The Copernican Revolution - Separating Science and Superstition

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Outline

Our universe viewed by the ancients

Greek cosmological models

Copernican Revolution

- Nicolaus Copernicus
- Tycho Brahe
- Johannes Kepler
- Galileo Galilei
- Isaac Newton

Science vs Superstition: it never ends

What the Ancients Knew

Mysterious cultures

- People of stonehenge, Plains Indians, Anasazi, Mayans
- ►left behind calendar-like constructions.

Well documented cultures

- Greek, but also Chinese, Babylonian, Egyptian, Arab
- ►left r ecords of lunar cycles, eclipses, comets, novae, star maps, models

Stonehenge

Check out:

http://witcombe.sbc.edu/earthmysteries/EMStonehenge.html

2950 BC – 1600 BC (3 phases)

What the Ancients Knew

Well documented cultures

- Chinese: comet records, zodiac, “year of the ___”

Babylonians: origin of western astrology, observations correlated to events, math

Egyptians: gods like Ra and Osiris, pyramids, Nile flooding

Arabs: upheld astronomy during dark ages, algebra,star names. Semantic distinction between astronomy and astrology – 1000 AD!

►All made astronomical measurements

► All had forms of astrology

Knowledge of the Ancient Greeks I.

Ideas and philosophies were rich and varied, some correct and some incorrect .

Thales of Mellitus (b. 624-547 BC):

universe is rational

predicted eclipse ~585 BC

Pythagoras (570-497 BC):

math inherent in nature

Earth and planets are spherical

Plato (428-347 BC):

Truth through pure thought over observations

Circle is most perfect form

Knowledge of the Ancient Greeks II.

Eudoxes of Cnidus (390-337 BC):

Nested (crystalline) sphere model

Aristotle (384-322 BC):

Earth is unmoving, heavens are perfect

Everything made of 4 elements: earth, water, wind, fire

If Earth rotated, we'd feel a wind

Phases of the Moon

If Earth revolved, the stars should exhibit parallax

Knowledge of the Ancient Greeks (cont.)

Parallax = the apparent motion or shifting of an object caused by the motion or shifting of the observer.

Stellar parallax – apparent motion of foreground stars due to Earth's orbital motion. (Typically <~ 0.1", biggest ~1.0" Proxima Cen.)

Knowledge of the Ancient Greeks III

Eratosthenes' method

Knowledge of the Ancient Greeks III

Philolaus (480-385 BC)

Earth in motion around invisible “fire”

Aristarchus (310-230 BC)

The Earth orbits around the Sun (!)

Eratosthenes (276-195 BC)

Measured circumference of the Earth.

Hipparchus (190-120 BC)

Discovered precession of Earth's spin axis

Uses epicycles, deferents and eccentrics in modelling motion of Sun and Moon.

Invents armillary sphere

Knowledge of the Ancient Greeks (cont.)

Earth's spin axis precesses with 26,000 yr period (Hipparchus 160-127 BC)

Retrograde motion of planets can be modelled with epicycles and deferents (Hipparchus)

Knowledge of the Ancient Greeks IV

Claudius Ptolemy (AD 83-161)

- Geocentric universe model
- Adopts Hipparchus' epicycles to reproduce retrograde motion of planets
- Added equants to better match speeds of planets
- Writings on Optics, Geography, Music
- Astronomy: “Mathematike Syntaxis” = “The Almagest”
- Astrology: “Tetrabiblios” relates horoscopes to Aristotelian philosophy

The Appearance of the Planets

Daily motion

Change brightness, position and angular speed across sky.

All orbit CCW as seen from “North”.

Usually eastward motion, occasional westward motionwe call ...

Planetary Configurations

Inferior planets

- Two conjunctions

Superior planets

- One conjunction
- Opposition

Synodic and Sidereal Periods

Synodic period: time interval between successive conjunctions or oppositions, 1→ 3

Sidereal period: time interval for one complete orbit relative to background stars, 1→2

Epicycles on Deferents

Ptolemy et al. desired uniform circular motions

Ptolemy's Model - complex!

Eccentric - displaces Earth from center

Equant – center of epicycle has uniform angular speed when viewed from this point

Period of planet around epicycle is synodic period.

Period of epicycle center around deferent center is sidereal period.

80+ epicycles

It works pretty well!

Occam's Razor (1348)

Accept the simplest explanation

Ptolemy's Model

Venus and Mercury on invisible "bar"

Speed is still a problem

Copernicus (1473-1543)

Polish Son of copperworker

a mathematician, astronomer, physician, classical scholar, translator, Catholic cleric, jurist, governor, military leader, diplomat and economist

Astronomy is avocation

Publications

On the Revolutions of the Heavenly Spheres (1543)

Little Commentary (1514)

Trigonometry, Narratio Prima (Rheticus)

Prutenic tables (1551)

Reluctant to publish because of fear of criticism, or fear of persecution by church

In 2005, skull recovered in Cathedral of Frauenberg

Copernicus

Is there something simpler? How about the Sun in the Center!!!?
Keep some Aristotelian ideas
    spheres (circles)
    uniform motion
Major Changes
    Earth centered (heliocentric)
    Earth rotates
    Earth is no different from the other planets and stars!
Established order of the planets
Less complicated explanation for retrograde motion

Copernicus

Predictions of existing observations are not better than Ptolemy's!!
Slightly simpler
    No equants
    Fewer epicycles (still a lot)
        If you remove epicycles?
            Copernicus does okay
            Ptolemy's is a disaster
Discriminating predictions not available

Tycho Brahe (1546-1601)

Danish nobleman
Built "Uraniborg" in Hven
Observed supernovae of 1572
Could not detect parallax
Develops Tychonic System
Wore metal nose
Hired Kepler in 1600
Furnished patrons with astrological predictions
Death (bladder or mercury)

Tycho Brahe

Left Kepler with 20 years of meticulous planet measurements.

- 5x better precision
  - 2 arc-minutes (1/30 of a degree) compared to 10 arc-minutes (1/6 of a degree)
  - 20 years of data
- Both Ptolemy and Copernicus's models are wrong!

Johannes Kepler (1571-1630)

Mathematician, astronomer, astrologer

Had religious convictions - *God had created the world according to an intelligible plan that is accessible through the natural light of reason*.

Geometry in nature – tries concentricregular solids for 4 years.

Astrology, numerology

"mother sold drugs"

Johannes Kepler

Supported Copernicus (heliocentric) and Galileo

Copernicus's Model

- Struggles to make it work
- Throws out circles and uniform motion

Tries Sun-focused ellipse idea

- A mistake causes him to put it aside
- It works!!
- Predicts all existing data including Tycho's
- Kepler's 3 laws

Kepler's 1st law

The planets follow elliptical paths with the Sun at one focus.

Kepler's 2nd Law

The planets vary their orbital speed such that they sweep out equal areas in equal

time intervals, as seen from the Sun.

Kepler's 3rd law

$P^2 = a^3$

Period increases with distance from the Sun.

Galileo (1564-1642)

1609 - uses telescope for astronomical observations

He supports Copernicus, Kepler

Experiments & observations refuted Aristotelian physics

- Free-fall, inclined plane, speed of light experiments
- Moons of Jupiter orbit Jupiter!
- Earth not the center!
- Phases of Venus include the gibbous phase!
- Spots on Sun
- Milky Way resolves into stars
- Saturn has ears?

"Father of Modern Physics"

Galileo and Jupiter

The "Galilean Moons": Io, Europa, Ganymede, and Callisto.
How could these moons be used to measure the speed of light?
Ole Roemer 1677

Galileo and Venus

Galileo observed Venus in a gibbous phase.
Which of these two models predict a gibbous phase?

Galileo's troubles

Galileo was more vociferous and brash than Copernicus and Kepler.

1610: Published *Sidereal Nuncius* (Starry Messenger)
1616: Galileo's book judged heretical and banned
1632: Published *Dialogue Concerning the Two Chief Systems*.

Simplicio speaks words of Pope Urban VIII.
Published in Italian

1633: Sentenced to house arrest.

1642: Dies in house arrest.

Isaac Newton (1643- 1727)

English physicist, mathematician, theologian, alchemist

Invents calculus

Urged by Halley to publish "Principia"*Philosophiæ Naturalis Principia Mathematica*

3 laws of motion

Universal law of gravitation

Can explain Kepler's laws!

Finally, we have a reason for the orbits!

"God governs all things and knows all that is or can be done."
Isaac Newton's "Fixes" to Kepler's Laws

Kepler I: The planets orbit in ellipses with the principle focus on the center of mass of the solar system, (not the Sun)

Kepler III: add the total mass of the system to the denominator ...

The Copernican Revolution ... *matching!*

Nicolaus Copernicus

Tycho Brahe

Johannes Kepler

Galileo

Newton

Observed gibbous phase of Venus

Made precision measurements of planets

Used ellipses to model solar system

Said gravity accelerates the planets

Revived the heliocentric model

Figuring out the remaining loose ends of the Solar System

Verification that Earth is in motion

- Ole Roemer's, 1677 - Jupiter Moon delays
- James Bradley, 1728 – aberration of starlight
- Frederick Bessel 1838 – first parallax

What is 1 Astronomical Unit???

- Use timings of Venus during transits across Sun
- Bounce radar off of Venus when near inferior conjunction

Science vs Superstition – it never ends

Other Copernican Revolutions

- Sun not at center of galaxy, or of Local Group, or of Local Supercluster, or of expansion of universe. *Are humans the only intel. life?*

"Crazies" coming out of the woodwork

- There are people at both extremes; pure skepticism and belief.

Each of us has to reconcile facts with beliefs.

See "The Demon-Haunted World: Science As a Candle in the Dark" - C. Sagan