

Lunar Sights

Objectives : How to input and interpret Lunar Distance, “Lunars”

Topics:

- Lunars Objective - To Tell Time at Greenwich Meridian (now UTC)
- Historic Background
- Accuracy Achieved
- Relevance Today
- Process Steps
- How to Input Lunar Sights into Celestial Navigation, an example
- Backyard Lunars
- What comes after Lunars tells Time at Greenwich Meridian
- Which Celestial Bodies paired with Moon make great Lunars sights.
- Tips to improve your Lunar accuracy
- Theory and Logic
- How to Analyze Lunar Sights using Celestial Navigation’s Calculate form

Lunar Distancing Background

- Objective of Lunars was to determine TIME at a Baseline Meridian, Greenwich. The baseline time is now UT/UTC.
- Ancient Greeks and Babylonians theorized the Moon could be used as a giant clock in the sky. The theory was that anyone on Earth could tell the same event's baseline meridian time by measuring the Moon's "distance" to another celestial body. The "distance", was an angle called Lunar Distance. And then after TIME determined for a baseline meridian, Longitude would be calculated using local time.
- 16th century mathematicians and astronomers advanced Spherical Triangles (aka Navigator's triangle) to the point where the math could be used to tell time by measuring the distance of the Moon to the Sun, planets, and stars.
- It takes the moon 27.32166 days to complete a full orbit around the earth respect to the background stars (Moon Sidereal month). Thus the Moon moves Eastward. Relative to the background celestial bodies, almost 13.2° per day. Which translates to 32.94 arc-min per hr., 0.55 arc-min per min, 0.2 arc-min per ~22 sec., 0.1 arc-min ~11 sec.
- You need a high quality sextant! If the navigator could measure 0.1 arc-min, then time accuracy would be no better than 11 seconds Since 4 seconds in time is 1 nm at the equator, 11 seconds in time is approximately ~3 nm. That's the limit for Lunar distance accuracy with a maritime sextant.
- The maritime sextant was designed to meet the need to measure Lunar Distance. Double reflecting to measure 120° angles or more. Higher magnification to determine more precisely when the celestial body touches the Moon (today 7x are common). Shades over the Horizon mirror for Sun-Moon distances. Eventually vernier next to micrometer drum to more precisely distinguish 0.1 - 0.2 min. of arc.
- Meanwhile, mathematician and astronomers worked on the position of the celestial bodies problem. Isaac Newton theory of gravity was crucial to initially calculating the Moon and other celestial body positions. But, it took more time to figure it out with sufficient accuracy. In 1752-1762, Johann Tobias Mayer calculated Lunar Distance tables and altitude corrections. And was awarded, after his death, some Longitude Prize monies. In 1767, Nevil Maskelyne included Lunar Distance tables in the first Nautical Almanac.

Lunar Distancing Background (continued)

- Then, John Harrison's H1 Chronometer was demonstrated 1736. And then successfully tested on a voyage to Jamaica in 1761. He won the largest share of the Longitude prize. An accurate chronometer would be set for Greenwich Time which then was used to determine Longitude.
- In 1802, Nathaniel Bowditch's American Practical Navigator contained Lunar Distance Tables and simplified procedures to clear the Lunar distances. This made the method more accessible to everyday navigators. He was an advocate for both chronometer and Lunars. Don't rely on one method!
- And the traditional practice was to make note in the ship log the Lunar's derived time and then use judgement updating chronometer error rate (Fast or Slow). The common practice, even today, is that no one directly changes the chronometer time. And for sight reduction, chronometer time with error rate (fast or slow) is referenced.
- You'd think that shortly after 1761, Lunar Distancing method would die-off. But, chronometers weren't widely available because an entire industry needed to be created to mass produce affordable chronometers.
- Captain Cook's first Pacific voyage (1768 - 1771) didn't have a chronometer and he charted much of the Pacific aided by Lunar Distancing as one of his tools. Captain Bligh (1789) used Lunar Distancing. Navigators on multi-year voyages would use Lunars to double check their chronometer if they had one.
- Lewis and Clark had a chronometer, sextant, artificial horizon equipment when they surveyed the Louisiana purchase (1804-6). John C. Fremont on his first expedition to California (1842) took a high quality sextant. They must have used a sextant for position and possibly used it for Lunars on land.
- Up to the 1850s, many ships lacked chronometers. Too few, too expensive. Chronometer improvements were made; adoption was slow, but inevitable. Eventually Lunars fell out of use. Bowditch Practical American Navigator reduced emphasis on Lunars in 1882. Tables were dropped in 1912. Nautical Almanac last published Lunar tables in 1907.

After Lunar Distancing, what was next?

- After computing time (Greenwich Time,...GMT....UT/UTC), calculate Longitude. Also, calculate Latitude using a Meridian Transit. And re-evaluate chronometer's error rate (number of min-sec fast or slow) for future sights.

How accurate was Lunars in the 1700s?

- The Longitude Prize was awarded if you could demonstrate a solution better than $.5^\circ$ longitude accuracy. Harrison was the big winner. And Tobias Mayer won some prize money for his work on Lunars. The $.5^\circ$ was not the estimate for accuracy; it was a threshold or goal for the award. If there is statistical analysis that identified accuracy, that would be beneficial.
- Ship Logs included Lunars along with Altitude Sights and DR positions. This was an indication that it was trusted.
- For over 100 years after chronometers were introduced, navigators found it to be a valuable tool.

How accurate is it Today?

- With a good quality sextant, well adjusted, and used with skill, the goal for your Lunar Distance observation should be consistently $+/- 0.2'$ accuracy. The limitation is your skill given the stability of the vessel. It is easier on land.

Is Lunars relevant today?

- Lunar gives the celestial navigator the opportunity to practice using their sextant. The more practice the better you become. Not only for Lunars, but for all sights. Practice makes perfect. Lunars can be done anywhere. At home in your backyard, near the water, on the water. You can do it during twilight, during the day, in the middle of night. Do it any time the Moon is visible, day or night. And of course, off-shore. The Celestial Navigation Plugin was designed to support practicing Lunar sights, UT/UTC determination, including "in the backyard". And, it is not tethered to the internet.
- Do you want to verify your sextant's arc error and then perhaps calibrate it? Lunar sights can help.
- OpenCPN's Celestial Navigation's plugin for Lunars is quick and easy. Input the sight and get immediate results. Change data and instantly see the TIME result change.

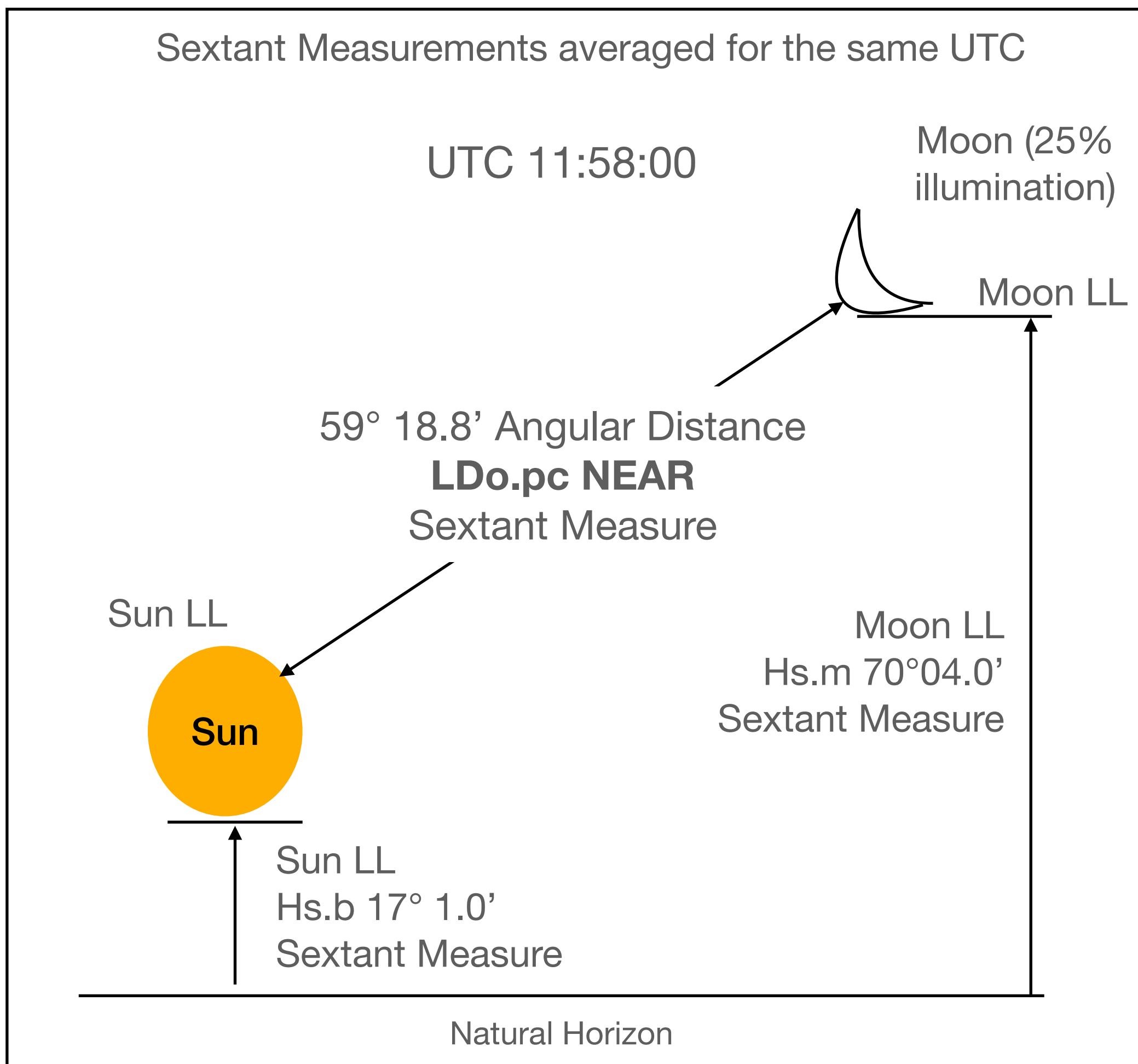
What are the Process steps to do Lunars on board Ship?

1. Measure an Altitude Sight of the Moon. One Sight.
2. Measure the Altitude Sight of the Celestial Body. One Sight.
3. Measure the Lunar Distance Angle of the Moon to your selected Celestial Body. Four Sights.
4. Hold the Sextant at an angle. The horizon mirror point to one object, and index mirror pointed to the other. Make sure the mirror that points to the sun has shades on to protect your eyes. Measure “edge” to “edge”.
5. Measure the Altitude Sight of the Celestial Body. Note the reverse order. One Sight.
6. Measure an Altitude Sight of the Moon. One Sight.
7. Average the Lunar Distance Angle/Time. Average the Moon Altitude Sight/Time. Average the Celestial Body Altitude Sight/Time. After averaging it, the 3 sets of sights should have roughly the same time.
8. Input the average measurements into the Celestial Navigation Sights form. Verify Index Error, Height of Eye, Temp/ Barometer (minor impact) in the Parameters form.
9. Input your DR Position (Open CPN’s “Boat position” is the default, which can be changed) in the Find form.
10. Input the average Ship’s Time in Time (UTC) form.
11. Press the “TIME” Button in the Sights form to see the results.

What are the Process Steps to do Lunars in your backyard?

You can eliminate Steps 1, 2, 5, and 6. You need to do Step 8 for the 3 sets of sights. When inputting Altitude for the Moon and for the Celestial Body, use Celestial Nav plugin’s Estimated Altitude. But you’ll need to have a Latitude and Longitude in order to estimate the Altitude (H_s) of the Moon and Celestial Body. After all, the 2 bodies need to be above the horizon for the estimated altitude to compute.

How to input this Lunar Sight



Observer Location (DR): N43°16.1', W 076° 58.8'
Date: Aug 18, 2025 (at UTC)
UTC: 11:58:00 (at UTC) an estimated time
Height of Eye (HOE): 2.44m (8 ft).
IE (Index Error): -0.8'
Temperature: 17 in °C (63 F)
Pressure: 1013 in mb (29.92" Hg)

Select Celestial Navigation Icon from Open CPN Menu

The Celestial Navigation opens with existing sights (Sights form).

A screenshot of the 'Celestial Navigation Sights' form. The table lists various sightings with columns for Type, Body, Time (UTC), Measurement, and Color. A context menu is open on the right side of the table, containing the following options: New (highlighted with a red oval), Fix, Duplicate, Clock Offset, Edit, Hide, Delete, Documentation, and Delete All. The 'Altitude Sun' row is highlighted with a blue background.

Type	Body	Time (UTC)	Measurement	Color
Altitude	Jupiter	2025-09-11 11:49:20	0° 00.0000'	blue violet
Lunar	Jupiter	2025-09-11 10:19:20	71° 15.7979'	Time Correction: 53 s
Altitude	Moon	2025-09-11 10:19:20	51° 50.9999'	blue violet
Altitude	Jupiter	2025-09-11 10:19:20	48° 28.9979'	blue violet
Altitude	Jupiter	2025-09-11 10:19:20	12° 55.0020'	blue violet
Altitude	Sun	2025-08-18 13:28:00	17° 01.0021'	purple
Altitude	Moon	2025-08-18 13:28:00	70° 04.0022'	purple

To input a new sight, select one of 2 options.

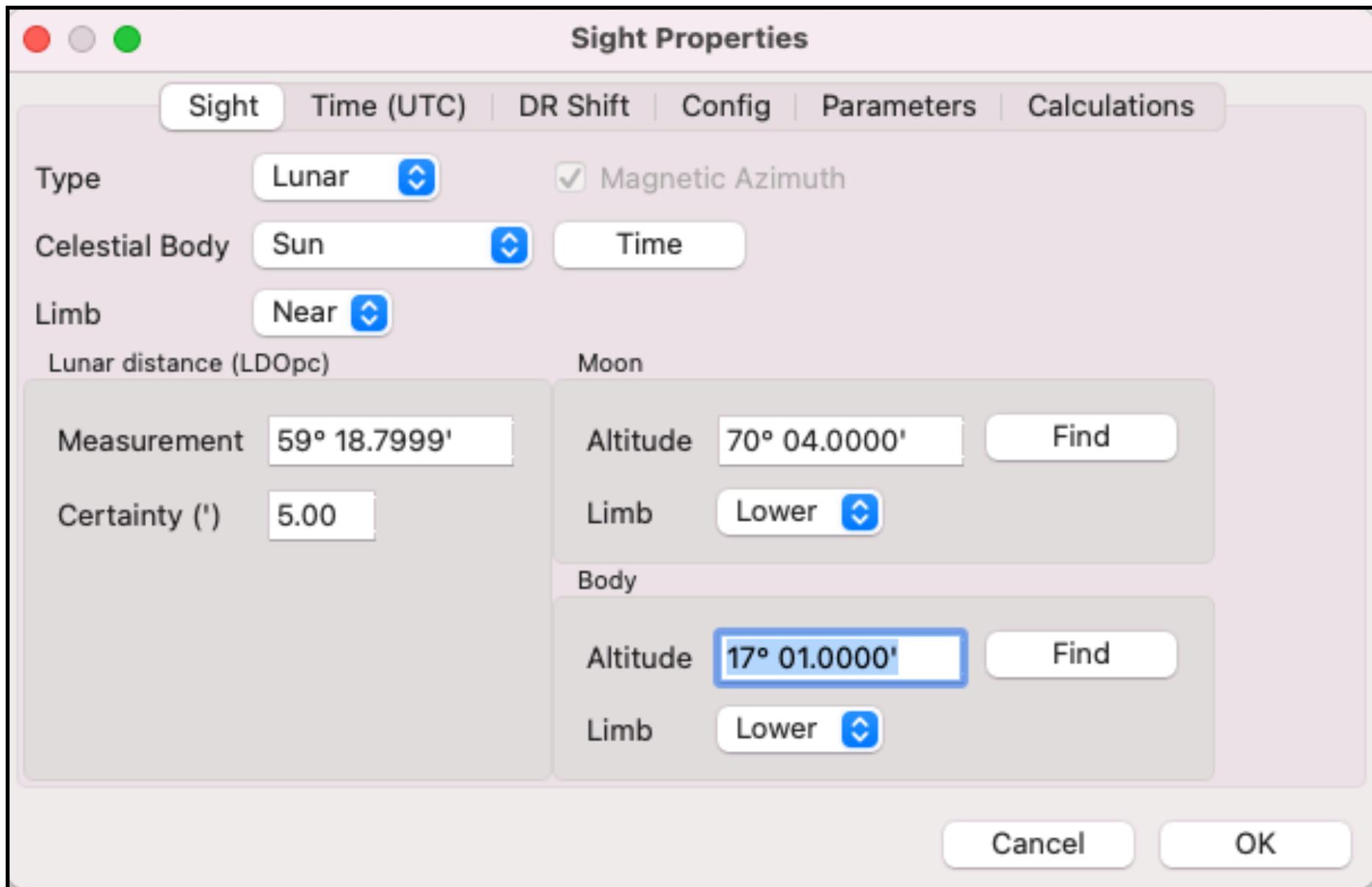
New or

Duplicate. If Duplicate, it will duplicate the highlighted sight. and then Edit the Duplicated Sight

Input the Measurements

For Lunars, there are 3 angle measurements to input. The angle between the Moon and the Celestial Body, the Altitude of the Moon (w/Limb) to the Horizon. The Altitude of the Body (only the Sun has a Limb) to the Horizon.

Sight Properties Form.



Type: select Lunar.

Celestial Body: select Sun

- Also available are Planets,
- 57 Navigation Stars and Polaris. 9 Stars known as Lunar Stars (see page 14 for more about a good selection).

Select Limb: select Near or Far

- Refer to the next illustration for examples of Near or Far.
- The body is **Near** when the closest edge of a celestial body (Sun, Star, Planet) is brought to the nearest visible edge of the moon.
- The body is **Far** when bringing the nearest edge of the body across the moon's face to the far side of the moon.

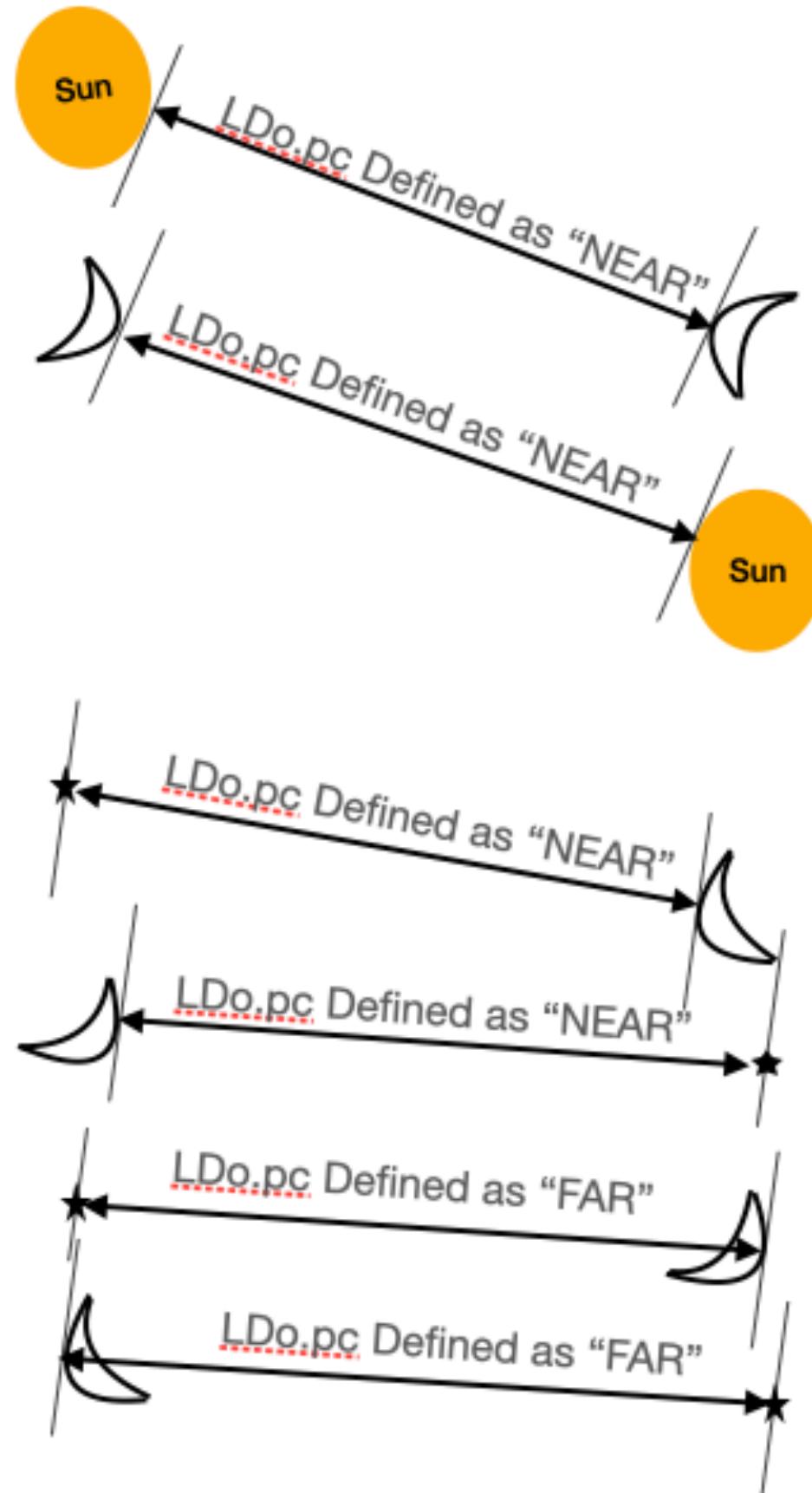
Measurement. Input Lunar Distance Angle between the Moon and the Celestial Body

New Feature - Sextant Measurements can be input in any of 3 OpenCPN supported “angles”. Decimal Degrees, Degrees-Min, and Degrees-Min-Sec. They will be redisplayed per display preferences. You can change preferences and sights are displayed in the changed preference

Near versus Far

Supported by Lunars

NOT Supported by Lunars



Sun Cases

Horns of the Moon are perpendicular to and point away from the Sun

NEAR equation for Sun

$$LDo = LDo.pc \text{ (incl IC)} + SDs \text{ PLUS SDm}$$

Note: LDo has no dip adjustment

Star and Planet Cases

NEAR equation

$$LDo = LDo.pc \text{ (incl IC)} \text{ PLUS SDm}$$

(Assume SD=0 for planets)

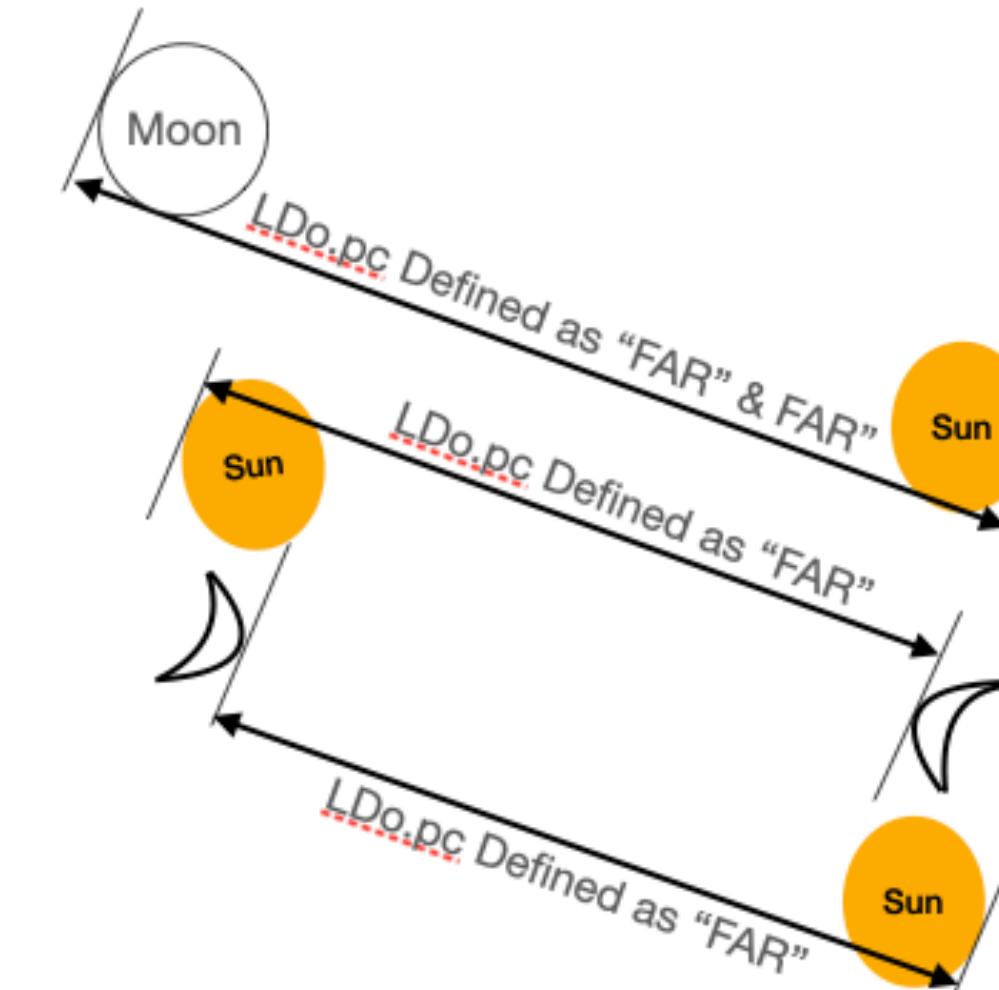
Note: LDo has no dip adjustment

FAR equation

$$LDo = LDo.pc \text{ (incl IC)} \text{ Minus SDm}$$

(Assume SD=0 for planets)

Note: LDo has no dip adjustment



Sun Cases (not supported)

Horns of the Moon are perpendicular to and point away from the Sun

FAR Edge of Moon to FAR edge of Sun

$$LDo = LDo.pc \text{ (incl IC)} \text{ MINUS SDs MINUS SDm}$$

Reason: Only can happen for Full Moon (1 day/mo)
Full Moon is 180° distant from Sun.

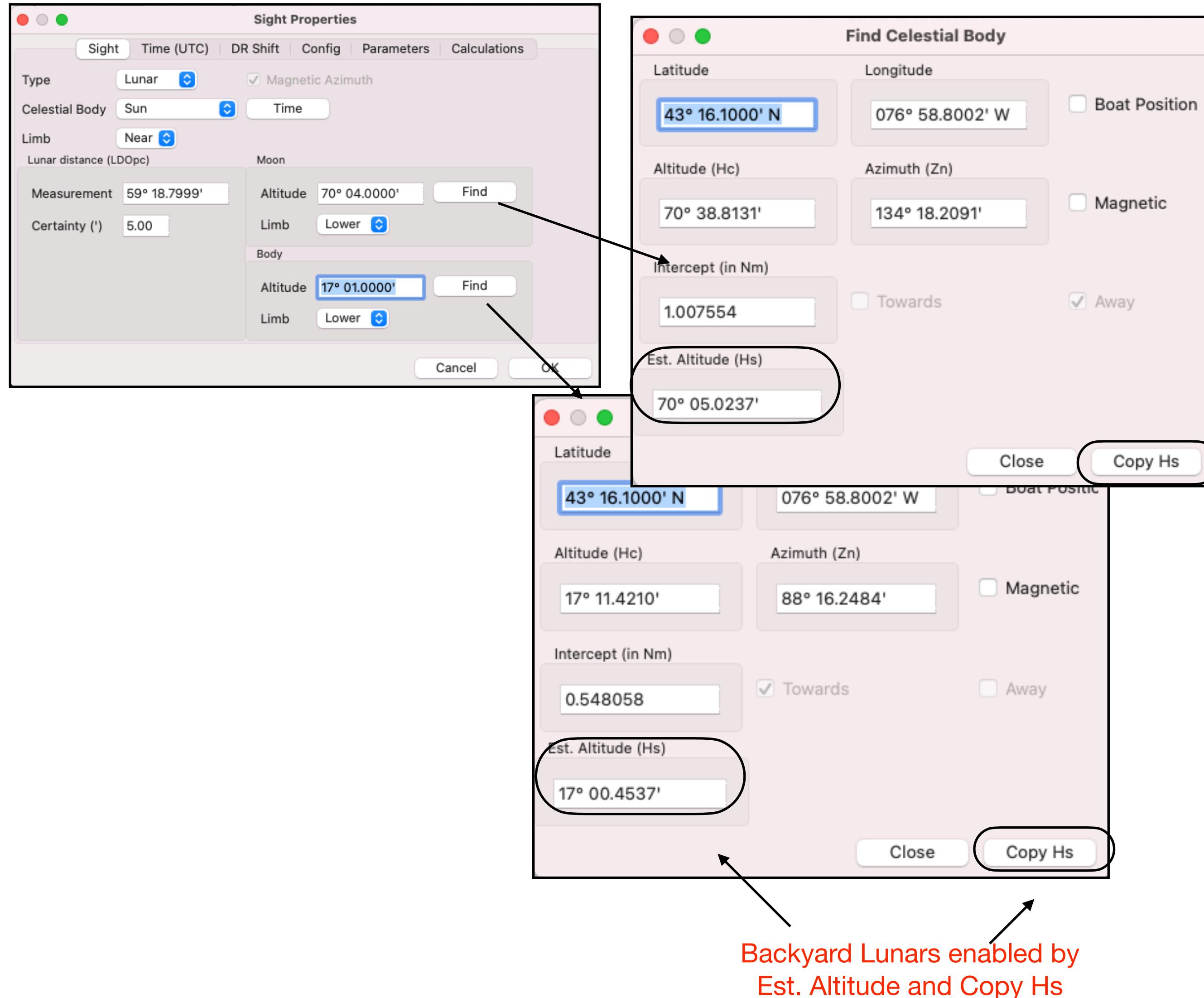
No marine sextant can measure more than 133 - 135°

Near Edge of Moon to FAR edge of Sun

$$LDo = LDo.pc \text{ (incl IC)} \text{ MINUS SDs PLUS SDm}$$

Reason: not able to see Near Edge of Moon
On Far Edge of the very bright Sun

Find Celestial Body to input Lat/Longitude & for Backyard Lunars



Latitude and Longitude defaults to “Boat Position”. Change Latitude or Longitude to your DR position. **New features** (1) Cel Nav is using OpenCPN’s standard angle formats (decimal degrees, degrees-min, degrees-min-seconds). It displays per your OpenCPN Display settings. (2) Latitude and Longitude saved with the sight in decimal degrees.

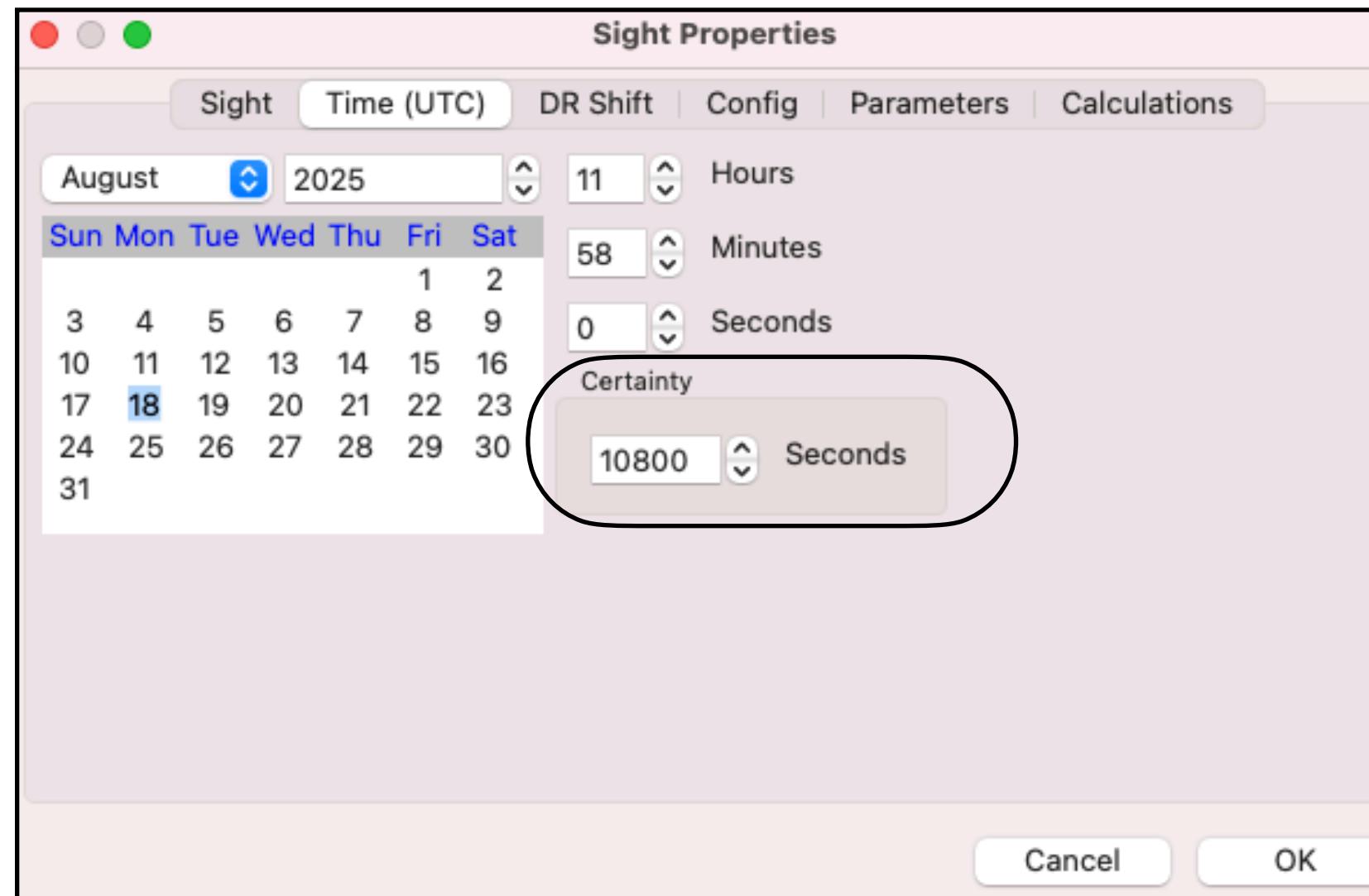
Caution for Longitude, input E or W. For now, - Longitude can’t be used for West, +Longitude for East.

Est. Altitude (Hs). New Feature. Cel Nav estimates an Hs by considering altitude adjustments (IE, Dip, SD/Limb, Refraction, Parallax, Augmentation). It serves three purposes.

1. Validate your sight measurement,
2. Plan your sights,
3. Enables you to do Lunars in the backyard or when you can’t see the horizon.

Press **Copy Hs** button to copy it to your Altitude Sight.

Caution estimate is within +/- 0.2' altitude from 1.5° to 90. It is not calculated for negative angles which happens when the body is below the horizon.

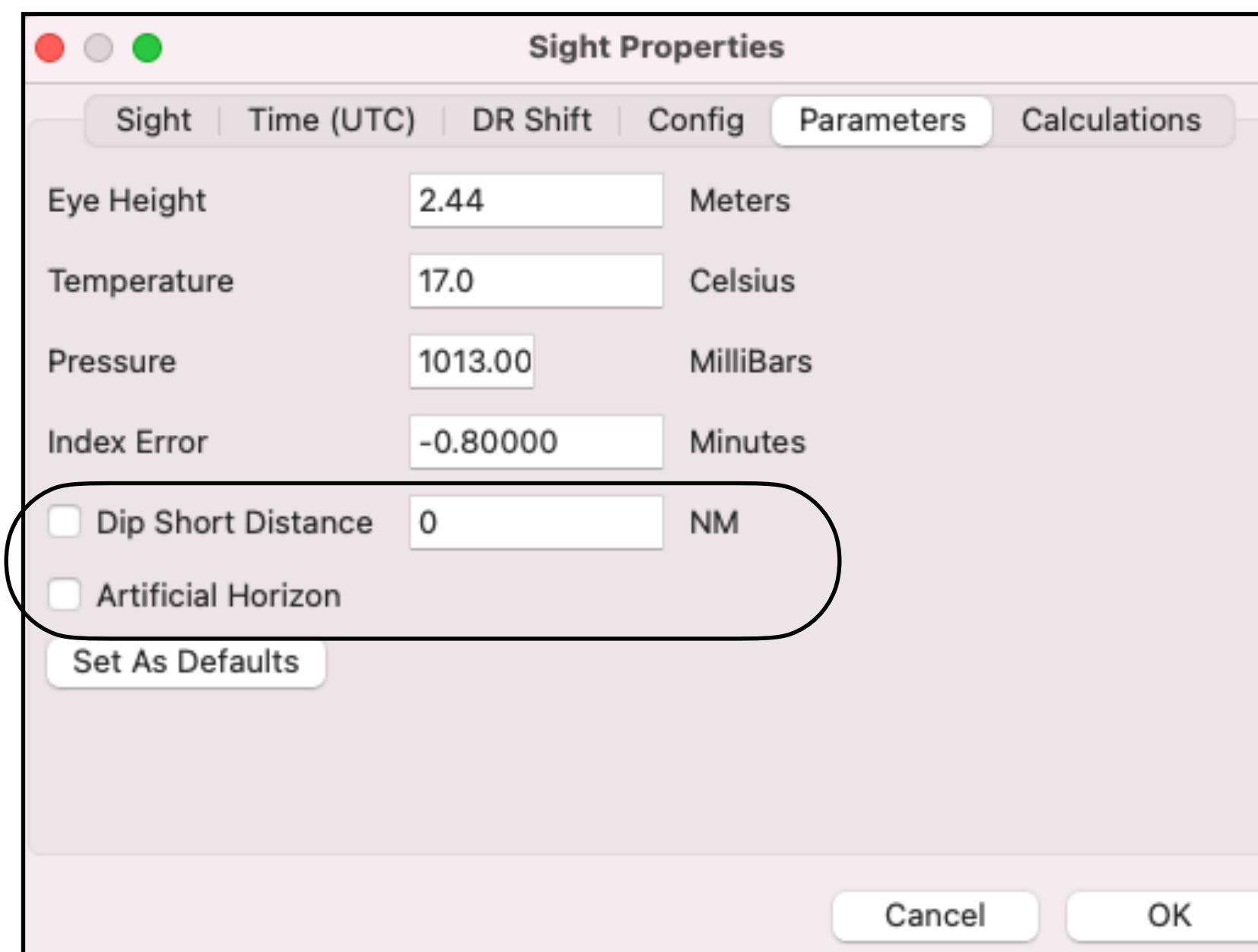


Time (UTC)

Input UTC like normal Altitude Sights.

Certainty. has always been part of the Cel Nav plugin and for altitude sights, it gives a visualization of Time uncertainty. Certainty is used by Lunar's algorithm to interpolate and find an estimated UTC. When Lunar Distance Tables were first published, Time to Lunar Distance table was reported every 3 hours, or 10800 seconds. For Lunars only, Certainty defaults to 10800 seconds and can be easily changed.

Try a smaller number. It must bracket the True UTC time. Recalculation is instantaneous.



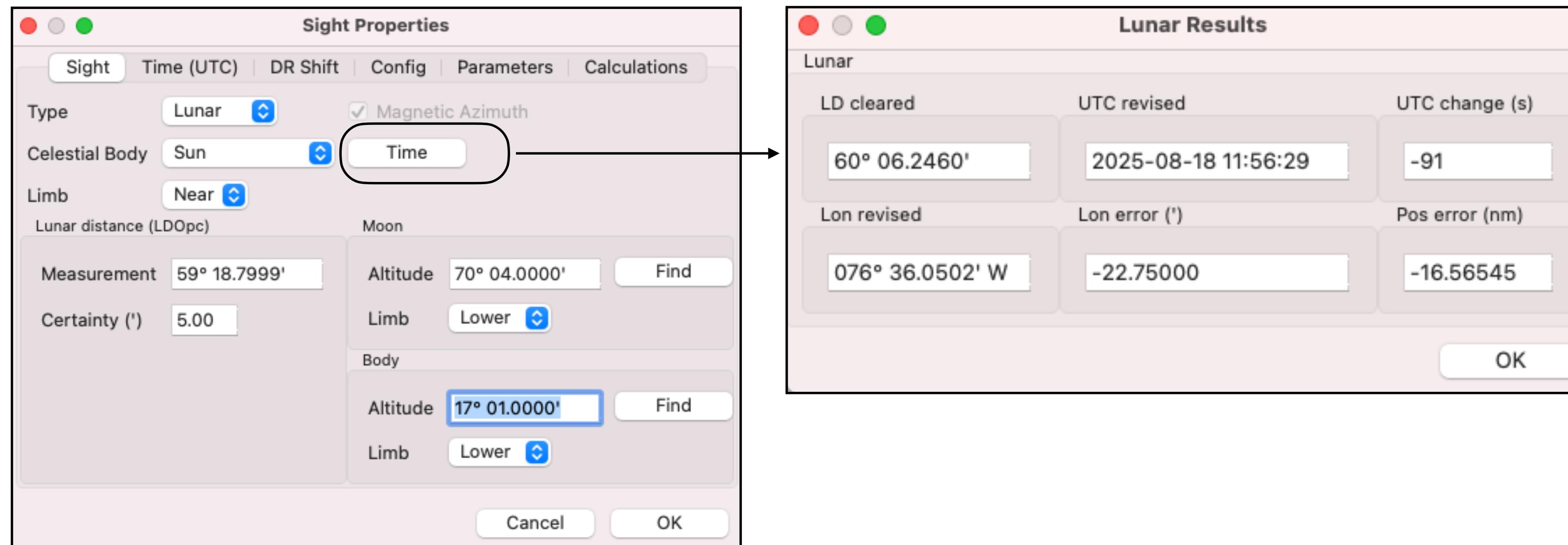
Parameters

No changes for Eye Height, Temperature, Pressure, Index Error. **New** Notice more significant digits. Useful if you converted from imperial

New Feature. Cel Nav allow sights for Dip Short or Artificial Horizon. This feature is meant for Altitude Sights (not Lunars)

Dip Short is intended for regular Altitude sights where you can't see the natural horizon. For Lunars, you can use Dip Short Distance if the altitude sights for the Moon and Celestial Body have the same Dip Short Distance (they won't generally). If they are greatly different, use with caution. It is better to use Eye Height = 0 and use the Estimated Hs for Lunars if you can't see the horizon.

For Lunar Distance Calculated UTC Time, Press TIME in Sight Properties Form



Lunar Distance Cleared. First output of the Lunars Calculation. Similar meaning as Hc (Altitude Computed). It includes altitude adjustments: Index Correction, Limb, Refraction, Parallax, Augmentation. See Theory and Logic section.

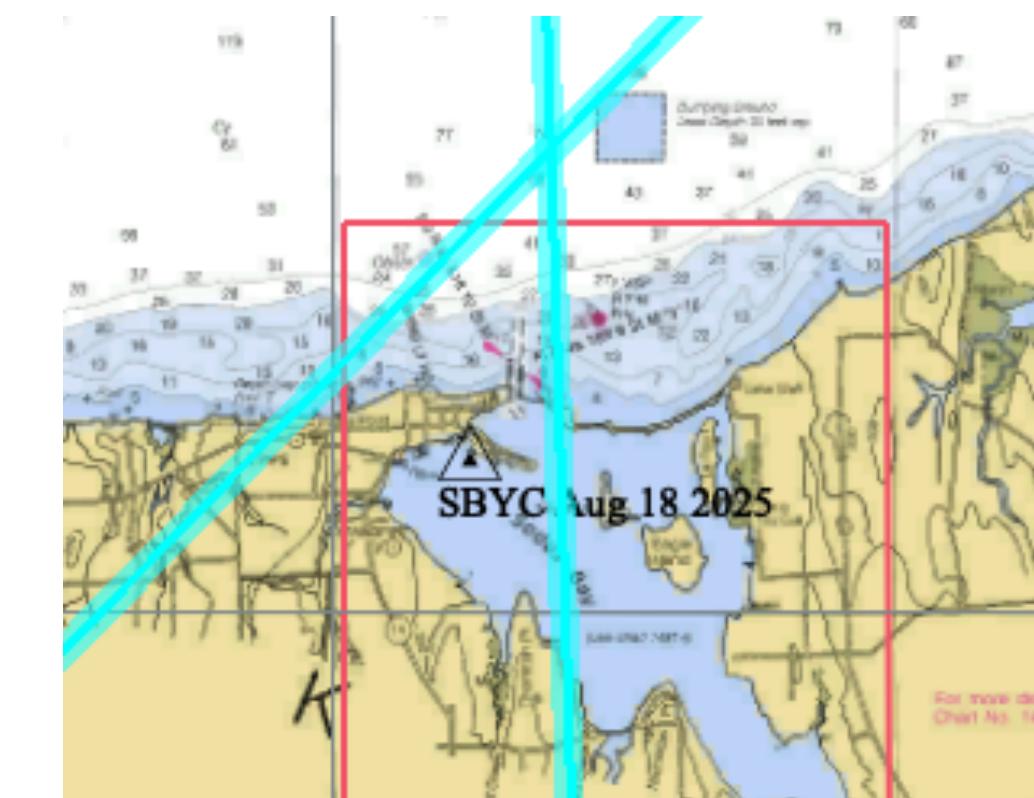
UTC revised is derived from Lunar Distance Cleared. It is the Time uniquely determined for the Lunar Distance Cleared.

UTC change (s) The difference between UTC that was input for the sight and the UTC derived from Lunar Distance Cleared.

The next outputs are simple heuristics. Earth revolves around the Mean Sun at .25 arc-min per second (15° per hour). -91 seconds is -22.8 arc-minutes change in Longitude. Position error is Longitude Error x Cos (Latitude) or -16.6nm.

After Calculating Time, calculate Longitude. That's the traditional Lunars next step!

Type	Body	Time (UTC)	Measurement	Color
Lunar	Sun	2025-08-18 11:58:00	59° 18.7999'	Time Correction: -91 s
Altitude	Sun	2025-08-18 11:58:00	17° 01.0000'	rgb(33, 255, 255)
Altitude	Moon	2025-08-18 11:58:00	70° 04.0000'	rgb(33, 255, 255)
Altitude	Sun	2025-08-18 11:56:29	17° 01.0021'	purple
Altitude	Moon	2025-08-18 11:56:29	70° 04.0022'	purple
Altitude	Venus	2025-08-17 11:00:00	27° 19.9980'	medium violet red
Altitude	Moon	2025-08-17 11:00:00	61° 46.3980'	medium violet red
Lunar	Venus	2025-08-17 10:04:29	39° 17.5981'	Time Correction: 0 s



Celestial Navigation Plugin offers an alternative way to analyze your position.

The Sun and a 1st qtr or 3rd qtr Moon (50% illumination) is known to make a great 2 body fix. The Sun and half Moon was the most frequent done Lunar sight. With Cel Nav, use the Sun LL and Moon LL altitude sights. “Duplicate” the Lunar sight, then EDIT to change the type to “Altitude” and change the UTC time or keep UTC the same. The above illustrates 4 sights created by using “Duplicate”. Two of the sights have the “eyeball” icon turned on. See 2 intersecting Line of Positions are plotted for those 2 sights? Is this a good 2 body fix? **Hint** - Open “Find Celestial Body” form and look at the Azimuth for the Sun and then for the Moon. What is the angle difference? Moon 25% illuminated.

Caution - A 2 body fix still has position risks. Try sensitivity analysis and change the Hs of the 2 bodies. Did you see the Fix drift? Celestial Nav plugin recalculates quickly. A 3 body to 4 body fix each at a minimum 60° spread is better. A Pinwheel is the best. Consider an additional sight for a running-fix. If the Lunar sight was done earlier in the morning (9am local time), a Meridian Transit will give you Latitude. The meridian transit plus the Sun-Moon could give a Running fix.

Notice - Measurement is shown at 4 significant digits for minutes. The angles are stored in decimal degrees to 6 significant digits in a file called, “sights.xml”. When converting from one standard to another, there is minor rounding for certain angles. The small rounding can be ignored because they are immaterial in the sight reduction calculations.

Which Celestial Bodies paired with the Moon make a great Lunar?

#1 Sun and 1st Qtr or 3rd Qtr (50% illumination) Moon

- The most frequent Lunars pair. It doesn't literally have to be 1Q/3Q Moon. The example was 25% illum. Use judgement
- With 1st or 3rd quarter Moon, after calculating time, you have an excellent 2 body fix.

#2 Planets (Venus, Mars, Jupiter, Saturn) and Moon

- Venus, Mars, Jupiter, Saturn travel along the Ecliptic plane. They make for a good pair with the Moon.
- In the Evening and through Twilight Morning and Evening, there is almost always at least 1 visible major planet.

#3 Bright Stars near the Ecliptic Plane with the Moon

- There were 9 Lunar reliable bright stars known as "Lunar Stars" Bright, close to the Ecliptic Plane, spread 360° East to West, and North to South. Lunar Distances were pre-calculated in the Nautical Almanac and Bowditch American Practical Navigator. There are a few others. Scored lower in the Lunar criteria. Vega and Deneb isn't on the list. That's because they aren't remotely close to the Ecliptic. They'd be poor selections to pair with moon to tell time.

Lunar Stars	SHA	Dec.	Others	SHA	Dec.
Aldebaran	291°	N17°	Arcturus	146°	N19
Altair	027°	N 9°	Enif	034°	N10°
Antares	112°	S27°	Nunki	075°	S26 ^a
Fomalhaut	015°	S30°	Procyon	244°	N5°
Hamal	328°	N24°	Riegel	281°	S8°
Markab	013°	N15°	Sirius	248°	S17°
Pollux	243°	N28°			
Regulus	208°	N12°			
Spica	158°	S11°			

SHA or Sidereal Hour Angle. Shows 360° spread
DEC or Declination. Shows North vs South Hemisphere stars

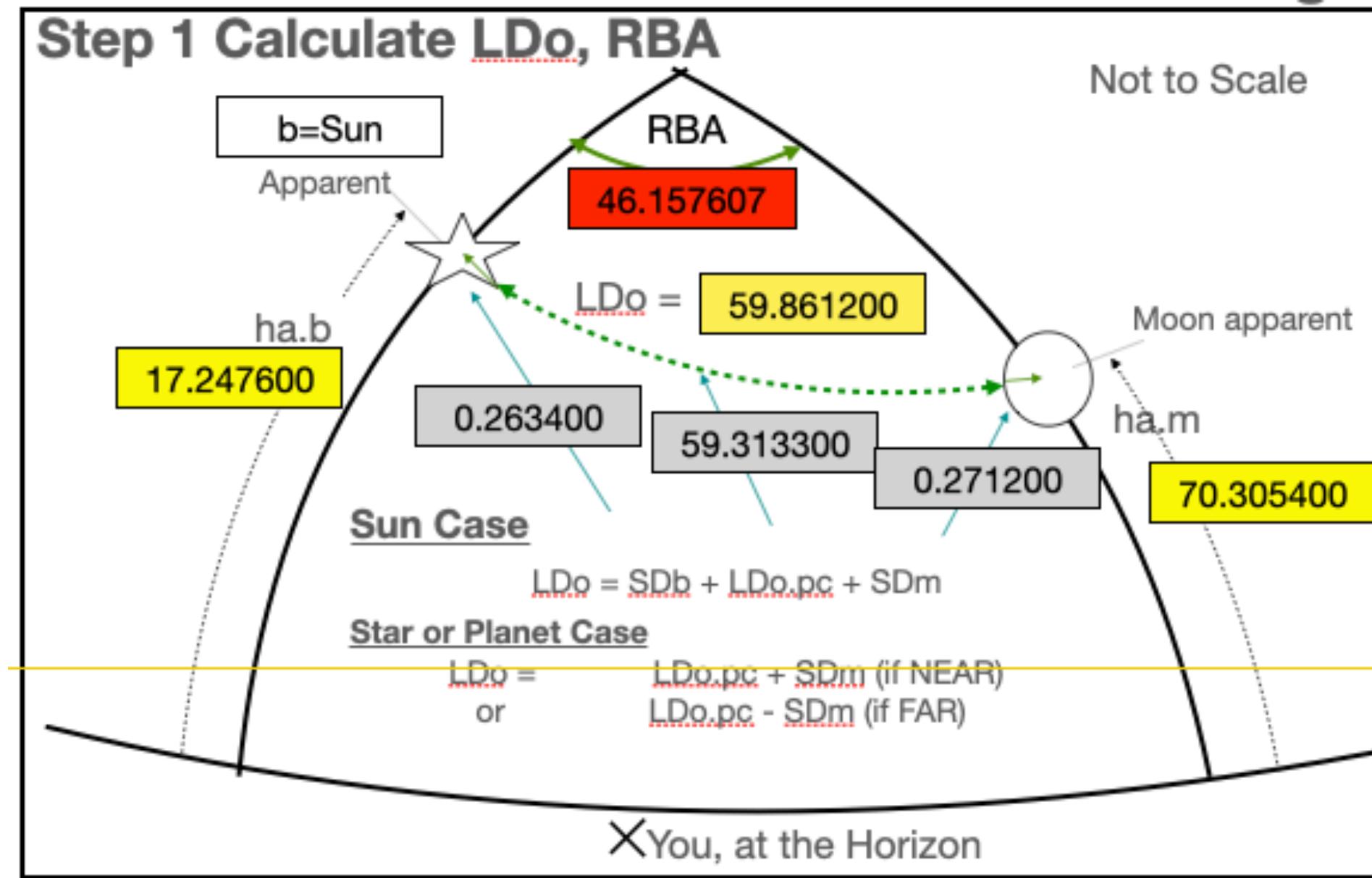
#4 Selection and what LD measurement to target

- While outdoors, pick a star/planet on the Moon's trajectory/path. Pick one NOT close to the Moon.
- If Lunar Distance is small, then the Lunar Distance cleared and time will be less accurate.
- If large (i.e. > 100°), it gets hard to sight the body with the moon. Although practice makes perfect.
- A good LD Range is 60° - 100°. 90° was considered optimal
- Moon or Celestial Body Altitude not near the horizon (5-10°?) because the atmospheric refraction can be unpredictable.

#5 Full or almost Full Moon and a Star or Planet. Difficult to Measure LD at night. Moon's glow washes out most stars

Theory and Logic - Spherical Triangle Method

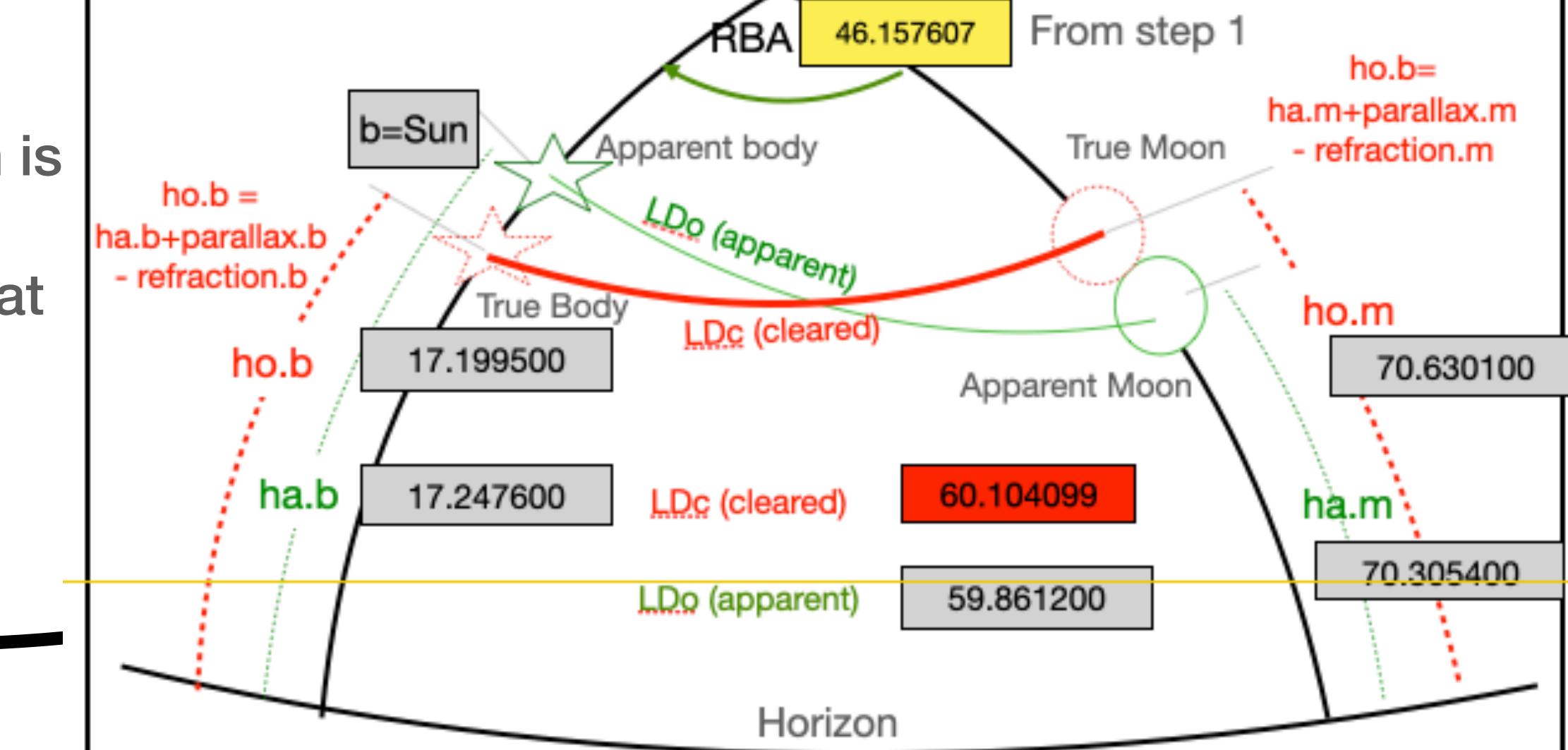
Calculations for Lunars is available to view in the Calculations form.



Step 1 illustrates LDo apparent and Ha altitude sights

Step 2 illustrates Ho and LD Cleared of the effect of Parallax and Refraction. Center of the bodies to Center of the Earth

Step 2 Calculate Ho, LDc



Step 3 Interpolate UTC

UTC from Predicted LDc at time 10:28, 13:28. interpolation is using the UTC form's "certainty" field.

Make the "certainty" smaller, but don't make it too small that the derived UTC is outside the range.

UTC	LDc °
10:28:00	60.9026
11:56:29	60.1041
13:28:00	59.2784

Derived UTC →

What expectation should you have for Accuracy?

- A high quality Sextant. Then minimize all adjustable Sextant Errors. They should be as close to 0 as possible.
- Your initial goal is to consistently achieve better than +/- 0.3' LDo measurement accuracy.
- Experienced Navigators can achieve between +/- 0.1' to +/- 0.2 LDo measurement accuracy. Which is between 3' to 6' Longitude.

Easier to achieve LDo measurement accuracy than Altitude sight measurement accuracy. Why? Because the LDo measurement has no DIP! And the problem with DIP is the uncertainty in the Height of Eye due to your vessel bobbing up and down, timing the swells when sighting the horizon, and unpredictable nature of refraction due to weather.

None of this DIP uncertainty exists when measuring Lunar Distance LDo. There is no DIP!

- You'll be shooting 2 Altitude Sights for Lunars. The purpose is to determine Parallax, Refraction, and Limb corrections. And for Lunars, these altitude sights don't need to be "spot on".
But, Altitude Sights can afterwards be used for a 2-body fix. Your Altitude Sight goal should initially be 1' or less "sight error". Sextant professionals consistently get no worse than 0.5' sight error. A few Navies are working towards .25nm position error. That gives you an idea of your runway for improvement. Dip correction uncertainty is the cause of some of the "Sight error", and the error depends on ship size and stability. So there is judgement to what goal is achievable.
- In the 1700's, Celestial mechanics was good enough for the times, but not perfect. Now the Commercial Edition of the Nautical Almanac is accurate mostly 0.0' error but occasionally 0.1' error. And U.S. Navy Observatory Celestial Data is better than that. Celestial Nav's error against the Commercial Edition of the Nautical Almanac is +/- 0.1 at 1 Standard Deviation. At least 50% of the time, it is 0.0'.
- The Lunar measurement in this example was off by 0.6'. Room for improvement! Try the following tips.

Tips to improve Lunar Accuracy

- A high quality metal sextant with good inspection report. No arc errors throughout the range.
- The higher the magnification, the better. 7X is readily available.
- Well Adjusted. Perpendicularity, then side and index error. Goal is as close to 0.0 as you can get because the errors really impacts Lunar Distance accuracy.
- The very best Lunar Distance Observation you can get. Altitude sight accuracy is not as important for TIME.
- Practice-Practice-Practice. Ship Navigators took sights almost daily. That's why they are so good.
- Select a celestial body that is traveling along the same trajectory plane as the Moon, as if they'd collide.
 - Start off with Sun, it gives the best result.
 - Then try Planets because they travel close to the Moon's trajectory.
 - Then "Lunar Stars". They were bright and close to the ecliptic (some closer than others).
- Don't select a celestial body near the Moon. The Cleared Lunar Distance and Time won't be as accurate.
- Select a body who's LD is between 60° to 100° . 90° is considered optimal. Larger LDo fixes problems when Moon travel path doesn't look like it will "collide" with the paired Lunar celestial body.
- Don't select a star that is far off the moon's path or far off the ecliptic (e.g. Vega).
- Ensure the sharpest focus. You want to see a clear outline of the Moon and Sun.
- Hold the sextant frame with both hands to avoid wobbling. Do small micrometer adjustments.
- Make sure the body is aligned (an imaginary line) to the center of the Field of View. That way, the sextant frame is aligned to the plane of the bodies. You'll be rocking your sextant to ensure the touch is tangent.
- Preset the sextant to the expected Lunar Distance. Then wait for the body to touch the Moon.
- In the Lunars chapter of Bowditch's American Practical Navigator, the editors recommended that the center of the body (planet, star) touches the moon. This indicates that the navigators used sextants with good magnification.
- Try not to do "live" adjustments to the micrometer. You'll be more successful by setting up your sextant to the predicted LD, then patiently wait for the "touch" to occur, and then MARK. And then for the next sight, turn the micrometer a little ahead for the next MARK and then wait.

Tips to improve Lunar Accuracy (continued)

- Bowdich chapter on Lunars has a lot of practical advice.
- Average the run of Sights

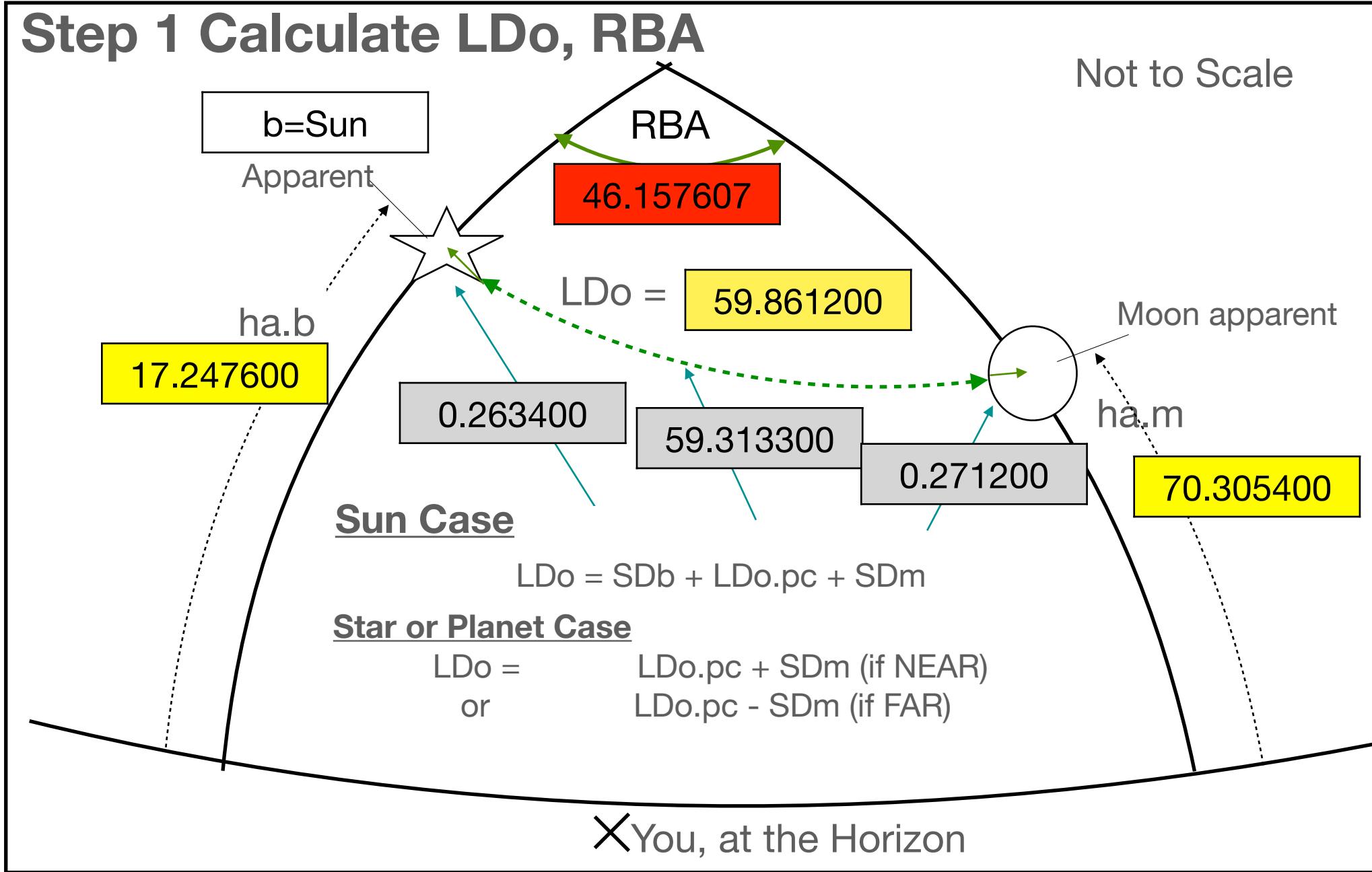
How to do a Run of sights for Lunars on the Ocean

A run of Sights that average to the same Time. Using a calculated average time and average measurement often results in better accuracy. Assuming the time between sights is say 1 minute, then sighting in this order will result in about the same average time for the 3 sets of sights. For example 8 observations

1. Altitude Sight for Moon
 2. Altitude Sight for Celestial Body
 3. Lunar Distance Observation 1
 4. Lunar Distance Observation 2
 5. Lunar Distance Observation 3
 6. Lunar Distance Observation 4
 7. Altitude Sight for Celestial Body
 8. Altitude Sight for Moon
- Average the Moon Altitude Sights 1 & 8
 - Average the Celestial Body Altitude Sights 2 and 7
 - Average the Lunar Distance Observations for 3, 4, 5, 6.
 - If Average TIME for the Sight data is roughly the same, use it for the Lunar Sight Reduction.

You don't have to be as systematic as the first option. You can plot the run of Hs sights for the 2 bodies and DLo measurements against elapsed minutes. Fit a line through the data, choose a common elapsed minutes time and read the Hs or DLo angles that are on the fitted line.

Step 1- Calculate LDo and Relative Bearing Angle



These calculations are shown in the Calculate Form

RBA	Bearing Angle between the Moon & body (aka DZ)
LDo.pc	LDo pre-cleared. hs Lunar Distance°
Apparent Altitude Corrected	
ha.b*	Body apparent Alt = hs.b +/- IC - dip +/- limb.b
ha.m*	Moon apparent Alt = hs.m +/- IC - dip +/- limb**.m
**Limb incl augmentation	
LDo	If Body = Sun AND Limb = "NEAR" then LDo.pc +/- IC + SDm + SDb If Body = star or planet & Body = NEAR then LDo.pc +/- IC + SDm If Body = star or planet & Body = FAR Then LDo.pc +/- IC - SDm
SDm	Semi-Diameter of Moon. Positive number.
SDb	Semi-Diameter of Sun. Positive number SD for stars and planets is 0.
Notes:	
*	<i>Refraction and Parallax/augmentation is not part of RBA in step 1</i>
**	<i>SD for LDo calculation of planets assumed to be 0</i>

$\cos(LDo) = \sin(ha.m) * \sin(ha.b) + \cos(ha.m) * \cos(ha.b) * \cos(RBA)$

Or

$\cos(RBA) = \cos(LDo) / \cos(ha.m) / \cos(ha.b) - \tan(ha.m) * \tan(ha.b)$

$\cos(RBA) = [0.502096] / [0.337007] / [0.955032] - [2.793721] * [0.310462]$

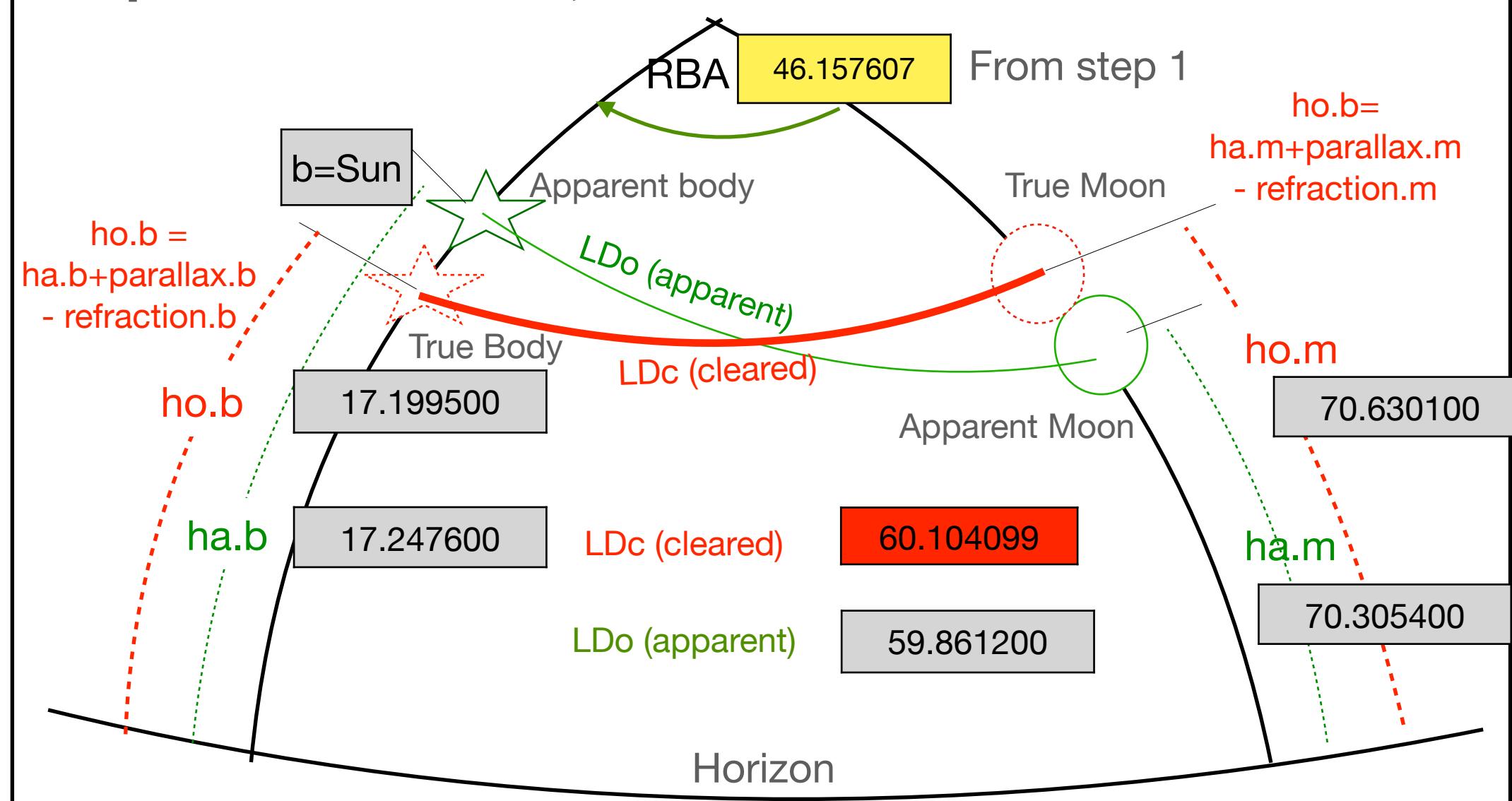
$\cos(RBA) = [0.692677] \quad RBA = [46.157607] \text{ degrees}$

The Celestial Nav's Calculate Form Shows the calculation

	LDo	ha.m	ha.b
b=Sun			
Limb	NEAR	LL	LL
LDO.pc, hs	59.313300	70.066700	17.016700
IC	0.013300	0.013300	0.013300
- dip		-0.045800	-0.045800
Limb (SD)		0.271200	0.263400
LD SDm	0.271200		
LD SDb	0.263400		
LDo/ha	59.861200	70.305400	17.247600
Radians	1.044775	1.227061	0.301027
Cos	0.502096	0.337007	0.955032
Tan	1.722401	2.793721	0.310462

Step 2- Calculate LD Cleared using Law of Cosines

Step 2 Calculate Ho, LDc



Recap Step 1

$$\cos(\text{RBA}) = \frac{0.502096}{0.337007} / \frac{0.955032}{2.793721} - \frac{2.793721}{0.310462}$$

$$\cos(\text{RBA}) = 0.6926770 \quad \text{RBA} = 46.157607$$

Step 2 Calculate LD

$$\cos(LD) = \sin(ho.m) * \sin(ho.b) + \cos(ho.m) * \cos(ho.b) * \cos(RBA)$$

$$\cos(LDc) = \frac{0.943397}{0.295700} + \frac{0.331666}{0.955281} * \frac{0.692677}{0.295700}$$

$$\cos(LDc) = 0.498426$$

$$LDc = 60.104099 \text{ Degrees} \quad 60^\circ 6.2459'$$

RBA	Relative Bearing Angle solved in Step 1		
LDo-pc	Pre-cleared Lunar Distance Sextant measure		
LDo	Lunar Distance observed		
ha.b	Body apparent altitude= hb +/-IC -dip +/-limb		
ha.m	Moon apparent altitude= hm +/- IC - dip +/- limb		
ho.b	ha.b + parallax.b - refraction.b		
ho.m	ha.m + parallax.m* - refraction.m		
LDc	Cleared Lunar Distance		
* Note: parallax for Moon includes augmentation as an additional altitude correction.			

	LDo	h.m	h.b
Body			b=Sun
LLimb	NEAR	LL	LL
LDo.pc/hs	59.313300	70.066700	17.016700
IC	0.013300	0.013300	0.013300
- dip		-0.045800	-0.045800
Limb		0.271200	0.263400
LD Limb.m	0.271200		
LD Limb.b	0.263400		
LDo/ha	59.861200	70.305400	17.247600
Radians	1.044775	1.227061	0.301027
Cos	0.502096	0.337007	0.955032
Tan	1.722401	2.793721	0.310462
Refraction		-0.005600	-0.050400
Parallax		0.330300	0.002300
dh		0.324700	-0.048100
ho		70.630100	17.199500
Radians		1.232728	0.300188
Cos		0.331666	0.955281
Sin		0.943397	0.295700

Step 1 and 2

$\text{Cos } (\text{LDo}) = \sin(\text{ha.m}) * \sin(\text{ha.b}) + \cos(\text{ha.m}) * \cos(\text{ha.b}) * \cos(\text{RBA})$

Or

$\text{Cos } (\text{RBA}) = \text{Cos } (\text{LDo}) / \text{Cos } (\text{ha.m}) / \cos(\text{ha.b}) - \tan(\text{ha.m}) * \tan(\text{ha.b})$

$\text{Cos } (\text{RBA}) = \frac{0.502096}{0.337007} / \frac{0.955032}{2.793721} - \frac{0.310462}{0.692677}$

$\text{Cos } (\text{RBA}) = 0.692677 \quad \text{RBA} = 46.157607 \text{ degrees}$

The Celestial Nav's Calculate Form Shows the calculation

Recap Step 1

$\text{Cos } (\text{RBA}) = \frac{0.502096}{0.337007} / \frac{0.955032}{2.793721} - \frac{0.310462}{0.692677}$

$\text{Cos } (\text{RBA}) = 0.692677 \quad \text{RBA} = 46.157607$

Step 2 Calculate LD

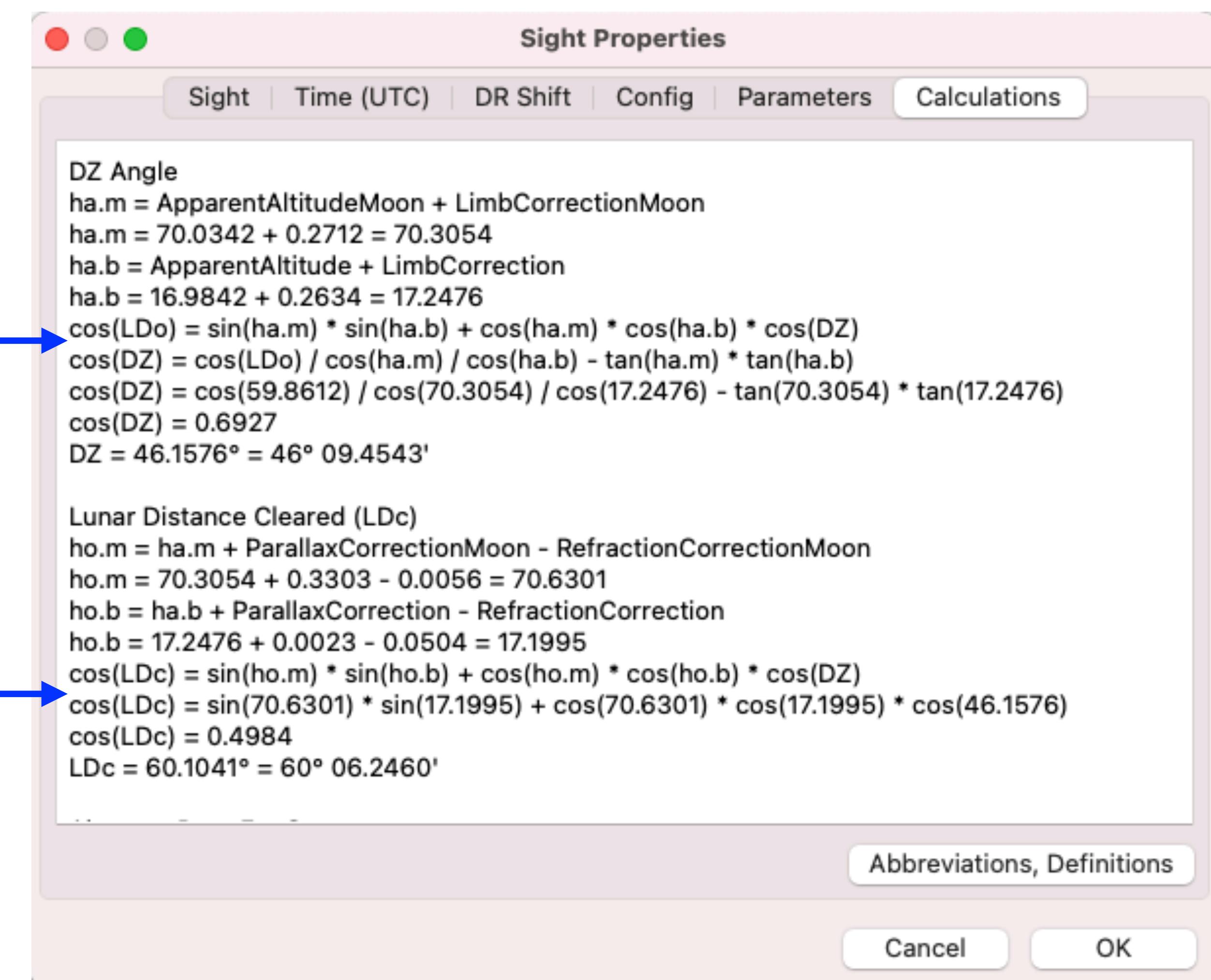
$\text{Cos } (\text{LDo}) = \sin(\text{ha.m}) * \sin(\text{ha.b}) + \cos(\text{ha.m}) * \cos(\text{ha.b}) * \cos(\text{RBA})$

$\text{Cos } (\text{LDc}) = 0.943397 * 0.295700 + 0.331666 * 0.955281 * 0.692677$

$\text{Cos } (\text{LDc}) = 0.498426$

$\text{LDc} = 60.104099 \text{ Degrees} \quad 60^\circ 6.2459'$

Calculations Form show the derivation details



New Feature - Angles are shown in Decimal Degrees and Degrees and Minutes to make it easier to use. Calculations are done in Decimal Degrees, 4 significant digits shown, but carried out using more digits

Step 3 Calculate UTC

Calculations Form show the calculations details

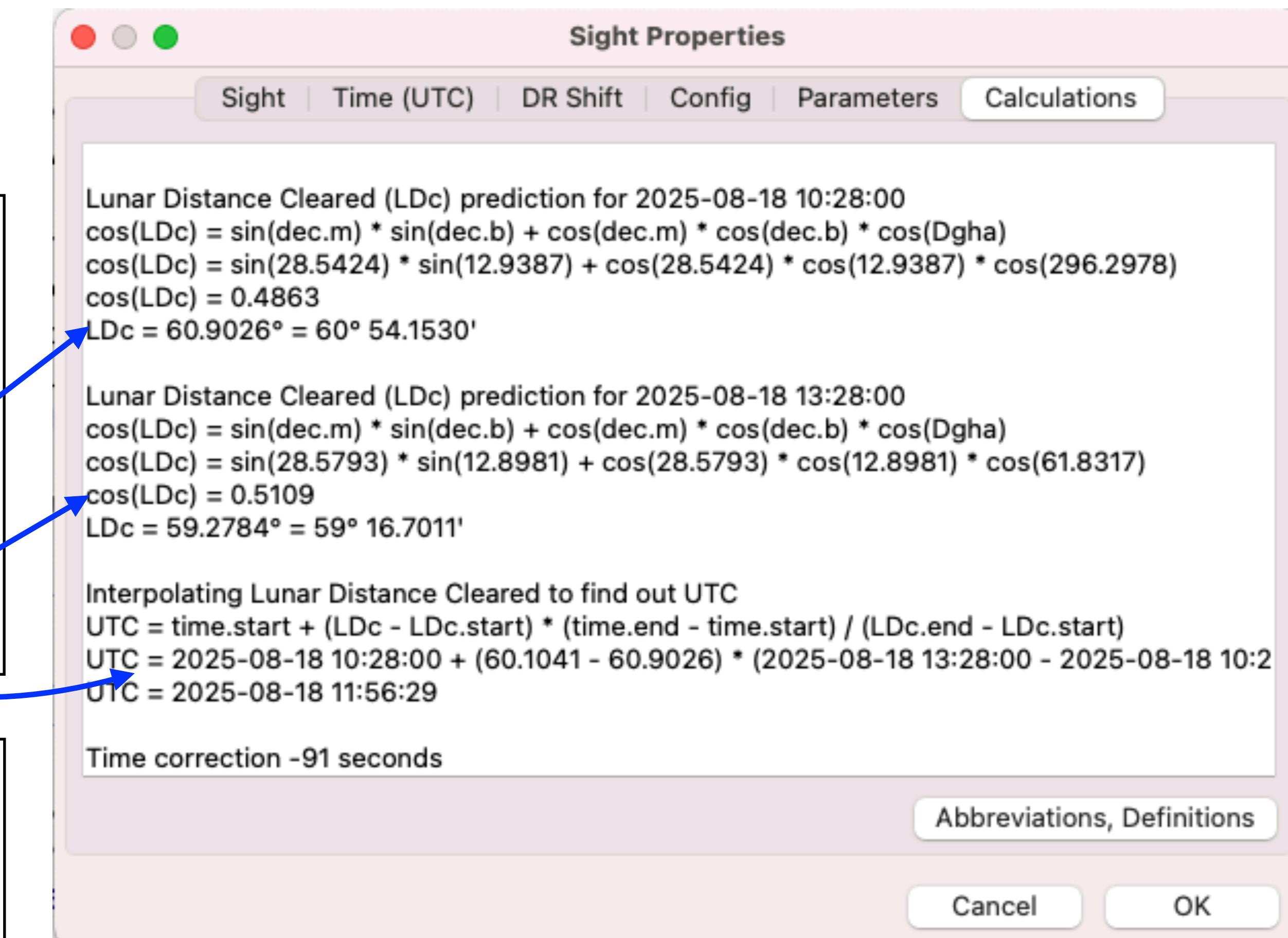
Step 3 Interpolate UTC

UTC from Predicted LDc at time 10:28, 13:28. interpolation is using the UTC form's "certainty" field.

You can make the "certainty" smaller, but don't make it too small that the derived UTC is outside the range.

Derived UTC →

UTC	LDc °
10:28:00	60.9026
11:56:29	60.1041
13:28:00	59.2784



Just an FYI . . .

Calculate $\frac{LDc \text{ change}}{UTC \text{ change}}$ = -32.5 arc-min per hour
or
-0.54 arc-min per minute

Roughly the same rate as Moon's movement across the celestial background. It can be a positive or negative number.

Calculate Lunar Distance Cleared (60.1041) by interpolating Predicted LDc of 13:28 and Predicted LDC of 10:28