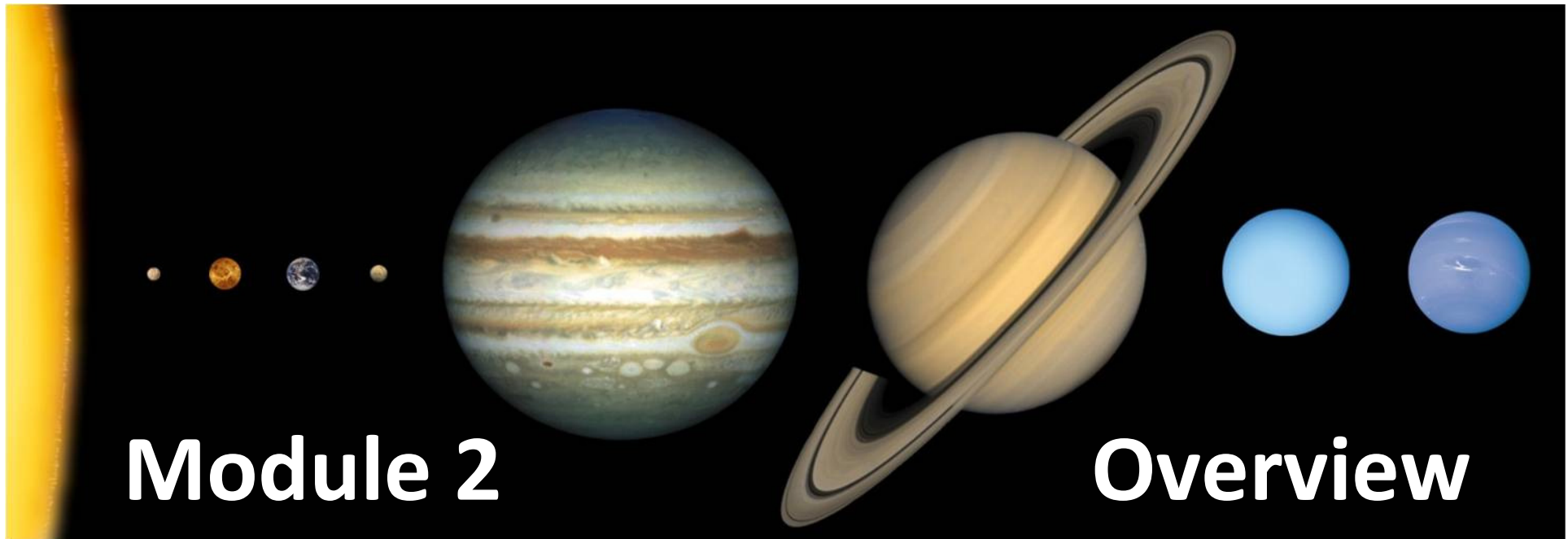


Earth Sciences 2150 – Fall 2023

Solar System and Planetary Science



**Scientific Background Concepts:
Revisiting what you need to know**

EASC 2150: The Solar System

The Plan for Today

Science and Earth Science 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'

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

(Andromeda Galaxy)



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

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

*But what does this
actually mean?*

*The Universe is over 13
billion years old.*

*But what does this
actually mean?*

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.
- The only solution is using **EXPONENTIAL NOTATION**.
So you need to know what this is and how to do simple calculations with such numbers.

If you can't solve $1.5 \times 10^8 / 5 \times 10^7$, you will need to look at materials/examples in Module 2!

The “Rule of Thumb” for Exponential Numbers:

Earth-Sun distance 1.5×10^8 km

Earth-Andromeda $\sim 2.4 \times 10^{22}$ km



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

Equals:

1.6×10^{14} times
more distant.....

Always look at the exponents in the number. Every difference of 1 in an exponent means a factor of 10. Negative exponents indicate very small numbers ($\lll 1$). The difference in exponents allows you to compare....

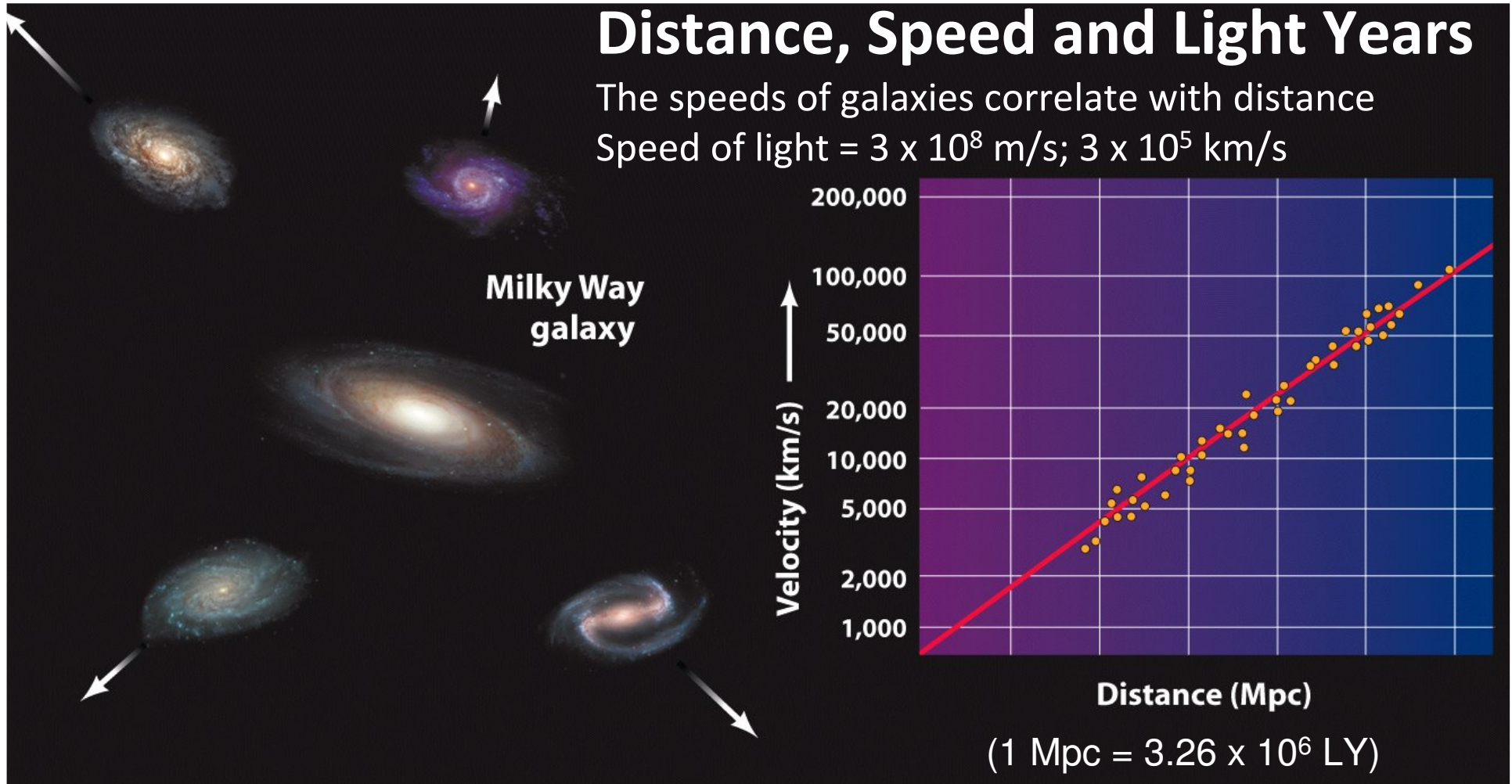
In exponential notation, the Andromeda Galaxy is about 2.4×10^{22} km away from us.....

It is INCONCEIVABLY more distant than the Sun!

Distance, Speed and Light Years

The speeds of galaxies correlate with distance

Speed of light = 3×10^8 m/s; 3×10^5 km/s



- 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??

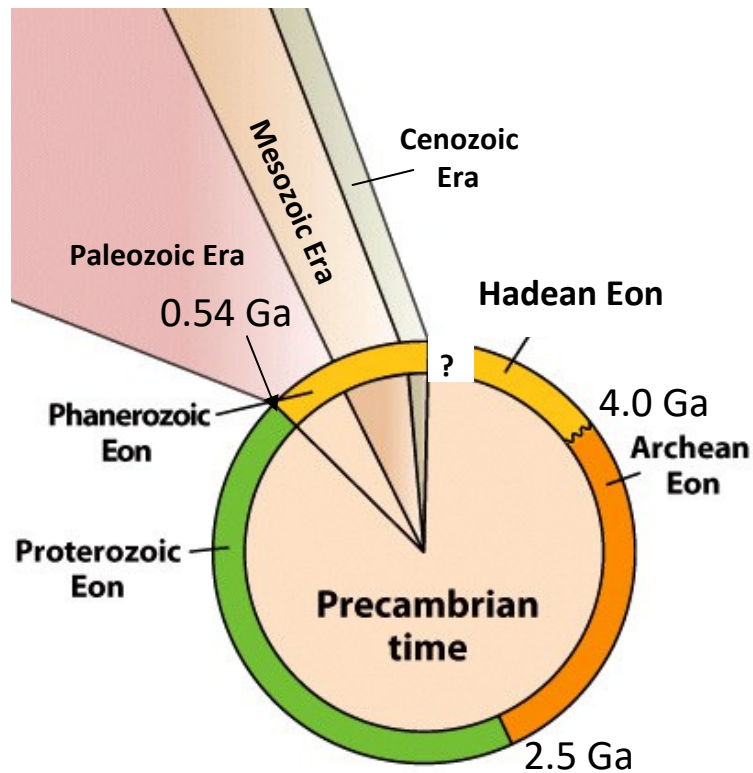
Astronomical Units and Light-Years

- 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. $1 \text{ AU} = 1.496 \times 10^8 \text{ km}$
~150 million km.
- For example, the planet Venus is 0.72 AU from the Sun. This distance could also be specified as $1.082 \times 10^8 \text{ km}$ or about ~ 110 million km.
- This simplifies comparisons in the Solar System.....
- Beyond, we use light years. If light travels at $3 \times 10^5 \text{ km/s}$, it covers about $9 \times 10^{12} \text{ km}$ in a full year ($\sim 3 \times 10^7$ seconds). **That is a very long distance! Note that PARSECS are not the same as Light Years.....**

Measurement and Units of Time

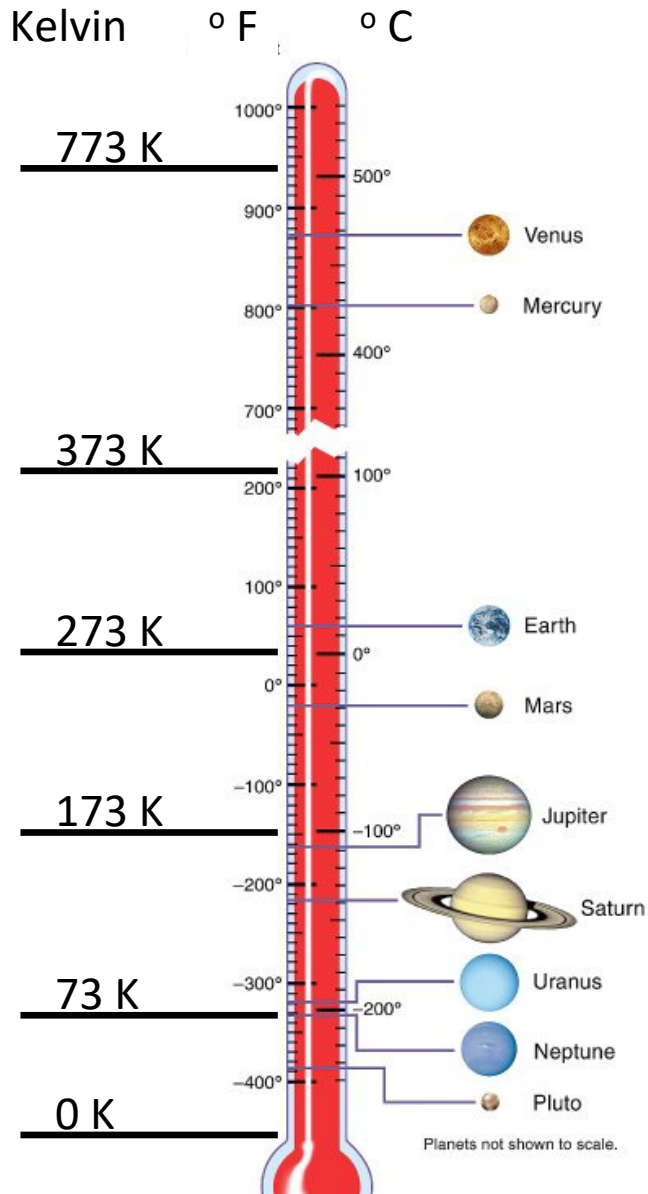
- Aside from the very early history of the universe, most of the time in this course we are confronted with incredibly long periods of time. Here are some common measurements.
- 1 million yrs = 1 m.y; 1 m.y ago = 1 Ma.
- 1 billion yrs = 1 g.y; 1 billion years ago = 1 Ga
(note that you may encounter b.y 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.

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.
- You will need to know at least the major divisions of the time scale.

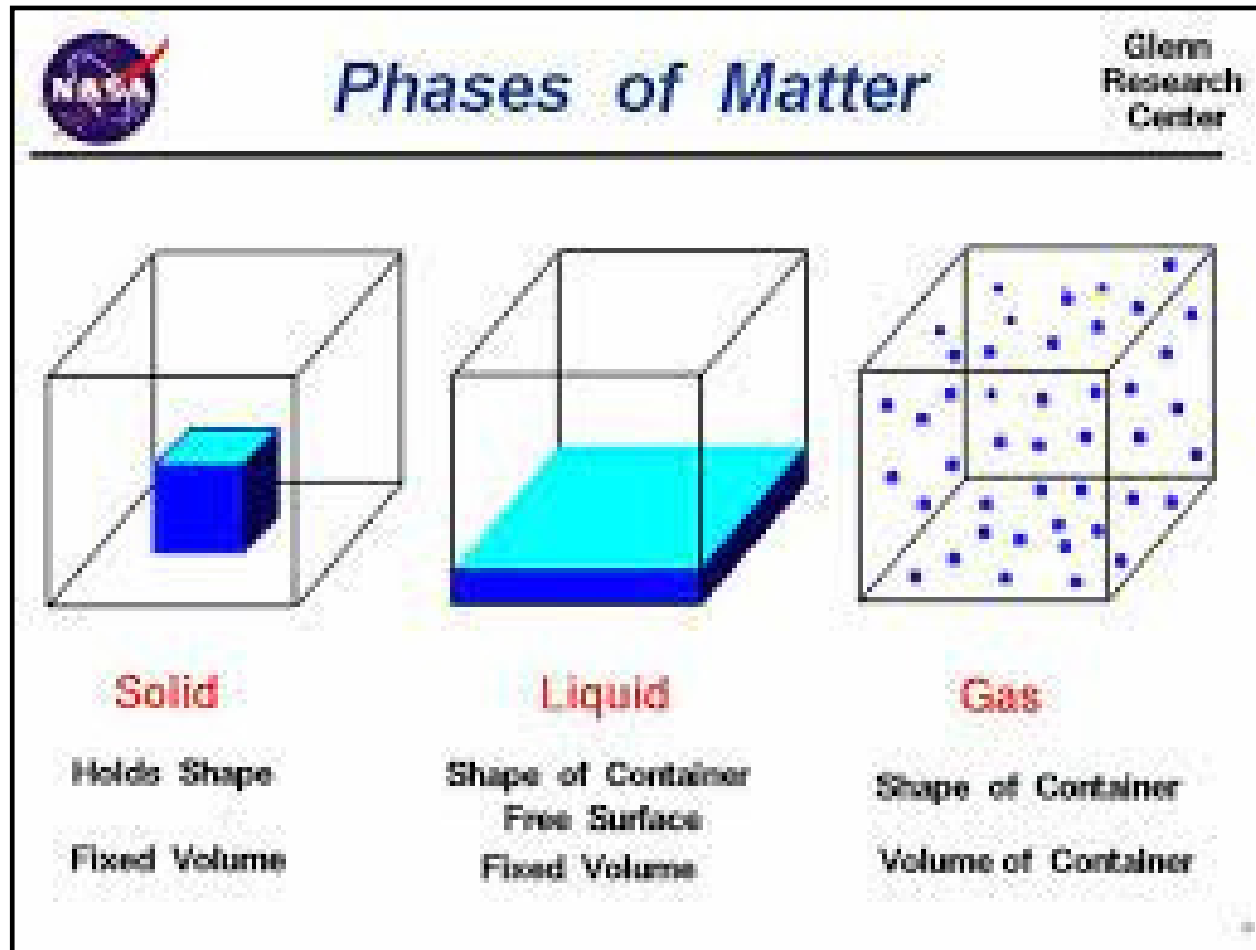


On the Kelvin Scale, Earth's temperature is about 290 K

Temperature Scales

- There is a wide range of temperatures in the solar system, from minus 240°C or so on Pluto to > 400°C on Venus. If we were to consider the Sun, temperatures get up to millions of ° C.
- In science, we commonly use the Kelvin Scale for temperatures. The units are the same, but 0° K is equivalent to – 273.15°C (**Absolute Zero**).
- There are very good reasons for using a scale that only contains positive numbers. Absolute Zero is as cold as it ever gets in the Universe.

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 H₂O, which can be liquid, solid or gas.

The Fourth and Most Common State of Matter

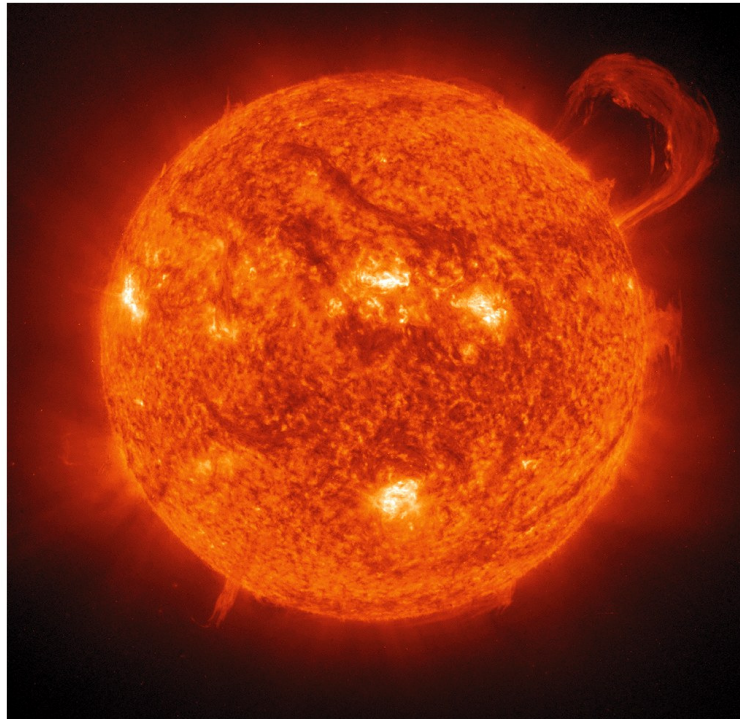
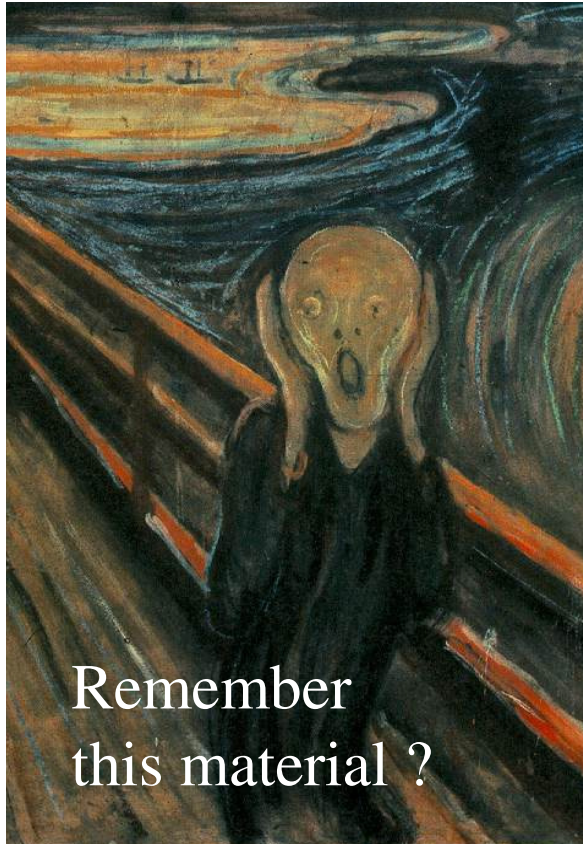


Figure 17.11a
Stock Image/SuperStock

There is a fourth state of matter that you may be less familiar with, but is actually dominant in the Universe. This is PLASMA: a high-temperature, ionized gas. It makes up the Sun and the stars.

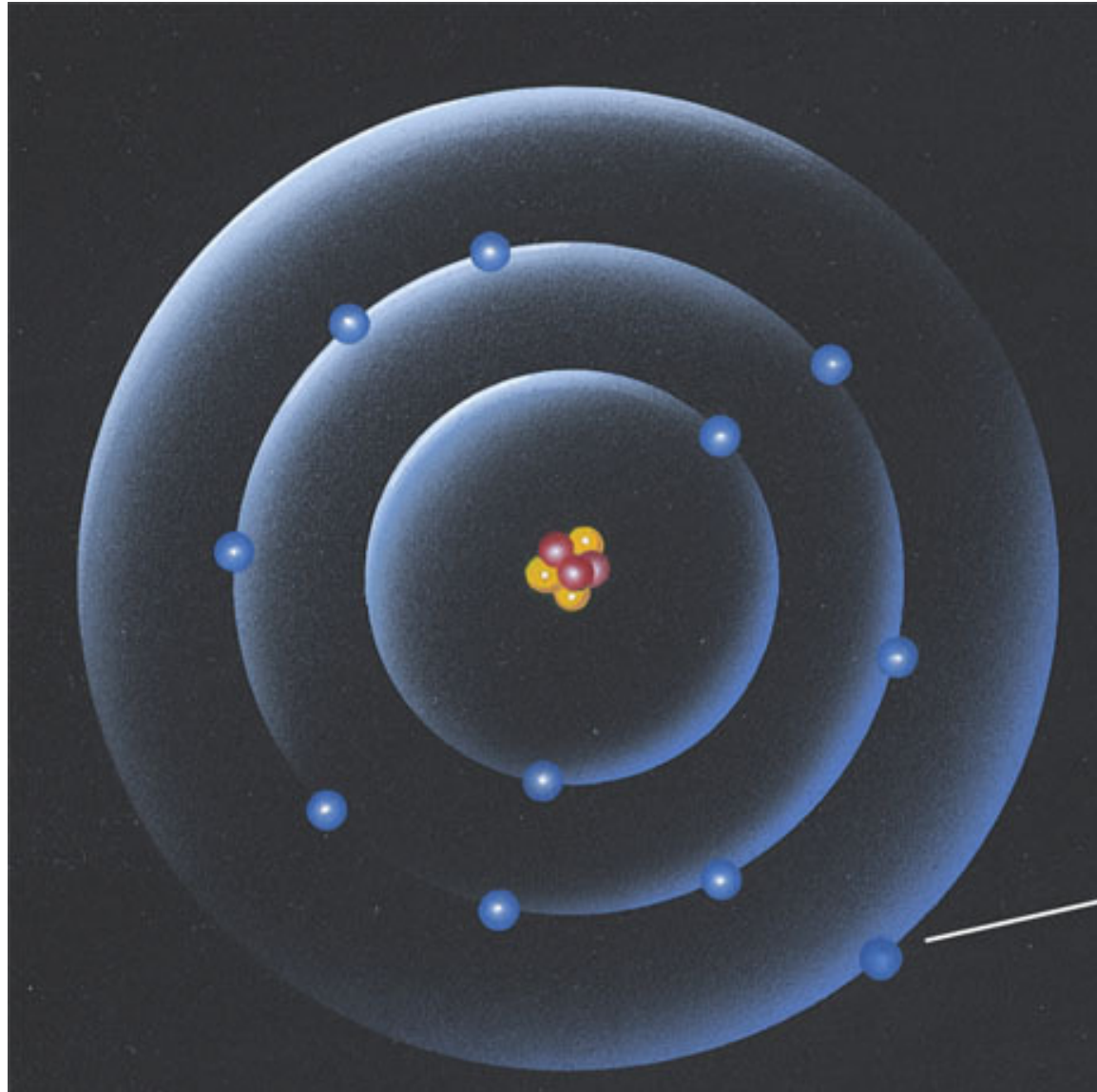
There are also things about matter that we just do not understand. The galaxy and the Universe contain more matter than can be accounted for by all the stars. We can't see this, so we call it "DARK MATTER"

Basic Chemistry: Atoms, Isotopes Ions and Molecules



Remember
this material ?

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



Elements and the Periodic Table – Crucial Knowledge

	1																	18
1	1 H	2											13	14	15	16	17	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg	3	4	5	6	7	8	9	10	11	12	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**															
	Lanthanides*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
	Actinides**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr		

If this graphic does not mean anything to you, there is a need To look at materials in Module 2, or other science books.

Elements and Isotopes – Not the same!

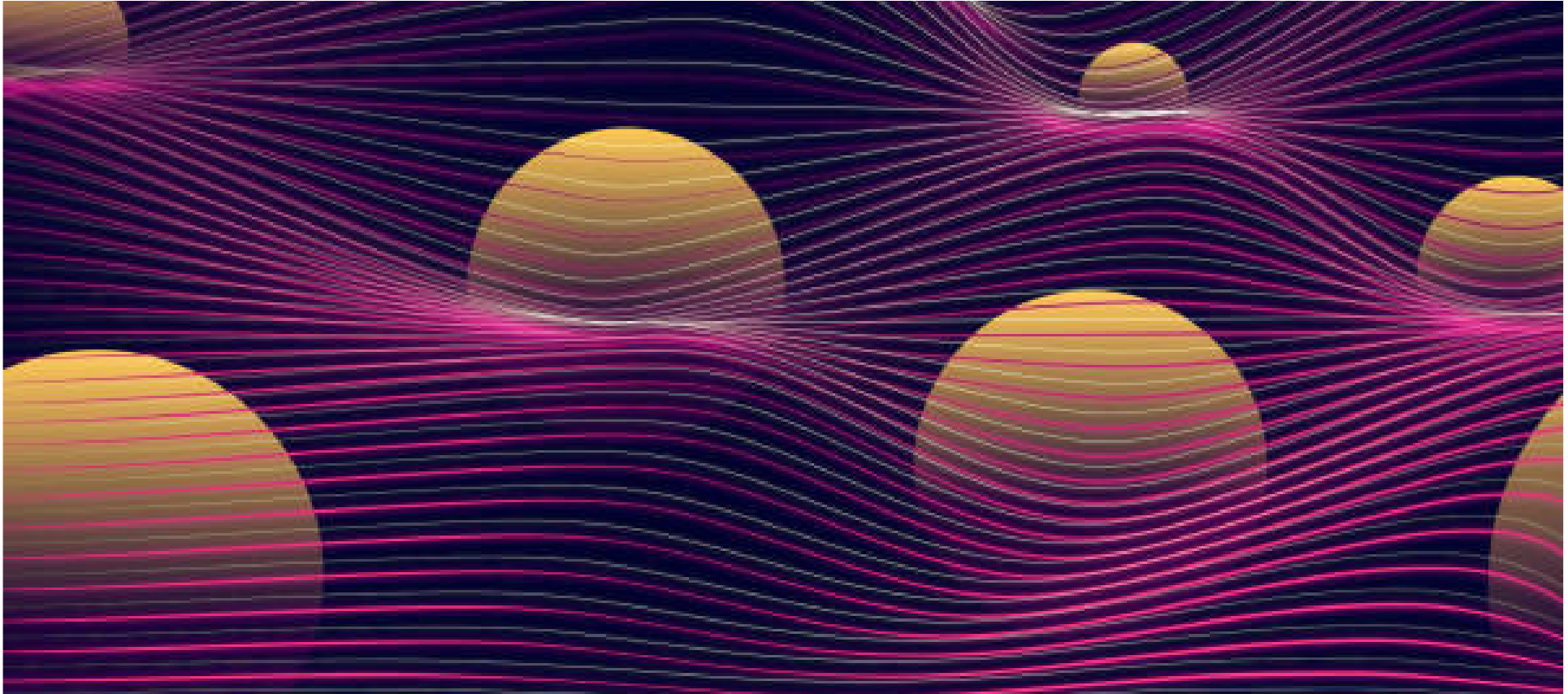
- **Elements (e.g., copper, oxygen, etc.) belong to different groups (metals, non-metals and semi-metals). They differ in their properties.**
- *Isotopes are VARIETIES of elements that share most chemical properties, but differ in atomic structure. Some are RADIOACTIVE – i.e., they change to another element, given enough time. Other isotopes are STABLE – they don't change over time, but just exist.*
- **Both are very important in Planetary Science: Radioactive isotopes provide natural clocks and stable isotopes provide 'fingerprints' for the ultimate sources of materials.**

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 (U) isotopes to 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, measurements of the ratios of stable hydrogen isotopes in comets are quite different to those measured for Earth's water. So it looks as if this theory must be incorrect.....maybe.*

If you don't know what ISOTOPES are – See Module 2!

Matters of Gravity – Keeping Us in Motion



- Gravity makes the world go round, and is a fundamental force across the Universe. Many aspects of it remain a real mystery, even though we know how it works. We'll discuss this in Module 4, and its use in science, but you will find this easier if you remember some basic Newtonian physics.

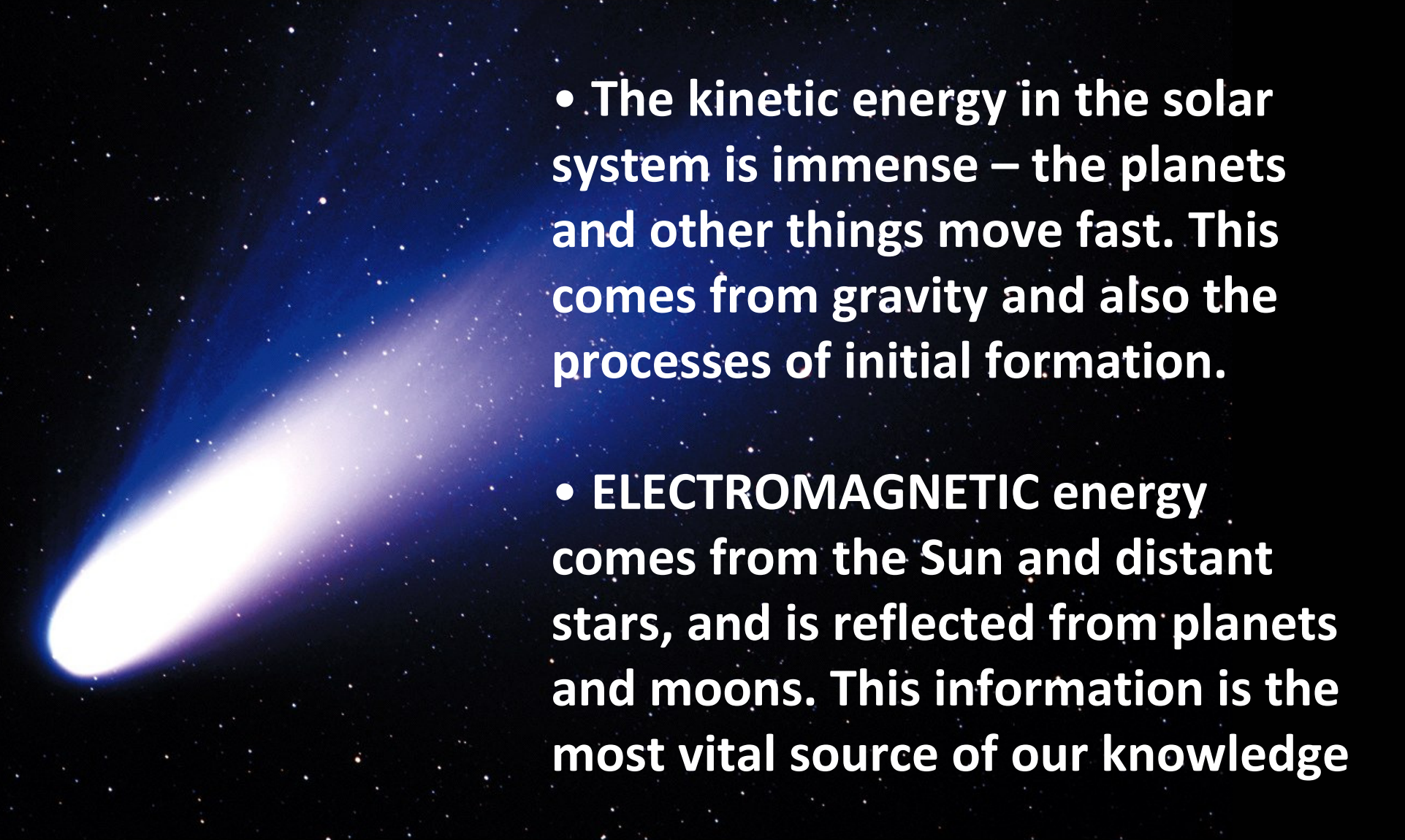
The Two-Edged Sword of Computer Models

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



- 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...

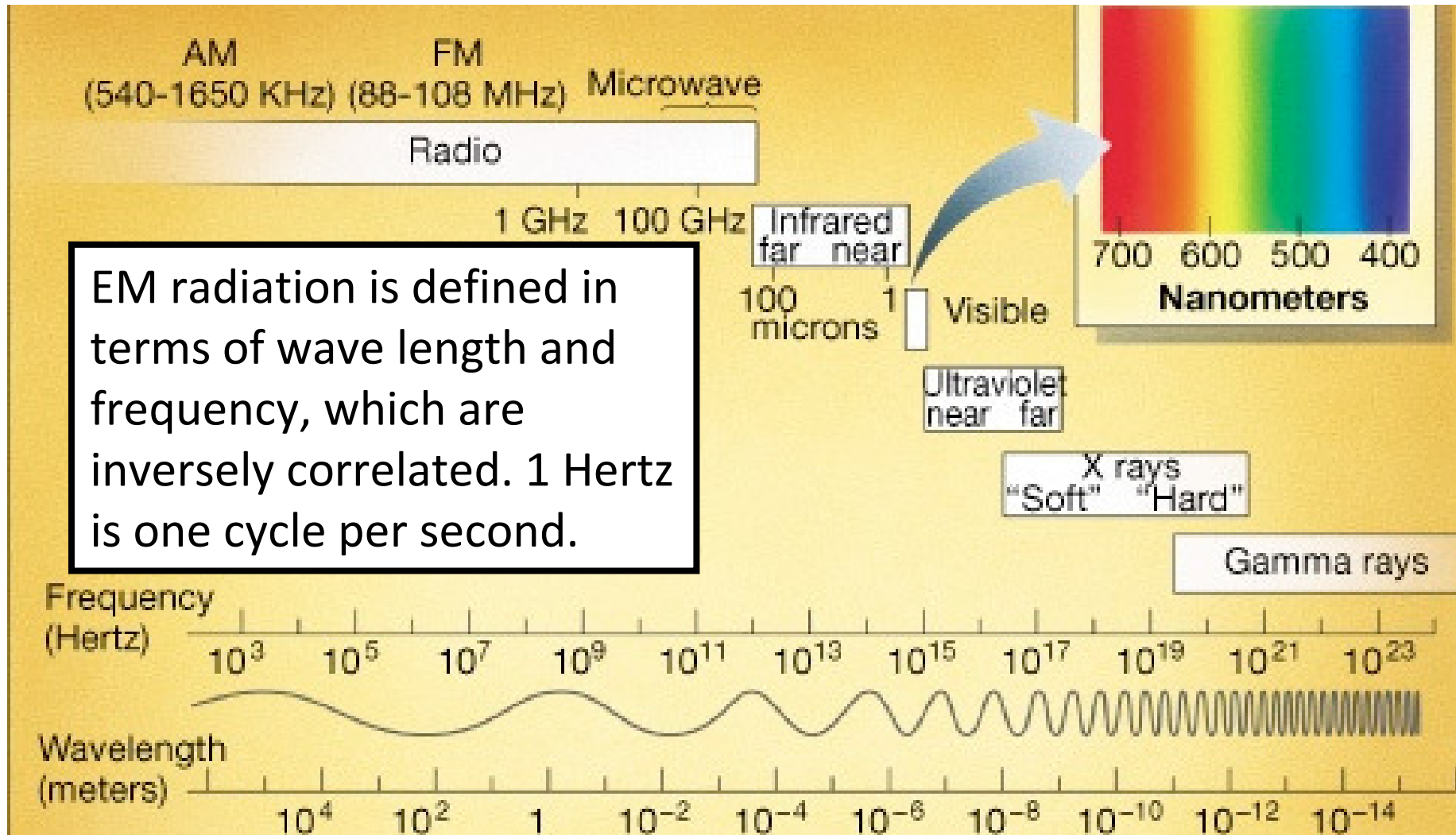
Energy in the Solar System – Some Concepts

- 
- A bright comet streaking across a starry night sky. The comet's tail is a long, glowing blue and white trail that tapers to a point on the left. The background is a dark, deep blue space filled with numerous small, white stars of varying brightness.
- The kinetic energy in the solar system is immense – the planets and other things move fast. This comes from gravity and also the processes of initial formation.
 - **ELECTROMAGNETIC** energy comes from the Sun and distant stars, and is reflected from planets and moons. This information is the most vital source of our knowledge

An understanding of some basic physics is important....

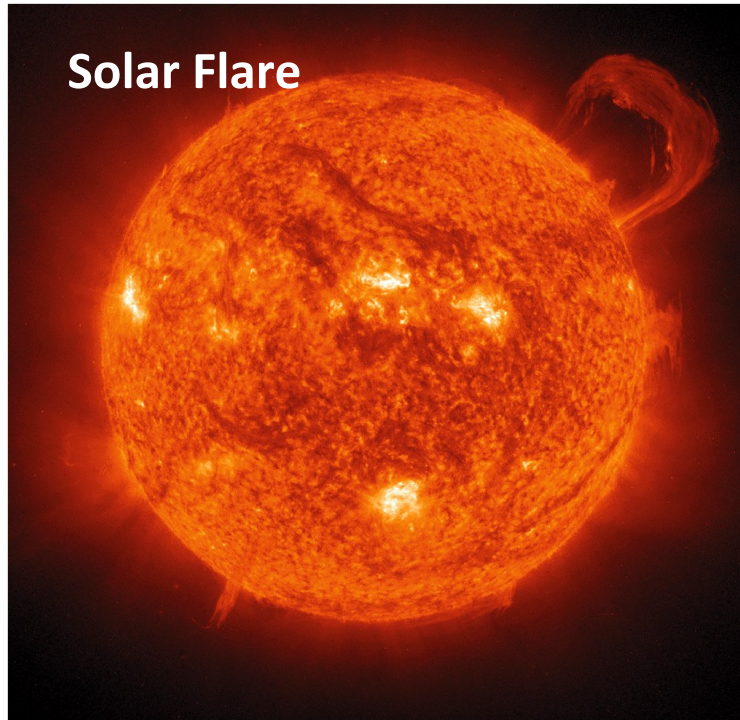
Important Regions of Electromagnetic Spectrum

(you should have a general idea of these – if not, see Module 2)



EM radiation is defined in terms of wave length and frequency, which are inversely correlated. 1 Hertz is one cycle per second.

- As the wavelength gets shorter, EM radiation is more energetic.
- Visible light is a very small region in the middle of the spectrum.



- Planets have internal energy as well, although some have lost most. This is both leftover from formation and produced by radioactive decay (fission).

- The most obvious energy source is the Sun. Its energy ultimately comes from Nuclear Fusion – it turns hydrogen atoms into helium. We can ‘analyze’ its energy output.... It tells us a lot about processes.



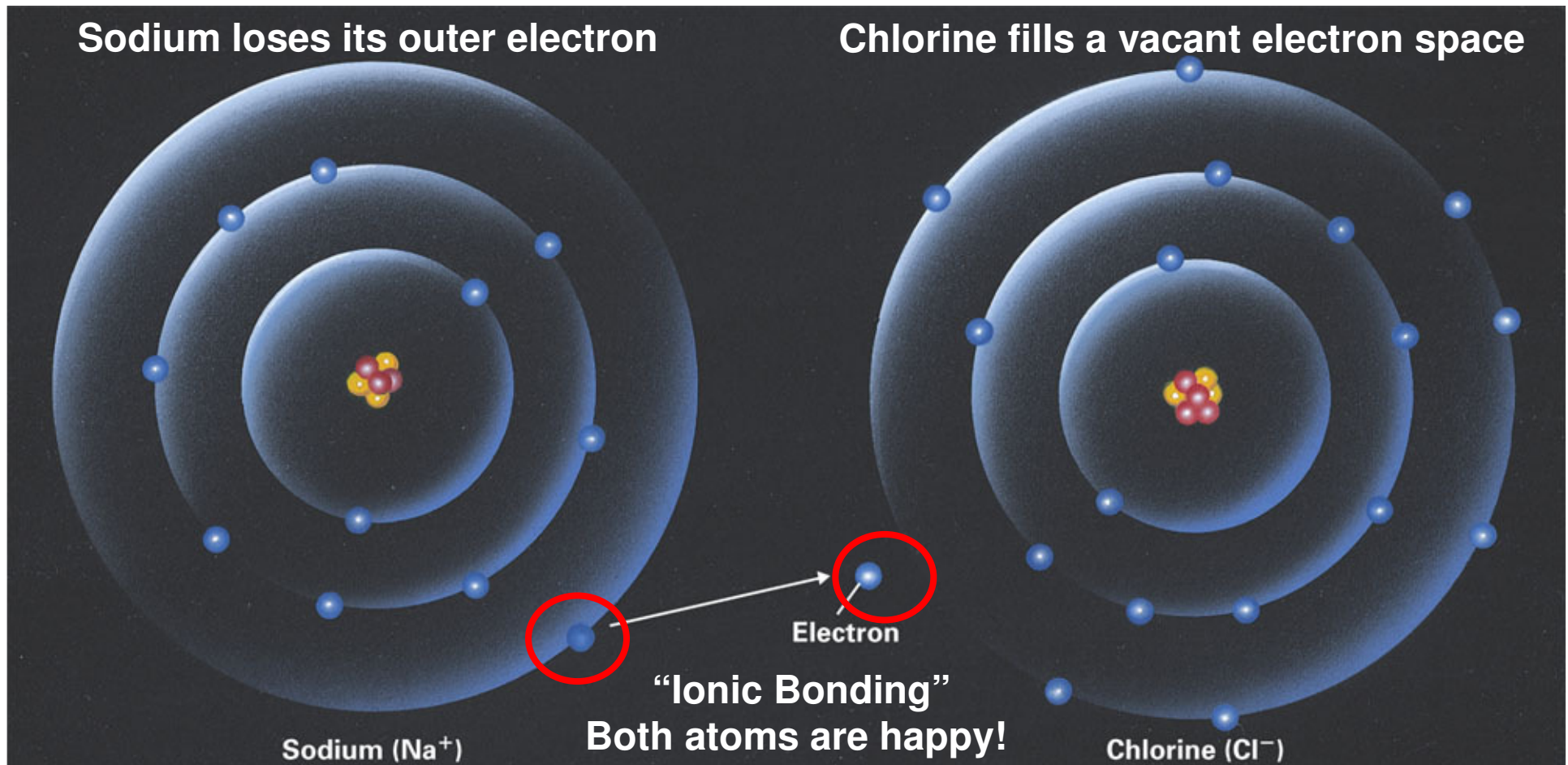


“We came all this way to explore the Moon, and the most important thing is that we discovered the Earth”

(William Anders, Apollo astronaut)

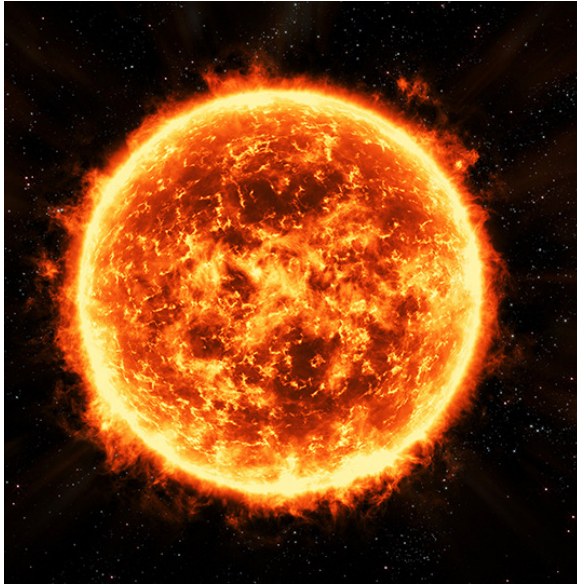
- This is an Earth Science course, and there are many common themes within Earth Science and “Planetary Science”.
- Knowledge of some Earth Science concepts is important as these are ‘reference points’ for things that we observe.

Minerals as the building blocks of many but not all things



If atoms are the building blocks of matter, it is “minerals” that are the building blocks of most planets. Minerals are naturally-occurring inorganic compounds, so we need to understand basics of chemistry. There are thousands of minerals (especially on Earth) but you will only need knowledge of a few very common ones. See Module 2! are

Chemical Elements in the Solar System



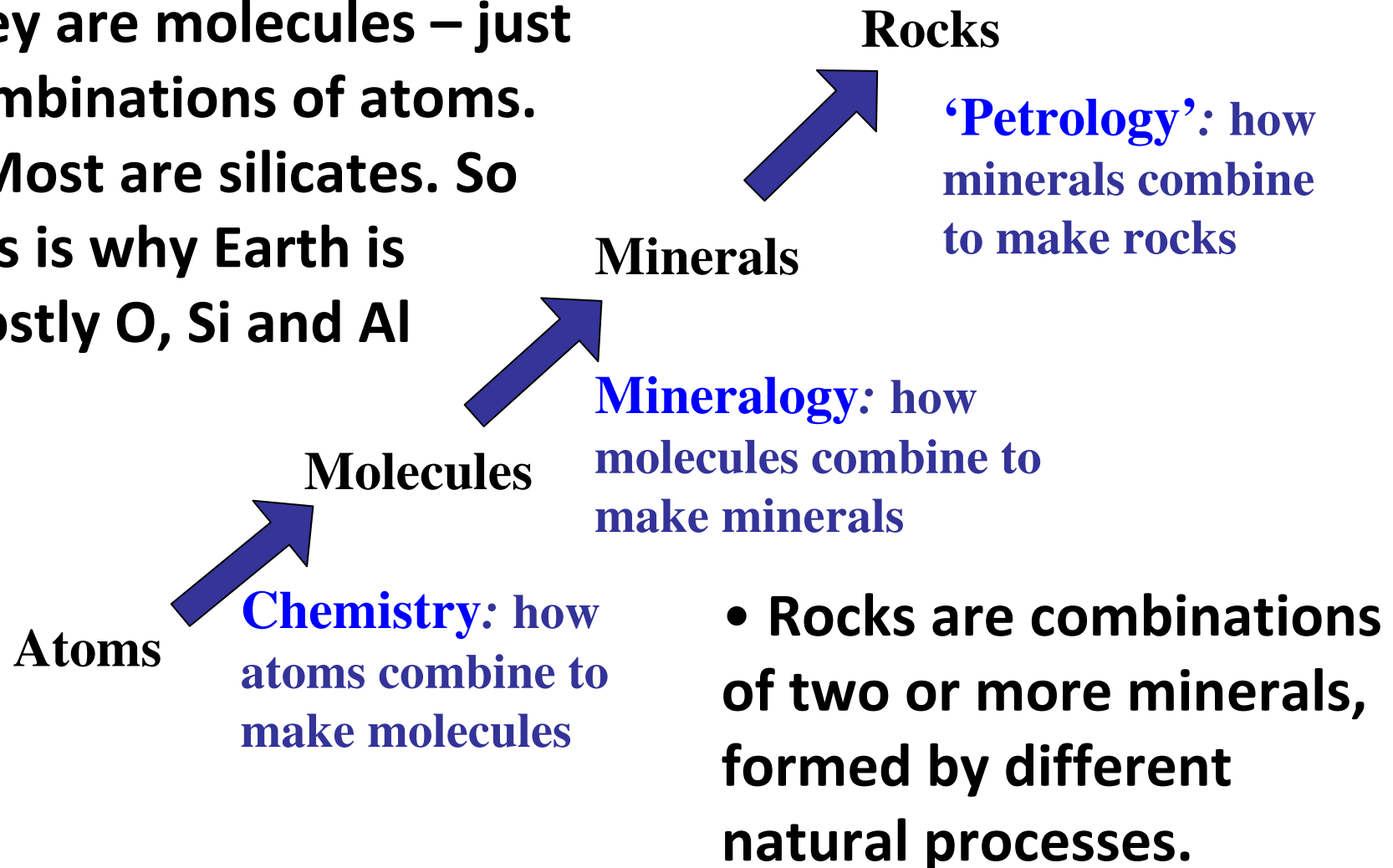
- The most abundant element in the Universe is hydrogen (H), followed by helium (He). This is also true for the Solar System, as virtually all mass is in the Sun, which is hydrogen, with lesser helium from fusion reactions.

- Gas- and Ice-giant planets are fairly similar in composition to the Sun, but terrestrial planets are more varied.
- The Earth's crust is actually mostly oxygen (O) followed by silicon (Si), aluminum (Al), iron (Fe), calcium (Ca) sodium (Na) and potassium (K).

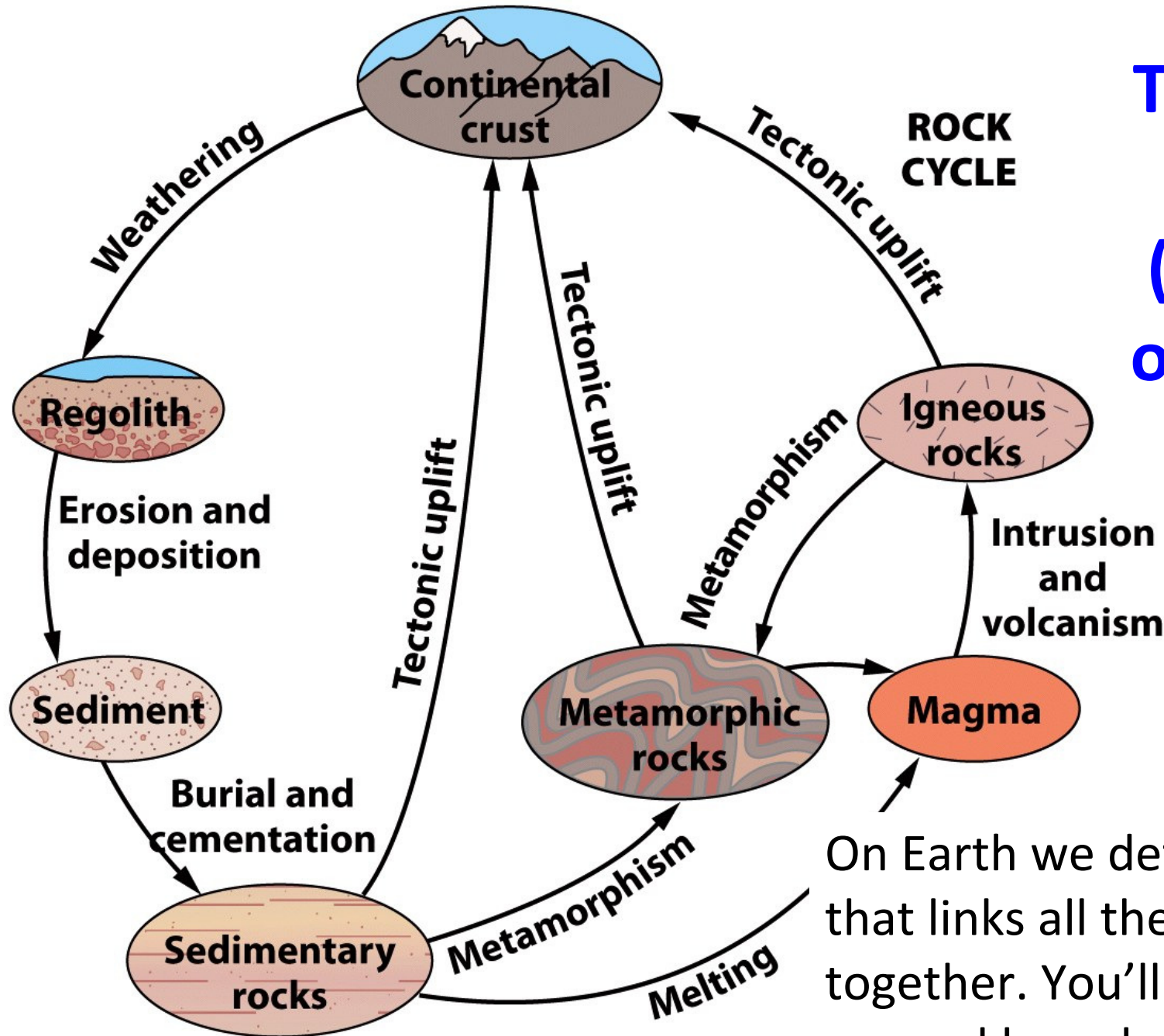


What are Minerals compared to Rocks?

- Minerals are natural chemical compounds, and they are molecules – just combinations of atoms.
- Most are silicates. So this is why Earth is mostly O, Si and Al



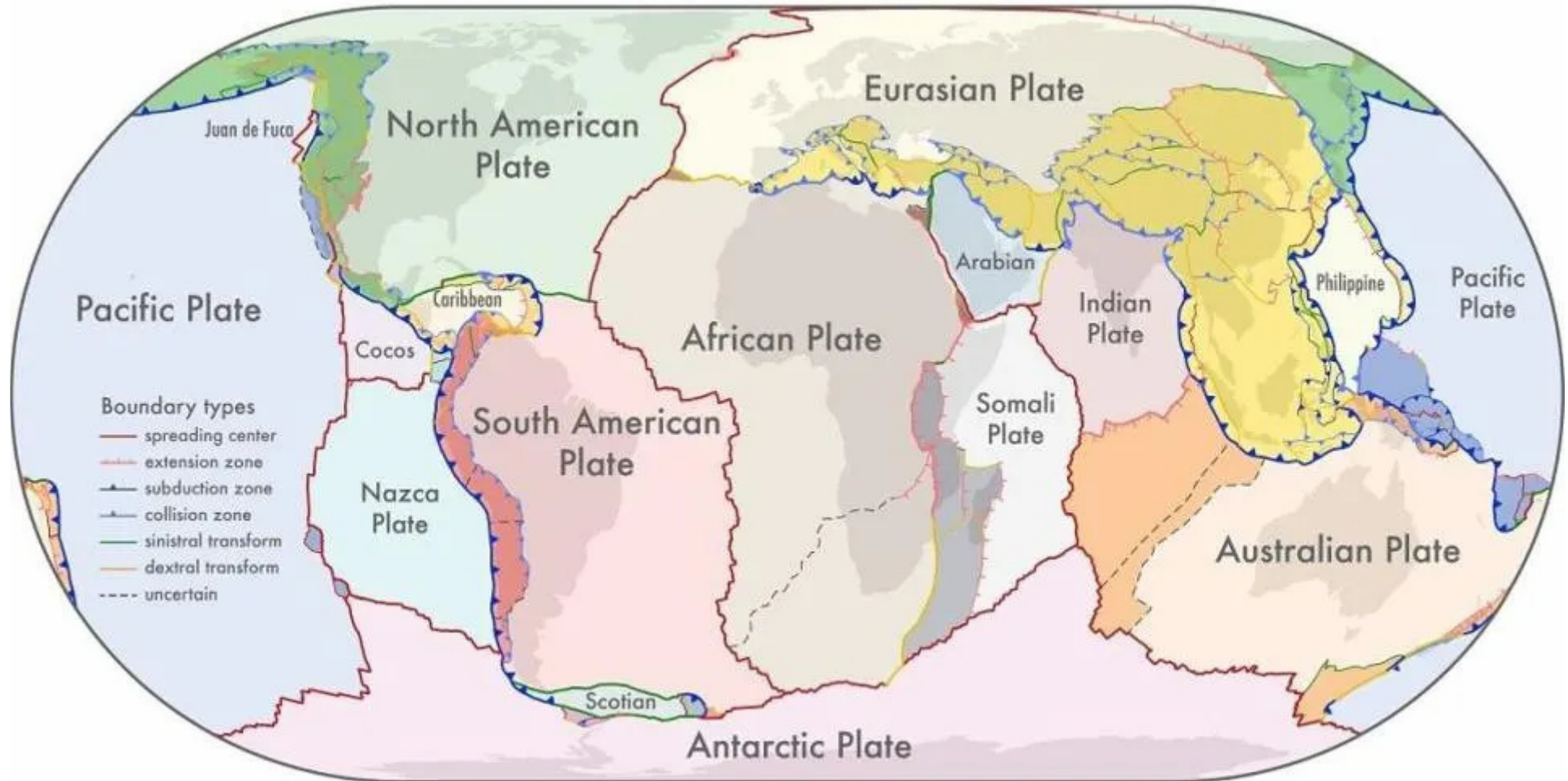
The Rock Cycle (as seen on Earth)



On Earth we define a 'cycle' that links all these types together. You'll need some general knowledge of this.

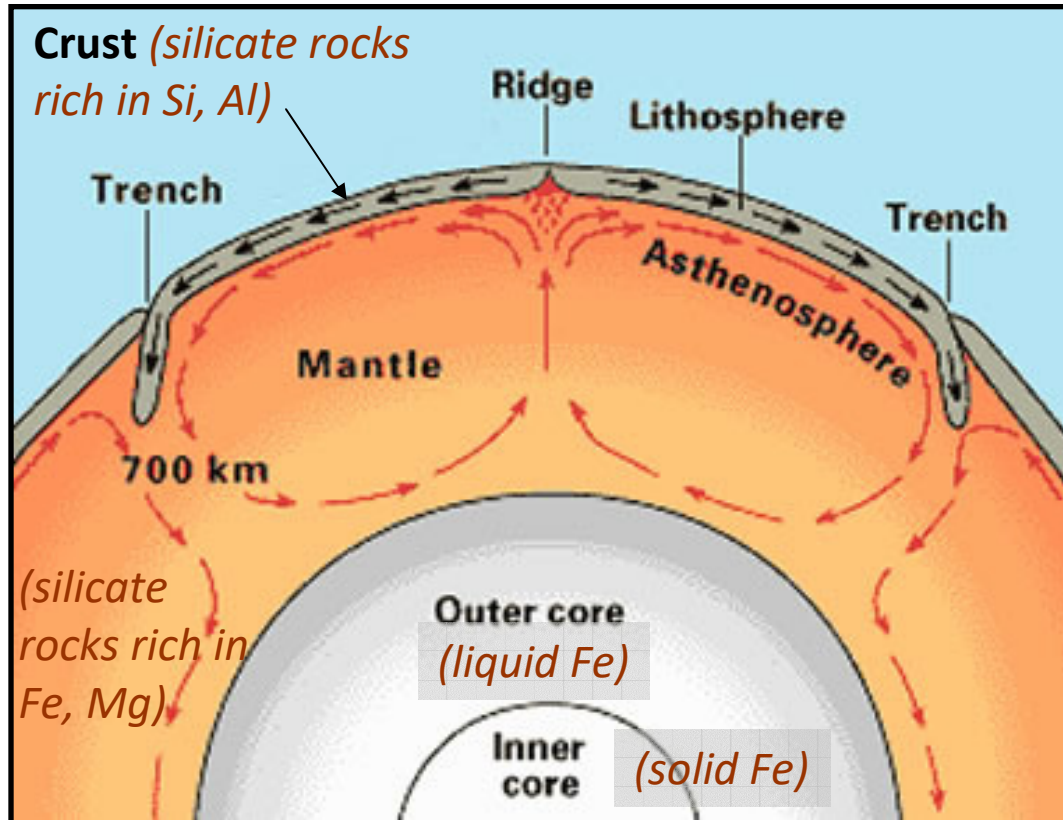
Figure 3.2
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Tectonic Plates, 2022



- The rock cycle, as we call it, is really a manifestation of the Earth as a Dynamic Planet. The crust of the Earth is divided into “plates” that are in relative motion. This is a major theme in Earth Science and we will explore it more when we talk about Earth in Module 7.

Internal Structure and Activity in Planets



- What happens on the surface of the Earth is in turn linked to internal processes, that cause the motions of the outer region we call the crust. These are ultimately linked to the loss of heat.

- Discussion of this is mostly deferred until we get to Module 7, but it is useful to keep this concept in mind. The other important thing to remember is that the internal structure and materials inside terrestrial planets define several ‘shells’

The Earth System Concept – A New Paradigm

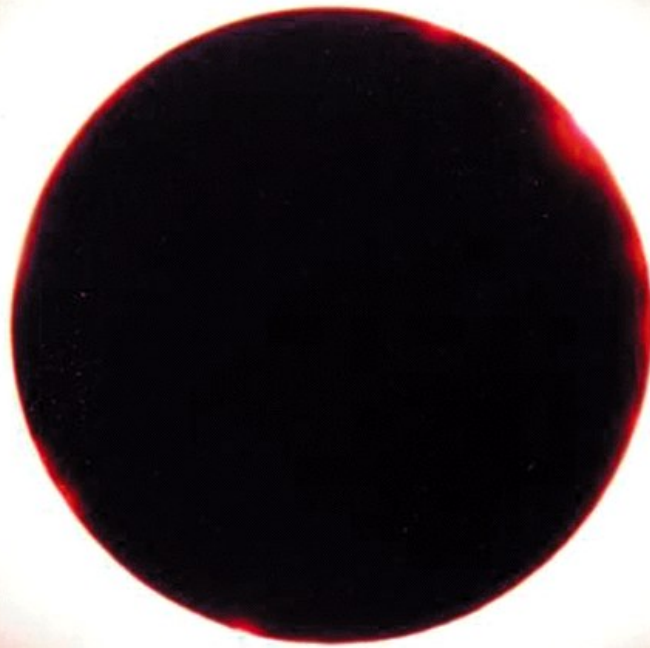


The Many “Spheres” of the Earth

- **The modern view of the Earth is that it is governed by interactions between the lithosphere (rocks), the hydrosphere (oceans), the atmosphere (air) and the biosphere (life of all kinds). The Biosphere may in the end be the most powerful influence over time.**
- *Whatever general knowledge you have about these topics or can gain will help you in understanding the really wide concepts in the course.*
- *Earth is not the only planet with a hydrosphere, and it is certainly not the only planet with an atmosphere. It may be the only planet with an “Extant” biosphere, but the possibility of an “Extinct” Martian biosphere is still there. A discovery would have huge implications.*

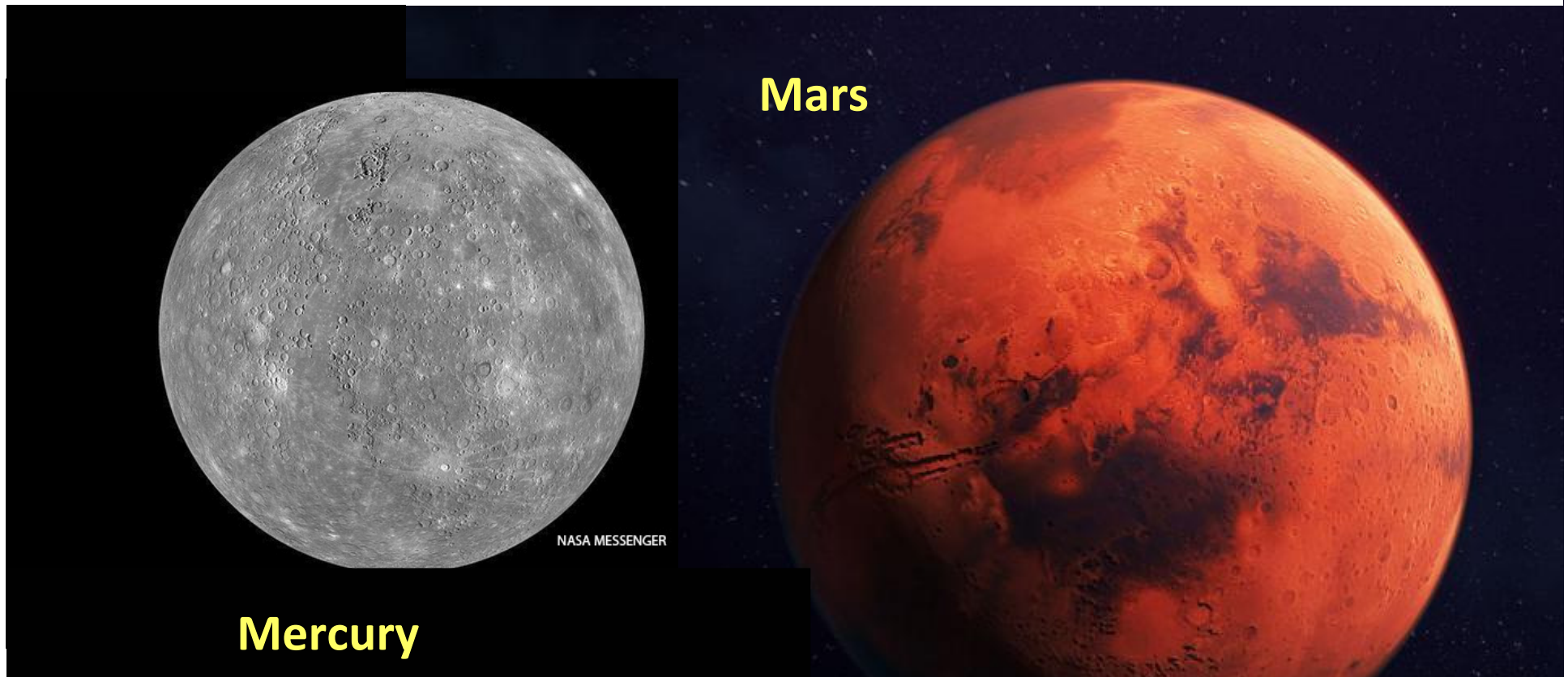
What's This?

How does it happen?



One of several topics for the next class.

Don't Neglect this Background Knowledge !



- The principles of science are **UNIVERSAL**. Many principles in Earth Science apply to other planets as well, especially in the inner system. On these worlds, the most abundant surface rock type is BASALT – very familiar from Earth. If you have Earth Science knowledge this will help. **If not, look at Module 2 and later modules will provide details.**