

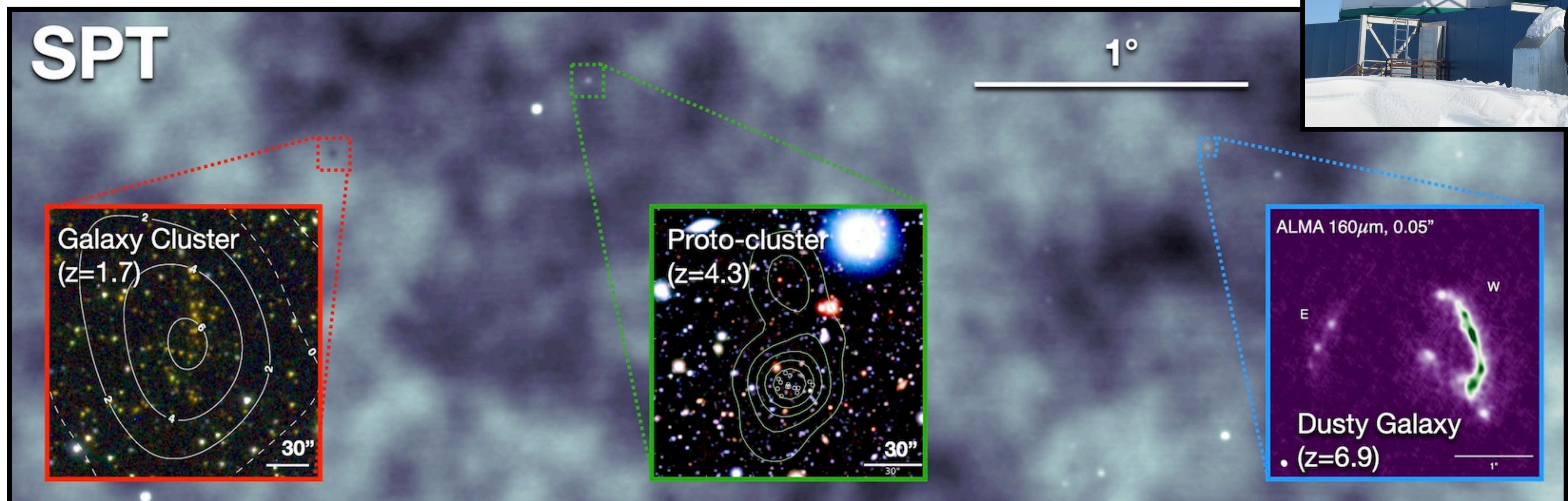
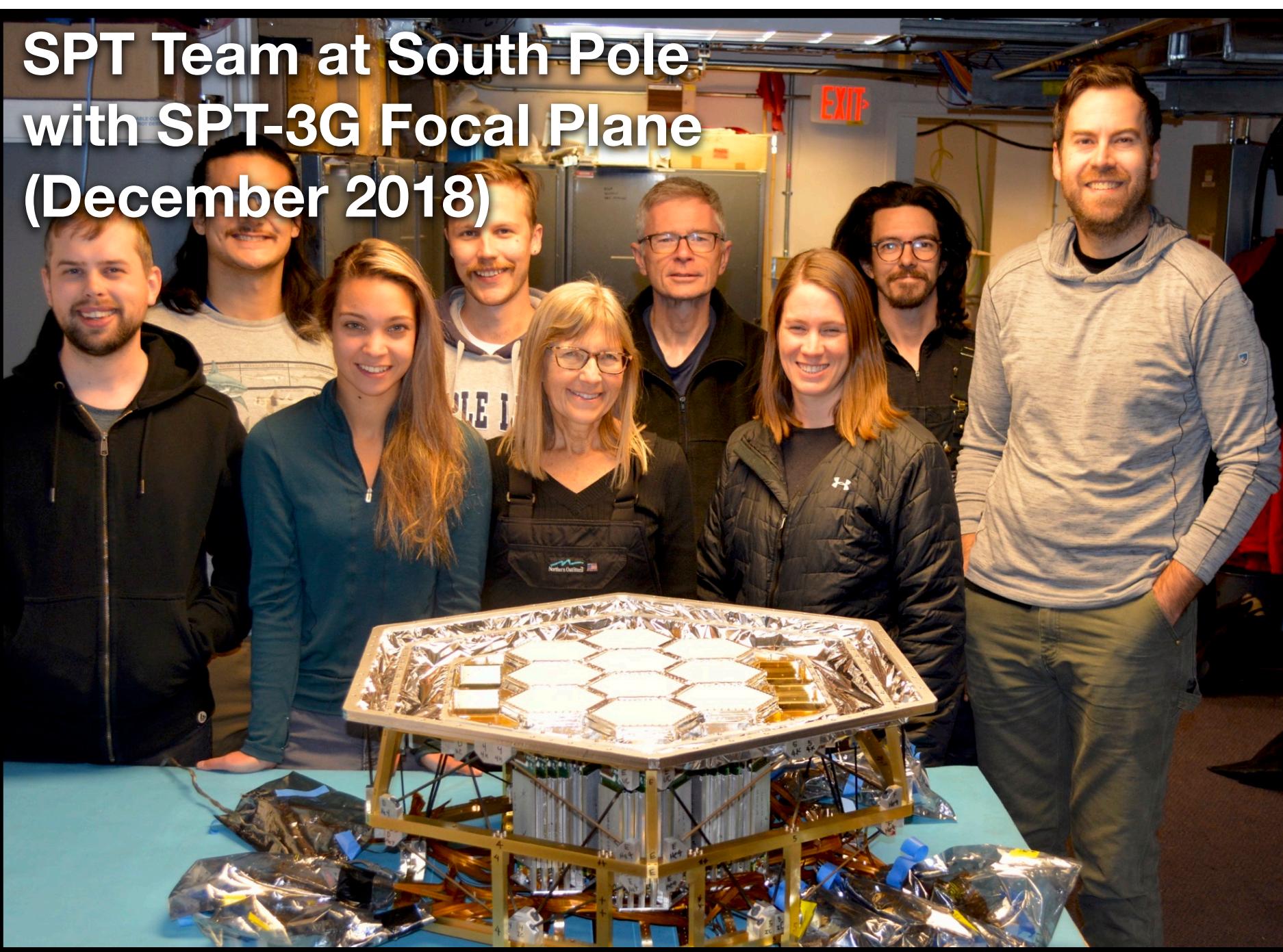
ASTR21200

Observational Techniques in Astrophysics
Spring 2024

Bradford Benson

Hello!

- I'm an experimental cosmologist who builds instrumentation to study the cosmic microwave background (CMB), working primarily on the South Pole Telescope (SPT)



Course TAs and Other Instructors:

Teaching Assistants (TAs/LAs):

- **Dillon Bass** ([dillonjb 'at' uchicago.edu](mailto:dillonjb@uchicago.edu))
- **Rohan Gupta** ([rohangupta 'at' uchicago.edu](mailto:rohangupta@uchicago.edu))

Knowledgeable People for Stone Edge Observatory (SEO) and this class:

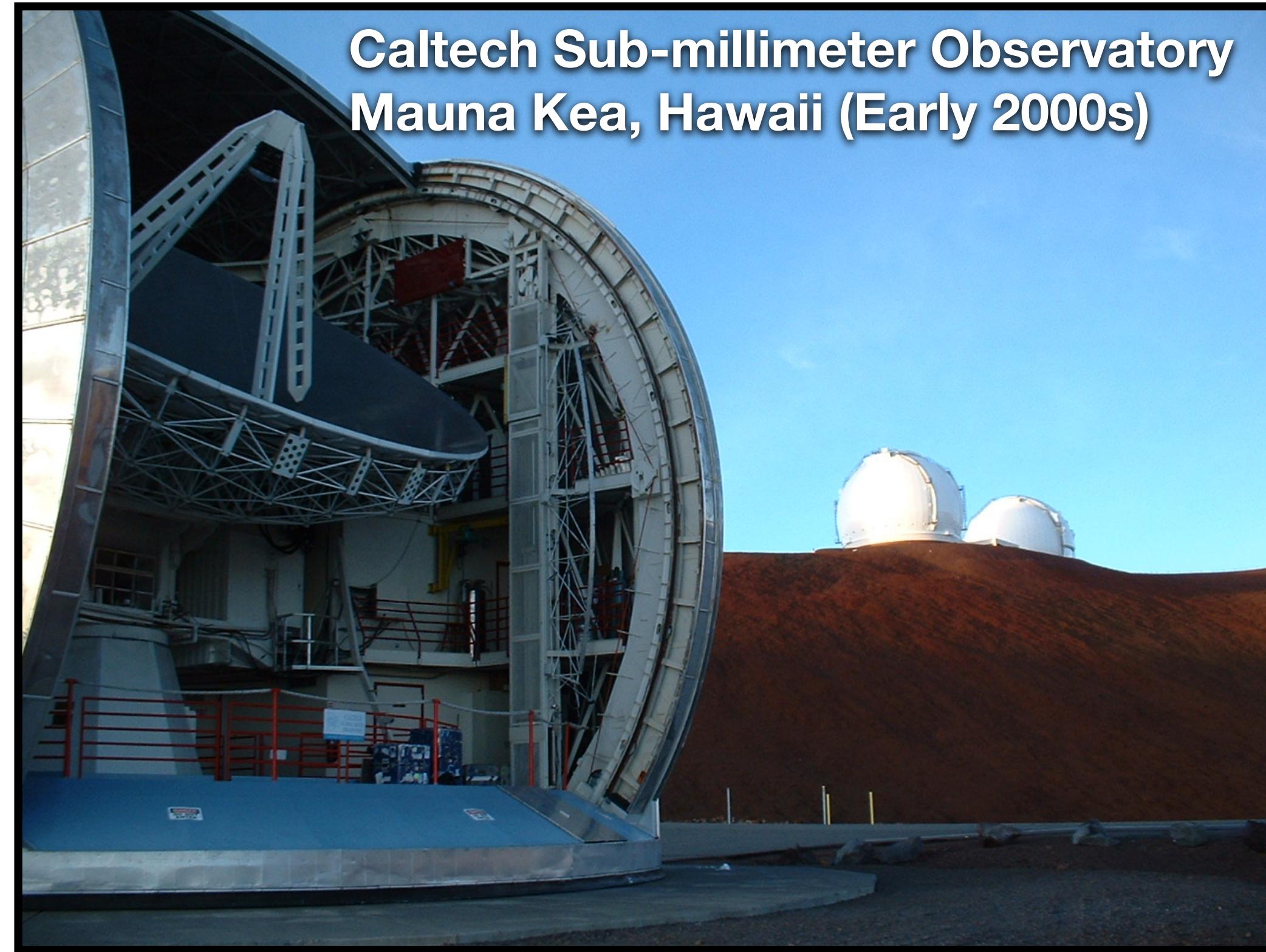
- **Dr. Al Harper** ([al 'at' oddjob.uchicago.edu](mailto:al@oddjob.uchicago.edu)) - Former instructor for this course
- **Dr. Amanda Pagul** ([apagul 'at' uchicago.edu](mailto:apagul@uchicago.edu)) - Support Astronomer for SEO
- **Dr. Marc Berthoud** ([berthoud 'at' astro.uchicago.edu](mailto:berthoud@astro.uchicago.edu)) - Research Engineer for SEO

See more details on the class wiki at:

https://github.com/bradfordbenson/ASTR21200_2024/wiki

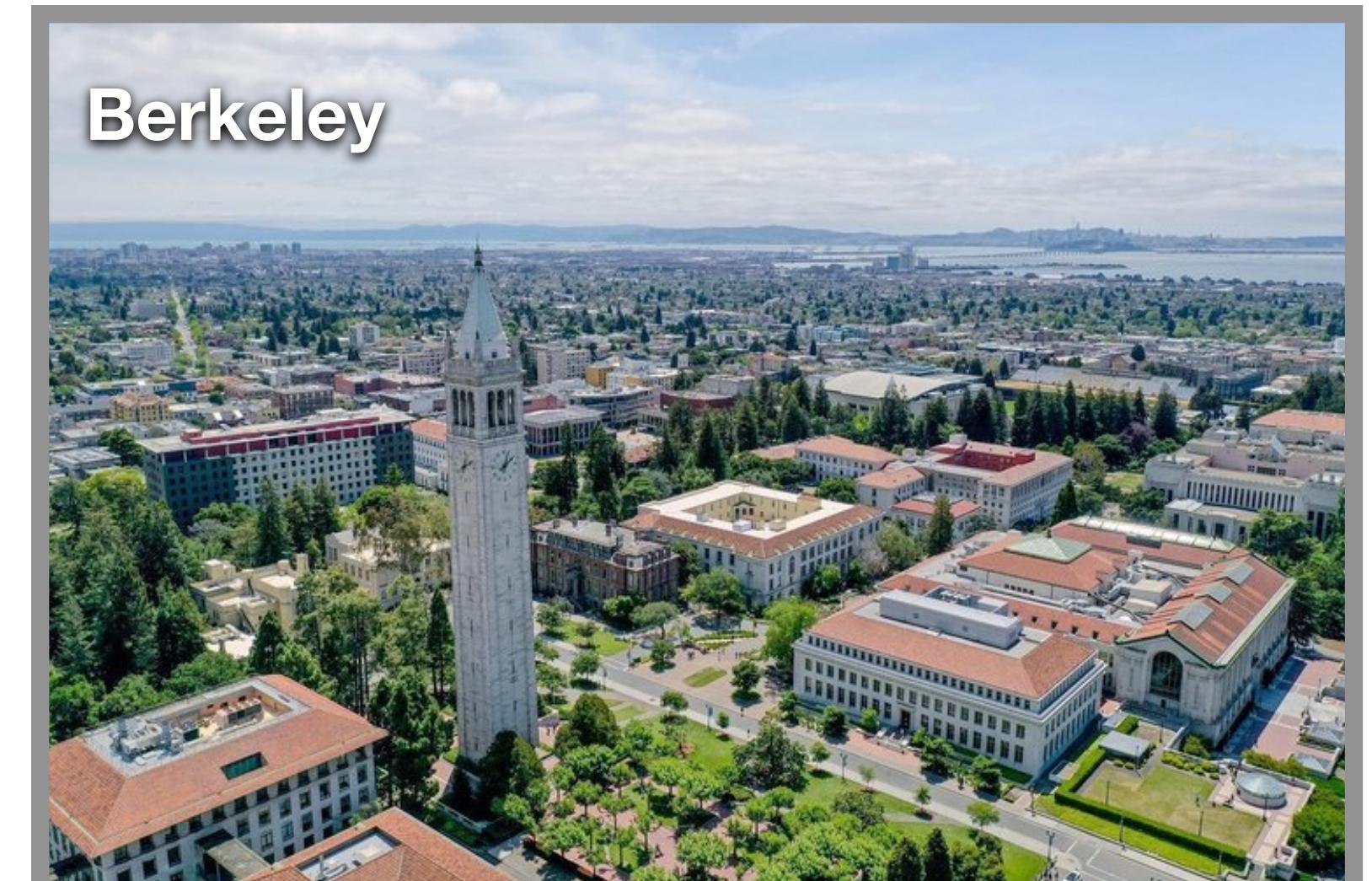
What do I do?

- I've been observing in Hawaii, Chile, Antarctica
 - Spent nearly 2-years at South Pole over 12 trips
- Written proposals for Hubble, Chandra, XMM space telescopes
- Spanning radio, microwaves, X-ray, optical, infrared wavelengths



My Bio

- **Undergrad:** U. Wisconsin-Madison
- **PhD:** Stanford University
- **Post-docs:** U. California-Berkeley, U. Chicago
- **Since 2013:** Professor at U. Chicago, Scientist at Fermilab

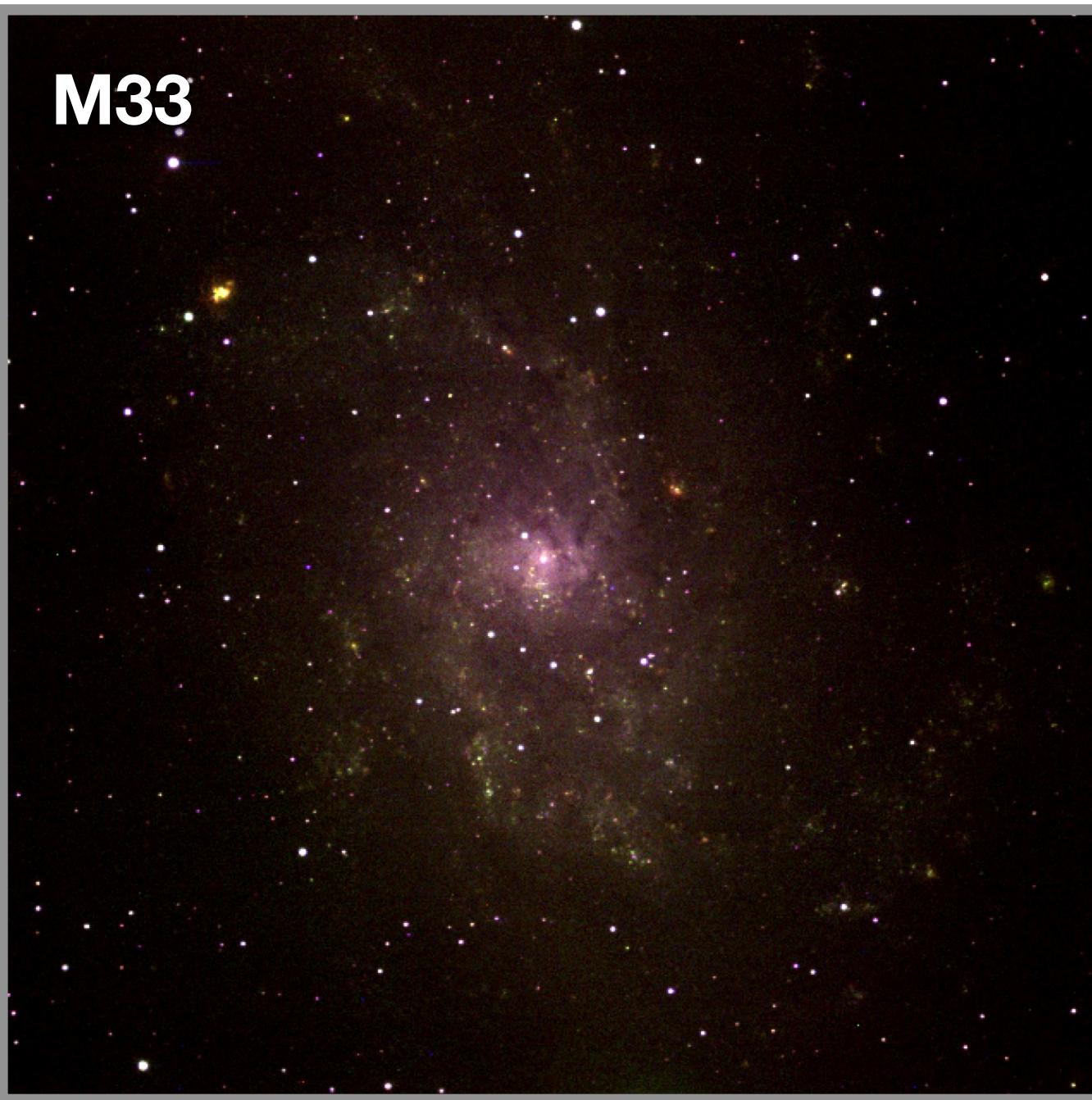
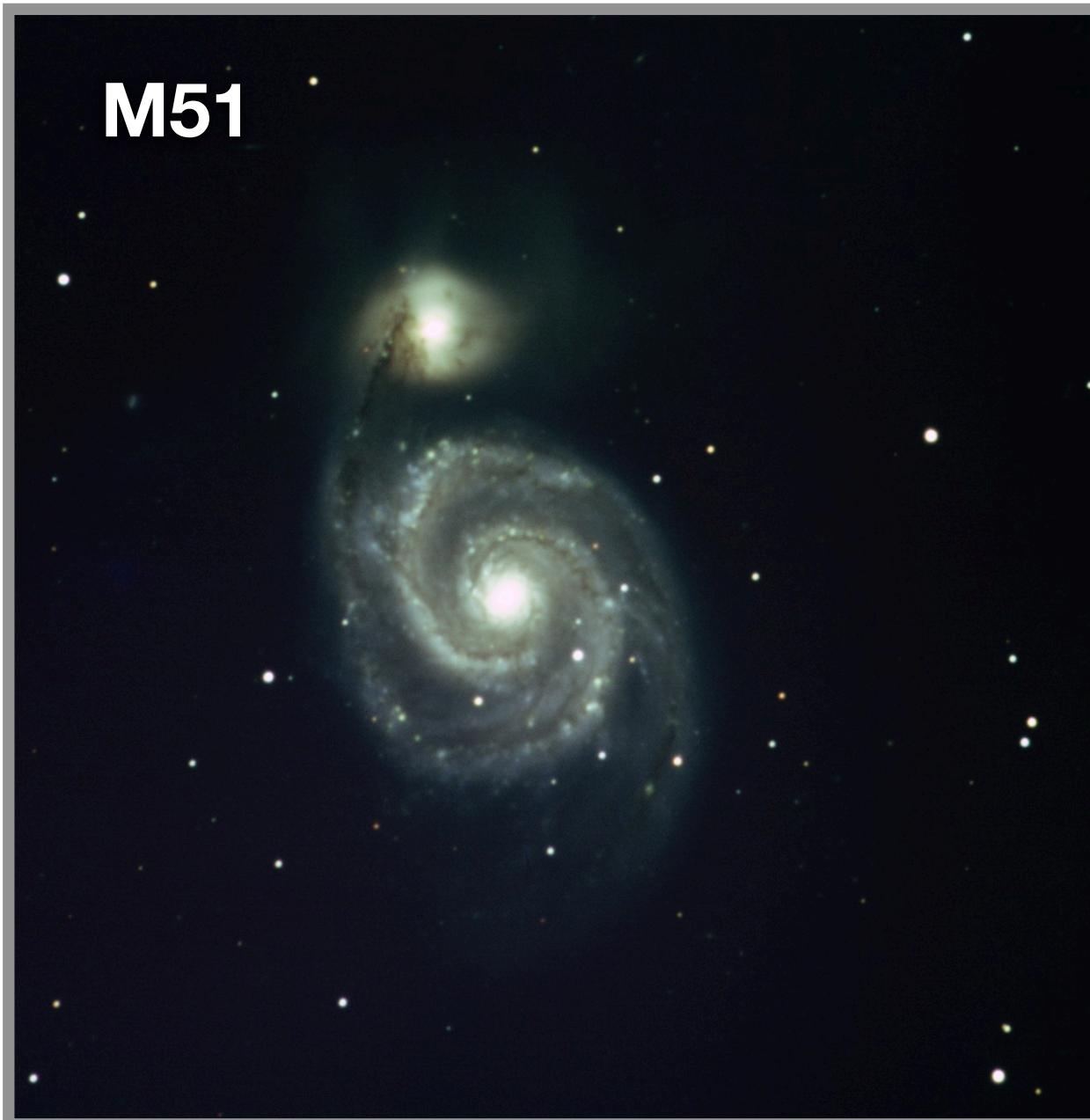


Course Purpose and Objectives

- Purpose: Teach you the basics of how to be an observational astronomer
 - Introduction to observational astronomy
 - Design, take, analyze and interpret astronomical observations
 - Report your work in lab reports and a scientific paper

Stone Edge Observatory (SEO)

- Located in Sonoma, CA, but operated by U. Chicago
- 0.5-m diameter aperture with a 26' x 26' field of view (FOV)
- Outfitted with a CCD with a set of standard broadband filters (g, r, i, z, ...)
- More info at:
 - <https://voices.uchicago.edu/stoneedgeobservatory/>
 - <https://sites.google.com/a/starsatyerkes.net/yerkesprojects/tools/telescope-upgrades/stone-edge-observatory?authuser=0>
 - On the class wiki!



How to be become an observational astronomer

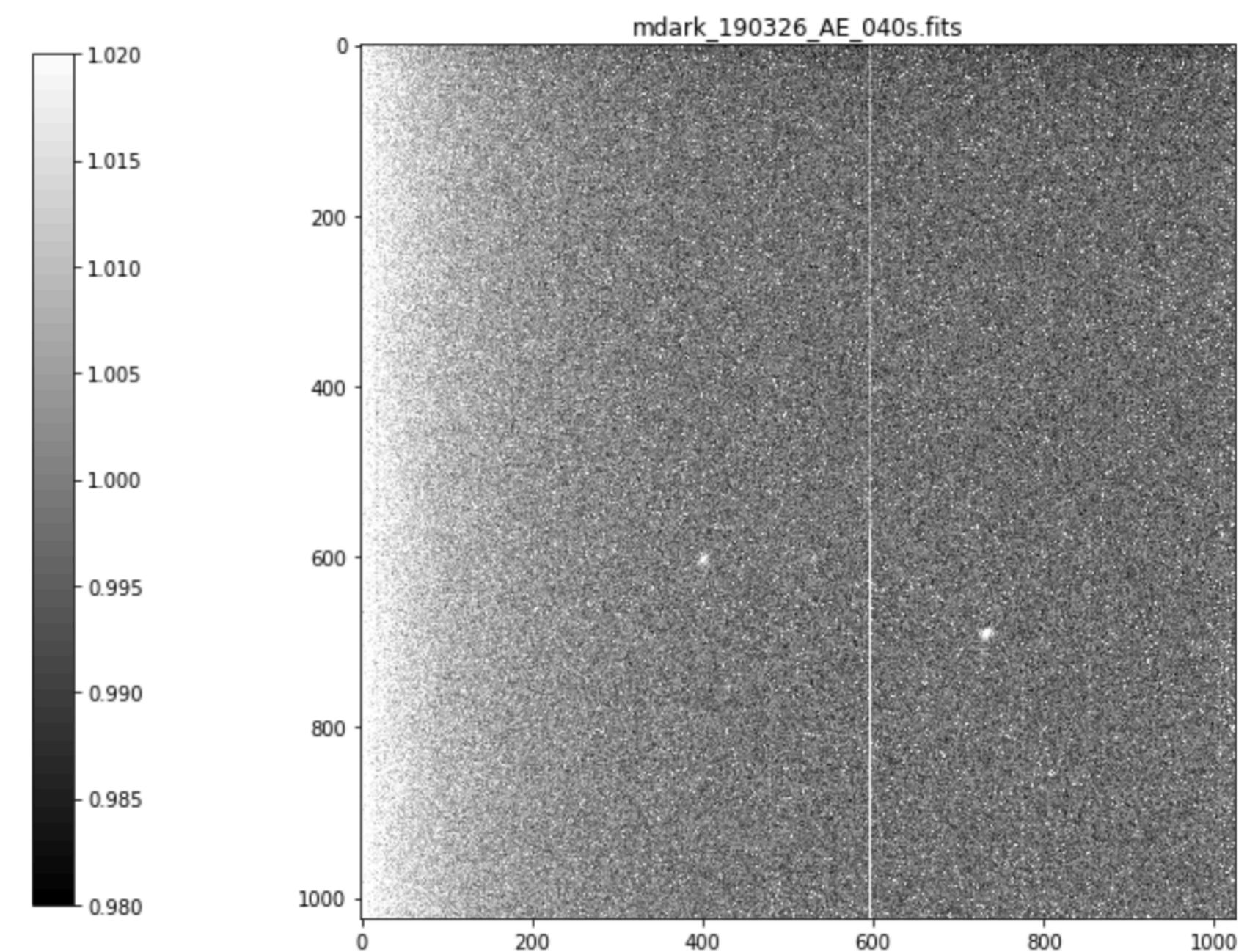
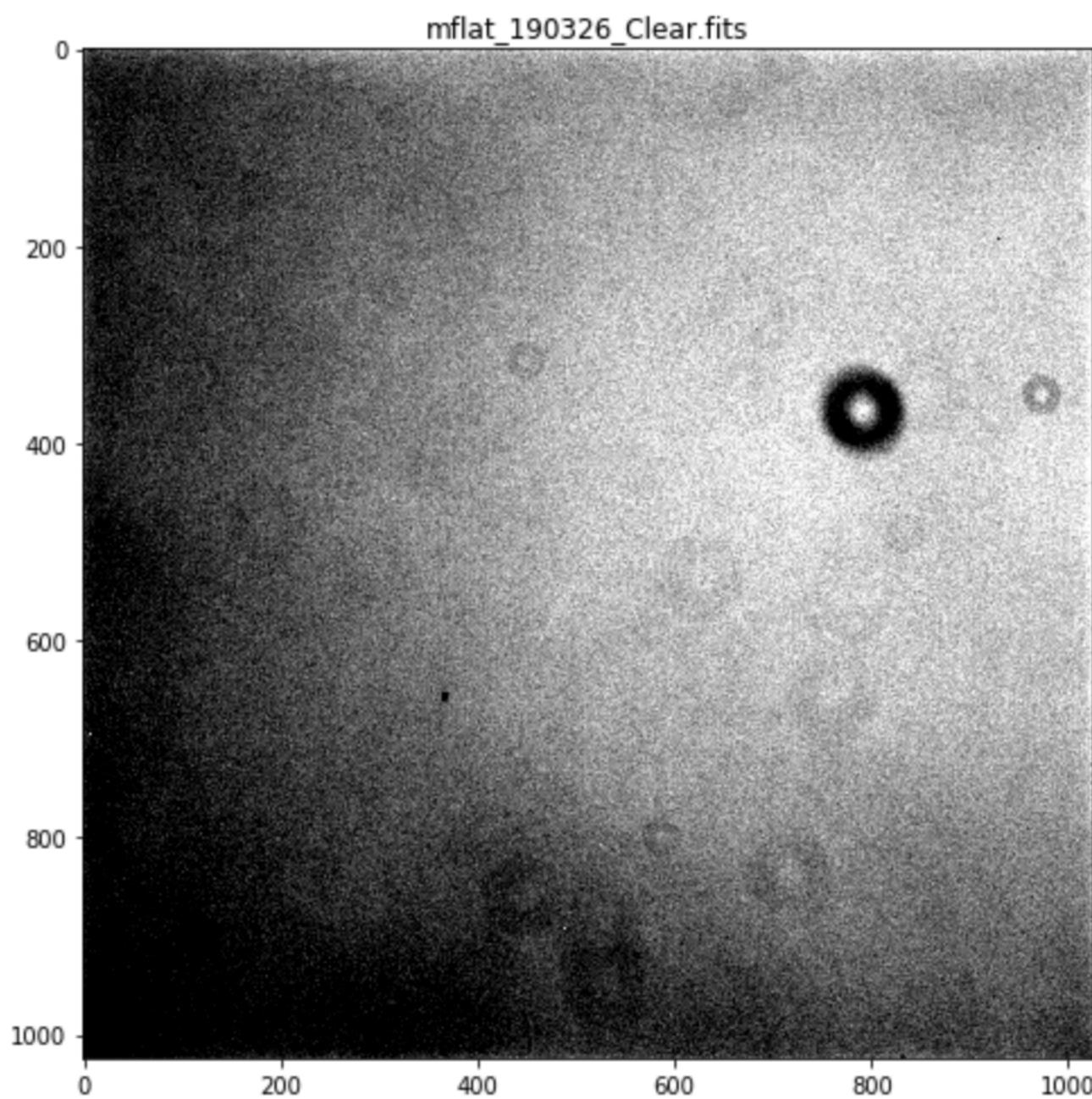
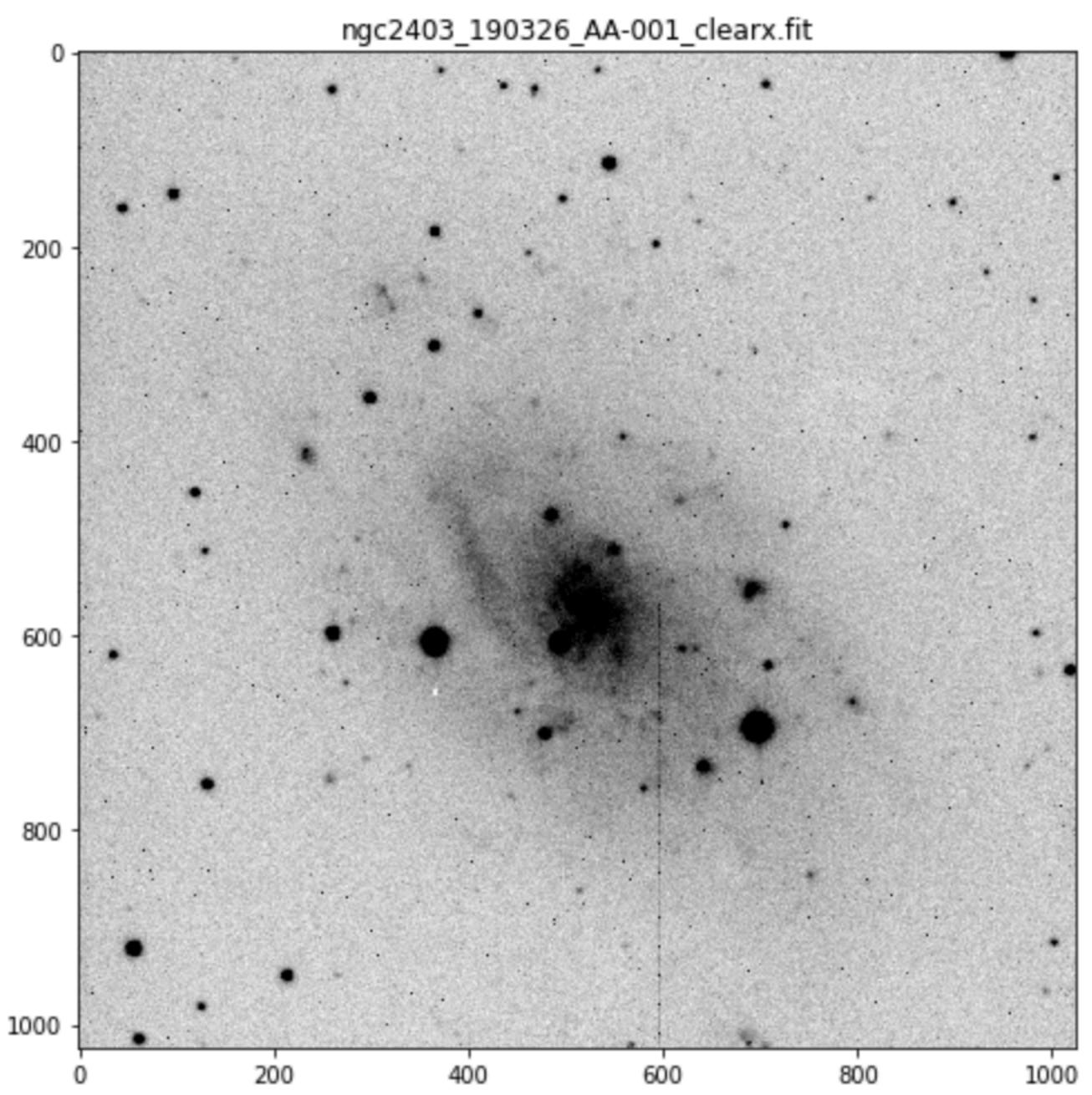
1. Come up with an interesting idea / hypothesis
2. Search for and analyze archival observations
3. Write a **telescope proposal**
4. Plan and execute your **observations**
5. Analyze your **data**
6. Write a journal paper
7. **Present your work** at conferences
- .

For this course, we'll deviate a bit

1. Come up with an interesting idea / hypothesis
2. Conduct and analyze **observations**
3. Journal paper -> **Lab report**
4. **Present your work** in class
- .

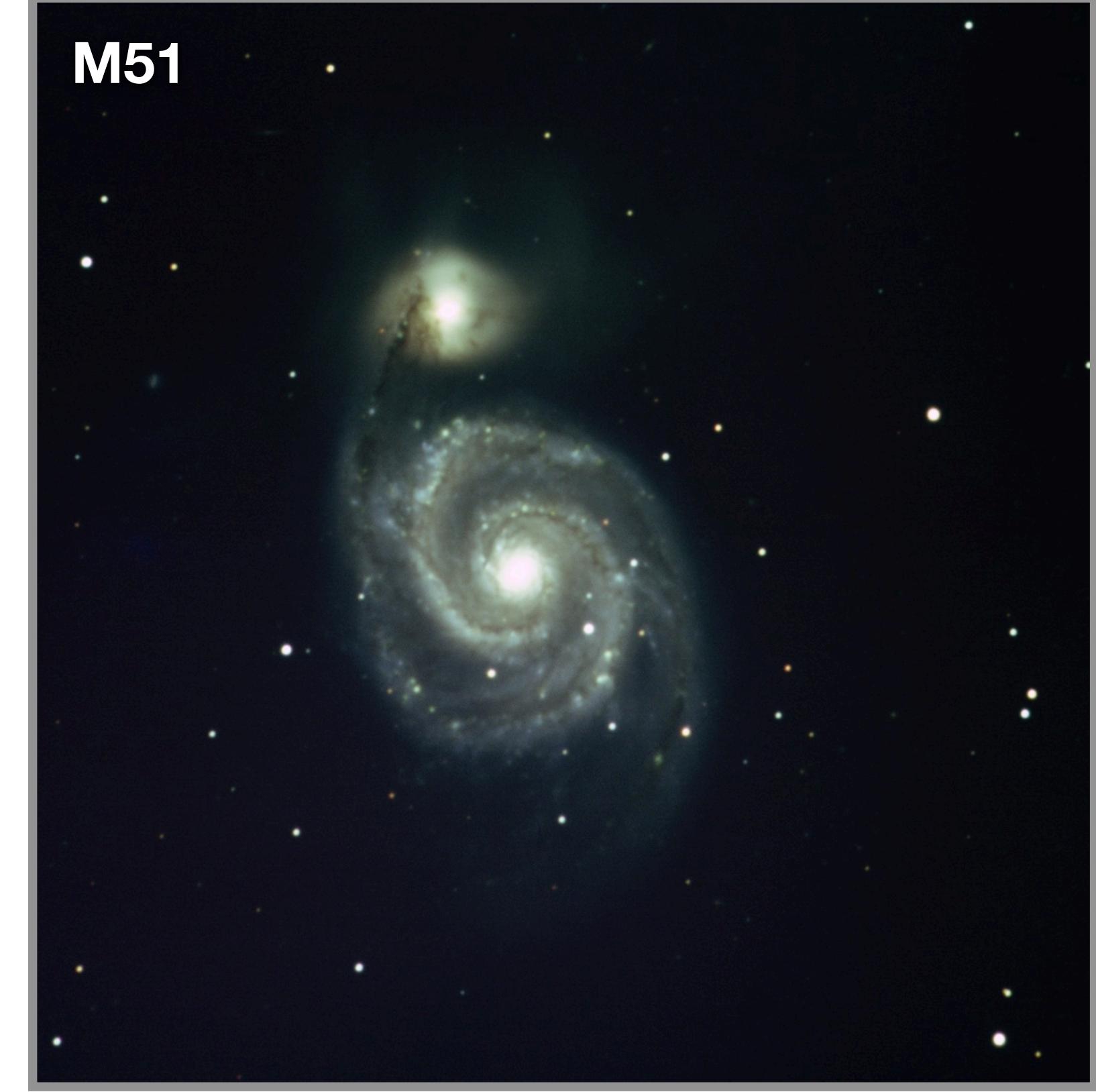
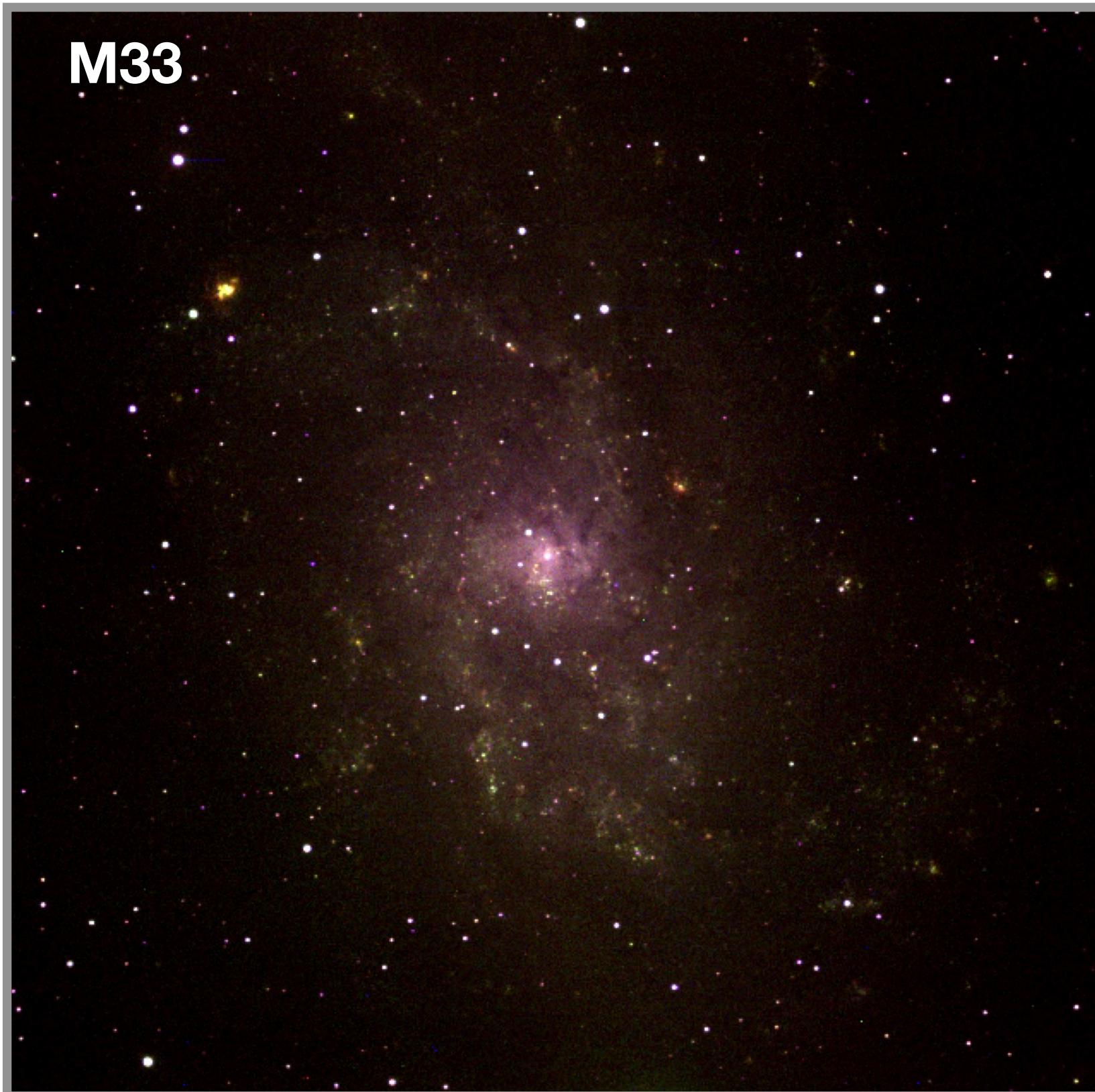
Lab1 - CCDs

- Measure properties of CCD cameras
- Understand the role of calibration data
- Familiarize yourself with the equipment



Lab2 - Optical Imaging

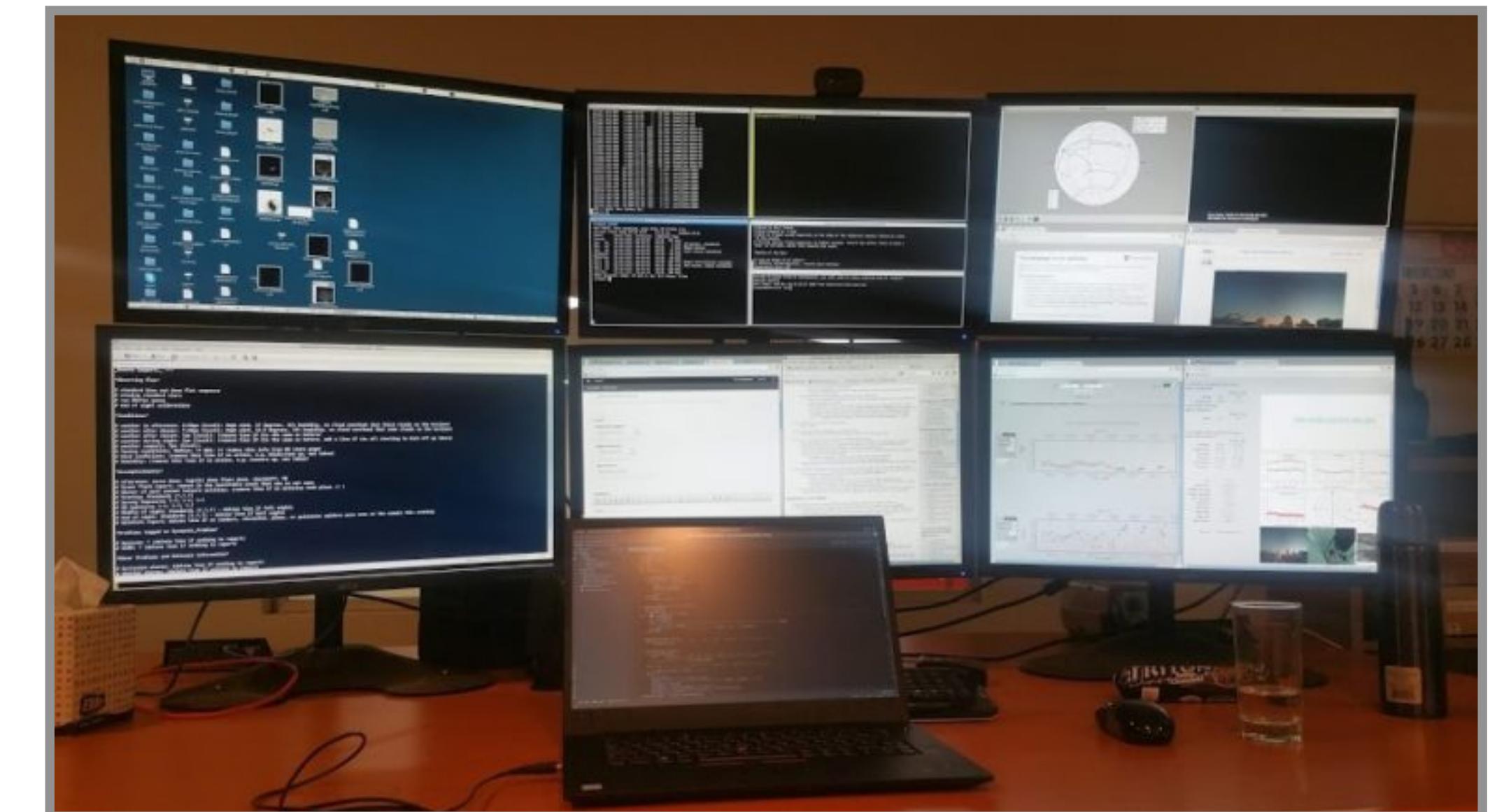
- Make RGB color images of nearby galaxies, to measure their size, and infer the expansion of the Universe (i.e., the Hubble constant)



Lab 3 - Your own project idea

- Come up with your own project idea!
- Make observations
- Do analysis
- Do a class presentation

Observing



- [https://astrobites.org/2016/02/04/
living-the-magellan-life-observing-at-
a-chilean-masterpiece/](https://astrobites.org/2016/02/04/living-the-magellan-life-observing-at-a-chilean-masterpiece/)

Data Analysis

- CCD cameras and digital image processing were revolutionary for astronomy
 - ~1980: First CCD cameras used on telescopes
- The Sloan Digital Sky Survey (SDSS), designed in the 90s, was one of the first “Big Data” projects, followed by the Dark Energy Survey (DES)
 - U. Chicago had leading roles on both projects!
- Today we are preparing for the Vera Rubin Observatory’s Legacy Survey of Space and Time (VRO/LSST), ~20 TB per night, every night for 10 years
- Research in astronomy requires programming, and statistical analysis of large datasets

Data Analysis

- Most astronomy research is done on Unix/Linux
 - “bash” is a Unix shell that provides an integrated scripting language
- *Python* is becoming ubiquitous in astronomy as a higher-level programming language, with [astropy](#) a widely used package with astronomy functions.
 - Other languages (e.g., *IDL*, *C*, *R*, *Fortran*) are sometimes used, depending on user-preference or the use case
- We will use several common astronomy software packages:
 - *Ds9*, *source extractor*, *astrometry.net*, etc.
 - See some common [Astronomy-software tools](#) on class wiki
- However, this is not a class on programming. We will provide basic instructions and help, but you will have to find many things out on your own (e.g., via google, online tutorials, other experts in your lab group, etc.)

Computing Resources

- SEO raw and reduced data will be on public webpage
- Run analysis on your laptop or using Google Collab
 - See [more options](#) on class wiki
- Back up your data, scripts, analyses, etc! (e.g., Google drive, Box, GitHub, etc.)

Class Structure

Class Times

- Tues & Thurs 500-620pm
 - 9 lectures in total over 9-week quarter
 - 9 “analysis help/hack” sessions to work on Labs with your group

Labs

- 3x Labs over the course of the quarter, starting in Week-3
- Will discuss more details as we get closer to Labs, but brief summary:
 - Work in groups of 3-5 students. Each student will need to submit their own report, either a Jupyter notebook or written report.
 - Schedule observing times with Stone Edge Observatory (SEO). Depending on weather, might need to schedule multiple nights.

Course Webpage

https://github.com/bradfordbenson/ASTR21200_2024
https://github.com/bradfordbenson/ASTR21200_2024/wiki



Home

bradfordbenson edited this page now · 7 revisions

Welcome to the ASTR21200 wiki!

Class time and place:

- Tuesday and Thursday, 5:00 - 6:20pm
- Hinds / HGS 101

Instructor:

- [Bradford Benson](#)
- Email: bbenson 'at' astro.uchicago.edu
- Office: Eckhardt Research Center (ERC) 589

TAs:

- Dillon Bass (dillonjb 'at' uchicago.edu)
- Rohan Gupta (rohangupta 'at' uchicago.edu)

Office hours:

- Brad: Thurs 12:00pm (ERC 589)

Knowledgeable People for SEO and this class:

- [Prof. Al Harper](#) (al 'at' oddjob.uchicago.edu) - Former instructor for this course
- [Dr. Amanda Pagul](#) (apagul 'at' uchicago.edu) - Support Astronomer for SEO
- [Dr. Marc Berthoud](#) (berthoud 'at' astro.uchicago.edu) - Research Engineer for SEO

Suggested textbooks:

- Observational Astronomy, D. Scott Birney (Cambridge University Press; 2nd edition, July 24, 2006)
- Measuring the Universe: A Multiwavelength Perspective, G. Rieke (Cambridge University Press, 2012)
- Data Reduction and Error Analysis for the Physical Sciences, P.R. Bevington & D. K. Robinson (McGraw-Hill Higher Education, 2003)
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- Lab1
- Lab2
- Lab3
- [Astro Data Archives](#)

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- ds9
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- Jupyter
- LaTeX
- Topcat
- Astrometry.net
- Coadd or Stack Images
- Image Add, Sub, Arithmetic
- Awk and Sed

Clone this wiki locally

<https://github.com/bradfordbenso>

Course Syllabus

<> Code Issues Pull requests Actions Project Wiki Security Insights Settings

https://github.com/bradfordbenson/ASTR21200_2024
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Class syllabus Linked to the Wiki

Edit New page

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- [Image Add, Sub, Arithmetic](#)
- [Awk and Sed](#)

Clone this wiki locally

<https://github.com/bradfordbenso>

ASTR 21200: Observational Techniques in Astrophysics

Spring 2024, University of Chicago

Class Hours: T/Th 5:00-6:20pm

Class Room: Hinds/HGS 101

Instructor: Bradford Benson

E-mail: bbenson@astro.uchicago.edu

Office: Eckhardt Research Center (ERC) 589

Course Website: https://github.com/bradfordbenson/ASTR21200_2024

Course Wiki: https://github.com/bradfordbenson/ASTR21200_2024/wiki

Course Description

Astronomers explore the universe by detecting and analyzing light from all over the electromagnetic spectrum. This is an observational lab course, focused on obtaining and analyzing astronomical data with optical telescopes, namely the Stone Edge Observatory.

Students will work in groups of 3-5 students to conduct observational experiments via labs. For all the labs, the students will be responsible for scheduling the observations, analyzing the resultant data, and reporting their work in lab reports.

1. Lab 1: Students will measure properties of astronomical CCD cameras and develop a calibration scheme for optical imaging.
2. Lab 2: Students will acquire color images of galaxies, measure their angular size and radial profile, and infer the expansion rate of Universe (i.e., the Hubble constant)
3. Lab 3: Students will propose their own project and undertake observations.

The course will include a lecture component, that is intimately intertwined with the experimental aspects of the course. The students will learn the basics of practical observational astronomy, such as determining the observability of selected targets, telescope and detector technology, the use of photometric and spectroscopic techniques, and methods of error, statistical, and time-series analysis. A limited number of homework sets will be assigned to facilitate comprehension of the lecture material. Data analysis will be performed using standard astronomy software packages, as well as one general-purpose programming language such as python. In addition, students will need to familiarize themselves with standard Linux tools. Tutorials will be provided during class-time and/or as homework. Towards the end of the course, the students will prepare a final oral presentation on their final Lab Project.

1

Course Schedule

The screenshot shows a GitHub repository interface. At the top, there are several navigation tabs: Code, Issues, Pull requests, Actions, Projects, Wiki (which is highlighted with a red circle), Security, Insights, and Settings. Below the tabs, the page title is "Schedule Spring 2024". There is a note that "bradfordbenson edited this page 18 minutes ago · 12 revisions". On the right side of the page, there are two buttons: "Edit" and "New page".

Schedule Spring 2024

bradfordbenson edited this page 18 minutes ago · 12 revisions

Week	Date	Topic	Lecture	Homework / Lab	Tutorial
1	Mar-19	Intro to Astro Observing	Lect-1	HW-1, Due Mar-26	Python-1: Visibility
	Mar-21	Practical Observing	Lect-2		
2	Mar-26	CCDs and Astronomical Images	Lect-3	[HW-2, Due Apr-2]	Python-2: CCD Images
	Mar-28	Intro to Stone Edge	Lect-4		Python-3: Astropy Fits
3	Apr-2	Intro to Labs and Lab1	Lect-5	Lab-1, Due Apr-16	Python-4: RGB Images
	Apr-4	(Analysis and Help/Hack Session)			
4	Apr-9	Statistics	Lect-6		
	Apr-11	(Analysis and Help/Hack Session)		[HW-3, Due Apr-23]	
5	Apr-16	Intro to Lab2	Lect-7	[Lab-2, Due May-2]	SEO Cheat Sheet
	Apr-18	(Analysis and Help/Hack Session)			
6	Apr-23	(Analysis and Help/Hack Session)			
	Apr-25	(Analysis and Help/Hack Session)			
7	Apr-30	Intro to Lab 3, Project Ideas	Lect-8	[Lab-3, Due May-16]	
	May-2	(Analysis and Help/Hack Session)			

https://github.com/bradfordbenson/ASTR21200_2024
https://github.com/bradfordbenson/ASTR21200_2024/wiki

The screenshot shows the GitHub wiki page for the repository. On the left, there is a sidebar titled "Pages 17" with a "General Information" section containing links like "Schedule" (which is circled in red), "SEO Observing Observatory (SEO)", "SEO Observing Calendar", and "SEO Data Archives". Below this are sections for "Labs and Observing" and "Computing Resources", each with a list of links. At the bottom, there is a "Clone this wiki locally" button with the URL "https://github.com/bradfordbenso".

Lecture notes
Homework
Labs
Tutorials

Will be linked to
“Schedule”

Course Schedule

https://github.com/bradfordbenson/ASTR21200_2024
https://github.com/bradfordbenson/ASTR21200_2024/wiki

Code

main 1 branch 0 tags

Go to file Add file <> Code

bradfordbenson Add files via upload 90e1ed2 yesterday 17 commits

- Documents Add files via upload 4 days ago
- Homework Add files via upload yesterday
- Labs Create temp 2 months ago
- Lectures Create temp 2 months ago
- Tutorials Update rdj2aa.py 5 days ago
- README.md Create README.md 2 months ago

README.md

ASTR21200

ASTR 21200 Observational Techniques in Astrophysics

About

ASTR 21200 Observational Techniques in Astrophysics

Readme 0 stars 1 watching 0 forks

Releases

No releases published Create a new release

Packages

No packages published Publish your first package

Languages

Jupyter Notebook 72.0% TeX 27.9%

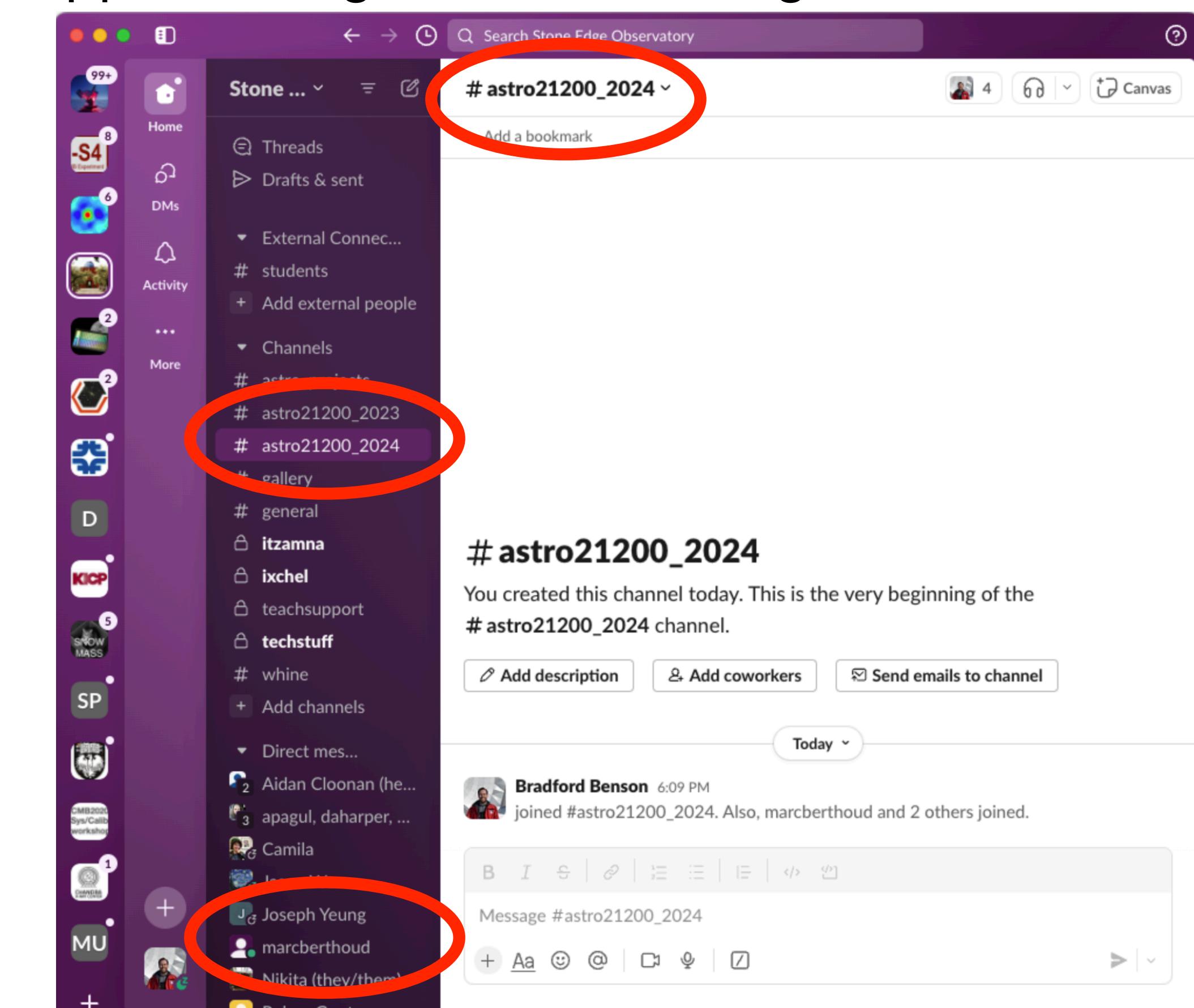
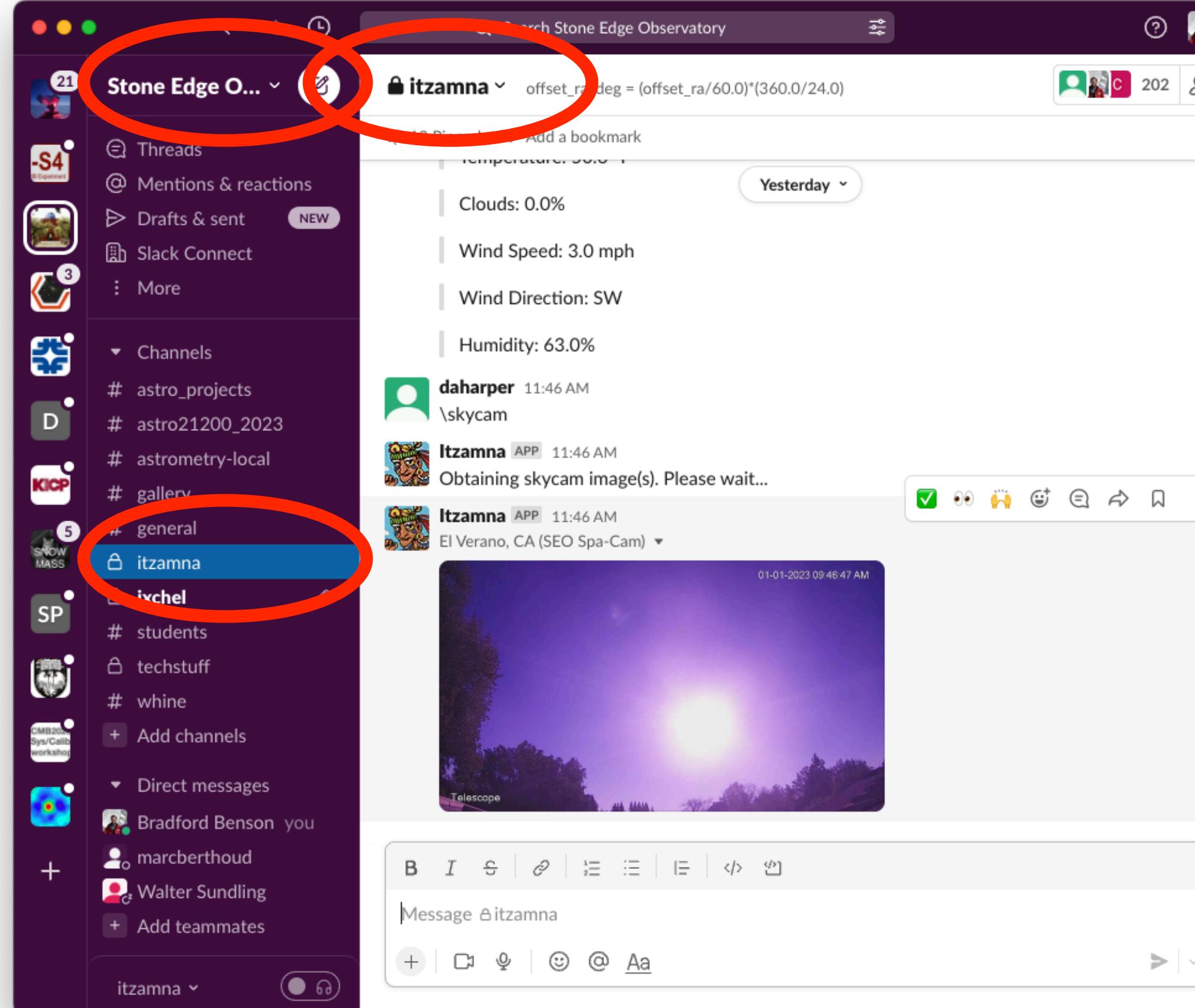
Python 0.1%

Lecture notes
Homework
Labs
Tutorials

Also linked to the GitHub code repo for the class

Course Slack

- Install the Slack App on your computer (or use web interface)
 - Look for email invitation to “stoneedgeobservatory.slack.com” channel
- Observing through SEO will be done through “itzamna” channel
- General questions about lectures, computing, etc., can take place in the “astro21200_2024” channel
- Private messages to lab-mates, instructor, TAs, can happen through “Direct Messages”



Grading

- Homeworks (30%)
 - 3x Homeworks (10% each)
 - First one is on canvas + wiki, and due next week Mar-26!
 - Submit HW and Lab reports via course webpage on **Canvas**:
 - <https://canvas.uchicago.edu/courses/56896>
- Labs (60%)
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- Final Presentation (10%)

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See Homework and Lab Schedule on the wiki!

Also on the wiki, you will find tutorials and readings that will help you with the homework and labs!

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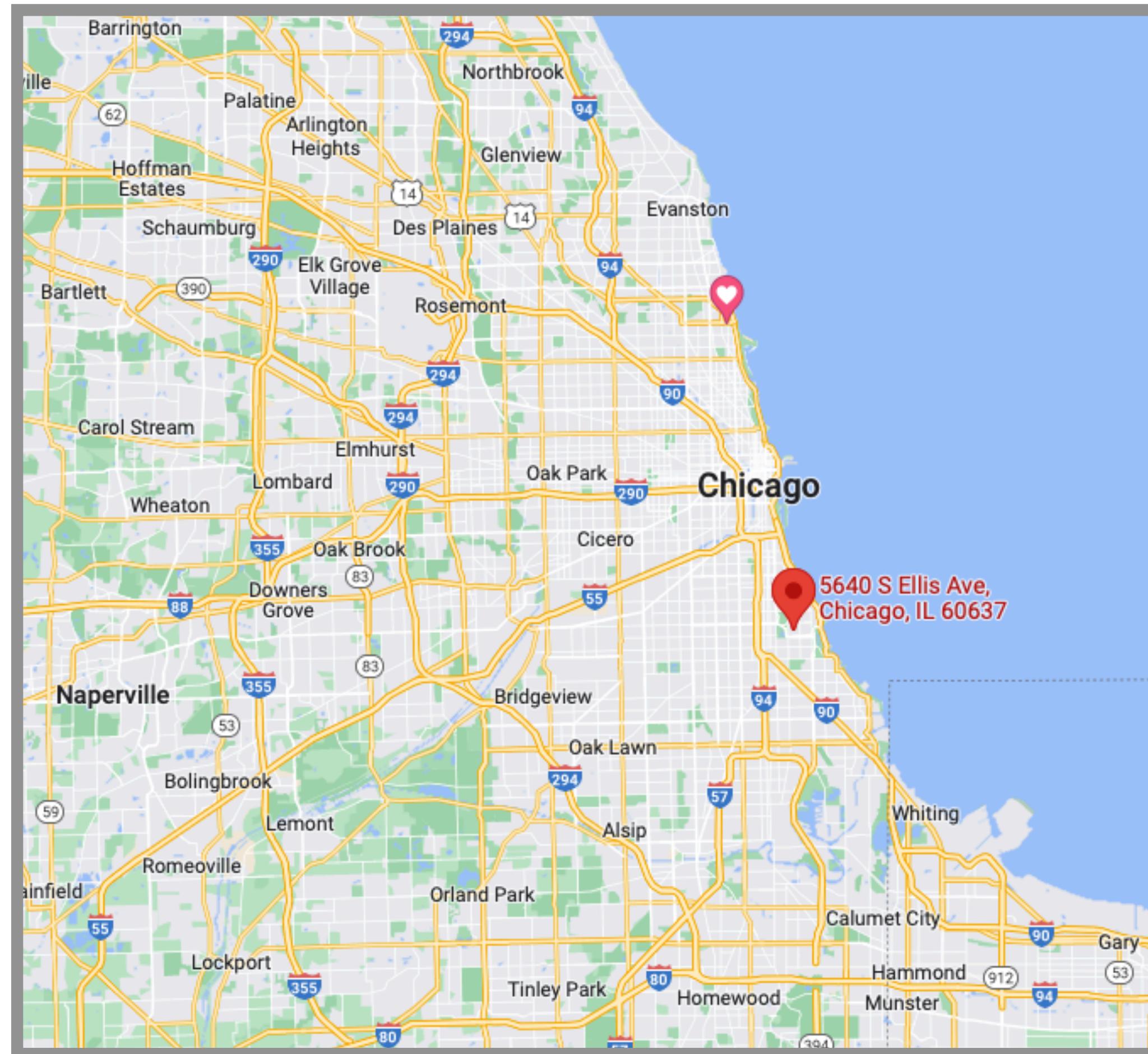
Any questions?

Astronomical Coordinate Systems

How do you find things on the sky?

Astronomical Coordinate Systems

How do you find things on the Earth? Maps!



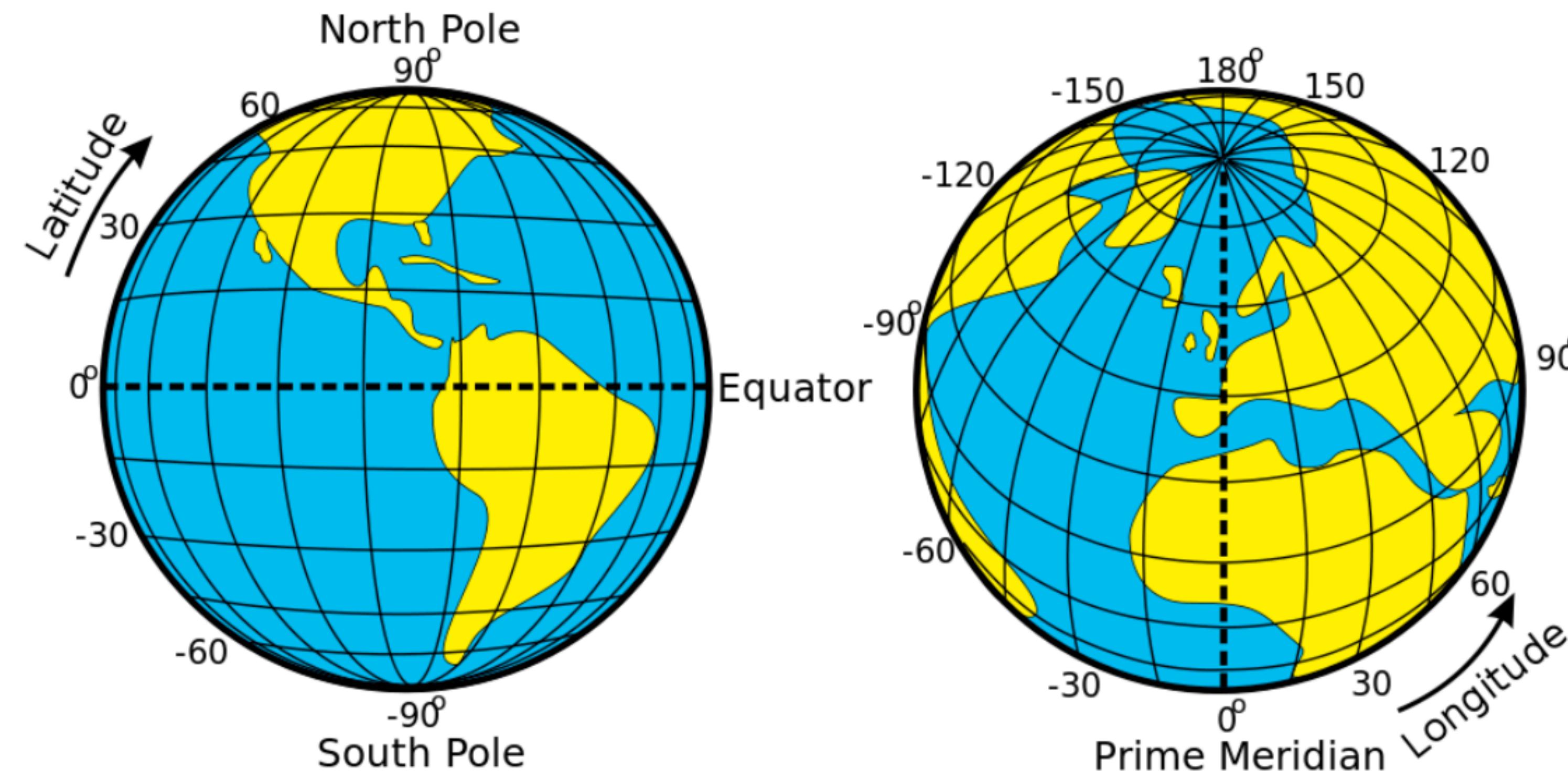
We look for patterns:

- U. Chicago is 7-miles South from downtown
- Eckhardt Research Center (ERC) is 1-block west of Reynolds Club

Astronomical Coordinate Systems

How do you find things on the Earth? Maps!

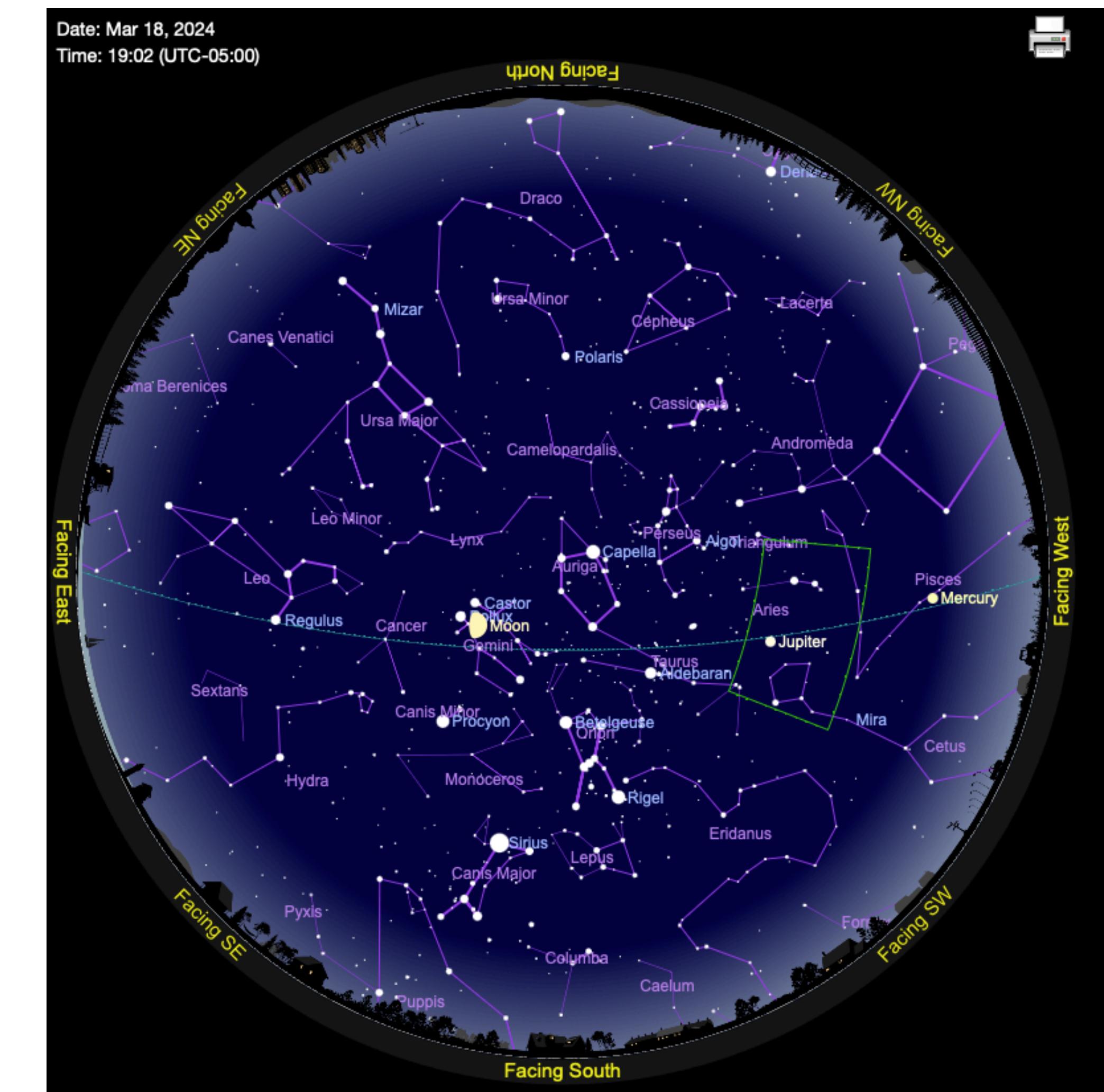
- Latitude and Longitude are angular coordinates related to Earth's rotation
 - Longitude goes from 0 to 360 deg, with Greenwich, England at 0 deg
 - Latitude goes from -90 to 90 deg, with Equator at 0 deg



Astronomical Coordinate Systems

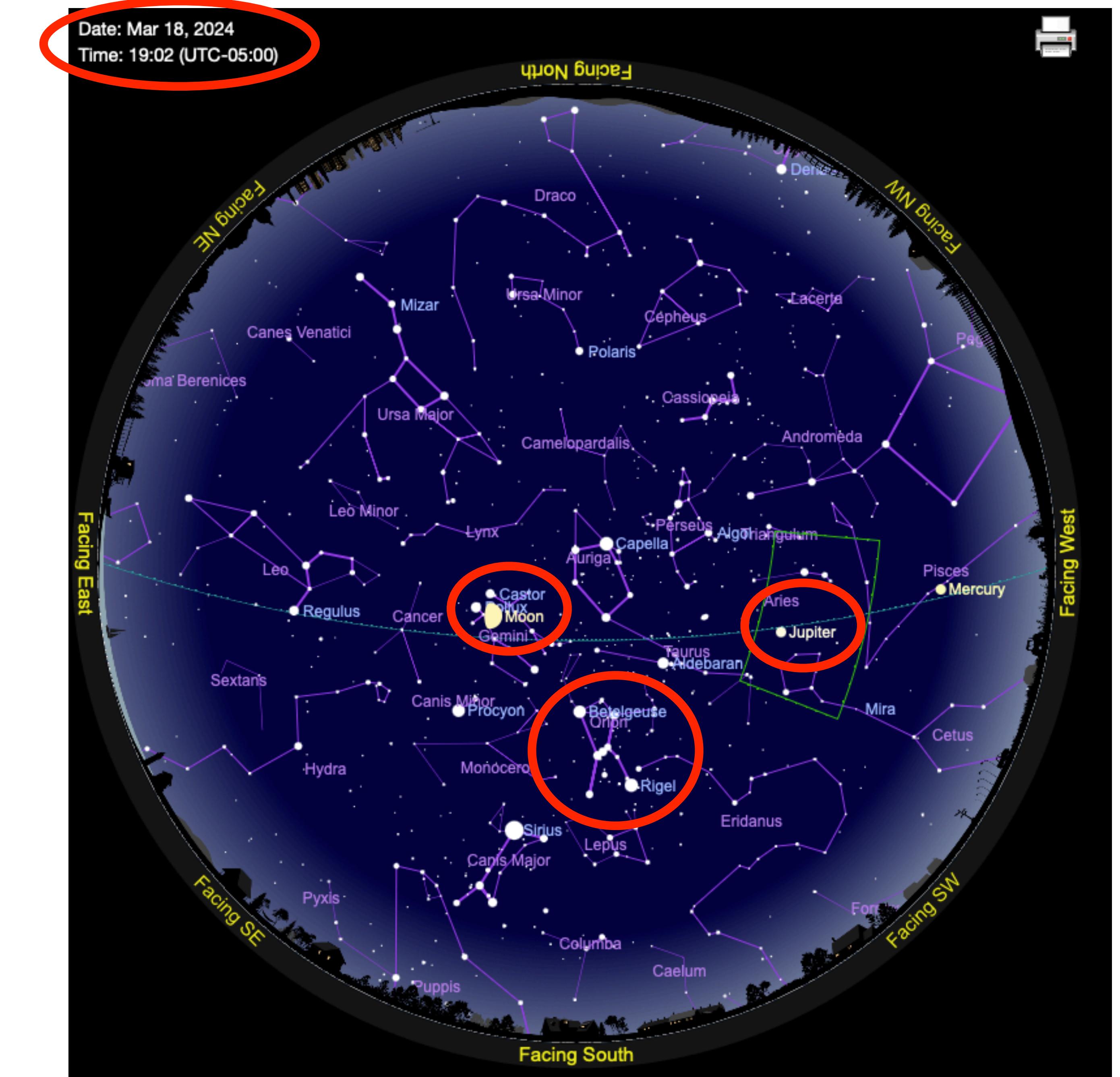
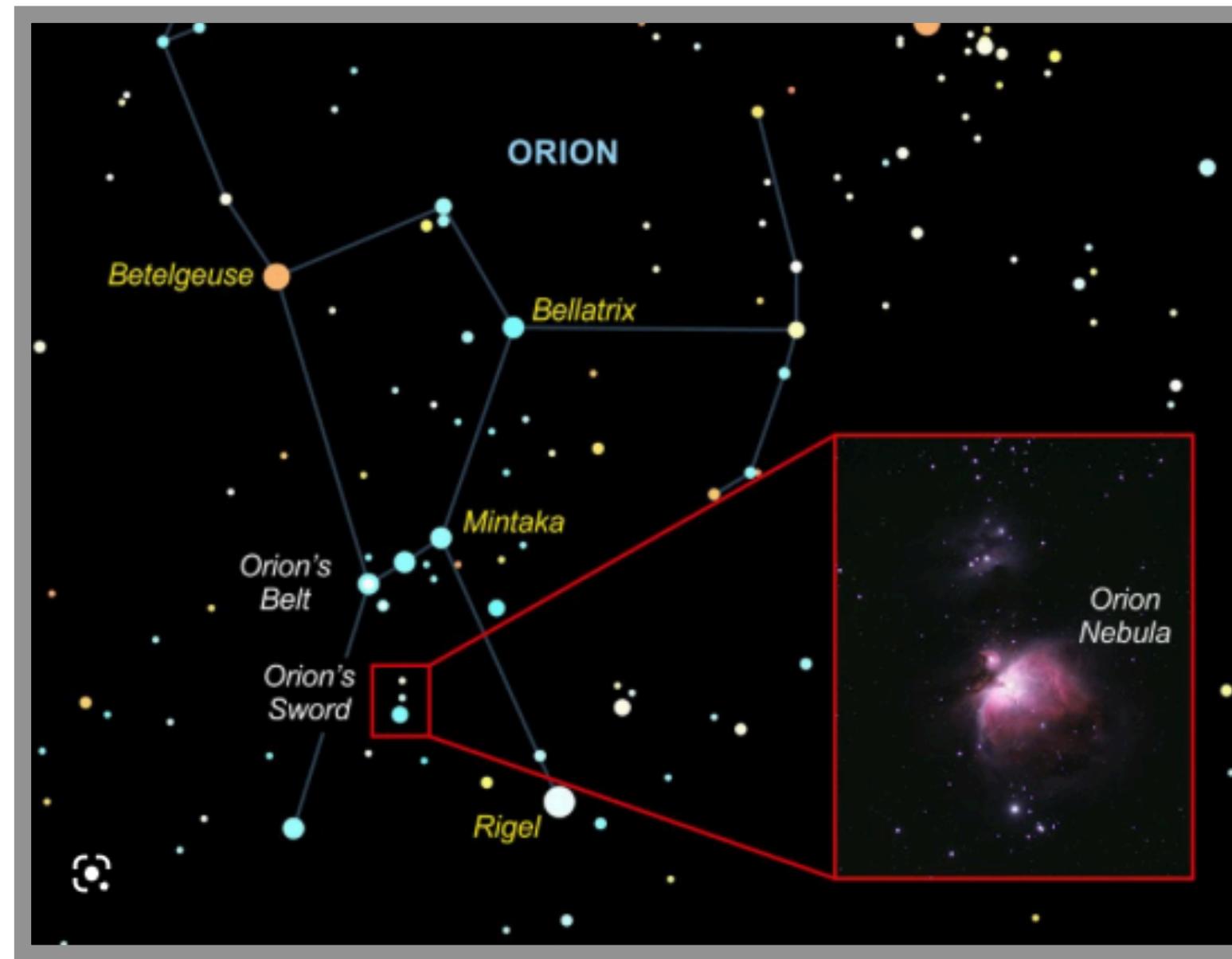
How do you find things on the Sky? Also Maps and Coordinates!

- Instead of looking “down” to the Earth, you are looking up at the Sky, so some things are flipped
 - Because of this “East” is “flipped” to the left because you are looking “up”
 - <https://skyandtelescope.org/interactive-sky-chart/>
- Also can use “pattern matching” to determine stars / objects relative to one another



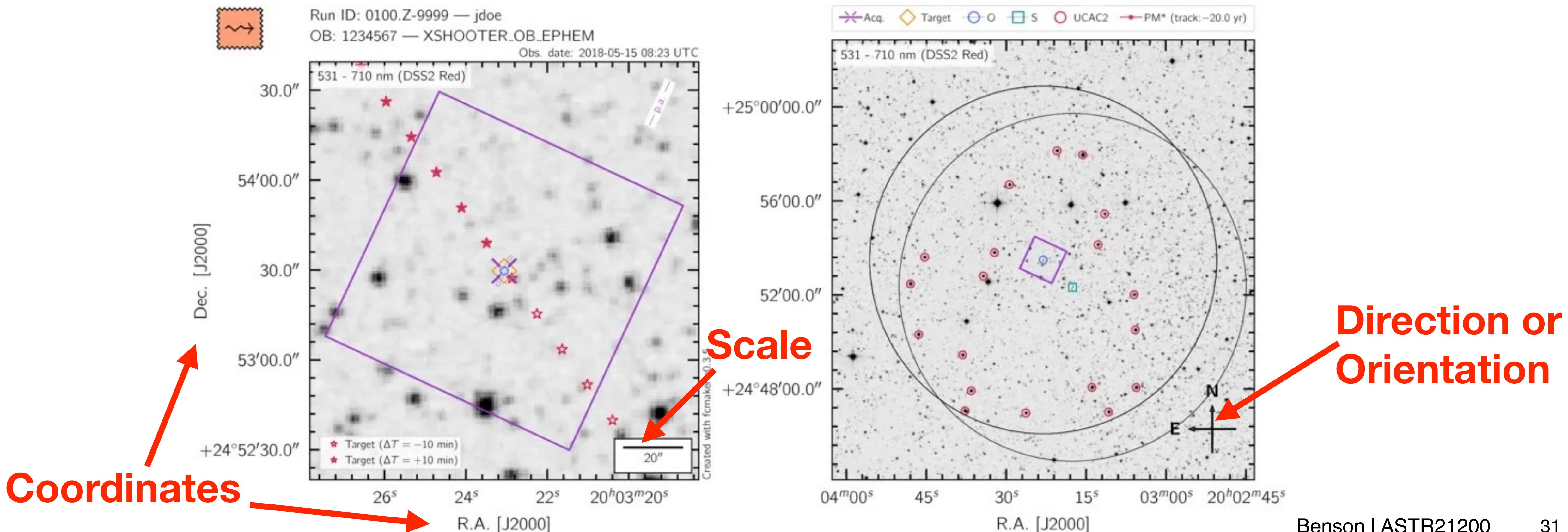
How to find the Orion Constellation

- Sunset about 7pm right now
- Jupiter is setting around 930pm, the Moon at about 4am
- Just after Sunset, find the Moon and Jupiter and look 1/3 in between both and South



Finding charts in professional astronomy

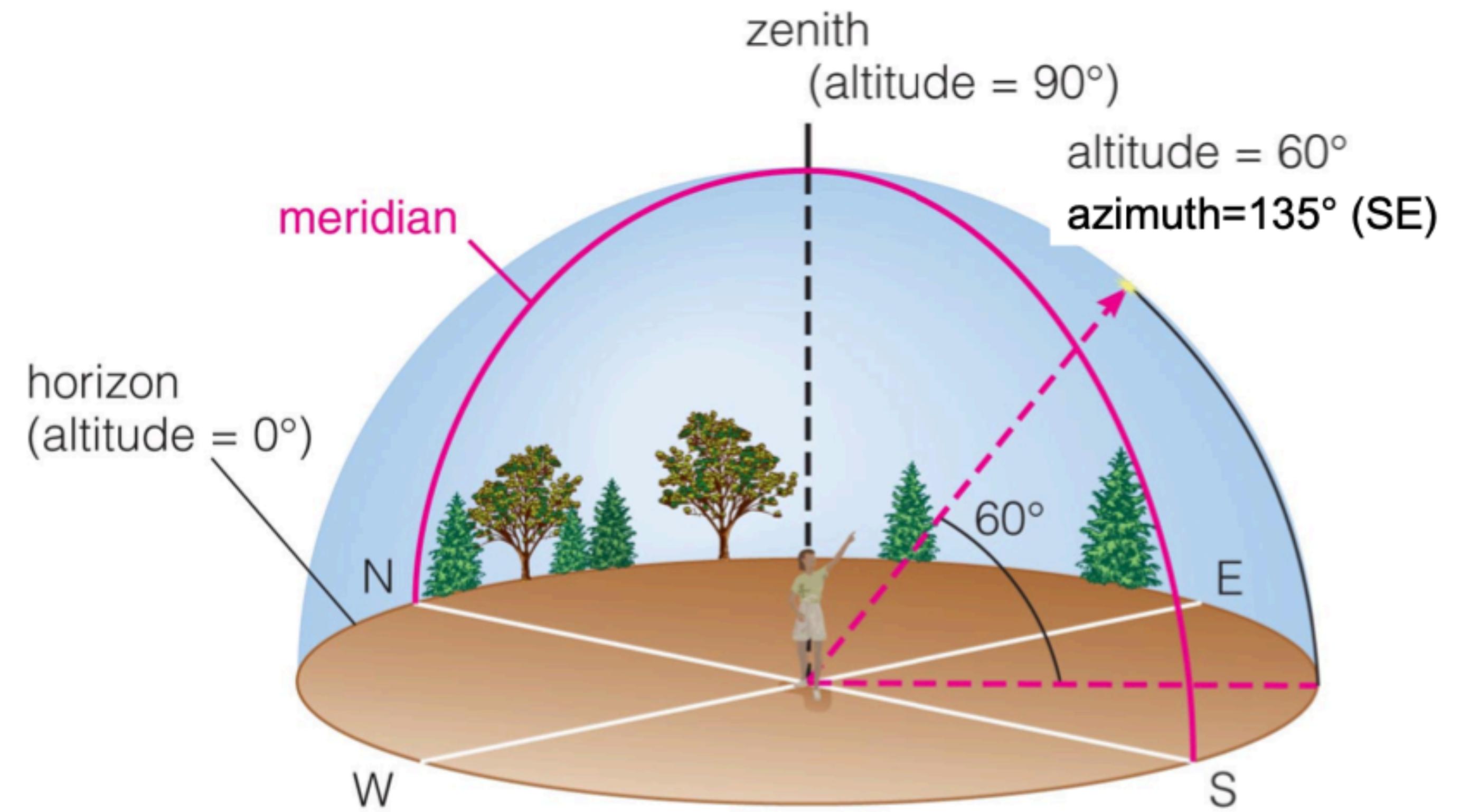
- Most “big telescopes” have relatively small (<0.5-deg) field of view (FOV)
 - e.g., Hubble “Wide Field Camera” only has a 2.7 x 2.7 arcmin FOV
- So need to make sure you are looking at the right object!



Alt/Az Coordinate System

The sky above a specific location at a specific time is a half sphere which can be described by 2 angular coordinates (Alt & Az)

- **Altitude (Alt):** angular distance to the horizon (sometimes called “elevation”)
- **Azimuth (Az):** angular distance from North
- **Zenith:** Point overhead
- **Meridian:** North-South line



Pearson Education

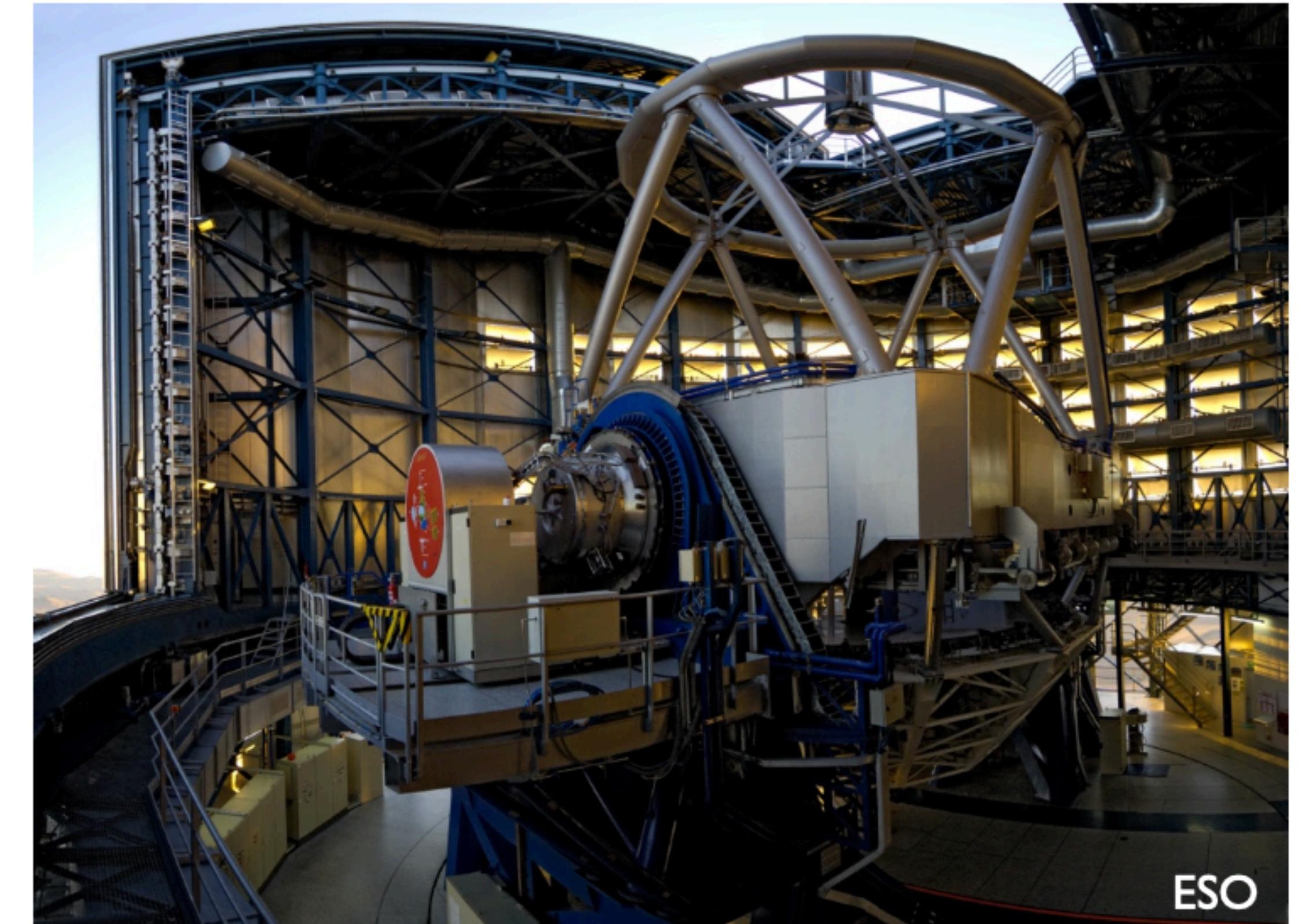
Alt/Az Coordinate System

The sky above a specific location at a specific time is a half sphere which can be described by 2 angular coordinates (Alt & Az)

Alt-Az telescope mounts are very simple and stable



8-inch Dobsonian
Telescope



Very Large Telescope
(8-meters)

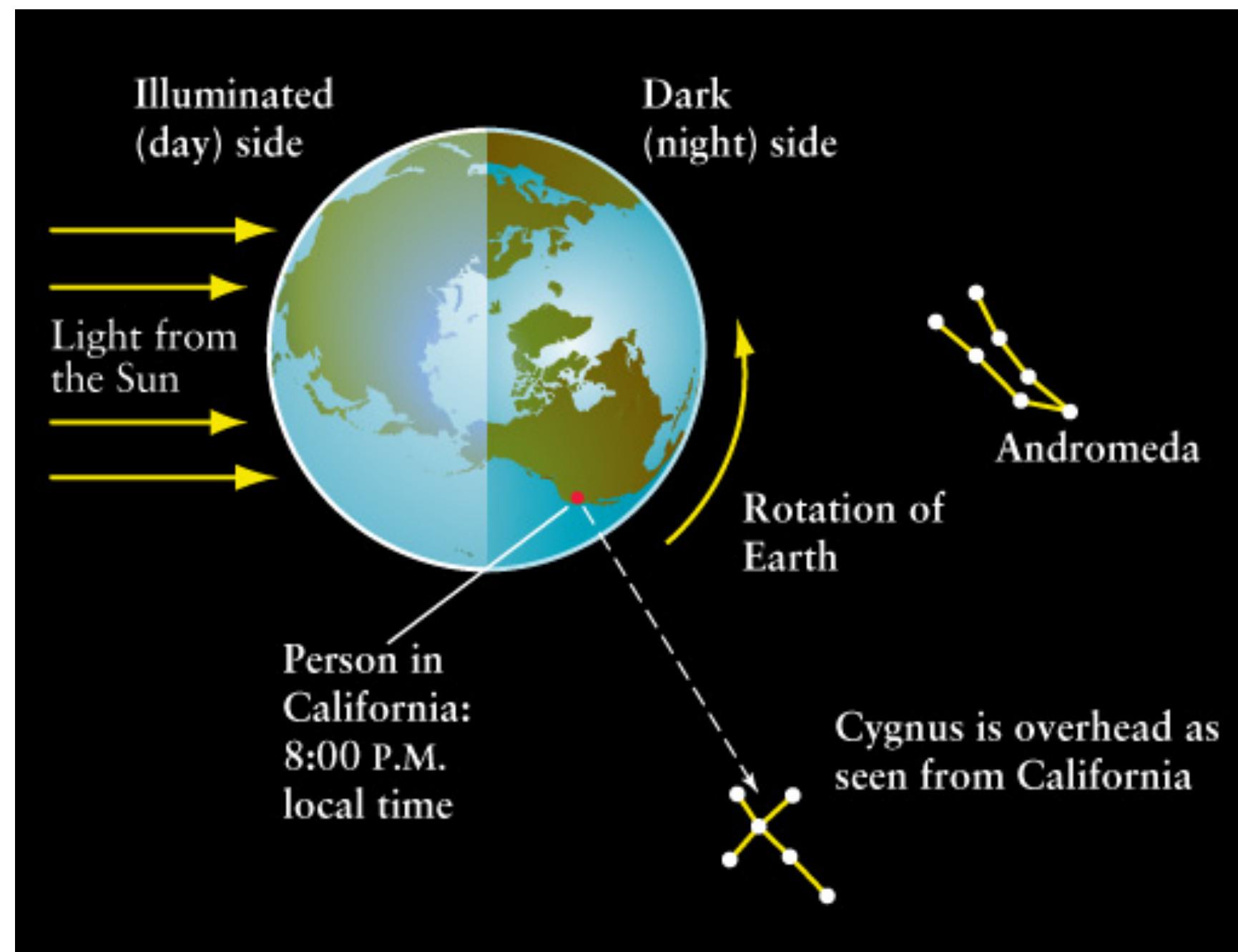


Alt/Az Coordinate System

- Altitude and Azimuth of an object vary with time
 - -> because of the rotation of the Earth!
- In practice, we use “sky” coordinates to locate objects
- Still you will need to approximately know the Alt and Az of your target to plan your observing for the night, e.g.,
 - Is my target “up”? (i.e., Altitude > 0-degrees)
 - Is my target “observable”? (i.e., Altitude > ~40-degrees)

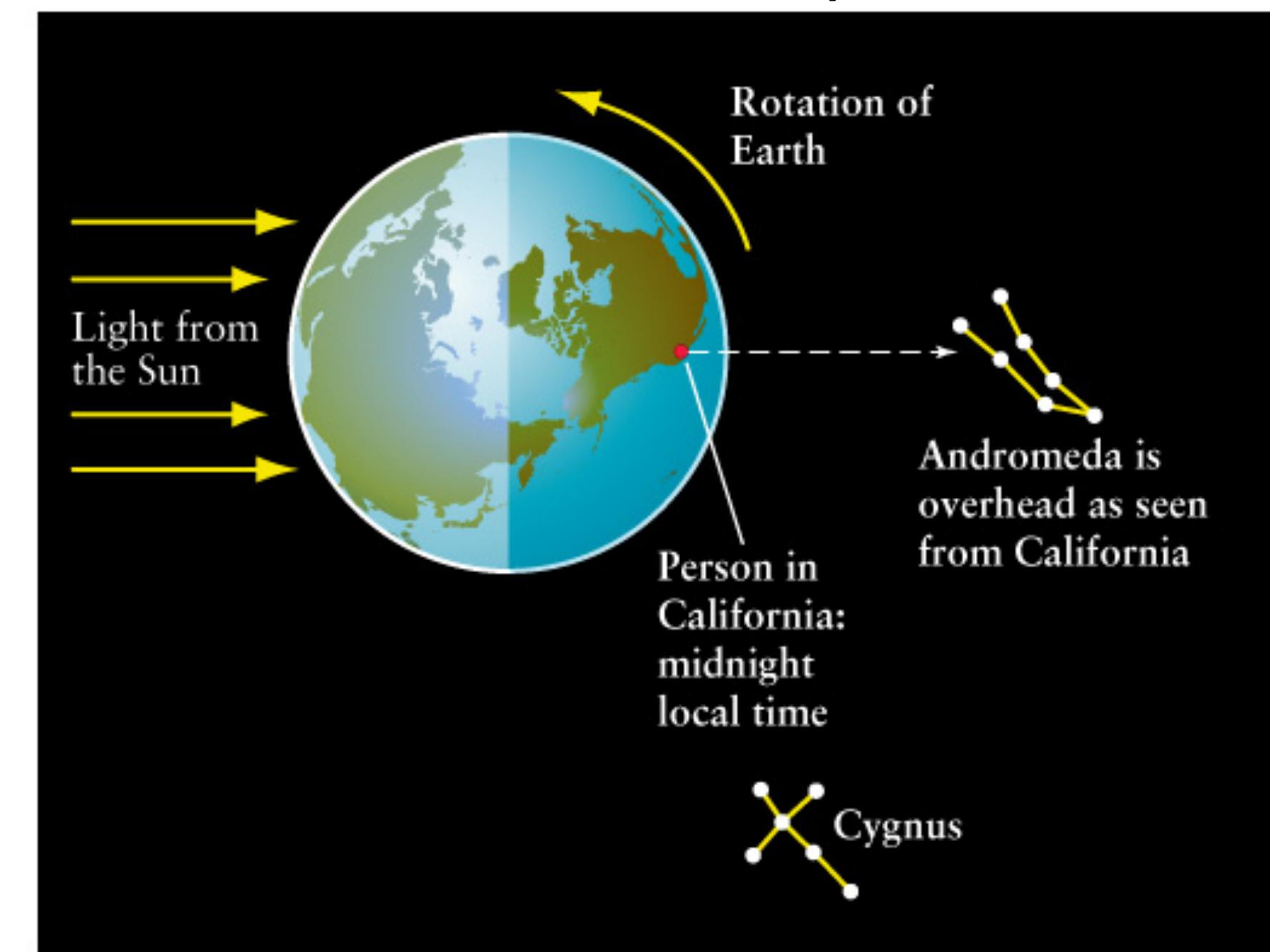
Rotation of the Earth

- Looking down on the North Pole, Earth rotates counter clockwise
- The Sky rotates from East to West
- Objects rise in the East, and set in the West
 - And “culminate” in the South when they cross the meridian



(a) Earth as seen from above the north pole

Andromeda is to the East; Cygnus is overhead

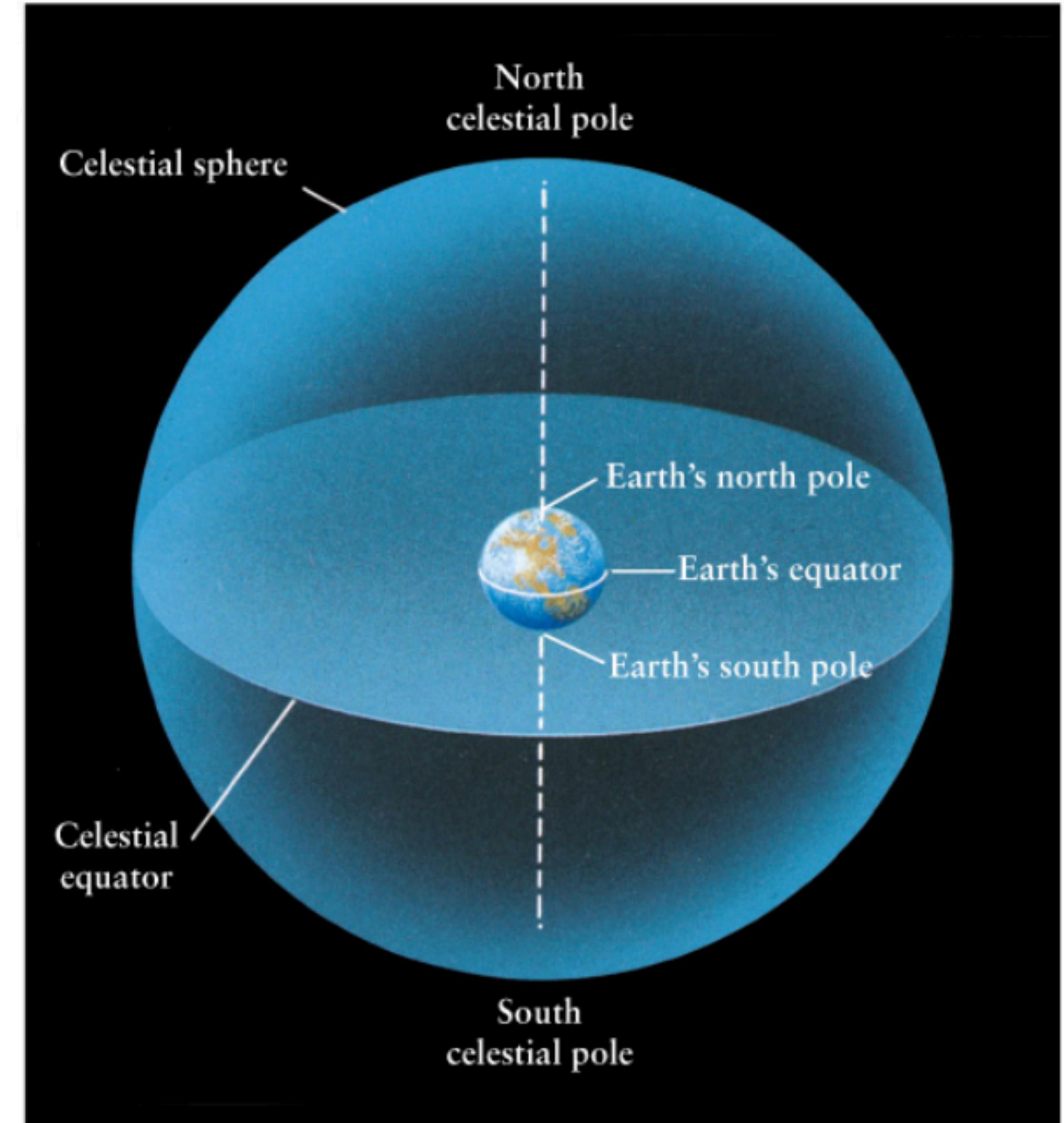


(b) 4 hours (one-sixth of a complete rotation) later

4 hrs later: Andromeda is overhead;
Cygnus is to the West

Celestial Sphere

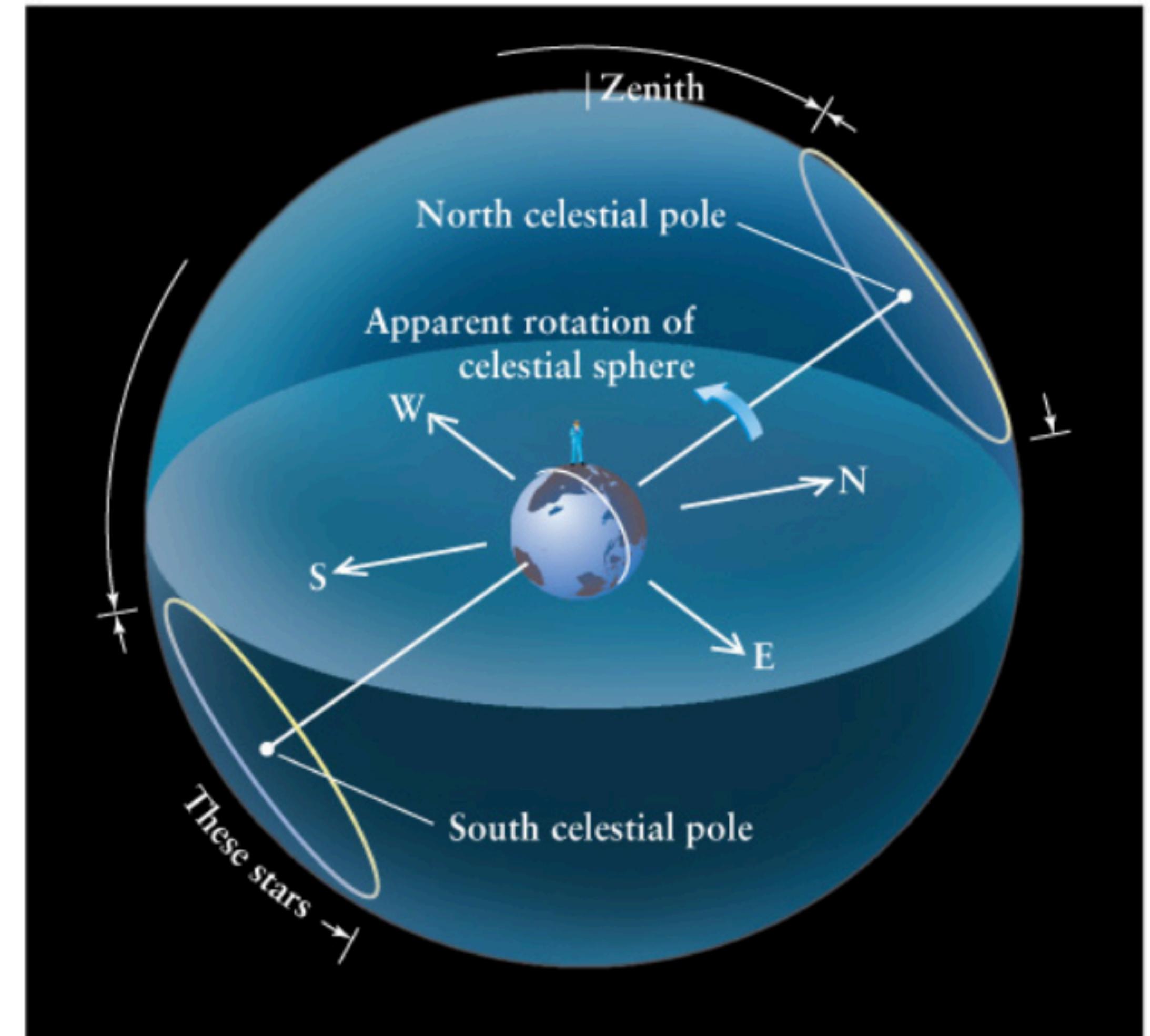
- **Celestial sphere:** Describe objects by their position on a sphere centered on the rotating Earth
- **Celestial North / South Pole:** projection of Earth's North / South Pole
- **Celestial Equator:** projection of Earth's equator



Bailey, Slater & Slater

Apparent Motion in the Sky

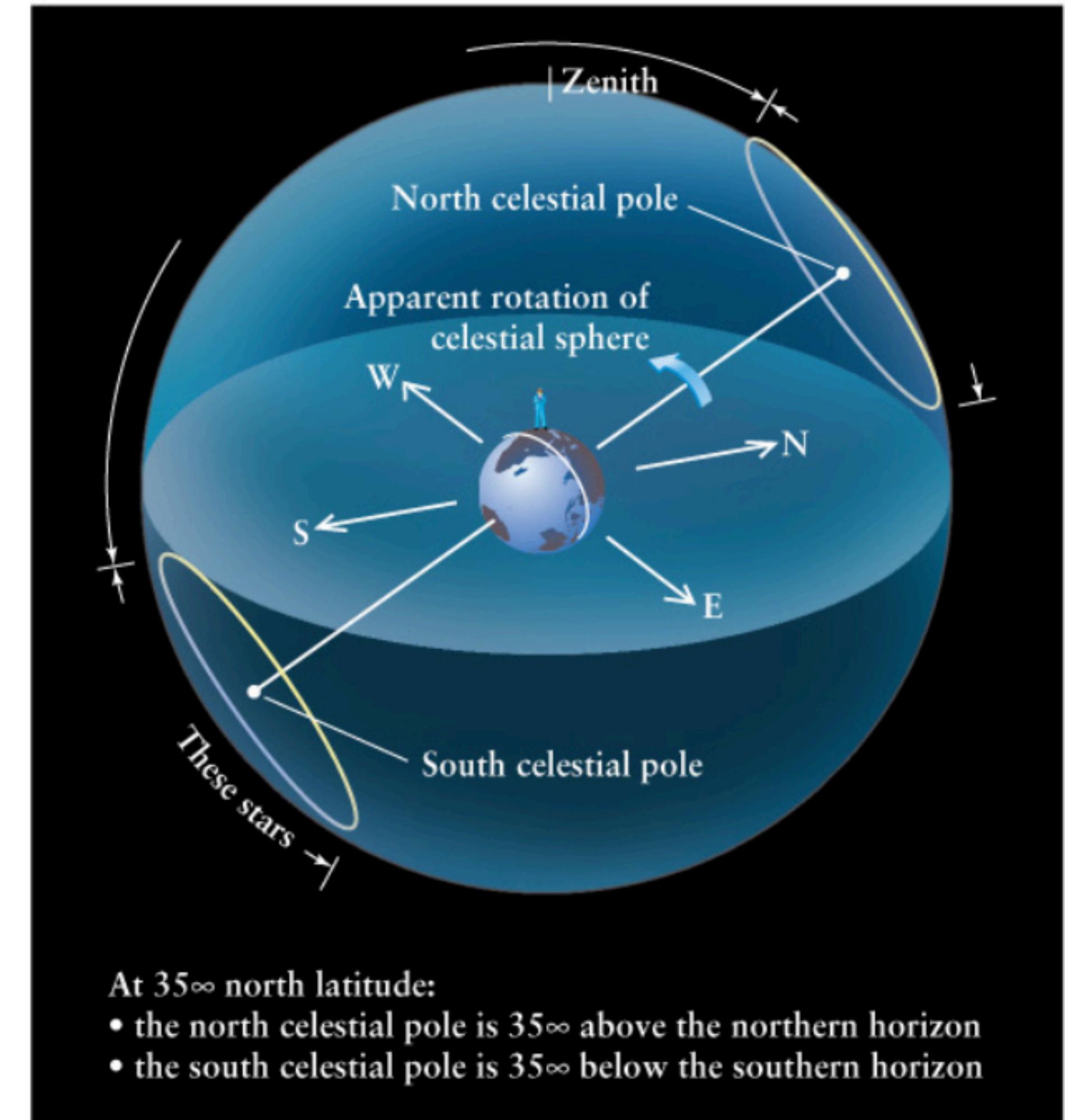
- Apparent sky motion depends on the latitude of the observer
- UChicago is at 41-deg North
- So North Pole is at what altitude?



Bailey, Slater & Slater

Apparent Motion in the Sky

- Apparent sky motion depends on the latitude of the observer
- UChicago is at 41-deg North
 - North Pole is at 41-deg altitude!
- Objects within 41-deg of NP are always “up” (i.e., “circumpolar”)
- We can never see objects within 41-deg of the South Pole
- All objects rise in the East, and set in the West

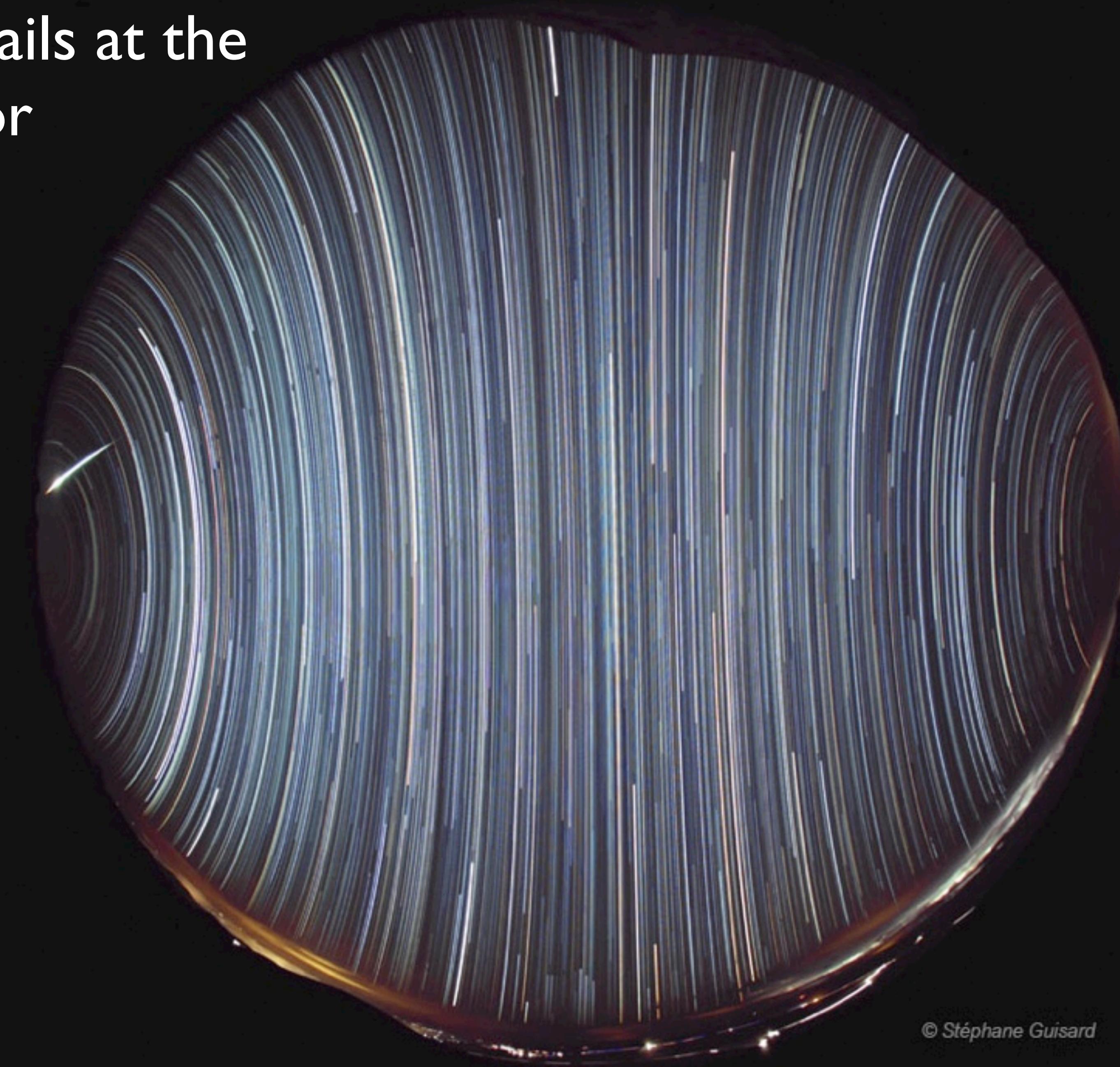


Bailey, Slater & Slater



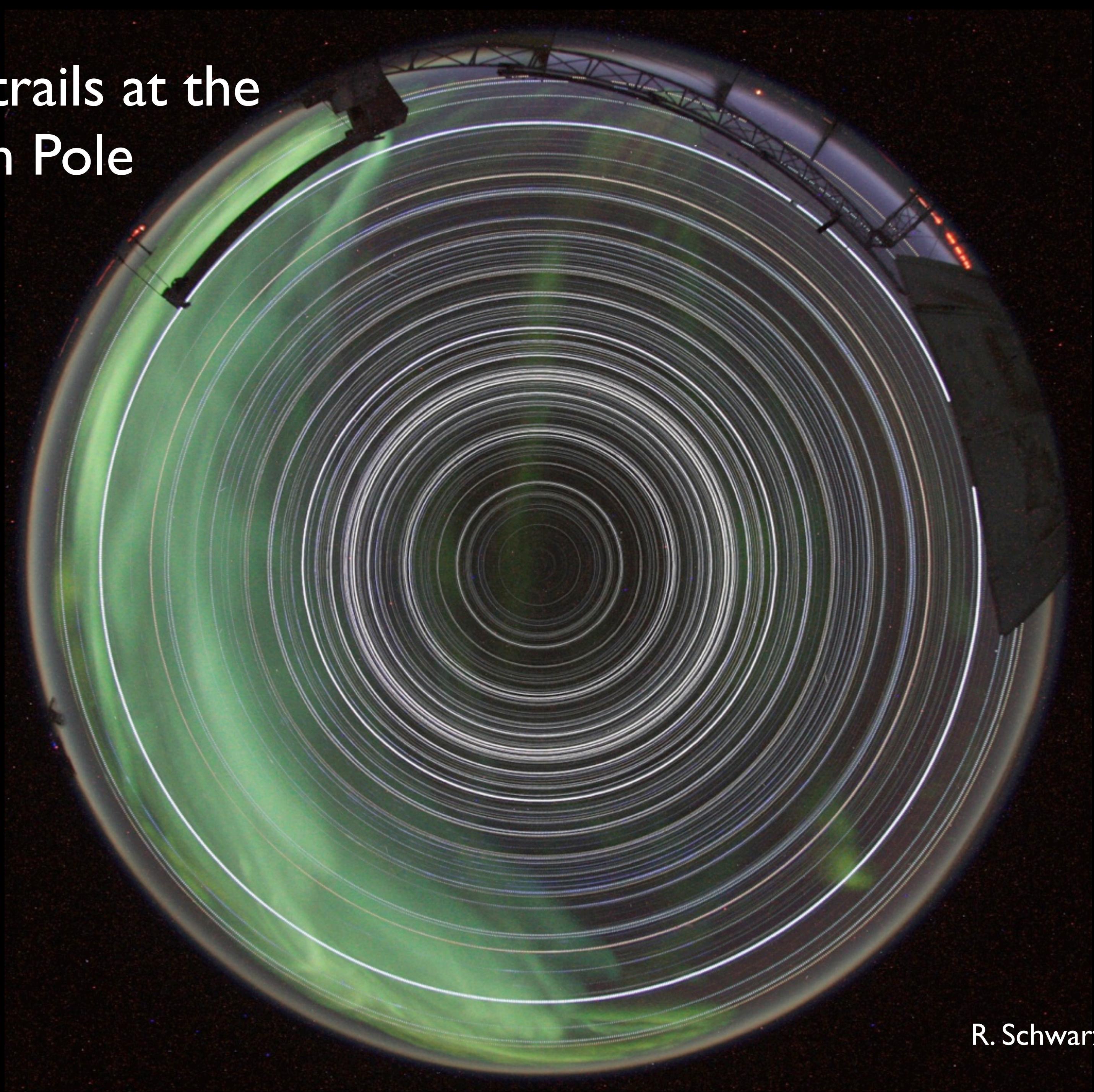
Star trails over CTIO, (c) Jose Delgado

Star trails at the equator



© Stéphane Guisard

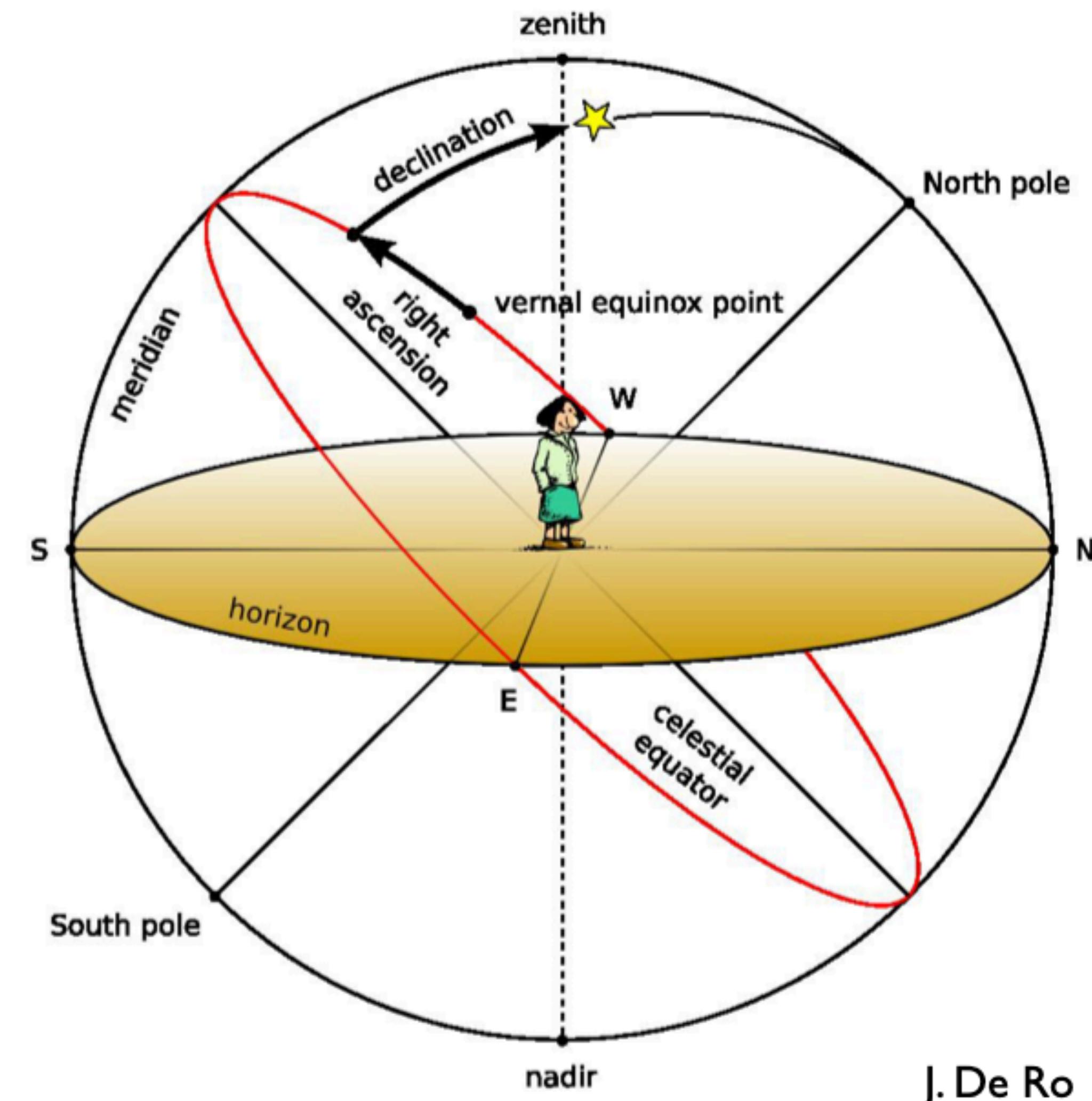
Star trails at the South Pole



R. Schwarz

Equatorial (RA/Dec) Coordinate System

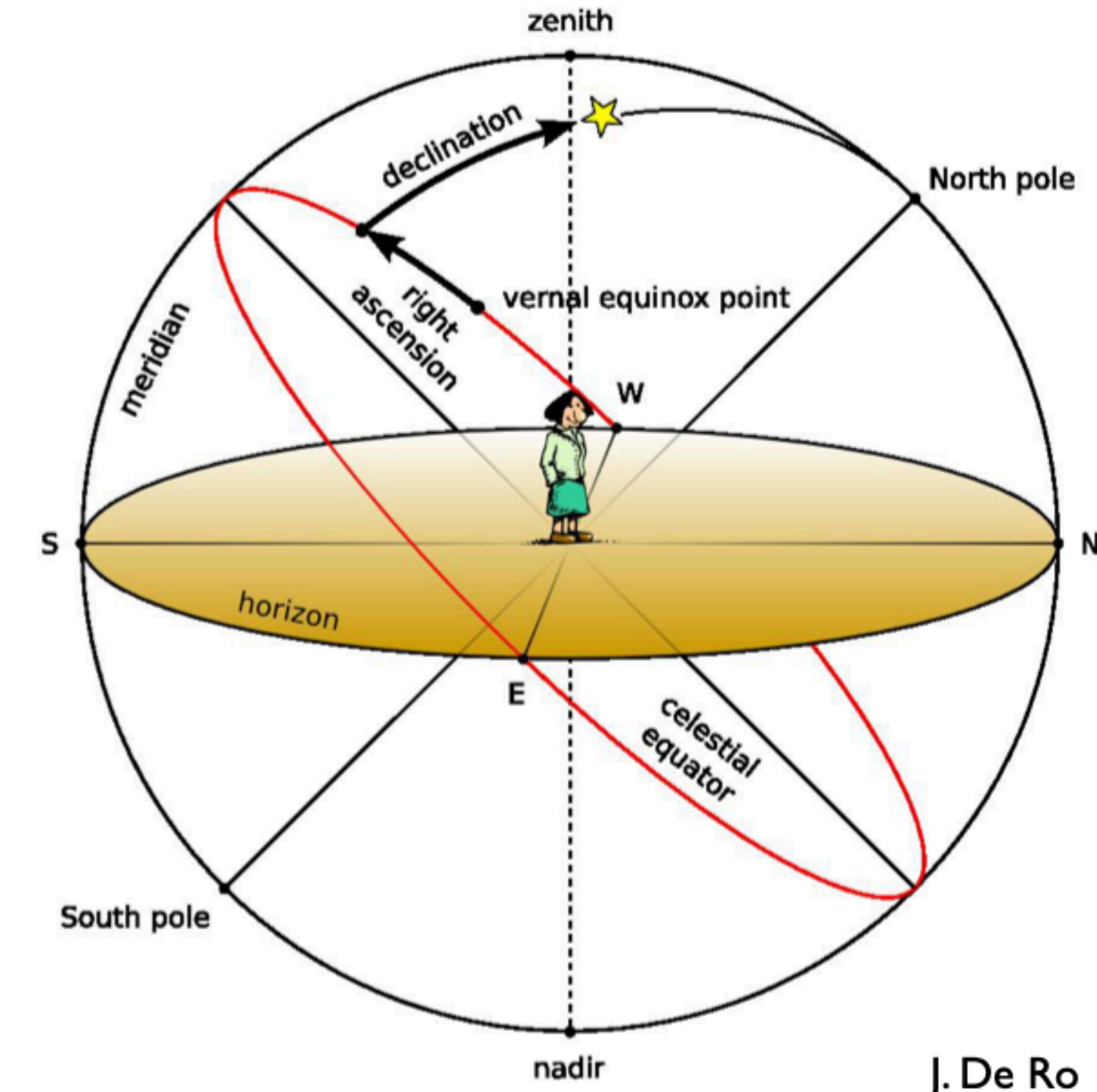
- Fixed to the celestial sphere, rotates with the sky
- **Declination (Dec, δ):** Angular distance from the celestial equator
- **Right Ascension (RA, α):** Angular distance from the vernal equinox (i.e., a special point on the equator)



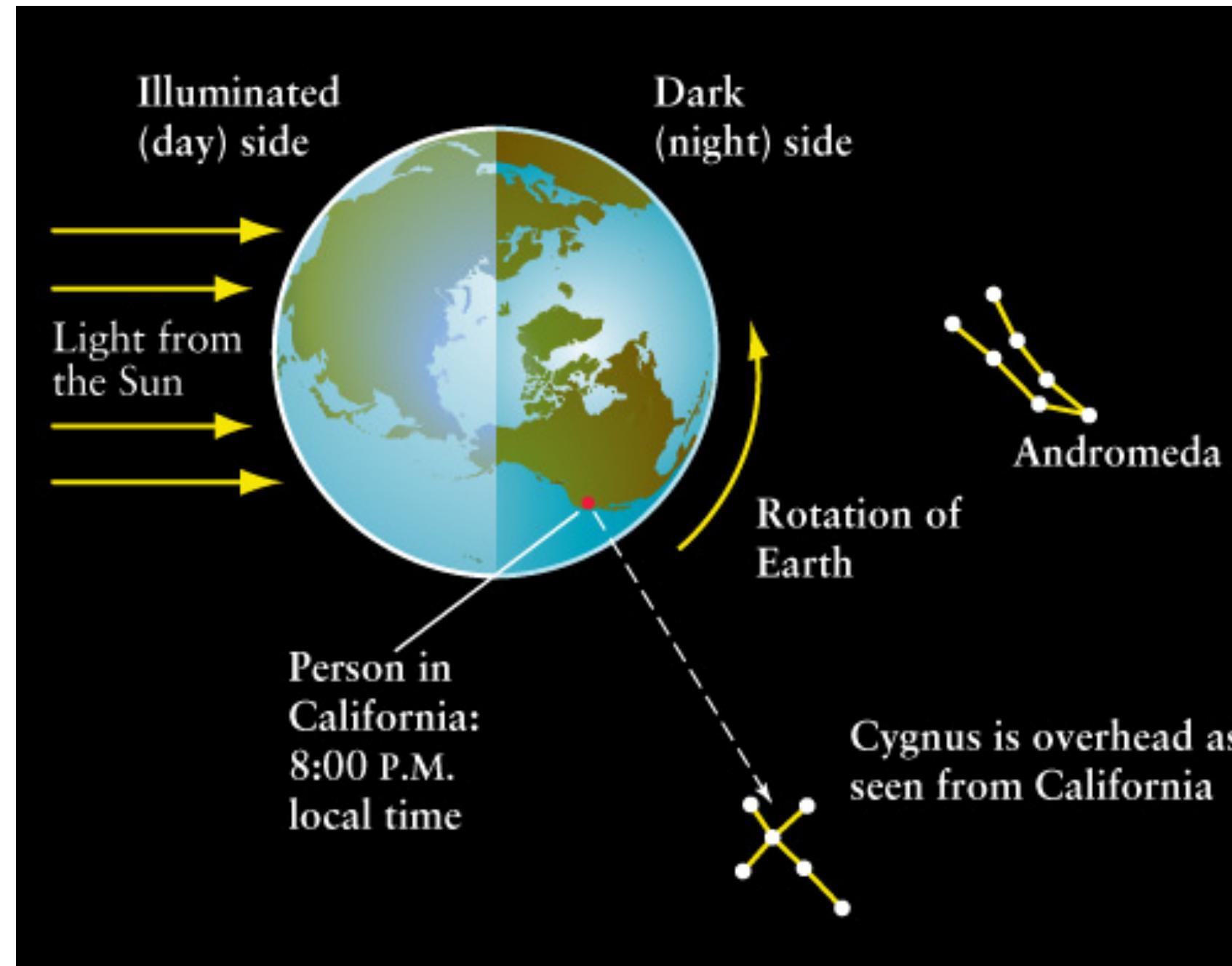
J. De Ro

Equatorial (RA/Dec) Coordinate System

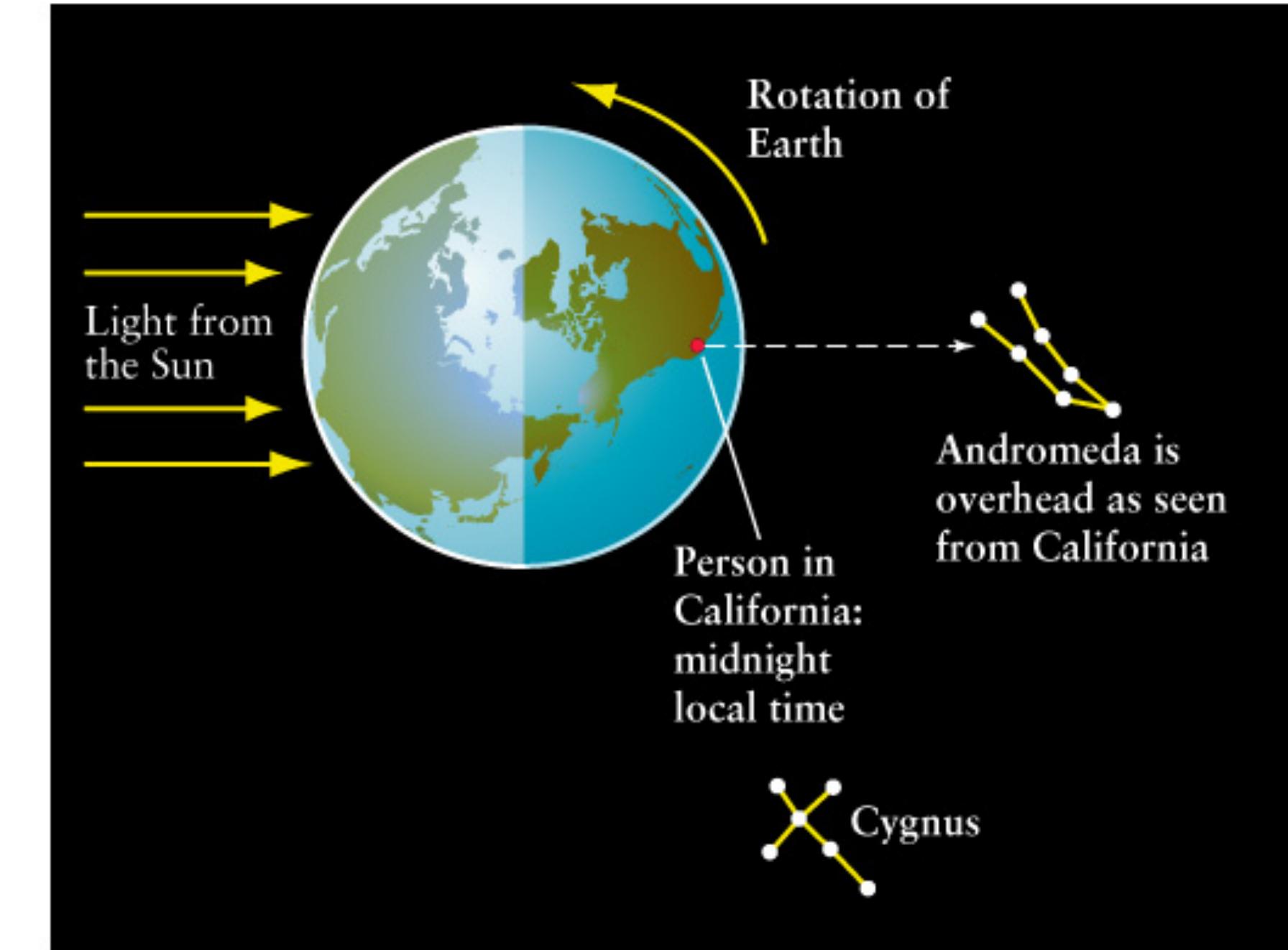
- **Declination (Dec, δ):** Measured in degrees, between $-90^\circ > \delta > 90^\circ$
- **Right Ascension (RA, α):** Angular distance from the vernal equinox (i.e., a special point on the equator). Can also be measured in degrees between $0^\circ < \alpha < 360^\circ$



Right Ascension (RA)



(a) Earth as seen from above the north pole

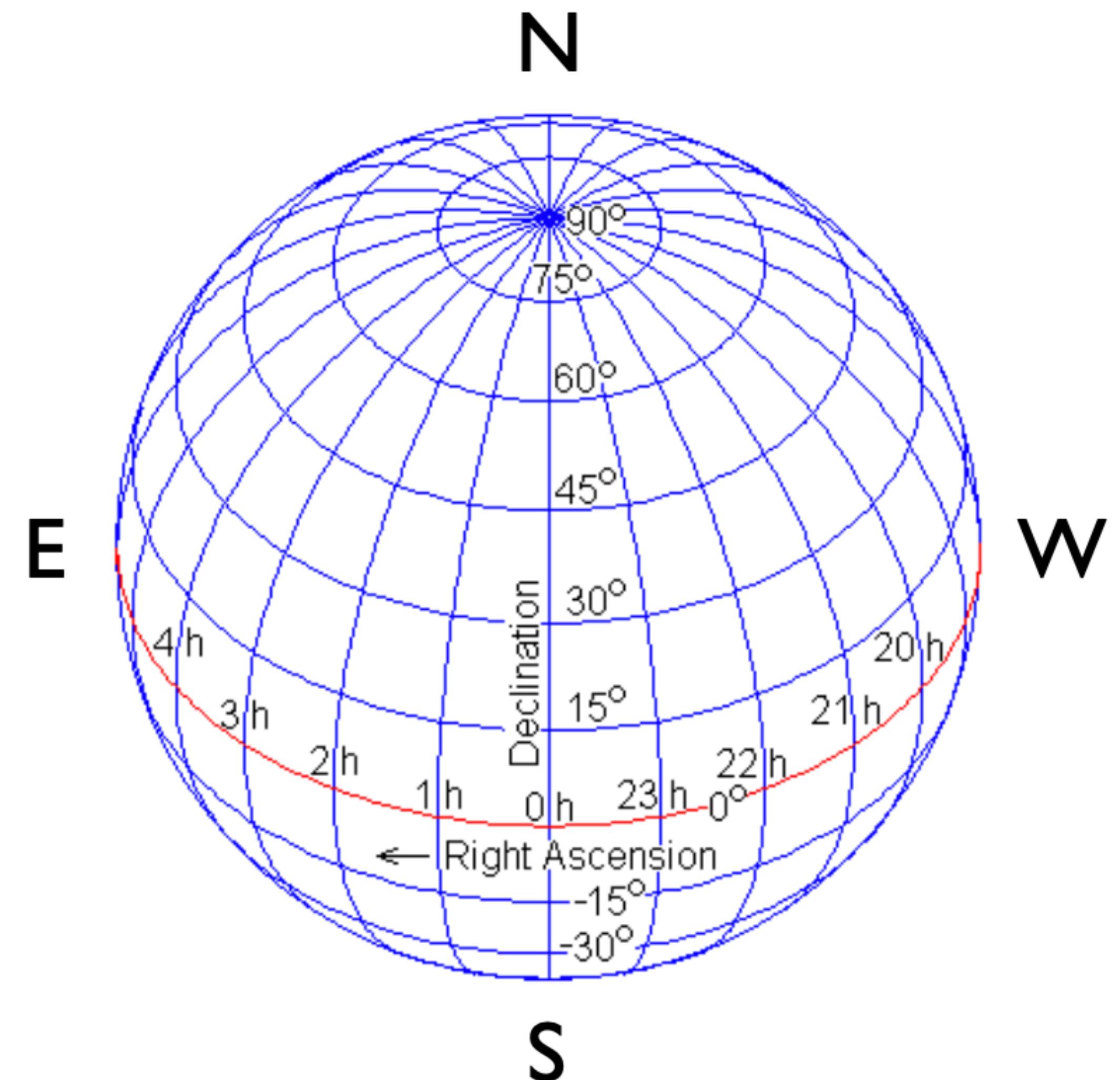


(b) 4 hours (one-sixth of a complete rotation) later

- A “natural” way to define RA is in units of time:
 - “Distance” between two points is given by the time interval between each of them passing the meridian
 - e.g., reference point (0h) culminates (passes meridian) at a certain time, all points that culminate 4-hrs later have **$\alpha = 4h$**

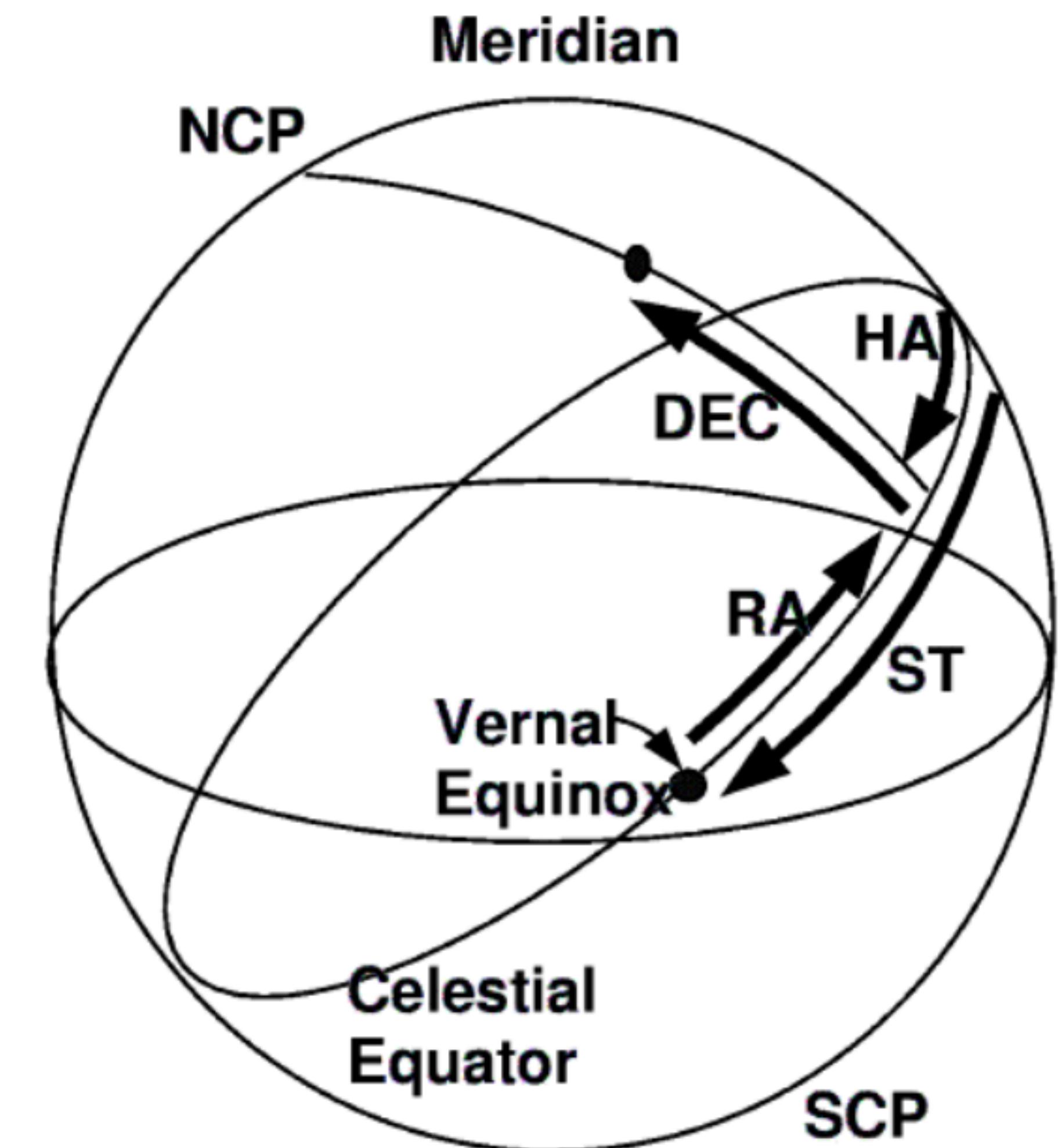
Right Ascension (RA), Local Sidereal Time (LST)

- Sky rotates East to West
 - East is “left”
- RA runs from right to left in astronomical maps
 - Larger RA values are on left of the image
- Local sidereal team (LST): RA of the objects currently culminating (on meridian)



RA, LST, and Hour Angle

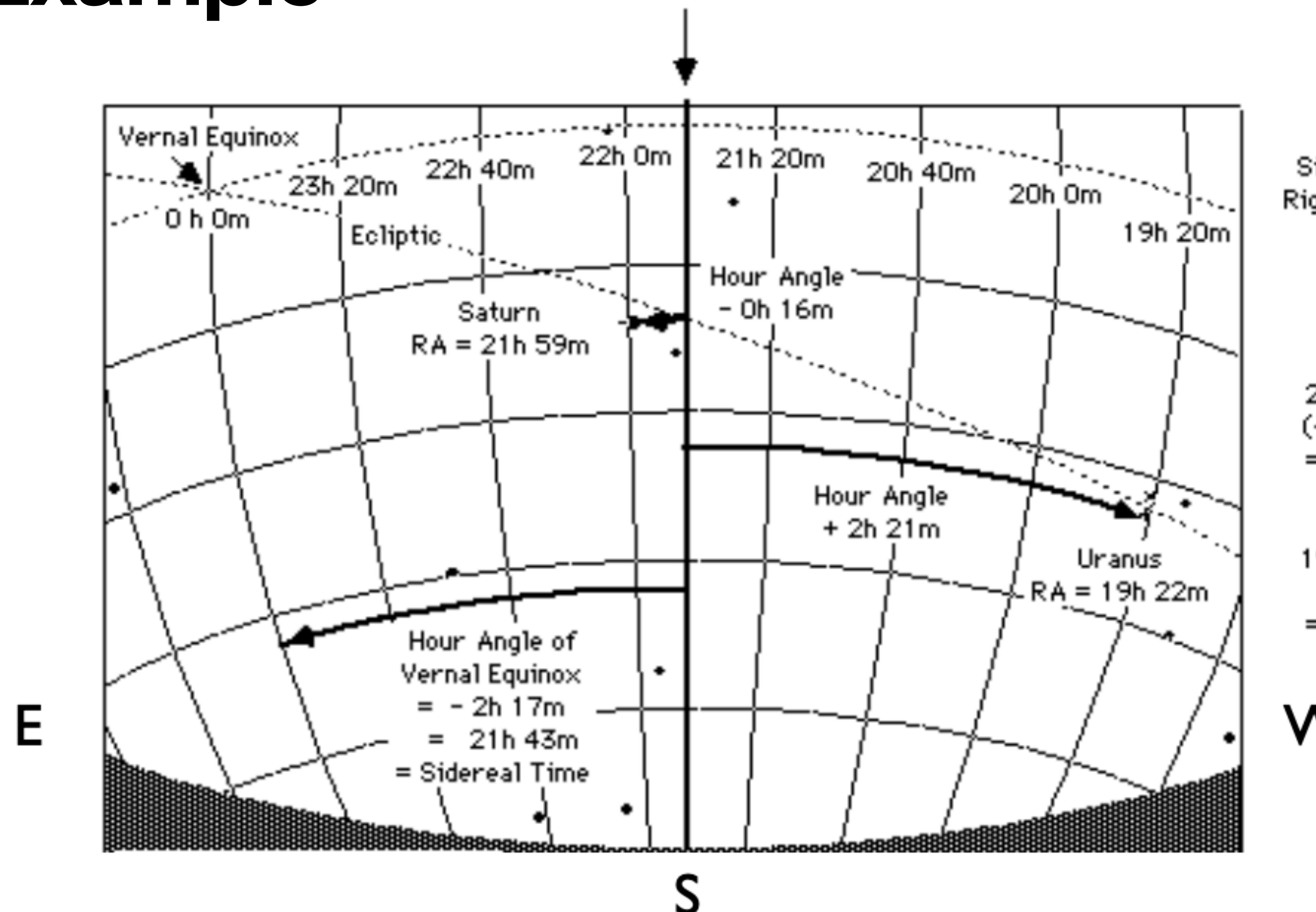
- Hour angle (HA): Time that has passed since object culminated
 - $HA = LST - a_{\text{object}}$
- $HA > 0h$: Object has already culminated, it is “setting” and in the Western half of the sky
- $HA < 0h$: Object is rising, is in the Eastern half of the sky, will culminate in HA hours



R. O'Connell

HA Example

Sidereal Time
= Right Ascension on Meridian
= 21 hrs 43 min



Sidereal Time =
Right Ascension +
Hour Angle

Saturn:
21h 59m RA +
(- 0h 16m) HA
= 21h 43m ST

Uranus:
19h 22m RA +
2h 21m HA
= 21h 43m ST

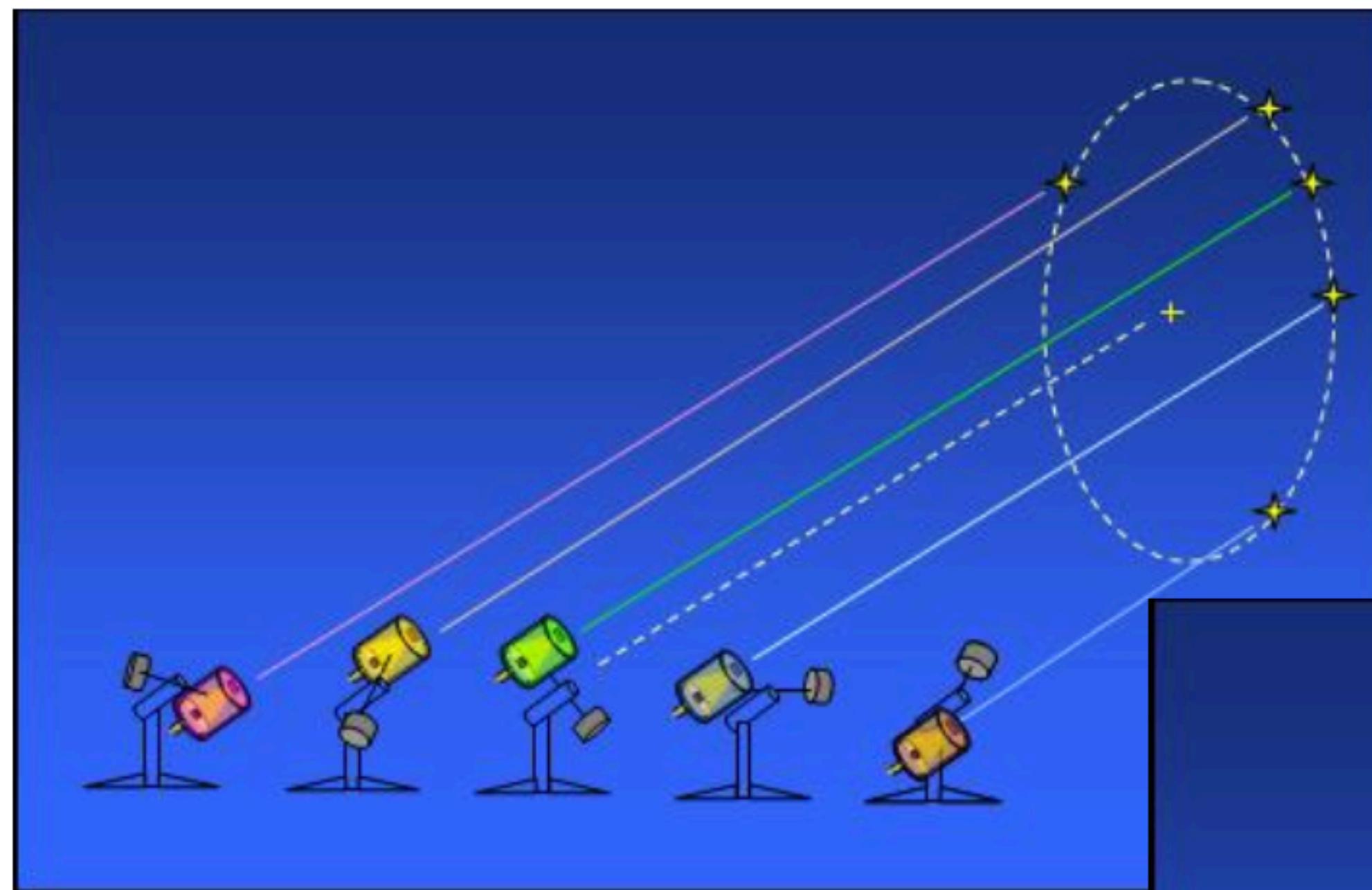
Equatorial Telescope Mounts

- **Alt/Az mounts:** need to track object in two axis, with variable speed
- **Equatorial mount:** One axis is parallel to Earth's rotation axis -> Need to track only in this axis with constant speed



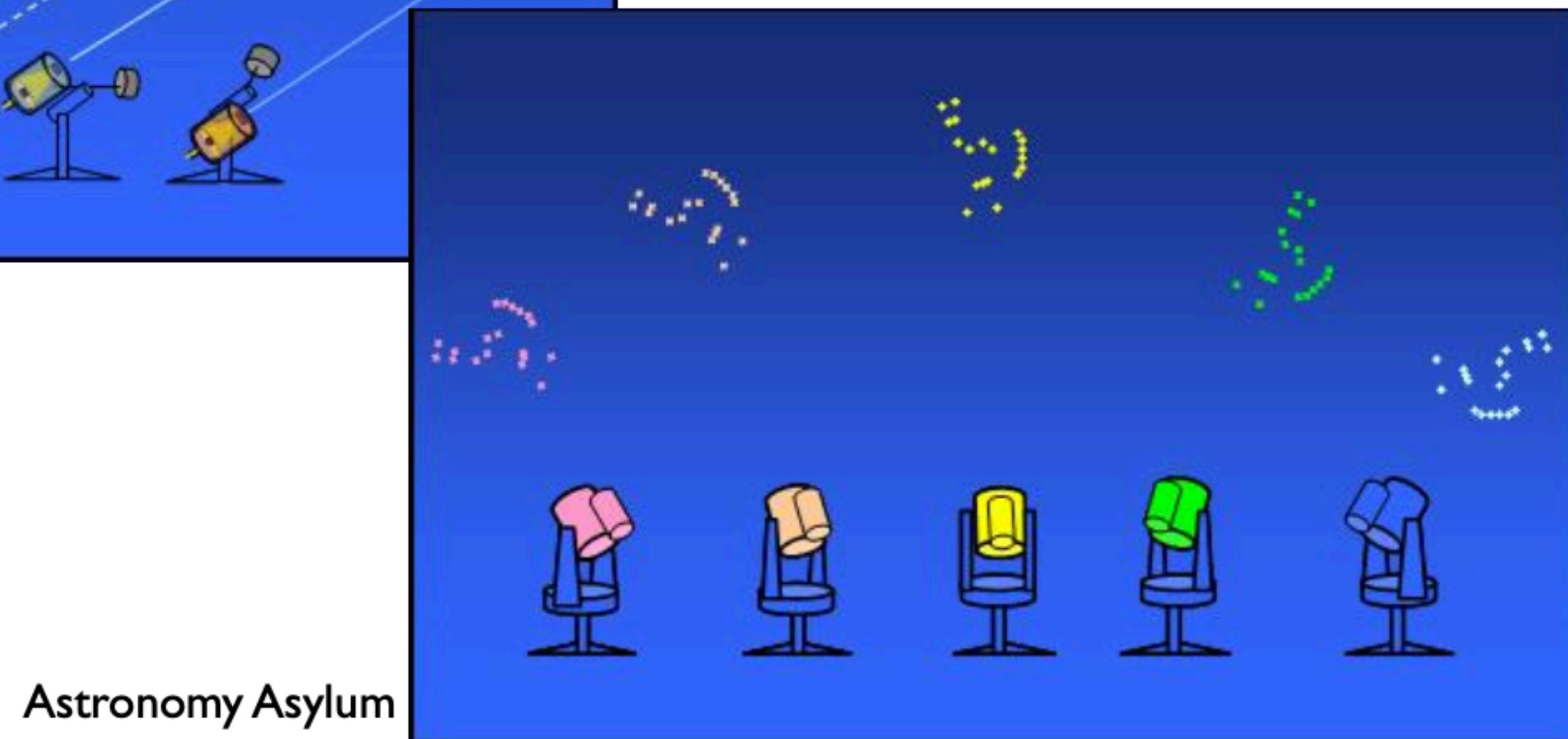
Equatorial Telescope Mounts

removes the need for a **field de-rotator**



equ. mount

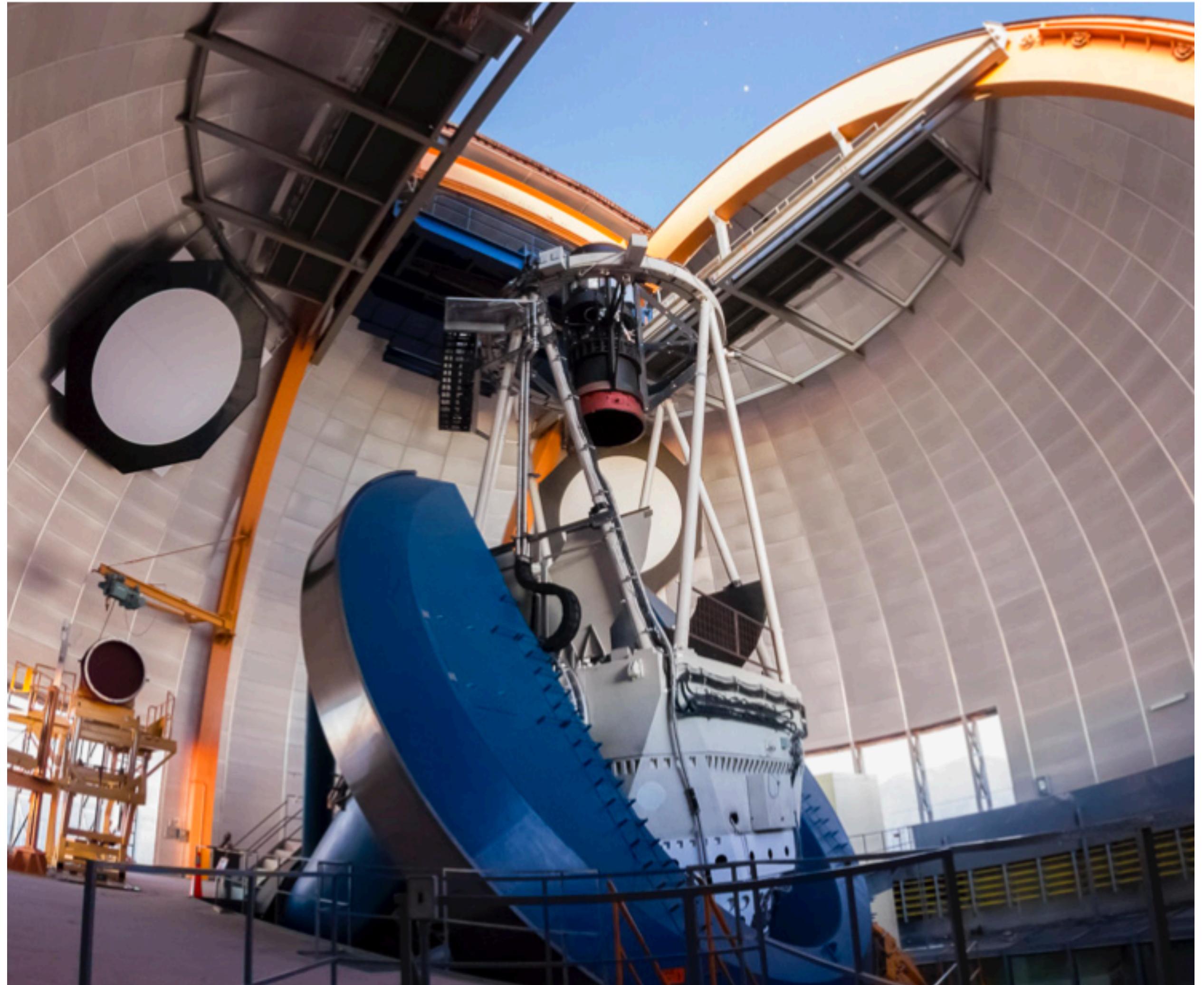
alt/az mount



Astronomy Asylum

Equatorial Telescope Mounts

- Not feasible for the largest telescopes
- But found on some intermediate class telescopes, e.g., the 4-meter telescopes on Kitt Peak and Cerro Tololo



R.A. and Dec Format

both can be expressed as degrees:

$$0^\circ \leq \alpha < 360^\circ$$

$$-90^\circ \leq \delta \leq +90^\circ$$

e.g. M31: $10.6847^\circ, +41.26875^\circ$

often expressed in sexagesimal system:

$$00^{\text{h}}42^{\text{m}}44.33^{\text{s}}, +41^\circ16'07.5''$$

$$00:42:44.33, +41:16:07.5$$

note:

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

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

$$1^{\text{m}} = 15^\circ/60 = 0.25^\circ = 15'$$

$$1^{\text{s}} = 15^\circ/3600 = 0.25' = 15''$$

Looking up Coordinates and Information on an Object

- SIMBAD astronomical database: <https://simbad.u-strasbg.fr/simbad/>

simbad.u-strasbg.fr/simbad/sim-basic?Ident=AR+Sco&submit=SIMBAD+search

AR Sco

other query modes : Identifier query Coordinate query Criteria query Reference query Basic query Script submission TAP Output options Help

Query : AR Sco C.D.S. - SIMBAD4 rel 1.5.8 - 2016.08.31CEST02:44:42

Available data : Basic data • Identifiers • Plot & images • Bibliography • Measurements • External archives • Notes • Annotations

Basic data :

V* AR Sco -- Variable Star of delta Sct type

Other object types: V* (V*,AN), IR (2MASS,SSTc2d), ds* ([Ref](#))

ICRS coord. (ep=J2000) : 16 21 47.28 -22 53 10.3 (Infrared) [60 60 90] [B 2003yCat.2246....0C](#)

FK5 coord. (ep=J2000 eq=2000) : 16 21 47.28 -22 53 10.3 [60 60 90]

FK4 coord. (ep=B1950 eq=1950) : 16 18 47.99 -22 46 07.8 [60 60 90]

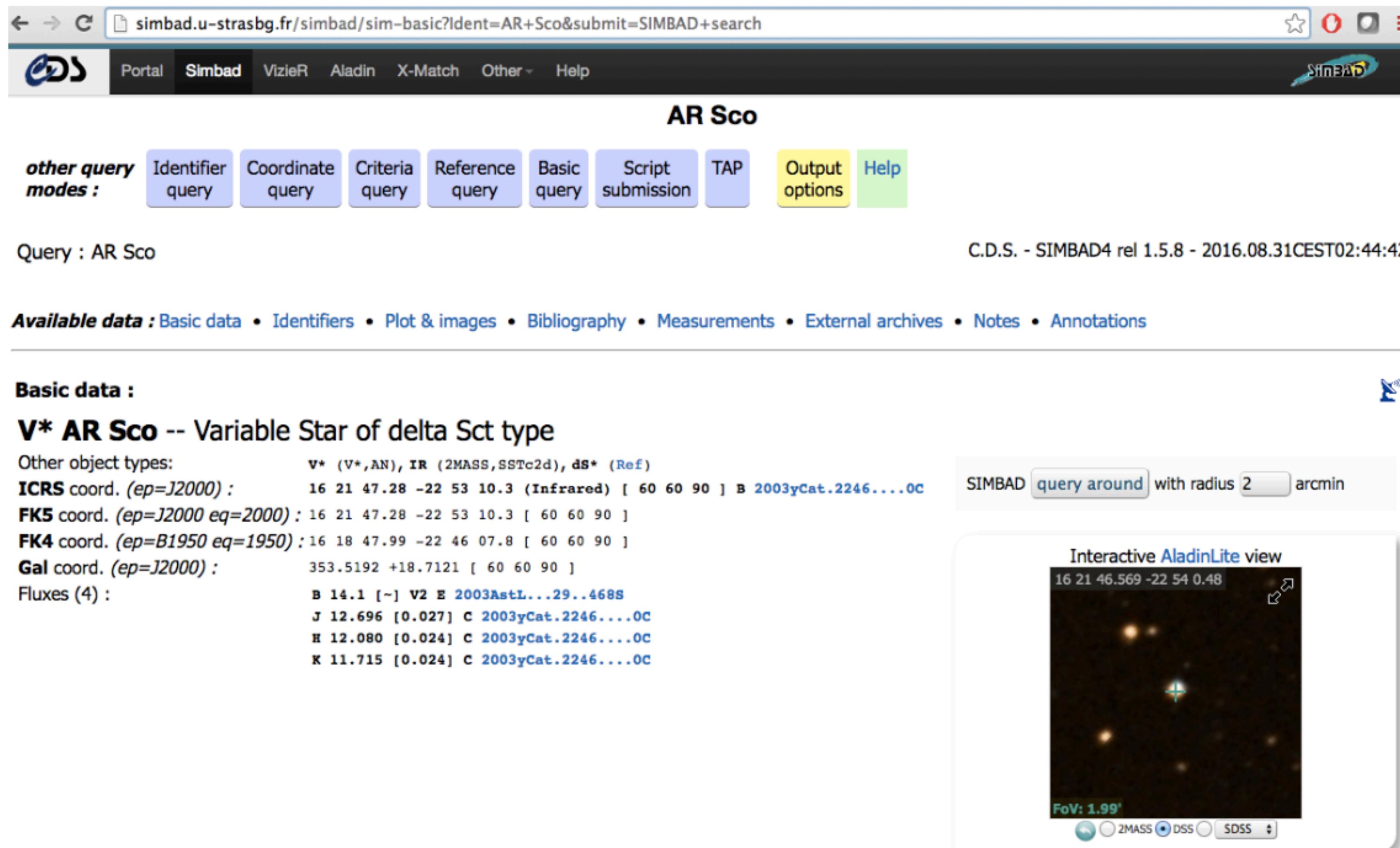
Gal coord. (ep=J2000) : 353.5192 +18.7121 [60 60 90]

Fluxes (4) :

B 14.1 [-] V2 E [2003AstL...29..468S](#)
J 12.696 [0.027] C [2003yCat.2246....0C](#)
H 12.080 [0.024] C [2003yCat.2246....0C](#)
K 11.715 [0.024] C [2003yCat.2246....0C](#)

SIMBAD [query around](#) with radius 2 arcmin

Interactive AladinLite view
16 21 46.569 -22 54 0.48
FoV: 1.99'
2MASS DSS SDSS



Looking up Coordinates and Information on an Object

- NASA/IPAC Extragalactic Database (NED): <https://ned.ipac.caltech.edu/>

NED results for object MESSIER 031

1 objects found in NED.

SOURCE LIST

Row No.	Object Name (* => Essential Note)	RA	EquJ2000.0 DEC	Object Type	Velocity/Redshift km/s z	Mag./ Qual Filter	Separ. arcmin	Number of Refs	Notes	Phot Posn	Vel/z	Diam	Assoc	Images	Spectra	
1	MESSIER 031	00h42m44.3s	+41d16m09s	G	-300 -0.001001	4.36	...	4055	23	147	20	31	7	2	Retrieve	Retrieve

Detailed information for each object

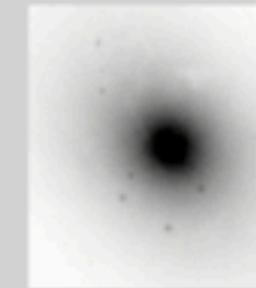
Object No. 1 - MESSIER 031

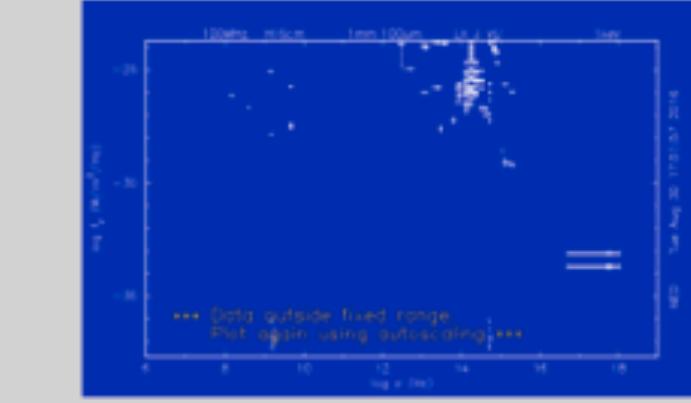
INDEX for MESSIER 031

Essential Data (jump to sub-section of this query report):

- [Essential Note](#)
- [Cross-IDs](#)
- [Coordinates](#)
- [Basic Data](#)
- [Quantities Derived from Redshift](#)
- [Redshift-Independent Distances](#)
- [Quick-Look Photometry and Luminosities](#)
- [Quick-Look Angular and Physical Sizes](#)
- [Classifications](#)
- [Foreground Galactic Extinction](#)
- [External Services](#)

Detailed Data (NED queries):

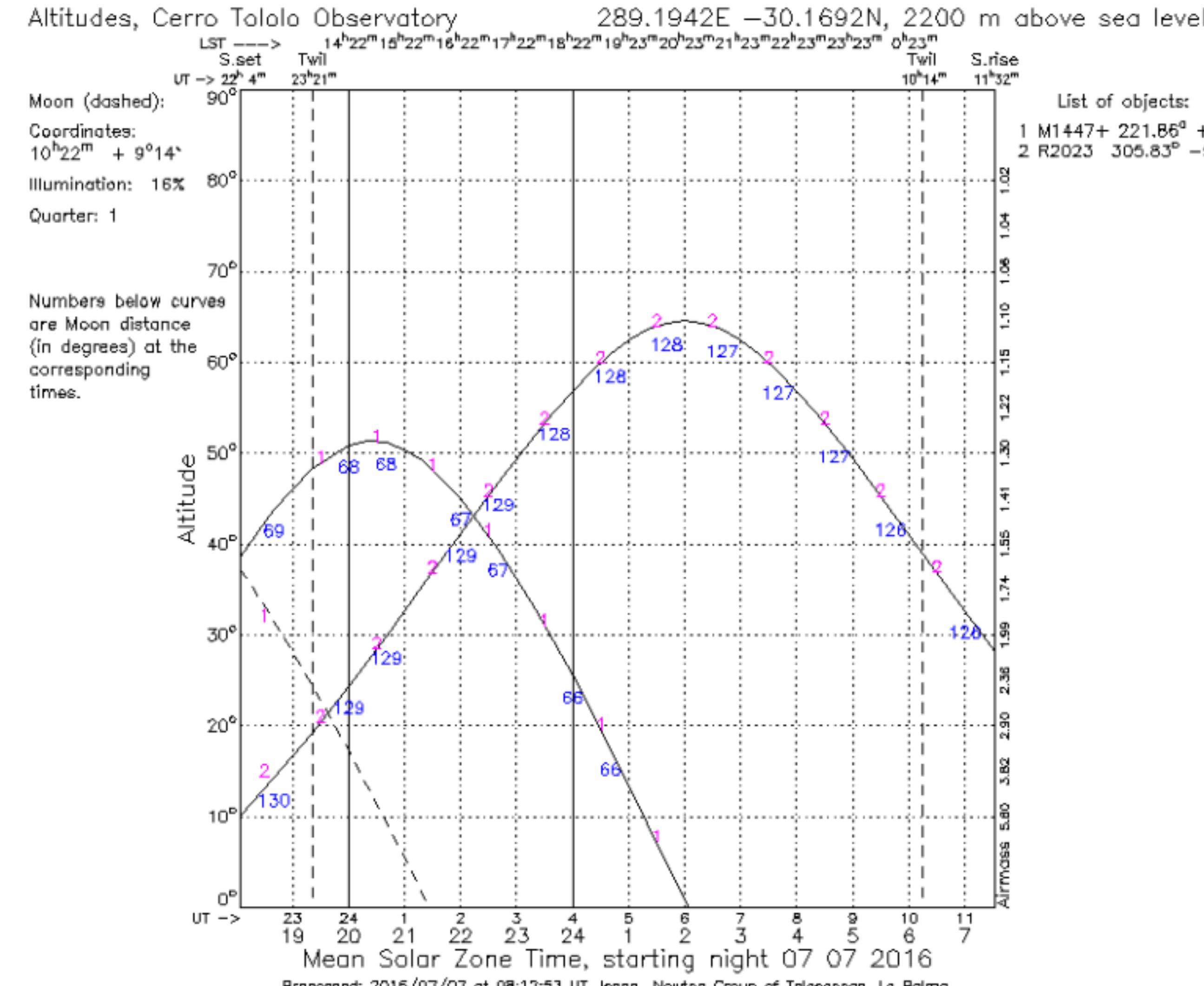
 [Images](#)

 [147 Photometric data point\(s\) and SED](#)

[Spectra](#)
[Redshift-Independent Distances](#)
[4055 Reference\(s\)](#)
[20 Position data point\(s\)](#)
[31 Redshift data point\(s\)](#)
[7 Diameter data point\(s\)](#)
[23 Note\(s\)](#)
[2 Association\(s\)](#)
[UGC data](#)
[RC3 data](#)

Object Visibility Tool

- “StarAlt”: <http://catserver.ing.iac.es/staralt/>
- Given catalog of object positions, StarAlt will plot their altitude vs time (and other features)
- Also see how to do this in python using week-1 tutorial linked on the wiki:
 - https://docs.astropy.org/en/stable/generated/examples/coordinates/plot_obs-planning.html

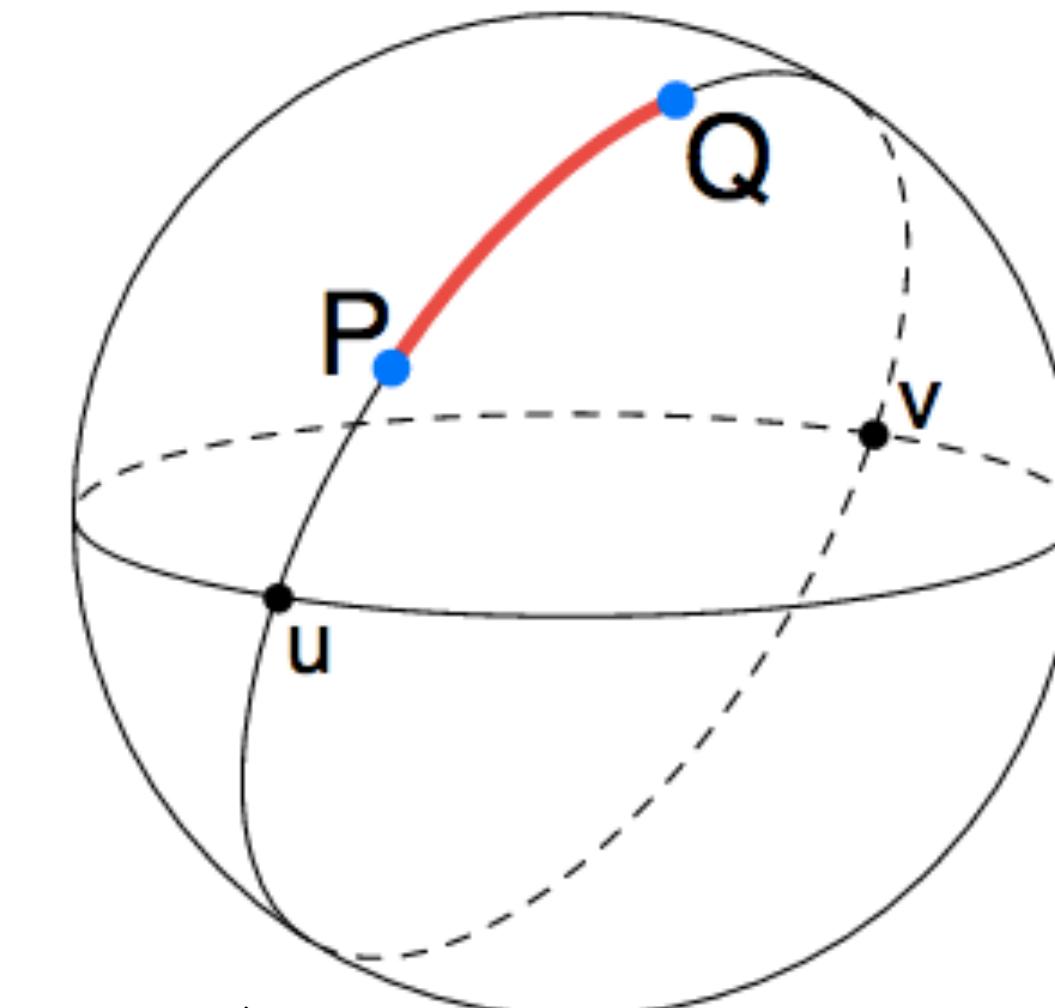


Distance between two objects

two objects at (α_1, δ_1) and (α_2, δ_2) - how far apart are they?

- surface of a sphere is non-Euclidian
- e.g. sum of angles in a triangle is $> 180^\circ$
- need to use spherical geometry

$$\cos(\gamma) = \cos(90^\circ - \delta_1) \cos(90^\circ - \delta_2) + \\ \sin(90^\circ - \delta_1) \sin(90^\circ - \delta_2) \cos(\alpha_1 - \alpha_2)$$

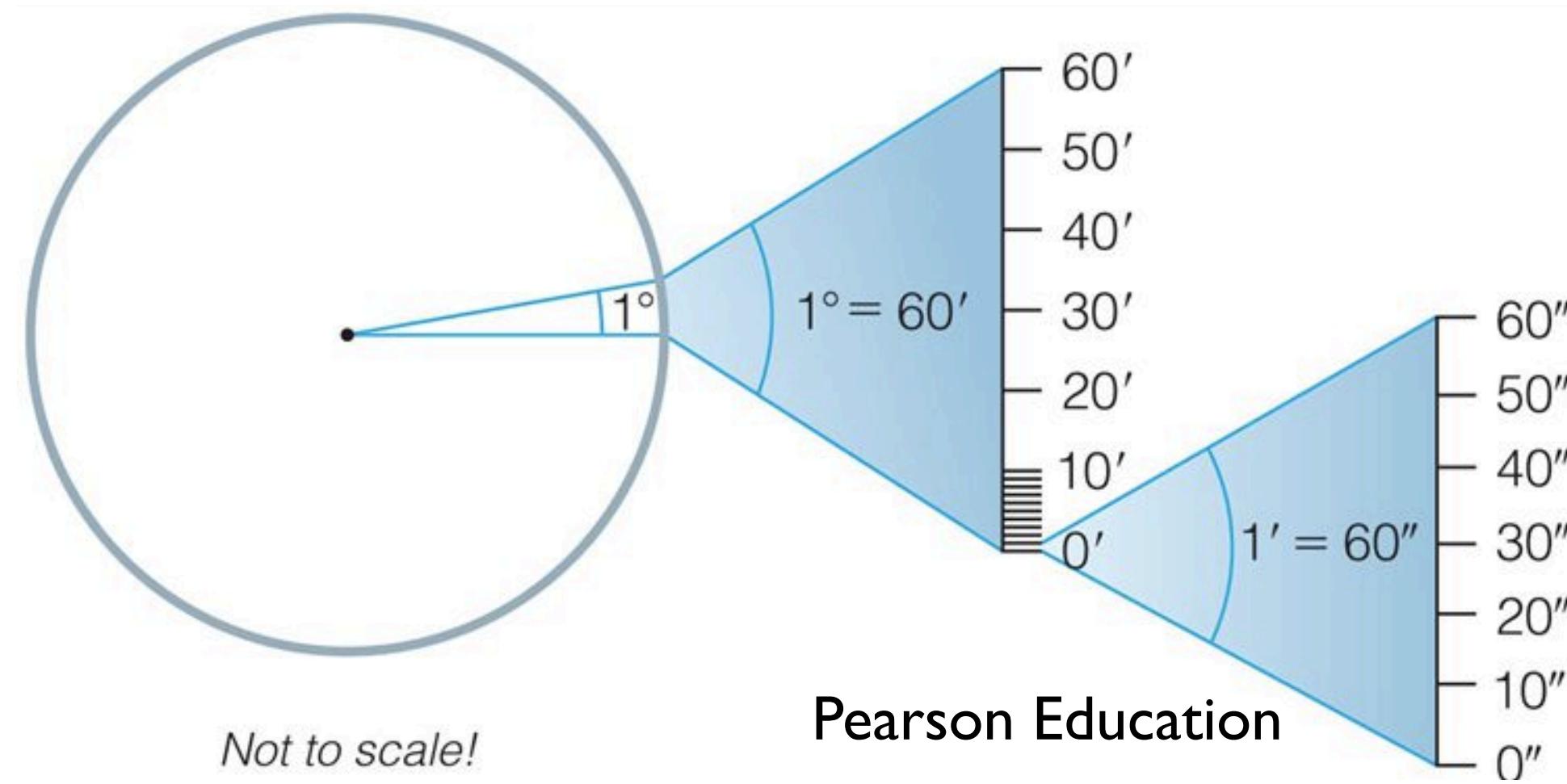


for small distances, can use Euclidian approximation;
HOWEVER, need to include $\cos(\delta)$

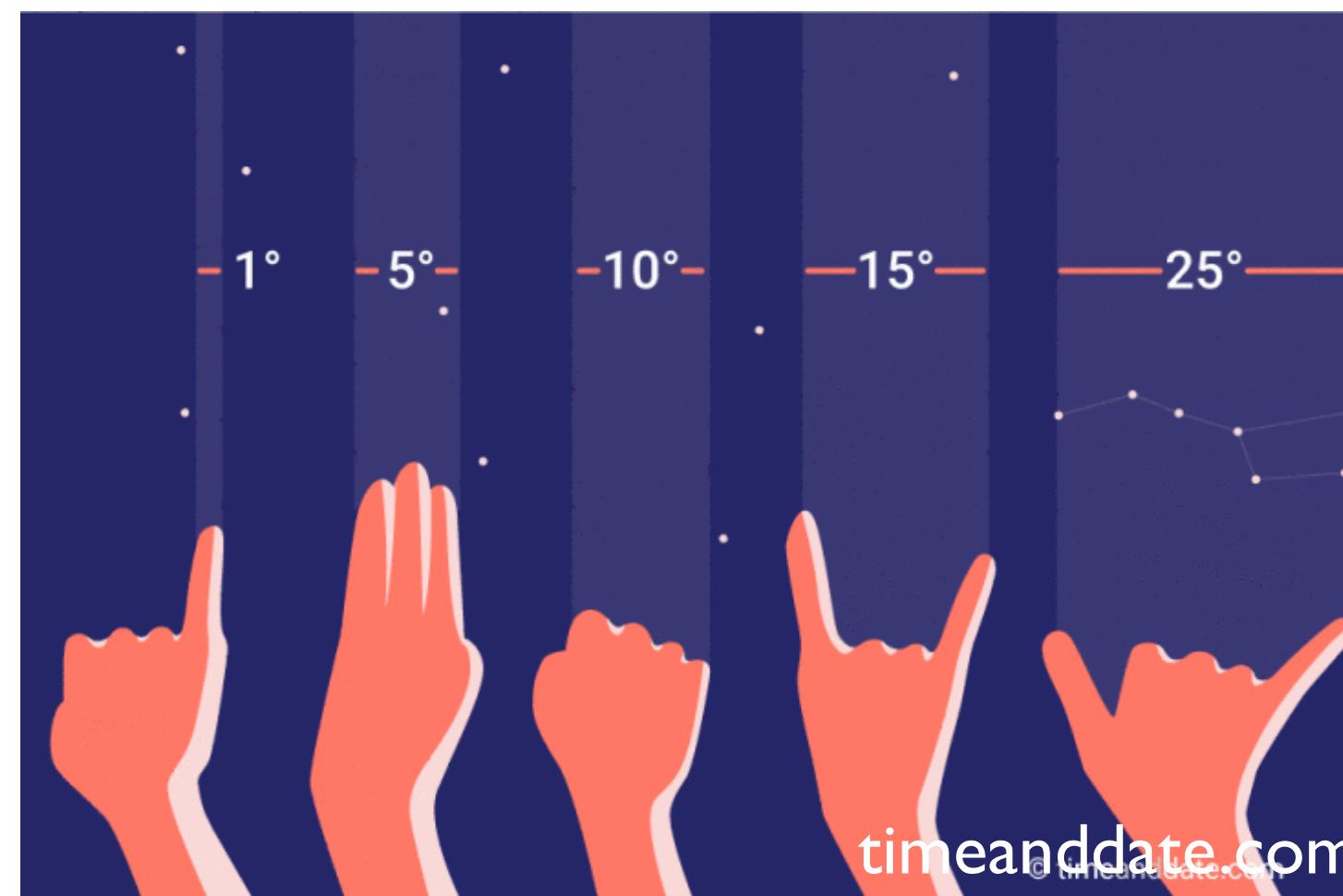
$$\gamma \simeq \sqrt{((\alpha_1 - \alpha_2) \cos(\delta_1))^2 + (\delta_1 - \delta_2)^2}$$

Lengths and Distances on the Sky

- Usually given in degrees ($^{\circ}$), arc minutes ('), and arcseconds(")

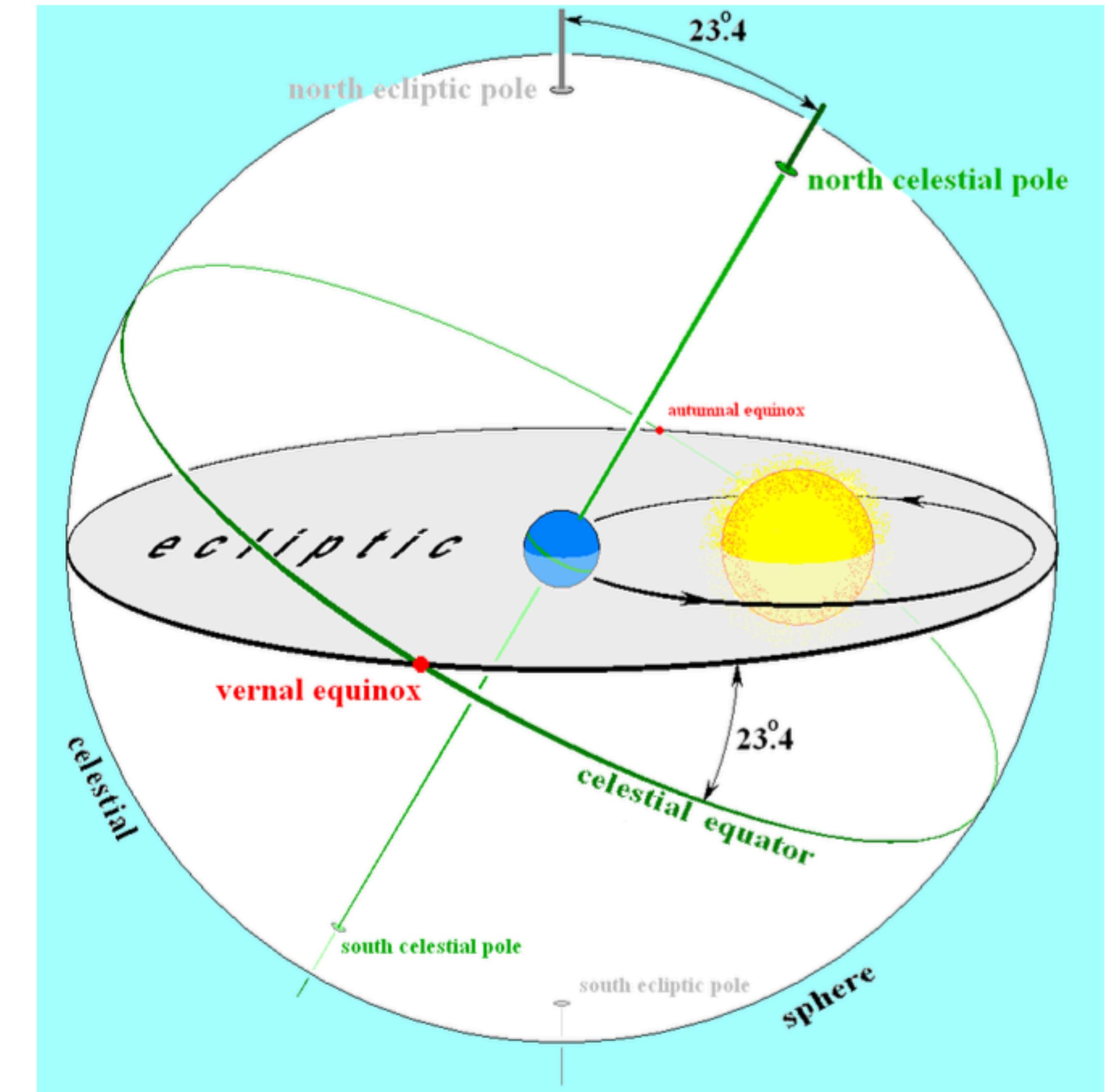


Moon: diameter is
 $\sim 0.5^{\circ} = 30'$



Ecliptic Coordinates

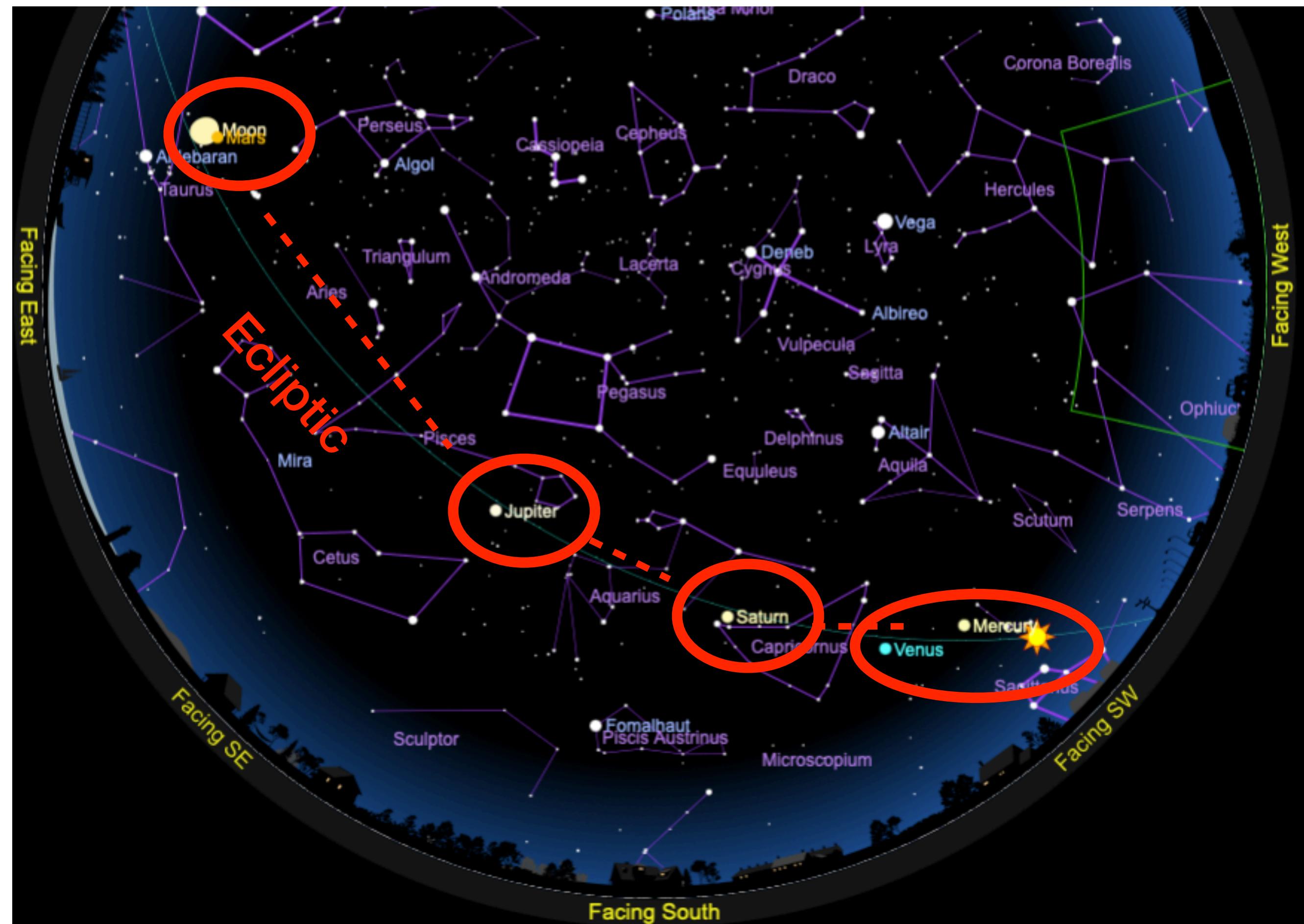
- Sun travels along the “Ecliptic”
- Equator and ecliptic intersect in two points: the equinoxes
 - Vernal (spring) equinox marks RA=0h



wikipedia

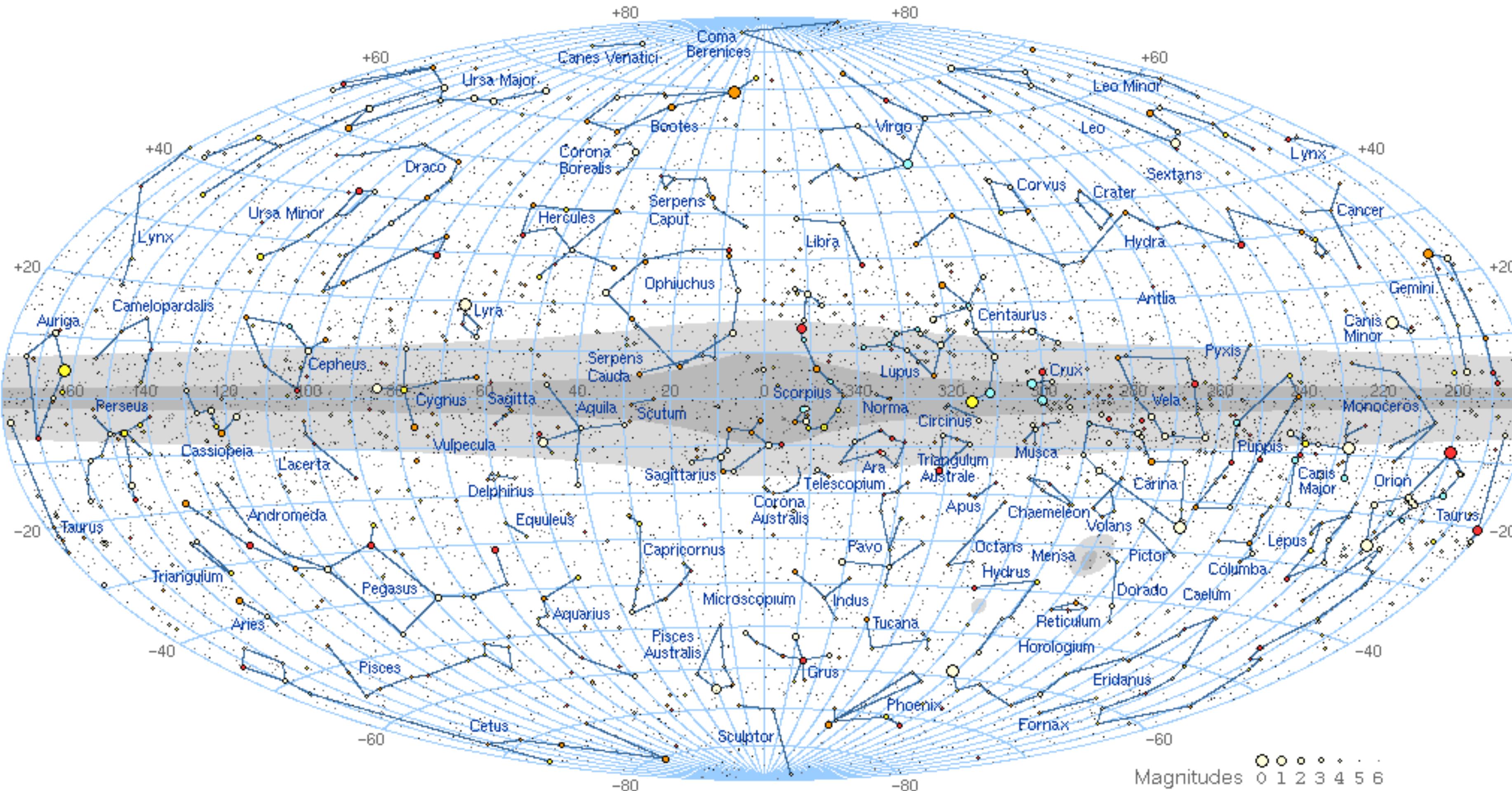
Solar System Objects

- Orbital planes of most planets and moons are similar to the Earth's orbital plane -> Moon and planets also approximately follow the ecliptic



Galactic Coordinates

- Can also use the plane of the Galaxy as the “equator”



Any final questions?

