

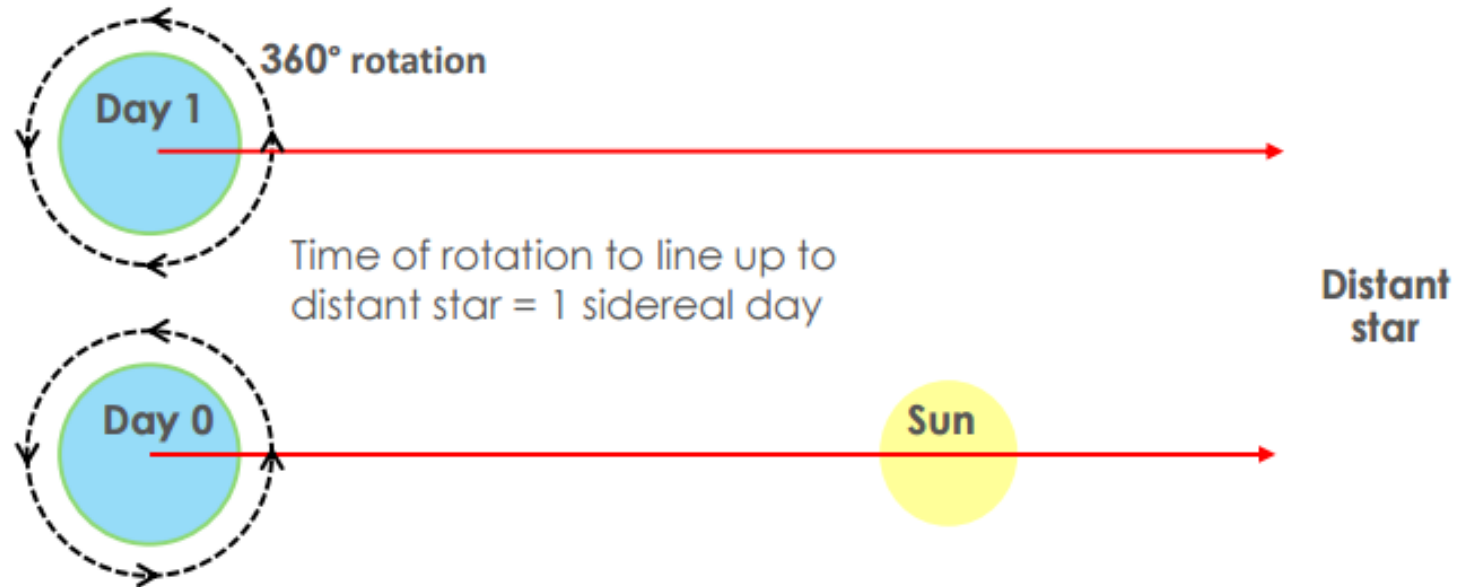
Topic 4: Time and  
the EMS System  
Part 1



# Sidereal and Synodic Days

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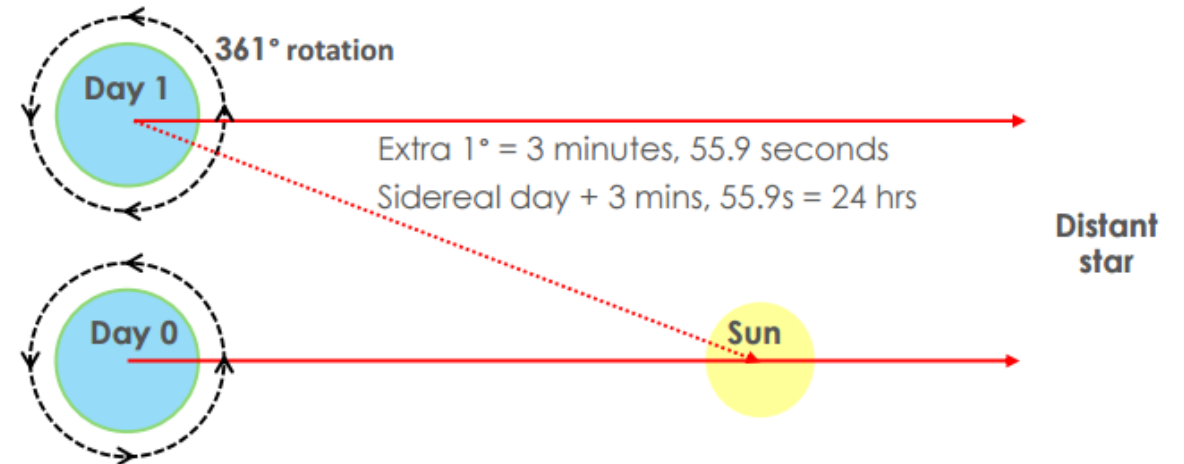
- Sidereal Day: The time taken for Earth to complete one full rotation ( $360^\circ$ ) relative to the background stars. This lasts 23 hours, 56 minutes, and 4 seconds.



# Sidereal and Synodic Days

- Synodic (Solar) Day: The time taken for the Sun to return to the same position in the sky as observed from Earth. This lasts 24 hours.
- The difference between sidereal and synodic days (and months) is due to the Earth's orbit around the Sun. It takes slightly longer to rotate so that the same part of the Earth is lined up with the Sun.

<https://www.youtube.com/watch?v=WWw4JY2dNXM>



Sidereal day:

1 Earth rotation relative to the stars

23hrs 56min (360°)

Earth Rotation

361°

Solar day:

1 Earth rotation relative to the Sun

24hrs (361°)

Earth rotates 366 times per 'normal' 365-day year relative to the stars



**Note:** this has nothing to do with leap years!  
(Leap years needed because Earth takes 365.24 days to orbit)

Sidereal Day = 23hr 56min 4sec

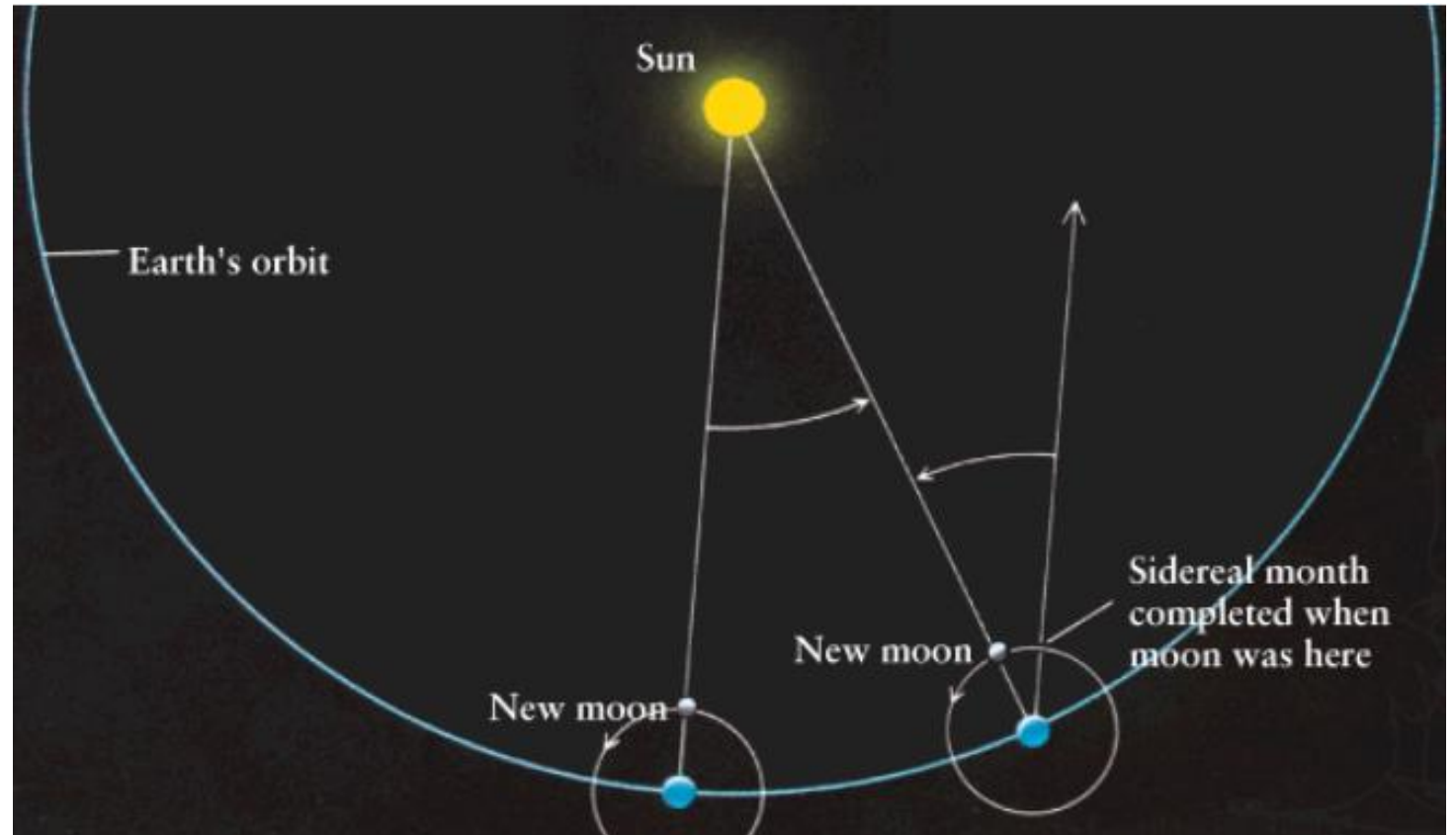
Solar Day = 24hrs

# Sidereal vs. Synodic (Solar) Months

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- Sidereal Month: 27.3 days (time taken for the Moon to orbit Earth relative to the stars).
- Synodic Month (often called Lunar Month): 29.5 days (time taken from one New Moon to the next).
- The difference is due to Earth's movement in its orbit.

<https://www.youtube.com/watch?v=c-N3u3lufK4>





# Lunar Phase Cycle

- The Moon is **non-luminous**; it reflects light from the Sun.
- Its apparent shape depends on how much of the illuminated side we can see from Earth
- There is one synodic month between each New/Full Moon (29.5 Days).
- **Waxing**: view of illuminated side is increasing
- **Waning**: view of illuminated side is decreasing
  
- <https://contrib.pbslearningmedia.org/WGBH/buac19/buac19-int-moonphaseint/index.html>

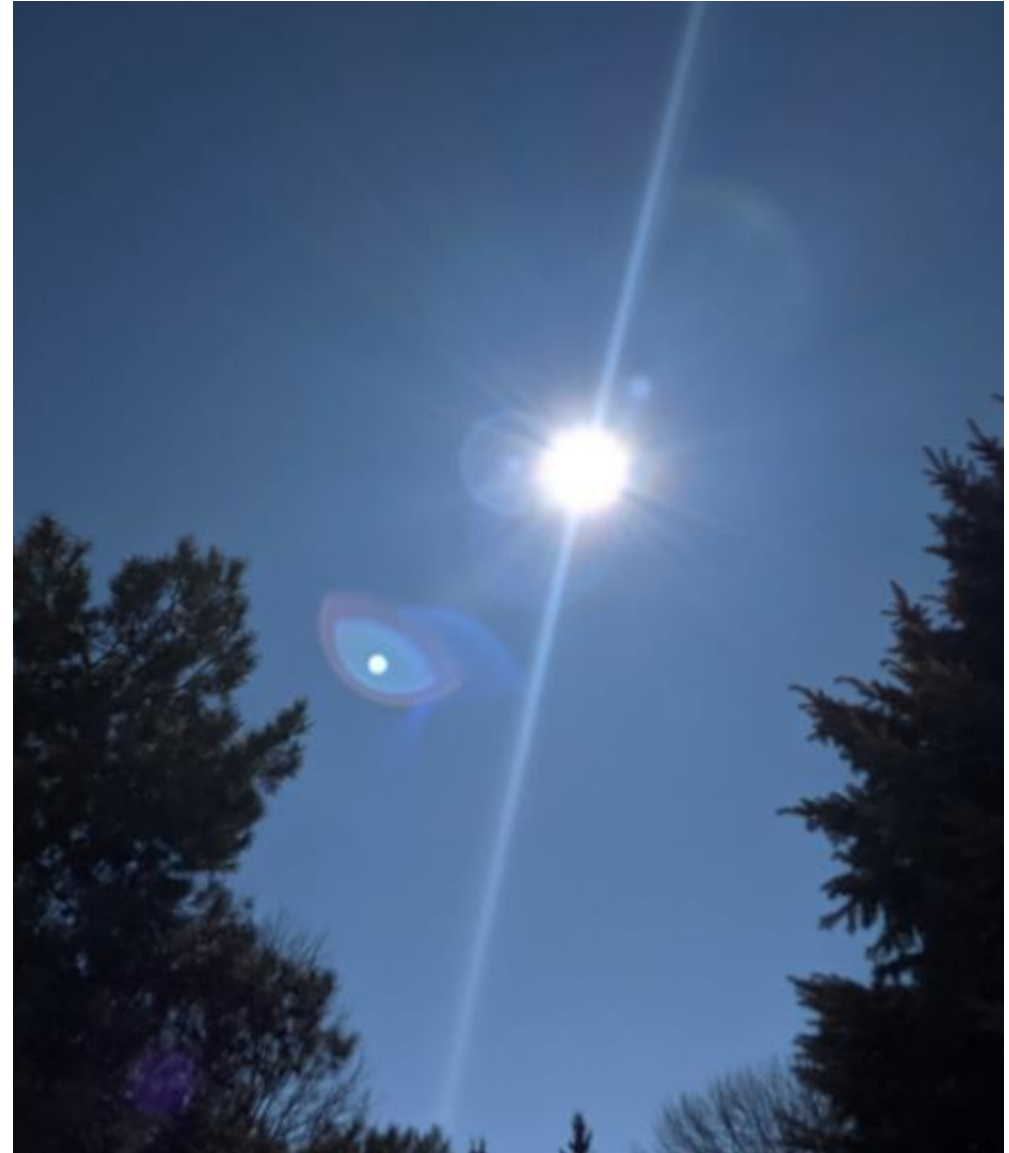


DIRECTION OF SUNLIGHT

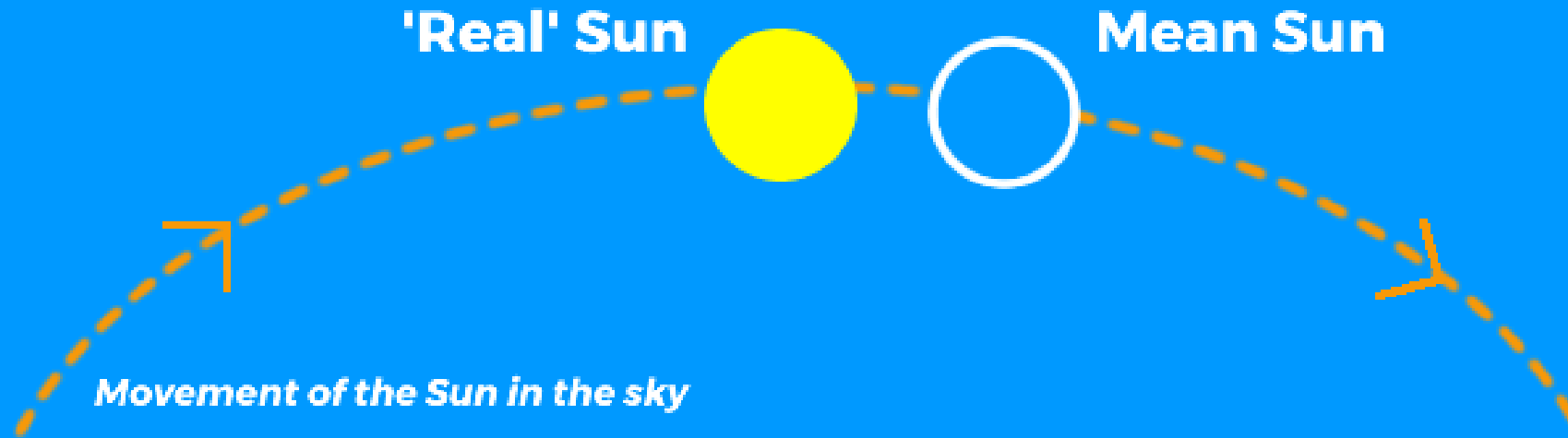
**KEY**  
 Time on Earth  
 Day  
 Phase

# Apparent Solar Time

- AST uses the Sun's position as a reference point
- Local (Apparent) Noon occurs when the Sun reaches its highest point (meridian) in the sky. This can be measured with a **shadow stick**.
- AST can be crudely measured by a **sundial**.
- The length of a solar day varies throughout the year (due to Earth's elliptical orbit and axial tilt)



# APPARENT MOTION OF THE SUN



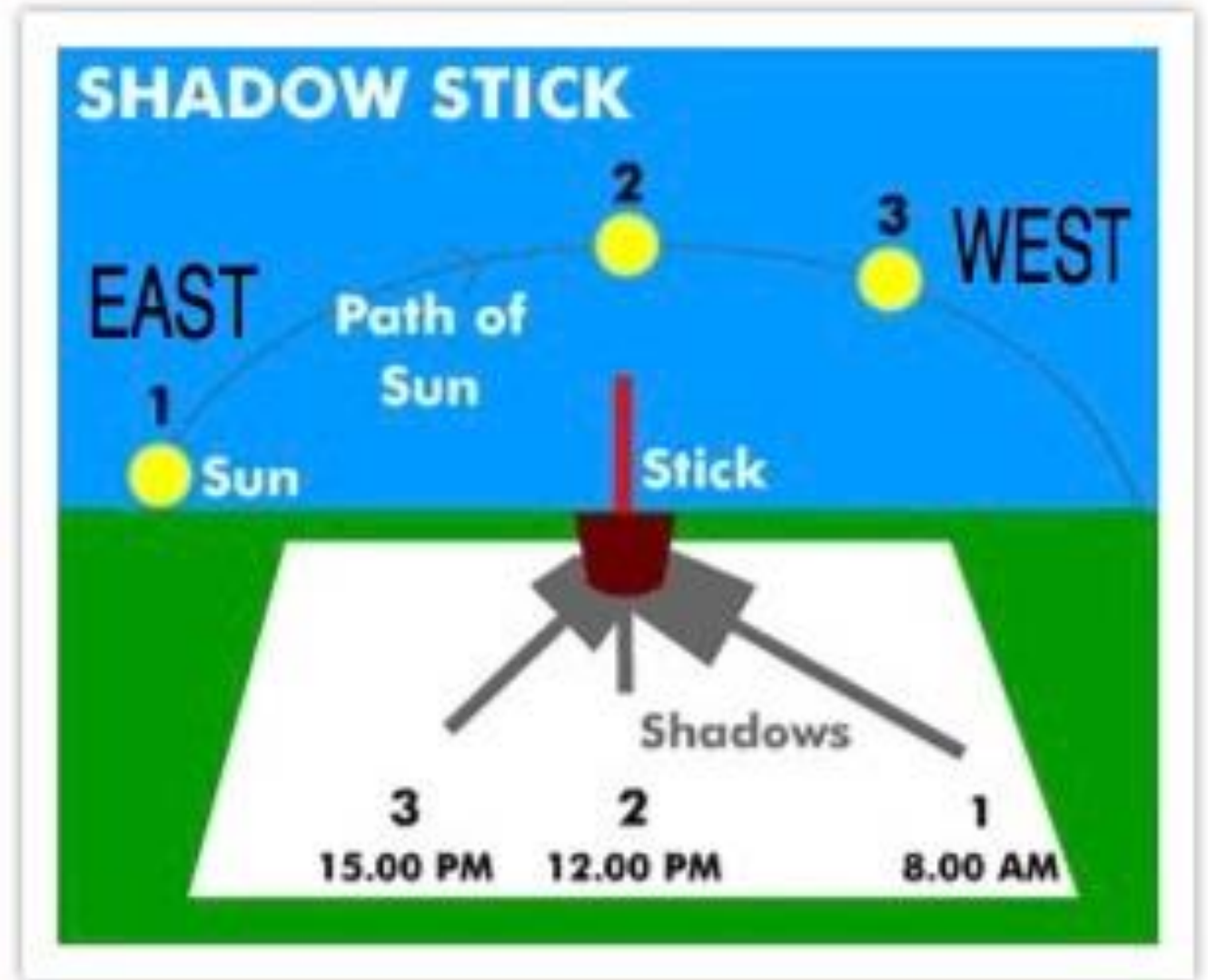
## Mean Solar Time

- AST varies through the year (meaning the real sun is not always at its highest at noon), so we correct for this using MST.
- Measured using a fictional '**Mean Sun**' that we assume moves at a constant speed across the meridian.
- As it is averaged, each day has the same length (24 hours) and is therefore more useful in people's day-to-day lives.
- It does, however, mean that the Sun's meridian is not always exactly at noon.

## Determining Local Noon (AST) Using Shadows

### Shadow Stick Method:

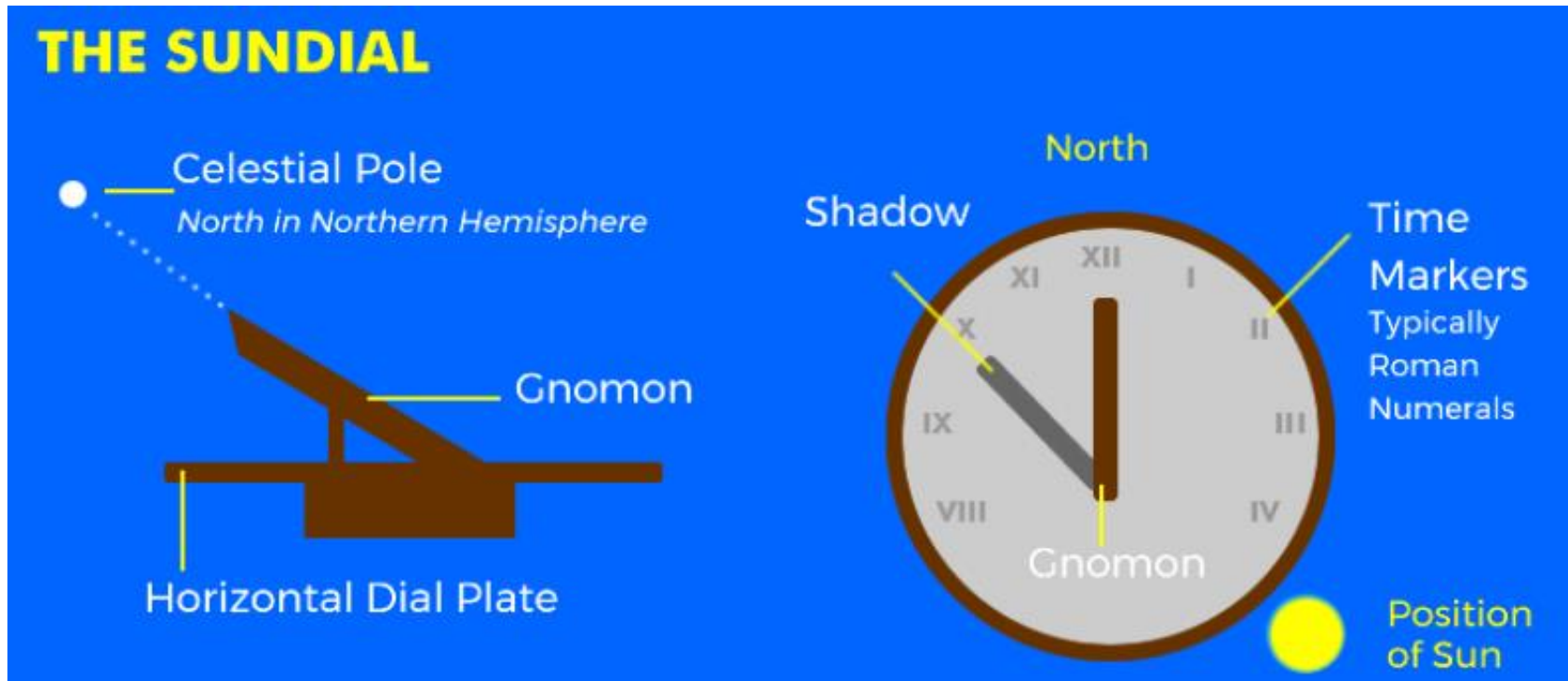
- Place a vertical stick in the ground.
- Mark the shortest shadow of the day - this occurs at local noon.





# Determining AST Using Sundials

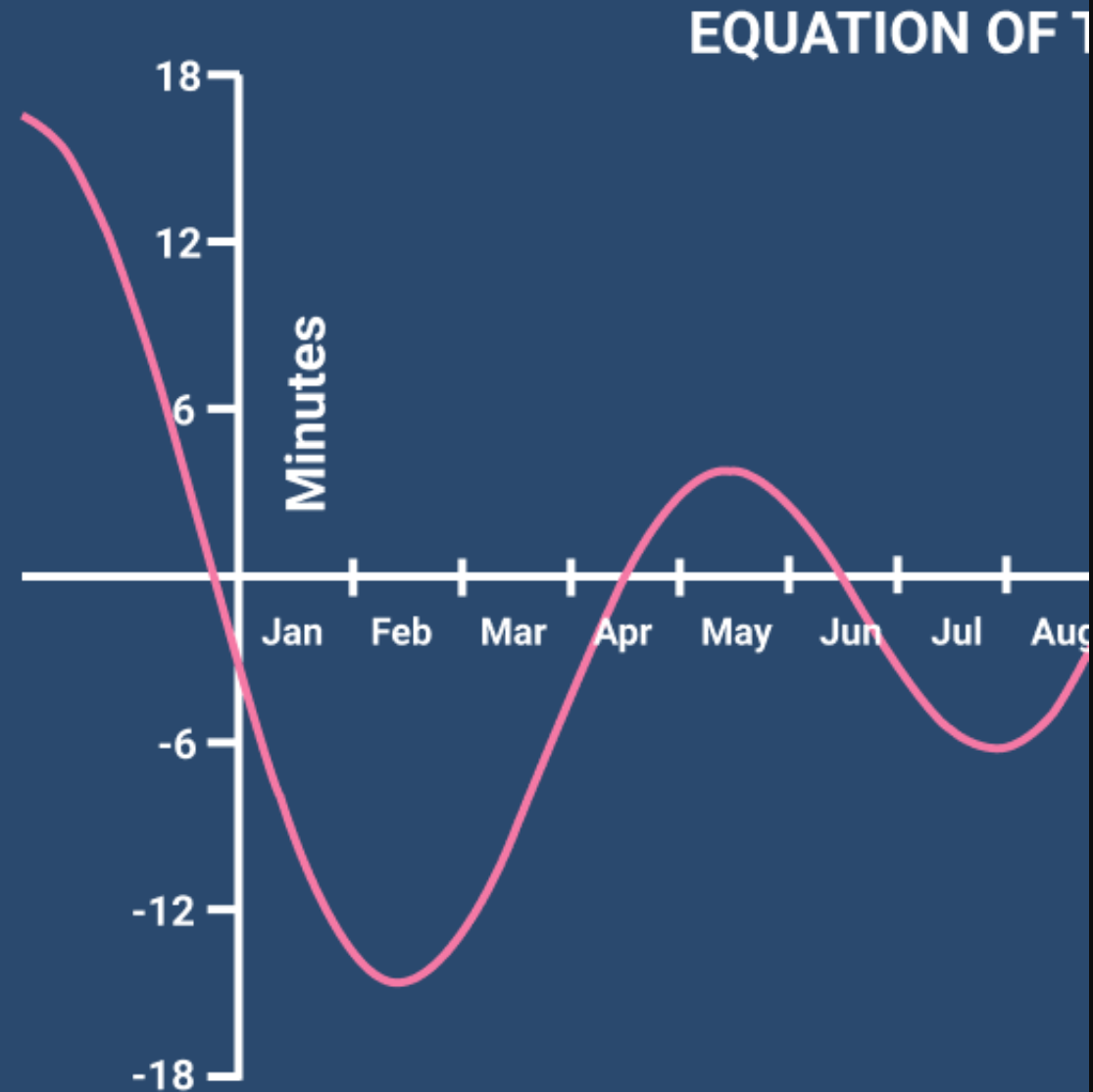
- The **gnomon** should point towards the celestial pole (aligning with Earth's axis), meaning the time markers can be space evenly
- Time is read where the shadows fall on the hour markers
- This shows Apparent Solar Time (AST)

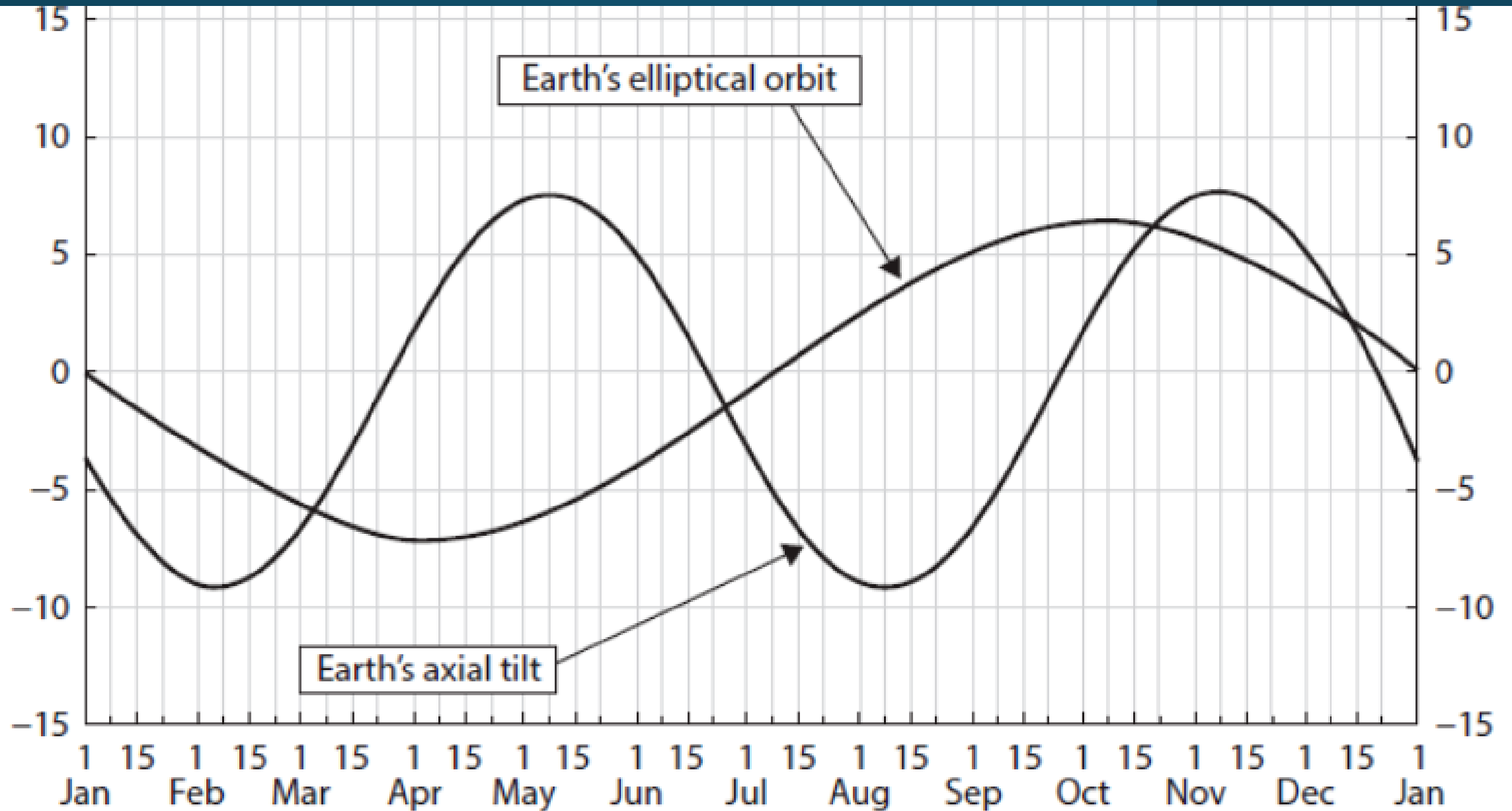


# The Equation of Time

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- **Equation of Time = Apparent Solar Time (AST) - Mean Solar Time (MST).**
  - This equation accounts for the small daily variations in the Sun's position.
  - The result of this calculation tells us how far ahead or behind the actual Sun is compared to the fictional 'Mean Sun'.
  - If we measure **AST** using a **Sundial** or **Shadow-stick** we can use the Equation of Time to calculate the equivalent local **MST** (or Local Mean Time **LMT**)
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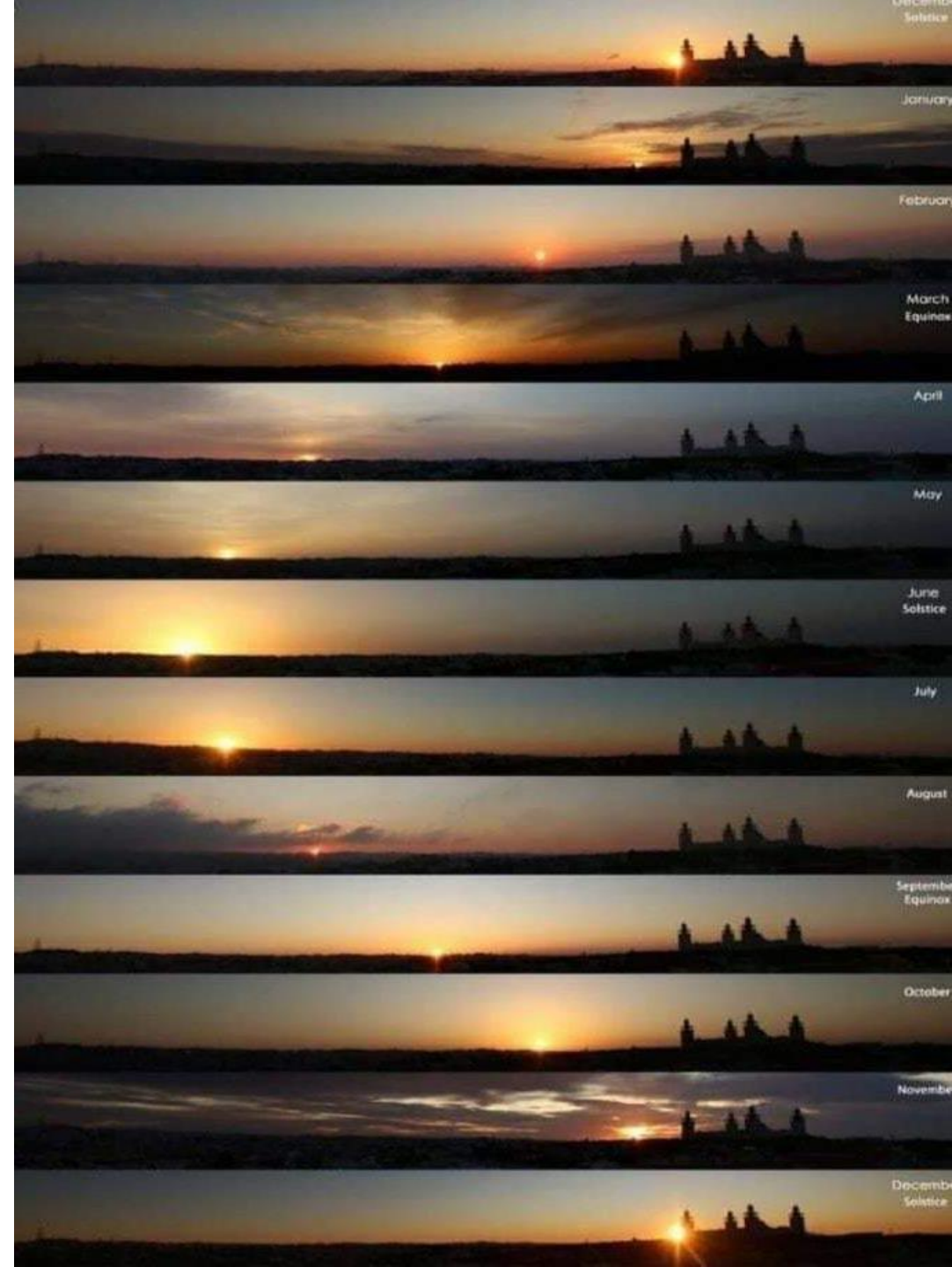


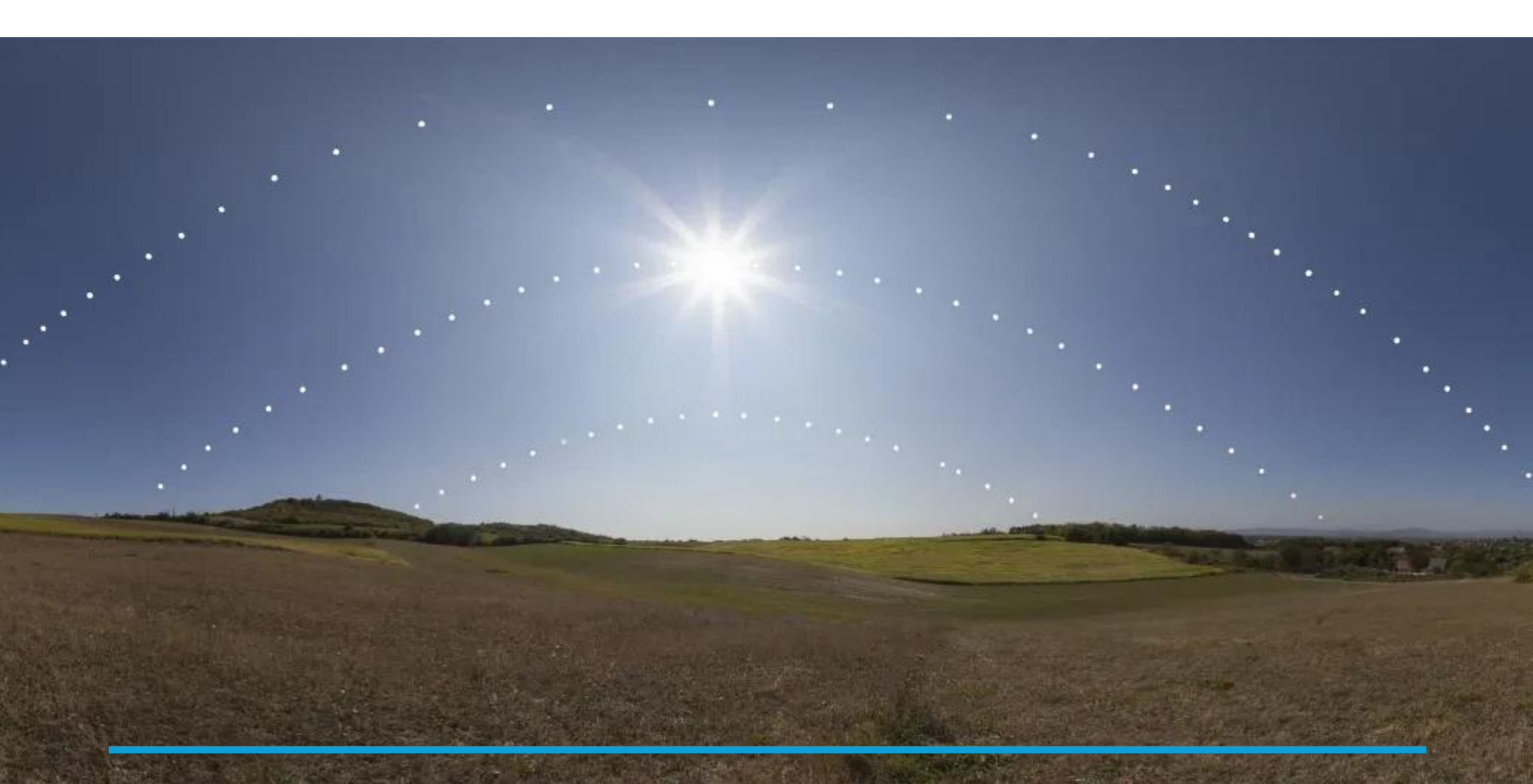


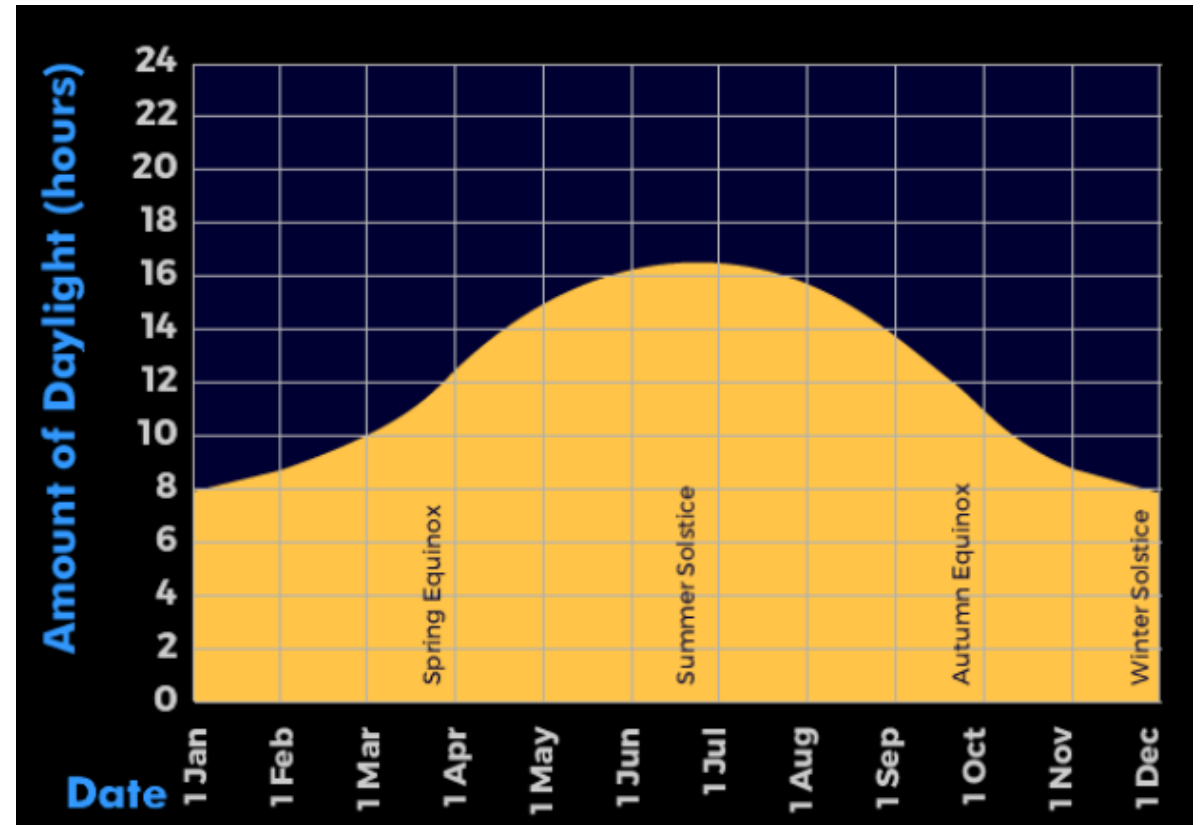
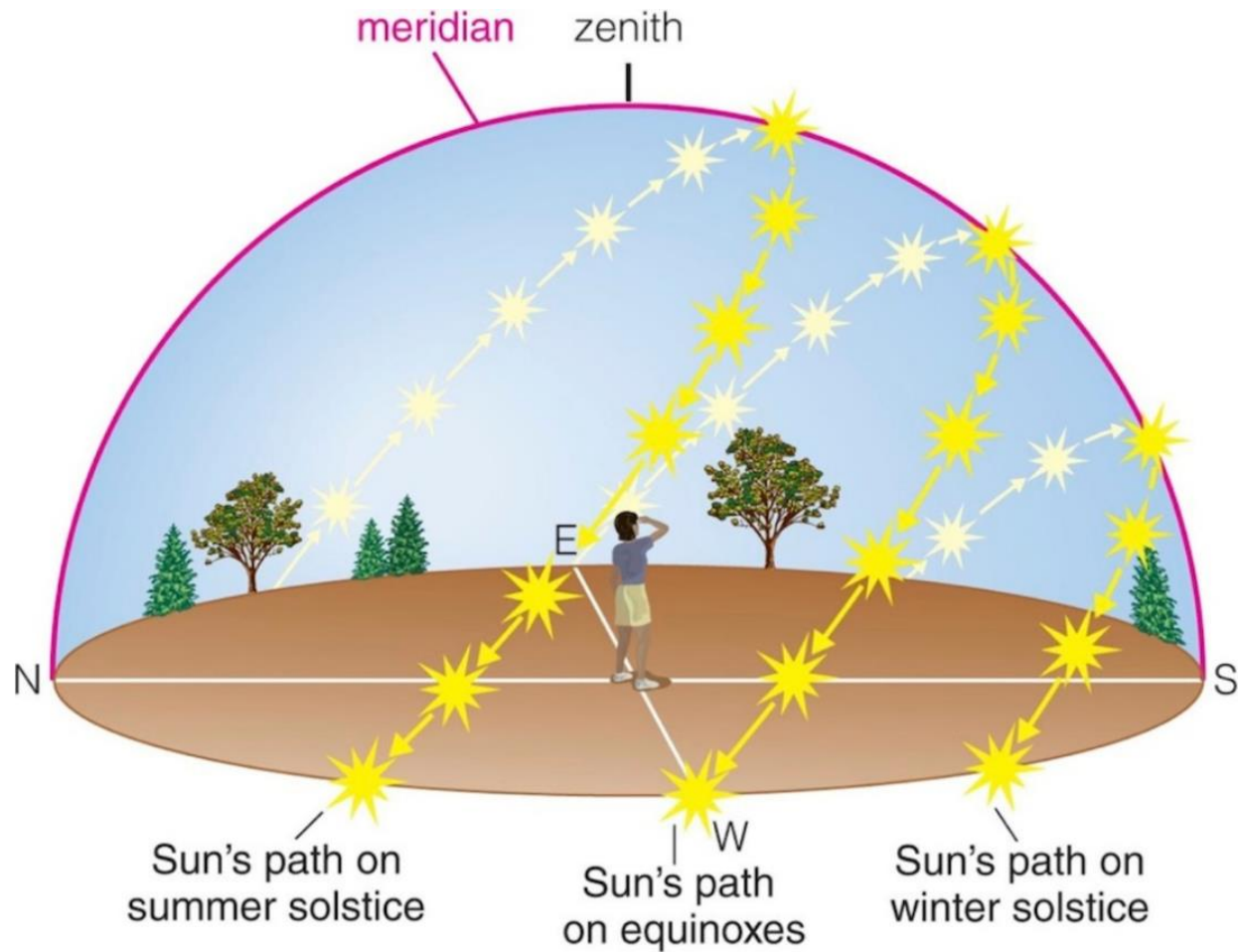
Topic 4: Time and  
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- The sunrise and sunset positions appear to change through the year due to the Earth's axial tilt and its elliptical orbit.







<https://www.earthspacelab.com/app/solar-time/>

# Time Zones

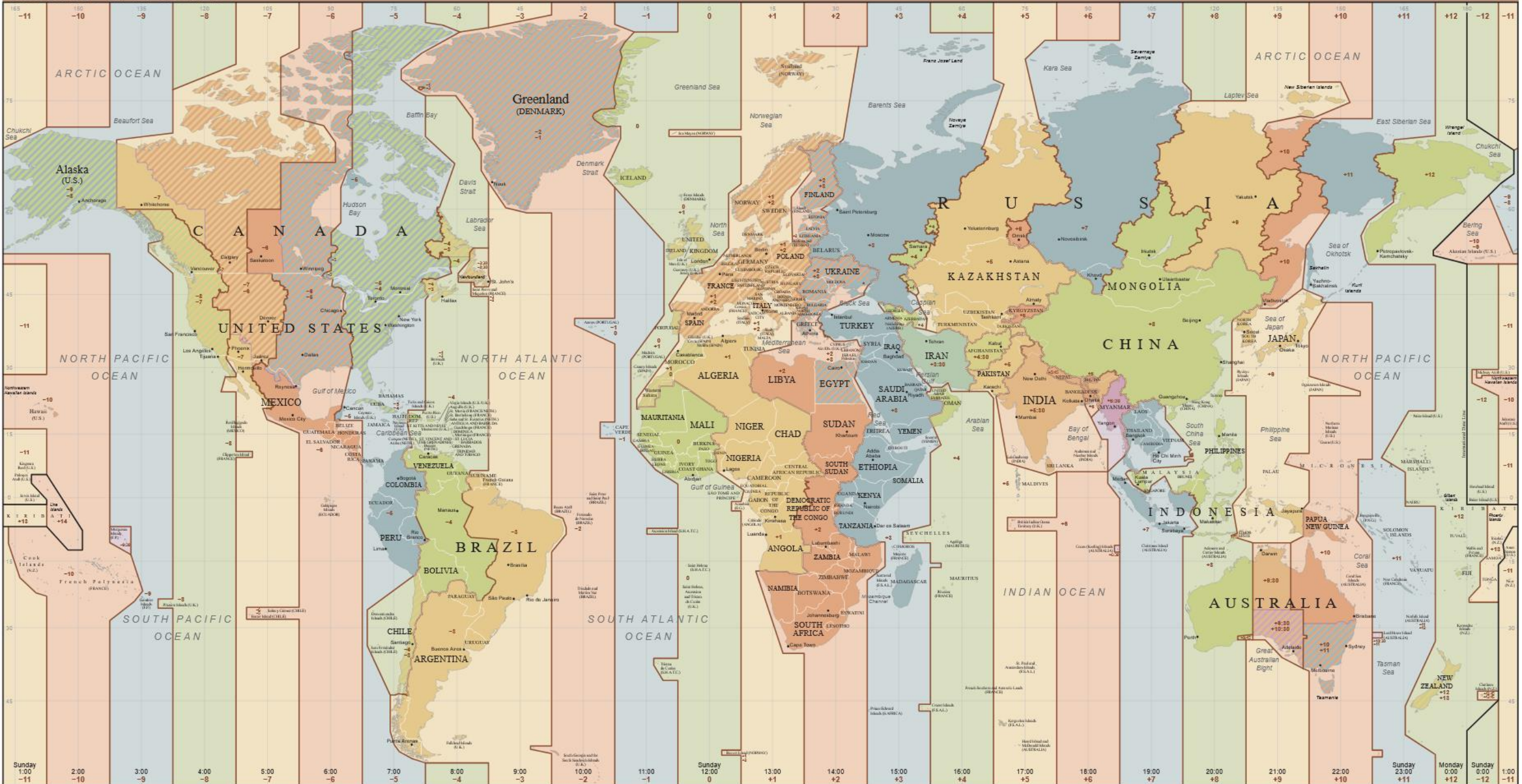
Our phones/watches are set to a particular **time zone**.

The reference time zone is called **Coordinated Universal Time (UTC)**, which shows the **Mean Solar Time** at the **Prime Meridian** ( $0^\circ$  longitude).

All other time zones are based on UTC and corrected with an **offset**. Our time zone is **Greenwich Mean Time (GMT)** which has a UTC offset of **zero**.

Time zones are  **$15^\circ$**  of longitude in width, which corresponds to a time difference of **1 hour** ( $360/24 = 15^\circ$ ) i.e. an observer with a longitude of  $15^\circ$  W would see the sun at its meridian 1 hour after someone at the prime meridian.

# TIME ZONES OF THE WORLD



\* These depend on observer's UTC+0 offset.

**North America, except Greenland:** From second Sunday in March to first Sunday in November.

**Chile:** From end of the January or February to end of the January or April.

**Islands with an offset:** The islands with an offset from the standard time zone, with the first offset used during the rest of the year.

**Europe, Greenland and Lebanon:** From Sunday before Easter to Sunday after Easter.

**Morocco:** From Sunday before Easter to Sunday after Easter.

**Japan:** From last Friday in April to end of the Thursday in October.

**Israel:** From Friday before Sunday in March to last Sunday in October.

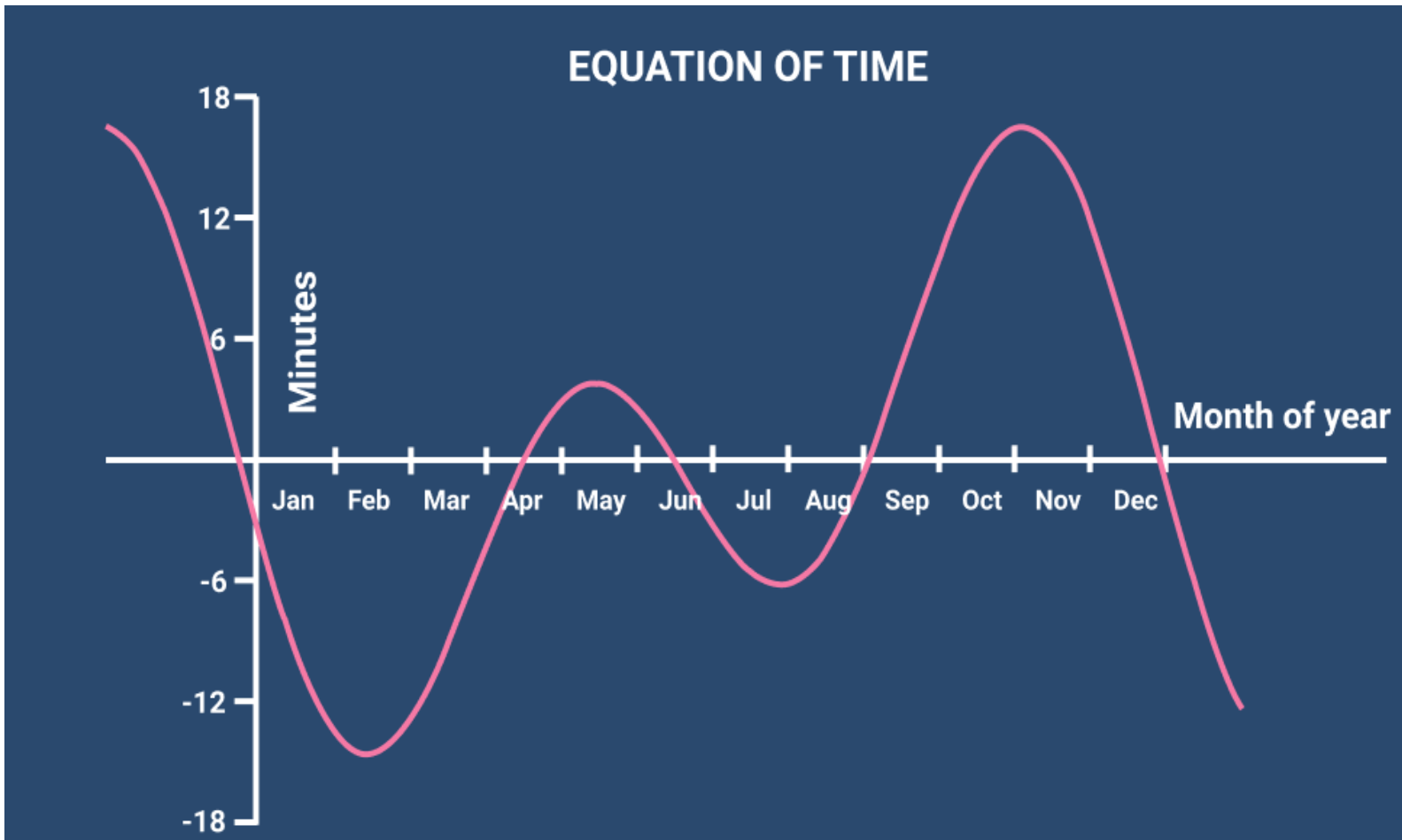
**Pakistan:** From second Sunday after Easter to Sunday before last Sunday in October.

**Australia:** From last Sunday in October to the Sunday in April.

**New Zealand:** From last Sunday in September to the Sunday in April.

# Finding your longitude using Local Mean Time

- If you are on the prime meridian then your Mean Solar Time (MST) will be the same as the Greenwich Mean Time (GMT).
- If you are WEST of the prime meridian then your Local Mean Time (LMT) will be fast i.e. read an earlier time than GMT.
- If you are EAST of the prime meridian then your LMT will be slow i.e. read a later time than GMT.
- Every degree of longitude will create a difference of 4 minutes between your LMT and GMT.
- This is due to the direction of rotation of the Earth (eastward).

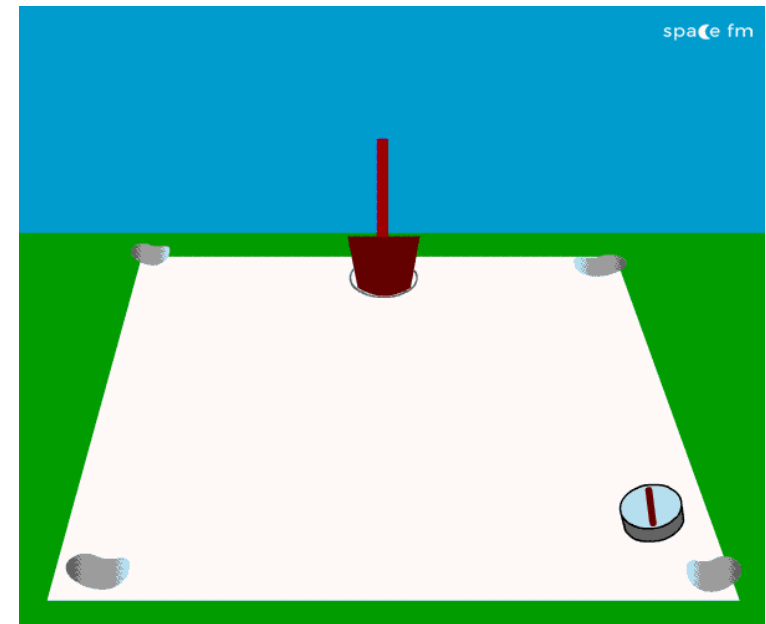


**Equation of Time = Apparent Solar Time (AST) - Mean Solar Time (MST).**

- Anything above 0 means that AST is ahead of MST (sundial reads a later time than the actual local time, and the Sun reaches its meridian early).
- Anything below 0 means that AST is behind MST (sundial reads an earlier time than the actual local time and the Sun reaches its meridian late).

# Finding your longitude: Shadow stick

1. Place a stick on a **level** surface, pointing at your **zenith**
2. Record the **time** (with an accurate watch set to GMT) at which the **shadow is shortest** (this is your local noon – 12:00 AST)
3. Use the Equation of Time to find the Local Mean Time from your AST of 12:00
4. Your **LMT** is **earlier** than the GMT time you recorded then you are **WEST** of the prime meridian, if it is **later** than the GMT time you recorded then you are **EAST** of the prime meridian.
5. Calculate your longitude: **each degree** of longitude corresponds to **4 minutes difference** of your LMT from GMT.



# Example:

- The shortest shadow (which happens at AST of 12:00pm) appears at 11:45 am according to your watch (set to GMT).
- The EoT for that day is -5 minutes.
- $EoT = AST - MST$ , so  $MST = AST - EOT$ .
- $MST = 12:00 - (-5) = 12:05$  pm.
- This is 20 minutes later the GMT of 11:45 am, so we are **East** of the prime meridian.
- Longitude =  $20/4 = 5^\circ$  **East**

# Finding your longitude: Sundial

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1. Read the time displayed by the shadow on the sundial (this is AST).
2. Use the Equation of Time to find the Local Mean Time from your measured AST.
3. Compare this LMT to GMT from an accurate clock.
4. If your LMT is **earlier** than the GMT time you are **WEST** of the prime meridian, if it is later than the GMT time you recorded then you are **EAST** of the prime meridian.
5. Calculate your longitude: each degree of longitude corresponds to 4 minutes difference of your LMT from GMT.

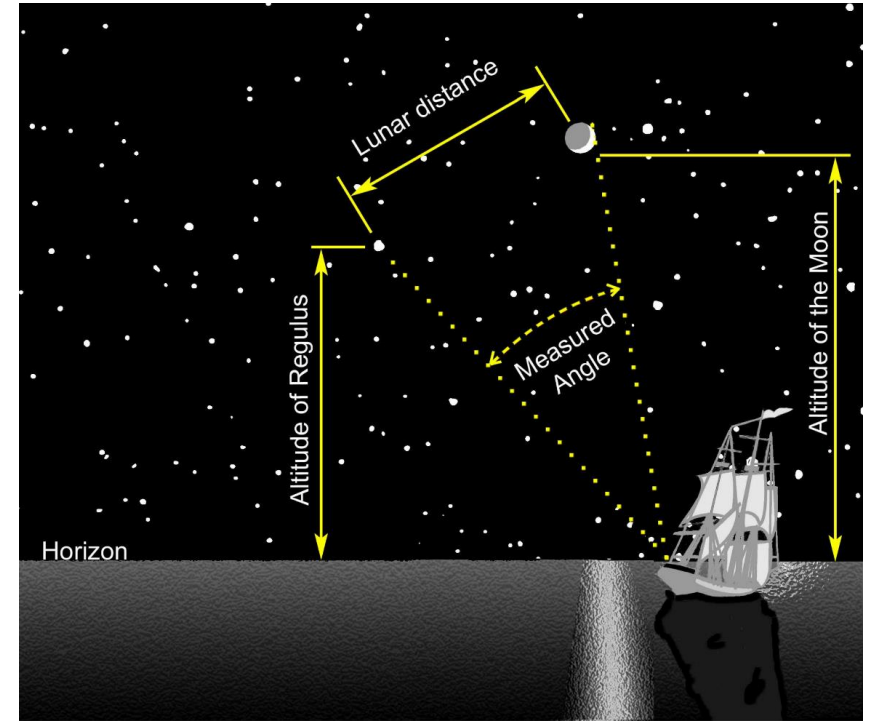


# Key Points

- Sun dials and Shadow sticks show **AST**
- You must use the **Equation of Time** to correct **AST** to **MST**
- Each degree of longitude will mean that your **Local Mean Time** (the **MST** at **your longitude**) will be different from GMT by **4 minutes**.
- If you are **West** of Greenwich and the prime meridian your LMT will show an **earlier time** than GMT
- If you are **East** of Greenwich and the prime meridian your LMT will show a **later time** than GMT

# Finding Longitude: Lunar Distance Method

- Measure the **angle** between the Moon and another bright object (e.g. a star such as Regulus) using a **sextant**.
- Anyone on Earth who can see the same two bodies will observe the **same angle**.
- Consult a prepared table (Nautical Almanac) to find the time at which specific angular distances will occur to find the **Local Mean Time**
- Compare this LMT to GMT to find longitude.



2011 January 19, 20, 21 (Wed, Thur, Fri)

SATURN		STARS		SUN		MOON					
GHA	Dec	Name	SHA	Dec	GHA	Dec	GHA	v	Dec	d	HP
281° 15' 2	4° 26' 6 S	Acamar	315° 19' 5	40° 15' 8 S	177° 22' 8	20° 27' 0 S	10° 09' 4	6' 1	21° 08' 5 N	7' 6	59' 3
296° 17' 6	26' 6	Achernar	335° 28' 0	57° 11' 1 S	192° 22' 6	26' 5	24° 34' 5	6' 0	00' 9	7' 7	59' 4
311° 20' 0	26' 6	Acruz	173° 11' 1	63° 09' 5 S	207° 22' 4	26' 0	30° 59' 5	6' 1	20° 53' 2 N	7' 8	
326° 22' 5	26' 6	Adhara	255° 13' 5	28° 59' 4 S	222° 22' 2	26' 5	53° 24' 6	6' 1	45' 4	8' 0	
341° 24' 9	26' 6	Aldebaran	290° 51' 1	16° 31' 9 N	237° 22' 0	26' 0	67° 49' 7	6' 2	37' 4	8' 1	59' 5
356° 27' 3	26' 6				252° 21' 8	24' 5	82° 14' 9	6' 1	29' 3	8' 3	
11° 29' 8	26' 6	Alioth	166° 21' 9	55° 53' 6 N	267° 21' 6	23' 9	96° 40' 0	6' 2	21' 0	8' 4	
26° 32' 2	26' 6	Alkaid	153° 00' 1	49° 15' 1 N	282° 21' 4	23' 4	111° 05' 2	6' 3	12' 6	8' 5	
41° 34' 6	26' 6	Alnair	27° 46' 2	46° 54' 5 S	297° 21' 3	22' 9	125° 30' 5	6' 3	04' 1	8' 7	59' 6
56° 37' 0	26' 6	Alnilam	275° 47' 8	1° 11' 5 S	312° 21' 1	22' 4	130° 55' 8	6' 3	19° 55' 4 N	8' 8	
71° 39' 5	26' 6	Alphard	217° 57' 5	8° 42' 6 S	327° 20' 9	21' 9	154° 21' 1	6' 3	46' 6	9' 0	
86° 41' 9	26' 6				342° 20' 7	21' 3	168° 46' 4	6' 4	37' 6	9' 1	
101° 44' 3	4° 26' 6 S	Alphecca	126° 12' 6	26° 40' 4 N	357° 20' 5	20° 20' 8 S	183° 11' 8	6' 4	19° 28' 5 N	9' 2	59' 7
116° 46' 8	26' 6	Alpheratz	357° 45' 5	29° 09' 3 N	12° 20' 3	20' 3	197° 37' 2	6' 5	19' 3	9' 4	
131° 49' 2	26' 6	Altair	62° 10' 2	8° 53' 9 N	27° 20' 1	19' 8	212° 02' 7	6' 5	09' 9	9' 4	
146° 51' 6	26' 6	Ankaa	353° 17' 5	42° 14' 9 S	42° 19' 9	19' 2	226° 28' 2	6' 5	00' 5	9' 7	
161° 54' 1	26' 6	Antares	112° 28' 6	26° 27' 3 S	57° 19' 7	18' 7	240° 53' 7	6' 6	18° 50' 8 N	9' 7	59' 8
176° 56' 5	26' 6				72° 19' 5	18' 2	255° 19' 3	6' 6	41' 1	9' 9	

# Finding Longitude: Horological Method

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- Navigators used a sextant to observe local apparent noon when the sun culminated (reached its highest altitude).
- They then used a table in the Nautical Almanac (which listed the Equation of Time for specific dates and times) to convert the observed local apparent time into local mean time.
- The navigator could then compare this local mean time with the Greenwich Mean Time shown on the H4 chronometer (not possible before accurate portable clocks were invented)
- The resulting time difference was converted into degrees, minutes, and seconds of longitude.

