The Copernican Revolution

Nicolaus Copernicus (1473 - 1543)
De Revolutionibus Orbium Coelestium (1543)
["On the Revolutions of the Celestial Spheres"]

The Ptolemaic Cosmology: Geocentric and Geostatic
The Sun, Moon, five planets, and the fixed stars of the Celestial Sphere all rotate about a central unmoving Earth. - **Claudius Ptolemy (c. 140)**

The Copernican Cosmology: Heliocentric and Geodynamic
The planets including the Earth rotate about the Sun which is at the center of the static Celestial Sphere. The Earth has two motions, an annual motion about the Sun and a diurnal rotation about its polar axis. - **Nicolaus Copernicus (1543)**

Other Dramatis Personae:

Aristotle (384 - 322 BCE)
The Classical World View: Aristotelian Physics and the Ptolemaic System

Aristarchus (310 - 230 BCE)
An Earlier Heliocentric and Geodynamic Cosmology.

(Saint) Thomas Aquinas (1224 - 1274)
Aristotle's Physics, Ptolemaic Cosmology, and Religious Doctrine

Observational Cosmology & The Celestial Sphere

The Fixed Stars and the Celestial Sphere

The appearance of the nighttime sky: Stars and Constellations
History: The Celestial Sphere as a physical reality

Time and the the Celestial Sphere

Diurnal (daily) Motions: The Celestial Poles. The Sidereal Day.
Seasonal (annual) changes - The motions of the Sun

Geography and the Celestial Sphere

Geographic latitude and the appearance of the sky
Geographic longitude and celestial phenomena

The Seven *Planetes* or Luminaries

••• Characterized by motions on the Celestial Sphere •••
The **Sun**: Motions and the ecliptic. Seasons and the length of the year.
The **Moon**: Motions and phases. The sidereal and synodic months.
(Solar-Lunar phenomena: Phases, eclipses, and tides)
The **Planets**: Mercury, Venus, Mars, Jupiter, Saturn,....
(Motions, configurations, brightness variations, synodic periods, ...)

... All basic naked-eye astronomy. But how is this to be explained other than by invoking the actions of the gods?

Theoretical Cosmology

"A theory consists of a system of hypotheses, their supporting assumptions or definitions, and their logical consequences or predictions."

Objectives

To construct a model ("hypothesis") which explains the observations
To derive predictions from that model
To use these predictions to test the model through additional observations
To amend, correct, or reject the model as needed

Constraints

The model should explain at least some of the observations
The model must be consistent with all available observations
.....and not just those motivating the model
The model must have some predictive power
(*i.e.*, the hypothesis must be falsifiable)

Desiderata

The hypothesis should be consistent with the "Laws of Nature"
.....whatever they are believed to be.
The number of initial or *ad hoc* assumptions should be small
..... *cf.* "Ockham's Razor"

The Classical World View: Aristotelian Physics

The Nature of Matter

Animate & Inanimate Matter (Plato, 428 - 348 BCE)
Moving and Nonmoving (Not “living” and “non living”)
The Sun, Moon, and planets were animate

The Classical Elements
Earth, Water, Air, Fire, Ether
Compare to: Solid, Liquid, Gas, Plasma, and “Quintessence”
....and the rôle of the ether

The Structure of Matter
Continuous or “Atomic”? (Democritus, 450 - 370 BCE)

The Motions of Matter (Aristotle, 384 - 322 BCE)
Celestial Matter and Mundane Matter
Impetus: The urge to stop
Celestial motions and the Prime Mover: Circular and Uniform Motion

The Nature of Light

Light as Material Particles
Photons and color
Light and heat

The Behavior of Light
Shadows, *etc.* : Light travels in straight lines
Brightness and distance
The Speed of Light: Instantaneous?
Transparent materials and atomism

Religious & Theological Issues

The Meddlesome Gods of Alexandria, Athens, and Rome

Aristotle and the Earth

A Spherical Earth

Elevation and visibility
Sinking ships and departing camels
Geographic latitude and the appearance of the sky
Geographic longitude and the timing and location of celestial events
Lunar eclipses and the Earth's shadow
.....as well as:
Philosophical considerations, and
the distribution of elephants

A Static Earth

Absence of a sense of motion?
Absence of the requisite/expected wind?
The trajectories of falling objects: The lack of impetus.
.....but most significantly:
The absence of an observable stellar parallax

A Geocentric Universe

There must be a center!
There is an attraction to the center ("*gravitas*")
The direction of "down" and the shape of the Earth

The Aristotelean Universe

(c. 300 BCE)

The Sun, Moon, and Planets in uniform circular motion about a static spherical Earth

Quantification: Early Astronomical Measurements

Aristarchus of Samos (310 - 230 BCE)

Geometrical Measurements of the relative distances and sizes of the Sun, Moon, and Earth
(... and a Heliocentric view of the universe)

Eratosthenes of Cyrene (276 - 194 BCE)

Determination of the sizes of the Earth

Hipparchus of Rhodes (190 - 120 BCE)

“Astrometry”, The Astrolabe, Precession, ...

The Ptolemaic Cosmology

***Claudius Ptolemaeus*, a.k.a. Ptolemy** (c. 90 - c.168 CE)
"The Almagest" - "The Great Syntaxis of Astronomy"
Starting Assumptions
A Spherical Earth (Observationally based - Aristotle)
A Static Earth (Aristotelian Physics. The Stellar Parallax)
An Earth-Centered Universe (A "center of attraction")
Uniform and Circular Celestial Motions (Requirements of "perfection")
A Support Structure and a Prime Mover (Aristotelean Physics.)

(The views of **Democritus** and **Aristarchus** have been scornfully discounted.)

Ptolemaic Hypothesis
A configuration of circles and epicyclic motions is constructed to explain:

- **The observed apparent motions of the Sun, Moon, Planets, and the "Fixed Stars" of the Celestial Sphere.**

- **The observed sequence of Lunar phases, Lunar and Solar Eclipses, and the periodic brightness variations of the planets**

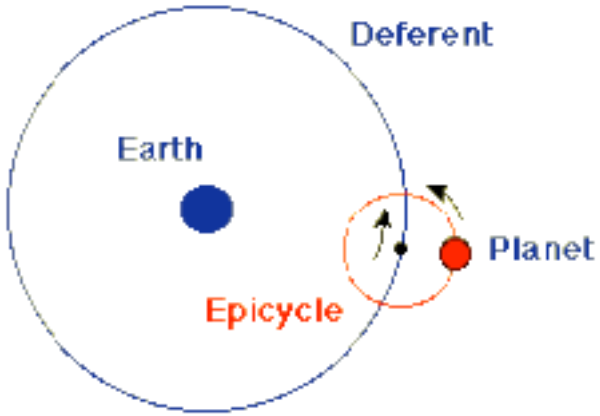
(The resulting "Ptolemaic System" seemed to accomplish all of the above excepting the last item - explaining planetary brightness variations.)

The Geometric Basis of the Ptolemaic Model

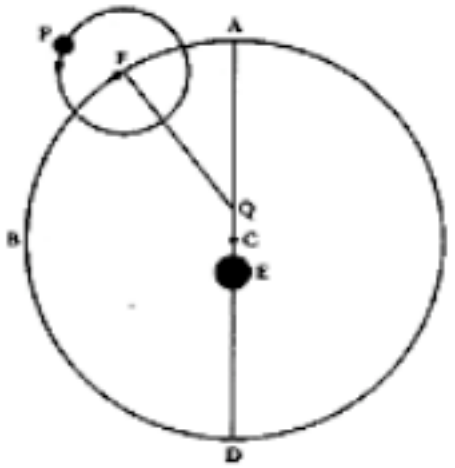
Hipparchus (c. 190 -120 BCE)

Describing the motions of the Sun and Moon
Deferents and Epicycles
(Offsets, Eccentrics, and Equant Points)
Fitting Parameters: Dimensions and Tilts, Periods and Phases

Successes and Failures



Basic Idea



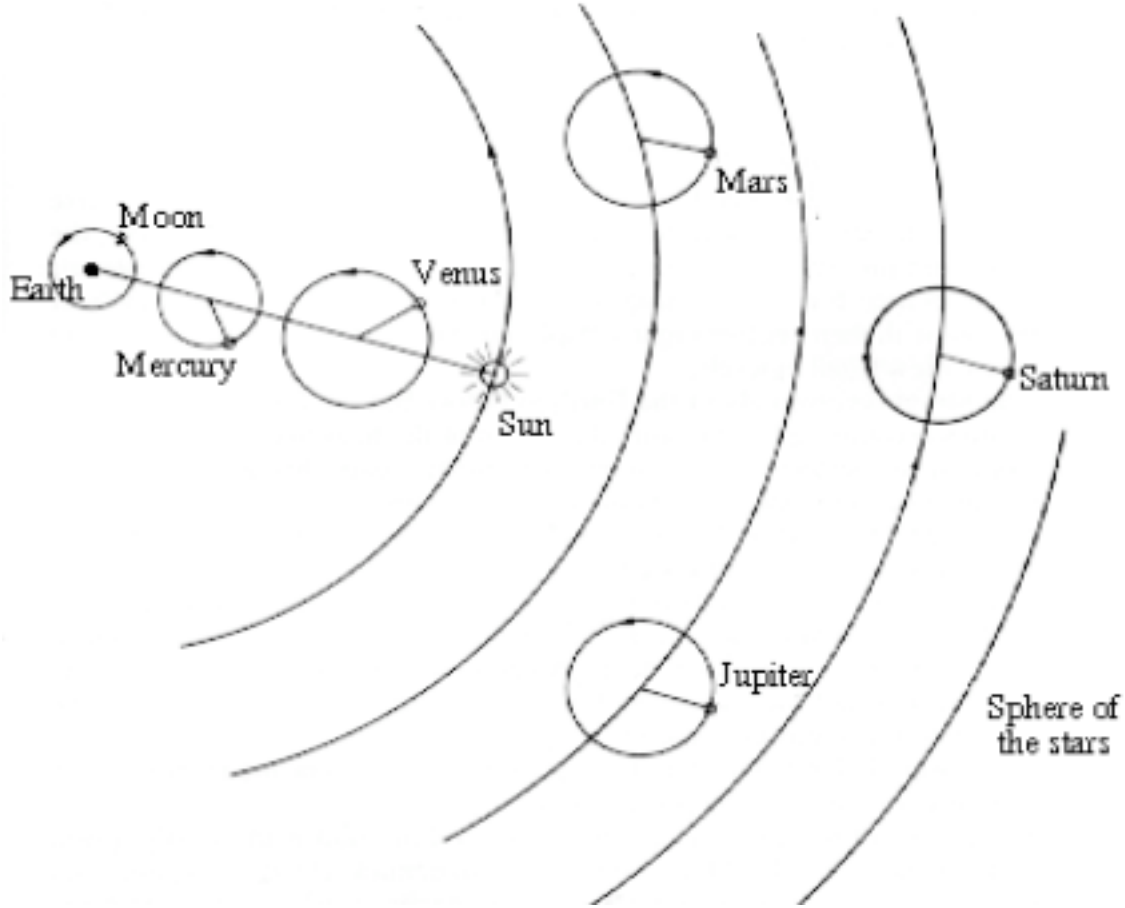
Added Complexities

Digression: Hipparchus' other observations, measurements, and discoveries.
(Star Maps, Stellar magnitudes, Length of the Year, Precession of the Equinoxes, ...)

The Ptolemaic System

"The Almagest"(c. 120 CE)

(Earth, Moon, Inferior & Superior Planets, the Sun, and the Celestial Sphere)



The **Celestial Sphere** rotates clockwise (westward) about the **Earth** with a period of one sidereal day. Motions in the above figure are then counterclockwise with respect to the Celestial Sphere. The Sun's period relative to the fixed stars is the sidereal year.