When Was Mars Last This Close?

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When Mars makes its very close approach to Earth in August, astronomers everywhere - and especially planetarians - will be asked when Mars last came this close, and when next it will come closer. The answer would be simple if it were a matter of a few hundred years, as planetary distances can be calculated quickly and accurately within a few thousand years of the present, but in this case the actual answer is more difficult to determine.

In August Mars comes closer to Earth than in the last 60,000 years. This article explains why this is so.

Essential to a solution of the problem is an understanding of the changing eccentricities of the orbits of the Earth and Mars. In 1994 Simon et al. (1) published an expression for the eccentricity of the orbit of the Earth (see Chapter 33 in *More Mathematical Astronomy Morsels*). Presently, the eccentricity is 0.0167 and decreasing. The next minimum of the eccentricity will be 0.0023 in about the year 29,500. Another, still deeper minimum (0.0006) will occur near A.D. 465,000 and near that epoch the orbit of the Earth will be almost exactly circular. But at other times the eccentricity can be as large as 0.06. The eccentricity of the orbit of the Earth reaches maximum values at intervals of about 100,000 years.

The eccentricity of the orbit of Mars appears to vary with a period of 96,000 years, which is superposed on a greater variation with a period of about 2,200,000 years. Presently the eccentricity varies around the value 0.09, but one million years ago its mean value was 0.03.

In the year 2000, the value of the eccentricity of the Martian obit was 0.0934. It is slowly increasing, and it will reach a maximum value of 0.1051 around A.D. 24,100. But 186,000 years later it will reach a still higher maximum, 0.1184, the largest within a two million time span around the present. Figure 1 shows the variation in the orbit of Mars during a time span of two million years. Oppositions of Mars occur at intervals of 780 days, or 25.6 months. Pages 63-96 of the second edition of my *Astronomical Tables of the Sun, Moon, and Planets* (Willmann-Bell, 1995) gives the complete list of all oppositions of Mars taking place between the years 0 (as astronomers call 1 B.C.) and A.D. 3000, and also the corresponding date when the distance of Mars to the Earth is a minimum. Mars is nearest to the Earth near the time of its opposition, but due to the eccentricities of the orbits, opposition and least distance don't coincide exactly. The time interval between Mars' opposition and its least distance to Earth can be as large as $8^1/_2$ days. In 2001, for instance, opposition took place on June 13 but least distance was on June 21.

Each opposition is followed by a very similar one 79 years later. For example, the very favorable opposition of 1956 was a close repetition of that of 1877, when Asaph Hall discovered the two satellites of Mars. This period corresponds to 79 revolutions of the Earth and 42 revolutions of Mars around the Sun. After 79 years, the oppositions of Mars repeat under nearly identical circumstances, with a delay of only 2 to 5 days in the year. The opposition of August 28, 2003, is a repetition of the oppositions of August 23, 1924 and of August 18, 1845.

In the course of centuries, close oppositions of Mars are gradually becoming more frequent. For example, Mars came to less than 0.375 AU from the Earth 11 times between the years 0 and 1000, and 15 times between 1000 and 2000, but 22 times between the years 2000 and 3000. This gradual improvement is due to the secular variations of both Mars and the Earth, resulting from the gravitational attractions of the other planets. The orbit of Mars is slowly becoming more elliptical, its eccentricity increasing from 0.09156 in the year 0 to 0.09430 in A.D. 3000. This allows it to approach closer to Earth. In August 2003 Mars comes closer to the Earth than at any time in the last several thousand years, although actually only a little closer than at the approach of 1924. Table 1 shows the closest approaches of Mars from the years 0 to 3000. The next time Mars will come closer than this August will be on August 28, 2287, when Mars will be 0.37225 AU distant. The least distance between Mars and the Earth during this millennium will be 0.37200 AU on September 8, 2729. Because the closest distance between the orbits con-

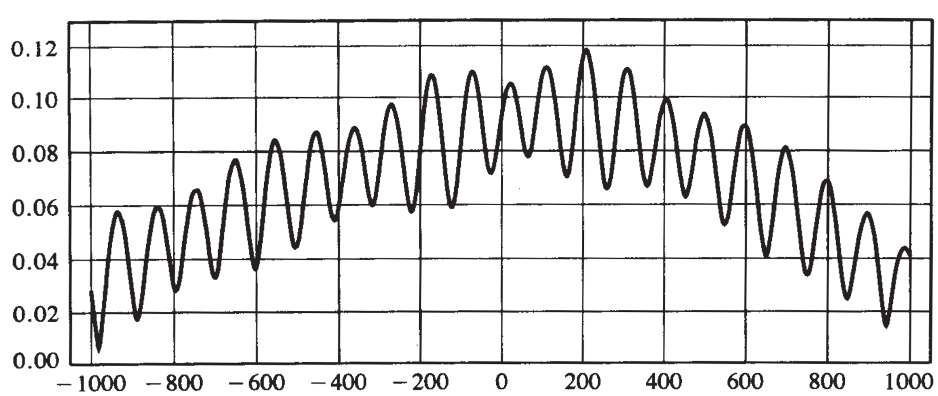

Figure 1: Variation of the eccentricity of the orbit of Mars during a time span of two million years. Horizontally: the time in thousands of years from A.D. 1850. (Figure 35a in *More Mathematical Astronomy Morsels*)

30 July 21	0.37458	1356 Aug. 10	0.37482	2287 Aug. 28	0.37225
235 July 17	0.37436	1403 July 31	0.37362	2366 Sept. 2	0.37239
314 July 21	0.37416	1482 Aug. 3	0.37306	2413 Aug. 21	0.37422
393 July 24	0.37421	1561 Aug. 7	0.37325	2445 Sept. 5	0.37296
472 July 28	0.37434	1640 Aug. 20	0.37347	2492 Aug. 24	0.37322
598 July 20	0.37440	1687 Aug. 9	0.37434	2524 Sept. 10	0.37364
677 July 24	0.37403	1719 Aug. 25	0.37401	2571 Aug. 30	0.37238
756 July 27	0.37369	1766 Aug. 13	0.37326	2603 Sept. 15	0.37485
835 Aug. 1	0.37391	1845 Aug. 18	0.37302	2650 Sept. 3	0.37201
914 Aug. 4	0.37459	1924 Aug. 22	0.37285	2729 Sept. 8	**0.37200**
961 July 23	0.37439	2003 Aug. 27	0.37272	2776 Aug. 27	0.37436
1040 July 27	0.37382	2050 Aug. 15	0.37405	2808 Sept. 11	0.37230
1119 July 31	0.37340	2082 Aug. 30	0.37356	2855 Aug. 31	0.37311
1198 Aug. 3	0.37346	2129 Aug. 19	0.37328	2887 Sept. 16	0.37292
1277 Aug. 7	0.37409	2161 Sept. 4	0.37459	2934 Sept. 5	0.37217
1324 July 26	0.37444	2208 Aug. 24	0.37279	2966 Sept. 20	0.37404

Table 1: Approaches of Mars to less than 0.375 AU to the earth, years 0 to 3000. (Table 36B in *More Mathematical Astronomy Morsels*)

tinues to decrease after A.D. 3000, still smaller distances will occur then. Between the years 3000 and 4000 the least Earth-Mars distance will be 0.37061 AU on September 25, 3818.

As the orbital eccentricity of Mars will continue to increase until A.D. 24,100, when it will be as large as 0.1051, the planet's perihelion distance will decrease accordingly. It appears that around A.D. 25,000, the least separation between the orbits will be only 0.3613 AU, its smallest value during the two million years around the present.

The next time Mars will come closer than this August will be on August 28, 2287 ...

Figure 2 shows how the least distance between the orbits of Mars and Earth has varied in the past. The two figure have been calculated on the base of work by the French astronomer Bretagnon (ref. 2 and 3). From this work I deduced that since the year 71,000 BC the least distance between the orbits of Earth and Mars has been larger than 0.3728 AU, with the consequence that closer approaches of Mars than that of 2003 happened more than 73,000 years ago. This was stated in my book.

After my book was published, I contacted Dr. Aldo Vitagliano (of Naples University, Italy) and asked him to investigate the motion of Mars by numerical integration. In April 2002, Prof. Vitagliano found that the last time Mars was closer to Earth than it will be in 2003, was on September 12 of the year -57616 (that is, 57617 B.C. of the historians). So, that was 60,000 years ago. The 73,000 years cited in my book was, after all, a good approximation. It should be noted that the aim of the articles by Bretagnon is to provide a good approximation of the evolution of the orbits in the course of two million years, not to provide a method for calculating accurate ephemerides. "Care must be taken with that date, September 12. To define that date, the Julian calendar has been extended indefinitely towards the past — as is custom for astronomers. However, we know that the Julian calendar is off by 1 day after about 130 years. So, after 58,000 years the calendar is off by about 446 days, or more than one year!"

References

Much of the text of this article, including the table and two figures, is taken from Chapters 33 - 36 in *More Mathematical Astronomy Morsels* by Jean Meeus, Willmann-Bell, Richmond, Virginia, 2002. For more information see: http://www.willbell.com/math/moremorsels .htm.

For a full list of Mars oppositions from the years 0 to 3000, see *Astronomical Tables of the Sun, Moon, and Planets*, second edition, Jean Meeus, Willmann-Bell, Richmond, Virginia, 1995.

(1) J. L. Simon, P. Bretagnon, J. Chapront, M. Chapront-Touzé, G. Francou, and J. Laskar, "Numerical expressions for precession formulae and mean elements for the Moon and the planets," *Astronomy and Astrophysics*, vol. 282, pages 663-683, 1994.

(2) P. Bretagnon, *Astronomy and Astrophysics*, vol. 30, pages 141-154, 1974.

(3) P. Bretagnon, *Milankovitch and Climate*, Part 1, pages 41-53, 1984.

(4) A. Vitagliano, personal communication to the author, 2002. ☆

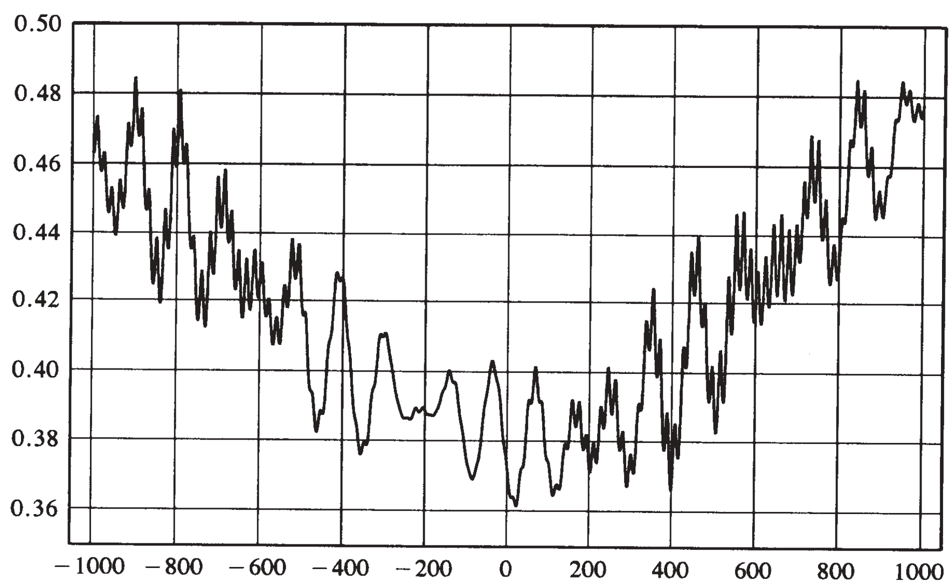

Figure 2: The least distance between the orbits of Mars and Earth (in AU) during a span of two million years. Horizontally: the time in thousands of years from A.D. 1850. (Figure 36c in *More Mathematical Astronomy Morsels*)