Lunar "West Pole" Prime Meridian

Bryce Walden[*], Robert D. McGown, Cheryl Lynn York, Thomas L. Billings[†]

Abstract

We impose coordinate systems on planetary surfaces to define locations, compute distances and areas mathematically, and give us a control grid for mapping. The poles, equator, and parallels of latitude are defined by the planet's intrinsic property of rotation, but placement of the Prime Meridian of longitude is arbitrary. Proper placement and use of the Prime Meridian can make the coordinate system easy and intuitive, or difficult and confusing. Current systems in use for the Moon (more than one are used) are awkward and out of date. We propose the Prime Meridian bisect a prominent feature close to the Moon's "West Pole": Mare Orientale (20°S, 95°W); and, that longitude increase from 0° to 360° in the direction of rotation. We call this the "Lunar West Pole Prime Meridian" system.

Today's "Mean Earth / Polar Axis" system dates from 1775 when mariners used the Moon to find longitude at sea. The mean sub-Earth point, in the center of the nearside, defines the Prime Meridian. Meridians are referenced in degrees east and west, or + and –, from this point. No significant lunar feature marks this Prime Meridian. This system is still used, with one major change: "east" and "west" were switched by international agreement in 1961. Earth's Prime Meridian has changed several times.

The lunar coordinate system should be convenient for those on the Moon and in space as well as those on Earth. It also should be referenced to an endogenous lunar feature, not another planet. The Lunar West Pole Prime Meridian system is an improvement over the present system for all users. Longitudes roughly from 0° to 195° are on the lunar nearside (includes libration) and 195° to 360° span the farside. Adding 5° to Earth's angle from the eastern horizon gives longitude directly. The all-positive numbering system makes computation of change or distance in longitude easier, and removes sources of error. This location of the Prime Meridian is clearly discernable from space: a naïve observer might easily pick Mare Orientale as a marker. The Lunar West Pole Prime Meridian system is useful, simple, elegant, intuitive, endogenous to the Moon, and conforms to modern standards.

Background

<u>Designing the Planetary Grid</u>. Humans impose coordinate systems on planetary surfaces to define locations, compute distances and areas mathematically, and provide a mapping control grid. The coordinate system is anchored to its parent body according to protocols. From time to time these protocols change, so at any given time different worlds may have different coordinate systems.

There are only a few things to consider when anchoring a coordinate system to a planetary surface: axis of rotation, which defines the Poles, Equator, and parallels of latitude; definition of "north," leading to or derived from the direction of rotation; location of the "Prime Meridian," the starting point for marking longitude; and direction of increasing longitude, either prograde (in the direction of rotation) or

[*] To whom correspondence should be addressed.
[†] All authors: Lunar Base Research Team, The Oregon L5 Society, Inc., P.O. Box 86, Oregon City, OR 97045-0007; website http://www.OregonL5.org; email lbrt@OregonL5.org

retrograde (opposite the direction of rotation).

North on the Moon coincides with Earth's north. The Equator is defined as the intersection of the planet's surface with the plane normal to the rotation axis at the center of mass. Latitude is defined as north (N,+) or south (S,–) and labeled as the angle between the equatorial plane and a vector drawn between the point of interest and the origin (NASA JPL 1995). The Moon's period of rotation (turning about its axis) is the same as its period of revolution (orbit around the Earth): one month. Looking down from the north, Earth spins counterclockwise, the Moon orbits Earth in a counterclockwise direction, and the Moon itself rotates counterclockwise. This direction is defined as prograde (*Figure 1*).

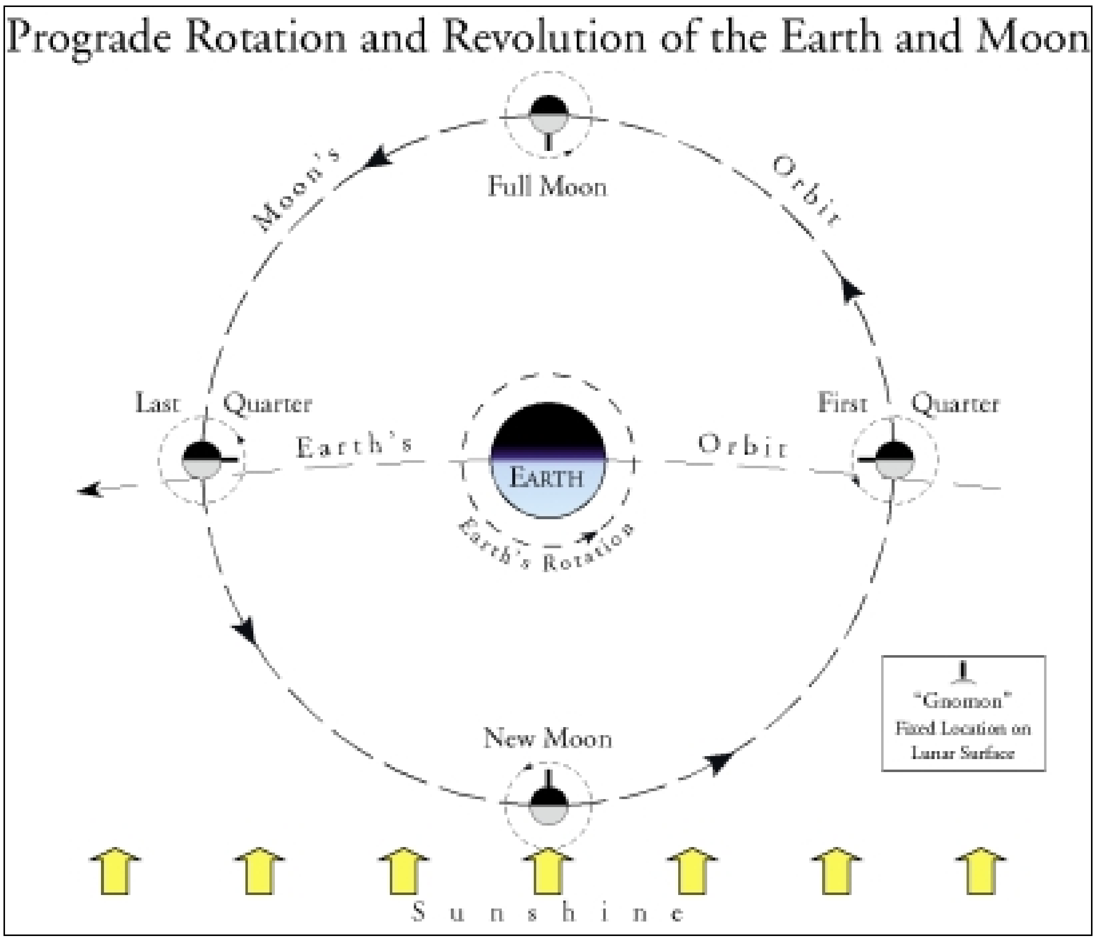

Figure 1: Rotation of the Moon

Lines of longitude are perpendicular to the equator and measured in degrees around it. The line of longitude that begins and ends the equatorial circle is called the Prime Meridian, and its value is 0° (sometimes 360°). Unlike the Equator, locked into position by intrinsic properties of the planet, there is no intrinsic position for the Prime Meridian. It is, in other words, arbitrary.

The Lunar Grid. "Selenodesy, or mapping of the Moon, began with Aristotle (384–322 BC) and has continued to today, building on the work of such famous astronomers as Galileo (1610), Langrenus (1645), Cassini (1680), Schröter (1791), and many others." (Vaniman *et al.* 1991) In 1514 Johann Werner first described the “lunar-distance” method to help mariners determine terrestrial longitude at sea. The Moon’s center, and precise locations of lunar features, were critical for this method and its variants, which drove lunar mapping for the next 350 years (Howse 1996; Sheehan and Dobbins 2001). One hundred years after that, men from Earth set foot on the Moon.

Michael Stennecken of Münster, Germany, discovered that published coordinates of lunar landing sites disagreed, because different lunar coordinate systems were used. His research on standards, and correspondence with NASA, JPL, and experts in the field such as Merton Davies,‡ resulted in his proposal to formally adopt the “Mean Earth / Polar Axis” system as the lunar standard, based on the most common current usage (Stennecken 1999a). German Astronomer Johann Tobias Mayer published the first lunar map using this system in 1575 (Thrower 1996). The Prime Meridian is specified as the intersection of the surface with the half-plane defined by the Z-axis, which is the axis of lunar rotation, and the X-axis, defined as normal to the Z-axis, vector in the equatorial plane in the mean direction of the Earth. Longitude is expressed as 0°–180° east (–) and 0°–180° west (+) of the Prime Meridian (Stennecken 1999a after Davies *et al.* 1987). (Note: traditional usage makes east positive; Stennecken may have inadvertently reversed this, or he is proposing to use the currently-favored “Planetographic” convention where longitude increases retrograde, against the rotation of the planet.)

Control points are another issue Davies raised with Stennecken (1999a). Control points are highly-defined locations from which other locations are measured. They can be anywhere, and need not lie on any particular point such as 0,0. Under the Mean Earth / Polar Axis system, point 0,0 is on the featureless plain of Sinus Medii in the center of the Moon’s face as seen from Earth. Before the Moon race, astronomers used the small (13 km diameter) bright crater Mösting A as their control point. In the Mean Earth / Polar Axis system, Mösting A is at 3°12'43.2"S, 5°12'39.6"W, not on the Equator or the Prime Meridian (Rükl 1990). Since 1969–72, the most accurately defined locations on the Moon are the Lunar Ranging Retroreflectors (LRRR), which have become the new control points for lunar cartography (Davies, in Stennecken 1999b). When laser accuracy is not required, Mösting A may still be used, since it is visible through telescopes from Earth without recourse to expensive Moon-rated lasers.

Today Earth stands ready to colonize the Moon, Mars, and space itself. When we place ourselves in the Moon boots of future settlers, we find the Mean Earth / Polar Axis system wanting. After careful thought, and looking to the future, we propose a new system for lunar longitude based on Mare Orientale and an all-positive prograde progression.

Precedents for Changing Standards

There is precedent for changing the location of a Prime Meridian and longitudinal references to it.

Terrestrial Precedents. The first known map to contain a Prime Meridian was centered on the influential island of Rhodes *ca.* 200 B.C. by Eratosthenes. Around A.D. 150, Claudius Ptolemy proposed using Alexandria for his Prime Meridian. In later works he adopted the westernmost point known to his society, the island Ferro

‡ Chair, IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 1994 (d. 2001)

(Hierro) of the Fortunate (Canary) Isles. Our proposed lunar system is somewhat analogous to this.

When Ptolemy's ***Geography*** was rediscovered by Europeans in the fifteenth century, it became one of the catalysts for the Age of Exploration. His definition for the Prime Meridian became the basis for much of the following three centuries' cartography. Influential maps perpetuated this standard, including those by Mercator (1569), Cassini (1669), Halley (1701), and even an 1808 map published by Laurie and Whittle of London (Thrower 1996, pp. 52–61).

Once the annual ***Nautical Almanac*** began publishing in 1767, based on the meridian of England's Royal Observatory at Greenwich, the vast majority of world shipping used tables and charts derived from it. That is why the International Meridian Conference of 1884 designated Greenwich as the official international Prime Meridian (Howse 1996, pp. 155–156).

Today's "fixed" standard is only a little more than a hundred years old, while the now-forgotten Prime Meridian of the Fortunate Isles was used for well over a millennium and a half. Clearly, such conventions can be and have been changed for the sake of convenience and efficiency.

Lunar Precedents. The Moon, too, has undergone changing standards. When the Moon was first observed and mapped, "astro*nomical* convention" defined east as the side facing eastward from a terrestrial perspective. During that time the "Eastern Sea," Mare Orientale, was named. In 1961, as the Moon became a world to visit and explore, the International Astronomical Union (IAU) adopted the opposite "astro*nautical* convention," designating the direction of rotation to be east, as it is on Earth (Rükl 1990). Consequently, Mare Orientale, the Eastern Sea, is now on the west limb of the Moon! It did not move, of course. Our changing perspective and need to reduce confusion and misunderstanding led to this change.

According to Vaniman (1991, p.60), "After 1974, a lunar longitude system of 360°, proceeding counterclockwise (increasing to the east) from the prime meridian, was adopted by international agreement for future cartography." Curiously, Vaniman uses the older system of ±180° in the 1991 book containing this statement, the ***Lunar Sourcebook*** (Heiken *et al*. 1991), probably because the Apollo data are in that format. Maps produced since 1974 by the National Geographic Society (Peele and Cook 1976), Sky and Telescope (1987), and others, also ignore this rule and continue to use the older convention. U.S. Geological Survey maps included in Greeley's 1987 ***Planetary Landscapes*** use the new standard progression, but longitude increases clockwise (retrograde) following the Planetographic standard (NASA JPL 1995). As Stennecken found, the field is full of confusion and inconsistencies. In addition, the face of the Moon as seen from Earth is split in two. And that's a problem.

"West Pole" Prime Meridian: A Fixed, Endogenous Lunar Standard

Tidal Lock. The current Mean Earth / Polar Axis lunar coordinate system is predicated on the fact that the Moon is tidally locked to the Earth, so that there *is* a mean sub-Earth point. The actual "sub-Earth" point on the Moon varies constantly due to ellipticity, inclination, and other factors of a naturally orbiting body. That is why we refer to the "mean" sub-Earth point. This statistical definition is less satisfactory than a geographically fixed point endogenous to the Moon.

We should nonetheless give consideration to the fact that a single face of the Moon is turned toward Earth at all times. Coordinates on the Earth-facing side will be used much more frequently than coordinates on the farside. In order to make calculations easier, the Prime Meridian should not be in the middle of the Earth-facing side, nor anywhere on that side (Walden 1999). Nearside longitudes should be in the range of smaller positive numbers, from 0°–180°, for ease of calculation.

Natural Monument. Planetographers often choose a distinctive feature of the planetary surface as the marker for the Prime Meridian (Archinal 2001). Scientists studying images can easily relate their study location to the map grid. Future space travelers can quickly align their view of the object with its coordinates, even at a distance. The fixed lunar landmark will not have the uncertainty of a statistical solution depending on another planet.

West Pole. Because the Moon keeps one face to the Earth, it is possible to speak of a "West Pole" and an "East Pole." Mare Orientale, arguably the most distinctive lunar feature, lies on the lunar limb only 5° west and 20° south of the lunar West Pole. Earthbound observers did not appreciate its dramatic appearance until 1967, when Lunar Orbiter 4 sent an image back to Earth that showed Mare Orientale in all its glory (*Figure 2*). Its position within a few degrees of the Moon's leading edge is another reason to favor it as a longitudinal monument.

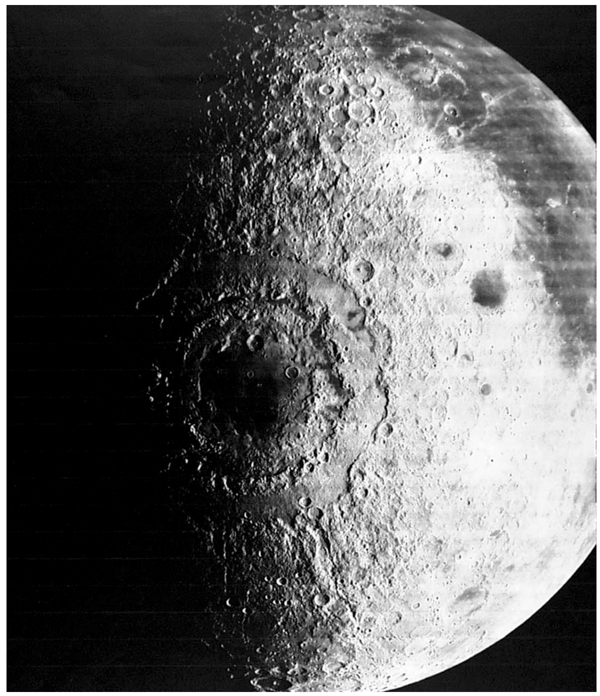

Figure 2: Mare Orientale (LO IV–187M, 1967) (NASA Image)

Proposal. We recommend the lunar Prime Meridian bisect Mare Orientale, a fixed lunar "bull's eye" feature at what is now 95°W 20°S, and that longitude increase prograde (to the east) from 0° to 360°, adhering to the Planetocentric standard recommended in 1974 (NASA JPL 1995; Vaniman *et al.* 1991). In a world so commonly visible from Earth, this appears to us a reasonable and useful choice. We call our proposal the "Lunar West Pole Prime Meridian" system.

Although we refer to the West Pole, we do not propose to exchange one exogenous standard for another. The fact that this feature is near the West Pole, and will be for a very long time, prompted us to coin a memorable term for the new system. What we are literally proposing is the "Mare Orientale Prime Meridian" system, which just happens to be nearly coincident with the lunar West Pole. We believe it is more important that the new standard is firmly fixed to Mare Orientale than that it have the "West Pole" name.

Advantages to Terrans. Moving the Prime Meridian would eliminate confusion regarding east and west. Longitude would be numbered continuously from 0°–360°, with longitudes 0° through 180° encompassing the maria-rich lunar nearside (actually 356.3° (i.e., –3.7°) to 193.7°, allowing for libration (Vaniman *et al.* 1991, pp. 58–9)). Likewise, the heavily cratered farside will have longitudes greater than 180°, so the two very different faces are also numerically distinct. This numbering is less ambiguous to laypeople. Astronautical and astronomical coordinates will no longer be confused. When features are referred to by their coordinates, they are more likely to be placed correctly.

An interesting effect of moving the Prime Meridian to Mare Orientale is that today's central indicator, Mösting A, will be even closer to indicating its cardinal point, at 3°12'43.2"S (no change), 90°12'39.6"E (96% closer in longitude to cardinal point 90°E). This should actually increase its usefulness to astronomers under the Lunar West Pole Prime Meridian system.

Advantages to Lunans. It seems reasonable to expect settlement of the Moon to concentrate on the nearside. Over time, there will be a fair amount of traffic among nearside bases. Frequently crossing the Prime Meridian and changing longitude from east to west and vice versa would be a bother. The same conditions would apply on the farside when crossing the anti-Meridian. The Lunar West Pole Prime Meridian system has only one crossing-point: the Prime Meridian. Even this is located slightly beyond the western limb, so settlements in that prime real estate, where Earth actually "sits" on the horizon, will be included in "nearside" low longitude numbers.

For lunar nearside locations, Earth itself is the premiere indicator of longitude, hanging as it does in roughly one place in the lunar sky for any given surface location. Adding 5° to Earth's angle from the eastern horizon gives approximate longitude directly. It makes more sense that Earth near the horizon represents either 0° or 180° and Earth overhead represents 90°, than under the present system where Earth overhead represents 0° and at the horizon represents a confusing + or – 90°.

Wider Acceptance. One reason the preferred 360° standard has not been more widely adopted is that the old ±180° standard is more obvious and intuitive given a Prime Meridian that bisects the visible face of the Moon. By relocating the Prime Meridian to Mare Orientale, all nearside longitudes progress consecutively from 0° to 180° and farside longitudes increase progressively from 180° to 360° (= 0°). There should be very little reason for people to revert to the older + and – system, but even if they did, nearside locations would still be positive, between 0° and +180°.

Conversion. Implementing the new system should not create much difficulty. Latitude will not change; longitude can be translated (from older maps and data based on the current lunar Prime Meridian) by simple addition and subtraction.

Fewer Errors. An east/west coordinate system duplicates longitude numbers with only a letter (E,W) or sign (+,–) to differentiate them. Misreading the one differentiating symbol can result in a dramatic error in location, which can have serious and even deadly consequences. A universally positive system such as we propose eliminates this potential source for significant error.

Easy Math. With all-positive longitude numbers and only one zero-point crossing, lunar longitude calculations are simplified, making it easier to use and less likely to produce errors, especially when done in the field or in one's head.

Indirect costs. Adopting a universally positive system should cut down on direct and indirect costs. Software for computing longitude and locations can have simpler algorithms, making it easier to write and taking up fewer processor cycles to implement. Reducing sources of error and confusion in reading maps or figures results in time and energy savings for users. Consequences of errors are also obviated, and these could be quite expensive in certain cases.

Summary

Looking ahead to future lunar development, we examined the lunar coordinate system from the point of view of potential lunar settlers and found it wanting. It is archaic, confusing, and dependent on another world for its definition. Even current maps are inconsistent and use differing standards. Two simple changes would bring the lunar coordinate system up to modern standards, improve utility, increase efficiency, and reduce errors.

Moving the lunar Prime Meridian roughly 95° westward to bisect Mare Orientale would lock it to an endogenous lunar feature and naturally split the Moon into nearside and farside domains. It also makes the traditional lunar marker, Mösting A, a more accurate monument. Numbering longitude prograde from 0° to 360° will reduce errors and make calculations easier. These changes are straightforward, and translation from the older system is simple.

Now is the time to adopt these changes, before we open bases and start settlement of Earth's Moon. With a new, intuitive and rational system in place, we can clarify and simplify lunar longitude for generations of students, astronomers, selenographers, and lunar settlers to come.

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