

The “Age of Reason”



The Middle (Dark) Ages

So what happened after the “fall” of Ionia?

- **Alexandria** “took over” until it fell (~ 650 CE?)
- fall of western **Roman Empire** ~ 500 CE, but eastern empire flourished ⇒ **Byzantine Empire**
- breakdown of western society was **dramatic**
- with **no** strong, central gov't, **education declined** as did **trade & interaction**; a “fractured” state
- rise of **dogma** (authoritative beliefs)
- start of **church, monasticism** (important - why?)

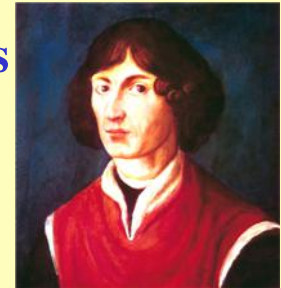
- **Muslims** preserved & enhanced Greek learning
- **Baghdad** became a center of learning ~ 800 CE (eg Al-Mamun's “House of Wisdom”)

- **algebra, decimal system, chess** - some based on Indian ideas! - brought to west by **Islamic scholars**



- **Istanbul** (“... not **Constantinople**”) fell in 1453 to **Ottoman (Turkish) Empire** causing exodus of scholars to west, igniting **Renaissance** (“rebirth”)

Nicolaus Copernicus (1473-1543)



- born & lived in **Poland**
- studied **law, medicine, theology & astronomy**
- ended up as (non-ordained) cathedral “canon”

Q: Why was his background important?

- believed *geocentric model too complex*
- resurrected *Aristarchus' Sun centered (heliocentric) model*
- explained *retrograde motion*
- published *“De revolutionibus orbium celestium”* in 1543 (!)
- book was *supposedly* placed in his hands *on his deathbed*



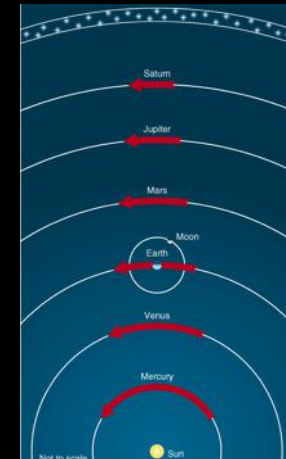
“Conversations with God”



Copernican System



Copernican System



Retrograde explained

Retrograde Motion in the Copernican System

*Q: Why didn't **De Revolutionibus...** cause uproar? (Catholic Church had no official stand for 50+ yrs)*

- lack of *supporting data* (ie. no telescopes, motion)
- **Copernicus** placed **Sun** at the center
- Earth *rotates* & *revolves*, explains *motions in sky*
- stars are *far away, much further than Sun*
- however, his **heliocentric model** retained *circular orbits* & *constant speed* for the planets and as a result, *planetary positions were not much better than those predicted by geocentric model*

Tycho Brahe

(1546 - 1601)

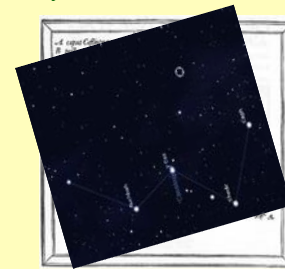
- *wealthy* Danish nobleman
- astrologer; *became* an astronomer
- **exceptional** observer

• **duel** at age 20 (after some drinking) over who was the better mathematician & lost tip of his nose (**prosthetic**)

• built two **observatories** (**Uraniborg, Stjerneborg**) on island of Ven (near Copenhagen)



- viewed a **supernova** in **Cassiopeia** (1572)
- **Stella Nova** - "new star"
- determined it had to be *far* from Earth - *how?*
- studied **comet** of 1577 & determined it moved *beyond the Moon* & some planets

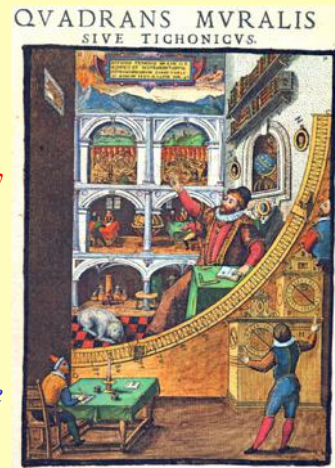


Q: How did this challenge the geocentric model?

- *accurate* measurements of *positions* using a *quadrant*

- collected data on *planetary positions* to an *accuracy of 1 arcminute* for 20 years

Q: Why is Brahe's accuracy so important? How accurate was the geocentric model?



Brahe's Stjerneborg



- lost "funding" in 1597; both observatories were abandoned & eventually destroyed

- relocated to *Prague*
- asked to revise/improve *astronomical tables*
- died following banquet
- likely to have been from *renal failure/uremia*



- hired *Johannes Kepler* but feared *competition...*
- begged *Kepler* upon his deathbed:
"Let me not seem to have lived in vain"
- examination of *Brahe's* hair samples – *mercury?*
- *poisoned* (by *Kepler*)? Or ... *ketoacidosis?*

Johannes Kepler

(1571 - 1630)

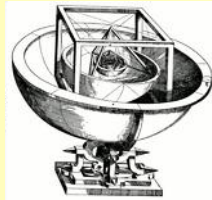


- *German* mathematician, astronomer & astrologer
- assistant during *Brahe's* final years in *Prague*
- *Brahe* was an *observer*; *Kepler* a *theorist*
- sought to merge his *religious convictions* with an *explanation* of the heavens *rooted in physical laws*
- believed in the *Copernican heliocentric model*

(eg) Kepler's theological convictions

- **heliocentric model** “fit” his religious views
- God's geometrical plan joined **physical & spiritual**
- **Sun** (Father), **Celestial Sphere** (Son), **space** (Holy Spirit)

- fit 6 known **planetary orbits** around nested **Platonic solids**
- **Mysterium Cosmographicum (1596)**



- **but...** accuracy was **marginal**
- needed **better data** to **constrain** ideas

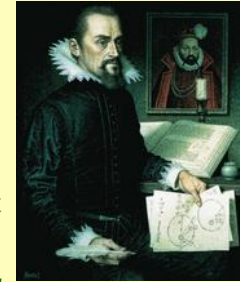
Q: Where could he get **better data**?

- **resented limited** access to **Brahe's data**

- used **Brahe's data** to try to **understand** planetary motion

- **tried** to fit **Mars' orbit** (**lucky!**)

- **after 3 years** found circular orbit that was **close** but still **disagreed** with **Brahe** by **up to 8 arcminutes**



“If I had believed that I could ignore those eight minutes I would have... since it was not permissible, those eight minutes pointed the road to a complete reformation...”

Laws of Planetary Motion

- **11 years** work to derive the **following three laws**:

I. Planets move around Sun in **elliptical** orbits.

II. Planets **change speed** as they move around Sun.

III. **Orbital periods** are **proportional to orbital size**.

- published I & II in **Astronomia Nova (1609)**

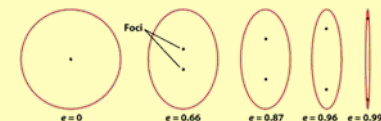
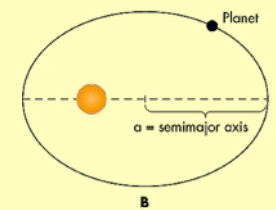
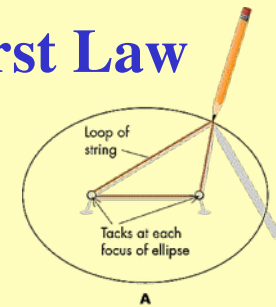
- **empirical**; no “cause” identified, though **Kepler** believed **The Father** (Sun) emitted “**motive power**”

Kepler's First Law

I. Planets move around Sun in **elliptical** orbits.

- **Sun** is at one **focus** (**nothing** at the other)

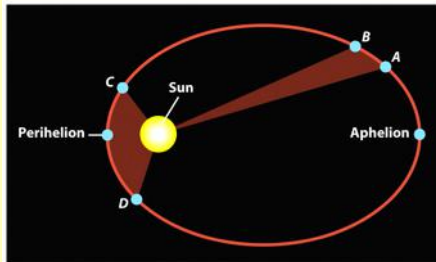
- **most orbits nearly circular** (eg) $e < 0.1$



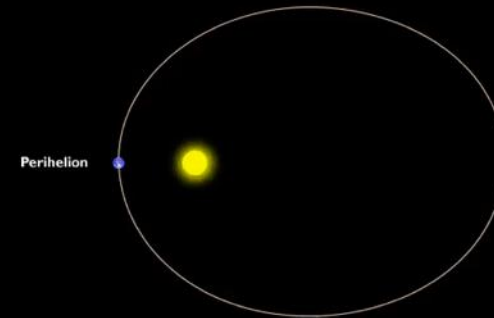
Kepler's Second Law

II. Planets *vary their speed* as they orbit the **Sun**, moving faster when close, slower when far away.

- **Kepler** noted that *a line connecting planet & Sun "sweeps out equal areas in equal times"*



Kepler's 2nd Law



Kepler's Third Law

III. *Orbital periods* are *proportional to orbital size*.

- the *time* for a planet to orbit the Sun (**period, P**) depends on the (average) *radius of its orbit (a)* as

$$P^2 = a^3$$

- **period** is measured in *years* & the *semi-major axis (a)* is measured in **astronomical units (AU)**

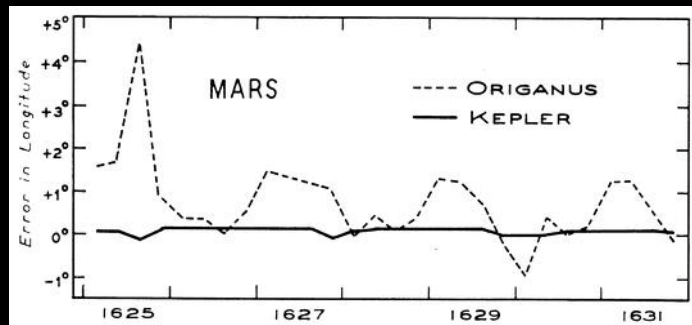
(eg) for **Jupiter** $P \sim 11$ years, so: $P^2 \sim (11)^2 = 121$
Hence, $a^3 = 121$ or $a \sim 5$ AU (**Jupiter** ~ 5 AU away)



CLICKER: For Saturn, $P \approx 30$ years, so a is *roughly*
(a) 5 AU (b) 10 AU (c) 30 AU (d) 1000 AU

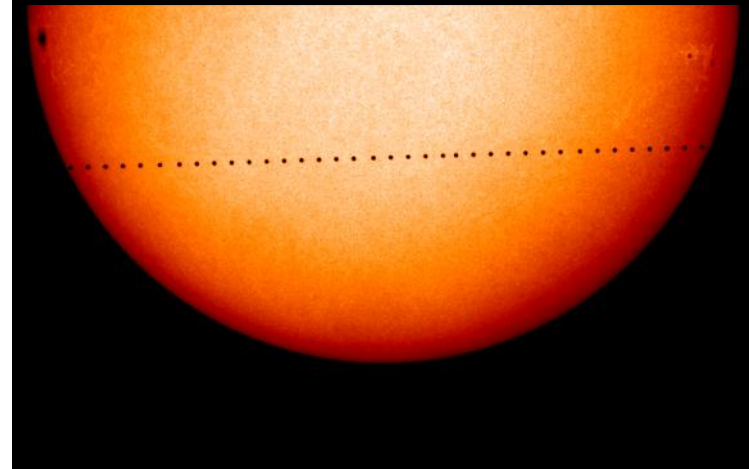
Q: What effect did the 3rd law have on our view of the solar system (universe) & our place in it?

Kepler's improved orbits



- Kepler's elliptical orbits improved the accuracy of the Copernican heliocentric model significantly

Gassendi sees Mercury transit



- **Kepler** published *Epitome Astronomia* (1617-21)
- summarized all of his **elliptical heliocentrism**
- **eventually** became his *most influential work*
- today, **Kepler** is viewed as the first **astrophysicist**

