

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)

gutezitate.com

...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.

www.quotecanyon.com

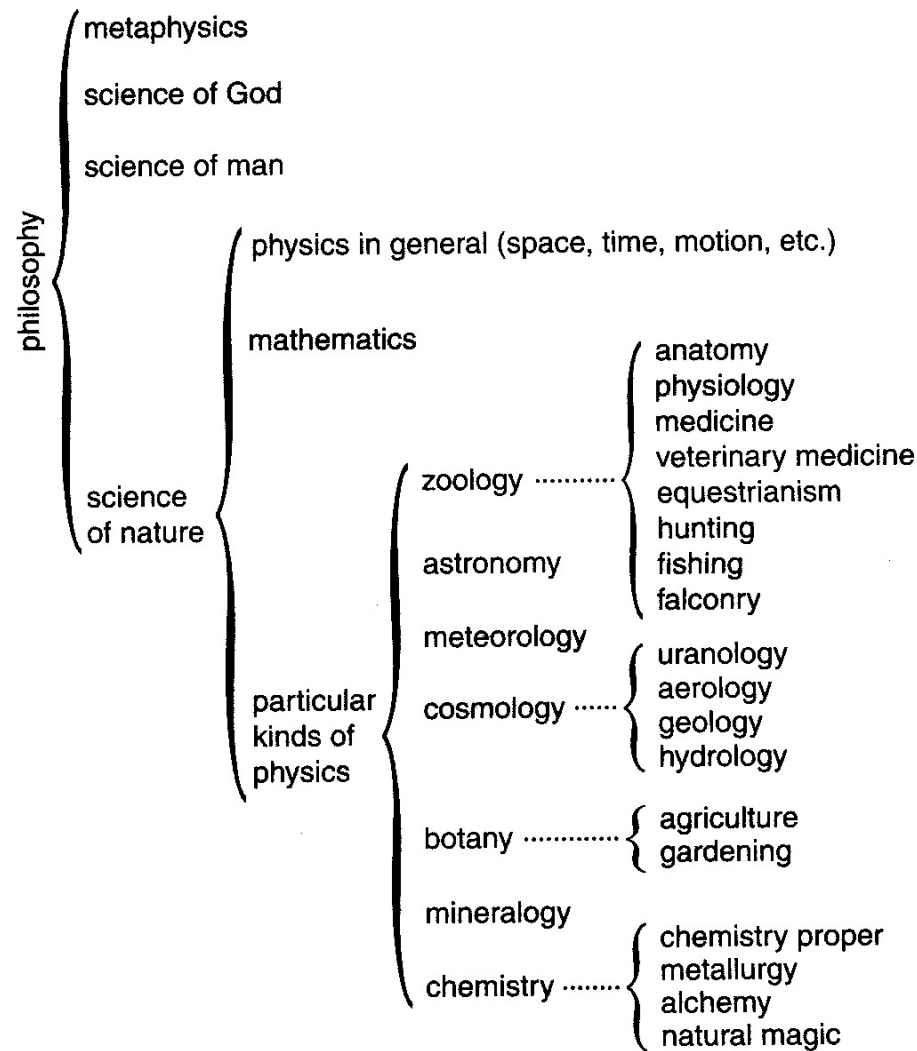
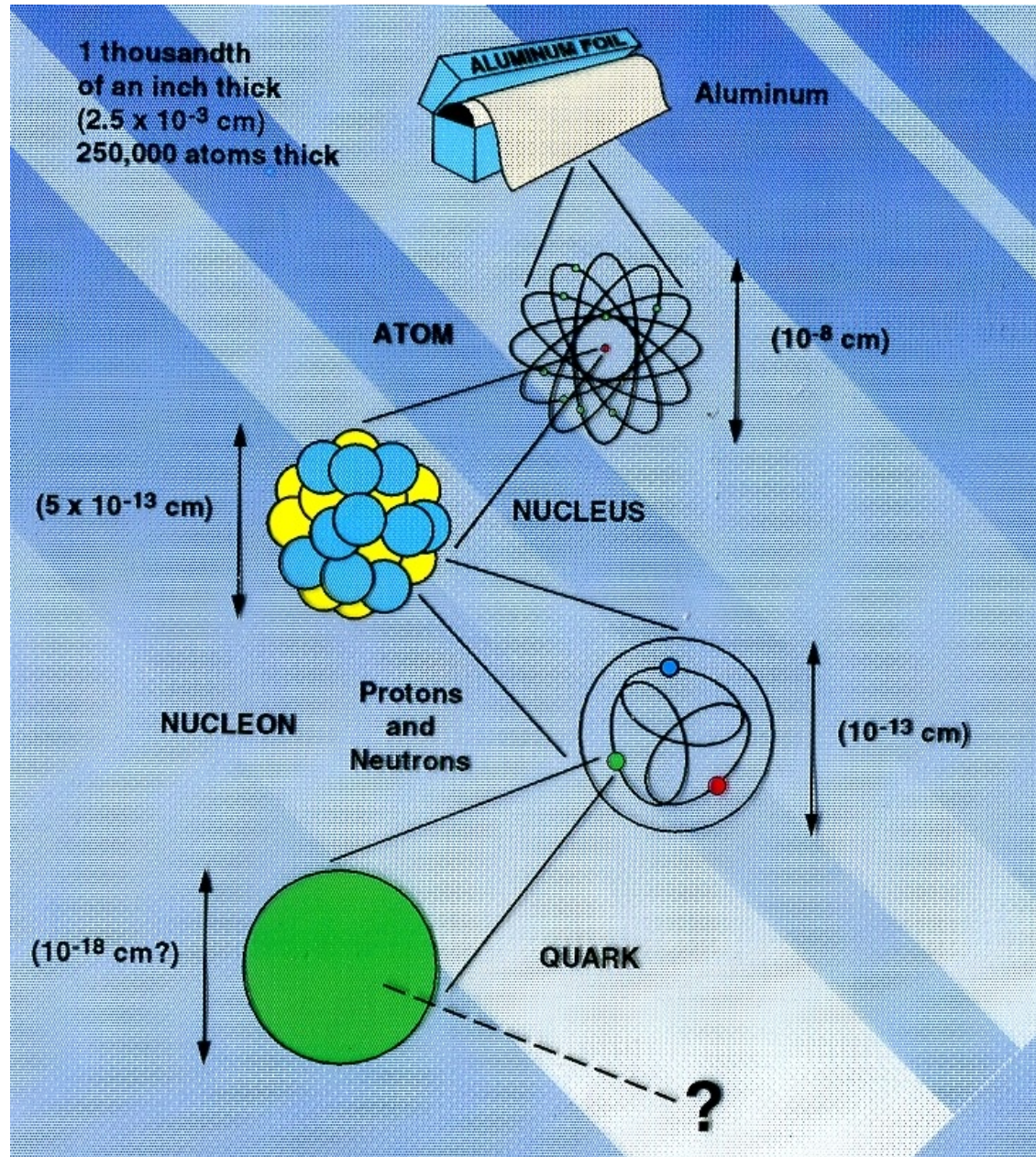


Figure 1. Tree of knowledge is the traditional scheme for organizing the categories of thought, as well as institutions such as university departments. Shown here is part of the tree adopted in the 18th-century *Encyclopédie* of Denis Diderot and Jean Le Rond d'Alembert. Note that the term *physics* had a rather different meaning then: Most of the sciences are classified as kinds of physics. (So are a few *nonsciences*.) 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, meteorology, and engineering

What is matter made of?



Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

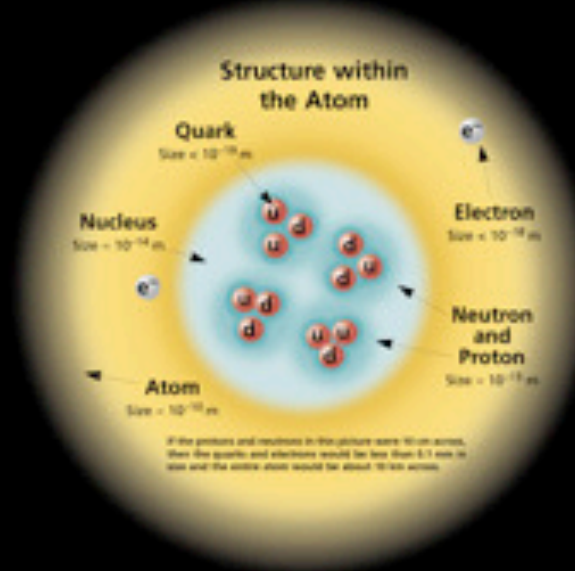
matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons $\text{spin} = 1/2$			Quarks $\text{spin} = 1/2$		
Flavor	Mass GeV/c^2	Electric charge	Flavor	Approx. Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	$2/3$
e^- electron	0.000511	-1	d down	0.006	$-1/3$
ν_μ muon neutrino	<0.0002	0	c charm	1.3	$2/3$
μ^- muon	0.106	-1	s strange	0.1	$-1/3$
ν_τ tau neutrino	<0.02	0	t top	175	$2/3$
τ^- tau	1.7771	-1	b bottom	4.3	$-1/3$

Spin is the intrinsic angular momentum of particles. Spin is given in units of \hbar , which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58 \times 10^{-27}$ GeV s $= 1.05 \times 10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt [eV], the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c² (remember $E = mc^2$), where 1 GeV = 10^9 eV = 1.60×10^{-10} joule. The mass of the proton is 0.938 GeV/c² = 1.67×10^{-27} kg.



BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c ²	Electric charge	Name	Mass GeV/c ²	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	-1	Color Charge Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the color of visible light. There are eight modes		
W^+	80.4	+1			
Z^0	91.187	0			

Color Charge
Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons, just as electric

ally-charged particles interact by exchanging photons, all strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and W and Z bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons.

the current infinite quarks and gluons, they are confined in color-neutral particles called **hadrons**. This confinement forces quarks into multiple alignments of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons, hence, these are the particles seen to emerge. Two types of hadrons have been obtained in nature: **mesons** of *anti baryons* only.

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$					
Baryons are fermionic hadrons. There are about 120 types of Baryons.					
Symbol	Name	Quark content	Electric charge	Mass G_e/c^2	Spin
p	proton	uud	1	0.938	1/2
\bar{p}	anti-proton	$\bar{u}\bar{u}\bar{d}$	-1	0.938	1/2
n	neutron	udd	0	0.940	1/2
\bar{n}	anti-neutron	$\bar{u}\bar{d}\bar{d}$	0	0.940	1/2
Λ	lambda	uds	0	1.116	1/2
$\bar{\Lambda}$	anti-lambda	$\bar{u}\bar{d}\bar{s}$	0	1.116	1/2
Ω^-	omega	sss	-1	1.672	3/2
$\bar{\Omega}^+$	anti-omega	$\bar{s}\bar{s}\bar{s}$	1	1.672	3/2

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic	Strong	
				Fundamental	Residual
Acts on:	Mass - Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag: for Two u quarks at:	10^{-42}	0.8	1	25	Not applicable to quarks
for two u quarks at:	10^{-42}	10^{-4}	1	60	
for two protons in nucleus	10^{-36}	10^{-7}	1	Not applicable to hadrons	20

Mesons $q\bar{q}$					
Mesons are bosonic hadrons. There are about 140 types of mesons.					
Symbols	Name	Quark content	Electric charge	Mass GeV/c^2	Spin
π^+	pion	$u\bar{d}$	+1	0.140	0
K^-	kaon	$s\bar{u}$	-1	0.494	0
ρ^+	rho	$u\bar{d}$	+1	0.770	1
B^0	B meson	$d\bar{b}$	0	5.279	0
η_c	charmonium	$c\bar{c}$	0	2.980	0

Mutter and Anderson

For every particle type there is a corresponding antiparticle, indicated by a bar over the particle symbol (unless + or - charge). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g. Z^0 , η , and K^0 in 80) are their own antiparticles.

Prepared:

These diagrams are an artist's conception of physical processes and have no meaningful scale. Green shaded are the cloud of gluons or the gluon field, and red lines the quarks.



ing web feature *The Particle Adventure* at cmap.adventure.lbnl.gov

made possible by the generous support of
National Laboratory
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Many Physics Education Projects. CPER is a non-profit organization, and educators. Send mail to: CPER, MS 50-208, Lawrence Berkeley National Laboratory, Berkeley, CA, 94720. For information on charts, text, research activities, and workshops, see:

<http://www.epl.gov/cpeg.html>

The Nucleus

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

At 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.

neutron

10^{-15} m

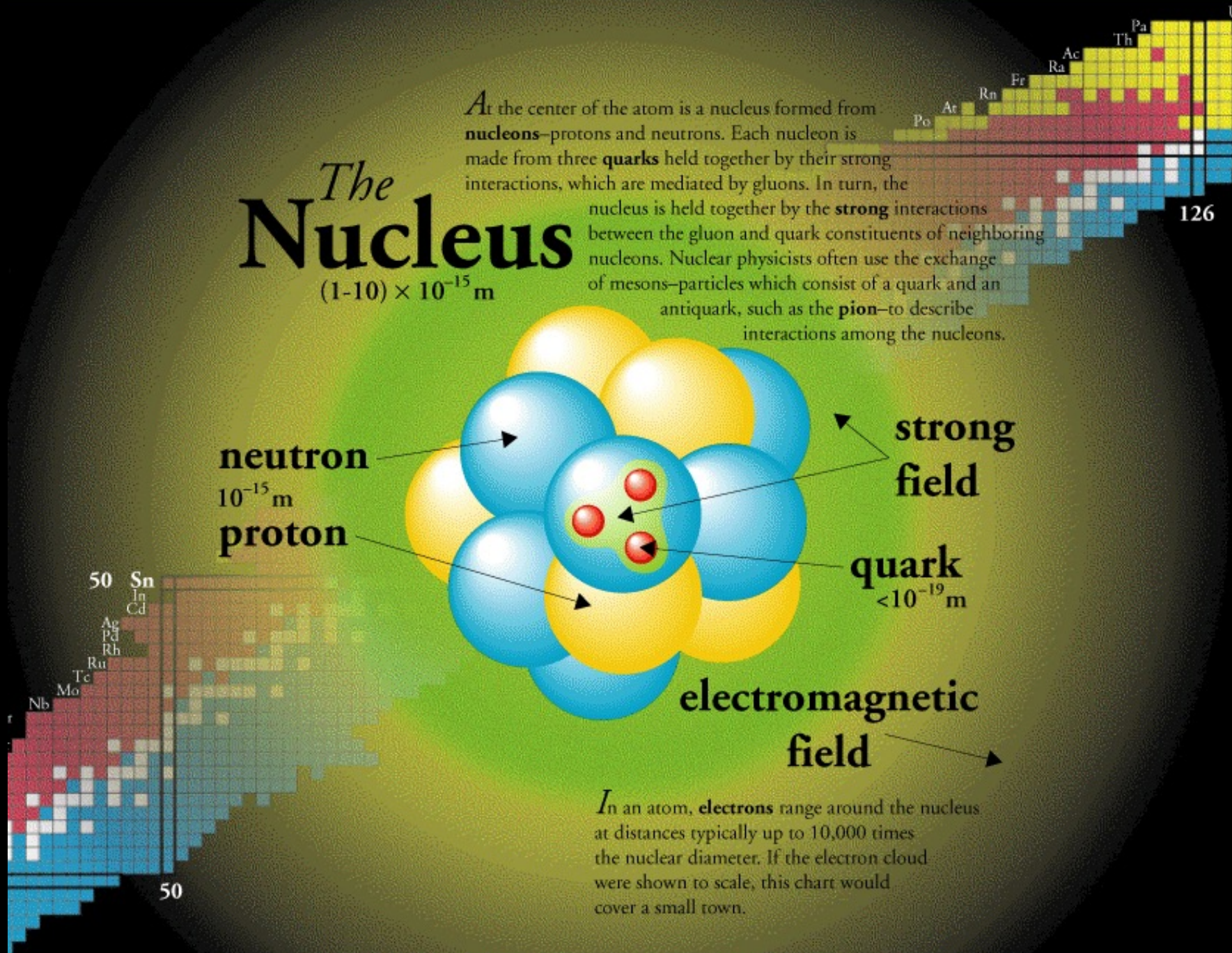
proton

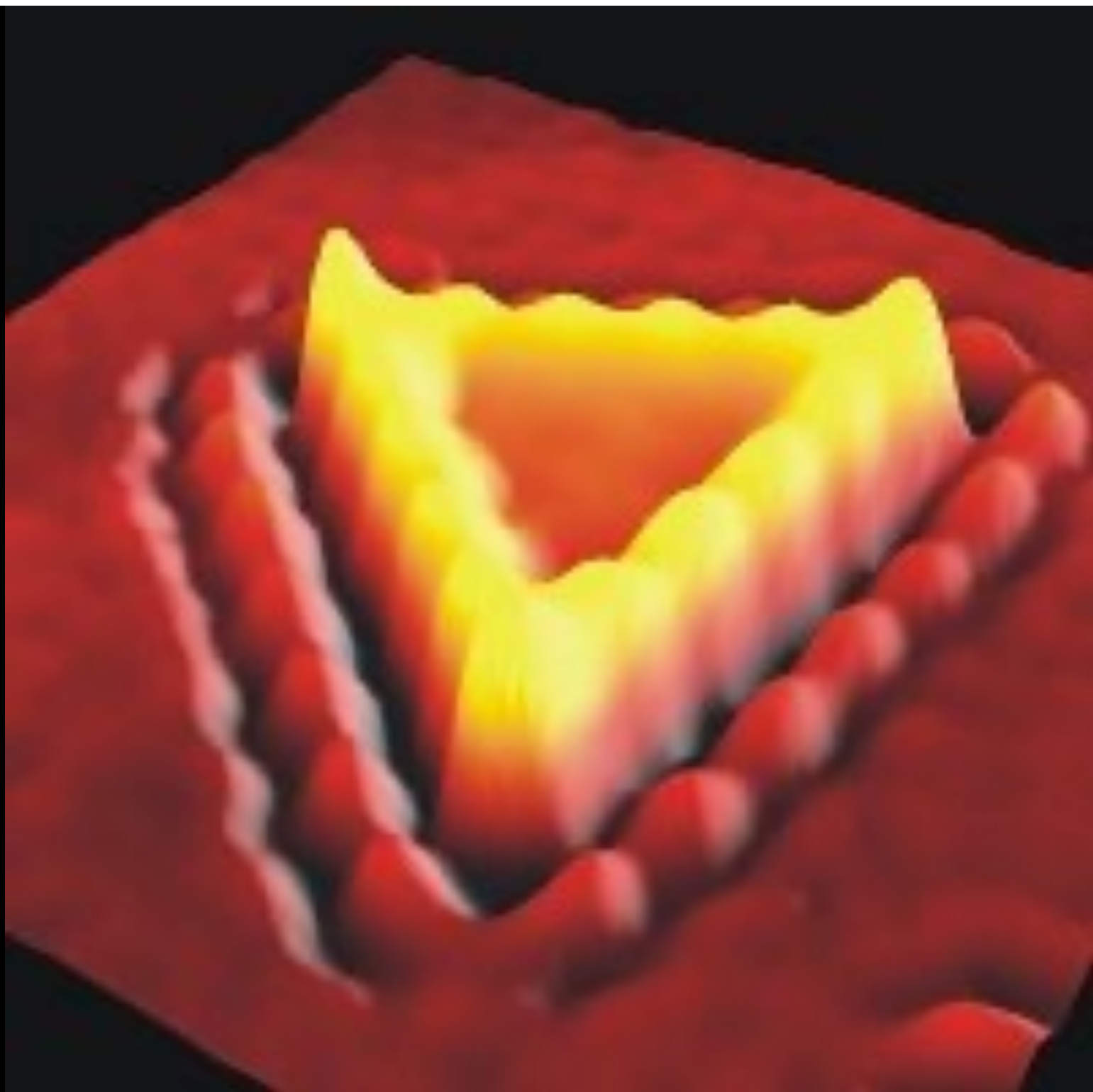
strong field

quark
 $<10^{-19} \text{ m}$

electromagnetic field

In 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 and Expanding Universe

Space is expanding from an initial moment called the Big Bang. As it expands, the universe becomes less dense and cools. All distant galaxies are moving apart from each other and away from us. On large scales, the universe looks the same in all directions and in all parts of space. There is no center. Our current understanding of the early universe is called the Big Bang model. We are continuing to learn from astronomical observations and from accelerator-based experiments.

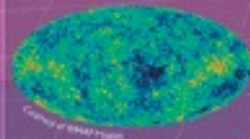
History of the Universe

Cosmology and Relics of History

Cosmology is the study of the universe as a whole. As in archaeology, cosmology finds clues to the past in relics. We can look back in time by looking out in space. Since light travels at a finite speed c , the closer we are looking back in time, the closer we are to the present. The laws of nature discovered on Earth are applied to the early universe and tested by observing relics.

A Relic from the Early Universe

The Cosmic Microwave Background (CMB) is a universal bath of lightwaves (photons) from the hot, dense, early universe. To one part in 100,000, the CMB is the same no matter where you look. The remaining tiny variations in the density of microwave (shown in figure) are seeds that later form galaxies and larger cosmic structures.



This is an image of the universe from the time when stars first formed. It is a map of the entire sky showing CMB light with the uniform part subtracted.

Age of the Universe

Studying the cosmic microwave background, the expansion of the universe, and the life cycles of stars leads to a marvelous agreement that the age of the universe is about 14 billion years (1.4×10^{10} years).

Four major eras in the expansion history:

Era 1 - Acceleration: Inflation Speeds Expansion

Observations seem to imply that the very early universe underwent an extremely rapid, accelerating expansion, called inflation. In a tiny fraction of a second, inflation expanded each part of space by a factor of at least 10^{25} . Before inflation, the portion of the universe visible to us today was a speck of space much smaller than a proton. As inflation ended, the visible universe had grown (very approximately) to the size of a ball.

Era 2-3 - Deceleration: Expansion Slows and Structure Forms

After inflation, the universe was a soup of fundamental particles, called a quark-gluon plasma. Photons and fast-moving particles, generically called radiation, gradually lost energy (cooled) as the universe expanded (the energy went into the expansion). Eventually, slow-moving matter became dominant over radiation. Over time, larger and larger structures grew from galaxies to clusters of galaxies to superclusters.

Simulation of matter distribution in the early universe that eventually yielded patterns and clusters of galaxies.

Era 4 - Acceleration: Dark Energy Speeds Expansion

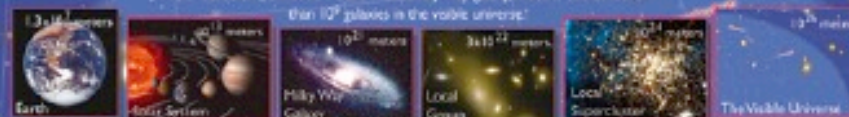
Astronomers had assumed that the current universe is dominated by matter, which would cause deceleration and might even reverse the expansion. So it was a great surprise in 1998 when observations showed that the expansion of the universe is now accelerating (see the "Accelerating Universe" plot). This implies the existence of a bizarre new form of energy, referred to as dark energy.

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.



Our Cosmic Address

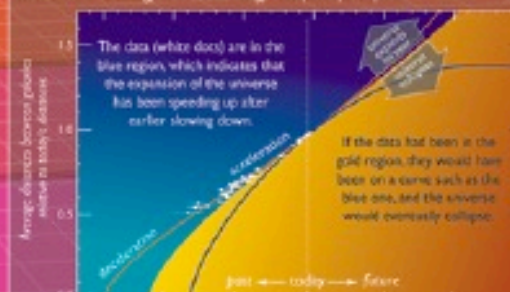
Our size is one of 4×10^{21} stars in the Milky Way galaxy, which is one of more than 10^9 galaxies in the visible universe.



The Accelerating Universe

By observing other astronomical relics, distant exploding stars called supernovae, astrophysicists are digging ever farther back into the history of the universe.

The plot shows data (white dots) from distant supernovae. The orange curve, with the best fit to the supernovae data, shows that billions (10^9) of years ago the expansion of the universe began to accelerate (the data curve upward slightly). This acceleration is attributed to a new form of energy called "dark energy" that pulls space apart.



Before the supernova research, physicists believed that the whole expansion history of our universe would lie in the gold region, where the expansion would be slowed by the attractive force of gravity. Now we see from the supernovae data that the expansion history lies in the blue region, where attractive and repulsive forces compete for dominance.

The Fate of the Universe

Whether the expansion of the universe will speed up, slow down, or even possibly reverse into collapse depends (according to gravitation theory) on the amount and types of matter and energy in it.

The ordinary matter (atoms and nuclei) that formed in the early universe can account for the visible mass in galaxies and clusters. But the amount of ordinary matter is a tiny fraction of the total mass needed to bind a galaxy or cluster together gravitationally and explain its internal motions. So an extraordinary new type of matter, not made of atoms or nuclei, must exist. It is called dark matter because it is not directly visible.

Even stranger, recent observations of supernovae in distant galaxies show that the expansion of the universe is in fact accelerating. An exotic dark energy may be causing this acceleration through a cosmic repulsion that overweighs the pull of gravity due to matter.

Composition of the Universe

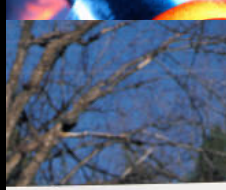


ORDINARY MATTER

The nature of dark energy and dark matter are two of the great questions facing cosmology and particle physics. Perhaps dark energy is the cosmological constant, introduced by Albert Einstein in 1917. Perhaps both are new parts of particle physics, tied to the very earliest moments of the universe and having to do with the nature of physics and spacetime itself.

Not all answers in science are known yet. With research and experiments under way in astrophysics, particle physics, and nuclear physics, we may be the first generation to learn what most of the universe is made of and what is the fate of the universe.

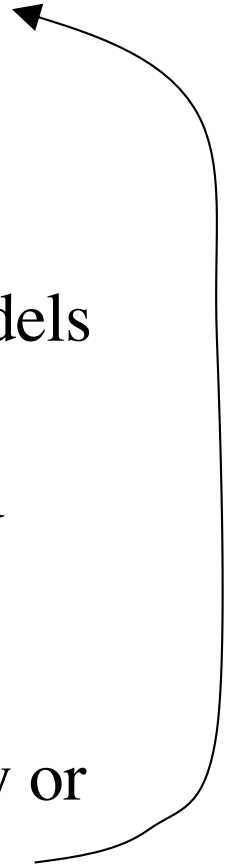
Learn more at
UniverseAdventure.org
and at **CPEPweb.org**



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

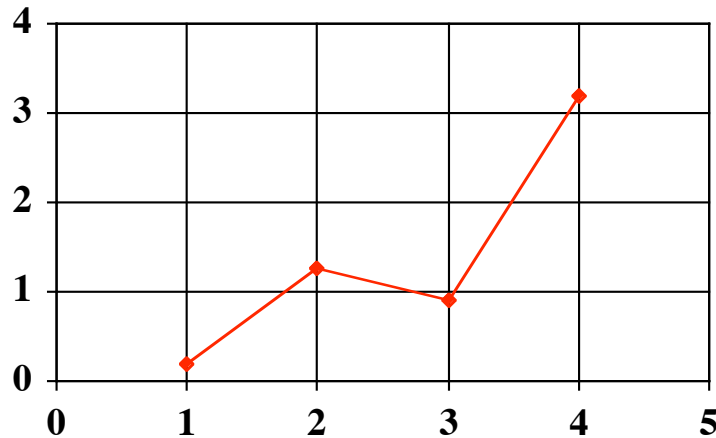
- Define (or refine the definition of) **observables** (concepts, “agents” or quantities that can be used to organize and explain your data).
Important: Give a **precise, operational** definition
- Develop mathematical relationships between different observables that both agree with your observations 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 ($H = \frac{1}{2} a t^2$).
- Develop a Model: Define gravitational force F (measure with bathroom scale). Define mass M . Write down $F = Ma$.
- Predict orbits of moon, satellites,...

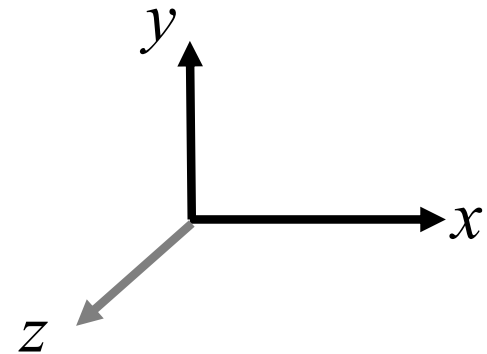
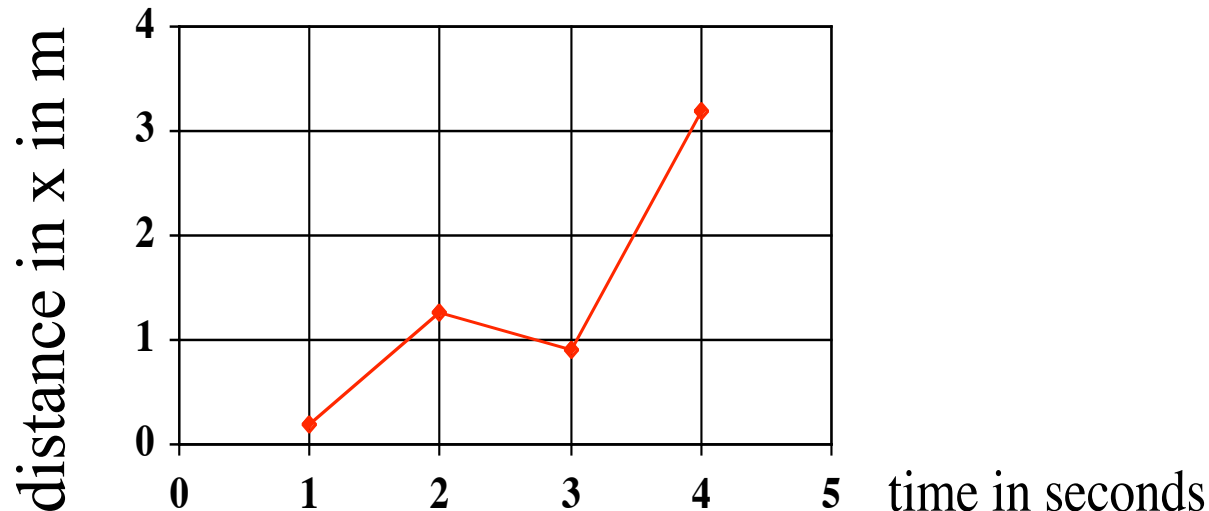
Quantities in Mathematics

- 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

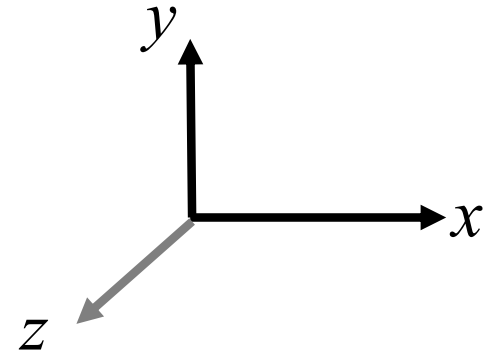
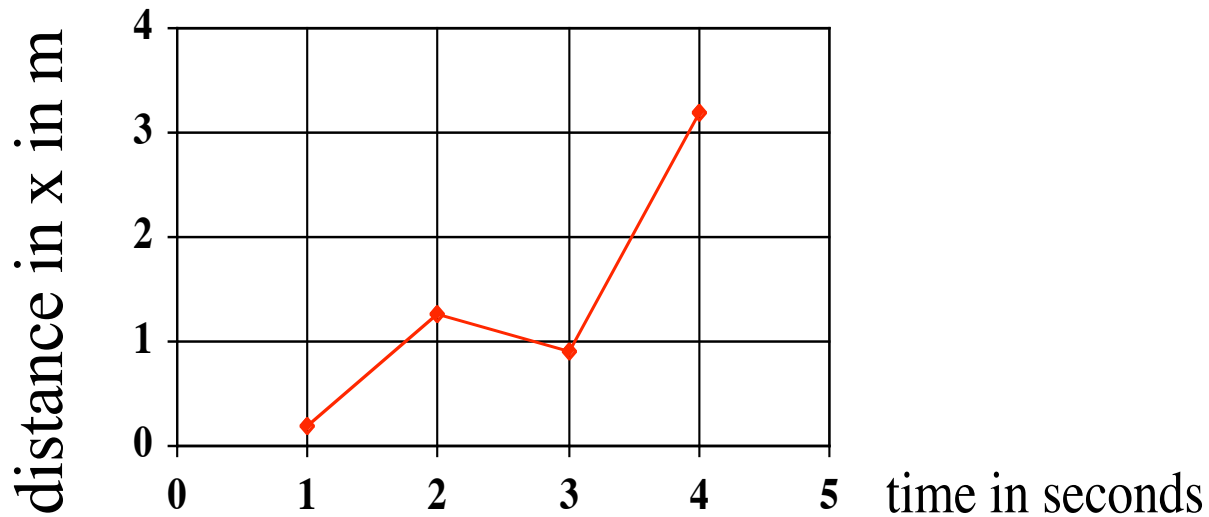


Quantities in Nature

- 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 ($10^6/\text{s}$), mg ($10^{-3}\text{g} = 10^{-6}\text{kg}$),
ns (10^{-9} s ; light travels 1 m in 3.336 ns)

Let's try this out...

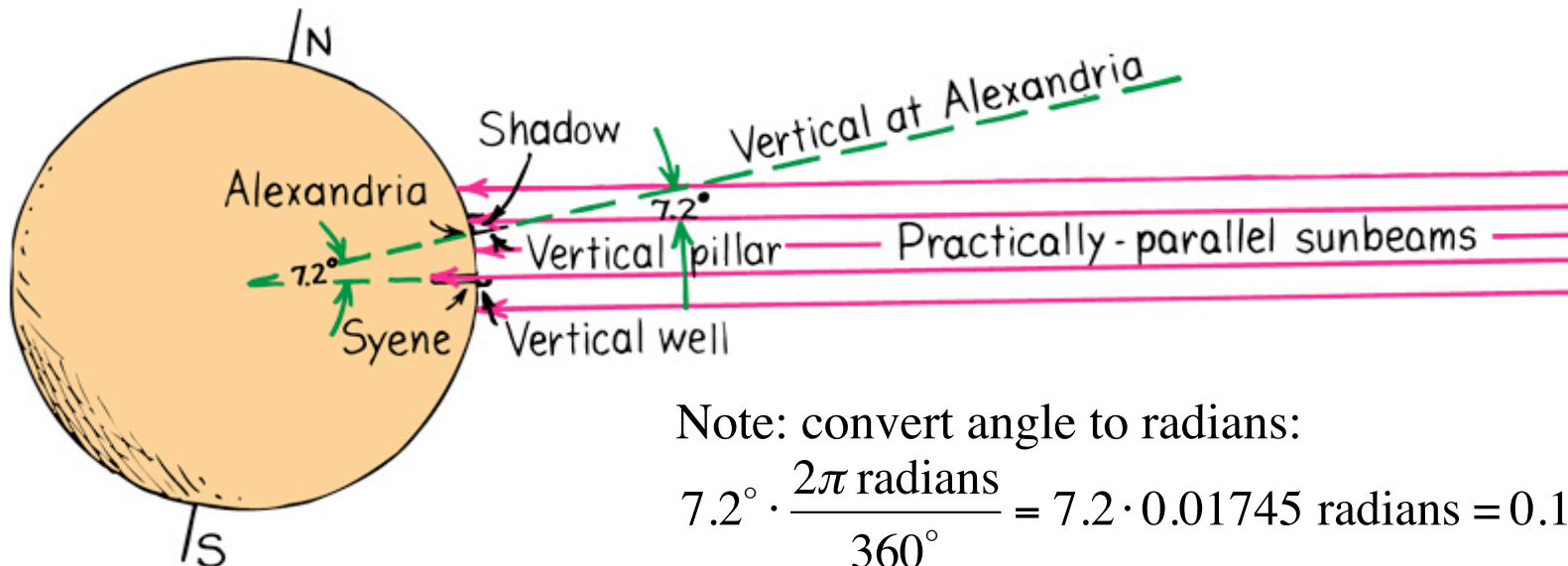
<http://www.wordwizz.com/pwrsof10.htm>

- 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] \times Height of pillar \Rightarrow
Angle [in radians] = Length of shadow / Height of pillar = $1/8 = 0.125$
- Angle [in radians] \times Radius = distance \Rightarrow
Radius = 800 km / 0.125 radians = 6400 km



Note: convert angle to radians:

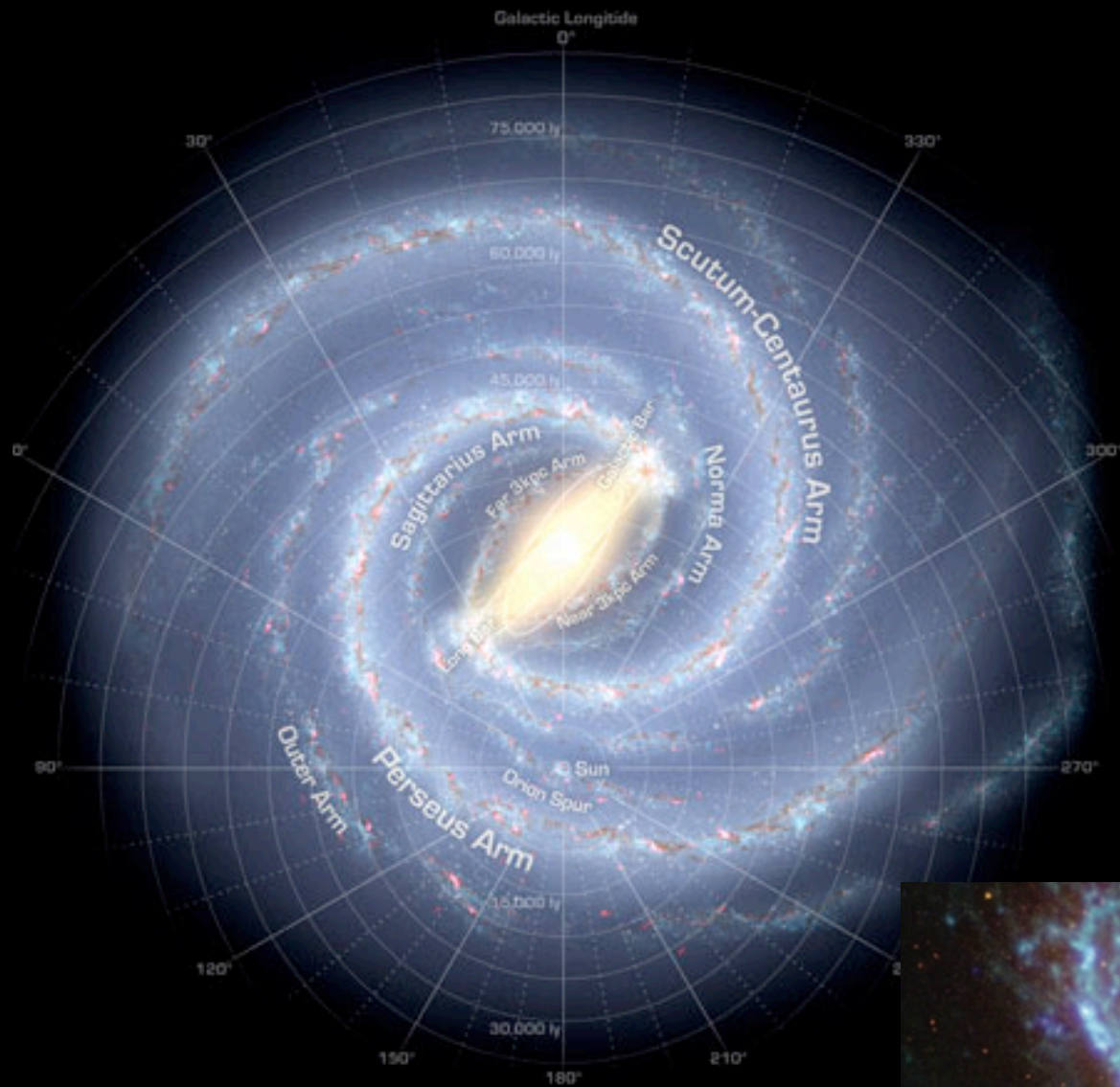
$$7.2^\circ \cdot \frac{2\pi \text{ radians}}{360^\circ} = 7.2 \cdot 0.01745 \text{ radians} = 0.1257 \text{ radians}$$



*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. . . .*

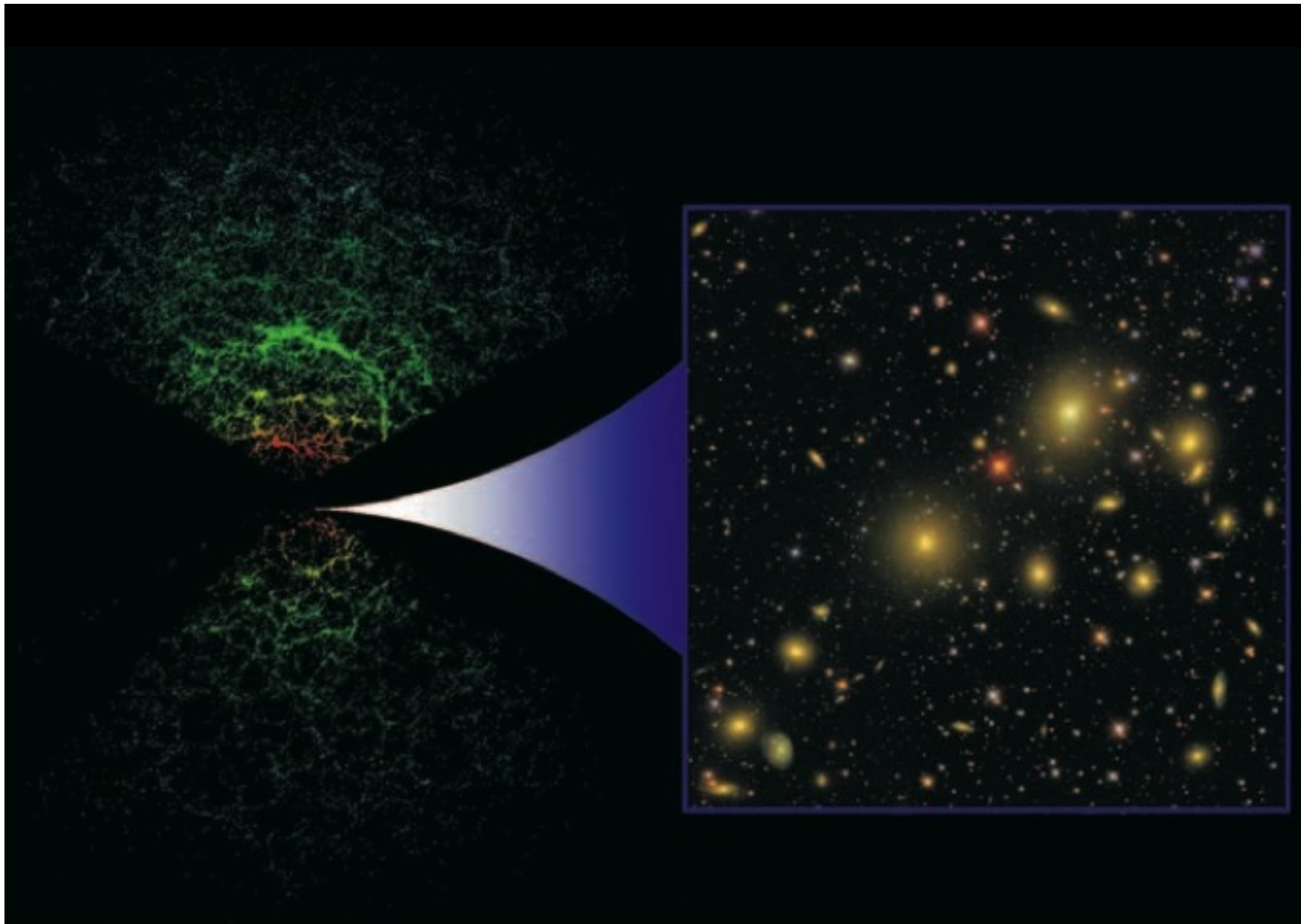
T. S. Eliot

Milky Way

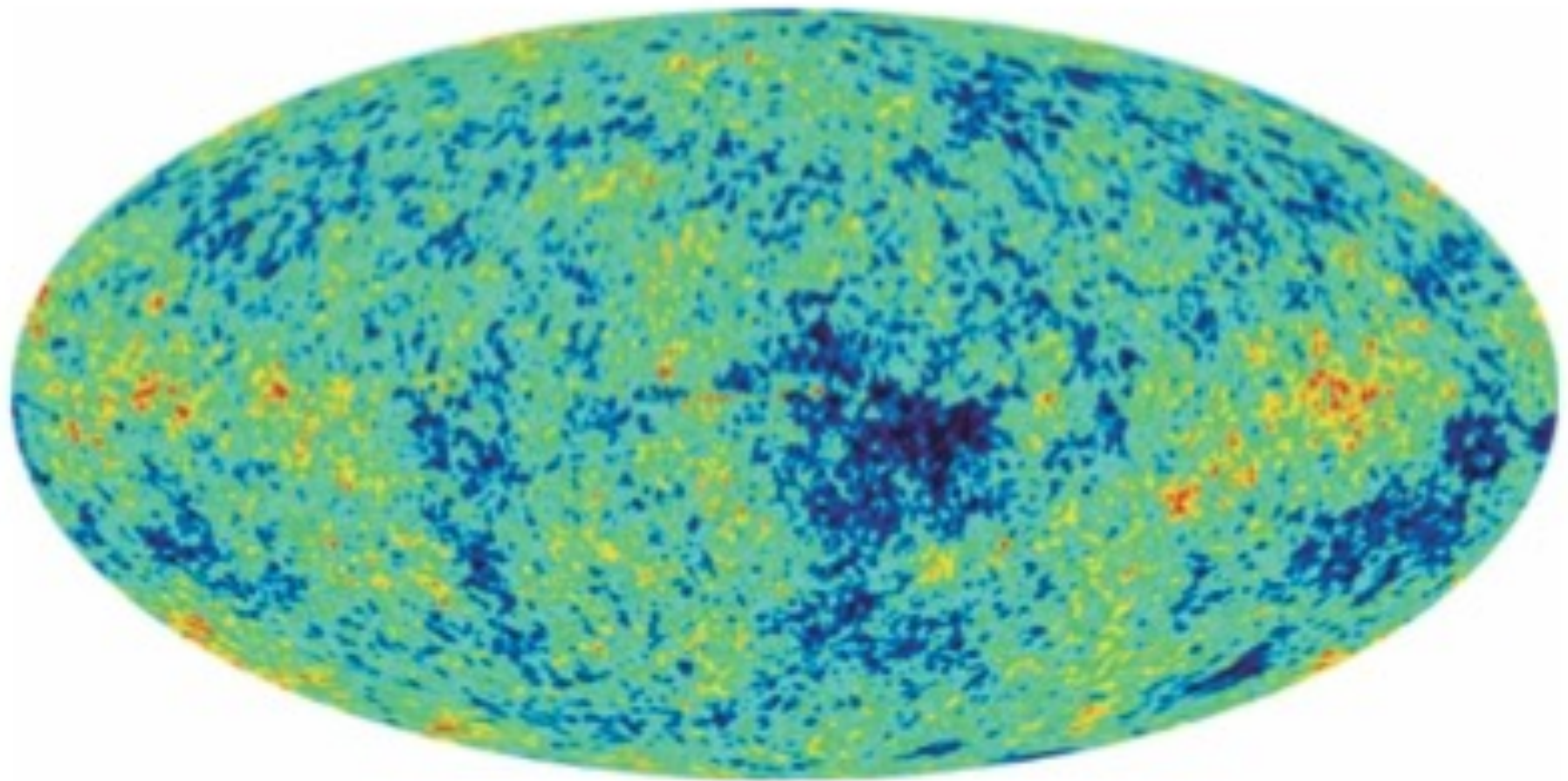


Andromeda

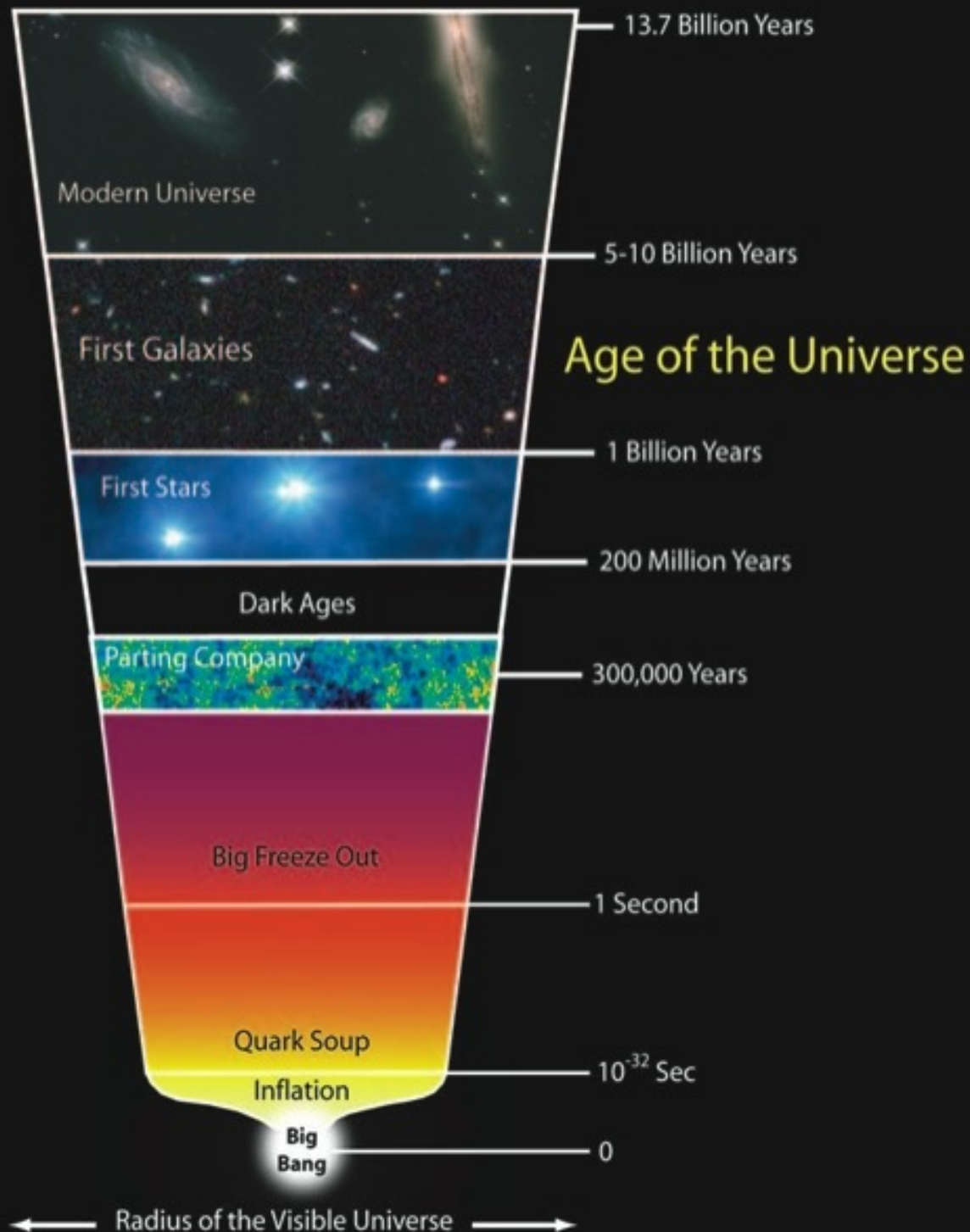




The large scale structure of our Universe



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*