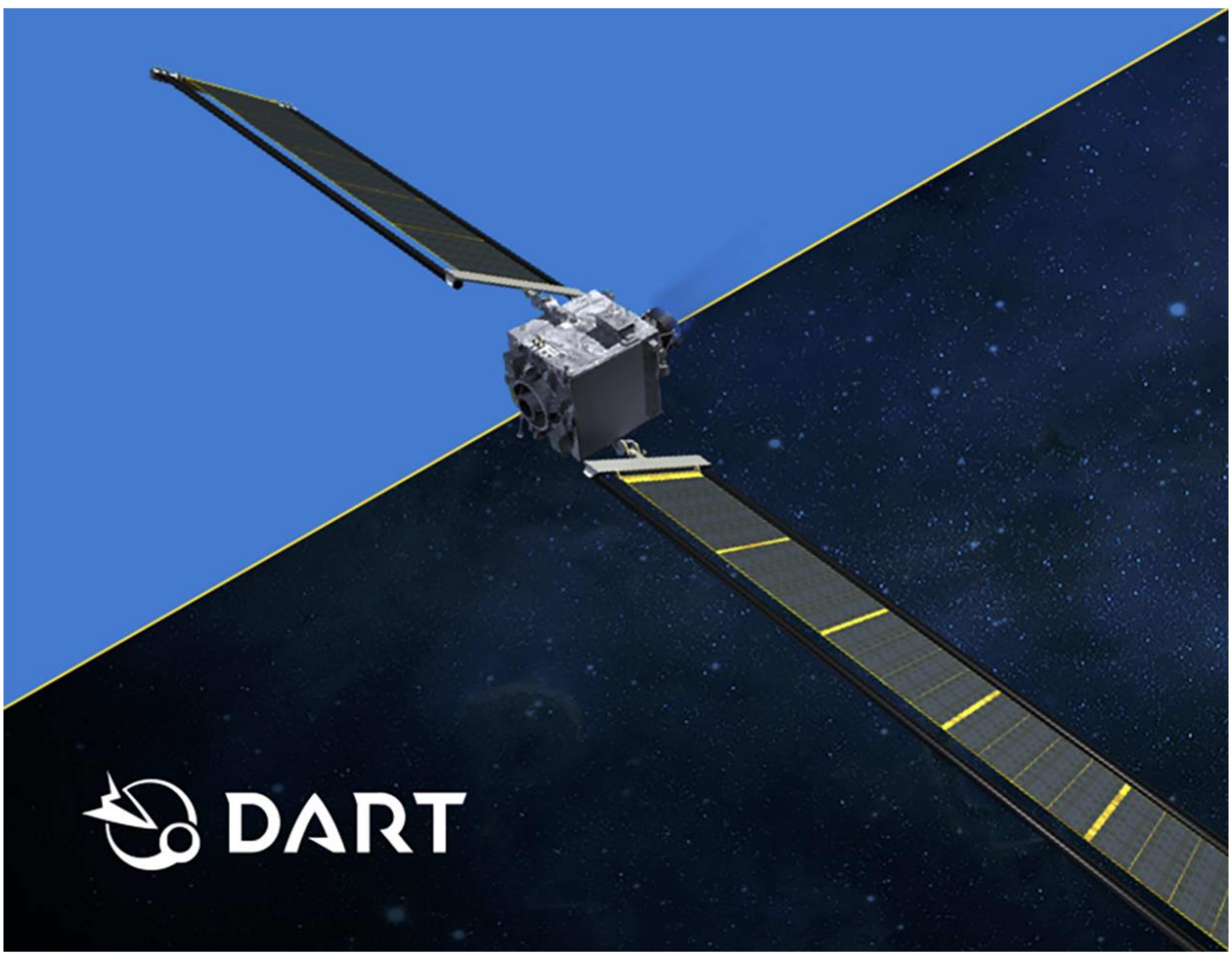
Dimorphos Coordinate System Description



Technical Content Approval

Prepared/Approved by:

Olivier Barnouin
DART Science Operations Center Lead; Proximity Operations Working Group Lead

Carolyn Ernst
DRACO Instrument Scientist

Terik Daly
DRACO Deputy Instrument Scientist

Reviewed by:

Andy Rivkin
DART Investigation Team Lead

Nancy Chabot
DART Coordination Lead

Mike Nolan
DART Investigation team member

Revision Log

Version	By	Description	Date
1	O.S. Barnouin	Release to accompany PDS delivery	Dec 2022
2	T. Daly, O.S. Barnouin	Updates for final PDS delivery and for consistency with the v004 shape model	Aug 2023

1. Introduction

This document defines and describes the coordinate system of the asteroid Dimorphos, which is the secondary asteroid in the binary Didymos asteroid system. Dimorphos was the target of NASA's Double Asteroid Redirection Test (DART). The DART spacecraft carried an imager, the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO). The DART spacecraft was accompanied by a Cubesat called LICIACube that was provided by the Italian space agency.

The coordinate system of Dimorphos is newly defined based on a shape model derived from DRACO images (Daly et al., 2023) and a pole, rotation rate, obliquity and orbit period of Dimorphos about Didymos determined from ground-based observations made by members of the DART Observations Working Group. The current version (v2) of the coordinate system document supersedes version 1 of this document, which described the coordinate system of a preliminary shape model reported in Daly, Ernst, and Barnouin et al. (2023).

2. The prime meridian

For a satellite such as Dimorphos, the location of the prime meridian is usually defined as the point closest to the primary body (in this case Didymos). However, observational constraints prevented DRACO or the LICIACube satellite from observing this location. In addition, the sub-Didymos area on Dimorphos was in shadow at the time of the DART encounter. We, therefore, follow the approach taken at Mercury (Davies and Batson, 1975), and use a surface feature that can be well recognized in DRACO images to anchor the prime meridian, and assign it a longitude consistent with 0 longitude pointing at Didymos.

We considered several factors in selecting a feature to use to anchor the prime meridian. First, boulders are the most prominent surfaces features on the asteroid, which makes a boulder a good candidate. Second, the feature should be far from the DART impact site to reduce the likelihood that its location was affected by the impact. Third, the feature had to be away from the limb seen in the images collected so as to avoid distortion. Fourth, the feature needed to be recognizable in moderate resolution images (~0.5 m/pixel) so that it could be discerned in several DRACO images and by the upcoming Hera mission, which will rendezvous with Dimorphos in the mid to late 2020s. Fifth, the feature should be near the equator to minimize correlation of the prime meridian with the pole orientation.

Figure 1 shows the boulder chosen to anchor the prime meridian of Dimorphos in unprojected DRACO images. A yellow arrow points to the chosen boulder. Table 1 gives the pixel-line location (with pixel [0,0] as the origin) of this anchor rock. Figure 2 shows the boulder in DRACO images projected on the v004 version of the Dimorphos shape model produced by the DART project and archived in the PDS, along with lines of latitude and longitude. A crest near the middle of anchor boulder defines the center of the feature. The prime meridian anchor feature is located at 239.1±0.2° E, 2.3±0.1° S.

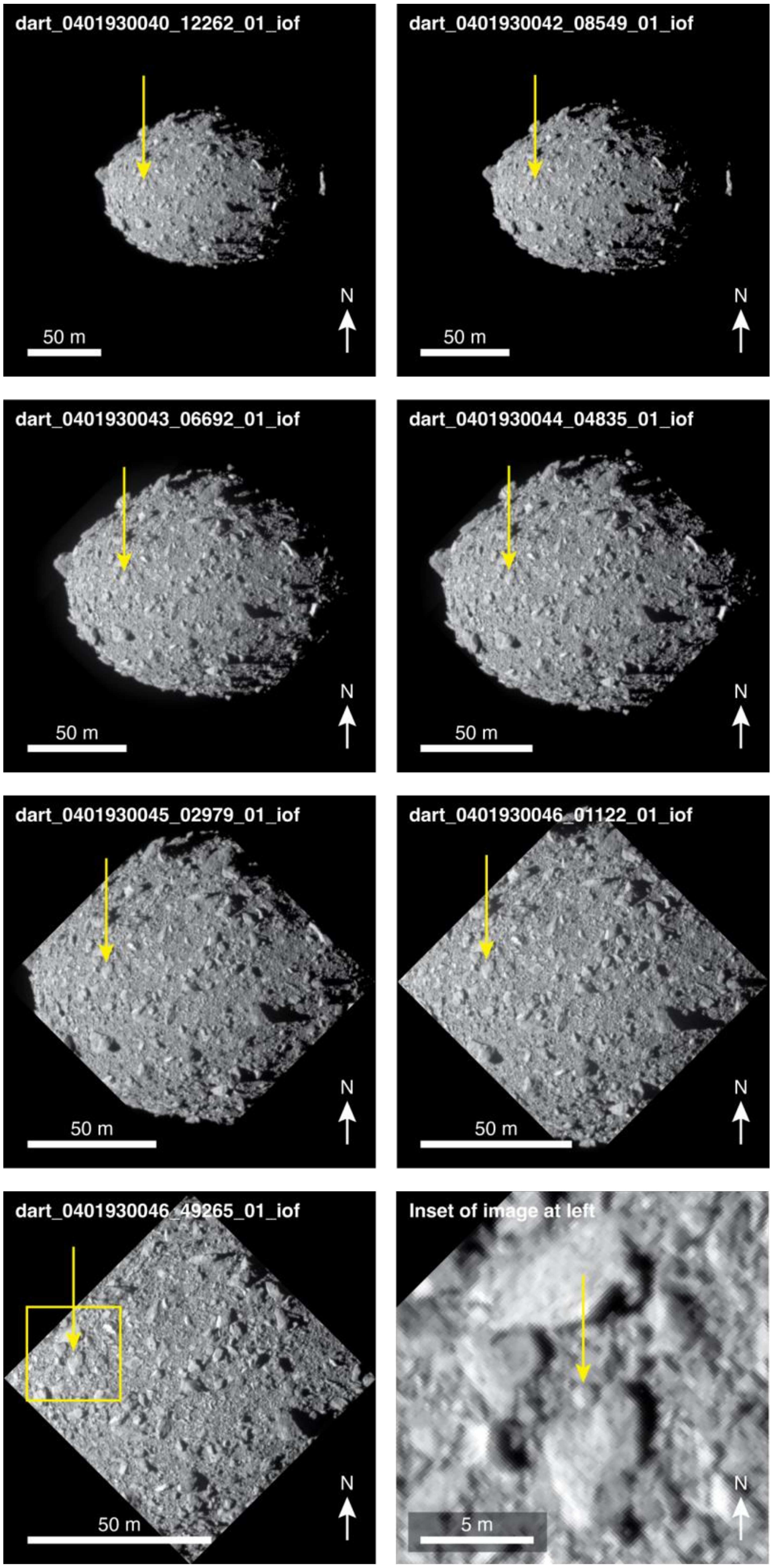
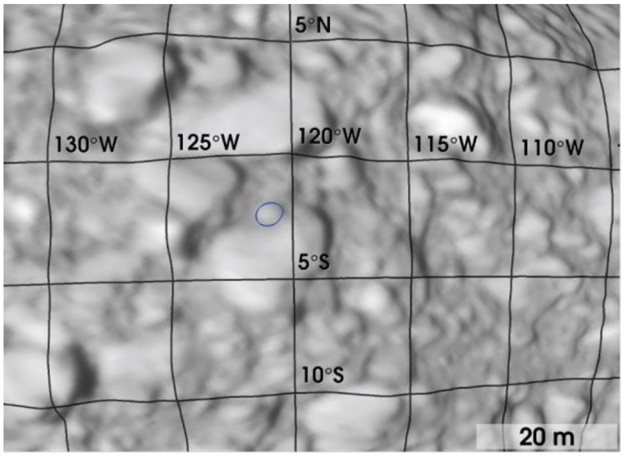


Figure 1. The boulder used to anchor the prime meridian of Dimorphos. This figure shows the chosen boulder (yellow arrow)o in several unprojected DRACO images. The white arow indicates the direction of Dimorphos' north pole. See Table 1 for the pixel-line location of the boulder in these and other DRACO images.

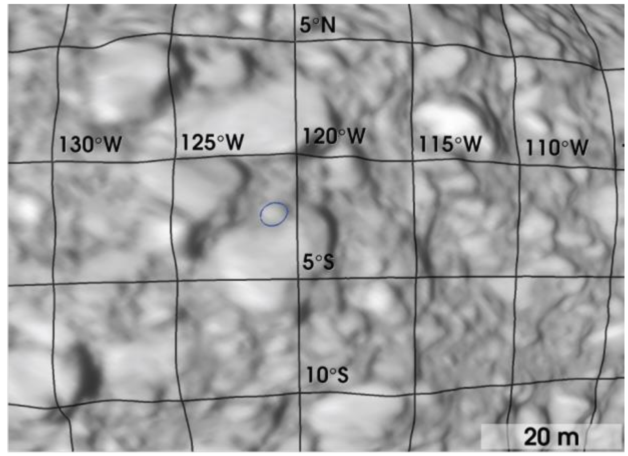
Table 1: Pixel-line location of feature used to define prime meridian.

Image name	Pixel	Line
dart_0401930034_23403_01_iof.fits	420	637
dart_0401930035_21546_01_iof.fits	419	649
dart_0401930036_19689_01_iof.fits	425	647
dart_0401930037_17832_01_iof.fits	434	648
dart_0401930038_15976_01_iof.fits	441	640
dart_0401930039_14119_01_iof.fits	460	635
dart_0401930040_12262_01_iof.fits	474	625
dart_0401930042_08549_01_iof.fits	513	599
dart_0401930043_06692_01_iof.fits	533	587
dart_0401930044_04835_01_iof.fits	559	566
dart_0401930045_02979_01_iof.fits	590	541
dart_0401930046_01122_01_iof.fits	620	512
dart_0401930046_49265_01_iof.fits	662	467

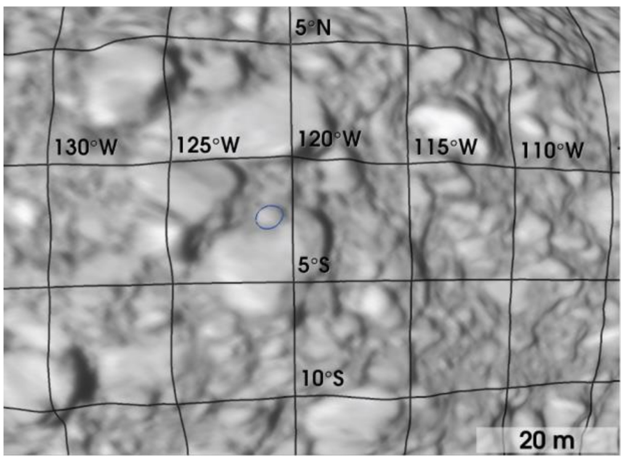
The chosen boulder is surrounded by four larger ones that make it easier to spot the anchor boulder in moderate-resolution images and will aid identification of the anchor rock in images taken by future spacecraft with different lighting conditions. The largest boulder lies to the north (+Z direction of the shape model) of the anchor rock and is ~12 m in length. That boulder is somewhat flattened and elongated. Its top surface slopes away from the equator. The center of this large boulder is located at ~238.8 °E, 1.3 °N. Its two ends rest on two smaller boulders to the west and northeast of the anchor boulder. The smaller boulder to the west of the anchor rock has a tent-like appearance; it measures ~7 m in diameter and is located at ~236.4 °E, 1.2 °S. The boulder to the northeast of the anchor rock is more uniform in size at ~3 m and has an apparent crest. It is located at ~242.2 °E, 0.5 °S. The boulder to the south of the anchor rock touches the anchor rock and is the second largest rock in the area, with a diameter of ~ 8 m. The center of the boulder to the south of the anchor rock is located at ~240.0 °E, -4.3°S.



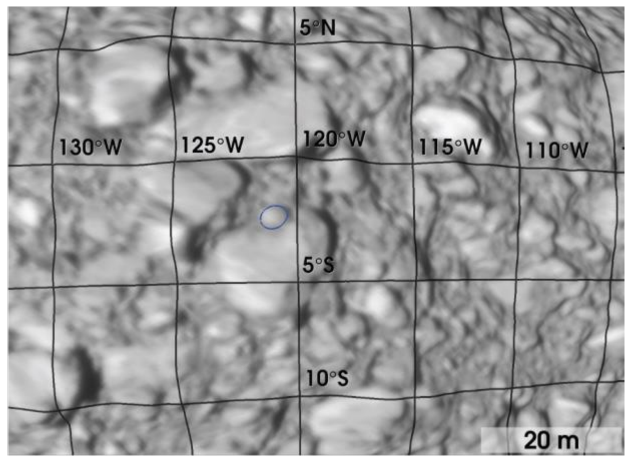
dart_0401930042_08549_01



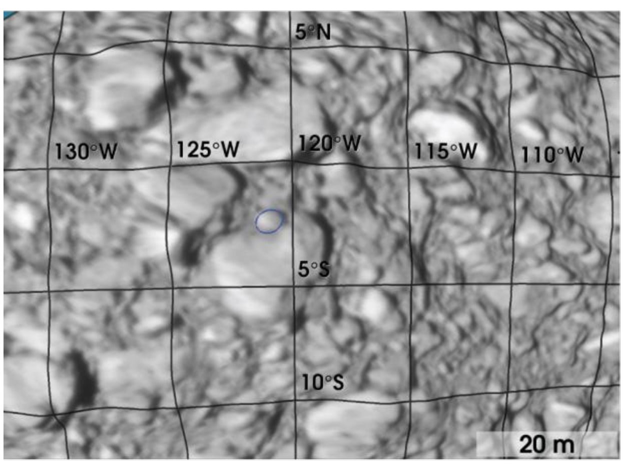
dart_0401930043_06692_01



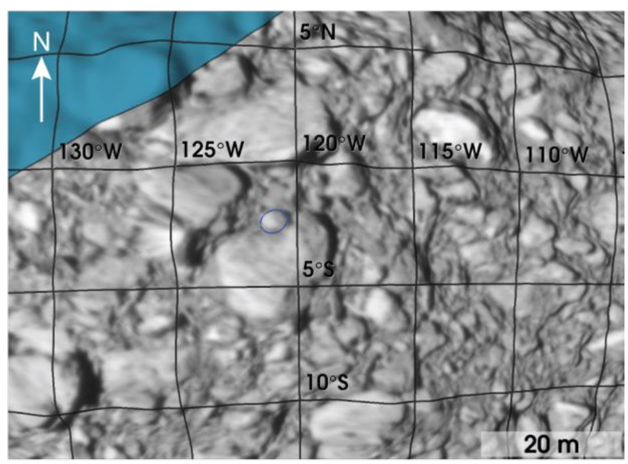
dart_0401930044_04835_01



dart_0401930045_02979_01



dart_0401930046_01122_01



dart_0401930046_49265_01

Figure 2. Location of prime meridian anchor rock for Dimorphos, located at 239.1±0.2E, 2.3±0.1S in several DRACO images projected onto the Daly et al. (2023) global shape model. Four larger boulders surround the prime meridian anchor rock to the are easy identifiable to the north (+Z direction of the shape model), south (-Z direction of the shape model), northeast and west of the anchor rock.

3. Pole Description

Using the International Celestial Reference Frame (ICRF; Archinal et al., 2018) Dimorphos' rotation state is modeled with $\{\alpha, \delta, W_0 + W_1 \Delta t + W_2 \Delta t^2\}$, where α represents the spin pole right ascension, δ represents the spin pole declination, W_0 represents the prime meridian angle, W_1 represents the rotation rate, and Δt represents the time elapsed since J2000 = JD 2451545.0, i.e. 2000 January 1 12 hours TDB (Barycentric Dynamical Time).

The set of pole parameters of Dimorphos used for the v004 shape model is given in Table 2. They are the result of data collected from ground-based telescopes between 2016 and 2023. An acceleration in the orbit period of Dimorphos and thus in spin rate (assuming Dimorphos was tidally locked before the DART impact) has been measured (Scheirich and Pravec, 2022; Shantanu et al. 2022) and is included in the rotation rate as W_2. These values, along with their histories, are archived at NAIF in the DART SPICE bundle as a Planetary Constants Kernel (PCK; didymos_system_14.tpc). Table 2 also reports the equivalent spherical body radius, R, of Dimorphos, and its best fit ellipsoid, with semi-major a, b and c extents along the X, Y, Z axes, respectively, based on the v004 shape model.

Table 2. Dimorphos coordinate system for the DIMORPHOS-MODEL-v004 global shape model.

α [deg]	δ [deg]	W_0 [deg]	W_1 [deg/day]	W_2 [deg/day^2]	R [km]	a [km]	b [km]	c [km]
66.83	-73.0	71.3	724.7237	1.1×10^{-6}	0.0750	0.0895	0. 0845	0.0575
±0.05	±0.3	±0.2	±0.0002	$\pm2.3\times10^{-7}$	±0.0013	±0.0005	±0.0020	±0.0005

4. References

Archinal, B.A. et al., 2018. Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements. *Celestial Mechanics and Dynamical Astronomy*, 130(3), pp.22346.

Davies, M.E., Batson, R.M., 1975. Surface coordinates and cartography of Mercury. *J. Geophys. Res.* 80, 241732430. doi:10.1029/JB080i017p02417.

Daly, R.T., Ernst, C.M, Barnouin, O.S., et al., 2023. Successful kinetic impact into an asteroid for planetary defence, *Nature,* 616, 443–447.

Daly, R. T. et al., 2023. An Updated Shape Model of Dimorphos from DART data. *Asteroids, Comets, and Meteors Conference* 2023, abstract 2118.

Scheirich, P. and Pravec, P., 2022. Pre-impact Mutual Orbit of the DART Target Binary Asteroid (65803) Didymos derived from Observations of Mutual Events in 2003 – 2021. *Planetary Science Journal,* 3:163.

Naidu, S.P., et al., 2022. Anticipating the DART impact: Orbit Estimation of Dimorphos using a Simplified Model. *Planetary Science Journal,* 3:234.