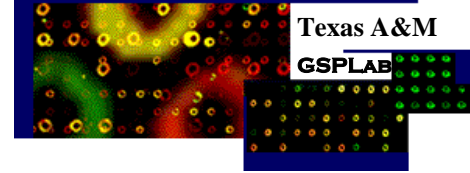


The Roots of Modern Science From Plato to Newton

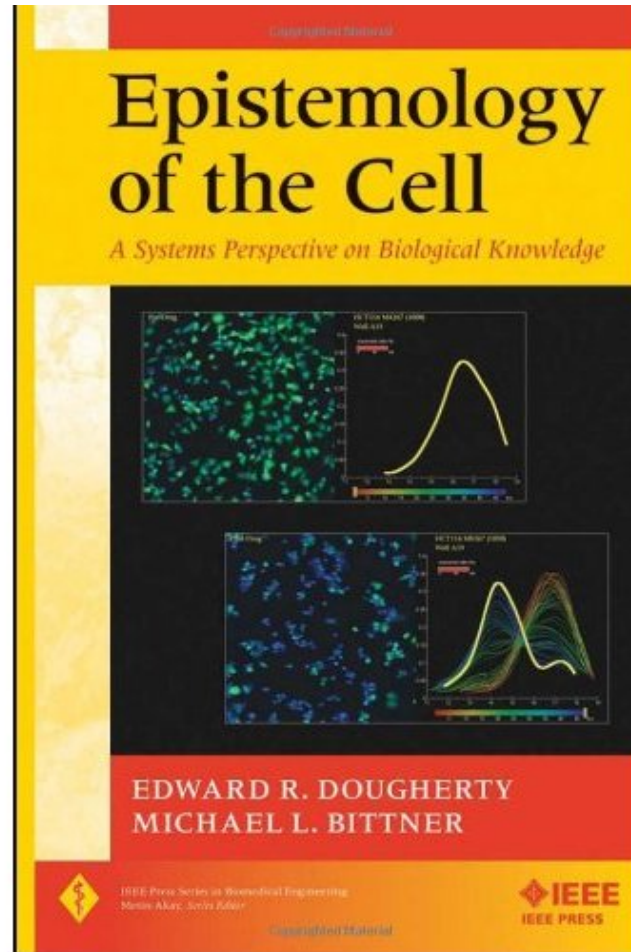
Ivan Ivanov

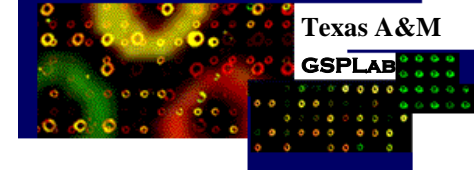
*Department of Veterinary Physiology and Pharmacology,
Genomic Signal Processing Lab,
Intercollegiate Faculty of Toxicology,
Institute for Applied Mathematics and Computational Science
Texas A&M University*

With Permission From My Mentor and Friend: Edward R. Dougherty
Department of Electrical and Computer Engineering
Center for Bioinformatics and Genomic Systems Engineering
Texas A&M University



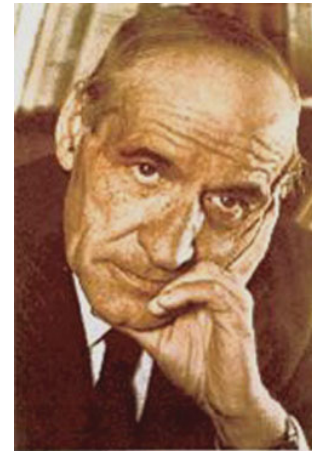
Book and The Context of Discussion

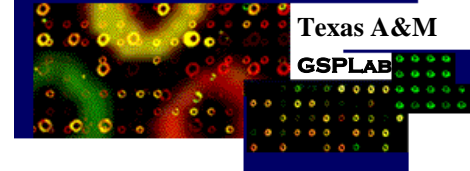




Rules of the Game

- **Jose Ortega y Gasset:** “Whoever wishes to have ideas must first prepare himself to desire truth and to accept the rules of the game imposed by it. It is no use speaking of ideas when there is no acceptance of a higher authority to regulate them, a series of standards which it is possible to appeal in a discussion.”
 - The foundations of a discipline lie in the rules of its game, without which there is no discipline.
 - For a science, its deepest foundations lie in scientific epistemology.
 - Above that they lie in its mathematical formulation of knowledge, experimental methods, and statistical characterization of validity.

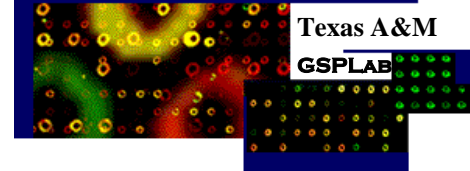




What is Epistemology

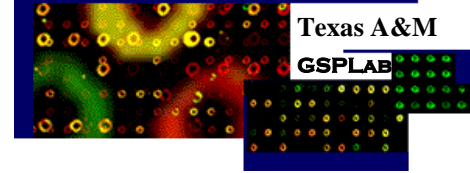
- **Wilhelm Windelband:** “The problems, finally, which arise from the questions concerning the range and limit of man’s knowing faculty and its relation to the reality to be known form the subject-matter of epistemology or theory of knowledge.”
 - Range [nature] of scientific knowledge
 - Limits of scientific knowledge
 - Relation of scientific knowledge to reality





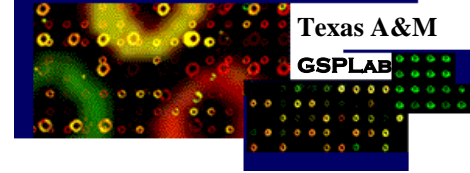
Nature, Limits, and Relation

- The nature of scientific knowledge is determined by its manner of representation and its criteria for truth.
- The limitations of scientific knowledge are determined by the limits of its form of representation and the degree to which its criteria of truth can be applied.
- The relation of scientific knowledge to reality is determined by the manner in which its representation is connected to physical phenomena and the relation between scientific truth and physical phenomena – and the relation between the phenomena and Nature.



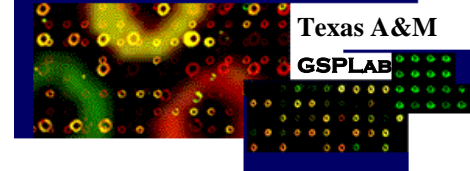
The Epistemological Problem in Biology

- Systems biology, and genomics in particular, raises the epistemological problem.
 - The role played by stochastic nonlinear dynamical systems precludes an uncritical reductionist realism.
- Genomics eliminates the possibility of an uncritical understanding, as did the “New Science” of Galileo/Newton and the relativity/quantum theories.
- Genomics must depend on a mathematical-experimental duality.
 - *A posteriori* reasoning cannot be trusted.



Experiment Dictates Epistemology

- Experiments yield measurements.
 - Quantitative or logical
- Scientific knowledge concerns relations among measurements, implying a mathematical model.
- Criteria of validity are required: the model is valid relative to the criteria and to the extent that it satisfies the criteria.
- The primary role of epistemology is to formalize these conditions.

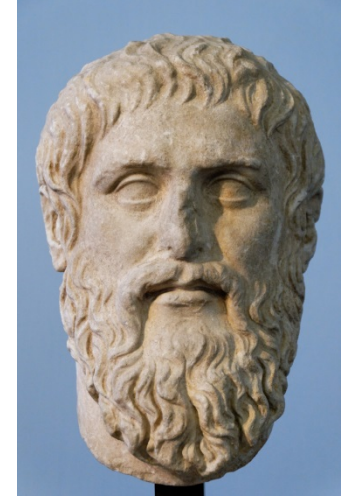
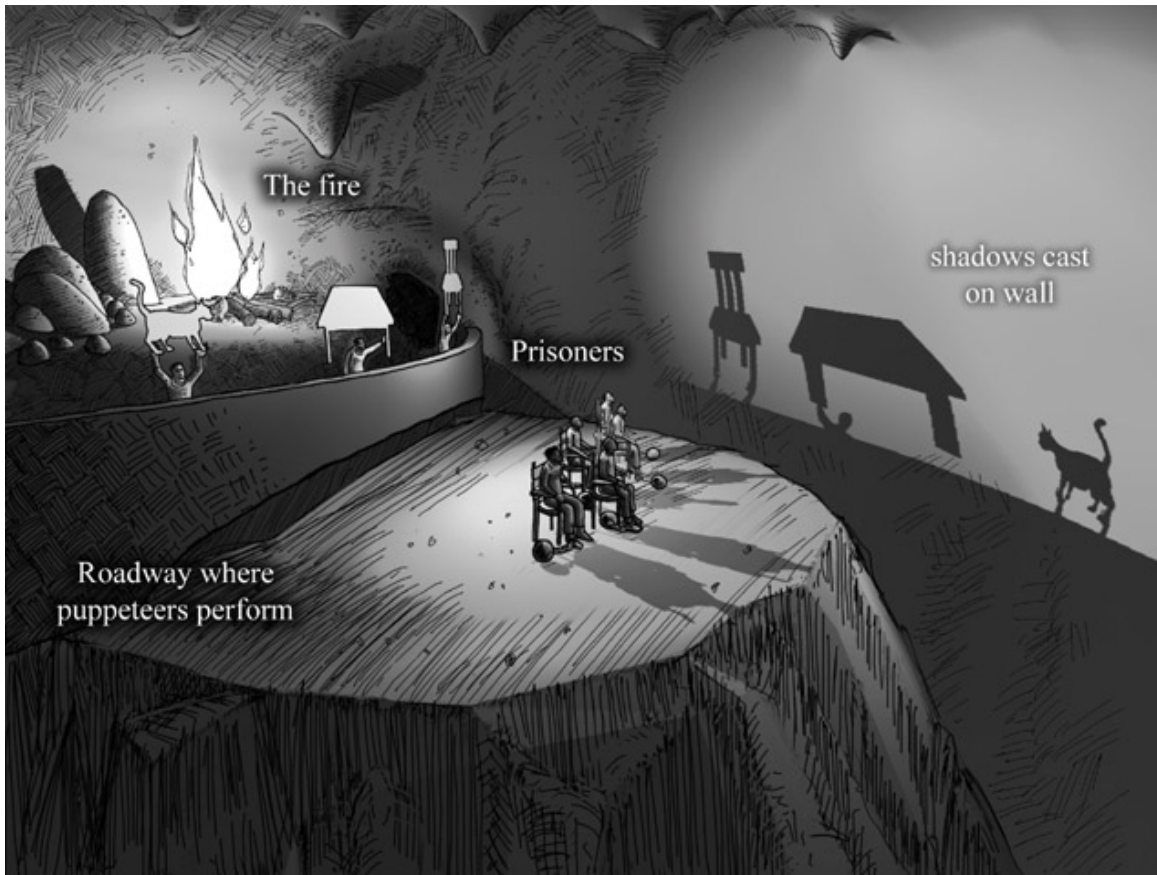


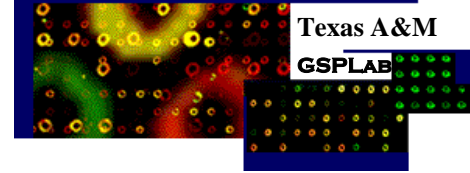
Everyday Versus Scientific Thinking

- Everyday categories of thought:
 - Informal in their meaning and criteria for truthfulness
 - Subjective
 - Naïve belief in the intelligibility of the “real world”
- Scientific categories of thought:
 - Formal in their meaning and criteria for truthfulness
 - Inter-subjective
 - Do not assume the intelligibility of the “real world”

Plato: *Allegory of the Cave*

- Plato (*The Republic*, 428 BC - 348 BC)



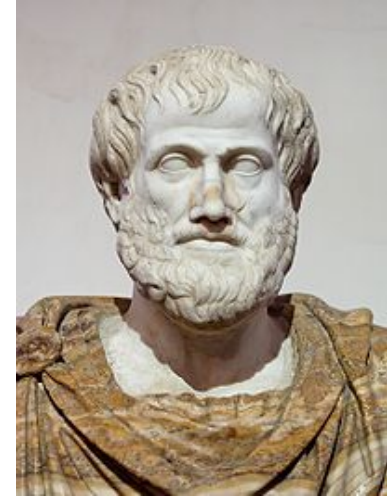


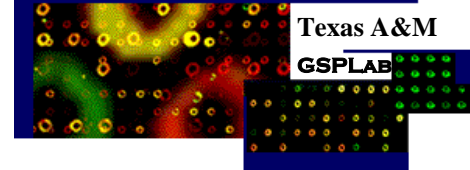
Plato: True Knowledge Concerns *Forms*

- We see only the ephemeral shadows of sensibility that are reflections of a deeper, permanent reality.
 - Empirical knowledge is shadow knowledge.
- True knowledge concerns the *forms* that constitute that deeper reality. These can only be reached by reason.
- Mathematical knowledge is true knowledge.
 - A triangle is a form that has permanence.
 - A physical instance of a triangle is only a crude shadow of a mathematical triangle.
- Like mathematics, metaphysical knowledge is not transient and concerns the truly real, not shadows.
 - Where does this leave scientific knowledge?

Aristotle (“The Philosopher”)

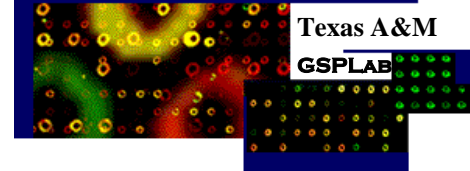
- **Aristotle (384 BC – 322 BC):** Analyzes the process and technique of reasoning.
 - What is reason?
 - What is the domain of reason?
- *Organon*: logical treatise
 - Major logic text for 2000 years
- Focus on definitions
 - Class of an object
 - Differences between objects in a class
- 10 categories of understanding
 - Substance, quality, quantity, relation,...





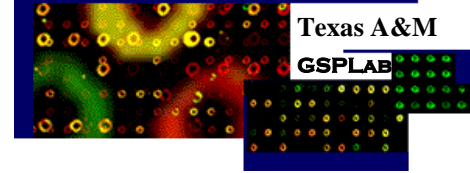
Some Basics of Aristotle

- Senses are the only source of knowledge.
 - Observation is necessary for science
 - No concept of model-based designed experiment
- Universals are concepts (general ideas).
 - Only individual objects exist in the material world.
- Basic axiom of logic is the principle of contradiction.
- Logical arguments are based on syllogisms.
- Major scientific work is in biology – classification.
 - Strongly empirical, as opposed to Plato
 - Somewhat paradoxical given his emphasis on causality as the ground of knowledge



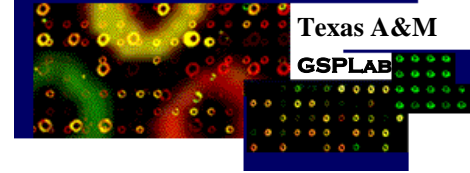
Aristotle on Causality and Understanding

- **Aristotle** (*Physics*): “Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the ‘why’ of it (which is to grasp its primary cause).”
- Four causes:
 - Material: “that out of which a thing comes to be and persists”
 - Formal: “the form or the archetype, the statement of its essence”
 - Efficient: “the primary source of the change or coming to rest”
 - Final: “the end, or that for the sake of which a thing is done”
- God is the first cause, uncaused; He is the prime mover (after which all movement is imparted).



Three Pillars of Aristotelian Science

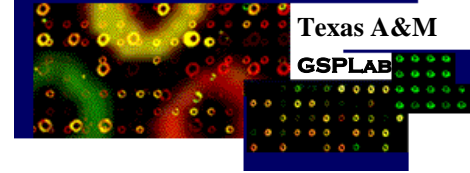
- Three points are basic to Aristotle's epistemology:
 - To know is to explain.
 - Explanation must involve a causal relation.
 - There is no demarcation between physics and metaphysics – the same categories being stated in the *Physics* and the *Metaphysics*.
- Much of the struggle to advance scientific epistemology has been to break down these three pillars.



Metaphysics Versus Science

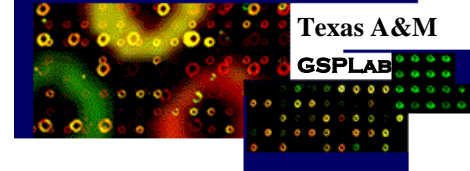
- **Wilhelm Windelband:** “The general questions which concern the actual taken as a whole are distinguished from those which deal with single provisions of the actual. The former, viz. the highest principles for explaining the universe, and the general view of the universe based on these principles, form the problems of *metaphysics*... The special provisions of the actual are Nature and History.”





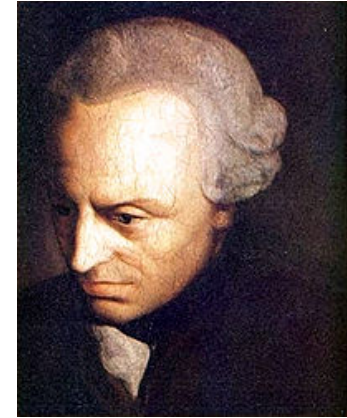
Metaphysics Concerns a Deeper Reality

- Metaphysics: grand issues that concern explaining the universe as a whole.
 - Metaphysical explanations go beyond individual conditions (provisions) within the world to a universality encompassing all individual conditions, not simply as a collection of conditions, but integrated within the context of the whole.
- Metaphysics does not concern this or that scientific principle but rather the deeper reality governing scientific principles in general.
 - As a metaphysical category, final causality does not refer to a specific purpose but rather to the teleological principle itself, that actions within the world have purpose.



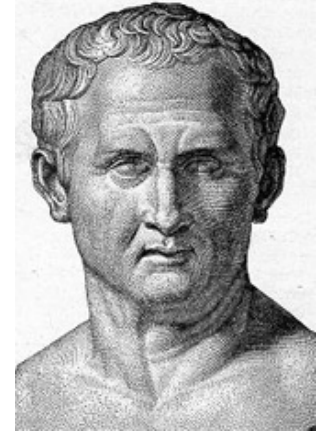
Demarcation

- **Immanuel Kant** (*Critique of Pure Reason*):
“Human reason... begins with principles, the truth and sufficiency of which are... insured by experience. With these principles it rises... to ever higher and more remote conditions. But it quickly discovers that, in this way, its labors must remain ever incomplete, because new questions never cease to present themselves; and thus it finds itself compelled to have recourse to principles which transcend the region of experience... It thus falls into confusion and contradictions... because the principles it employs, transcending the limits of experience, cannot be tested by that criterion. The arena of these endless contests is called **Metaphysic.**”



Cicero on the Argument from Design

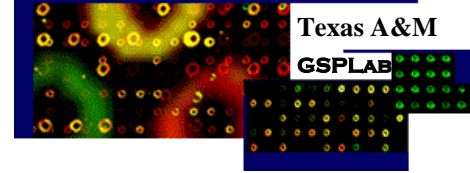
- **Cicero** (106 BC – 43 BC, *De Natura Deorum*, On the Nature of the Gods): “When you see a sundial or a water-clock, you see that it tells the time by design and not by chance. How then can you imagine that the universe as a whole is devoid of purpose and intelligence, when it embraces everything, including these artifacts themselves and their artificers?”
 - A teleological argument
 - Not an argument based on order or complexity



Lucretius on Natural Selection

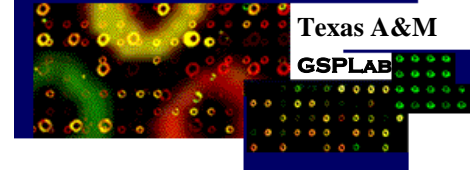
- **Lucretius** (99 BC – 55 BC, *De Rerum Natura*, *On the Nature of Things*): “Nothing arises in the body in order that we may use it, but what arises brings forth its own use... It was no design of the atoms that led them to arrange themselves in order with keen intelligence... Many were the monsters that the earth tried to make... It was in vain; nature denied them growth, nor could find food or join in the way of love... Many kinds of animals must have perished then unable to forge the chain of procreation... for those to which nature gave no protective qualities lay at the mercy of others, and were soon destroyed.”





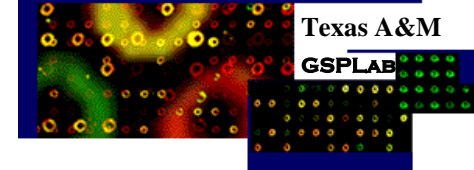
Timeline I

- Middle Ages: 325 (Council of Nicaea) - 1300 AD
- Dark Ages: 565 (Death of Justinian) - 1095
- Mohammad: 570-632
- Avicenna (Ibn Sina): 980-1037
 - Aristotelian: reason is the arbiter of knowledge
 - Contingent beings require a first cause; hence, God must exist
 - Universals truly exist in the mind of God, like Plato's forms; they "exist" as concepts (abstract ideas) in the human mind
 - Knowledge of the natural world is gained through observation
 - Reason for philosophers; prophets for parables to insure the moral order
 - Influenced medieval philosophy, including St. Thomas Aquinas



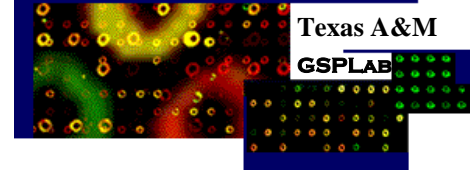
Timeline II

- Al-Ghazali: 1058-1111
 - Critique of reason: reason depends on causality and causality is merely temporal regularity (Hume)
 - Reason cannot prove the existence of God or immortality, without which there is no moral order, without which civilization cannot survive (Kant)
- Crusades: 1095-1291 (fall of Constantinople, 1204; fall of Jerusalem, 1244)
 - Movement of knowledge from the Muslem world to Europe
- Mongol invasion: 1219-1258



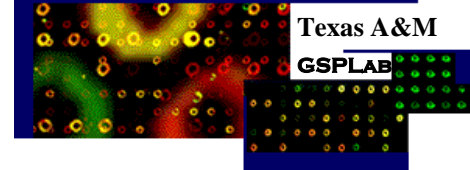
Timeline III

- Abelard: 1079-1142
 - Universals are concepts (like Avicenna)
 - *Yes and No*, 1120: “That faith should be founded on human reason, and the contrary,” – Truths of Scripture must agree with reason
 - “By doubting we come to inquiry and by inquiry we arrive at truth.”
- Averroes: 1126-1198
 - Religious dogma must be minimized to be reconciled with reason
 - Negligible influence in Islam, but sweeps Europe (France and England)



Timeline IV

- Thomas Aquinas: 1225-1274
 - Answers Averroes in defense of Christianity
 - Aristotle must be adapted for consistency with religious dogma
 - Augustine (heart) versus Aquinas (intellect)
- Roger Bacon: 1214-1294 – empiricism (Locke)
- William of Ockam: 1288-1348 – Parsimony – “Ockam’s razor”
 - Opposed causality because it would limit God’s power.
- Martin Luther: 1483-1546 – “That whore, reason.”
 - 1517: Posts his 95 theses on door of the Castle Church of Wittenberg

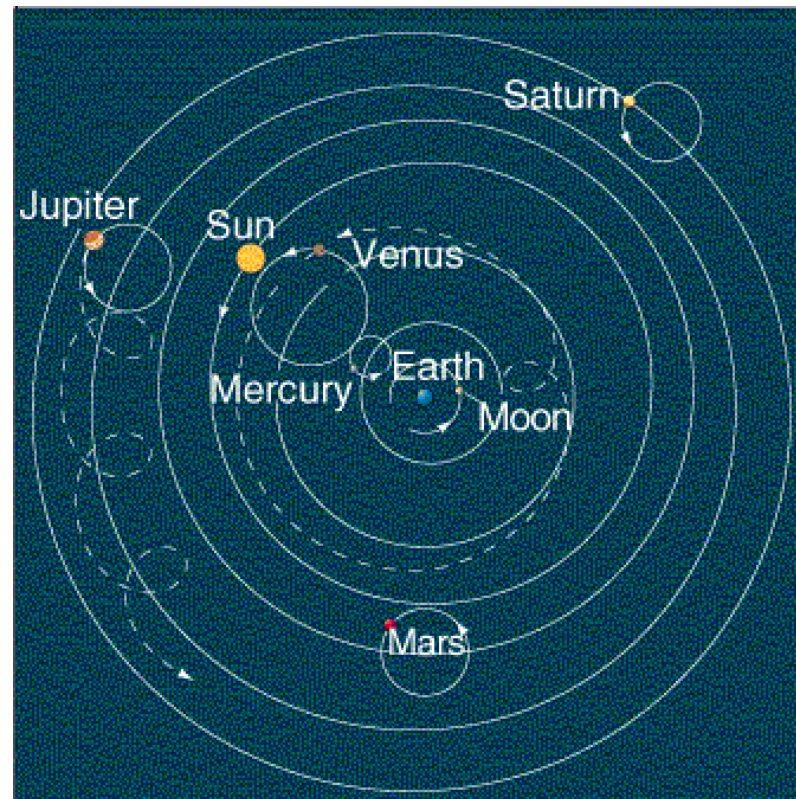


Timeline V

- Nicolaus Copernicus: 1473-1543
 - *De Revolutionibus Orbium Coelestium (On the Revolutions of the Celestial Spheres)*, 1543
- Francis Bacon: 1561-1626
 - *Novum Organum (The New Organon)*, 1620
- Galileo Galilei: 1564-1642 – “Father of Modern Science”
- Isaac Newton: 1642-1747
 - *The Principia: Mathematical Principles of Natural Philosophy*, 1687
- John Locke: 1632-1704
 - *An Essay Concerning Human Understanding*, 1690
- David Hume: 1711-1776
 - *A Treatise of Human Nature*, 1738
- Immanuel Kant: 1724-1804
 - *Critique of Pure Reason*, 1781

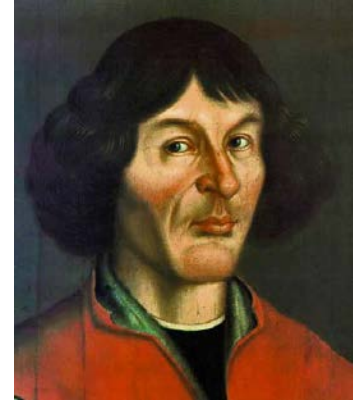
Ptolemy: The Geocentric Theory

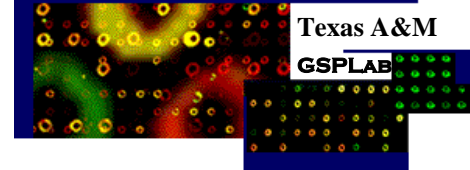
- Claudius Ptolemy (90 - 168): Earth is fixed.
 - Requires complex epicycles and eccentrics.



Copernicus: The Heliocentric Theory

- Nicolaus Copernicus (*De Revolutionibus Orbium Coelestium*, On the Revolution of the Celestial Orbs, 1543): Circular orbits about sun
 - Sun is fixed
 - Retains some extraneous mathematical attributes
 - Data fitting, no theory
 - No better predictions than the geocentric model
 - Less complex than the geocentric model
- Forerunners:
 - Aristarchus of Samos (310 BC - 230 BC), Nicole Oresme (1330-1382), Nicholas of Cusa (1401-1464), Leonardo da Vinci (1452-1519).





Is the Theory True?

- *De Revolutionibus* Preface: “Many scientists, in view of the already widespread reputation of these new hypotheses, will doubtless be greatly shocked by the theories of this book... However...the master's hypotheses are not necessarily true; they need not even be probable. It is completely sufficient if they lead to a computation that is in accordance with the astronomical observations...Let us grant that the following new hypotheses take their place beside the old ones which are not any more probable.”
 - Prudent and not written by Copernicus
 - The basic question: What is the nature of scientific knowledge?

The Basic Events

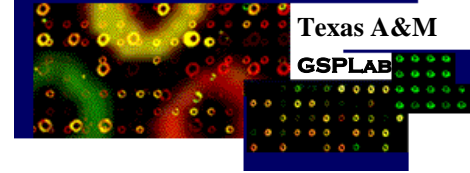
- **Will and Ariel Durant** (*Story of Civilization*): “The basic events in the history of modern Europe”:
 - *De Revolutionibus Orbium Coelestium* (Nicolaus Copernicus)
 - *Philosophiae Naturalis Principia Mathematica* (Isaac Newton)
 - *The Origin of the Species* (Charles Darwin).
- The basic events that have driven the philosophic, religious, and political evolution of Western Civilization.



Johannes Kepler

- Kepler's Laws (1609-1619): Elliptical orbits
 - I. Each planet moves in an elliptical orbit for which one focus is the sun.
 - II. Each planet moves faster when near the sun than when further from it, and a radius drawn from the sun to the planet covers equal areas in equal times.
 - III. The square of the time of revolution of a planet around the sun is proportional to the cube root of its mean distance from the sun.
- Kepler's theory is structurally different than that of Copernicus because it involves mathematical laws that characterize planetary motion.
- The next step in unification is gravitational theory.

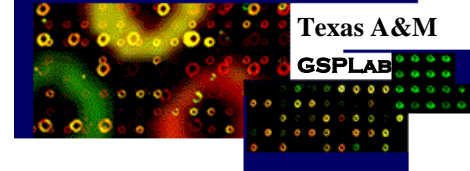




Bacon: Knowledge via Induction

- *Novum Organum* (*New Organon*, 1620): The new instrument, science, replaces Aristotle.
- Separates physics and metaphysics: material and efficient causes to physics, formal and final causes to metaphysics.
 - The efficient and the material are “superficial.”
- Law, or “form,” is not within Nature; rather, it is metaphysical and governs Nature.
- Knowledge is reached by the “logical” process of induction upon observing one event, the effect, repeatedly following the other, the cause, without exception.





Bacon on Scientific Law

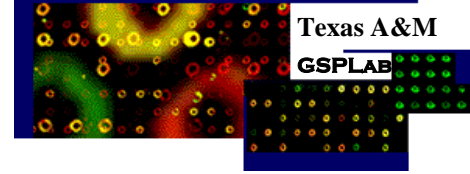
- **Francis Bacon** (*Novum Organum*, 1620): “For though in nature nothing really exists besides individual bodies, performing pure individual acts according to a fixed law, yet in philosophy this very law, and the investigation, discovery, and explanation of it, is the foundation as well of knowledge as of operation. And it is this law with its clauses that I mean when I speak of *forms*.... Whosoever is acquainted with forms embraces the unity of nature in substances the most unlike, and is able therefore to detect and bring to light things never yet done.”



Bacon on Observation and Knowledge

- **Francis Bacon** (*Novum Organum*, 1620):
“Man being the servant and interpreter of Nature, can do and understand so much only, as he had observed, in fact or in thought, of the course of Nature; beyond this he neither knows anything nor can do anything.... Human knowledge and human power meet in one; for where the cause is not known, the effect cannot be produced. Nature to be commanded, must be obeyed.”

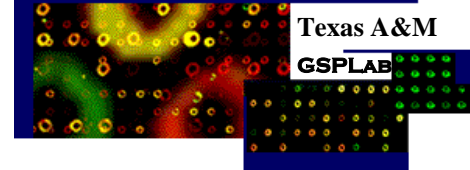




Bacon on Planned Experiments

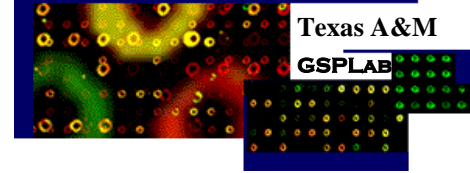
- **Francis Bacon** (*Novum Organum*, 1620):
“There remains simple experience which, if taken as it comes, is called accident; if sought for, experiment. But this kind of experience is...a mere groping, as of men in the dark... But the true method of experience, on the contrary, first lights the candle, and then by means of the candle shows the way; commencing as it does with experience duly ordered and digested, not bungling or erratic, and from it educing axioms, and from established axioms again new experiments.”





Bacon's Idols of the Mind

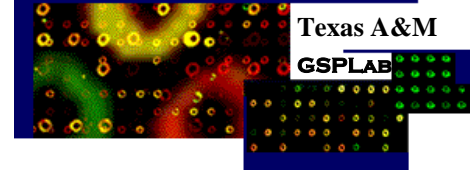
- *Idols of the tribe*: fallacies common to humanity in general
 - “All perceptions, of both the senses and the mind, bear reference to man and not to the universe.”
 - “For what a man had rather were true, he more readily believes.”
- *Idols of the cave*: personal or parochial prejudices
 - “Everyone has a cave or den of his own, which refracts and discolors the light of nature.”
- *Idols of the marketplace*: fallacies arising from association
 - “Words are imposed according to understanding of the crowd.”
- *Idols of the Theater*: Uncritical acceptance of dogma and popular theories
 - “Received systems of philosophy are so many stage-plays, representing worlds of their own creation.”



Bacon on Empiricism versus Rationalism

- **Francis Bacon** (*Novum Organum*, 1620):
“Those who have handled sciences have been either men of experiment or men of dogmas. The men of experiment are like the ant, they only collect and use; the reasoners resemble spiders, who make cobwebs out of their own substance. But the bee takes a middle course: it gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own.”

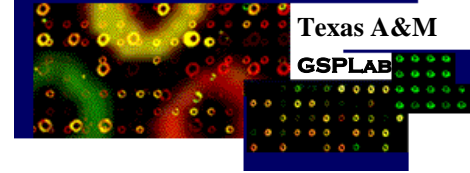




On Francis Bacon

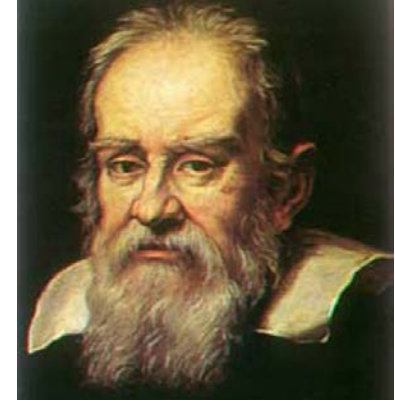
- **Jean le Rond d'Alembert** (*The Encyclopedie*, Vol. 1, 1751): “At the head of these illustrious personages should be placed the immortal Chancellor of England, Francis Bacon whose works, so justly esteemed,... deserve our study even more than our praise. When we consider the sane and spacious views of this great man, the multitude of subjects surveyed by his mind, the boldness of his style,...we are tempted to regard him as the greatest, the most universal, and the most eloquent of philosophers.”

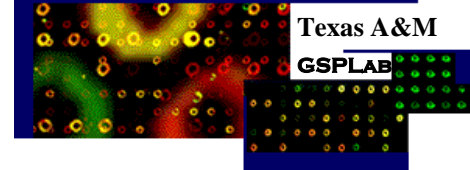




Galileo on Idols of the Marketplace

- **Galileo** (*Two New Sciences*, 1638): *Salviati*:
“You should say that everyone knows that it is called ‘gravity.’ But I am not asking you for the name, but the essence of the thing. We don’t really understand what principle or what power it is that moves a stone downwards, any more than we understand what moves it upwards after it has left the projector, or what moves the moon round.”
 - Names allow people to speak as if they understood, when in fact they tell us nothing about the essence or behavior of the phenomena.



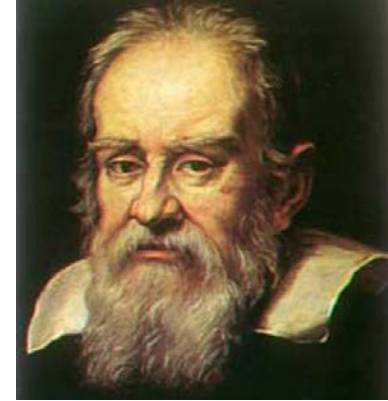


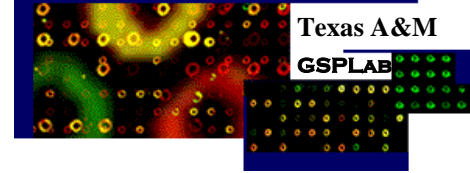
Galileo Brackets Causality

- **Galileo: *Salviati*:** “The present does not seem to me to be an opportune time to enter into the investigation of the cause of the acceleration of natural motion, concerning which various philosophers have produced various opinions.... Such fantasies, and others like them, would have to be examined and resolved, with little gain. For the present, it suffices our Author that we understand him to want us to investigate and demonstrate some attributes of a motion so accelerated (whatever be the cause of its acceleration) that the momenta of its speed go increasing, after its departure from rest, in that simple ratio with which the continuation of time increases.”
 - He brackets causality to get on with mathematical description.

Nature is Written in Mathematics

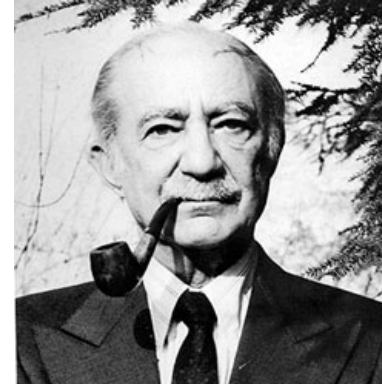
- **Galileo** (*The Sidereal Messenger*, 1610):
“Philosophy [nature] is written in that great book which ever is before our eyes – I mean the universe – but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The book is written in mathematical language, and the symbols are triangles, circles and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wanders in vain through a dark labyrinth.”

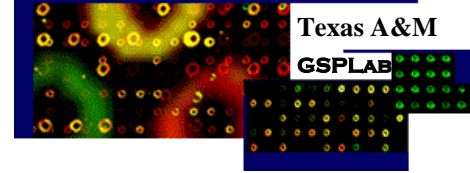




Science Reveals the Grandeur of God

- **Morris Kline:** “The search for the mathematical laws of motion was an act of devotion; it was the study of the ways and nature of God and His plan of the universe. The Renaissance scientist was a theologian, with nature instead of the Bible for his subject....Galileo said, ‘Nor does God less admirably reveal himself to us in Nature’s actions than in the Scripture’s sacred dictions.’ ...These men sought mathematical relations that would reveal the glory and grandeur of God’s handiwork.”

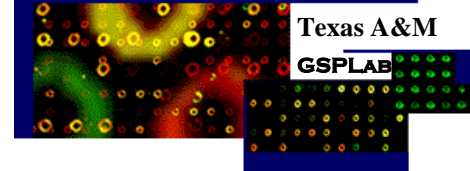




Newton Brackets Causality

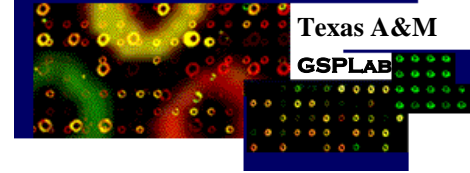
- **Isaac Newton** (*Philosophiae Naturalis Principia Mathematica*, 1687): “For I here design only to give a mathematical notion of these forces, without considering their physical causes and seats.”





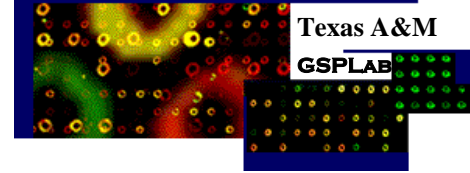
Newton's Laws of Motion

- I. Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
- II. The change of motion is proportional to the motive force impressed, and is made in the direction of the straight line in which that force is impressed.
- III. To every action there is always opposed an equal reaction.
- Using the laws of motion and the inverse square law, he mathematically derived a planetary theory.
- Law: Particles, planets, and stars subject to same law.



Laws of Motion – No *A Priori* Hypotheses

- **Isaac Newton:** “Hitherto I have not been able to discover the cause of those properties of gravity from the phenomena, and I frame no hypothesis; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy....It is enough that gravity does really exist, and acts according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies, and of our sea.”



Science Is Constituted Within Mathematics

- **Isaac Newton:** “But our purpose is only to trace out the quantity and properties of this force from the phenomena, and to apply what we discover in some simple cases as principles, by which, in a mathematical way, we may estimate the effects thereof in more involved cases: for it would be endless and impossible to bring every particular to direct and immediate observation. We said, in a mathematical way, to avoid all questions about the nature or quality of this force.”
 - He avoids all questions about the nature of gravity.
 - System does not include all factors, but has sufficient predictive power to “estimate” effects in general settings (can be tested).