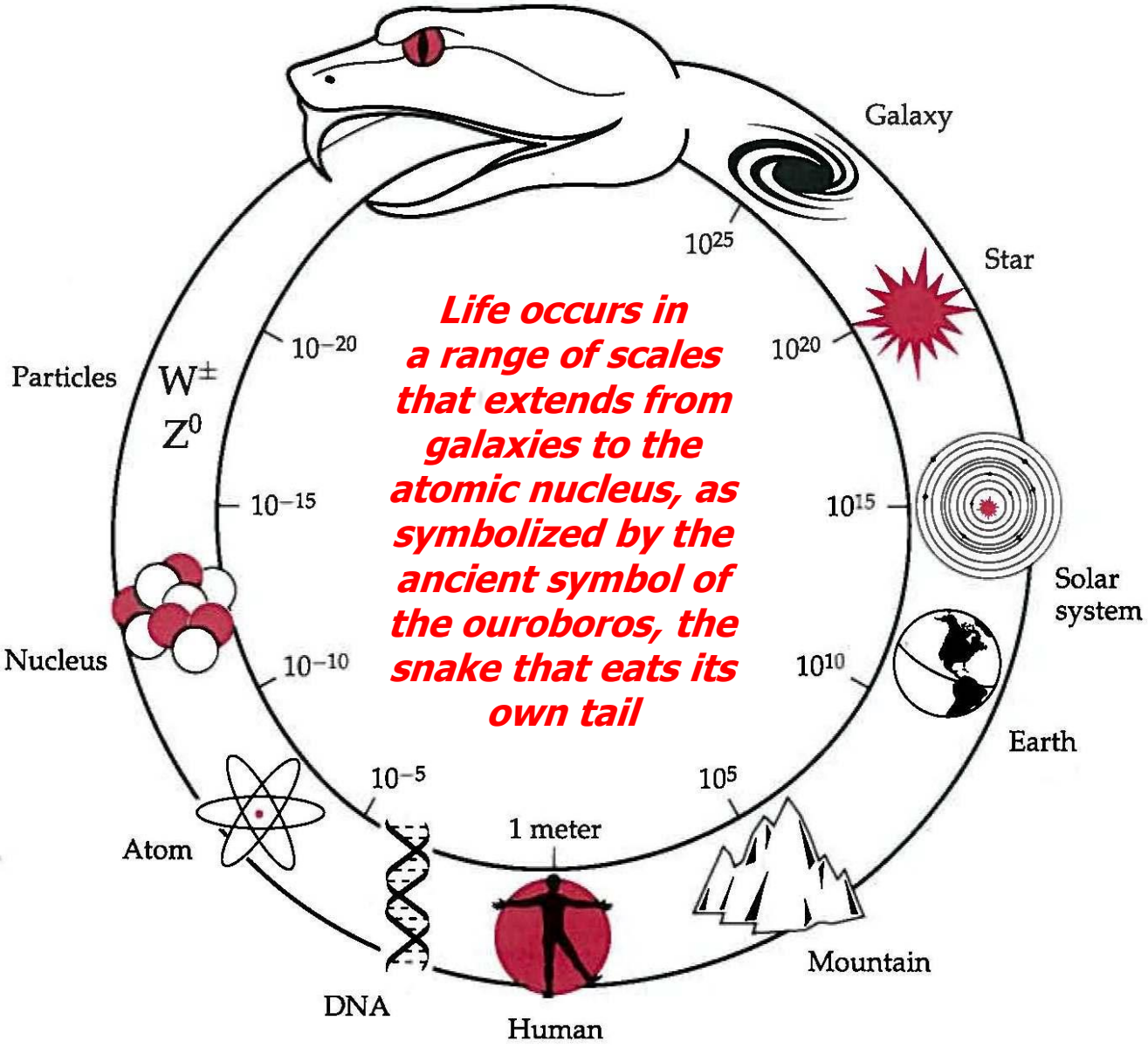
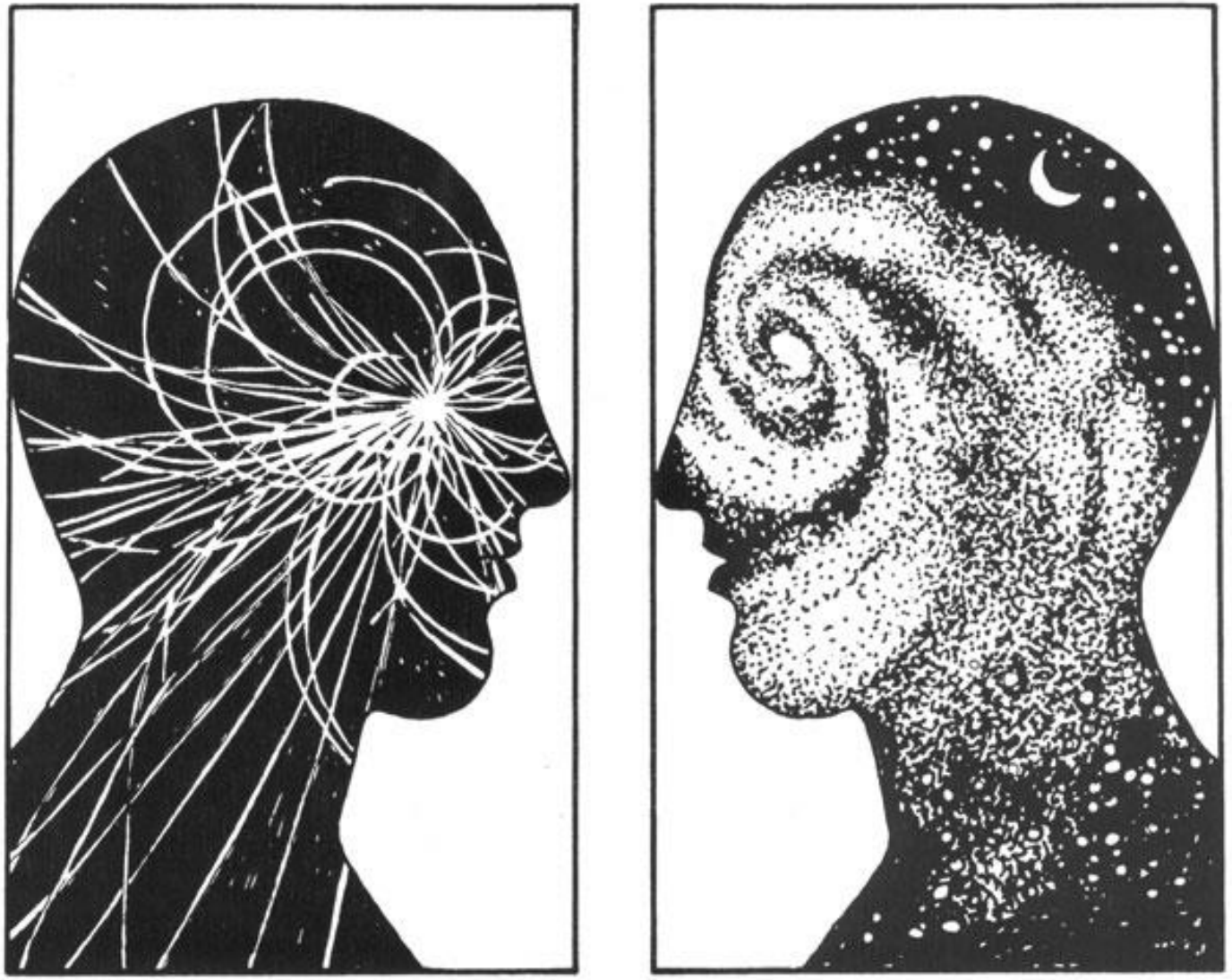
ASTRONOMY
EXPLORING SPACE & TIME

Matter and Radiation

Unity


Galaxy
10^{25}
Star
10^{20}
10^{15}
Solar system
10^{10}
Earth
10^{5}
Mountain
1 meter
Human
10^{-5}
DNA
10^{-10}
Atom
Nucleus
10^{-15}
10^{-20}
Particles
$W^{\pm}$
Z^{0}
Life occurs in a range of scales that extends from galaxies to the atomic nucleus, as symbolized by the ancient symbol of the ouroboros, the snake that eats its own tail

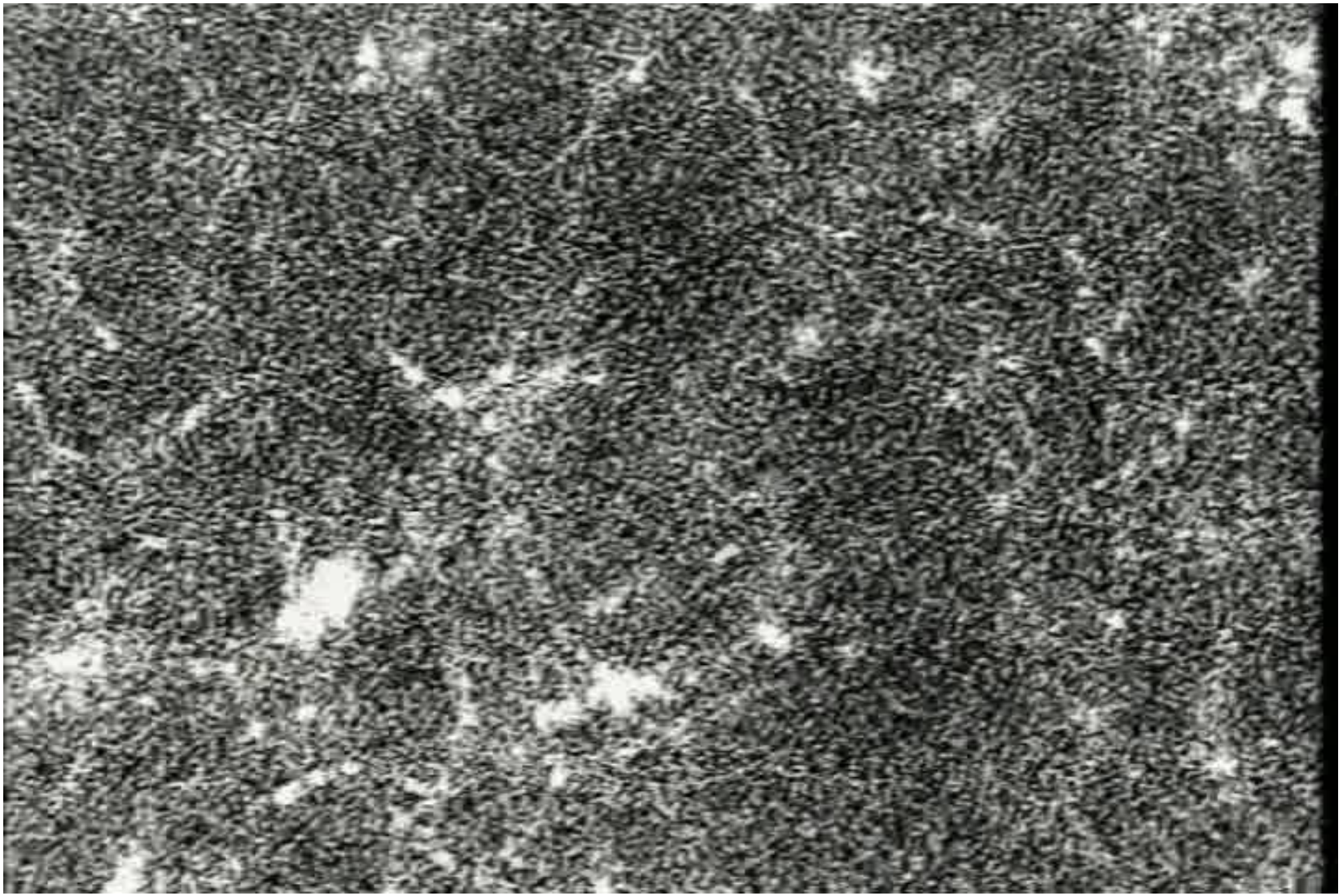


We are made of tiny particles and we are part of an enormous galaxy, yet we keep both within our heads

Cosmic Zoom

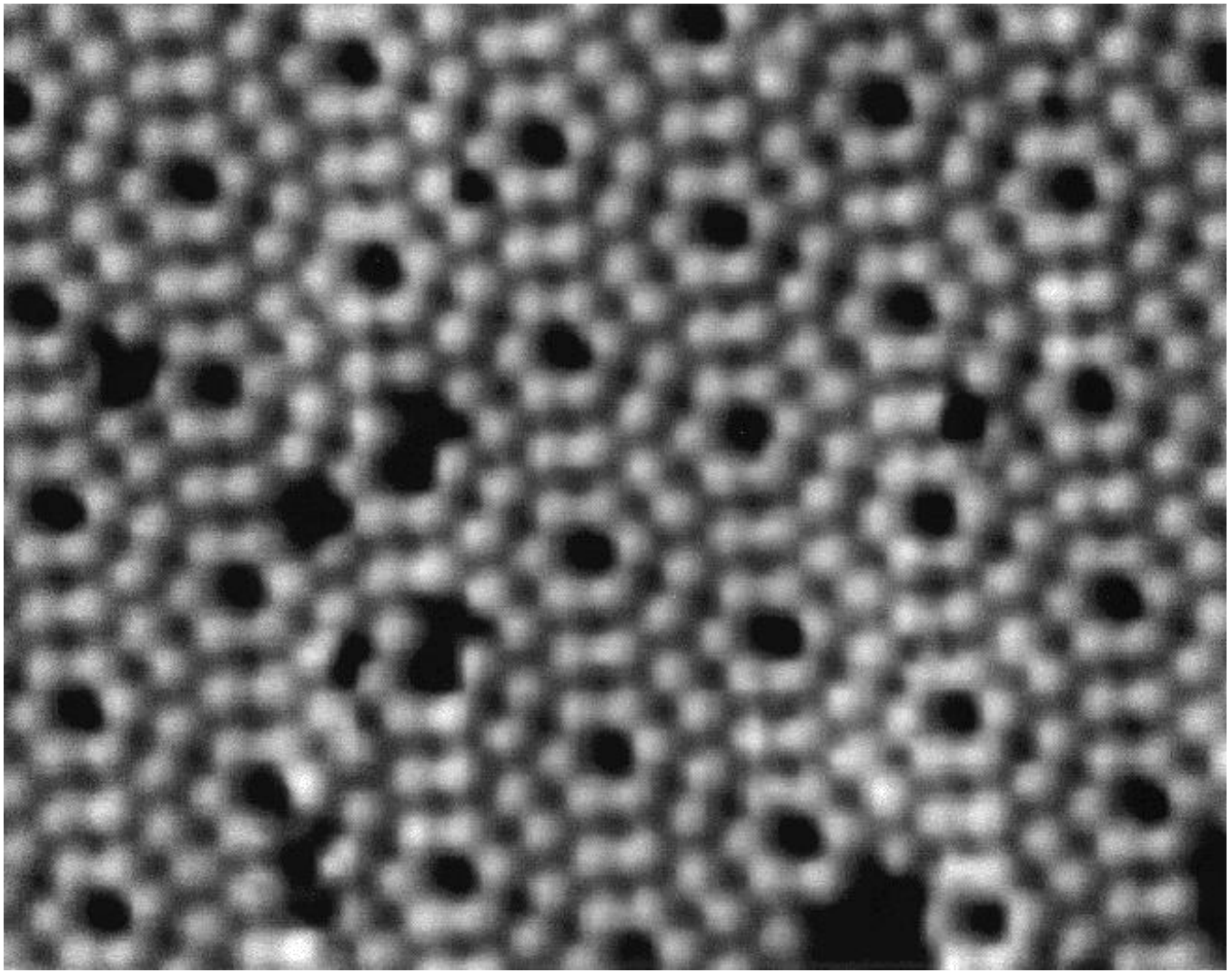
***Cosmic Voyage* (1997)**

Cosmic Zoom

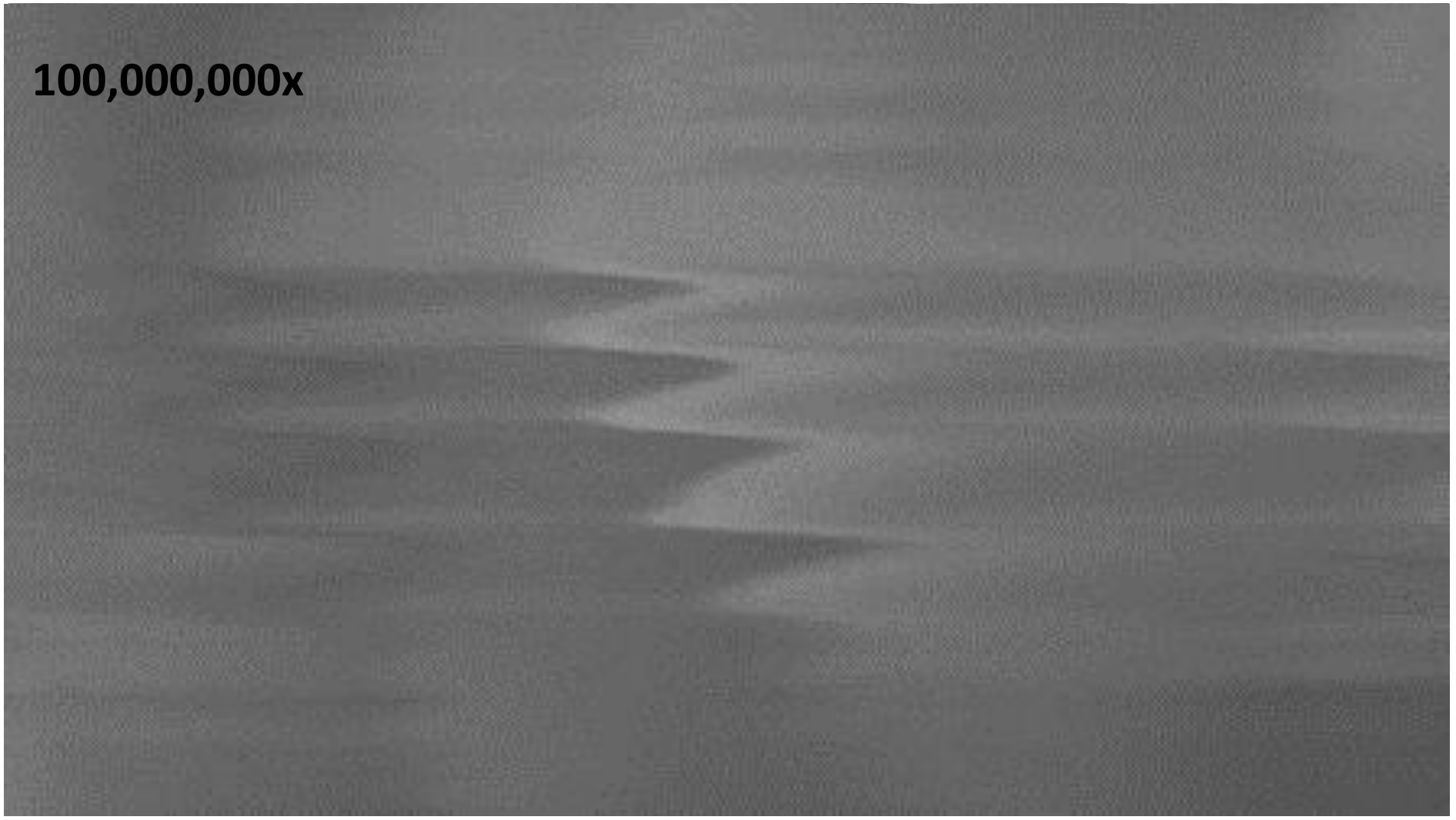


***Cosmic Voyage* (1997)**

Atoms

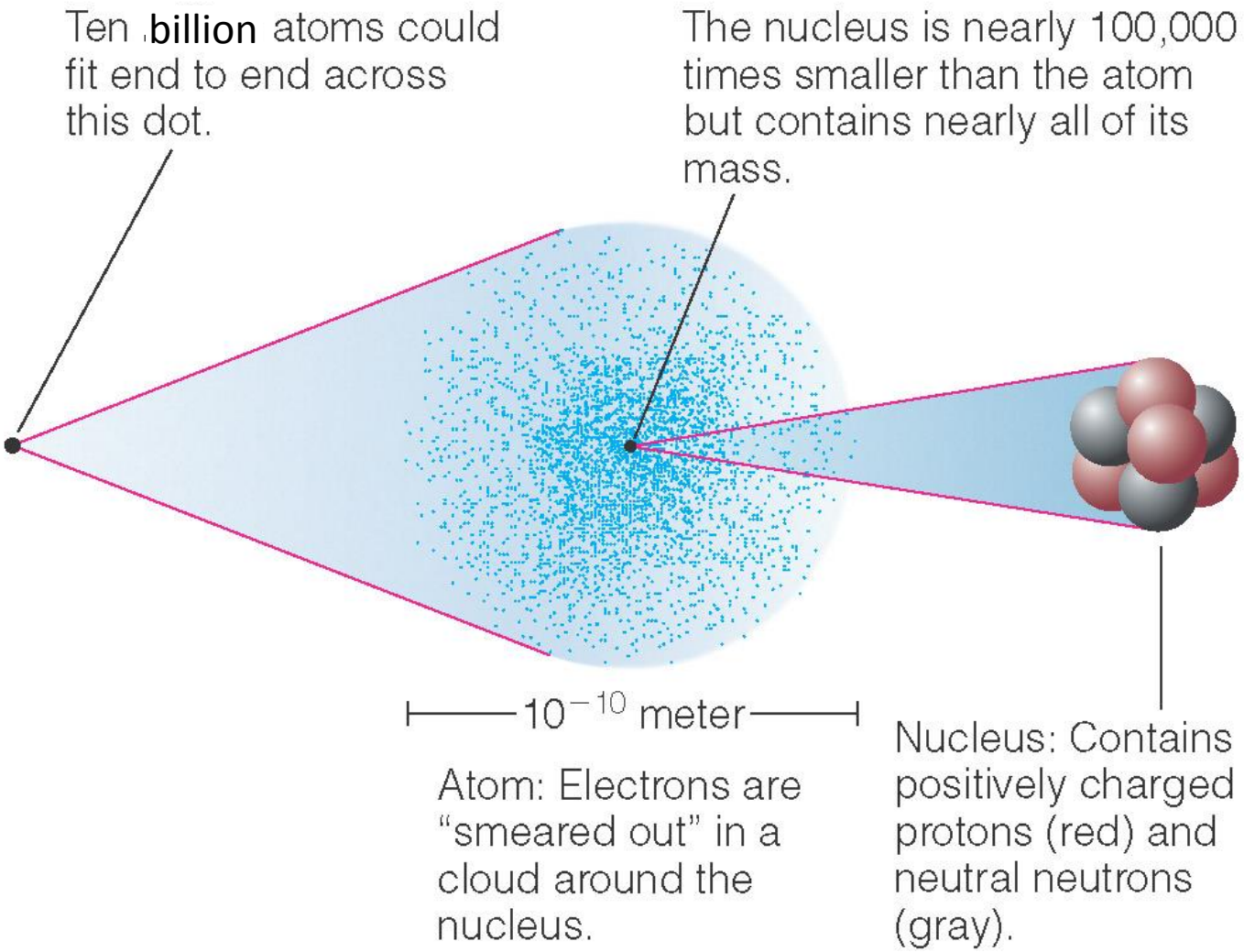


Matter Zoom



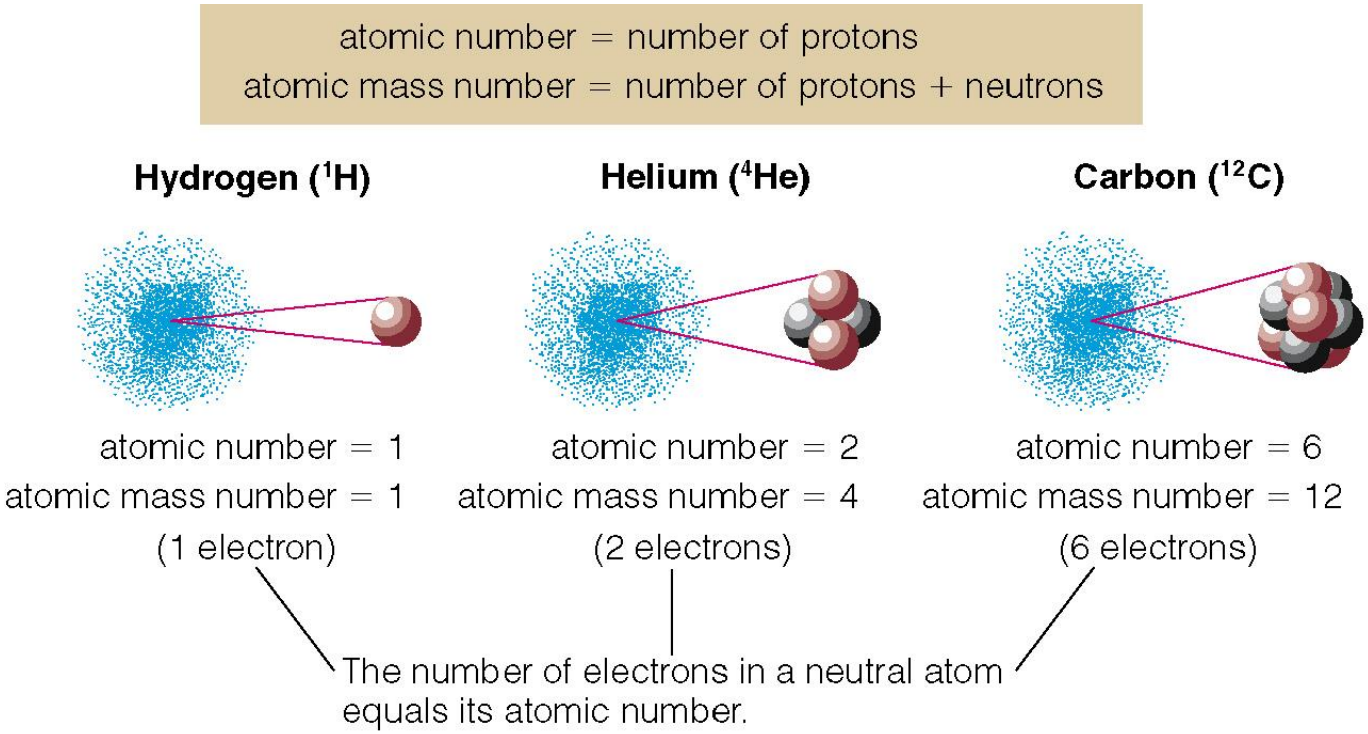
What is Matter?

Atomic structure:



Atomic Terminology

- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + neutrons

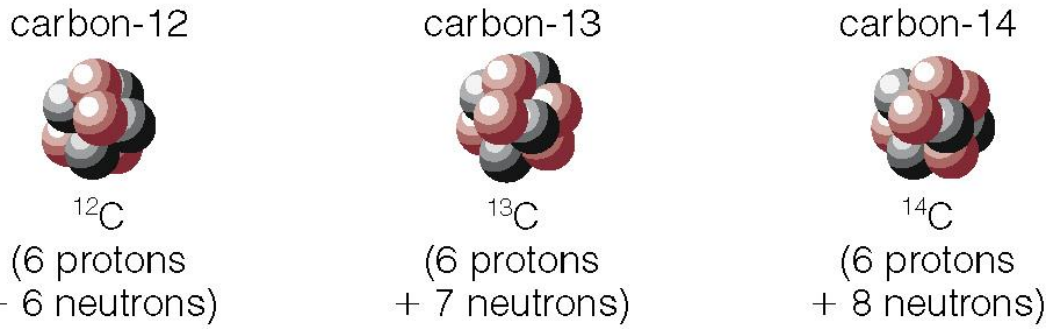


Isotopes

- Isotope: the nucleus contains the same # of protons but different # of neutrons. (^{4}He, ^{3}He)

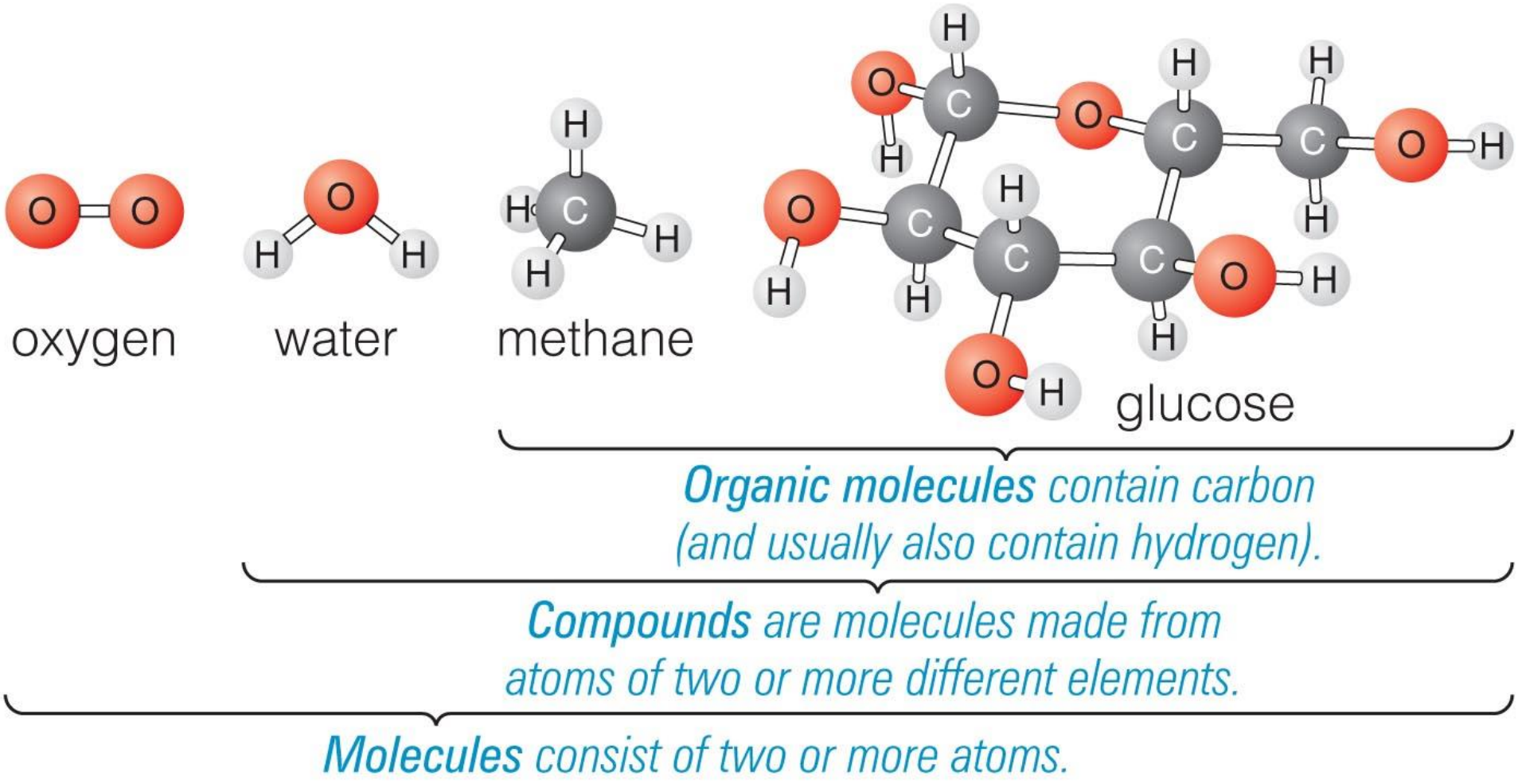
Different isotopes of a given element contain the same number of protons but different numbers of neutrons.

Isotopes of Carbon

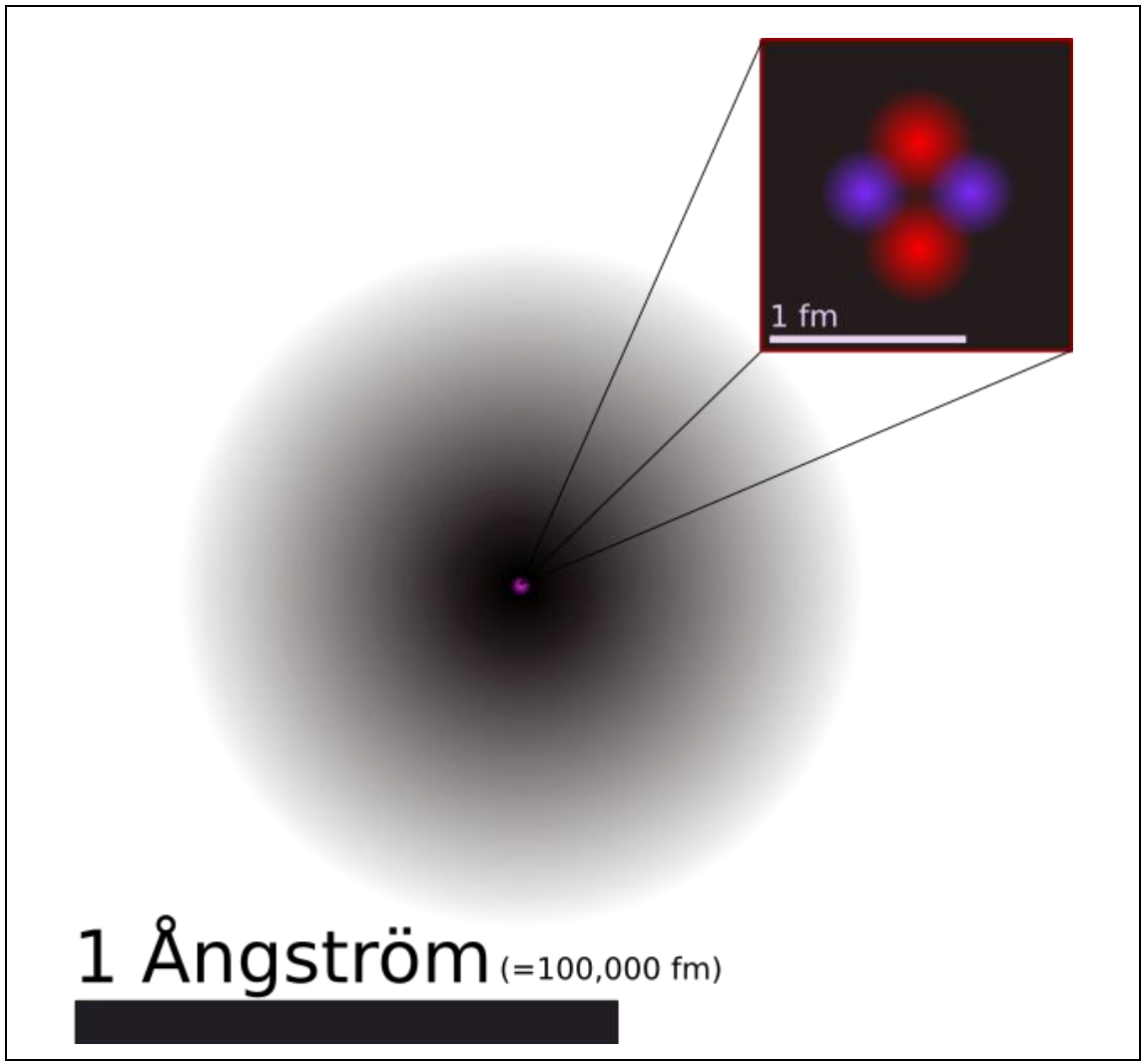


Molecules

- Molecules: consist of two or more atoms (H_2O, CO_2)



Empty Space



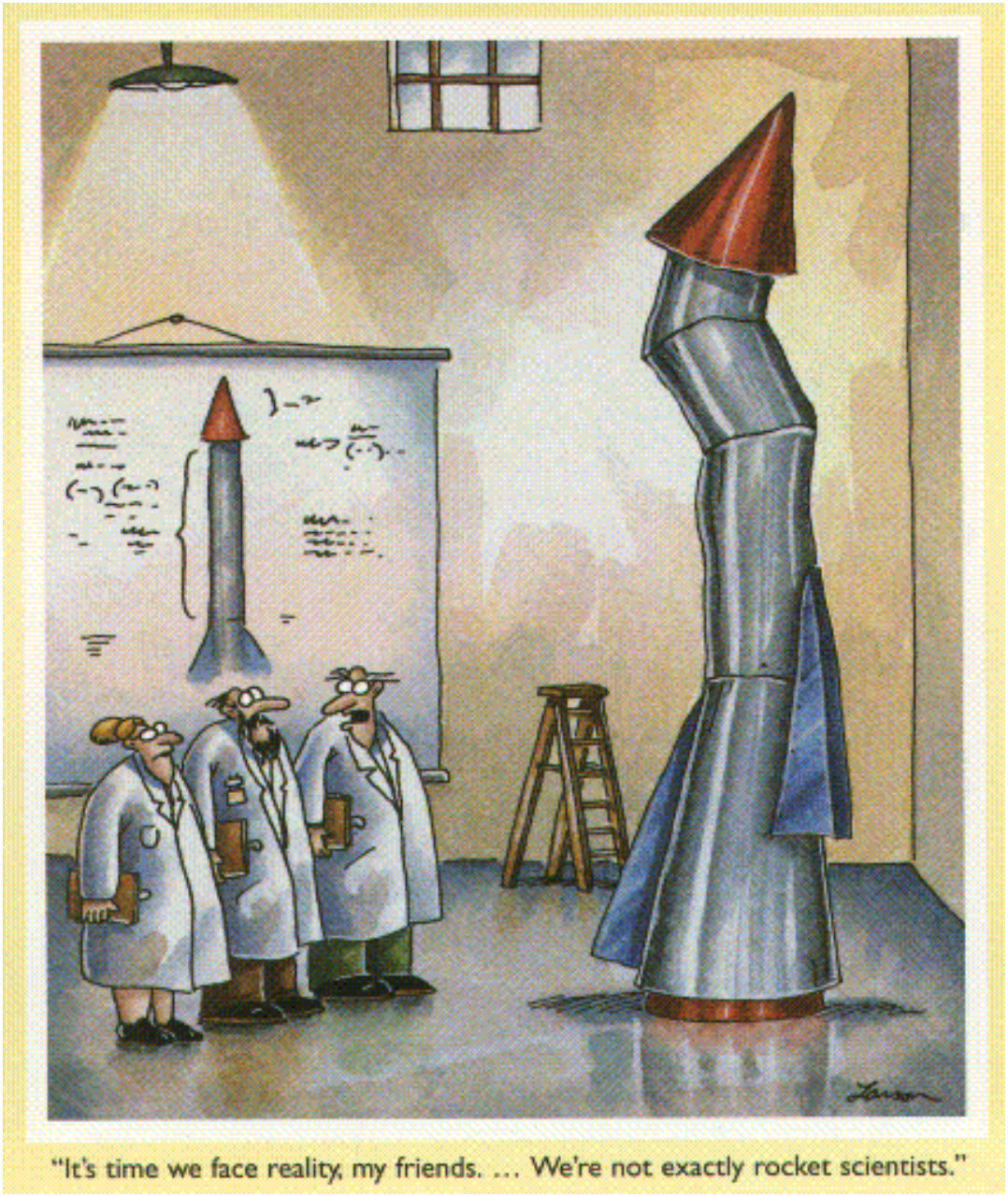
The solidity of matter is an illusion. A small nucleus is contained within a much larger electron cloud.

The negative charge of the electrons acts to keep atoms well separated in a solid. But most of the mass is in the tiny nucleus.

99.999999999999999% space

A sand grain of diameter 0.5mm weighs about 3 grams.
The sand is SiO_2, molecules 60 times hydrogen mass.

10^{19} atoms

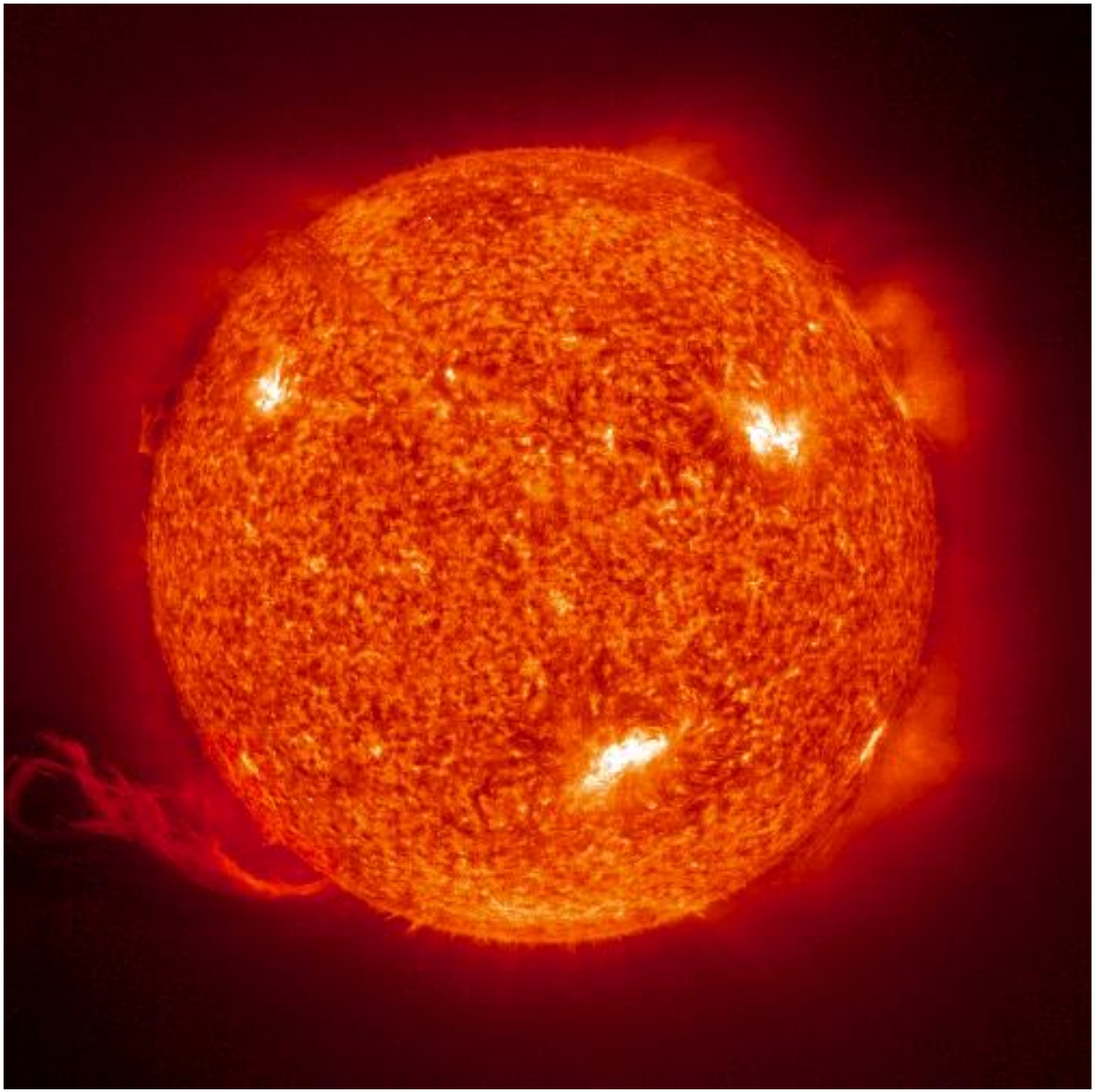


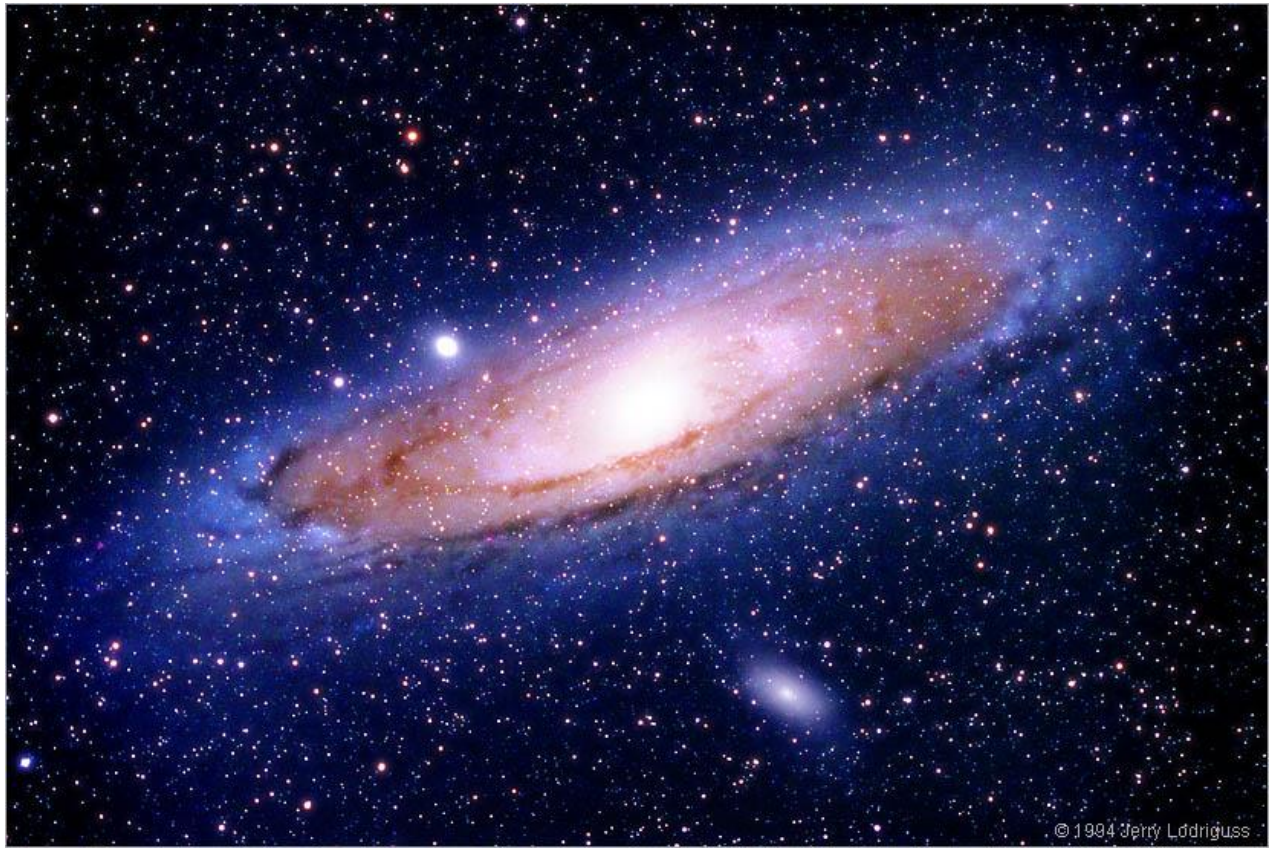
A normal adult weighs about 60 kg. Humans are mostly made of water, H_2O, molecules about 17 times the mass of hydrogen.

10^{28} atoms

One solar mass is 2 x 10^{30} kg. Which is an enormous factor larger than a single hydrogen atom 2 x 10^{-27} kg. The Earth is about 330,000 x less massive.

10^{57} atoms





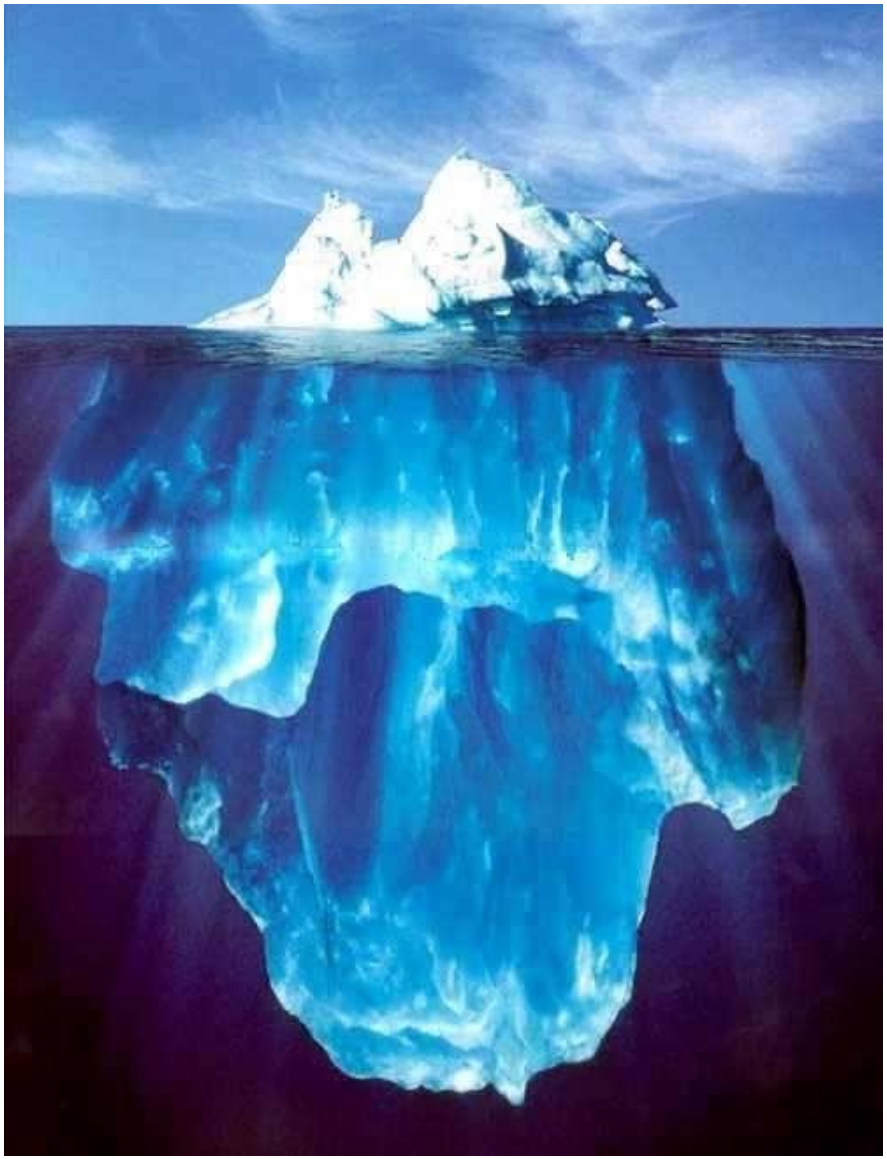
The typical galaxy contains 10^{12} stars

The whole universe contains 10^{11} galaxies

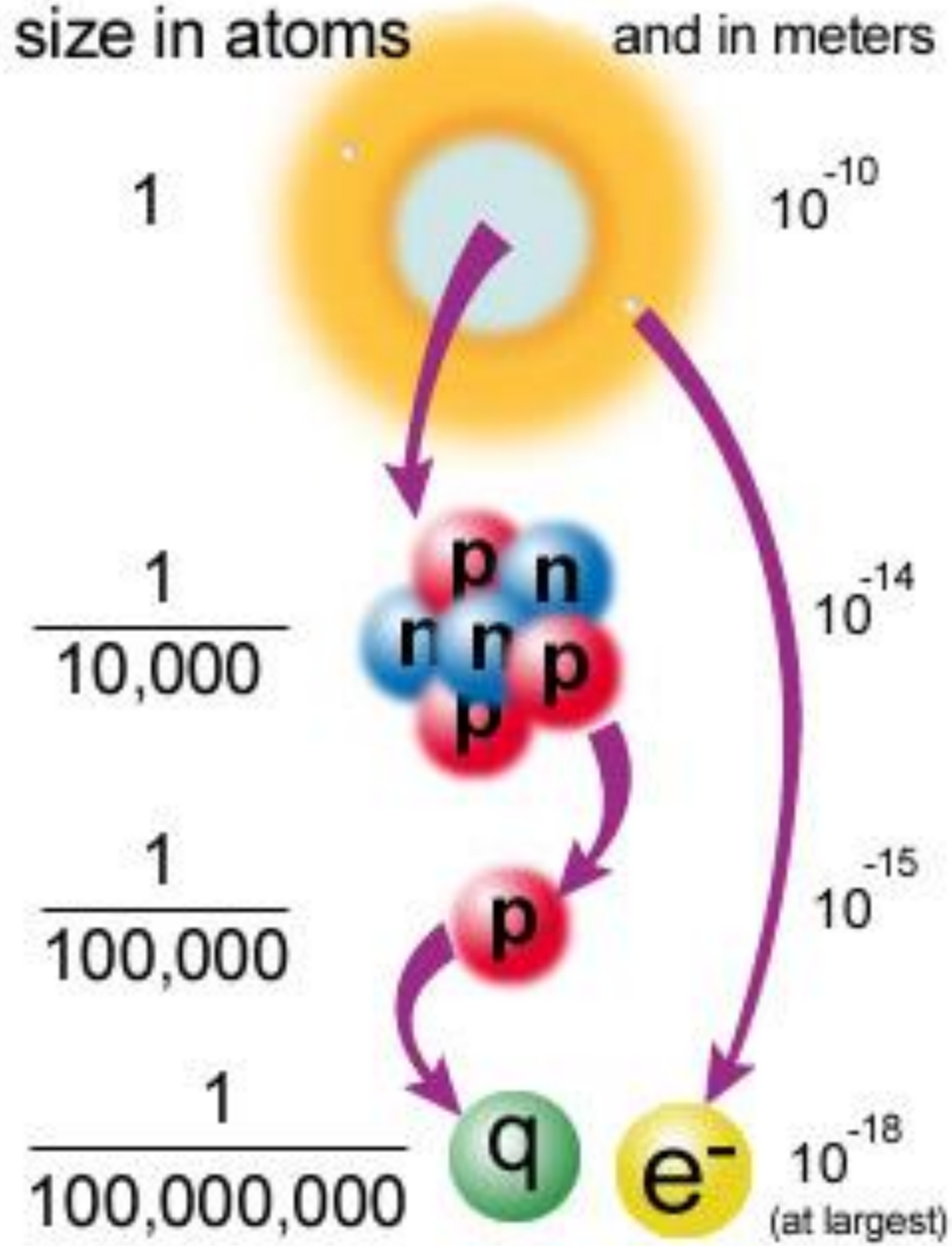
10^{69} atoms

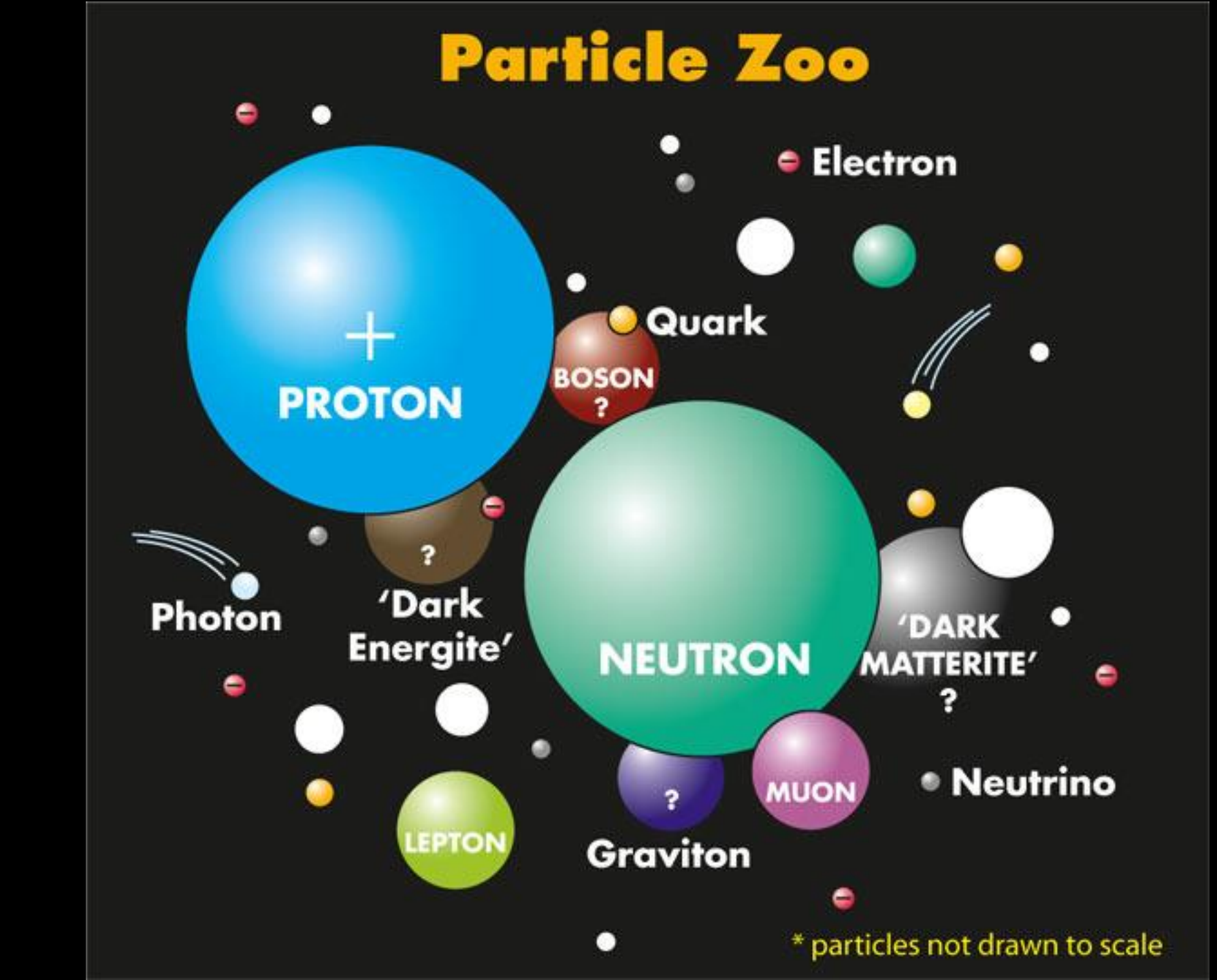
10^{80} atoms

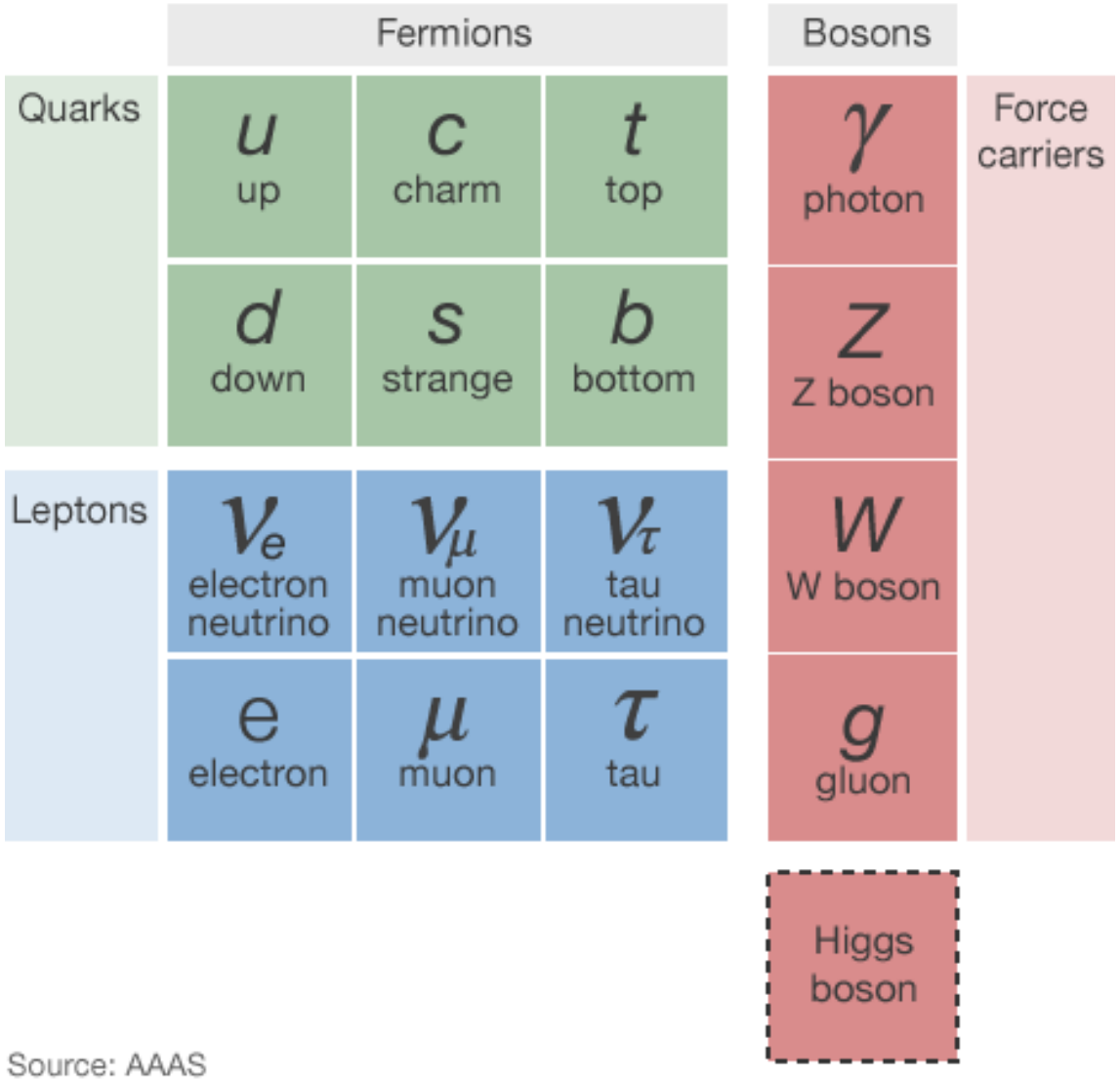
Substructure



Experiments in the 1960's and 1970's showed that, just as atoms are not simple and fundamental, so protons and neutrons are made of much smaller particles that were named quarks.

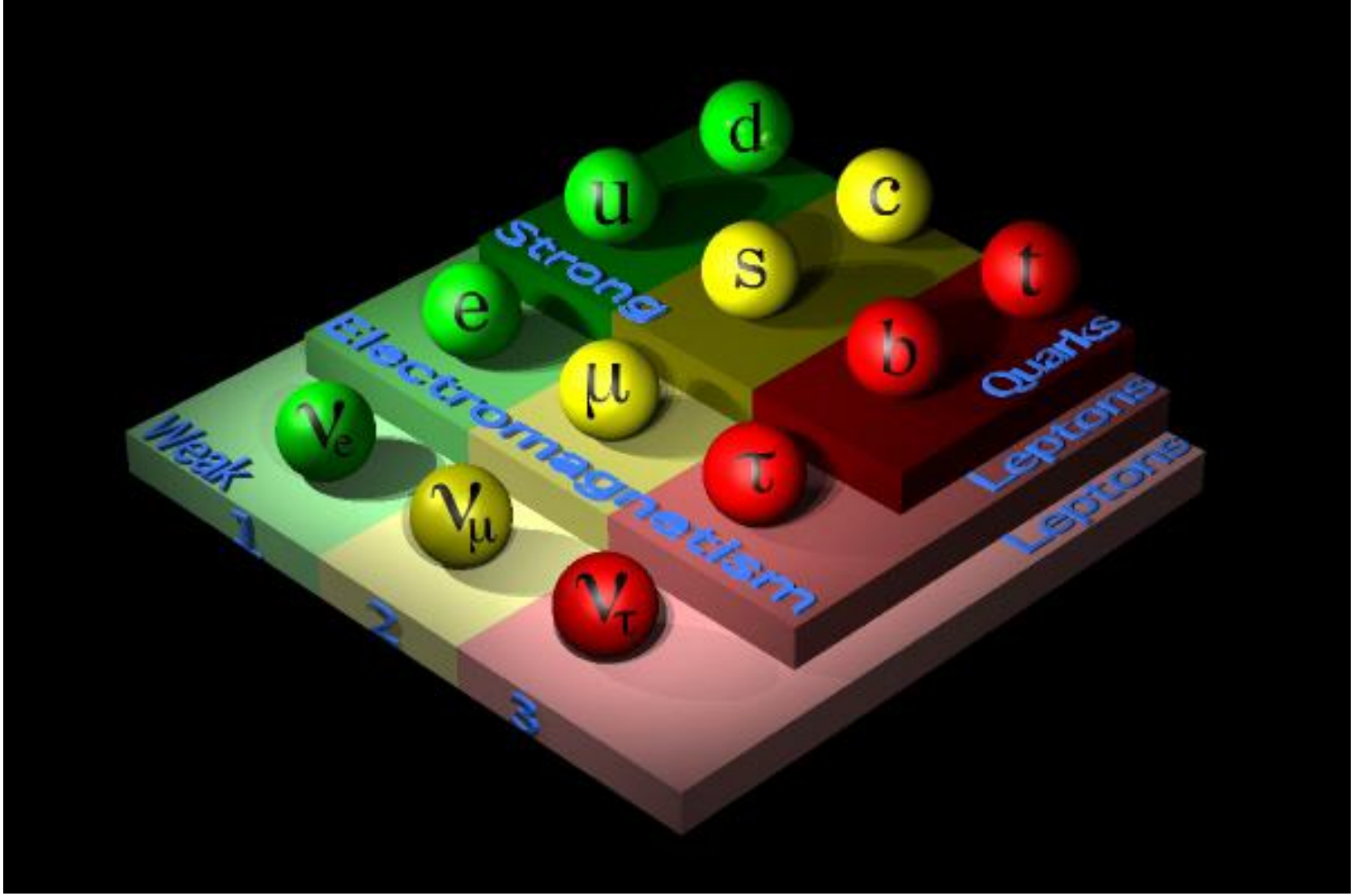



Particle Zoo
Electron
+
PROTON
Quark
BOSON
?
?
'Dark
Energite'
Photon
NEUTRON
'DARK
MATTERITE'
?
Neutrino
MUON
?
Graviton
LEPTON
* particles not drawn to scale

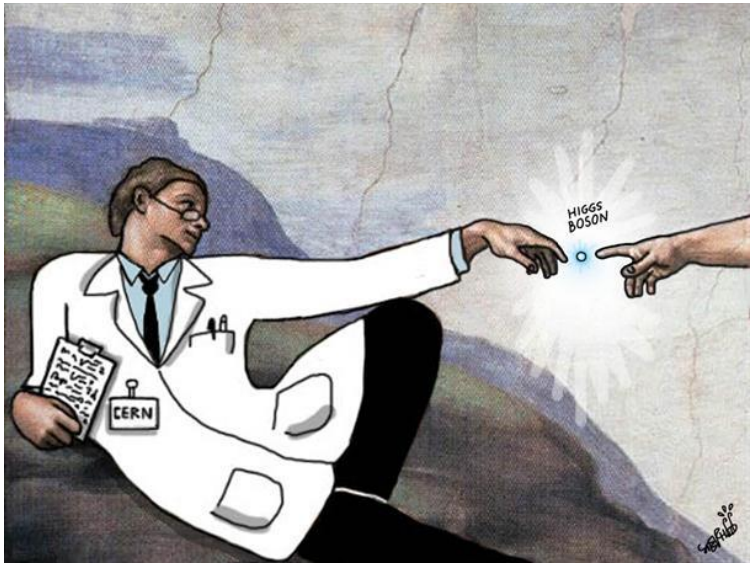


This arrangement has multiple generations of particles and their anti-particles, so it is not very elegant or simple. This has led physicists to suppose that there may be a deeper and much simpler level of sub-atomic structure.

Origin of the masses?



The forces are associated with particular families of particles. But just as these particles are secondary manifestations of strings, the individual forces are manifestations of a single underlying “superforce.”



Do *you* understand the "Higgs Boson"?

Are you looking at the boson right now?

- yes → Don't lie to a flow chart.
- no → Do you understand particle theory?

Do you understand particle theory?

- i love it! → Are you getting particle theory confused with candy?
- yes → What do you think of when you hear about "fields"?

Are you getting particle theory confused with candy?

- no → What do you think of when you hear about "fields"?
- wait, you have candy? → You don't understand it, but you can learn to pretend you do.

What do you think of when you hear about "fields"?

- kickball! → You don't understand it, but you can learn to pretend you do.
- physics → Is your name "Peter Higgs"?

Is your name "Peter Higgs"?

- no → You don't understand it, but you can learn to pretend you do.
- yes → "Peter Ware Higgs"?

"Peter Ware Higgs"?

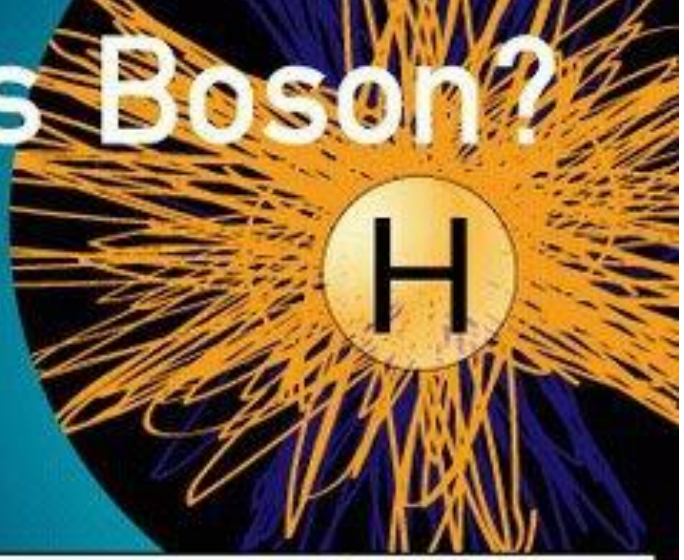
- no → You don't understand it, but you can learn to pretend you do.
- yes → You almost understand it after a few drinks.

The Higgs Boson Explained

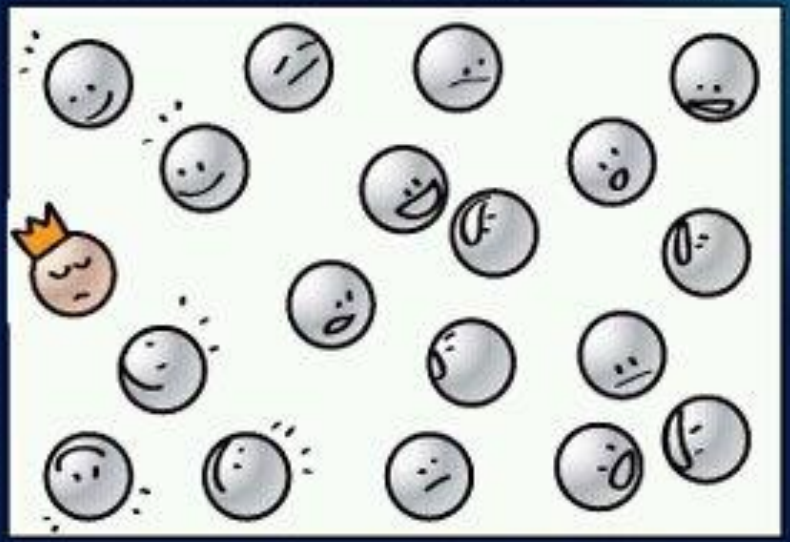
The Higgs Boson Explained

What is a Higgs Boson?

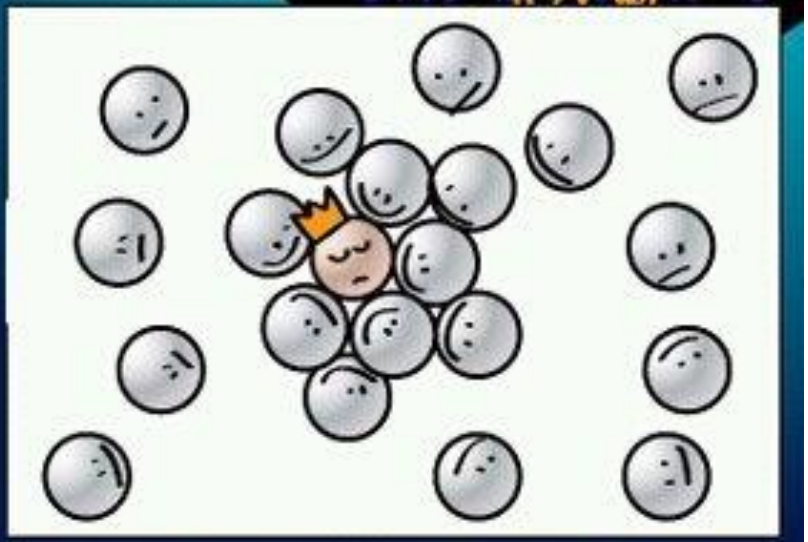
The elusive Higgs boson, if found, would complete the Standard Model of physics. It is thought that matter obtains mass by interacting with the Higgs field. If Higgs did not exist, according to the model, everything in the universe would be massless.



The "cocktail party" analogy



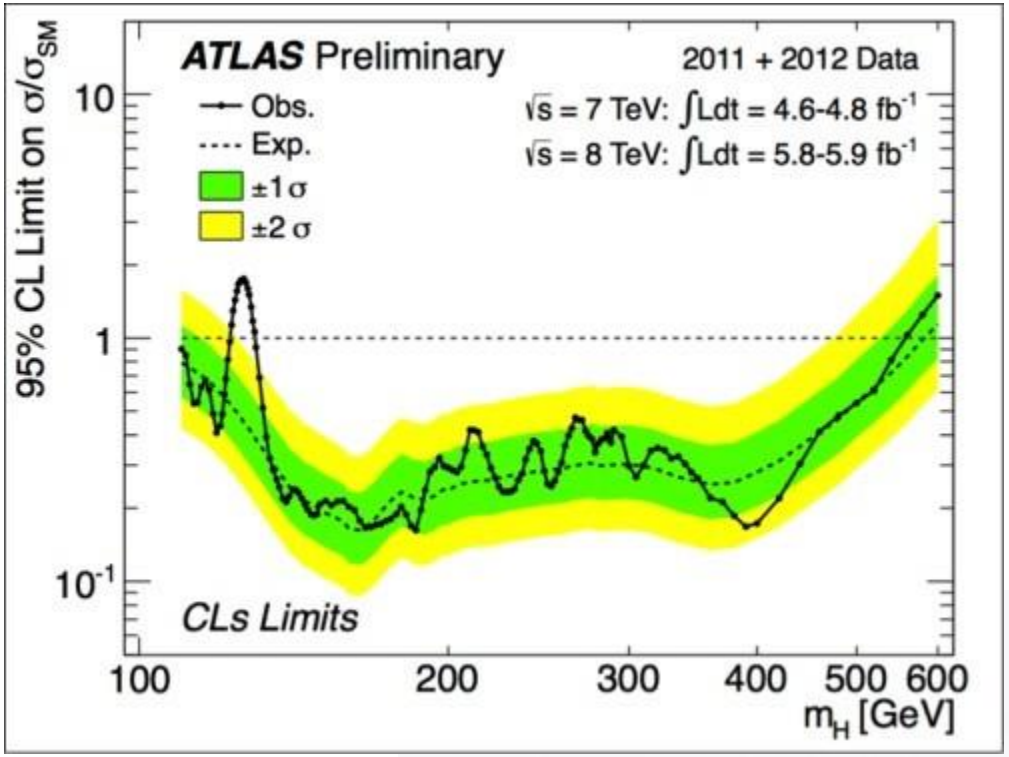
Imagine a party where guests are evenly spaced around the room. The room of guests represents the Higgs field, which is everywhere in the universe. Suddenly a celebrity enters. Guests notice the celebrity and rush in closer to be near her, forming a tight knot.

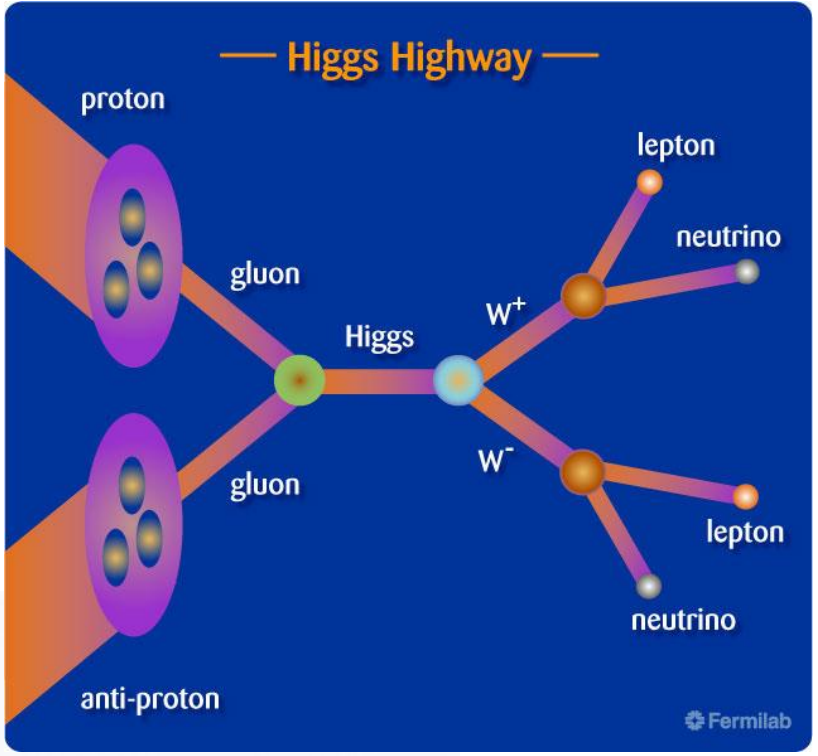


As the celebrity passes through the room, the concentrated clump of guests surrounding her gives the group additional momentum. The clump is harder to stop than one guest alone would be, and so we can say that the clump has acquired mass.

SOURCE: CERN


CERN Cafeteria
Outside Geneva, Switzerland
June 16, 2011





We have observed a new boson with a mass of

125.3 ± 0.6 GeV

at

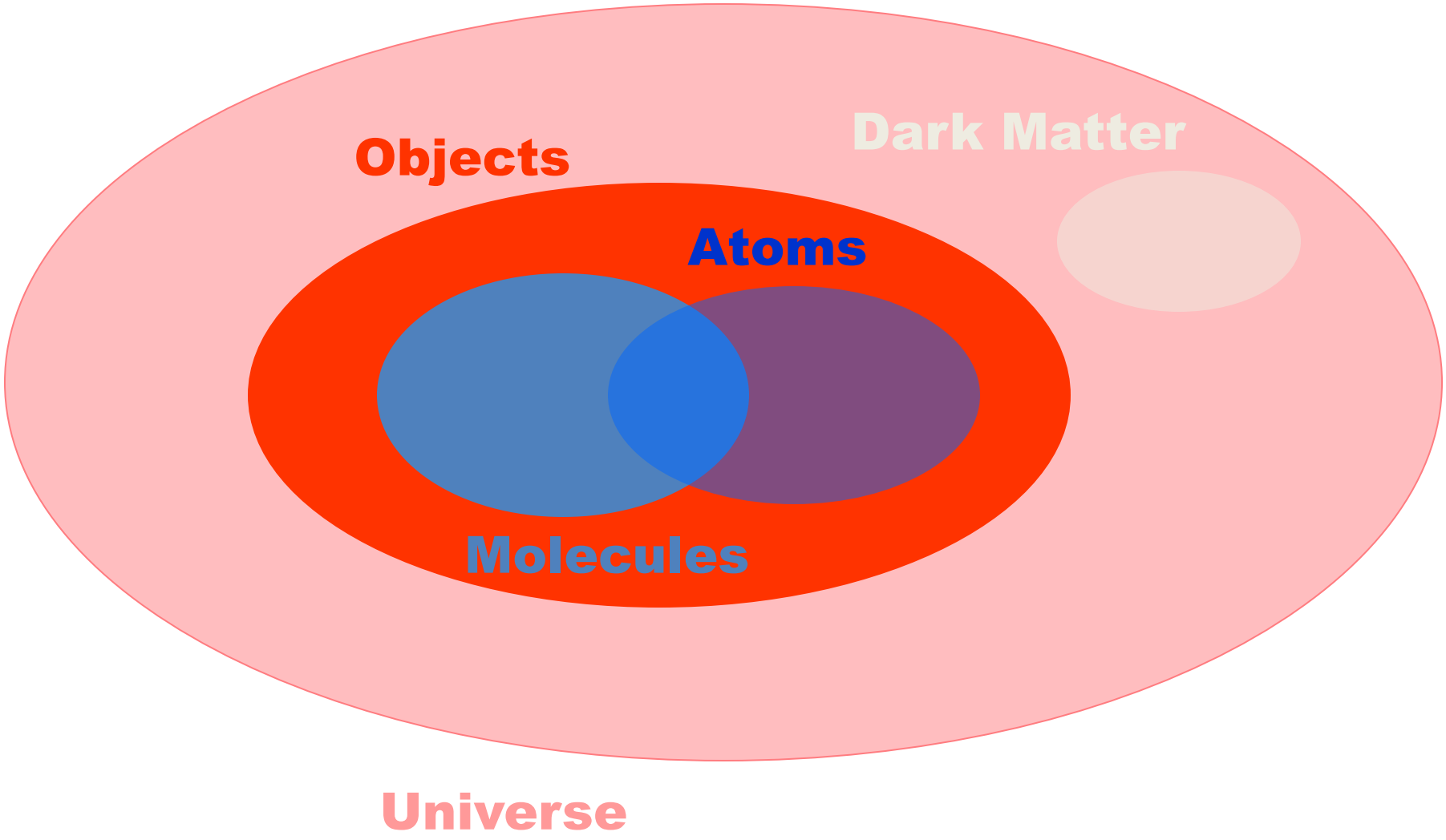
4.9 σ significance

Anti-Matter

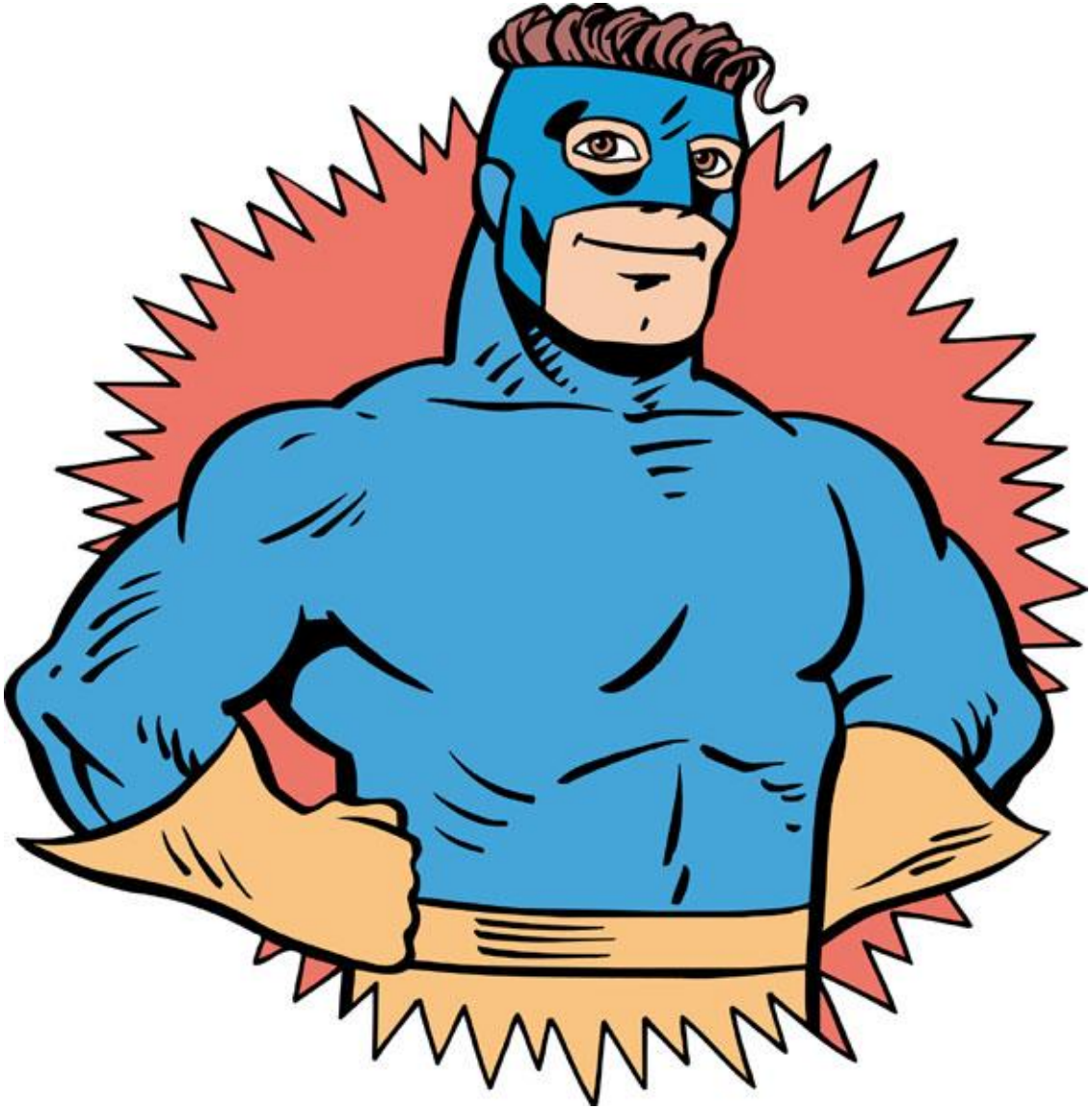
Every particle has an anti-particle twin and they were equally abundant in the early universe, but they met…

…and mostly annihilated to give radiation early in the universe leaving us 10^9 x more photons than particles.

TOP DOWN



Forces

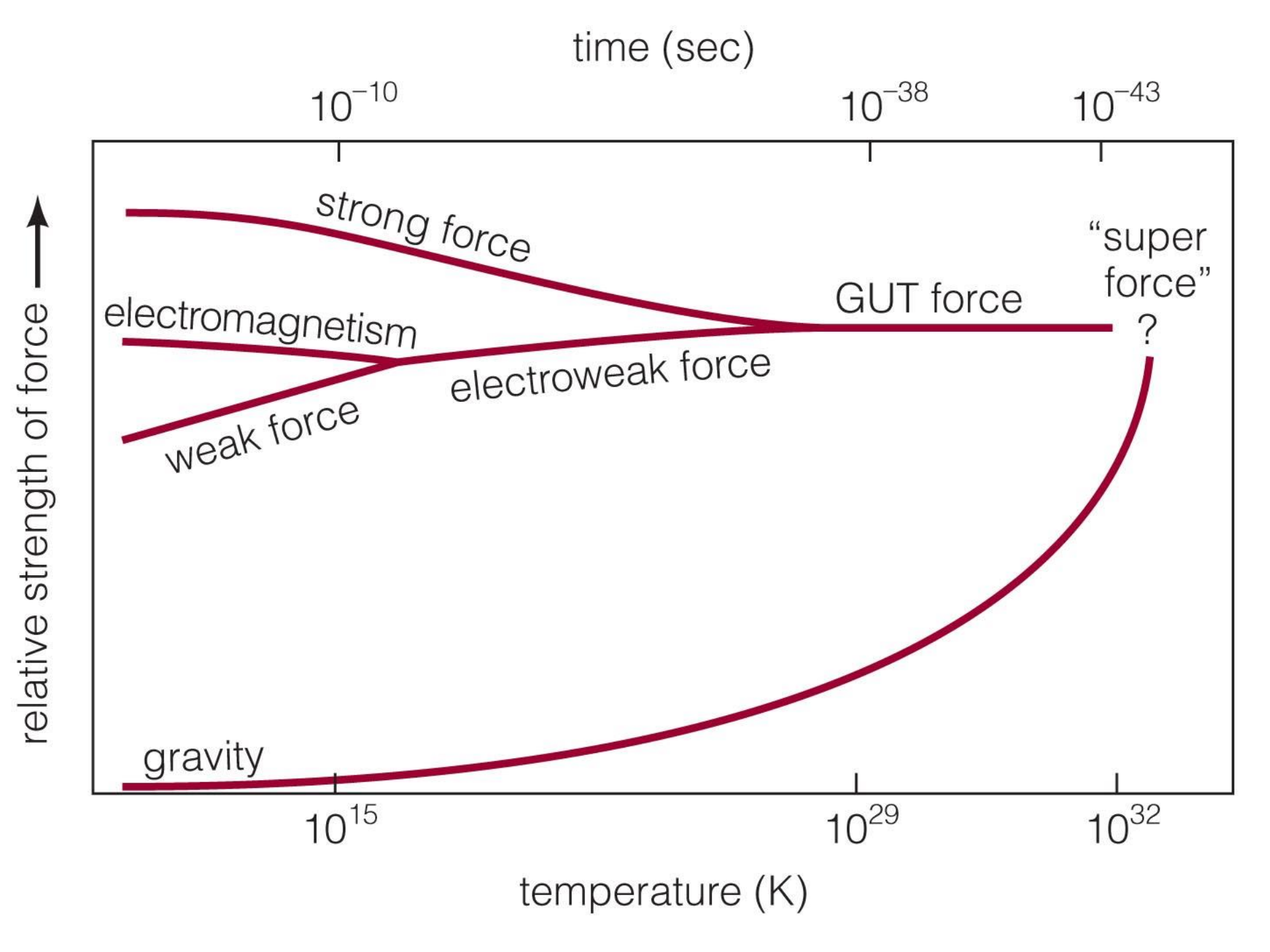


Four Forces

	Gravity	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons

Strength: 10^{-38} 10^{-19} 0.0073 1

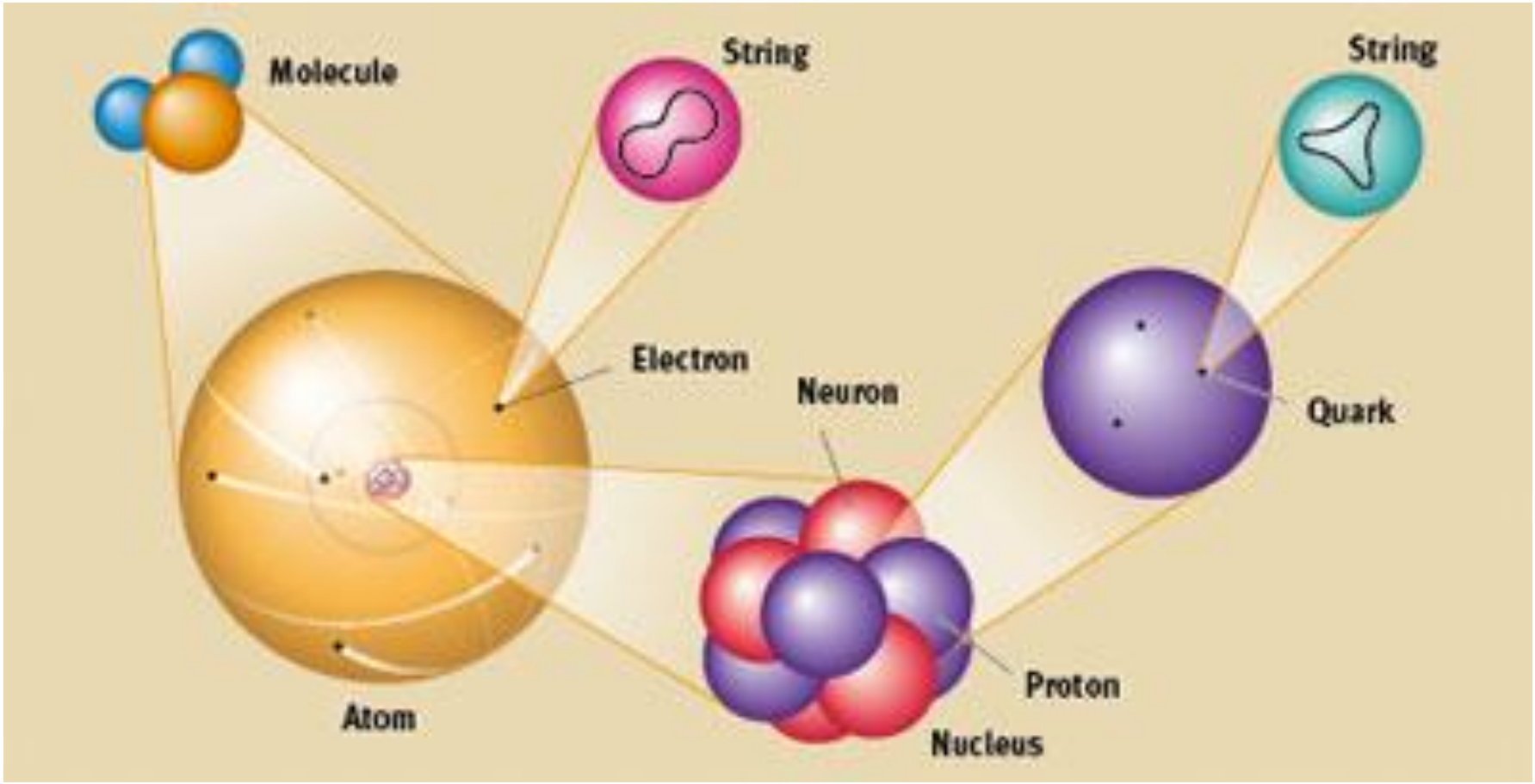
Range: Infinite Subatomic Infinite Subatomic


time (sec)
10^{-10}
10^{-38}
10^{-43}
strong force
electromagnetism
weak force
electroweak force
GUT force
"super force"
?
gravity
relative strength of force
10^{15}
10^{29}
10^{32}
temperature (K)

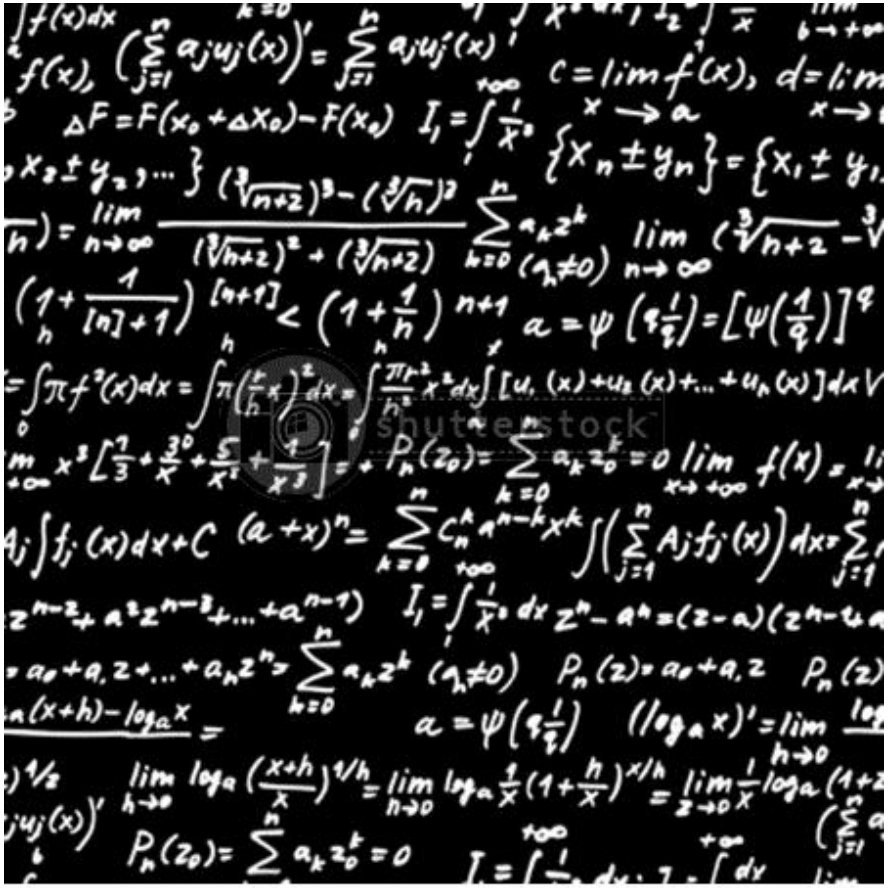
Theory of Everything

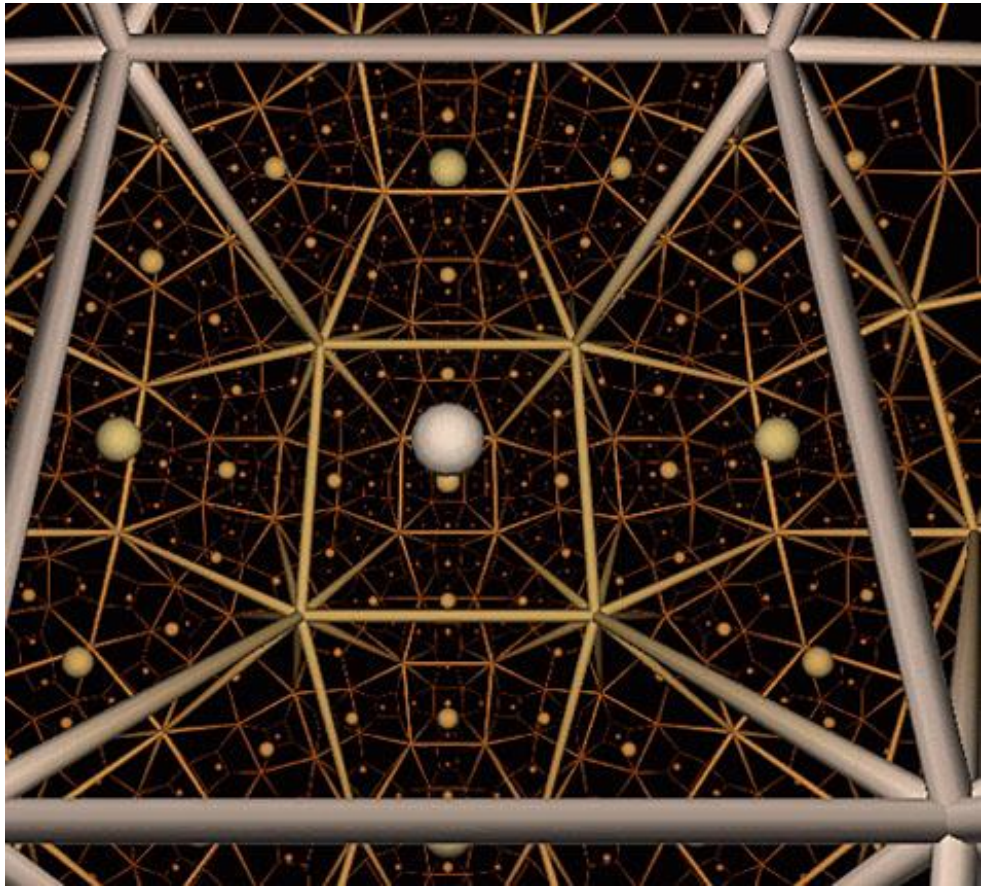
Theory of Everything

String Theory



String theory postulates dynamic 1-dimensional entities that are only noticeable on scales of 10^{-43} meters, which is 33 orders of magnitude smaller than atomic scales!

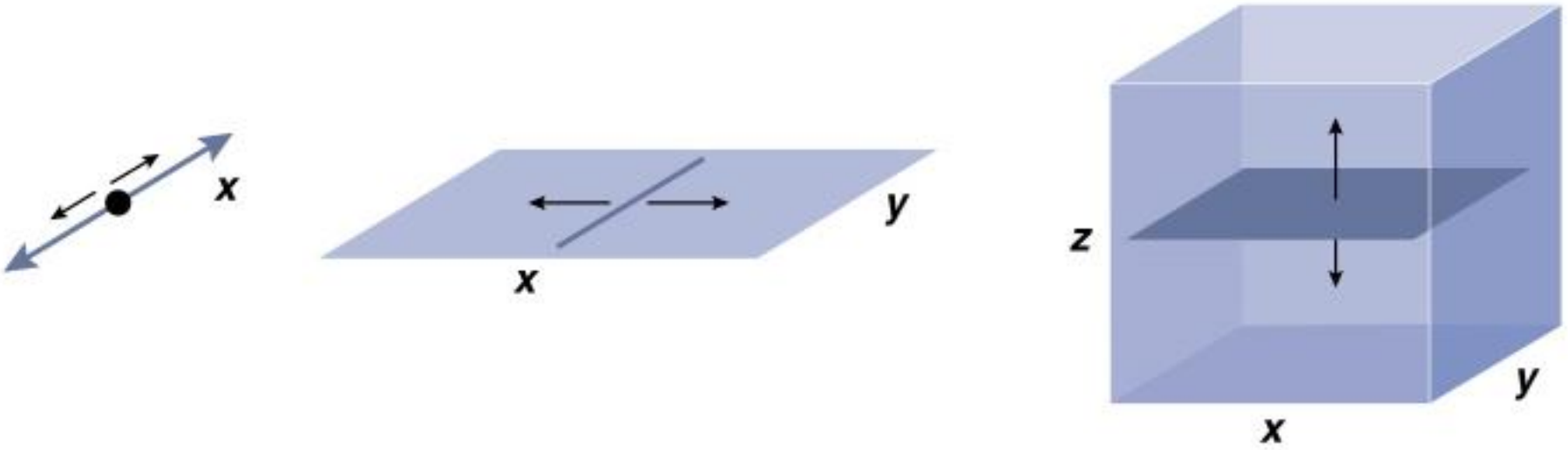




String theory is based on beautiful but very difficult mathematics. The 10-dimensional space-time that the theory is based on has never been observed.

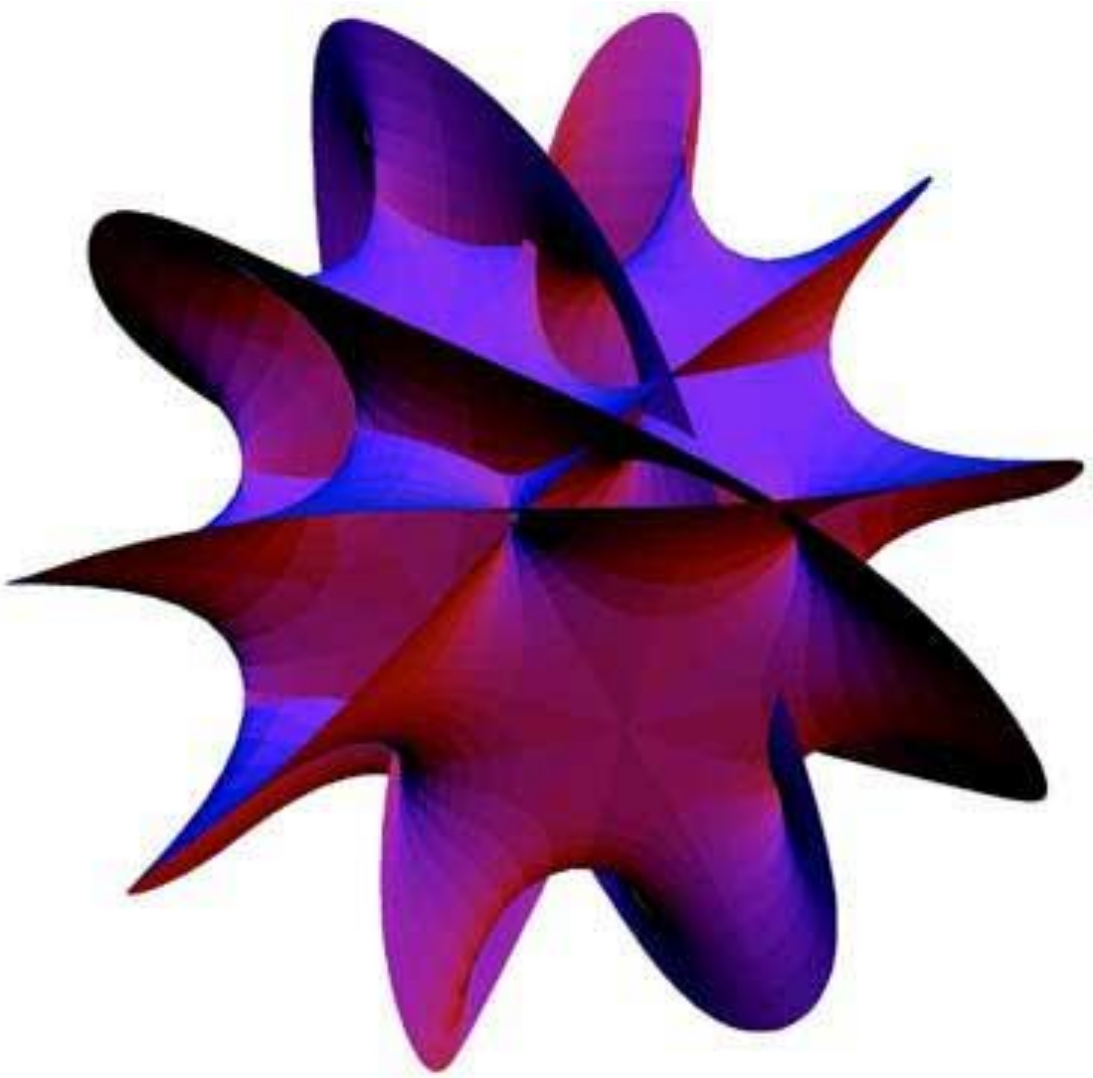
1 – 2 – 3 – 4 Dimensions

dimension… an independent direction of possible motion



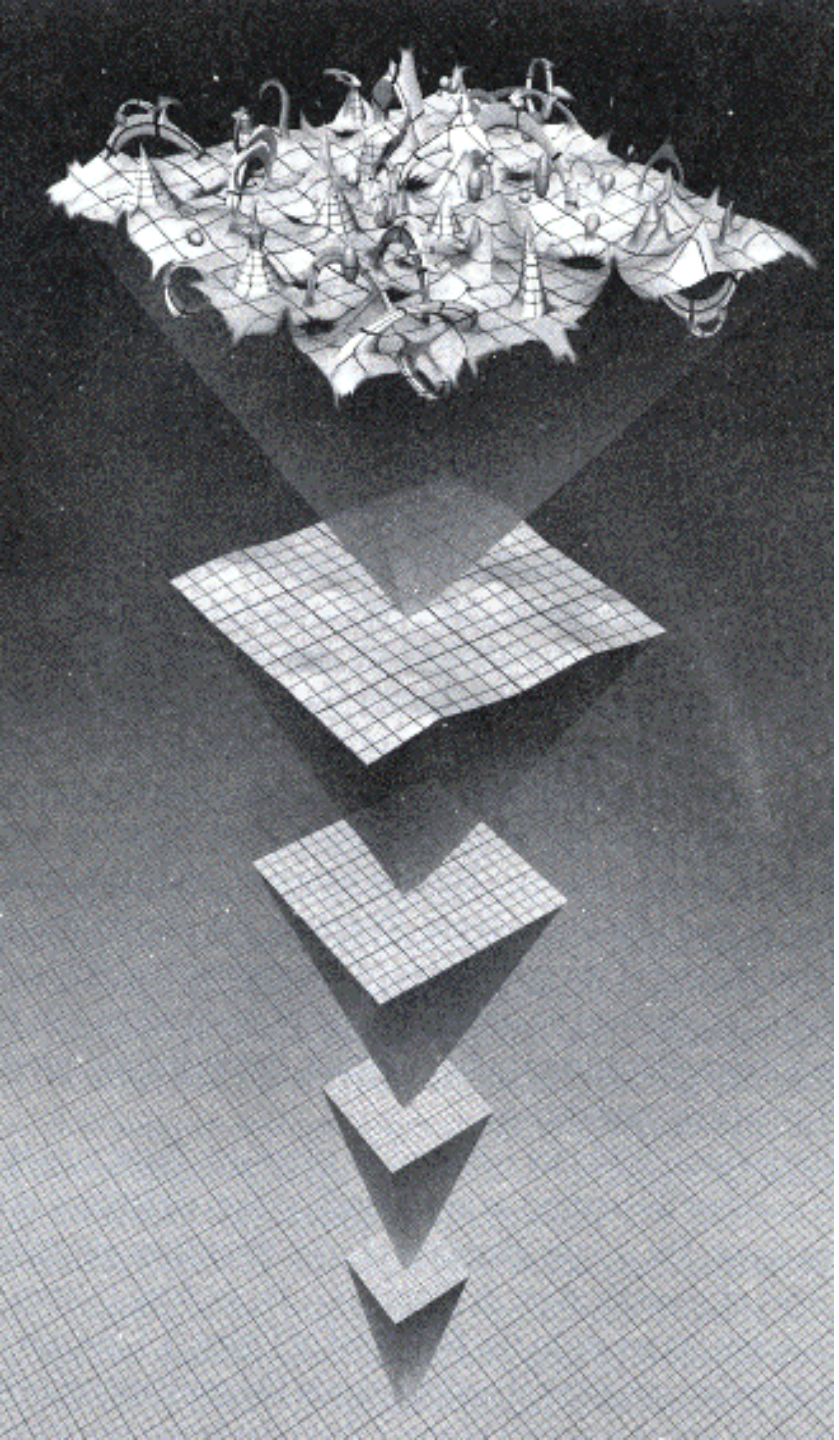
- A point moved in one direction creates a line (1D)
- A line moved in a direction 90º to itself creates a plane (2D)
- A plane moved in a direction 90º to itself creates a space (3D)
- A space moved in a direction 90º to itself creates a 4D space

Hidden Dimensions

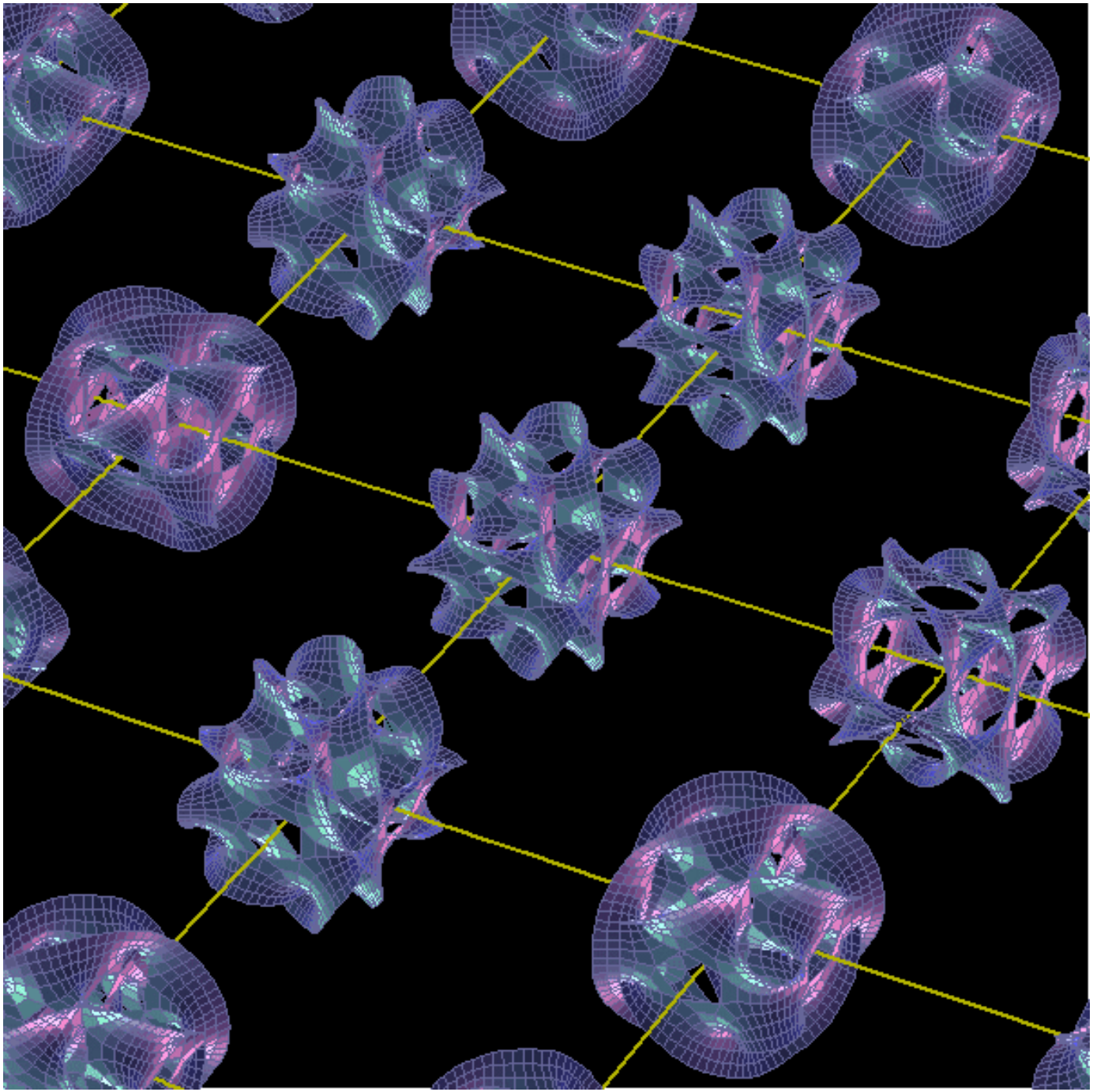


In string theory there are hidden dimensions. The favored theory has ten dimensions of space and time, all but four of which are tiny, and only seen or manifest at high energies.

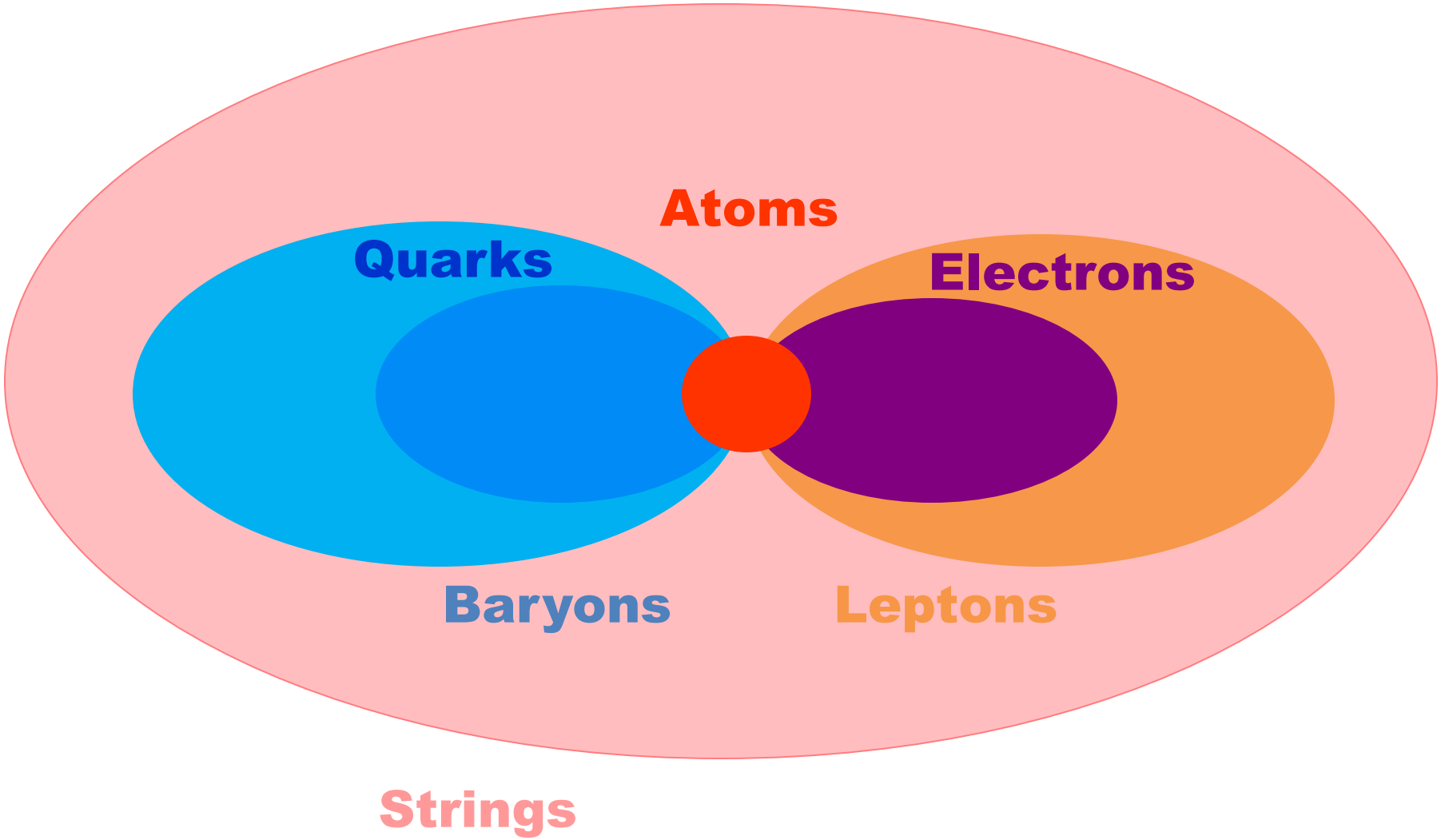
This is a subspace of a 6-dimensional object, which was constructed within 4 dimensions; then it was projected down to 3 and then presented here in 2.



In string theory, the smoothness and the emptiness of space are illusions. If we could imagine ourselves at the incredibly tiny Planck scale of 10^{-43} meters, we would see a chaotic version of space-time. At every point, the six hidden dimensions that are not apparent in the everyday world would be easily apparent...

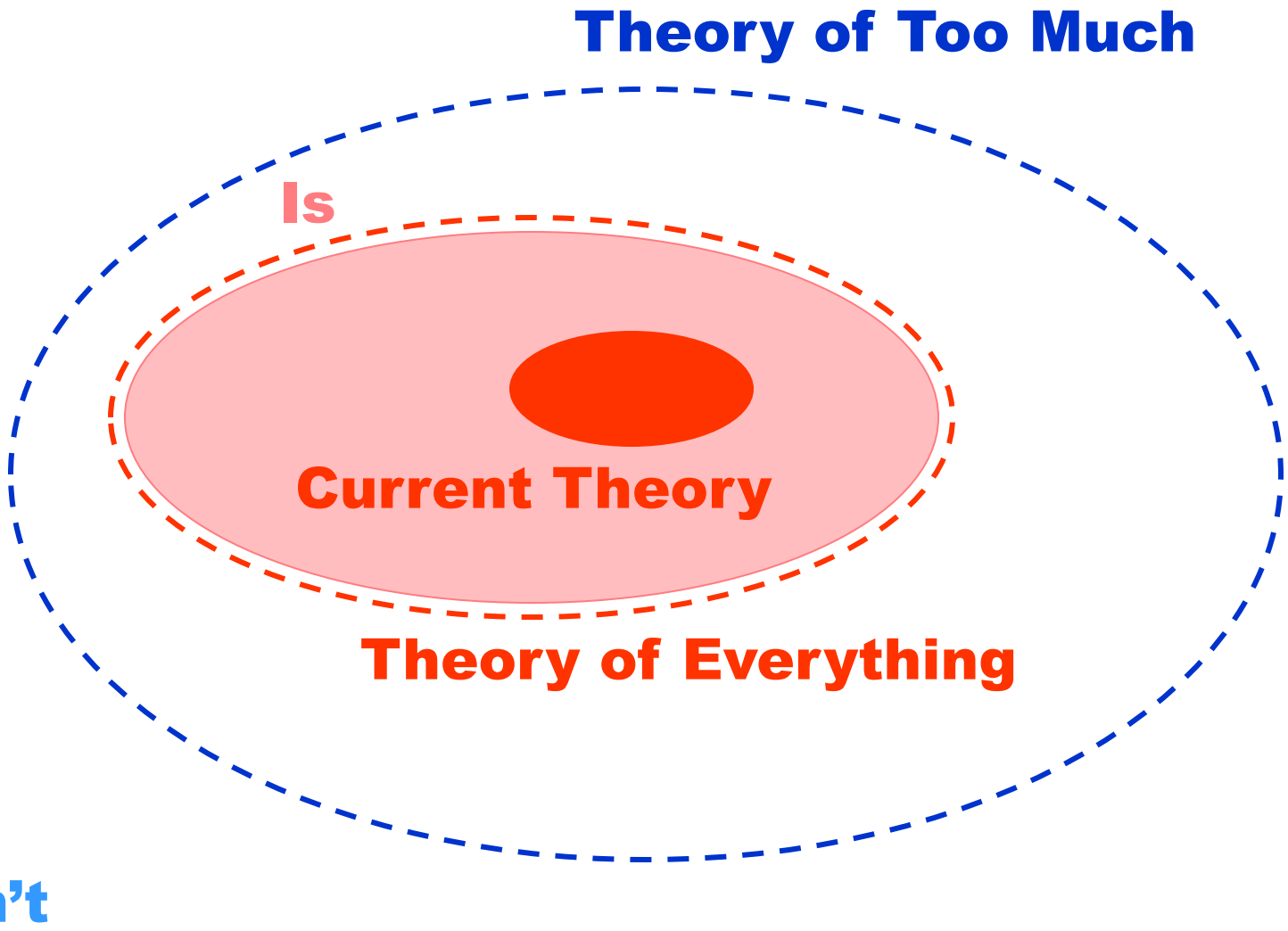


BOTTOM UP



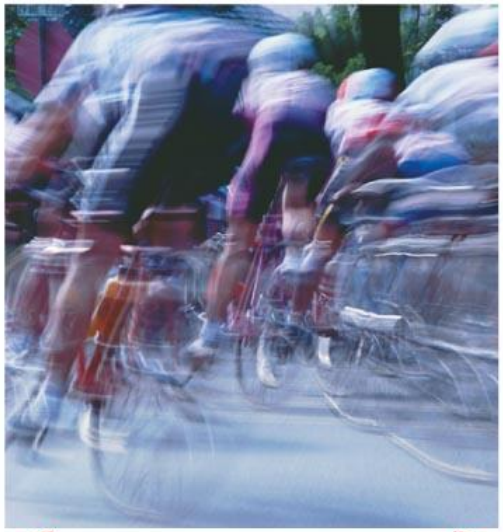
Theories of Everything

THE ROLE OF THEORY



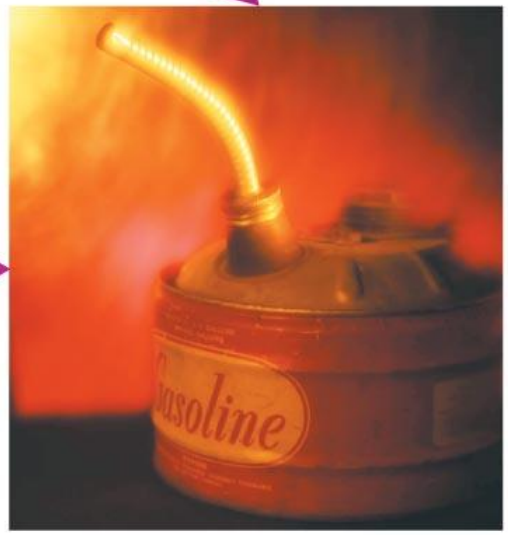
Forms of Energy

Energy can be converted from one form to another.



kinetic energy
(energy of motion)

radiative energy
(energy of light)



potential energy
(stored energy)

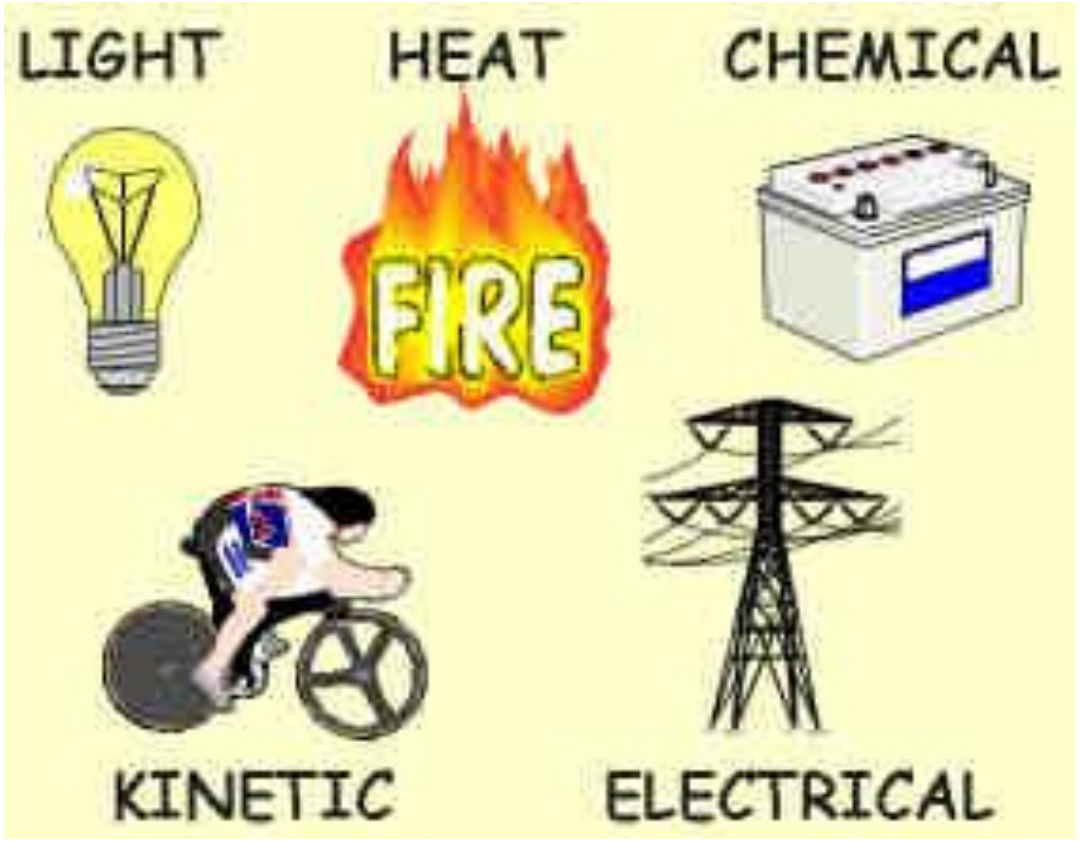
Energy is a very broad concept. It is anything that can make matter move or change.

Energy changes forms constantly but is not created or destroyed: this is a fundamental law of physics.

Energy can be **kinetic**, the overall motion of an object

Energy can be **radiant**, light or other electromagnetic waves

Energy can be **potential**, stored in a number of ways

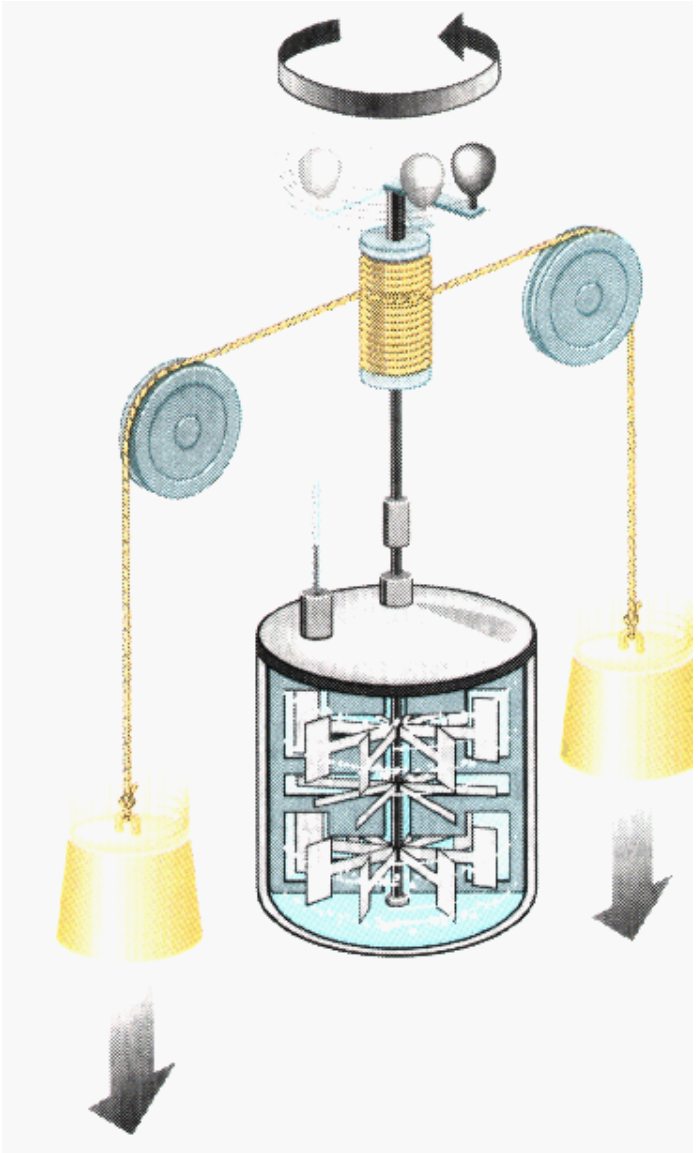


- Chemical bonds
- Electric fields
- Magnetic fields
- Gravity fields
- Elastic (materials)

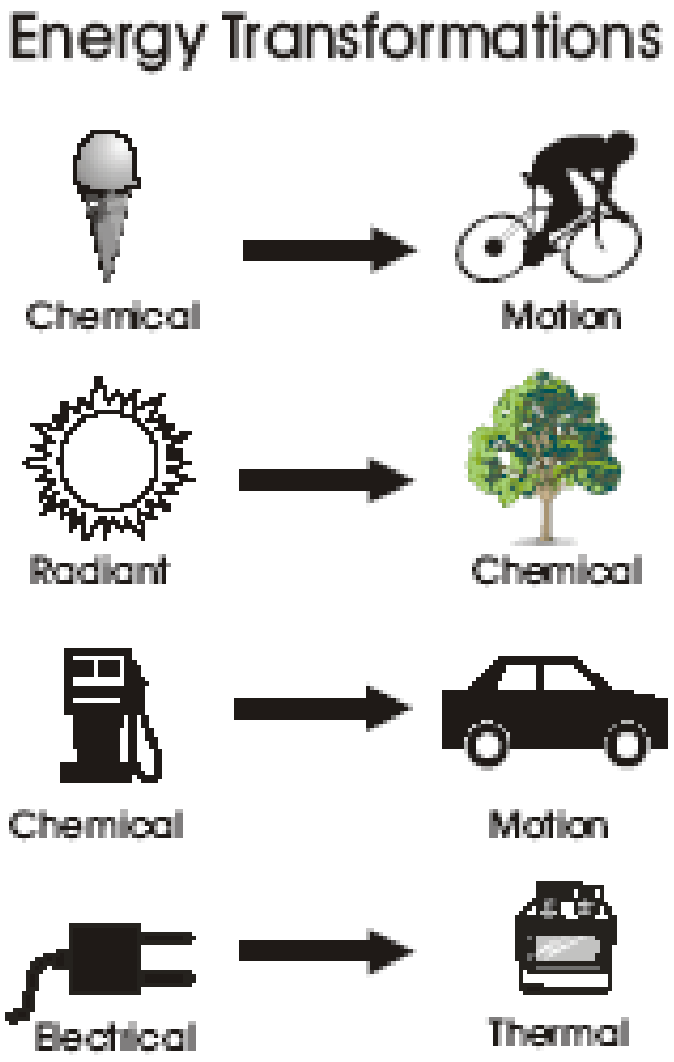
Energy Conservation

Energy never appears or disappears even though it might seem to. It just changes from one form to another, but the total amount stays the same.

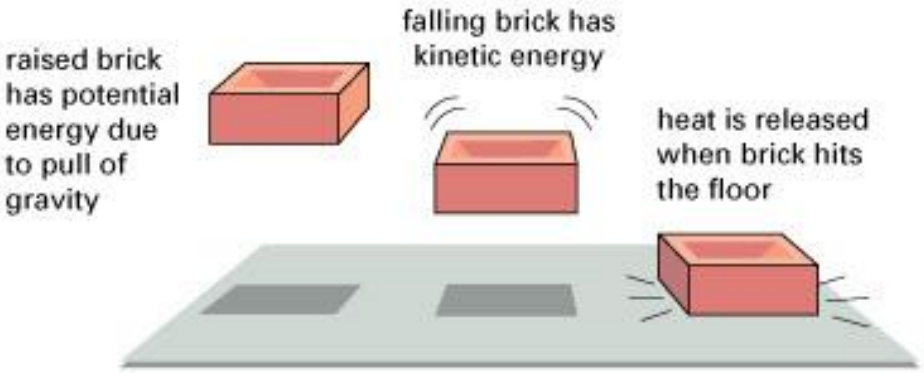
This was demonstrated in 1650 by Huygens using a setup where falling weights drove paddles in water. He showed that gravitational potential energy lost as the weights fell is the same as the thermal energy gained by the water when its temperature rises slightly. Energy is exactly conserved.



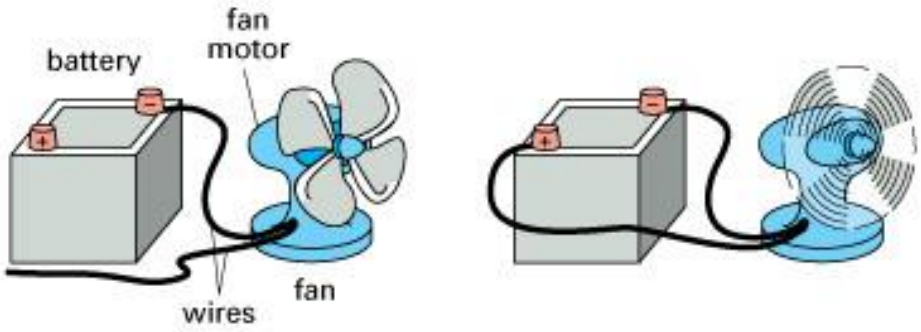
Energy Transformation



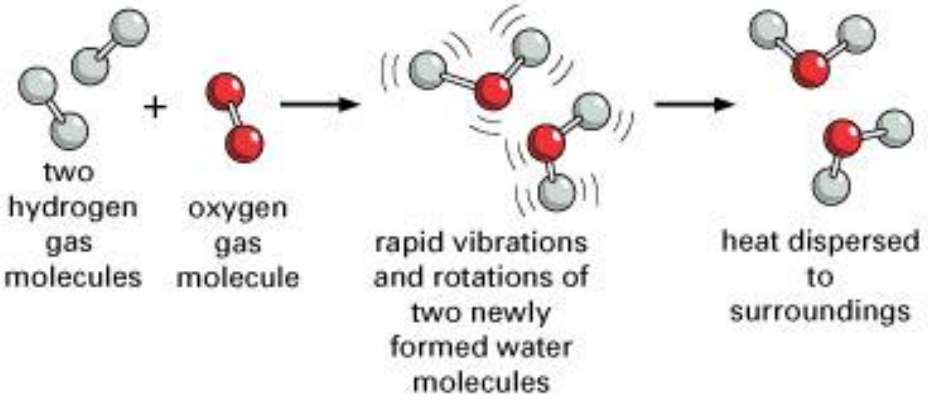
- Energy released from chemical bonds in food lets muscles work to give kinetic energy to a bike.
- Light energy from the Sun can create stored chemical energy in the cells of living things.
- Energy released from chemical bonds in fuel drives mechanical parts of an engine, moving a car.
- Electrical potential energy can create a current that generates heat energy to cook food.



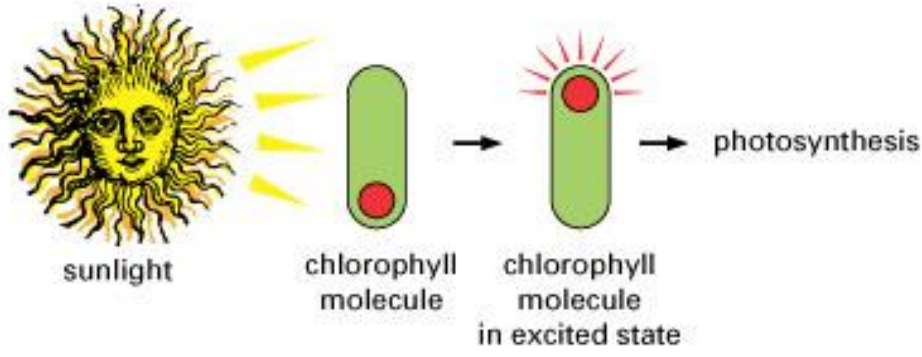
potential energy due to position → kinetic energy → heat energy



chemical bond energy → electrical energy → kinetic energy



chemical bond energy in H_2 and O_2 → rapid molecular motions in H_2O → heat energy



electromagnetic (light) energy → chemical bond energy

A Big Problem

U.S. ENERGY CONSUMPTION BY SOURCE

BIOMASS 2.9%
renewable
Heating, electricity, transportation

HYDROPOWER 2.7%
renewable
Electricity

GEOTHERMAL 0.3%
renewable
Heating, electricity

WIND 0.1%
renewable
Electricity

SOLAR & OTHER 0.1%
renewable
Light, heating, electricity

PETROLEUM 38.1%
nonrenewable
Transportation, manufacturing

NATURAL GAS 22.9%
nonrenewable
Heating, manufacturing, electricity

COAL 23.2%
nonrenewable
Electricity, **manufacturing**

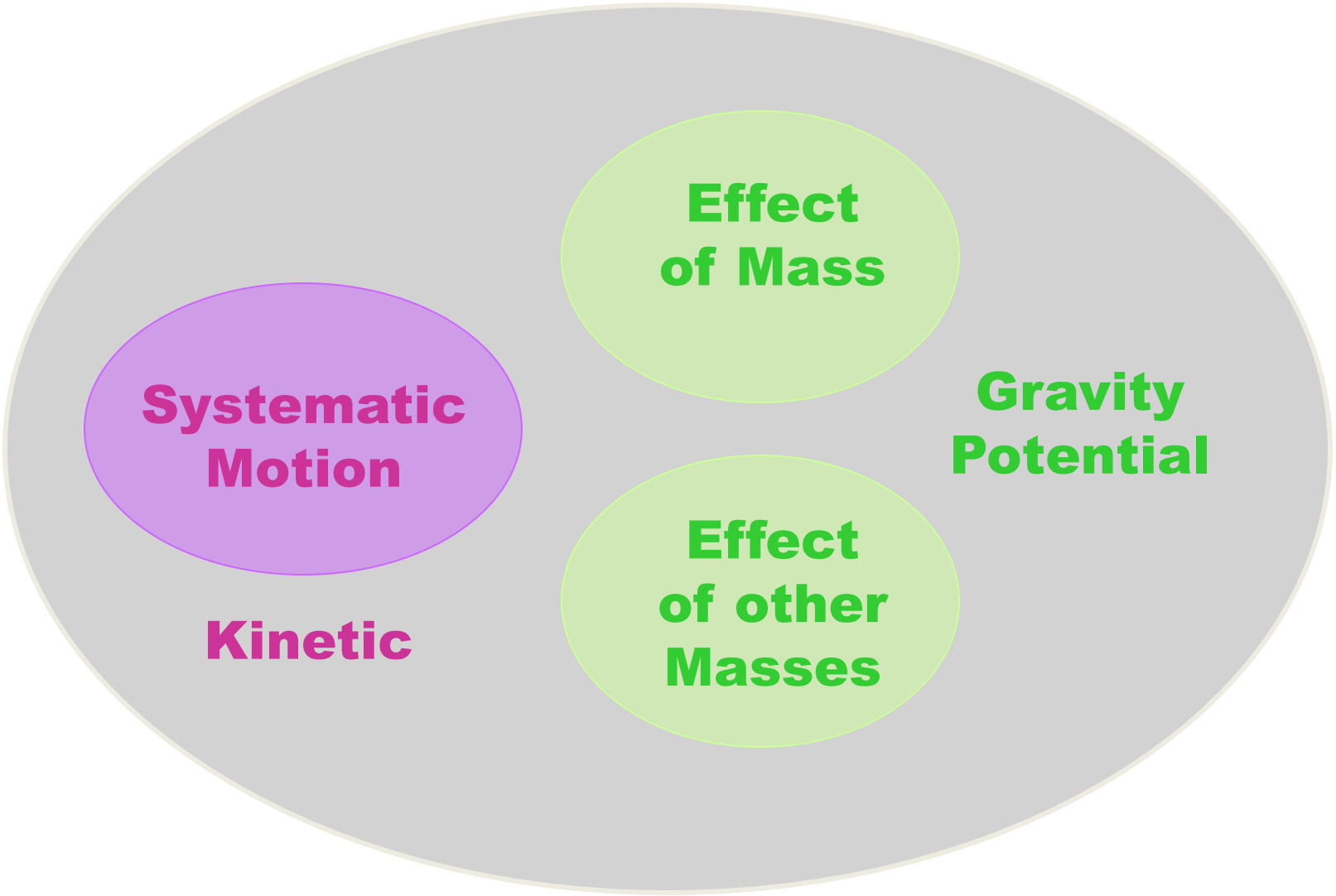
URANIUM 8.1%
nonrenewable
Electricity

PROPANE 1.7%
nonrenewable
Manufacturing, heating

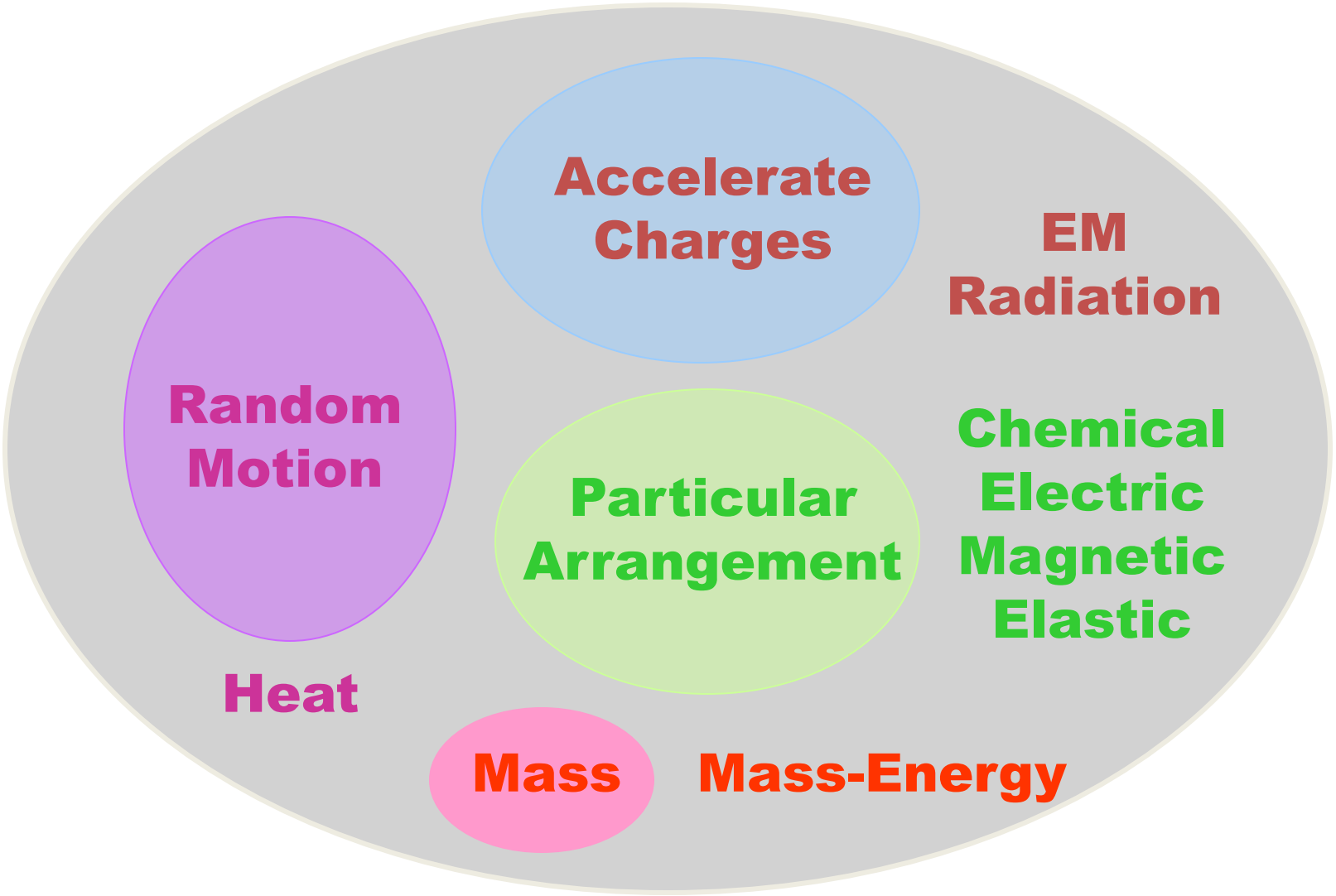
These sources of energy are clean and renewable but are only 6% of U.S. consumption.

These sources of chemical energy can't be replaced and produce lots of carbon dioxide as a byproduct.

FORMS OF ENERGY



FORMS OF ENERGY

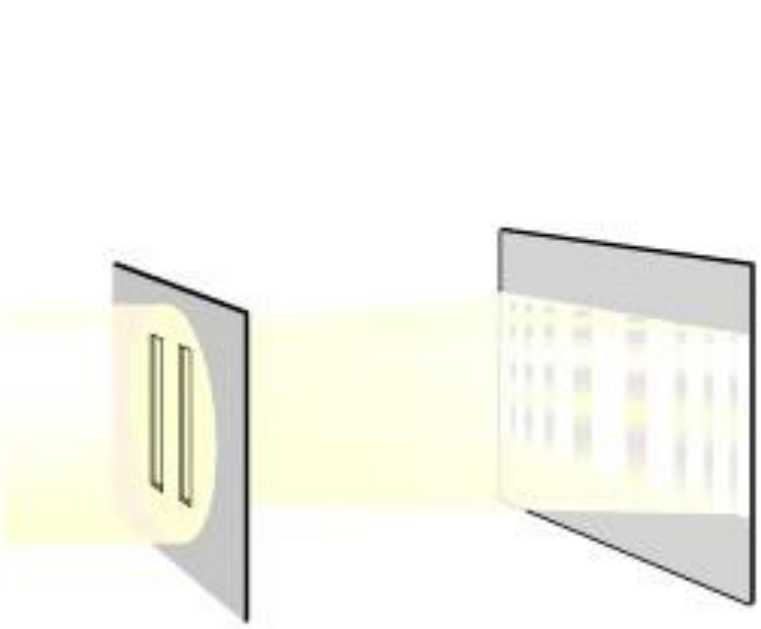


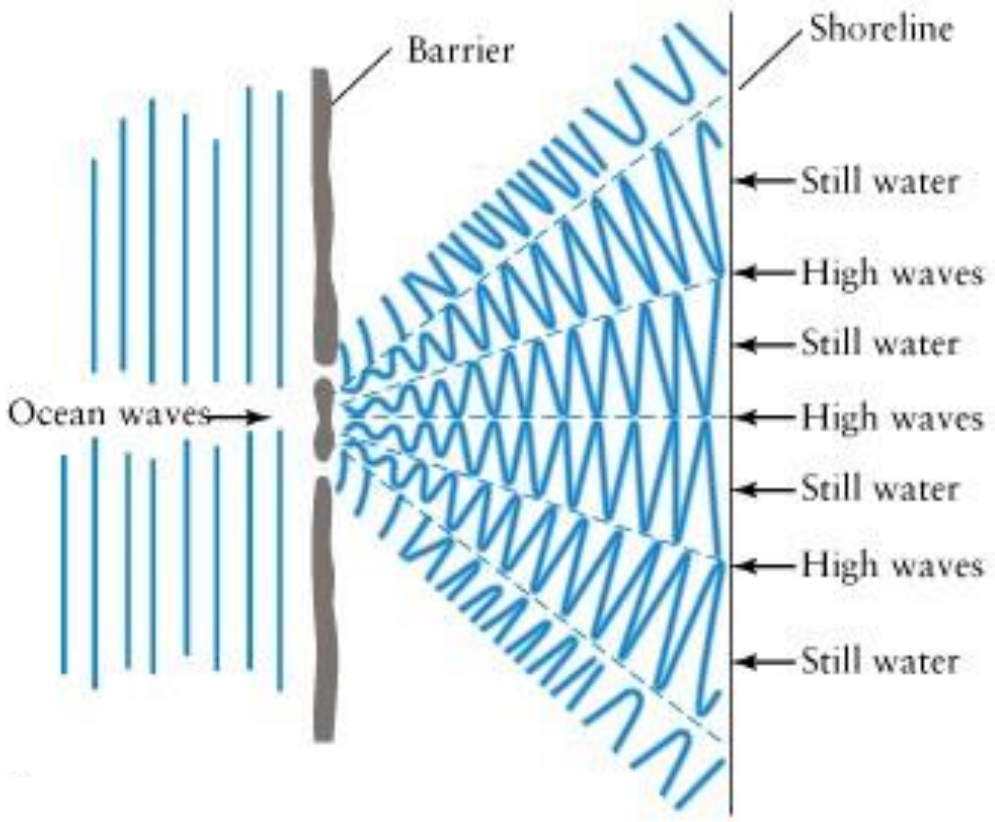
Light

What is Light?

- In the 17th Century, Isaac Newton argued that light was composed of little particles while Christian Huygens suggested that light travels in the form of waves.
- In the 19^{th} and 20^{th} Centuries, Maxwell, Young, Einstein and others showed that light behaves both like a particle and a wave, depending on how you observe it.

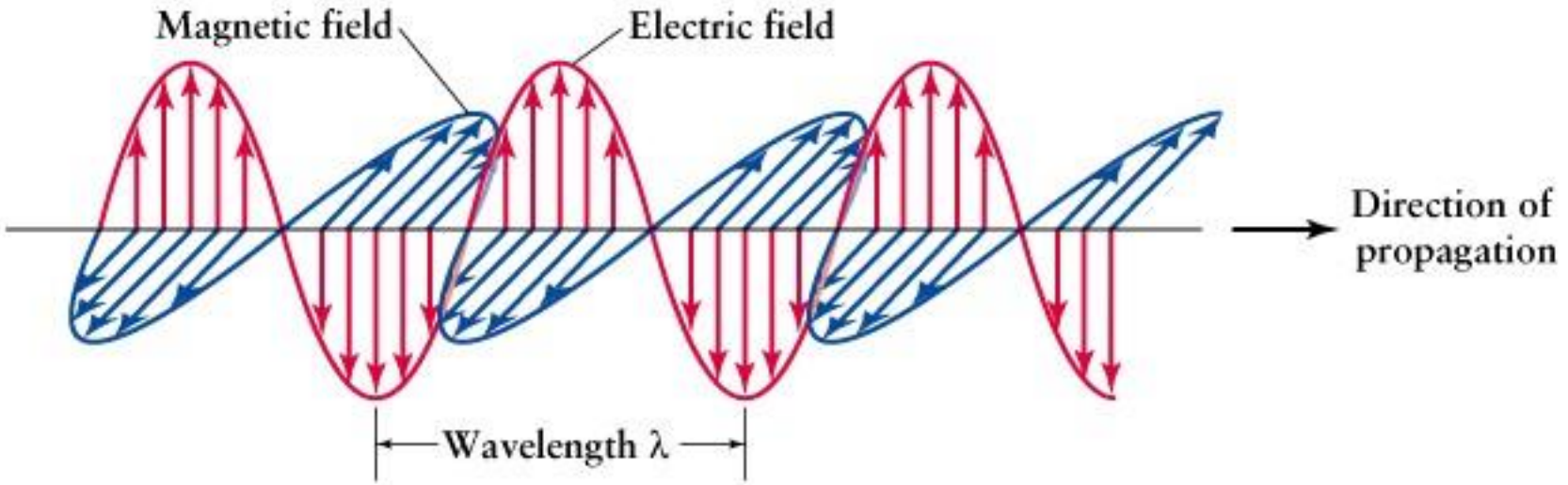
Thomas Young's interference experiment





Light arriving at a screen though two slits made alternating bands of light and dark, which makes no sense if light is a particle (their intensities would just add) but does make sense if it is a wave (the high and low amplitudes combine to add and subtract intensities).

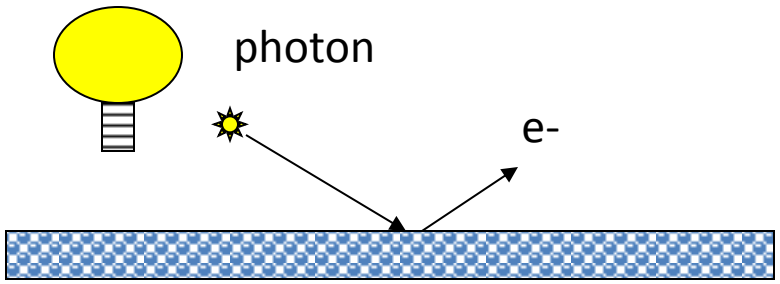
Scottish physicist James Clerk Maxwell showed mathematically in the 1860's that light must be a combination of electric and magnetic fields.



Light is created when electric and magnetic charges accelerate (when they are static they create a field and when they accelerate they create a wave).

In 1905 Einstein calculated the energy of a particle of light (a **photon**) and proposed the photoelectric effect (electrons liberated by the energy of light).

$$E_{photon} = hc/\lambda$$

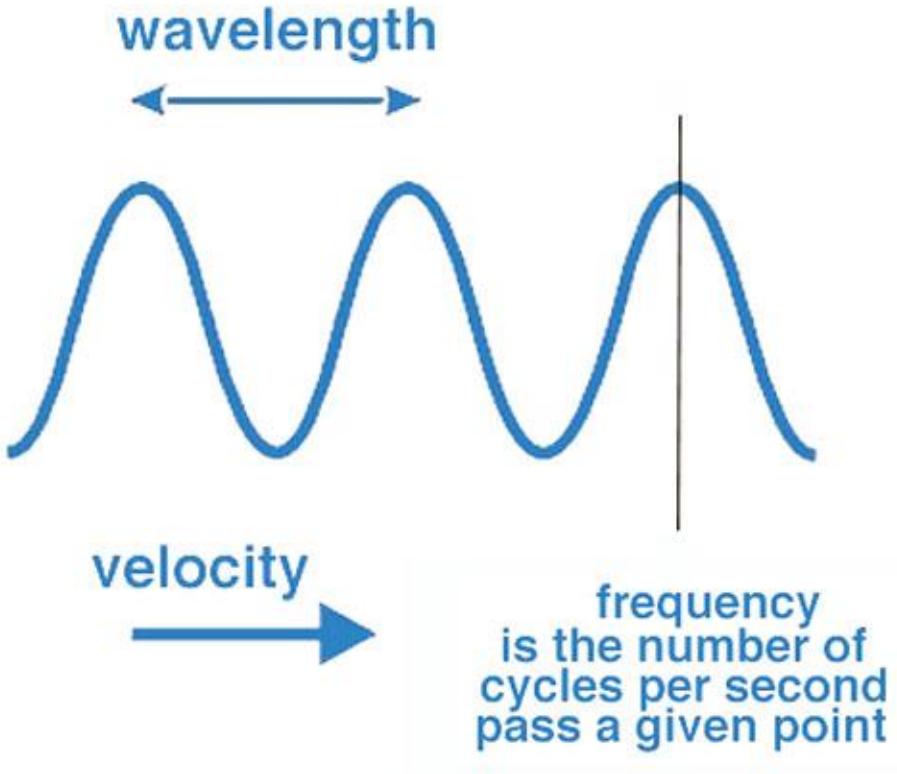


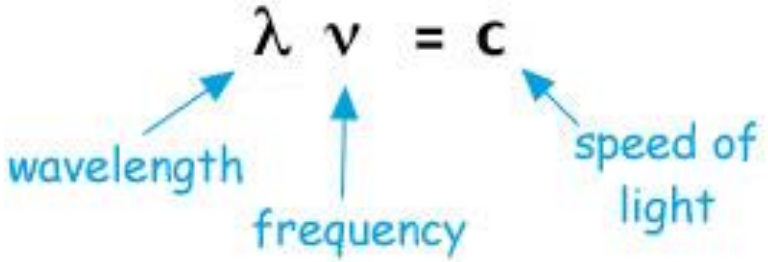
The energy of a photon is set by **h**, or Planck's constant, a very small number.

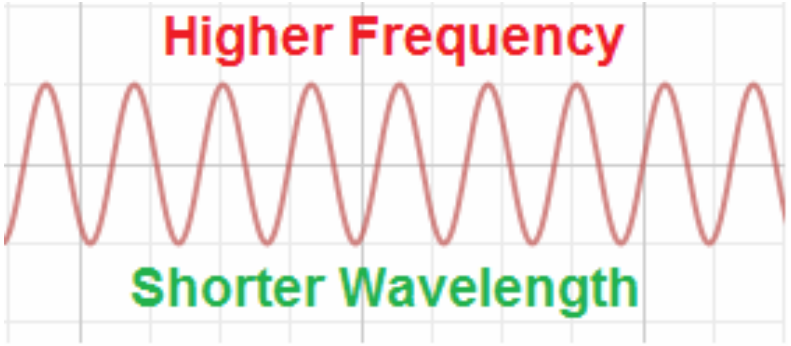
The speed of light, **c**, is super-fast, 300,000 km/sec

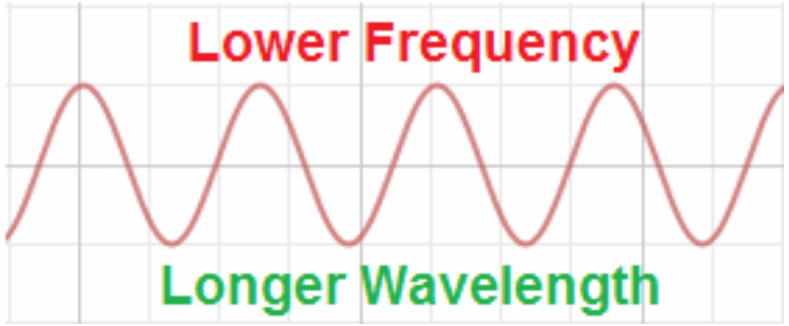
Properties of Light

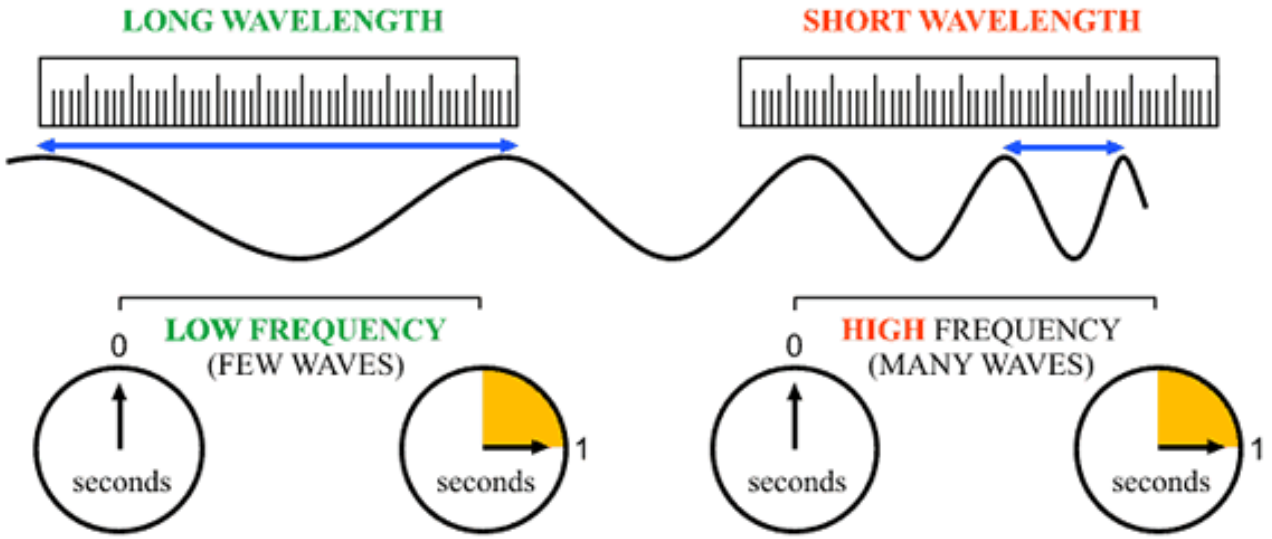
There is an inverse relationship between **wavelength** (red is long, blue is short) and **frequency**. The product of the two is the speed of light, a universal constant.



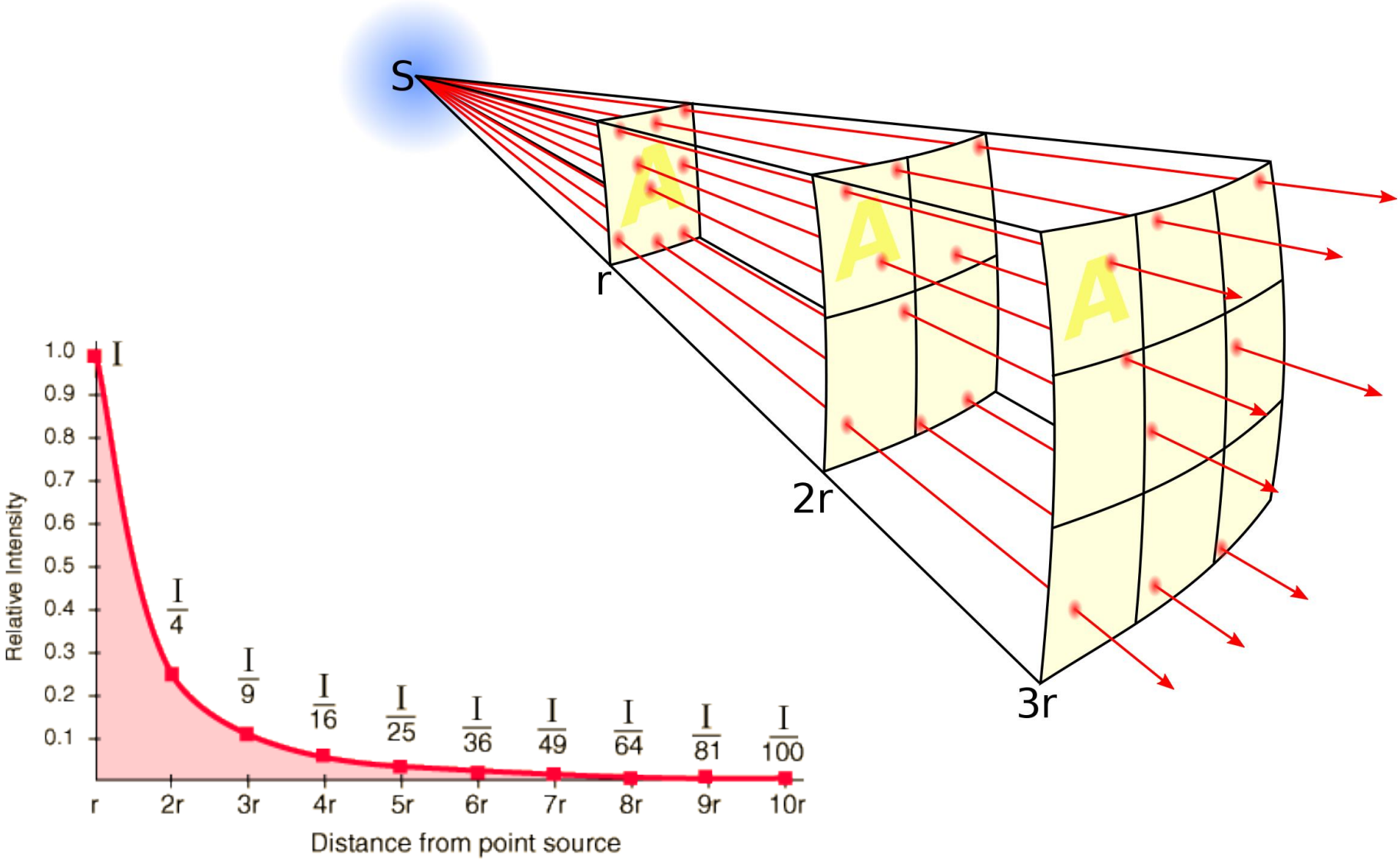



Higher Frequency
Shorter Wavelength

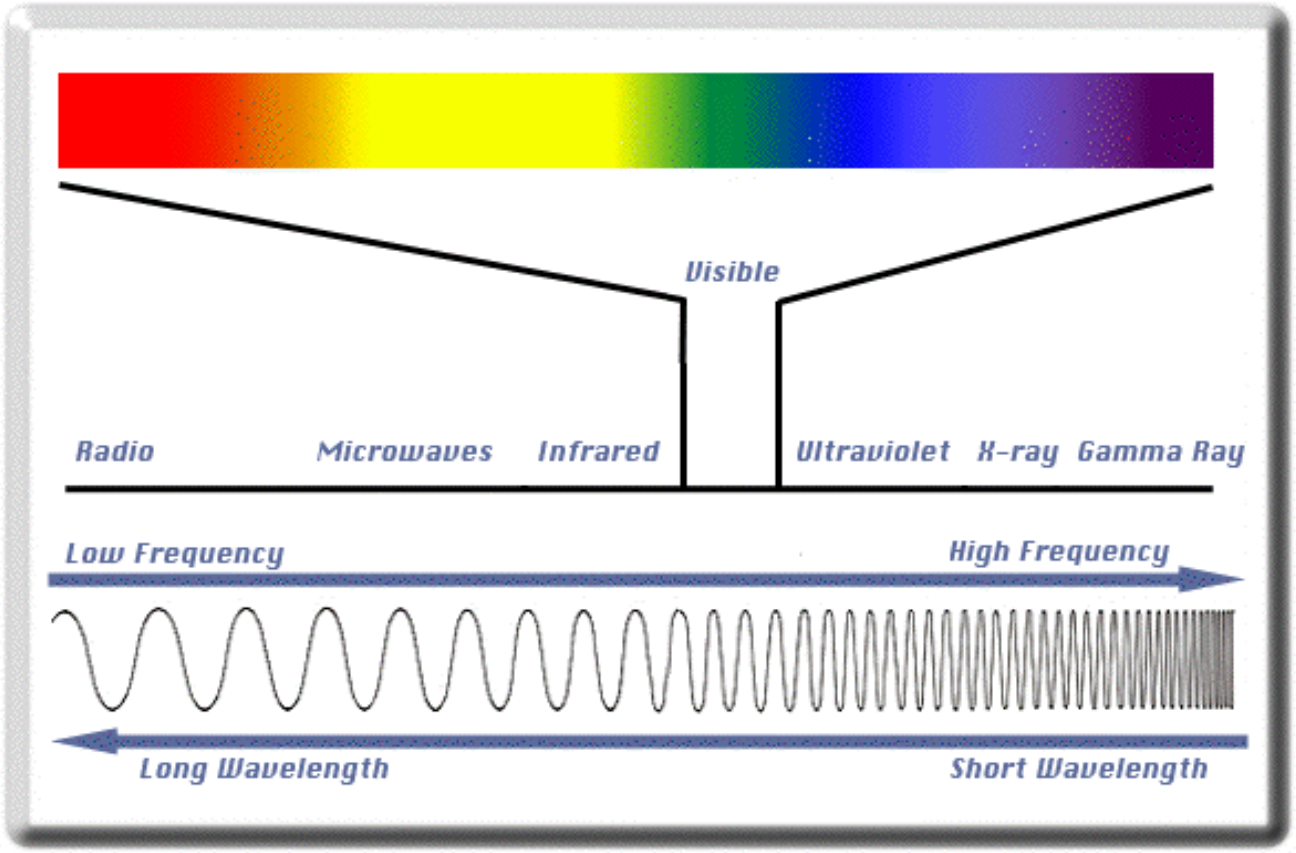

Lower Frequency
Longer Wavelength


LONG WAVELENGTH
SHORT WAVELENGTH
LOW FREQUENCY
(FEW WAVES)
HIGH FREQUENCY
(MANY WAVES)
0
seconds
1
seconds
0
seconds
1
seconds

Inverse Square Law



Radiation



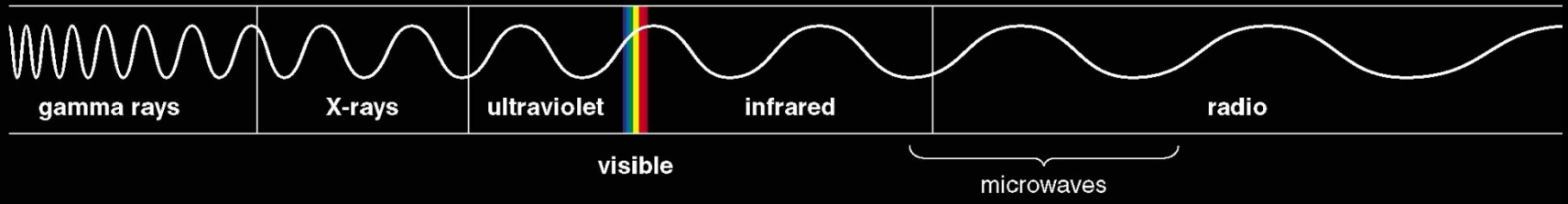
Light is just a narrow sliver of a wide range of waves of electromagnetic energy, all traveling at 300,000 km/s.

The Electromagnetic Spectrum

wavelength (meters) ← shorter — longer →

10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2}

size of wavelength



frequency (hertz) ← higher — lower →

10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6}

energy (electron-volts)

10^{6} 10^{4} 10^{2} 1 10^{-2} 10^{-4} 10^{-6} 10^{-8}

sources on Earth

cosmic sources

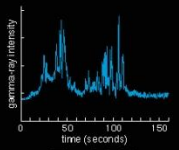


Fig. 13.15 gamma ray burst

Fig. 13.14 black hole accretion disk

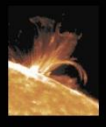


Fig. 10.15 Sun's chromosphere

Fig. 6.2a Sun

Fig. 8.10 planets, star-forming clouds

Fig. 12.2 planets, star-forming clouds

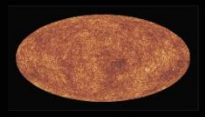
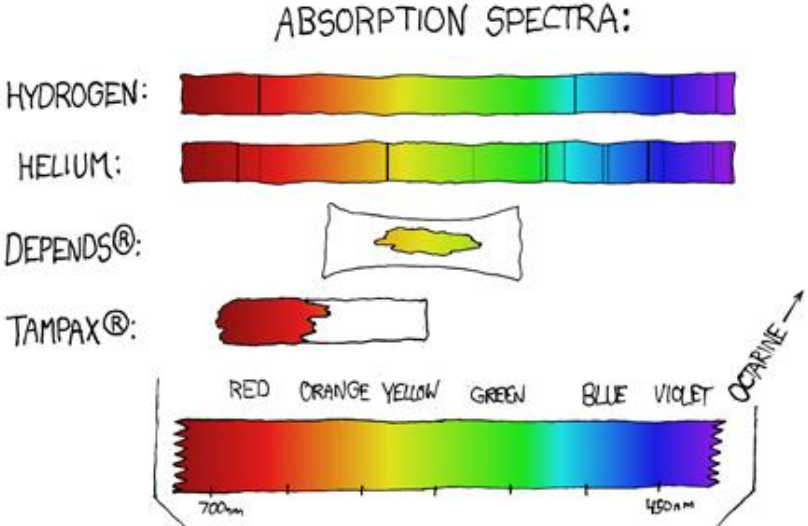


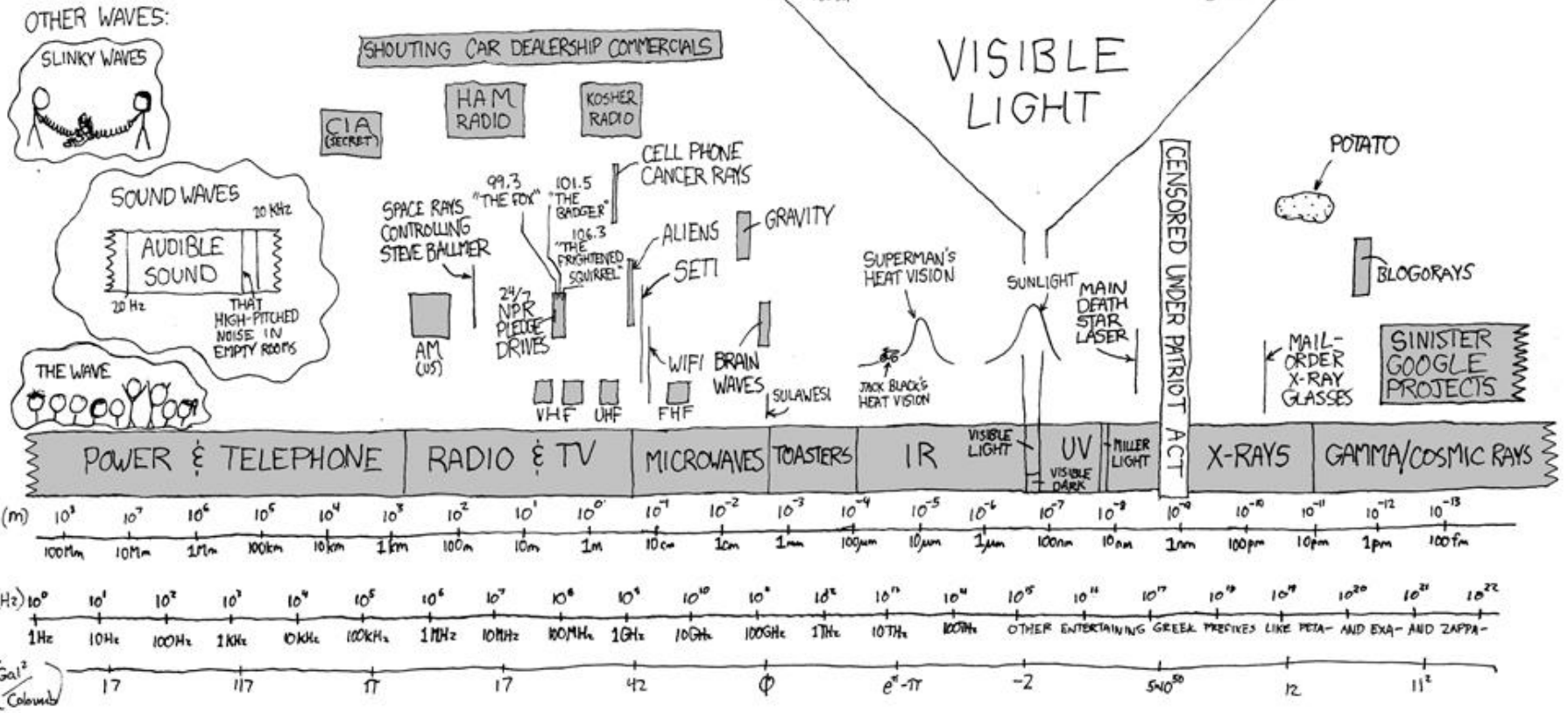
Fig. 17.14 cosmic microwave background

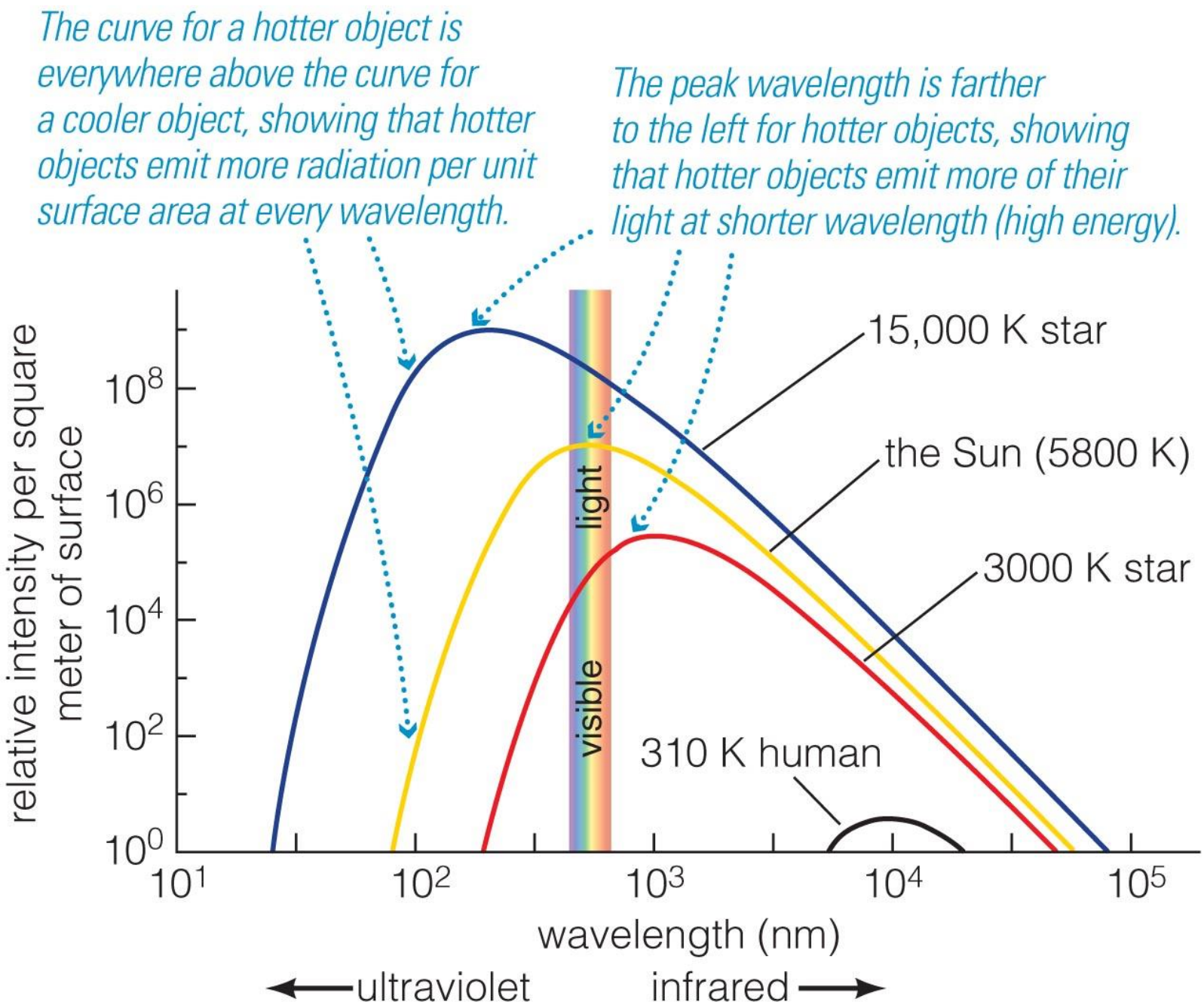
Fig. 15.30 radio galaxy

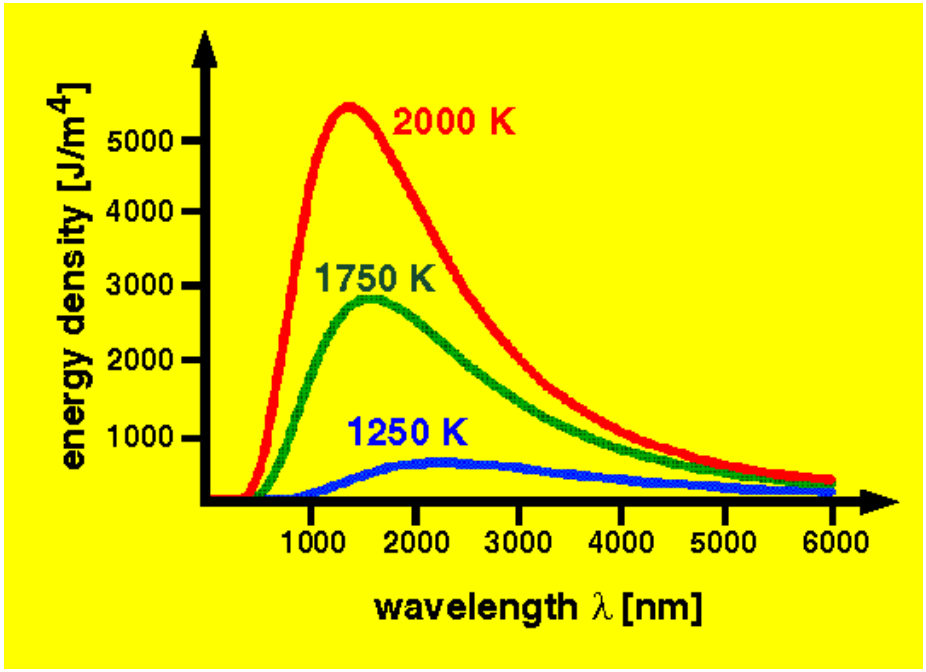
THE ELECTROMAGNETIC SPECTRUM

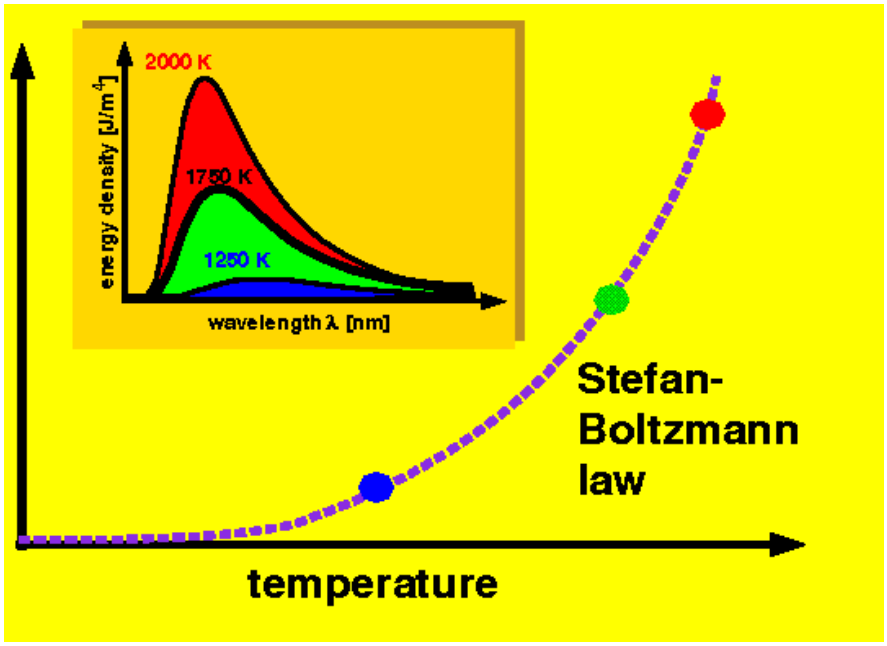
THESE WAVES TRAVEL THROUGH THE ELECTROMAGNETIC FIELD. THEY WERE FORMERLY CARRIED BY THE AETHER, WHICH WAS DECOMMISSIONED IN 1897 DUE TO BUDGET CUTS.

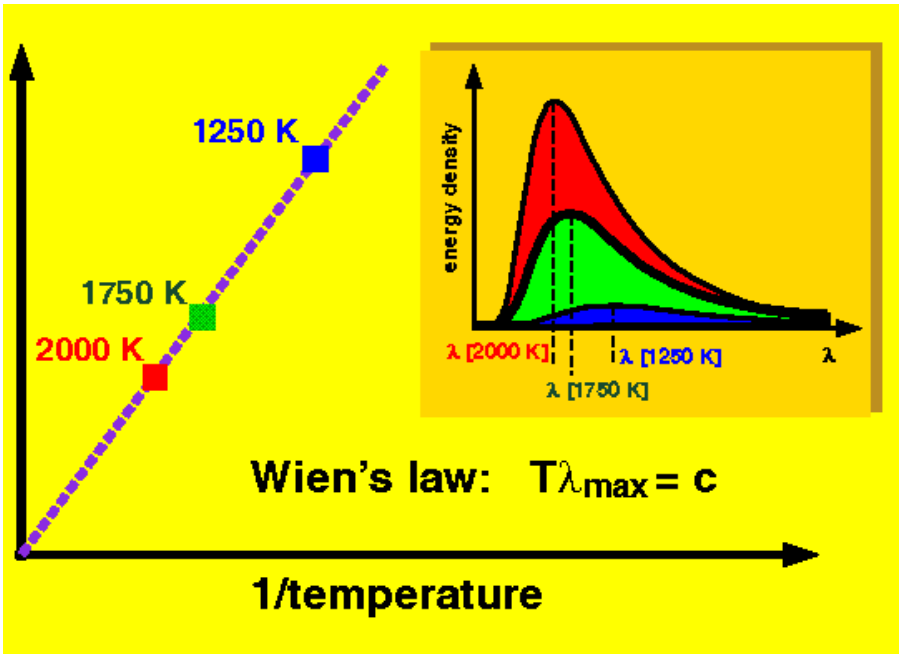




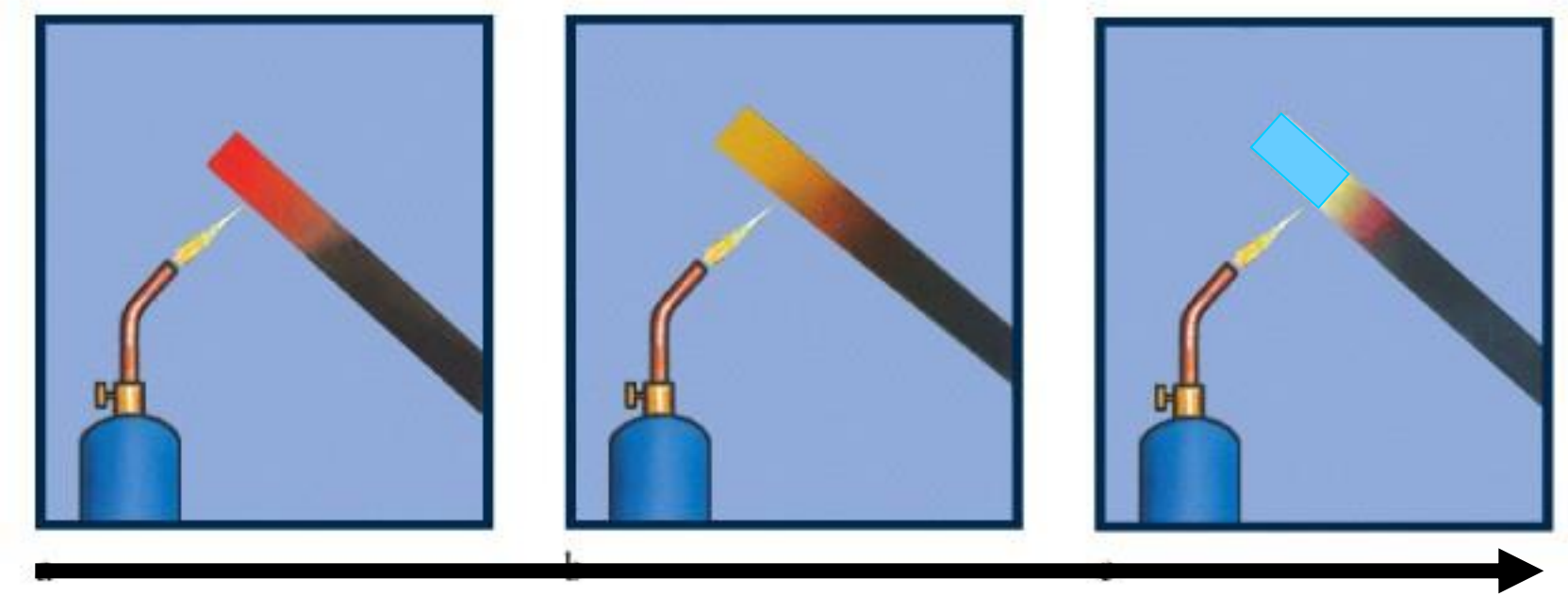

The curve for a hotter object is everywhere above the curve for a cooler object, showing that hotter objects emit more radiation per unit surface area at every wavelength.
The peak wavelength is farther to the left for hotter objects, showing that hotter objects emit more of their light at shorter wavelength (high energy).
relative intensity per square meter of surface
10^8
10^6
10^4
10^2
10^0
15,000 K star
the Sun (5800 K)
3000 K star
310 K human
light
visible
10^1
10^2
10^3
10^4
10^5
wavelength (nm)
ultraviolet
infrared


energy density [J/m^4]
5000
4000
3000
2000
1000
2000 K
1750 K
1250 K
1000
2000
3000
4000
5000
6000
wavelength λ [nm]


2000 K
energy density [J/m^4]
1750 K
1250 K
wavelength λ [nm]
Stefan-
Boltzmann
law
temperature


1250 K
1750 K
2000 K
energy density
λ [2000 K]
λ [1250 K]
λ [1750 K]
λ
Wien's law: Tλmax = c
1/temperature

A cool object, one at room temperature, emits radiation at wavelengths too long for the eye to detect. As it heats up, the radiation it emits shifts to shorter wavelengths (red light then blue light).



increasing temperature

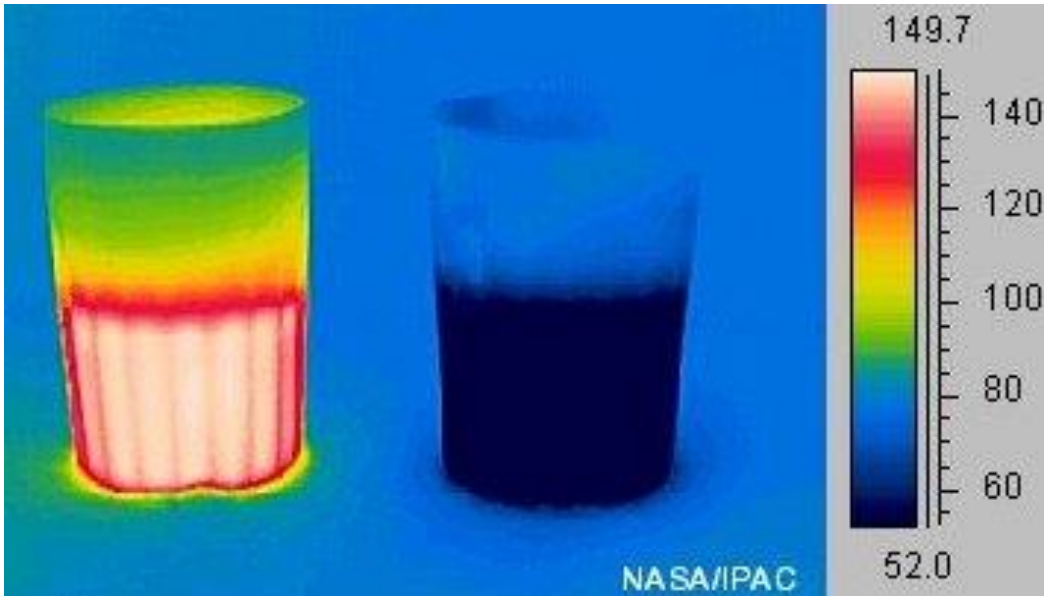
Heat Energy

Infrared Vision

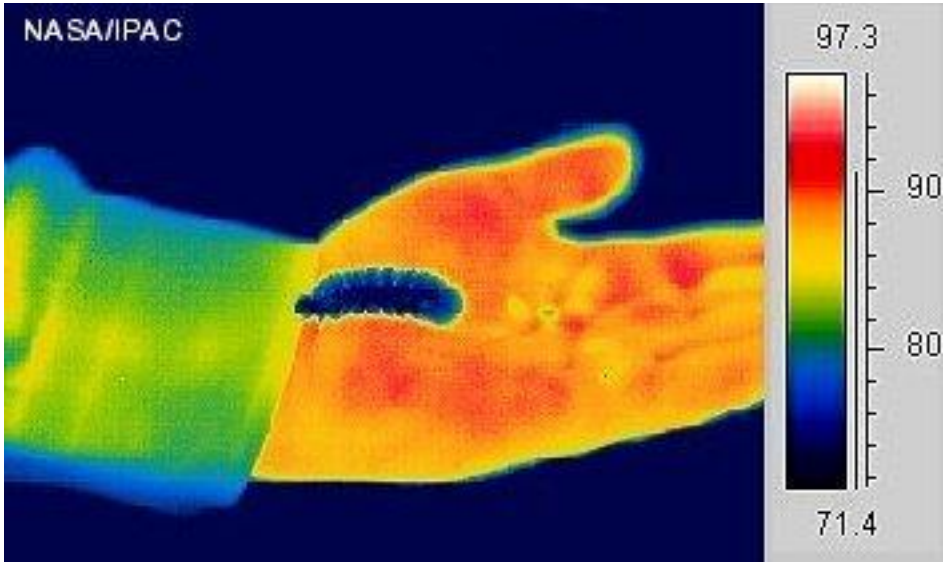
Infrared Vision

A normal photo of two glasses doesn't tell you which is hot and which is cold, unless you think the color is telling you

In the infrared image it is clear. A hot liquid radiate more infrared energy than a cold one

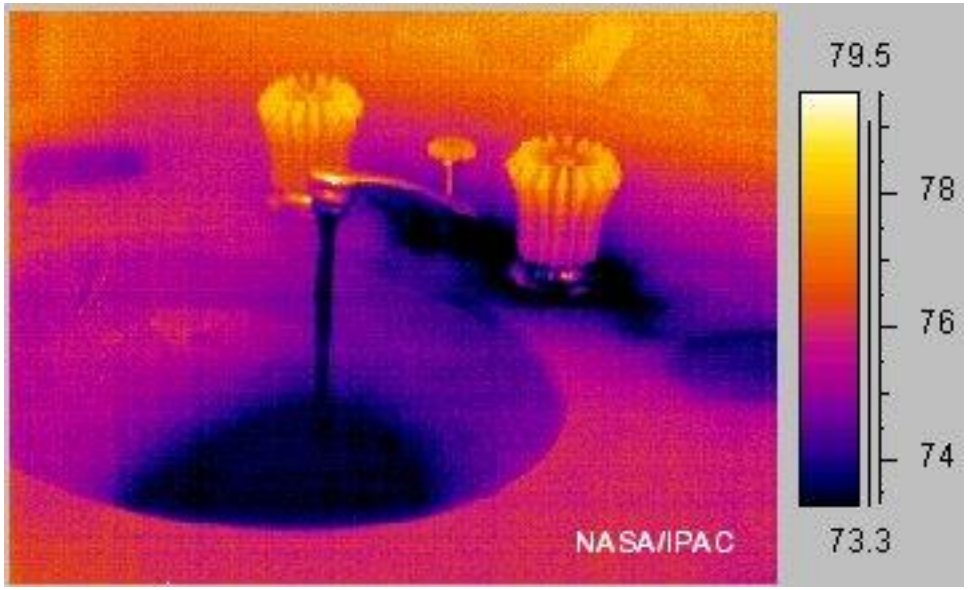


You can easily tell the difference between the cold-blooded animal and…

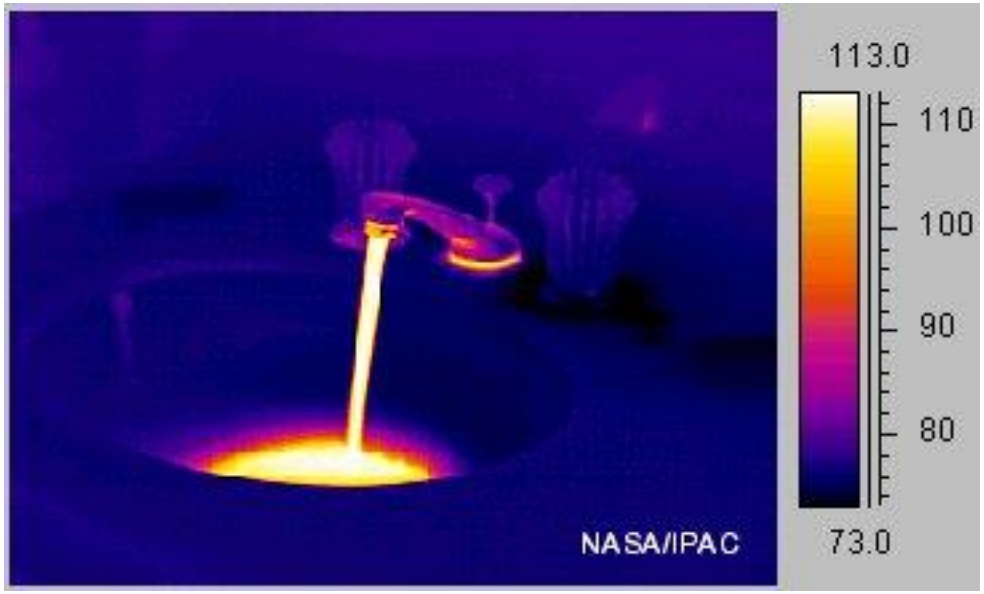


…the warm-blooded one

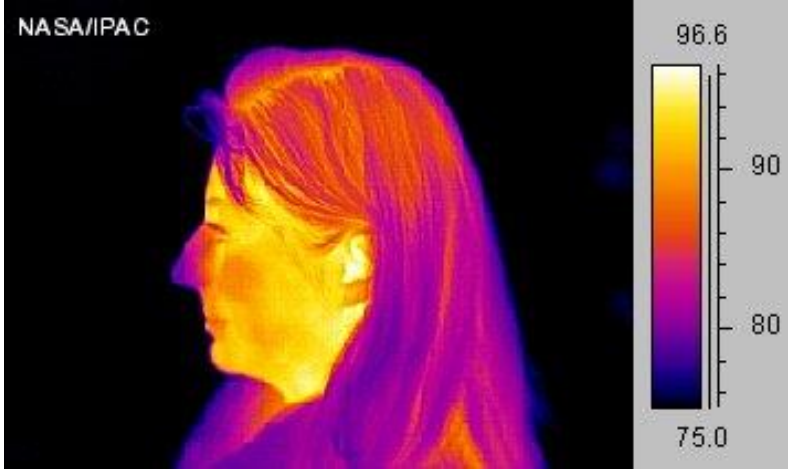
Or the cold tap….



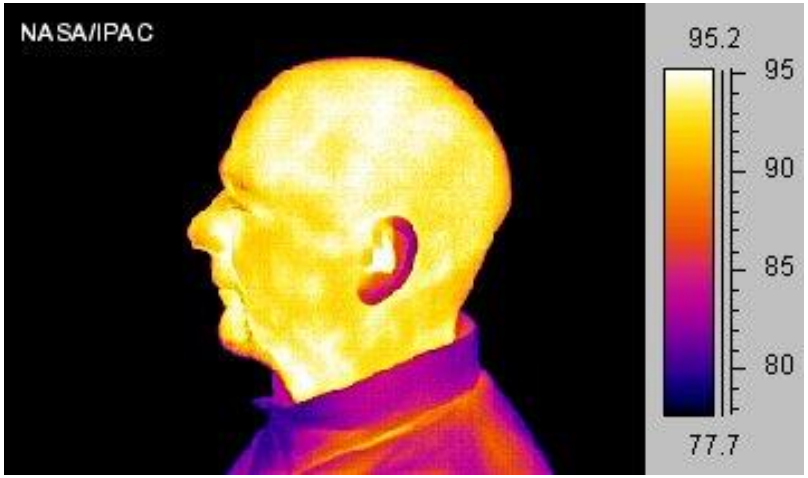
and the hot tap.




NASA/IPAC
95.8
95
90
85
80
77.9


NASA/IPAC
96.6
90
80
75.0


NASA/IPAC
95.9
95
90
85
80
79.1


NASA/IPAC
95.2
95
90
85
80
77.7


NASA/IPAC
92.7
90
80
70
66.5


NASA/IPAC
92.3
90
80
70
61.4

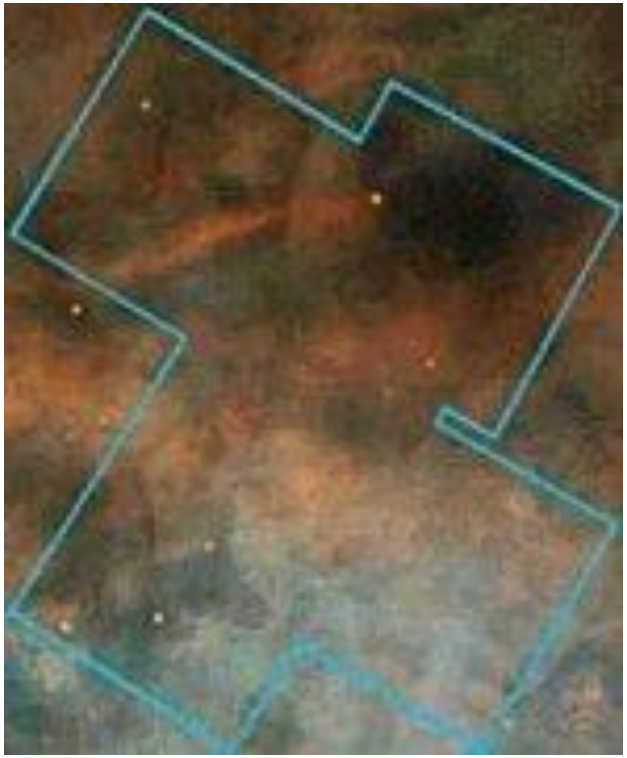
Familiar materials often behave differently with regard to infrared light. Here the polythene bag is opaque to light but…

…transparent to infrared

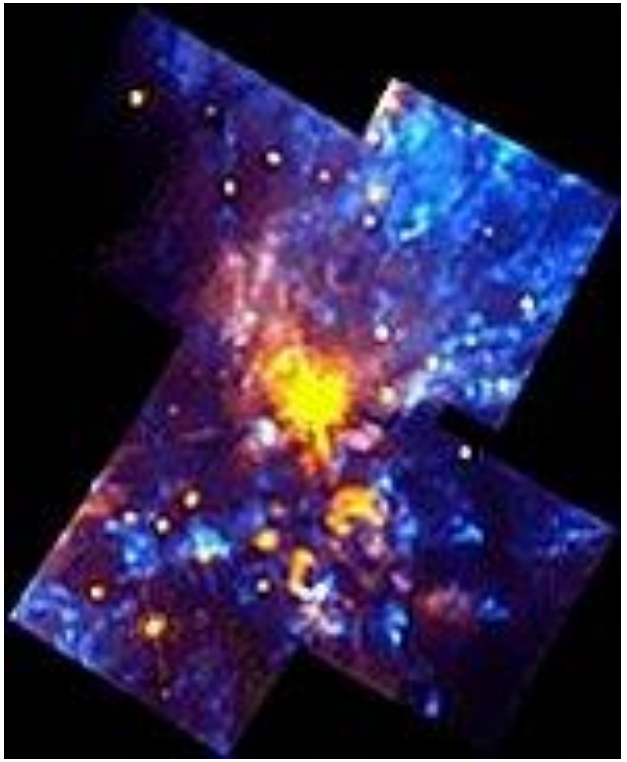
This one is tougher. Guess which colors of pen ink will show up the strongest in the infrared

Black, because it will absorb all light and so heat up more. All the darker colors absorb more light and get a bit hotter than a pale color like yellow

OPTICAL

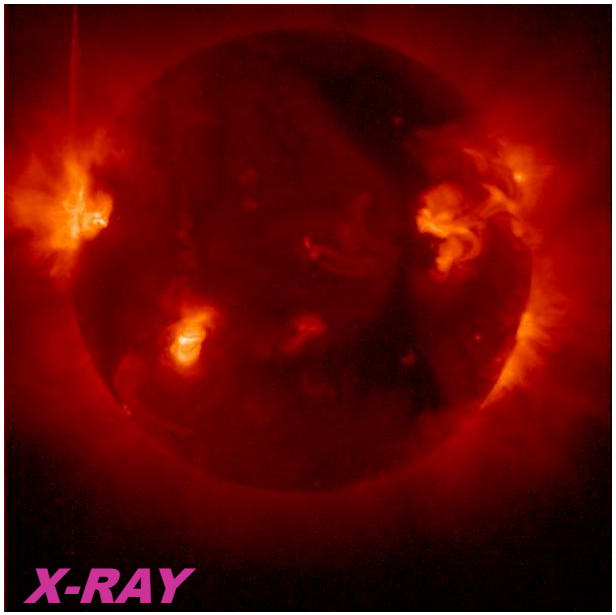


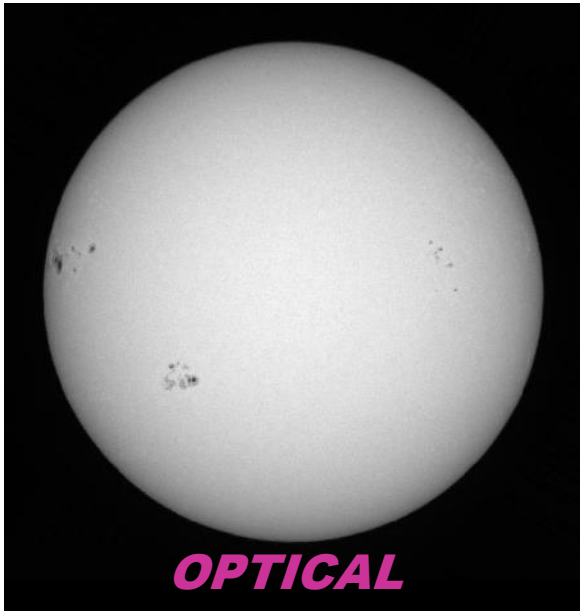
INFRARED

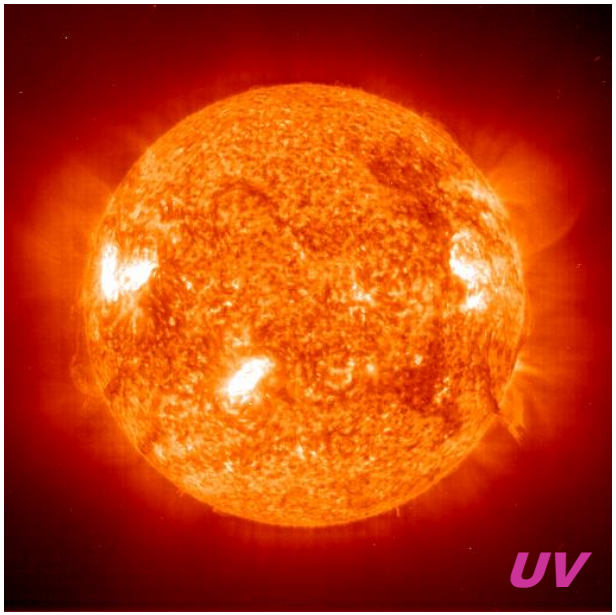


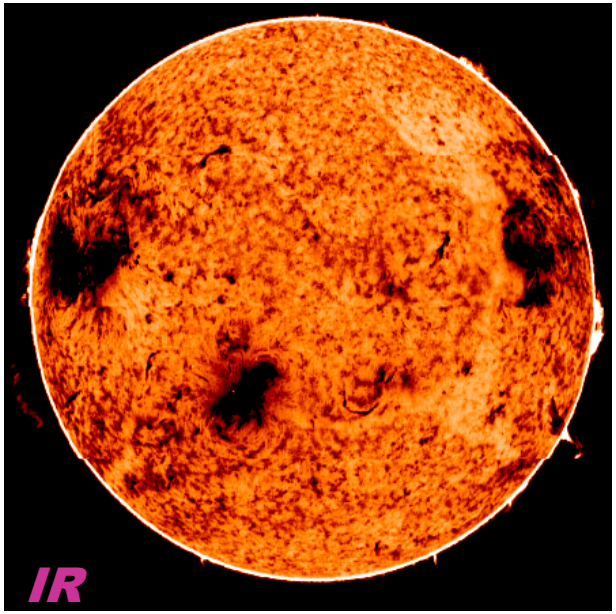
The star forming regions of the Milky Way are obscured by gas and dust, but infrared radiation is unaffected and escapes easily, revealing the star cluster embedded deep within the cloud

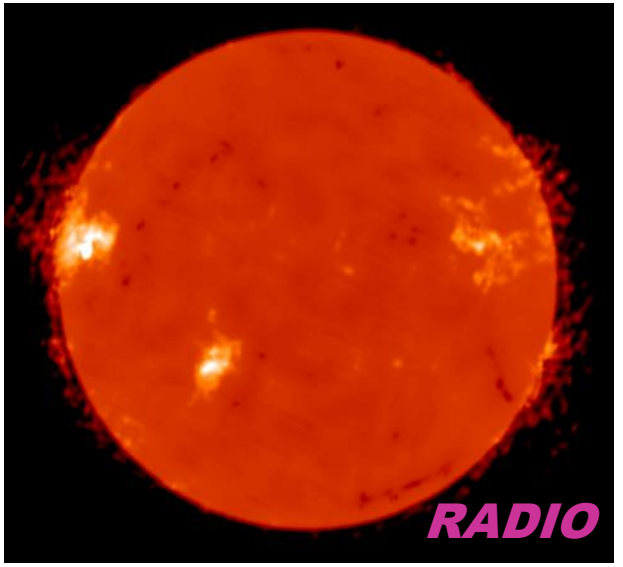
The Sun



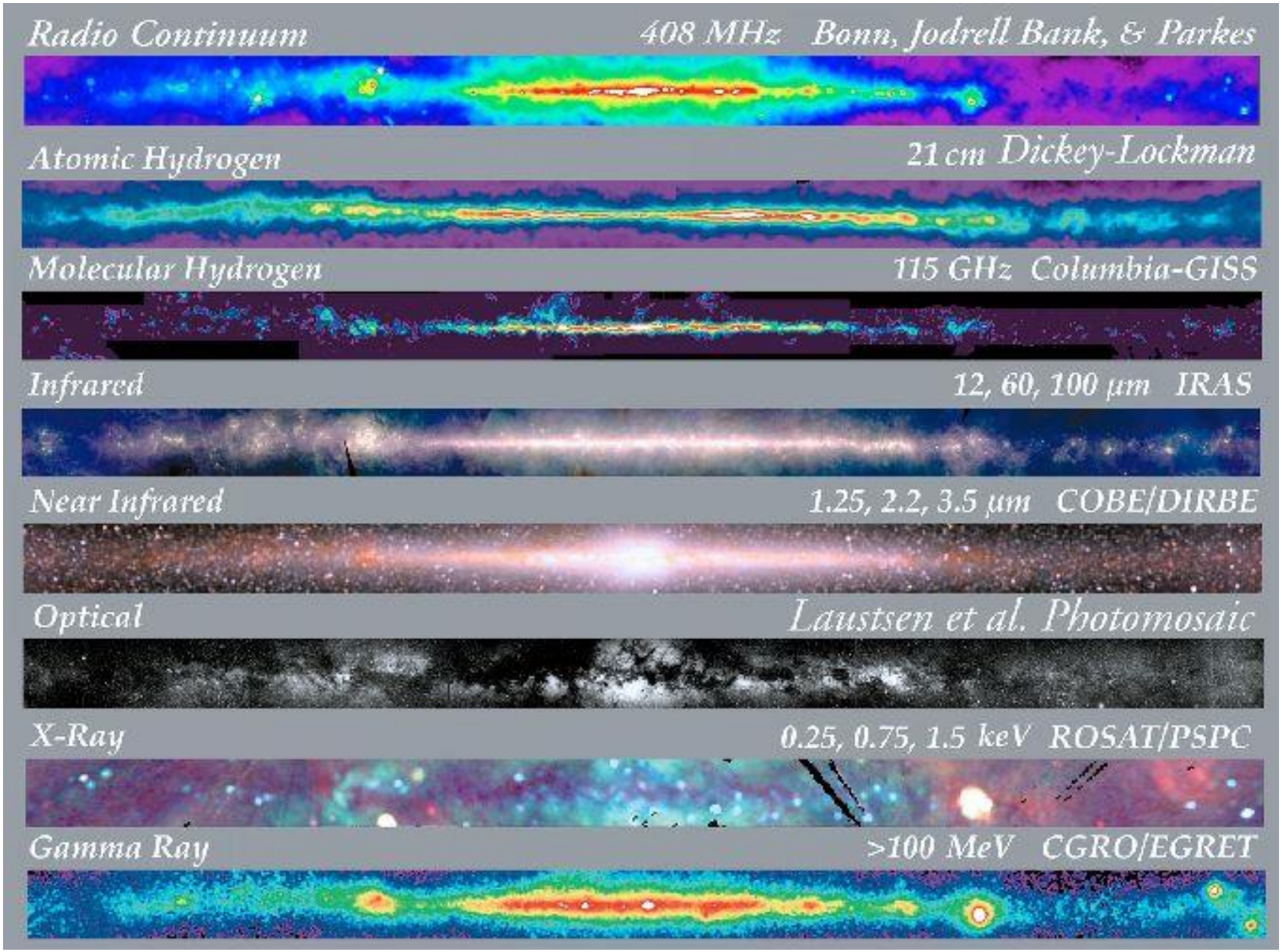




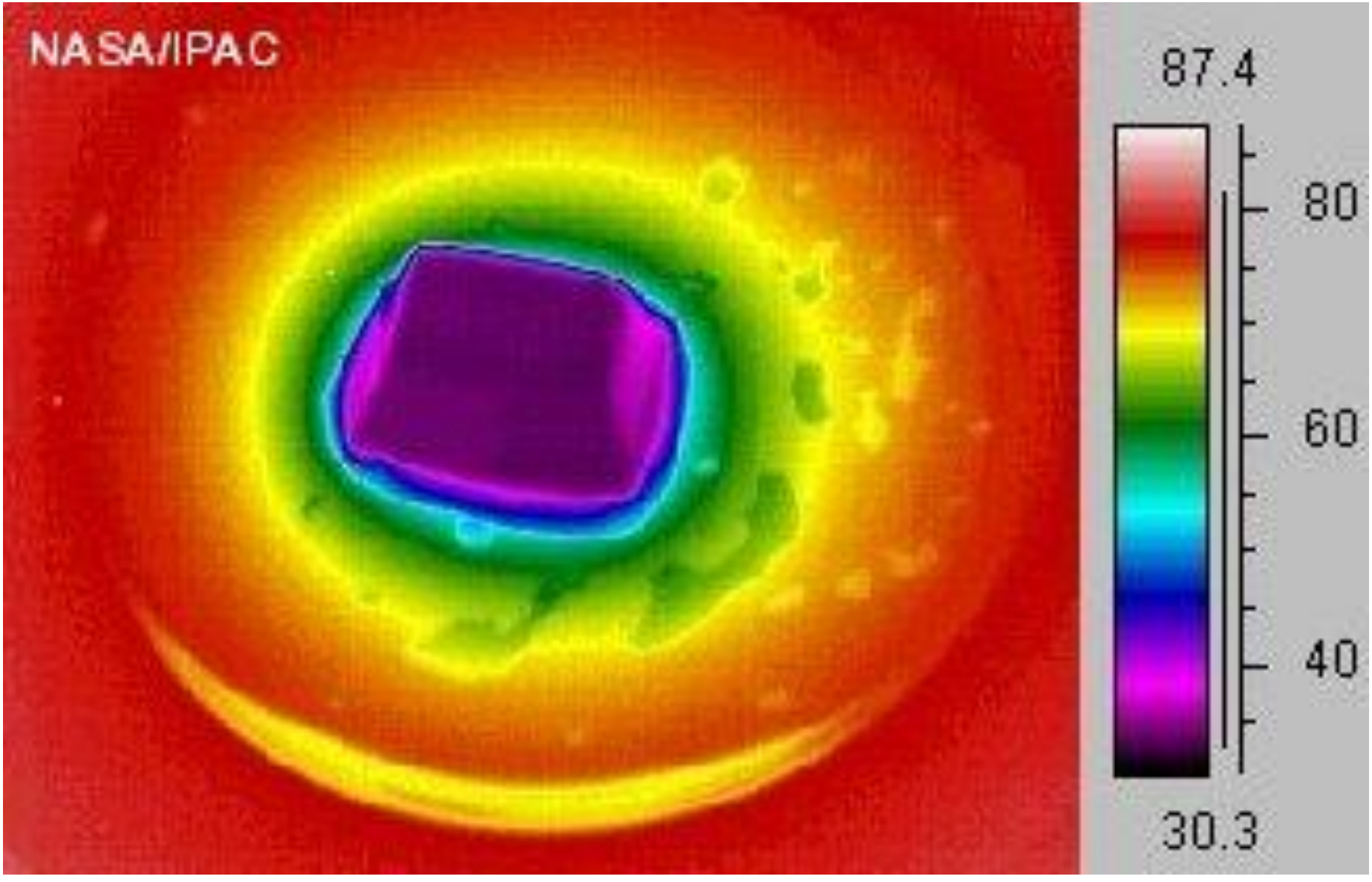




The Milky Way



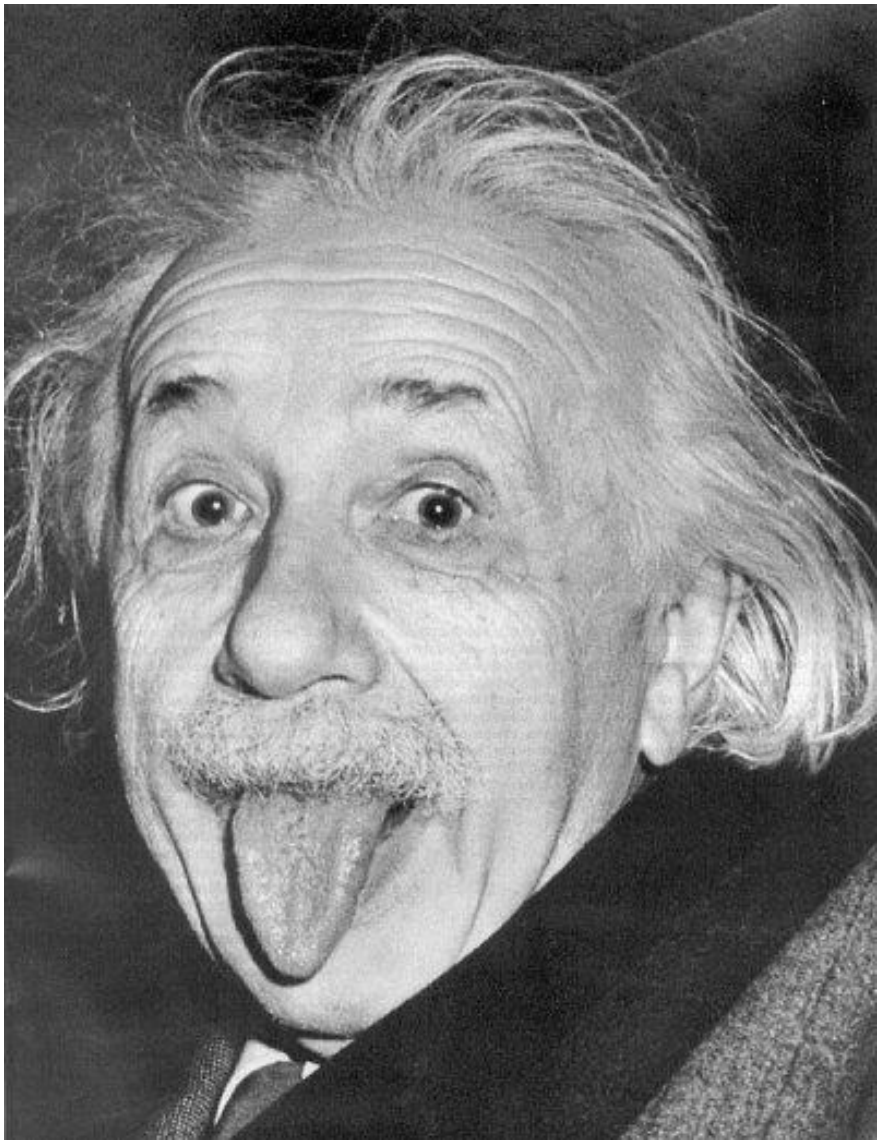
CHECK OUT THESE FAMILIAR OBJECTS, SEEN IN HEAT



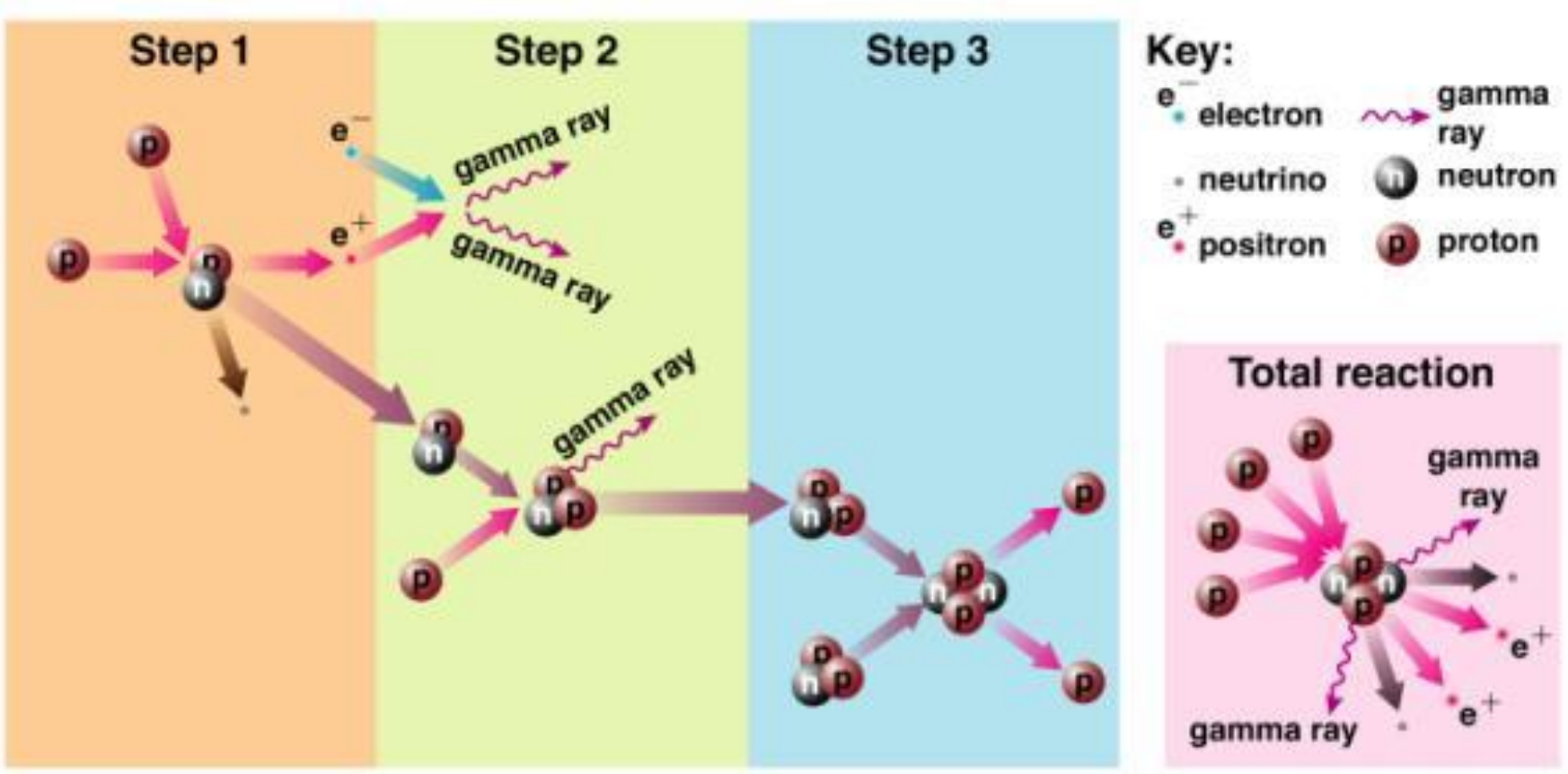
The Infrared Sky

The Infrared Sky

Mass-Energy

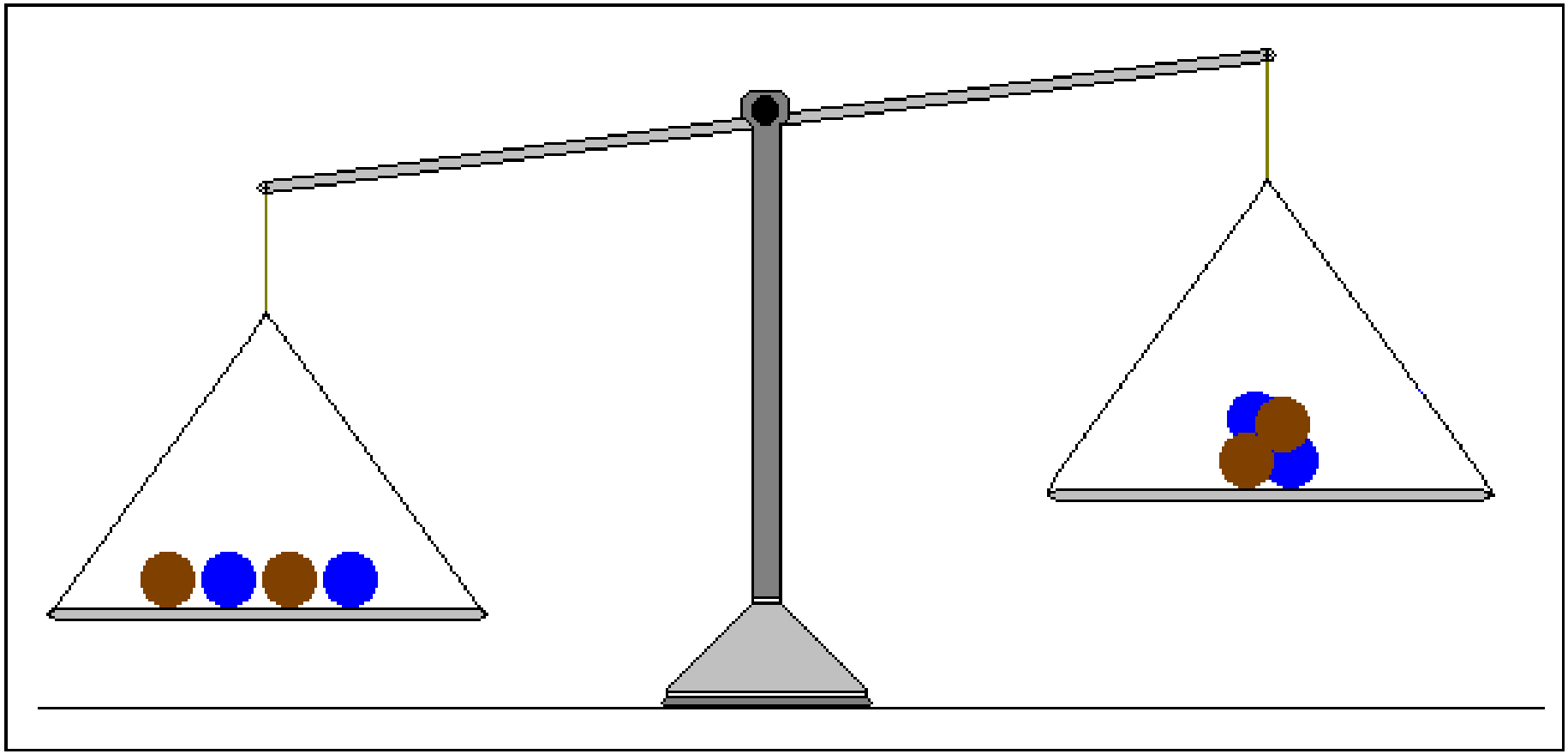


Fusion



The three-step fusion reaction in the Sun and all stars like the Sun converts hydrogen into helium.

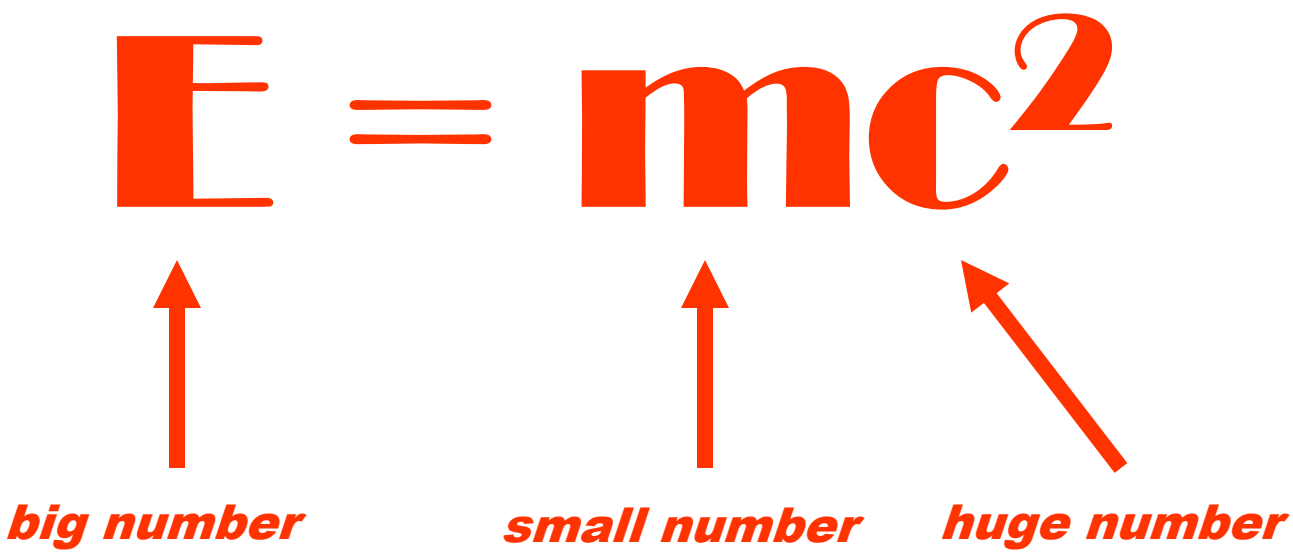
Fusion



But the helium nucleus that results is a bit lighter than the sum of its two protons and two neutrons.

Mass-Energy

Another way to think about this is that the energy that holds the helium nucleus together has a tiny amount of equivalent mass, and that energy can get released going by fusion from hydrogen to helium. But, energy is only converted with 0.7% efficiency.



When 0.7% of the mass of a hydrogen atom is converted into radiant energy it's an enormous amount relative to the mass involved.

The mass-energy in the ink in the dot at the end of a sentence in a book could power a typical family home for a year.

Big Mac Units:

100g of chemical energy is 2.5 x 10^6 J

That patty has a mass-energy of 10^{16} J

Fusion in the Sun

fusion reaction: $4\,H \Rightarrow He^4 + \text{energy}$

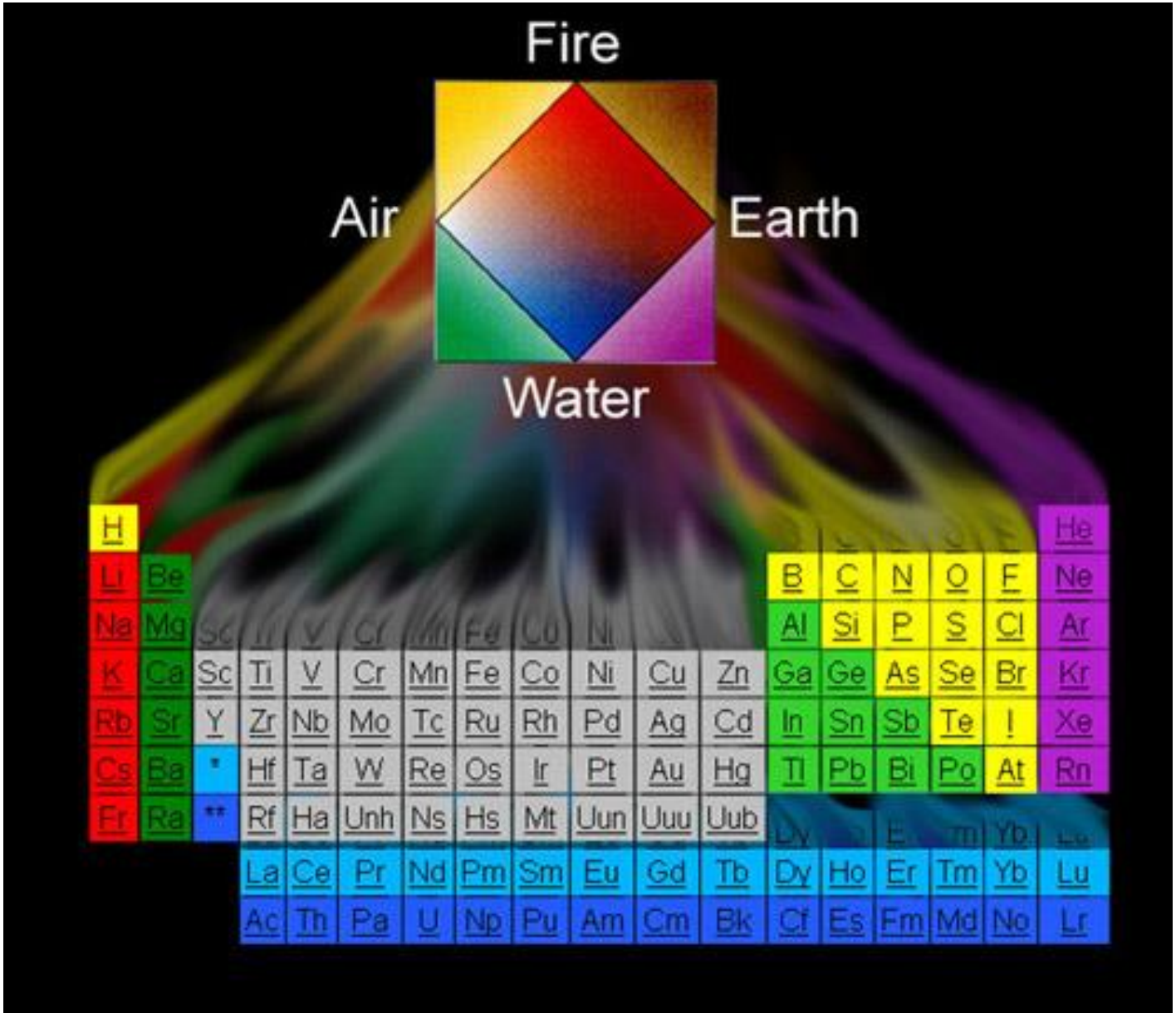
where does the energy come from? $E = mc^2$

fuel consumption of the sun per second:

675 000 000 tons hydrogen
fuse into 653 000 000 tons of helium

Conversion of 22 000 000 tons of matter into energy

Chemistry

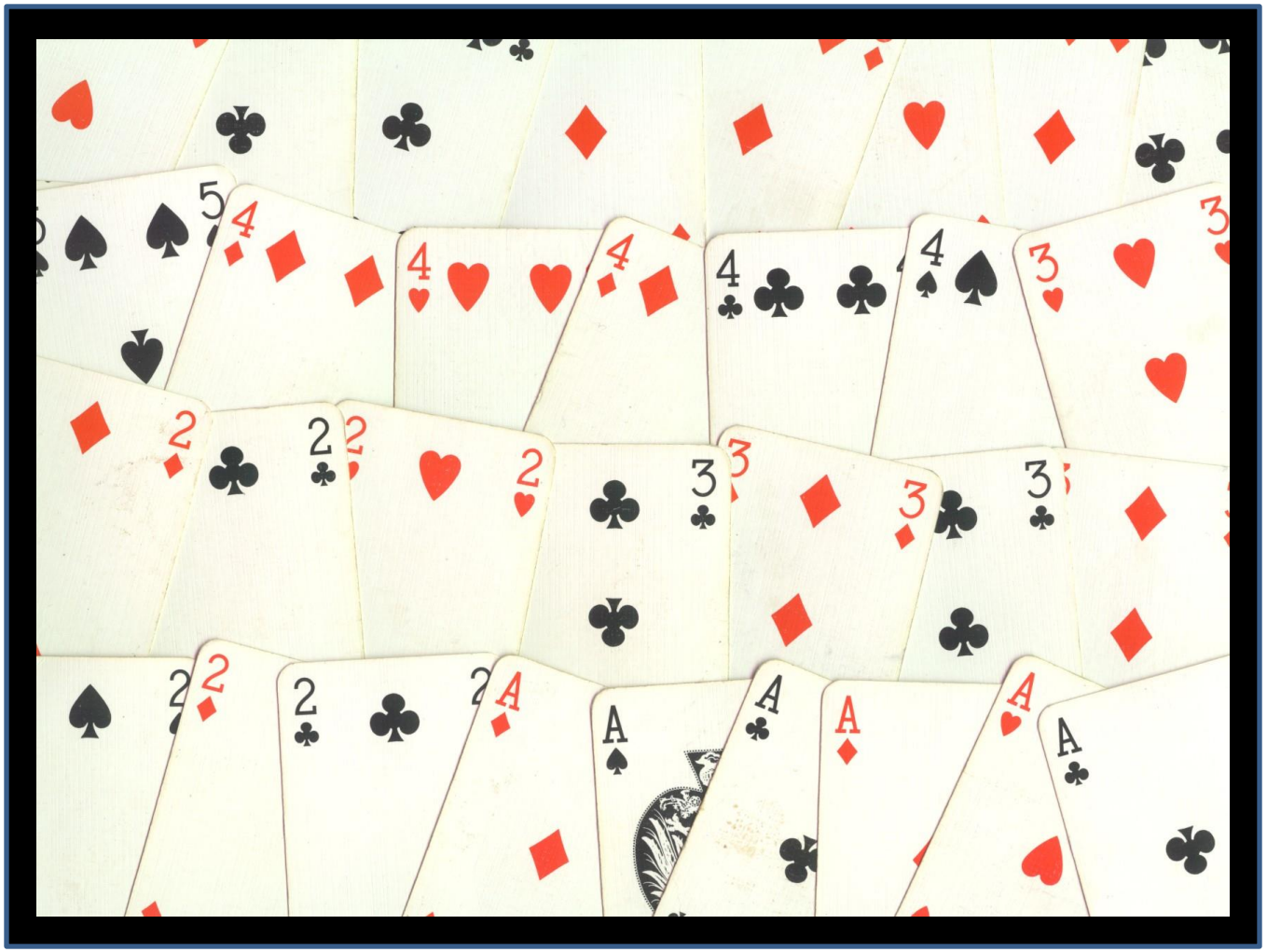

Fire
Air
Earth
Water
H
He
Li Be
B C N O F Ne
Na Mg
Al Si P S Cl Ar
K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr
Rb Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In Sn Sb Te I Xe
Cs Ba * Hf Ta W Re Os Ir Pt Au Hg Tl Pb Bi Po At Rn
Fr Ra ** Rf Ha Unh Ns Hs Mt Uun Uuu Uub
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr

Chemical Ingredients

The Sun		Humans		Earth's Crust	
H	91%	H	61%	O	47%
He	9%	O	26%	Si	28%
O	0.078%	C	11%	Al	8%
C	0.033%	N	2.4%	Fe	5%
Ne	0.011%	Ca	0.23%	Ca	3.6%
N	0.010%	Ph	0.13%	Na	2.8%
Mg	0.004%	S	0.13%	K	2.6%

We are enriched in carbon, nitrogen and oxygen (as water) compared to stars. All elements beyond helium are made in stars. The most massive stars make the heaviest elements.

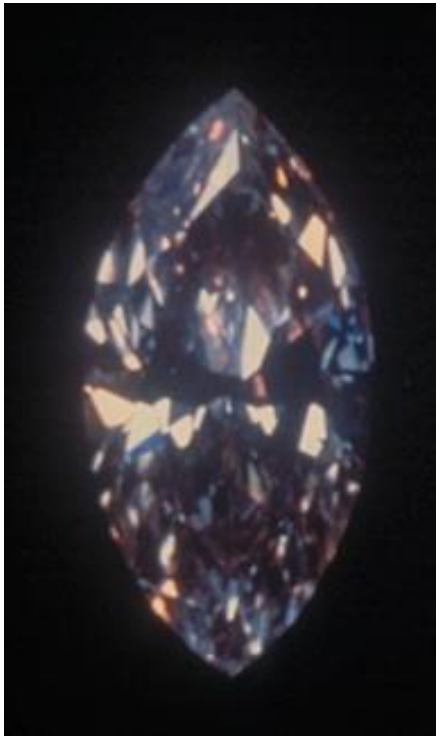
Helium



Like all the face cards in a deck. Helium was forged by fusion within the first few minutes after the big bang.

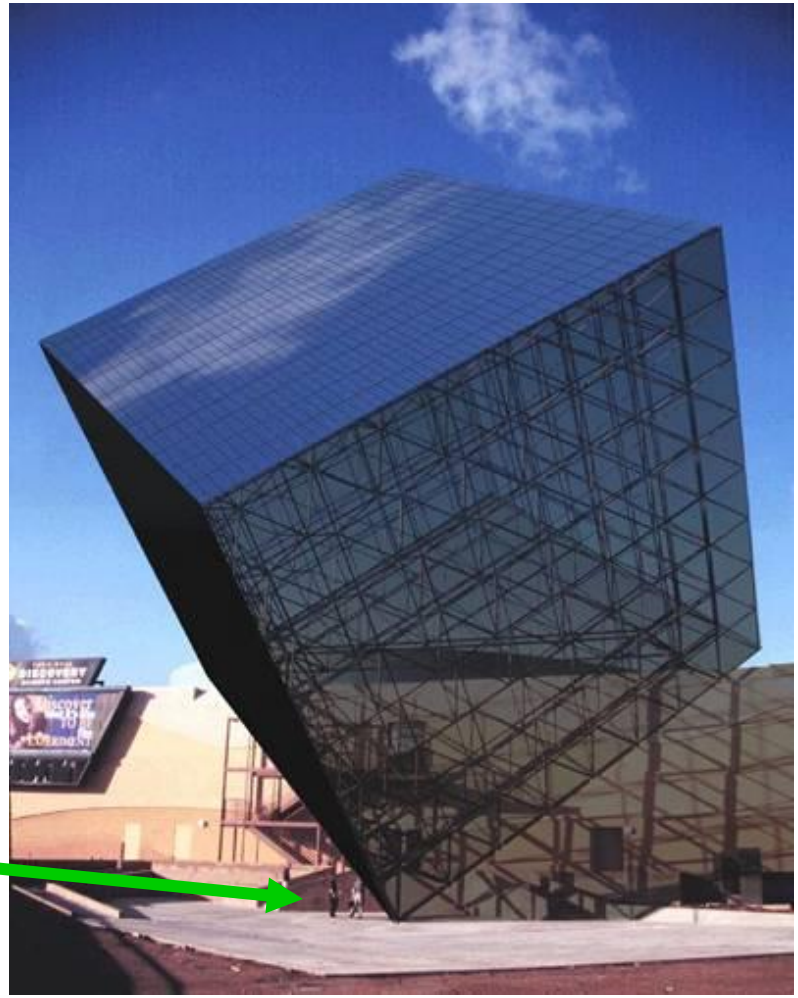

The Universe
is 1/4 Helium

Carbon



In 60 decks, only a single “atom.” Carbon is a trace element in the universe, yet it is essential for life as we understand it.

Gold

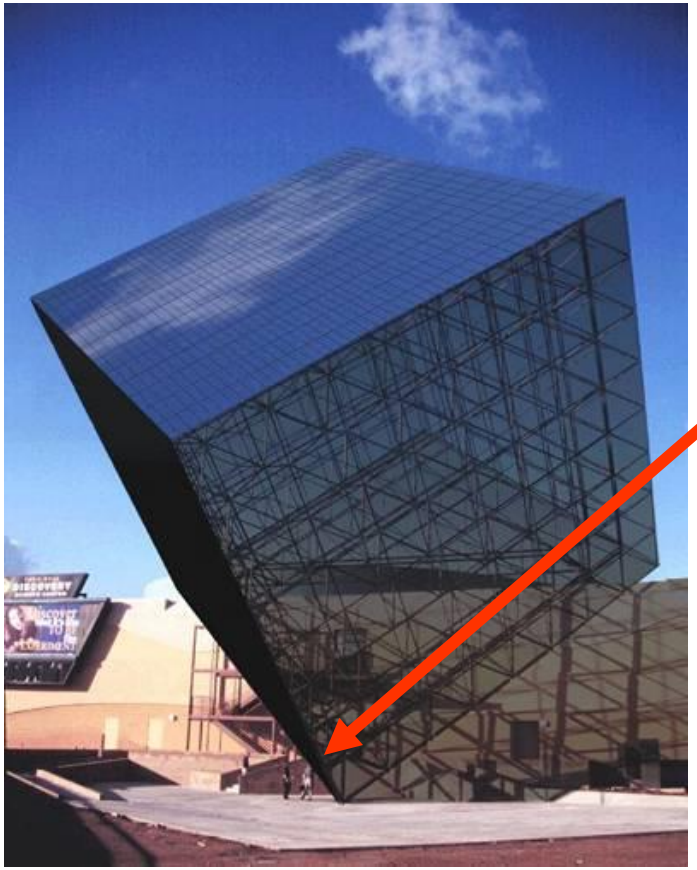


Imagine the cube filled with cards, and note the size of a person

Only one gold “atom” in the entire cube; gold is a trace element.

The Story of Gold

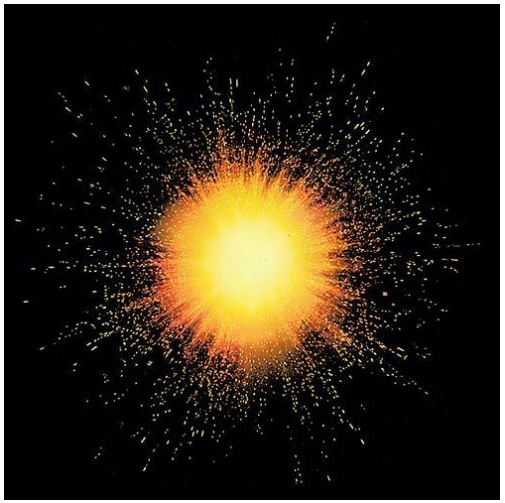
Gold is valuable because it is rare: a cosmic abundance of only 0.5 parts per billion!



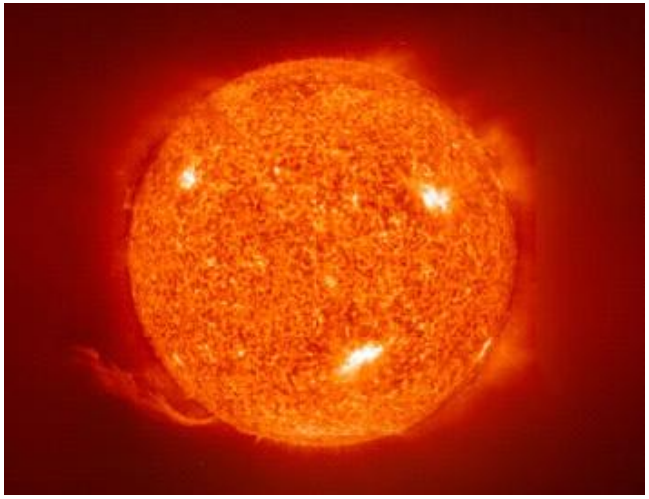
What does this mean? Imagine we filled this cube with playing cards representing the abundance of atoms in the universe. (Note person…)

On average in the cosmos, only one card in the entire cube would be a gold atom!

The Story Starts Long Ago and Far Away...



Protons and electrons (hydrogen) are created in the big bang some 14 billion years ago.

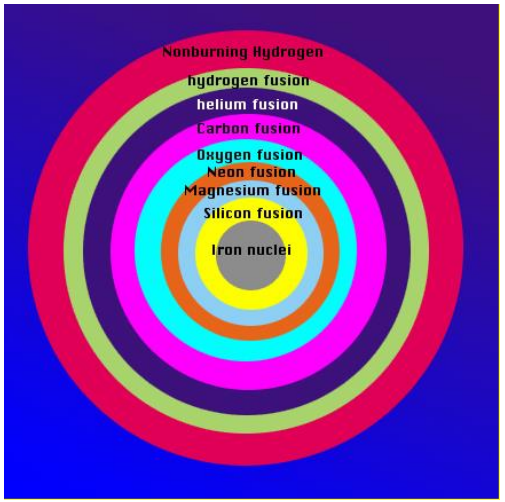


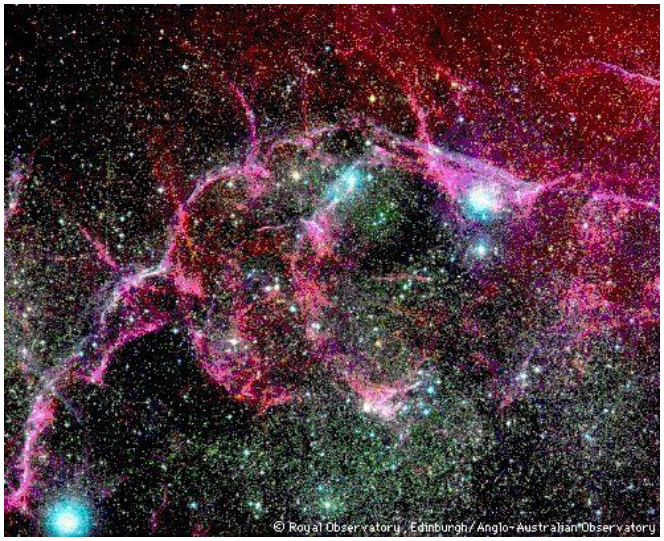
Hydrogen is fused to carbon in a star a little more massive than the Sun.

Carbon is ejected into space in the planetary nebula phase at the end of the star's life.

…and Continues Closer to Home

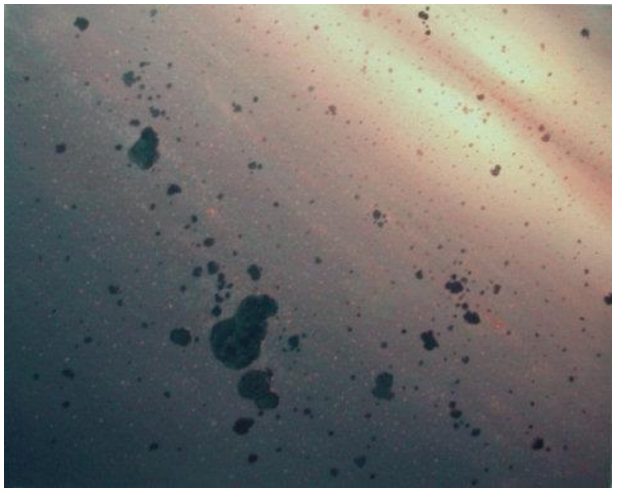
Incorporated into a new massive star, carbon rapidly ascends a chain of fusion up to iron.

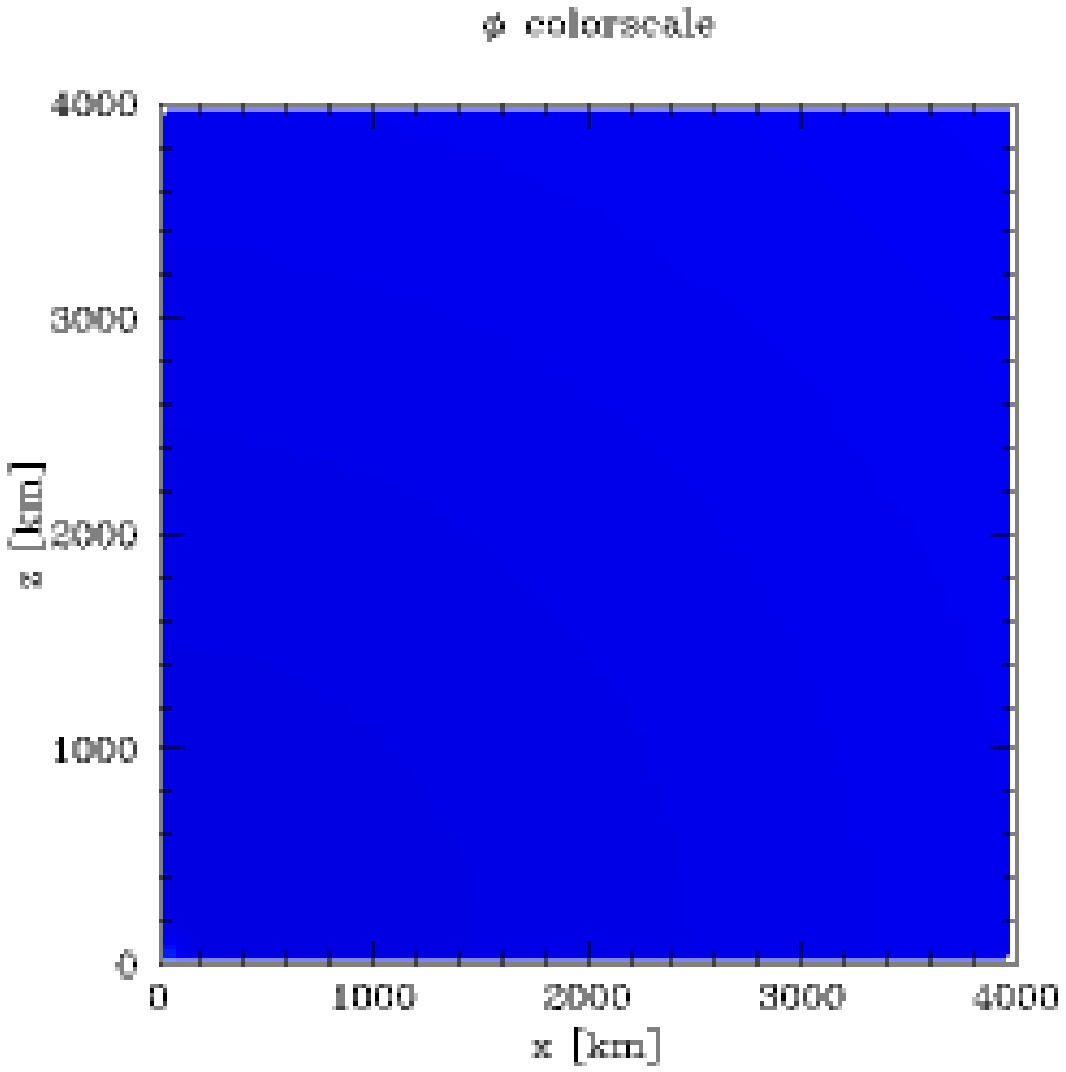




Iron is fused in minutes all the way up to gold in the blast wave of the dying star.

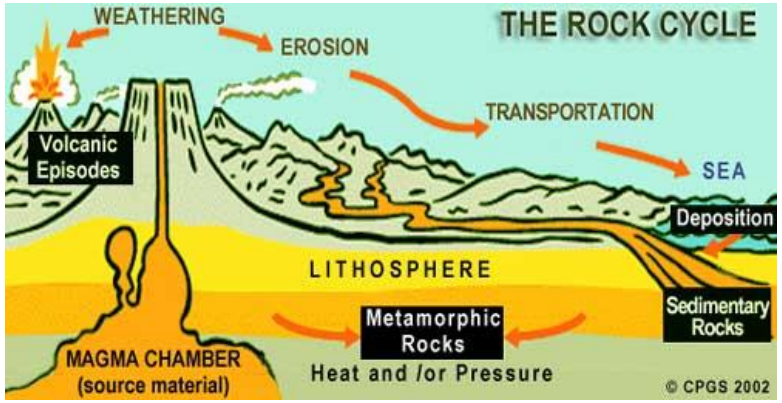
The gold atom finds itself of the outskirts of the solar nebula as the solar system forms.



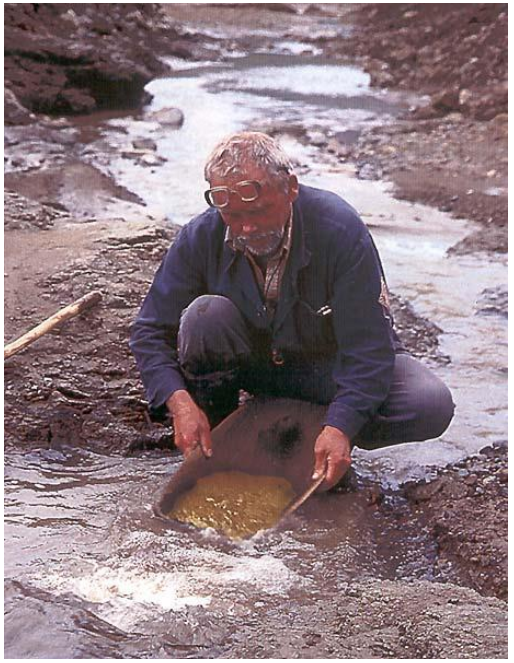


The massive star collapses with the loss of all pressure support as fusion stops. The cool gas falling in meets the hotter gas rushing out and the result is a shock wave that accelerates the gas and heats it quickly to billions of Kelvin.

A Terrestrial Journey of 4.5 Billion Years



The gold churns inside the Earth for billions of years.

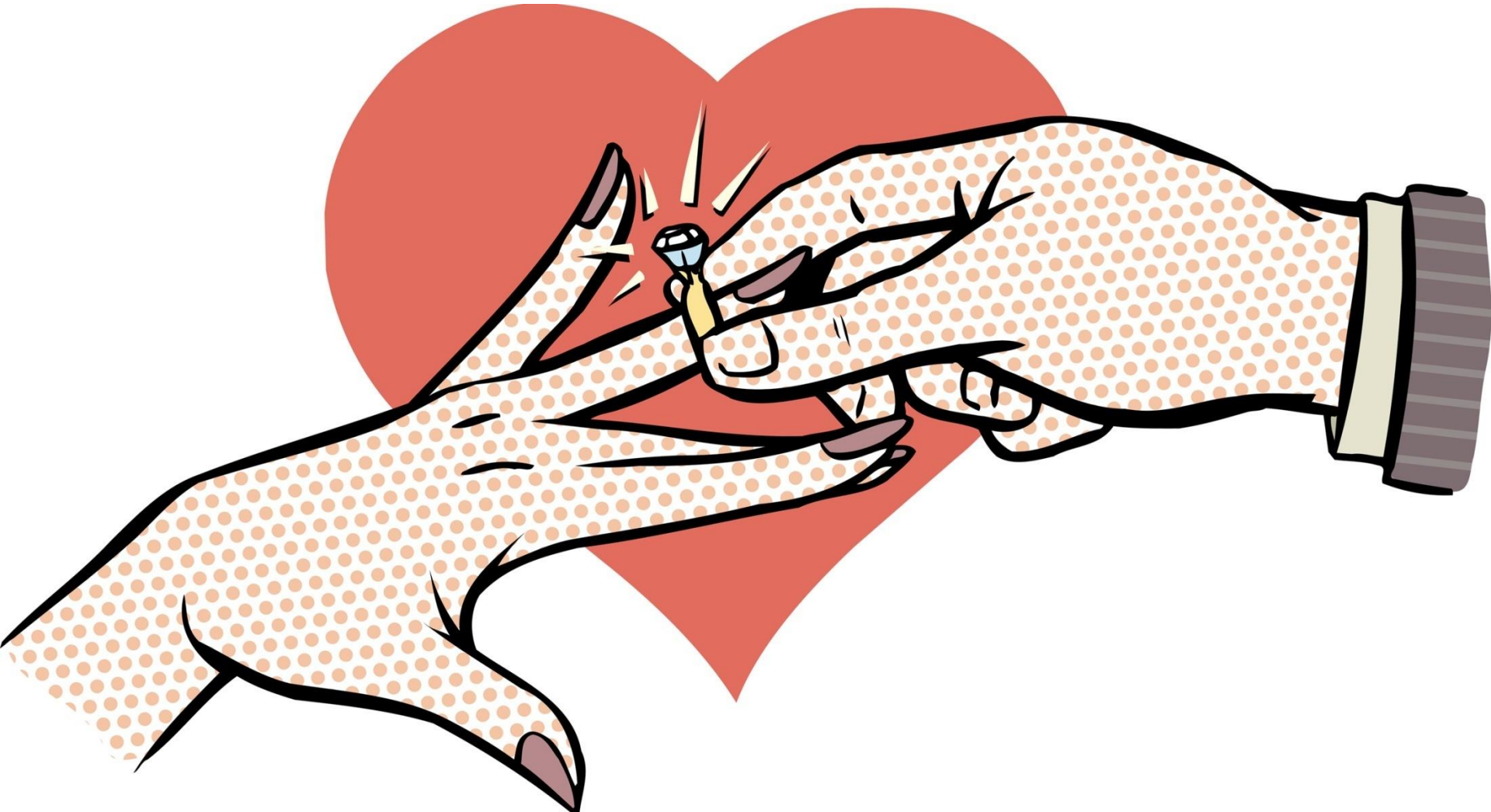


Then begins its relatively short time in the hands of humans.

The object of beauty and desire, after its long and eventful cosmic journey.

Gold atoms were forged in the explosions

of dying stars billions of years ago



Spectra

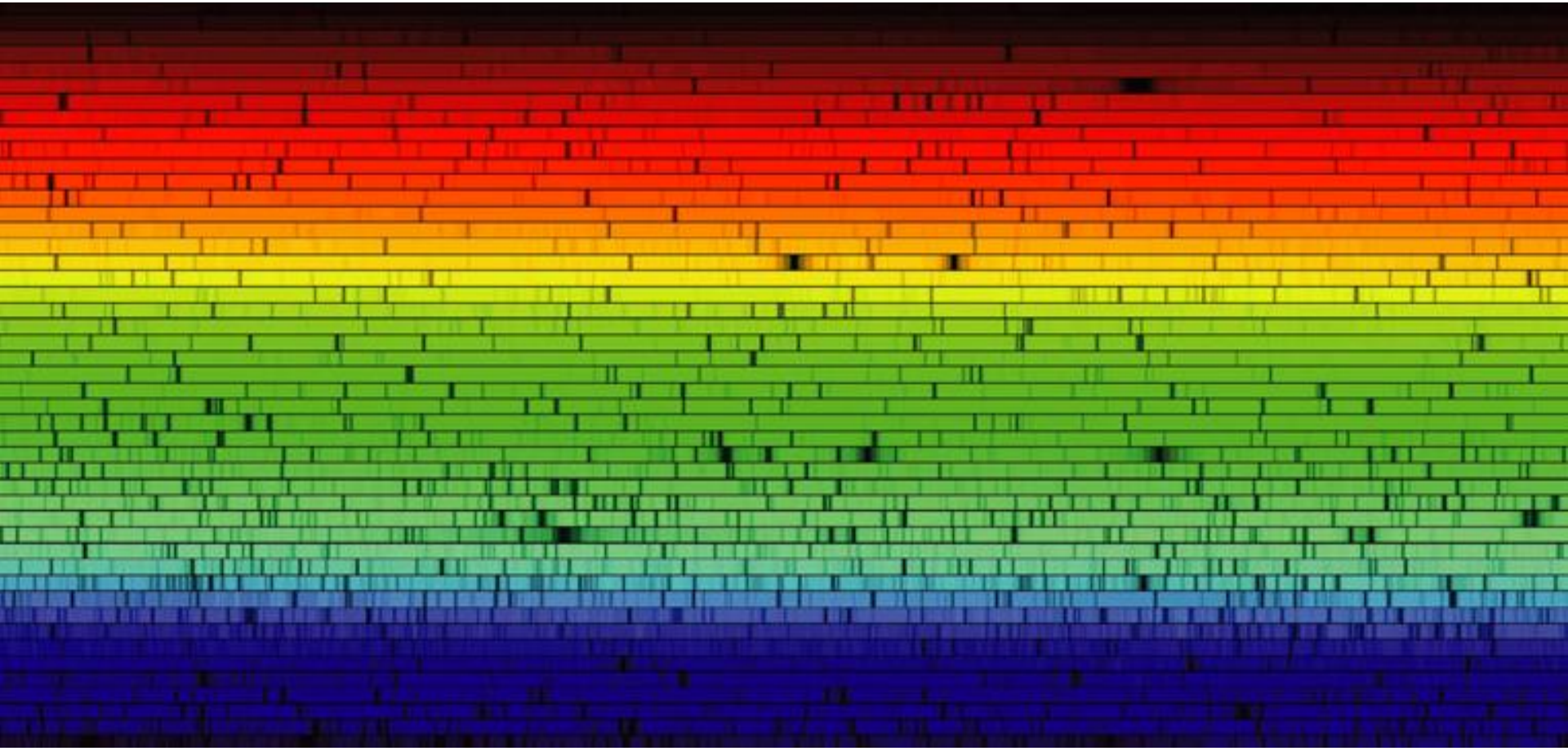
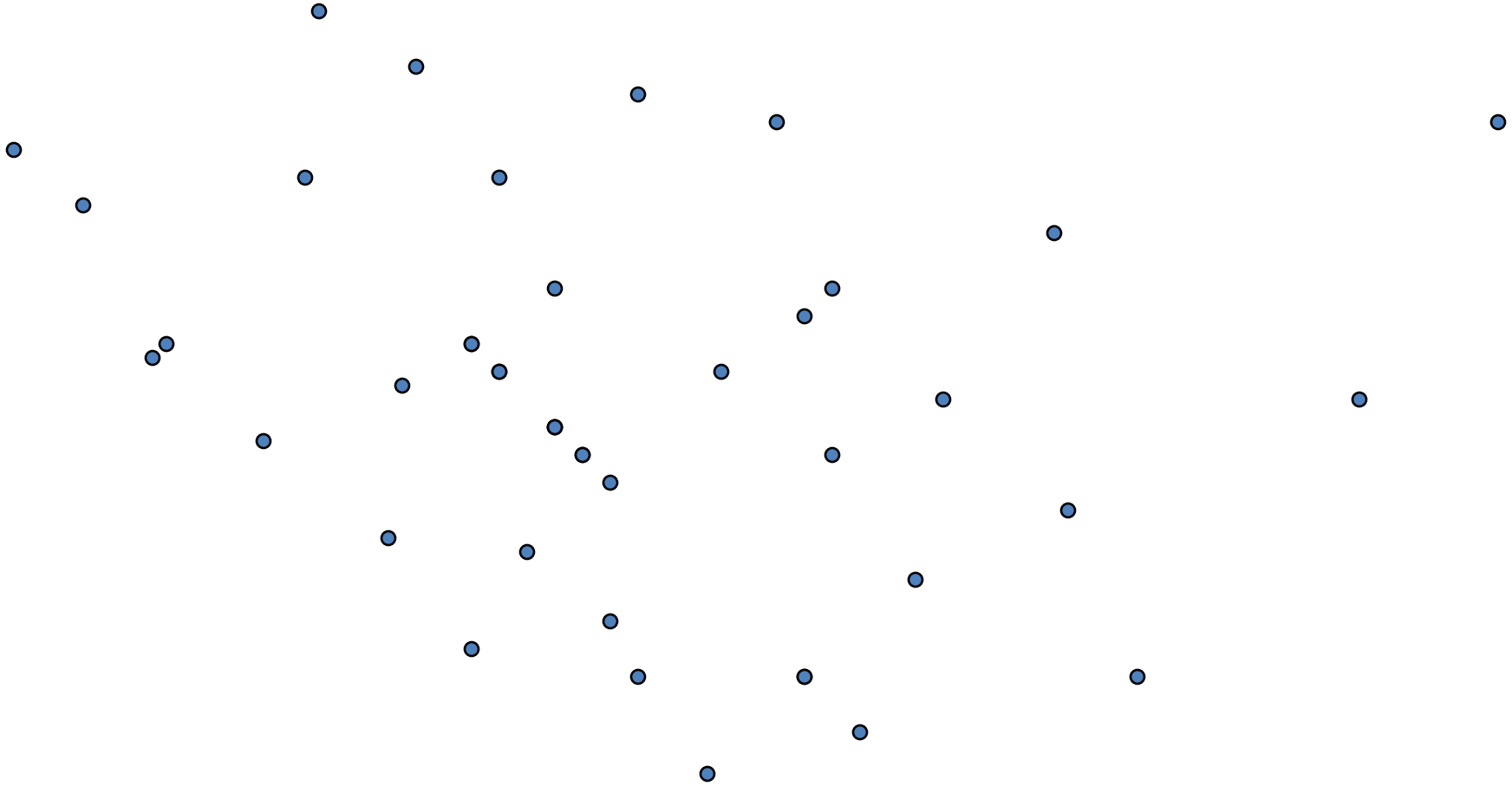
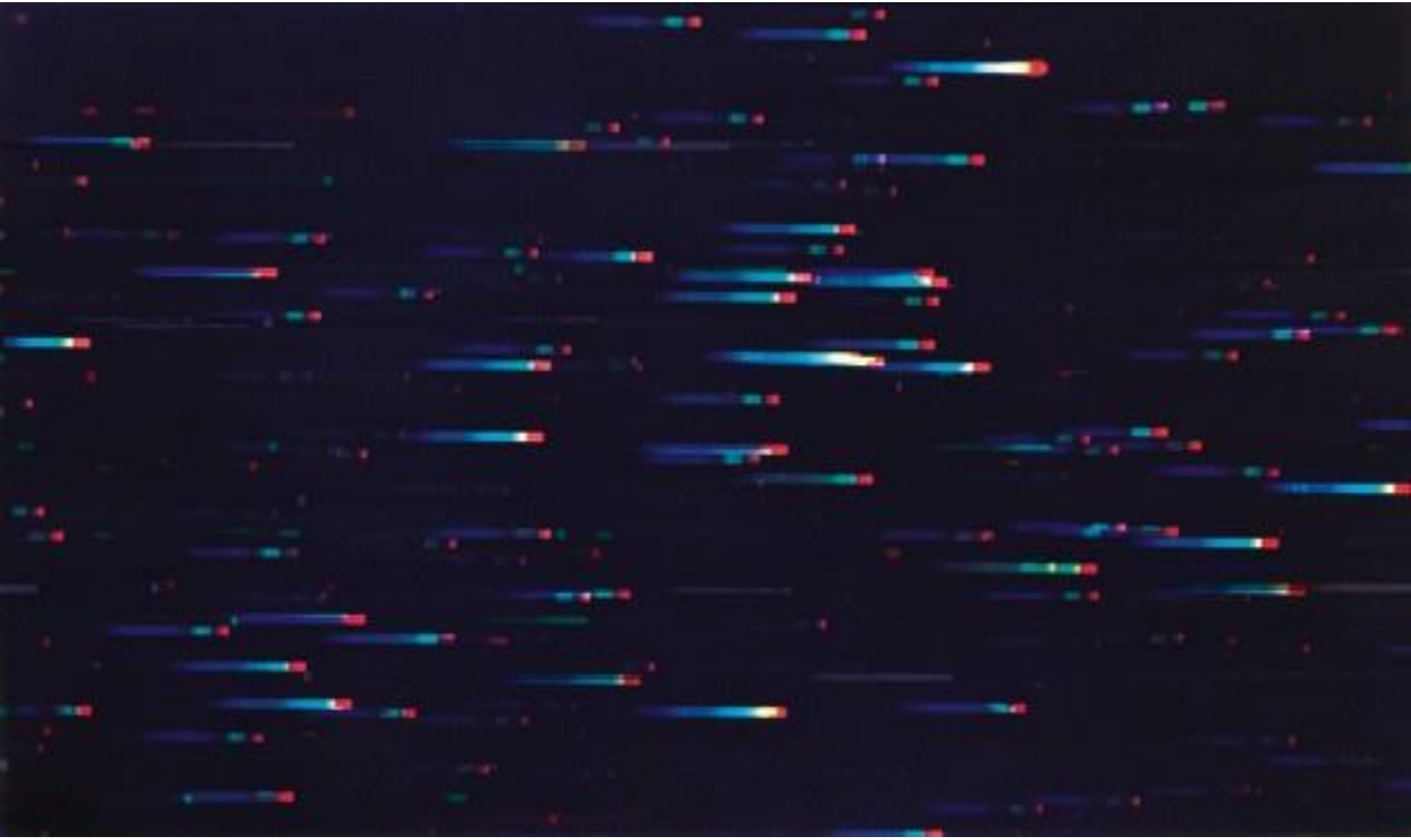


Image of a Star Cluster



Spectra of a Star Cluster



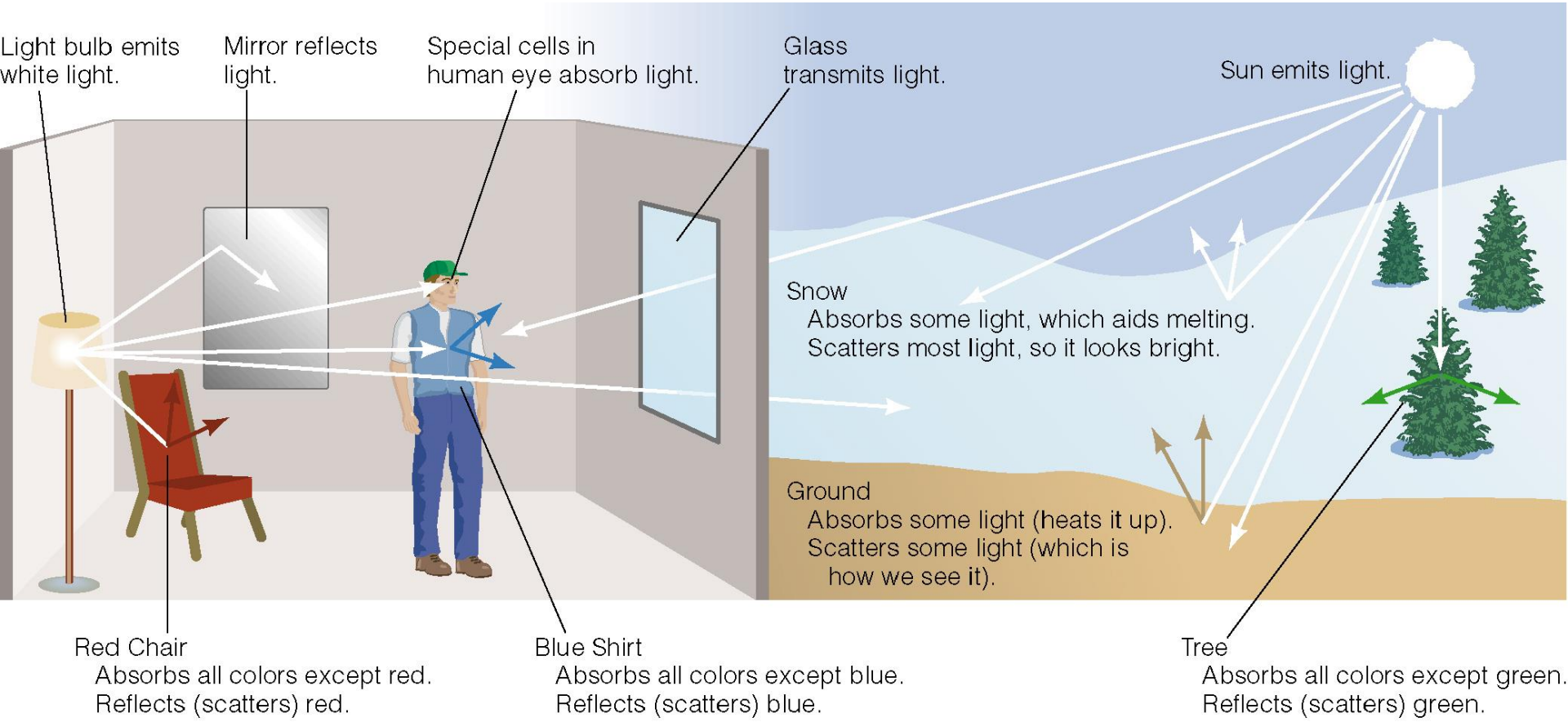
Light Interacts with Matter

- Emission
- Absorption
- Transmission
- Reflection or Scattering

Everything we know about the universe is the result of these interactions

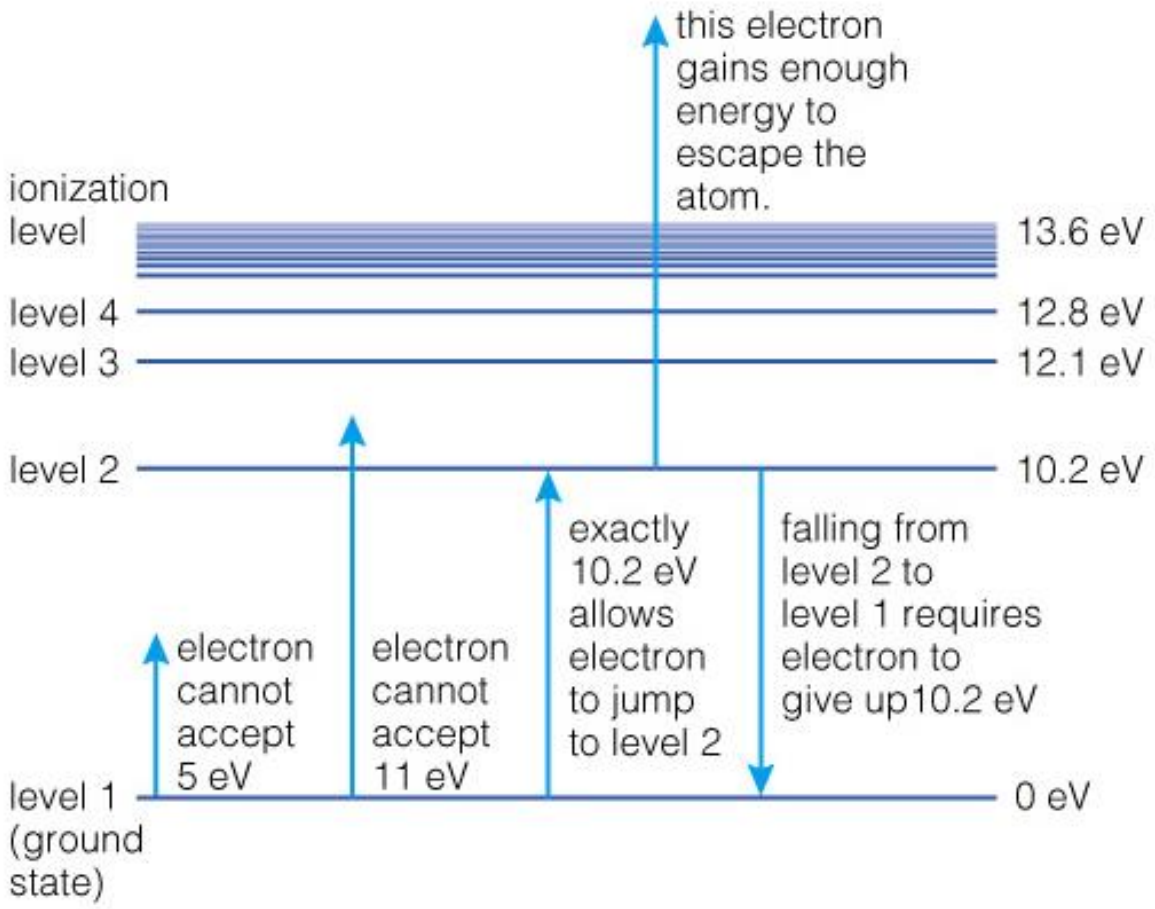
Terminology:

- **Transparent: transmits light**
- **Opaque: blocks (absorbs) light**



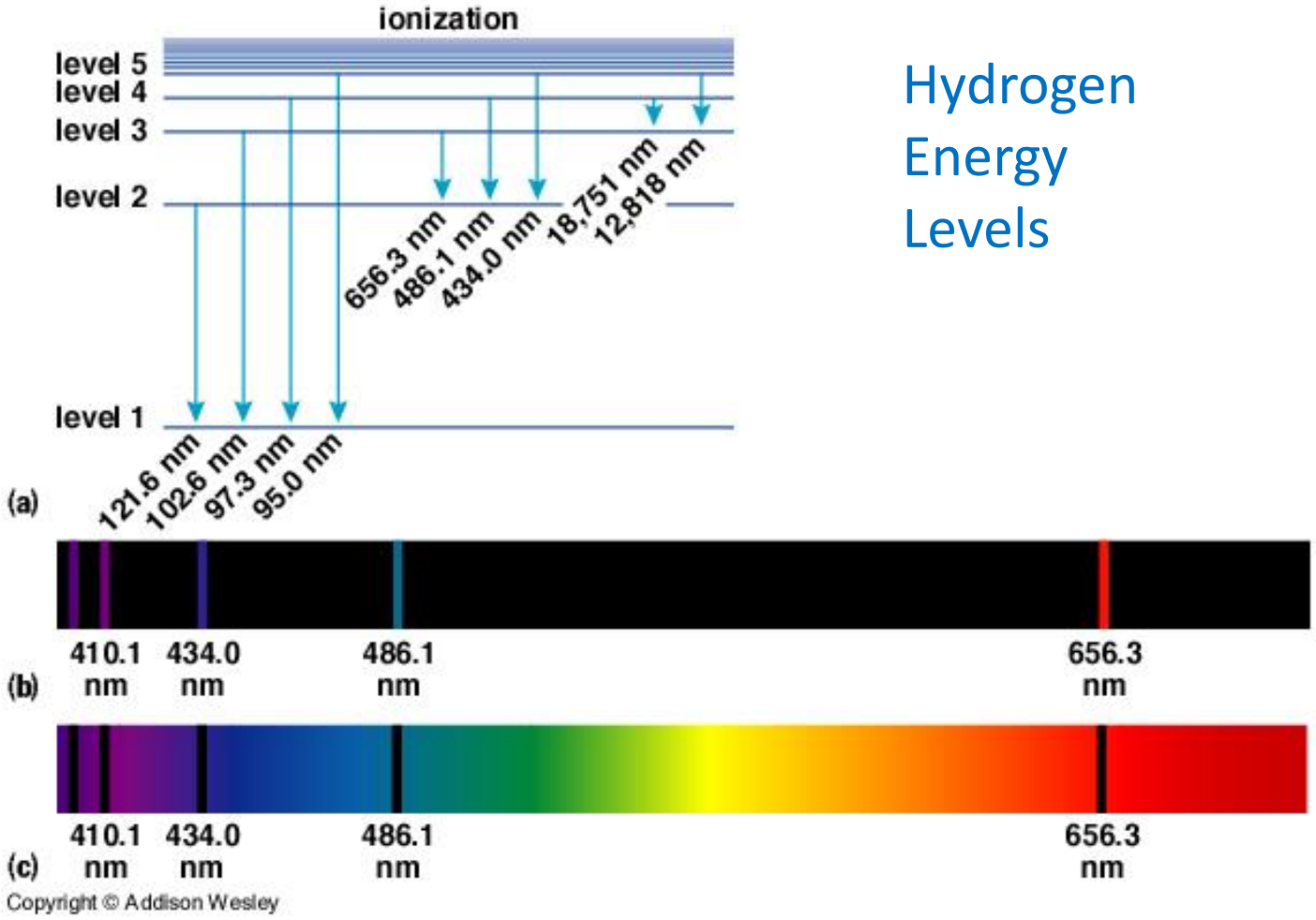
Applied to a distant object like a planet, this can give us important physical information ⇒ remote sensing

Atomic Energy Levels



- Electrons in every atom have distinct energy levels
- Each chemical element, ion or molecule, has a unique set of energy levels

Distinct energy levels lead to a distinct pattern of emission or absorption lines

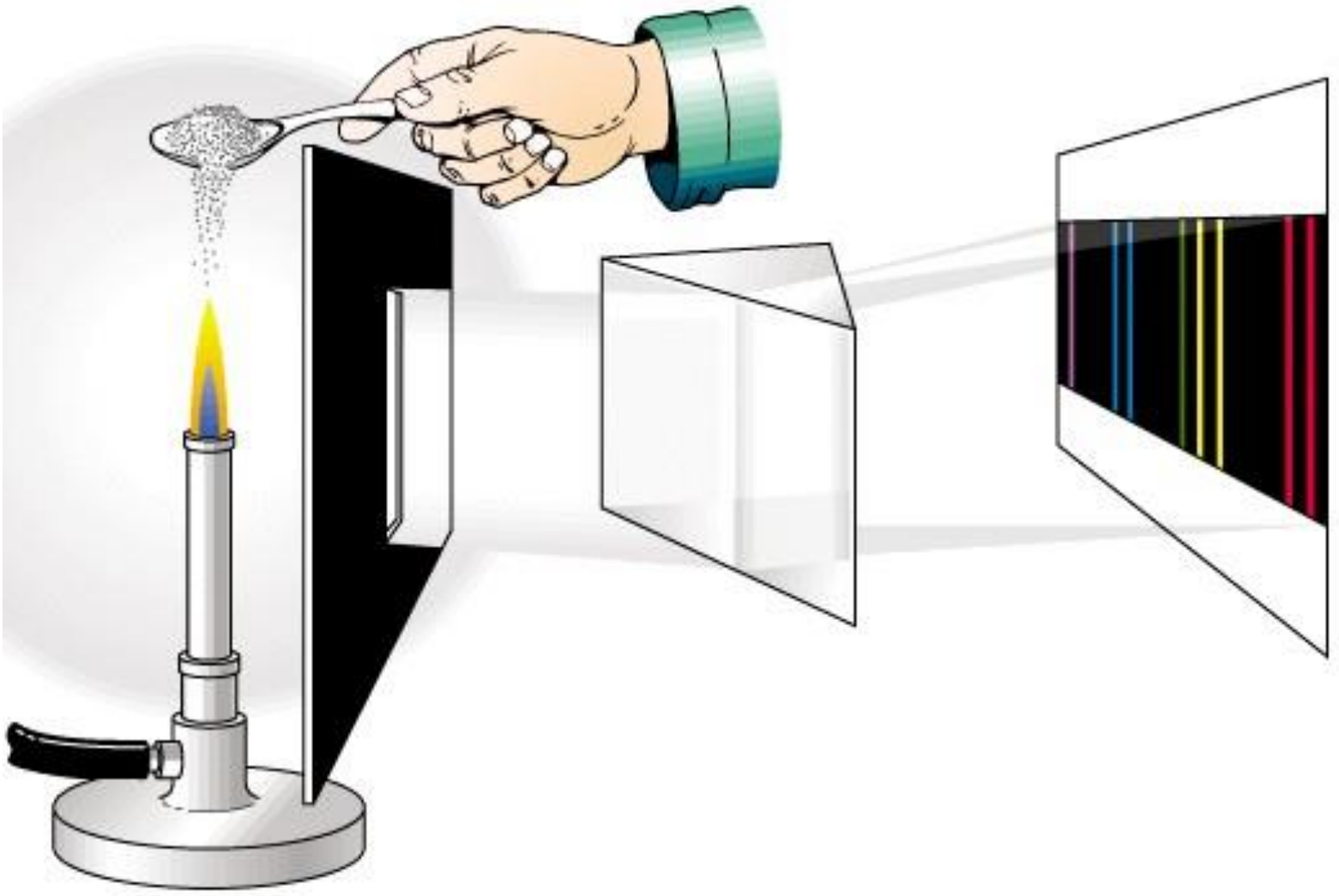


Hydrogen Energy Levels

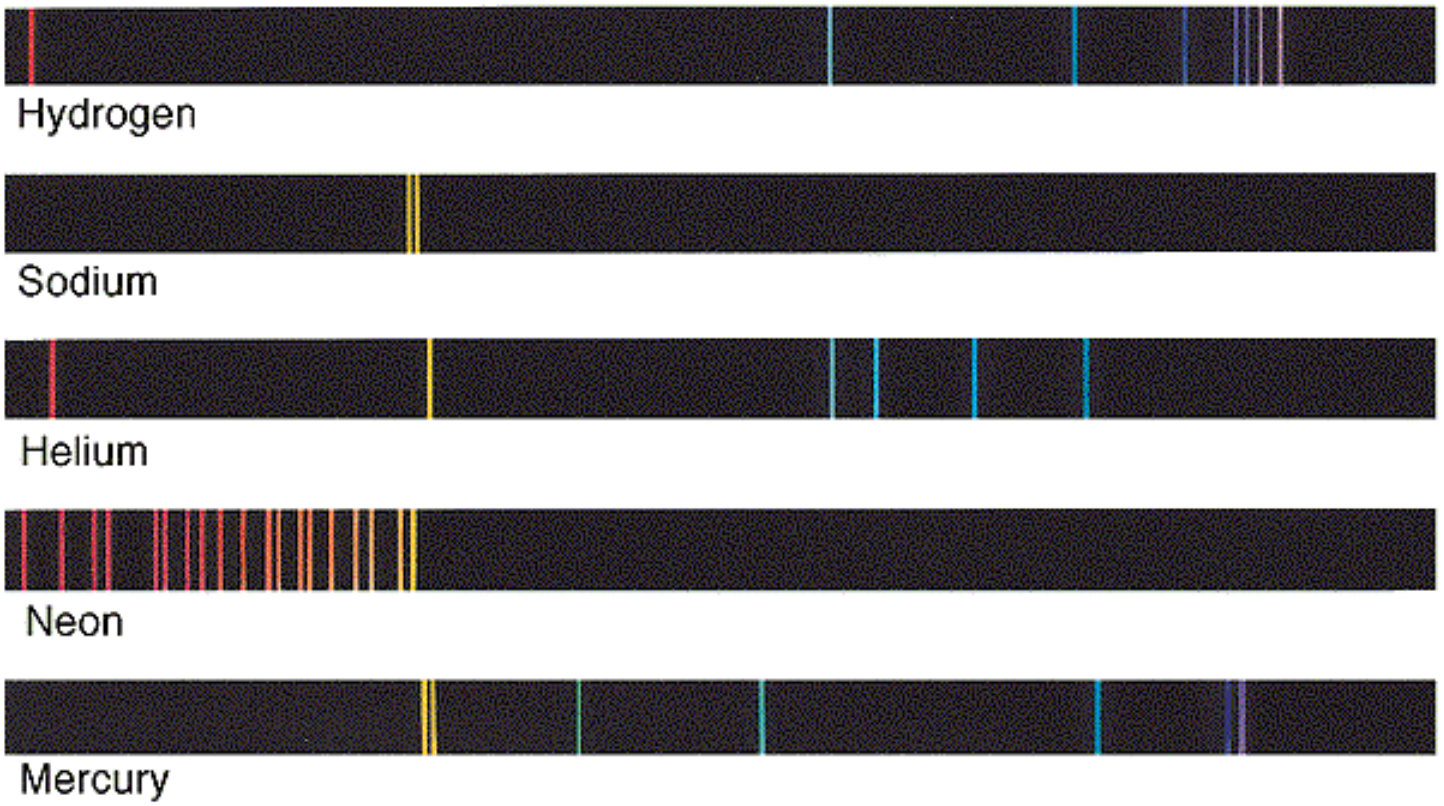
Emission: atom loses energy

Absorption: atom gains energy

Each chemical element produces its own unique set of spectral lines when it is excited or gains energy.



Chemical Fingerprints



- Atoms, ions, and molecules have unique spectral "fingerprints"
- We identify chemicals in gas by spectral lines (to 1 part in 10^{12}!)
- With additional physics, we can figure out abundances of the chemicals, and often temperature, pressure, and much more.

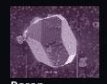
Periodic Table of Elements
Google Image Top Results


Hydrogen


Helium


Lithium


Beryllium


Boron


Carbon


Nitrogen


Oxygen


Fluorine


Neon


Sodium


Magnesium


Aluminum


Silicon


Phosphorus


Sulfur


Chlorine

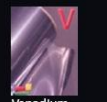

Argon


Potassium


Calcium

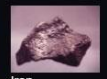

Scandium


Titanium

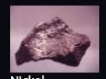

Vanadium


Chromium

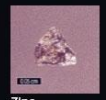

Manganese


Iron


Cobalt


Nickel


Copper


Zinc


Gallium


Germanium

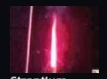

Arsenic


Selenium


Bromine


Krypton


Rubidium


Strontium


Yttrium


Zirconium

Niobium

Molybdenum

Technetium

Ruthenium

Rhodium

Palladium

Silver

Cadmium

Indium

Tin

Antimony

Tellurium

Iodine

Xenon

Cesium

Barium

Hafnium

Tantalum

Tungsten

Rhenium

Osmium

Iridium

Platinum

Gold

Mercury

Thallium

Lead

Bismuth

Polonium

Astatine

Radon

Francium

Radium

Rutherfordium

Dubnium

Seaborgium

Bohrium

Hassium

Meitnerium

Darmstadtium

Roentgenium

Ununbium

Ununtrium

Ununquadium

Ununpentium

Ununhexium

Ununseptium

Ununoctium

Lanthanum

Cerium

Praseodymium

Neodymium

Promethium

Samarium

Europium

Gadolinium

Terbium

Dysprosium

Holmium

Erbium

Thulium

Ytterbium

Lutetium

Actinium

Thorium

Protactinium

Uranium

Neptunium

Plutonium

Americium

Curium

Berkelium

Californium

Einsteinium

Fermium

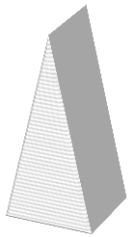
Mendelevium

Nobelium

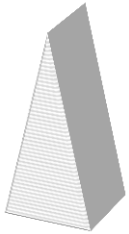
Lawrencium

Types of Spectra

Hot/Dense Energy Source

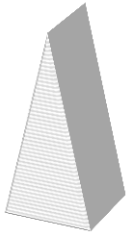


Continuous Spectrum



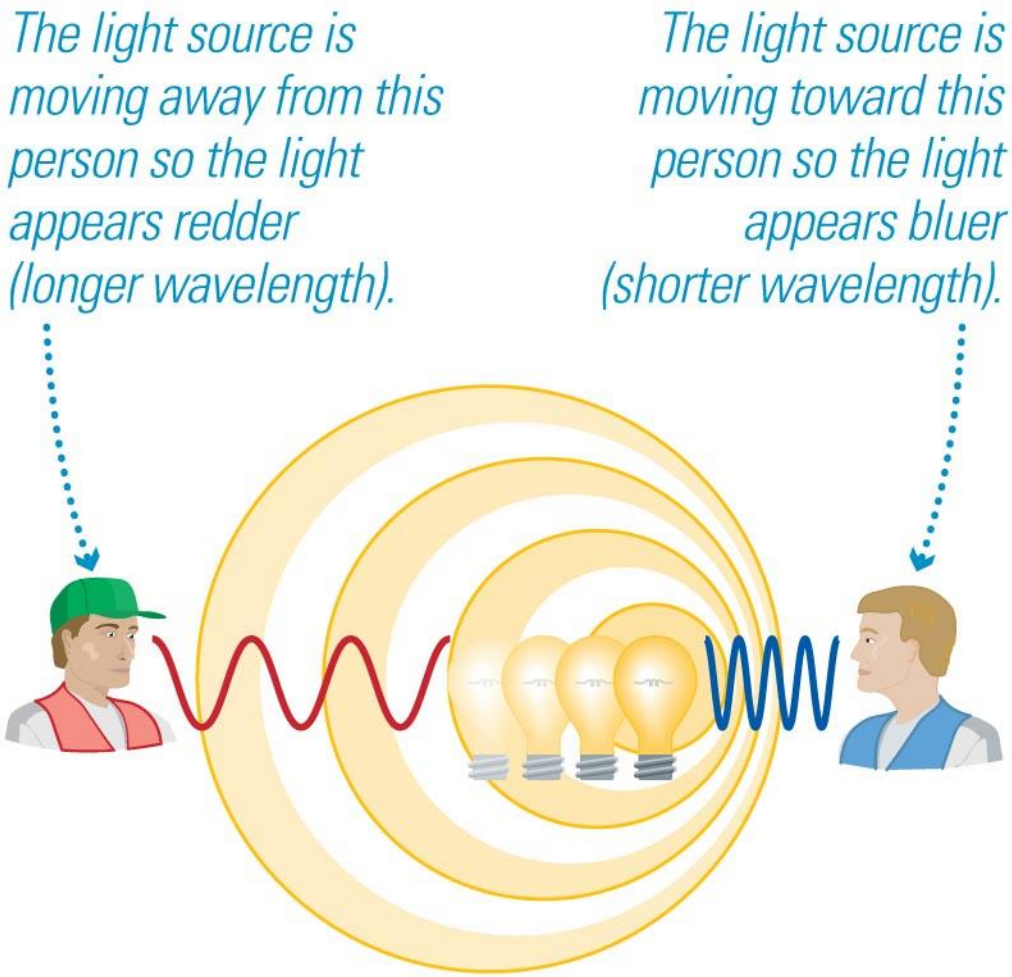
Emission Line Spectrum

Hot/Dense Energy Source



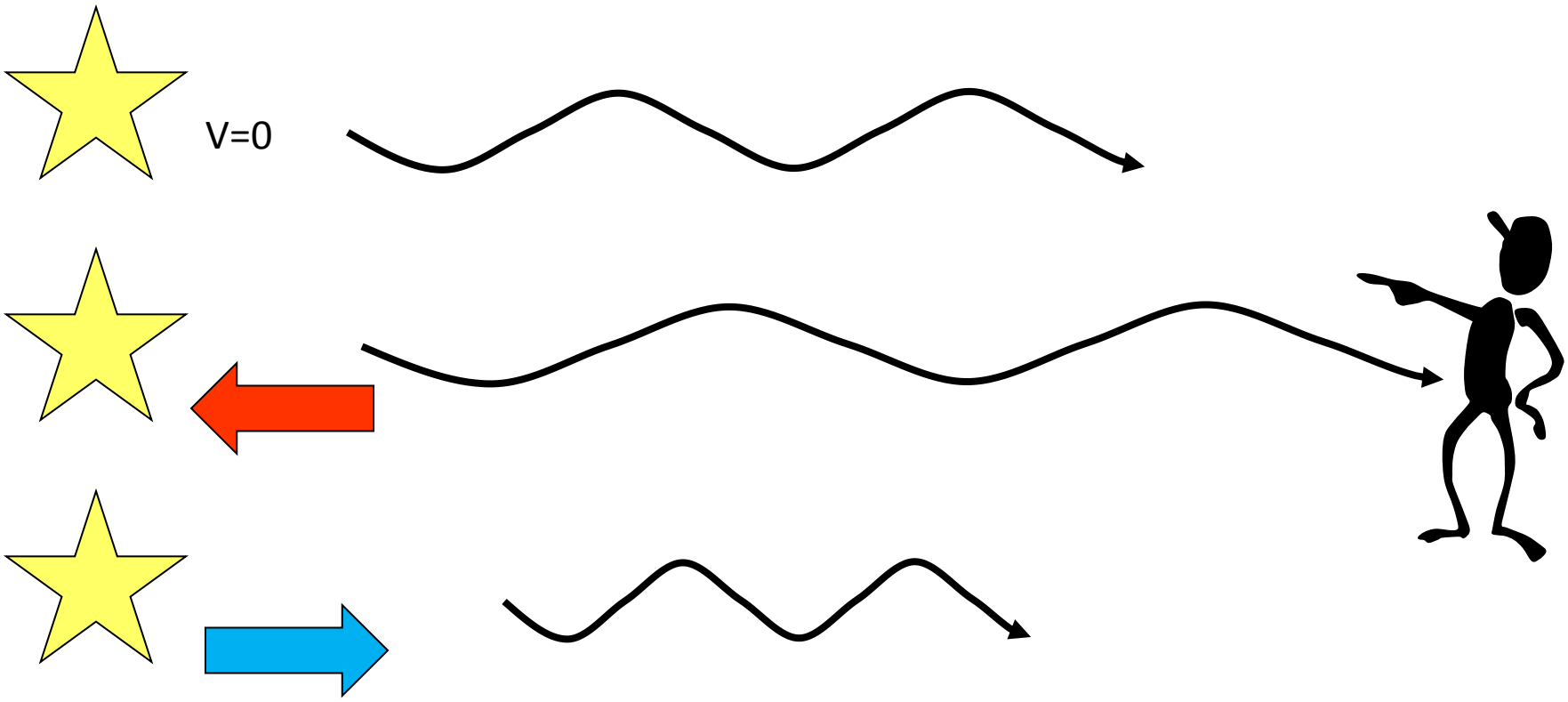
Absorption Line Spectrum

Doppler Effect

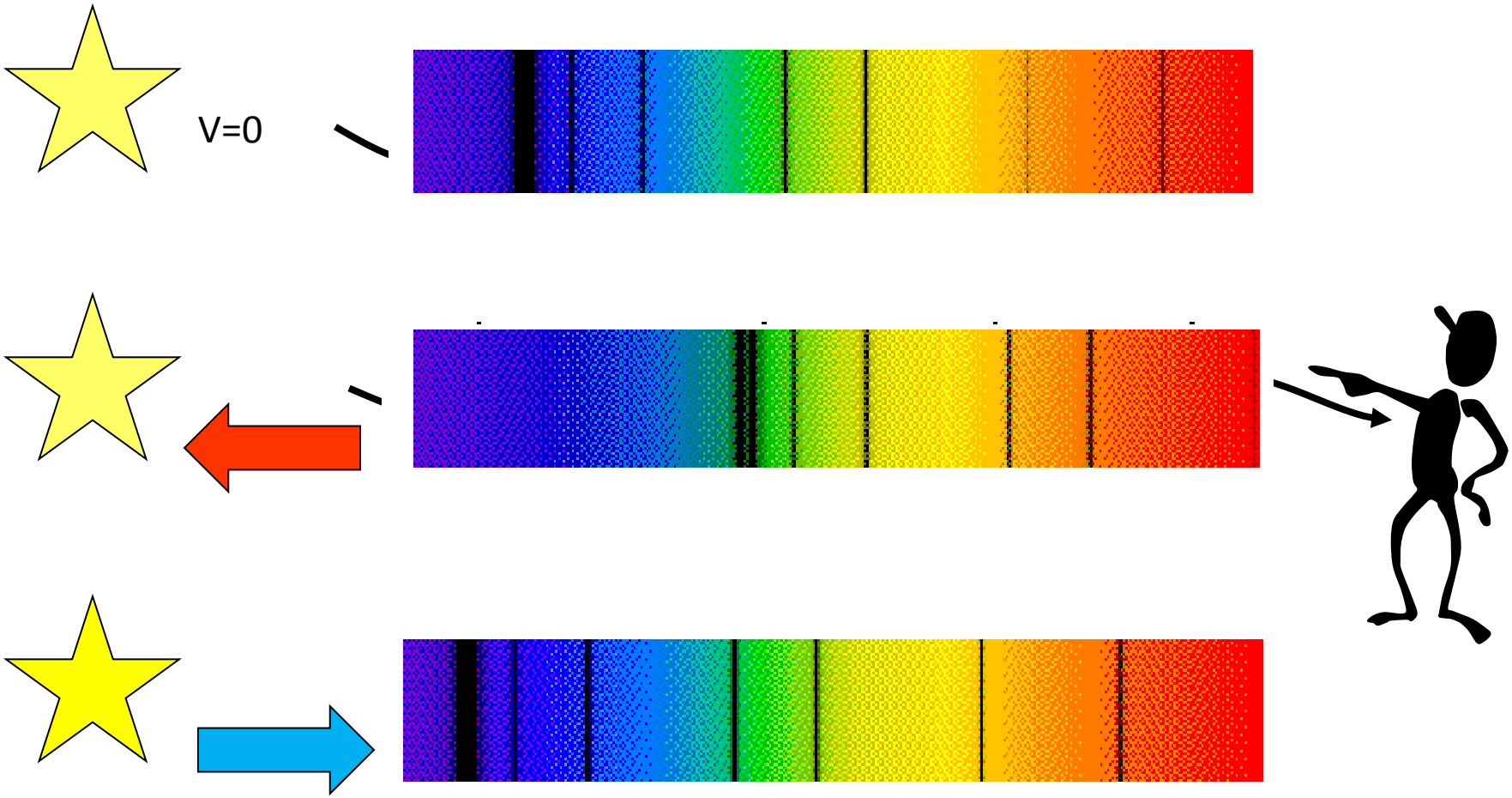


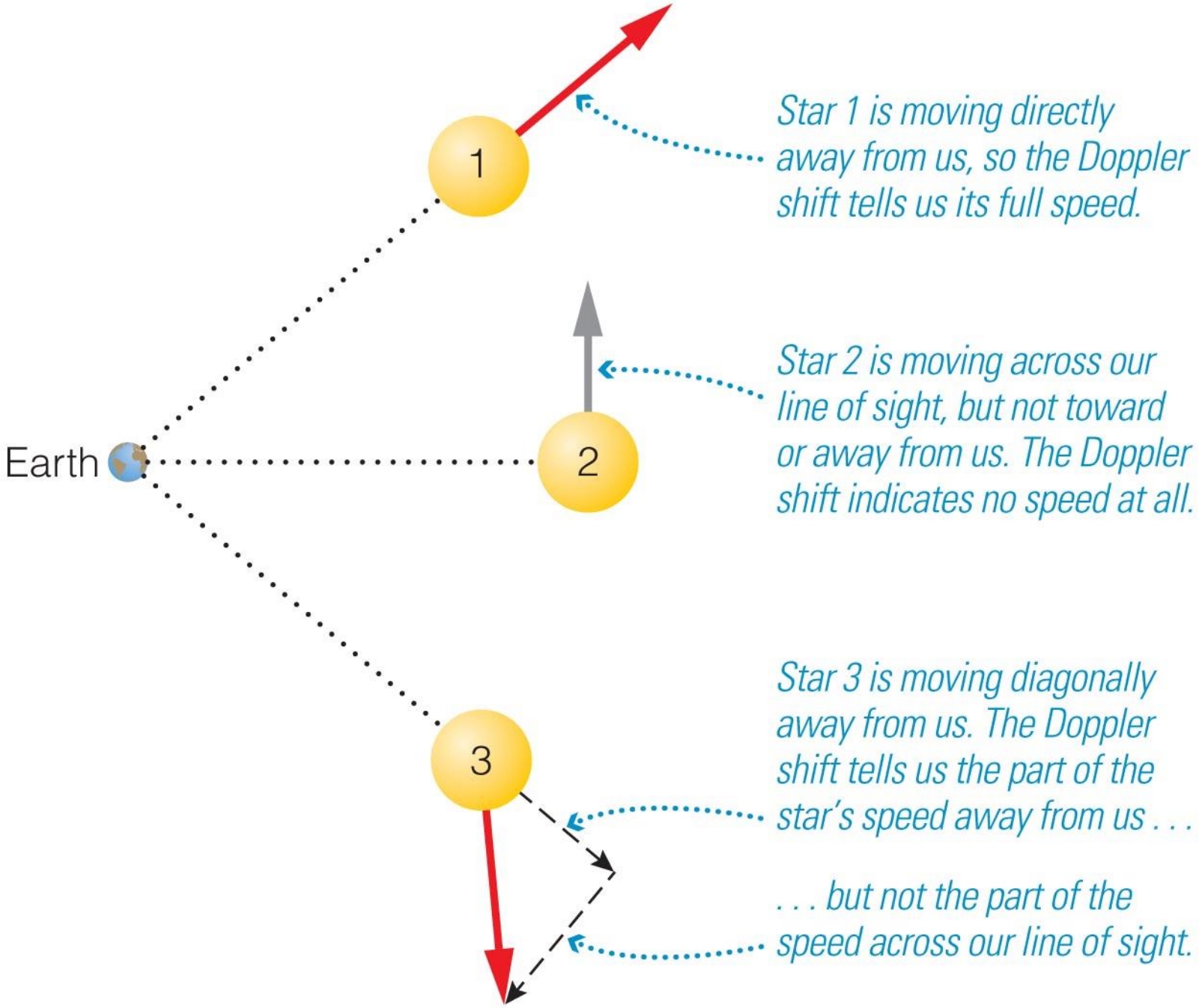
We get the same basic effect from a moving light source (although the shifts are usually too small to notice by eye).

When something which is giving off light moves **towards** or **away** from you, the wavelength of the emitted light is changed or shifted. The higher the speed, the larger the shift.



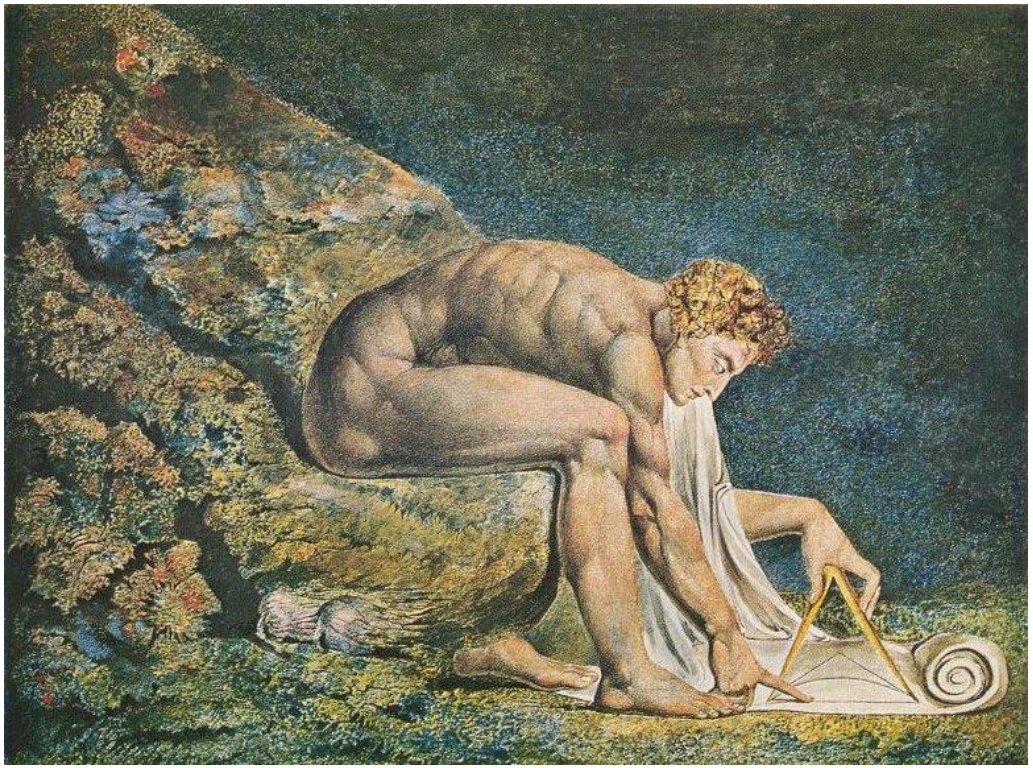
Astronomy Application



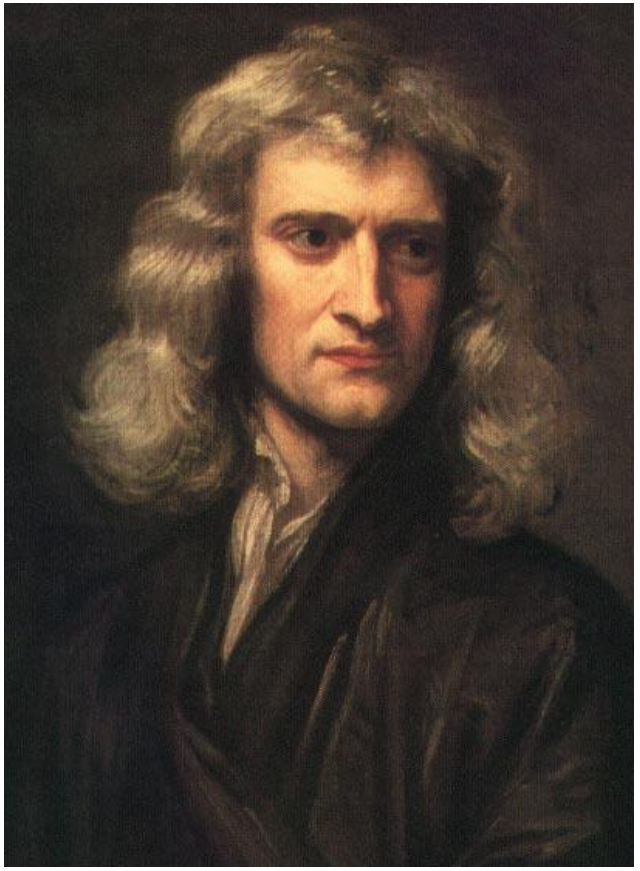

Earth
1
2
3
Star 1 is moving directly away from us, so the Doppler shift tells us its full speed.
Star 2 is moving across our line of sight, but not toward or away from us. The Doppler shift indicates no speed at all.
Star 3 is moving diagonally away from us. The Doppler shift tells us the part of the star's speed away from us . . .
. . . but not the part of the speed across our line of sight.

Gravity

Newton



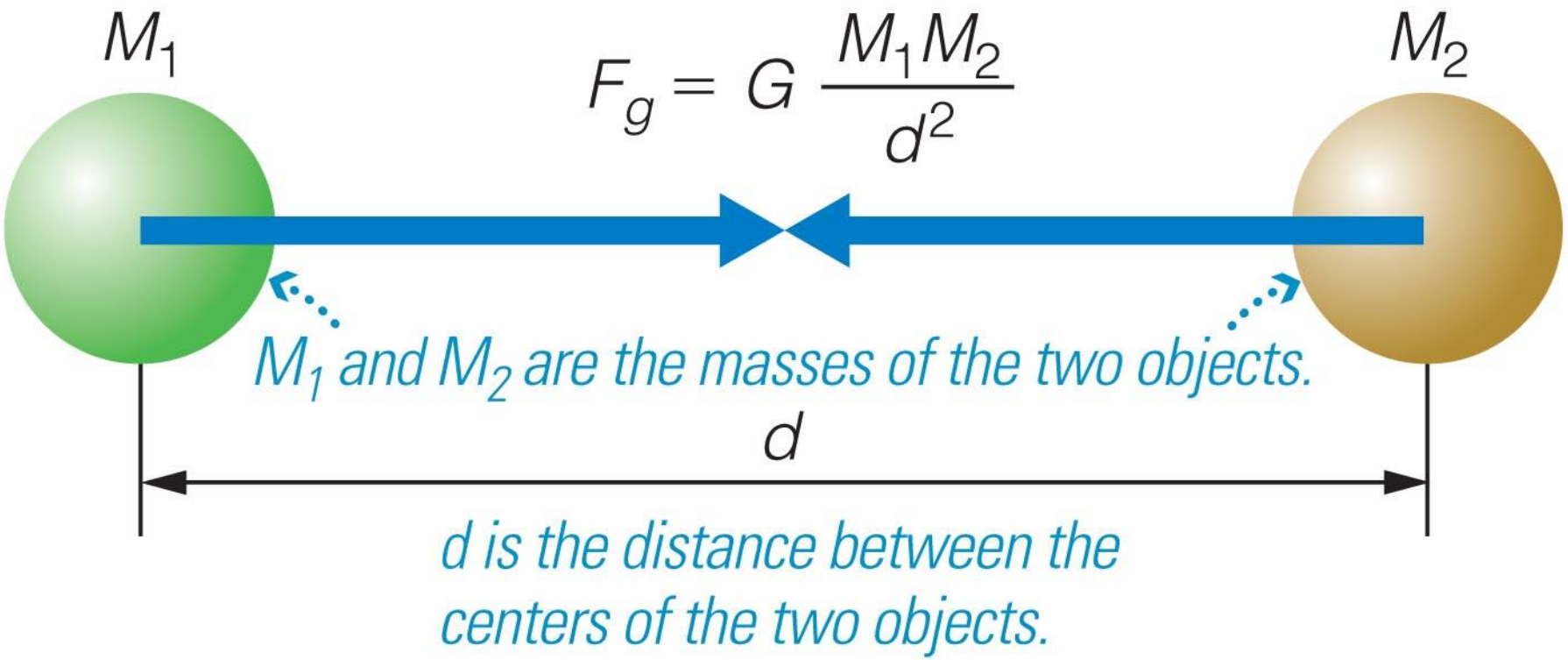
The bard of gravity united the motions of terrestrial and celestial objects.



His theory was stunningly confirmed by a successful prediction of the return of Halley's comet. Asked about action at a distance he said "I frame no hypothesis"

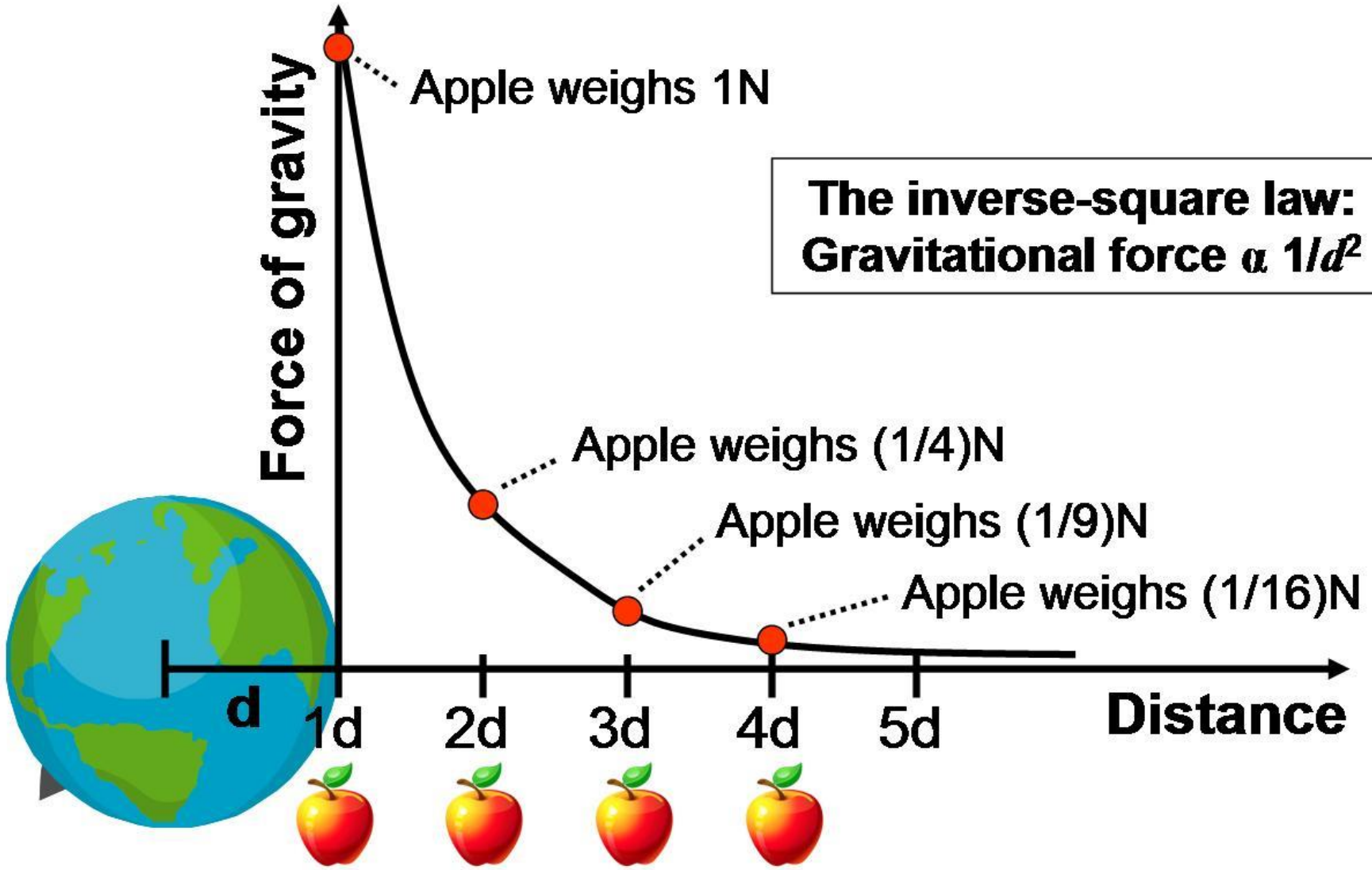
Gravity

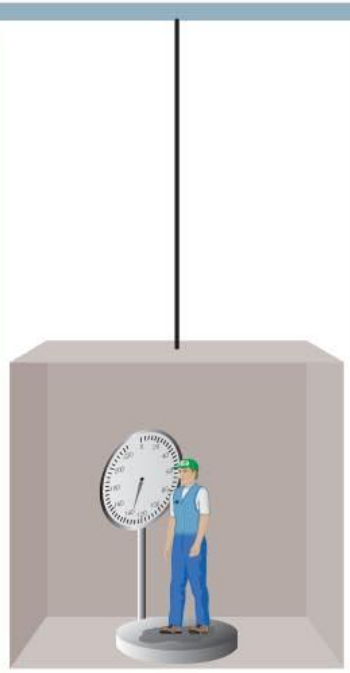
*The **universal law of gravitation** tells us the strength of the gravitational attraction between the two objects.*



Note: Newton's theory is exact only in the artificial case of two bodies; in all realistic cases it requires a suitable computational approximation.

Inverse Square Law



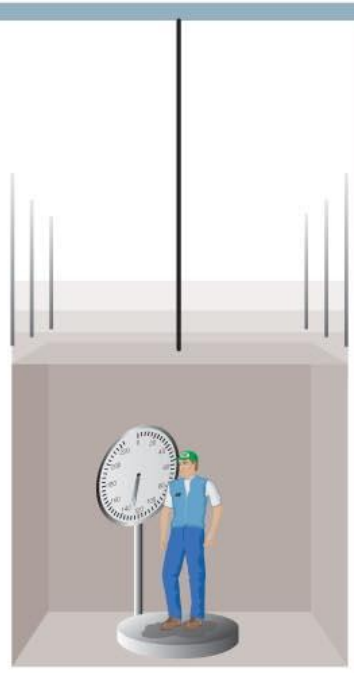


When the elevator moves at constant velocity (or is stationary)…

…your weight is normal.

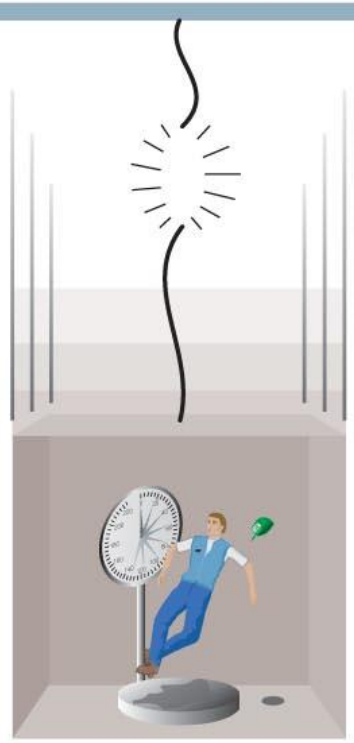
When the elevator ***accelerates*** *upward…*

…you weigh more.



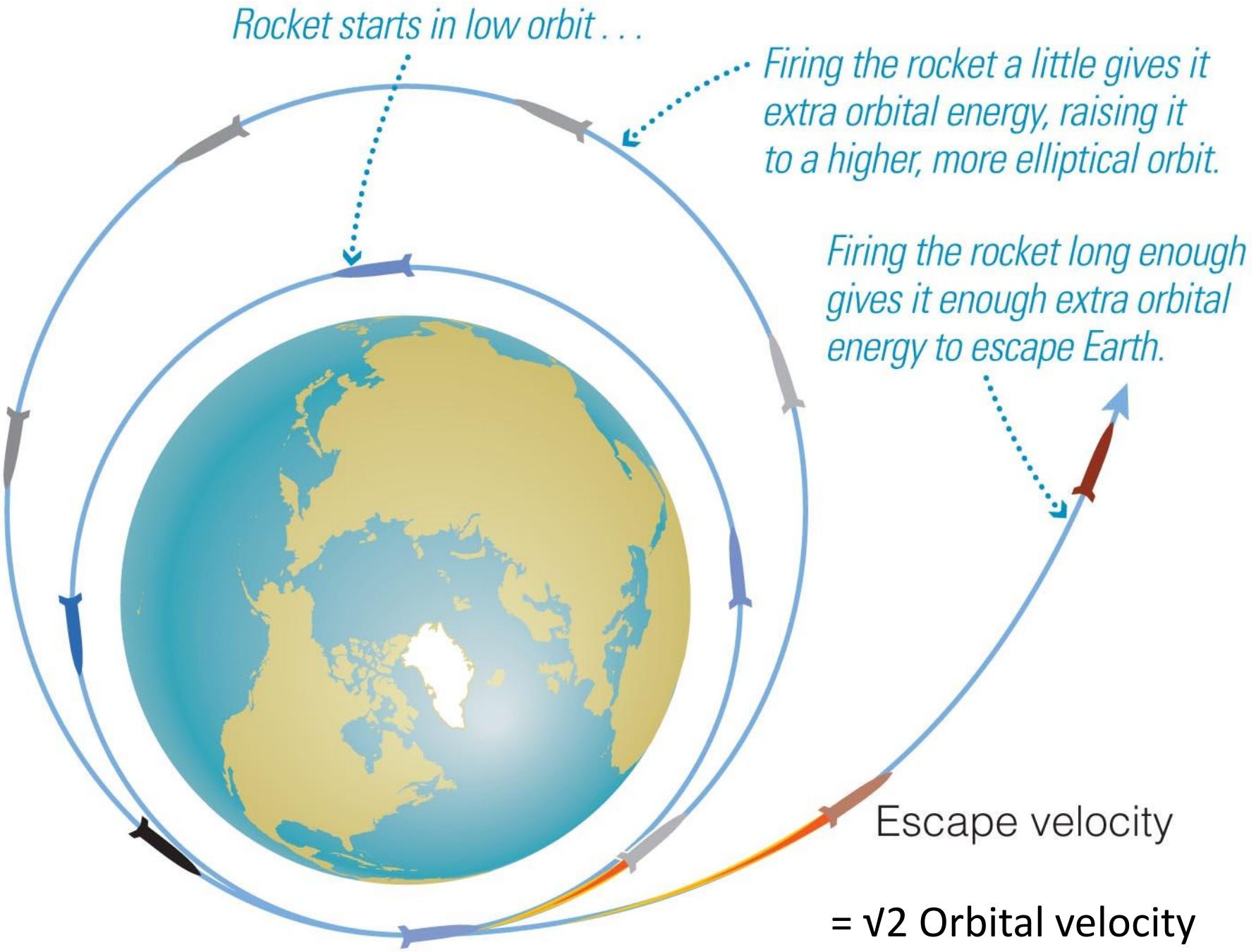
When the elevator ***accelerates*** *downward…*

…you weigh less.

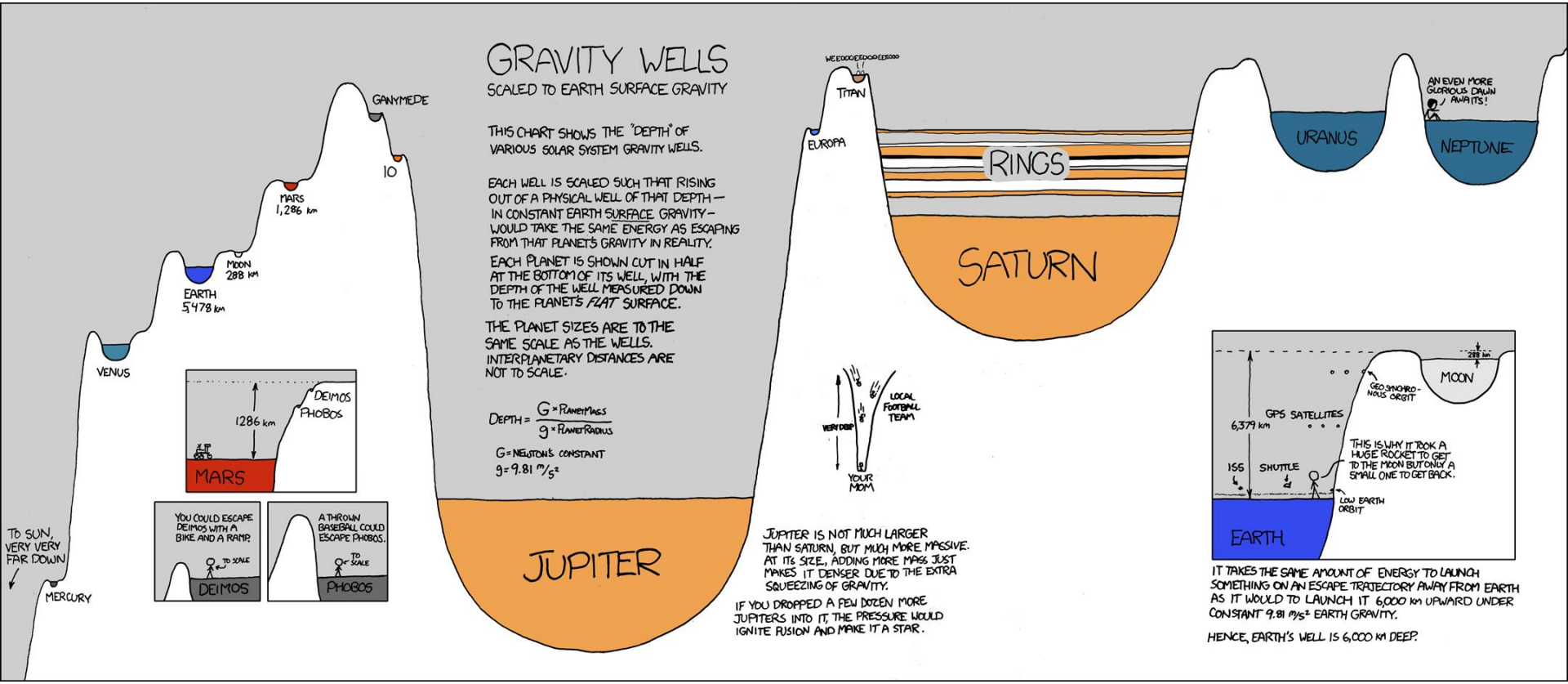


If the cable breaks so that you are in ***free-fall****…*

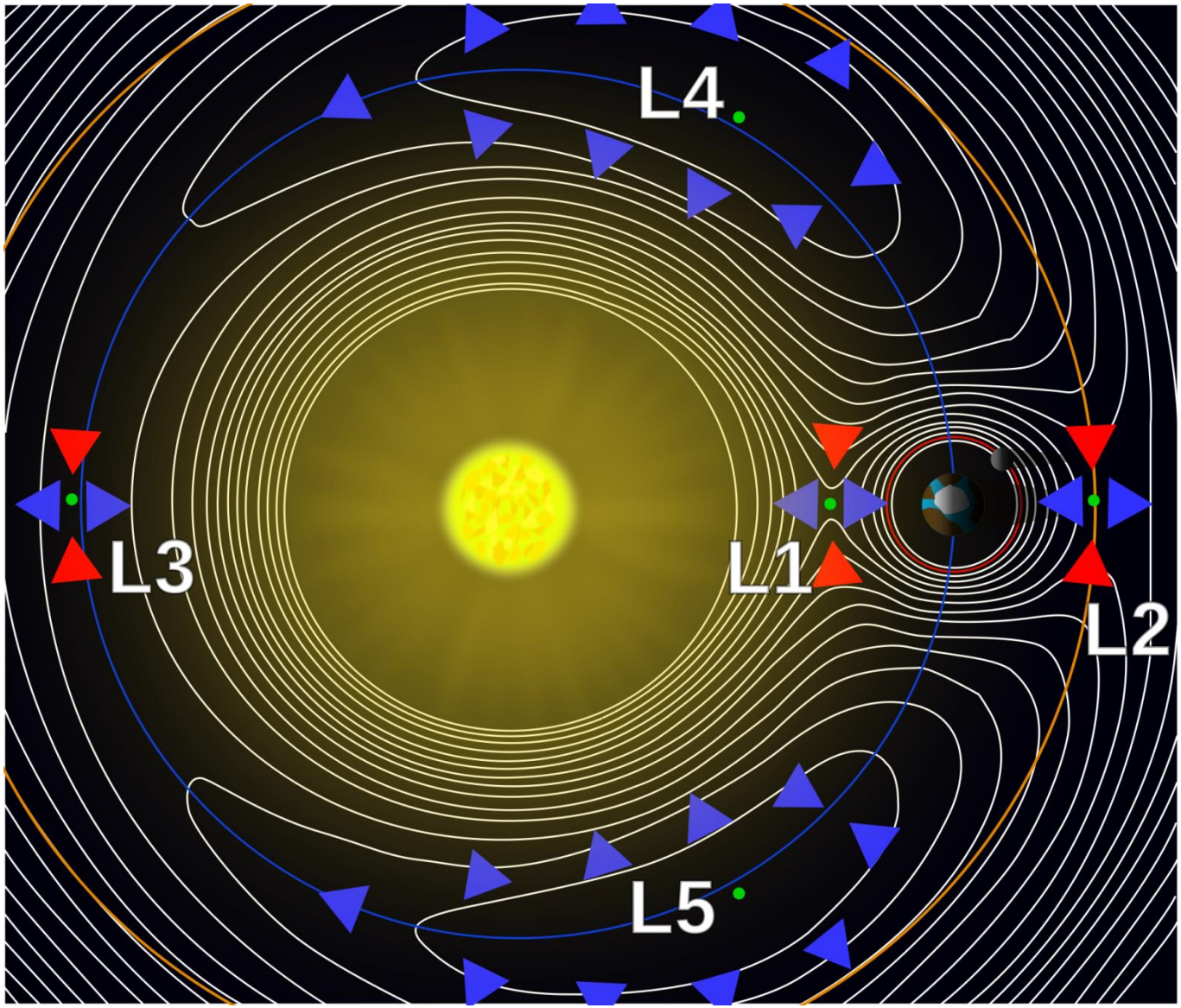
…you are weightless.

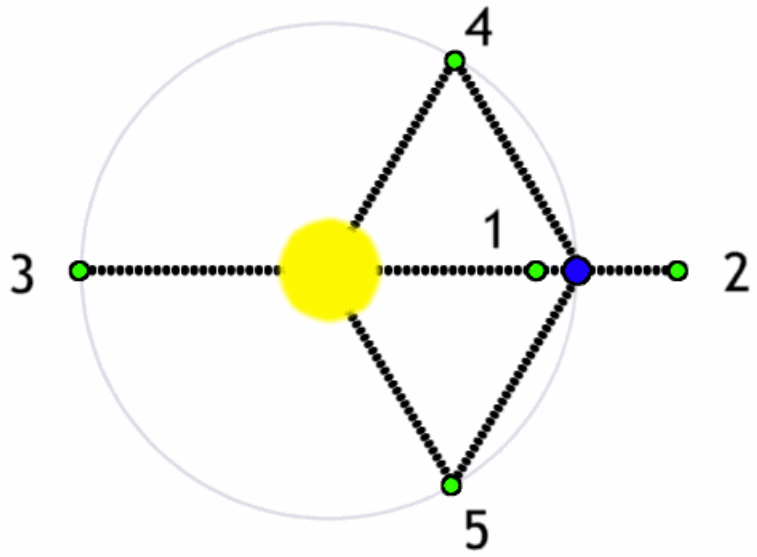

Rocket starts in low orbit . . .
Firing the rocket a little gives it extra orbital energy, raising it to a higher, more elliptical orbit.
Firing the rocket long enough gives it enough extra orbital energy to escape Earth.
Escape velocity
= √2 Orbital velocity

Gravity Potentials



Lagrange Points



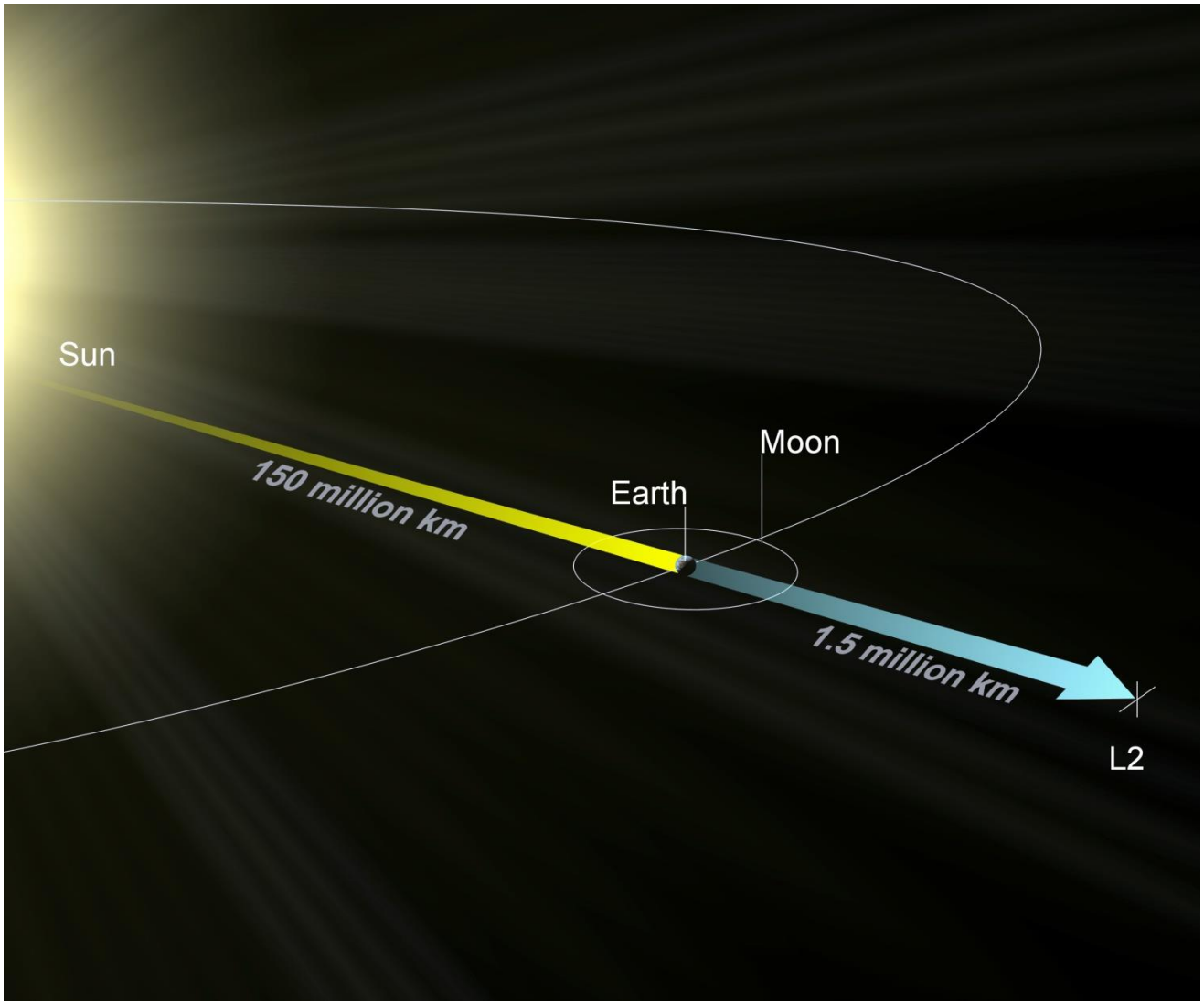


L1: The gravity of the Sun and Earth partially cancels. The Earth's gravity weakens the force pulling the object to the Sun, so increases its period.
L2: The extra pull of the Earth's gravity decreases the orbital period of the object, until at the Lagrange point it equals the period of the Earth.
L3: The combined gravitational pull of Earth and Sun gives object same period as the Earth.

UNSTABLE

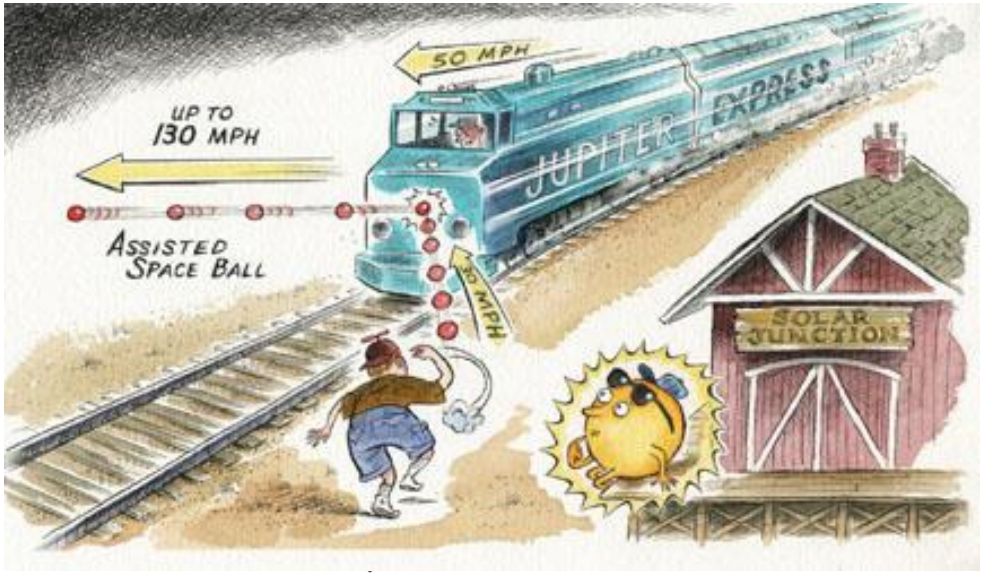
L4 and L5: Form an equilateral triangle with the object, so forces are in the same ratio of the masses, and act through barycenter of the system.

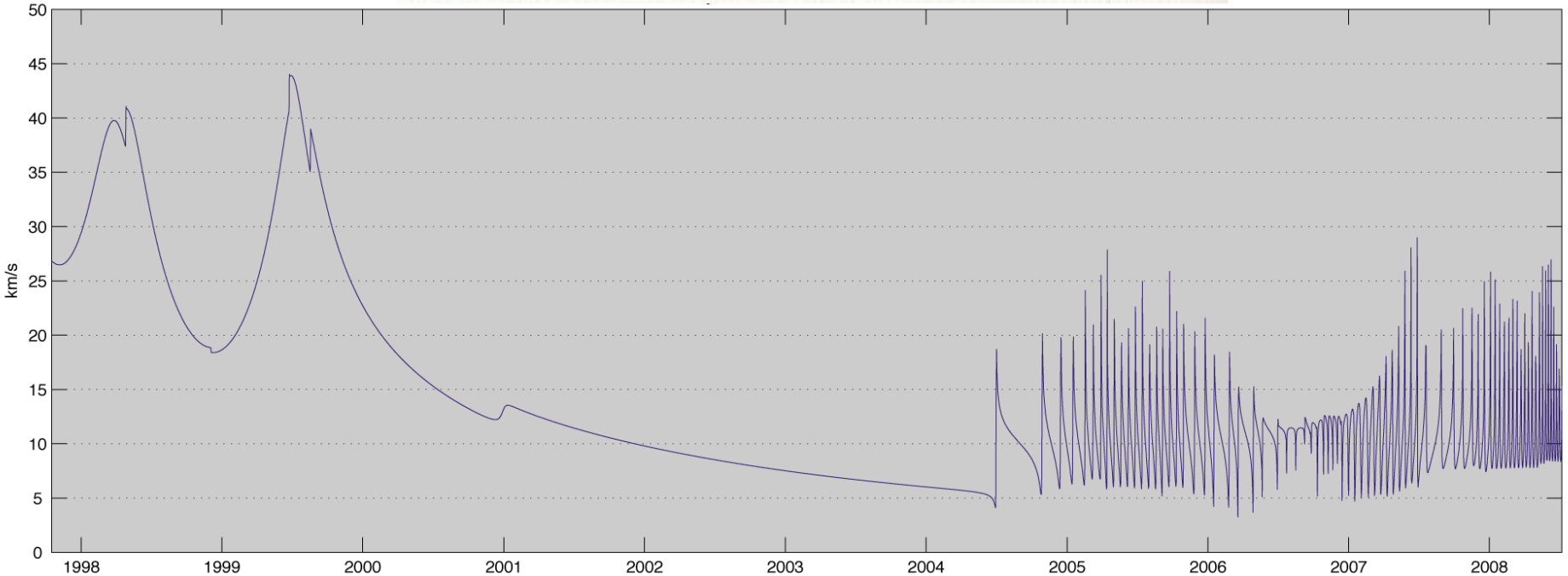
STABLE



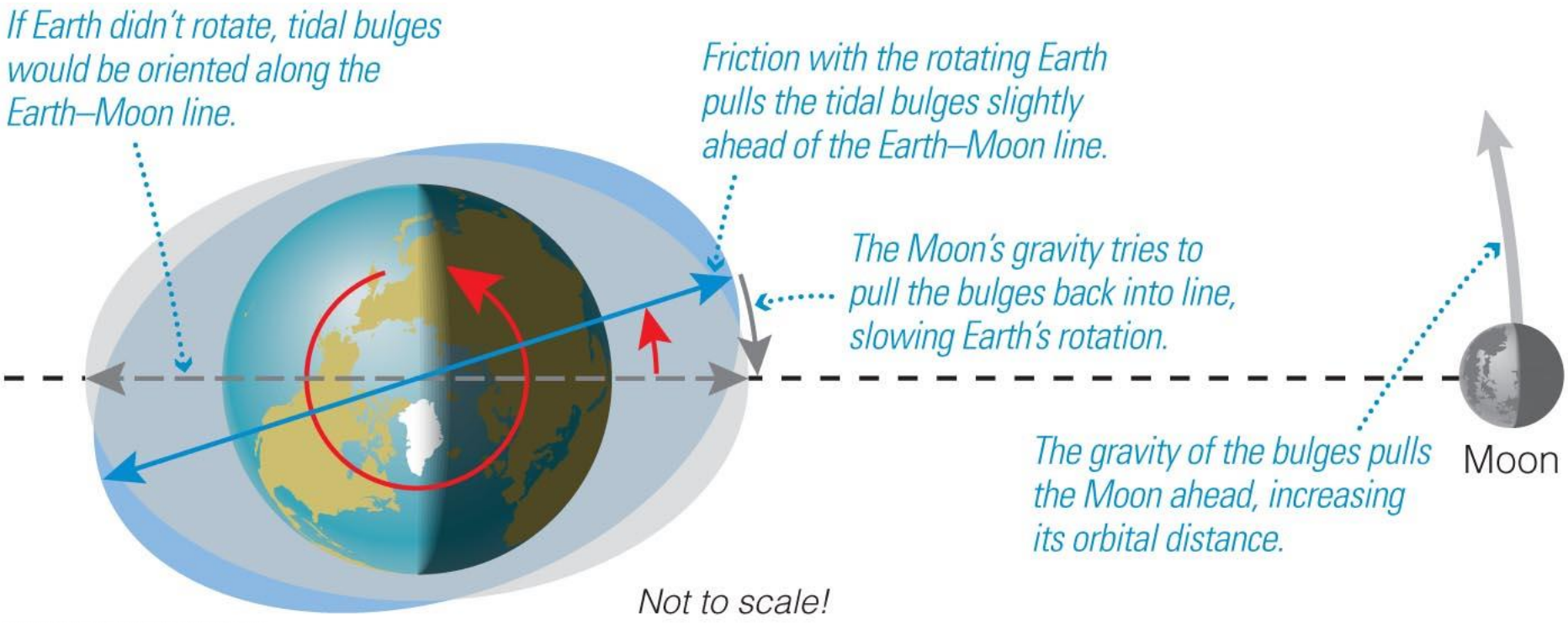
L2 is favored for space-based observatories: WMAP, Herschel, and Planck are already there, Gaia and JWST are going there.

Assist for Cassini

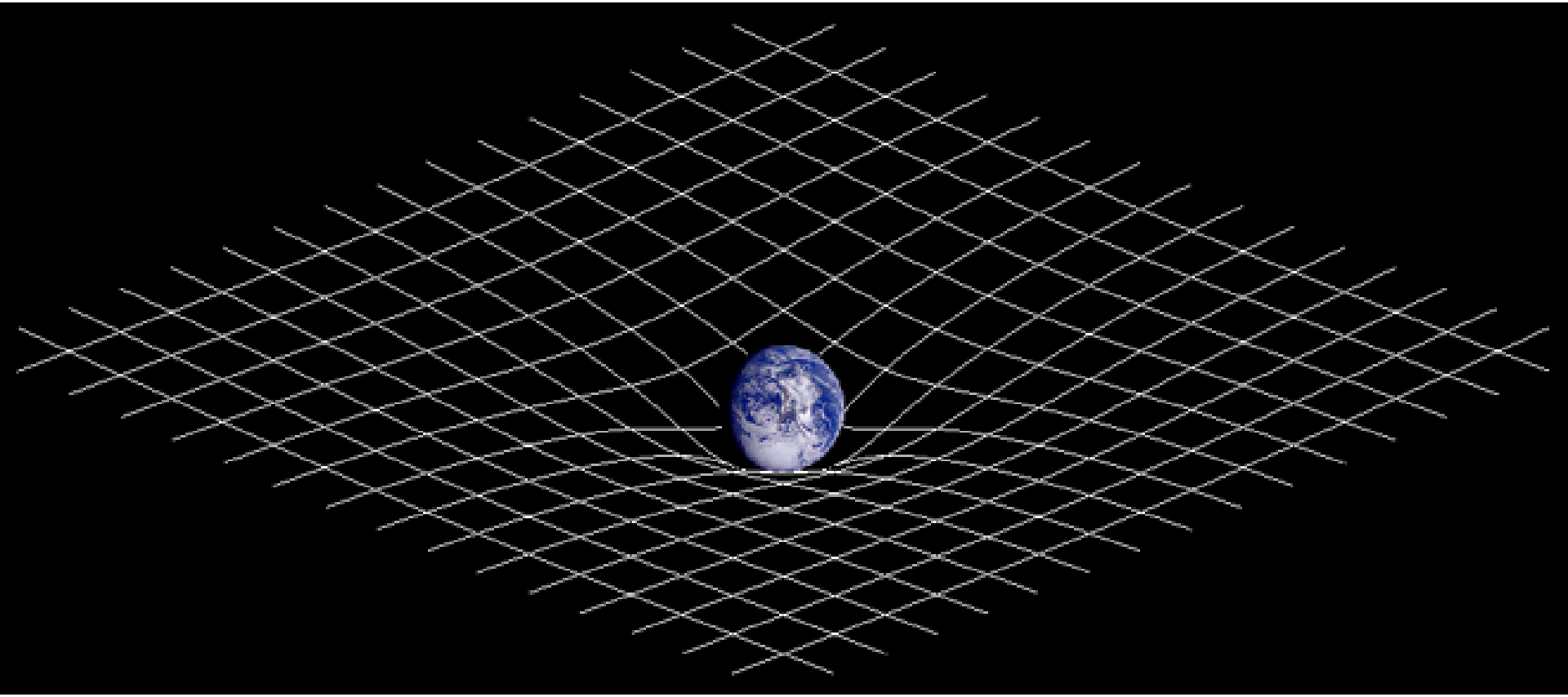




Tides

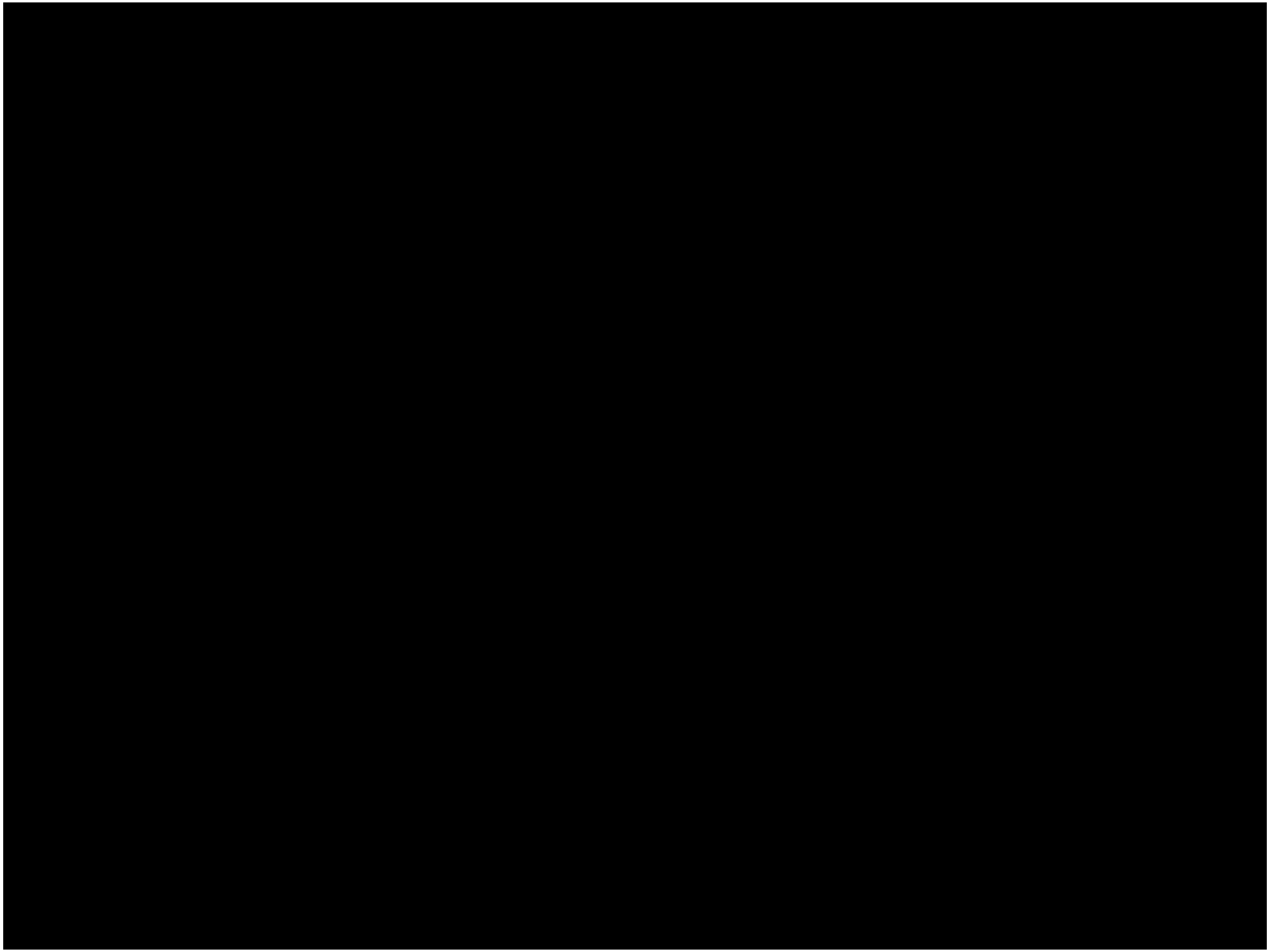

If Earth didn't rotate, tidal bulges would be oriented along the Earth–Moon line.
Friction with the rotating Earth pulls the tidal bulges slightly ahead of the Earth–Moon line.
The Moon's gravity tries to pull the bulges back into line, slowing Earth's rotation.
The gravity of the bulges pulls the Moon ahead, increasing its orbital distance.
Moon
Not to scale!

Curved Space

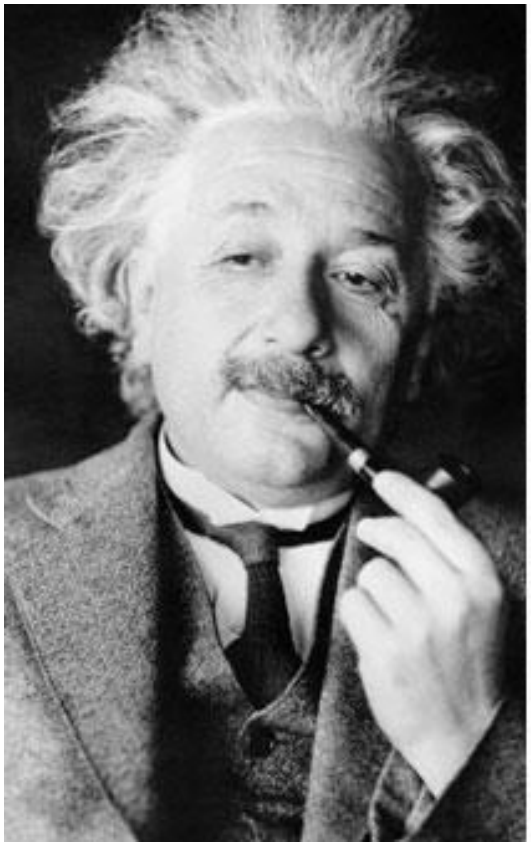


Space-Time Rap

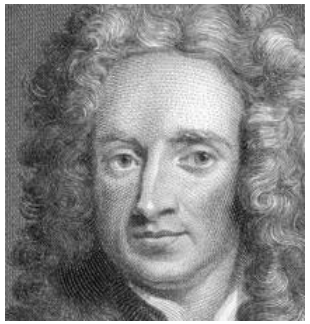
Space-Time Rap



Einstein and Newton



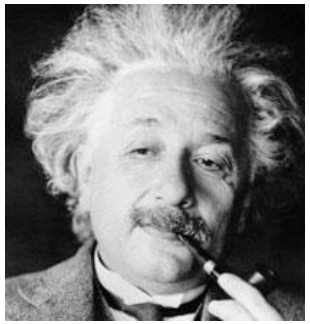
These great scientists had very different ways of thinking about the nature of **gravity** and **space**.



Newton

Mass and energy are very different things.

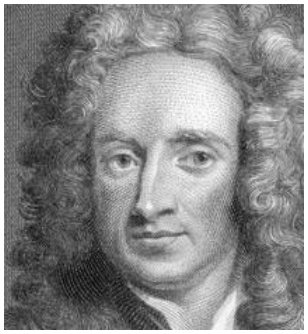
Space and time are very different things; both are linear & both are infinite in extent.



Einstein

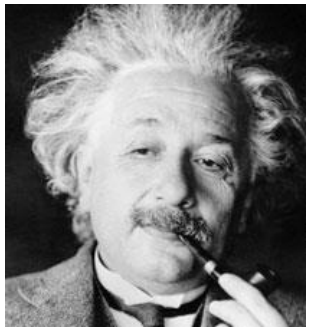
Mass and energy are interchangeable: $E=mc^2$

Space and time are interchangeable: part of the 4-dimensional space-time.



Newtonian Concept:

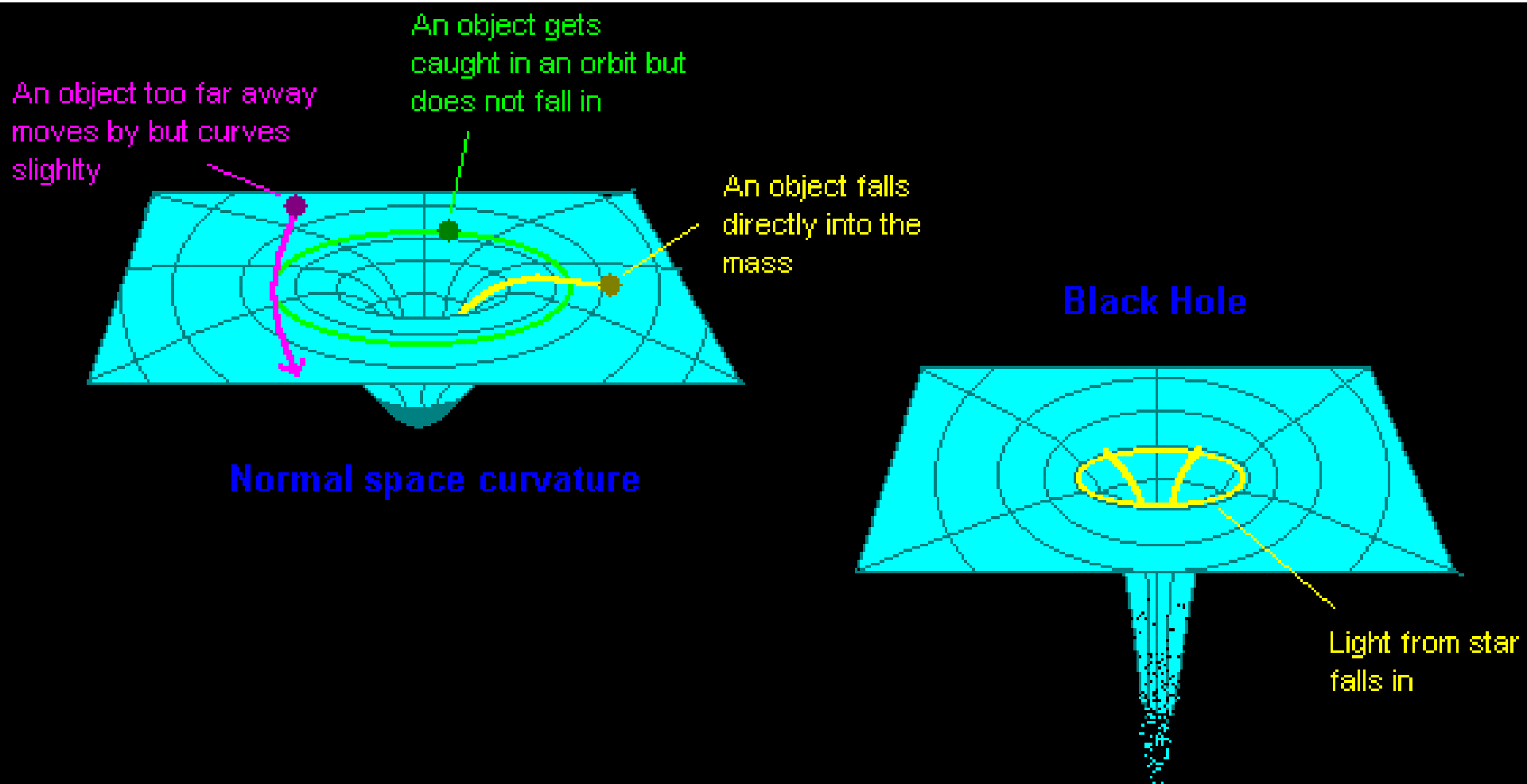
Mass tells gravity how much force to exert; force tells mass how to move.



Einsteinian Concept:

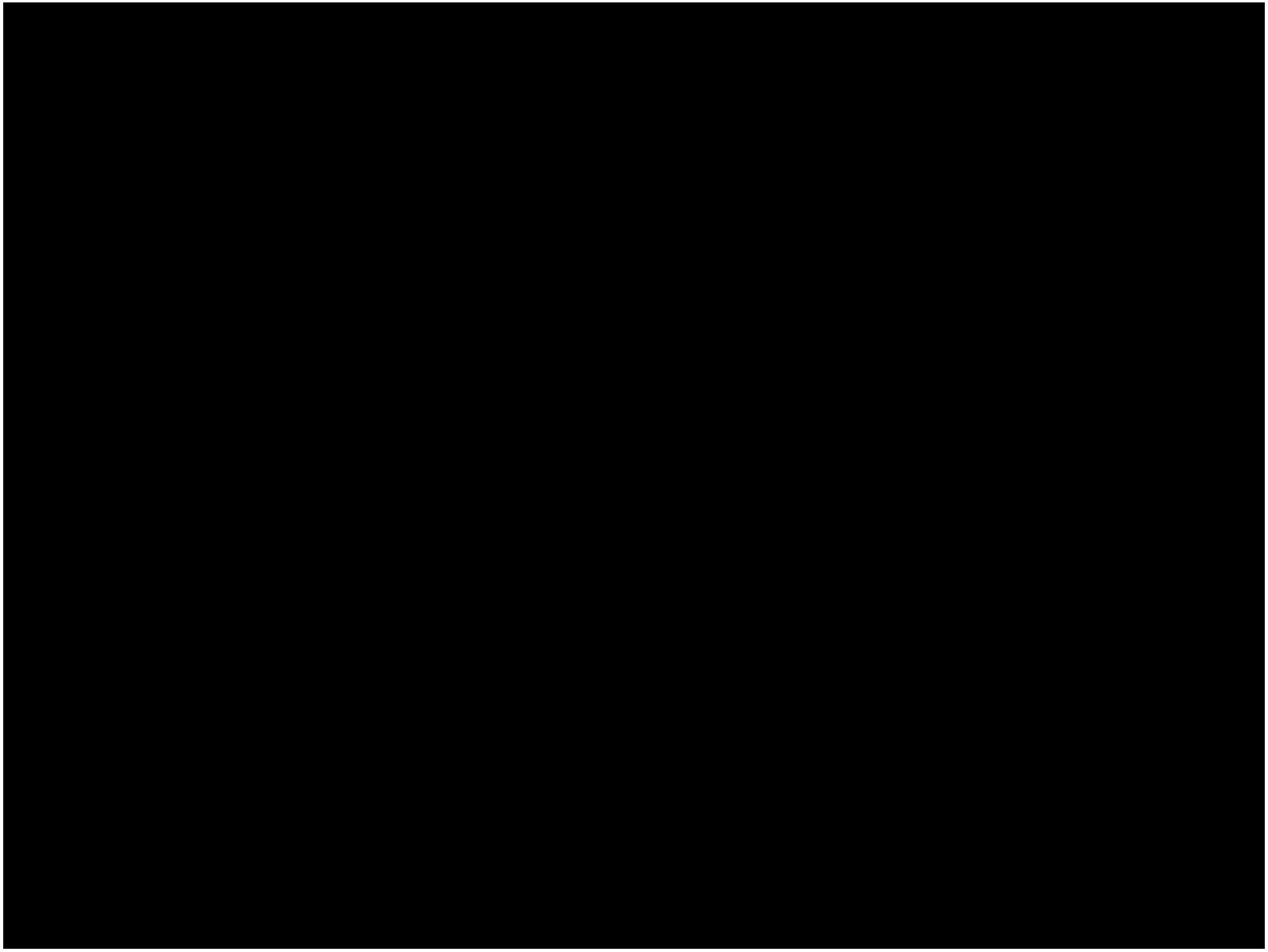
Mass-energy tells space-time how to curve, while curved space-time tells mass-energy how to move.

Objects with lots of mass (and energy) curve space (and distort time) nearby.

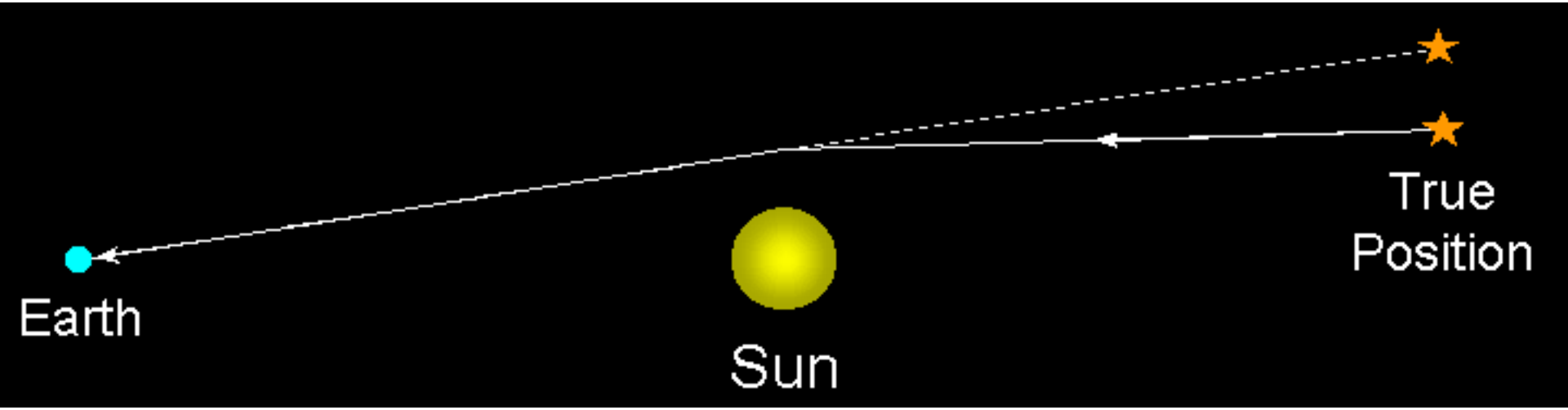


Space-Time Distortion

Space-Time Distortion



Mass and energy cause space to be curved. Curvature causes an **observed** bending of the path of light. The deflection angle for a galaxy is small,1 second of arc.

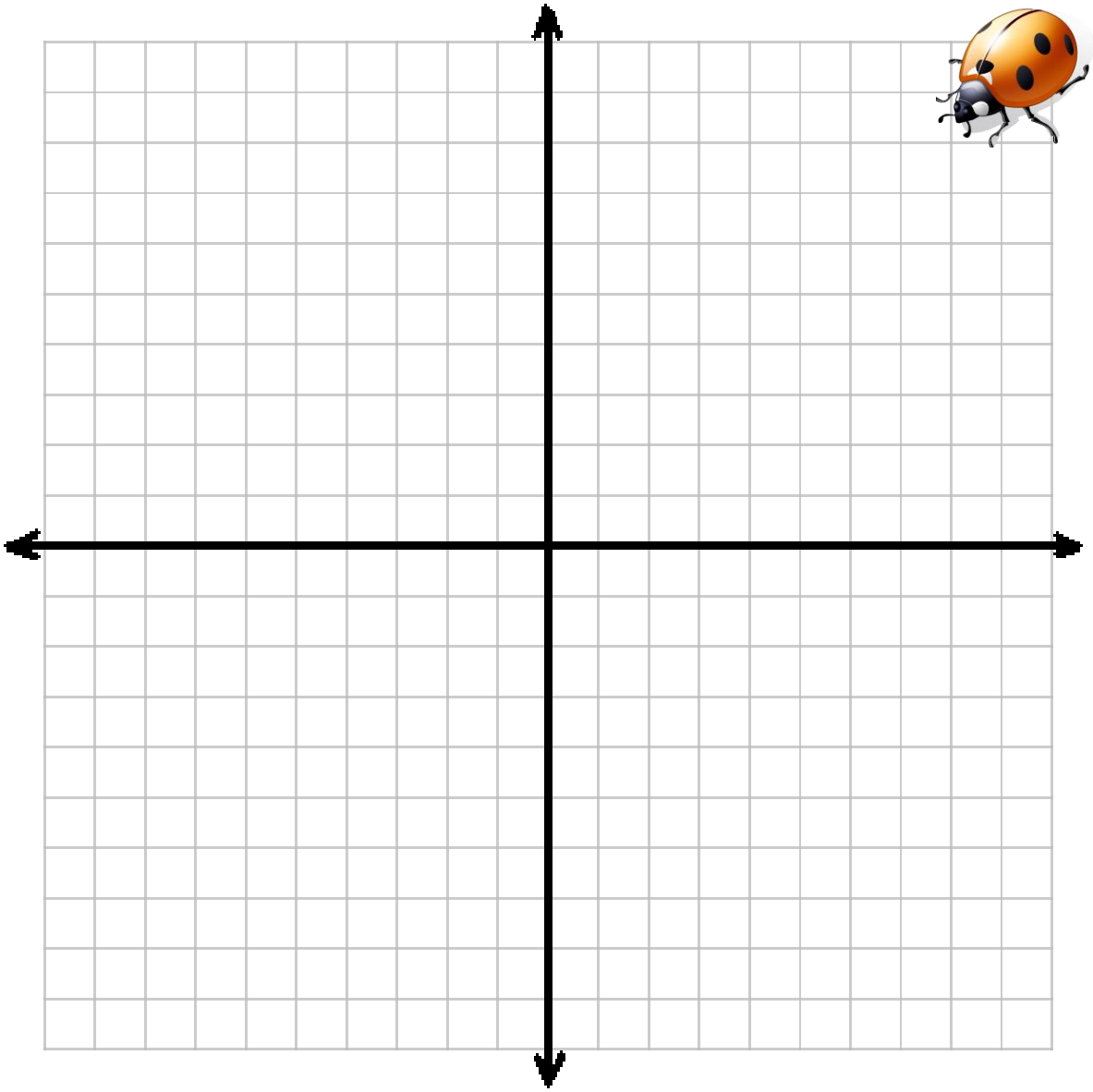


This is called “gravitational lensing” It was predicted in the 1930’s and finally observed in the 1970’s as a multiply-imaged quasar observed at the local MMT.

Newton's view of space:

Rectilinear & rigid (not expanding or contracting)

Think of a bug crawling over a fixed grid on graph paper.

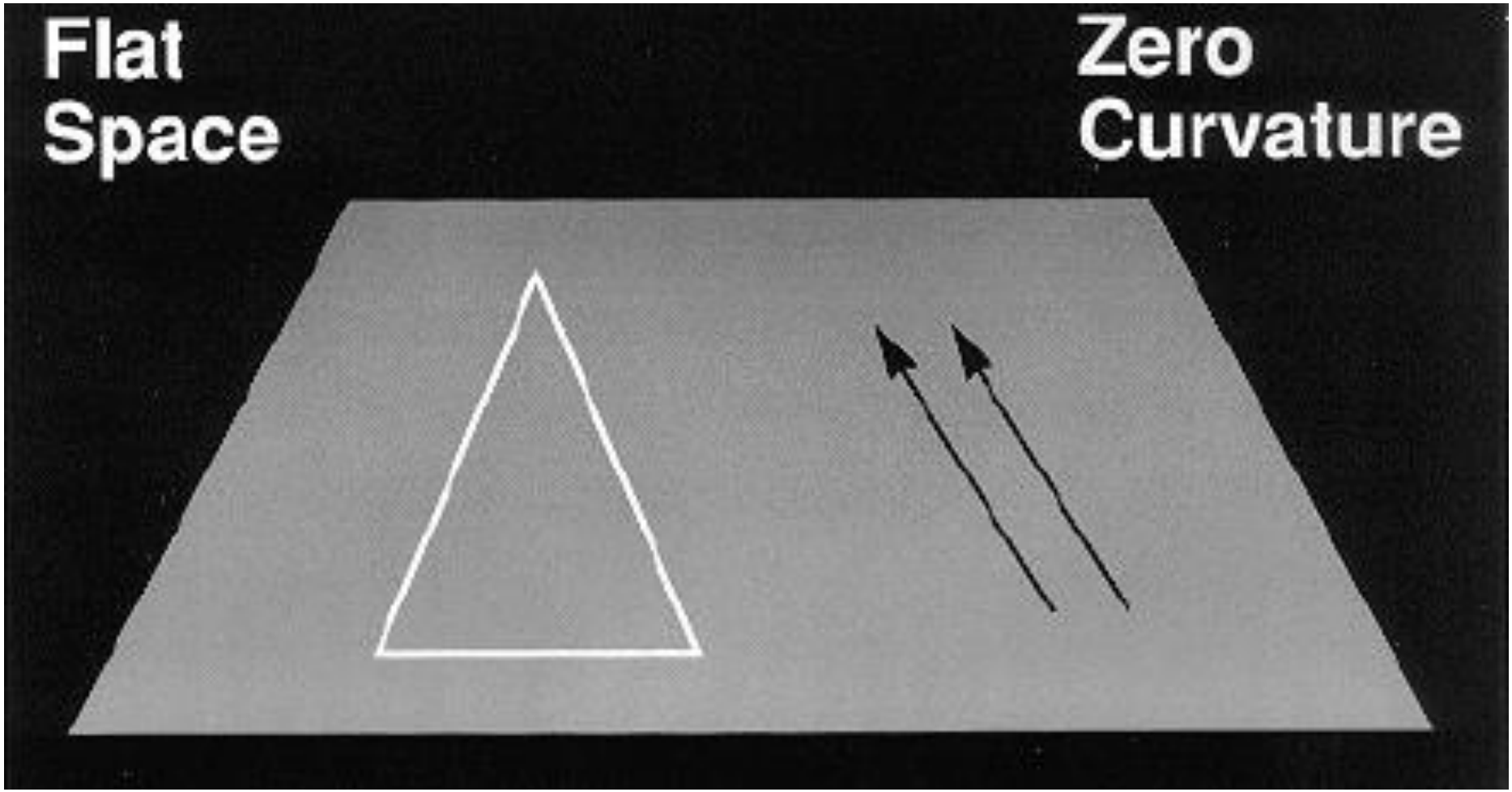


Einstein's view of space:

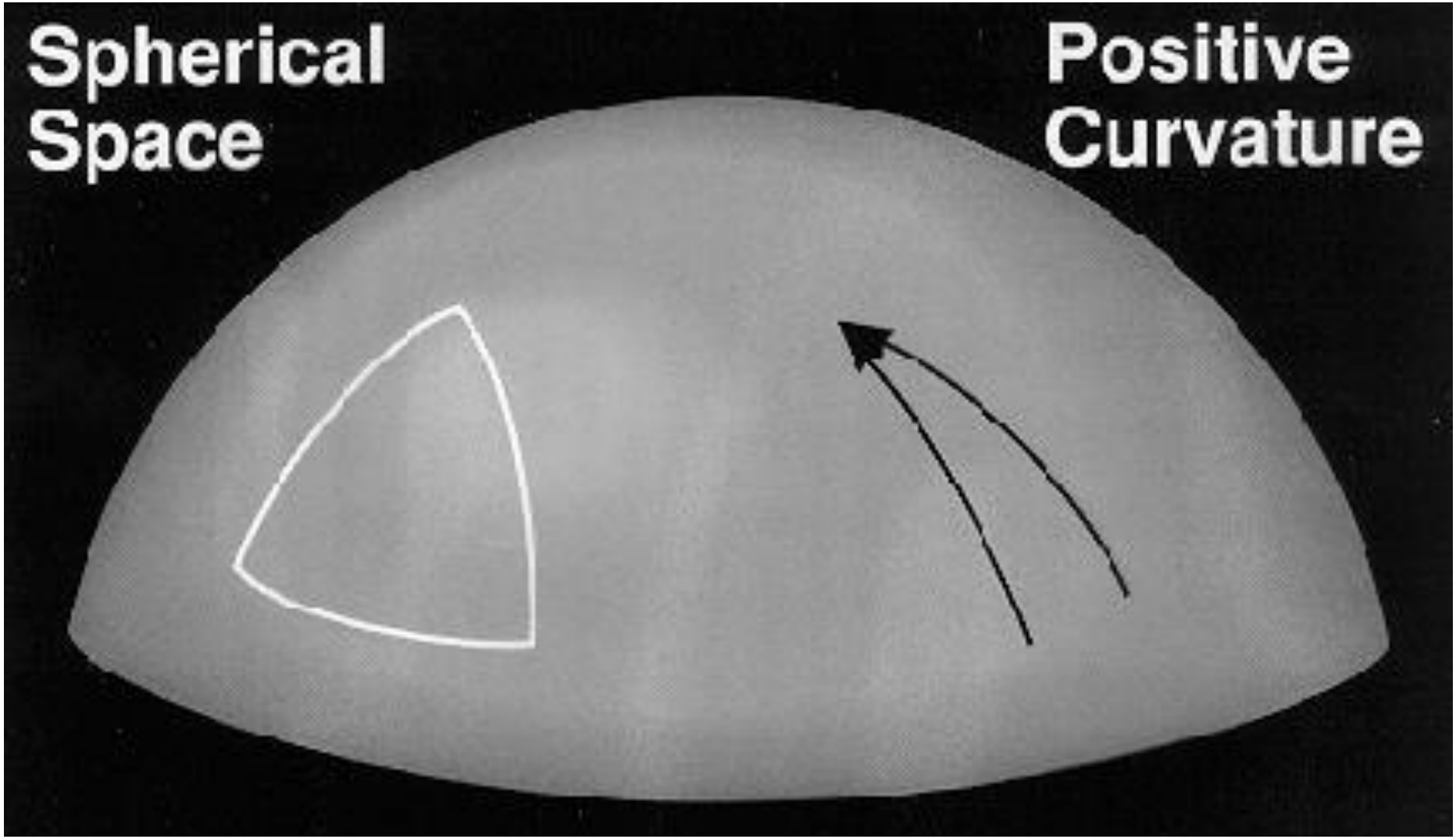
Curved & wavy (can also expand or contract)

Think of a bug crawling over a rumpled rubber or paper sheet.

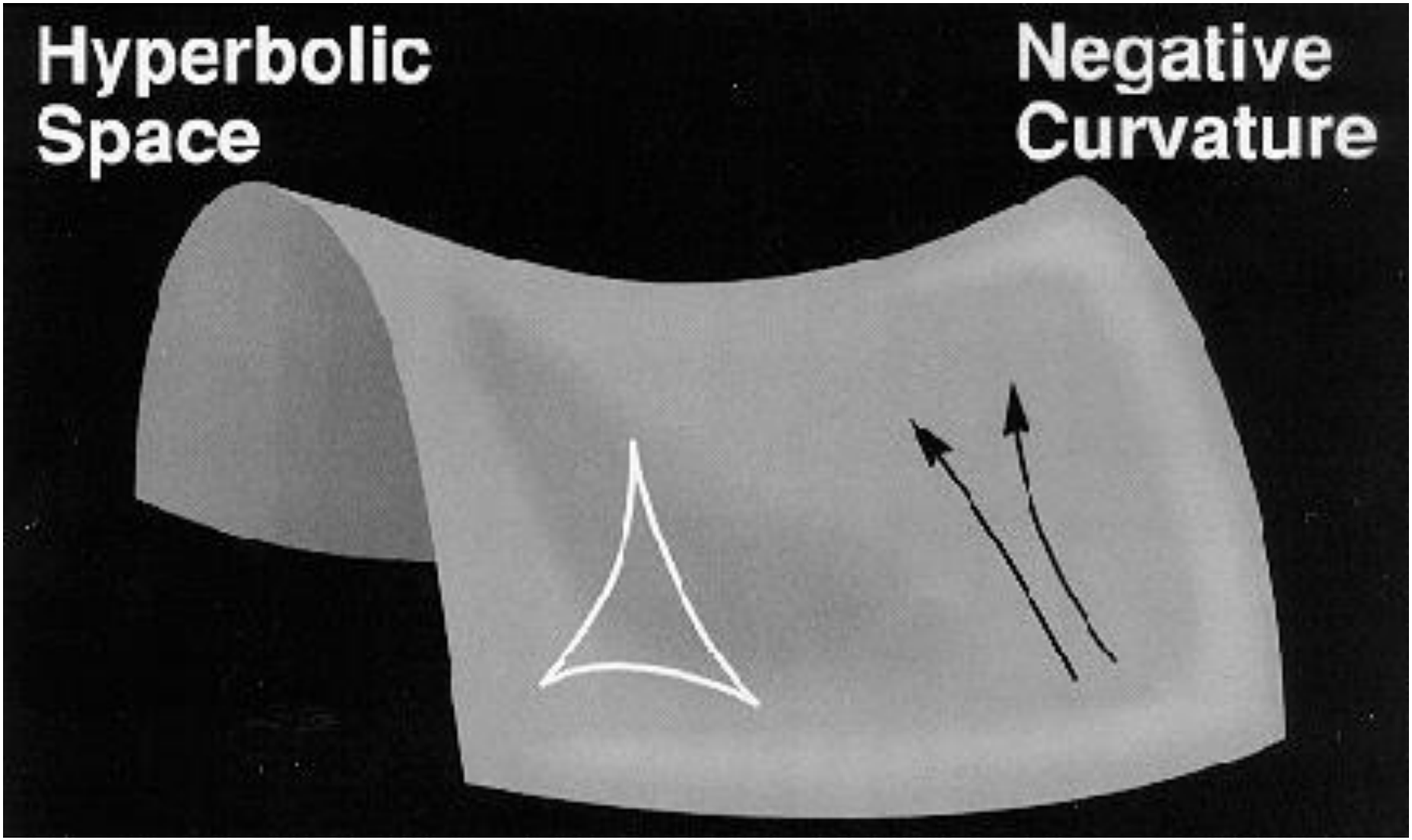
(1) This 2D space is **flat** (or Euclidean):

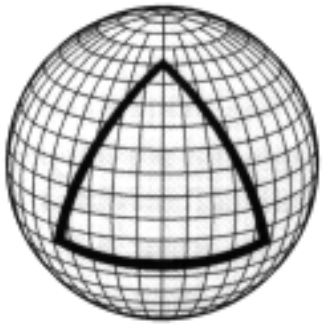


(2) This 2-d space is **positively** curved:

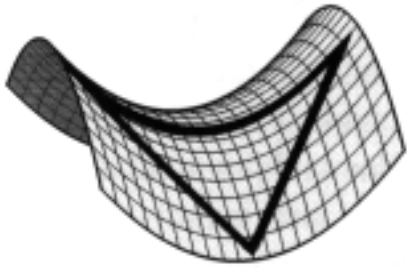


(3) This 2-d space is **negatively** curved:

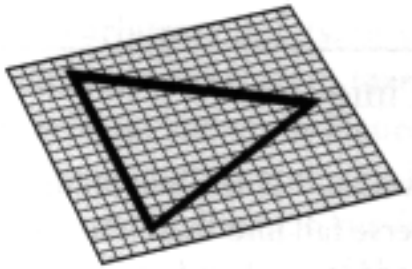




Positive Curvature



Negative Curvature



Flat Curvature

If space has **positive curvature**, it has a **finite volume**, but **no boundary**. The zero and negative cases are infinite.

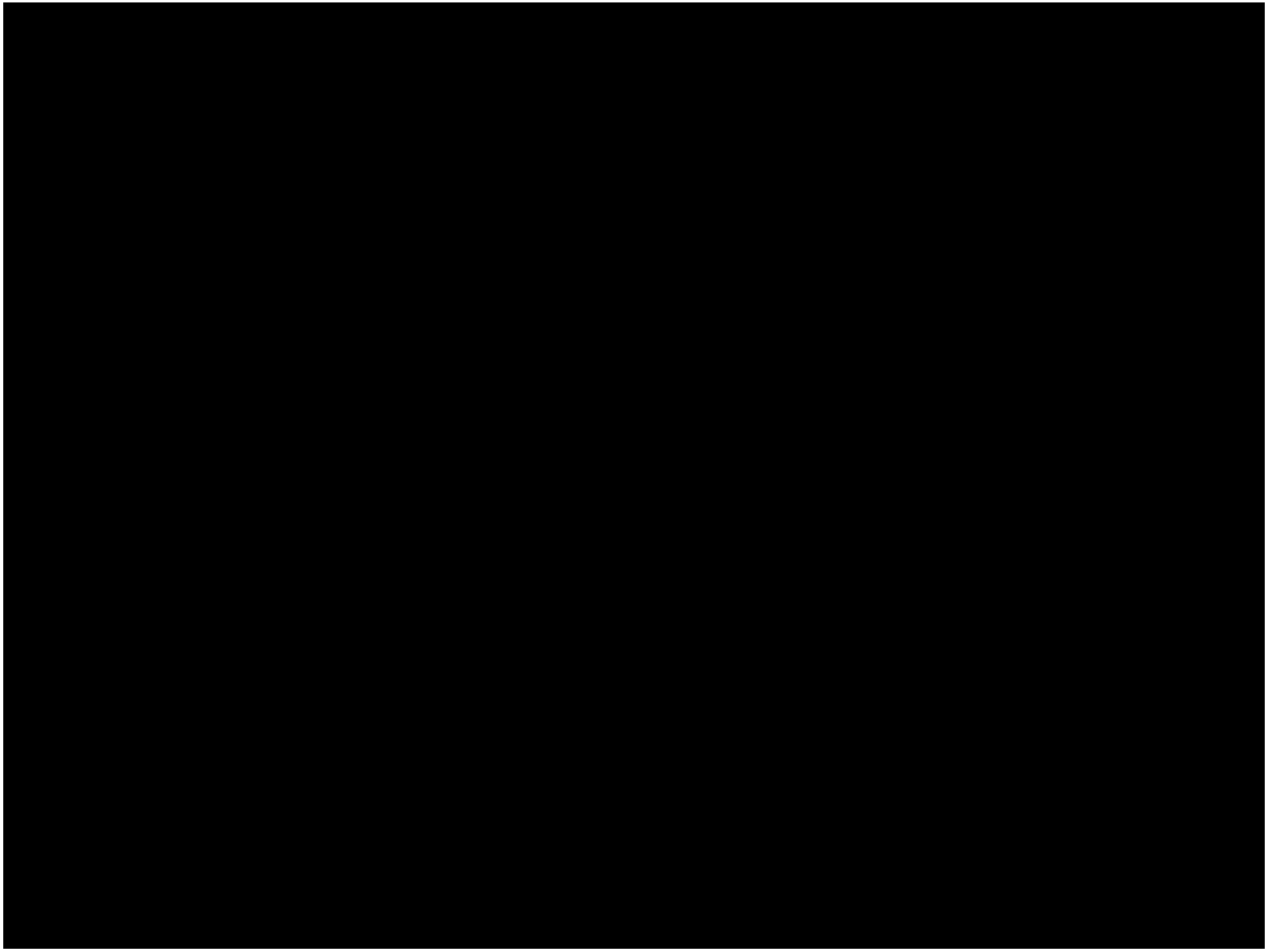
Analogy: the Earth's surface has **positive curvature**. It has a **finite area**, but **no edge.** The curvature can apply locally (black hole) or globally (the entire universe).

Special Relativity

Special Relativity

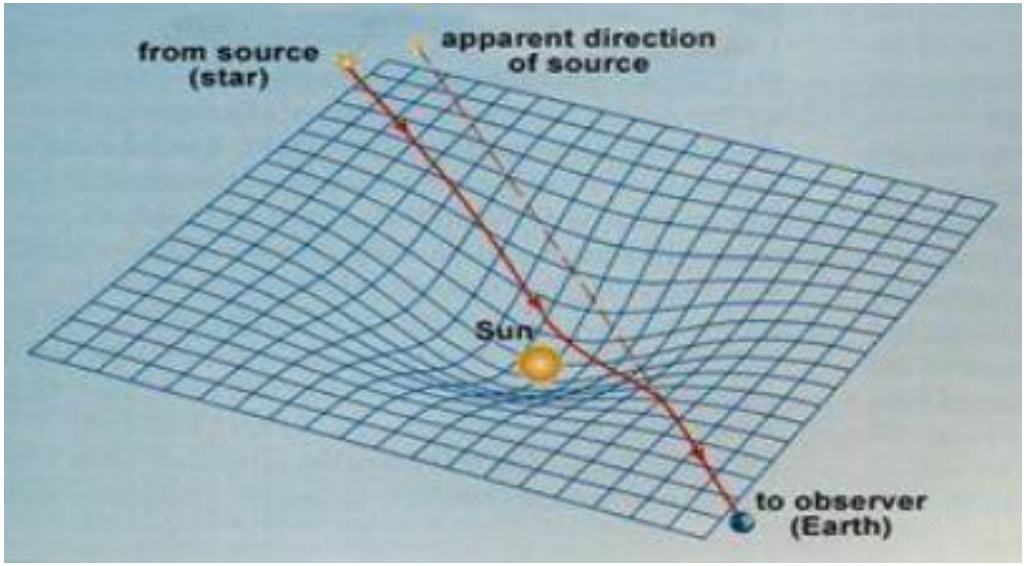
General Relativity

General Relativity

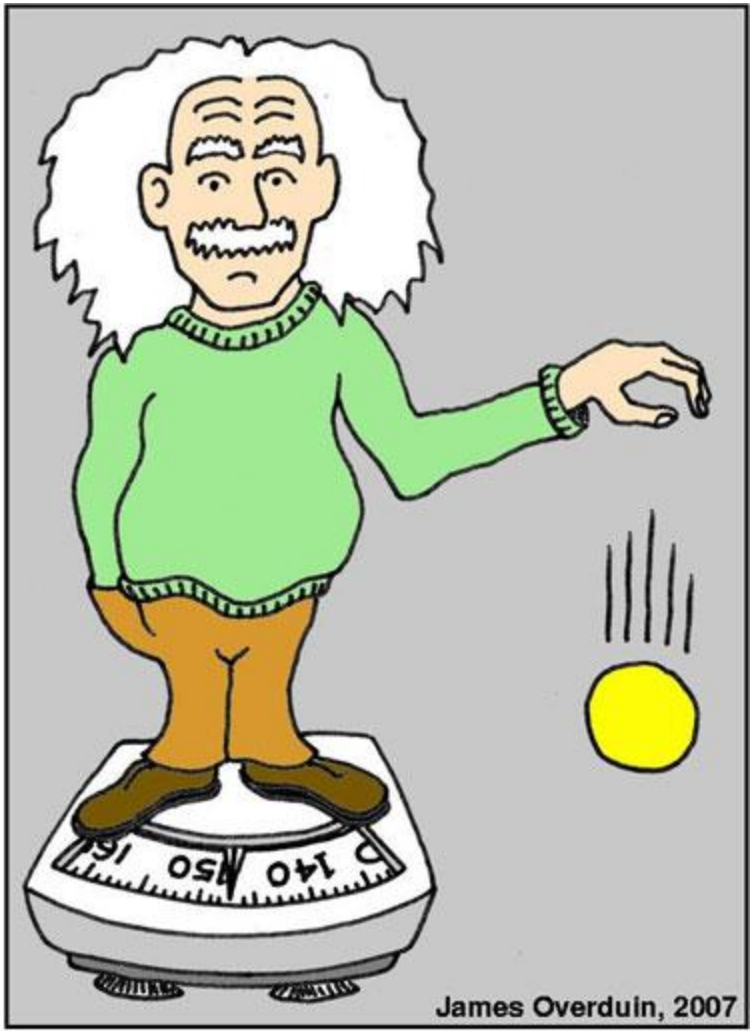


General Relativity

General relativity is Einstein's masterwork. It's framed around the equivalence principle, the fact that the ***gravitational and intertial masses of an object are identical***. He said that there's no way to distinguish between a change in an object's motion due to gravity and a change in motion due to any other force.



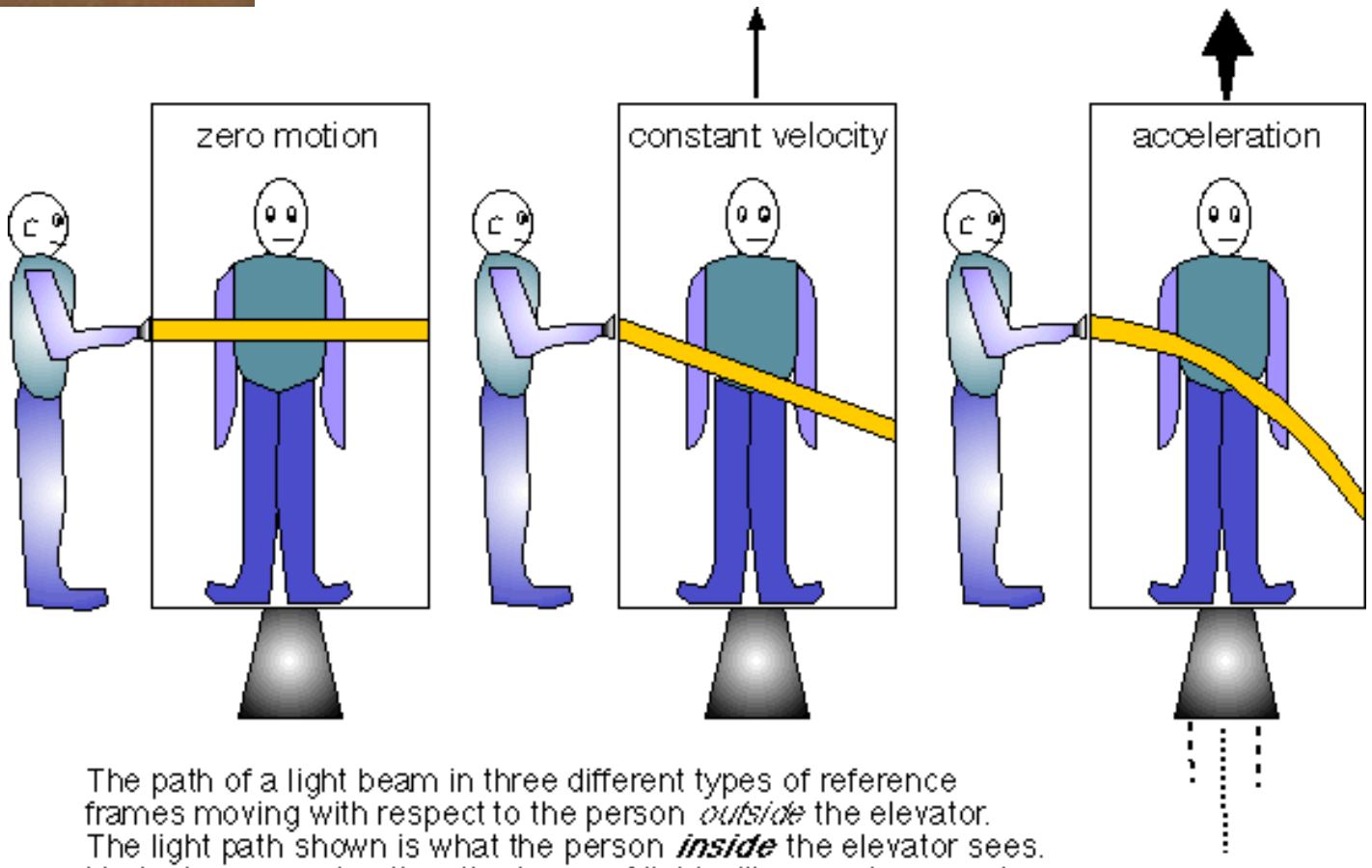
This premise led him to a new, geometric theory of gravity in which mass-energy causes curvature of space-time.



There's no way to distinguish between free-floating in deep space, and free fall in gravity.

There's no way to distinguish between acceleration upward and being stationary in gravity.

Now think of someone shining a light beam across a sealed elevator. If the elevator is in accelerated motion, the light beam deflects downward. But this can't be distinguished from an elevator stationary in a gravity field.



The path of a light beam in three different types of reference frames moving with respect to the person *outside* the elevator. The light path shown is what the person ***inside*** the elevator sees. Under large acceleration, the beam of light will curve downward. It should also do that in a region of strong gravity.