# Star Sights for Celestial Navigation

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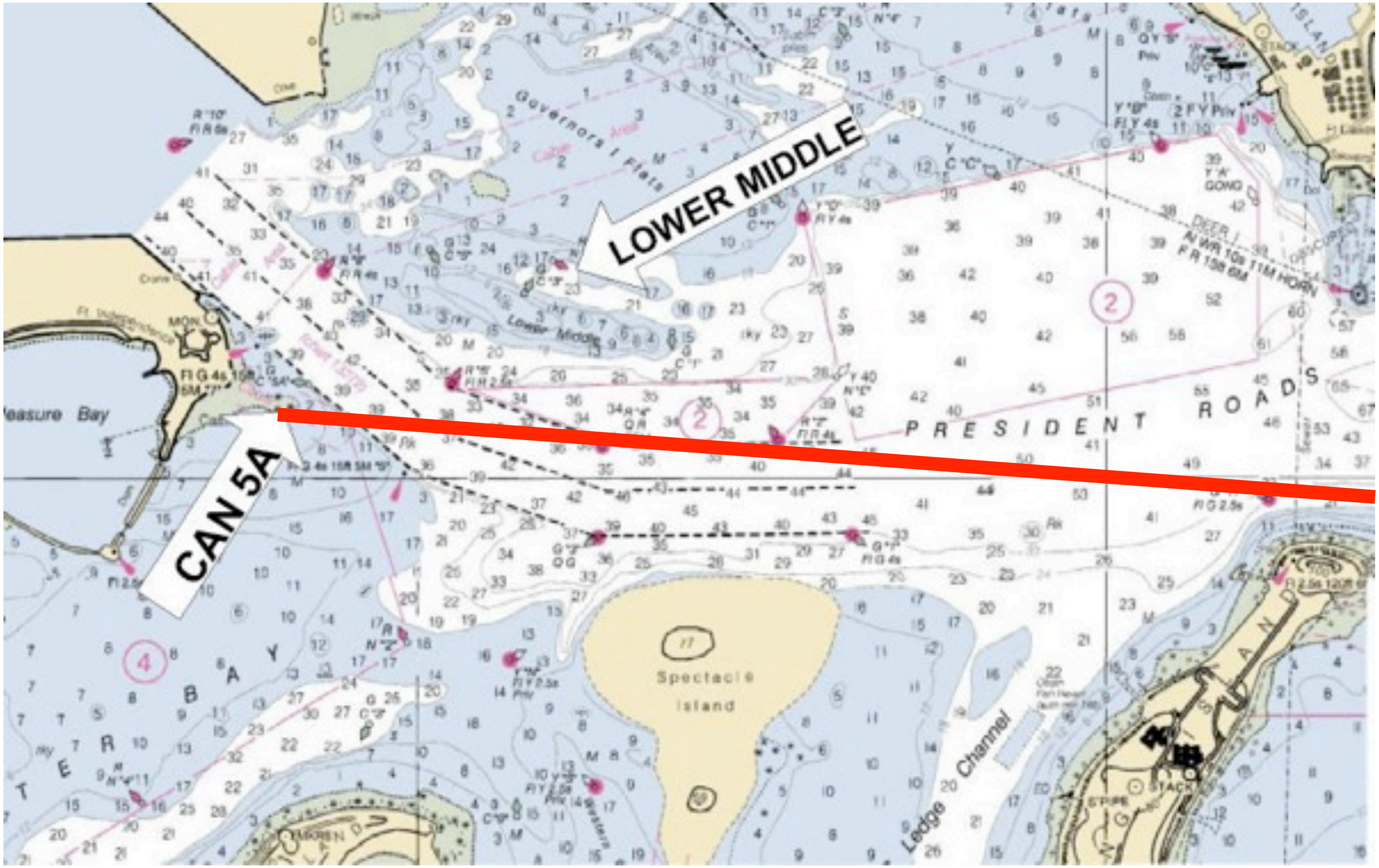
MIT Bluewater Sailing School 2015

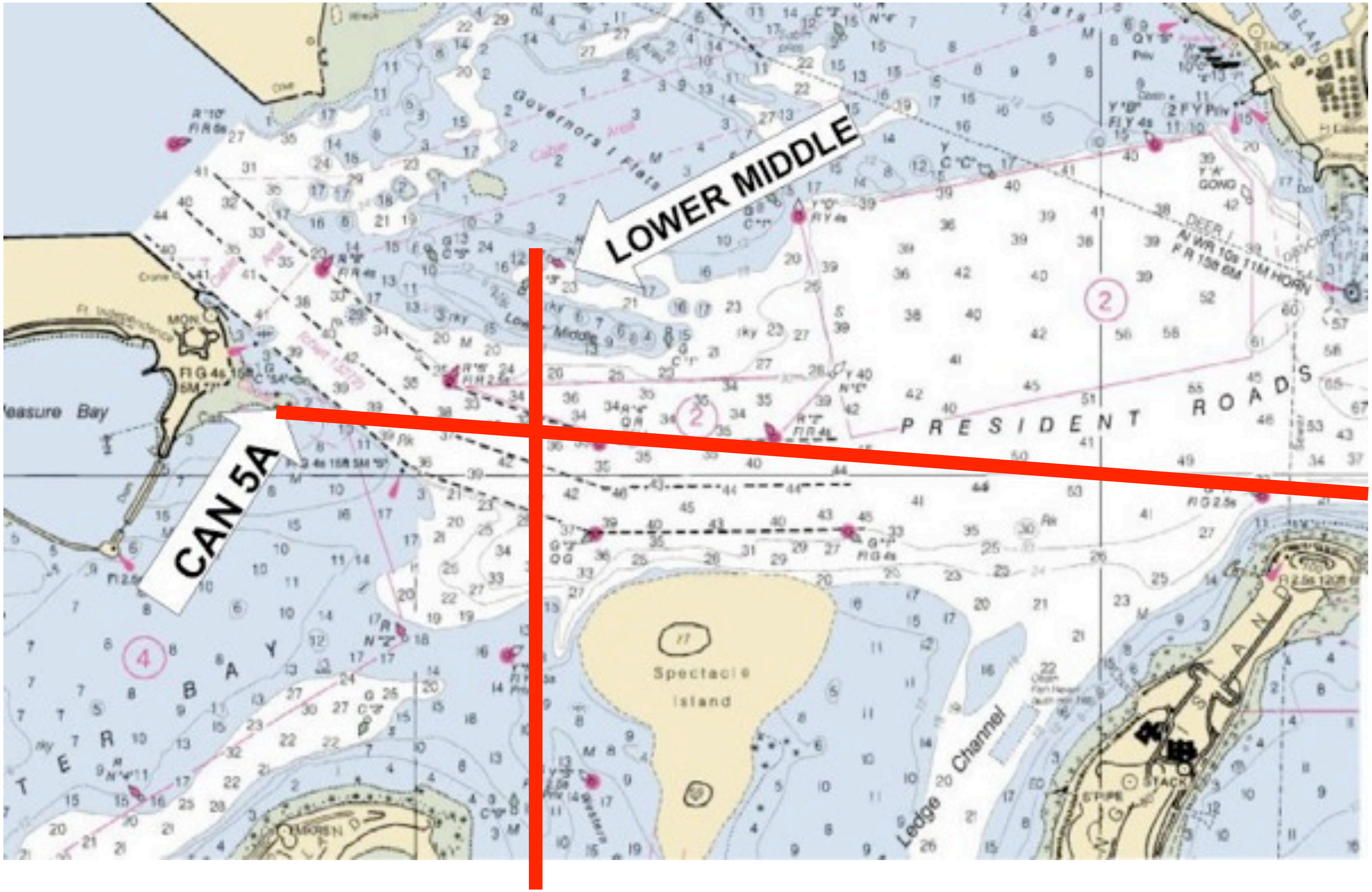
# Tools and Resources

- Sextant
- Clock
- The Nautical Almanac
- Sight Reduction Tables (H.O. 229)
  - Available here: http://msi.nga.mil/NGAPortal/MSI.portal
    - Select "Publications" on the left
    - Pick from the Dropdown Menu

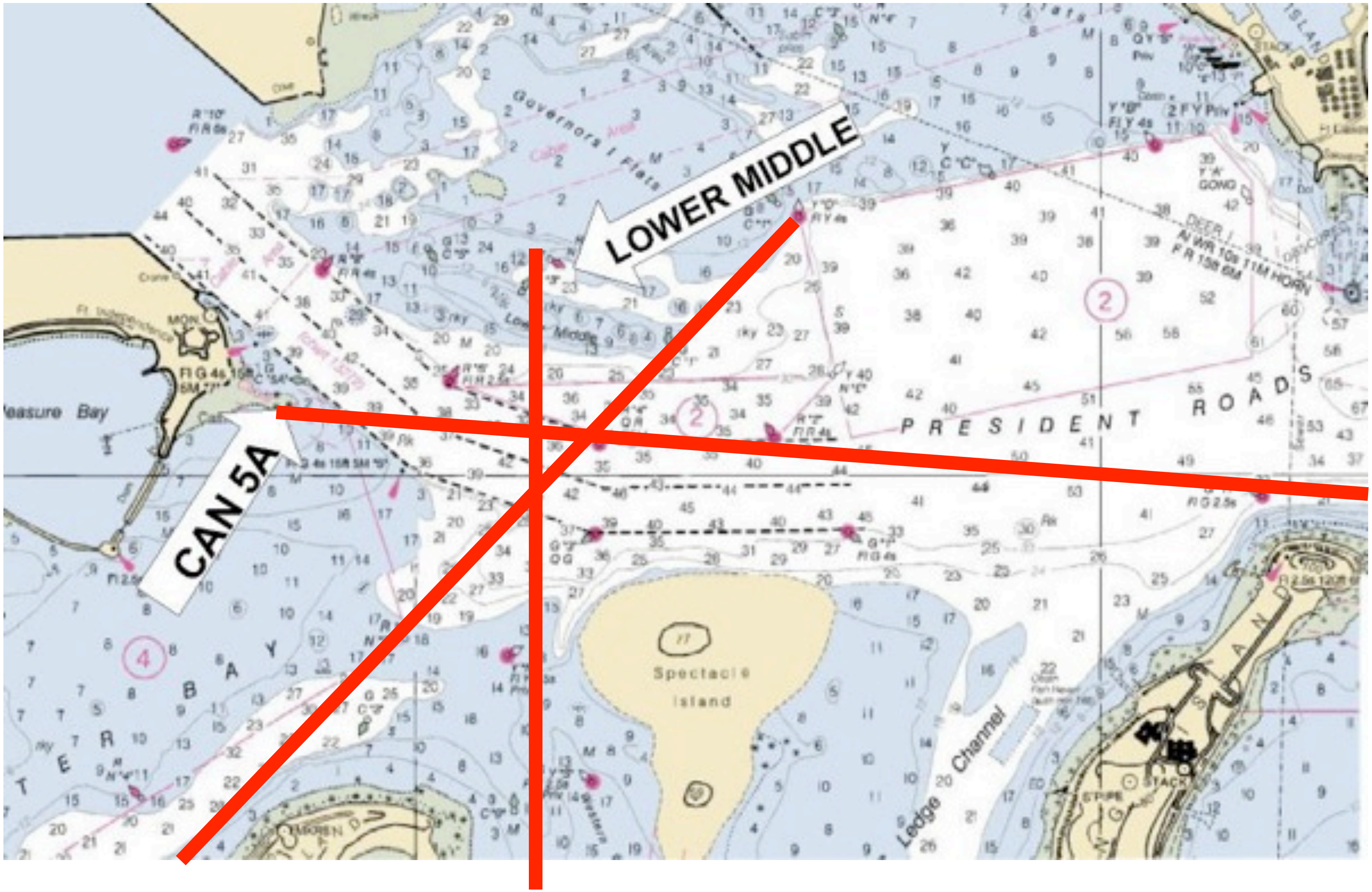
# Line of Position, LOP



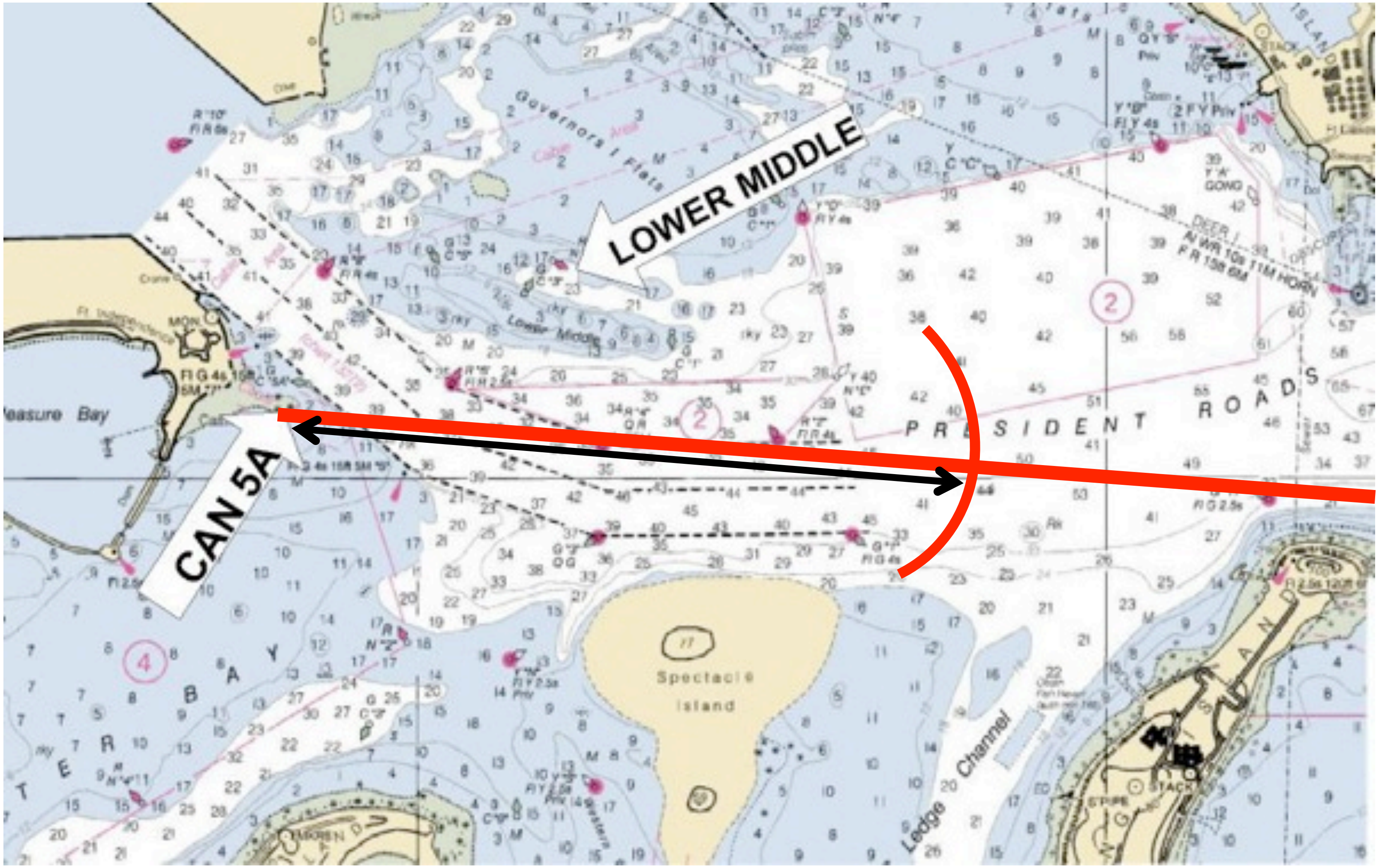
# Fix From Bearings



# 3rd LOP gives error estimate



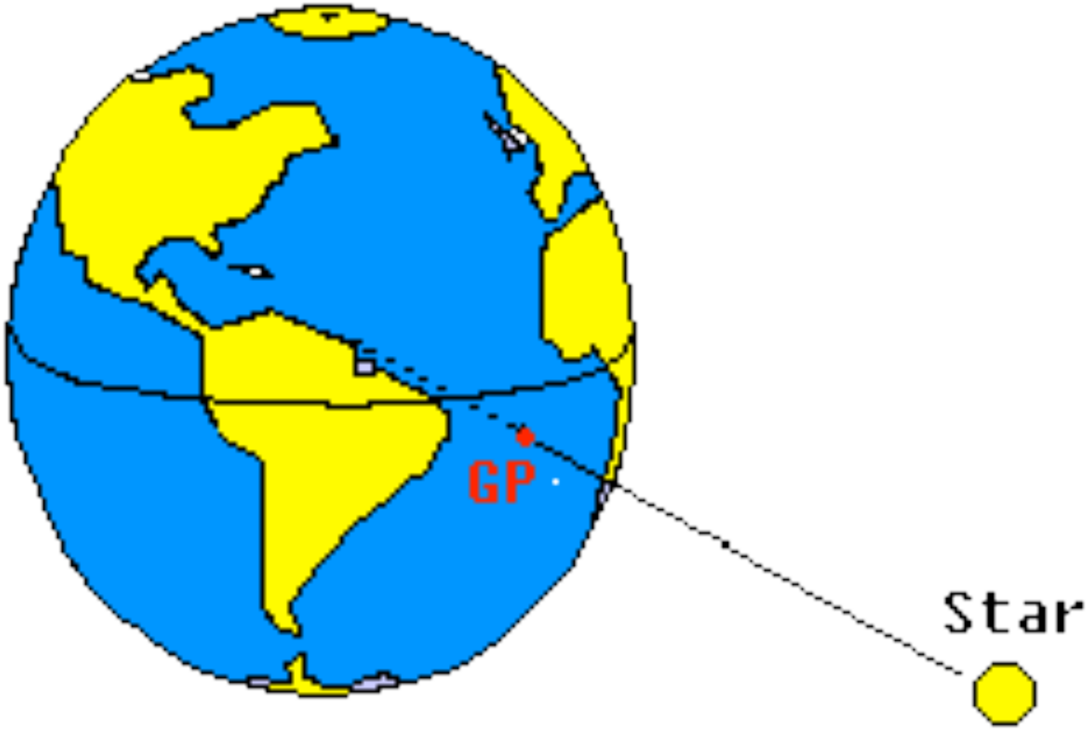
# Fix from Bearing, Range



# Why does a "Fix Work"?

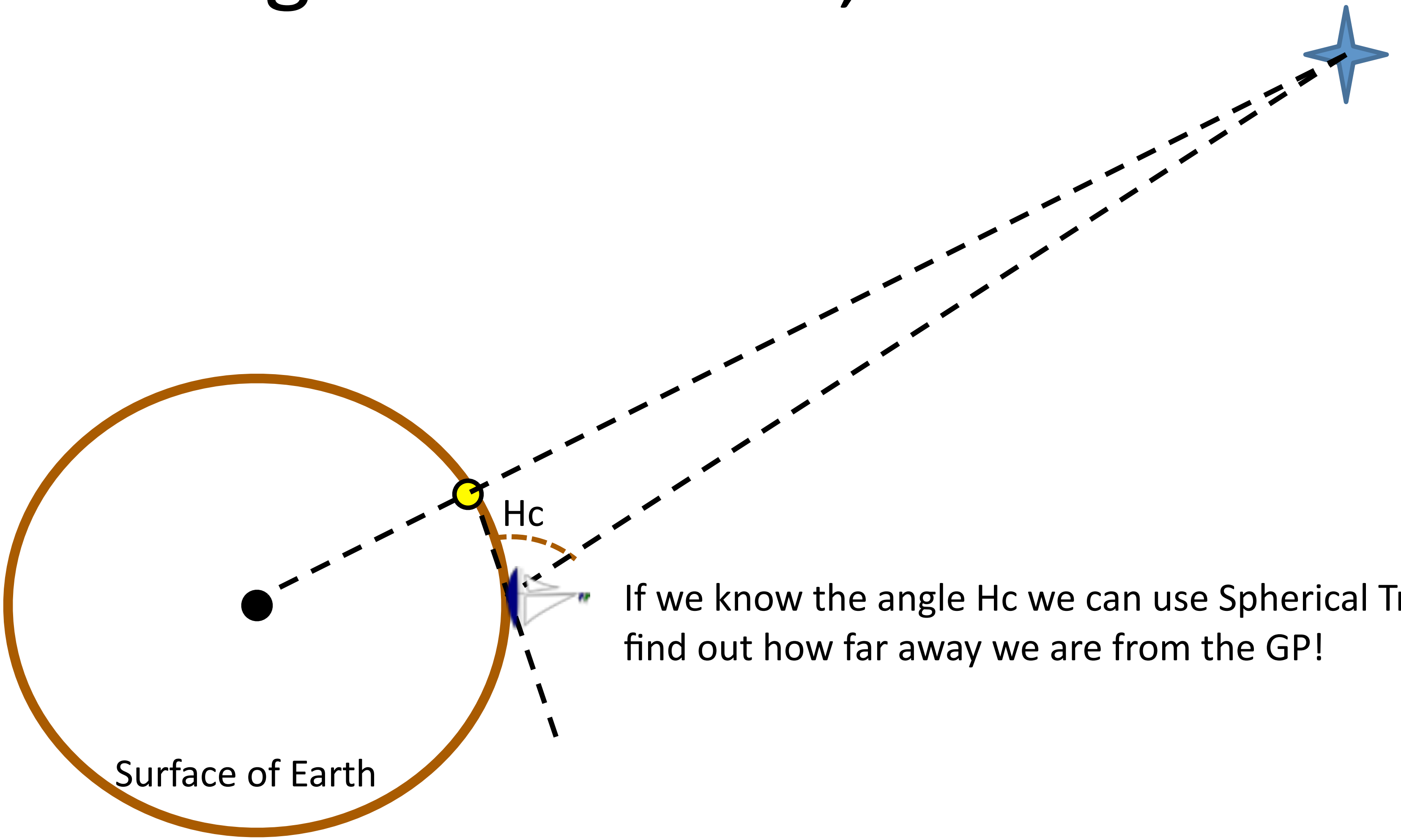
- We know the precise locations of the sight buoys
- We can Measure the relative position
  - Bearings from a compass
  - Ranges from a radar

# Geographic Position, GP



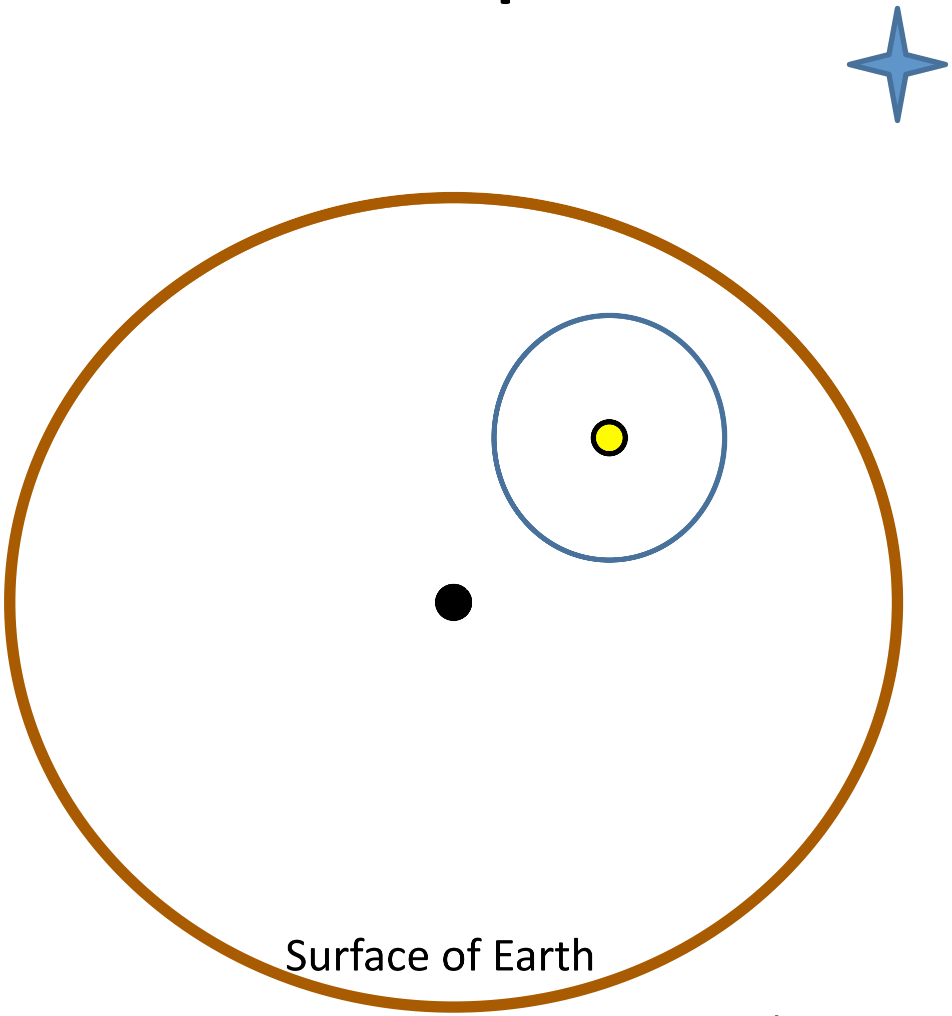

Draw a line from the Center of the Earth to the Celestial Body
The intersection with the surface of the earth is the GP of the Celestial Body
GP changes with time (but not where you are looking from!)
The Nautical Almanac has the GP of the navigable celestial bodies.

# Height Calculated, Hc




If we know the angle Hc we can use Spherical Trig to find out how far away we are from the GP!

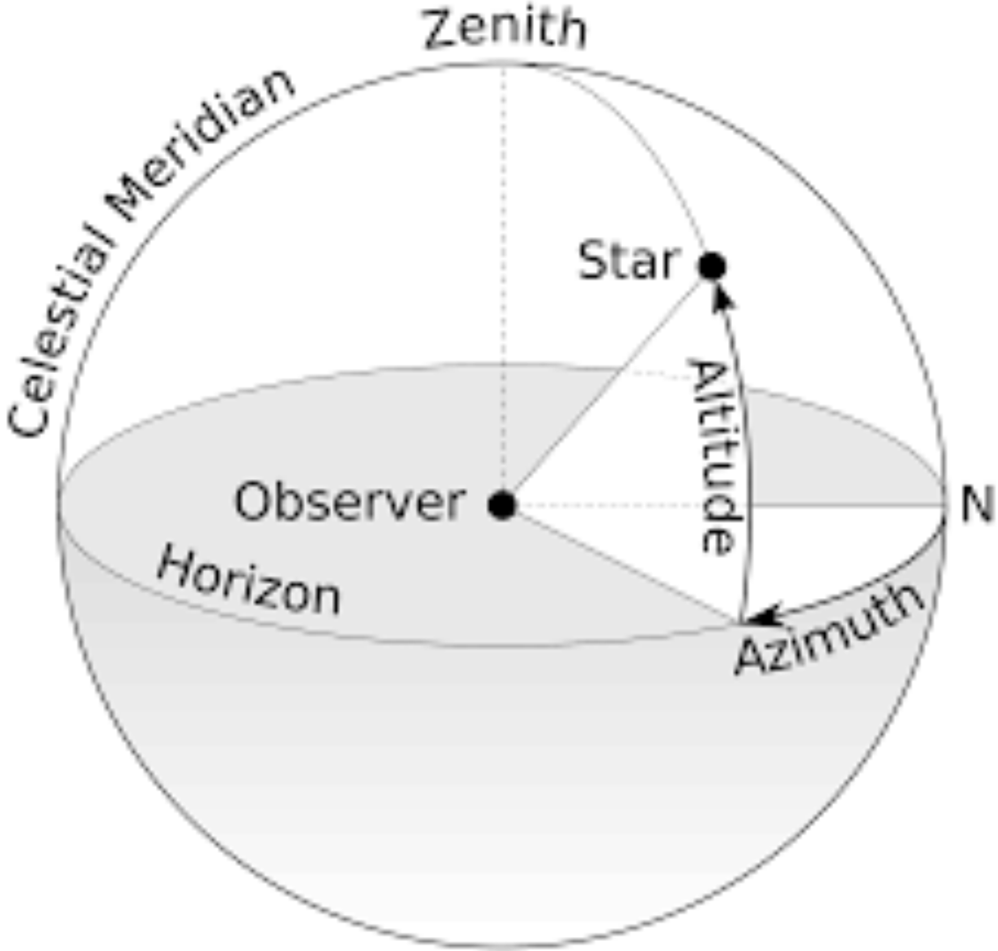
# Circle of Equal Altitude



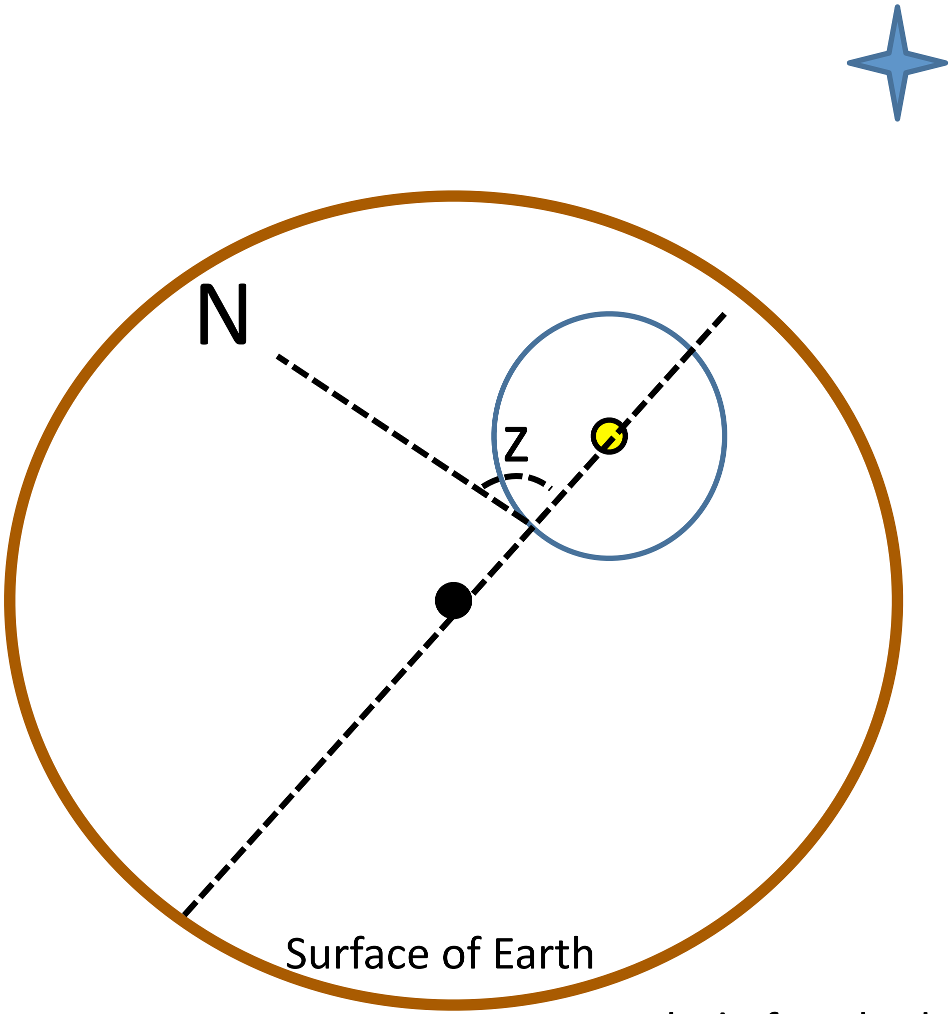

Hc is the same everywhere on the Circle!

Constant distance from GP

# Azimuth, Z

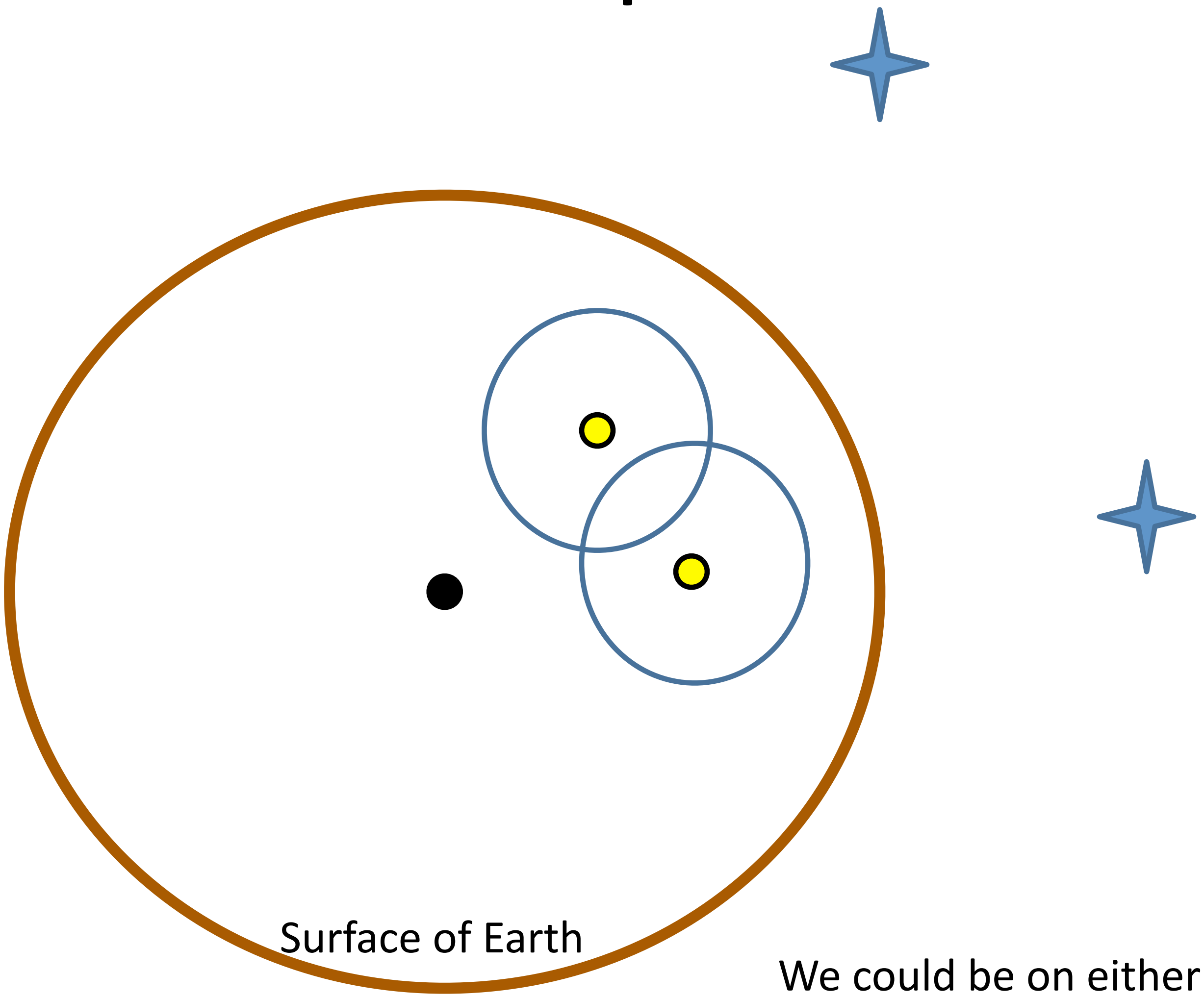

Zenith
Celestial Meridian
Star
Altitude
Observer
N
Horizon
Azimuth

# Azimuth, Z



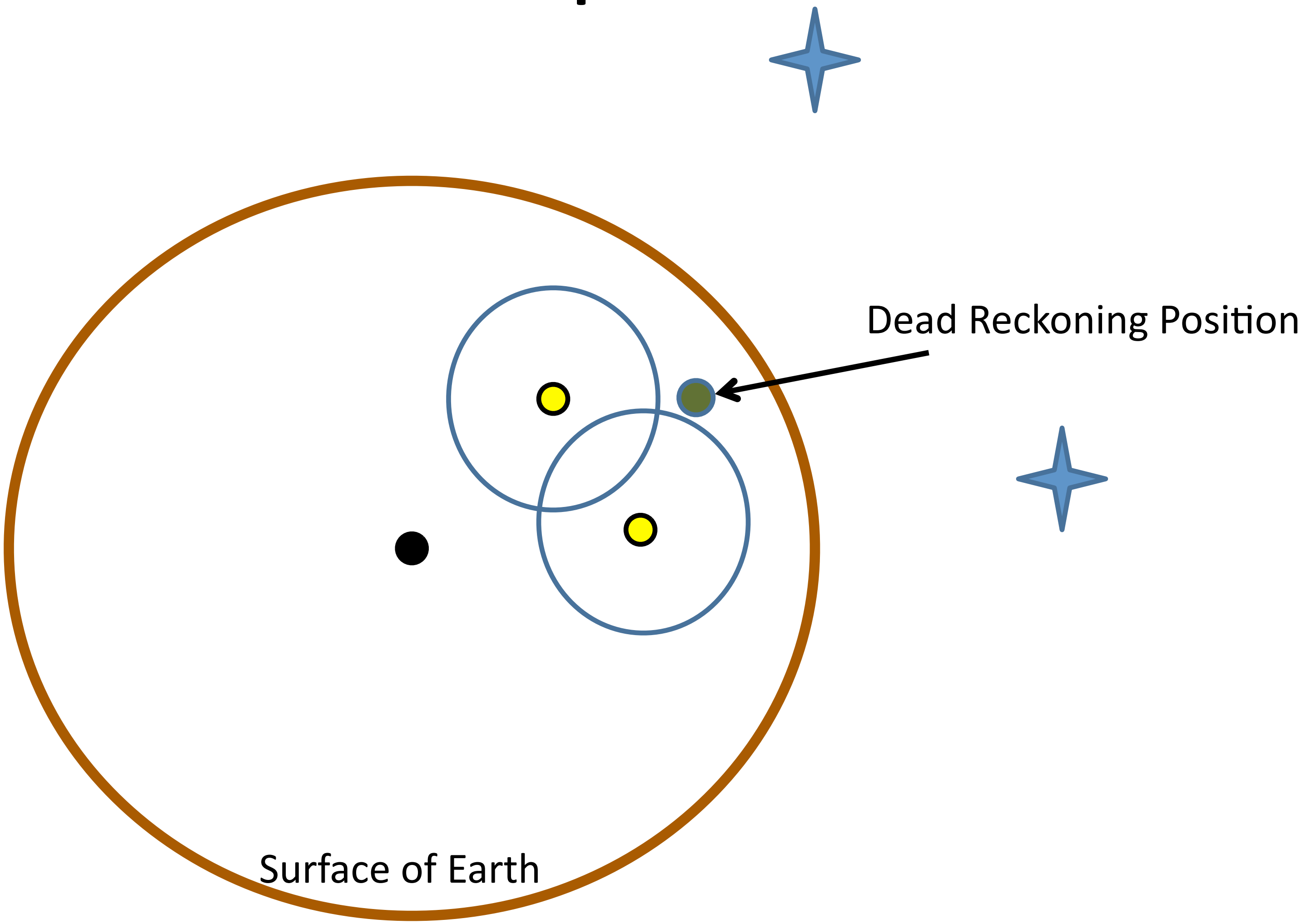

Aha! If we had the Azimuth and the Hc
We could figure out where we are on
the Circle of Equal Altitude

# Two Circles of Equal Altitude

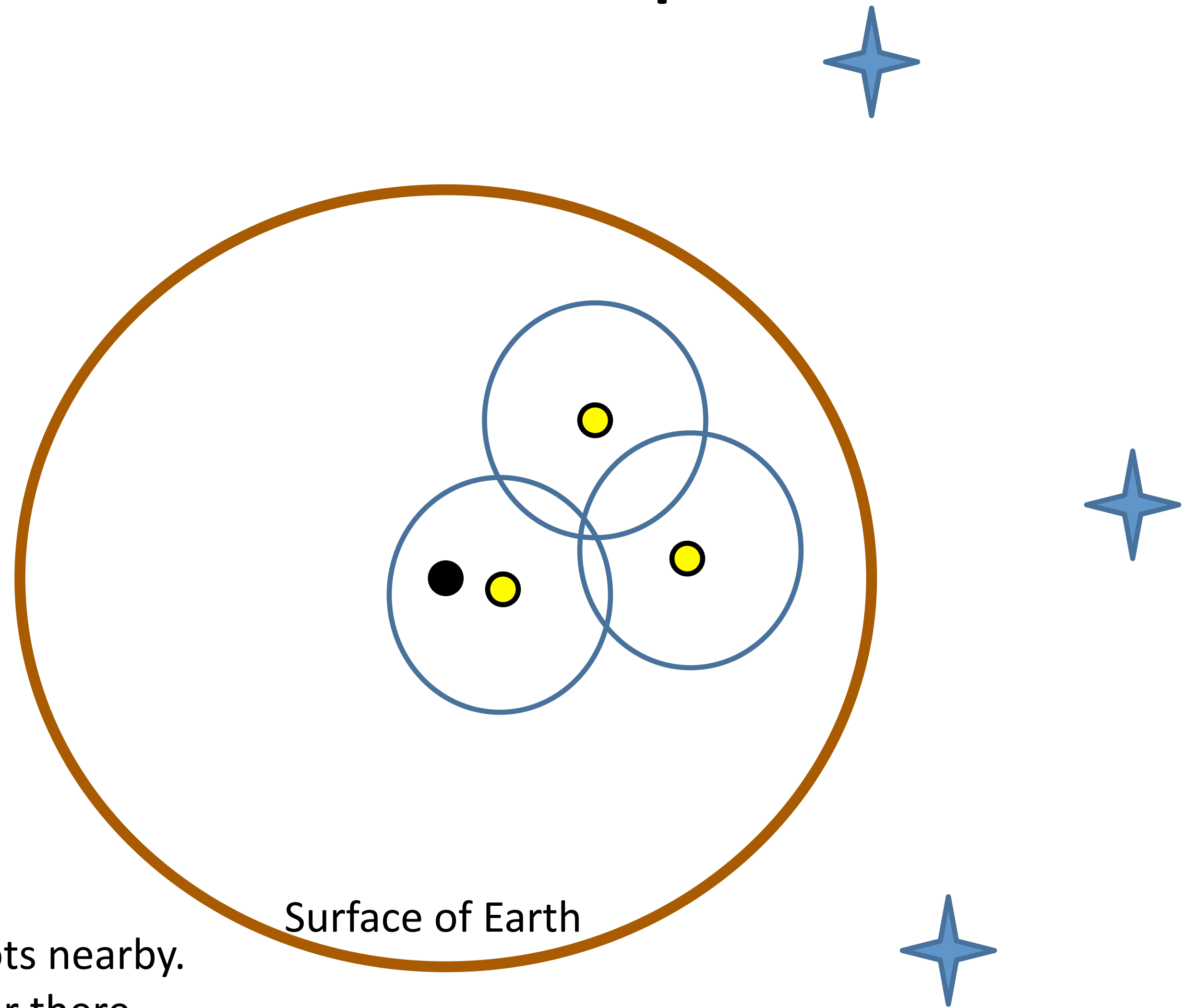



We could be on either circle!
They agree in two places!
Where could we be?

# Two Circles of Equal Altitude



# Three Circles of Equal Altitude




Now we've got 3 spots nearby.
We are probably near there

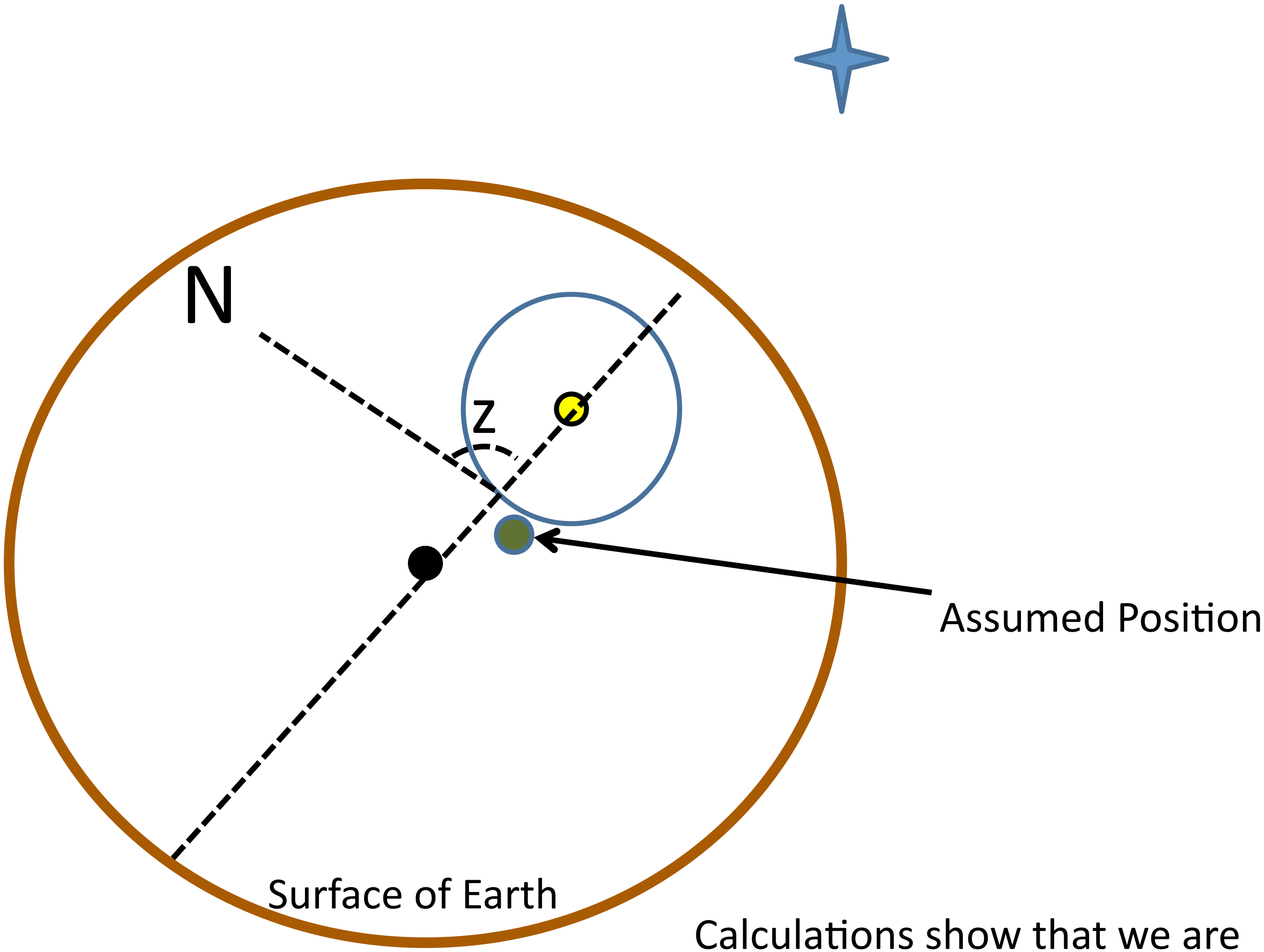
# The Challenge

- We can’t directly measure Hc
  - We can figure it out!
- We don’t have a tool that gives us Z precisely
  - More Math
- Once we have them, How do we get a position on a chart?

# The Secret Sauce

- We don’t know the exact location where we take a sextant observations from (that’s what we want to know!)
- If we make an educated guess for where we are (Assumed Position, AP) we would have observed the body at an altitude (Hc) and an azimuth (Z).
- The error between what we actually see and what we would have seen from the AP will tell us how far we are from the AP.
- We do this because we can’t plot LOP’s to all the GPs on a flat sheet of paper due to the massive scales involved

# Secret Sauce




Calculations show that we are a little north end east of our AP

# Process Overview

1. Correct the sextant altitude (hs) to obtain observed altitude (ho).
2. Determine the body's GHA and declination (dec.).
3. Select an assumed position (AP) and find its local hour angle (LHA).
4. Compute altitude and azimuth for the AP.
5. Compare the computed and observed altitudes.
6. Plot the line of position.

# Part one: Hs to Ho (for stars)

1. **Body:** **T**he name of the body whose altitude you have measured.
2. **Index Correction:** Obtained from zeroing the instrument
3. **Dip:** Correction for the height of eye of the observer . It is always negative; table are in *The Nautical Almanac*.
4. **Sum:** Add the two entries above
5. **Sextant Altitude:** Enter the altitude of the body measured by the sextant.
6. **Apparent Altitude:** Apply the correction determined above to the measured altitude and enter the result as the apparent altitude.
7. **Altitude Correction:** Every observation requires an altitude correction. *Nautical Almanac*
8. **Additional Correction:** accounts for pressure and temperature. Table A-4 located at the front of the *Nautical Almanac*
9. **Correction to Apparent Altitude:** Sum the altitude correction and the additional correction
10. **Observed Altitude:** Apply the Correction to Apparent Altitude algebraically to the

# Part Two: Local time to GMT

1. **Date:** Enter the local time zone date of the sight.
2. **DR Latitude:** Enter the dead reckoning latitude of the vessel.
3. **DR Longitude:** Enter the dead reckoning longitude of the vessel.
4. **Observation Time:** Enter the local time of the sight as recorded on the ship's chronometer or other timepiece.
5. **Watch Error:** Enter a correction for any known watch error (1 second fast is -1s).
6. **Zone Time:** Observed Time + Watch Error.
7. **Zone Description: (+/-)**: Time shift from watch to GMT. (+) for DR longitude west of the Greenwich Meridian.
8. **Greenwich Mean Time:** Zone Time + Zone Description

# Part Three: LHA and Declination

1. Determine the body's GHA
2. Determine an assumed longitude
3. Algebraically combine the two quantities, remembering to subtract a western assumed longitude from GHA and to add an eastern longitude to GHA
4. Extract the declination of the body from the appropriate *Almanac* table, correcting the tabular value if required.

# Part Four: Reduction Tables

1. Enter *Pub. 229* to determine azimuth and computed altitude.
2. Compares computed and observed altitudes to calculate the altitude intercept.
3. Plot the LOP

# Example

On May 16, 1995 we take the following readings:

| Star | Sextant Altitude | Zone Time |
|---|---|---|
| Kochab | 47° 19.1' | 20-07-43 |
| Spica | 32° 34.8' | 20-11-26 |

Height of Eye is 48 feet

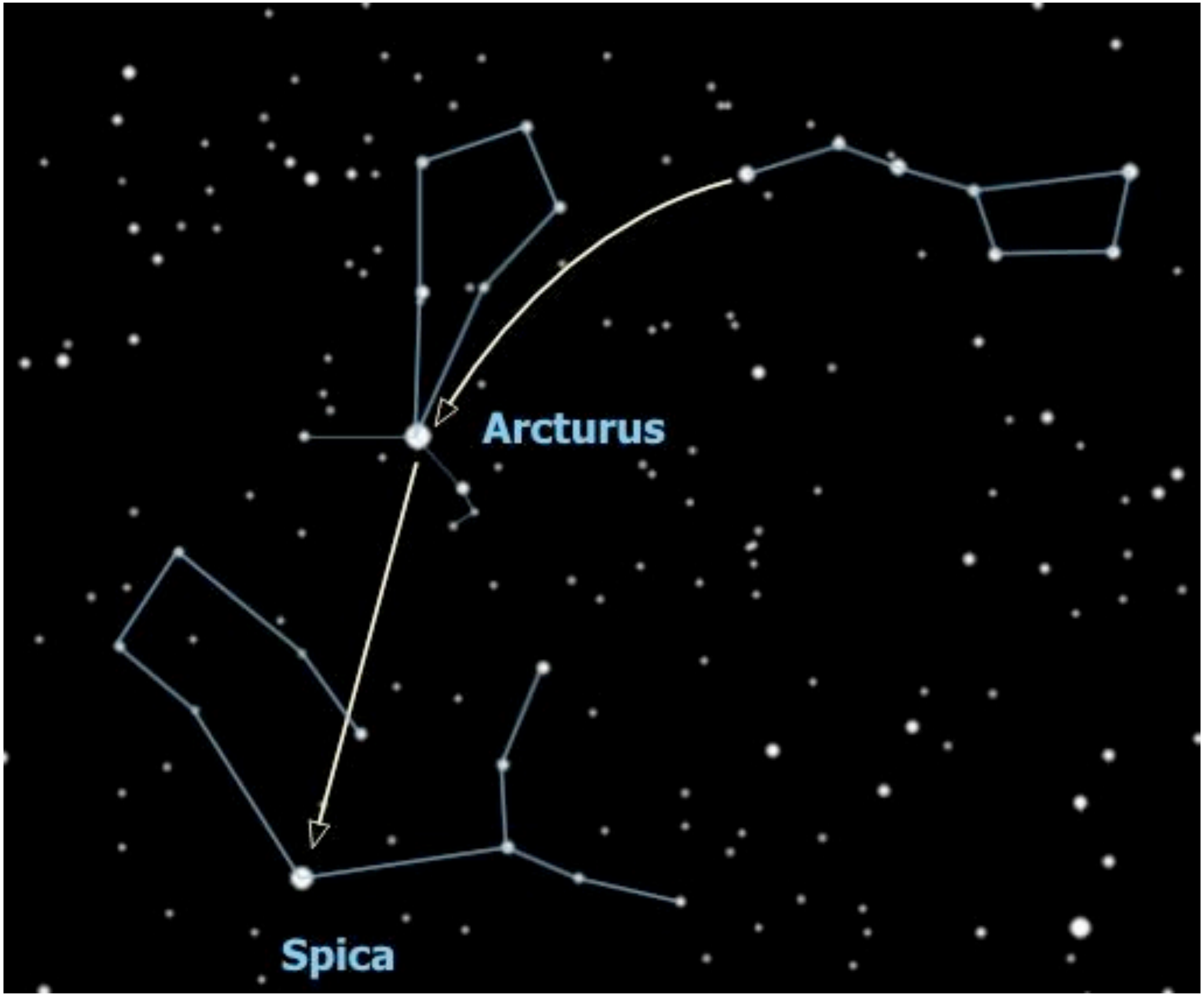
index correction (IC) is +2.1'.

The DR latitude for both sights is 39° N.

The DR longitude for the Spica sight is 157° 10'W.

The DR longitude for the Kochab sight is 157° 08.0'W.

# Where is Spica?



# Answers to Part One

| | |
|---|---|
| Body | Spica |
| Index Correction | +2.1' |
| Dip (height 48 ft) | -6.7' |
| Sum | 2.1’ + (-)6.7’ = -4.6' |
| Sextant Altitude (hs) | |
| Apparent Altitude (ha) | |
| Altitude Correction | |
| Additional Correction | |
| Horizontal Parallax | |
| Correction to ha | |
| Observed Altitude (ho) | |

*Nautical Almanac* table entitled “DIP.”

# Answers to Part One

| | | | |
|---|---|---|---|
| Body | | Spica | |
| Index Correction | | +2.1' | |
| Dip (height 48 ft) | | -6.7' | |
| Sum | 2.1’ + (-)6.7’ = | -4.6' | |
| Sextant Altitude (hs) | | | 32° 34.8' |
| Apparent Altitude (ha) | 32° 34.8‘+ (-4.6’) = | | 32° 30.2' |
| Altitude Correction | | | |
| Additional Correction | | | |
| Horizontal Parallax | | | |
| Correction to ha | | | |
| Observed Altitude (ho) | | | |

# Answers to Part One

| | | |
|---|---|---|
| Body | Spica | |
| Index Correction | +2.1' | |
| Dip (height 48 ft) | -6.7' | |
| Sum | 2.1’ + (-)6.7’ = -4.6' | |
| Sextant Altitude (hs) | | 32° 34.8' |
| Apparent Altitude (ha) | 32° 34.8‘+ (-4.6’) = | 32° 30.2' |
| Altitude Correction | | -1.5' |
| Additional Correction | | 0 |
| Horizontal Parallax | | 0 |
| Correction to ha | -1.5’ + 0 + 0 = | -1.5' |
| Observed Altitude (ho) | 32° 30.2‘ – 1.5’ = | <u>32° 28.7'</u> |

# Part Two

| | |
|---|---|
| Date | 16 May 1995 |
| DR | Latitude 39° N |
| DR | Longitude 157° 10' W |
| Observation Time | 20-11-26 |
| Watch Error | 0 |
| Zone Time | 20-11-26 |
| Zone Description | +10 |
| GMT | 06-11-26 |
| GMT Date | 17 May 1995 |

# Select Assumed Position, AP

- Select an AP longitude closest to the DR but which results in a whole degree when combined with GHA
- Latitude equal to that whole degree closest to the DR position
  - This makes using the tables easier

# Part Three

| | |
|---|---|
| Tab GHA Ares | 324° 28.4‘ |
| GHA Increment | 2° 52.0‘ |
| SHA | 158° 45.3‘ |
| GHA | |
| +/- 360° | |
| Assumed Longitude | |
| LHA | |
| Tabulated Dec/*d* | |
| *d* Correction | |
| True Declination | |
| Assumed Latitude | |

Daily Pages
*Nautical Almanac*

Increments and Corrections table
*Nautical Almanac (11 Min 28 Sec)*

# Part Three

| | | | |
|---|---|---|---|
| Tab GHA Ares | | 324° 28.4‘ | (1) |
| GHA Increment | | 2° 52.0‘ | (2) |
| SHA | | 158° 45.3‘ | (3) |
| GHA | (1)+(2)+(3) = | 486° 05.7' | |
| +/- 360° | | | |
| Assumed Longitude | | | |
| LHA | | | |
| Tabulated Dec/*d* | | | |
| *d* Correction | | | |
| True Declination | | | |
| Assumed Latitude | | | |

# Part Three

| | | |
|---|---|---|
| Tab GHA Ares | 324° 28.4‘ | (1) |
| GHA Increment | 2° 52.0‘ | (2) |
| SHA | 158° 45.3‘ | (3) |
| GHA (1)+(2)+(3) = | 486° 05.7' | |
| +/- 360° | not required | |
| Assumed Longitude | 157° 05.7' | |
| LHA | GHA - 157° 05.7‘ = 329° | |
| Tabulated Dec/*d* | | |
| *d* Correction | | |
| True Declination | | |
| Assumed Latitude | | |

(-) for West

Chosen nearest DR Longitude (157 ° 10’) so LHA will become a whole Degree

# Part Three

| | | | |
|---|---|---|---|
| Tab GHA Ares | | 324° 28.4‘ | (1) |
| GHA Increment | | 2° 52.0‘ | (2) |
| SHA | | 158° 45.3‘ | (3) |
| GHA | (1)+(2)+(3) = | 486° 05.7' | |
| +/- 360° | | not required | |
| Assumed Longitude | | 157° 05.7' | |
| LHA | | 329° | |
| Tabulated Dec/*d* | | S 11° 08.4'/n.a. | |
| *d* Correction | | —(star) | |
| True Declination | | S 11° 08.4' | |
| Assumed Latitude | | N 39° contrary | |

Daily Pages
*Nautical Almanac*

DR latitude is north while the star's declination is south.
We will need this for the next part

# Part Four: Sight Reduction

- Find the page in the *Sight Reduction Table* corresponding to an LHA of 329° and an assumed latitude of N 39°, with latitude contrary to declination.

- The body's whole degree of declination is 11°. -> The tabulated altitude is 32° 15.9'.
- This value is for a declination of 11°; the true declination is 11° 08.4'. Therefore, interpolate. The difference between the tabulated altitudes for 11° and 12° is given in *Pub. 229* as the value d; in this case, d = -53.0.

$$\frac{8.4'}{60'} * -53.0 = -7.3$$

# Part Four: Sight Reduction

| | |
|---|---|
| Dec Inc / + or - d | 8.4' / -53.0 |
| hc (tabulated) | 32° 15.9' |
| Correction (+ or -) | -7.4' |
| hc (computed) | 32° 08.5' |

Azimuth, z ← H.O. 229 with LHA, assumed latitude, and declination to find z

Zn

# Part Four: Sight Reduction

| | |
|---|---|
| Dec Inc / + or - d | 8.4' / -53.0 |
| hc (tabulated) | 32° 15.9' |
| Correction (+ or -) | -7.4' |
| hc (computed) | 32° 08.5‘ |
| | |
| Azimuth, z | 143.3° |
| Zn | |

In Northern Latitude,

LHA > 180° then Zn  = Z

LHA < 180°, then Zn = 360° – Z

# Part Four: Sight Reduction

| | |
|---|---|
| Dec Inc / + or - d | 8.4' / -53.0 |
| hc (tabulated) | 32° 15.9' |
| Correction (+ or -) | -7.4' |
| hc (computed) | 32° 08.5‘ |
| | |
| Azimuth, z | 143.3° |
| Zn | 143.3°T |

# Intercept, a

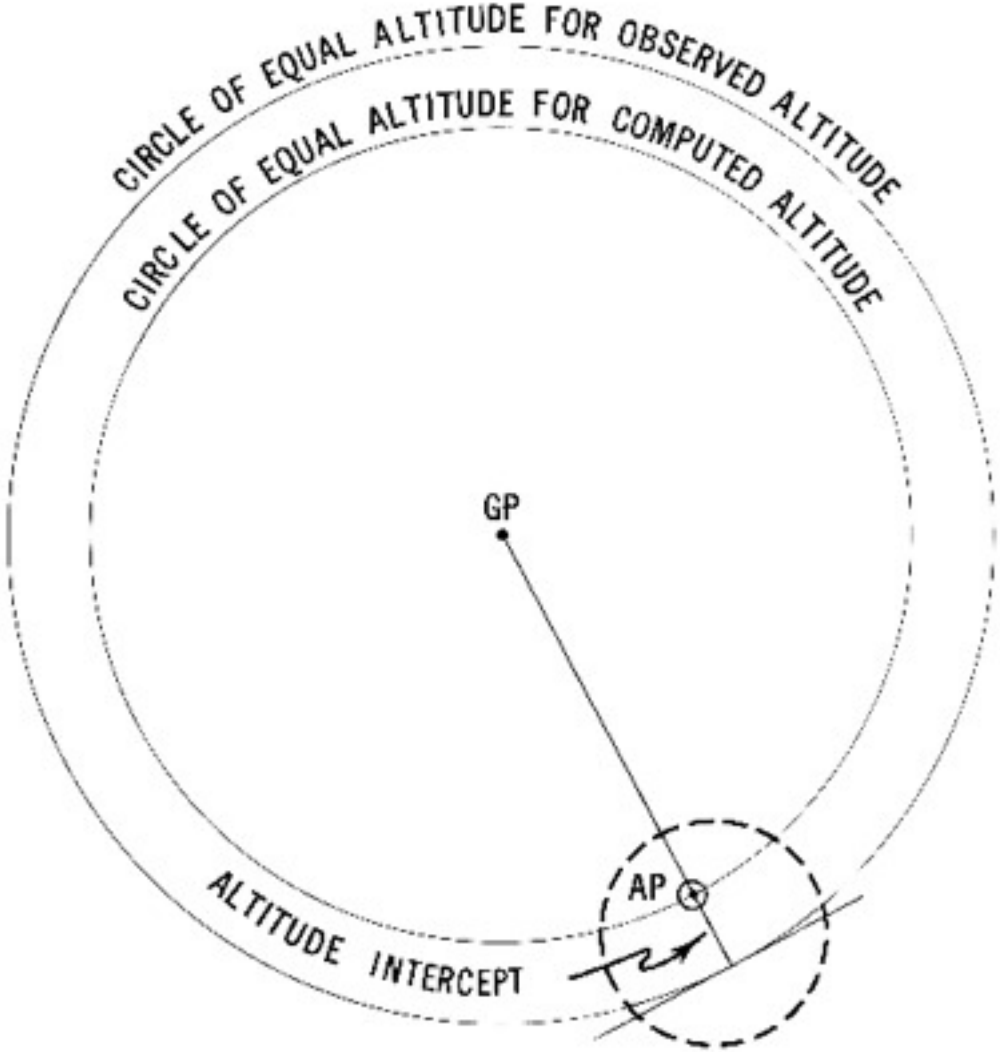
ho    32°28.7’

–hc  <u>32°08.5’</u>

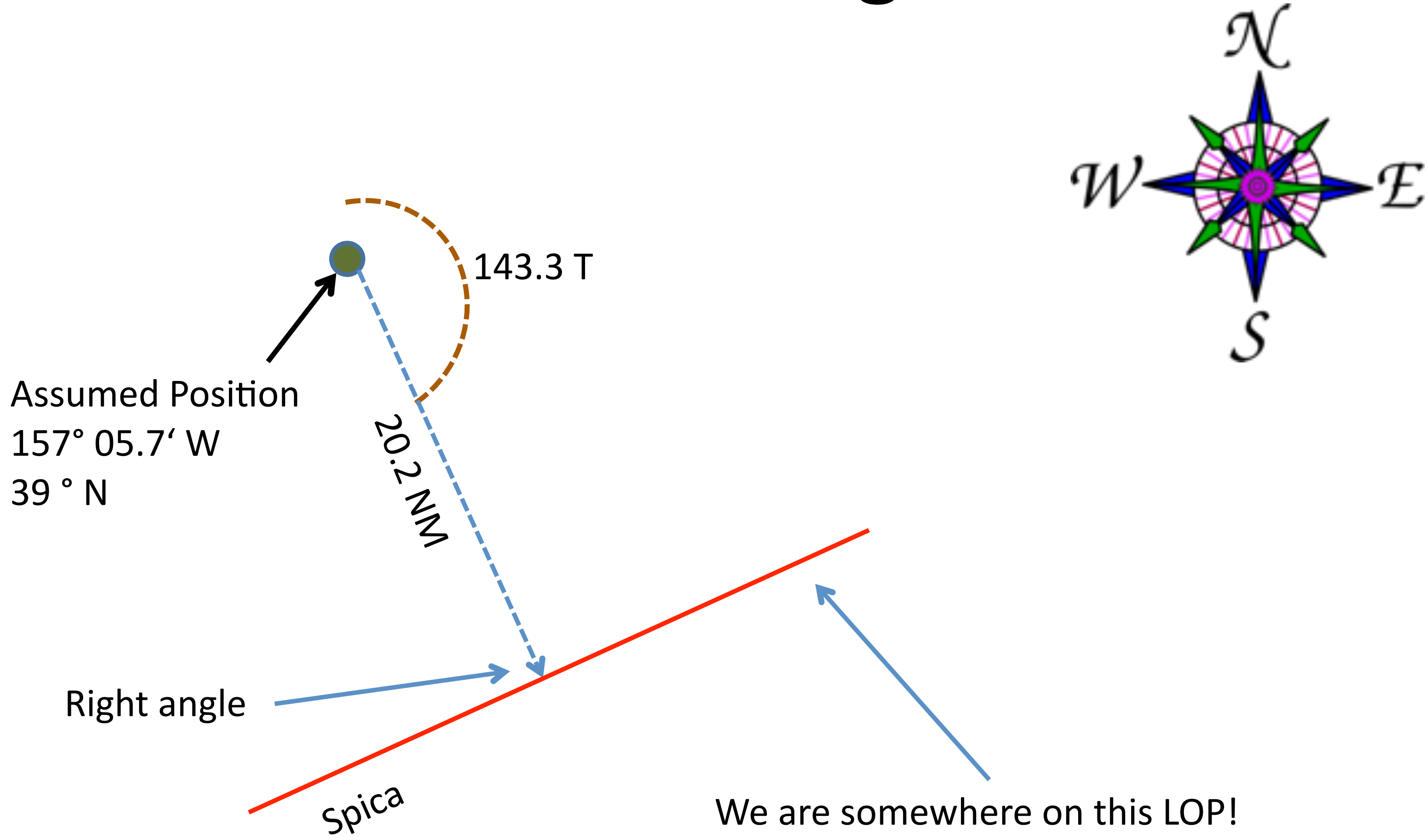
=    20.2 NM

The difference between the computed altitude (hc) and the observed altitude (ho) is the **altitude intercept** (a).

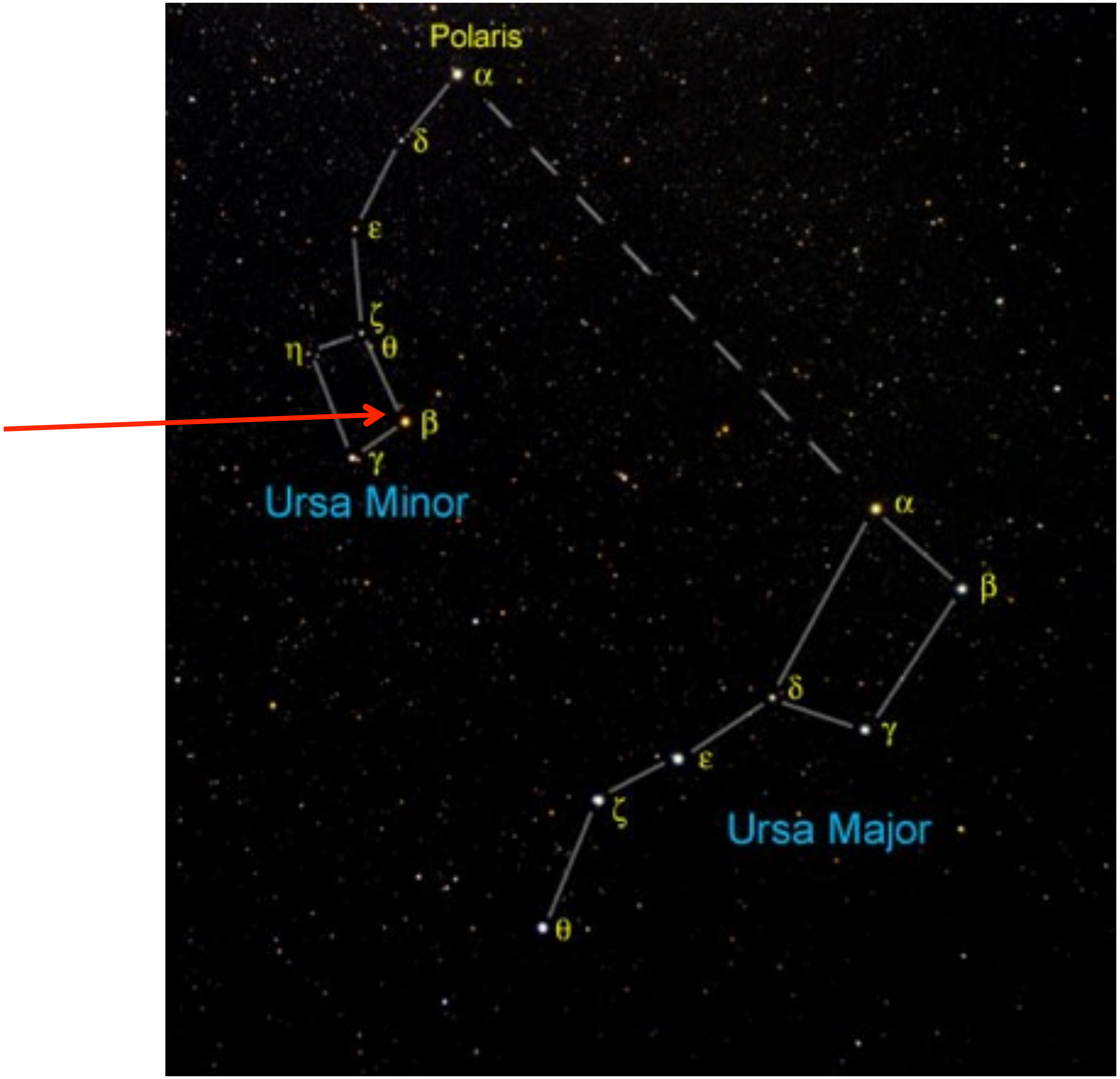
HoMoTo!



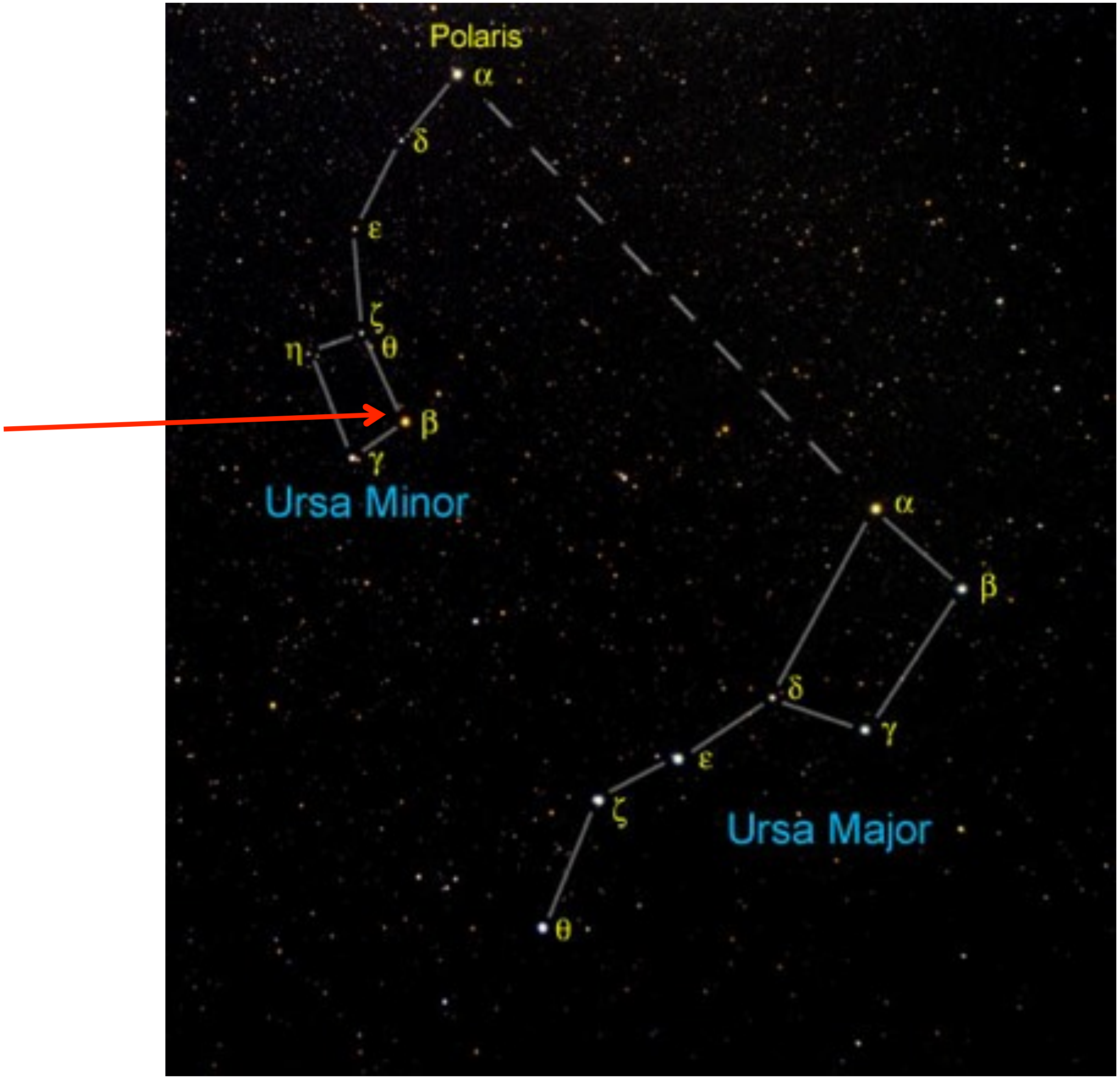
# Plotting


N
W
E
S
143.3 T
Assumed Position
157° 05.7‘ W
39 ° N
20.2 NM
Right angle
Spica
We are somewhere on this LOP!

# Where is Kochab?



# Where is Kochab?

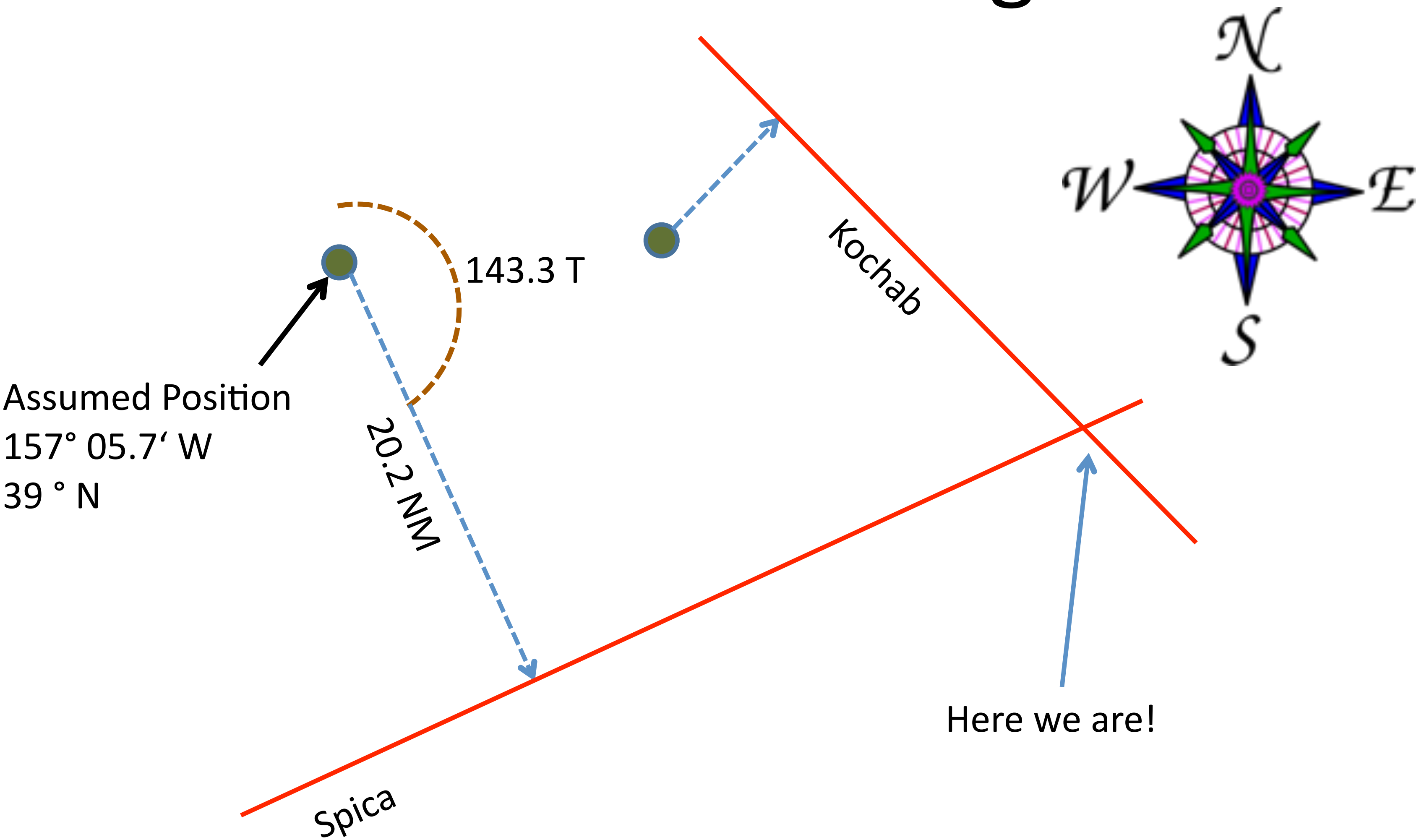


# Kochab Answers

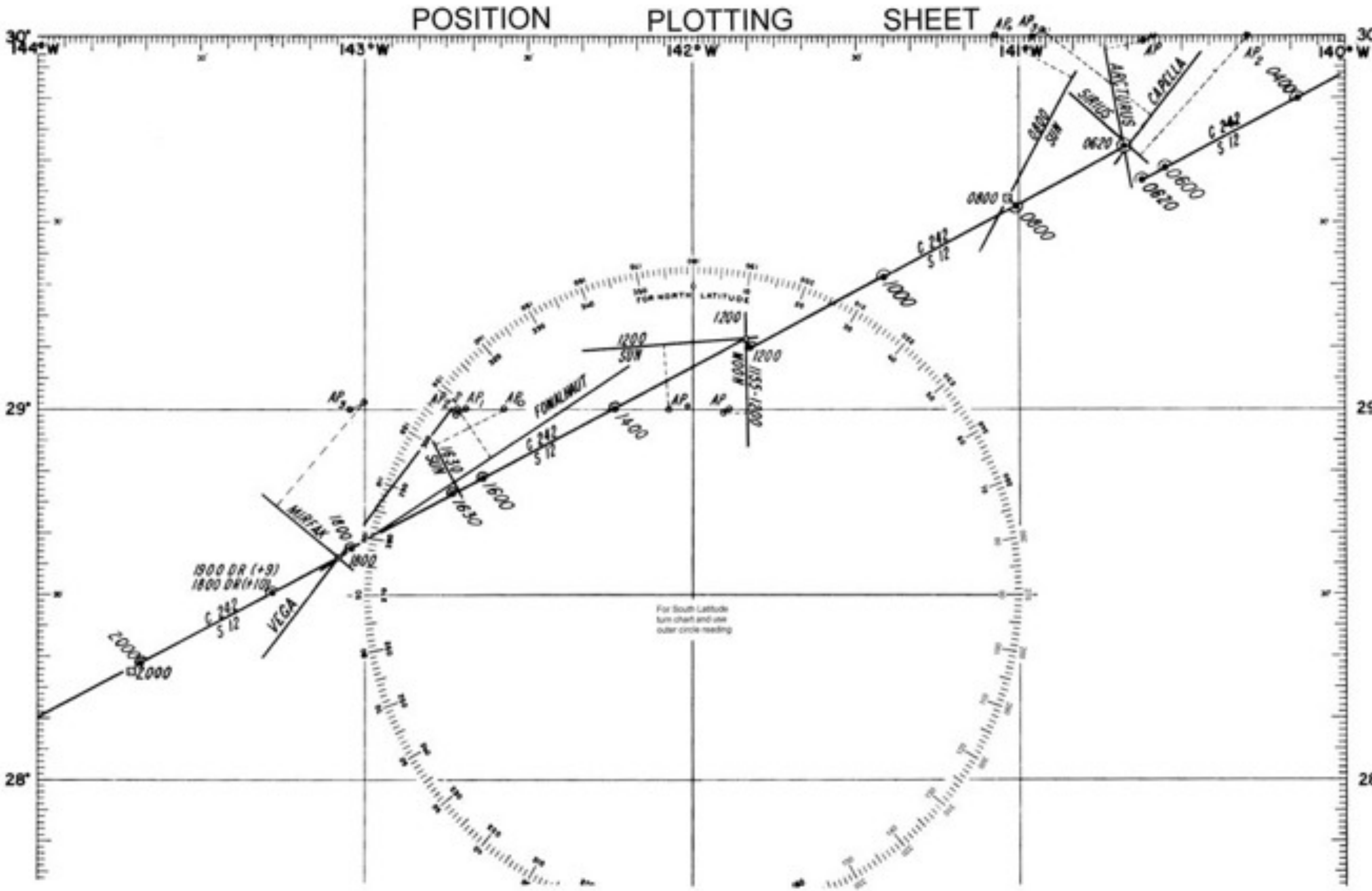
| | |
|---|---|
| Body | Kochab |
| Index Correction | +2.1' |
| Dip Correction | -6.7' |
| Sum | -4.6' |
| hs | 47° 19.1' |
| ha | 47° 14.5' |
| Altitude Correction | -.9' |
| Additional Correction | not applicable |
| Horizontal Parallax | not applicable |
| Correction to ha | -9' |
| Ho | 47° 13.6‘ |
| | |
| Date | 16 May 1995 |
| DR latitude | 39°N |
| DR longitude | 157° 08.0' W |
| Observation Time | 20-07-43 |
| Watch Error | 0 |
| Zone Time | 20-07-43 |

| | |
|---|---|
| Tab GHA | 324° 28.4' |
| GHA Increment | 1° 56.1' |
| SHA | 137° 18.5' |
| GHA | 463° 43.0' |
| +/- 360° | not applicable |
| Assumed Longitude | 156° 43.0' |
| LHA | 307° |
| Tab Dec / *d* | N74° 10.6' / n.a. |
| *d* Correction | not applicable |
| True Declination | N74° 10.6' |
| Assumed Latitude | 39°N (same) |
| Dec Inc / + or - | d 10.6' / -24.8 |
| hc | 47° 12.6' |
| Total Correction | -4.2' |
| hc (computed) | 47° 08.4' |
| ho | 47° 13.6' |
| a (intercept) | 5.2 towards |
| Z | 018.9° |
| Zn | 018.9° |

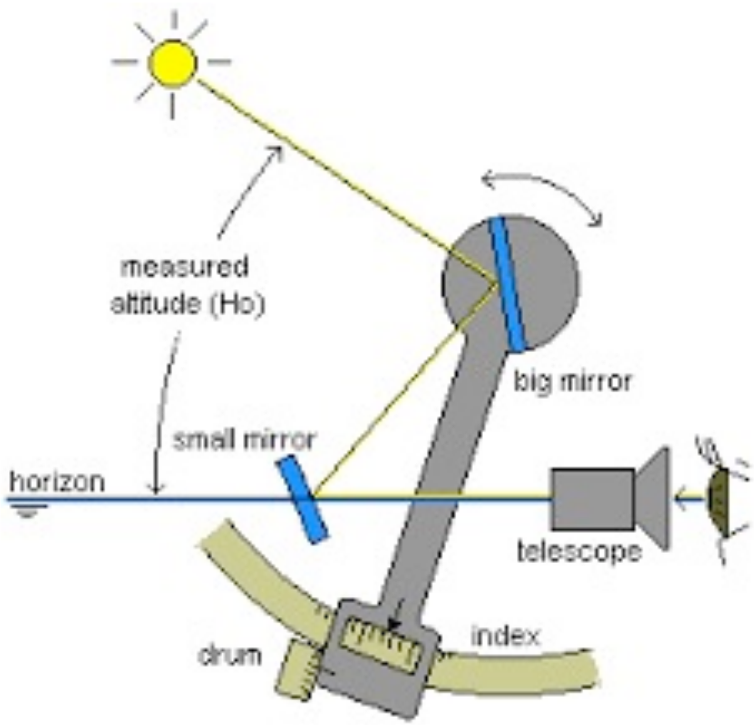
# Part 5: Plotting



# Typical Plotting Sheet at Sea

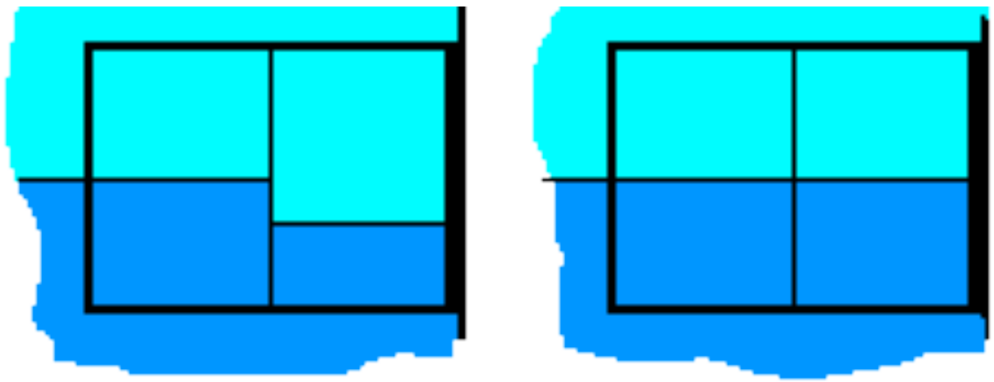


# Measuring with a Sextant




http://youtu.be/DrAkrgZRb9Y

# Measuring IE

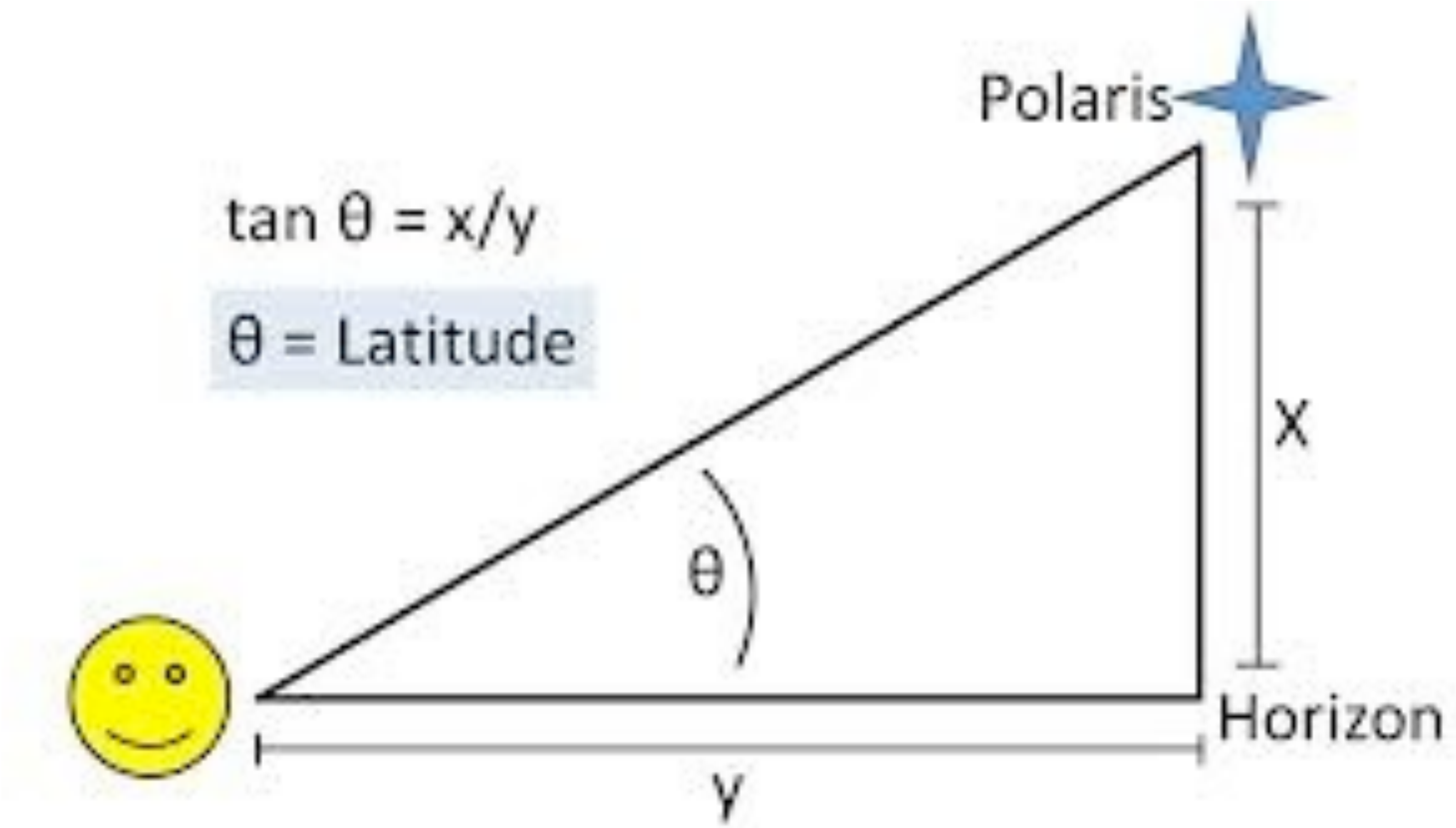


What does the instrument say about a flat plane?
it should be 0.0 degrees.

# Other Celestial Techniques

- Sun Lines
- Noon Sights
- Polaris
- Planets
- Moon
- Tahitian (Equatorial) Navigation
- Arctic  Navigation

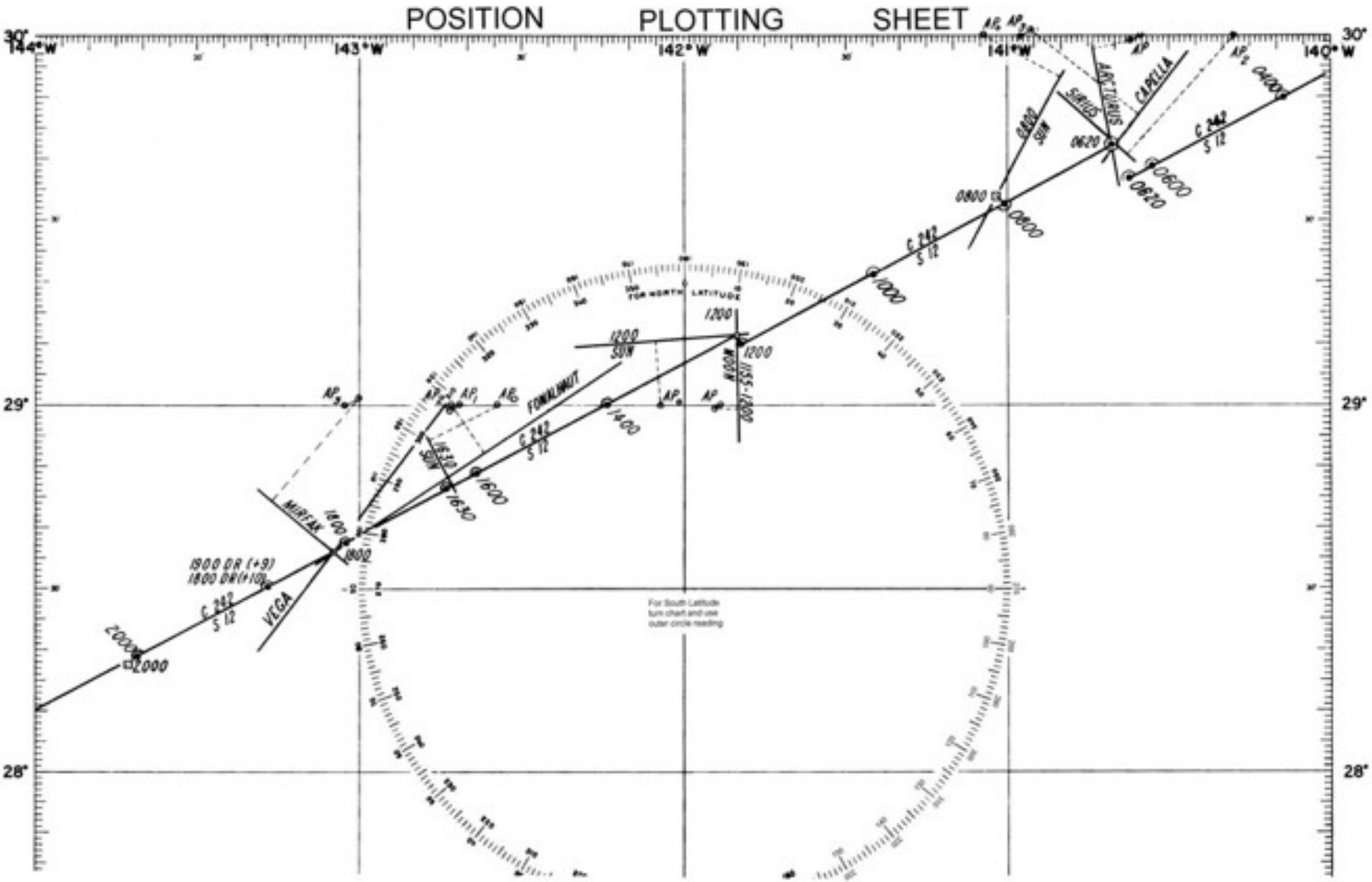
# Polaris



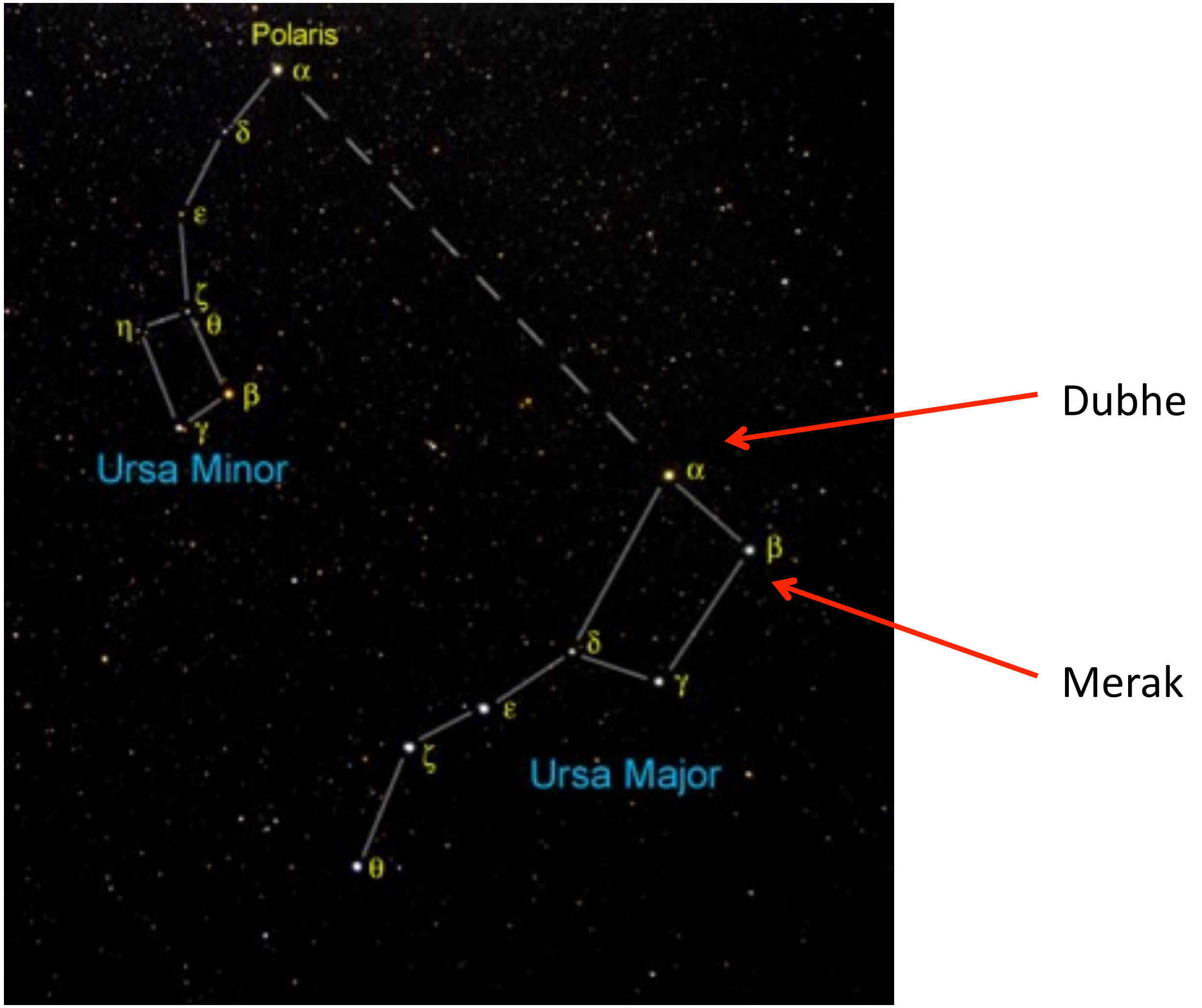
# Celestial Routine

- 0530
  - Compute the time of morning twilight
  - Plot the dead reckoning position for that time
- 0600 (Twilight)
  - take and reduce celestial observations for a fix
- 1030
  - reduce a Sun sight for a morning Sun line
  - Calibrate Clock with Radio tick
- 1200 (Local Apparent Noon, LAN)
  - obtain a Sun line and advance the morning Sun line for the noon fix.
  - Compute a longitude determined at LAN for an additional LOP
- 1430
  - again take and reduce a Sun sight
- 1730 (Twilight)

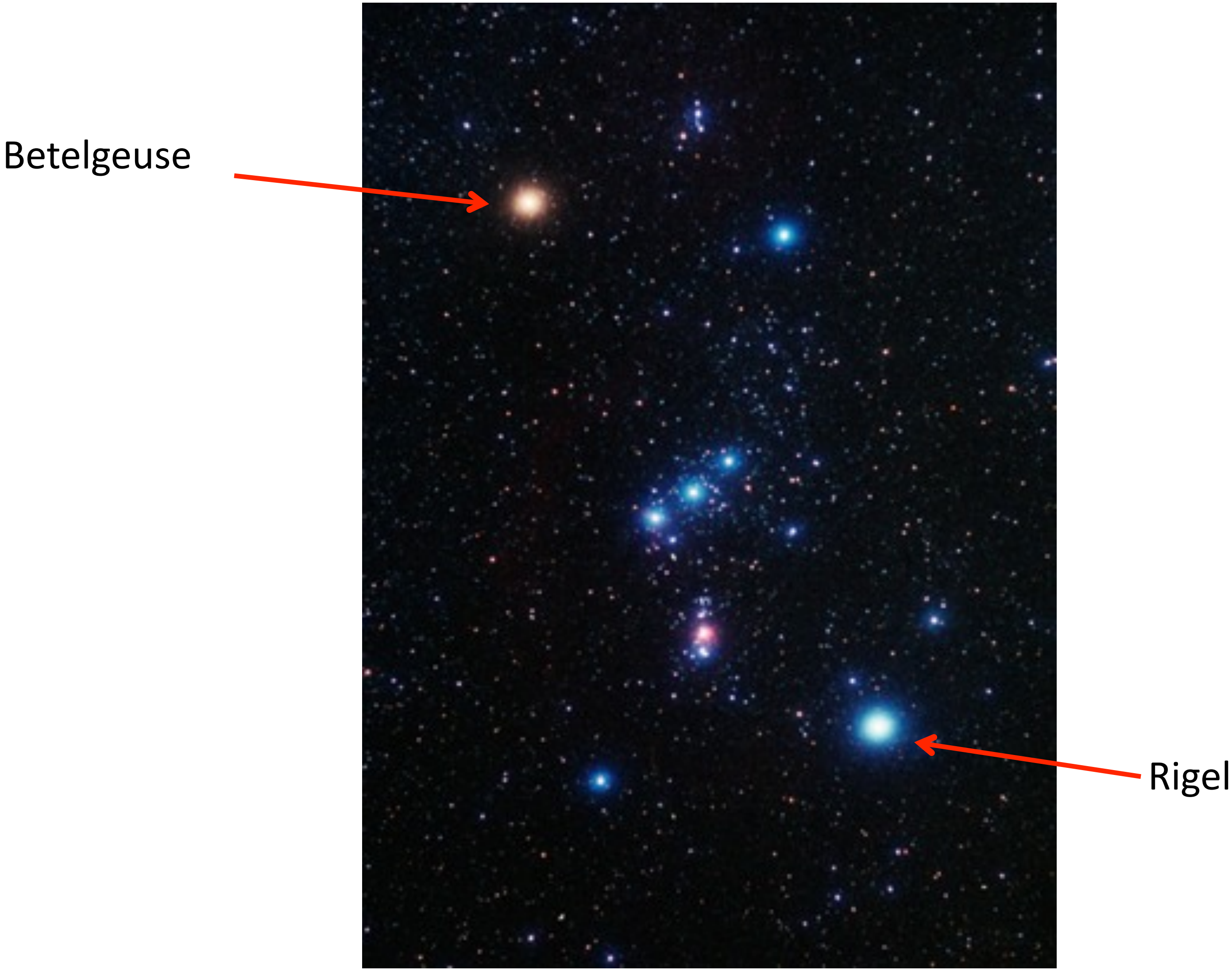
# Typical Plotting Sheet at Sea

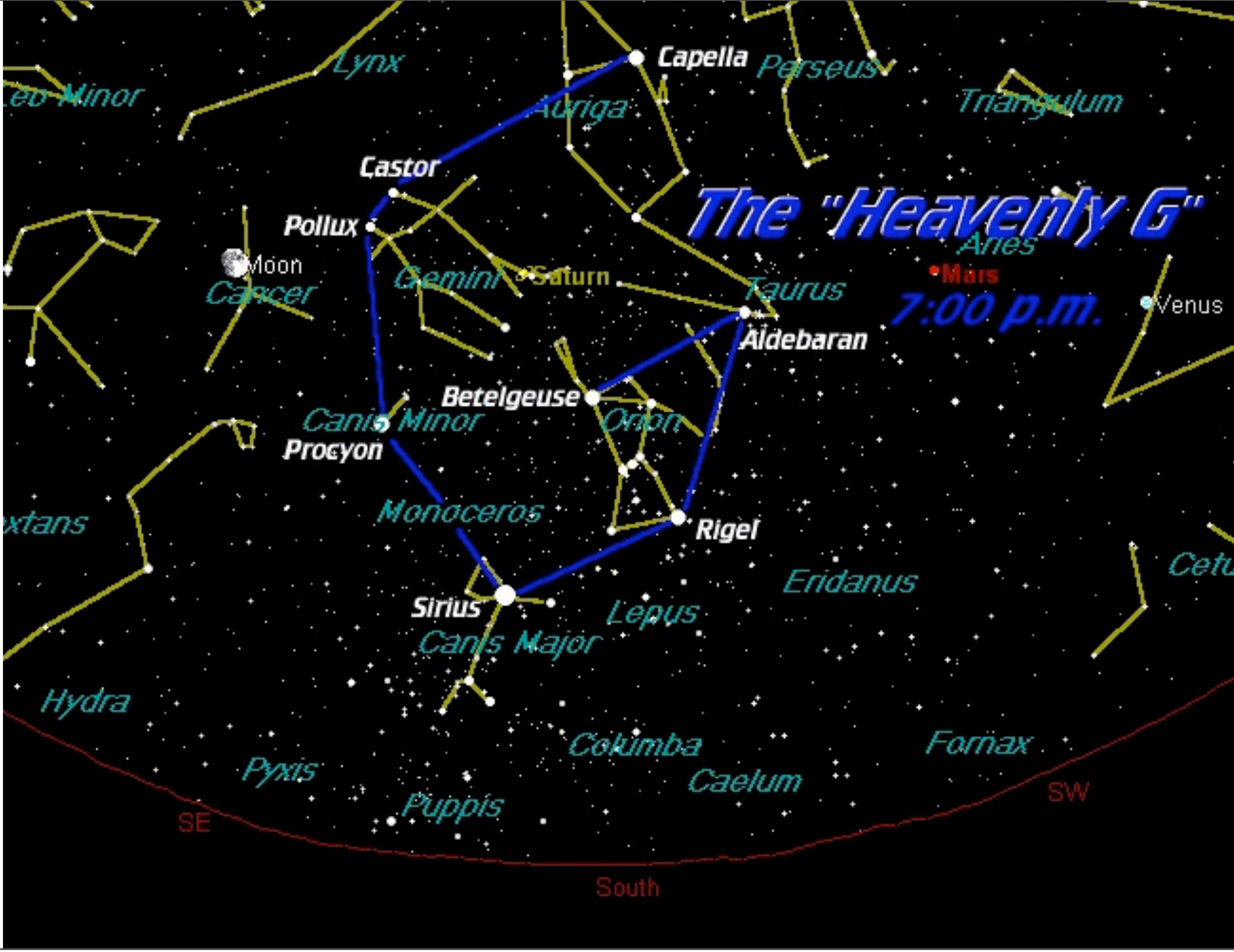


# Other Navigation Stars



# Other Navigation Stars





Lynx
eo Minor
Capella
Perseus
Auriga
Triangulum
Castor
Pollux
Moon
Cancer
Gemini
Saturn
The "Heavenly G"
Aries
Mars
Taurus
7:00 p.m.
Venus
Aldebaran
Betelgeuse
Orion
Canis Minor
Procyon
Monoceros
xtans
Rigel
Cetu
Eridanus
Sirius
Lepus
Canis Major
Hydra
Columba
Fornax
Caelum
Pyxis
Puppis
SE
SW
South

Reference Materials:

http://msi.nga.mil/MSISiteContent/StaticFiles/NAV_PUBS/APN/Chapt-20.pdf