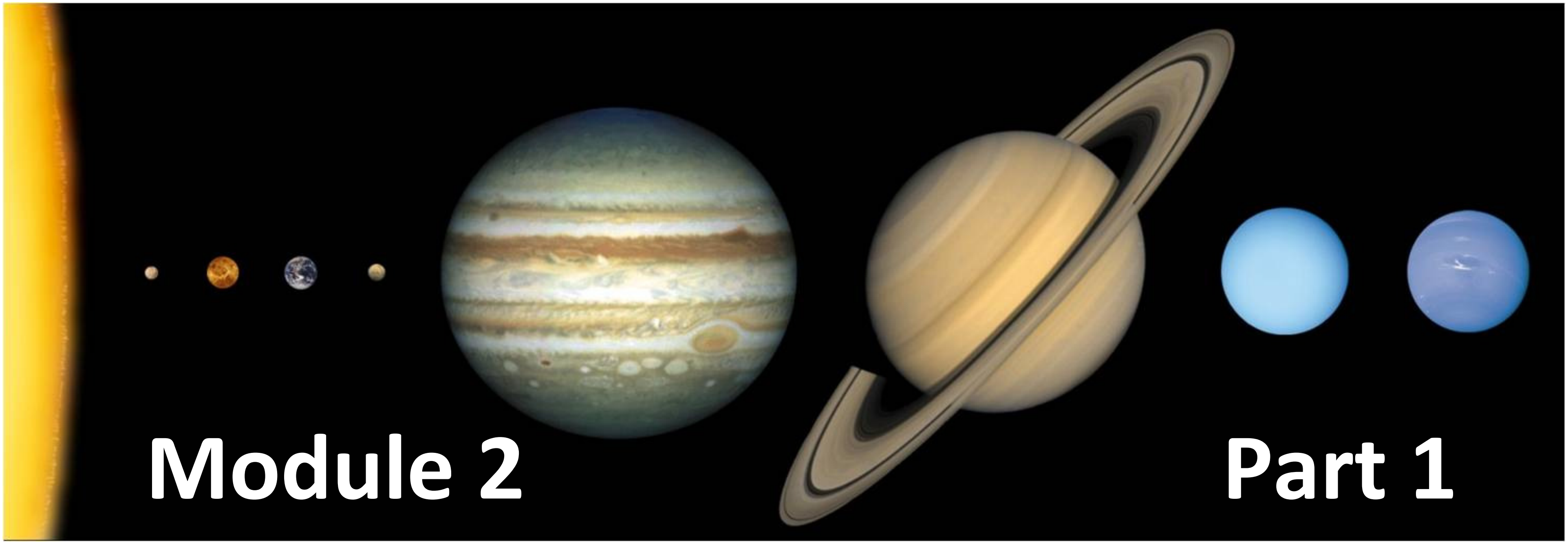
Earth Sciences 2150 – Fall 2022
Solar System and Planetary Science



Module 2

Part 1

Scientific Background Concepts: Revisiting what you need to know

EASC 2150:The Solar System
The Plan for Today

Important Scientific Concepts

- This is a science course, and an **Earth Science** course, even though there are no prerequisites. So it is in your interest to have a review of some background science, and also some basic geological concepts, including:
- Dealing with the enormous range of numbers involved…
- Concepts of Geological Time and ‘Cosmological Time’
- Structure of matter: particles, atoms, elements, isotopes.
- Minerals, rocks, and some key aspects of Earth Sciences.
- Some concepts related to energy in the Universe.
- Some other things that we might call ‘Essential Physics’

- The Earth is just one planet in one solar system. The scale of the system is huge, but nothing even close to the scale of the wider universe.

You are HERE!

(actually the Andromedra Galaxy)

- The Solar System is about 4.6 billion years old.
- Probably about 300 billion stars in our Galaxy.
- The number of galaxies in the universe is not known
- The Universe is at least 93 billion light years across.

Some Things We Need to Know and Understand: First, dealing with numbers!

Andromeda is the closest galaxy to ours. But 'close' is a relative term, because it is located 2.5 million light years from us.

(Andromedra Galaxy)

But what does this actually mean?

The Universe is over 13 billion years old.

But what does this actually mean?

Large numbers quickly become totally incomprehensible…. Like Government Debt Statistics…..

Dealing with Big and Small Numbers: Exponential Notation

- We will discuss atoms (**very small**) and planets, moons and stars (**very large**), and galaxies **(huge)**…
- … also the distances between planets (**very long**) and wavelength of x-rays (**very short**).
- Everyday units such as metres and kilograms become cumbersome because of these enormous ranges.
- e.g. Mass of a hydrogen atom = 0.00000000000000000000000000167 kg
- Mass of the Sun = 1988920000000000000000000000000 kg
- The only solution is using **EXPONENTIAL NOTATION**

Would a few commas help?

- Mass of Sun = 1,988,920,000,000,000,000,000,000,000,000 kg

(Makes it a bit easier to count the zeros…)

How about using larger units of mass?

- 1,000,000 = 1 million (6 zeros)
- 1,000,000,000 = 1 billion (9 zeros)
- 1,000,000,000,000 kg = 1 trillion (12 zeros)
- 1,000,000,000,000,000,000 = 1 million trillion (18)
- Mass of Sun= 1,988,920 trillion trillion kg (24 zeros)

or… approx 2,000,000 trillion trillion

= 2 million trillion trillion kg (30 zeros)

How about using scientific prefixes?

- kilo = 1,000 (a thousand) e.g. 1 kilometre = 1000 m
- mega = 1,000,000 (a million); giga = 1,000,000,000 (same thing as a billion, think of gigabytes of storage). You might have Terabytes (same thing as a trillion, or 1000 Gb)

- 1,000 grams = 1 kilogram (kg)
- 1,000 kilograms = 1 megagram (Mg); or a metric tonne.
- 1,000,000 kilograms = 1 gigagram (Gg)
- 1,000,000,000 kilograms = 1 teragram (Tg); or 1 million tonnes….we can go on like this forever.
- Mass of Sun = 1,988,920,000,000,000,000 billion tonnes.

Dealing with Unimaginable Numbers

Are any of these methods useful?

Not really. They may have use in a given context, or for things of a certain size range, but they are mostly a source of confusion.

How can we reduce this confusion?

Why not just count the zeros?

- This is the principle of “scientific notation”, also known as “exponential notation” or “powers of ten notation”. Why ten? - count your fingers!
- $1{,}000 = 1 \times 10^{3}$
- $1{,}000{,}000 = 1 \times 10^{6}$
- $1{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000{,}000 = 1 \times 10^{30}$
- Mass of Sun = 1.98892×10^{30} kg (~ 2×10^{30} kg)
- Note that the exponent (30 in this case) means move the decimal place 30 places to the right.

Another Example

- The distance between Earth and the Sun is approximately 149,600,000,000 metres. Or, more conveniently 149,600,000 kilometres,
- This can be written more conveniently in exponential notation as 1.496×10^{11} metres. Check that this is so by starting with 1.496 and moving the decimal point 11 places right
- We can approximate it (if we choose) as about 1.5×10^{11} metres (or 1.5×10^{8} km).
- The distance between Earth and the Moon is 384,400 km – What is this in Exponential Form??

- 3.84×10^{5} km - but we'll call it 4×10^{5}

An Example of a Calculation…

How much further would it take to get to the Sun from Earth compared to getting to the Moon, if speed is constant?

We divide the distance to the Sun by the distance to the Moon….but how, exactly?

1.5×10^8 divided by 4×10^5

$= 0.375 \times 10^3 = 3.75 \times 10^2$

= 375 times longer

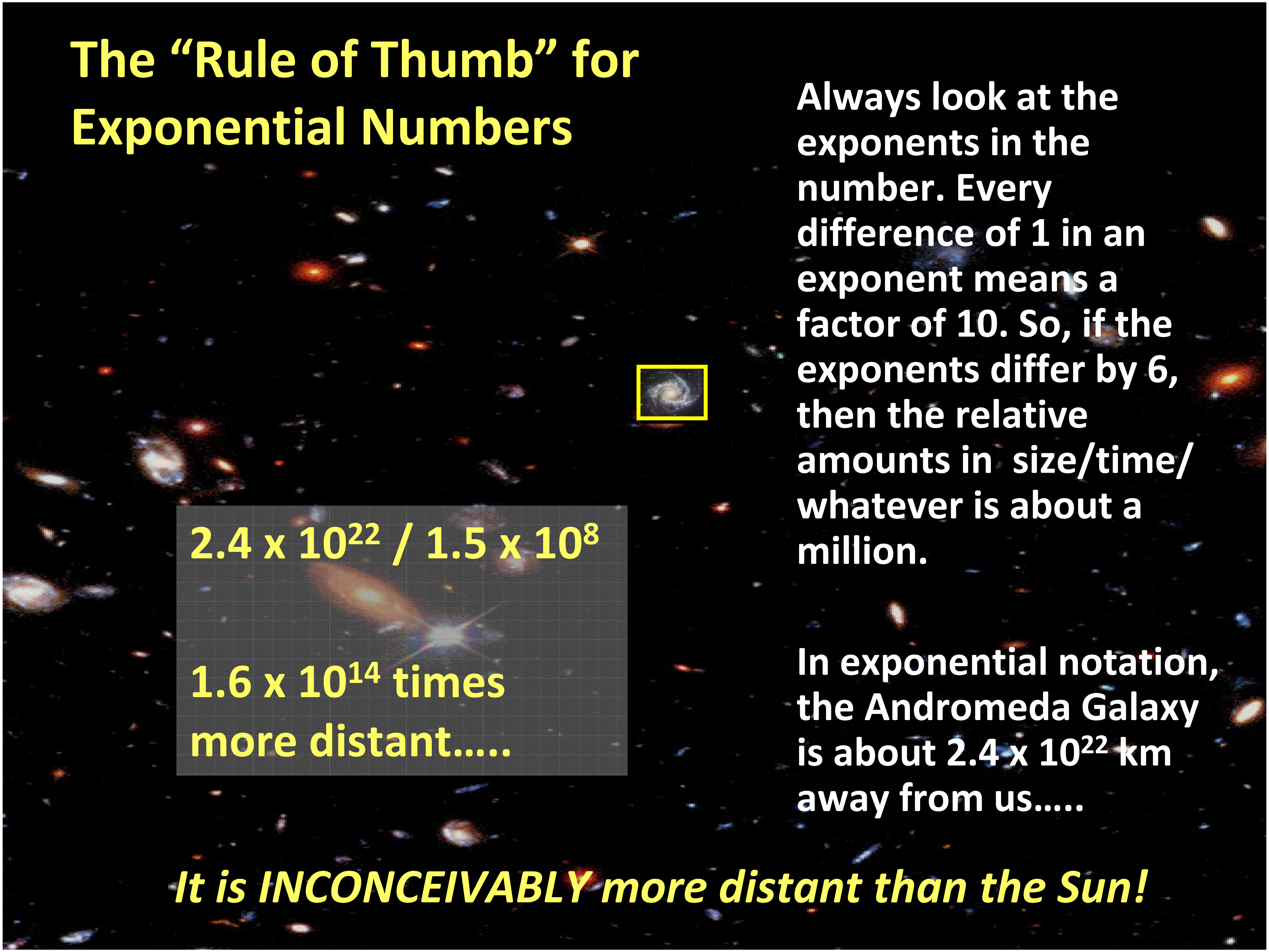
Multiplying and Dividing Exponentials

We multiply or divide the first part of the number in the usual way: e.g., 1.5 divided by 4 is 0.375. But we then SUBTRACT the *exponents*: e.g., 8 – 5 = 3.

If we multiplied the same numbers, what would the answer be ?

1.5×10^{8} multiplied by $4 \times 10^{5} = 6 \times 10^{13}$

The “Rule of Thumb” for Exponential Numbers



Always look at the exponents in the number. Every difference of 1 in an exponent means a factor of 10. So, if the exponents differ by 6, then the relative amounts in size/time/whatever is about a million.

In exponential notation, the Andromeda Galaxy is about 2.4×10^{22} km away from us.....

$2.4 \times 10^{22} / 1.5 \times 10^{8}$

1.6×10^{14} times more distant.....

It is INCONCEIVABLY more distant than the Sun!

Some Exponential Numbers You Might Already Know About

- Can anyone tell me what 6×10^{23} represents? This one is just a number; it has no units.

- How about this one ? : 3×10^{8}

(a clue here – the units represent speed)

- And finally, try this one. What about 3.15×10^{7}

(a clue here - the units represent time)

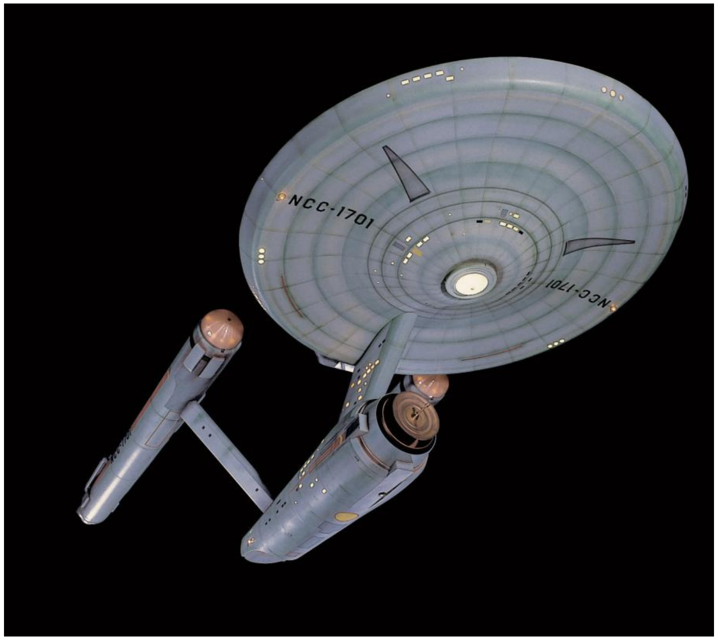
These are all important in physical science. And some may surprise you.

A small glass of water (18 g) has 6 x 10^{23} water molecules in it

(AVOGADRO'S NUMBER)

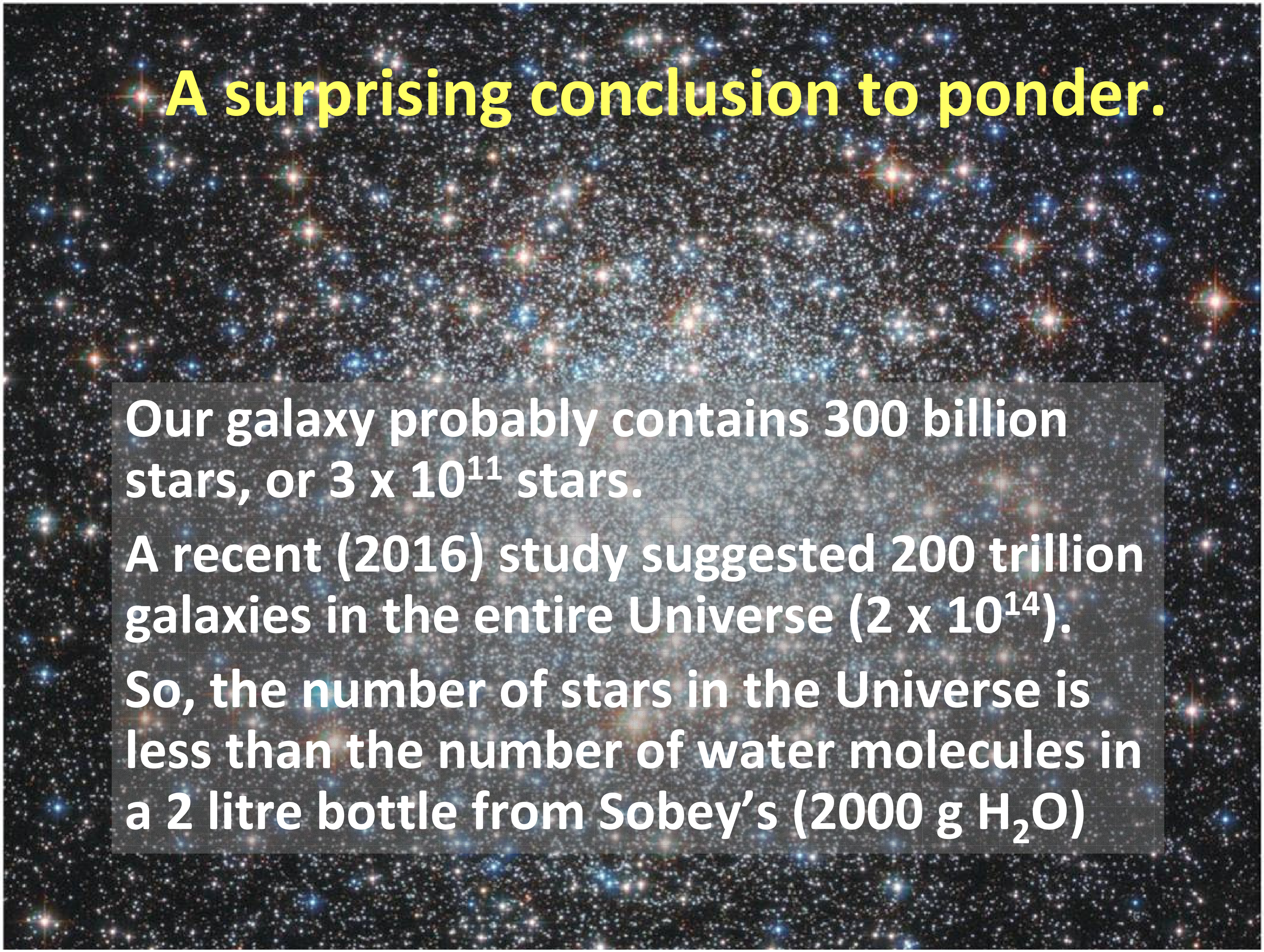
There are about 3.15 x 10^{7} seconds in a year.

(About 31 milion)



The Starship Enterprise has to travel enormous distances with the help of its fictional warp drive and dilithium crystals. But the laws of physics decree that no object can move faster than the speed of light (C) which is about 3 x 10^{8} metres per second. We'll come back to this one at the end of our course……

A surprising conclusion to ponder.



Our galaxy probably contains 300 billion stars, or 3 x 10^{11} stars.

A recent (2016) study suggested 200 trillion galaxies in the entire Universe (2 x 10^{14}).

So, the number of stars in the Universe is less than the number of water molecules in a 2 litre bottle from Sobey's (2000 g H_2O)

Exponential notation also works for extremely small numbers

- For example 3 x 10^{-4} means that we start with 3 and move the decimal point 4 places to the **left** giving…

3 x 10^{-4} = **0.0003**

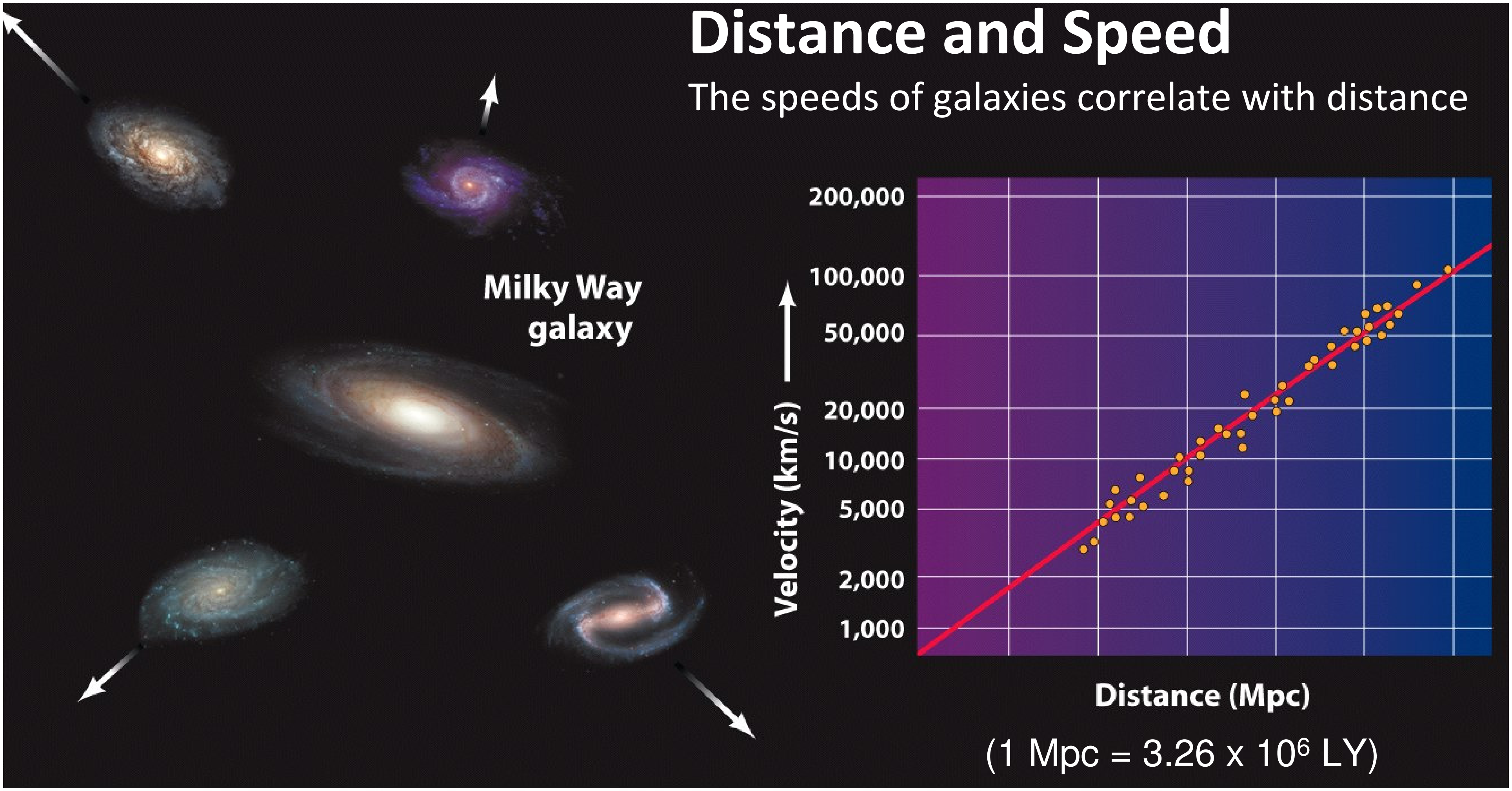
- The diameter of a hydrogen atom = **1 x 10^{-10}** m = **0.0000000001 m**.

(Start with 1 and move decimal point 10 places left.)

- The wavelength of x-rays is ~ 10^{-9} m, the wavelength of visible light it is ~ 10^{-6} m.
- Calculations for negative exponents follow same rule.

Distance and Speed

The speeds of galaxies correlate with distance



(1 Mpc = 3.26 x 10^6 LY)

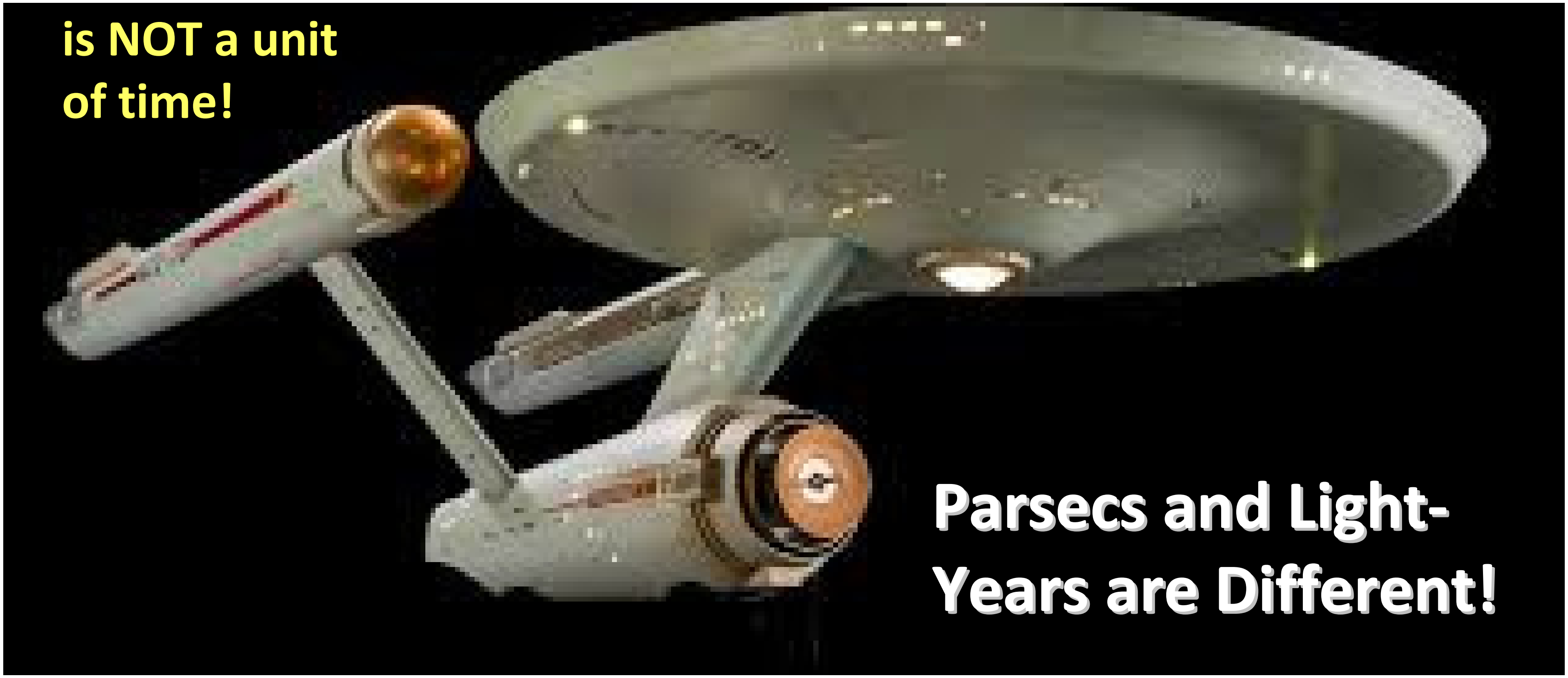
- As the previous examples illustrate, distances are large in the universe, even if the speed of light is immense. Some distant galaxies are moving at almost half that speed. What kinds of distance measures do astronomers and planetologists use??

Astronomical Units and Light-Years

- Exponential notation is helpful in specifying large and small numbers but we have other tricks to deal with distances.
- Special units are used routinely in astronomy.
- The **Astronomical Unit** (**AU**) is the distance between the Earth and Sun. By definition the Earth is situated 1 AU away from the Sun. 1 AU = 1.496 x 10^8 km ~150 million km.
- For example, the planet Venus is 0.72 AU from the Sun. This distance could also be specified as 1.082 x 10^8 km ~ 100 million km.
- This simplifies comparisons in the Solar System

Astronomical Units and Light-Years

- Distances outside the solar system are so huge that they are specified in units of **light-years**.
- A light-year is the distance that light travels in a year.
- Light travels at ~3 x 10^8 m/sec and there are ~3 x 10^7 seconds in a year.
- 1 light-year is approximately 9 x 10^{15} m (or 9 x 10^{12} km) or 6 x 10^4 AU.
- So, the nearest stellar neighbour for the Solar System is Proxima Centauri, at a distance of some 4.25 light years. Or 2.5 x 10^5 AU – about 250,000 times as far away as our Sun.
- **The Parsec, used in stellar astronomy, is about 3.26 light years. It has a different origin rooted in *angles*, and allows quick calculation from observations.**



is NOT a unit of time!

Parsecs and Light-Years are Different!

- In Sci-Fi, there is often some mixing up of Parsecs and Light Years. But a starship captain needs to know the difference! Parsec is a contraction of ***Parallax Second***. Parallax is a method used to estimate the distance of objects, based on their apparent 'displacements'. It is based on trigonometry, so it is an angular measurement. A 'second' is 1/3600 th of a degree. We will explain the idea of Parallax later in the course.

Proxima Centauri is a Hell of a Long Way Away. But the good news is that it may have a planet….

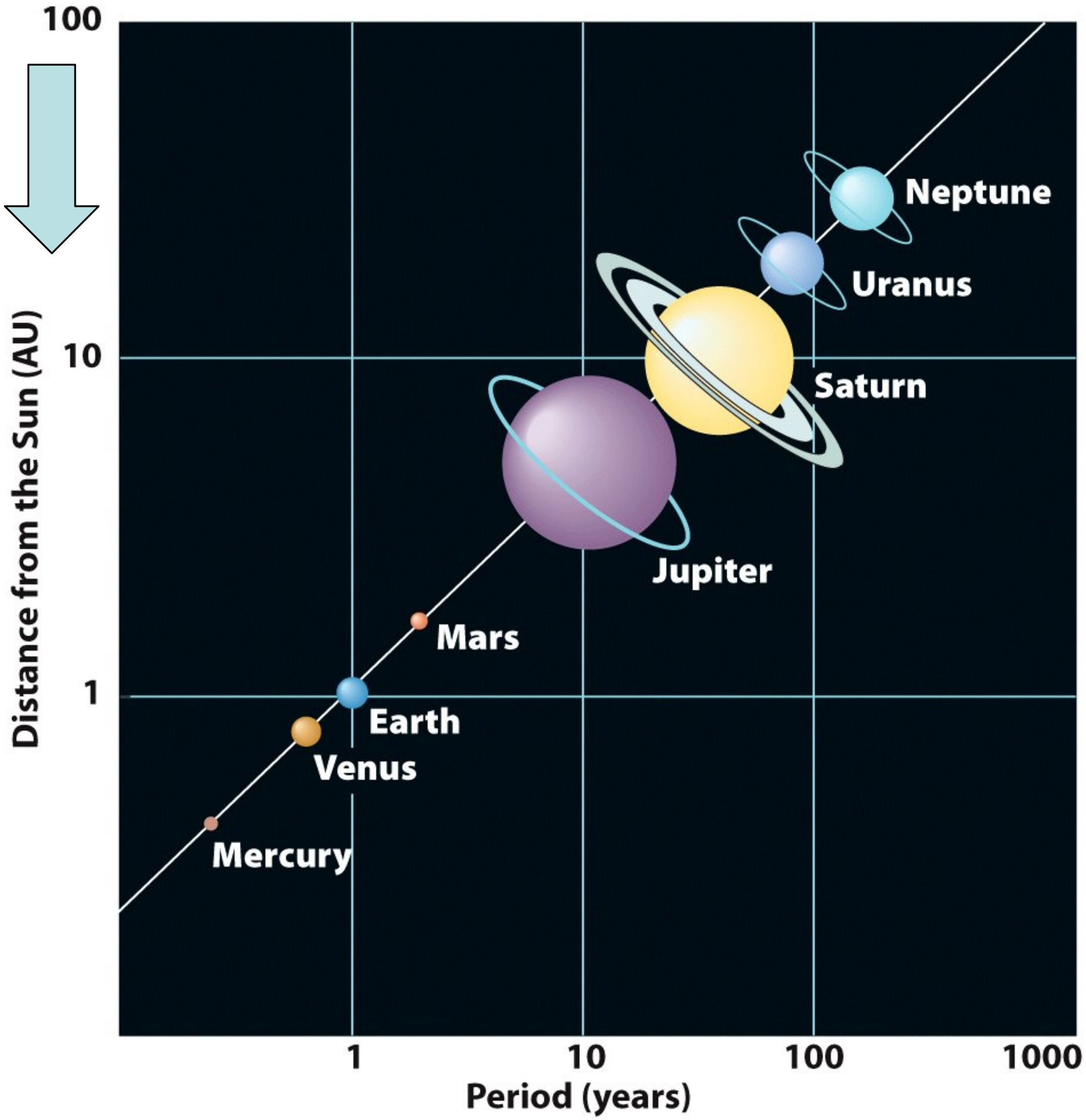
https://www.newscientist.com/article/
mg23130884-100-proxima-b-closest-earth-like-planet-discovered-right-next-door/

1 LY is 6×10^4 A.U. : 4.2 LY is about 250,000 times distance to the Sun

In 2016, astronomers reported evidence for a rocky ‘exoplanet’ in the Proxima Centauri system, about 4.2 light years from Earth, and possibly in a habitable zone. Packing bags may however be premature, as this red dwarf star emits large amounts of X-rays.

Another important use of exponential notation is drawing graphs

- Some graphs describe processes occurring over a huge <u>range</u> of timescales or distances or size.
- e.g. the expansion of the universe needs to be considered from tiny fractions of a second to billions of years…..how can we show this?
- Instead of a ‘linear’ graph going left to right in even units a ‘logarithmic’ graph goes up in units of powers of 10. It allows much easier representation of quantities that cover large ranges. These are widely used in science.

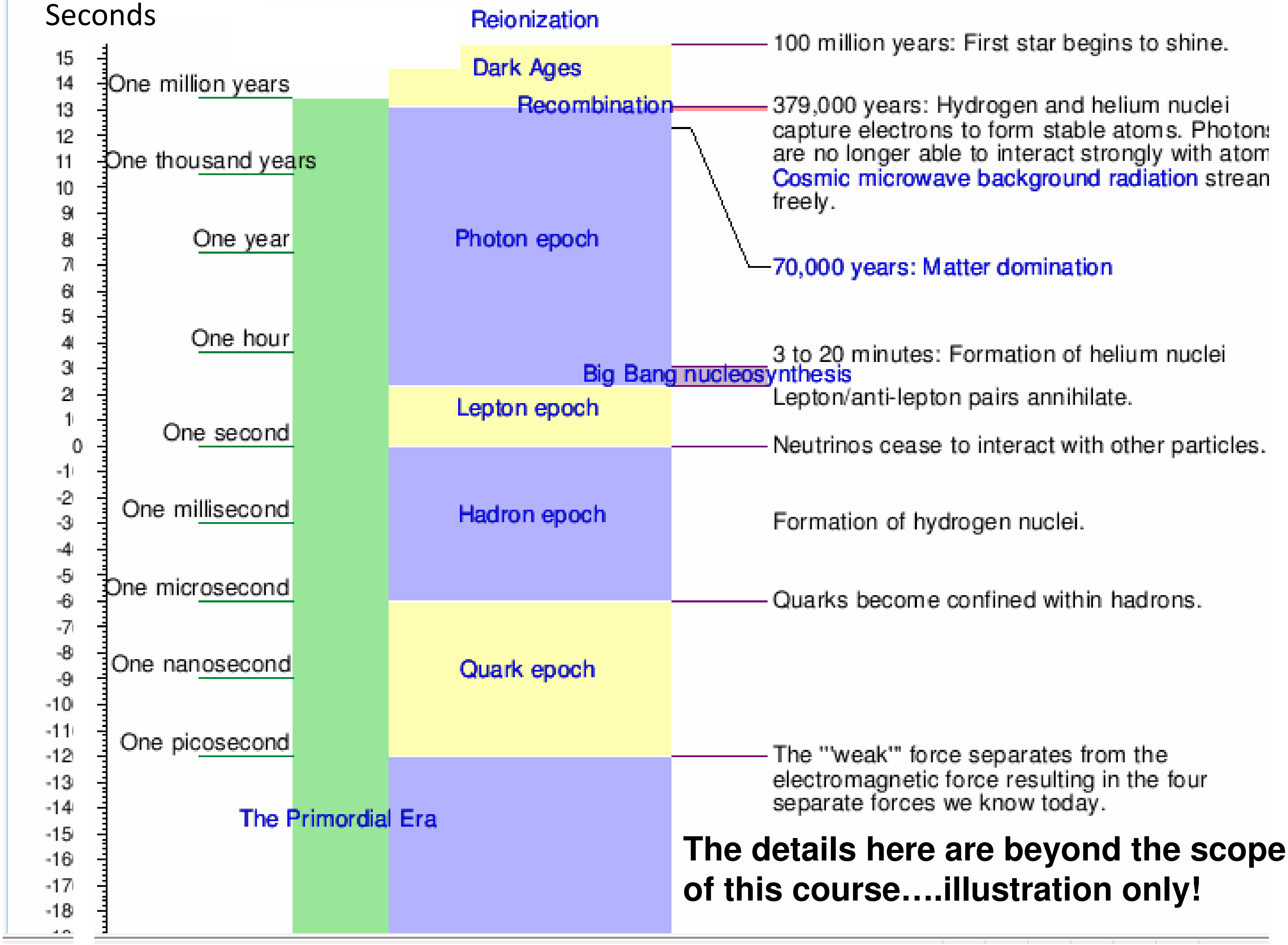


- A graph like this could not be constructed without the use of logarithmic scales….it would be huge, and all the inner planets would be in a tiny corner.

- We often find that patterns emerge when log scales are employed……

- Example: The orbital period (year) of planets vs distance. We see a SYSTEMATIC linear trend indicating mathematical links

Or, for, example, part of the early history of the universe…….



100 million years: First star begins to shine.

379,000 years: Hydrogen and helium nuclei capture electrons to form stable atoms. Photon are no longer able to interact strongly with atom Cosmic microwave background radiation strea freely.

70,000 years: Matter domination

3 to 20 minutes: Formation of helium nuclei

Lepton/anti-lepton pairs annihilate.

Neutrinos cease to interact with other particles.

Formation of hydrogen nuclei.

Quarks become confined within hadrons.

The "weak" force separates from the electromagnetic force resulting in the four separate forces we know today.

The details here are beyond the scope of this course….illustration only!

Measurement and Units of Time

- Aside from the very early history of the universe, most of the time in this course we are confronted with incredibly long periods of time. Here are some common measurements.
- 1 million yrs = 1 M.y; 1 m.y ago = 1 Ma.
- 1 billion yrs = 1 G.y; 1 billion years ago = 1 Ga

(note that you may encounter B.y and Ba in some older resources).

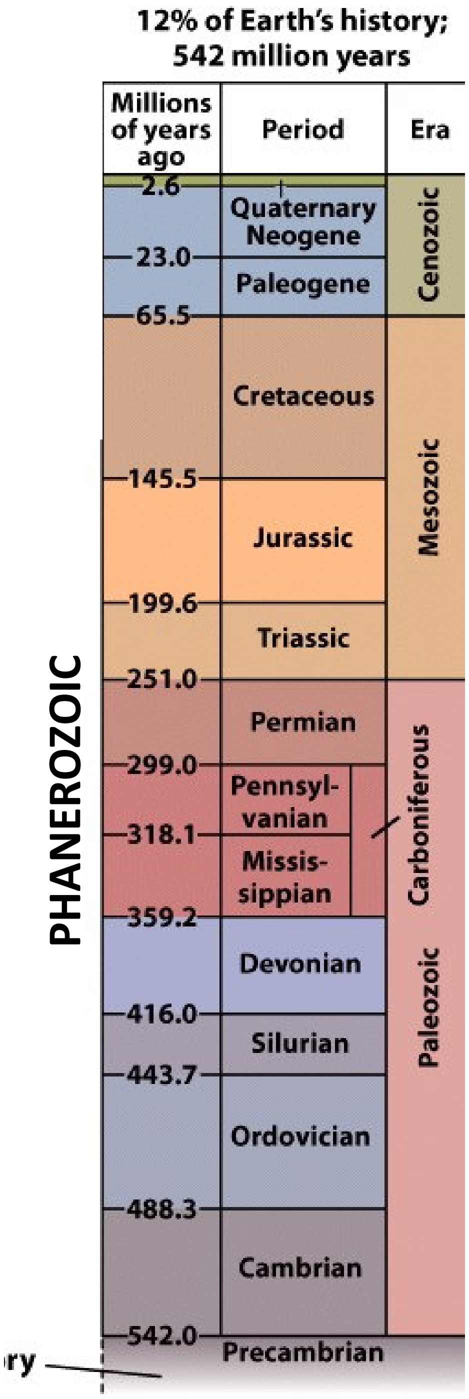
- The Earth formed about 4.567 Ga (4567 Ma); this is also roughly the time of formation of the Solar System. The Human Species is less than 2 million years old – a tiny fraction of this time.

Geologic time compressed into a single year

Compress for example, the entire 4.5 billion years of geologic time into a single year. On that scale, the oldest rocks we know date from mid-March. Living things first appeared in the sea in May. Land plants and animals emerged in mid-November, and the widespread swamps that formed the Pennsylvanian coal deposits flourished for about four days in early December. Dinosaurs became dominant in mid-December, but disappeared on the 26th, at about the time the Rocky Mountains were first uplifted. Man-like creatures first appeared during the evening of the 31st, and the most recent continental ice sheets began to recede about one minute and 15 seconds before midnight. Rome ruled the western world for 5 seconds from 11.59:45 to 11.59:50. Columbus ‘discovered’ America 3 seconds before midnight, and the science of geology was born with the writings of James Hutton just slightly more than one second before the end of our eventful year of years.

*(from Don Eicher’s book **Geologic Time**, first published in 1978)*

The Geological Time Scale

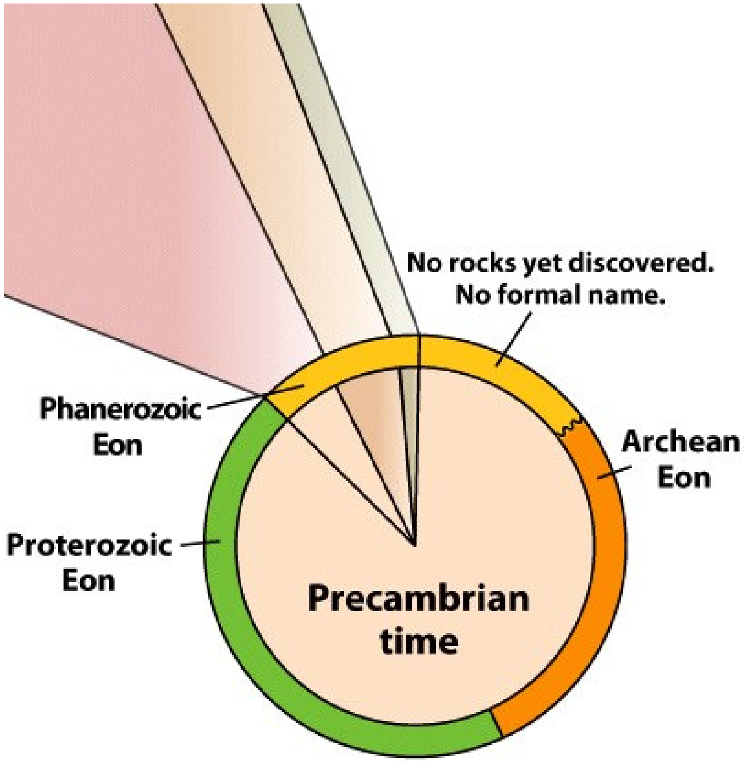


- This shows the geological time scale used internationally, and some of these names will be familiar if you have done any Earth Science courses. Some should be familiar anyway, like "Jurassic", from "Jurassic Park"

- There are also time-scales that we apply to planetary bodies such as the Moon and Mars.

- The **Phanerozoic Era** (when fossils are common) is a mere 12% of the entire history of Earth. The **Precambrian** is a much more immense period of time, but it is likely that life was around in some form from very early times.

The Full Geological Time Scale



- The oldest rocks on the Earth formed at about 4.0 Ga, but we do find materials (mineral grains) that are as old as 4.4 Ga.
- How do we know?

- The period of time when life becomes abundant and diverse is only about 12% of the age of the Earth. However, we think that life has been around since at least 3.8 Ga.

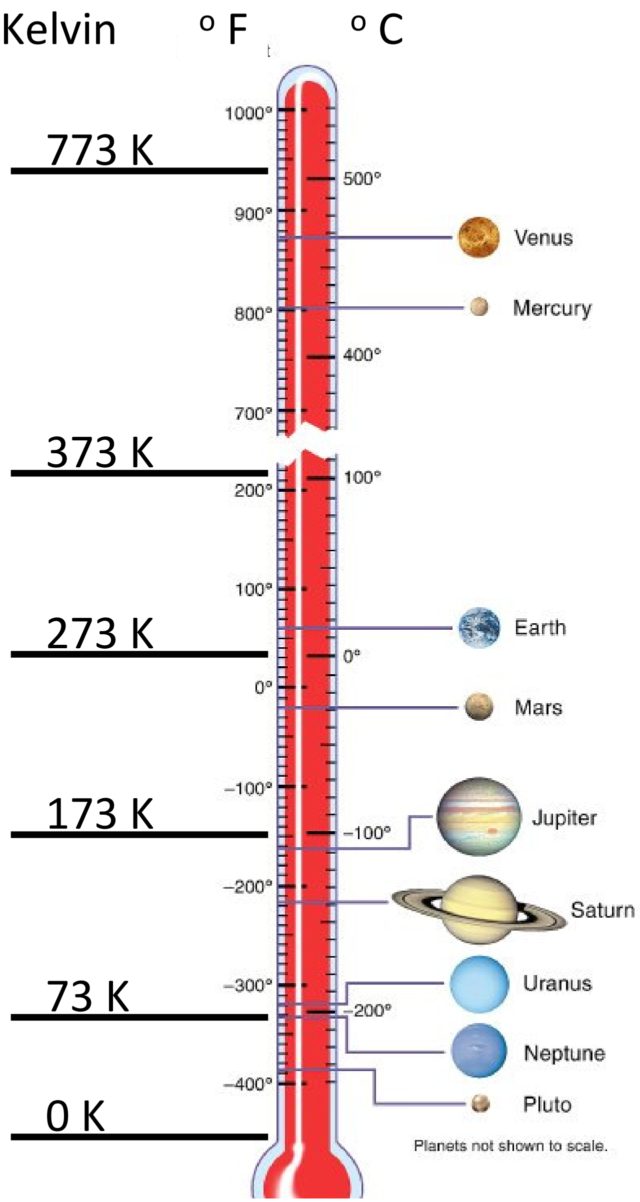
- The Solar System has existed for only about one-third of the time that the Universe has existed. It is hard to know the age of the Universe with certainty, but current estimates are around 13.8 Ga.

Temperature Scales

- There is a wide range of temperatures in the solar system, from minus 240ºC or so on Pluto to > 400ºC on Venus. If we were to consider the Sun, we have temperatures that are millions of º C in the interior.

- In science, we commonly use the Kelvin Scale for temperatures. The units are the same, but 0º K is equivalent to – 273.15ºC **(Absolute Zero)**.

- This is the lowest possible temperature, when there is no motion of atoms or molecules.

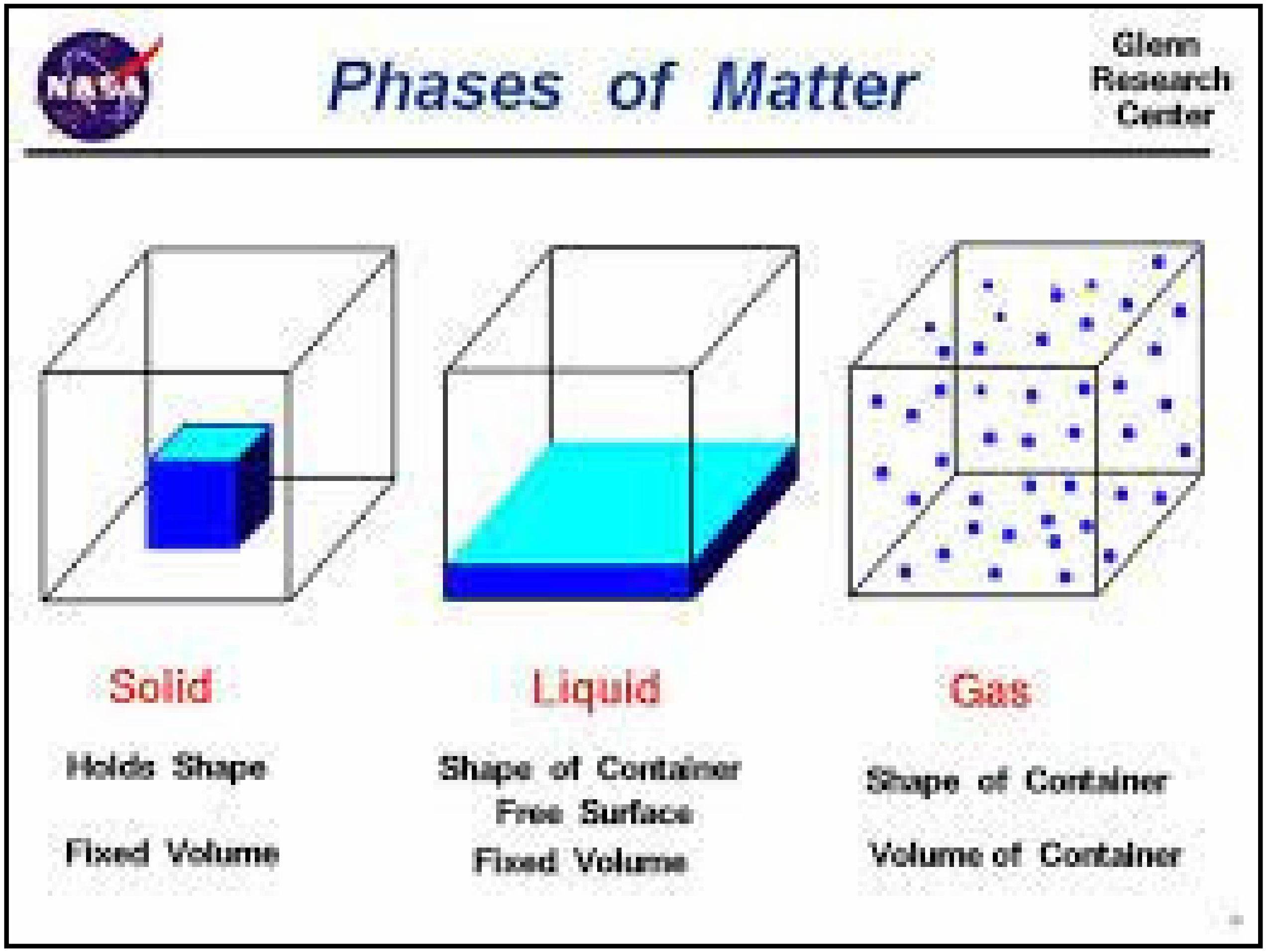


On the Kelvin Scale, Earth's temperature is about 290 K

Why do we use the Kelvin Scale anyway?

- Largely because it is a measure that is *always positive*, and the starting point for the scale is the lowest possible temperature.
- Temperature is a measure of the motion of atoms or molecules, which ceases at -273.15^{o}C
- Remember that other temperature scales are ***artificial***: designed to use familiar measures such as the freezing and boiling points of water, or the human body temperature.
- Using negative numbers in physics equations causes a lot of mathematical complications!
- Earth’s average temperature: 17^{o}C or 290 K

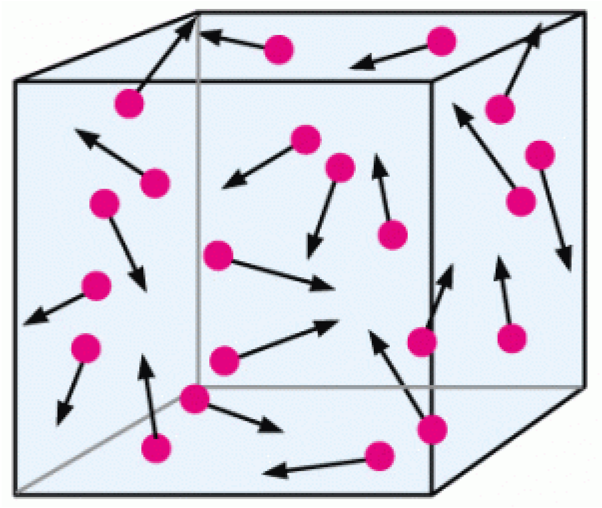
The Three Familiar States of Matter



- You all should know this. Most types of matter can exist in various forms, which have distinct character. The most obvious example is H_2O, which can be liquid, solid or gas.

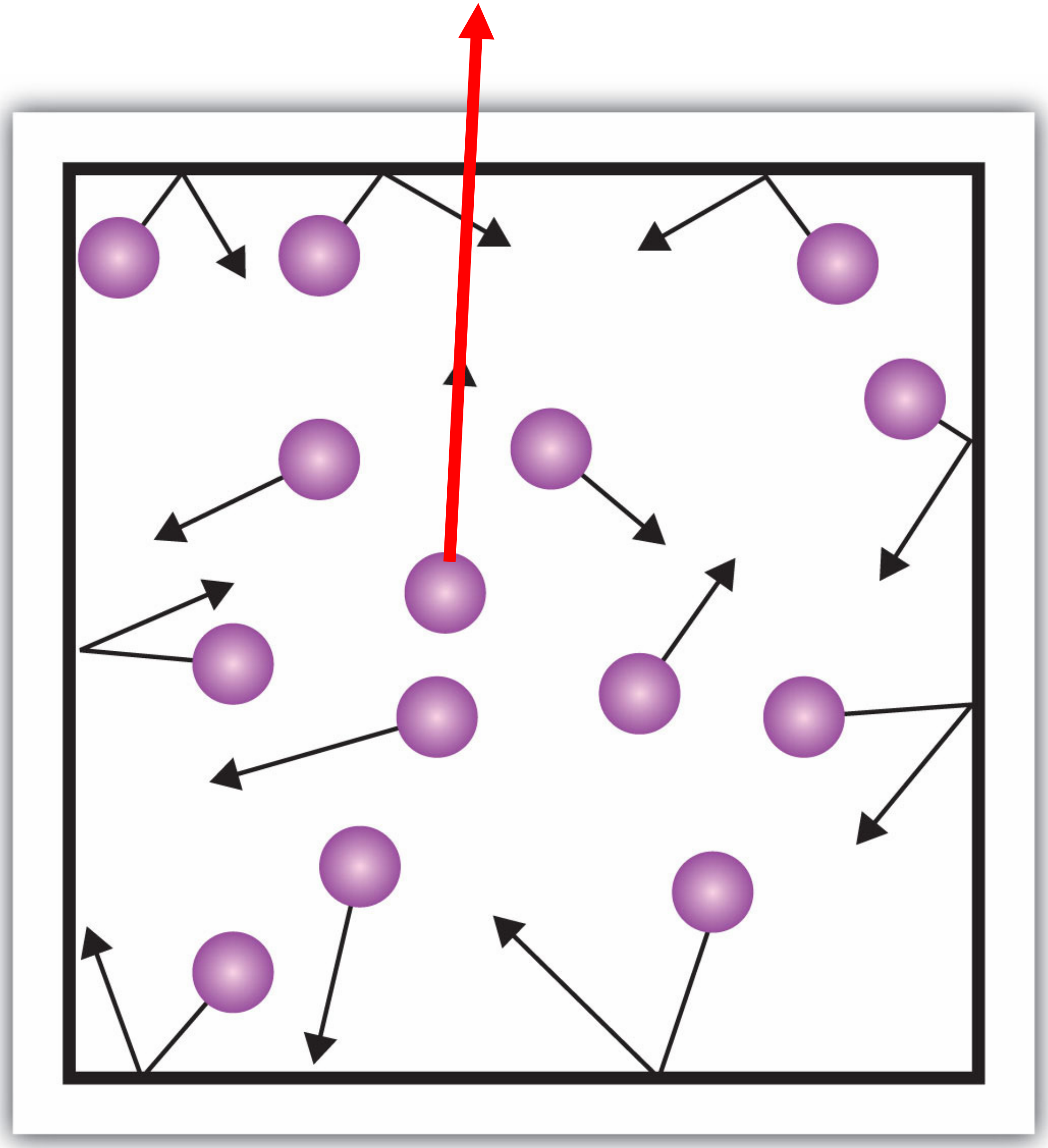
States of Matter – Changes with Conditions

- The matter we know generally changes state in response to temperature – becoming a liquid when hot, and a gas when really hot. However, the state of matter can also relate to Pressure.
- The molecules or atoms in matter are in motion (this gives us heat), and those in liquids and gases move faster than those in solids.
- The physical behaviour of a given state of matter will also depend on conditions. Butter is a solid, but you can’t spread it straight from the fridge. At room temperature it is softer.

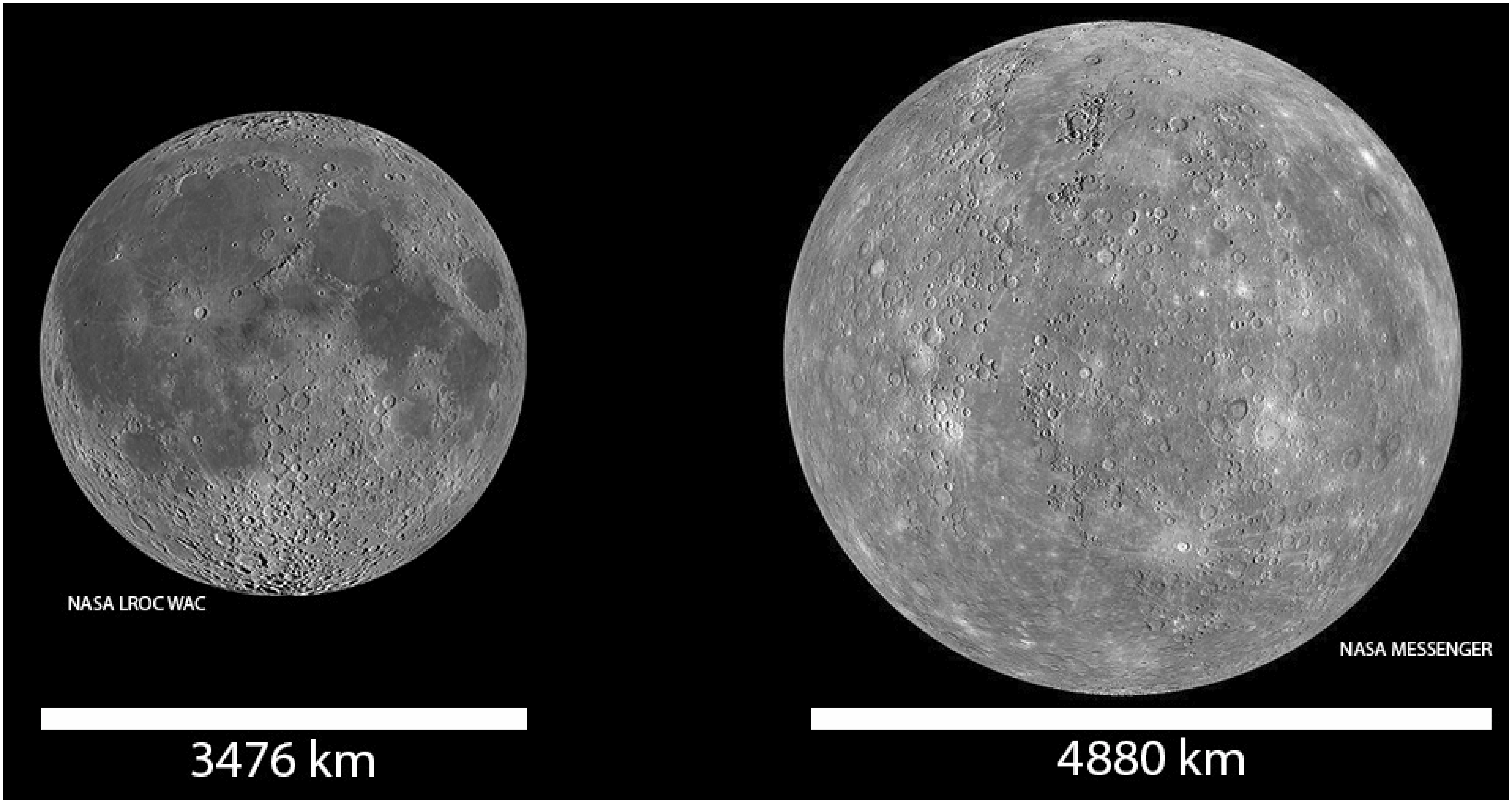


Atoms and molecules will move faster at higher temperatures, but in reality their speed will vary in any substance. In the atmosphere of a planet, some small gas molecules may achieve speeds that are more than “Escape Velocity” – they are lost.

This gas molecule can escape a planet’s gravitational field, but most will not do this. But imagine the situation at higher temperatures…..

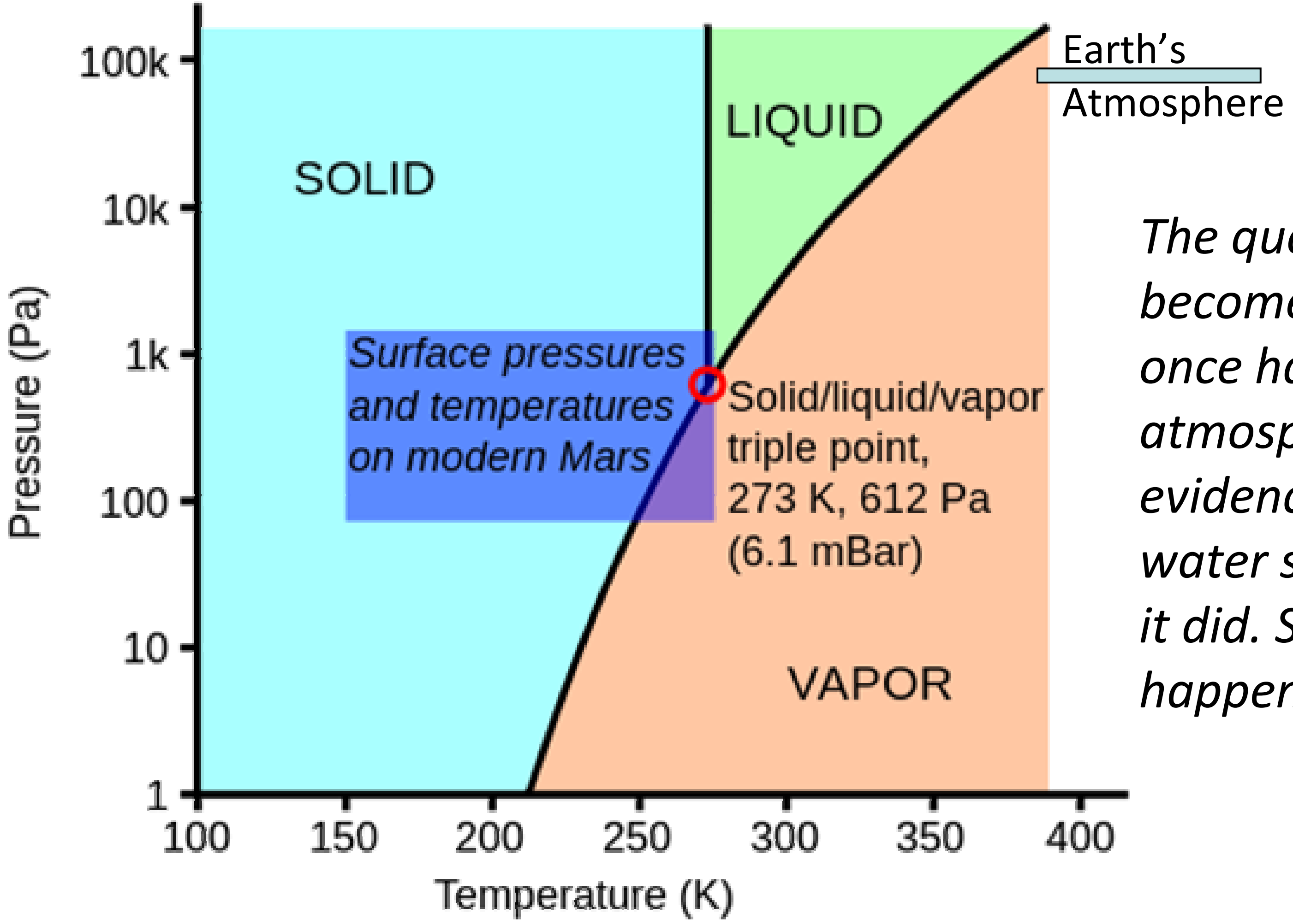


Why don't the Moon and Mercury have Air?



- The answer lies in size and temperature. These are small worlds that have weak gravity. Both experience wide temperature ranges so gas molecules or atoms will be lost to space as they move too fast.

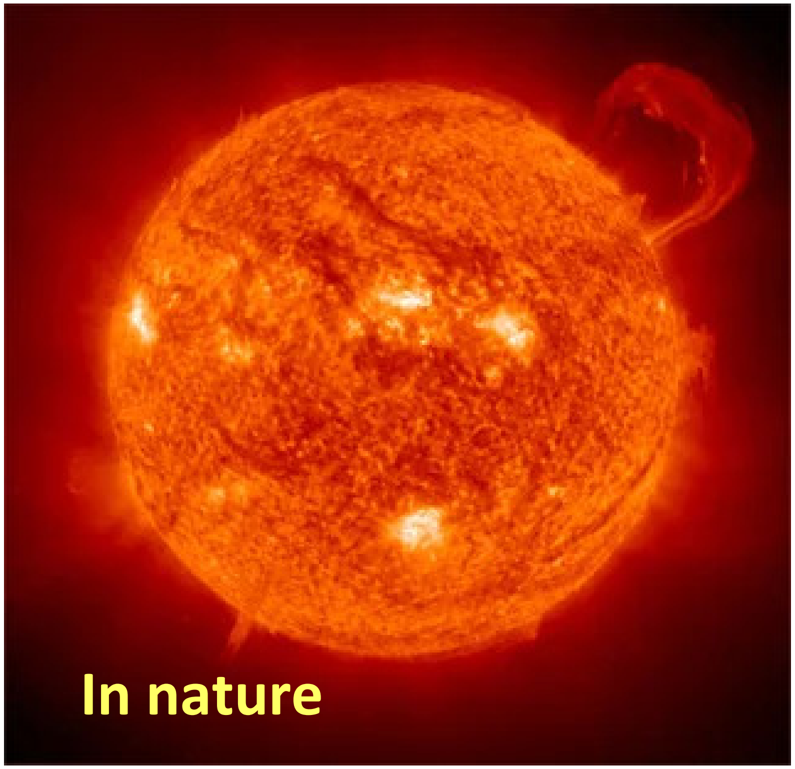
Can water exist on Mars? If so, when?

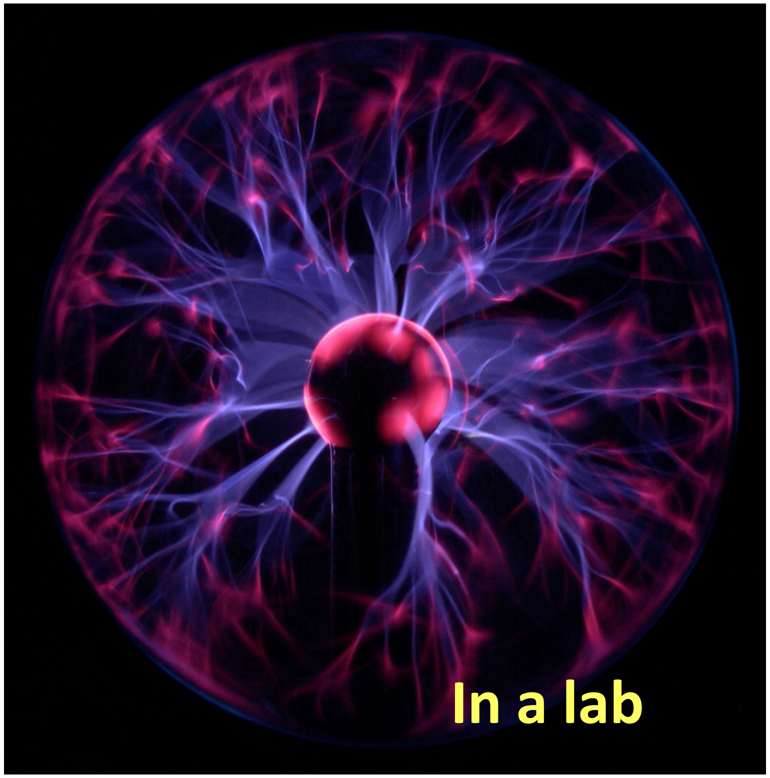


The question then becomes "did Mars once have a thicker atmosphere?". The evidence for ancient water suggests that it did. So what happened?

- Current pressures and temperatures on Mars are generally below the 'triple point' in the water phase diagram. This means that only solid and vapour phases of water can exist (unlike the Earth).

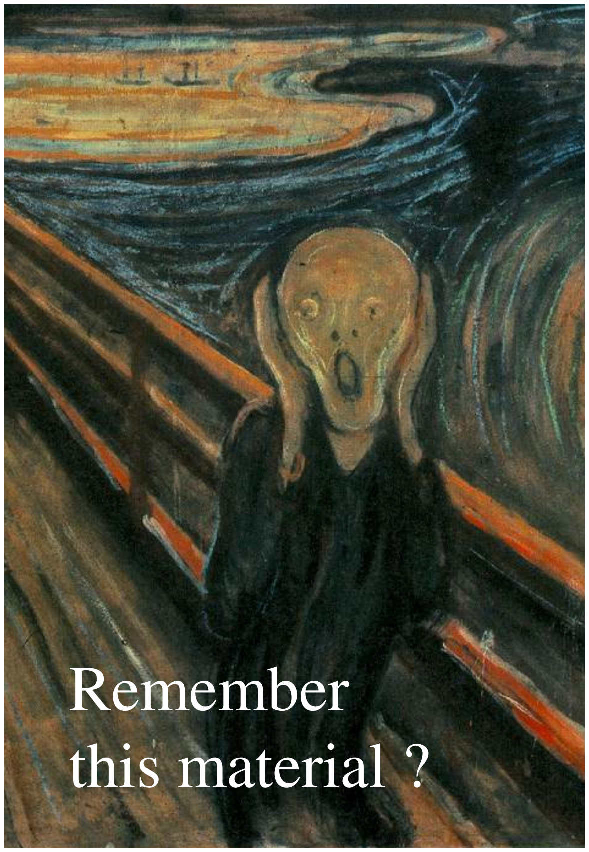
Plasma – A Fourth State of Matter



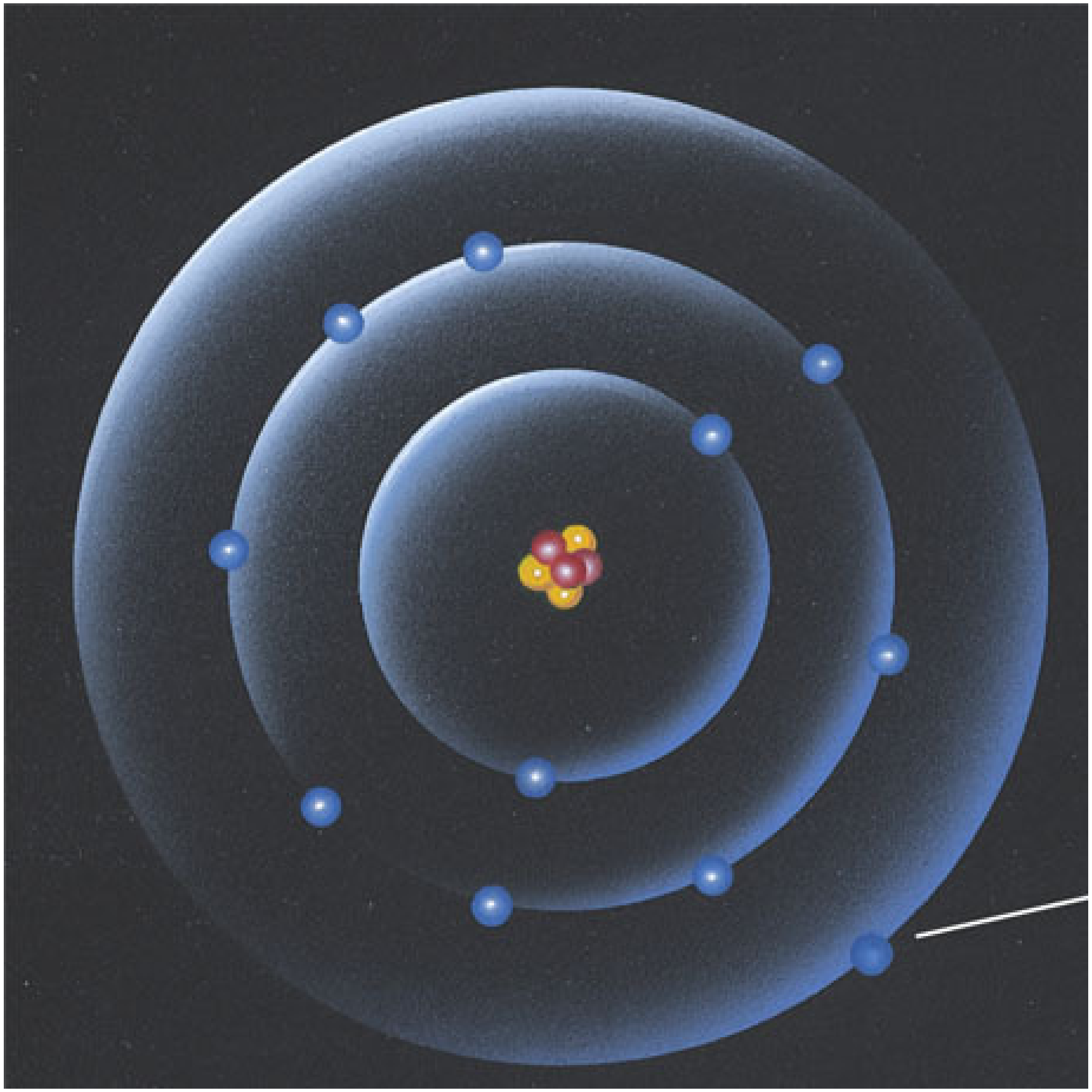


- The most abundant state of matter in the Universe is not a solid, liquid or gas – but PLASMA. This is electrically conductive hot matter made of ionized gas and ‘free’ electrons (to follow).
- On Earth, we see it as lightning and flames. In the universe, it forms stars and other things like nebulae.

Basic Chemistry: Atoms, Isotopes Ions and Molecules



This is high-school science. We are not going to do this in detail, but this is a short ‘refresher’.

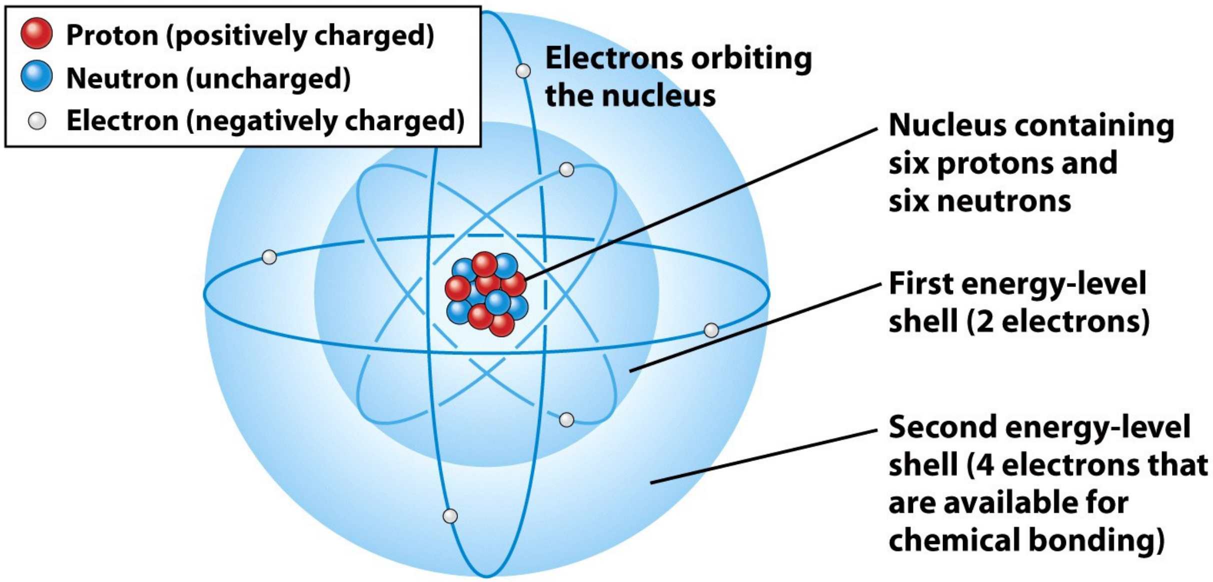


Elements and Atoms -

- An **element** is the basic component of chemistry ("*a substance that cannot be resolved into simpler substances by chemical means*"). Elements are organized on the Periodic Table of elements. You know what this is.
- An **atom** is the basic unit of an element ("*the smallest particle of an element that retains all the physical and chemical properties of the element*").
  - **Example**: a piece of copper wire consists entirely of the element copper. It contains a huge number of individual copper atoms, each identical to all the others. (*What do we mean by the word "huge"?* 63.5 grams of copper contains 6 x 10^{23} atoms of copper.

Every atom is made up of combinations of three different atomic particles:

- **Electrons** (-1 electrical charge; very small mass)
- **Protons** (+1 electrical charge; large mass)
- **Neutrons** (0 electrical charge; mass = proton + electron)

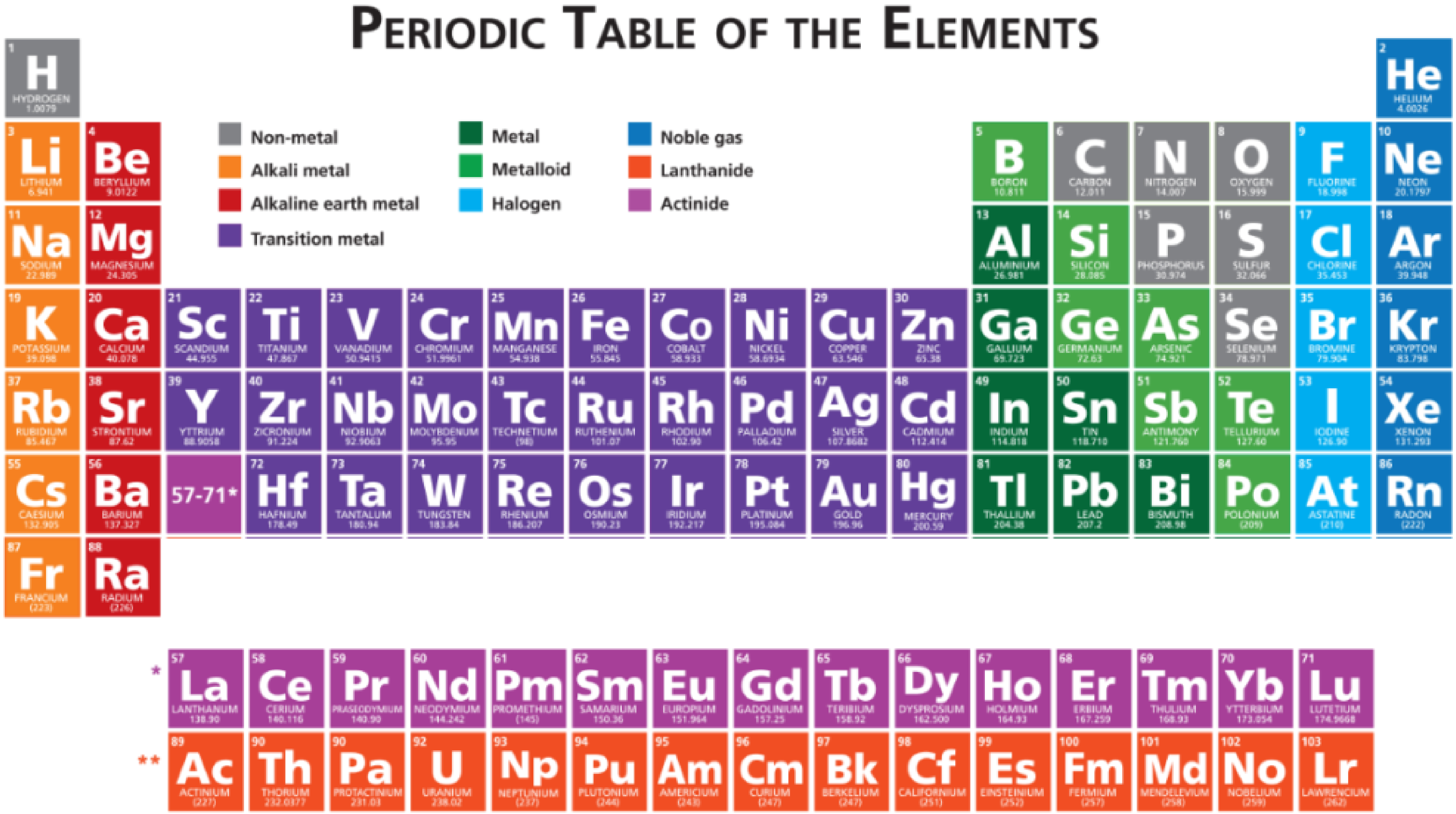

A Single Atom of Carbon-12 (Schematic Diagram)

A simplified version of the structure of an atom, showing the nucleus and two electron shells.
(Merali and Skinner text, Fig. 2.1)

- The **protons** and **neutrons** in an atom are combined in the central part of the atom, a region that is known as the ***nucleus***.

- The **electrons** in an atom are arranged in ***electron shells*** located at different distances around the nucleus.

This should look familiar to you from school



PERIODIC TABLE OF THE ELEMENTS

- ⬜ Non-metal
- 🟧 Alkali metal
- 🟥 Alkaline earth metal
- 🟪 Transition metal
- 🟩 Metal
- 🟩 Metalloid
- 🟦 Halogen
- 🟦 Noble gas
- 🟧 Lanthanide
- 🟪 Actinide

1 H HYDROGEN 1.0079																	2 He HELIUM 4.0026
3 Li LITHIUM 6.941	4 Be BERYLLIUM 9.0122											5 B BORON 10.811	6 C CARBON 12.011	7 N NITROGEN 14.007	8 O OXYGEN 15.999	9 F FLUORINE 18.998	10 Ne NEON 20.1797
11 Na SODIUM 22.989	12 Mg MAGNESIUM 24.305											13 Al ALUMINIUM 26.981	14 Si SILICON 28.085	15 P PHOSPHORUS 30.974	16 S SULFUR 32.066	17 Cl CHLORINE 35.453	18 Ar ARGON 39.948
19 K POTASSIUM 39.098	20 Ca CALCIUM 40.078	21 Sc SCANDIUM 44.955	22 Ti TITANIUM 47.867	23 V VANADIUM 50.9415	24 Cr CHROMIUM 51.9961	25 Mn MANGANESE 54.938	26 Fe IRON 55.845	27 Co COBALT 58.933	28 Ni NICKEL 58.6934	29 Cu COPPER 63.546	30 Zn ZINC 65.38	31 Ga GALLIUM 69.723	32 Ge GERMANIUM 72.63	33 As ARSENIC 74.921	34 Se SELENIUM 78.971	35 Br BROMINE 79.904	36 Kr KRYPTON 83.798
37 Rb RUBIDIUM 85.467	38 Sr STRONTIUM 87.62	39 Y YTTRIUM 88.9058	40 Zr ZICRONIUM 91.224	41 Nb NIOBIUM 92.9063	42 Mo MOLYBDENUM 95.95	43 Tc TECHNETIUM (98)	44 Ru RUTHENIUM 101.07	45 Rh RHODIUM 102.90	46 Pd PALLADIUM 106.42	47 Ag SILVER 107.8682	48 Cd CADMIUM 112.414	49 In INDIUM 114.818	50 Sn TIN 118.710	51 Sb ANTIMONY 121.760	52 Te TELLURIUM 127.60	53 I IODINE 126.90	54 Xe XENON 131.293
55 Cs CAESIUM 132.905	56 Ba BARIUM 137.327	57-71*	72 Hf HAFNIUM 178.49	73 Ta TANTALUM 180.94	74 W TUNGSTEN 183.84	75 Re RHENIUM 186.207	76 Os OSMIUM 190.23	77 Ir IRIDIUM 192.217	78 Pt PLATINUM 195.084	79 Au GOLD 196.96	80 Hg MERCURY 200.59	81 Tl THALLIUM 204.38	82 Pb LEAD 207.2	83 Bi BISMUTH 208.98	84 Po POLONIUM (209)	85 At ASTATINE (210)	86 Rn RADON (222)
87 Fr FRANCIUM (223)	88 Ra RADIUM (226)																
	*	57 La LANTHANUM 138.90	58 Ce CERIUM 140.116	59 Pr PRASEODYMIUM 140.90	60 Nd NEODYMIUM 144.242	61 Pm PROMETHIUM (145)	62 Sm SAMARIUM 150.36	63 Eu EUROPIUM 151.964	64 Gd GADOLINIUM 157.25	65 Tb TERIBIUM 158.92	66 Dy DYSPROSIUM 162.500	67 Ho HOLMIUM 164.93	68 Er ERBIUM 167.259	69 Tm THULIUM 168.93	70 Yb YTTERBIUM 173.054	71 Lu LUTETIUM 174.9668	
	**	89 Ac ACTINIUM (227)	90 Th THORIUM 232.0377	90 Pa PROTACTINIUM 231.03	92 U URANIUM 238.02	93 Np NEPTUNIUM (237)	94 Pu PLUTONIUM (244)	95 Am AMERICIUM (243)	96 Cm CURIUM (247)	97 Bk BERKELIUM (247)	98 Cf CALIFORNIUM (251)	99 Es EINSTEINIUM (252)	100 Fm FERMIUM (257)	101 Md MENDELEVIUM (258)	102 No NOBELIUM (259)	103 Lr LAWRENCIUM (262)	

- The periodic table is a logical arrangement of chemical elements, ordered by atomic number (number of protons). Columns of elements in the table have similar properties.

Number of Electrons in an Atom – Nature of ‘ions’

- Added together, the **total number of electrons** contained in all the electron shells of an atom **equals the number of protons** in the nucleus of that atom – this balances the electrical charges.
- **Example**: A carbon atom has atomic number = 6, and so has 6 protons in its nucleus and 6 electrons in its electron shells. This maintains the neutrality of atoms.
- Since electrons and protons have equal but opposite electric charges, it follows that **atoms are electrically neutral** (*i.e.* the positive charge contributed by the protons exactly cancels the negative charge contributed by the electrons).
- Atoms become ions (charged atoms) by losing or gaining electrons. Ions are either **Cations (+)** or **Anions (-)**.

Are all Atoms of an Element the Same – NO!

- All atoms of a given element contain the same **number of protons** in their nucleus. This determines behaviour.
- However, atoms also contain **neutrons**, and the number of neutrons can vary, without affecting chemical properties. Most elements have more than one **isotope**. An **isotope** of an element has the same number of protons but different number of neutrons.
- Isotopes are extremely important in science. Most importantly, some isotopes are **UNSTABLE** – over time they change into another isotope of another element. The rate at which they change can be measured.
- Consequently, Radioactive Isotopes provide **Natural Clocks** that we can use to date minerals and rocks.
- Secondly, stable isotopes of light elements (e.g., Oxygen, Sulphur) can react differently in various processes.

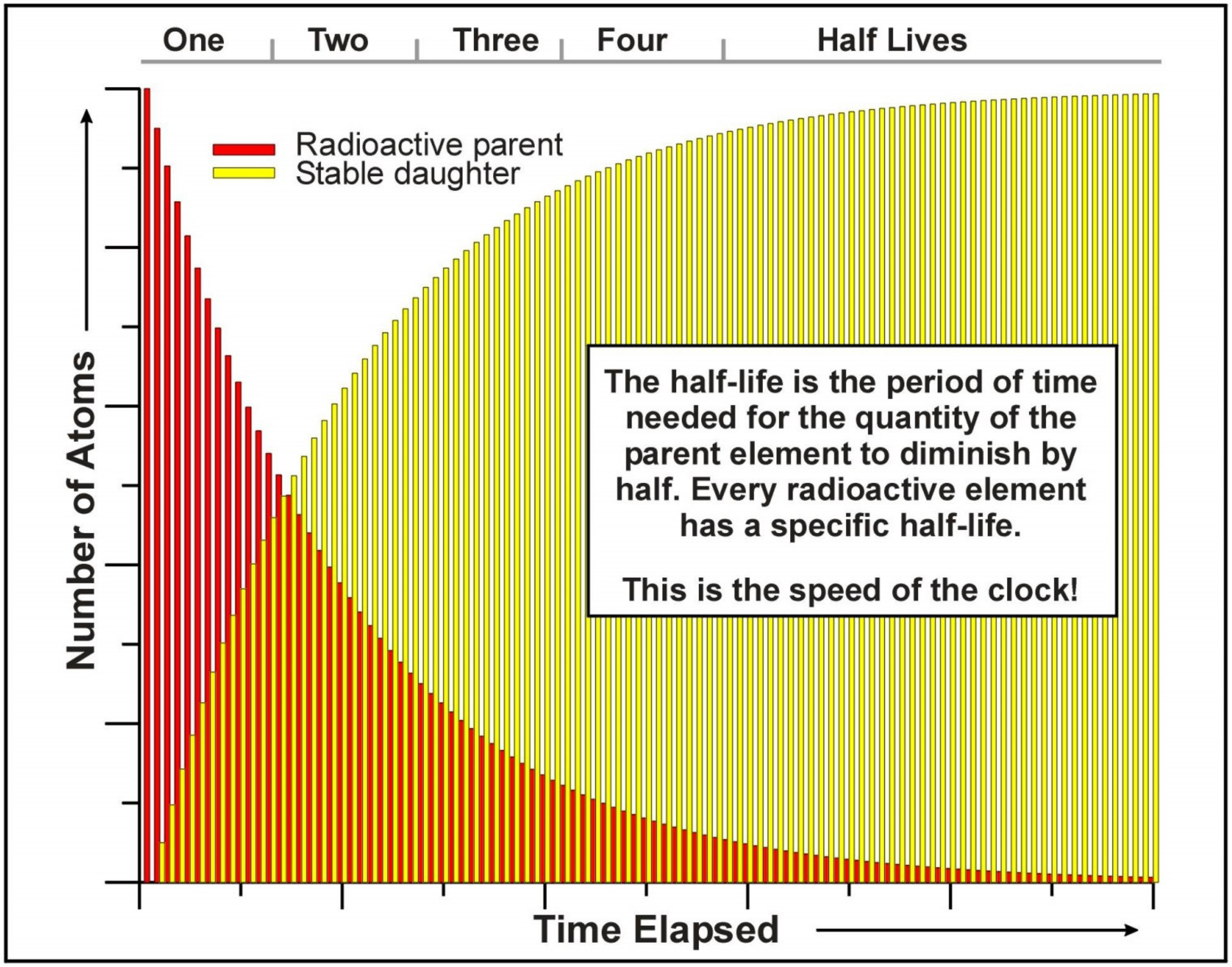
Neutrons make Isotopes - some examples

- **Example**: All atoms of **carbon** have **atomic number = 6** and so have 6 protons in their nucleus.
  - Some carbon atoms have **6 neutrons**, some have **7 neutrons** and some have **8 neutrons** meaning that there are **three** common **isotopes** of carbon having **atomic mass numbers** of **12** (*6p + 6n*), or **13** (*6p + 7n*) or **14** (*6p+ 8n*).
- These 3 carbon isotopes are designated $^{12}\mathrm{C}$, $^{13}\mathrm{C}$ and $^{14}\mathrm{C}$.
- Hydrogen has 3 isotopes: $^{1}\mathrm{H}$, $^{2}\mathrm{H}$ (deuterium) and $^{3}\mathrm{H}$ (tritium). “Heavy water” is made with deuterium. Oxygen has two common isotopes, $^{16}\mathrm{O}$ **and** $^{18}\mathrm{O}$. Uranium has lots of isotopes, some more radioactive than others, e.g., $^{235}\mathrm{U}$, $^{238}\mathrm{U}$.

- Isotopes are valuable. Radioactive isotopes provide us with geological clocks which we can use to date rocks and events. Stable isotopes trace processes, or give us ‘fingerprints’.

The Use of Isotopes – Two Examples.

- **How old is the Earth and the Solar System?**
- *We consider meteorites to be the building blocks of the terrestrial planets. By using the decay of two uranium isotopes to different isotopes of lead (Pb), we can calculate ages older than 4.5 Ga for most of them.*
- **Where did water in the oceans come from?**
- *A popular idea was that it came from comets, which are mostly ice. However, a few measurements of the ratios of hydrogen isotopes in comets suggest that these are quite different to those in Earth's water. So it looks as if this theory must be incorrect……*



The half-life is the period of time needed for the quantity of the parent element to diminish by half. Every radioactive element has a specific half-life.

This is the speed of the clock!

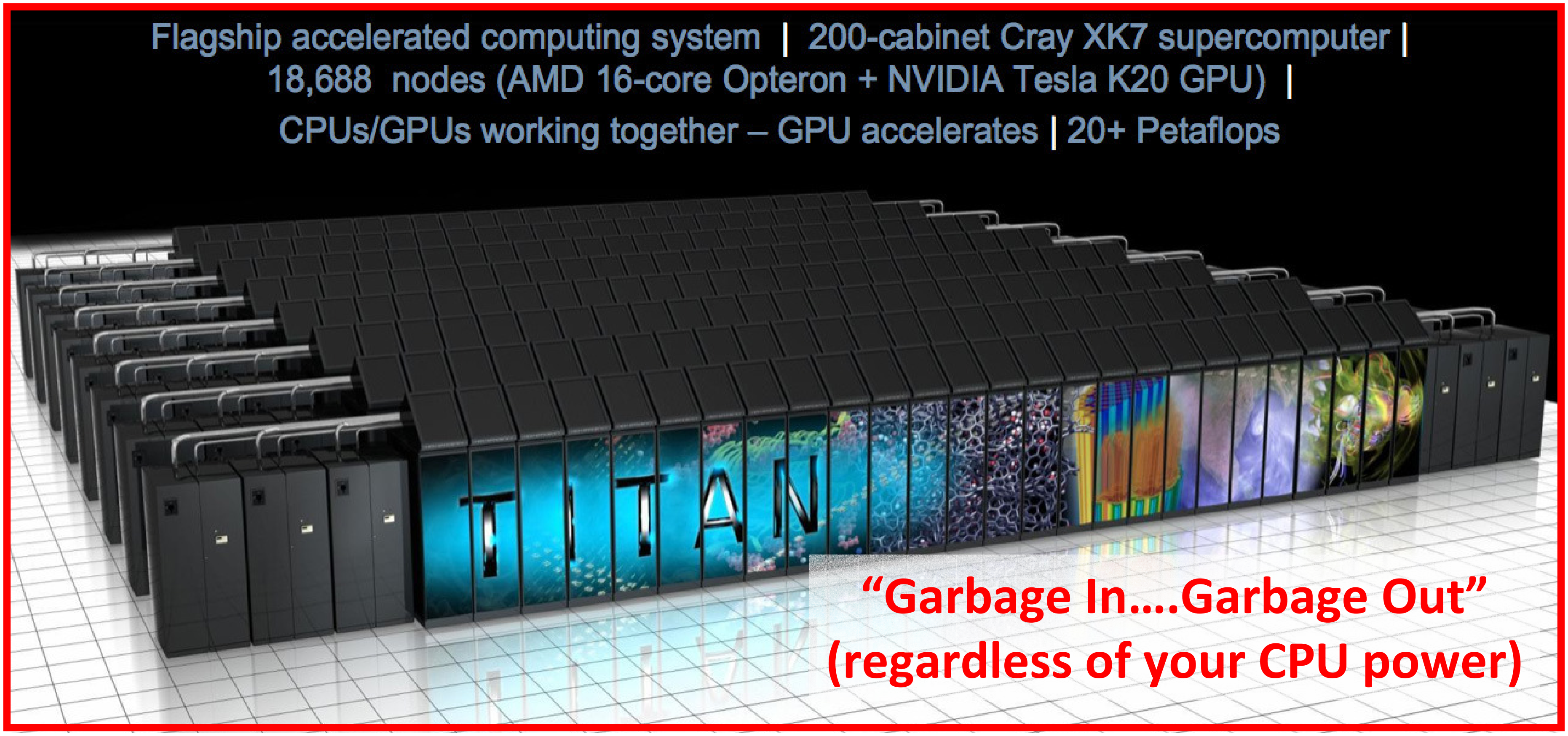
The rate of decay depends on the amount of that element left – and the 'half-life' is a measure of the speed of any natural clock. What happens after MANY half-lives have passed?

- The concept of "Half-Life" is IMPORTANT. This is the period of time needed for HALF the atoms of a radioactive isotope to decay to a 'daughter isotope'. We can measure this in a laboratory, so we have a way of understanding the speed of the clock.

The Role of Extinct Isotopes

- If we look at the radioactive isotopes that exist today, we find that all NATURAL radioactive elements that are PRIMARY (meaning that they start a chain of decay, rather than being some intermediate product) have very long half lives (> 700 My). They are the only ones left around.
- **But what about the Solar System in the Past?**
- In the early days of the Solar System, there were many other radioactive isotopes around that are now extinct. They were important sources of energy and, because their daughter isotopes still exist, we can still use them to understand very early processes.

The Two-Edged Sword of Computer Models


Flagship accelerated computing system | 200-cabinet Cray XK7 supercomputer |
18,688 nodes (AMD 16-core Opteron + NVIDIA Tesla K20 GPU) |
CPUs/GPUs working together – GPU accelerates | 20+ Petaflops

“Garbage In….Garbage Out”
(regardless of your CPU power)

- 21st Century planetary science inevitably makes extensive use of computer models, especially to solve hugely complex problems like planetary motions or solar fusion reactions.
- These are valuable, but it is important to know their limits…

Kerr's Rules of Computer Model Theory

(unpublished at the moment, and likely to remain so!)

- (1) Every computer model, no matter its complexity, depends on assumptions and inputs. If these turn out to be false or inaccurate, the results may be invalid.
- (2) Computer models that use 'ensemble prediction' (multiple runs that vary inputs and assumptions) are more reliable, if the results indeed converge.
- (3) If a model says that something is impossible or highly unlikely, this is more likely to be correct than the conclusion that something *may be* possible.
- (4) Just because a computer model concludes that something is *possible*, if does not prove that it actually happened that way.

Summary Slides – Some Key Points from The Class (Module 2 – Part 1)

- Summary slides are not provided for this class as it represents background. Elsewhere, these will provide a summary of the really important 'take-home' points from classes. However, don't assume that this is the limit on what we expect you to learn from the class, because some of the details in individual topics should also be absorbed. It's a guide to key concepts only.

- This is background science material and you can find it in many sources. The Seeds and Backman text has some information in Chapter 1 (Here and Now) and in Chapter 6 (Light and Telescopes); also in Chapter 7 (Atoms and Spectra). You may wish to consult some other basic scientific textbooks for some other material. Introductory Earth Science textbooks commonly have some background on physics and chemistry and also will cover some of the topics summarized in Part 2 of this module.