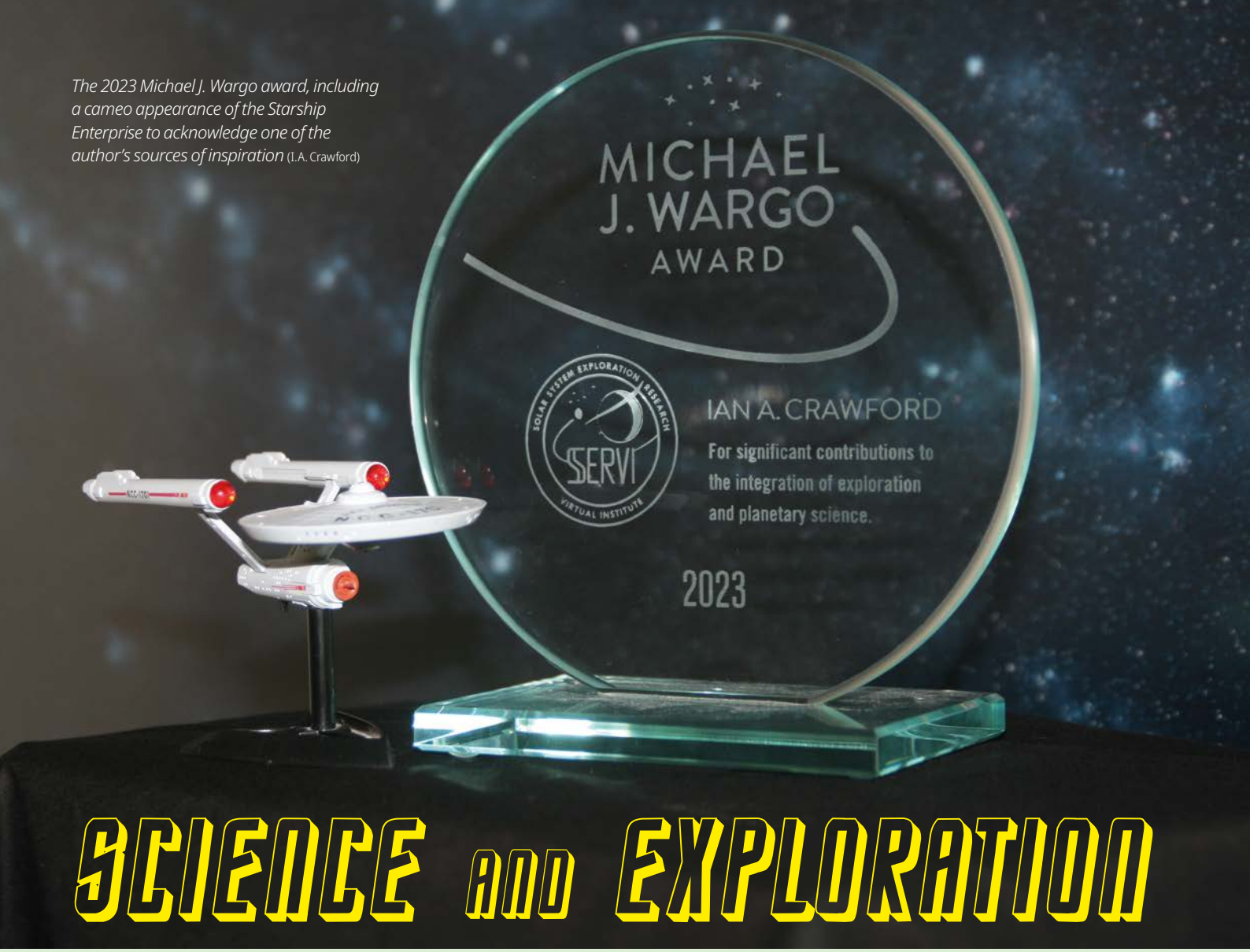


The 2023 Michael J. Wargo award, including a cameo appearance of the Starship Enterprise to acknowledge one of the author's sources of inspiration (I.A. Crawford)

SCIENCE AND EXPLORATION

The Wargo Award is given annually to scientists or engineers for integrating science and exploration throughout their careers. Here 2023 winner Ian Crawford pays tribute to his influences and sources of inspiration, and outlines his hopes for the future.

It was a great and totally unexpected honour to receive the 2023 Michael J. Wargo Award from NASA's Solar System Exploration Research Virtual Institute (SSERVI); I would like to thank the SSERVI awards panel, and the colleagues who nominated me. I didn't know Mike Wargo personally, although he was a ubiquitous and enthusiastic presence at international lunar science conferences when I was starting in the field some 20 years ago. Mike sadly passed away in 2013 at far too early an age, and it's fantastic that SSERVI created this award both to honour him, a former NASA chief exploration scientist, and to further cement the close ties between space science and exploration that he espoused so passionately.

As some colleagues will know, I had a 15-year career as an observational astronomer at University College London, specialising in studies of the interstellar medium (ISM), before changing direction to work on lunar and planetary science (including astrobiology) at Birkbeck from 2003 onwards. At first sight, these topics seem very different, but to my mind they are linked in several ways. Most straightforwardly, the ISM is the material from which planetary systems form. However, I have long felt that there is another connection related to the future of space exploration – if we are ever to fully understand the origin and evolution of planets, and any life that may have evolved upon them, then we will need to conduct *in-situ* measurements. For planets orbiting other stars, this will require a programme of interstellar exploration (another long-time interest; e.g. Crawford 1990) which, of necessity, will involve traversing (and perhaps utilising) the ISM. However, any programme of interstellar exploration will presumably have to be built on a significant spacefaring capability within our own solar system. This, in turn, is likely to build on experience gained on, and resources obtained from, Earth's Moon. Indeed, the pivotal role of the Moon for the future of space exploration was nicely summed up by Kraft Ehricke (1985): "If God had wanted man to become a spacefaring species, He would have given [us] a Moon".

Although the Moon is of great scientific interest in its own right (e.g. Flahaut *et al.* 2023), space exploration won't end at the Moon, but will move outwards through the solar system, and, eventually, to the stars. But it will *start* with the Moon! This, at any rate, was the logic that led me from a career in interstellar astronomy to one in lunar and planetary science.

No one can make such a career change without a great deal of help from many people. My wife, Naoko Yamagata, and all my former and current colleagues at UCL and Birkbeck have supported me during this transition, and so too have all my PhD students and post-docs with whom I have worked over the years. I would not have achieved anything in planetary science without them.

Going further back, I can identify three deeper sources of inspiration.

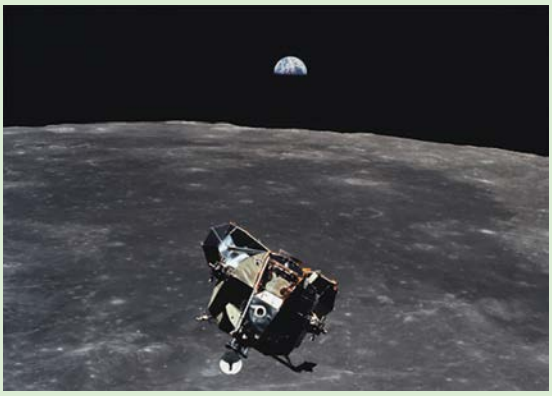
Sources of inspiration

The first of these was the Apollo programme (figure 1). I was just short of eight years old in July 1969 and the Moon landings had a major influence on my subsequent interests in astronomy and space exploration. Don't let anyone tell you that human space

exploration isn't inspirational, because I, and many other scientists of my generation, are living proof that it is. It is important to understand that inspirational events like Apollo can be leveraged by good parents and good teachers (and I was fortunate to have both) to achieve positive educational outcomes. For example, the first 'public' talk that I ever gave was about Apollo. It was to my primary school class in 1971 following one of the Moon landings (either Apollo 14 or 15). Of course, I only had that opportunity because my teacher at the time (Mrs Cotton if I recall correctly) knew of my interests and invited me to stand up in class and talk about them. But Mrs Cotton, and doubtless many other teachers like her around the world, was only able to leverage this educational opportunity because people were actually landing on the Moon.

The second influence I should acknowledge is my parents, and I especially want to highlight my father's influence. My father was a dentist by profession, but he had an amateur interest in astronomy and so encouraged my interests. He also insisted, I think probably against my mother's wishes, on waking me up to watch Neil Armstrong step onto the lunar surface. Much later, both my parents were supportive of my desire to study astronomy at university, despite surely having doubts about whether it would ever get me a proper job, and for that I will always be grateful.

The third major influence on my career was science fiction. *Star Trek* (figure 2) was (and remains!) a major influence – bear in mind that the original series was first broadcast in the UK in July 1969, just eight days before the first Moon landing; fact and fiction became mutually reinforcing. Somewhat later, the 1970s TV series *Space 1999* also left a strong impression, with its portrayal of a sizeable lunar outpost called Moonbase Alpha (figure 3). Since this early exposure to the genre, I have been an avid reader of SF, which instilled in me a sense of the potential for discovery that awaits us in the universe. For this source of inspiration, I am grateful to another teacher, Mr Hardman, who one day, probably in 1975 or 1976, brought a large box containing his own personal SF collection into our classroom and encouraged us to borrow books from it. If memory serves, the first of these that I read was *Pebble in the Sky* by Isaac Asimov, and the visceral sense of future possibilities that I gained from it, and dozens of other, often rather more sophisticated, SF stories over the years has never left me. Still, I keep coming back to *Star Trek* – not so much for its portrayal of scientific exploration, which often wasn't its main focus, but for its optimistic vision of the future. I think Gene Roddenberry's vision of a united humanity exploring the universe together was, and is, a noble one, and one to which we should continually aspire (I'll return to this theme later).



1 *The ascent stage of Apollo 11's Lunar Module Eagle returns to the Command Module Columbia in July 1969* (NASA)

"One could argue that nature has been engaged in a process of self-exploration since the beginning, as increasingly complicated structures and processes have come into existence"

Exploration, science; science, exploration

The main purpose of SSERVI's Wargo Award is to encourage the integration of space science and exploration, so I would like to a add a few observations on this topic. Some of the wisest words I have come across on scientific exploration are due to Craig McLean of the US National Oceanic and Atmospheric Administration (quoted by Schrope 2001): "Without exploration we would continue on a familiar path, with familiar subjects, enjoying an occasional surprise. But with exploration our purpose is to discover these surprises."

Although in principle this argument applies equally to robotic and human exploration, there are reasons to believe that having humans on planetary surfaces (at least for the Moon and Mars) will enable discoveries, especially the kind of serendipitous discoveries that McLean was referring to, that are unlikely to be made otherwise (e.g. Spudis 2001, Crawford 2012).

For several years, space agencies have promulgated the mantra: "Exploration enables science and science enables exploration" (e.g. SSERVI 2023). I agree that this captures the positive feedback (aka 'virtuous circle') that exists between science and exploration as understood by contemporary space agencies (where 'exploration' is generally associated with human spaceflight and 'science', for some inexplicable reason, is not). However, it worries me that this phrasing perpetuates what

2 *Star Trek's creator Gene Roddenberry (centre) photographed with some of the cast and then-NASA Administrator James Fletcher (left) in front of the Space Shuttle test vehicle Enterprise in September 1976.* (NASA)

3 *Moonbase Alpha from the 1970's TV show Space 1999. A lunar base like this would yield numerous scientific and societal benefits (Crawford 2017) but a quarter of a century on from 1999 we are still waiting for one!* (ITV Studios)

I see as a false dichotomy between science and exploration. This dichotomy has unfortunately been institutionalised by some space agencies through the creation of separate directorates for science and exploration in a way that is not always helpful to the fundamental task of exploring the universe.

When I gave the acceptance speech on which this article is based, I was happy to assert that science is the more fundamental activity. Science is generally understood to be the systematic attempt to understand the universe in all its complexity, whereas exploration, as narrowly understood, benefits only a subset of scientific investigations. For example, exploration has enabled discoveries of the natural world that could not have been made otherwise, such as new flora and fauna discovered in distant parts of the world during the European Age of Exploration from the 15th to the 18th centuries, whereas other scientific discoveries don't rely on exploration in this geographical sense; Galileo and Leeuwenhoek didn't have to travel to new places to make their discoveries, for example. Here, I am reminded of Allan Chapman's (2009) observation that the sailing ships during the Age of Exploration should themselves be viewed as scientific instruments, like the microscopes and telescopes of the same period, because they likewise enabled discoveries that could not have been made without them. From this perspective, exploration can indeed be seen as a tool of science.

However, on reflection, there is a deeper sense in which exploration can be seen as the more fundamental activity. Indeed, one could argue that nature has been engaged in a process of self-exploration since the beginning, as increasingly complicated structures and processes (e.g. fundamental particles, stars, atoms, molecules, planets, life, consciousness, etc) have come into existence. Once life appeared, it has been engaged in a remorseless, albeit unconscious, exploration of biological possibilities, resulting in ever increasing complexity and diversity (e.g. Dennett 1995). It seems clear that this kind of biological exploration confers survival advantages and will be favoured by natural selection. We don't know when or how reflexive consciousness emerged from these evolutionary processes but it is certainly present in *Homo sapiens*, making us a "local embodiment of a Cosmos grown to self-awareness" (Sagan 1980). Among other momentous consequences, this enabled humanity to explore, and colonise, most of the habitable surface of our home planet long before the advent of systematic science (e.g. Gamble 1993). Viewed from this perspective, science can be seen as a locally and recently evolved ('discovered') tool of exploration.

So, yes, "exploration enables science and science enables exploration", but there is a lot more to this at first sight rather superficial expression than initially meets the eye.

A sense of perspective

I want to conclude with some thoughts on the wider relevance of space exploration for society. I agree with Carl Sagan, whose book *The Cosmic Connection* (1973) had a great influence on me as a teenager, that the most important of these is the perspective that space exploration provides on human activities. Only space exploration can show the Earth in its true cosmic setting (figure 4), and with this perspective comes social and political implications. Foremost among these is that we all live on the same small planet and, as Gene Roddenberry intuited with Star Trek, a politically divided world somehow doesn't gel with the reality of our cosmic setting or with the task of exploring our cosmic surroundings. The United Federation of Planets may still be a distant dream but that doesn't prevent us from working towards something like it (e.g. Crawford 2015), or at least towards greater international cooperation in space exploration.

The first article that I ever had published, while an undergraduate astronomy student at UCL, was 'On the formation of a global space agency' (Crawford 1981), an idea to which I have returned many times (most recently in Crawford 2023). At first sight, it looks like there hasn't been much progress in the past 40 years – I am still waiting for a world space agency, just as we are still waiting for Moonbase Alpha. However, I believe that both are worth striving for, and that there is reason for optimism. For example, the creation of the International Space Exploration Coordination Group (ISECG 2023) shows that governments and space agencies recognise the underlying logic of global cooperation in space, and that the Moon is the next obvious focus for human space exploration (GER 2018). Perhaps ISECG could become the foundation on which a global space agency might be built?

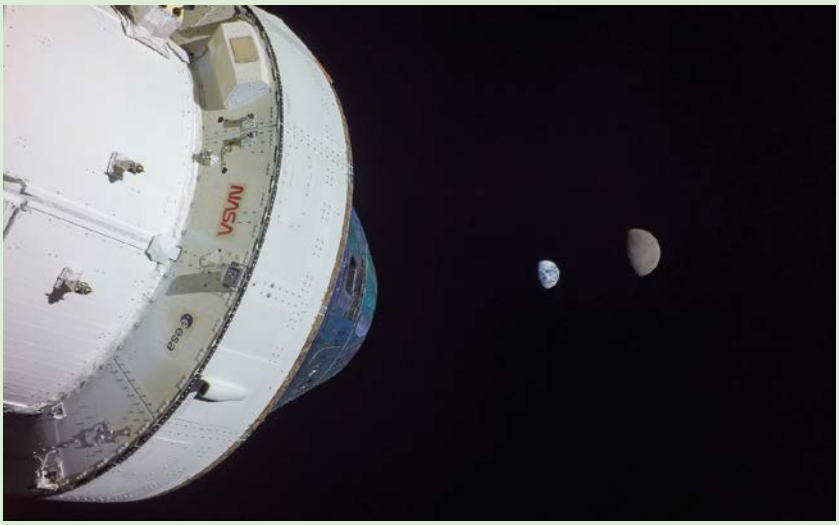
This may seem naïve, but positive institutional change is possible if enough people work for it. Consider the European Space Agency (ESA), whose logo can be proudly seen on the European Service Module of NASA's Artemis I mission in figure 4. When my parents were the age I was when Apollo 11 landed on the Moon, an institution like ESA would have seemed the purest fantasy, for at least two reasons. Firstly, space travel was not yet a reality and, outside a handful of visionaries, was largely considered to be physically impossible. Secondly, Europe was tearing itself apart in the Second World War. The idea that these warring nations would miraculously come together to cooperate peacefully in a seemingly impossible activity like space exploration would have appeared absurd. Yet here we are, less than a human lifetime later, with space travel a reality and ESA not just existing but flourishing. I think this is a tremendous example for the world. Perhaps in another 80 years we will have thriving human outposts on both the Moon and Mars, and be contemplating sending probes to the nearest stars, all coordinated by a World Space Agency. However, this won't happen on its own – achieving a future like this will require hard work and dedication from all of us. ●

AUTHOR

Ian Crawford (i.crawford@bbk.ac.uk) is professor of planetary science and astrobiology at Birkbeck, University of London, and a former vice-president of the RAS.

REFERENCES

Chapman A 2009 *Astron. & Geophys.* **50** 1.27
Crawford I A 1981 *Spaceflight* **23** 316
Crawford I A 1990 *Quart. J. Roy. Astron. Soc.* **31** 377
Crawford I A 2012 *Astron. & Geophys.* **53** 2.22
Crawford I A 2015 *'Interplanetary federalism' in The Meaning of Liberty Beyond Earth* Cockell C S ed. (Springer) 199
Crawford I A 2017 *Astron. & Geophys.* **58** 6.18
Crawford I A 2023 *Nature* **618** 457
Dennett D C 1995 *Darwin's Dangerous Idea: Evolution and the Meanings of Life* (Penguin).
Ehricke K A 1985 in *Lunar Bases and Space Activities of the 21st Century* Mendell W W ed. (Lunar and Planetary Institute) 827
Flahaut J *et al.* 2023 *npj Microgravity* **9** 50
Gamble C 1993 *Time Walkers: The Prehistory of Global Colonisation (Alan Sutton).*
GER 2018 *The Global Exploration Roadmap* bit.ly/3ETuHkr
ISECG 2023 *International Space Exploration Coordination Group* bit.ly/3ZBjE90
Sagan C 1973 *The Cosmic Connection* (Hodder & Stoughton)
Sagan C 1980 *Cosmos* (Abacus)
Schrope M 2001 *Nature* **412** 672
Spudis P 2001 *Earth Moon Planets* **87** 159
SSERVI 2023 go.nasa.gov/3tcHewR



4 Earth and the Moon, as seen from the uncrewed Artemis I spacecraft in November 2022. Note how small the Earth looks from just beyond the Moon. The author believes that this perspective carries with it important social and political implications (NASA)