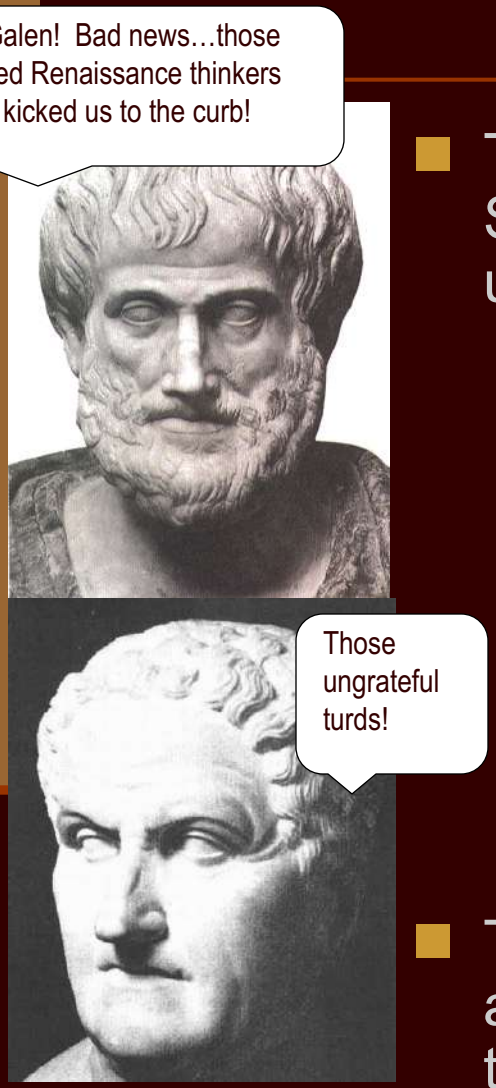
Chapter 16

Toward a New Heaven and a New Earth: The Scientific Revolution and the Emergence of Modern Science

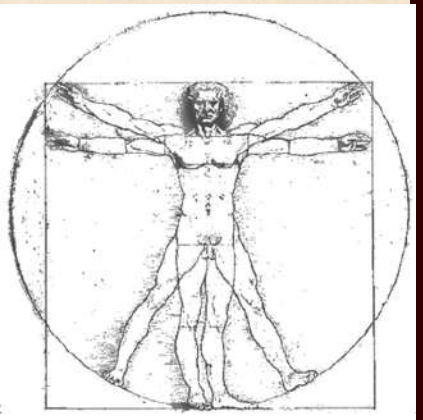
Scientific Revolution: Introduction



- The 16th and 17th centuries witnessed SWEEPING CHANGES in the scientific view of the universe.
  - Earth-centered view of universe gave way to sun-centered view (**geocentric** vs. **heliocentric**)
  - Sun became one of millions of stars
  - **Telescope** and the **microscope** altered perception of humankind's place in the grand scheme
  - Instigated a profound rethinking of moral, religious AND scientific matters
  - Faith and reason had to be reconciled, as did faith and science
- These new ideas and methods of science, known as **natural philosophy**, challenged modes of thinking associated with late medieval times: **scholasticism and Aristotelian philosophy.**

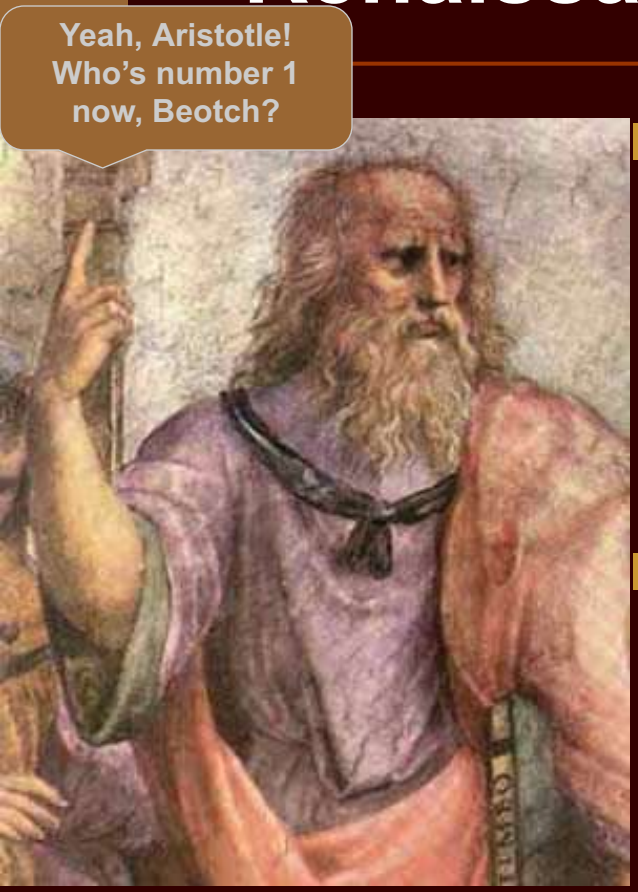
Background to the Scientific Revolution: Medieval and Renaissance Influence

Hey remember me?



- Medieval Science – sparked by plague, early medicine
- Renaissance scholars' **knowledge of Greek**, made additional classical works available –
  - Some suggested a heliocentric model of the universe!
  - Not surprising that the largest advances made were in the areas that the GREEKS dominated in the classical period – astronomy, mechanics, medicine.
- **Not all the classical authorities agreed** – this was discovered in the Renaissance period.
- Rediscovery of **classical mathematicians** and emphasis on **Plato** promoted the idea that math held the key to all the secrets of the universe – Copernicus, Kepler, Galileo and Newton bought into this. Renaissance Humanists – found contradictions of Aristotle and Galen

Background to Scientific Revolution: Renaissance and Reformation



Plato

- Magical element in the Scientific Revolution – the idea of **Renaissance Hermeticism:** world embodied divinity and all humans had a "divine spark" that gave them the power to understand and employ natural power to benefit the world.
- Renaissance artists' impact on scientific study
  - Close Observation of Nature
  - Perspective and Anatomical Proportions
  - **Leonardo**: universal genius but isolated, ideas not transmitted to all
- **Reformation's** challenge to Church/Faith-based "truths" allowed for opportunity to question tradition

Background to Scientific Revolution: Skepticism and Exploration?

I doubt it.

Michel de Montaigne – the best-known skeptic of his day and Pierre Bayle.

- **Skepticism**: belief no certain "truths" could be reached
  - **Montaigne's** *Essays*
  - **Pierre Bayle** (1647-1706); his *Historical and Critical Dictionary:* problem of distinguishing truth from opinion and stressed religious toleration.
- **Exploration:** new medicines, diseases, wealth, foods, products, beliefs, AND people
  - Technological Innovations
  - Knowledge of the variety of human types and human customs and cultures tended to undermine old thought
  - As philosophers viewed human diversity, they gained a sense of the *relative nature of social institutions*
  - Belief in an absolute, God-given set of values become more difficult to justify
  - Jesuit missionaries, the most traveled of educated men, stressed natural goodness and alertness of the peoples they met
  - Others came to praise non-Christian religions for their virtues

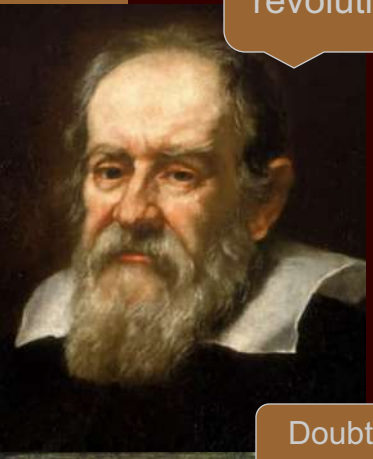
Emphasis on Evidence

- New Sense of Evidence
  - In English law (Bill of Rights, 1689) new rules of evidence were put into use, with less discretion by judges.
  - hearsay evidence was not allowed, and accused were allowed legal counsel.
  - Confessions could not be extracted by torture--and there was a new search into the validity of confessions in general.
  - torture continued to be used in Europe, nonetheless
- Historians began to insist on evidence and turned to greater use of archival sources.
  - The science of authenticating coins, manuscripts, etc. was begun.
  - Others began to rethink the age of the world.

Backlash and Fear?

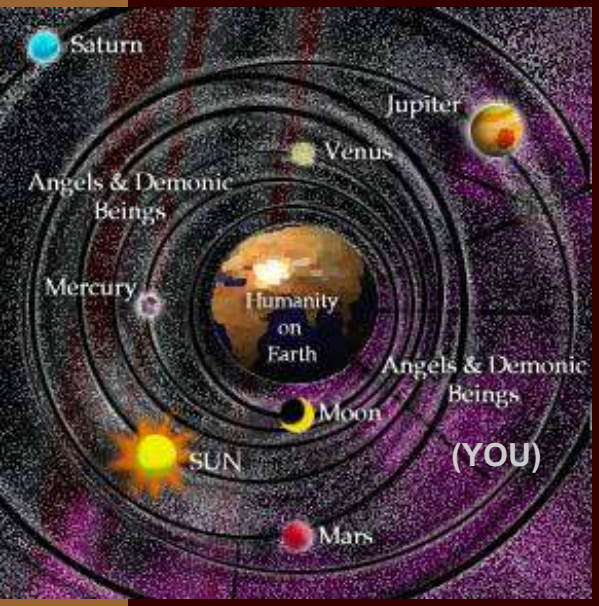
- Changes and challenge to tradition, as well as the "new science," brought a backlash of superstition and persecution
  - rapid political, religious, and scientific changes created fear and anxiety among all sectors of society
  - exploded into Europe's worst **witchhunt.** (witchcraft "craze" of late 16th and early 17th century, *malleus malificarum* in full force)
- **Gullibility** and the tendency toward over-belief still persisted…
  - Lack of dividing lines between chemistry/alchemy, astronomy/astrology
  - Charlatans: Nostradamus and Paracelsus

But…was it a ***Revolution***?



- Not everything associated with the "new" science was necessarily NEW: Many of the 16th and 17th century thinkers were *re*-examining and *re*-thinking theories and data from the ancient world and Middle Ages!
- Term ***revolution*** implies a rapid, collective change
  - It was NOT rapid, nor was it collective.
  - It had many false starts, wrong ideas, and only really involved a few hundred people laboring in crude, isolated labs across Poland, Italy, Bohemia, France and Great Britain.
- In addition, it wasn't just the *scientists* who contributed – artisans and craftspeople helped to construct instruments and execute experiments.
- The term "scientist" didn't even exist until the 1830's, but by the end of the 17th century, new scientific concepts and methods were so impressive that they set the standard for **assessing the validity of knowledge** in the Western world.

Toward a New Heaven: A Revolution in Astronomy



Geocentric Model

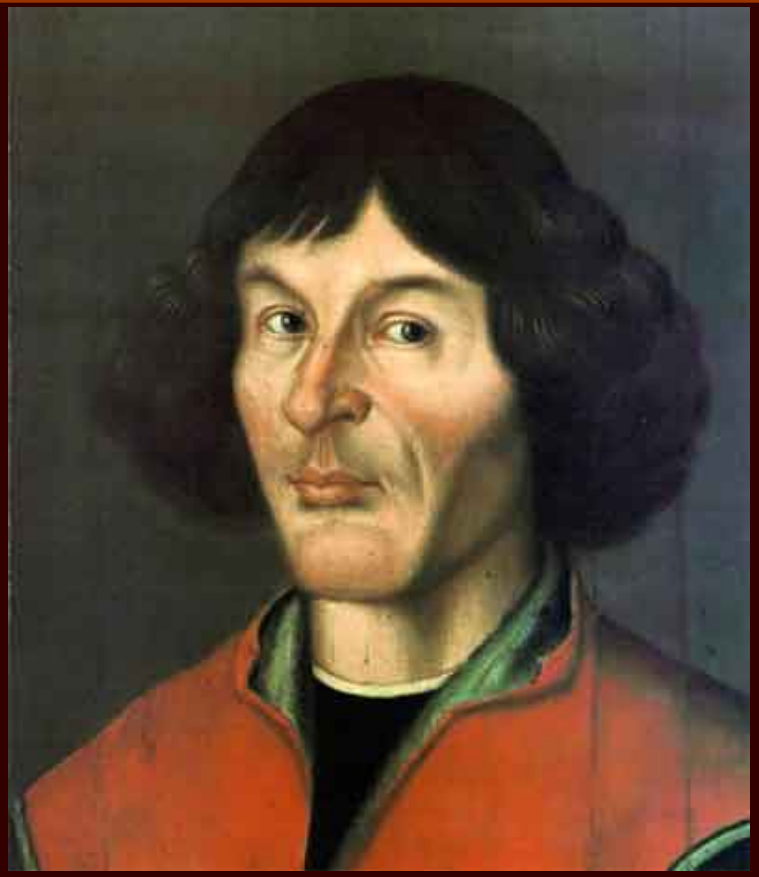
- The medieval model of the universe blends the ides of Aristotle (384-322 BCE), Ptolemy (83-161 CE), Galen and Christian theology.
  - Postulated that the universe was a series of concentric spheres with a motionless earth at the center
  - Earth was imperfect and made of earth, air, fire and water, while the "spheres" – that numbered 10, were "perfect" heavenly bodies made of crystalline "quintessence" that revolved around it
  - The universe was finite
  - Beyond the 10th sphere was the heavens where God and saved souls were.
- The medieval church upheld this view, which seemed to mesh with scripture
  - When astronomers started to discover that their observations couldn't confirm this theory, they tried desperately to make their observations "fit" – however ridiculous these attempts may have been
  - These astronomers were largely CHRISTIANS, and felt torn over their discoveries.

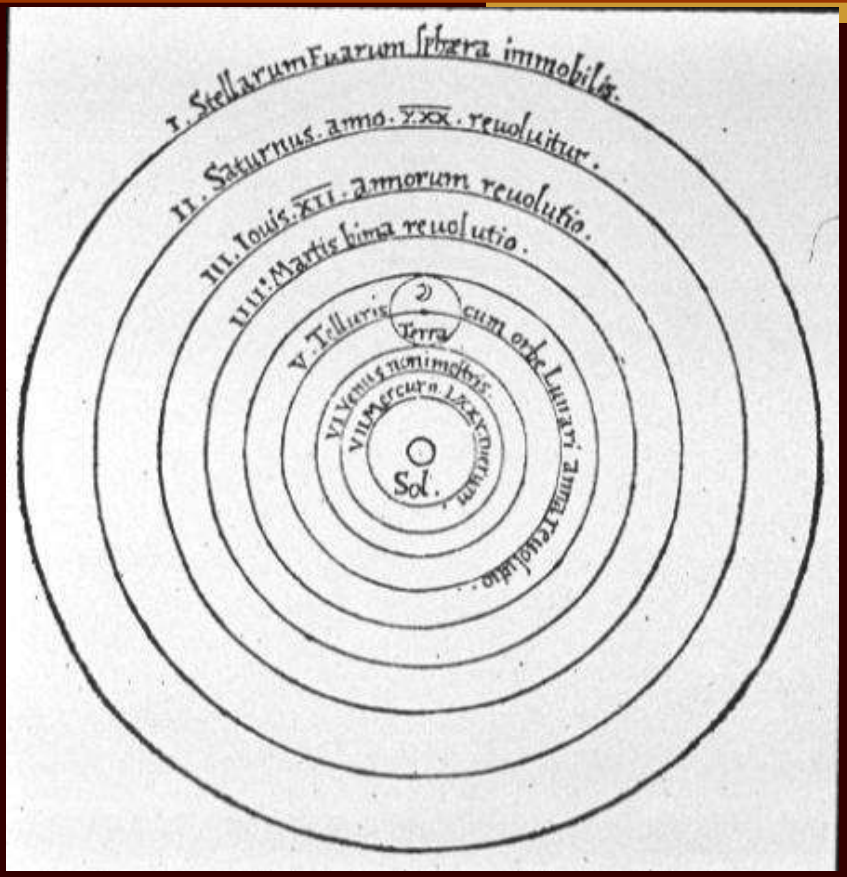
Toward a New Heaven: A Revolution in Astronomy

Copernicus' Heliocentric Theory

- **Nicolaus Copernicus** (1473 – 1543)
- ***On The Revolution of the Heavenly Spheres***
- Published on his death-bed out of fear of the Church!
- Earth and planets revolve around sun!
- Creates doubt about the Ptolemaic system
- Most people had no idea what Copernicus had discovered

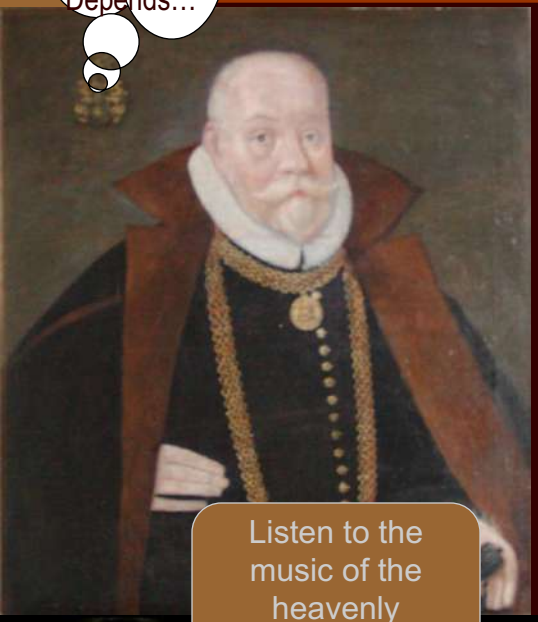
Toward a New Heaven: Copernicus and His Theory





A Revolution in Astronomy Brahe and Kepler

If only if I had just excused myself at that dinner party…or just worn my Depends…

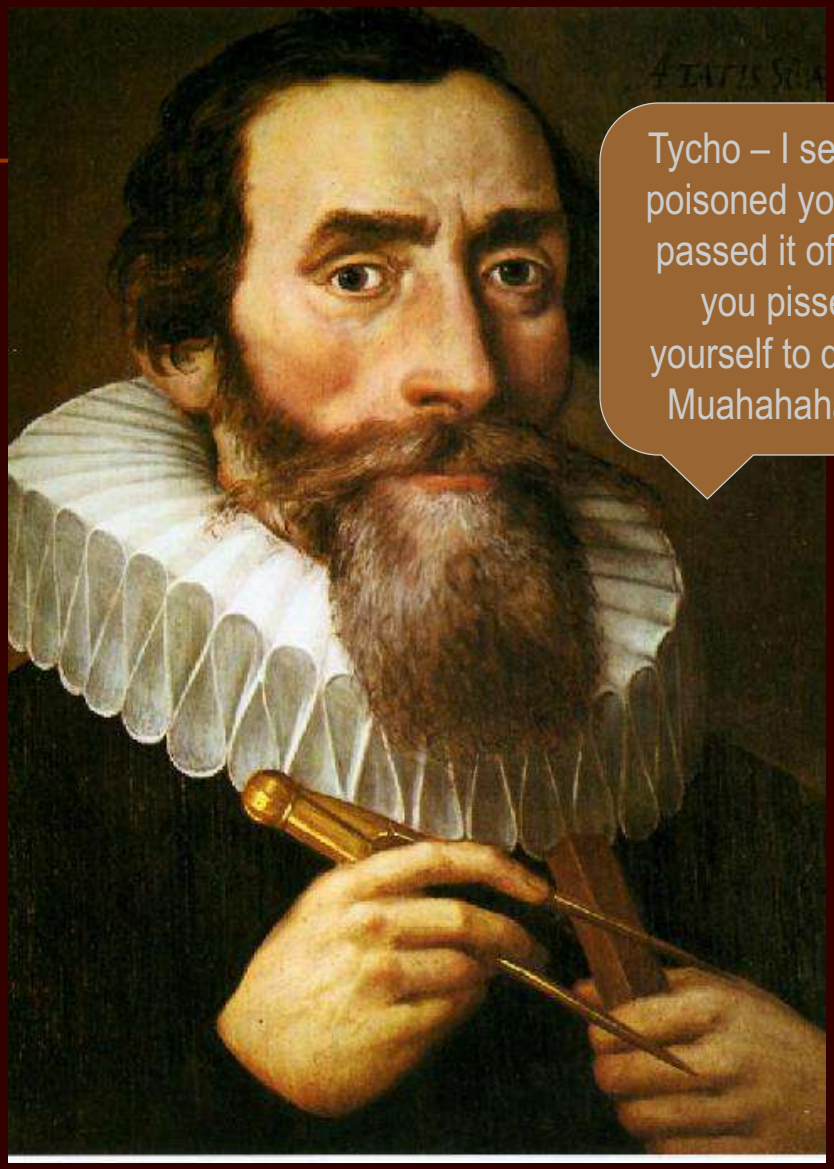


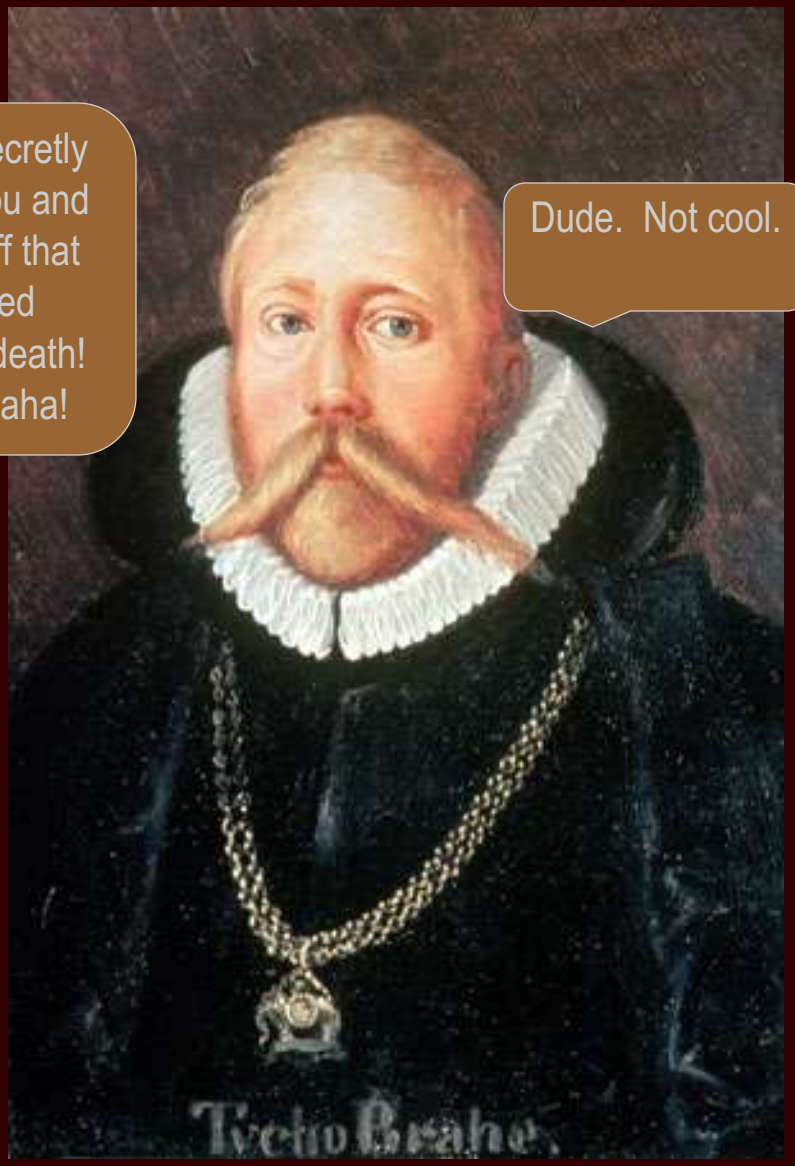
Listen to the music of the heavenly spheres!

Lay off the hallucinogens, Johannes!

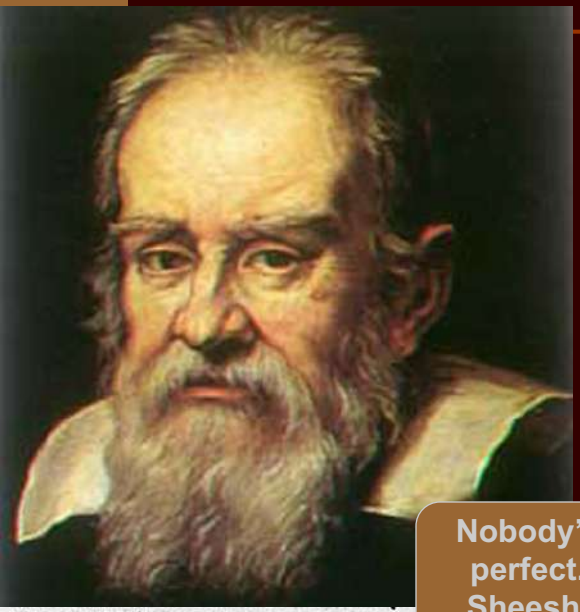
- **Tycho Brahe (1546 – 1601)**
  - Gathered data about the movement of the heavens
  - Remained a devout Christian.
  - Tried to "prove" Copernicus wrong
  - Duel gone wrong – lost bridge of nose at age 20 and had a metal prosthetic!
  - Unfortunate, "explosive" ending of his life, or…was he murdered by Kepler? (mercury)
- **Johannes Kepler (1571 – 1630)**
  - managed to clean up Copernican errors by showing that planets moved in elliptical orbits
  - Developed Laws of Planetary Motion
  - His revised theory was simple, had clear proof in mathematics, and it could be tested by observations.
  - The "real world" did correspond to the purely rational world of mathematical harmony.
  - *Harmony of the Worlds* (1619) and the "Music of the Spheres"
  - Discredits Ptolemaic System

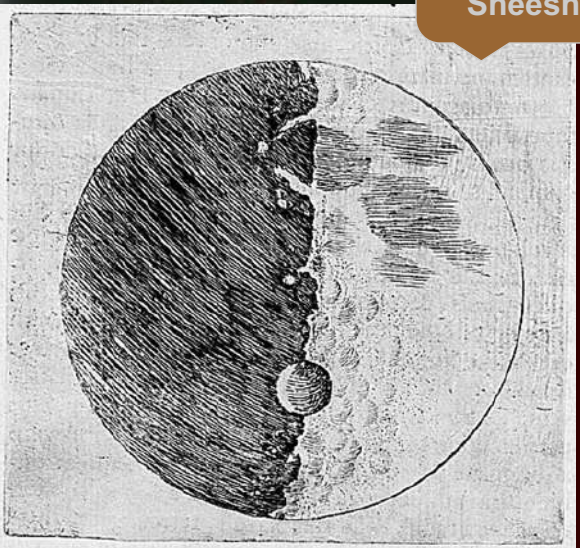
Or…


Tycho – I secretly poisoned you and passed it off that you pissed yourself to death! Muahahahaha!


Dude. Not cool.

A Revolution in Astronomy: Galileo Galilei (1564-1642)

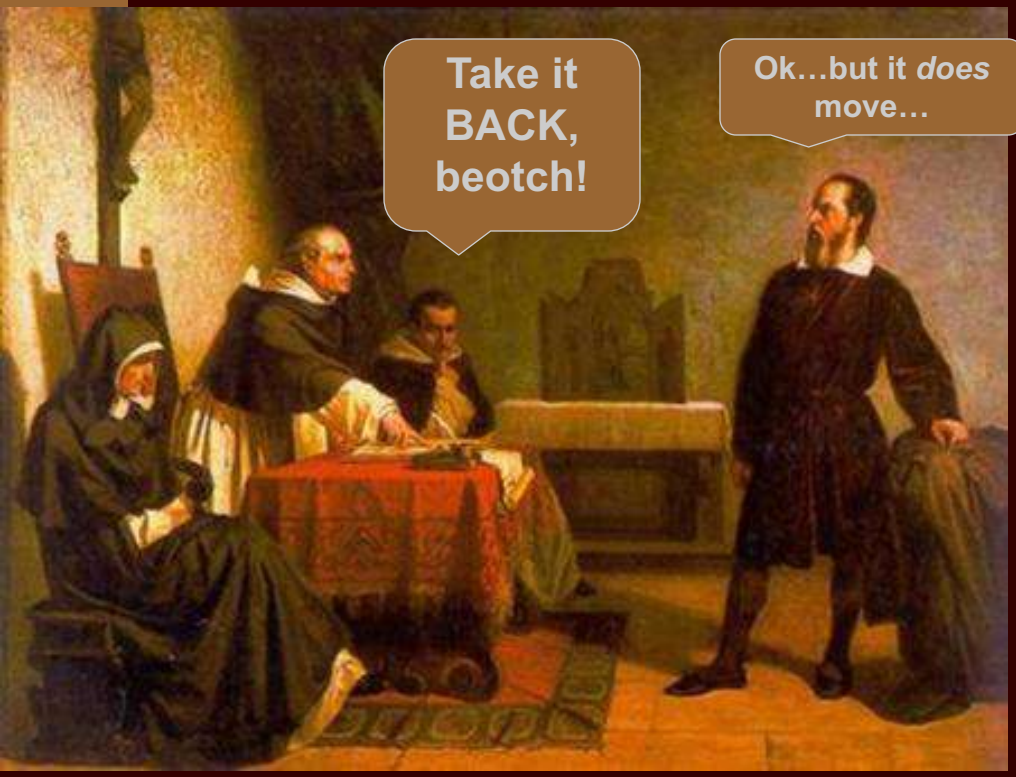




Nobody's perfect. Sheesh.

- **Galileo Galilei (1564 – 1642)**
  - Use of the telescope
  - ***The Starry Messenger*** **(1610)**
  - Scientific leadership passes to England, France and the Netherlands
  - Moon had craters, the sun had spots, Jupiter had moons clearly rotating, and the stars were clearly much further away than had been thought.
  - Uniformity of matter in the universe.
  - Developed mathematical laws of motion on earth--falling bodies, dynamics/inertia.
  - These ideas shattered notions based on Aristotelian logic and long accepted by the Church as the truth.
  - Galileo, fiery and stubborn, was not the one to remain quiet about his findings.

A Revolution in Astronomy: Galileo's *Dialogues* and Trial



The Trial of Galileo

- Though many leading churchmen quietly agreed with Galileo, "Mother Church" condemned the new heresy and banned Galileo's book, ***Dialogue on Two World Systems*** (Simplicio, Sagredo, Salviati)
- When Galileo refused to keep quiet, the Church tried and convicted him, holding him under house arrest until his death.
- The book was published, in Protestant Holland.

Sir Isaac Newton (1642 – 1727)

Nature and nature's laws lay hid in night;
God said "Let Newton be" and all was light.

-A. Pope

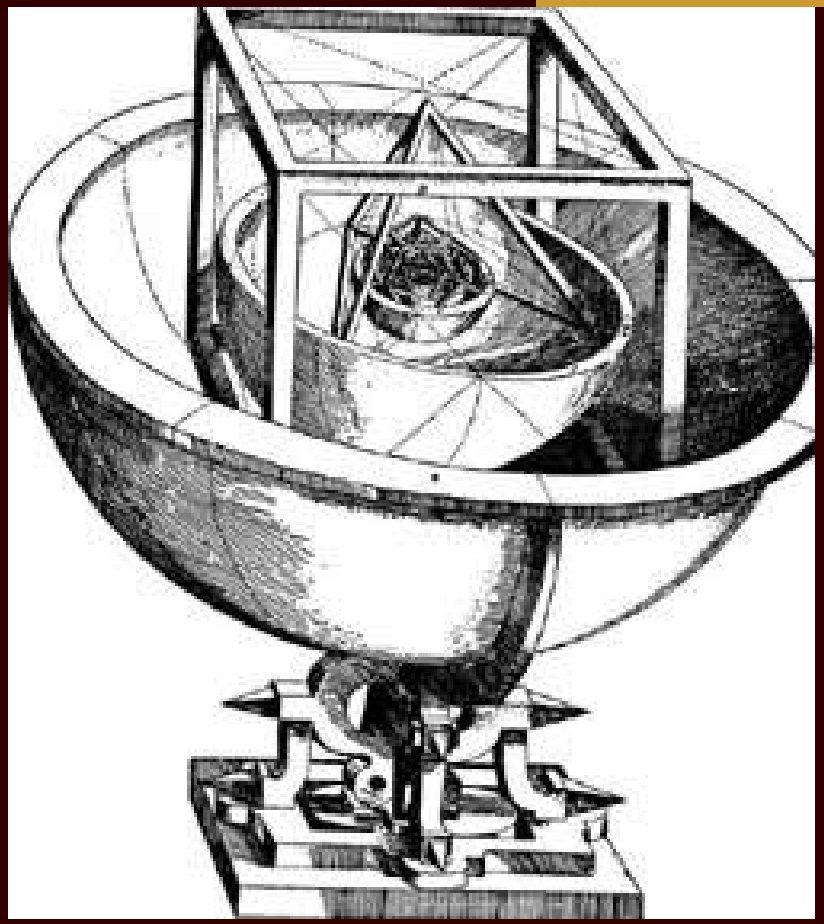
- Brought Kepler and Galileo together by proving why planets tend to fall to the sun and thus moved in elliptical orbits.
- Universal gravitation
- In his *Principia Mathematica: The Mathematical Principles of Natural Philosophy* (1687), presented **three laws of motion.**
- The theory required calculus, new measurements of the earth's size, and experiments with the pendulum.
- World seen in **mechanistic terms**
- Idea of the **"World Machine"** born
- Chair of Mathematics at Cambridge University
- Times were changing – acceptance!

Newton's Impact

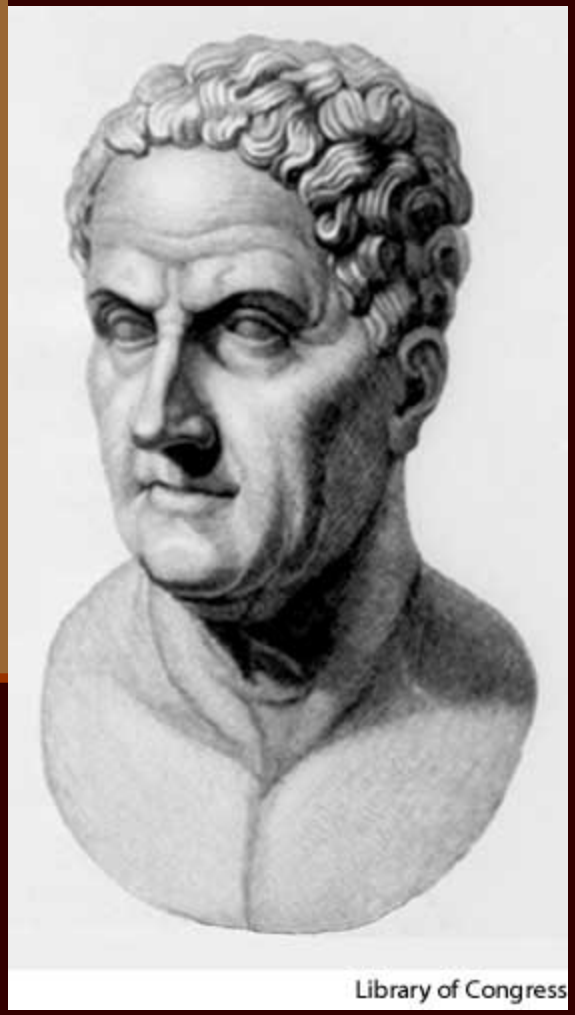
Newton discovers the first "Gay Pride" rainbow.

- Newton's work led to chronometers and the ability to precisely determine longitude; map-making (cartography) became a science.
- Math (and better metallurgy) produced much better artillery
- Artillery meant warfare was more expensive--with advantages to larger nations with more efficient central governments.
- Improve firearms also gave Europeans a major advantage over non-Europeans.
- Steam power also resulted from improvements in science:
  - Scientists, mechanics, and instrument makers combined to produce the steam engine
  - a practical non-scientist, Thomas Newcomen finally put all the pieces together (and getting all the credit, not to mention the cash).

Isaac Newton (1642 – 1727)



Advances in Medicine: Galen's Legacy



- Through the Middle Ages, **Galen** was the authority in medicine.
- Galen relied upon animal dissection to create a picture of human anatomy, and was often inaccurate
- Though humans were dissected in late middle ages, Galen's texts still guided the dissection, so not much changed.
- Galen also governed views on physiology and believed that there were 2 different blood systems.
- **4 humors** theory of Galen's dominated medical treatment, and color of urine determined levels. Bleeding/purging used to treat.

Advances in Medicine: The Legacy of the Four Humors

The Four Humors

Melancholic:
moody
glum
"emo"

Choleric:
irritable
hot-tempered

Sanguine:
happy
healthy
passionate

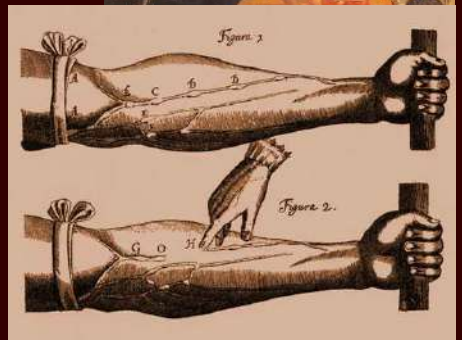
Phlegmatic:
slow
droopy

Advances in Medicine

Medical Practice

Illustrations from the *Livre de Chirurgie* (13th c.) show the physician treating patients suffering from a variety of complaints. Regardless of the horror presented by the injury (note the stake through the leg, center right) or the repulsiveness of the symptoms (diarrhea, top left), the neatly dressed physician is always calm and reassuring. The illustrations are unaccompanied by captions. They are intended to serve as a guide to the information elsewhere in the text and to be explained by someone knowledgeable.

Advances in Medicine – Galen Challenged!



- **Paracelsus (1493 – 1541)**
  - Born Auroleus Phillipus Theostratus Bombastus von Hohenheim (1493-1541) of Zurich
  - Was a cantankerous, pompous physician who offended all in his wake…
  - Did realize that Galen and Aristotle were incorrect – understood that illness was caused by **chemical imbalance**.
  - Early drug treatments using principle that "**like treats like**" rather than Galen's "contraries cure."
  - Sometimes he was correct, sometimes terribly wrong
- **Andreas Vesalius (1514 – 1564)**
  - ***On the Fabric of the Human Body*** (1543)
  - Dissection of a human body
  - Corrects Galen's errors
- **William Harvey (1578 – 1657)**
  - ***On the Motion of the Heart and Blood*** (1628)
  - Circulation of the blood

Women and Modern Science: General Trends

- In Middle Ages, women were discouraged from pursuing scholarly learning – unless they had entered religious orders.
- Traditional roles enforced: daughter, wife, mother.
- Secular humanists of the Renaissance changed this, as elite women had the opportunity to learn classical and Christian texts.
- Many Northern Humanists and Italian Renaissance humanists encouraged women to participate in learning and even pursue a life of scholarship – *but this was an elite few.*
- Women were also attracted to the Scientific Revolution – and had some opportunities b/c in the 17th century, science was not yet monopolized by university system, and was studied informally – so women's exclusion from university didn't really set them back as much.

Women and Modern Science: England

- Women who were noble and had the time could participate informally in scientific networks
- **Margaret Cavendish (1623 – 1673)**
  - Observations upon Experimental Philosophy
  - Grounds of Natural Philosophy
  - Attacked rationalist and empiricist approaches to scientific knowledge
  - Corresponded with many scientists; translated scientific works into English.
  - Was still denied membership in the Royal Society, though she was allowed to attend a meeting.

Women and Modern Science: Germany

- **Less formal tradition rooted in the craft industry opened science to women there.**
- **Between 1650-1710, 14% of all astronomers in Germany were women.**
  - **Maria Sibylla Merian** (1647-1717) **18th century entomologist**
    - Trained in her father's illustration workshop and became a talented sketch artist.
    - She wrote books comprised of illustrations of the phases of insect life
    - ***Wonderful Metamorphosis and Special Nourishment of Caterpillars***
    - ***Metamorphosis of the Insects of Surinam*** which she completed while traveling to the Dutch Colony there.
  - **Maria Winkelmann** (1670-1720)
    - Learned astronomy with her father and uncle
    - Married well-known astronomer Gottfried Kirch.
    - **Winkelmann** became his assistant at the astronomical observatory in Berlin & independently discovered a comet.
    - After his death, she applied for but was denied a post at **the Berlin Academy**, on the grounds that "mouths would gape"

Debate Over the Nature of Women: *Querelles des Femmes*

- Men saw women as inherently base, prone to vice, easily swayed, and sexually insatiable – and in need of control by men
- Women joined the debate, arguing that women also had rational minds and could benefit form education, and since women were pious, chaste, and temperate, they didn't need men's authority over them
- In the end, the *S.R. didn't help women resolve the issue favorably*
- Science was used as a tool to find new "support" for traditional views of women's place in the world
  - Wm. Harvey argued that women only supplied the matter and men the "vivifying force" in the reproductive process
  - Anatomy was used against women too as the womb was touted as the perfect instrument for childbearing and so women should be governed by it
  - Women's pelvises were portrayed as larger and skulls as smaller to "demonstrate" and justify male superiority
- Making medicine more institutionalized in universities and scientific societies hurt women, as midwives were moved out of their roles and men took over the birthing process (less so in lower classes)

A New View of Humankind:
Francis Bacon (1561-1626) and Inductive Reasoning

Bacon the Lawyer: Begin with specific observations and facts and synthesize them to draw broad conclusions, like one would build a court case.

- Bacon wrote *The Great Instauration* where he called for an overhaul of knowledge and science and *Novum Organum*, in which he insisted on inductive reasoning
- Reason from the concrete, particular to the abstract, general
- Rejected traditional ideas and preconceptions
- Favored empiricism, with knowledge to be derived from observation and experience.
  - Experimentation
  - Control and domination of nature
- He also wrote *New Atlantis*, portraying a scientific utopia where there was no break between pure science and technological invention
  - Bacon had no influence on actual science
  - he lacked knowledge of the new work being done in his time
  - he failed to understand the role of mathematics, which involves deductive logic rather than empiricism.

A New View of Humankind:
Descartes (1596 – 1650) and Deductive Reasoning

Descartes the Mathematician: Start with the generalization and from there, draw out the specific parts that justify it, like a mathematical proof.

- *Discourse on Method* (1637)
- "I think, therefore I am."
- God exists because man (imperfect) could conceive of perfection, it could only have come from a perfect being (God)
- **Cartesian Dualism**
  - Universe contains 2 things God created: "thinking substance" and everything else in the world except it – matter.
  - Matter can be understood as it is subject to physical laws.
  - Mind and body separate entities then!
- Father of modern rationalism and deductive reasoning

The Scientific Societies: Background

Commemorating Charles II and the founding of the English Royal Society

- During the 17th century, greater emphasis was placed on scientific learning and many changes facilitated the discovery and spread of scientific knowledge.
- Many secular leaders appointed scientists to their courts or even built laboratories for them.
- Scientific societies sanctioned by the state emerged, as well as their publications/journals to spread the new learning.
- Eventually, many states realized that science and the technology that resulted from it could be harnessed to bolster the state's position and power

The Scientific Societies: Development

- **Academy of Experiments (1657)**
  - founded by Galileo's pupils in Florence through Medici patronage
  - Lab closed down when Medici withdrew funding in 1667.
- **English Royal Society (1662)**
  - Informal meetings at London and Oxford
  - Given formal charter in 1662 by Charles II, but received little encouragement from government
  - Published the journal ***Philosophical Transactions*** beginning in 1665 for scientists to share their work
- **English Royal Observatory (1675) founded in Greenwich**
- **French Academie des Sciences (1666)**
  - Informal meetings in Paris
  - Formally recognized by Louis XIV (1666) and received a great deal of royal support AND control
  - Published the ***Journal des Savants*** starting in 1665, that printed results of experiments for scientists and educated laypeople alike
- **Berlin Academy of Science (1700)**
  - created by the King Frederick I of Brandenburg-Prussia
  - Devoted to betterment of the state
- **St. Petersburg Academy of Sciences (1725) founded by Peter the Great**

Science and Religion in 17th century: General Trends

- Church had enjoyed having final say in all matters, including natural philosophy
- When S.R. hit, many scientists doubted the church's position on these matters
- While Galileo tried to keep matters separate, the Church's decision to silence him seemed to forever pit science against religion
- As science gained more ground, religion suffered, and Europe became more secularized.
- Attempts to ease the antagonism between religion and science ultimately failed.
- People did not leave the church over this
- Gap between Christianity and science widened significantly at this time
- Many scientists were religious and found this split to be tragic
- Some attempted to comment on the implications of this…

Science and Religion: Blaise Pascal (1623 – 1662)

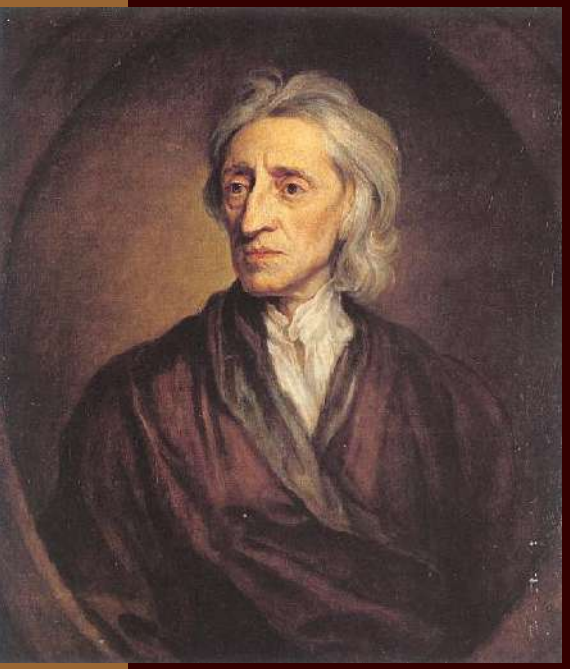
- Sought to keep science and religion united
- Mystical vision (1654)
- ***Pensées*** (Thoughts)
- Sought to convert rationalists to Christianity
- Christianity not contrary to reason
- Reason had limits!

Benedict (Baruch) Spinoza (1632-1677)

Spinoza rockin' the Jewfro!

- Disagreed with Descartes that God was separate from matter.
- God didn't just create the universe, he WAS the universe.
  - This theory is called **pantheism** or **monism**.
  - Wrote ***Ethics Demonstrated in the Geometrical Manner*** to explain his theory.
  - God is no longer the transcendent creator of the universe who rules it via providence, but Nature itself, understood as an infinite, necessary, and fully deterministic system of which humans are a part.
  - Humans find happiness only through a rational understanding of this system and their place within it.
  - believed one should live his life based on a stern, pure ethical code.
  - Scarcely read because of his "impiety," his ideas spread slowly.

John Locke (1632-1704) on Religion



- More reassuring, and thus more widely read than Spinoza.
- He favored an established church, but called for toleration for all but Catholics (seen as adherents of a foreign power) and atheists (lacking a basis of moral responsibility).
- His ***Essay Concerning the Human Understanding*** (1690) stated that all knowledge is derived from sensate experience, since the mind at birth is a ***tabula rasa***.
- He believed the environment was all-important; all crime, false ideas, and superstitions came from bad environment
- His ideas became the basis of confidence in the possibility of social progress, with government playing the key role.

Political Theory: The School of Natural Law

- Political theory is practical, for it deals with what IS rather than what OUGHT to be.
- Machiavelli began by ignoring the scholastic notion of what is the “best” form of government to examine how rulers actually behaved.
  - rulers worked on one principle: what advanced their power
  - no concern for morality.
- The seventeenth century returned to the classical notion of **natural law**.

Political Theory: The School of Natural Law

- **Natural Law** – a universal "right" and "wrong" exist *naturally*
  - No king can make right that which is wrong.
  - No people, by its will as a people, can make just that which is unjust.
  - Right and law, in the ultimate sense, exist outside and above all peoples.
- Man is rational and can discover natural--or universal--law by his reason.
- Ironically, both **absolutism** and **constitutionalism** have been justified by reference to natural law.

Political Theory: Thomas Hobbes (1588-1679)

- Disliked the disorder and violence of civil war (lived through Wars of Religion)
- He concluded that man "in a state of nature" lacked even the rudimentary ability for self-rule
  - Man was quarrelsome, vicious, and brutal
  - Life was "solitary, poor, nasty, brutish, and short."
- Out of fear, men made a contract
  - A ruler was given *absolute* power to enable a maintenance of order.
  - Absolutism was to produce civil peace, individual security, and the rule of law.
  - Absolute power existed to promote the individual welfare--not as a means to a totalitarian state.
- ***Leviathan (1651)***
  - social contract allowed for absolute rule
  - Rebellion vs. social contract forbidden!

Political Theory: John Locke (1632-1704)

- **Agreed that government was a contract, *but* man was inherently good, only hindered by lack of public authority.**
- **Man had inalienable rights--life, liberty, and property.**
- **By his own power he could not protect his rights, so he set up a government to enforce the rights of all.**
- **The contract has mutual obligations - if the ruler violates them, he people have the right of rebellion.**
- **Locke took a specifically English event (the Glorious Revolution) and gave it universal meaning, influencing many later thinkers.**
- **He carried over ideas that were basically medieval, but in a specifically secular way.**
- ***Two Treatises on Government* (1689)**
  - **Book 1:** no government can be justified by an appeal to the divine right of kings.
  - **Book 2**: all men are created equal in the state of nature by God. The only legitimate governments are those which have the consent of the people. Thus, any government that rules without the consent of the people can be overthrown

Summary

- The scientific revolution forever changed Europeans' view of the universe and their place in it.
- The Ptolemaic-Aristotelian world of the MA was overturned and the heliocentric dominated
- Descartes and Bacon led all to believe reason could be the solitary tool needed to understand nature
- A rift between church and science grew
- The earth – with its albeit diminished role in the universe – was governed by natural laws that could be understood with reason
- People recognized science's rational superiority
- Science offered new ways to exploit resources for profit
- This would lead into the Enlightenment…

Discussion Questions

- How did the Middle Ages and the Renaissance contribute to the Scientific Revolution?
- Why were advances in Mathematics so important during the Scientific Revolution?
- Why did religious leaders react so negatively to the new advances in Science, especially in astronomy?
- Why is Newton's Principia called the "hinge point of modern scientific thought?
- How did women come to play such an important role in the Scientific Revolution?
- How did Pascal try to "keep science and religion united?" Why?

Web Links

- The Scientific Revolution Homepage
- The Alchemy Website
- The Galileo Project
- Internet History of Science Sourcebook
- Luther and Science
- Historical Anatomies on the Web