Celestial Navigation Primer

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Outline

- What is and why do celestial navigation?
  - Magic and mystery of Ham Radio
    - https://youtu.be/k4Q1A8IE9Vs?t=352
- Tools used
- What is the Ground Point of a heavenly body
- Times and Assumed Position (DR)
- Finding the Ground point
- Where am I?
- Fun (Not above your head)
  - ENTER QUESTIONS IN THE CHAT

Disclaimer

DO NOT OFFER YOUR SERVICES AS A CERTIFIED NAVIGATOR ON THE BASIS OF THIS PRESENTATION.

DO CONTINUE TO EXPERIMENT, ASK QUESTIONS AND PRACTICE THE TECHNIQUES.

What is and why do celestial navigation?

- Finding your location using the objects in the sky. Hopefully this part is over your head
- Produce a Latitude and Longitude estimate
- Used for millennia - Historically significant
- Resilient to failures of electronic navigation
- Not just for Earth position anymore
  - Apollo sextant, ISS, Deep Space . see links at end
- Handy for finding stars and planets.
- Fun

Tools used

- Angles: Sextant or Survey equipment.
  - Leveling is important.. Bubbles, Horizons and pendula
- Time: UT(GMT) at Greenwich England
  - e.g. Local time at an assumed position,
- Mean Solar Time tools
  - Watches and Chronometers
  - Radio (WWV) and Telephone (see April QST pg 66)
  - NIST website: https://www.time.gov/
    - NIST-F2 is accurate to one second in 300 million years
  - Cell phone connected to a service
  - GPS clocks
- Computation:
  - Tables and calculators
  - https://thenauticalalmanac.com/TNACompact/2022_Nautical_Almanac_compact_version.pdf

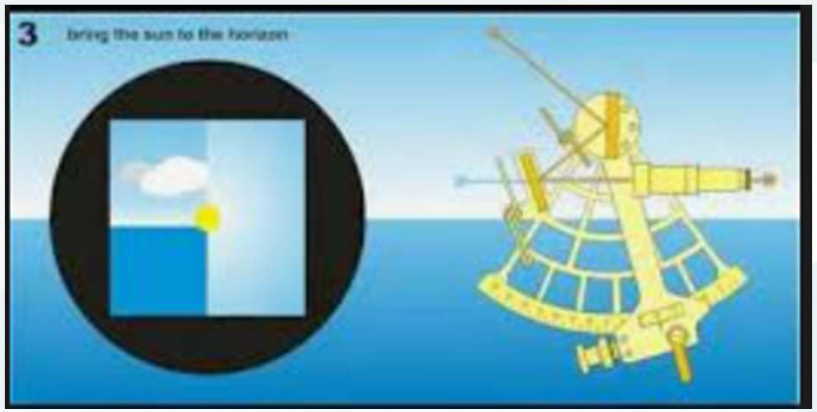
Time Signals- by telephone
WWV 303-499-7111
WWVH 808-335-4363
CHU English:
613-745-1576 provides Eastern time)

Time signals- by Radio
WWV
(Fort Collins, Colorado)
2.5, 5, **10**, 15, 20 MHz

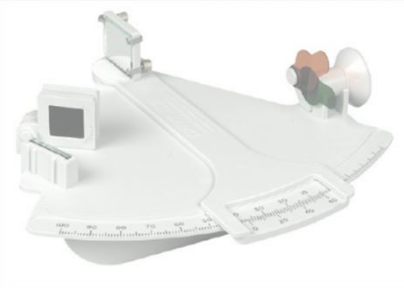
WWVH
(Kauai, Hawaii)
2.5, 5, 10, 15 MHz

CHU (Ottawa, Canada)
3330, 7850, and 14,670 kHz (USB)

The Nautical Sextant



- Mostly used to measure angles in degrees and minutes <u>from the horizon</u> using 2 mirrors. This angle is called ALTITUDE and designated as H.
  - First sextant made by John Bird, in the year 1757 in London
  - Note that the Horizon is not always visible. Nor are the sun and stars

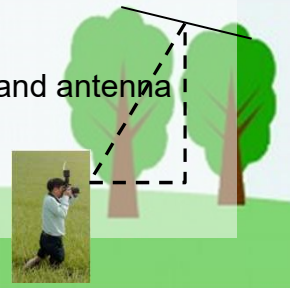


- There are 60 minutes in a degree and 60 seconds in a minute
- Example Ho = 45° 30’ 6” or 45 degrees + 30 minutes + 6 Seconds.

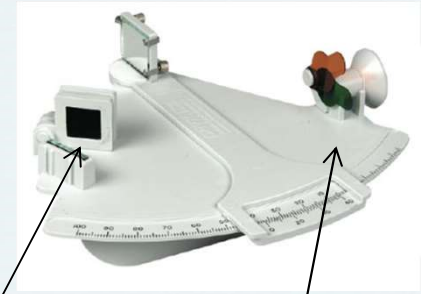
Angle conversions can be tricky

- 45° 30’ 6” is 45 degrees + 30/60 degrees + 6/60 minutes
- Degrees: 45 + 0.5 + (0.1)/60 = 45.5016666 degrees
- Minutes.. 45*60 + 30 + 6/60 = 2700+30+0.1 = 2730.1 minutes

- Example use.. How High is your antenna?
  - Pick a point on a structure at the height of your eye such that you will be on relatively even ground
  - Set sextant for 45 degrees and walk away from the point to be measured until the point you picked and antenna match in the split mirror.
  - The distance you walked plus your eye height is the height of the antenna



CAUTION



- **NEVER LOOK DIRECTLY AT THE SUN!!!!!!!!**
- SEXTANTS HAVE SPECIAL FILTERS (often 2)
- USE BOTH INDEX FILTERS FIRST
- IF THE SUN IS BEHIND A CLOUD AND DIM, CONSIDER REMOVING ONLY ONE
- THE HORIZON SHADES ARE **NOT** SUN FILTERS
- *NOTE: BLINDNESS WAS A COMMON OCCUPATIONAL HAZARD FOR MANY EARLY NAVIGATORS.*

Hour Angles and Hours

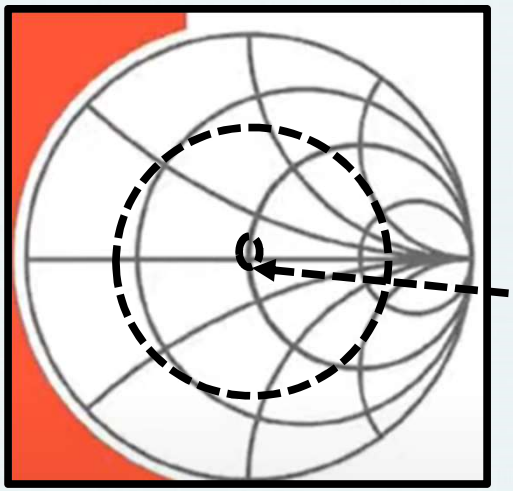
- **Hour angles** are like Longitude and measured from a chosen reference Hour Angle. They are in degrees and arc minutes
- Examples
  - Greenwich Hour Angle (GHA) is from Longitude 0° (Greenwich,UK)
  - Siderial Hour Angle (SHA) is measured from the GHA of the First Point of Aires going westward.
- **Hours** are time and it takes 24 hours for the earth to make one rotation or 360 degrees. We use the average for the year.
  - 360/24 = 15 degree hour angle per hour of time (One time zone)
  - 1 minute of angle is 1/60 of a degree. 60 minutes= 1 degree
  - **1 angular minute of Latitude on the earth's surface is also 1 nautical mile. Note that 1 minute of longitude varies in distance with latitude**
  - 4 seconds (60/15) of time represents a Ground Point moving 1 nautical mile or 6076.1 feet. Accurate time measurement is important

Angle Measurement Options

- Nautical Sextant
  - ($60 for 60 seconds , $2000 for maybe 6 seconds)
- Aviation Sextant. Bubble for level
- Artificial Horizon (Measures twice the angle)
  - Pan with water, oil or molasses
- Protractor and construction level ($10, ½ degree)
- Survey Equipment ($20,000, 1 sec)
- GOTO Telescope ($100-$10000)
- Astrolabe (225 BCE, 1459AD earliest for Nav)

What is a Ground Point (GP) of a heavenly body?

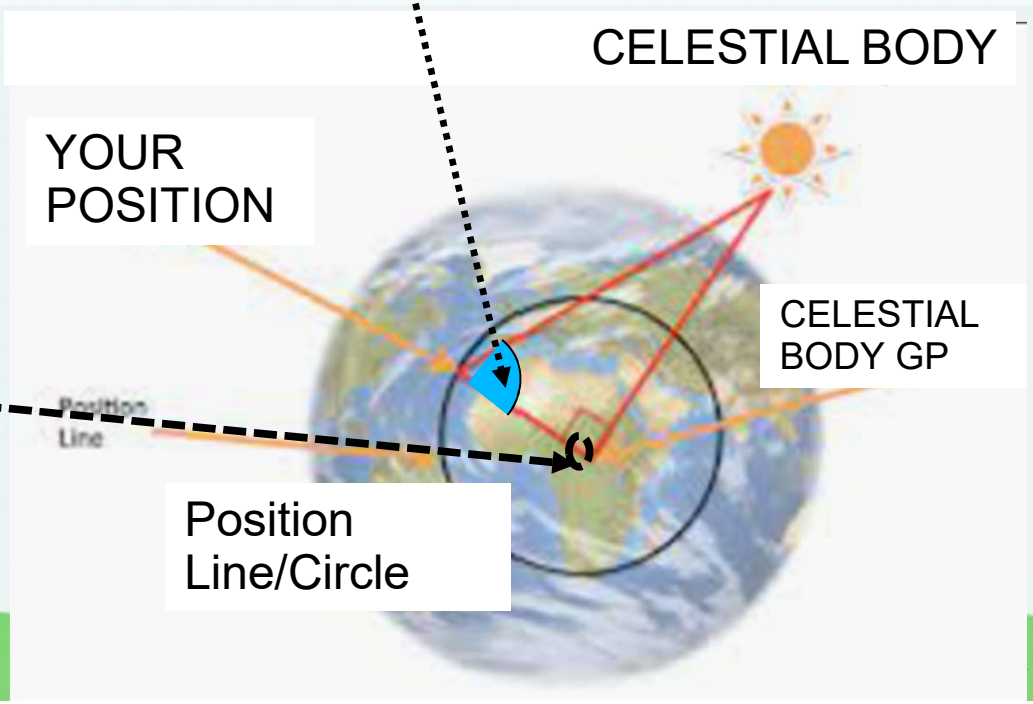
- The point when the body (STAR) is directly overhead (called the **Zenith**).
- If you are anywhere on a **position circle**, the Altitude (H) measured is the <u>same</u>
- The GP Changes with time as the earth turns.
- Computing the Ground point is a skill you need to find out where you are after measuring the angle to bodies at a specific points in time.



Smith Chart analogy

GP is like SWR =1

SWR is a circle



Finding the Ground Point

- We need to find the GHA and the Declination of the ground point. Examples later
- Current options:
  - Use the annual Nautical Almanac
    - Cost options $67, $10, $5, $0 (online)
  - Many online and apps can be used but these require the internet or a computer.
  - Spreadsheet will be provided by me

Where am I?

1)From my assumed position I can compute the direction (Z) to the ground point and the altitude of the body (Hc). Somewhat tedious.

2)I won't measure Hc unless I am really at the assumed position. I then modify the position by 1 nautical mile in the direction of Z for every minute of difference to what I measure.

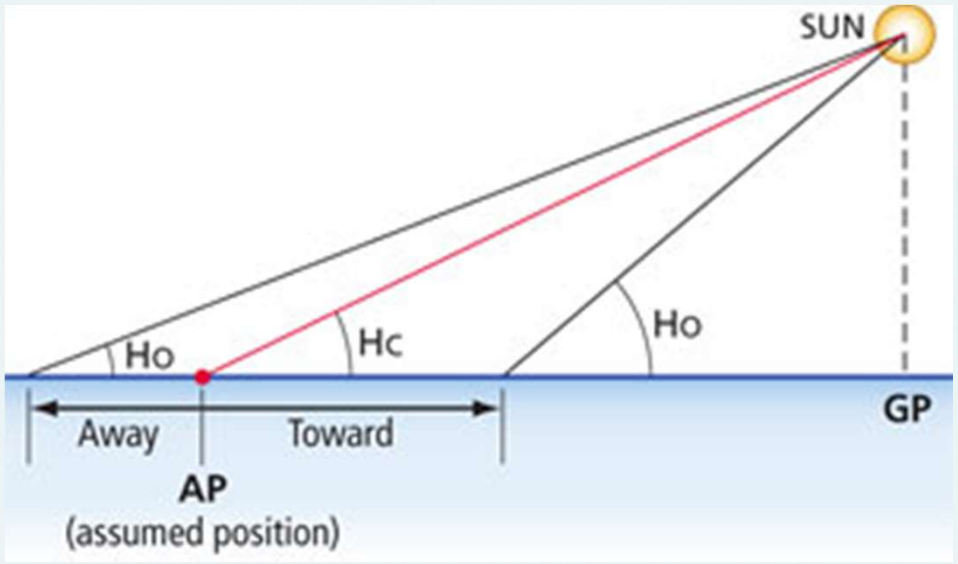
3)A smaller measured angle means I am further away and a larger angle means I am closer to the ground point.

4)This is done for at least 2 Ground Points and the intersection of the 2 circles is WHERE I AM.

Were am I - Illustrations

Ref: https://pbps.org/celesnav.html

Where I am.. Item 3



Item 4

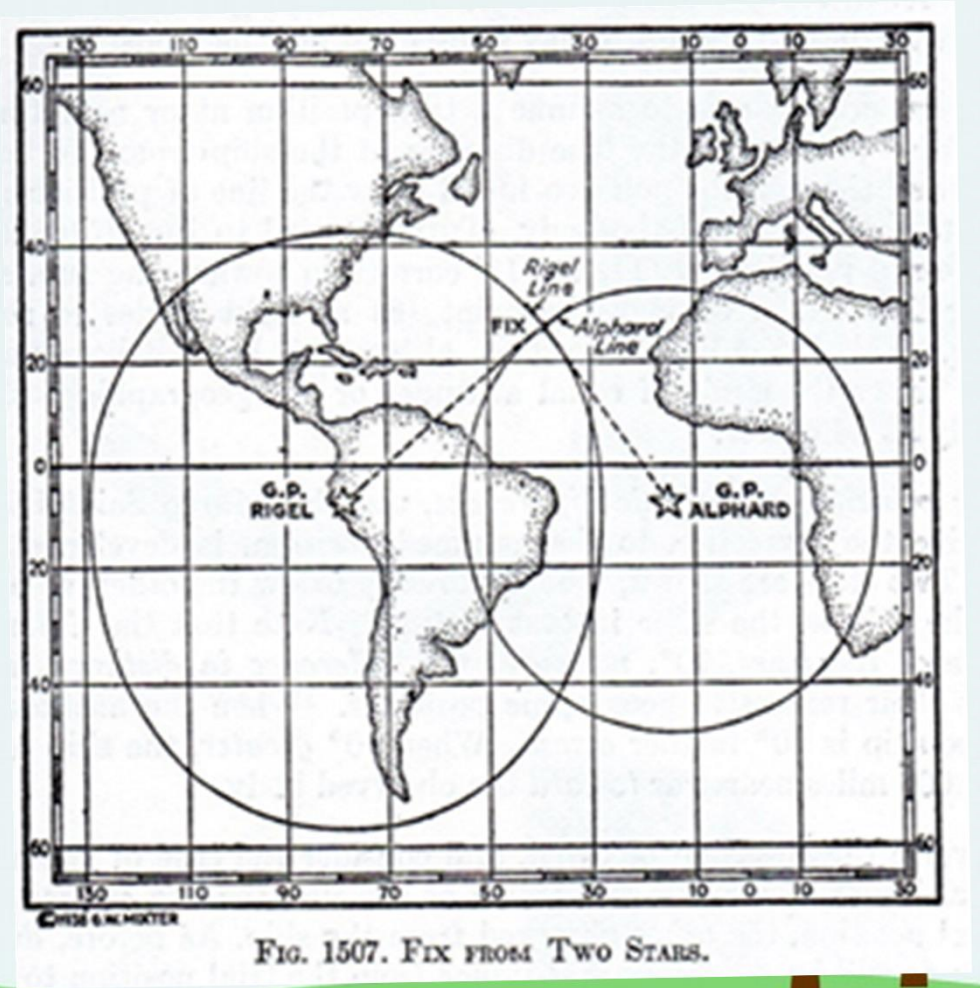
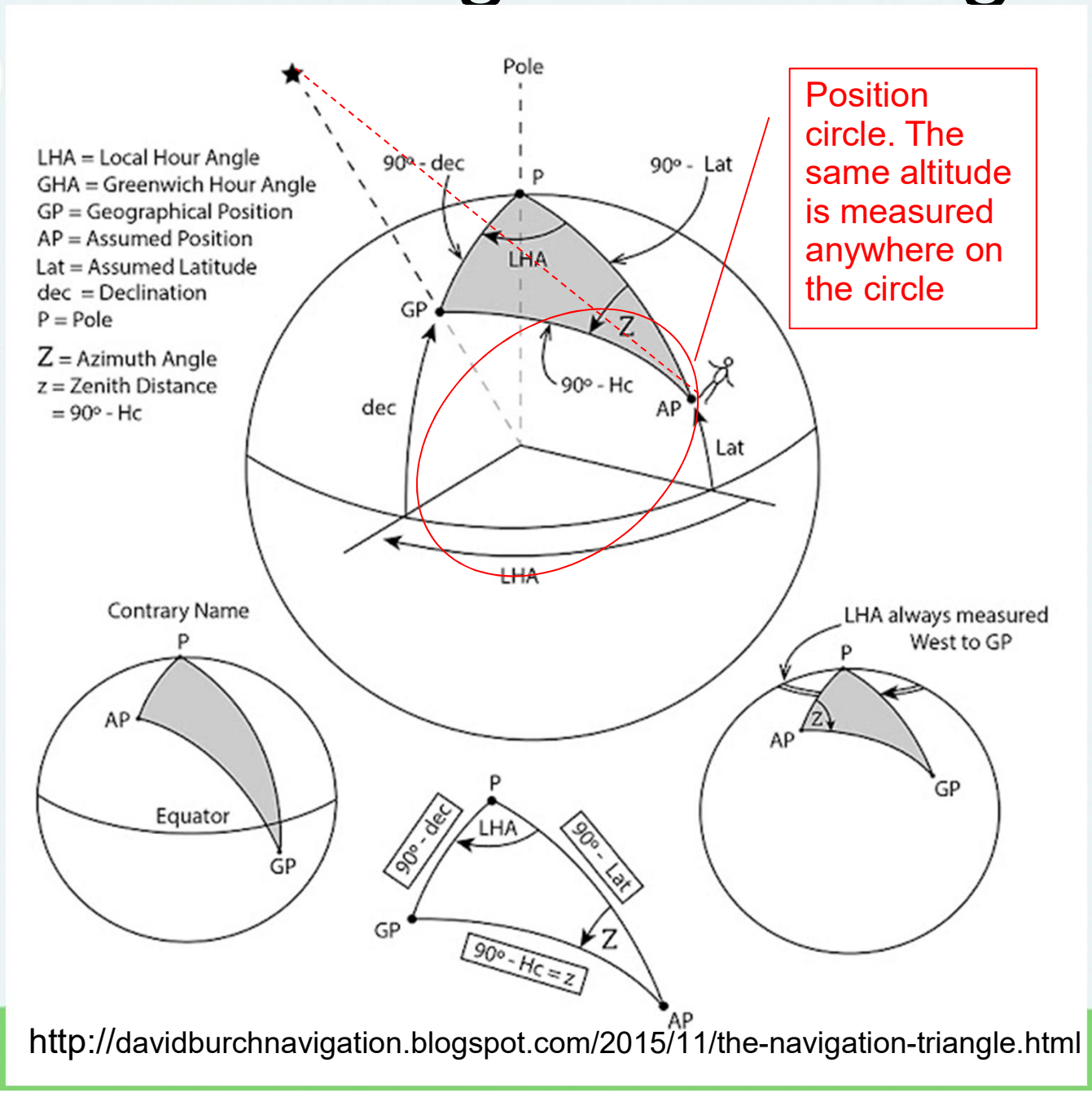


Fig. 1507. Fix from Two Stars.

The Navigation Triangle



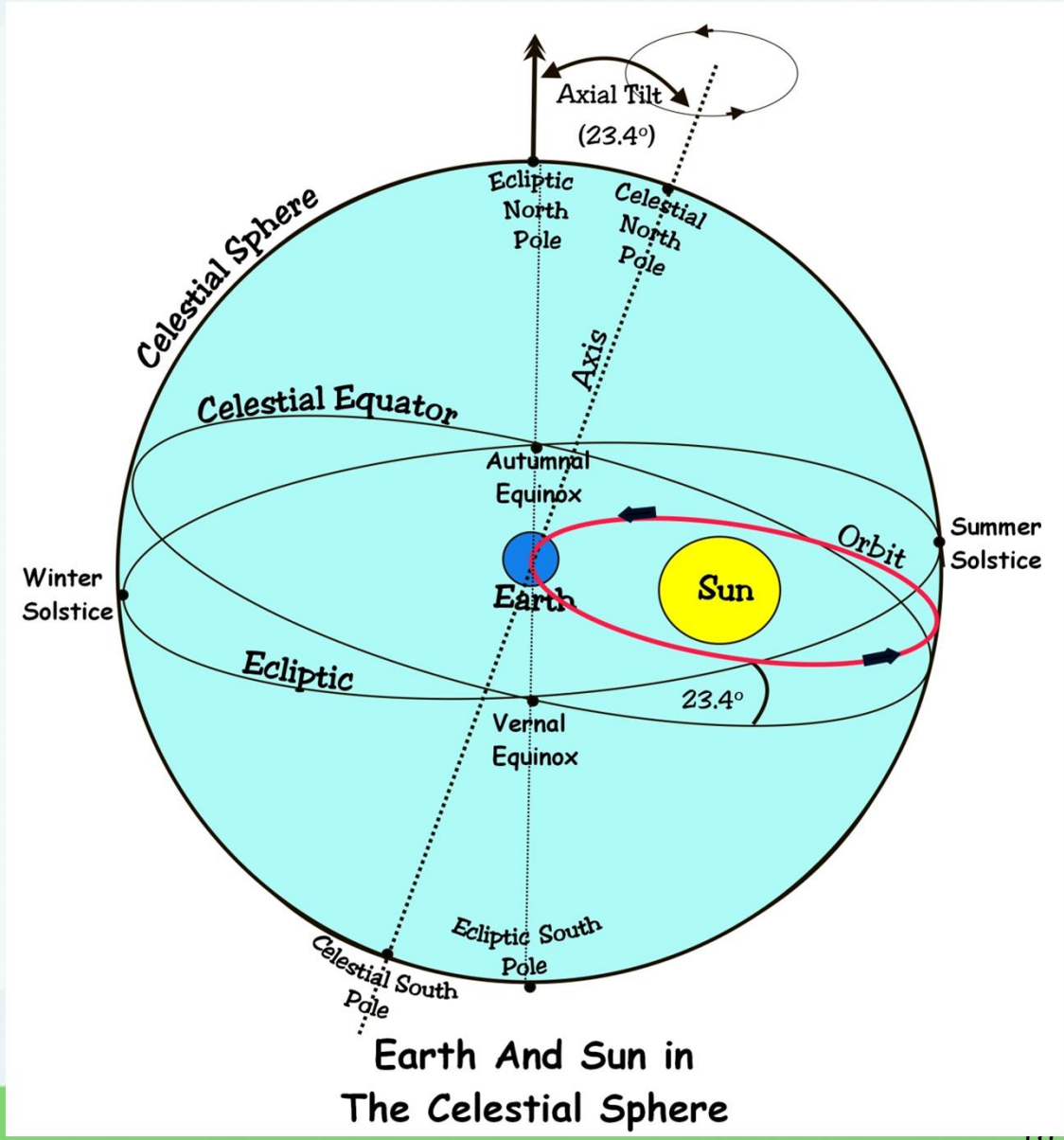
http://davidburchnavigation.blogspot.com/2015/11/the-navigation-triangle.html

Correction of Hc by Ho

- H**c** - The **computed** altitude of the body at the assumed position from a good guess.
- H**o** – The **observed**/measured altitude of the body. Corrections are typically applied to this value. (Height of eye(DIP), Index error, Refraction, Parallax)
- Z – The Azimuth or direction to the body at the assumed position. Around Noon, the peak altitude of the sun indicates True South (Z=180°)

The Earth and our Sun

- Notes on 2 Equators
  - Celestial North Pole is the North Pole
  - The Ecliptic North Pole would be the North Pole if the Earth wasn't tilted 23.4°
  - The Equators meet when the overhead sun crosses the Earth Equator



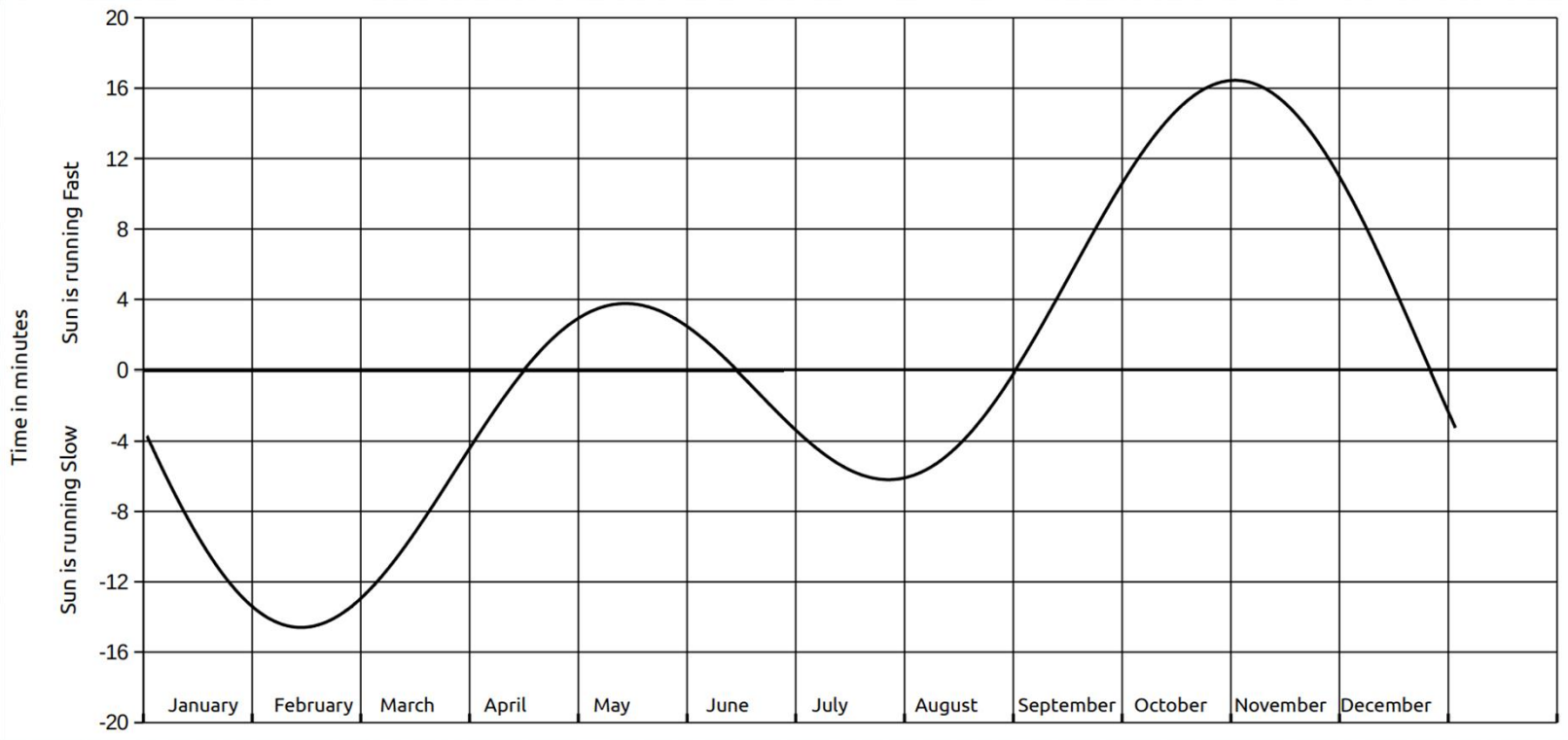
Times and Assumed Position (DR)

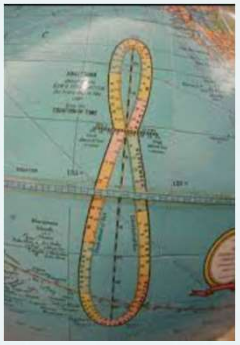
- Watch time and Sidereal time
  - Watch time is based on a 24 hour Day.
  - Sidereal Day.. A ground point move 15° + 2.5’ per hour. A **sidereal day** on Earth is approximately 86164.0905 seconds (23 h 56 min 4.0905 s or 23.9344696 h). The First Point or Aries moves a this rate
  - The Earth moves around the sun during a given day so the position of the sun is not in the same place 24 hours later.
- Dead Reckoning (DR)
  - Guessing an “assumed position” is okay because you usually have some idea where you are.
  - If you knew where you were yesterday and have some idea on how fast and in what direction(s) you went, computing a new position is called dead reckoning.
  - A celestial “fix” will attempt to improve that guess
  - Repeat.

The Equation of Time(2022)

Time difference(minutes) between Sun time (Sun Dial) and Watch Time

- NOTE: this can be as much as 16 minutes!





Analema on a globe

What is my sun GHA?

My QTH in Portsmouth is at Longitude **71°** *44' 47"* West of Greenwich England. Not Greenwich RI

This angle is **4h44m***35.465s* of time from GMT and almost the 5 hours we use for EST. New York is 5 hours(75°W)

- FYI My QTH Latitude is N 41° 30' 04". Independent of time

Conversion of Arc to Time

0° - 59°			60° - 119°			120° - 179°			180° - 239°			240° - 299°			300° - 360°			0' - 59'		0" - 59"	
°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	°	h	m	'	m s	"	s
0	0	00	60	4	00	120	8	00	180	12	00	240	16	00	300	20	00	0	0 00	0	0.00
1	0	04	61	4	04	121	8	04	181	12	04	241	16	04	301	20	04	1	0 04	1	0.07
2	0	08	62	4	08	122	8	08	182	12	08	242	16	08	302	20	08	2	0 08	2	0.13
3	0	12	63	4	12	123	8	12	183	12	12	243	16	12	303	20	12	3	0 12	3	0.20
4	0	16	64	4	16	124	8	16	184	12	16	244	16	16	304	20	16	4	0 16	4	0.27
5	0	20	65	4	20	125	8	20	185	12	20	245	16	20	305	20	20	5	0 20	5	0.33
6	0	24	66	4	24	126	8	24	186	12	24	246	16	24	306	20	24	6	0 24	6	0.40
7	0	28	67	4	28	127	8	28	187	12	28	247	16	28	307	20	28	7	0 28	7	0.47
8	0	32	68	4	32	128	8	32	188	12	32	248	16	32	308	20	32	8	0 32	8	0.53
9	0	36	69	4	36	129	8	36	189	12	36	249	16	36	309	20	36	9	0 36	9	0.60
10	0	40	70	4	40	130	8	40	190	12	40	250	16	40	310	20	40	10	0 40	10	0.67
11	0	44	71	4	44	131	8	44	191	12	44	251	16	44	311	20	44	11	0 44	11	0.73
12	0	48	72	4	48	132	8	48	192	12	48	252	16	48	312	20	48	12	0 48	12	0.80
13	0	52	73	4	52	133	8	52	193	12	52	253	16	52	313	20	52	13	0 52	13	0.87

Where is the Sun?

- Find its GHA in the tables of the Nautical Almanac based on the calendar day and the hour. The Declination is in the table next to it.
- Example: March 14,2022 at 1 pm (1300) and 7 pm (1900) Eastern Standard Time. Note that we are in Daylight time from this weekend so this is 8pm tonight
- First adjust to GMT (Universal Time)
  - Add 5 hours to EST or 4 hours to EDST so
    - 13:00EST + 5:00 = 18h
    - 19:00EST + 5:00 = 0h on the 15th

Where is the Sun - cont'd

DUT1 = UT1-UTC = -0.0692 sec ΔT = TT-UT1 = +69.2532 sec

h	Sun		Moon				
Mon	GHA	Dec	GHA	ν	Dec	d	HP
0	177°40.1	S02°37.6	45°53.2	10.6'	N24°13.3	-6.1'	55.0'
1	192°40.3	36.6	60°22.9	10.7'	24°07.1	-6.2'	55.0'
2	207°40.4	35.6	74°52.6	10.7'	24°00.8	-6.4'	55.0'
3	222°40.6	·· 34.6	89°22.3	10.7'	23°54.4	-6.5'	55.0'
4	237°40.8	33.7	103°52.0	10.8'	23°47.8	-6.6'	55.1'
5	252°40.9	32.7	118°21.8	10.8'	23°41.2	-6.7'	55.1'
6	267°41.1	S02°31.7	132°51.6	10.8'	N23°34.4	-6.8'	55.1'
7	282°41.3	30.7	147°21.4	10.8'	23°27.5	-7.0'	55.1'
8	297°41.5	29.7	161°51.3	10.9'	23°20.5	-7.1'	55.1'
9	312°41.6	·· 28.7	176°21.2	10.9'	23°13.4	-7.2'	55.2'
10	327°41.8	27.7	190°51.1	10.9'	23°06.1	-7.3'	55.2'
11	342°42.0	26.8	205°21.1	11.0'	22°58.7	-7.4'	55.2'
12	357°42.2	S02°25.8	219°51.1	11.0'	N22°51.3	-7.5'	55.2'
13	12°42.3	24.8	234°21.1	11.0'	22°43.7	-7.7'	55.3'
14	27°42.5	23.8	248°51.1	11.1'	22°35.9	-7.8'	55.3'
15	42°42.7	·· 22.8	263°21.2	11.1'	22°28.1	-7.9'	55.3'
16	57°42.8	21.8	277°51.3	11.1'	22°20.2	-8.0'	55.3'
17	72°43.0	20.8	292°21.5	11.2'	22°12.1	-8.1'	55.3'
18	87°43.2	S02°19.8	306°51.6	11.2'	N22°03.9	-8.2'	55.4'
19	102°43.4	18.9	321°21.9	11.2'	21°55.6	-8.3'	55.4'
20	117°43.5	17.9	335°52.1	11.3'	21°47.2	-8.5'	55.4'
21	132°43.7	·· 16.9	350°22.4	11.3'	21°38.7	-8.6'	55.4'
22	147°43.9	15.9	4°52.7	11.3'	21°30.1	-8.7'	55.5'
23	162°44.1	14.9	19°23.0	11.4'	21°21.3	-8.8'	55.5'
	SD.=16.1	d=1.0		S.D.=15.1			

Tue	GHA	Dec	GHA	ν	Dec	d	HP
0	177°44.2	S02°13.9	33°53.4	11.4'	N21°12.5	-8.9'	55.5'
1	192°44.4	12.9	48°23.8	11.4'	21°03.5	-9.0'	55.5'
2	207°44.6	12.0	62°54.3	11.5'	20°54.5	-9.1'	55.6'
3	222°44.8	·· 11.0	77°24.8	11.5'	20°45.3	-9.2'	55.6'
4	237°44.9	10.0	91°55.3	11.5'	20°36.0	-9.3'	55.6'
5	252°45.1	09.0	106°25.9	11.6'	20°26.6	-9.4'	55.6'
6	267°45.3	S02°08.0	120°56.4	11.6'	N20°17.1	-9.5'	55.7'
7	282°45.5	07.0	135°27.1	11.6'	20°07.5	-9.7'	55.7'

March 14, 1 pm EST
18h GHA 87° 43.2'
DEC S 02° 19.8'

March 15, midnight
0h GHA 177° 44.2'
DEC S 02° 13.9'

Note: Sun is about 2 degrees below (S) but nearing the equator.

It will cross on March 20th at the First Point of Aries.

But I measured 38° at 11:40:30AM

The almanac is <u>on the hour</u> so we should make a correction to GHA for the actual time of a measurement

40 min+30 sec is 40.5/60 hours or 0.675 hours

18	87°43.2	S02°19.8
19	102°43.4	18.9

This correction is called interpolation.

The 3 steps are:

Take the next GHA for the next hour and subtract the hour before your measurement ,, (102°43.4’ – 87°43.2’) = 15° 0.2’

Multiply by 0.675 based on the extra time of 40m30s

= 10.12725° or 10° 8’

Add this to the GHA of the earlier hour.

- 87°43.2’ + 10° 8’ = 97° 51.2’

Not obvious! Just wanted to do an example.

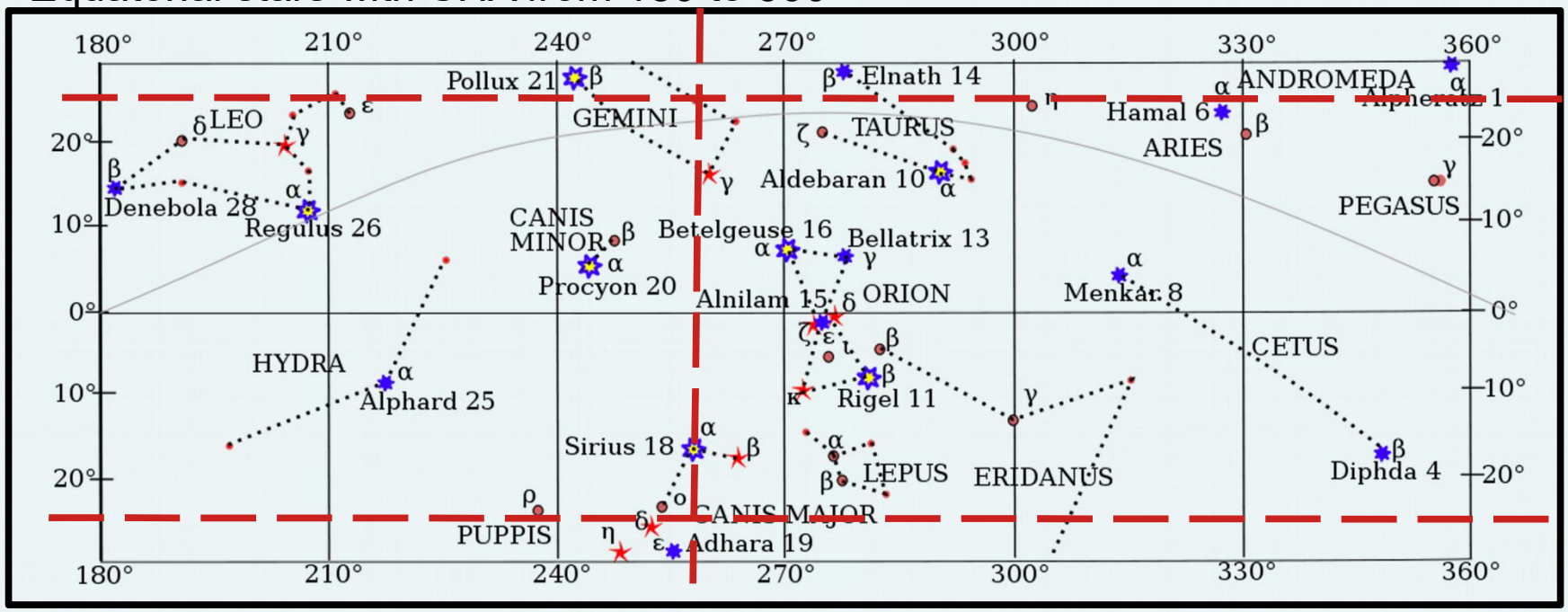
Star Position: SHA and Declination

- **First Point of Aries.** This is the reference GHA for fixing the positions of all celestial bodies in the celestial sphere.
- The Almanac gives the GHA of Aries for each hour of each day but if you know it at any point in time, the GHA of Aries moves 15 degrees + 2.5 minutes each hour. This is also 902.46923 minutes of arc for each hour of time.
- On March 20, 2022, the GHA of Aries at UT = 12:00 (Noon Greenwich Mean Time) is 358.000 degrees)
- **Sidereal Hour Angle** (SHA) is defined as the angle between the meridian of the First Point of Aries and the meridian of the celestial body.
- SHA is measured westwards from Aries (Right Ascension is measured eastward)

Equatorial stars- Eastern Hemisphere

The equatorial region of the celestial sphere's eastern hemisphere includes 17 navigational stars from Alpheratz in the constellation Andromeda to Denebola in Leo. It also includes stars from the constellations Cetus, Aries, Taurus, Orion, Canis Major and Minor, Gemini, and Hydra. **Of particular note among these stars are "the dog star" Sirius, the brightest star in the sky, and four stars of the easily identified constellation Orion.**

Equatorial stars with SHA from 180 to 360



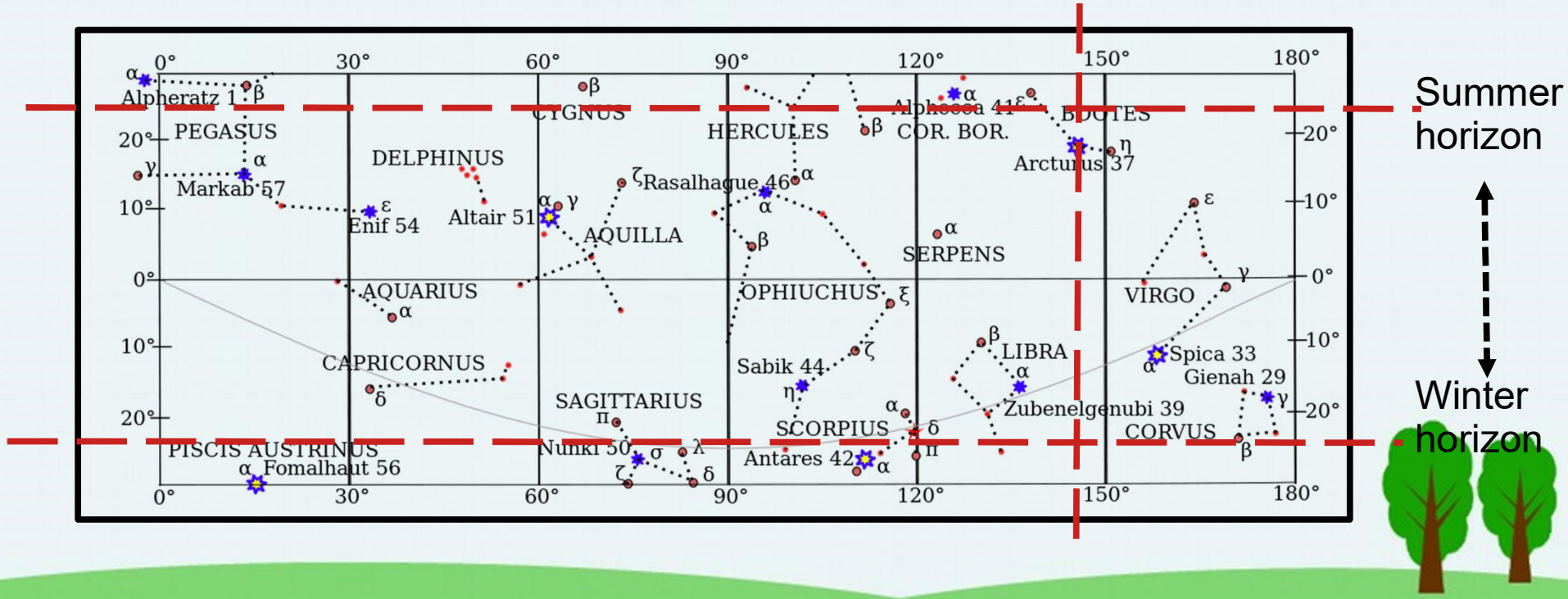
Summer horizon

Winter horizon

Equatorial stars - Western Hemsiphere

The equatorial region of the celestial sphere's western hemisphere includes 13 navigational stars from Gienah in the constellation Corvus to Markab in Pegasus. It also includes stars from the constellations Virgo, Bootes, Libra, Corona Borealis, Scorpio, Ophiuchus, Sagittarius, and Aquila. **The variable star Arcturus is the brightest star in this group.**

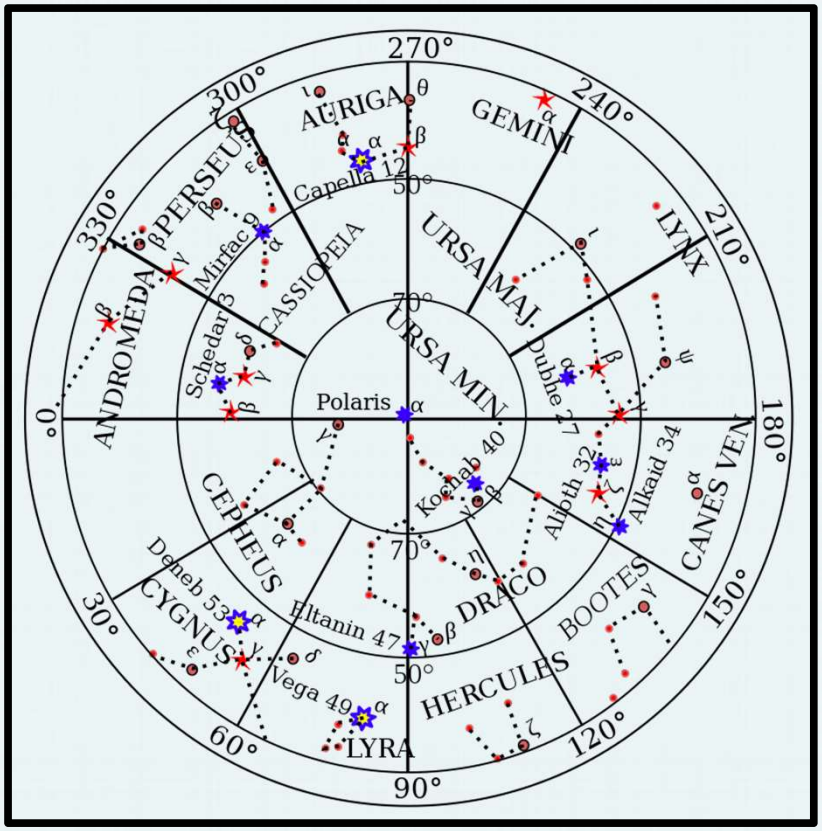
Equatorial stars with SHA from 0 to 180



Northern navigational stars

The 11 northern stars are those with a declination between 30° north and 90° north. They are listed in order of decreasing sidereal hour angle, or from the vernal equinox westward across the sky. Starting with Schedar in the constellation Cassiopeia, the list includes stars from the constellations Auriga, the Great and Little Bears, Draco, Lyra and Cygnus. The two brightest northern stars are Vega and Capella.

In the star chart to the right, declination is shown by the radial coordinate, starting at 90° north in the center and decreasing to 30° north at the outer edge. Sidereal hour angle is shown as the angular coordinate, starting at 0° at the left of the chart, and increasing counter-clockwise.



Sirius at 1 pm and 7pm EST

March 14, 15, 16 UT (

Mon	Aries GHA	Ver GHA
0	171°35.6	222°54.1
1	186°38.1	237°54.2
2	201°40.5	252°54.2
3	216°43.0	267°54.2
4	231°45.5	282°54.2
5	246°47.9	297°54.3
6	261°50.4	312°54.3
7	276°52.8	327°54.3
8	291°55.3	342°54.3
9	306°57.8	357°54.3
10	322°00.2	12°54.3
11	337°02.7	27°54.4
12	352°05.2	42°54.4
13	7°07.6	57°54.4
14	22°10.1	72°54.4
15	37°12.6	87°54.4
16	52°15.0	102°54.4
17	67°17.5	117°54.4
18	82°19.9	132°54.4
19	97°22.4	147°54.4
20	112°24.9	162°54.5
21	127°27.3	177°54.5
22	142°29.8	192°54.5
23	157°32.3	207°54.5
Mer.pass.:	12:32	v0.0 d0.3

T	GHA	GHA
0	172°34.7	222°54.5
1	187°37.2	237°54.5
2		252°54.5
3	217°42.1	267°54.5
4	232°44.6	282°54.5
5	247°47.1	297°54.5

First find the GHA of the First Point of Aries.

March 14, 1 pm EST
18h GHA 82° 19.9’

March 15, midnight
0h GHA 172° 34.7’

Then get the SHA of Sirius:
258° 28.2’

Then add the GHA of Aries
..Next Slide

	Dec	GHA	Dec	GHA	Dec	GHA	Dec
	S15°52.0	223°10.7	S19°47.4	183°09.6	S06°02.3	208°39.0	S15°35.8
	51.7	238°11.2	47.0	198°11.5	02.1	223°41.2	35.8
	51.3	253°11.8	46.5	213°13.4	01.8	238°43.4	35.7
	50.9	268°12.3	46.1	228°15.3	01.6	253°45.6	35.6
	50.7	283°12.8	45.7	243°17.2	01.4	268°47.8	35.5
	50.4	298°13.4	45.3	258°19.1	01.2	283°50.0	35.4
	S15°50.1	313°13.9	S19°44.8	273°21.0	S06°00.9	298°52.2	S15°35.4
	49.7	328°14.4	44.4	288°23.0	00.7	313°54.4	35.3
	49.4	343°14.9	43.9	303°24.9	00.5	328°56.6	35.2
	49.1	358°15.5	43.5	318°26.8	00.2	343°58.8	35.1
	48.8	13°16.0	43.1	333°28.7	06°00.0	359°01.0	35.0
	48.5	28°16.5	42.6	348°30.6	05°59.8	14°03.2	35.0
	S15°48.1	43°17.0	S19°42.2	3°32.5	05°59.5	29°05.4	S15°34.9
	47.8	58°17.5	41.8	18°34.4	59.3	44°07.6	34.8
	47.5	73°18.1	41.3	33°36.3	59.1	59°09.8	34.7
	47.1	88°18.6	40.9	48°38.2	58.8	74°12.0	34.6
	46.8	103°19.2	40.4	63°40.1	58.6	89°14.2	34.6
	46.5	118°19.7	40.0	78°42.0	58.3	104°16.4	34.5
	S15°46.2	133°20.2	S19°39.5	93°43.9	58.1	119°18.6	S15°34.4
	45.8	148°20.8	39.1	108°45.8	57.9	134°20.8	34.3
	45.5	163°21.3	38.7	123°47.7	57.7	149°23.0	34.2
	45.2	178°21.8	38.2	138°49.6	57.4	164°25.2	34.2
	44.8	193°22.3	37.8	153°51.5	57.2	179°27.4	34.1
	44.5	208°22.9	37.3	168°53.4	57.0	194°29.6	34.0

Canopus	263°53.3	-52°42.7
Sirius	258°28.2	-16°45.0
Adhara	255°07.6	-29°00.4
Procyon	244°53.1	5°10.0

Stars

	SHA	Dec
Alpheratz	357°37.5	29°12.6
Ankaa	353°09.9	-42°11.4
Schedar	349°34.2	56°39.5
Diphda	348°49.9	-17°52.1
Achernar	335°22.4	-57°07.7
Hamal	327°54.1	23°33.9
Polaris	315°25.3	89°21.7
Acamar	315°13.8	-40°13.3
Menkar	314°08.8	4°10.4
Mirfak	308°31.8	49°56.4
Aldebaran	290°42.4	16°33.1
Rigel	281°06.1	-8°10.8
Capella	280°25.4	46°01.3
Bellatrix	278°25.4	6°22.1
Elnath	278°04.8	28°37.6
Alnilam	275°40.1	-1°11.4
Betelgeuse	271°02.1	7°24.6
Canopus	263°53.3	-52°42.7
Sirius	258°28.2	-16°45.0
Adhara	255°07.6	-29°00.4
Procyon	244°53.1	5°10.0
Pollux	243°26.0	27°58.4
Avior	234°15.2	-59°35.0
Suhail	222°47.7	-43°31.5
Miaplacidus	221°38.0	-69°48.6
Alphard	217°49.8	-8°45.4
Regulus	207°36.6	11°51.5
Dubhe	193°43.2	61°37.9
Denebola	182°27.0	14°26.8
Gienah	175°45.6	-17°39.9
Acrux	173°02.0	-63°13.2
Gacrux	171°53.6	-57°14.2
Alioth	166°14.5	55°50.3
Spica	158°24.5	-11°16.6
Alkaid	152°53.5	49°12.0
Hadar	148°38.8	-60°28.6
Menkent	148°00.0	-36°28.7
Arcturus	145°49.8	19°03.9
Rigil Kent.	139°43.0	-60°55.4
Kochab	137°19.0	74°03.6
Zuben'ubi	136°58.4	-16°08.0
Alphecca	126°05.5	26°38.2
Antares	112°18.6	-26°28.8
Atria	107°14.8	-69°03.7
Sabik	102°05.4	-15°45.2
Shaula	96°13.5	-37°07.1
Rasalhague	96°00.7	12°32.4
Eltanin	90°43.3	51°28.8
Kaus Aust.	83°35.7	-34°22.4
Vega	80°34.9	38°47.9
Nunki	75°50.8	-26°16.1
Altair	62°02.4	8°55.4
Peacock	53°09.8	-56°39.7
Deneb	49°27.7	45°21.3
Enif	33°41.4	9°58.4
Al Na'ir	27°36.3	-46°51.3
Fomalhaut	15°17.4	-29°30.5
Scheat	13°47.8	28°12.0
Markab	13°32.5	15°19.3

Are you still awake?

- Last step is to add the SHA of the specific star to the reference for all of them.
- GHA Aries + SHA of Star = GHA of Star

First Point of Aries + SHA of Sirius = GHA of Sirius

March 14, 1 pm EST
18h GHA 82° 19.9’ + 258° 28.2’ = 340° 48.1’

March 15, midnight
0h GHA 172° 34.7’ + 258° 28.2’ = 420° 62.9’
Complication...
420° is more than 360° (one revolution) so this is really the same as 60 degrees.
And 62.9 minutes is also 1 degree + 2.9 min
The result at midnight is then 61° 02.9’

Useful links

- https://www.nauticalalmanac.it/en/navigation-astronomy/celestial-navigation.html
- https://www.nauticalalmanac.it/en/navigation-astronomy/celestial-navigation.html
- Apollo sextant
  - https://astronomy.com/news/2018/06/the-story-of-the-apollo-sextant
- ISS
  - https://www.boatus.com/expert-advice/expert-advice-archive/2019/june/sextant-in-space
- Deep Space
  - https://technology.nasa.gov/patent/NPO-TOPS-26
- Astronomy for the visually impaired
  - https://wonderdome.co.uk/astronomy-visually-impaired/