Astronomy AST-1002
Section 0459
Discover the Universe
Fall 2017

Instructor: Dr. Francisco Reyes

Web Page:
http://www.astro.ufl.edu/~freyes/classes/ast1002/index.htm

Textbook: Astronomy: A Beginners Guide to the Universe:
Chaisson and McMillan, 8th Edition
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In this web page you will find the syllabus, copies of Power Point presentations, form and instructions for the Observing Project, scores, homework and other class material.

We may be using Canvas later in the semester

Office hours: Monday 1:00-2:30 PM and Wednesday, 12:30-1:30 PM (or by appointment)
Astronomy is an amazing and interesting field!
Let’s take a look to some recent news and discoveries

Images of the Total Solar Eclipse August 21, 2017
Images and sequence courtesy of Dr. Naibi Marinas, UF Astronomy Dept.

A sequence of the phases of the eclipse

Solar Corona
Images of the Sun from 08/26/2015

Visual image showing sunspot 2403

Magnetic field configuration (Solar Dynamic Observatory, UV image)
A few recent news and discoveries: Comets

An image of the nucleus of Comet 67P taken by the Rosetta spacecraft on August, 2015. Taken when the comet was near the closest distance from the Sun.
These are the first high resolution images of jets of gas ejected from the nucleus of a comet!
The size of the nucleus is about 4 km

Comet Siding Spring C/2013 passing close to Mars (132,000 km from its surface) on October 19, 2014!
It was the first time to see a comet passing so close to a terrestrial planet!
Mars was at 1.6 AU from Earth
More recent and interesting news

Jets of water vapor in Enceladus (A satellite of Saturn) imaged by the Cassini spacecraft. Molecules present in the jets are water, carbon dioxide, methane and ammonia. The satellite has a diameter of 500 km. The Cassini spacecraft is at the present in orbit around Saturn.

Discovery of an exoplanet with a mass close the mass of Earth and orbiting a star inside the habitable zone. Discovered by the Kepler spacecraft team. Reported on April, 2014. The system Kepler-186 has 5 planets and it is located at 500 light years from Earth.
More news on the exploration of the Solar System

- **New Horizon** spacecraft: Pluto fly-by on July 14, 2015. This is the first spacecraft to reach Pluto. It is providing the first high resolution images of Pluto.

- **Curiosity** rover landed on Mars in August 2012. It has been analyzing and taken images of the Martian soil.
More news on exploration of the Solar System

The search for life in the solar system.

- Europa (a satellite of Jupiter). It has an ocean of liquid water under the frosted crust. The energy to maintain liquid water comes from dissipation of tidal heat.

This satellite is the target for a mission that may launch around 2020
More news on exploration of the Solar System

- Titan (a satellite of Saturn). It has a thick atmosphere composed of complex organic molecules (Hydrocarbons).
- It has lakes of liquid methane on its surface and an ocean of liquid water under the frozen surface.
- At the present, the Cassini spacecraft is in orbit around Saturn and exploring Titan.
Chapter 0:
Charting the Heavens

Reading assignment: Chapter 0 “Charting the Heavens”
Learning outcome

- Understand the basic levels of structure of the Universe
- Understand how astronomers use the “celestial sphere” to represent the sky. What is a constellation? The celestial coordinate system used to locate objects and the use of angular measurements to locate and find distances in the celestial sphere
- Account for the motions of the Sun, moon, planets and stars in the celestial sphere
- Understand why the tilt of the rotational axis of Earth is related to the seasons
- Explain the changing appearance of the moon (lunar phases)
- Understand the reasons for having solar and lunar eclipses and what are the phases of the moon for these two types of eclipses.
- Understand the geometric method used to measure distances and sizes to objects inaccessible.
- Distinguish between a scientific theory and a “theory” (or “idea”) used in common language.
We will study our solar system…

Stars and star clusters…

We will continue with the Sun…

Nebulae…

Pleiades Cluster (Seven Sisters, Subaru)

Ring Nebula (Planetary nebula)
We will explore our Galaxy, the Milky Way and other galaxies...

Andromeda Galaxy, the closest spiral galaxy to the Milky Way (our galaxy)
And beyond...

Cluster of galaxies
Abell 2744
An interesting question: What is our place in the universe?
Understanding SIZES and DISTANCES in Astronomy

In this class we will use the metric system. In this slide let’s use the English system. It may help to give you a better idea of distances:

- The Moon is 240,000 miles away
  Driving at 80 miles/hour, it would take 3000 hours to get there - or about 4 months!

- Distance to nearest star (Alpha Centauri): 20,000,000,000,000 miles or $2 \times 10^{13}$ miles

- Size of our galaxy (Milky Way): 200,000,000,000,000,000 miles or $2 \times 10^{17}$ miles

- Distance to the Andromeda galaxy (The closest spiral galaxy):
  20,000,000,000,000,000,000 miles or $2 \times 10^{19}$ miles
Scale model of the Universe

If the Earth were the size of an eraser tip.....

• The Moon is 1 foot away
• The Sun is just over a football field away (125 yards)
• The nearest star is 16,000 miles away! (About twice the diameter of the Earth)
Commonly Used Distance Units:

In astronomy (and in sciences in general) we use the metric system. In astronomy we have to deal with large distances, we need to use powers of ten.

- 1 m (meter) $\cong$ 1 yard

- 1 km (kilometer) = 1,000 m = $10^3$ m $\cong$ 0.62 miles

- 1 AU (Astronomical Unit) = Distance from Earth to Sun = 150,000,000 km ($150 \times 10^6$ km) (~93,000,000 miles).

The AU is a useful unit to measure distances within the solar system.

- 1 light-year (ly) = Distance traveled by light in 1 year = $10^{12}$ km.

Light-year is a useful unit to measure distances within the Milky Way and to other galaxies.

(Speed of light $c = 300,000$ km/s = $3 \times 10^5$ km/s = 186,000 miles/s)
How long does it take light to reach Earth from:

\[ \text{Velocity} = \frac{\text{space}}{\text{time}}, \quad v = \frac{s}{t} \quad t = \frac{s}{v} \quad \text{for light, } t = \frac{s}{c} \]

The Moon? \( \rightarrow 1.4 \text{ seconds (Distance} \sim 385,000 \text{ km)} \)

The Sun? \( \rightarrow 8 \text{ minutes (Distance} \sim 150 \times 10^6 \text{ km)} \)

Nearest star (Alpha Centauri)? \( \rightarrow 4 \text{ years (4 ly)} \)

Center of our Galaxy? \( \rightarrow 26,000 \text{ years (26,000 ly)} \)

Andromeda Galaxy? \( \rightarrow 2 \times 10^6 \text{ years} \)

Distant galaxies? \( \rightarrow \text{billions of years} \ldots \)

When we see the nearest star, we see the star has it was 4 years ago.

We see distant galaxies has they were billions of years ago.

\( \Rightarrow \text{Important: We see distant objects as they were in the past!} \)
Our study of the Universe begins by examining the Sky: stars, planets, the Sun, the Moon

**Constellations** are random configurations of stars. The names of most of the constellations are known from ancient times.

Humans have the tendency to connect bright stars into patterns and configurations and form figures.

Some constellations are given names of mythological heroes or animals. There are 88 constellation in the sky.
An example of a constellation: Orion the Hunter

This is what you see in the sky

This is what the ancient saw

This is what it is in space

Stars making up a constellation are generally not close together in space
The celestial sphere

• Stars appear to be attached to a giant “sphere” extended around the Earth and rotating East to West

• This is called the Celestial Sphere

• The motion of the stars from East to West is the result of the Earth’s rotation from West to East

• The celestial equator: The projection of the terrestrial equator onto the celestial sphere

• Earth’s rotation axis intersects the celestial sphere at the North and South celestial poles
If we take a long exposure image, stars appear to rotate around the North Celestial Pole:

Polaris (North Star) is close to the North Celestial Pole
The celestial coordinates

The projection of the terrestrial coordinate system of longitude and latitudes on the celestial sphere generates the set of celestial coordinates.

The celestial coordinates are called Right Ascension (RA) and Declination (Dec or dec).

Ecliptic: Path of the Sun in the celestial sphere
Celestial Coordinates

**Right Ascension** = Time to rotate through a given angle (The angle is measured in hours-minutes-sec)

Similar to Longitude on Earth (The reference, 0 hours of RA is at the position where the Celestial equator crosses the Ecliptic, the vernal equinox).

Range of values: 0 to 24 hours

**Declination** = Angle in degrees north/south of the Celestial equator

Similar to Latitude on Earth (The reference, 0 degrees of Dec is at the Celestial equator)

Range of values: 0 to +90 degrees and 0 to -90 degrees

(+ values in Northern hemisphere, (-) values in Southern hemisphere)
What about angles on the sky? How do we measure them?

A practical way to estimate angles in the sky
The Moon and the Sun, coincidentally, have nearly the same angular size or angular diameter, about 0.5 degrees.

- The Moon is about 380,000 km away but only 3,300 km diameter
- The Sun is 150,000,000 km away and about 1,400,000 km diameter

Angular diameter (Around 0.5 degrees)
Earth’s Rotational and Orbital Motion

The Earth *rotates* on its axis once every *day*.
The Earth *orbits* the Sun once every *year*.

This generates two types of days, sidereal and solar days

- **Solar day** = 24 hours (one rotation of the Earth relative to the Sun)

- **Sidereal day** = 23 hr 56min (one rotation of the Earth relative to a reference star)

- The Earth must rotate an extra 0.986 degrees to face the Sun. Earth takes about **4 minutes** to rotates 0.986 degrees
Over the course of a year, the dark (night) side of the Earth (night-time) faces different directions in the sky. Thus, we see different stars and constellations in the night sky during different months.

The zodiac is a special set of 12 constellations that happen to lie in the same plane as the Earth’s orbital plane around the Sun. If we could see the stars during the day, the Sun would appear to move through these constellations over the year.

The apparent path of the Sun through the sky (and through the zodiac constellations) over the course of a year is called the **ecliptic**.
Motion of Sun along the ecliptic on the celestial sphere throughout the year.

The Sun crosses the celestial equator twice a year; at the **vernal equinox** around March 21st and the **autumnal equinox** around September 21st. Summer **solstice** occurs around June 21. Winter **solstice** occurs around December 21.
How the motion of the Sun along the ecliptic appears to observers on Earth?
The Sun reaches its highest point in the sky when it crosses the meridian around June 21 (Summer solstice). The Sun rises early and sets later in the day. The Sun stays up in the sky longer during the summer. It reaches the lowest point when it crosses the meridian on December 21 (Winter solstice). The Sun rises late and sets earlier. It stays up in the sky a shorter period.

Zenith: the point in the sky straight overhead
Meridian: the circle that passes through the Zenith and the two celestial poles
Path of the Sun in summer and winter

Path of the Sun in the summer and winter

Path of the Sun in summer and winter from a mid northern latitude looking south
The Sun’s trajectory for the winter solstice (Dec. 21, 2015) from a location north of England
Let’s consider the following statement:

“We have seasons because the Earth is closer to the Sun in summer and farther from the Sun in winter”

An answer:
It make sense: It is hotter in the summer so Earth must be closer to the Sun in summer and farther from the Sun in winter.
Let’s consider some facts…

Fact: Actually it is the opposite, Earth is closer to the Sun during the north hemisphere winter and farther during the north hemisphere summer (Reason: Earth has an elliptical orbit)

Another fact: *When it is summer in north America, it is winter in Australia*)

• Seasons are opposite in the N and S hemispheres, so the argument about distance from the Sun is invalid.

Distance cannot explain the seasons.

• The real reason for seasons involves Earth’s axis tilt.
The Earth rotation axis is tilted 23.5° from the perpendicular to the plane of the ecliptic.

Why is this important?
The reason for the seasons:
The 23.5 degrees tilt of the Earth rotational axis

Colder temperatures in winter are a result of:

• Sun stays lower in the sky during the day (sunlight less direct).

• Sun is above the horizon for shorter periods (shorter days).
Another view of the reason for the seasons: The angle of illumination of the Sun

Questions:
• What would happen to the seasons if the rotational axis is perpendicular to the ecliptic?
• What would be the orientation of the ecliptic respect to the celestial equator if the rotational axis is perpendicular to the plane of the ecliptic?
An important effect: Precession of the Equinoxes

Gravitational pull of the Sun and the Moon on the Earth causes the Earth’s spin axis to \textit{precess} - like a top that is spinning down.

As a result, the celestial poles point in different directions in the sky as the Earth \textit{precesses}. For example, the north celestial pole is now close to the star Polaris, but in 9,000 years, it will be close to the star Vega. The Precession period is \(~26,000\) years.
An important effect: Precession of the Equinoxes

Tropical year: The interval of time from one equinox to the next. It correspond to 365.242 solar days.

Sidereal year: The interval of time for the Earth to complete one orbit around the Sun. It is 365.256 solar days long, 20 minutes longer than the tropical year.

The reason for the difference between the tropical and sidereal year is due to precession.

The tropical year is the year in our calendar. The seasons will remain on the same months. But the constellations will change.

Example: Orion is a winter constellation for the north hemisphere. In 13,000 years it will be a summer constellation.
The Moon: Why do we see phases?

- The Moon emits no visible light of its own → shines by reflecting light from the Sun.
- The half of the Moon facing the Sun is always lit.
- We see a combination of lit and dark areas.
Phases of the Moon

- Half of Moon is illuminated by Sun and half is dark.
- We see a changing combination of the bright and dark faces as the Moon orbits the Earth.
- Depending on the angle between the Moon and the Sun as seen from Earth, is the combination of bright and dark areas that we see.

Important:
- At **new moon**, we only see the dark half area of the moon.
- At **full moon** we only see the illuminated half area of the moon.

Examples of rising and setting times of the moon:
- At **new moon**, the moon rises at sunrise and sets at sunset.
- At **full moon**, the moon rises at sunset and set at sunrise.
The Moon and Sun

- The Moon played an important role in ancient astronomy.
- Calendars and religious observances were tied to its phases and cycles.
- Our calendar is based on the lunar orbit.

**Lunar Phases:**

- The Moon goes through phases based on its position relative to the Earth and Sun.
- The complete cycle of lunar phases from new moon to the next new moon takes about 29 days. The **age** of the moon is the number of days since the **new** moon.
- We always see the same face of the Moon. It rotates on its axis in exactly the same time it takes to orbit the Earth (**Synchronous rotation**). We will explore this later in Chapter 5.

![Lunar Phases Diagram](image-url)
Sidereal and Synodic month

- **Sidereal month**: The time for the moon to complete one revolution respect to a reference star. The duration of the sidereal month is 27.3 days.

- **Synodic month**: The time for the Moon to complete a full cycle of phases (Example from new moon to the next new moon). The reference is the Sun. The duration of the synodic month is 29.5 days.
Eclipses

Lunar Eclipse

• The Earth blocks the Sun’s light from the Moon
• The Sun and the Moon must be in opposite direction as seen from Earth
• The phase of the moon must be **full** Moon
• Can be seen from anywhere on the Earth where the Moon is visible
Solar Eclipse

• The Moon blocks the Sun’s light from the Earth (Coincidentally, the Moon and Sun have the same angular size, around 0.5 degrees!)

• The phase of the Moon must be **new** Moon

• Solar eclipses can only be seen from specific places on Earth, along a narrow path

• Three types of solar eclipses: Total, partial and annular
Another view of a solar eclipse
This is what you see in a total solar eclipse
Why some solar eclipses are annular?
The elliptical orbit of the Moon

The Moon's orbit around Earth is an ellipse. One side (perigee) is closer to Earth than the other (apogee).

Apogee? Perigee? Can't remember which is which? An old astronomer's trick: The "a" in "apogee" stands for "away."

Note: In this diagram, the eccentricity of the Moon's orbit is exaggerated for clarity.
The moon has an elliptical orbit

- The minimum distance is around 356,000 km
- The maximum distance is around 406,000 km

- When the moon is at the maximum distance, the angular diameter of the moon is smaller than the angular diameter of the sun. A condition for an annular solar eclipse

- When the full moon coincide when it is at the minimum distance (at perigee) it is normally called “Super Moon” (Not an astronomical term)

- On Sunday December 3rd the full moon will coincide when the moon is close to perigee (closest distance ~357,492 km on December 4th). Largest in 2017.
Total solar eclipse paths from 2009 to 2030
The last total solar eclipse of August 21, 2017
Next total eclipse for the US: April 8, 2024
The path of totality for the August 21, 2017 total solar eclipse
The Moon’s orbital plane is tilted 5 degrees to the ecliptic (plane in which Earth orbits the Sun).

Eclipses therefore occur only when the Moon crosses the ecliptic while it is a new or full moon.

For other configurations (Moon-Sun-Earth), the moon will be “above” or “below” the ecliptic.
Parallax and stellar parallax: How do we determine distances to nearby stars?

The concept of **parallax**
The apparent displacement of the foreground object (pencil) respect to the background as the observer’s location changes (distance between eyeballs) is known as **parallax**.

Why is elementary geometry important for measuring distances in astronomy?

**Stellar parallax**
A nearby object (planet or star) will change position respect to the background of stars if it is observed from two sites separated by a terrestrial diameter. If we measure the angle of displacement of the object and we know the length of the baseline (Earth diameter) we can calculate the distance to the object. The amount of parallax is inversely proportional to an object’s distance.
Science and the Scientific Method

Science is a step-by-step process for investigating the physical world and the natural phenomena using natural laws and observed phenomena. In general it is a slow process. It require careful observations and testing before one can start to formulate an idea to explain a phenomenon. Experimentation and observation are important part of the inquire.

A **theory** or a framework of ideas to explain a set of observations that can also make predictions about a phenomenon are part of the process. But the **theory** must be testable. The assumptions and predictions are subject to experimentation. The observations must verify the predictions of the theory.

A **theory** in science has a different meaning from the normal use of the word “theory”. It is not just an “idea” to explain something.

The scientific method involve **theory** and **experimentation**.

A phenomenon can be discovered during an observation, then a theory must be constructed to explain the phenomenon and make predictions. A **theory** in Physics and other sciences including Astronomy may involve **equations**. The process can start at any point in the circle and may continue forever.