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ESLAB 2008, Symposium 42. Cosmic Cataclysms and Life: Abstracts

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Molecules from the interstellar medium to life on planets

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Contrary to decades of astronomical thought, the interstellar medium in our galaxy, i.e. the material between the stars, is actually quite rich in molecular material. Gas phase molecules and condensed-phase molecular carriers have now been observed in many astrophysical environments, and a wide variety of chemical compounds have been identified – over 140 in the gaseous state. In fact, molecular material appears to follow a complex life cycle, which begins with the active chemistry in circumstellar ejecta of evolved stars. Some circumstellar environments are carbon-rich and produce a unique synthesis where compounds with multiple carbon-carbon bonds are created. Molecular material from circumstellar shells appears to survive as these objects evolve into planetary nebula and their ejecta become part of diffuse clouds. Diffuse clouds subsequently collapse into dense clouds, carrying along some fraction of the chemical imprint of previous formation processes. This cycling of molecular gas can provide dense clouds with C-rich starting material, which accelerates organic chemistry in these objects. Furthermore, many molecular clouds eventually collapse into protostellar disks and then solar systems. While some of the matter in the pre-solar nebula is processed into planets, other molecular material survives in near-pristine form in comets, meteorites, and interplanetary dust particles, as evidenced by unusual isotope ratios. These objects can bring select interstellar compounds to planetary surfaces via exogenous delivery, many which are organic in nature, and some containing the biogenic element, phosphorus. In fact, life is thought to have begun on Earth after the period of Late Heavy Bombardment, when delivery of interstellar matter was probably at its maximum. Therefore, interstellar chemistry may have had an influence on the early biochemistry that led to terrestrial life. This scenario and the possible biogenic pathways from stars to planetary systems will be discussed. New astronomical observations tracing the molecular life cycle will be presented.

The chemical evolution of the Milky Way and the galactic habitable zone

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I will present a brief overview of our current understanding of the evolution of the Milky Way. I will then discuss the concept of Galactic Habitable Zone (GHZ), which was introduced a few years ago as an extension of the much older concept of Circumstellar Habitable Zone. However, the physical processes underlying the former concept are hard to identify and even harder to quantify. That difficulty does not allow us, at present, to draw any significant conclusions about the extent of the GHZ: it may well be that the entire Milky Way disk is suitable for complex life.

Synthesis of interstellar and circumstellar molecules

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A global inventory of interstellar and circumstellar molecules will be presented. Molecules are commonly thought of as diagnostic tools of primarily cool media, but they can be very useful probes also of the physics and chemistry of violent media, including mass outflows and shocks. When seeking to understand the various phenomena we will encounter both successes and challenges. We will attempt to draw a roadmap for the future development of the field, with particular emphasis on pre-biotic species and/or potential 'life-molecules'.

Delivery of complex organic compounds from planetary nebulae to the Solar System

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The last phase of stellar evolution from the asymptotic giant branch (AGB) to proto-planetary nebulae, to planetary nebulae represents the most active period of synthesis of organic compounds in a star's life. Both inorganic and organic molecules and solids are found to form in the circumstellar envelopes created by stellar winds. Over 50 gas-phase molecules, including rings, radicals, and molecular ions have been identified by millimeter-wave and infrared spectroscopic observations through their rotational and vibrational transitions.

Infrared spectroscopic observations of emissions from the stretching and bending modes of aliphatic and aromatic compounds have revealed a continuous synthesis of organic material from the end of the AGB to proto-planetary nebulae, to planetary nebulae. These results show that complex carbonaceous compounds can be produced in a circumstellar environment over a period of only a few thousand years. Most interestingly, there are a number of unidentified emission features which are almost certainly carbonaceous in nature but their exact chemical composition is unknown. These include the 21 and 30 micron emission features, and the extended red emission observed in proto-planetary nebulae and planetary nebulae.

Isotopic analysis of meteorites and interplanetary dust collected in the upper atmospheres have revealed the presence of pre-solar grains similar to those formed in evolved stars. This provides a direct link between star dust and the solar system and raises the possibility that the early solar system was chemically enriched by stellar ejecta with the potential of influencing the origin of life on Earth.

So the last shall be first, and the first last – stellar birth and the fate of protoplanets

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There is increasing evidence that violent eruptions from protostars, so-called FU Ori events, are more common than previously thought. Recently, we were able to show that arc- or ring-like reflection nebula

often associated with young stellar objects are the relics of this activity. They are surfaces of wind-blown bubbles which become apparent by light scattered off the swept-up dust grains. The underlying cause for the outburst is a strong increase of the stellar accretion rate over a couple of years which, in turn, leads to both an enormous brightening and an enhanced mass-loss through a poorly-collimated wind. The increase in accretion results from a disk instability which, in our model, is due to matter raining from the protostellar envelope down on the disk. Thus, occasionally, the disk becomes unstable, collapses, and forms dense eddies which spiral inwards due to gravitational torques. Eventually, they fall onto the young star. This scenario of burst mode accretion is consistent with observational findings. As a consequence, many but not all potential protoplanets will be swallowed by the star until the envelope is consumed.

Star and planet formation in young massive clusters

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The majority of stars, and presumably of planets, form in rich clusters dominated by a few massive stars emitting most of their energy in the UV. Images of the Orion Nebula, the prototype of massive star forming regions, obtained with the Hubble Space Telescope reveal that UV radiation from the environment can dramatically affect the structure and lifetime of young circumstellar disks. External irradiation photo-evaporates the disks, while it affects the transfer of angular momentum, the formation of gravitational instabilities in the disk mid-plane, as well as grain growth, annealing and mixing. These mechanisms pose strong temporal constrains on the planet formation process and may eventually determine the appearance of planets germane to life. We illustrate the most recent findings on the physics of photovaporated disks, mostly on the basis of the data taken for the HST Treasury Program on the Orion Nebula.

Revealing the relevance of spiral arm crossings to earth cataclysms using Gaia

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Gaia is ESA's next generation space astrometry mission. It will measure parallaxes and proper motion to unprecendented accuracy for hundreds of millions of stars (all sky, complete to G = 20), plus radial velocities for brighter stars. From these data we can construct an accurate 6D phase space map (3D positions, 3D velocites) for stars out to more than 10kpc. In this paper, I describe how Gaia can shed light on two phenomena implicated in Earth cataclysms, namely spiral arm crossing and impacting asteroids. Several papers have reported a correlation and possible causal connection between spiral arm passages and ice ages and/or mass extinctions. One possible mechanism is the proximity to massive stars during such passages: the cosmic ray flux from type Ib/II supernovae within 10 pc could increase terrestrial cloud cover (through water drop nucleation) and thus lower global temperatures for millions of years. A second mechanism is that the passage of the solar system through regions of higher stellar or gas density could perturb the Oort cloud and send minor bodies onto a collision course with the Earth. Using Gaia's phase space map, we can deduce the gravitational potential of the Galaxy and accurately determine the present velocity of the Sun. Via numerical integration we can then reconstruct the path of the Sun over the last billion years and examine whether past ice ages and mass extinctions coincide with spiral arms passages. While they found some correlation between arm passages and ice ages, the results depended heavily on the poorly known pattern speed of the spiral arms. With Gaia we can dramatically improve this analysis: the astrometric accuracies are better than Hipparcos by a factor of 500 (12-25 μas compared to 1000 μas) and it observes many more stars (1 billion rather than 120 000). We can deduce the Sun's orbit more accurately by mapping the potential at higher spatial resolution. Moreover, we can measure the positions and velocities of the spiral arms from their OB star population (without assuming a rotation curve or needing to know the extinction). For an OB star 4kpc from the Sun observed through 4 magnitudes of extinction (G = 15), Gaia will determine its distance to an accuracy of 13 % and its space velocity to about 1 km/s. I will show how Gaia can do this for some 50 000 OB stars within a few kpc. The result is a more accurate model for the spiral arms and stronger conclusions on the correlation between arm passages and Earth cataclysms. I will also describe Gaia's census of potentially impacting asteroids and comets. Gaia will detect some 16 000 NEOs. While ground-based surveys will discover many NEOs in the coming years, Gaia can derive accurate orbits and is sensitive to parts of the parameter space which cannot be easily reached from the ground.

A case study of a protostellar system

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Protostellar disks are evidently the region where planets form. Further there structure will have a tremendous impact on the emergence of life whether as a source of comets to deliver water or as the source of the materials that will form planetary surfaces and atmospheres. The structures of such disks, as well as their evolution during the first gigayear of stellar evolution is a very active research topic today. Unfortunately, most of the objects that can be studied – especially in an evolutionary context are at least 150 pc away from us and it will be the emergence of the ALMA submm-array that will have the spatial resolution that will allow a detailed study of the processes leading to planetary formation. In the meantime we are left with a small number of objects which are either close enough, large enough or oriented in such a fortuitous way that at least a 'snapshot' of the early stages can be discerned.

In this paper we review such an object – L1551 IRS5. This object have been the topic of more than 200 refereed papers in the last 30 years. The stellar system forming consist of a low-mass binary (0.8 & 0.3 solar masses) orbiting each other at a distance of about 50 AU. Each is surrounded by a small (30 AU) dusty disk, while the whole aggregate is orbited by a flat 1000 AU diameter dust envelope. Further out we find another flattened system consisting mostly of molecules and having kinetic temperatures of 10–100 K. The mass of this envelope is several solar masses and is an enormous reservoir of angular momentum which is being shedded through a massive molecular outflow.

This whole process is extremely violent. Massive outflows, shocks within the ambient medium producing ultraviolet radiation and X-rays, the creation of planetesimals, who through collisions either grow to planets or are ground down to dust and ejected from the system or swallowed.

Cataclysms in planet formation

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When Earth-like planets form out of (sub-)μm-sized protoplanetary dust, the mass of the final object has increased by a factor of approx. 10^{40}.

The growth scenario over these 40 orders of magnitude is not uniform but changes due to the occurrence of physical processes or crucial transitions, some of which have cataclysmic ramifications for the formation of planets. The most important critical stages in planet formation and the major scientific questions to be addressed are:

- The transition from direct growth to fragmentation: at which dust-aggregate size does this happen?
- The increasing radial drift of growing protoplanetary bodies: how can the potential loss of meter-sized objects into the central star be prevented?
- The transition from van der Waals growth to growth aided by the ensemble gravity: under which conditions can this happen?

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- The transition from ensemble gravity to individual gravity: are the primordial planetesimals massive enough to grow by gravitational capturing?
- The transition from orderly growth to runaway growth: are the timescales for planet formation sufficiently small?

With the recent developments in numerical methods and laboratory experiments, we are now at a stage to tentatively address these questions. Provisional answers will be given at the conference.

The fraction of uninhabitable extrasolar planetary systems due to massive bombardment

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Many nearby Sun-like stars have debris disks, containing dust made by the collisions of comets or asteroids. Measuring the dust signal allows us to estimate the numbers of colliding bodies and consider if they could pose an impact hazard on any terrestrial planets in the system. Using far-infrared data from Spitzer, I estimate that a quarter of systems could have impacts so severe as to sterilize the planetary surface, but a half of systems may be comparably 'clean' to the Sun. These latter could be continuously habitable in the sense of low bombardment, but then some icy-comet bombardment may be needed for a terrestrial planet to have ocean water. The relation of debris disks and giant planets around Sun-like stars is discussed.

Dynamics of the Late Heavy Bombardment

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I will start presenting our model for the origin of the Late Heavy Bombardment (LHB) of the terrestrial planets, sometimes called 'the Nice model'. This model argues that the giant planets had initially quasi-circular and co-planar orbits and orbital separations much smaller than today. They were surrounded by a massive planetesimal disk, extended up to 30–35 AU. As a consequence of the interaction of the planets with the planetesimal disk, the giant planets suffered orbital migration, which slowly increased their orbital separation. If the ratio of the orbital periods of Saturn and Jupiter was initially less than 2, these planets had to cross eventually their mutual 1:2 mean motion resonance, thereby triggering a global instability in the planetary motion. The current orbital configuration could then be achieved from the gravitational interaction between the planets and the disk particles. The LHB would have been caused by the consequent dispersion of the trans-Neptunian planetesimals, but also by the escape of approximately 90% of the main belt asteroids, during a phase of fast planet migration that followed the 1:2 resonance crossing. The model also explains the current structure of the Kuiper belt, and the capture of some primordial trans-Neptunian objects on orbits typical of the Trojans of the giant planets, irregular satellites and outer main belt asteroids.

The main weakness of the Nice model is that the initial conditions of the giant planets were just postulated. More recently, we have studies the dynamics of the giant planets embedded in the proto-planetary gas disk, using hydro-dynamical simulations. The only systems that we found to reach a steady state are those in which the planets are locked in a quadruple mean motion resonance (i.e. each planet is in resonance with its neighbor). In total we found 6 such configurations. For some gas disk parameters, these configurations are characterized by a negligible migration rate, thus explaining why there are no 'hot Jupiters' in our Solar System. After the disappearance of the gas, and in absence of planetesimals, only two of these six configurations (the least compact ones) are stable for a time of hundreds of millions of years or more. I will explain how these two configurations can lead to an evolution similar to that described by the Nice model, which removes the arbitrary character of the initial conditions in our original work.

I will also briefly discuss the possibility that an analog of the LHB is occurring in some extrasolar debris disks with large ages and bright IR-excess.

Cosmochemical constraints on the Late Heavy Bombardment

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MNHN

We will review the cosmochemical constraints on the late heavy bombardment. We will focus on the Earth light elements relative abundance and isotopic composition, on the PGEs abundance. We will also discuss the meteoritic records inferred from the chemical/petrographic properties of regolith breccia.

A new chronology for the Moon and Mercury

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Craters represent one of the most spectacular surface features of solid bodies of the Solar System. Cratering studies provide a fundamental tool for age determination of planetary terrains. Since the beginning of the lunar exploration, age estimate for the lunar terrains were derived, followed by the detailed chronology models for the Moon and other terrestrial planets. Recently, thanks to a fleet of new space missions (e.g. Mars Express to Mars, Messenger to Mercury, and Kaguya to the Moon) this field of research entered a new exiting phase, where accurate age estimates provide means for detailed geological studies.

In this paper we present a new model for dating the surface of the Moon, obtained by simulating the incoming flux of impactors and converting it into a size distribution of resulting craters. We compare this model with the standard chronology for the Moon showing their similarities and discrepancies. In particular, we derive implication for a non-constant flux in recent times and also we revise the late heavy bombardment hypothesis. We also show the potential of our model for accurate dating of other inner Solar System bodies, showing the case of Mercury.

If we had no Moon: Earth, Life, and SMART-1

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The Earth has a large moon, making it unique in the inner solar system. Mercury and Venus have no moons, and Mars has only two small asteroid-sized objects orbiting it. We look at the effect the Moon has had on the Earth, and explore how different our world would be if we had no planetary companion. Would life have evolved differently, or even appeared on Earth without the Moon?

The Earth formed 4.56 billion years ago, and the Moon formed about 30 million years later. At that time, the Earth was a magma ocean. An impactor about the size of Mars struck the Earth at an oblique angle, and removed some of the magmatic mantle. This mantle was put in orbit around the Earth, together with some of the debris from the impactor itself, and this material eventually formed the Moon.

The effect of the Moon's tidal forcing on the Earth was extremely high at this time, to the point that the early magma ocean was affected. This provided some additional energy to the heating from radioactive elements present, but after the radiogenic heating decayed, the Moon still was a source of heating that may have had some geological effect, keeping the Earth's magma hot and perhaps forcing additional convection in the Earth's mantle.

The Moon has been a stabilizing factor for the axis of rotation of the Earth. If you look at Mars, for instance, that planet has wobbled quite dramatically on its axis over time due to the gravitational influence of all the other planets in the solar system. Because of this obliquity change, the ice that is now at the poles on Mars would sometimes drift to the equator. But the Earth's moon has helped stabilize our planet so that its axis of rotation stays in the same direction. For this reason, we had much less climatic change than if the Earth had been alone. And this has changed the way life evolved on Earth, allowing for the emergence of more complex multi-cellular organisms compared to a planet where drastic climatic change would allow only small, robust organisms to survive.

Giant impacts and the formation of terrestrial planets

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Once planetesimals a few kilometers in size are formed in the proto-planetary nebula, their collisional evolution leads to the formation of bodies of increasing sizes. As their masses grow, gravitational scattering leads to higher random velocities and therefore to more and more energetic collisions. Towards the end of the process, when bodies reach planetary sizes and collide with velocities equal or even larger than their own escape velocity, the energy involved in such events becomes so large that they can dramatically affect the planets themselves. It is argued that signatures of such energetic events are still visible in the present day solar system.

The Moon, for example, is currently thought to have formed following such an event that involved the forming Earth and a body about 1/10 of its mass. The collision resulted in the formation of a proto-lunar accretion disk constituted from debris stemming from the projectile as well as of matter ejected from the proto-Earth's mantle. The evolution of such a debris disk is believed to lead to the formation of the Moon. While the giant impact theory is currently regarded as the most plausible lunar formation scenario, many aspects remain uncertain. These involve the dynamics of the event itself and the subsequent evolution of the proto-lunar accretion disk.

Another compelling case for a giant impact can be made for Mercury. In this case, the collision is invoked to blast away a significant portion of the mantle in order to explain the unusually high mean density of the planet. Numerical investigations have helped to define the class of impacts required to achieve the required mantle loss as well as the subsequent fate of the ejected material and have established that a giant impact was indeed a viable scenario. The origin of Mercury is one of the main science goals of two space missions: NASA's Messenger already collecting data and ESA's mission BepiColombo, to be launched in 2013.

Projectile identification in terrestrial and lunar impact structures

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During crater formation on a planetary body a small amount of meteoritic material is incorporated into the impacted lithologies, inducing a measurable geochemical signal in these molten/shocked rocks that differs from the crustal signature. This signal can confirm the impact origin of the structure and in ideal cases determine the precise nature and provenance of the projectile. At least three geochemical methods are capable of detecting very small amounts of meteoritic material present in impact-related lithologies. The use of platinum group elemental (PGE) patterns sometimes allows a precise characterization of the projectile type. So far, the record is rather incomplete. Of the terrestrial craters larger than 1 km, most of the projectiles have only been characterized to the level of chondrites or iron meteorites. This is insufficient to link them to asteroid families or disruption events, or to identify possible changes in the frequency or type of impacted meteorites through time. Seven of the Phanerozoic structures (>1.5 km) for which the projectiles have been characterized down to the level of specific class types, are ordinary chondrites (OC). Only one, the Chicxulub crater stands out as a carbonaceous chondrite. Recent work on other impact structures such as Sääksjärvi, Rochechouart, Gardnos, and Dellen reveals another recurrent type of projectile: non-magmatic iron (NMI) meteorites. Based on the existing record, OC and NMI seem to be the two most common types of impactors falling on Earth since the beginning of the Phanerozoic. Discussing collisions on the Earth-Moon system, several other crucial questions surface. It is currently difficult to judge if the rate of impact remained constant through time, or if it varied, with possible higher collision rates during specific periods, as apparently indicated by recent data. The constancy of the source of these projectile is another key question, has the projectile provenance changed through geological time? Although our present knowledge on projectile population distribution and on the existence of periods with abnormal bombardment rates is incomplete, terrestrial and lunar projectile identification studies have unraveled a few simple trends that need to be confirmed.

The meteorite impact in a new prehistory of life

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A new idea of possible synthesis of the complex organic compounds (OC) in supper-high velocity impact (SHVI)-generated plasma torch were proposed and experimentally confirmed. Previously unknown and found experimentally new feature of impact generated plasma torch has allowed to develop the original concept of the prehistory of life. According to this concept the intensive synthesis of complex OC arose during meteoritic bombardment in first 0.5 billion years during formation of planets. This the most powerful and destructive action in the Earth history could play the decisive role and prepare the conditions for origin of the life. In the interstellar gas-dust clouds, the synthesis of simple OC may be explained by identical process occurring in the plasma torch SHV- collisions between the dust particles.

In-depth study of physical processes occurring during the plasma torch fly away make it possible to advance a hypothesis according to which the plasma-generated unbalanced asymmetric electric and magnetic fields and circularly polarized plasma emission may lead to the initial insignificant breaking the mirror symmetry in processes of isomer generation in this medium and determinate the «sign» of asymmetry of bioorganic world.

It has been shown experimentally that the plasmachemical processes in the torch have high catalytic properties and assure the rise of the chemical reactions rates by 10–100 millions times. In the process of the plasma fly-away this in turn can assure fast forming the simple and complicated OC including highly forked polymers.

Laboratory experiment of modeling of SHV-impact plasma torch by influence laser, working in Q-switch regime has shown the possibility of synthesis of high-molecular $\sim$4000 a.m.u OC. by impact of micrometeorite with effective diameter 100 mkm composed of only H, C, N and O in inorganic form. The obtained mass-spectra evidence to the some signs of self – assembly and ordering.

Having the giant energy, the meteorite impact is capable to inject the new-created complicated OC deep inside the space body surfaces, including subsurface water reservoirs, such as, for example, on Europe, Encilade and Titan. In this case, the meteorite impact, have no nature alternative in creation the initial conditions for origin of extra-terrestrial life. Such a possibility was confirmed by laboratory impact modeling experiment, in which plasma torch was created under the water surface.

The important feature of this new concept is the possibility of its experimental verification. This could be done in experiment with collision of two body's, projectile and target, lunched from counter-flying satellites.

Free molecular oxygen derived from a giant cometary impact during the impact cataclysm

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The most intense period of extraterrestrial impacts (the impact cataclysm) on Earth occurred ca. 3.9 Ga, 500–600 millions years after accretion. During this period, the Earth's surface was aggravated by tens of thousands of impact events and many of the impactors were probably huge (>100 km) comets. Some of these comets had impact energies sufficient to evaporize partly or entirely early ocean. The geochemical (isotopic) evidence indicates that the impact cataclysm is nearly coincident with the earliest life. This implies that the impacting huge comets could shape the early biologic evolution. On the other

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hand, these impacts were also probably devastating for the early development of life.

Based on a previously described approach, I explore a possibility that some enormous comets of the cataclysm period with an appropriate energy/mass could create considerable amounts of free molecular oxygen. This oxygen was generated through the dissociation of cometary H2O vapor with subsequent escape of hydrogen into interplanetary space. I also discuss some possible geochemical and biological effects of this high molecular oxygen during the cataclysm episode.

Cataclysmic bombardment throughout the inner solar system

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The Apollo program demonstrated that the Earth-Moon system was targeted by impacting asteroids and comets far more frequently than that suggested by the small number of surviving impact craters on Earth. Because Apollo missions returned samples to Earth, a quantitative chronology of that impact flux began to emerge, indicating most impact craters on the Moon were produced during an early period of bombardment that ended between 3.80 and 3.85 Ga. These ages led to speculation that similar impact cratering events on the Earth affected the origin and early evolution of life on our planet. Because impact cratering is a continuing process, we also realize that the processes, even at scales far smaller than basin-forming events, pose a hazard for modern life.

Argon-Ar, U-Pb, and Rb-Sr analyses of Apollo-era samples suggest early bombardment may have been particularly intense in a less than or equal to 200 Myr interval that ended approximately 3.85, which is consistent with more recent analyses of lunar meteorites. Although the source of debris remains controversial, geochemical and geological fingerprints suggest an asteroid source. This bombardment is a process that appears to have also affected the entire inner solar system and, thus, potentially habitable conditions on early Mars too.

However, the details of the impact flux remain murky, because so few samples have been analyzed and many of those analyzed are without geologic context. Consequently, one of the most important scientific goals of renewed lunar exploration, both robotic and human, will be to collect appropriate samples to deduce impact cratering's effect on the fabric of life on Earth. Specifically, a collection of impact melts unambiguously tied to large craters and basins are needed for detailed petrologic, geochemical, and radiometric age analyses. These should be selected to represent the entire distribution of relative ages among large basin-forming events, and of lunar geographic locations. The highest priority sample is an impact melt sample from the South Pole-Aitken basin-forming event.

These same samples can also be used to test the source of projectiles. This will, in turn, permit an analysis of the delivery of biogenic elements during, and environmental consequences of, the bombardment. Some of the consequences were detrimental, but these same impact events may have generated vast hydrothermal systems that were critical for the origin and early evolution of life.

Effects of impacts on the atmospheric evolution of Mars

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Early in its history, Mars probably had a denser atmosphere with sufficient greenhouse gases for sustaining the presence of stable liquid water at the surface. Impacts by asteroids and comets could have played a significant role in the evolution of the Martian atmosphere, not only by causing atmospheric erosion but also by delivering material and volatiles to the planet. We investigate the atmospheric loss and the delivery of volatiles using an analytical model that takes into account the impact simulation results and the flux of impactors given in the literature. The atmospheric loss and the delivery of volatiles are calculated in order to obtain the atmospheric pressure evolution. Our results suggest that, even for the most efficient erosion model, impacts alone can hardly explain the loss of significant atmospheric mass during the Noachian and since the Late Noachian (about 3.7–4 Gyr ago). A period with intense bombardment of meteorites could have increased the atmospheric loss, but to explain the loss of a speculative massive atmosphere in the Late Noachian, other factors of atmospheric erosion and replenishment need also to be taken into account.

Influx of organics by bombardment vs their in-situ formation on the primitive Earth

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It will be shown that organic syntheses in the atmosphere and water bodies on the primitive Earth produced vastly more materials of biological interest,with a huge variety, as compared with the meager list of simple organics found in meteorites and comets. The same pathways of organic syntheses occured in dense interstellar clouds, in the solar nebula and on the primitive Earth. Only that on Earth the density of the atmosphere and the availability of energy sources were much larger. Hence what is the rational of the contribution of cometary and meteoritic impacts to the inventory of biologically important materials on the primitive Earth? In other words, astrobiology should stop being considered as the purveyor of 'life' materials to the Earth.

Impact driven scenario for interplanetary transfer of life

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'Panspermia', coined by S. Arrhenius in 1903, suggests that microscopic forms of life, e.g., bacterial spores, can be dispersed in space by the radiation pressure from the Sun thereby seeding life from one planet to another or even beyond our Solar System. Being ignored for almost the rest of the century, the scenario of interplanetary transfer of life has received increased support from recent discoveries, such as the detection of Martian meteorites and the high resistance of microorganisms to outer space conditions. With the aid of space technology and adequate laboratory devices the following decisive step required for viable transfer from one planet to another have been tested: (i) the escape process, i.e. impact ejection into space; (ii) the wandering through space over extended periods of time; and (iii) the landing process, i.e. non-destructive deposition of the biological material on another planet. In systematic shock recovery experiments within a pressure range observed in Martian meteorites (5–50 GPa) a vital launch window of 5–40 GPa has been determined for spores of Bacillus subtilis and the lichen Xanthoria elegans, whereas this window was restricted to 5–10 GPa for the endolithic cyanobaterium Chroococcidiopsis. Traveling through space implies exposure to high vacuum, an intense radiation regime of cosmic and solar origin and high temperature fluctuations. In several space experiments the biological efficiency of these different space parameters has been tested: extraterrestrial solar UV radiation has exerted the most deleterious effects to viruses, as well as to bacterial and fungal spores; however shielding against this intense insolation resulted in 70% survival of B. subtilis spores after spending 6 years in outer space. Lichens survived 2 weeks in space, even without any shielding. The entry process of microorganisms has been recently tested in the STONE facility attached to the heat shield of a reentry capsule. The data support the scenario of 'Lithopanspermia', which assumes that impact-expelled rocks serve as interplanetary transfer vehicles for microorganisms colonizing those rocks. However, special conditions are required to allow natural transfer of viable microbes from planets in extra-solar systems to a planet in our Solar System and vice-versa.

Evidences support an extraordinary event, possibly an impact during the proterozoic for phosphorus abundance on the Earth

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The stromatolites of Precambrian Aravalli Supergroup outcropping around Udaipur, Rajasthan, India are composed either of only carbonate (dolomite) or phosphate and carbonate (carbonate fluorapatite). The phosphate bearing stromatolites of the same age are found to occur at China, Russia and Australia also. The stromatolites of Aravalli Supergroup have been classified as two distinct lithofacies: the carbonate stromatolite facies and the phosphate bearing stromatolite facies. There is a sharp and abrupt contact between these two facies. This abrupt contact is of considerable importance as it marks a diastem characterizing a period of overall change in the environment. The Earth, during its geological history has been subjected to several catastrophic episodes caused due to extraordinary high energy events; such as due to impacts by extraterrestrial bodies. These events caused mass extinctions or sometimes emergence of new species. A biodiversity curve drawn on the Sepkoski's data demonstrate a few exponential rise in the number of faunal and floral families, for instance at Pc/C Boundary; or mass extinctions such as at P/T or K/T Boundary. Fossil cyanobacteria of 20 to 100 micrometer diameter, occurring singly or in massed colonies have been found in the phosphate bearing stromatolites of Aravalli Supergroup whose maximum age is 2500 Ma. These cyanobacteria because of the absence of competitors had a luxuriant growth. They accumulated abnormal amount of phosphorus and formed a workable deposit of phosphorite owing to their post-mortem alteration. The point of discussion is: why phosphorus shows sudden abundance in the milieu which otherwise is absent in the immediately underlying carbonate stromatolites? Bushinski postulated 'upwelling' events for the abundance of phosphorus at some time-units in the Phanerozoic. However during the Precambrian era there was no sufficient amount of dead life that could sink at the bottom of the oceans to release phosphorus to upwell later. It can therefore be argued that the sharp boundary (diastem) between the two types of stromatolites noted at Udaipur expresses a possibility of an extraordinary event, possibly an impact that inundated the Earth with phosphorus. Phosphorus is an essential ingredient of proteins, the building blocks of the living beings. Its abundance after this event might be the reason for the emergence of the advanced species. Another question for discussion is the chemical constituents of life. Carl Sagan, once suggested the possibility of life on some planets constituted of elements other than carbon, calcium, phosphorus and water! On the same supposition, I speculated (at IGC, Japan) the possibility of earliest life with no phosphorus as its constituent, that though with the present bias of life needing ADP-ATP seems unlikely. Well! But do we need a paradigm shift?

Europa: a major target in the solar system for astrobiology

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Europa is one of the icy moons of Jupiter, and is probably the main fascinating target for astrobiologists in the Solar System. Images taken by Voyager and Galileo strongly suggest that the ice surface has been recently reorganized and a deep water ocean existing beneath this thick water ice crust could explain these surface modifications. Moreover, at depth, this mass of liquid water could be in contact with the silicate core. All these features would allow water-rock interactions and hydrothermal processes, providing to the Europa ocean all chemicals that might be used as carbon and energy sources and electron acceptors for life. Based on our knowledge on life on Earth, and particularly at deep-sea hydrothermal vents, or deeper, living entities could thrive in such conditions (low temperature, elevated hydrostatic pressure, darkness, etc) independantly from the sun energy.

In the framework of the ESA Cosmic Vision program, the mission 'Laplace' (leader M. Blanc, France) has been pre-selected with others for further studies. This mission dedicated to Europa and the Jupiter System is presently under study by a joint ESA/NASA Science Definition Team, to which japanese and russian scientists are associated. The question of a surface element (lander, impactor, penetrator), an essentail tool for astrobiologists, is still discussed.

Scientific arguments for astrobiological exploration of Europa and the latest developments in the preparation of the mission will be presented.

Habitability on planetary surfaces

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Life on Earth is one of the outcomes of the formation and evolution of the Solar System and has adapted to every possible environment on planet Earth. Recent discoveries have shown that life can exist in extreme environments, such as hydrothermal vents, in deserts and in ice lakes in Antarctica. These findings expand our notion of where life may occur elsewhere in the Universe and as well the definition of the 'planetary habitable zone'.

Looking at our Solar System three objects have been studied in more detail concerning extinct and extant life or prospects for life, namely Mars, Europa and Titan. Planet Mars and Saturn's moon Titan have recently been visited by spacecraft and have shown new exciting worlds relevant for the study of life. The objective of international future planetary exploration programs is to implement a long-term plan for the robotic and human exploration of Solar System bodies. Mars has been a central object of interest in the context of extraterrestrial life. The search for extinct or extant life on Mars is one of the main goals of space missions to the red planet during the next decade. We review the current knowledge on the prospects for life on planetary bodies in our Solar System and present laboratory and field studies that provide important limits to exobiological models, support current and planned space missions and address issues of planetary protection.

Compound model to analyze water in terrestrial planets formation

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In its gaseous and solid forms, water is present in the most distant galaxies, among the stars and in discs around them, in exoplanets' atmospheres, in the Sun, in its planets and their satellites and ring systems and in comets. In its liquid form, it has played an essential part in the appearance, development and maintenance of terrestrial life. In Solar System science, the origin of water on Earth remains one of the most important subjects of debate and controversy. In younger planetary systems, water is being discovered where terrestrial planets may be forming. The process of calculating how much water terrestrial planets can have, or its relative contributions from different sources, is complicated by the lack of information about the history of formed planetary systems or the lack of sharpness of conventional telescopes to see deep into forming ones. Whereas enough data are not available and no telescope offers the necessary resolution, it is possible to use theoretical models and dynamical simulations to study the past and the future of planetary systems. Using previous researches and available data for the Solar System, a model was created to define a possible planetary formation and water distribution for the evolution of the inner disk, where terrestrial planets can form. Although initially using Solar System's data, it is easily expansible for other planetary systems with small adaptations. In the model, the mass available is distributed in planetary embryos and planetesimals, before and after the snow line of the system respectively. The model is compound by the most recent endogenous and exogenous theories about water distribution, which defines how much water an embryo could absorb locally and how much can come from ice bodies beyond the snow line. It is projected to realistically describe the beginning of the late stage of planetary formation, and dynamical simulations are used to analyze the final

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possible configurations. The goal is to understand if and how terrestrial planets with large amount of water can form in different planetary systems. The model was applied to Solar-type systems with one giant planet as Jupiter or two giants as Jupiter and Saturn, and in these systems the D/H ratio of the water was used as a discriminator among different possible sources of water. It was also adapted and applied to a forming planetary system, the disc around MWC 480, in where water vapor evidence was detected where terrestrial planets would form. In this talk, the created model and its applications' results will be presented and discussed.

The Sun, geomagnetic polarity transitions, and effects on system Earth

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Earth is embedded in the solar wind, this ever streaming extremely tenuous ionized gas emanating from the Sun. It is the geomagnetic field which inhibits the solar wind plasma to directly impinge onto the terrestrial atmosphere. It is also the geomagnetic field which moderates and controls the entry of energetic particles of cosmic and solar origin into the atmosphere. During geomagnetic polarity transitions the terrestrial magnetic field can decays down to about 10% of its current value. Also, the magnetic field topology changes from a dipole structure to quadrupole and octupole dominated fields. What happens to the system Earth during such a polarity transition, that is during episodes of a weak transition field? Which modifications of the configuration of the terrestrial magnetosphere can be expected? Is there any influence on the atmosphere because of intensified particle bombardment? What are possible effects on the biosphere? A review is provided on the current understanding of the problem based on a special research program of the German Science Foundation.

Gamma-ray Bursts and the Earth

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Gamma-ray bursts (GRBs) are likely to have made a number of significant impacts on the Earth during the last billion years. The gamma radiation from a burst within a few kiloparsecs would quickly deplete much of the Earth's protective ozone layer, allowing an increase in solar UVB radiation reaching the surface. This radiation is harmful to life, damaging DNA and causing sunburn. In addition, NO_2 produced in the atmosphere would cause a decrease in visible sunlight reaching the surface and could cause global cooling. Nitric acid rain could stress portions of the biosphere, but the increased nitrate deposition could be helpful to land plants. We have used a two-dimensional atmospheric model to investigate the effects on the Earth's atmosphere of GRBs delivering a range of fluences, at various latitudes, at the equinoxes and solstices, and at different times of day. We have estimated DNA damage levels caused by increased solar UVB radiation, reduction in solar visible light due to NO_2 opacity, and deposition of nitrates through rainout of HNO_3. I will discuss results of this modeling and more recent work to extend to a broader range of event duration and spectral characteristics.

Survival under damaging radiation: a balance between adequate repair and failing of the repair system?

Van Oostveldt, P.M.V., Van Oostveldt, K., De Vos, W., Meesen, G., Dieriks, B.
Ghent University

The survival of bio-systems in space conditions is dependent on numerous conditions. During evolution of life a well developed DNA damage repair system has been developed. The living system can only survive if the repair systems work adequate. Therefore at least 3 levels of cell organisation should be effective. First a fast and accurate damage detection system is necessary. This stops the growing process in order to prevent the generation of mutated cell components and decide whether the damage should be repaired or the cell should commit suicide. This detection system must switch off when the damage is repaired. The second level is the presence and mobilisation of cofactors, proteins and enzymes that will perform the repair. Damage of these molecules will prohibit effective repair and further cell development even if only minor DNA damage is present. The third level deals with the specific DNA damage repair system which recognises the mismatch and strand breaks and performs the necessary repair.

The direct effect of ionizing radiation is the generation of reactive oxygen radicals which interact not only with the genetic material but also with different cellular components of the living system. Given a hostile environment it should also be necessary that the enzymes and cofactors executing the repair are functioning in a correct way. This means that the damage resistance of the repair complex is as important as the repairing mechanism itself. Only when the basic repair system is working correctly, recovery from a ionizing radiation damage can be guaranteed.

Therefore the set up of a specific protection strategy will not only depend on the performance of the damage repair system but also on the stability of macromolecules and organelles. This equilibrium is strongly dependent on the effect of different cofactors. In recent years different food additives and small molecules or even nanoparticles as nanoceria were reported to give protection to oxidative stress.

In our lab we developed single cell analysis techniques to follow the dynamics of different cell organelles and the localization of specific radiation induced modifications. We applied these methods to analyse the effect of HZE particles during a FOTON M3 mission and found clear cellular variation correlated with the impact of HZE particles. Experiments testing the protective effect of different anti-oxidants in relation to damage response were evaluated.

Solar Forcing, Atmospheric Escape, and the Habitability of the Earth-Like Planets

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The solar wind and the solar XUV/EUV radiation constitute a permanent forcing of the upper atmosphere of the inner (Earth-like) planets in our solar system. The effect of solar forcing is to ionize, heat, chemically modify, and slowly erode the upper atmosphere throughout the lifetime of a planet. Atmospheric erosion is due to thermal and non-thermal escape. Gravity constitutes the major protection mechanism for thermal escape, while non-thermal escape, driven by a combination of XEUV ionization and ionospheric plasma energization, requires magnetic field protection. The strong dipole magnetic field of the Earth exemplifies the latter, while the lack of a strong intrinsic magnetic dynamo at Mars and Venus leads to a direct solar wind access to their topside atmosphere. The obvious question is therefore if this is the reason for why Mars and Venus, planets lacking a strong intrinsic magnetic field, have so much less water than the Earth. Climatologic and atmospheric loss process over evolutionary timescales of planetary atmospheres can only be understood if one considers the fact that the radiation and plasma environment of the Sun has changed substantially with time. Standard stellar evolutionary models indicate that the Sun after its arrival at the Zero-Age Main Sequence (ZAMS) 4.5 Gyr ago had a total luminosity of $\approx 70\%$ of the present Sun. This should have led to a much cooler Earth in the past, while geological and fossil evidence indicate otherwise. In addition, observations by various satellites and studies of solar proxies (Sun-like stars with different age) indicate that the young Sun was rotating more than 10 times its present rate and had correspondingly strong dynamo-driven high-energy emissions which resulted in strong X-ray and extreme ultraviolet (XUV) emissions, up to several 100 times stronger than the present Sun. Further, evidence of a much denser early solar wind and the mass loss rate of the young Sun can be determined from collision of ionized stellar winds of the solar proxies, with the partially ionized gas in the

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interstellar medium. Empirical correlations of stellar mass loss rates with X-ray surface flux values allows one to estimate the solar wind mass flux at earlier times, when the solar wind may have been more than 1000 times more massive. Conclusions drawn on basis of the Sun-in-time-, and a time-dependent model of plasma energization/escape are that: 1. Solar forcing is effective in removing volatiles, primarily water, from planets, 2. planets orbiting close to the early Sun were subject to a heavy loss of water, the effect being most profound for Venus and Mars, and 3. a persistent planetary magnetic field, like the Earth's dipole field, may provide a sufficient protection against solar forcing induced atmospheric/hydrospheric modification and escape – with important implications for the evolution of life and for the habitability of a planet.

Planetary magnetic fields and solar forcing: implications for atmospheric evolution

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The solar wind and the solar XUV/EUV radiation constitute a permanent forcing of the upper atmosphere of the planets in our solar system, thereby affecting their habitability. The effect of these two forcing terms is to ionize, heat, chemically modify, and slowly erode the upper atmosphere throughout the lifetime of a planet. Atmospheric erosion is due to thermal and non-thermal escape. Strong gravity constitutes the major mechanism counteracting thermal escape, while the non-thermal escape caused by the ionizing X-rays and EUV radiation and the solar wind require protection from planetary magnetic fields. We now have evidence that, although the total luminosity of the young Sun was about 70 % of today's, it had much stronger high-energy and particle emissions. This is because the Sun was rotating some 10 times faster than today and it has since been spinning down because of mass loss. Observations of solar proxies for different evolutionary stages indicate that the emissions of the young Sun in X-rays, far ultraviolet and ultraviolet were stronger than today by factors of 1000–100, 60–20, and 20–10, respectively. It has also been found that the particle emissions would have been 100–1000 times more intense in the past. Such environment of intense energy and particle emissions was undobtedly a major player in shaping the atmospheres of planets and determining their evolution. In this talk I will review the evidence for a much more magnetically active Sun in the past and address the influence that the enhanced emissions may have had on the Solar System planets. I will also discuss some implications relevant to exoplanets.

Impact of high energy radiation on the biota: gamma ray bursts and soft gamma repeaters

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Universidade de Sao Paulo

We present in this work a unified, quantitative synthesis of analytical and numerical calculations of the effects caused on an Earth-like planet by a Gamma-Ray Burst (GRB), considering atmospheric and biological implications. The main effects of the illumination by a GRB are classified in four distinct ones and analyzed separately, namely the direct gamma radiation transmission, UV flash, ozone layer depletion and cosmic rays. The 'effectiveness' of each of these effects is compared and lethal distances for significant biological damage are given for each one. We find that the first three effects have potential to cause global environmental changes and biospheric damages, even if the source is located at great distances (up to approx. 100 kpc). Instead, cosmic rays would only be a serious threat for very close sources. Such events of population depletion could have significant ecological and evolutive impact, leading to processes of extinction and/or speciation, which are analyzed using a second order, inertial, modeling of an ecosystem.

As an example of observed similar event, the possible effects from the giant flare of SGR1806–20 of Dec 27, 2004 on the biosphere are addressed. In spite of not having the same luminosity of a GRB, most of the parameters of this recent giant flare event are well known and serve as a calibration for our study. Through statistical modeling of the sources, we propose that giant flares may have happened close enough to Earth in order to have caused significant biological impact on the exposed biota.

A wavelet based analysis of cosmic ray variation

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Faculté Des Sciences de Tunis

In this work we present estimated results of the wavelet power spectrum analysis from the solar modulation and cosmic ray data incorporated in time dependent cosmic ray variation. Since the solar activity can be described as a non linear chaotic dynamic system, methods such as neural networks and wavelet methods should be very suitable. Thus we have computed our results by writing a programs through Matlab. Many have used wavelet techniques for studying solar activity. We have analyzed, reconstructed cosmic ray variation, better we have depicted periods or harmonics other than the 11-year solar modulation cycles.

Strategies for life detection

Selsis, F.
CNRS

On Earth, oxygenic photosynthesis efficiently converts and stores solar energy into chemical energy. Combined with the biogeochemical cycling of carbon, this biological process keeps the outer layers of the planet (the surface, the ocean, the atmosphere) in a chemical steady state that could not be sustained by abiotic processes alone. As a consequence, and for at least the last 2.5 billion years, our planet has been exhibiting spectral features inherited from life, in particular the deep 9.6 microns O_3 and the 760 nm O_2 bands. These features can be detected from parsecs away, even with a low spectral resolution for IR the O_3 feature, as soon as the photons from the Earth can be distinguished from those from the Sun. Searching for similar biosignatures in the spectrum of terrestrial exoplanets should be achievable with the next generation of space observatories, starting with JWST.

However, instruments that would be designed and optimized to search for these Earth-like signatures may not provide the bets way to explore the diversity of extrasolar 'terrestrial' planets. The last decade of extrasolar planet observation has indeed unveiled an unexpected variety of planets: Jupiter- and Neptune-sized planets at extremely small orbital distance, planets with high excentricities, compact multiple systems, planets with an extremely low or high density. We will show that an even larger diversity is expected within these low-mass planets, making predictions on their atmospheric properties, habitability and spectral appearance extremely difficult. Current models are extrapolated from the Earth case by changing one or few parameters and do not, by far, cover the range of possible situations. We will discuss the crucial need to develop an expertise in the modeling of this variety of planets and atmospheres. Such effort will be required to analyse and understand the spectral observations of potentially habitable planets, that may be achieved as early as 2013 with JWST (if transiting habitable are found around some of the nearest M stars), and later with more ambitious programs dedicated to the search for biosignatures, like Darwin/TPF-I or the New Worlds Observatory.

Evolution of a Habitable Planet – Assembling the Puzzle

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Harvard-Smithsonian Center for Astrophysics

This talk will focus on new results of the evolution of Habitable Planets – through geological time, through their position in the Habitable Zone as well as around host stars of different stellar classes. What are the remotely detectable signatures of frozen worlds, desserts, or different biota?

The detection and characterization of Earth-like planets is approaching rapidly and dedicated space observatories are already in operation (CoRoT), in development (Kepler, JWST), or in planning (Darwin, Terrestrial Planet Finder). In my talk I will focus on the fascinating new results and models and the signs of potential habitability of such rocky terrestrial planets.

How common are extrasolar late heavy bombardments?

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Whether the Late Heavy Bombardment (LHB) inhibited the development of early life on Earth or, in fact, spurred on evolution, it is clear that it would have had a major effect on life on Earth. Such events could also occur in other planetary systems. Observations of a number of debris discs show a higher than expected mid-IR excess indicating a large quantity of dust close to the star. To investigate whether such observations may be explained by an LHB-like event, we develop a model of how the Solar System would have appeared to a distant observer during its history based on the Nice model. The Nice model suggests that the migration of the giant planets destabilised the orbits of Kuiper belt objects and asteroids, causing them to be thrown into the inner Solar System leading to the LHB. We compare our results with observed debris discs and evaluate the plausibility of detecting an LHB-like process in extrasolar systems. We find a significant increase in the mid-IR flux during the LHB, and comparison with the statistics of debris disc evolution shows that such depletion events occurring at several hundred Myr must be rare.

The Vega system: quiescent or cataclysmic?

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In 1984, Vega became the first main-sequence star known to possess circumstellar dust. Now, almost twenty-five years later, it has become clear that Vega is much more than an archetype debris disk star. Various observational and theoretical results all suggest a view of a complex planetary system that contains a massive Kuiper-belt analog, two or more presumed giant planets, a huge outer dust disk, and a massive zodiacal cloud very close to the star. While some of the observational data can be understood with standard 'quiescent' models, some others may indicate that the Vega system is currently undergoing a transient phase of its evolution, similar to the Late Heavy Bombardment in the early solar system.

The search for life in the Universe

Owen, T.C.
University of Hawai

Humans have wondered about the existence of extraterrestrial beings ever since they first looked curiously at the stars. This curiosity was a blend of fear and a kind of cosmic loneliness, emotions that furnished some of the energy powering many religions. We still wonder about this fascinating possibility. The difference now is that we have sufficient knowledge and technological capability to replace endless speculation with scientific experiments. Modern knowledge spans studies of life on Earth to observations of other planetary systems.

Our technological prowess is giving us increasingly sophisticated searches for life or its remnants on the planets and moons of our own solar system. These searches have traditionally focussed on Mars, and this focus is still evident. But there has been recent interest in Europa and Titan, satellites that may have subsurface oceans of liquid water. Meanwhile, a dedicated group of scientists using steadily improving radio telescopes and receivers search for signals from intelligent civilizations elsewhere in the cosmos. This is the ultimate shortcut to satisfying our curiosity barring actual visits by aliens. Despite much interest in such visits there have been remarkably few of them given how extremely interesting we think we are. This talk will provide a review of the results from these different approaches and assess their future prospects.

New Insights Into the Causes of Mass-Extinction Events

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Next to the origin of life and a small number of crucial evolutionary break-throughs, global mass-extinction events are among the most dramatic incidents in the history of life on Earth. After decades of research, the causes for most of these events remain obscure. Moreover, the discovery of apparent periodicities of extinctions – although still debated – raises new questions about their origin.

From a methodological point of view, two issues are of particular importance in this context: First, the research community faces the challenge to develop models of the connection between proposed causes and their ecologic effects, often via changes of the Earth's climate. And secondly, a fundamental understanding of potential causes of cyclic extinctions can be drawn from detailed studies of single events.

In my talk, I will review recent research on suggested causes of extinction events and present a critical appraisal of the evidence for periodic extinctions as well as current ideas on their drivers. Furthermore, I will describe novel insights into extinction stimuli and will outline the most promising lines of future research, with a particular focus on the role of climate modeling in extinction research.

Late stage evolution of planetary systems: the case of V391PEGB

Silvotti, R.
INAF

Most of the 300 extra solar planets presently known are hosted by main sequence stars similar to our Sun. When their core hydrogen runs out, main sequence stars undergo a red giant expansion that modifies the planetary orbits and can easily reach and engulf the inner planets. The same will happen to our solar system in about 5 Gyr and the fate of the Earth is matter of debate. The detection of the first planet orbiting a post-red giant star, V 391 Peg b, opens new perspectives and new questions.

The ultimate cataclysm, the orbital (in)stability of terrestrial planets in exoplanet-systems including planets in binaries

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In long-term numerical studies of the Solar-system J. Laskar discovered a chaotic behavior for the planetary motion. Orbital variations of the terrestrial planets were caused by the influence of the gas giants, although the planetary orbits are nearly circular.

Considering the numerous discovered extra-solar planetary systems we are faced with high eccentric planetary motion, so that long-term stability studies are necessary, especially in the case of multi-planetary and binary systems.

In this overview about orbital stability of terrestrial planets, the situation in the Solar-system will be discussed in brief before analyzing the long-term stability of Earth-like planets in:

(i) single-star – single-planet,
(ii) single-star – multi-planet and
(iii) double star systems.

Dynamical studies of planetary motion in double star systems are very important since observations have shown that more than 60% of the stars in the solar neighborhood form double or multiple star systems.

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Differences in meteor flux rates in outer solar system planetary bodies as compared with inner solar system bodies

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Introduction: The outer bodies the outer solar system are likely in a situation where they receive a different amount and composition of in-falling bolides. They are closer to the Kuiper Belt which is the source for com-ets and has frozen volatiles.

The author proposes that this would mean that because there is less outgassing of bolides before impact from being closer to the sun as occurs in bolides in the rocky Inner solar system. This might increase the volume of material that impacts. Another factor is that the gravitational sweep of the large planetary bodies in the outer solar system would create a greater gravity well encompassing a greater area that would mean a greater number of meteors. The author pro-posed before that while the Cassini mission was being planned that meteor flux rates be examined in the upper atmosphere of Saturn and flux rates on the moons of Saturn. Mission constraints prevented this phenomena being looked at. Meteor trails would leave trails that could be detected in the visual and other electro-magnetic spectrum around Saturn. As they are detected around Earth. These trails which are essential the dust grains that burn up and leave an ionization trail in the upper atmosphere of planetary bodies are at a micro level the same amalgamation process that occurred in the formation of all of the planetary bodies in our Solar system.

It might also be possible that the back-ground streams of meteors in the Outer Solar system are different due to the distance from the Inner Solar system. The Suns gravity well itself might concentrate or disperse the background dust and other non-volatile as a factor of the distance from the Sun. A type of Bode's Law for smaller Solar system bodies down to dust particles.

Conclusion: The data that came back from the major Jupiter and Saturn missions might contain data of the appearance and potential measurement possibility of meteor flux rates in Outer Solar system bodies that could be compared with data from Earth. This data might begin to indicate different flux rates and composition as a factor of distance from the Sun.

SMART-1 study of impact basins and the cataclysmic Bombardment of the Earth-Moon system

Foing, B.H.[1], *SMART-1 Team, STWT*[2],
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We report on SMART-1 results on impact basins relevant to the study of the cataclysmic bombardment that affected the early Earth.

After the Earth started to cool, the first crust started to float on top of the magma. During this period the Earth was subjected to increased meteor bombardment. The bombardment had been very intense at the beginning of the solar system and then had started to decline, but about 500 million years after the birth of the Earth, there was a burst of impactors. This lasted for about hundred million years, and we call this 'the late heavy bombardment.' Many of the large basins on the Moon are evidence of this late heavy bombardment period. In this way, the Moon is a history book.

Because the Moon is smaller than the Earth, the Moon's radiogenic heating dissipated much faster. After about one billion years, the interior of the Moon did not evolve much, and surface changes mostly were due to impacts. The Earth was hit more often than the Moon, however, because Earth is larger and has more gravity. This increased gravity also caused the impactors to be accelerated to higher velocities towards the Earth.

So many bombardments would have sterilized our planet. If life had appeared before this period, it would have been extinguished unless it found a way to retreat into niches where it could be protected from these global catastrophes.

Geochemical analysis of materials excavated by the large South Pole – AitkenImpact event

Borst, A.M., Bexkens, F., Foing, B., Koschny, D.
ESA/ESTEC

Geochemical analysis of materials excavated by the PreNectarian South Pole – Aitken impact event.

The South Pole – Aitken (SPA) Basin, situated on the southern farside of the Moon, is currently one of the highest priority targets for future sample return missions. This PreNectarian basin (>3.9 Ga) measures 2500 km in diameter with a depth of up to 13 km and is recognised to be the largest impact structure in the Solar System, possibly formed during the Late Heavy Bombardment. Due to its size and age, this basin offers a great opportunity to gain valuable insights in 1) the impact record and early cataclysms in our solar system, 2) the nature of large impact events and 3) the composition and evolution of the Lunar interior. In order to optimize the scientific gain gathered by future sample return missions, preliminary ground-based remote sensing observations are necessary. In this context, we study the geochemical signatures of the exposed rock types and try to identify geological units that likely contain this highly desired information.

Previous research using multispectral and gamma-ray data obtained by the Clementine and Lunar Prospector missions revealed the localised presence of noritic and gabbroic/troctolitic rocks, exposed underneath the mixing regolith layer, which represent either impact melt or uplifted lower crustal rocks. The research presented here aims at improving mineralogical descriptions of the mafic rock types and units within the South Pole – Aitken Basin using a similar approach as described by Tompkins and Pieters. Multispectral data from Clementine ultraviolet/visible and near-infrared cameras are used and processed in ENVI. The method relies on diagnostic shapes of band absorptions for key mafic minerals olivine and high Ca-pyroxene, in order to discriminate between geologic units of noritic, gabbroic and troctolitic compositions. Geomorphological maps are produced to provide a geological context for the identified geochemical units.

We synthesise our results with a companion complementary study of the global geological structure of the SPA Basin using Clementine altimetry and gravity data obtained by LIDAR instruments.

Based on both mineralogical and structural analysis local mosaics of SMART-1 high resolution AMIE images will be produced to provide improved geological context for areas exposing deep crustal materials. In particular we have studied the Bhabha-Bose region located in central SPA Basin, previously proposed as a possible sample return landing site.

The global geological context and impact signatures in the lunar SPA Basin: the biggest cataclysm in the solar system

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The giant South Pole – Aitken basin (SPA) is the largest recognised impact structure in the solar system. The basin is located on the far side of the moon and measures 3500 km in diameter, including the outermost ringstructure. It is believed to be one of the oldest lunar structures, >4 billion years. Due to its old age and maturity the SPA structure has been severely reworked, and primary ejecta have been redistributed by later impacts. The smoothing effects of later, smaller impacts on original basin structure and topography complicates studies of the primary impact signature of the basin structure. Here, we combine Clementine and SMART-1 data to provide additional constraints on the large-scale structure of the SPA impact basin. To learn more about this giant cataclysm.

The impact's outer ring is best developed on the north-eastern side of the basin. Two possible explanations for this observation have been brought forward: (1) The ring structure is simply best preserved in this

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area because by chance it has not been reworked by later impacts as extensively as the rest of the outer ring. (2) The SPA was formed by an oblique impact of a low density body. Such an impact could also explain the extremely low depth-diameter ratio of the basin.

Clementine LIDAR gravity and topography data is used to address the large-scale structure of the South Pole – Aitkin Basin. Using the IDL and ENVI software gravity and topography profiles across the SPA with different orientations have been produced and compared. The results are also used to quantify the mass distribution as a result of the basin forming impact and later impacts, to try and assess how mass was distributed during and after the impact. The Clementine data is augmented with mosaics of high-resolution SMART-1 AMIE images to improve on a detailed description of the geological context of the SPA. One SMART-1 orbit is mosaiced, producing a north-south profile through the SPA which will be compared with the topography and gravity profiles.

In a companion study (A.M. Borst *et al*., this conference) Clementine UV/VIS and NIR images are employed to constrain the geochemical signatures of exposed rock types within the SPA Basin. A synthesis of our studies enables a comparison between structures and mineralogical compositions/soil maturity, and may lead to the identification of possible landing sites for future sample return missions.

Searching for the oldest Earth fossils on the Moon

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When some of giant impactors hit the Earth 4 billion years ago, the explosion caused rocks and dirt from Earth to shoot up and away from our planet. Some of that projected material flew all over the solar system, and some of it landed on Mars and on the Moon. There could be a few hundred kilograms of Earth material per square kilometer of the Moon's surface, buried under a few meters of lunar soil. It would be interesting to retrieve those rocks and bring back samples of the early Earth. Almost nothing from this time period has survived on the Earth because of tectonic recycling of the crust plates or because of atmospheric weathering.

We would try to detect some organics within those rocks, and that could tell us about the history of organic chemistry on Earth. Some of these rocks could even have preserved fossils of life. Such rocks could help us look further back into the life fossil record, which now stops at 3.5 billion years ago.

This way, we could possibly learn about the emergence of life on Earth, thanks to the cataclysmic bombardment and transport.

The impact-induced Mass Extinction of Marine Plankton at the Cretaceous-Paleogene Boundary

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The Cretaceous-Paleogene boundary (KPB) represents one of the most dramatic turnovers in the fossil record for marine calcareous plankton (mainly foraminifera and coccolithophores) that formed calcite deposits that gave the Cretaceous name. In the world ocean more than 90% of calcareous plankton was extinguished at that boundary; this mass extinction appears to have been sudden and inevitably led to the catastrophic collapse of the whole oceanic life.

The biogenic calcite-poor KPB clays throughout the world deposited in shallow marine settings consists of a very thin (2–4 mm) 'impact' layer overlain by a relatively thick marly layer. Various paleontological, mineralogical and geochemical data as well geological data all apparently support a genetic relationship between the deposition of the KPB clays and the asteroidal impact at Chicxulub (Yucatan Peninsula, Mexico).

Because the impact target at Chicxulub is a predominantly carbonate-rich marine sedimentary rock combined with some minor sedimentary anhydrite (calcium sulfate), a massive amount of acid-forming gas CO2 was instantaneously released into the atmosphere accompanied with lesser amount of another acid-forming gas SO2.

The effects of increasing impact-induced atmospheric CO2 on calcareous plankton is better understood now due to current increasing anthropogenic input of atmospheric CO2. According to theory, a massive amount of impact-derived atmospheric CO2 would accumulate globally in the sea surface, since this gas enters seawater by air-sea exchange. The net effect of this accumulation would be a decrease of the sea surface pH (leading to an 'acidification') and calcium carbonate saturation state, causing a physiological and biocalcification crisis for marine calcareous plankton. In my opinion, this crisis was perhaps a significant factor in causing the mass extinction of marine calcareous plankton at the KPB, creating large a deficiency of biogenic calcite in the boundary clays worldwide. If this is a true, then experimental data and observations would indicate that the global acidification of the world ocean and the subsequent physiological/biocalcification crisis for marine calcareous plankton at the KPB lasted only a few decades at most; in contrast, a production of these species remained very low for several hundred thousand years after the impact.

A potential large impact in 536AD

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Near 536 A.D., famine, frost, and darkness were recorded both in the Irish and Chinese historical documents. The purpose of this article is to identify a possible cause of the dust veil: a cometary or meteoritical impact. The hypothesis of the 536 A.D. atmospheric changes can be examined through dendrochronology, Greeland ice cores, and history. Firstly, dendrochronology is the study of the growth of tree rings. It is useful because by measuring the growth rate we can deduce the atmospheric environment of a certain period in time. We will concentrate on the tree rings of the Irish oak because of the historical evidences. The dendrochronology of the Irish oak shows that the narrowest rings were in 540 A.D. to 542 A.D. The stunted growth probably was caused by poor temperature and environment. Secondly, we will examine the Greeland Dve-3 core to determine whether the poor growth was triggered by volcanic activities. The ice core shows that the acid layer of the volcanic activity. The acid layer from the volcanos in the Greenland core moved from 540 A.D. ±10 to 516 A.D. ±4 indicates that the hypothesis of volcanic activities on Earth that brought about the famine in 536 A.D. was not substantiated. Thirdly, the Irish history recorede tha the 'dust veil' and 'running stars' were shining for 20 days, and there were many earthquakes. Both in China and Byzantium in 530 A.D., Halley's comet was recorded that the comet continued to shine for 20 days. In both China and Europe, black clouds, earthquakes, crop failures, frost, and dust veil were recorded. In China, the dragons fought in the ponds and the trees were broken when 'a dragon' passed by. Although the Chinese thought that the comet was connected with the fall of the dynasty, the power struggles between the states within China would rather be the main cause for the poor political conditions, economical conditions, and livelihood. On top of that, the poor atmospheric environment compounded the problem. Overall, the comet or bolide is a possible cause from the recorded documents. The most plausible hypothesis, up until now, is that a comet or a meteorite hit the Earth. It is because the hypothesis of volcanic dust veil contradicted with the evidence of the acid layer in the ice core. However, if a bolide struck the Earth, it would have brought about the reduced sunlight, atmospheric changed, failure of crops, plagues, and earthquakes. Thus, we may have a clue on the cause of the atmospheric changes. If a bolide hit the Earth at this point and caused global effects the current threat might be more than expected. The explosion of Thera, a terrestrial event caused the downfall of several civilizations as would an meteorite impact of the extent hypothesized above to have occurred during the early middle ages.

Jupiter – friend or foe?

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A widely and long held belief is that the planet Jupiter has acted to shield the Earth from potentially hazardous impacts, lowering the impact flux experienced by our planet, and hence making conditions here more clement for the evolution of life. Furthermore, it is widely believed that, without a 'Jupiter', planets such as our Earth could be rendered un-inhabitable by an impact regime significantly more violent than that we experience in our Solar System.

Surprisingly, given how widely this belief is held, very little work has been carried out to address the question of Jupiter's role in the Earth's impact regime. Therefore, we have been carrying out detailed studies of this problem. The results are far from what we expected. To date, we have examined the effect that varying the mass of a Jovian planet would have on the impact flux experienced by the Earth, with impactors sourced from each of the three reservoirs known to supply projectiles within our Solar System (the Asteroid belt, the Oort cloud, and the trans-Neptunian objects). Rather than acting as a shield, it seems that the presence of a Jovian planet can actually enhance the rate of impacts experienced by a terrestrial planet, with the most 'hazardous' mass being one approaching that of the planet Saturn. To either side of this case, the impact rate is observed to as a function of mass, with low impact regimes being experienced for very low Jovian masses, and moderate but decreasing regimes as the mass of the planet reaches, and exceeds that of Jupiter.

In future work, we aim to study the effect of Jovian location on the flux, with a long term goal of applying our studies of habitability to extrasolar planetary systems. The ultimate goal of this suite of work is to finally answer, once and for all, the question 'Jupiter – Friend or Foe?', and to answer the corresponding question for exoplanetary systems.

Effects of cosmic rays on living systems and reverse of geomagnetic polarity

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In result of experimental research we found, that functional state of living systems are modulated by 'dose' ratio of the geomagnetic field (GMF) variations and the secondary component of Cosmic rays (CR). We revealed the possible mechanisms for modulation of organism functional state: 1) alterative regulation by GMF variations and neutron intensity near the Earth's surface, when the one in a two component has maximum value and other – minimum value; 2) complementary (additional) regulation, when the values of the GMF variations and neutron intensity near the Earth's surface reciprocally supplement each other; 3) prevalent regulation by GMF variations or neutron intensity near the Earth's surface, when the one in a two component has predominant significance over other. By comparison of functional state of human blood in the years with high (1991) and low (1996, 2008) geomagnetic activity we found that the decrease of geomagnetic activity and the increase of intensity of CR impact on composition of peripheral blood. An increase of 20 percent of the secondary CR near the Earth's surface produces the increase of leucocytes, the decrease of hemoglobin, lymphocytes, thrombocytes and the appearance of immature forms of blood cells. Our experiments carried out during a great solar events, when the solar particle fluxes in the near-earth space increased by a factor of 100 000 and when the secondary cosmic rays near the Earth's surface increased of 100 percent, revealed the multiple lesion of DNA containing material in cell systems. Our experiments allow us to assume that the reverse polarity and the increase of CR during the epoch with low strength of GMF could be inducing the drastic reformation in living systems. Some of such reformations could be incompatible with life of organisms. When we studied the connection between a number of insect and terrestrial tetrapods families and the duration of periods with normal and reverse polarities from Cenozoic period (84 Mya) towards the Neogene (23-0 Mya), we found that the duration of periods of normal and reverse polarities decreased from Paleogene to Neogene. In concordance with the rate of changes of the magnetic polarity, the number of living families is increasing. Following each reverse polarity, the dipole field strength is fluctuating. This means that the geomagnetic cut-off should be also fluctuating during changes of polarity from a minimum to maximum. Catastrophic consequences for living organisms of reverse polarities could be occur under the low of geomagnetic cut-off, the high exposure to cosmic rays and the long duration of such situation.

Gamma-Ray bursts – spectral structure and implications for life

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Since its launch in November 2004, NASA's Swift Gamma-Ray Burst Mission has fired a new era in gamma-ray burst (GRB) study. Before the launch of the satellite these sudden ultra-energetic photon flashes, that travel cosmological distances to reach us, would leave no more than a gamma radiation trace of mere seconds in length. However, Swift's multi-wavelength instruments (BAT, XRT, and UVOT) have enabled the evolution of the flashes to be tracked across several regions of the electromagnetic spectrum, for periods of up to weeks. Understanding this multi-wavelength behavior is key to assessing the astrobiological implications of these phenomena.

Aboard the Swift satellite, the BAT(Burst Alert Telescope) processes count-rate data into light curves (histograms) in four energy bands. These light curves exhibit striking complexity and diversity in the time domain. However, when mapped into the frequency domain and re-presented as power density spectra, certain important time correlations that are buried beneath the erratic behavior may be exposed. GRB progenitor theory at this stage is somewhat embryonic (possible progenitors include hypernovae, the merging of two highly magnetized neutron stars, or mergers of neutron stars with black holes), and rests a lot on our ability to isolate key time correlations that point towards the central mechanism. Therefore, analysis techniques of this kind play a crucial role in GRB research.

This work has 3 aspects: Firstly, I produce power density spectra from Swift Level 0 data products for GRB 050505, GRB 050603, GRB 050525A and GRB 050904, by way of the Discrete Fourier Transform. I develop numerical methods for Fourier analysis of unevenly sampled burst data, such as that provided by the Swift Observatory. Secondly, I analyze these spectra in the light of current GRB theory, and seek to isolate key features that may point towards the central mechanism. Thirdly, I discuss the relationship between gamma-ray bursts and life, and in so doing, bring together current ideas about the sterilization effects of GRB radiation on planetary systems in a given galactic volume, as well as the biological, climatic and atmospheric effects of this radiation on the Earth, and its possible relation to the mass extinction of the Late Ordovician period.

A catastrophic event in Venus' history: the loss of water

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The ESA Venus Express spacecraft is in orbit since 11 April 2006, and since then it delivers plenty of data in all major scientific fields of the mission: Atmospheric composition, structure and dynamics, clouds and haze, thermal balance, plasma and escape processes, and surface. Measurements from the ASPERA4 experiment indicate that hydrogen and oxygen escape from the atmosphere, as a results from the strong interaction between the solar wind and the upper atmosphere.

This discovery shed new light on the loss of water, which constitutes a catastrophic event in the history of our neighbour.

This paper outlines the Venus Express scientific achievements to date, describes the escape measurements, and tries to summarise the history of Venus.

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Differences between the impact regimes of the terrestrial planets

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The impact regimes of the terrestrial planets are of great interest to planetary scientists across a wide range of disciplines, from those studying the formation of the planets, to dynamicists interested in the Late Heavy Bombardment, and planetary migration, to those attempting to date planetary surfaces through techniques such as 'crater counting'. One important question within this field is the nature of the impactors falling upon each planet – are they predominantly cometary or asteroidal in nature? Through a series of detailed n-body simultions, we have examined the variations in impact flux between the planets Venus, the Earth and Mars, for a variety of source populations, with the goal of obtaining a better understanding of any similarities, and any differences, between the sources of impactors which reach these bodies. Our simulations highlight that the inner Solar system is truly a dynamic place, and that different worlds within the system may have experienced significantly different impact regimes over the course of their birth and evolution.

In particular, we find that, for a Solar system similar to that we see today, the planet Mars would experience far more 'asteroidal' impacts per cometary impactor than either the Earth or Venus, a result of the dynamical pathways driving these dynamically disparate objects to their final destination.

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