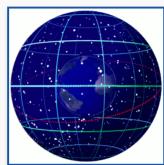


# Ch1 Lecture Notes

## OBSERVATIONAL ASTRONOMY

### CHAPTER 1: THE CELESTIAL SPHERE AND COORDINATE SYSTEMS



1

## CELESTIAL SPHERE



2

## HEAVENLY SPHERES

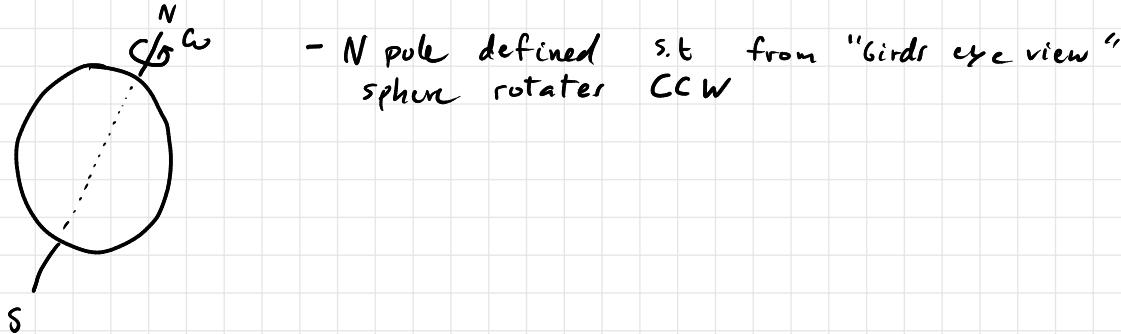


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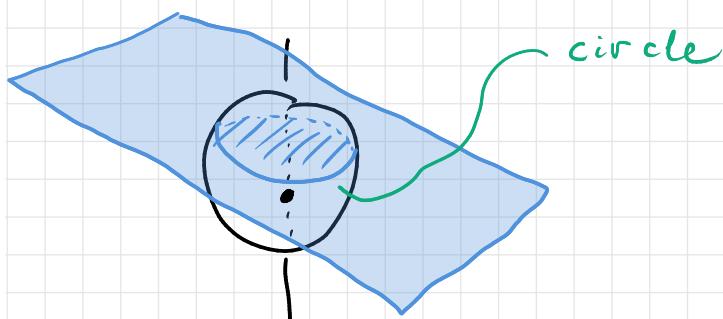
Societies used to think the celestial spheres was the true arrangement of the heavens.

Multiple observations & ideas force astronomy to abandon this model, but the celestial sphere is still a useful tool.

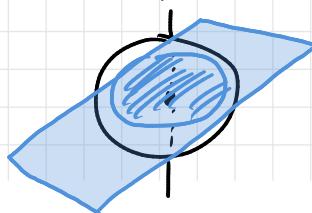
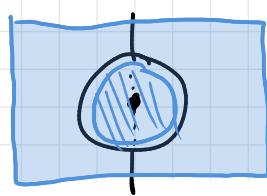
Assume a rotating sphere. The axis of rotation defines the N & S poles



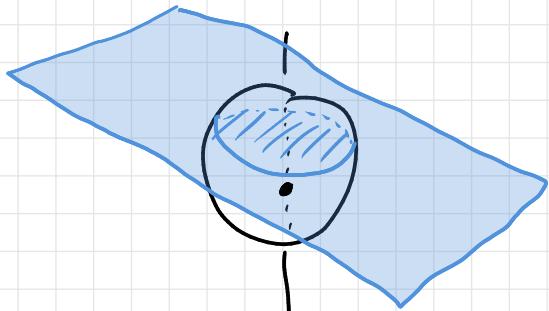
An arbitrary plane can slice through the sphere & trace out a circle



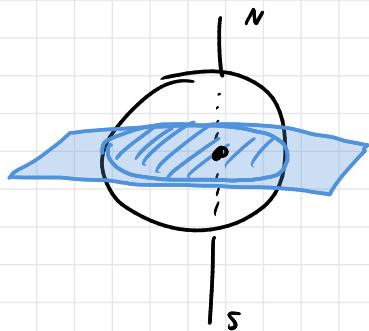
A great circle is created when an intersecting plane encompasses the center of the sphere



A small circle is created when an intersecting plane does not encompass center of the sphere

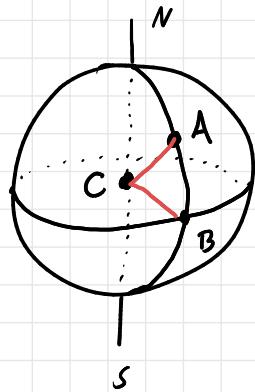


The **fundamental plane** is the great circle that is perpendicular to the rotation axis



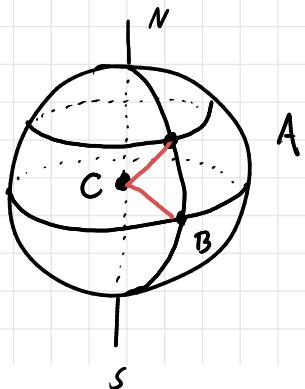
- on Earth we call this the equator
- what we call the fundamental plane will change depending on the coordinate system an astronomer is working with.

Now consider a point A on the sphere by making a great circle that includes the poles



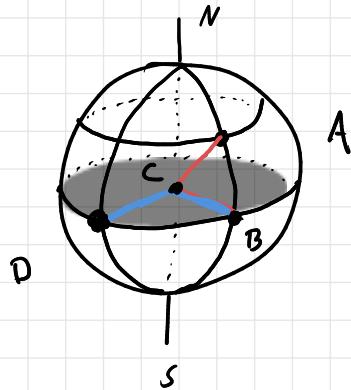
$$\angle BCA = \text{latitude (on Earth)}$$

Make a small circle // to the fundamental plane & intersects A



- all points on this small circle have the latitude

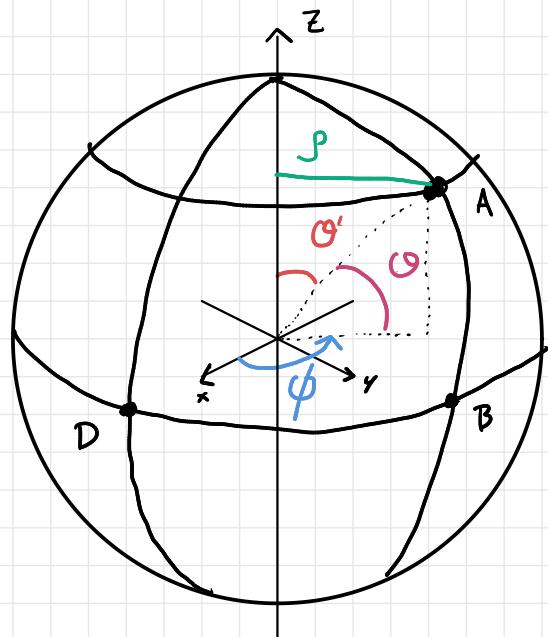
We need one more great circle to get the longitude of A.



$$\angle DCB = \text{longitude of } A$$

The NDS meridian is the prime meridian. (where  $\phi = 0^\circ$ )

On Earth this is Greenwich England



$\phi$  = azimuthal angle

$\theta$  = polar angle

note that  $\phi$  &  $\theta$  labels are opposite by mathematics convention

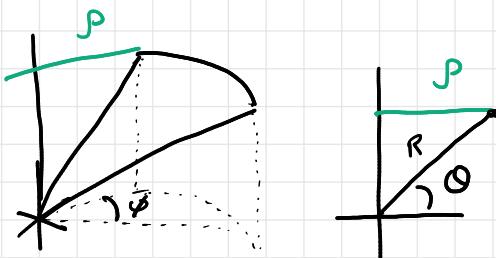
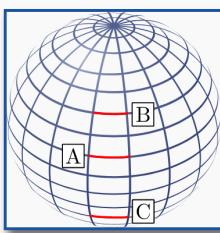
$$0 \leq \phi \leq 2\pi$$

$$0 \leq \theta' \leq \pi \quad \text{or} \quad -\frac{\pi}{2} \leq \theta \leq \frac{\pi}{2}$$

## PQ: LONGITUDINAL DISTANCES

The radius of Earth is  $R_E = 6378.1\text{km}$ . What is the physical distance between two meridians separated by  $1^\circ$  at the following latitudes?

- A. At the equator  $\theta = 0^\circ$ .
- B. At Norfolk VA  $\theta = 36.88^\circ$ .
- C. Near Outpost 31 in the Antarctic  $\theta = -70.7^\circ$ .



$$s = \text{arc length} = R\phi$$

$$s = R \cos \theta \cdot \phi$$

$$s = R \cos \theta \cdot \phi$$

$$A) \quad s = (6378.1\text{km}) \left(1^\circ \frac{\pi \text{ rad}}{180^\circ}\right) \cos(0^\circ) = 111.3\text{ km}$$

$$B) \quad s = (6378.1\text{km}) \left(1^\circ \frac{\pi \text{ rad}}{180^\circ}\right) \cos(36.88^\circ) = 89.04\text{ km}$$

$$C) \quad s = (6378.1\text{km}) \left(1^\circ \frac{\pi \text{ rad}}{180^\circ}\right) \cos(-70.7^\circ) = 36.79\text{ km}$$

Astronomers use several spherical coordinate systems depending on their needs.

For example: we all know the sun is the center of the solar system, but it is perfectly valid to work in a reference frame where Earth is the center.

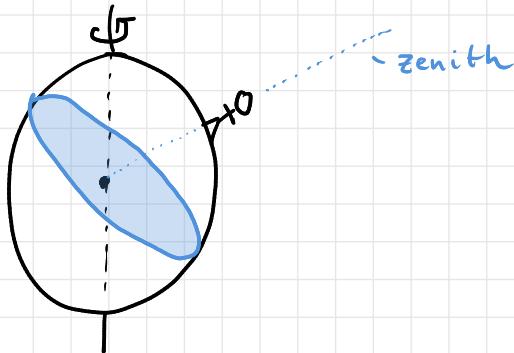
- run `Orbital_Transformation.py` script from Nick Lucid (science4sym)

We will discuss 4 coordinate systems in this chapter. Key differences are what is that coordinates fundamental plane.

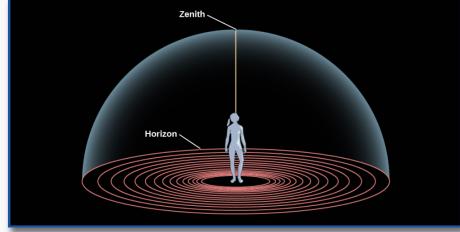
- Altitude - azimuth
- Equatorial
- Ecliptic
- Galactic equator

Altitude - azimuth (aka horizon system, alt-az system)

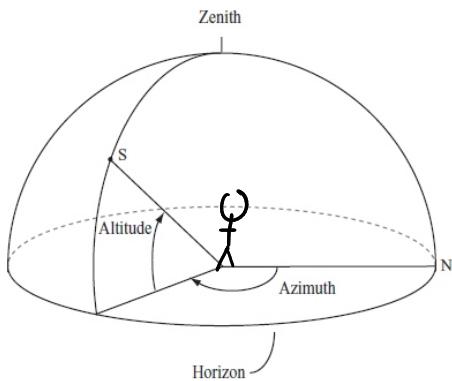
The fundamental plane is the observers horizon



ALTITUDE-AZIMUTH COORDINATES



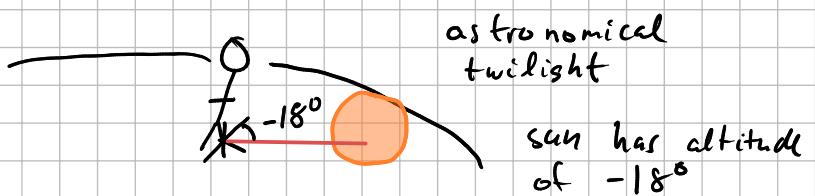
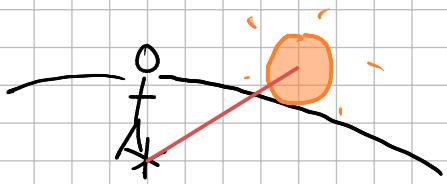
Coordinates: Altitude & Azimuth



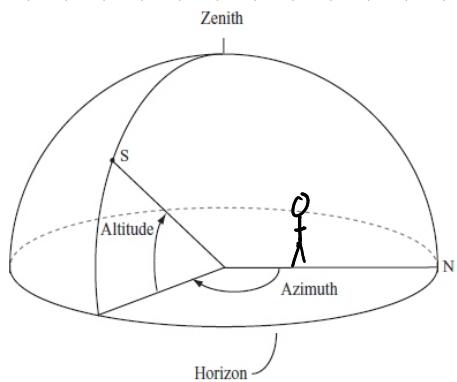
go to stellarium & show view at different locations on Earth

Note cancel Tuesday Jan 17 class (Isaac appointment)

Altitude varies from  $0 - 90^\circ$ . An object beneath the horizon has negative altitude.



- Our 2nd coordinate, the azimuth is taken to be zero degrees due North.
- Azimuth increases due East!



## THEODOLITE

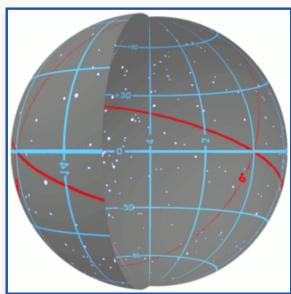
Measure angles from visible points.



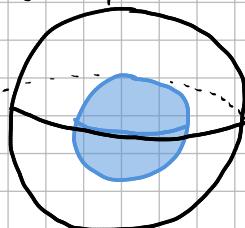
- Can use tools like a theodolite to measure altitude & azimuth
- This is a rotating reference frame since Earth rotates towards the East  
↳ causes objects to "move" East to West
- Useful for tellers where to find objects at the persons geographic location  
↳ not good for permanent description of stellar object positions

## Equatorial Coordinates

### EQUATORIAL COORDINATES



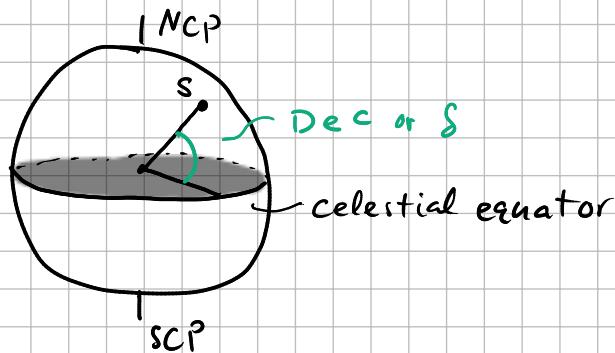
Imagine Earth inside a hollow sphere w/ the equator of Earth and this hollow sphere co-planar



Coordinates: declination & right ascension  
(Dec) (RA)

- Earth's axis of rotation defines the N & S celestial poles (NCP & SCP)
- Declination measures angle N or S of celestial equator

*polaris  
nearest star*



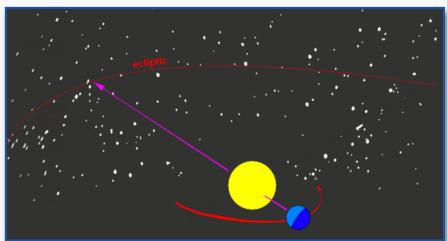
- + for objects in N hemisphere
- for objects in S hemisphere

denoted as Dec or  $\delta$   
L measured in degrees  
 $-90^\circ \leq \delta \leq 90^\circ$

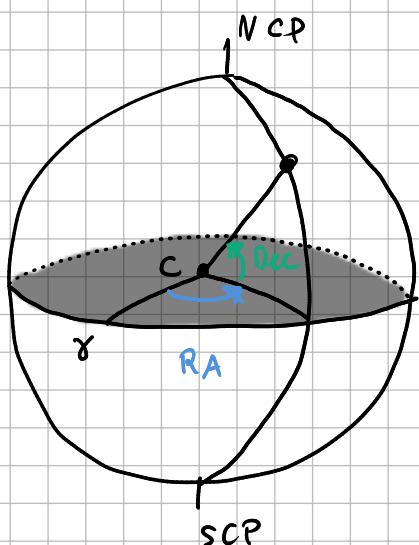
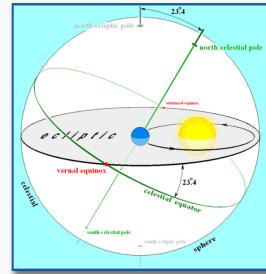
- Right ascension measures CCW angle in fundamental plane
  - L RA =  $0^\circ$  at March equinox ( $\gamma$  or V) (vernal equinox in N-hemisphere)
  - when Sun's path crosses celestial equator from S  $\rightarrow$  N
  - Ecliptic ~ March 20

### ECLIPTIC

Path of the Sun on Celestial Sphere



### ECLIPTIC FROM EARTH'S VIEW



- denoted as RA or  $\alpha$
- L measured in units of time

$$0^\circ \leq \alpha \leq 24\text{ hr}$$

$$360^\circ = 24\text{ hr}$$

or

$$15^\circ = 1\text{ hr}$$

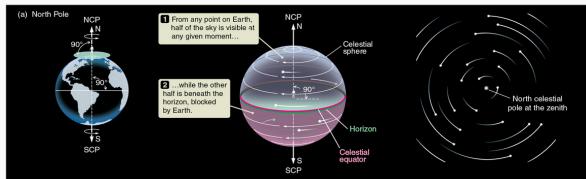
Side Note : Because Earth is a spinning top, its axis of rotation precesses.

Around year 3,100 Gamma Cephei will be the North star

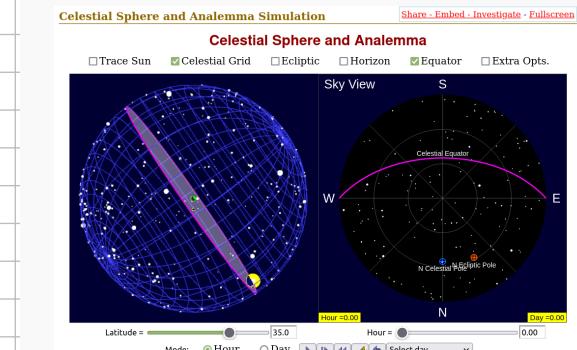
Demo: Gyroscope

How much of the celestial sphere you see depends on your location on Earth.

## VIEWS OF THE CELESTIAL SPHERE



## CELESTIAL SPHERE MOTION

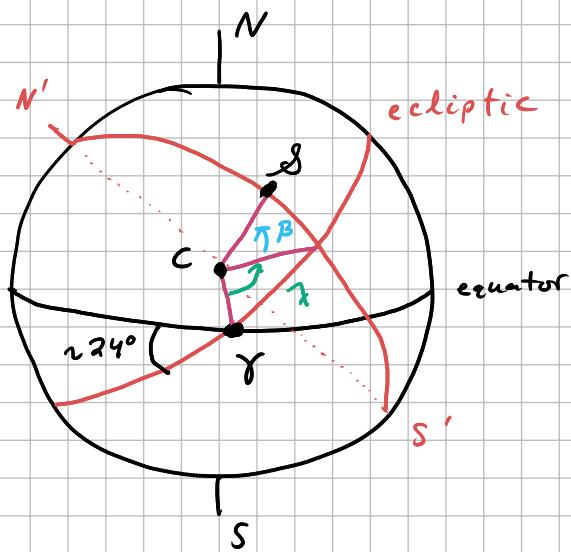


Q: Where is the best place to build ground based telescopes

## Ecliptic Coordinates

fundamental plane is the ecliptic (apparent path of Sun)

coordinates: ecliptic latitude ( $\beta$ ), ecliptic longitude ( $\lambda$ )  
L vernal equinox is where  $\lambda = 0^\circ$



ecliptic system  
superimposed onto the  
equatorial system

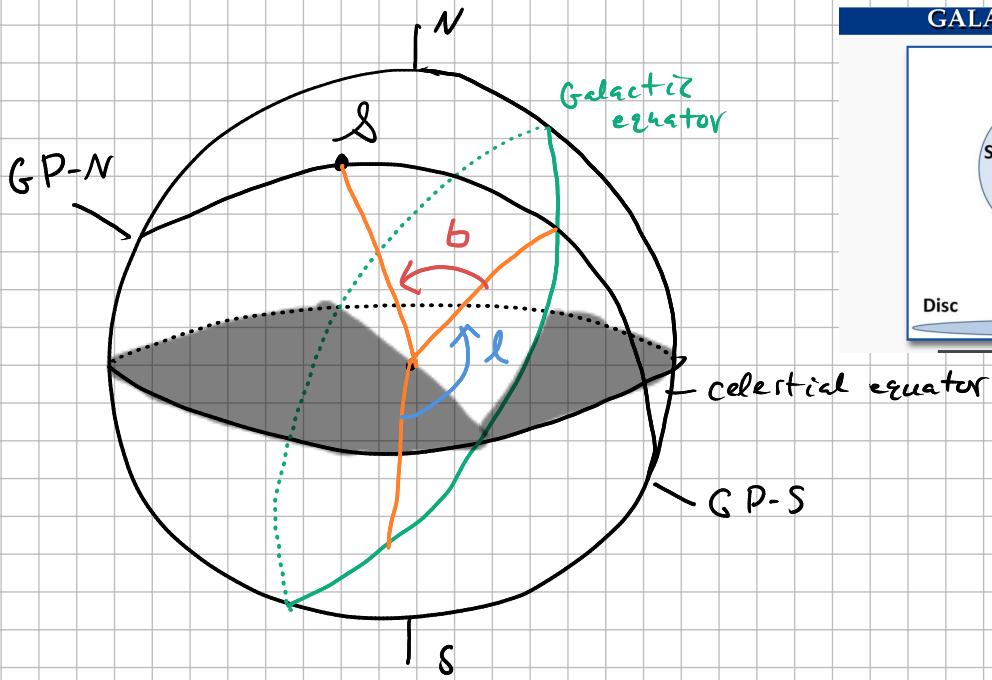
- useful for people studying the motion of the planets

## Galactic Coordinates

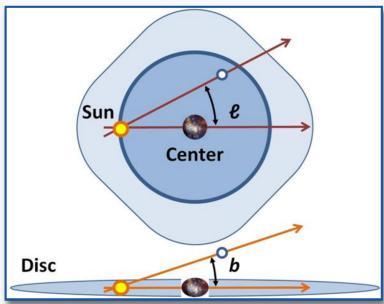
fundamental plane is the galactic equator  
a great circle on the center line of the Milky Way on sky

coordinates: galactic latitude ( $b$ ), galactic longitude ( $l$ )

$l = 0$  towards center of Milky Way (in Sagittarius constellation)



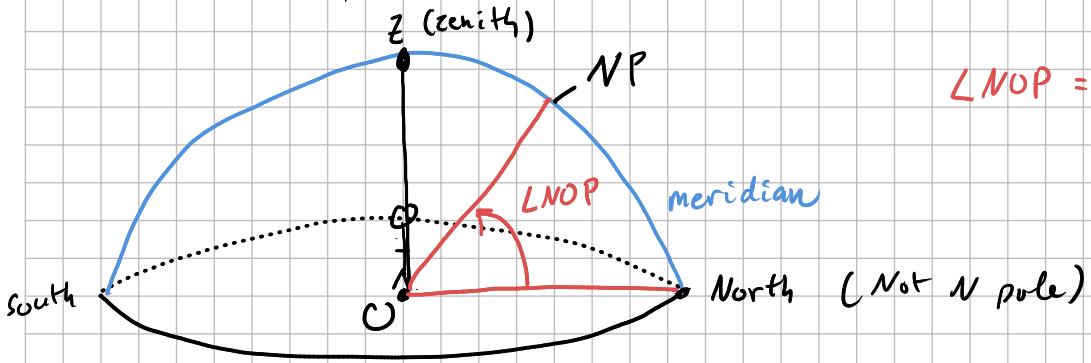
GALACTIC COORDINATES



The galactic coordinates cannot be directly measured and must be calculated (Ch4)

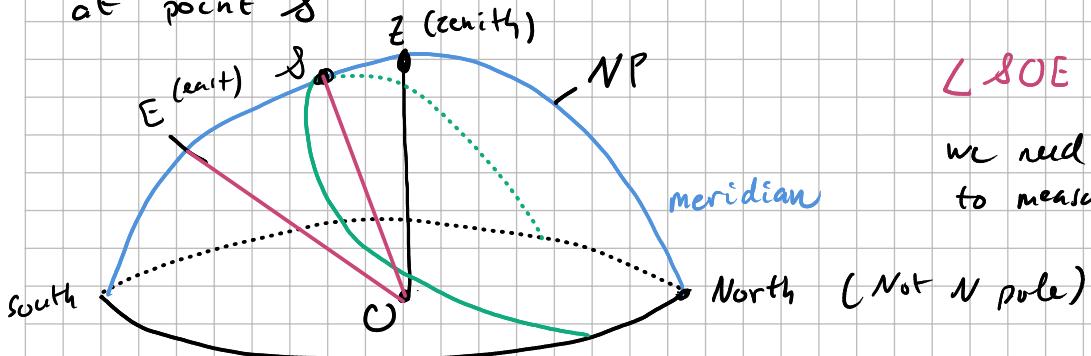
### Measuring Stellar Coordinates

Take an arbitrary observer and draw their view of the celestial sphere



$\angle LNOP$  = latitude of observer

Now draw the small circle representing the path of a star.  
This star rises in the East, sets in the West & crosses the meridian at point  $\delta$



$\angle LSOE$  = declination

We need precise way to measure this angle

