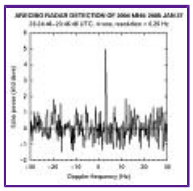
Radar Refinement of the Orbit of Asteroid 99942 Apophis (2004 MN4)

The several-hundred-meter asteroid 99942 Apophis (2004 MN4) was discovered in June 2004 and lost until it was rediscovered in December 2004. Integration of the orbit calculated from the half-year-long set of optical astrometry revealed an extremely close approach to Earth on April 13, 2029. Arecibo delay-Doppler radar astrometry obtained during the last week in January 2005 showed the object to be several hundred kilometers closer than had been predicted by the optical position measurements.



First radar echo from asteroid 2004 MN4

This correction refined our estimate of the orbit and predicted a 2029 approach to the geocenter at a distance of:

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0.000242 +/- 0.000058 AU
36200    +/- 8700     km
0.094    +/- 0.023    Earth-Moon distances
5.7      +/- 1.4      Earth radii
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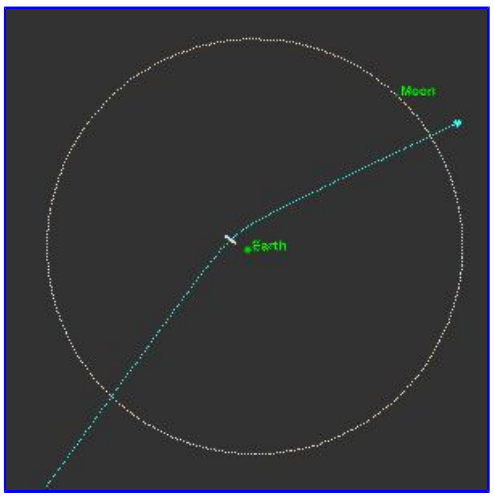
This is 28,000 km closer than predicted by the pre-radar (optical-only) orbit and closer than geosynchronous satellites.

The asteroid's 2029 flyby is closer than any known past or future approach by natural objects larger than about 10 meters (other than objects that have entered Earth's atmosphere).

2004 MN4 is expected to reach 3rd magnitude for observers in Europe, Africa, and western Asia, where it will be visible to the unaided eye.

Approaches as close as the 2029 event, by objects as large as 2004 MN4, are very rare, occuring on average at intervals longer than a thousand years.



Click here to enlarge this sketch of the asteroid's most likely trajectory during its 2029 close approach as predicted using the Jan. 2005 radar astrometry. Since the asteroid's position in space is not perfectly known at that time, the white dots at right angles to the blue line are possible alternative positions of the asteroid. Neither the nominal position nor any of its possible alternative positions touches the Earth, effectively ruling out an Earth impact in 2029.

There are several opportunities for radar observations of this object before 2029. The predicted echo signal-to-noise ratios in the following table use current radar system parameters and our recent results for the asteroid's radar signature.

		<----Arecibo---->		<---Goldstone--->	
Year	Month	SNR/Date	SNR/Run	SNR/Date	SNR/run
2005	Jan	14	5	8	1
2005	Aug	6	2	0	0
2006	May	5	2	1	0
2013	Jan	33	10	11	1
2020	Oct	7	3	1	0
2021	Mar	110	26	8	1
2028	Sep	7	2	0	0

Click here to go to the 2004 MN4 news story on the NASA Near Earth Object Program's web site.

Click here to go to the 2004 MN4 Earth Impact Risk summary page of the NASA Near Earth Object Program's web site.

Click here to go to a University of Michigan press release on how the 2029 encounter will alter the asteroid's spin state. For a better version of that site's animation showing what such spin-state alteration might look like, click here.i

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Below are three IAU Circulars reporting radar results for this asteroid. The last two report radar detections in Aug. 2005 and May 2006, and refine the above results.

Circular No. 8477
Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
Mailstop 18, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
IAUSUBS@CFA.HARVARD.EDU or FAX 617-495-7231 (subscriptions)
CBAT@CFA.HARVARD.EDU (science)
URL http://cfa-www.harvard.edu/iau/cbat.html ISSN 0081-0304

2004 MN_4

On 2004 Dec. 20, K. E. Smalley (cf. MPEC 2004-Y25) identified an object placed on the 'NEO Confirmation Page' on Dec. 18 (following its discovery by G. J. Garradd via the Siding Spring Survey) with 2004 MN_4 (which had been recorded at Kitt Peak on June 19 and 20; cf. MPS 109613). Although the recognition of further prediscovery observations by Spacewatch on Mar. 15 (MPEC 2004-Y70) precluded the possible 2029 Apr. 13 earth impact discussed extensively in the WWW during 2004 Dec. 23-27 [notably on the Jet Propulsion Laboratory (JPL) and Pisa NEODys "risk pages"], it was clear that the object would then make an unusually close approach. L. A. M. Benner, JPL; M. C. Nolan, National Astronomy and Ionosphere Center, Arecibo Observatory; J. D. Giorgini, S. R. Chesley, and S. J. Ostro, JPL; and D. J. Scheeres, University of Michigan, report: "Arecibo delay-Doppler radar astrometry obtained on 2005 Jan. 27, 29, and 30 significantly refines the 2004 MN_4 orbit. On Jan. 29.0 UT, the range was 294 km closer to the earth than the pre-radar orbit solution predicted. This correction results in a 2029 approach to the geocenter of only 0.000245 +/- 0.000060 AU (36700 +/- 9000 km or 5.7 +/- 1.4 earth radii, 3-sigma uncertainties), which is just below geosynchronous orbit and 28000 km closer than predicted by the pre-radar ephemeris. During its close approach, it is likely that tidal torques will significantly alter the object's spin state."

2005 February 4 (8477) Daniel W. E. Green

Circular No. 8593
Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
Mailstop 18, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
IAUSUBS@CFA.HARVARD.EDU or FAX 617-495-7231 (subscriptions)
CBAT@CFA.HARVARD.EDU (science)
URL http://cfa-www.harvard.edu/iau/cbat.html ISSN 0081-0304

(99942) APOPHIS

J. D. Giorgini, L. A. M. Benner, S. J. Ostro, Jet Propulsion Laboratory; M. C. Nolan, Arecibo Observatory; and M. W. Busch, California Institute of Technology, report: "Arecibo (2380-MHz, 12.6-cm) radar observations of (99942) Apophis = 2004 MN_4 (cf. IAUC 8477) made during Aug. 7.655-7.769 UTC produced a CW detection and a Doppler measurement of 8186.8 Hz at Aug. 7.713, a correction of +0.3 +/- 0.2 Hz (+18.9 +/- 12.6 mm/s) relative to nominal prediction. Including this Doppler correction in a new orbit estimate and n-body gravitational propagation increases the 2029 April 13.9 Earth-center miss-distance from 5.77 +/- 0.39 to 5.86 +/- 0.12 Earth radii, reducing the along-track position uncertainty at closest approach from +/- 1957 to +/- 757 km; the volume of the spatial uncertainty region decreases from 173000 to 39800 km**3. The new Doppler measurement increases the predicted nominal Earth close approach in 2036 from 0.005 to 0.14 AU. However, we have found that computational noise intrinsic to 64-bit representations of real numbers used in arithmetical operations, exacerbated by the close Earth encounter in 2029, can accumulate trajectory-prediction error exceeding the radius of the earth by 2036. Using more precise 128-bit representations, the specified local error tolerance was reduced from 10**-14 to 10**-19 and the maximum predictor/corrector order (used for step-size and error-control decisions) increased from 14/15 to 21/22. This approach reduces

error growth in the integration due to the finite representation of
real numbers and permits examination of those specific orbit
variations in 2036 for which trajectory offsets comparable to the
size of the earth are significant."
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2005 September 2 (8593) Daniel W. E. Green

Circular No. 8711
Central Bureau for Astronomical Telegrams
INTERNATIONAL ASTRONOMICAL UNION
Mailstop 18, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
IAUSUBS@CFA.HARVARD.EDU or FAX 617-495-7231 (subscriptions)
CBAT@CFA.HARVARD.EDU (science)
URL http://cfa-www.harvard.edu/iau/cbat.html ISSN 0081-0304

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(99942) APOPHIS
L. A. M. Benner, J. D. Giorgini, and S. J. Ostro, Jet
Propulsion Laboratory; M. C. Nolan, Arecibo Observatory; and M. W.
Busch, California Institute of Technology, report that Arecibo
(2380-MHz, 12.6-cm) radar observations of minor planet (99942) =
2004 MN_4 during May 6.497-6.562 UTC yielded a 5.5-sigma
continuous-wave detection and a Doppler measurement of -118256.8 Hz
at May 6.534, for a correction of +0.1 +/- 0.1 Hz (+6 +/- 6 mm/s)
relative to the nominal prediction. An orbit estimation
incorporating the new Doppler measurement with 779 optical
measurements spanning 2004 Mar. 15-2006 Mar. 26, along with the
four Doppler and two range measurements from observations in 2005,
increases the 2029 Apr. 13.9 earth-center miss-distance by 450 km,
from 5.86 +/- 0.11 to 5.93 +/- 0.09 earth radii, and reduces the
along-track-position uncertainty at closest approach from +/- 730
to +/- 570 km (cf. IAUC 8593). The volume of the one-standard-
deviation spatial uncertainty region decreases by 23 percent, from
261000 to 201000 km**3, and the nominal predicted earth-close-
approach distance in 2036 increases from 0.168 to 0.276 AU, moving
the statistical earth encounter to a lower-probability region
within the distribution of possible orbits.

2006 May 17 (8711) Daniel W. E. Green