ENIGMA OF SPACE AND THE RATIONALE FOR SPACE EXPLORATION

Associate Professor K. Arichandran
School of Electrical & Electronic Engineering, Nanyang Technological University Singapore

1.0 INTRODUCTION

This article was put together in part as notes for the 16th Professor Chin Fung Kee Lecture. The lecture series was set up in 1990 in memory of Professor Chin Fung Kee, Faculty of Engineering University of Malaya. Way back in the 1960's, I was an undergraduate and I had the privilege of being mentored and guided by him.

In this talk I have taken the opportunity to discuss some aspects of the physics of space and the major effort that is being made by scientists and engineers to explore space. Presently only the major economic powers are in a position to take space exploration seriously. However this should not be deterrent for the young in any country, to learn about these matters and work in a spirit of international scientific and technical collaboration.

Up to almost the 1960's humans have been Earthbound. We knew about space, but more in the sense as a place where other planets, comets and stars reside. There are many scientific theories of what is beyond the Earth that needs investigation. It is normally understood that the space far beyond Earth and in between heavenly bodies is empty. Is this really so? The words "the enigma of space" in the title of the lecture allows us to see what scientists have managed up to now, to discover of the true nature of space.

The space normally referred to by astronomers is the space of the "large" where planets and stars roam. However, there is also the space of the "small" where atoms and its constituents reside. Is this space not empty as well and does it not carry with it the same signature as space elsewhere?

The present view on this is that for "large space" with massive stars and galaxies the effects of gravitation become important. For this reason the understanding of General Theory of Relativity (GR) is sketched out. The path to understanding GR is helped by knowing first the Special Theory of Relativity (SR). Without the help of GR it is difficult to follow for example why our Universe is expanding.

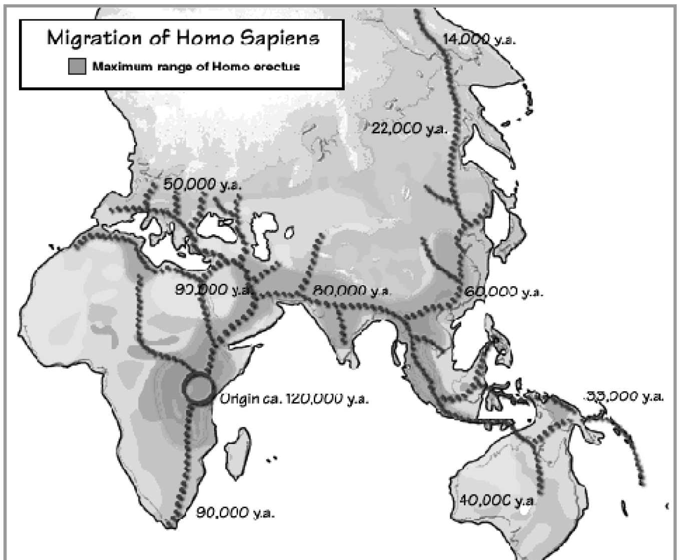
The genesis for the expansion, the so-called "BigBang" is speculative. It is conjectured that a singular event of massive energy must have occurred in space-time and over time evolved into the Universe we have inherited. The possible models for this singular event relate to "small space" physics that is typical of nuclear dimensions and elementary particle physics.

The size of things

Proton	10^{-15} meters
Hydrogen Atom	10^{-10} meters
Building	100 meters
Particle Accelerator	27 km
Diameter of Earth	12700 km
Diameter of Sun	1,400,000 km
Solar System	5,913,520,000 km (By Pluto's Orbit)
Milky Way	100,000 light years
Observable Universe	10 billion light years

2.0 HUMANITY AND THE URGE FOR EXPLORATION

Allow me to refer to the 2006 March issue of the National Geographic Magazine. The cover story reads "The Greatest Journey Undertaken" (slide 2.1)



The greatest journey undertaken

Humans have evolved from one form to another over a long period of time. The latest form, the Modern Man has a short history. We began approximately 200,000 years ago in mid-Africa. There is compelling evidence that there is an uninterrupted DNA trail to all native persons around the World.

It is observed (slide 2.1) that the trail of modern man from Africa has been more linear and more eastward. The journey to Australia is almost 20,000 km long. If human settlements had moved 100 m per year it would take 200,000 years to reach Australia from Africa. If instead of a linear trail humans had traveled more symmetrically in all directions (approximately 1.50 degrees fan-out) say in 200 directions we would still be 100 km out of Africa, perhaps no further than Egypt and the rest of the Earth unexplored.

It is clear that humans have a tendency for following the leader (herd mentality) and an almost linear trail has allowed us to populate the outer reaches on the surface of the Earth sooner. There was probably a survival pressure to move from Central Africa but once we moved, we kept moving. Could this not be partly curiosity and the urge to explore?

2.1 WHY EXPLORE: ARE WE HARD-WIRED TO BE CURIOUS?

What is the physiology of the brain that could explain curiosity over our lifetime? There are several empirical studies that show human impulses are based on biology. The major ones are self-preservation, bonding (gregariousness and sex) and the pursuit of resources (greed).

In order to survive, animals above the primitive level must understand the niche in which they live. In addition, they must discover any changes in that niche to be able to respond to those changes. The drive for survival requires that the individual should be concerned about the changes in the immediate vicinity. Those that will affect one personally are the most important. The most effective way to discover changes is to go looking for them. In a sense curiosity drives us towards exploration. Curiosity causes a tension within and exploration relieves.

The greatest advantage of curiosity is the increase in neurological connections it makes possible. Investigating the unusual creates new pathways in the brain. More the pathways, more the responses to stimuli, and greater the likelihood of a proper response to another novel situation. Curiosity strengthens these learned responses.

2.2 HISTORY OF THE EVOLUTION OF THE IDEAS OF SPACE

It is clear to us now, that to understand our surroundings; we have to know about matter and the space separating in between and beyond. The people of the ancient civilizations of the Tigris/ Euphrates valley, the Nile valley and the Indus valley may have appreciated these but no clear records are available. Most often the ancients thought in terms of mythological human like forms and figures as the cause and rationale for the events of this world. The dominance of such anthropomorphic thinking is a characteristic from the early days and only in the last two centuries, science has shown an alternative.

Historical records of the thinking of the Greek philosophers Thales (636-546 BC), Democritus (460-370 BC), Aristotle (384-322 BC) show a number of concepts expressed that touched on matter and space. Thales put forth the idea that the world arose from the waters. Water is the one and only source from which the world springs by condensation and evaporation. In his view something cannot issue from nothing and neither can it vanish into nothingness. He thereby denies the “creatio ex nihilo” the world’s creation out of a void.

2.2.1 GALILEO AND NEWTON AND THE SCIENTIFIC METHOD

The first observational ideas on matter and space came about in the early 1500’s. The method of science namely hypothesis, experiment, theory and experimental verification came to the forefront at this time. The astronomers: Copernicus (1473-1543) of Poland, Tycho Brahe (1571-1630) of Denmark, Johannes Kepler (1531-1630) of Germany, Galileo (1564-1642) of Italy, Newton (1642-1727) of England was the major scientific figures of this period. Through their observations and theoretical speculation they clarified the ideas on the orbits of planets around the Sun.

The scientific work of Galileo and Newton extended beyond astronomy. It is well known that Newton formulated the equation of motion of mass particles based on the experimental evidence gathered by Galileo. In writing the equations, Newton had to explicitly consider that motion was possible in any of a number of directions of space or a combination thereof.

2.2.2 PERCEPTION OF SPATIAL DIRECTIONS AND DIMENSIONS

How do we gather that there are at least 3 independent directions for space? The idea for this comes from geometry: the geometry of a line, of a surface, of a solid body. It is clear that if we are on a line we cannot explore a surface. Therefore we need to conceptualize that the geometry of a surface should have one more independent direction than that of a line. In the same way to describe a solid body we need one more direction than that of a surface. These ideas are perceptual and well understood by all.

Mathematicians took this a bit further. They represented the independent directions as different co-ordinate axis and showed any point may be described by a set of co-ordinates appropriate to the space. The word dimension is normally used to label the number of co-ordinates that are required to adequately represent a point in that space.

Since we can perceive lines, surfaces and solids we can show any of these can be described by three coordinates. This is captured in the well known statement, that we live and perceive in three dimensions.

The next question is: how should we represent physical phenomena in space. The mathematical description overtakes our physical perception and or intuition for a number of complex phenomena. In such cases the independent co-ordinates used to adequately describe the phenomena would define the dimension for the “space of the phenomena”.

For example the dimension for the physics of a simple mass-spring: it can be one-dimensional if it is constrained or six-dimensional if it is not constrained. There are obvious generalizations of this for an N-particle system.

3.0 THE EVOLUTION OF THE PHYSICS OF SPACE FROM THE TIME OF NEWTON

Newton wrote the equations for the motion of a point mass:

$$\frac{d\tilde{p}}{dt} = F$$

as referred to an inertial co-ordinate system.

In his equations, Newton implied the time ‘t’ is absolute for all observers. Inertial systems move with constant velocity w.r.t each other and have no acceleration.

In accordance with this equation an observer moving with a constant velocity will also represent the force in the same way, since acceleration is not affected by a constant shift in velocity.

The equation of motion is therefore invariant for observers on such inertial co-ordinate systems. The transformation to convert from one inertial system to another are referred to as Galilean transformations.

Every aspect of mechanics appeared well settled until when the equations governing the electromagnetic (EM) field were formulated in 1864 by Maxwell. Then new perspectives arose that contradicted with those that were implied by Newtonian Mechanics.

One of the exciting implications of Maxwell’s equations was the possibility that EM fields and light can propagate in free space at a velocity determined by

$$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

Maxwell's equations

Name	Differential Form	Integral Form
Gauss' Law	$\nabla.\tilde{D} = \rho$	$\int_S \tilde{D}.d\tilde{A} = \int_V \rho dV$
Gauss' Law for Magnetism (Absence of magnetic monopoles)	$\nabla.\tilde{B} = \rho$	$\int_S \tilde{B}.d\tilde{A} = 0$
Faraday's Law of Induction	$\nabla \times \tilde{E} = -\frac{\partial \tilde{B}}{\partial t}$	$\int_C \tilde{E}.d\tilde{l} = -\frac{d}{dt}\int_S \tilde{B}.d\tilde{A}$
Ampere's Law (with Maxwell's extension)	$\nabla \times \tilde{H} = \tilde{J} + \frac{\partial \tilde{D}}{\partial t}$	$\int_C \tilde{H}.d\tilde{l} = \int_S \tilde{J}.d\tilde{A} + \frac{d}{dt}\int_S \tilde{D}.d\tilde{A}$

This velocity depends on the permittivity and permeability of free space. Since these are constants of free space it meant all observers moving with constant velocity with each other would measure the same values and obtain the same computation for the speed of light. This was not in accord with the Galilean transformations.

(E field under Galilean transformation)

$$E(x,t) = E(x-ct)$$
$$E' = (x',t') = E(x,t) = E(x'+v_x t'-ct') = E(x'-(c-v_x)t')$$

3.1 THE SEARCH FOR ETHER

The fact that EM fields can propagate in free space was a surprise and was difficult to understand from the then mechanistic view point of Nature. It raised a number of issues and possibilities. Amongst these were:

1)The wave propagation to exist it must be in an elastic media: how could free space have such properties.
2)In free space the elastic media cannot have a density and yet support vibrations and hence wave propagation.
3)The whole of space must be filled by this special material labeled as Ether.
4)There should be a change of velocity of light as seen by observers on different inertial co-ordinate systems.

In 1887 Michelson and Morley conducted a sensitive light velocity experiment to detect the presence of the ether and the velocity change in light paths in two different directions. One path was along the orbital velocity of the Earth and the other was transverse to it. The experiment came with a null answer. These measurements effectively weakened the argument for the existence of Ether.

The equations of Maxwell, as mentioned earlier, did not preserve the same mathematical form when subjected to a Galilean transformation.

Electric field as modified by Galilean transformation

$$\frac{\partial^2 E}{\partial x^2} - \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2} = 0$$

$$\frac{\partial^2 E'}{\partial x'^2} - \frac{1}{c^2}\frac{\partial^2 E'}{\partial t'^2} - \frac{2v_x}{c^2}\frac{\partial^2 E'}{\partial x'\partial t'} - \frac{v_x}{c^2}\frac{\partial}{\partial x'}[v_x \frac{\partial E'}{\partial x'}] = 0$$

This indicated either Maxwell's equation were wrong or in the alternative the Galilean transform itself needs to be corrected if it was to preserve Maxwell's Equations. Einstein decided to take the latter route and searched for a transform of coordinate-axis that would ensure Maxwell's equations and consequently the constancy of the speed of light is preserved.

3.2 SPECIAL THEORY OF RELATIVITY

In 1905 Albert Einstein developed the Special Theory of Relativity (SR) to explain why a null result was obtained by Michelson Morley. Since experiments in free space confirm the constancy of the 'speed of light' for different inertial co-ordinate systems, it is clear that

i) The concept of ether is not necessary
ii) Time is not absolute
iii) Time is subject to the some transformation requirements:

$$x' = \gamma(x - vt),\ y' = y, z' = z, t' = \gamma(t - \frac{v}{c^2}x)$$
$$\gamma = \sqrt{\frac{1}{1-\beta^2}}, \beta = \frac{v}{c}$$

The above transformation of co-ordinates between the primed and non-primed inertial co-ordinate systems show that time is not absolute and is dependant on position and the state of motion. This brought about a major change in the concept of space and time. No more can they be thought as independent. Henceforth they became part of a 4 dimensional space-time continuum.

In recapitulating, it is clear that the ideas of SR were necessary, in order to ensure Maxwell's equations have the same form under co-ordinate transformations of inertial co-ordinate systems. That is, observers moving with constant relative velocity must see the same physics. Out of this requirement, the original Newton's equations got modified; specifically the momentum parameter had to be redefined.

Newton dynamic parameters as required by Lorentz transformation; SR have a modified form, some of these are:

$$\rho = \frac{m_o \mathrm{u}}{\sqrt{1-u^2/c^2}} \qquad \mathrm{F} = \frac{d\rho}{dt}$$
$$dW = F.dr \qquad P = F.u$$
$$P = \frac{dT}{dt} = F.u \qquad \frac{dT}{dt} = \frac{d}{dt}[\frac{m_0 c^2}{\sqrt{1-u^2/c^2}}]$$
$$T = \frac{m_0 c^2}{\sqrt{1-u^2/c^2}} + \text{constant}$$
$$E = T + m_o c^2 = \frac{m_0 c^2}{\sqrt{1-u^2/c^2}}$$
$$E^2 = p^2 c^2 + m_0^2 c^4$$

Maxwell's equations on the other hand remained unchanged. Some of the relevant equations imputing these can be gleaned from the accompanying set of equations.

$$F = q(E + \frac{1}{c} v \times B)$$
$$\nabla.B = 0, \nabla \times E + \frac{1}{c}\frac{\partial B}{\partial t} = 0$$
$$\nabla.E = \rho, \nabla \times B - \frac{1}{c}\frac{\partial E}{\partial t} = \frac{j}{c}$$
$$E_1^{'} = E_1, E_2^{'} = \gamma(E_2 - \beta B_3), E_3^{'} = \gamma(E_3 + \beta B_2)$$
$$B_1^{'} = B_1, B_2^{'} = \gamma(B_2 + \beta E_3), B_3^{'} = \gamma(B_3 - \beta E_2)$$

4.0 GRAVITY: NEWTON AND EINSTEIN

SR was a pure kinematic theory, mainly concerned with the transformation of co-ordinates between different observers and was driven by the need to preserve the constancy of the speed of light c amongst them.

Gravity was a physical effect between masses and Newton between 1666 and 1687 (Principia) had formulated an equation to describe this effect and in particular the motion of planets as affected by the Sun. Between 1905 and 1915 Einstein thought about gravitational effects and puzzled over a number of salient features of the Gravitational Law as proposed by Newton.

i) The mass m as used in the force equation of motion (inertial mass) is the same as used by Newton for gravitational attraction. This was verified by the experiments of the Hungarian baron Etvos in 1905.
ii) This implies, that all bodies of big or small mass, accelerate in the same way under gravity
iii) In view of the above, gravity and its effects, disappear under co-ordinate systems that accelerate as defined by the local gravity value at any point in space. That is gravity is transformed away in reference frames in free fall.

4.1 EQUIVALENCE PRINCIPLE

Based on the above, Einstein captured these ideas as a new physical concept: the Equivalence Principle (EP). The part that refers to mass only is referred to as the Weak EP. The part that refers to both mass and acceleration is referred to as the Strong EP.

By combining SR with Strong EP, Einstein in 1915 obtained the transformation laws for co-ordinate systems that have acceleration, this he referred to as the General Theory of Relativity (GR). There are a number of aspects about GR.

1) The metric tensor description used by Einstein allows a geometrical description of the space time continuum as affected by gravity.
2) In a space time continuum where gravity is absent, the metric tensor is simple and constant. It does not show any 4 D space curvature. In such regions SR transformations are valid.
3) In general GR has to be used where gravity effects are present and in such a case the 4D space curvature is non-zero.
4) The GR equations of Einstein relate the 4D space curvature to the (mass-energy density) energy-momentum tensor present at each location.

4.2 EINSTEIN'S FIELD EQUATIONS

Einstein Field Equations (EFE) may be written in the following form

$$R_{ab} - \frac{1}{2} R g_{ab} = \frac{8\pi G}{c^4} T_{ab}$$

$$G_{ab} = R_{ab} - \frac{1}{2} R g_{ab}$$

$$G_{ab} = 8\pi T_{ab}$$

Here R_{ab} is the Ricci tensor, R is the Ricci scalar, g_{ab} is the metric tensor, T_{ab} is the stress-energy tensor, and the constants are π (pi), G (the gravitational constant) and c (the speed of light).

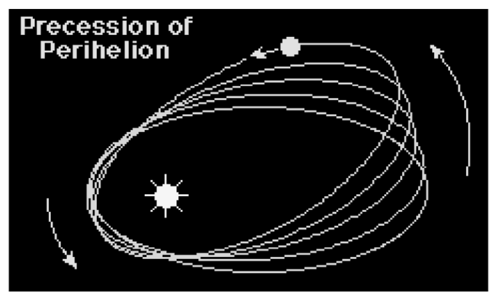
If the energy-momentum tensor T_{ab} is zero in the region under consideration, then the field equations are also referred to as the vacuum field equations. By setting $T_{ab} = 0$ in the full field equations, we see that the vacuum equations can be written as $R_{ab} = \frac{1}{2} R g_{abb}$. By reversing the trace of this equation, we get the precisely equivalent form $R_{ab} = 0$.

In the case of nonzero cosmological constant, the equation is $R_{ab} = \frac{1}{2} R g_{abb} - a g_{ab}$ (the constant is called the cosmological constant) for which the reversed trace form is $R g_{abb} = a g_{ab}$.

4.3 GENERAL THEORY OF RELATIVITY AND PREDICTIONS

There are a number of effects predicted by Einstein based on GR. They are all related to "large scale" space events. Some of these are:

1. The orientation of Mercury's orbit is found to precess in space over time, only part of this can be accounted for by perturbations in Newton's theory. There is an extra 43 seconds of arc per century in this precession that is predicted by the Theory of General Relativity and observed to occur (recall that a second of arc is 1/3600 of an angular degree). This effect is extremely small, but the measurements are very precise and can detect such small effects very well.



2. Einstein's theory predicts that the direction of light propagation should be changed in a gravitational field. Precise observations indicate that Einstein is right, both about the effect and its magnitude.
3. The General Theory of Relativity predicts that light coming from a strong gravitational field should have its wavelength shifted to larger values (a red shift) Once again, detailed observations indicate such a red shift, and that its magnitude is correctly given by Einstein's theory.
4. The electromagnetic field can have waves in it that carry energy and that we call light. Likewise, the gravitational field can have waves that carry energy and are called gravitational waves. These may be thought of as ripples in the curvature of space-time that travel at the speed of light.

4.4 IS SPACE EMPTY?

Amongst the questions that some of the ancient philosophers including Greek philosopher Thales raised was whether space can really be empty. That is space and the vacuum of space, is it nothing? It is obvious that when matters or gases fill a spatial volume, then that space is certainly not empty. But what happens if we evacuate all matter, including all vapors and gases: can then space be deemed empty.

The present evidence from Physics is that even vacuum has zero-point energy fluctuation in any volume of space. This comes about from Quantum Mechanics and the uncertainty relationship: $\Delta E \times \Delta t \geq \frac{h}{2\pi}$ where ΔE is the resolution in energy, Δt is the resolution in time, h is the planck's constant.

Moreover as is clear we have a variety of radiation processes propagating through space, these certainly can convert to mass or virtual particles (i.e. with small lifetimes) at any point in space and at any given time. This conversion between mass and energy is as predicted by Special Theory of Relativity.

It does appear then both Quantum mechanics and Relativity bedevil the possibility of even in imagination thinking of space being really empty. Even within the small volume of the atom, the space between electrons and the nucleus is not empty.

Perhaps further understanding of Nature would give us a new set of situations where this may have different answers.

5.0 SPACE EXPLORATION

We are now almost 50 years, beginning from the 1960's into space exploration. Over this period we have witnessed a number of space missions that have explored initially the Earth and subsequently the nearby planets of Mercury, Venus and Mars. Space probes have been sent to the Sun and latterly in 2006 to Pluto, the furthest of the known nine planets of the Solar system. Since the 1990's, the idea on Pluto being the ninth planet of the solar system was under review. It is now considered a dwarf planet.

Almost the greater majority of this activity has come from USA and Russia. The European space consortiums have participated only selectively. The need to go for space arises for a number of reasons. The first drive is to put in place civilian space platforms for communications, navigation, weather prediction, ground resource monitoring and surveillance. The second drive is for defense applications. The final drive is for scientific and technological reasons.

Although the USA and Russia have taken the lead in space, over time the rest of the world would become active participants under collaborative programs such as for example the International Space Station (ISS). The major constraint presently is the high cost of developing space facilities, such as satellite fabrication facilities and launch pads. The time frame to develop a specific space mission is typically between three to five years involving from hundreds to thousands of specialized technical personnel. In major countries where space agencies operate, be it NASA in USA, ESA in Europe, the count for personnel is between 10,000 to 50,000. The budget for major space programs like the Space Shuttle run in excess of US$100 billion over a program cycle of 20 years.

Apollo Program Source: http://en.wikipedia.org/wiki/Project_Apollo	$135 Billion (2006 Dollars) or $25.4 Billion (1969 Dollars)
Space Shuttle Source: wikipedia	As of 2005, $145 Billion
International Space Station Source: http://www.csa.int/csaHS/ESAQHA0VMOC_iss_0.html	For the period of at least 10 years, total cost 100 Billion Euros
Hubble Space Telescope Source: http://www.spacetelescope.org/about/faq.html	Currently estimated to be US$4.5 to 6 billion in addition to 593 million Euros

5.1 THE DEVELOPMENT OF SPACE PROGRAMS

The scientific and technical manpower that the USA depends on for its space effort is truly multinational. Young persons from all parts of the world go to the USA for education and in most cases do postgraduate work or get into employment. A small, but a significant number of the University research effort is related to space science. A number of employment positions in technology are in space related industries. Eventually a reasonable proportion of the young, from all over the World, gets to be fully engaged in major space programs.

The space program itself must have a mission or purpose. It starts off with a small group of scientists or a business organization or a department of the Government wanting to achieve a particular scientific task or setup a space facility or install a space system. The initial idea would be canvassed, explored and costed. After a period of persuasion, and examination of alternatives, it may either be aborted or supported. If the latter happens then a dedicated technical and management team would be put in place to draw up schedules, timelines, risks and costs. Once the program gets going it would be reviewed periodically, often quarterly, and in the early phase either a go or no go signal may be given. As any space program is of high cost, the question of sustainability and long term benefits do weigh in.

5.2 THE DEVELOPMENT OF HUMAN CAPACITY FOR SPACE MISSIONS

The world needs the development of extremely talented persons. Space effort is not possible without such talent and in equal measure dedication. Presently there is a crisis in the Universities in attracting the best brains to Science and Engineering. There are several easy and lucrative attractions for the young.

In part space programs carry with it a wonderment that draws the whole world together. Who would not know of the first men on the Moon, way back in 1969 or the spectacular achievement of the shuttle program and the tragic loss of the Challenger in the 1980's and Columbia very recently in 2003? Beyond these are the space probes to Mars, the Hubble optical telescope and the Chandra X-ray space platforms.

There is real science and precise technology in each and every one of these. Glamorizing such feats would be meaningful and would help to impart interest and enthusiasm in the young. Hopefully such effort would ensure continuity of the scientific base that the world has sustained over the last 500 years from the time of Galileo. Professor Stephen Hawking in a recent address at Hong Kong University called on mankind to be prepared to migrate, to other stars or planets for no one can be certain that the Earth continues to remain habitable.

5.3 SPACE AS THE ULTIMATE FRONTIER

Humankind has always looked upwards from the Earth to look for salvation. At least primitive tribes all over the World, who have been untouched by ideology, do so. Human civilization has given us a number of positive values however there are a number of areas where we do not truly know, yet are steadfast with our beliefs and prejudices. At one time we prayed to the Sun, the planets and to the Moon. From the knowledge we have gained through science and space exploration we know how limiting this was.

A pursuit of science and engineering would take us along to clarify some of the mysteries that excites us and quite often bedevils us. Questions such as to how life began on Earth, why do we age, why do we disease are major conundrums to yet to be solved. Equally what happened during the BigBang, what is the fate of our Earth or that of the Universe as a whole need scientific exploration and discovery?

In this sense space exploration will give us gains that cannot be costed for effort. We have started and we must keep going. For ultimately, space is the last frontier. ■

ADDENDUM
Synopsis

The perspective on space and in particular extra terrestrial or outer space has varied from ancient times. At one time it was held as a mystery to be feared. In some religions it is thought as the location for afterlife. In recent times scientific inquiry and the marvels of space engineering have helped to clarify the mystery. But more work remains to clarify the enigma of Space.

Scientific enquiry based on observation, hypothesis and theory poses the questions. Space experiments with sophisticated instruments placed both in outer space and on Earth help to validate hypotheses and the theories. Latterly the placing of such experiments away from the Earth and its atmosphere has become more beneficial and vital. It has become a need.

As part of this need Man has gone to the Moon, scientific probes have been landed on Mars and the International space station orbits the Earth. These and similar effort requires the training of space scientists, engineers, astronauts. It takes time, manpower and money. The quantums are large and perhaps a significant portion of the GDP of any country.

Why this endeavour should be undertaken is explored in this lecture. A survey of the major ideas on the science of space as well as the engineering aspects of space exploration would be outlined.

Questions on the intrinsic properties of space had intrigued scientists including Newton and Maxwell. The most significant clarification arose from the ideas of Relativity presented by Einstein. The question whether there could be any region of space which could be absolutely free of matter and energy is still open. Given that absolute zero degree Kelvin is still not attainable and that there exists a zero-point energy fluctuation of vacuum, as required by Quantum Mechanics, seem to point that space is not “empty”.

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PROFILE

Associate Professor K. Arichandran obtained his Bachelor of Engineering (Honours) degree in 1965 and Doctor of Philosophy in 1971 from the University of Malaya. He is a Professional Engineer registered with the Board of Engineers, Malaysia and a Senior Member of IEEE (USA).

Associate Professor Arichandaran started his career as a Tutor at the University of Malaya from 1965 to 1968, Assistant Lecturer from 1968 to 1971, Lecturer from 1971 and became Associate Professor in 1983. He was the Academic Visitor, Imperial College, London in 1973, Visiting Scientist, Massachusetts Institute of Technology, Boston, USA in 1979 and Academic Visitor, University of Sydney in 1986. He was Member of the University Malaya Senate from 1984 to 1990 and Dean, Faculty of Engineering, University of Malaya for 1989/1990. He was Member of the Board of Management, Centre for Wireless Communications (CWC), Singapore from 1996 to 2001 and Member of Radio Standards Advisory Committee (RSAC) of IDA from 1999 to 2002. He also served occasionally as reviewer of IEEE papers, PhD External Examiner and as Session Chairman and Session Organizer for conferences held in Singapore and overseas.

Since 1996, he has been involved with the development of Satellite Engineering facilities, designs and systems, including installation and commissioning of VHF/UHF/S-band ground station tracking facility and development of the X-Sat micro satellite space bus. He was also involved in the development of Syllabus for final year Digital Signal Processing course in 1994/95, final year Cellular Radio System Design course in 1995/1996, final year Stochastic Processes elective course in 2001/2002 and final year Satellite Engineering elective course in 2004/2005.

Associate Professor Arichandran has also published extensively in numerous overseas and local Journal and Conferences.