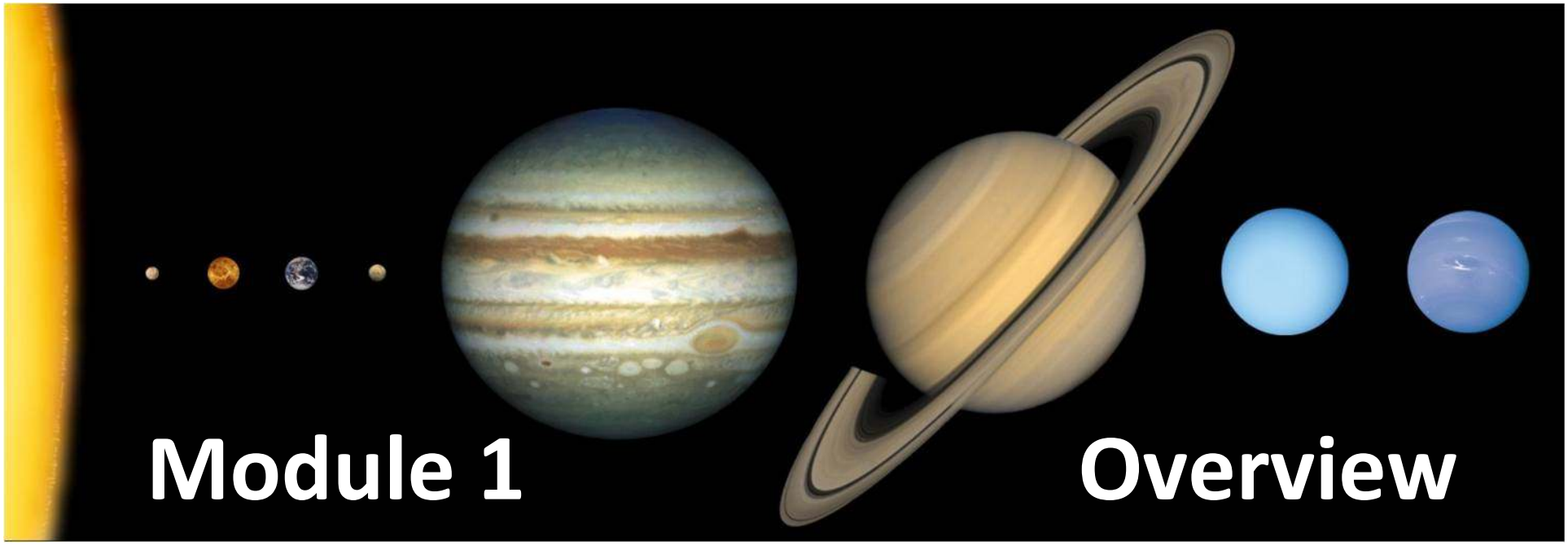
# Earth Sciences 2150 – Fall 2023

## Solar System and Planetary Science




## Introduction to the Course: An Overview of Plans and Voyages

# EASC 2150: The Solar System
# The Plan for Today

## Course Introduction

- We have already given you some information about course logistics and organization. You also need to read the Course Outline and the "Getting Started" document.
- This **Introduction** gives you a picture of the breadth of this course and where we will go in our 'virtual spaceship'.
- It introduces some important concepts that we will need.
- Don't forget that this an **Earth Science** course……
- It does not have any prerequisites. But it assumes basic high-school science knowledge. **Module 2 of the course reiterates this, and also provides some introductory Earth Science concepts. Some of you will need to look at these.**

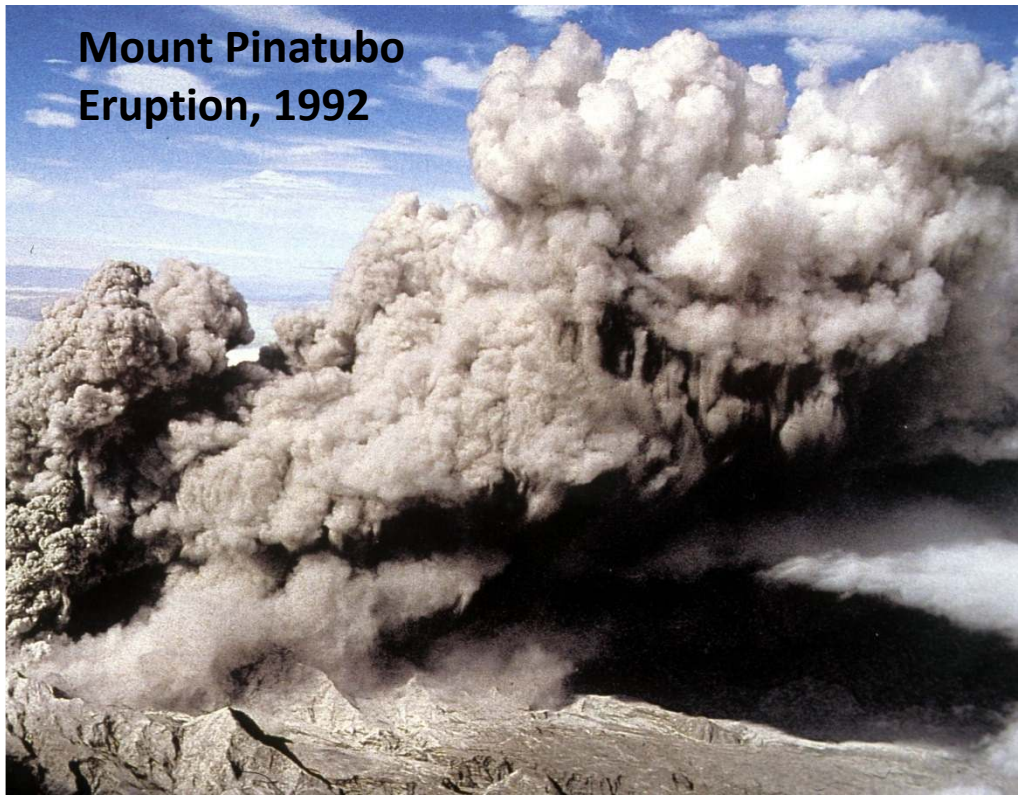
# Modules, Classes and File Types

- There are 13 **Modules** in this course, and most of these are split into two **Classes** (each ~ 50 mins). This was the nor for in-person evening sessions up tp 2020.
- There are additional shorter **Classlets** (5 – 15 mins) that cover topical issues in Planetary Science; in part these come from student feedback and research.
- Each **class** consists of a PDF file that contains slides from lectures. These go with a 'podcast' (MP3 file) that contains narration, information and discussion. File names are the same, aside from extensions.
- **In-person Classes** are now summaries of the key points and topics for each module, but do not contain all the details. You need to look at online material.


– The Earth is just one planet in one solar system. In the end, if we want to understand planets, we need to look outward. This is “Planetology” or “Planetary Science”
You are HERE!
(Andromeda Spiral Galaxy)
– The solar system is on an arm of the Milky Way galaxy.
– Our Sun is one of at least 300 billion stars in this galaxy.
– The number of galaxies in the universe is not yet known with any confidence, but is beyond imagination.

# Interested in Earth Science? Consider EASC 1000.

**The course is called "Earth Systems" and introduces a wide range of topics and concepts. Most find it interesting….**

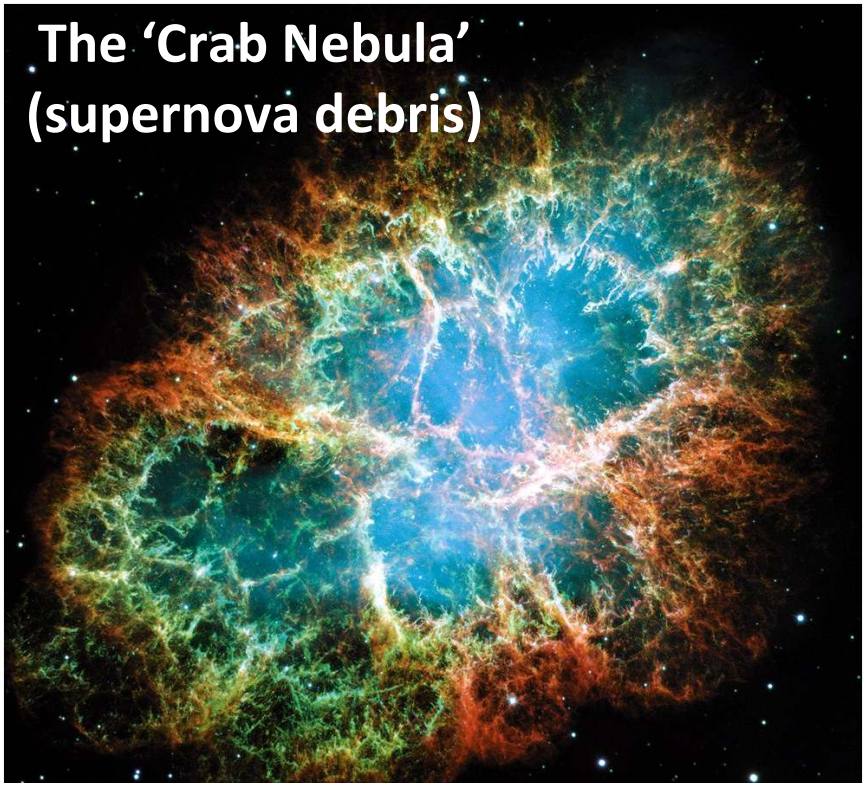




**If you have already done EASC 1000, you will find this an advantage as it includes some very basic Planetary Science. However, some Earth Science background is in Module 2**

# Interested in Astronomy? Consider PHYS 2151

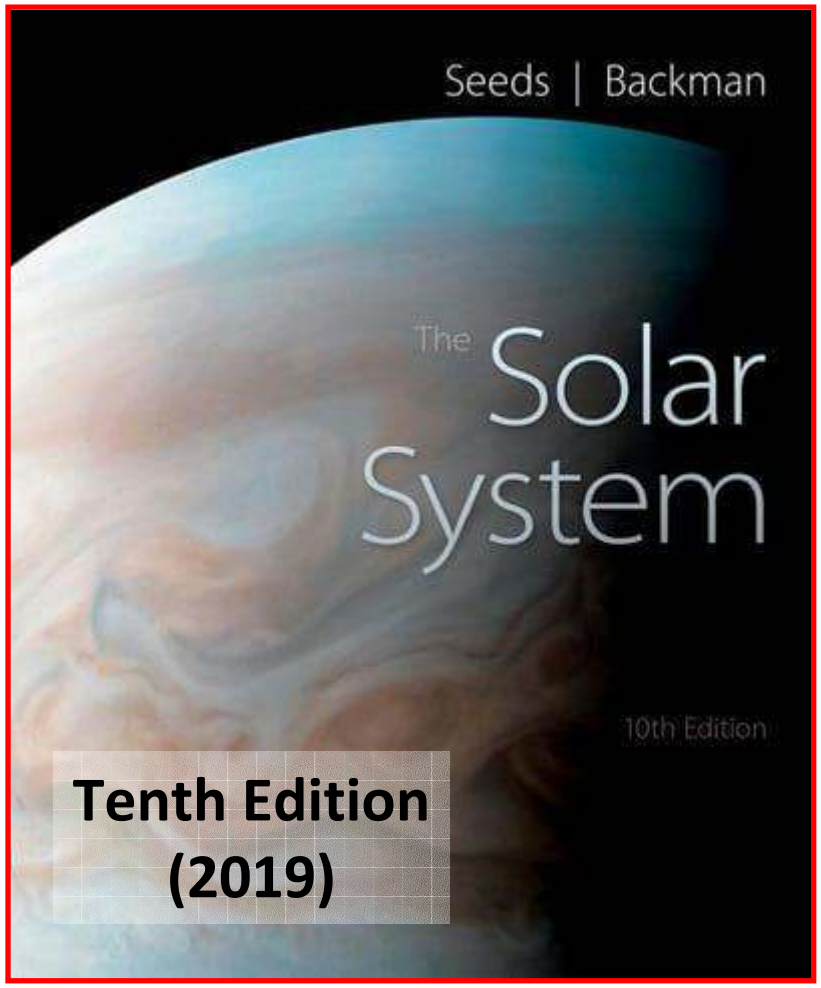
**The course is called "Stellar Astronomy and Astrophysics" and is focused on stars, galaxies and the wider universe.**





**In this course we will touch on some of these topics, but we stay *mostly* within our Solar System. The course textbook contains some material that is relevant to PHYS 2151.**

# Information on the Course Textbook




**Tenth Edition (2019)**

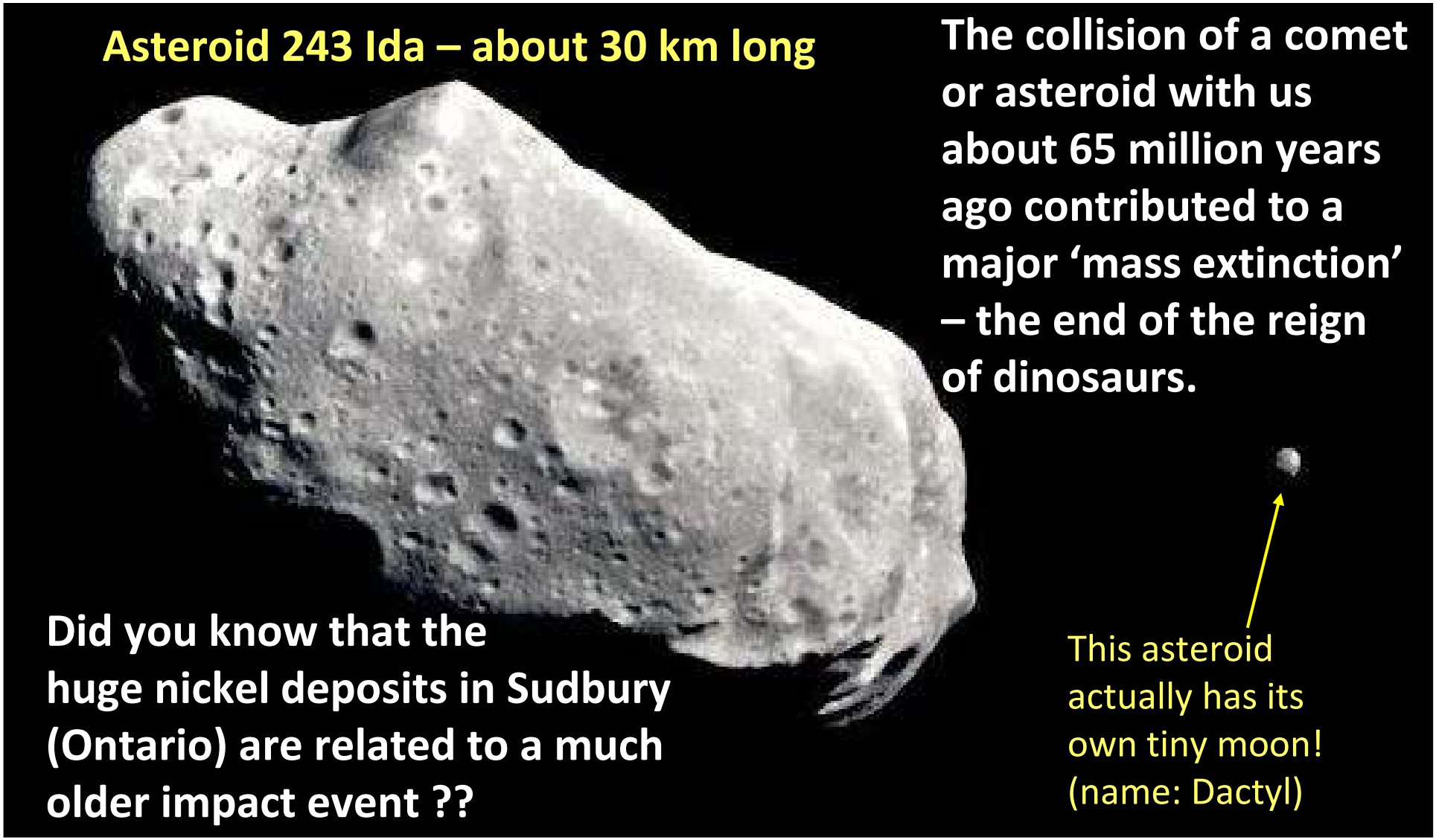
***www.cengage.com***

***See Instructions or purchase through MUN Bookstore***

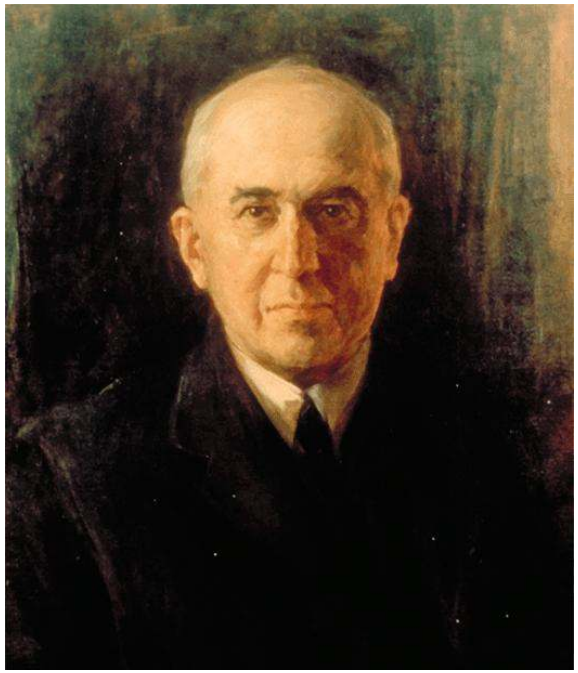
- **There is a new textbook for 2021, and I am very impressed with it so far.**
- **If you like, you can buy a hardcopy – and it is a nice book to have. But parts will in time become dated…..**
- **Much good information is present in other texts.**
- **An earlier edition (~2010) of this is available as a PDF on the internet.**


EASC 2150: Course Overview
We start at the Big Bang and we close out with the end of the World!
But why are Earth Scientists interested in the wider Solar System?

– You might think that other worlds are not relevant to geologists, but let's not forget that visitors from elsewhere in the solar system can 'impact' us greatly.



# Milutin Milankovitch (1879-1958)

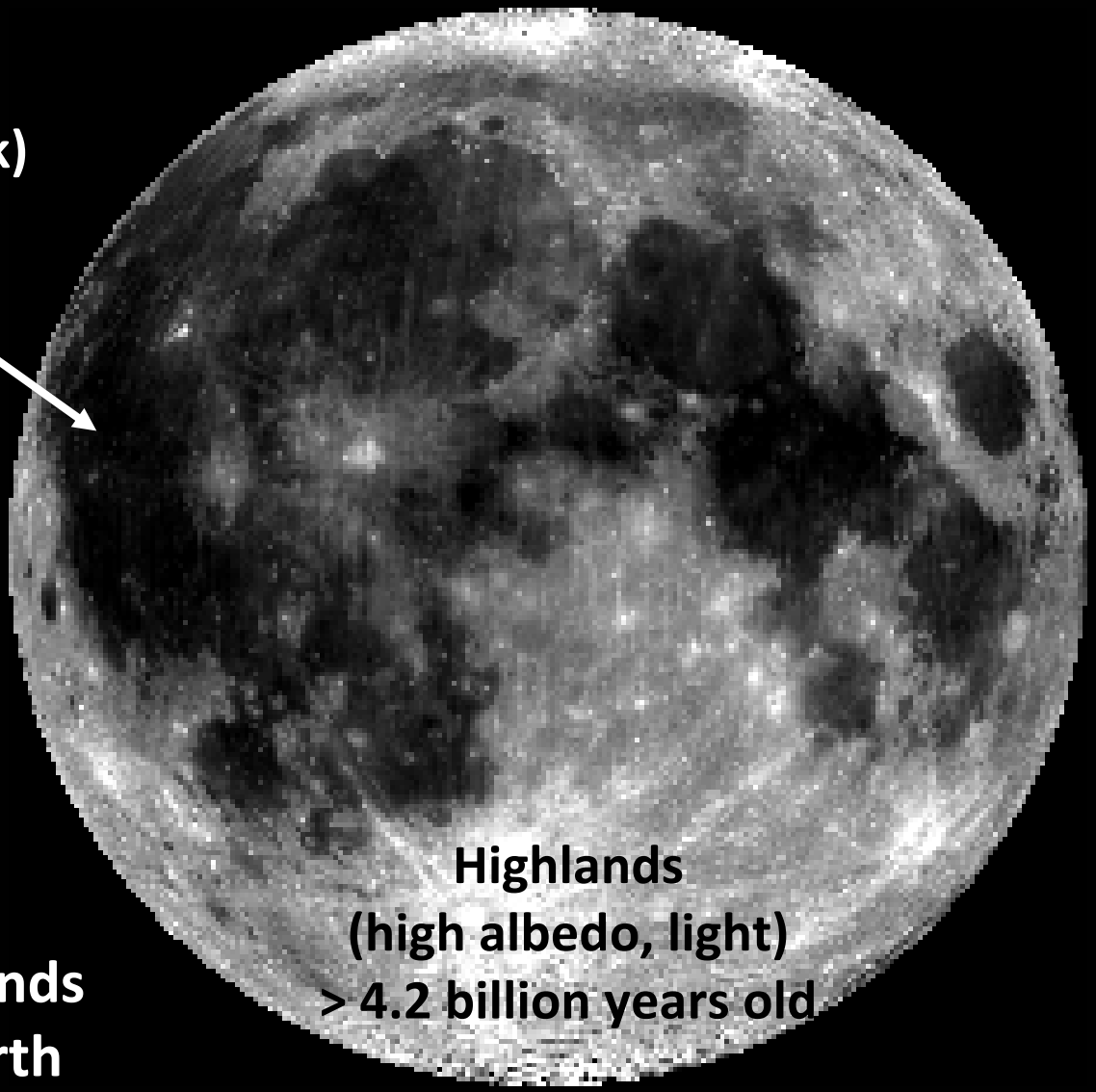


***Milankovitch's ideas and calculations are all the more amazing when you consider that computers did not exist in his time.***

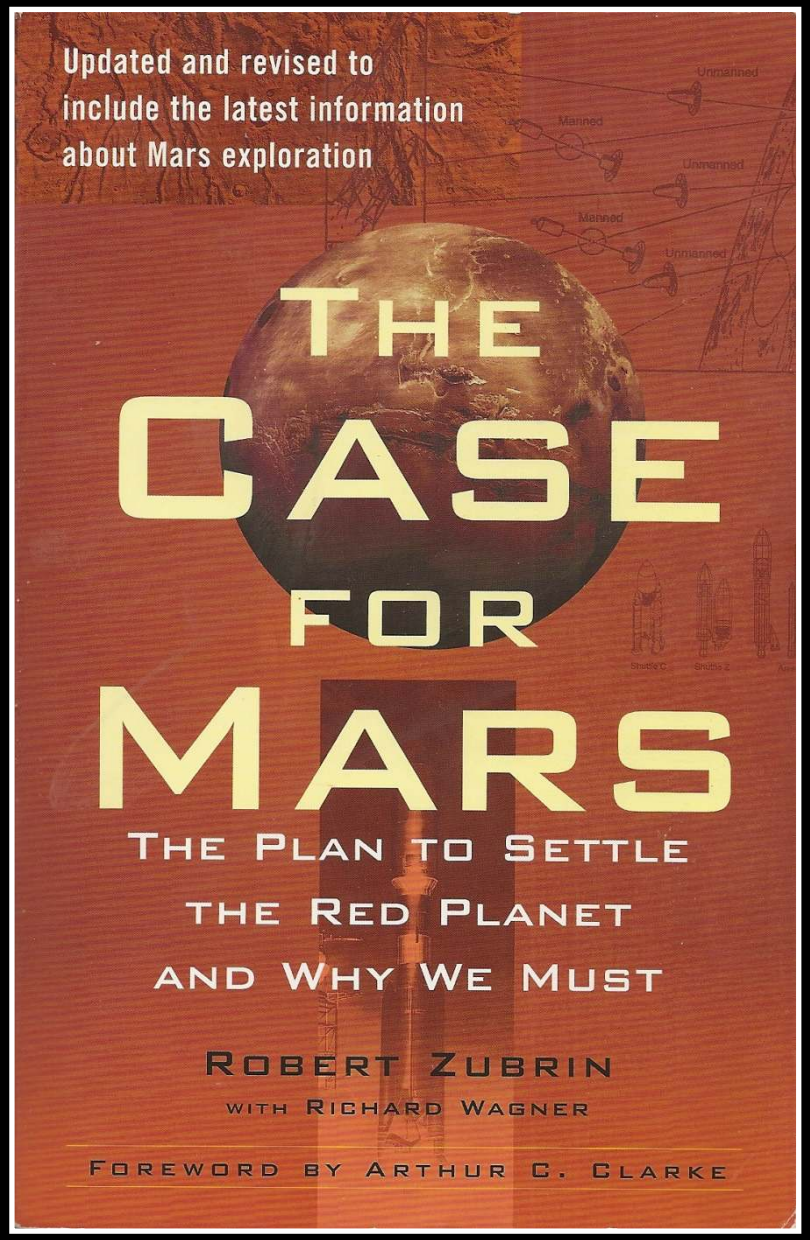
- The Serbian astrophysicist Milutin Milankovitch developed a significant theory relating Earth's orbital motions and long-term climate change.

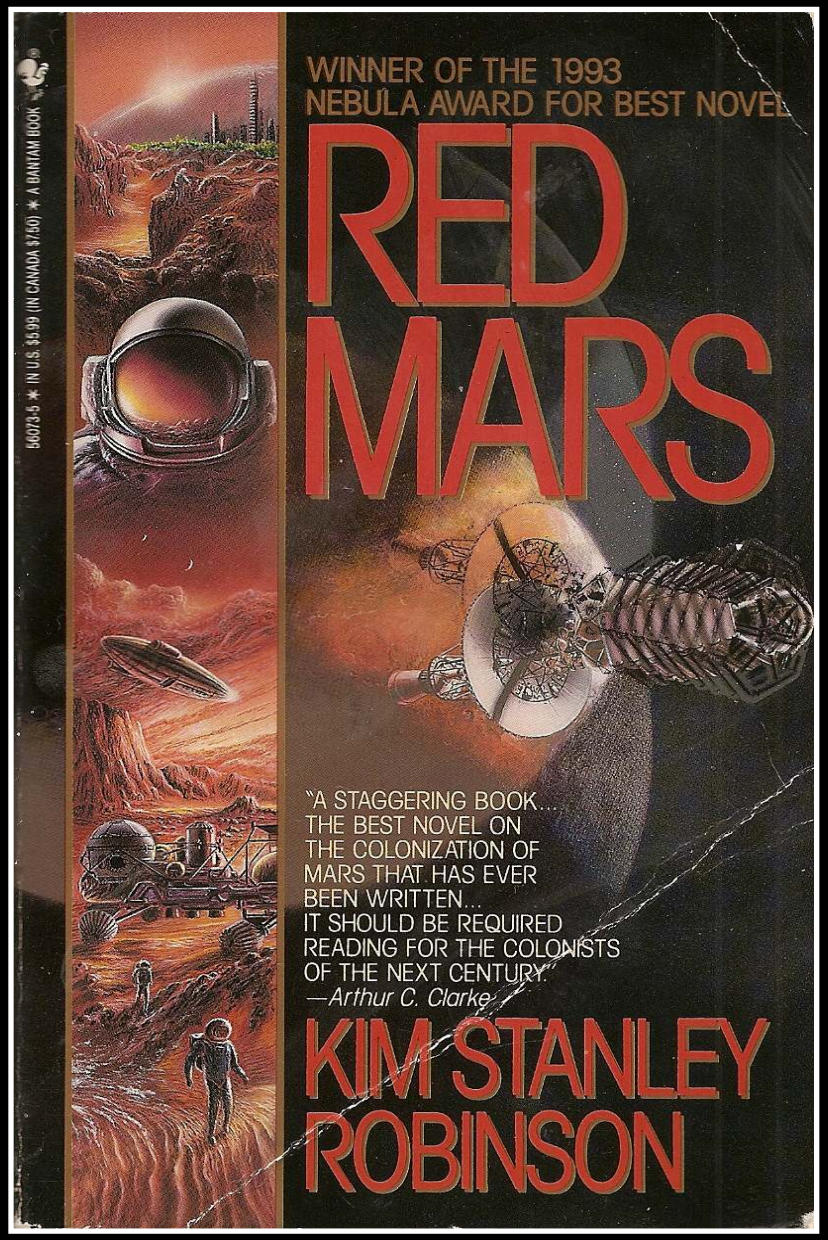
- The **Milankovitch Theory** states that as the Earth travels around the sun, cyclical changes in orbital eccentricity and the Earth's rotation parameters result in long-term variations in the amount of solar energy that reaches us. Which in turn influences our climate….although we now influence it in other ways. *This has nothing to do with human-caused climate warming.*

# The "Man in the Moon" gives important clues about the early history of our own Earth.




The Lunar Mare formed > 3.5 billion years ago; Very few rocks of this age are known on Earth. The Mare attest to intense early bombardment by asteroids. Rocks as old as the Lunar highlands Just do not exist on Earth




**Interplanetary exploration and colonization is a recurrent theme in Sci-Fi, but one day it may be a reality…..so we need to find things out.**

*Australopithecus, Africa, ~ 3 Ma*

*Neil Armstrong, the Moon, 1969*

# Indirect Results – Most Modern Tech!

– The famous TV show “Star Trek” is considered to have predicted most of the modern tech we take for granted – but the REAL space program gave us the research…

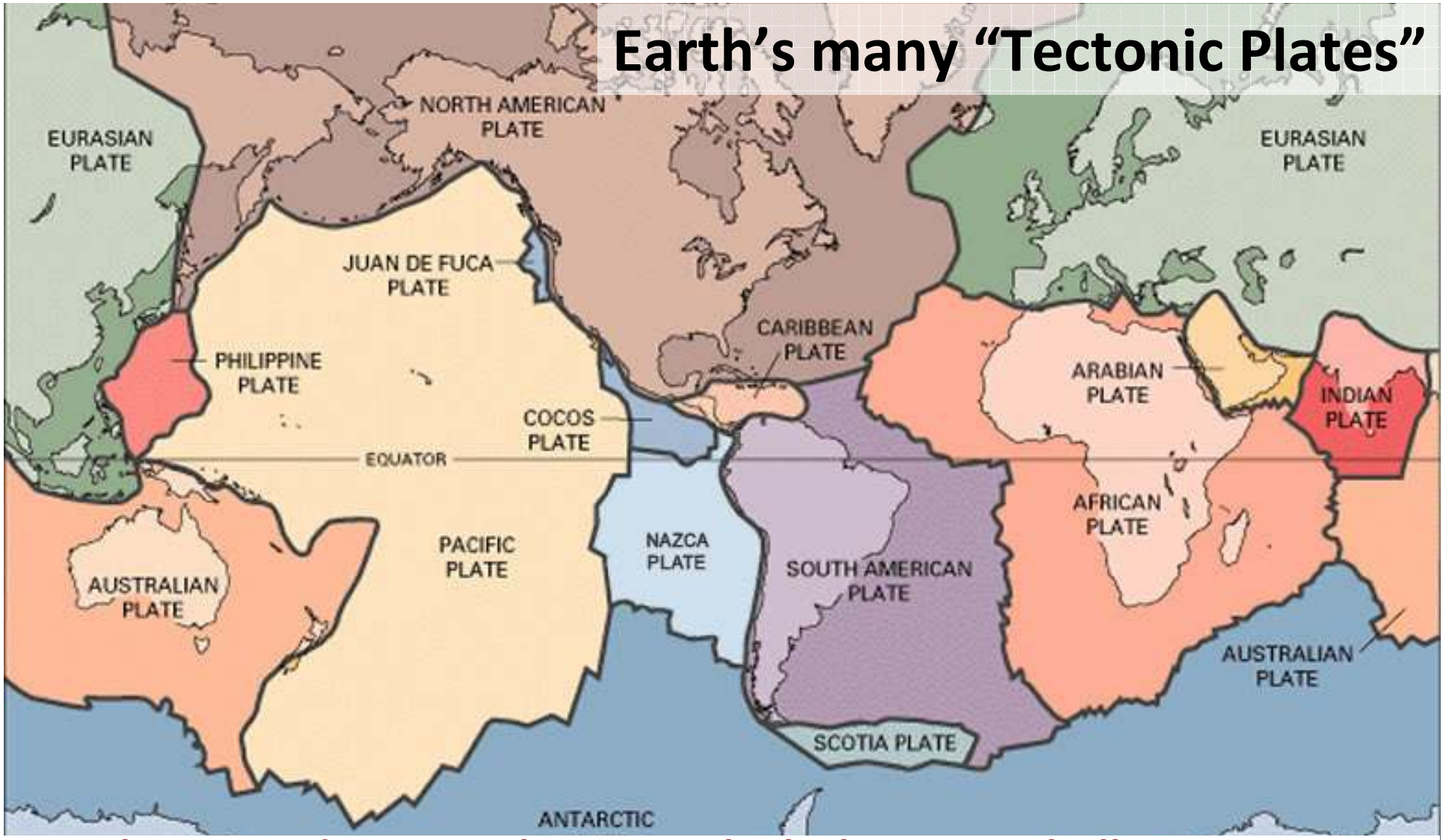
*NASA – The Blue Marble Image, 2005*

- **One thing that you all know – or should know – is that the Earth is a unique place in the solar system. As the trite saying goes, 'there is no Planet B'.**

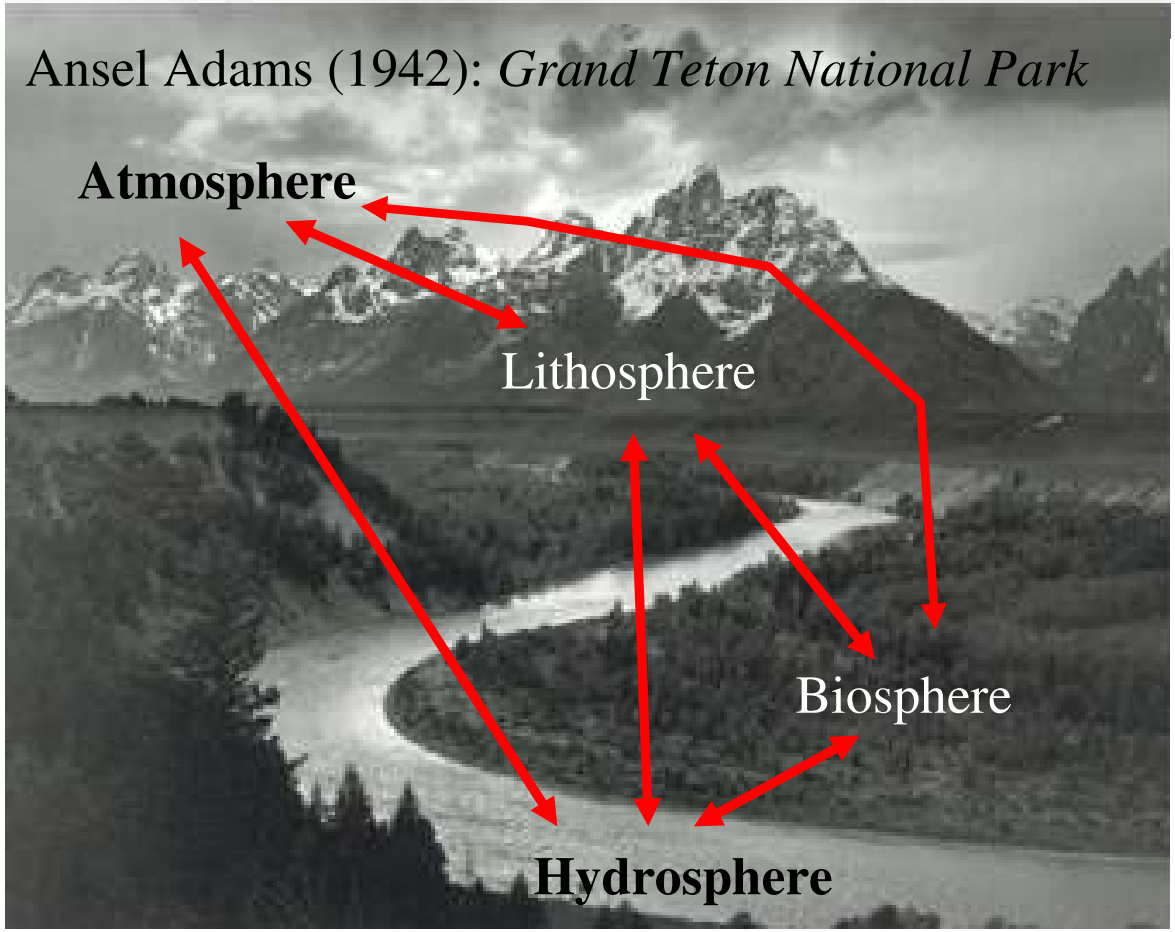
- **Why is this? Do we just happen to have a planet fitted out for life? Or has life on Earth *changed* the environment of the Earth?**

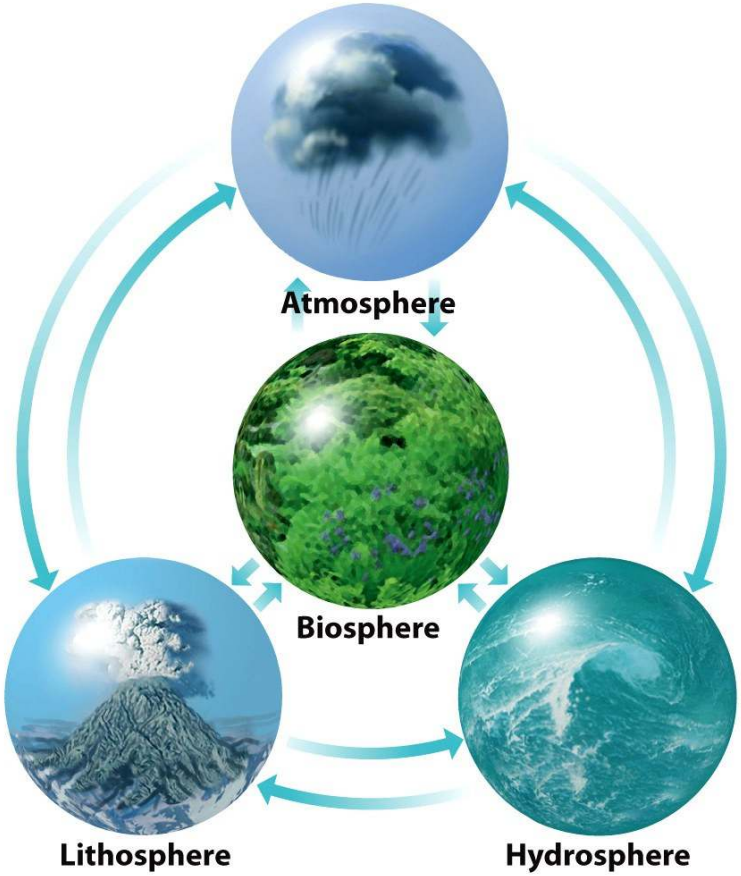
- **Many think so….**

# Earth's many "Tectonic Plates"



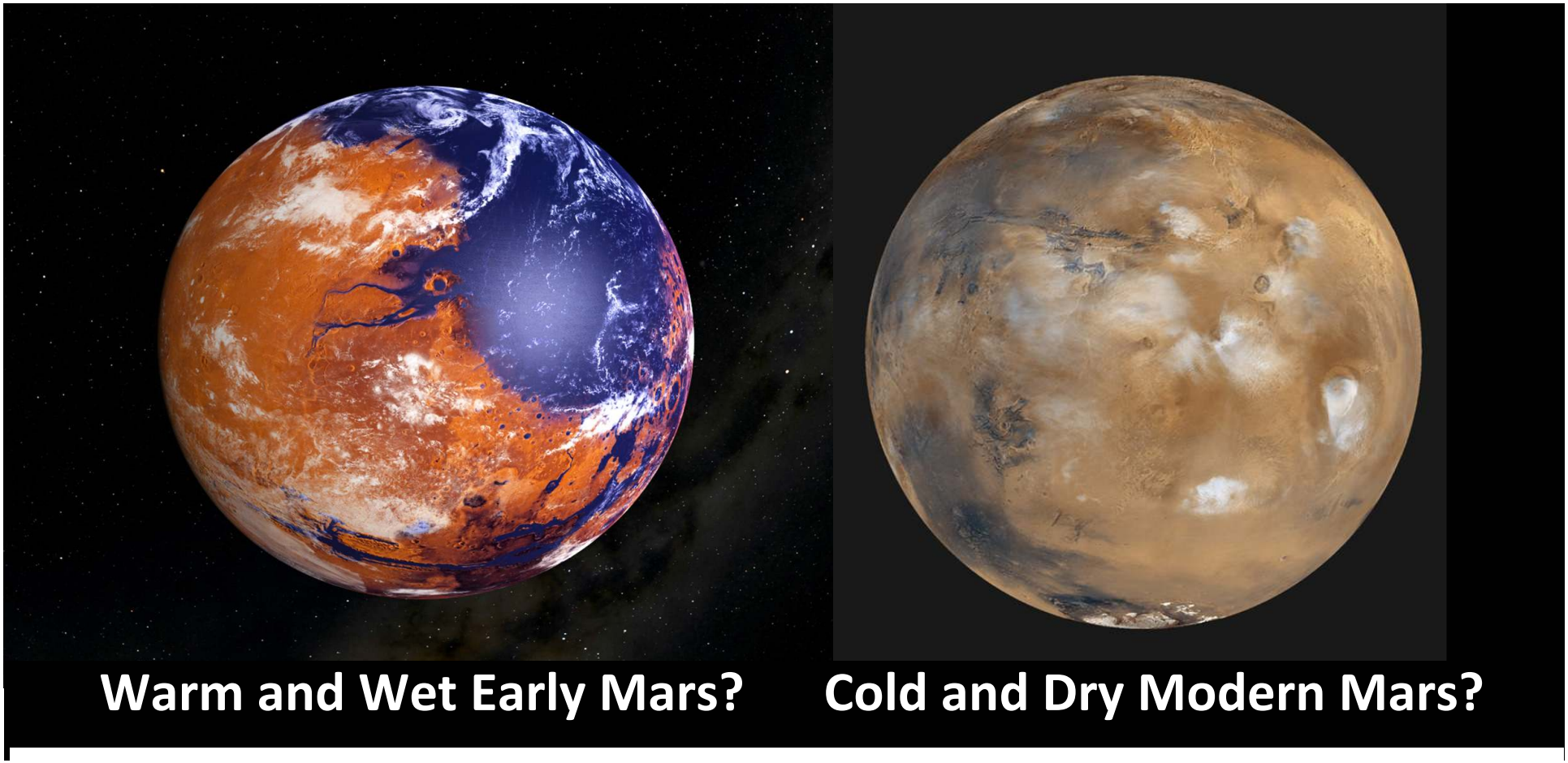

**We live on a dynamic planet in which the outer shell is in constant but very slow motion, driven by the internal heat – this gives us earthquakes, volcanism, and many other things. Do we see evidence of such processes elsewhere in the Solar System?**




## EARTH SYSTEMS and the "GAIA HYPOTHESIS":

***For many years, there were thoughts that Earth processes were all connected, band this led to the idea of the EARTH SYSTEM. It operates like a huge ecosystem or even like a self-regulating living system. Life doesn't just exist on Earth; rather, its long-term influence likely developed what we see. Ours is a living planet…….***




- If the Earth is an **Evolving Planetary System**, what about other worlds? Have they changed through cosmic or geologic time?
- We know with some confidence that Mars once had running water, and perhaps was warmer, with a thicker atmosphere.
- We need to understand these changes and their implications.
- We now know that we ***can*** alter our own planet's environment…..

Radar Image of Venus' Surface.
Vast barren plains of lava…..

Temperatures that will melt metals.
Crushing poisonous atmosphere.
Sulfuric acid rain (maybe?)
But could there be life in its clouds?


Venus is Earth's evil twin sister. But how did a planet that is almost identical to Earth in many physical parameters end up like Hell? What went wrong?

But is it possible that some phosphine gas in its clouds indicates primitive life?

**Some things are familiar – for example, Martian volcanoes have much in common with those of Earth. These also occur on Venus. But other things are alien in appearance and unknown in origin. Remember that just as Earth has evolved over time, so have some other planets. But there must be common threads…..**

*Olympus Mons, Mars – the largest volcano in the solar system (Digital Artist: Kees Veenenbos)*

# Where We've Been and are Heading……..

• Human Solar System exploration began with **Pioneer 6** (December 1965) . This primitive interplanetary probe was still travelling out there in Dec. 2000.

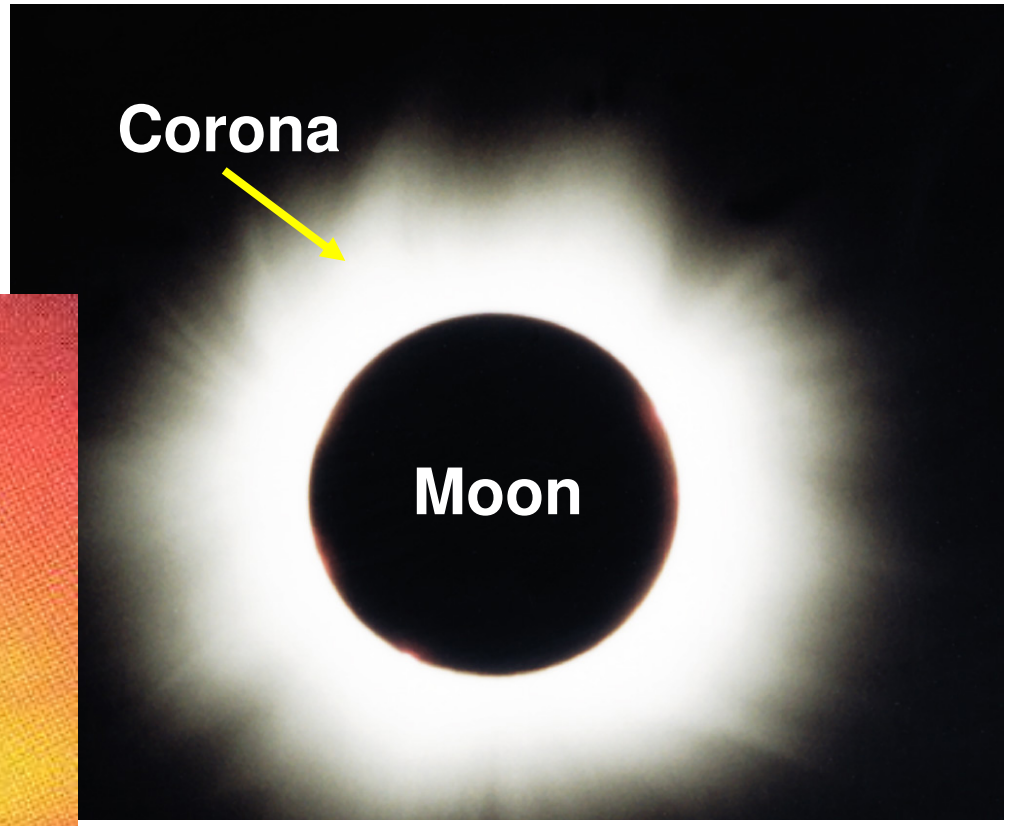
• In 1969, we landed on the Moon – the **Apollo Era**
• In 1977, the **Voyager Missions** began; to the outer solar system and beyond. Mind-blowing excursions!
• **Later robotic exploration** of other planets (Mercury, Mars, Jupiter, Saturn) – also asteroids, comets, etc. Surface exploration of Mars by several robotic rovers.
• **New Horizons** - flew past Pluto in July 2015
• **New mission** to explore the outer part of the Sun launched in 2018; many other ongoing missions.

# Course Structure and Modules

- We are currently in Module 1, which is a general introduction. Module 2 will provide key science concepts for some of you.
- The Course then broadly has two parts
- PART 1 – This deals with background principles and methods, and topics that relate largely to the overall geometry, origin, and evolution of the Solar System. It also covers ‘exoplanets’.
- PART 2 – This is a tour through the planets and other important bodies in the System, and it ends with discussions of life, here and beyond.

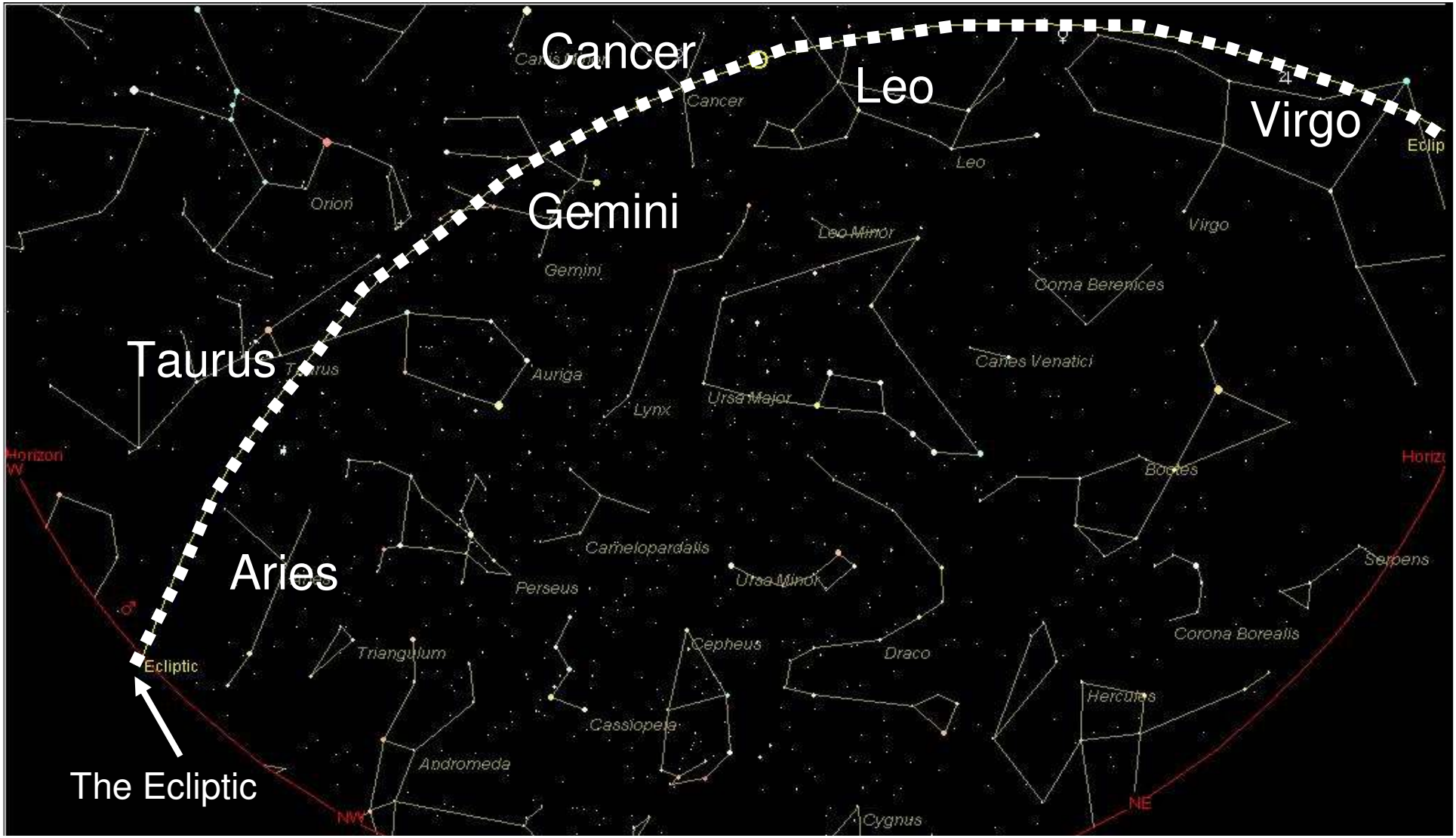
# Stargazing is nothing new to Humanity

*Stonehenge – and many other early monuments – were simple calendars based on Solar motion.*




*Total solar eclipse – here we see the corona (atmosphere), which is normally invisible to us. Eclipses were very important to early peoples, with mystical aspects.*

# Stars, Constellations, Planets and the Ecliptic

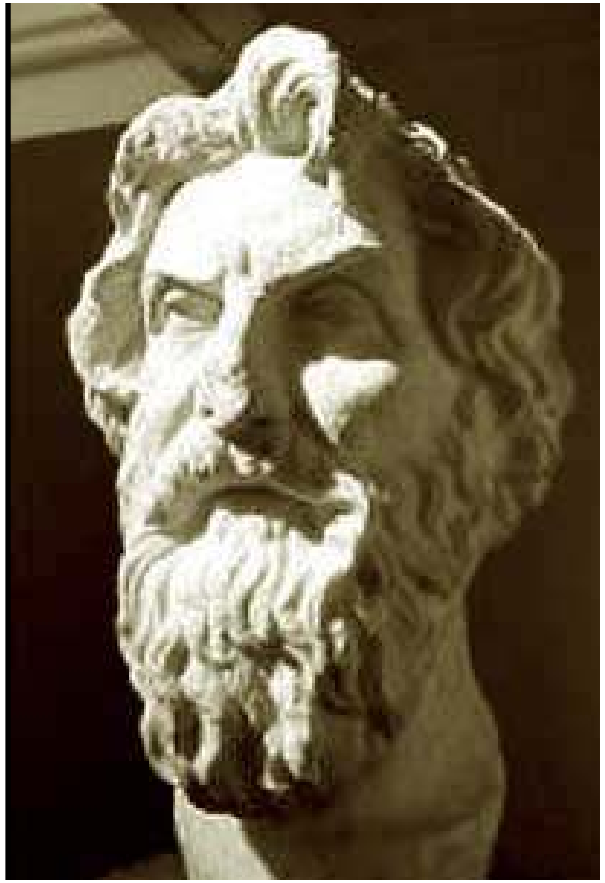



**What do the signs of the Zodiac mean? Why are there 12 of them?**
**What is the "Ecliptic" and why is it so important?**

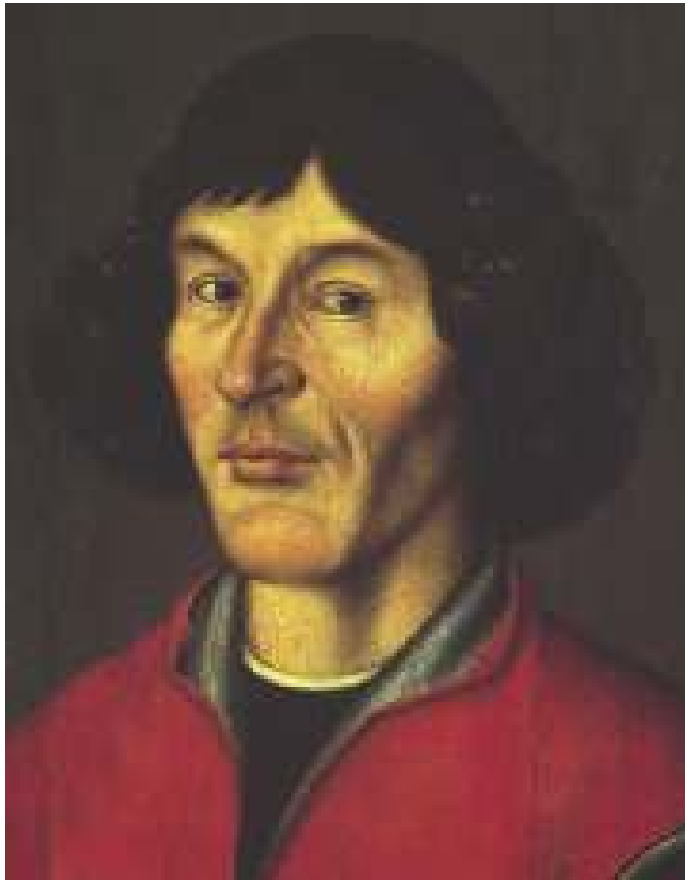
Note that in this image we clearly see the varied colours of stars. Also, we see variations in brightness – and also apparent size.

We will then consider some “Big Picture” things. Stars, Galaxies, the Wider Universe. Prepare to feel insignificant. “Stars are like dust”.

# The Evolution of Modern Ideas over Time

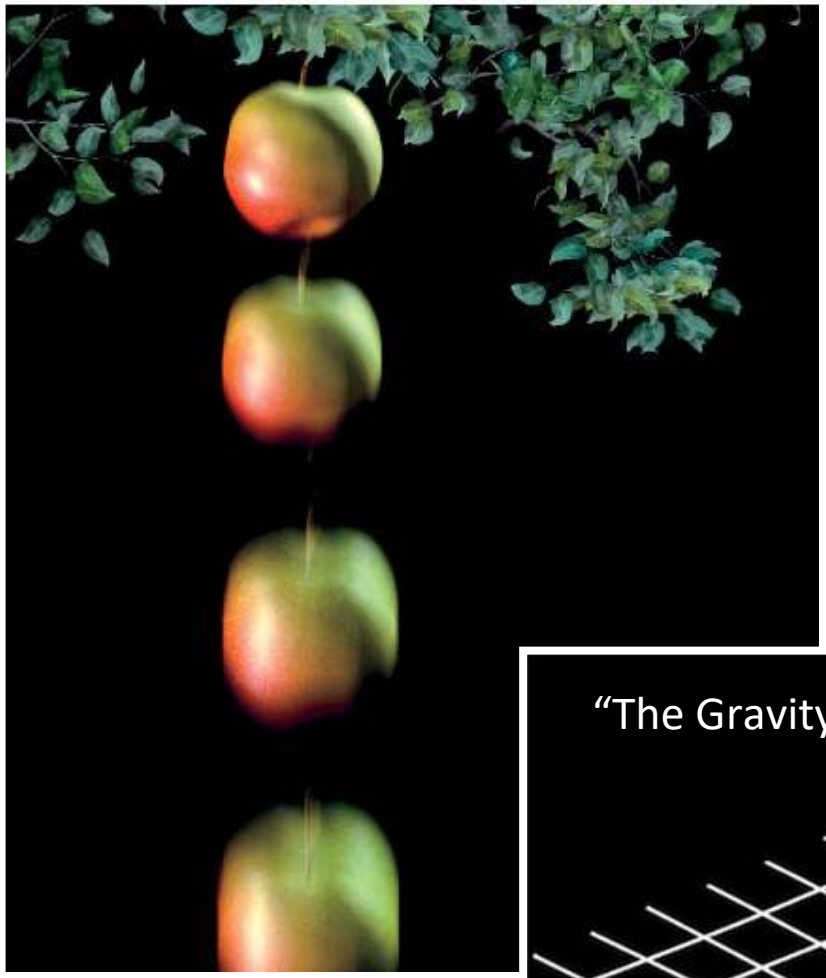


Aristarchus of Samos
(310-230 BCE).
Ahead of his times!



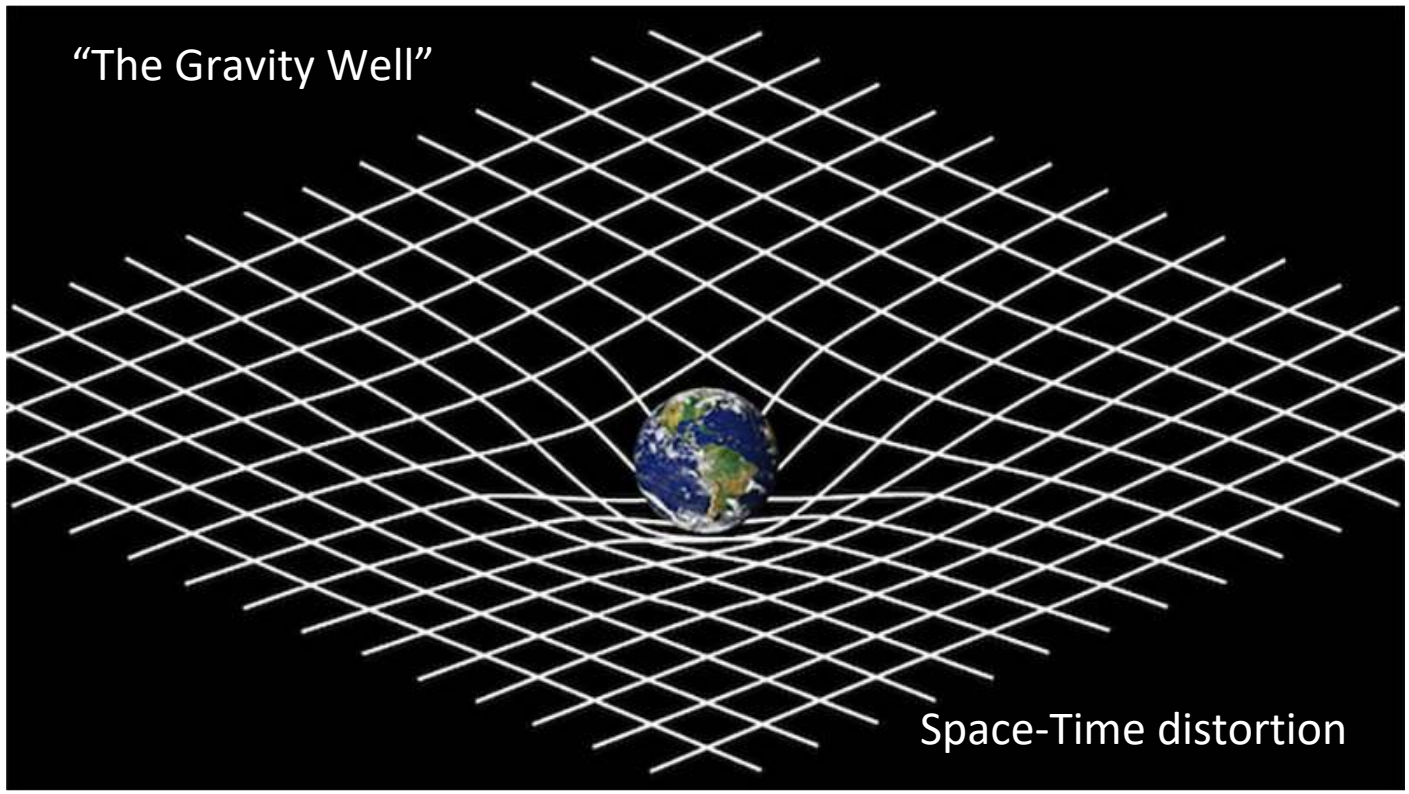
Nicolas Copernicus
(1473 – 1543)
Modern Astronomy!

Sir Isaac Newton
(1642 – 1727)
Father of Physics!



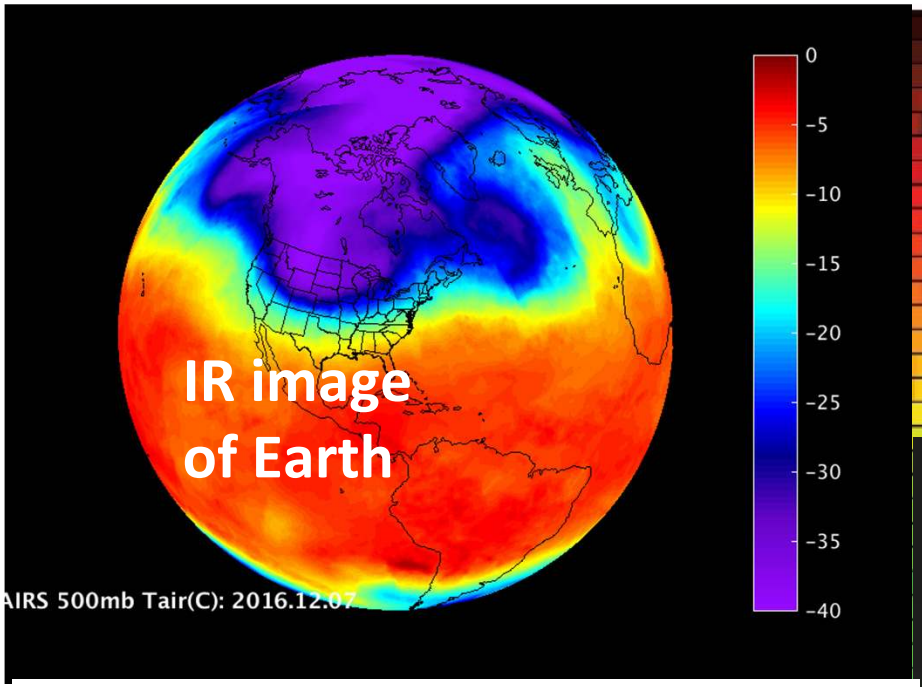
## Planetary motions and forces – from Newton's apple and gravity to Einstein's view of space-time.

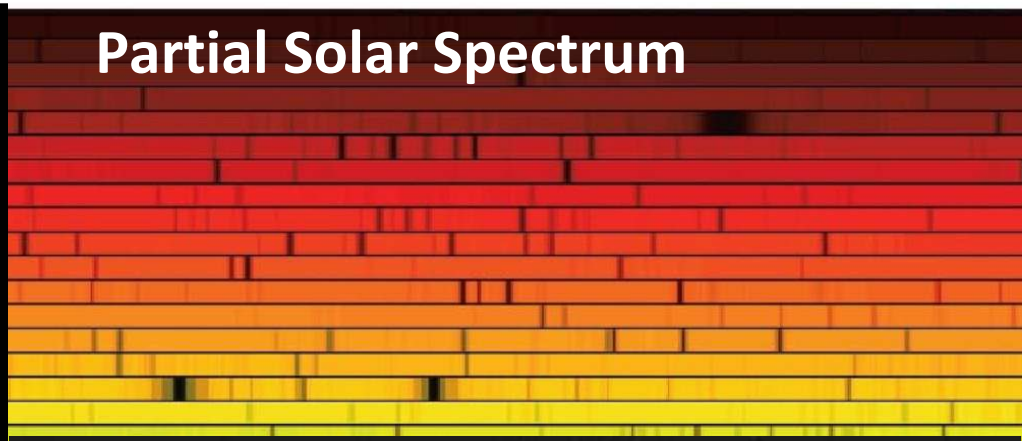
$$F = G\frac{m_1 m_2}{r^2}$$

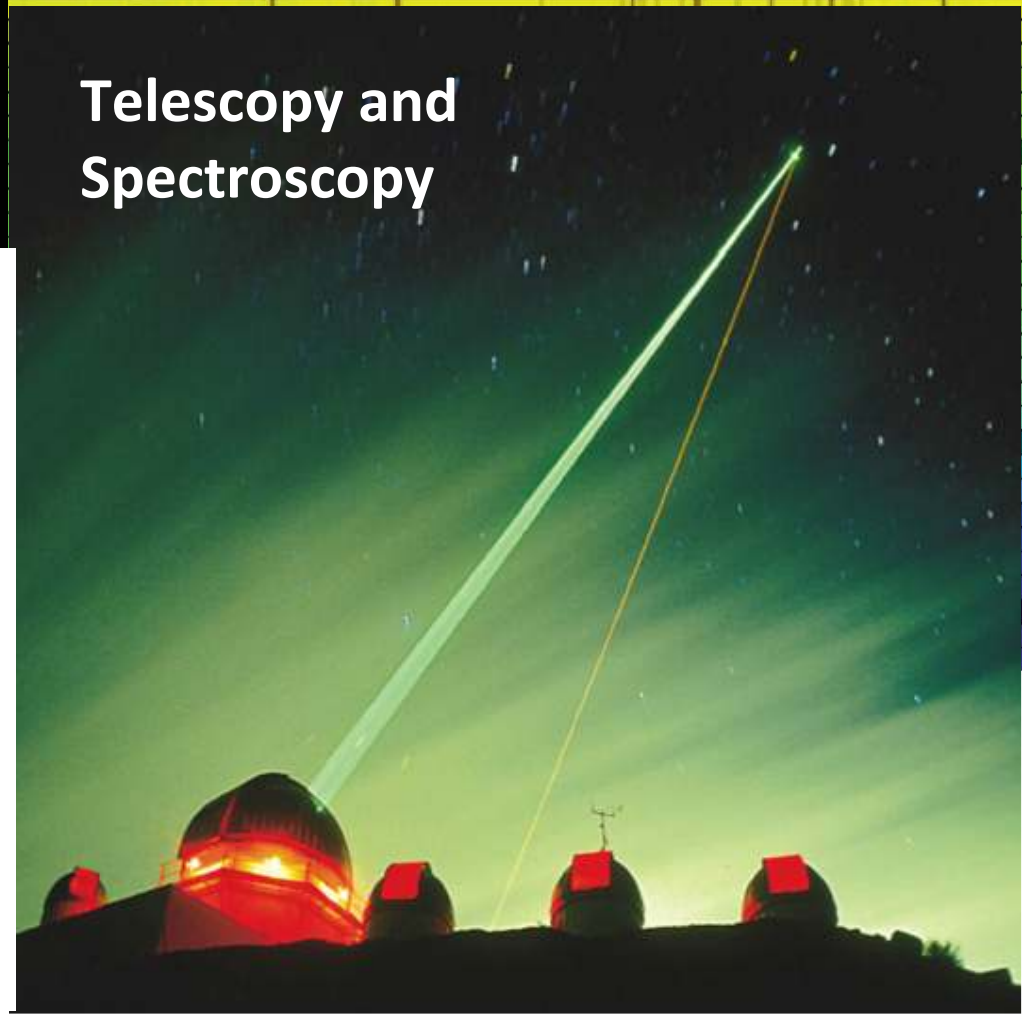



# $E = mc^2$

An equation that almost everyone knows……

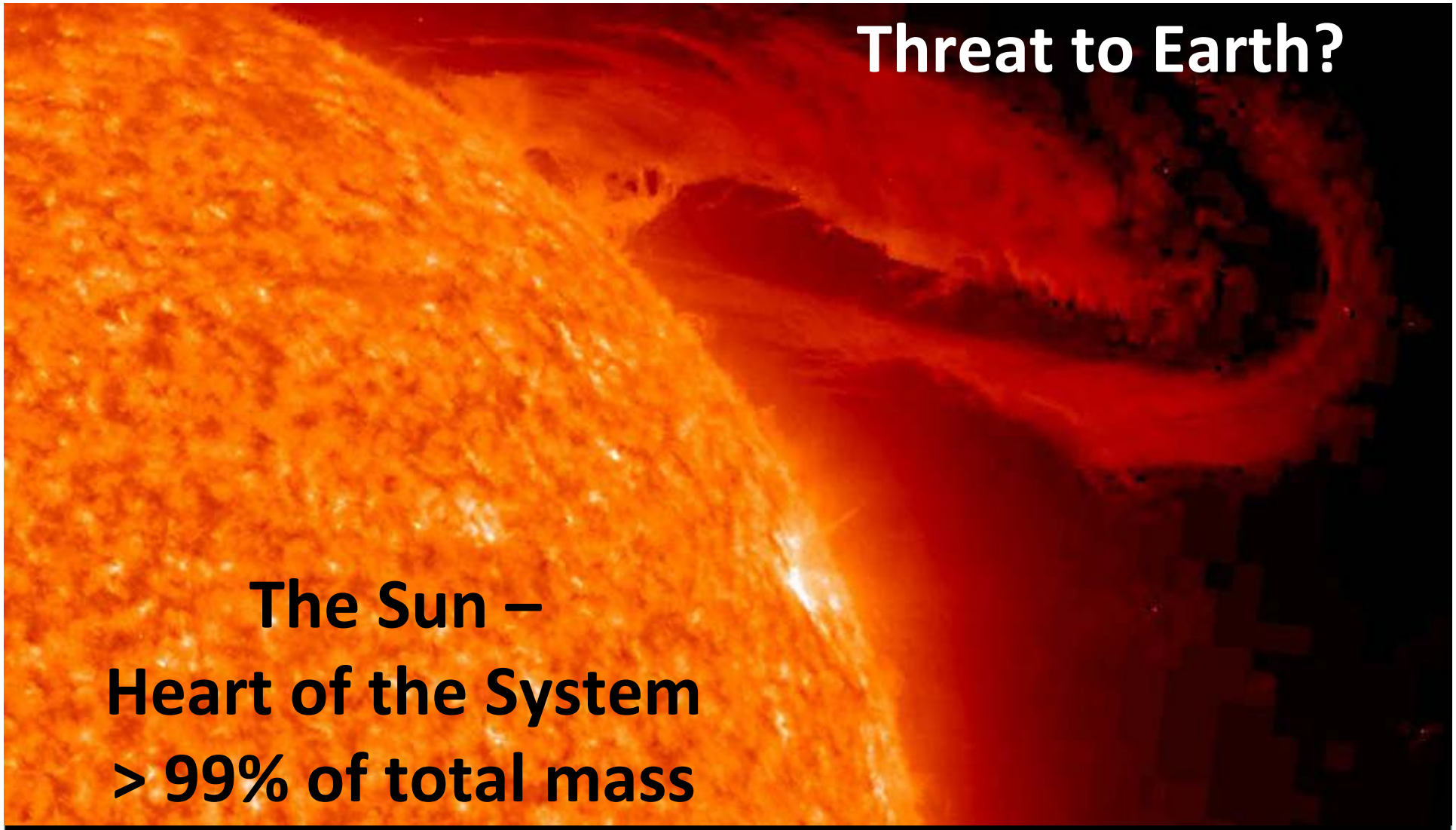


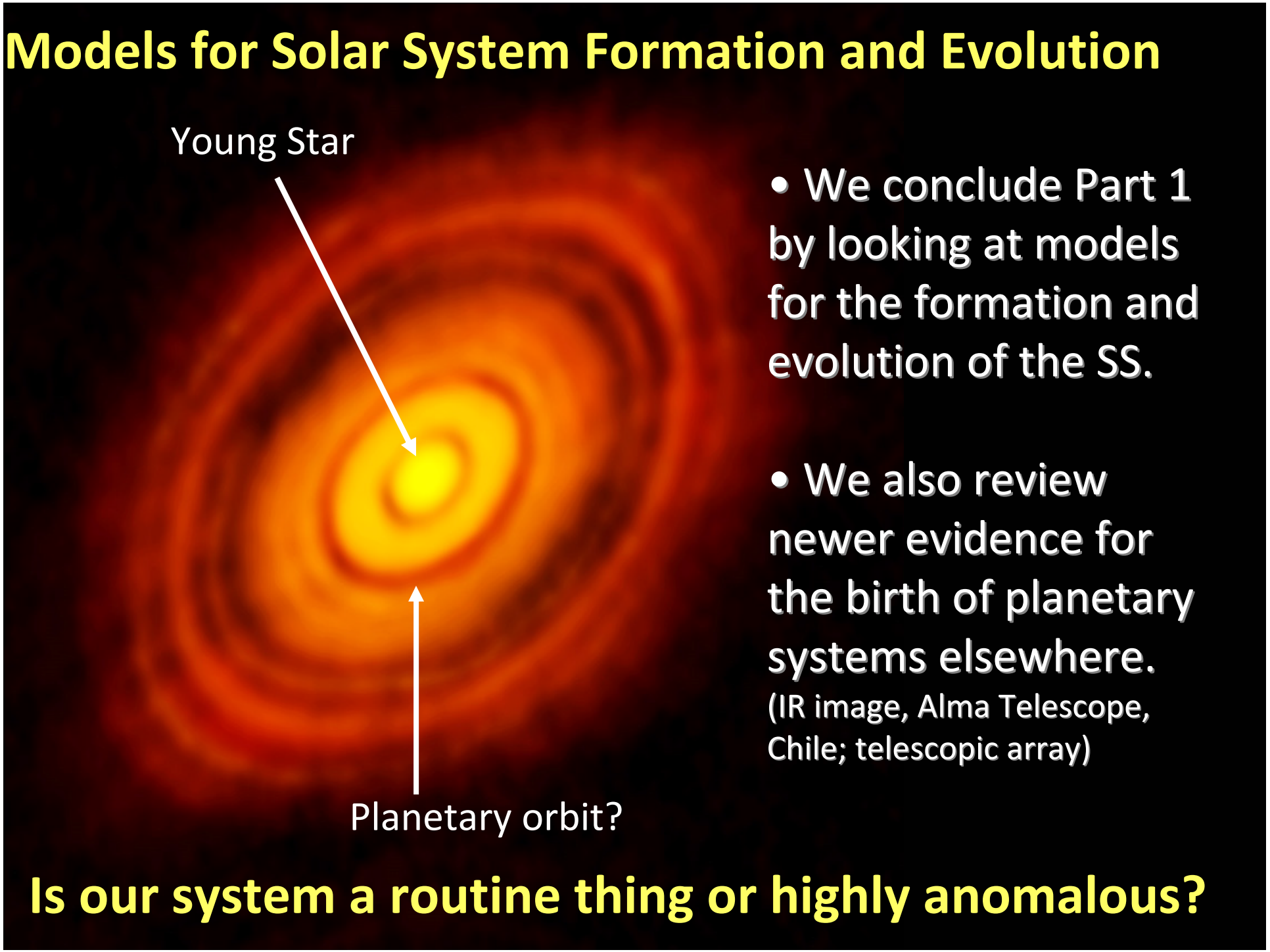

# Energy in the Cosmos

- **Much of what we learn comes from the use of remote sensing using EM radiation – and this is also the primary source of energy in the Universe.**




- We will consider the Sun, which essentially defines the system, and without which we would not exist. How does it work? Is it always benevolent or potentially hazardous? How long will it exist? What is the evidence for other planets near other suns?

# Models for Solar System Formation and Evolution

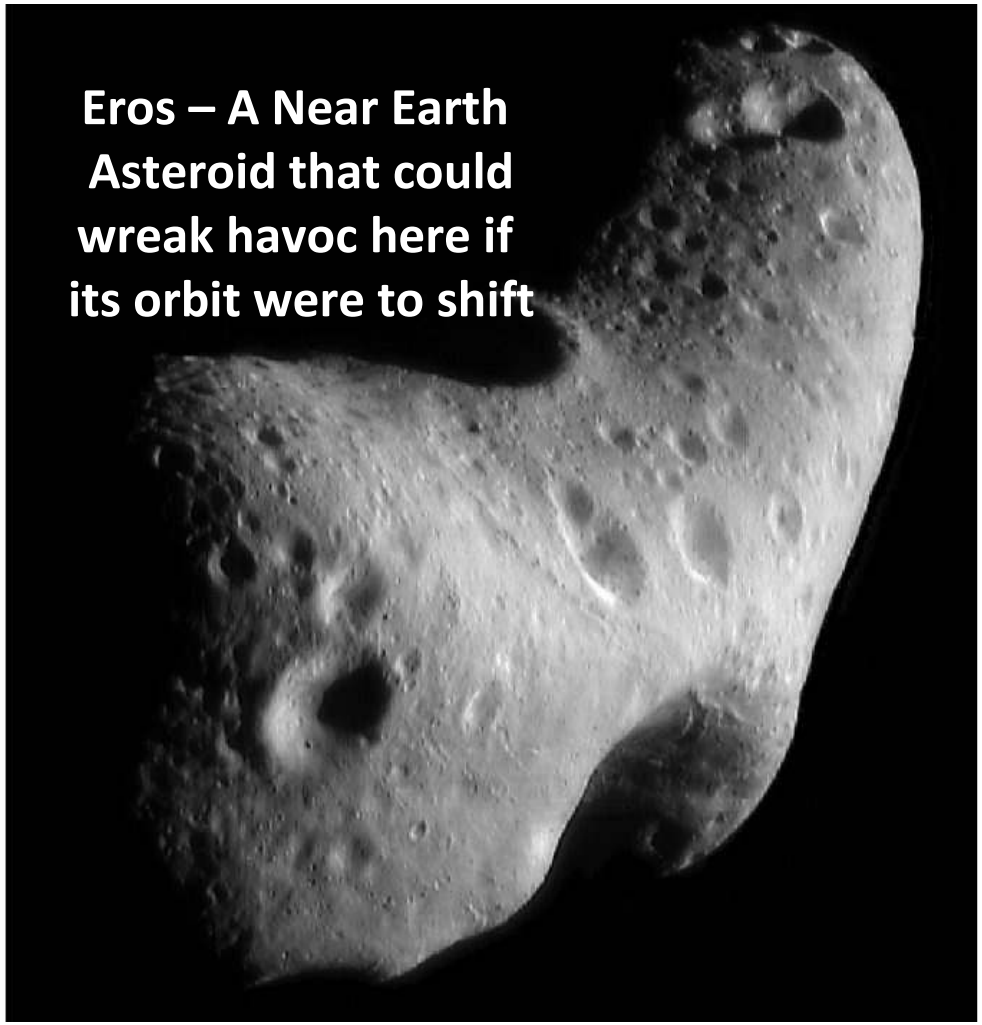



- We conclude Part 1 by looking at models for the formation and evolution of the SS.

- We also review newer evidence for the birth of planetary systems elsewhere.
(IR image, Alma Telescope, Chile; telescopic array)

**Is our system a routine thing or highly anomalous?**

# Asteroids and Meteorites – Construction Debris Vital Information about the Earliest Solar System



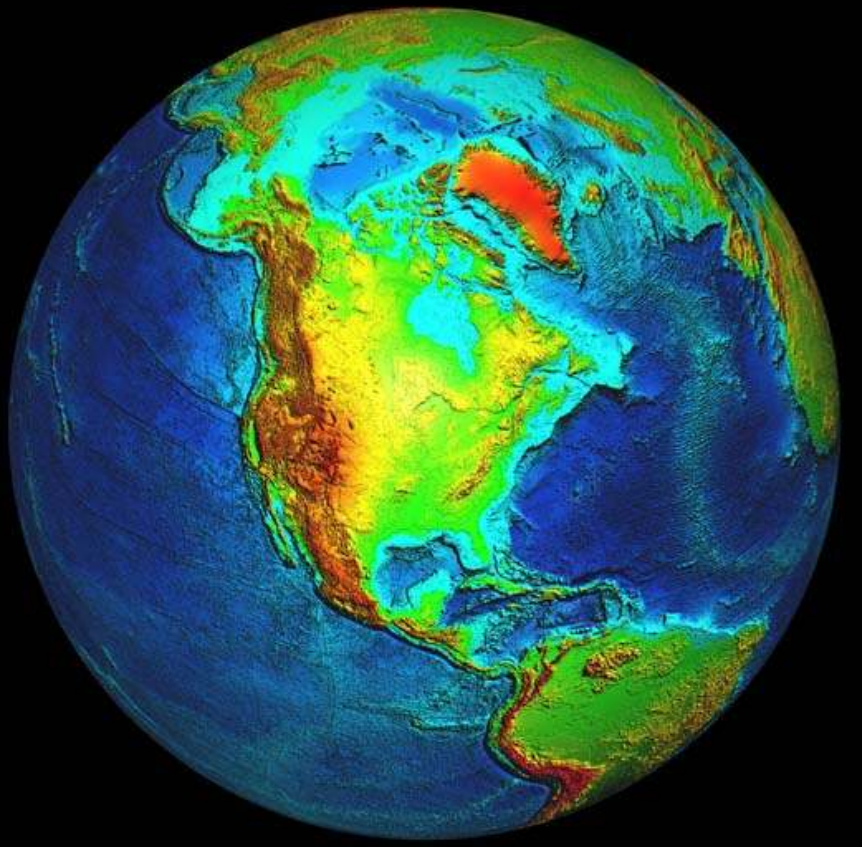


- These are the key to the formation of the terrestrial planets. They tell us about our own world as well as the birth and death of others.


- **Historically, comets were commonly regarded as bad omens**
- **Predicting comets was a *major* challenge for the ancients.**
- **These are icy and gaseous objects, and they come from the outer limits of the system. They remain very mysterious in many ways.**

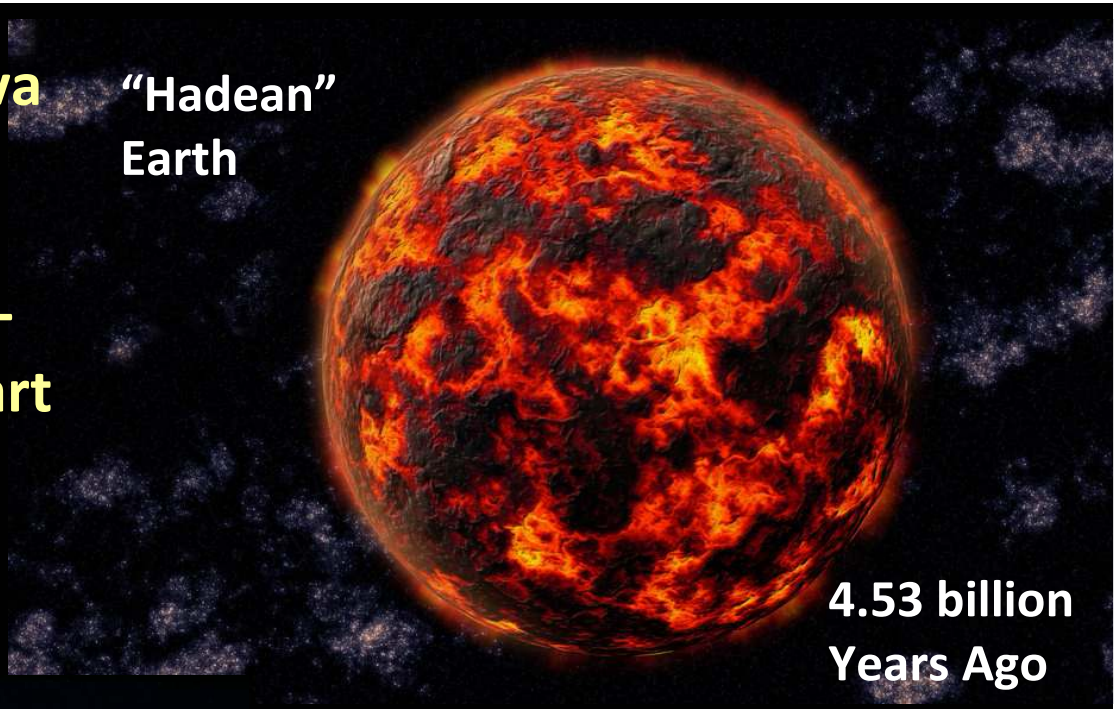
# The Living Blue Planet: Truly Amazing

"How strange that we should call it Earth, when so clearly it is Sea"
– Arthur C. Clarke, author of "2001, A Space Odyssey"



Surface Elevation of Earth with Ocean Water Removed (red = high; blue = low)

- Earth at the beginning. Lava oceans, huge meteorite impacts, poisonous gases, rapid rotation, irradiated – a hostile cradle for the start of life's journey.





- Earth today. Temperate, with oceans, oxygenated atmosphere, 24h day, safe from radiation, full of life at all scales - A world transformed, mostly because it's alive.

**Life (and Humanity) are part of the EARTH SYSTEM !**

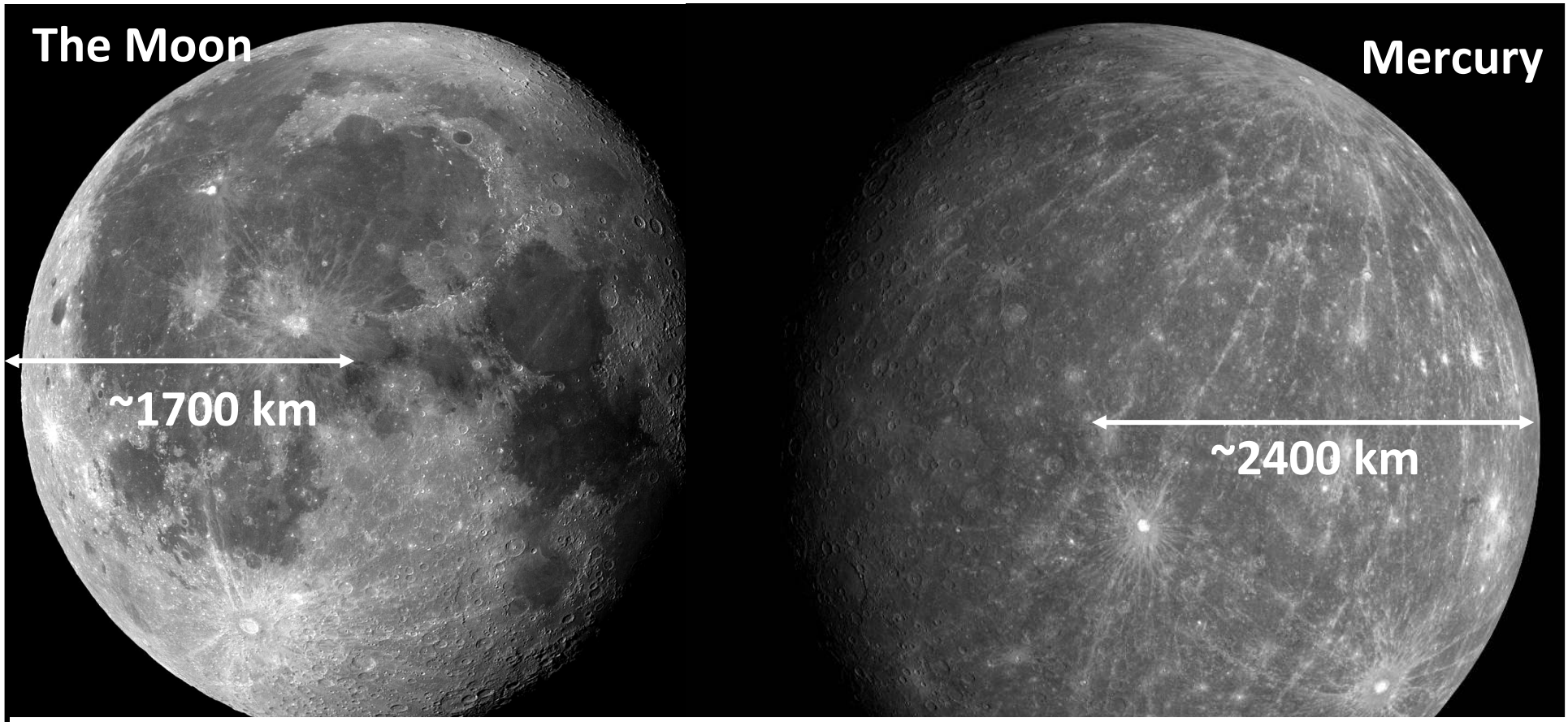
# How do we cover the Earth in Two Classes?

- With considerable difficulty!

- If you have completed an Earth Science course this will help, but **if not you need to look at Module 2.** This will really help you with some important concepts.

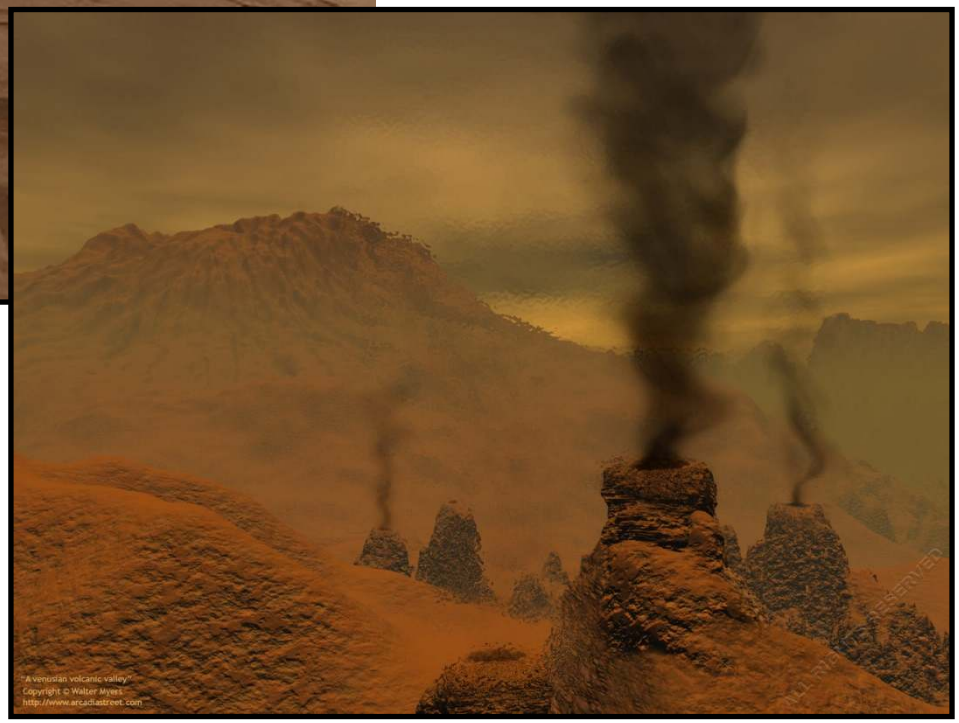
- We break discussion into two parts. The first tackles the Solid Earth – i.e., internal structure, rock types, continents, oceans, plate tectonics, etc., etc. The second part focuses on Earth's surface environment and its controls, with emphasis on the atmosphere and the hydrosphere (water) – the latter is especially critical from a planetology viewpoint. But they are connected.

# The Moon and Mercury – Parallels and Contrasts



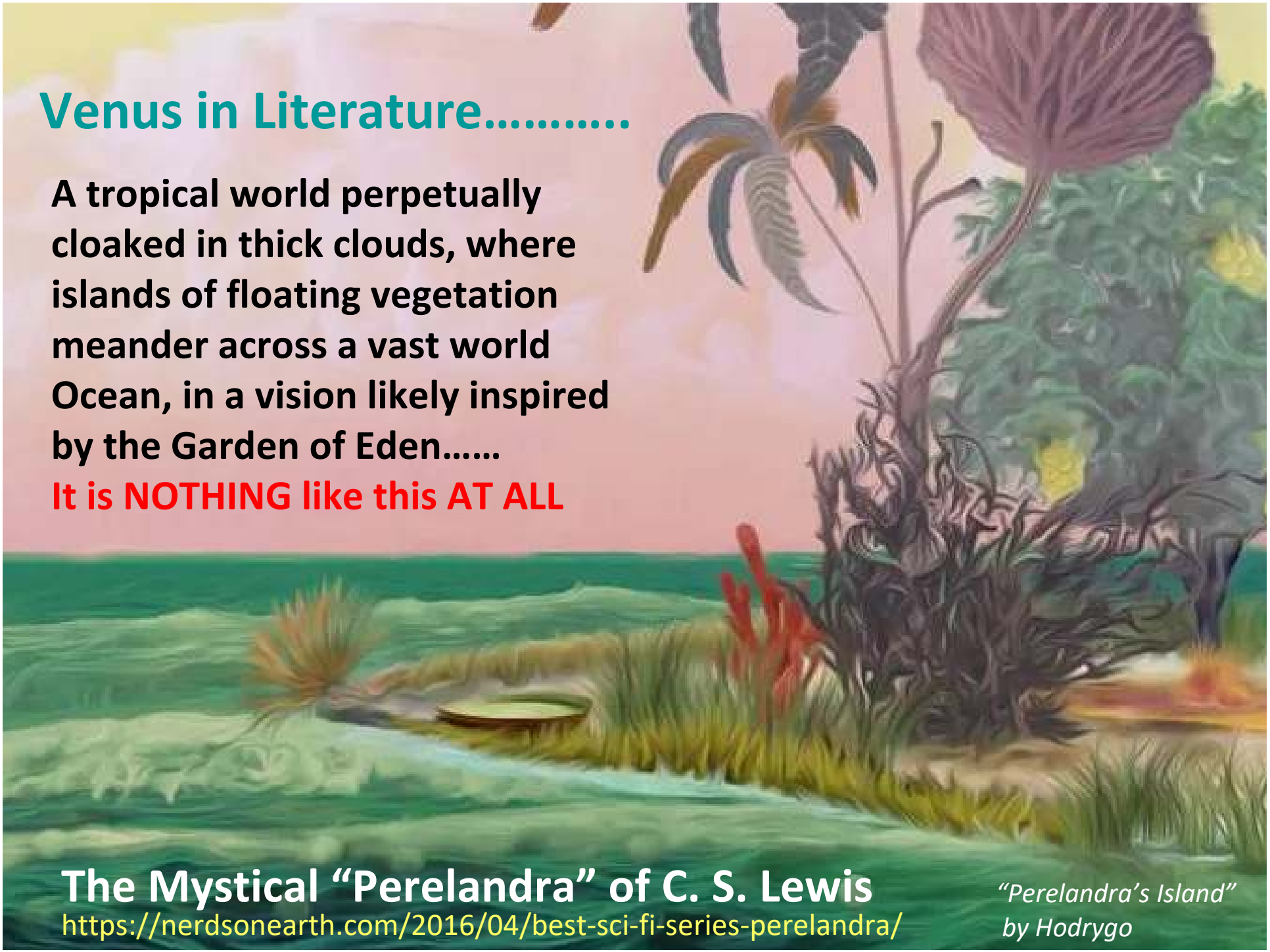

- The Moon may be a satellite but it's planet-sized. It plays a vital role in aspects of the Earth's stability but may have been formed through an event that could have been catastrophic. Mercury is similar in many ways, but rather different in others. These help us understand 'small terrestrial planets'. Could we ever live on either of them?


**An image of a typical Venusian landscape from a Soviet Venera lander, shortly before it melted down and died. Venus may have processes that are like Early Earth….maybe.**



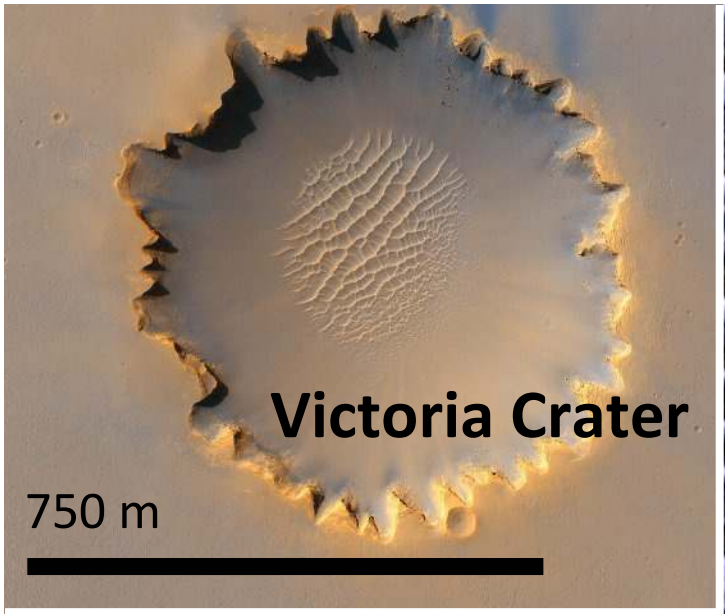
Digital Artist Walter Myers created this work intended to visualize the volcanic landscapes of the planet. But compared to Earth, Venus is actually pretty flat.

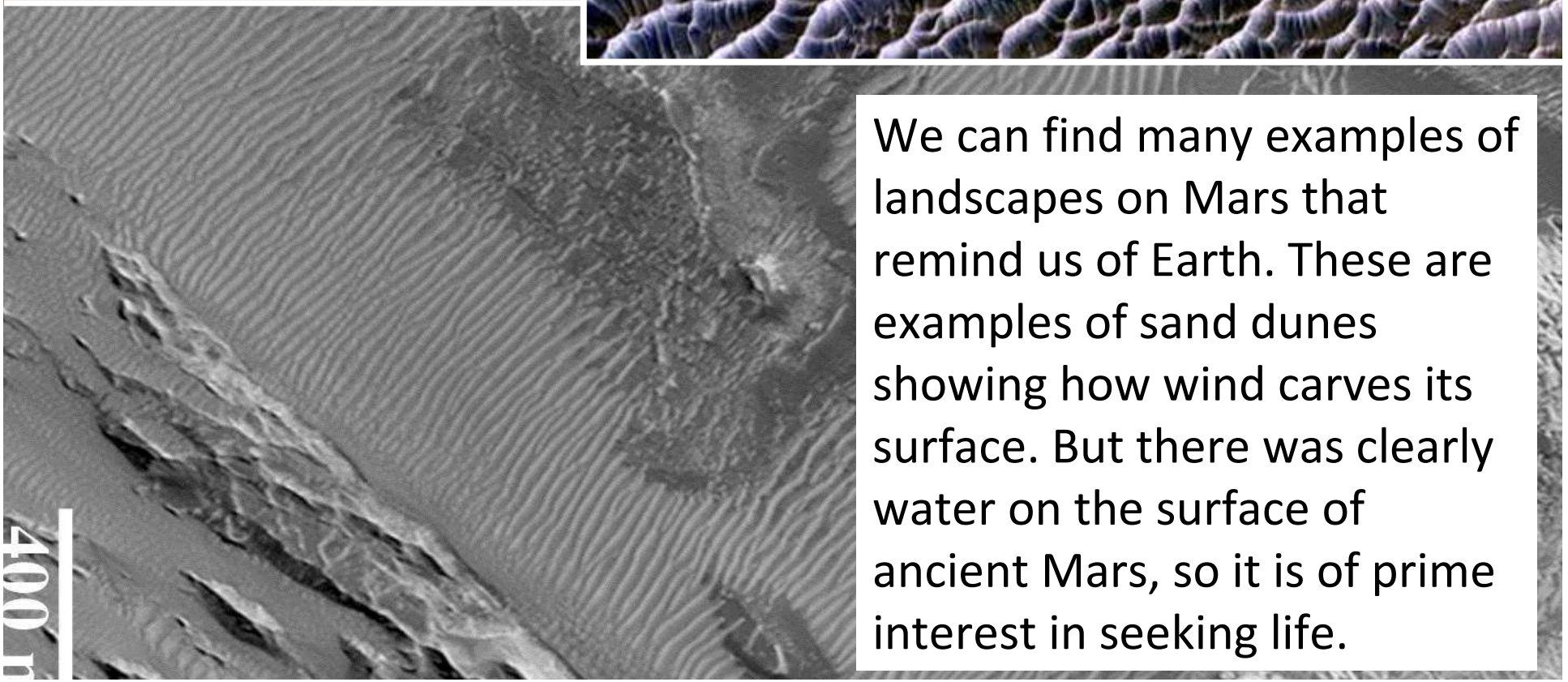
(for more of Walter's interesting work, see [www.arcadiastreet.com](http://www.arcadiastreet.com))


Venus in Literature……
A tropical world perpetually cloaked in thick clouds, where islands of floating vegetation meander across a vast world Ocean, in a vision likely inspired by the Garden of Eden……
It is NOTHING like this AT ALL
The Mystical "Perelandra" of C. S. Lewis
https://nerdsonearth.com/2016/04/best-sci-fi-series-perelandra/
"Perelandra's Island" by Hodrygo

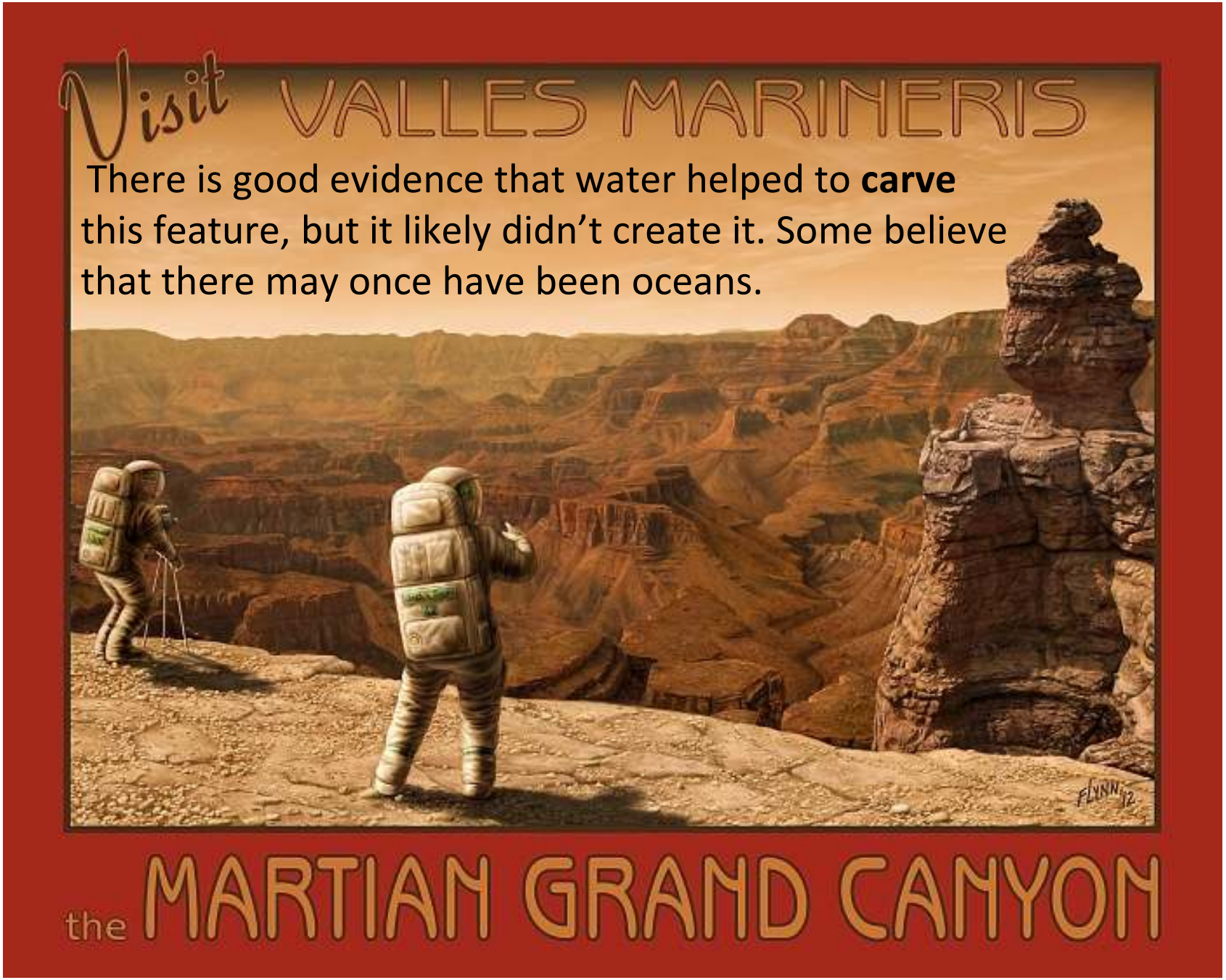
# Mars – The Best Real Estate Available


- Mars is a fascinating world, and parts of it are Earth-like if you compare it to our desert regions. It once had running water, and we find ancient sedimentary rocks. Will we find fossils one day?
- "Mars ain't the kind of place to raise your kids; in fact, it's cold as Hell" (Elton John, from "Rocket Man"). But it's the best bet we have.

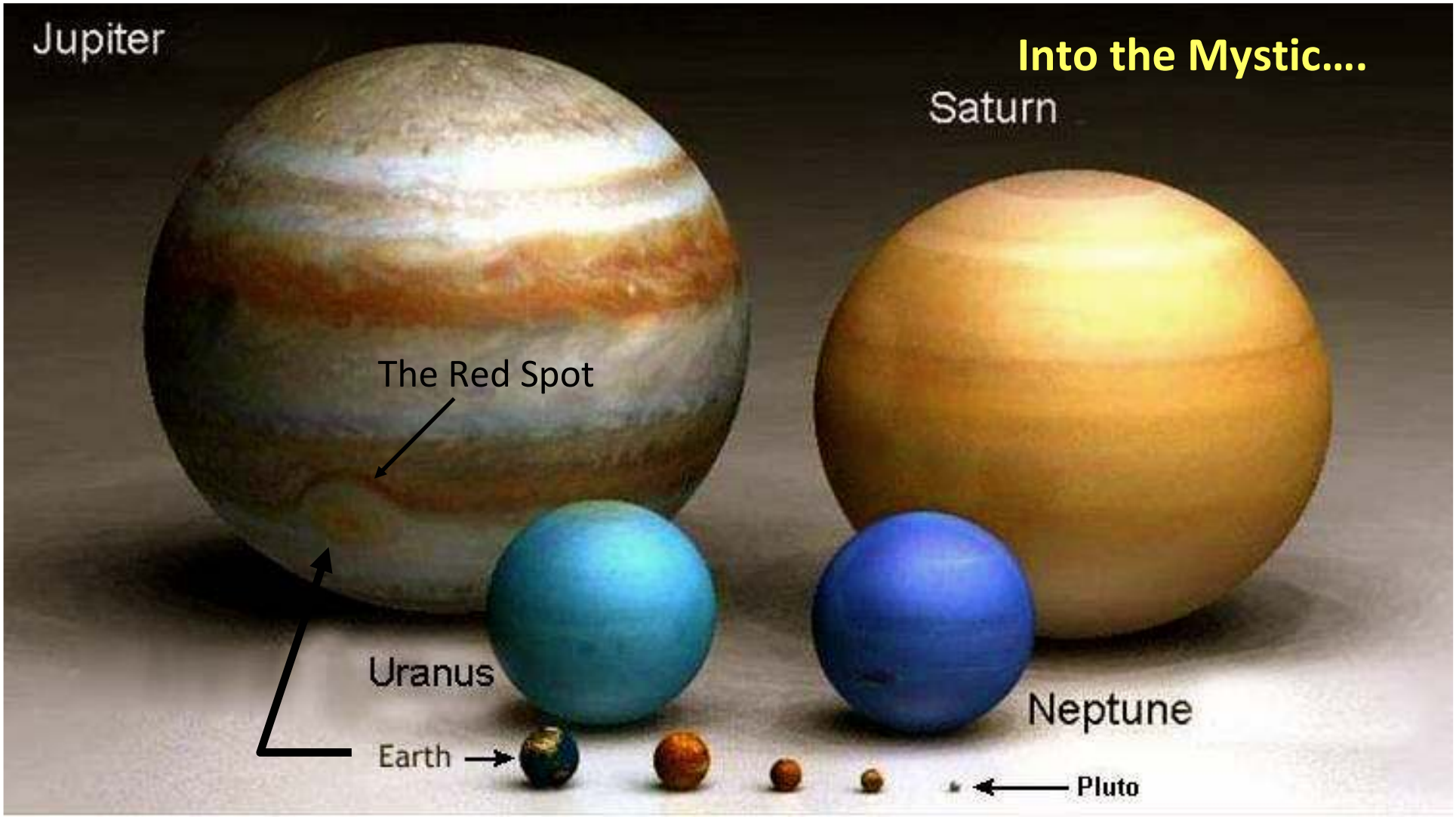


We can find many examples of landscapes on Mars that remind us of Earth. These are examples of sand dunes showing how wind carves its surface. But there was clearly water on the surface of ancient Mars, so it is of prime interest in seeking life.



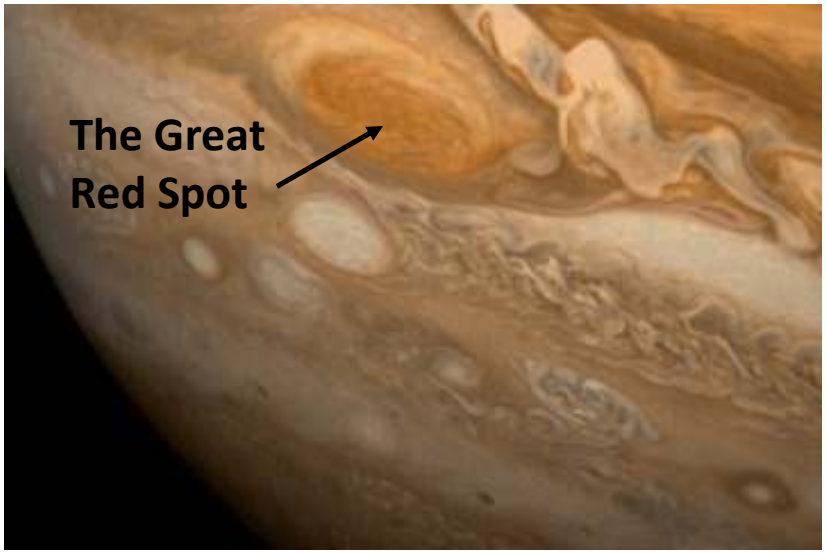

**This is probably not an accurate analogy in Planetary Science !**

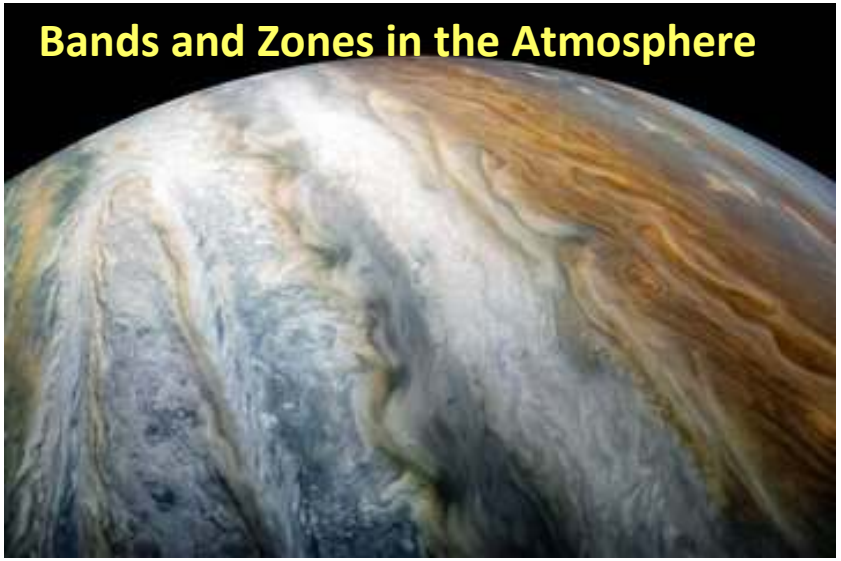



• And then, the Outer System. All the rules break down, and we enter a truly alien realm. But, remember that on the scale of the Universe, gas giants and ice giants are likely the most common planets. But are our giants anomalous??

# The Ongoing Juno Mission – Some Information

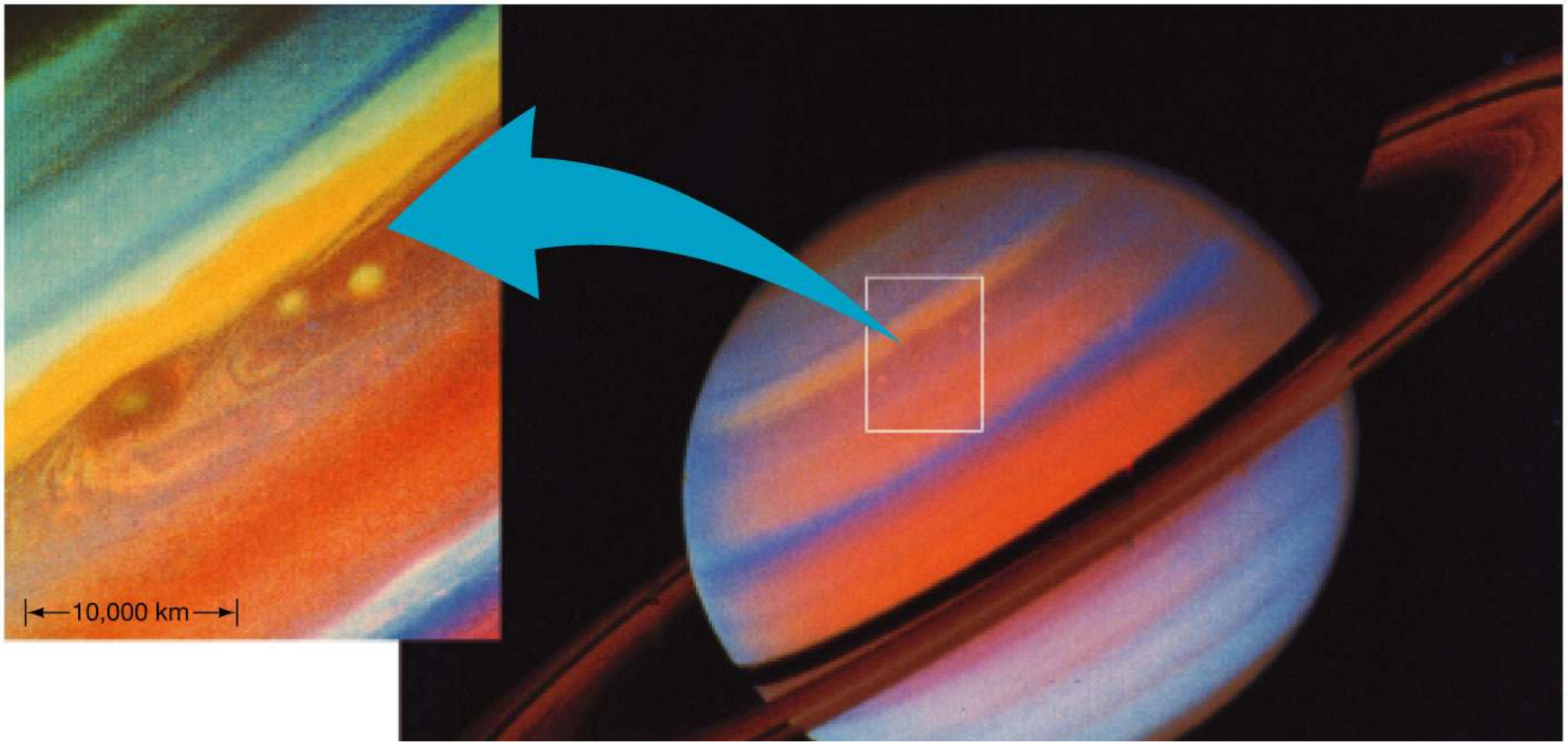
- Juno is an orbiting space probe, named for Jupiter's wife.
- It is in a polar orbit that will eventually allow it to image and monitor all parts of the planet's atmosphere and other physical aspects like magnetic fields and radiation.
- It is gathering vast amounts of information, but is best-known for its stunning visual imagery.



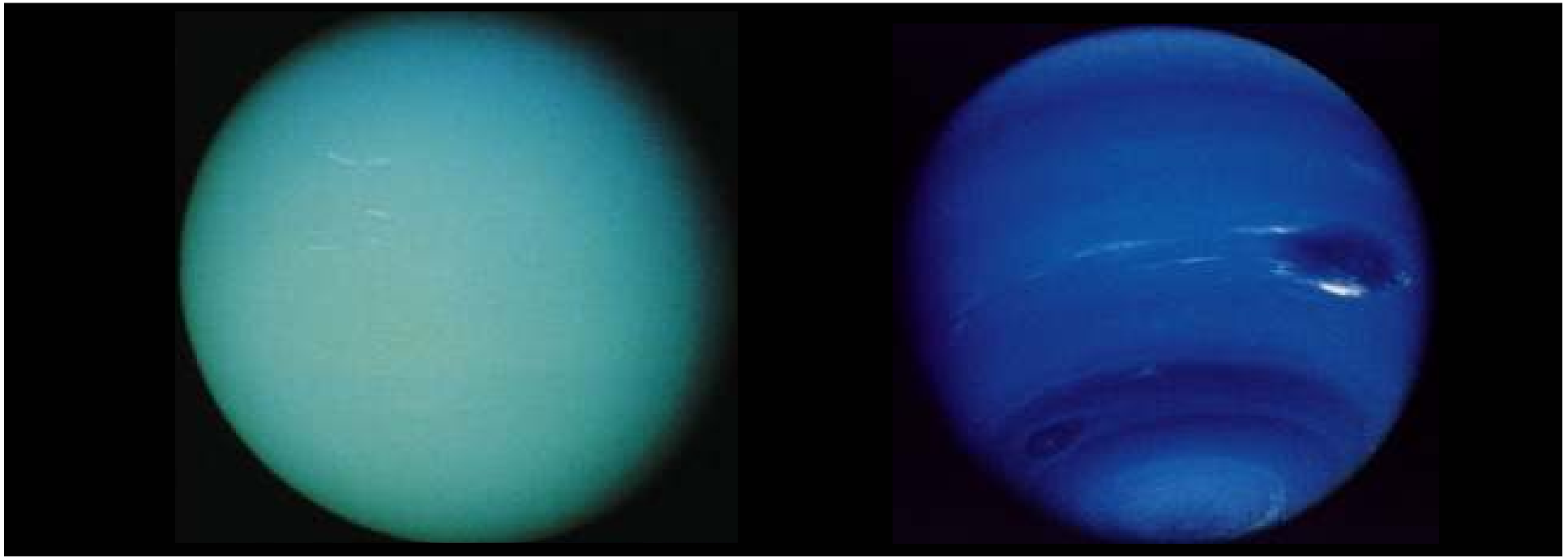

**Many things about the giant outer planets remain mysterious. They also have an amazing collection of interesting moons.**

# Saturn: The Beauty of the Solar System…….




• Enhancement of images (like false colour technique) gives amazing views of banding and weather systems that are closely similar to those more easily seen on Jupiter. The pattern of zonal flows in the atmosphere is different than seen on Jupiter, although no clear reason for this is apparent. These worlds are different in many ways.

# Uranus and Neptune – The Blue Twins



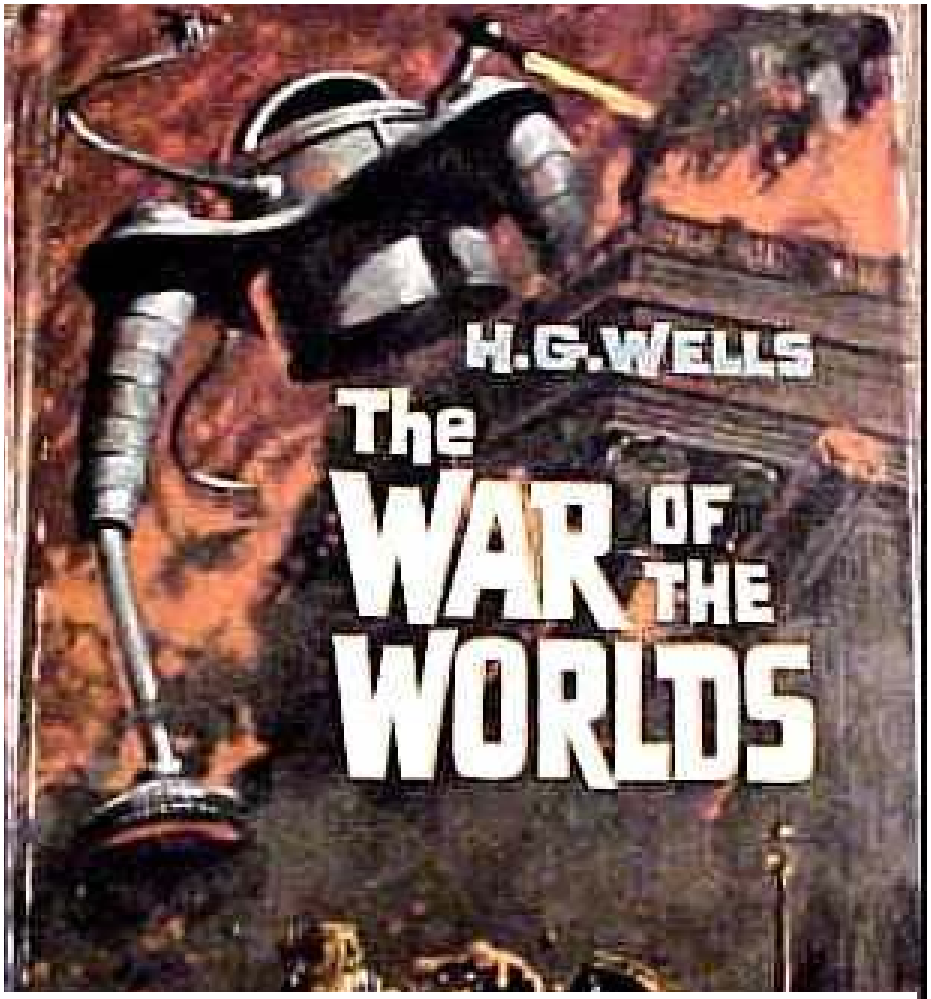
- These are almost twins, in gorgeous blue shades. But we know little about them compared to Jupiter and Saturn. Information is largely from Voyager missions.
- Affinities with Jupiter and Saturn, but also important differences. Many satellites but only one large moon (Triton, at Neptune) which is very odd.

# Encounter with Arrokoth – January 2019

- **The New Horizons mission is now out in the Kuiper Belt, beyond the orbit of Pluto. It has its encounter with Arrokoth in January 2019: it is the most distant object yet visited.**

- **The complete data were downloaded at a speed of 1-2 Kb per second – it took > 2 years to completely transfer all the information to Earth, and will take longer to digest it.**

*(False colour NASA image)*


- **We close our voyage with the biggest question of all – LIFE!**
- We can document the evolution of life on Earth, and we now better understand that it has influenced the history of the planet.
- Where might we look for life in our system, even if extinct? Might there be life around other stars? Are we being looked for by others?

# So, could several galactic species drink together?

- In the original “Star Wars” movie, there is a famous scene where members of several ‘intelligent’ species are drinking together in a sleazy bar on the planet Tatooine. But could this happen? Is there life in the stars? If so, what are the chances of two or more species coexisting in time? It doesn’t seem likely that they’d all enjoy alcohol.
- We will discuss the famous ‘Drake Equation” and its implications……

- As you now know, we have a lot to learn and a very long way to go…..

- But before we can relax in our acceleration couches, we need some background science language and some Earth Science concepts.

- If you think your basic science is rusty, or you have never done any Earth Science; you need to look at Module 2!

**"Space News" Items are topical items linked to the main subjects of each module, and will appear on the site as we go.**

- ***These are in the same format – I call them 'classlets'. I invite you to do your own reading and look for suitable items – send me details and links. In this way, you can actually CONTRIBUTE to the course as you learn……..***