CDS Gaia tutorial

Tutorial "Access to Gaia in CDS services" - Gaia data workshop @ Heidelberg

Thomas Boch

For easy access to URLs and easy copy/paste, an online version of the instructions is available at http://cds.unistra.fr/~boch/gaia-workshop-nov2016/ .
A PDF version is also available.

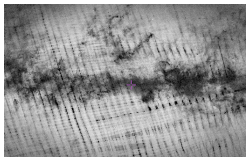
Each section (numbered 1. to 7.) can be done independently.
Sections 1 to 6 do not require any prerequisite ; section 7 requires some Python knowledge.

1. Explore Gaia DR1 in **Aladin Lite**: density map and HiPS

Open http://cds.unistra.fr/Gaia/DR1/AL-visualisation.gml in your browser. By default, it shows a density map of Gaia DR1 sources. You can zoom in, zoom out and pan around.

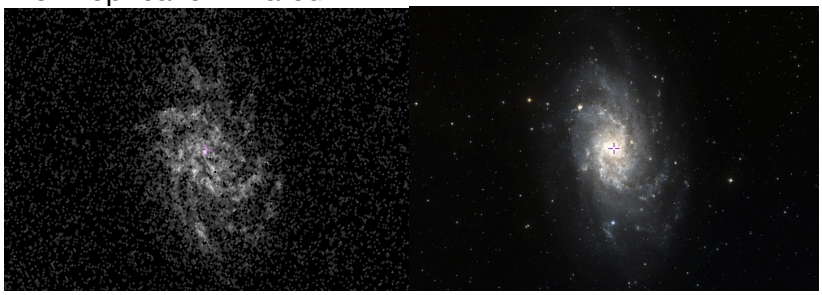
For now, switch off the layer *Gaia DR1 sources*

Notice the satellite scanning patterns near the galactic center.



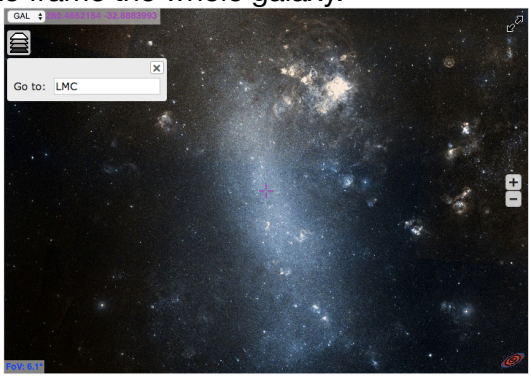
Click on the icon  to jump to a given target. Type in *Andromeda* and submit. Zoom in if needed. The Andromeda galaxy is clearly visible.

Repeat the same process for objects *M 33* and *NGC 55*.
You can switch the base image layer to DSS or 2MASS and see how these galaxies look like in optical or infrared.



Switch to the DSS image layer, and jump to *LMC* (Large Magellanic Cloud). Adjust zoom

to frame the whole galaxy.



Switch on the *Gaia DR1 sources* HiPS progressive catalogue. When the field of view is large, only the brightest sources are displayed.

Click on one of the source and see the associated measurements displayed in the right panel.
As you zoom in, fainter stars appear.
Click on another object and select *More details* to see the VizieR page with the whole set of measurements.

NB: the same steps can be performed in Aladin Desktop. Type http://cds.unistra.fr/Gaia/DR1/hips/GaiaSourceDR1-density-map-8192/ in Aladin command bar and submit to load the Gaia density map. HiPS progressive catalogues can be loaded from the HiPS form (menu Fille —> Open, tab HiPS, then open node Catalog)

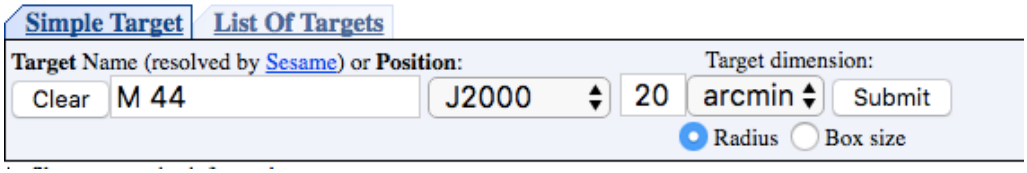
2. Query Gaia tables in **VizieR**

2.1 Query table I/337/gaia

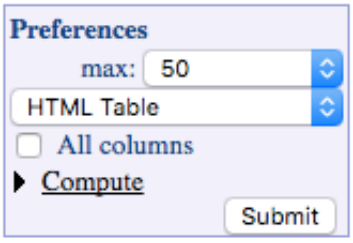
Open VizieR homepage http://vizier.u-strasbg.fr/viz-bin/VizieR in your browser, type *Gaia* in the first text field and submit

Click on I/337/gaia

Type Cen A as the target name and 20 arcmin for the search radius and submit

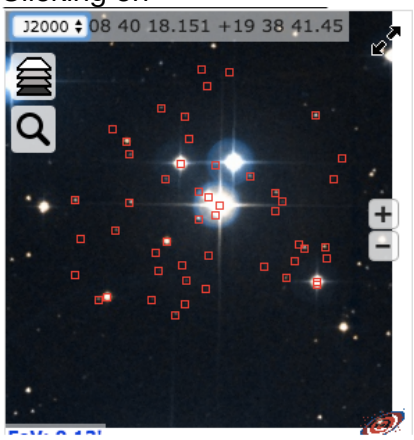


By default, VizieR outputs the result an HTML table, limited to 50 rows.
This limit, as well as the output format, can be modified from the left sidebar shown below:

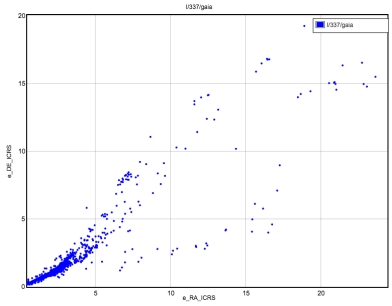


Change the maximum to 9999 and resubmit to get the whole list of rows in the requested cone.

Clicking on start AladinLite will show the sky positions of the rows in Aladin Lite.

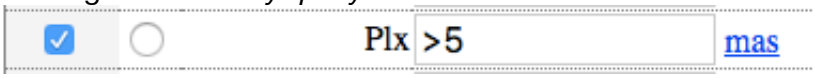


Clicking on plot the output will let you visualize 2D scatter plots on catalogue attributes.



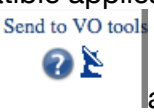
In our resut, only default columns are visible. Click on *Modify query*, select a few more columns and *Submit.* Check that the selected columns are visible in the output.

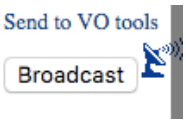
We are now going to add a constraint on our positional query, in order to keep only sources with parallax measurement greater than 5 mas.
Click again on *Modify query* and add the constraint:



Submit. You should retrieve 14 sources matching the constraint.

This result can be easily transmitted to Virtual Observatory tools:

- Fire up a SAMP-compatible application (either Topcat or Aladin).
- Click on the antennae 

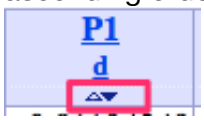
at the top right corner of the page
- accept connection
- click on Broadcast 

2.2 Query table I/337/cepheid

Go back to http://vizier.u-strasbg.fr/viz-bin/VizieR , search for *Gaia* and select the Cepheids table I/337/cepheid

Submit, change the max. number of rows to *Unlimited* as to retrieve all the 599 rows.

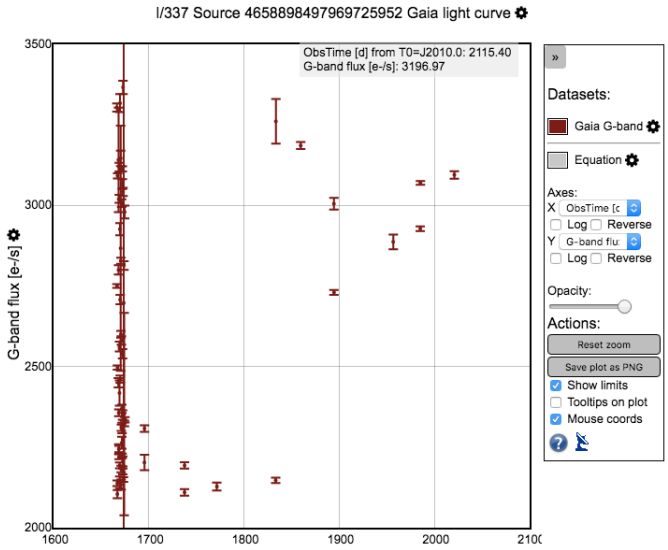
Click twice on the arrows above P1 label to sort the rows according to the period, in ascending order.



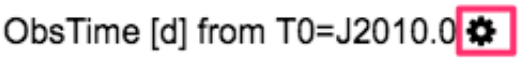
The first row is now the star with the shortest period.
Clicking on the corresponding fov link will show the different measurements for this star.

Click on 

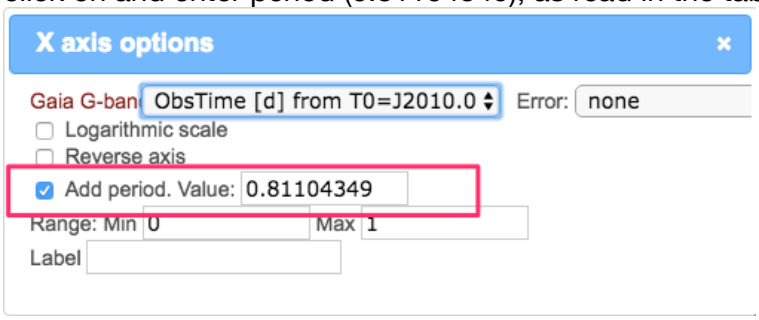
to display the light curve of this star.

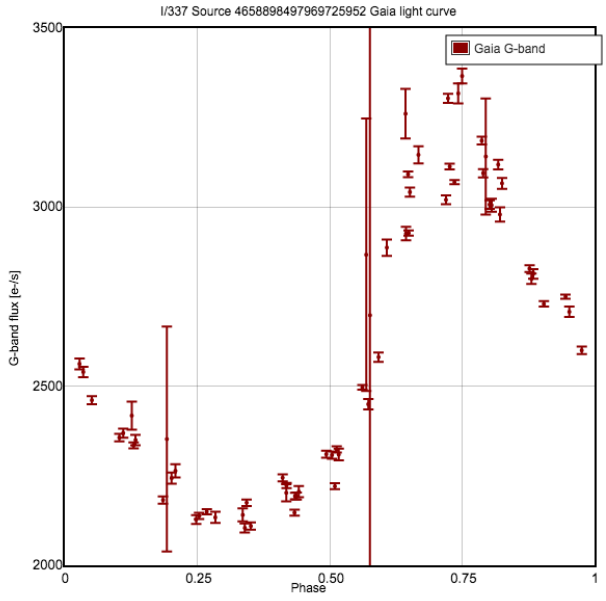


We will now fold according to the cepheid period :

- click on the X axis label 

- click on and enter period (0.81104349), as read in the table





3. Retrieve Gaia measurements for stars in globular clusters, selected from **Simbad**

Open http://simbad.u-strasbg.fr/ and click on Queries by criteria

Type the following search expression

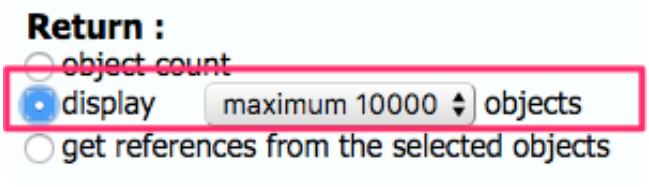
```
otype = '*inCl' & Bmag>11 & Bmag<12 & nbref>5
```

This query will search for *stars in cluster* having *magnitude B between 11 and 12* and *cited in more than 5 papers*

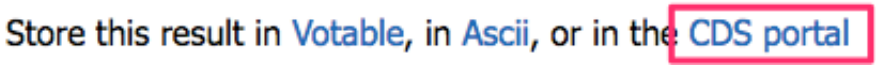
Submit query. 1638 objects match the criteria

Number of objects: 1638

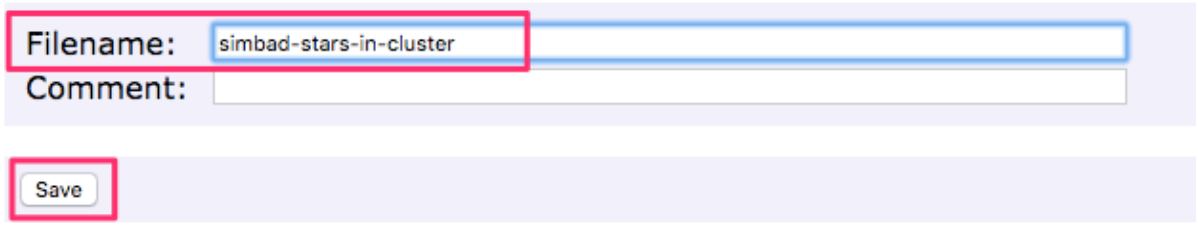
Go back to the query page, select Display and resubmit the query.



Go to the bottom of the result page, and store result in the CDS Portal

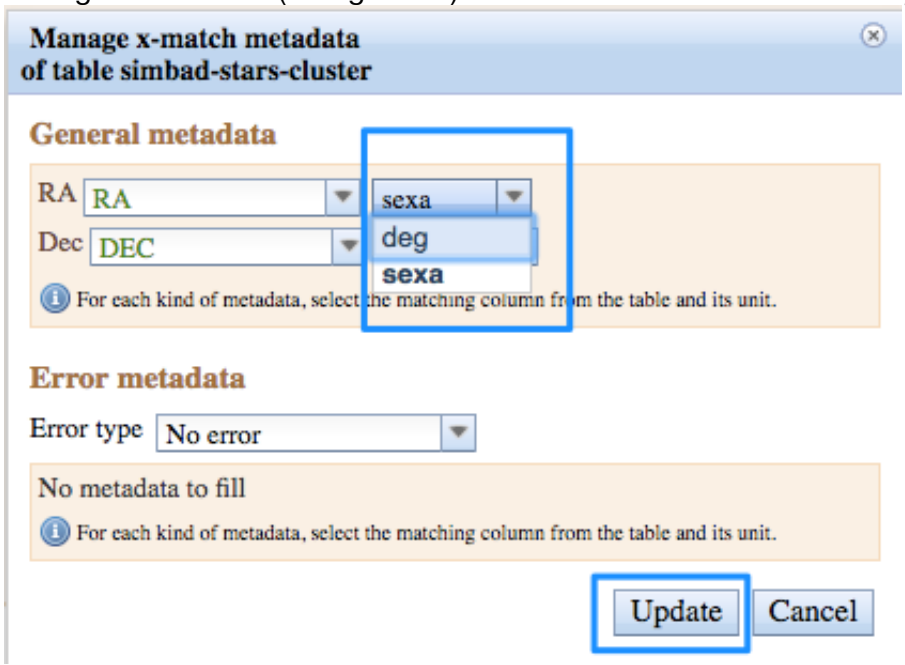


On the following page, change the filename and click on *Save*



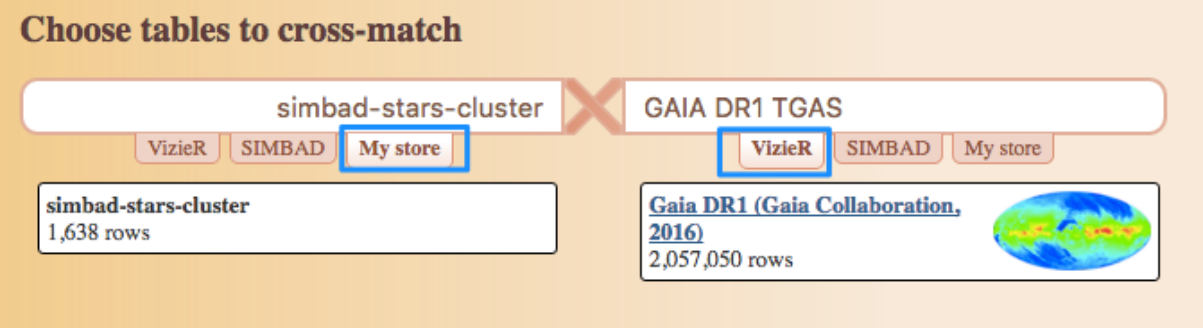
We can now use this result as input for the cross-match service.

Go to http://cdsxmatch.u-strasbg.fr/
At the top of the page, click on *Table management* and on *Add metadata* for the table we previously saved.
Change unit to *sexa* (sexagesimal) for both *RA* and *DEC and* click *Update*.

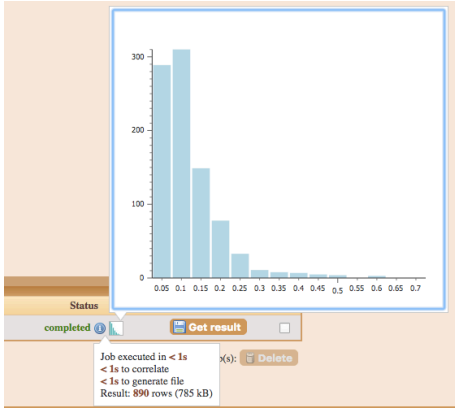


Go back to the 

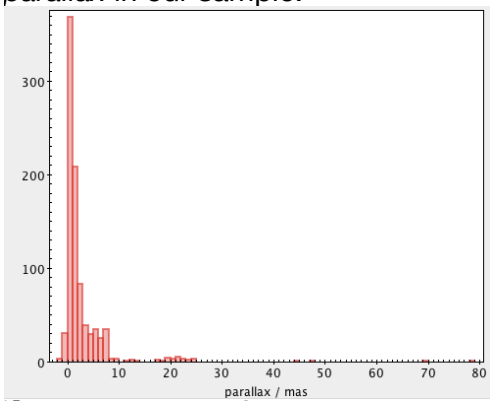
tab
Choose *simbad-stars-cluster* as the 1st table and *GAIA DR1 TGAS* as the 2nd one.



Open the *Options* panel, change *Radius* to *1 arcsec* and submit by clicking on *Begin the X-Match*
You can follow computation progress in the bottom table. Once the job is completed, click on the info icon to get a summary of the result and click on the histogram icon to see the distribution of distances for found associations.



Download the result as a VOTable, and load it in Topcat (*File —> Load table*)
Create an histogram (*Graphics —> Histogram Plot*) and visualize the distribution of the *parallax* in our sample.



4. Gaia data in Aladin Desktop

In this part, we will learn how to access to and visualize Gaia data from Aladin Desktop.

Launch Aladin with the following command:

```
java -Xmx1024M -jar Aladin.jar -beta
```

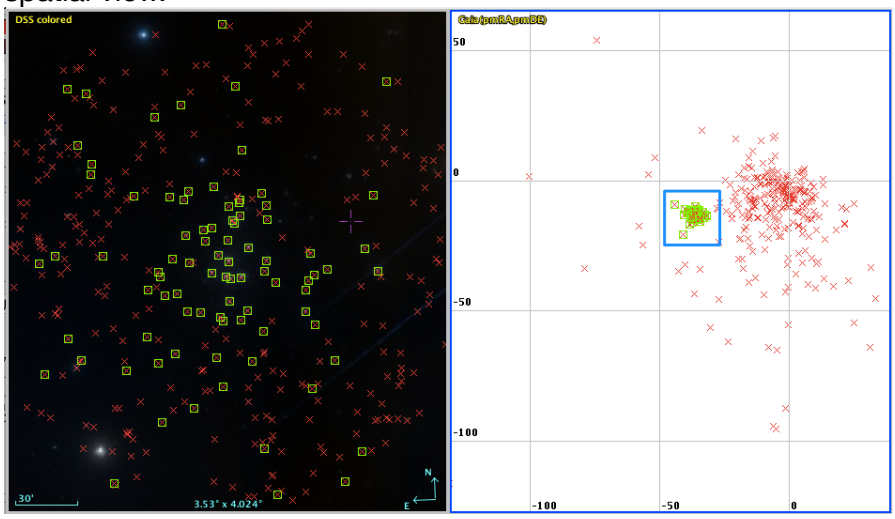
4.1 Visualize proper motion of Gaia stars in **Aladin Desktop**

In the location bar at the top of the main Window, type *Praesepe* and submit. Zoom out to see the whole open cluster
Open the server selector: menu *File —> Open*

Gaia DR1 can be accessed from a dedicated tab 

.
Click on the Gaia tab, change radius to *2°*, select table *I/337/tgasptyc* and *Submit*.

From menu *Catalog*, select *Create a scatter plot* and plot *pmRA* vs *pmDE.*
Stars which are member of Praesepe are clustered around *(pmRA=-35mas/yr, pmDE=-12mas/yr)*
Select these points in the scatter plot and notice they are automatically selected in the spatial view.



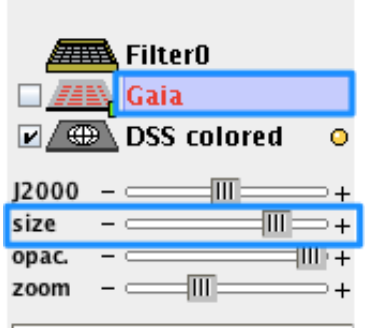
Go back to a single panel (menu *View —> Panels —> 1 panel)*

Create a filter by clicking on the icon 

and select the predefined filter *Draw proper motions of stars.*
To make the arrows bigger, switch to *Advanced mode* edit the filter as below and *Apply*:

```
{
  draw white plus
  draw pm(10*$[pos.pm;pos.eq.ra], 10*$[pos.pm;pos.eq.dec])
}
```

Size of arrows can also be controlled with a slider available in the stack after selecting the Gaia catalogue plane:



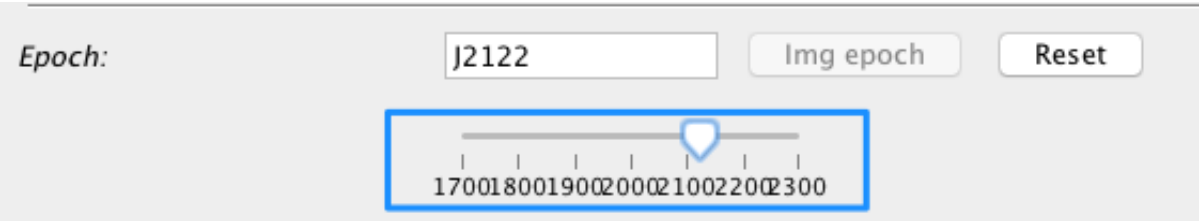
Select a few sources by drawing a rectangle. Associated measurements appear at the bottom of the window:

_RAJ2000	_DEJ2000	_V	TYC	HIP	Source	RA_ICRS	e_RA...	DE_ICRS	e_DE...	Plx	e_Plx	pmRA	e_pmRA	pmDE
129.6049097	21.2526305	VizieR	1398-1997-1		664744732785677056	129.6048809442	0.354	21.2526445233	0.12	1.68	0.89	-6.437	3.041	3.368
130.7211003	20.8192389	VizieR	1399-1306-1	42766	664845303740260992	130.7209334337	0.273	20.8191802958	0.164	5.31	0.31	-37.438	0.081	-14.054
130.7217203	20.8974635	VizieR	1399-1155-1		664849152030957056	130.7216811425	0.302	20.8974006679	0.149	2.35	0.84	-8.778	2.986	-15.071
130.9713256	21.1779188	VizieR	1399-1574-1		664861143579642752	130.971275802	0.211	21.1779127841	0.132	1.9	0.41	-11.153	1.292	-1.433
130.6370591	21.1788744	VizieR	1398-1797-1		664869905312917248	130.6370942179	0.384	21.1788399182	0.174	2.22	0.91	7.856	3.122	-8.279
131.1743821	21.1033794	VizieR	1399-1178-1		664879251161368832	131.1743508377	0.38	21.1033819252	0.574	2.34	0.67	-6.989	1.312	0.612
130.3687735	21.2281063	VizieR	1398-2317-1		664919589494596480	130.3687460395	0.412	21.2281753854	0.177	3.8	0.98	-6.133	3.325	16.587

As the catalogue contains positions, proper motions along with the epoch of observation, Aladin can compute the positions at a different epoch:

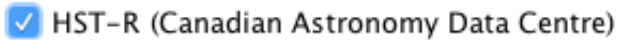
- select the Gaia plane and click on the icon 

to open the *Properties window*
- move the slider to visualize stars position at the corresponding epoch



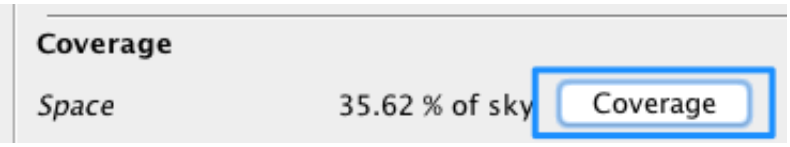
4.2. Retrieve Gaia sources within HST coverage

Goal: In this subsection, we will learn to use MOCs in order to retrieve Gaia data which are in the common coverage between HST and SDSS observations.

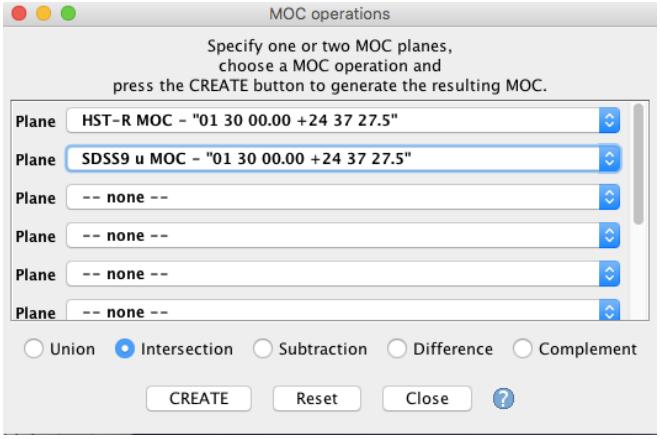
Open the server selector (*File —> Open*) and click on the HiPS tab. Expand the nodes *Image—>Optical—>SDSS* and select *SDSS9 colored*. Expand also nodes *Image—>Optical—>HST* and select *HST-R* 

Submit.
The 2 corresponding HiPS are loaded. For each HiPS plane:

- Right-click on its label, select *Properties*
- Click on *Coverage* to load the corresponding MOC



Open menu *Coverage —> Logical operations* , select the 2 MOCs and compute intersection.



The resulting MOC plane is the common coverage between SDSS9 and HST-R.
VizieR tables can be queried to retrieve only sources within a given MOC:

- open the server selector
- select the *MOC* tab, in the right hand panel
- select the MOC plane we just created
- enter following VizieR table ID: GAIA-DR1
- change maximum number of rows to *unlimited*
- submit

Zoom in and pan around to verify that returned rows fall into the MOC coverage.

5. Access to CDS cross-match service from Topcat : find Gaia and 2MASS couterparts for a list of sources and draw a color-color diagram

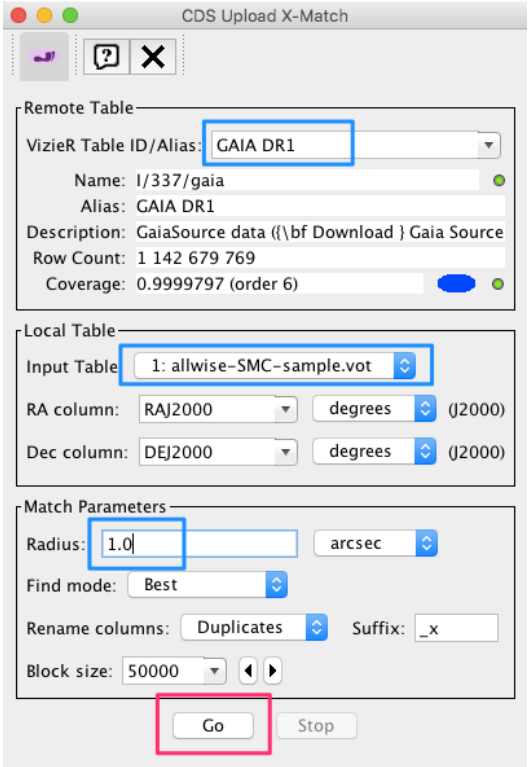
Download on your machine the table located at http://cds.unistra.fr/~boch/gaia-workshop-nov2016/data/allwise-SMC-sample.vot
It is a sample of 313k AllWISE sources located in the Small Magellanic Cloud.

Launch topcat:

```
java -Xmx1024M -jar topcat-full.jar
```

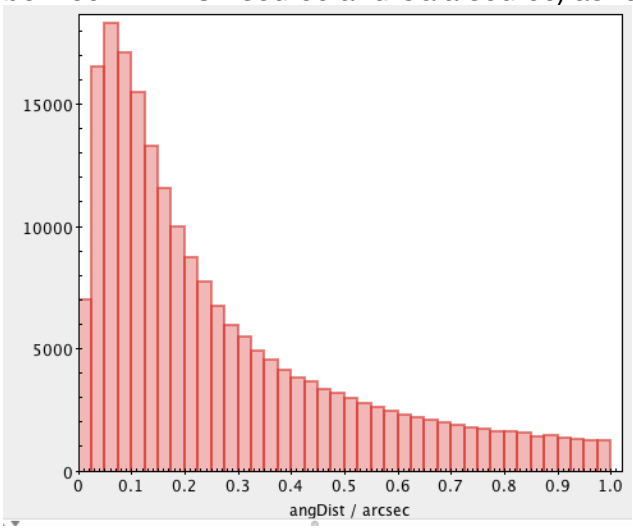
Load the table (*File —> Load Table*)

Open the *CDS X-Match* window from *VO —> CDS Upload X-Match*
Select *Gaia DR1* in the list of VizieR tables
Select *allwise-SMC-sample.vot* as the input table.
Set the match radius to *1 arcsec* and submit.

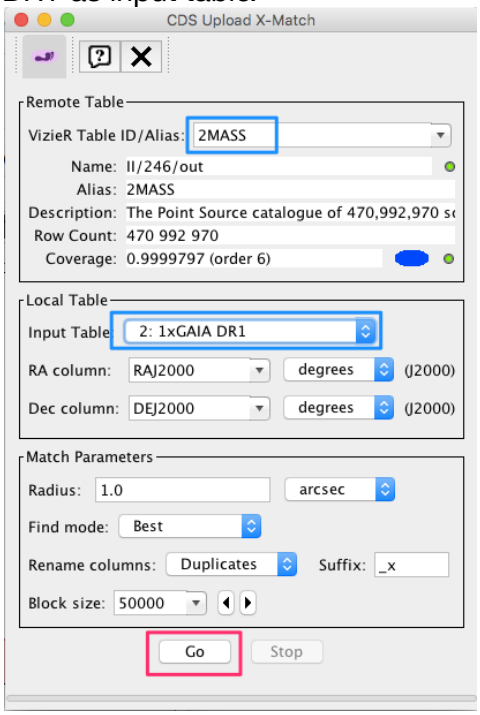


Once the cross-match is done, open the result table and notice that each row contains the fields of the original file plus the fields coming from the Gaia data.

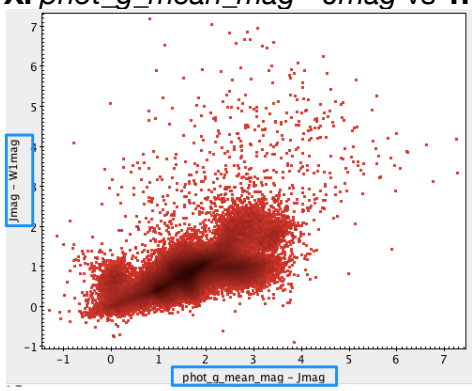
Click on icon  and create the histogram for column *angDist* (separation in arcsec between AllWISE source and Gaia source) as to assess the quality of the match.



In order to retrieve J, H, K magnitudes, we will now search for counterparts in 2MASS. Open the *CDS X-Match* window, select 2MASS in the list of VIzieR tables and *1xGAIA DR1* as input table.



We should retrieve 185,417 rows.
Create a scatter plot for this result (*Graphics —> Plane Plot*) and plot
X: *phot_g_mean_mag - Jmag* vs **Y:** *Jmag - W1mag*



6. More complex queries with **TAP VizieR**

6.1 Select high proper motions stars

Goal: retrieve 10 TGAS stars with higher proper motion near the galactic center

Go to TAP VizieR web interface: http://tapvizier.u-strasbg.fr/adql/

Search tables for the *Gaia* keyword.

Select *I/337/tgas* and click on Construct your query at the top right

Click on *Sky area* and enter *Galactic center* as cone center
Update radius to *5 deg, max records* to *10* and click on *Update query*
Click on *Quickview* to get a preview of the result

Edit the query to keep only source_id, ra, dec and compute total proper motion:

```
SELECT TOP 10 source_id, ra, dec, sqrt(pmra*pmra+pmdec*pmdec) as pm
FROM "I/337/tgas"
WHERE 1=CONTAINS(POINT('ICRS',"I/337/tgas".ra,"I/337/tgas".dec),
CIRCLE('ICRS', 266.416833, -29.007806, 5.))
```

Click on *Quickview* to get a preview

We still need to sort the result according to the proper motion value, using the `ORDER BY` clause.

The final query should look like this:

```
SELECT TOP 10 ra, dec, sqrt(pmra*pmra+pmdec*pmdec) as pm
FROM "I/337/tgas"
WHERE 1=CONTAINS(POINT('ICRS',"I/337/tgas".ra,"I/337/tgas".dec),
CIRCLE('ICRS', 266.416833, -29.007806, 5.))
ORDER BY pm DESC
```

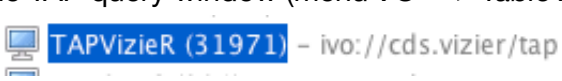
Click on *Run* to launch the query and retrieve the result in the requested format.

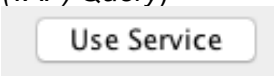
6.2 Recreate HR diagram from Gaia DR1 paper

Goal: we will recreate figure 3c of the Gaia Data release 1 paper
(https://arxiv.org/pdf/1609.04172v1.pdf)

Launch Topcat: `java -Xmx1024M -jar topcat-full.jar`

Open the TAP query window (menu *VO —> Table Acces Protocol (TAP) Query*)

Select 

and click on 

In the appendix of https://arxiv.org/pdf/1609.04172v1.pdf , table B.1 provides with the ADQL query used to create the HR diagram:

```
SELECT gaia.source_id, gaia.hip,
gaia.phot_g_mean_mag+5*log10(gaia.parallax)-10 as g_mag_abs,
hip.b_v
FROM gaiadr1.tgas_source as gaia
inner join public.hipparcos_newreduction as hip
on gaia.hip = hip.hip
WHERE gaia.parallax/gaia.parallax_error >= 5 and hip.e_b_v > 0.0
and hip.e_b_v <= 0.05 and
```

```
2.5/log(10)*gaia.phot_g_mean_flux_error/gaia.phot_g_mean_flux <=
0.05
```

This query is meant to be executed on GACS archive at ESA. A few changes must be made in order to make it work with TAP VizieR:

- In TAP VizieR, `gaiadr1.tgas_source` is named …
  and `public.hipparcos_newreduction` is named …
- columns `b_v` and `e_b_v` respectively are named `B-V` and `e_B-V`

As the dash is a special character in ADQL, the column name must be put between double quotes: `"B-V"` and `"e_B-V"`

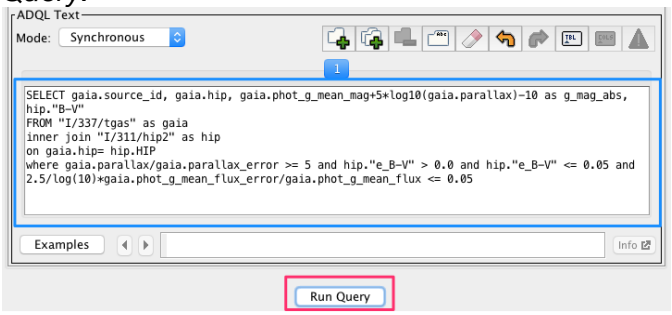
- column `hip` is named `HIP`

We will also add position fields ra and dec from TGAS

The updated ADQL query to be typed in Topcat is:

```
SELECT gaia.ra, gaia.dec, gaia.source_id,
gaia.hip, gaia.phot_g_mean_mag+5*log10(gaia.parallax)-10 as
g_mag_abs,
hip."B-V"
FROM "I/337/tgas" as gaia
inner join "I/311/hip2" as hip
on gaia.hip= hip.HIP
where gaia.parallax/gaia.parallax_error >= 5 and hip."e_B-V" > 0.0
and hip."e_B-V" <= 0.05 and
2.5/log(10)*gaia.phot_g_mean_flux_error/gaia.phot_g_mean_flux <=
0.05
```

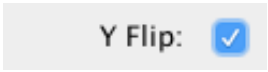
Copy/paste this query in the ADQL text panel, at the bottom of the window and *Run Query:*



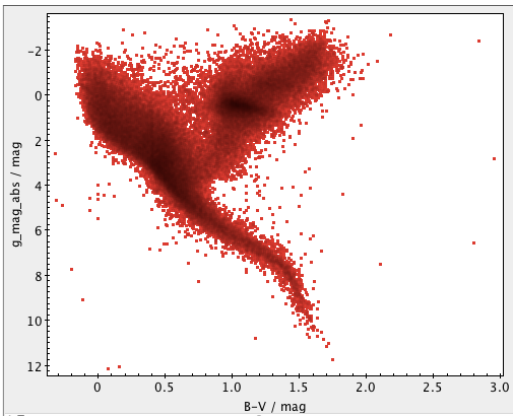
We should retrieve 74,817 sources.

Create a scatter plot (*Graphics —> Plane Plot*) and select *B-V* for **X** axis and *g_mag_abs* for **Y** axis.

Click on 

and flip Y axis 

.
Here is our HR diagram!



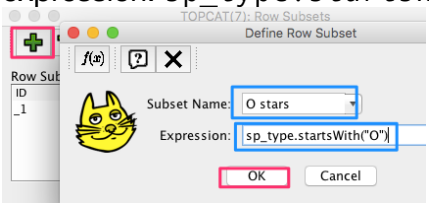
6.3 Retrieve spectral types from Simbad

We will now try to retrieve the spectral types of our sources, by querying Simbad through the CDS cross-match service.

Click on  , select *simbad* in remote table list.
Select *TAP_1_I_337_tgas,I_311_hip2* as input table and launch cross-match at 1 arcsec.

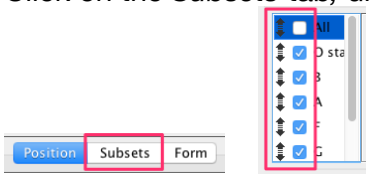
On the result table, we will create some subsets according to the spectral type of the star.

Click on  and define a new subet named *O stars* matching the following expression: `sp_type.startsWith("O")`

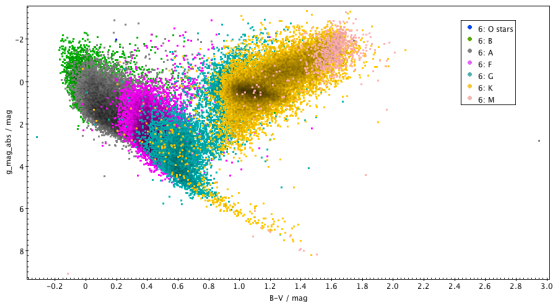


Repeat the same steps to create subsets for spectral types **B, A, F, G, K** and **M**.

Once the 6 spectral types have been created, plot the HR diagram following steps of section 6.2
Click on the *Subsets* tab, unselect *All* and select all 6 subsets:



You should end up with the following plot:



7. Accessing **CDS services** with **Python**

In this part, we will redo part of the previous sections, but in a programmatical manner, using Python.
A static version of the notebook is available at https://github.com/tboch/VO-access-GaiaDR1/blob/master/notebooks/gaia-cds-services.ipynb , providing examples on how to access Gaia data from CDS services.

If you want to modify the notebook and adapt queries to your own use cases, you can either:

- download the iPython notebook locally to run on your own laptop (requirements: *Python3* and libraries *astropy, astroquery, numpy, mocpy*).
- run it from mybinder. No need to install anything and you can still interact/update the notebook.