Introduction to Astronomy & Astrophysics (PHY F215)

Kaushar Vaidya
Ph.D. (Astronomy)

- vastness and scales (sizes, time, temperature-pressure) (philosophical, exo-planets, detection, alien)
- nothing like anything
- application of physics

Scope and Objective

This course will introduce a student to the current understanding of the celestial objects starting from planets to stars to galaxies to the whole Universe. We will make use of the Physics and Mathematics learned up to first year undergrad level, and the knowledge of the up-to-date astronomical observations (spanning the entire electromagnetic spectrum) of these celestial objects, to know the working of these objects, and to find an order in the grand scheme of things called – the Universe.

Books & Coverage

Textbook

An Introduction to Modern Astrophysics

Bradley Carroll & Dale Ostlie

Reference Book

The Physical Universe

Frank Shu

	Lecture No.	Learning Objectives	Topics to be covered	Reference Section
Prerequisite Physics	1-2	Celestial Mechanics	Celestial Sphere, Coordinate Systems, Kepler's Laws, Virial Theorem	Ch.1, Ch.2
	3-4	The Continuous Spectrum of Light	Parallax, Magnitude Scale, Wave Nature of Light, Blackbody Radiation, Quantization of Energy, Color Index	Ch. 3
	5-6	The Interaction of Light and Matter	Spectral Lines, Photons, The Bohr Model of the Atom, Quantum Mechanics and Wave-Particle Duality	Ch. 5
	7-8	Telescopes	Basic Optics, Optical Telescopes, Radio Telescopes, Infrared, Ultraviolet, X-ray, and Gamma-Ray Astronomy	Ch. 6
Stellar Structure & Atmosphere	9-10	Binary Systems and Stellar Parameters	Classification of Binary Stars, Mass Determination Using Visual Binaries, Eclipsing Binaries, Search of Extrasolar Planets	Ch.7
	11-12	The Classification of Stellar Spectra	Formation of Spectral Lines, H-R Diagram	Ch. 8
	13-16	Stellar Atmospheres	Description of Radiation Field, Stellar Opacity, Radiative Transfer, Transfer Equation, Profile of Spectral Lines	Ch. 9
	17-20	Interiors of Stars	Hydrostatic Equilibrium, Pressure Equation of State, Stellar Energy Sources, Energy Transport, Main Sequence	Ch. 10
	21-22	The Sun	Solar Interior, Solar Atmosphere, Solar Cycle	Ch. 11
ISM & Star Formation	23-25	Interstellar Medium and Star Formation	Interstellar Dust and Gas, Formation of Protostars, Pre-Main Sequence Evolution	Ch. 12
Stellar Evolution & End-States of Stars	26-28	Main-Sequence and Post-Main-Sequence Evolution	Evolution on the Main Sequence, Late Stages of Stellar Evolution, Stellar Clusters	Ch. 13
	29-30	Fate of Massive Stars	Post-Main-Sequence Evolution of Massive Stars, Classification of Supernovae, Gamma Ray Bursts, Cosmic Rays	Ch. 15
	31-32	Degenerate Remnants of Stars	White Dwarfs, Chandrasekhar Limit, Neutron Stars, Pulsars	Ch. 16
	33-34	Black Holes	GTR, Black Holes	Ch. 17
Galactic Astrophysics & Cosmology	35-37	Nature of Galaxies	Morphology of the Milky Way Galaxy, Kinematics of the Milky Way, Galactic Center, Hubble Sequence, Spiral, Elliptical, and Irregular Galaxies	Ch. 24, Ch. 25
	38-39	Structure of the Universe	Extragalactic Distance Scale, Expansion of the Universe, Cluster of Galaxies	Ch. 27
	40-42	Cosmology and Early Universe	Newtonian Cosmology, CMBR, Relativistic Cosmology, Observational Cosmology, The Very Early Universe and Inflation, The Origin of Structure	Ch. 29, 30

Evaluation Scheme

EC No.	Evaluation Component	Duration	Weightage (%)	Date, Time & Venue	Remarks
1.	Mid-Sem Test	90 Min.	30	TBA	Closed/Open Book
2.	Tutorial Tests, Assignments	TBA	20		Closed Book/Open Book
3.	Project/Viva	TBA	10	TBA	Closed Book/Open Book
4.	Comp. Exam	3 Hour	40	08/05	Closed/Open Book

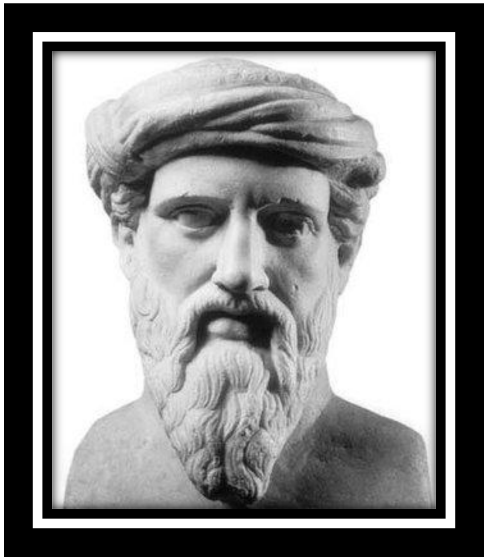
History of Astronomy

Stonehenge, England (2000-3000 BC)

Maya Writing (300-900 AD)

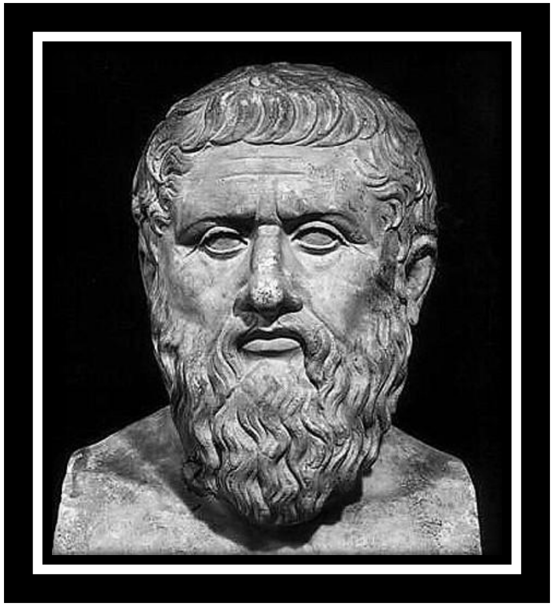
Maya Pyramid (300-900 AD)

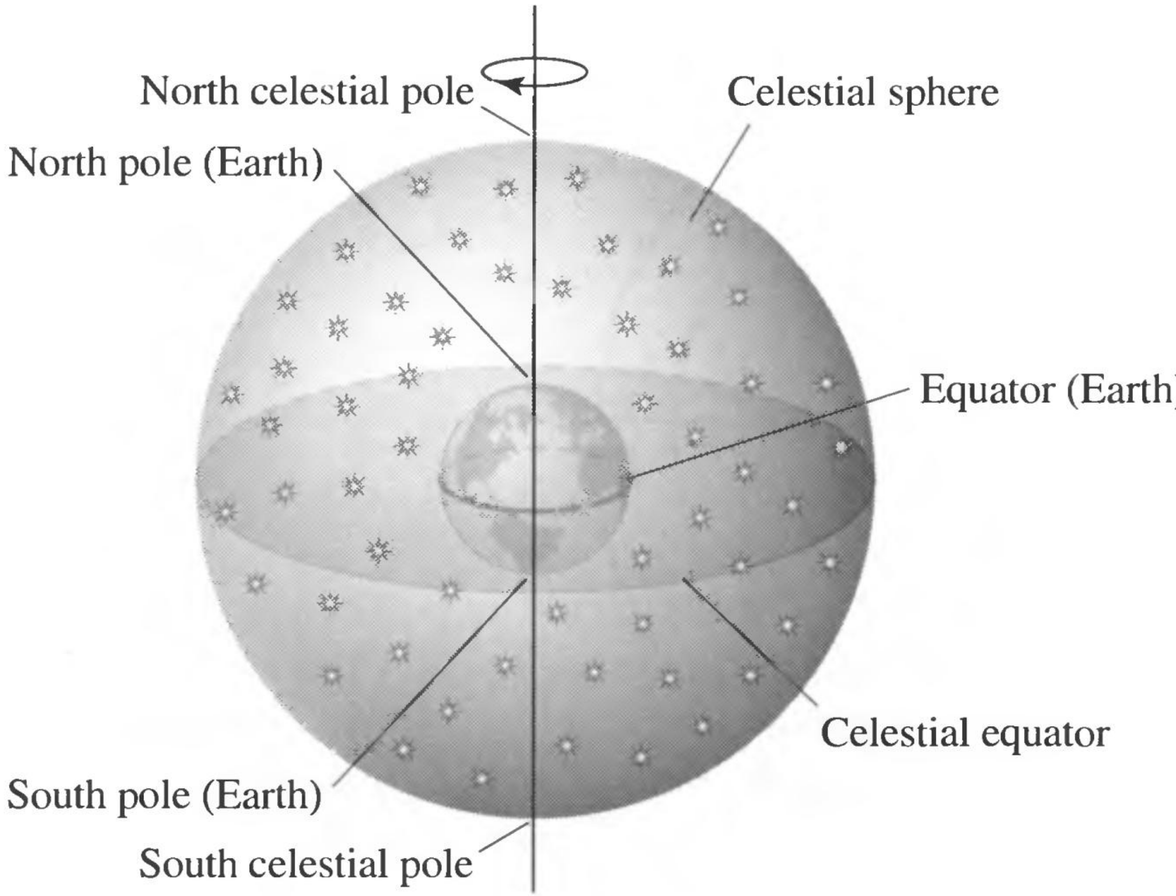
Pythagoras (570—490 BC) study of music intervals and geometry of right angle demonstrated for the first time the relationship between nature and numbers.



The Geocentric Universe

Plato (427—347 BC) proposed that celestial bodies should move about Earth with a uniform speed and follow a circular motion with Earth at the center of that motion.



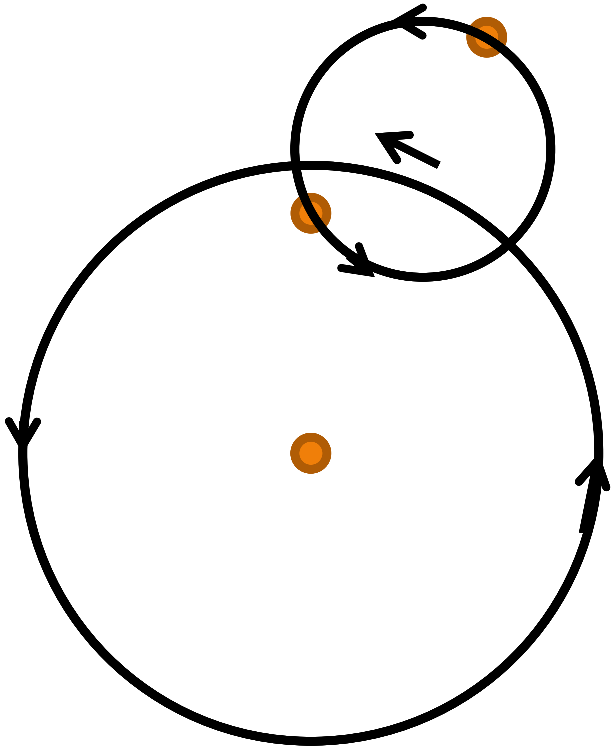

North celestial pole
Celestial sphere
North pole (Earth)
Equator (Earth)
Celestial equator
South pole (Earth)
South celestial pole

Wanderers – The Rule Breakers

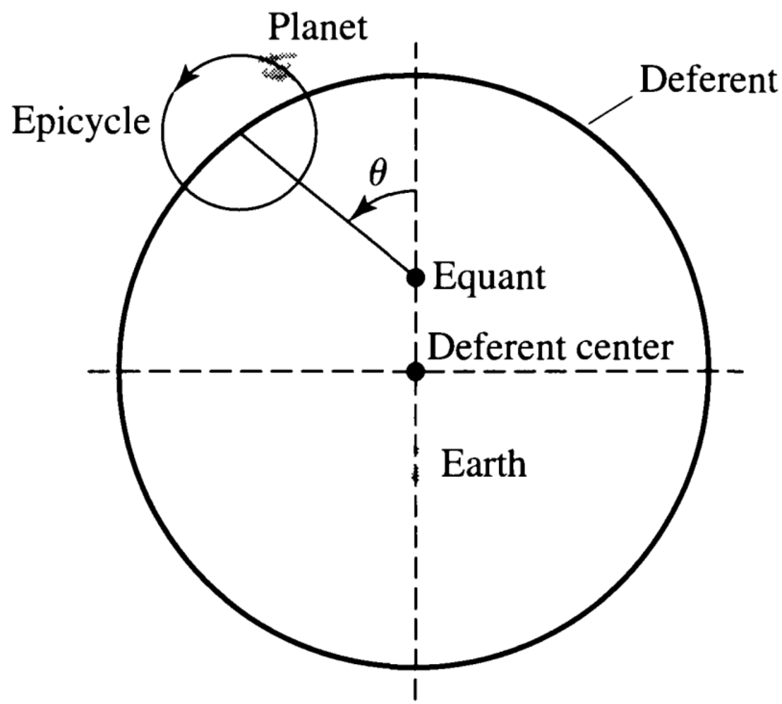
The Retrograde Motion of Mars in 2008

Image Source: APOD by Tunc Tezel

Hipparchus (190 – 120 BC)



‘Fixing’ the Problem: Circle upon Circle
The Ptolemaic System



Ptolemy's 13 volumes— *Almagest*

Ptolemy (90 – 168 AD) calculated the sizes and rotation rates of the epicycles and deferents by using data of planets of hundreds of years and could predict the paths of sun, moon and planets with high accuracy.

So, what was the problem?

The Ptolemaic system was highly complex and treated each planet differently. There was no unified way of explaining the planetary motion.

The Heliocentric Model

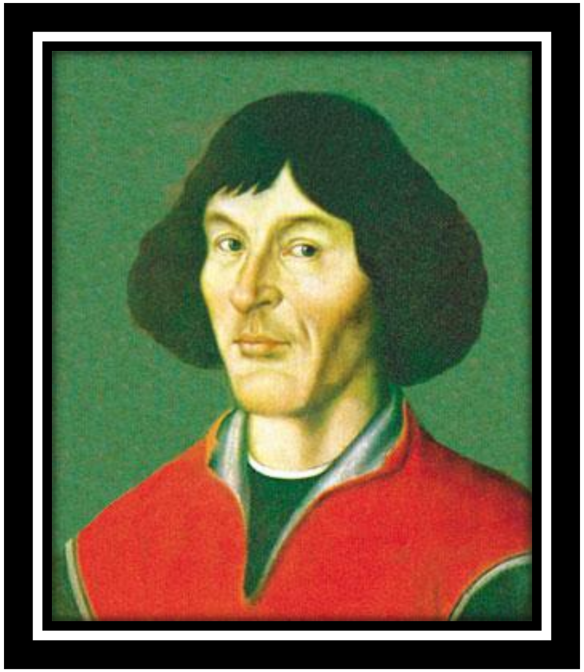
Aristarchus (310 – 230 BC)

- Demonstrated Sun is bigger than Earth
- Developed the first Heliocentric Model
- Proposed that the Earth rotates on its axis once a day– hence the daily rising and setting of sun, moon, and stars
- Explained the retrograde motion of planets

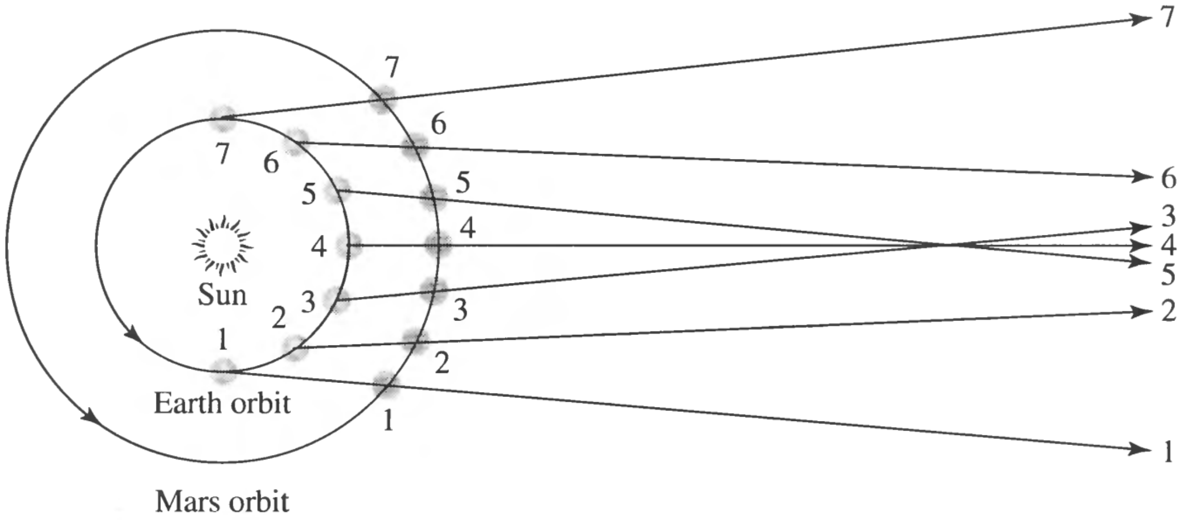
But, there were no 'buyers' of this simpler model for another 2000 years!

Nicolaus Copernicus (1473-1543)

Copernicus developed a ‘new’ model placing the Sun at the center of the Universe and could explain both the retrograde motion and the arrangement of planets in the solar system.



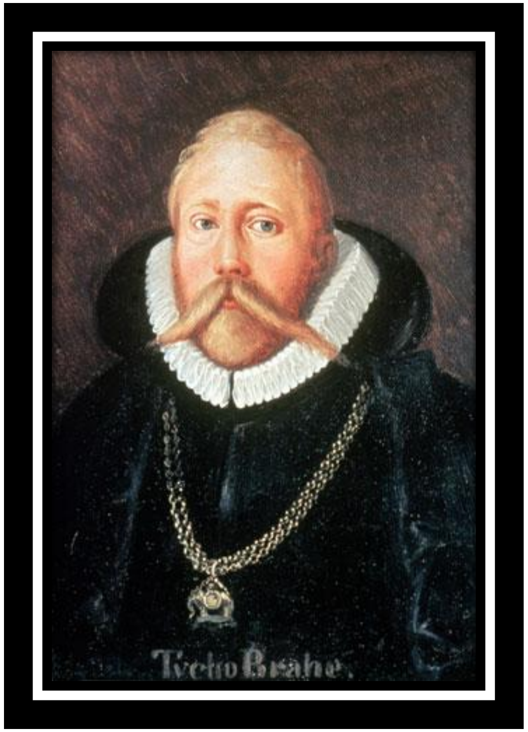
Retrograde Motion Explained



Tycho Brahe (1546 – 1601)

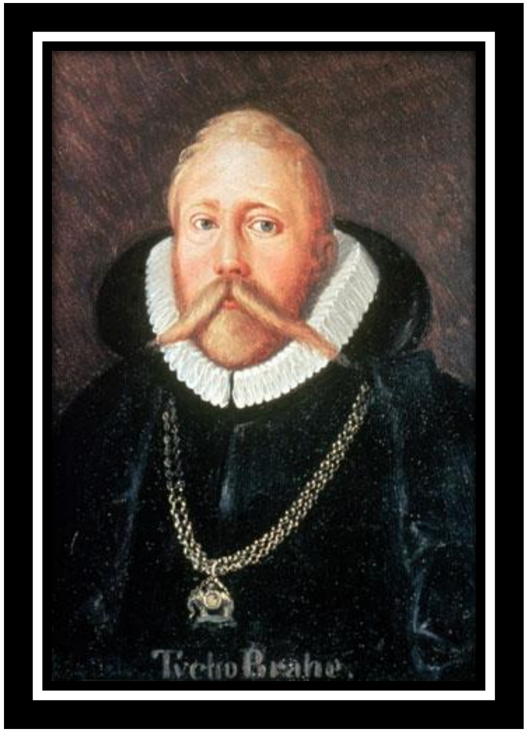
Tycho tried to measure the parallax of the 1572 Supernova and a comet in 1577 but could not find any parallax.

The new ‘stars’ convinced Tycho that the heavens are not unchanging!
& he concluded that the new ‘stars’ must be too far away.



Tycho Brahe (1546 – 1601)

Tycho failed to detect any parallax for nearby stars as well hence concluded that the Heliocentric model was wrong.

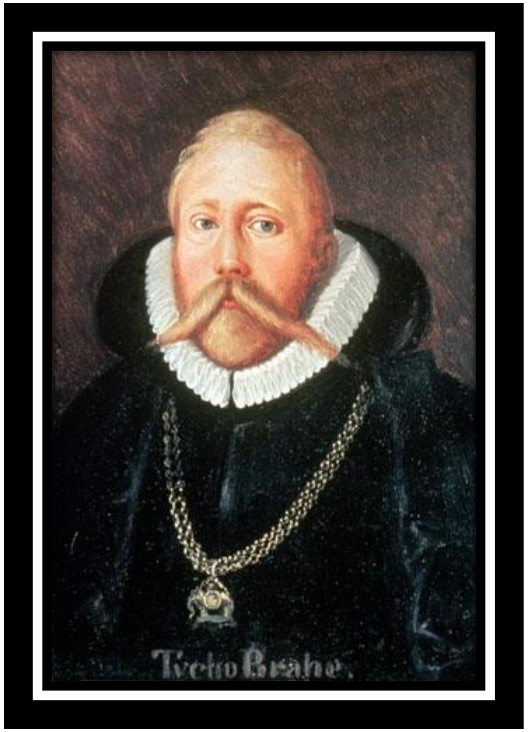


He built sophisticated equipments in his observatory and made painstaking observations of the celestial objects for 20 years!

Tycho Brahe (1546 – 1601)

Tycho failed to detect any parallax for nearby stars as well hence concluded that the Heliocentric model was wrong.

His accuracy was 4′ (one eighth of a full moon!)



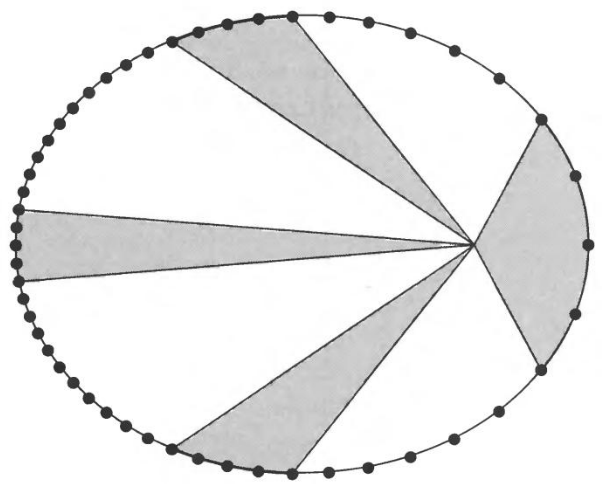
Johannes Kepler (1571 – 1630)

Using the wealth of the data that Brahe had accumulated, Kepler eventually came up with his three laws of planetary motion.

Kepler’s First and Second Laws

A planet orbits the Sun in an ellipse with the Sun at one focus of the ellipse.

A line connecting a planet to the Sun sweeps out equal areas in equal time intervals.



Kepler's Third Law

$$P^2 = a^3$$

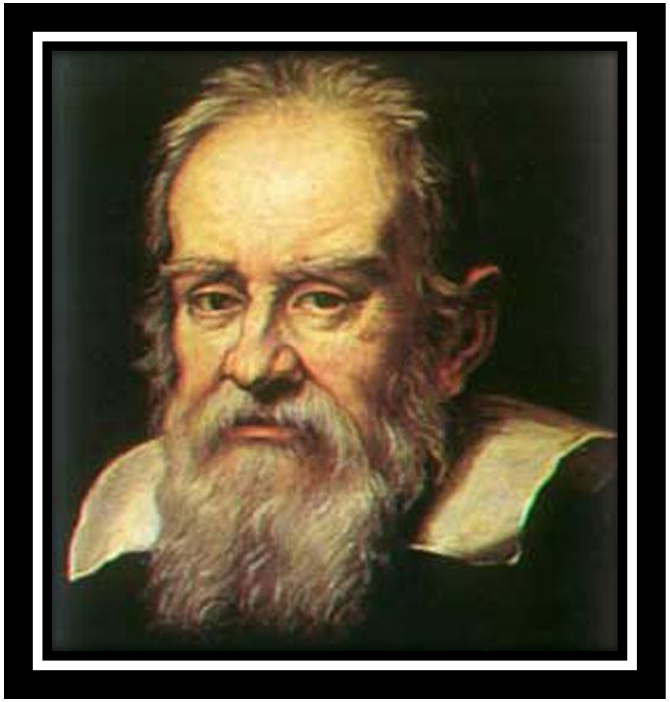
Where P is the orbital period of the planet in *years,* and a is the average distance of the planet from the Sun, in *astronomical units* (AU).

1 AU = 1.496×10^{11} m

But why were the planetary orbits the way they were?

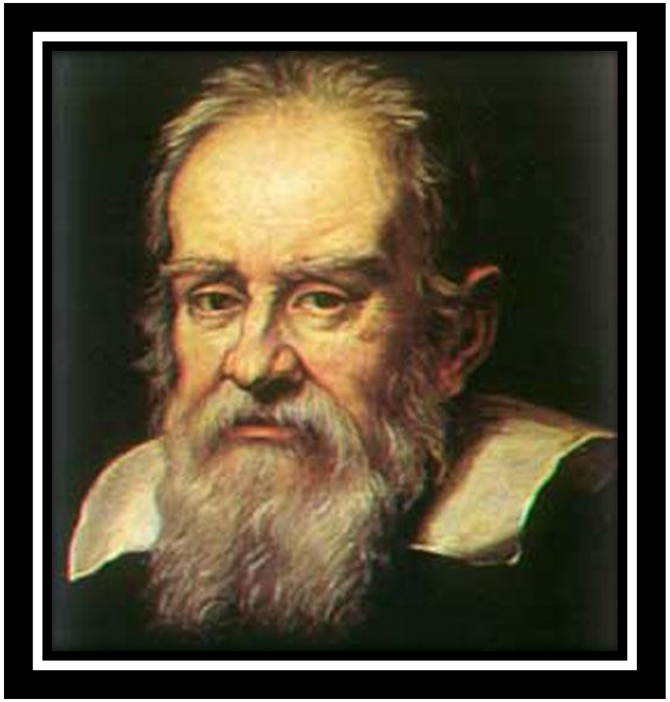
Galileo Galilei (1564 - 1642)

Galileo proposed the concept of inertia. He was the first to realize that objects near the surface of the Earth fall with the same acceleration regardless of their weight.



Galileo Galilei (1564 - 1642)

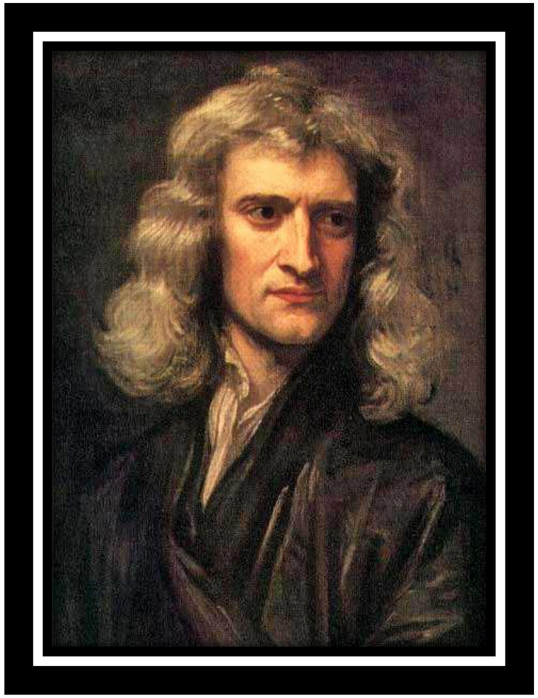
Galileo made the first ever telescope around 1608 and watched the craters of the Moon, rings of Saturn, different phases of Venus, and the moons of the Jupiter.



In 1632, the Church put him under house arrest for the rest of his life and banned all his work.

Isaac Newton (1642 - 1727)

Using the Mathematical techniques that he devised, Newton, formulated the Laws of Gravitation and explained the Physics behind Keplerian orbits.



Derivation of Kepler’s Laws

Section 2.3 – First Assignment

The Virial Theorem

For a gravitationally bound system in equilibrium, the total energy is one-half of the time-averaged potential energy of the system.

$$\langle E \rangle = \frac{1}{2} \langle U \rangle$$

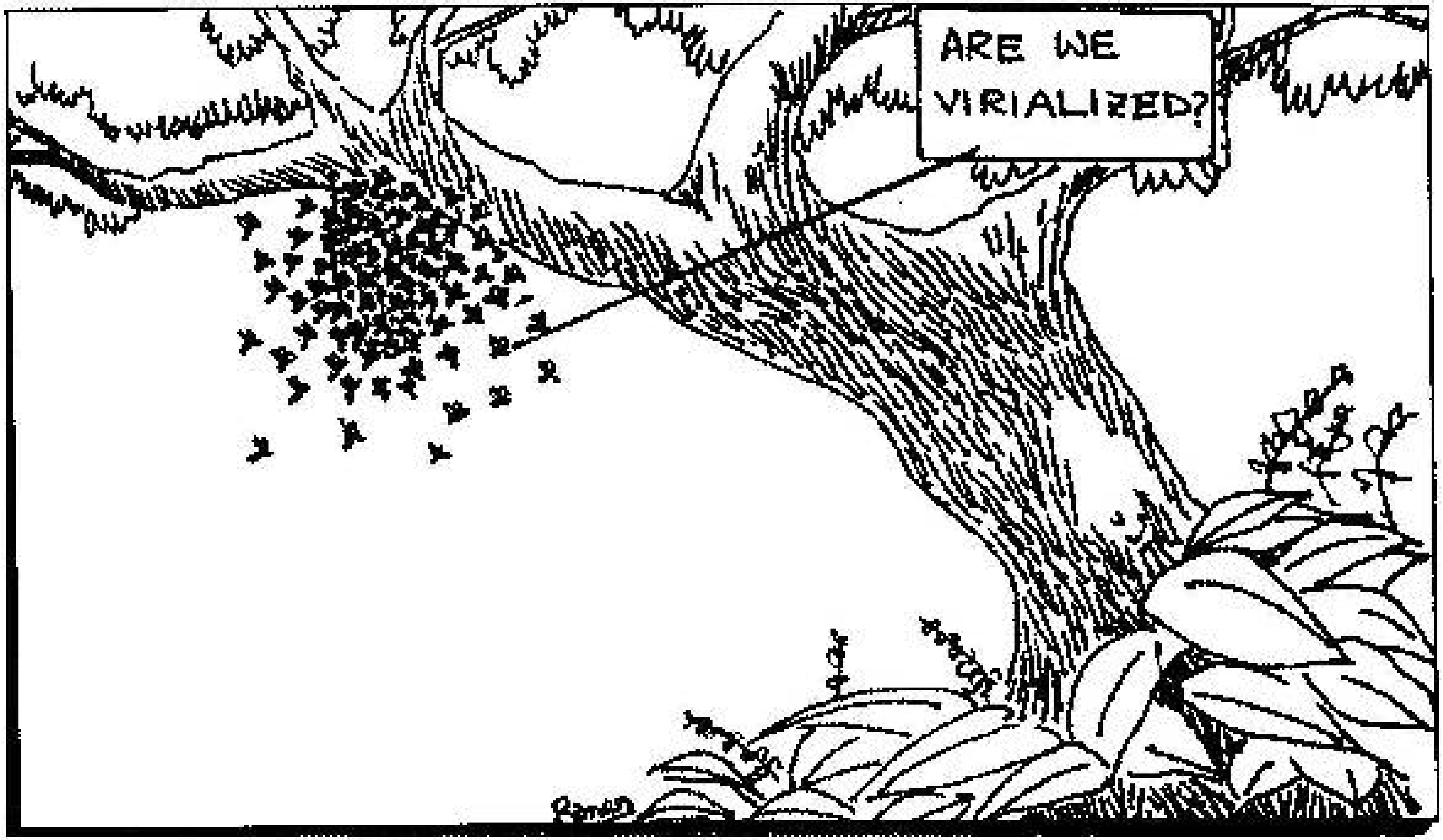


Image Source: Cartoons by Prof. Biman Nath
Published in “Mercury” 1999

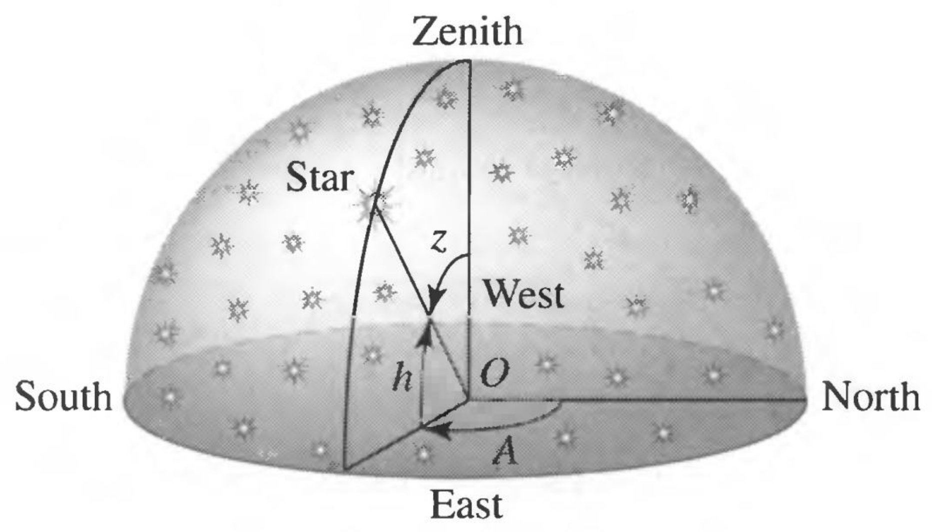

EQUATION TABLE

Positions on the Celestial Sphere

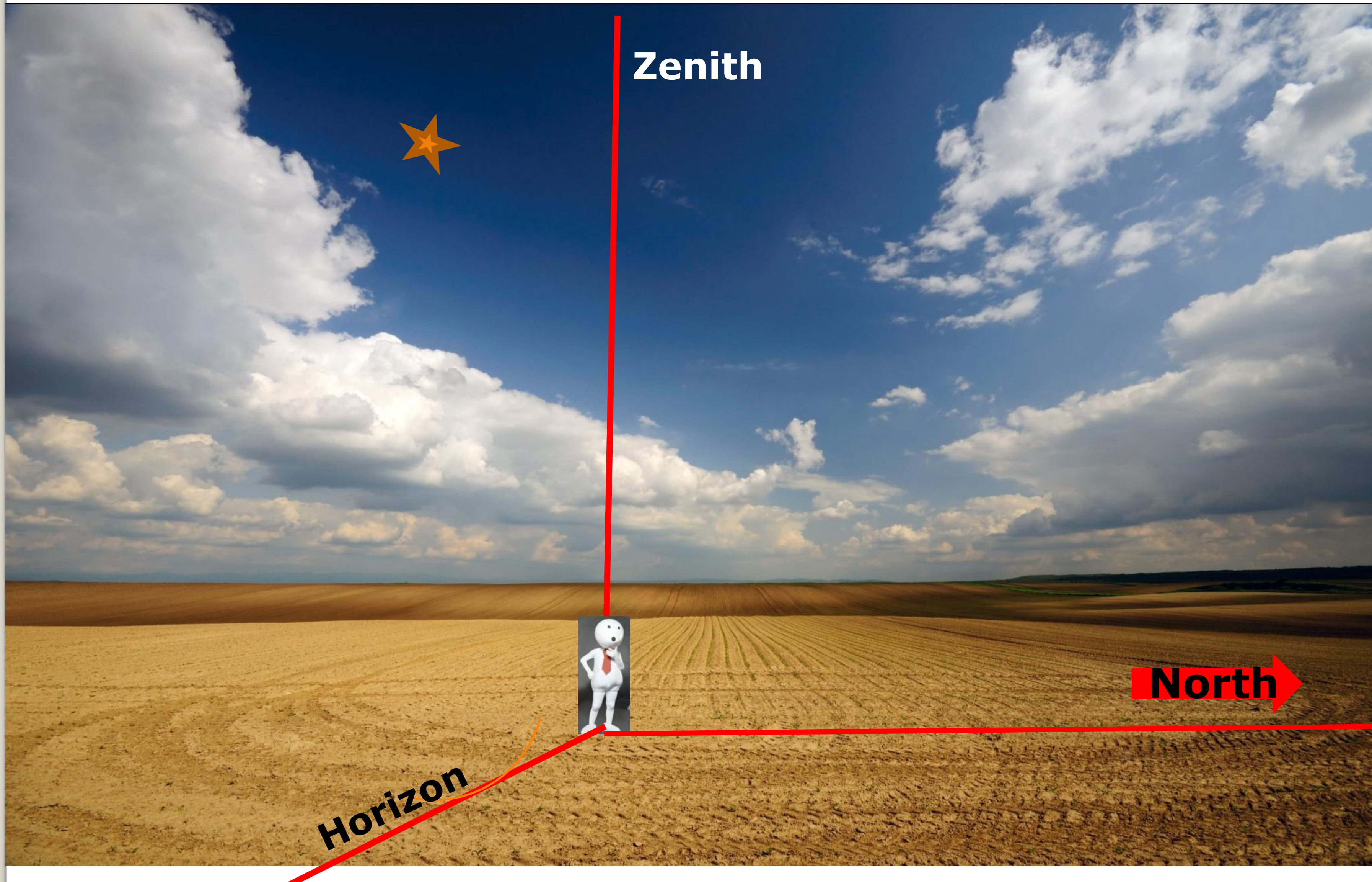
The Altitude Azimuth Coordinate System

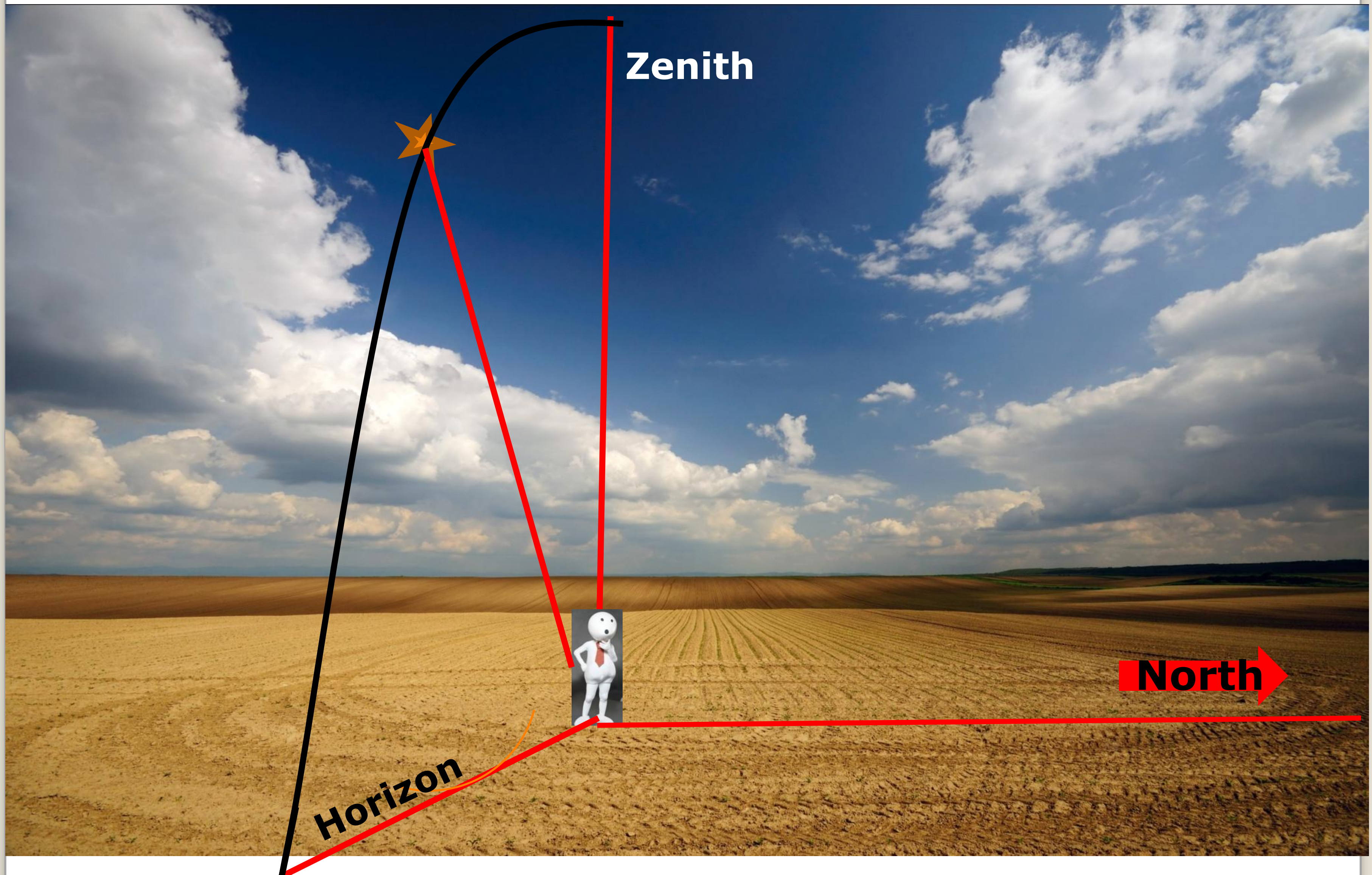
Pros: Easy to define and understand

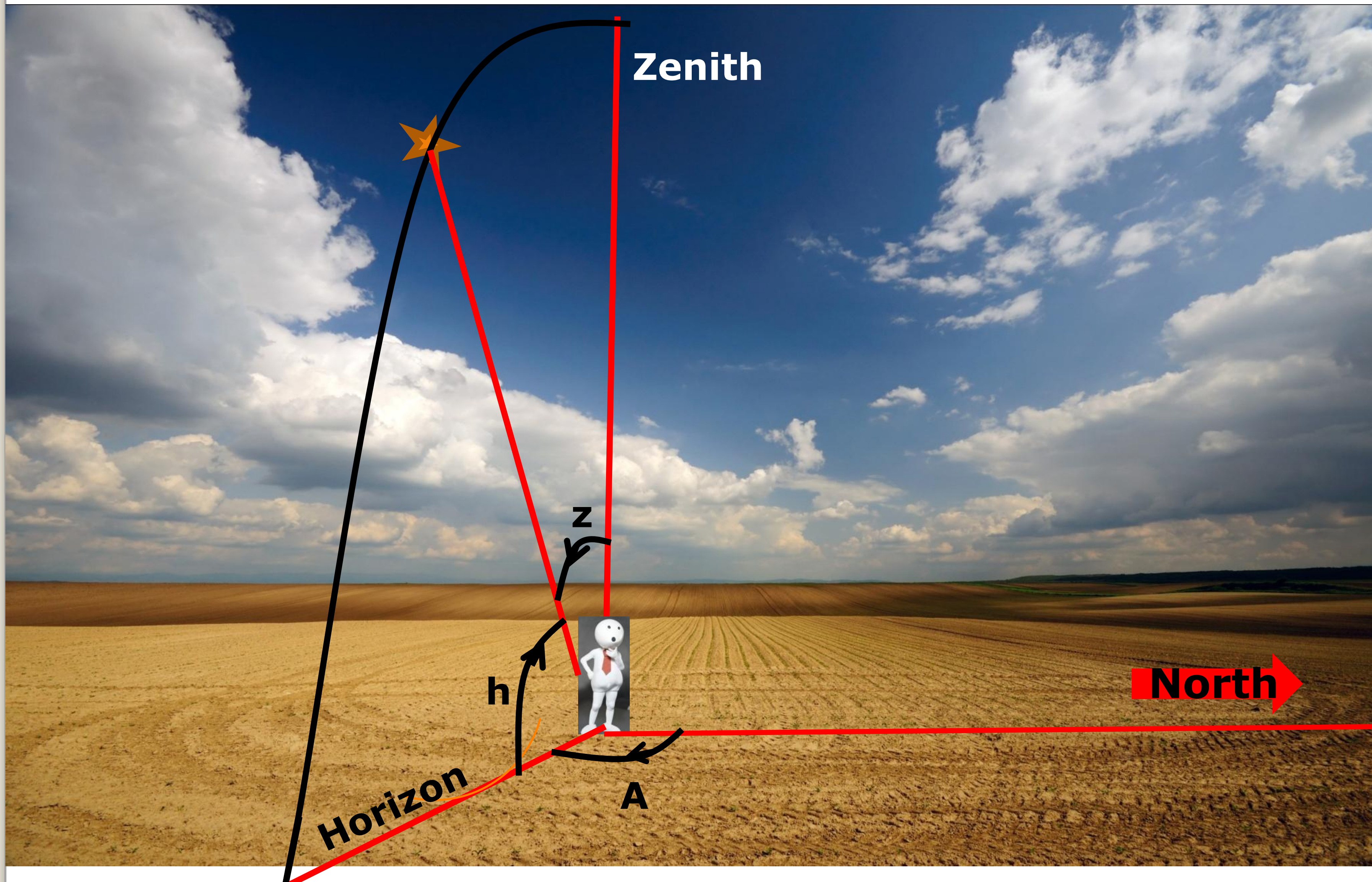
Cons: Coordinates of stars are observer-dependent and are not constant



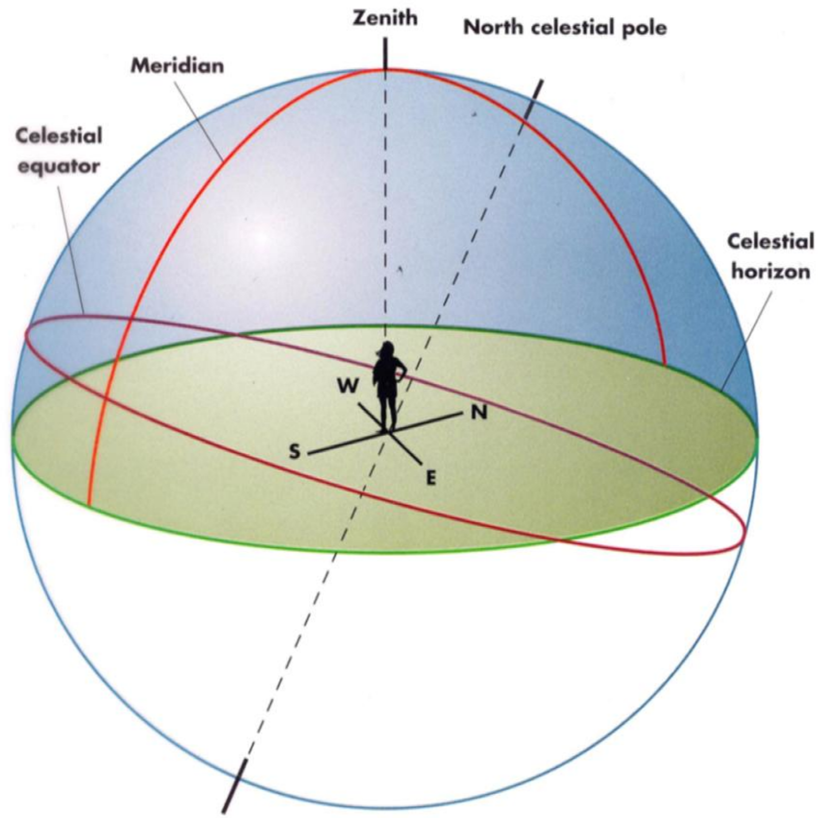

North
I am here now,
how do I start?


Zenith
North
Horizon


Zenith
North
Horizon


Zenith
z
h
North
Horizon
A

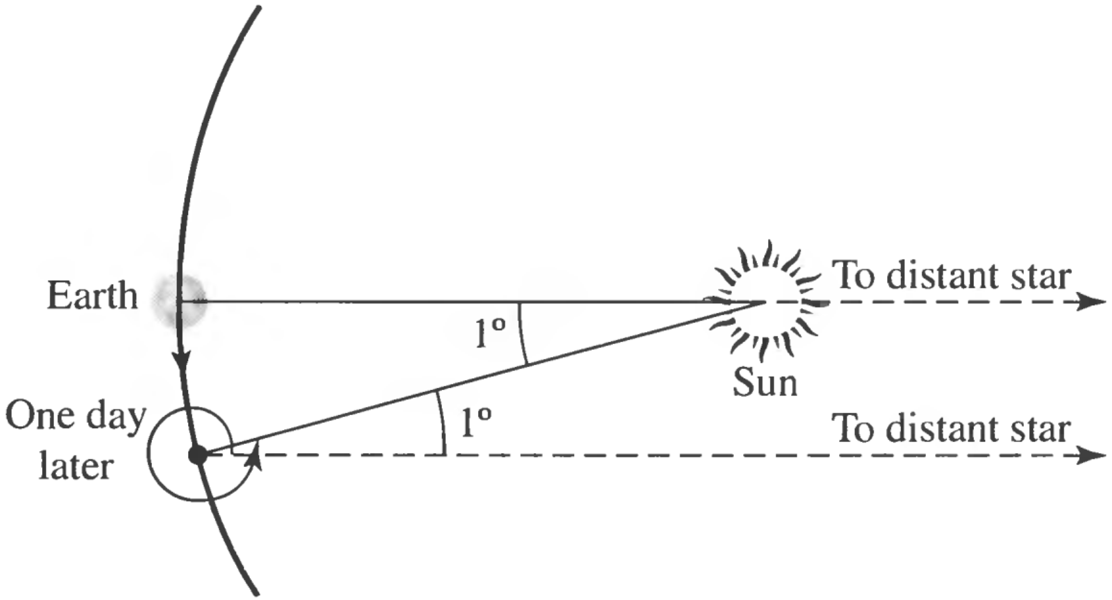
TA 5
The meridian and the celestial sphere (Fig. 2-4)



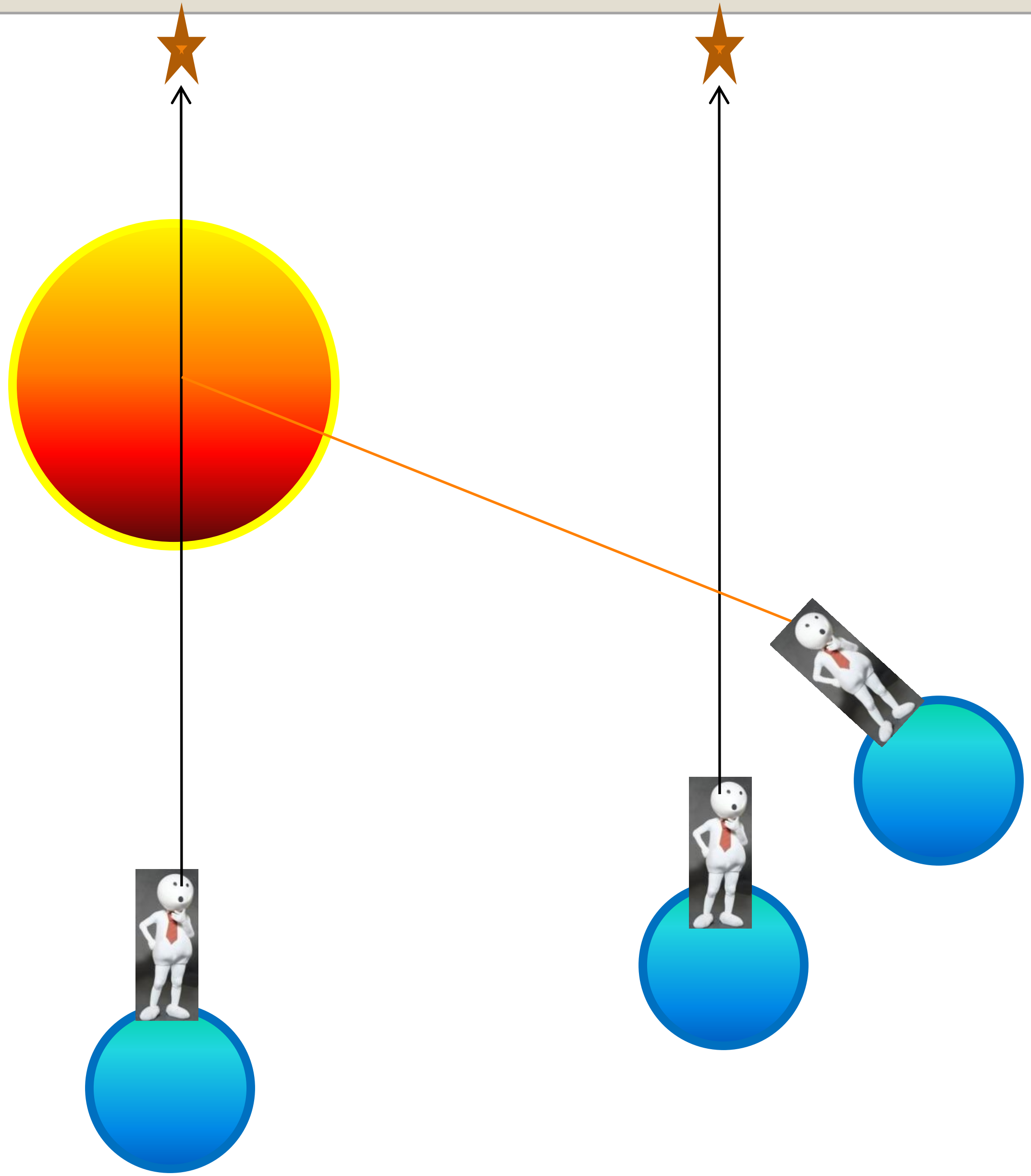
For use with Fix: *Astronomy: Journey to the Cosmic Frontier*

What is the time by your watch?

Excuse me, do you mean Solar time or Sidereal time?

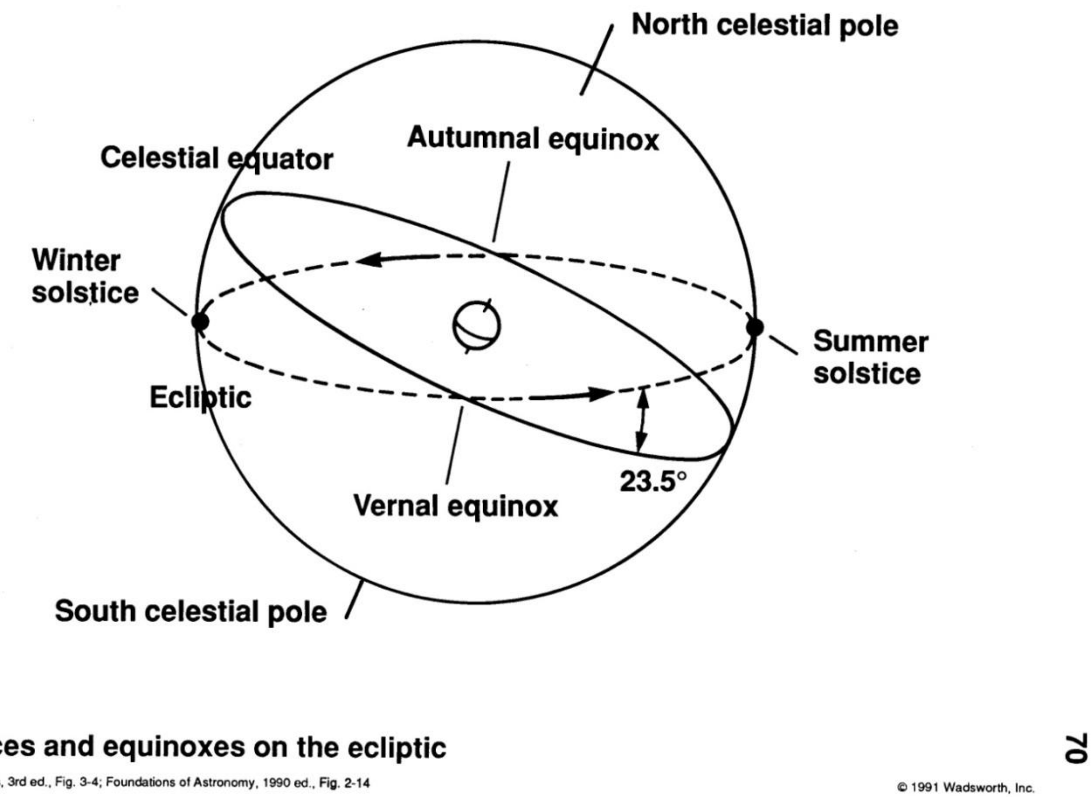


The Sidereal Day is shorter by about four minutes!



Oh, I hate winter!

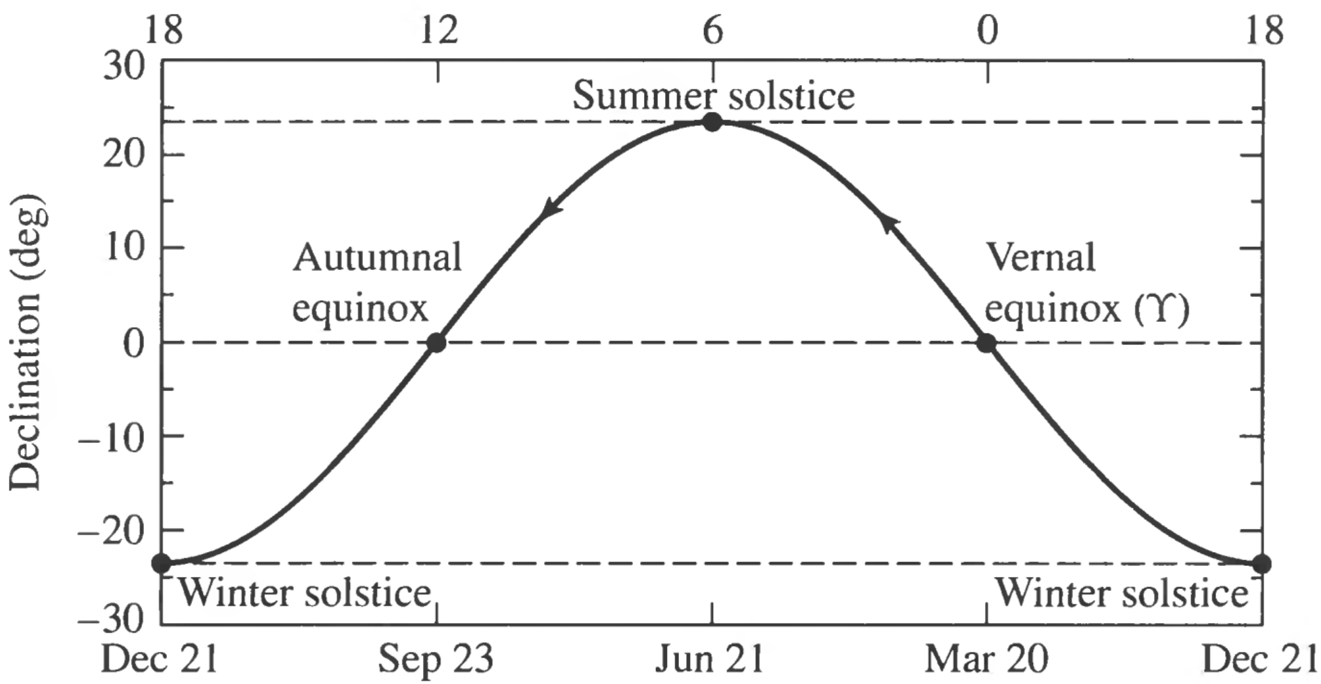
Blame the tilt of the Earth's spin axis!



Solstices and equinoxes on the ecliptic

Image Source: Seeds/Horizons – 3rd Ed.
Foundations of Astronomy 1990

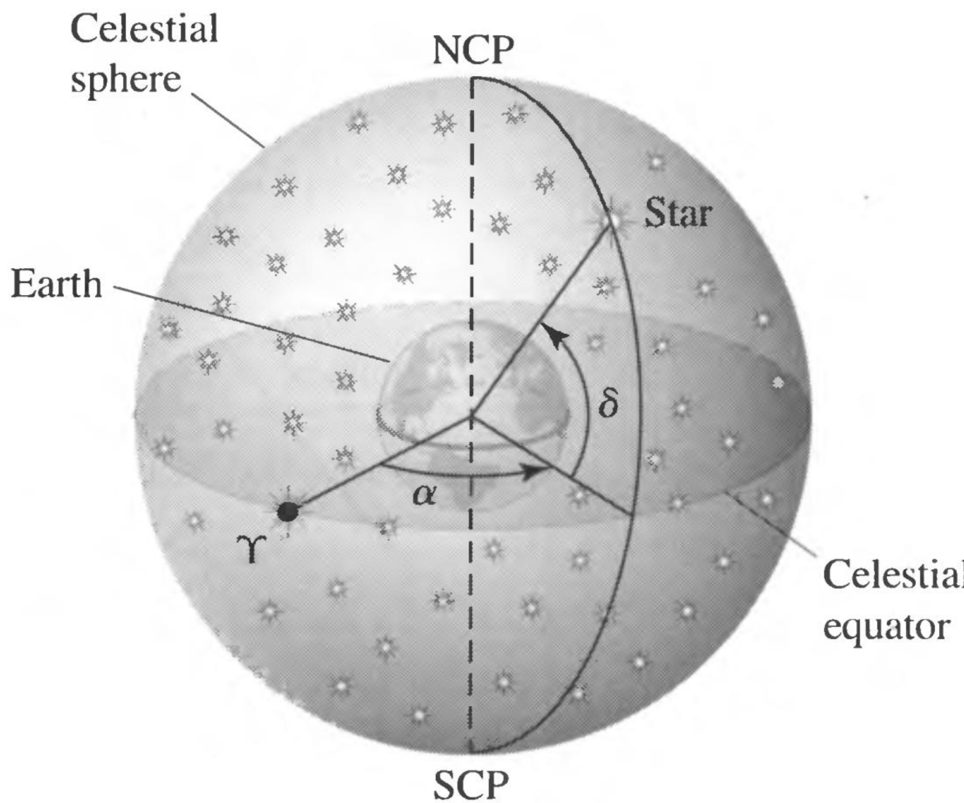
The Ecliptic Across Equator



The Equatorial Coordinate System

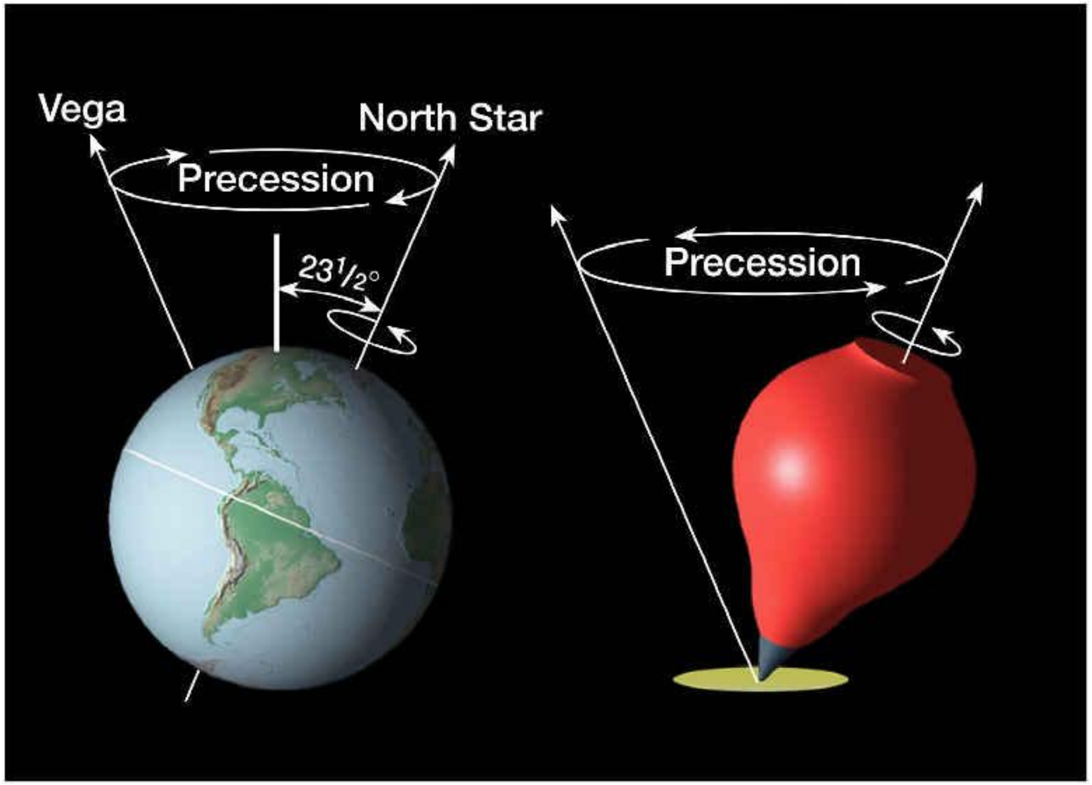
Pros: Nearly constant positions of objects

Cons: Less straightforward



Precession means

You need to apply corrections for precision!



Corrections for J2000.0 Equatorial Coordinates

$$\boxed{\begin{aligned}\Delta\alpha &= M + N \sin\alpha \tan\delta \\ \Delta\delta &= N \cos\alpha,\end{aligned}}$$

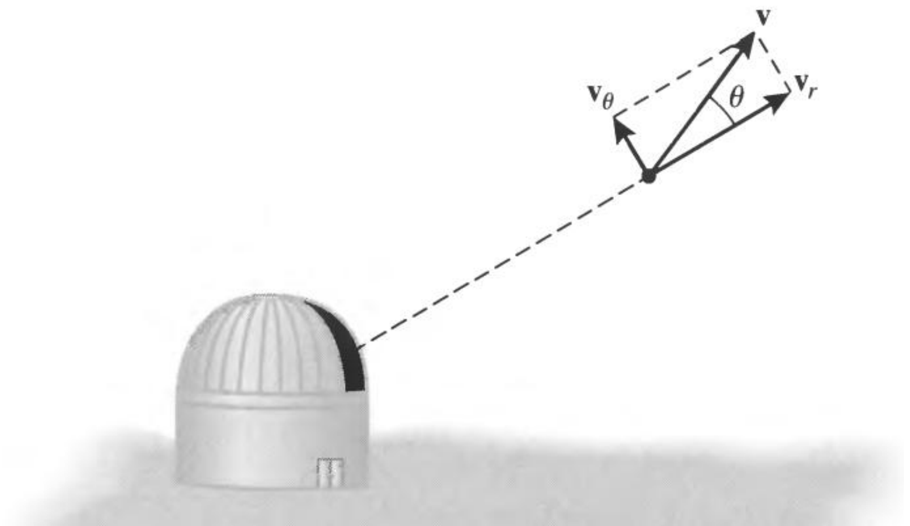
$$M = 1\overset{\circ}{.}2812323T + 0\overset{\circ}{.}0003879T^2 + 0\overset{\circ}{.}0000101T^3$$

$$N = 0\overset{\circ}{.}5567530T - 0\overset{\circ}{.}0001185T^2 - 0\overset{\circ}{.}0000116T^3$$

$$T = (t - 2000.0)/100$$

But, how do we know stars are in motion?

Radial Velocity and Proper Motion



Radial Motion: Doppler Shift in spectral lines

Proper Motion: $\boldsymbol{\mu} = \frac{d\theta}{dt} = \frac{v_\theta}{r}$, useful in membership determination

Assignments: 2.6, 2.7, 2.8, 2.11, 2.12, 2.14