THE PONTIFICAL ACADEMY OF SCIENCES

Plenary Session on

SCIENTIFIC INSIGHTS INTO THE EVOLUTION OF THE UNIVERSE AND OF LIFE

31 October-4 November 2008

VATICAN CITY 2008

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

WELCOME, COMMEMORATIONS, SELF-PRESENTATIONS AND INTRODUCTION Chair: Prof. Nicola Cabibbo	
9:00	*Welcome* **Prof. Nicola Cabibbo**, President of the Pontifical Academy of Sciences
9:05	*Commemorations* • **Giampietro Puppi** (N. Cabibbo) • **Te-Tzu Chang** (P.H. Raven) • **Kai Siegbahn** (M.G.K. Menon) • **Carlo Enrico di Rovasenda** (G. Cottier) • **Joshua Lederberg** (D. Baltimore)
9:25	*Self-Presentation of New Members* • **Aaron J. Ciechanover** • **Stanislas Dehaene** • **José G. Funes** • **Takashi Gojobori** • **Krishnaswamy Kasturirangan** • **Klaus von Klitzing** • **Yuan-Tseh Lee** • **Cesare Pasini** • **Ignacio Rodríguez-Iturbe** • **Govind Swarup** • **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*
12:45	Lunch at the Casina Pio IV
***Session I* INSIGHTS INTO THE EVOLUTION OF THE UNIVERSE Chair: Prof. M. Govind K. Menon**	
15:00	**Prof. Martin J. Rees** *The Emergence of Complexity from 'Simple' Beginnings* Discussion
15:40	**Prof. Govind Swarup** *Scientific Quest into Evolution of Life in the Universe* Discussion
16:20	**Prof. Stephen W. Hawking** *The Origin of the Universe* Discussion
17:30	Coffee Break
18:00	**Prof. Vera Rubin** *What We Know, and What We Do Not Know, About Our Universe* Discussion
18:40	**Prof. Antonino Zichichi** *Rigorous Logic in the Theory of Evolution* Discussion

19:20	**Prof. José G. Funes** *Galaxy Evolution* Discussion
19:50	**Prof. Rudolf Muradian** *Understanding the Great Numbers of the Universe* Discussion
20:20	General Discussion
20:30	Dinner at the Casina Pio IV

Saturday, 1 November 2008

	Session II **INSIGHTS INTO THE EVOLUTION OF LIFE** **Chair: Prof. Nicole M. Le Douarin**
9:00	**Prof. Albert Eschenmoser** *The Search for the Chemistry of Life's Origin* Discussion
9:40	**Prof. John Abelson** *The Birth of Oxygen* Discussion
10:20	**Prof. Marshall W. Nirenberg** *The Genetic Code and Evolution* Discussion
11:00	Coffee Break
11:30	**Prof. David Baltimore** *RNA and Evolution* Discussion
12:10	**Prof. Giorgio Bernardi** *The Role of Chance in Evolution* Discussion
12:50	**Prof. Rafael Vicuña** *Bacterial Evolution: Random or Selective?* Discussion
13:20	Lunch at the Casina Pio IV
	Chair: Prof. Wolf J. Singer
15:00	**Prof. Werner Arber** *From Microbial Genetics to Molecular Darwinism and Beyond* Discussion
	Session III **INSIGHTS INTO HUMAN EVOLUTION**
15:40	**Prof. Luigi L. Cavalli-Sforza** *Human Evolution as a Historical Process, and the Forces that Drive it* Discussion
16:20	Coffee Break
16:50	**Prof. Takashi Gojobori** *The Evolutionary Origin and Process of the Central Nervous System: Comparative Genomics Approach* Discussion
17:30	**Prof. Christian de Duve** *From the Past to the Future of Life* Discussion

18:10	**Prof. Wolf J. Singer** *The Epigenetic Shaping of Brain Architectures, a Necessary Prerequisite for Cultural Evolution* Discussion
18:50	**Prof. Francis S. Collins** *The Language of God: A Scientist-Believer Looks at the Human Genome* Discussion
19:30	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

Chair: Prof. Werner Arber	
9:00	**Prof. Yves Coppens** *The Bunch of Prehumans and the Emergence of the Genus* Homo Discussion
9:40	**Prof. Fiorenzo Facchini** *Culture in the Hominization and its Implications in an Evolutionary View* Discussion
10:10	Coffee Break
11:30	**Audience with His Holiness Benedict XVI**
13:00	Lunch at the Casina Pio IV
15:00	**Prof. Stanislas Dehaene** *Cognition, Consciousness, and Culture: Understanding Human Specificity and Its Grounding in a Primate Brain* Discussion
Session IV **THEOLOGICAL, PHILOSOPHICAL AND SOCIETAL ASPECTS** **Chair: Prof. Nicola Cabibbo**	
15:30	**H.Em. Cardinal Carlo M. Martini** *Evolution: a Biblical Reading* Discussion
16:10	**Fr. Prof. Jean-Michel Maldamé** *Evolution et création – Sortir d'une fausse opposition entre hasard et création* Discussion
16:50	**Prof. Ulrich Lüke** *The Human Being – God's Plan or Just a Strange Coincidence?* Discussion
17:30	Coffee Break

18:00	**Prof. Gereon Wolters** *The Catholic Church and Evolutionary Theory* Discussion
18:40	**H.Em. Cardinal Georges Cottier** *Evolution: a Philosophical Approach* Discussion
19:20	Dinner at the Casina Pio IV

Tuesday, 4 November 2008

9:00	**Prof. Jürgen Mittelstrass** *Naturalness and Directing Evolution. Some Philosophical Remarks* Discussion
9:30	General Discussion
10:00	Coffee Break
	Session V **IMPACT OF HUMAN ACTIVITIES: EVOLUTION, ARTIFICIAL INTELLIGENCE, COGNITIVE SCIENCE AND PUBLIC PERCEPTION** **Chair: Prof. Jürgen Mittelstrass**
10:30	**Prof. Ingo Potrykus** *Plant Breeding as an Example of Directed Evolution* Discussion
11:00	**Prof. Antonio M. Battro** *Digital Intelligence: the Evolution of a New Human Capacity* Discussion
11:30	**Fr. Prof. Stanley L. Jaki** *Evolution as Science and Ideology* Discussion
12:00	**Prof. Pierre J. Léna** *The Teaching of Evolution* Discussion
12:30	**Prof. Maxine F. Singer** *The Latest Challenge to Evolution: Intelligent Design* Discussion
13:00	Final General Discussion
13:30	Lunch at the Casina Pio IV
15:30	Closed Session for Academicians
18:30	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 in 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

Digital Intelligence: the Evolution of a New Human Capacity

Our society has created a new digital environment, a "virtual" environment where "each generation will become more digital than the preceding one" (N. Negroponte). We must search the explanation of this new and universal "digital intelligence" in the great plasticity of the human brain and its capacity to "recycle" old neural networks (S. Dehaene). Essentially we observe two basic and universal digital skills, the "click option", an elementary decision "to click or not to click", and the "digital heuristics", a series of click options, a network of decisions during the navigation in the virtual space. The click option is related to the executive attention networks, mainly the anterior cingulate and lateral prefrontal areas of the brain. It has been studied in simple cognitive key-press experiments (M. Posner). The heuristics, instead, is similar to the exploration of our common environment. In fact, we find consistent and scale-invariant spatial features as paths, borders, zones, nodes and landmarks in the perception and exploration of any environment, small or large, natural or artificial, in landscapes and townscapes (K. Lynch). These features become relevant in many situations, for instance in the support of the tracking skills of a hunter or in the high performance of a taxi driver in a modern city, where an increase of the hippocampi in the brain of experts drivers has been observed (E. Maguire). The digital analogues of these spatial features are the links, toolbars, folders, buttons and icons of the computer interface and we can hypothesize similar navigation-related structural changes in the brain during the acquisition of a digital skill. Moreover, many early and exceptional digital talents are appearing in all cultures and, on the other side, some brain pathologies that impair the normal acquisition and development of language or mathematics may preserve the use of these basic digital skills, even in extreme cases like right or left hemispherectomized children. We are clearly facing a new cultural evolution without frontiers in the digital era. Many education initiatives around the world, as OLPC, the one laptop per child program (www.laptop.org), show the early unfolding of the digital intelligence in children of the most diverse cultures and socio-economic conditions at early ages. Children can use computers in creative ways, they learn and teach with remarkable ease in the new digital environment. Our challenge now is how to use the new – and universal- digital intelligence in the search of truth, beauty and good.

Antonio M. Battro

The Role of Chance in Evolution

The most famous sentence from *The Origin of Species* (Darwin, 1859), "This preservation of favourable variations and the rejection of injurious variations I call Natural Selection", suggests a dichotomy in the fate of "variations" and is generally interpreted accordingly. This sentence was immediately followed, however, by another one which still is only exceptionally quoted: "Variations neither useful nor injurious would not be affected by natural selection". In other words, Darwin distinguished not two, but three kinds of variations: advantageous, deleterious and neutral. While advantageous variations expand in the progeny (by positive, or Darwinian, selection), the deleterious ones tend to disappear (by negative, or purifying, selection), and the neutral ones may come out of their limbo to be fixed (like the advantageous variations), or to disappear (like the deleterious ones). Incidentally, the concept of neutral variations is absent in Wallace (1858). Neutral variations were simply obliterated by the selectionists (the neo-darwinians: Fisher, 1930; Haldane, 1932) although not by all of them (see Wright, 1931). They were, however, resurrected by the neutral theory, which broke the long predominance of the selectionist theories (see Mayr, 1963). Indeed, Kimura (1968, 1983) claimed that "the main cause of evolutionary change at the molecular level – changes in the genetic material itself – is random fixation of selectively neutral or nearly neutral mutants". Darwin's *survival of the fittest* was replaced by Kimura's *survival of the luckiest*, and darwinian and neo-darwinian evolution were substituted by "non-darwinian evolution" (King and Jukes, 1969). Kimura's revolutionary proposal started a neutralist/selectionist debate, which is still going on (see Graur and Li, 2000) and which concerns the important issue of the role of chance in evolution. A very significant modification of the neutral theory was the nearly neutral theory of Ohta (1973, 1992), who proposed that a substantial fraction of changes are caused by random fixation of nearly neutral changes, a class that "includes intermediates between neutral and advantageous, as well as between neutral and deleterious classes" (Ohta, 2002). I will briefly present a new theory, the neo-selectionist theory of evolution, which is based on many years of investigation on genome organization and evolution. This theory may be seen as an ultra-darwinian theory, in that even neutral and nearly neutral changes are finally controlled by natural selection. This theory brings us back from the survival of the luckiest to the survival of the fittest, or, in other words, from chance to necessity. Incidentally, this quasi-deterministic view is in sharp contrast with Monod's view. • All References will be found in the following article: Bernardi G. (2007). The neo-selectionist theory of genome evolution. *Proc. Natl. Acad. Sci. USA* 104: 8385-8390.

Giorgio Bernardi

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 for the independent repetition of experiments, and the 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. 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 us 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 an 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 Language of God: A Scientist-Believer Looks at the Human Genome

All living organisms carry information using the elegant DNA molecule, and the complete DNA instruction book of an organism is called its genome. The human genome is made up of 3.1 billion DNA letters, and history is likely to record the complete decoding of this instruction book in 2003 as one of humankind's most significant scientific achievements. That foundation has now provided the opportunity for dramatic progress in understanding hereditary factors in human illness, setting the stage for an era of individualized prevention and rational therapeutics. Furthermore, analysis of the human genome across many different population groups has emphasized the close relatedness of all humans, documenting our shared inheritance as descendants of a common founder pool of about 10,000 individuals, who most likely lived in East Africa about 100,000 years ago. Not only the human genome has been deciphered, but so has the genome of dozens of other vertebrates, including our closest relative, the chimpanzee. As the DNA sequence represents a detailed digital code, the comparison of genomes of different species provides an unprecedented opportunity to assess Darwin's theory of evolution. The conclusion that all living things are descended from a common ancestor is now essentially inescapable. That conclusion clearly also applies to humans, as comparison of our genome to that of the chimpanzee and other species is simply inconsistent with special creation. While some atheists have pointed to these discoveries as diminishing God's role in creation and being in conflict with the Book of Genesis, and some fundamentalist believers have rejected the scientific findings on those same grounds, there is no need for those extreme views to carry the day. In fact, thoughtful analysis of Genesis going back to St. Augustine would suggest that the ultraliteral interpretations insisted upon by some believers today are not required by a thoughtful analysis of the language of the Scriptures. Nonetheless, the battle between the scientific and spiritual worldviews seems to be heating up. In

the view of this scientist-believer, this conflict is destructive and wholly unnecessary. A 'Bios (life) through Logos (God's word)', or 'BioLogos' perspective, in which a Creator God, being outside of space and time, used the process of evolution to carry out a creative plan, is entirely consistent with a sensible reading of Scripture and a rigorous analysis of current scientific data. What is needed now is a real dialogue between science and theology, and a rejection of the shrill and entrenched extremist positions that have been dominating the conversation. In the BioLogos view, science is seen as a means of uncovering the details of God's creation, and can even represent a form of worship. Our goal should be to develop a new theology of celebration that incorporates discoveries about the universe in a way that augments rather than diminishes the awe we feel for its Creator.

■ Francis S. Collins

Cognition, Consciousness, and Culture: Understanding Human Specificity and its Grounding in a Primate Brain

One of the key outstanding scientific questions for the 21st century concerns the evolutionary origins of human cognitive competence. How is the human brain architecture organized to support our cognitive abilities? And by what evolutionary process did this architecture emerge? The human species is primarily characterized by its remarkable cultural competence – the capacity to acquire, from its peers, a great variety of mental tools that were not anticipated by evolution. This competence rests, in the final analysis, on the plasticity of the developing brain which authorizes the transformation of evolutionarily older pathways and the laying-down of novel "neuro-cultural" circuits. Within the space of a few years, the child's brain acquires new specializations and competences unique to the culture in which it is embedded. Thanks to education, a spoken language, a writing system, and many other motor, mathematical or artistic competences get inscribed in the brain for the rest of life. Based on recent cognitive neuropsychological evidence, I shall briefly review our current understanding of the human specificity in three areas where it seems most evident: language development, cultural transmission, and consciousness. In each case, we begin to understand how the human mind arises from a complex anatomical and functional architecture of nested neuronal networks, largely inherited from our primate evolution, yet importantly reorganized to support flexible symbolic manipulations unique to humans. **Language development** Language was rightly seen by Descartes as one of the defining features of the human species. My laboratory, under the leadership of Ghislaine Dehaene-Lambertz, has obtained some of the first images of the brain organization for language in 2-to3 month-old infants. Remarkably, a circuit remarkably similar to adults is already in place and can be activated by listening to short sentences. It seems to be hierarchically organized and involved a progression from the bilateral auditory areas towards the left posterior temporal lobe, the bilateral superior temporal sulci, the temporal poles, and Broca's area in the left frontal gyrus. Anatomical precursors of this hierarchical organization are already present in the monkey brain, but the middle temporal gyrus is considerably more expanded in humans and a massive bundle of temporo-frontal connections, the arcuate fasciculus, has seen a large expansion and lateralization towards the left hemisphere. In a nutshell, just after birth, the infant's brain is already biased for language acquisition through the presence of lateralized and hierarchically organized circuits. These early biases precede any overt production of language, even in the elementary form of babbling. However, they shape the early processing of language inputs from the child's environment. **Acquisition of a culture** Cortical specialization exists not only for language, but also for many other domains of cultural competence of the human species. For instance, recognition of written words is systematically associated with the left ventral occipito-temporal cortex, and mental arithmetic with the bilateral intraparietal sulci. This reproducibility of the brain's major cognitive circuitry is remarkable, because although there might have been a specific evolution for language, reading and arithmetic are clearly too recent inventions to have exerted any selective impact on the evolution of specific brain circuits. My proposal is that cultural inventions such as reading invade cortical circuits that initially evolved in a very different context, but are capable of partially "recycling" for novel uses unique to the human species. Each cultural object must thus find its cortical niche, a neuronal circuit which is already structured but exhibits enough plasticity to be reconverted to a novel use. Neuro-imaging and neurophysiological findings support the "cultural recycling" hypothesis by showing precursors of the human adult specialization in infants and even in primate brains. For instance, in 3-month-old infants, the ventral occipito-temporal pathway already activates during visual object recognition, and the dorsal occipito-parietal pathway during the extraction of the numerosity of a set of dots. A similar ventral/dorsal distinction also exists in the macaque monkey, including the presence inferotemporal neurons responding to an "alphabet" of elementary visual shapes, and parietal neurons responding to number. Human education radically expands these abilities by allowing them to become activated, not only directly (e.g. by seeing a set comprising five objects), but also indirectly through the use of cultural symbols (e.g. by seeing the Arabic digit 5 or hearing the word "five"). **Conscious workspace** Symbolic linkages seem to be unique to humans – as is the ability for metaphor, which implies the *de novo* creation of innovative links between otherwise distinct domains. Various neuroscientists such as Luria, Fuster or Goldman-Rakic have emphasized the behavioral flexibility of the human brain and its link to the huge expansion of the frontal lobes in humans. White matter bundles underlying the prefrontal cortex, in particular, seem to have expanded considerably in humans. Guy Elston and his colleagues have described anatomical correlates of this massive increase in connectivity at the dendritic level, where pyramidal cells exhibit a considerably larger number of branches and synaptic contacts in humans than in other species, particularly in prefrontal cortex. Jean-Pierre Changeux and I have explored the theoretical proposal that this connectivity increase, although made possible by small genetic changes, led to a major alteration of the cognitive processing style associated with human prefrontal cortex. In our "global workspace" model, prefrontal cortex is seen as a hub for information exchange that already exists in other non-human primates, but has expanded in the human species and serves to break the processing modularity of other cortical regions, thus allowing for information exchanges that would not otherwise be possible by direct point-to-point connections. We further propose that what we subjectively experience as consciousness is the global availability of information that results from its entry into this neuronal "workspace" with divergent long-distance axons. According this view, although considerable specialized processing can occur non-consciously, access to consciousness is specifically associated with the entry of information relevant to

the goals of the organism into a capacity-limited workspace system that serves to dispatch information to other processors. Neuroimaging experiments have begun to explore the predictions of this theory, by using simple experimental paradigms in which identical or very similar stimuli do or do not lead to conscious perception. Whenever a piece of information accesses consciousness, neuroimaging experiments reveal the sudden ignition of a distributed parieto-prefrontal system and the simultaneous top-down amplification of relevant posterior networks. Long-distance causality relations and phase-coherent oscillations are temporarily established across the relevant cortical areas, thus creating a transient metastable brain-scale assembly. This capacity to transiently link otherwise distant areas may have been a key ingredient in the emergence of human cognitive flexibility and symbolic competence.

Stanislas Dehaene

From the Past to the Future of Life

After more than 3.5 billion years of biological evolution, culminating, in the last few million years, in a dramatic increase of the size and power of the human brain, our species has emerged as by far the most successful in the entire history of life on Earth. Unfortunately, the fruits of our success may contain the seeds of our downfall, written in our genes by natural selection, which has privileged qualities that were useful to our immediate survival and proliferation under prevailing conditions, with no regard for long-term consequences. As a result, we now endanger, by our very success, the material, biological and human conditions that are essential for the survival of humanity on this planet. Our only hope to escape the fate that is threatening us – and, with us, much of the rest of the living world – lies in humanity's unique ability to act consciously, purposefully, and responsibly *against* natural selection. We must stop using our intelligence for the sole purpose of exploiting natural resources for our own benefit; we must curb our innate urge to fight and prevail to achieve our selfish goals; we must cease to consider ourselves the holders of *the* truth and to shun those who think otherwise. Those traits were useful to our ancestors in the distant past and helped them gain their fantastic planetary success. They are no longer beneficial to us. On the contrary, if allowed to continue ruling human behavior, they will spell our ruin. We must urgently learn, instead, to practice rationality, foresight, empathy, tolerance, and wisdom. Those qualities are not written in our genes; but they can be acquired epigenetically by education. For this to happen, however, the educators must themselves be educated. Religious leaders, through their ability to influence huge numbers of people, are uniquely placed to do this. They, accordingly, bear an immense responsibility for the future of humankind and all of life on Earth.

Christian de Duve

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, ac-

cumulation 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

Culture in the Hominization and its Implications in an Evolutionary View

The process of hominization reveals changes in the behavior of the Hominid which marks the appearance of man. This can be recognized when the Hominid realizes strategies of subsistence revealing intelligence and capacity for reflection. The products of instrumental and housing technology, when reveal planning and innovation and take on a symbolic value in the life context, suggest the presence of man. Symbolism, as attribution of a specific significance to something, not only belongs to art or religion (that go over the biological sphere: spiritual symbolism) or to linguistic communication (social symbolism), but it should be recognized even at what man produces intentionally by the technique, if it takes a meaning in the life context (functional symbolism). Ability to project and symbolism make the culture, which characterizes the human behaviour. This attitude is typically human since the origins of man, whatever its manifestations may be (pebble culture or leptolithic culture; hunt organization or artistic and aesthetic manifestations). Innovation and intentional transmission for learning are fundamental in this respect. We discusse on the age when a Hominid can be considered a human being, but if we assume culture as a criterion of presence of man (that is in presence of signs of reflected psychisme, capacity of thought and self-awareness, including the technological expressions), than the hominid can be considered human, whatever its physical evolution level may be. The culture represents a discontinuity in the evolutionary process, because it is not a biological property and does not follow biological laws. Dobzhansky spoke of transcendence for the human threshold, because the rules of human societies are different from those of animal world. The implications of culture in an evolutionary view relate to different levels. On the *palaeontological* level: the higher cognitive functions appear related to the development of cerebralization that characterizes the evolutionary direction of Primates. On the *evolutionary* level: culture enters in the mechanisms of evolution of species, as is a factor capable of facing and contrast intentionally natural selection On the *ecological* level: culture assumes a role of mediation in adaptation to the environment and can be considered "ecological niche" of the human species. On the *phenomenological* level: culture, as expression of higher cognitive capacities, represents a discontinuity to the properties and biological laws, and gives man a conscious subjectivity and freedom (matter starks thinking). On a *philosophical* level: the nature of discontinuity calls into question the spiritual dimension and thus leads to a transcendent sphere (ontological gap); On the *cosmological* level: by thought and conscience the entire universe is thought and becomes conscious. On the *moral or ethical-social* level: in hominization culture activates a process of "humanization" of the physical and social environment, but the future is exposed to the advantages and the risks of human freedom. All that gives man an uniqueness in living world, with the ability to ask questions about itself, its history and its future, and to seek answers.

FIORENZO FACCHINI

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.

Evolution as Science and Ideology

Evolution as science is the mechanism of evolution as specified by Darwin. Evolution as ideology ranges from sheer materialism to revelationary theism. These two meanings of evolution intermingled already in Darwin's publications and the immediate reaction to them. The second phase of that intermingling is found in the reaction to the discovery of Mendel's genetics. The third phase is constituted by the temporary eclipse of Darwinism in the early part of the twentieth century. The fourth is tied to the rise of the synthetic theory of evolution which culminated around the centenary of the *Origin of Species*. The latest or fifth phase is tied to the biochemical approaches to life's origin and to space exploration. The analysis of these phases supports the need for a radical separation of those two meanings of evolution if a sane cultural atmosphere is to prevail.

Stanley L. Jaki

The Teaching of Evolution

Since a decade and worldwide, the need for a high quality scientific education for all children and youngsters is strongly advocated, put forward and supported by the scientific community and the Academies of science. While this action is partly caused by the reluctance of the young generation, especially in developed countries, to choose scientific careers, other important motivations do exist. The need to understand scientific reasoning and scientific issues becomes essential for citizens; sharing the prodigious adventure of contemporary science and its beauty, participating to it are a matter of justice. New curricula, new pedagogies, new training plans and ressources for teachers are conceived and shared worldwide, beginning what could be a revolution in education. Yet, in a globalized world, the combination of the universality of science, as a factor of understanding, development and peace, with the respect of cultural diversity remains a challenge for education. The subject of evolution appears to be at the heart of a possible confrontation of science with religions and inherited representations of nature in the various cultures. Specifying what is legitimate for science to enounce, with its power and its limits, and explaining why this legitimacy does exist, appear essential in order to avoid misunderstandings on the very nature of science, and unnecessary conflicts. Such conflicts appear in today's world and in some cases, invade the schools and confront the teachers with difficult issues which may greatly hamper the very goal of a sound and needed science education. Under the theme of evolution obviously stand the historical emergence of man, the hominisation process, and more broadly the apparition of life on Earth, followed by the whole of biological evolution. But the subject is much wider, since biological evolution on Earth is inscribed in a greater landscape, namely the cosmic evolution, on which astrophysics constantly provides new insights. The emergence of radical novelty is not entirely specific of biological evolution, but also characterizes numerous steps in cosmic evolution. The recent discovery of exo-planets, the wide prospects their ever increasing number offers, broaden the scope of hypothesis and research on biological evolution. Teaching evolution must now take in account this *grand récit* of nature, told by contemporary science. Evolution is characterized by successive transformations appearing in nature, the causes of which are being investigated by science with its methods of questioning, evidence, proof, test and refutation. But the emergence of radical novelties, in the course of evolution, also provokes for many students the question of origins, or even creation. This may lead to a complete mix-up between scientific and metaphysical thought: this confusion clearly appears in the popular vision of the big-bang as being *a creation ex nihilo*, a confusion which was already clarified long ago in the Western thought by Tertullien and Augustin. In face of these challenges and sometimes crisis, the need for sound guidelines, issued by the scientific community, has emerged. In United States, the *National Academy of Sciences* has published in 2006 a revised high quality booklet *Science, evolution and creationism*. In the same year, sixty-eight Academies in the world have jointly elaborated and adopted a document on *The Teaching of evolution*, which could be used to guide school systems and teacher training, and is currently translated in French. Should the Pontifical academy of sciences produce its own Statement on the matter? At the dawn of the Darwin Year 2009, the special status of the Pontifical Academy among Academies in the world, its previous work on educational issues, its ethical and moral role suggest a special responsability for formulating explicitely a clear and unambiguous statement, which would inspire and guide teachers and teaching institutions in their willingness to properly communicate the truth and sense of beauty, revealed by the *grand récit* of contemporary science.

Pierre J. Léna

The Human Being – God's Plan or Just a Strange Coincidence?

In the present debate between creationist theology and evolutionary biology a new front seems to be opening up on old battlegrounds long considered pacified. The main opponents in this battle are a bible-orientated creationism and a materialist and reductionist version of evolutionary biology. What the debate is mainly focusing upon is the concept of coincidence and the consequences which are supposed to ensue from it for humankind and the image that it forms of itself. Some evolutionary biologists claim that due to the randomness of mutation there is no sense in evolution. The only sense they are prepared to admit is an exclusively population-dynamic interpretation of religion. 'Religion survives, because it produces offspring, not because it is true' (von Hayek). Its sense is accordingly said to lie in a 'side effect' of religion, an optimized care for offspring, which is ultimately believed to be its main function. The first aim of this present paper is to clarify, also for the sake of sciences, the concept of coincidence which is often insufficiently specified in biology. What must be distinguished is: 1) objective coincidence, as it is seen to be observable and stochastically quantifiable, but not reconstructible in causal analysis, with phenomena of quantum physics and 2) subjective coincidence, as it occurs in biology for instance, which is in principle accessible to a causal analysis, though not in practice, for practical reasons. Secondly, the paper discusses the question of whether any philosophical conclusions touching on our image of mankind can be reasonably drawn from the concept of subjective coincidence. Does the concept of coincidence as it is seen in biology warrant the assumption that there is no aim, no plan, no sense in evolution (as Monod, Wilson an others have claimed)? Can we conclude from the biological fact that in the course of evolution innumerable species have died out or not developed to any recognizable degree that there is basically no tendency, no direction, no improvement and no increase in complexity (Wuketits etc.)? Both questions must clearly be denied, because without disclaiming the theory of evolution in any sense, it is perfectly possible to interpret the 'randomness' of mutation as an exploratory, innovative and distributive element in a larger plan. Man forms part of an evolutionary process which, not having any knowledge of the origin and the end, he only vaguely understands and cannot approach from an objective viewpoint. Scientifically speaking, he can only speculate about the entirety of this process in a philosophically interesting manner, without staying on the ground of science proper. The physical build of birds reflects the laws of aerodynamics, which they 'extract' from nature, which surrounds them, with-

out any active consciousness. In this case, Man as an extrinsic and superior observer is able in retrospect to discover a plan in the birds' phylo- and ontogenesis, which as far as we know, they themselves cannot understand although they put it into practice. As long as evolutionary biology intends to remain on the ground of science, it must not make any universal claims that transcend what is quantifiable in an empirical manner. A theory of evolution that is philosophically loaded will change into metaphysics, without knowing it or allowing others to know it. If the theory of evolution runs through this change, either in general or with respect to any of its elements (such as 'random' mutation or 'necessary' selection), it runs away from being a science.

Ulrich Lüke

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

Evolution et création – Sortir d'une fausse opposition entre hasard et création

Le but de la communication est de sortir des impasses suscitées par le refus actuel de reconnaître la valeur de la théorie synthétique de l'évolution, tant celle des créationnistes que celle du courant dit Intelligent Design. Pour ce faire, l'attention se portera sur le point qui sert à justifier leur refus : la place du hasard dans le processus de la vie. La démarche se fait en sept points. Le premier donne le sens des termes qui sont liés à la notion commune de hasard dans les sciences et dans la philosophie de la nature. Le deuxième pose la question de savoir si la connaissance de Dieu abolit le hasard pour relever les fondements de cette interrogation et la perspective dans laquelle elle s'inscrit (prédictibilité, aléatoire, statistique…). Le troisième précise la place de la référence au hasard dans la théorie de l'évolution et en donne le statut de cette référence. Le quatrième point entre dans la dimension métaphysique de la question en développant le sens métaphysique du terme hasard : la contingence. Le cinquième point donne le sens exact du terme création, distingué de ses emplois métaphoriques dans les sciences. Le sixième point examine les diverses manières de comprendre l'action de Dieu et désigne les options fondamentales des débats actuels à la racine des exclusions indues, faites tant par l'apologétique que par l'athéisme. Le septième point, enfin, s'interroge sur la référence à la finalité dans les sciences et dans la théologie. Au terme, il apparaît que le rejet de la théorie synthétique de l'évolution au nom de la foi repose sur une erreur tant scientifique que théologique.

Jean-Michel Maldamé

The Genetic Code And Evolution

My colleagues and I deciphered the genetic code between 1961 and 1966. The DNA that we inherit from our parents contains the information that is needed to make the thousands of kinds of RNA and proteins that are the molecular machinery of the body. DNA consists of 4 kinds of letters, T, C, A, and G, in long sequences. DNA is transcribed to RNA that also consists of long sequences of 4 kinds of letters, U, C, A, and G. The sequence of letters in RNA determines the sequence of the 20 common kinds of amino acids found in proteins. The average protein consists of about 300 amino acid residues, but some large proteins consist of thousands of amino acid residues. The two strands of DNA are held together by hydrogen bonds between the letters, termed bases, which are on opposite strands of DNA. T pairs with A, and C pairs with G. The bases in mRNA are translated on ribosomes by transfer RNAs (tRNAs) each specific for an amino acid, which is covalently attached to the tRNA. The tRNAs have anticodons that are complimentary to the codons in mRNA. Aminoacyl-tRNA synthetase enzymes catalyze the attachment of amino acids to tRNAs with high specificity for both amino acids and tRNAs. My colleagues and I found that 3 letters in mRNA, termed a codon, correspond to one amino acid residue in protein and that codons usually are read sequentially. With a 4 letter alphabet there are 64 possible combinations of 3 letter codons. Sixty one of the 64 codons were assigned to amino acids and 3 codons were assigned to termination of protein synthesis. The number of codons per amino acid varies from 1 to 6. In most cases synonym codons contain alternate 3rd bases. Codons have been found for two additional amino acids that rarely are incorporated into protein. Selenocysteine is the 21st amino acid and corresponds to the termination codon, UGA, when the mRNA contains a stem-loop secondary structure in the 3' region of the UGA codon. A number of special factors are required for the incorporation of selenocysteine into protein. Pyrrolysine corresponds to the termination codon, UAG, which is incorporated into some proteins only in a few species of bacteria. After we had deciphered the genetic code in *E. coli* we asked whether the genetic code is universal; i.e., whether the code had been retained during evolution. We determined the genetic code of an amphibian, *Xenopus leavis*, and a mammal, the hamster, and found that the genetic codes were identical to that of *E. coli*. These results have had a profound philosophical effect on me. Subsequently, small variations were found in the genetic code in some organisms and in the mitochondria of different organisms. The mitochondrial genome encodes only about 10 proteins, so it is likely that small changes in the mitochondrial genetic code may be tolerated that might be lethal if expressed in cells whose

genomes encode thousands of proteins. Despite the small variations that have been found, the genetic codes used by all forms of life on this planet that have been studied are very similar. These results strongly suggest that the genetic code appeared very early during biological evolution, that all forms of life on Earth descended from a common ancestor, and therefore, that all living things on Earth are related to one another.

MARSHALL NIRENBERG

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 Emergence of Complexity from 'Simple' Beginnings

In 1859, Darwin proposed how 'while this planet has been cycling on according to the fixed law of gravity, from so simple a beginning, forms most wonderful have been and are being evolved'. These are the famous closing words of his 'Origin of Species'. Cosmologists aim to extend the evolutionary story back before Darwin's simple beginning' – indeed back to an epoch, long before there were any stars, when everything sprouted from an intensely hot 'genesis event', the so called Big Bang, nearly 14 billion years ago. The first microsecond is shrouded in mystery but the emergence of our complex cosmos from simple beginnings is the outcome of processes that we can understand, even though the details still elude us. By combining theories and observations, astrophysicists have begun to understand how the first stars formed, how they assembled together to make galaxies, and how simple atoms of hydrogen and helium gradually get transmuted into carbon, oxygen, silicon, and iron, the building blocks of planets and then of life. And how, on at least one planet around at least one star, a biological process led to atoms assembling into creatures like ourselves, able to ponder the wonder and the mystery. The emergence of complexity depends crucially on the role of gravity – the dominant force on large scales – and on the apparent contingency that the laws of microphysics allow complex chemistry. Indeed the very large and the very small – cosmos and microworld – are two great frontiers of science; it is a challenge for 21st century scientists to unify them. But there's a third frontier: the very complex. We can trace nearly 14 billion years of cosmic history, and detect galaxies more than 10 billion lightyears away. But this immense domain of space and time may be only a tine fraction of physical reality. The timespans lying ahead may be even longer than those that have so far elapsed. We humans are probably not the culmination of evolution on Earth. Any creatures that witness the death of the Sun six billion years hence, here on Earth or

far beyond, will surely not be human; they could be as different from us as we are from bacteria. And 'our' cosmos, the aftermath of our big bang – could extend vastly further than the domain accessible to our telescopes (which is limited by how far light can travel since the big bang). Moreover, 'our' big bang could itself be just one of an infinite number. The laws of nature seem to prevail uniformly throughout the domain we can observe, But they may not be truly universal: in this hugely expanded cosmic perspective, they could be just parochial by-laws, But what, then, would be the universal laws?

■ MARTIN J. REES

What We Know, and What We Do Not Know, About Our Universe

Every civilization, from the time of the earliest humans to the present day, tells stories about the universe. What is known at each epoch is limited by the available technology. During the last century, we learned that we live in a galaxy of ~200 billion stars; at the center of our Galaxy is a Black Hole. Our sun, an average star, is located 30,000 light years from the galactic center. The light that reached us today from the center of our Galaxy began its journey when civilization on earth was just starting its migration across the ancient land bridge now covered by the Bering Sea. Our sun carries its planets with it as it orbits the center of the Galaxy at a speed of 500,000 miles/hour. Even with this high velocity, it takes ~200 million years for the sun to complete one orbit about the center of the Galaxy. We know that the universe is populated by billions of galaxies, and that galaxies are moving away from each other, thus expanding the universe. Equally important, we understand that everything evolves: stars are born, evolve, and die. New stars arise from their remains. Galaxies grow by acquiring neighborhood dust, gas, stars, and smaller galaxies. Luminous galaxies and clusters of galaxies populate the universe. However, in the second half of the 20th Century, observations of rapidly moving stars far from the centers of their galaxies led astronomers to conclude that the stars are moving in response to matter that we cannot see. This dark matter is not radiating at any wavelength, and constitutes most of the matter in the universe. Evidence of dark matter comes from its gravitational effects on the bright matter that we see. A few smart scientists are brave enough to consider an alternative explanation. They suggest that Newton's laws of motion should be modified to describe the orbital motions of stars that are far from the centers of their galaxies. There is a precedent for modifying Newton's laws of gravity. Almost 100 years ago, Einstein used his new relativity theory to modify Newtonian gravitational theory in order to account for peculiarities in the orbit of Mercury, the planet closest to our Sun. As early as 1784, discussions of dark stars were in the literature, although attempts to evaluate the density of these non-luminous objects were rare before the early part of 20th Century. Even more mysterious is dark energy, a force that may be causing the expansion of the universe to accelerate. I believe that our knowledge of the universe is vastly incomplete. In the past century, fundamental features have been discovered every decade. It is unlikely that we have suddenly reached the end of discoveries. The science stories we tell today identify the state of our science at the present time. Future generations will learn more, and tell more complete stories about the universe.

■ VERA C. RUBIN

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 bi-

ological 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

The Epigenetic Shaping of Brain Architectures, a Necessary Prerequisite for Cultural Evolution

The knowledge that is stored in brains and the programs according to which this knowledge is processed for perception and action reside in the functional architectures of neuronal networks. These architectures are to a large extent determined by genetically encoded instructions and become expressed during ontogenetic self-organization. Thus, evolution can be considered as a cognitive process through which organisms acquire knowledge about the world that is expressed in the architecture of their brains. This knowledge is then utilized for the organization of perception and executive functions. However, brain architectures are also influenced by epigenetic factors. Due to the protracted postnatal development of brain structures in higher mammals, functional architectures are specified not only by genetic instructions but to a substantial extent also by experience. This option of epigenetic modifiability opened up a new way of transgenerational transfer of information because knowledge about the world, acquired by the parental generation, could be passed on to the offspring through imitation and intentional education and transcribed into brain architectures just as it is the case for genetically stored information. Knowledge acquired during biological evolution and during early life is addressed as implicit knowledge because subjects have no conscious recollection of possessing this knowledge. This is evident for knowledge acquired during biological evolution. For knowledge installed during early development this is due to the fact that brains of young infants are not yet capable of forming episodic memories. For this reason subjects are usually not aware of having this implicit knowledge nor can they question its contents. Therefore, implicit knowledge has the connotation of convictions and priors. Later during development when episodic memory accompanies the formation of memories, subjects can usually remember the context in which they have acquired a particular knowledge. This knowledge also gets imprinted in the brain circuits and is therefore difficult to modify but it can at least be questioned. It is proposed that this second path for the transgenerational transmission of information is one of the essential ingredients of cultural evolution. Furthermore, it is discussed that cultural differences in early acquired, implicit knowledge about social conditions and value systems are likely to lead to different perceptions of the same reality and are the cause for intercultural conflicts. Because of the implicit nature of the cognitive schemata, these conflicts cannot be resolved within the framework of the categories „right" and „wrong" but require for their appeasement a new culture of tolerance.

WOLF J. SINGER

Scientific Quest Into Evolution of Life in the Universe

After the earth cooled about 4 billion years ago, chemical evolution began and gave rise in due course to viruses, fungi, the cell, prokaryotes, eukaryotes, mammals, primates, homo-erectus and humans. There is considerable scientific evidence that Darwin's emphasis on evolution by natural selection has played an important role in the growth of millions of species. The agrarian development by humans over the last 10000 years gave rise to philosophy, culture and myths. Scientific experimentation, and theoretical developments over the last few hundred years have vastly expanded our understanding of the evolution of the Universe. Surely there are many unanswered questions, but our experimental tools are getting sharper and more powerful and will continue to answer many puzzles. Anthropology, fossil records, modern genetics, astronomy and astrophysics are now rapidly contributing to our scientific quest into the evolution of the Universe and of life on the earth. There are many exciting challenges, e.g. synthesis of living cells that scientists working in the field of synthetic biology hope to demonstrate at least partially, a daunting task but possibly tractable. Another interesting question is whether there is any evidence of bacterial life elsewhere in our solar system. The successful descent of the sophisticated Phoenix probe in the polar region of Mars on 26th May 2008 may provide valuable data in this regard. Some other probes have landed on Mars in recent years. Also orbiting satellites by ESO and NASA are exploring moons of the outer planets such as Jupiter and Saturn. Such explorations of our solar system will elucidate our understanding of the origin and evolution of life on the earth. There are billions of galaxies in our Universe. Each has billions of stars including our Galaxy. Life developed on the earth relatively fast and hence it seems likely that it has existed elsewhere. During the last decade astronomers have already discovered over 250 planets orbiting some nearby stars. Presence of methane has been discovered on one of these planets. Over the next ten years, more than 2000 planets are likely to be found around many stars. Both NASA and ESO are planning to launch satellites to search for any spectroscopic signs of ozone, carbon dioxide, methane, water etc. towards earth like cool planets. Finally, the question: are we alone? Our scientific civilization is only a few thousand years old, negligible compared to the age of 5 to 10 billion years of most stars. Over the last few decades radio astronomers have made searches towards several selected nearby stars using some of the large radio telescopes for any signals that may have been sent by an extra-terrestrial civilization. No signal has been detected so far but the results have helped in determining upper limits on the power flux density incident at the earth. I plan to summarize these results and their implications. Recently the SETI institute in California has set up a special radio telescope for such searches. Much more exciting is the proposed search with the Square Kilometer Array (SKA) that is planned to be constructed during the next decade by more than 17 countries including India. The sensitivity of SKA will be at least 50 times higher than any existing radio telescope. Over the next 20 years, SKA will search towards millions of stars for any signals sent by an advanced civilization and also any leakage signals from their radars or fixed and mobile transmitters.

GOVIND SWARUP

Giorgio Bernardi was awarded degrees at the University of Padua and the University of Strasbourg (France). He spent most of his scientific career with the Centre National de la Recherche Scientifique (CNRS), first at the Centre for Research on Macromolecules in Strasbourg, then at the Jacques Monod Institute in Paris. Since 1998 he has been the President of the Stazione Zoologica Anton Dohrn in Naples and head of its Laboratory of Molecular Evolution. He has published over three hundred and fifty papers in the fields of molecular genetics and molecular evolution, as well as the book *Structural and Evolutionary Genomics: Natural Selection in Genome Evolution* (2004). He is also the Editor-in-Chief of *GENE* and the Chairman of the International Society of Molecular Evolution.

Francis Collins is a physician-scientist and Director of the National Human Genome Research Institute at the U.S. National Institutes of Health. He was previously awarded degrees from the University of Virginia, Yale University, and the University of North Carolina. He led the successful effort to sequence the human genome, ensuring that all of this information was placed in the public domain. Prof. Collins now leads the U.S. research effort to apply this knowledge to human health. In recognition of these achievements, he has twice been a recipient of the Gairdner Foundation International Award, was elected to the Institute of Medicine and the U.S. National Academy of Sciences, and was awarded the Presidential Medal of Freedom in 2007. He has a deep interest in the interface between science and faith, and is the author of *The Language of God: A Scientist Presents Evidence for Belief* (2006).

Yves Coppens was awarded degrees at the University of Rennes and at the Sorbonne. In France, he worked at the National Centre for Scientific Research, the National Museum of Natural History, and the College of France, where he now holds the position of Professor Emeritus. In his own country he is a Member of the Academy of Sciences and the National Academy of Medicine and he is also a Member of the Royal Academy of Sciences of Belgium. He has received a large number of national and international prizes and honours and is the author of numerous books, including *La plus belle histoire du monde* (1996), *Le genou de Lucy* (1999), *Aux origines de l'humanité* (2001, 2002), *Homo sapiens* (2004), as well as over four-hundred scientific papers.

Fiorenzo Facchini, Professor of Anthropology in the University of Bologna from 1978 to 2005, was Responsible of the Unit of Anthropology in the Department of Evolutionistic and Experimental Biology and of the Museum of Anthropology in the same University. Now he is Emeritus Professor of the University of Bologna. Member of many scientific Societies, among them the Academy of Sciences of Bologna, the Italian Institute of Anthropology, the Academy of Natural Sciences of Kazakhstan, the New York Academy of Sciences. International Prize 'Fabio Frassetto' of the Accademia Nazionale dei Lincei (2002). Coordinator of National Programs on the human peopling in Italy granted by the Ministry of University (1998, 2000, 2002). Fiorenzo Facchini developed researches in different fields: human growth, genetic human polymorphisms, ancient populations, prehistoric culture, palaeoanthropology, human adaptation and modernization in Kazakhstan. He organized two expeditions in Kazakhstan (1993) and Kirghizistan (1994) to study the human adaptation to high altitudes and co-ordinated a research on the effects of the modernization in Kazakhstan (2002-2005). He is author of about 400 papers published in national and international journals and of many books, among them: *Il cammino dell'evoluzione umana*, Jaca Book, Milano, 1985, 1995; Croatian edition); *L'uomo. Le origini*. Jaca Book, Milano 1991 (French, Germany, Spanish, Croatian, Japanese editions), *Dizionario enciclopedico di Paleoantropologia e preistoria* (in coll, con A. Broglio e A. Beltran), Jaca Book, Milano, 1993; *Antropologia*, Utet, Torino, 1988, 1995; *Evoluzione umana e cultura*, La Scuola, Brescia, 1999; *Origini dell'uomo ed evoluzione culturale. Profili scientifici, filosofici e religiosi.* Jaca Book, Milano, 2002; *E l'uomo venne sulla terra,* Ed. S. Paolo, 2005 (Spanish edition), *L'avventura dell'uomo.* Ed. S. Paolo, 2006; *Le origini dell'uomo e l'evoluzione della cultura.* Jaca Book, Milano, 2006 (French, German, Croatian, Spanish, Dutch editions); *Le sfide dell'evoluzione. In armonia tra scienza e fede.* Jaca Book, Milano, 2008; *Popoli della yurta. Il Kazakhstan tra preistoria e modernità* (a cura di), Jaca Book, Milano (in press).

Ulrich Lüke was born in 1951 in Münster, Germany. He studied biology, philosophy and theology at the University of Münster and the University of Regensburg. He was ordained priest in 1980 and teacher at the Gymnasium Petrinum till 1992 in Recklinghausen (Ruhrgebiet). 1990 PhD in theology, Münster. Between 1992 and 1998 he works as a parish priest in some villages in the country (Münsterland). 1996 Habilitation for systematic theology, Münster. Getting a professor he taught philosophy at the University of Applied Sciences Freiburg in 1998, at the Theological Faculty of Paderborn history of philosophy from 1999-2001. Since 2001 he is chair of the theological institut at the University RWTH Aachen, Germany, with a side job as a parish priest in Kornelimünster. His main interest is the interface between biology and theology, between science and religion. Publications include: Evolutionäre Erkenntnistheorie und Theologie. Eine kriti-

sche Auseinandersetzung aus fundamentaltheologischer Perspektive, Stuttgart 1990; Bio-Theologie. Zeit – Evolution – Hominisation, Paderborn 1996, 2. Aufl. 2001; Mensch – Natur – Gott. Naturwissenschaftliche Beiträge und theologische Erträge, Münster 2002; Das Säugetier von Gottes Gnaden. Evolution – Bewusstsein – Freiheit, Freiburg 2006, 2. Aufl. 2007

Cardinal Christoph Schönborn was ordained priest in 1970; was appointed Auxiliary Bishop of Vienna in 1991; Coadjutor Bishop of Vienna in 1995; Archbishop of Vienna in 1995; and Cardinal in 1998. He studied at Le Saulchoir, the University of Vienna, the Catholic Institute of Paris, and the Sorbonne. He taught at the University of Fribourg, where he became Professor of Dogmatic Philosophy. Since 1998 he has been President of the Austrian Bishops' Conference. He is a member of the Pontifical Council on Culture and a number of other bodies of the Holy See, and during the 1980s, in particular, he was a member of a number of important commissions working for interconfessional dialogue. He played an important role in the drafting of the *Catechism of the Catholic Church*. In June 2005 he published an article on evolution in *The New York Times* of notable impact and he has spoken at length on this issue in his catechetical lectures given at his cathedral in Vienna. In addition, he organised two meetings of the circle of former students (*Schülerkreis*) of Joseph Ratzinger, with the participation of His Holiness Benedict XVI, on the subject of creation and evolution.

Gereon Wolters was born in 1944 in Leiffarth, Germany. From 1965 to 1972 he studied Catholic theology, mathematics and philosophy at the universities of Innsbruck, Kiel and Tübingen. 1977 PhD in philosophy, University of Konstanz. 1986 Habilitation for philosophy and for history of science. Since 1988 professor of philosophy and history of science, especially biological science. Since 1986 visiting professor at the University of Zurich (Department of Zoology). Since 2004 member of the German Academy of Scientists (*Leopoldina*) (Halle), section for philosophy of science (since 2006 chairman) and member of the senate of the *Leopoldina*. 2008-2012 chairman of a *European Science Foundation* Program 'European Perspectives in the Philosophy of Science'. Publications include: *Basis und Deduktion* (1980); *Mach I, Mach II, Einstein und die Relativitätstheorie* (1987); 'Einschränkungen der Forschungsfreiheit aus ethischen Gründen' (1991); ed. (with James R. Lennox) *Concepts,Theories, and Rationality in the Biological Sciences* (1995); 'The Idea of Progress in Evolutionary Biology' (1997); 'Evolution as Religion' (1999); 'Darwinistische Menschenbilder' (1999); 'Evolving Concepts of Nature' (2000); 'Hans Jonas' Philosophical Biology' (2001); 'Eugenetica in Vaticano' (2004); 'La materia di cui è fatta la vita: concezioni filosofiche del vivente' (2006); ed. (with Peter Machamer) *Thinking About Causes: From Greek Philosophy to Modern Physics* (2007).

For the biographies of the Academicians of the PAS, cf. Pontificia Academia Scientiarvm, *Year Book* (Vatican City 2008), p. 15 ff.

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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 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:

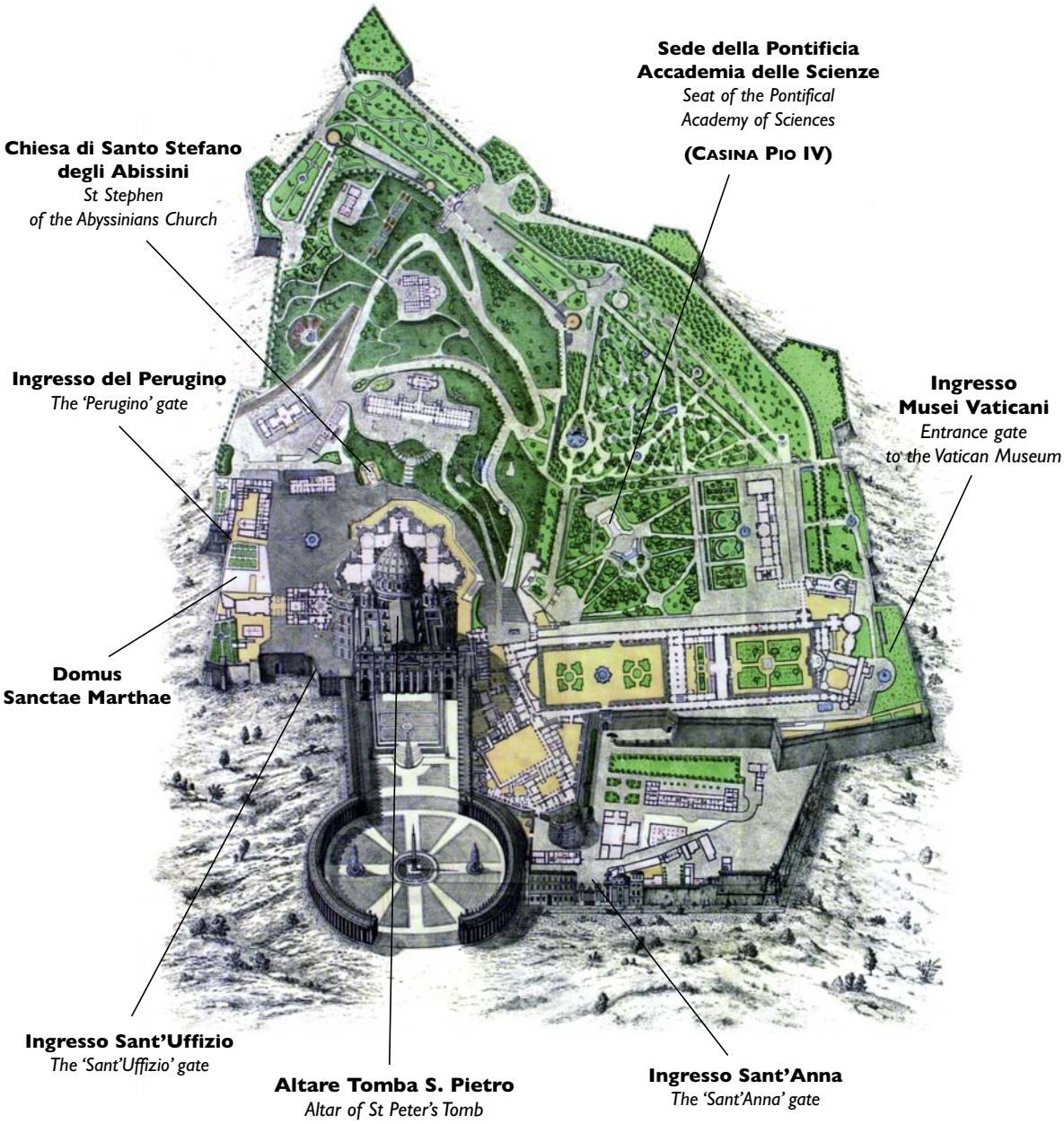
a) the points on which agreement was reached;

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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