Tutorial :
Using the Lunar Craters Database from VESPA with ALADIN and TOPCAT

In this tutorial you will learn to :

- **create a 3D HEALPix view of the Moon from a global JPEG mosaic using ALADIN**
- **import a data catalogue from the VESPA portal to ALADIN**
- **display in ALADIN key information from a data catalogue that was imported from VESPA, on a 3D HEALPix view of the Moon**
- **use TOPCAT to process, plot and analyse data and data subsets**

1) Start TOPCAT and ALADIN

Nota: In this tutorial, the beta version of ALADIN shall be used. It is available at the following link: https://aladin.u-strasbg.fr/java/Aladin.jar

a) To launch ALADIN in beta mode, run the following command line at the terminal:

```
java -Xmx6g -jar Aladin.jar -beta
```

The 'Xmx6g' option is optional, but allocates to java enough memory to allow ALADIN to function normally.

b) Display a map of the Moon in ALADIN. For that (only in ALADIN beta) go to Collections > Solar System > Earth > Moon, then load for example 'Moon Lunar Recognition Orbiter WAC Global Morphologic Map' (first in the list).

Nota: With the official version of ALADIN (not the beta version), it is necessary to generate the HiPS of this lunar map. For this, the procedure is detailed at the end of this tutorial.

c) Switch the frame to 'Planet' and the projection to 'Spheric' (drop-down menus at the top right of the ALADIN window). It is possible to superimpose a grid of coordinates on the map by clicking on the 'grid' icon at the bottom left of the window.

2) Get data from VESPA and broadcast it to TOPCAT and ALADIN

a) Go to http://vespa.obspm.fr/

b) In 'Custom Service', look for
- Resource Url: http://voparis-cdpp.obspm.fr/tap
- Schema Name: lunar_crater_database

c) Select 'Query' (above the 'Custom Service' button), and look for craters larger than 60 km in diameter. Enter 'diameter > 60' in the ADQL query, then 'Submit' at the bottom. It will execute the following ADQL query:

'select * from lunar_crater_database.epn_core where diameter > 60'

d) Click on ‘lunar_crater_database’, then on ‘All metadata’ -> ‘Send Table’

e) In java, accept the data transfert via SAMP. Data should be then broadcast to TOPCAT and ALADIN. If not, then the SAMP hub may not be activated. In this case it has to be activated manually by clicking on the plug icon  at the bottom right corner of the main TOPCAT window.

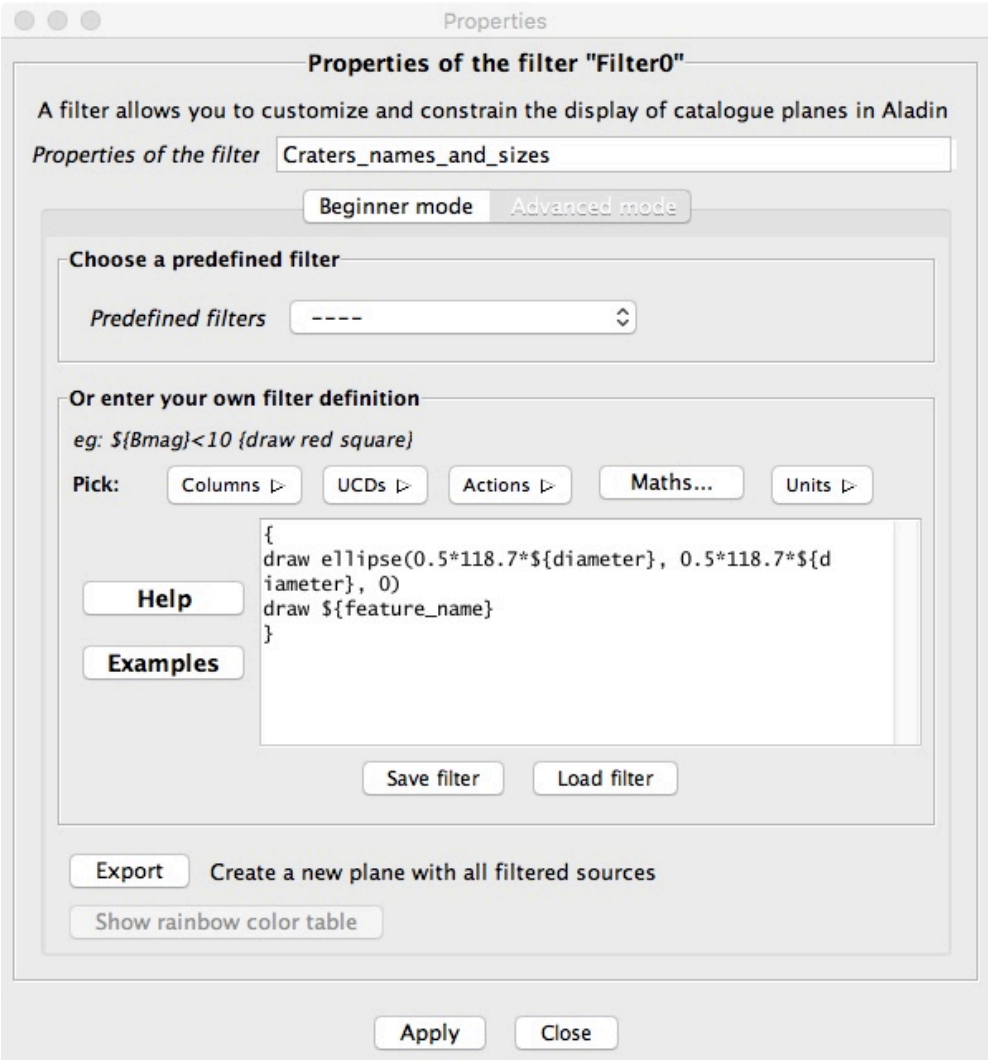
3) Display key information in ALADIN

a) It is possible to choose what information to display by adding filters. For example, start by displaying the name of each crater, and represent it by a circle corresponding to its diameter. For that, go to 'filter' 

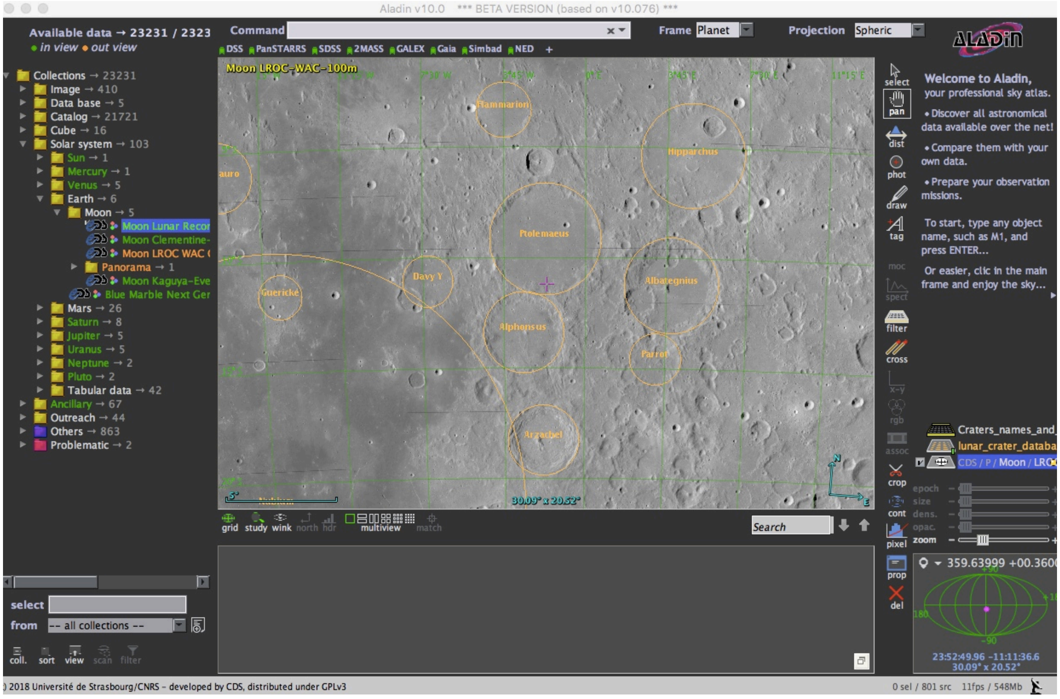
, on the right of the main ALADIN window, then go to ‘expert mode’ and copy-paste the following command (cf screenshots 1 et 2):

```
{
draw ellipse(0.5*118.7*${diameter}, 0.5*118.7*${diameter}, 0)
draw ${feature_name}
}
```

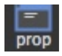
118.7 corresponds to the scale that is for the Moon 118.7 second of arc per km.



Screenshot 1

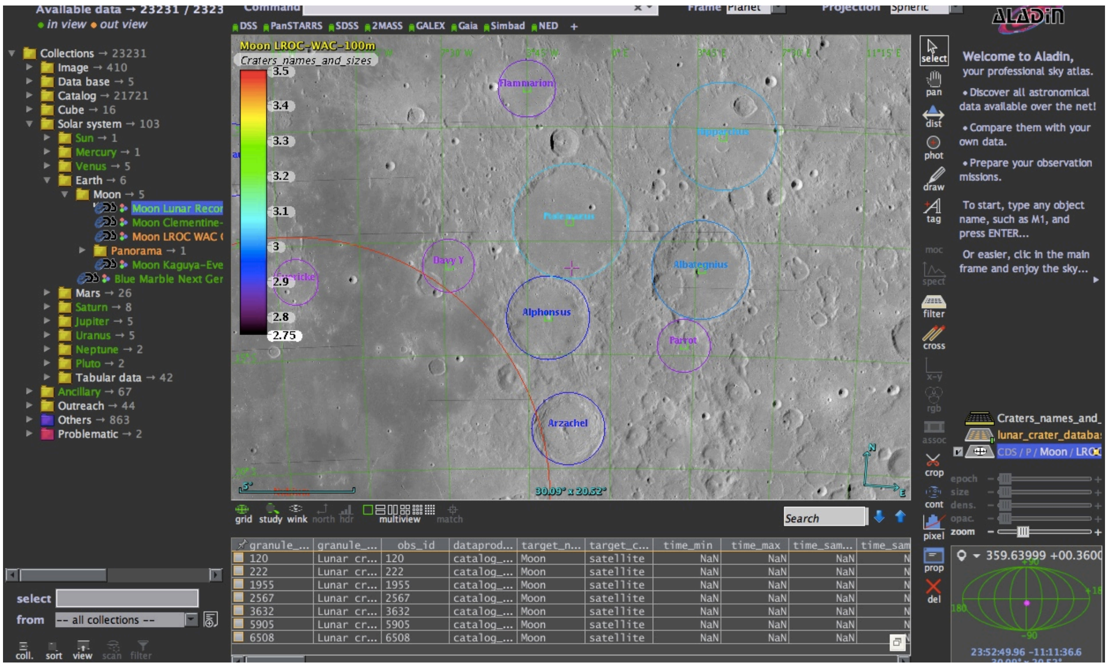


Screenshot 2

b) The color of these craters can then be coded according to their depth. For that, modify the created filter by selecting it in the images stack, click on properties  and paste the new following command:

```
{
draw ellipse(0.5*118.7*${diameter}, 0.5*118.7*${diameter}, 0) rainbow(${apparent_depth},2.75,3.5)
draw ${feature_name} rainbow(${apparent_depth},2.75,3.5)
}
```

2.75,3.5 is the color scale, and is optional. If left empty, ALADIN will automatically adjust the color scale to the maximum and minimum of the selected column ('apparent_depth' in this case).



Screenshot 3

c) It is possible to display the color scale by clicking on the 'show color table' button in the window defining the filter's properties.

d) The select tool at the top right of the display area then allows to display information concerning craters desired below the image (cf screenshot 3).

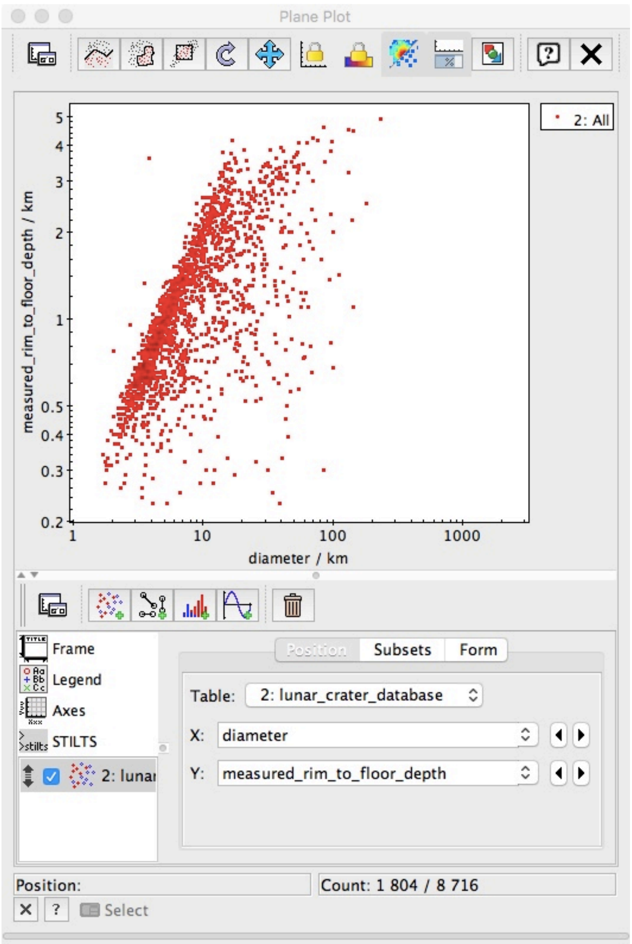
4) Data analysis with TOPCAT

/ First analysis: plot of the depth of the crater versus the diameter, measurements and models.

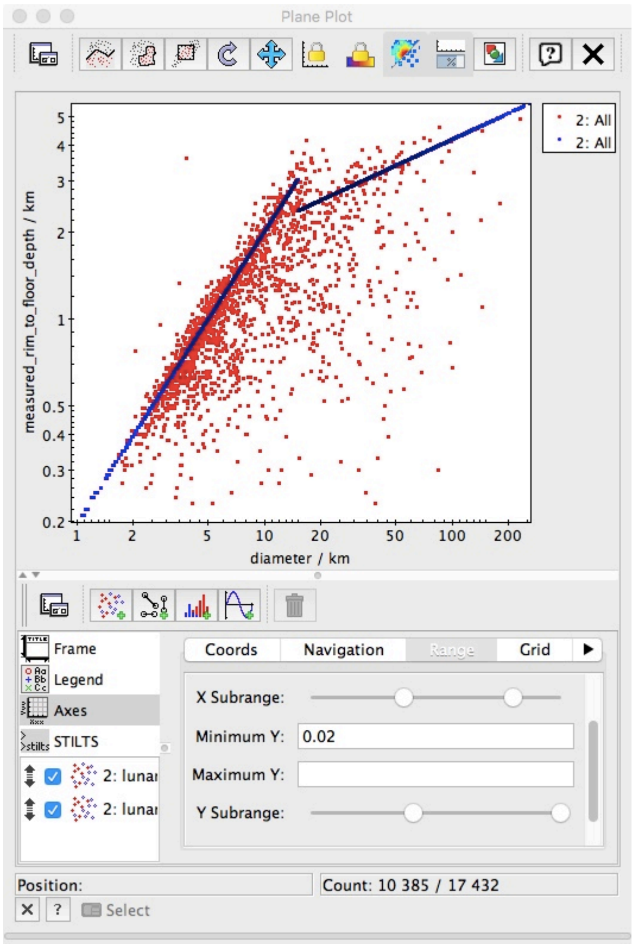
a) On the VESPA portal, start by recovering all the data (and not anymore craters larger than 60 km in diameter). To do this, simply delete the ADQL query 'diameter> 60' and resubmit the form. Then again, 'all metadata -> send table'.

NOTA: This new, more complete table is also sent to ALADIN. We then see that the filter defined in the previous step includes these new craters. To preserve the previous filter, simply add the condition '$ {diameter}> 60'. The filter becomes:

${diameter}>60
{
*draw ellipse(0.5*118.7*${diameter}, 0.5*118.7*${diameter}, 0) rainbow(${apparent_depth}, 2.75,3.5)*
draw ${feature_name} rainbow(${apparent_depth},2.75,3.5)
}
To edit a filter, select it and click on 'properties'.



Screenshot 4



Screenshot 5

b) The new table also appears in TOPCAT. It has the same name 'lunar_crater_database' as the previous one, but has more lines. It is possible (optional) to delete the first one using 'file -> discard table'

c) In TOPCAT, select the table containing all the lines (the last one added), then open a plane plot window (icon 'plane plot' or graphic -> plane plot) 

d) Plot the measured rim to floor depth versus diameter (see screenshot 4).

e) Add a new plot: 'add a new positional plot control to the stack' 

f) Plot the modeled rim to floor depth (column 'rim_to_floor_depth') versus crater diameter (see screenshot 5).

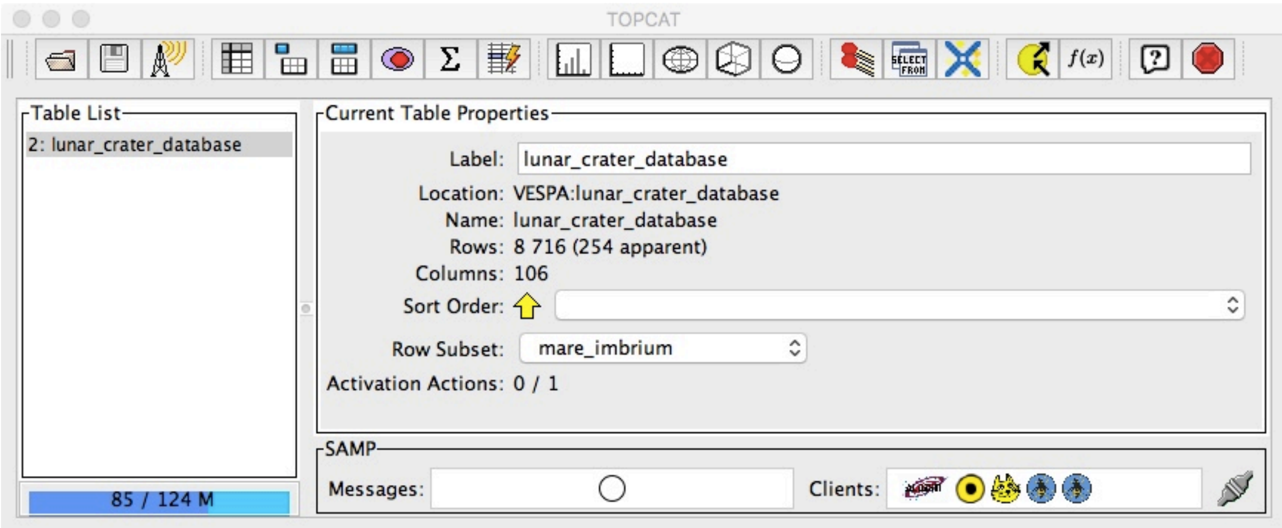
g) Adjust the axes if necessary.

// Second analysis: density of craters in two different lunar regions.

The aim is to compare the crater density between Mare Imbrium and a more craterised plateau.

First, in TOPCAT, select the craters belonging to each of the regions. Mare Imbrium is a large impact basin centered on the coordinate point (32.8 ° N, 15.6 ° W), with a diameter of 1145 km. We therefore choose a region of 1145 km in diameter centered on this point by calculating the distance around a great circle (or Haversine). This equation, which defines the distance between two points of respective latitudes $lat1$ and $lat2$ and longitudes $lon1$ and $lon2$ on a sphere of radius R as:

$$D = R \arccos(\sin(lat1) \cdot \sin(lat2) + \cos(lat1) \cdot \cos(lat2) \cdot \cos(lon2 - lon1))$$



Screenshot 6

This equation is already included in TOPCAT as the skyDistanceDegrees function. In the Lunar Crater Database, latitude and longitude are stored respectively in the c2min and c1min columns. To select craters inside Mare Imbrium, the equation becomes:

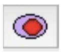
$$\frac{1145}{2} = R_{Moon} \arccos(\sin(32.8°) \cdot \sin(c2min) + \cos(32.8°) \cdot \cos(c2min) \cdot \cos(c1min - (-15.6°)))$$

Or alternatively

$$\frac{1145}{2} > skyDistanceDegrees(c1min, c2min, -15.6, 32.8) \times \frac{10921}{360}$$

Where 10921 is the lunar equatorial perimeter.

a) In TOPCAT, create a new subset:

- ‘display row subsets’ 
- ‘define a new subset using algebraic expression’ .

Subset name: mare_imbrium
Expression: 1145./2 > skyDistanceDegrees(c1min, c2min, -15.6, 32.8) * 10921/360

b) Send the selection to display in ALADIN: select ‘mare_imbrium’ in the ‘current table properties’ window of TOPACT (see screenshot 6) and click on the ‘transmit table to all applications using SAMP’ icon 

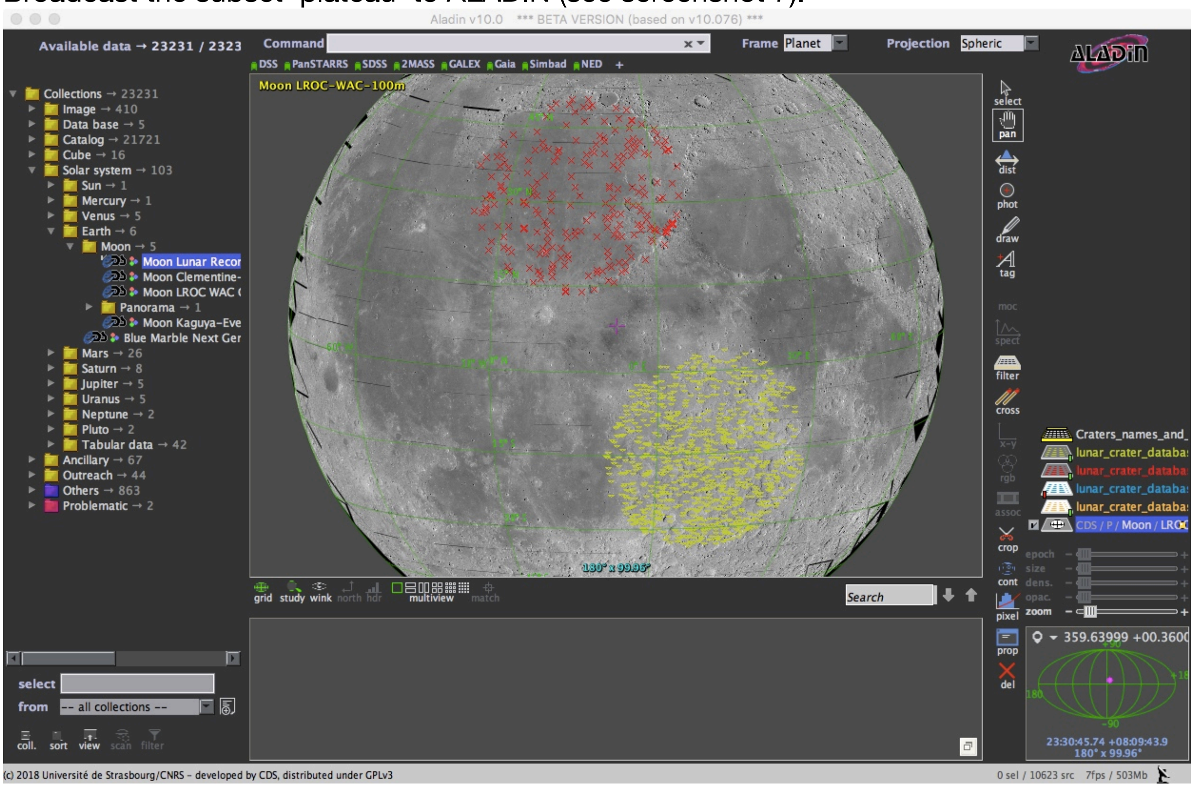
Nota: The previously created filter can mask the selection if still active. Click on it on the image stack to hide it .

c) In TOPCAT create a geographical selection of craters the same size as Mare Imbrium in the high plateau, for example centered on (15°S, 10°E):

- ‘display row subsets’ 
- ‘define a new subset using algebraic expression' .

Subset name: plateau
Expression: 1145./2 > skyDistanceDegrees(c1min, c2min, 10, -15) * 10921/360

d) Broadcast the subset ‘plateau’ to ALADIN (see screenshot 7).



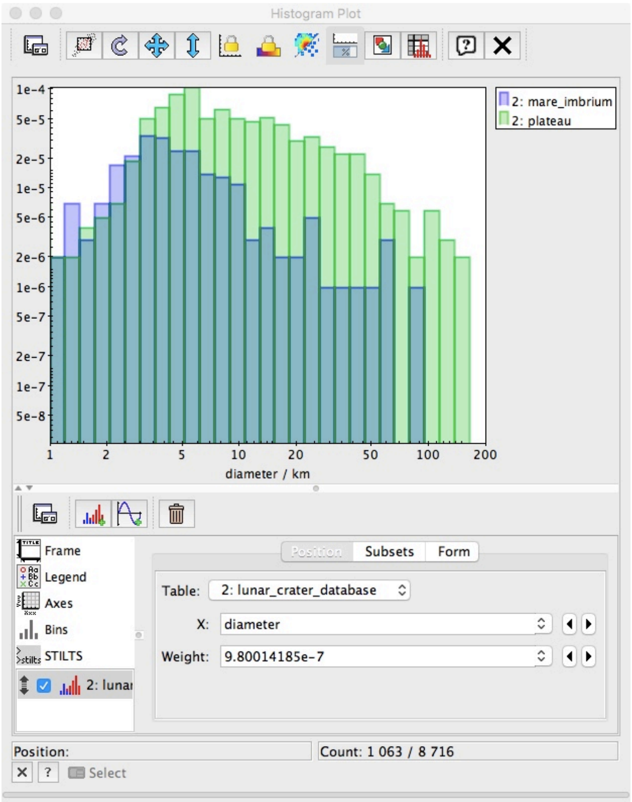
Screenshot *7*

e) Plot the crater density as a function of the crater size for both regions, in a histogram plot (see screenshot 8):

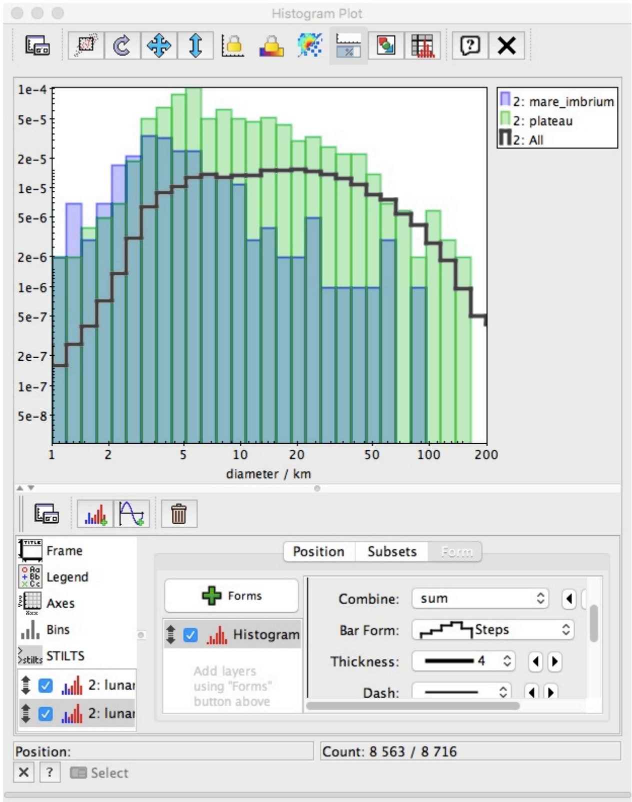
Open a new histogram plot window 
Table: lunar_crater_databas
X: diameter
weight: 9.80014185e-7

To get a crater density per square kilometer, the weight has to be the inverse of the area A considered. Here, $A = 2\pi R_{Moon}^2 \left(1 - \cos \frac{D}{R_{Moon}}\right)$

f) In 'the Subsets' tab, un-select 'all' and select 'mare_Imbrium' and 'plateau' to display their histograms. Adjust if necessary (xlog, ylog, bin size).

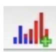


Screenshot 8



Screenshot 9

g) It is also possible to add to this plot the histogram corresponding to all the craters of the Moon. However, selecting 'all' in the subset tab is not appropriated because a different weight needs to be applied to the global data, as the area considered is the whole Moon: $S_{Moon} = 3.793 \times 10^7$ km^2. A new plot has to be added to the window

Add a new histogram plot to the current window 
Table: lunar_crater_database
X: diameter
weight: 2.63643554e-8

h) In the ‘subsets’ tab, check that ‘all’ is the only subset selected. The view can be adapted in the ‘form’ tab (see screenshot 9)

III Crater density for craters larger than 4 km

The aim here is to count only craters larger than 4km in diameter. The first step is then logically to create a new subset containing all the craters larger than 4km in the database, which will be crossmatched with the previously created subsets.

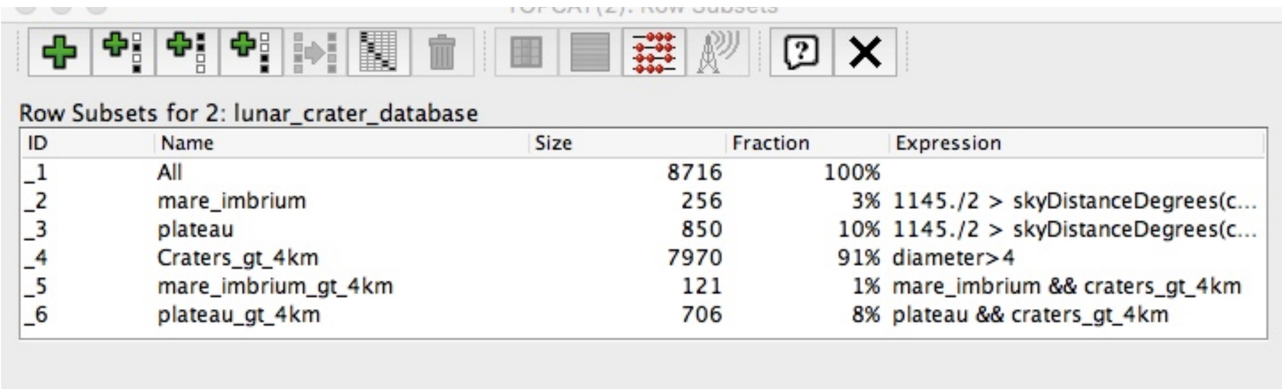
a) Create a new subset: ‘display row subsets’ then ‘define a new subset using algebraic expression’.
Subset name: craters_gt_4km
Expression: diameter>4

b) Create a new subset: ‘display row subsets’ then ‘define a new subset using algebraic expression’.
Subset name: mare_imbrium_gt_4km
Expression: mare_imbrium && craters_gt_4km

c) Create a new subset: ‘display row subsets’ then ‘define a new subset using algebraic expression’.
Subset name: plateau_gt_4km
Expression: plateau && craters_gt_4km

d) It is possible (optional) to broadcast these subsets to ALADIN for display, by selecting the subset in the main TOPCAT window and clicking on ‘transmit table to all applications using SAMP’.

The number of craters larger than 4 km are directly displayed in the TOPCAT subsets window (see screenshot 10)



Row Subsets for 2: lunar_crater_database

ID	Name	Size	Fraction	Expression
_1	All	8716	100%	
_2	mare_imbrium	256	3%	1145./2 > skyDistanceDegrees(c...
_3	plateau	850	10%	1145./2 > skyDistanceDegrees(c...
_4	Craters_gt_4km	7970	91%	diameter>4
_5	mare_imbrium_gt_4km	121	1%	mare_imbrium && craters_gt_4km
_6	plateau_gt_4km	706	8%	plateau && craters_gt_4km

Screenshot 10

Dividing the number of craters by the area A of each region gives the respective densities for Mare Imbrium and the selected plateau region:

$D_{Imbrium} = 1.2 \times 10^{-4}$ km^{-2}

$D_{plateau} = 6.9 \times 10^{-4}$ km^{-2}

They can be added for comparison to figure figure 1, from Heiken et al. 1991, Lunar Sourcebook: A User's Guide to the Moon (http://adsabs.harvard.edu/abs/1991QB581.L766.....) :

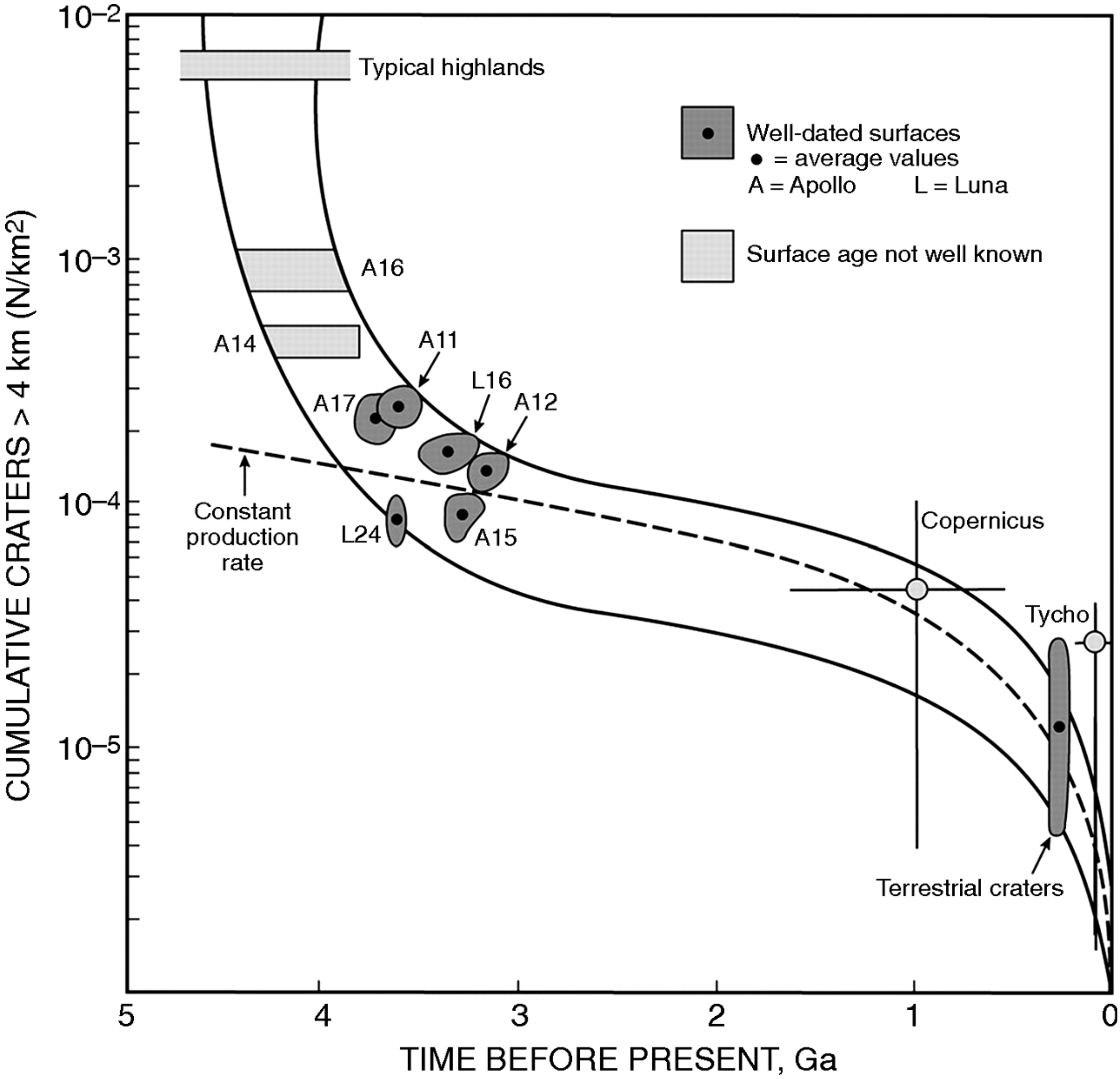


Figure 1 : Number of craters larger than 4 km in diameter per square kilometer as a function of surface age on the Moon, from Heiken et al. 1991, Lunar Sourcebook: A User's Guide to the Moon *http://adsabs.harvard.edu/abs/1991QB581.L766.....)*

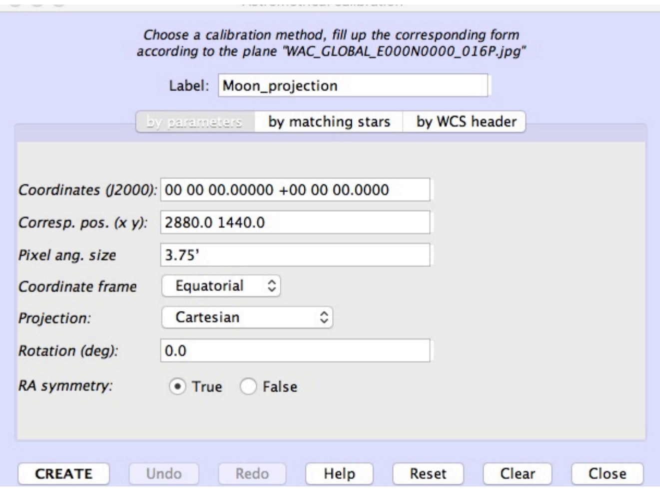
Additional step, in case of use of the official version of Aladin, which does not support the projection on Solar System objects: preparing a support in Aladin to display the data

a) Get a lunar map from LROC (http://lroc.sese.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/EXTRAS/BROWSE/WAC_GLOBAL/WAC_GLOBAL_E000N0000_016P.TIF) 16 px/deg —> 5760 × 2880 px

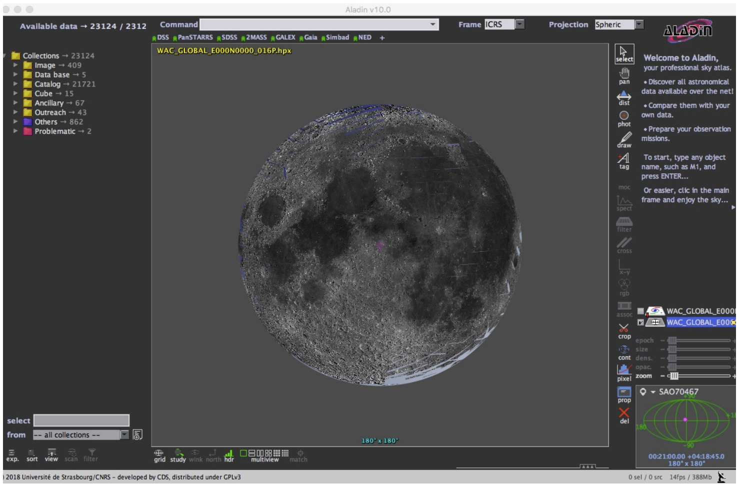
b) Convert image to jpg (convert WAC_…016P.TIFF WAC_…016P.jpg, or in the image viewer using ‘save as’ or ‘export’ functions)

c) Load in ALADIN as a local file (Edit -> load local file)

d) The official version of ALADIN does not support the representation of planets or satellites. The best solution is to choose the ICRSd repository, which displays a grid in degrees. The overlays generated later will normally work but the grid displayed by Aladin (grid icon at the bottom left of the image) will be false in longitude.



Screenshot 11



Screenshot 12

e) To create a HiPS ALADIN needs information:
- image -> astrometrical calibration (cf screenshot 11)
- fill as follows (3.75’=360*60/5760)
Corresp. Pos. (x y) : 2880 1440
Pixel ang.size : 3.75’
Coordinate frame : Equatorial
Projection : Cartesian
Rotation : 0
RA Symmetry : True

- —> CREER

f) Tools > Generate a HiPS based on… > the current image

g) Switch to spheric projection (on the top right of the main ALADIN window (see screenshot 12)