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DATA FROM CATALOGUES OF SOLAR SYSTEM OBJECTS IN EDUCATION

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Abstract

This contribution contains attractive examples that use catalogues of astronomical objects available at Astronomia web pages (astronomia.zcu.cz) to improve the teaching of selected astronomical topics. The main focus is to Solar system objects, list of numbered minor planets is used to demonstrate the current position of objects in the Solar system, to construct a Kirkwood gap graph or to interactively verify Kepler's laws. I put emphasis on involving students in practical activities, so the results of my research are several worksheets. All worksheets include basic procedure. Each part of worksheet is complemented by sub-questions that deepen knowledge of students and it provides welcomed feedback for teacher. All these features are available as online applications on web pages and it can be used during ICT lessons. I tried worksheets on a significant sample of secondary school pupils and university students. As a result I discovered that students usually do not have possibility to solve this kind of exercise (using data from catalog of astronomical objects) at school. Students cannot handle basic transactions in the Excel spreadsheet, especially inserting formulas into cells, data sorting or constructing a simple chart.

Keywords

Catalogues, Kepler's laws, minor planet, Kirkwood gap, interactive, application, multimedia, education

Introduction

Exercises introduced in this article are focused on improving the quality of teaching of selected astronomical topics using various catalogues of astronomical objects. These topics include Hertzsprung-Russell diagram, Kepler's laws or astronomical objects on the sky. Exercises are prepared to use them immediately during the lessons; even the Framework Educational Programme in Czech Republic contains just few specific areas of the Astronomy and the Astrophysics.

The original idea was to prepare and use raw data from catalogues only. Students can continue to work with them. I found out during my previous analysis that this direction is not suitable, Physics and Astronomy disappeared from these exercises. Unfortunately lack of fundamental knowledge of Computer Science has been a major difficulty for students to understand the basic Physics and Astronomy principles. As an improvement I considered interactive online web applications that use the data from the catalogues of astronomical objects. These applications do a lot of routine and tedious activities and thereby simplify operations of students on the computer so they can again begin to focus on Physics and Astronomy.

Finally I realized a graphical output (as online web applications) from several catalogues. Using these applications I prepared practical exercises in the form of worksheets for students and methodology sheets for teachers. Main goal were practical activities for students representing an important task for them. Exercises should be used during the Physics, Geography, Science, and ICT or other lessons. They lead students to use computers by unusual way. The key requirements for preparation of these exercises were to use data from the catalogues of astronomical objects and multimedia (like computer, internet, etc.) Another issue was to improve key competencies. I created worksheets containing the general procedure for solving each task. There are several sub-questions that deepen the knowledge of students and provide an important feedback for the teacher. I am aware that these exercises are time-consuming. It may involve using them within the special seminars, hobby groups or as a concrete task during Astronomy or Physics Olympics.

Initial Research of this Topic

Information about astronomical objects is collected since ancient time in various catalogues and lists. Currently we have a huge number of catalogues. According to the Strasbourg Astronomical Data Centre there is known more than 13,000 catalogues to January 2015. There should be possible to find a lot of interesting data. Practical exercises using multimedia resources and information technology is one of the modern trends in education. It is not a difficult issue to equip schools with modern computer technology; the weak point can be to use them effectively or prepare didactically valuable education materials.

During my initial research I did not find any Czech internet pages containing summary about usage of catalogues of astronomical objects or using their so complex visualization. During the validation process I was focused on certain areas only: whether the involvement of students in solving practical problems raise students' motivation to astronomy, or key competencies will increase during solving of practical worksheets, or how students evaluate these exercises in terms of their matter of complexity and interest.

The actual use of catalogues of astronomical objects is not very common in schools. Just around 5 % of respondents said that their teachers use Astronomia pages during the lesson. There can be two causes – lack of computer technology usage in general and how amount of teachers spend teaching astronomical knowledge (as mentioned before in relation with Framework Educational Programme). It is possible that they do not have a time for this topic during Physics lessons. On the other hand, catalogues of astronomical objects can be used in other subjects, e.g. during Computer Science.

I used data for list of minor planets from official Minor Planet Center (MPC) available at www.minorplanetcenter.net. Web pages of MPC do not have any graphical output of these data. They are available just in the text form – as a file with size of tens of MB. As mentioned before it is not suitable to use them directly in the education process. Another option is to use data directly from NASA at neo.jpl.nasa.gov/orbits/. There is available online application displaying the current position of the minor planet in the solar system. This page has been an inspiration for me during creating of applications on Astronomia web pages. Application from NASA is based on the Java applet; this one can cause performance problems, it should be a safety risk etc. Nevertheless the NASA application itself does not contain other additional features like verification of Kepler's laws, current position of group of objects in the Solar system, construction of Kirkwood gap graph.

A part of initial research was also to verify who deals with this topic around the world. I found out just one really relevant contribution related to this topic – article “Astronomy Teaching with Astronomical Catalogues” written by Oostra and published in The Physics Teacher in 2006.

Oostra’s article is focused on the usage of catalogues of astronomical objects at the Andean University. His goal was to teach students during independent experiments. The author wrote many of guides how to use real observations, but he always found a number of limitations. A helpful measure was to use online catalogues of astronomical objects. It refers to the fact that online catalogues are on the internet, but most of them are intended for professional usage and they are not suitable for direct usage at school. Another issue was that there are not prepared any exercises to use these data effectively. His article mentions some topics, but without further elaboration: the list of minor planets should be used to demonstrate distribution of minor planets, Trojans or Hilda groups, Kirkwood gaps. His focus was also to a discussion with students to reflect their opinion. Otherwise there is just routine execution of a worksheet without further effect. Usage of real data brings another advantage; students will experience how science really works and what can influence the results. This type of task can be even oriented for non-technical students.

Multimedia Textbook Astronomia

Project Astronomia is a multimedia textbook established already in 2000 (and regularly updated) available online at web address astronomia.zcu.cz. It contains sorted information in Czech language about planets of Solar system, deep–sky objects, stars and other objects in the Universe. These pages are collected from many relevant sources, usually translated from the English ones. Currently there is no plan to create an English version of these pages. On the other hand, one unique part is prepared also in English mutation. It is focused on Catalogues of Astronomical Objects; it is already an integral part of Astronomia web pages. There are more than six hundred thousand objects in total volume of about 180 MB of data. Catalogues should be in general divided into three categories. Firstly as deep–sky objects (nebulae, stars clusters and galaxies) are located in three of them – NGC, Messier and IC catalogues. The second area are stars, there is a list of constellations (88 items), Gliese catalogue (contains 3 803 nearby stars), Hipparcos catalogue (118 218 stars) and a part of astronomical database SIMBAD (118 171 stars with HIP equivalent from Hipparcos catalogue). The third area is focused on objects in solar system – planets and their moons, and a list of minor planets – till January 2015 (list is updated monthly) we have known more than 400 thousand numbered minor planets. An important issue is to update values in catalogues from credible sources with the permission of their authors.

Online Applications using Data from Catalogues

I have prepared several online interactive applications using data from catalogues of astronomical objects available on Astronomia web pages. These applications can be used for demonstration of following issues (in the brackets there is a name of used catalogue):

- Analysis of Minor planets parameters (minor planets)
- Kirkwood gaps (minor planets)
- Historical development of Minor planets (minor planets)
- Current location of Minor planets in the Solar system (minor planets)
- Kepler's laws demonstration (minor planets)
- Apparent magnitude of Minor planet calculation (minor planets)
- Surface temperature of Minor planet estimation (minor planets)
- Online HR diagram construction (stars)
- Sun below horizon, Sunset and Sunrise, Twilights (stars)
- (Circumpolar) constellations (stars)
- Length of (astronomical) night (equinox, solstice) (stars)
- Sidereal and Solar time (stars)
- Nebulae, star clusters and galaxies on the sky (deep–sky)

It is not practicable to describe all possible options and features of these applications in this contribution. Use previous list of application as an overview to be able to decide which application you can use for education at your classroom. And not only at school; application related to deep-sky can be used before visiting observatory or observing the sky at night. For more detailed description visit Astronomia for English guidepost available at link astronomia.zcu.cz/katalogy/education/.

In this article I consider just for catalogues containing objects of solar system – mainly list of numbered minor planets. There are several interesting examples of using this list – some of them are supported by worksheet.

List of Minor planets

1) The Minor planet in Opposition

Initially we should consider the following question:

"*The minor planet (15925) Rokycany is in opposition.*
Is it visible by telescope located at Rokycany Observatory?"

Anyone can choose any minor planet for this task. To solve this task we have to find the date where the considered minor planet is in opposition. We will find the date of this event (opposition) on the web page astronomia.zcu.cz/katalogy/minorplanet-15925 (this page is valid for minor planet Rokycany; it contains Table with information related to selected minor planet and Image with the location of the minor planet in the Solar system) by changing the day, the month and the year (see Fig. 1) – the opposition occurs when the Sun, Earth, and the minor planet are approximately in a straight line. Then we will calculate the apparent magnitude of the minor planet and compare it with the limiting magnitude of the telescope. Apparent magnitude m (as seen on the night sky) of the minor planet should be calculated by simple formula

$$m = H + 5\log\Delta + 5\log r \tag{1}$$

where H is absolute magnitude of minor planet (available from the table above the image), Δ is distance in astronomical units of the minor planet from the Sun (available from image at au), r is distance in astronomical units of the minor planet from the Earth (also available from image at au).

More exact value (with influence of configuration of all related objects) of the apparent magnitude is written on the image with the location of the minor planet in the Solar system.

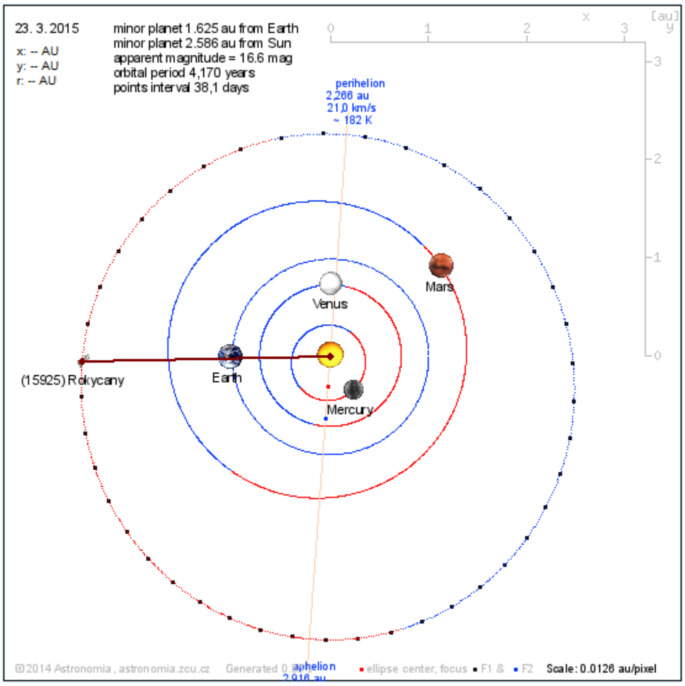

Fig. 1: Minor planet (15925) Rokycany in the opposition during 2015

In the above case for the opposition during 2015 the apparent magnitude of the minor planet (15 925) Rokycany is calculated by application to 16.6 mag. Calculation by formula (1) give us the result $m = H + 5\log \Delta + 5\log r = 12.9 + 5 \log 2.6 + 5 \log 1.6 = 16.0$ mag. The estimated telescopic limiting magnitude given by www.cruxis.com/scope/limitingmagnitude.htm is 15 mag (for telescope aperture 508 mm, power 150, reflector and naked eye limiting magnitude near the zenith for nearby of village 5.0 mag). Comparison of both values (15 mag < 16 mag; note the brighter the object appears, the lower the value of its magnitude) means that the minor planet Rokycany is not observable by the observatory telescope with naked eye. There is also the influence of type of opposition, whether the opposition occurs during the aphelion or the perihelion.

For this exercise I did not prepare worksheet. The main message is just the initial question about the minor planet in the opposition and its visibility. Students can evaluate influence of type of opposition. They should find the rule how to decide whether the minor planet is visible or not. Another issue should be to find the method how to improve the visibility. By using this application (on Fig. 1) teacher/student can demonstrate the position of Earth, Sun and minor planet during the discovery. This date is listed in the table above. All these result could vary time to time because list of minor planets are regularly (monthly) updated. It is basically up to teacher how to use this task (just the initial message and nothing else – as problematic exercise; all together and go step by step with teacher; prepare some questions and let students to find answers), several hints were already mentioned before.

2) Kepler's laws

All three Kepler's laws describing the motion of objects around the Sun should be demonstrated with the same application as previous example (Fig. 2), including showing the location of foci and the centre of the ellipse, the perihelion, and the aphelion.

The Kepler's first law is placing the Sun at one of the two foci of an elliptical orbit. Position of the Sun is marked with a yellow symbolic image; the black square shows the position of the first focus. The second focus is shown by a blue square. The red square indicates the centre of the ellipse. As a note to students should be given an information that red one (centre) and blue or black ones (foci) are not the same. Distances of the minor planet at the perihelion and the aphelion are calculated including the velocity at these points.

The Kepler's second law says that a line segment joining a minor planet (planet or object in general) and the Sun sweeps out equal areas during equal intervals of time. The orbital radius and angular velocity of the minor planet in the elliptical orbit vary – see different values of distance and velocity at perihelion and aphelion on Fig. 2. The equal areas can be demonstrated by interactivity of the application. The light blue highlighted area has from 0.496 au^2 to 0.498 au^2 and it is calculated automatically by Heron's formula (all three side lengths of the triangle are known). Small difference (error is around 0.4 %) between areas at perihelion and aphelion is given by simplifying of calculation to triangle instead of circular sector. The base of the isosceles triangle is not really the line segment for the elliptical orbit. This small error given by simplicity of an application is not an obstacle to show to students validity of this law, but we should mention them these discrepancies.

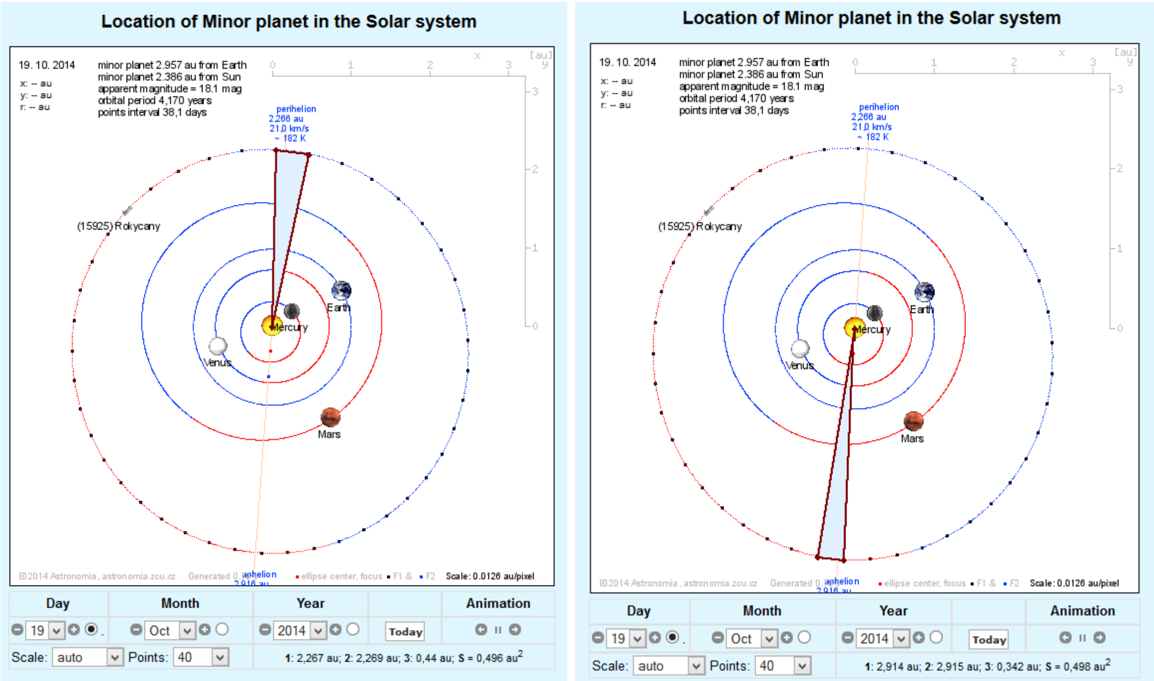

Fig. 2: Comparison of the area in the perihelion (left) and the aphelion (right). The area is almost the same = 0.496–0.498 au^2.

The Kepler's third law is equation that says that the square of the orbital period of a planet is proportional to the cube of the semi–major axis of its orbit. The semi–major axis can be calculated from distances of minor planet at perihelion and aphelion. The sum of these two distances divided by two is equal to the semi–major axis. The orbital period axis can be calculated from the semi–major and compared with the value given at catalogue.

I prepared worksheet for Kepler's laws (available in PDF form in Czech/English language on astronomia.zcu.cz/katalogy/education/, see Fig. 3) using described application. Worksheet contains six areas – description of ellipse, introduction of list of minor planets, selection of minor planets, all Kepler's three laws study and analysis.

Ellipse is the fundamental of Kepler's first law. During my worksheet analysis on 77 students (from high school and university, autumn 2012) I found that just 13 % of students correctly solved all issues (describe ellipse, mark Sun location, eccentricity) regarding ellipse. Common mistake for more than third of the students was to describe the distance from focal point to centre as eccentricity, correct answer is $a{\cdot}e$ (semi-major axis times the eccentricity). Most of the students did not answer the question related to Sun location; just third of them correctly marked it at one of the (common) focal point.

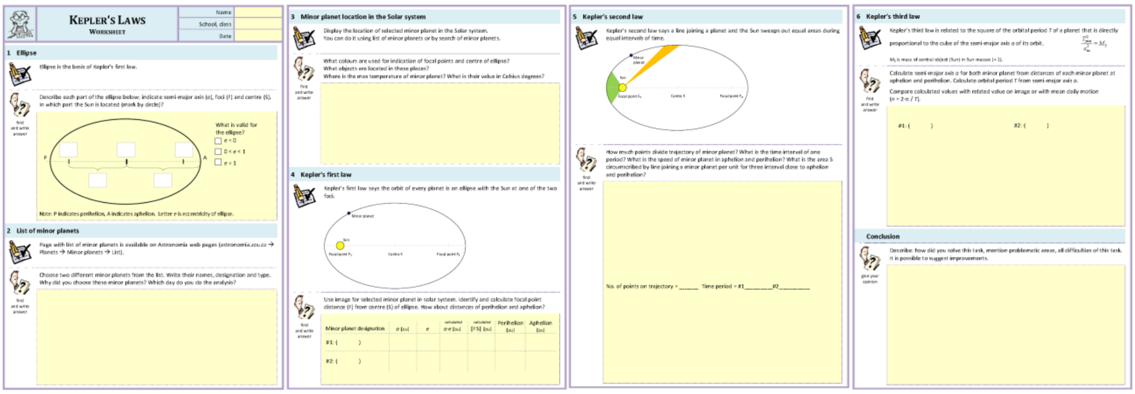

Fig. 3: Worksheet for Kepler's laws, available in PDF form at Astronomia

During the introduction of list of minor planet students have to select two minor planets and describe the reason for their selection. Some of the reasons was interesting – selection of last discovered minor planet (it means student realize regular updating of this list), selection of name related to some location (town, city) or minor planet visible by naked eyes (it is just one – 4 Vesta). Students were also asked to type the date of analysis – most of them use the date when lesson held, one of them uses date of birthday. In this case teacher should inform students about the influence of time on calculating a location of minor planet at solar system.

For aphelion and perihelion there is a calculation of temperature of minor planet at those distances from the Sun. This temperature is for information only; there is not calculation of the influence to non-spherical shape of some minor planets, their rotation, varied albedo etc. With this one teacher can explain that distance from the Sun is not indicative for the formation of seasons on Earth; e.g. minor planet (40786) 1999 TR30 with very similar eccentricity to Earth has temperature difference between aphelion and perihelion 3 K only.

Second part of worksheet is focused to Kepler's laws. Students are using online application, filling the tables and finding answers to questions. In case of Kepler's first law around two third of students successfully solved task related to semi-major axis, eccentricity, distances, aphelion and perihelion. Around half of students solved task related to Kepler's second law focused to comparison of several areas per unit time close to perihelion and aphelion. Finally Kepler's third law is more numerous; students should calculate semi-major axis (and then orbital period) from distances of minor planet at the nearest and the farthest points. Analysis said that one fifths of students were able to solve this one; there is a questions what was the reason; whether lack of knowledge of students or placement of this point at the end of worksheet. More experiments for Kepler's third law are in the topic called Kirkwood gaps.

3) Kirkwood gaps

A Kirkwood gap is a gap or dip in the distribution of main–belt minor planets by semi–major axis (or equivalently by orbital period). They correspond to the location of orbital resonances with planet Jupiter. There are very few minor planets with semi–major axis near 2.50 au, period 3.95 years, which would make three orbits for each orbit of Jupiter (hence, called the 3:1 orbital resonance). This part is also suitable to practice of Kepler's third law.

A relatively small number of minor planets (the Alinda family and the Griqua family) have been found to possess high eccentricity orbits which do lie within the Kirkwood gaps. These orbits slowly increase their eccentricity on a timescale of tens of millions of years, and will eventually break out of the resonance due to close encounters with a major planet.

They were first observed by Daniel Kirkwood in 1886. When he arranged minor planets by their distance from the Sun, he noted several gaps, now named Kirkwood gaps in his honour. He also correctly explained their origin in the orbital resonances with Jupiter. There were just 91 known minor planets by 1866 (Fig. 4).

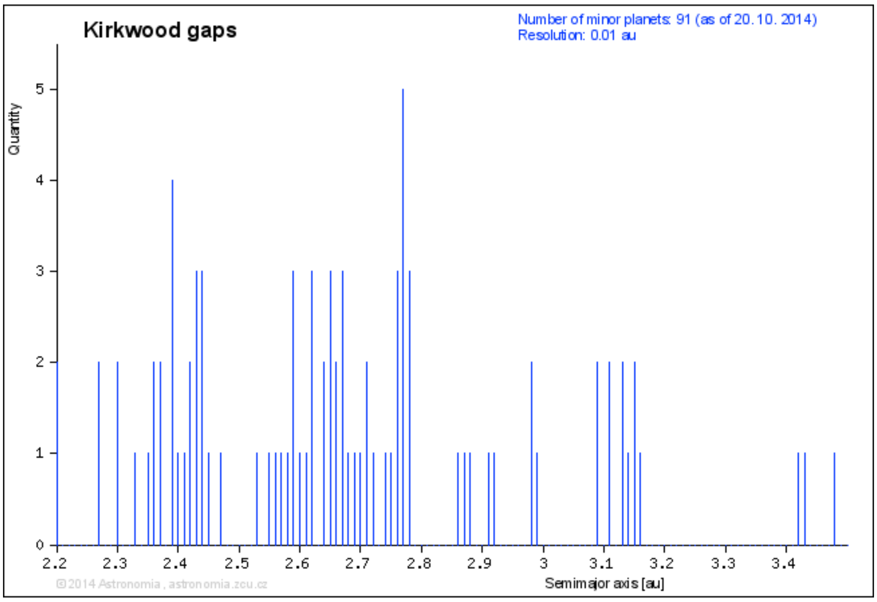

Fig. 4: Minor planets distribution by 1866 when Daniel Kirkwood discovered gaps

A part of the Analysis of Minor planets parameters is a special feature called Data Export (Fig. 5) – allow to export selected data to text file (possible to process them in Excel spreadsheet during ICT lesson) or directly as an image more suitable to Physics lessons (see at link astronomia.zcu.cz/katalogy/education/2407-minor-planets-analysis). It is possible to choose items as each want/need it. As an output format CSV or PNG can be chosen. There are three special analyses – the Kirkwood gap (contribution of minor planets on semi–major axis), the historical development (contribution of minor planets in time) and the current location of minor planets in the Solar system.

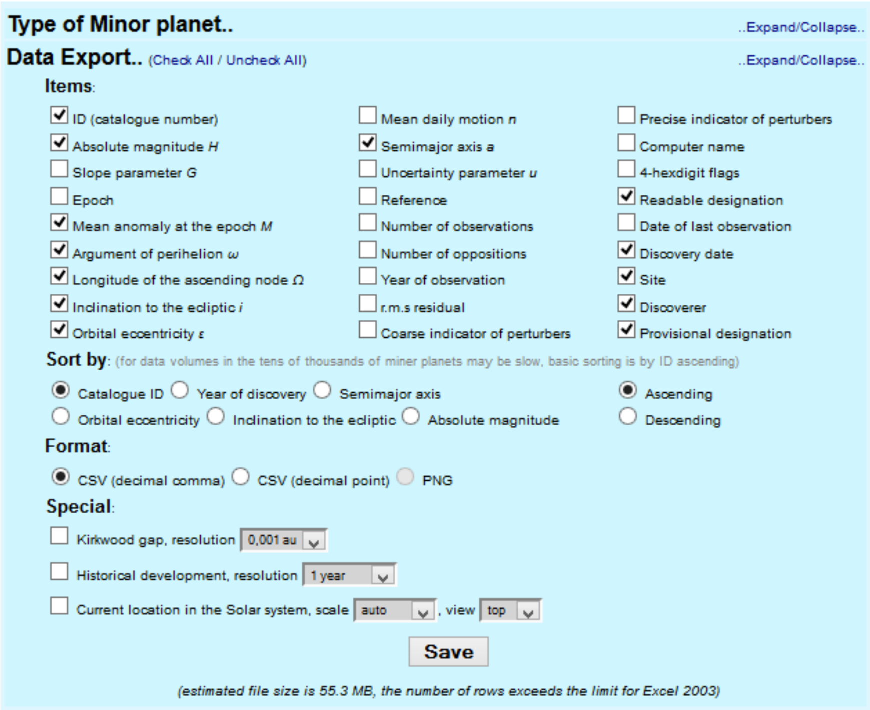

Fig. 5: Data Export from Analysis of Minor planets parameters

Special analysis Kirkwood gap shows graph of semi–major axis on a quantity of minor planets. There can be found mentioned Kirkwood gaps (most prominent are at distances 2.50 au, 2.82 au, 2.95 au and 3.27 au), see Fig. 6. They correspond to the location of orbital resonances with the planet Jupiter (3:1 – place of Alinda family, 5:2, 7:3 and 2:1 – place of Griqua family). There are totally more than 415 000 numbered minor planets in the Solar system on January 2015, the semi–major axis lies at distances from 0.6 au to 740 au. When limited to the inner (within orbit of Saturn – 9.5 au) of the Solar system, still we have majority of minor planets – 99.93 %.

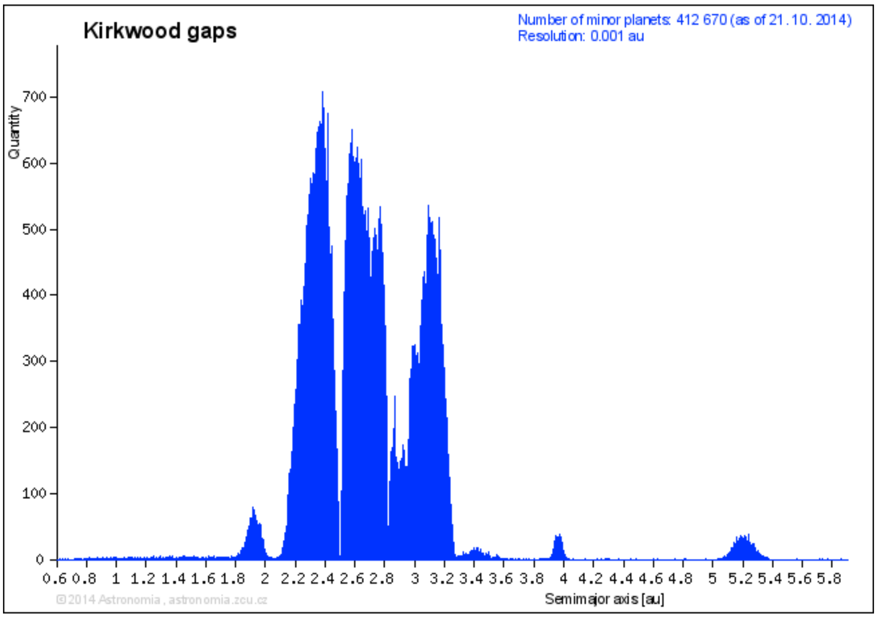

Fig. 6: Kirkwood gaps visible on distribution of minor planet in inner part of the Solar system

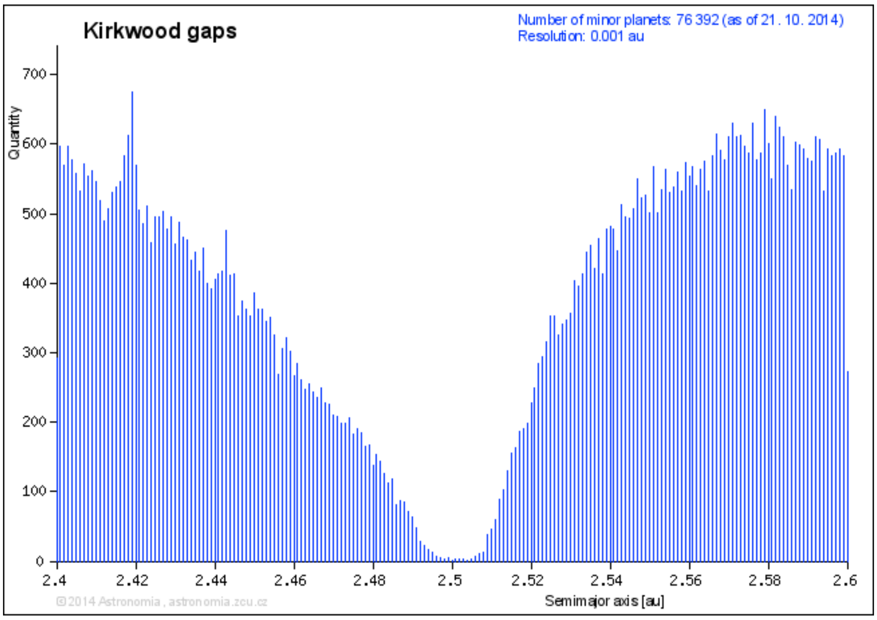

Fig. 7: Close look up to prominent Kirkwood gap at a distance of 2.5 au (resonance 3:1 with Jupiter)

Distribution of minor planets close to one of the Kirkwood gap at a distance of 2.5 au is visible on Fig. 7. There are shown more than 75 thousand minor planets with resolution of distribution on horizontal axis 0.001 au. Even with this huge amount of data, gap is still visible at around 2.5 au. It is possible to find from the exact data (CSV file) that from 2.496 au to 2.504 au lays around 25 minor planets only (average value is 3 minor planets per 0.001 au). The total average value for resolution of 0.001 au is around 380 minor planets for the distances from 2.4 au to 2.6 au.

4) Hilda family

There are only two areas on Fig. 6 where orbital resonance with Jupiter creates a stable group of minor planets. They are located at around 4 au (resonance 3:2, the Hilda family) and at around 5.2 au (resonance 1:1, the Trojan group).

The Hilda family are a dynamical group of minor planets in a 3:2 orbital resonance with Jupiter. The Hildas move in their elliptical orbits so that their aphelia put them opposite Jupiter, or 60 degrees ahead of or behind Jupiter at the L_4 and L_5 Lagrangian points. As can be seen on page with the analysis of minor planets parameters (just to choose Hilda group at Type of Minor planet), Hilda's orbit has a semi–major axis between 3.7 au and 4.1 au, an eccentricity less than 0.3, and an inclination less than 20°. There are around 1750 minor planets at this group with orbital period 2/3 of Jupiter. The Hildas taken together constitute a dynamic triangular figure with slightly convex sides and trimmed apexes in the triangular libration points of Jupiter. The minor planets stream within the sides of the triangle is about 1 au wide. See Fig. 8.

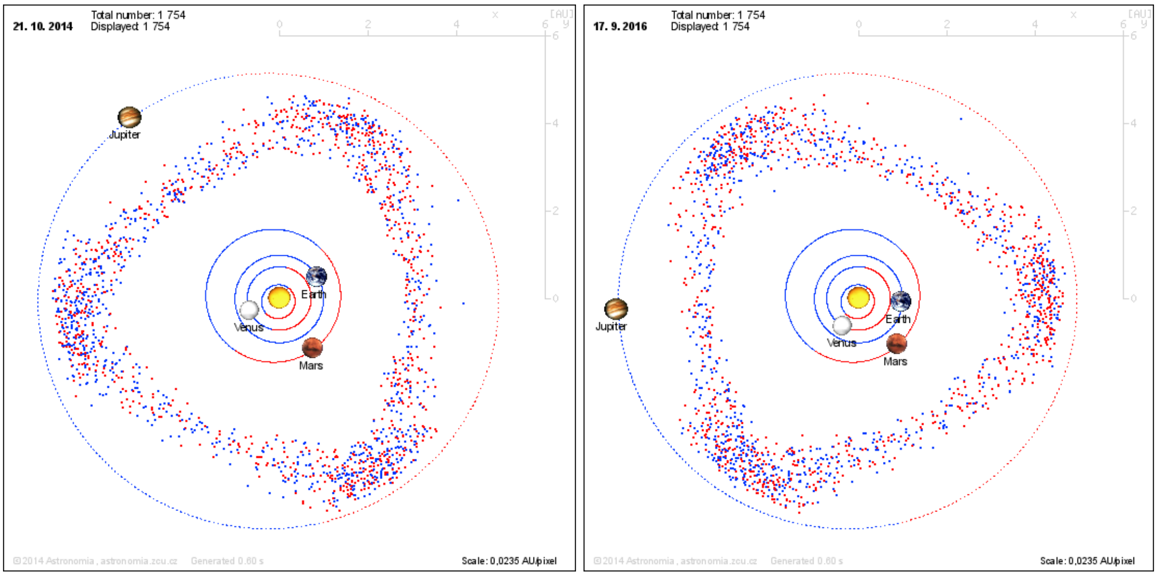

Fig. 8: The Hilda family of minor planets create in the Solar system in long–term view the equilateral triangle with apexes at Lagrangian points

The Jupiter Trojans are a large group (more than 4 000 ones) of minor planets orbit around one of the two Lagrangian points of stability (see Fig. 9). The interval of semi–major axis is from 4.8 au to 5.4 au, while mean value is 5.2 au, see the distribution that can be easily (directly as an image or as a raw data to Excel spreadsheet) created from the data from catalogue on Fig. 9. There are two options in case of raw data. Simpler one is to use special format Kirkwood gap that prepare already sorted distribution of minor planets or to use just semi–major axis distances for more than 4 000 objects. Value of semi–major axis given at 6 digits resolution should be rounded to 3 digits (resolution 0.001 au) and with using of the pivot table; distribution of minor planets can be easily calculated.

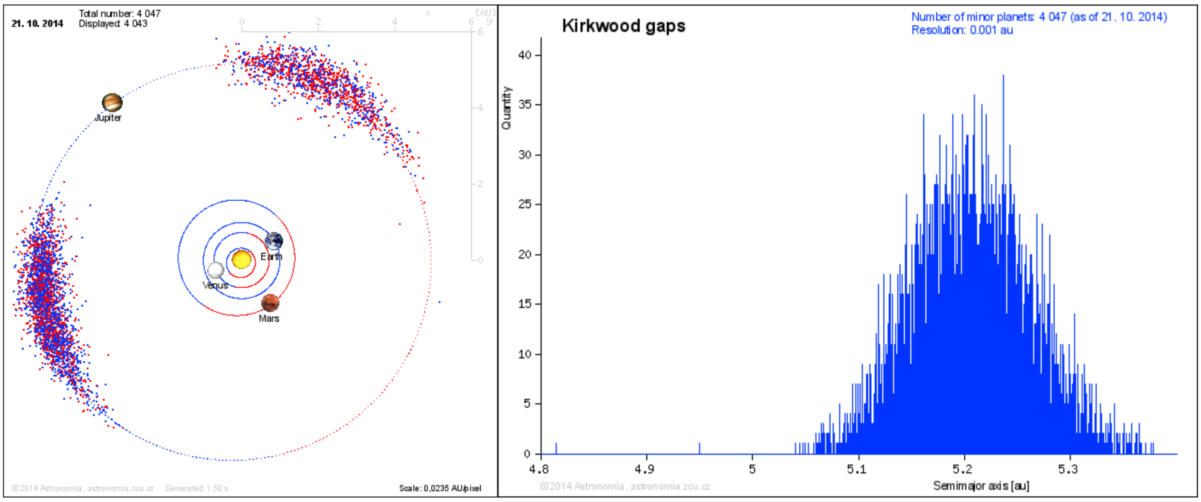

Fig. 9: The Trojan family of minor planets lies in the Solar system in Lagrangian points of Jupiter (left), distribution of the Trojan family in the Solar system (right)

Conclusion

I applied all worksheets for several times on a significant sample of high school pupils and university students. As a result I discovered that students usually do not have possibility to solve this kind of exercise (using data from catalog of astronomical objects) at school. Analysis of my hypothesis says there are less than half of students that are able to effectively use information on Internet based on some procedure (in my case worksheet). This finding is not encouraging. It should be also related to popularity of worksheets for students. Further analysis should find more interesting method. I found out that ambitiousness of worksheets is around in the middle of scale, which means students do not consider the exercises as too simple or too complex. If the ambitiousness of the exercises is too simple, students are able to use computers to solve practical exercises. Unfortunately I cannot say it is true; it means for students is difficult to solve practical exercises using multimedia.

I also realized basic research related to comparison of exercises based on raw data (first type) and online applications (second type). Both types of exercises are similar for students. Around 34 percents of students consider as too complex first type of exercises. For second type it is similar, 36 percents. In case of too simple, the situation is as follow: 30 percents for first type, 37 percents for second type. In general, this trend may be due to the low ability of students to solve Science exercises. Worksheets more focused on Astronomy appear to them as demanding as task in application (Excel) not so familiar with it. Students cannot handle basic transactions in the Excel spreadsheet, especially inserting formulas into cells, data sorting or constructing a simple chart.

This type of worksheets is not possible to solve easily without computer and access to internet to Astronomia web pages. One comment from student says: “It is not possible to find answers on Wikipedia”. I am convinced that this is the main reason to have this kind of exercises. Students have to do some activities to find correct answer not only use Google, Wikipedia etc.

Any experiences with the above applications, comments, ideas or suggestions, please, let me know. I will keep the applications updated and fully working as long as it will be possible. It means you can implement them into your education process. I will be also grateful to have a feedback (or at least information) from teachers that they are using these exercises.

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