Basic Concepts of Ground-Based Observing

La Silla Observing School 2025

Ana Jimenez-Gallardo, Feb. 10

A bit about myself…

Ana Jimenez-Gallardo

- 2nd year ESO Fellow
- Duties in Paranal
- Born in Spain, PhD and postdoc in Italy
- ESO Student for one year
- Science: multifrequency observations of AGN and galaxy clusters
- Love animals, reading, video games, and arts and crafts
- This is my first lecture ever!

What we will see...

Coordinates and Times

Introduction to Telescopes

Atmospheric Effects

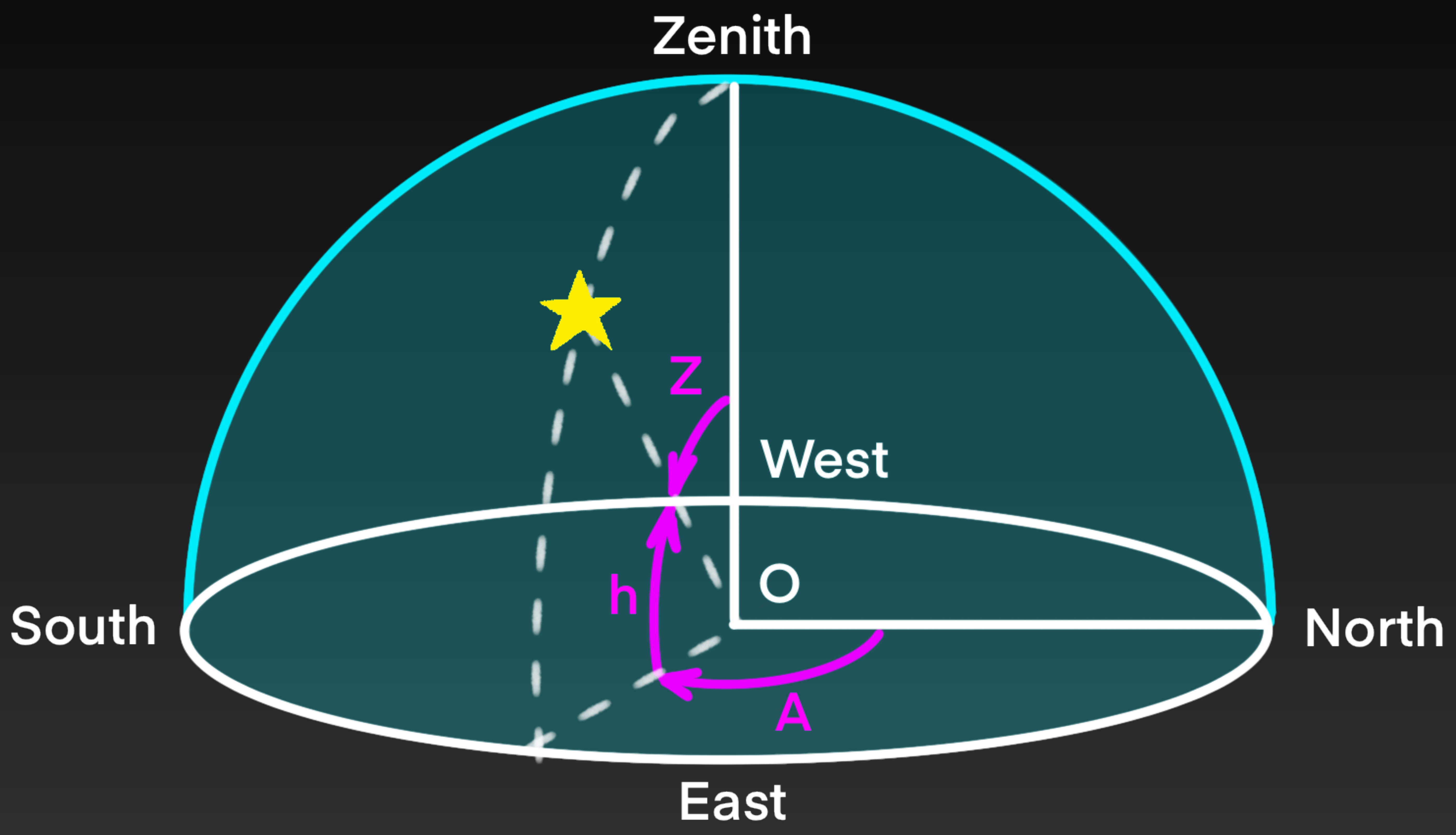
Telescope Design

Coordinates and Times

Horizon coordinates - Altitude/Azimuth

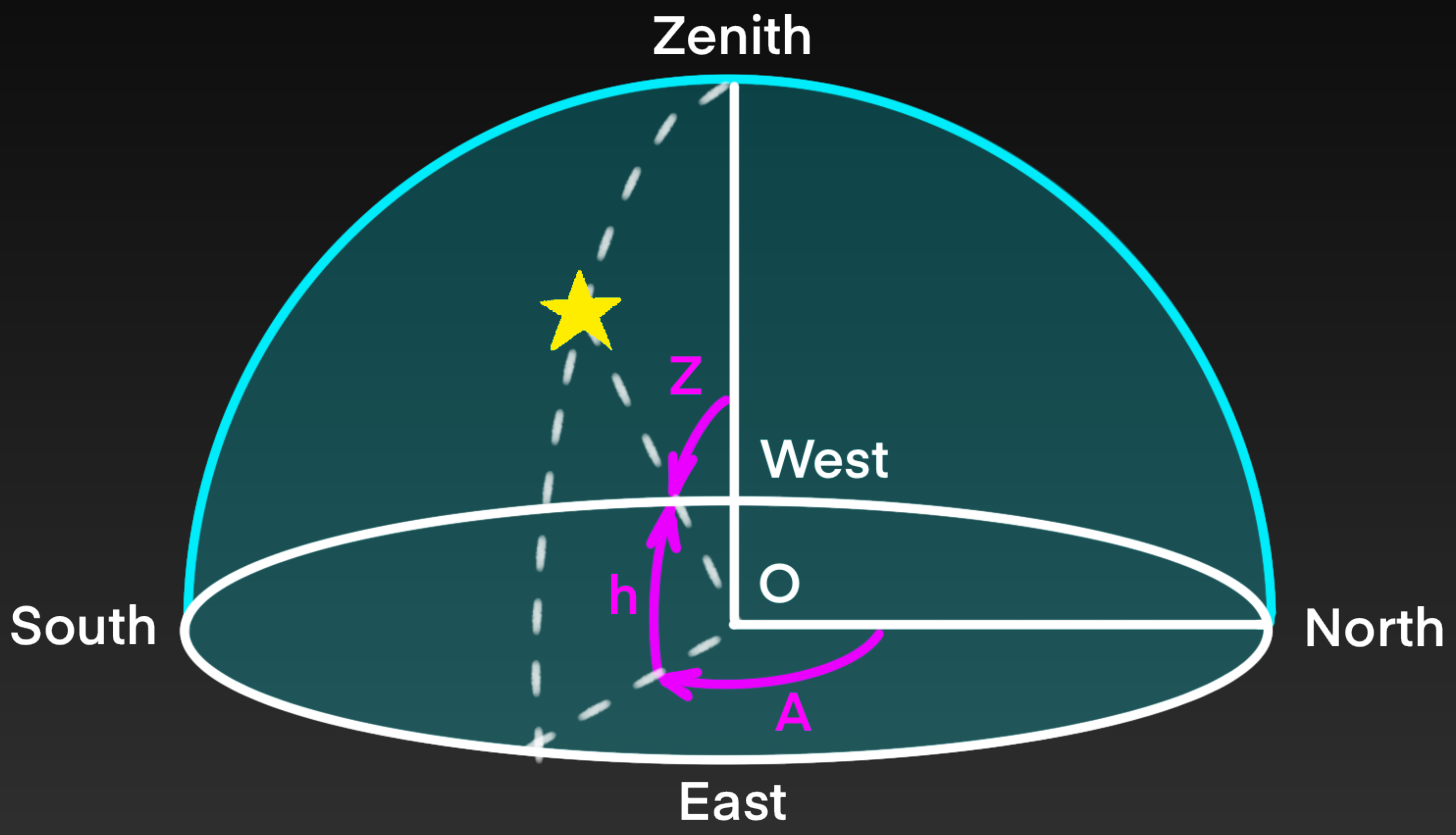
Horizon Coordinates - Altitude/Azimuth

- Origin -> Observer
- Fundamental plane -> Tangent to the surface of the Earth at the position of the observer



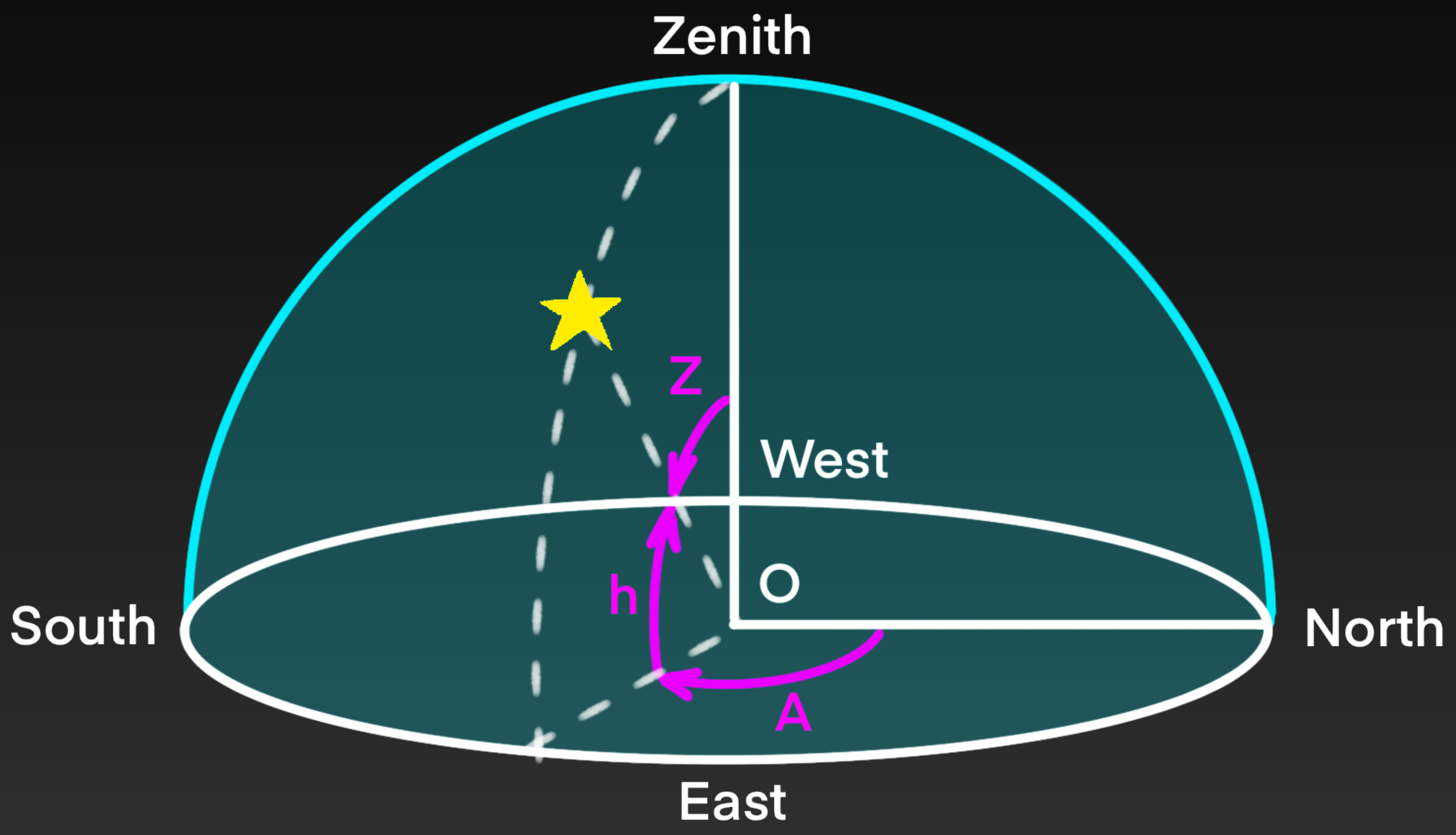
Horizon Coordinates - Altitude/Azimuth

- Origin -> Observer
- Fundamental plane -> Tangent to the surface of the Earth at the position of the observer
- Towards zenith
- Towards the North



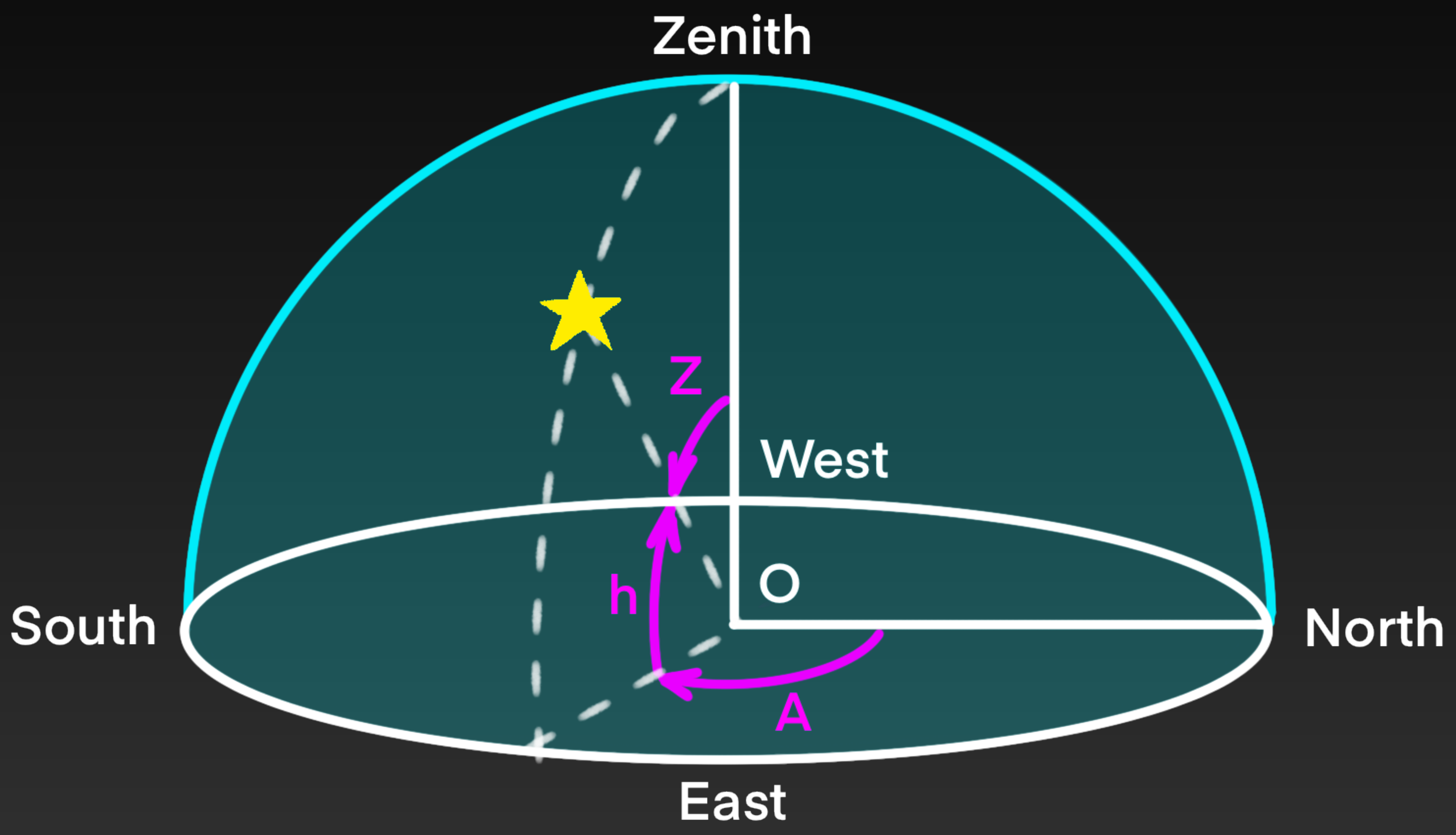
Horizon Coordinates - Altitude/Azimuth

- Origin -> Observer
- Fundamental plane -> Tangent to the surface of the Earth at the position of the observer
- Towards zenith
- Towards the North
- Altitude (h) -> from the horizon to the target
- Azimuth (A) -> from the North to the target along the horizon



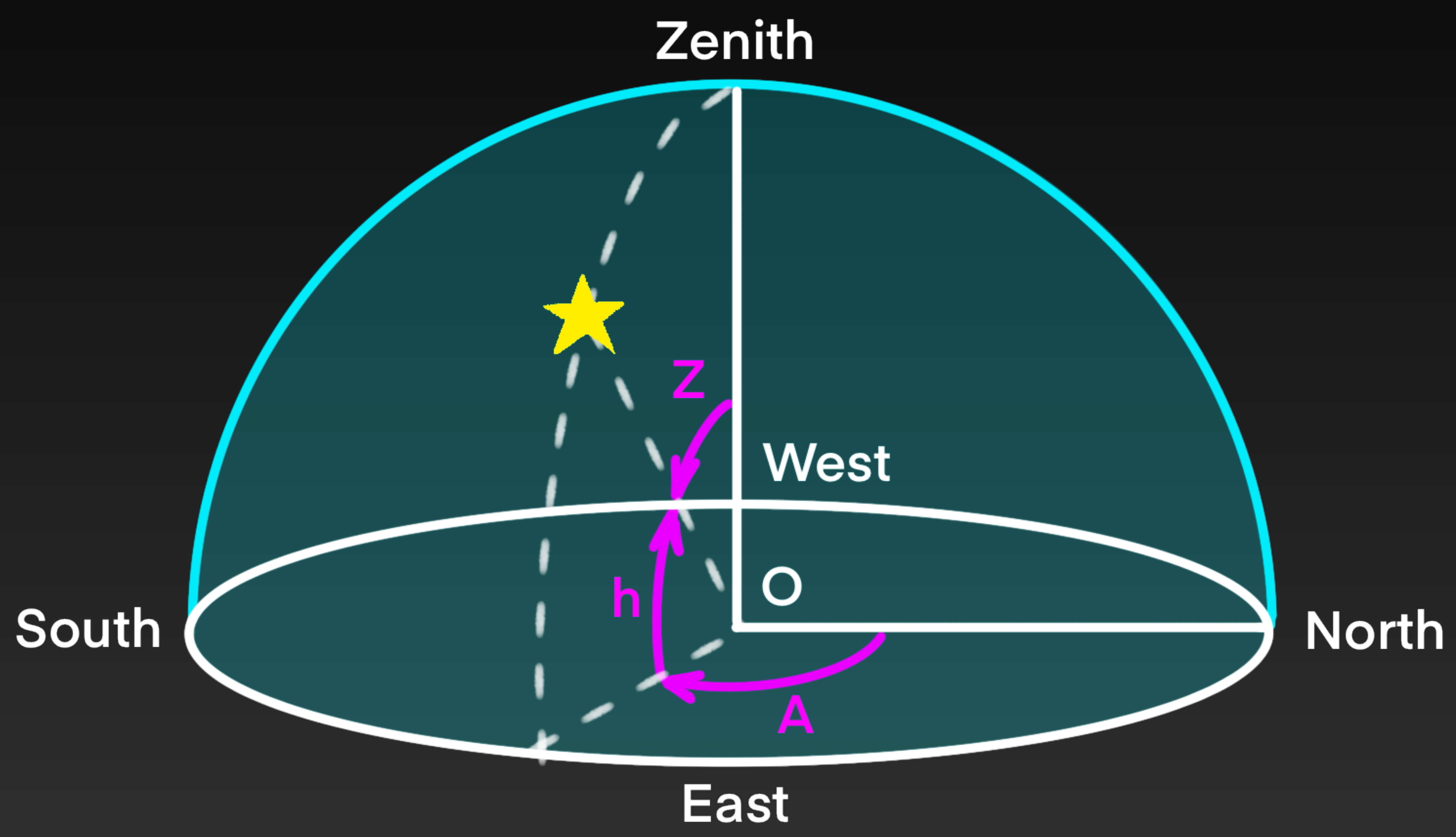
Horizon Coordinates - Altitude/Azimuth

- Altitude (h) -> from the horizon to the target
- Azimuth (A) -> from the North to the target along the horizon
- Zenith Angle: z = 90 deg - h
- CONSTANTLY CHANGING!



Horizon Coordinates - Altitude/Azimuth

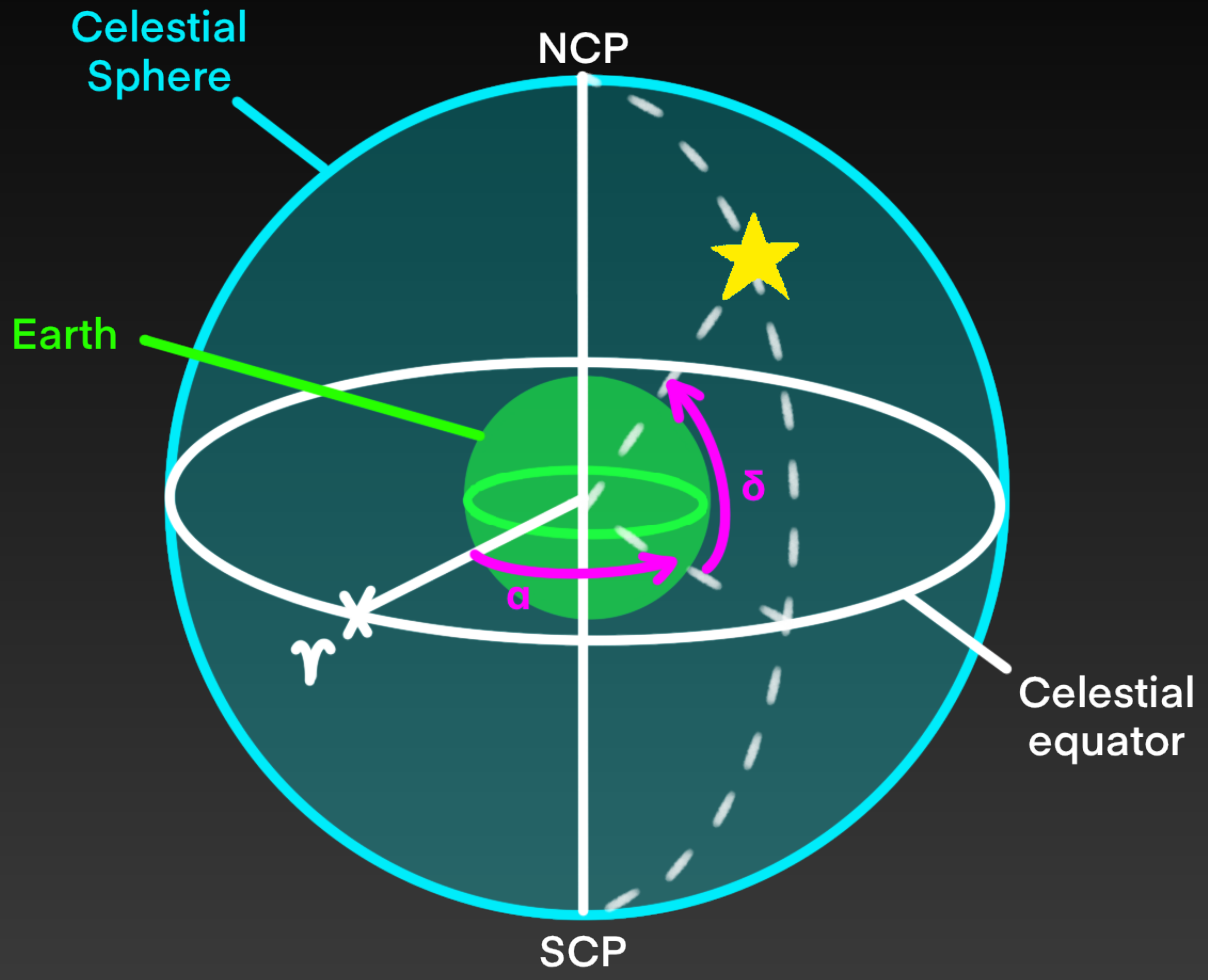
- Altitude (h) -> from the horizon to the target
- Azimuth (A) -> from the North to the target along the horizon
- Zenith Angle: z = 90 deg - h
- Mostly used to define the position of the telescope or how high the target is on the sky
- E.g.: Minimum elevation VLT UTs: 20 degrees
- Avoiding zenith crossing



Equatorial Coordinates

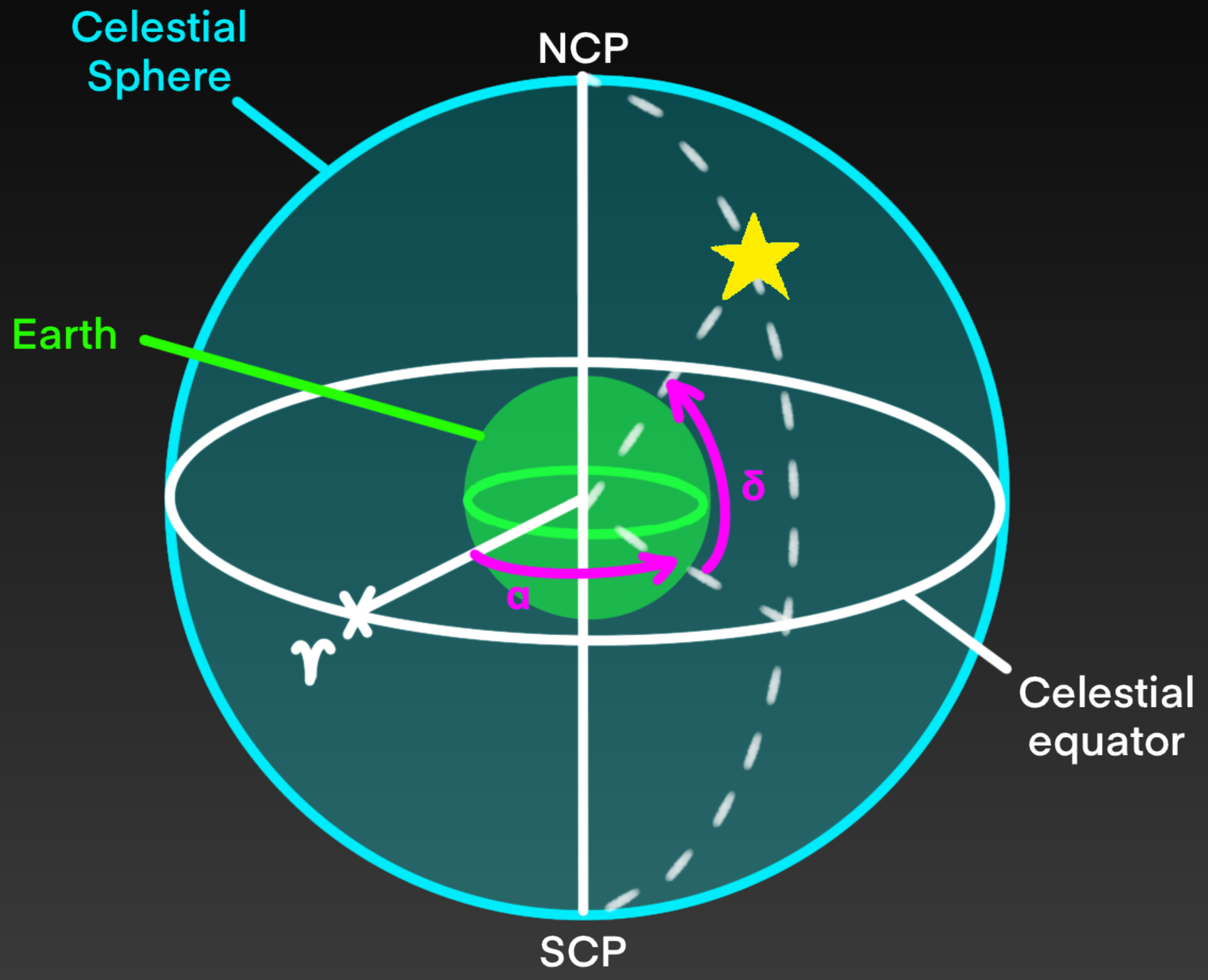
Equatorial Coordinates

- Origin -> Center of the Earth
- Fundamental plane -> Earth's Equator
- Earth's polar axis



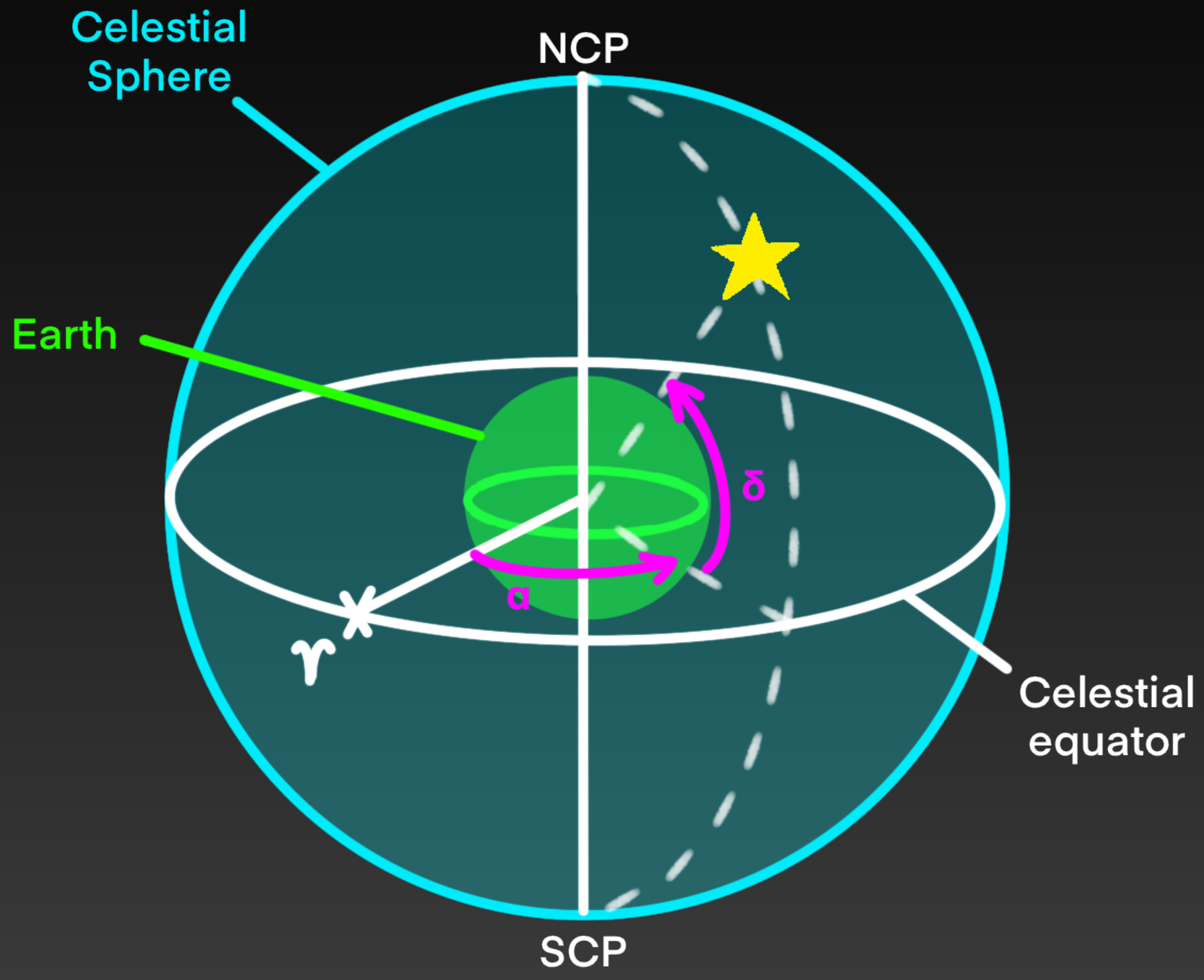
Equatorial Coordinates

- Sources are located in the "Celestial Sphere"
- Celestial Equator: proyection of the Earth's Equator the celestial sphere
- Celestial poles: Intersection of the celestial sphere and the Earth's polar axis



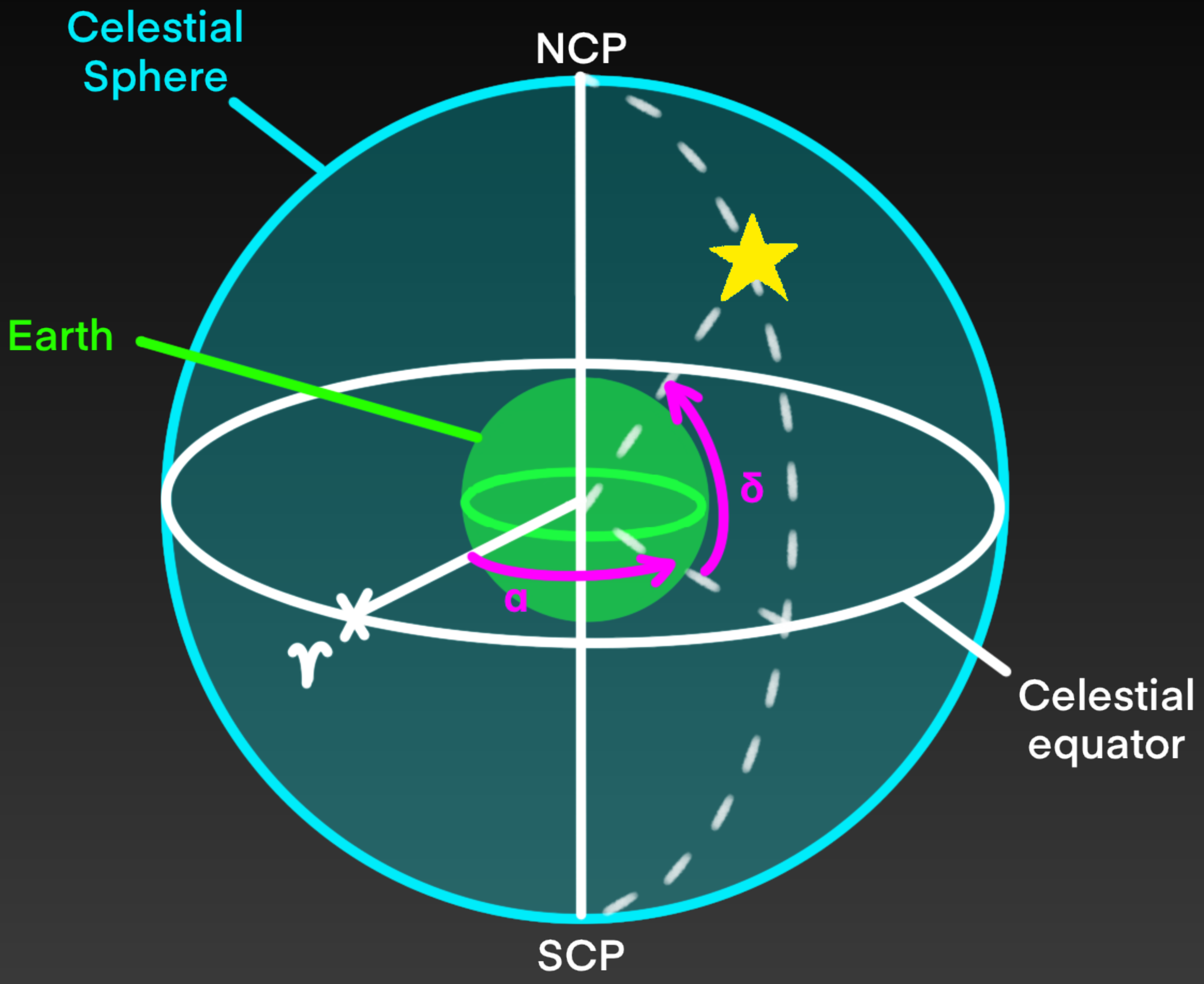
Equatorial Coordinates

- Origin -> Center of the Earth
- Fundamental plane -> Earth's Equator
- Earth's polar axis
- Line joining the origin with the position of the Sun in the Celestial Sphere at the beginning of the spring (in the Northern Hemisphere)



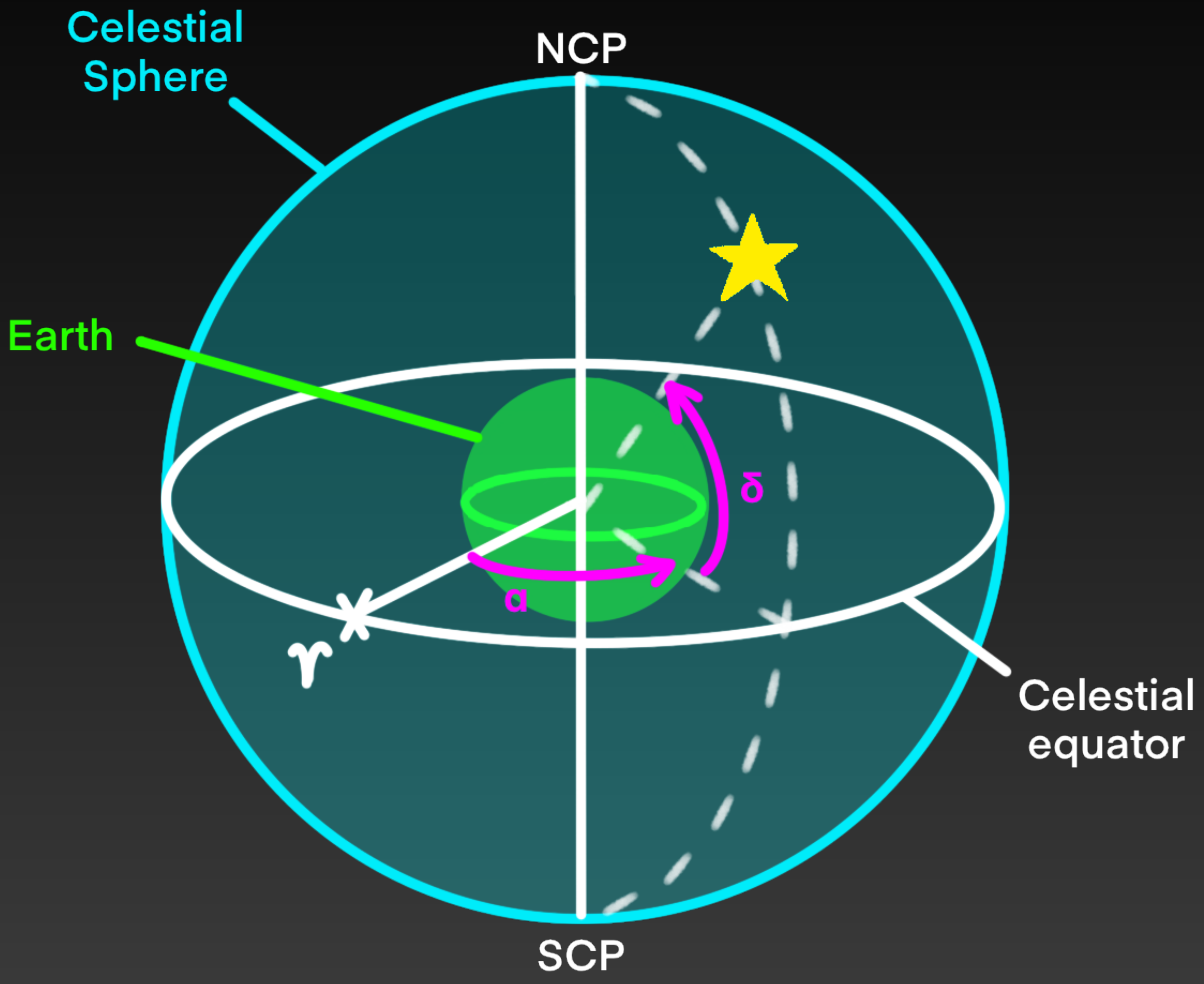
Equatorial Coordinates

- Earth's polar axis
- Line joining the origin with the position of the Sun in the Celestial Sphere at the beginning of the spring (in the Northern Hemisphere)
- Declination (Dec. or δ): vertical angle from the equator to the pole
- Right Ascension (RA or α): from the RA origin to the target along the equatorial plane



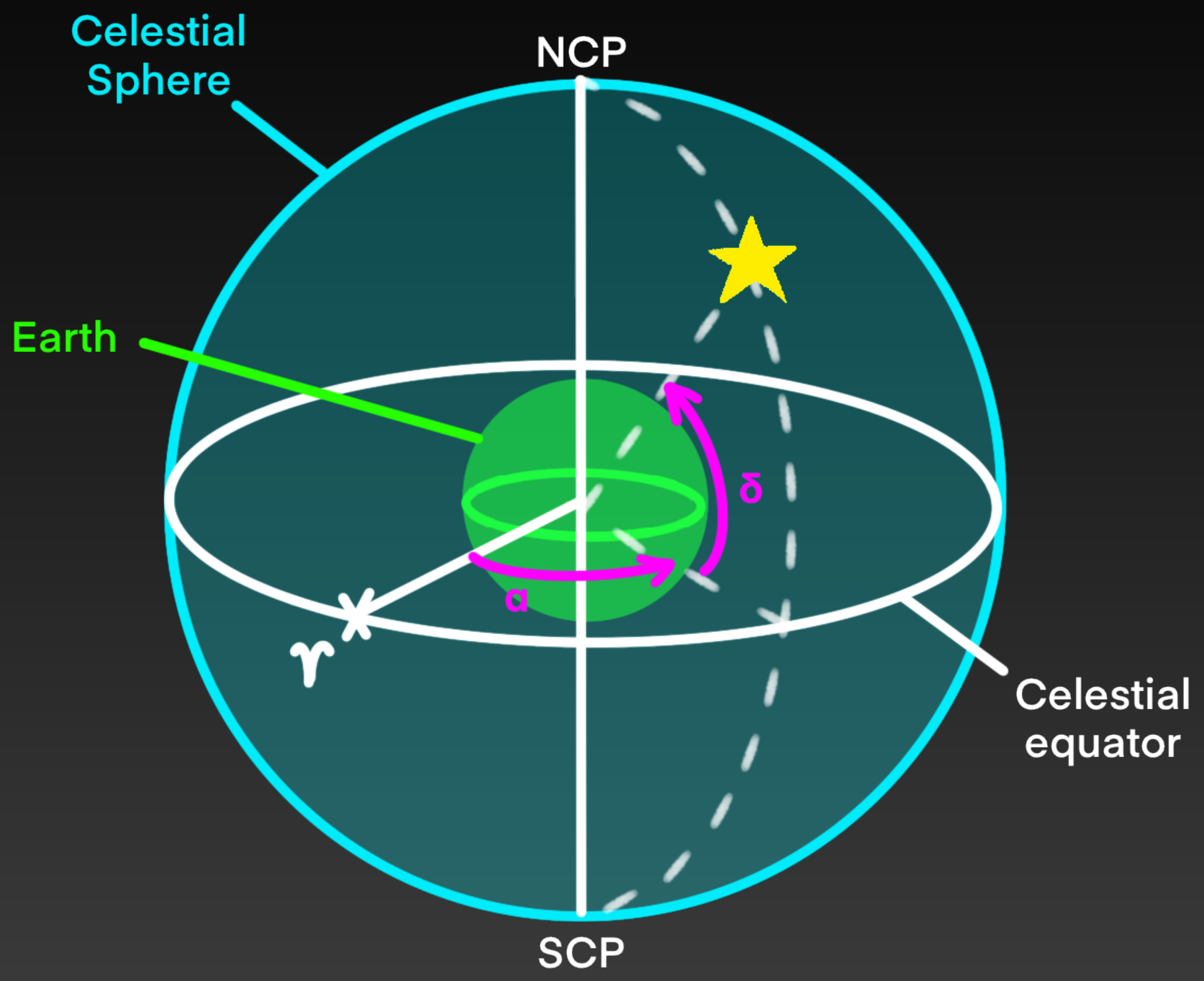
Equatorial Coordinates

- Declination (Dec. or δ): vertical angle from the equator to the pole -> similar to longitude
- Right Ascension (RA or α): from the RA origin to the target along the equatorial plane -> similar to latitude
- RA can be expressed in hours with 1 h = 15 degrees



Equatorial Coordinates

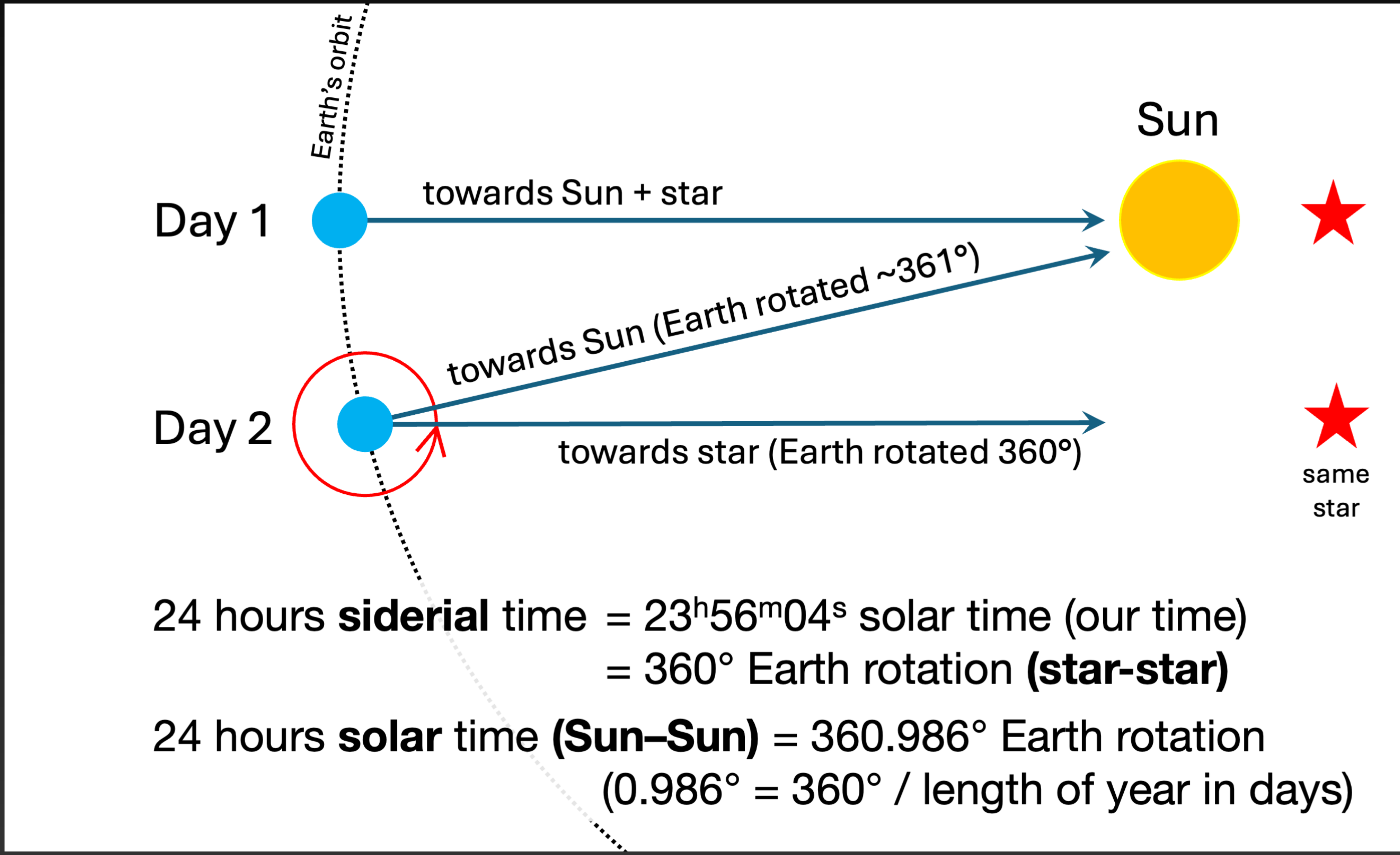
- Declination (Dec. or δ): vertical angle from the equator to the pole
- Right Ascension (RA or α): from the RA origin to the target along the equatorial plane
- RA can be expressed in hours with 1 h = 15 degrees

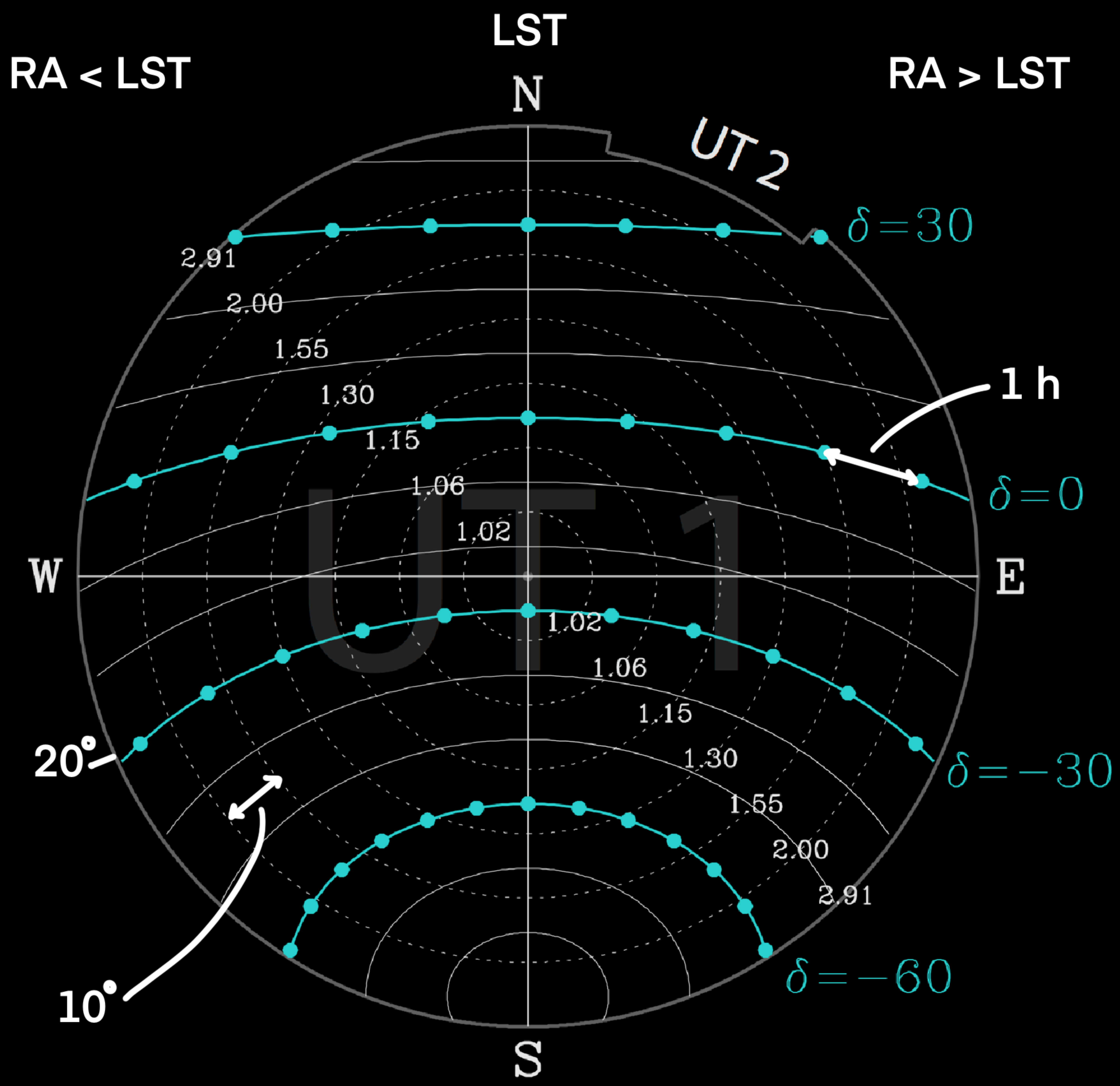


Local Sidereal Time

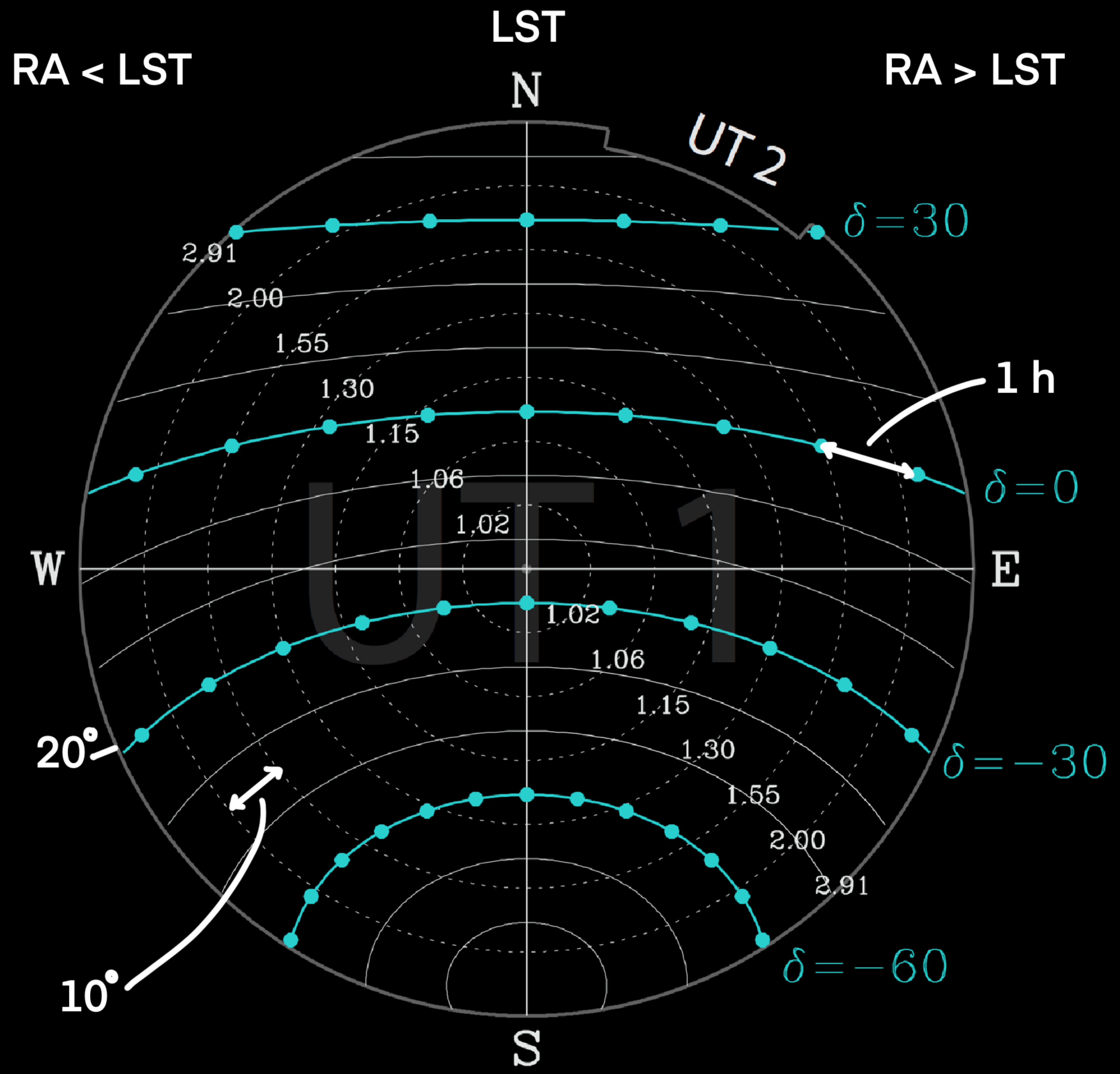
Local Sidereal Time

- Meridian: plane joining the Zenith with the Celestial Poles
- Local Sidereal Time (LST): RA of the Meridian
- Also related with the time it takes the Sun to do a full lap with respect to the stars
- A star with RA = a will cross the meridian at LST = a

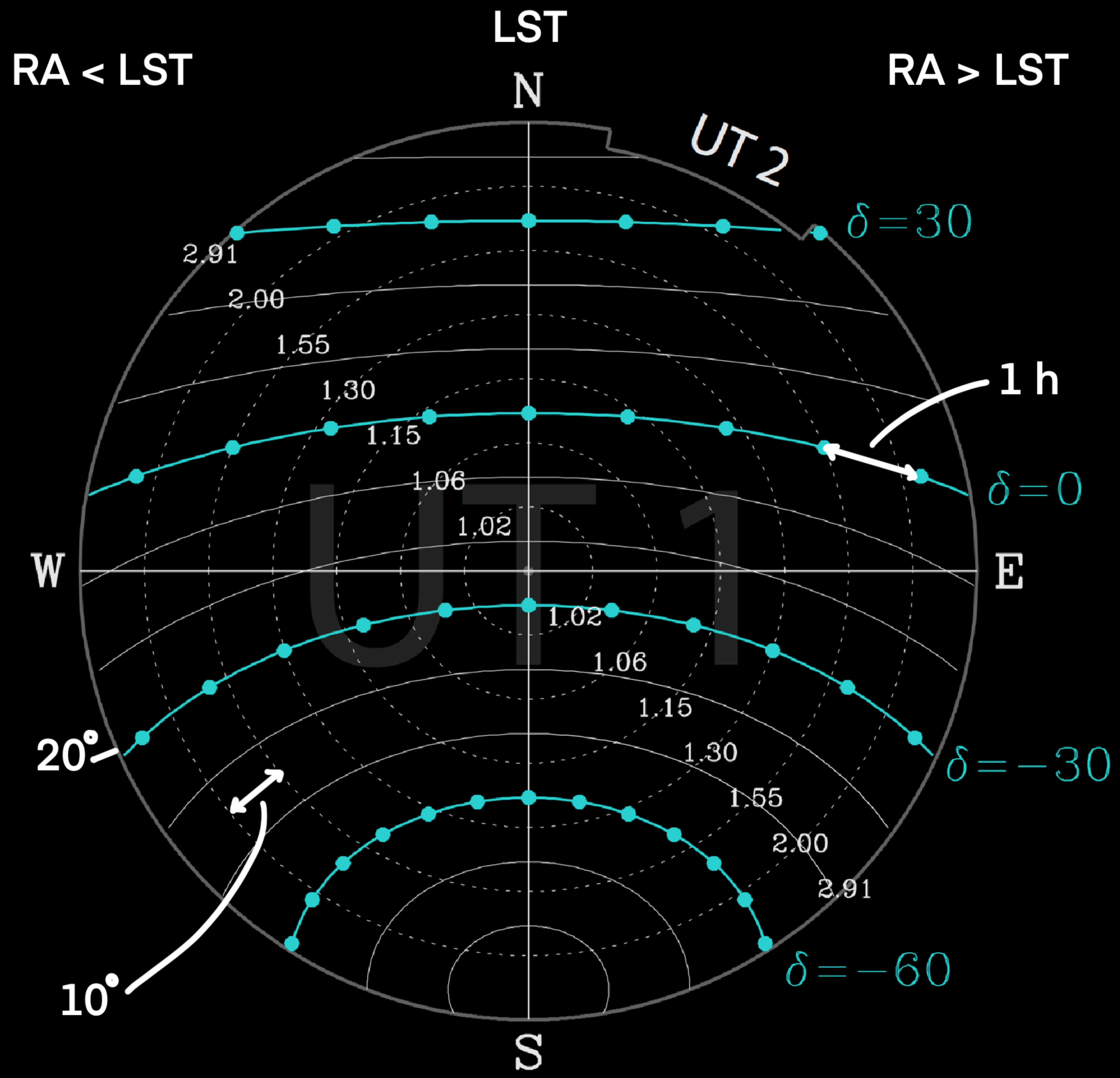



LST
RA < LST
RA > LST
N
UT 2
δ=30
2.91
2.00
1.55
1.30
1.15
1.06
1.02
1 h
δ=0
UT 1
W
E
1.02
1.06
1.15
1.30
1.55
2.00
2.91
20°
δ=−30
10°
δ=−60
S

- In Paranal
- LST ~3 h
- Target: RA ~5 h, Dec ~ -10 deg
- What would be its elevation seen from UT1?



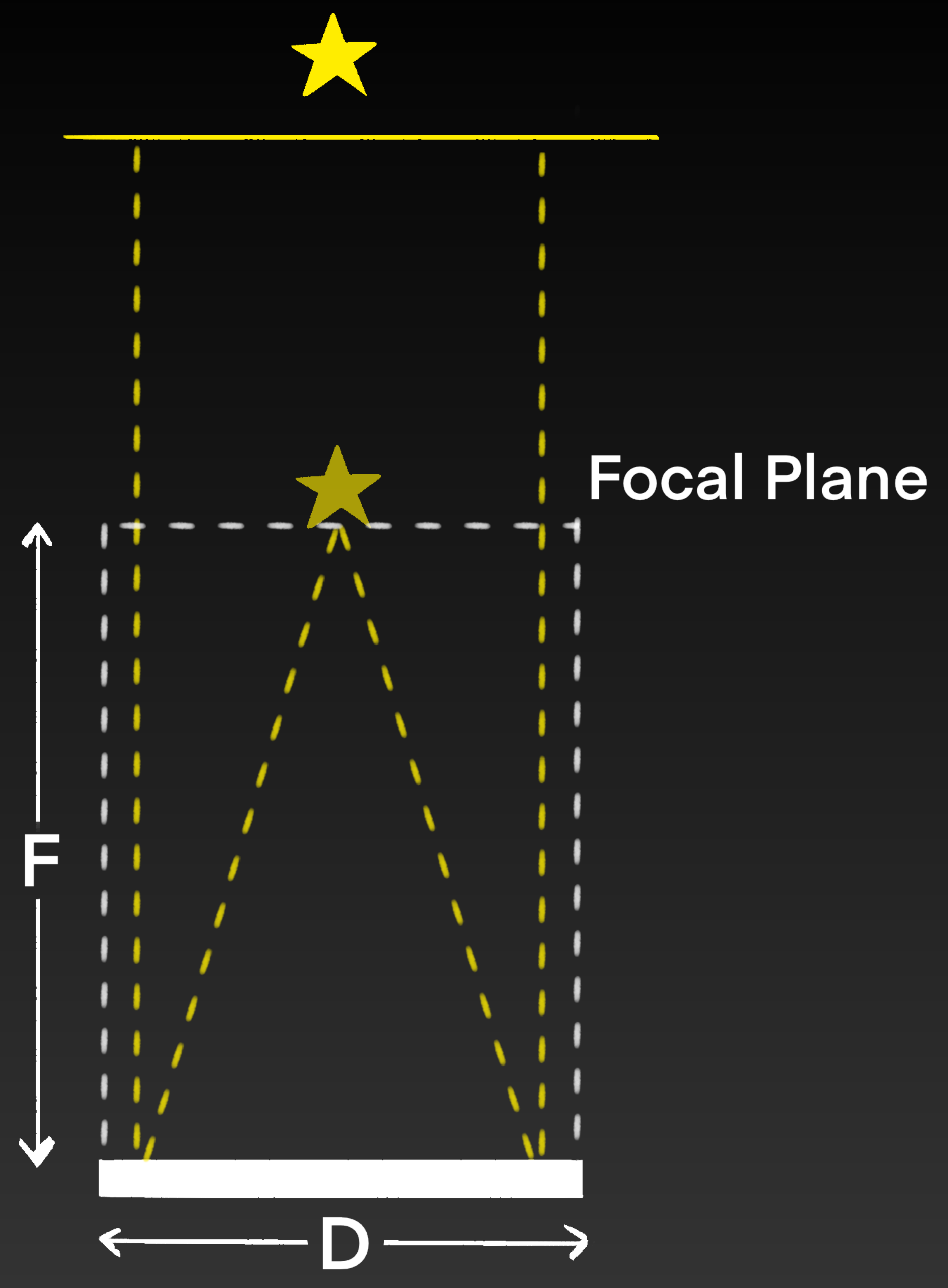
- In Paranal
- LST ~9 h
- Target: RA ~5 h, Dec ~ -10 deg
- What would be its elevation seen from UT1?
- How much longer can we observe?



Introduction to Telescopes

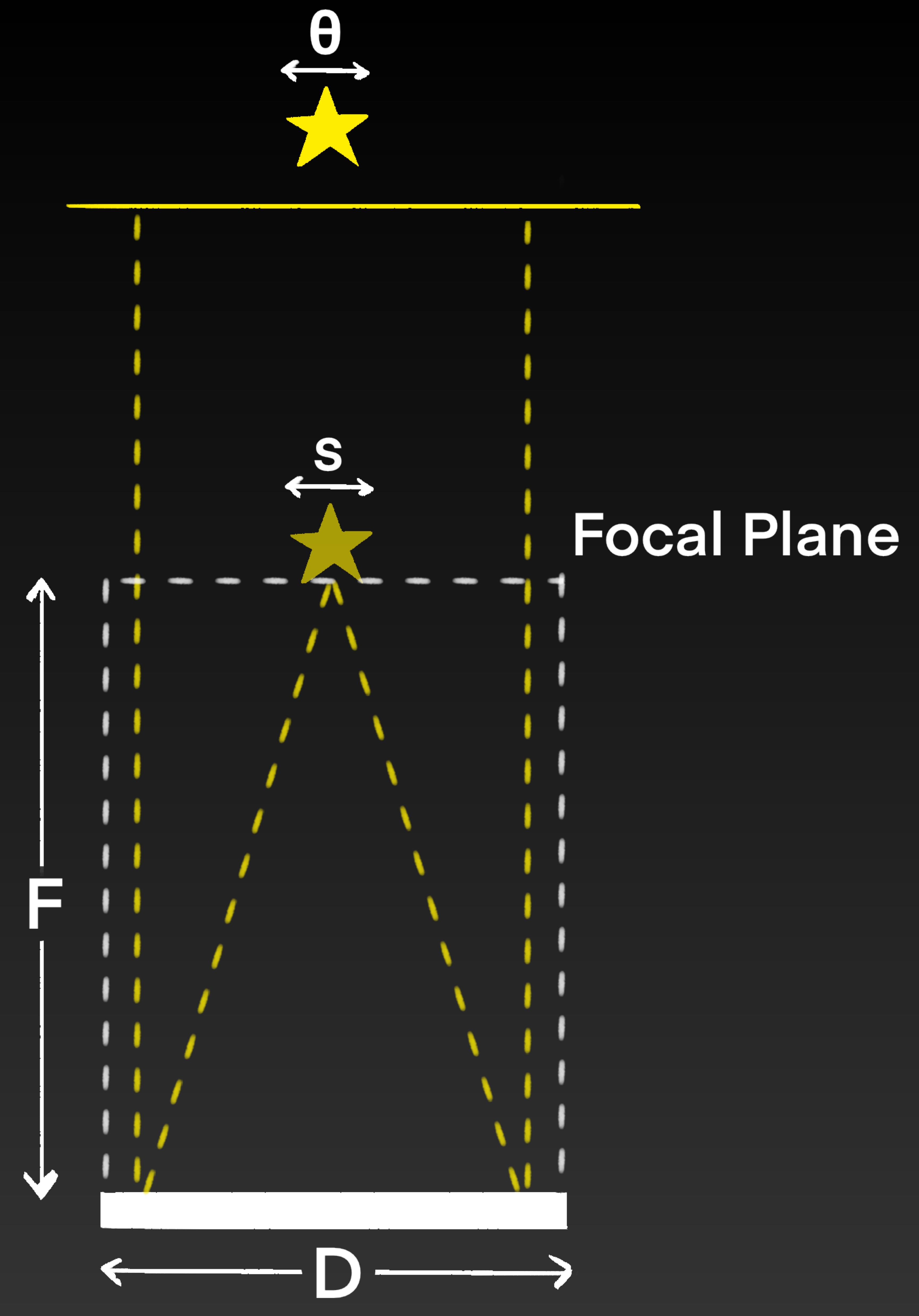
Optical and Infrared Telescopes

- Astronomical sources at infinity create a wavefront that arrives parallel to the telescope.
- Images are projected on the Focal Plane



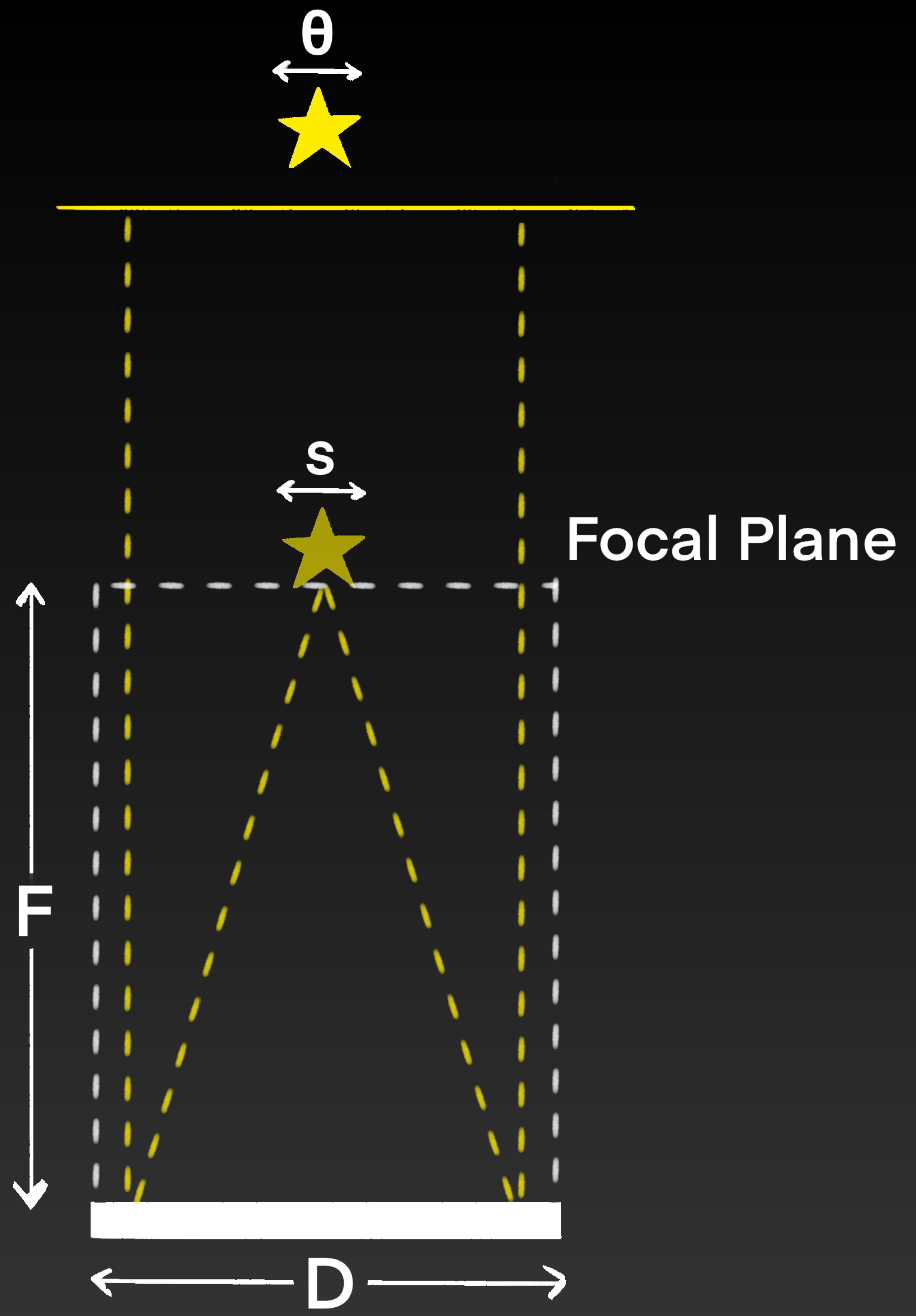
Optical and Infrared Telescopes

- Collective area: D^2



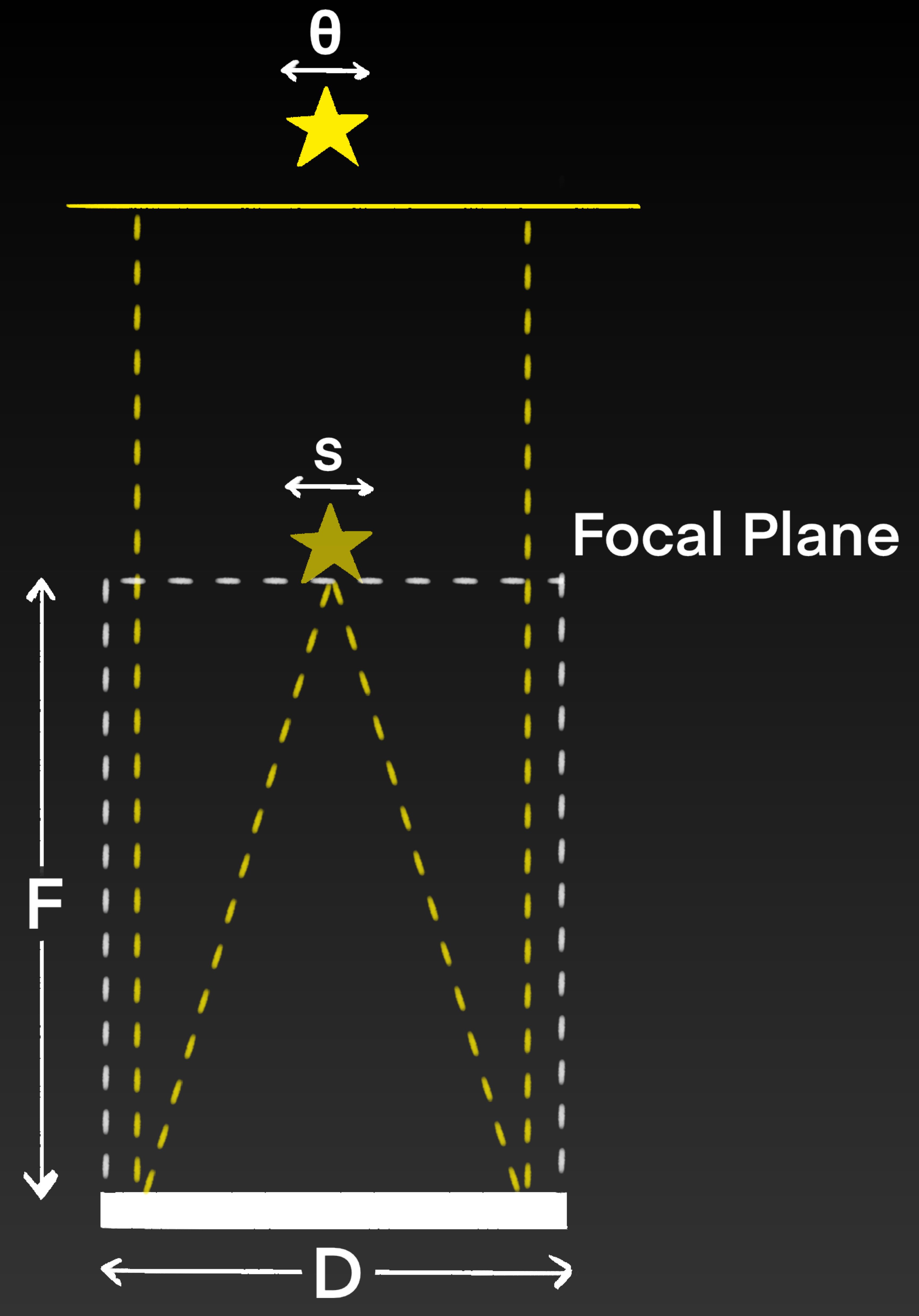
Optical and Infrared Telescopes

- Collective area: D^2
- NTT -> D = 3.58 m
- VLT UTs -> D = 8.20 m -> 5 times more collective area than NTT
- ELT -> D = 39 m -> 22 times more collective area than VLT UTs



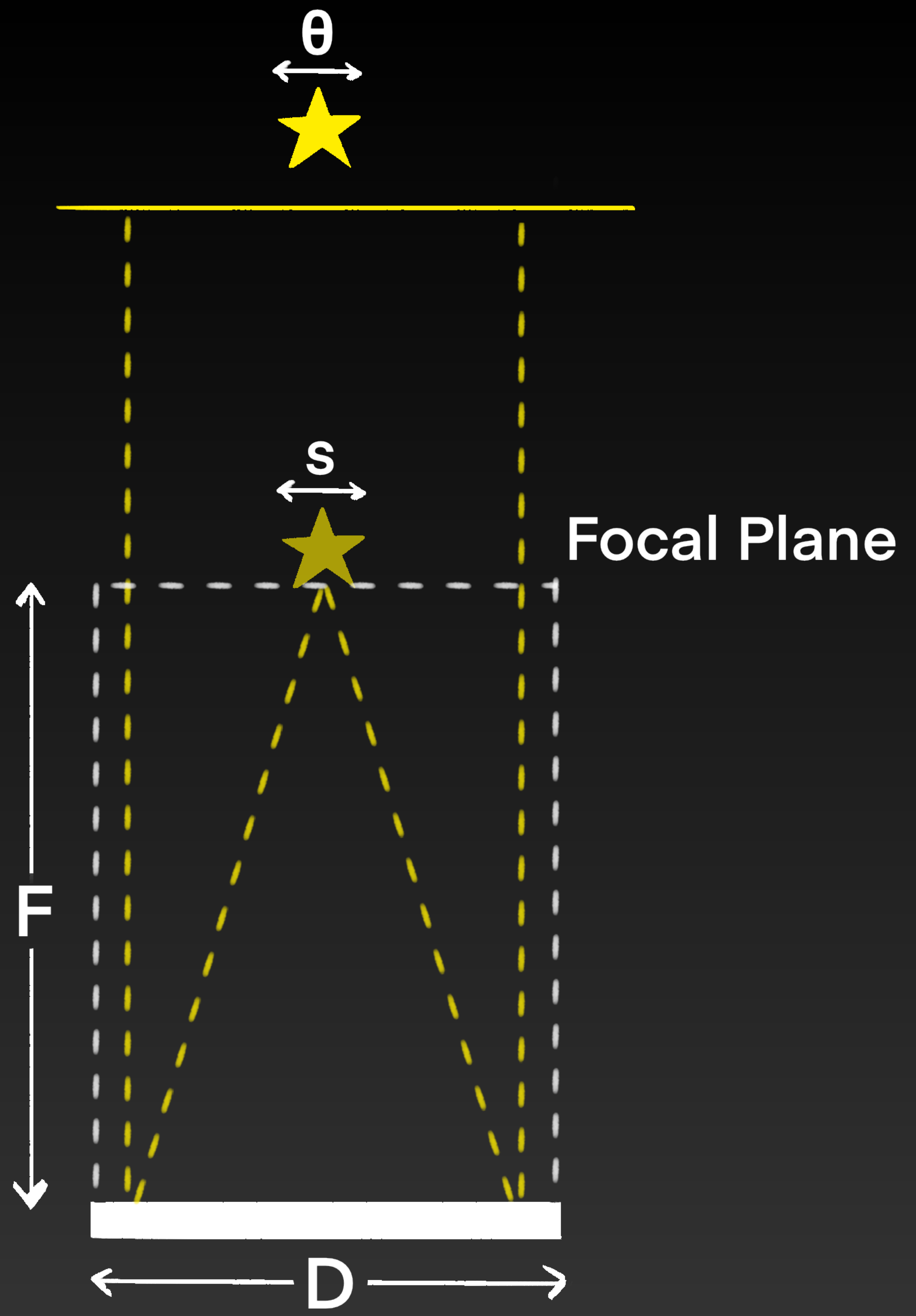
Optical and Infrared Telescopes

- Collective area: D^2
- Focal Length: F
- Plate scale (p): $p = \theta/s = 1/F$



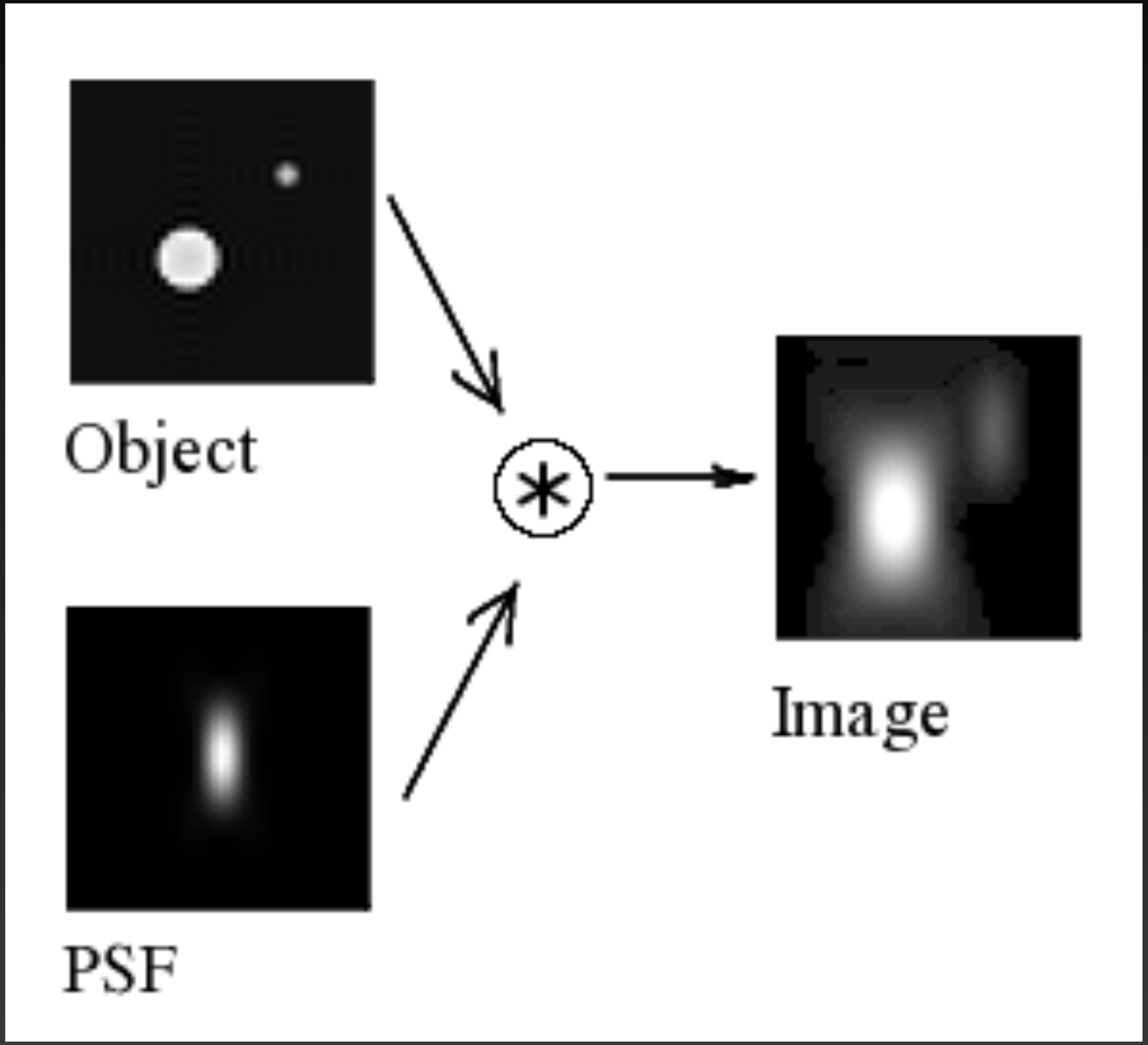
Optical and Infrared Telescopes

- Collective area: D^2
- Focal Length: F
- Plate scale (p): $p = \theta/s = 1/F$
- Angular Resolution: $R = \lambda/D$



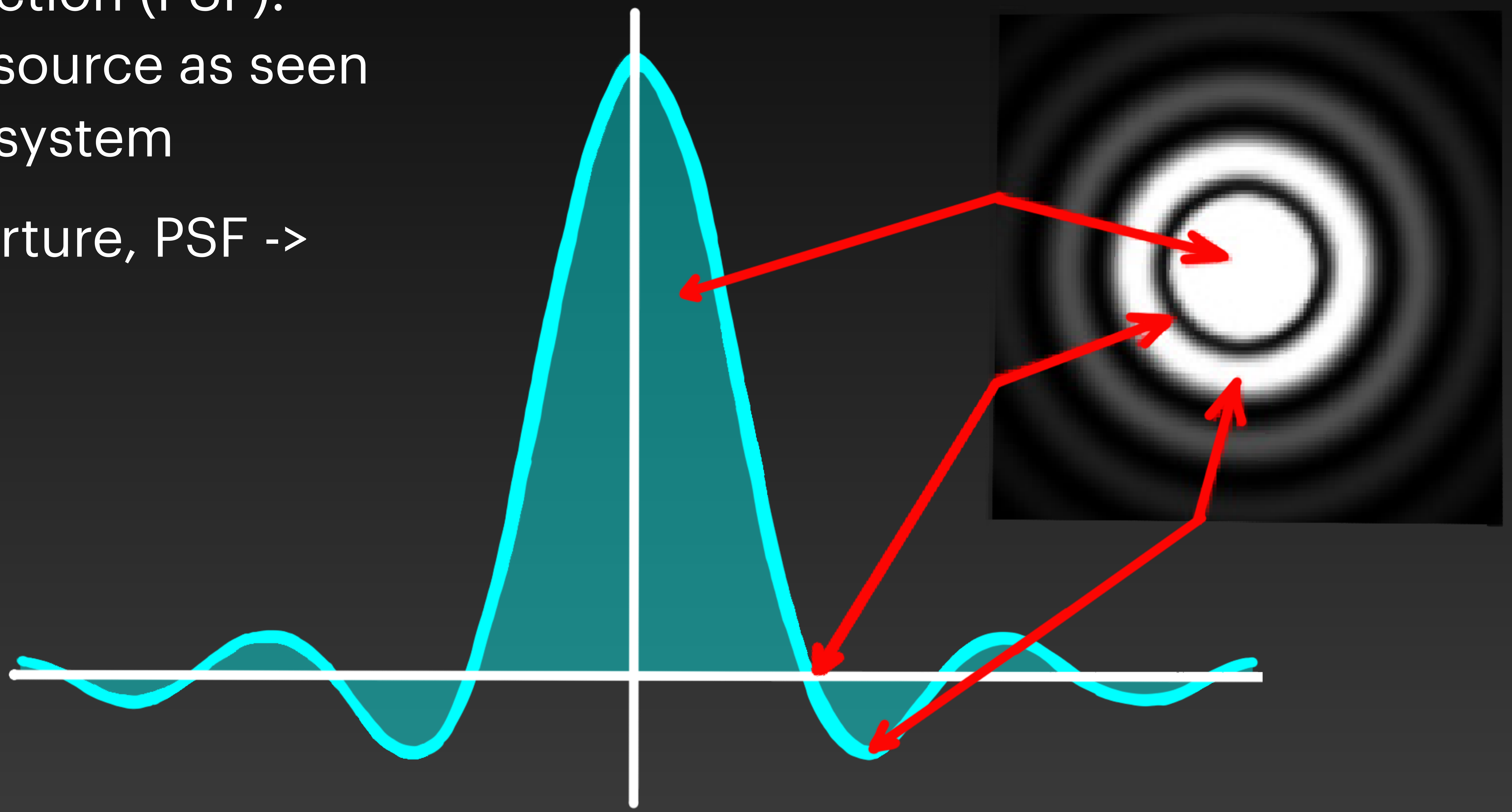
Optical and Infrared Telescopes

- Point Spread Function (PSF): Image of a point source as seen from an imaging system



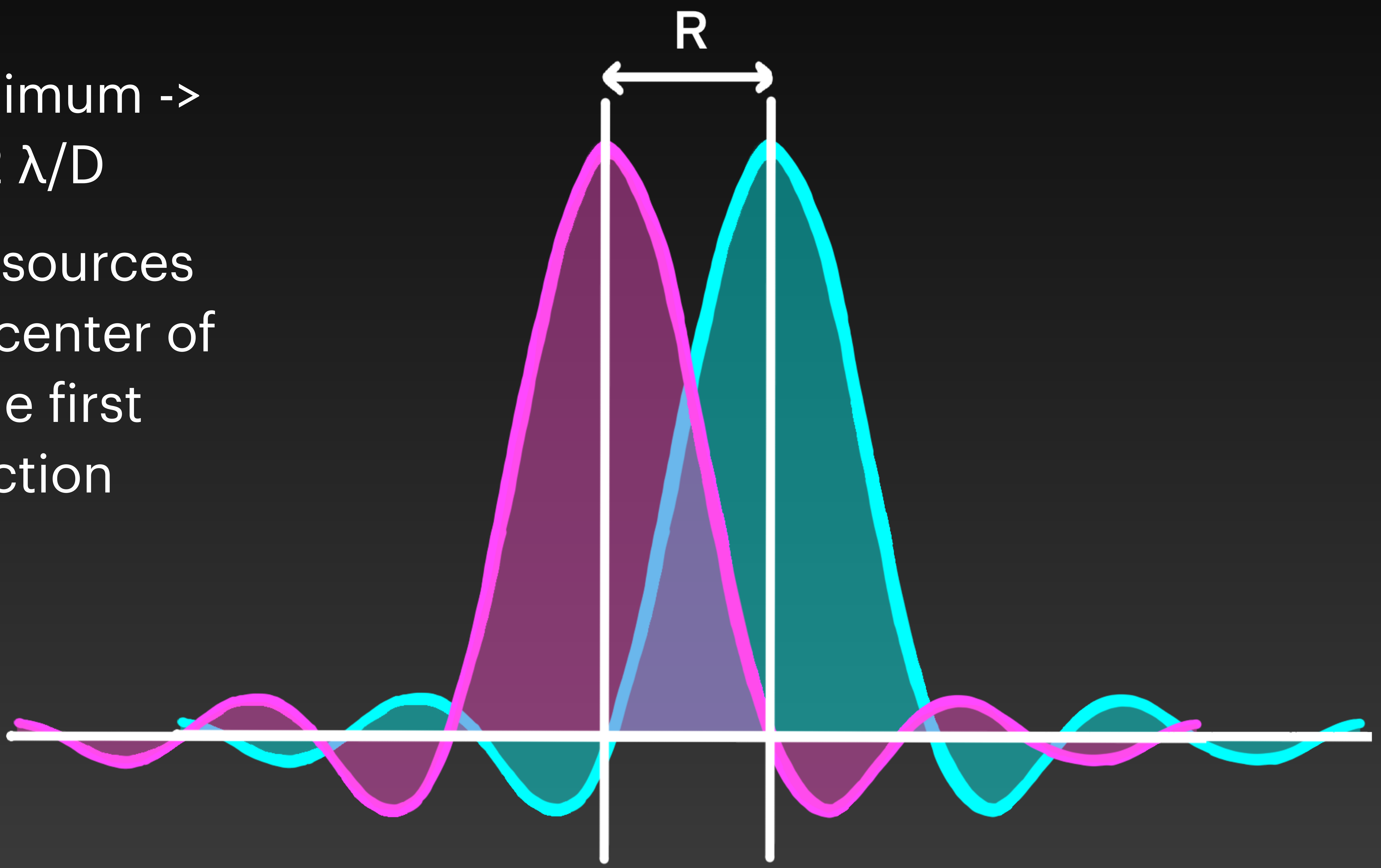
Optical and Infrared Telescopes

- Point Spread Function (PSF): Image of a point source as seen from an imaging system
- For a circular aperture, PSF -> Airy Disk



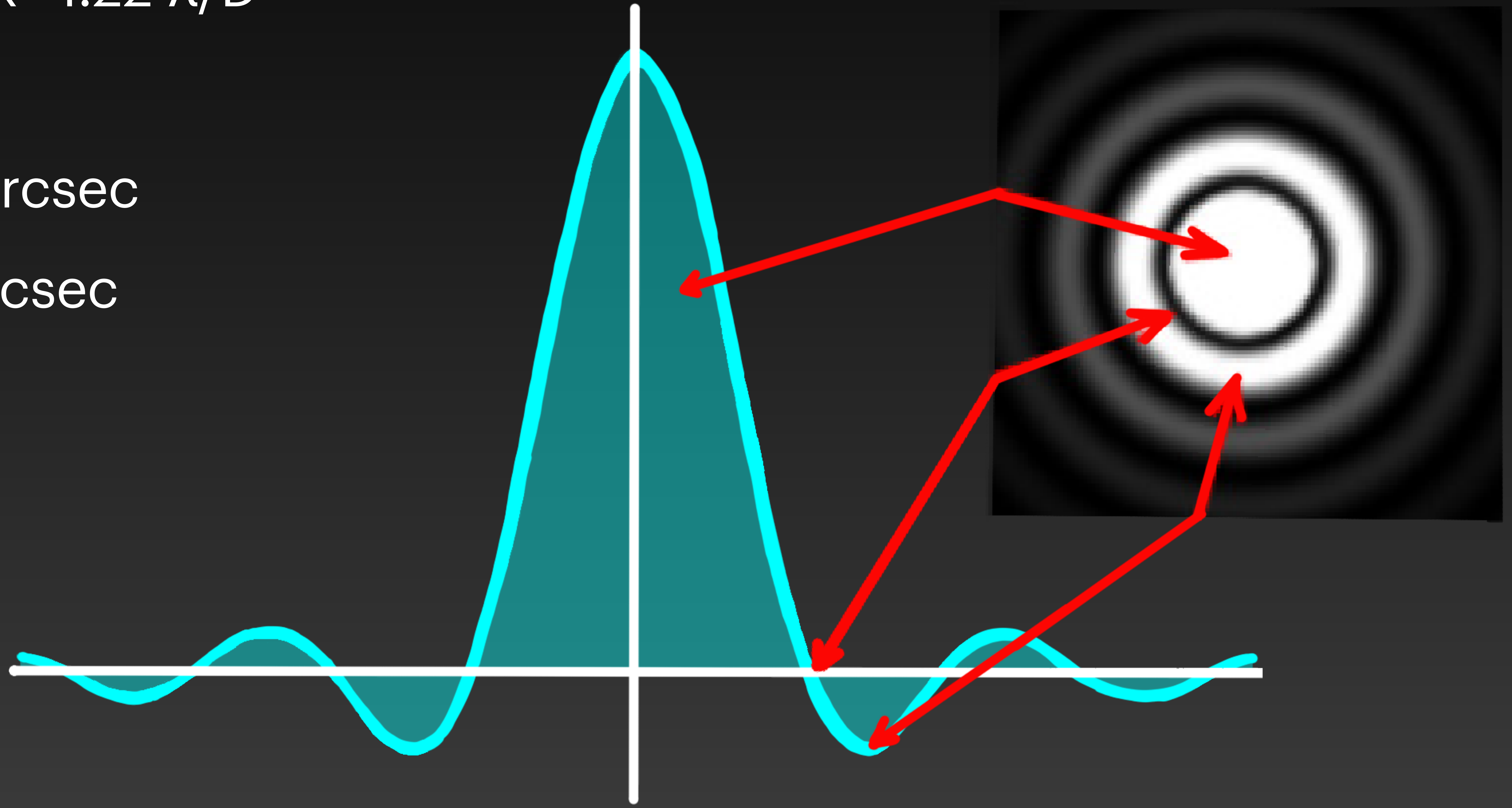
Optical and Infrared Telescopes

- Position of the first minimum -> diffraction limit: R ~1.22 λ/D
- Rayleigh criterion: two sources are resolved when the center of one Airy disk falls on the first zero of the other diffraction pattern



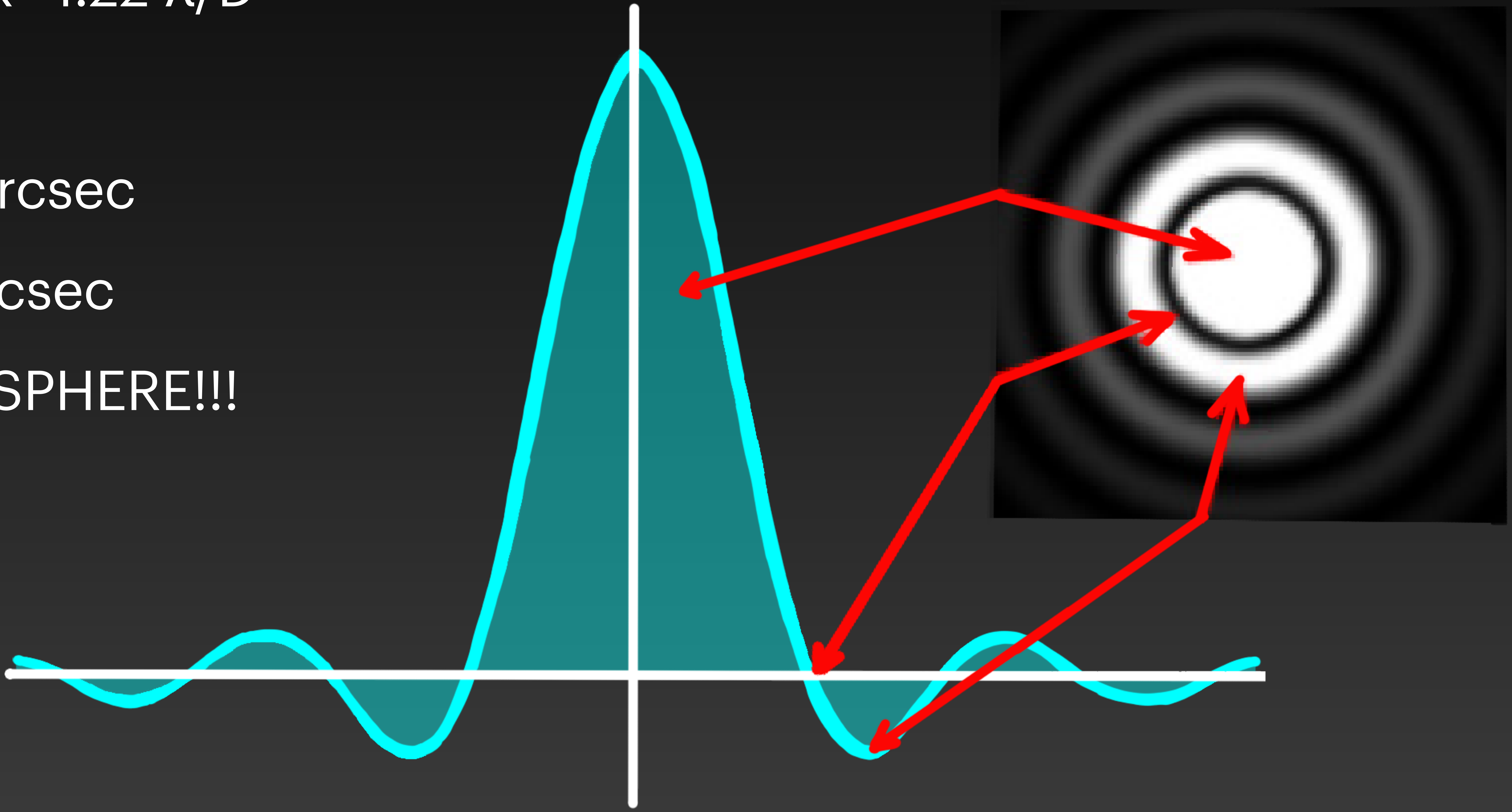
Optical and Infrared Telescopes

- Diffraction limit: R ~1.22 λ/D
- For 500 nm
- NTT -> R ~0.035 arcsec
- VLT -> R ~0.015 arcsec



Optical and Infrared Telescopes

- Diffraction limit: R ~1.22 λ/D
- For 500 nm
- NTT -> R ~0.035 arcsec
- VLT -> R ~0.015 arcsec
- However... ATMOSPHERE!!!



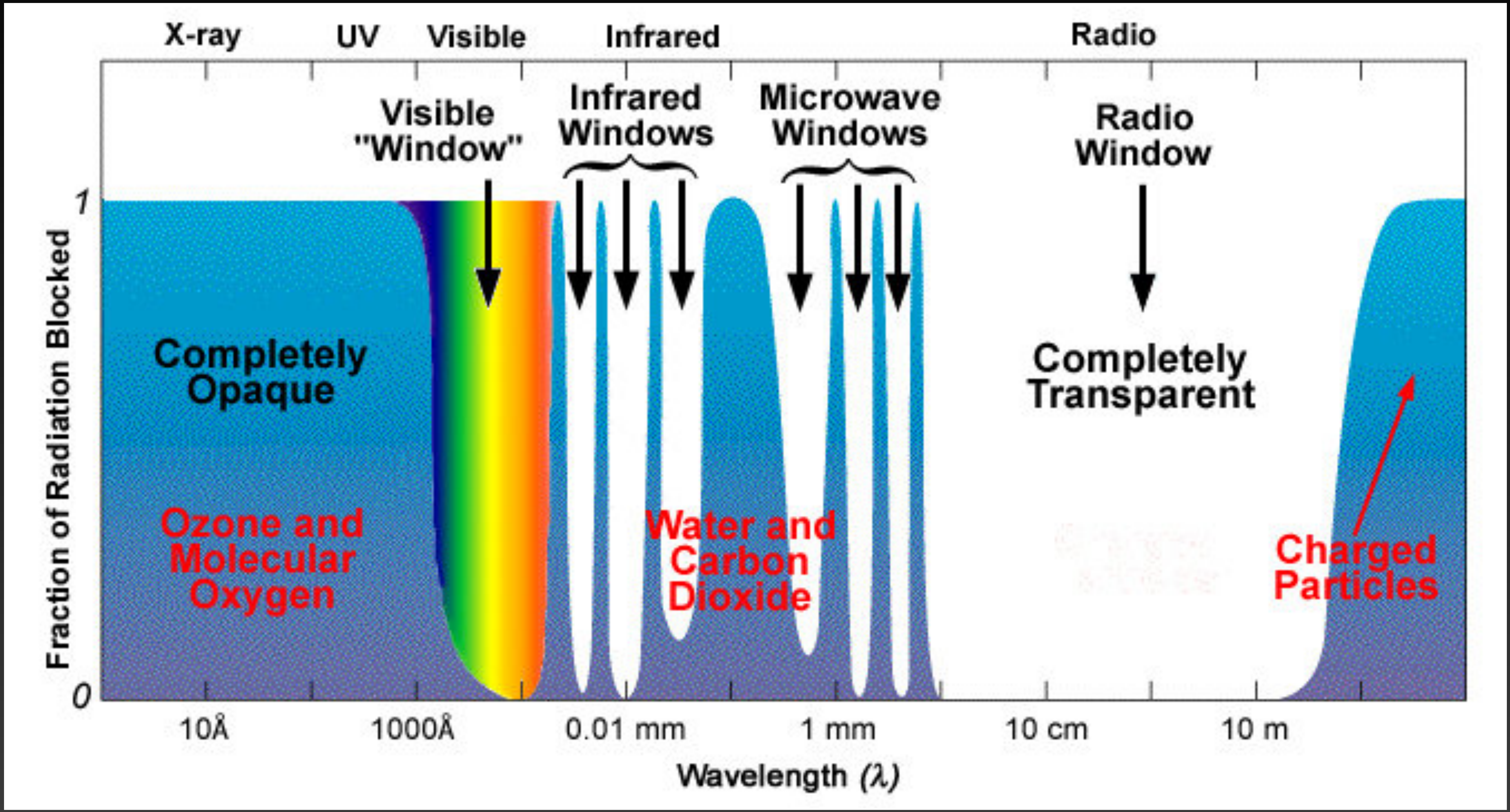
Atmospheric Effects

Atmospheric Effects

- Transmission
- Turbulence
- Airmass and Altitude
- Sky Background
- Extinction
- Cloud coverage and humidity

Atmospheric Transmission

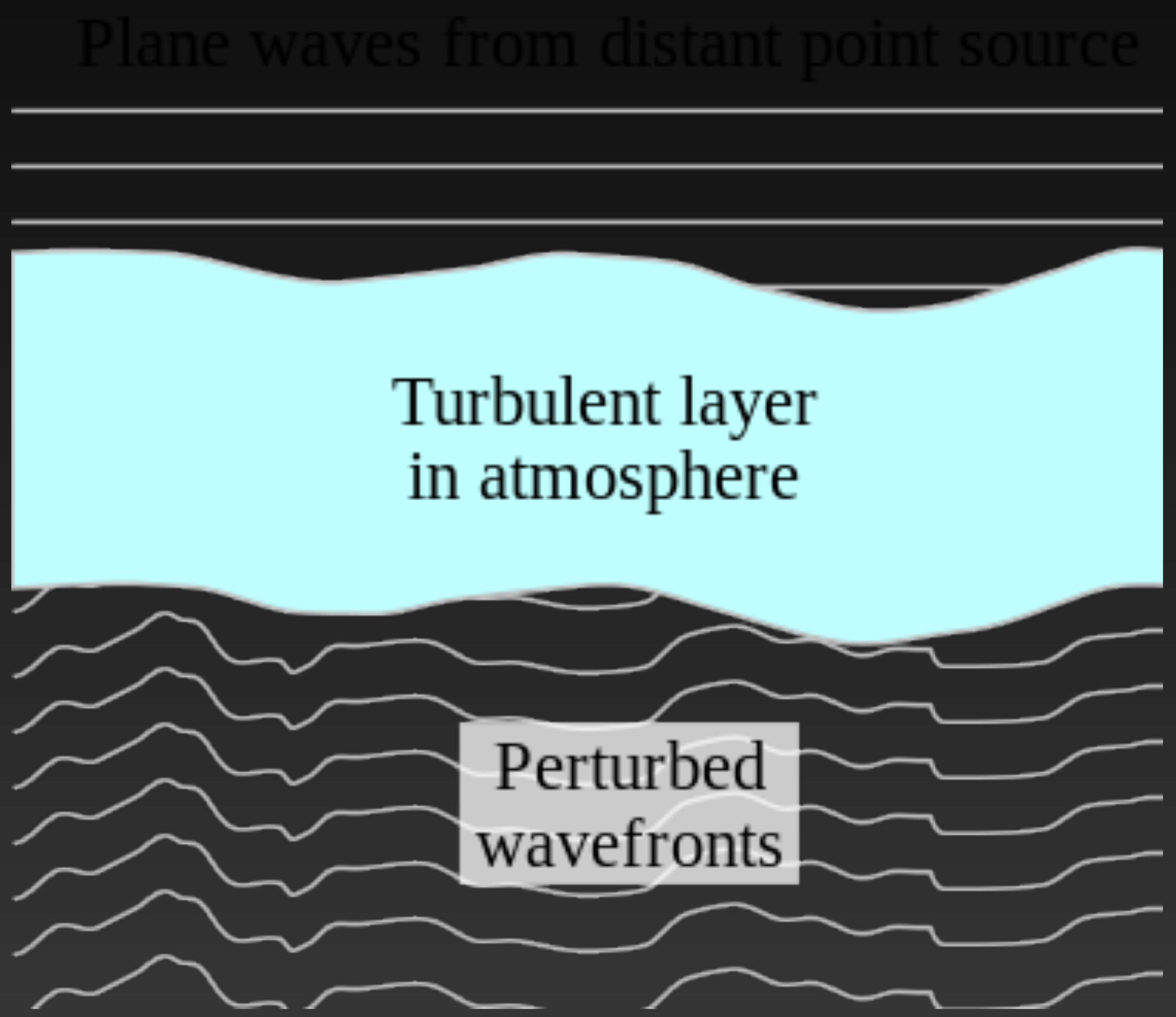
Atmospheric Transmission



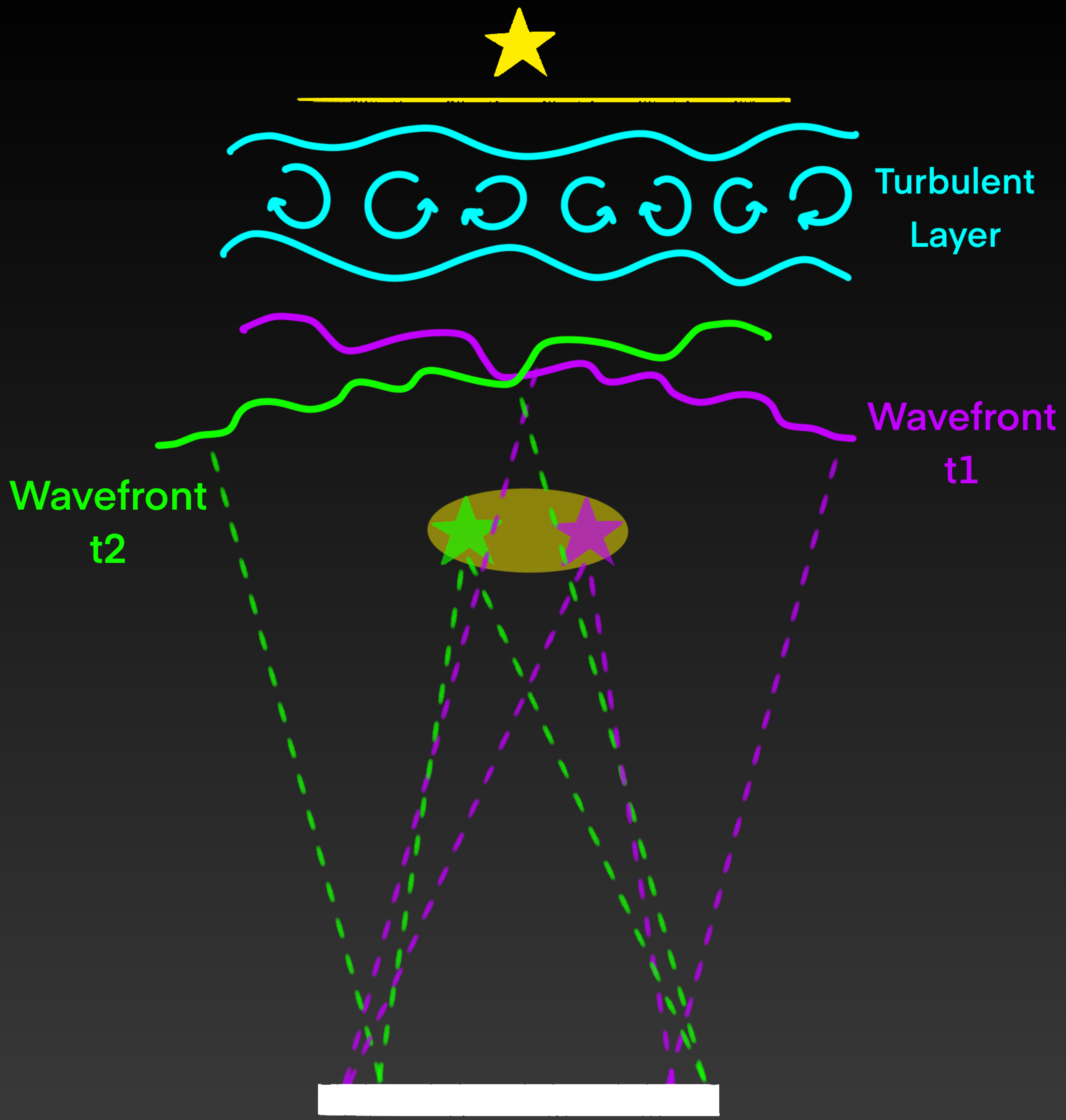
Atmospheric Turbulence

Atmospheric Turbulence

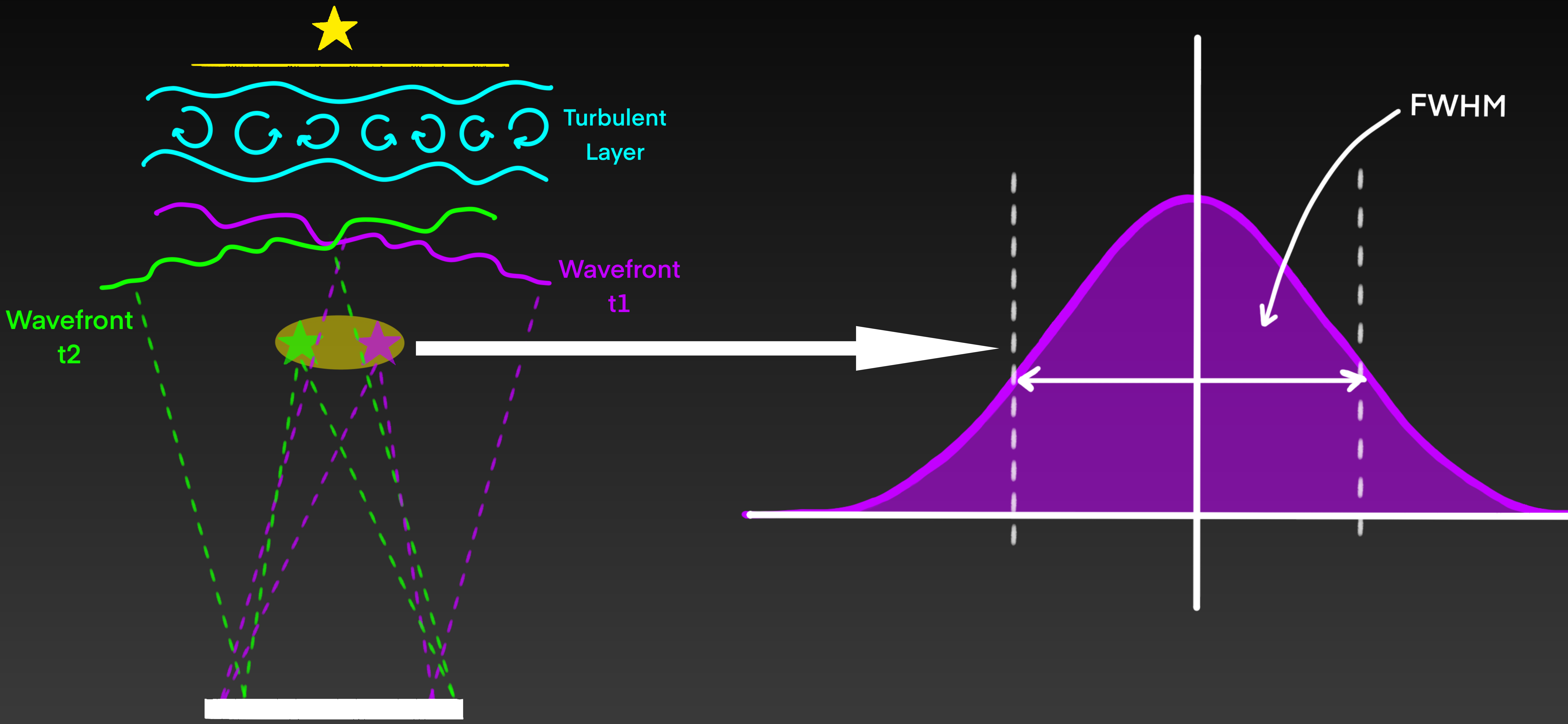
- Flat wavefronts from a point source at infinity get distorted due to atmospheric turbulence



Atmospheric Turbulence

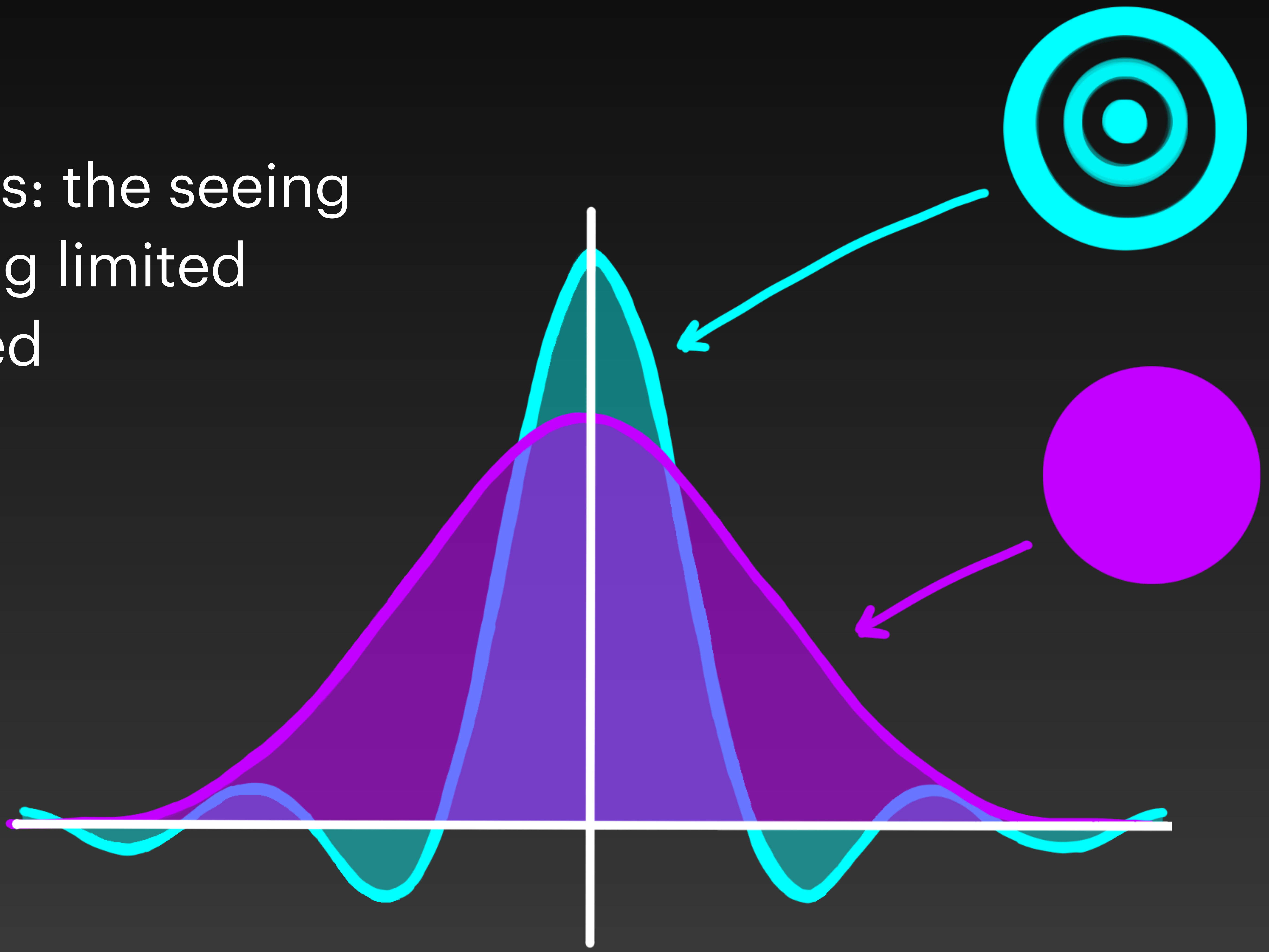


Atmospheric Turbulence



Seeing

- Ground-based observations: the seeing dominates the PSF -> seeing limited instead of diffraction limited



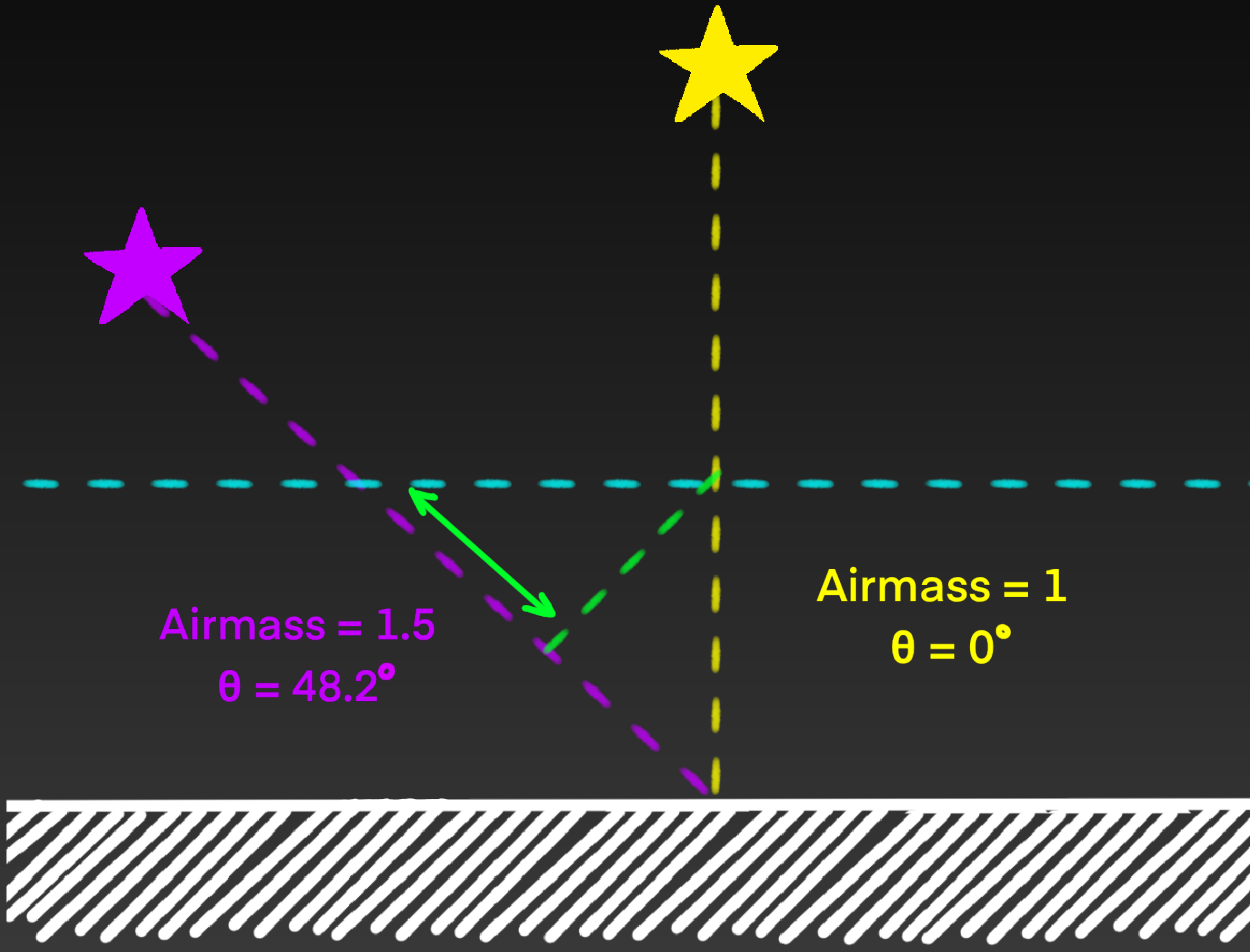
Seeing

- Good seeing: ~0.6 - 1.0 arcsec
- Poor seeing: > 2.0 arcsec

Airmass and Altitude

Airmass and Altitude

- Increase with the size of the atmospheric layer along the line of sight:
  - Observatories built at high altitudes
  - Airmass: X = sec(z), where z is the zenith angle



Additional things to consider...

Atmospheric effects

- Atmospheric transmission: limits observing bands
- Turbulence: reduces image quality
- Light pollution: increases sky background

Atmospheric effects

- Atmospheric transmission: limits observing bands
- Turbulence: reduces image quality
- Light pollution: increases sky background
- Dust and molecules: changes in extinction

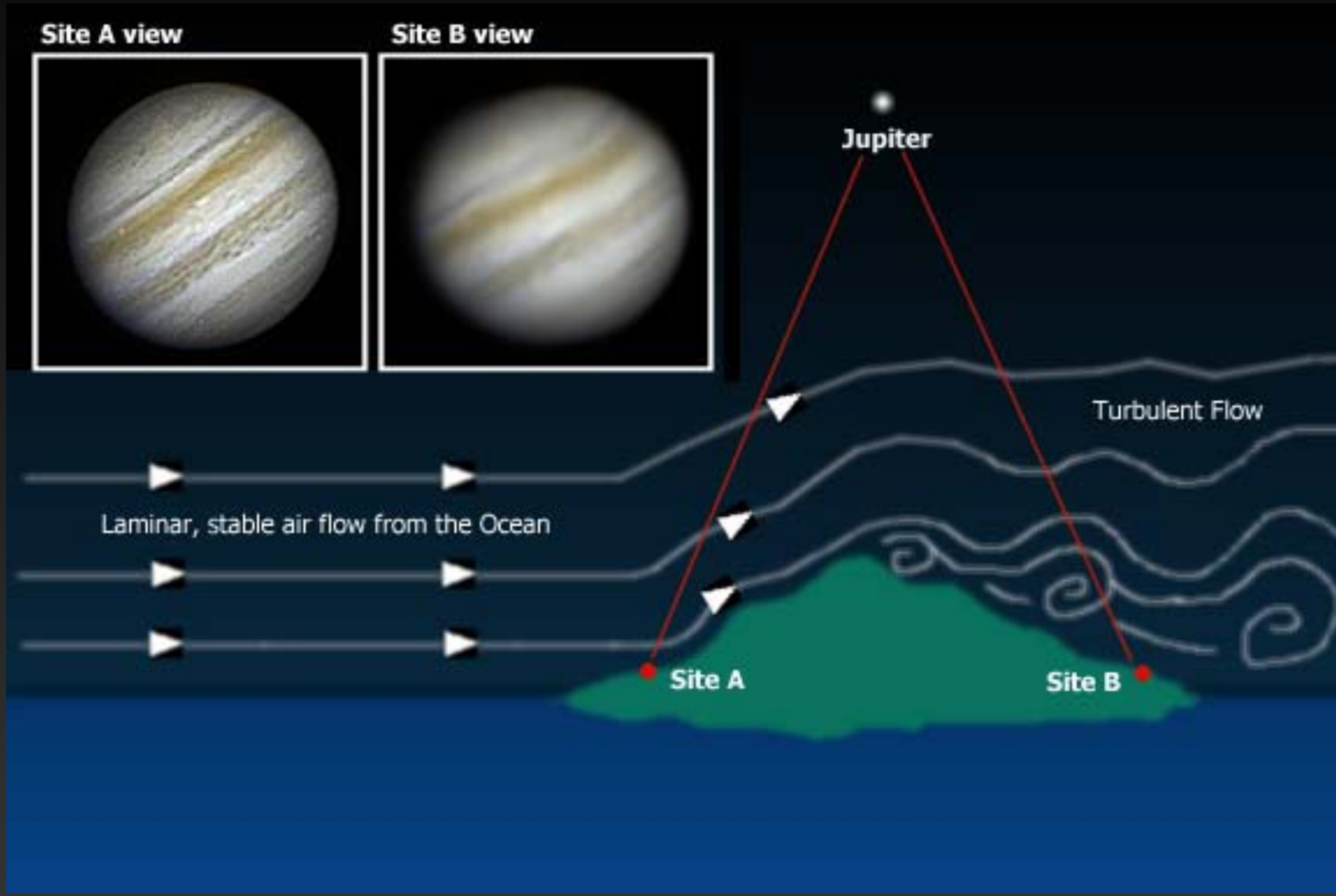
Atmospheric effects

- Atmospheric transmission: limits observing bands
- Turbulence: reduces image quality
- Light pollution: increases sky background
- Dust and molecules: changes in extinction
- Clouds and humidity: changes in transparency and transmission

Atmospheric Effects

Best places to build an observatory

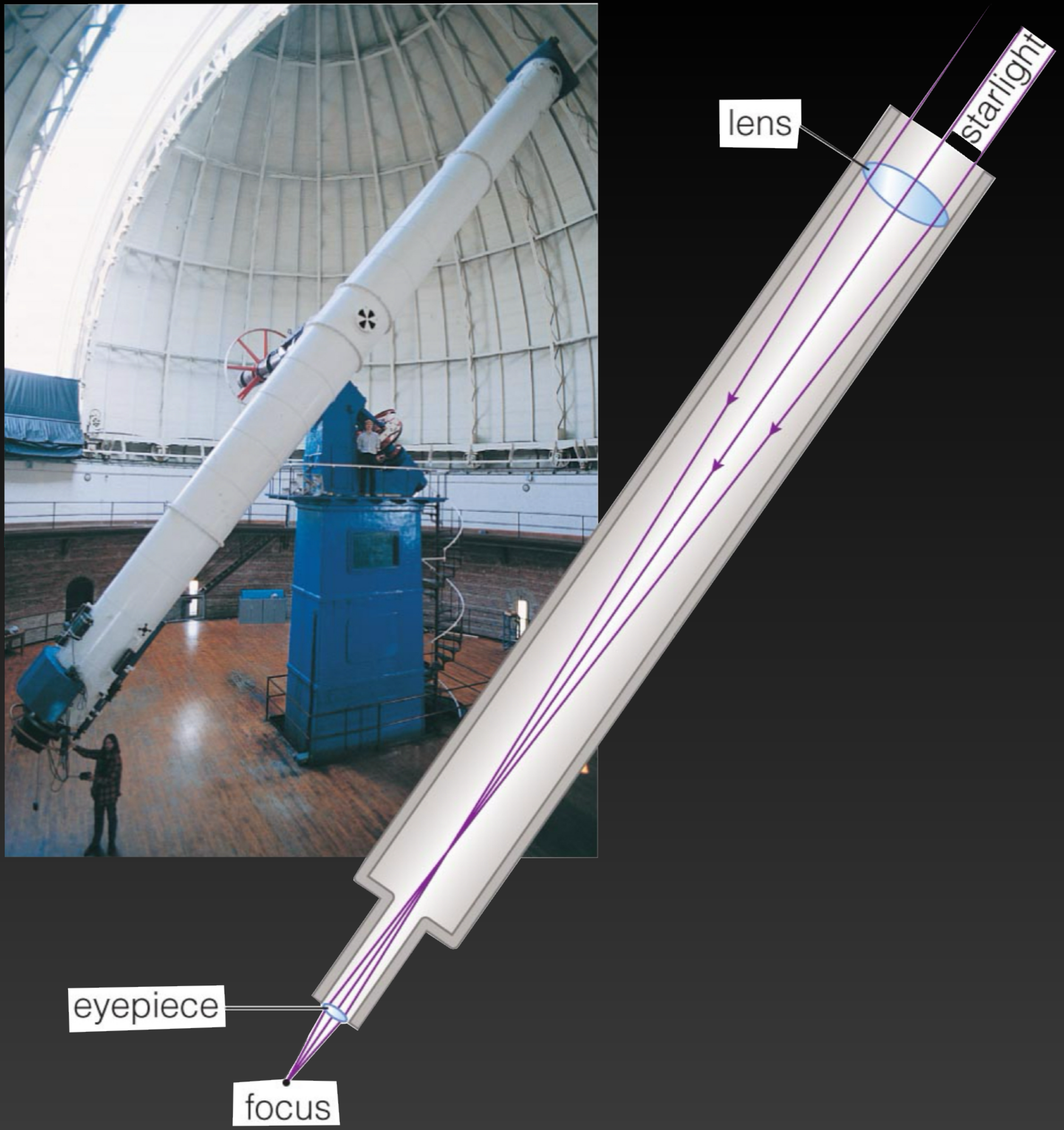
- Low sky background -> isolated
- Low cloud cover and humidity -> desert regions
- High altitude-> less atmosphere
- Low turbulence -> coastal regions with winds from the sea



Telescope Design

Refractors

- Use lenses
- All first telescopes were refractors

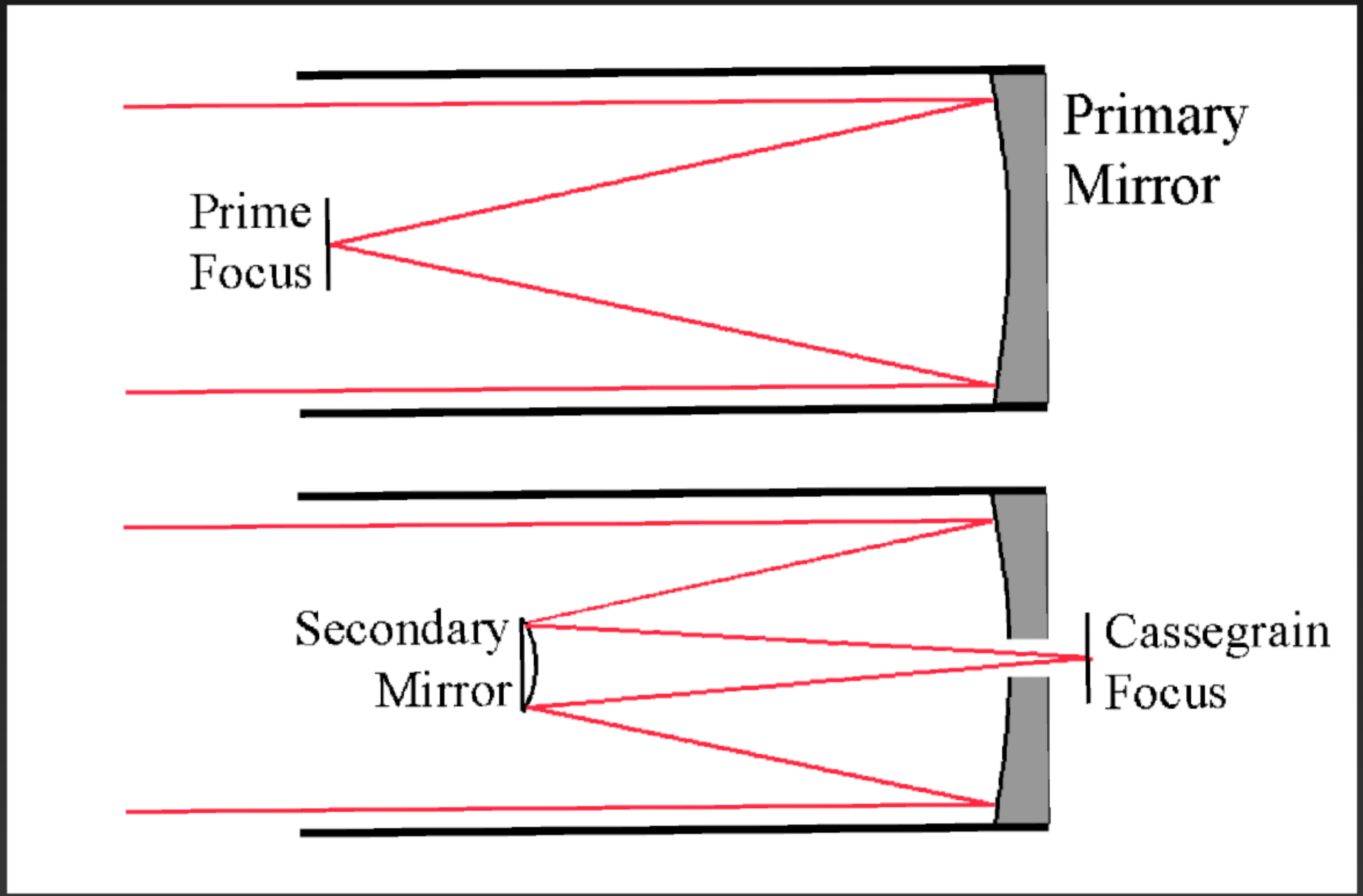


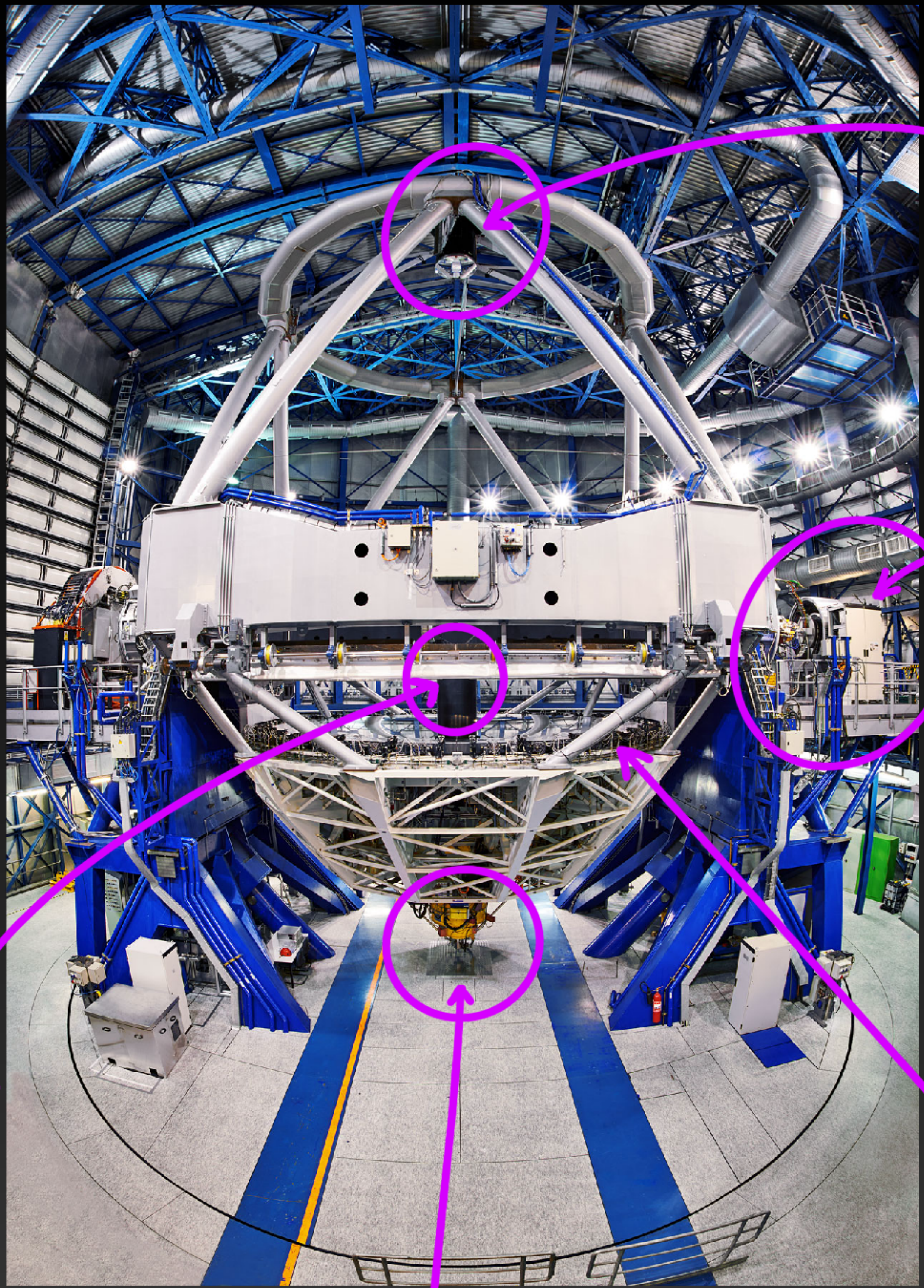
Refractors

- They needed to be very long
- Lenses had to be very big and heavy -> could sag out of shape
- They had to have very few imperfections -> very costly

Reflectors

- Use mirrors instead of lenses





Reflectors
Advantages

- Only the mirror surface has to be perfect
- Easier to keep in place than a lens
- Light path can be bended so the telescope can be shorter and the focus can be moved
- Larger mirrors than lenses can be built