Discovering the Night Sky
Guiding Questions

1. What methods do scientists use to expand our understanding of the universe?
2. What makes up our solar system?
3. What are the stars? Do they last forever?
4. What are galaxies? What do astronomers learn by studying them?
5. How does measuring angles help astronomers learn about objects in the sky?
6. What is powers-of-ten notation, and why is it useful in astronomy?
7. Why do astronomers measure distances in astronomical units, light-years, and parsecs?
8. How does studying the cosmos help us on Earth?
To understand the universe, astronomers use the laws of physics to construct testable theories and models

• **Scientific Method**
  – A reiterative process based on observations, logic, and skepticism

• **Hypothesis**
  – A concept or idea that seems to explain a phenomenon or set of observations

• **Model**
  – A set of hypotheses that have withstood observational or experimental tests

• **Theory**
  – A set of related hypotheses can be pieced together into a self consistent description of natural observations

• **Laws of Physics**
  – Theories that accurately describe the workings of physical reality, and have stood the test of time and been shown to have great and general validity
iClicker Question

• **What defines the scientific method?**
  A A set of related hypotheses can be pieced together into a self consistent description of natural observations
  B A concept or idea that seems to explain a phenomenon or set of observations
  C A reiterative process based on observations, logic, and skepticism
  D A set of hypotheses that have withstood observational or experimental tests
  E Theories that accurately describe the workings of physical reality, and have stood the test of time and been shown to have great and general validity
By exploring the planets, astronomers uncover clues about the formation of the solar system.

The star we call the Sun and all the celestial bodies that orbit the Sun:
- including Earth
- the other seven planets
- all their various moons
- smaller bodies such as asteroids and comets
By studying stars and nebulae, astronomers discover how stars are born, grow old, and die.
By observing galaxies, astronomers learn about the origin and fate of the universe.
Astronomers use angles to denote the positions and apparent sizes of objects in the sky.

- The basic unit of angular measure is the **degree** (°).
- Astronomers use angular measure to describe the apparent size of a celestial object—what fraction of the sky that object seems to cover.
- The **angular diameter** (or **angular size**) of the Moon is \( \frac{1}{2} \)° or the Moon **subtends** an angle of \( \frac{1}{2} \)°.
If you draw lines from your eye to each of two stars, the angle between these lines is the **angular distance** between these two stars.
The adult human hand held at arm’s length provides a means of estimating angles.
Angular Measurements

- Subdivide one degree into 60 **arcminutes**
  - minutes of arc
  - abbreviated as 60 arcmin or 60´
- Subdivide one arcminute into 60 **arcseconds**
  - seconds of arc
  - abbreviated as 60 arcsec or 60”

\[
1° = 60 \text{ arcmin} = 60´ \\
1´ = 60 \text{ arcsec} = 60”
\]
Powers-of-ten notation is a useful shorthand system for writing numbers.
**Common Prefixes for Powers of Ten**

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<th>Symbol</th>
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Astronomical distances are often measured in astronomical units, parsecs, or light-years

- **Astronomical Unit (AU)**
  - One AU is the average distance between Earth and the Sun
  - \(1.496 \times 10^8\) km or 92.96 million miles

- **Light Year (ly)**
  - One ly is the distance light can travel in one year at a speed of about \(3 \times 10^5\) km/s or 186,000 miles/s
  - \(9.46 \times 10^{12}\) km or 63,240 AU

- **Parsec (pc)**
  - the distance at which 1 AU subtends an angle of 1 arcsec or the distance from which Earth would appear to be one arcsecond from the Sun
  - \(1\) pc = \(3.09 \times 10^{13}\) km = 3.26 ly
Parallax

When you are at position B, the tree appears to be in front of this mountain.

When you are at position A, the tree appears to be in front of this mountain.

Position A  Position B
Parallax of a nearby star

In January, the nearby star appears to be here.

In July, the nearby star appears to be here.

The closer the star, the more its apparent position shifts as seen from Earth.

Parallax of an even closer star
Careful measurements of the parallaxes of stars reveal their distances

\[ d = \frac{1}{p} \]

- Relation between a star’s distance and its parallax

- Distances to the nearer stars can be determined by parallax, the apparent shift of a star against the background stars observed as the Earth moves along its orbit.
- Parallax measurements made from orbit, above the blurring effects of the atmosphere, are much more accurate than those made with Earth-based telescopes.
- Stellar parallaxes can only be measured for stars within a few hundred parsecs.
Barnard’s star has a parallax of 0.54 arcsec

\[ d = \frac{1}{p} = \frac{1}{0.547} = 1.83 \text{ pc} \]

Because 1 parsec is 3.26 light-years, this can also be expressed as

\[ d = 1.83 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}} = 5.96 \text{ ly} \]
At a distance of 1 parsec, a length of 1 AU subtends an angle of 1 arcsec.
The Small Angle Formula

\[ D = \frac{\alpha d}{206265} \]

- \( D \) = linear size of object
- \( \alpha \) = angular size of object (in arcsec)
- \( d \) = distance to the object
Small Angle Formula Example

• On July 26, 2003, Jupiter was 943 million kilometers from Earth and had an angular diameter of 31.2”.

• Using the small-angle formula, determine Jupiter’s actual diameter.

\[
D = \frac{31.2'' \times 943 \times 10^6 \ km}{206265} = 1.43 \times 10^5 \ km
\]
Astronomy is an adventure of the human mind
Discovering the Night Sky
Part 2
Guiding Questions

1. What role did astronomy play in ancient civilizations?
2. Are the stars that make up a constellation actually close to one another?
3. Are the same stars visible every night of the year? What is so special about the North Star?
4. Are the same stars visible from any location on Earth?
5. What causes the seasons? Why are they opposite in the northern and southern hemispheres?
6. Has the same star always been the North Star?
7. Can we use the rising and setting of the Sun as the basis of our system of keeping time?
8. Why are there leap years?
Naked-eye (unaided-eye) astronomy had an important place in ancient civilizations

- **Positional astronomy**
  - the study of the positions of objects in the sky and how these positions change
- **Naked-eye (unaided-eye) astronomy**
  - the sort that requires no equipment but human vision
- Extends far back in time, across all cultures
  - British Isles Stonehenge
  - Native American Medicine Wheel
  - Aztec, Mayan and Incan temples
  - Egyptian pyramids
Eighty-eight constellations officially cover the entire sky

- Ancient peoples looked at the stars and imagined groupings
  - Pictures in the sky
  - Different cultures different pictures
- We still refer to many of these groupings
- Astronomers call them **constellations** (from the Latin for “group of stars”)
  - Parts are asterisms
Modern Constellations

- On modern star charts, the entire sky is divided into 88 regions
  - Each is a constellation
- Most stars in a constellation are nowhere near one another
- They only appear to be close together because they are in nearly the same direction as seen from Earth
  - Need to think in three dimensions
The appearance of the sky changes during the course of the night and from one night to the next

- Stars appear to rise in the east, slowly rotate about the Earth and set in the west.
- This diurnal or daily motion of the stars is actually caused by the 24-hour rotation of the Earth.
(a) Earth as seen from above the North Pole

- **Illuminated (day) side**
- **Dark (night) side**
- **Light from the sun**
- **Rotation of the Earth**
- **Person in California: 8:00 P.M. local time**
- **Cygnus is overhead as seen from California**
- **Andromeda**
(b) 4 hours (one-sixth of a complete rotation) later
Annual Motion

• The stars also appear to slowly shift in position throughout the year.
• This is due to the orbit of the earth around the sun.
• If you follow a particular star on successive evenings, you will find that it rises approximately 4 minutes earlier each night, or 2 hours earlier each month.
It is convenient to imagine that the stars are located on a celestial sphere.

- The celestial sphere is an *imaginary* object that has no basis in physical reality.
- However, it is still a model that remains a useful tool of positional astronomy.
- Landmarks on the celestial sphere are projections of those on the Earth.
• **Celestial equator** divides the sky into northern and southern hemispheres.

• **Celestial poles** are where the Earth’s axis of rotation would intersect the celestial sphere.

• Polaris is less than 1° away from the north celestial pole, which is why it is called the **North Star** or the Pole Star.

• Point in the sky directly overhead an observer anywhere on Earth is called that observer’s **zenith**.

  - **Nadir** is directly opposite the zenith.
At any time, an observer can see only half of the celestial sphere. The other half is below the horizon, hidden by the body of the Earth.

At 35° north latitude:
- the north celestial pole is 35° above the northern horizon
- the south celestial pole is 35° below the southern horizon

Circumpolar stars

- At any time, an observer can see only half of the celestial sphere
- The other half is below the horizon, hidden by the body of the Earth
(a) At middle northern latitudes
(b) At the north pole
(c) At the equator
The seasons are caused by the tilt of Earth’s axis of rotation

- The Earth’s axis of rotation is not perpendicular to the plane of the Earth’s orbit
- It is tilted about $23\frac{1}{2}^\circ$ away from the perpendicular
- The Earth maintains this tilt as it orbits the Sun, with the Earth’s north pole pointing toward the north celestial pole
The Reason for the Seasons

Spring in the northern hemisphere; autumn in the southern hemisphere

Summer in the northern hemisphere; winter in the southern hemisphere

Winter in the northern hemisphere; summer in the southern hemisphere

Autumn in the northern hemisphere; spring in the southern hemisphere
Facts about the Seasons

- During part of the year the northern hemisphere of the Earth is tilted toward the Sun.
- As the Earth spins on its axis, a point in the northern hemisphere spends more than 12 hours in the sunlight.
- The days there are long and the nights are short, and it is summer in the northern hemisphere and winter in the southern hemisphere.
- The summer is hot not only because of the extended daylight hours but also because the Sun is high in the northern hemisphere’s sky.
- As a result, sunlight strikes the ground at a nearly perpendicular angle that heats the ground efficiently.
- This situation reverses six months later.
The Sun is high in the midday summer sky...

... so a shaft of sunlight is concentrated onto a small area, which heats the ground effectively and makes the days warm.

The Sun is low in the midday winter sky...

... so the same shaft of sunlight is spread out over a larger area and less heating of the ground takes place.

(a) The Sun in summer
(b) The Sun in winter
The Sun appears to trace out a circular path called the **ecliptic** on the celestial sphere tilted at 23 ½ degrees to the equator.

The ecliptic and the celestial equator intersect at only two points.

Each point is called an **equinox**.

The point on the ecliptic farthest north of the celestial equator that marks the location of the Sun at the beginning of summer in the northern hemisphere is called the **summer solstice**.

At the beginning of the northern hemisphere’s winter the Sun is farthest south of the celestial equator at a point called the **winter solstice**.
In winter in the northern hemisphere, the Sun rises in the southeast and sets in the southwest.

During summer in the northern hemisphere, the Sun rises in the northeast and sets in the northwest.

On the first day of spring and the first day of fall, the Sun rises precisely in the east.
Regions of the Earth’s surface are marked by the Sun’s position in the sky throughout the year.

(a) Earth at winter solstice  (b) Earth at summer solstice
The Moon helps to cause precession, a slow, conical motion of Earth’s axis of rotation.
Precession causes the gradual change of the star that marks the North Celestial Pole.
Positional astronomy has played an important role in keeping track of time

- Apparent solar time is based on the apparent motion of the Sun across the celestial sphere, which varies over the course of the year.
- Mean solar time is based on the motion of an imaginary mean sun along the celestial equator, which produces a uniform mean solar day of 24 hours.
- Ordinary watches and clocks measure mean solar time.
- Sidereal time is based on the apparent motion of the celestial sphere.
• *Local noon* is defined to be when the Sun crosses the **upper meridian**, which is the half of the meridian above the horizon.
Local solar noon on March 21 is at this location on Earth.

Earth moves about 1° around its orbit in one day...

...so Earth must make a complete rotation plus 1° to bring this location to local solar noon on March 22.
Astronomical observations led to the development of the modern calendar

- The day
  - based on the Earth’s rotation
- The year
  - based on the Earth’s orbit
- The month
  - based on the lunar cycle
- None of these are exactly the same as nature so astronomers use the average or mean day and leap years to keep the calendar and time consistent
(b) A day’s motion of the Sun along the ecliptic
NOTE: This ellipse is GREATLY exaggerated.

(a) A month’s motion of the Earth along its orbit.
Astronomy Jargon

- angle
- angular diameter (angular size)
- angular distance
- angular measure
- arcminute
- arcsecond
- astronomical unit (AU)
- Big Bang
- black hole
- degree (°)
- exponent
- galaxy
- gamma-ray burster
- hypothesis
- kiloparsec (kpc)
- laws of physics
- light-year (ly)
- megaparsec (Mpc)
- model
More Astronomy Jargon

- Antarctic and Arctic Circles
- apparent solar day
- apparent solar time
- autumnal equinox
- celestial equator
- celestial sphere
- circumpolar
- constellation
- declination
- diurnal motion
- ecliptic
- epoch
- equinox
- lower meridian
- mean solar day
- mean sun
- meridian
- meridian transit
- nadir
- north celestial pole
- positional astronomy
- precession
- precession of the equinoxes
- right ascension
- sidereal clock
- sidereal day
- sidereal time
- sidereal year
- south celestial pole
- summer solstice
- time zone
- tropical year
- Tropic of Cancer
- Tropic of Capricorn
- upper meridian
- vernal equinox
- winter solstice
- zenith
- zodiac