Does the Moon Turn Upside Down Below the Equator?

Myth Memo 1

Alvy Ray Smith
21 September 2001

Two commonly held beliefs about the equator are (1) that the moon phase appears upside down below the equator—using my Northern Hemisphere bias—and (2) that water spins down the drain in the opposite direction there too. The brief answer is that neither of these is true. I will deal with the moon myth here. The fluid vortex myth is treated on the web in several places rather well[1]. The moon myth is a little bit harder to dispel. In fact, myth is perhaps too strong a word as you will see, because there are many cases where the moon does flip over, or approximately so. It's just not generally true.

First, let's define terms. I have carefully said that the moon *phase* is supposed to turn upside down. The phase is what we mean when we use the terms crescent moon, half moon, full moon, and so forth. When people say, "the moon turns upside down," they mean that the moon they saw yesterday at home in Seattle, say, is upside down when viewed today in Ecuador, say, or Tanzania, or Bora Bora. That is, if the moon in Seattle were a crescent moon, then in Bora Bora it is a crescent moon turned upside down, they say. Strictly speaking, "upside down" would mean the crescent moon has apparently rotated 180°, but in this paper I will allow the term "upside down" to refer to any rotation near 180°. Jump ahead to Fig 7 if you want a clear idea of what I mean by "rotation of the phase of the moon". In particular, I do not mean that the lunar phase is changing.

The phase of the moon is to be distinguished from features of the moon, like craters. It is well-known that the moon always presents the same face to the earth and that we cannot see, therefore, the backside of the moon. So the features of the moon stay constant, as seen from earth, while the phase changes all month long every month. On any given day, however, the phase of the moon is a constant, from anywhere on earth. It may rotate with respect to the viewer, as described above or in Fig 7, but the phase itself is constant—a crescent moon stays a cres-

[1] In case you are dying of curiosity, water goes down the drain in the direction of initial displacement, regardless of the hemisphere. There *is* a force, the Coriolis force, that *in ideal circumstances*, would force the vortex in opposite directions, but the ideal circumstances never occur except in very carefully controlled experiments—I think this care has been exercised only once or twice in history. Very large vortices *are* affected by this force. Hurricanes spin in opposite directions in the two hemispheres. A bathtub drain or a flushing toilet vortex are trivial in comparison and are, for *all* practical purposes unaffected by Coriolis. It is the direction the pipe is pointing, for example, that determines vortex direction, not the hemisphere. See, for example, http://www.ems.psu.edu/~fraser/Bad/BadCoriolis.html for further details. My thought exercise for this one is this: Imagine standing at the equator with a bucket of water. Start it spinning. Now, while it is spinning, step across the equatorial line. Do you really imagine that the water would stop, change directions, and start spinning the other way? Of course not. It's just a line.

cent moon. You may think of the phase of the moon on any particular day as being attached to the moon, so if the phase appears to rotate so do the features of the moon. What we will have to say about rotation of the phase of the moon, therefore, can also be said about rotation of its features.

For quick review, moon phase is caused by direct sunlight. It is not caused by the shadow of the earth, a surprisingly common misconception. Earth shadow has its own name—eclipse—which seldom happens. The moon phase changes because the moon circles around the earth once a month[2]. The sun is a giant flashlight out there in space that illuminates the moon from one direction[3]. As the moon swings around us, we can sometimes see the lit side, sometimes not, or only parts of it. These are the phases. The phase of the moon appears the same to anyone on earth, at a given time, to whom the moon is visible. But the angle that the (constant) phase makes with the horizon changes. Hence the problem discussed here.

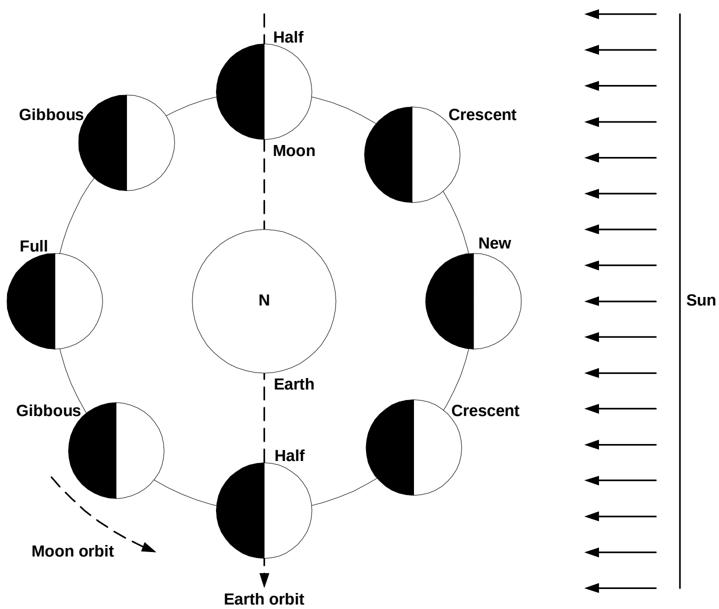

Fig 1. View of the earth, in orbit about the sun, from above the north pole. The sun illuminates the moon in orbit about the earth, shown in eight positions along this orbit. The phases of the moon are the moon as seen from earth, being constantly lit by the sun as shown regardless of orbital position. The phases in the top, or first, half of the moon's orbit are its waxing phases; those in the bottom, or second, half its waning phases.

First, I present an intuitive argument. Then in the section called **Real Data**, I appeal to real data from a software program to support the intuition. You can make this a much shorter read by simply leaping to that final section.

Here are some simplifying approximations. We will later discuss how much effect these have on our argument (as you might imagine, not much). Meantime, they greatly simplify presentation of it. We will approximate the geometry of the

[2] Approximately.

[3] This direction changes slightly because the earth-moon combination is moving slowly, once a year, around the sun. Just think of it as constant for this exercise and you won't be far off.

earth-moon as follows: The moon orbits around the earth in the equatorial plane of the earth. We will also assume the sun is at infinity so it illuminates the earth and moon with parallel rays. We also assume, for now, that there are no seasons. That is, the earth is not tilted with respect to the plane of its orbit about the sun. This last is a large assumption and will be revisited later. So our model system is illustrated in Fig 1, which also illustrates the phases of the moon.

One problem with Fig 1 is that if it were exactly true, then the moon would go into eclipse behind the earth every month. So just know that this is not so, that the moon is full (completely sunlit) in general when it is “behind” the earth with respect to the sun. This is because the moon’s orbit is angled slightly with respect to the earth’s about the sun. Nevertheless, we shall ignore this small angle (5° or so) to keep the geometry simple. See Fig 5 for more details of the arrangement.

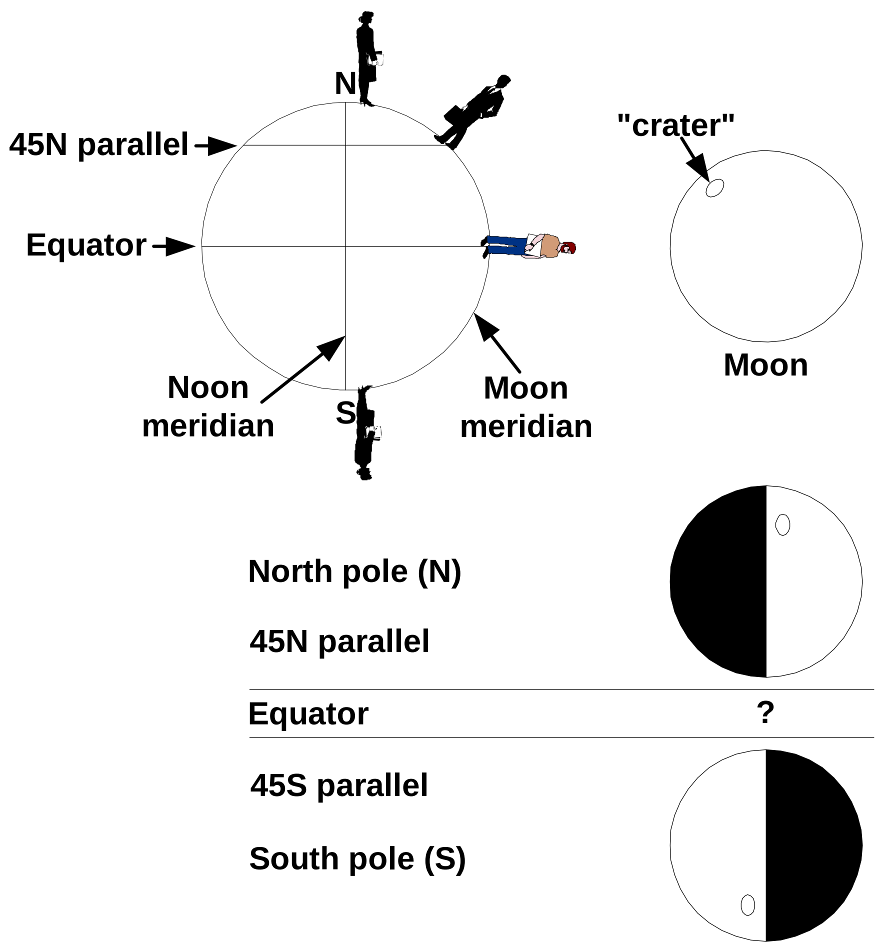

Fig 2. View of the earth and moon from the sun, at the waxing half moon phase. People along the Moon meridian see the half moon at two different angles, depending on hemisphere. This is not true for the person at the equator who can see the half moon at any angle.

To use the simplified model for understanding moon phase, consider the following: Assume that the moon is half full, at the top position in Fig 1—that is, it is a waxing half moon. Now look at the earth-moon system from the side of the sun, as in Fig 2. A feature, supposed to represent a crater, is drawn on the moon’s face for orientation, and to help distinguish feature rotation from phase rotation (crater not shown in Fig 1). Two of the features labeled in the figure are not familiar. The *noon meridian* is the line along the surface of the earth from north to south pole that passes nearest the sun on the daylight side of the earth shown in Fig 2. The *Moon meridian* is the one running along the limb of the earth from the sun's view—that is, the meridian that passes nearest the moon[4]. These two "features" are not features of the earth in that they are not attached to the earth as are the equator and 45th parallel. Instead they change as the earth daily rotates on its axis.

There are persons shown on the surface of the earth standing at the north and south poles, the equator, and the 45th parallel north (45N, also known as the the latitude 45°N), looking at the moon. What do they see? Consider the woman at the north pole. She sees the bright (sunlit) side of the moon on its right; the dark (unlit) on its left. So she sees the moon phase represented to the right of "North pole (N)" in Fig 2. The man at the 45N parallel would see the same thing. In fact, someone walking down this particular meridian from the north pole toward, but not at, the equator would always see the same moon phase. Now consider the woman at the south pole and walking up the same meridian toward, but not at, the equator. She sees, when looking at the moon, the dark side on its right, the bright side on its left, and hence the half moon phase illustrated at the bottom of Fig 2. Notice that the moon (phase) has turned upside down in this case, meaning that the bright and dark patterns have swapped sides of the disk. Or another way to say it is that the apparent phase (eg, a cresecent) has rotated 180°, as have the features of the moon. This is a case where the phase has "turned upside down", and the features have too.

What happens at the equator on this special meridian, that we are calling the Moon meridian? Here the answer can be anything because there is no defined direction "looking at the moon". The little man looks straight up, head back presumably, and can see the phase (half moon in our example) rotate to any angle by spinning his body around.

Now let's try the meridian that is 90° away from the one just considered, the noon meridian, in our simplified model. Fig 3, left column, shows the results. We already know what persons at the north and south poles see, from Fig 2. What does a person see at the equator on this noon meridian, when looking at the moon? He sees the lit half on top and the unlit on bottom, as shown in Fig 3. I have also drawn what a person sees from 45°N and 45°S. You will note that a person walking from the north pole to the south (without the earth spinning) would see the phase of the moon rotate counterclockwise by the amount of the latitudinal change he makes.

To be concrete, let's consider a person in Seattle at about 48°N and another one at the same time in the Galapagos Islands on the equator. Let's assume they are both on the same meridian (they are not) and that the moon is a waxing half moon again, as before. Let's assume it is noon, so they are on the noon meridian. Then the person in the Galapagos sees the moon rotated 48° from what the Seat-

[4] I capitalize Moon meridian because otherwise it looks confusingly like noon meridian.

tle person sees. Is that upside down? No. Upside down would be 180°, so not even close.

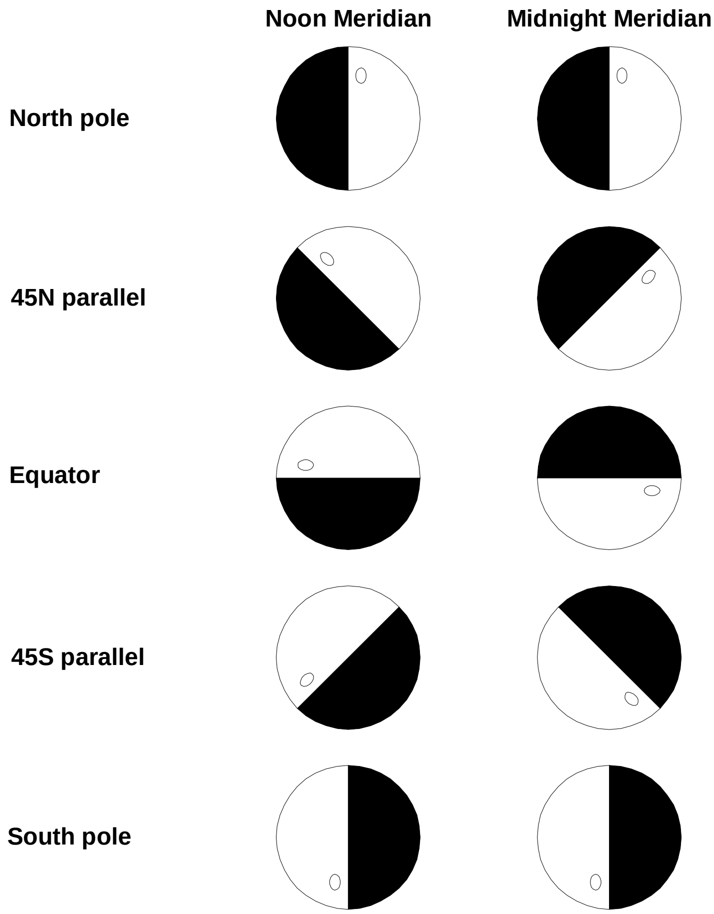

Fig 3. The left column illustrates the rotation of the waxing half moon as seen from various positions along the noon meridian; the right column similarly for the midnight meridian.

Fig 3, right column, shows the case for positions along the *midnight meridian*—that is, the continuation of the noon meridian on the dark side of the earth[5]. In this case, the phase of the moon rotates clockwise by the amount of the latitudinal change. Notice that we don't need to consider the left side of Fig 2, front or back, because the moon is not visible from there.

Where would you have to be to see the moon upside down from that in Seattle at 48°N? Notice that 48°S on the same meridian doesn't suffice. That only rotates the moon phase 96° from Seattle's view. The answer is that you would have to walk around the great circle of this particular meridian to a point 48°S on the opposite side of the earth—diametrically opposite Seattle—to get the upside down phenomenon. There's not much there but water, and it would be on the midnight side of earth. Let's use Easter Island on about the correct meridian, but at about 27°S. The relative phase of the moon would have rotated about 201° or,

[5] "Meridian" sometimes refers to the entire great circle. Here I mean only half of a great circle—a line of constant longitude—from north pole to south pole.

equivalently, 159° from that seen in Seattle. That's a candidate for "upside down", I suppose. The lesson is this: On this extreme meridian, we can get the moon to turn upside down by passing diametrically through the earth to a point on the opposite side. This is indeed a case of changing hemispheres and observing the moon go upside down.

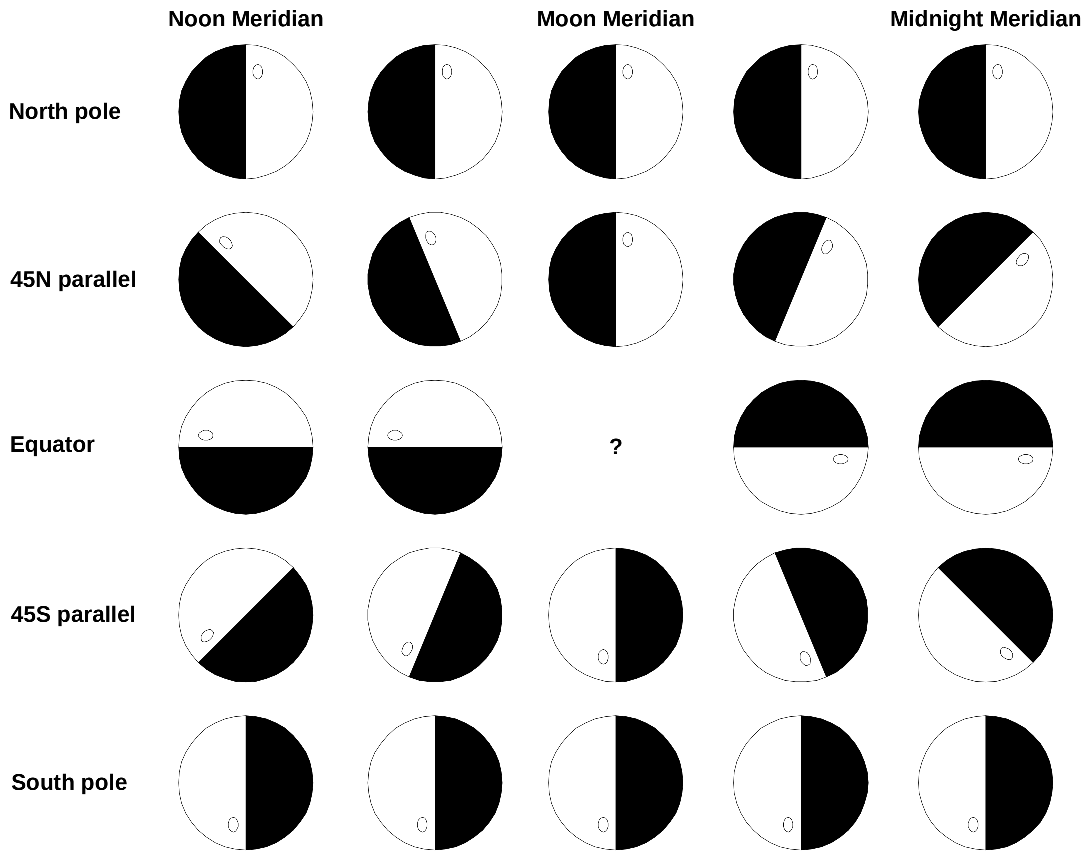

Fig 4. A combination of Fig 2 and Fig 3 with two additional meridians added which can be thought of as the 3 o'clock and 9 o'clock meridians using the noon and midnight meridians as examples of clock names. Then the Moon meridian is the 6 o'clock meridian. The angles shown are not accurate—eg, that for 3 o'clock meridian and 45N parallel—but are indicative.

In Fig 3, notice that the moon as seen at the equator on the noon and midnight meridians are the reverse of one another (but the features have changed sides left-right). This is similar to the first case above, in Fig 2, where we imagined our little persons along the meridian nearest the moon. In this case, as we walk along the equator from the noon meridian to the midnight meridian (again assuming the earth is not spinning), the moon angle stays constant until we are forced to flip our head around to keep the moon in view, at which point the moon does turn upside down. At the point of closest approach to the moon, we have another one of those singular points where the angle can be anything. In fact, this is the same point as before. So, here on the equator, we get the moon to turn upside down without changing hemispheres (imagine being slightly to one side or the other of the equator). Notice that walking around the equator from noon to midnight meridian, without the earth turning, is equivalent to standing on the equator and watching the moon for half a day as the earth turns.

What happens at other latitudes as the day progresses (or as our person walks around a line of constant latitude, without the earth turning)? Consider 45°N. We simply read off the row of Fig 3 labeled "45N parallel" to determine what the person sees on the noon meridian and on the midnight meridian, and Fig 2 shows what is seen on the Moon meridian halfway between. As one walks along this parallel (earth not turning) then the angle has to change smoothly from one position to the other. I have tried to summarize all this in Fig 4, with two additional intermediate meridians.

Notice that a person walking down the 3 o'clock meridian (see caption of Fig 4), the earth not spinning, would see, with lots of slop in the term, the moon turn "upside down", as on the Moon meridian. Similarly for the 9 o'clock meridian. Notice that the 3-45N (3 o'clock meridian, 45N parallel) position of the phase is exactly 180° from the 9-45S position. So it is not passing through the earth diametrically that does the true flip, as the noon and midnight meridians seemed to indicate. Perhaps this is the source of the moon upside down myth? Because it is "sort of" true for many positions on earth? Particularly at prime moon watching times (eg, 9p)? We will have to revisit this after we correct our geometry model for reality.

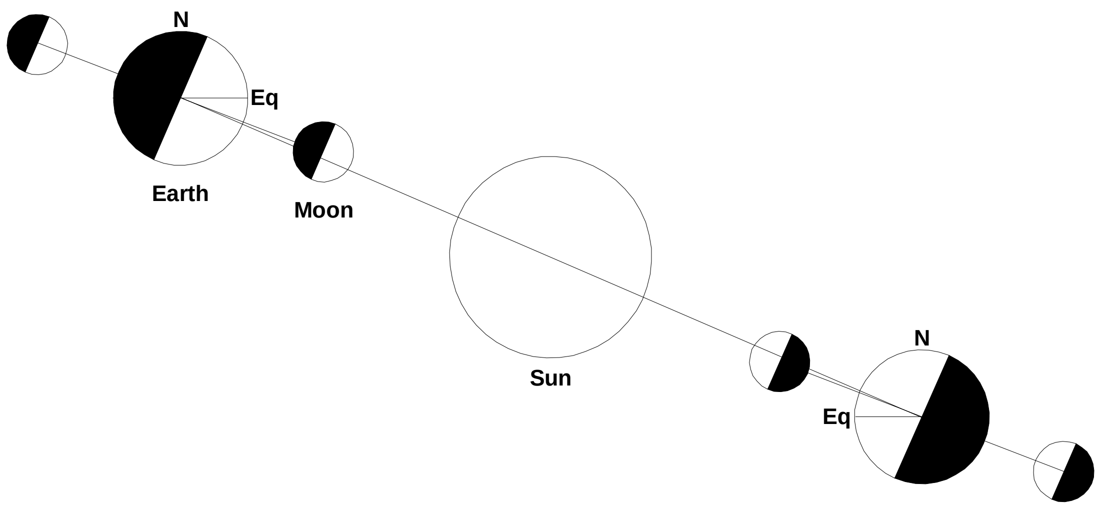

Fig 5. The earth-moon system in orbit about the sun, showing the effect of the tilt of the earth. Two positions of the earth-moon system are shown along the orbit. The one on the left corresponds to summer in the southern hemisphere; the one on the right to summer in the northern. These are, respectively, the positions for winter and summer solstices. The moon is shown in two positions along its orbit about the earth, for each solstice position. The plane of the moon orbit is slightly out of the plane of the earth orbit but only slightly so. The line across the earth caused by its intersection with the plane of its orbit is called the *ecliptic*. (Eq = equator, N = north pole).

I have used the half moon in all my examples above. This does not matter. Exactly the same arguments go through regardless of which phase one chooses. You might want to rerun the arguments using a waxing crescent moon, for example. You still look at the sun-moon system from the sun's view as for the half moon case above. Now, when the little woman at the north pole looks out at the moon, she sees the (lit) crescent on her right side and the completely unlit side on her left. And so forth. The concept of Moon meridian holds, being still the meridian through the point on the equator closest to the moon at any one time. Although noon and midnight meridians still exist, they are not the meridians we wish to argue, namely the meridian 90° west of the Moon meridian and the meridian opposite that one, or 90° east of the Moon meridian. So you can see that the clock-related names for the extreme meridians are not good choices in general. I will call them moon, moon+45E, moon+45W, moon+90E, moon+90W meridians from now on, for former names moon, 9 o'clock, 3 o'clock, midnight, and noon, respectively. The clock related conjecture above about the source of the moon myth is called into question by this removal of the time related names.

All of the preceding uses a highly simplified geometrical model of the solar system. Most importantly, the approximately 23° tilt of the earth, which causes our seasons, is not taken into account. See Fig 5.

So Fig 2 is correct if we relabel the equator as the ecliptic and think of the parallels and poles as being relative this rather than the equator. Thus the north pole becomes the point 90° north of the ecliptic, and the 45N parallel is the the line 45° north of the ecliptic. This is true for any time of the year.

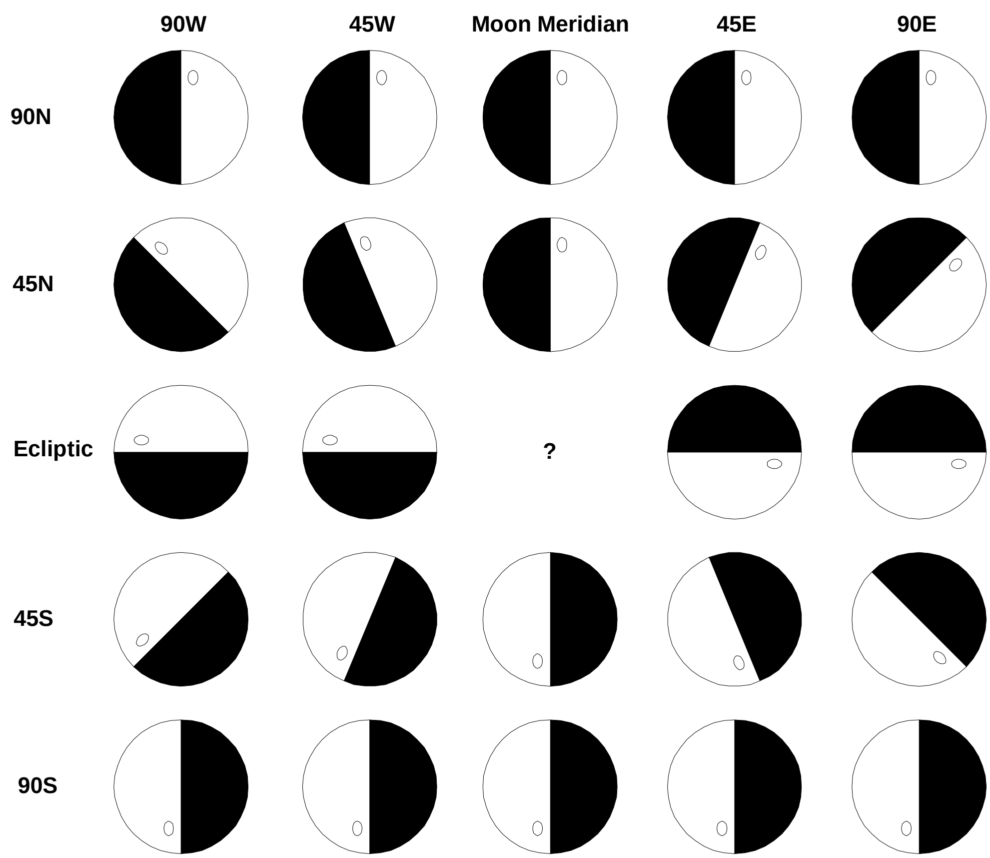

Fig 6. Fig 4 redrawn with labels corrected for seasons—that is, for the tilt of the earth.

You might wonder why I didn't just label the figures this way from the beginning. It is because we are not fluent in plotting locations on the surface of the earth relative the ecliptic. Where exactly is Seattle relative the ecliptic? There really isn't an answer because the ecliptic, and the coordinate system tied to it, slide over the surface of the earth as the earth turns. I have redrawn Fig 4 with the corrected labels as Fig 6.

The arguments made for the appearance of the moon phase are seen, from Fig 6, to be unchanged if one determines phase from positions along the meridians measured relative the position of the ecliptic. However, as already mentioned, the underlying locations on earth become difficult to determine. Nevertheless, we can say some strong things about moon phase rotation. It is clear that there are positions on the earth's surface at any given time where the moon does indeed "turn upside down" relative another position. There are even more positions where this is only roughly so—and this is probably the source of the moon myth. But there are many positions where it simply is not true, even roughly. Therefore, *it is generally not true that the moon turns upside down in the two hemispheres*. As we have seen, and shall see below more strongly, it is even possible to get the moon to turn upside down in the same hemisphere.

Before proceeding, let me suggest a refocusing of the problem which perhaps better captures what people are claiming when they say the moon turns upside down south of the equator. I believe they are remembering the moon phase angle at their home *at some particular time of day*, such as early evening. So when they compare the moon phase angle at another location, typically across the equator, they are viewing the moon there at roughly the same time of day. So rather than comparing moon phases at the same actual, or absolute, time in two different locations, it perhaps is more consonant with the real meaning of the claim to compare them at roughly the same (local) time of day.

Real Data

At this point, I am going to assume that you have built up an intuition about the complex nature of the underlying problem—that you can get the moon to rotate almost any way you want by choosing appropriate pairs of points and times. I believe that this is about as far as we can go using intuitive models, so I am now going to invoke a software astronomy program to give real answers. You might wonder why I didn't do this in the first place. It is because I have often found myself in arguments (seldom are they mere discussions) about this problem in remote places, certainly remote from a computer program, where intuitive models are important. The most recent such place, for example, was in remote Tanzania on a safari.

My software program is Starry Night Pro from SPACE.com Inc (see www.starrynight.com) . This program allows one to choose or specify locations on earth's surface, using familiar longitude and latitude. From a given location one can choose a view centered on the moon with the local horizon horizontal. This seems to be a reasonable way of fixing what is meant by moon phase angle: It is the angle established by the two extremes of the lit portion of the moon phase relative the local horizon, which is presumably parallel to a line through the viewer's two eyes. Starry Night Pro then allows one to change to another location, with the same view—that is, local horizon horizontal, centered on the moon. At any one location, one can alter time at will. I have used increments of one hour to generate the moon phase angle changes in Fig 7, which is comprised of tiny portions of the screens actually displayed in Starry Night Pro[6]. Since the contrast of these images is low, I have added, by hand, a red line connecting the two endpoints of the crescent moon visible on this date. The number below each image is the angle in degrees of that line by my measurement (not by Starry Night Pro), with 0° being horizontal, crescent above, and positive angles increasing counterclockwise.

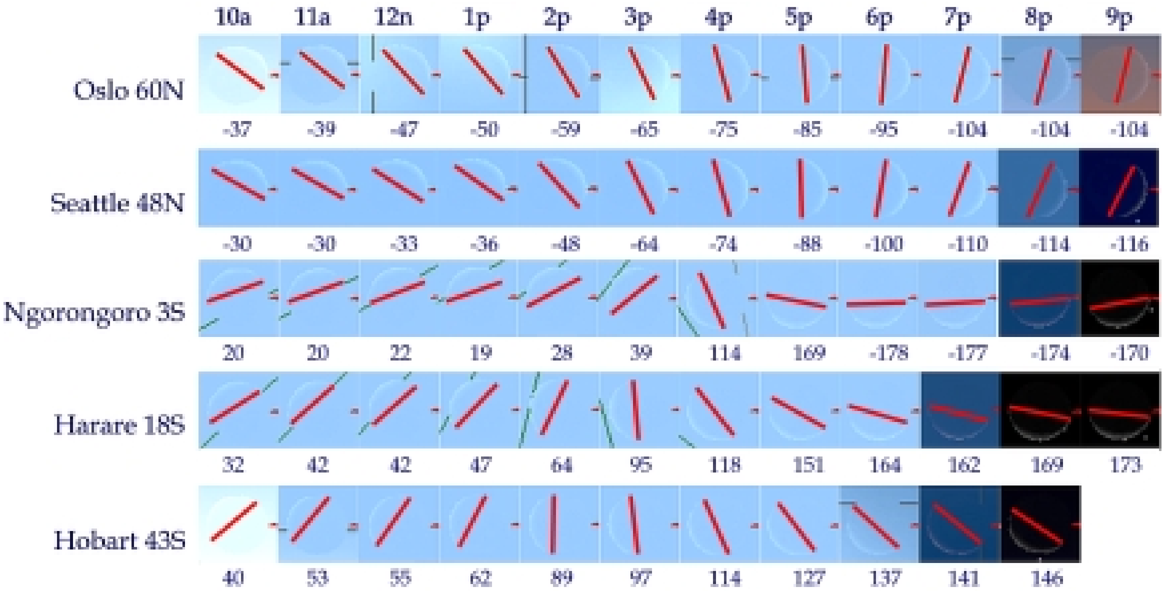

Fig 7. Actual moon phase data for 21 Aug 2001 as generated by Starry Night Pro for Oslo, Norway (11°E); Seattle, USA (122°W); Ngorongoro Crater, Tanzania (35°E); Harare, Zimbabwe (31°E); and Hobart, Australia (147°E). Local times are shown in each location. The moon is below the horizon for other hours in each location. The horizon is horizontal for each view. The number underneath is the angle of rotation of the cresecent moon.

Fig 7 is arranged vertically like Fig 4, but the columns are lines of constant local time, not earth meridians. As argued above, this is to compare moon phases in different locations at apparently comparable times of day. Thus if you observed the 6p moon phase in Ngorongoro Crater near the equator and then transported yourself to Seattle, you might be prone to compare the 6p moon phase there to what you remembered in Tanzania[7]. If you did, then Fig 7 shows that the moon phase would look quite different, rotated by about 90°, but not upside down. On the other hand, if you do a strict time comparison between the two locations, for example 10a in Seattle and 9p in Ngorongoro[8], you would see the moon almost turn upside down. I contend that one doesn't ordinarily mean to compare a morning moon to an evening moon. For one thing, these are the

[6] Starry Night also works.

[7] We will ignore the fact that you probably couldn't make it back from Tanzania to Seattle in time to make this comparison.

[8] This uses the 11 hour difference in time between the two locations relative Greenwich, ignoring daylight savings time variations, which barely affect the statement anyway.

only two hours that could be compared in this case because the moon is not visible in both places for any other hours.

Notice that one can make the moon turn upside down without changing hemispheres, as previously deduced in our model experiments. Consider watching the moon all day, while it is visible, at Ngorongoro Crater. Between 2p and 5p the moon flips almost upside down, being very loose with the definition of "upside down".

Notice also that the moon turns almost upside down when changing hemispheres from Oslo to Hobart, if phases are compared during 10a to 4p, local time, in both places. After that it gets harder to claim that full upside down has been achieved, although there has indeed been a substantial rotation.

Consider the -95° rotation of the crescent moon seen in Oslo at local time 6p. Then consider someone at Hobart. If that person watches long enough, he will eventually see a case where the crescent moon is rotated 85°, or upside down—in this case, sometime between 1p and 2p local time.

Notice that changing hemispheres from Seattle to Harare causes an apparent flip only for the 3p slot (or the 2p-4p slots, if being very loose). At other times it is nowhere near a flip, being more like 90° rotation instead.

So let's repeat the conclusion of this exercise: The moon *in general* does not turn upside down when changing hemispheres, even if one is rather sloppy about the meaning of upside down—say, 180° ± 20°. However, there are clear situations where the moon does turn upside down. In particular, if one watches long enough during a day, he will generally see an exact upside down for a short while. It is perhaps these situations that have been reported and repeated until the idea has taken root as a general "fact". In any event, since it is sometimes true, once a day at least, it is heavy handed to refer to the moon "myth" as I have done.

Acknowledgement. To my friend Dick Shoup who improved several of my wordings, sharpened some of my points, particularly the conclusion.