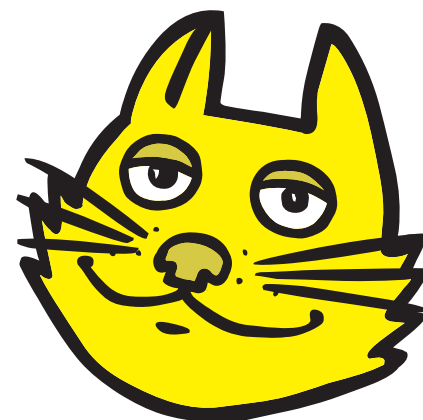


TOPCAT and how to use it for Gaia

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\$Id: tcgaia_esac.tex,v 1.7 2016/11/04 08:10:11 mbt Exp \$

TOPCAT

- very short intro

Accessing Gaia-DR1 Data from TOPCAT

- ESA 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

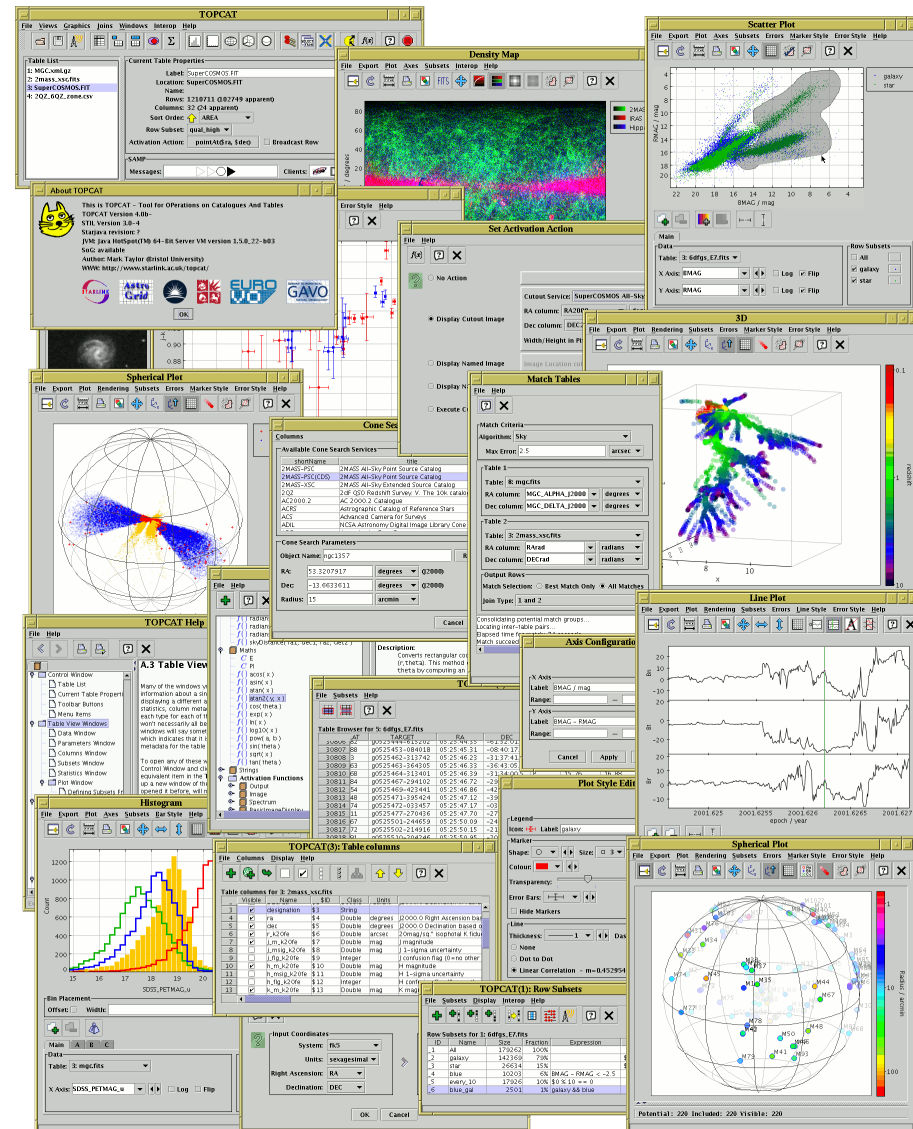
Capabilities:

- 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](#)

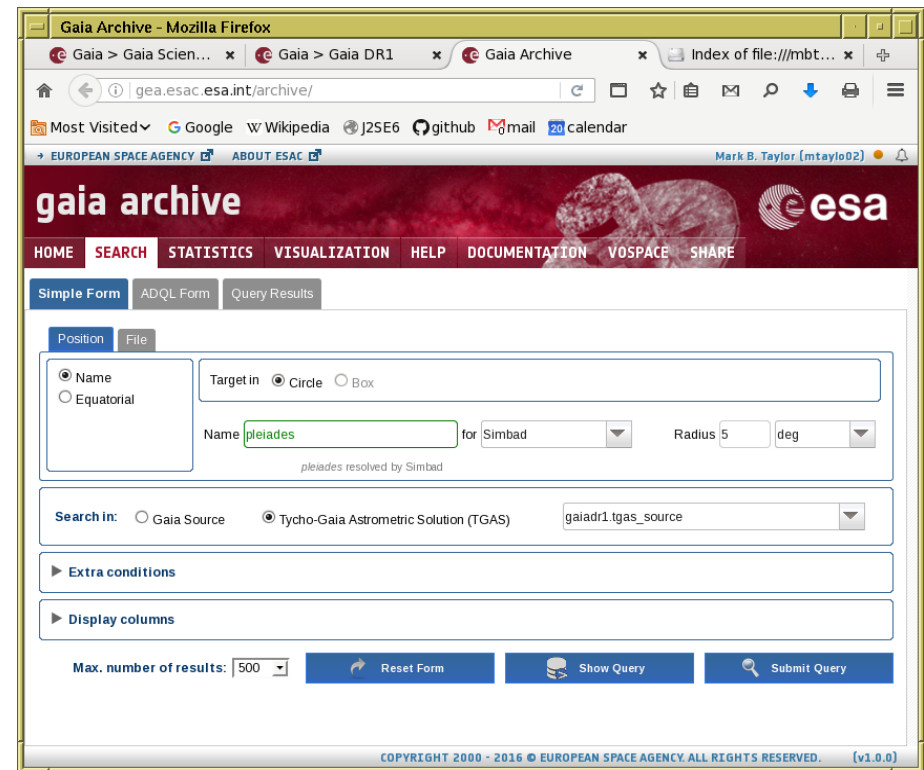
<http://www.starlink.ac.uk/topcat/>



Data Access: ESA “TAP+” Web Interface

ESA Web interface

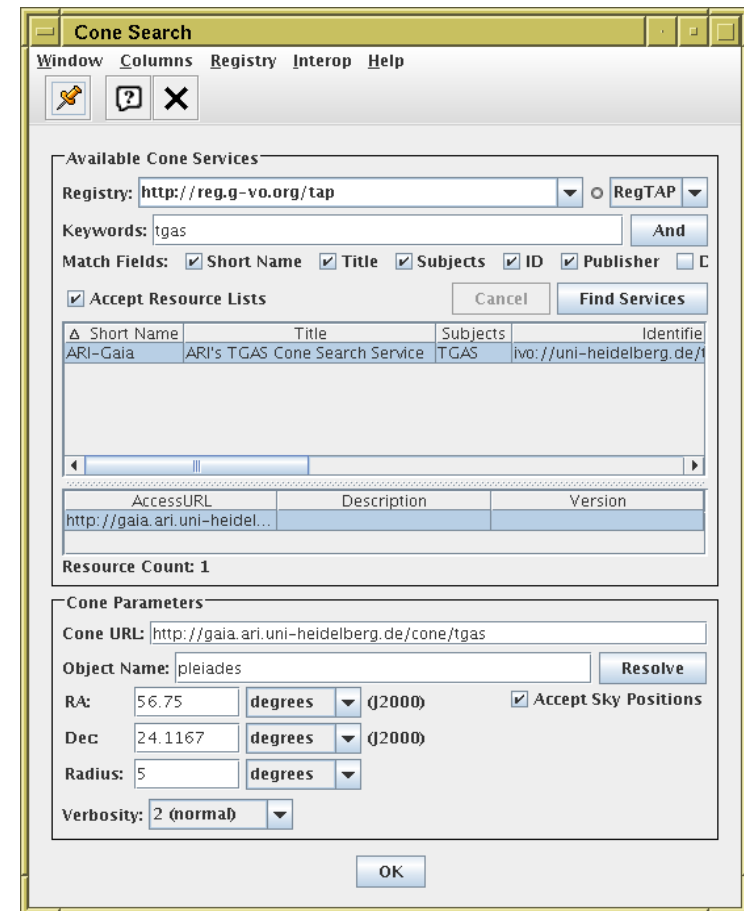
- Details
 - ▷ <http://gea.esac.esa.int/archive>
- Suitability:
 - ▷ large or complex queries
 - ▷ has all Gaia DR tables
 - ▷ persistent uploads
 - ▷ result table management
 - ▷ precalculated neighbour tables
 - ▷ share results with collaborators
 - ▷ large compute resources
 - ▷ ...
- Usage:
 - ▷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



Data Access: Cone Search

Use TOPCAT's Cone Search window

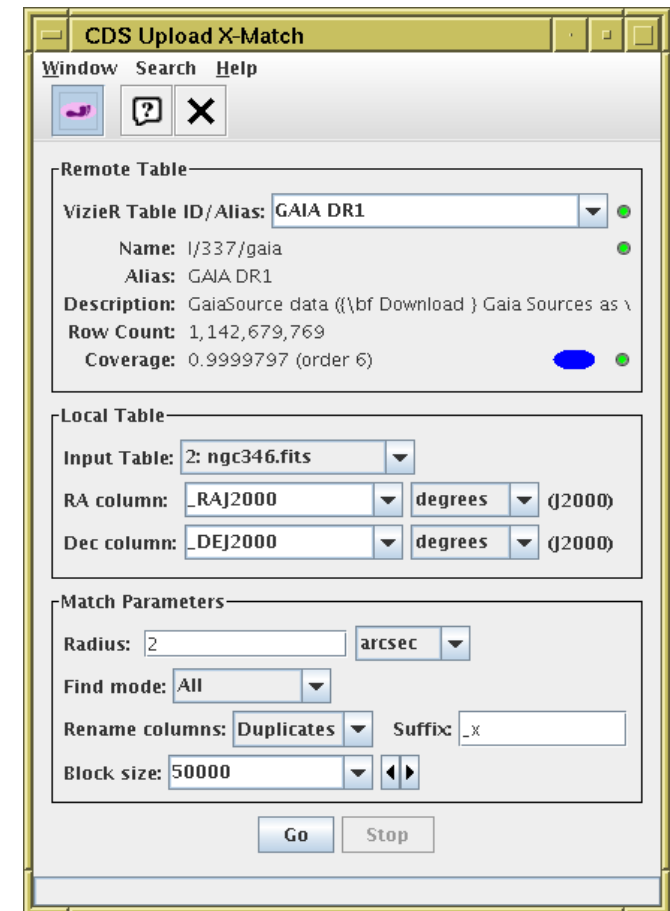
- Details:
 - ▶ Retrieves all Gaia/TGAS sources within a given radius of a given sky position
- Suitability:
 - ▶ If you want all Gaia sources in given sky region
 - ▶ Only selects on position (but can restrict further in TOPCAT)
 - ▶ Limit: 10 million rows
- Usage:
 - ▶  **VO|Cone Search** menu item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



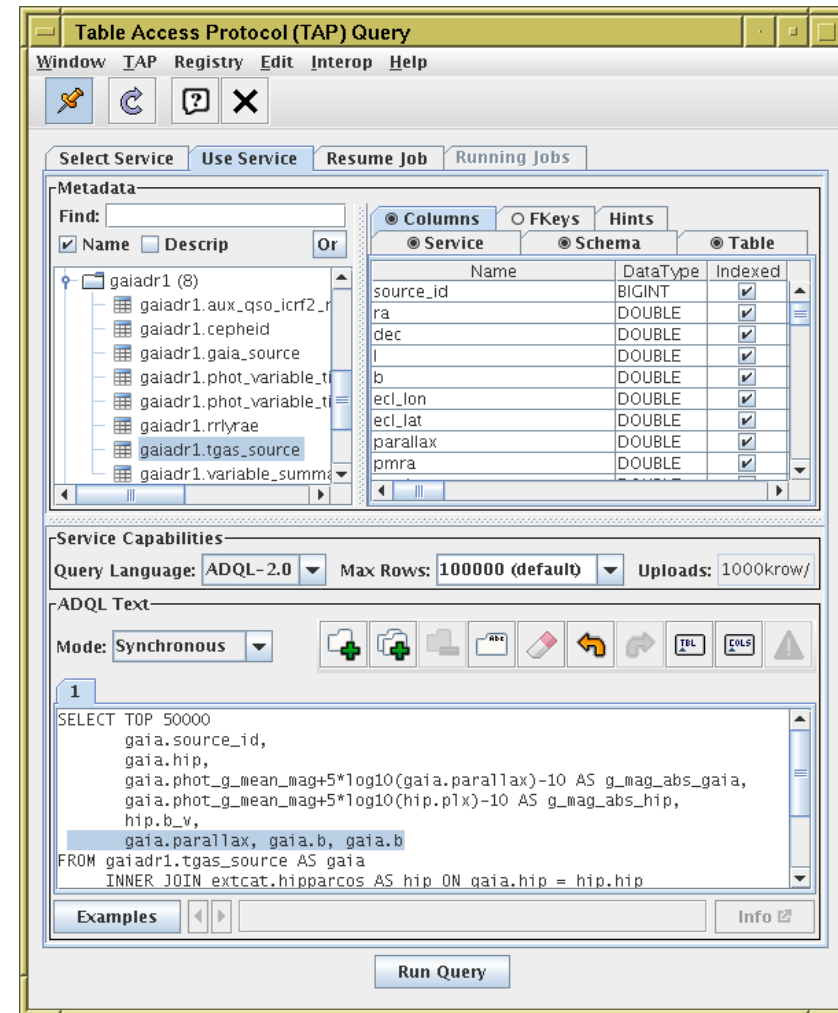
Data Access: TOPCAT TAP Window

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

- Details:
 - ▶ Talks directly to ESA/ARI TAP services, and other non-Gaia TAP servers
 - ▶ Similar functionality, different GUI to ESA web interface
- 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:

- ▶ Assemble e.g. from TGAS downloads (there are other ways):

```
% wget -r -np -nd -A fits http://cdn.gea.esac.esa.int/Gaia/tgas_source/fits/  
% stilts tcat in="'echo TgasSource_000-000-*.fits'" out=tgas_source.fits
```

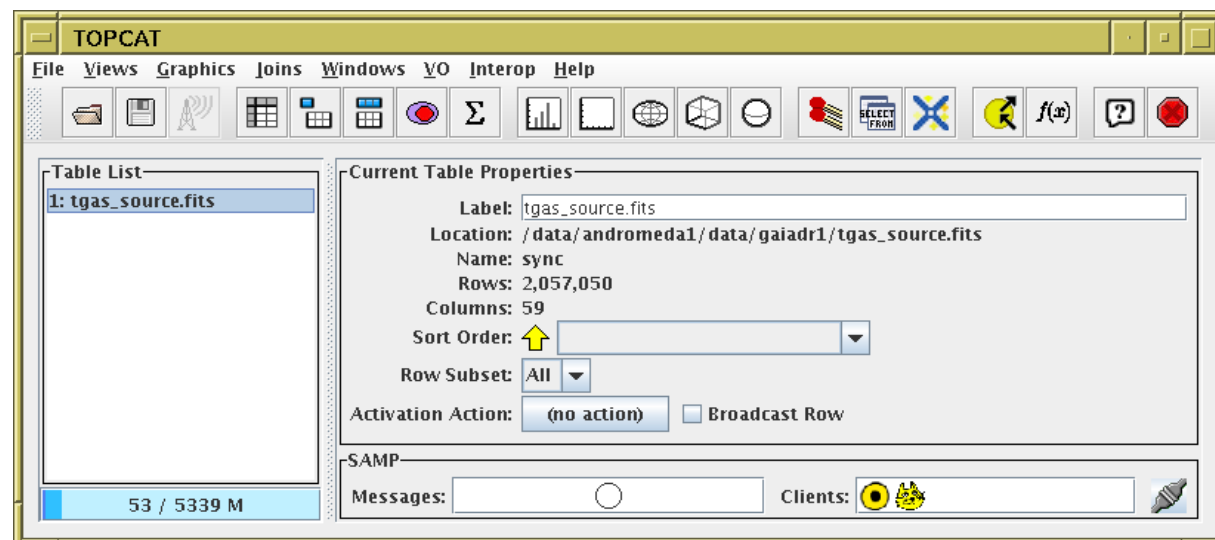
- ▶ Size: 2 057 050 rows × 60 columns, ~660 Mb

- 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 μ_ϖ , σ_ϖ
- Visualise cluster and non-cluster sources: in 3d space, showing proper motions

A.1: TGAS Cone Search

The screenshot shows the TOPCAT Cone Search window. The 'Available Cone Services' section has 'Registry' set to 'http://reg.g-vo.org/tap' and 'Keywords' set to 'tgas'. The 'Match Fields' section has checkboxes for 'Short Name', 'Title', 'Subjects', 'ID', 'Publisher', and 'C'. The 'Accept Resource Lists' checkbox is checked. Below this is a table with one row: 'ARI-Gaia', 'ARI's TGAS Cone Search Service', 'TGAS', and 'ivo://uni-heidelberg.de/t'. The 'Resource Count' is 1. The 'Cone Parameters' section has 'Cone URL' set to 'http://gaia.ari.uni-heidelberg.de/cone/tgas', 'Object Name' set to 'pleiades', 'RA' set to '56.75' degrees (J2000), 'Dec' set to '24.1167' degrees (J2000), 'Radius' set to '5' degrees, and 'Verbosity' set to '2 (normal)'. The 'Accept Sky Positions' checkbox is checked. An 'OK' button is at the bottom.

Δ Short Name	Title	Subjects	Identifie
ARI-Gaia	ARI's TGAS Cone Search Service	TGAS	ivo://uni-heidelberg.de/t

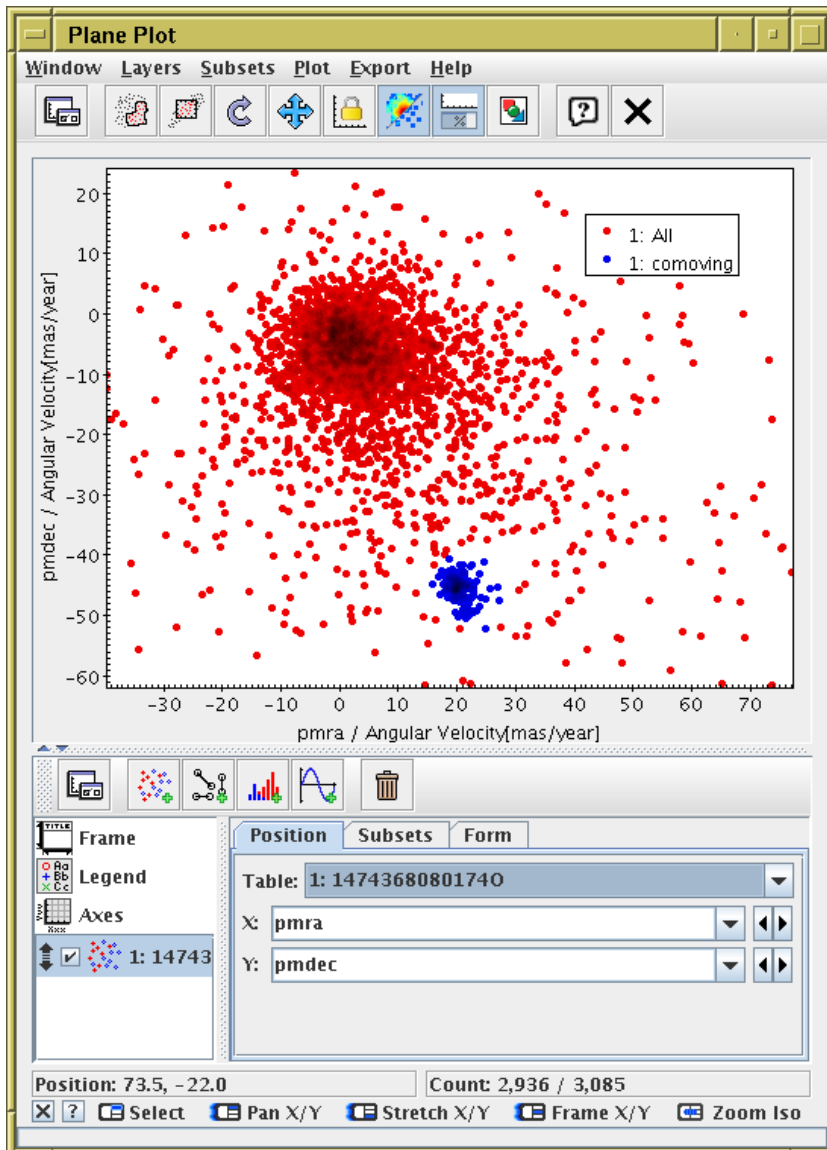
AccessURL	Description	Version
http://gaia.ari.uni-heidel...		

Resource Count: 1

Cone URL	Object Name	RA	Dec	Radius	Verbosity
http://gaia.ari.uni-heidelberg.de/cone/tgas	pleiades	56.75 degrees (J2000)	24.1167 degrees (J2000)	5 degrees	2 (normal)

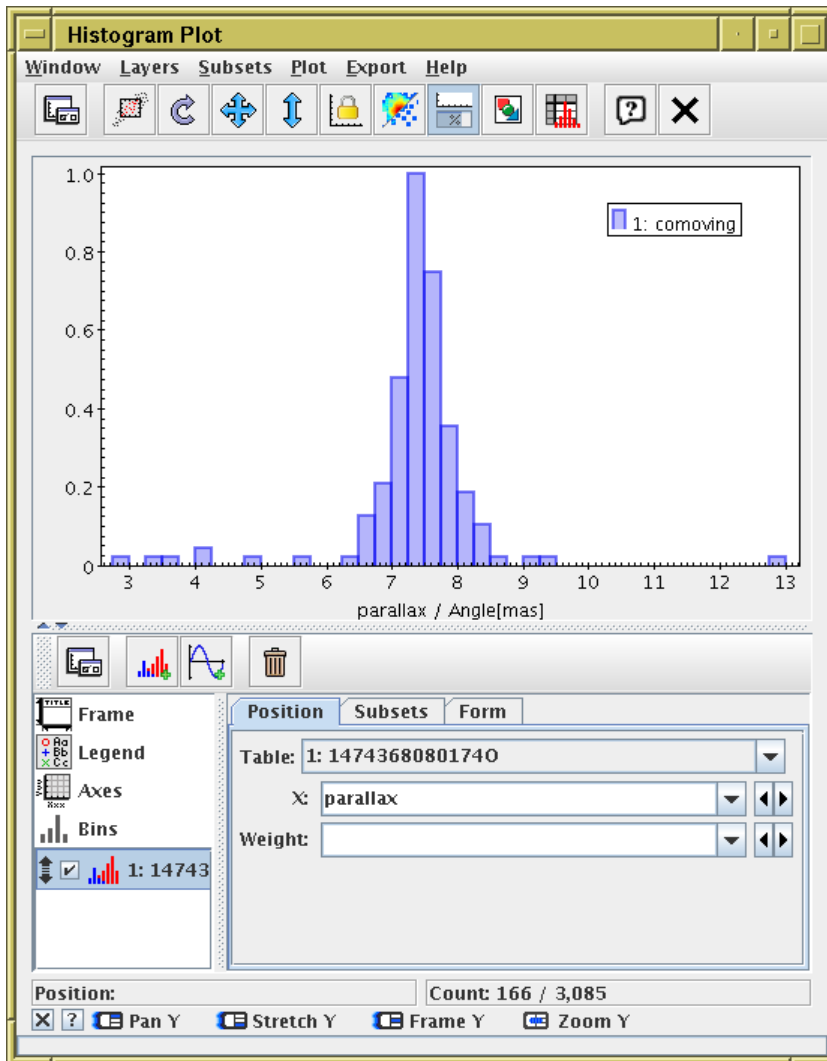
- Want to query TGAS sources within 5° of Pleiades
- Use TOPCAT Cone Search window:
 - ▶  **VO|Cone Search** menu item
 - ▶ **Keywords:** "tgas"
 - ▶ **Object Name:** "pleiades" + **Resolve**
 - ▶ **Radius:** "5"
- ... there are other ways to do it

A.2: Proper motion plot



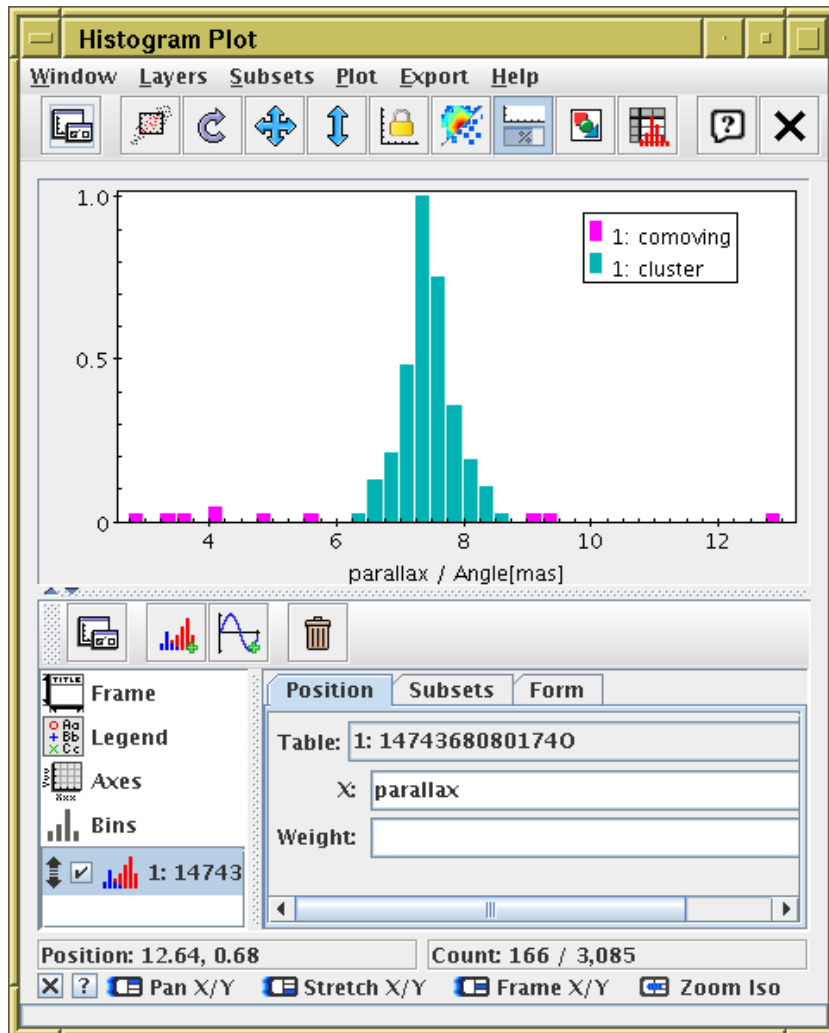
- Plot sources in proper motion space:
 - ▶  **Graphics|Plane Plot** menu item or toolbar button
 - ▶ **X:** "pmra"
 - ▶ **Y:** "pmdec"
 - ▶ Note overdensity far from (0,0)
- Graphically select this comoving cluster as new Subset
 - ▶  button, drag mouse,  again
 - ▶ **New Subset Name:** "comoving"
+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

A.3: Parallax histogram



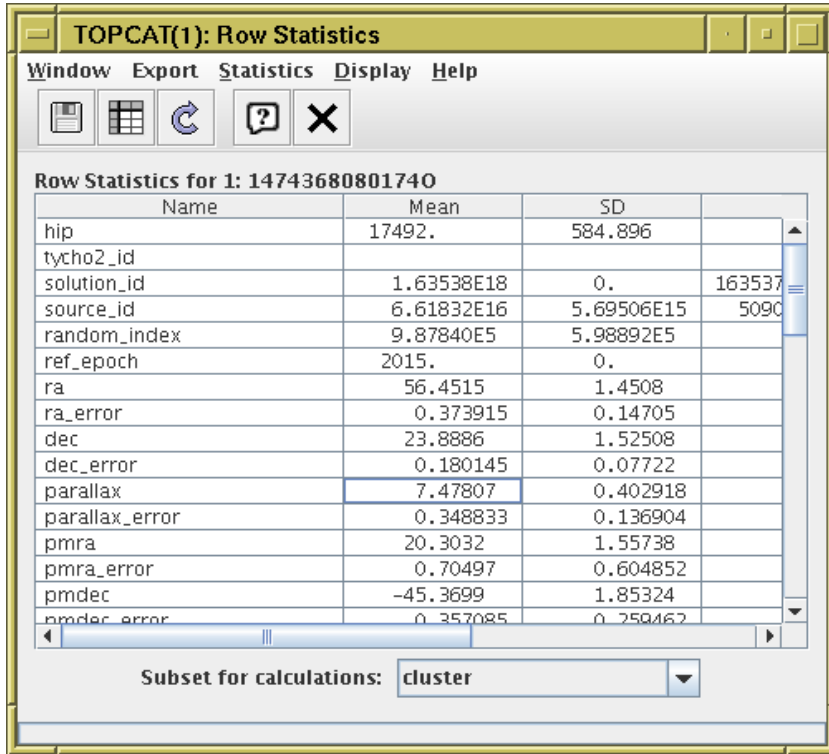
- Plot parallax histogram of comoving subset
 - ▶  **Graphics|Histogram plot** menu item or toolbar button
 - ▶ **X:** “parallax”

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

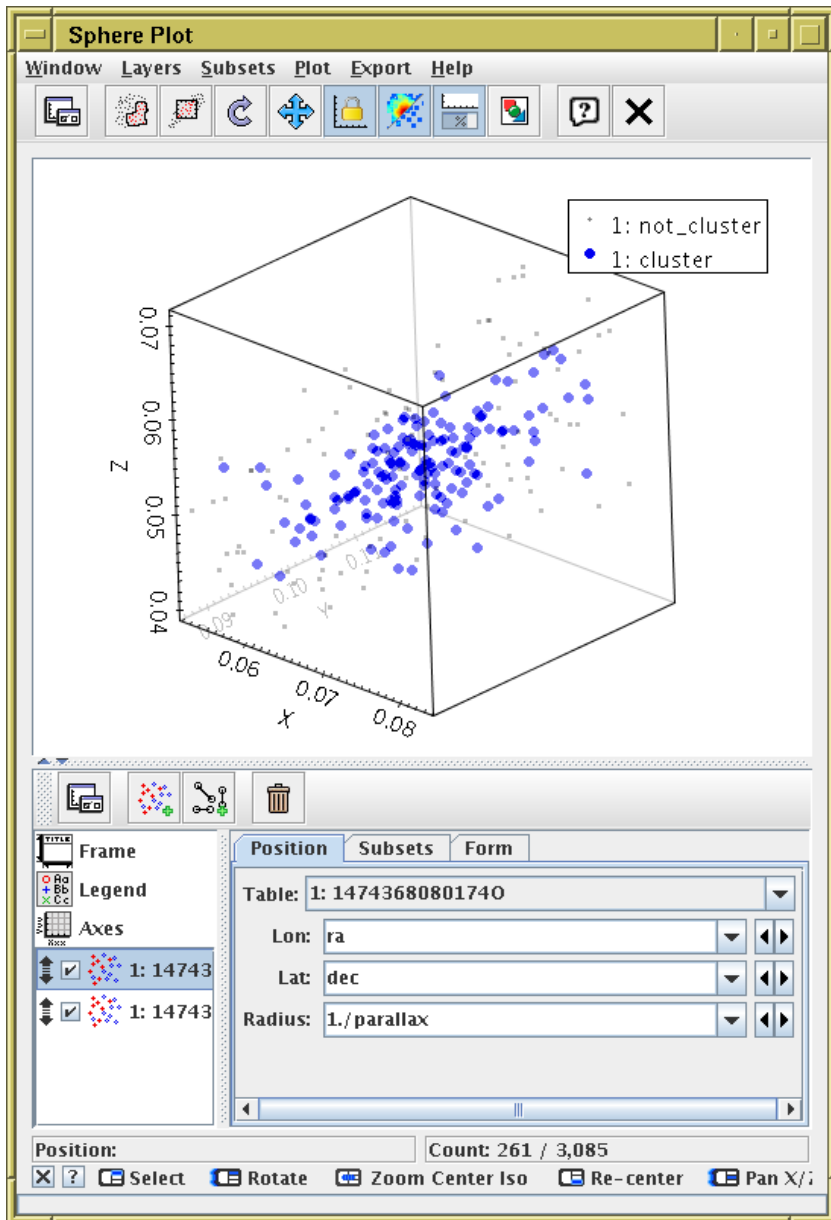
Row Statistics for 1: 14743680801740

Name	Mean	SD
hip	17492.	584.896
tycho2_id		
solution_id	1.63538E18	0.
source_id	6.61832E16	5.69506E15
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

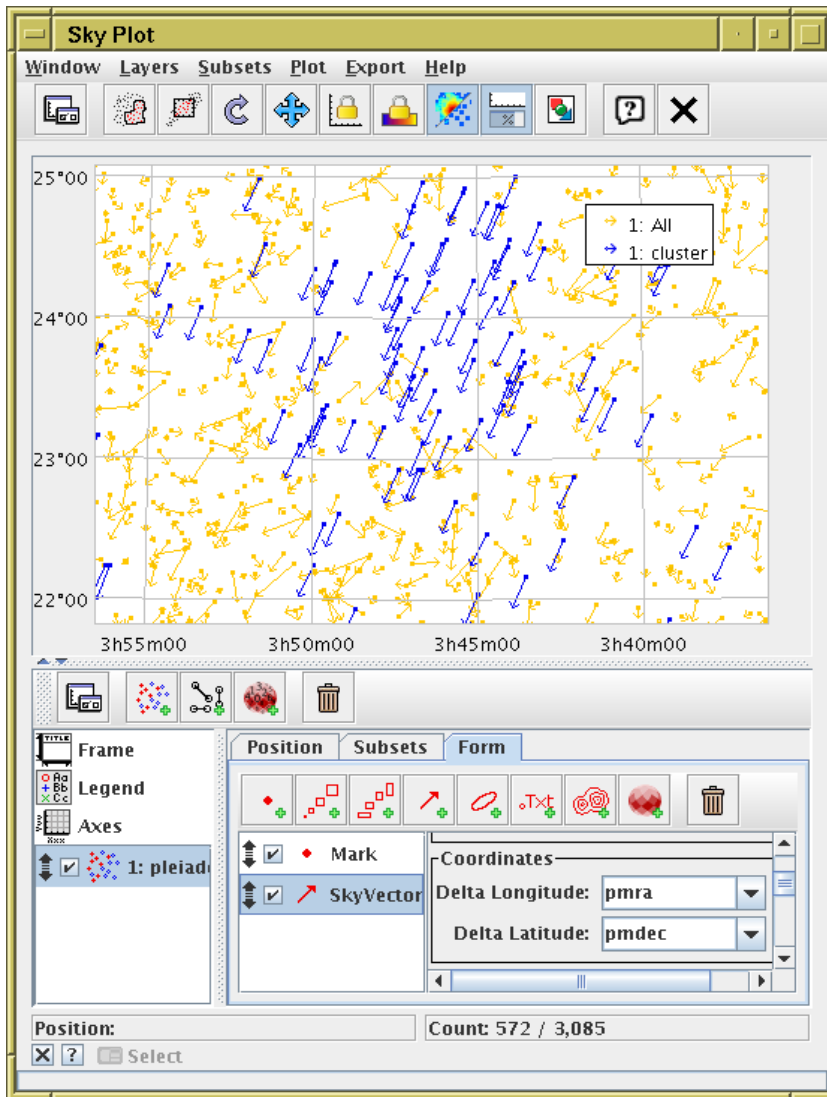
-  **Views|Column Statistics**
menu item or toolbar button
- **Subset for Calculations:** “cluster”
- See **Mean** and **Stdev** columns for **parallax**
- → Pleiades $\mu_{\varpi} \approx 7.5 \pm 0.4$ mas
 - ▷ $\Rightarrow \mu_D \approx 1000./7.5 \approx 133 \pm 7$ pc
 - ▷ ... but careful with priors
 - ▷ ... but $\sigma_{\varpi}/\varpi < 0.15$
for all cluster members
(exercise: show this!)
so it's probably OK

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)
([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
 - ▷ 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'. Under 'Catalogue Selection', 'By Keyword' is selected with 'Keywords' 'Gouliermis'. A table of search results is displayed below.

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 et al. 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

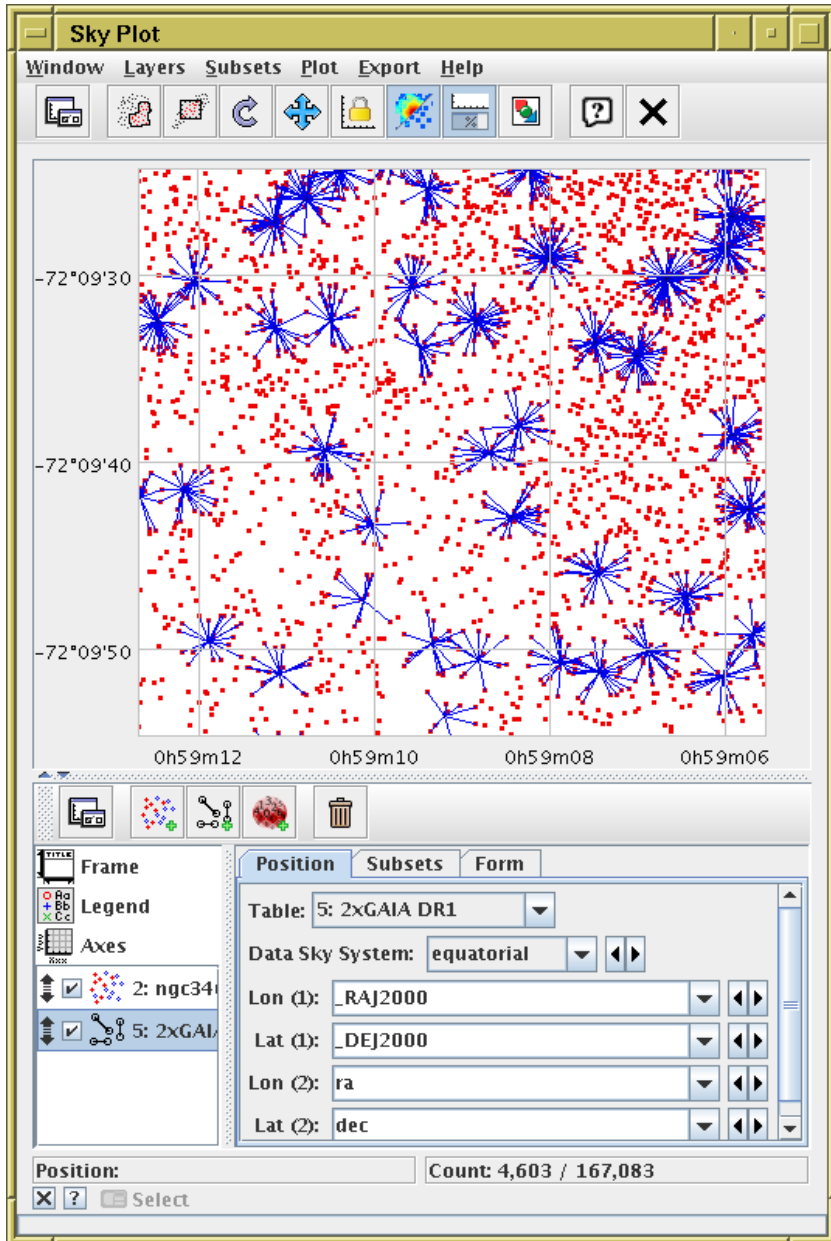
Rename columns: Duplicates Suffix: _x

Block size: 50000

Go Stop

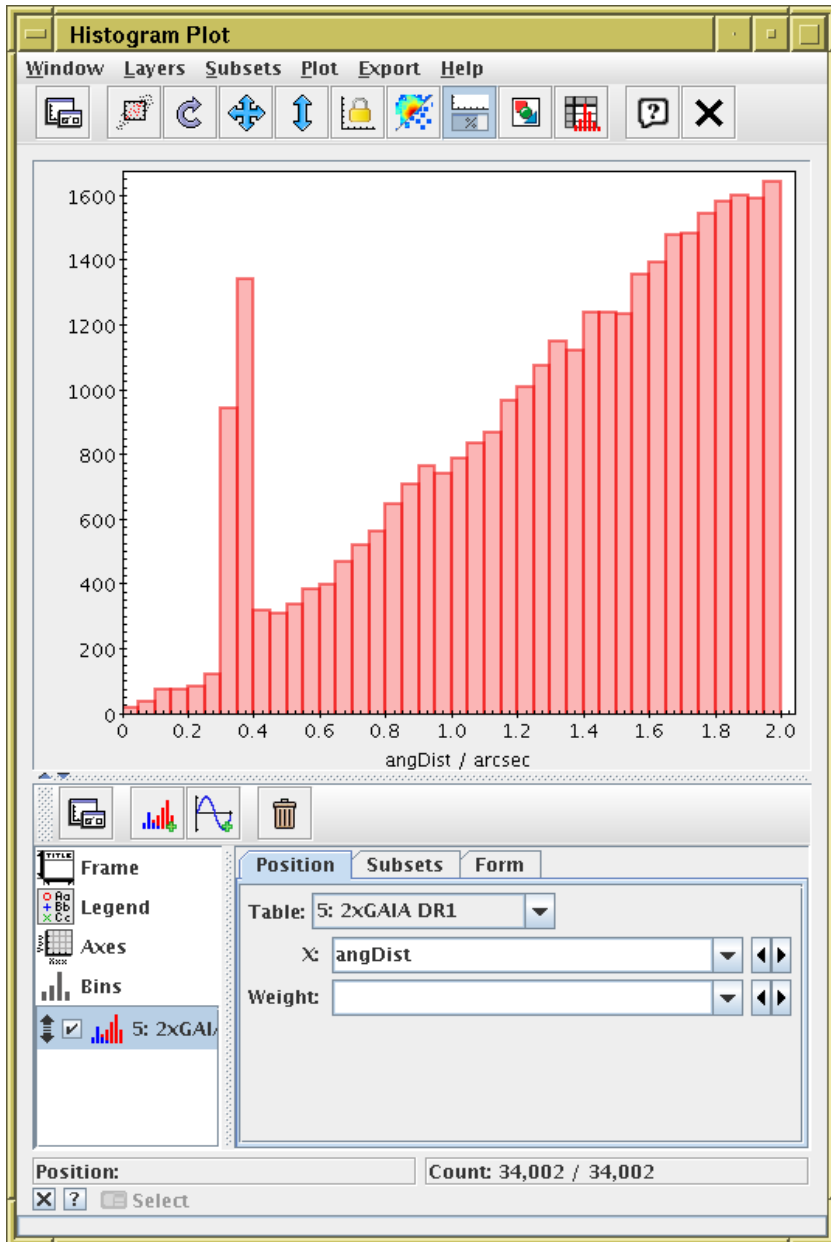
-  **VO|CDS Upload X-Match**
menu item or toolbar button
- **VizieR Table ID:** “GAIA DR1”
- **Radius:** “1” arcsec
- **Find mode:** All

B.3: Plot crossmatch results



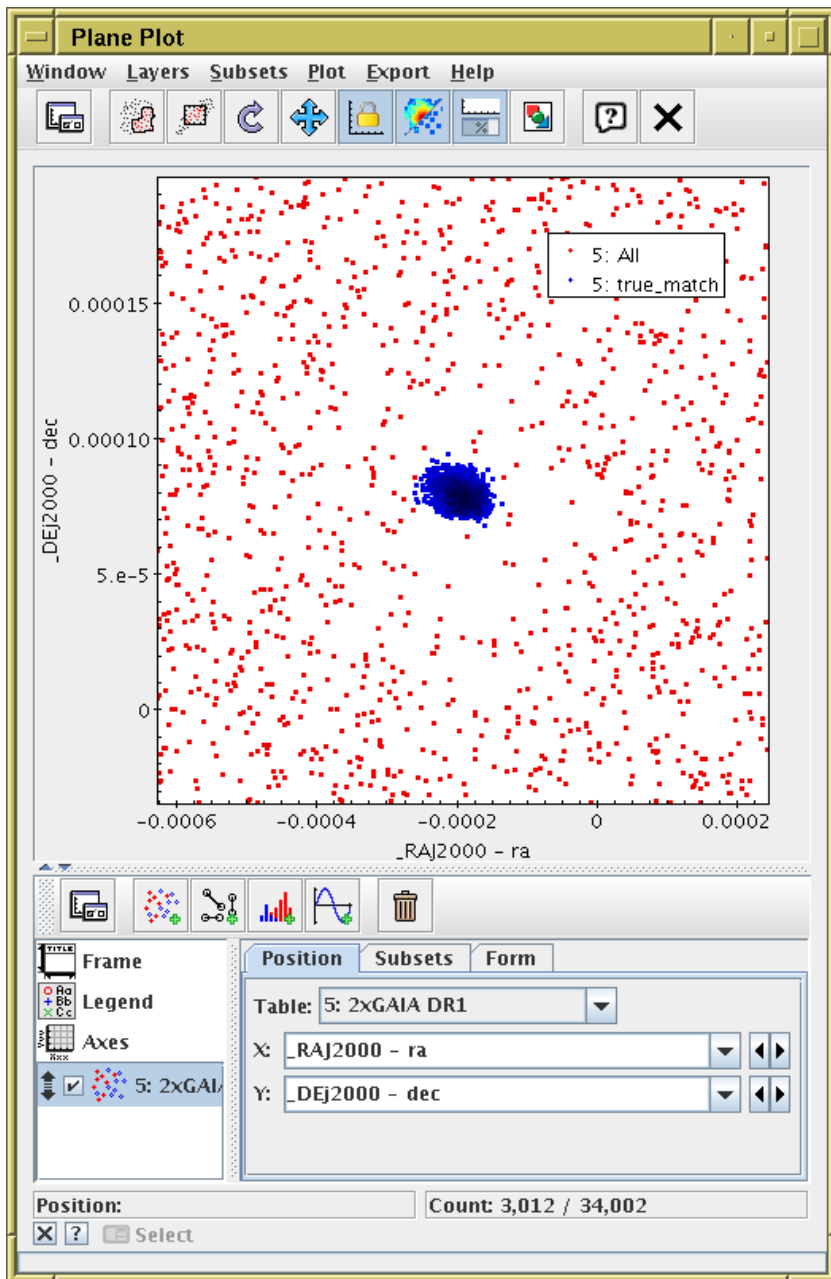
-  **Graphics|Sky Plot**
menu item or toolbar button
-  Plot NGC 364 points
-  Plot Gaia ↔ Gouliermis associations
(*[Goul]* *_RAJ2000*, *_DEJ2000*, *[Gaia]* *ra*, *dec*)
- ... too many

B.4: Plot crossmatch offsets



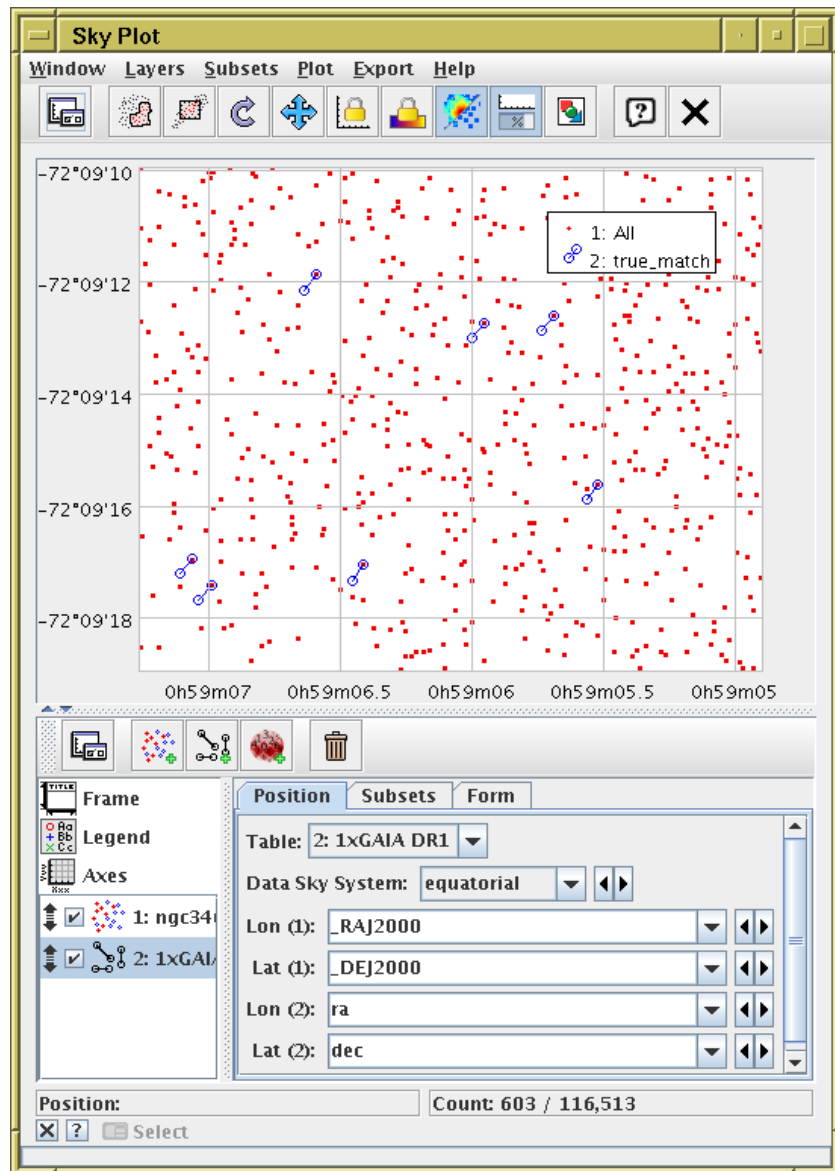
-  **Graphics|Histogram plot**
menu item or toolbar button
- **X:** “*angDist*”
(Gaia—Gouliermis association distance)
- (some) true associations near 0.35 arcsec

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:

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

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

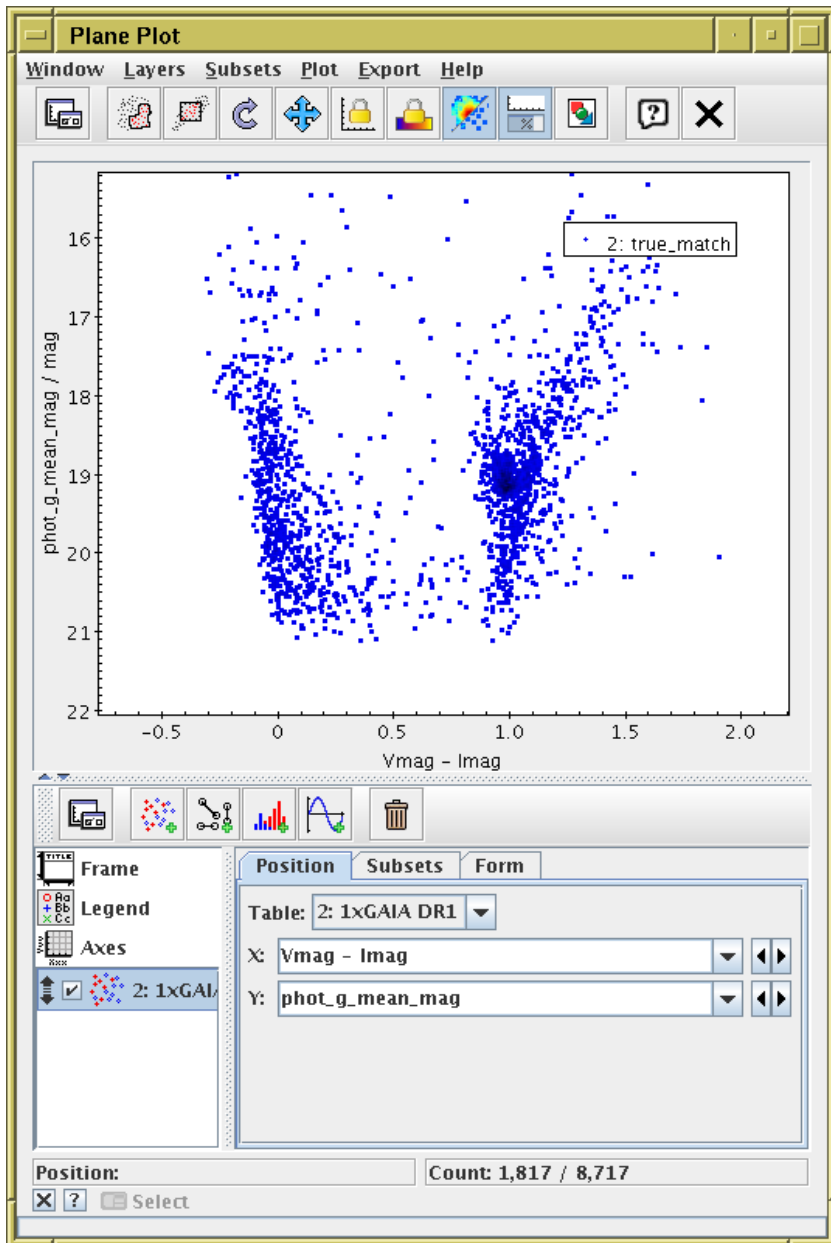
so proper motion:

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

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

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

B.7: Combine HST and Gaia photometry



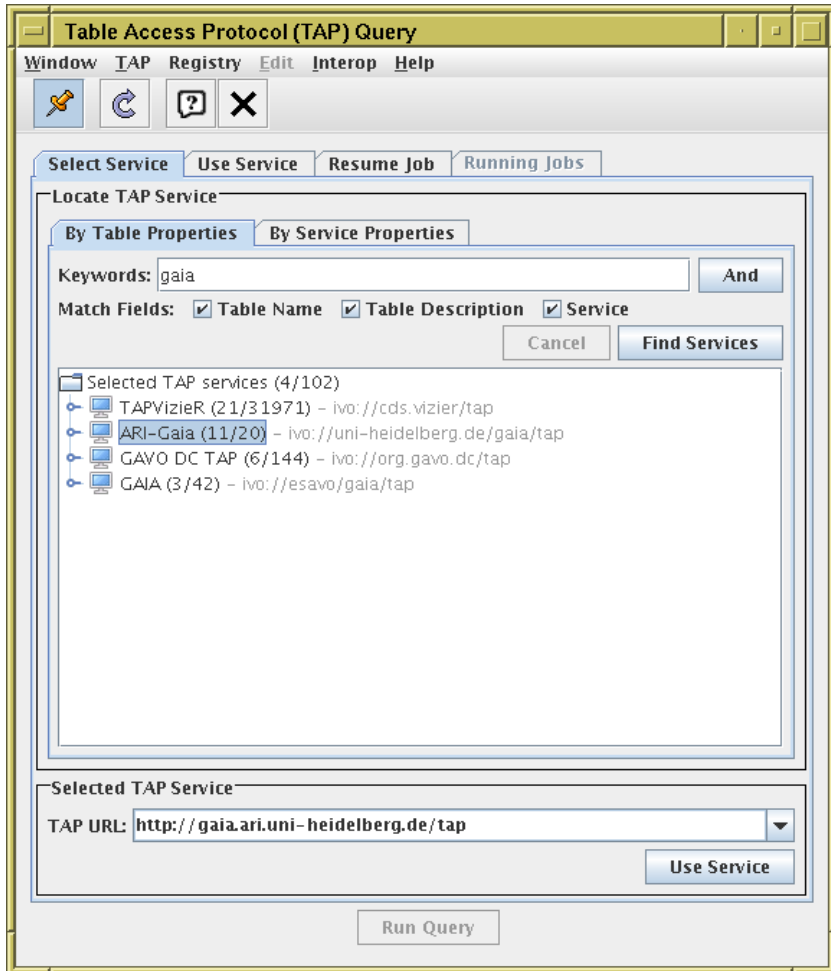
- Joined table now has Gaia G-band photometry alongside HST V/I-band photometry

Example C: TGAS-Hipparcos CMD

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

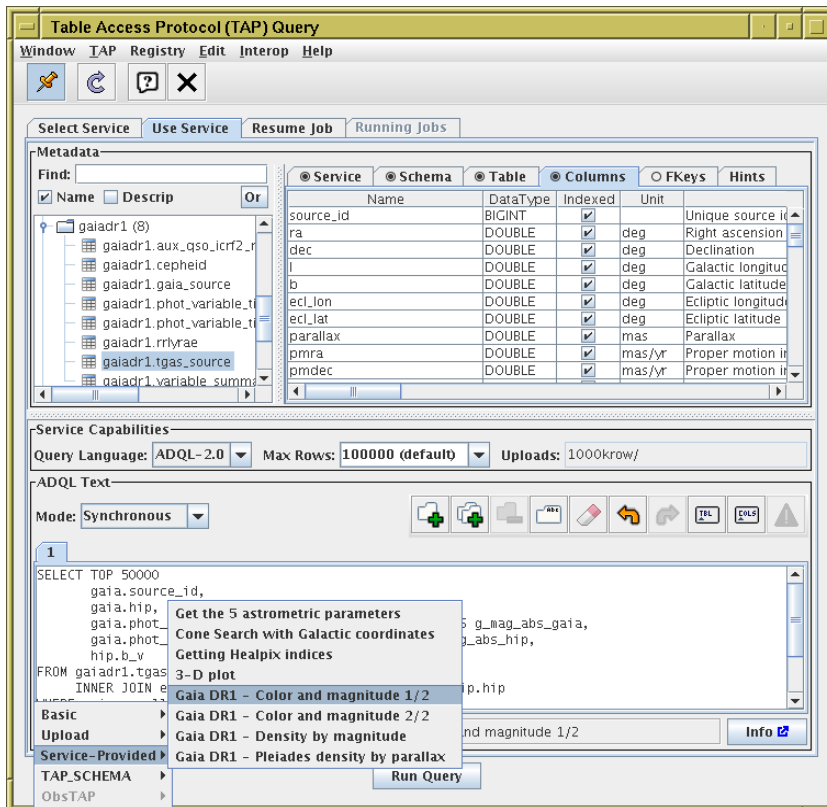
- Point TOPCAT TAP client at ARI-Gaia service
- Use **Examples|Service-Provided|Gaia DR1 Color and Magnitude** menu
- Plot Hipparcos $B - V$ vs absolute Gaia G
- Adjust TAP query to get more columns
- Colour-code points in CMD by parallax? galactic latitude?

C.1: Locate Gaia TAP service



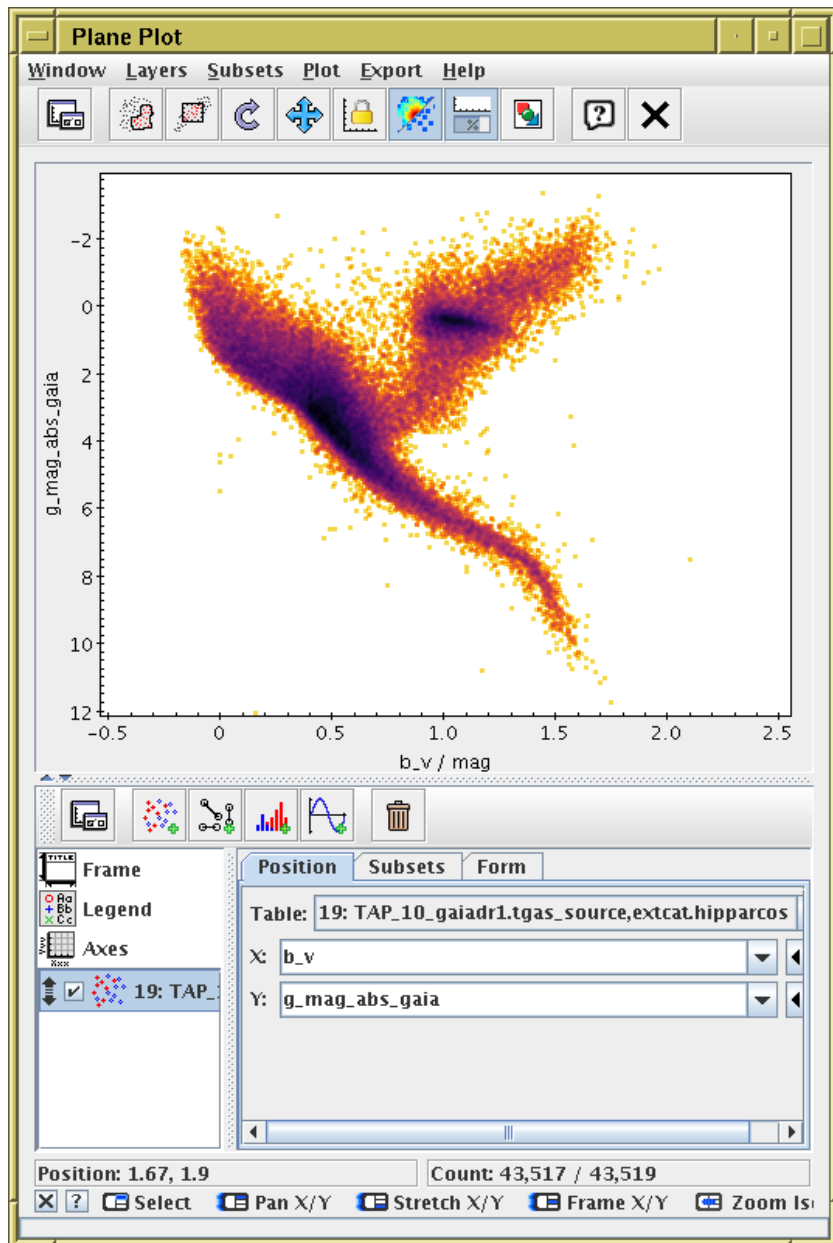
-  **VO|Table Access Protocol (TAP) Query** menu item or toolbar button
- **Select Service** tab, **Keywords:** “gaia”
- Select **ARI-Gaia**
- Hit **Use Service** button/tab

C.2: Execute Example CMD query



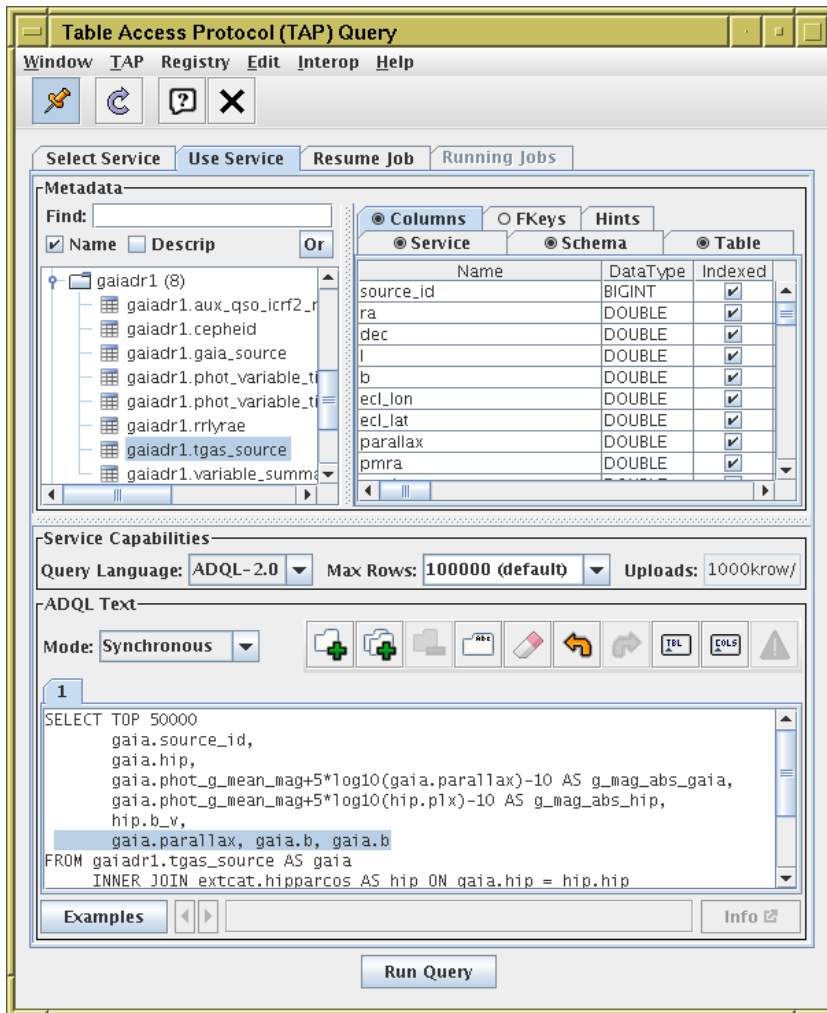
- Use **Examples** menu near bottom of window
- Select **Service-provided—Gaia DR1 - Color and magnitude**
- See ADQL is entered in window
- Hit **Run Query** to execute it

C.3: Plot CMD



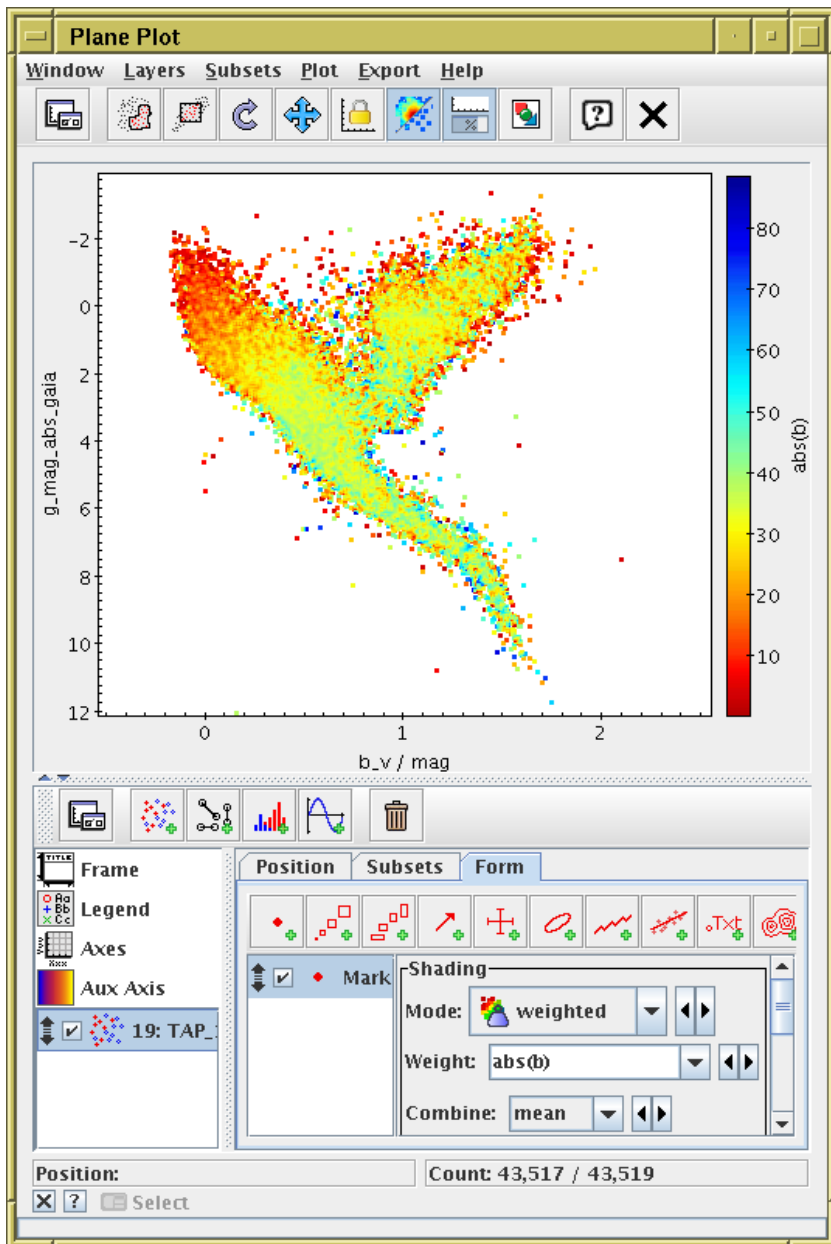
-  **Graphics|Plane Plot**
menu item or toolbar button
 - **X:** “b_v”
 - **Y:** “g_mag_abs_gaia”
 -  **Axes** control, use **Y Flip** checkbox
- ... it's almost too easy.

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



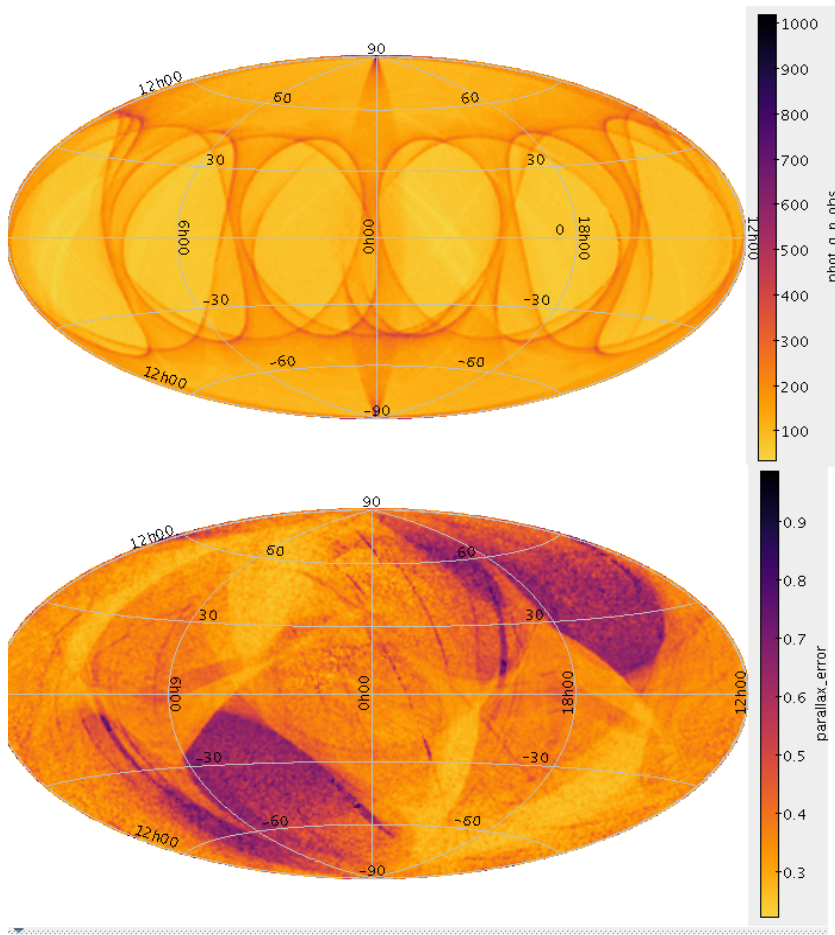
- Adjust the plot
- Use Weighted or Aux mode to colour points
- Find anything interesting? (maybe not)

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>