TOPCAT

• Short introduction

Accessing Gaia Data from TOPCAT

• By sky region
• Database query
• Match catalogue against Gaia
• Epoch photometry

Gaia-friendly features in TOPCAT

• Error ellipse plotting
• Astrometric functions

Examples

• Cluster Identification
• Local Hertzsprung-Russell Diagram
• Match against local catalogue
• Epoch Photometry
• Parallaxes and Distances
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/
TOPCAT can:

- Read/write tables in multiple formats
- View/edit data
- View/edit metadata
- Calculations and statistics (expression language)
- Interactive visualisation
- Make/combine/display row selections in various ways (linked views)
- Crossmatching
- Access external data services (VO and others)
- Trigger some event when a row is selected *(major recent changes at v4.6)*
- Talk to other astro tools (SAMP)

**Scalability:**

- Millions of rows, hundreds of columns (on modest hardware)
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**
- GUI
- Interactive
- Easy to use
- Good for data exploration
- Exploratory phase
- few \( \times 10^6 \) rows

**STILTS**
- Command line
- Scriptable
- Reproducible
- Good for batch/programmed use
- Production phase
- Unlimited size (for most things)

Typical usage:

- start off with TOPCAT
- maybe move on to STILTS for more specialised requirements
- TOPCAT STILTS control helps constructing plot commands
There are lots of ways to get Gaia data!

- From within TOPCAT
- Externally, then load into TOPCAT

Different options for different requirements

- By sky region
- All-purpose database query
- Match catalog X against Gaia
- Epoch photometry
  ... and others
Data Access: Sky Region

Load all Gaia sources in a given part of the sky

- TOPCAT Cone Search window
  - VO|Cone Search menu item
  - Keywords: “gaia dr2”
  - Find Services
  - Gaia DR2 CS services (+ row limits):
    - ARI-Gaia (10M)
    - GAVO: Gaia DR2-light (100k)
    - VizieR: I/345 (50k)
    - ... others
  - Fill in:
    - Object Name or RA/Dec
    - Radius
    - Verbosity (number of columns)

- Other options:
  - GACS Basic search
  - ARI Cone Search web page (estimates source count from radius)
    - http://gaia.ari.uni-heidelberg.de/
  - TAP
Data Access: TAP/ADQL

All-purpose database queries

- TOPCAT TAP window
  - Browse column/table metadata
  - View service options/capabilities
  - Results loaded directly into TOPCAT
  - ADQL syntax highlighting
  - ADQL editing features (multi-tab, undo/redo)
  - Access to multiple Gaia TAP services (and non-Gaia)
  - Integrated table upload (TAPUPLOAD.t<n> syntax)

- Other options:
  - GACS web page
  - Python TAP clients (PyVO, AstroQuery)
  - STILTS tapquery
Data Access: Match Catalog X against Gaia

Find all Gaia counterparts for a given catalogue

- **TOPCAT CDS Upload X-Match window**
  - Load X, then use **CDS X-Match window**
  - Very fast, millions of rows while you wait
  - Not all gaia_source columns returned (34/96)
  - Service sometimes overloaded → jobs rejected

- **TAP Upload match in TOPCAT TAP window**
  - Load X, then use **TAP UPLOAD.t<n>** in ADQL
  - Very flexible
  - Upload table size limits apply
  - Somewhat fragile (uploaded table column names)

- **TOPCAT pair match window**
  - Load Gaia and X in same region, then match
  - Suitable for matches in the same (sky?) region, up to a few million sources

- **Use pre-calculated archive match tables**
  - High-quality matches already done for large tables
  - AllWISE, RAVE, SDSS DR9, 2MASS, ...
Data Access: Epoch Photometry

Acquire time-series data for a Gaia source

- **Background**
  - DR2 Epoch Photometry: light curves (G, RP, BP) for 550,737 sources
  - Flux/Time data is not available *directly* from the database
  - `gaia_source` table contains column `epoch_photometry_url`, links to time-series VOTable

- **TOPCAT Activation Window**
  - Set up Activation Action in TOPCAT:
    - Load Table
    - Plot Table
  - Table Location: `epoch_photometry_url`
  - Can be configured to happen
    - on explicit request
    - whenever a row/point is clicked

- **Other options**
  - Cut’n’paste URL from `epoch_photometry_url` column into Load window

- More linked products (spectra for BP, RP, RVS) coming in DR3+! *(via datalink_url)*
Gaia-friendly Features

Introduced with Gaia data in mind

- Error ellipse plotting
- Astrometry functions
  - Distance estimation
  - Astrometry propagation to earlier/later epoch
**Error Ellipse Plotting**

Astrometry errors!

- `gaia_source` comes with 5 astrometric params \((ra, \, dec, \, parallax, \, pmra, \, pmdec)\)
- ... and 5 errors \((ra\_error, \, dec\_error, \, parallax\_error, \, ...)\)
- ... and 10 correlations \((ra\_dec\_corr, \, ra\_parallax\_corr, \, ...)\)

**TOPCAT** can plot them for you

- `XYCorr` (Cartesian space), `SkyCorr` (sky positions)
- Easy to use with `gaia_source`; just enter
  - Position: \(x, \, y\)
  - Error: \(x\_error, \, y\_error\)
  - Correlation: \(x\_y\_corr\)

- Note Gaia `ra, \, dec` errors are usually too small to see
Astrometry errors!

- `gaia_source` comes with 5 astrometric params (`ra, dec, parallax, pmra, pmdec`)
- ... and 5 errors (`ra_error, dec_error, parallax_error, ...`)
- ... and 10 correlations (`ra_dec_corr, ra_parallax_corr, ...`)

**TOPCAT** can plot them for you

- `XYCorr` (Cartesian space), `SkyCorr` (sky positions)
- Easy to use with `gaia_source`; just enter
  
  | Position: x, y |
  | Error: x_error, y_error |
  | Correlation: x_y_corr |

- Note Gaia `ra, dec` errors are usually too small to see
Astrometry functions are provided in TOPCAT’s expression language

- Estimating distance (and errors) from parallax:
  - Uses *Exponentially Decreasing Space Density* Bayesian prior
  - Follows Luri et al. (2018) and Astraatmadja & Bailer-Jones (2016)
  - Calculates best estimate and quantiles of distance, given parallax, parallax_error and length scale
- Propagation of astrometric parameters to earlier/later epoch
- Versions available with or without errors (22 or 6 arguments)
Note:

- These stars are very close together
- Positional errors are very small, especially at t=0
Examples of TOPCAT working with Gaia data

- Cluster Identification
- Local Hertzsprung-Russell Diagram
- Match against local catalogue
- Epoch Photometry
- Parallaxes and Distances

⚠️ **WARNING: Use with caution!**

- These are examples of how to use TOPCAT, not necessarily of DR2 best usage
- Read the DR2 documentation and release papers before publishing
Example: Cluster Identification

Identify M4 members by proper motion clustering

- Cone Search M4, $r=0.3\degree$; returns $\sim62,000$ rows
- Sky Plot — cluster visible
- Proper Motion space plot $\text{pmra}$ vs. $\text{pmdec}$
- Make graphical selection of comoving objects
- Colour-Magnitude diagram $\text{bp-rp}$ vs. $\text{phot_g_mean_mag}$, view selection (Subsets tab)
- Plot cluster $\text{parallax}$ histogram & Gaussian fit

Before DR2, this only worked for the Pleiades!
Example: Local Hertzsprung-Russell Diagram

Plot HRD for nearby sources (nominally < 100 pc)

- (Loosely) follows Lindegren et al. (2018) Appendix C
- Get all sources with ϖ > 10 mas with small errors in ϖ, RP, BP:

  SELECT ra, dec, parallax, phot_g_mean_mag, bp_rp, 
  phot_g_mean_mag + 5*log10(parallax/100) as mg, 
  astrometric_excess_noise, 
  phot_bp_rp_excess_factor 
  FROM gaiadr2.gaia_source 
  WHERE parallax > 10 
  AND parallax_over_error > 10 
  AND phot_bp_mean_flux_over_error > 10 
  AND phot_rp_mean_flux_over_error > 10

  ▶ 338,833 sources — 
  use parallax>15 for a smaller sample

- Plot BP-RP vs. absolute G magnitude
- Examine astrometric_excess_noise dependence (weighted plot)
- Improve HRD with excess noise cut
- Plot BP-RP vs. phot_bp_rp_excess_factor; select subset graphically to identify photometrically noisy data
- Improve HRD with photometry error cut
Example: Match Against Local Catalogue

Locate Gaia counterparts for observed members of NGC 188 (open cluster in Cepheus)

- CDS upload X-Match
- Examine \texttt{angDist} histogram
- New subset \texttt{angDist} < 0.4

- Does this show cluster dynamics?
  More likely Platais/Gaia astrometry discrepancies.
**Example: Epoch Photometry**

Examine light curves for Anomalous Cepheids

```sql
SELECT g.ra, g.dec, g.designation,
g.epoch_photometry_url,
v.pf, v.peak_to_peak_g
FROM gaiadr2.gaia_source AS g
JOIN gaiadr2.vari_cephheid AS v
USING (source_id)
JOIN gaiadr2.vari_classifier_result as c
USING (source_id)
WHERE c.best_class_name = 'ACEP'
AND v.pf IS NOT NULL
```

Use **Activation Window Load Table** for one row

- Plot 3-band flux, flux_error
  - vs. time
  - vs. phase: `phase(time, param\$pf)`

Use **Plot Table** action to plot folded time series when plotted points are clicked

- Trick: Aux colour `band.charAt(0)%3`

*Note: some functionality requires TOPCAT v4.6-1*
Example: Parallaxes and Distances

View foreground & background stars towards M31

- Cone Search M31, $r=1.3^\circ$
  - Services: ARI-Gaia, DR2-light, ...
  - Returns $\sim100,000$ rows

- Sky plot — M31 visible
- Histogram of parallax (or $1/\text{parallax}$) — no interesting features
- Define subsets using parallax and parallax_error
  - $\text{parallax}-2*\text{parallax_error}<0$: mostly foreground
  - $\text{parallax}-2*\text{parallax_error}>0$: mostly background (incl. M31)
  - NULL_parallax: mostly crowded regions (incl. M31)

Alternative: use Bayesian distance estimation

- TOPCAT provides functions
  - $\text{distanceEstimateEdsd(parallax,parallax_error,1)}$,
  - $\text{distanceQuantilesEdsd(parallax,parallax_error,1,qpoints)}$
- But understand what you’re doing