DRAFT BOOKLET

THE PONTIFICAL ACADEMY OF SCIENCES

Plenary Session on

SCIENTIFIC INSIGHTS INTO THE EVOLUTION OF THE UNIVERSE AND OF LIFE

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But the big problem is that were God not to exist and were he not also the Creator of my life, life would actually be a mere cog in evolution, nothing more; it would have no meaning in itself. Instead, I must seek to give meaning to this component of being. Currently, I see in Germany, but also in the United States, a somewhat fierce debate raging between so-called “creationism” and evolutionism, presented as though they were mutually exclusive alternatives: those who believe in the Creator would not be able to conceive of evolution, and those who instead support evolution would have to exclude God. This antithesis is absurd because, on the one hand, there are so many scientific proofs in favour of evolution which appears to be a reality we can see and which enriches our knowledge of life and being as such. But on the other, the doctrine of evolution does not answer every query, especially the great philosophical question: where does everything come from? And how did everything start which ultimately led to man? I believe this is of the utmost importance. This is what I wanted to say in my lecture at Regensburg: that reason should be more open, that it should indeed perceive these facts but also realize that they are not enough to explain all of reality. They are insufficient. Our reason is broader and can also see that our reason is not basically something irrational, a product of irrationality, but that reason, creative reason, precedes everything and we are truly the reflection of creative reason. We were thought of and desired; thus, there is an idea that preceded me, a feeling that preceded me, that I must discover, that I must follow, because it will at last give meaning to my life. This seems to me to be the first point: to discover that my being is truly reasonable, it was thought of, it has meaning. And my important mission is to discover this meaning, to live it and thereby contribute a new element to the great cosmic harmony conceived of by the Creator.

(Meeting of the Holy Father Benedict XVI with the Clergy of the Dioceses of Belluno-Feltre and Treviso, Church of St Justin Martyr, Auronzo di Cadore, Tuesday, 24 July 2007).

Scientific Insights into the Evolution of the Universe and of Life

INTRODUCTION

WERNER ARBER & NICOLA CABIBBO

Research into the origins and evolution of the universe, of matter and of life belongs to the focal topics of the natural sciences. The Pontifical Academy of Sciences has repeatedly paid attention to these questions both in plenary sessions and in specialised meetings. In recent years relevant basic scientific knowledge has been considerably enriched, in particular by the introduction of novel and powerful research strategies. Cosmic investigations can reach ever greater distances, while particle physics and the nanosciences allow scientists to explore structures of ever smaller dimensions. The results of these largely interdisciplinary studies considerably enrich our knowledge about natural reality and they also raise new questions. These concern, for example, a postulated multiverse or dark matter and, more generally, cosmic evolution. In the life sciences more precise structural knowledge on genetic information and on gene products provides insights not only into functional characteristics but also into molecular mechanisms that contribute to the occasional generation of genetic variants – the drivers of biological evolution.

By definition, evolution implies a changing reality. This is what the sciences have postulated as holding both for the inanimate cosmos and for the living world. Ever more powerful research strategies continue to strengthen the validity of these postulates.

The Council of the Pontifical Academy invites the Academicians to present in the forthcoming Plenary Session any scientific contributions that may validate or falsify evolutionary theories and can provide a deeper insight into the evolutionary processes of the living and of the non-living world. This might allow our Academy to update its own knowledge basis and to transmit this knowledge to human society for an actualisation of its science-based worldview. Scientific knowledge forms – in addition to traditional wisdom, religious beliefs and educational values – an essential part of the orientating knowledge that serves us for taking individual and socio-political decisions.

In these scientific debates the Council of the Academy proposes to focus more on the evolutionary process as such than on the postulated origins of things which, however, shall also be discussed. It is our intention to strengthen our knowledge on the dynamics of evolution in its historical dimensions and also to provide prospective views on upcoming developments into the far future. Contributions on the specific impact that human activities may have on evolutionary processes will also be welcome. The Council also expects to be able to draw from the Plenary Session conclusions that are of relevance to the subject of the creation of something out of nothing and the various forms – of an evolutionary kind as well – in which this participation in being, caused by the Being in essence, is realised. Indeed, for Thomas Aquinas, expressing a philosophical perspective, everything that is by participation is (or is caused) by the Being in essence. Thus not even the evolutionary processes of the universe and life can be excluded from emanation from the universal principle of being.

Wissenschaftliche Einsichten in die Evolution des Universums und des Lebens

EINFÜHRUNG

WERNER ARBER & NICOLA CABIBBO

Die Forschung nach dem Ursprung und der Evolution des Universums, der Materie und des Lebens gehören zu den Hauptthemen der Naturwissenschaften. Die Päpstliche Akademie der Wissenschaften hat des öfteren, bei Plenarsitzungen und bei spezifischen Tagungen diesen Themen Aufmerksamkeit gewidmet. In den letzten Jahren ist es zu einer Erweiterung des entsprechenden grundlegenden wissenschaftlichen Wissens gekommen, vor allem durch die Einführung von neuen und effizienten Untersuchungsstrategien. Die Weltenforschung ist imstande, immer größere Entfernungen zu überwinden, während die Teilchenphysik und die Nanowissenschaften es den Wissenschaftlern ermöglichen, Strukturen von immer kleineren Dimensionen zu erforschen. Durch die Ergebnisse dieser vornehmlich interdisziplinären Studien nimmt unsere Erkenntnis über die natürliche Realität beträchtlich zu, und dabei tauchen auch neue Fragen auf. Diese betreffen zum Beispiel ein postuliertes Multiversum oder dunkle Materie und allgemein die Evolution des Kosmos. In den Lebenswissenschaften gibt eine genauere Kenntnis über die Struktur der genetischen Information und der Genprodukte Einblick nicht nur in funktionelle Charakteristiken, sondern auch in molekulare Mechanismen, die zur gelegentlichen Bildung von genetischen Varianten – der Triebkraft der biologischen Evolution – beitragen.

Die Evolution impliziert per definitionem eine sich verändernde Wirklichkeit. Das haben die Wissenschaften sowohl für den unbelebten Kosmos als auch für die lebendige Welt postuliert. Immer effizientere Forschungsstrategien bestätigen die Gültigkeit dieser Postulate.

Der Vorstand der Päpstlichen Akademie der Wissenschaften ladet die Akademiker dazu ein, in der bevorstehenden Plenarsitzung wissenschaftliche Beiträge vorzustellen, durch die Evolutionstheorien verifiziert oder falsifiziert werden können und die einen tieferen Einblick in den Evolutionsprozess der lebendigen und der leblosen Welt vermitteln können. Dies ermöglicht unserer Akademie, ihr eigenes grundlegendes Wissen zu ergänzen und dieses Wissen der menschlichen Gesellschaft zu vermitteln für eine Aktualisierung ihrer auf Wissenschaft beruhenden Weltanschauung. Wissenschaftliche Kenntnisse bilden – zusammen mit traditioneller Weisheit, religiösem Glauben und erzieherischen Werten – einen grundlegenden Teil des Orientierungswissens, das uns bei individuellen und sozialpolitischen Entscheidungen dient.

Der Vorstand der Akademie schlägt vor, dass sich die wissenschaftlichen Debatten mehr auf den Evolutionsprozess als solchen konzentrieren sollten als auf den postulierten Ursprung der Dinge, der aber ebenfalls diskutiert werden soll. Wir beabsichtigen, unser Wissen über die Dynamik der Evolution in ihren geschichtlichen Dimensionen zu erweitern und auch vorausblickende Ansichten über kommende Entwicklungen in die ferne Zukunft beizusteuern. Willkommen sind auch Beiträge, die einen spezifischen Einfluss von menschlichen Aktivitäten auf den Evolutionsprozess behandeln. Der Vorstand erwartet ferner, mittels der Plenarsitzung zu Schlüssen zu gelangen, die bedeutend sind für das Thema der Schöpfung von etwas aus dem Nichts und der unterschiedlichen Formen – auch evolutionärer Art – in denen die Teilhabe am Sein, gründend auf dem Sein in seiner Essenz, verwirklicht ist. In einer philosophischen Sichtweise ausgedrückt, ist für Thomas von Aquin tatsächlich all das, was am Sein teilhat, in seiner Essenz beim Sein (oder davon verursacht). Daher können nicht einmal die Evolutionsprozesse des Universums und des Lebens von der Emanation des universellen Prinzips des Seins ausgeschlossen werden.

INTRODUZIONE

WERNER ARBER & NICOLA CABIBBO

La ricerca sulle origini e sull'evoluzione dell'universo, della materia e della vita è uno degli argomenti chiave delle scienze naturali. La Pontificia Accademia delle Scienze ha spesso rivolto la sua attenzione a tali questioni, sia nelle sue sessioni plenarie che durante gli incontri specializzati. Negli ultimi anni le principali conoscenze scientifiche a riguardo si sono notevolmente arricchite, in particolare con l'avvento di strategie di ricerca innovative e potenti. La ricerca cosmica raggiunge distanze sempre maggiori, mentre la fisica delle particelle e le nanoscienze permettono agli scienziati di esplorare strutture di dimensioni sempre più piccole. I risultati di questi studi, generalmente interdisciplinari, arricchiscono notevolmente il nostro sapere nel campo della realtà naturale e sollevano nuovi interrogativi riguardanti, per esempio, un presunto multiverso, la materia oscura e, più in generale, l'evoluzione cosmica. Nelle scienze naturali, una conoscenza strutturale più precisa delle informazioni genetiche e dei prodotti genici ci fornisce nuovi elementi non solo riguardanti le caratteristiche funzionali ma anche i meccanismi molecolari che contribuiscono alla generazione occasionale di varianti genetiche – il motore dell'evoluzione biologica.

Per definizione, l'evoluzione implica una realtà che cambia. Questo è ciò che le scienze suppongono sia per il cosmo inanimato, sia per il mondo animato. Strategie di ricerca sempre migliori continuano a rafforzare la validità di queste supposizioni.

Il Consiglio della Pontificia Accademia invita gli Accademici a presentare, durante la prossima Sessione Plenaria, un contributo scientifico che possa confermare o, al contrario, confutare le teorie sull'evoluzione e che offra uno sguardo più approfondito sui processi evolutivi del mondo animato e inanimato. In questo modo sarà possibile per la nostra Accademia aggiornare le proprie conoscenze di base e trasmetterle alla società umana, per un aggiornamento di quella visione del mondo che abbia basi scientifiche. Il sapere scientifico costituisce – insieme alla saggezza tradizionale, alla fede religiosa ed ai valori dell'educazione – una parte essenziale delle conoscenze orientative che ci servono a prendere decisioni individuali e sociopolitiche.

In questi dibattiti scientifici il Consiglio dell'Accademia suggerisce di concentrarsi più sul processo evolutivo come tale che sulle origini postulate delle cose che, tuttavia, saranno anche oggetto di discussione. Lo scopo è quello di consolidare le nostre conoscenze sulla dinamica dell'evoluzione nelle sue dimensioni storiche e, inoltre, di fornire possibili opinioni sugli sviluppi sia prossimi che in un lontano futuro. Sono ben accetti anche contributi sull'impatto specifico che le attività umane potrebbero avere sui processi evolutivi. Il Consiglio si auspica, altresì, di poter trarre, dalla Sessione Plenaria, conclusioni che siano rilevanti per quanto riguarda il tema della creazione di qualcosa dal nulla e le varie forme – comprese quelle evolutive – nelle quali questa partecipazione dell'essere, causata dall'Essere per essenza, viene realizzata. Infatti, per San Tommaso d'Aquino, dal punto di vista filosofico, tutto ciò che è per partecipazione è (o è causato) dall'Essere per essenza, perciò non si possono ritenere esclusi dal derivare dal principio universale dell'essere neanche i processi evolutivi dell'universo e della vita.

THURSDAY, 30 OCTOBER 2008

13:30	Council Meeting
19:30	Dinner at the Casina Pio IV

FRIDAY, 31 OCTOBER 2008

9:00	*Welcome* **Prof. Nicola Cabibbo**, President of the Pontifical Academy of Sciences
9:05	*Commemoration of Professors* **Giampietro Puppi** • **Te-Tzu Chang** • **Carlo Enrico di Rovasenda**
9:25	*Self-Presentation of Professors* **Aaron J. Ciechanover** • **José G. Funes** • **Takashi Gojobori** • **Krishnaswamy Kasturirangan** • **Klaus von Klitzing** • **Yuan-Tseh Lee** • **Cesare Pasini** • **Ignacio Rodríguez-Iturbe** • **Edward Witten**
11:00	Coffee Break
11:30	*The Subject of the Meeting* **Prof. Werner Arber**, Coordinator of the Meeting and PAS Academician
11:45	**H.Em. Cardinal Christoph Schönborn** *The Reflections of Joseph Ratzinger Pope Benedict XVI on Evolution* (provisional title)
12:45	Lunch at the Casina Pio IV
	Session I **INSIGHTS INTO THE EVOLUTION OF THE UNIVERSE** Chair: **Prof. Nicola Cabibbo**
15:00	**Prof. Martin J. Rees** (invited) *New Approaches to the Evolution of the Universe* (provisional title) Discussion
15:40	**Prof. Stephen W. Hawking** *The Origin and Destiny of the Universe* (provisional title) Discussion
16:30	**Prof. Pierre J. Léna** *Evolution and Space* (provisional title) Discussion
16:50	**Prof. Antonino Zichichi** *Rigorous Logic in the Theory of Evolution* Discussion
17:30	Coffee Break
18:00	**Prof. José G. Funes** (to be defined) Discussion
18:20	General Discussion

Session II **INSIGHTS INTO THE EVOLUTION OF LIFE** Chair: **Prof. Nicole M. Le Douarin**	
18:40	**Prof. Albert Eschenmoser** *The Search for the Chemistry of Life's Origin* Discussion
19:20	**Prof. Marshall W. Nirenberg** *The Genetic Code* Discussion
20:00	Dinner at the Casina Pio IV

SATURDAY, 1 NOVEMBER 2008

9:00	**Prof. David Baltimore** *RNA and Evolution* Discussion
9:40	**Prof. Rafael Vicuña** *Bacterial Evolution: Random or Selective?* Discussion
10:20	**Prof. Ingo Potrykus** *Plant Breeding as an Example of Directed Evolution* Discussion
11:00	Coffee Break
11:30	**Prof. Fotis C. Kafatos** *Evolution: What the Insect World Tells Us* (provisional title) Discussion
12:10	**Prof. Werner Arber** *From Microbial Genetics to Molecular Darwinism and Beyond* Discussion
12:50	General Discussion
13:10	Lunch at the Casina Pio IV
Session III **INSIGHTS INTO HUMAN EVOLUTION** Chair: **Prof. Werner Arber**	
15:00	**Prof. Luigi L. Cavalli-Sforza** *Human Evolution as a Historical Process, and the Forces that Drive it* Discussion
15:40	**Prof. Christian de Duve** *The Facts of Human Life* (provisional title) Discussion
16:20	**Dr. Robert J. White** *Origin of the Human Species (Mind) Requires Divine Intervention* Discussion
17:00	General Discussion
17:20	Coffee Break

Session IV **THEOLOGICAL, PHILOSOPHICAL AND SOCIETAL ASPECTS** Chairperson: **Prof. Nicola Cabibbo**	
18:00	**H.Em. Cardinal Carlo M. Martini** *Evolution: a Biblical Reading* (provisional title) Discussion
18:40	**Fr. Prof. Michael Heller** *The Early Evolution of the Universe: Problems and Concepts* Discussion
19:00	**Fr. Prof. Jean-Michel Maldamé** *Création par évolution* Discussion
19:40	**Fr. Prof. Stanley L. Jaki** *Evolution As Science and Ideology* Discussion
20:00	Dinner at the Casina Pio IV

SUNDAY, 2 NOVEMBER 2008

8:30	Departure from Domus Sanctae Marthae to visit the Papal Villa at Castel Gandolfo
10:00	Holy Mass at Castel Gandolfo
11:00	Presentation of the Pius XI Medal
13:00	Lunch at the Papal Villa
15:00	Departure from Castel Gandolfo and return to the Domus Sanctae Marthae
18:30	Dinner at the Casina Pio IV

MONDAY, 3 NOVEMBER 2008

9:00	**Prof. Jürgen Mittelstrass** *Naturalness and Directing Evolution. Some Philosophical Remarks* Discussion
9:40	**H.Em. Cardinal Georges Cottier** *Evolution: a Philosophical Approach* (provisional title) Discussion
10:20	General Discussion
10:40	Coffee Break
11:30	***Audience with His Holiness Benedict XVI***
13:00	Lunch at the Casina Pio IV
Session V **EVOLUTION, ARTIFICIAL INTELLIGENCE AND COGNITIVE SCIENCE** Chairperson: **Prof. Jürgen Mittelstrass**	
15:00	**Prof. Antonio Battro** *Digital Intelligence* Discussion

Session VI **EVOLUTION, PUBLIC PERCEPTION AND POLICIES** Chairperson: **Prof. Nicola Cabibbo**	
15:40	**Prof. Maxine F. Singer** *The Latest Challenge to Evolution: Intelligent Design* Discussion
16:20	Final General Discussion
17:00	Coffee Break
17:30	Closed Session for Academicians
18:30	Dinner at the Casina Pio IV

TUESDAY, 4 NOVEMBER 2008

	Coffee Break
	Lunch at the Casina Pio IV
	Coffee Break
	Dinner at the Casina Pio IV

From Microbial Genetics to Molecular Darwinism and Beyond

In a scientific historical synopsis of genetics and evolutionary biology, the role played by microbial genetics for the development of molecular Darwinism will be outlined. The knowledge acquired in experimental investigations allows us to define three natural strategies to generate genetic variants: local changes in the DNA sequences, intragenomic DNA rearrangements and DNA acquisition by horizontal gene transfer. The resulting genetic variants drive biological evolution, while natural selection, together with the, at any time available, genetic variants, directs the evolutionary progress. The theory of molecular Darwinism postulates that products of evolution genes promote in synergy with a number of non-genetic elements the occasional generation of genetic variants. Philosophical, world view aspects of the postulated duality of the genome will be discussed, as well as consistencies between the acquired scientific knowledge and traditional wisdom such as that reflected in the Old Testament.

WERNER ARBER

Human Evolution as a Historical Process, and the Forces that Drive It

My origin as an experimenter in bacterial genetics led me to appreciate the strength of the scientific method for understanding the world around us, thanks to the experimental approach. Doubt about the validity of experiments and their interpretation is frequent, hence the need of independent repetition of experiments, and of generation of new ones in order to improve their capacity to confirm and expand an explanation based on a specific hypothesis, model or theory. The experimental approach forms the core of the scientific process, thanks to which we reach, in due time, a practically universal consensus on the explanations of the world around us, through a rich, often animated and occasionally protracted discussion of the different hypotheses, models and theories that are continuously presented and modified. By contrast, the historical sciences and the other more abstract fields of research, including philosophy, cannot make and repeat controlled observations, and rarely if ever seem to achieve agreement on theories. Genetics explains evolution with a theory that uses four basic factors or forces to explain the change in successive generations of the composition of populations of organisms belonging to the same species: a) *mutation*, causing rare, discrete, mostly spontaneous changes of DNA generating novelties of inherited characteristics; b) *natural selection*, the ensemble of changes in the composition of populations taking place at every generation because of differences in the probability to survive to reproduction ages and in fertility in the environment in which individuals live, determined by the inherited characters they carry; e) *random genetic drift*, statistical variation in the number of progeny per individual, a chance mechanism the effects of which are predictable by fundamental probability laws; d) *migration*, displacements in space of individuals and populations that generate genetic exchanges between populations of the same species occupying different areas, and allow the expansion of successful species like ours to the whole world. Clearly the last three factors demand demographic information, and the first mostly biological studies. The understanding of the continuous and automatic adaptation to the environment in which we live, made possible and inevitable by natural selection, demands knowledge of our physical and biological environment, i.e. ecology. Knowledge of the past is made possible by archaeology and palaeontology. The structure of human groups is the cause and effect of social interactions studied by anthropology and sociology. The communication among individuals has major importance for regulating social and individual behaviour, and humans have maximized it through the development of language. The study of evolution for organisms as slowly evolving as humans suffers from the same problems of historical research: it cannot use a controlled repetition of observations, modifying at will the conditions so as to test their possible causal roles. But the disciplines listed above can contribute greatly to the study of human genetic evolution, as each of them allows to analyze the same historical process from different points of view. Therefore a multidisciplinary approach can be of great help for all the disciplines, allowing a sort of “repetition” of the historical process by viewing it from different points of view, that can help clarify causal relations and even complicated interactions between various causal factors. Science has undergone enormous specialization of disciplines, and the collaboration between specialists of the appropriate disciplines is becoming absolutely necessary, even if the specialized jargons and concepts generated by every discipline make it at times

difficult. It has already given some important fruit, and one conclusion I would like to emphasize is that drift, i.e. the effect of chance, is more important than previously believed, especially for selectively neutral changes, which is true of the majority of mutations. Many seem to be scared by the consideration that chance has powerful effects on evolution, but the randomness of mutation and drift has advantages. Moreover all variation of living organisms is under the control of natural selection, that filters automatically inherited changes advantageous to the maintenance of all living species, and does it equitably, within the constraints created by the great variety of living organisms. The last phenomenon mentioned above, the development of human language, is the major difference between humans and the other Primates. It is only one of degree but it has given enormous power to another type of evolution, parallel and interactive with the genetic one: the evolution of culture, intended very generally as shared knowledge — including custom, that usually but not always favours social interactions, and also prejudice (that most often does not, almost by definition). Culture has supplemented biological mutation in producing novelties in the form of inventions, i.e. solutions targeted to perceived needs, while mutations are spontaneous and random. Also inventions are relatively rare, but they can spread fast within, and slightly more slowly between populations thanks to cultural transmission, which is only in part *vertical* (from parent to offspring) but is becoming more and more *horizontal* (from anybody to anybody), and makes cultural change faster and faster, as we are witnessing every day. But every species has a chance of becoming extinct. Cultural evolution is becoming so fast, and its negative consequences are often so difficult to predict or prevent, that the chance of extinction of our species has probably been increased by it. We should do everything to make sure that common sense may prevail.

LUIGI LUCA CAVALLI-SFORZA

The Search for the Chemistry of Life's Origin

The supreme property of chemical matter is its potency to have given rise to the emergence of life. Yet life's origin continues to be one of the big unanswered questions of natural science. This notwithstanding, the idea of the emergence of life to have taken place on Earth (or elsewhere) through a transition of chemical matter from *dead* into *living* as a consequence of the workings of the second law of thermodynamics is a central *postulate* of contemporary natural science. The induction of this process by the second law is considered to have been contingent by one group of scientists, imperative according to the belief of others; to both groups the origin of life is conceived as a natural process as much as Darwinian evolution is seen as such, the reality of the latter demanding the reality the former. Such a statement may collide with views of religious nature about evolution and, therefore, life's origin. In this context, and from the rigorous standpoint of experimental science, it may seem in order to remind us of the fact that, in referring to an event supposed to have occurred more than three billion years ago, the scientific view on the origin of life is bound to have, by obvious reasons, the status of a hypothesis; not a hypothesis in the strict *Popper*'ian sense, but nevertheless one that is amenable to experimental scrutiny at least as far such is possible in the attempt of reconstructing a pre-historic process that left us no 'fossils', except life itself.

Life as we know it is a chemical life; thus, within science, it is chemistry that is supposed to play the central role in the interdisciplinary effort to pursue the challenge of scrutinizing the scientific view of life's origin experimentally. Challenged, in fact, is in particular synthetic organic chemistry, not only because the molecular work horses of life are organic molecules, but also – and perhaps most importantly – because an eventual understanding of life's origin will have to rely on experimental demonstrations of the potential of chemical systems to undergo the transition from non-living to living in the laboratory. The eventual aim of such research will be to explore what it means for chemical matter to be alive at a lowest level of complexity, a state of matter intended to be meant by a currently used definition of *minimal* chemical life: a chemical system is alive when, in a given environment, it is self-sustaining and capable of undergoing Darwinian evolution. In the reality of the laboratory, contemporary experimental science is 'light years' of research away from achieving such a 'total synthesis' of artificial chemical life by the bottom-up approach starting from organic molecules. The difficulties of this task sharply contrast with the media-effective promises of (at least some) scientists working in what they call 'synthetic biology', an emerging field that pursues a top-down approach towards the goal of a 'partial-synthesis' of living cells.

A central part of the empirical foundation of the scientific view on life's origin is the experimentally broadly documented generational elementarity of the basic molecular building blocks of life: carbohydrates, alpha-aminoacids, nucleobases, (certain) cofactors, and (certain) lipids. In the wake of the famous Miller-Urey experiment in 1953 which initiated the research field of 'prebiotic chemistry', it has been convincingly shown that most of these building blocks are elementary molecules in the sense that

their formation from (essentially) the elements and excess energy can be spontaneous and proceed under an extraordinarily broad variety of potentially geochemical conditions. Amazing and chemically highly significant coincidences were observed between the constitutional spectrum of products formed under such experimental conditions and the spectrum of organic compounds found in carbonaceous meteorites, coincidences that strongly support the notion of the operation of an intrinsic chemical determinism in the generation of life's molecular building blocks. Such findings led to the concept of a *heterotrophic* origin of life, in which accumulated organic material on the primordial Earth (essentially free of molecular oxygen) is supposed to have gradually organized itself and eventually have led to the formation of informational oligomers systems, such as oligonucleotides and/or tagged oligopeptides, that may have been capable to self-replicate, mutate, thereby create specific catalytic properties and, therefore, evolve in a natural chemical environment. Extensive experimental research during the last five decades aiming at a demonstration of the feasibility of such a scenario of 'chemical evolution' has met with results that can be considered to be a partial success on the chemical level; but at the same time – and this perhaps more importantly – these results must be interpreted to have uncovered the intrinsic weaknesses of, and enormous difficulties connected with, such a scenario for life's origin. Major difficulties refer to problems of concentration, accumulation and selection of reactants, combinatorial reactivity of organic molecules, activation of monomers for the formation of oligomers, turnover of template catalysis in oligomer replication, chemical nature of a primordial metabolism, scarcity of potentially prebiotic catalysts, compartmentalization of reaction sites, and last but not least cellularization.

Some but not all of these problems are eased – at least conceptually - in an alternative view of biogenesis, one that is referred to as the *autotrophic* origin of life. In such models, all the organic material of geochemical and/or extraterrestrial descent generated under excessive energy conditions may have been largely if not completely irrelevant to the actual self-organization process that was leading to life. The basic requisites of such models are a common source of energy (thermal, radiative, or chemical), a common source of carbon (cyanide, carbon monoxide, carbon dioxide), an environment containing the hydrides of oxygen, nitrogen and sulfur besides minerals, and a common (compartementalized) reaction site for a chemistry that is supposed to have been capable of giving rise to the emergence of autocatalytic reaction cycles. It is through such cycles that a primordial chemistry is envisaged to have channeled itself towards a degree of directionality and order by imposing reaction and product selectivity on what otherwise (in the absence of specific reaction-catalysts) would have been a highly multidirectional or even chaotic geochemistry.

Irrespective of whether researchers adhere to the concept of a heterotrophic or autotrophic biogenesis, they agree on the point that whatever the geochemical, physical, locational circumstances and the workings of primordial chemistry may have been, what eventually must have arisen are chemical systems that had the capability to replicate autocatalytically. Replication cycles could have been either self-templating replication processes of informational oligomers, or any kind of molecular reaction cycles that autocatalytically replicate their constituents. In loose analogy to contemporary biology, the two types of cycles are referred to as primordial versions of "genetic" and "metabolic" cycles, respectively. A primordial emergence of replicating informational oligomer systems with the potential to evolve is considered to have been *the* essential event in life's origin according to the "geneticists' school of thought". The "metabolists" maintain what the "geneticists" deny, namely, that autocatalytic "metabolic" cycles also may have had an evolutionary potential and, therefore, that it may have been their emergence that marks the origin of life. Implicit in this view is that such cycles were a prerequisite for a subsequent emergence of genetic systems.

There is a third group of researchers ("compartmentalists") who, irrespective of the dichotomies just mentioned, put on top of everything the fact that all life known on Earth is cellular; they determinedly deny that one can refer to a chemical system as being alive as long as such a system does not operate in a cellular compartment. While the fundamental role of compartmentalization for the capability of a system to efficiently evolve is not an issue, the nature of the compartments and the compartmentalization in the self-organization process remain a matter of debate and a topic for experimental studies.

Experimentally, the problem of the origin of life is being pursued worldwide by 'geneticists', metabolists, and 'compartmentalists' along directions that are determined by the preconceptions the members of the three camps are adhering to. There is no harm in this, on the contrary, in a science that aims at retrodicting the past, prejudices can be powerful motors for important experiments done by the prejudiced. Ultimately, a spectrum of such prejudice-driven research may – and that is one of the strengths of science – produce a platform of *facts*, upon the interpretation of which the community of researchers can eventually agree.

ALBERT ESCHENMOSER

Galaxy Evolution

Galaxies are the building blocks of the universe, tracers of cosmic evolution over the last 13 billion years. They are also the crossroads of Astrophysics, the true link between the present universe we observe and the properties of the early universe. I will review the two processes that rule galaxy evolution, hierarchical clustering process and the secular evolution. Hierarchical clustering is a violent and rapid mechanism that dominated the growth of galaxies at early times. On the other hand, secular evolution is slow but will be dominant in the future universe. I will discuss the observational evidence for both processes.

José G. Funes, S.J.

The Early Evolution of the Universe: Problems and Concepts

There are several problems plaguing all approaches (superstrings, M-theory, loop gravity, quantum groups, noncommutative geometry) to the very early evolution of the Universe: • The structural problem: How to find a mathematical structure rich enough to unify quantum physics and the theory of gravity? • The nonlocality and the background independence problem: After Belle's inequalities, when the EPR thought experiment can be performed in laboratory, we are facing the plethora of nonlocal effects based on entanglement, decoherence, delayed time experiments. How to reconcile them with the time honoured causality and reality postulates? There id a growing feeling that the future quantum gravity theory should be background-independent theory (be it space-time or some other stage-like field). How to achieve this? • The problem of time and dynamics: It seems that the final theory cannot avoid the problem of dynamics, and consequently the problem of time. Which time, if this theory is supposed to be background free? There are some hints (also from the side of noncommutative geometry) that the fundamental level of physics is a temporal. If so, what about dynamics? • The problem of probability: The laws of quantum mechanics, in their standard formulation, are intrinsically probabilistic. Is this a peculiarity of quantum mechanics that will disappear if we have the 'final theory'? Or is it a fundamental property of nature? Quantum probability exhibits some essential differences as compared with classical probability. Are they but variations of some more general probabilistic measure theory? • The generation of matter and space-time problem: Einstein's field equations suffer from a certain duality: their left hand side is purely geometric, whereas their right hand side contains a physical phenomenological entity, called energy-momentum tensor. There were two strategies to get rid of this duality. Einstein himself claimed that it is the matter term (the energy-momentum tensor) that should generate geometry of space-time (this philosophy led to various formulations of Mach's Principle), whereas Wheeler proposed that *vice versa* there are various configurations of space-time that should generate various species of elementary particles (Wheeler's geometrodynamics). Neither of these programs turned out to be successful. If the final theory should be background free, it should provide a mechanism of space-time generation. Should we go a step further and not only try to explain the generation of space-time, but also its material content? • The singularity problem: It is almost commonly believed that the final theory should be singularity free, but this will be not known until we have this theory. It seems that, as far as the existence of the initial singularity is concerned, one can expect either 'yes' or 'not' answers from the final theory. However, if the mathematical structure of the future theory is supposed to be truly more general than the mathematical structures of the present general relativity and quantum physics, is a 'third answer' possible? Could this third answer be related to the probabilistic character of the final theory? And how it would influence dynamical properties of the final theory? These and some other questions will be discussed at some length.

Michael Heller

Modern Life Sciences and Evolution

The process of biological evolution is the foundation stone of modern life sciences. This process was originally inferred with high confidence by comparative studies of similar species that occupy distinct ecological and behavioural niches. More recently, genomic analysis in numerous micro-organisms, plants and animals has revealed a panorama of very ancient, shared and yet diversified types of genes and putative regulatory DNA elements. Experimental biology has confirmed broad functional conservation and progressive diversification of such genes and regulatory elements, consistent with temporal series of the corresponding species, as inferred from the fossil record. A process of neutral evolutionary change has also been documented, deepening our understanding of continuous, even clock-like molecular changes in the DNA. These apparently represent a continuous generation of variants, which are then selected or lost, by positive or negative selection, or by stochastic as well as geologically driven processes of ecological isolation and speciation. In this context, the theory of biological evolution must be understood not according to the popular meaning of theory as an unproven concept,

but as a scientifically established complex process whose description is subject to refinements as more knowledge accumulates. The "creationist science" that is promoted by some fundamentalist currents is simply not an alternative, and undermines the important goal of linking spirituality with logic.

FOTIS C. KAFATOS

Understanding the Great Numbers of the Universe

Physicists describe the world using 'fundamental' or 'universal' constants. In some way the basic physical characteristics of the world depends on the numerical value of such constants. If they change, the world would change drastically. Some important constants are: the speed of light (c), the Planck constant ($\hbar$), the gravitational constant (G), the proton mass (m_p), etc. Although physicists know quite well the numerical values of this constants, there is no theory, which can predict this values from the first principles. John Barrow in his book *The Constants of Nature* tells: 'This is the Holy Grail of fundamental physics and it means the numerical calculation of one of the constants of Nature. This has never been done. So far, the only way we can know their values is by measuring them. This seems unsatisfactory. It allows the constants that appear in our theories to have a huge range of different possible values without overthrowing the theory'. Instead, for description of physical reality, more appropriate seems to use a pure dimensionless numbers. The important role of dimensionless combinations of fundamental constants in describing essential characteristics of physical world was noticed first by Hermann Weyl and further elaborated by Sir Arthur Eddington and Nobel laureates Dirac and Chandrasekhar. Some of this 'large' or 'great' numbers are proportional to 10^{40}, its square 10^{80}, cube 10^{120} and power 3/2 10^{60}. The aim of present report is to show that using Chew-Frautschi-Regge spin – mass paradigm it is possible to derive old and some new Great Numbers relations from simple unifying principle. In the first time in the history of physics and astronomy large number coincidences are derived from physical principle, without any 'numerology'. Cosmological implications of this relations are explored.

RUDOLF MURADIAN

Plant breeding as an example of 'directed' evolution

Crop and forage plants which cover most of our cultivated land and provide, directly or indirectly, most of our food, have not evolved naturally but through intervention of man. Breeders have used the principles of evolution – creation of genetic variation, hybridisation and subsequent selection of the best adapted to specific ecological niches – in several ways: They have increased the frequency of mutation, thus creating more genetic variation. They have encouraged novel genome combinations and recombinations by interspecific hybridisation and embryo rescue. And they have given evolution specific directions by selecting for traits (genes) in their interest, and against undesired traits (genes). And they have combined numerous desired traits (genes) in ever improved varieties to exploit the potential nature has provided them with. Virtually all plants used to date in agriculture and horticulture are not "natural" but "intensely genetically modified" in the interest of man. These plants have little chance for survival in any natural environment, but require continuous care in agricultural habitats. None of these biologically disadvantaged plant varieties would ever have evolved without the intervention of man and they would disappear within few generations without the continuous care provided by farmers in the artificial habitats of agriculture. Without these interventions into natural evolution, there would be no food for the great majority of mankind, and there would not have been the development of culture and civilization as we have experienced in history on the basis of agriculture. Thus far, up into the 80's of the 20th century, the approach to man-made evolution was based on 'trial and error' and 'learning from experience' and knowledge was limited to 'phenotypes'. Thousands of novel varieties for all our crop and forage plants where developed and were consumed without any special precaution. And there was virtually no harm to the consumer. Of course, there were dramatic effects on the environment. Monocultures of crop plants were replacing natural vegetation where ever agriculture was established. The effect was, however, not entirely negative. Numerous plant species could invade – as 'weeds' – the agricultural land, and relatively monotonous natural forests were replaced by a rich novel flora of pre-industrial agriculture. What is, however, most important: on the basis of these massive, 'uncontrolled and unpredictable alterations of the genomes' mankind could increase from a few millions to over 6 billions. With the advent of molecular biology and plant cell culture a refinement and extension of the adoption of plants to the needs of mankind was possible which is now based on 'knowledge and understanding'. Complex phenotypic traits can be analysed on the level of genes, their regulatory signals, and their interactions with other genes in biochemical pathways and cellular networks. Genes for desired traits and appropriate regulatory sequences can be isolated, newly combined, and their function predicted and tested experimentally. They then can be introduced selectively into otherwise unaltered genomes, thus providing 'direction' for evolution even before selection. Undesired

traits such as anti-nutrients or allergens can be inactivated and traits which are not available in a given species can be introduced from other species. These and other technological possibilities enable breeders to exert 'direction' and to 'predict' novel phenotypes by not only selecting gene combinations from increased variation, but by planning variation and gene combinations 'a priory' and making more efficient use of the potential nature is providing to us. This improved technological possibilities are urgently needed to secure food for an increasing world population, from agricultural production systems which are faced with increasing shortages in land, water, manpower, energy, and capital and which are requested to produce food for more and more people with less and less negative impact onto the environment. To save the last remaining refuges of natural environments is only possible if we can produce more food on the agricultural land already in use. There is no alternative to intensive and sustainable production systems. And this requires careful exploitation of science and technology. Paradoxically, as long as 'man-made evolution' was based on 'trial and error', without any other knowledge base than 'experience and phenotype' it was considered 'natural' and was accepted by our society. Now where the same is based on knowledge, science, prediction, and controlled experimentation, the same process is discredited as being un-natural, highly dangerous, and unethical, and of unacceptable risk to mankind and environment. This present attitude lacks any justification from science, experience, logic, and common sense – but it is a widespread psychological fact, and difficult to change with argumentation based on science and logic. This is extremely unfortunate, especially for those underprivileged poor in developing countries, for which food insecurity and malnutrition is an outstanding problem, which takes a daily toll of 24 000 lives per day. Many of these lives could be saved, if Western societies would change their hostile attitude towards this knowledge-based progress in plant breeding technology, which is nothing else but a more sophisticated continuation of the use of genetic modification to the benefit of mankind. Blocking the use of these modern genetic approaches to plant improvement is not justified and has the consequence of hundreds of millions of avoidable deaths.

INGO POTRYKUS

The Latest Challenge to Evolution: Intelligent Design

Science and technology have entered peoples' lives worldwide. People everywhere eagerly adopt new technologies that are themselves dependent on advances in science. And yet, after more than a century and a half and affirmation by countless scientific findings, evolution by common descent and natural selection is still rejected by millions of people. This rejection is stronger in the United States than in most other nations. Decades of polls demonstrate that more than 60 percent of the U.S. population is unconvinced. The most serious real consequence of these views is the continuing battle over the teaching of evolution in U.S. public schools. One reason for the repeated emergence of this debate is the structure of school governance in the U.S. Educational policies are set by the approximately 17,000 separate, local school boards. These boards make final decisions about curricula and textbooks. The members of the school boards are either elected by the local community or appointed by a mayor; in either case local politics is a powerful element in the making of educational policy. The central government has no authority or power to decide on school policy because the U.S. Constitution does not assign that authority to the federal government. The Constitution also provides an effective tool whereby citizens can challenge local decisions to undermine the teaching of evolution. The first amendment to the U.S. Constitution states that Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof. In view of this, 40 years of rulings made by the United States Supreme Court, the ultimate arbiter of legal issues in the nation, support the teaching of evolution. More than 40 years ago, the Court declared unconstitutional state laws outlawing the teaching of evolution. The Court declared the teaching of creationism, the Biblical creation story, in U.S. public school science classrooms unconstitutional and thus illegal. They also declared unconstitutional the teaching of so-called 'creation science' including 'balanced treatment', that is, the presentation of both scientific evolution and creationism. In each case, the Court concluded that creationism is a religious teaching. Nevertheless, individuals, local school boards, state legislatures, and national politicians continue to seek ways to circumvent the law. Recent attacks on the teaching of evolution are based on the old notion that there are aspects of LIVING things that cannot be explained by anything other than an intelligent design. Examples such as eyes and the immune system are described as being 'irreducibly complex' and thus, designed. To try to avoid conflict with the Constitution, the intelligent design proponents decline to say anything about the nature of the implied designer and thus any implication that intelligent design implies a supernatural deity. They present no scientific experiments or observations to support their ideas. Attempts to introduce intelligent design into school curricula were dealt a major blow when, in 2005, a Federal court in Pennsylvania ruled that intelligent design was repackaged creationism and unconstitutional. Most dangerous to science is

the intelligent design community's claim that their concept is scientific and that the definition of science needs to be changed to allow other than natural explanations of natural phenomena. If they were to prevail, science as we know it would be destroyed. This conflict is not going away soon. Already there is evidence of new packaging by those who object to teaching scientific evolution in U.S. schools. And, the movement has begun to move outside the borders of the U.S. to other countries. It is essential in coping with this situation that the scientific community underscore that the issue is what is taught in science classrooms in public schools, not what is taught in history or philosophy. Some students will retain their own religious views; that is their right and privilege in a democratic society. At the same time, however, their science educations must be about science; they can accept or reject the conclusions, but they should learn to understand what scientific research teaches about the natural world. This talk will describe the scientific knowledge about a few of the 'irreducibly complex' biological phenomena that are the focus of the intelligent design community. It will examine how modern biological investigations demonstrate that far from 'irreducibly complex' these very phenomena are already understood. Data will be drawn from studies on the various beak shapes and sizes in Darwin's Galapagos finches, from the development of eyes, and from growing knowledge of the role of development in evolutionary change.

MAXINE F. SINGER

Origin of the Human Species (Mind) Requires Divine Intervention

Central to our ability to explore and understand the origins and evolutional development of the universe, and even of life itself, is the human brain. All that mankind has come to know and will understand in the future, is processed and stored in this most complex and sophisticated organic system. This structure is also the physical repository for human cognitive and ethical performance. This presentation will emphasize the unique structures and patterns of neural organization that are responsible for our intelligence, as well as man's ability to morally and ethically manipulate the environment and its population. The origin and evolution of the human brain itself will be examined from an anthropological standpoint demonstrating the neuro-anatomical similarities and differences between our brains and those of our closest subhuman relatives. In addition, while acknowledging the closeness of man to subhuman primates (i.e. the chimpanzee) in a genetic sense (99% identical), it will be emphasized that there are small significant differences involving the DNA of the neocortex. While this may, in time, help to explain the incredible and unique capabilities of the human mind when compared to that of the apes, something will still be missing. We will argue that at some time in the biological evolutionary course divine intervention with the introduction of a soul/spirit was required to create the unique human species. We will further argue that with the infusion of a soul/spirit at the time of human conception we are, in a sense, witnessing a replication of the creation process of mankind itself. The latest advances in molecular genetics and neuro-imaging will be presented to support the thesis that divine intervention was necessary in the origin and development of man emphasizing that: 'we are created in the image and likeness of God'.

ROBERT J. WHITE

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BOON FALLEUR Thierry
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WITTEN Edward
ZICHICHI Antonino

Memorandum

1) Every day a bus will leave the Domus Sanctae Marthae at 8:45 for the Academy fifteen minutes before the beginning of the session. A bus will depart from the Academy at the end of each session (about 21:00) to take participants back to the Domus Sanctae Marthae. From 31 October to 3/4 November, lunch and dinner for the participants will be served at the Academy except on Sunday, 2 November, when only dinner will be served after the visit to the Papal Villa at Castel Gandolfo.

2) Every day, except Sunday, Holy Mass will be held at 7:00 at the Domus Sanctae Marthae for those who would like to attend.

Note
Please give your **form for the refunding of expenses** to the secretariat at least one day before your departure so that you can be refunded immediately.

Standing Rules for Meetings

1. The Academy invites a number of illustrious scholars who have especially studied a given question and have arrived at different conclusions to meet in Rome at its headquarters, the 'Casina Pio IV', situated in the Vatican City, so as to make a joint examination of all the data on the question.

2. The chief aim of these discussions is to endeavour to reach a common view on the subject of the meeting, but when this is not possible to formulate precisely the reasons for this inability. The scholars invited to these meetings undertake in advance to concentrate their efforts on this.

3. A critical examination of these reasons should lead either to agreement on a partial or provisional solution or else to the conclusion that, on the basis of the information presently available, it is impossible to establish unity on the question concerned. In the latter event the scholars involved will be called upon:

a) to define the reasons why agreement appears to be impossible for the present;

b) to specify the kind of research work it would be desirable to undertake in order to solve the problem.

4. The invitation will be addressed by the Academy to only a small number of representatives of each branch of learning: these will be selected from scholars who are not connected with the Academy. These representatives will be joined during the discussions by members of the Academy who are experts in the same discipline. This invitation, moreover, will apply only to the study of one precise question by each branch of learning.

5. The debates will be strictly private and will take the form of papers and talks in the presence only of a few members of the Pontifical Academy of Sciences who have special knowledge of the subject under discussion.

6. The conclusions arrived at will be published in the form of a 'Statement' (to which may be added individual notes) mentioning:

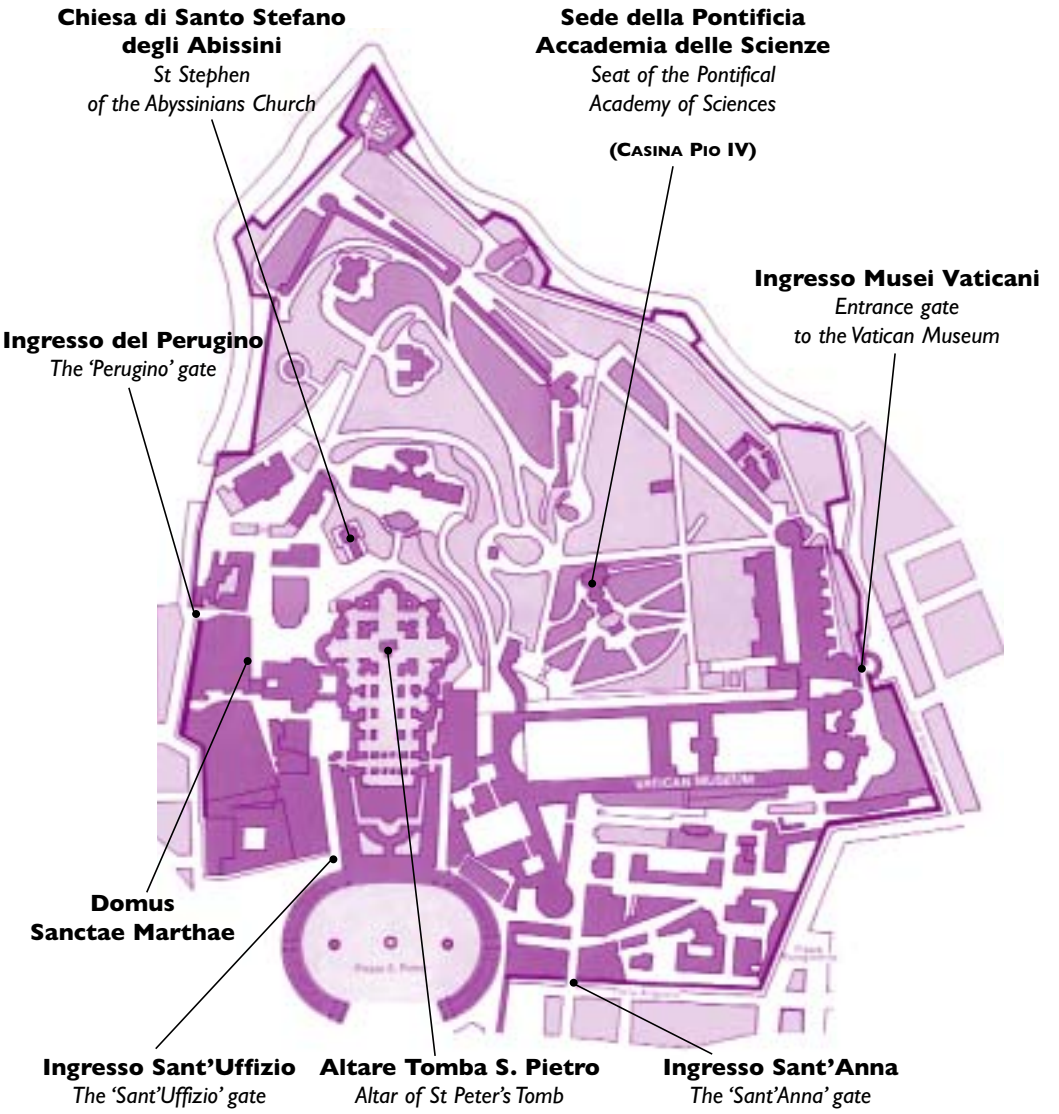
a) the points on which agreement was reached;

b) the points on which it was impossible to reach agreement;

c) the reasons why it was not possible to reach agreement;

d) suggestions about the research work that appears most appropriate in order to arrive at a solution of the difficulties.

7. The 'Statement' arrived at will be immediately printed and transmitted by the Pontifical Academy of Sciences to all the centres of learning which might be interested in it.



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