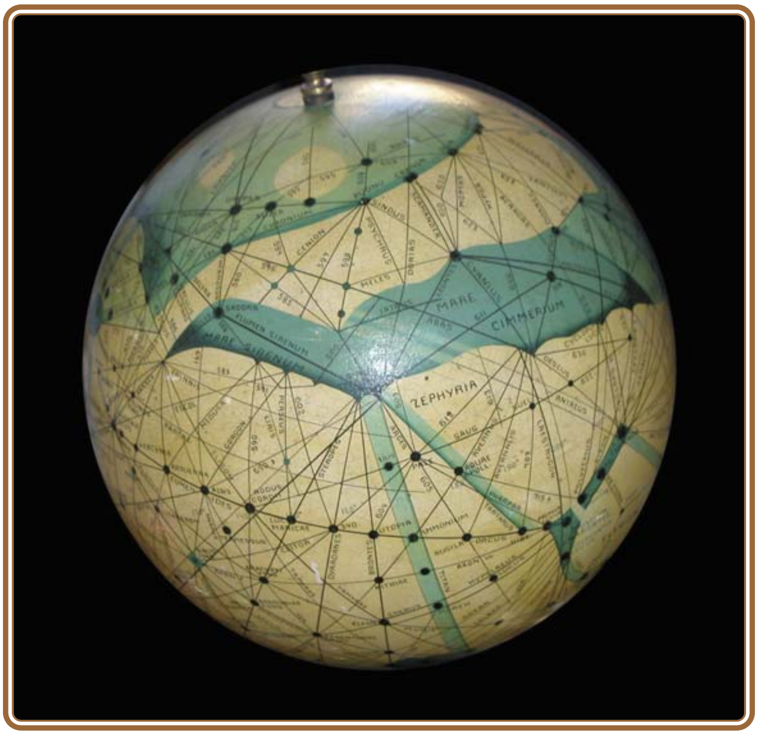
THE PONTIFICAL ACADEMY OF SCIENCES

Study Week on

Astrobiology

6-10 November 2009 • Casina Pio IV



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PONTIFICIA ACADEMIA SCIENTIARVM

VATICAN CITY 2009

Beyond its historical dimension, this mystery of salvation also has a cosmic dimension: Christ is the sun of grace who, with his life, 'transfigures and enflames the expectant universe' (cf. Liturgy). The Christmas festivity is placed within and linked to the winter solstice when, in the northern hemisphere, the days begin once again to lengthen. In this regard perhaps not everyone knows that in St Peter's Square there is also a meridian; in fact, the great obelisk casts its shadow in a line that runs along the paving stones toward the fountain beneath this window and in these days, the shadow is at its longest of the year. This reminds us of the role of astronomy in setting the times of prayer. The Angelus, for example, is recited in the morning, at noon and in the evening, and clocks were regulated by the meridian which in ancient times made it possible to know the 'exact midday'.

The fact that the winter solstice occurs exactly today, 21 December, and at this very time, offers me the opportunity to greet all those who will be taking part in various capacities in the initiatives for the World Year of Astronomy, 2009, established on the fourth centenary of Galileo Galilei's first observations by telescope. Among my Predecessors of venerable memory there were some who studied this science, such as Sylvester II who taught it, Gregory XIII to whom we owe our calendar, and St Pius X who knew how to build sundials. If the heavens, according to the Psalmist's beautiful words, 'are telling the glory of God' (Ps 19[18]: 1), the laws of nature which over the course of centuries many men and women of science have enabled us to understand better are a great incentive to contemplate the works of the Lord with gratitude.

Benedict XVI, Angelus, St Peter's Square,
Fourth Sunday of Advent, 21 December 2008

INTRODUCTION

Prof. Jonathan I. Lunine, chair of the Scientific Organizing Committee
Dr. José G. Funes, S.J., Director of the Vatican Observatory

Astrobiology is the study of life's relationship to the rest of the cosmos: its major themes include the origin of life and its precursor materials, the evolution of life on Earth, its future prospects on and off the Earth, and the occurrence of life elsewhere. Behind each of these themes is a multidisciplinary set of questions involving physics, chemistry, biology, geology, astronomy, planetology, and other fields, each of which connects more or less strongly to the central questions of astrobiology. Stimulated by new capabilities for scientific exploration on and off the Earth, astrobiology seems to be establishing itself as a distinct scientific endeavor.

The study of Astrobiology is a quite appropriate subject for the Pontifical Academy of Sciences which has a multi-disciplinary membership.

The study week being undertaken by the Pontifical Academy of Sciences has an ambitious agenda: to bring together leading scientists in these diverse fields, to share the latest results of their own research and provide a broader perspective of how these results impact other areas of astrobiology. To accomplish these goals successfully will not be easy, because the language – really, to be honest, the jargon – of each of the fields represented by the speakers is not broadly understood. How does one explain to an astronomer the intricacies of chemical markers of biological activity in ancient Earth sediments? Or conversely, how can a molecular biologist be briefed with adequate depth on the latest astronomical techniques for detecting planets? The paradox of astrobiology is that, while one might regard it as a rather narrow and specialized endeavor, one cannot hope as an individual to adequately understand the span of traditional disciplines that form the backbone of the field.

The study week, then, is very much a cross-disciplinary education for experts in one field to gain insight and understanding in other more distant disciplines – but always under the reasonably well-defined rubric of astrobiology. This is nothing new: for the 13 years that astrobiology has been recognized as a nascent field unto itself, scientists have been educating each other in an effort to understand one another's fields. But oftentimes this comes in the environment of the frenetic 'annual conference', that phenomenon of modern scholarship in which the maximum number of talks is packed into the space of a few days, leading to a kind of intellectual bazaar in which scientists shop for nuggets of information (usually, for convenience, in their own discipline), check to make sure that competitors are not hawking the very wares they seek to proffer, or (rarely), venture forth into sessions outside of their own expertise, to puzzle over just what is being said. More focused workshops in astrobiology, as in other sciences, of course occur; but most often in one subfield. In any given month geologists might be meeting in Vancouver to pour in depth over the latest results on the most ancient appearance of fossils in the terrestrial rock record, while in Rio astronomers pour over new data on the abundance of the life-forming elements in nearby star-forming regions, and in Potsdam planetary scientists discuss the latest evidence for life occurring beneath the oxidizing surface of Mars.

The present study week is not a unique event, but it is a relatively rare one. A focused week in which (relatively) cloistered astrobiologists confront each other's fields of research and try to understand them is a difficult but heady undertaking. To make this feasible in a practical amount of time, we have carefully selected speakers who can make their own particular fields of research understandable to astrobiologists from other fields, indeed even to the intelligent layman, and who can connect their research to the broader problems of astrophysics.

The program is organized into eight sessions. Session 1, on **The Origin of Life**, concerns the difficult problem of the mechanisms by which molecules became organized in such a way as to permit life to begin. Life as we know it on Earth is built on a structure of proteins and nucleic acid polymers which carry the information to build the proteins from their constituent amino acids. While complex, life is a very specific and selective organic chemistry: out of the broad range of possible organic acids that abiotic systems can produce, life utilizes just a handful; likewise, life largely utilizes just left-handed amino acids and right handed sugars. There is much more to the biochemistry of life than this, but it is exemplary of the challenge chemists and biochemists face in understanding how the cacophony of abiotic organic chemistry evolved into the structured symphony of life. Likewise, teasing out of the scant geologic record of the early Earth some indication of the environmental conditions under which life formed is an extremely difficult task, because geologic activity – the forces of tectonics, erosion, impacts of asteroidal material – have largely erased the evidence of the Earth's environment in its first half-billion years after formation.

Session 2, **Habitability Through Time**, concerns the problem of how the Earth has been able to sustain life over its long geologic history. Here the geologic record is more ample than that during the time life is presumed to have begun (and, it should be made clear, we have no precise understanding of when that in fact occurred). But now the processes are more complex: a variety of scales of space, time and energy come into play. The Sun itself, which is often tacitly regarded as the stable sustainer of the liquid water essential for life as we know it, was approximately 30% less bright early in the Earth's history than it is today. Yet geological evidence for liquid water on Earth's surface when the Sun was so faint suggests that our atmosphere must have provided a much stronger greenhouse effect than, and been quite different from, that of today. Episodes of severe glaciation in the geologic record suggest that from time to time the atmospheric 'thermostat' failed.

How life – even at the molecular level – and the environment have interacted over geologic time is the subject of Session 3, **Environment and Genomes**. Molecular signatures of the biochemical reactions sustaining life remain in the geologic record, giving us hints of the changes over vast periods of time. Lessons from life forms that live in extreme environments, such as submarine vents and the Earth's driest deserts, aid the interpretation of this record. The relatively sudden appearance of animal life late in the Earth's history remains a mystery whose solution might be found in both the environment of the time and the workings of the genome.

Earth seems to be unique in our solar system in terms of its abundant life, and yet we cannot be sure that life is not present on Mars or elsewhere in the solar system. Session 4, **Detecting Life Elsewhere**, explores the prospects and techniques for finding life in a variety of environments elsewhere in the solar system, beyond Mars to the asteroids and the moons of Jupiter and Saturn.

Whether or not life exists elsewhere within our own solar system, the vast Milky Way Galaxy of which we are a part contains over 100 billion stars. If planets are a common feature of such stars, might life be as well? The next three sessions explore in a systematic fashion the detection, formation, and properties of planets around other stars: 'extrasolar planets'. Session 5, **Search Strategies for Extrasolar Planets**, explains the various techniques used to find planets around other stars and determine their properties. Already, about 380 extrasolar planets are known, and the number of stars searched suggests that at least 10% of stars similar in properties to our own Sun have at least one planet. Session 6, **Formation of Extrasolar Planets**, details progress in understanding how planets form as a part of the process of the formation of stars. Two outstanding questions are what determines when a rocky planet like the Earth will form versus a gas giant like Jupiter, and is the process of planet formation materially different around stars much smaller than our Sun. Finally, Session 7, **Properties of Extrasolar Planets**, brings to bear computer modeling, astronomical data and a bit of speculation on the question of the properties of extrasolar planets as a function of the properties of, and distances from, their parent stars.

Ultimately, much of the fascination of astrobiology comes from the question of whether sentient life forms exist on other worlds, and whether forms of life alien to our own in fact coexist with us – today – on our own home world. Session 8, **Intelligence Elsewhere and Shadow Life**, explores both these issues. The search for intelligent life elsewhere is being conducted by listening to the cosmos with radio telescopes in an effort to pick up a signal of inarguably artificial origin. A search for life with a biochemistry different from that of all the known life on Earth – what has been termed 'shadow life' – on our own planet is a fascinating possibility but one fraught with daunting difficulties.

Astrobiology is an effort to use a diverse range of scientific techniques, focused on targets from the molecules in cells to the vast cosmos around us, to provide a deeper appreciation of humankind's place in the cosmos. It is a recognition of the remarkable intricacies of all that is within and around us and a 21st century realization of the psalmist's recommendation (*Ps* 111:2) to delight in its study.

Friday, 6 November 2009

9:00	*Word of Welcome, and Greeting by the Holy Father* **H.Em. Card. Giovanni Lajolo**
9:20	*Outstanding Questions in Astrobiology* **J.I. Lunine**
Session 1 • Origin of Life (Chair J.I. Lunine)	
10:00	*Kinetics, Catalysis, and the Origin of Metabolism* **S.D. Copley**
10:40	Coffee break
11:10	*Towards a Theory of Life* **S. Benner**
11:50	*The Geological Record of Early Life on Earth (and its Limitations)* **F. Westall**
12:30	*Discussion on Session 1* **J.I. Lunine** (lead)
13:10	Lunch at the Casina Pio IV
Session 2: Habitability Through Time (Chair E.J. Gaidos)	
14:50	*The Earliest Earth's Atmosphere* **F. Selsis**
15:30	*Evolution of Earth's Atmosphere and Climate* **J.F. Kasting**
16:10	*Snowball Earth: Causes, Occurrences & Habitability* **J.L. Kirschvink**
16:50	Coffee break
17:20	Discussion on Session 2 **E.J. Gaidos** (lead)
Session 3: Environment and Genomes (Chair F. Westall)	
18:00	*Life & Environment in Earth's Middle Age* **A.H. Knoll**
18:40	*Molecular Signatures of Life Through Time* **R.E. Summons**
19:20	Dinner at the Casina Pio IV

Saturday, 7 November 2009

9:00	*Submarine Hydrothermal Vents: Limits of Life, Early Evolution and the Search for Habitable Planets* **J. Baross**
9:40	*Conditions During the Emergence of Animal Life* **E.J. Gaidos**
10:20	Coffee break
10:50	*The Atacama Desert as an Analog Model for Mars* **R. Vicuña**
11:30	*Discussion on Session 3* **F. Westall** (lead)
	Session 4 • Detecting Life Elsewhere (Chair A.H. Knoll)
12:10	*Europa: Next Destination in the Search for Life* **M. Blanc**
12:50	Lunch at the Casina Pio IV
14:30	*Titan and Enceladus: Astrobiological Analogs with Earth* **A. Coustenis**
15:10	*Life in Water-Rich Asteroids?* **J.C. Castillo-Rogez**
15:50	*Early Mars: Cradle or Coffin?* **R. Pierrehumbert**
16:30	Coffee break
17:00	*Discussion on Session 4* **A.H. Knoll** (lead)
18:00	Dinner at the Casina Pio IV

Sunday, 8 November 2009

7:00	Bus leaves Domus Sanctae Marthae on pilgrimage to Assisi
12:00	Holy Mass at the Basilica of St Francis in Assisi celebrated by H.Em. Card. Giovanni Lajolo
13:30	Lunch at Assisi
19:00	Dinner at the Casina Pio IV

Monday, 9 November 2009

Session 5 • Search Strategies for Extrasolar Planets (Chair C. Impey)	
9:20	*Search and Characterization Strategies* **S. Seager**
10:00	*Review of Detected Low Mass Planets* **C. Lovis**
10:40	Coffee break
11:10	*Study of Exoplanet Atmospheres and the Small Star Opportunity* **D. Charbonneau**
11:50	*Low-Mass Planets Around Faint Nearby Dwarf Stars* **D. Minniti**
12:30	*Discussion on Session 5* **C. Impey** (lead)
13:10	Lunch at the Casina Pio IV
Session 6 • Formation of Extrasolar Planets (Chair D. Minniti)	
14:30	*Formation of Giant Planets* **W. Benz**
15:10	*Formation of Earth-Sized Planets* **S.N. Raymond**
15:50	*Discussion on Session 6* **D. Minniti** (lead)
16:30	Coffee break
Session 7 • Properties of Extrasolar Planets (Chair R.T. Pierrehumbert)	
17:00	*Characterising Exoplanet Atmospheres, from Gas Giants to Terrestrial Habitable Planets* **G. Tinetti**
17:40	*Habitability of Exoplanets* **D.D. Sasselov**
18:20	*Discussion on Session 7* **R.T. Pierrehumbert** (lead)
19:00	Dinner at the Casina Pio IV

Tuesday, 10 November 2009

9:00	*Briefing on Proceedings Volume* **J.G. Funes/C. Impey**
	Session 8 • Intelligence Elsewhere and Shadow Life (Chair S.A. Benner)
9:30	*SETI Turns 50* **J.C. Tarter**
10:10	*Searching for Multiple Origins of Life* **P. Davies**
10:50	Coffee break
11:30	*Discussion on Session 8* **S.A. Benner** (lead)
12:10	*Reflections on the Future of Astrobiology* **C. Impey**
12:50	*Final Remarks and Work on the Summary Statement* All
13:30	Lunch at the Casina Pio IV

Submarine Hydrothermal Vents: Limits of Life, Early Evolution and the Search for Habitable Planets

JOHN BAROSS

The two types of hydrothermal vent environments, magma-driven and peridotite-hosted, offer many contrasting habitat conditions for microbial communities. These environments span a wide range of chemical and physical conditions that include almost all of the extremes in temperature, Eh, salinity and heavy metal concentrations that limit where life can exist. Moreover, vent microorganisms have adapted to habitat conditions that include flowing fluids, porous spaces within basalt, sulfides and sediments, the surfaces of rocks and animals and the subseafloor potentially to depths in the crust exceeding 6 km. Hydrothermal systems produce volatiles, such as H_2, H_2S, CH_4, CO, CO, and trace metals that are important sources of carbon and energy, and nutrients for organisms. The sources of volatiles include magma degassing, water/rock reactions, and abiotic reduction of CO_2 to methane and possibly other organic compounds. All of these reactions take place in the subseafloor and are not always dramatically expressed on the seafloor. Recently, a peridotite-hosted hydrothermal vent environment was discovered on the Mid-Atlantic Ridge. This environment, named the 'Lost City Hydrothermal Field' is a source of high concentrations of hydrogen and methane and organic acids and hydrocarbons produced abiotically from serpentinization reactions that take place in the crust. Hallmark characteristics of both types of high temperature hydrothermal vent microbial communities are that they utilize hydrogen as a primary energy source and they exist as biofilms. This is interesting in that there are parallels between the energy metabolic reactions of these microbial biofilms and the chemistry of the H_2-CO_2 redox couple that are present in hydrothermal systems, thus indicating the possibility that vent autotrophy might provide clues about the kinds of reactions that initiated the chemistry of life. Moreover, an argument can be made that obtaining evidence for active tectonics and hydrothermal activity on any planetary body (presently or in the past), mechanisms that are vital for extracting life-supporting volatiles and elements from rocks and creating diverse environmental settings, would increase the probability for its ability to support life.

Towards a Theory of Life

STEVEN A. BENNER

One of the most reductionist definition-theories for life holds that it is a self-sustaining chemical system capable of Darwinian evolution. While this has been advanced as a universal definition-theory, it is clearly Earth-centric, as it conforms closely to the features of the terran life that we know. This talk will survey four general approaches that have exploited this definition in the Benner laboratory to understand the concept of 'life' as a universal, assessing its likely form and distribution in the cosmos. The first works backwards in time from modern life, using biotechnology to resurrect ancient genes and proteins for study in the laboratory. Another works forward in time, starting with simple organic molecules that are formed without life, to ask how these might have self-assembled to give the first living systems. The third considers 'weird' environments in the solar system, those that deviate significantly from those on Earth that hold terran life. The last involves synthesis, where self-replicating Darwinian systems are constructed artificially to see what emergent properties in biology they can yield. Together, these four approaches are constraining the 'black box' that capture the phenomenon of 'life' according to current reductionist theories of life to understand the potential and limitations of such simple models.

The Formation of Giant Planets

WILLY BENZ

Since the discovery in 1995 of the first planet outside the solar system by the Swiss astronomers Michel Mayor and Didier Queloz, over 350 exoplanets have now been found. While most of them are giant planets, stunning improvements in the detection techniques allows today the discovery of planets only a few times more massive than the Earth. With increasing numbers, the population of exoplanets begins to provide strong constraint to planet formation models. Quantitative comparisons between observations and theoretical calculations are becoming possible through a population synthesis approach. Such comparisons allow identifying the major uncertainties and their observational consequences. In this talk, I will briefly review the recent progress in the theory of giant planet formation and pinpoint these major uncertainties. In addition, I will stress the importance of considering the formation of giant and terrestrial planets simultaneously and self-consistently.

Europa: Next Destination in the Search for Life

MICHEL BLANC

The exploration of the Jovian System and its fascinating satellite Europa is one of the priorities presented in ESA's 'Cosmic Vision' strategic document. The Jovian System indeed displays many facets. It is a small planetary system in its own right, built-up out of the mixture of gas and icy material that was present in the external region of the solar nebula. Through a complex history of accretion, internal differentiation and dynamic interaction, a very unique satellite system formed, in which three of the four Galilean satellites, Europa, Ganymede and Callisto are locked in the so-called Laplace resonance. The energy and angular momentum they exchange among themselves and with Jupiter contribute to various degrees to the internal heating sources of the satellites. While all three are likely to host sub-surface oceans, only Europa's ocean is believed to extend between its geodynamically active icy crust and its silicate mantle, possibly providing the main conditions for habitability. For this very reason, Europa is one of the best candidates for the search for life in our Solar System. We will review our current understanding of how these habitability conditions may be fulfilled at Europa, and what measurements need to be performed there with a dedicated mission to Europa. To understand in a more generic way habitability conditions around giant planets, we also need to go beyond Europa itself and address two more general questions at the scale of the Jupiter system: to what extent is its possible habitability related to the initial conditions and formation scenario of the Jovian satellites? To what extent is it due to the way the Jupiter system works? For these reasons NASA and ESA are embarking on a joint mission to the Jupiter system, involving an orbiter of Europa and an orbiter around Ganymede, the largest moon in the solar system. Pending final selection in the ESA Cosmic Vision implementation process, the mission would launch in 2020, some three years after the anticipated completion of Cassini.

Life in Water-Rich Asteroids?

Julie C. Castillo-Rogez

Large, low-density C-type asteroids are abundant in the main belt. The most prominent of these objects is the dwarf planet Ceres, which presents an advanced stage of evolution. Ceres is almost twice as large as Enceladus, and both objects contain more than 50% of water in volume. Although asteroids cannot benefit from tidal heating like outer planet satellites, their proximity to the Sun warrants an everlasting supply of energy. Observations with the Hubble Space Telescope and geophysical modeling indicate that Ceres is likely to be differentiated. Besides, warm surface temperatures may promote the preservation of a deep liquid layer, if the water shell contains second-phase volatile impurities and hydrated minerals. Indeed, even if Ceres were 'frozen', i.e., its interior were in thermal equilibrium with its surface, then its internal temperature would still reach at least 180 K in low-latitude regions. These conditions offer a context suitable to endogenic activity involving the exchange of material between the interior and the surface. Recent ground-based observations indicate the presence of brucite and magnesite at the surface of Ceres, the signature of pervasive hydrothermal alteration whose origin, surficial or due to internal processes, remains to be understood. The many questions raised by astronomical observations of Ceres will hopefully be answered by the *Dawn* Mission that will visit the protoplanet in 2015. The *Dawn* Mission is instrumented with the capability to measure composition and constrain internal properties and geological evolution. This information will help better assess the astrobiological potential of the dwarf planet. Other, large C-type asteroids may also harbor habitable conditions as a result of warm surface temperature. We will review the main characteristics of these protoplanets, discuss possible formation scenarios for these objects, address their genetic link to meteorites, and discuss their habitability potential. We will also present ongoing plans for the future exploration of these objects and the techniques that can be used for constraining their internal structure and habitability.

The Study of Exoplanet Atmospheres and the Small Star Opportunity

David Charbonneau

When exoplanets are observed to transit their parent stars, we are granted direct estimates of their masses and radii, permitting us in turn to infer a bulk composition and a likely formation history. Perhaps most intriguingly, transiting planets also afford studies of their atmospheres, both through the study of starlight transmitted during transit, and through the modulation of infrared emission when the planet disappears behind its parent star during an event known as secondary eclipse. In the past decade, these methods have yielded stunning advances in our understanding of gas giant exoplanets and their atmospheres. Yet it is only during the last months of 2009 that astronomers have uncovered the first transiting examples of much smaller bodies composed primarily of rock and ice. Should we succeed in finding examples of such planets in the habitable zones of low-mass stars, then we could undertake the study of their atmospheres in the next 5 years and jumpstart our hunt for biomarkers in the atmosphere enshrouding a world orbiting another star.

Kinetics, Catalysis and the Origin of Metabolism

Shelley D. Copley

Catalysts are essential for life; nearly every reaction that occurs in extant cells is catalyzed by an enzyme. Catalysts must have been essential for the emergence of life, as well, enabling a proto-metabolic network that supplied the precursors of macromolecules. Early catalysts such as minerals and small molecules would likely have been inefficient relative to the prodigious enzymes of today, but still important for accelerating rates of useful reactions. Although the importance of rate acceleration by catalysts is obvious, a less-appreciated role for early catalysts would have been to prune complex proto-metabolic networks by channeling molecules through particular pathways and thereby allowing accumulation of higher concentrations of a few components, rather than low concentrations of many components. This principle will be illustrated by experiments showing that pyruvate is converted to different products by different minerals found in hydrothermal vents. These results suggest that mapping of catalytic reactivity space with respect to mineral type, small molecules, temperature, and pH is needed to delineate the various microenvironments that may have contributed to proto-metabolism and the suite of molecules available for life. A model for how early catalysts may have promoted the emergence of the RNA World will also be discussed.

Titan and Enceladus: Astrobiological Analogs with Earth

Athena Coustenis

Titan is currently the only confirmed exobiotic environment known to us. It is also perhaps the most intriguing object in our Solar System. Our understanding of Titan, and of its kronian sibling Enceladus, has been greatly enhanced by the data returned by the Cassini-Huygens mission since 2004 and still operating on the spot. Thus, we know today that the thick atmosphere layer – covering the satellite's mysterious surface – is essentially made of nitrogen, with small amounts of methane and hydrogen. The combination among these mother molecules produces an exciting organic chemistry in Titan's atmosphere, with hydrocarbons and nitriles (one of the latter, HCN, is a prebiotic molecule). The organic chemistry, climate conditions, meteorology, methane cycle and other aspects of the surface make Titan an extremely important astrobiological place. Similarly, a strong bioastronomical potential is afforded by Enceladus who is surrounded by an atmosphere created by water ice and organics ejections coming from the interior. I will discuss our current understanding of the astrobiological aspects of the two satellites as inferred from current and past observations. After the Cassini-Huygens mission, there will remain several unanswered questions on the astrobiological aspects of the satellites which will require a future mission with an optimized orbital tour, specific in situ elements and advanced instrumentation, such as the Titan Saturn System Mission studied in 2008.

Searching for Multiple Origins of Life

Paul Davies

Astrobiologists are aware that extraterrestrial life might differ fundamentally from known life, and considerable thought has been given to possible signatures that might attach to weird forms of life on other planets. So far, however, very little attention has been paid to the possibility that our own planet might also host microbial communities of weird life – that is, life as we do not know it. If life arises readily in earthlike conditions, as many astrobiologists contend, then it may well have started many times on Earth itself, raising the question of whether one or more shadow terrestrial biospheres of alternative life forms have existed in the past, or still exist today. The issue is critical to the question of whether or not we are alone in the universe, because if life has started from scratch many times on Earth, it is likely also to have started on many earthlike planets. In my talk I shall discuss possible signatures of weird life, and outline some simple strategies for seeking evidence of a shadow biosphere.

Conditions During the Emergence of Animal Life

Eric J. Gaidos

Animal life emerged in the late Precambrian before 540 million years ago (Ma), and perhaps as early as ca. 600 Ma. This pivotal event was accompanied by low-latitude glaciations and large excursions in the isotopic composition of inorganic carbon in surface waters. It was preceded by a long interval in which the deep ocean was sulfidic and the concentration of oxygen in the atmosphere was well below the modern value. The link between oxygenation of the oceans and the appearance of animals in the fossil record is widely accepted, but the causal relationships between marine biogeochemical cycles, climate, and atmospheric composition are controversial. I describe how high marine sulfide might have maintained low oxygen, high methane, and declining carbon dioxide (CO_2) in the Precambrian atmosphere, and how Earth may have escaped from this condition only when low CO_2 and marine bicarbonate (HCO_3-) triggered a 'biotic crisis' near the end of the Precambrian. The tempo of planetary change depended on the luminosity evolution of the Sun and the abundance of sulfur in magmas and volcanic gases, and may be different on planets around other stars.

Reflections on the Future of Astrobiology

Chris Impey

Astrobiology is a young and exciting, interdisciplinary field of science. In a few decades, the terrestrial frontier has seen insights into the range of life on Earth and its origin, and the varied mechanisms by which life turns energy into information. Meanwhile, the extraterrestrial frontier has witnessed the discovery of about 400 exoplanets, some of which are nearly Earth-like, the identification of several habitable locations in the Solar System, and the use of new technology to search for extraterrestrial intelligence with increased sensitivity. The future of astrobiology will be most sharply defined by the discovery of life beyond Earth. History may not a good guide to the future, just as life on Earth may not be a good guide to the characteristics of biology elsewhere. It is of course possible that scientists' optimism about the broad predisposition of the universe for life is misplaced, rendering biology rare and difficult to detect. Nonetheless, this talk will hazard guesses on how the subject may evolve and what the best research avenues might be to make the breakthrough discovery.

Habitability of the Earth and Evolution of Its Atmosphere

James F. Kasting

Earth is comfortably within the habitable zone of the Sun – the region where liquid water can exist on a planet's surface – so it may not seem surprising that the Earth has remained habitable, and inhabited, throughout most or all of its recorded history. Solar luminosity has increased by 40 percent from its original value during that time, however, so a complex interplay of factors was needed to actually keep the planet fit for life. Chief amongst these factors was the negative feedback between atmospheric CO_2 and climate provided by the carbonate-silicate cycle. All other things being equal, low surface temperatures on the early Earth would have led to slower rates of silicate weathering, and thus to buildup of volcanic CO_2, which would have helped offset the lower temperatures by providing greenhouse warming. Models based on CO_2 feedback alone, however, predict more CO_2 than is consistent with various CO_2 indicators, specifically paleosols and siderite banded iron-formations. This suggests that CH_4 may have played a role, as well. The CH_4 greenhouse effect is complicated, though, because too much CH_4 can lead to formation of hydrocarbon haze, which creates an anti-greenhouse effect that can cool the planet. The details of how this haze forms and how it interacts with incident solar radiation are still being worked out. I will provide an update on where this modeling stands. I will also talk about the controversial O and Si isotopic evidence for hot Archean climates and how this evidence can be weighed against other climate indicators.

Snowball Glaciation: Lessons for Habitability on Earth and Elsewhere

Joseph L. Kirschvink & Timothy D. Raub

Earth's glacial record has become more frequent but less severe as the planet has aged. Although many Precambrian glaciations supported sea ice in tropical to equatorial latitudes, well within a 'Snowball Earth' zone predicted by ice-albedo runaway in energy-balance models, it remains uncertain whether Precambrian interglacial Earth supported a polar ice mass. All Precambrian glaciations display geochemical evidence of syn- and post-glacial oxidation (Raub & Kirschvink, 2008). Beneath the modern Antarctic ozone hole, ultraviolet photochemical reactions trap frozen H_2O_2; this same process oxidizes icy moons like Europa and Enceladus. Prior to terrestrial atmospheric oxygenation, such ice-bound peroxides might reach parts-per-thousand levels, sufficient for oxidized meltwater to hypothetically force the original evolution of oxygen-mediating enzymes. As-yet unrecognized Archean polar ice caps might similarly account for 'whiffs' of trace oxygen (Anbar *et al.*, 2007, Frei *et al.*, 2009) without invoking the specter of oxygenic photosynthesis (Kirschvink & Kopp, 2008). If the accumulation of peroxide in polar glaciers is the only mechanism that can drive *de novo* evolution of molecular oxygen-mediating enzymes, there is an interesting implication for Astrobiology: Earth-like planets too close to their parent Star to form glaciers will probably never experience oxyatmoversion and will be unlikely to have animal life.

Life and Environments in Earth's Middle Age

Andrew H. Knoll

Astrobiological interest in Earth history commonly focuses on life's first and most recent chapters, the origin of cells and the emergence of complex organisms. Much of Earth's physical and biological history, however, played out during the long interval between these events, and it can be argued that both the nature and timing of animal evolution reflect the events of Earth's middle age. The interval in question began with the initial rise of oxygen in surface oceans and environments, an event well documented in the rock record but imperfectly understood in terms of process. Increasingly, geochemical data suggest that the world that emerged from this transition was not our modern Earth, with oceans oxygenated from top to bottom, but, after ca. 1800 Ma, a long lasting intermediate state in which a moderately oxygenated atmosphere and surface ocean lay above by an oxygen minimum zone that tended toward euxinia. Paleontological data suggest that eukaryotic microorganisms populated the oceans during this interval, some of them with the capacity for simple multicellularity or cell differentiation. Nonetheless, both fossils and molecular biomarkers suggest that the diversity, complexity and ecological footprint of eukaryotes remained low until ca. 800 Ma. Emerging geochemical data suggest that this paleontologically observable blossoming of eukaryotic diversity corresponds not to a sharp increase in oxygen levels but rather to the statistical replacement of euxinic subsurface waters by ferruginous water masses. Latest Proterozoic oxygen increase does, however, correlate with the expansion of macroscopic animals, as well as red and green algae characterized by complex multicellularity. All complex multicellular organisms have active transport mechanisms for oxygen, signaling molecules and nutrients, circumventing the strong constraints imposed by diffusion. The chicken-and-egg problem of whether size increase reflects or promotes active transfer of molecules within organisms might be solved by considering the relationships among size, metabolism, and differentiation as a positive feedback loop, nudged in the right direction by late Neoproterozoic environmental change.

Review of Detected Low-Mass Planets

CHRISTOPHE LOVIS

Since 2004, a new population of extrasolar planets, having masses below 20-25 Earth masses, has been emerging from planet-search surveys. This has become possible thanks to important progress in the planet detection sensitivity of the two main observational techniques currently dominating the field: high-precision radial velocities and transit photometry. In the Neptune mass regime and below, hydrogen is probably not the main constituent of planets any more, but is replaced in this role by ices and rocks. The recent discoveries are therefore unveiling for the first time a population of 'solid' planets, although most of their properties remain to be explored. In this presentation I will review several examples of low-mass planets and planetary systems, and discuss some of their orbital and physical characteristics. First guesses regarding their overall abundance in our Galaxy can also be made. I will conclude with the prospects of detecting habitable planets, with a mass similar to the Earth and located at the appropriate distance from their parent star, in the near future.

Outstanding Problems in Astrobiology

JONATHAN I. LUNINE

Astrobiology is the study of life as a cosmic phenomenon: its major themes include the origin of life and its precursor materials, the evolution of life on Earth, its future prospects on and off the Earth, and the occurrence of life elsewhere. Behind each of these themes is a multidisciplinary set of questions involving physics, chemistry, biology, geology, astronomy, planetology, and other fields, each of which connects more or less strongly to the central questions of astrobiology. Stimulated by new capabilities for scientific exploration on and off the Earth, astrobiology seems to be establishing itself as a distinct scientific endeavor. The outstanding problems in astrobiology can be laid out schematically but conveniently in the form of an equation first written 50 years ago by Frank Drake. The equation enumerates the number 'N' of observable extraterrestrial civilizations in our Milky Way Galaxy as equal to $R \times f_p \times n_e \times f_l \times f_i \times f_c \times L$, where R is the rate of formation of suitable stars (it is sufficient to assume those similar in mass and composition to the Sun) in our galaxy, f_p the fraction of stars with planets, n_e the average number of such planetary systems with a habitable, or life-sustaining, environment, f_l the fraction of habitable planets on which life actually forms, f_i the fraction of those life-bearing planets with intelligent life, f_c the fraction of those intelligence-bearing planets with a civilization technically capable of transmitting signals, and L the average lifetime of such a civilization. The first three terms are known or in the process of being determined today by astronomical techniques on the ground and in space. The fourth term can be constrained by determining whether life – of independent origin from that on Earth – exists in habitable environments elsewhere in the solar system (Mars, Europa, Enceladus, Titan). The fifth term is more tenuously connected to data, but the history of life on Earth and the late onset of complex, intelligent beings has suggested to some that while primitive life might be common, intelligent life could be a rare phenomenon in the cosmos.

Low-Mass Planets Around Faint Nearby Dwarf Stars

DANTE MINNITI

There has been great progress in the search and characterization of extrasolar planets. In particular, current searches are focussing on planets less massive than Neptune orbiting nearby dwarf stars. A few of these systems are already known, and it is expected that some transiting low mass planets will become available in the next few years. I will describe SIMPLE, a new high-resolution near-IR spectrograph for the E-ELT being build at Arcetri. SIMPLE is a canonical cross-dispersed Echelle spectrograph designed to have a resolving power of 100,000, covering from 0.8 to 2.5 microns in a single frame. SIMPLE at the E-ELT will allow to characterize the atmospheres for transiting low mass exoplanets, and also to search for potential atmospheric biomarkers. I will also describe our current Carnegie-Catolica search for extrasolar planets around nearby stars with the Magellan 6.5m telescope with MIKE, presenting the main results for the 11 exoplanets discovered so far. These are long period, massive planets orbiting generally in eccentric orbits. Future plans to extend the Magellan Planet Survey will be also discussed.

Early Mars: Cradle or Cauldron

RAYMOND T. PIERREHUMBERT

There is abundant evidence that large quantities of liquid water existed at the surface of Mars very early in the planet's history. This evidence takes the form of river-like features, surface mineralogy, and stratigraphy of the Noachian crust of the planet. One view of the climate of Early Mars holds that these features arise from eons-long periods of warm, wet equable climates, arising from an early massive atmosphere rich in greenhouse gases. Another holds that the climate consisted of long periods of frozen cold-dry climates followed by brief periods of hot torrential rains following giant impacts. I will review the basic physics underpinning both of these views,the implications for evolution of life, and the prospects for settling which is correct by further exploration of Mars, Mars is the archetype for the problem of determining the outer edge of habitable zones around stars. Generalizations of the Early Mars habitability problem, and applications to other planetary systems (notably about Gliese 581) will be discussed.

Formation of Earth-Sized Planets

Sean N. Raymond

Rocky ('terrestrial') planets are thought to form in a series of dynamical steps, starting from micron-sized dust grains in gaseous protoplanetary disks. Duriing the last phase of growth, km-sized planetesimals and Moon-sized planetary embryos collide to form full-sized planets on a 100 million year timescale. It is during this phase that Earth's final composition was determined by the composition of material within its feeding zone. A key question is the source of Earth's water: the current leading theory is that the water was delivered via collisions with primordial asteroidal material. Extrapolating to planets around other stars requires an understanding of the dynamics of extra-solar planets – including orbital migration and planet-planet interactions – and their effect on terrestrial planet growth. I will discuss the prospects for water-rich Earth-like planets to exist in 'hot Jupiter' systems as well as in the known systems of extra-solar (giant) planets, many of which likely underwent dynamical instabilities.

Search and Characterization Strategies for Habitable Worlds

Sara Seager

Fourteen years ago after the first discovery of exoplanets orbiting sun-like stars, few believed that exoplanet atmosphere observations were possible. Seven years ago, after the Hubble Space Telescope observation of the transiting HD 209458b atmosphere, many skeptics challenged it as a one-object, one-method success. With over two dozen exoplanet atmospheres observed today, we have solidly entered the first stage of exoplanet atmosphere research. I will briefly review the highlights of hot Jupiter atmosphere studies: detection of molecular spectral features; constraints on atmospheric vertical structure; and diversity of day-night temperature gradients. I will show what we can robustly infer from the two best transiting hot Jupiter atmosphere data sets: HD~189733b and HD~209458b, using a new atmospheric temperature and abundance retrieval method. As hot Jupiter observations and interpretation are maturing, the next frontier is super Earth atmospheres. Theoretical models are moving forward with observational hopes pinned on the James Webb Space Telescope, scheduled for launch in 2014. Further in the future lies realistic attempts to answer the enigmatic and ancient question, 'Are we alone?' via atmospheric biosignatures. Many of us are working hard to ensure we will have Earth analog targets for atmosphere observations in our life time. I will finish with a description of the lowest cost and nearest term chance we have for directly imaging Earth analog atmospheres: a space-based Terrestrial Planet Finder telescope that is a combination of the James Webb Space Telescope and a separately built and launched external occulter.

Habitability of Exoplanets

Dimitar D. Sasselov

The talk will review planetary habitability from the aspect of observable features of exoplanets, which relate to planet structure, atmosphere, and specific global geochemical cycles.

The Earliest Earth Atmosphere

Franck Selsis, Eric Hébrard, Alessandro Morbidelli, Ignasi Ribas

The early history of our planet is usually presented as the succession of two periods. During the first one, the Hadean, frequent catastrophic asteroids/comets impacts maintained conditions preventing life, and even complex chemistry, from occurring on Earth. The end of the Hadean is generally dated around 3.9-3.8 Gyrs ago (Ga), when impact rates decreased to bearable values. It is only during the second period, the Archean, that living organisms are assumed to have been able to evolve and spread in Earth's environment. As a matter of fact, the oldest – and debated – possible traces of life have been found at the very beginning of the Archean, around 3.8 Ga in the form of ^{12}C-enriched sediments. In this picture, which represents the most accepted view (often given in academic textbooks), the physical and chemical conditions at the transition between Hadean and Archean are regarded as the relevant context for prebiotic chemistry and the origins of life. However, the standard model for the atmosphere of the Earth 3.9-3.8 Ga ago does not seem to produce complex organics at high enough a rate to sustain efficient prebiotic processes (unlike in the Urey-Miller experiment). Therefore, scientists often invoke an external delivery of asteroidal/cometary organics or a sub-surface production in hydrothermal vents. We would like here to revisit this scenario by considering a more recent view of the bombardment history. We will show that the Earth could have been habitable as early as the end of the planetary accretion around 4.4 Ga and that life could have survived a Late Heavy Bombardment event that occurred between 3.9 and 3.8 Ga. We will show how the conditions during the earliest habitable period of the Earth, when our planet was subjected to the irradiation of the young but active Sun, differ from the ones that are usually assumed for the context of the origins of life. We will then discuss the implications for prebiotic chemistry.

Molecular Signatures of Life Through Time

Roger E. Summons

Fossil hydrocarbons are commonly interpreted as diagenetic products of biochemicals, and therefore as proxies for organisms and biosynthetic pathways that have existed in the past. They can be particularly informative about organisms that leave no visible fossil evidence of their prior existence. Further, since many organisms proliferate only under stringent environmental restrictions, the fossil hydrocarbons may also serve as indicators for those conditions. An example would be fossil pigments derived from green and purple sulfur bacteria, photosynthetic bacteria that use hydrogen sulfide as an electron donor, which serve as proxies for the presence of sulfide in the photic zone of ancient seas. Another example would be the biosynthetic pathway leading to sterols which requires molecular oxygen in several steps. Thus, the detection of fossil hydrocarbons with these carbon skeletons far back in Earth history has been used to infer the antiquity of oxygenic photosynthesis. This presentation will focus on two aspects of the geologic record of fossil hydrocarbons. Firstly, using data from petroleum through the ages we will examine the successions in ocean plankton. These results are informative about an evolving composition of marine algal groups though time and, in particular, the nature of photosynthetic communities accompanying extinction and radiation events at the end of the Proterozoic, Paleozoic and Mesozoic Eras. We also report our most recent results concerning the detection of indigenous steranes and triterpanes in sediments from the late Archean through studies of cores from the Pilbara Craton obtained through the NASA Archean Biosphere Drilling Project and the Agouron Institute drilling in the Kaapvaal Craton of South Africa.

SETI Turns 50

Jill C. Tarter

Since the publication of the first scientific paper on the Search for Extraterrestrial Intelligence in *Nature* in September of 1959, SETI has been capturing the imaginations of young and old, scientist and layperson, in cultures around the globe, and SETI has become an innovative, scientific exploration. Within the past few years we have lost the pioneering authors of the first SETI paper, but the radio astronomer who conducted the first SETI search is still active, and a new generation of researchers are slowly beginning to replace the old guard. SETI is now sheltered under the larger umbrella of astrobiology, but it is far from a risk-free enterprise. From a single narrowband channel receiver exploring two stars, the search capacity has increased by more than 14 orders of magnitude in 50 years and SETI is well positioned to continue taking advantage of exponential improvements in multiple technologies. SETI has endured a roller-coaster funding saga that has included both federal and private support, and no support at all. As a science it is confounded by the persistent public misperception that it has something to do with UFOs. This talk will trace the history, detail the current status, and forecast the future of SETI, while trying to make some guesses about technologies not yet invented and discussing the question – What if SETI succeeds?

Characterising Exoplanet Atmospheres, from Gas Giants to Terrestrial Habitable Planets

Giovanna Tinetti

Half a century ago, Space Age began with the launching of the Sputnik. Now at the completion of a fairly detailed study of the planets of our own solar system, we are at the dawn of the Age of Exoplanets. More than 300 exoplanets, i.e. planets orbiting a star different from our Sun, are now known thanks to indirect detection techniques. In the first decade after their initial discovery in 1995 by Mayor and Queloz, the task was to find more and more of these astronomical bodies: the biggest, the smallest; the hottest, the coolest. In recent years, attention has switched from finding planets to characterising them. Among the variety of exoplanets discovered so far, special attention is devoted to those planets which transit their parent star. Most recent observations, in fact, have proved being possible to use the wavelength dependence of the reduction in the brightness of the central star as the planet passes in front to identify key chemical components in the planet's atmosphere. Molecules such as water, methane, carbon monoxide and dioxide have already been detected in the atmospheres of hot, giant exoplanets with Hubble and Spitzer Space Telescopes or from the ground. These planets are unsuitable for life, but the next generation of space telescopes -the James Webb Space Telescope or other mission concepts entirely devoted to the observation of exoplanet atmospheres- will guarantee the characterisation of fainter targets, in particular telluric planets in the habitable zone of their parent star.

The Atacama Desert as a Model Habitat in Astrobiology

Rafael Vicuña and Armando Azúa

The search for life in the Universe relies on the thorough understanding of life as we know it. Although biased by the single example we find on Earth, lifeforms and the habitats they use in our planet provide us with helpful models for astrobiology focused questions. One of these models is the Atacama Desert, which is the driest and probably the oldest extant desert on Earth. To survive in the hyperarid conditions prevailing in the place, lifeforms have had to adapt to very low air humidity levels, an almost complete absence of rain events, highly saline soils and high solar radiation. Still, in spite of this adaptation process, the harsh environmental factors cause that parts of the Atacama Desert are almost devoid of microbial life. These characteristics have made Atacama Desert a prime analog model for the planet Mars and many research teams are conducting experiments on various astrobiologically oriented topics. Regions within this desert are intensively being used for testing of biosignature detecting instruments and robots to be flown in future space missions. Some sites are also being studied as analogs for understanding the origin of life on Earth. Our work is focused on the understanding of the molecular and physiological adaptations of extremophiles living in the Atacama Desert. More specifically, we are studying different habitats, from salt pans to caves, describing the diversity of microorganisms living in them and the microenvironmental parameters to which these microorganisms have adapted. In particular, we are interested in the study of the evolutionary adaptations that arose to cope with limiting water availability for photosynthesis in cyanobacteria and micro-algae. So far, we have found that even small changes in the microenvironmental landscape cause dramatic changes in biodiversity, suggesting that life-supporting places behave like evolutionary islands with accelerated rates of speciation. Our data also suggest that small changes in a few key parameters of the abiotic landscape can have huge impacts on the habitability of extreme environments, even in scales of centimeters. This patchiness of life spreading needs to be considered when looking for life elsewhere in the universe. Thus, unless the sampling procedures in a specific site are very well designed, a negative result in the search for biosignatures may not necessarily reflect absence of life.

The geological record of early life on Earth (and its limitations)

Frances Westall

The geological record of early life on Earth is very patchy but what has been preserved provides us with a fascinating insight into the ecology of the primitive Earth. Destruction or severe alteration of the Earth's earliest crust by plate tectonic activity and crustal processes limits the availability of well-preserved rocks, the oldest of which are younger than 3.5 billion years old (Ga), a billion years after the consolidation of the crust. Two areas of ancient crust are particularly well-preserved, the Barberton greenstone belt in eastern South Africa and the Pilbara greenstone belt in NW Australia. The traces left behind by primitive life forms in these rocks exhibit a remarkable level of evolution, as far as can be interpreted from the chemical, isotopic and morphological biosignatures. The information provided by these biosignatures is, however, limited by many factors including lack of preservation of certain species or whole communities of microorganisms, severe degradation of the organic molecules making up the microorganisms, lack of resolution in certain analytical techniques (specifically, isotopic), contamination of the ancient rocks by younger microorganisms, and abiogenic precipitations mimicking simple microbial morphologies. Despite these limitations, the early record of life documents an Earth that appears to have been widely colonised by prokaryote-like microorganisms that lived and interacted with their immediate microcosms in exactly the same way as modern prokaryotes. Organisms obtaining their energy from reduction-oxidation processes of inorganic and organic substances colonised the surfaces of the volcanic rocks and sand grains (the early Earth was characterised by volcanic rocks and detritus) and probably inhabited hydrothermal environments. The widespread development of microbial mats in shallow water littoral environments suggests that life had also learnt how to obtain energy using sunlight (photosynthesis). This ability was of fundamental importance in the further evolution of life since the energy produced by this process is far greater than that produced by chemotrophic metabolisms. All these processes occurred on an Earth that had very little free oxygen. It is widely believed that one of the major causes of the appearance of oxygen in the atmosphere was the ability of certain organisms to split the water molecule and to liberate oxygen during a more advanced version of photosynthesis (oxygenic). This type of metabolism was even more energetically-productive. Evidence from molecular fossils suggests that this metabolism was established by 2.7 Ga, whereas certain microbial structures, such as large stromatolites existing in older rocks 2.8 Ga indicate that oxygenic photosynthesisers had already taken hold on the Earth. Further complexification of life required significant resources in energy and, thus, the availability of oxygen.

Study Week on
Astrobiology

BIOGRAPHIES OF PARTICIPANTS

John Baross. Professor, School of Oceanography and Center for Astrobiology and Early Evolution, University of Washington, Seattle, WA. John Baross received a BS degree in microbiology and chemistry from San Francisco State University and a PhD degree in marine microbiology from the University of Washington. His research specialty is the ecology, physiology and molecular phylogeny of microorganisms from hydrothermal vent and subseafloor environments. Dr. Baross has particular interests in the microbiology of extreme environments and in the significance of submarine hydrothermal vent systems for the origin and evolution of life and for the possibility of life on other planets in similar settings. Recently, he co-edited with Woodruff Sullivan, *Planets and Life – The Emerging Science of Astrobiology* (Cambridge Press, 2007). Dr. Baross is a fellow of the American Academy of Microbiology, an associate member of the National Academy of Sciences, and a member of the American Society for Microbiology, the American Association for the Advancement of Science, The American Chemical Society, the American Geophysical Union, and the International Society for the Study of the Origin and Evolution of Life. He has previously served on several committees including service as co-chair of the National Research Council (NRC) Committee on the Origins and Evolution of Life (2000-2003), the Committee for a Review of Programs to Determine the Extent of Life in the Universe (2001-2002) and as a member of the Ridge Inter-Disciplinary Global Experiments (RIDGE) Steering Committee and of the RIDGE Observatory Coordinating Committee. He also served as chair of the NRC Task Group on The Limits of Organic Life in the Universe (2004-2007) and as a member of the Steering Group for the Workshop on Size Limits of Very Small Microorganisms (1998-1999), the Task Group on Sample Return from Small Solar System Bodies (1997-1998), and the Ad Hoc Task Group on Planetary Protection (1991-1992). Dr. Baross is currently the chair of the Scientific Advisory Council (SAC) for the International Census of Marine Microbes (ICoMM) and a member of the International Founders Committee, the 'Deep Carbon Observatory', sponsored by the Sloan Foundation.

Steven A. Benner received is B.S. and M.S. in Molecular Biophysics and Biochemistry from Yale University, and his Ph.D. in Chemistry from Harvard University. Following two years as a Junior Fellow at the Harvard Society of Fellows, he served on the faculty of Harvard University, the Swiss Federal Institute of Technology, and the University of Florida. He is presently a Distinguished Fellow at the Foundation for Applied Molecular Evolution and The Westheimer Institute for Science and Technology, which he founded. His research seeks to combine two broad traditions in science, the first from natural history, the second from the physical sciences. Towards this goal, his group works in fields such as organic chemistry, biophysics, molecular evolution, bioinformatics, geobiology, and planetary science. He contributed to the founding of several new fields, including synthetic biology, paleogenetics, and computational bioinformatics. He co-chaired with John Baross the National Research Committee's 2007 panel on the 'Limits to Organic Life in the Solar System', advised the design of missions to Mars, and invented technology that improves the medical care of some 400,000 patients each year suffering from infectious diseases and cancers.

Willy Benz was born on 6 July 1955 in Neuchatel. He studied physics at the University of Neuchatel and received his PhD in natural sciences at the University of Geneva in 1984 for his doctoral thesis in astrophysics. He then went on to do post-doctoral work at Los Alamos National Laboratory (USA) and at Harvard University. In 1987 he was appointed assistant professor at Harvard University. He later taught at the University of Arizona and at the University of Geneva. Willy Benz has been a professor at the Physics Institute at the University of Bern since 1997, becoming institute director in 2002. His commitment to teaching and research was recognized in 1988 with the Milton Fund Award and a year later with the Thomas Temple Hoopes prize for excellence in undergraduate teaching. In 2005 he was named 'Corresponding Member' of the International Academy of Astronautics. Since 2003 he has also been a member of the Space Science Advisory Committee of the European Space Agency, ESA. Willy Benz has been a member of the Swiss Science and Technology Council since 2004.

Michel Blanc dedicated the early years of his scientific career to the Earth magnetosphere and ionosphere, first with models of electric field systems, then with global models of the magnetosperic convection and of radiation belts. Since the early 1990's, he has obtained important new results on planetary magnetospheres, in particular on plasma transport and radiation belts in the highly axisymetric environment of Saturn. He has played a lead role in the Cassini/Huygens mission as an Interdisciplinary Scientist in Magnetospheres and Plasma Science. He is lead European scientist on a mission (Europa Jupiter System Mission) to orbit Jupiter's moons Europa and Ganymede. He is leading the efforts for structuring the planetary science community in Europe in the context of the major science missions of ESA and the Europlanet program. He is Vice-President for Research at the Ecole Polytechnique of France.

Julie C. Castillo-Rogez is a planetary scientist in the Planetary Ices group at the Jet Propulsion Laboratory, California Institute of Technology. She received her PhD in geophysics from Rennes University, France. She came to JPL in 2002 to participate in the planning and implementation of observations by the *Cassini-Huygens* mission at Saturn's satellites. Since then, she has been involved in the science definition of several prospective missions to the outer Solar system, devising measurements to determine the internal structure of icy satellites. Castillo-Rogez is also an expert in the numerical modeling of small icy objects, satellites and asteroids. Her primary interest is the search for heat sources that can explain outstanding properties observed at these objects. In order to better constrain tidal dissipation mechanisms in icy satellites, she co-founded in 2007 the JPL Ice Physics Laboratory, and became the study lead for the *Planetary Tides Simulation Facility*. This is the first and only experiment in the world capable of measuring the dissipation factor of ice in the actual conditions of stress, temperature, and frequencies at icy satellites. She has also been recently involved in the modeling of large water-rich asteroids, such as Ceres and Pallas, in order to evaluate the astrobiological potential of these large protoplanets and mission targets. For the past five years, Castillo-Rogez has co-organized workshops (e.g., Small Ice-Silicate Body Workshops in Winthrop, WA in 2006, 2008, 2009; The Science of Solar System Ices, Oxnard, CA, May 2008) to promote interdisciplinary research pertaining to small icy objects. She is co-editing a monograph, the *Science of Solar System Ices*, that will summarize the state of knowledge of ice properties relevant to Solar system objects.

David Charbonneau is the Thomas D. Cabot Associate Professor of Astronomy at Harvard University. His research focuses on the development of novel techniques for the detection and characterization of planets orbiting nearby stars. As a graduate student, he used a 10cm telescope to make the first detection of an exoplanet eclipsing its parent star, which yielded the first ever constraint on the composition of a planet outside the Solar system. Dr. Charbonneau was a founding member of the Trans-Atlantic Exoplanet Survey, which used a worldwide network of humble automated telescopes to survey hundreds of thousands of stars to detect 4 more exoplanets by this technique. Dr. Charbonneau also pioneered the use of space-based observatories to undertake the first studies of the atmospheres of these distant worlds: In 2001 he used the Hubble Space Telescope to study directly the chemical make-up of the atmosphere enshrouding one of these exoplanets, and in 2005, he led the team that used the Spitzer Space Telescope to made the first direct detection of the light emitted by an exoplanet. He is currently leading the MEarth Project and is a member of the NASA Kepler Mission Team. Each of these projects aims to detect Earth-like planets that might be suitable abodes for life beyond the Solar system. Dr. Charbonneau earned his PhD in astronomy from Harvard University, and received his undergraduate degree in math and physics from the University of Toronto. He was named an Alfred P. Sloan Research Fellow (2006-2008), and awarded the David and Lucile Packard Fellowship for Science and Engineering (2006-2011), the NASA Exceptional Scientific Achievement Medal (2006), and the Alan T. Waterman Award from the US National Science Foundation (2009).

Shelley D. Copley obtained an A.B. in Biochemical Sciences (1980) and a Ph.D. in Biophysics (1987) from Harvard University. After post-doctoral work at MIT and the University of Colorado at Boulder, she joined the Department of Chemistry and Biochemistry at the University of Colorado at Boulder in 1990. She moved to the Department of Molecular, Cellular and Developmental Biology in 2000. Research in the Copley lab centers on the molecular evolution of catalysts and metabolic pathways, beginning approximately 3.8 billion years ago before the emergence of life on earth, and continuing to the present day, when microbial evolution due to anthropogenic perturbations is still occurring. Projects that focus on evolution of protein enzymes address the evolutionary potential of promiscuous enzyme activities, the assembly of novel metabolic pathways from multiple promiscuous enzymes, and the factors that hinder the performance of enzymes that have recently been recruited to serve new functions. Efforts to study the origin of life, and specifically the emergence of proto-metabolic networks, focus on the roles of mineral and small molecule catalysts under simulated hydrothermal vent conditions and on the potential role of peptides as cofactors for ribozymes.

Athena Coustenis is Director of Research at the Centre National de la Recherche Scientifique (CNRS) of France. As an astrophysicist she works in the field of Planetology at the Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique (LESIA) of Paris-Meudon Observatory, France. Her research is devoted to the investigation of planetary atmospheres and surfaces, with emphasis on Titan, Saturn's largest satellite. She has also contributed to an effort to uncover the nature of the atmosphere surrounding the extrasolar planets. She has led many observational campaigns from the ground using large telescopes (CFHT, UKIRT, VLT, etc) and has used the Infrared Space Observatory (ISO) to conduct planetary investigations. She is Co-Investigator of three of the instruments (CIRS, HASI, DISR) aboard the Cassini-Huygens space mission to Saturn and Titan. The success of the mission has led her to devote most of her time to the analysis and interpretation of the data recovered, using her own radiative transfer codes and other analysis tools. In 2007 and 2008 she was Leading European Scientist for the study of a mission planned to return to Titan and Enceladus for a thorough exploration called Titan Saturn System Mission (TSSM). She has received several NASA and ESA Group Achievement Awards for the Cassini-Huygens Program. She is also: President of the International Commission for Planetary Atmospheres and Environment (ICPAE); Member of the Committee of the Division of Planetary Sciences (DPS); President of the Division for Planetary Sciences of the European Geophysical Union (EGU). She has organised/convened many planetary sessions in the International colloquia of EGU, IAMAS, AOGS, DPS, EPSC, Goldschmidt Conference and IPPW. She teaches at a Post-Master level at Paris VII University. She is a Head Guest Editor for several special issues of *Planetary and Space Sciences* since 2003, and a member of the Editorial Board of *Astronomy & Astrophys. Reviews*. She has written more than 100 scientific papers and several articles for the public, as well as two books on Titan, with co-author Fredric Taylor (the most recent one is: *Titan: exploring an Earth-Like World*, published by World Scientific Publishers in 2008). She has made several TV appearances in connection to Titan, Cassini and the extrasolar planets. She has delivered many public lectures on Planetology and participated in television documentaries. She is actively involved in the preparation of the IYA09.

Paul Davies is a British-born theoretical physicist, cosmologist, astrobiologist and best-selling author. He held academic appointments at the Universities of Cambridge, London and Newcastle upon Tyne, until 1990, when he moved to Australia, as Professor of Mathematical Physics at The University of Adelaide, and later as Professor of Natural Philosophy at Macquarie University in Sydney, where he helped establish the NASA-affiliated Australian Centre for Astrobiology. He joined Arizona State University in 2006 as Director of *Beyond*, a research center devoted to exploring the 'big questions' of science, such as the origin of the universe, the origin of life and the nature of time. His research has been mainly on the theory of quantum fields in curved spacetime, with applications to black holes and the inflationary era of the very early universe. He was also one of the first to champion the idea that life on Earth may have originated on Mars, and that there may be a shadow biosphere on Earth. Davies has written or co-authored 28 books. The most recent, *The Eerie Silence*, is on the subject of SETI, and will be published early in 2010. In 1995 he was awarded the Templeton Prize for his work on the deeper meaning of science. He was also awarded the Faraday Prize by The Royal Society and the Kelvin Medal by the UK Institute of Physics. In June 2007 he was named a Member of the Order of Australia in the Queen's birthday honors list. The asteroid 1992 OG was renamed (6870) Pauldavies in recognition of his work on cosmic impacts.

Eric J. Gaidos is an Associate Professor of Geobiology in the Department of Geology and Geophysics at the University of Hawaii at Manoa. He is also a graduate faculty in the Department of Oceanography, a research affiliate of the Institute for Astronomy, and a faculty member in the undergraduate Global Environmental Science program. His research ranges from the evolution of microbial genomes and the emergence of sociality and cooperation in biological systems, to the exploration of 'extreme' environments on Earth as analogs to extraterrestrial habitats and the search for planets around other stars. Gaidos received his undergraduate and graduate degrees in physics from Caltech and MIT, respectively. He was a postdoctoral fellow at the Center for the Detection of Life at the NASA Jet Propulsion Laboratory before joining UH in 2001. Gaidos is convinced of the importance of a sound public understanding of science and the role of science in public policy. In 2001 he was a visiting fellow at the Board on Life Sciences of the U.S. National Academies, and he teaches a postgraduate course on communicating science to the public and science documentary film making. He is an independent filmmaker and his current project, 'Glass: Four Centuries of Shaping Starlight' will premier in January 2010 for the International Year of Astronomy.

Chris Impey is a University Distinguished Professor and Deputy Head of the Department, in charge of all academic programs. His research interests are observational cosmology, gravitational lensing, and the evolution and structure of galaxies. He has 160 refereed publications and 60 conference proceedings, and his work has been supported by $18 million in grants from NASA and the NSF. As a professor, he has won eleven teaching awards, and he has been heavily involved in curriculum and instructional technology development. Impey is a past Vice President of the American Astronomical Society. He has also been an NSF Distinguished Teaching Scholar, a Phi Beta Kappa Visiting Scholar, and the Carnegie Council on Teaching's Arizona Professor of the Year. Impey has written over thirty popular articles on cosmology and astrobiology and co-authored two introductory textbooks. His first popular book *The Living Cosmos*, was published in 2007 by Random House; his second popular book called *How It Ends*, will be published in 2010 by Norton. He recently was a co-chair of the Education and Public Outreach Study Group for the Astronomy Decadal Survey of the National Academy of Sciences.

James F. Kasting Ph.D., FAAAS is Professor of Geosciences, Pennsylvania State University. He is on the Editorial Boards of *Astrobiology* and *Geobiology*. He is a member of the NASA Advisory Council Astrophysics Subcommittee. His research interests are atmospheric evolution, planetary atmospheres, and paleoclimates. He has also considered the habitability criteria of other stellar systems and planets and is broadly considered the world leader in the field of planetary habitability. Jim coauthored *The Earth System*. The first book of its kind that addresses the issues of global change from a perspective of Earth as a system, *The Earth System* offers a solid emphasis on lessons from Earth history that may guide decision-making in the future. Jim was elected Fellow of the American Association for the Advancement of Science in 1995, Fellow of the International Society for the Study of the Origin of Life in 2002, Fellow of American Geophysical Union in 2004, Fellow of Geochemical Society in 2008, and Fellow of American Academy of Arts and Sciences in 2008. He won the Oparin Medal from the International Society for the Study of the Origin of Life in 2008. He authored *Ups and downs of ancient oxygen*, and coauthored *Hydrodynamic planetary thermosphere model: 1. Response of the Earth's thermosphere to extreme solar EUV conditions and the significance of adiabatic cooling*, *Habitable planets around the star Gliese 581?*, *Abiotic formation of* O_2 *and* O_3 *in high-*CO_2 *terrestrial atmospheres*, *Evidence for hot early oceans?*, *Paleoclimates, ocean depth, and the oxygen isotopic composition of seawater*, *Atmospheric Composition and Climate on the Early Earth*, and *Palaeoclimates: the First Two Billion Years*. Born January 2, 1953, Jim earned his B.A. (Summa Cum Laude) in Chemistry and Physics at Harvard University in 1975. He earned his M.S. in Physics and Atmospheric Science from the University of Michigan in 1978 and his Ph.D. in Atmospheric Science from the University of Michigan in 1979.

Joseph L. Kirschvink is the Van Wingen Professor of Geobiology at the California Institute of Technology, where he heads a research group dedicated to the study of weakly magnetized biological and geological materials. Besides conducting basic science in rock and paleomagnetism, Joe has originated several hypotheses aimed at increasing our understanding of how biological evolution has influenced, and has been influenced by, major events on the surface of the Earth. His major contributions include the discovery of tiny crystals of biologically precipitated magnetite in specialized cells of migratory and homing animals, which provides a solid biophysical basis for understanding magnetic effects on animal behavior, and led to the discovery of this new category of sensory receptor cells. Another of Joe's ideas that is generating much interest recently is that the entire Earth may have actually frozen over several times in Earth history, resembling a 'Snowball', causing some of the most severe crisis in the history of life on Earth. He and collaborators have also identified several episodes of rapid True Polar Wander during Neoproterozoic time, which paved the way for the Cambrian explosion of life.

Andrew H. Knoll is the Fisher Professor of Natural History at Harvard University. He received his B.A. in Geology from Lehigh University in 1973 and his Ph.D., also in Geology, from Harvard in 1977. Following five years on the faculty of Oberlin College, Knoll returned to Harvard as Associate Professor of Biology. He has been a member of the Harvard faculty ever since, serving as Professor of Biology and Professor of Earth and Planetary Sciences. Professor Knoll's research focuses on the early evolution of life, Precambrian environmental history, and, especially, the interconnections between the two. Paleontological discoveries in Knoll's lab include the microfossil assemblages of Svalbard, from which basic principles of Proterozoic paleoecology were developed; exceptionally preserved Mesoproterozoic fossils from Siberia and northern Australia, which provide some of our oldest evidence of eukaryotic biology; and phosphatized, silicified, and compressed fossils from the Ediacaran Doushantuo Formation, China, that record both early animals and a terminal Proterozoic radiation of algae. Knoll has also applied insights gained from geobiological and paleoenvironmental research on early Earth rocks to Mars, serving on the science team of NASA's MER rover mission that has provided our first geologist's-eye exploration of our planetary neighbor. Additionally, Knoll chaired the subcommission of the International Commission of Stratigraphy that established the Ediacaran Period, the first new period of the geologic time scale to be ratified in more than a century. Knoll is the author of the 2003 book *Life on a Young Planet* (Phi Beta Kappa Book Award) and editor, with Paul Falkowski, of the 2007 volume *Evolution of Primary Producers in the Sea*. Professor Knoll's honors include the Honorary Fellowship in the European Union of Geosciences, the Paleontological Society Medal, the Wollaston Medal of the Geological Society of London, and membership in the US National Academy of Sciences.

Cardinal Giovanni Lajolo, President of the Pontifical Commission for Vatican City State and President of the Governorate of Vatican City State, was born on 3 January 1935 in Novara, Italy. He was ordained a priest on 29 April 1960 and holds licentiates in theology and philosophy from the Pontifical Gregorian University, and a doctorate in canon law from the Kanonistiches Institut of the Ludwig Maximilian University in Monaco, Germany. He entered the diplomatic service of the Holy See in 1970 and served at the nunciature in Germany. In November 1974 he was called to Rome and served on the Council for Public Affairs of the Church. On 3 October 1988, he was appointed titular Archbishop of Caesariana and secretary of the Administration of the Patrimony of the Holy See. He was ordained a bishop on 6 January 1989. On 7 December 1995, he was appointed apostolic nuncio in Germany and concluded some diplomatic accords with the Länder. He was then appointed secretary for Relations with States of the Secretariat of State on 7 October 2003, and in September 2004 and 2006 he represented the Holy See at the general assembly of the United Nations. On 15 September 2006 he was named president of the Pontifical Commission for Vatican City State and President of the Governorate of Vatican City State. Created and proclaimed Cardinal by Benedict XVI in the consistory of 24 November 2007, of the Deaconry of Santa Maria Liberatrice a Monte Testaccio (St. Mary Liberatrice a Monte Testaccio). Member of: Congregation for Bishops; Pontifical Council for Culture; Administration of the Patrimony of the Apostolic See.

Christophe Lovis. I am a postdoctoral researcher in the extra solar planet group at the Department of Astronomy of the University of Geneva, Switzerland. I obtained my Ph.D. in Astronomy and Astrophysics at the same institution in 2007. My work has been mainly focused on the search for low-mass extra solar planets using in particular the HARPS instrument, which has discovered the majority of super-Earths and ice giants known today.

Jonathan I. Lunine is Professor of Planetary Sciences and Physics and a Galileo Circle Faculty Fellow at the University of Arizona, Tucson. He is the David Baltimore Distinguished Visiting Scientist at NASA's Jet Propulsion Laboratory. His research interests center broadly on the formation and evolution of planets and planetary systems, the nature of organics in the outer solar system, and the processes that lead to the formation of habitable worlds. He is an interdisciplinary scientist on the NASA/ESA/ASI Cassini mission to Saturn, and on the NASA/ESA/CSA James Webb Space Telescope, as well as co-investigator on the NASA Juno mission under development for launch to Jupiter. He serves on the US National Academy of Sciences Committee leading the Decadal Survey for Astronomy and Astrophysics. Dr. Lunine is the author of over 200 scientific papers and of the books *Earth: Evolution of a Habitable World* (Cambridge University Press, 1999), and *Astrobiology: A Multidisciplinary Approach* (Pearson Addison-Wesley, 2005). He is a fellow of the American Association for the Advancement of Science and of the American Geophysical Union, which awarded him the James B. Macelwane medal. Other awards include the Harold C. Urey Prize (American Astronomical Society) and Ya. B. Zeldovich Award of COSPAR's Commission B. He earned a B.S. in Physics and Astronomy from the University of Rochester in 1980, followed by M.S. (1983) and Ph.D. (1985) degrees in Planetary Science from the California Institute of Technology.

Dante Minniti is Full Professor at the Department of Astronomy and Astrophysics of the Pontificia Universidad Catolica in Chile, and Adjunct Scholar at the Vatican Observatory. He did the undergraduate studies in Astronomy at the Universidad de Cordoba (Argentina), and obtained the PhD in 1993 at the University of Arizona (USA). He was Postdoctoral Fellow of the European Southern Observatory in1993-1996, and a Lawrence Livermore National Laboratory Postdoctoral Fellow in 1996-1998. He has been a member of the MACHO Collaboration since 1996, and of the SuperMACHO Collaboration since 2001. He has obtained several international research grants from NASA (USA), ALFA (European Union), CONICYT (Chile), CONICET (Argentina), CNRS (France), ICTP (Italy), etc. He was awarded the John Simon Guggenheim Fellowship Prize in 2005 in recognition for his work on stellar populations. Last year he was appointed Director of Research and Doctorate of Universidad Catolica, and was also awarded the Scopus Prize 2008 in the area of Physics and Astronomy. He is referee for the leading journals in Astronomy, and for national and international funding agencies, and has also been member of various scientific committees, such as the Scientific and Technology Committee of the European Southern Observatory and the Gemini International Telescope Allocation Committee. His broad research interests include: Extrasolar Planets and Astrobiology, Gravitational Microlensing, Globular Clusters, Stellar Populations, Stellar Evolution, Galaxy Formation and Galactic Structure. He is author of 202 refereed publications, that accumulate more than 6200 citations in the literature to date, yielding Hirsch_index = 43 (source: ADS). His recent book *Mundos Lejanos* sold more than 1000 copies in one year. He is currently leading the ESO Public Survey 'VISTA Variables in the Via Lactea', and actively teaching and supervising students and postdocs at Universidad Católica, and giving public Astronomy talks.

Raymond T. Pierrehumbert, who obtained his PhD from MIT in 1980, is currently the Louis Block Professor in Geophysical Sciences and the College at the University of Chicago. He studies the physics of climate, especially regarding the long-term evolution of the climates of Earth and Mars. He directs the Climate Systems Center, which was established with a $3.6 million grant from the National Science Foundation to develop software for rapidly conducting advanced climate simulations. Pierrehumbert was an author of the Intergovernmental Panel on Climate Change's Third Assessment Report (1997-2001). He also was a member of the National Research Council's Panel on Abrupt Climate Change and its Societal Impacts

(2000-2001), and currently serves on the National Oceanic and Atmospheric Administration's Panel on Abrupt change. Pierrehumbert was a Guggenheim Fellow in 1996-1997.

Sean N. Raymond received his PhD in Astrophysics from the University of Washington (Seattle, USA) in 2005. He then spent four years as a researcher and NASA Postdoctoral Program fellow at the University of Colorado. Starting in November 2009, he is a full-time researcher for the CNRS at the Observatoire de Bordeaux in France. His research focuses on the formation, habitability, and long-term evolution of planets both in the Solar System and in other planetary systems. He also studies tidal effects on close-in planets which affect the orbital and thermal evolution.

Dimitar D. Sasselov is a Professor in the Astronomy Department, Harvard University, a founding Director of the Harvard Origins of Life Initiative, and a Senior Advisor in the sciences, Radcliffe Institute for Advanced Study, Harvard University. Dimitar Sasselov has been a professor at Harvard since 1998. He arrived to the Harvard-Smithsonian Center for Astrophysics in 1990 as a Center post-doctoral Fellow. Between 1999 and 2003 he was the Head Tutor of the Astronomy Department. Dimitar was born in Bulgaria, and was educated at Sofia University, where he received his Ph.D. in Physics in 1988, almost concurrently working on his degree at the University of Toronto, Canada, where he received his Ph.D. in Astronomy in 1990. His research explores the many modes of interaction between radiation and matter: from the evolution of hydrogen and helium in the early universe to the study of the structure of stars. He is very fond of unstable stars – ones that pulsate regularly and allow us to determine distances to other galaxies. Most recently his research has led him to explore the nature of planets orbiting other stars. He has discovered a few such planets – with novel techniques that he hopes to use to find planets like Earth. He is the director of the new Harvard Origins of Life Initiative – a multidisciplinary center bridging scientists in the physical and in the life sciences, intent to study the transition from chemistry to life and its place in the context of the Universe.

Sara Seager is the Ellen Swallow Richards Associate Professor of Planetary Science and Associate Professor of Physics at MIT. Before joining MIT in 2007, she spent four years on the senior research staff at the Carnegie Institution of Washington preceded by three years at the Institute for Advanced Study in Princeton, NJ. Her PhD is from Harvard University and her BSc in math and physics from the University of Toronto. Professor Seager's research focuses on theoretical models of atmospheres and interiors of all kinds of exoplanets. Her research has introduced many new ideas to the field of exoplanet characterization, including work that led to the first detection of an exoplanet atmosphere. She was part of a team that co-discovered the first detection of light emitted from an exoplanet and the first spectrum of an exoplanet. Professor Seager is the 2007 recipient of the American Astronomical Society's Helen B. Warner Prize.

Franck Selsis works at the *Laboratoire d'Astrophysique de Bordeaux*, a department of both the University of Bordeaux and CNRS. His research is dedicated to the origin, evolution of planetary atmospheres, in particular the atmosphere of extrasolar planets and the Earth. Beside these main research fields, he contributed in a variety of topics such as interstellar and prebiotic chemistry, meteor prediction and observation. His PhD (2000, University of Bordeaux), addressing the search for spectral signatures of life on exoplanets and prebiotic chemistry on Early Earth is considered as the first PhD on Astrobiology defended in France. In 2004, after a 3 year postdoc in the Center for Astrobiology in Madrid, Spain, he obtained a CNRS permanent researcher position in the team of Gille Chabrier at the Ecole Normale Supérieure de Lyon, France. Within this team he worked on many theoretical aspects of the modeling of extrasolar planets, on the interpretation of several observations of giant exoplanets atmosphere using space telescope and on space observatory projects, such as Darwin, aiming at the characterization of terrestrial exoplanets. In 2008, he received a grant from the European Research Council (ERC) to start an independent research team in Bordeaux, on a project called E_3ARTHS (*Exoplanets and Early Earth Atmospheric Research: THeories and Simulations*). The goal of this team is to develop the modeling tools that are necessary to explore the diversity of exoplanets and to understand the spectral and photometric observations of exoplanet atmospheres that we are already able to obtain. Another important topic of the team (which gathers 5 permanent researchers, 3 postdocs and 3 PhD students) is the evolution of the atmosphere of Earth during the first half of its history, in particular in the context of the origins and evolution of Life. In 2009, he received the *Researcher of Year* award of the French region Aquitaine.

Roger E. Summons is Professor of Geobiology in the Department of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology. Prior to taking up that appointment in 2001 he was at the Australian Geological Survey Organisation, formerly known as the Bureau of Mineral Resources, Geology and Geophysics in Canberra. Over a period of 18 years at AGSO and BMR he was a member, then leader, of a research team studying the distinctive nature and habitat of Australian petroleum and the evolution of the biogeochemical carbon cycle. At MIT his research group studies the co-evolution of Earth's early life and environment, lipid biosynthetic pathways, hydrothermal ecosystems, biological mass extinction events and the origins of fossil fuels. Professor Summons was awarded BSc (1969) and PhD (1972) degrees in Chemistry from the University of NSW. He also undertook postdoctoral research in the Genetics Department at Stanford University and in the Research Schools of Chemistry and Biological Sciences at the Australian National University, Canberra. He was elected Fellow of the Australian Academy of Science in 1998, Fellow of the American Geophysical Union in 2006, Fellow of the Royal Society in 2008 and is author or coauthor of c. 250 research papers in organic chemistry, geochemistry and geomicrobiology.

Jill C. Tarter holds the Bernard M. Oliver Chair for SETI (Search for Extraterrestrial Intelligence) and is Director of the Center for SETI Research at the SETI Institute in Mountain View, California. Tarter received her Bachelor of Engineering Physics Degree with Distinction from Cornell University and her Master's Degree and a Ph.D. in Astronomy from the University of California, Berkeley. She served as Project Scientist for NASA's SETI program, the High Resolution Microwave Survey, and has conducted numerous observational programs at radio observatories worldwide. Since the termination of funding for NASA's SETI program in 1993, she has served in a leadership role to secure private funding to continue this exploratory science. Currently, she serves on the management board for the Allen Telescope Array, a joint project between the SETI Institute and the UC Berkeley Radio Astronomy Laboratory. When this innovative array of 350 6-m antennas begins operations at the UC's Hat Creek Radio Observatory, it will simultaneously survey the radio universe for known and unexpected sources of astrophysical emissions, and speed up the search for radio emissions from other distant technologies by orders of magnitude. Tarter's work has brought her wide recognition in the scientific community, including the Lifetime Achievement Award from Women in Aerospace, two Public Service Medals from NASA, Chabot Observatory's Person of the Year award (1997), Women of Achievement Award in the Science and Technology category by the Women's Fund and the San Jose Mercury News (1998), and the Tesla Award of Technology at the Telluride Tech Festival (2001). She was elected an AAAS Fellow in 2002 and a California Academy of Sciences Fellow in 2003 (and CAS Scientific Trustee in 2007). In 2004 *Time Magazine* named her one of the Time 100 most influential people in the world, and in 2005 Tarter was awarded the Carl Sagan Prize for Science Popularization at Wonderfest, the biannual San Francisco Bay Area Festival of Science. In 2006 Tarter became a National Advisory Board member for the Center for Inquiry's Office of Public Policy in Washington, DC. She is also a Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP) Fellow. Tarter was one of three Technology, Education, Design (TED) prize winners in 2009. Tarter is deeply involved in the education of future citizens and scientists. In addition to her scientific leadership at NASA and SETI Institute, Tarter has been the Principal Investigator for two curriculum development projects funded by NSF, NASA, and others. The first, the *Life in the Universe* series, created 6 science teaching guides for grades 3-9 (published 1994-96). Her second project, *Voyages Through Time*, is an integrated high school science curriculum on the fundamental theme of evolution in six modules: Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution and Evolution of Technology (published 2003). Tarter is a frequent speaker for science teacher meetings and at museums and science centers, bringing her commitment to science and education to both teachers and the public. Many people are now familiar with her work as portrayed by Jodie Foster in the movie *Contact*.

Giovanna Tinetti is a lecturer at the University College London and a Royal Society University Research Fellow. She coordinates there a team on extrasolar planets since 2007. G. Tinetti obtained a MSc and a PhD in theoretical physics from the University of Torino, Italy, but her scientific interests slowly shifted to Astrobiology and Extrasolar Planets during her PhD thesis with Prof. Luigi Sertorio. She then moved to the US in 2001, to join one of the NASA Astrobiology Institute team at the Jet Propulsion Laboratory in Pasadena. In those years she could complete her apprenticeship in planetary and atmospheric science, thanks to the interaction with Prof. Yuk Yung's team at the California Institute of Technology. In particular, she focused her research on the detection of biosignatures in the atmospheres of terrestrial habitable planets, in support of NASA mission concepts for exoplanet characterization, such as the Terrestrial Planet Finder. In 2005, G. Tinetti was awarded an European Space Agency (ESA) fellowship to move to Paris at the Institut d'Astrophysique and work on exoplanet atmosphere characterization, using the transit technique. Her idea to use Infrared transmission spectroscopy to detect molecules in the atmosphere of transiting extrasolar planets, was proven to be successful by later observations with the Spitzer and Hubble Space Telescopes. In particular, G. Tinetti and collaborators pioneered the detection of molecules such as water vapour (2007), methane (2008) and carbon dioxide (2009) in the atmospheres of hot, giant transiting exoplanets, the easiest targets to be observed by nowadays instruments. The discovery of methane, in particular, accomplished with colleagues Dr. Mark Swain and Gautam Vasisht from JPL, received the Edward Stone Award and the NASA Group Achievement Award in 2009. Among her activities, G. Tinetti is a member of advisory boards expected to guide future optimal strategies to search for habitable worlds, such as the Exoplanet Roadmap Advisory Team, appointed by ESA, and the Blue Dot Team, representing the European exoplanet community.

Frances Westall is Director of Research at Centre de Biophysique Moléculaire, Orléans, France (CNRS). Her research interests are the geological context of the origin of life, scenarios for the origin of life, earliest evidence for life on Earth and the importation of prebiotic molecules to the Earth, as well as the search for life on Mars. She is the ExoMars Microscope co-Team Coordinator. Westall serves on the Comité de Programmes scientifique, French Space Agency (CNES), the European Science Foundation's European space science advisory committeeand the Mars Exploration Panel Advisory Group goals committee. Her BSc with Honors in Geology is from the University of Edinburgh, U.K., and her Ph.D. in Marine Geology is from the University of Cape Town, South Africa.

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

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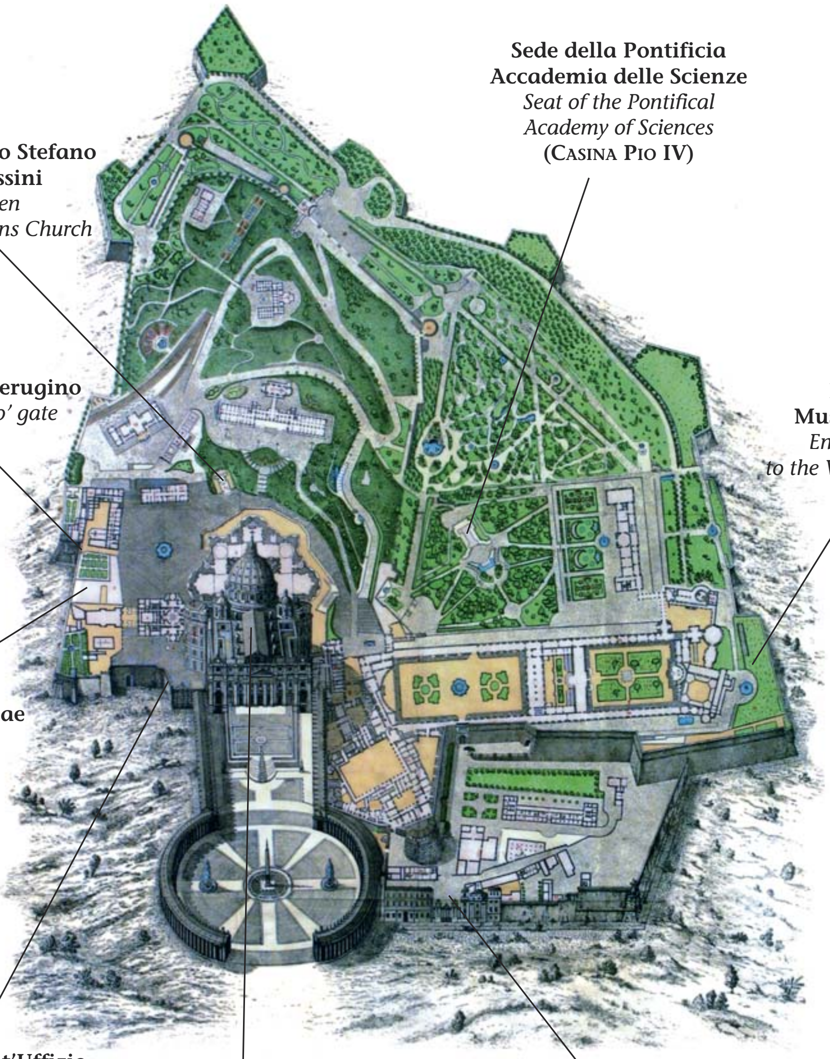
Memorandum

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 after dinner at the end of the afternoon sessions to take participants back to the Domus Sanctae Marthae. Lunch and dinner for the participants will be served at the Academy every day except on Sunday, 8 November, when only dinner will be served after the pilgrimage to the Basilica of St Francis in Assisi.

2) On Sunday, for those wishing to attend, there will be a day-trip to the Basilica of St Francis in Assisi, where Mass will be held at 12:00, followed by lunch at the Franciscan Abbey. If you would like to attend, please inform the Secretariat as soon as possible, and a bus will pick you up at 7:00 from the Domus Sanctae Marthae.

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.



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FRONT COVER:
The globe of Mars, hand-painted around 1916 by Ingeborg Bruhn, is based on the maps of Percival Lowell (Vatican Observatory).