Chapter 01: The Copernican Revolution

1.1: The Motion of the Planets

Wanderers in the Heavens

Planets Move

- Pattern of background stars appears fixed
- Planets move with respect to this fixed background
- Sun, Moon, Mars, Mercury, Jupiter, Venus, Saturn
- **Prograde**: Observed motion across sky is from west to east
- **Retrograde**: Observed motion is backwards, from E to W

The Geocentric Universe

Aristotle's Model: 350BC

- As simple as it gets: Earth at center, everything orbits the earth on simple circular paths
- Supported by casual naked-eye observations
- Aristotle had sophisticated parallax argument for stationary earth
- Disadvantage: Cannot explain retrograde motion

Aristarchus' Model: 300BC

- Not everybody was buying what Aristotle was selling
- Aristarchus correctly put sun at center, planets (including Earth) in orbits around sun
- Weight of authority: Aristotelian model wins because Aristotle has a stronger reputation and Aristarchus cannot solve the parallax problem

Ptolemy's Model: 140AD

- Refines the Aristotelian model, but keep stationary earth at center
- **Deferent**: Main circle of planet's path around the earth
- **Epicycle**: Smaller circle on top of deferent
- Advantage: Epicycles on deferents can explain retrograde motion
- Disadvantage: Increasingly inelegant, needs a crazy number of tweaks to make it agree with the increasing volume of observational data

The Heliocentric Model of the Solar System

Copernicus: How Not to Stage a Revolution

- Liked the simplicity and elegance of a sun-centered solar system
- Wrote a book about it, but was afraid to publish (with good reason)
- Allowed it to be published as he literally lay dying, but with a preface that essentially denied the contents
- All of Europe yawned...and ignored the book for a good 50 years

1.2: The Birth of Modern Astronomy

Galileo's Historic Observations

Galileo: How Not to Stage A Revolution

- First person to use a telescope to make astronomical observations
- Wrote about what he saw, and what it inevitably implied...in Italian, not Latin
- Writing books filled with heretical ideas in the language of the masses is a serious problem if you happen to live in Italy in the early 17th century

Galileo: What He Saw and What It Meant

- Terrain of the moon: Craters and mountains mean that that the moon is not a perfect, smooth spherical celestial orb
- Sunspots: The sun is rotating, and it is not a perfect, smooth unblemished celestial orb

Notes and Sketches

- Moons of Jupiter: Not everything orbits the earth--these things orbit Jupiter
- Phases of Venus: full cycle of phases means that Venus cannot be in between the earth and the sun all the time

The Ascendancy of the Copernican System

- Everybody did not suddenly agree on the same day: Hey, let's all be Copernicans now!
- Just like anybody else, scientists can be stubborn and reluctant to change their minds (and it took certain powerful institutions until 1983 to determine that Galileo was right after all and probably should not have been condemned for heresy...)
- Consider also the rate of information exchange in the 17th century

1.3: The Laws of Planetary Motion

Brahe's Complex Data

Tycho Brahe: How Not to Stage a Revolution

- The depth of his OCD dazzles the mind: Spent virtually every night of his adult life making astronomical observations
- Made his own instruments (very carefully and very accurately)
- Believed that the planets circled the sun, but the sun circled the stationary earth: sort of a hybrid of geo- and heliocentric models

Kepler's Simple Laws

Johannes Kepler: How Not to Stage a Revolution

- Excellent mathematician, but not much of a physical theoretician
- Inherited Tycho's data, spent 30 years working it over
- Literally thirty years, because he had a fairly dramatic personal life

Kepler's First Law

- Planets orbit the sun
- Orbits are **elliptical** (eccentricity is low)
- Sun at one **focus**, other focus is empty

Kepler's Second Law

- Planets sweep out equal area in equal time
- This means that closer = faster: Orbital speed ≠ constant
- **Perihelion**: When a planet gets closer to the sun, it speeds up
- **Aphelion**: As a planet moves farther away from the sun, it slows down

Kepler's Third Law

- $P^2 = a^3$
- This means that closer = faster
- A planet closer to the sun will complete one orbit in less time than a planet farther from the sun
- The math can actually be pretty easy if you use the right set of units

The Dimensions of the Solar System

Astronomical Unit

- 1 astronomical unit = 1 AU = average distance from Earth to sun
- Kepler #3: Measure distance in AU, measure time in years

How to Measure How Far

- You can take advantage of the fact that speed of light is constant: distance = (speed) · (time)
- Since we know the speed of light, if we can bounce a signal off an object we can find its distance
- Measure how much time passes from sending the signal to receiving the reflection: total time = there and back
- distance = (speed of light) · (½ total time)

Notes and Sketches

Direct vs Indirect Measurement

- You can bounce a signal off the moon or a planet and get a reflection
- You can't bounce a signal off the sun—you would never find the reflection, since the sun is emitting its own light all the time
- To measure from Earth to moon or Earth to a planet: Direct measurement
- To measure from earth to sun requires indirect measurement

1.4 Newton's Laws

The Laws of Motion

Newton #1: Inertia Law

- Inertia = object's resistance to change in motion
- Mass measures inertia: More mass means more inertia
- Object (whatever it is) wants to continue doing what it is doing (at rest or in motion)
- Force is required to change the state of motion of an object

Newton #2: Force Law

- Quantifies Newton #1
- F = ma or a = F/m
- Acceleration = change in motion (speed or direction)
- More force, more acceleration
- Apply the same amount of force: Less mass, more accel (more mass, less accel)

Newton #3: Action-Reaction Law

- For every action, there is an equal and opposite reaction
- Forces come in pairs
- Force pairs act on two different objects (force on ball because of bat, force on bat because of ball)

Gravity

- Every mass is attracted to every other mass in the universe
- Force of gravity is always attractive (pulls masses toward each other)

Inverse Square Law

- Force is inversely proportional to square of distance
- Double the distance, ¼ the force: $(\frac{1}{2})^2 = \frac{1}{4}$ the force
- Half the distance, four times the force: $(1/\frac{1}{2})^2 = (2)^2 = 4$

Orbital Motion

- Orbits are not possible without gravity
- Actually, stars and planets themselves are not possible without gravity
- Actually, it is practically impossible to understand anything about the structure of the universe without getting to grips with gravity

Using Gravity to Weigh Things that Don't Fit on the Bathroom Scale

- You can combine Newton #2 with Newton's law of gravity (we'll skip the math)
- You get a relationship that lets you find the mass of objects whose distance and speed are known through observation

Kepler's Laws Reconsidered

- Newton's Laws explain why objects move
- Kepler's Laws describe how they move
- Newton must be used to refine Kepler
- Rewrite Kepler #3 for more general circumstances

The Circle of Scientific Progress

- Geocentric: Entire Ptolemaic theory must be thrown away
- Heliocentric: Copernican model just needs revision
- Newton: Continually tested, improved understanding and wider application without additional revision

Notes and Sketches