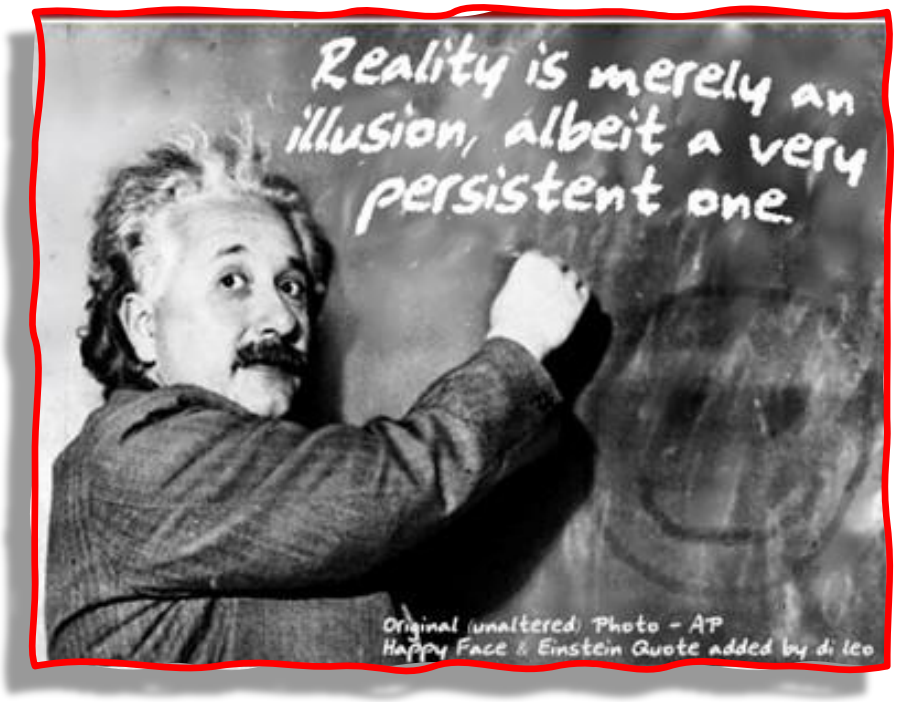
LECTURE NOTES FOR WEEK 2: SCIENCE

(BASED ON THE READING "PARADIGMS LOST" BY DAVID P. BARASH)



What is Science?

"Science does not purvey absolute truth, science is a mechanism.
It's a way of trying to improve your knowledge of nature,
it's a system for testing your thoughts against the universe and seeing whether they match."
—Isaac Asimov

Plato's *Allegory of the Cave* teaches us that we can be fooled by the world around us, by what we can "see" with our own eyes or what we are taught in education and what is accepted/assumed knowledge (think about the news, social media, claims on the internet, pseudoscience, hoaxes, bad science, misconceptions, misinterpretations, strange histories, commercials, products, conspiracies, government perspectives, stories, fake news, …).

This ancient story illuminates a path out of ignorance and towards wisdom, but the path is not an easy one. It's difficult to face a new and different truth that contradicts our old comfortable notions. We will see these ideas echoed in the changing **paradigms** of science. As you go through these notes, keep in mind the **Enlightenment Interpretation** that Jim gave us in last week's opening lecture on *The Allegory of the Cave.*

Paradigm & Paradigm Shift

Definition of Paradigm:

- ✓ "... It stands for the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community." Thomas S. Kuhn, The Structure of Scientific Revolutions, 1962, 1970
- ✓ A worldview, a way of looking at reality; a frame of reference
- ✓ Thinking inside a particular box

It's the way you think (and ask questions) about the world with the knowledge and understanding you have *at the moment* (think of the prisoner in the cave and then outside: Paradigm Shift … a change of worldview, the way you see and think about reality).

Why is this important in the world of science and the impact of scientific discoveries? From Barash's article:

- ✓ "Many scientific findings run counter to common sense and challenge our deepest assumptions about reality."
- ✓ "[the] paradox [is] that the more we learn about reality, the less central and self-important is our own species."

Examples of Paradigm Shifts:

- ✓ Flat Earth -> Spherical
- ✓ Geocentric -> Heliocentric (in today's lesson)
- ✓ Unchanging Earth -> Continental Drift (proposed by Alfred Wegener, early 1900s; rejected at first)
- ✓ Unchanging species -> Evolution (all life is connected; all life changes. A future lesson.)
- ✓ Mysterious causes of disease -> an explanation involving bacteria and viruses
- ✓ A world without nuclear energy -> the creation of the atomic bomb and all its consequences
- ✓ Etc. (think of some discoveries or inventions in your own life and how they changed the way you behave and see the world).

"Our reality hasn't become unstable;
it's just that our understanding of reality is of necessity a work in progress."
—David Barash

Patterns: The Origins of Science

- ✓ The fundamental assumptions of science:
  - there is order in the universe.
  - we believe that the universe is understandable
  - we assume that there is an external reality independent of the human mind (although this can get weird in some interpretations of modern physics).
- ✓ Once we observe regularities or patterns, we think we may be able to figure out why they occur … and when ... We seek out a causal relationship, *i.e.*, if this action happens then that event will follow …
- ✓ Mathematics is a tool that provides the precision needed to describe nature … to make predictions.
- ✓ After studying these patterns, science—or more specifically—the **Scientific Method** is the powerful tool used to understand the ***natural world*** by asking the big question, **'**How does the Universe work (now, in the past, and in the future)?' ***Science seeks natural explanations for natural occurrences***.

Generally, these are the important parts of a scientific method:

- ✓ **Observe:** Patterns, Behaviour, Facts, Laws of Nature
- ✓ **Ask Questions:** Why is the world this way? What is the cause of a particular behaviour? What will change? *Etc. And if this is followed by a 'What If?' question, this can lead to the next step:*
- ✓ **Explain:** Construct **hypotheses** (educated guesses). Given your understanding of the world, it's your best attempt at an explanation of what is going on. You use the **Principle of Simplicity** (Ockham's Razor), with which we assume that the best explanation of reality is probably the simplest.
- ✓ Armed with your hypothesis/hypotheses, you make **a prediction(s)** of what will happen next.
- ✓ **Test: Experiment** (technological manipulation or observation). And test again, and again. Other experts also do their own testing to check your results and predictions.
  In testing our ideas, there is an important concept called **Falsifiability** and it's this: **experiment can never prove a scientific theory as absolutely true,** only falsify it; in other words, (try to) prove it wrong. Science can never assume that we have found the absolute truth of a thing as new evidence can change everything. Paradigms are not permanent. A scientific theory must make predictions that can be potentially falsified; science requires the possibility to prove a hypothesis wrong. ***If an idea, hypothesis, or theory cannot be tested, then it is not a scientific statement, and it is not science.***

In short, once you guess as to how reality works, you have to be prepared to be proven wrong … then change your guess or tweak it until you have a better description of the world … which again gets tested … From Barash's article:

- ✓ "The capacity for self-correction is the source of science's immense strength…"
- ✓ "Science is a process, which, unlike ideology, is distinguished by intellectual flexibility, by a graceful, grateful (albeit sometimes grudging) acceptance of the need to change our minds, as our understanding of the world evolves."

In principle this is what one strives for; in practise, it's not always easy …

Two Paradigms and a Paradigm Shift: An Example of Science at Work

Ancient Greek "Commonsense" Observations (what we see)

When the ancient Greeks looked at the world around them, seeing the behaviour of the motion of celestial objects, they observed (and believed) that ….

- ✓ ***The Heavens (all the stars and celestial objects) are perfect*** and unchanging (like the idea of a circle), the Earth is not. Earth's imperfections are obvious, but the ancient Greeks believed that circles represented perfection. Circles are objects that are unchanging and pure of form (the ancient philosopher Plato had quite an influence here).
- ✓ All of the Heavens spin ***around*** the Earth (see time-lapse image to right). If you carefully watch the stars move across the sky, you'll see them circle or orbit around the North Star (if you live in the Northern Hemisphere), carving out paths of perfection (same pattern in the southern hemisphere except you can't see the very dim south star).
- ✓ Over the course of time, the planets wander (move) across the starry background, apparently circling the Earth.
- ✓ The Sun and the Moon rise and set. They *appear* to circle the Earth.

Star Trails above the Saint-Étienne – Gorges de la Loire Nature Reserve in France.
[Source: 0x010C /CC BY-SA].

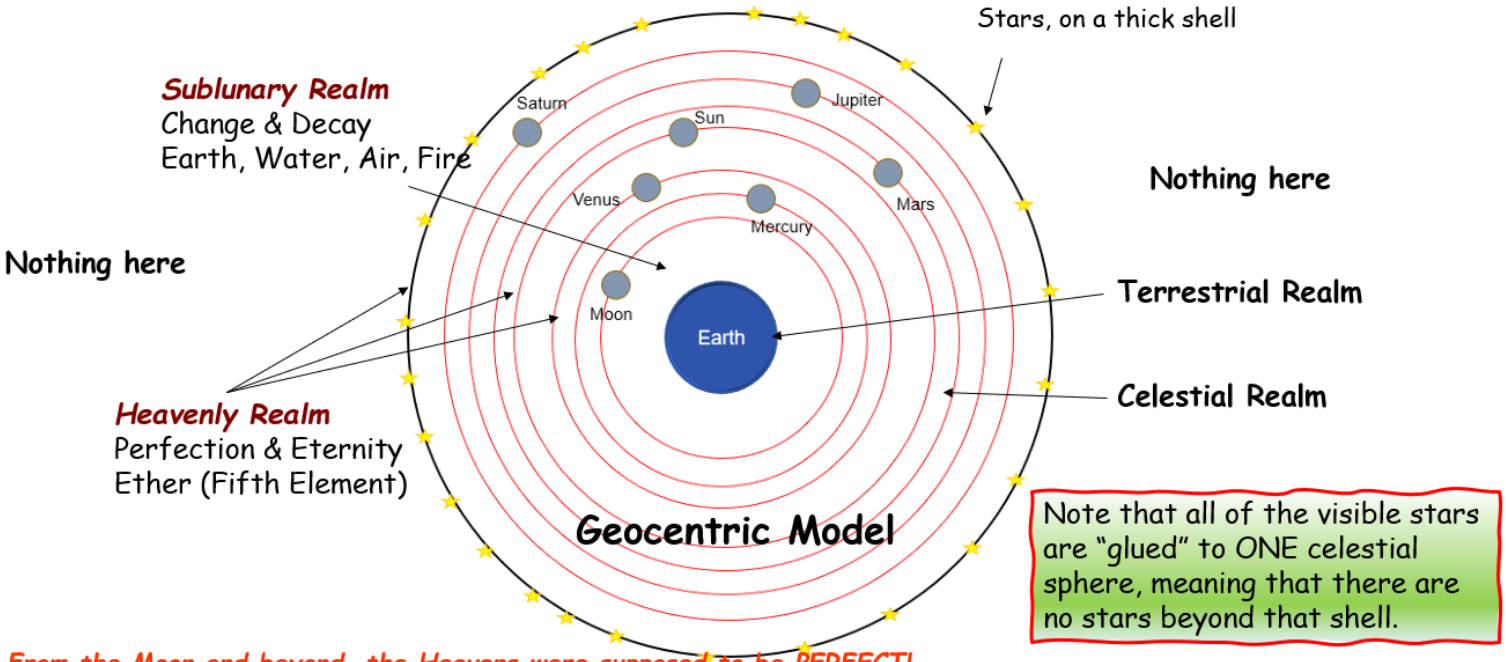
- ✓ The Earth ***does not move through space*** because ***we do not feel it!*** According to the physics of the day, if the Earth did move through space, then the atmosphere or flocks of birds would be left behind ... and if you jump up, you will not land in the same spot because the Earth would move on without you (Try it. Do you land in the same spot or does the wall in your room rush up to smack you?).
- ✓ The Earth ***does not spin on an axis*** because we do not feel it! Similar logic: if it's spinning then you should get thrown off into space.

Ancient Greek Hypotheses (educated guess(es) to explain what we see and why the world behaves a certain way)

- ✓ The Earth and the Heavens are two different, *distinct* realms.
- ✓ Gravity only operated on Earth, not the Heavens (motion in the Heavens had nothing to do with gravity).
- ✓ All this perfectly circular motion is explainable if the stars were attached to a gigantic ***Celestial Sphere*** that rotated around a stationary Earth.
- ✓ The known planets are attached to spheres distinct from the one with the stars, as were the Sun & the Moon. Picture the universe like having the layers of an onion.

It was COMMON SENSE to conclude that the Earth is at the centre of the Universe:

Geocentric (Earth-centered) Paradigm



From the Moon and beyond, the Heavens were supposed to be PERFECT! Circles and Spheres were considered pure and perfect.

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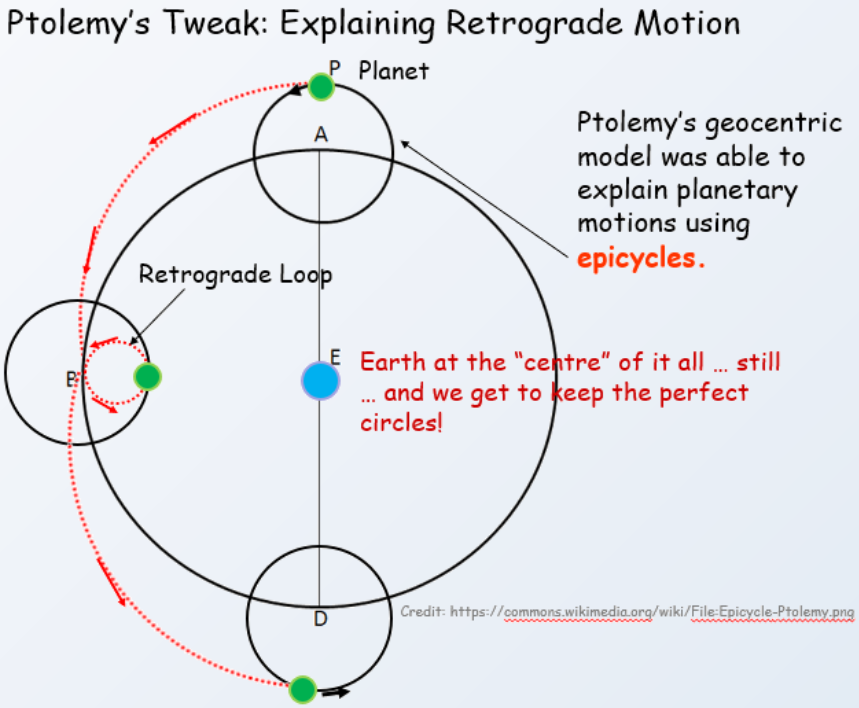
Crisis Point: This view of the Geocentric universe worked ... for the most part, but *retrograde motion* (planets looping backwards) was a problem. Visit Three Years of Saturn for animation.

Here's the Fix: Claudius Ptolemy & the Ptolemaic Model (90-168 CE)

- ✓ So how does Ptolemy's model explain retrograde motion? He introduced even more circles or *epicycles*: a planet not only orbited Earth on a large circle known as the deferent (actually the Earth was not dead centre to this motion), but it also followed a smaller circular path called the epicycle. (Optional: Visit Ptolemy tried to use deferents and epicycles to explain retrograde motion)



- ✓ Planets *really do* go backward in this model, but this "preserved" the assumptions of *Perfection and Eternity* built into the ancient geocentric model, as well as our centrality.
- ✓ His description of the universe stood unchallenged for almost 1400 years, until Copernicus and Galileo. Aside from tweaking and messier epicycles, it worked for the most part.

Another Explanation of the Same Observations: A New Paradigm

Nicholas Copernicus (1473-1543) sought to simplify the increasingly "messy" Earth-centred universe, as the Geocentric model was now riddled with more and more epicycles (and more spheres) to adjust for the observed discrepancies in the motion of the stars and planets as the years progressed. Copernicus was a religious man (he worked for the Church), but grew uncomfortable with the convoluted and complicated cosmology, believing that God would create a more elegant (and simpler) universe.

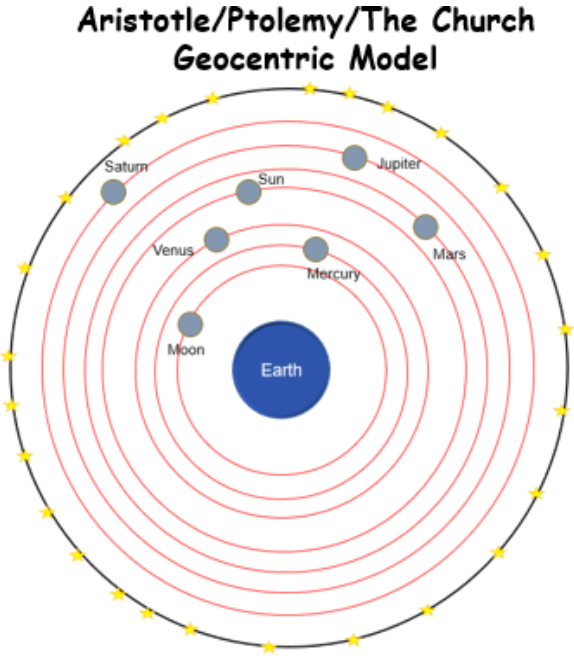
As he proposed his ideas, he was careful to suggest that his "musings" were really harmless speculation and not a true reflection of reality; he was fully aware that any suggestion that the Geocentric view was wrong would be considered blasphemy by the religious authorities (and could mean death).

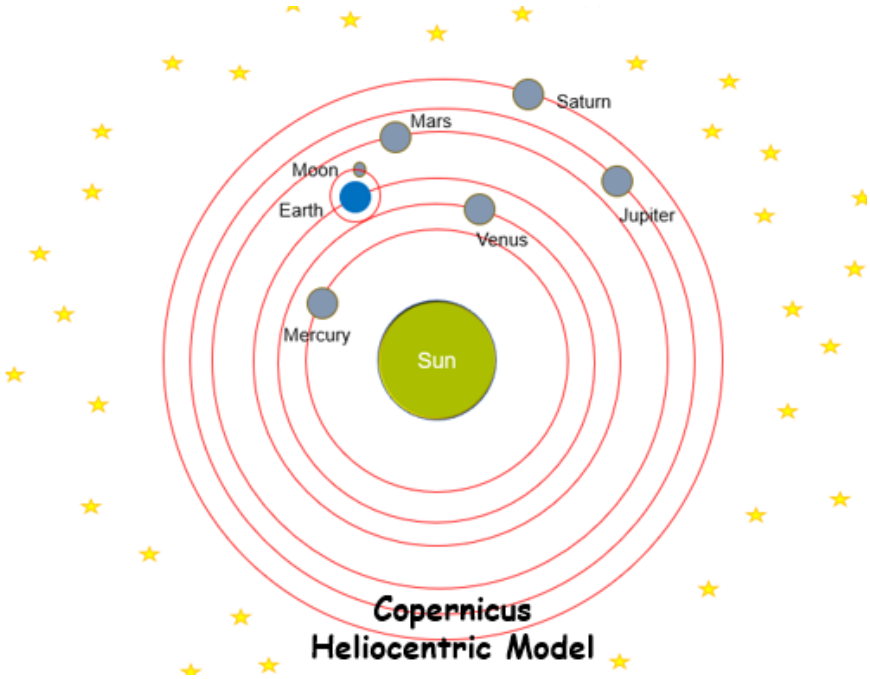
He revived the ancient idea of Aristarchus of Samos (a Heliocentric, Sun-centered system) and proposed hypotheses based on the following "what if" scenarios:

What if … ?

- ✓ the Earth is NOT at the centre of the universe, but our Sun is.
- ✓ the Earth rotates on an axis, which explains the daily movements of the Heavens (why we have day and night).
- ✓ the Earth's axis of rotation is tilted to explain the Sun's path during the year (higher in the sky in summer).
- ✓ the planets (and the Earth!) move counterclockwise around the Sun (if viewed from above the North Pole) … in circular (perfect) orbits. It was still difficult to escape the lure of the circle.
- ✓ the Moon orbits the Earth (like in the good old days of centrality).
- ✓ (Optional, see how Copernicus explained retrograde motion)

So we have two paradigms (versions) of reality (actually, there were other guesses on how the universe was structured):





They both worked equally well (or equally badly), but one, the Geocentric model, had been around a very long time, and was supported by some very smart people. Its predictive power was very useful for calendars, harvests, seasons, and religious events, so there was no compelling reason to make the switch, even if the Heliocentric model held a more elegant simplicity. ***There was no evidence in support of Heliocentricity*** … at the time. It took about 73 years to get some evidence for Copernicus, and it took the invention of a paradigm-shifting technology called the telescope.

To repeat: in science you must have evidence/observation or experimental testing.
If an idea cannot be subjected to any testing, then it is not in the realm of science.
The experiment/observation must be reproducible (testable again and by someone else).

What happens when there is evidence for the new model (transitioning from the Geocentric to the Heliocentric view of the world), a new way at looking at the world around you? See *Kuhn's Paradigm Shift* (credit: Humber Professor Nathan Radke & his Multi-Coloured Pom-Poms)

Evidence in Support (sort of) of Copernicus: Galileo and the Telescope

- ✓ Galileo Galilei (1564-1642): astronomer, mathematician, philosopher, scientist; founded the modern approach to science.
- ✓ He studied and measured the motions of material objects, refuting Aristotle's physics of motion (example: if you drop two objects from the same height, the heavier object will hit the ground first—not true; but to be fair, Aristotle did have a better explanation of gravity than Copernicus).
- ✓ **So, if ancient wisdom could be wrong about these matters, could it be wrong about the Geocentric system?**
- ✓ The newly invented telescope had great military use, such as spotting enemy ships from afar … ***BUT…***

  Galileo turned his telescope ***skyward!*** He took a closer look at the so-called Perfect Heavens and discovered ***evidence*** that damaged the credibility of the ancient Geocentric universe, a view held by most for over a thousand years.
- ✓ His observations supported Copernicus' Heliocentric model (although ***not*** **a final, convincing proof that the Earth moved**).

He discovered that The Heavens Were Not Perfect!

Here is what he saw:

- ✓ Our moon had craters and hills, like the impure Earth.
- ✓ Venus had full phases like the Moon; it was ***changing. This can only happen in the Heliocentric model, not Geocentric.***
- ✓ Jupiter appeared to have four satellites (moons) ***orbiting it***, when all celestial bodies were supposed to orbit the Earth only. It looked like a tiny solar system.
- ✓ The Sun had blemishes or spots, and they also moved.
- ✓ Saturn looked very strange with lateral bulges (its rings).
- ✓ There were more stars in the heavens than there should have been … countless, individual stars. It seemed to show that there were more stars out there, farther and farther away … The universe was far larger than we were *told* …

Physical evidence contradicted assumed truths and as knowledge of these discoveries spread, the transition to a new paradigm began.

This was the beginning of the end of an Earth-centred view as humanity slowly transitioned to the Heliocentric View of the Universe … a paradigm shift.

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- ✓ In 1610, Galileo published a small, widely circulated, book called "The Starry Messenger" (in Latin), showing (off) his discoveries, his evidence that the old beliefs of celestial perfection were wrong.
- ✓ In 1613, he published the "Sunspot Letters" … in Italian not Latin, so many more people could read it (Latin was typically the language used by higher authorities and scholars)
- ✓ The Inquisition began to take notice. This was an institution, working for the church, which was on the lookout for heretics and blasphemers and followers of other religions; these "crimes" could be punishable by death. Claiming that the Earth was not the centre of the universe could get you sentenced, jailed, tortured, or executed.

Galileo's Famous Response to his Critics (1615):

"That the intention of the Holy Ghost [through the Scriptures/Bible] is to teach us how one goes to heaven, not how heaven goes." (S. Drake)

- ✓ In 1632 he published his book "Dialogue Concerning the Two Chief World Systems – Ptolemaic and Copernican," where he "attacked" the Ptolemaic (Geocentric) viewpoint.
- ✓ Published in Italian, reaching a lot more people.
- ✓ It was banned within 5 months.
- ✓ Galileo was called before the Inquisition for his heresy.
- ✓ He was forced to retract his view and suffered house arrest.
- ✓ His work was placed on the Index of Banned Books until 1835.
- ✓ In 1992, he finally got an "apology" from the Vatican ("formal recognition of error…").
- ✓ It took some time, but we finally obtained concrete evidence that the Earth does move and it's not the centre of all creation. The words of the "escaped prisoner" were finally heeded.
- ✓ *R.I.P. Galileo.*

Plato's Cave Revisited

- ✓ In Plato's *Allegory of the Cave*, when the prisoner escaped to the outside world, he found another level of understanding, where new knowledge replaced the assumed (received) knowledge of the past. Now imagine the prisoner seeing the night sky for the first time, watching the movement of bright objects that displayed perfect circular motion around the Earth. Imagine the prisoner making these observations over a period and creating a hypothesis describing a universe where Earth, obviously, was at the centre of all things. After all, this is what common sense observation tells you. Logic and reason tells you that this must be "true."
- ✓ As we have learned, the prisoner may have replaced the ignorance of the cave with another darkness; of course, he has learned something: he can look back and see how he was wrong in the past. The scientific approach would be to question his new reality as well: Is this world system true? Is there yet more to be discovered? Will new evidence in the future change the worldview … again? Should questioning cease?
- ✓ And as you would note from our lesson, many years later the escaped prisoner would create a new hypothesis of reality, with evidence finally supporting the idea that the celestial spheres were nothing but illusion. And, with this, should the prisoner now rest and declare that he has learned all there is to know?
- ✓ In short, this is part of your obligation in understanding the world accurately, in critically thinking about what is shadow and what is not, what is "true" and what is false. The world around you provides a complexity and confusion of possible shadows.
- ✓ The scientific method is a tool to help you sort it out and make important decisions that affect *you* directly.

For Testing

BIG HINT: If you understand these key terms and ideas, this will alleviate any stress or anxiety for the upcoming quiz and test (scientific translation: your epinephrine, norepinephrine, cortisol, oxygen and glucose levels will remain within normal operating parameters. In other words, you'll be cool).

- ✓ What is a Paradigm and a Paradigm Shift?
- ✓ Describe the Geocentric and Heliocentric models of the universe.
- ✓ What is the commonsense evidence in support of the Geocentric Model?
- ✓ What is science? What is the scientific method?
- ✓ What did Galileo see with his telescope that was so disruptive? Why was it disruptive?
- ✓ Hypothesis
- ✓ Falsification
- ✓ Principle of Simplicity
- ✓ Why is "flexibility" and "self-correction" important for science?
- ✓ How does science and the scientific method fit in with the ideas of *The Allegory of the Cave*?

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