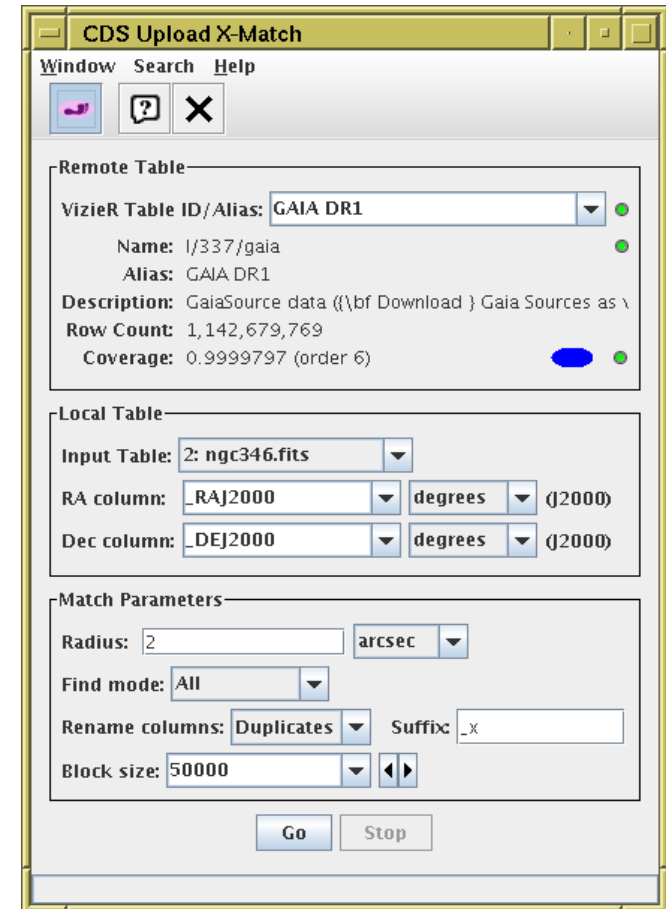
- Details:
 - ▷ Retrieves all Gaia/TGAS sources within a given radius of a given sky position
- Suitability:
 - ▷ If you want all Gaia sources in given sky region
 - ▷ Only selects on position (but can restrict further in TOPCAT)
 - ▷ Limit: 10 million rows
- Usage:
 - ▷  **VO|Cone Search** menu item
 - ▷ **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

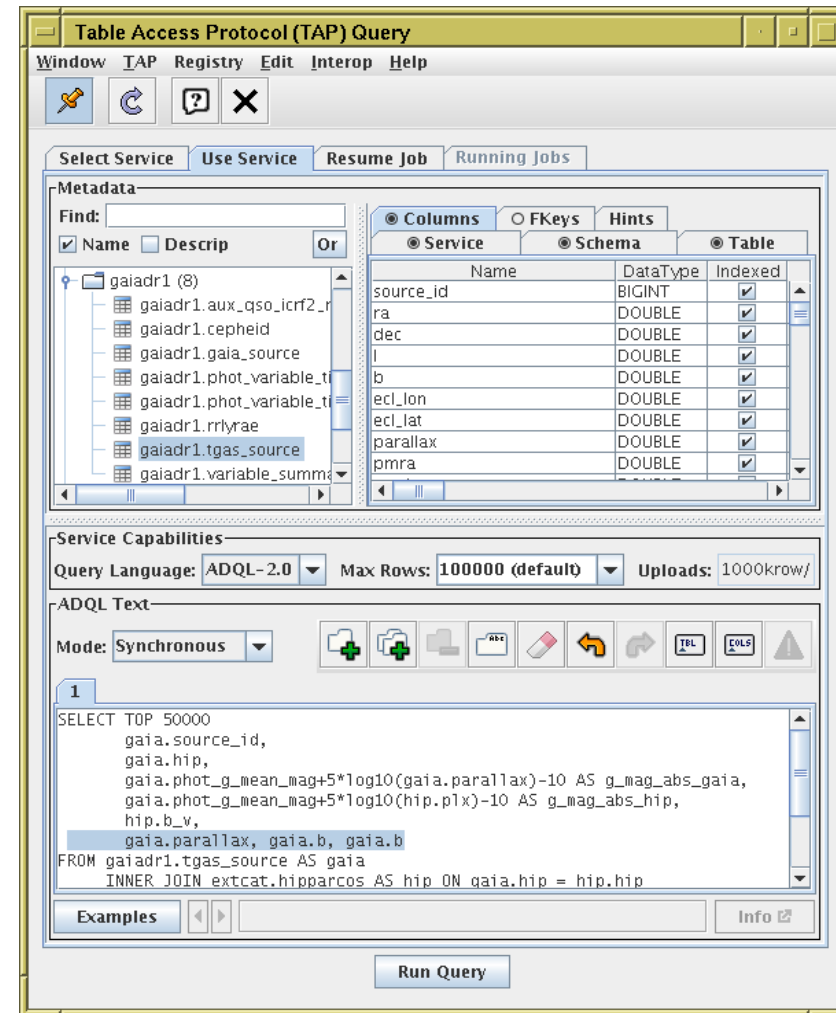
- Details:
 - ▷ Fast, scalable service for crossmatching VizieR tables
 - ▷ TOPCAT can use it for crossmatch of loaded table against Gaia
- Suitability:
 - ▷ Nearest/all nearby Gaia sources for each row of local table
 - ▷ Scales to millions (or more) of rows
 - ▷ Not all columns returned
 - ▷ Only selects 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:
 - ▶ Talks directly to GACS/ARI TAP services, and other non-Gaia TAP servers
 - ▶ Similar functionality, different GUI to GACS web interface
- Suitability:
 - ▶ Suitable for ADQL queries
 - ▶ Better integrated into TOPCAT than GACS 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 (GACS), 10^7 rows (ARI)
- Usage:

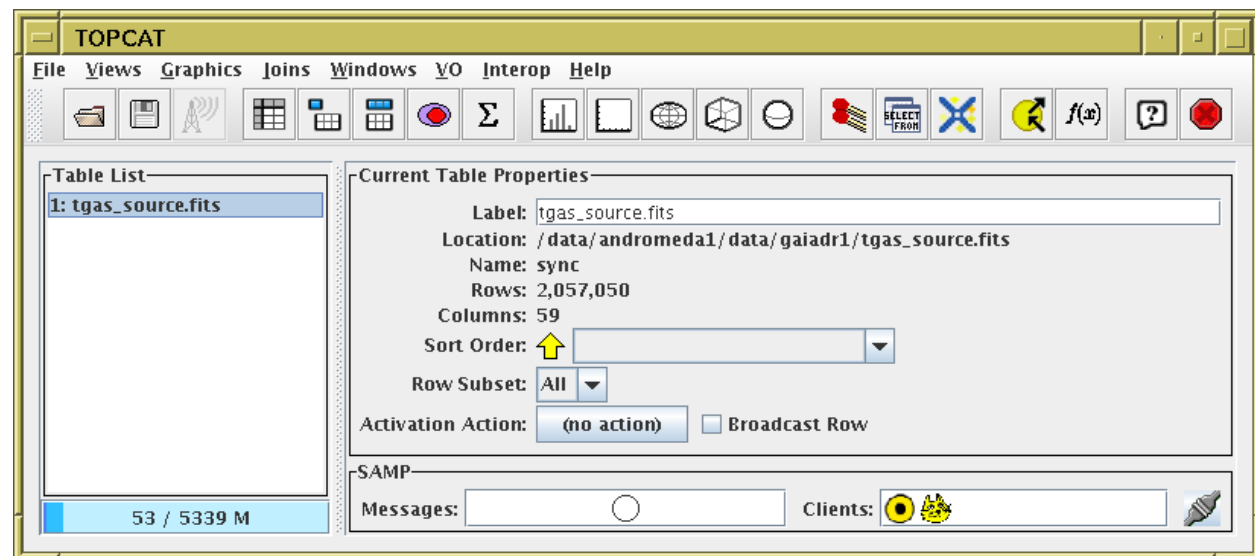


- ▶  **VO|Table Access Protocol (TAP) Query** menu item or toolbar button
- ▶ Select Service **Keywords**: "gaia" → [ARI-Gaia](#) or [\[ESA\] GAIA](#)
- ▶ Docs: <http://www.starlink.ac.uk/topcat/sun253/TapTableLoadDialog.html>

Data Access: TGAS Download

Use monolithic TGAS FITS file

- Details:
 - ▷ Download to local disk, e.g.:
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:

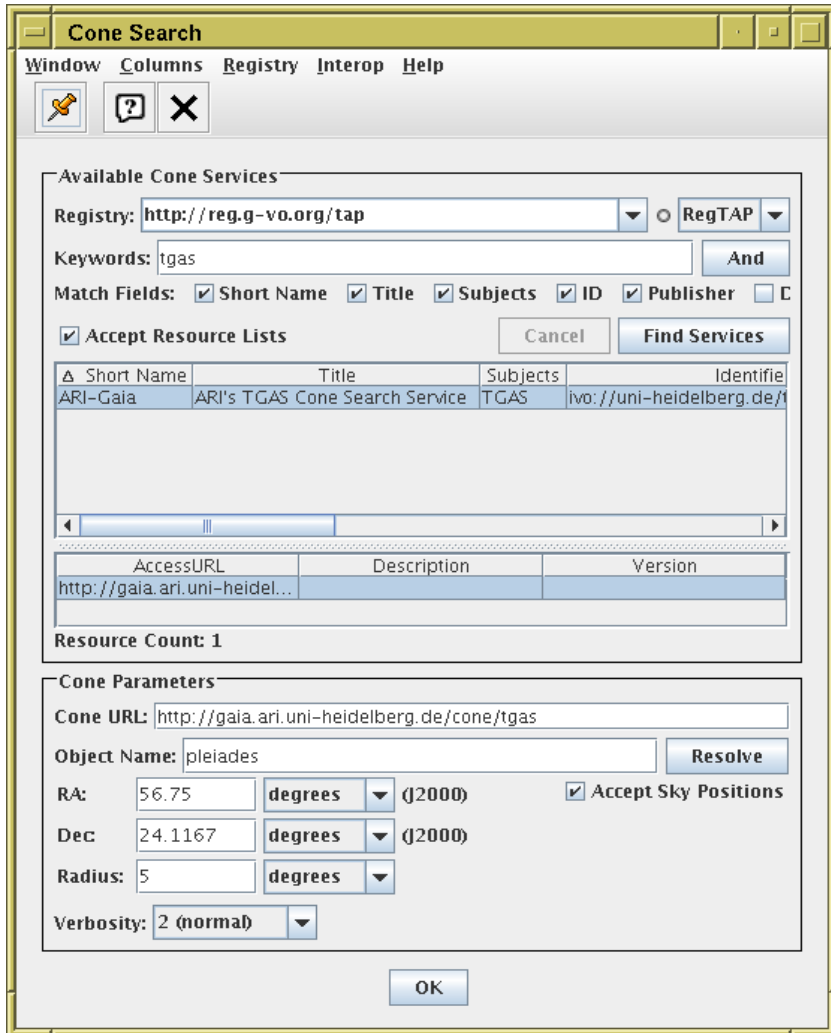
- ARI-Gaia web page (<http://gaia.ari.uni-heidelberg.de/>)
 - ▷ nice GUI
 - ▷ precalculated statistics, single source search + TAP, Cone Search, more to come
- CDS X-Match web page (<http://cdsxmatch.u-strasbg.fr/xmatch>)
 - ▷ allows VizieR/Gaia crossmatch as well as local/Gaia crossmatch
- VizieR (<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 distance

Determine parallax of Pleiades (following Gaia-DR1 paper)

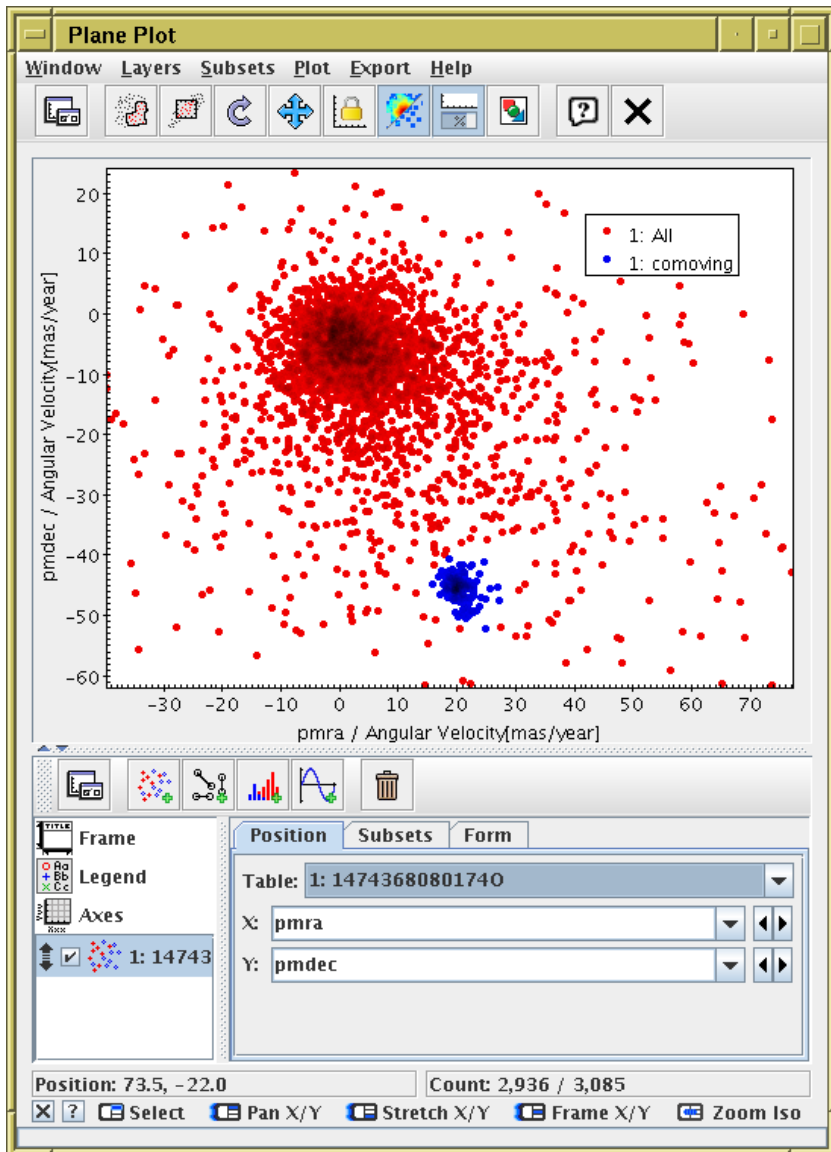
- Cone search TGAS within 5° of Pleiades
- Plot `pmra` vs `pmdec`
- Identify comoving sources, create subset graphically
- Plot `parallax` histogram of comoving subset
- Restrict subset further to exclude parallax outliers
- Use Statistics window to determine cluster $\mu_\varpi, \sigma_\varpi$
- Visualise cluster and non-cluster sources: in 3d space, showing proper motions




A.1: TGAS Cone Search



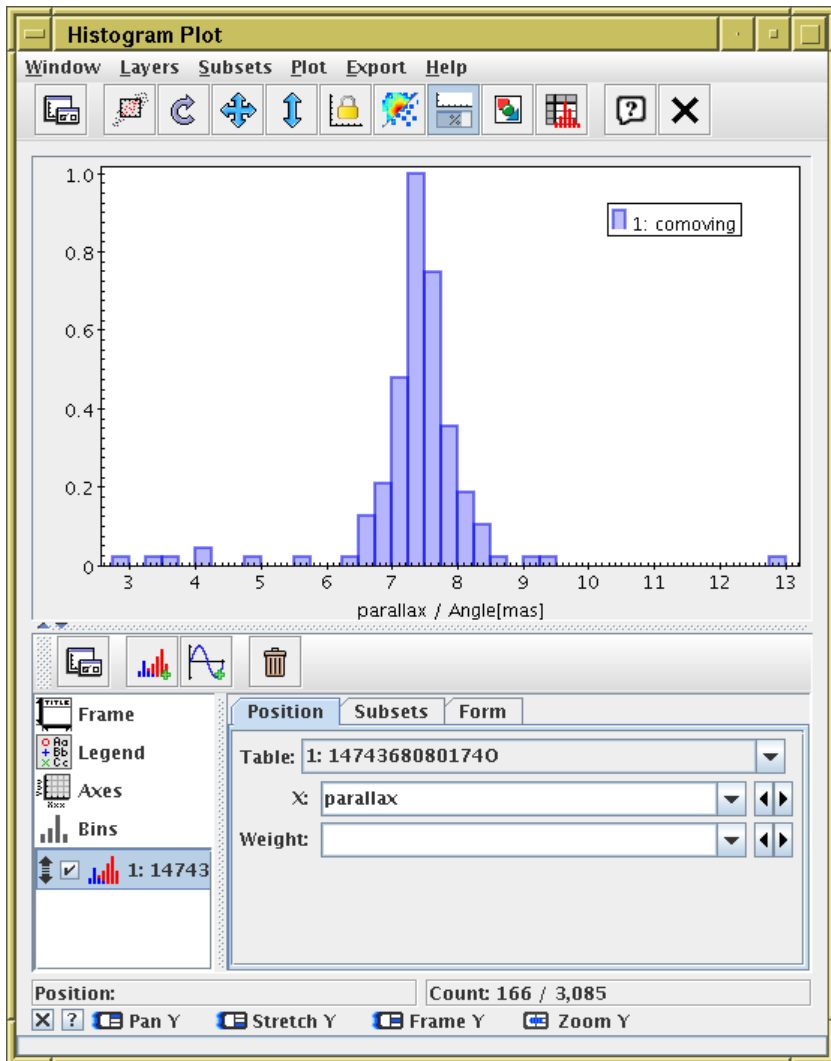
- Want to query TGAS sources within 5° of Pleiades
- Use TOPCAT Cone Search window:
 - ▶  **VO|Cone Search** menu item
 - ▶ **Keywords:** “tgas”
 - ▶ **Object Name:** “pleiades” + **Resolve**
 - ▶ **Radius:** “5”
- ... there are other ways to do it


A.2: Proper motion plot



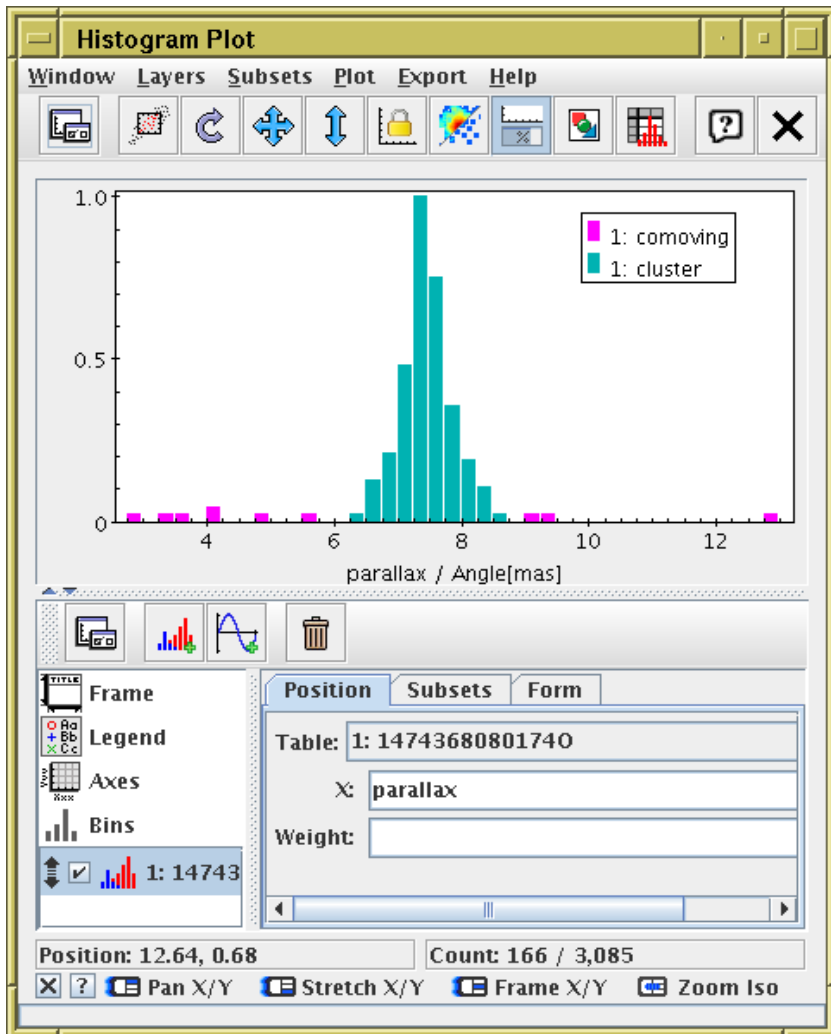
- Plot sources in proper motion space:
 - ▶  **Graphics|Plane Plot** menu item or toolbar button
 - ▶ **X:** “pmra”
 - ▶ **Y:** “pmdec”
 - ▶ Note overdensity far from (0,0)
- Graphically select this comoving cluster as new Subset
 - ▶  button, drag mouse,  again
 - ▶ **New Subset Name:** “comoving”
+ **Add Subset**



A.3: Parallax histogram



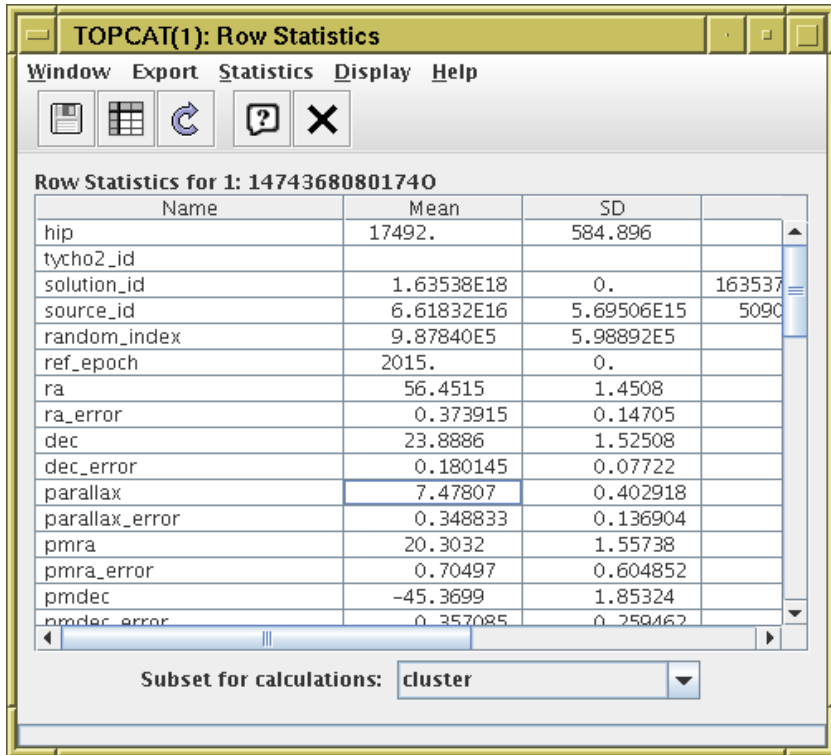
- Plot parallax histogram of comoving subset
 - ▷  **Graphics|Histogram plot** menu item or toolbar button
 - ▷ **X:** “parallax”

A.4: Exclude proper motion outliers



- Restrict comoving subset further to exclude parallax outliers
 - ▶  **Views|Row Subsets** menu item or toolbar button
 - ▶  toolbar button to create new algebraic subset
 - ▶ **Subset Name:** “cluster”
 - ▶ **Expression:** “comoving && parallax>6 && parallax<9”

A.5: Cluster proper motion statistics



TOPCAT(1): Row Statistics

Window Export Statistics Display Help

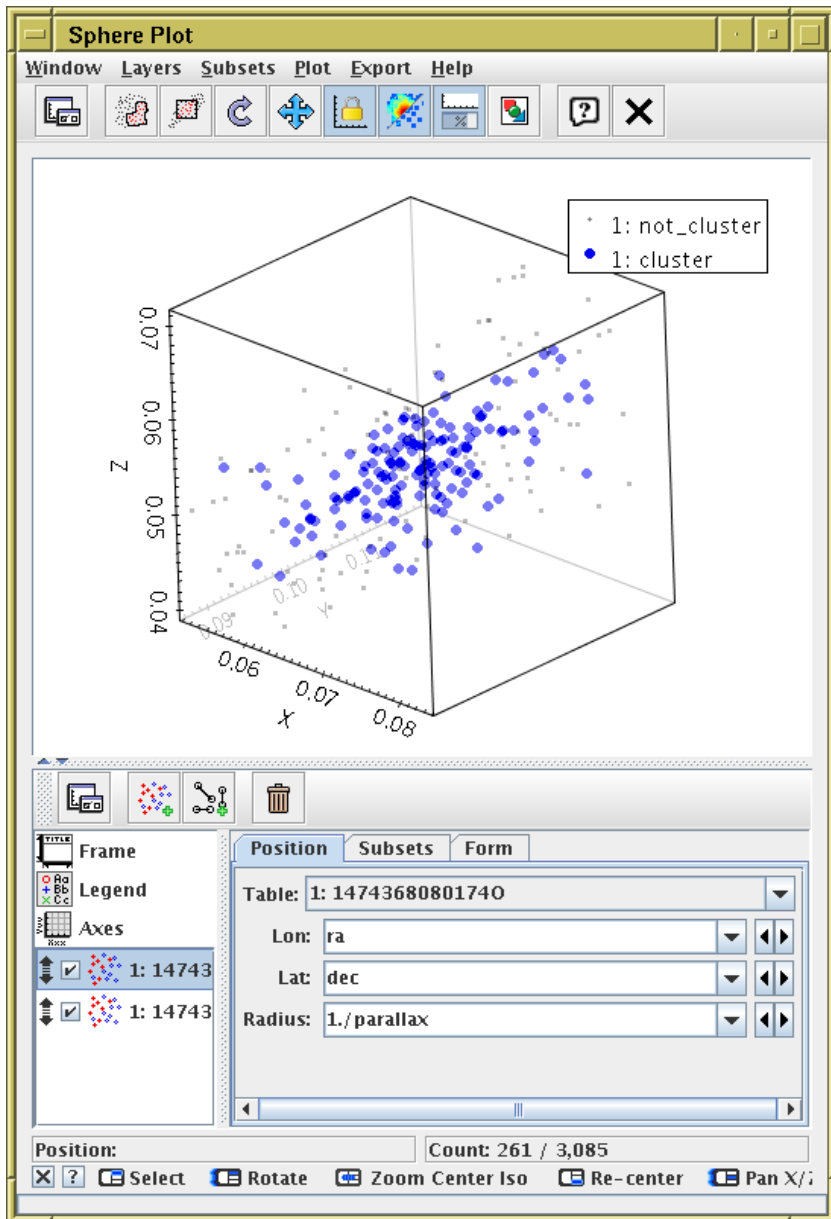
Row Statistics for 1: 14743680801740


Name	Mean	SD	
hip	17492.	584.896	
tycho2_id			
solution_id	1.63538E18	0.	163537
source_id	6.61832E16	5.69506E15	5090
random_index	9.87840E5	5.98892E5	
ref_epoch	2015.	0.	
ra	56.4515	1.4508	
ra_error	0.373915	0.14705	
dec	23.8886	1.52508	
dec_error	0.180145	0.07722	
parallax	7.47807	0.402918	
parallax_error	0.348833	0.136904	
pmra	20.3032	1.55738	
pmra_error	0.70497	0.604852	
pmdec	-45.3699	1.85324	
pmdec_error	0.357085	0.250462	

Subset for calculations: cluster

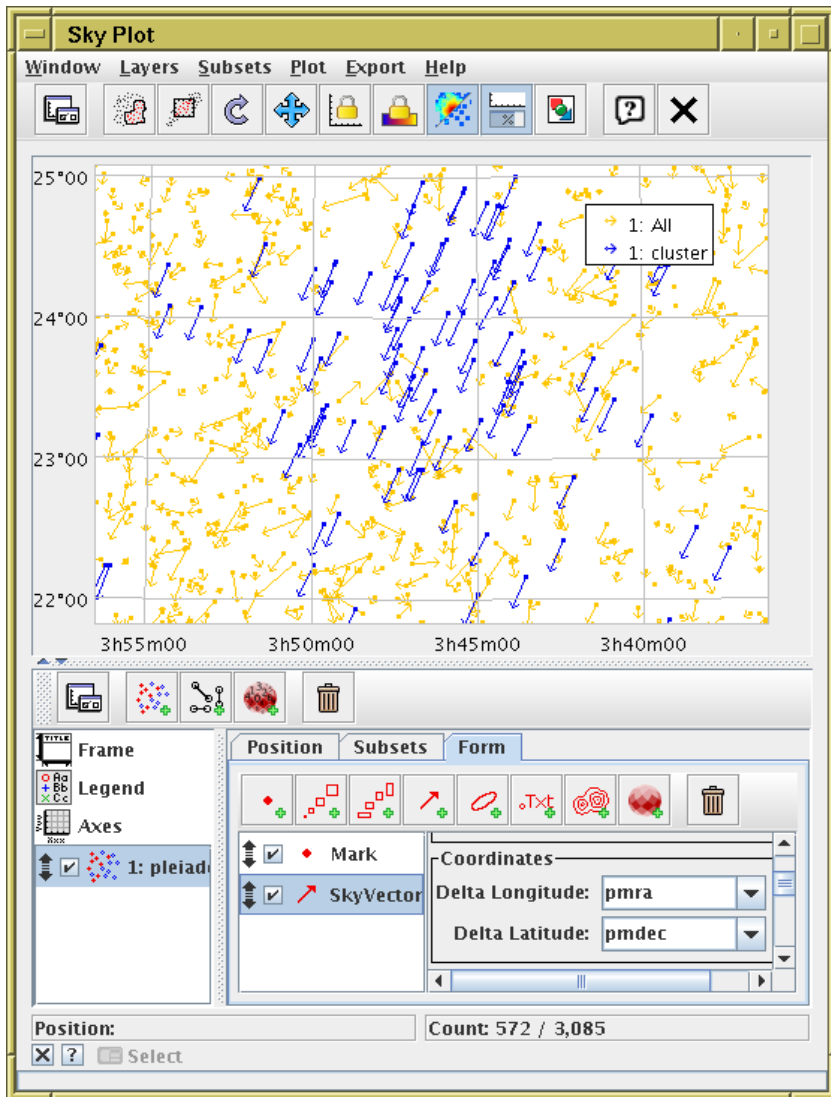
- Σ Views|Column Statistics menu item or toolbar button
- Subset for Calculations: “cluster”
- See Mean and Stdev columns
- → pleiades parallax $\approx 7.5 \pm 0.4$ mas
- careful with priors if converting to distance
- ... but parallax_error/parallax is quite high for all cluster members



A.6: 3d cluster positions



-  **Graphics|Sphere Plot**
menu item or toolbar button
- **Subsets** tab: select **cluster** subset only
- **Lon:** “ra”
- **Lat:** “dec”
- **Radius:** “1./parallax”
- Cluster positions are visible in 3d space
- You can turn on **All/comoving** subsets too

A.7: 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

Example B: Crossmatch with local catalogue

Match with Gouliermis et al. 2006 (NGC 346 HST/ACS photometry)

- 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
 - ▶ G magnitudes for Gouliermis sub-sample ($\sim 1\,800/99\,000$ sources)

B.1: Acquire NGC 346 catalogue

VizieR Catalogue Service

Window Help

VizieR Server
Server:

Row Selection

Cone Selection

Object Name:

RA: (J2000)

Dec: (J2000)

Radius:

All Rows

Maximum Row Count:

Column Selection

Output Columns:


Catalogue Selection

By Category By Keyword Surveys Missions

Keywords:

Sub-Table Details Include Obsolete Tables

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 (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

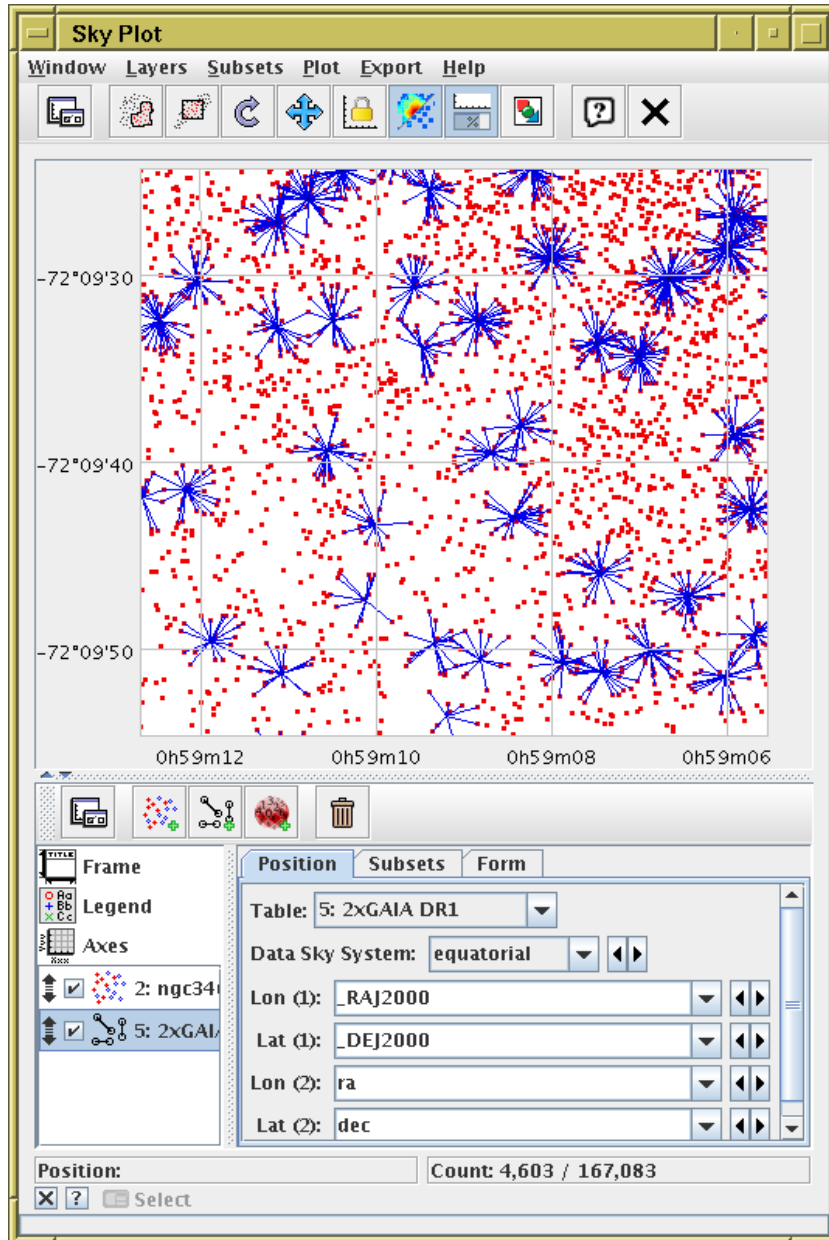
Rename columns: Duplicates Suffix: _x




Block size: 50000

Go Stop

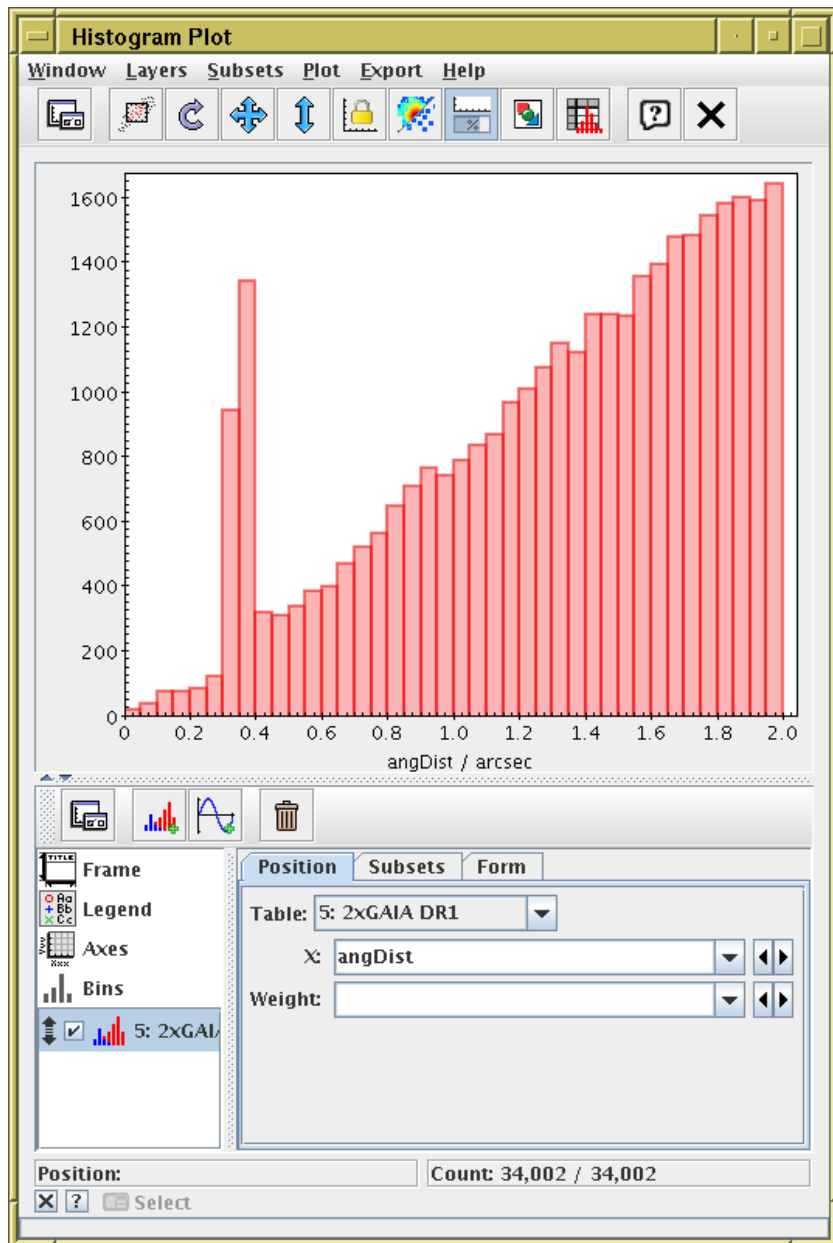
-  VO|CDS Upload X-Match menu item or toolbar button
- VizieR Table ID: “GAIA DR1”
- Radius: “1” arcsec
- Find mode: All


B.3: Plot crossmatch results



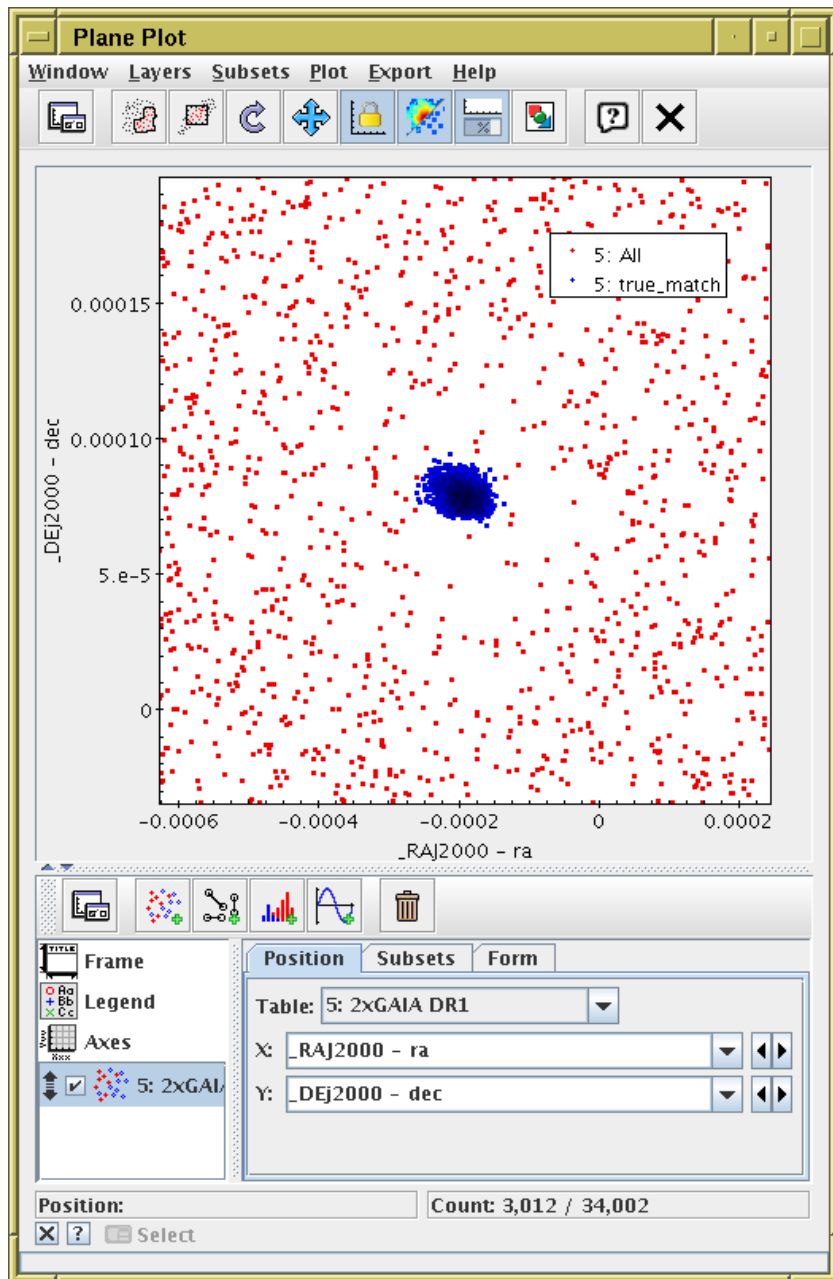
-  **Graphics|Sky Plot**
menu item or toolbar button
-  Plot NGC 364 points
-  Plot Gaia ↔ Gouliermis associations
(*[Goul]* _RAJ2000, _DEJ2000, *[Gaia]* ra, dec)
- ... too many



B.4: Plot crossmatch offsets



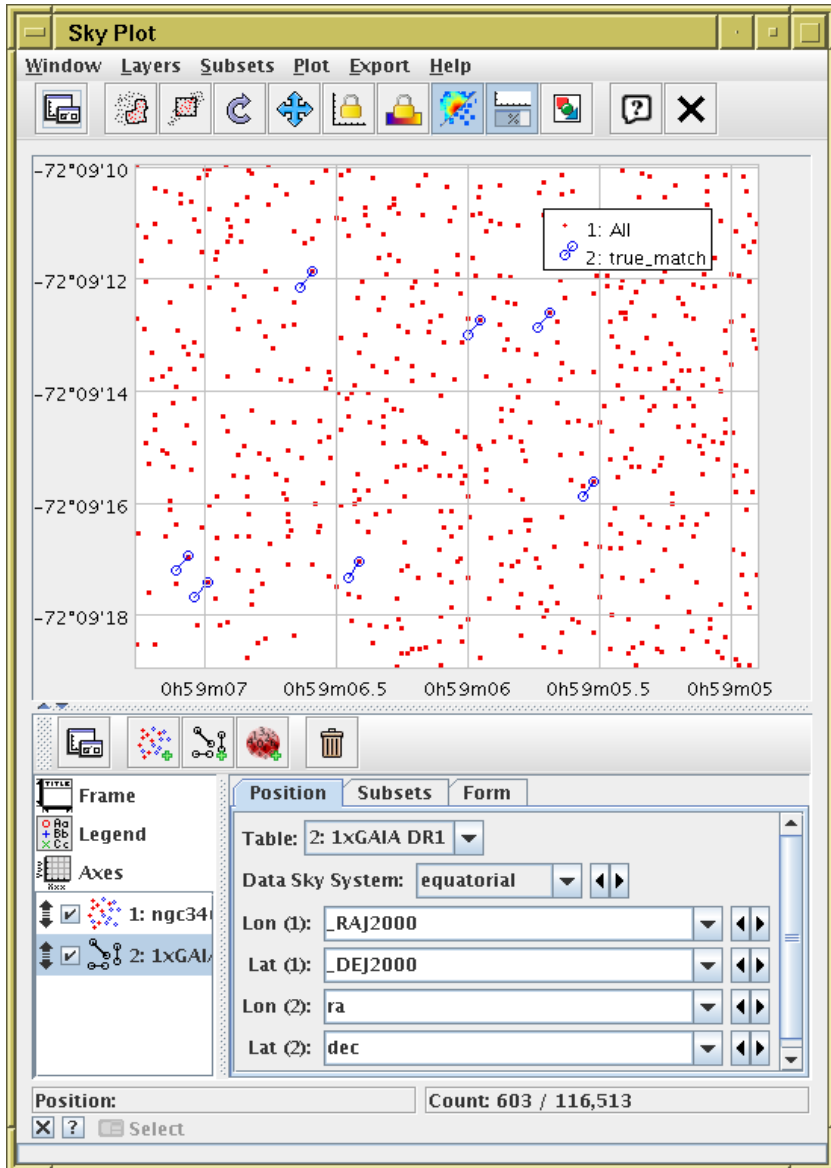
-  **Graphics|Histogram plot**
menu item or toolbar button
- **X:** “angDist”
(Gaia—Gouliermis association distance)
- (some) true associations near 0.35 arcsec

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 & Gaia observations (1992?–2015.0):

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

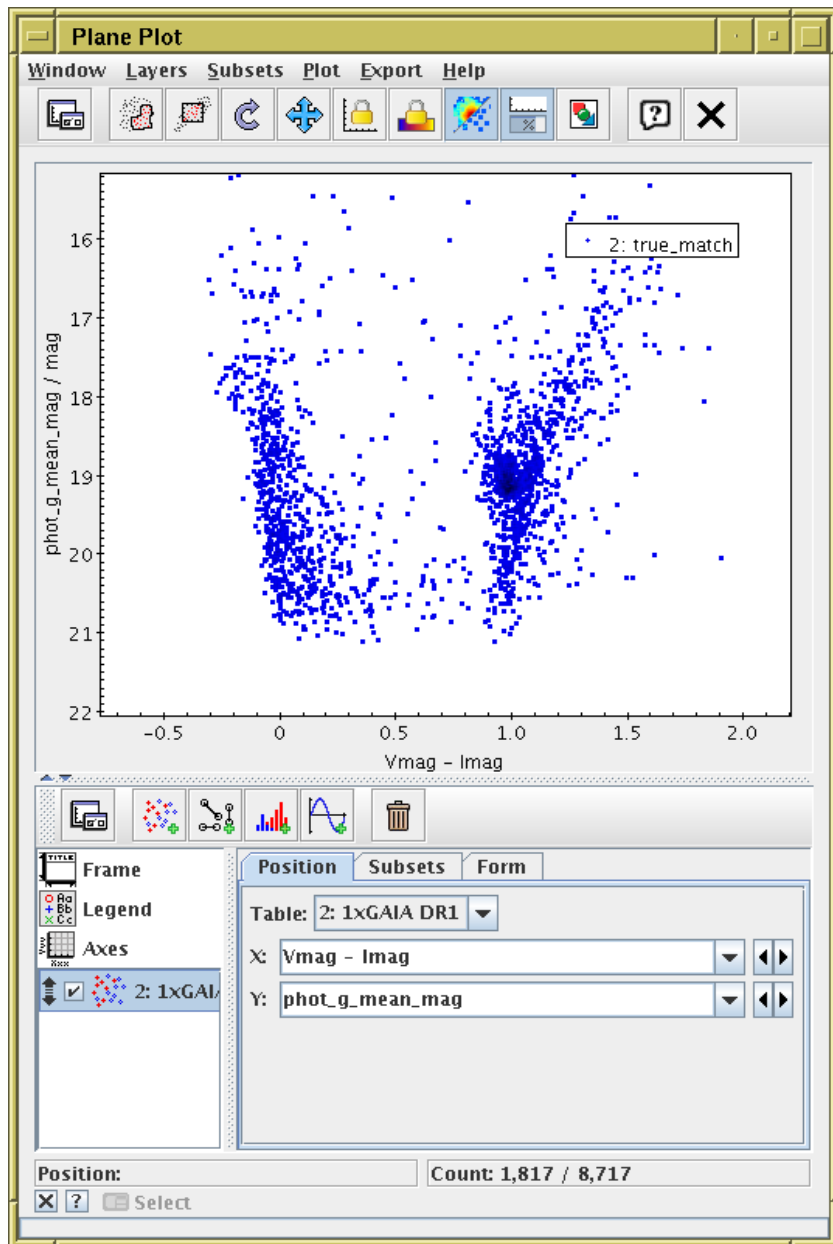
$$\overline{\Delta\delta} \approx -284 \pm 15 \text{ mas}$$

so proper motion:

$$\mu_{\alpha^*} \approx +9.1 \text{ mas.yr}^{-1}$$

$$\mu_{\delta} \approx -12 \text{ mas.yr}^{-1}$$

B.7: Combine HST and Gaia photometry



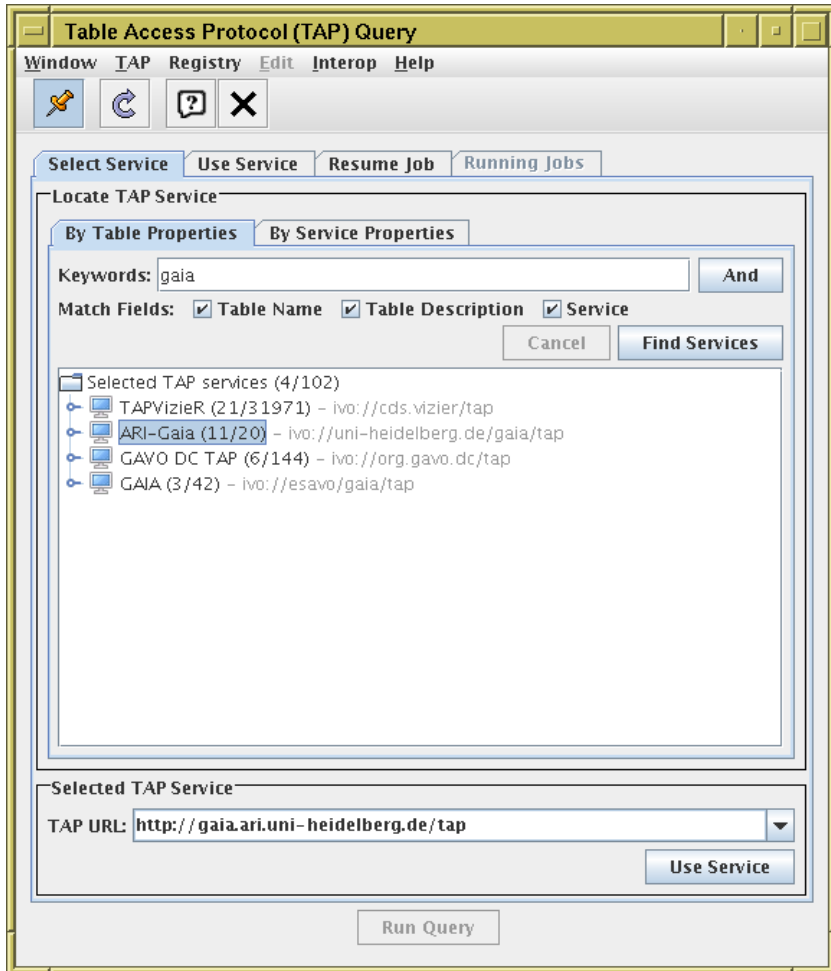
- Joined table now has Gaia G-band photometry alongside HST V/I-band photometry


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

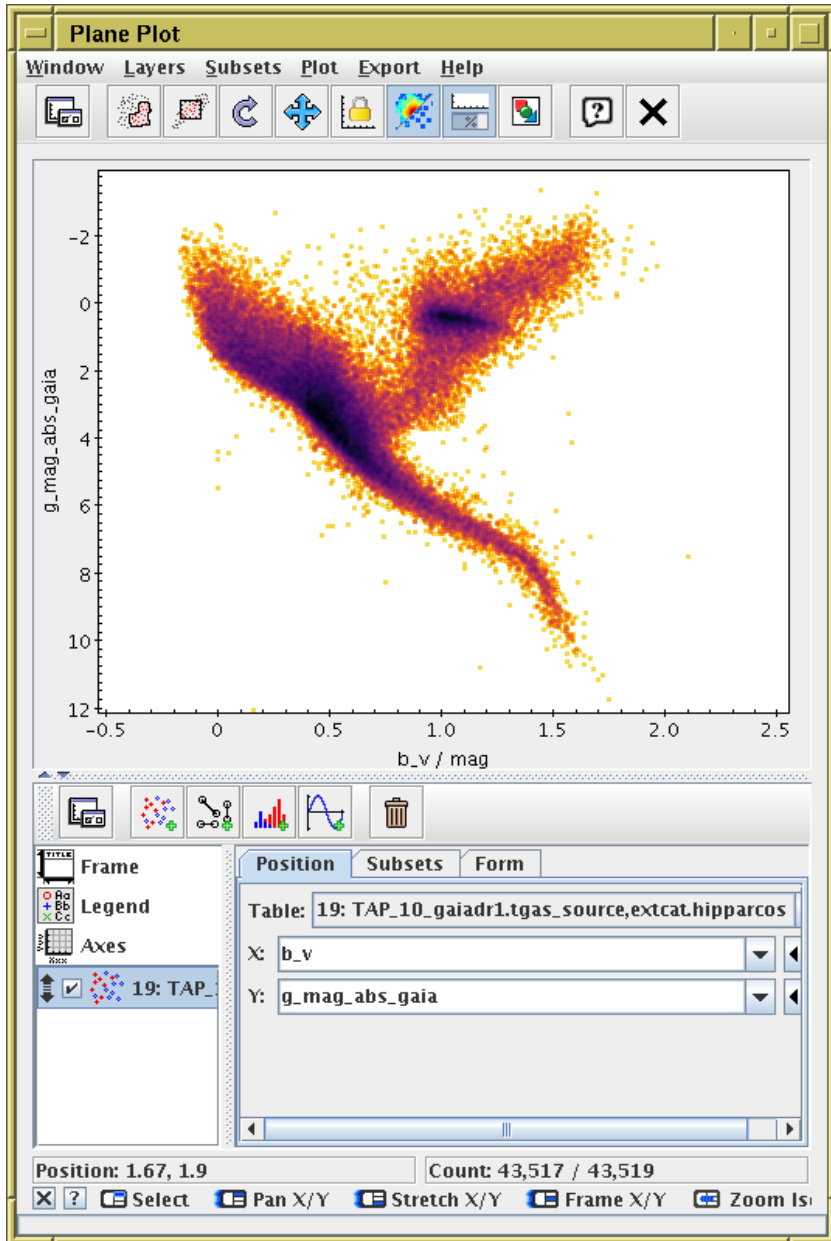
C.2: Execute Example CMD query



The screenshot shows the 'Table Access Protocol (TAP) Query' window. The 'Metadata' section displays a table with columns: Service, Schema, Table, Columns, FKKeys, and Hints. The 'Columns' column is expanded, showing a list of columns with their data types, indexed status, and units. A context menu is open over the 'Columns' column, listing various query examples such as 'Get the 5 astrometric parameters', 'Cone Search with Galactic coordinates', and 'Gaia DR1 - Color and magnitude 1/2'. The 'Run Query' button is visible at the bottom of the context menu.

Service	Schema	Table	Columns	FKKeys	Hints
		source_id	BIGINT	✓	Unique source id
		ra	DOUBLE	✓	deg Right ascension
		dec	DOUBLE	✓	deg Declination
		l	DOUBLE	✓	deg Galactic longitude
		b	DOUBLE	✓	deg Galactic latitude
		ecl_lon	DOUBLE	✓	deg Ecliptic longitude
		ecl_lat	DOUBLE	✓	deg Ecliptic latitude
		parallax	DOUBLE	✓	mas Parallax
		pmra	DOUBLE	✓	mas/yr Proper motion in RA
		pmdec	DOUBLE	✓	mas/yr Proper motion in Dec

- 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

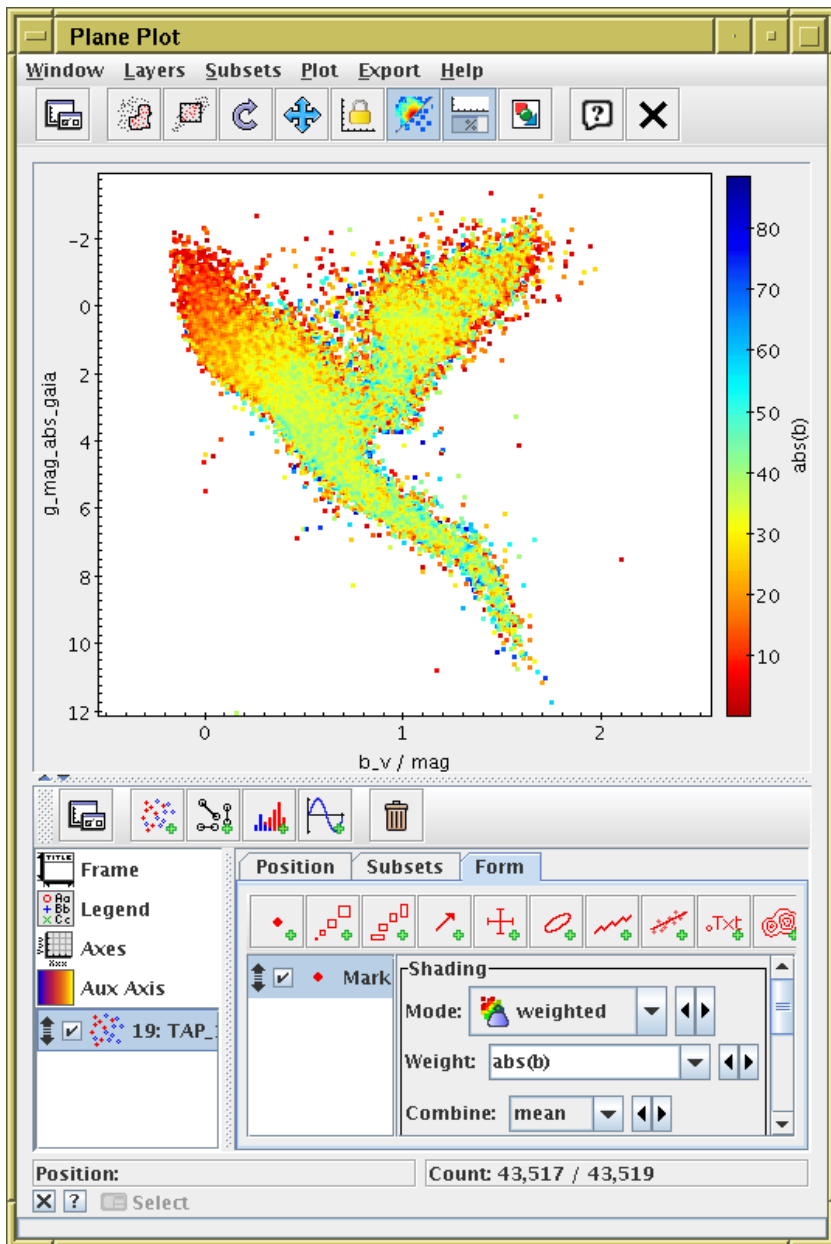
The screenshot shows the 'Table Access Protocol (TAP) Query' window. The 'Metadata' section displays a tree view of tables and a table of columns. The 'Service Capabilities' section shows 'Query Language: ADQL-2.0', 'Max Rows: 100000 (default)', and 'Uploads: 1000krow/'. The 'ADQL Text' section shows a query in 'Synchronous' mode:

```
1
SELECT TOP 50000
  gaia.source_id,
  gaia.hip,
  gaia.phot_g_mean_mag+5*log10(gaia.parallax)-10 AS g_mag_abs_gaia,
  gaia.phot_g_mean_mag+5*log10(hip.plx)-10 AS g_mag_abs_hip,
  hip.b_v,
  gaia.parallax, gaia.b, gaia.l
FROM gaiadr1.tgas_source AS gaia
INNER JOIN extcat.hipparcos AS hip ON gaia.hip = hip.hip
```

At the bottom, there is a 'Run Query' button.

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

C.5: Use customised query results



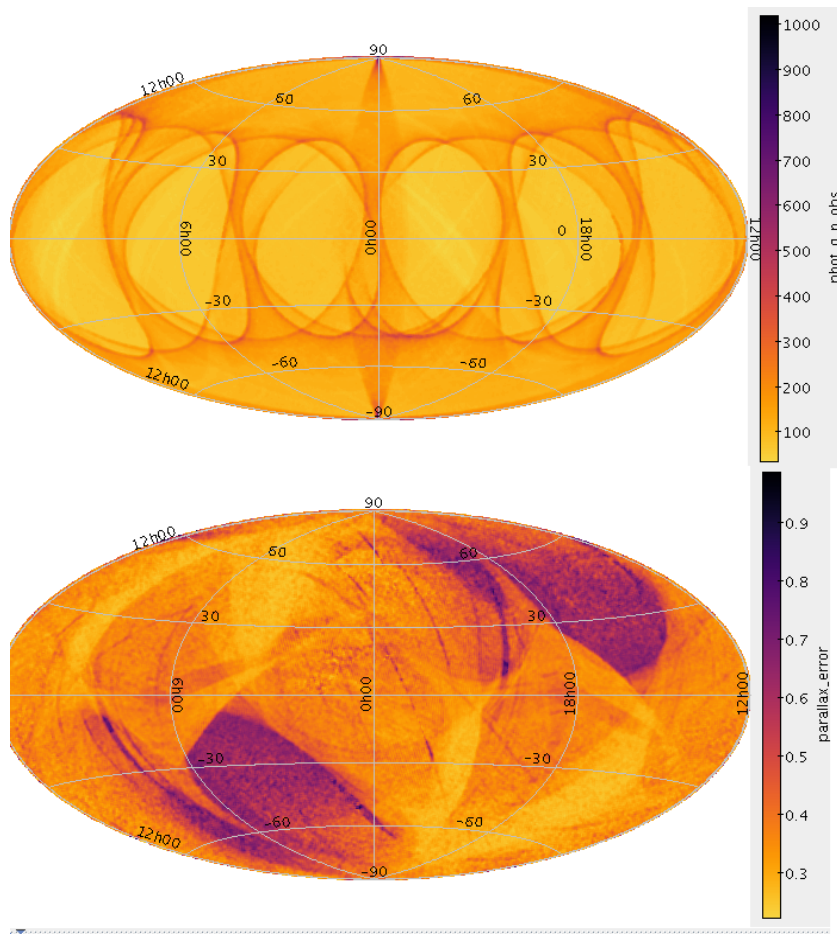
- Adjust the plot
- Use Weighted or Aux mode to colour points
- Find anything interesting? (maybe not)

Example D: All-sky density

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

Most of TOPCAT's capabilities can be scripted

- STILTS: from command line (e.g. un*x shell)
- JyStilts: from Jython (python interface, but not CPython)

Details

- Not covered in this talk!
- But some examples available:
 - See <http://www.star.bristol.ac.uk/~mbt/gaia/tutorial.html>
- Full documentation and examples in <http://www.starlink.ac.uk/stilts/>

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>