MERCURY'S REFERENCE FRAMES AFTER THE MESSENGER MISSION.

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Introduction: The Mercury Surface, Space ENvironment, GEochemisty, and Ranging (MESSENGER) spacecraft has provided many new insights about the innermost planet. With the detailed information about shape [1,2], gravity field [3,4], and rotation state [3,4,5] of Mercury, it is advisable to verify the validity of Mercury's reference frames. Thus, we discuss the dynamical, the principal-axes, the ellipsoid, as well as the cartographic reference frames. We also describe the reference frame adopted by the MESSENGER science team for the release of their cartographic products and we provide expressions for transformations from this frame to the other reference frames. We summarize the performed measurements of Mercury's rotation based on terrestrial radar observations [6] as well as data from the Mariner 10 [7] and the MESSENGER missions [3,4,5].

MESSENGER reference frame: This cartographic frame is currently used for all data products from the MESSENGER mission. The rotation parameters are based on Earth-based radar [6] and MESSENGER radio science measurements [3]. Since the analysis of MESSENGER data revealed Mercury's rotation rate to be significantly different [3,5] from the previously assumed rotation rate [8], the prime meridian constant W_0 was revised [9]. The prime meridian of Mercury is defined by assigning the longitude 340° E (20° W) to the center of the small crater Hun Kal. The previous rotation rate, based on the assumption of a 3:2 spin-orbit resonance, dates back to pre-Mariner 10 time and leads to a longitudinal offset of 0.0519° (2.2 km) in Hun Kal's position in MESSENGER images. Recent photogrammetric analysis of more than 10,000 MESSENGER images in the H-6 (Kuiper) quadrangle of Mercury [10,11] confirmed the adopted prime meridian constant within 220 m.

Dynamical frame: Mercury's rotation state is tied to its orbital motion through a 3:2 spin-orbit resonance. This property allows to define a dynamical reference system, which can be realized by accurate analysis of Mercury's ephemeris [12]. Within the dynamical frame the prime meridian is defined as the mean location of the sub-Solar point at every second pericenter passage of Mercury. Interestingly, the cartographic frame defined by the crater Hun Kal and the dynamical frame do not coincide. The difference amounts to 0.12° (5.12 km) in longitude at the midterm of the orbital phase of the MESSENGER mission.

Principal-axes frame: The principal-axes reference system is defined by the principal components of Mercury's moment of inertia. The low-degree gravity field coefficients reflect the mass distribution within the planet and can be used to derive the orientation of the principal axes. Considering Mercury's gravity field estimates based on MESSENGER radio science data [3,4] we derived the transformation from the MESSENGER to the principal-axes reference frame. We further found that the principal-axes frame coincides with the dynamical frame within the measurement accuracy.

Ellipsoid frame: Due to the strong tidal force from the Sun Mercury's global shape can be characterized by a tri-axial ellipsoid and allows a definition of an ellipsoid reference system. Contrary to the cartographic, dynamical and principal-axes reference systems which have their origin at the center of mass, the ellipsoid reference system is related to the center of figure. The ellipsoid frame can be obtained from any kind of topographic measurements including radar ranging [13], limb profiles [2], laser altimetry [14], radio link occultation [1], and stereo images [15]. While there are hints at an offset between the center of mass and the center of figure in the order of 100 m, the orientation of the long axis of the ellipsoid frame is consistently offset from the axis of smallest inertia through all available data sets. The weighted average of estimates from all available studies suggests a longitudinal offset of 16.7°±1.7° between these two reference frames.

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