JET PROPULSION LABORATORY **INTEROFFICE MEMORANDUM**

IOM 392R-21-008

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TO: Distribution

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SUBJECT: JPL orbit solution 104 of Dimorphos.

This IOM documents orbital solution 104 of Dimorphos, which is an update to solution 101 documented in IOM 392R-21-004. The new solution fits 10 additional data points obtained between December 2020 and January 2021. The formal 3σ orbital phase uncertainty of solution 104 during the planned Double Asteroid Redirection Test (DART) mission impact in September-October 2022 is 5.4°.

1 Methods

We used the methods documented in IOM 392R-21-004 for estimating solution 104. We used all the observations listed in Table 1 of IOM 392R-21-004 as well as 10 additional observations that we received from Nick Moskovitz (personal communication) for generating solution 104. The additional observations are listed in Table 1.

Table 1: Mutual event times measured in observations from 2020 and 2021. All times are one-way light-time corrected to reflect the time of the events at the asteroid, not the times that they were observed at Earth.

Calendar date (UTC)	Julian date	Contact	Occulted/Eclipsed object	Event type	1σ Uncertainty (days)
2020 Dec 12 14:21:50	2459196.0985	1.5	Primary	Occultation	0.004
2020 Dec 12 15:00:34	2459196.1254	3.5	Primary	Occultation	0.004
2021 Jan 12 15:06:46	2459227.1297	1.5	Secondary	Occultation	0.013
2021 Jan 17 14:26:00	2459232.1014	1.5	Secondary	Occultation	0.007
2021 Jan 18 08:22:50	2459232.8492	1.5	Primary	Occultation	0.011
2021 Jan 18 09:00:17	2459232.8752	3.5	Primary	Occultation	0.007
2021 Jan 18 09:14:41	2459232.8852	1.5	Primary	Eclipse	0.007
2021 Jan 18 09:40:45	2459232.9033	3.5	Primary	Eclipse	0.017
2021 Jan 20 01:54:20	2459234.5794	1.5	Secondary	Occultation	0.006
2021 Jan 20 03:40:19	2459234.6530	3.5	Secondary	Eclipse	0.011

Table 2: Best-fit orbital parameters of solution 104. M_0, n_0 and $\dot{n}$ were fit. Pole (λ, β) is not estimated and is from Scheirich and Pravec (2021) (DART internal report). The osculating period is derived from n_0. GM_{sys} is the standard gravitational parameter of the system and is derived from the estimated value of n_0 and assumed value of the semimajor axis at epoch. $\chi^2_\nu = \chi^2/(n_{obs} - n_{est})$ is the reduced χ^2, where n_{obs} is the number of observations and n_{est} is the number of estimated parameters.

Parameter	Value	1σ uncertainty
M_0 (°)	79.4	1.8
Period (h)	11.9216289	0.0000028
n_0 (rad s^{-1})	1.46400233e-04	0.00000035e-4
$\dot{n}$ (rad s^{-2})	5.0e-18	1.0e-18
Epoch (TDB)	2011-08-21.5	
χ^2	21.6	
χ^2_ν	0.37	
$(\lambda, \beta)^\circ$	$(320.6, -78.6)^\circ$	
GM_{sys} (m^3 s^{-2})	37.0362727488241445575	

Table 3: Covariance matrix corresponding to solution 104 in Table 2 at epoch 2011 August 21.5 TDB. Units of the parameters are in radians and seconds.

	M_0	n_0	$\dot{n}$
M_0	1.03430820e-03	3.66676452e-13	-3.09701468e-20
n_0	3.66676452e-13	1.22137708e-21	-1.00063187e-29
$\dot{n}$	-3.09701468e-20	-1.00063187e-29	9.93383023e-37

2 Results

2.1 Best-fit solution

We adopted the best-fit orbit pole reported by Scheirich and Pravec (2021) of ecliptic $(\lambda, \beta) = (320.6, -78.6)^\circ$. Table 2 shows the best-fit parameters and formal 1σ uncertainties of solution 104 and Table 3 shows the corresponding covariance. Figure 1 compares projections of best-fit parameters and corresponding formal 3σ uncertainties of solution 104 with solution 101 and a shorter data-arc solution. The formal 3σ uncertainty of solution 104 during the planned DART impact date of 2022 October 01 is 5.4°. Based on tests performed in IOM 392R-20-001, we recommend that the formal uncertainties derived from the covariance matrix in Table 3 be multiplied by 1.3.

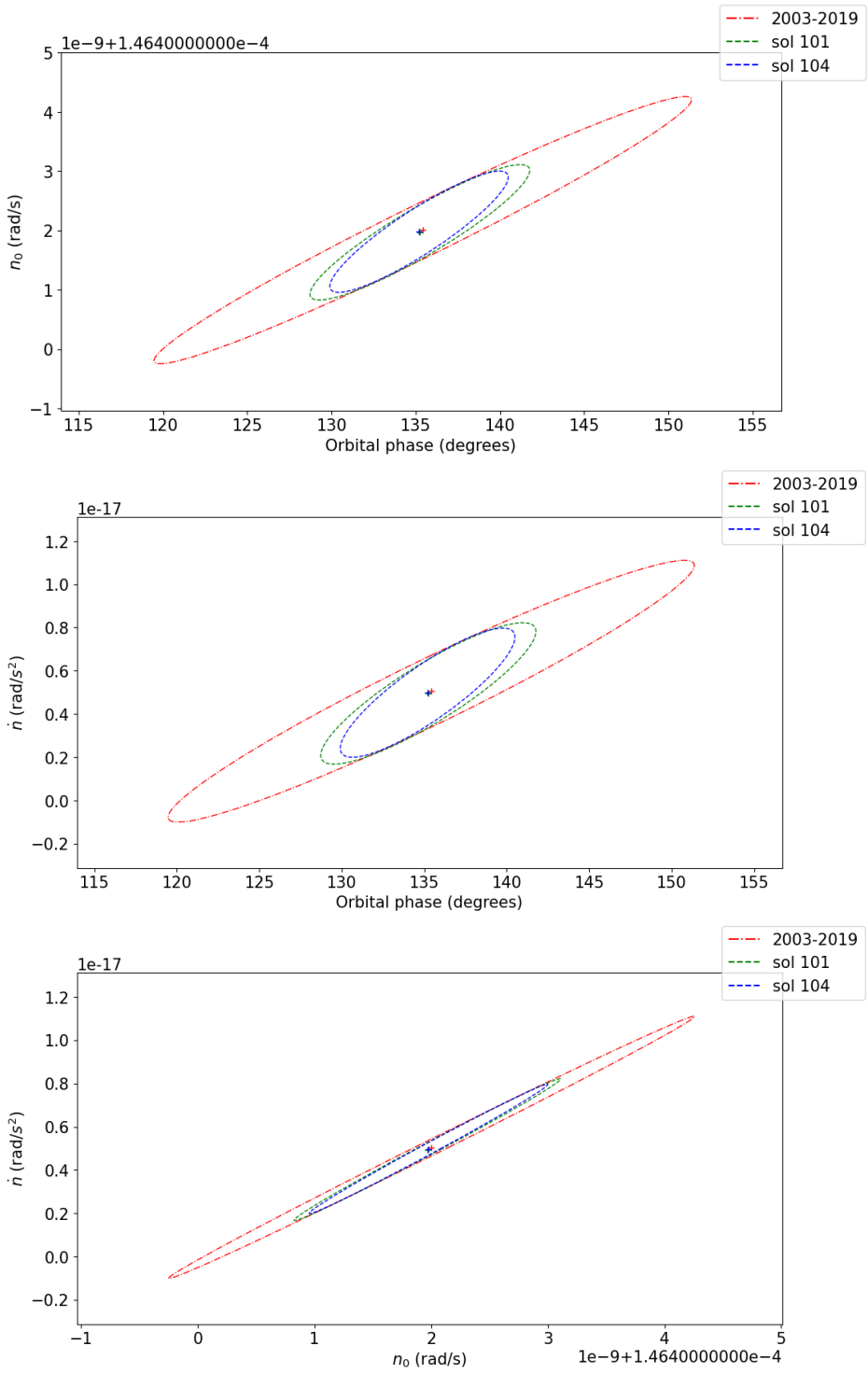

Figure 1: Projections of the best-fit parameters and their 3σ uncertainties for various orbital solutions of Dimorphos. Solution using a data-arc of 2003-2019 is shown in red. Solution 101, published in IOM 392R-21-004, is shown in green. Solution 104, the current best-fit solution, is shown in blue. Solutions are mapped to epoch 2022-Sep-25 23:26:04 UTC, which is the DART impact date corresponding to the first launch opportunity at 2021-Nov-18 06:28:10 UTC.

Delivery

SPICE IDs. We are using a new extended SPICE ID scheme for SPICE kernels delivered in support of the DART mission. This scheme derives the SPICE ID from the asteroid's IAU number from

$$\text{SPICE ID} = \text{IAU No.} + 20{,}000{,}000.$$

This SPICE ID generally refers to the barycenter of a system, including for solitary asteroids. If this number is prepended with a single digit from 1–9 then the ID refers to a specific component of a multi-body system, with '9' being used to designate the primary body. For the Didymos system the following SPICE IDs apply.

SPICE ID	Associated Position
20065803	Didymos system barycenter
120065803	Dimorphos center of mass (secondary body)
920065803	Didymos center of mass (primary body)

Files. The following files and documentation for Dimorphos are available from the JPL Solar System Dynamics (SSD) FTP server

`ftp://ssd.jpl.nasa.gov`

in the directory `pub/eph/small_bodies/dart/`, which will be the base directory for DART file deliveries from SSD. Within the `dart` directory are three sub-directories as follows:

`dart/didymos/` This directory holds the current ephemeris files for the Didymos system barycenter.

`dart/dimorphos/` This directory holds the current ephemeris and related files for Dimorphos:

- `dimorphos_s104.bsp` - SPK file containing the ephemeris of Dimorphos (120065803) relative to the primary (920065803) and of 920065803 relative to the Didymos system barycenter (20065803). The latter was computed by assuming a secondary to primary mass ratio of 0.0071 from Naidu et al. (2020).

  The time span of the SPK file is from 2000-Jan-01 to 2030-Dec-31. The associated covariance is listed in Table 3. We suggest scaling the formal uncertainties derived from this covariance by a factor of 1.3 in order to capture contributions from unmodeled parameters.

- `dimorphos_s104.tpc` - Planetary Constants Kernel (PCK) file that describes the orientation of dimorphos. The PCK file is designed to keep the body-fixed x-axis of Dimorphos oriented towards the system barycenter.

`dart/doc/` This directory includes miscellaneous documentation files.

Acknowledgement

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References

Naidu, S. P., Benner, L. A. M., Brozovic, M., Nolan, M. C., Ostro, S. J., Margot, J. L., Giorgini, J. D., Hirabayashi, T., Scheeres, D. J., Pravec, P., Scheirich, P., Magri, C., and Jao, J. S. (2020). Radar observations and a physical model of binary near-Earth asteroid 65803 Didymos, target of the DART mission. *Icarus*, 348:113777.

Scheirich, P. and Pravec, P. (2021). Results from modeling of photometric data of Didymos (2003 – 2021). Technical report, DART internal report.

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