Body-Fixed Coordinate Systems for Asteroid (4) Vesta

Revision history:

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This document describes four body-fixed coordinate systems defined for Asteroid (4) Vesta, including IAU-2000, Dawn-Claudia, Claudia Prime, and Claudia Double-Prime. All four coordinate systems for Vesta are defined in inertial reference frame J2000. The epoch of the orientation constants for Vesta is J2000, which is Julian ephemeris date (JED) 2451545.0. Three coordinate systems (IAU-2000, Dawn-Claudia, Claudia Double-Prime) have been used in the literature and in Dawn mapping products under various circumstances. The Claudia Double-Prime system was selected for the PDS Dawn archive, as that coordinate system complies with IAU guidelines for maintaining the definition of the Prime Meridian "to within the accuracy of previous determinations." The Claudia Prime is included in this document for historical purposes.

The "IAU-2000" coordinate system is defined by the spin pole of Vesta at RA=301º±5º, Dec=+41º±5º, prime meridian parameter W0=292.0º (Thomas et al., 1997), and rotation period 0.2225 8873±0.0000 0004 d (Drummond et al., 1998). The pole orientation of Vesta used by this coordinate system was measured using the then highest-resolution images acquired by *Hubble Space Telescope* (*HST*) in 1994 and 1996, with pixel sizes of 54 km and 38 km on Vesta, respectively, both covering one full rotation of Vesta. In *HST* images, a quasi-circular, dark spot is visible near the equator on the north side (Zellner et al., 1997; Binzel et al., 1997). It is about 200 km across, showing the highest brightness contrast with the background in the visible wavelengths among all albedo features. Zellner et al. (1997) suggested a name "Olbers" for this feature, and Thomas et al. (1997) defined the prime meridian to be through the center of this broad feature. The PCK file defining this coordinate system is dawn_vesta_v00.tpc and dawn_vesta_v01.tpc. This coordinate system was subsequently adopted by International Astronomical Union's (IAU) working Group on Cartesian Coordinates and Rotational Elements (WGCCRE) in 2000 as the formal coordinate system for Vesta (Seidelmann et al., 2002), and has since been used in various ground-based observations (e.g., Zellner et al., 2005; Carry et al., 2010; Reddy et al., 2010) and later *HST* observations (Li et al., 2010).

The Dawn spacecraft began orbiting Vesta in August 2011 and departed in September 2012 (Russell et al., 2012a). During the approach and orbital phase around Vesta, the project team refined the measurement of rotation characteristics of Vesta to a

much higher precision than before through topographic mapping and precise Doppler measurements. The updated pole orientation of Vesta is RA=309.03º±0.01º, Dec=+42.23º±0.01º, and the rotation period is 0.2225 8865 2±4×10^{-10} d (Russell et al., 2012b). The revised pole orientation is 6.2º towards east and slightly north in J2000 inertial frame from the pole determined by Thomas et al. (1997). The revised rotation period of Vesta is shorter by 4.5E-08 d (3.9 ms) than previously determined by Drummond et al. (1998). The "Dawn-Claudia" coordinate system is defined based on these updated values. Longitude in the Dawn-Claudia coordinate system is defined by the center of a 620-m diameter, morphologically distinct crater at -1.6º latitude and 356.0º longitude (Fig. 1), whose name "Claudia" was proposed by the Dawn project team and accepted by the IAU. In the IAU-2000 coordinate system, the center of Claudia Crater is at +4.3º latitude and 145.0º longitude at J2000 standard epoch. The prime meridian parameter W0 for Dawn-Claudia coordinate system is 75.39º (Russell et al., 2012b), and is ~150º east of the prime meridian in the IAU-2000 coordinate system. This coordinate system is defined in PCK file dawn_vesta_v04.tpc. A detailed comparison between the surface features of Vesta visible in previous *HST* images and in Dawn high-resolution maps of Vesta can be found in Reddy et al. (2012a). The prime meridian defined in the Dawn-Claudia coordinate system was designed to set up a quadrangle mapping scheme following Greeley and Batson (1990) in which the quadrangle boundaries avoid passing through any major geological features. This coordinate system was adopted by the Dawn project team late in 2011 as the mapping work began. All of the team's mapping products use this Dawn-Claudia coordinate system (e.g., Roatsch et al., 2012). This coordinate system is not accepted by the IAU.

In response to a requirement from NASA Headquarters to submit data to the Planetary Data System (PDS) in an IAU-compliant coordinate system, a third coordinate system was defined, the "Claudia Prime" system, that uses the same pole orientation and rotation period as the Dawn-Claudia coordinate system, i.e., at RA=309.03º, Dec=+42.23º, and period 0.2225 8865 2 d, but shifts the prime meridian west by 140º to W0=295.39º. This prime meridian lies ~10º east of the prime meridian in the IAU-2000 coordinate system. The center of Claudia Crater is at -1.6º latitude and 136.0º longitude in this coordinate system at J2000 epoch. The PCK file, dawn_vesta_v05.tpc, defines the Claudia Prime coordinate system. This particular shift in the prime meridian preserves, to a large extent, the quadrangle mapping scheme in use by the project. This coordinate system has not been used in any data product. It is preserved for historical purpose.

In order to be fully compliant with IAU WGCCRE recommendations (Archinal et al., 2011), a fourth coordinate system has been defined, namely "Claudia Double-Prime". This system attempts to exactly register the prime meridian with the previously IAU-adopted coordinate system (IAU-2000). The pole orientation and the rotation period of Vesta used in this coordinate system are, again, the same as those used in the Dawn-Claudia and in the Claudia Prime coordinate systems, i.e., with the pole at RA=309.03º, Dec=+42.23º, and rotation period 0.2225 8865 2 d. The prime meridian in this coordinate system is at W0=285.39º, or 10º west of that in the Claudia Prime coordinate system, and within 1º of the prime meridian in the IAU-2000 coordinate system. The center of Claudia Crater is at -1.6º latitude and 146.0º longitude in this coordinate system at J2000 epoch. The PCK file defining this coordinate system is dawn_vesta_v06.tpc. This coordinate system is the only

one deemed compliant with the previous IAU-2000 system, and is expected to be adopted by the IAU WGCCRE as an approved coordinate system for Vesta. The Dawn data submitted to PDS are associated with this coordinate system. However, it should be noted that all of the Vesta science papers published by the Dawn Science team, as well as the talks that have been given at scientific conferences, have presented results in the Claudia system.

Table 1 summarizes the four coordinate systems described in this documents. Fig. 2 shows the albedo map derived from the Dawn data in a latitude-longitude projection in the Claudia Double-Prime coordinate system, and the relationship between the four coordinate systems described in this document.

The exact transformation between the IAU-2000 coordinate system and others varies periodically with time at the rotational period of Vesta because of the different rotational axis used. The exact re-projection of the previous *HST* maps of Vesta using the IAU-2000 coordinate system onto any other three coordinate systems has to be regenerated using the original images with the updated pole, because the previous projection of individual images onto longitude-latitude grid was not accurate. A simple re-projection will not result in correct maps. The update on rotational period causes a slow, secular drift in longitude for the coordinate transformation at a rate of 0.06º per year. The transformation between any pairs of Claudia-based coordinate systems (Dawn-Claudia, Claudia-Prime, and Claudia Double-Prime) is simply a shift in longitude, based on the W0 parameters as listed in Table 1.

Note that the values IAU_VESTA and VESTA_FIXED for the label keyword COORDINATE_SYSTEM_NAME are synonyms in the Dawn dataset. They do not distinguish between the various Claudia-based coordinate systems. To know which coordinate system is intended it is necessary to refer to the SPICE kernels cited in the label.

Table 1. Summary of four body-fixed coordinate systems defined for Vesta described in this document. Note that the latitude of Olbers feature is approximate due to its large size. The parameters listed here are taken from the relevant PCK files. The coordinates of Olbers Regio and Claudia Crater are both referred to their respective centers at the standard epoch J2000. RA=Right Ascension,Dec=Declination,Wdot=rotation rate (deg/day), W0 = Prime Meridian Sub-Earth Longitude at the J2000 Epoch.

	Pole RA	Pole Dec	Wdot	W0	Olbers Regio (lat, lon)	Claudia Crater (lat, lon)	PCK File
IAU-2000	301.0º	41.0º	1617.332776	292.0	+10º, 0º	+4.3º, 145.0º	dawn_vesta_v01.tpc
Dawn-Claudia	309.031º	+42.235º	1617.3329428	75.39º	+11º, 210º	-1.6º, 356.0º	dawn_vesta_v04.tpc
Claudia Prime				295.39º	+11º, 350º	-1.6º, 136.0º	dawn_vesta_v05.tpc
Claudia Double-Prime				285.39º	+11º, 0º	-1.6º, 146.0º	dawn_vesta_v06.tpc

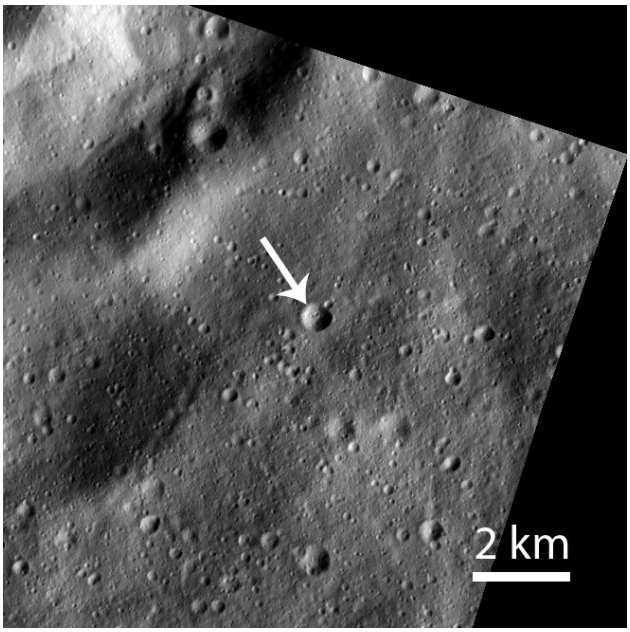

Fig. 1. FC image showing the Claudia crater (marked by arrow) that is used to define the prime meridian of the Claudia-based coordinate systems on Vesta. This image was taken during LAMO Cycle 17 on Apr 1, 2012, through clear filter. North is up and east is to the right. The scale bar is 2 km.

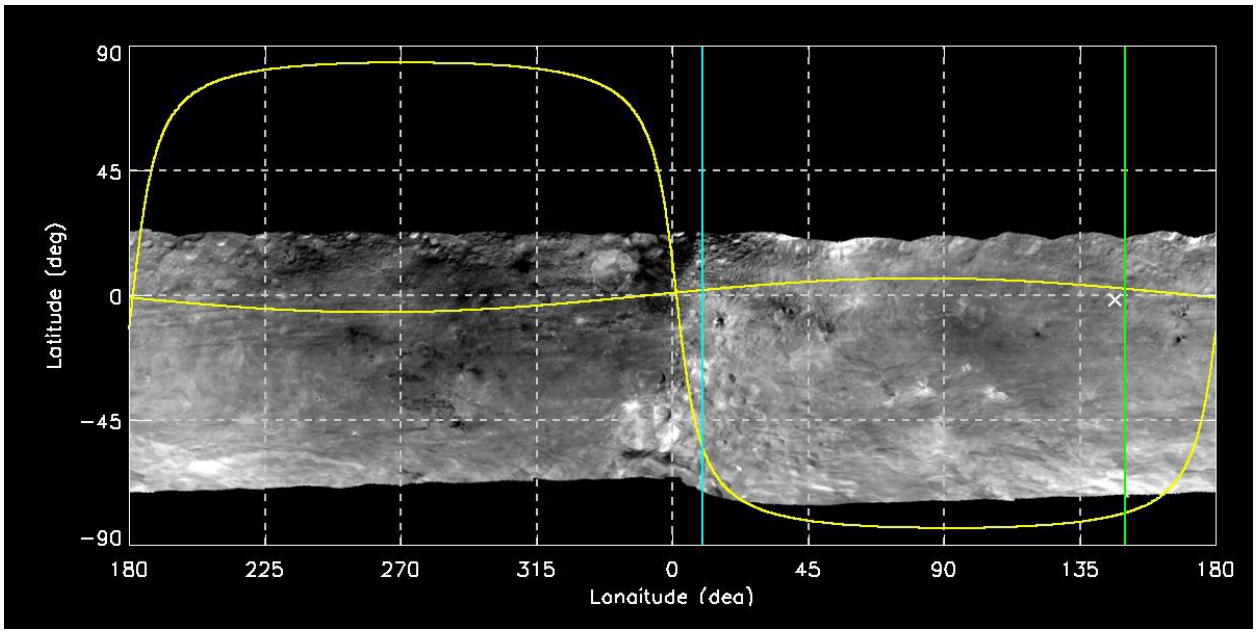

Fig. 2. The albedo map of Vesta at 750 nm wavelength as derived from the Dawn Framing Camera images collected on July 24, 2011 (Reddy et al., 2012b), shown in a latitude-longitude projection in the Claudia Double-Prime coordinate system. The latitude-longitude grid, shown in dashed lines, is in the Claudia Double-Prime coordinate system. The yellow lines show the 0º - 180º longitude great circle and the equator in the IAU-2000 coordinate system at epoch J2000. The green line marks the prime meridian in the Dawn-Claudia coordinate system. The blue line marks the prime meridian in the Claudia Prime coordinate system. The "x" symbol at latitude -1.6º and longitude 146.0º marks the position of the center of Claudia crater, which is used to anchor the coordinate systems on Vesta.

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