The History of Astronomy

Please pick up your assigned transmitter.
When did mankind first become interested in the science of astronomy?

1. With the advent of modern computer technology (mid-20th century)
2. With the development of the theory of relativity (early 20th century)
3. With the invention of the telescope (~ A.D. 1600)
4. During the times of the ancient greeks (~ 400 – 300 B.C.)
5. In the stone and bronze ages (several thousand years B.C.)
The Roots of Astronomy

• Already in the stone and bronze ages, human cultures realized the cyclic nature of motions in the sky.

• Monuments dating back to ~ 3000 B.C. show alignments with astronomical significance.

• Those monuments were probably used as calendars or even to predict eclipses.
Stonehenge
Stonehenge

• Constructed 3000 – 1800 B.C. in Great Britain
• Alignments with locations of sunset, sunrise, moonset and moonrise at summer and winter solstices
• Probably used as calendar.
Other Examples around the World

Big Horn Medicine Wheel (Wyoming)
Other Examples around the World

Caracol (Mexico); Maya culture, approx. A.D. 1000
Why is it so difficult to find out about the state of astronomical knowledge of bronze-age civilizations?

1. Written documents from that time are in a language that we don’t understand.
2. There are no written documents from that time.
3. Different written documents about their astronomical knowledge often contradict each other.
4. Due to the Earth’s precession, they had a completely different view of the sky than we have today.
5. They didn’t have any astronomical knowledge at all.
Ancient Greek Astronomers

- Models were based on unproven “first principles”, believed to be “obvious” and were not questioned:

  1. Geocentric “Universe”: The Earth is at the Center of the “Universe”.

  2. “Perfect Heavens”: The motions of all celestial bodies can be described by motions involving objects of “perfect” shape, i.e., spheres or circles.
• **Ptolemy**: Geocentric model, including *epicycles*

Central guiding principles:

1. Imperfect, changeable Earth,
2. Perfect Heavens (described by spheres)
What were the epicycles in Ptolemy’s model supposed to explain?

1. The fact that planets are moving against the background of the stars.
2. The fact that the sun is moving against the background of the stars.
3. The fact that planets are moving eastward for a short amount of time, while they are usually moving westward.
4. The fact that planets are moving westward for a short amount of time, while they are usually moving eastward.
5. The fact that planets seem to remain stationary for substantial amounts of time.
Epicycles

The ptolemaic system was considered the “standard model” of the Universe until the Copernican Revolution.

Introduced to explain retrograde (westward) motion of planets

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At the time of Ptolemy, the introduction of epicycles was considered a very elegant idea because …

1. it explained the motion of the planets to the accuracy observable at the time.
2. it was consistent with the prevailing geocentric world view.
3. it explained the apparently irregular motion of the planets in the sky with “perfect” circles.
4. because it did not openly contradict the teaching of the previous authorities.
5. All of the above.
The Copernican Revolution

Nicolaus Copernicus (1473 – 1543): Heliocentric Universe (Sun in the Center)
New (and correct) explanation for retrograde motion of the planets:

Retrograde (westward) motion of a planet occurs when the Earth passes the planet. This made Ptolemy’s epicycles unnecessary.

Described in Copernicus’ famous book “De Revolutionibus Orbium Coelestium” (“About the revolutions of celestial objects”)
In the Copernikan “Universe”, the orbits of planets and moons were ...

1. Perfect Circles
2. Ellipses
3. Spirals
4. Epicycles
5. None of the above.
Johannes Kepler (1571 – 1630)

• Used the precise observational tables of Tycho Brahe (1546 – 1601) to study planetary motion mathematically.

• Found a consistent description by abandoning both
  1. Circular motion and
  2. Uniform motion.

• Planets move around the sun on elliptical paths, with non-uniform velocities.
Kepler’s Laws of Planetary Motion

1. The orbits of the planets are **ellipses** with the sun at one focus.

Eccentricity \( e = \frac{c}{a} \)
Eccentricities of Ellipses

1) $e = 0.02$
2) $e = 0.1$
3) $e = 0.2$
4) $e = 0.4$
5) $e = 0.6$
Eccentricities of planetary orbits

Orbits of planets are virtually indistinguishable from circles:

Earth: $e = 0.0167$

Most extreme example:
Pluto: $e = 0.248$
2. A line from a planet to the sun sweeps over equal areas in equal intervals of time.
Are all four seasons equally long?

1. Yes.
2. No, summer is the longest; winter is the shortest.
3. No, fall is the longest; spring is the shortest.
4. No, winter is the longest; summer is the shortest.
5. No, spring is the longest; fall is the shortest.
Why is the summer longer than winter?

1. Because of the precession of the Earth’s axis of rotation.
2. Because of the moon’s 5° inclination with respect to the Ecliptic.
3. Because the Earth is rotating around its axis more slowly in the summer (→ longer days!).
4. Because the Earth is closest to the sun in January and most distant from the sun in July.
5. Because the Earth is closest to the sun in July and most distant from the sun in January.
Kepler’s Third Law

3. A planet’s orbital period \( (P) \) squared is proportional to its average distance from the sun \( (a) \) cubed:

\[
P_y^2 = a_{\text{AU}}^3
\]

\( (P_y = \text{period in years}; \ a_{\text{AU}} = \text{distance in AU}) \)

Orbital period \( P \) known → Calculate average distance to the sun, \( a \):

\[
a_{\text{AU}} = P_y^{2/3}
\]

Average distance to the sun, \( a \), known → Calculate orbital period \( P \):

\[
P_y = a_{\text{AU}}^{3/2}
\]
It takes 29.46 years for Saturn to orbit once around the sun. What is its average distance from the sun?

1. 9.54 AU
2. 19.64 AU
3. 29.46 AU
4. 44.31 AU
5. 160.55 AU
Think critically about Kepler’s Laws: Would you categorize his achievements as physics or mathematics?

1. Mathematics
2. Physics
Isaac Newton (1643 - 1727)

- Adding physics interpretations to the mathematical descriptions of astronomy by Copernicus, Galileo and Kepler

**Major achievements:**

1. Invented Calculus as a necessary tool to solve mathematical problems related to motion
2. Discovered the three laws of motion
3. Discovered the universal law of mutual gravitation
Newton’s Laws of Motion (I)

1. A body continues at rest or in uniform motion in a straight line unless acted upon by some net force.

An astronaut floating in space will float forever in a straight line unless some external force is accelerating him/her.
Velocity and Acceleration

Acceleration ($\vec{a}$) is the change of a body’s velocity ($\vec{v}$) with time (t):

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$

Velocity and acceleration are directed quantities (vectors)!
Which of the following involve(s) a (non-zero) acceleration?

1. Increasing the speed of an object.
2. Braking.
3. Uniform motion on a circular path.
4. All of the above.
5. None of the above
Velocity and Acceleration

Acceleration ($\vec{a}$) is the change of a body’s velocity ($\vec{v}$) with time ($t$):

$$\vec{a} = \Delta \vec{v} / \Delta t$$

Velocity and acceleration are directed quantities (vectors)!

Different cases of acceleration:

1. Acceleration in the conventional sense (i.e. increasing speed)
2. Deceleration (i.e. decreasing speed)
3. Change of the direction of motion (e.g., in circular motion)
A ball attached to a string is in a circular motion as shown. Which path will the ball follow if the string breaks at the marked point?

5) Impossible to tell from the given information.
Newton’s Laws of Motion (II)

2. The acceleration $\vec{a}$ of a body is inversely proportional to its mass $m$, directly proportional to the net force $\vec{F}$, and in the same direction as the net force.

$$\vec{a} = \frac{\vec{F}}{m} \Leftrightarrow \vec{F} = m \vec{a}$$
Newton’s Laws of Motion (III)

3. To every action, there is an equal and opposite reaction.

The same force that is accelerating the boy forward, is accelerating the skateboard backward.
The Universal Law of Gravity

• Any two bodies are attracting each other through gravitation, with a force proportional to the product of their masses and inversely proportional to the square of their distance:

\[ F = - G \frac{Mm}{r^2} \]

(G is the Universal constant of gravity.)
According to Newton’s universal law of gravity, the sun is attracting the Earth with a force of $3.6 \times 10^{22}$ N. What is the gravitational force that the Earth exerts on the sun?

1. 0
2. $1.75 \times 10^{18}$ N
3. $3.6 \times 10^{22}$ N
4. $1.95 \times 10^{29}$ N.
5. Depends on the relative speed of the Earth with respect to the sun.