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A computer program calculating the closest approaches of asteroid to the mean orbits of meteoroid streams

M. Kováčová and L. Neslušan

Astronomical Institute of the Slovak Academy of Sciences
059 60 Tatranská Lomnica, The Slovak Republic(E-mail: mkovacova@ta3.sk)

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Abstract. Meteoroid particles can collide with asteroids. If a meteoroid is large, it can trigger asteroid activity; an outburst of brightness occurs. When the meteoroids in a stream cross a region of interplanetary space, the flux of these meteoroids is considerably larger than that of sporadic meteoroids in the same region. Therefore, the probability of a collision is significantly larger there. To map the passages of a given main-belt asteroid through the known meteoroid streams, we created a computer program which calculates the characteristics of the close approaches of the asteroid to the mean orbits of known meteoroid streams. The public-domain program is available along with this article and on: https://github.com/neslusan/BELTCROSS2. It contains the executable static-binary code as well as the Fortran source code. In the article, we give a more detailed description of the program.

Key words: computer program – dynamics of meteoroid stream – main-belt asteroids – collisions between asteroids and stream meteoroids

1. Introduction

Asteroids and comets belong to the small bodies of the Solar System. In the past, it was thought that these categories were clearly distinguishable. Then objects with dynamically asteroidal orbits, but comet-like activity started to be discovered. The first such object, comet 107P/Wilson-Harrington, alternatively known as asteroid 4015 Wilson-Harrington, was discovered in 1949 (Cunningham, 1950).

This class of objects is also known as active asteroids. At the time of writing this paper, there were known about forty active main-belt asteroids. The active asteroid can be defined by (1) a semi-major axis smaller than the semi-major axis of Jupiter, (2) a Tisserand's parameter with respect to Jupiter $T_J > 3.08$ and (3) the presence of cometary features such as a coma and/or tail(s). The limit $T_J = 3.08$ (rather than the usual 3.0 for distinguishing asteroids and comets) was chosen due to the slightly eccentric orbit of Jupiter which differs from a circular orbit, which figures in the restricted 3-body problem. Thus, Encke-type comets (comet 2P/Encke has $T_J = 3.02$) and quasi-Hilda comets

($T_J \sim 2.9{-}3.04$) are excluded from the group of objects with $T_J > 3$ (Jewitt et al., 2015).

The activity of comets is caused by the sublimation of ice and accompanying dust removal (Whipple, 1951). In the case of active asteroids, several possible mechanisms of activity accompanied by a mass loss are discussed. For example, Hsieh et al. (2010) considered the process of ice sublimation and dust ejection as a source of activity of 133P/Elst-Pizarro (asteroidal designation 7968 Elst-Pizarro). The mechanism of rotational instability was suggested for asteroids P/2012 F5 (Gibbs) (Drahus et al., 2015) and 6478 Gault (e.g. Kleyna et al., 2019; Devogèle et al., 2021).

A meteoroid impact can also trigger an observable activity. At the first time, this mechanism was found to be the most probable mechanism to explain the activity of asteroid P/2010 A2 (Kim et al., 2017a,b). It was discovered, being already active, on January 6, 2010 by the Lincoln Near Earth Asteroid Research (LINEAR). In the case of trigerring of activity by an impact, it is more likely that this is caused by a stream meteoroid which moves around the Sun in a corridor with a relatively much higher density of meteoroids than the density of sporadic meteoroids. (The term "corridor" refers to an interplanetary space around the mean orbit of a stream. The orbits of all stream meteoroids are situated within this space.) For example, this hypothesis was applied to asteroid 596 Scheila by Neslušan et al. (2016) as an attempt to explain its activity. Instead of a fast rotation, such collisions are the most likely cause of the activity of 6478 Gault according to Ivanova et al. (2020).

Other mechanisms which can cause observable activity include the electrostatic forces, radiation pressure sweeping, and thermal fracture or dehydration (e.g. Jewitt, 2012; Jewitt et al., 2015). However, the activity of a real object may be triggered by different mechanisms operating together (Jewitt et al., 2015).

In this work, we present a tool which can help to gain some data that a researcher needs when he wants to estimate a probability that activity of an asteroid was triggered by a meteoroid impact. The probability of such the impact is high when the asteroid crosses a compact, numerous stream, since the number density of meteoroids in such the stream is larger than that in the neighboring interplanetary space. To reveal if this mechanism of the triggering of activity is relevant in the case of a specific outburst of asteroidal activity, one needs to know, in the first step, whether the asteroid passed through a corridor of numerous meteoroid stream a short time before its activity occurred. Unfortunately, the compactness and numerosity of the streams in the interplanetary space (the main belt in our context) is unknown for a majority of the showers. We nevertheless predict the passages of a given asteroid through every known streams. An evaluation whether the stream can contain enough meteorids to collide with the asteroid should be additionally done by the researcher.

To help answering this question, we created a computer program that calculates the minimum orbit intersection distance (MOID) between the nominal orbit of a given object and the mean orbit of each known meteoroid stream. For the close approaches of the orbits (a low MOID), the program gives their dates in a selected year. The description of the input data and program itself is given in the next section.

2. Description of program

2.1. Description of the code

The code consists of five executable files: "moid.exes", "relvel.exes", "basicdate.exes", "datelist.exes", and "arrange.exes". These files were compiled as the static binary files, therefore no compiler is needed to run them. They can be run, in the above-mentioned order, on any computer with a 64-bit processor. The corresponding source codes are also available on-line at https://www.astro.sk/caosp/Eedition/FullTexts/vol54no1/pp7-19.dat/. The basic norm was the Fortran 77.

In the UNIX/Linux operation system, the files can be run by using the single script named "calcdate.sh'. The speed of the calculation depends on the properties (mainly operation frequency) of the processor and selection of a specific asteroid (the number of the close approaches to the mean orbits of streams is different for various objects). However, the calculation does not typically exceed 15 seconds. The time of running of the first program, "moid.exes", is the longest one; the other programs need only a fraction of a second to be completed.

Before the running the code, the input must be prepared. The input and output data are described in the next two sub-sections.

2.2. Input data

2.2.1. Input data characterizing the investigated object

The characteristics of the object under interest should be edited by the user of the program into the input file named "object.dat". The object may not necessarily be a main-belt asteroid. However, its orbit must be elliptic and its eccentricity should be low (say $e < 0.5$). Otherwise the calculation of the MOID is not very precise for the approaches at a large value of true anomaly.

The following parameters should be inserted into the file "object.dat": the name of the object (15 characters in maximum), semi-major axis (in [au]), eccentricity [1], argument of perihelion [deg], longitude of ascending node [deg], inclination [deg], date (year-month-day) of the epoch the nominal orbit is referred to, mean anomaly of the object at the moment of epoch [deg], year of investigation of close approaches, and critical MOID [au], i.e. the upper value of MOID the user is interested in.

2.2.2. The known meteoroid streams

Currently, more than eight hundreds of meteoroid streams, which correspond to the meteor showers observed in the Earth's atmosphere, are known[1] (Jopek & Kaňuchová, 2014). We suppose that the known streams represent a majority of the streams crossing the region of the main asteroid belt. The provided program calculates the MOID of the orbits of an asteroid under the interest just with the mean orbits of these streams.

Because of the orbital similarity, the meteoroids of a given stream can approach a specific asteroid within a short arc of its orbit. The asteroid periodically passes this arc during a short time interval, with the period equal to its orbital period. The arc is situated around the point of the asteroid's orbit which is the nearest point to the mean orbit of the stream meteoroids. This is the reason why we think that the calculation of the MOID between the known, osculating orbit of the asteroid and the mean orbit of stream is useful. The points relevant to the MOID are specified by their true anomalies relevant to both orbits. The true anomaly of the asteroid can then be used to find the time when the asteroid passes the point of minimum approach to the mean orbit of a given stream.

In more detail, the mean orbits of the meteoroid streams in the List of All Showers of the Meteor Data Center (MDC) of the International Astronomical Union (IAU) are used as the default input related to the meteoroid streams; see the first footnote. In the list, the mean characteristics of some showers are given by two or more author teams. We call the set of parameters given by one author as a "solution" of the shower/stream. In total, the used list of meteoroid showers/streams contained 1305 solutions with a complete set of mean parameters. In calculations, all these solutions are taken into account. However, when we sum all the passages of an asteroid through a stream (Sect. 3) and this passage is predicted for more than a single solution, then the passage is regarded, of course, as a single event.

The input data-file with the meteoroid-stream orbits is named "allshowers.d". The data about one solution are in one line. The file contains, in the individual columns, the serial number of a solution, the official IAU number of a meteor shower, the identification number of solution (the solution can be identified with these two last numbers), mean parameters which are the solar longitude [deg], right ascension and declination of geocentric radiant [deg], geocentric velocity [$\mathrm{km\,s^{-1}}$], semi-major axis [au], perihelion distance [au], eccentricity, argument of perihelion [deg], longitude of ascending node [deg], and inclination [deg]. In the last column, the number of meteors in the given solution is presented. This parameter can be useful in an estimate of the actual numerosity of the stream. If the number of meteors is large, i.e. the number density of

[1] The list of the known meteor showers can be found on the web pages of the Meteor Data Center of the International Astronomical Union: https://www.ta3.sk/IAUC22DB/MDC2022/Roje/roje_lista.php?corobic_roje=4&sort_roje=0 (as a default input file, we provide the list downloaded on August 19, 2022).

meteoroids is large in the part of the stream corridor crossing the Earth's orbit, then the overall number density of the stream can also be large. We note that a large number density of the stream can be expected when the number of meteors of the corresponding, Earth-observable meteor shower exceeds ~ 50, ~ 500, or ~ 2000 in the case of photographic, video, or radar observations of the shower, respectively.

On the other-hand, a low number of meteors do not necessarily indicate a low number density of the stream, because there can still be a larger number density in a part of the corridor situated farther from the Earth's orbit. In this case, information about the number density of meteoroids is not available, in fact. The default file "allshowers.d" can be completed, by the user, with the new solutions, which occur meanwhile.

2.3. Resultant data

2.3.1. Metadata

Each of the first four executable files produces an output file, which is the input into the next file. File "moid.exes" produces the data file named "moid.dw'. It contains the characteristics of the approaches within the critical MOID (selected by the user in the input file "object.dat"). If there is the sub-critical MOID for one, post-perihelion or pre-perihelion, arc of stream's orbit, then also the characteristics of the approach, regardless it is sub-critical or super-critical, for the other arc are given.

The characteristics of a given approach are written to five lines. The first line contains: the name of the object (a 15-character string in maximum), true anomalies of the object at the moment of its approach to the post-perihelion and pre-perihelion arcs of the stream orbit [deg], and the MOID for the post-perihelion and pre-perihelion arcs of the stream orbit [au].

The second line contains: the IAU number of the stream the object approached, the solution number of this stream, the number of meteors detected in the corresponding solution of a meteor shower, and true anomalies of the points in the post-perihelion and pre-perihelion arcs of the stream's mean orbit which are nearest to the object's orbit [deg]. The third line contains the mean orbital elements of the stream the object approached. These elements are given in order: perihelion distance [au], eccentricity [1], argument of perihelion [deg], longitude of ascending node [deg], and inclination to the ecliptic [deg].

The fourth (fifth) line contains the rectangular heliocentric ecliptical coordinates [au] of the asteroid and the stream meteoroid moving in the mean orbit of the stream at the moment of their closest approach on the post-perihelion (pre-periheion) arc of the meteoroid orbit.

Program "relvel.exes" produces its output data file named "relativeV.dw" with additional characteristics of the closest approaches. The characteristics of the given closest approach of the object to either post-perihelion or pre-perihelion arc of the stream's mean orbit are given in four lines. The first line contains the name of the object (a 15-character string), true anomaly of the object at the moment of the closest approach [deg], MOID [au], the relative velocity between the object and the meteoroid moving in the mean orbit of the stream at the moment of the closest approach [$\mathrm{km\,s^{-1}}$], and the angle between the heliocentric velocity vectors of the object and the meteoroid in the mean orbit at the moment of the closest approach [deg].

The characteristics in the second line are: the IAU number and solution number of the stream the object approached, the number of detected meteors in the corresponding solution of a meteor shower, and an indicator of the arc of the stream orbit to which the object approached (value 1 indicates the post-perihelion and value -1 the pre-perihelion arc).

In the third line of given characteristics, there are the rectangular heliocentric ecliptical coordinates [au] of the asteroid and the stream meteoroid moving in the mean orbit of the stream, both at the moment of the closest approach of both objects on the arc of meteoroid orbit specified in the 2nd line. The fourth line contains the rectangular components of the heliocentric ecliptical velocity vector [$\mathrm{au\,day^{-1}}$] of the asteroid and components of an analogous vector of the stream meteoroid moving in the mean orbit of the stream, again at the moment of the closest approach of both objects on the arc of the meteoroid orbit specified in the 2nd line.

Program "basicdate.exes" produces the output data file "basicdate.dw". It contains further characteristics of the closest approach of the object to the post-perihelion and/or pre-perihelion arc of the mean orbit of a stream. The first of the two lines characterizing one approach contains: the name of the object (a 15 character string), the IAU number and solution number of the stream the object approached to, the number of detected meteors in the corresponding solution of a meteor shower, the true anomaly [deg] of the object at the moment of the closest approach, time of the closest approach [Julian date], orbital period of the object [day], indicator of the arc the object approached to (value 1 indicates the post-perihelion and value -1 the pre-perihelion arc), MOID [au], the mean orbital elements of the stream in order perihelion distance [au], eccentricity [1], argument of perihelion [deg], longitude of ascending node [deg], inclination [deg], relative velocity [$\mathrm{km\,s^{-1}}$] between the object and meteoroid moving in the stream's mean orbit at the moment of the closest approach, and angle [deg] between the velocity vectors of the object and meteoroid in the mean orbit at the moment of the closest approach.

The second line of the approach characteristics in "basicdate.dw" contains the rectangular heliocentric ecliptical coordinates [au] of the asteroid at the moment of their closest approach, T_a, on the arc of the meteoroid orbit specified in the first line (columns 1$-$3), the rectangular components of the heliocentric ecliptical velocity vector [$\mathrm{km\,s^{-1}}$] of the asteroid (columns 4$-$6) and the components of an analogous vector [$\mathrm{km\,s^{-1}}$] of the stream meteoroid moving in the mean orbit of the stream at the moment T_a on the arc of the meteoroid orbit specified in the first line (columns 7−9).

Program "datelist.exes" finds out all close passages of the object through the meteoroid streams in the given year. This year is specified by the user in the input file "object.dat". The output is written into two files "unarranged????.d" and "unarr_vect????.d". Question marks in these names stand for the year of the investigation. The characteristics of each close approach (within the specified MOID) of the object to the mean orbit of the stream are provided in one line in each of both files. The individual columns in the output file "unarranged????.d" ("unarr_vect????.d") are the same as in the final output "datelist????.dat" ("vectors????.dat") − see the next sub-section.

2.3.2. List of predictions

As mentioned at the end of the previous sub-section, the final result is produced by the code "datelist.exes" and recorded to the output data files named "unarranged????.d" and "unarr_vect????.d". The last code named "arrange.exes" arranges the found close approaches in order of their increasing date. The final output data are stored in files "datelist????.dat" and "vectors????.dat". The characteristics of each approach are listed in one line in each file.

The columns of file "datelist????.dat" contain: the IAU number (IAUNo.) and solution number (Sol.) of the solution of a meteor shower, which corresponds to the stream the object approached to. Further, there is given the number of detected meteors of the shower (n). If $n = -1$, then the number of meteors is unknown. Then, the characteristics go on with the MOID [au] of the closest approach, heliocentric distance [au] of the meteoroid in the position of the closest approach (r_rel), relative velocity [km s^{-1}] (v_rel) between the object and meteoroid moving in the stream's mean orbit at the moment of the approach, angle [deg] between the velocity vectors of the object and meteoroid, and the date [year month day] of the closest approach.

File "vectors????.dat" contains the rectangular heliocentric ecliptical coordinates [au] of the asteroid at the moment of their closest approach, T_a, on the arc of the meteoroid orbit specified in the first line (in columns 1−3), the rectangular components of the heliocentric ecliptical velocity vector [km s^{-1}] of the asteroid (columns 4−6), and the components of an analogous vector [km s^{-1}] of the stream meteoroid moving in the mean orbit of the stream on the arc of the meteoroid orbit specified in the first line (columns 7−9). Both vectors are given in time T_a.

The heliocentric velocity vector of the possible impactor can be expected not be the same as the heliocentric velocity vector of the meteoroid moving in the mean orbit, of course. Nevertheless, both impactor and hypothetical meteoroid in the mean orbit will obviously move in a similar orbit, therefore a rough match of both vectors can be expected. Thus, an eventual approximate agreement of the velocity vector of an impactor found in a simulation of the impact and that of the meteoroid in the mean orbit is an indication supporting the hypothesis of an impactor from the specific stream.

3. Remark about the total approaches

Beside creating the program, we intended to clarify a wider context of the usage of the program. In this course, we estimated the total number of passages of all main-belt asteroids through all known meteoroid streams per year. To find this number, we considered the known asteroids with characteristics published on-line by the Minor Planet Center (MPC) of the IAU[2]. From the list of all asteroids, we selected those with a relatively reliable orbit, which had been determined on the basis of observations in, at least, three oppositions. We delimited the main belt by the perihelion distance larger than the aphelion distance of the orbit of Mars, $q > 1.666$ au, and by the aphelion distance smaller than the perihelion distance of Jupiter, $Q < 4.951$ au. The list of such asteroids contained 1,020,990 objects.

It appears that there is a huge number of close approaches of asteroids to the known meteoroid streams. For example, we performed the calculations for the approaches with a MOID lower than 0.05 au. The widths of stream corridors are unknown, therefore it is impossible to determine an average critical MOID. It seems that the width may exceed 0.15 au (the MOID of comet 1P/Halley, the parent body of the Orionids, from the Earth's orbit was found to be 0.155 au (Neslušan et al., 1998), therefore the width of the Orionid stream has to be larger than this MOID). However, some minor, diffuse showers can move in a narrower corridor. The value of 0.05 au may be regarded as a good compromise for a characteristic width of the stream.

For the critical MOID equal to 0.05 au, we found 23,202,210.5 passages of asteroids through the meteoroid streams a year. In more detail, this result is the average of passages in ten years, from 2023 to 2032. During this decade, the number varies from 22,981,394 to 23,348,851 and only 624 to 829 of 1,020,990 objects considered were found not to pass through any stream. In a year, the asteroid, that was found to cross the streams most frequently, passed the streams 109 times (asteroid 554211). The distribution of the number of passages in each of five years (2023−2027) is shown in Fig. 1. From this figure one can read that the largest number of meteors approached the mean orbit 11 to 12 times (in years 2023 and 2024, it was 11 times and in the other three years 12 times). We further found that the average number of approaches varied from 22.5 to 22.9. The median number was the same in these years; specifically, a half of all considered asteroids approached to the mean orbit of a stream more than 18 times per year.

It would be interesting to know an average probability that an inactive main-belt asteroid becomes active due to a meteoroid impact. Unfortunately, we do

[2] https://www.minorplanetcenter.net/iau/mpc.html (downloaded on August 3, 2022)

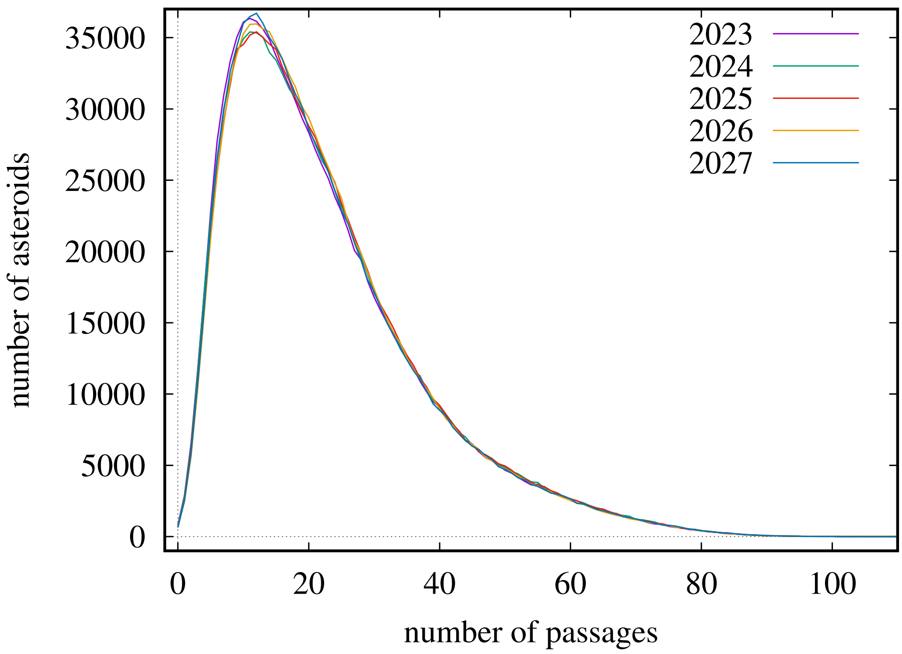

Figure 1. The distribution of the number of passages of asteroids through the known meteoroid stream within the distance of 0.05 au in a given year.

not have the sufficient input data to estimate such a probability. The width of the orbital corridor of meteoroid streams and the number density of meteoroids in the streams and sporadic background is unknown. The size-distributions of meteoroids is known only for several streams and only in the region around the Earth's orbit.

4. Some examples of possible triggering

There are several known asteroids, which were discovered to be inactive, but later a significant increase in brightness was observed. One may ask whether their outburst might have been triggered by an impact of a stream meteoroid. To answer this question, it is necessary to know, except of other, whether the asteroid passed through a stream or streams a certain period before the activity occurred. In this section, we provide such information about the passages of three asteroids, 493 Griseldis, 6478 Gault, and 62412 (2000 SY178), for the period starting two months before their outburst, or before their first outburst, and ending in time of their outburst, or the last observed outburst.

Table 1. The dates of the closest approaches of asteroids 493 Griseldis, 6478 Gault, and 62412 (2000 SY178) to the meteoroid streams in the period starting two months before their first observed outburst and ending in time of their last observed outburst. The listed parameters are: IAU - the official IAU number of shower, S. - the number of solution of the shower (some showers were reported by more than a single author team), n - number of meteors, arc - arc to which the asteroid approached, MOID - the minimum orbit intersection distance [au], r_{obj} - heliocentric distance of the asteroid [au], v_{rel} - its relative velocity in respect to a meteoroid moving in the mean orbit of the stream [km s^{-1}], and the angle between the velocity vectors of the asteroid and the meteoroid [deg], all at the moment of the closest approach of the asteroid to the mean orbit of the stream. The date of the closest approach is given in the last column.

IAU	S.	n	arc	MOID	r_{obj}	v_{rel}	angle	date
				493 Griseldis				
#0351	0	519	post-perih.	0.0111	2.36	28.30	107.28	2015 1 23.31
#0370	0	739	pre-perih.	0.0122	2.34	20.38	99.67	2015 1 29.31
#0354	0	823	post-perih.	0.0399	2.34	24.78	101.99	2015 1 29.31
#1115	0	7	post-perih.	0.0562	2.34	25.42	104.59	2015 1 31.31
#0165	2	89	pre-perih.	0.0857	2.33	21.94	100.14	2015 2 2.31
#1171	0	801	post-perih.	0.0272	2.29	28.56	113.85	2015 2 19.31
#0727	0	10	pre-perih.	0.0068	2.28	15.35	86.26	2015 2 22.31
#0513	0	77	pre-perih.	0.0598	2.27	16.05	84.84	2015 2 27.31
#0324	1	4	post-perih.	0.0614	2.26	25.23	97.45	2015 3 4.31
#1073	0	66	pre-perih.	0.0353	2.23	24.04	82.14	2015 3 14.31
#0428	1	22	pre-perih.	0.0614	2.22	16.17	85.83	2015 3 16.31
#0564	0	33	post-perih.	0.0446	2.22	28.96	97.41	2015 3 17.31
#0324	0	203	post-perih.	0.0416	2.22	25.98	97.76	2015 3 19.31
				6478 Gault				
#0219	1	17	pre-perih.	0.0547	2.13	15.39	45.88	2013 7 21.58
#0263	0	2	pre-perih.	0.0789	2.14	18.65	80.98	2013 7 22.58
#0219	0	5	pre-perih.	0.0983	2.14	22.98	60.64	2013 7 22.58
#0018	0	18	pre-perih.	0.0954	2.15	29.50	103.92	2013 7 27.58
#0094	1	2	post-perih.	0.0776	2.16	27.26	105.56	2013 8 2.58
#0714	0	7	pre-perih.	0.0431	2.16	13.52	33.88	2013 8 3.58
#0202	1	949	post-perih.	0.0506	2.18	35.10	104.14	2013 8 12.58
#0173	2		pre-perih.	0.0701	2.19	21.88	93.00	2013 8 16.58
#0289	0		pre-perih.	0.0436	2.21	21.67	91.57	2013 8 26.58
#0025	1	53	pre-perih.	0.0295	2.22	17.82	60.63	2013 8 31.58
#0173	3	288	pre-perih.	0.0559	2.23	21.27	93.30	2013 9 2.58
#0038	0	3	post-perih.	0.0636	2.24	40.35	148.90	2013 9 9.58
#0096	6	74	post-perih.	0.0653	2.25	24.95	102.53	2013 9 11.58
#1054	0	26	pre-perih.	0.0644	2.25	33.63	85.76	2013 9 12.58
#0017	2	22	pre-perih.	0.0516	2.26	17.10	62.07	2013 9 17.58
#0017	1	25	pre-perih.	0.0503	2.27	16.03	58.35	2013 9 19.58
#0631	0	57	pre-perih.	0.0630	2.27	16.04	60.33	2013 9 20.58

Table 1. Continued.

IAU	S.	n	arc	MOID	r_{obj}	v_{rel}	angle	date
#0096	2	7	post-perih.	0.0069	2.27	26.87	108.07	2013 9 21.58
#0449	0	7	post-perih.	0.0089	2.27	10.30	33.23	2013 9 21.58
				62412 SY178				
#1091	0	159	pre-perih.	0.0299	3.03	12.17	48.16	2014 2 1.18
#0232	0	2	pre-perih.	0.0077	3.04	8.05	47.25	2014 2 7.18
#0803	0	77	post-perih.	0.0608	3.05	14.66	87.40	2014 2 25.18
#0645	0	10	pre-perih.	0.0944	3.05	33.69	133.51	2014 2 28.18
#0199	0	6	post-perih.	0.0822	3.06	17.79	83.97	2014 3 18.18
#0069	0		pre-perih.	0.0808	3.07	15.16	90.79	2014 3 27.18
#0069	1	70	pre-perih.	0.0588	3.07	14.94	90.51	2014 4 2.18
#1132	0	1721	pre-perih.	0.0152	3.09	15.46	91.58	2014 4 22.18
#1042	0	16	post-perih.	0.0881	3.09	15.64	88.73	2014 4 27.18

The outburst of 493 Griseldis occurred on March 17−21, 2015 (Tholen et al., 2015). According to Chandler et al. (2019), 6478 Gault started its comet-like activity in 2013 and this activity persists until the present (the first outburst was detected on September 22, 2013). The mechanism of this long-term activity is probably something other than a meteoroid impact. The outburst of 62412 (2000 SY178) was detected, for the first time, on March 28, 2014 and lasted until May 2, 2014 (Sheppard & Trujillo, 2015).

The dates of the passages of these objects through some streams, before their first outburst, are listed in Table 1. The structure of this table is the same as the output from the computer program written into file "datelist????.dat". Specifically, we provide the dates for the closest approaches of a given asteroid within the MOID equal to 0.1 au. During the two-month period before the outburst, each of them passed through a few streams.

493 Griseldis crossed the corridors of the December σ-Virginids, #428 and 61-Ursae Majorids, #564 immediately before the outburst. As well it also crossed the ϵ-Perseids, #324 when its activity increased. Of these, the 61-Ursae Majorids and ϵ-Perseids are the established showers according to the MDC List of Established Showers. On February 19, 2015, the asteroid passed through quite a numerous shower − the January γ-Camelopardalids, #1171. In year 2015, this asteroid passed through 66 streams. It is significantly more than the average or median number of passages.

Immediately before the first outburst, 6478 Gault crossed the orbital corridors of the δ-Arietids, #631, the established shower Northern δ-Cancrids, #96, and April β-Sextantids, #449. The last shower was meanwhile removed from the Working List, therefore its existence is questionable. One to three days before the outburst, it also crossed the corridor of established Northern Taurids, #17, which are numerous, though the number of meteors of their solutions in Table 1 is not very large. The number of passages of the asteroid through the streams in 2013 was 70, which is also a much larger number than the average or median.

Asteroid 62412 (2000 SY178) crossed the established stream Southern μ-Sagittariids, #69, immediately before its first outburst. In this case, we can see an uncertainty of our calculation due to uncertain data on meteor streams. The closest approach on March 27, 2014 is predicted for the solution No. 0 of the shower. For solution No. 1, the closest approach is calculated to occur on April 2, 2014, i.e. 6 days later. During the 62412's activity, the object passed a relatively numerous stream of 3-Sagittariids, #1132, on April 22, 2014. However, the calculations resulted in only 21 passages of this asteroid through the meteoroid stream in 2014, which is comparable to the average.

We could see that several passages of the asteroids through the meteoroid streams occurred in all these randomly selected examples. In two cases, this number significantly exceeded the average (see the distribution of passages in Fig. 1). Nevertheless, further information would be needed if one wanted to evaluate the probability that the activity was triggered by a meteoroid impact.

5. Conclusion

We created a computer program to calculate the MOID between the orbit of a Solar-System small body and the known set of mean orbits of known meteoroid streams. When the MOID is low enough, then we can assume that the object passed or will pass through the orbital corridor of the stream. Such a passage or passages are the necessary condition to suspect that the activity could be triggered by an impact of a meteoroid, which is a member of the stream. The program, static-binary executable files as well as the source code, are public-domain and, therefore, available along with this article. It is also accessible on the GitHub service: https://github.com/neslusan/BELTCROSS2

The program can be especially useful to check if an asteroid, which was observed to become active, passed through a meteoroid stream, and through which stream, a short time before the beginning of the activity. The basic characteristics of the closest encounter of the asteroid with the stream are provided by the program.

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