SIMPLICITY AND COMPLEXITY IN NATURE

• SOME SUCCESS STORIES:
  - Human-scale physics: MOTION
    ELECTRICITY AND MAGNETISM
    HEAT
  - Quantum physics: ATOMS
    MOLECULES
    ELEMENTARY PARTICLES
• PHYSICS OF THE VERY SMALL:
  - Astrophysics/Cosmology: STARS (life and death)
    CHEMISTRY OF UNIVERSE
    EVOLUTION OF UNIVERSE
• PHYSICS OF THE VERY LARGE:
  - Complex Phenomena: WEATHER
    BRAIN
    LIFE
    HUMANS

The reductionist approach has been VERY successful…Why?
There is simplicity in the apparent complexity of Nature

• It is possible to understand and predict the behavior of many phenomena with simple, general laws (e.g. gravity)

PHYSICS IS THE METHOD BY WHICH WE UNCOVER THIS SIMPLICITY

UNDERSTANDING NATURE \rightarrow SEARCH FOR LAWS OF PHYSICS

HOW DID IT ALL START? AND WHERE?
# THE PRE-SOCRATICS (ca. 620-470 BCE)

Questions about Nature answered within Nature

## 1. IONIAN SCHOOL: Miletus
   What is the stuff of cosmos? “Physis”
   - Thales
   - Anaximander
   - Anaximenes
   - Heraclitus

## 2. ELEACTIC SCHOOL: Elea
   Radical Monism: One Being
   - Parmenides
   - Zeno

## 3. PYTHAGOREAN SCHOOL: Croton
   Mathematical mysticism: Number is All
   - Pythagoras
   - Philolaus

## 4. ATOMISTIC SCHOOL: Abdera
   All things made of atoms
   - Democritus
   - Leucippus
I. Ionian School:

• Questions are asked
• what is the stuff cosmos is made of?

Thales of Miletus (ca. 624-545 BCE)

First to suggest single substance: WATER
Universe is a living organism (unifying Nature with body)
Search for simplicity in Nature
Earth is a circular disk surrounded by water

Anaximander of Miletus (ca. 611 - 546 BCE)

Universe is infinite in extension and duration
Raw material is unknown substance: all things born from it and
“Boundless: The cosmic breath” return to it
First mechanical model of cosmos
Anaximenes of Miletus

Air is basic stuff: Different densities --> different substances
fire --> water --> earth --> stones
Stars attached to crystalline spheres (key idea in astronomy for 2,000 years…)

Heraclitus of Ephesus (fl. Ca. 500 BCE); “The Obscure”

“All things are in flux and nothing is stable” (river)
Balance in cosmos achieved from tension between opposites
“logos” (bow and arrow)
Basic substance is fire: Transformation
Emphasis in **PROCESS: BECOMING**

IONIANS ➔ BECOMING
II. Eleatic School: (fl. 5th BCE in Elea, Italy)

Parmenides of Elea (ca. 515 - 450 BCE)
  * Radical Monism: There is one Being, Immutable
    ➔ change is second-rate reality
  * Eon: Cosmic Deity - ungenerated, all-pervading
  * What IS cannot change for… **BEING**
  * Physics as search for immutable laws
  * Zeno and his paradoxes of motion

III. Pythagorean School: (fl. 6th - 5th BCE in Croton, Italy)

Mathematical mysticism: “All is number”
  all things have forms, and forms are described by numbers

Pythagoras of Samos (ca. 585 - 510 BCE)
  * Legendary; possible pupil of Anaximander
  * Synthesis of philosophy and religion: rational and mystical
  * Knowledge is gateway to the Divine:
    numbers are the bridge between human reason and divine mind
  * Self-transcendence through the beauty of numbers (“ekstasis”)


Pitch of note depends on length of string

* pleasing sounds correspond to simple ratios: 2/1 - Octave 3/2 - Fifth
* expression of quality as quantity: mathematization of sensorial experience
* beauty (HARMONY) can be expressed mathematically
* Numbers have form:

\[ 4 = \quad 6 = \]

* get square numbers by adding odd numbers:
\[ 1 + 3 = 4 \quad 5 = 9 \quad 7 = 16 \quad 9 = 25 \ldots \]

* The harmony of the spheres
  * Earth is spherical
IV. Atomistic School: (fl. 4th BCE)

* All things are made of indivisible, fundamental dense bricks: atoms
* Reconciliation of change and immutability

CHANGE (Heraclitus) ⏺️ IMMUTABILITY (Parmenides)

*Quantitative change - qualitative immutability
  → synthesis of being and becoming
* Leucippus (fl. 450-420 BCE): basic ideas
* Democritus (ca. 460-370 BCE): The Laughing philosopher - detailed elaboration; infinitely many, infinitely many shapes moving in the Void
  - compare with modern atoms: not infinite in number, not indivisible, not hard
* extension to humans, emotions; liberation from fear; Lucretius
Precursors of Change

• Philolaus (ca. 550 BCE)
  A Pythagorean
  Breaks away with geocentrism:
  ➔ earth moves around a “central fire”
  ➔ postulates the “antichton”

• Heraclides of Pontus (ca. 350 BCE)
  Studied under Plato and Aristotle
  Earth rotates around its axis!
  Mercury and Venus rotate around Sun!

• Aristarchus of Samos (ca. 310 - 230 BCE)
  Meticulous observer: puts Sun in the center!!
  Resistance from Aristotelians and absence of stellar parallax (cosmos would be too big)