RECOMMENDATIONS FROM THE IAU WORKING GROUP ON CARTOGRAPHIC COORDINATES AND ROTATIONAL ELEMENTS. Brent Archinal[1] and the IAU Working Group on Cartographic Coordinates and Rotational Elements. [1]U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001, USA barchinal@usgs.gov.

Overview: Approximately every 3 years since 1979, the Working Group on Cartographic Coordinates and Rotational Elements (hereafter the "WG") of the International Astronomical Union (IAU) has, after most IAU General Assembly (GA) meetings, issued a report recommending coordinate systems and related parameters (body orientation and shape) that can be used for making cartographic products (maps) of solar system bodies. These recommendations, which are open to further modification when indicated by community consensus, are intended to facilitate the use and comparison of multiple datasets by promoting the use of a standardized set of mapping parameters. This abstract is intended to draw attention to the WG's efforts, our previous reports, and our just published report [1] covering 2012-2015. The WG encourages input and is available to assist users, instrument teams, and missions. See our website [2] for additional information.

Operation of WG: The Working Group consists of 18 volunteers, including C. Acton, B. Archinal (Chair), A. Conrad (Acting Vice Chair), G. Consolmagno, T. Duxbury, D. Hestroffer, J. Hilton, L. Jorda, R. Kirk, S. Klioner, D. McCarthy, K. Meech, J. Oberst, J. Ping, K. Seidelmann, D. Tholen, P. Thomas, and I. Williams. Our most recent report also included substantial input from the late M. A'Hearn. Volunteers may join the WG at any time, and usually join for at least a three-year term to help with each new report following the IAU GA. The WG looks at new determinations of coordinate systems (e.g., body sizes and orientations) that preferably have been published in refereed papers, and makes recommendations as to which to use, based where possible on consensus decisions.

As a volunteer organization, the WG has no resources to verify results or conduct its own research so it relies only on published results and community input. For that reason, it is sometimes not possible to recommend one set of results over another. The WG cannot verify or "bless" any particular results. The WG has no "enforcement" powers, but tries, in reflecting the long term planetary community consensus, to make persuasive recommendations.

The WG does not deal with issues related to the formats of mapping products; such issues have largely been left to individual map developers, archiving organizations such as the NASA Planetary Data System (PDS), the IPDA (International Planetary Data Alliance), or the NASA Mars Geodesy and Cartography and Lunar Geodesy and Cartography Working Groups (MGCWG [3], LGCWG [4]) and individual missions. Input from such organizations has been welcomed by the WG and the frequency of interaction highlights the strong need for such organizations at mission, space agency, and international levels. We also look forward to working with and receiving input from two new related organizations, IAU Commission A3 on Fundamental Standards, and the NASA Mapping And Planetary Spatial Infrastructure Team (MAPSIT) [5]. Input from such organizations has been welcomed by the WG and the frequency of interaction highlights the strong need for such organizations at mission, space agency, and international levels. As pointed out at the 2012 IAU General Assembly [6] a substantial body of IAU recommendations exist that have been developed over many decades of input by IAU members, national space agencies, and other institutions. Care should be taken to follow such recommendations or to present well-reasoned arguments why they should be changed. The IAU and its Working Groups stand ready to help authors, journal editors, and missions understand and follow IAU recommendations.

Defining Longitude: One recent issue is the question of how the definition of longitude should be updated on Solar System bodies. The WG addressed this issue in its first report [7] and reiterates in our new report [1] that once an observable reference feature at a defined longitude is chosen, the longitude definition origin should not change except under extraordinary circumstances (such as for example a change in or loss of the feature). Given that our definition of longitude is primarily for mapping surface features, it is more logically tied to data related to the surface of the body (e.g., direct imaging or altimetry) than to dynamical data (e.g., the principal axes of inertia for resonantly or synchronously rotating bodies such as Mercury [8], the Moon, or Jovian or Saturnian satellites). Once such a feature has been adopted, changing to a longitude system defined by some other method should be avoided. Note that this recommendation does not preclude the use of smaller or more precisely determined features, multiple features, or even human artifacts to define longitude, as long as the original definition is maintained to the level of precision at which the feature can be located in new data. Some shift in longitude of previously identified features may occur whenever new data are available and processed, but this is minimized at least in the vicinity of the defining feature.

Coordinate System for (4) Vesta: In August 2011, the NASA/DLR/ASI Dawn mission proposed using a longitude system with a large (~155°) rotation from the previous [9] system. Many reasons were expressed for this new system, but the WG replied in both September 2011 and March 2012, after careful and extensive consideration, that the arguments were not compelling enough to ignore previous usage by the planetary community and the WG's previous recommendations.

Unfortunately, the mission began publishing results using only their rotated system. This resulted in substantial confusion. However, because the NASA Planetary Data System requires that data product archives follow various international and NASA standards including those of the IAU, the mission ultimately proposed a new system which the PDS accepted, agreeing with IAU recommendations. This system is described in the archive [10] (with W_0=285.39º). The WG ultimately formally accepted this system and recommended it for general use [1, 11].

General Changes: Following extensive discussion, substantial updates have been incorporated by the WG into our new report. An overview follows. *First*, based on the experience with Vesta, the WG has reworded and clarified its recommendations regarding updating longitude. *Second*, mission and community input indicates a need for the WG to differentiate between planetary body shapes and sizes for image projection and scientific modeling vs. a reference surface for elevation and map scale. In particular, long-accepted values for the latter are documented for the Moon and (now recommended for) Titan. *Third*, after considerable input from the community, including from New Horizons mission personnel, the discussion of terminology for the poles (hemispheres) of small bodies has been modified, e.g. to indicate that following community practice, cardinal directions can still be used informally or as shorthand for directions on small bodies (which formally have only positive and negative directions). *Fourth*, updates to the orientation models of Jupiter and Saturn are not recommended at this time, as we await community consensus on a model for Jupiter and final results from the Cassini mission regarding the orientation of Saturn.

Changes for Specific Bodies Under Discussion: Formulas for the Earth's orientation (which were previously given for comparison purposes only) have been removed in order to avoid confusion over their accuracy. The MGCWG has recommended a new orientation model for Mars [12], which the WG in turn has recommended for use; in addition, more precision in longitude is provided by fixing the position of the Viking 1 lander. Neptune's rotation model has been updated based on new results from Karkoschka [13]. Individual members of the WG worked with Dawn mission personnel to arrive at a suitable way to update the existing orientation model for Ceres. New or updated orientation values are recommended for (52) Europa, (511) Davida, and (2867) Šteins. The declination of the pole of (243) Ida has been corrected. Orientation data were added for comet 9P/Tempel 1 based on the Stardust NExT flyby [14], for 19P/Borrelly based on the DS1 flyby and subsequent ground-based measurements [15], for 103P/Hartley 2 based on the EPOXI flyby [16], and for 67P/Churyumov-Gerasimenko based on the pre-perihelion approach mapping from the Rosetta orbiter [17]. Data for Mercury, (1) Ceres, and the radii for (134340) Pluto and Charon [18] have also been updated based on recent mission results and papers. The size of the Sun was updated per an IAU Resolution and sizes are given for (16) Psyche and (52) Europa, and the size of (25143) Itokawa has been corrected.

Other recommendations: We repeat our previous recommendations that planning and efforts be made to make controlled cartographic products. We now recommend that common formulations should be used for orientation and size and that historical summaries of the coordinate systems for given bodies should be developed. We point out that for planets and satellites planetographic systems have generally been historically preferred over planetocentric systems; and that in cases when planetographic coordinates have been widely used in the past, there is no obvious advantage to switching to the use of planetocentric coordinates.

Request for Input: The WG desires continued input from the planetary community, especially regarding the systems for specific bodies, the operation of the WG, our proposed question submitting process, and posting of updates via the WG website. We encourage volunteers to become WG members and help with our efforts. Our membership is open to all. Contact the lead author of this abstract for additional information.

Acknowledgements: Funding for B. Archinal has been provided via a NASA-USGS Interagency Agreement on Planetary Spatial Data Infrastructure.

References: [1] Archinal et al. (2018) *CMDA*, doi 10.1007/s10569-017-9805-5, in press. [2] http://astrogeology.usgs.gov/groups/IAU-WGCCRE. [3] Duxbury et al. (2002) *ISPRS*, 34, pt. 4, http://astrogeology.usgs.gov/groups/ISPRS. [4] Archinal and the LGCWG (2009) *LPS XL*, Abstract #2095. [5] Radebaugh et al. (2017), LEAG Annual Meeting, Abstract #5053. [6] Meech et al. (2012) *Inquires of Heaven*, no. 10, p. 6, http://www.astronomy2012.org/ih. [7] Davies et al. (1980) *Celest. Mech.*, 22, 205-230. [8] Margot (2009) *CMDA*, 105, 329-336, DOI: 10.1007/s10569-009-9234-1. [9] Thomas et al. (1997) *Icarus*, 128, 88–94; also see [1]. [10] DAWN mission, (2012) http://sbn.psi.edu/archive/dawn/fc/DWNVFC2_1A/DOCUMENT/VESTA_COORDINATES/VESTA_COORDINATES_120918.PDF. [11] Archinal et al. (2013) http://astropedia.astrogeology.usgs.gov/download/Docs/WGCCRE/IAU-WGCCRE-Coordinate-System-for-Vesta.pdf. [12] Kuchynka et al. (2014) *Icarus*, 340, 229. [13] Karkoschka, E. (2011) *Icarus*, 215, 439. [14] Belton et al. (2011) *Icarus* 213, 345. [15] Soderblom et al. (2004) *Icarus*, 167, 4; Mueller et al. (2010) *Icarus*, 209, 745. [16] Thomas et al. (2013) *Icarus*, 222, 550; Belton et al. (2013) *Icarus*, 222, 595; Farnham and Thomas (2013) DIF-C-HRIV/MRI-5-HARTLEY2-SHAPE-V1.0, NASA PDS. [17] Preusker et al. (2015) *A&A*, 583, A33; Scholten et al. (2015) https://map.tinyurl.com/67P-frame2, NASA PDS and ESA PSA. [18] Nimmo et al. (2017) *Icarus*, 287, 12.