# Astronomy 20:
## Basic Astronomy and the Galaxy
## Fall 2004

**http:// www.astro.caltech.edu/~george/ay20/**

# Lecture 1:

- The class logistics
- A bit of history
- The nature of astronomy as a science
- Coordinates, times, and units

# The Evolution of Astronomy

- From astrology to classical astronomy (~ positional astronomy and cellestial mechanics) to astrophysics
- A strong and growing connection with physics, starting with Newton … Today astronomy is one of the most exciting branches of physics
- Astronomy is still growing rapidly: **you** can make history!
- Many important developments happened in Pasadena (Hale, Hubble, Zwicky, Baade, Minkowski, Sandage, …)

# Astronomy as a Branch of Physics

- Using the apparatus of physics to gather and interpret the data: assume that our physics is universal (and we can test that!)
- Astronomical phenomena as a “cosmic laboratory”
  - Relativistic physics (black holes, high □, …)
  - Cosmic accelerators (HECR) and the early universe
  - Matter in extreme conditions (e.g., neutron/quark stars, GRBs, high & low density plasmas …)
- Astronomical discoveries as a gateway to the new physics (e.g., dark matter and dark energy; neutrino mixing; inflation; etc.)
- The changing sociology and demographics of astronomy

# The Nature of the Astronomical Inquiry

- The peculiar nature of astronomy as a science
  - Is it like history? Geology? Paleontology? (are there extinct species of astronomical objects?)
  - Observing vs. experiments, and repeatability
  - A single object of study: universe as a whole, CMBR… But the experiments are repeatable
  - Non-repeatable phenomena, e.g., SNe, GRBs, microlensing events… But there are *classes* of them
- Observing a narrow time-slice of the past light cone
  - Using “symmetry” principles (e.g., Copernican, cosmological) as a substitute for unobtainable information
  - t (astronomy) << t (universe) ➞ inevitable biases
- Observing the past, or deducing it from the fossil information (e.g., galaxy formation and evolution)

# Information Flows in the Universe

- Physical parameters → Observables (but possibly in a very convolved manner - complex phenomena)
- Unresolved imagery/photometry: a very low information content; resolved imagery: morphology
- Spectroscopy is where most of the physics is!
- Primary continuum spectra (thermal, synchrotron…) : a low information content; abs./em. lines encode most of the interesting information
- Thermalization by dust erases information from the original energy flux (e.g., the power sources of ULIRGS)
- Different phenomena → different signals (some spectrum regions may be favored)

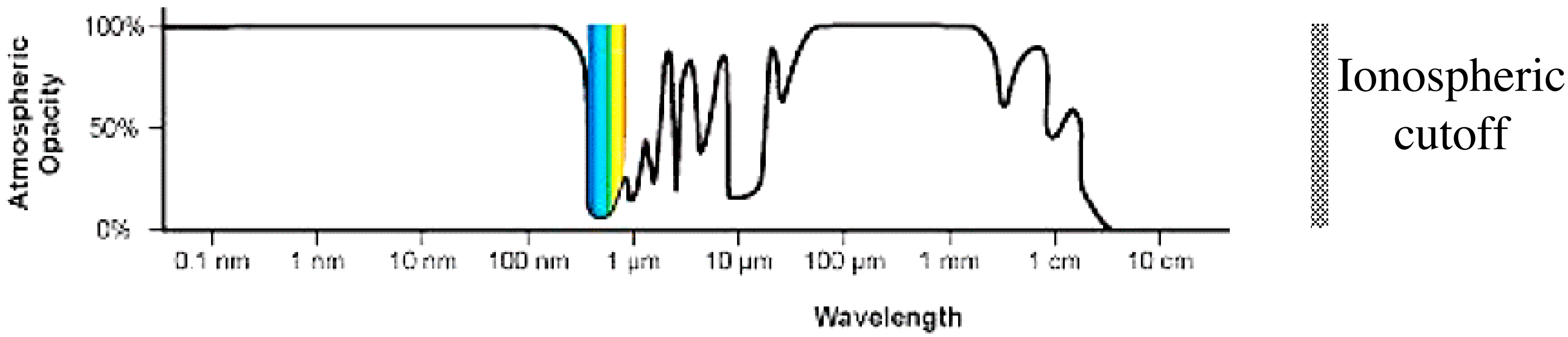
# Information Channels in Astronomy

- Mostly electromagnetic!  Methodologies:
  - Single-channel photometry
  - 2D imaging (photometry, morphology, positions/motions)
  - 1D spectroscopy
  - 2D (long-slit) spectroscopy
  - 3D data cubes (2 spatial + 1 spectro)
  - All can include polarimetry
  - All can be time-resolved (synoptic) or not
  - All can be single-dish, some (all?) can be interferometric
- Particles:
  - Cosmic rays:  Cherenkov, particle detectors, geochemistry
  - Neutrinos:  big tanks of something …
- Gravity Waves:  LIGO/LISA type interferometers
- Dark Matter:  lab detectors, gravitational lensing

# Fundamental Limits to Measurements and Selection Effects

- S/N Poissonian and quantum limits of detection
- Geometrical optics limits of angular resolution
- Opacity of the Earth's atmosphere and the Galactic ISM (example: soft X-rays and the missing baryons)
- Obscuration by dust in galaxies
- Turbulence of the atmosphere/ISM: erasing the spatial information
- Convolved backgrounds and foregrounds (examples: CMBR, CIRBs)
- And the "un-natural" limits: politics, funding, social psychology …

# Atmospheric Transmission Windows



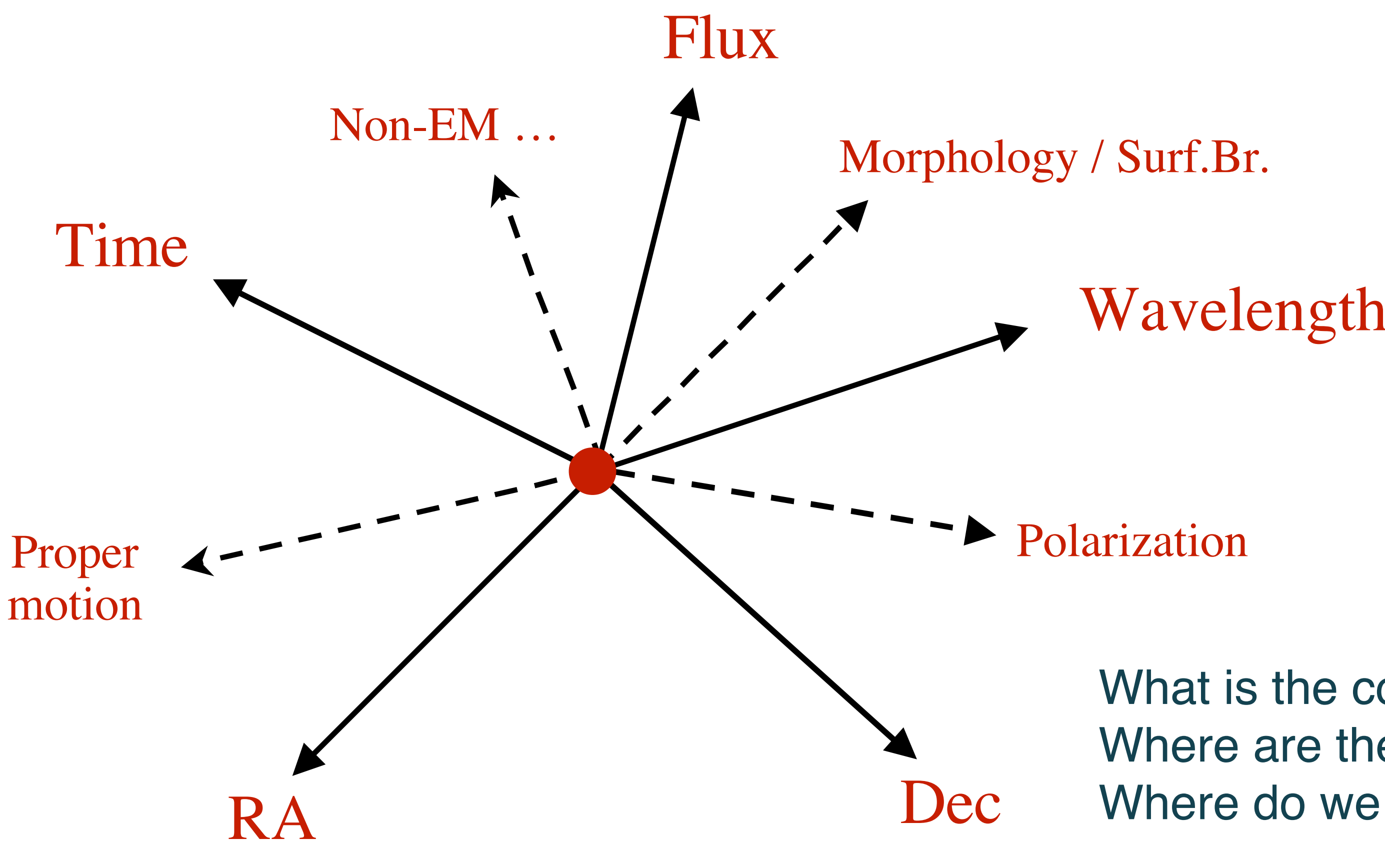

And that is why we need space observatories!

**But there as an even more profound limitation:**

The Galactic "atmosphere" - the interstellar medium - also absorbs very long wavelengths, and hard UV / soft X-rays (the interstellar fog); and of course the dust absorbs the blue/UV light (the interstellar smog).

This may be very important: perhaps 90% of the baryons in the universe are in the form of a "warm" ($T \sim 10^5$ K) gas, which emits mostly soft X-rays

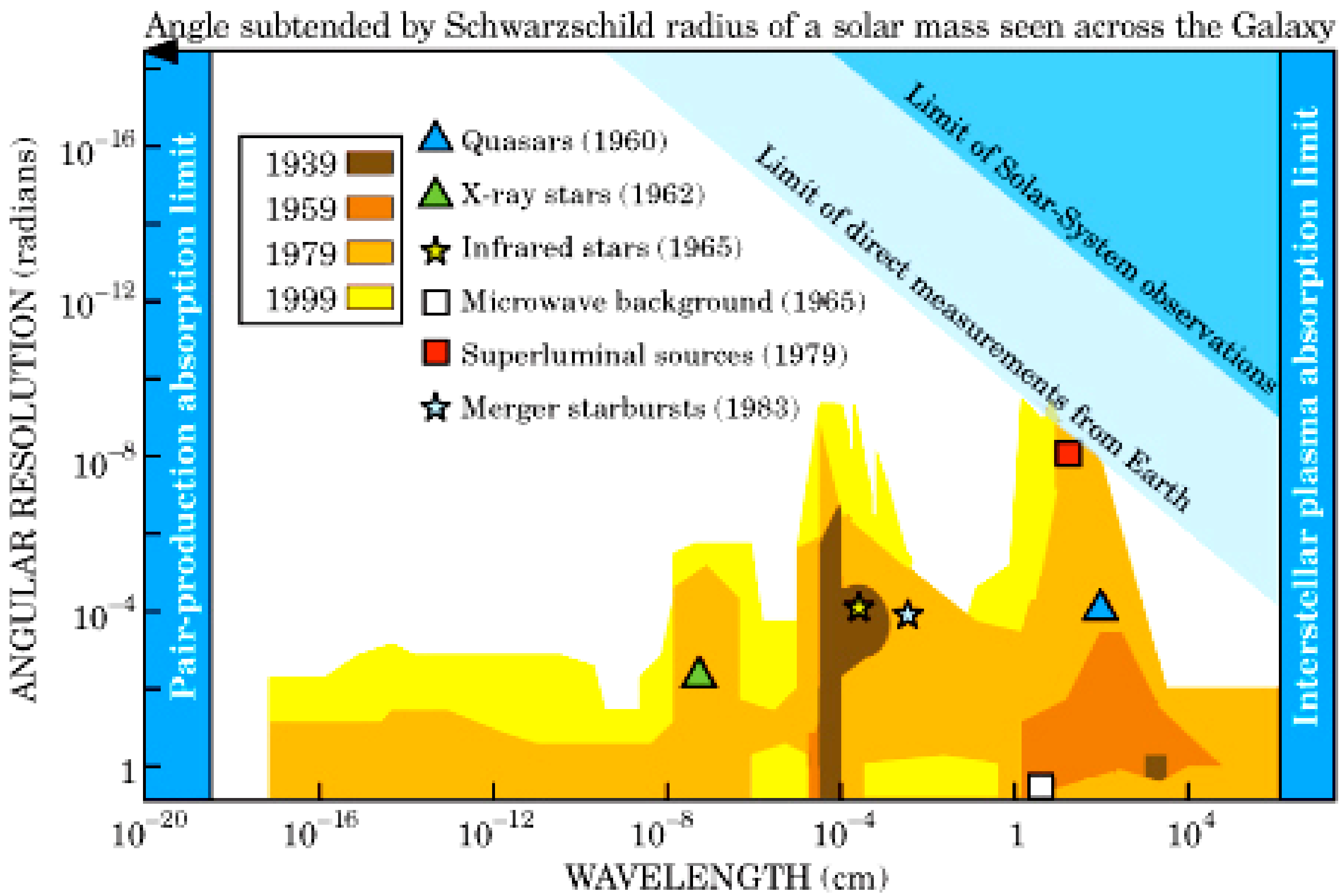
# Taking a Broader View: The Observable Parameter Space




What is the coverage?
Where are the gaps?
Where do we go next?

Along each axis the measurements are characterized by the **position, extent, sampling and resolution.** All astronomical measurements span some volume in this parameter space.

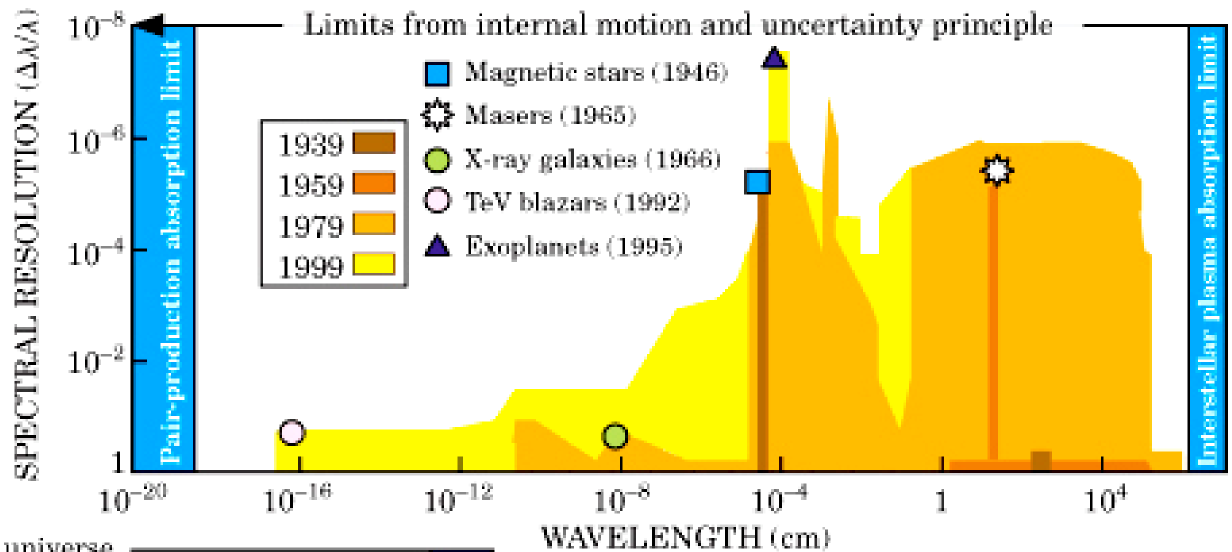
# Covering the Observable Parameter Space

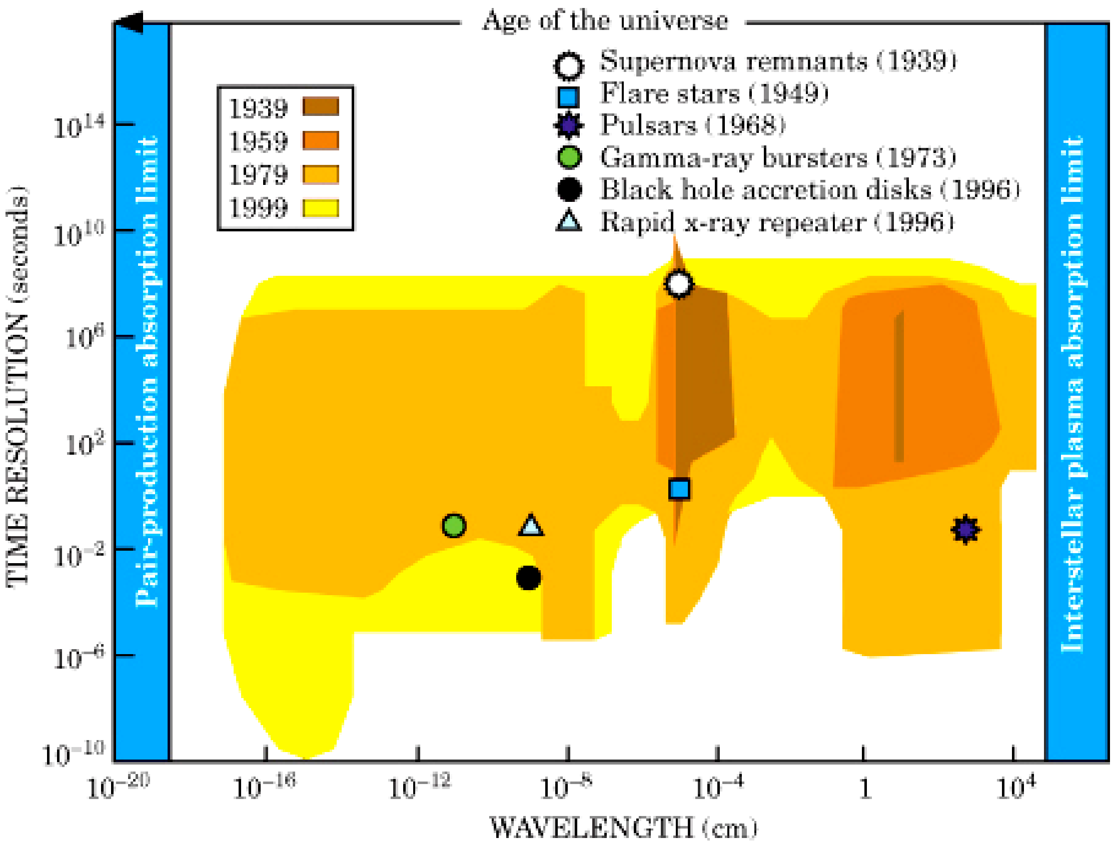



(examples from M. Harwit)

As the sensitivity and angular resolution at different wavelengths improve, new types of objects and phenomena are discovered

# Covering the Observable Parameter Space




(examples from M. Harwit)

… and then there is the ability to cross-match sources found at different wavelengths *(example: the discovery of quasars)*

# The Observable Parameter Space

- Every observation (including surveys) carves out a finite hypervolume of the OPS, and is thus limited
- Some parts of the OPS are much better explored than others (e.g., the time domain; the low surface brightness universe; the sub-mm/FIR sky at high angular resolution and low flux levels; the FUV/soft-X universe; etc.)
- New discoveries are often made in previously unexplored regions of the OPS, e.g.,
  - New □ regimes (radio, X-ray, FIR …)
  - New resolution domains (e.g., in time: pulsars)
  - Sometimes more than once (e.g., AGN); a finite number of distinct fundamental phenomena in the universe?

# How Are Discoveries Made?

- **Conceptual Discoveries:** e.g., Relativity, QM, Branes, Inflation … *Theoretical, may be inspired by observations*
- **Phenomenological Discoveries:** e.g., Dark Matter, QSOs, GRBs, CMBR, Extrasolar Planets, Obscured Universe …

*Empirical, inspire theories, can be motivated by them*

New Technical Capabilities → Observational Discoveries ↔ Theory

**Phenomenological discoveries are made by:**

- Pushing along some parameter space axis
- Making new connections (e.g., multi-□)

Different astrophusical phenomena populate different parts of the OPS, and require different observables and measurement methodologies - and vice versa.

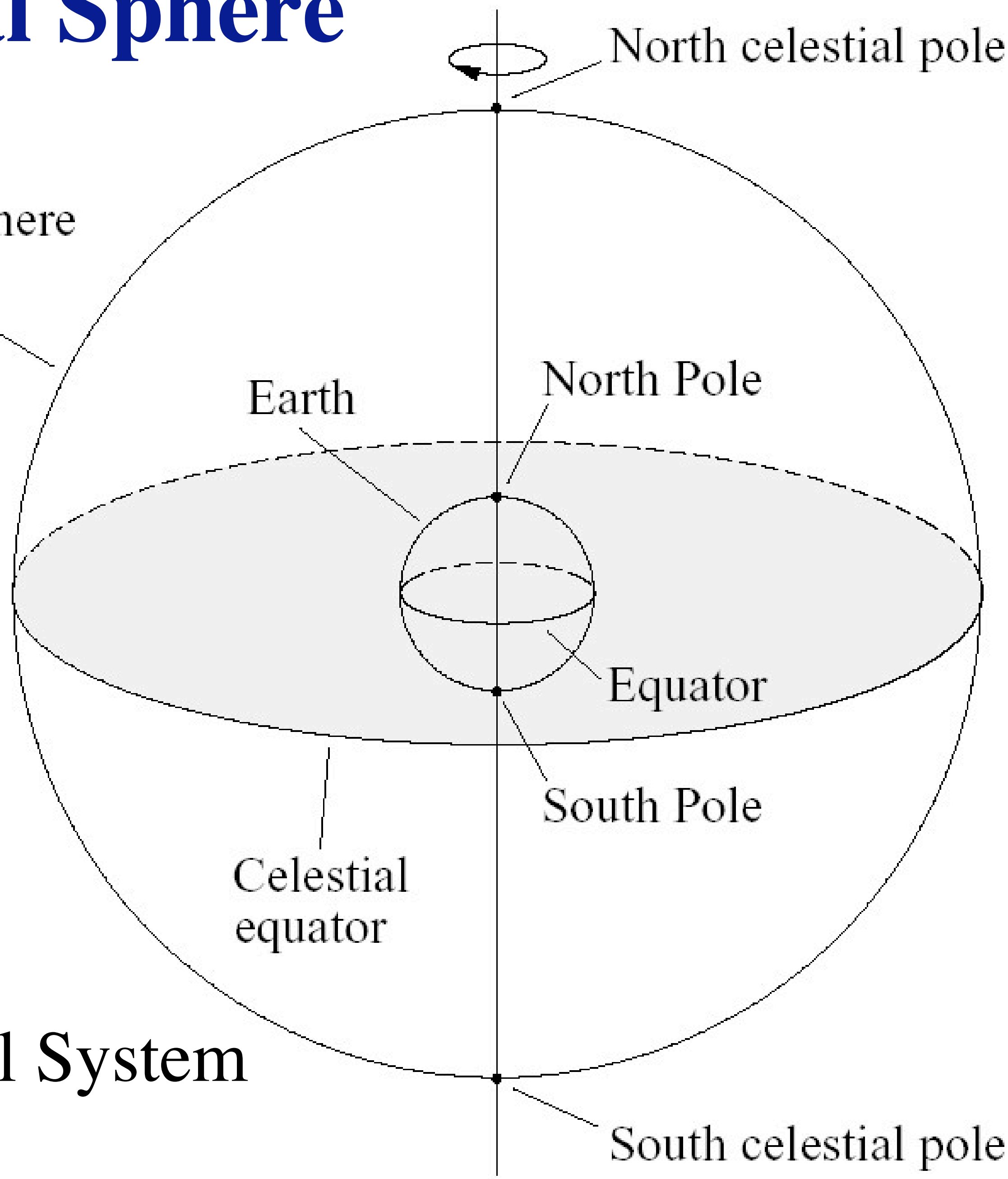
# Making Discoveries in Astronomy

- **Technological Roots of the Progress in Astronomy:**
  - 1960's: the advent of electronics and access to space

    *Quasars, CMBR, x-ray astronomy, pulsars, GRBs, …*
  - 1980's - 1990's: VLSI → cheap computers, digital detectors (CCDs etc.)

    *Galaxy formation and evolution, extrasolar planets, CMBR fluctuations, dark matter and energy, GRBs …*
  - 2000's and beyond: information technology: The next golden age of discovery in astronomy?
- Targeted measurements vs. broad searches/surveys
- Systematic exploration vs. serendipitous
- Objects/sources vs. phenomena/processes

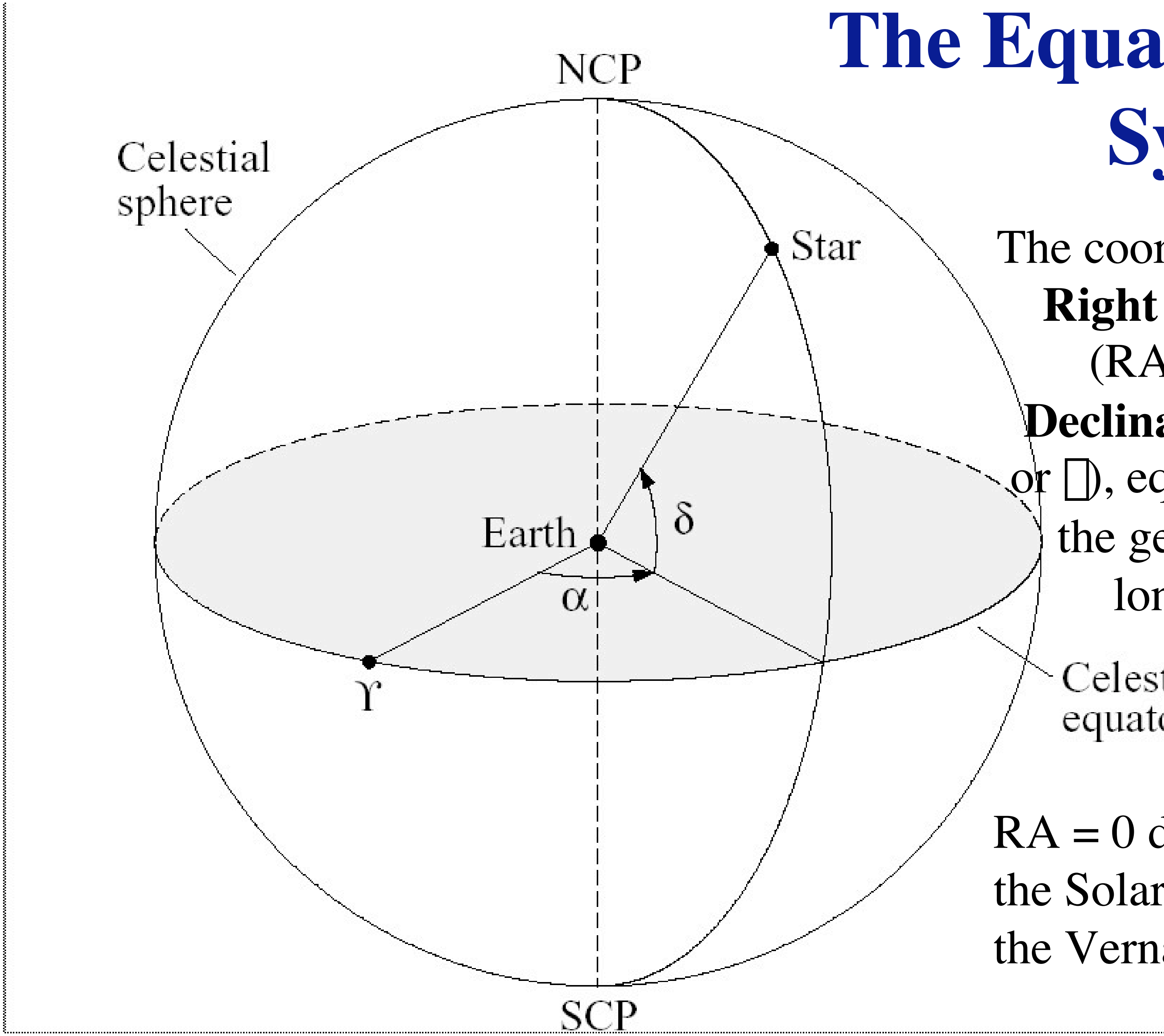
# The Celestial Sphere




Think of it as an outward projection of the terrestrial long-lat coordinate system onto the sky

→ the Equatorial System

# The Equatorial System



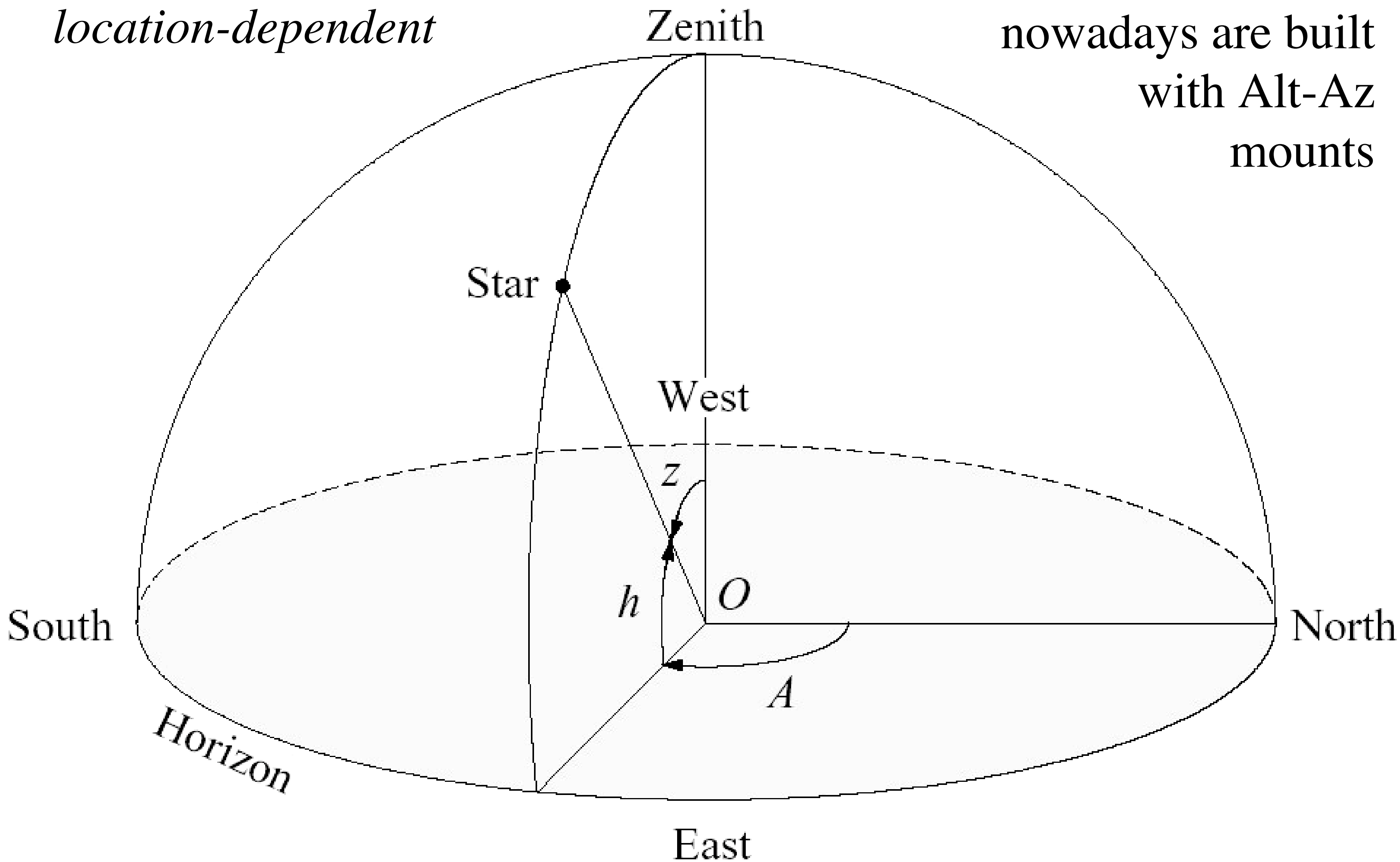

The coordinates are **Right Ascension** (RA, or ) and **Declination** (Dec, or ), equivalent to the georgaphical longitude and latitude

RA = 0 defined by the Solar position at the Vernal Equinox

# The Alt-Az Coordinate System

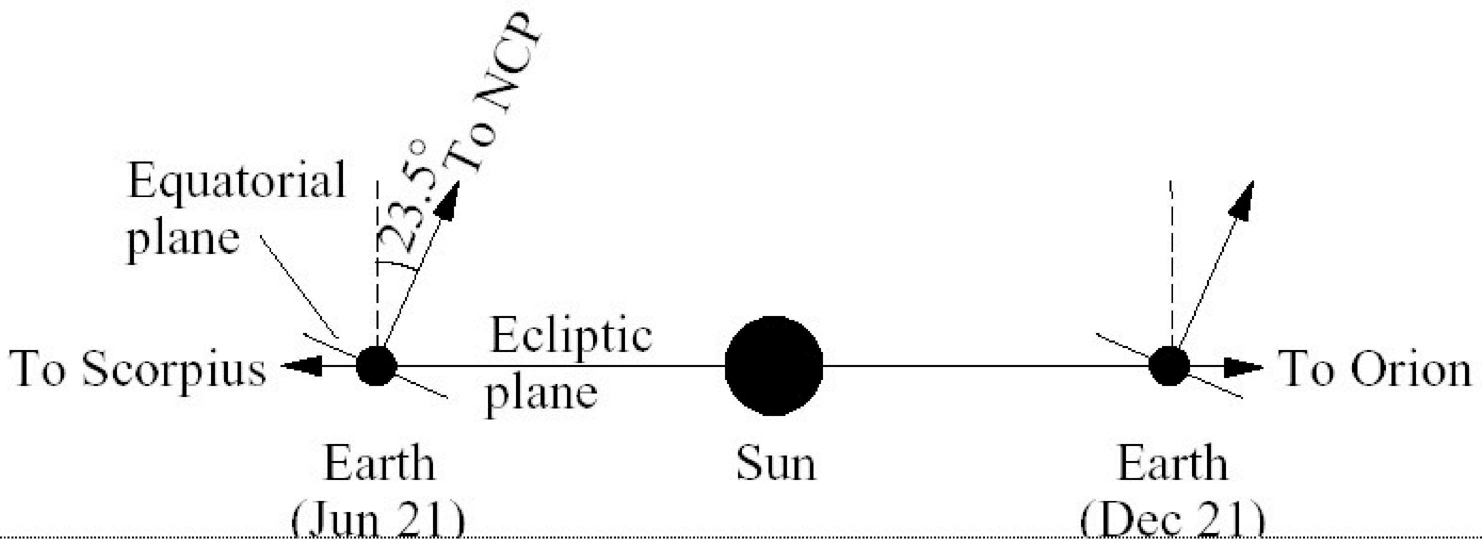
It is obviously *location-dependent*

Most telescopes nowadays are built with Alt-Az mounts



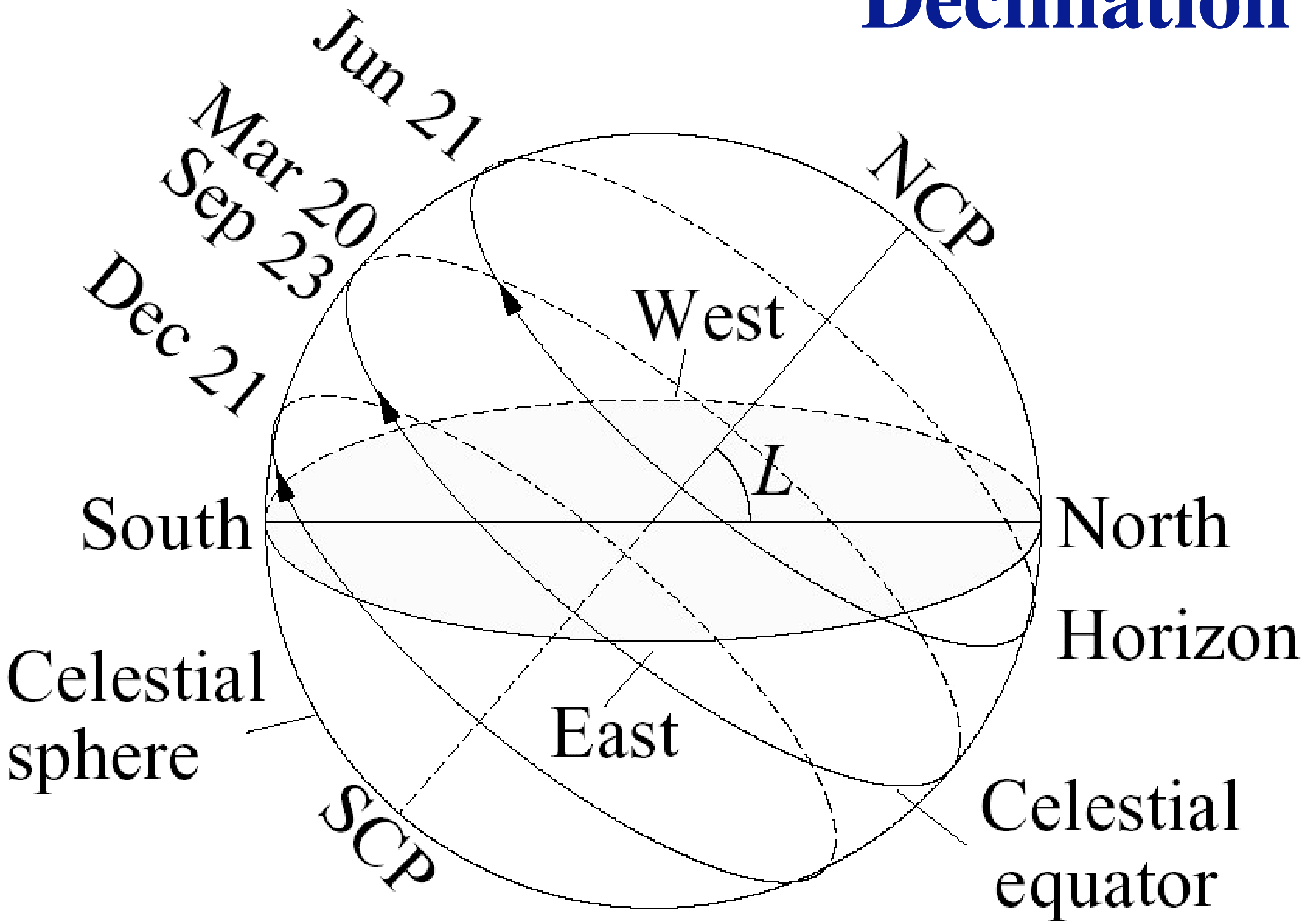
# Other Common Cellestial Coordinate Systems

**Ecliptic:** projection of the Earth's orbit plane defines the Ecliptic Equator. Sun defines the longitude = 0.

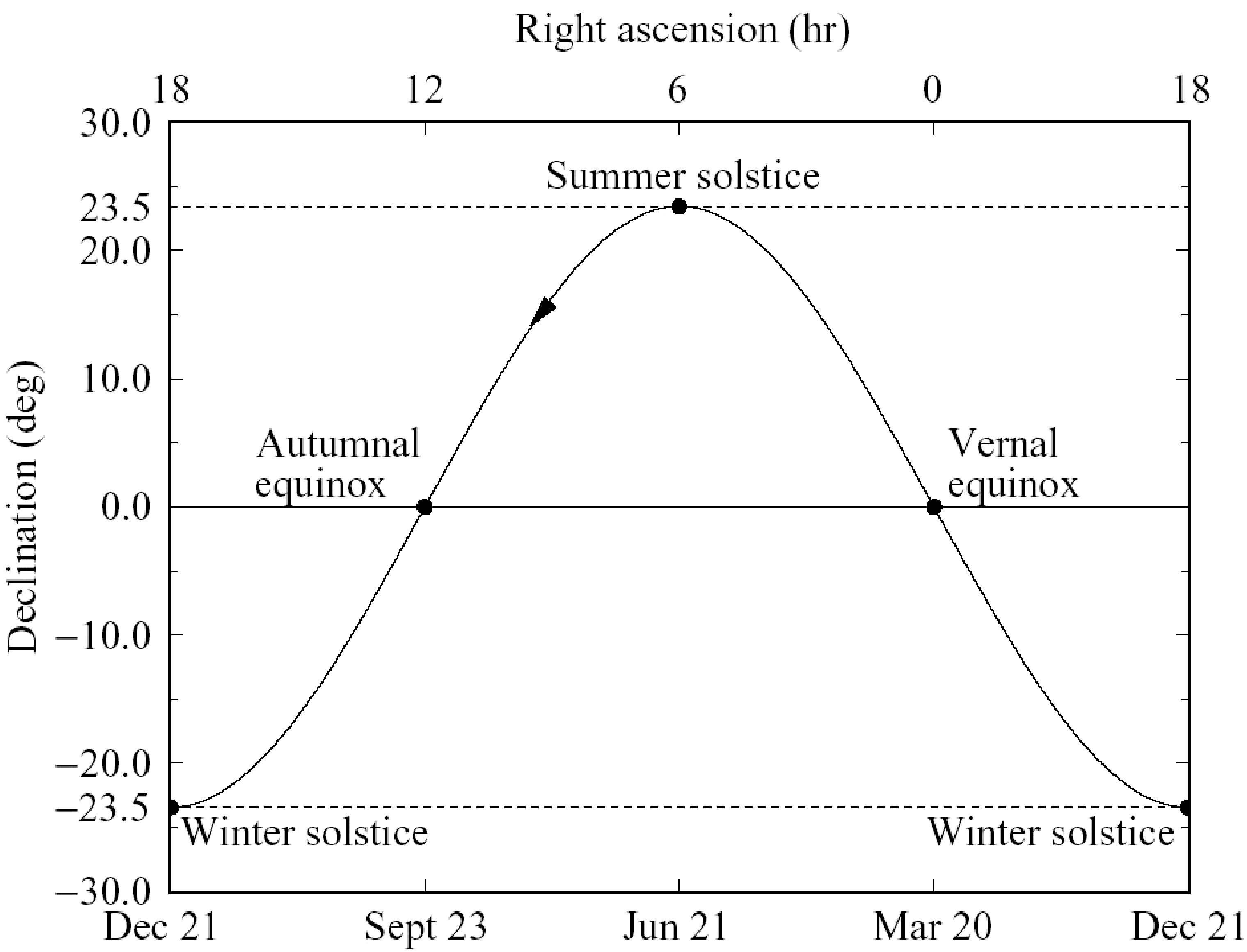



**Galactic:** projection of the mean Galactic plane is close to the agreed-upon Galactic Equator; longitude = 0 close, but not quite at the Galactic center. (□,□) □ $(l,b)$

# The Seasonal Change of the Solar Declination

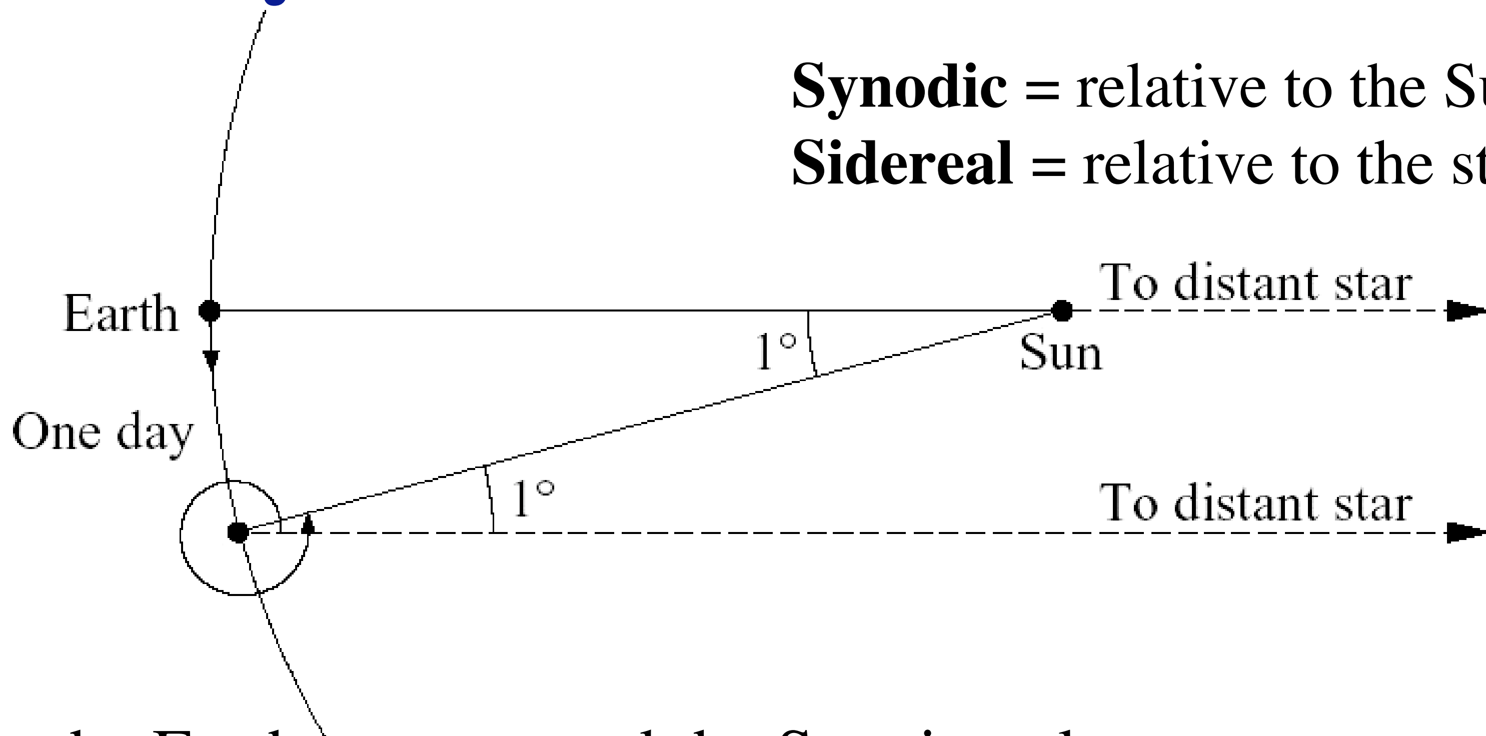


# Annual Solar Path



# Synodic and Sidereal Times

**Synodic** = relative to the Sun
**Sidereal** = relative to the stars




As the Earth goes around the Sun, it makes an extra turn. Thus:

Synodic/tropical year = 365.25 (solar) days

Sidereal year = 366.25 (sidereal) days

**Universal time**, UT = relative to the Sun, at Grenwich

**Local Sidereal Time** (LST) = relative to the celestial sphere

= RA now crossing the local meridian (to the South)

# The Precession of the Equinoxes

- The Earth's rotation axis precesses with a period of ~ 26,000 yrs
- It is caused by the tidal attraction of the Moon and Sun on the the equatorial bulge of the Earth, which is caused by the centrifugal force of the Earth's rotation
- There is also *nutation* (wobbling of the Earth's rotation axis), with a period of ~ 19 yrs

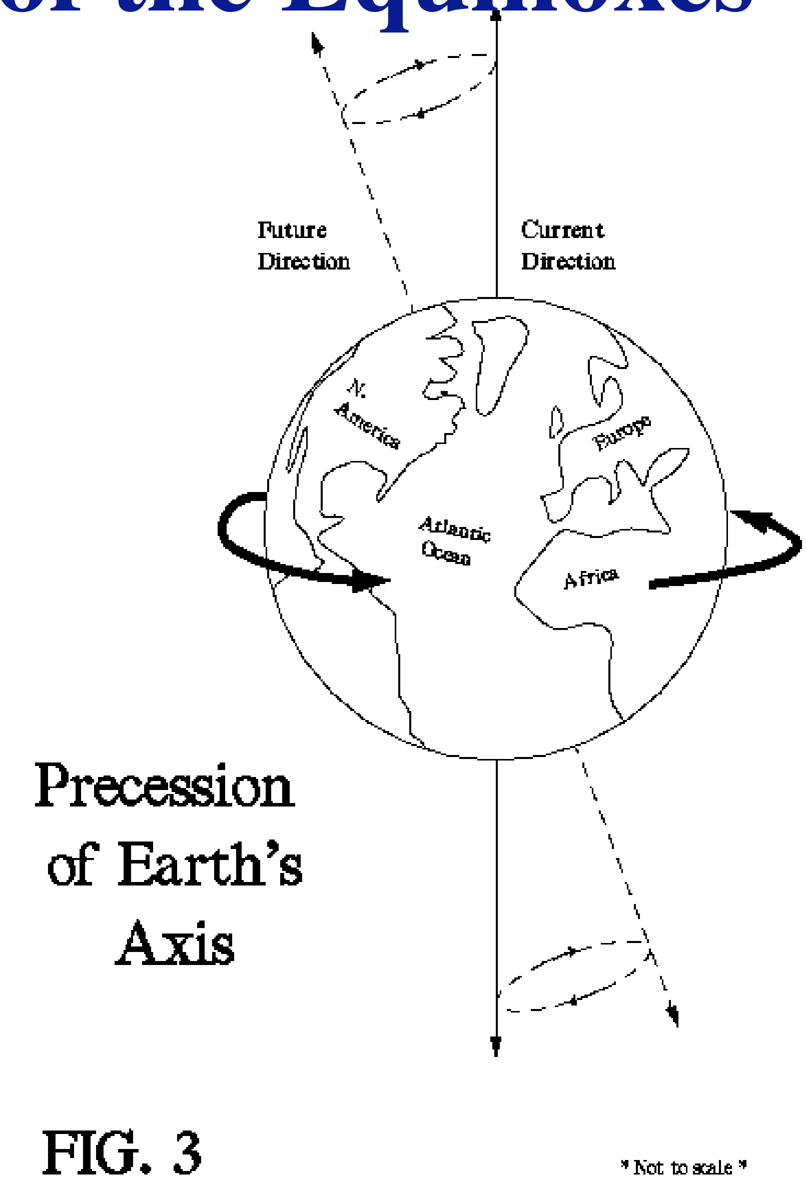
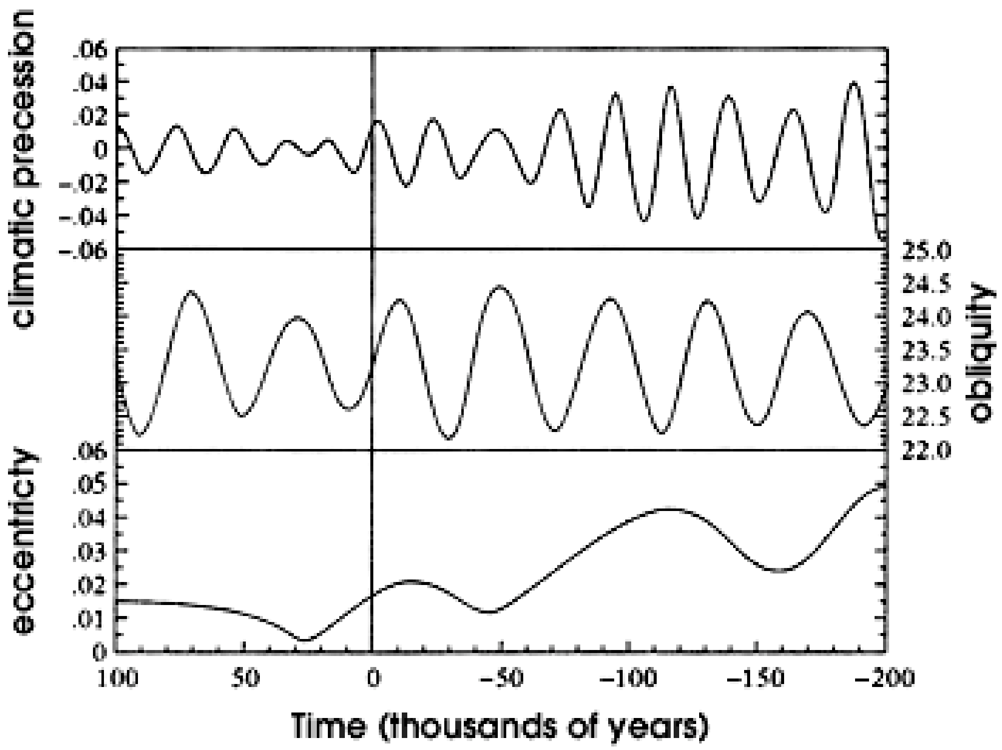



FIG. 3

# Earth's Orbit, Rotation, and the Ice Ages

**Milankovich Theory:** cyclical variations in Earth-Sun geometry combine to produce variations in the amount of solar energy that reaches Earth, in particular the ice-forming regions:

1. Changes in obliquity (rotation axis tilt)
2. Orbit eccentricity
3. Precession




These variations correlate well with the ice ages!

# Some Commonly Used Units

- Distance:
  - Astronomical unit: the distance from the Earth to the Sun, 1 au = $1.496 \times 10^{13}$ cm
  - Light year: c $\times$ 1 yr, 1 ly = $9.463 \times 10^{17}$ cm
  - Parsec: the distance from which 1 au subtends an angle of 1 arcsec, 1 pc = $3.086 \times 10^{18}$ cm = 3.26 ly = 206,264.8 au
- Angle:
  - Usually in "hex", e.g., $12^{\circ}\ 34'\ 56.78''$, or 12.5824389 deg, except for RA, which is usually given in *time* units, e.g., $12^{h}\ 34^{m}\ 56.789^{s}$. Note that □□ [deg] = □□ [h] $\times$ 15 cos □
- Mass and Luminosity:
  - Solar mass: 1 $M_{\odot} = 1.989 \times 10^{33}$ g
  - Solar luminosity: 1 $L_{\odot} = 3.826 \times 10^{33}$ erg/s

# Distances and Parallax

- Distances are necessary in order to convert apparent, measured quantities into absolute, physical ones (e.g., luminosity, size, mass…)
- Stellar parallax is the only direct way of measuring distances in astronomy! Nearly everything else provides relative distances and requires a basic calibration
- Small-angle formula applies:

  **D** [pc] = **1** / □ [arcsec]

- Limited by the available astrometric accuracy (~ 1 mas, i.e., D < 1 kpc or so, now)