# PHYSICS IN LIFE AND THE END OF ALL THINGS

## An Inaugural Lecture

## Presented by

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The Vice Chancellor and Chief Executive,
The Deputy Vice Chancellors and other Principal Officers,
The Pro-Chancellor and Chairman of the Governing Council,
Members of the Governing Council (here present),
Deans of Faculty,
Former Inaugural Lecturers,
Directors of Institutes and Centres,
Heads of Departments and Administrative Units,
Distinguished Colleagues,
My lords Spiritual and Temporal,
Lions and Lionesses,
Ladies and Gentlemen.

## Prologue

It is with a heart full of gratitude to God and indescribable sense of fulfilment that I stand here today to deliver the 78th inaugural lecture of this great institution. Although I am one of the oldest serving professors in my faculty, I don't think there would have been a better opportuned time to deliver this lecture than today. From available records, this is the second inaugural lecture in Physics; the first was delivered by my distinguished colleague and friend, Professor (Mrs.) F. N. Okeke. In her lecture, we were told that Physics is life and life is Physics. I would like to complement that statement by saying that "Physics is everything but everything is not Physics". This and more you will be hearing from me today - what makes Physics a unique field of study!

The title of this lecture suggests two broad themes. The first theme involves utilization of basic principles of Physics in explaining certain issues of life. Three worlds of Physics are described to provide us with a glimpse of how some aspects of human experiences and activities (including beliefs) could be understood in terms of basic physical principles in each world. The purpose is to bring out my personal experience (based on mental processes by which I understand Physics) of how theoretical physicists think and to show (with every good intention) how real and exciting Physics can be and how miserable life could be without physics. Some biblical examples (e.g. the origin of sin and salvation together with life in the flesh and spirit, and the concept of hell and eternity) are used to make the lecture less boring and to bring out some deeper appreciation of what non physicists are missing.

The second theme to be developed here involves some research problems in astrophysics and cosmology which include; the origin, evolution and ultimate end of the universe. I must say that it is in this second theme that I did all the research that made me a professor. You will be hearing my contributions towards attempts so far made for a better understanding of the universe we inhabit in this lecture.

As part of the epilogue, I have attempted to answer the question "Is there life elsewhere in the universe?"

**What is Physics and what makes Physics so unique?**

Physics is a unique subject. No field of human endeavour has made as tremendous impact on human existence as we have found in Physics. I usually define Physics as a study of observations of natural phenomena and the laws that govern them.

Physics differs from philosophy and religion which are all theories and no practical and from Botany which is all practical and no theory. Creativity in Physics requires that theories must be confronted point by point with a number of independent experiments unlike in creative Arts.

Physics uses mathematics that differs from the ones employed in Engineering and Statistics. Engineering mathematics requires exact solutions while Statistics only deals with approximations (Statistics is the study of probabilities). In Physics, we seek both. Physics differs from Social Sciences in that we need logical and systematic approach to natural phenomena to understand the present and to predict future events. Actually, the beauty and strength of a good physical theory lies on its predictive power, which must be confirmed by observation (experiment). The Judiciary uses several sections and subsections of the law to try one single offence but one law of Physics can explain a number of natural events. Biology in general is a descriptive science but Physics is quantitative in addition. These illustrations simply emphasize the unique status of Physics among other fields of endeavour.

**Physics in Life Experiences**

Nature is composed of matter and energy. Mendeleev first constructed the Periodic Table which contains over a hundred elements, but each element is built up of more fundamental particles; electrons and nucleons (protons and neutrons). Particle physics has however firmly established the existence of sub nuclear particles (quarks and leptons) so that protons and neutrons are no longer regarded as elementary particles. Based on their masses, there are three generations of leptons (electron and electron neutrino, muon and muon neutrino, and taun and taun neutrino). There are also three generations of quarks (up and down, strange and charm, and top and bottom). Three quarks combine together to form baryons (e.g. protons and neutrons) and two quarks combine together to form mesons ($\Pi$, K, $\eta$, etc). Leptons combine with quarks to form atoms of chemical elements. An aggregate of two or more atoms form molecules. You and I are aggregates of molecules of different chemical elements.

Physics is usually studied in three scales or dimensions (worlds). The smallest scales correspond to the world of Quantum Physics, ranging from the size of the atom in Angstrom ($1A^0 = 10^{-10}m$) down to the size of the nucleus in fermis ($1f = 10^{-15}m$). At intermediate scales, distances are measured in metre which is fifteen (15) orders of magnitude larger than that in the quantum scales. This is the scale or world of Classical (Newtonian) Physics.

At largest scales, is the Relativity Physics, in which distances are measured in parsec $(1pc \approx 10^{16} m)$ about 15 orders of magnitude larger than that in Newtonian scale, and the velocities of objects approach that of light (3 x $10^8 m/s$).

Each of these Physics worlds is dominated by one or more of the four fundamental forces that rule the physical universe:

- **Gravity:** Gravity is a long range force that holds matter together and dominates other forces at largest scales. It is however, the weakest force in nature.
- **Electromagnetic Force:** This is a long range force that binds nucleons together with electrons to form atoms of chemical elements. It is about $10^{39}$ times stronger than gravity. Electromagnetic force is not as apparent in nature as gravity is in everyday life because matter appears neutral in nature.
- **Strong Nuclear Force:** The protons and neutrons are 'glued' together to form nuclei of atoms by the strong nuclear force. It is a short range force (< $10^{-15} m$) and is about $10^{41}$ times stronger than gravity.
- **Weak Nuclear Force:** This is a short range force (< $10^{-17} m$) and $10^{28}$ times stronger than gravity. It is the force that is responsible for the conversion of neutrons into protons during radioactive $\beta$-decay of the nucleus.

## The World of Quantum Physics

Quantum Physics was developed by Max Planck (1858 - 1947) and Albert Einstein (1879 - 1955) to explain some observational results/experiments that could not be understood in terms of the prevailing classical mechanics which appeared to have been fully developed at the end of the 19th century. This modern Physics is based on the law of objective probability and one of its unique aspects is that nature is quantized i.e. physical quantities can take values that are a multiple of some fundamental value. Some of the basic concepts of quantum mechanics together with my personal interpretations/understandings are discussed below.

- **Uncertainty Principle and Commutation Relation.**

As mentioned above, quantum mechanics was established based on the principle of indeterminacy as opposed to the law of determinism of classical mechanics. This follows from the Heisenberg's uncertainty principle which, for position ($x$), and momentum ($p$) of a particle, is given by: $\Delta x \Delta p \geq \frac{\hbar}{2}$ ($\hbar$ represents Planck's constant). In other words, some physical quantities can be mutually exclusive meaning that they cannot be measured simultaneously to any arbitrary precision – a precise knowledge of one canonical variable precludes a precise knowledge of the other. In terms of wave-particle duality in nature, any attempt to determine the particle properties will automatically eliminate any possibility of simultaneously observing any aspect of the wave-like properties. This is the principle of "Onye na enyo, isi ya anaputa." The more you peep, the more you are likely to be seen.

- **Compatible and Complementary Variables**

Observable parameters obeying the uncertainty principle are called complementary variables (as opposed to compatibles). We can write the uncertainty principle using the canonical commutation relation (based on Poisson bracket notation) $[x_m, p_n] = i\hbar\delta_{mn}$ and $[x_m, x_n] = [p_m, p_n] = 0$. This first expression is valid for complementary variables while the second holds true for compatibles. Two physical observables are said to be compatible if the operators representing them have a common set of eigen functions.

The concept of commutation relations shows that unlike algebraic variables, quantum mechanical operators do not, in general, commute. Actually, compatibility relation holds for non degenerate cases; $\boldsymbol{A\psi_n = a_n\Phi_n}$ provided that $\boldsymbol{a_n \neq a_m}$ for all $\boldsymbol{n \neq m}$**.** However, in degenerate systems in which two or more eigen functions of the same operator have the same eigen value (i.e. different modes of vibration have the same frequency), the commutation relation does not necessarily hold. The degree of degeneracy is important in determining the properties of a system. For strong degeneracy, both the energy and momentum of the system are independent of temperature.

Marriage is a bound system and because degeneracy is a fact quite common of physical systems, we expect that complementarity principle should be stressed more in marriage than the compatibility principle. As a matter of fact, the Pauli's exclusion principle states that no two electrons occupying the same state should have all quantum numbers equal (at least, the spin must be anti-parallel). Complementary traits are expected to provide a source of strength to marriage relationship and should not be regarded as weak points.

- **Wave Functions and Operators**

In quantum mechanics, we assume that the wave function $\psi_n$ contains all the properties that define the $n^{th}$ state of the particles and use it to obtain the expectation values of the Hamiltonian and other operators. One way of achieving this is by introducing the raising (or creation) operator $\boldsymbol{a}^+$ and annihilation (or lowering) operator $\boldsymbol{a}$. In general, these two operators can be written in Dirac formalism to give

$$\boldsymbol{a}^+ / \psi_n \rangle = \sqrt{\hbar\omega(n+1)} / \psi_{n+1} \rangle$$

(1)

and

$$\boldsymbol{a} / \psi_n \rangle = \sqrt{\hbar\omega n} / \psi_{n-1} \rangle .$$

(2)

Here $\boldsymbol{a}^+$ and $\boldsymbol{a}$ are used as Hamiltonian operators and $\hbar\omega$ corresponds to the energy eigen value. An operator generally operates on a function and makes it something else. There are several such operators in nature – things that have brought about both positive and negative influences in the society. These include hard drugs, peer group influence, spiritism/occultism, etc. For instance, when a child is left to negative forces, he/she becomes something else and there are a lot of such influences in schools and society.

The two equations show that successive application of $\boldsymbol{a}^+$ to $\psi_n$ raises its state in a step-wise fashion while successive application of $\boldsymbol{a}$ indicates the reverse. In particular equation (1) shows that if $n$ = 0, $\boldsymbol{a}^+ / \psi_0\rangle = \sqrt{\hbar\omega} / \psi_1\rangle$. In other words, the zeroth point energy is not zero, meaning that something can be created out of nothing! This is simply the creation process in Genesis chapter one. Thus, a quantum world is where something can be created out of nothing. This is the realm of creative faith, which is the substance of things hoped for, the evidence of things not seen; through faith, we understand that the worlds were framed by the word of God, so that things that are seen were not made by things which do not appear (Heb. 11: 1, 2). We are admonished in Mark 11: 22 – 24, "…..Have faith in God. For verily I say unto you, that whosoever shall say unto this mountain; Be thou removed, and be thou cast into the sea; and shalt not doubt in his heart, but shall believe that those things which he saith shall come to pass; he shall receive whatsoever he saith. Therefore, I say unto you, what things soever ye desire, when ye pray, believe that ye receive them, and ye shall have them". Thus, "….Death and life are in the power of the tongue; and they that love it shall eat the fruit thereof (Prov. 18: 21)". There is creative and destructive power in the tongue.

Equation (2) gives us the origin of sin and the definition of temptation. In the Garden of Eden, the Devil applied the operator $\boldsymbol{a}$ on Adam and he fell into sin (a type of potential well with infinite walls). Temptation therefore implies an application of $\boldsymbol{a}$ to lower the moral state of man. The Holy Spirit is given to help raise our fallen human state through application of $\boldsymbol{a}^+$. This is the essence of having an altar - a place of spiritual trafficking where covenants are serviced. A man without an effective altar labours under the influences of neighbouring altars which may be releasing $\boldsymbol{a}^+$ or $\boldsymbol{a}$. Here, the law of substitution "The righteous is delivered out of trouble and the wicked cometh in his stead (Prov. 11: 8)" is upheld.

- **Potential Barrier Penetration**

The Schrödinger equation, $\frac{d^2\psi}{dx^2}+\frac{2m}{\hbar^2}(E-V)\psi=0$, gives the proper description of quantum mechanical systems. The solution to this second order linear differential equation leads directly to the quantization of energy for bound systems where the wave function must vanish at the boundaries.

For free particles ($V = 0$), the energy levels are not quantized but rather they form a continuum. Classically, if $V > E$, a particle incident on a barrier can only be reflected. In quantum mechanics however, the particle can tunnel through the barrier (barrier penetration). A typical example is the $\alpha$-particles which emerge from the atomic nucleus with energies less than those needed to overcome the combined effect of the strong nuclear and electromagnetic forces.

Man is always physically limited once $V > E$, i.e., he cannot overcome his potential barriers. But this is as far as his physical body is concerned, a number of things that are impossible physically have been known to be possible in the realm of the spirit. For example, we have traveled through space and closed doors without inhibitions in our dreams. Christ was able to appear before His disciples at the upper room, with doors and windows shut after his resurrection (Jn. 20:19). Philip in Acts 8 was caught away from the Ethiopian eunuch, thus overcoming the law of gravity. This is also the principle behind witchcraft.

- **De Broglie Relation**

The de Broglie equation relates particle and wave properties through $p=\frac{h}{\lambda}$ ($\lambda$ is the wavelength and $h$, Planck's constant); i.e. it ascribes a wave property to particles - the wave-particle duality. This equation is also used to define the boundary between wave and particle nature of matter. The wave- particle duality places a limitation on the precision with which we can determine all the properties of a particle.

In the same manner, the human soul relates the physical and spiritual properties of man – the body (flesh) - spirit duality of man. This body – spirit duality places limitations on human characteristics. “The natural man does not understand the things of the spirit of God for they are foolishness towards him, neither can he understand them because they are spiritually discerned” (1 Corinthians 2: 14). That is why Paul wrote in Galatians 5:16 -17; “This I say then, walk in the Spirit, and ye shall not fulfill the lust of the flesh. For the flesh lusteth against the Spirit and the Spirit against the flesh: and these are contrary one to the other: so that ye cannot do the things that you would”. Thus, the battle for the mind is quantum in origin. This is why the Bible says in Proverbs 4: 23 “Keep thy heart with all diligence; for out of it are the issues of life”.

## The World of Classical Mechanics

Classical mechanics was developed by Isaac Newton (1642 - 1727). Here, time is universal and space Euclidean: bodies can be located at a point at any given time. As time evolves, everybody moves along a definite path which can be described by a smooth curve in some coordinate system. The properties of matter are governed by averages over aggregates of atoms and molecules. I call this world ordinary because it is where ordinary people do their businesses; ordinary level students do their geometries; Pythagoras theorem, cosine and sine rules and other trigonometric functions are very valid.

## The Law of Absolute Determinism

Unlike, the quantum world, the state of any system can be absolutely determined based on laws of motion once the initial conditions are fully specified à priori. This is the law of objective determinism. Hence, we can specify the state of a system $\xi$ by eight quantities; three spatial coordinates, three component momenta, energy and time i.e. $\xi(x, y, z, p_x, p_y, p_z, E, t)$ or simply

$\xi(r, p, E, t)$. The evolution of $\xi$ can be absolutely determined at any instant once the initial state $\xi_0 = \xi\ (r_0, p_0, E_0, t_0)$ is known. If the eight physical parameters are independent, we have an evolution of $\xi$ based on eight equations whose physical meanings become evident once $\xi$ is defined. For example if $\xi$ is the Hamiltonian ($H(r,p,t)$), then from Hamilton's equations of motion we have: $-\frac{dH}{dr} = \dot{p}$ (generalized force); $\frac{dH}{dp} = \dot{r}$ (generalized velocity) and $\frac{dH}{dt} \equiv power$. In this example' r represents the generalized coordinates. However, the eight parameters are not in most practical cases, all mutually independent. In Cartesian coordinates for example, we have $\frac{dr}{dt} = v$ (velocity), $\frac{dp}{dt} = f$ (impulse) $\frac{dE}{dt} = power$ and $\frac{dE}{dt} = force$. Now $\frac{dp}{dx} = ?$ (has no physical meaning, perhaps due to complementarity principle). Nature in this realm is dominated by laws of non-relativistic mechanics and thermodynamics.

- **Newton's First Law of Motion**

The first law is the law of inertia, which states that everybody continues in its state of rest or uniform motion unless impressed forces act on it. This law explains why adults find it difficult to change both their attitudes and their perceptions. Over the years, an adult develops inertia or resistance to change independent of the nature of the impressed force.

- **Newton's Second Law of Motion**

The second law is the force law which is a second order linear differential equation – the state of rest or motion of a system can only be altered by introduction of a force. Simply put, $F = \frac{d}{dt}(mv)$. Here m is referred to as the inertial mass of the body and represents the constant of proportionality between force **F** and acceleration ($\frac{dv}{dt}$). We need force to change the state of our inertia and that explains why we need sanctions to change some habits once formed.

- **Newton's Third law of Motion**

The third law is the law of equality between action and reaction. This is equivalent to the law of retribution and explains why the Golden Rule says "Do unto others as you would like others do unto you"; and also, the law of sowing and reaping, "Whatsoever a man sows, that shall he also reap (Galatians 6:7)".

- **Hooke's Law**

Hooke's law is the law of deformation, which describes the maximum load a mechanical system can sustain without breaking or causing a permanent strain.

In this ordinary world where ordinary people do their business, one is faced with stress of varying magnitudes and once one's elastic limit is exceeded, irreparable physical and emotional disorders can follow including stroke and death. Temptations also come in form of pressure and once our elastic limit is exceeded we succumb. That was the case of Samson in Judges 16. "And it came to pass, when she pressed him daily with her words, and urged him, so that his soul was vexed unto death; That he told her all his heart… (Judges 16: 16 - 17)". He told her all his heart- both the necessary and the unnecessary. Men should beware of women intrigues! "It is better to dwell in a corner of the house top than with a brawling (cantankerous) woman in a wide house (Prov. 21: 9)". Marriages are today producing all manner of physically and emotionally deformed men and women because of problems that exceed their carrying capacities.

- **The Law of Entropy**

The second law of thermodynamics is based on the concept of entropy - nature flows in the direction of increasing entropy (disorder). Because internal forces do not vanish, physical systems are not always at equilibrium (i.e. entropy, $\Delta S > 0$ always). This means that order does not come naturally - work is needed to enforce law and order, otherwise the world will be in chaos. To this end, "…..a child left to himself bringeth his mother to shame" (Prov. 29: 15).

It should be noted that the amount of energy released in phase transitions (e.g. latent heat of fusion or vapour) is enormous with a sudden increase in entropy. For example, the heat required to melt a unit mass of ice at 0℃ is equivalent to the amount of energy required to raise the temperature of the same mass of water from 0℃ to its boiling point at100℃. This explains why the change involved in transition into adolescence has brought untold hardships in many homes due to the enormous amount of physical and emotional energies involved. In fact, each new stage in child birth and upbringing presents its set of challenges, some of which can be so tempestuous that some parents get tired and would want to give up. No wonder Paul wrote to the Galatians "….My little children of whom I travail in birth again until Christ be formed in you (Gal. 4: 19)".

Because internal forces do not vanish, human desires are insatiable. These internal forces may come from expectations from family, friends, society and even church. When these forces are not controlled they may lead to a large increase in entropy and a good example of the physics of chaotic phenomena is heart attack. Many cases of insomnia come from increase in the internal energy of the human system. The process of ageing (gerontology) is also controlled by the law of entropy.

## The World of Relativistic Mechanics

In the relativistic world, there is no absolute motion; everything is relative. The special theory of relativity is based on two postulates enacted by Albert Einstein in 1905; the principle of relativity and the principle of the constancy of the speed of light.

### ➢ The Principle of Relativity

The principle of relativity states that the laws of physics are the same in all inertial frames. This implies that the laws of physics are absolute, universal and the same for all inertial observers.

Invariance of Newton's laws of motion with respect to transformation between frames of reference in uniform motion with velocity $v$ in the $x$ - direction demands that $x' = x - vt$, $y' = y$, $z' = z$, and $t' = t$. From Newton's second law of motion, $\ddot{x}' = \ddot{x}$, showing that forces are the same in all inertial frames. This is known as Galilean transformation. In the relativistic regime, the transformation between the frames of reference in relative uniform motion is given by the Lorentz transformation:

$x' = \gamma(x - vt)$, $y' = y$, $z' = z$ and $t' = \gamma\left(t - \frac{v^x}{t^2}\right)$, where

$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$ is the Lorentz factor. Here again, the invariance of Newton's second law is upheld, i.e. $\ddot{x}' = \ddot{x}$. The principle of relativity thus gives us a means of expressing the laws of physics in different frames of reference and the laws that hold for one inertial observer must hold for any other inertial observer.

- **The Principle of Constancy of the Speed of Light**

This postulate states that the speed of light in free space has the same value $c$ for all observers independent of their relative motion. That is to say that light moves at speed $c$ in all inertial frames. This is contrary to Galilean transformation which would give different velocities to different observers. The speed of light does not change with direction of travel.

**Implications of Special Relativity**

There are three fundamental consequences of the special theory of relativity; measurement of distance, time and mass depends on the velocity of the observer. As velocity increases, distance becomes shorter (length contraction), clocks slow down (time dilation) and masses increase ($m = \gamma m_0; m_0 \equiv restmass$).

This means a new consideration of the fundamental nature of space and time.

- **Time Dilation and Length Contraction**

This new consideration of the fundamental nature of space and time was first considered by Moses in Psalm 90: 4 and reaffirmed by Apostle Peter in 2 Peter 3: 8. "A thousand years to you are like one day". This clearly states that measurements of length and time intervals are different for different observers in different inertial frames of reference. "For my thoughts are not your thoughts, neither are your ways my ways, saith the Lord; for as the heavens are higher than the earth so are my ways higher than your ways and my thoughts than your thoughts (Isaiah 55: 8 - 9)". God's time in the frame of heaven is different from man's clock on earth. As an illustration, let us do a back of envelope calculation of how many years have elapsed in the time of heaven since Christ left the earth. Let us assume that heaven is somewhere within our galaxy about 1 light year ($1Lyr$) away (which is just the distance to the nearest star) and that Christ left with a speed of $0.99999998c$ (the number of significant figures corresponds to the precision to which $c$ has been determined). He measures his distance as,

$$d' = \frac{d}{\gamma} = 1 \times \sqrt{1 - 0.99999998} = 1.3 \times 10^{-4}\, Lyrs\,.$$

He also measures His time to be $t' = \frac{d'}{v} = \frac{1.3 \times 10^{-4}}{0.99999998} \approx 1.3 \times 10^{-4}\, yrs = 0.5 days\,.$

On earth, the distance is still $1Lyr$ but we measure the time to be $\frac{d}{v} = \frac{1}{0.99999998} \approx 1yr$ Hence 1 day in heaven will be equivalent to $\frac{1}{0.5} = 2yrs$ on earth. Christ left the earth about 2,000 years ago. This is equivalent to 1000 days ≈ 3yrs in the frame (clock) of heaven. People don't grow old in eternity! Jim Reeves, the popular musician, calls it a land where we will never grow old.

Actually, the statement made by Moses and Peter requires a time dilation and length contraction factor of about $2.76 \times 10^{-6}$ which is about two (2) orders of magnitude higher than the current precision to which *c* is determined. Also, our assumption that heaven is somewhere in our galaxy could be wrong. However, our illustration clearly indicates that relativistic mechanics is a tale of two worlds in which both observers in relative motion measures the same speed of light (*c*) and uses the same physics but their measurement of distances and times are different.

## General Theory of Relativity

Special relativity as described above is restricted to uniformly moving observers but not accelerated motion. Newton's law of gravitation shows that gravity accelerates objects in gravitational fields. There is therefore need to generalize the theory to include the effects of gravity (accelerating frames). This generalization is known as Einstein's Theory of General Relativity. Actually, it took Einstein eight years to develop this formulation after his theory of special relativity.

In general relativity, gravity (which is the dominant force at largest scales), curves space and light. Space and time are unified together, and mass and energy are equivalent ($E = mc^2$).

The implication of the above is that the geometry of space time is non-Euclidean which is to say that the shortest distance between two points is not a straight line but a geodesic, the sum of the angles of a triangle is not always$180^0$. This shows that Pythagoras theorem, cosine and sine rules are all approximations.

- **Black Holes and Concept of Eternity**

In Newtonian physics, the velocity of escape of a body (e.g. a rocket or space shuttle) from the surface of the earth is $v_{esc} = \sqrt{\dfrac{2GM}{R}} = 11.2$ km/*s*, where *M* and *R* are the mass and radius of the earth, and *G* is the universal gravitational constant.

Now, suppose the escape velocity equals the velocity of light (i.e. $v_{esc} = c$), we can write $R_s = \frac{2GM}{c^2}$. Here $R_s$ defines the event horizon and is called Schwarzschild radius. Actually, the Schwarzschild metric (space-time interval) for the curvature of space-time (in spherical co-ordinates, $r$, $\theta$, $\varphi$) near a point mass is

$$ds^2 = \left(1 - \frac{R_s}{R}\right)dt^2 - \left(\frac{c^2}{1 - \frac{R_s}{R}}\right)\left[dr^2 + r^2 d\theta^2 + \sin^2 \theta d\varphi^2\right]$$

(3)

Now, for time-like event, $ds = d\tau = \left(1 - \frac{R_s}{R}\right)^{1/2} dt$, where $d\tau$ is the proper time. The frequency is $\nu_o = \left(1 - \frac{R_s}{R}\right)^{1/2} \nu_e$ and redshift $z = \left(1 - \frac{R_s}{R}\right)^{-1/2} - 1$.

Here the subscripts $o$ and $e$ represent observed and emitted respectively.

- **The Event Horizon**

The Schwarzschild radius defines the event horizon; no external observer can see beyond that horizon. That is to say that all events occurring at distance $R < R_s$ are not visible to the outside observer and also anybody within this radius is gone forever. $R_s$ therefore, mark a point of no return and any object that has this radius becomes a black hole. It is called a black hole because neither matter nor light can escape from it. To form such an object requires that matter be compressed to especial density such as when a massive star 'dies'.

Now, as $R \to R_s$, $t \to \infty$ and $z \to \infty$, so that light signal cannot propagate beyond $R_s$; at $R_s$, light rays bend backwards.

The implication is that the powerful gravity of the black hole twists space and time around it so that clocks slow down as they approach $R_s$ and appear to stop at $R_s$. At this point time changes into eternity. Once inside $R_s$, the speed exceeds the speed of light and nothing (not even light) can escape, i.e. no travel or communication with the outside world is possible. This is why at death; man goes eternally on a journey of no return.

- **Hell Fire**

Hell fire is illustrated in the story of the rich man and Lazarus as a place of torment in flame (Luke. 16:5). Actually, a person falling into a black hole sees outside clocks ticking faster and visible photons blue shifted towards x-rays and $\gamma$-rays i.e. rains of very high energy photons become unbearable. This is hell. Classical General Relativity tells us that a black hole can grow in size and mass (hell can enlarge itself, Prov. 27: 20) and can last forever (nothing gets out once inside). Even where a black hole evaporates through Hawking radiation due to quantum effects, the rate is so slow that it would take about $10^{63}$ years for a black hole of three solar masses to completely evaporate. This is more than 50 orders of magnitude when compared with the present age of the universe.

**Astronomy and Astrology**

Before I start with the second theme of my lecture which has to do with the subject of astrophysics and cosmology, let me quickly differentiate between astronomy and astrology which are often confused, especially among lay people. Astronomy is the scientific study of stars, planets etc while astrology is the belief that the appearance of stars (or constellations) and planets in the sky governs human fate and activities on the earth.

**Cosmology and Physics**

The ancient Greeks believed that the earth and its human population were at the centre of the cosmos but it was not until early 1500s that Copernicus proposed the heliocentricity of the universe. This earned him serious opposition and sanctions from the church authorities. The use of telescopes in the seventeenth century revealed that our sun is one of the $10^{11}$ stars in our Milky Way galaxy and there are about $10^{11}$ of such galaxies in the universe and each having as many stars as our galaxy. The Milky Way belongs to a concentrated group of galaxies called the local group. There are clusters of galaxies that contain up to 1,000 galaxies and super clusters of galaxies. The galaxies form the building block of the universe and our location on earth or sun or Milky Way galaxy does not place us at any privileged position.

Cosmology deals with the application of physics to the largest possible scales of the universe, including its origin, evolution and future.

**The Big Bang Model**

Today almost all astronomers believe that the Big Bang model (proposed by Gamow in 1946), which states that the universe started from a very hot dense state at time 0.01 seconds and expanded with time till today, about 15 billion years later, is the correct theory that describes its origin and evolution. The Big Bang model is usually described based on three observationally consistent assumptions.

- **Einstein's Law of Gravity**

The theory of general relativity which tells us that the global geometrical properties can be determined by the total density and energy content of the universe is the valid theory to describe Physics on cosmological scales.

- **The Cosmological Principle**

This states that the universe is isotropic and homogeneous (locally, it appears lumpy but at cosmological scales, it appears the same to all observers in all directions). This is also known as Copernican principle.

- The third assumption states that the energy-momentum tensor of the universe is well-approximated by that of a perfect fluid.

**The Triumphs of Big Bang**

There are compelling observational evidences that support that big bang actually occurred.

- ***Expansion of the Universe***

The expansion of the universe was discovered by Edwin Hubble in 1929. This shows that the galaxies are receding from each other at a speed that is proportional to their distance of separation. In other words, the galaxies are moving away from each other as the universe expands. Stated mathematically, $v = Hr$ (where $H$ is the Hubble's constant).

- ***The Microwave Background Radiation* (*MWBR*)**

The microwave background radiation (MWBR) or cosmic background radiation (CBR) was discovered by Arne Penzias and Robert Wilson in 1965, which has an isotropic black body spectrum corresponding to 2.7 K. The results obtained from the Cosmic Background Explorer (COBE) in 1992 have confirmed that the irregularities in the spectrum led to the formation of structures in the universe.

- ***Abundance of Light Elements***

The primordial nucleosynthesis shows that the abundances of light elements D, $^3$He, $^4$He and $^7$Li are in the ratio predicted by the Big Bang model. Heavier elements were synthesized in stars.

**The Failures of Big Bang Model**

Despite the robust success of the Big Bang model outlined above, there are still some observations and fundamental questions about the initial conditions of the universe left unexplained and unanswered by the Big Bang theory. These unsolved problems are outlined below.

- ***The Horizon Problem***

The horizon problem arises from the isotropy of the MWBR. Radiation from the opposite sides of the sky appears to be in thermal equilibrium (at the same temperature) whereas there has not been enough time for the two regions to have interacted with each other due to finite nature of the speed of light. It can be shown that any two regions separated by more than $2^0$ would not be causally connected.

- ***The Flatness Problem***

Why is the present density of the universe so close to the closure value i.e. the amount required to make the universe spatially flat? This is a serious problem because it seems coincidental that of all the possible universes we could obtain from Big Bang, the present universe appears nearly flat. Actually, from equation (4), if $\Omega = \Omega_m + \Omega_\Lambda > 1$ it would grow as the universe expands and becomes infinite when gravity overpowers expansion. On the other hand, if $\Omega < 1$, it decreases as the universe expands and would have become zero by now. Each of these scenarios has far reaching implications for the universe: the universe could have either recollapsed or the expansion would have been so rapid that structures would not have formed. In other words, Ω = 1 is an unstable critical point and yet, the value of Ω today appears so close to 1. It therefore follows that, it is only when Ω = 1 that it remains 1 for all times. It has been shown that for Ω to be within an order of magnitude or 1 today (i.e. from 0.1 to 10) requires an accuracy of one part in $10^{59}$ i.e. $\Omega = 1 \pm 10^{-59}$.

- ***The Relic Problem***

Did the early universe contain equal number of matter and anti-matter? If the answer is yes, where are the anti-particles today? One of such particles is the magnetic monopole proposed in the Grand Unified Theory (GUT).

**Inflationary Paradig**m

In 1981, Alan Guth combined general relativity and quantum mechanics (Physics at largest and smallest scales) to solve the unsolved problems of the Big Bang model. He showed that a universe totally empty of matter could be unstable and decay spontaneously by creating pairs of particles until it produced the hot dense state that we call Big Bang.

He reintroduced the Einstein's cosmological constant (which Einstein had earlier called his greatest blunder) and showed that it was needed for the universe to be created. The cosmological constant presupposes that the vacuum consists of a constant energy density and a negative pressure which causes the universe to expand exponentially. This is called inflation - an era during which the universe expanded exponentially, $R(t) = \exp(Ht)$.

Inflation explains how on observable scale, the universe appears to be homogeneous and isotropic as shown by the MWBR. Because the scale factor grows exponentially, a sub-horizon sized region which was originally in thermal contact was 'inflated' to become larger than the presently observable universe. This explains the horizon problem.

Also, at inflation, space became stretched and became flat and the curvature constant, $k = 0$. This explains the flatness problem. In addition, the exponential expansion of the universe during inflation could dilute away any relic particle thereby solving the relic problem. During the inflation which lasted from $10^{-34} - 10^{-32}$ seconds, the universe expanded by a factor ~ $10^{30}$!

**The Cosmic History of the Universe**

The universe is believed to have passed through different epochs or era (time periods) as it expanded and cooled since Big Bang till now. The temperature scales with the scale factor of the universe as $\frac{1}{R(t)}$ and redshift as ~ $(1 + z)$ so that the earliest stages could be extremely hot. For the purposes of this lecture, I will divide the thermal history of the universe unto five different epochs; the Planck epoch, the hadronic epoch, the lepton epoch, the radiation epoch and the matter epoch.

- **The Planck Epoch ($T > 10^{26}$K; $0 \leq t \leq 10^{-43}$sec)**

The physics of the Planck era is not known but open to speculation. It is believed that the four forces that rule the universe (gravity, electromagnetic, weak- and strong-nuclear forces) were united into one single superforce at this epoch, which was dominated by quantum cosmological effects. However, we do not have an adequate physics that can combine gravity and quantum mechanics (Theory of Quantum Gravity).

The fluctuations of temperature ($\frac{\delta T}{T} \approx 10^{-5}$) observed in the MWBR by COBE is believed to have originated during the Planck era and later modified during inflation ($10^{-35}$ seconds after Big Bang). Particle physicists believe that gravity separated from the other three forces (electromagnetic, strong- and weak nuclear forces, which were still indistinguishable) in the Grand Unified Epoch. In the Grand Unification Theory (GUT), strong, weak and electromagnetic forces are unified so that only two forces ruled the universe; gravity and GUT. The GUT era ended at $T \sim 10^{26}$ K and $t \sim 10^{-10}$ seconds. Later, during inflation, as a result of phase transition, electroweak force separated from the strong-nuclear force. Three forces, gravity, strong and electroweak forces, now ruled the universe. As the universe expanded and cooled, the temperature dropped to a level where the electroweak forces decoupled and we have the four forces that now rule the universe. This took place at the end of inflation.

- **The Hadron Era ($10^{12} < T < 10^{15}$K; $10^{-10} < t < 10^{-6}$sec)**

The hadron era corresponds to the creation of baryons and anti-baryons (the most massive elementary particles) from photon - photon collisions. Hadron is a technical name for bound state of quarks (either baryons that consist of three quarks or mesons that consist of a quark and anti-quark), which we have earlier seen to constitute the fundamental particles that build up protons and neutrons. Baryons generally mean heavy particles and it is believed that all heavy elementary particles were created during this epoch, through strong interactions.

As the universe continued to expand and cool, the pair creation, $\gamma + \gamma \rightarrow p + \overline{p}$ (i.e. proton + anti-proton) and/or $\gamma + \gamma \rightarrow n + \overline{n}$ (i.e. neutron + anti-neutron) continued as long as the thermal energies of photons exceeded the rest mass energy of the particles created ($KT >> m_o c^2$). At the same time, there was pair annihilation (particle + anti-particle $\longrightarrow \gamma$). This dynamical process of pair creation and annihilation dominated the early universe, and the particles and radiation were in equilibrium. The theory that tries to explain why there is more matter and rarely any anti-matter in the present universe is known as baryogenesis, which we have earlier seen as relics problem.

- **The Lepton Era ( $10^9 < T < 10^{12}$K ; $10^{-6} < t < 10$ sec)**

This is the light particle era when particles with small mass were created. As the expansion and cooling continued, the wavelengths of photons continued to stretch, thereby lowering the photon energy till $KT < m_o c^2$ so that baryon pair creation stopped. Nevertheless baryons continued to combine together to produce photons, and thus fell out of equilibrium with radiation.

Although, the universe was, at this stage, too cold for photons to produce hadrons, it was hot enough to produce leptons (electrons, positrons, muons and neutrinos), $\gamma + \gamma \rightarrow e^- + e^+$. In other words, photon energy was still above the rest mass energy of electrons (leptons). The leptons are now in equilibrium with radiation, only neutrinos decouple. Also, neutrons decay through the weak interaction, to form protons and electrons; $n \rightarrow p + e^- + \gamma$, leaving an excess of protons over neutrons, which is important for the epoch of nucleosynthesis. This relative abundance of neutrons and protons is held in equilibrium by the weak nuclear interaction.

- **The Epoch of Primordial Nucleosynthesis ($10^8 < T < 10^9$K; $10 < t < 10^3$sec)**

As the expansion and cooling process continued, protons and neutrons fused together to form deuteron, which in turn fused together to form helium. Before this time, atomic nuclei formed were broken up by high energy photons and stable nuclei could only be formed when $T \sim 10^9$ K. This is the era of nucleosynthesis during which 75% of hydrogen, 25% of helium and traces of heavier elements, up to lithium, were formed. These constitute the cosmic abundance of light elements which have been confirmed observationally. The first generation of stars was formed out of these primordial elements; heavier elements as we see today were processed in stars.

Radiation continued to interact with matter, thus preventing electron capture by the nucleus to form neutral atoms. The free electrons made the universe opaque to radiation through scattering process. Thus, radiation and matter were still coupled together.

- **The Matter Era ($10^9 < T < 3$K; $10^3 < t < 10^{13}$sec)**

As the universe cooled sufficiently, electrons combined with atomic nuclei to form neutral matter. This is the era of recombination and the universe became transparent to radiation i.e. radiation and matter decoupled from each other to produce the surface of last scattering observed today as MWBR. Later, matter became clumpy to form large scale structures; galaxies, clusters of galaxies, stars, planets and life, etc. Galaxy formation took place at $T \sim 10$K and $t \sim 10^6 - 10^9$yrs, while stars formed later and continues to form today.

The early universe was dominated by radiation. This corresponds to the epoch of baryogenesis through the lepton era to the era of nucleosynthesis. The latter universe is matter-dominated and includes from the time of last scattering to today.

## The Future of the Universe

One of the cardinal problems in cosmology is the question of whether the universe is open or closed; will the Hubble expansion continue forever or do we have enough matter to stop the expansion and perhaps reverse it to contraction? We have earlier seen that if $\Omega < 1$, the universe expands forever. The implication is that all stars and galaxies will eventually use up their energies and become white dwarfs or black holes. The universe becomes cold and dark and all lives will end. On the other hand, if $\Omega > 1$, the expansion slows down and eventually stops and possibly recollapses to a singular point for another Big Bang. This means that everything will end in a Big Crunch. Which of these two fates is our portion?

Based on theoretical models which describe the expansion rate and geometry (depending on the composition of the universe), there are some fundamental parameters which can be obtained observationally and which can be used to address the above questions.

- ***The Deceleration Parameter***

The deceleration parameter $q = \frac{4\pi G\rho}{3H^2}$ describes the rate of deceleration of the universe due to its matter content of density ($\rho$) or equivalently, the density parameter $\Omega = \frac{\rho}{\rho_c} = 2q$, which describes the present dimensionless mass density of the universe (the ratio of the density of the universe to its closure density $\rho_c$, i.e. the ratio of gravitational potential energy due to matter content of the universe to the kinetic energy of expansion).

- ***The Hubble's Constant***

The Hubble's constant $H_0 = \frac{\dot{R}}{R}$ describes the present rate of expansion of the universe based on the scale factor of the universe ($R$) and its first derivative.

- ***The Cosmological Constant***

The cosmological constant can be parameterized in terms of density parameter of the vacuum field $\Omega_\Lambda = \frac{\Lambda c^2}{3H^2}$. These parameters are related through

$$H^2(\Omega_m + \Omega_\Lambda - 1) = \frac{kc^2}{R^2},$$

(4)

where $k$ is the curvature term and can take values $k$ = 0, 1 or -1 for flat, closed or open universe respectively.

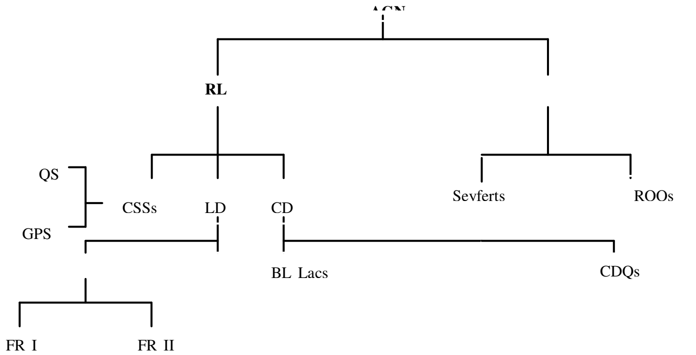
**The Hubble's Constant and the Age of the Universe**

From the Hubble's law, the Hubble's constant ($H$) has the unit of inverse of time, so that once $H$ is known, the expansion age of the universe $t = H^{-1}$ can be calculated. Currently, its value is $H$ = 75 km/s/Mpc, so that

$$t = \frac{1}{H} = \frac{1Mpc}{75km/s} = \frac{3.1\times10^{19}\,km/s}{75km} = 4.1\times10^{17}\,s \approx 1.3\times10^{10}\,yrs.$$

**Observational Cosmology and Extragalactic Radio Astronomy**

Observational cosmology is the study of distant galaxies with hope of determining the fundamental parameters that describe the structure and evolution of the universe. Some of these distant galaxies show violent activities in extremely compact regions of their nuclei resulting in enormous emission of radiation in the radio, infrared, ultraviolet and x-ray wavelengths and are called active galactic nuclei (AGNs). Those that show very strong radio emission (with ratio of radio luminosity at $\lambda$ = 6cm to-optical B-band at $\lambda$ = 4400A$^0$ $\geq$ 10) are said to be radio loud AGNs while those that have weak radio emission (2 - 3 orders of magnitude




**NOTE:** RL = Radio Loud; RQ = Radio Quiet; CSSs = Compact Steep Spectrum Sources; LD = Lobe Dominated; CD = Core Dominated; FR I = Fanaroff-Riley class I; FR II = Fanaroff-Riley class II; RGs = Radio Galaxies; LDQs = Lobe Dominated Quasars; BL Lacs = BL Lacertae Objects; RQQs = Radio Quiet Quasars.

***Fig.1**: **The AGN zoo** (Urry and Padovani 1995).*

weaker) are said to be radio weak. The various classes that form the AGN zoo are illustrated in Fig. 1.

## Radio Loud AGNs

Radio-loud AGNs observed at low radio frequencies consist of steep-spectrum lobe-dominated (with spectral index $\alpha > 0.5\,; S_\nu \approx \nu^{-\alpha}$) radio galaxies and quasars. They are generally characterized by two extended radio structures (called lobes) straddling a more compact component coincident with the nucleus of the parent object. High dynamic maps have revealed that the two lobes are linked to the core by one or two jet-like features and some of these lobes contain regions of high surface brightness called hot spot (see Fig. 2)

In contrast, high frequency surveys are dominated by flat-spectrum core-emissions and these sources are said to be core-dominated and include core-dominated quasars (CDQs) and BL Lacertae objects (BL Lacs).

**Radio-Quiet Objects**

Radio-quiet AGNs have weak radio emissions coming from very compact regions. They lack extended radio components and well-collimated jets. They include seyfert galaxies (seyfert I and seyfert II) and radio quiet quasars. Seyfert galaxies show unusually very strong emission lines (Seyfert Is) and some have broad emission lines as ell (Seyfert IIs).

**Steep Spectrum Compact Sources**

Not all radio sources observed at high frequencies are core-dominated. A small fraction of high-frequency radio surveys using very long base-line interferometers (VLBI) technique have been observed to have steep spectra. These sources are characterized by small linear dimensions and steep spectra, and are called compact steep spectrum sources (CSSs). Some of these sources have their spectra peaked at GHz frequencies and are called gigahertz-peaked sources (GPSs) and some are compact symmetric objects (CSOs).

The major research interest in extragalactic radio astronomy is not only to use these objects as tools for cosmological studies but also whether the different classes of AGNs can be unified together. In addition, the phenomenology of the compact steep spectrum sources; whether they are young sources in their early stage of evolution, or old sources confined in an unusual dense environments or larger sources seen in projection need to be understood. These formed the major thrust of my research activities which now follow.

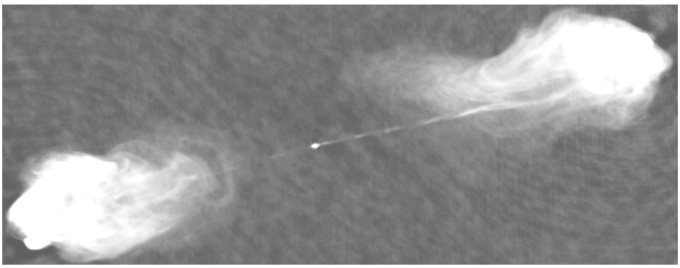


***Fig. 2: Unified structure of a galaxy*** *(Urry and Padovani, 1995)*

**My Research Activities**

I first joined the Astrophysics Research Group of the Department of Physics and Astronomy, under the able leadership of late Professor S. E. Okoye, as a Masters Degree student, in 1982. At that time, we were holding weekly seminars on Tuesdays where preprints and reprints from leading astronomy groups in the world were reviewed.

I effectively joined the international astronomy community in research activities at frontiers of knowledge in extragalactic radio astronomy and cosmology as a PhD student in 1984. My first research output was published in 1991 in Astrophysical Journal (one of the top journals in astrophysics). That was what gave me my PhD in 1991. It was the tradition in the Research Group to have at least one publication in top (high impact factor) journal before one could be allowed to defend his Ph.D. thesis. I am proud to say that this tradition still persists today and has helped the group in maintaining world class research activities with well over hundred publications in high Impact Factor (IF) journals. This tradition is based on the belief that professionalism can never be developed without dedicated hard work at the frontiers of knowledge. In fact, it is on record that Prof. J. O. Urama is one of the few professors that emerged from the first introduction of IF assessment in 2008 and Dr. A. E. Chukwude's professorial assessment report (based on IF) is currently being awaited from external assessors.

**The Angular Size - Redshift Relation: Principles and Practice**

The angular size – redshift ($\theta - z$) relation for extragalactic radio sources is one of the potential classical cosmological tests which was in the front burner of research in the 1970s and early 1980s. The ($\theta - z$) relation predicts that, at any world model (parameterized by $H_0$ and $\Omega_0$), the angular size ($\theta$) should first decrease as redshift ($z$) increase up to a minimum at some $z$ (depending on the value of $\Omega_0$) and then increase thereafter. Unfortunately, the observed ($\theta - z$) data do not follow the prediction of any standard world model. Rather, the data show a monotonic decrease of $\theta$ with $z$ as would be expected in Euclidean world model, i.e. $\theta \sim z^{-1}$. Investigations into the cause of the discrepancy between model and observation gave rise to plethora of conflicting results.

- **Linear Size Evolution**

A simple interpretation of the observed ($\theta - z$) data is to assume linear size evolution in the sense that linear sizes ($D$) of extragalactic radio sources were smaller at earlier epoch due to the increase in the temperature and density of the intergalactic medium (IGM) with cosmological epoch (e.g. Okoye and Onuora, 1982). This evolution takes the form; $D \sim (1 + z)^{-x}$, with $1 \leq x \leq 2$ depending on the value of $\Omega_0$.

- **Luminosity Selection Effects**

In flux density limited source samples, there is a strong correlation between luminosity ($P$) and redshift due to the ubiquitous Malmquist bias so that the observed ($\theta - z$) data could be equally explained by an inverse correlation between $P$ and $D$ without invoking linear size evolution (e.g. Masson 1980). The effect of sample flux density limit on the $\theta - z$ relation investigated by Ubachukwu and Onuora (1991) showed that luminosity selection effect alone could not account for the observed $\theta - z$ data.

- **Luminosity-Dependent Linear Size Evolution**

Kapahi (1987, 1989) considered four complete samples of radio galaxies of similar luminosities at different redshifts and showed that linear sizes of radio galaxies depend more on redshift than radio luminosity. Oort et al (1987) and Singal (1988) combined a large number of surveys and were able to separate the linear size dependence on redshift and luminosity. They found $D \sim P^{0.3} (1 + z)^{-3}$. This implies steeper linear size evolution that was obtained previously.

- **Physical Basis for Size Evolution**

My first research paper (Ubachukwu et al. 1991), which was part of my Ph.D. work, provided a physical basis for luminosity dependent linear size evolution. We were able to develop an analytical model based on the propagation of radio source components through the IGM in which pressure balance is achieved through the ram pressure of the IGM. This model showed that, for suitable assumptions which could be made about the magnetic field and energies of the radio source component, the linear size should vary with luminosity and redshift according to the relation; $D \sim P^{q}(1 + z)^{-n}$, with $q \approx 0.3$ *and* $2 \leq n \leq 3$.

**Problem with Size Evolution**

The nature and amount of size evolution required to explain the observed ($\theta - z$) data have given different results as shown below:

- Kapahi (1987) found $D \sim (1 + z)^{-3}$ for $\Omega_0 = 1$ and $D \sim P^{0.3}$ at constant redshift for radio galaxies.
- Oort et al. (1987) found $D \sim P^{0.3} (1 + z)^{-3}$ for radio galaxies.
- Barthel and Miley (1988) obtained $D \sim P^{-0.3} (1 + z)^{-3}$ for a sample of steep spectrum quasars.
- Singal (1993) showed that $D \sim P^{0.4} (1 + z)^{0.2}$ for quasars and $D \sim P^{0.4} (1 + z)^{-3}$ for FRII galaxies.
- Nilson et al. (1993) obtained $D \sim P^{-0.2} (1 + z)^{-0.2}$ for radio galaxies with log $P_{178} > 43$ erg/s and $D \sim P^{-0.4} (1 + z)^{0.3}$ for quasars.
- Neeser et al. (1995) found $D \sim (1 + z)^{-1.7}$ with no $D$ - $P$ correlation.
- Buchalter et al. (1998) found no evidence for linear size evolution.
- Blundel et al. (1999) obtained $D \sim P^{0.1} (1 + z)^{-1.9}$ for radio galaxies and quasars.

## Conflict Resolution

In an attempt to resolve the conflicting results shown above, Ubachukwu (1995) developed a simple mathematical formalism for separating the effects of luminosity from those of cosmological size evolution and showed that $x = n - q\beta$ which relates the apparent linear size evolution parameter x to its true value n and that which arises from luminosity selection effects present in the sample and is represented by the product $q\beta$. This was able to provide a quantitative resolution in the amount and nature of size evolution occurring in a radio source population. The result obtained by Buchalter et al. (1998) and which was published in the Astrophysical Journal was largely derived from this formalism.

We have used this formalism not only to explain the *D* (*P*, *z*) data (Ubachukwu 1997a, b; Ubachukwu et al. 1999) but also to explain the observed variation of spectral index with radio luminosity and redshift (Ubachukwu et al. 1996), as well as the variation of depolarization and spectral index asymmetries with radio luminosity and redshift (Ubachukwu, 1998a, b, c; Ubachukwu et al. 2002).

- **The Luminosity–Redshift and Size-Luminosity tracks.**

In addition, Ubachukwu and Ogwo (1998) carried out an extensive work which resulted in the reconstruction and reconciliation of available data and showed that the plethora of contradictory results in the literature could be ascribed to the change in the $P - z$ slope at some $z$ cutoff $z_c = 0.2 - 0.3$ coupled with a change in the $D - P$ slope at some Log $P \approx 43$ (ergs/sec). This has a serious implication for the radio source unification paradigm and relativistic beaming hypothesis that follows.

## Radio Source Unification Theories

The general consideration for the unification of extragalactic radio sources is based on two assumptions: pure orientation (for radio quiet AGNs) or orientation coupled with relativistic beaming (for radio-loud AGNs). It is believed that, for powerful radio loud

AGNs, there are three classes of object separated by two cone angles $\phi_1$ and $\phi_2$.

- When the radio axis falls within $\phi_1$ with respect to our line of sight, the beamed component dominates, and the radio source appears as a flat-spectrum core-dominated quasar (CDQ) with highly polarized and superluminal core.
- When the radio axis lies within some intermediate angle $\phi_1 < \phi < \phi_2$, with respect to the line of sight, the object appears as steep spectrum lobe – dominated quasar (LDQ).
- When the radio axis falls outside the cone angle $\phi_2$ ($\phi_2 < \phi \leq 90^o$), the optical quasar nucleus is completely obscured from our view by the molecular and geometrically thick disk/torus and the radio source appears as a narrow line radio galaxy (FRII type). These half-opening angles $\phi_1$ and $\phi_2$ are generally defined by the Lorentz factor $\gamma = \left(1 - \beta^2\right)^{-1/2}$, where $\beta$ is the speed in units of the speed of light.

In the Barthel's (1989) unification scheme for radio galaxies and quasars, these two classes of object are expected to be similar in all their observed properties except those that are aspect-dependent. In particular, both radio galaxies and quasars are expected to have similar size distributions in the luminosity – redshift plane. I have already pointed out that available results in the literature appear conflicting.

Ubachukwu and Onuora (1993) showed that the angular size - redshift data for extragalactic radio sources could be interpreted in terms of radio source orientation scheme with little or no size evolution required. Also, Ubachukwu (1996; 1998d, e) found that the angular sizes of FRII galaxies exceed those of LDQs by a factor of ~ 2, which in turn exceed those of CDQs by a factor of ~ 2, which is consistent with the unification models. Furthermore, Ubachukwu and Ogwo (1998; 1999) have shown that the apparent discrepancies in the linear size distributions of radio sources disappear once these classes of objects are properly matched in their redshifts. Recently, we (Alhassan et al. 2013) have used the change in the $P$ - $z$ slope to offer an alternative interpretation for the observed absence of correlation in the relationship between core radio power ($P_c$) and core-dominance parameter ($R$) for sub-samples of BL Lac objects and radio galaxies.

**Radio Source Orientation and Cosmology**

The interpretation of the $\theta$ - $z$ data usually assume that radio sources are randomly distributed in the sky. However, according to Barthel's (1989) unification theory, quasars are the powerful radio galaxies seen at closer angles to our line of sight while the radio galaxies form the non-aligned parent population. The $\theta$ - $z$ relation can thus be written (e.g. Ubachukwu 1998d) as

$$\theta = \theta_0 A(z) \sin\phi \, , \quad (5)$$

where $\theta_0$ is the intrinsic size of the source, $A(z)$ is a known function of $z$ for any world model and $\phi$ is the angle the radio source axis makes with our line of sight. Ubachukwu (1997a) showed that the de-projected $\theta$ - $z$ data for core-dominated quasars is consistent with a low density universe with $\Omega_m = 0.02$. It must be pointed out that this is also compatible with an inflationary universe with $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$. This implies that an open universe with low baryon density is compatible with inflationary model.

**Statistical Tests of Relativistic Beaming Models.**

In the relativistic twin beam model (e.g. Rees 1971, Blandford and Rees 1974, Scheuer 1974), Doppler effects are inevitable especially for radio sources whose radio axes are close to our line of sight. This will have a profound influence on orientation-dependent properties of AGNs. The various parameters which have been used to test the beaming and orientation hypothesis include:

- The ratio of core- to lobe-radio luminosity ($R$),

$$R = \frac{P_C}{P_E} = \frac{R_T}{2}\left[(1-\beta\cos\phi)^{-2} + (1+\beta\cos\phi)^{-2}\right],$$

(6)

where $R_T$ is the value of $R$ at $\phi = 90^0$, $\beta = \frac{v}{c}$ is the speed of the component in units of $c$.

- The core- to hotspot- distance ratio ($Q$),

$$Q = \frac{\theta_2}{\theta_1} = \frac{1+\beta\cos\phi}{1-\beta\cos\phi},$$

(7)

or equivalently, the fractional separation difference ($x$) given by:

$$x = \frac{Q-1}{Q+1} = \beta\cos\phi.$$

(8)

- The apparent motion statistics (apparent velocity $\beta_{app}$/proper motion $\mu$),

$$\beta_{app} = \frac{\beta\sin\phi}{1-\beta\cos\phi},$$

(9)

and

$$\mu = g(q_0, H_0, z)\frac{\beta\sin\phi}{1-\beta\cos\phi},$$

(10)

where $g$ ($q_0$, $H_0$, $z$) is a known function of $z$ for any Friedmann-Robertson-Walker universe.

- The projected linear size ($D$)

$$D = D_0 \sin\phi,$$

(11)

where $D_0$ is the intrinsic size of the source.

- The spectral index asymmetry parameter.
- The depolarization asymmetry parameter.
- The bend angle $\Phi$.
- The apparent flux ratio ($R^*$) , which is the ratio of the flux densities in the opposite lobes, given by:

$$R^* = \left(\frac{1+\beta\cos\phi}{1-\beta\cos\phi}\right)^{2+\alpha}.$$

(12)

We have carried out extensive statistical tests of relativistic beaming models based on these parameters and some models have also been developed to explain the observed data.

The crucial parameters for the beaming models are; the Lorentz factor ($\gamma$) and the orientation angle ($\phi$). The determination of these two parameters is necessary for any quantitative tests of the beaming and orientation hypotheses. We have used the ratio of the core-luminosity to lobe luminosity ($R$) as a beaming parameter and the linear size as orientation parameter. Ubachukwu (1995) used the observed $R$-distribution to obtain median values of $\phi_{med} \approx 31^o$ and $69^o$ respectively for lobe dominated quasars and radio galaxies. Ubachukwu (1998d) used the observed $R$ - $D$ data to obtain $\phi_{med} \approx 24^o$ and $40^0$ for lobe- and core-dominated quasars respectively. It was also shown that $\gamma = 5$ is consistent with the Orr and Browne (1982) model but ≈ 12 if FRII galaxies form the unbeamed parent population as in the Barthel (1989) model. Ubachukwu and Chukwude (2002) investigated the $R$ - $D$ data for core-dominated quasars and their results are consistent with $\gamma \approx 6 – 16$ and $\phi_m \sim 9^o – 16^o$ (See also Ubachukwu et al. 2005; Ubachukwu and Ogwo 2005, 2011; Alhassan et al. 2011; Odo et al. 2011). In a more recent analysis (Odo et al. 2012) using the $R$ - $D$ data for BL Lac objects, we obtained $\gamma \approx 7 – 20$, with $\phi_m \sim 5^o – 12^o$. Analyses based on spectral index and depolarization asymmetries were carried out by Ubachukwu (1998a, b) and Ubachukwu et al. (2002).

However, Onuchukwu and Ubachukwu (2012, 13) developed a kinematic model for the structural asymmetries and simple relativistic beaming/radio source orientation for LDQs using $D$, $R$, $Q$, $R^*$ and $\Phi$ as asymmetric parameters, which shows that larger sources are less asymmetric, indicating that other potential factors than beaming may have also come into play. In the relativistic beaming/orientation model, smaller sources should be more asymmetric due to geometric projection effects and differences in light travel times from the two radio components.

**The Phenomenology of Compact Steep Spectrum Sources**

The phenomenology of compact steep spectrum sources (CSSs) appears hard to explain. Although Fanti et al. (1990a, b) have used statistical arguments to show that only a small fraction (< 33%) of CSSs could have been larger sources seen in projection, it is not clear whether these sources are small because they are embedded in a high density environment or because they are young sources in their early stages of evolution (e.g. Dallacasa et al. 1995).

Onuora and Ubachukwu (1995) studied the nature and environment of these sources based on their angular sizes and showed that they are either young sources or relatively weak sources in dense, active media where star formation is continuing. Ubachukwu and Ogwo (1999) examined their redshift and luminosity dependence in the context of the quasar/galaxy unification scheme and showed that the behaviour of their linear sizes in the luminosity – redshift plane is similar to that of their more extended counterparts. More recently, Ezugo and Ubachukwu (2010) developed a dynamical model for the evolution of CSSs using a semi-empirical relationship between their spectral turnover and linear sizes and showed that CSSs reside in high density environments.

**The Fate of the Universe**

I have shown in the course of the lecture that the superluminal motion statistics is consistent with a flat universe with $\Omega_m = 1$, provided that $\gamma$ is not a function of redshift. The implication is that we have just enough matter to stop the expansion of the universe (but not enough to reverse the expansion to contraction) - expansion will continue forever but the universe will be getting cooler as it expands until it ends in a 'Big Chill'. However, the result I presented based on the $\theta - z$ data for core-dominated quasars gave $\Omega_m = 0.02$, showing that there is not enough matter in the universe to stop the expansion and the universe will expand forever in a steadily decreasing rate until it becomes frozen. Ubachukwu (1995) actually used a model for luminosity evolution developed by Ubachukwu et al. (1993) to place an upper limit of $\Omega_m = 0.4$.

Other results based on inflationary model give $\Omega_m = 0.3$ and $\Omega_\Lambda = 0.7$. This implies that the universe, though spatially flat, is accelerating and not decelerating and will expand forever, cooling as it does so until it gets to a temperature of absolute zero (i.e. cold and dark). It will eventually end up in a Deep Freeze.

**The Fate of the Sun and Earth**

The sun is a cloud of gas (with mass of about $10^{30}$kg; 7 $\times 10^5$km radius and 60000K temperature) held together by gravity and prevented from collapse by the thermonuclear reaction taking place at its core. It consists of 70% hydrogen (*H*), 28% helium (*He*) and 2% heavier elements. The sun generates its energy by conversion of its *H* into *He* and this energy is transported to the earth through convection and radiation at a rate of 3.8 x $10^{33}$ ergs per second. As long as this nuclear fusion lasts, the sun will continue to shine.

As the sun continues to use its mass reserve, its radius reduces (shrinks) and the luminosity increases. This has a grave consequence upon the earth. Initially water in the atmosphere dries up and later oceans will dry up and the earth will be like Venus today - completely gaseous!! According to 2 Peter 3:10, "….. The heavens will pass away with a terrible noise and the heavenly bodies will disappear in fire, and the earth and everything on it will be burned up".

The sun ends its main sequence phase when all *H* has been converted into *He* in the nucleus. It then enters into *He* burning (conversion of *He* into carbon and oxygen), after which it ends up as a white dwarf.

**Epilogue**

We have come to the end of the story which has been unfolded in this inaugural lecture. I now give a brief summary of what I have tried to convey in the course of the lecture. I have attempted to develop the lecture along two broad themes, but how far I have succeeded in achieving this is for you audience to judge.

The first theme provided the unique status of Physics among other sciences and human endeavours. The three 'worlds' of Physics were developed to illustrate my personal experience based on mental processes by which I understand Physics and these include:

**The World of Quantum Physics**

- The wave-particle duality of nature as indicated by Heisenberg's uncertainty principle and complementarity principle have been used to illustrate the physical-spiritual duality of man - man is a spirit that lives in a physical body and his action in any plane is limited by the other plane.
- Creation stems from quantum fluctuations of an empty space as contained in Genesis Chapter one.
- Creation and annihilation of particles come through application of raising/creation operator ($\boldsymbol{a}^{+}$) and the lowering/annihilation operator ($\boldsymbol{a}$) respectively. This illustrates how godliness and perversion, produced by the two opposing forces, are found in nature.

**The World of Classical Mechanics**

- Newton's laws of motion tell us why adults find it difficult to change their ways and why force is needed to bring about conformity.
- By Hooke's law, we see that once elastic limit is exceeded, permanent strain is inevitable with disastrous attendant consequences.
- Phase transitions are always accompanied by enormous energy which explains why a change into adolescence causes a lot of concerns to parents.

- Because internal energy never vanishes (i.e. entropy $\Delta S > 0$) physical and emotional stress must continue to increase. Violence and natural disasters will continue to rise together with lawlessness and number of reprobates in the world.

**The World of Relativistic Mechanics**

- Relativity is a story of two worlds where two different observers use the same Physics but measure different time, length and mass. Based on some putative assumptions, we were able to see that it is not yet three years since Christ left the earth.
- The Physics of black hole reveals the concept of eternity where in death man goes eternally on a journey of no return with all communications severed. It also describes hell as a physical place where visible light is blue shifted towards x-ray and $\gamma$-ray spectra - extreme high energy radiation.

In the second theme which deals with the origin, evolution and possible fates of the universe, together with my contributions to knowledge in extragalactic radio astronomy and cosmology we were able to learn the following:

- The universe passed through a hot dense phase and expanded – the Big Bang.
- The inflationary model of the universe was introduced to explain some of the unanswered questions in the Big Bang model.
- I have (together with my research team) been able to develop some models that reconciled many conflicting reports in the literature as well as provide some quantitative analyses of observations that have led to a better understanding of the universe in which we live.
- From our present knowledge, the universe will expand forever and end either in a Big Chill or in a Big Deep Freeze.
- The sun will end up as a white dwarf and the earth in a fervent heat as water in the atmosphere and ocean dries up.

**Are We Alone in the Universe?**

Before I finally end the formal part of the lecture, let me quickly address the question I raised in the prologue “Is there life elsewhere in the universe?”

The search for evidence of extraterrestrial intelligence (SETI) is aimed at providing a scientific basis for the belief that we may not be alone in the universe and suggests where we can search for other worlds. Since life as we know it is a planetary phenomenon, the most likely place to look is extra solar planets. However, planets are not easy to observe due to the star light that obscures them, but we can observe their effects on the motion of stars. So far:

- About 908 extra solar planets have been discovered.
- Although some of these planets lie within habitable zones (range of distances around a star in which conducive temperature is possible i.e. where water is liquid), they are more massive than the earth and do not have the correct temperature.
- Probabilities based on Drake equation (that quantifies the number of civilizations that might exist in the galaxy) are quite low, meaning that life is rare in our galaxy.
- The time required for a two-way communication appears to exceed the life time of a technical civilization, and there is no scientific evidence that intelligent creatures have visited the earth.
- Interstellar travel is almost impossible.
- The search is still on, but in my opinion, hope is very dim.

**Caution**

And further, by these, my son, be admonished: of making of books (models) there is no end; and much study (too many models) is a weariness of the flesh (Ecclesiastes 12: 12).

***Acknowledgments***

I want to use this opportunity to acknowledge God and some of the people (both living and dead) who have played one role or the other in shaping my academic career and my destiny in general.

First and foremost, I thank God for keeping me alive to present this inaugural lecture. I appreciate His inestimable love for me, His faithfulness and all other benefits I have received from Him. I acknowledge that all I am and all I have been able to do are because of His abundant grace and mercies. To Him be all the glory.

I would want to appreciate my parents, Chief N. O. Ubachukwu (Odu of Ichi) and Madam Alice Ubachukwu (both late) who without my permission brought me into this world. My father laboured tirelessly to ensure that all his children are successful in life. He provided me with every material thing I needed to make it in life, including marrying a wife for me. My mother taught me the law of social economics “if anyone should not work, let him not also eat”.

To my elder brother, Engr. F. U. Ubachukwu, who was the first person to introduce me to Physics in December 1971, I am grateful. I still remember boasting to a school mate at the end of my class three in 1972 that no mother has conceived any problem I would fail in Heat in O’level Nelkon. That statement came as a result of the solid foundation you laid for me in that subject. You can today see the fruit.

My decision to pursue a life career as a university teacher came as a result of a challenge from a fellow student who, after one of our Ichi Students Union meetings in 1975, jokingly told me that I would end my career in Emodi Street, Onitsha, where my father was doing his business as number 1 Bata Distributor in Nigeria and where most of my peers, at that time, were ending their careers. I swore that day that I would never stop reading until there are no more books to read. I felt fulfilled, when in November, 1991, I defended my Ph.D. Thesis.

I will forever remain grateful to my supervisor and mentor, Prof. S. E. Okoye (of blessed memory) who supervised my B.Sc. and M.Sc. Project Reports in 1980/81 and 1982 - 84 respectively and also my Ph.D. thesis (1984 - 1991). He taught me that a firm understanding of research problems cannot be attained by cutting corners, but by a great deal of hard work. Here is an excerpt from one of his letters (while he was away in London due to ill health) in 1991. "…What matters is the quality of training, not so much as how long it takes. The time to compare yourself with others will perhaps be in 5 or 10 years time. At that point, the relevant issue will be how useful the training has been and what progress one has made with that training as a base. The important thing is that I am now convinced you won't let anybody down if you are released to answer Dr so and so at this stage". I am glad that I did not let you or anybody down and within eight years of my release, I was qualified to be assessed for professorship. All my teachers from primary school to the university are highly appreciated also.

My immediate elder brother, Ikemefuna, made a lot of investments to make my life as comfortable as possible. He bought me a mobyllete which I used as an undergraduate student. That 'bike' helped me a lot not only in running around for my lectures (especially in my first year as a 'flatter') but in coordinating numerous extracurricular activities, including serving as a chorister in Christ Church Chapel, Class Rep. for three consecutive years, President Physics Students Association, President, Oraifite Old Students Association (UNN chapter), Organizing Secretary, Student Christian Movement of Nigeria (UNN Branch).

My younger brother, Chief (Sir) Emefiona Ubachukwu (Nkpu Ogiliga), the Chairman of Ekwugha Kindred (which is the ancestral name of Ubachukwu family) has been a blessing to the entire kindred. He was instrumental in bringing about my first trip abroad in 1994. That trip opened up several research opportunities which took me to many countries of the world. He was very supportive in some of these trips.

I would want to say a big thank you to Prof. P. N. Okeke on whose recommendation I got a research visit to Hartebesthoek

Radio Astronomy Observatory, Krusgersdorp, South Africa, where most of the works that made me a professor were concluded in February, 1997.

Professor C. E. Okeke stood by me when, for a period of about seven years, my life appeared to be standing still. An Ibo adage has it that when a child washes his hands, he eats with the elders. I washed my hands by 1998 but it was not until 2005 that I joined the elders to eat as a professor.

Let me quickly recognize some of my professional colleagues and friends who have made some positive impact in my life. My current Head of Department, Prof. (Mrs.) Rose Osuji was my practical partner for three years in our undergraduate years. Prof. C. M. I. Okoye (Emens) is Dean of my Faculty and a bosom friend together with his wife, Uzo. Dr. Ifeanyi Obiakor was my classmate and the friendship we developed in our undergraduate days still persists even over twenty years since he left the services of the University. Dr. A.B.C. Ekwealor was my roommate at 354 Nkrumah Hostel during my postgraduate studies. Prof. (Mrs.) F. N. Okeke is a friend indeed. She has been a dependable friend in times of need. Prof. J. O. Urama is a wonderful gift. Prof. A. O. E. Animalu is an intellectual giant. He belongs to a different league where Physics has gone both philosophical and mystical. Dr. J. U. Chukudebelu is both a father and a friend. To the rest of the staff of Physics, both past and present, since I joined the services of this University in 1991, I say God bless you. My association with Prof. Amagh Nduka of the Federal University of Technology, Owerri (FUTO) during my Sabbatical Leave in the 2011/2012 academic year reinforces my belief that there is a harmony in all branches of science, which could only be found in cosmology. Chief J.O.J Okoye and Dr Obi Mokwe have been long standing friends, right from our secondary school days.

I would also want to appreciate all the members of Astrophysics Group in the days of Prof. S. E. Okoye; Prof. Chidi E. Akujor, who is a personal friend; Dr. (Mrs.) Leslie Onuora, who was my second supervisor and trained me in the art of writing journal articles; Profs. W. Anyakoha, Dr. J. O. Ukwungwu, Charles McGruder II and a host of others.

To every staff of Computer Science, where I did my first and second missionary journeys as a Head of Department, I say, remain blessed. I also salute all the members of staff of the School of Postgraduate Studies, where I am currently serving as the Dean.

I want to thank all my professional children; Dr. (Mrs.) J. N. Ogwo of Abia State University who together with her husband has been a blessing to my family. Dr. A. E. Chukwude is a beloved son. Dr. J. Alhassan received more push from me than any other. Others include: Dr. J. Ezugo (NAU), Dr F. C. Odo, Dr C. Onuchukwu (ANSUU), Dr. Umahi (EBSU) who was my M.Sc. student, Mrs. C. Onah, Faith Ugbo, etc.

To my immediate family, I can say the words of Psalm 16: 6 "The lines are fallen unto me in pleasant places; yea I have a goodly heritage." My gentle and brilliant wife, Prof. (Mrs.) Patience Obiageli Ubachukwu (Baby), you are, of a truth, a goodly heritage. You are the wife of my youth and of my bosom by divine ordination. You have always placed family interests above your personal ambition. I thank God that those sacrifices were not in vain. Today, you are not only a Ph.D. holder in Parasitology and Entomology; you are also a fellow professor. I thank God for the five boys; Chibundo, Eziama, Chidiebere, Daberechi and Ugochukwu and for making them a goodly heritage. My prayer for you all is that as you have seen us (your parents) work assiduously to provide you the best we can and to achieve our goals in life, you should work even harder not only to achieve your own goals in life but also encourage your children, our grand children, to achieve their own goals in their generation. I have always told you that I owe you two things in this life; to help you make it in life through honest labour and to take you back to your root. This is a debt you will owe your own children (my grand children).

I would like to thank my in-laws: Prof. D. N. Ezeasor and all the members of Ezeasor family for their love and care, and for giving me their goodly and godly daughter.

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I would also wish to acknowledge the warm fellowship I have enjoyed in the Student Christian Movement (SCM) for about thirty six years now, both at the national, sectoral, zonal and branch levels. I appreciate my national president, Mr. C. Ojum; my sectoral president, Mr. U. Nkwunowo and my current President in the Township Fellowship, Dr. V. C. Ejere. Other SCM members at various levels some of which are Prof. and Dr. (Mrs.) E. C. Ibezim, Prof. and Mrs. M. Okonta, Dr. and Mrs. Solomon Agbo, Hon. and Barr. Goddy Ogenyi, Dr. and Mrs. Vin Onodugo, Mr. and Mrs. Solomon Ani, Sir and Lady (Prof.) BAC Onwurah, Sir (Dr) and Lady A. E. Onwurah, Prof. (Mrs.) P. Onokala, Bro. and Sis. Austine Okeke, Lady (Dr) Ogo Amucheazi, Mrs. Joy Wosu, Sir (Barr) and Lady Chike Ngwu, Evangelist P. N. Okoronkwo, Pastor and Mrs. Onyekachi etc, together with their families, are highly appreciated.

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**Thank you all for coming and for listening. God bless you richly.**

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# INAUGURAL LECTURES OF THE UNIVERSITY OF NIGERIA, NSUKKA

1. **Prof. K. Nzimir o – 1976**
   **Title:** the Crisis in the Social Sciences: The Nigerian Situation

2. **Prof. Chika Okonjo – 1976**
   **Title:** Economic Science, Imperialism and Nigerian Development.

3. **Prof. K. S. Hegde, Vet. Medicine – 1977**
   **Title:**

4. **Prof. D. I. Nwoga – 1977**
   **Title**: Visions Alternatives: Literary Studies in a Transitional Culture.

5. **Prof. J. A. Umeh – 1977**
   **Title:** Land Policies and Compulsory Acquisition of Private Land for Public Purposes in Nigeria.

6. **Prof. D. C. Nwafo – 1984**
   **Title:** The Surgeon as an Academic

7. **Prof. G. E. K. Ofomata – 1985**
   **Title:** Soil Erosion in Nigeria: The views of a Geomorphologist.

8. **Prof. E. U. Odigboh – 1985**
   **Title:** Mechanization of cassava production and processing: A Decade of Design and Development.

9. **Prof. R. O. Ohuche – 1986**
   **Title:** Discovering what Learners have attained in Mathematics.

10. **Prof. S. C. Ohaegbulam – 1986**
**Title:** Brain surgery: A luxury in a Developing Country like Nigeria.

11. **Prof. I. C. Ononogbu – 1998**
**Title:** Lipids: Your Friend or Foe.

12. **Prof. V. E. Harbor-Peters – 2001**
**Title:** Unmasking some Aversive Aspects of Schools Mathematics and Strategies for averting them.

13. **Prof. P. O. Esedebe – 2003**
**Title:** Reflections on History, Nation Building and the University of Nigeria.

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