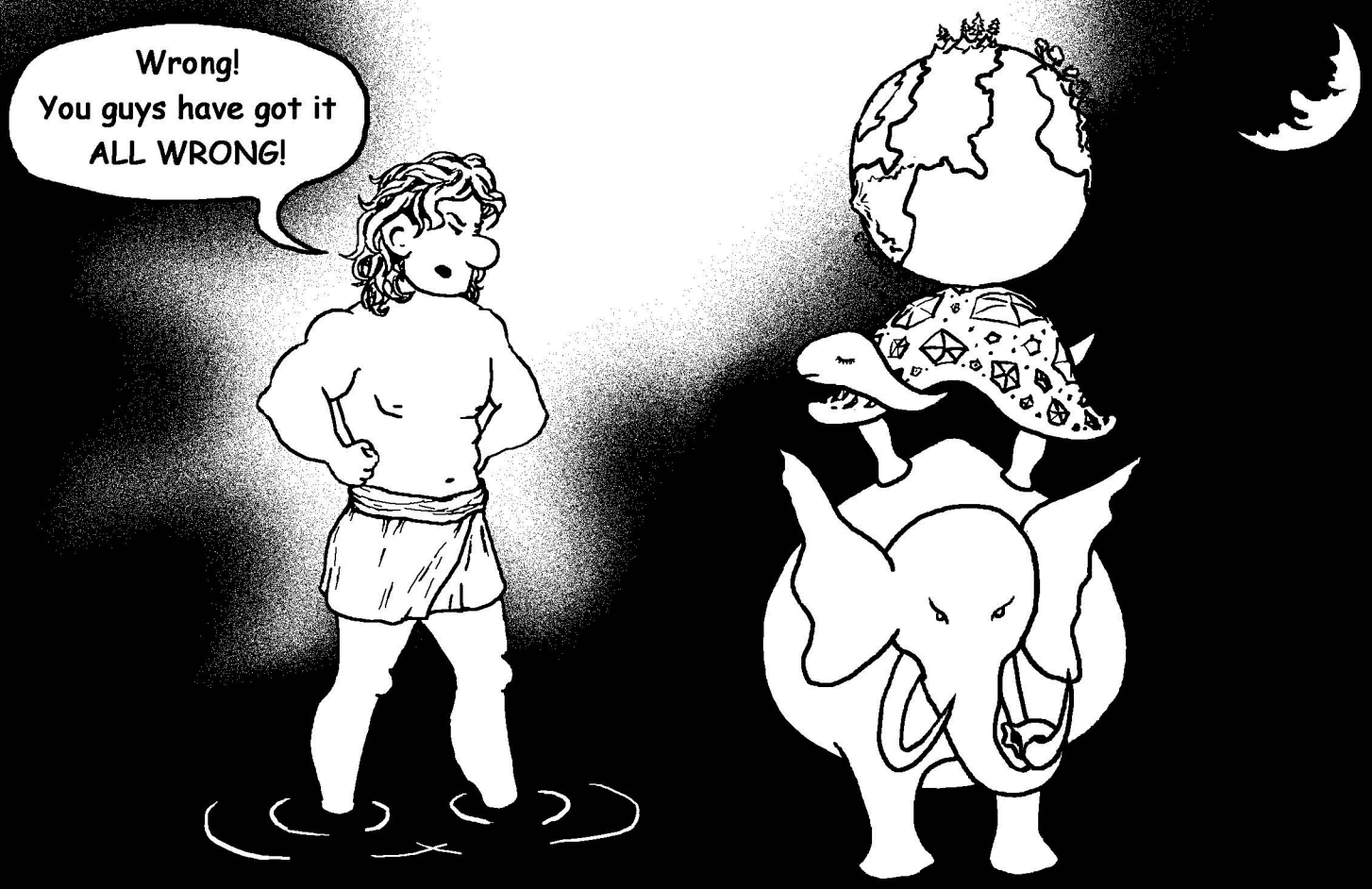
STORY OF ASTRONOMY



Written and Illustrated by

Uday Patil

AN EKLAVYA PUBLICATION

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Story of Astronomy
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To Mihir

. . . the biggest fan of my artwork

PREFACE

Why study astronomy? There are millions and billions and trillions of galaxies and solar systems in the big wide universe. The beacon of our own solar system, the sun, is a rather insignificant star by cosmic standards. Extraordinary conditions on earth gave birth to life and consciousness. Our amazing ability to reason enables us to seek more, know more about our own origins, about our legitimate place in the vastness of the cosmos. We know much more about the universe than our ancestors did, but there is a lot more to know. There are still many unanswered questions.

The subject matter of astronomy is, well, astronomical. Our knowledge in this field did not come to us overnight. It has evolved over several thousand years. The history of astronomy spans the history of mankind itself. Not surprisingly, this history is as interesting and complex as the science itself. This picture-book is not about the science of astronomy. It is an attempt to recount its evolution in the form of a story.

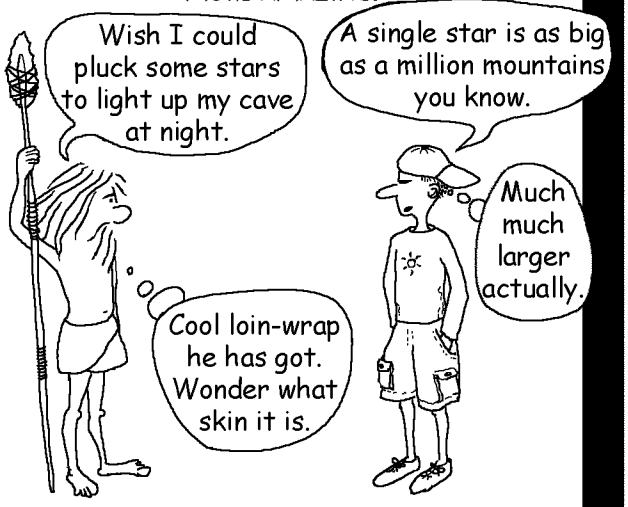
It is impossible to squeeze such a rich and intricate story into a tiny comic book. I have picked a small subset of events that seemed important historically. Lots of theories and controversies which are still being debated have been omitted. I have used material most readily available and picked versions easy to narrate. So at places it may appear that I have taken sides, but this was certainly not my intention.

Authoring this book wouldn't have been possible without all the help I received. I must thank Sir Ratan Tata Trust for the financial support and Arvind Gupta for the guidance he provided right from conception till the printing of this book. I also thank Prof. J. V. Narlikar and Dr. Pradeep Gothoskar for reviewing the manuscript in great detail and providing invaluable feedback. I also want to mention my wife Pallavi for being there to share the excitement with me over every page completed.

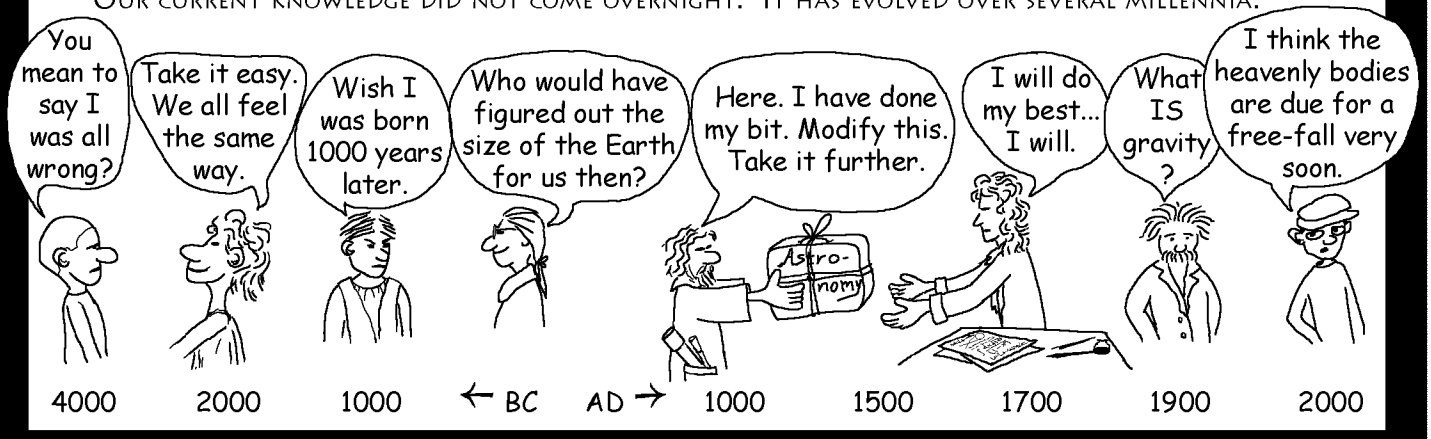
Uday Patil

The night sky always evoked a sense of deep wonder. Our ancestors were mesmerized by the beauty of the stars. Nobody could touch or feel them. This perhaps added to their mystique.

One thing is for sure - the sky looked pretty much the same 10,000 years ago as it does today. Yet what we know now about stars is very different from what the ancients knew. If anything, our knowledge of astronomy has made the sky look all the more amazing.



Our current knowledge did not come overnight. It has evolved over several millennia.



This story will outline the long and passionate quest that has widened the frontiers of astronomy.

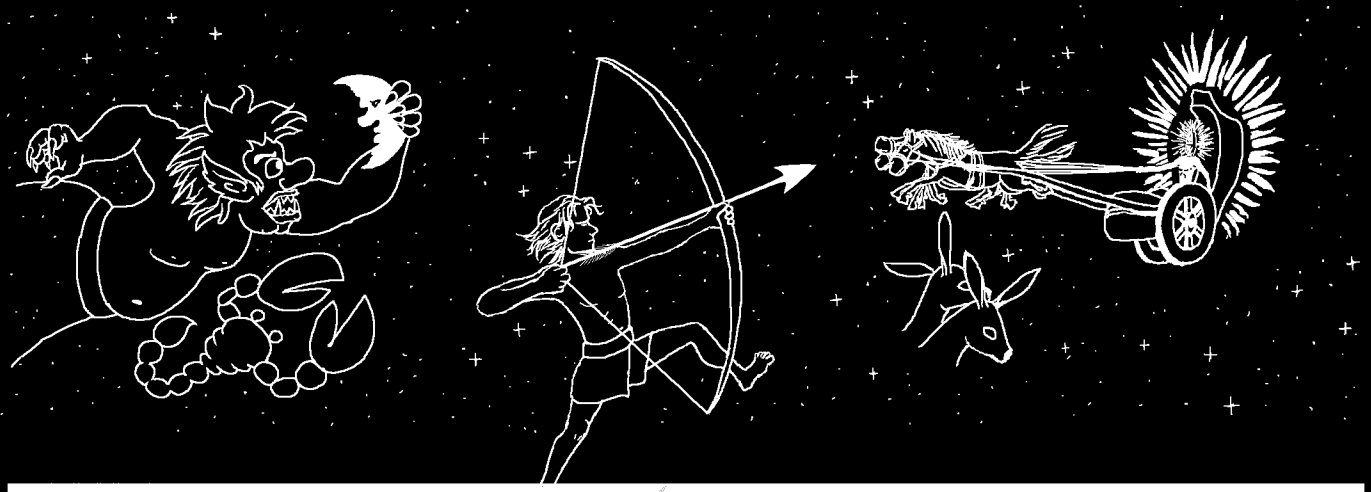
Do we know everything there is to know about the universe? Far from it. All the time we are making new discoveries and deepening our knowledge.

It has always been the case - the more we know, the more there is to know.

Our ancestors were mesmerized by the magnificent night sky. It evoked a sense of wonder, awe and even fear. They saw the stars strewn in different patterns. People saw ogres, fishes, animals and lovely women in the stars. They made beautiful stories out of them.

You can take the Neanderthal out of the Ice Age but you can't take the Ice Age out of the Neanderthal.

The Sun, the Moon and the Stars played an important role in the mythology and the folklore of every culture.



The Indians believed that our Earth - a large flat mass - was supported by a pack of elephants. The elephants, in turn, stood on the back of a giant turtle swimming in the ocean. Sometimes the turtle got tired carrying all this weight and shook its body causing earthquakes.

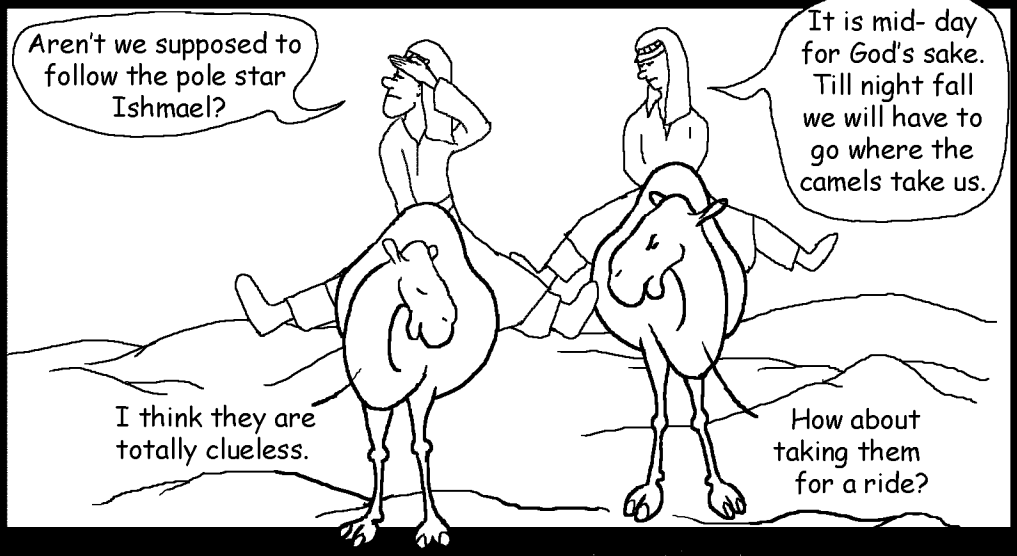
The Greeks had their own stories. Titans were powerful Gods in Greek mythology. ATLAS - the Titan warrior - was responsible for supporting the sky and preventing it from falling on earth. The popular picture of Atlas carrying the earth is a recent misconception.

Such stories were more than just a product of a fertile imagination. They were early attempts at explaining the universe.

They formed the earliest cosmologies, or theories of the universe.

In the absence of calendars and clocks the sky also served as a useful reference for time and direction.

It helped nomads and navigators reach their destination.

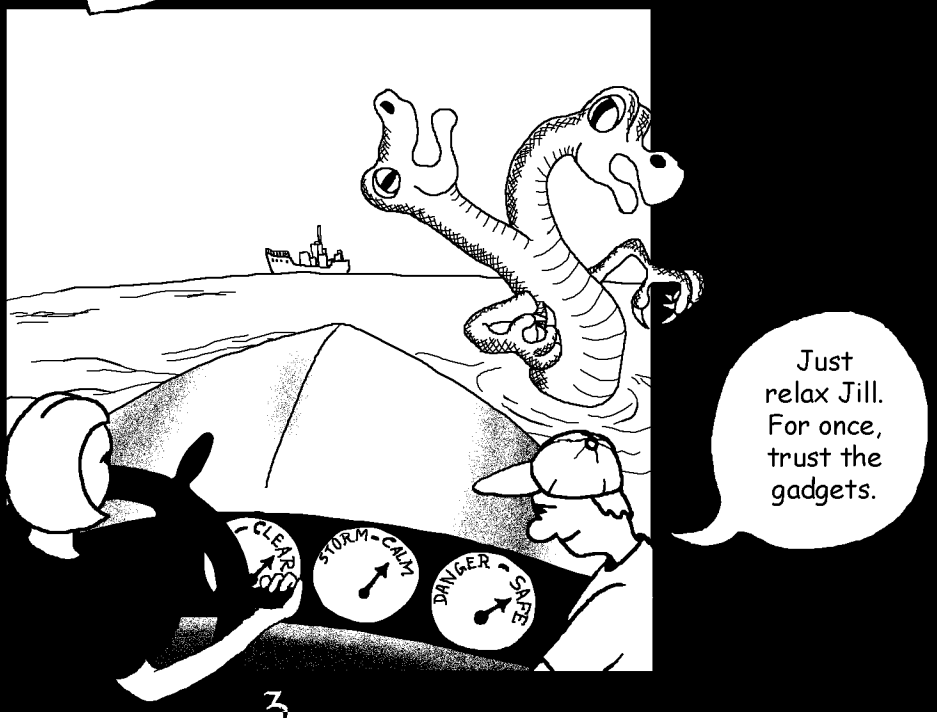


Sailors found the sky very useful too. In the midst of the vast ocean the stars helped them find their bearings.

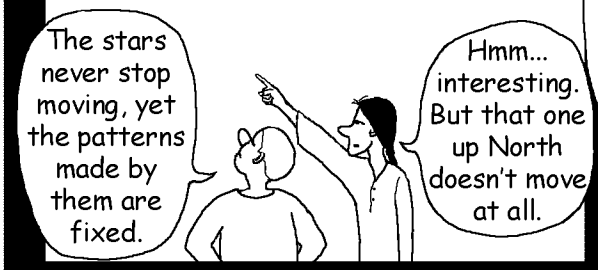
Development in astronomy led to advances in the science of navigation. Sailors learnt to interpret the position of stars and cross the oceans.

Navigating by stars is still practiced.

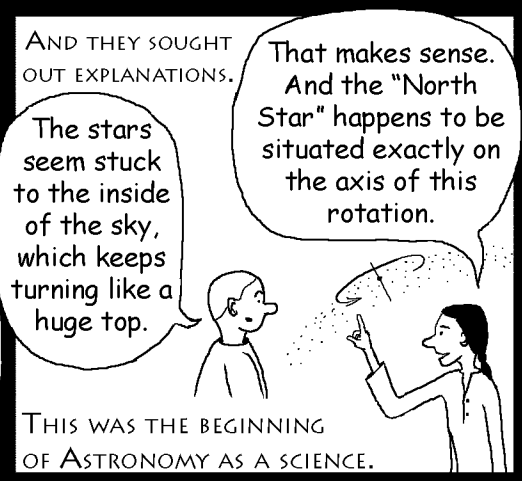
However, modern ships and boats use navigation technology comprising of satellites, radio waves and electronic gadgets to steer them through the high seas.



The Sun, the Moon and the stars all moved across the sky. That much was common knowledge. But there were keen observers who saw patterns.



And they sought out explanations.



This was the beginning of Astronomy as a science.

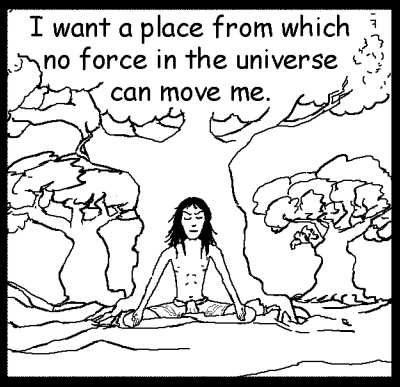
The "North Star" or the "Pole Star" – because it stood still at one place – enjoyed a special status in ancient astronomy.

All the other stars – the entire celestial dome – rotated around the "Pole Star". Thus "Polaris" became the anchor point for studying the night sky.

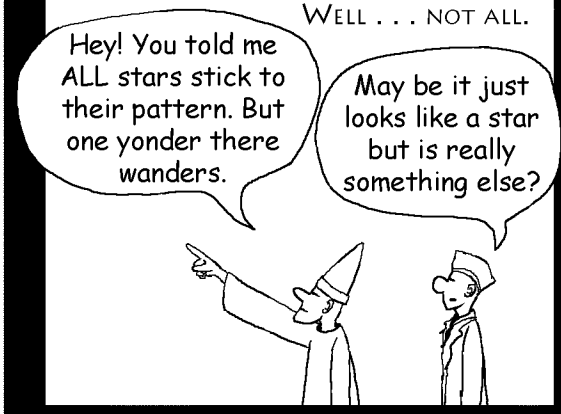
In India, the North Star is called Dhruva after the mythological prince who transformed into the star.

One day, five year old prince Dhruva was sitting on his father's lap. Dhruva's stepmother, the beautiful but wicked queen, couldn't stand this sight. She pushed Dhruva off his father's lap to make place for her own son.

Deeply hurt, Dhruva left home in search of a place from where he **COULD NOT** be dislodged. After a long penance, he was transformed into a stationary star – fixed at one point in space.

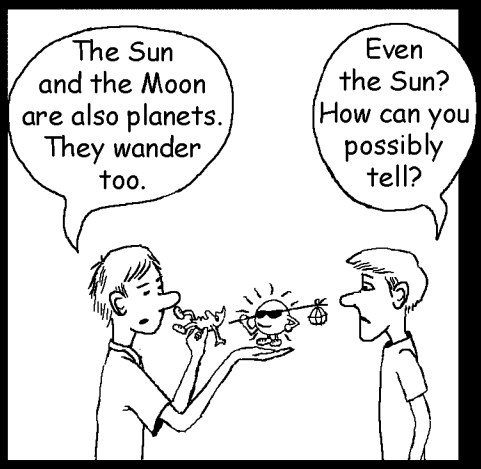


Did all stars move in a pattern? Well . . . not all.



Indeed, a few bright stars strayed from the pattern. The Greeks called them **PLANETS** which meant wanderers. These wandering stars kept drifting across the fixed stellar pattern.

Even the Sun and the Moon were not fixed to the pattern of stars. They wandered too.

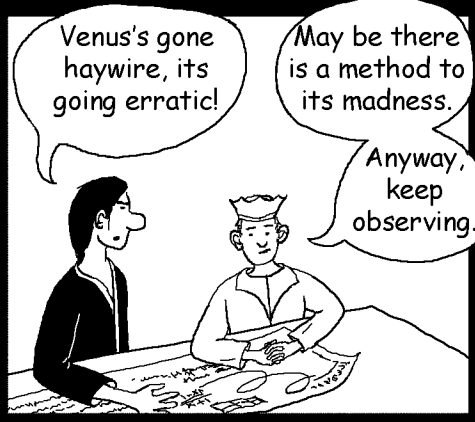


There were five star-like planets. They were named after Greek Gods.

If you added to them the Sun and the Moon then the number of planets increased to seven.

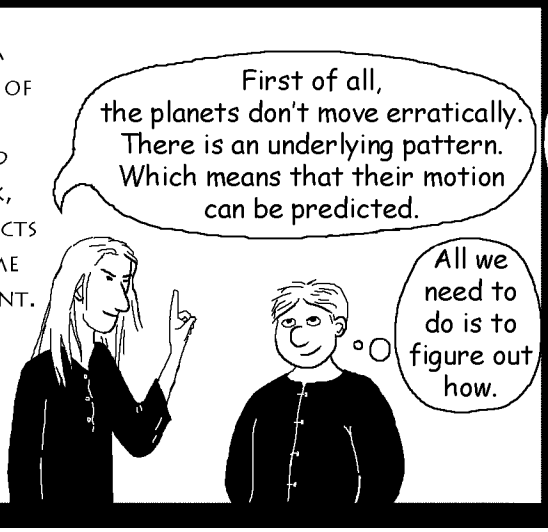
Star patterns moved pretty fast. Their motion was noticeable within a few minutes. On the other hand the relative motion of planets on the stellar tapestry was much slower.

It took several days, often several months of careful observation to notice the movement of the planets. To study their motion was long and tedious.

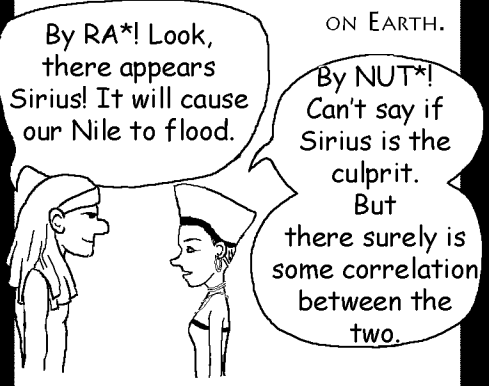


It took centuries of collective effort before some patterns started emerging out of piles of observed data.

As a result of this hard work, two facts became apparent.



Secondly, changes in the sky seemed to have effects on Earth.

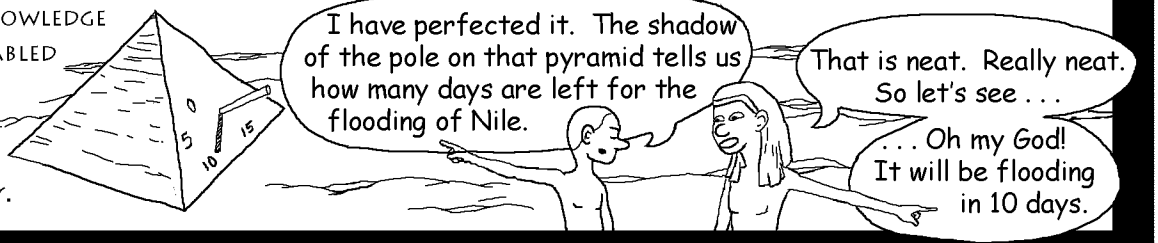


*Ra-Sun God; Nut-Sky Goddess.

In Egypt, life was governed by the annual flooding of Nile.

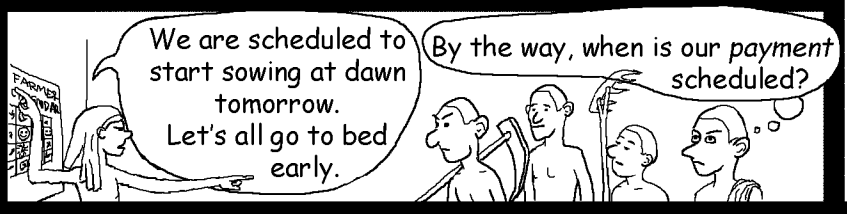
When they saw the bright star **SIRIUS** appearing just before the sunrise, they knew it would soon be time for the flood.

The Egyptians' knowledge of astronomy enabled them to predict the reappearance of Sirius with pinpoint accuracy.

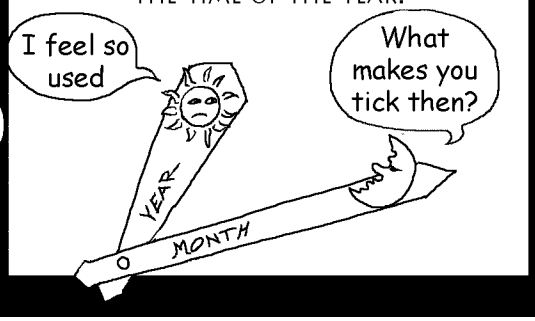


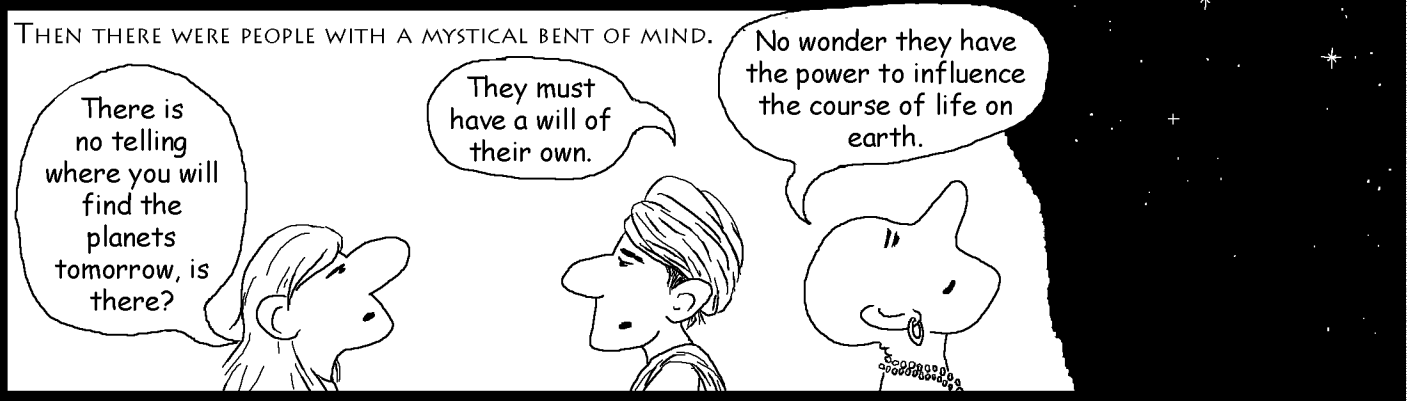
For systematic prediction of natural phenomena, a good system for tracking time was needed. This gave birth to the calendar. The circling of the Sun across the stellar pattern marked one year. One complete phase cycle of the Moon marked a month.

Both farming as well as administration of the state could now be planned and executed, like clock work.

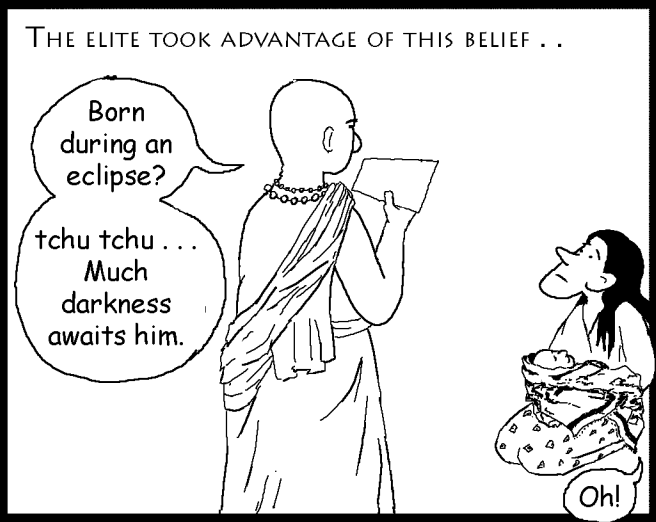


The Sun, the Moon and the stars became time keepers. Their daily rotation around the Earth told the time of the day while their wandering within the stellar pattern indicated the time of the year.

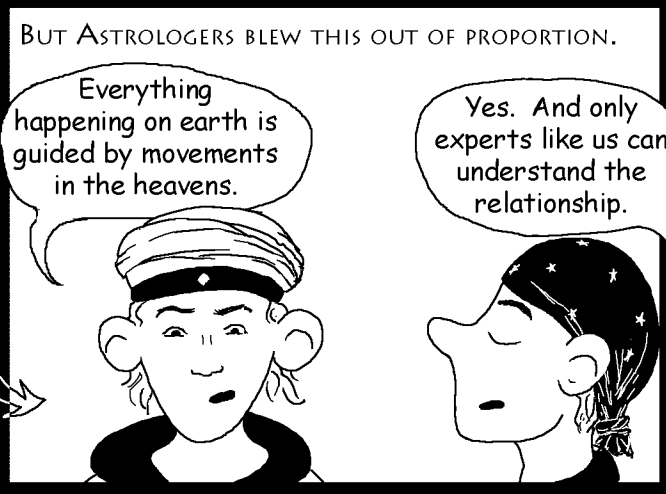




THUS ASTROLOGY WAS BORN. PEOPLE CAME TO BELIEVE THE PLANETS AFFECTED THEIR LIVES.



INDEED THERE WAS SOME EVIDENCE SUGGESTING THE INFLUENCE OF HEAVENLY BODIES ON EARTHLY PHENOMENA.

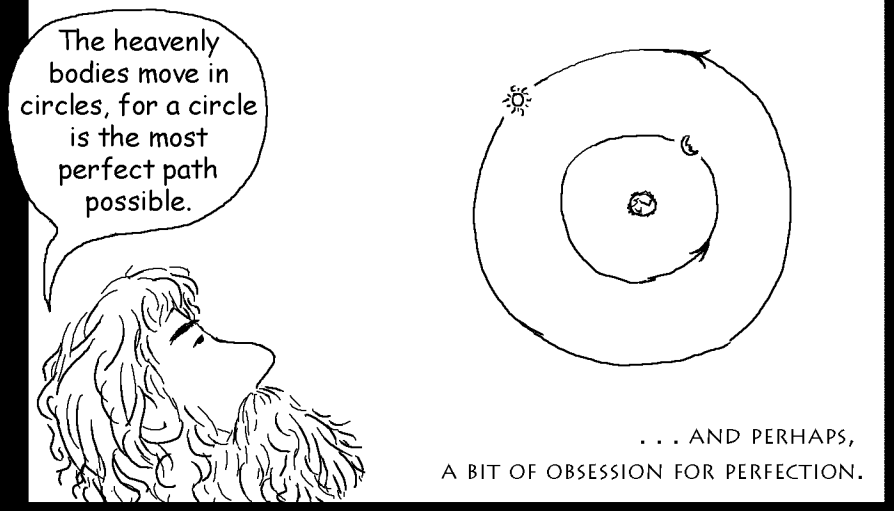


ASTROLOGY THRIVES EVEN TODAY, ESPECIALLY IN UNDERDEVELOPED COUNTRIES.
IN INDIA, THERE ARE MANY MORE ASTROLOGERS THAN ASTRONOMERS.
SOME UNIVERSITIES EVEN OFFER DEGREE COURSES IN ASTROLOGY.

On the other hand, there were those who looked at the sky with a scientific interest.

For Aristotle, astronomy was a branch of philosophy.

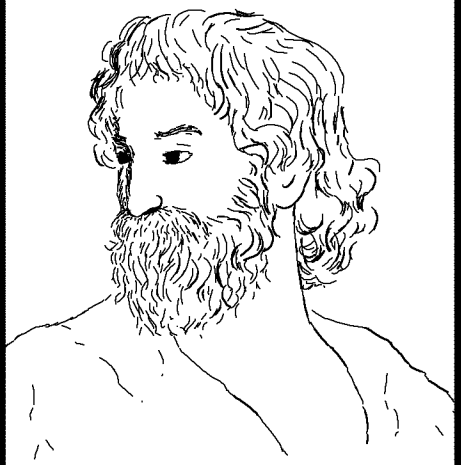
He had his own way with logic . . .



. . . and perhaps, a bit of obsession for perfection.

The evolution of modern astronomy can be traced back to the writings of Aristotle, the famous Greek philosopher.

Aristotle 384 - 322 BC



This Greek philosopher was the first one to formulate a comprehensive system of philosophy. His writings covered a variety of topics - politics, morality, aesthetics, metaphysics, logic and science. He was the first one to undertake a formal study of logic.

His thoughts had a strong influence on many philosophical and theological traditions. Aristotelian philosophy is still an active field of study.

He influenced many people in history, the most well known being his student Alexander The Great.

It has been said that Aristotle's ideas remain the most influential thought system ever put together by a single mind. His philosophy shaped the intellectual development of many cultures.
Like with many fields, his ideas had a strong influence on astronomy. The role of spheres and circles went unquestioned for a good two thousand years.

It is not clear whether Aristotle's influence on astronomy was a boon or a hurdle. But his real contribution to science lies in the trend he started.
He asked questions about the universe.
He attempted explanations for phenomena that people took for granted.

THE SCIENTIFIC QUEST CONTINUED. THE STELLAR PATTERN WAS CAREFULLY MAPPED.

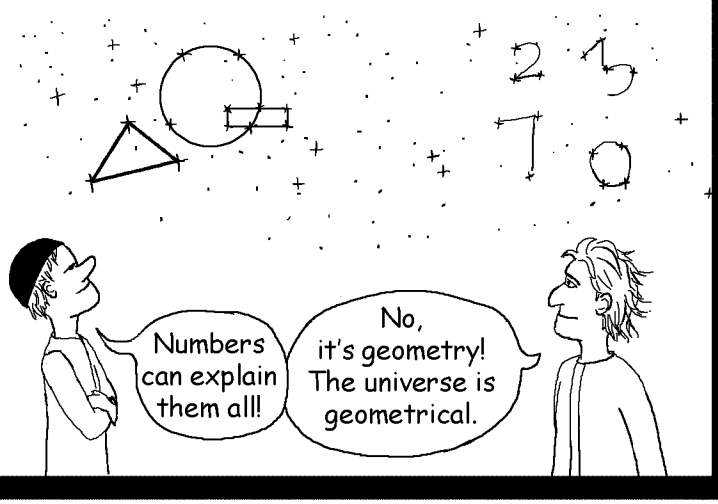
EACH REGION OF THE NIGHT SKY WAS IDENTIFIED WITH THE LOCAL PATTERN OF BRIGHT STARS CALLED A **CONSTELLATION**.

MAPPING THE STELLAR PATTERN MADE IT POSSIBLE FOR THE MOTION OF PLANETS TO BE MEASURED WITH ACCURACY. THE NEXT STEP WAS TO UNDERSTAND THIS MOTION.

ASTRONOMERS STROVE HARD TO IDENTIFY SIMPLE PRINCIPLES THAT COULD EXPLAIN THE COMPLEX MOTION OF PLANETS.

IN TRYING TO MAKE SENSE OF THE MOTION OF PLANETS ASTRONOMERS USED MATHEMATICS.

OBVIOUSLY, THEY USED THE MATHEMATICS THEY WERE MOST FAMILIAR WITH.

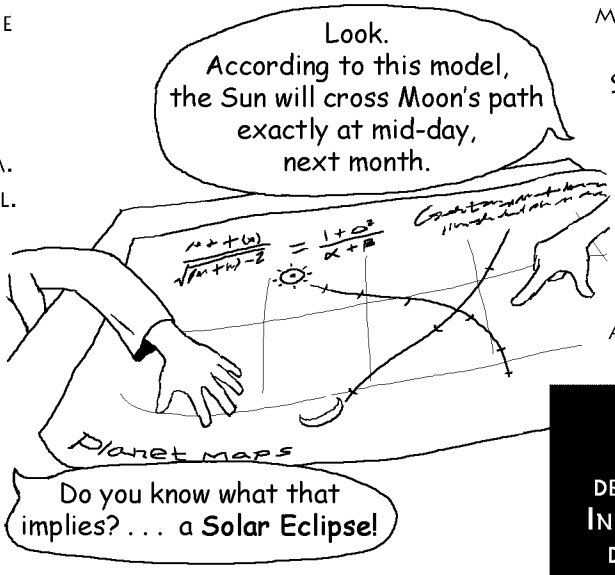


ASTRONOMERS TRIED TO EXPLAIN THE MOTION OF PLANETS USING SIMPLE MATHEMATICAL MODELS. IT MEANT USING A FORMULA TO TELL THE POSITION OF THE PLANETS AT ANY GIVEN TIME.

IF SUCH A MODEL COULD ACCURATELY LOCATE THE POSITION OF A PLANET A FEW HUNDRED YEARS BACK, IT SHOULD HELP IN PINPOINTING ITS POSITION IN THE DISTANT FUTURE TOO.

THE SUCCESS (OR ACCURACY) OF THESE MODELS DEPENDED ON THE SOPHISTICATION OF THE MATHEMATICS INVOLVED. THE EGYPTIAN MODELS WERE BASED ON A PRIMITIVE NUMBER SYSTEM. THEY WERE NOT VERY SUCCESSFUL.

THE BABYLONIANS DID BETTER BECAUSE OF THE WAY THEY REPRESENTED NUMBERS. THEIR SCHEME WAS QUITE SIMILAR TO THE MODERN DECIMAL SYSTEM. INSTEAD OF 10 THEY USED A BASE OF 60. THE LEGACY OF THE BABYLONIANS STILL LINGERS ON. AN HOUR IS DIVIDED INTO SIXTY MINUTES AND EACH MINUTE INTO SIXTY SECONDS.



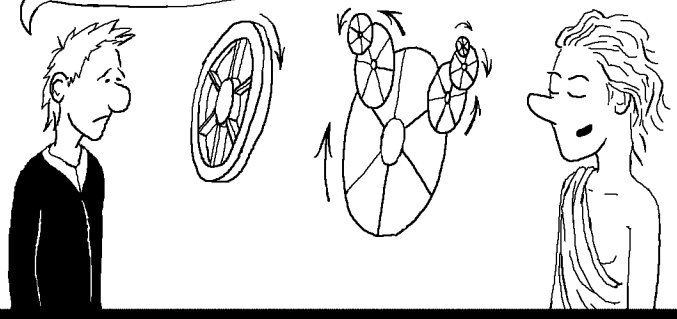
BEING ABLE TO PREDICT THE MOTION OF THE PLANETS WELL IN ADVANCE MEANT A LOT. SOLAR AND LUNAR ECLIPSES, THOUGHT TO BE RANDOM PHENOMENA UNTIL THEN, BECAME PREDICTABLE. ECLIPSES WERE IMPORTANT EVENTS IN RELIGION. NATURALLY, RELIGIOUS ACTIVITIES GOT MIXED WITH ASTRONOMY.

MATHEMATICS PLAYED AN IMPORTANT ROLE IN THE DEVELOPMENT OF ASTRONOMY. IN TURN, ASTRONOMY WAS THE DRIVING FORCE THAT LED TO MAJOR ADVANCES IN MATHEMATICS.

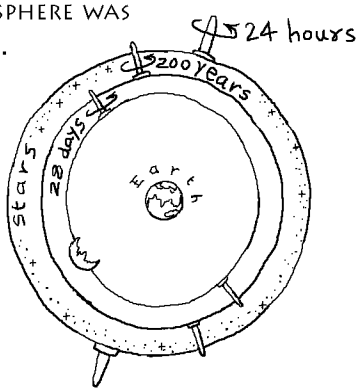
The initial models of planetary motion were circular.

How can simple circles explain the complex motion of a planet?

Isn't it fascinating? A combination of simple motions can be very complex.



The first models were based on CONCENTRIC SPHERES. These imaginary spheres turned uniformly on their axes like tops. The axis of one sphere was fixed in another.

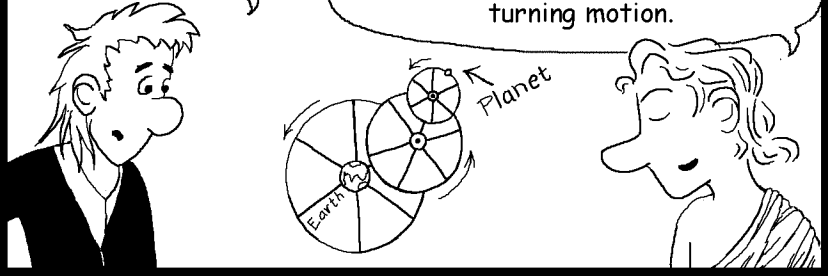


Each planet required several concentric spheres to model its motion.

Then there were EPICYCLES. In this model, each planet was fixed on a turning wheel whose center was fixed on another turning wheel (which in turn might have been attached onto another turning wheel).

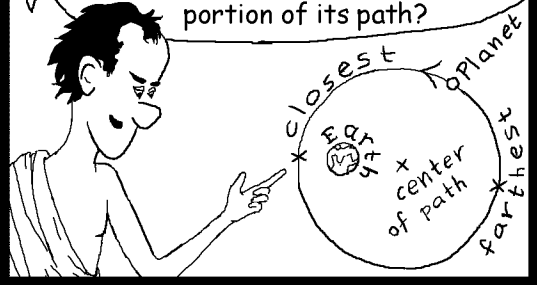
Now that surely can give rise to complex motion.

Epicycles are beautiful. The whole machine may look complex, but each wheel executes the simplest turning motion.



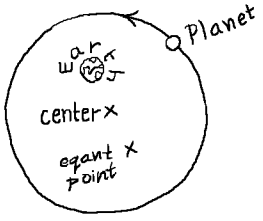
Yet another concept was the ECCENTRIC CIRCLE. It helped in explaining the speed variations of planets.

See how a uniformly moving planet appears faster when it is close to us and slower when it is at the farther portion of its path?



Amongst the circle based models, the EQUANT POINT was the most complex construct. It also turned out to be the most powerful tool in modeling planetary motion. It was used for over a millennium and a half.

The planet orbits along an eccentric circle but not uniformly. However, its motion appears uniform if viewed from a particular point in space. I call this point the **Equant Point**.



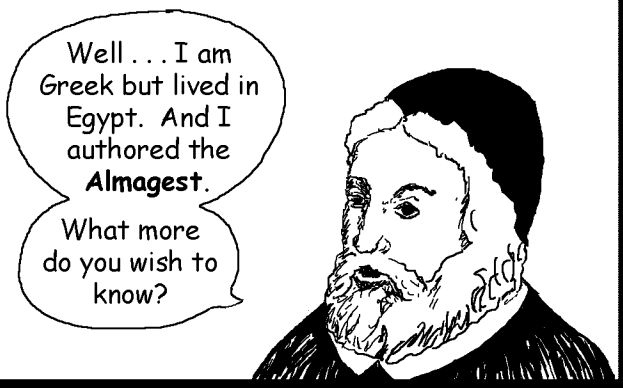
That's awfully complicated. But ... whatever works ...

Collectively, these models quite successfully captured the motion of the planets. The spheres and the circles were only mental constructs and not physical entities. But they helped in building simple yet precise models.

The predictive abilities of models decided their success or failure.

The Greek astronomer, Ptolemy, was the first to combine all these modeling techniques. He worked out the first accurate model to explain the motion of planets.

Ptolemy was a Greek astronomer. His actual name was Claudius Ptolemaeus. Not much is known about his personal life.



ALMAGEST is the popular name of the book Ptolemy wrote. The original title in Greek, **Megale Syntaxis** meant Mathematical Compilation. It was later translated into Arabic with the name **Al Majisti** (or The Greatest) and then later into Latin with the name **Almagestum**.

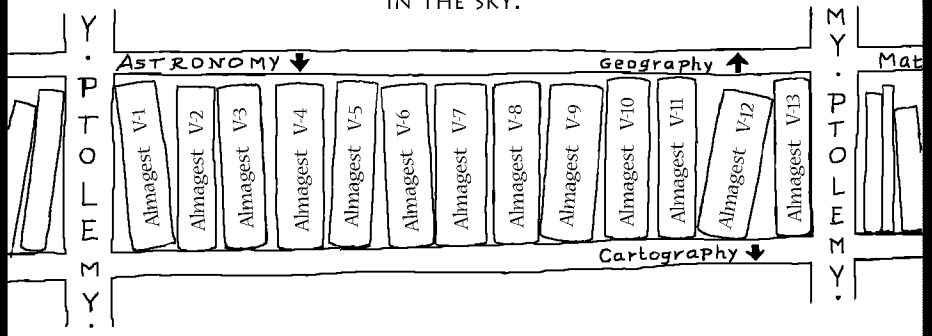
It was indeed a magnificent treatise on astronomy.

Claudius Ptolemaeus 85-165 AD

Ptolemy lived in Alexandria (Egypt). He was an astronomer, mathematician, geographer and cartographer. He was the author of the first treatise on astronomy popularly known as ALMAGEST.

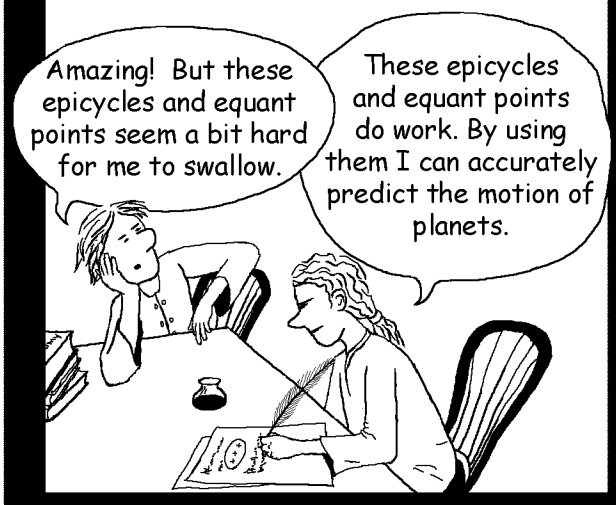
His work in astronomy reigned supreme for 1400 years.

The Almagest was an extensive work filling 13 volumes. It catalogued 1000 stars and various phenomena observed in the sky.

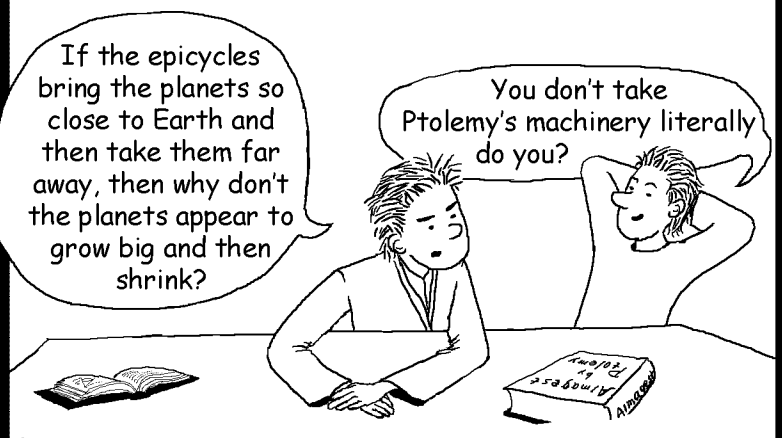


Most importantly, it was a compilation of techniques by past astronomers as well as Ptolemy's own inventions in modeling planetary motion.

The success of Ptolemy's work lay in the predictive power of his models.



But there were problems.

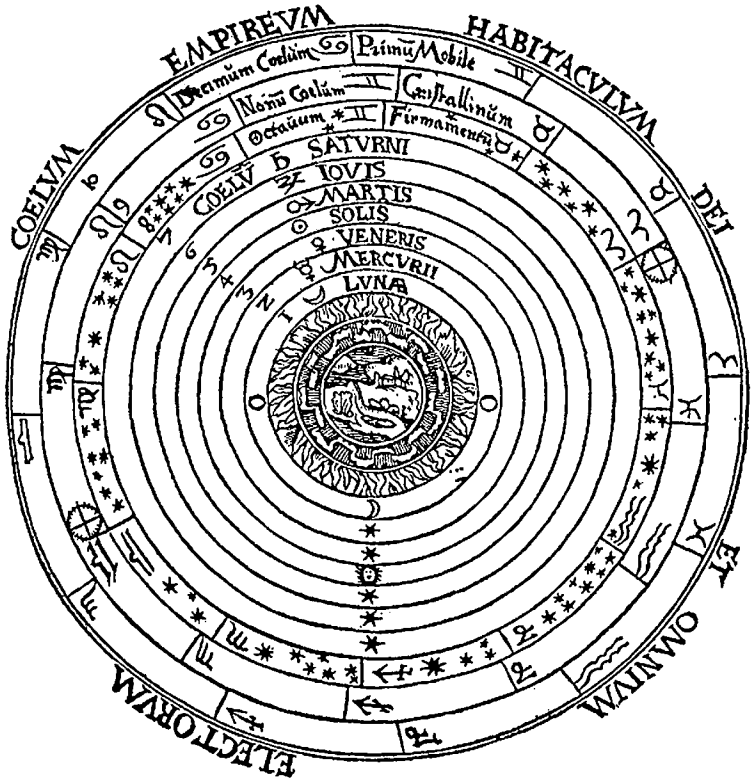


It was accepted that the epicycles, the equant points and all the machinery of Ptolemy's models were only mental constructs. They only modeled the observed movement of planets and not the physical reality.

The universe described by Ptolemy was Earth centric. The Sun, the Moon and the star-like planets revolved around Earth according to a conceptual machinery made up of epicycles and equant points. Each planet occupied a distinct spherical shell. All the stars were fixed to a rotating sphere just beyond the farthest planet.

Apart from minor modifications, the Ptolemic model of the cosmos survived practically unaltered for over 1400 years. During these centuries, ALMAGEST was translated and read like the bible across the world.

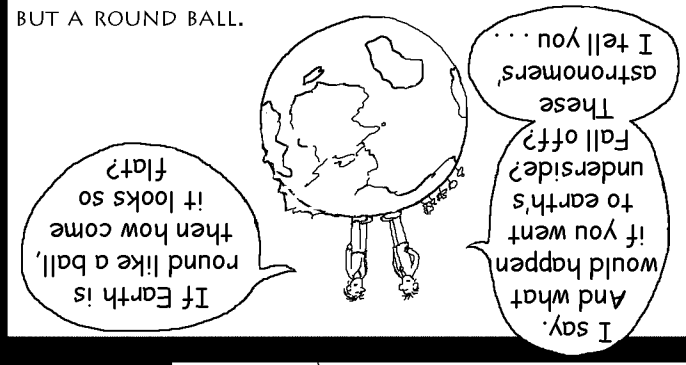
Schema huius præmissæ diuisionis Sphærarum.



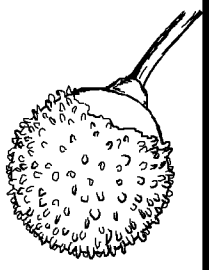
In light of our current knowledge, Ptolemy's understanding of the universe was grossly erroneous. But during his time (and for centuries to come) this view of the cosmos was treated as the gospel.

It took the combined efforts of several brilliant people to challenge Ptolemy's model. The brave views of Copernicus, the elliptical orbits of Kepler and the telescope invented by Galileo finally trashed Ptolemy's world-view and put an end to the Dark Ages of astronomy.

By 1000 BC, astronomers had figured that the Earth was not a flat disk but a round ball.



ARYABHATA, the famous Indian astronomer **(500 AD)** gave a beautiful analogy to visualize how the Earth would look from far away.

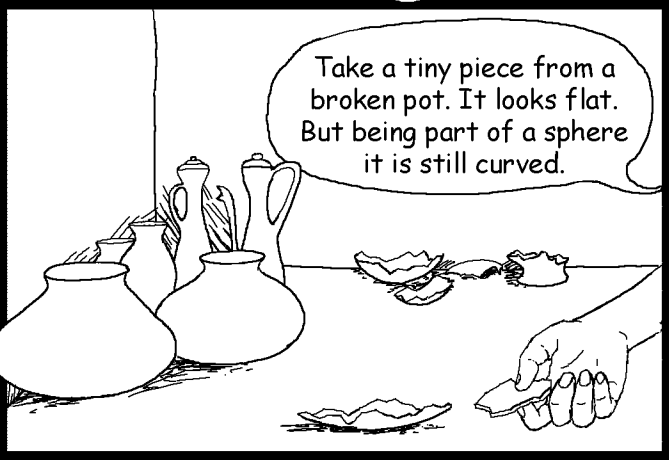


Like tiny flowers popping out of the ball-like fruit of the Kadamba tree....

we stand on the surface of a spherical earth - **down** being *towards* the center and **up** meaning *away* from it.

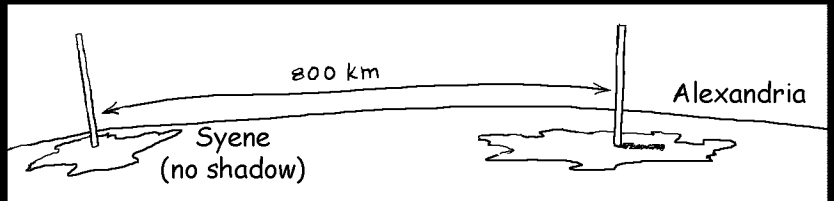
But if the earth is like a ball, then why does it appear flat?

There are good reasons for that.



Then what made some people insist that Earth was a giant ball? There was evidence. . . solid evidence.

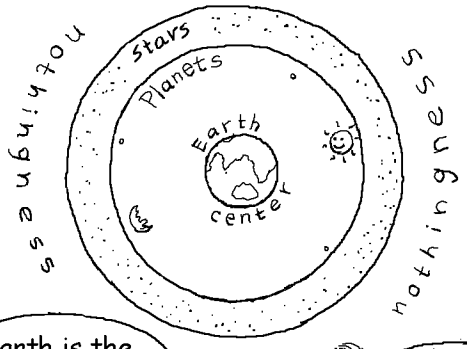
But how big was the Earth? The Greek scholar **ERATOSTHENES** figured it out around **240 BC.** If the Earth was a sphere then the Sun's light should strike different places at different angles. It was known that a vertical pole in Syene (near Egypt) cast no shadow on June 21 at noon. Eratosthenes measured the shadow cast by another pole on the same day at noon in Alexandria – a place **800** km from Syene.



With this information Eratosthenes easily calculated the circumference of Earth as 40,000 km.

Who could have imagined?
The Earth we live on...
a giant ball...
its circumference
a staggering 40,000 km... and
which is open to the sky on all sides.

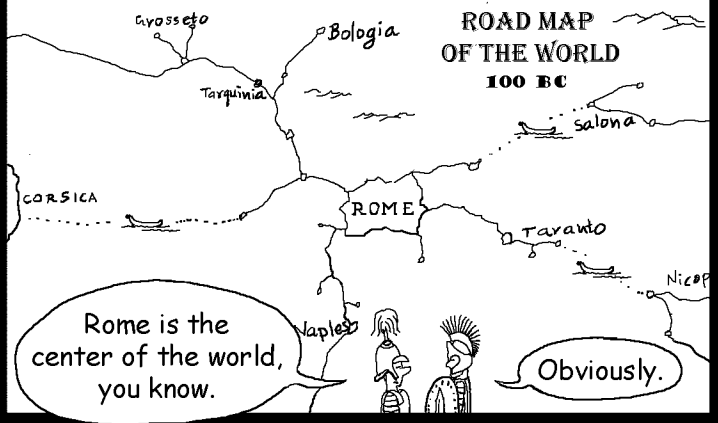
The Sun, the Moon, the planets and even the stars all seem to revolve around us. Naturally, the early astronomers thought the Earth was the center of all this motion.



Earth is the center of the universe, you know.

Obviously.

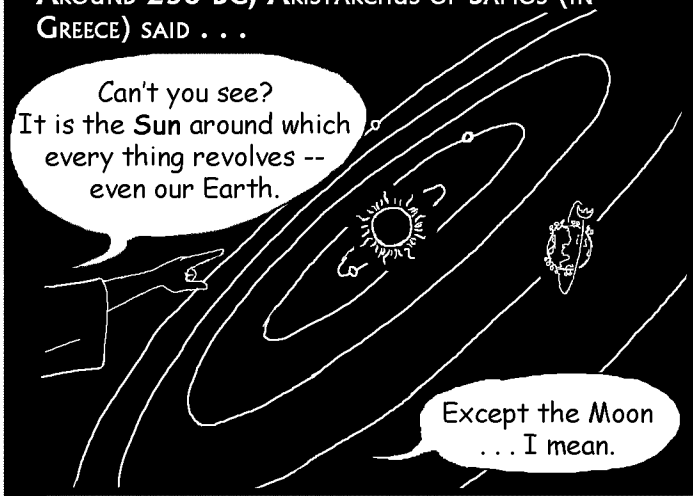
Today we know that the Earth is not the center of the universe. In fact there is no such thing as the center of the universe. The idea is as silly as the Romans believing that Rome was the center of the world.



Rome is the center of the world, you know.

Obviously.

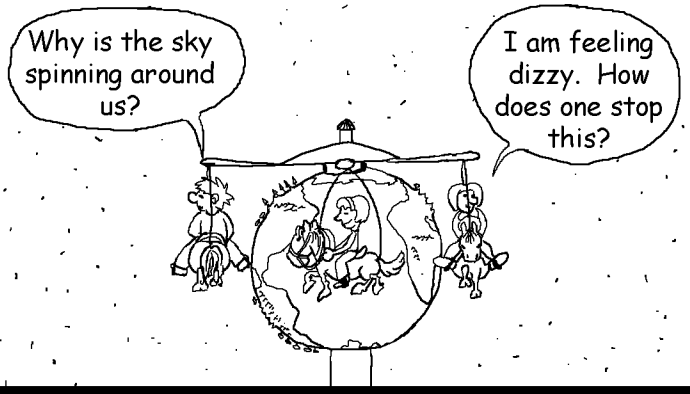
Quite early in history, many thinkers thought that it was the Sun (and not the Earth) around which the Earth and other planets revolved. Around 250 BC, Aristarchus of Samos (in Greece) said . . .



Can't you see? It is the **Sun** around which every thing revolves -- even our Earth.

Except the Moon . . . I mean.

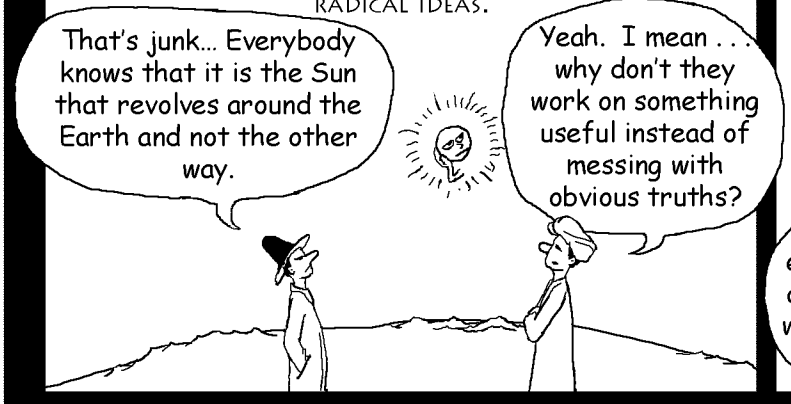
Around 500 AD, Aryabhata argued that the Earth spun on its own axis, like a top, completing one rotation every day. He said it was this rotation which made the stars and planets appear to be revolving around us. (It is like how a merry-go-round makes the world spin.)



Why is the sky spinning around us?

I am feeling dizzy. How does one stop this?

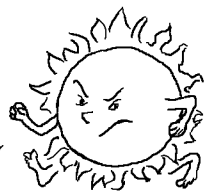
Unfortunately, these theories fell on deaf ears. The world, it seems, was still not ready for such radical ideas.



That's junk... Everybody knows that it is the Sun that revolves around the Earth and not the other way.

Yeah. I mean . . . why don't they work on something useful instead of messing with obvious truths?

So, for several thousands of years the Earth was to remain the center of the universe and the Sun was made to revolve around it.



When will they get the picture right?

Don't waste your energy. It is going to be a long while before that will happen. Keep circling me for now.

The credit goes to Nicholas Copernicus, for finally stopping the Sun and setting the Earth into motion.

Pwhoo . . . at last! Thanks Nicholas. I couldn't have taken it much longer.

Hey, don't push me. I need some warming up you know.

It had to happen some day. Don't worry, I will always be there with you.

Nicolaus Copernicus 1473-1543

Born in Poland he was a mathematician, astronomer, physician, translator, economist, military leader and much more. He was the first to propose a scientifically based heliocentric cosmology. His treatise titled De Revolutionalibus Orbium Coelestium (on the revolution of the celestial spheres) was the harbinger of the scientific revolution. He is known as the Father of Modern Astronomy.

Astronomers were dissatisfied with existing models.

Why can't I ever get things right?

I feel we are barking up the wrong tree.

Ptolemy's models (centuries old) needed refinement, or replacement.

Yeah. And what about the size of the Moon? Why doesn't it appear huge when it comes close to us as the model says?

I am really tired of this retrograde motion you know.

Somebody help us . . . please.

This kind of error is not acceptable.

Epicycles are mere models. What do the planetary paths really look like?

May be our mathematics is poor.

Ancient philosophers had conjured only a fuzzy picture of the heliocentric universe. Copernicus's theory, on the other hand was not just an idea but a complete set of solutions.

He spent 30 years working out the mathematical details of his new schema.

Copernicus was courageous enough to challenge the dominant, unquestioned theory of his time. He said:

Ptolemy's models can not be improved any further. The basic premise of his theory is faulty.

If the Sun is placed at the center of all motion, then everything will become simple. Follow evidence and challenge age-old established truths.

The retrograde motion of planets is an illusion caused by the motion of our own Earth around the Sun.

Venus and Mercury orbit the Sun too, just like our Earth. They stick close to the Sun because their orbits are smaller.

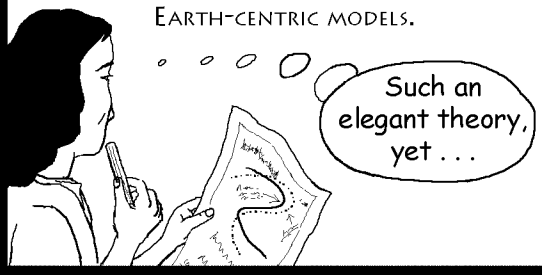
See, it is so simple yet so accurate.

I don't see it. Do you?

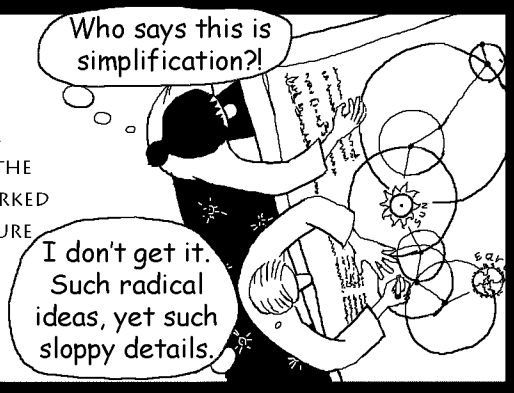
His theory demystified several complicated aspects of planetary motion. His contemporaries however failed to appreciate his work.

It took more than a century for Copernicus's ideas to be accepted. The Sun Centric (Heliocentric) model was a radical departure from the Earth Centric model. Astronomy finally emerged out of its dark ages.

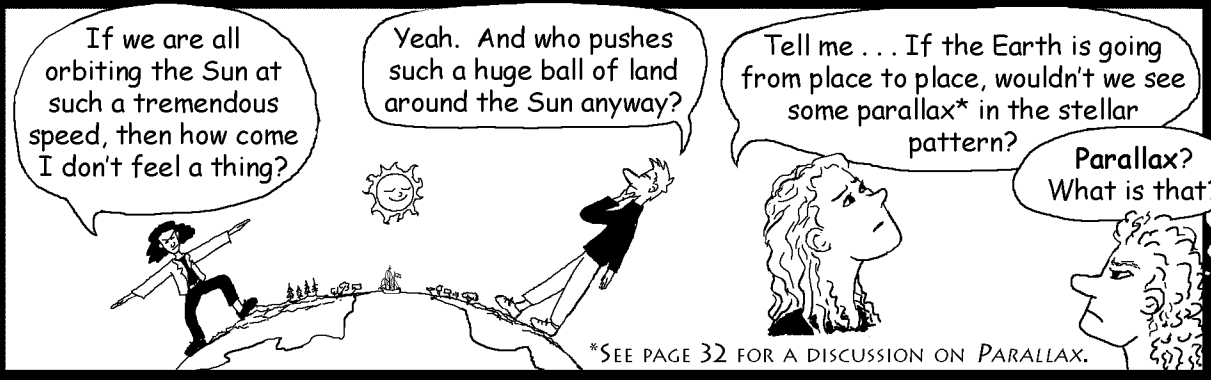
Unfortunately, the Copernican models (based on his Sun-centered theory) did not prove to be an improvement over Ptolemy's Earth-centric models.



The reasons were twofold. Firstly, Copernicus did not recognize the elongated nature of the orbits. Instead he worked out a complex structure of epicycles. Secondly, he worked on faulty observations.



The practical problems related to prediction were not the only issues. There were conceptual ones too.

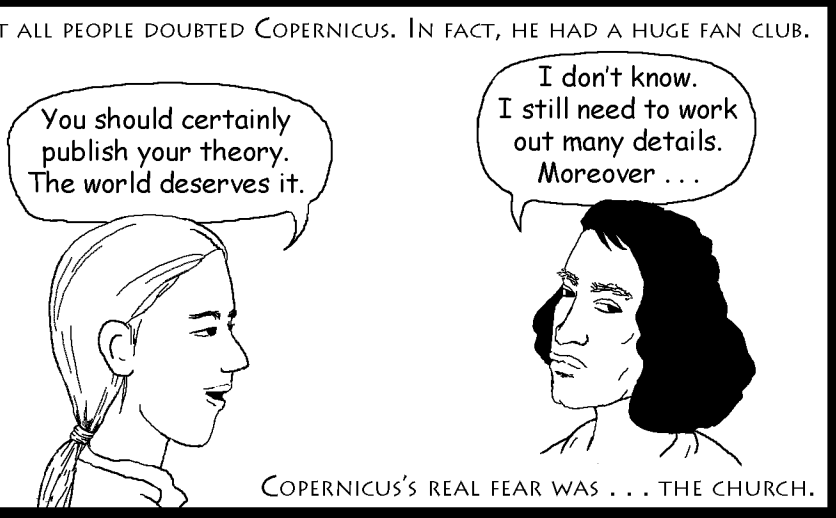


*See page 32 for a discussion on *Parallax*.

Answers to such fundamental questions came much later. They not only eliminated doubts about the heliocentric theory but also provided deeper insight into the working of the universe.

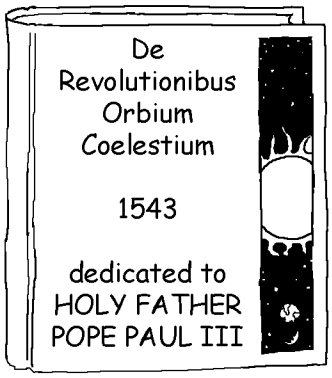
But for now, they posed a hurdle to the Copernican Picture.

Not all people doubted Copernicus. In fact, he had a huge fan club.

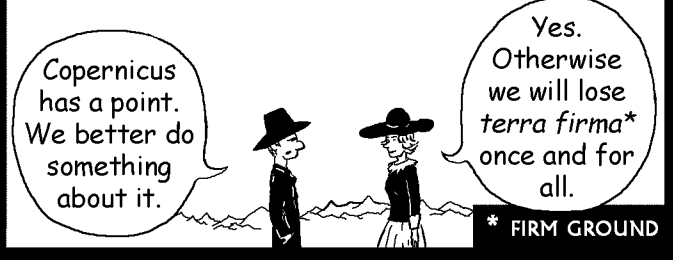


Copernicus's real fear was . . . the church.

Copernicus knew. If the church rejected his ideas then only the good lord could save them. He certainly didn't want to offend the church. His assistant – a really smart chap – played it safe, and still brought out the book.



Unfortunately, the book failed to gain the popularity it deserved. Copernicus's Theory languished for more than a century. But the merits of the heliocentric theory couldn't be ignored completely. Not surprisingly, astronomers fought hard to protect the good old Geocentric Picture.



It was Tycho Brahe, the Danish astronomer, who proved to be the strongest setback to the Copernican picture. He said . . .

True. All planets orbit the Sun, except the Earth and the Moon. In fact the Sun, along with its pack of satellites revolves around a fixed Earth (which of course is the true center of the universe).

Tycho's attack on the Copernican picture was, in some sense, perfect. It retained everything from the Copernican theory and yet managed to put the Earth back into the center of the universe. In fact, Tycho's picture was identical to that of Copernicus in terms of relative motion of the planets, and relative motion was all that could be observed.

What Tycho really did was to shift the coordinate system. He took the Copernican motion of planets but made earth the center for describing this motion. A shift in the coordinate system does not affect any relative motion.

Thus, Tycho both sidelined the Copernican Theory and at the same time incorporated it completely into his own.

Tycho Brahe 1546 - 1601

Born in Denmark. Built the Uraniborg Observatory (Heavenly Castle) - the first modern research institute. He was passionate about precise observations.

He failed to see the sun as the center. But his contribution to astronomy was significant in its own right. He was the first to give prime importance to accuracy of observations.

If your observations are erroneous, your theory is bound to be faulty. Just look at Copernicus.

Tycho did not have much trust in the existing data.

I believe in taking full responsibility for my theories you know.

A major part of his life was spent making accurate observations as well as in building precision instruments.

Tycho worked with a team of assistants for over a decade. The data he collected served as a reliable source of information for future astronomers.

Let me make it clear to you... this data is from Tycho. If your model shows a deviation then blame your model not the data.

Later

Tycho invited young Kepler to assist him in his work. This arrangement had a profound impact on the future of astronomy.

Kepler found Tycho's data extremely useful to support his own laws of planetary motion. Kepler's work played a decisive role in establishing the heliocentric picture once and for all.

Tycho's successor, Johannes Kepler, thought that modeling motion was not enough.

A mere description of planetary motion doesn't satisfy me.

What else would you like to do Johannes?

I want to know why the planets move the way they do. What force keeps them on their paths?

Don't they move according to God's will?

Does he mean planetary motion is a matter of Physics and not just Geometry?

Unfortunately, Kepler's ideas on the *physical basis* of planetary motion remained vague. In light of our current understanding, they were simply faulty.

The Sun emits a magnetic force which circulates and keeps the planets in motion. In its absence the planets will come to an instant halt.

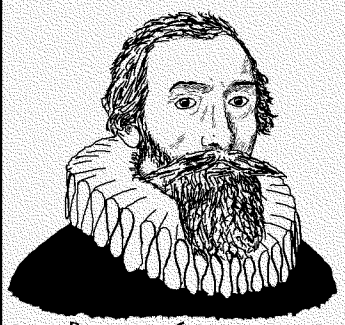
How interesting!

And how magical!

But his modeling of planetary motion was simply phenomenal. In the beginning of the 17th century, Kepler presented the world with three new laws.

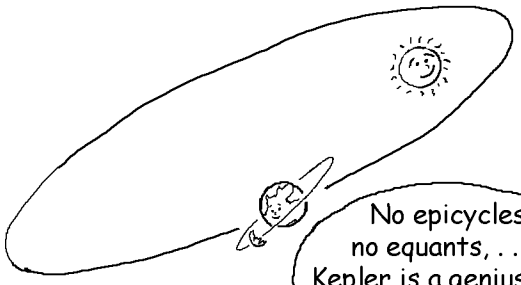
They are now popularly known as Kepler's laws. They played a fundamental role in the first successful physical theory of the universe that emerged during the following decades.

Johannes Kepler 1571-1630



Born in Germany - a mathematician, astronomer and astrologer; world renowned for his three laws governing planetary motion. He saw astronomy as celestial physics and played a major role in reviving the Copernican world-view.

It was the mark of a genius when he replaced the complicated machinery of epicycles with just one curve, the ELLIPSE, to describe a planetary orbit.



No epicycles, no equants, . . . Kepler is a genius.

Yes. It's frightfully simple, yet deadly accurate.

Kepler's orbital model was starkly simple and deadly accurate. The elliptical orbit came to be known as Kepler's first law.

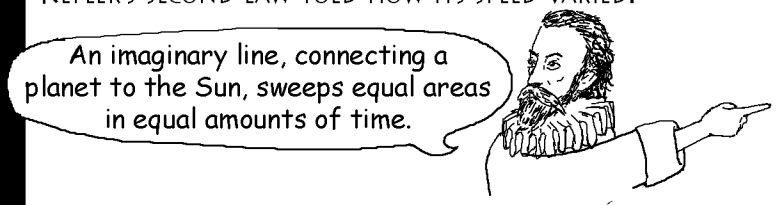
Interestingly enough, Tycho's data, which Kepler had direct access to, played a crucial role in his achievements. The precision of this data convinced Kepler of the erroneous nature of the models based on epicycles. So he sought new alternatives (and picked the ellipse).

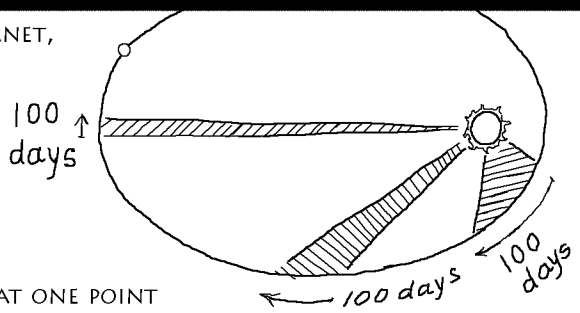
By Jove! I could swear there is no other possibility.

Tycho's data was the best one could have obtained using the naked eye. But it was nothing compared to the precision achieved during later decades through the use of the telescope.

If Kepler had access to telescopic data, he would have realized that planetary orbits weren't perfect ellipses either. Tycho's data was perhaps *just right* for him to arrive at a firm conclusion.

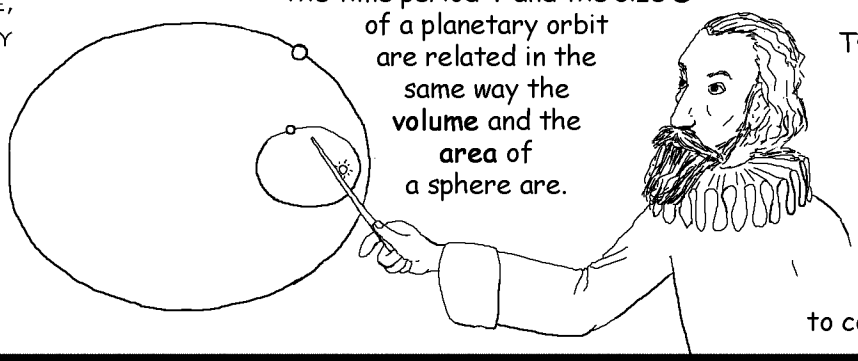
While the first law was about the path traversed by a planet, Kepler's second law told how its speed varied.





According to this law, if you knew the speed of a planet at one point on its orbit, you could easily figure out its speed at all other

Impressive as the first two laws were, his third law really took the cake. It pointed out an extremely simple relationship existing between the orbital period of a planet and its orbital size.



Mathematically,

T^2 / S^3 = constant.

For example, a planet with an orbit that is 4 times larger than another will take 8 times as long to complete its cycle.

There was a perfect match between the available data and Kepler's elliptic models. Ptolemy had initiated a stellar quest. Kepler finally arrived at a conclusion. Kepler's theory marked the end of one journey and the beginning of another.

The striking thing about Kepler's laws was that they applied uniformly to all planets (excluding of course the Moon). There was something very fundamental about them. Kepler's laws not just described the movement of planets but they captured the very essence of this motion. A deeper study of Kepler's laws would certainly throw light on the mechanics of the universe.

This was precisely what happened. Kepler's laws, aided by Galileo's telescope and powered by Newton's mathematical equations, started a new era of Celestial Physics.

The 17th century perhaps was the most exciting period in the history of astronomy.

Kepler had been an ardent proponent of the Copernican picture right from the very beginning. But his elliptical orbits did nothing to revive the heliocentric picture. What Tycho did to the Copernican theory could also be done to Kepler's. The sun (along with its pack of planets) going around the earth was consistent with elliptical astronomy too.

Fortunately, the Moon did not obey Kepler's third law. Kepler's explanation was that it did not revolve around the Sun like the other planets and hence doesn't behave like they do. But if Tycho's picture were true, then why did the Sun (which revolved around the Earth) behave differently than the Moon and similar to the planets revolving around it? Kepler had a strong case there.

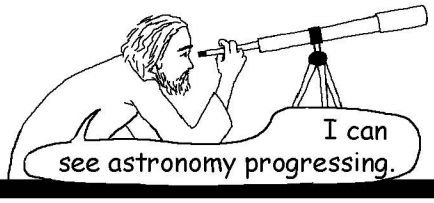
But it took persistent effort from Galileo followed by the emergence of the physical theory by Newton to put the geocentric picture completely to rest.

Regardless of all this, the **Elliptical Astronomy** of Kepler was regarded as ***the astronomy***, and in effect overshadowed all other theories of the past.

Contrary to popular belief, Galileo did not invent the telescope.

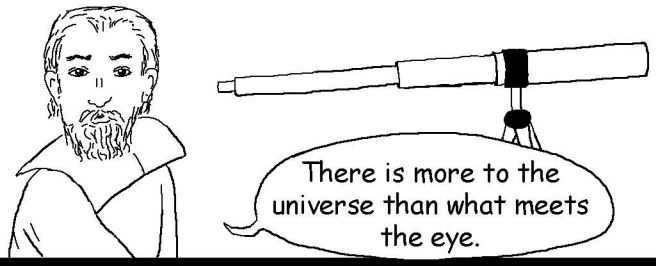
When Galileo got wind of a new device that made distant objects to appear closer, he wasted no time.

He brought the new invention home, studied it and made several improvements . . .



. . . and started watching the sky.

What the telescope revealed to him set astronomy on a new track.



The telescope accomplished two things. Firstly...

Secondly, the ability of the telescope to reveal great detail meant. . .

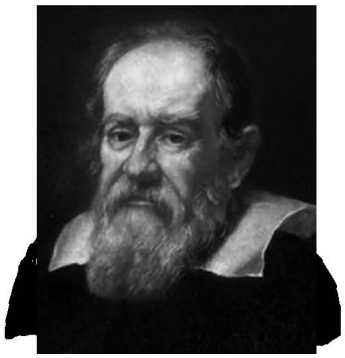
It is like Copernicus being known for the heliocentric theory, though the idea had been around for more than a 1000 years. But the credit goes to Copernicus for working the idea into a full fledged theory for the **first time.**

Similarly, Galileo championed the use of the telescope in astronomy. He also spent a lifetime improving the instrument.

Through it, he saw a host of celestial phenomena that no human being had seen till then.

Galileo and his telescope together revolutionized observational astronomy.

Galileo Galilei 1564-1642



Born in Italy. He pioneered the use of the telescope in astronomy. He discovered many objects hitherto invisible to the naked eye. He saw things which no one had ever seen before. Galileo revived the Copernican heliocentric view of the cosmos. He pioneered the use of quantitative experiments. He also undertook a systematic study of motion. He has been hailed as the father of modern observational astronomy, the father of modern physics and the father of science.

Galileo's theory went against the established doctrine of the church. Consequently, Galileo's last years were spent under house arrest.

What Kepler's findings did to astronomy theory, Galileo's telescope did to observational astronomy.

Among the first things Galileo discovered in the sky were innumerable stars too faint to be visible to the naked eye.

Who would have thought! Even the milky way is a crowding of stars.

The telescope enlarged the planets a bit. The stars on the other hand appeared brighter but still retained their point-like appearance.

What could this mean? May be the stars are unimaginably far from us.

Which kind of explains why we don't see stellar parallax even if the Earth orbits the Sun.

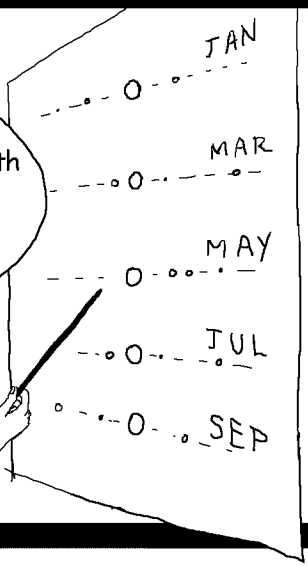
Galileo, like his contemporary Kepler, was also an ardent advocate of the Copernican picture. His telescopic discoveries helped revive the heliocentric theory.

His most exciting discovery was the moons of Jupiter. For months he observed what appeared like three stars following Jupiter closely.

Wait a minute. They looked like stars. But why are they wandering?

And why are they following Jupiter?

They are actually going back and forth in a straight line through Jupiter. I know what is happening.



Surely, there was nothing special about Earth. It had just one moon. Jupiter had several. This further supported the Copernican hypothesis.

Galileo saw many more interesting things.

Venus has phases just like the Moon.

Saturn has wings, which appear and disappear.

The moon is not a smooth ball. Its surface is full of bumps and pits.

Galileo's exciting discoveries galvanized half-yawning astronomers into action. They wanted to search the heavens too.

Cool! New things to discover every day.

I must get going.

I have a lens to grind.

The telescope gained popularity. It became indispensable for observational astronomy.

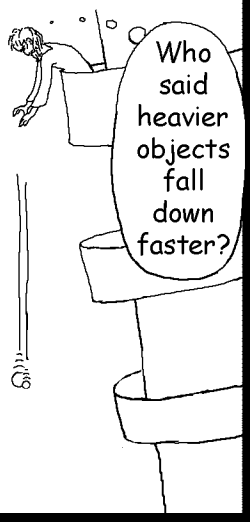
The instrument has evolved over the centuries. But it still enjoys the same status today as it did in Galileo's time.

I want to become an astronomer dad.

I had guessed as much son. Here is your telescope money.

A PURELY GEOMETRICAL UNDERSTANDING OF PLANETARY MOTION HAD NOT HELPED TO PROVE THE HELIOCENTRIC THEORY. GALILEO UNDERTOOK A SYSTEMATIC STUDY OF THE PHYSICS OF MOTION.

HE CONDUCTED EXPERIMENTS . . .



. . . AND DREW HIS OWN CONCLUSIONS.

Uniform motion is a natural state of bodies. No external agent (or a force) is needed to keep an object moving uniformly.

The state of rest is only a special case of uniform motion. Inertia which keeps a body at rest also keeps it in motion and prevents it from stopping on its own.

HIS IDEAS WERE QUITE RADICAL.

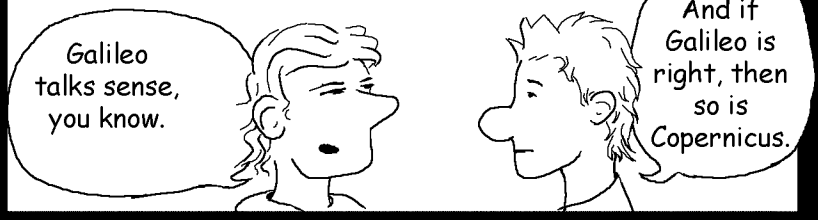
It is the abruptness in movement (like setting an object into motion, or stopping one which is already moving) that requires an external force.

If you are moving *uniformly*, even at a tremendous speed, you won't feel a thing.

However, abruptness in motion is felt immediately.

THIS CAN BE EASILY TESTED BY ANYONE USING AN ELEVATOR.

GALILEO'S PHYSICAL THEORIES OF MOTION WENT A LONG WAY IN RE-VALIDATING COPERNICUS'S MODEL.



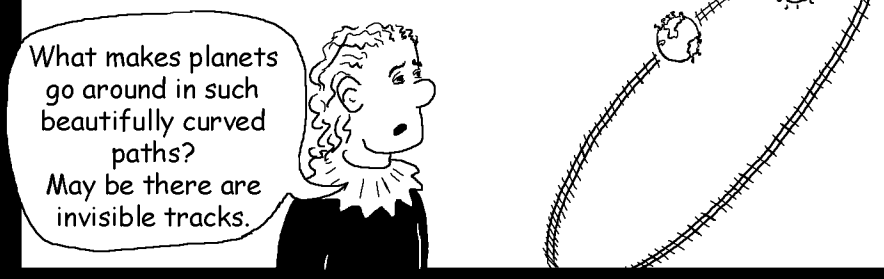
GALILEO'S IDEAS ON MOTION BECAME THE FOUNDATION UPON WHICH THE THEORY OF PHYSICS BLOSSOMED.

GALILEO FORMED HIS IDEAS ABOUT THE UNIVERSE BASED ON A SOLID FOUNDATION OF OBSERVATION AND LOGIC. HIS THEORY WAS RADICAL AND CONTRADICTED THE EXISTING NOTIONS, ESPECIALLY THOSE FROM THE HOLY SCRIPTURES. THE CHURCH TOOK THIS AS A THREAT.

GALILEO WAS IMPRISONED. HIS WRITINGS WERE BANNED. HE SPENT HIS LAST YEARS UNDER HOUSE ARREST.

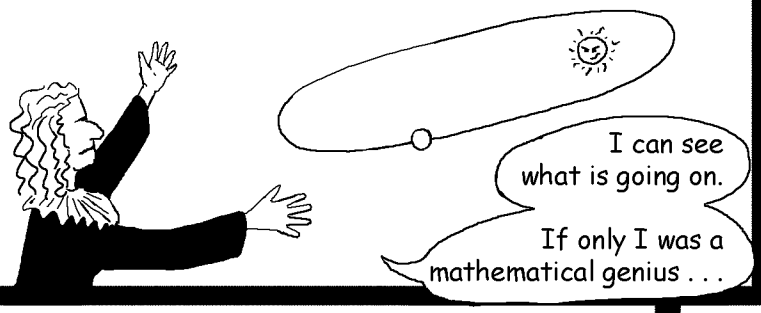
IT TOOK ALMOST 400 YEARS FOR THE CHURCH TO CATCH UP WITH GALILEO AND WITH SCIENCE. IN 1992, POPE JOHN PAUL II APOLOGIZED ON BEHALF OF THE CHURCH FOR THE WAY THE GALILEO AFFAIR WAS HANDLED. HE ALSO PUBLICLY ACCEPTED THAT EARTH WAS NOT STATIONARY.

Kepler had urged the astronomers to look at planetary motion as celestial physics. Galileo had arrived at some fundamental understanding of motion. But when it came to planetary orbits, nobody had a real clue.

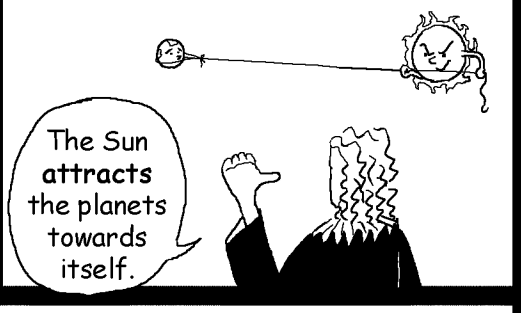


It was Robert Hooke who first came up with a correct explanation.

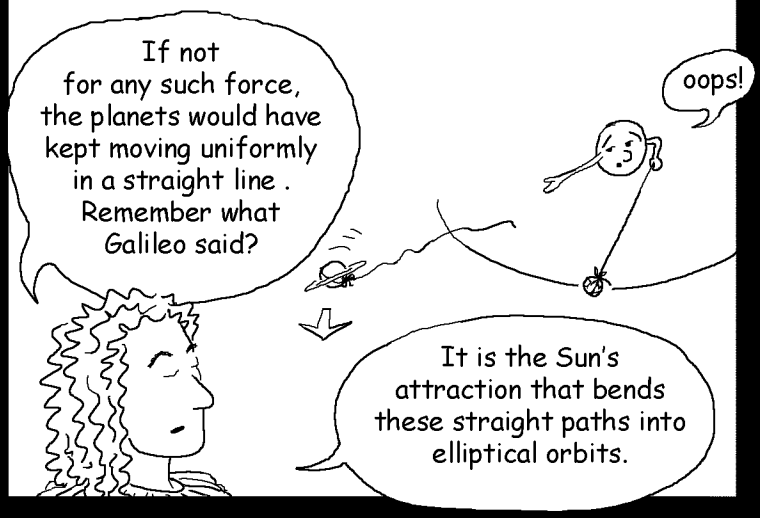
Hooke exhibited great intuition, but lacked the mathematical ability required to shape his ideas into a scientific theory.

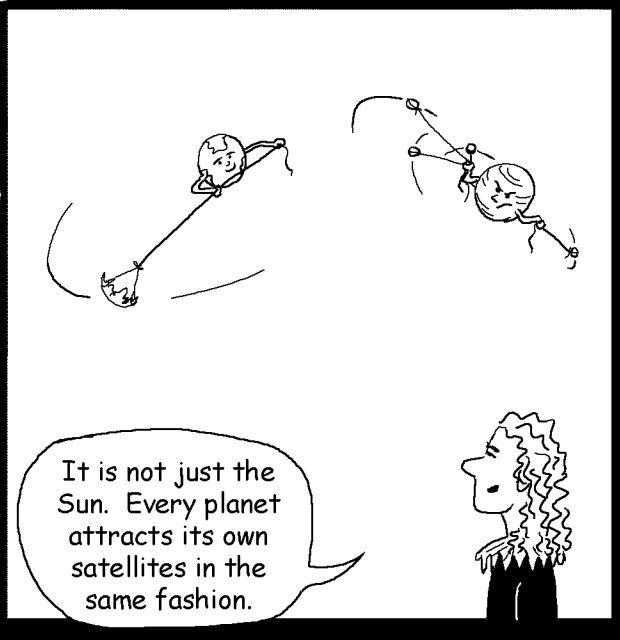


In fact, it was Hooke who first recognized **gravitational attraction** . . .



. . . and the role gravity played in celestial mechanics.





Hooke also said that this gravitational attraction was stronger for nearer objects as compared to those far away. That is why planets closer to the Sun revolved faster than those with larger orbits.

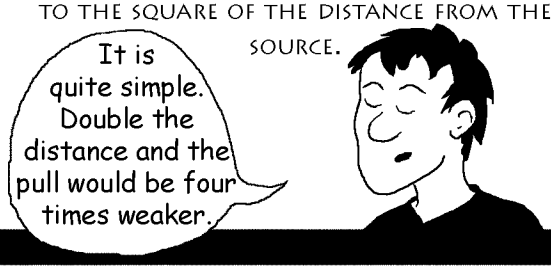
Hooke's ideas were quite appealing, accept that they were ideas without mathematical details to support them. Fortunately, Newton, the mathematical genius, had also been thinking along similar lines. He eventually worked out a full fledged scientific theory, and brought celestial physics to a conclusion.

The contributions of Galileo and Robert Hooke were promising. But they did not constitute an understanding of celestial mechanics. The fire started by Kepler's discoveries could not be pacified with qualitative explanations. There was a dire need for a physical theory to enunciate Kepler's laws with mathematical precision.

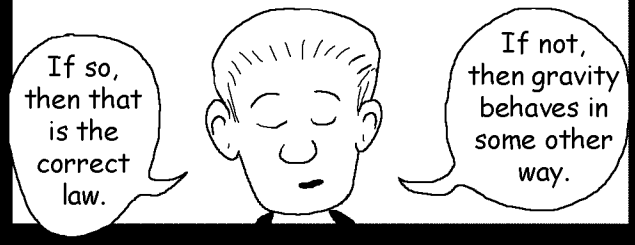
The credit goes to Isaac Newton. He not only worked out the minutest details of such a theory, but also invented the requisite mathematics.

Hooke intuitively felt that as one went further away from the Sun its gravitational pull gradually diminished. But what was the exact relationship between the distance from the Sun and the pull of gravity? It was still a mystery.

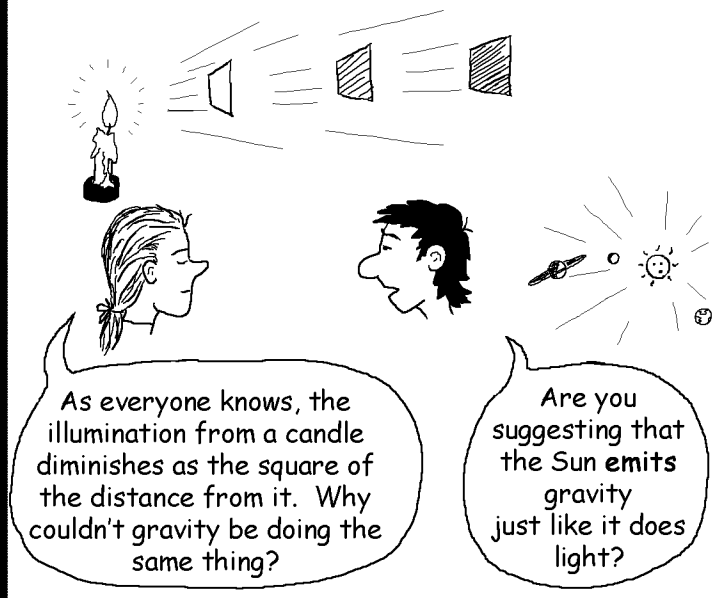
Eventually, gravitation was found to obey the **inverse square law.** This law says that the strength of the gravitational pull diminishes in proportion to the square of the distance from the source.



The real question was, *did the inverse square law of gravitation lead to elliptical orbits?*



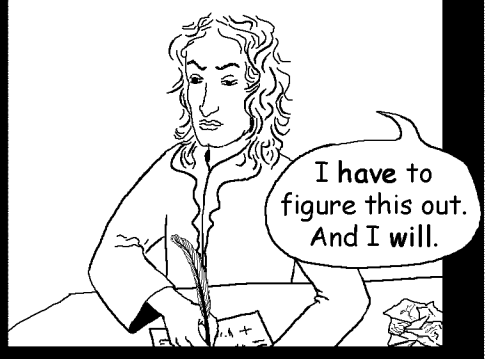
The inverse square law was not so hard to conceive. In fact it was quite a natural candidate to be considered.



Robert Hooke claimed that the inverse square law of gravity would give rise to elliptical orbits. But he refused to furnish any proof.

At last Hooke went to Isaac Newton for a discussion. By now Newton was well established as a reputed mathematician. Unfortunately, this meeting resulted in a clash.

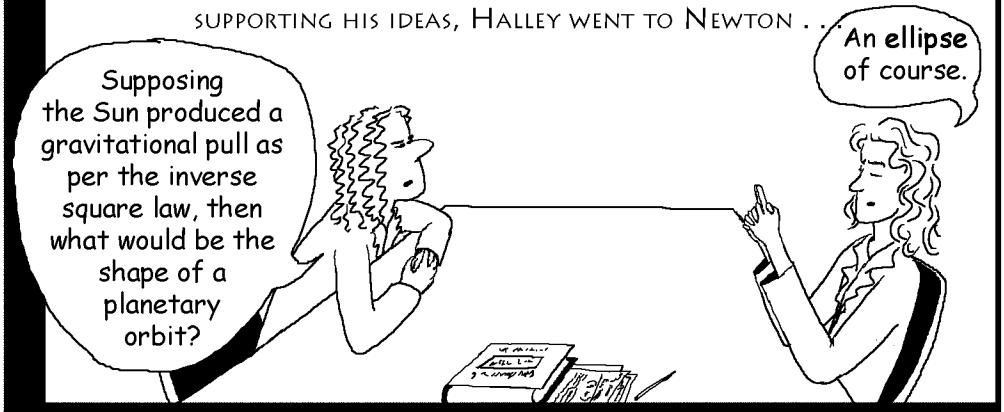
Newton was deeply offended. He retreated into a shell, but only to undertake a deeper study of the matter.



After his meeting with Hooke, Newton worked out a theory of gravitation. But he kept the results to himself.

Fortunately about the same time, Edmond Halley - a young member of the Royal Society - was also keenly interested in a physical theory of celestial mechanics.

Disappointed with Hooke for not providing any mathematical details supporting his ideas, Halley went to Newton . . .



This meeting was indeed consequential. A little later Newton sent Halley a small article with details of his mathematical theory.

Halley's excitement was boundless.

Newton's small article contained results beyond Halley's expectations. With the assumption of an inverse square law of gravitation, Newton had showed that a planetary orbit will be elliptical (Kepler's first law), with a speed variation obeying Kepler's second law and an orbital period in accordance with the third.

Newton's results meant an end to the confusion that had reigned for two thousand years. A clearer picture of the universe began to emerge.

There was a simple set of principles which guided the motion of heavenly bodies.

Recognizing the potential of Newton's work, Halley coaxed him to publish the theory.

Isaac Newton
1643-1727

Born in England. He invented Calculus, probably his greatest contribution to the world of science. (The claim for inventing Calculus was also shared by Lebenitz, resulting in a controversy, which has never been settled.)

He worked out a theory of Dynamics, giving a concrete and mature shape to Physics. Through the application of Calculus and Dynamics, he worked out the first physical theory of astronomy.

He also studied the behavior of light. He invented the *reflecting telescope* (also known as the Newtonian telescope).

Newton was a perfectionist. He would rather not publish at all than publish a half baked article and risk criticism and ridicule.

Sorry Edmond. I am afraid this work is not publishable.

Only after much coaxing, did he relent and set to work on a publishable version of his theory.

I will see what I can do. This will take some time though.

Prose Text

Dialog Text

Newton worked hard on it for the next three years. He finally came up with his masterpiece. His theory was to become the bible of physics for the next two hundred years.

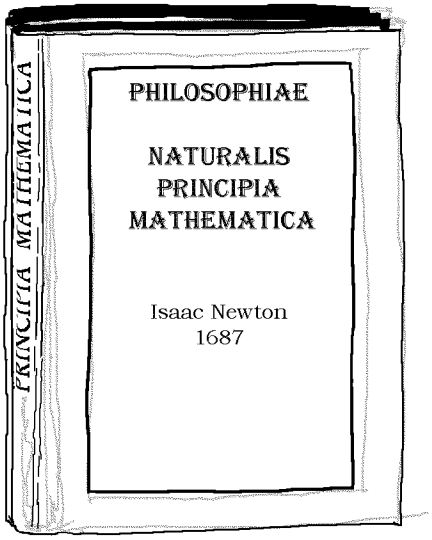
Now, THIS certainly is publishable.

Within those three years, Newton had expanded his original nine-page article into a seminal work and published it under the impressive title

Philosophiae Naturalis Principia Mathematica

or

Mathematical Principles of Natural philosophy.



Popularly known by the short name **Principia Mathematica** (or simply Principia) it spanned three volumes.

In no time, **Principia** became the gospel, and its author a legend.

Look, how neatly he has laid the foundation for motion. Is every object guided by the same set of principles?

And every planet attracts every other? How fascinating!

$f = ma$

$f = G\frac{Mm}{r^2}$

I tell you . . . Newton is the voice of God.

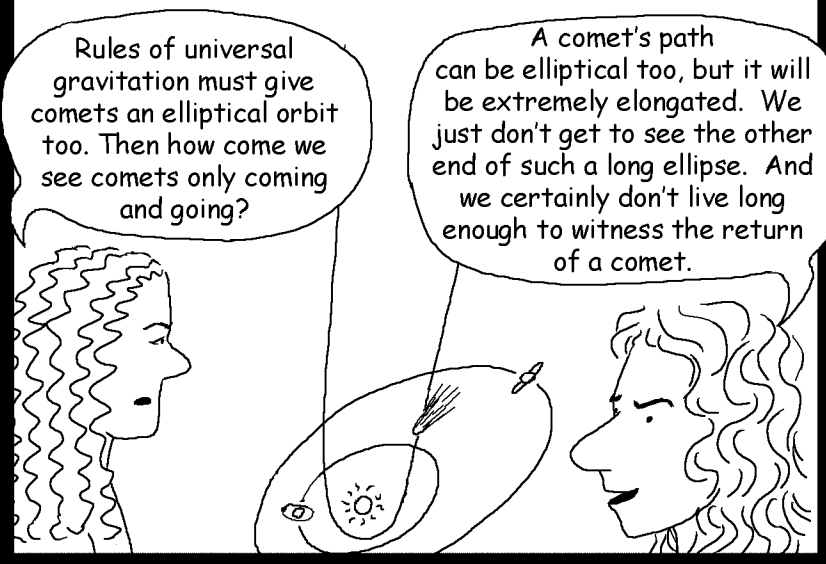
Principia did three things: It

a) laid out the principles governing the motion of objects,
b) gave a precise description of how every object attracted every other object in the universe, and finally,
c) combined the two to explain why the planets moved the way they did.

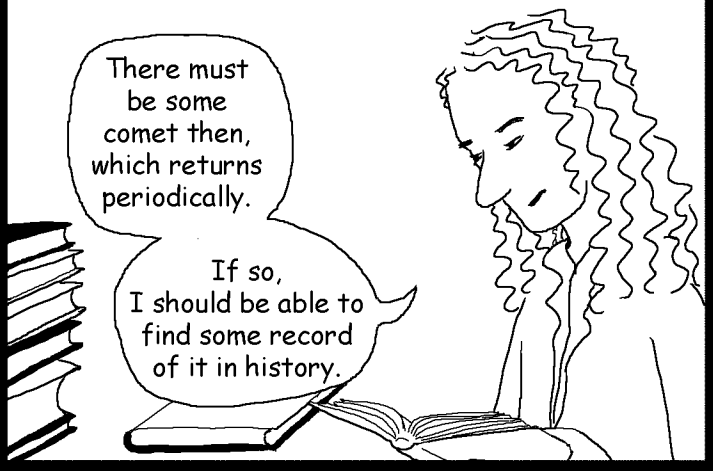
The first two were brilliant yet simple pieces of work. To explain the motion of planets precisely was a complex mathematical task. Newton only initiated it.

Right from the beginning Halley had taken a keen interest in Newton's work. In fact it was Halley who used his personal funds to finance the publication of Principia.

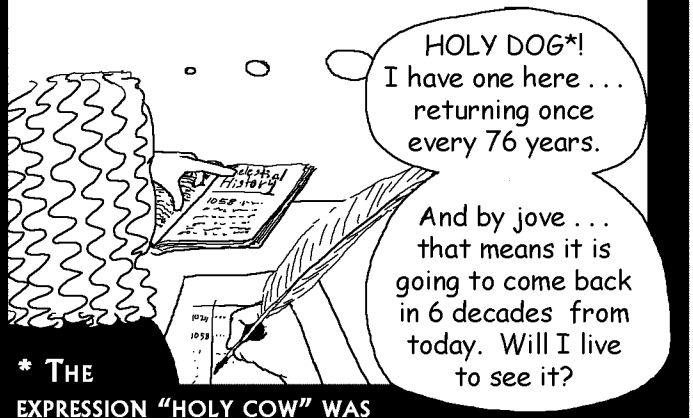
Halley played a pivotal role in popularizing Newton's theory. This brought him much fame.



Halley, who had great faith in Newton, set off to verify this theory.

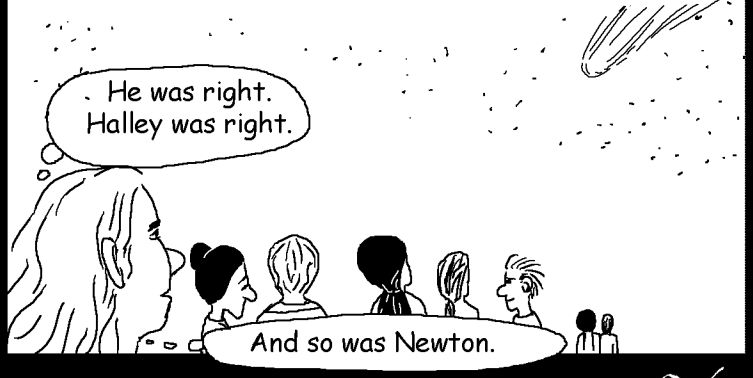


He delved through piles of historic data. Surely enough, he managed to identify one periodical sequence of comet sightings.



* The expression "holy cow" was not invented till the British went to India.

A comet was spotted in 1758 just as Halley had predicted. It was an historic event indeed. Sadly enough, Halley had died almost two decades earlier.



The Halley's Comet continues to visit the Sun once every 76 years or so, just like Halley had predicted.

Even today the Halley's Comet draws the attention of the whole world. Its reappearance is a great crowd puller.

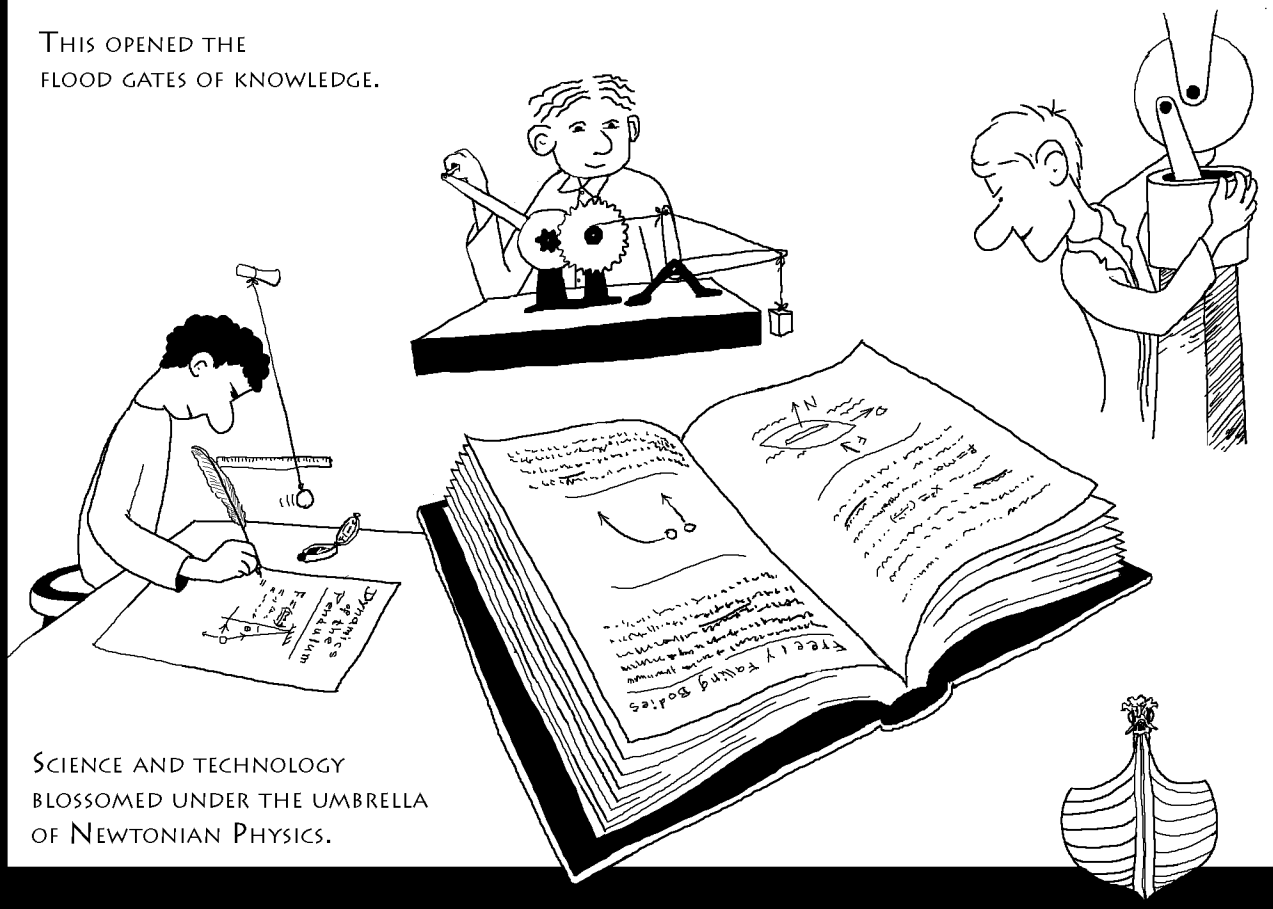
Keep on the look out for Halley's Comet on its next predicted visit sometime around 2061.

The laws of motion presented in **Principia** were not limited to celestial bodies. They applied to all things.

Soon scientists started applying Newton's laws of motion to all possible physical phenomena they encountered.

Much to their delight, everything they investigated seemed to fit within the framework described in **Principia.**

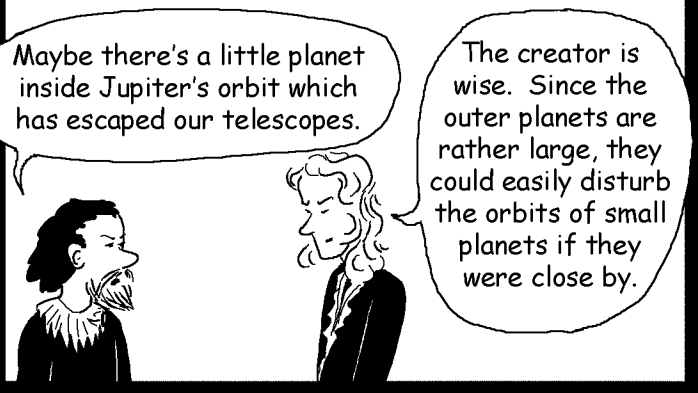
This opened the flood gates of knowledge.



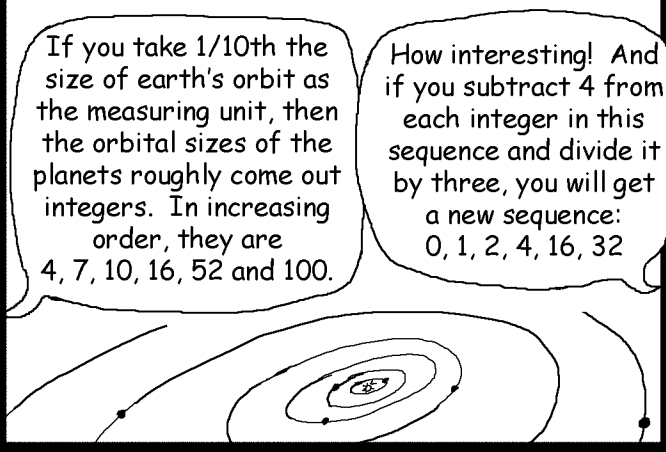
Science and technology blossomed under the umbrella of Newtonian Physics.

Newtonian Physics ruled the physical sciences and engineering for two hundred years.
Newton seemed to have revealed the Secrets of Nature.
People started reposing their faith in scientific enquiry.
Science and technology would henceforth power the engines of growth.

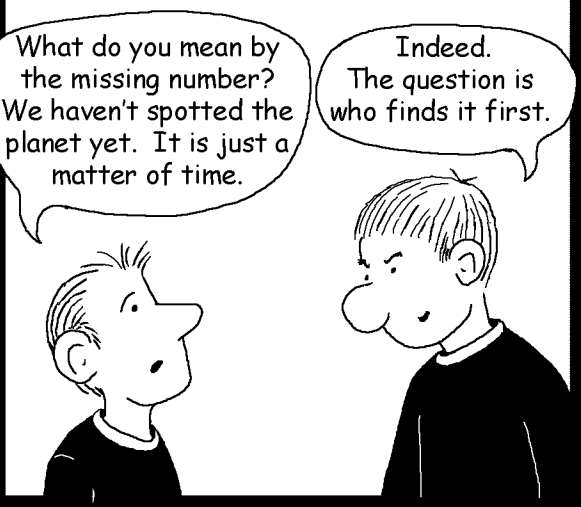
Some people found a striking void in the solar system. There was a huge gap between the four inner planets and the two outer planets. How does one explain this anomaly?



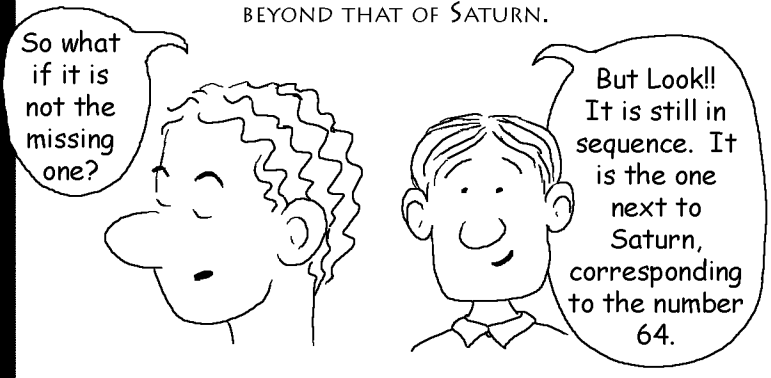
Some people thought that the orbital sizes of planets followed a sequence.



Such a strikingly simple sequence could hardly be a coincidence. Astronomers strongly believed that the sequence was a law followed by the orbital sizes of the planets-except for the missing number 8.



In 1781, William Herschel, an amateur astronomer, discovered a new planet. It was named **Uranus**. Interestingly, its orbit did not lie within that of Jupiter where the search for the missing planet was on, but well beyond that of Saturn.



The fact that the newly found planet Uranus had an orbital size that fitted the law was very encouraging. This, if anything, resulted in intensifying the search for the missing planet corresponding to number 8.

In 1801, an Italian astronomer called Giuseppe Piazzi spotted a tiny object moving in the region of the missing planet. Three more tiny objects were found in the same region within the next few years.

By 1891 more than 300 asteroids had been found. All orbited the Sun in the region of the missing planet - which corresponded to the number 8 in the sequence.

Even today, nobody really knows how the asteroids originated. According to a widely accepted theory the disruptive pull of Jupiter prevented these fragments from forming a planet.

The movement of Uranus was puzzling.

I have taken everything into consideration. Yet Uranus keeps deviating from the predicted path.

Maybe Newton's laws are not valid at such large distances.

Indeed, one could question the validity of Newton's theory at the edge of the solar system, or . . .

Perhaps we haven't considered everything that needs to be considered. May be there is another planet we haven't yet seen which keeps pulling Uranus out of its course.

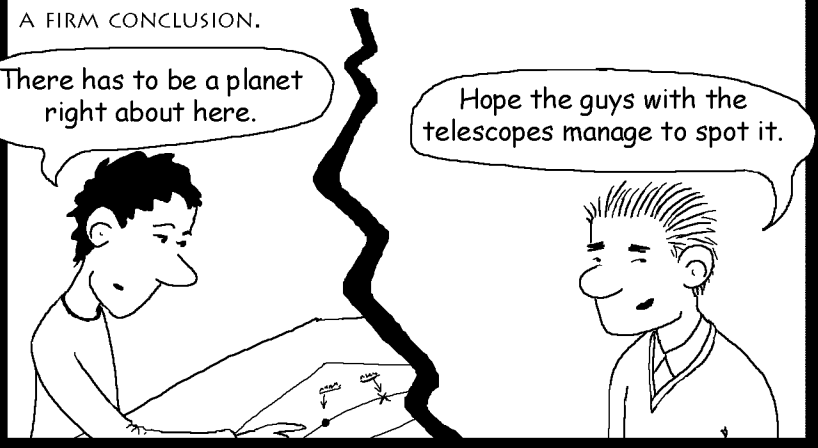
In the 1840s, two bright mathematicians, John Couch Adams and Urbain Le Verrier, set to work independently.

Suppose there is an unseen object that is pulling Uranus out of its track.

Under the assumption that Newton's theory was correct, the two mathematicians did calculations and arrived at a firm conclusion.

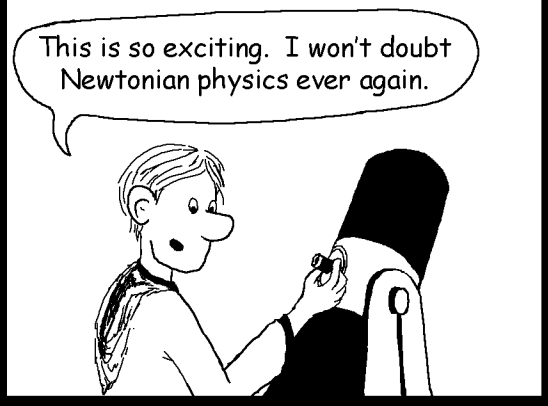
There has to be a planet right about here.

Hope the guys with the telescopes manage to spot it.



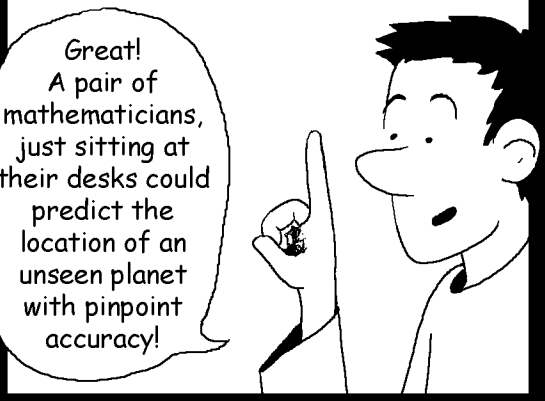
In 1846, a new planet traversing an orbit was spotted, exactly where the mathematicians predicted it to be.

This is so exciting. I won't doubt Newtonian physics ever again.



The discovery of Neptune (as the newly discovered planet was called) marked the highest achievement of Newtonian Physics.

Great! A pair of mathematicians, just sitting at their desks could predict the location of an unseen planet with pinpoint accuracy!



Dramatic as the prediction and discovery of Neptune was, its existence did not account for the deviation of Uranus's path completely. A small discrepancy left unexplained was attributed to yet another unseen planet. Naturally, astronomers tried to predict the location of this 9th planet of the solar system. In 1930, a tiny body (one fifth the size of our moon) was located roughly where the predictions pointed out. It was named Pluto.

Today we know that Pluto is too tiny to cause any noticeable deviation in the path of Uranus. The discrepancy between its predicted and observed paths was due to incorrect estimation of Neptune's mass. By an amazing coincidence, Pluto was found where a miscalculation predicted it to be.

In 2006, Pluto was no more considered a planet but one of many **DWARF PLANETS** orbiting the Sun beyond Neptune.

Newton's physics thrived for a good 200 years.

It is nothing compared to the 1500 years of supremacy enjoyed by Ptolemy, but during these 200 years, Newton's theory has covered most of the physical phenomena known to humankind.

After Neptune's discovery another unusual thing caught the attention of astronomers. It was the orbit of Mercury.

See how Mercury's orbit keeps turning? This can't be explained by the combined pull of all the other known planets.

Are you suggesting that there is another planet like Neptune yet undiscovered?

Some people thought that there was a planet with a tiny orbit which evaded sighting because of the Sun's glare. The fictitious planet was named **Vulcan**.

I swear I saw Vulcan yesterday. Don't know where it's hiding now.

Numerous false sightings of Vulcan were reported, but never proved.

In 1915 the famous German physicist Albert Einstein came up with a new theory of gravitation called the General Theory of Relativity. It was a completely new way of looking at gravity. According to Einstein's theory, Newtonian theory of celestial mechanics was only approximately correct.

Wait a minute. According to Einstein, all elliptical orbits precess like that of Mercury.

Mercury's precession matches with Einstein's theory perfectly. I have gone through the calculations myself.

Einstein's General Theory of Relativity eliminated the need to look for another planet. Vulcan remained fictitious.

Newton's theory failed here. Thanks to Einstein, we were saved in time.

It would have been cool to have a new planet though. I kind of liked the name Vulcan.

That Newton's theory was only approximate was hard to swallow, but the evidence was compelling. Moreover Einstein's theory was radically beautiful. According to Einstein, space and time were interwoven into a fabric. He said that gravity was not a force at all but a force-like illusion caused by the space-time fabric which bent paths of freely moving objects.

Einstein argued that the space-time fabric that bends paths of objects also bends the path of light. This phenomenon known as gravitational lensing was carefully measured and it matched well with Einstein's calculations. The General Theory of Relativity was slowly accepted as a superior theory for understanding celestial mechanics.

Einstein's theory of gravitation has stood its ground for almost a century. It is still the best theory available to explain celestial motion.

Kepler had figured out the fundamental nature of planetary orbits. Newton's brilliant mathematics had revealed the underlying physical mechanism.

That takes care of the planets. But what about all those stars?

Oh . . . I can predict the stars better than you can do the planets. The stars will stay fixed forever!

Since the very beginning of the history of astronomy, two ideas hadn't changed much . . .

The stars are beautiful little things, aren't they?

I say. And they are stuck to the inside of a giant sphere.

The fixed pattern of stars was the foundation upon which the entire study of planets was based. But the stars themselves failed to intrigue the human mind.

Stars are beautiful but boring.

They are quite useful though.

How far away were the stars from the Earth? This was the most natural question to ask. But no one really had a clue.

How far are the stars? Could you knock one down for me?

I don't know. It is worth a shot though. Pass me a stone, will you?

There was no observational evidence that could have given away the distance of the stars from the Earth. Astronomers made their own guesses. Almost anything went.

The *stellar sphere* is beyond all the planets. Otherwise the planets would keep bumping into it, wouldn't they?

I agree with you. But I would place the stars just beyond Saturn, the farthest of planets.

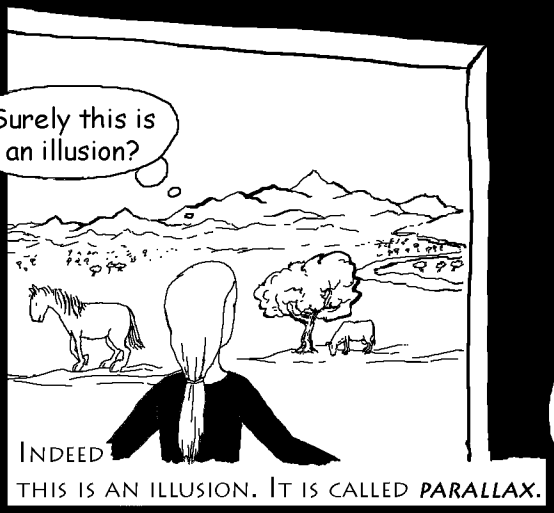
The strongest hint came from the heliocentric theory of Copernicus.

If the Earth travels a huge distance while orbiting the Sun, then how come we don't see any parallax* in the pattern?

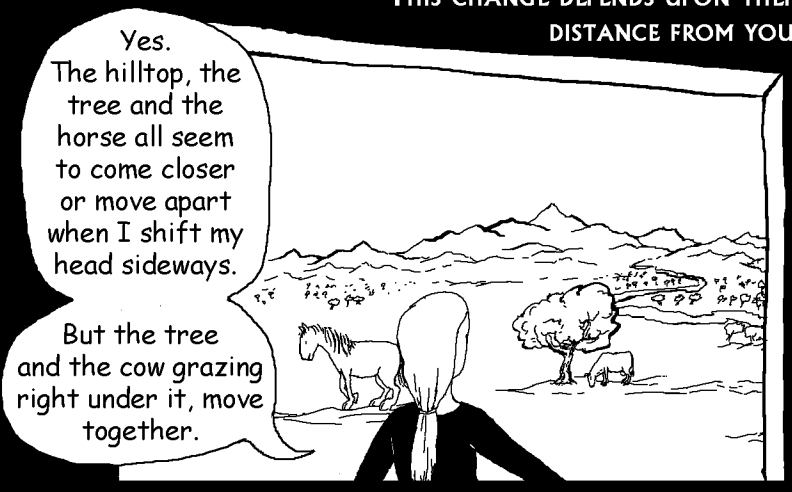
That's bothered me too. Maybe the Earth's orbit is a tiny speck compared to the huge distances of the stars.

* What is parallax?

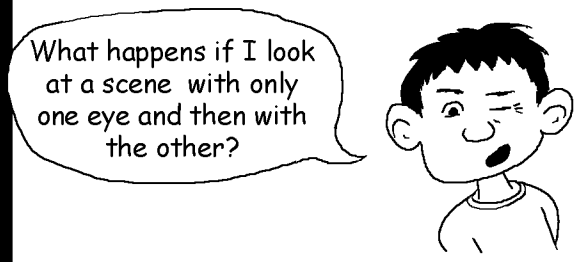
HAVE YOU EVER NOTICED THE SCENERY THROUGH THE WINDOW SHIFTING AS YOU MOVE YOUR HEAD?



PARALLAX IS REALLY ABOUT NEARBY AND FARAWAY OBJECTS. AS YOU CHANGE YOUR VIEWING LOCATION, THE THINGS IN VIEW SEEM TO CHANGE THEIR RELATIVE POSITIONS TOO. THIS CHANGE DEPENDS UPON THEIR DISTANCE FROM YOU.

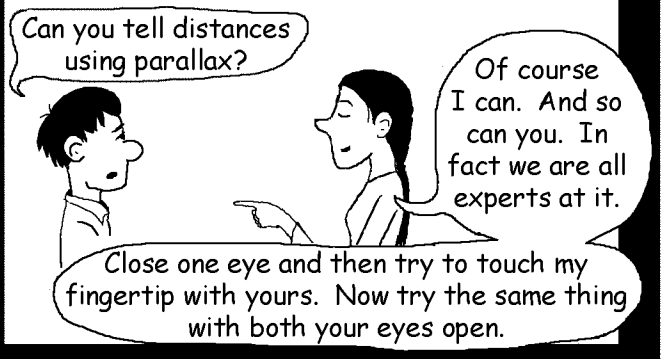


EVEN OUR TWO EYES SEE DIFFERENT IMAGES BECAUSE THEY LOOK AT THE WORLD FROM TWO DIFFERENT LOCATIONS.

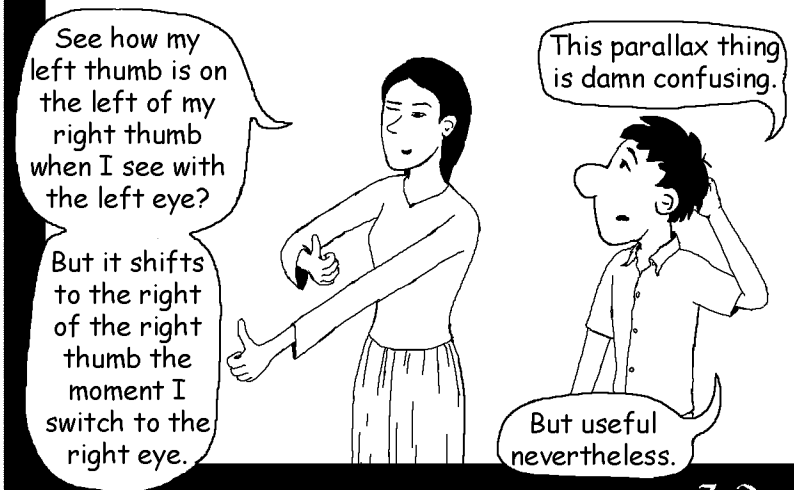


NOT SURPRISINGLY, SWITCHING BETWEEN EYES GIVES AN EFFECT SIMILAR TO THAT RESULTING FROM MOVING YOUR HEAD FROM SIDE-TO-SIDE.

PARALLAX IS VERY USEFUL. THE EXTENT TO WHICH THE RELATIVE POSITIONS OF OBJECTS SHIFT ALSO GIVES US AN IDEA ABOUT THEIR DISTANCES FROM US.



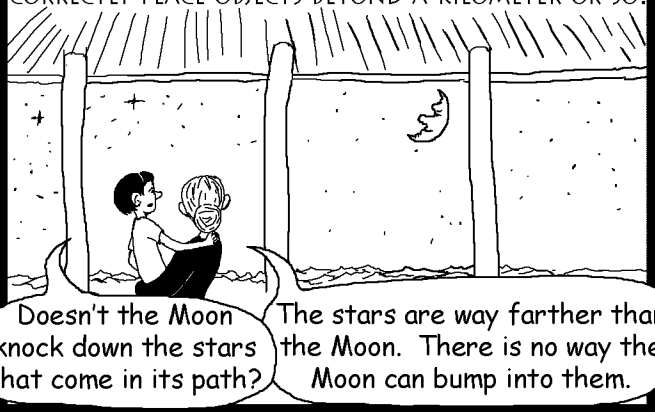
POSITION YOUR TWO THUMBS IN FRONT OF YOUR NOSE, ONE CLOSE TO IT AND THE OTHER FARTHER AWAY. NOW ALTERNATE BETWEEN YOUR EYES.



THE IMAGES FROM OUR TWO EYES ARE PROCESSED BY OUR BRAIN TO FIGURE OUT THE DISTANCES OF OBJECTS. THIS COMBINING OF TWO IMAGES, CALLED STEREO VISION, GIVES US A THREE DIMENSIONAL VIEW OF THE WORLD.

FOCUS ON A POINT IN BETWEEN THE TWO WINDOWS ABOVE. NOW SLOWLY MOVE THE POINT OF FOCUS AWAY FROM YOU INTO THE PAPER TILL YOU SEE EXACTLY THREE WINDOWS. WHAT DO YOU SEE IN THE MIDDLE ONE?

Our stereo vision is quite good for estimating distances of nearby objects but it fails to correctly place objects beyond a kilometer or so.

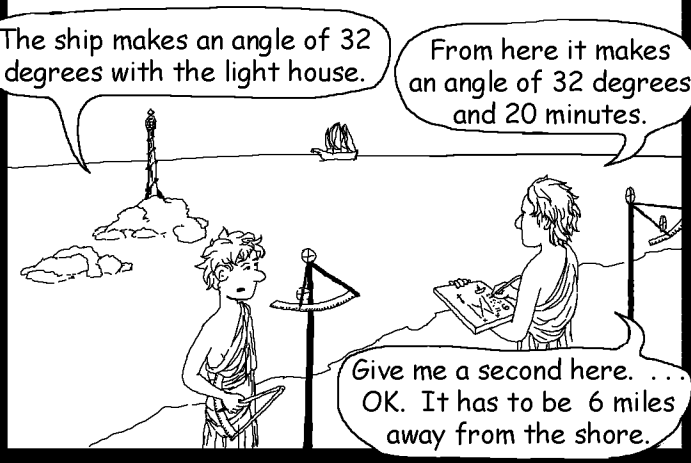


Objects more than a kilometer away appear almost the same to both eyes. At best we can infer that those objects must be very far away.

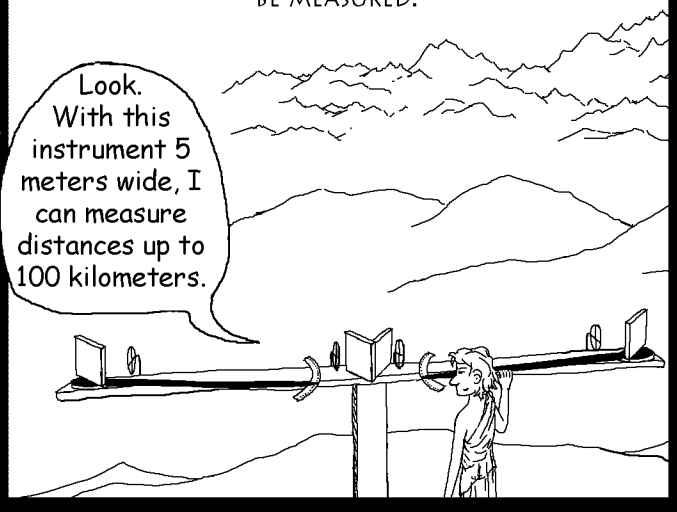
Our stereo vision can not help us in estimating the distances of heavenly bodies.

The ancient Greeks, having mastered Geometry, had figured out how to measure far away distances using parallax.

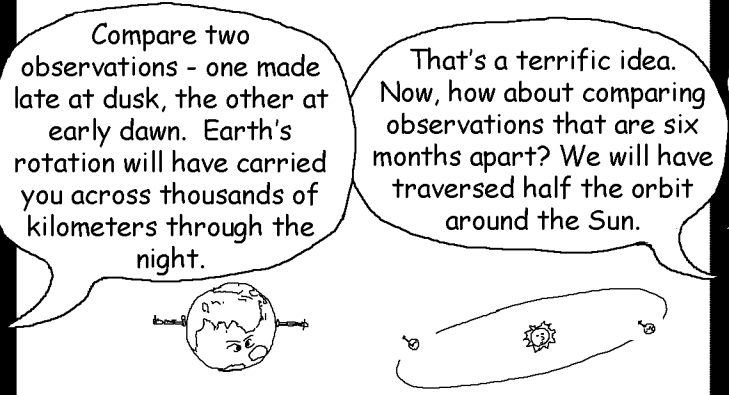
They viewed a scene from two points with a separation much larger than that between our eyes. By comparing these images they could estimate distances of objects beyond the range of stereovision.



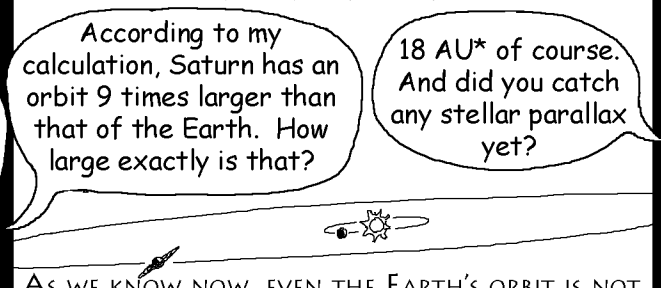
The wider the separation between two viewing locations, the farther the distance that could be measured.



To measure astronomical distances using parallax, one has to choose two viewing locations that are thousands of kilometers apart.



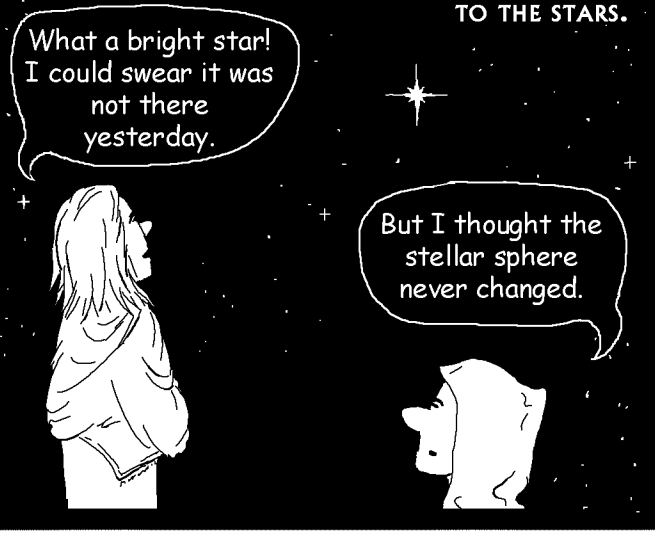
This is called **annual parallax.** In the early days, when the size of Earth's orbit was still not known, annual parallax could yield only relative distances.



As we know now, even the Earth's orbit is not large enough to observe **stellar parallax** easily. The stars were simply too far. But the search went on.

*AU - Astronomical Unit - see page 36

In the end it was a strange stellar activity which drew the attention of astronomers to the stars.



A bright star was spotted by Tycho in 1572. It was called **nova**, meaning *new star*.

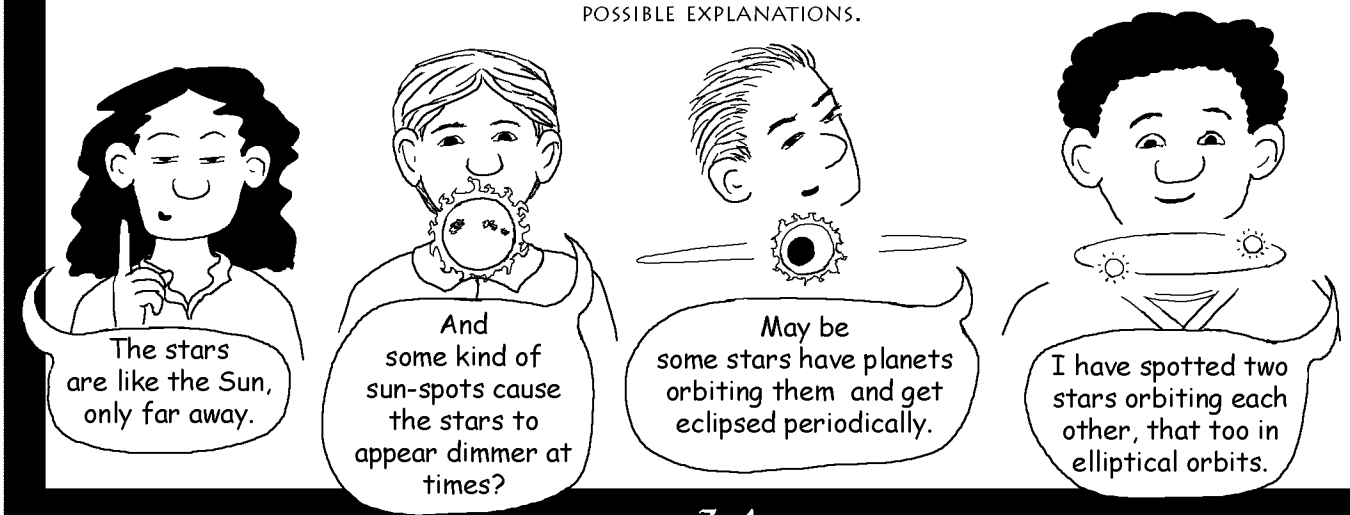
More novae (plural of nova) were spotted over the coming decades. Many disappeared within a few days. Some kept disappearing and reappearing.

This stellar phenomenon drew the attention of astronomers. The newly invented telescope made a big difference.

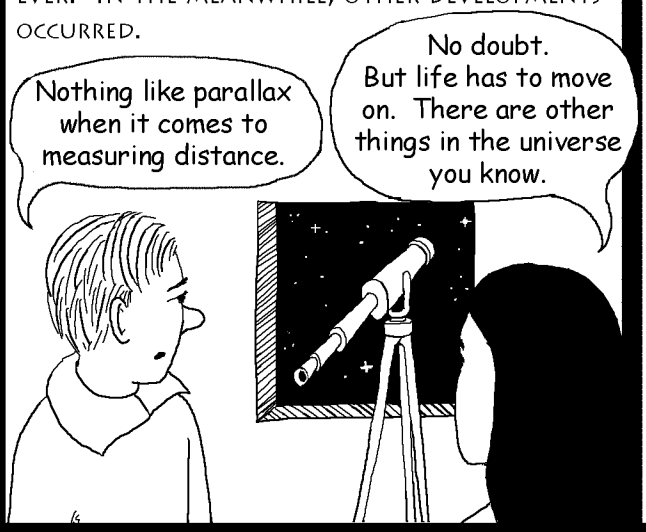
How did the astronomers miss all this stellar activity until now? For one, none of the bright stars varied. So before the telescope, the change in brightness of stars was difficult to notice. It was also assumed since the days of Ptolemy that the sphere of stars was unchangeable. Why spend time gazing at the immutable stars? Well, the nova changed it all. Now the astronomers were back studying the stars.

And once scientists started looking for stellar activity, they soon found it in abundance. The universe was full of variable stars.

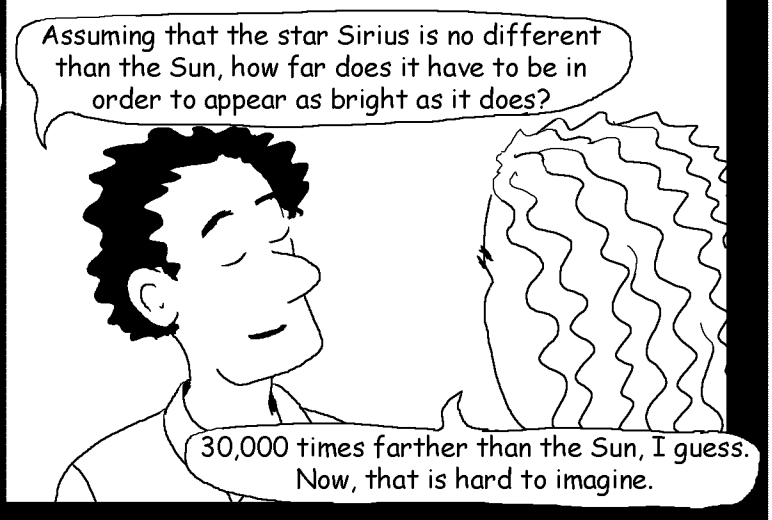
Some stars varied erratically while some showed periodic variations. Something was going on. This stellar activity excited the scientific community. Lots of astronomers came up with possible explanations.



Observing stellar parallax was as hopeless as ever. In the meanwhile, other developments occurred.

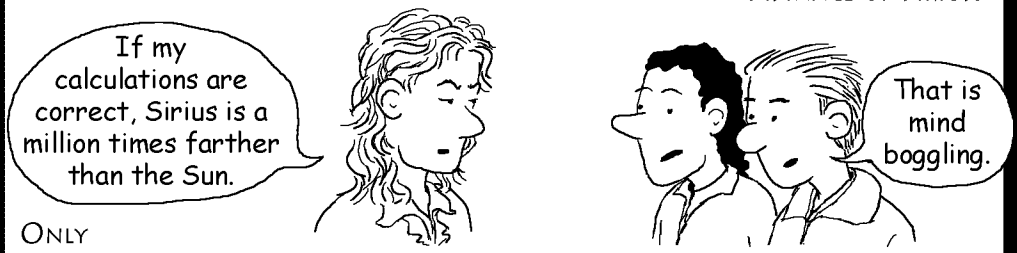


In mid 1650, the Dutch physicist Christiaan Huygens estimated the distance between Sirius and Earth.



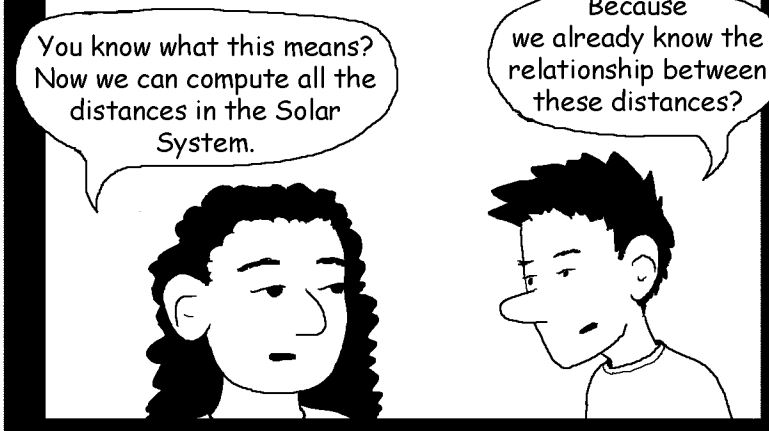
Huygens' assumption was baseless, and his methodology crude. Astronomers didn't even know how far the Sun was. But his estimate helped people to begin appreciating the vastness of the universe.

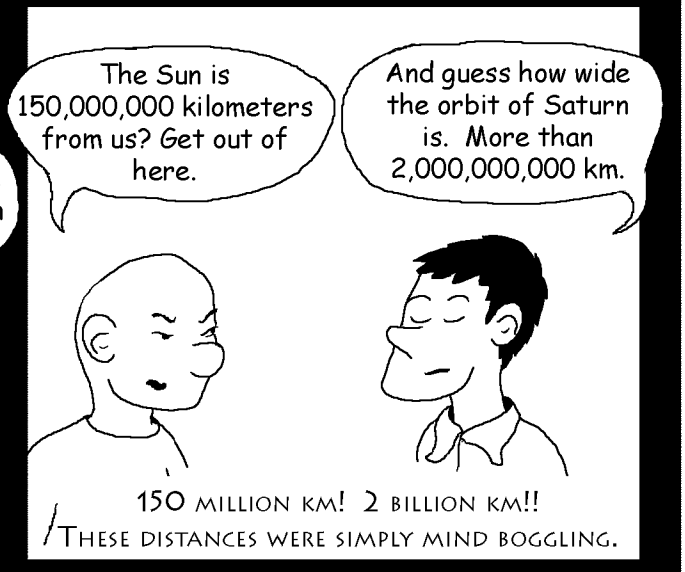
Based on similar assumptions, Newton too had estimated the distance of Sirius.



Only Newton's small coterie of friends knew this estimate. They were amazed.

In 1671, Giovanni Cassini, an Italian-French astronomer, figured out the distance between Earth and the planet Mars.

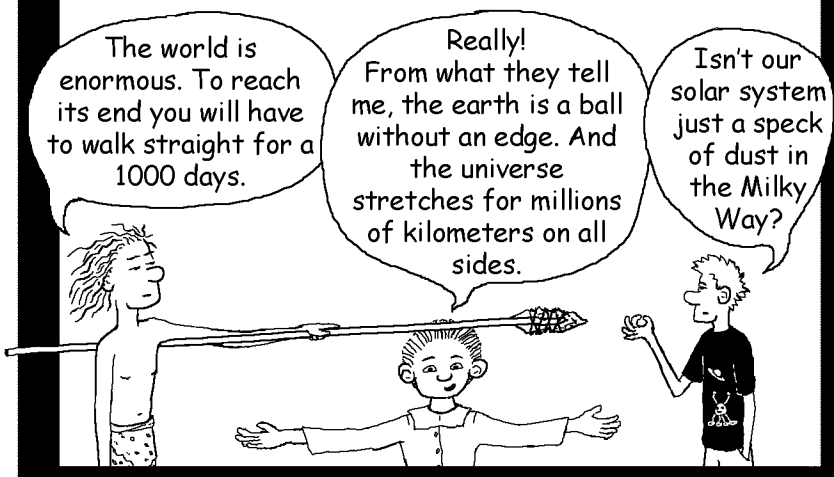




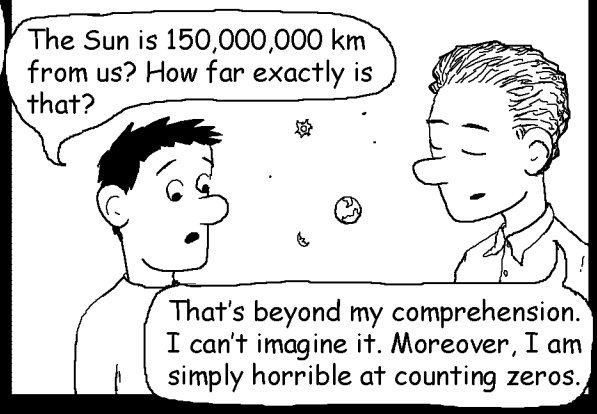
If our sun and its planets – the Solar System itself was so huge, how large then was the sphere of stars? Newton estimated the "star sphere" to be a staggering 2,000,000,000,000,000 km.

Were all stars actually fixed to a sphere as assumed? Or were they all scattered at different distances from us - the farther ones appearing fainter? In that case, how large would the universe be?

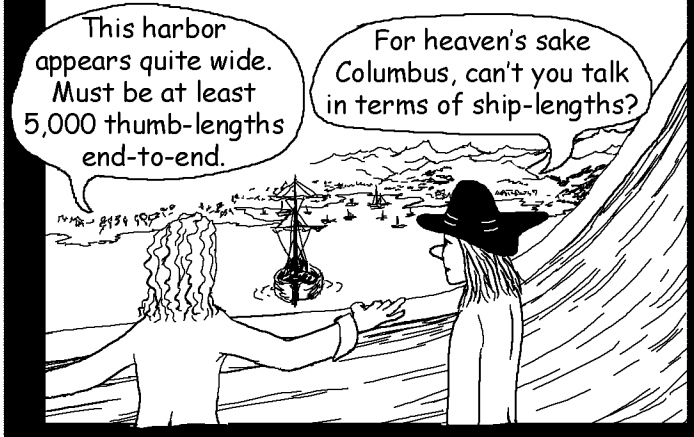
The world was vast, everyone agreed. But how large? Throughout history people have had different beliefs.



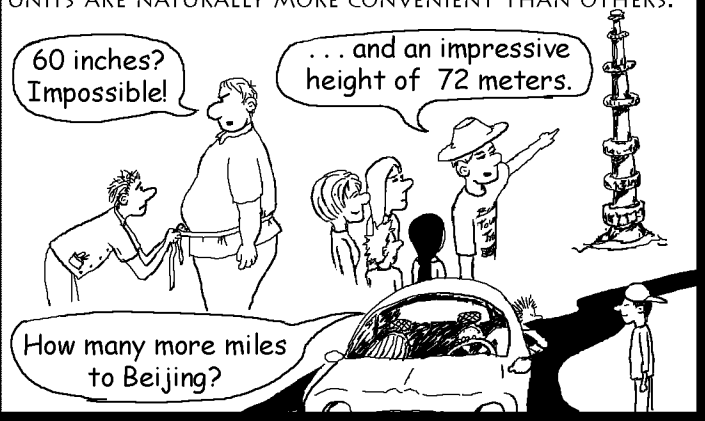
Many times in history, people came to the conclusion that the universe was much larger than what it was believed to be. And every time it challenged their imagination.



Like any other physical quantity, a distance can be expressed only in terms of another distance. Usually a widely familiar distance, called a unit, is used to quantify other distances.

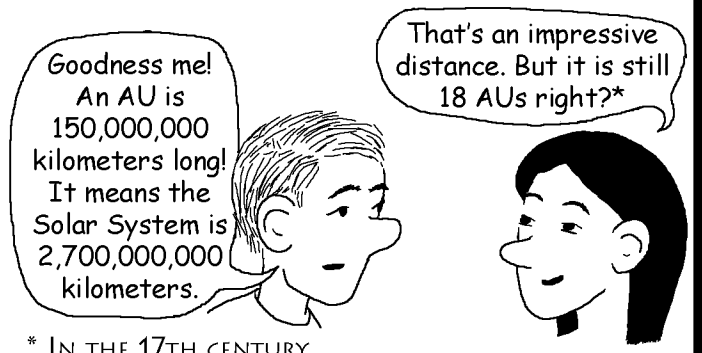


Depending on the length being measured, some units are naturally more convenient than others.



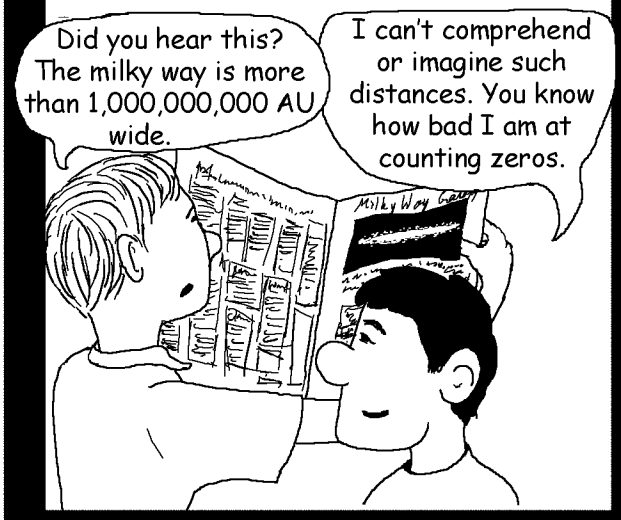
When the Solar System was under analysis, the distance between the Sun and the Earth was taken as the unit natural for expressing the distances involved. This distance was called the ASTRONOMICAL UNIT written **AU** for short.

Interestingly, when it came into use, the size of the astronomical unit itself was unknown. But since the ratios of distances in the solar system had been figured out, the AU served its purpose. Later in 1672, the actual value of AU was estimated in miles. Ever since the AU has continued to be the natural unit associated with the solar system.



* In the 17th century, the solar system ended at Saturn.

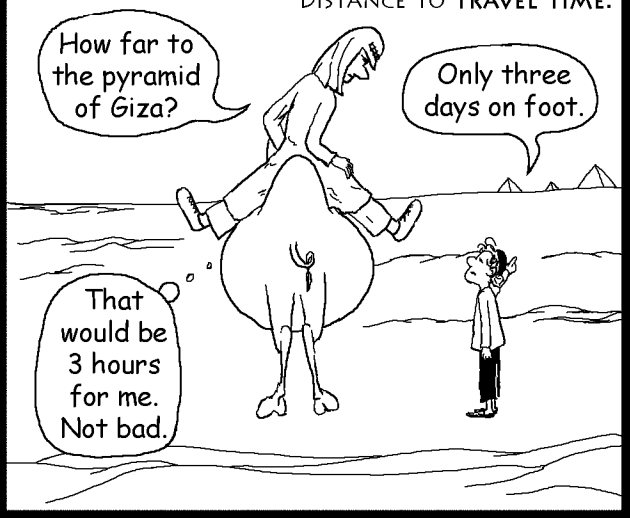
The AU did great as a natural unit for interplanetary distances. But was it good enough for the stellar world?



There was an urgent need for a new unit for expressing the distances of far away stars.

What would it be?

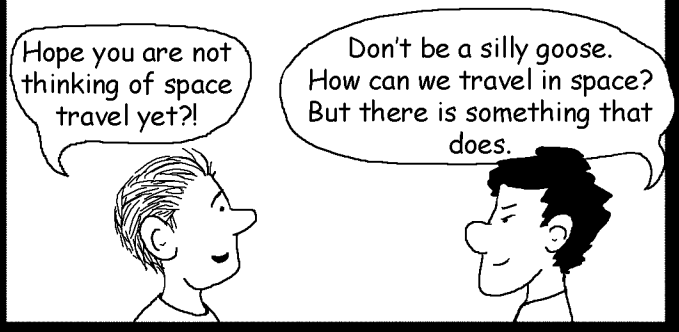
Human beings are travellers at heart. Right from our nomadic days we have equated distance to **travel time.**



The use of travel time to express distance is still very much in fashion.

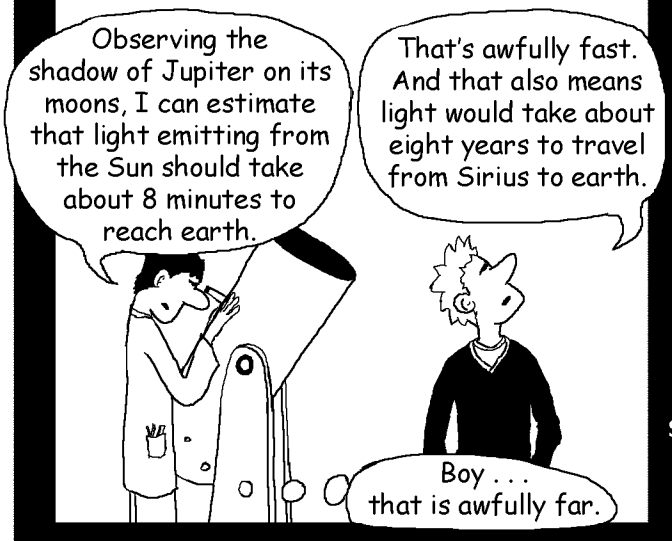
* by bus in this context.

Could one talk about astronomical distances in terms of travel time?

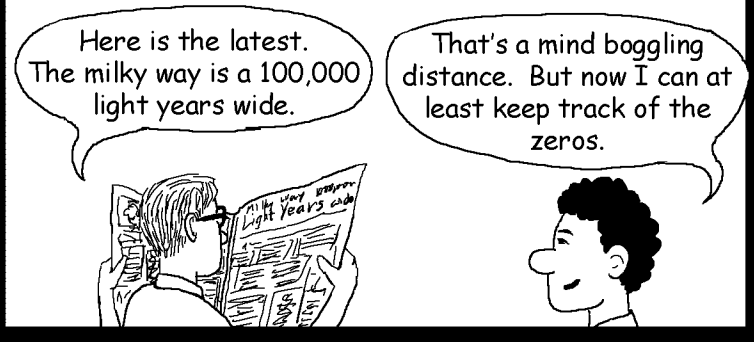


If there was anything that travelled across the universe, and was familiar to us, it was **LIGHT.**

Light moved with a terrific speed. Scientists devised experiments to figure out how fast it travelled.



The distance covered by light traveling in space for one whole year is called a Light Year. It soon became a very convenient unit for measuring stellar distances.



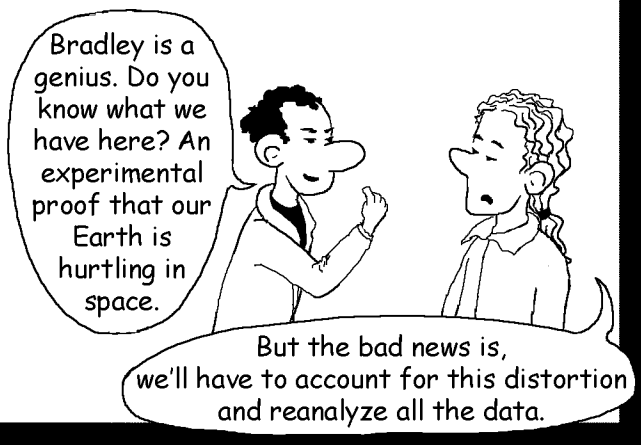
Light can go around the Earth 7 times in a single second. Can you imagine how far it can travel in one whole year? It would be about **9,000,000,000,000** kilometers, or **60,000 AU.**

While the astronomers were on the look out for stellar parallax, other important developments took place.

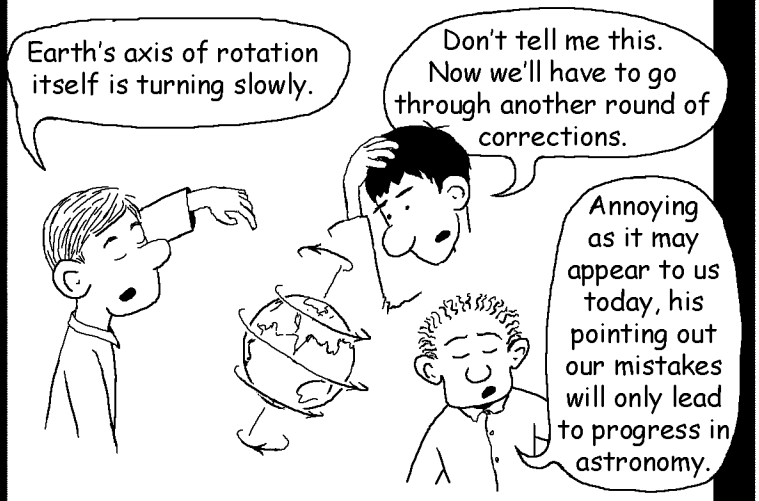
In 1728, James Bradley pointed out that...

Ever noticed how the rain drops falling vertically down, appear to be coming at an angle, if you are running?

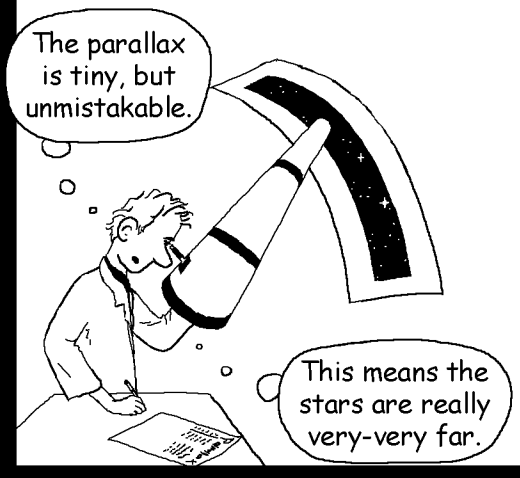
A careful analysis of past data showed that there was indeed a distortion of stellar positions indicating the motion of Earth around the Sun.



In 1748, Bradley noticed yet another source of error.

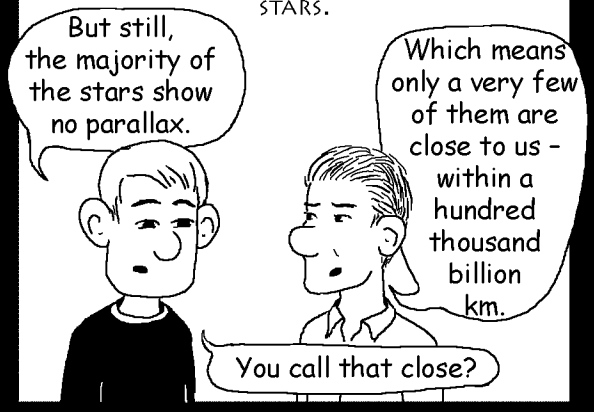


It was worth the wait, when finally, Friedrich Bessel, a German astronomer, detected a stellar parallax in 1838.



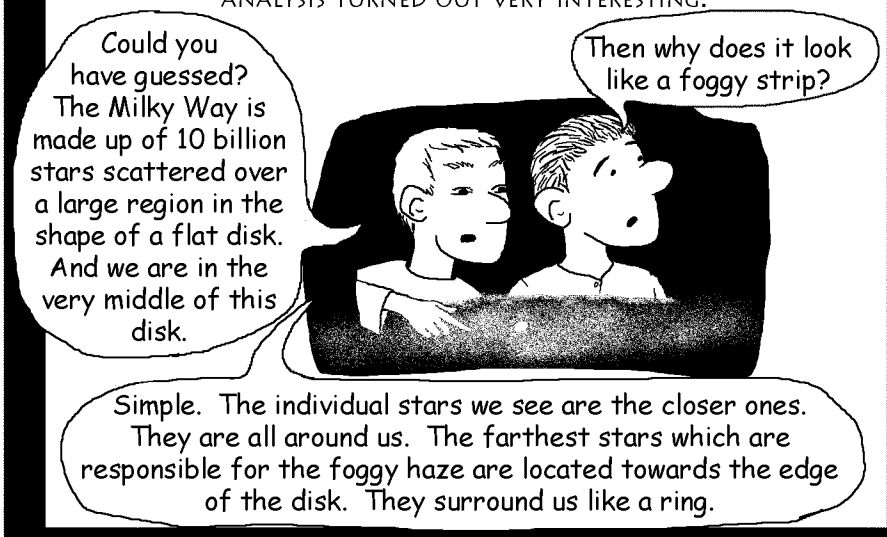
Bessel wouldn't have been able to detect a stellar parallax without the latest improvements in the telescope. And of course he was lucky enough to stumble upon one of the very few stars with an easily detectable parallax.

Soon hordes of astronomers were detecting and measuring parallax in stars.



Even the nearest stars are thousands of times farther than the outer limits of the solar system.

The first thing Galileo's telescope revealed was that the sky held many-many more stars than were visible to the naked eye. In the mid 1700s, William Herschel, an amateur astronomer, studied how the stars were scattered across the sky. His analysis turned out very interesting.



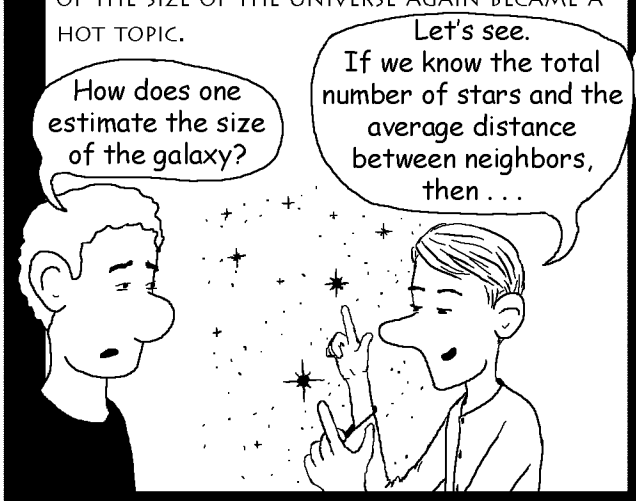
The Milky Way popularly came to be known by its Greek name Galaxy.

Herschel had no idea how large the galaxy was. He mistakingly believed the solar system to be in the middle of the galaxy. But the important thing was Herschel had figured out the large scale structure of the known universe.

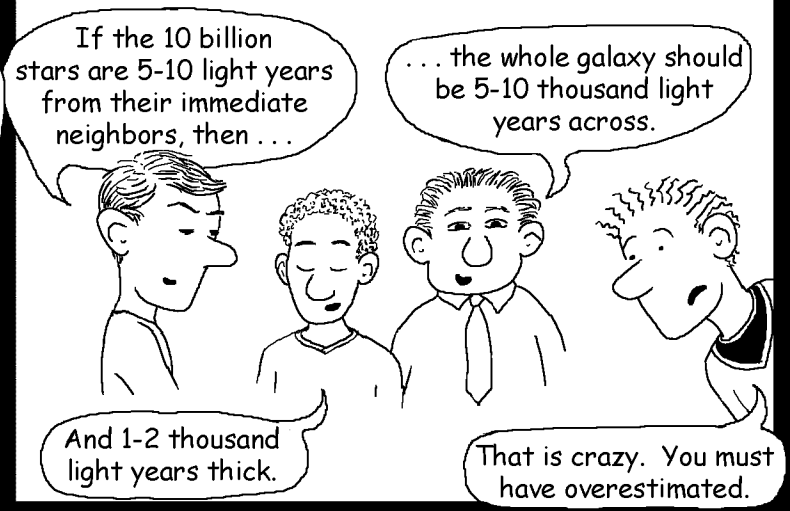
The disk shaped galaxy filled with billions of stars was the universe, and the Sun was one such star in the galaxy.

This picture of the universe stayed for the next 150 years.

In the 19th century, when Bessel succeeded in detecting stellar parallax, the question of the size of the universe again became a hot topic.



This estimate was crude but gave a concrete size to the universe.



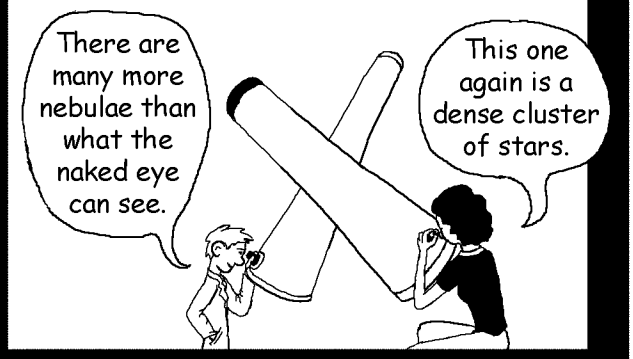
On the contrary, the initial estimates of the size of the galaxy were quite below the mark. More powerful telescopes and additional discoveries showed the Milky Way to be far larger than assumed earlier.

According to current estimates, the Milky Way has over 200,000,000,000 stars scattered in the form of a huge disk - 100,000 light years wide, with a central bulge 10,000 light years thick.

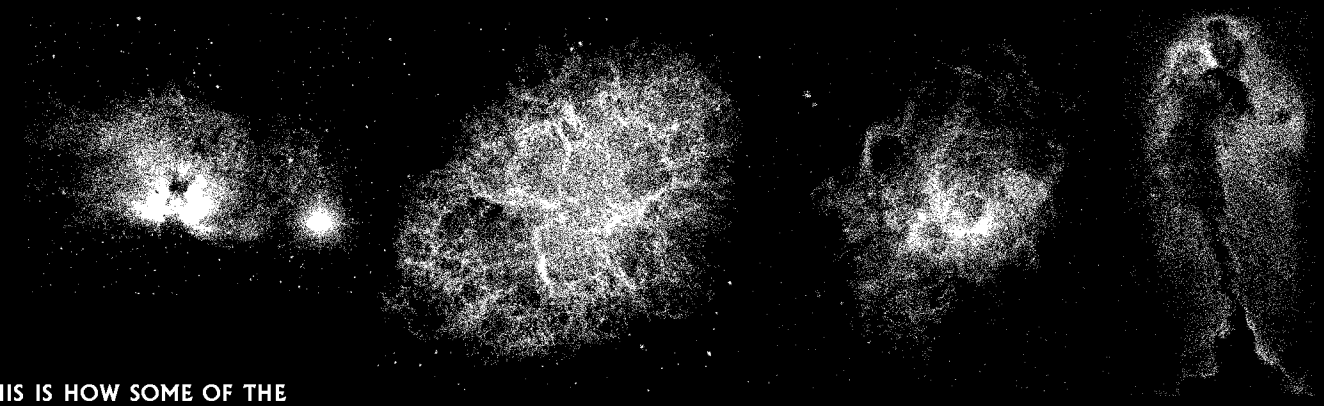
And our own solar system is somewhere between the center and the edge of this disk.

Other than the planets, the Moon, the stars and the Milky Way, the night sky had some foggy patches. They were called nebulae (plural for nebula meaning a cloud in Latin).

Needless to say, the telescope revealed a lot about nebulae.

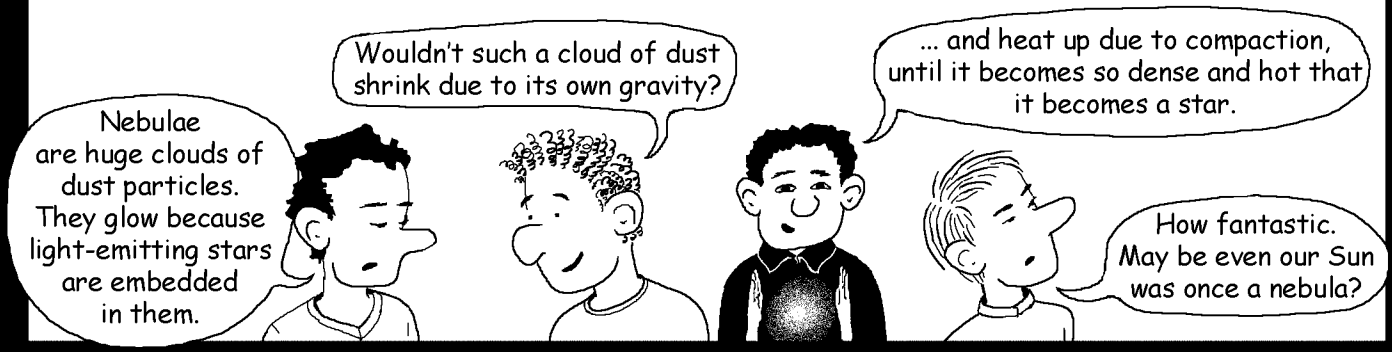


The true nebula looked like gas hanging among the stars even through the best of the telescopes.



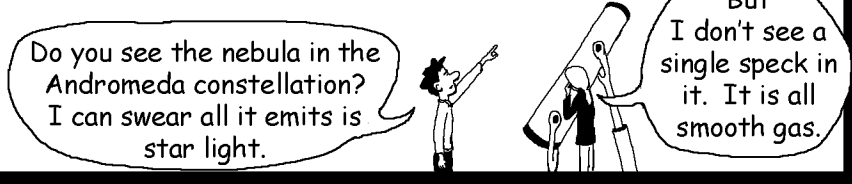
This is how some of the nebulae appear through the modern telescopes.

What were these nebulae? What was this foggy gas doing amongst stars? Nebulae gave rise to many questions. And there were many theories.



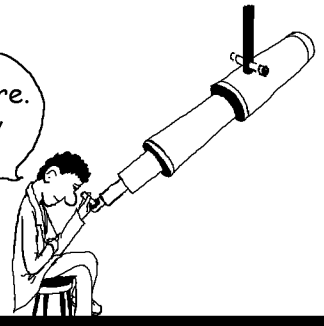
The nebulae showed a great variation in shape, size and glow. But the kind of light coming from these interstellar clouds was very different than that from the stars.

But there was one exception.



This nebula located in the Andromeda constellation came to be known as the Andromeda Nebula.

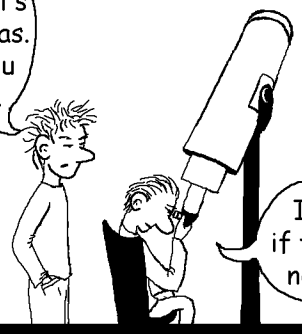
Hey! I do see a speck in there. I wonder why nobody noticed it before.



But the tiny spot disappeared within no time.

I don't see anything. It's just plain gas. May be you imagined.

I wonder if that was a nova then.



In the following decades, many transient spots were witnessed in the Andromeda Nebula.

Are these novae located inside the nebula? Or they simply happen to be in the line of sight.

Surely there must be a way to find that out.

Heber Curtis, an American astronomer, studied the occurrence of novae across the whole sky and came to a conclusion.

There are one too many novae appearing in that small region of the sky.

These novae must belong to Andromeda Nebula.

As always, many questions were raised and many theories proposed.

Why are they so faint? And are they novae in the first place?

Andromeda Nebula is so far away that even its novae are fainter than the faint stars.

How is this possible? If what you are saying is true, then the nebulae has to be much farther than the outer limits of the universe.

If the nebula is that far, it would be impossible to figure out whether it is a cloud of dust or a dense cluster of stars.

That is enough speculation. What we need is some solid proof.

In 1917, Edwin Hubble, an American astronomer, resolved the Andromeda Nebula into a vast but dense collection of extremely faint stars.

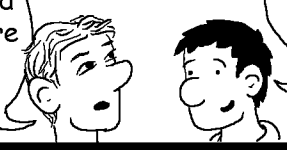
Surely this is too far off to be part of the Milky Way.

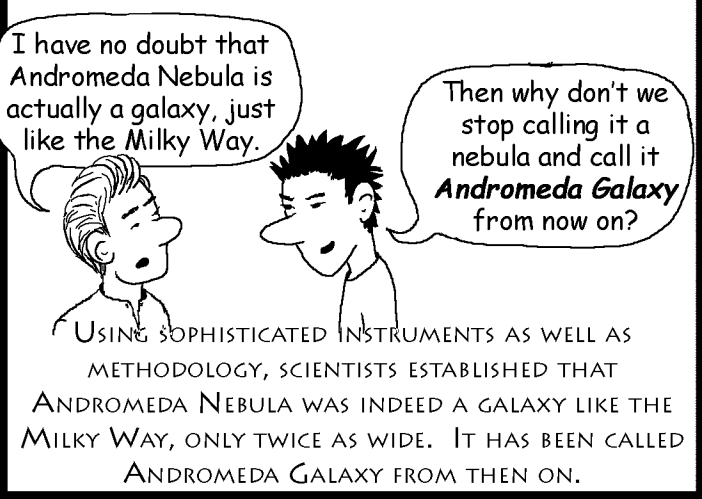
Could this nebula be a whole galaxy in its own right?

The theory that the Andromeda Nebula was a separate and distant galaxy fitted most observations.

Yet again the universe turned out to be much more complex than we thought.

And much larger than we could have imagined.





Using sophisticated instruments as well as methodology, scientists established that Andromeda Nebula was indeed a galaxy like the Milky Way, only twice as wide. It has been called Andromeda Galaxy from then on.

In 1952 the Andromeda Galaxy was estimated to be an astonishing 2 million light years away from us.

Was that all there was to the universe? Two galaxies separated by a mind blowing distance? The astronomers seemed to know better.

It came as no big surprise when many more galaxies were discovered soon after.

So what is our current picture of the universe?

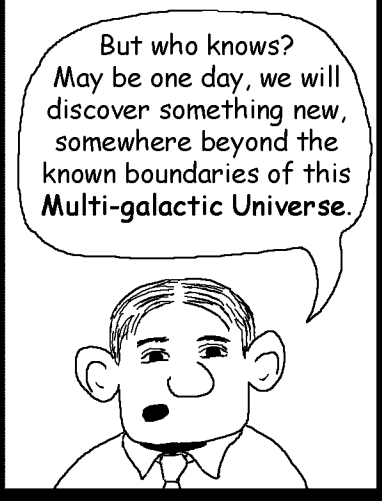
The universe is scattered with galaxies . . . around 100,000,000,000 (a hundred billion) of them grouped into clusters. Each galaxy cluster is made up of thousands of galaxies.

The average sized galaxy has 100,000,000,000 (hundred billion) stars and is 100,000 light years across.

The expanse of the universe is estimated to be around 200,000,000,000 (two hundred billion) light years.

There is a vast space separating stars in a galaxy as well as galaxies in a cluster. In fact, the universe is mostly vast, empty space. Well . . . this space is not really empty . . . because there is a faint light flooding every corner of the universe.

That is crazily big. But is that all there is to the universe? Yes . . . for now.

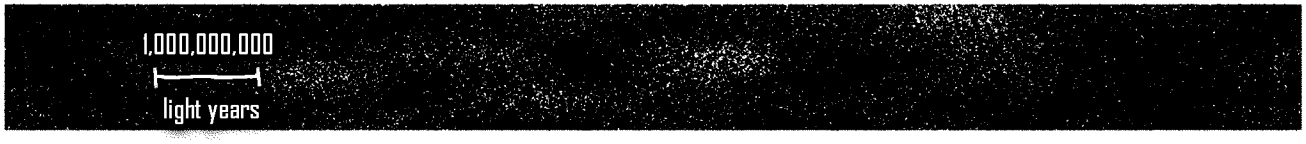


Where are we located within the enormous universe we live in? Where do our Earth, our Solar System, our Milky Way lie in relation to the billions and billions of galaxies making up the cosmos?

The night sky we see is dominated by the stars neighboring us. I would like to travel far away from all the stars and all the galaxies and take a perspective look at the universe.

Suppose we had the ability to travel to any place in the universe. You move away as far from the Earth as possible. What would you see? A swarm of faint dots. Are these stars? Galaxies?

No. Each tiny dot you see is a cluster of galaxies. An average sized cluster contains a thousand galaxies. There are more than a hundred million clusters scattered across a vast space.



Let us start locating the earth. Suppose we take a small chunk from this view along the direction we came from. If we zoom into this piece, we can make out the individual galaxies in the clusters.

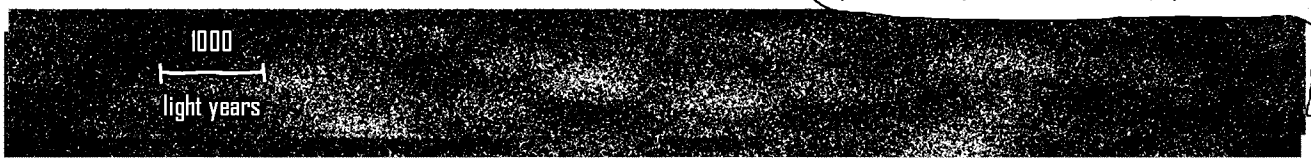
Surely one of these galaxies is our Milky Way?

Indeed. Let us zoom further into a tiny piece of this space neighboring our galaxy.

Ah! This looks like the Milky Way. And the other galaxy over there has to be Andromeda.

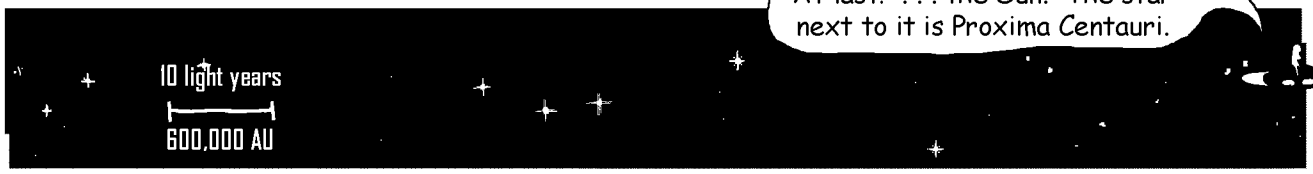
It is time to look for our Sun. Again we zoom into a small region of the Milky Way in the direction of the Solar System.

Not good enough. All I see is a crowd of stars. We need to zoom further in.



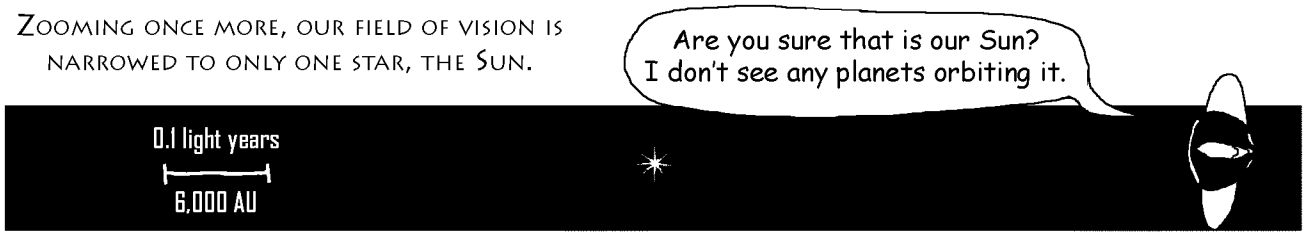
We take another step towards our destination. Now we can distinctly see individual stars.

At last! . . . the Sun. The star next to it is Proxima Centauri.



That has been quite a journey so far. But we still have a long way to go before we reach home.

Zooming once more, our field of vision is narrowed to only one star, the Sun.



To see the structure of the solar system, we need to step much closer.

It is about time we started looking for the planet we call home. Let us plunge right into the Solar System.

Now that the Earth has been located, the rest of the journey is trivial.

We are almost there. Zoom in one last time and it is time to . . .

The light year has ceased to be the natural unit it once used to be.

They say the universe is more than 10,000,000,000 light years wide.

You mean 10^{10} light years. That would be 10^{26} meters.

Milky Way Daily

Sports

Stocks

Yet, the light year plays a special role in picturing the universe.

A distance expressed in light years explicitly tells the time it takes light to cover that distance.

So what I see today is what the Andromeda Galaxy looked like 2,000,000 years ago?

Correct. That's how long light takes to reach us from Andromeda.

If this is how it looked 2,000,000 years ago, what does it look like now?

Probably not any different. A galaxy doesn't change much in a few million years. But there is no way of knowing for sure.

The deeper we look into space, the farther back we dig in time.

These are the distant most objects in the universe.

Then they must also be the most ancient.

These most distant objects, named **Quasars**, are probably young galaxies of a new born universe. Because of their vast distance, we don't really know their shape.

One thing is for sure. These quasars actually look very much different than how they appear through the telescope.

And they would be in a different location too. What we're seeing now is a billion-year-old movie!

According to our current understanding the most distant quasars mark the beginning of the universe. If we see nothing beyond them, it is probably because nothing existed before them.

Makes sense doesn't it?

But who knows. May be one day . . .

Indeed, if the story of astronomy has taught us anything... no theory is final.

Ever since Galileo used the telescope 400 years ago this instrument has been inseparably linked to astronomy.

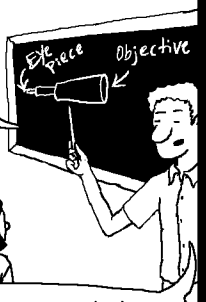
Whatever can be seen with the naked eye has already been seen. The telescope is our only hope.

I have seen everything this telescope could show me. I need a more powerful one.

Advancement in observational astronomy essentially meant improvement in the telescope.

The first telescopes (called Galilean Telescopes) consisted of two lenses.

. . . a large lens called the **objective** and a small one called the **eyepiece**.



The larger the objective, the more light it can catch and the more things it can show.

In 1700 William Herschel constructed a 40 feet long telescope. Its Objective had a diameter of 4 feet.

The Galilean Telescope had some inherent problems.

It's difficult to grind large lenses. They are so bulky, they sag with their own weight.

Why don't I see a sharp image?

And why are the edges always colored and hazy?

Newton's deep insight into the nature of light made him replace the objective lens with a curved mirror.

A glass lens bends different colors of light through different angles. Since white light is made up of many colors, we end up with a *rainbow* of images.

A mirror serves the same purpose as a lens - it focuses light. But unlike a lens, a mirror focuses all colors identically.

Moreover, the mirror had only one surface to be ground and was much lighter compared to a lens. The Reflecting Telescope (also known as the Newtonian Telescope) still remains the darling of amateur astronomers.

Constructing better telescopes was only one of the challenges. Astronomers had to grapple with dust and fluctuations in the atmosphere which limited the observational power of telescopes.

Let us take our telescope to the Himalayas - far away from this madding crowd.

Do we have to give up this worldly life to take a peek into the heavens?

Today, most of the observatories are reclusive retreats situated on mountain tops.

These days the clearest pictures of the cosmos are obtained through telescopes planted in space.

Brrrrrr . . . . it sure is cold out here.

But by Jupiter, what a view!

Some telescopes orbit the earth while others have traveled across the solar system. Well known Space Telescopes like Hubble and Voyager have sent us innumerable pictures of the universe - informative as well as breathtakingly beautiful.

As the telescopes advanced to reveal the sky in greater and greater detail, an equally powerful development took place.

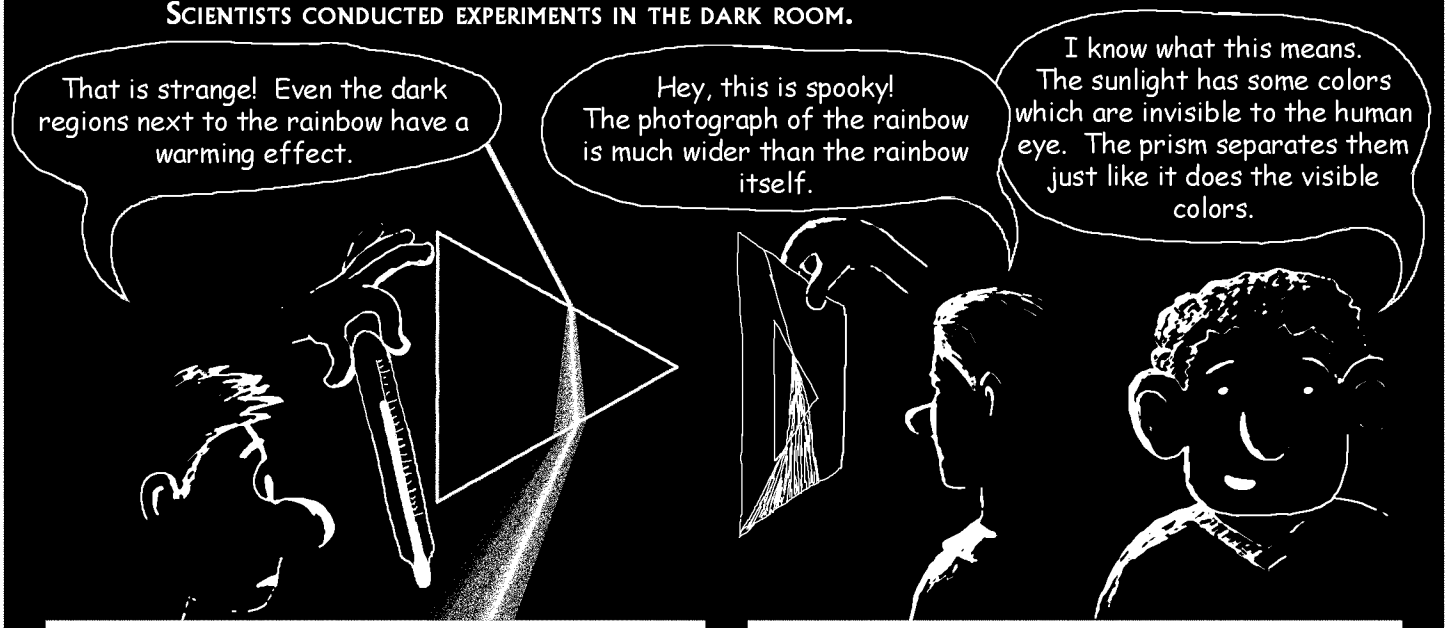
This discovery by Newton in 1666 had profound implications.

The ancients knew that light passing through crystals yielded a rainbow-like pattern. But they thought it was the crystal which rendered the colors.

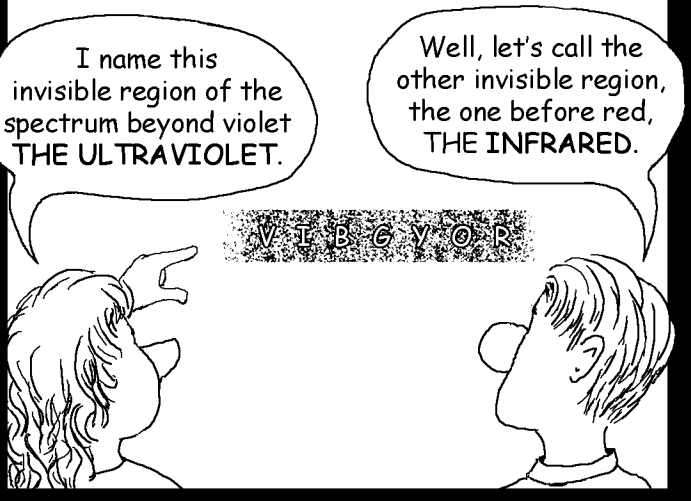
But after Newton's explanation, the focus shifted from crystals to light.

During the 18th century people discovered that light contained much more than a rainbow of colors.

Scientists conducted experiments in the dark room.



The range of colors, including the invisible ones, was called the **spectrum**.



According to modern theory, light is made up of waves. Light of different colors have different wavelengths. Within the visible spectrum (the rainbow colors), red has the longest wavelength and violet has the shortest. Ultraviolet light has an even shorter wavelength. Infrared corresponds to a wavelength longer than that of red.

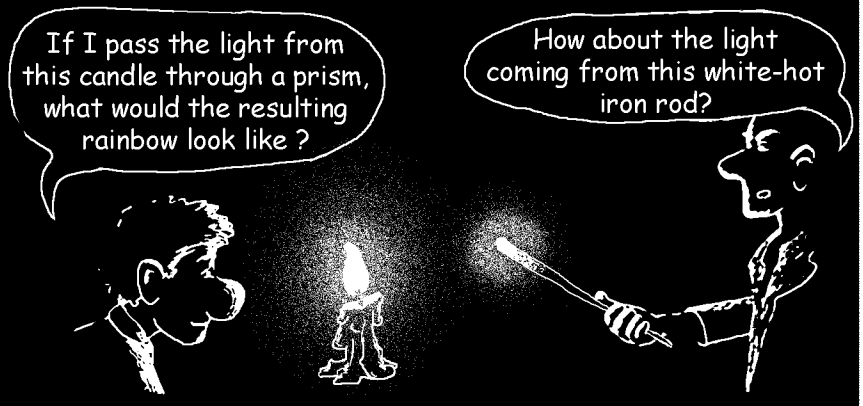
Today we know that the full spectrum of light in the universe extends much beyond the infrared and the ultraviolet. Visible light constitutes but a tiny portion of this.

Just like the colors of the rainbow, different parts of the invisible spectrum are also given names; x-rays, gamma rays, micro waves, radio waves, etc.

In 1835, Auguste Comte, a French philosopher said . . .

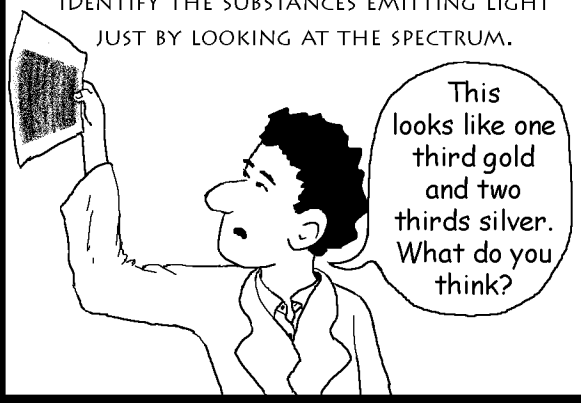
He was to be proved wrong very soon.

In the 19th century, a series of investigations brought the study of the light spectrum into the heart of astronomy.



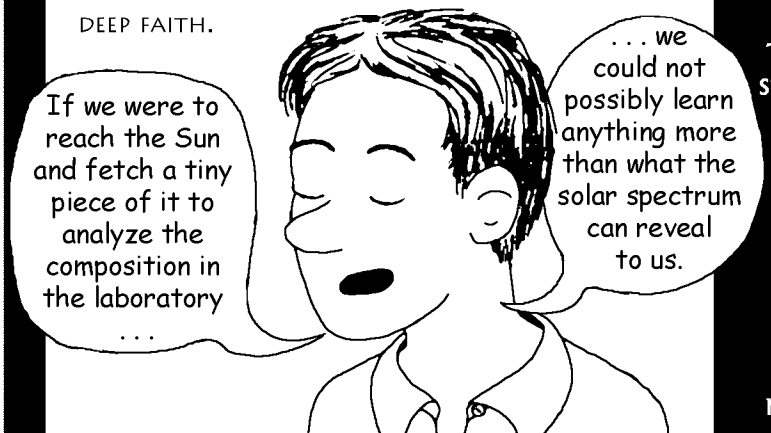
Light emitting from different sources was investigated.

Much to their excitement, scientists found that different materials, when heated, gave out different spectra. After much study, they were able to identify the substances emitting light just by looking at the spectrum.



Astronomers were thrilled with this new ability.

Soon this excitement got converted into a deep faith.



The element Helium (used in floating balloons) was first identified through the solar spectrum. Later on it was isolated in the laboratory.

Spectra from planets, stars, nebulae, galaxies, etc. were analyzed in detail. This lead to theories which talked about what constituted stars and nebulae and how that matter burned to produce light.

Spectroscopy shifted the focus from the geometrical structure of the universe to the physical processes happening there.

Newton had established the physics of how heavenly bodies moved in space and how they interacted with one another. Spectroscopy made it possible to study the physical processes occurring within each celestial object.

Today Astronomy is considered a branch of Physics.

Modern telescopes rely on our deeper understanding of light.

A wide range of Electromagnetic Radiation comes from space. Visible light constitutes only a tiny fraction of this.

But what good is the invisible part of this radiation then?

Ah! It may be invisible to the human eye but it's still detectable. Haven't you had your bones photographed using X-rays?

Invisible light can be photographed on film. Advance electronics have given us artificial retinas which see much more than the human eye can.

A digital camera for example uses an electronic retina. Electronic retinas can capture invisible light too.

Point a TV remote towards a digital camera. What do you see in the display panel?

Most modern telescopes capture invisible light. They are named after the region of the spectrum they are sensitive to: Infrared Telescopes, X-Ray Telescopes, Radio Telescopes, etc.

Are you sure this is a telescope? It looks more like a TV dish antenna.

As a matter of fact it does. But if you open that little box you will find an elaborate eyepiece as well as an electronic retina. The dish itself serves as the objective mirror.

As mountain tops are good for visible-light telescopes, radio telescopes are best located in valleys. The surrounding mountains shield unwanted radiation from artificial sources.

I love this place. Only my mobile catches no signal!

Often there are groups and arrays of radio telescopes collectively imaging the sky.

Why an array of telescopes? What can 10 telescopes show that can't be seen by a single one?

When it comes to radio telescopes, one plus one is two. The more radiation they capture the better.

The largest single-dish telescope today is situated at Arecibo, Puerto Rico. The dish is a fixed 305 meters wide cement bowl and the eyepiece hangs from cables.

We believe we have seen the farthest and the ancient most objects of our universe. Assuming that our belief is true, is there anything left to be explored?

You bet there is. Even our closest neighbor is hardly explored.

Indeed, there are infinitely many things yet to be explored. The current space program has several agendas.

The first and the foremost is to satisfy our curiosity. To know what all is out there.

Additionally we have several practical goals too.

One major agenda is to protect life on earth from getting obliterated.

There is a faint chance that a huge meteorite may someday hit earth. This may wipe out all life on the planet.

We should be able to detect such an event well in advance and divert the course of such a meteorite.

We are likely to make our planet unlivable. Some think that the only way the human race can *survive itself* is to colonize space.

It was not easy, but was worth it.

Just in time too!

It would be naive and arrogant to think that life exists only on earth. But we may need to travel far to encounter alien life.

. . . We have made contact! . . . repeat . . . we have made contact . . . over.

. . . zgrooftah# . . . morei . . . zgrooftah . . . finnn!

Deep space travel, meeting other life forms and learning more about the universe will certainly widen our horizon. Maybe it will even help us in conquering our prejudices, pettiness and greed and consider ourselves as one earth, one people.

We are Earthlings. Nice to meet you.

Rego, you were right! There is life outside Zoorka.

They appear friendly. So weird looking they are though.

THE END

12+

Do all stars move in a pattern?

And what about the planets? Why do they wander?

If the earth is round like a ball, then
how come it looks so flat?

Does the sun emit gravity just like it does light?

What is parallax and how does it help measure
astronomical distances?

The subject matter of astronomy is, well, astronomical.
Our knowledge in this field did not come to us overnight.
It has evolved over several thousand years.
The history of astronomy spans the entire history of
mankind. Not surprisingly, this history is as interesting and
complex as science itself.

This picture-book is not about the science of astronomy.
It is an attempt to recount its evolution
in the form of a story.

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