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# Why send humans into space? Science and non-science motivations for human space flight

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A B S T R A C T

Although humans have been going into space for more than 50 years, it is still a fair question to ask why, given the expense and the risk. While there are scientific returns from having humans in space, it is often argued that science could be better served without a human presence. Here, I make a case for having a human presence in space to conduct a variety of scientific investigations, most notably those in the life sciences that involve humans as test subjects. There are aspects of the results from such investigations, and from the particular characteristics that make them especially challenging to perform, that are often overlooked. Non-scientific rationales for a human presence in space are also discussed briefly. Overall, when the relevance of the space sciences as a whole is considered, human space research has as much justification as other forms of space science, and in the end it is the quest for understanding our place in the universe that drives all of these scientific ventures.

## 1. Introduction

The question arises from time to time as to why we – as a nation, a group of nations, or a species – should send people into space. It is dangerous and expensive, and the case might be made that scientific discoveries in space can be better accomplished without human presence. There may be some truth to these claims, but still there are compelling reasons – scientific and otherwise – for maintaining a human presence in space and expanding that presence outward from Earth. Some of these aspects have been presented in an ongoing series in this journal [1–3], and the dialog in those articles covers many of the key points for and against human space flight. Admittedly there are points that argue against human space flight. Exploration (depending on how it is defined) and inspiration can be achieved in other ways, and while a valid role for government might be to provide inspiration to the population, it is debatable that human space flight is the most cost-effective means to do so. This is a worthwhile debate because human space flight is expensive, in terms of many different resources. Nevertheless I provide some new facets to some of the common justifications for human space flight, and propose a few that have not been discussed previously in any detail.

Before recounting some of these reasons, it should be recognized that it is not self-evidently *necessary* to send humans into space. In fact it is not *necessary* to do any research in space at all. The varieties of space-related research represent a continuum, encompassing planetary probes, land- and space-based observatories covering multiple resolutions and wavelengths, and human missions to low-earth orbit and beyond. There is sometimes a desire – especially in the physical-sciences community – to see human spaceflight research as a unique entity apart from the broader scope of the space sciences. But it should be recognized that there is no self-evident requirement for any of this research at all – anywhere along the continuum. (Given this, there should be a rigorous and transparent discussion in the scientific community of the varieties of science supported by space flight, their outcomes, and their value to society.)

(In the following, I omit discussion of conventional "spinoffs," which are widely promoted and consist mainly of technology developments. While these are significant and have had great impact (remote monitoring, clean rooms, etc.), they generally do not require a human presence in space.)

## 2. Science benefits

Scientific research is often offered as a compelling reason to send people into space. It is generally regarded as worth the risk and the danger. As stated by one of the astronauts who serviced the Hubble Space Telescope (HST) multiple times [4]: "I can say without hesitation that traveling to space to upgrade the instruments and ensure the future of the Hubble Space Telescope was worth the potential risk to my life."

But this scientific rationale for human presence is only partially convincing. Robotic missions and automated probes have provided incredible return in the physical sciences, as even the most cursory

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perusal will show: the Mars rovers, Pioneer and Voyager probes, and a myriad of others over many decades. The physical sciences (especially astronomy) have far outpaced the life sciences in discoveries from space research (10,000 papers and counting just from the Hubble Space Telescope [5]). These missions typically do not require human presence in space, and in fact the local environmental contamination generated by humans can be detrimental to the operation of space-based observatories. “Within the research community, it is almost an article of faith that robotic missions are always the best way of doing science in space.” [6].

Nevertheless, humans have been critical in the repair and improvement of the Hubble Space Telescope, with five servicing missions carried out by astronauts. Some of these missions involved on-orbit manipulations that were not intended to be performed when HST was designed, and in at least one case a human was called on to apply more force to remove an intransigent handrail than would conceivably have been granted to a remote manipulator. Human ability and judgment in these cases are directly responsible for the continued scientific productivity of Hubble [7].

Then there are the life sciences, where interaction with biological samples is typically needed. This could include dissections, fixatives, and experimental manipulations and observations of various kinds. While it might be argued that plant and cell investigations could be accomplished under automation, a stronger case can be made that animal investigations benefit from the intervention of a human operator, for at least two reasons. First, in an unusual and stressful environment such as space flight, animals might be more comfortable and exhibit more natural behavior in the presence of a familiar human. Second, given the persistent habit of biological organisms to generate unexpected responses in unusual situations, it would be wise to have an experienced observer on hand to document anything out of the ordinary. (Of course due care must be taken that the human presence does not contaminate the experimental ecosystem, for example via shared microbiota.)

This brings us to human research: research on human physiology, behavior, and performance in space. This can be in support of space exploration, or for fundamental scientific value. It has been suggested that, in purely scientific terms, the return on investment in human research in space cannot be justified [2,8], in comparison with the scientific return from other ventures such as HST. With regard to standard measures of scientific productivity, and contributions to basic knowledge, it is hard to argue this point. However, there are several additional factors to consider when it comes to judging the value of human research. It must be recognized, first, that sending humans into space is not the same as doing human-subjects research in space; the former has been done for more than 50 years, but the latter is relatively new and still evolving. This type of research is, furthermore, very difficult, for a number of reasons. First, the experimental conditions are poorly controlled. Given the operational pace of space missions, and the fact that the astronauts themselves serve as test operators as well as subjects, it is difficult or impossible to control (or even determine) what these subjects do immediately preceding a given experiment, what medications they might be taking, or what their sleep and food status might be. This is because operational concerns currently take precedence over science, which is natural given the high cost of human space flight and the great number of different tasks demanded of astronauts. Second, the number of subjects available for any single experiment is usually small for even the most ambitious experiments, with few repetitions and therefore small numbers of data points. This is due to the fact that space flight is still an expensive venture available to only a select few, and so the population from which to select research subjects is small to begin with. Finally, logistical issues make it difficult to change experiments in light of new results, data return can be slow, and training and upload considerations require finalizing experiment details far in advance. All of these differ from how the best science is typically performed in the lab.

Therefore we can say that perhaps the lower science return from research on humans in space (relative to that of the other space sciences) is because this research has not yet been performed in a manner that is analogous to that of the best laboratory-based science on Earth. We have yet to send an astronaut into space, for an extended period of time, with the sole purpose of performing biological and physiological experiments, noting anomalies, and exploring new leads. This is how laboratory science is generally performed in this field, but we have yet to have the resources to do it this way in space. A reasonable case can be made that this research community should be congratulated for performing as well as it has, given these many complications.

It has further been argued that there is no reason to do research to understand human adaptation and performance in space if we didn't send humans into space in the first place. In other words, there is no inherent scientific benefit to studying humans in space [9]. This is sometimes extrapolated to make the case that, since non-human missions in areas other than physiology can provide better science return, there is no need to send people into space at all [2]. The argument falters on at least two key points. First, there are interesting and important things in human physiology that have been learned, if not solely due to space flight then certainly furthered by it [3]. (Examples include counterintuitive values of central venous pressure in 0 g, and the role of gravity in gas mixing in the lung.) Second, human spaceflight, due to its inherent complexity and the need to account for a myriad of interconnected factors [10], can be a driver to encourage broad-based interdisciplinary approaches to problems in human health on Earth. If one of the major insights gained from space exploration overall is the special character and apparent fragility of “spaceship Earth,” then the associated awareness of all of the interconnected factors that relate to human health and well-being is also a legitimate outcome. In this sense, human space flight focuses the mind: when a small number of people is placed in a confined, closed, and stressful environment for a long period of time, synergies and interconnections between physiological, psychological, and environmental subsystems cannot be ignored [11,12]. It is typical today in most research institutions to study these aspects in a highly discipline-specific manner; properly addressing the myriad factors relevant to successful human space flight can help to break down these disciplinary barriers. (Recognition of a similar shortcoming and need for an integrative approach in patient care is one factor that led to the “generalist specialist” model of hospitalist [13].) This aspect of human space flight has not been taken advantage of to its fullest extent, and it can be done in the context of other space flight activities such as lunar and Martian exploration. Not only are the shared and isolated environments of space habitats ideal to explore closed ecosystems, but the small sample sizes inherent in space life-sciences research can lead to statistical innovations relevant to rare diseases and longitudinal studies on Earth.

More to the point, however, is an implicit assumption that seems to underlie many discussions of these issues: discoveries in the physical space-sciences are more important than those in the space life-sciences. It is worth examining this assumption. It is not inherently obvious that, for example, knowing the composition of galaxies is more important than understanding how humans respond to altered gravity and other stressors of space flight. If it is to be argued that understanding “the universe” in astronomical terms is important “just because it's inherently interesting,” the same reasoning can be applied to humans in space – and maybe even more so, since a part of “understanding our place in the universe” (to which astronomy contributes) is understanding our place as human organisms in that universe [14] (which includes how we fare off the planet, how we might populate other bodies, etc.). As one example of this form of “astrobiology,” consider the recently discovered problem of persistent changes in vision in astronauts on long-duration missions to ISS [15]. This problem appears to arise from the head-ward redistribution of body fluids in space due to the lack of a net gravitoinertial force vector, which in turn produces a chronic increase in intracranial pressure, causing cerebrospinal fluid to impinge on the back of the eye and change its shape. We would not know about this possible effect of prolonged fluid shift if the vision problems had not been reported by astronauts themselves (another case for having the human observer). What does this tell us about life that might exist elsewhere, in either reduced or increased gravity levels relative to Earth? What evolutionary selections might have occurred in different planetary settings to avoid this issue, which might have not only an effect on vision but possibly on neural function if maintained for longer durations? If we wish to consider not only the possibility of life beyond Earth but what forms it might take, here is an example of how human space flight can contribute to that discussion. This is especially powerful when combined with Earth-based analog facilities, which mimic some of the effects of space flight (isolation, confinement, extended fluid shift and lack of g loading); examining the differential effects between space flight and analogs helps to understand better the selective pressure of gravity specifically.

To return once more to the question raised above: who is to say that any space research needs to be done at all? Who says that we have to study the stars and the planets? We do not have to send humans into space, it is true. Yet it seems to be a tacit assumption that there is more benefit to understanding planetary atmospheres or star formation than to understanding human responses to space. Both facets, to be honest, are relatively meaningless to most people in practical terms. However, both expand the mind and challenge the spirit, and both help us to understand the universe around us. The latter is clearly the case for astronomy and astrophysics, but it is also true for humans in space. This is not at all to argue against any specific form of space research, but to point out that non-human exploration of space does not have as strong a claim to superiority as some would like to believe. Human space flight might be dismissed as a meaningless and absurd romantic notion. But then so, to many people, is trying to identify the structure of the universe and its genesis. The selection by scientists of an area in which to perform their research is not as dispassionate as many would have us believe [16]. What drives them to investigate one thing versus another is often hard to explain, and it is likely that most scientists are driven by the pure interest and joy of discovery than by any explicit cost-benefit analysis, and in this sense as well the biology of space flight is an interesting and valid scientific pursuit.

## 3. Why not robots?

Another oft-heard argument is that robotic missions alone can perform as well, or better, than humans. A compelling case might be made that, since space is so unique, we don't know what to look for (what scientific observations to make). If only automated systems are sent, the ability to observe the unexpected is limited – automated systems can be very sophisticated but to a great extent they look for what they've been designed to look for. Humans (properly trained scientific observers) can notice and respond to the unexpected, which is often more important than what is expected (serendipitous discoveries). They can also make repairs and modifications when necessary, just as in a lab on Earth [17]. An example is the famous “Earthrise” photograph taken by the crew of Apollo 8 which has inspired generations of people and is credited with helping to start the environmental movement. Although the crew was briefed on this possible photographic opportunity, it was not a specific part of the flight plan, and only acute observation and quick action on their part enabled the acquisition of that picture [18,19].

Another way to think about the automation aspect is to consider this question: if you are a researcher, would you trust a robot in your lab instead of a human? Research is by definition an exploration of the unknown, and in this endeavor humans still make the best lab scientists. That the operational pace of current missions is not conducive to making and pursuing unexpected observations does not obviate the basis of this justification. It is well-defined interactions between humans and robots, using the best attributes of both, that will provide the best scientific return. Issues of data bandwidth and communications delay argue for having humans in the vicinity of any exploration venue.

## 4. Practical non-science benefits

There are also tangible reasons to have humans in space that do not involve science *per se* which accrue naturally from the magnitude of the endeavor. Governmental, institutional, and international arrangements are put into place to support human space flight, providing a model for broader interactions. The engineering and intellectual (including research) infrastructure that is needed often provides the basis for other aspects of space exploration that do not involve humans. A crucial aspect is that political and public support for human space flight can often be leveraged for space flight more broadly [20]. The American Apollo program to land men on the moon was a non-military battle in the Cold War with the Soviet Union; science *per se* was never a major justification. Nevertheless, NASA took the opportunity of strong political and public support for Apollo to build a national infrastructure that has supported space science (of all types) and exploration for decades, and that has reached far beyond the lunar landing. (Much of this was spearheaded by NASA Administrator James Webb, after whom the James Webb Space Telescope is now appropriately named) [21].

## 5. Non-science intangible benefits

Scientific and tangible benefits are not the only reasons to send humans into space. Human space flight is difficult and challenging. Therefore it serves to measure “the best of our abilities” (as stated by President Kennedy in his support of the Apollo Program). It displays the capabilities of a nation (or culture or ideology or partnership), not just in technology but also in how major resources can be organized to address large complex goals. This was a part of the argument for the Apollo program [22]. Kennedy's early speech is still worth noting: “We choose to go to the Moon in this decade and do the other things, not because they are easy but because they are hard. Because that goal will serve to organize and measure the best of our abilities and skills …” It seems not unreasonable to propose that one legitimate role of a government might be to provide such inspiration to its citizens, and human spaceflight has provided this uniquely in at least a few cases as noted below [3].

Along similar lines, one of the very real products of the Apollo program is the current generation of engineers and scientists who were inspired and motivated by great scientific and technological accomplishments. There might be no Microsoft [23] or Amazon if there were no Apollo. A quote from the founder of the latter is especially to the point [24]: “Millions of people were inspired by the Apollo Program. I was five years old when I watched Apollo 11 unfold on television, and without any doubt it was a big contributor to my passions for science, engineering, and exploration.” Thus, spinoffs from space are not just technological but include a population that is inspired to acquire education and to solve hard problems. This educated populace generates new answers for earthly problems. One might counter that this inspiration does not require human spaceflight, but those entrepreneurs mentioned here have specifically attributed their motivations and aspirations to the Apollo program of human space flight. Human space flight is inspiring in a unique way.

## 6. Bottom line

A primary justification for human space flight would almost certainly be based on the science to be performed and the discoveries to be made. And, as noted, there is such a case to be made. But one could ask, more generally, why science in the realm of space is of any value at all. This type of scientific pursuit could be in one of two categories. The first is as a basis for a useful technology, such as in support of human space exploration. Clearly, if it is accepted that humans must go into space (for any number of reasons), then there must be scientific research to enable their health and performance. There is little disagreement on this. The second scientific category would be as a means of identifying and elucidating basic mechanisms and understanding how the universe works. This is a primary justification for the other space sciences. As applied to justify human presence in space, there may be room for improvement in practice, but this is a valid purpose for human research in space.

But more simply and fundamentally, human space flight is a form of exploration. It *expands the human experience* [25]. Robots and automated machines can be sent to perform many tasks, but it is not the same experience [17,20]. The increasing interest in passengers willing to pay significant sums for short flights with commercial suborbital operators also attests to the human desire to *be there* – to have an experience that will be almost unique and hopefully personally meaningful. In all realms of endeavor we applaud the human element.

Those in the larger science community sometimes take the position that human space flight detracts from "real" space exploration and science, possibly based on a belief that the funds allocated to human space flight would go to these other space sciences if human space flight were eliminated. This is a false dichotomy. For reasons just stated, it is quite possible that without human space flight there might not be public support for any space flight at all. The *political reality* is that space exploration is not just a science program; science is not necessarily the main driver or even the highest priority. This is a national (and international) effort, and therefore many other considerations legitimately come into play. Space flight in all its manifestations is a form of exploration. By "exploration" most space scientists seem to think of *scientific exploration* but that is only one aspect. There is also exploration in the sense of pushing limits and expanding boundaries. For some people, this is justification enough for human space flight, but there is indeed more as I have endeavored to show here.

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