confinement, known as plasma disruptions, which can lead to large j x B forces on the in-vessel components, will also need to be rehearsed in ITER.

ITER is a formidable technological challenge that must be met before physics investigations can even begin. ITER contains 400 tonnes of superconducting Nb_3Sn and NbTi within its 48 coils and will have to demonstrate 2 decades of superconducting magnet operation. It must demonstrate that the auxiliary heating methods developed over the past three decades allow us to heat the plasma up to the point where alpha particle heating takes over. It must demonstrate the handling of high heat fluxes on the plasma facing components, especially in the divertor. It must demonstrate the capability of pumping the helium ash out of the vessel, tritium handling and fuelling. Reactors will ultimately have to produce their own tritium in breeding blankets by making use of the $n+Li^7 \rightarrow He^4+T+n$ or the $n+Li^6 \rightarrow He^4+T$ reactions, where the reacting neutrons are produced by the fusion reactions in the plasma. ITER must perform functional tests of concepts of tritium breeding blankets required for a reactor.

There remains one important technology issue that ITER is not designed to deal with, which concerns the testing of radiation resilient low activation materials that will be required for a reactor. Due to its low average operational duty cycle as a research installation, neutron induced damage in the structural materials inside the vessel, built mainly from conventional austenitic steel, will not be an issue in ITER, nor will ITER be a suitable test environment for the most stringent requirements of materials developers. The development of materials suitable for fusion reactors requires an effort parallel to the construction and operation of ITER and will involve the construction of the International Fusion Material Irradiation Facility IFMIF, a beam/target neutron source, which will generate continuous 14MeV neutron loads comparable to those of a reactor in a small test volume for material samples.

ITER is not an end in itself. It is the bridge between the devices built in the 1980's and a demonstration power plant. The essential role of ITER is to validate the tokamak fusion concept as a viable approach to power production and to develop the reactor technologies needed for any fusion power plant. The endeavour will also spur valuable fundamental advances in physics and technology. In view of the promise of fusion and of the necessity of developing new sources of energy that are environmentally acceptable and close to inexhaustible, we believe that ITER is a step well worth taking. The members of the ITER design teams have steadfastly brought this project to the point of fruition all through the difficult times of the successive design phases. Let their effort be crowned by success.

About the authors

Jo Lister and **Henri Weisen**, of British and Luxembourg origins, are involved in experimental tokamak research at the CRPP-EPFL in Lausanne, Switzerland. Jo Lister is currently chairman of the EPS Plasma Physics Division. Both authors are engaged in extensive international collaborations and are fervent supporters of a positive decision to go ahead with ITER.

References

[1] www.jet.efda.org

[2] "ITER Physics Basis", Nuclear Fusion 39 (1999), by the ITER Physics Basis Editors, ITER Physics Expert Groups, ITER Joint Central Team and Physics Integration Unit

[3] www.iter.org

Astronomy and Astrobiology

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Astrobiology is the study of the origin of life on Earth, and whether life may exist elsewhere in the Universe. This article will seek to convey some of the new discoveries in Astronomy which relate to Astrobiology and which have energised the field. These discoveries are little isolated illuminated patches and it is difficult to link them together into a coherent picture. More questions are raised than answered, but this is only as it should be; we do not understand the origin of life, but we are beginning to assemble pieces of the puzzle.

An overview

For the range of life as we know it, we need an abundance of the elements oxygen, carbon, hydrogen, nitrogen and also traces of many others, such as magnesium, silicon, iron, aluminium, sodium, potassium, chromium, manganese, phosphorous and more, even including tungsten. All heavy elements necessary for life have been created in the interior of stars in the 13,500 million years since the Big Bang. The massive first star in the Universe [1] was formed roughly one million years after the Big Bang and exploded as a supernova. In this explosion, small amounts of elements heavier than H (and He) were made from nuclear reactions at the very high temperatures of the explosion.

The Universe reassembled, so to speak, after this first destructive event to make a generation of new stars. Perhaps 100 million years later the first galaxies formed. Their component stars were quite unlike our Sun. They were again massive, and exploded as supernovae, spreading heavy elements throughout their host galaxies. This created a medium enriched in heavier elements between the stars, an "interstellar medium". A new generation of stars formed in this interstellar medium in turbulent knots of gas with high local density, and ultimately, as for all stars, through the overwhelming force of gravitational attraction.

Recent simulations suggest that this new generation of stars contained stars was of similar mass to the Sun [2]. These stars would have been much longer-lived than earlier stars. However biology was not yet feasible since the abundance of heavy elements was still very low, for example 100 times below that of the Milky Way. Sufficient raw materials for rocky planet formation, let alone life, were still lacking. Further generations of stars lived and died, each enriching the medium between the stars with heavy elements. As time has gone by, 1.7% of H atoms created in the Big Bang have been converted into elements heavier than He.

Nine thousand million years after the Big Bang, in one of the spiral arms of the Milky Way, a Galaxy among more than 10^{11} others, a particular cloud of gas - the "pre-solar nebula" - containing the elements necessary for life, began to undergo gravitational collapse and formed the Sun. There was a sufficient abundance of elements such as oxygen, silicon, iron, magnesium, aluminium and sulphur to form rocky planets. At this juncture, we enter a realm in which our ignorance is paramount. After a few hundred million years, single cell organisms appear to have formed, though how this happened from the bare chemical ingredients of

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biochemistry remains one of the outstanding mysteries of biology. Putting this problem in biology to one side, we will concern ourselves with the problem in Astronomy of how the ingredients for biochemistry became available for evolution into living organisms.

Young stars and planets around other stars

What were the physical conditions in the gas around the very early Sun when the planets were forming? What molecules were present in this solar nebula and in what form did they become incorporated into the Earth: in a nutshell, what is the interstellar-Earth connection? Answers to these questions come from both astronomical observations and from the analysis of meteorites. First Astronomy: to study how the Sun and planets formed, we observe stars which we believe may one day be similar to the Sun, but which are forming "now" - that is, as we see them now. The closest and most heavily studied active star-forming region is the Orion Nebula, which we see as it was 1500 years ago. An infrared image of this region is shown in figure 1. In the last decade, using the Hubble Space Telescope and ground-based telescopes such as the Canada-France-Hawaii Telescope (CFHT) and the European Southern Observatory Very Large Telescope (VLT), the angular and hence the spatial resolution has become good enough to resolve objects at the distance of Orion on the scale of the solar system, that is, better than 100 Earth-Sun distances (100 Astronomical Units or AU).

Data from the Hubble Space Telescope show that very young stars ("protostars") caught in the act of formation can be surrounded by disks of dusty gas, from 50 to 1000 AU in diameter. Figure 2 shows a large (1000 AU) protostellar disk seen near edge-on in the Orion Molecular Cloud. The mass of material in this disk is enough to make more than 700 Earths - or a little more than 2 Jupiters. The inner, denser part of this disk is where planets may form, in a plane just as around the Sun. However, until a few years ago, it was only a well-informed guess that there were planets around other stars.

Our ignorance of the presence of planets around other stars has now been dispelled, only to reveal our ignorance of how planets form. In 1995, Mayor and Queloz reported a planet around the star 51 Pegasi [3]. This was the first detection of an extra-solar planet around a solar-type star and it has been followed by the detection of 123 or more planets. Some stars have been found to have two or three planets in orbit around them. For technical reasons, detections have only been made of massive planets [4], some sizeable fraction of the mass of Jupiter, which is 300 times more massive than the Earth. Therefore we still do not know if there are any Earth-like planets in orbit around other stars. Be that as it may, in many cases massive planets have been found to orbit eccentrically, approaching very close to or moving very far from their host star, in defiance of any existing theory of planet formation. Such orbits are inimical to life, since any nascent biological system would be alternately frozen and thermally decomposed. By contrast, a good candidate for life would be a planet (with an atmosphere) which performs a circular orbit at a radius such that water would not boil or freeze - in a so-called "habitable zone", comparable to that of the Earth. Liquid water appears essential to the evolution of life. The search for less massive and more bio-friendly planets is accelerating with the NASA Kepler mission (2007), the largely French COROT mission (2007), the European Space Agency EDDINGTON (maybe) and the GAIA missions (~2011), the NASA Terrestrial Planet Finder (2015) and the European Space Agency DARWIN (2015+) mission. Later missions, for example DARWIN, will also seek to find evidence for life on extra-solar planets through analysis of the planetary atmosphere gases.

▲ **Fig. 1:** The Orion Nebula imaged in the infra-red using the European Southern Observatory Very Large Telescope (VLT). The bright Trapezium stars lie at the centre of the image. To the north of the Trapezium may be seen red emission which delineates the Orion Molecular Cloud, where young stars ("protostars") are forming. This image is 180,000 by 180,000 Earth-Sun distances (AU) in scale, that is, roughly 2.7x2.7 light years. Credit : Mark McCaughrean and the European Southern Observatory (ESO)

Gas and Dust around very young stars

The gas around protostars is 90% molecular hydrogen, H_2, with 10% by number of He. A few ten thousandths of the total number density provide carbon monoxide, water, ammonia and an array of dozens of other molecules (and ions), both familiar such as alcohol and less familiar such as HCO^+. The total number density ranges from a few hundred particles per cubic centimetre (cm3) to more than 10^{11} per cm^3 close to hot massive stars. The gas temperature may be as low as 10K but for short periods of weeks, months or years may be heated to temperatures as high as 5000K or more. Small particles ("dust grains") composed of magnesium and iron silicates and carbon-based graphitic composites make up 1% of the total mass of the gas. These particles range in size from "large molecule" dimensions of a few tens of Ångstroms to microns, with many more smaller particles than larger. These grains are very cold, at typically 10K, and observations show that they are coated with a cocktail of water, ammonia, carbon dioxide and other ices. A striking effect of the presence of grains is to obscure visible starlight and create what Herschel called "holes in the sky" where there are apparently no stars. One of the most dramatic illustrations of the obscuring effects of grains is shown in Figure 3 which shows the Horsehead Nebula (Barnard 33), a dust cloud which obscures from our view in the visible part of the spectrum the stars which lie behind. The Horsehead nebula lies close to the Orion Nebula in Figure 1 that now becomes a focus of our account.

First, more than 1000 stars have formed in the Orion nebula in the last one million years and many stars are indeed evident in Figure 1: this is a prime site for observing star formation in operation [e.g.5,6]. Second, many different gas phase molecules have also been observed in the Orion Nebula. For example in a recent radioastronomy survey covering quite a narrow range of frequency [7], more than 15 different chemical species were found, including methanol, dimethyl ether (CH3-O-CH3), ethyl and methyl cyanide, sulphur dioxide, deuterated ammonia and others. To give a taste of the future, just four to five years away, the European Southern Observatory Atacama Large Millimetre Array (ALMA) will achieve a level of sensitivity in perhaps ten seconds of observing time which would require 100 hours on the telescope used in the radio-observations described in [7]. When we come to consider the message of meteorites below, we should recollect the rich molecular harvest which radioastronomy has yielded, and the still richer harvest which is just around the corner with ALMA.

Star and planet formation

How did the thousand stars in Orion form in the last one million years and how may planets have formed around them? Stars form in the cores of dusty, dense molecular clouds, such as the Orion molecular cloud associated with the Orion Nebula. This is known because at long wavelengths very young stars may be imaged buried deep in the Orion Molecular Cloud. However, the manner in which stars form remains a very contentious issue. Nature seems to perform the act of star formation - and perhaps planet formation - very readily, but it remains beyond us to create a unified model that includes the vital physics and chemistry. Certainly gravitational collapse is dominant in the brief final stage in the innermost part of the zone where the protostar is forming. However in the disk, such as that shown in Figure 2, where the planets are created, and around the protostar in general, the physics and chemistry are not known. Suffice it to say that giant planet formation is the subject of two opposing models, in the one case supposing a slow process of accretion over a period of many millions of years [8] and in the other case the formation of planets through turbulently created self-gravitating clumps of gas and dust in the disk, with an accompanying timescale of about 1000 years [9]. The factor of 1000 or more between the timescales associated with the two models speaks volumes for our imperfect understanding of planet formation.

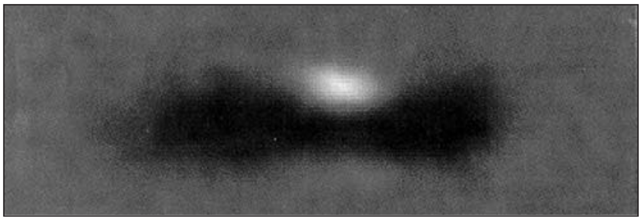
What is observed when we look at regions where very young stars are forming, so-called "protostellar zones"? Protostars are strongly obscured in the visible because the light that they emit is absorbed and scattered by dust in the dense gas surrounding them, just as visible light is blocked out by dust in the Horsehead nebula, in figure 3. Emission is less strongly obscured in the infrared and so observations of the very earliest period of star formation are performed at the longer infrared wavelengths. It turns out that a beacon of the early stages of star-formation is emission of very hot molecular hydrogen (H_2) in the infrared spectral region around a wavelength of 2 microns. H_2 emission reveals that gas is bursting out of the protostar at speeds of 5 to 50 km/s in collimated outflows, at right angles to the plane of the disk where planets are expected to form. These flows crash into the surrounding gas, creating so-called "interstellar shocks". The shocked gas is heated and compressed by the supersonic impact and, H_2, the major constituent of the gas, emits light in the infrared as the gas cools from several thousand degrees and returns eventually to 10K. A graphic representation of a shock buried within the Orion molecular cloud is shown in Figure 4 [10]. Here we see hot H_2 moving towards us with radial velocity components up to ~20 km/s relative to the surrounding cooler gas. This H_2 ploughs through cold gas ahead of the shock and extensive chemical processing takes place. High temperature chemistry may proceed while dust grains crash into molecules at velocities of tens of km/s, the ices on their surface evaporate or are blasted off and the grains may be etched, introducing silicon and iron into the gas phase. These events take place in a medium that is already of considerable chemical complexity, as seen above from radioastronomy observations [7]. Thus the gas around the protostar becomes a veritable witches' brew of organic chemicals. Some proportion of these chemicals condense once more onto the surface of the dust grains, and are ripe for further processing by ultraviolet light, where it can penetrate into the medium, or through spontaneous surface chemical reactions or by low energy electrons which continually bombard dust grain surfaces.

The detailed nature of the complicated chemistry around protostars remains unknown, but it is a problem which laboratory experiments are starting to address. For example, it has been shown that ultraviolet irradiation of an ice mixture of water, methanol, ammonia, carbon monoxide and carbon dioxide yields 16 different amino-acids [11].

The chemical wealth of meteorites

While we may be ignorant of how molecules are synthesised around protostars, we do have entirely independent information on the final outcome of some of the chemical events in the inner protostellar disk. This information is provided through the chemical analysis of primitive meteorites. These meteorites are recent, million year old chips off much older parent bodies and the chips carry the chemical signature of the era in which the parent bodies formed.

The Murchison meteorite, which fell in Australia in 1969, is one of the most primitive meteorites known and carries the signature of the era in which the Earth was first forming, 4500 million years in the past. Many grains are found within the matrix of the meteorite and are remnants of the dust grains within the dusty clouds forming the pre-solar and solar nebulae. Murchison contains 2%-2.5% by weight of carbon and 0.09% to 0.16% by weight of nitrogen, in the form of a variety of organic matter, diamond, macromolecular organics (for example large polycyclic aromatic hydrocarbons), the bases of DNA and RNA and at least 79 different amino-acids. Of these amino-acids, there are 8 which are chemically the same as those found in present-day biochemistry, in which there are 20 active amino-acids. Seven diamino-acids have also been identified: these are constituents of peptide nucleic acids [12] which have been proposed as the earliest progenitors of life, predating RNA or DNA. A variety of sugar and sugar-related compounds has been identified in quantities similar to



▲ **Fig. 2:** A Hubble Space Telescope image of a disk of dusty gas around a protostar in the Orion Molecular Cloud taken through a medium-band continuum filter at 547 nm. The diameter of the disk is about 1000 Earth-Sun Distances (AU). The bright patch of light seen in the central part of the image is light from the hidden protostar reflected off clouds of dust surrounding this region. Image taken from M.J.McCaughrean and C.R.O'Dell, "Direct imaging of circumstellar disks in the Orion Nebula", Astron.J. 111, 1997 amino-acids [13]. In addition more than 50 organic acids (carboxylic acids) up to C_{10} are present in Murchison [14]. As techniques are refined, the suite of molecules essential to living systems becomes ever broader and more suggestive of an extraterrestrial contribution to the origin of life.

One further point exemplifies the interstellar-Earth connection. In cold interstellar clouds at 10K, the precursors to the dense dusty presolar and solar nebulae, thermochemistry and surface chemical mechanisms drive molecules to replace their H atoms with D atoms, that is, to become preferentially deuterated. The deuterium to hydrogen ratio in the cosmos is $\sim 2 \times 10^{-5}$. However it has proved possible to observe with radioastronomy such exotic species as triply deuterated ammonia (ND_3) [15] with an abundance orders of magnitude greater than expected on the basis of the cosmic D/H ratio. D/H fractionation, as it is called, is diagnostic of chemical processing within a very cold interstellar cloud. and thus of an interstellar molecular origin. The amino-acids in Murchison are found to have a D/H ratio which is several times greater than observed in terrestrial amino-acids. Thus the Murchison amino-acids show a clear trace of their interstellar ancestry in their relation to compounds such as deuterated ammonia, formaldehyde (HDCO, D_2CO), acetic acid and other possible precursor chemicals from which amino-acids are likely to have been formed.

The Interstellar-Earth Connection: the delivery of biochemicals from space

It is certainly fascinating that so diverse and relevant a range of biochemicals, exemplified in the Murchison, could be synthesised in the solar nebula at the time of formation of the Earth. But does this have any bearing on the origin of life on Earth? In particular, is it possible that a significant budget of biochemicals were delivered ready-made to the early Earth?

First, it is generally accepted, through crater counting on the Moon, that the early Earth was subjected to an intensive "period of bombardment" by asteroids and comets. These may themselves have delivered significant quantities of material to the early Earth. At all events, the Earth would have been subjected to heavy bombardment up to 3.9 thousand million years ago, a process gradually decreasing and largely ceasing at 3.5 thousand million years.

At this point we introduce micrometeorites. These are tiny meteorites of typically 100 microns in size, larger than interstellar grains but much smaller than familiar meteorites. Dedicated scientists, notably the micrometeorite pioneer Michel Maurette and his colleagues [16], have extracted large quantities of micrometeorites from sites in Antarctica. Studies have established that Antarctic micrometeorites (AMMs) are ancient and date back to the period of bombardment. It is also known that they contain a significant budget of "organic carbon" (carbon contained in organic chemicals). Because of the small size of AMMs, analytic techniques cannot show that AMMs contain the inventory of biochemicals that Murchison contains - but we will suppose that some do so.

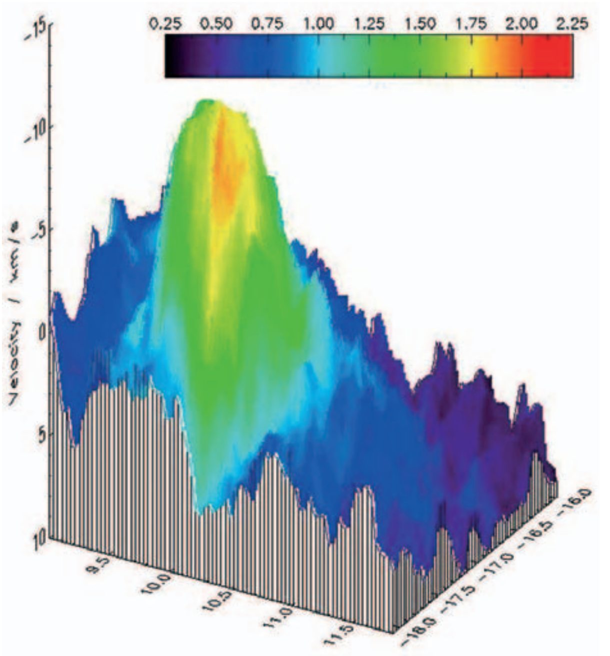
Detailed observations of AMMs show that 75% of smaller micrometeorites (50-100 microns) passed though the atmosphere of the Earth without strong melting. Hence the delicate organic chemicals which they are assumed to contain survived the passage to Earth. The present-day inventory of organic carbon falling to the Earth in the form of micrometeorites is ~500 tons per year. This is roughly 5×10^5 times more than falls to Earth through the impact of carbon-containing meteorites, such as Murchison. The inference is that micrometeorites make the strongly dominant contribution in the delivery of organic carbon to the Earth not only at the present time but throughout the entire history of the Earth. There is now a difficult and uncertain extrapolation back in time: how much organic carbon was delivered to the Early Earth during the period of bombardment by micrometeorites? Michel Maurette in [16] suggests a figure of 1000 increase in flux of micrometeorites to the early Earth compared to the present day. This implies that the amount of organic carbon delivered by micrometeorites during the entire period of bombardment would have been 100 times greater than the total budget of organic carbon in the present-day biosphere. No doubt this figure could be questioned by other experts, but there is at least a large margin for error.

This is as far as we can go today while remaining on reasonably safe ground. To summarise, the Big Bang followed by supernovae and the passage of generations of stars within galaxies created the 36 elements that are necessary for all life on Earth. Clouds of dust and gas formed between the stars and in their midst stars and planets were created. Prebiotic molecules, that is, biochemicals, formed in interstellar space, both in the gas phase and on the cold surfaces of dust grains. On the surface of dust grains, Nature creates a laboratory in which there is locally a very high concentration of molecules, ripe for the production of larger species. Processing by high energy photons, cosmic rays and cold electrons allows molecular complexity to develop. Around protostars further chemical processing is induced by shock heating and etching, both within the protostellar disk in which planets form and around the disk in supersonic outflows of gas. The resulting primeval soup in space contains many vital precursors of biochemistry. Molecules are processed time and again in an active region such as Orion, cycled from gas to surface, becoming eventually encapsulated and protected within larger particles. These particles grow, by accretion - perhaps - to form rocky planets, or

◄ **Fig. 3:** The Horsehead Nebula, Barnard 33, in the Orion Complex. This dusty cloud of gas obscures from view the starfield that lies beyond it. The Orion Molecular Cloud, part of the Orion nebula, shown in Figure 1, lies close by in the sky and at a similar distance from the Earth. Image taken using the European Southern Observatory Very Large Telescope. Credit : European Southern Observatory (ESO).

maybe become part of the early Earth through a much more rapid process of gravitational collapse. Micrometeorites rained down upon the early Earth between 4.5 and 3.5 thousand million years ago, seeding the Earth with the basic ingredients of biochemistry. If this is a correct scenario, then it surely gives a prodigious kick-start to the evolution of life upon Earth, with the ingredients of biochemistry ready laid-out for evolution to begin. A great puzzle is of course to relate what we know of the physics and chemistry of star-forming regions to the inventory of molecules in Murchison and other meteorites.

I conclude with two conjectures. The first is this: similar biochemical material will have landed on Mars during the "period of bombardment". Given that Mars may be a fossil of the early Earth, we may find traces of early life upon Mars, initiated in the way suggested above for the Earth. Perhaps the Mars rovers, Spirit and Opportunity, that at this time are still actively exploring Mars, will shed some light on this. The second conjecture is this: the Sun is a reasonably typical star and there are more than 10,000 million stars similar to the Sun in the Milky Way. One presolar and solar nebula is likely to be much like another and thus, if Earth-like planets exist elsewhere, then they too may be bombarded by the molecular manna that appears to have been the lot of the early Earth. This supply of biochemicals may be found wherever Sun-like stars with planets are found. The widespread occurrence of "extremophiles", ice lovers, rock-dwellers, thermophiles, suggests that with the right biochemicals and over a broad range of conditions, life may evolve. Perhaps therefore life may be found throughout the Universe.



▲ **Fig. 4:** Molecular hydrogen emission from a star-forming region in the Orion Molecular Cloud (see Figure 1) in the infrared at a wavelength of 2.121 microns. The image shows the plane of the sky, measured in arcseconds on the x and y-axes, where 1 arcsecond = 450 Earth-Sun distances (AU), with radial velocity relative to the local standard of rest on the vertical axis. The scale is 200 times smaller than the scale in Figure 1. Colours refer to the brightness of emission. Data show the presence of an interstellar shock travelling at 15 to 20 km/s out of the plane of the sky. Data obtained using the Canada-France-Hawaii Telescope [10].

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David Field is a Professor of Physics at the University of Aarhus. He received his PhD and ScD at the University of Cambridge and worked at the University of Göttingen (1973-1975) and thereafter at the University of Bristol until 1999. His main interests are in electron-molecule collisions and observational astronomy of star-forming regions.

References

[1] T. Abel, G. L. Bryan, M.L.Norman (2002) The formation of the First star in the Universe, Science, 295, 93

[2]V. Bromm, A. Loeb, (2003) The formation of the first low-mass stars from gas with low carbon and oxygen abundances, Nature, 425, 812

[3] M. Mayor and D.Queloz, (1995) A Jupiter-mass companion to a solar-type star, Nature, 378 , 355

[4] M.A.C. Perryman (2000) Extra-solar Planets Rep.Prog.Phys. 63, 1209

[5] O'Dell, (2001) The Orion Nebula and its associated Population, Ann.Rev.Astyron.Astrophys 39, 99

[6] F. Lacombe, E. Gendron, D. Rouan, Y.Clénet, D. Field, J.L.Lemaire, M. Gustafsson, A-M. Lagrange, D. Mouillet, G. Rousset, G.; and 5 coauthors (2004), VLT/NACO infrared adaptive optics images of small scale structure in OMC1, Astr.Astrophys. 417, L5

[7] P.Schilke, D.J.Benford, T.R.Hunter, D.Lis, T.G.Phillips, (2001), A line survey of Orion KL from 607 to 725 GHz, Astrophys J. Supp. Ser. 132, 281

[8] J.B.Pollack, O. Hubickj, P.Bodenheimer, J.L.Lissauer, M.Podolak and Y.Greenzweig, (1996), Formation of the Giant Planets by Concurrent Accretion of Solids and Gas. Icarus, 124, 62

[9] A.P.Boss (2002), Evolution of the solar nebula. V. Disk instabilities with varied thermodynamics. Astrophys.J. 576, 462

[10] M.Gustafsson, L.E.Kristensen, Y.Clénet, D.Field, J.L.Lemaire, G. Pineau des Forêts, D.Rouan and E. Le Coarer, (2003), New insight into shocks and star formation in Orion: first light with GriF. Astron.Astrophys. 411, 437

[11] G.M.Munoz Caro, U.J.Meierhenrich, W.A.Schutte, B.Barbier, A. Arconers Segovia, H.Rosenbauer, W.H-P. Thiemann, A.Brack and J.W.Greenberg, (2002), Nature, 416, 403

[12] P.E.Neilsen, (1999) Peptide Nucleic Acids. Methods and Protocols. Methods in Molecular Biology, Humana Press. ISBN. 0-89603-976-5

[13] G.Cooper, N.Kimmich, W. Belisle, J. Sarinama, K.Brabham, L. Garrel. (2001) Carbonaceous Meteorites as a source of sugar-realted organic compounds fro the early Earth. Nature 414, 879

[14] Y.Huang, Y.Wang, M. De'Rosa, M.Fuller and S. Pizzarello (2004) Molecular and compound-specific isotopic study of monocarboxlyic acids in Murchison and Antarctic meteorites. Lunar and Planetary Science XXXV, 1888

[15] F.F.S. van der Tak, P. Schilke, H.S.P.Müller, D.C.Lis, T.G.Phillips and E.Roueff, (2003) Triply Deuterated ammonia in NGC1333, Astron.Astrophys. 388, L53

[16] M. Maurette, Micrometeorites on the early Earth. Chapter 7 of "The molecular origins of Life: assembling pieces f the puzzle", ed. . Brack. CUP 1998. ISBN 0 521 56475 1. This is an excellent introductory text to Astrobiology, though becoming a little out-of-date in places.