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

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ABSTRACT

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