

Body-Fixed Coordinate Systems for Asteroid (4) Vesta

Revision history:

- August 20, 2012, first draft by Jian-Yang Li (Planetary Science Institute, jyli@psi.edu)
- September 18, 2012, revised by Jian-Yang Li (Planetary Science Institute, jyli@psi.edu). Resolved the liens from PDS Dawn data reviews, and fixed typos and format.
- December 14, 2012, revised by Joseph N. Mafi (PDS/PPI, jmafi@igpp.ucla.edu). Fixed additional typos found in the PDS Dawn data review.
- October 17, 2013, revised by Joseph N. Mafi (PDS/PPI, jmafi@igpp.ucla.edu). Updated opening paragraph.

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 $RA=301^{\circ}\pm 5^{\circ}$, $Dec=+41^{\circ}\pm 5^{\circ}$, prime meridian parameter $W0=292.0^{\circ}$ (Thomas et al., 1997), and rotation period $0.2225\ 8873\pm 0.0000\ 0004$ 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 $RA=309.03^\circ \pm 0.01^\circ$, $Dec=+42.23^\circ \pm 0.01^\circ$, and the rotation period is $0.2225\ 8865\ 2 \pm 4 \times 10^{-10}$ d (Russell et al., 2012b). The revised pole orientation is 6.2° 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 4.5×10^{-8} 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 -1.6° latitude and 356.0° 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 $+4.3^\circ$ latitude and 145.0° longitude at J2000 standard epoch. The prime meridian parameter W_0 for Dawn-Claudia coordinate system is 75.39° (Russell et al., 2012b), and is $\sim 150^\circ$ 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 $RA=309.03^\circ$, $Dec=+42.23^\circ$, and period $0.2225\ 8865\ 2$ d, but shifts the prime meridian west by 140° to $W_0=295.39^\circ$. This prime meridian lies $\sim 10^\circ$ east of the prime meridian in the IAU-2000 coordinate system. The center of Claudia Crater is at -1.6° latitude and 136.0° 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 $RA=309.03^\circ$, $Dec=+42.23^\circ$, and rotation period $0.2225\ 8865\ 2$ d. The prime meridian in this coordinate system is at $W_0=285.39^\circ$, or 10° west of that in the Claudia Prime coordinate system, and within 1° of the prime meridian in the IAU-2000 coordinate system. The center of Claudia Crater is at -1.6° latitude and 146.0° 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.

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 0.06° 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.

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

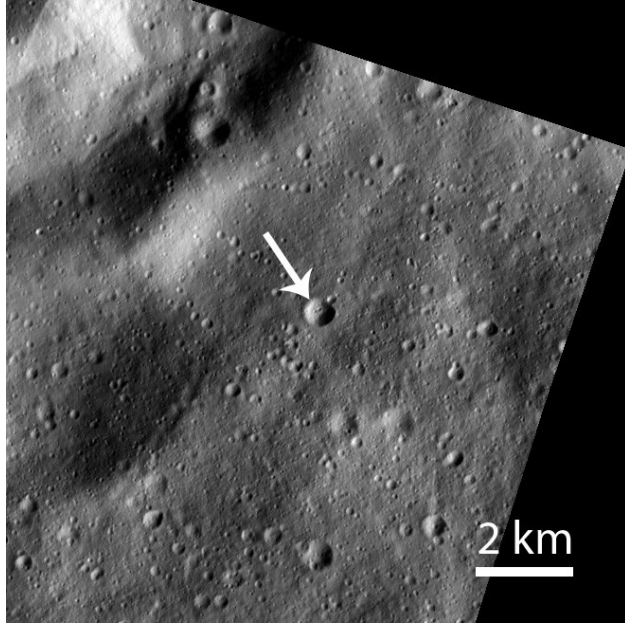


Fig. 1. FC image showing the Claudia crater (marked by arrow) that is used to define the prime meridian of the Claudia-based coordinate systems on Vesta. This image was taken during LAMO Cycle 17 on Apr 1, 2012, through clear filter. North is up and east is to the right. The scale bar is 2 km.

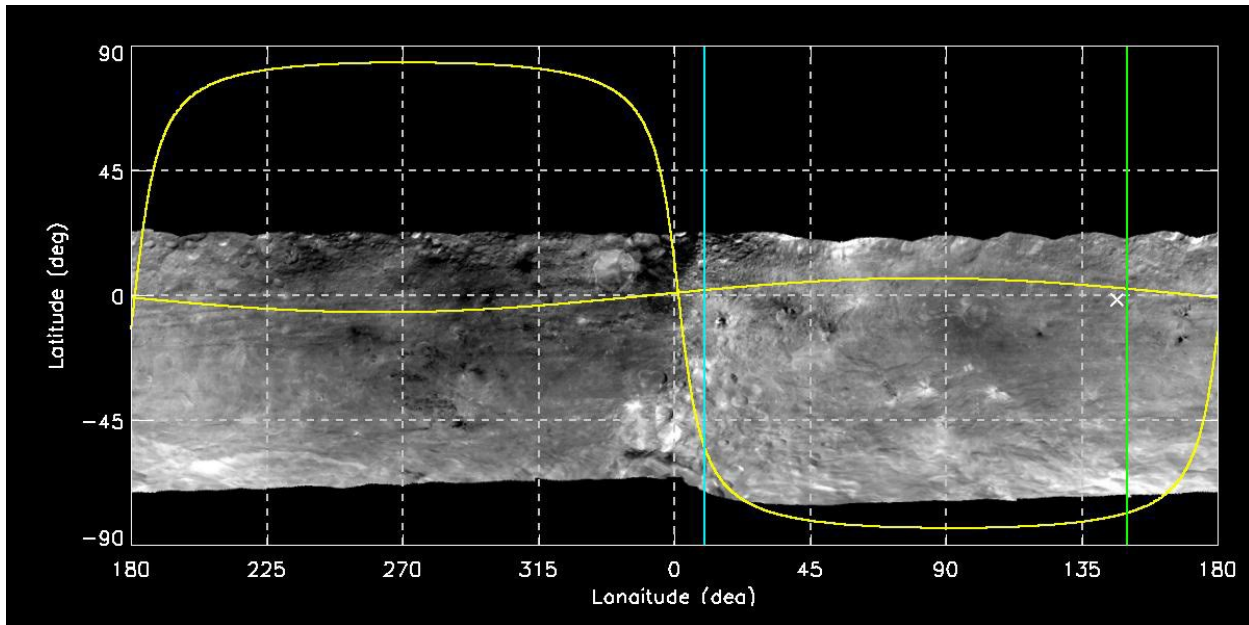


Fig. 2. The albedo map of Vesta at 750 nm wavelength as derived from the Dawn Framing Camera images collected on July 24, 2011 (Reddy et al., 2012b), shown in a latitude-longitude projection in the Claudia Double-Prime coordinate system. The latitude-longitude grid, shown in dashed lines, is in the Claudia Double-Prime coordinate system. The yellow lines show the 0° - 180° 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 -1.6° and longitude 146.0° marks the position of the center of Claudia crater, which is used to anchor the coordinate systems on Vesta.

References:

- Archinal, B.A., et al., 2011. Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2009. *Celest. Mech. Dynam. Astron.* 109, 101-135.
- Binzel, R.P., Gaffey, M.J., Thomas, P.C., Zellner, B.H., Storrs, A.D., Wells, E.N., 1997. Geologic mapping of Vesta from 1994 Hubble Space Telescope images. *Icarus* 128, 95-103.
- Carry, B., Vernazza, P., Dumas, C., Fulchignoni, M., 2010. First disk-resolved spectroscopy of (4) Vesta. *Icarus* 205, 473-482.
- Drummond, J.D., Fugate, R.Q., Christou, J.C., Hege, E.K., 1998. Full adaptive optics images of Asteroids Ceres and Vesta; Rotational poles and triaxial ellipsoid dimensions. *Icarus* 132, 80-99.
- Greeley, R., Batson, R.M., Planetary Mapping. Cambridge Univ. Press, 1990.
- Li, J.-Y., et al., 2010. Photometric mapping of Asteroid (4) Vesta's southern hemisphere with Hubble Space Telescope. *Icarus* 208, 238-251.
- Reddy, V., Gaffey, M.J., Kelley, M.S., Nathues, A., Li, J.-Y., Yarbrough, R., 2010. Compositional heterogeneity of Asteroid 4 Vesta's southern hemisphere: Implications for the Dawn mission. *Icarus* 210, 693-706.
- Reddy et al., 2012a. In preparation for *Icarus*.
- Reddy et al., 2012b. Color and albedo heterogeneity of Vesta from Dawn. *Science* 336, 700-704.
- Roatsch, Th., et al., 2012. High resolution Vesta High Altitude Mapping Orbit atlas derived from Dawn Framing Camera images. In revision for *Planet. Space Sci.*
- Russell, C.T., et al., 2012a. Dawn completes its mission at 4 Vesta and prepares for 1 Ceres. In preparation for Asteroids, Comets, and Meteors 2012 conference preceeding.
- Russell, C.T., et al., 2012b. Dawn at Vesta: Testing the protoplanetary paradigm. *Science* 336, 684-686.
- Seidelmann, P.K., et al., 2002. Report of the IAU/IAG Working Group on cartographic coordinates and rotational elements of the planets and satellites: 2000. *Celest. Mech. Dynam. Astron.* 82, 83-111.
- Thomas, P.C., Binzel, R.P., Gaffey, M.J., Zellner, B.H., Storrs, A.D., Wells, E., 1997. Vesta: Spin pole, size, and shape from HST images.
- Zellner, B.H., et al., 1997. Hubble Space Telescope images of Asteroid 4 Vesta in 1994. *Icarus* 128, 83-87.
- Zellner, N.E.B., Gibbard, S., de Pater, I., Marchis, F., Gaffey, M.J., 2005. Near-IR imaging of Asteroid 4 Vesta