



# STORY OF ASTRONOMY

Wrong!  
You guys have got it  
ALL WRONG!



Written and Illustrated by

Uday Patil

STORY  
OF  
ASTRONOMY

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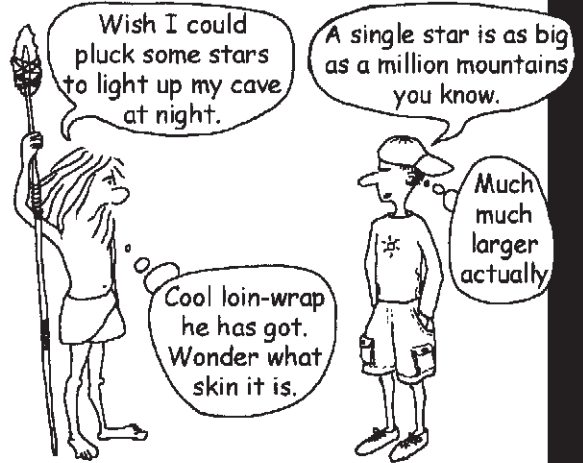
Uday Patil

# A Journey from Antiquity Into the Future

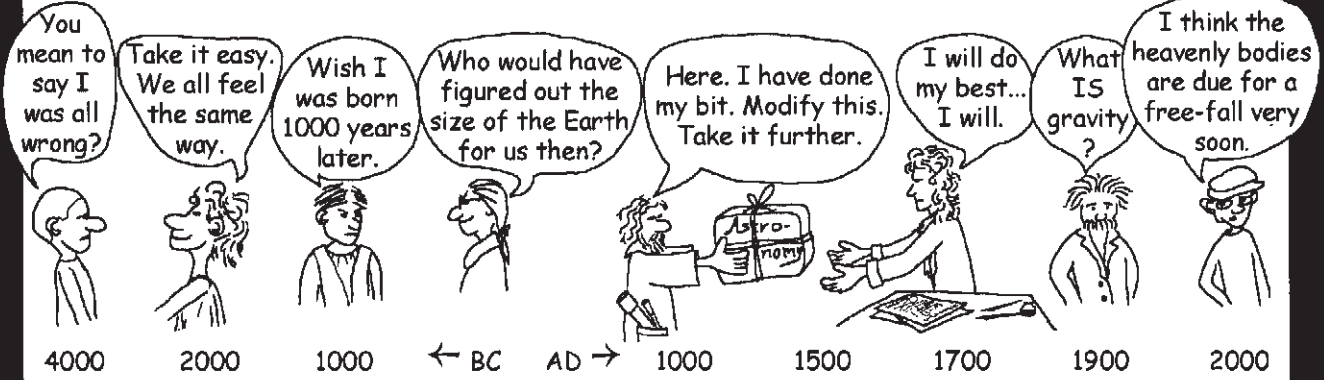


THE NIGHT SKY ALWAYS EVOKED A SENSE OF DEEP WONDER. OUR ANCESTORS WERE MESMERIZED BY THE BEAUTY OF THE STARS. NOBODY COULD TOUCH OR FEEL THEM. THIS PERHAPS, ADDED TO THEIR MYSTIQUE.

ONE THING IS FOR SURE - THE NIGHT SKY LOOKED PRETTY MUCH THE SAME 10,000 YEARS AGO AS IT DOES TODAY. YET WHAT WE KNOW TODAY 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.

**Drama In the Heavens**



Do you see what I see Nomi?

I do Zog, I do.

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.

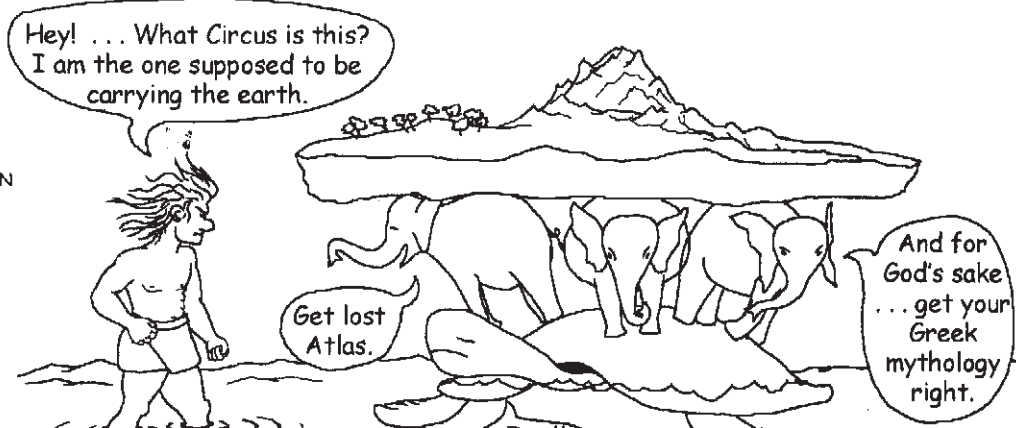
You can take the Neanderthal out of the Ice Age but you can't take the Ice Age out of the Neanderthal.

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 MADE 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.



SUCH STORIES WERE MORE THAN JUST A PRODUCT OF A FERTILE IMAGINATION. THEY WERE EARLY ATTEMPTS TO EXPLAIN THE UNIVERSE.

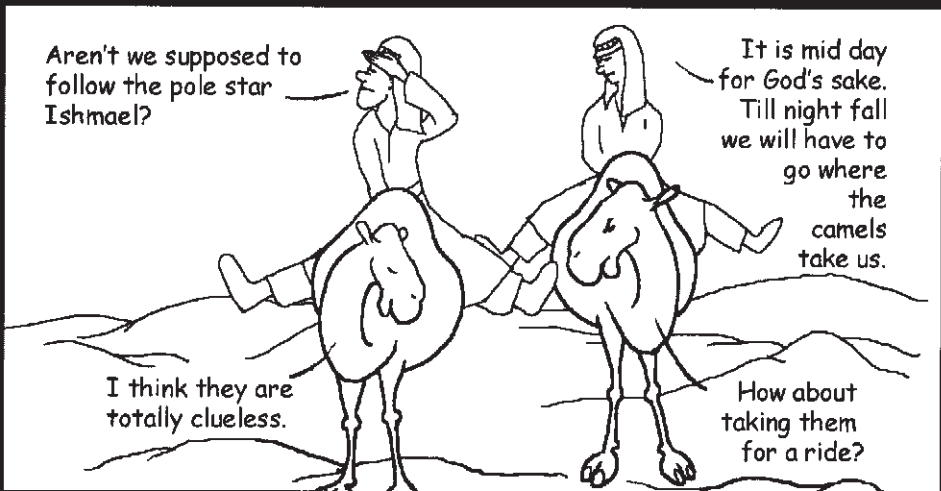
I will gladly give up MY position. Anybody?

THEY FORMED THE EARLIEST COSMOLOGIES, OR THEORIES OF THE UNIVERSE.

**It's Dark - Time to Make a Move**

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.



Aren't we supposed to follow the pole star Ishmael?

It is mid day for God's sake. Till night fall we will have to go where the camels take us.

I think they are totally clueless.

How about taking them for a ride?

SAILORS ON THE HIGH SEAS FOUND THE SKY VERY USEFUL TOO. IN THE MIST OF THE VAST OCEAN THE STARS HELPED THEM FIND THEIR BEARINGS.

DEVELOPMENT IN ASTRONOMY LED TO ADVANCES IN THE SCIENCE OF NAVIGATION. SAILORS COULD OBSERVE STARS MORE ACCURATELY AND CROSS THE OCEANS.



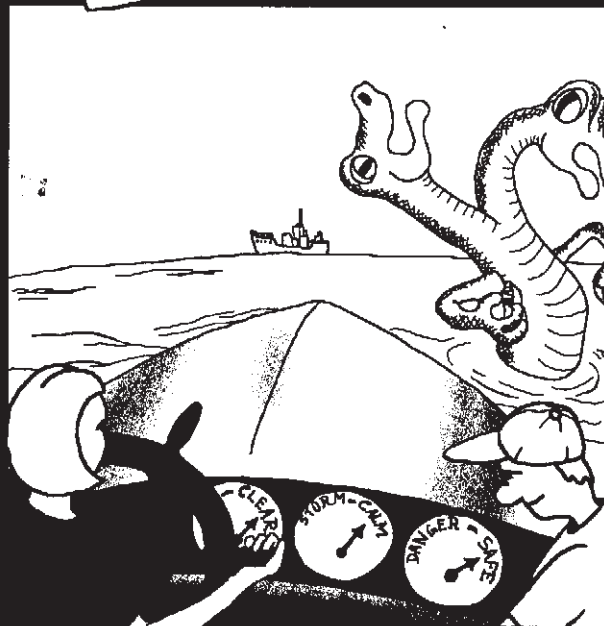
Damn these #@%& clouds.

Can't see a single star.

Splendid! Simply splendid! Just when we were entering the Bermuda Triangle.

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.



Jack... I think we are in big trouble

Just relax Jill. For once, trust the gadgets.

**That ain't no Star. It Moves!**

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.

The stars never stop moving, yet the patterns made by them are fixed.



Hmm... interesting. But that one up North doesn't move at all.

AND THEY SOUGHT OUT EXPLANATIONS.

The stars seem stuck to the inside of the sky, which keeps turning like a huge top.



That makes sense. And the 'North Star' happens to be situated exactly on the axis of this rotation.



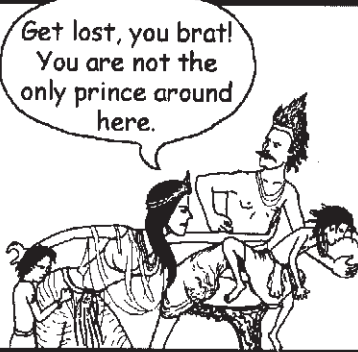
THIS WAS THE BEGINNING OF ASTRONOMY AS A SCIENCE.

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.

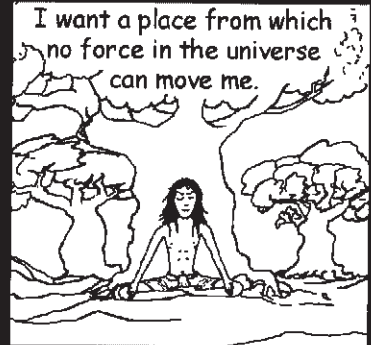
IN INDIA, THE NORTH STAR IS CALLED DHRUVA AFTER THE MYTHOLOGICAL PRINCE WHO TRANSFORMED INTO THE STAR.

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 FATHERS LAP TO MAKE PLACE FOR HER OWN SON.



Get lost, you brat! You are not the only prince around here.

DEEPLY HURT, DHRUVA LEFT HOME IN SEARCH OF A PLACE FROM WHERE HE COULDN'T BE DISLODGED. AFTER A LONG PENANCE, HE WAS TRANSFORMED INTO A STATIONARY STAR - FIXED AT ONE POINT IN SPACE.



I want a place from which no force in the universe can move me.

DID ALL STARS MOVE IN A PATTERN? WELL... NOT ALL.

Hey! You told me ALL stars stick to their pattern. But one yonder there wanders.



Maybe it just looks like a star but is really something else?



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.

The Sun and the Moon are also planets. They wander too.



Even the Sun? How can you possibly tell?

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.

## Keeping Track of Time

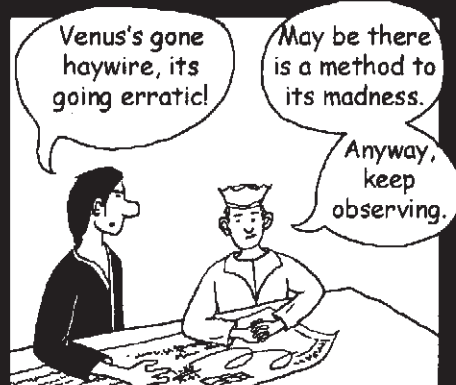
STAR PATTERNS MOVED PRETTY FAST. THEIR MOTION WAS NOTICEABLE WITHIN A FEW MINUTES. ON THE OTHER HAND THE RELATIVE MOTION OF PLANETS ON THE STELLAR TAPESTRY WAS MUCH SLOWER.



These planets are snail slow! I'll be long dead before I find anything about them.

Consider yourself lucky if you even get a clue.

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.



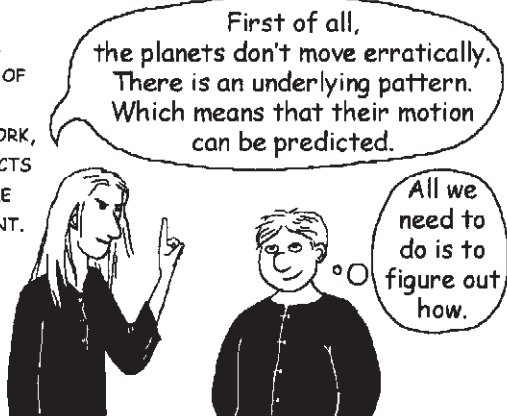
Venus's gone haywire, its going erratic!

Maybe there is a method to its madness.

Anyway, keep observing.

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.



First of all, the planets don't move erratically. There is an underlying pattern. Which means that their motion can be predicted.

All we need to do is to figure out how.

SECONDLY, CHANGES IN THE SKY SEEMED TO HAVE EFFECTS ON EARTH.

By RA\*! Look there appears Sirius! It will cause our Nile to flood.

By NUT\*! Can't say if Sirius is the culprit. But there surely is some correlation between the two.

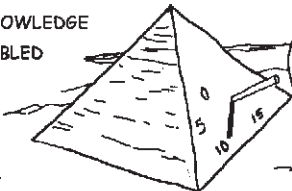


\* RA-SUN GOD, NUT-SKY GODDESS.

IN EGYPT, LIFE WAS GOVERNED BY THE ANNUAL FLOODING OF NILE.

WHEN THEY SAW SIRIUS RISING JUST BEFORE THE SUN THEY KNEW IT WOULD SOON BE TIME FOR THE FLOODING - INUNDATION OF THE NILE.

THE EGYPTIAN'S KNOWLEDGE OF ASTRONOMY ENABLED THEM TO PREDICT THE REAPPEARANCE OF SIRIUS WITH PINPOINT ACCURACY.



I have perfected it. The shadow of the pole on that pyramid tells us how many days are left for the flooding of Nile.

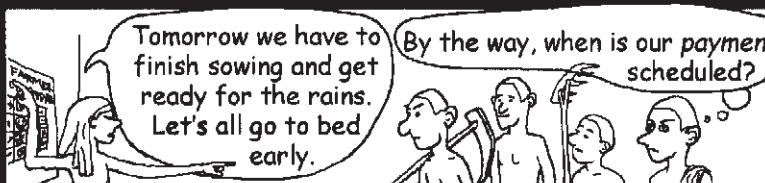
That is neat. Really neat. So let's see...

... Oh my God! It will be flooding in 10 days.

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.

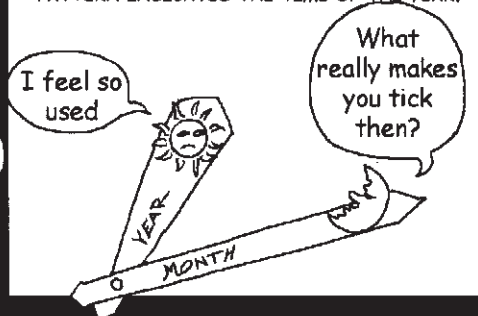
BOTH FARMING AS WELL AS ADMINISTRATION OF THE STATE COULD NOW BE PLANNED AND EXECUTED, LIKE CLOCK WORK.

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.



Tomorrow we have to finish sowing and get ready for the rains. Let's all go to bed early.

By the way, when is our payment scheduled?



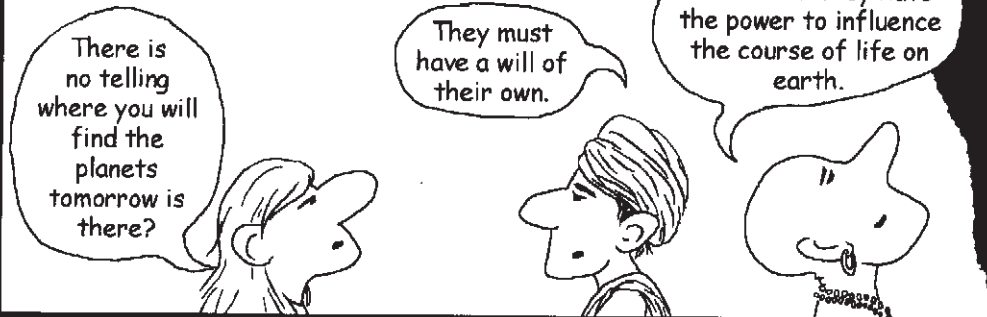
I feel so used

What really makes you tick then?



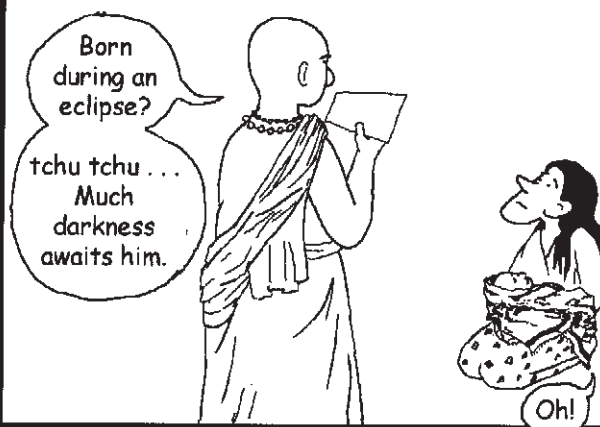
**Astrology**

THEN THERE WERE PEOPLE WITH A MYSTICAL BENT OF MIND.

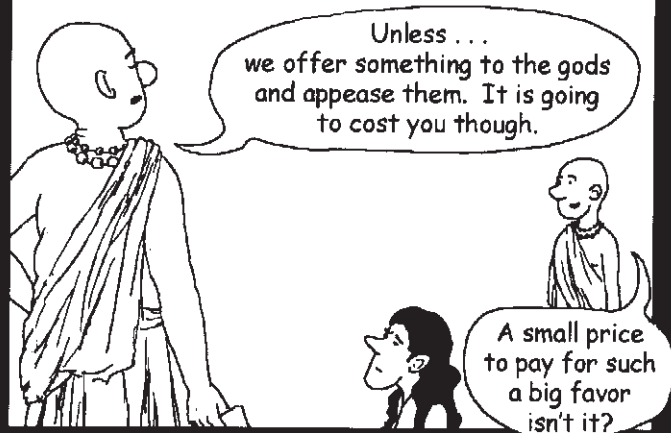


THUS **ASTROLOGY** WAS BORN. PEOPLE CAME TO BELIEVE THE PLANETS AFFECTED THEIR LIVES.

THE ELITE TOOK ADVANTAGE OF THIS BELIEF . . .



. . . AND MADE A LIVELIHOOD OUT OF IT.



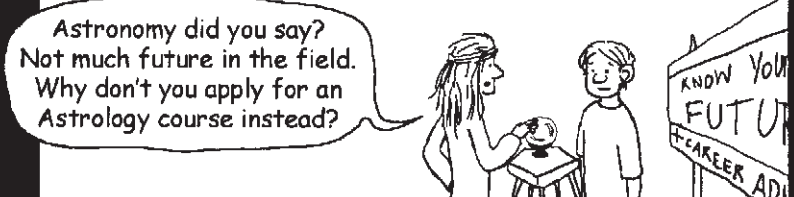
INDEED THERE WAS SOME EVIDENCE SUGGESTING THE INFLUENCE OF HEAVENLY BODIES ON EARTHLY PHENOMENA.



BUT **ASTROLOGERS** BLEW THIS OUT OF PROPORTION.



**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**.





## Aristotle

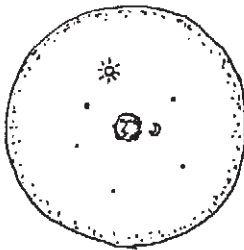
ON THE OTHER HAND, THERE WERE THOSE WHO LOOKED AT THE SKY WITH A SCIENTIFIC INTEREST.

Why do stars form patterns? And why do planets wander?



You mean there could be a reason behind why things are the way they are?

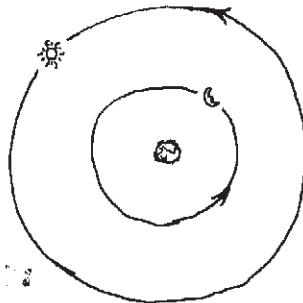
FOR ARISTOTLE, ASTRONOMY WAS A BRANCH OF PHILOSOPHY.



I believe the universe is spherical because the sphere is the most perfect shape.

HE HAD HIS OWN WAY WITH LOGIC.

The heavenly bodies move in circles, for a circle is the most perfect path possible.

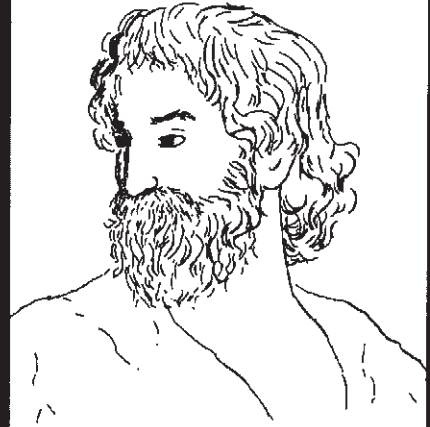


IT HAS BEEN SAID THAT ARISTOTLE'S IDEAS REMAIN THE MOST INFLUENTIAL THOUGHT SYSTEM EVER PUT TOGETHER BY A SINGLE MIND. HIS PHILOSOPHY SHAPED THE INTELLECTUAL DEVELOPMENT OF MANY CULTURES.

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.

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 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.

## Models of Motion

TO TRACK THE WANDERING PLANETS PRECISELY, THE STELLAR PATTERN WAS CAREFULLY MAPPED.

What?!  
After dividing their land  
these silly men are now  
dividing the sky?



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.

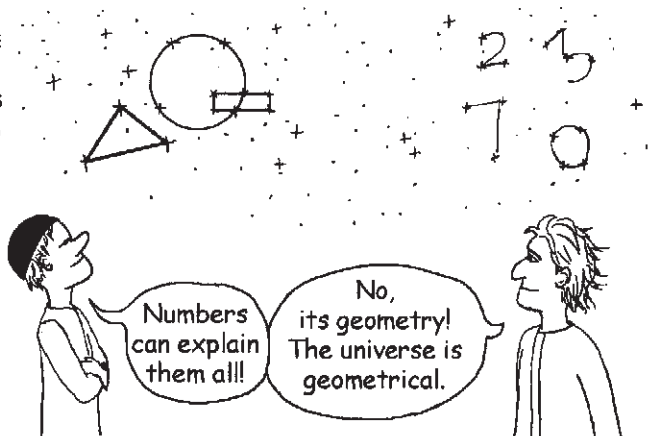
I can't make head or tail of this movement of planets. I think they are possessed.

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

I think they just look complex. Maybe there are simple principles underlying their motion. We must try to figure them out.

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

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



Numbers can explain them all!

No, it's geometry! The universe is geometrical.

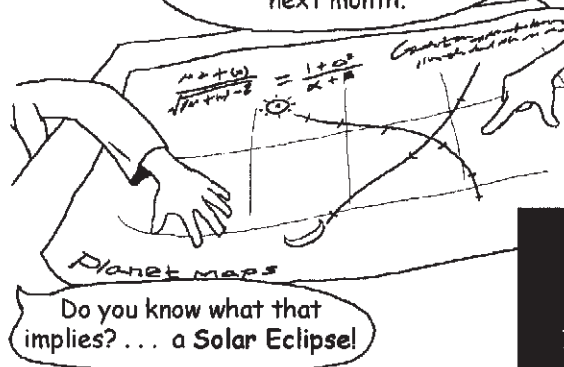
ASTRONOMERS TRIED TO EXPLAIN THE MOTION OF PLANETS USING SIMPLE MATHEMATICAL MODELS. IT MEANT USING A FORMULA TO TELL THE POSITION OF THE PLANET AT ANY GIVEN TIME.

IF SUCH A MODEL COULD ACCURATELY LOCATE THE POSITION OF A PLANET A FEW HUNDRED YEARS BACK IT SHOULD ALSO 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.

Look.  
According to this model,  
the Sun will cross the Moon's  
paths exactly at mid-day,  
next month.



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.

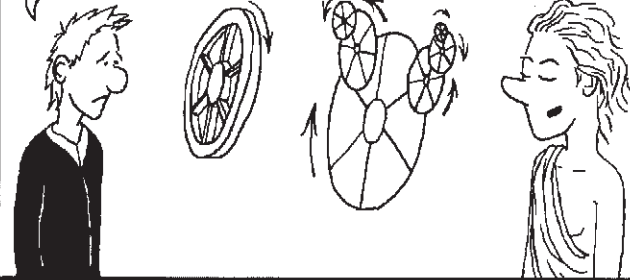
MATHEMATICS PLAYED AN IMPORTANT ROLE IN THE DEVELOPMENT OF ASTRONOMY. IN TURN, ASTRONOMY WAS THE DRIVING FORCE THAT LED TO MAJOR ADVANCES IN MATHEMATICS.

# Wheels of Motion

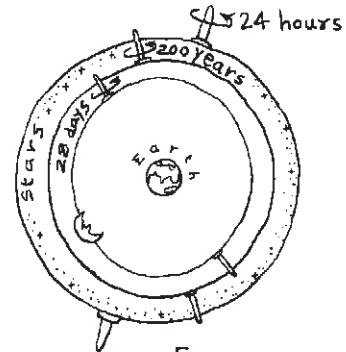
THE INITIAL MODELS OF PLANETARY MOTION WERE CIRCULAR.

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 SPHERES TURNED UNIFORMLY ON THEIR AXES LIKE TOPS. THE AXIS OF ONE SPHERE WAS FIXED IN ANOTHER.

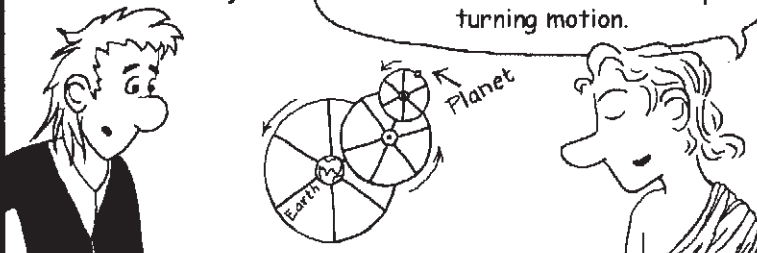


EACH PLANET REQUIRED SEVERAL CONCENTRIC SPHERES TO MODEL ITS MOTION.

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).

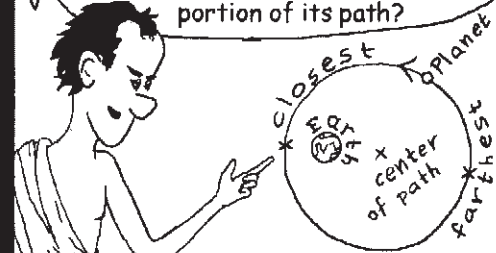
Now that surely can give rise to complex motion.

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



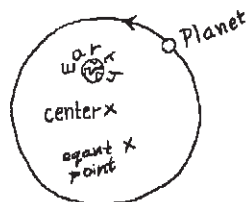
YET ANOTHER CONCEPT WAS THE ECCENTRIC CIRCLE. IT HELPED TO EXPLAIN THE SPEED VARIATIONS OF PLANETS.

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 ... what ever works ...

COLLECTIVELY, THESE MODELS QUITE SUCCESSFULLY CAPTURED THE MOTION OF THE PLANETS. THE SPHERES AND THE CIRCLES WERE STILL 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 - the Greek Astronomer from Egypt

PTOLEMY WAS A GREEK ASTRONOMER. HIS ACTUAL NAME WAS CLAUDIUS PTOLEMAEUS. NOT MUCH IS KNOWN ABOUT HIS PERSONAL LIFE.

Well... I am Greek but lived in Egypt. And I authored the Almagest.

What more do you wish to know?



ALMAGEST IS THE POPULAR NAME OF THE BOOK PTOLEMY WROTE. THE ORIGINAL TITLE IN GREEK, *MEGALĒ 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.

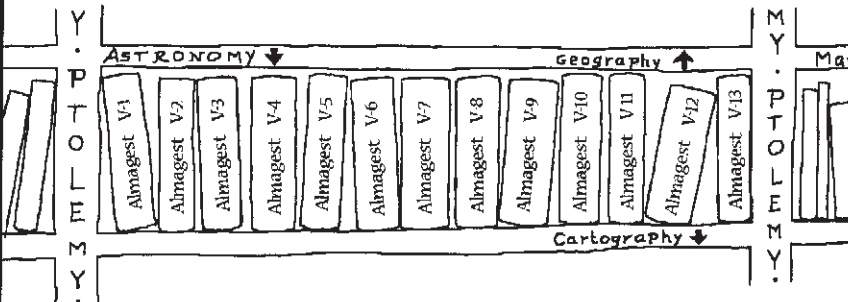
CLAUDIUS PTOLEMAEUS 85-165 AD



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.

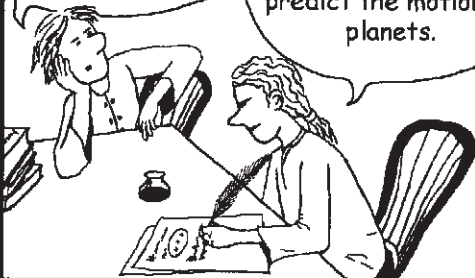


MOST IMPORTANTLY, IT WAS A COMPILATION OF TECHNIQUES BY PAST ASTRONOMERS AS WELL AS PTOLEMY'S OWN INVENTIONS IN MODELING PLANETARY MOTION.

THE SUCCESS OF PTOLEMY'S WORK LAY IN THE PREDICTIVE POWER OF HIS MODELS.

Amazing! But these epicycles and equant points seem a bit hard for me to swallow.

These epicycles and equant points do work. By using them I can accurately predict the motion of planets.



BUT THERE WERE PROBLEMS.

If the epicycles bring the planets so close to Earth and then take them far away, then why don't the planets appear to grow big and then shrink?

You don't take Ptolemy's machinery literally do you?



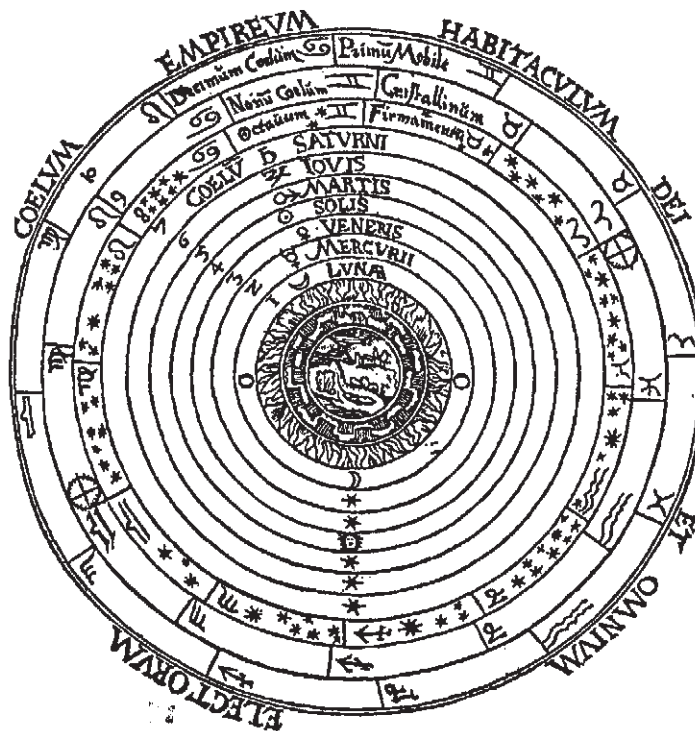
IT WAS ACCEPTED THAT THE EPICYCLES, THE EQUANT POINTS AND ALL THE MACHINERY OF PTOLEMY'S MODELS WERE ONLY MENTAL CONSTRUCTS. THEY ONLY MODELED THE OBSERVED MOVEMENT OF PLANETS AND NOT THE PHYSICAL REALITY.

## Ptolemaic Universe

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 A BIBLE ACROSS THE WORLD. IT WAS TREATED AS THE ULTIMATE WORK ON ASTRONOMY.

Schema huius praeiudicatae diuisionis Sphaerarum.

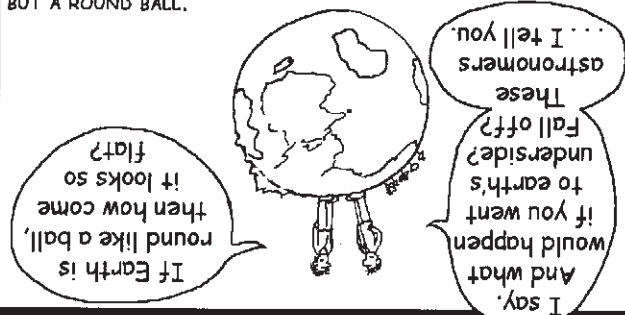


IN LIGHT OF OUR CURRENT KNOWLEDGE, PTOLEMY'S UNDERSTANDING OF THE UNIVERSE WAS GROSSLY ERRONEOUS. BUT DURING HIS TIME (AND FOR CENTURIES TO COME) THIS VIEW OF THE COSMOS WAS TREATED AS THE GOSPEL.

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.

# Flat Earth - Round Earth

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



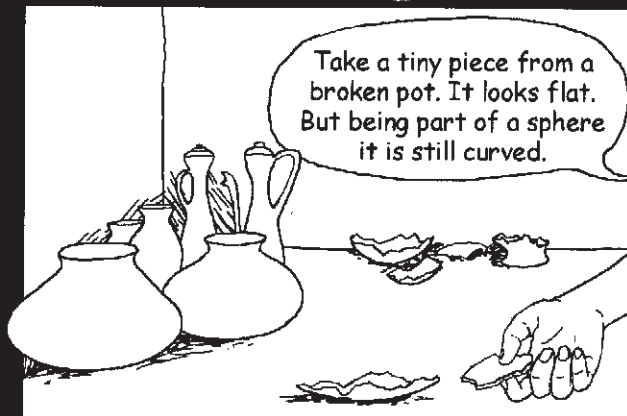
**ARYABHATA,**  
THE FAMOUS  
INDIAN  
ASTRONOMER  
(500 AD)  
GAVE A  
BEAUTIFUL  
ANALOGY  
TO VISUALIZE  
HOW THE EARTH  
WOULD LOOK FROM  
FAR AWAY.

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; and up meaning away from its center.

BUT IF THE EARTH IS LIKE A BALL, THEN WHY DOES IT APPEAR FLAT?



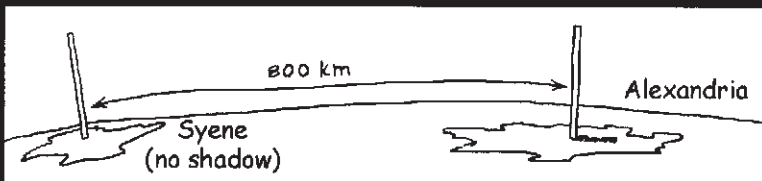
THERE ARE GOOD REASONS FOR THAT.



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.

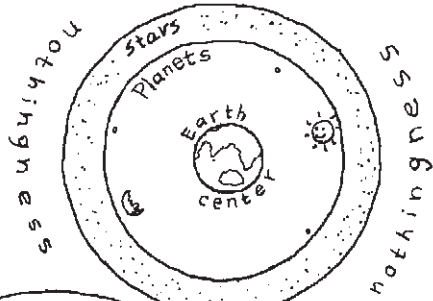
Who could have imagined? The earth we live on . . . a giant ball . . . its circumference a staggering 40,000km . . . and which is open to the sky on all sides.





# The Geocentric Theory

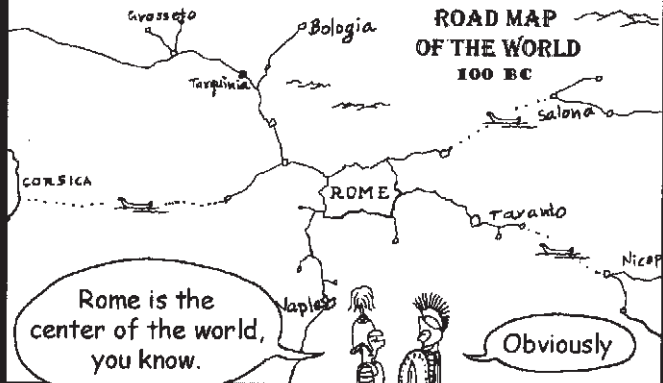
THE SUN, THE MOON, THE PLANETS AND EVEN THE STARS ALL SEEM TO REVOLVE AROUND US. NATURALLY, THE EARLY ASTRONOMERS THOUGHT THE EARTH WAS THE CENTER OF ALL THIS MOTION.



Earth is the center of the universe, you know.

Obviously.

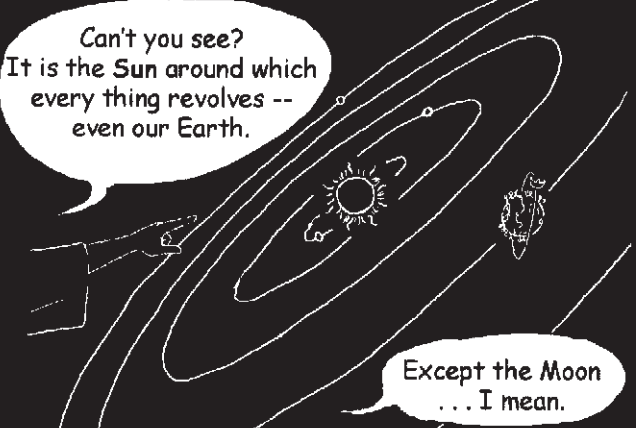
TODAY WE KNOW THAT THE EARTH IS NOT THE CENTER OF THE UNIVERSE. IN FACT THERE IS NO SUCH THING AS THE CENTER OF THE UNIVERSE. THE IDEA IS AS SILLY AS THE ROMANS BELIEVING THAT ROME WAS THE CENTER OF THE WORLD.



Rome is the center of the world, you know.

Obviously.

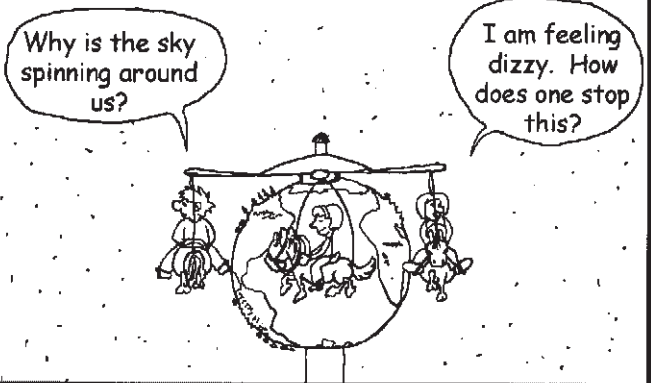
QUITE EARLY IN HISTORY, MANY THINKERS THOUGHT THAT IT WAS THE SUN (AND NOT THE EARTH) AROUND WHICH THE EARTH AND OTHER PLANETS REVOLVED. AROUND 250 BC, ARISTARCHUS OF SAMOS (IN GREECE) SAID . . .



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

Except the Moon ... I mean.

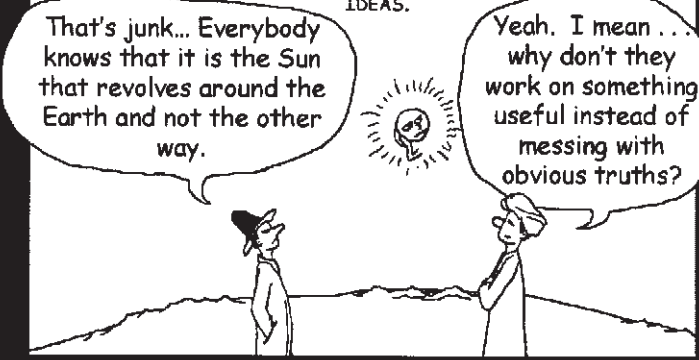
AROUND 500 AD, ARYABHATA ARGUED THAT THE EARTH SPUN ON ITS OWN AXIS, LIKE A TOP, COMPLETING ONE ROTATION EVERY DAY. HE SAID IT WAS THIS ROTATION WHICH MADE THE STARS AND PLANETS APPEAR TO BE REVOLVING AROUND US. (IT IS LIKE HOW A MERRY-GO-ROUND MAKES THE WORLD SPIN.)



Why is the sky spinning around us?

I am feeling dizzy. How does one stop this?

UNFORTUNATELY, SUCH 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.



# Copernicus

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 REVOLUTIONIBUS ORBIUM COELESTIUM (ON THE REVOLUTION OF THE CELESTIAL SPHERES) WAS THE HARBINGER OF MODERN ASTRONOMY.

ASTRONOMERS WERE DISSATISFIED WITH EXISTING MODELS.

PTOLEMY'S MODELS (CENTURIES OLD) NEEDED REFINEMENT, OR REPLACEMENT.

Why can't I ever get things right?

I feel we are barking up the wrong tree.

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.

Epicyles are mere models. What do the planet paths really look like?

Maybe 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.

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.



HE SPENT 30 YEARS WORKING OUT THE MATHEMATICAL DETAILS OF HIS NEW SCHEMA.

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.



HIS THEORY DEMYSTIFIED SEVERAL COMPLICATED ASPECTS OF PLANETARY MOTION. HIS CONTEMPORARIES HOWEVER FAILED TO APPRECIATE HIS WORK.

I don't see it. Do you?

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. Copernicus is now universally recognized as the father of modern astronomy.

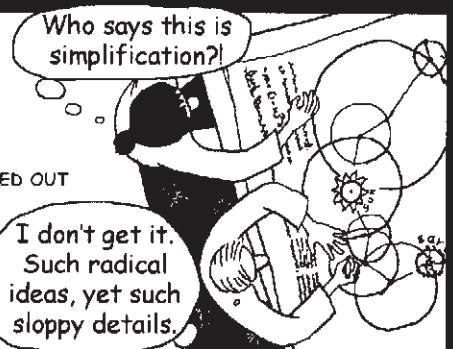
# The Heliocentric Theory

UNFORTUNATELY, THE COPERNICAN MODELS (BASED ON HIS SUN-CENTERED THEORY) DID NOT PROVE TO BE AN IMPROVEMENT OVER PTOLEMY'S EARTH-CENTRIC MODELS.



Such an elegant theory, yet ...

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.



Who says this is simplification?!

I don't get it. Such radical ideas, yet such sloppy details.

THE PRACTICAL PROBLEMS RELATED TO PREDICTION WERE NOT THE ONLY ISSUES. THERE WERE CONCEPTUAL ONES TOO.

If we are all orbiting the Sun at such a tremendous speed, then how come I don't feel a thing?

Yeah. And who pushes such a huge ball of land around the Sun anyway?

Tell me ... If the Earth is going from place to place, wouldn't we see some parallax\* in the stellar pattern?

Parallax? What is that?



\*SEE PAGE 32 FOR A DISCUSSION ON PARALLAX.

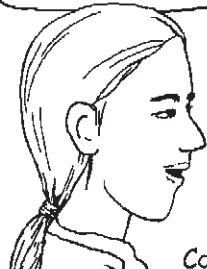
ANSWERS TO SUCH FUNDAMENTAL QUESTIONS CAME MUCH LATER. THEY NOT ONLY ELIMINATED DOUBTS ABOUT THE HELIOCENTRIC THEORY BUT ALSO PROVIDED DEEPER INSIGHT INTO THE WORKING OF THE UNIVERSE.

BUT FOR NOW, THEY POSED A HURDLE TO THE COPERNICAN PICTURE.

NOT ALL PEOPLE DOUBTED COPERNICUS. IN FACT, HE HAD A HUGE FAN CLUB.

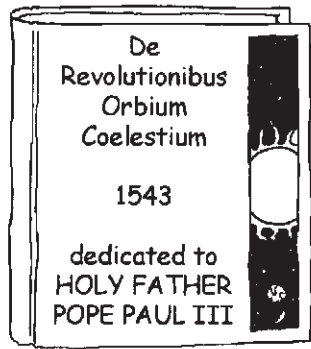
You should certainly publish your theory. The world deserves it.

I don't know. I still need to work out many details. Moreover ...



COPERNICUS'S REAL FEAR WAS REJECTION BY 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.

Copernicus has a point. We better do something about it.

Yes. Otherwise we will lose terra firma\* once and for all.

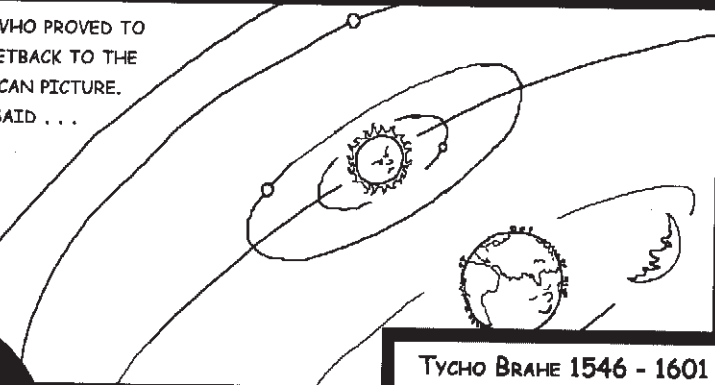


\* FIRM GROUND

# Tycho

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.

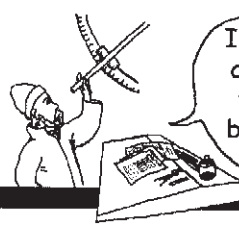
THUS, TYCHO BOTH SIDELINED THE COPERNICAN THEORY AND ALSO INCORPORATED IT COMPLETELY INTO HIS OWN.



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.

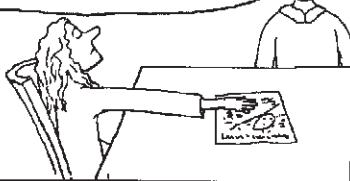


I believe in taking full responsibility for my theories you know.

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.



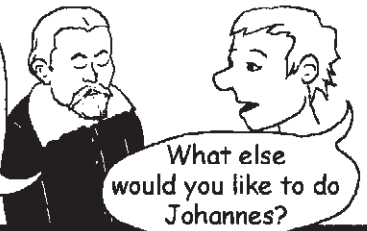
LATER TYCHO INVITED YOUNG KEPLER TO ASSIST HIM IN HIS WORK. THIS ARRANGEMENT HAD A PROFOUND IMPACT ON THE FUTURE OF ASTRONOMY.

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.

**Kepler 1571 - 1630**

TYCHO'S SUCCESSOR, JOHANNES KEPLER THOUGHT 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**

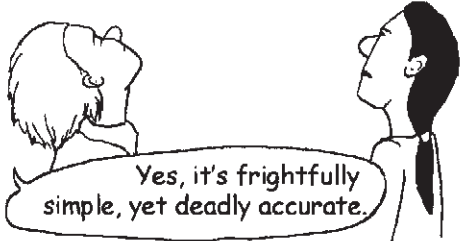


BORN IN GERMANY - A MATHEMATICIAN, ASTRONOMER AND ASTROLOGER; WORLD RENOWNED FOR HIS THREE LAWS GOVERNING PLANETARY MOTION. HE SAW ASTRONOMY AS CELESTIAL PHYSICS AND PLAYED A MAJOR ROLE IN REVIVING THE COPERNICAN WORLD VIEW.

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.

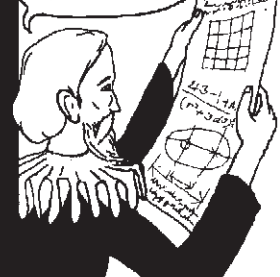


Yes, it's frightfully simple, yet deadly accurate.

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.



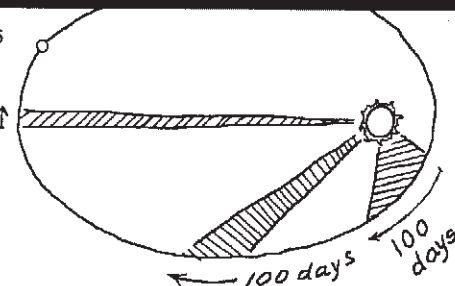
## Elliptical Astronomy

WHILE THE FIRST LAW WAS ABOUT THE PATH TRAVERSED BY A PLANET, KEPLER'S SECOND LAW TOLD HOW ITS SPEED VARIED.

An imaginary line, connecting a planet to the Sun, sweeps equal areas in equal amounts of time.

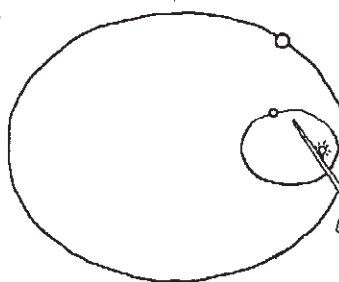


100 days

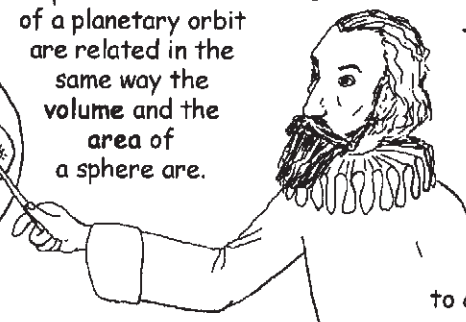


ACCORDING TO THIS LAW, IF YOU KNEW THE SPEED OF A PLANET AT ONE POINT ON ITS ORBIT, YOU COULD EASILY FIGURE OUT ITS SPEED AT ALL OTHER LOCATIONS.

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.



The time period  $T$  and the size  $S$  of a planetary orbit are related in the same way the volume and the area of a sphere are.



Mathematically,  
 $T^2 / S^3 = \text{constant}$ .

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 INITIATED 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.

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.

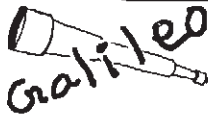
REGARDLESS OF ALL THIS, THE ELLIPTICAL ASTRONOMY OF KEPLER WAS REGARDED AS *THE ASTRONOMY*, AND IN EFFECT OVERSHADOWED ALL OTHER THEORIES OF THE PAST.



**Galileo**

CONTRARY TO POPULAR BELIEF, GALILEO DID NOT INVENT THE TELESCOPE.

Then why is Galileo's name inseparably associated with the telescope?



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. GALILEO'S THEORY WENT AGAINST THE ESTABLISHED DOCTRINE OF THE CHURCH. SO, GALILEO'S LAST YEARS WERE SPENT UNDER HOUSE ARREST.

GALILEO PIONEERED THE USE OF QUANTITATIVE EXPERIMENTS. HE ALSO UNDERTOOK A SYSTEMATIC STUDY OF MOTION.

GALILEO HAS BEEN HAILED AS THE FATHER OF MODERN OBSERVATIONAL ASTRONOMY, THE FATHER OF MODERN PHYSICS AND THE FATHER OF SCIENCE.

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.



There is more to the universe than what meets the eye.

THE TELESCOPE ACCOMPLISHED TWO THINGS. FIRSTLY ...



The universe is filled with objects we never knew existed before.

SECONDLY, THE ABILITY OF THE TELESCOPE TO REVEAL GREAT DETAIL MEANT ...

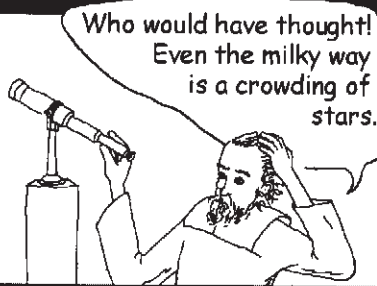
... far more accurate observations. Tycho's data will soon become history.



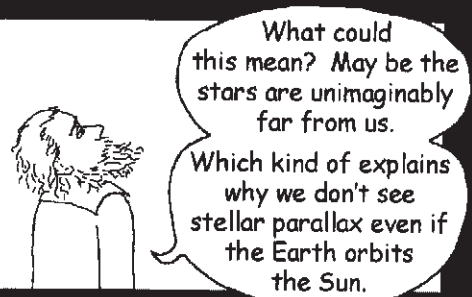
WHAT KEPLER'S FINDINGS DID TO ASTRONOMY THEORY, GALILEO'S TELESCOPE DID TO OBSERVATIONAL ASTRONOMY.

**Galileo's Discoveries**

AMONG THE FIRST THINGS GALILEO DISCOVERED IN THE SKY WERE INNUMERABLE STARS TOO FAINT TO BE VISIBLE TO THE NAKED EYE.



THE TELESCOPE ENLARGED THE PLANETS A BIT. THE STARS APPEARED BRIGHTER BUT STILL RETAINED THEIR POINT LIKE APPEARANCE.



GALILEO, LIKE HIS CONTEMPORARY KEPLER WAS ALSO AN ARDENT ADVOCATE OF THE COPERNICAN THEORY. HIS TELESCOPIC DISCOVERIES HELPED REVIVE THE HELIOCENTRIC THEORY.

HIS MOST EXCITING DISCOVERY WERE THE MOONS OF JUPITER. FOR MONTHS HE OBSERVED WHAT APPEARED LIKE THREE STARS FOLLOWING JUPITER CLOSELY.

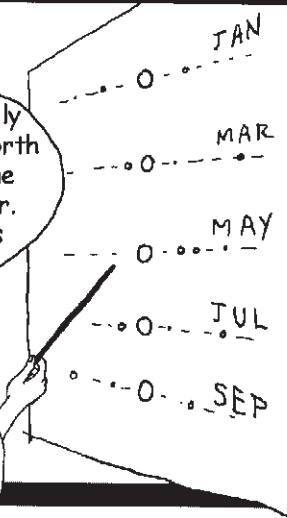
Wait a minute. They looked like stars. But why are they wandering?



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 FOUR. 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.

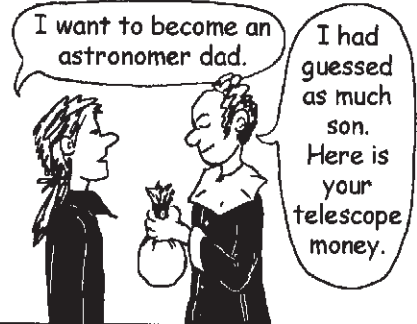


GALILEO'S EXCITING DISCOVERIES GALVANIZED HALF-YAWNING ASTRONOMERS INTO ACTION. THEY WANTED TO SEARCH THE HEAVENS TOO.



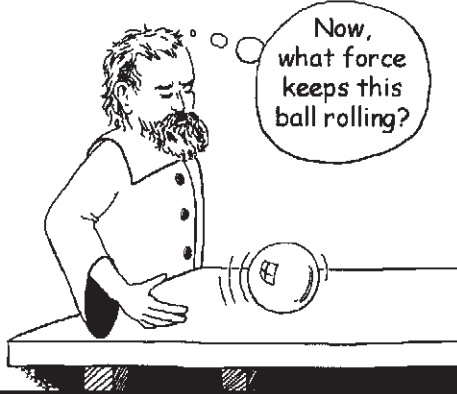
THE TELESCOPE GAINED POPULARITY. IT BECAME INDISPENSABLE FOR OBSERVATIONAL ASTRONOMY.

THE INSTRUMENT HAS EVOLVED OVER THE CENTURIES. BUT IT STILL ENJOYS THE SAME STATUS TODAY AS IT DID IN GALILEO'S TIME.

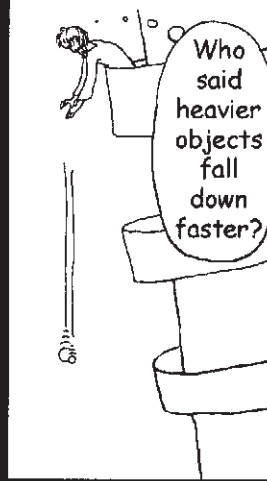


# Galilean Physics

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.

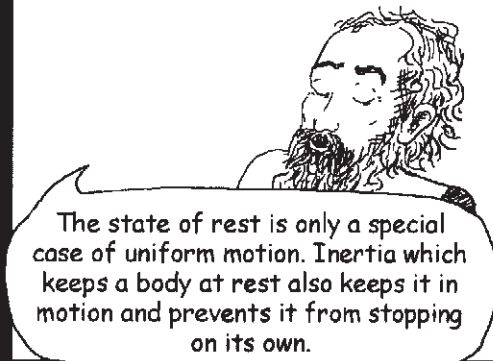


HE CONDUCTED EXPERIMENTS . . .



. . . AND DREW HIS OWN CONCLUSIONS.

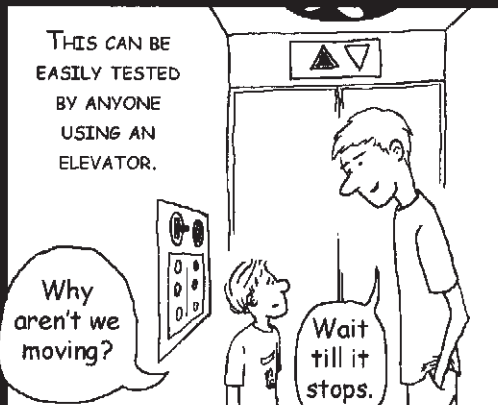
Uniform motion is a natural state of bodies. No external agent (or a force) is needed to keep an object moving uniformly.



HIS IDEAS WERE QUITE RADICAL.

It is the abruptness of motion-like setting an object (at rest) 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.



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



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



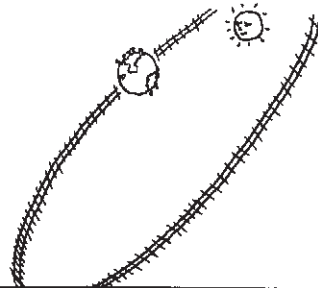
GALILEO WAS IMPRISONED. HIS WRITINGS WERE BANNED. HE SPENT HIS LAST YEARS UNDER HOUSE ARREST.

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.

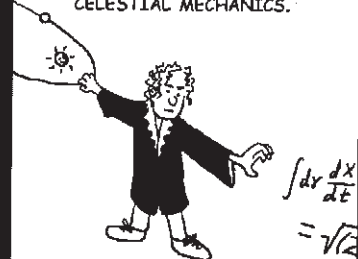
**Hooke**

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.

What makes planets go around in such beautifully curved paths? May be there are invisible tracks.



IT WAS ROBERT HOOKE WHO SERVED AS A BRIDGE BETWEEN KEPLER'S MODELS AND NEWTON'S MATHEMATICAL THEORY OF CELESTIAL MECHANICS.



$$\int dv \frac{dx}{dt} = \sqrt{2}$$

HOOKE EXHIBITED GREAT INTUITION, BUT LACKED THE MATHEMATICAL ABILITY REQUIRED TO SHAPE HIS IDEAS INTO A SCIENTIFIC THEORY.



I can see what is going on.

If only I was a mathematical genius...

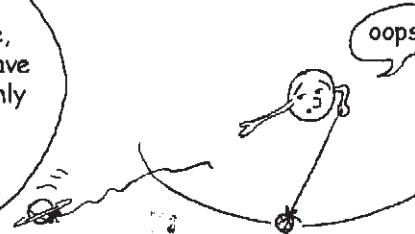
IN FACT, IT WAS HOOKE WHO FIRST RECOGNIZED GRAVITATIONAL ATTRACTION...



The Sun attracts the planets towards itself.

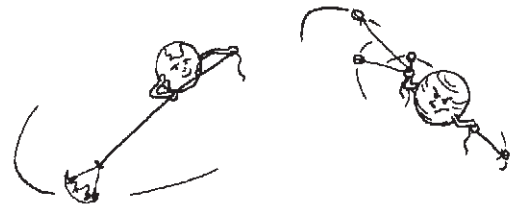
... AND THE ROLE GRAVITY PLAYED IN CELESTIAL MECHANICS

If not for any such force, the planets would have kept moving uniformly in a straight line. Remember what Galileo said?



oops!

It is the Sun's attraction that bends these straight paths into elliptical orbits



It is not just the Sun. Every planet attracts its own satellites in the same fashion.



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.

## Inverse Square Law

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.

THIS 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.

It is quite simple. Double the distance and the pull would be four times weaker.



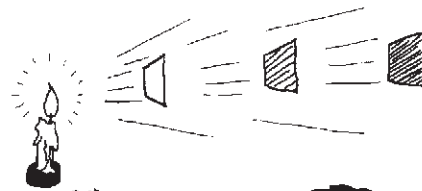
THE REAL QUESTION WAS, 'DOES THE INVERSE SQUARE LAW OF GRAVITATION LEAD TO ELLIPTICAL ORBITS?'

If so, then that is the correct law.



If not, then gravity behaves in some other way.

THE INVERSE SQUARE LAW WAS NOT SO HARD TO CONCEIVE. IN FACT IT WAS QUITE A NATURAL CANDIDATE TO BE CONSIDERED.



As everyone knows, the illumination from a candle diminishes as the square of the distance from it. Why couldn't gravity be doing the same thing?

Are you suggesting that the Sun emits gravity just like it does light?

ROBERT HOOKE CLAIMED THAT THE INVERSE SQUARE LAW OF GRAVITY WOULD GIVE RISE TO ELLIPTICAL ORBITS. BUT HE REFUSED TO FURNISH ANY PROOF.



Won't.

AT LAST HOOKE WENT TO ISAAC NEWTON. BY NOW NEWTON WAS WELL ESTABLISHED AS A REPUTED MATHEMATICIAN. UNFORTUNATELY, THIS MEETING WITNESSED A CLASH OF IDEAS.

But if only I could convince him.

How dare he contradict my ideas?



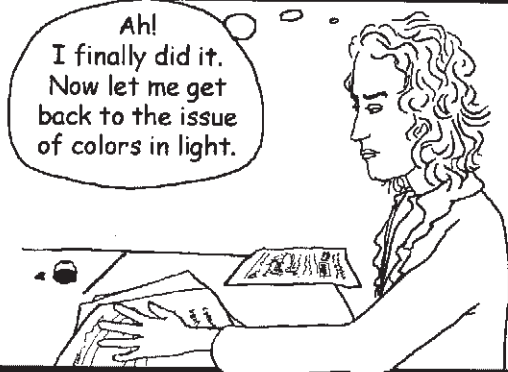
NEWTON WAS DEEPLY OFFENDED. HE RETREATED INTO A SHELL, BUT ONLY TO UNDERTAKE A DEEPER STUDY OF THE MATTER.



I have to figure this out. And I will.

**Newton 1642-1727**

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...



**ISAAC NEWTON  
1643-1727**

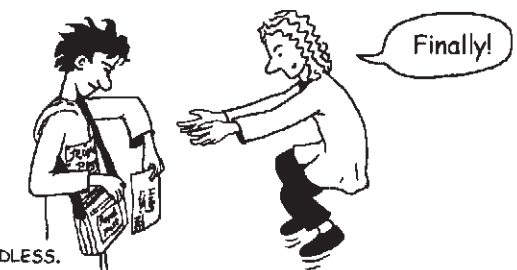


BORN IN ENGLAND. HE INVENTED CALCULUS, PROBABLY HIS GREATEST CONTRIBUTION TO THE WORLD OF SCIENCE. (THE CLAIM FOR INVENTING CALCULUS WAS ALSO SHARED BY LEBENITZ, RESULTING IN A CONTROVERSY, WHICH WAS NEVER SETTLED.)

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).

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.

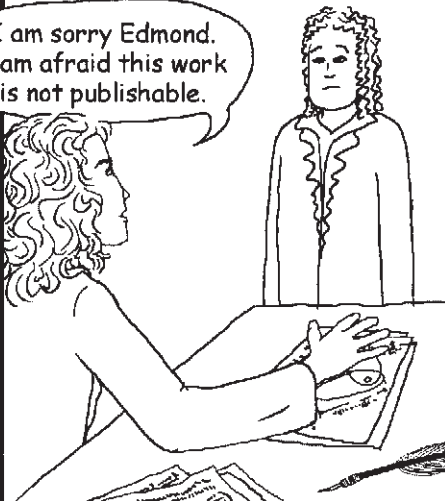


RECOGNIZING THE POTENTIAL OF NEWTON'S WORK, HALLEY COAXED HIM TO PUBLISH THE THEORY.



NEWTON WAS A PERFECTIONIST. HE WOULD RATHER NOT PUBLISH AT ALL THAN PUBLISH A HALF BAKED ARTICLE AND RISK CRITICISM AND RIDICULE.

I am 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.

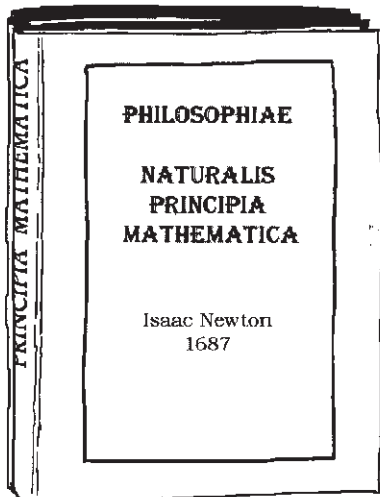


NEWTON WORKED HARD ON IT FOR THE NEXT THREE YEARS. HE FINALLY CAME UP WITH HIS MASTERPIECE. HIS THEORY WAS TO BECOME THE BIBLE OF PHYSICS FOR THE NEXT TWO HUNDRED YEARS.

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.

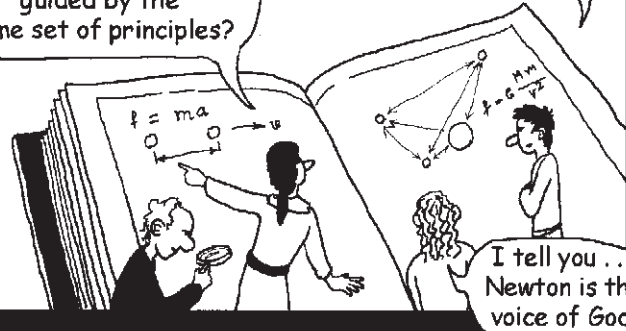


POPULARLY KNOWN BY THE SHORT NAME **PRINCIPIA MATHEMATICA** (OR SIMPLY **PRINCIPIA**) IT SPANNED THREE VOLUMES.

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!



**PRINCIPIA** DID THREE THINGS: IT

- A) LAID 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.

# Halley's Comet

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.

I am indebted.

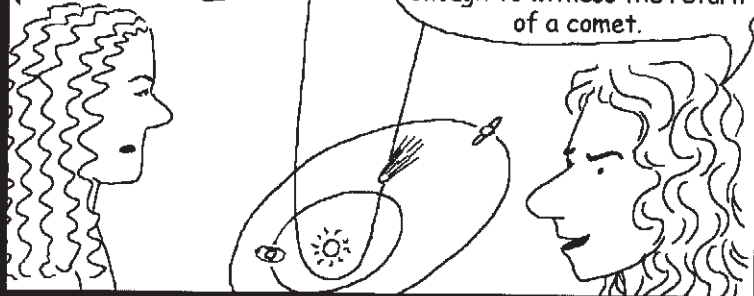


The pleasure is all mine. And here is your personal copy.

HALLEY PLAYED A PIVOTAL ROLE IN POPULARIZING NEWTON'S THEORY. THIS BROUGHT HIM MUCH FAME.

Rules of universal gravitation must give comets an elliptical orbit too. Then how come we see comets only coming and going?

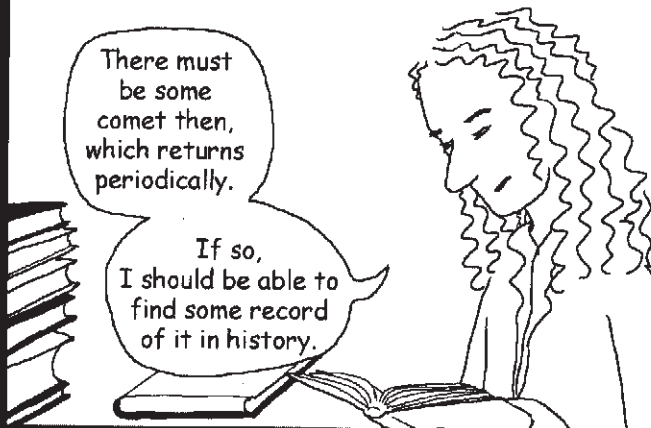
A comet's path can be elliptical too, but it will be extremely elongated. We just don't get to see the other end of such a long ellipse. And we certainly don't live long enough to witness the return of a comet.



HALLEY, WHO HAD GREAT FAITH IN NEWTON, SET OFF TO VERIFY THIS THEORY.

There must be some comet then, which returns periodically.

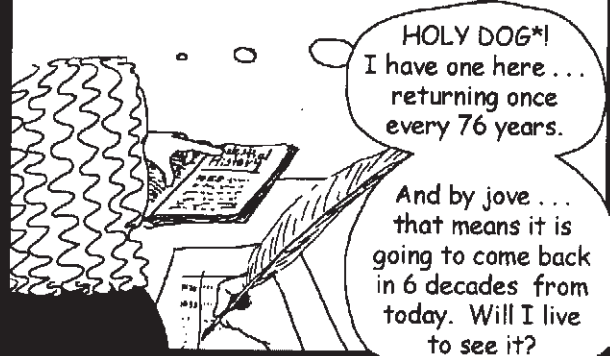
If so, I should be able to find some record of it in history.



HE DELVED THROUGH PILES OF HISTORIC DATA. SURELY ENOUGH, HE MANAGED TO IDENTIFY ONE PERIODICAL SEQUENCE OF COMET SIGHTINGS.

HOLY DOG\*! I have one here... returning once every 76 years.

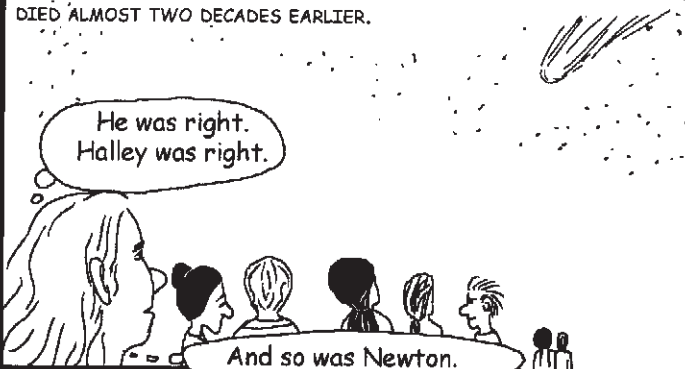
And by jove... that means it is going to come back in 6 decades from today. Will I live to see it?



\* 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.

He was right. Halley was right.



And so was Newton.

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.

## Newtonian Physics

THE LAWS OF MOTION PRESENTED IN PRINCIPIA, WERE NOT LIMITED TO CELESTIAL BODIES. THEY APPLIED TO ALL THINGS.

You mean to say I wouldn't be able to walk if the ground doesn't push me forward?

Try walking on ice and then you will know what I mean.

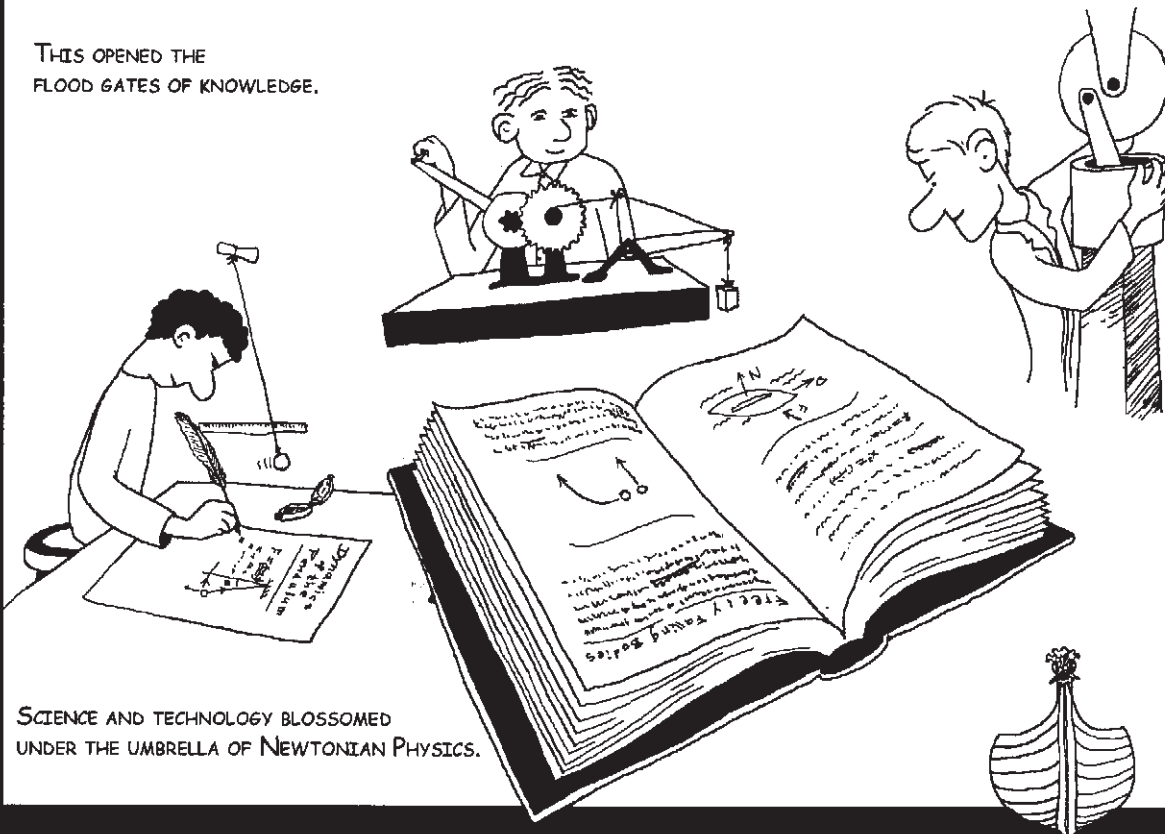


SOON SCIENTISTS STARTED APPLYING NEWTON'S LAWS OF MOTION TO ALL POSSIBLE PHYSICAL PHENOMENA THEY ENCOUNTERED.



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.

## The Mystery of the Missing Planet

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?

Maybe there's a little planet inside Jupiter's orbit which has escaped our telescopes.

The creator is wise. Since the outer planets are rather large, they could easily disturb the orbits of small planets if they were close by.



SOME PEOPLE THOUGHT THAT THE ORBITAL SIZES OF PLANETS FOLLOWED A SEQUENCE.

If you take 1/10th the size of earth's orbit as the measuring unit, then the orbital sizes of the planets roughly come out integers. In increasing order, they are 4, 7, 10, 16, 52 and 100.

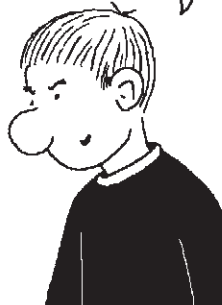
How interesting! And if you subtract 4 from each integer in this sequence and divide it by three, you will get a new sequence: 0, 1, 2, 4, 16, 32



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.

What do you mean by the missing number? We haven't spotted the planet. That is all.

The question is who finds it first.



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.

So what if it is not the missing one?



But Look! It is still in sequence. It is the one next to Saturn, corresponding to the number 64.



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.

I think these are pieces of the missing planet which was shattered into fragments due to some cosmic accident.



Well, in that case there might be more of them. Let's call them Asteroids.



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.

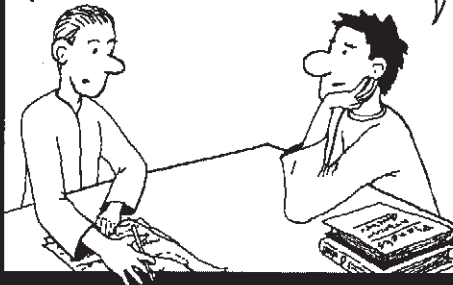
EVEN TODAY, NOBODY REALLY KNOWS HOW THE ASTEROIDS ORIGINATED. ACCORDING TO A WIDELY ACCEPTED THEORY THE DISRUPTIVE PULL OF JUPITER PREVENTED THESE FRAGMENTS FROM FORMING A PLANET.

## Triumph Of Newtonian Physics

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 for 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 1840, TWO BRIGHT MATHEMATICIANS, JAMES AND JONES SET TO WORK INDEPENDENTLY.

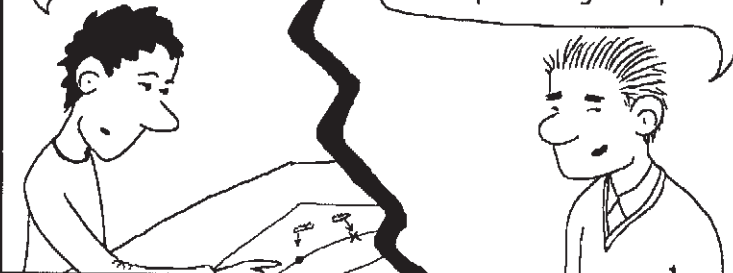
Let us suppose there is an unseen object that is pulling Uranus out of its track.



UNDER THE ASSUMPTION THAT NEWTON'S THEORY WAS CORRECT, THE TWO MATHEMATICIANS DID CALCULATIONS AND ARRIVED AT A FIRM CONCLUSION.

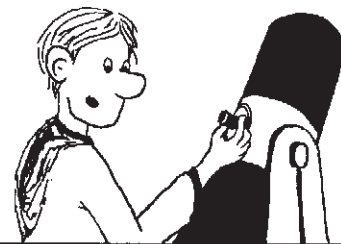
There has to be a planet right about here.

Hope the guys with the telescopes manage to spot it.



IN 1846, A NEW PLANET TRAVERSING AN ORBIT WAS SPOTTED, EXACTLY AS PREDICTED BY JOHN AND JAMES.

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  $\dot{\bar{2}}$  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.



## Beyond Newton

NEWTON'S PHYSICS THRIVED FOR A GOOD 200 YEARS.

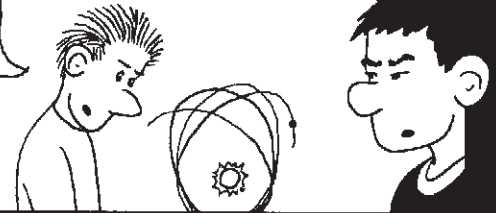
It is nothing compared to the 1500 years of supremacy enjoyed by Ptolemy, but during these 200 years, Newton's theory has covered most of the physical phenomena known to humankind.



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.

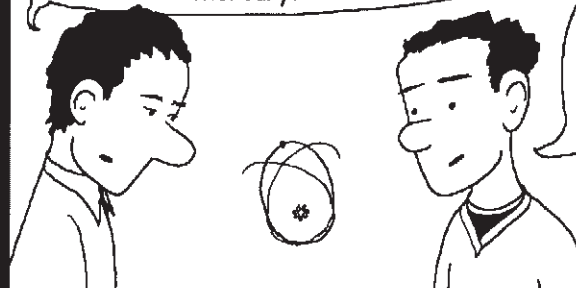


NUMEROUS FALSE SIGHTINGS OF VULCAN WERE REPORTED, BUT NEVER PROVED.

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.

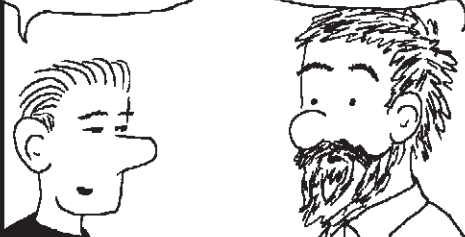
Mercury's precession matches with Einstein's theory perfectly. I have gone through the calculations myself.



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.

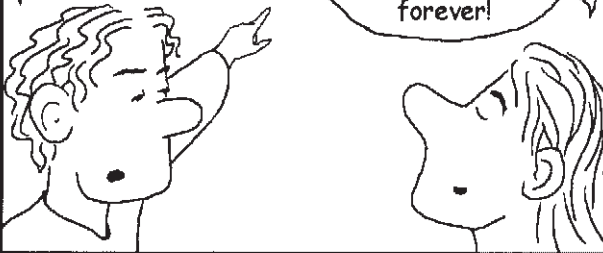


# What About The Stars?

KEPLER HAD FIGURED OUT THE FUNDAMENTAL NATURE OF CELESTIAL MOTION. NEWTON'S BRILLIANT MATHEMATICS REVEALED ITS 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.

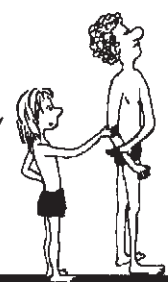
They are quite useful though.



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?

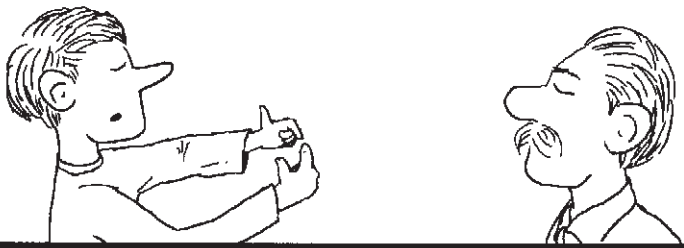
I don't know. It is worth a shot though. Pass me a stone will you.



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?

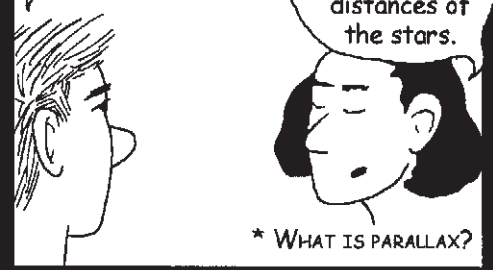
I agree with you. But I would place the stars just beyond Saturn, the farthest of planets.



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.

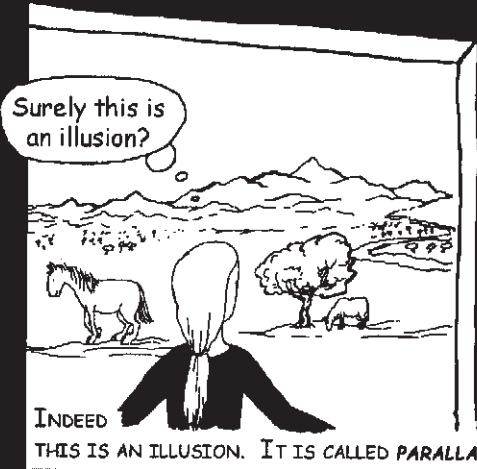


\* WHAT IS PARALLAX?

# What Is Parallax?

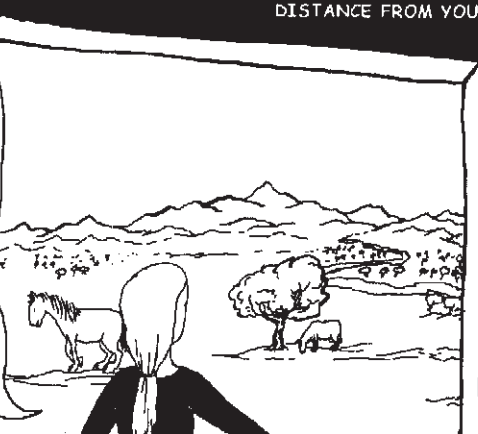
HAVE YOU EVER NOTICED THE SCENERY THROUGH THE WINDOW SHIFTING AS YOU MOVE YOUR HEAD?

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.



Yes. The hilltop, the tree and the horse all seem to come closer or move apart when I shift my head sideways.

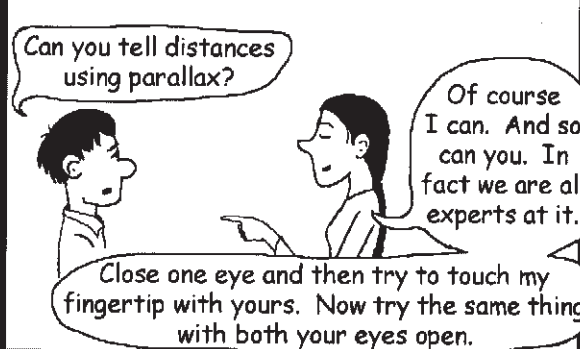
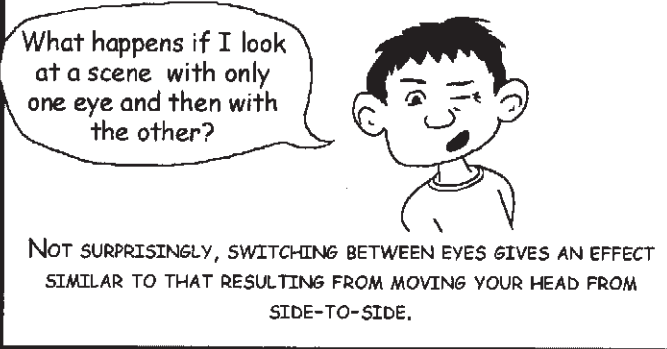
But the tree and the cow grazing right under it, move together.



INDEED THIS IS AN ILLUSION. IT IS CALLED PARALLAX.

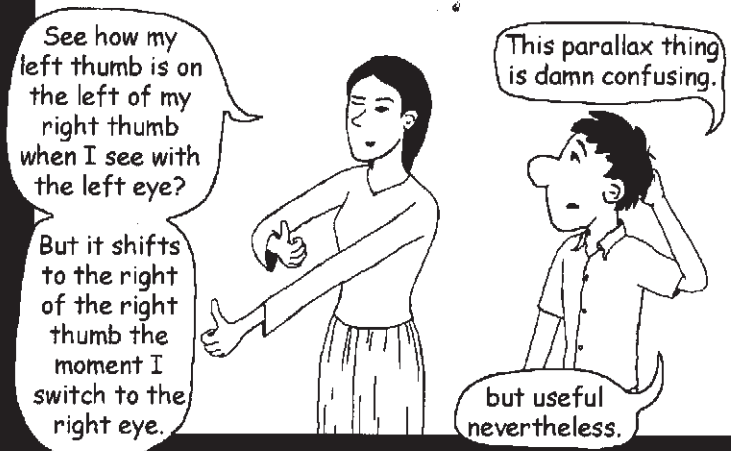
EVEN OUR TWO EYES SEE DIFFERENT IMAGES BECAUSE THEY LOOK AT THE WORLD FROM TWO DIFFERENT LOCATIONS.

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 FACE, ONE CLOSE TO IT AND THE OTHER FARTHER AWAY. NOW ALTERNATE BETWEEN YOUR EYES.

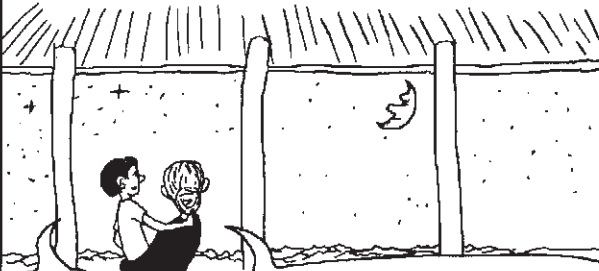
THE IMAGES FROM OUR TWO EYES ARE PROCESSED BY OUR BRAIN TO TELL US THE DISTANCES OF OBJECTS. THIS COMBINING OF TWO IMAGES, CALLED STEREO VISION, GIVES US A THREE DIMENSIONAL VIEW OF THE WORLD.



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?

# Annual Parallax

OUR STEREO VISION IS QUITE GOOD FOR ESTIMATING DISTANCES OF NEARBY OBJECTS BUT IT FAILS TO CORRECTLY PLACE OBJECTS BEYOND A KILOMETER OR SO.



Doesn't the Moon knock down the stars that come in its path?

The stars are way farther than the Moon. There is no way the Moon can bump into them.

OBJECTS MORE THAN A KILOMETER AWAY APPEAR ALMOST THE SAME TO BOTH EYES. WE CAN ONLY 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.

It is not so elegant as stereo vision, but still very effective.



THEY VIEWED A SCENE FROM TWO POINTS WITH A SEPARATION MUCH LARGER THAN THAT BETWEEN OUR TWO EYES. BY COMPARING THESE IMAGES THEY COULD ESTIMATE DISTANCES OF OBJECTS BEYOND THE RANGE OF STEREO VISION.

The ship makes an angle of 32 degrees with the lighthouse.

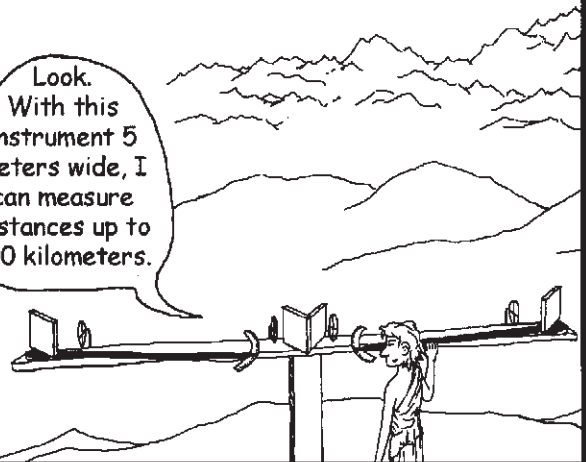
From here it makes an angle of 32 degrees and 20 minutes.



Give me a second here. ... OK. It has to be 6 miles away from the shore.

THE WIDER THE SEPARATION BETWEEN TWO VIEWING LOCATIONS, THE FARTHER THE DISTANCE THAT COULD BE MEASURED.

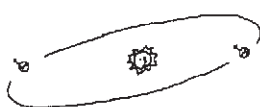
Look. With this instrument 5 meters wide, I can measure distances up to 100 kilometers.



TO MEASURE ASTRONOMICAL DISTANCES USING PARALLAX, ONE HAS TO CHOOSE TWO VIEWING LOCATIONS THAT ARE THOUSANDS OF KILOMETERS APART.

Compare two observations - one made late at dusk, the other at early dawn. Earth's rotation will have carried you across thousands of kilometers through the night.

That's a terrific idea. Now, how about comparing observations that are six months apart? We will have traversed half the orbit around the Sun.



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.

According to my calculation, Saturn has an orbit 9 times larger than that of the Earth. How large exactly is that?

18 AU of course. And did you catch any stellar parallax yet?

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.

## Stellar Activity

IN THE END IT WAS A STRANGE STELLAR ACTIVITY WHICH DREW THE ATTENTION OF ASTRONOMERS TO THE STARS.

What a bright star. I could swear it was not there yesterday.



But I thought the stellar sphere never changed.



A BRIGHT STAR WAS SPOTTED BY TYCHO IN 1572. IT WAS CALLED NOVA, MEANING NEW STAR.

Hey ... Where did that Nova go?



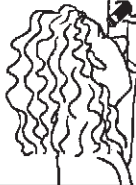
Looks like it went the way it came.



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.

This is something. The stars keep varying in brightness.

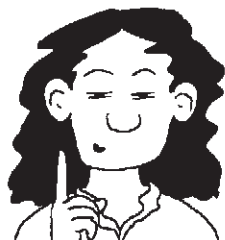


At least some of them do.

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.

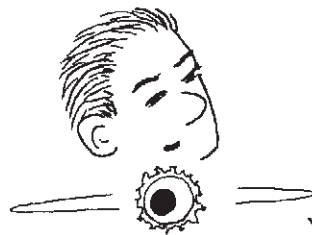
SOME STARS VARIED ERRATICALLY WHILE SOME SHOWED PERIODIC VARIATIONS. SOMETHING WAS GOING ON. THIS STELLAR ACTIVITY EXCITED THE SCIENTIFIC COMMUNITY. LOTS OF ASTRONOMERS CAME UP WITH POSSIBLE EXPLANATIONS.



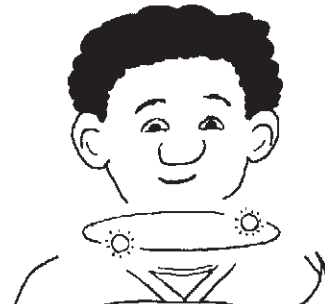
The stars are like the Sun, only far away.



And some kind of sun-spots cause the stars to appear dimmer at times?



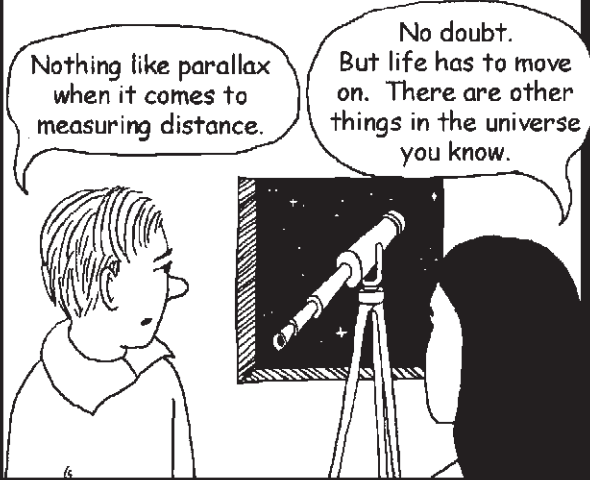
Maybe some stars have planets orbiting them and get eclipsed periodically.



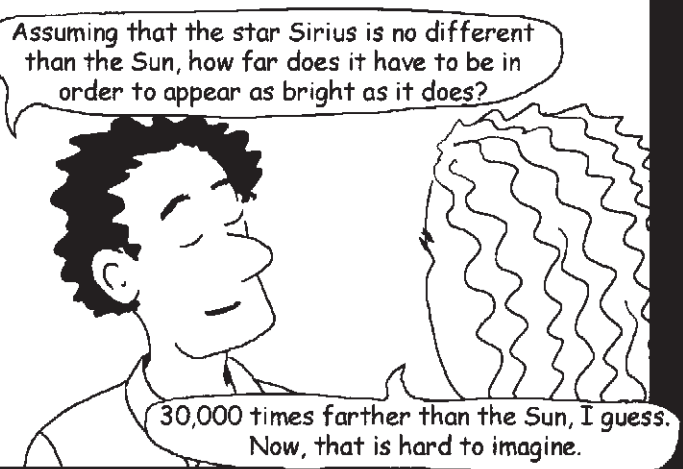
I have spotted two stars orbiting each other, that too in elliptical orbits.

**That Is Really Far**

OBSERVING STELLAR PARALLAX WAS AS HOPELESS AS EVER. IN THE MEANWHILE, OTHER DEVELOPMENTS OCCURRED.

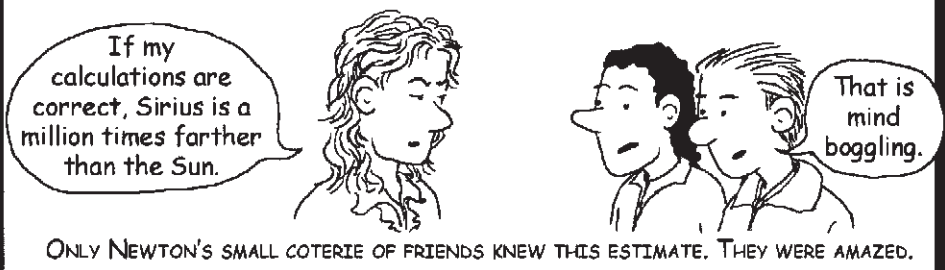


IN MID 1650, THE DUTCH PHYSICIST CHRISTIAAN HUYGENS ESTIMATED THE DISTANCE BETWEEN SIRIUS AND EARTH.

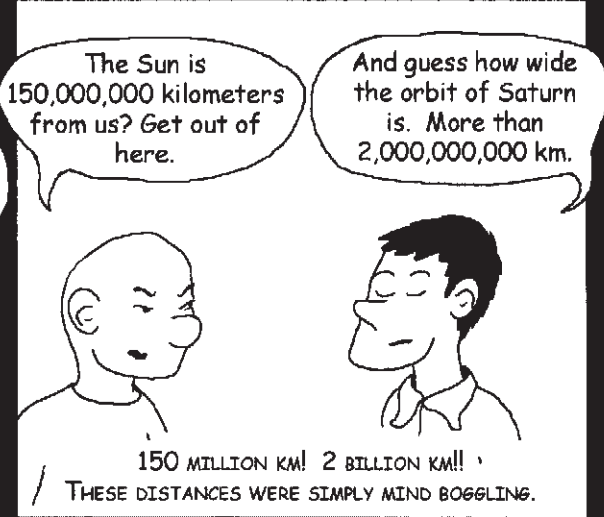
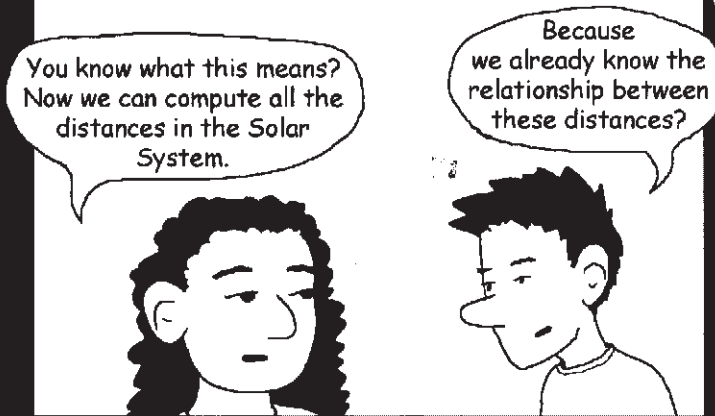


HUYGENS' ASSUMPTION WAS BASELESS, AND HIS METHODOLOGY CRUDE. ASTRONOMERS DIDN'T EVEN KNOW HOW FAR THE SUN WAS. BUT HIS ESTIMATE HELPED PEOPLE TO BEGIN APPRECIATING THE VASTNESS OF THE UNIVERSE.

BASED ON SIMILAR ASSUMPTIONS, NEWTON TOO HAD ESTIMATED THE DISTANCE OF SIRIUS.



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 ACCORDING TO THEIR RANGE OF BRIGHTNESS? IN THAT CASE, HOW LARGE WOULD THE UNIVERSE BE?



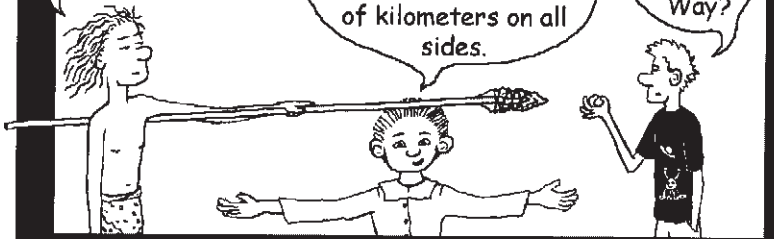
# Astronomical Unit

THE WORLD WAS VAST, EVERYONE AGREED. BUT HOW LARGE WAS IT? THROUGHOUT HISTORY PEOPLE HAVE HAD DIFFERENT BELIEFS.

The world is enormous. To reach its end you will have to walk straight for a 1000 days.

Really! From what they tell me, the earth is a ball without an edge. And the universe stretches for millions of kilometers on all sides.

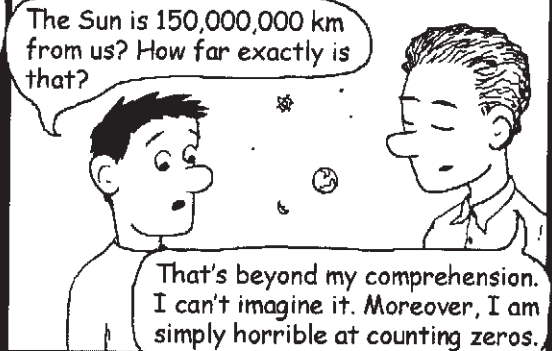
Isn't our solar system just a speck of dust in the Milky Way?



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.

The Sun is 150,000,000 km from us? How far exactly is that?

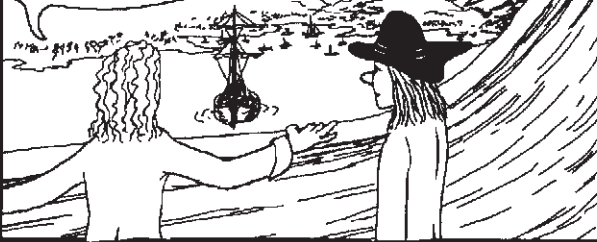
That's beyond my comprehension. I can't imagine it. Moreover, I am simply horrible at counting zeros.



LIKE ALL PHYSICAL QUANTITIES, DISTANCES COULD ONLY BE EXPRESSED WITH REFERENCE TO A STANDARD. USUALLY A KNOWN DISTANCE - A UNIT IS USED TO QUANTIFY OTHER DISTANCES.

This harbor appears quite wide. Must be at least 5,000 thumb-lengths end-to-end.

For heaven's sake Columbus, can't you talk in terms of ship-lengths?

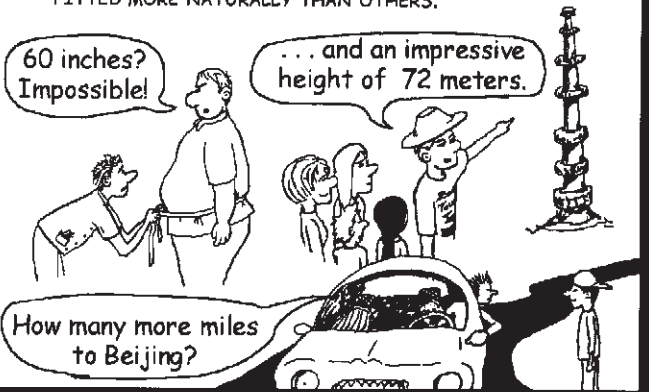


DEPENDING ON THE SITUATION, SOME UNITS FITTED MORE NATURALLY THAN OTHERS.

60 inches? Impossible!

... and an impressive height of 72 meters.

How many more miles to Beijing?



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.

Do you know that Earth's orbit is 2 AU in diameter?

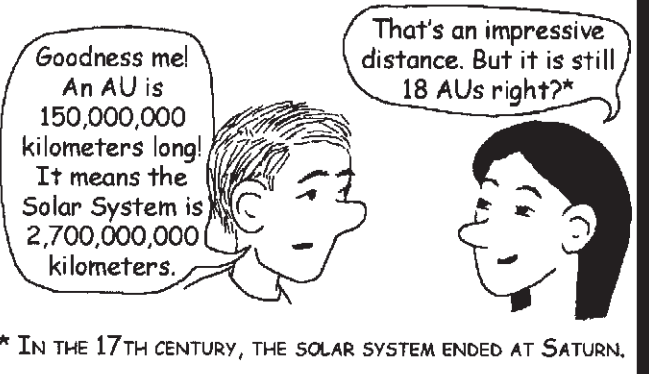
Don't state obvious facts mister. Now, did you know that Saturn's orbit is 18 AU wide?



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.

Goodness me! An AU is 150,000,000 kilometers long! It means the Solar System is 2,700,000,000 kilometers.

That's an impressive distance. But it is still 18 AUs right?\*



\* IN THE 17TH CENTURY, THE SOLAR SYSTEM ENDED AT SATURN.



# Light Year

THE AU DID GREAT AS A NATURAL UNIT FOR INTERPLANETARY DISTANCES. BUT WAS IT GOOD ENOUGH FOR THE STELLAR WORLD?

Did you hear this? The milky way is more than 1,000,000,000 AU wide.

I can't comprehend or imagine such distances. You know how bad I am at counting zeros.



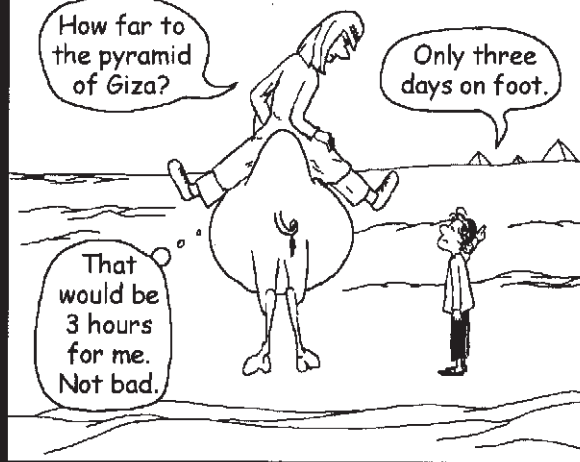
THERE WAS AN URGENT NEED FOR A NEW UNIT FOR EXPRESSING THE DISTANCES OF FAR AWAY STARS. WHAT WOULD IT BE?

HUMAN BEINGS ARE TRAVELLERS AT HEART. RIGHT FROM OUR NOMADIC DAYS WE HAVE EQUATED DISTANCE TO TRAVEL TIME.

How far to the pyramid of Giza?

Only three days on foot.

That would be 3 hours for me. Not bad.



THE USE OF TRAVEL TIME TO EXPRESS DISTANCE IS STILL VERY MUCH IN FASHION.

... only two hours\* from here.

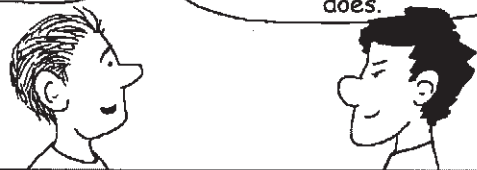


\* BY BUS IN THIS CONTEXT.

COULD ONE TALK ABOUT ASTRONOMICAL DISTANCES IN TERMS OF TRAVEL TIME?

Hope you are not thinking of space travel yet?!

Don't be a silly goose. How can we travel in space? But there's is something that does.

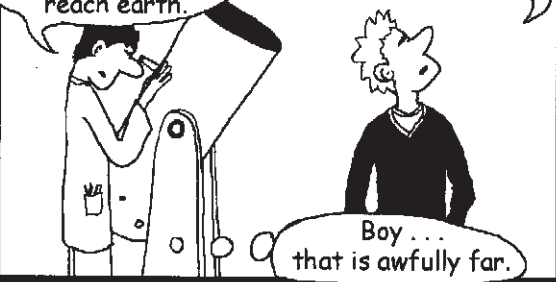


IF THERE WAS ANYTHING THAT TRAVELLED ACROSS THE UNIVERSE, AND WAS FAMILIAR TO US, IT WAS LIGHT.

LIGHT MOVED WITH A TERRIFIC SPEED. SCIENTISTS DEvised EXPERIMENTS TO FIGURE OUT HOW FAST IT TRAVELLED.

Observing the shadow of Jupiter on its moons, I can estimate that light emitting from the Sun should take about 8 minutes to reach earth.

That's awfully fast. And that also means light would take about eight years to travel from Sirius to earth.



Boy ... that is awfully far.

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.

Here is the latest. The milky way is a 100,000 light years wide.

That's a mind boggling distance. But now I can at least keep track of the zeros.



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.

## Stellar Parallax At Last

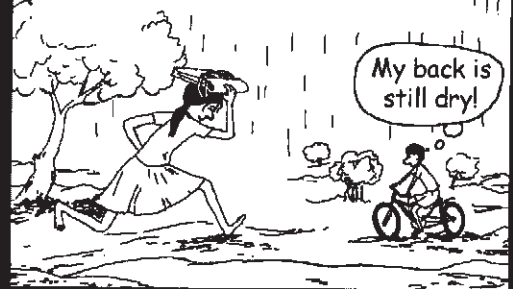
WHILE THE ASTRONOMERS WERE ON THE LOOK OUT FOR STELLAR PARALLAX, OTHER IMPORTANT DEVELOPMENTS TOOK PLACE.

IN 1728, JAMES BRADLEY POINTED OUT THAT . . .

... if the Earth is hurtling in space, then the light reaching us will appear to be coming at an angle slightly different than the actual. This will cause a minute distortion in the observed position of heavenly bodies.

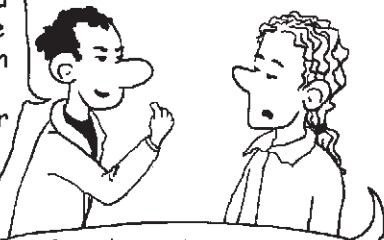


EVER NOTICED HOW THE RAIN DROPS FALLING VERTICALLY DOWN, APPEAR TO BE COMING AT AN ANGLE, IF YOU ARE RUNNING?



A CAREFUL ANALYSIS OF PAST DATA SHOWED THAT THERE WAS INDEED A DISTORTION OF STELLAR POSITIONS INDICATING THE MOTION OF EARTH AROUND THE SUN.

Bradley is a genius. Do you know what we have here? An experimental proof that our Earth is hurtling in space.



But the bad news is, we'll have to account for this distortion and reanalyze all the data.

IN 1748, BRADLEY NOTICED YET ANOTHER SOURCE OF ERROR.

Earth's axis of rotation itself is turning slowly.

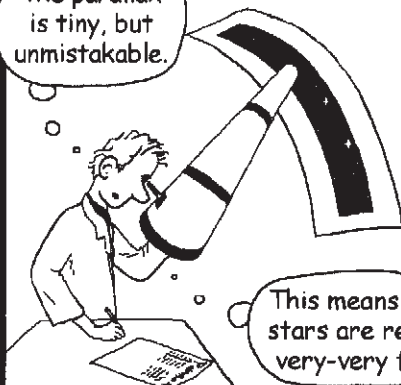
Don't tell me this. Now we'll have to go through another round of corrections.



Annoying as it may appear to us today, his pointing out our mistakes will only lead to progress in astronomy.

IT WAS WORTH THE WAIT, WHEN FINALLY, FRIEDRICH BESSEL, A GERMAN ASTRONOMER, DETECTED A STELLAR PARALLAX IN 1838.

The parallax is tiny, but unmistakable.



This means the stars are really very-very far.

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 COME ACROSS ONE OF THE VERY FEW STARS WITH A DETECTABLE PARALLAX.

SOON HORDES OF ASTRONOMERS WERE DETECTING AND MEASURING PARALLAX IN STARS.

But still, the majority of the stars show no parallax.

Which means only a very few of them are close to us - within a hundred thousand billion km.



You call that close?

EVEN THE NEAREST STARS ARE THOUSANDS OF TIMES FARTHER THAN THE OUTER LIMITS OF THE SOLAR SYSTEM.

## The Galactic Universe

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.

Could you have guessed? The Milky Way is made up of 10 billion stars scattered over a large region in the shape of a flat disk. And we are in the very middle of this disk.



Simple. The individual stars we see are the closer ones. They are all around us. The farthest stars which are responsible for the foggy haze are located towards the edge of the disk. They surround us like a ring.

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 19<sup>TH</sup> CENTURY, WHEN BESSEL SUCCEEDED IN DETECTING STELLAR PARALLAX, THE QUESTION OF THE SIZE OF THE UNIVERSE AGAIN BECAME A HOT TOPIC.

How does one estimate the size of the galaxy?

Let's see. If we know the total number of stars and the average distance between neighbors, then ...



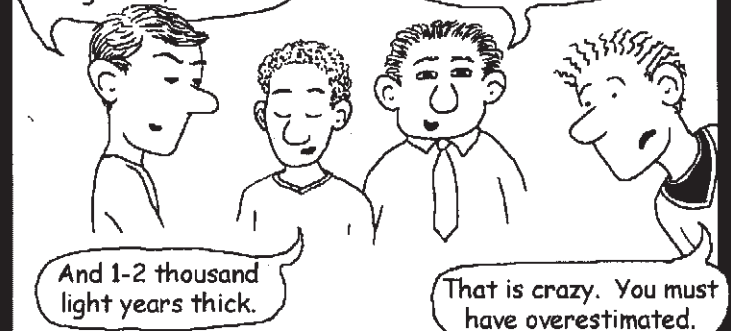
THIS ESTIMATE WAS CRUDE BUT GAVE A CONCRETE SIZE TO THE UNIVERSE.

If the 10 billion stars are 5-10 light years from their immediate neighbors, then ...

... the whole galaxy should be 5-10 thousand light years across.

And 1-2 thousand light years thick.

That is crazy. You must have overestimated.



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.



## Nebulae - Celestial Clouds

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).

I have been observing that little cloud over there for weeks. It hasn't moved a bit.



Look's as if it is stuck to the stellar sphere. I don't think it is the kind which will bring us rain.

NEEDLESS TO SAY, THE TELESCOPE REVEALED A LOT ABOUT NEBULAE.

There are many more nebulae than what the naked eye can see.



This one again is a dense cluster of stars.

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.

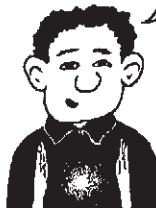
Nebulae are huge clouds of dust particles. They glow because light-emitting stars are embedded in them.



Wouldn't such a cloud of dust shrink due to its own gravity?



... and heats up due to compaction, until it becomes so dense and hot that it becomes a star.



How fantastic. May be even our Sun was once a nebula?



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.

Do you see the nebula in the Andromeda constellation? I can swear all it emits is star light.

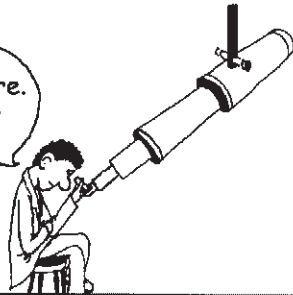


But I don't see a single speck in it. It is all smooth gas.

# Andromeda Nebula

THIS NEBULA LOCATED IN THE ANDROMEDA CONSTELLATION CAME TO BE KNOWN AS THE ANDROMEDA NEBULA.

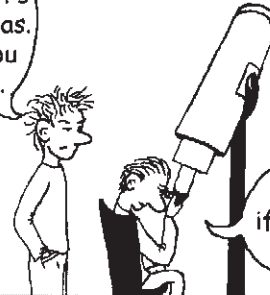
Hey!  
I do see a speck in there.  
I wonder why nobody noticed it before.



BUT THE TINY SPOT DISAPPEARED WITHIN NO TIME.

I don't see anything. It's just plain gas. Maybe 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.

This is all 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.

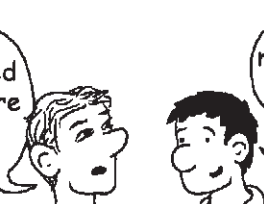


Could this nebula be a whole galaxy in its own right?

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.





## Multigalactic Universe

I have no doubt that Andromeda Nebula is actually a galaxy, just like the Milky Way.



Then why don't we stop calling it a nebula and call it *Andromeda Galaxy* from now on?



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.

That is long enough to fit 20 galaxies end to end.



That is going too far.



Is there an end to the expanse of the universe?



This universe is crazy.

WAS THAT ALL THERE WAS TO THE UNIVERSE? TWO GALAXIES SEPARATED BY A MIND BLOWING DISTANCE? THE ASTRONOMERS SEEMED TO KNOW BETTER.

You really think there are more galaxies?



I can assure you the universe will always have something more in store for us.



IT CAME AS NO BIG SURPRISE WHEN MANY MORE GALAXIES WERE DISCOVERED SOON AFTER.

What did I tell you?



This is crazy. The Milky Way, which was once taken for the whole universe, is actually one out of a swarm of galaxies?



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.

But who knows? May be one day, we will discover something new, somewhere beyond the known boundaries of this Multi-galactic Universe.





# The Universe in Chunks

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 IS A CLUSTER OF GALAXIES. AN AVERAGE SIZED CLUSTER CONTAINS MORE THAN A THOUSAND GALAXIES. THERE ARE MORE THAN A BILLION SUCH 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 HAVE A LONG WAY TO GO BEFORE WE REACH HOME.

## Back Home

ZOOMING ONCE MORE, OUR FIELD OF VISION IS NARROWED TO ONLY ONE STAR, THE SUN.

Are you sure that is our Sun?  
I don't see any planets orbiting it.

0.1 light years  
6,000 AU



TO SEE THE STRUCTURE OF THE SOLAR SYSTEM, WE NEED TO STEP MUCH CLOSER.

Now I see some dots.  
Must be the outer planets.

60 AU



IT IS ABOUT TIME WE STARTED LOOKING FOR THE PLANET WE CALL HOME. LET US PLUNGE RIGHT INTO THE SOLAR SYSTEM.

That one looks like Saturn and the other one is Jupiter. That tiny one must be Mars ... EARTH!

0.6 AU  
100,000,000 km



NOW THAT THE EARTH HAS BEEN LOCATED, THE REST OF THE JOURNEY IS TRIVIAL.

We have zoomed in quite a bit now. Yet the Earth appears no larger than a dot. Could you have imagined we live on such a tiny ball floating in space?

1,000,000 km



WE ARE ALMOST THERE. ZOOM IN ONE LAST TIME AND IT IS TIME TO ...

Prepare for LANDING!

10,000 km

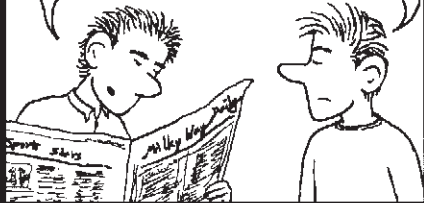


# Space And Time

THE LIGHT YEAR HAS CEASED TO BE THE NATURAL UNIT IT ONCE USED TO BE.

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

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

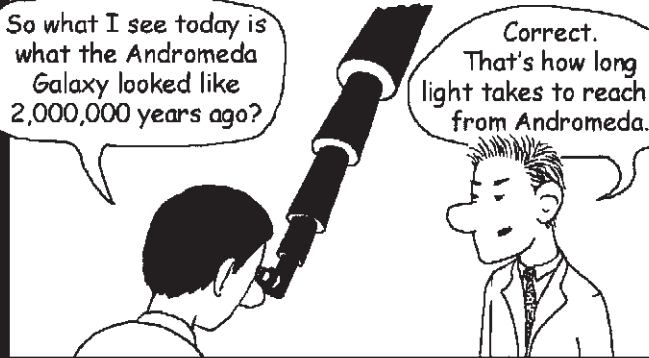


YET, THE LIGHT YEAR PLAYS A SPECIAL ROLE IN PICTURING THE UNIVERSE.

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?

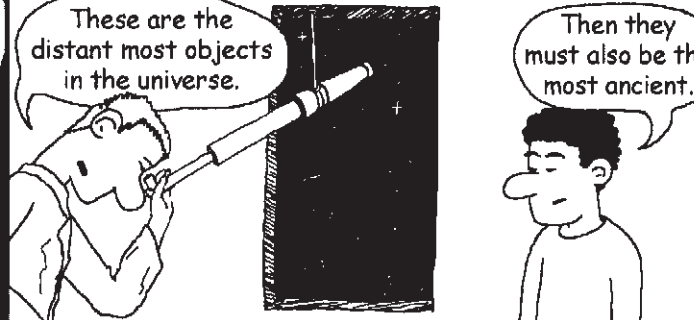
Probably not any different. A galaxy doesn't change much in a few million years. But there is no way of knowing for sure.



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.

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.

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!

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.

# Evolution Of Telescopes

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.

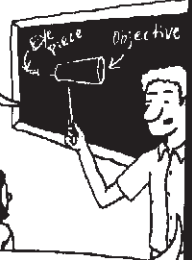


I have seen everything this telescope could show me. I need a more powerful one.

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 GRIND 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.



# Spectrum

AS THE TELESCOPES ADVANCED TO REVEAL THE SKY IN GREATER AND GREATER DETAIL, AN EQUALLY POWERFUL DEVELOPMENT TOOK PLACE.

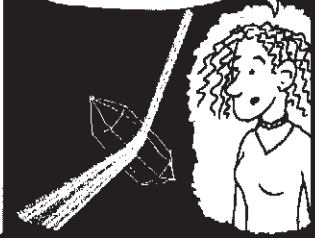
Look! Sunlight is made up of several colors. The prism splits the beam into its colored components.



And if you recombine these components, you again get the white light you started with.

THE ANCIENTS KNEW THAT LIGHT PASSING THROUGH CRYSTALS YIELDED A RAINBOW-LIKE PATTERN. BUT THEY THOUGHT IT WAS THE CRYSTAL WHICH RENDERED THE COLORS.

After all crystals are magical aren't they?



THIS DISCOVERY BY NEWTON IN 1666 HAD PROFOUND IMPLICATIONS.

BUT AFTER NEWTON'S EXPLANATION, THE FOCUS SHIFTED FROM CRYSTALS TO LIGHT.

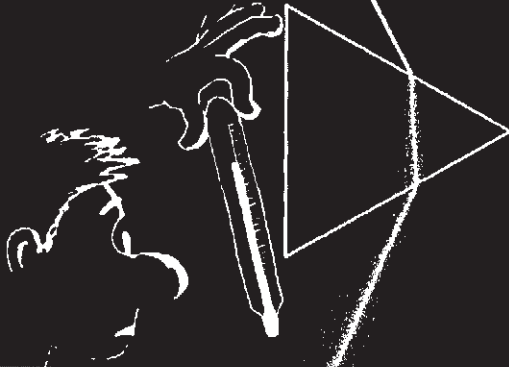
DURING THE 18TH CENTURY PEOPLE DISCOVERED THAT LIGHT CONTAINED MUCH MORE THAN A RAINBOW OF COLORS.

SCIENTISTS CONDUCTED EXPERIMENTS IN THE DARK ROOM.

That is strange! Even the dark regions next to the rainbow have a warming effect.

Hey, this is spooky! The photograph of the rainbow is much wider than the rainbow itself.

I know what this means. The sunlight has some colors which are invisible to the human eye. The prism separates them just like it does the visible colors.



THE RANGE OF COLORS, INCLUDING THE INVISIBLE ONES WAS CALLED THE SPECTRUM.

I name this invisible region of the spectrum beyond violet THE ULTRAVIOLET.

Well, let's call the other invisible region, the one before red, THE INFRARED.

V I B G Y O R



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 IS JUST 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.

# Spectroscopy

IN 1835, AUGUSTE COMTE, A FRENCH PHILOSOPHER SAID . . .

Humans would NEVER be able to tell what the STARS are made of!



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.

If I pass the light from this candle through a prism, what would the resulting rainbow look like?



How about the light coming from this white-hot iron rod?



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.



This looks like one third gold and two thirds silver. What do you think?

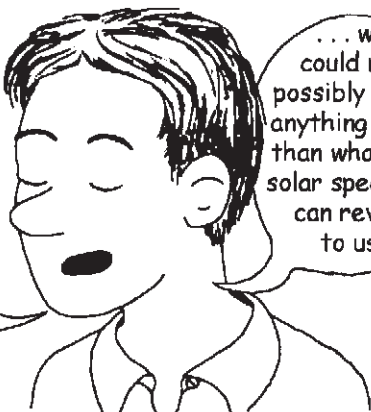
ASTRONOMERS WERE THRILLED WITH THIS NEW ABILITY.

This is really exciting! Why don't we look at the spectra of stars? Maybe we can tell what elements are responsible for their glow.



SOON THIS EXCITEMENT GOT CONVERTED INTO A DEEP FAITH.

If we were to reach the Sun and fetch a tiny piece of it to analyze the composition in the laboratory . . .



. . . we could not possibly learn anything more than what the solar spectrum can reveal to us.

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

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.

TELESCOPES MEANT FOR INVISIBLE LIGHT ARE USUALLY THE REFLECTING (NEWTONIAN) TYPE.

MOST MODERN TELESCOPES CAPTURE INVISIBLE LIGHT. DEPENDING ON THE REGION OF THE SPECTRUM THEY ARE SENSITIVE TO, THEY ARE NAMED 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?

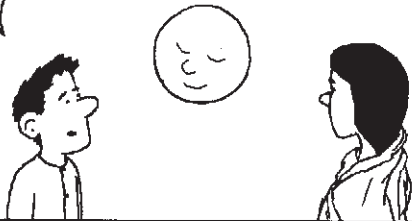
When it comes to radio telescopes, one plus one is two. The more radiation they capture the better.

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.

# Space Exploration

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 INFINITE 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 earth.

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.

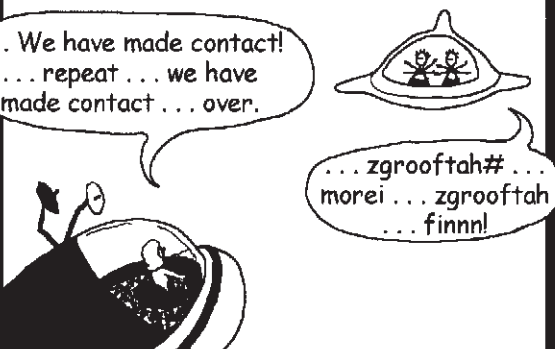
Just in time too!



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.

Reg, you were right! There is life outside our planet.

They appear friendly. Can't make out what they are trying to say though.



# THE END