The Role of Astronomy in Society and Culture
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Welcome address

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Mr Chairman,

Distinguished guests,

Ladies and Gentlemen,

It is a great pleasure for me to open the IAU-UNESCO Symposium on *The Role of Astronomy in Society and Culture* which is taking place at the UNESCO Headquarters this week.

Last week, on Thursday and Friday, IAU and UNESCO organised a very successful opening ceremony of the International Year of Astronomy. Our Director-General, Mr Matsuura Koïchiro, reminded the audience that UNESCO started its cooperation with IAU in the preparation of the IYA in 2005 when the UNESCO Member States decided to recommend to the United Nations that it declares 2009 as the international year as proposed by Italy and co-sponsored by Brazil, France Japan and the United Kingdom. In 2007, the UN General Assembly, in turn, designated UNESCO as the lead agency in the UN System in recognition of our experience in two fields: in science education and in establishing the link between the astronomical sciences and culture. We are determined to work very closely with the IAU and related partners to make this Year a success. The Director-General announced that Mr Jean-Michel Jarre, UNESCO Goodwill Ambassador accepted to take on the special responsibility for ensuring that throughout the Year, many events will be organized in order to bring culture and science together to enable a sustained lively interest in the Year by the general public. Mr Jarre stressed the natural link between the work of scientists and artistic expression. On Friday evening of last week, we had already a very successful demonstration of a science-inspired cultural event namely *The Sun Rings* performed by the Kronos Quartet with the UNESCO choir. Mr Jarre informed us that he plans in the coming months – around August– to organise in Spain a major event bringing music and celestial observation.

The Opening Ceremony last week gave us a unique opportunity to hear the views of high-level ministerial policy-makers from countries actively supporting the Year. It was most encouraging to listen to the strong positive messages of support to science by decision-makers. It was clearly stated that we are living a golden age for science and celebrating the *Annus Mirabilis* of Astronomy. There is a clear political consensus on the importance of the success of the scientific method analysing fundamental questions asked by our modern complex knowledge-based society. Astronomy and cosmology revealed to us in a most unexpected way the evolution of the universe that over the last 13.7 billion years became "fertile" and led us to the necessary conditions to see the birth of life and the development of our conscience. Decision-makers underlined the importance of international cooperation in astronomy in order to stimulate its scientific development and to guarantee further expansion of its impressive observational infrastructure. They

see astronomy as an important element in re-launching the engine for new economic development by stimulating science and technology. This should give us hope in building up a better future for generations to come. The industrialists present last week also stressed the need to build new partnership with the scientific and policy-making communities to combine efficiently intellectual capacity and the necessary resources to promote innovation to prompt fundamental and applied research and to build a highly motivated workforce.

All the speakers stressed the need to launch a major investment in education to stop young people from abandoning science and technology as study subjects and turn to careers that are perceived to be more rewarding. Therefore, we are very pleased that through our cooperation with the International Astronomical Union, we can convey the excitement of personal discovery, the pleasure in sharing fundamental knowledge about the Universe and the realisation of human's place in it. Astronomy is one of the oldest scientific pursuits of humanity and is making fundamental contributions towards contemporary technological, social and economic development. Therefore, a better understanding of the origins and functioning of the universe will lead us to a better comprehension of the planet and to a more sustainable development of the Earth system and its resources. This inspirational aspect of IYA embodies an invaluable resource for humanity and contributes in the achievement of the goal of universal primary education.

The IYA educational programme intends to add quality to primary education by providing teachers and students access to basic astronomy studies worldwide, giving equal chances globally to access knowledge will result in the development of international cooperation with scientific research and relevant applications, and its broader effect will be to assist the developing world to match the western world. Through Space Education Programme, UNESCO brings a new dimension to science education by introducing new knowledge, values and perspectives on our planet and the universe. The programme enhances space subjects and disciplines in schools and universities in developing countries through international workshops for teachers and students and by introducing space-related subjects in their curricula.

Science and Education Programme is closely working with UNESCO Basic Sciences Programme that encompasses physics and astrophysics, and leads to strengthen education at university level, and strongly stimulates North-South and South-South cooperation. UNESCO was the basis for the creation of CERN where the scientific community works towards a better understanding of the origins of the universe and its expansion, and on the study of dark matter. In a similar way, UNESCO is closely associated to the creation in November last year of the Pierre Auger Observatory in Malargüe, Province of Mendoza, Argentina, where scientists from all over the world explore the mysteries of high-energy cosmic rays.

One of our goals in IYA is to improve the gender-balance representation of scientists at all levels and greater involvement of under-represented minorities in scientific and engineering careers. Gender equality is a priority concern of the whole scientific community regardless of its geographical location. The problems and difficulties are dissimilar in different regions and continents. We have created partnerships with the private sector to address this issue where I would like to mention the l'Oréal Prize for "*Women in Science*" which has rewarded exemplary women scientists in fields related to astronomy, and has helped young women in starting their research careers.

Ladies and gentlemen, I would briefly like to mention that the thematic sessions we held last week in the opening ceremony were also very relevant to the debates that will take place in this week's symposium. We learned more about the history of astronomy and the important developments taking place in diverse cultural environments all over the

world. We heard several speakers alluding to the important contributions made by people with different cultural backgrounds, speaking different languages and pursuing different objectives, some focussing more on basic sciences, others on evolutionary scenarios. From the beginning of mankind people have been exploring time and used the study of the sky to develop calendars that have helped them in planning their economic activities and in achieving food security. Many civilisations developed mythical, metaphysical and religious diversities linked to astronomy.

In this respect, I would briefly like to refer to a programme created by our *World Heritage Centre* and implemented in close collaboration with IAU. This project on *Astronomy and World Heritage* aims at establishing a link between science and culture to highlight the cultural and scientific values of properties and monuments connected with astronomy.

My review of the presentations and discussions held during the opening ceremony shows you that the thematic of this week's symposium on the *Role of Astronomy in Society and Culture* was already briefly evoked and that we look forward to more in-depth discussions these coming days. In addition, I would like to mention that the international press agencies expressed a great interest in IYA. The press coverage on radio and on television is very encouraging. During the press conference at UNESCO, many questions were raised especially on this link between astronomy and society.

May I express my appreciation for the excellent work of the organising committee and in particular to Dr David Valls-Gabaud for having put together an excellent interdisciplinary programme covering basic sciences, social science, education and culture.

I would also like to thank all the speakers and participants for being with us. I hope that during your work, you will find time to visit the exhibits related to astronomy and arts in the neighbouring rooms and I wish you every success in your deliberations.

We would like to invite you to visit us here again in June for conferences on the *Invisible Universe* and in July on *General Relativity*, as well as in December on *Space and Astronomy*. With our Member States, we have organised several events in different part of the world†

Ladies and gentlemen, in closing, let us recall that the universe is not only more amazing than we imagine it is, it is more amazing than we are even able to imagine it to be.

Thank you.

† Please visit our website for more information at `www.astronomy2009.org` and `www.unesco.org/iya2009`.

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The role of astronomy in society and culture

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Abstract. As an ancient and multidisciplinary field, astronomy is an ambassador for all sciences. Astronomy's broad appeal, whether from its cultural interest of our place in the universe, or its practical aims such as sea- or space navigation, is well recorded in history from ancient to modern times, and sky-awareness, more generally, began prehistorically. Astronomy's perceived role and purpose has continually developed over the ages. In all, astronomy is not to be viewed as a narrow subject operating in isolation but one that has contributed comprehensively to the advancement of society.

Keywords. Art, society, sociology, culture

The history of the development of science and its application through technology is as important as any other part of our heritage in understanding the nature of modern human existence. One might go further to say that the pursuit of science is the only truly universal culture, understood equally and subject to the same mental and practical engagement everywhere on the globe. Astronomy is perhaps the best example of this universality of science, which, as Thomas Jefferson put it, implies that "*The field of knowledge is the common property of all mankind, and any discoveries we can make in it will be for the benefit of yours and of every other nation, as we as our own.*"†

The very same sky, as observed by different cultures, while leading to different interpretations in space and time (see, e.g. Shlain 1991; Bertola 1995, 2003; Kemp 2006), nevertheless builds on astronomical knowledge which is valid across cultures just as arithmetic is, a fact that perhaps best illustrates the failure of the post-modernist and social constructivist accounts of scientific activities (see Bouveresse 1999; Boghossian 2006; Bensaude-Vincent 2003; Weinberg 2001; Sokal 2008).

In his anti-science (and anti-arts) diatribe, Rousseau (1751) wrote, quite rightly, that "*Astronomy was born of superstition.*". In contrast with the astrological superstition, astronomy has, however, evolved and made progress by applying the scientific method to objects which cannot be experimented with. Before this modern phase, the pre-Socratic philosopher Thales, and then Anaximander, of Miletus insisted that all observed events must have rational, discoverable causes (e.g. Cropsey 1995; Singer 2001). This truly revolutionary idea was not always easily accepted by political or spiritual authorities, which often based their power on presumed priviledged links to natural phenomena. The use, by politicians or religious authorities, of astronomical concepts to justify their ruling power has been a constant over time and space. This does not imply however that scientists should be held responsible for their discoveries of natural phenomena and their

† Letter to Henry Deaborn, June 22, 1807.

understanding. While it has been argued, since R. Oppenheimer, that the development of atomic bombs gave a thoroughly different meaning to the social responsibility of scientists, the practical uses of astronomy have not led – so far – to similar criticisms. Again, the fact that astronomy is not an experimental science per se, but rather an observational one, does also make a difference.

It can be argued that astronomy has, in fact, been the scientific discipline that, on the contrary, led the assault against the established authorities which based their rule on the *application* of astronomical discoveries to society. Likewise, astronomy has contributed to the process whereby "*the role of science in weakening religious certitude [is] one of its greatest contributions to civilization*." (Weinberg 2009, p. 216). In his preface to the second edition (1787) of *Kritik der reinen Vernunft*, Kant described the process:

> "*It is only the principles of reason which can give to concordant phenomena the validity of laws, and it is only when experiment is directed by these rational principles that it can have any real utility. Reason must approach nature with the view, indeed, of receiving information from it, not, however, in the character of a pupil, who listens to all that his master chooses to tell him, but in that of a judge, who compels the witnesses to reply to those questions which he himself thinks fit to propose. To this single idea must the revolution be ascribed, by which, after groping in the dark for so many centuries, natural science was at length conducted into the path of certain progress.*"†

The history of astronomy is also the history of political interference with science that does not support some ideological beliefs, a long tradition rooted in the anti-Enlightenment movements (Sternhell 2006) and which unfortunately remains true to this day (e.g. Harwit 1996; Gross, Levitt & Lewis 1996). The implications for society are profound. As the Union of Concerned Scientists stated in the context of the so-called intelligent design attacks, non-scientific beliefs cannot be accepted as science, not only because the public understanding of science is eroded and the integrity of science diminished, but also becuse the decisions for our future could be based on unsubstantiated information.

In this context, media play a key role in transmitting scientific discoveries to the public, and all too often misunderstandings and misconceptions are amplified (e.g. Barrosa and Pullen 2008; Plait 2002), not to mention the pervasive image of the "mad scientist", from Faust to Dr Strangelove. It is one of the social responsibilities of astronomers to ensure that – besides emotions – the reasoning which led to the discovery is transmitted properly across society (e.g. Schatzman 1989). For example, *Universe Awareness* (UNAWE) is an international programme that aims to inspire young disadvantaged children with the size, scale and beauty of the universe, and their own placing on the globe, illustrating the multicultural origins of modern astronomy to broaden children's minds, awaken their curiosity in science and stimulate global citizenship and tolerance. The project is motivated by the premise that the formative ages of 4 to 10 years play an important role in the development of a human value system. UNAWE was one of the eleven Cornerstone Projects chosen to celebrate the International Year of Astronomy 2009.

In another approach, the relations that astronomy enjoys with the arts, across time and space, certainly help conveying part of the excitement, if not the rational process, to the public at large (e.g. Kemp 2006; Hockney 2001; Weinberg 2010; Lévy-Leblond 2010).

In modern times (Van Helden 2009), astrophysics – unique in encompassing the application of physics as a whole – has been extraordinarily successful in revealing a consistent picture of the development of the universe from an intensely hot and dense almost homogeneous beginning to its enormously expanded and widely complex present state.

† in J.M.D. Meiklejohn's (1855) classic translation.

Largely this has been achieved by close conjunction of theoretical analysis and observational evidence in complementary, supportive ways. In recent decades the advent of new lines of thought, sophisticated computational advances and a wide range of powerful astronomical telescopes and instruments working from the ground and in space has led to fundamentally new understanding of the structural and chemical development of the universe over almost the whole of cosmic time. But, let us not forget, biological complexity is in another league altogether.

We are now at a startling juncture in recognising the existence – but not the nature – of the so-called dark matter and dark energy that the evidence shows together account for 95% of the mass-energy content of the universe and fundamentally influence its productive past developmentand its ultimate dissipation. And the advancing knowledge brings an appreciation that life forms and the macroscopic properties of the universe are logically inter-linked and that our universe may be just one in a limitless multiverse.

Today, astronomy is seen foremost as a scientific endeavour and the foundation of modern science. Explaining the structure and phenomena observed in the sky inspired Newton and Einstein to make their fundamental discoveries whose universality changed our understanding of nature. Our growing knowledge in science has come about from studies both in earthly laboratories and of physical phenomena observed in the sky. Within the universal expansion that began with the Big Bang about fourteen billion years ago it is now possible literally to see that the structural formation of the galaxies of stars has been evolving over most of cosmic time. To gain understanding of the universe in space and time astronomers need to apply the entirety of accumulated knowledge in the physical sciences. In turn, the discoveries continually push the borders of scientific knowledge. Alongside this are the engineering and technology challenges of producing ever more versatile and accurate instrumentation and detectors, building ever larger and more precise telescope structures both on the ground and orbiting in space to receive radiation from the furthest and faintest objects in the sky, and devising ever more sophisticated means of computational analysis and modelling.

The practice of astronomy thus is both at the cutting edge of knowledge and widely multidisciplinary, enabling it to boost the advance of science and technology together: astronomy is a tool for development. It is interesting and gratifying, therefore, to see already present or coming in Africa such major instruments as the Southern African Large Telescope (SALT), the High Energy Stereoscopic System (HESS) as the largest gamma ray detector in the world, the radio Karoo Array Telescope, and, possibly, the Square Kilometre Array as the largest radio telescope array in the world.

While science as a whole seems to have become less appealing at the university level, astronomy maintains wide public appeal and is a generator of public interest in science, and remains attractive to students. Consequently the introduction of astronomy-oriented courses has greatly increased student intake in physics. And again, astronomy – more than narrower scientific subjects – equips students with modern skills that are also widely applicable outside the academic *milieu*.

Astronomy is a subject that naturally promotes partnership and cooperation internationally: the same sky is studied by all; the same goals in understanding are sought; common data-bases are accumulated and accessed; telescope facilities commonly are open to international guest observers; and international cooperation in construction and operation of major new facilities is universal. The unique early formation of the IAU and the global activities of the IYA, are just two examples that testify to this. But there is a humanitarian side too. Astronomy, high among all scientific endeavours, in its practice transcends national borders and international constraints. A good example of bringing like-minded people in many post-conflict countries together is the project Enhancing as-

tronomical research and observation in South-East Europe and Ukraine of the UNESCO Regional Bureau for Science and Culture in Europe (UNESCO-BRESCE). This has the objective of strengthening astronomical cooperation in the sub-region, and between this and countries outside. It has been successful both in enhancing international cohesion and in raising the collective scientific productivity and international standing of the partner institutions.

The Astronomy and World Heritage initiative is a UNESCO World Heritage Centre thematic programme. The objective is to acknowledge the intertwined cultural and scientific values of properties connected with astronomy. The efforts of civilisations through the ages demonstrating sky

awareness and the will to understand or interpret what they see in the sky are often reflected in rock carvings, grand structures, architecture and other cultural representations. And the evidence of the more direct scientific activity in astronomy is borne through the existence of the many significant observational instruments and observatories that have been built over the centuries and which remain as beacons of humankind's search for fundamental knowledge about the universe. The identification, safeguarding and promotion of all these properties are the three lines of action for the implementation of this World Heritage programme.

But additionally, it is very important to recognise the natural dimension to the recognition of astronomical heritage – the preservation, from our vantage point, of the quality of the night sky itself through avoidance of overwhelming air pollution and extraneous light. While natural heritage sites are common in the World Heritage List, the local upper hemisphere of our heritage is all but forgotten. Most people now growing up in cities rarely experience the extraordinarily endowed night 'skyscape' still accessible to astronomers at the remote mountain sites where major observatories are now placed. While action on this fundamental loss has been widely urged for a long time, an important recent initiative `Starlight` – a Common Heritage has been launched through an international conference in 2007 on the island of La Palma in the Canaries (itself a UNESCO Man and the Biosphere reserve), home to the Spanish internationalised Observatorio de Roque de los Muchachos of the Instituto de Astrofísica de Canarias. This is a global campaign in defence of the values associated with the night sky and the general right to observe the stars, emphasising the value of this endangered heritage for science, education, culture, technological development, nature conservation, tourism and, not least, quality of life. It is open to the participation of all scientific, cultural, environmental, and citizens' organisations and associations, as well as other public and private bodies. At this ripe time in world awareness of the unsustainable environmental track we all are taking, this is a powerful move to drive home this all-enveloping heritage issue.

Astronomy has also become a "Big Science" in many respects, which has led to new relations with the five" Ms": money, manpower, machines, military and the media, the outcome of which remains to be seen. On the other hand, while astronomy is one of the few sciences where amateurs play an essential role, we are witnessing an evolution of the discipline whereby the public also becomes involved. The phenomenon of "*citizen science*" (see also Conner 2005, for earlier examples) started in astronomy with the wellknown `Seti@Home` programme which allows the public to let their computers analyse data gathered at radiotelescopes with the hope to detect interesting features possibly associated with extraterrestrial signals (see http://setiathome.ssl.berkeley.edu). More recent initiatives, which require some previous training, are Galaxy Zoo (galaxyzoo.org), Planet hunters (www.planethunters.org) and more generally the `ZOOUNIVERSE` (www.zoouniverse.org), which are leading to new generations of truly citizen scientists. Remarquably, this was already envisioned in the 19th century, when Camille Flammar-

ion famously stated "*Nous sommes tous des citoyens du Ciel*", or, as William Huggins described in 1891, "*Astronomy, the oldest of the sciences, has more than renewed her youth. At no time in the past has she been so bright with unbounded aspirations and hopes.*"

An increasingly wider fraction of the society in the 21st century participates to the quest for the understanding of a universe, which, as the British geneticist J.B.S. Haldane (1927) described, remains a never-ending puzzle: "*I have no doubt that in reality the future will be vastly more surprising than anything I can imagine. Now my own suspicion is that the Universe is not only queerer than we suppose, but queerer than we can suppose.*"

References

Barrosa, M. and Pullen, L. 2008, *CAP Journal*, 4, 18
Bensaude-Vincent, B. 2003, *La science contre l'opinion. Histoire d'un divorce* (Paris: Les empêcheurs de penser en rond)
Bertola, F. 1995, *Imago Mundi. La rappresentazione del cosmo attraverso i secoli* (Cittadella: Biblos)
Bertola, F. 2003, *Via lactea. Un percorso nel cielo e nella storia dell'uomo* (Cittadella: Biblos)
Boghossian, P. 2006, *The fear of knowledge: against relativism and constructivism* (Oxford: Oxford University Press)
Bouveresse, J. 1999, *Prodiges et vertiges de l'analogie* (Paris: Raisons d'agir)
Conner, C. D. 2005, *A people's history of science. Miners, midwives and "low mechanicks"* (New York: Nation Books)
Cropsey, J. 1995, *Plato's world. Man's place in the cosmos* (Chicago: The University of Chicago Press)
Gross, P. R., Levitt, N., & Lewis, M.W.(eds) 1996, *The flight from science and reason* (New York: The New York Academy of Sciences)
Haldane, J. B. S. 1927, *Possible Worlds and Other Papers* (London: Chatto & Windus), p. 286
Harwit, M. 1996, *An exhibition denied. Lobbying the history of Enola Gay* (New York: Springer Verlag)
Hockney, D. 2001, *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters* (London: Thames and Hudson)
Kemp, M. 2006, *Seen | Unseen: Art, Science, and Intuition from Leonardo to the Hubble Space Telescope* (Oxford: Oxford University Press)
Lévy-Leblond, J. M. 2010, *La science n'est pas l'art* (Paris: Hermann)
Plait, P. C. 2002, *Bad Astronomy: Misconceptions and Misuses Revealed, from Astrology to the Moon Landing "Hoax"* (New York: Wiley)
Rousseau, J. J. 1751, *Discours sur les sciences et les arts* (Genève, Barillot & fils; in fact Paris: Noël-Jacques Pissot)
Schatzman, E. 1989, *La Science menacée* (Paris: Odile Jacob)
Shlain, L. 1991, *Art and physics. Parallel visions in space, time and light* (New York: Harper and Collins)
Singer, S. J. 2001, *The splendid feast of reason* (Berkeley: University of California Press)
Sokal, A. D. 2008, *Beyond the hoax: science, philosophy and culture* (Oxford: Oxford University Press)
Sterhell, Z. 2006, *Les anti-Lumières: Du XVIIIe siècle à la guerre froide* (Paris: Fayard)
Van Helden, A. 2009, *Experimental Astronomy*, 25, 3
Weinberg, D. H. 2010, in *Josiah McElheny: A Prism*, L. Neri and J. McElheny (eds) (New York: Skira/Rizzoli Books)
Weinberg, S. 2001, *Facing Up: Science and its Cultural Adversaries* (Cambridge: Harvard University Press)
Weinberg, S. 2009, *Lake views. This world and the universe* (Cambridge: Harvard University Press)

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Astronomical exploration and the public imagination

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1. Introduction

Humans have a need to understand where they fit in the cosmos. Driven by the unlimited possibilities of human imagination the night sky has been and is one of the most powerful stimulators of curiosity. In pre-modern times, farmers, pastoralists, travelers, even city dwellers unhampered by light pollution, had many opportunities to observe and wonder on the mysteries of the starry night. In this, the International Year of Astronomy marking the 400th anniversary of Galileo's telescopic observations (that is also the 200th anniversary of the birth of Charles Darwin) there are many explorations using the advanced and expensive instruments that society provides for satisfying the public curiosity and, of course, that of the astronomers trained to ask and answer the questions. However, it is a truism that scientific answers always raise new questions that could not have been asked raised prior to the preceding answers. The more we know the more we know about what we do not know; the task of scientific inquiry, or, for that matter, inquiry in general, is endless.

The questions touch on matters of fundamental interest; how did the cosmos begin, what happened before the beginning, if anything, how did life begin, and how did sentient beings, such as humans, evolve to devise the instruments, make the observations, compose the theories, answer the questions and raise many others.

Parallel with astronomical advances, biological research has progressed rapidly. It can now more readily investigate the deep history of origins, including the history of contemporary genomes using the information contained within the genome itself as well as in fossils. Analogous to the great distances outward observed by astronomers to study origins, biologists can look inward at small dimensions to tell the story of how inorganic matter, rocks, patterns, and energy became biology.

I am not an astronomer; my training has been in medicine and biochemistry. My acquaintance with astronomy came from my rôle as the former Director of the NASA Astrobiology Institute. In the spirit of the theme of this Symposium, astronomy in society and culture, I have been asked to speak on astronomy and the public imagination and I will briefly address several topics that relate to this issue.

2. Human and robots in space research

The astronomical and space research process raises the question of what it means to be human. In the area of space exploration, at a practical level, should space missions be robotic or human? There is a basic human need to explore and to go beyond their planet of origin. Space is a continuation of the human quest to seek the mysterious and unknown. Human missions are much more expensive and dangerous than robotic exploration. Are humans needed for exploration? Are there limitations to robotic possibilities? Can a robot

Figure 1. Harrison Schmidt, Ph.D., last human on the Moon.

be programmed to select, see and analyse phenomena that have never been previously experienced and for which they were not and could not be programmed?

Harrison Schmidt, the geologist who, along with astronaut Eugene Cernan, spent 75 hours on the Moon during the Apollo 17 mission (17-19 December 1972), expressed this eloquently in his article "*Field Trip to The Moon*"†:

> *The third EVA provided an opportunity to study the large boulders that had rolled and bounced down the north wall of the valley. From them, we hoped to learn more about what happens when large objects from space hit, break, and partially melt planetary crusts. During the detailed examination of one very large boulder, the unexpected discovery of a subtle contact between two types of impact generated debris units, one intrusive into the other, again proved the worth of the trained human eye in exploration. Questions often arise as to whether robotic exploration of the Moon or any other planet would be less expensive than human exploration and provide all the essential scientific return. This question, of course, can never be answered to everyone's satisfaction if only because of sincere disagreements over what constitutes "essential science". Clearly, robotic systems will and must make increasingly important contributions, however, the spontaneous human observation, integration, and interpretation of the total dynamic situation involved in space activities, and a calculated human response to that situation, will be as irreplaceable in the future as throughout the past.*

Schmidt's argument appears to be that there is a human need for exploration and discovery, forged by human imagination that is not possible with programmed or self-learning robots. The personality of HAL, the computer in Stanley Kubrick's and the late Arthur Clarke's 1968 masterpiece movie (and later novel), "*2001: A Space Odyssey*" puts a fascinating take on the question. It posits a deadly contest between the wills of the very intelligent computer and the human crew‡. HAL was programmed to complete a successful mission and could not appreciate nuanced deviations from this goal that had to be altered by events that took place during the trip. Would a human decision maker

† `fti.neep.wisc.edu/neep602/LEC1/trip.html`

‡ HAL's name was derived from the acronym for Heuristically programmed ALgorithmic Computer, not as a one letter downward removed from IBM, the initials of the International Business Machines company, as is popularly supposed.