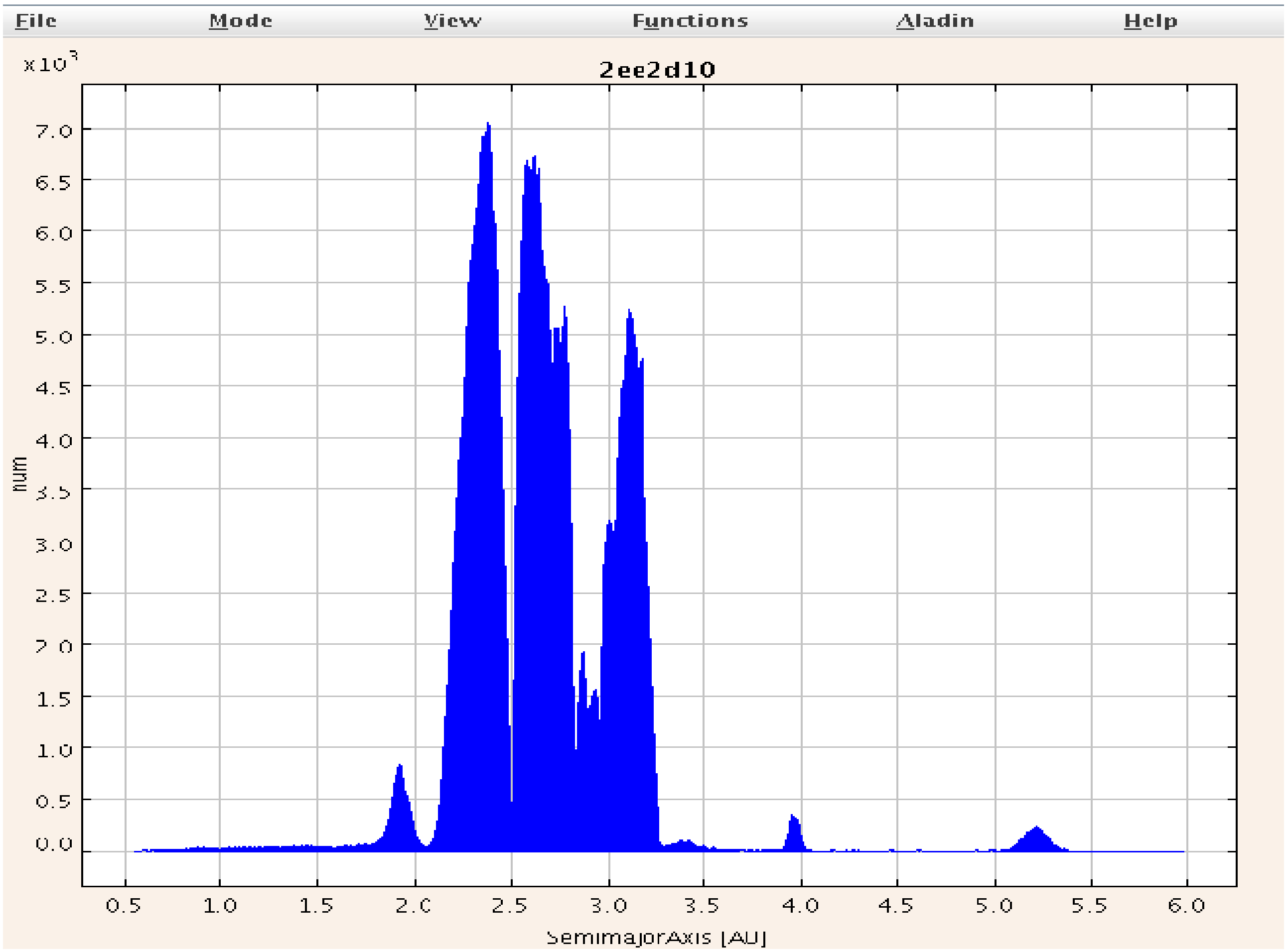
Example for the
usage of the
Virtual Observatory

The asteroids

Information and contacts: **http://vo-for-education.oats.inaf.it** - **iafrate@oats.inaf.it**



Florian Freistetter, ZAH, Heidelberg
florian@ari.uni-heidelberg.de

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Within this use case you learn about asteroids, a very interesting and actual topic in view of the exploration of the solar system and of the study of planet formation. You find the main characteristics of their orbits by querying asteroid databases and determine their distribution within the solar system

If used in the classroom thid use case os of intermediate difficulty requiring the (guided) query of online electronic databases and rather extended use of histograms.

Asteroids in the solar system

There are not only planets in our solar system. There are also many asteroids – a leftover from the times of planet formation.

Initially, our Sun was surrounded by a large disk of gas and dust. The particles in the disc collided with each other and formed larger and larger objects, resulting in the planets we know today. But not all pieces were used to build planets. In the outer regions of our solar system no large planets were formed and in the inner parts it was the large Jupiter who circumvented the formation of additional planets close to its orbit.

Those remaining pieces of planet formation are the objects we today call „asteroids“. The first one was discovered in 1801 and astronomers first thought it was a new planet between the orbits of Mars and Jupiter. But in the following years one found more and more such „planets“ in the same region, so that it was evident that this „planets“ are a different kind object – the „planetoids“ or „asteroids“ as they were then called.

Today we know about some hundred thousand asteroids between the orbits of Mars and Jupiter – they form the so called „asteroid belt“ or „main belt of asteroids“. But asteroids can be found also in other places in the solar systems. In 1992 one found an asteroid orbiting outside the orbit of Neptune. It was the first object of the „Kuiperbelt“ - a much larger belt of asteroids than the one between Mars and Jupiter.

Due to the dynamical interaction between asteroids and planets, some asteroids were scattered away from their belts and thus we can find asteroids almost anywhere in the solar system.

All data concerning asteroids are administrated by the *Minor Planet Center (MPC)* of the *International Astronomical Union (IAU).* (http://www.cfa.harvard.edu/iau/mpc.html). They archive and analyze all observations of asteroids, calculate their orbits and publish them for the scientific community. The IAU also decides on how the asteroids are named.

The large database of the MPC can be accessed via the Virtual Observatory and it is thus possible to use this data to learn about the basic properties of asteroids.

The database of the MPC

The complete MPC-database can be accessed via the German Virtual Observatory (GAVO):

http://dc.zah.uni-heidelberg.de/mpc/q/pla/form

This form can be used to search the database for the most common parameters. These includes the orbital elements, that are the numbers that define the shape and position of the asteroid orbits around the Sun.

The **semimajoraxis a** of the asteroids defines how large the ellipse of the orbits is, or, in other words, how far it will be from the Sun on the average. It is measured in astronomical units (AU) where one AU is the average distance between Sun and Earth.

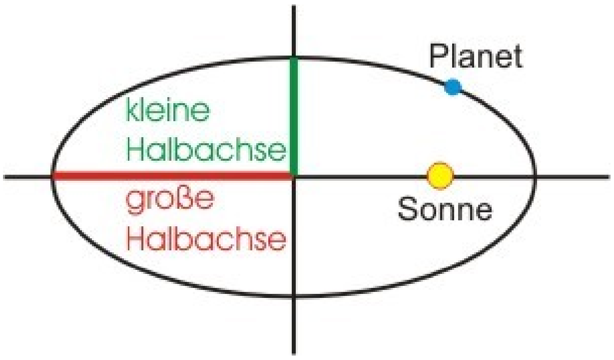


Figure 1: Semimajor Axis

The deviation of the ellipse from a perfect circle is measured by the **eccentricity e**. It is a number between 0 and 1 where 0 would describe a circle.

Semimajor axis and eccentricity describe the size and shape of the orbit. One now needs three angles to describe the orientation and position of the orbit in space.

The first one is the **inclination i**. It describes how much the orbit is inclined with respect the ecliptic. The ecliptic is the reference plane in the solar system and corresponds with the average orbital plane of the Earth.

The **longitude of the ascending node** (**Ω**)**.** is the second angle. One calls the point where the orbit passes the ecliptic from North to South *descending node*. The point where the orbit passes the ecliptic plane from north to south is the *ascending node*. The angle between the line connecting *Sun* and *ascending node* and the line connecting *Sun* and *vernal point* is called the l*ongitude of the ascending node*. Note that the vernal point is the reference point for the astronomical equatorial coordinate systems.

The **argument of perielium (ω)**. is the third angle. It is the angle between the line connecting the *Sun* and the *perielium of* the orbit (the point closest to the Sun) and the line connecting *Sun* and *ascending node*.

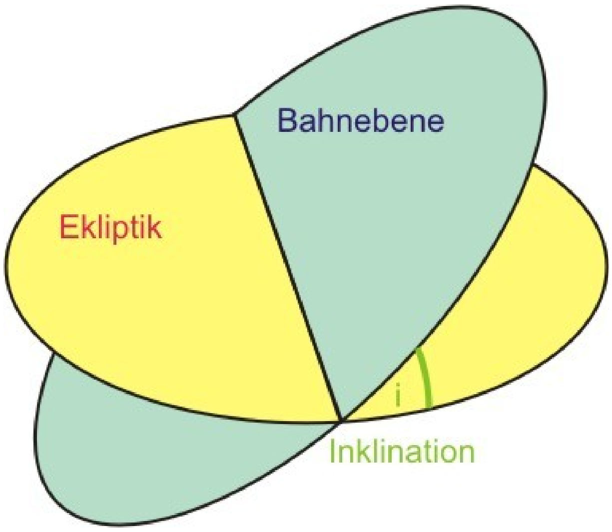


Figure 2: Inclination

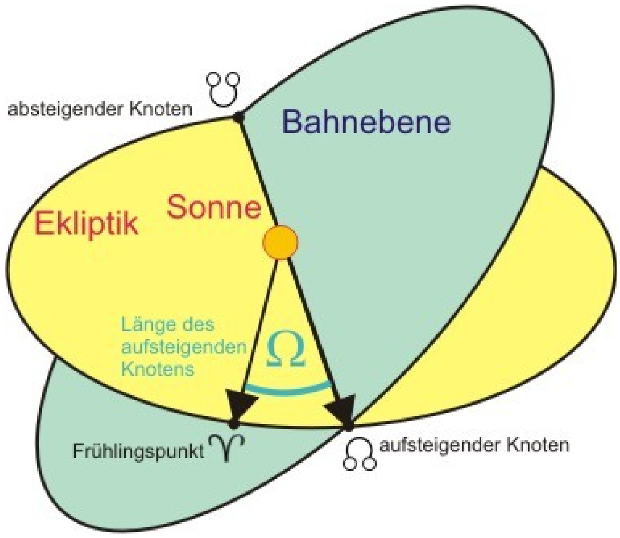


Figure 3: Longitude of the ascending node

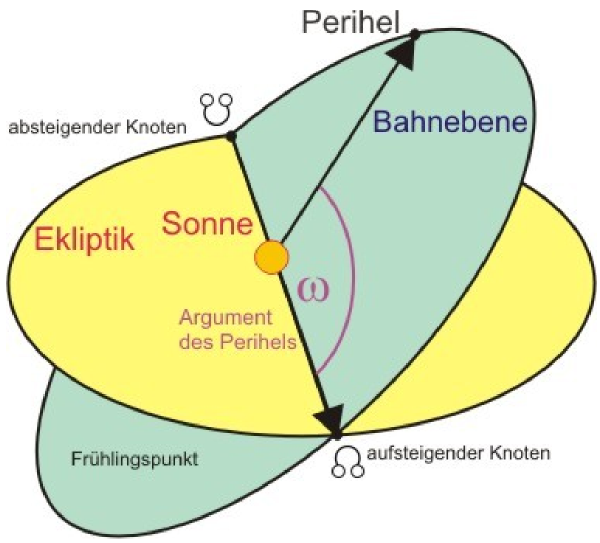


Figure 4: Argument of Perihel

Those three angles (i, Ω, ω) uniquely define the position of the orbital ellipse in space. But there is still one parameter missing: we need a number to define the *position of the object* along its orbit!

There are different possibilities; most common is the use of the mean anomaly. To define the mean anomaly, one uses a „mean object" that has the same orbital period as the real object and also passes the perielium at the same time. But the mean object moves with a constant (angular) velocity along a circular orbit with a radius equal to the semimajor axis of the real object.

The angle between the line connecting the *center of the circle* and the *mean object* and the line connecting the *center of the circle* and the *perielium* is called mean anomaly.

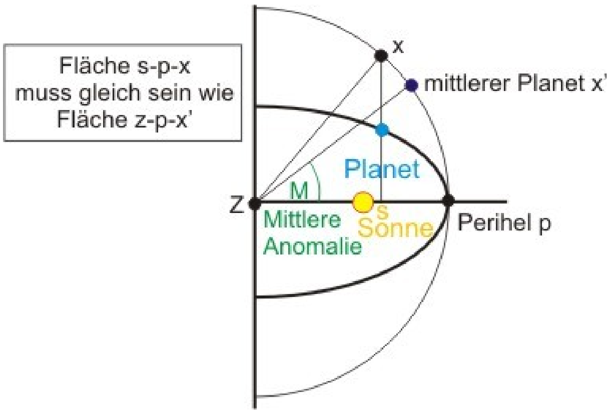


Figure 5: Mean Anomaly

The Database of the MPC can be searched for all this parameters; additionally one can search for the *epoch* (the time when these values were determined) and the *magnitude H* of the object.

The distribution of asteroids in the solar system

One of the first question that can be answered with the database is: where are the asteroids in our solar system and how are they distributed? Although the main belt of asteroids between Mars and Jupiter is most commonly known, there are asteroids also in other regions. This can be checked easily. Mars has a mean distance from the Sun of 1.52 AU; Jupiter of 5.2 AU – in between is the main belt of asteroids.

We now can search for asteroids with semi major axes between 6 and 7 AU. Are there such objects outside the main belt?

To find out, we enter

6 .. 7

in the field for the semimajor axis in the form (do not forget the spaces before and after the dots!). This selects all objects from the database with semimajor axis between 6 and 7 AU (if you click the link on the right of the field, you get detailed information on what you can enter there).

Figure 6: Help

At the end of the form, we select „HTML" as *Output Format* which will display the results directly in the browser. The field „Sort by" allows us to sort the output and with „Limit to" we can set an upper limit to the number of results (for now, we can leave both fields unchanged).

Clicking on „Go" starts the database query and displays the results:

Designation	H [mag]	G	Epoch	M [deg]	w [deg]	W [deg]	i [deg]
37117	13.2	0.15	K096I	169.277	180.095	248.605	13.7859
E5627	11.1	0.15	K096I	10.0591	344.811	94.875	18.6956
K04RE1W	14.4	0.15	K096I	102.785	157.11	164.272	7.67171
K05C16R	14.0	0.15	K096I	105.375	313.267	140.132	9.38849
K05V00D	14.2	0.15	K096I	68.0015	178.272	173.037	172.912
K05W03Y	13.5	0.15	K096I	28.8802	309.222	190.233	29.4105
K07D50P	14.6	0.15	K096I	35.7633	153.446	36.7728	3.06425
K07H45U	15.8	0.15	K096I	34.7416	45.4958	197.806	5.8942
K09B80L	16.3	0.15	K096I	14.4312	8.09372	93.7242	9.02906
K09D02P	14.0	0.15	K093A	15.3702	126.428	0.79999	26.9995

Figure 7: Database query

There are 10 asteroids with a distance between 6 and 7 AU in the database. So there really are asteroids outside the asteroid belt. This can be made more clear, if one plots a diagram showing the distribution of the asteroids in the solar system.

One could obtain all entries of the database and use an external program to plot a histogram. But the virtual observatory offers a more direct method to get a histogram: the usage of the *„Astronomical Data Query Language“ (ADQL),* a variation of the more popular database language SQL.

To formulate a ADQL-Query, we go to the respective form:

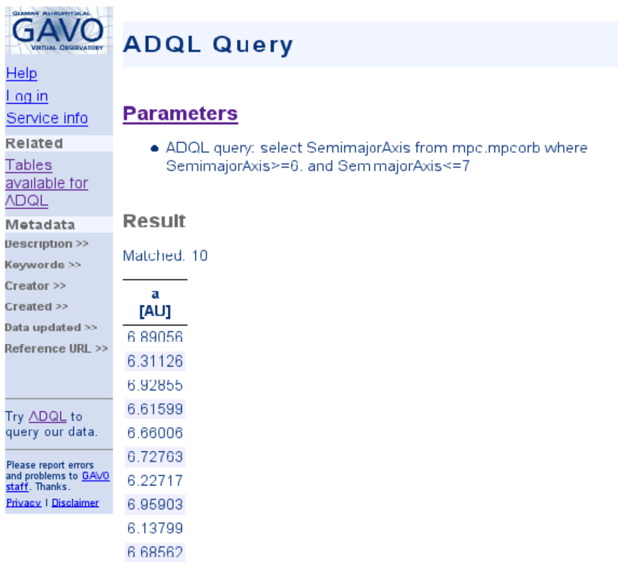
http://dc.zah.uni-heidelberg.de/__system__/adql/query/form

Here we can enter various ADQL commands. The syntax is simple – a detailed description can be found here: http://www.ivoa.net/Documents/latest/ADQL.html

To repeat the former search in ADQL, we can use this command:

select SemimajorAxis from mpc.mpcorb where SemimajorAxis>=6. and SemimajorAxis<=7

select X from Y chooses a certain parameter X (in our case the semimajor axis) from the database Y (which is called *„mpc.mpcorb“*)[1]. Since *select X from Y* would deliver ALL entries from the database, we restrict the query with *where SemimajorAxis>=6. and SemimajorAxis<=7* and thus obtain only asteroids between 6 and 7 AU. The result are the same 10 asteroids as before:



a [AU]
6.89056
6.31126
6.92855
6.61599
6.66006
6.72763
6.22717
6.95903
6.13799
6.68562

Figure 8: ADQL-query

To obtain a histogram, we have to proceed as follows: first, we round the values for the semimajor axis up to two decimal places. So, instead of *select SemimajorAxis* we choose *select round(SemimajorAxis,2)*. Then we group similar values for the semimajor axis and count how many objects fall in every group. The complete ADQL command now reads:

select count(*) as num, ii from
(select round(SemimajorAxis,2) as ii from mpc.mpcorb where SemimajorAxis>=0 and SemimajorAxis<=50)
as q group by ii
order by ii

1 You can find the internal names of all parameters here: http://dc.zah.uni-heidelberg.de/__system__/dc_tables/show/tableinfo/mpc.mpcorb

As borders for the semimajor axis we chose the region between 0 and 50 AU – the whole planetary region of the solar system. The query delivers a long list of numbers:

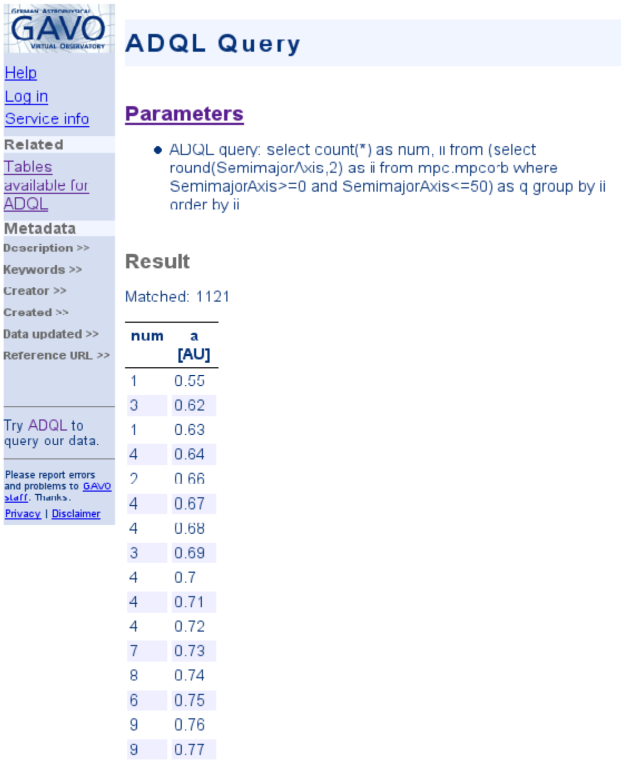


Figure 9: ADQL-query

It would be much better to get a graphical representations. Therefore we change the „Output Format“ to „*VOPlot*“.

We now get the following graphic as a result:

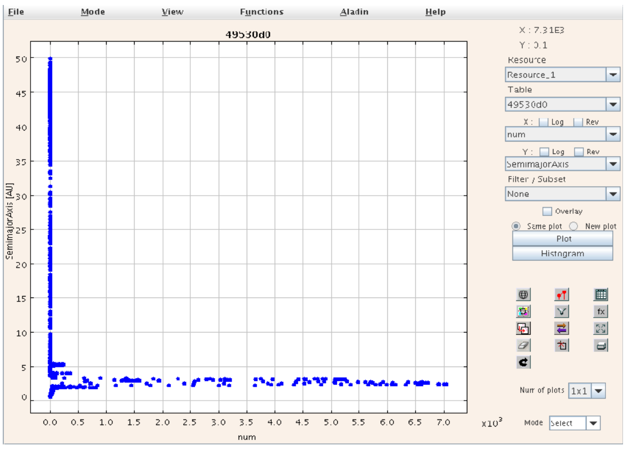


Figure 10: Graphics with VOPlot

It still looks not very instructive, thus we modify the diagram. First, we switch the x and y-axis by using the fields for „X“ and „Y“ in the right part of the VO-Plot window. The X-field should show „SemimajorAxis“ and the Y-field „num“. Clicking on „Plot“ redraws the plot.

Using the button „Plot Format“: we can modify the graphic further. To display the data as histogram, we choose „Impulses“ and, in the advanced menu, the „Marker Style“ „pixels“.

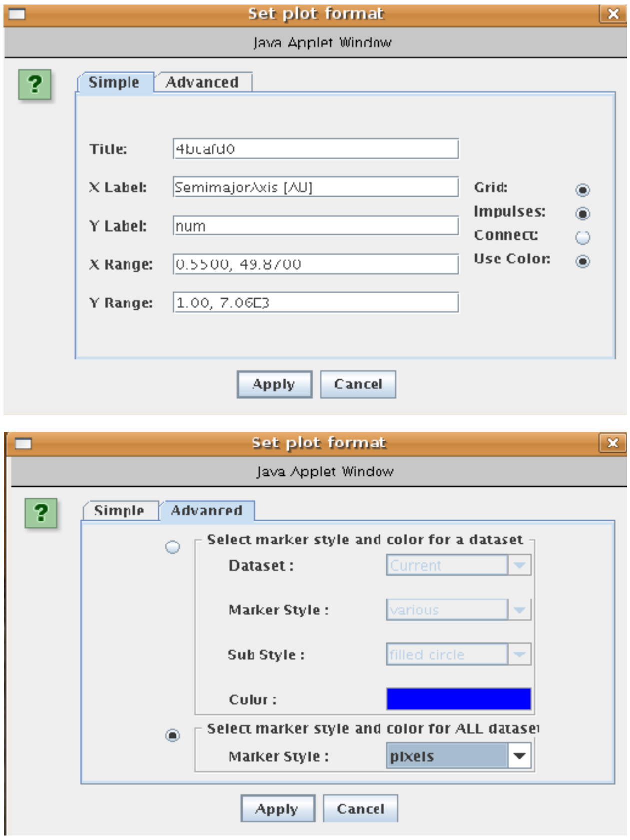


Figure 11: Formatting the data

Clicking on „Apply“ makes the changes:

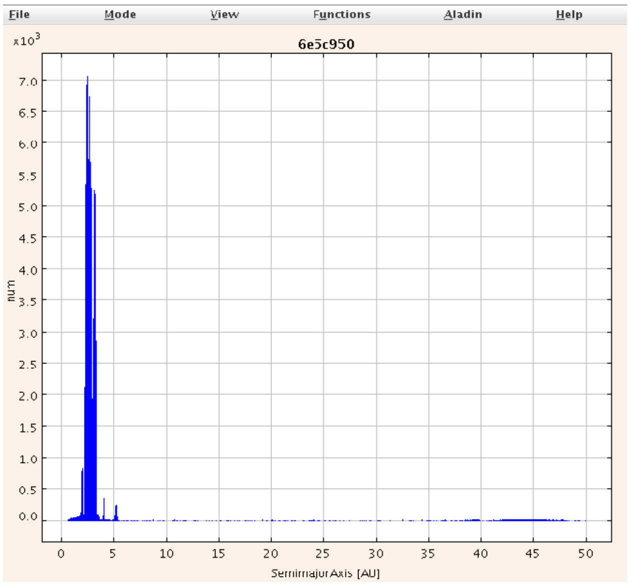


Figure 12: Modified histogram

We now can see a clear peak of the asteroids between 0 and 5 AU – that is where the mainbelt is! But there is also a very small peak between 38 and 48 AU – the location of the Kuiperbelt.

The different asteroid belts

To investigate the main belt between Mars and Jupiter in more detail, we plot a new histogram, but this time only use semimajor axis between 0.5 and 6 AU. The result should look like this:

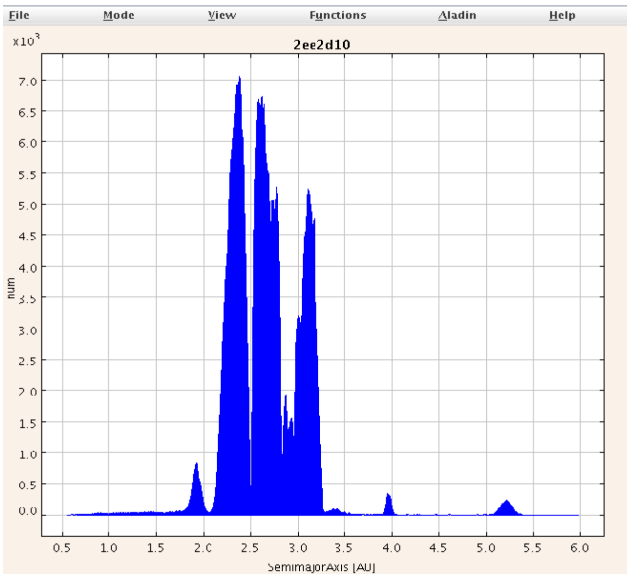


Figure 13: The mainbelt

One can see a clearly that the asteroids are not distributed equally – there are gaps, e.g. close to 2.1 or 2.5 AU and peaks, e.g. close to 1.9 or 2.4 AU. The gaps are called *Kirkwood-Gaps* and are caused by Jupiter.

They show the position of the so called „mean-motion resonances“. That are the regions where the mean orbital period of an asteroid would be in a ratio of two small integers. Periodically, Jupiter and the asteroid are in the same relative position and the over time the gravitational disturbances can add up and throw the asteroid out of its orbit, leaving a gap.

Challenge: Use Keplers third law to calculate the respective resonances from the position of the gaps. Which ratio do the orbital periods have compared with Jupiter? Are there also resonances at the positions of the peaks? Why is there a peak exactly at Jupiter position?
As mentioned in the former section, there is also an asteroid belt at the outer edge of the solar system. This belt is called „Kuiperbelt“ and it is much larger than the mainbelt – although up to now very few of its asteroids have been actually discovered.

To view the distribution of asteroids, we again plot a histogram, this time for objects between 37 and 50 AU.

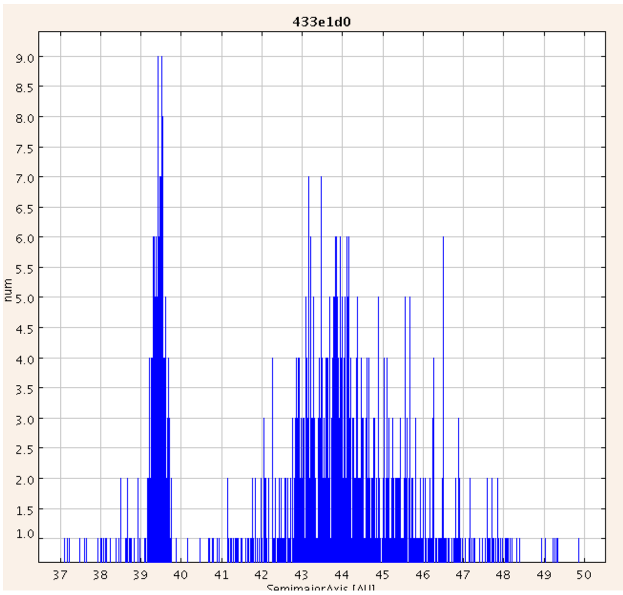


Figure 14: The Kuiperbelt

We can see a clear peak at 39.5 AU. Again, this is a resonance (this time a protective one) – a 2:3 resonance with Neptune. Belonging to this group is also Pluto – and thus this subgroup of asteroids is also called the „Plutinos“.

Farther out, between 40 and 50 AU, one finds the classical Kuiperbelt-objects.

Ideas for additional analysis

- Besides mainbelt and Kuiperbelt – are there any other large populations of asteroids anywhere in the solar system?

- What are NEOs and Centaurs?

- What does the distribution of the other orbital elements look like? (e.g. eccentricity or inclination). Are there differences between the different populations of asteroids?