WHERE IS THE LUNAR ARCTIC CIRCLE?

The Question

Could we see the moon looking due north from anywhere near Palmer, Alaska, our home town? Is the lunar Arctic Circle nearby, where there's a day the moon never sets?

You'd think after fifty years I'd know that answer, or someone would have a picture. Accurate predictions require more than my meager knowledge of astronomy, meteorology, and geography. There is a vast network of helpful astronomers and moon specialists, many readily accessible on various web forums. The few I've contacted have been very helpful in developing this question.

So, I pass this question on to you, and hope your curiosity may be piqued and the answer found.

What is the Lunar Arctic Circle?

I could find no definition of the lunar Arctic Circle by searching the web. Several definitions and locations appear possible, from simplified astronomical averages to actual observations. The simple version, derived similarly to the solar Arctic Circle, is described first.

Dictionaries define the solar Arctic Circle as where the sun doesn't set on the summer solstice nor rise on the winter solstice, and place it about 66.5^{o} North latitude. Local knowledge and a good ephemeris tell us the midnight sun is visible considerably south of the Arctic Circle, and the winter solstice sun can be seen well north of the Arctic Circle. Thus, this solar Arctic Circle appears to be an arbitrary construct or average, rather than a measured value.

The furthest north where the sun appears directly overhead (only one day each year, on the summer solstice) is easily measured, and is called the Tropic of Cancer. It is located at $\sim 23.5^{o}$ north of the equator, which can be determined from the apparent movement of the distant stars. The tropics and equator are observable geocentric constructs, lying on lines between the centers of the earth, observer, and sun on the solstices and equinox respectively.

The Arctic and Antarctic Circles seem to be technically only the converse of the Tropics; $\sim 23.5^{o}$ from the poles, rather than from the equator. Sunset or sunrise do not occur precisely at these circles on the solstices because the events occur on the horizon, involving several large deviations and uncertainties compared to geocentric observations.

The lunar plane is tilted $\sim 5.2^{o}$ (somewhat variable) from the solar ecliptic, indicating the maximum declination of the moon north of the equator is $\sim 28.7^{o}$. Thus, the latitude of the lunar Arctic Circle would then be $\sim 61.3^{o}$. This would supposedly be the lowest northern latitude where you could see the moon due north, where there would be one full day sometime when the moon never sets and another when it never rises. Just like for the sun and the solar Arctic Circle, this would appear to be an artificial construct not supported by ground based observers. This simplified construct, called the Geocentric Lunar Arctic Circle, is shown in Figure 1.

The Geocentric Lunar Arctic Circle, Accounting for Variations in the Moon's Orbit

Even the simple geocentric Lunar Arctic Circle is variable and hard to predict. The moon reaches its extreme declination on an 18.6 year cycle. Theoretically, the moon can be seen due north from a point on the lunar Arctic Circle only once in this cycle. If it is cloudy then or the sun's too bright, wait another 18 years. Then, the extreme declination marking the lunar Arctic Circle will be slightly different - it's no wonder few know where the lunar Arctic Circle lies.

We are approaching the most extreme declination in the last four cycles. According to NASA[1] and Meeus[2], the moon will reach its northernmost declination (28° 43' 22") in more than 70 years on September 15, 2006.

Accurate predictions of the moon's position are very challenging. Clues to this difficulty in predicting the moon are provided by Geniet[3], who describes the many aspects determining lunar declination, including variations in the ecliptic, lunar inclination, perturbations, parallactic fluctuations, and others. LunarPhase Pro[4], which has a pretty good ephemeris program, indicates the maximum declination for 9/15/06 will be 27° 56'. The Virtual Moon Atlas[5], another nifty lunar ephemeris and atlas, indicates the maximum declination in the next couple years will be 28° 10', but it will occur on 4/2/06. These ephemerides do agree that the moon will reach a maximum declination of 27 degrees or more during most months for the next couple years.

Since NASA has actually been to the moon, their predictions of its location are widely accepted. Thus, a geocentric construct might place the lunar Arctic Circle at about 61.275° (61° 16.5') N latitude, based on this current 18.6 year maximum declination. Interestingly, the lunar Antarctic Circle is not at the same south latitude this cycle due to eccentric orbit.

Ground Truth

Predicting the lunar Arctic Circle for an actual observer is much more difficult than astronomical predictions. The ephemerides are calculated for geocentric positions. When you are looking at the sun or moon at the horizon, you are no longer on the geocentric line, but have moved off the line by the radius of the earth. This topocentric view gives different relative positions of the celestial bodies due to parallax. The sun's position will change little (<.003°) due to its vast distance compared to the earth's radius, but the moon will be shifted ~1° (54-61 arcminutes)[6] from its geocentrically calculated position. Thus, the never-set topocentric lunar Arctic Circle is shifted about a degree north of the geocentric lunar Arctic Circle, but the never-rise circle is shifted about a degree to the south.

While geocentric observations are between centers of celestial bodies, rise of the sun or moon is defined as the first appearance of the upper limb at the horizon. The moon's apparent radius

[1] NASA; RP1349 Lunar Ephemeris; http://sunearth.gsfc.nasa.gov/eclipse/TYPE/moon4.html
[2] Jean Meeus; Mathematical Astronomy Morsels; p27; 1997
[3] http://www.iol.ie/~geniet/eng/archaeocosmology.htm
[4] LunarPhase Pro; V2.12; http://www.nightskyobserver.com
[5] Virtual Moon Atlas; Light Version 2.01; http://www.astrosurf.com
[6] US Naval Observatory; Rise, Set, and Twilight Definitions; http://aa.usno.navy.mil/faq/docs/RST_defs.html

varies from .25-.28° (15-17 arcminutes)[6], moving the apparent Lunar Arctic Circle to the south for the "moon doesn't set" observation.

A greater variable is the bending of light near the horizon, caused by atmospheric refraction. Light bends as it enters denser air near the surface. Standard atmospheric refraction is ~.57° (34 arcminutes)[6], but can be much greater in northern latitudes, sometimes two degrees or more. Extreme arctic winter inversions may result in bending of 5° (the Novaya Zemlya effect[7]).

Although computer programs exist for calculating atmospheric refraction, predicting horizontal refraction at any spot is much more difficult than predicting weather. As light passes from the moon to the observer, it traverses hundreds of miles and multiple layers of atmosphere, with varying indices of refraction. Accurate refraction prediction, just a couple days in advance or even instantaneously, may be the real frontier of this problem. Global coverage of weather satellites with linked computers might now provide adequate meteorological tools, but real time refraction predictions are apparently not yet available.

The US Naval Observatory, historically charged with providing astronomical data for ship navigation, gives a brief summary of these difficulties in predicting moon rise/set in northern latitudes[8], and provides a calculator for determining the moon rise/set times[9] (with carefully qualified accuracy at northern latitudes, largely due to refraction uncertainties).

These modifications to the lunar Arctic Circle are shown in the Figure 2 sketch and summarized in Table 1. The net result is the most likely observable ("anthropocentric") and geocentric lunar Arctic Circles are approximately the same latitude, which are marked on the Figure 3 local map.

Table 1 Latitudes of Lunar Arctic Circle; Summary of Factors (decimal degrees)

Latitude	Correction	Local Towns	Description
61.28°		Eagle River	Geocentric Lunar Arctic Circle; converse of the maximum declination this 18.6 year nodal cycle
62.24°	+.96 ± .06°	South of Talkeetna	Topocentric correction due to parallax; earth surface to moon center
61.97°	-.27 ± .02°	Caswell (N of Willow)	Rise/set definition correction from viewing upper limb of moon (moon is barely visible)
61.40°	-.56 ± ~4°	Birchwood	Correction due to standard atmospheric refraction. Average values of correction factors
61.27°	Extremes of corrections	Elmendorf, Fort Richardson	Most likely lowest latitude able to observe the moon due north on 9/14/06 according to Naval Observatory; "Anthropocentric Lunar Arctic Circle"
57.5°		Pilot Point	North moon possibly visible, extreme inversions

Note that the latitude calculated by the US Naval observatory where the moon doesn't set, 61.27°, applies the extremes of the astronomical correction factors, since it is an extreme event.

[7] Wayne Davidson; http://www.eh2r.com/mp/data.html; and Science Frontiers Online, 1981; http://www.science-frontiers.com/sf015/sf015p12.htm

[8] US Naval Observatory; http://aa.usno.navy.mil/faq/docs/RST_defs.html#top

[9] US Naval Observatory; http://aa.usno.navy.mil/data/docs/RS_OneYear.html#notes

Then there is the local topography; the Naval Observatory presumes open ocean observations. Obviously, viewers from a high hill with a far distant northern horizon can observe the effect further south than locations where hills to the north obscure a low moon. Palmer and Wasilla look north to the Talkeetna Mountains, rising sometimes >5^{o}. Further west, the mountains drop off, and parts of Anchorage have a relatively unobscured northern view.

This discussion has focused on the positive "the moon was visible all day", rather than the negative "the moon didn't rise today", which is the converse ground-based observation of the lunar Arctic Circle. Just as for the sun, latitudes determined by these two observations will be offset some distance from the geocentric construct. If the weather a couple hundred miles south of the line is consistently warmer than that a similar distance north of the line, offsets will differ.

So What?

This is just a curious little question, maybe somewhat interesting to those living in these latitudes. There may be poetic comfort to note you observed, on or near the lunar Arctic Circle, one day the moon never set. Because the event is so rare in these latitudes, one must be prepared. And, if you do observe it, take pictures, since few will otherwise believe you.

To aid viewers, Table 2 lists the 3-4 days each month through 2006 with the best chances of observing the moon due north, according to NASA. Also listed are the moon rise and set times for 61.27^{o}, the lowest latitude the moon doesn't set according to the Naval Observatory, (at 149^{o} 52' W, 61^{o} 16' N, approximately 3.5 miles north of 5th Ave. and Gambell St.). Although the greatest lunar declination occurs on 9/15/06, the day the moon doesn't set is 9/14/06. It should be due north at ~8:20 PM (9:20 PM, local daylight saving time). A tall building in downtown Anchorage, or further south from the hillside, might offer better chances of an unobstructed northern horizon. Take a compass and camera with a telephoto lens.

There might be opportunity for some serious science here, too. Atmospheric refraction is the greatest variable for accurate predictions. Careful measurement of refraction correlated to atmospheric conditions may enable better understanding and prediction of meteorology and effects of global warming, besides predicting latitudes of extreme moonset.

Perhaps there are photos from calibrated web cams from similar circumpolar latitudes; if not, then that's a scholar's project. Perhaps science classes around the globe might think it's neat to find out and report if the lunar Arctic Circle is observed nearby.

Maybe then you could tell me if the moon I saw back in the late 80's, driving home from Anchorage, might have really been due north.

Happy observing, take a picture for me.

Ralph Hulbert

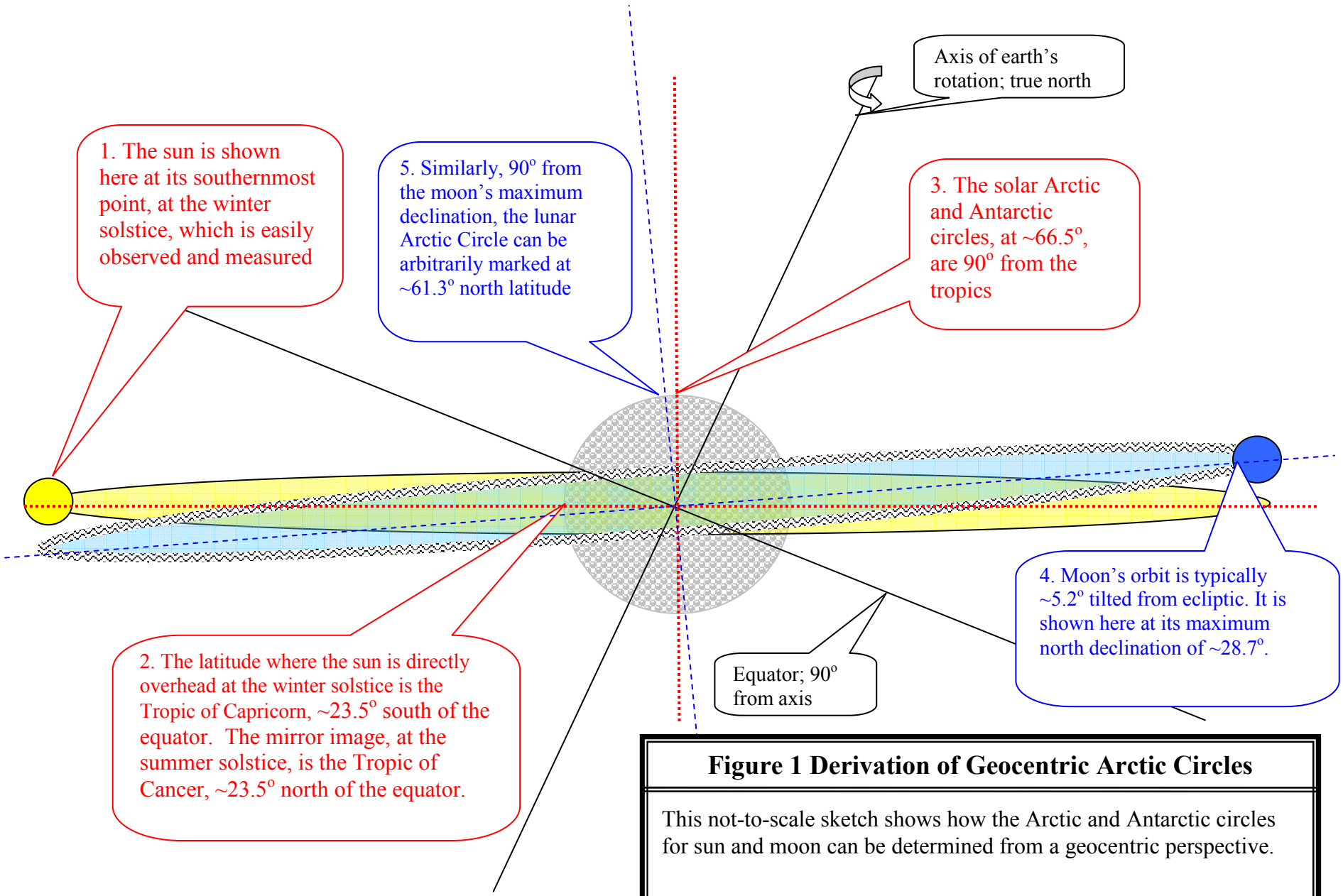

Figure 1 Derivation of Geocentric Arctic Circles

This not-to-scale sketch shows how the Arctic and Antarctic circles for sun and moon can be determined from a geocentric perspective.

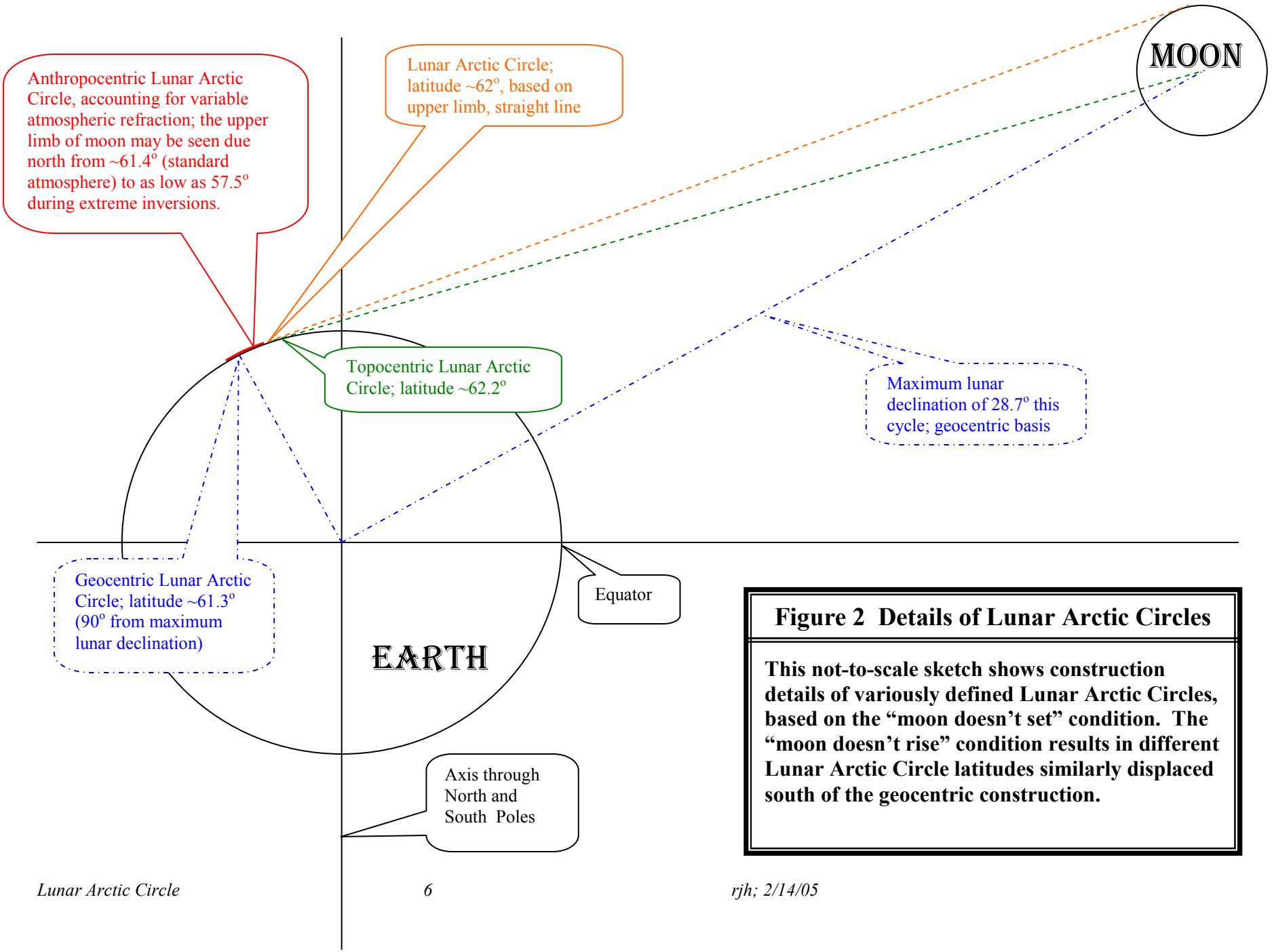

Figure 2 Details of Lunar Arctic Circles

This not-to-scale sketch shows construction details of variously defined Lunar Arctic Circles, based on the "moon doesn't set" condition. The "moon doesn't rise" condition results in different Lunar Arctic Circle latitudes similarly displaced south of the geocentric construction.

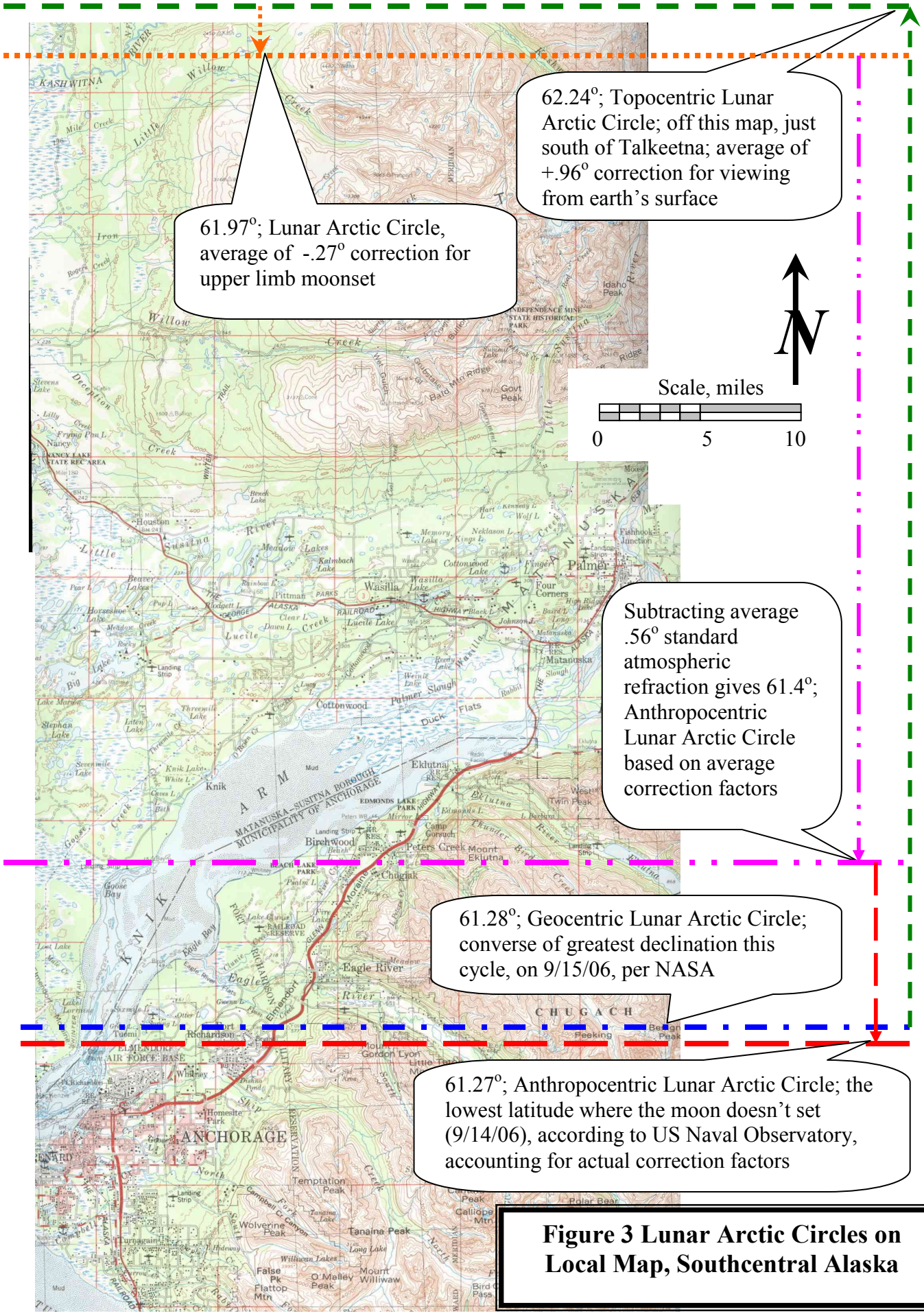

Figure 3 Lunar Arctic Circles on Local Map, Southcentral Alaska