Acta Astronautica ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at SciVerse ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

Searching for alien artifacts on the moon

P.C.W. Davies [a,*], R.V. Wagner [b]

[a] Beyond Center for Fundamental Concepts in Science at Arizona State University, PO Box 871504 Tempe, AZ 85287, USA
[b] School of Earth and Space Exploration Lunar Recon Oribiter Sci Ops Cn, Arizona State University, Tempe, AZ, 85287, USA

ARTICLE INFO

Article history:
Received 5 March 2011
Received in revised form
7 October 2011
Accepted 29 October 2011

Keywords:
SETI
Lunar reconnaissance orbiter
Extraterrestrial technology
Nuclear waste
Lava tubes
Regolith

ABSTRACT

The Search for Extraterrestrial Intelligence (SETI) has a low probability of success, but it would have a high impact if successful. Therefore it makes sense to widen the search as much as possible within the confines of the modest budget and limited resources currently available. To date, SETI has been dominated by the paradigm of seeking deliberately beamed radio messages.

However, indirect evidence for extraterrestrial intelligence could come from any incontrovertible signatures of non-human technology. Existing searchable databases from astronomy, biology, earth and planetary sciences all offer low-cost opportunities to seek a footprint of extraterrestrial technology. In this paper we take as a case study one particular new and rapidly-expanding database: the photographic mapping of the Moon's surface by the Lunar Reconnaissance Orbiter (LRO) to 0.5 m resolution. Although there is only a tiny probability that alien technology would have left traces on the moon in the form of an artifact or surface modification of lunar features, this location has the virtue of being close, and of preserving traces for an immense duration.

Systematic scrutiny of the LRO photographic images is being routinely conducted anyway for planetary science purposes, and this program could readily be expanded and outsourced at little extra cost to accommodate SETI goals, after the fashion of the SETI@home and Galaxy Zoo projects.

Published by Elsevier Ltd.

1. Background

In 2010 the Search for Extraterrestrial Intelligence (SETI) was 50 years old, and the anniversary provided an appropriate opportunity to take stock. In particular, there have been calls to widen the search by considering not just purposefully-directed radio messages, but the most general signatures of intelligence [1]. Alien intelligence, if it exists, or has existed, might have endured for a very long duration, measured in millions, tens or hundreds of millions or even (in principle) billions of years, and will almost certainly be dominated by post-biological intelligent systems [1,2]. Thus it may lie far beyond human capacity to meaningfully extrapolate regarding its specific characteristics. If we therefore have no fixed idea what to look for, it makes sense to search all available and emerging databases for "artificiality," whether deliberate (as in a message) or inadvertent (as in environmental impact). We argue that the criteria for searching a database should be primarily tied to cost rather than plausibility. If it costs little to scan data for signs of intelligent manipulation [3], little is lost in doing so, even though the probability of detecting alien technology at work may be exceedingly low. A good example, already discussed in the literature [4,5], is genomic SETI—the "message-in-a-bottle" scenario in which an extraterrestrial civilization long ago uploaded a message into the DNA of some terrestrial organisms, either robotically or using viral vectors. Genome sequencing is taking place on a grand scale anyway, the results freely available

* Corresponding author.
E-mail address: deepthought@asu.edu (P.C.W. Davies).

0094-5765/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.actaastro.2011.10.022

on the internet, and it would cost almost nothing to search the genomic database using a simple algorithm to seek out signs of intelligent manipulation.

In this paper we discuss a new database resource: the photographic mapping of the lunar surface to a resolution of 0.5 m, currently being conducted by the Lunar Reconnaissance Orbiter (LRO). (For a review of the mission in general, see Chin et al. [6], and of the camera system in particular, see Robinson et al. [7]). A persistent science fiction theme is that of an alien artifact left on the moon's surface long ago (for example, Clarke [8]). Such an artifact might originate in several ways, for example, discarded material from an alien expedition or mining operation, instrumentation deliberately installed to monitor Earth, or a dormant probe awaiting contact (a variant on the message-in-a-bottle theme). Alien technology might also manifest itself in mining or quarrying activity, or even construction work, traces of which might persist even after millions of years. Whatever may be the reason for alien artifacts or engineering processes on the moon, the question that we address here is whether we could in principle detect such a thing using LRO data or similar foreseeable surveys.

The moon has several factors in its favor as a place to search for alien artifacts. First, it is close. Instruments based on Earth can observe the surface in reasonably high detail, and instruments on the moon can communicate with Earth at high bandwidths. Second, it is largely unchanging. The only major source of erosion and deposition comes from meteorite impacts, which occur at a very slow rate (the seismometer on Apollo 12 detected only one grapefruit-sized impactor a month within a 350 km radius). The process of 'gardening,' whereby continual disruption of the lunar surface by impacts leads to eventual burial, has been studied in the context of locating terrestrial meteorites on the moon [9]. Calculations indicate that it could take hundreds of millions of years for an object a few tens of meters across to vanish by this process beneath the dust and regolith [10,11]. However, gardening also serves to re-expose buried objects over a long period of time. Third, the moon is tectonically inactive, so any activity caused by an artifact (heat, strong magnetic field, radioactivity, etc.) will show up clearly, rather than being hidden by other processes such as might occur on Earth. Thus any messages or traces of technological activity left on the moon will likely still be around today, and should be possible to locate without the vast expense that would go into searching more distant bodies, such as Mars. The question, then, is what forms these artifacts might take, and why they might have been left.

There are many conceivable reasons that aliens would leave artifacts on the moon, including some that humans may not even be able to guess at. If for the sake of argument we assume an alien species with roughly human-like reasoning and motivation, there are four main classes of artifacts or technological modifications that we should consider

1) *Messages.* These are artifacts specifically designed to be found and interpreted by an intelligent species that developed on Earth.
2) *Scientific instruments.* These are observational devices sent across interstellar space as robotic probes, or left behind by an alien expedition or colonization wave, to record data, perhaps about the development of life on Earth, over a long period of time, and may or may not still be active.
3) *Trash.* Objects left behind by an alien expedition or colonization wave, without any regard to whether or not they survived intact. These could range from landing stages of spacecraft to spent radiogenic or other power sources.
4) *Geo-engineering structures.* Not artifacts per se, but changes to the moon's surface caused by mining, quarrying or construction activities.

A key issue is when such a probe might have been sent, or a visitation may have taken place, because that will affect the detectability of any traces. Studies of extra-solar planets suggest that earthlike planets may be common in the galaxy [12]. The galaxy is about 13 billion years old, but the solar system formed only about 4.5 billion years ago. If we restrict attention to carbon-based life, then the probability for life to emerge will slowly rise as a function of the availability of carbon and related elements. An estimate of the age distribution of terrestrial planets has been given by Lineweaver [13]. Of course, we have no idea what the absolute probability is for life to arise on a terrestrial-type planet once it exists. It could be very rare [14,15], but for the purposes of this paper we shall adopt the optimistic position of Davis and Lineweaver [16] that the probability for abiogenesis it is not exceptionally low, and that there are consequently many planets with life in our galaxy (and others). In spite of the steady increase over time of the relative probability for life to emerge, there is no reason to rule out the possibility that planets with life existed long before Earth formed, and that planets with intelligent life and technological communities existed, and have existed, over astronomical time scales [17,1]. Thus there is no reason to suppose that an alien probe would have been sent to the solar system, or an alien visitation taken place, in the relatively recent past (e.g. within the epoch of human habitation on Earth), as opposed to the very far past. If the solar system were visited, say, two billion years ago, it may be exceedingly difficult to identify any traces of alien technology even on a fairly large scale. If the time scale was, say, one hundred million years, there is more likelihood of us finding traces, but our best hope is if we are dealing with a time scale of a few million years or less.

2. Messages

This is the most attractive possible artifact type to find, as it shows that not only does alien intelligence exist, but that it cares (or cared) about communicating with other intelligent beings, and may even be willing to impart knowledge and wisdom to us. A message would likely be placed where it could be easily located, and might also have some sort of beacon attached, so that orbital instruments would be able to find it even if the message capsule was buried. However, the details of these features can vary widely depending on when the putative aliens

Please cite this article as: P.C.W. Davies, R.V. Wagner, Searching for alien artifacts on the moon, Acta Astronaut. (2011), doi:10.1016/j.actaastro.2011.10.022

visited, and how long they expected the message to need to last.

If aliens (or their probes or robotic surrogates) visited in the last few thousand years, they would know that there was a developing technological society on Earth, and they might leave a simple capsule in or near an existing landmark, such as a large fresh crater like Tycho, perhaps with a radio beacon or a splash of paint to further mark its location. In this case, the message could probably be spotted by orbital photography such as LRO. Messages designed to last only a few million years would probably be similar, although any beacon would need to be detectable through a few centimeters of regolith. However, messages designed for such a timescale might be unlikely unless the aliens could have predicted the eventual rise of technological civilization based merely on the discovery that Earth hosted one or more species of big-brained tool-making animals.

In the case of a message designed to last hundreds of millions of years all bets are off. Over such a time scale, any given point is likely to be hit by a meteorite large enough to destroy artifacts on the surface made out of any known material, so to survive for $>10^8$ years the message would need to be securely buried at depth. Therefore, it would also need a beacon that is detectable through at least several meters of regolith. This could be long-wavelength radio, a strong magnetic field, or (in principle) something more exotic such as a neutrino generator. It could also, of course, involve some form of more advanced technology as yet unknown to us. In any case, there would probably be no visual evidence left on the moon's surface to attract our attention that anything of interest was in the area. However, there might still be a way to narrow the search. The north and south poles are obvious choices for placing messages, but thanks to the moon's tidally-locked orbit, there are other points that can be uniquely pin-pointed over a long period of time, such as the sub-Terran point (the point directly below the Earth) and its antipode, and the centers of the leading and trailing hemispheres in the moon's orbit. One of these might be deliberately chosen as the site of a message in the knowledge that these points would have significance to a scientifically literate terrestrial community. But without any surface features to indicate the presence of a subsurface artifact, detection would have to depend on ground-penetrating radar or deliberate excavations by future manned expeditions.

3. Scientific instruments

These would be nearly as good as an actual message if we found them, as they would not only prove the existence of alien intelligence, they would tell us something about what the beings were interested in, and possibly allow us to communicate with them if they are somehow monitoring the instruments. However, finding instruments would be much harder than finding a message, as the aliens would have no incentive to make an instrument easy to spot. Even a large radio telescope on the far side of the moon (to shield it from potential radio traffic from any future terrestrial technological society) might be just a few tens of meters across. Furthermore, an instrument would likely be coated in lunar dust after a few hundred years, making it had to distinguish from a mundane geological feature. The best way to identify an active instrument would probably be to look for signs of its power source. Solar panels, if kept clean enough to keep the instrument powered, would probably appear as large black geometric shapes. Radiogenic sources would likely produce detectable gamma radiation, as there is little incentive for the aliens to go to the effort of shielding the reactor. More exotic power sources might also produce detectable radiation, although we cannot currently predict what these might be, so there is no good way to actively search for them.

Of the above, solar is the easiest to find with current data, such as from the LRO, and there is an obvious place to look for solar arrays. At the north and south poles, there are regions that are in near-perpetual sunlight, usually very close to permanently-shadowed craters that could be used to hold instruments that require very low temperatures, such as infrared telescopes. Thus, looking at high-resolution images of these areas should reveal whether or not there are alien solar arrays installed. However, there is very good high-resolution coverage of the lunar poles thanks to the LRO NAC camera, and no obvious solar arrays have been found so far.

4. Trash

Any alien expedition that set down on the moon is likely to have left some trash behind, as it is expensive to haul material out of any gravity well, even one as shallow as the moon's. Aliens might not have been as wasteful as the Apollo missions, that left most of the equipment behind, along with half of the landing spacecraft, but they might still have left something. Finding small artifacts such as dropped tools is probably hopeless, but larger structures such as habitat domes or solar arrays might still be visible millions of years later.

One particular form of trash – spent radioactive fuel – is an attractive target. Nuclear waste may contain radionuclides with very long half lives, leaving traces that are detectable for millions of years or even longer. (The Oklo natural nuclear reactor discovered in Gabon, West Africa, went critical about 2 billion years ago, and has been intensively studied; see, for example, Petrov et al. [18]) Any deposits of plutonium, a good nuclear fuel, would stand out as a product of alien technology because the half life of this element is much less than the age of the solar system, so any primordial plutonium on the moon would have decayed long ago. If a nuclear waste dump were found, it should be possible to date both the age of the fuel and the time that it was discarded. Nuclear material left on the surface of the moon would eventually become buried, but for a long time it would still produce a distinctive signature as a radiation source (assuming it was unshielded) that could readily be detected from orbit on a future mission suitably equipped to search for gamma rays. However, it is unlikely that the LRO could assist in searching for nuclear waste, even if it is not

Please cite this article as: P.C.W. Davies, R.V. Wagner, Searching for alien artifacts on the moon, Acta Astronaut. (2011), doi:10.1016/j.actaastro.2011.10.022

buried, given that it would probably be small and inconspicuous.

A good place to look for alien trash is inside one of the lava tubes located in the lunar maria. So far, three large skylights have been discovered by the LRO, each about 100 m across, which might lead down into a subsurface network, and several lunar pits point to a subsurface labyrinth [19]. Lava tubes have been proposed as an ideal location to establish a human base, as they would provide protection from radiation and meteorites; perhaps aliens would come to the same conclusion. Furthermore, the same factors that make lava tubes attractive as a habitat imply that any artifacts left behind would endure almost indefinitely, undamaged and unburied. The downside is that there is no way to really investigate this possibility from orbit, so any confirmation or refutation will require a new robotic or human mission to the surface.

5. Geo-engineering structures

If aliens used lunar material as a resource, they may have carried out mining or quarrying activities, or even have built large structures that could still be detected from photographic surveys. The main difficulty in identifying the scars of major geo-engineering work would be to distinguish them from naturally occurring features. A round open-cast mine, for example, may after some millions of years come to resemble an impact crater or collapsed lava tube at first sight, and only a careful analysis of the topography might reveal signs of artificiality. Excavations with more distinctive topography (spirals, rectangles, etc.) would be more conspicuous. Because we have no idea of the motives, capabilities or agenda of a very advanced alien technological community, we cannot guess what form of surface modification might ensue from an alien presence, even a fleeting one, on the moon. It therefore pays to be as broad as possible when seeking signs of past geo-engineering activity.

6. Seeking artifacts using current data

The best available visible-light imagery of the moon comes from the Narrow Angle Camera (NAC) on the Lunar Reconnaissance Orbiter, which has been orbiting the moon since mid-2009 [7]. It has imaged over 25 percent of the lunar surface at resolutions down to 50 cm/pixel, in a variety of lighting angles. This dataset is so good that several artifacts have in fact already been found, in both the Instrument and Trash categories. However, all of them were created by humans. These artifacts include not only the Apollo landing sites, which are easily identified by the thin dark trails of dust kicked up by the astronauts, but also all of the NASA and Soviet unmanned probes, which, with the exception of the two soviet rovers that left kilometers-long tracks, have nothing to mark their location but their slightly odd-looking shadows, and sometimes a small halo of disturbed dust from the landing rockets. However, in all of these cases, the people who found the artifacts already knew approximately where to look, so they only needed to comb through a few NAC images before they found the lander or rover they were searching for. For alien artifacts, we don't have the luxury of knowing what latitude and longitude to target, so we need to study the entire surface. Focusing on some regions of special geological interest would help, but there would still be hundreds of images to look through.

The huge amount of data from the NAC is both its best feature and the greatest obstacle to using it as a resource for seeking alien artifacts. Each NAC frame is 500 megapixels, and takes between 30 min and an hour to analyze in sufficient detail to be able to locate artifacts such as the Surveyor landers. So far more than 340,000 NAC images have been released to the public, and that number will likely approach 1,000,000 by the time it has achieved 100 percent coverage. From these numbers, it is obvious that a manual search by a small team is hopeless. It might be possible to scan the entire dataset by "crowdsourcing" the work to a few tens of thousands of people over the Internet, and in fact this approach is being taken by the website MoonZoo.org, which is trying to classify as many features on the moon as possible by having people look at a few NAC frames each, and record what they find. The downside to this approach is that with so many people involved, there will be differences in opinion on what is and isn't important. Without a lot of organization and dedication, many images will get skipped and many potentially interesting features overlooked. Nevertheless, this project will doubtless result in some claims of alien artifacts, and one or more of them might conceivably be correct.

An alternative method of searching a large number of images is computer automation. One of us (RW) has written software able to identify simple pits as part of the in-house LRO data analysis program currently being conducted at Arizona State University. This system is able to run through about 200 images per hour. It merely filters the images, identifying the features most likely to be pits, and presents them for a human analyst to decide whether the features are interesting or not. However, it does allow a human to search thousands of images each day for a specific feature.

Although automated searching offers great promise, a major obstacle is that computer software can only search for specific features that have been programmed in advance. Thus, for example, crater detection algorithms are now fairly sophisticated [20,21]. However, when it comes to "artificiality" there is inevitably an element of judgment involved at the outset as to what would constitute evidence. Certain features, such as regular geometrical shapes or sharp angles, are relatively easy to deal with, but more subtle traces, for example, partially buried smooth surfaces or quarry boundaries, offer a greater challenge. As any forensic scientist can attest, physical evidence for intervention by an intelligent agent may be very subtle and require multiple lines of evidence and a lifetime of experience for it to become apparent. Because we have no clear idea of what to look for, the task is doubly difficult. Nevertheless, the NAC data is being gathered anyway, and the cost of searching this amazing resource, either by eye or by software, is relatively modest.

Please cite this article as: P.C.W. Davies, R.V. Wagner, Searching for alien artifacts on the moon, Acta Astronaut. (2011), doi:10.1016/j.actaastro.2011.10.022

7. Conclusion

The moon is an excellent place to store artifacts or discard trash, both human and alien, but locating them presents a challenge. It may be possible to narrow down the search area through careful reasoning, but that requires making assumptions about alien motives, technology and psychology, which may be completely wrong. Ideally, humans will look at high-resolution images of the entire moon, searching for anything unusual. The LRO Laboratory at Arizona State University currently employs a small pool of students and faculty to search the NAC images for interesting features, but the photographic data is accumulating far faster than the students' ability to keep up. It would take a very long time at the current rate to survey the entire lunar surface, so some form of automation is needed. Automation, however, currently requires assumptions about what an artifact will look like, which brings us back to the problem of trying to guess an alien agenda. In the near term the best strategy may be to recruit large numbers of amateur enthusiasts, after the fashion of the Galaxy Zoo project [22], to scrutinize the NAC images by eye as they become publicly available.

We acknowledge that the likelihood of finding any trace of alien activity on the moon is exceedingly low. Even if the moon has been visited by a probe or expedition there is no reason to suppose that this would have happened in the recent past, so we may be dealing with time scales measured in tens of millions of years or longer. In spite of the highly preserving environment of the lunar surface, the problems of identifying very ancient remains or traces of alien activity are formidable. But these problems are not insurmountable, and the strategies we have outlined in this paper offer a low-cost approach to what would undoubtedly be one of the greatest scientific discoveries of all time.

Acknowledgments

We should like to thank Chris McKay and Mark Robinson for helpful discussions.

References

[1] P.C.W. Davies, The Eerie Silence: Renewing Our Search for Alien Intelligence, Houghton Mifflin Harcourt, NY, USA, 2010.
[2] S. Shostak, Confessions of an Alien Hunter: a scientist's search for extraterrestrial intelligence, National Geographic, 2009.
[3] R.A. Freitas, The search for extraterrestrial artifacts (SETA), J. Brit. Inter. Soc. 36 (1983) 501–506.
[4] H. Yokoo, T. Oshima, Is bacteriophage phi X174 DNA a message from an extraterrestrial intelligence? Icarus 38 (1979) 148–153.
[5] P.C.W. Davies, Do we have to spell it out? New Scientist 183 (2004) 30.
[6] G. Chin, S. Brylow, M. Foote, J. Garvin, J. Kasper, J. Keller, M. Litvak, I. Mitrofanov, D. Paige, K. Raney, M. Robinson, A. Sanin, D. Smith, H. Spence, P. Spudis, S. Stern, M. Zuber, Lunar reconnaissance orbiter overview: the instrument suite and mission, Space Sci. Rev. 129 (2007) 391–419.
[7] M.S. Robinson, S.M. Brylow, M. Tschimmel, D. Humm, S.J. Lawrence, P.C. Thomas, B.W. Denevi, E. Bowman-Cisneros, J. Zerr, M.A. Ravine, M.A. Caplinger, F.T. Ghaemi, J.A. Schaffner, M.C. Malin, P. Mahanti, A. Bartels, J. Anderson, T.N. Tran, E.M. Eliason, A.S. McEwen, E. Turtle, B.L. Jolliff, H. Hiesinger, Lunar reconnaissance orbiter camera (LROC) instrument overview, Space Sci. Rev. 150 (2010) 81–124.
[8] A.C. Clarke, 2001: A Space Odyssey, Penguin, London, 1965.
[9] I.A. Crawford, E.C. Baldwin, E.A. Taylor, J.A. Bailey, K. Tsembelis, On the survivability and detectability of terrestrial meteorites on the moon, Astrobiology 8 (2) (2008) 242–252.
[10] C.T. Pillinger, Solar-wind exposure effects in the lunar soil, Rep. Prog. Phys. 42 (1979) 897–961.
[11] A. Tsuchiyama, et al., Three-dimensional structure of Hayabusa samples: origin and evolution of Itokawa regolith, Science 333 (6046) (2011) 1125–1128.
[12] S. Arbesman, G. Laughlin, A scientometric prediction of the discovery of the first potentially habitable planet with a mass similar to Earth, PLoS ONE 5 (10) (2010) e13061.
[13] C.H. Lineweaver, The galactic habitable zone and the age distribution of complex life in the Milky Way, Icarus 151 (2001) 307–313.
[14] B. Carter, The anthropic principle and the implications for biological evolution, Philos. Tr. R Soc. 310 (1983) 347–363.
[15] D.S. Spiegel, M. Turner, Life might be rare despite its early emergence on Earth: a Bayesian analysis of the probability of abiogenesis, arXiv, 1107.3835, 2011.
[16] T.M. Davis, C.H. Lineweaver, Does the rapid appearance of life on Earth suggest that life is common in the universe? Astrobiology 2 (3) (2002) 293–304.
[17] M. Livio, How rare are extraterrestrial civilizations and when did they emerge? Astrophys. J. 511 (1999) 429–431.
[18] Yu.V. Petrov, A.I. Nazarov, M.S. Onegin, V.Yu. Petrov, E.G. Sakhnovsky, Natural nuclear reactor at Oklo and variation of fundamental constants: computation of neutronics of a fresh core, Phys. Rev. C 74 (2006) 1–17.
[19] J.W. Ashley, A.K. Boyd, H. Hiesinger, M.S. Robinson, T. Tran, C.H. van der Bogert, R.V. Wagner, Lunar pits: sublunarean voids and the nature of mare emplacement, Lunar Planet. Sci. 42 (2011) 2584–2585.
[20] G. Salamunićcar, S. Lončarić, Open framework for objective evaluation of crater detection algorithms with first test-field subsystem based on MOLA data, Adv. Space Res. 42 (1) (2008) 6–19.
[21] E.R. Urbach, T.F. Stepinski, Automatic detection of sub-km craters in high resolution planetary images, Planet. Space Sci. 57 (7) (2009) 880–887.
[22] S.P. Bamford, et al., Galaxy zoo: the dependence of morphology and colour on environment, Mon. Not. R. Astron. Soc. 393 (2009) 1324–1352.

Paul Davies is Director of the Beyond Center for Fundamental Concepts in Science at Arizona State University. His research spans cosmology, astrobiology and theoretical physics. He has made important contributions to quantum field theory in curved spacetime, with applications to inflationary cosmology and black holes. He was among the first to champion the possibility that microbial life could be transferred between Mars and Earth in impact ejecta. He also runs a major cancer research program funded by the National Cancer Institute. He is the author of 28 books, including most recently The Eerie Silence: Renewing Our Search for Alien Intelligence.

Robert Wagner is an undergraduate student at Arizona State University majoring in Earth and Space Exploration. He works as a Research Technician in the Lunar Reconnaissance Orbiter Science Operations Center, where he is responsible for image evaluation and assessment. He has broad expertise in earth sciences and computing.