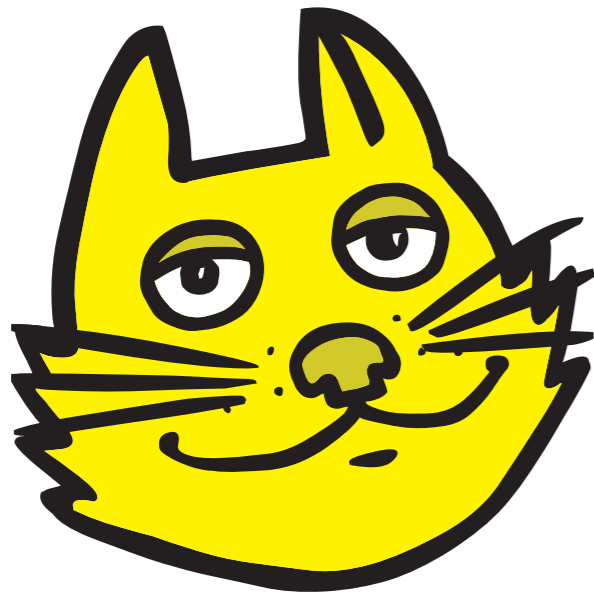


TOPCAT and Gaia XP Spectra



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Applications WG
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Online

20 October 2022



`$Id: tcxp.tex,v 1.13 2022/10/17 15:40:02 mbt Exp $`

Outline

Working with array-valued data:

- DataLink refresher, Gaia DR3 as example
- Using TOPCAT with DataLink services
 - ▷ Example: DR3 XP spectra using Activation Actions
- Using TOPCAT with array-valued columns
 - ▷ Example: DR3 XP spectra in table rows
- Summary of relevant TOPCAT/STILTS features

XP Sampled Spectra

Gaia XP Sampled Spectra data product, new in Gaia DR3

- Spectral data from BP + RP low-resolution spectrometry instruments
- Reconstructed from XP Continuous Spectra (coefficients)
- Available for 34M / 1.8G sources at DR3
- 343-row wavelength, flux, flux_error tables
- Wavelength values same for all sources

Access

- Delivered only via DataLink from ESA TAP service
- Available in other forms elsewhere

	wavelength <i>nm</i>	flux $Wm^{-2}nm^{-1}$	flux_error $Wm^{-2}nm^{-1}$
1	336.0	1.8571556E-17	9.309491E-18
2	338.0	1.0335697E-17	7.1697286E-18
3	340.0	8.157212E-18	5.6923542E-18
4	342.0	1.1108474E-17	5.036669E-18
5	344.0	1.3550346E-17	4.7585802E-18
6	346.0	1.1722847E-17	4.8270174E-18
7	348.0	8.0488636E-18	5.0007076E-18
8	350.0	7.61149E-18	5.4267143E-18
9	352.0	1.1499628E-17	6.0736378E-18
10	354.0	1.4324368E-17	6.5763125E-18
11	356.0	1.1296319E-17	6.1475095E-18
12	358.0	6.8084405E-18	5.7133638E-18
...
341	1016.0	4.218802E-16	5.3699563E-17
342	1018.0	4.2090065E-16	5.3001684E-17
343	1020.0	4.3125362E-16	5.3213895E-17

DataLink and Gaia DR3

Multiple “ancillary” data products are associated with each DR3 source

- These items are bulky (array-valued) and in general not available in the database (by direct ADQL query)
- Each source may have none, some or all of 6 items:
 - ▷ **XP sampled spectrum**, XP continuous spectrum, RVS spectrum, epoch photometry, MCMC gsphot, MCMC MSC
- There is a (DataLink) **Links Table** associated with each `gaia_source` table row
 - ▷ Each row describes one ancillary product
- How to find the Links Table?
 - ▷ *Either*: From service-specific documentation
 - Gaia DR3 links table URL is <https://gea.esac.esa.int/data-server/datalink/links?ID=<designation>>, where `<designation>` looks like `Gaia+DR3+30343944744320` (see DR3 docs)
 - ▷ *Or*: Use a (DataLink) **Service Descriptor**
 - Returned with result VOTable from suitable VO queries
 - Maps result table row to Links Table URL (using some ID value in the table)
 - For ESA Gaia DR3, query SELECT must include `designation` column (to use as ID)

ID	description	semantics	content_type	access_url
Gaia DR3 30343944744320	MCMC MSC, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=MCMC_MSC
Gaia DR3 30343944744320	XP mean sampled spectra, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=XP_SAMPLED
Gaia DR3 30343944744320	XP mean continuous spectra, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=XP_CONTINUOUS
Gaia DR3 30343944744320	MCMC GSP-Phot, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=MCMC_GSPPHOT
Gaia DR3 30343944744320	Epoch photometry, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=EPOCH_PHOTOMETRY
Gaia DR3 30343944744320	RVS mean spectra, source Gaia DR3 30343944744320	#this	application/x-votable+xml	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+30343944744320&RETRIEVAL_TYPE=RVS

Note: Gaia DR3 is just one (important) example — many other services use DataLink in the same way

TOPCAT and DataLink

TOPCAT features for working with DataLink services:

- Reports Service Descriptors in Parameters Window
- Provides Activation Actions to view/use Links Tables when parent table row is **activated**
 - ▷ **Invoke Service** action displays Links Table located by service descriptor
 - ▷ **View Datalink Table** action displays Links Table given explicit root URL
- Displayed Links Table has options to follow the links in it:
 - ▷ Select data product of interest
 - ▷ Specify an action on that data product (e.g. Load table into TOPCAT, Plot table columns, ...)
 - ▷ When next parent table row (source) is activated, the corresponding row is selected, and action can be auto-invoked

Example: DataLink and Activation Actions

View XP Sampled spectra for points in a plot of interest



Query gaia_source table to plot HR diagram of nearby stars:

```
SELECT designation, source_id, ra, dec, parallax, bp_rp, phot_g_mean_mag,  
       phot_g_mean_mag+5*log10(parallax/100) AS mag_g  
FROM gaiadr3.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  
      AND astrometric_excess_noise < 1  
      AND has_xp_sampled = 'true'
```

- ▶ Select on `has_xp_sampled` to ensure spectra are available
- ▶ Must SELECT `designation` to get Service Descriptor

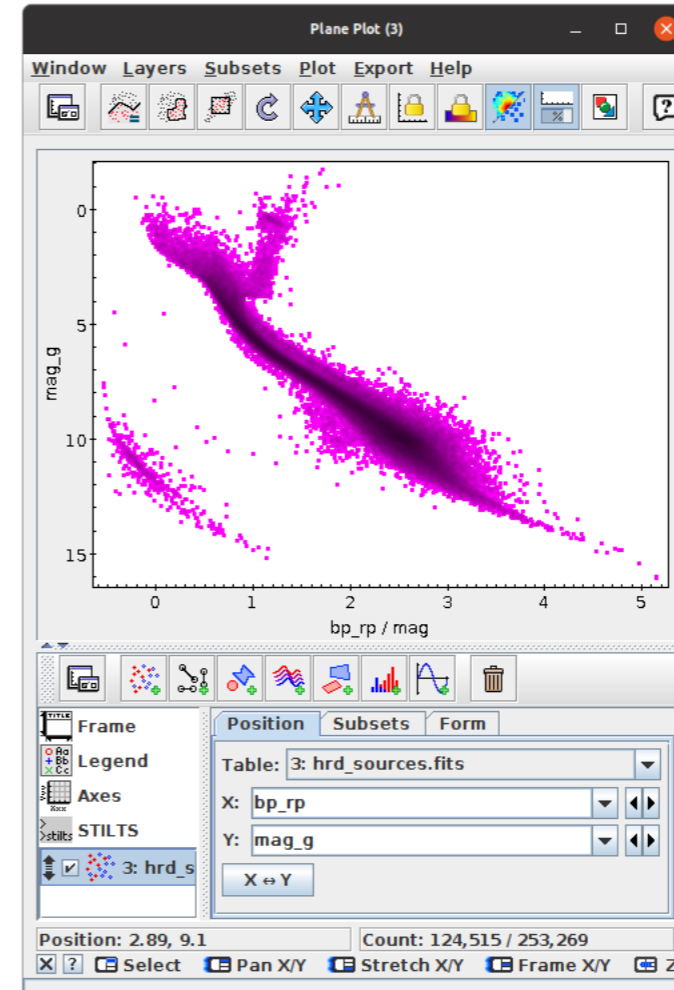


View Service Descriptor in **Parameters Window**



Set up **Activation Action**

- ▶ Select checkbox for **Invoke Service**
- ▶ Service **Action** is **View DataLink Table**
- ▶ Select **XP mean sampled spectra** row of DataLink table
- ▶ Configure to **Plot Table** on DataLink load and **Auto-Invoke**
- ▶ Set up plot to taste
 - clicking on point in plot displays spectrum
(works best with TOPCAT v4.8-6 or later)



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The screenshot shows the TOPCAT software interface. The main window, titled "Plane Plot (3)", displays a plot of magnitude (mag_g) versus parallax. The plot shows a dense distribution of stars, with a prominent sequence of stars. The plot is overlaid with a grid. The "Table Parameters" window is open, showing the parameters for the table "TAP_3_gaiadr3.gaia_source". The parameters are listed in a table with columns for Name and Value.

Name	Value
Name	sync
Column Count	8
Row Count	124515
QUERY_STATUS	OK
QUERY	SELECT designation, source_id, ra, dec, par...
CAPTION	How to cite and acknowledge Gaia: https://...
PAGE	
PAGE_SIZE	
JOBID	16655789168250
JOBNAME	16655789168250
Service_ancillary	accessURL: https://gea.esac.esa.int/data-s... Service Descriptor: Retrieve Data

The "Table Parameters" window also shows a "Service_ancillary" section with the following details:

- Name: Service_ancillary
- Class: ServiceDescriptor
- Shape: [empty field]
- Units: [empty field]
- Description: Service Descriptor: Retrieve DataLink file containing ancillary data for source
- UCD: [empty field]
- Utype: [empty field]
- Value:

```
accessURL: https://gea.esac.esa.int/data-server/datalink/links
standardId: ivo://ivoa.net/std/DataLink#links-1.0
Input parameters: ID (column=designation)
```

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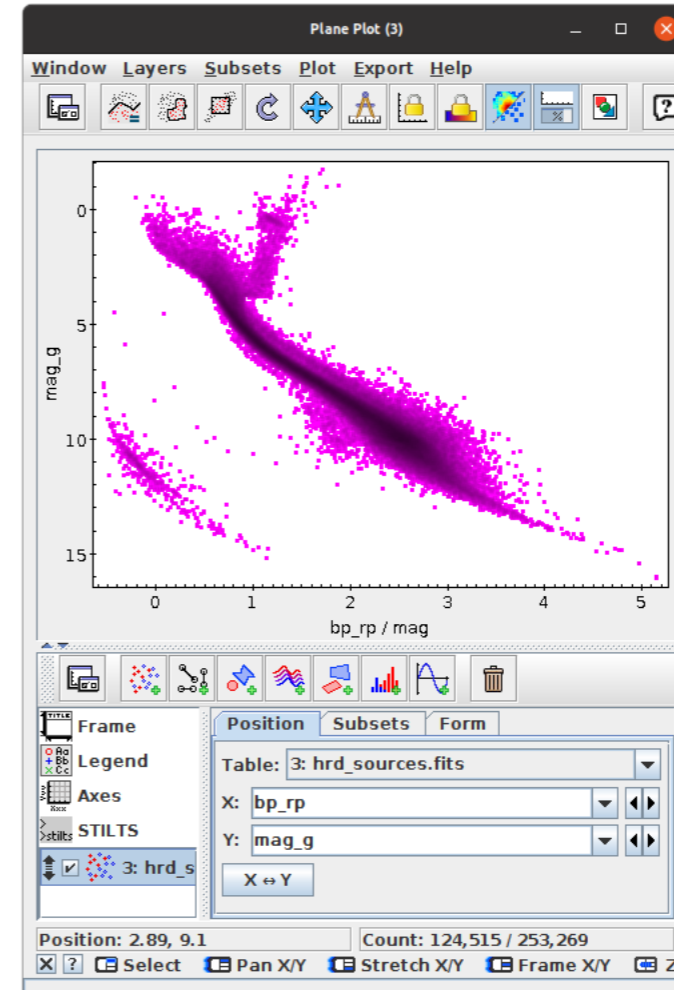


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The screenshot shows two windows from the TOPCAT software. The top window, titled 'Plane Plot (3)', displays a scatter plot of stars with 'mag_g' on the y-axis (ranging from 0 to 15) and an unlabeled x-axis (ranging from 0 to 1). The stars are colored in shades of purple and blue, forming a clear main sequence and a branch. The bottom window, titled 'TOPCAT(5): Activation Actions', shows the configuration for an activation action. The 'Actions' list includes 'Use Sky Coordinates in' (checked), 'Invoke Service' (checked), 'Send Sky Coordinates', 'Display HiPS cutout', 'Send HiPS cutout', 'Delay', 'Execute code', 'Run system command', 'SAMP Message', and 'Send row index'. The 'Configuration' section shows the 'Action' set to 'View DataLink Table'. The 'Status' section shows 'Invoke now on row 85086'. The 'Results' table at the bottom shows the following data:

Seq	Row	Status	Message
5	80084	OK	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+4122597029
6	80089	OK	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+4122667123
7	123123	OK	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+6133931765
8	85086	OK	https://gea.esac.esa.int/data-server/data?ID=Gaia+DR3+4373306541

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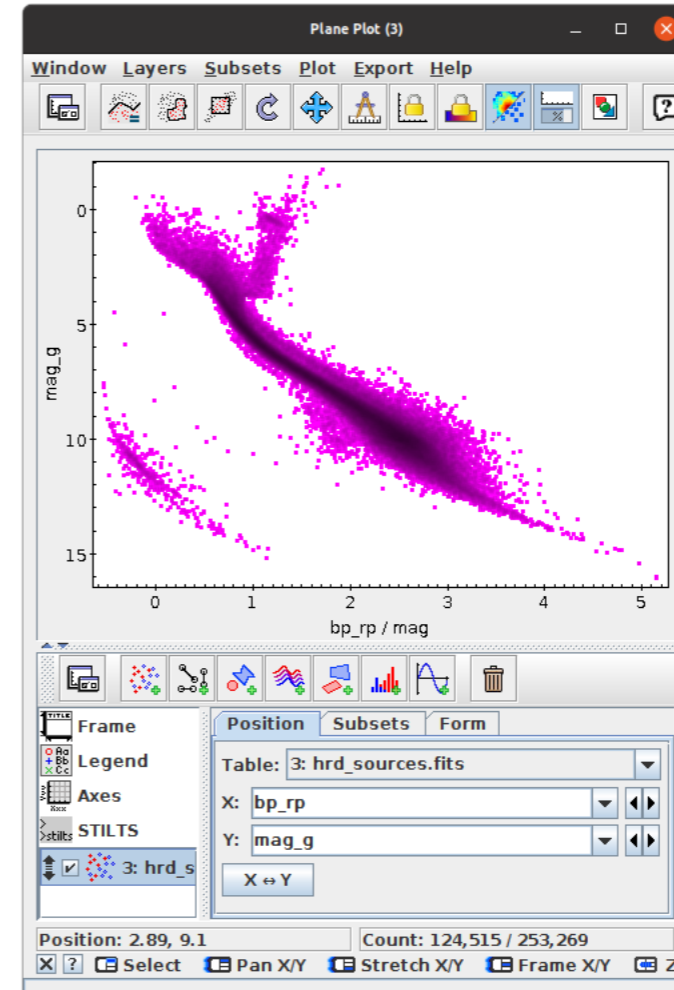


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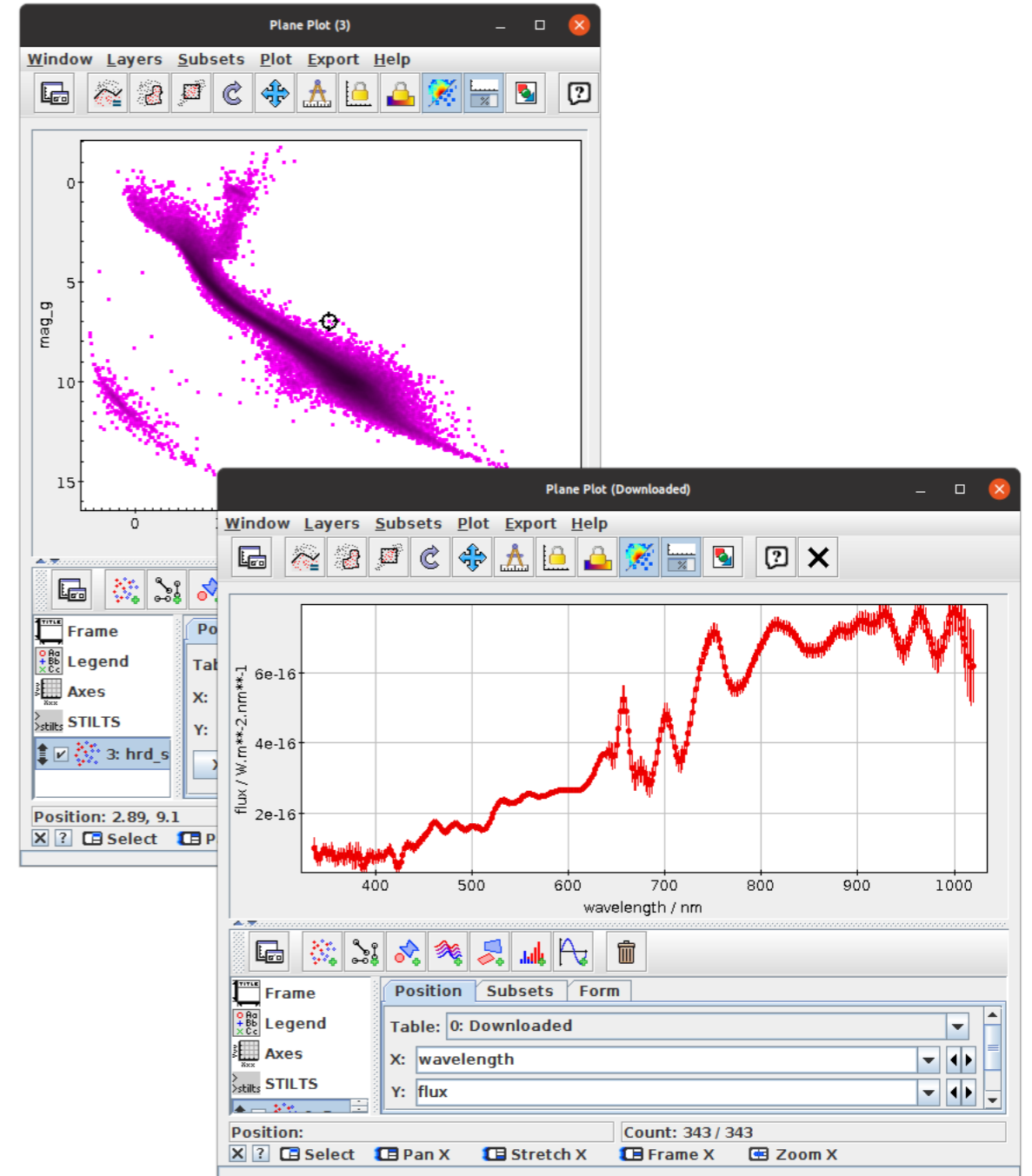


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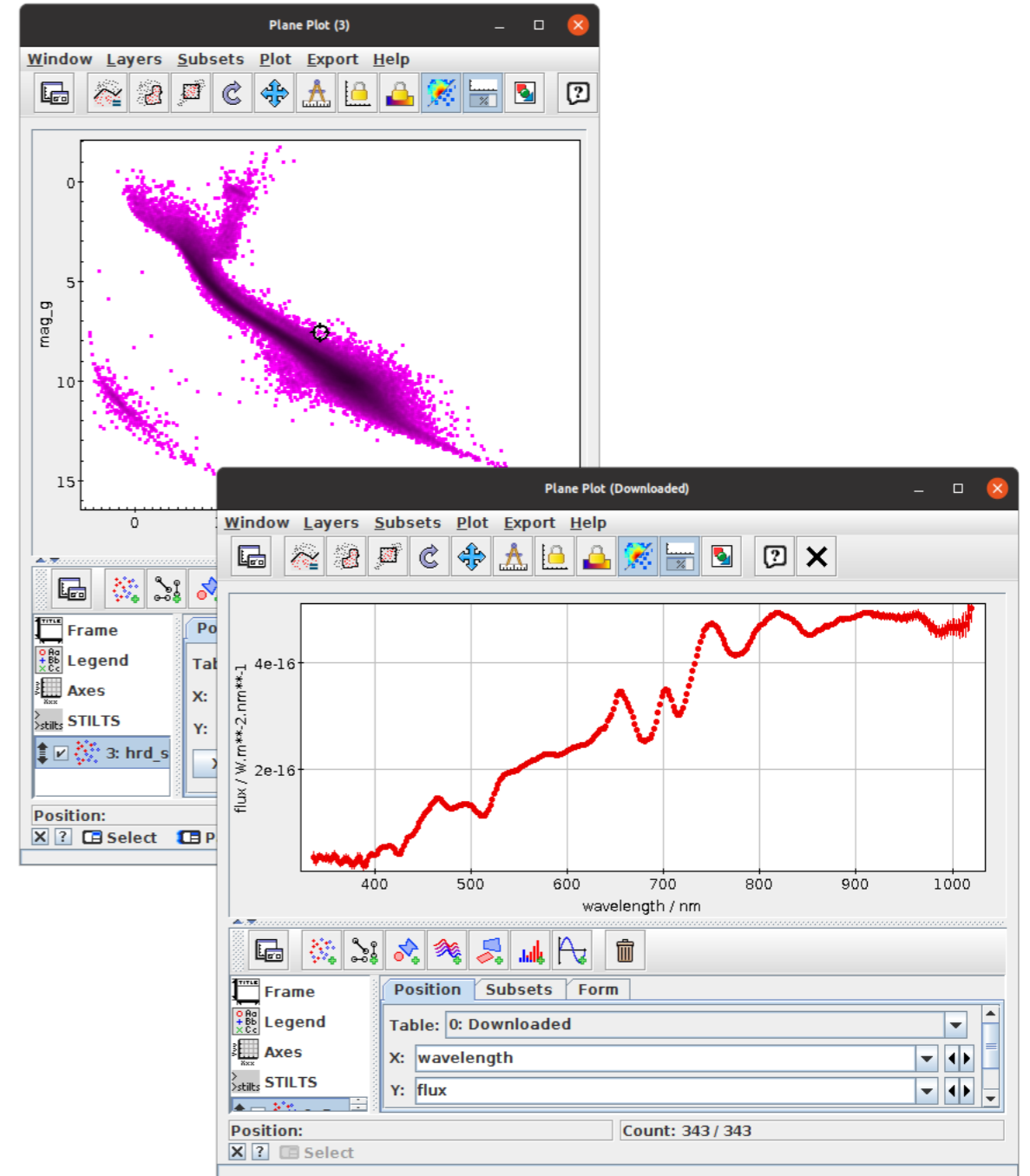


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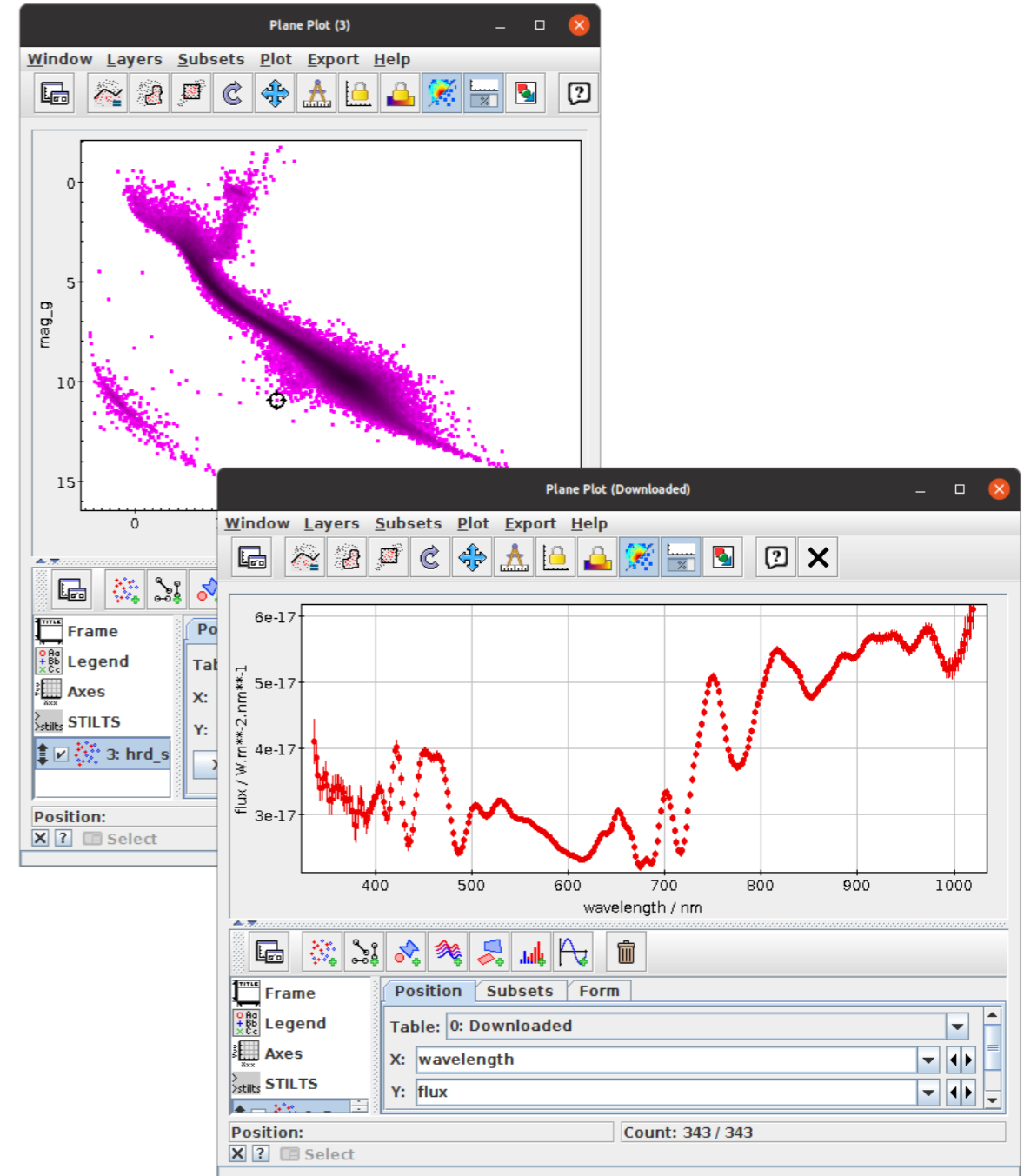


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Example: DataLink and Activation Actions

View XP Sampled spectra for points in a plot of interest



Query `gaiadr3.gaia_source` table to plot HR diagram of nearby stars:

```
SELECT designation, source_id, ra, dec, parallax, bp_rp, phot_g_mean_mag,
       phot_g_mean_mag+5*log10(parallax/100) AS mag_g
FROM gaiadr3.gaia_source
WHERE parallax > 10
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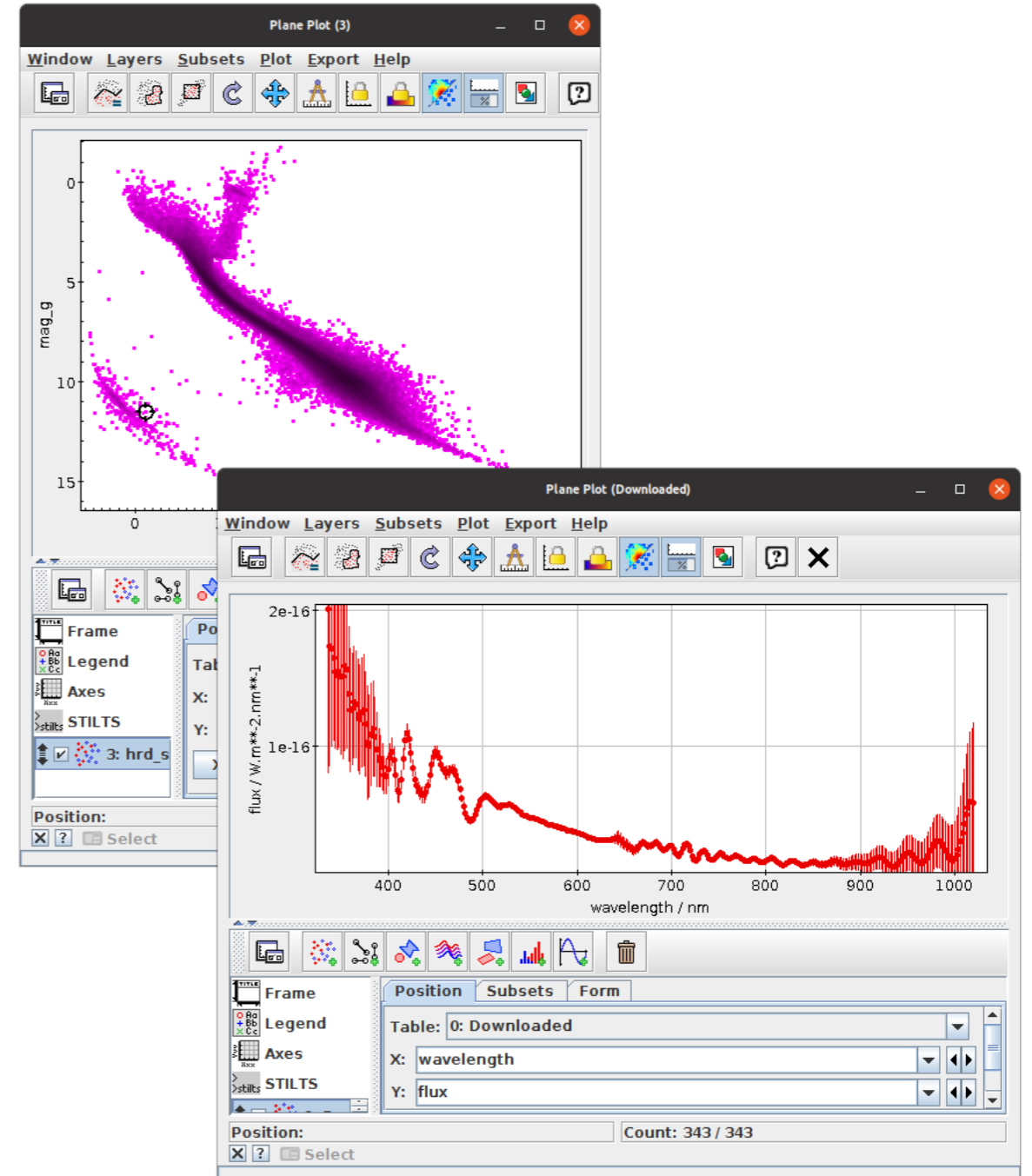


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Spectra as Arrays

Working with multiple spectra

- DataLink works fine for looking at one spectrum at a time
- Sometimes you want to manipulate (e.g. visualise) multiple spectra at once
- To do that in TOPCAT you need array-valued columns
 - ▷ One spectrum per row
 - ▷ `fluxes` column and maybe matching `wavelengths` and `flux_errors` columns (same number of elements in each array)

How to get tables with spectra as array columns? Options for Gaia DR3 XP spectra:

- Use STILTS `arrayjoin` command (form of spectrum URLs is from [ESA DataLink service docs](#)) — requires STILTS \geq v3.4-6
 - ▷ For each row, adds N -element array-valued columns `wavelength`, `flux`, `flux_error` from N -row downloaded XP table

```
stilts arrayjoin in=dr3-sources.vot \  
                atable="https://gea.esac.esa.int/data-server/data?RETRIEVAL_TYPE=XP_SAMPLED&RELEASE=Gaia+DR3&ID="+source_id' \  
                icmd=progress \  
                out=sources-with-xp.fits
```

- ARI-Gaia TAP service has table `gaiadr3.xp_sampled_mean_spectrum` (though ESA Gaia TAP service does not)

- ▷ Array-valued `flux` and `flux_error` columns are available in the database

```
SELECT source_id, ra, dec, parallax, flux, flux_error, ...  
FROM gaiadr3.xp_sampled_mean_spectrum  
NATURAL JOIN gaiadr3.gaia_source  
WHERE ...
```

- ▷ Can use expression `sequence(343,336.0,2)` for wavelength array

- See also `gedr3spec` tables in GAVO DC TAP service (lower resolution spectra, but for more sources)

Example: Spectra as Arrays



Get some White Dwarf spectra

```
SELECT source_id, bp_rp, phot_g_mean_mag+5*log10(parallax/100) AS g_abs
FROM gaiadr3.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
  AND astrometric_excess_noise < 1
  AND has_xp_sampled = 'true'
  AND bp_rp BETWEEN -0.63 AND 1.21
  AND phot_g_mean_mag+5*log10(parallax/100) BETWEEN 7.4 AND 15.5

stilts arrayjoin in=wd_hrd.fits icmd=progress out=wd_spectra.fits \
  atable="https://gea.esac.esa.int/data-server/data?RETRIEVAL_TYPE=XP_SAMPLED&RELEASE=Gaia+DR3&ID="+source_id'
```



View them using the XYArray plot

- Use array functions to normalise them
 - If X Values are blank, array index is used instead
 - Plot mean spectra etc using **StatLine/StatMark** form
 - Linked views using subsets
 - To highlight activated row, use **Activated** subset
 - To select single/multiple rows from plot, use **Handles** layer
- (most of these features require recent versions)

Example: Spectra as Arrays



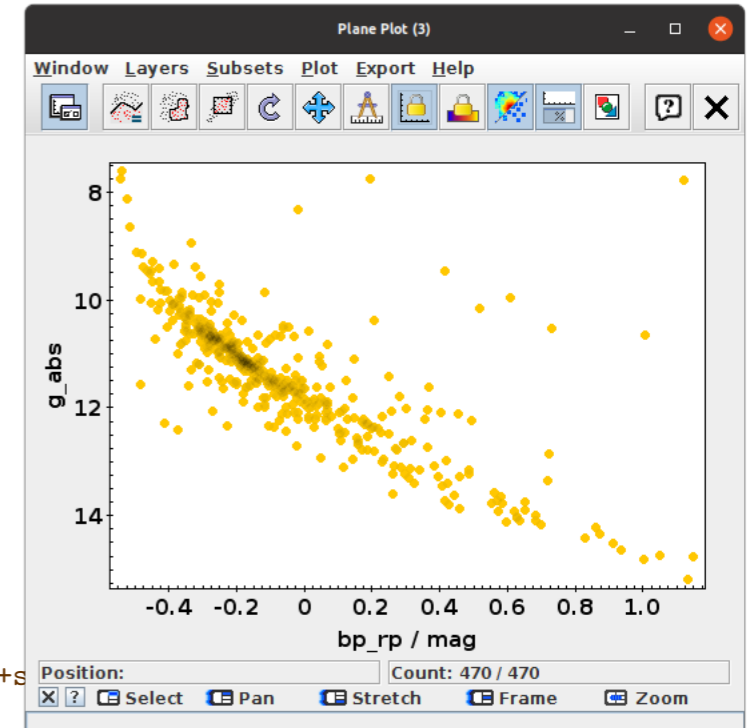
Get some White Dwarf spectra

```
SELECT source_id, bp_rp, phot_g_mean_mag+5*log10(parallax/100) AS g_abs
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WHERE parallax > 10 AND parallax_over_error > 10
  AND phot_bp_mean_flux_over_error > 10 AND phot_rp_mean_flux_over_error > 10
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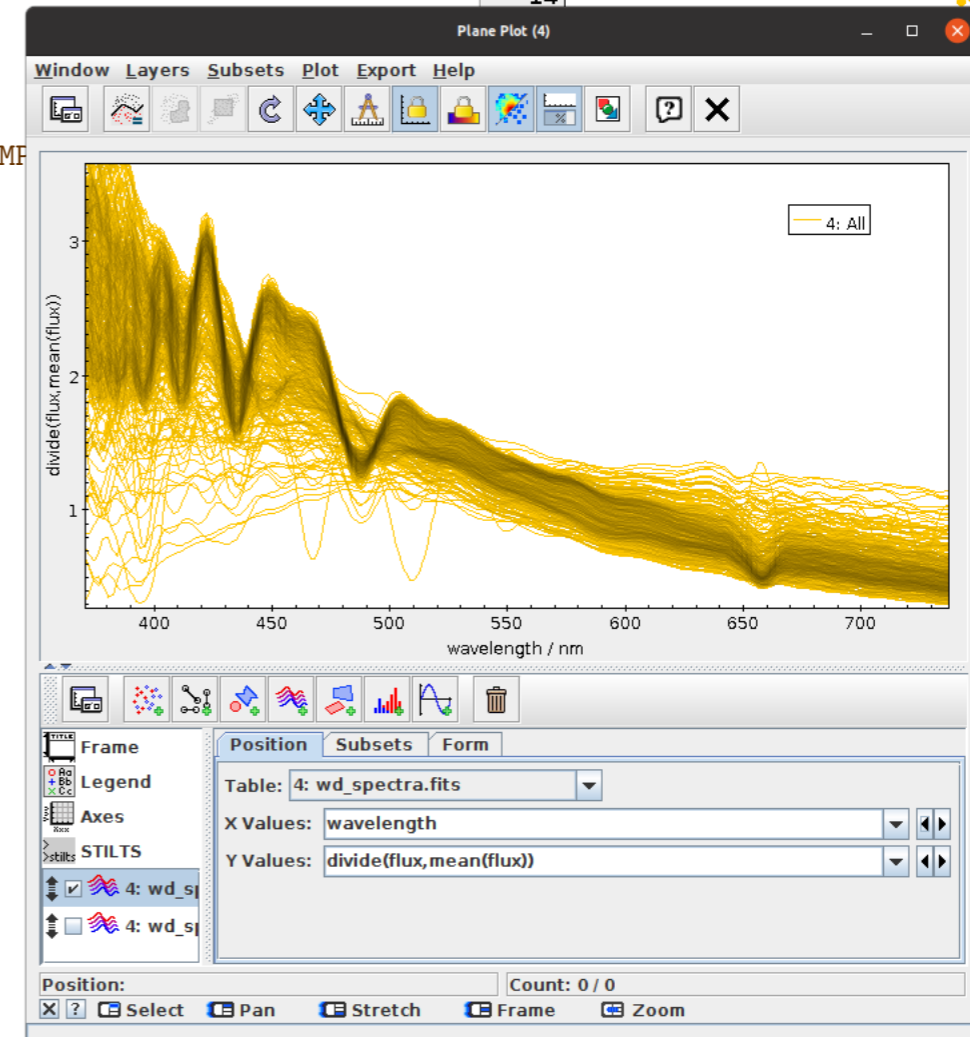
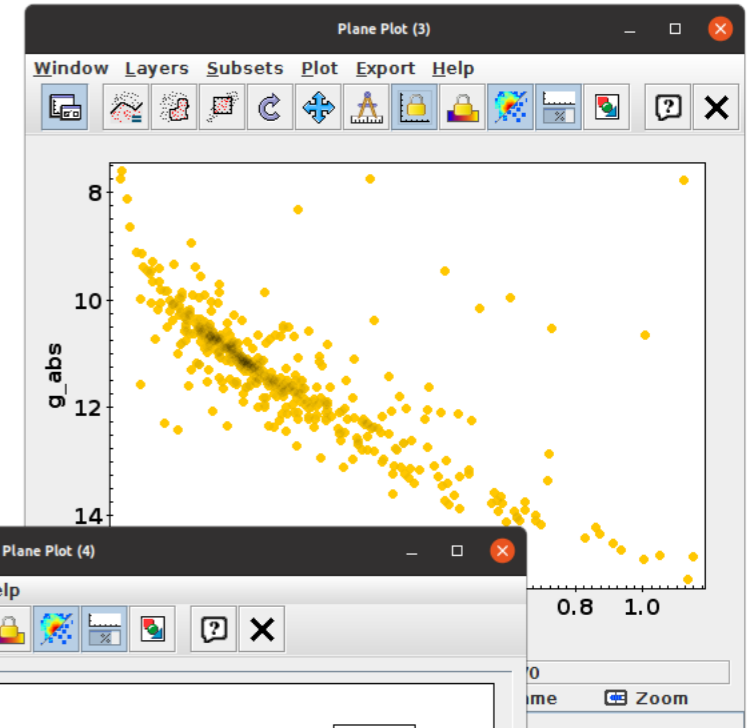
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stilts arrayjoin in=wd_hrd.fits icmd=progress out=wd_spectra.fits \
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Example: Spectra as Arrays



Get some White Dwarf spectra

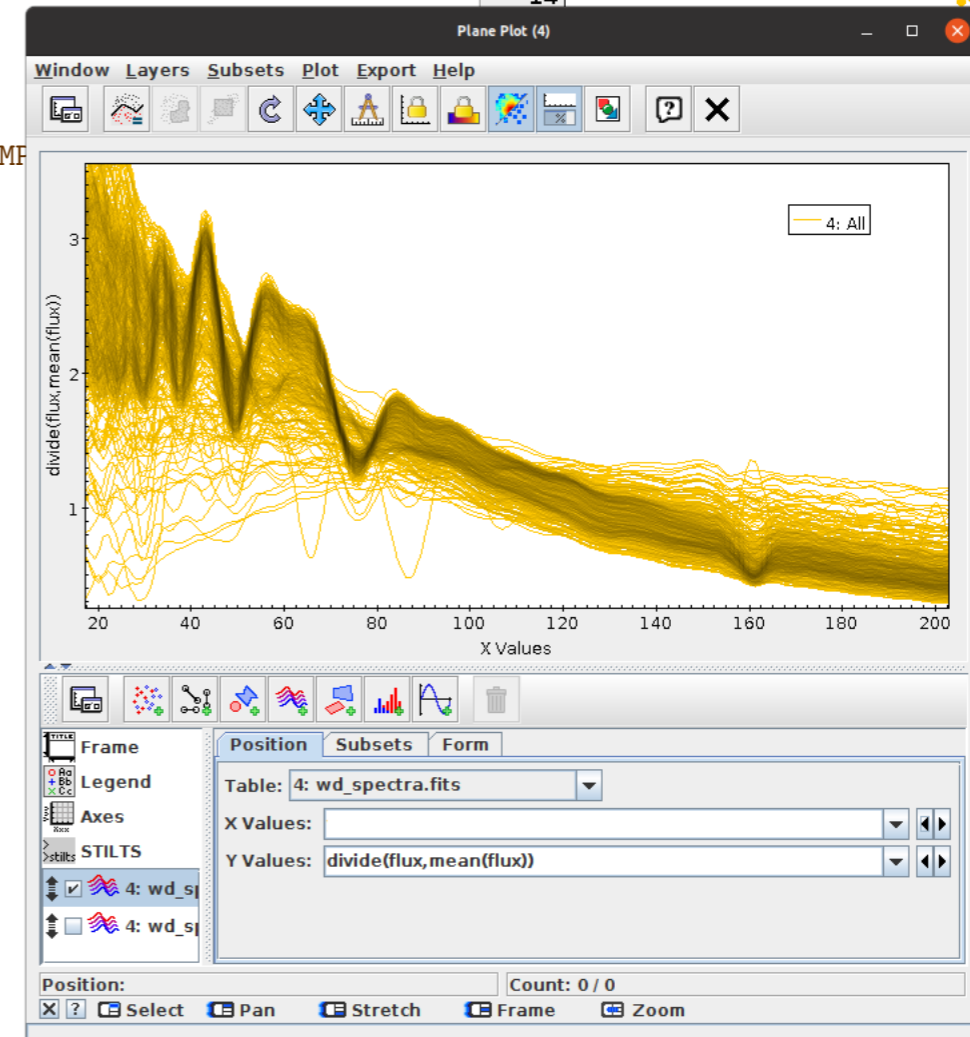
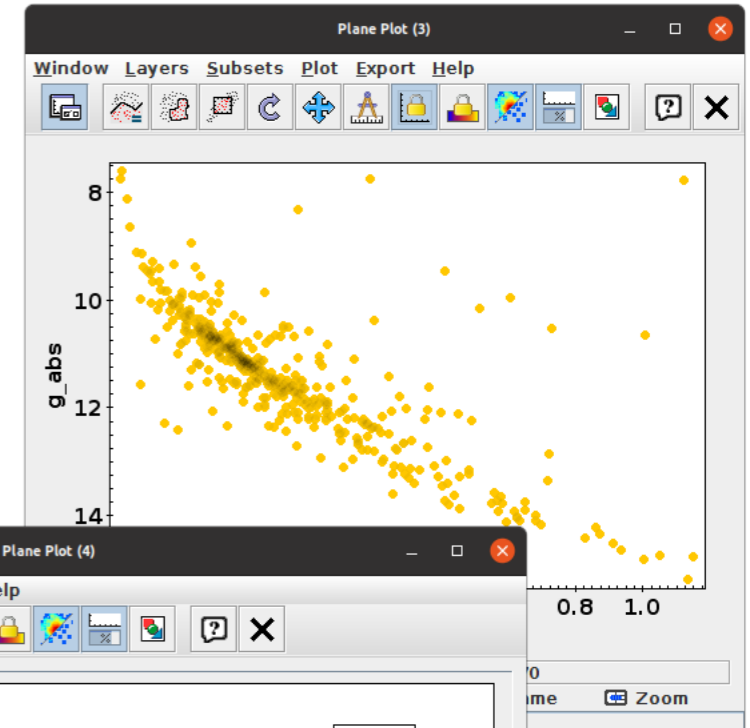
```
SELECT source_id, bp_rp, phot_g_mean_mag+5*log10(parallax/100) AS g_abs
FROM gaiadr3.gaia_source
WHERE parallax > 10 AND parallax_over_error > 10
  AND phot_bp_mean_flux_over_error > 10 AND phot_rp_mean_flux_over_error > 10
  AND astrometric_excess_noise < 1
  AND has_xp_sampled = 'true'
  AND bp_rp BETWEEN -0.63 AND 1.21
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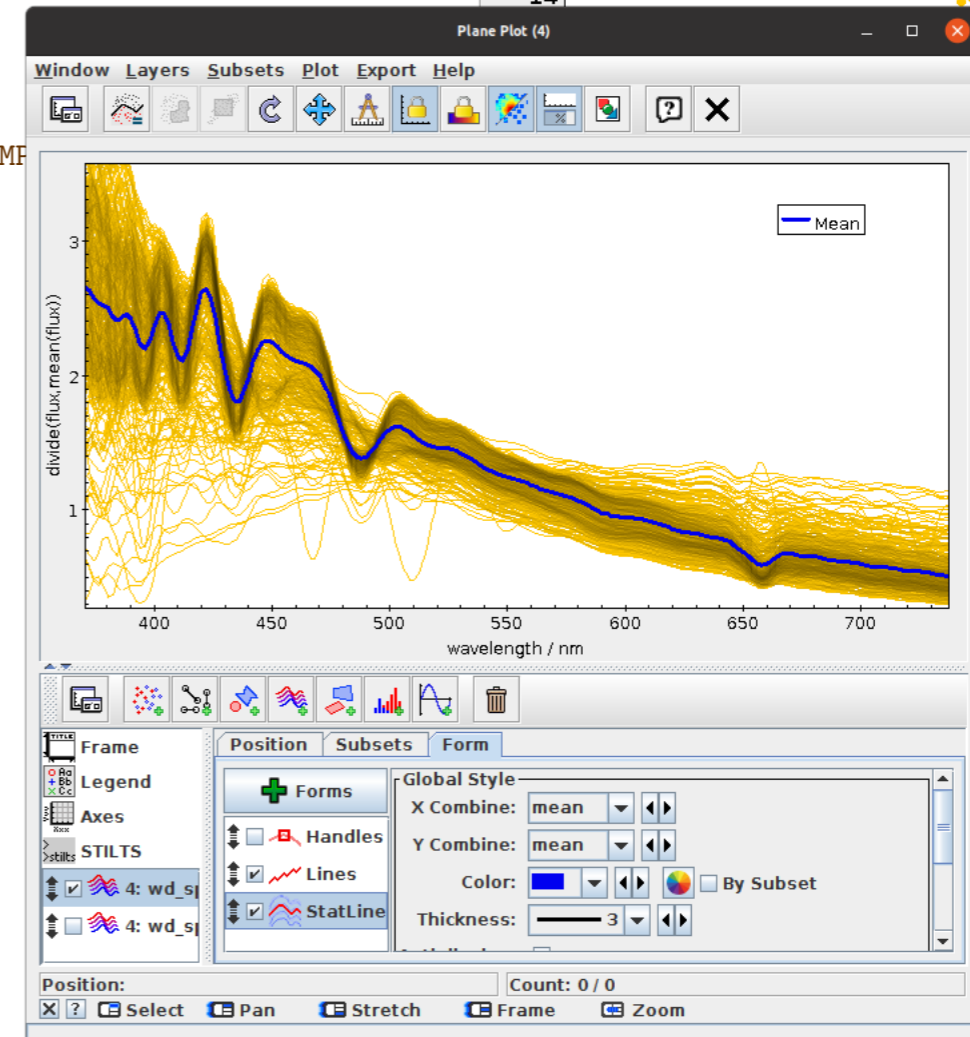
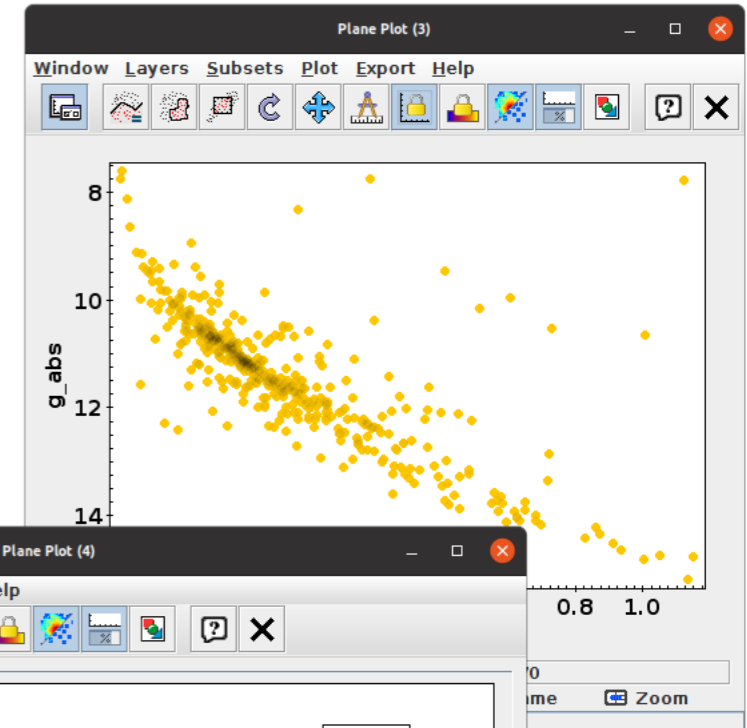
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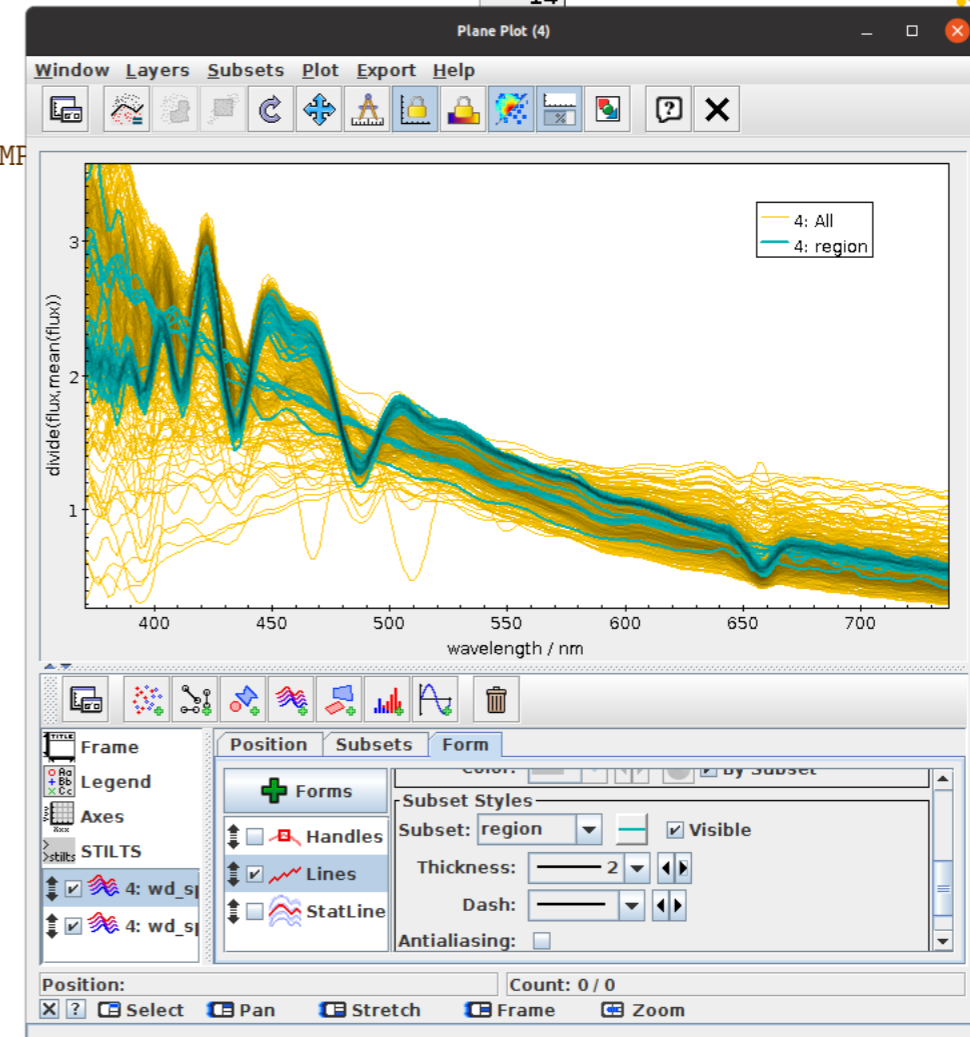
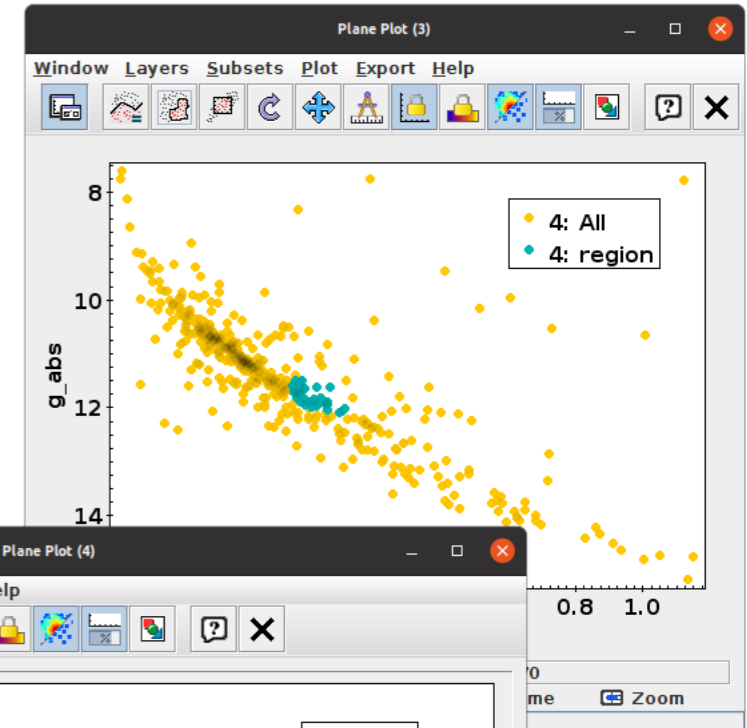
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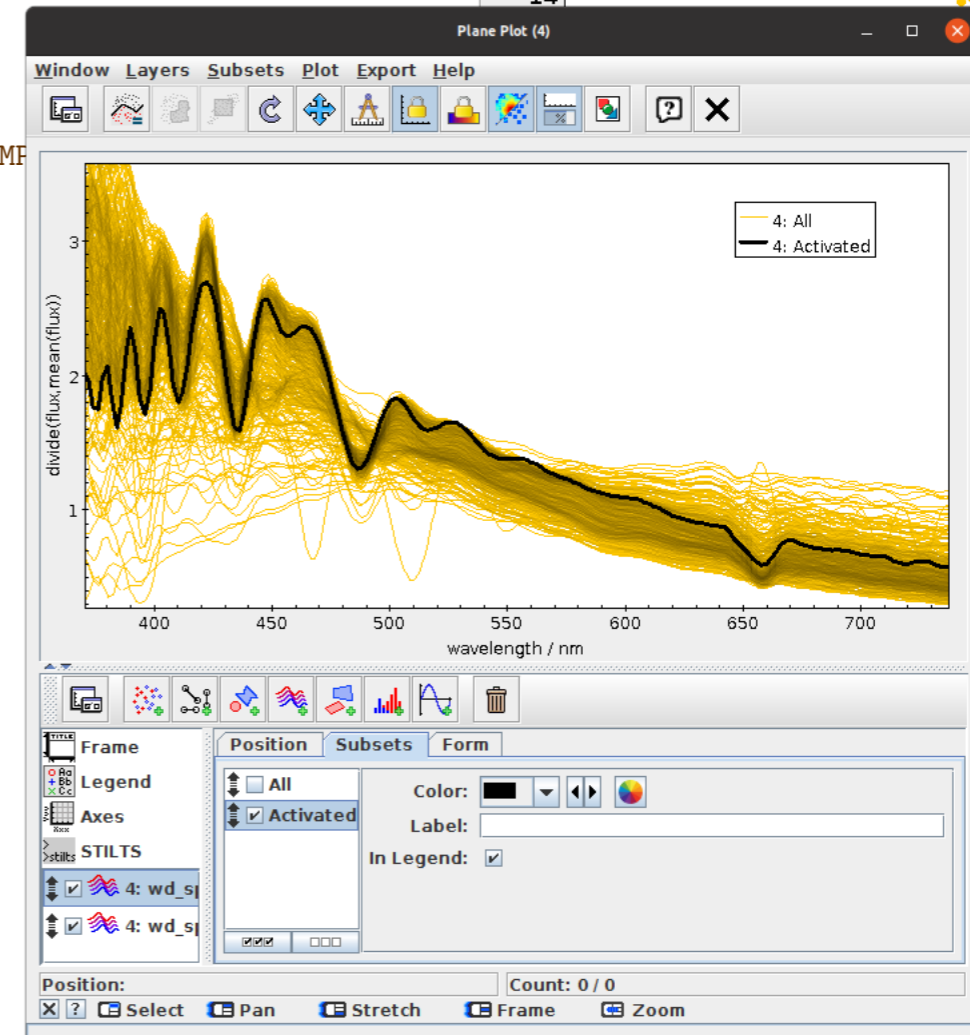
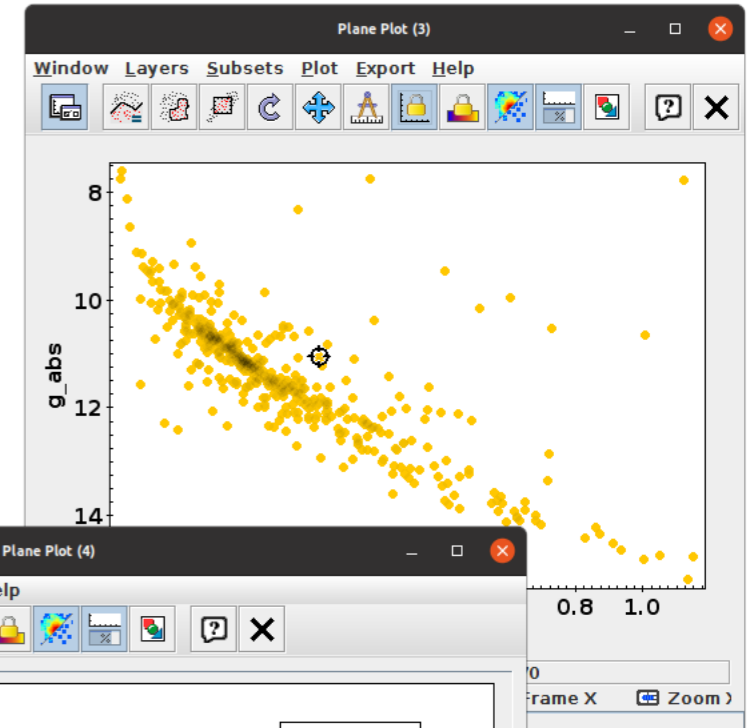
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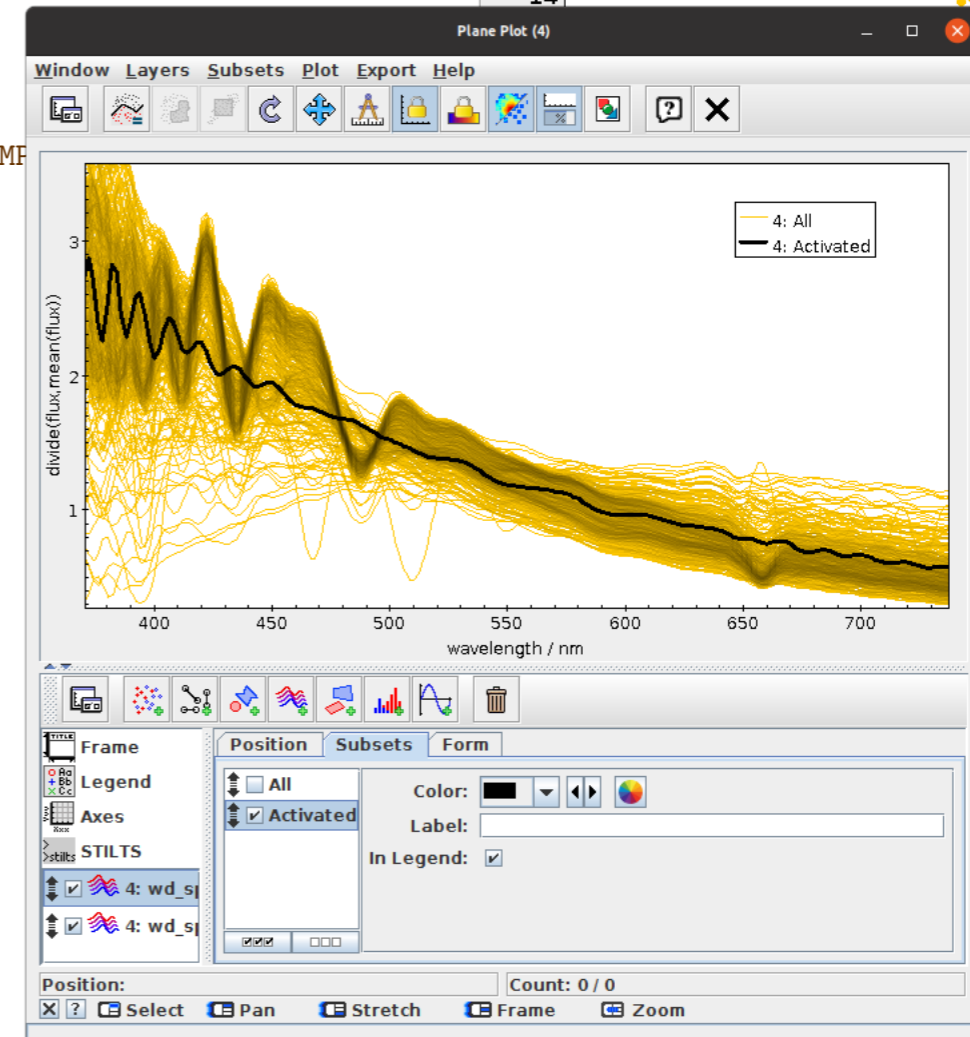
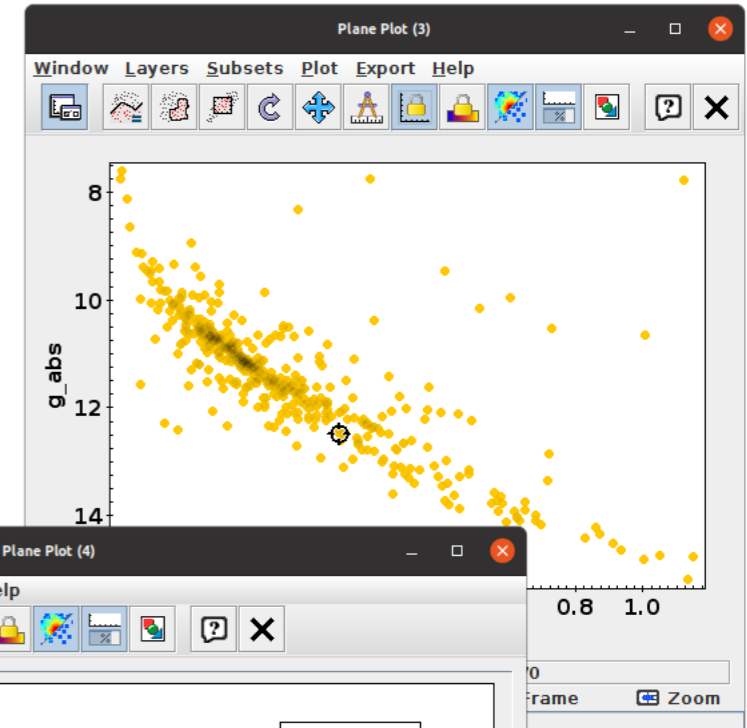
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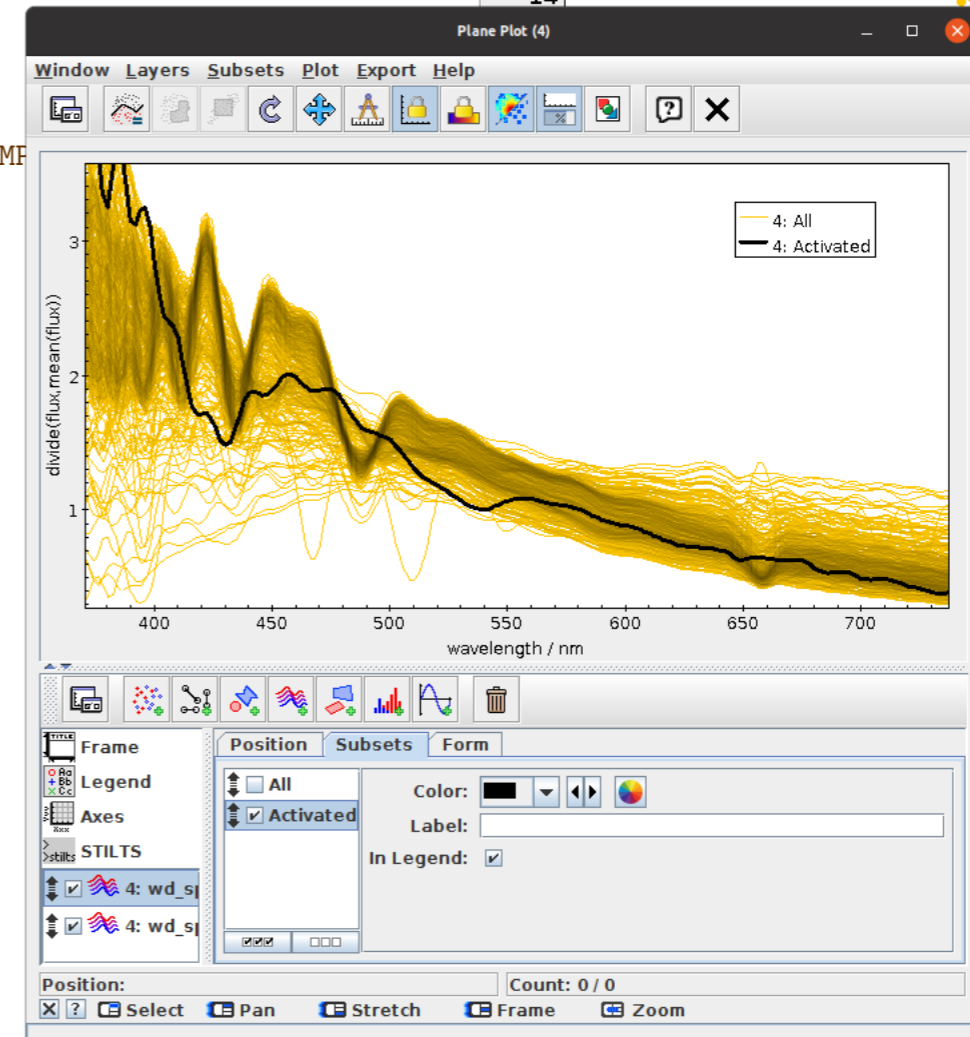
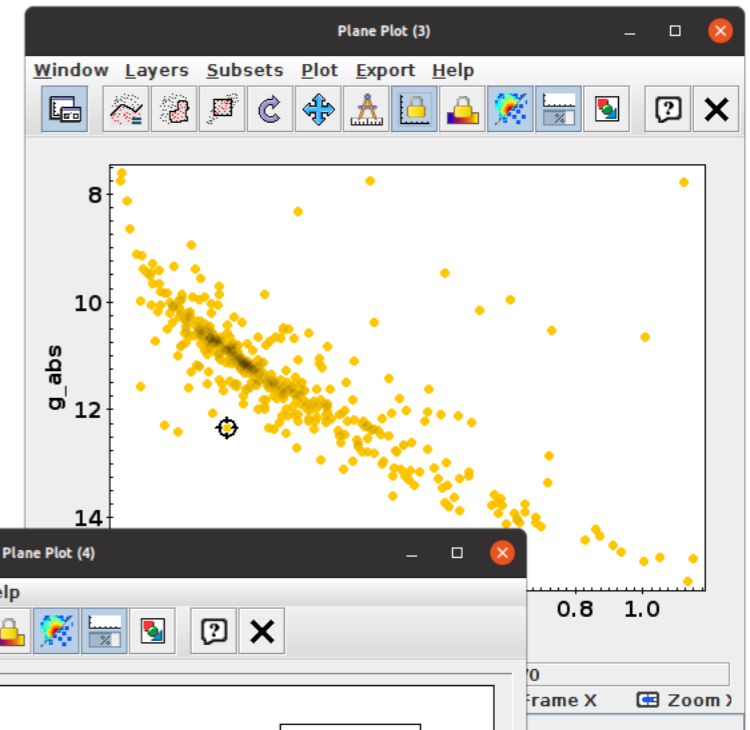
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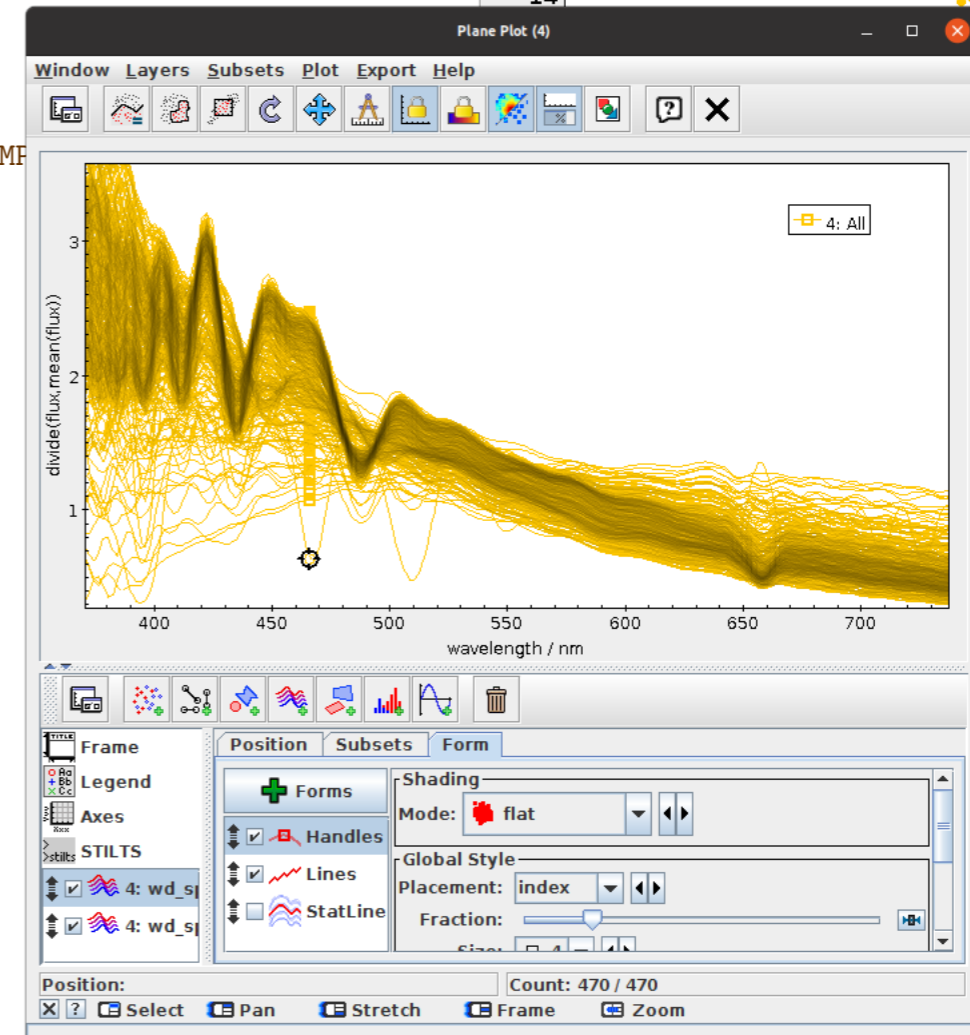
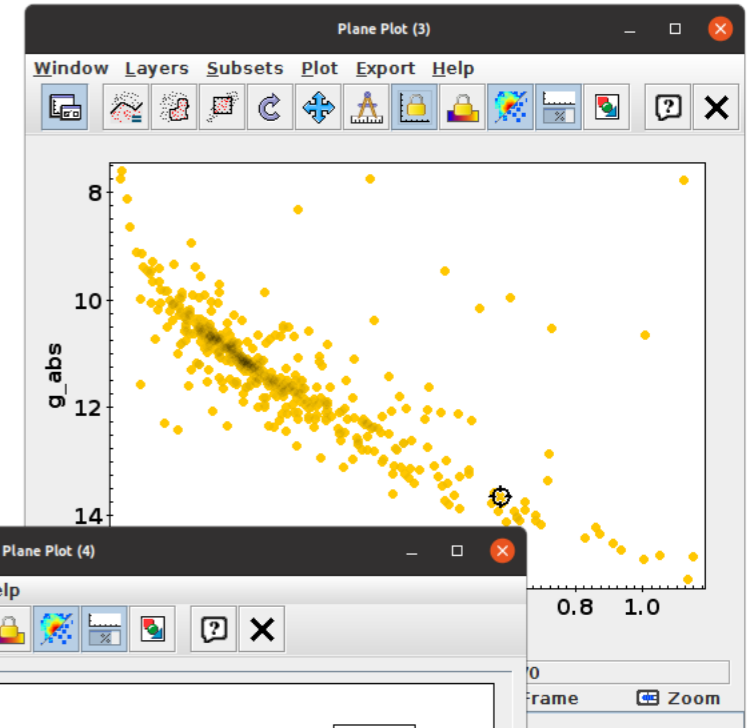
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Data Access:

- Activation Actions
 - ▷ **Invoke Service** understands `Service Descriptors`
 - ▷ **View Datalink Table** using `{links}` Endpoint and ID column — *New!*
- Auto-invoke row from DataLink table (Load, Plot, Send, ...)
- STILTS `arrayjoin` command — *New!*

Visualisation:

- XYArray plots
- Activation Subset — *New!*
- XYArray Handle plot layer — *New!*
- StatMark/StatLine and ArrayQuantile plot layers — *New!*

Array manipulation

- Array collapse functions: `mean`, `median`, `minimum`, `maximum`, `quantile`, ...
- Array combination functions: `multiply`, `divide`, `add`, `subtract`, ...
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TOPCAT web page:

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

More examples at GAVO blog:

<https://blog.g-vo.org/>

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