Welcome to PHYS101N 2021

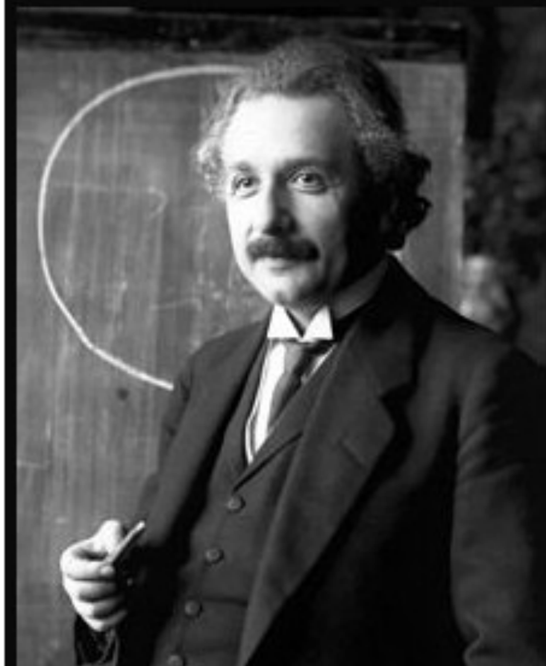
Have you...

A. Checked out the Blackboard and Web sites for our course?
B. Read the syllabus?
C. Registered and obtained a license for TurningPoint?
D. Signed up for and attended Lab?

Why Science?

1. Because most humans have an innate desire to understand the world around them, what everything is made of and where it came from
2. Because the most important decisions the people of this planet must make depend on a scientific understanding of the world
3. Because scientific research has brought us the marvels of modern technology (from rockets to computers) and is indispensable for our economy, health care and security
4. What's your reason?

Why Science?



Sollen sich auch alle schämen, die gedankenlos sich der Wunder der Wissenschaft und Technik bedienen, und nicht mehr davon geistig erfasst haben als die Kuh von der Botanik der Pflanzen, die sie mit Wohlbehagen frisst.

(Albert Einstein)

…just one guy's opinion, but he also said: (supposedly...)

Jeder ist ein Genie! Aber wenn Du einen Fisch danach beurteilst, ob er auf einen Baum klettern kann, wird er sein ganzes Leben glauben, dass er dumm ist.

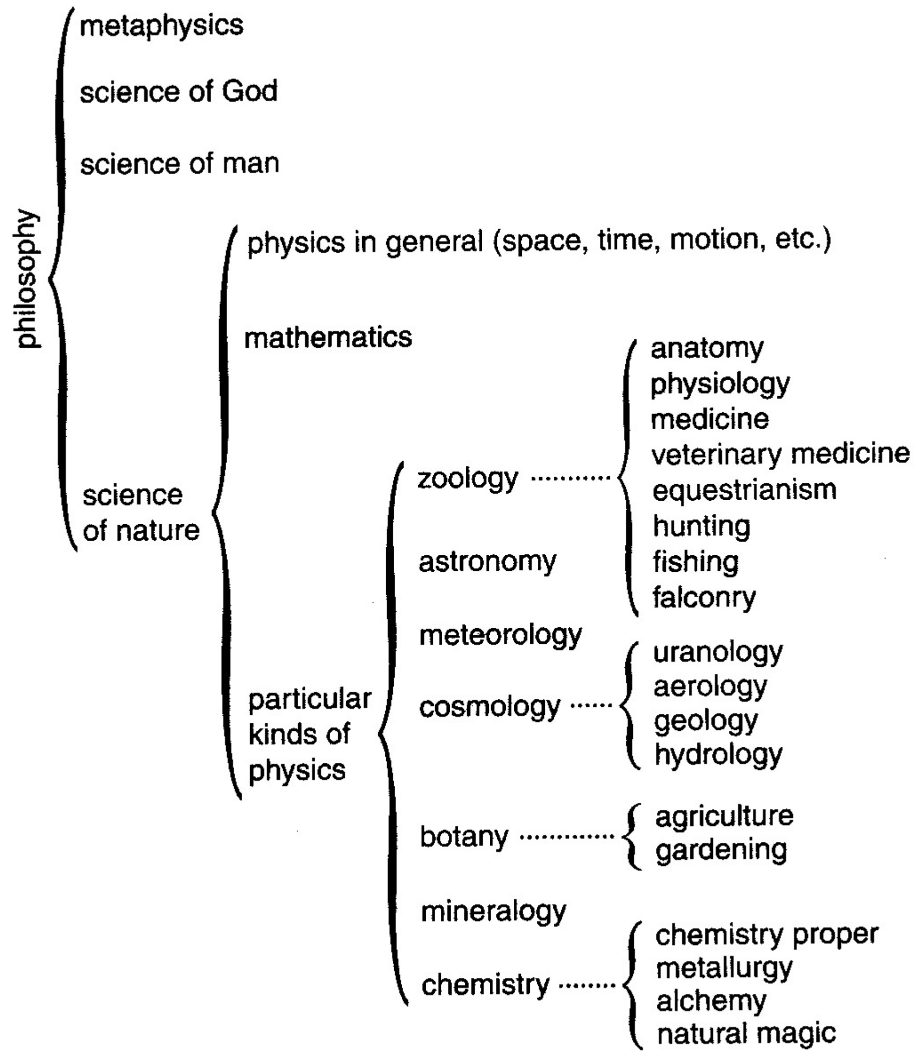
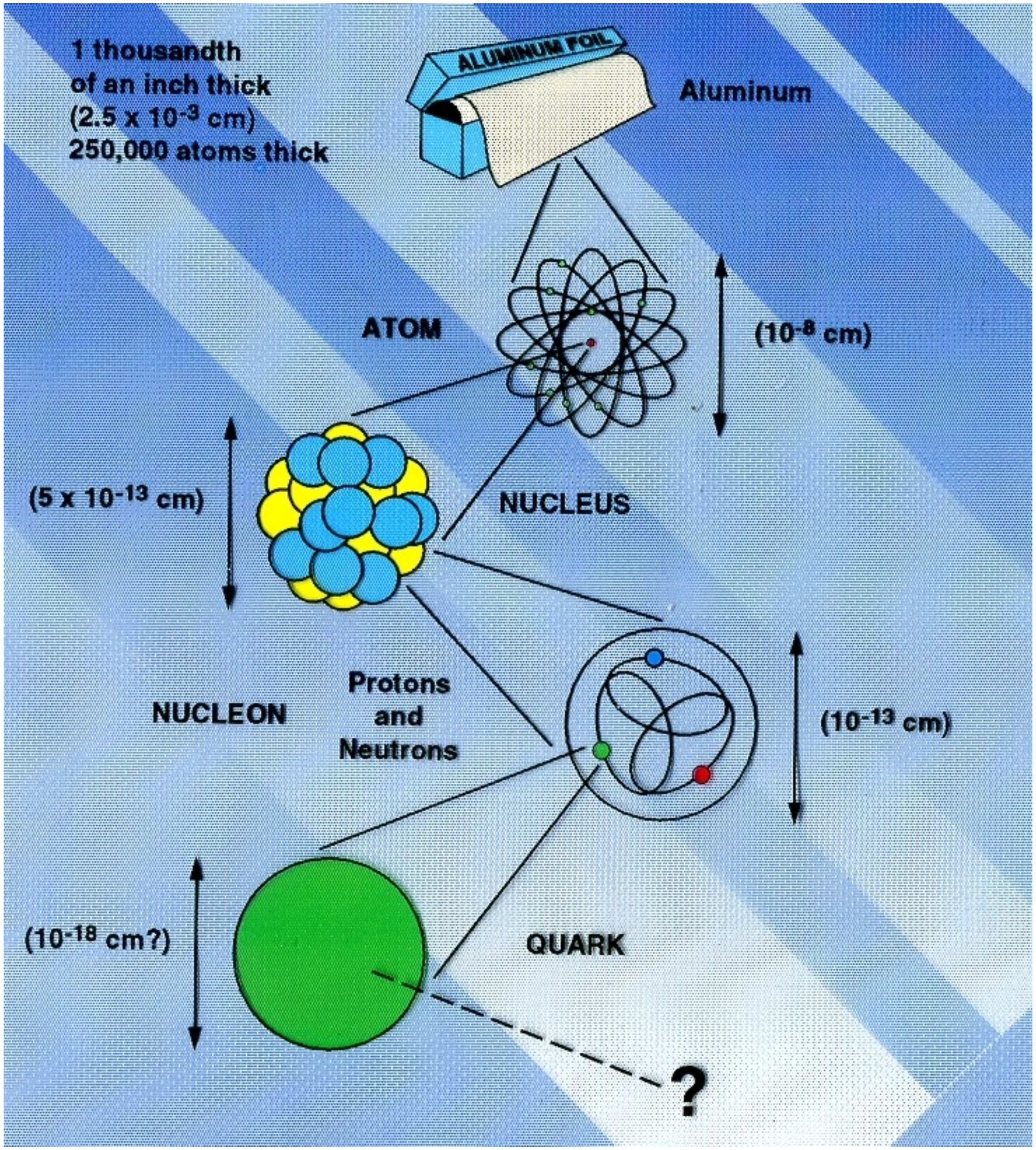


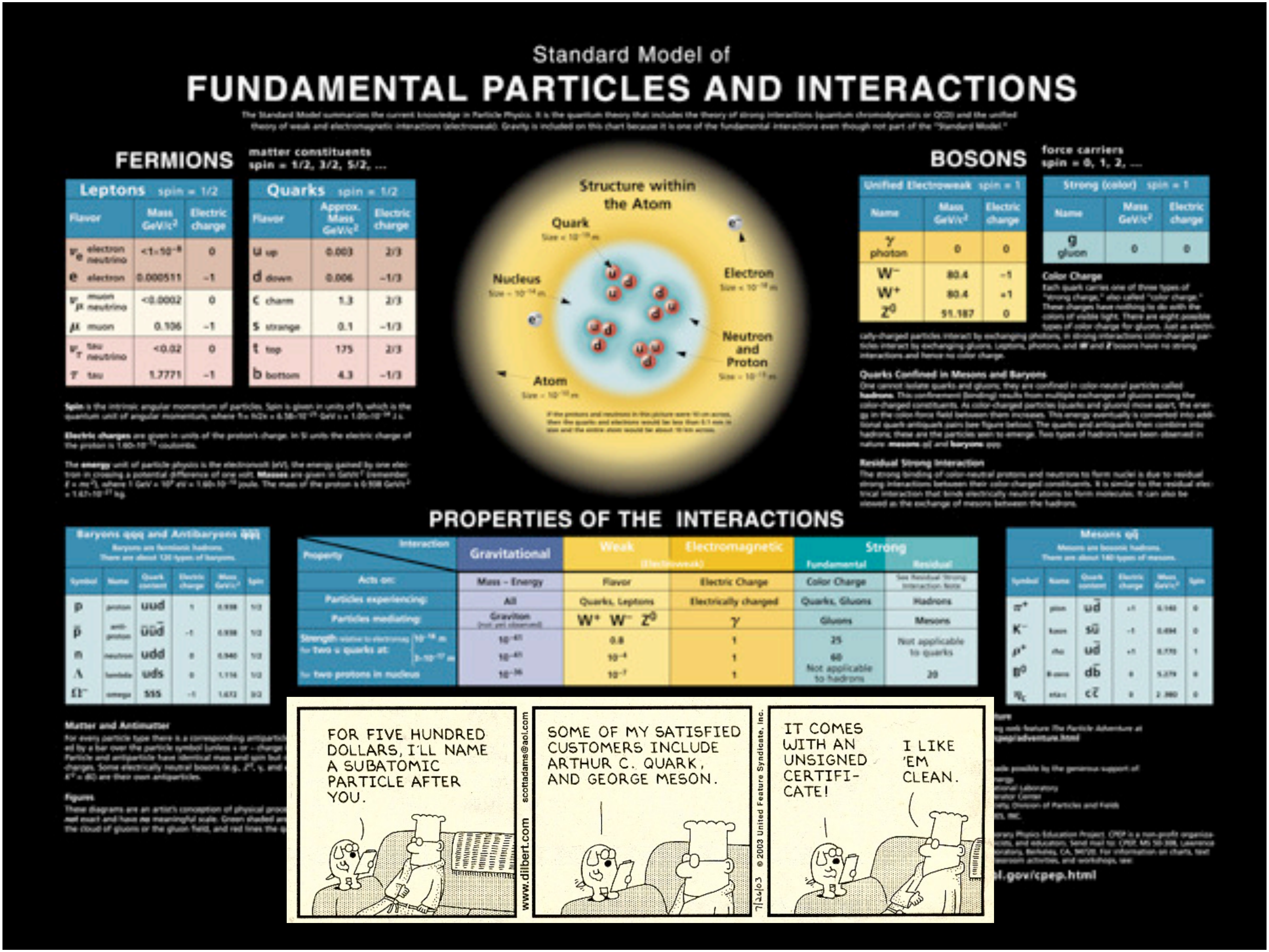
Figure 1. Tree of knowledge is the traditional scheme for organizing the categories of thought, as well as institutions such as university departments. Shown here is part of the tree adopted in the 18th-century *Encyclopédia* of Denis Diderot and Jean Le Rond d'Alembert. Note that the term *physics* had a rather different meaning then: Most of the sciences are classified as kinds of physics. (So are a few *non*sciences.) In modern times the proliferation of crosslinks between disciplines raises doubt that any treelike structure can represent human knowledge.

What is Physics?

A. The study of the most fundamental constituents of the world around us
B. A way to describe motion
C. A set of Laws about forces and their effects
D. A method to observe, categorize, understand and predict natural and technological phenomena
E. A science that underpins all of chemistry, biology, astronomy, geology, metereology, and engineering

What is matter made of?

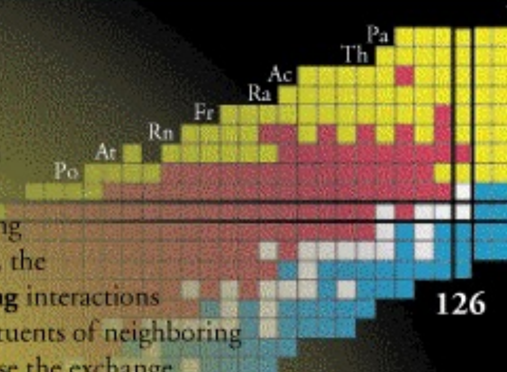


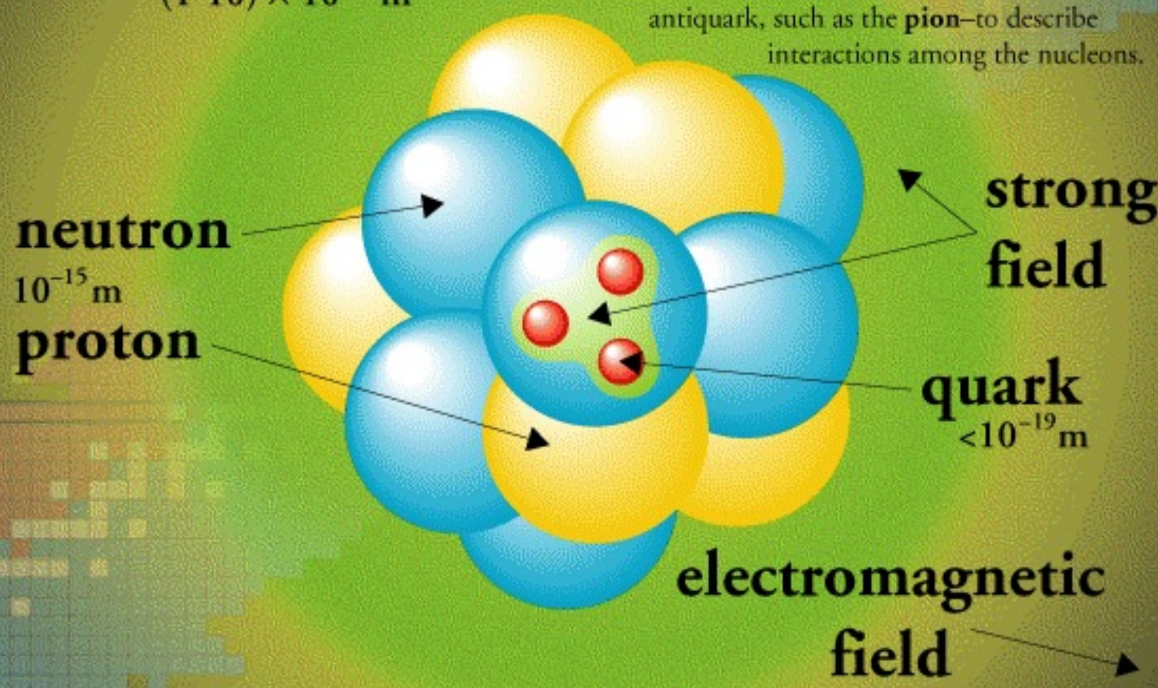

Standard Model of
FUNDAMENTAL PARTICLES AND INTERACTIONS
FERMIONS
matter constituents
spin = 1/2, 3/2, 5/2, ...
Leptons spin = 1/2
Quarks spin = 1/2
Structure within the Atom
Quark
Nucleus
Electron
Neutron and Proton
Atom
BOSONS
force carriers
spin = 0, 1, 2, ...
Unified Electroweak spin = 1
Strong (color) spin = 1
Color Charge
Quarks Confined in Mesons and Baryons
Residual Strong Interaction
PROPERTIES OF THE INTERACTIONS
Gravitational
Weak
Electromagnetic
Strong
Acts on:
Particles experiencing:
Particles mediating:
Mass – Energy
Flavor
Electric Charge
Color Charge
All
Quarks, Leptons
Electrically charged
Quarks, Gluons
Hadrons
Graviton
Gluons
Mesons
Not applicable to quarks
Not applicable to hadrons
Baryons qqq and Antibaryons
Mesons
Matter and Antimatter
Figures
FOR FIVE HUNDRED DOLLARS, I'LL NAME A SUBATOMIC PARTICLE AFTER YOU.
scottadams@aol.com
www.dilbert.com
SOME OF MY SATISFIED CUSTOMERS INCLUDE ARTHUR C. QUARK, AND GEORGE MESON.
© 2003 United Feature Syndicate, Inc.
IT COMES WITH AN UNSIGNED CERTIFI-CATE!
I LIKE 'EM CLEAN.

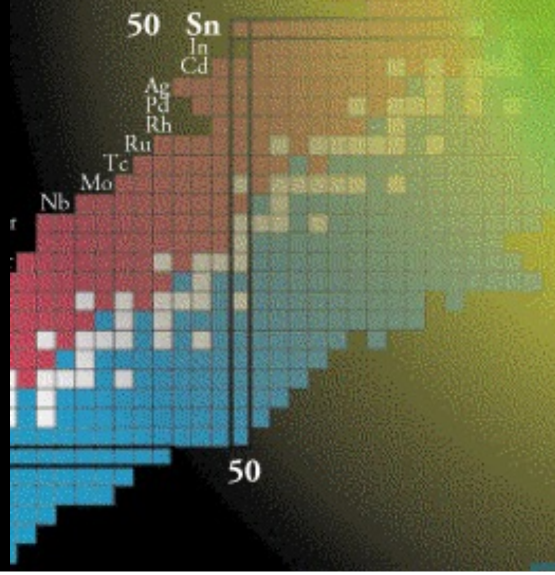
The Nucleus

$(1\text{-}10) \times 10^{-15}$ m

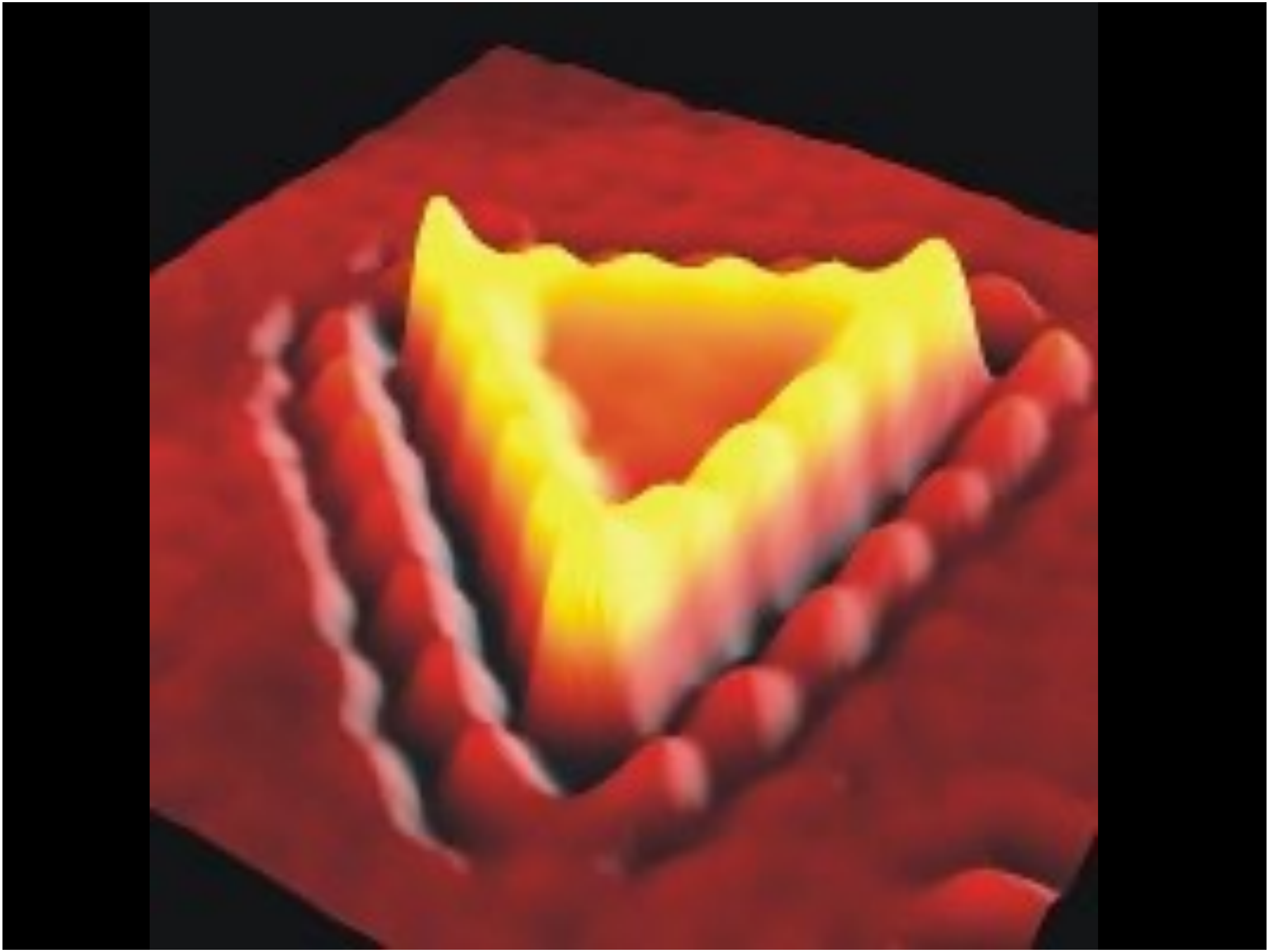
*A*t the center of the atom is a nucleus formed from **nucleons**–protons and neutrons. Each nucleon is made from three **quarks** held together by their strong interactions, which are mediated by gluons. In turn, the nucleus is held together by the **strong** interactions between the gluon and quark constituents of neighboring nucleons. Nuclear physicists often use the exchange of mesons–particles which consist of a quark and an antiquark, such as the **pion**–to describe interactions among the nucleons.

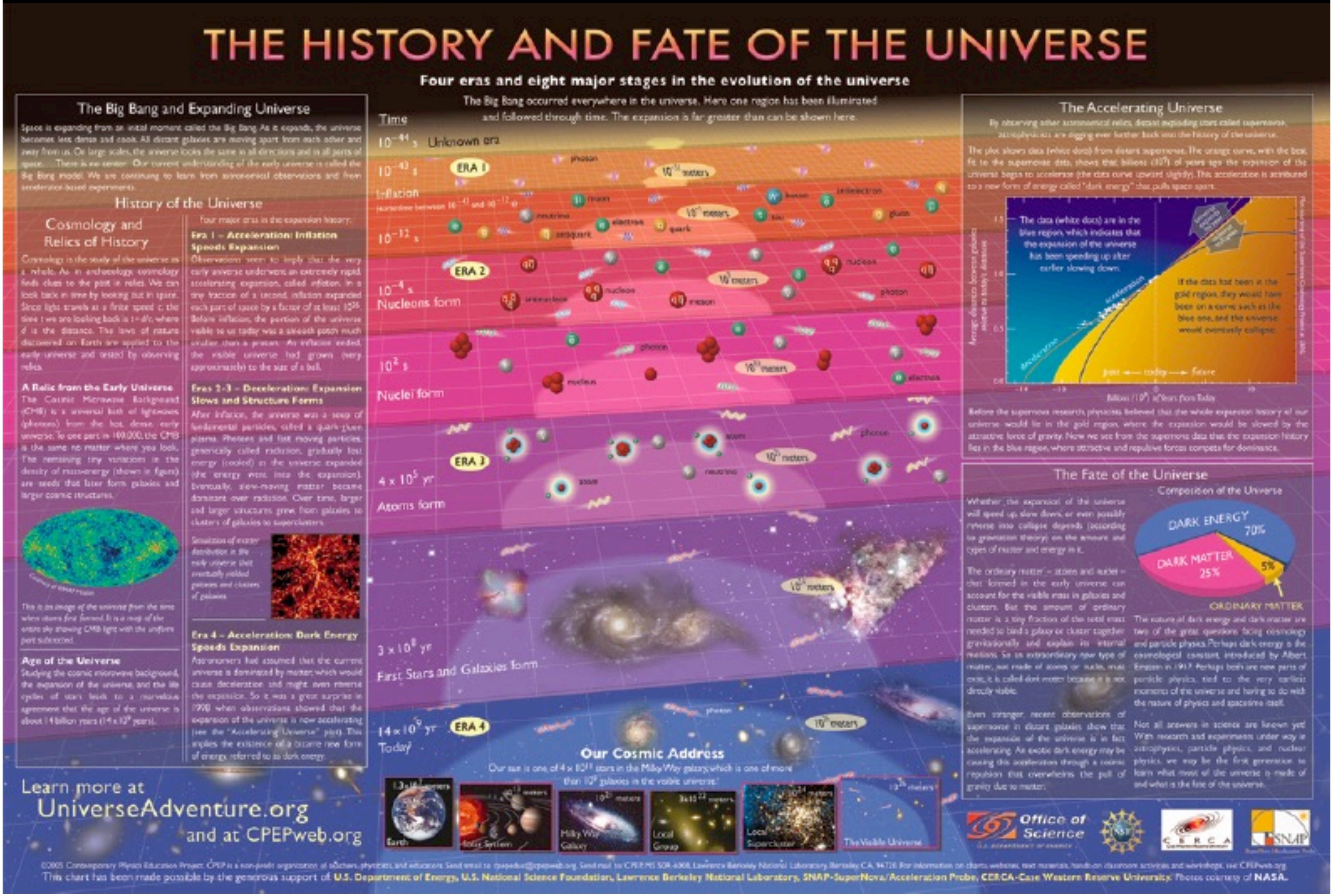






*I*n an atom, **electrons** range around the nucleus at distances typically up to 10,000 times the nuclear diameter. If the electron cloud were shown to scale, this chart would cover a small town.




THE HISTORY AND FATE OF THE UNIVERSE
Four eras and eight major stages in the evolution of the universe
The Big Bang occurred everywhere in the universe. Here one region has been illuminated and followed through time. The expansion is far greater than can be shown here.
The Big Bang and Expanding Universe
History of the Universe
Cosmology and Relics of History
A Relic from the Early Universe
Age of the Universe
Era 1 – Acceleration: Inflation Speeds Expansion
Eras 2-3 – Deceleration: Expansion Slows and Structure Forms
Era 4 – Acceleration: Dark Energy Speeds Expansion
Time
Unknown era
ERA 1
Inflation
ERA 2
Nucleons form
Nuclei form
ERA 3
Atoms form
First Stars and Galaxies form
ERA 4
Today
Our Cosmic Address
Earth
Solar System
Milky Way Galaxy
Local Group
Local Supercluster
The Visible Universe
The Accelerating Universe
The Fate of the Universe
Composition of the Universe
DARK ENERGY 70%
DARK MATTER 25%
5%
ORDINARY MATTER
Learn more at
UniverseAdventure.org
and at CPEPweb.org
Office of Science
CERCA
SNAP


40
30
20
125
100

About this Course

- Learn how to describe motion of objects and to distinguish between force-free motion and motion in the presence of a force.
- Define fundamental concepts like Force, Energy, Momentum, Angular Momentum, Gravity.
- Find out how these concepts can explain and predict motion (dynamics) or stable equilibrium (statics).
- Study the electrostatic and magnetostatic force.
- Get a glimpse of electromagnetic induction and Maxwell’s theory of electromagnetism…

The Scientific Method

- Conduct systematic, reproducible (and quantitative) observations and measurements
- Determine and record the relevant parameters and observables
- Define (mathematical, geometrical, conceptual,…) models that describe and relate these quantities to each other
- Develop general theories (or "Laws") that organize and explain large numbers of observations and models
- Derive testable predictions and test them
- Toss any theories that either cannot be tested rigorously or that fail those tests.

Measurements

- How do we specify and quantify “what’s going on”?
- What are the relevant features and parameters? How do we measure them?
- Define idealized objects, constructs and situations and distinguish what’s important from “annoying” details that may obscure that.
- Repeat measurements under different conditions (varying parameters).
- Translate into the language of math: Numbers.

Math Pop Quiz

A farmer wants to plow his field. It takes him 5 gallons of fuel just to drive there with his tractor. The remaining fuel needed is directly proportional to the surface area of the field (2 acres takes double as much fuel as 1 acre).

If the field is a perfect square with 500 yards on each side, the total amount of fuel needed is 10 gallons. How much fuel would be needed if the field is a square with 1000 yards on each side?

Develop a Model

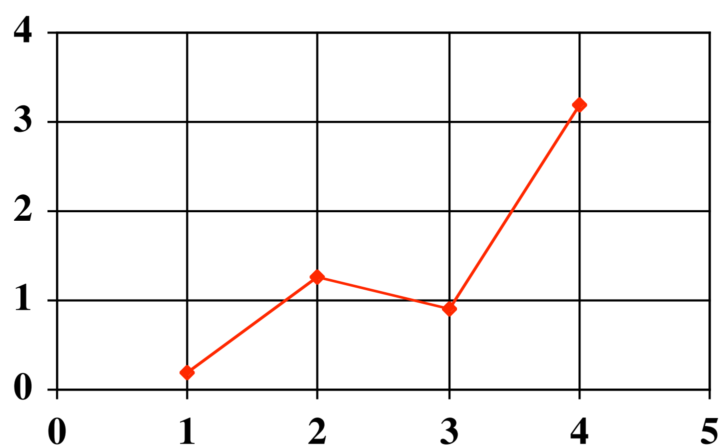
- Define (or refine the definition of) **observables** (concepts, “agents” or quantities that can be used to organize and explain your data).
  Important: Give a **precise**, **operational** definition
- Develop mathematical relationships between different observables that both agree with your observations and can be used to predict the outcome of future experiments.
- If you found a really fundamental relationship which passes all tests in widely varying situations, call it a “Law”.
- A coherent, interconnected collection of Laws is called a “Theory”.
- If a proposed “scientific theory” can not be tested by observation (because either it doesn’t predict any observable phenomena or because it is formulated such that it will “automatically” pass any such test) then we are dealing with “Pseudoscience”.

Example: Falling Objects

- Measurements: Position in time. Ignore air resistance. Drop from different heights. Record time, height, speed...
- Describing Measurements: Draw diagrams of speed *vs*. time. Observe that speed increases linearly with time (constant acceleration a). Find that total drop in height equals 1/2 times acceleration times drop time squared ($H = {}^{1}/_{2}\, a\, t^2$).
- Develop a Model: Define gravitational force F (measure with bathroom scale). Define mass M . Write down $F = Ma$.
- Predict orbits of moon, satellites,...

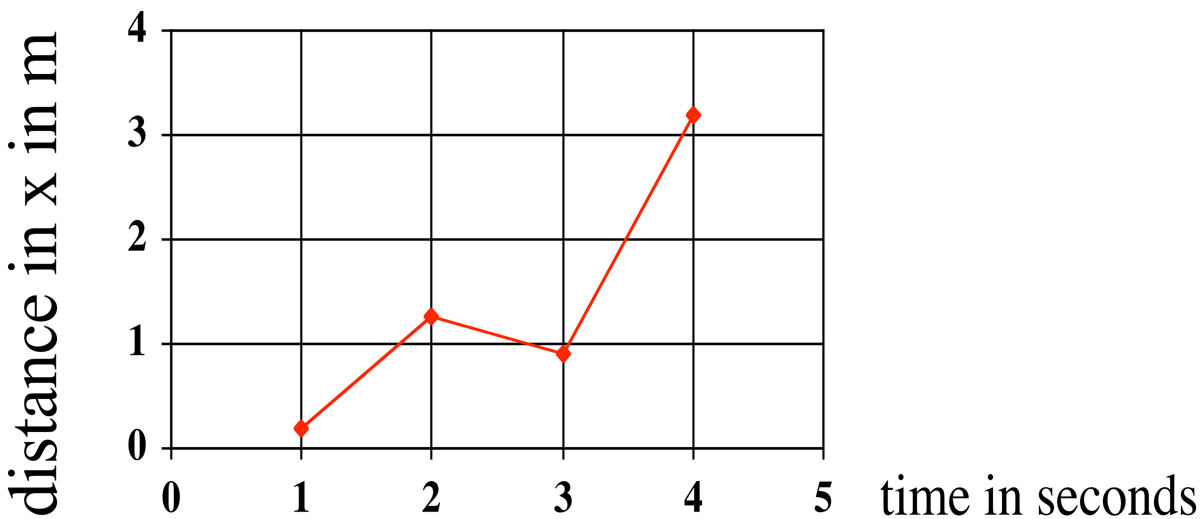
Quantities in Mathematics

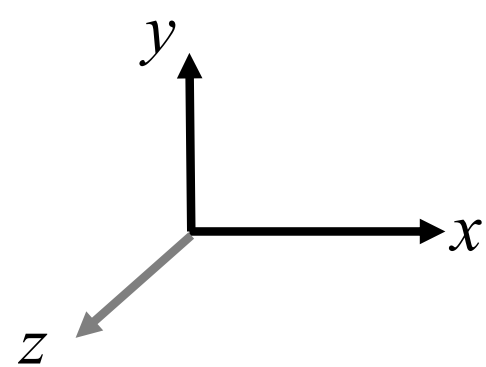
- Numbers (integer, fractions, real, complex,…). "Infinite" precision
- Normally do not have units
- Can "visualize" as sizes (lengths) of bars, distances, etc.
- Example: plot of y vs. x



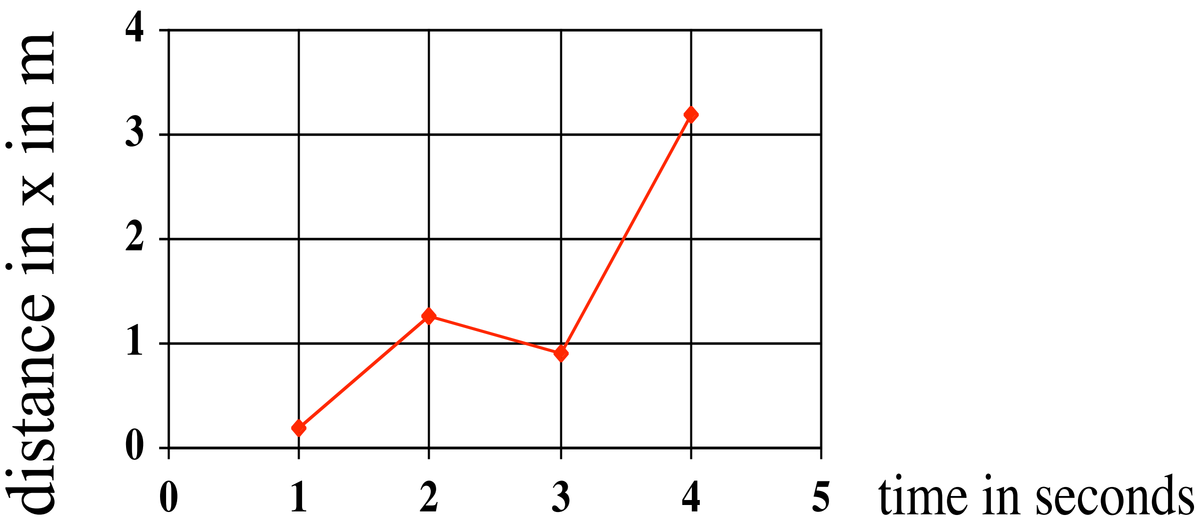
Quantities in Nature

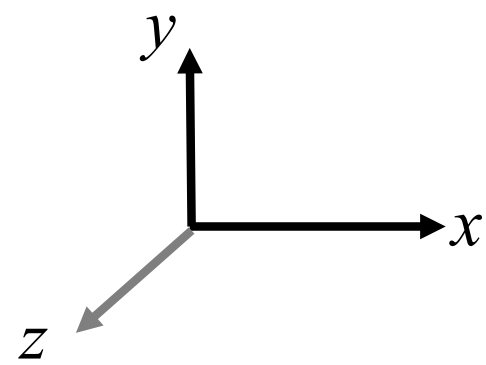
- Describe properties of something - “how fast”, “how high”, “how hot”
- Can be measured (observables) -> representation by numbers, but with limited precision (don’t show more digits than warranted - usually 3-4); **usually** has units
- Can “visualize” as sizes (lengths) of bars, distances, etc.
- Example: plot of x vs. t - NOTE: Do not take assume the graph shows a literal rendition of a trajectory!





Does this graph describe an object that moves...





A. Sideways?

B. Up?

Observables

- Things we can measure quantitatively.
- Require an **operational** definition: How to measure?
- Can be simple number, but most often have a **dimension** and a **unit**.

Example: Distance

- Dimension: Length
- Unit: m (Meter)
- Operational definition: Compare with “standard meter”: ruler, tape measure, 1/10,000,000 of distance from pole to equator, standard meter in Paris, distance traveled by sound in 1/340 of a second, …
- Distance traveled by light in 1/299,792,458 of a second.
- Write result as, *e.g.*, “8.3 m”

Example: Duration

- Dimension: Time
- Unit: s (second)
- Operational definition: Compare with number of elapsed "standard seconds": swing (left to right) of 1m pendulum, 1/86,400 of a day,…
- 9,192,631,770 times the period of the oscillation of a cesium-133 clock.
- Write result as, *e.g.*, "1 hour = 3600 s"

Example: Mass (Inertia)

- Dimension: Mass
- Unit: kg (kilogram)
- Operational definition: Compare with “standard kilogram”: Scale weight, platinum-iridium cylinder in Paris…
- A mass that would correspond to a quantum-mechanical wavelength of $6.62607015 \times 10^{-34}$ m if it moved at speed of 1 m/s.

Some Remarks:

- Many more units are possible (and in use) for each observable. Example: cm, inch, foot, mile, nautical mile, furlong,...
- We will use **only** SI units introduced above and their derivations/combinations (except in problems).
- All observables must **always** be quoted with their proper units. All numerical manipulations of quantities (including conversion factors) must always include units (they behave like any other "constants" in Algebra).

Big and tiny Numbers

- Use exponents:
  $9.193 \cdot 10^9$ instead of 9,192,631,770 ; $3.336 \cdot 10^{-9}$ instead of 1/299,792,458 .
- Use prefixes for units:
  k = “kilo” = 10^3, M = “Mega” = 10^6 , G = “Giga” = 10^9,
  d = “deci” = 10^{-1}, c = “centi” = 10^{-2}, m = “milli” = 10^{-3},
  μ = “micro” = 10^{-6}, n = “nano” = 10^{-9}, p = “pico” = 10^{-12}
  Examples:
  km (1000 m), MHz (10^6/s), mg (10^{-3}g = 10^{-6} kg),
  ns (10^{-9} s; light travels 1 m in 3.336 ns)

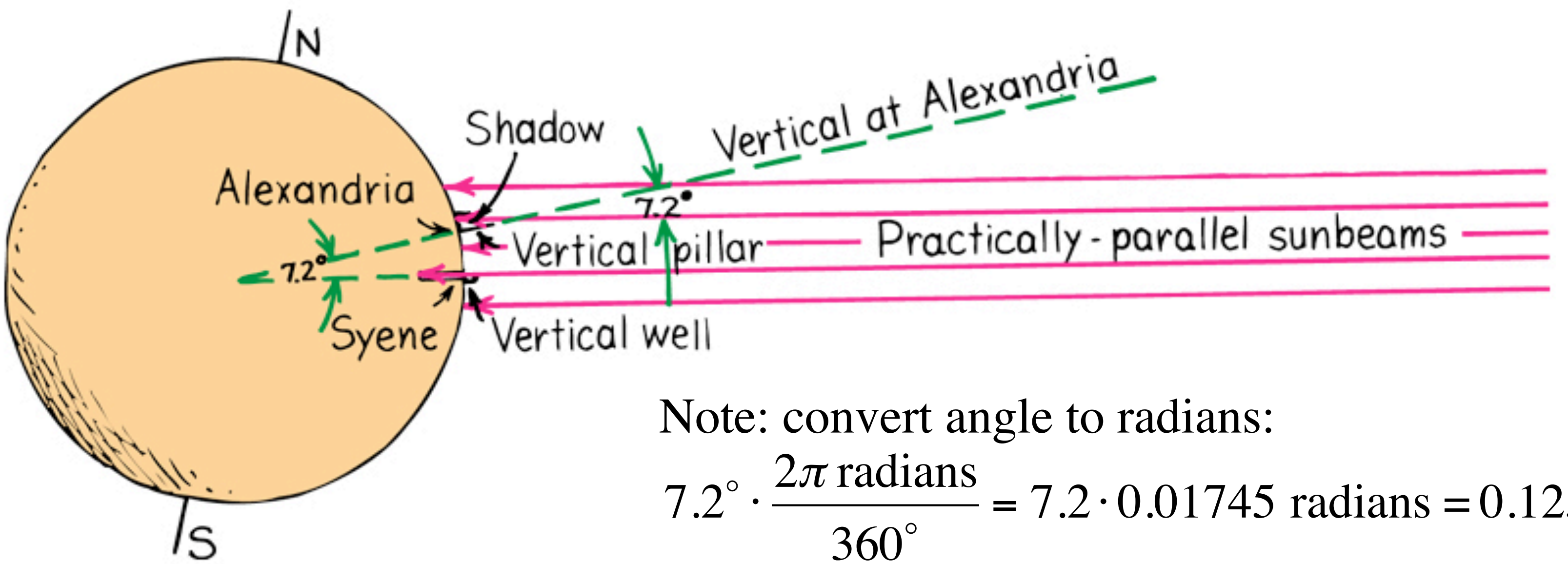
Let's try this out…

http://www.wordwizz.com/pwrsof10.htm

- Begin at everyday scale - 1m
- Proceed "downwards" to smaller and smaller sizes (attometer)
- Expand outwards to larger and larger sizes (the whole universe) - with many stops along the way…

How large is our home planet?

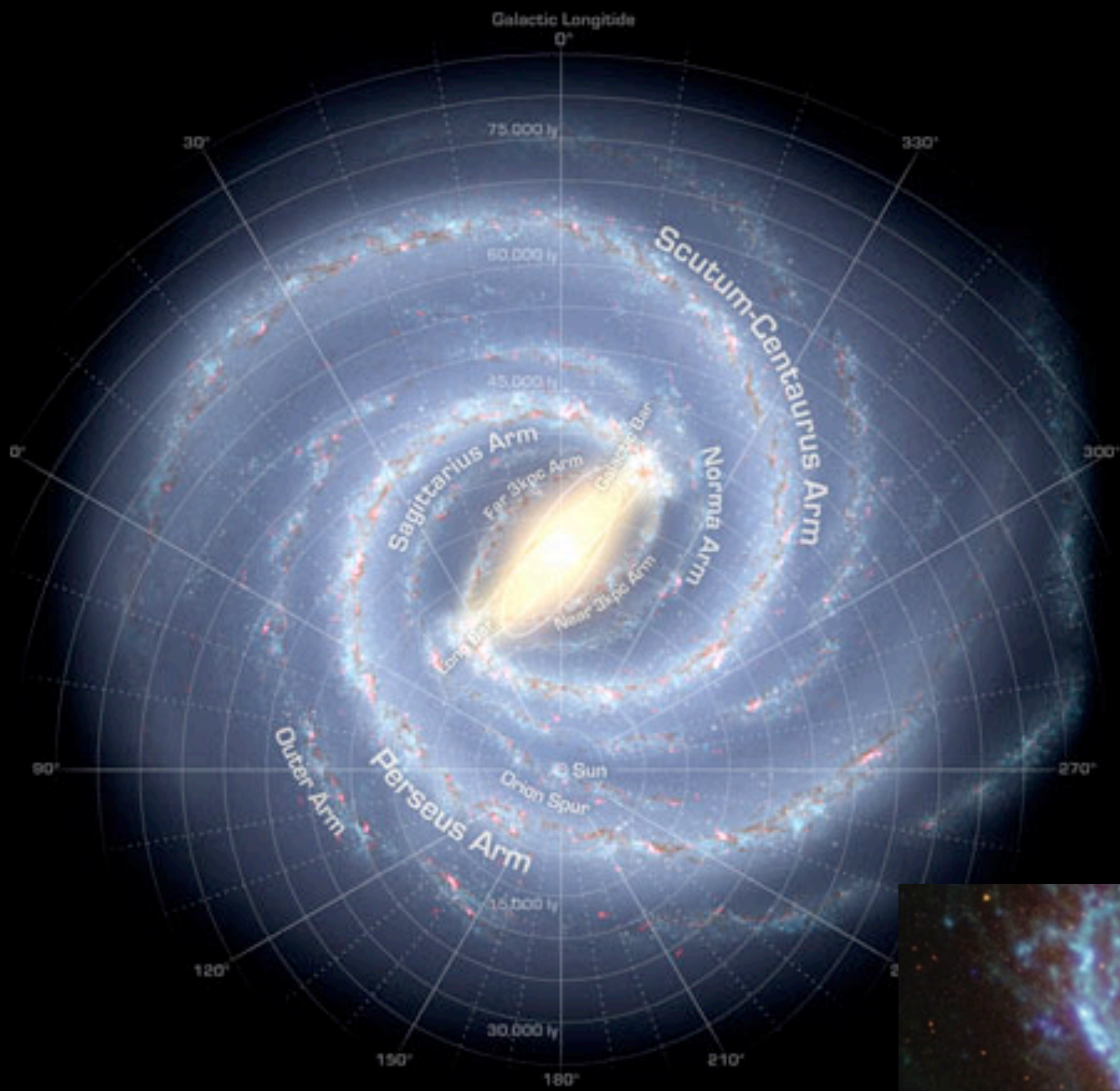
- Find 2 cities about 800 km apart
- When the sun is exactly overhead in one, measure angle at other one:
  Length of shadow = Angle [in radians] x Height of pillar =>
  Angle [in radians] = Length of shadow / Height of pillar = 1/8 = 0.125
- Angle [in radians] x Radius = distance =>
  Radius = 800 km / 0.125 radians = 6400 km



Note: convert angle to radians:

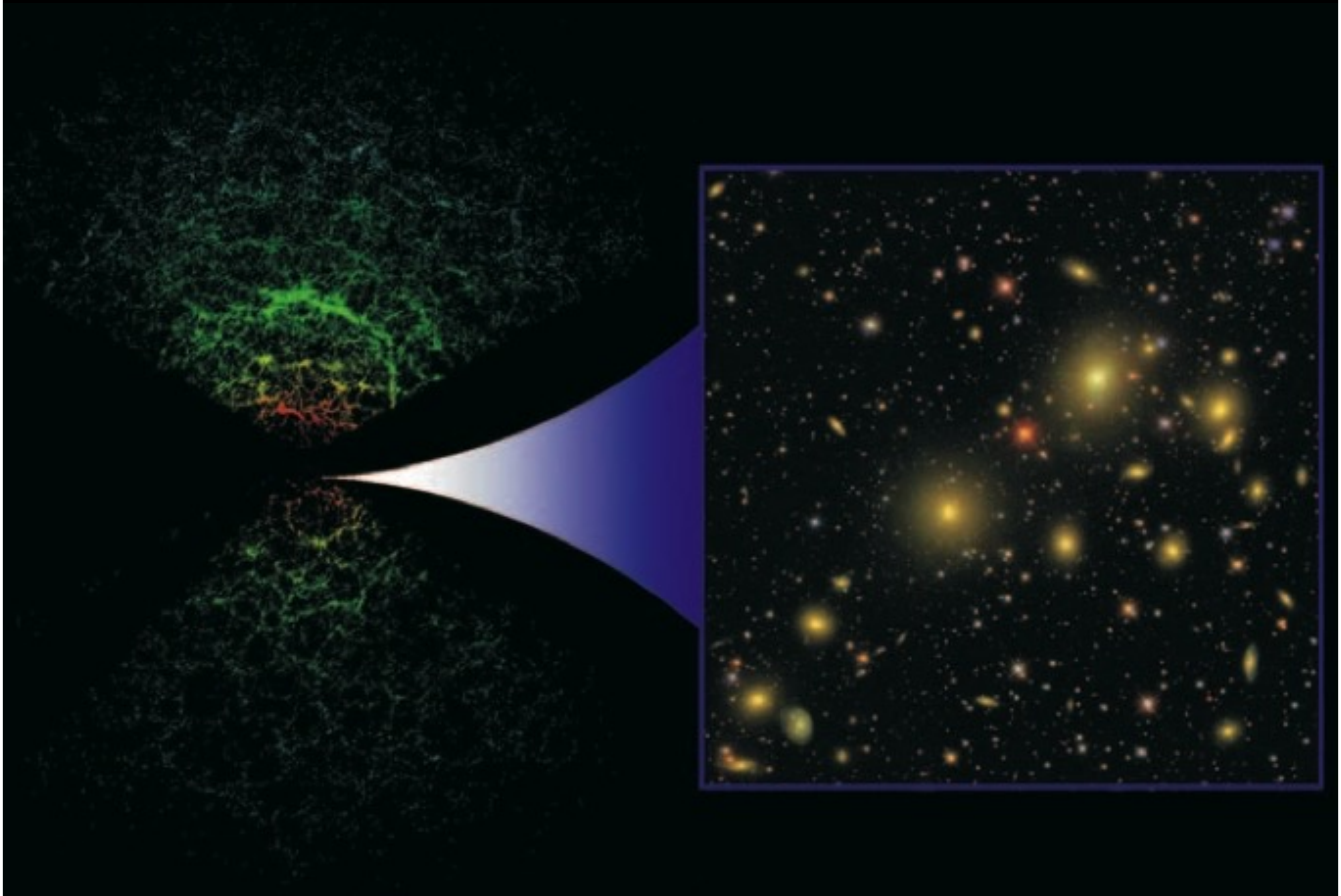
$$7.2^\circ \cdot \frac{2\pi \text{ radians}}{360^\circ} = 7.2 \cdot 0.01745 \text{ radians} = 0.1257 \text{ radians}$$


We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time. . . .
T. S. Eliot

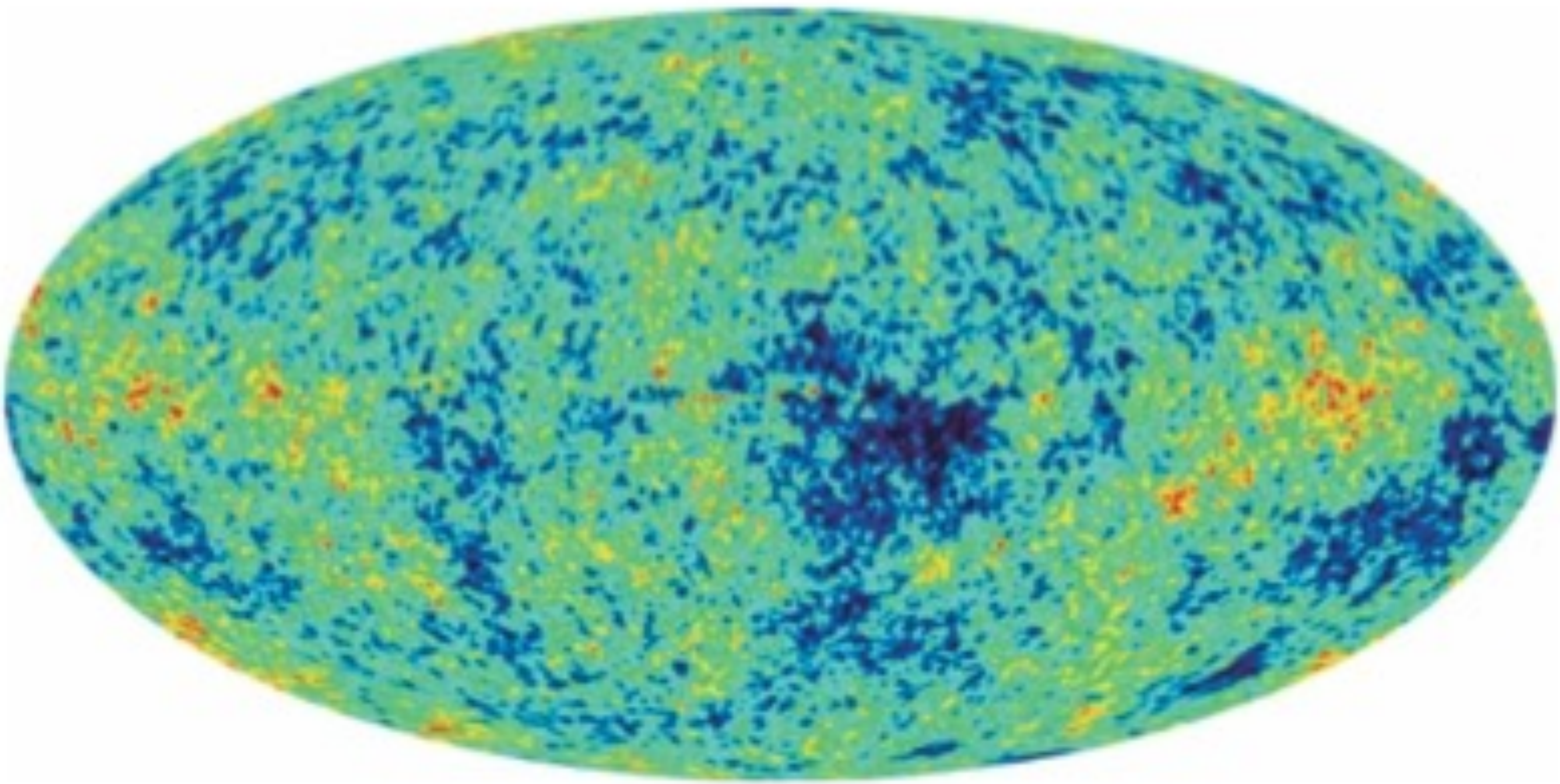


Milky Way

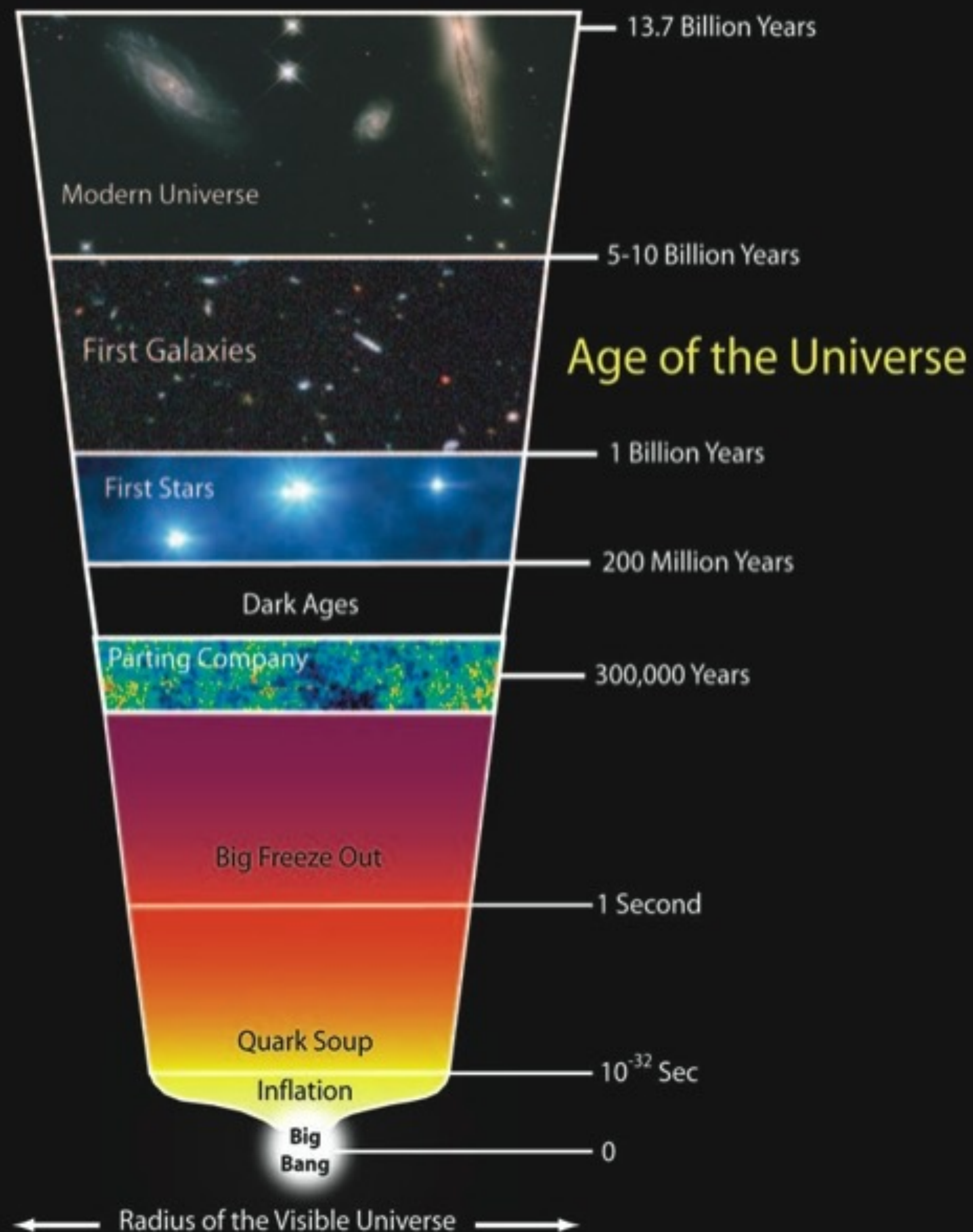
Andromeda



The large scale structure of our Universe



The 3K microwave background showing density fluctuations in our Universe at age 300,00 years



http://universeadventure.org/ A brief summary of the Universe

- About 14 billion years old (give or take a billion) - began in a “big bang”
- About 14 billion light years large (the part we can see at least)
- Expanding at a rate of 0.0000000075% per year
- **Accelerating** expansion!
- Approximate temperature today: 3 K = -465 F
- 100’s of billions of Galaxies, containing 100’s of billions of Stars each (many of them with planets), plus gas clouds, dust, neutron stars, black holes, quasars,… and *dark matter* and *dark energy*