Visualising Large Datasets in TOPCAT v4

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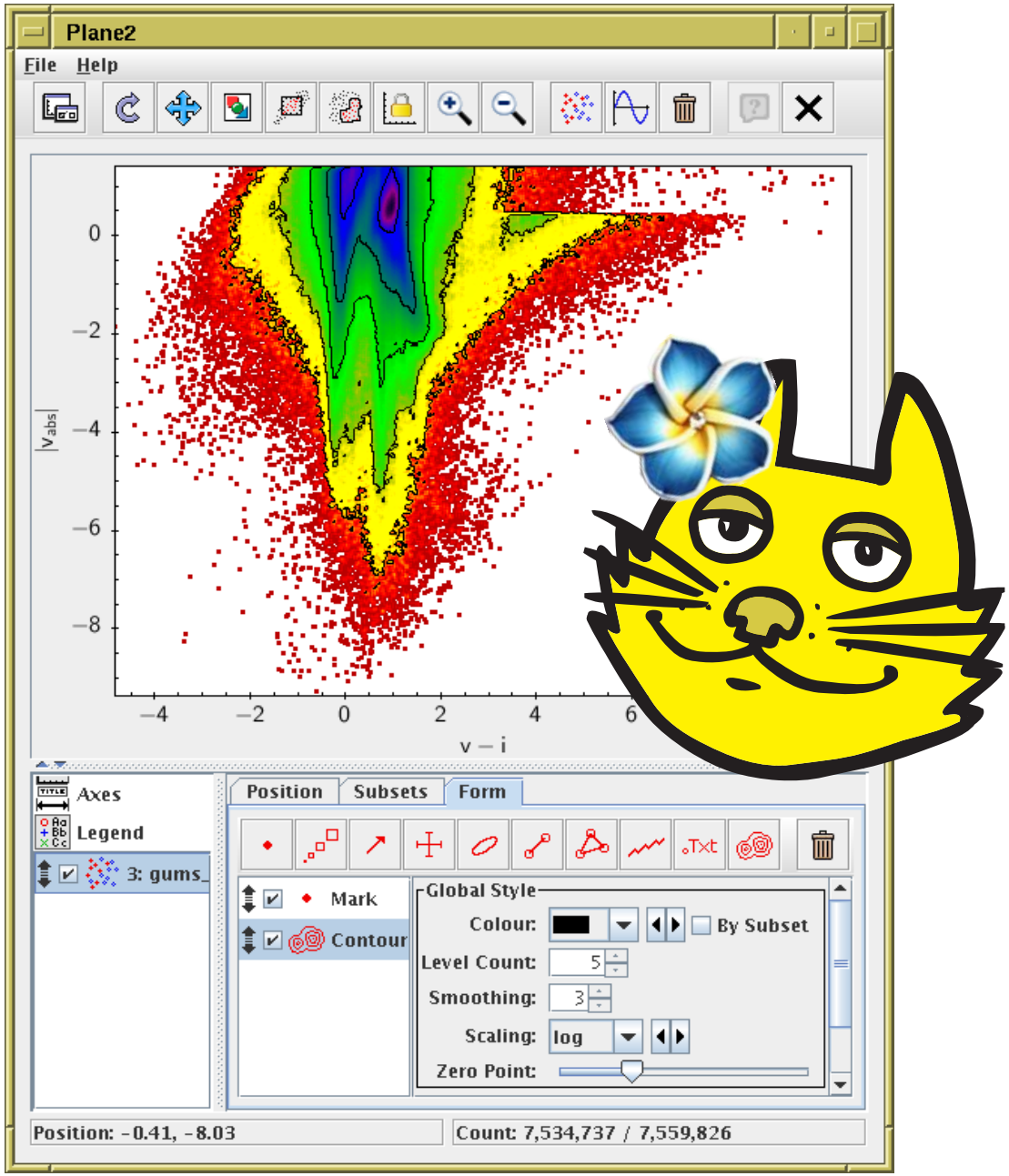
Mark Taylor
(University of Bristol)



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What is TOPCAT?

TOPCAT — Tool for OPerations on Catalogues And Tables

"Does what you want with tables"

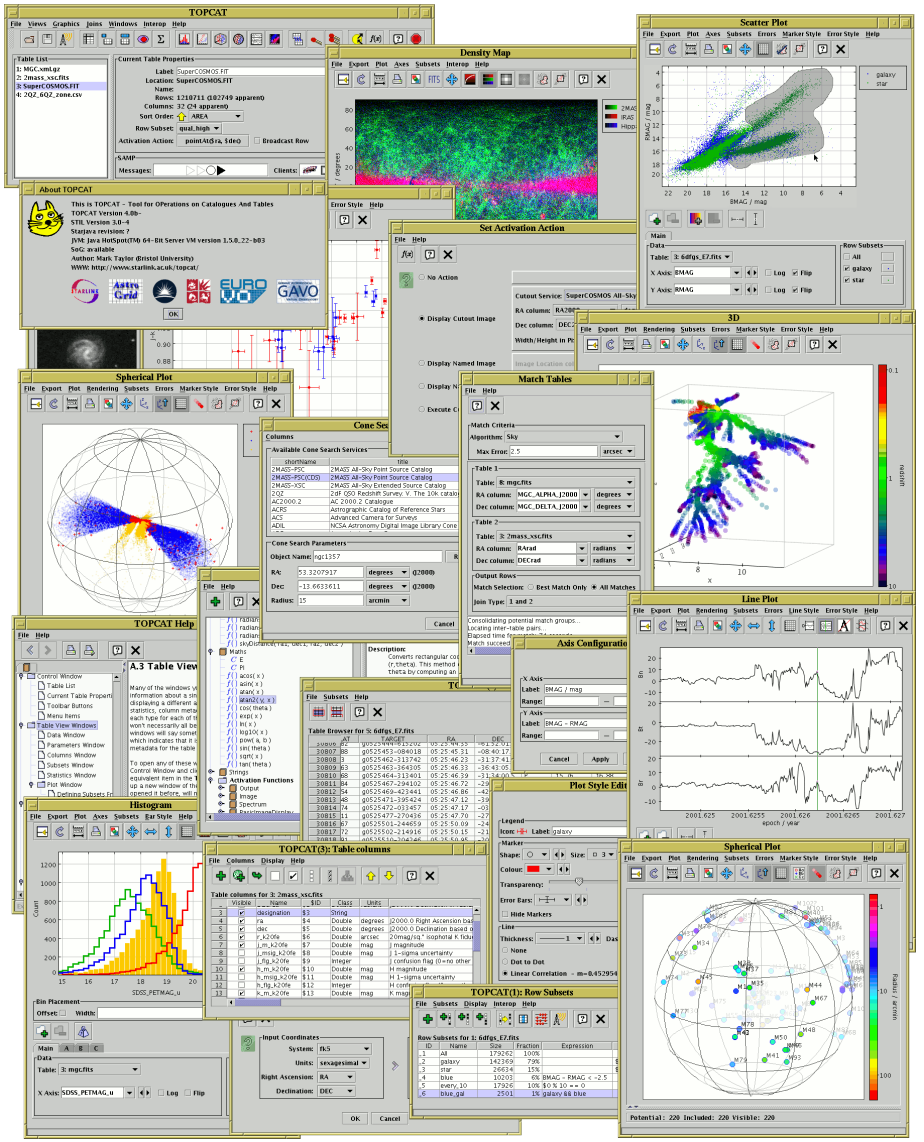
Desktop Java GUI application

Key capabilities include:

- Visualisation
- Crossmatching
- Row selections
- Linked views
- Powerful expression language
- Good communications
  (file formats, other tools, data services, VO)

For *doing science* with tables

Version 4 (2013):
rewrite visualisation from scratch



Comprehensible Visualisation

Q: How do you visualise ∼10,000,000 2D/3D points

... using <1,000,000 pixels?

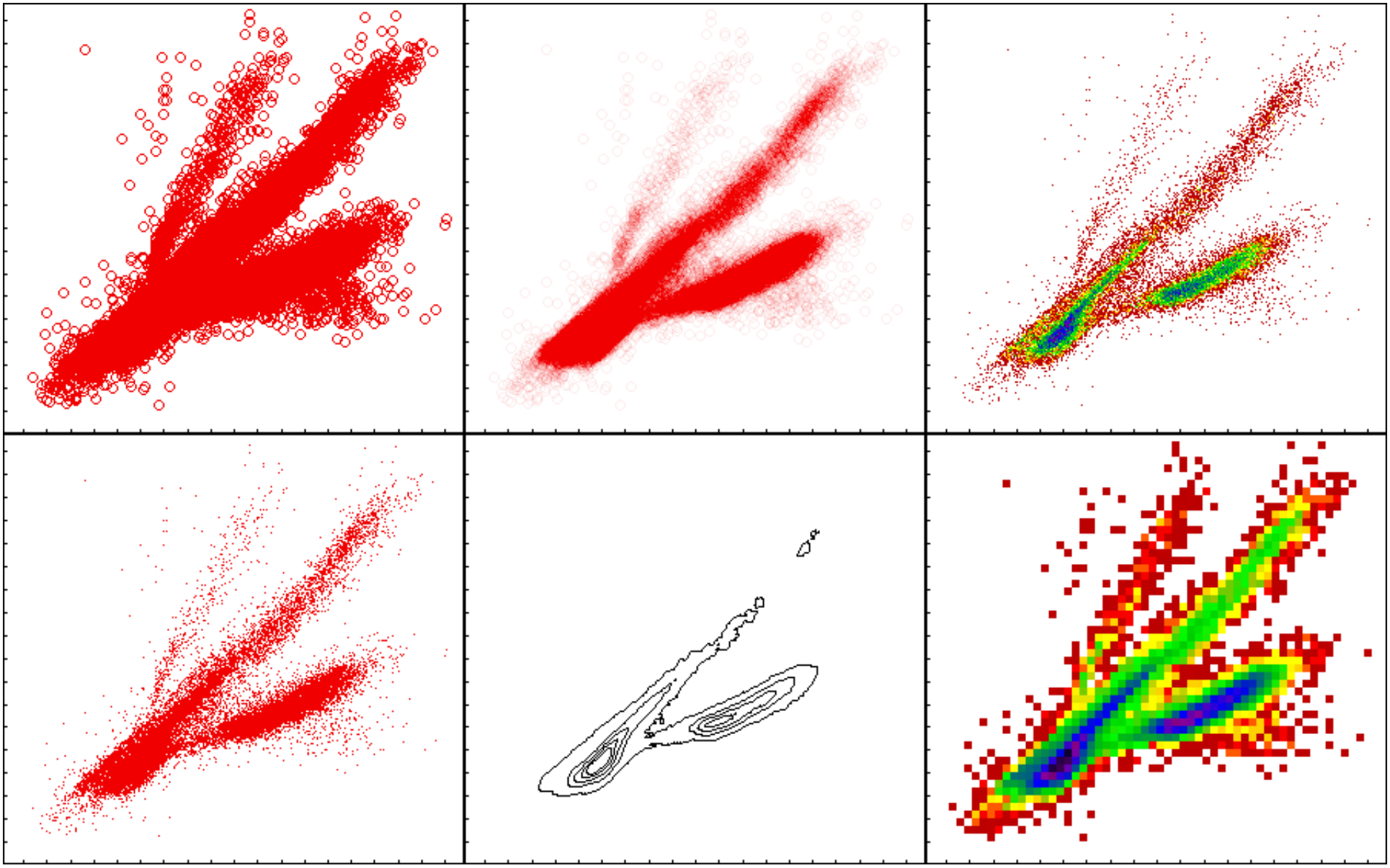
... so both large and small scale structure is visible?

... presenting multiple dimensions?

A: Key requirements:

- Fast and easy interactive **navigation**
- Single plot type that works at both **high and low densities**
- Extensive **configurability**

High/Low Density Plots



Hybrid Scatter/Density Plot

Convolve a single-pixel density map with multi-pixel marker shape

- Each plotted point paints a marker shape on pixel grid *(configurable marker shape)*
- Pixel color is determined by how many markers hit it *(configurable color map)*

Other ways to look at it:

- A single-pixel density map
  with a shaped 1-bit smoothing kernel
- A scatter plot
  with non-standard compositing

Result:

- Low density regions:
  it's a single-color scatter plot
- High density regions:
  it's a smoothed density map

Multi-Dataset Plots

Color maps:

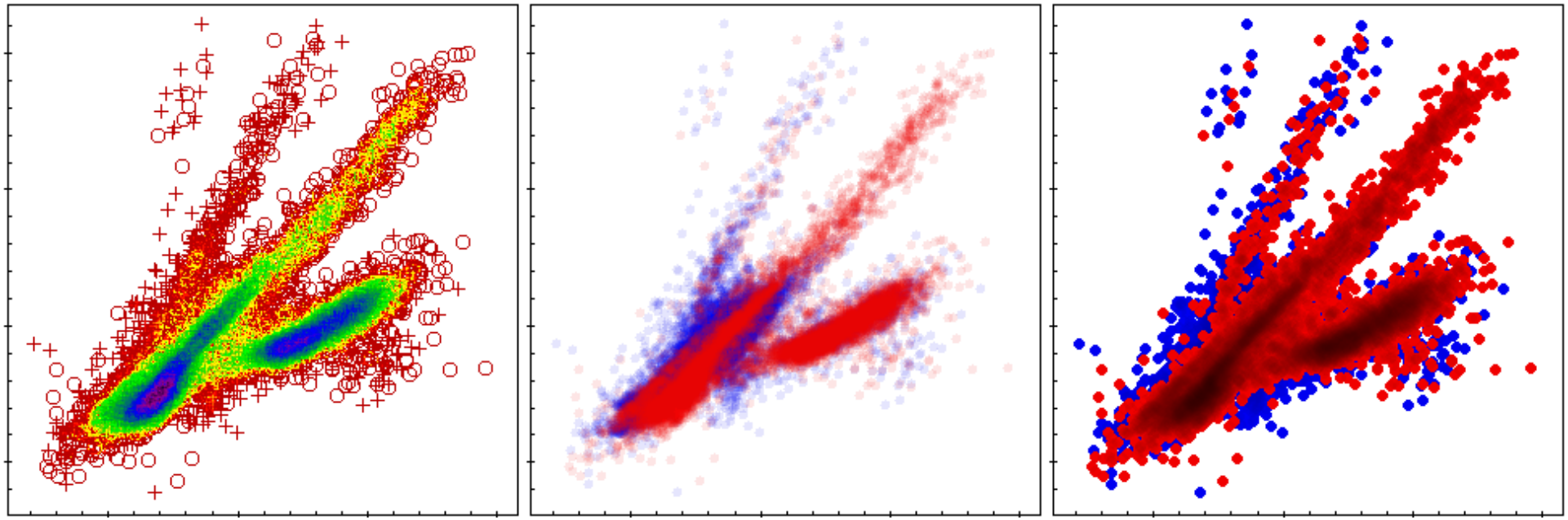
- Full-color maps (e.g. rainbow) are good for single-component plots

  ... but not so good for multi-component (especially 3D)

  ... and no good for point color coding

- By default use darkening map
  - ▷ Scale (Hue, Saturation, Value) *Value* of dataset base color
  - ▷ Use `asinh` ramp auto-scaled from data

- Provide other options too



Navigation: 2D

2D gestures — fairly obvious

- Mouse drag to pan
- Mouse wheel to zoom around mouse position

Notes:

- No multi-touch support in J2SE ☹
  would require native code
- Wheel zoom needs a wheel
- Wheel zoom currently only isotropic
  — anisotropic options TBD
- Other zoom options supplied
  (slider, enter explicit range),
  but less convenient

Navigation: 3D

3D — pan/zoom not obvious (2D gestures, 3D space)

- Left button: drag to rotate round center
- Wheel: zooms in/out round center
- Right button: click to re-center
  - ▷ Break screen-normal degeneracy using "center of mass" along line of sight. Click on dense blob or isolated point works. Generally does what you want.

Notes:

- Zoom around cursor would be possible, but slow and unstable if center of mass is determined each frame
- Not so easy to navigate to distant low-density regions — but do you want to?

Performance

Target:

- User makes tweaks to plot (pan, zoom, marker shape/color, contour levels, density/aux color map/clip, vector size scaling, error bar style, font size, ...)

  $\longrightarrow$ Plot updates immediately ($\ll$1 second)

- User tries a different plot (different coordinate values, adds vectors/ellipses, ...)

  $\longrightarrow$ Plot updates quickly ($\leq$ a few seconds),
  but if necessary take more time to cache data for later use

Lots of tricks

- Smart multi-level caching (column data, per-layer density maps, plot image)
- Plot-sensitive rendering schemes (monochrome, opaque, Z-buffer, ...)
- Pluggable data storage management (primitive array, table interface, mapped file, ...)
- Build pixel map/manage compositing by hand
- Pack coords into primitives (RGBA+z$\longrightarrow$`double`, RA+Dec$\longrightarrow$`int[3]`)
- Careful thread management (multi-threading TBD)
- Marker pixel map pre-calculation
- ...

... work in progress

Configurability

Many configuration options to manage

- Tens of options required to specify a given plot:
  - ∼20 options for axes
    (coord log/flip, axis ranges, axis annotations, grid options, . . .)
  - ∼10 options per data layer
    (marker color/size/shape, color map/scale, compositing options, label, . . .

    ⇒ usability challenge
- ∼100 options (and counting) in the application as a whole
  - Several axis types:
    2D, 3D, Sky, Sphere, Time Series
  - Many layer types:
    Points, Vectors, Error bars, Elipses, Analytic functions, Lines, Contours,
    Text labels, Polygons, Spectrograms . . .

    ⇒ implementation challenge

Configuration Usability

Try to combine extreme flexibility with ease of use

- Everything is configurable
- ... but has sensible defaults
- Plots auto-populate and auto-range

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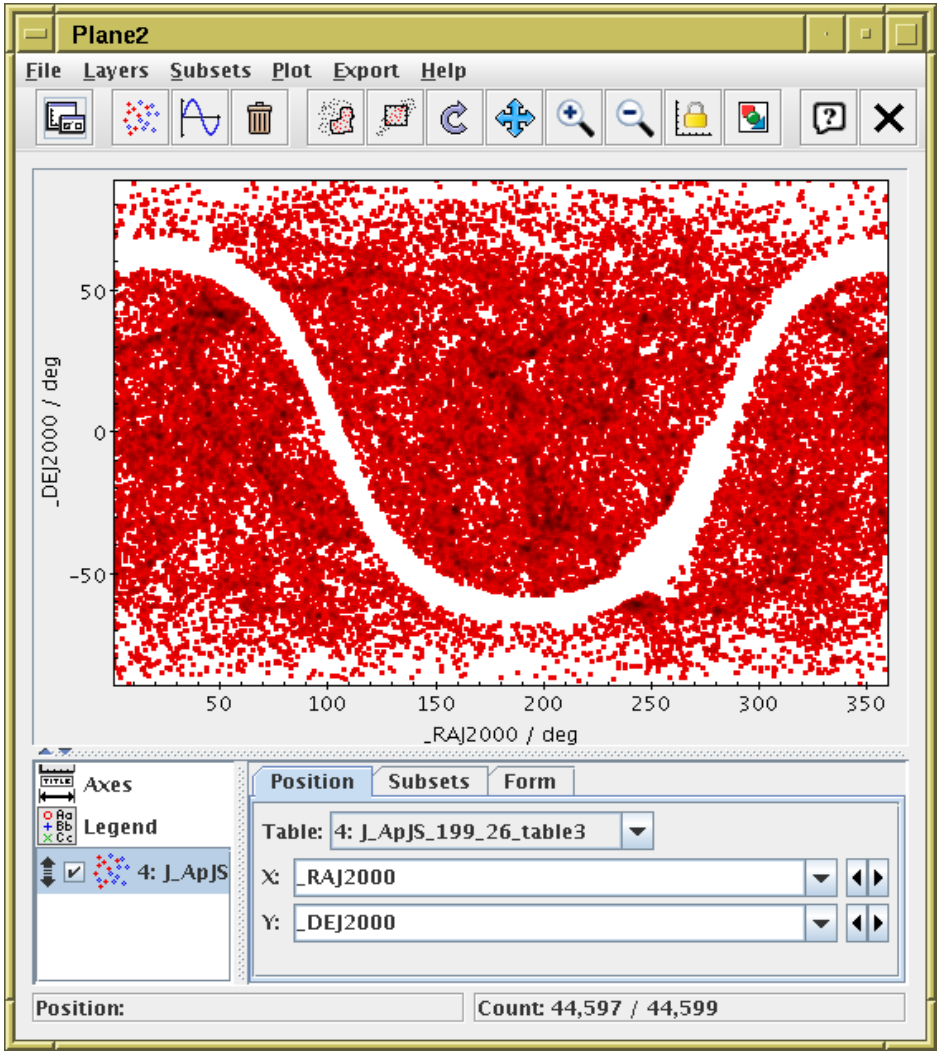
Good:



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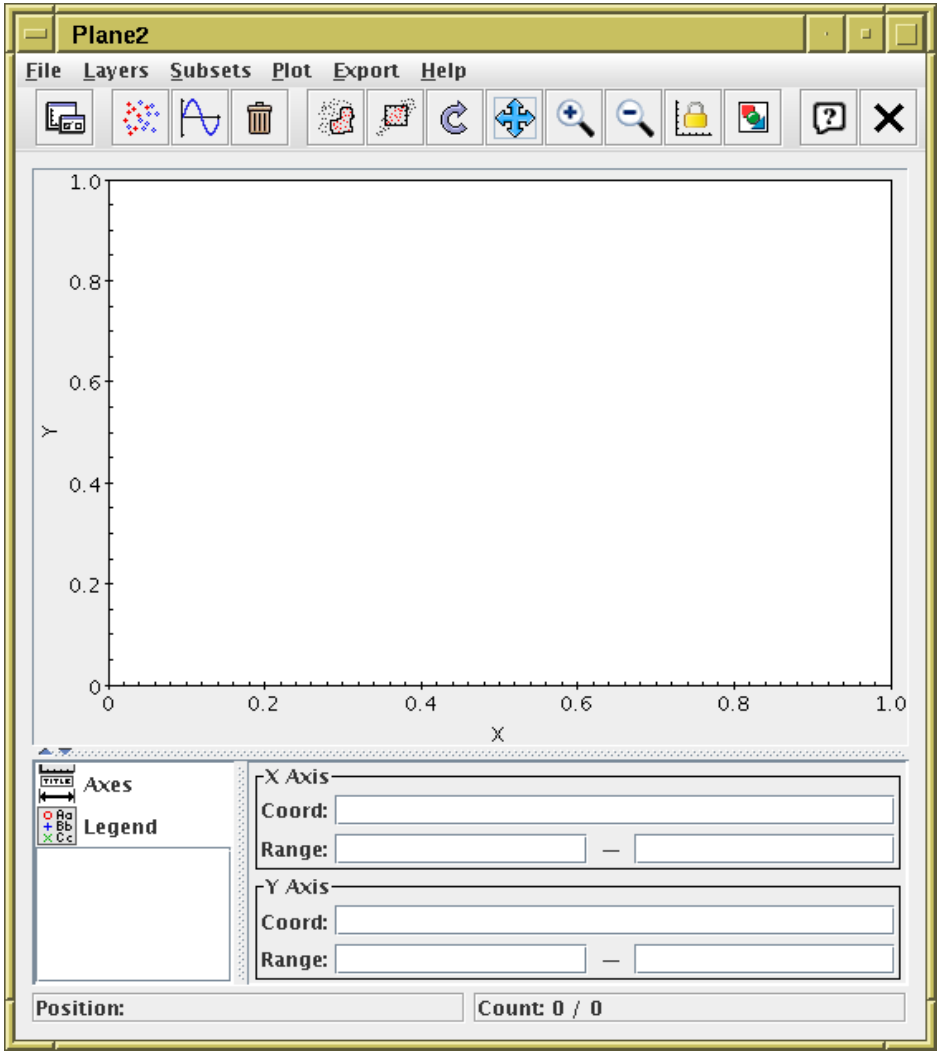


Configuration Implementation

ConfigKey grouping:

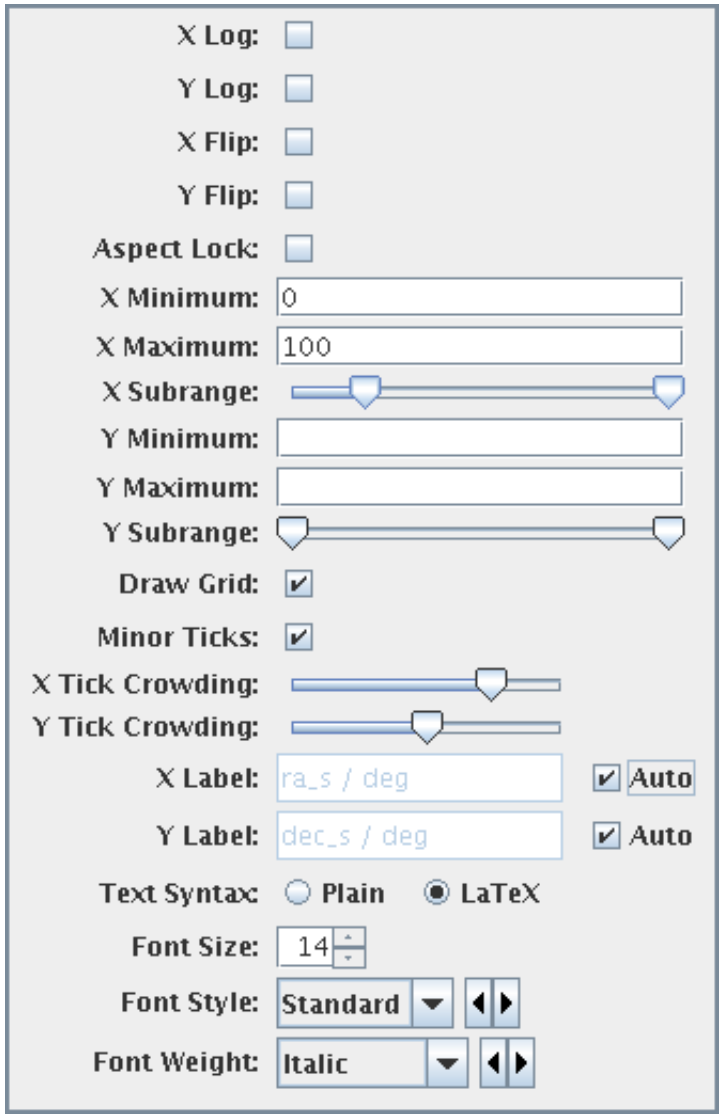
- 1 group for axes
- 1 group per data layer

Each ConfigKey has:

- Name
- Description
- Type
- Default
- GUI control
- value↔string mapping

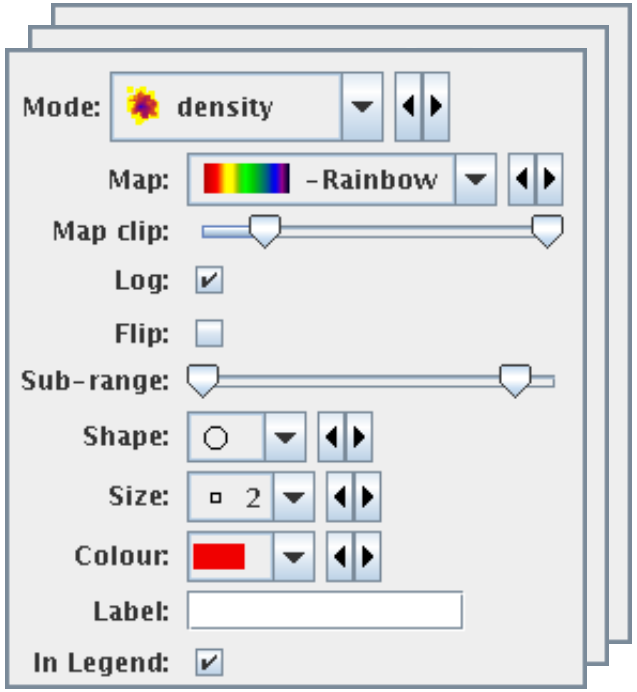
Use them to:

- Build GUI
- Specify plot from GUI
- Specify plot from shell, API, SAMP, ...
- Build documentation



← Axes config

Data layer config



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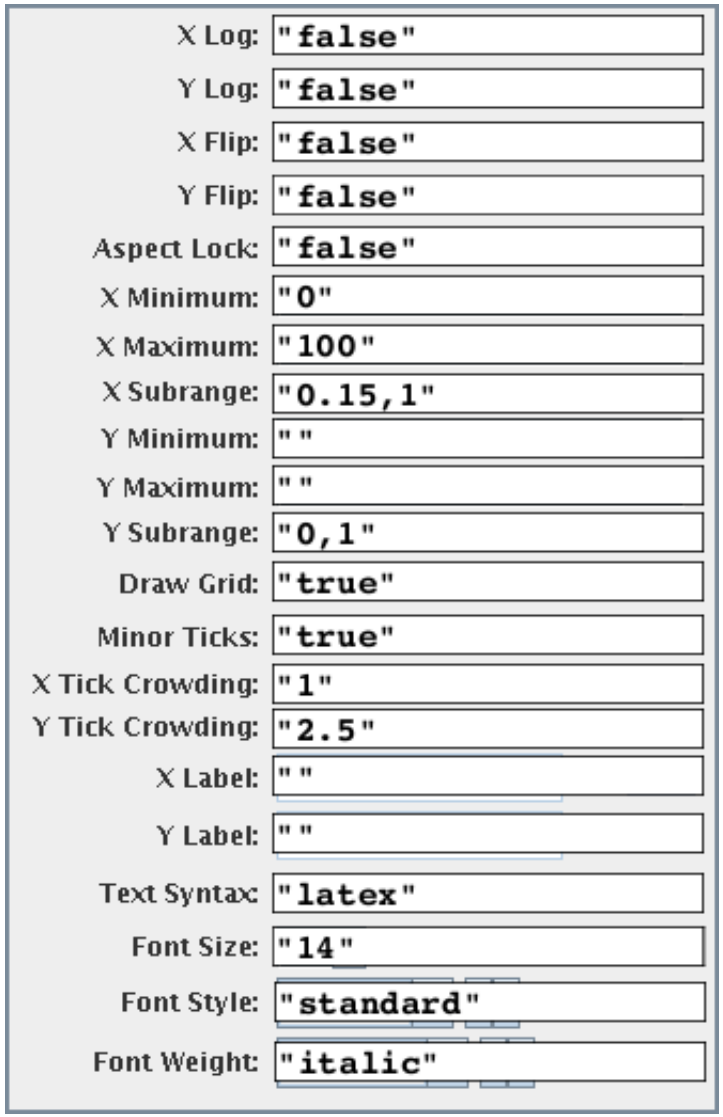

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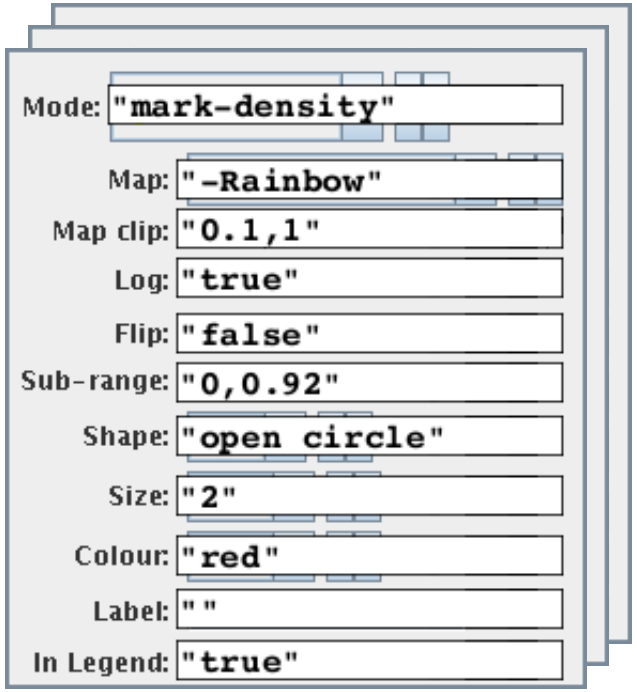

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Current status:

- In public release, but not yet replacing old-style plots (hidden in **Graphics** menu)
- Many plot/layer types: vectors, ellipses, contours, analytic functions, all-sky, color/size coding, ...
- Performance: 1 Mrow: good; 10 Mrow: usable; 300 Mrow: reported

Coming soon:

- More plot/layer types (stacked time series, histogram, plot grid, regions, ...)
- External control (STILTS, public API, SAMP)
- Performance improvements ($\times 10$?)