Bennu Coordinate System Description
Version 0.1 February 4, 2019
Version 1.0 May 7, 2019
Version 2.0 June 17, 2021
Version 2.1 August 19, 2021

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The Bennu coordinate system is newly defined since May 9, 2019 based on updates to the global shape model (Daly et al. 2020), and refined measurements of pole rotation rate and obliquity following the completion of sampling at Bennu, on Oct 20, 2020. The new surface feature used to define the prime-meridian (Figure 1) is near what researchers had used as a prime meridian during preparations for the OSIRIS-REx mission (e.g. Nolan et al., 2013; Lauretta et al., 2017, Barnouin et al, 2019), to within the resolution of those models. The choice of an earlier prime meridian completed in May of 2019, used initially for Touch-And-Go (TAG), had some limitations during preparation for TAG. Although the feature used was distinctive and near the original "planning" prime meridian developed from Radar data, it suffered from being at moderate latitudes, and on the surface of a fairly large boulder whose estimated altitude has changed more dramatically in improving shape models than other flatter portions of the surface. Both factors complicated the geolocation of images collected by the OSIRIS-REx mission as the accuracy of the shape model increased via the use of high-resolution (5cm ground sample distance) OSIRIS-REX laser altimetry (OLA) data, where the accuracy improved from <1 m to <15cm. To remedy this issue, we modified the location of the prime meridian to within a cluster of rocks, in a flat region of the asteroid at zero degrees latitude. The presented pole orientation takes into account updates to the pole, from improvement in gravity measurements, surface topography, imaging and a better estimate of the asteroid spin-up. The surface feature used to define the location of the prime meridian is changed from earlier models, although the location of the prime meridian has not (to within the uncertainty in the previous models). The initial distinctive feature used to identify the prime meridian location remains important as a guide to the final prime meridian cluster of rocks. The location of the prime meridian and pole were obtained from imaging collected by OSIRIS-REx CAMera System (OCAMS) which include a narrow (POLYCAM) and wide (MAPCAM) angle imager, and the development of shape model using the OSIRIS-REx laser altimeter (Daly et al., 2019, 2020).

Prime Meridian Feature Description

The prime meridian can be initially identified with lower resolution images by looking for a distinctive boulder that is located near -20°of latitude (Figure 1a-b.) This boulder is the third largest on the asteroid and is easy to identify in global images of Bennu. The boulder looks like a tent, with a near triangular face on the side of the boulder facing the equator. Moving north from this boulder to the equator of the asteroid, we enter a crater. In that crater at higher spatial resolution, there is a cluster of rocks surrounding 0,0. This star shaped cluster is located just south of a distinct flat-topped boulder visible in the 5 cm DTMs (l_00050mm_alt_ptm_0045n35750_v20.obj) and images of the region (Figure 1 c and d). The prime meridian is defined at the top surface of the rock in the center of star-like rock cluster. The exact location in the local 5 cm DTM (l_00050mm_alt_ptm_0045n35750_v20.obj) generated with OLA data is given by facet ID# 10865486 (Figure 1d). This is equivalent to pixel-line location (1-based) (779, 427) in the OCAMS PolyCam image collected on March 21, 2019 at UTC 20:58:46 (Figure 1e and g). This rock cluster center is also visible in PolyCam image collected on March 28, 2019 at UTC 20:29:32 (Figure 1h) at pixel-line location (746, 614). The image coordinates start in the lower left-hand corner of each image.

Pole Description

Using the International Celestial Reference Frame (ICRF; Archinal et al., 2011) Bennu's rotation state is modeled with $\{\alpha, \delta, W + W_1\Delta t + W_2\Delta t^2\}$, 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. In the case of Bennu, an acceleration of the rotation rate by Yarkovsky–O'Keefe–Radzievskii–Paddack (YORP) effect, has been measured (Nolan et al., 2019, Hergenrother et al., 2019) and is included in the presented results for the rotation rate as W_2. The pole and rotation phase parameters were estimated by the OSIRIS-REx Navigation Team. They find that the rotation state has unmodelled variations at the ~20-cm level so that the absolute calibration of the rotation state with respect to the shape model has uncertainties at that scale, which corresponds to approximately 0.04 degrees of rotation. The

uncertainties given below are with respect to the mean offsets. The initial and current set of pole parameters and body axes derived from the OSIRIS-REx data are given in Table 1. We present the feature defining the prime meridian in Figure 1. Table 1 also reports the equivalent spherical body radius, **R,** of Bennu, and its best fit ellipsoid, with semi-major **a, b** and **c** along its x, y, z axes, respectively**.** These constants along with their history are archived in the PDS in the OSIRIS-REx SPICE archive as a Planetary Constants Kernel (PCK).

Table 1. Bennu coordinate systems for delivered shape models

Model	α[deg]	δ [deg]	$W0$ [deg]	W_1 [deg/day]	W_2[deg/day^2]	R [km]	a [km]	b [km]	c [km]	Data Range
SPC v020	85.46 ±0.11	–60.36 ±0.15	135.8156 ±1.6	2011.14645095 ±0.001	1.815e-06 ±0.26e-6	0.2449 ±0.00012	0.2524	0.2463	0.2294	Nov 1 2018 – Jan 17 2019
ALT v020 and v021	85.459 ±0.006	–60.365 ±0.004	150.48977 ±0.0085	2011.143058731885 ±0.000133	2.0 e-6 ±0.1 e-6		0.283065	0.271215	0.249720	Nov 1 2018 – Oct 20 2020

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Figure:

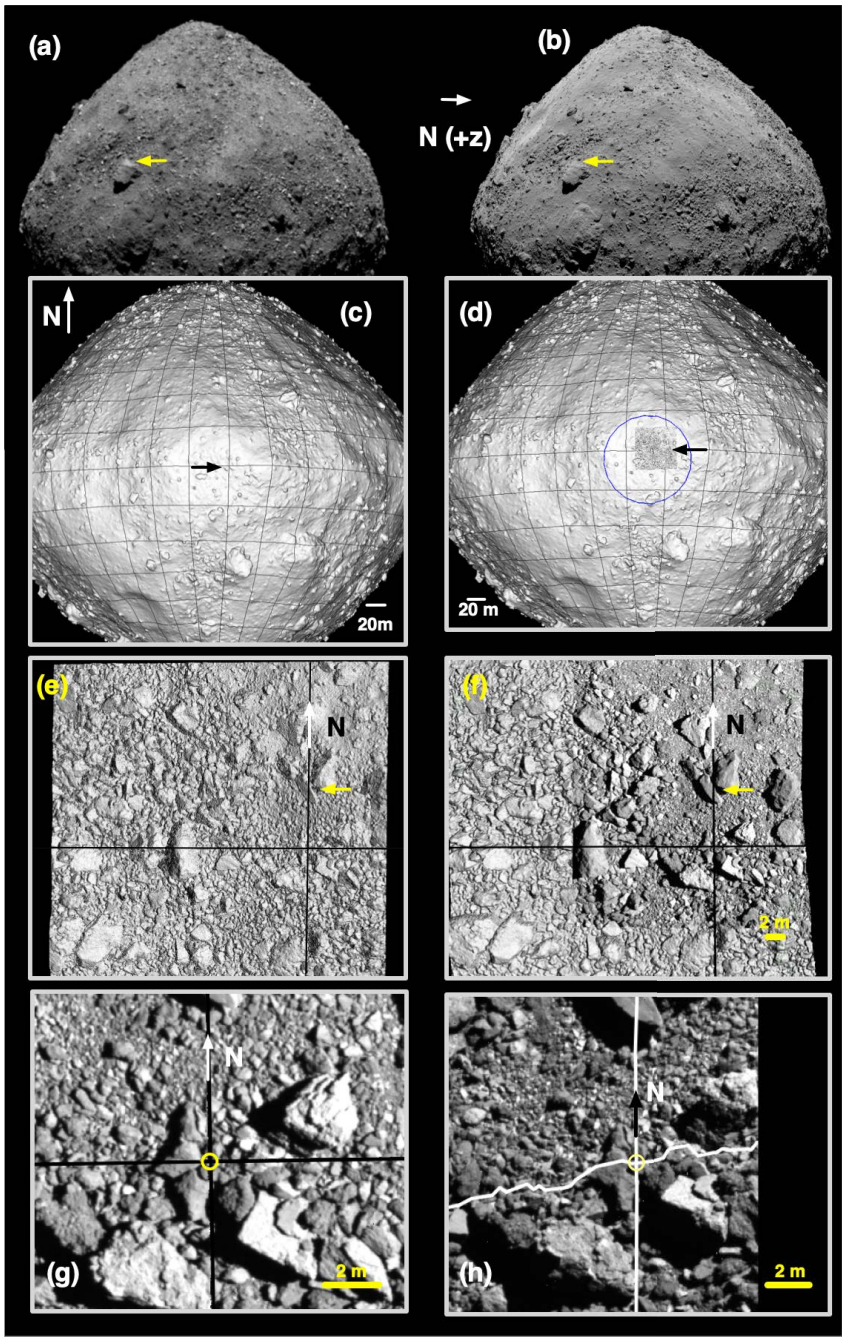

Figure 1: The definition of the prime meridian for Bennu: (**a) OCAMS** image collected on 13 December 2018 at 03:39:07 UTC; (**b**) Rendering of the OLA GDTM for the same viewing conditions captured by the OCAMS image shown in (a). Yellow arrows in (a) and (b) show the prime meridian rock used as a guide to identify the ultimate location of the actual prime meridian on Bennu. **(c**) The final location of the prime meridian is found in a crater at the equator as seen in the global OLA DTM (g_00880mm_alt_obj_0000n00000_v020.obj). **(d)** The final location of the prime meridian in the local OLA DTM (l_00050mm_alt_ptm_0045n35750_v20.obj) overlain on the global DTM. **(e)** Zoomed up version of (d). **(f)** OCAMS image (obtained March 21, 2019 at UTC 20:58:46) overlain on the local OLA DTM seen in (e). **(g**) is the same OCAMS images but zoomed up relative to what is shown in (e) and has an emission angle near 0°. **(h)** is an OCAMS images collected on March 28, 2019 at UTC 20:29:32 with and emission angle of about 30°. The yellow arrows in (e) and (f) show the location of an obvious flat top rock, which is

a second marker to help identify the location of the prime meridian. The prime meridian is located in a cluster of smaller rocks that forms a star-like pattern south of this flat rock. This location is shown by the circle in (g) and (h).