# More machine than human?

*The End of Astronauts: Why Robots Are the Future of Exploration, Donald Goldsmith and Martin Rees, Harvard U. Press, 2022, $25.95*

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*Physics Today* **76** (4), 50–51 (2023);
https://doi.org/10.1063/PT.3.5220

sciences, had been weakened by defeat in World War I and was subject to an international scientific boycott by the former Allies (see the article by Dirk van Delft, PHYSICS TODAY, April 2022, page 30). Denmark had been neutral during the war and retained ties with Germany, which lent an air of impartiality to Copenhagen. It became a site where scientists from both sides could meet and exchange ideas.

The unstable economic situation in Germany and the Austro-Hungarian successor states also aided Bohr's institute. Not only did Bohr attract postdoctoral scholars from the newly independent countries of Austria, Hungary, and Poland who might previously have studied in Germany, but economically stable Copenhagen began to look more appealing to young German scholars, including Heisenberg, Friedrich Hund, and Pascual Jordan, who would never have left home before the war. All three worked under Bohr via fellowships provided by the US Rockefeller Foundation.

As the subtitle suggests, *The Copenhagen Network* approaches the early years of quantum mechanics from the perspective of postdoctoral scholars like Heisenberg, Hund, Jordan, and Pauli. I do have to quibble with Kojevnikov's ahistorical use of the word "postdoctoral," which was employed only seldomly in the 1920s or 1930s. But his decision to center the book on the early-career experience is innovative. Kojevnikov rightly points out that senior scholars with permanent positions, like Bohr and Max Born, held incredible power over the quantum postdocs, who made crucial breakthroughs while holding temporary positions with minimal job security. (Sound familiar?)

I suspect the main reason the mythologized version of quantum history remains persistent is because many of the major players in the revolution—including Bohr, Heisenberg, Born, Dirac, and Jordan—remained active into the 1960s and 1970s. As elder statesmen of physics, they propagated a burnished version of the quantum origin story that became part of the discipline's collective memory. But hagiography isn't history. *The Copenhagen Network* admirably depicts the quantum revolution as the messy, uncertain reality it was.

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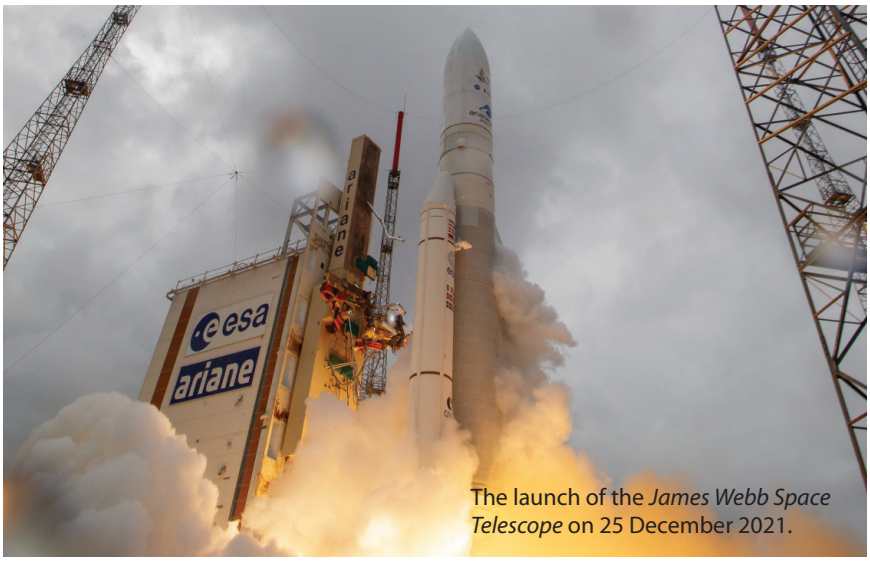


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The launch of the *James Webb Space Telescope* on 25 December 2021.

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The past two years have seen the start of a new era in spaceflight: On 25 December 2021, the *James Webb Space Telescope* (*JWST*) was launched, and on 11 December 2022, the *Orion* spacecraft splashed down in the Pacific Ocean after its voyage to the Moon. The two missions highlight the tension between science and exploration that forms the subject of *The End of Astronauts: Why Robots Are the Future of Exploration*. The purely robotic *JWST* was launched without any assistance from the astronauts who were so critical to the success of its predecessor, the *Hubble Space Telescope*. The *Orion* spacecraft, on the other hand, marks NASA's renewed commitment to human exploration beyond low Earth orbit.

Authored by Donald Goldsmith, an astronomer and science writer (and, in the interest of full disclosure, a longtime friend of mine), and Martin Rees, the former UK astronomer royal, *The End of Astronauts* argues that almost all space science—including the exploration of the Moon, Mars, and beyond—should be carried out only by robotic explorers. While acknowledging the deep, vicarious exhilaration of watching flesh-and-blood ambassadors explore other worlds, Goldsmith and Rees argue that robotic probes, orbiters, landers, and even helicopters have brought us startling images and detailed knowledge of Mars, Jupiter, Saturn, Pluto, and other objects in our solar system at modest cost when compared with crewed spaceflight and at no risk to human life. More powerful artificial intelligence, improved mechanical dexterity, and expanded remote sensing, they assert, will inexorably tilt the cost–benefit ratio even further in favor of robotic exploration.

## The End of Astronauts

### Why Robots Are the Future of Exploration

**Donald Goldsmith and Martin Rees**
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In nine chapters, the authors address the human imperative to explore regions ever farther from our home planet: low Earth orbit, where crewed space stations and *Hubble* repair missions occur; the Moon, which is a site of past glories but also ambitious future plans that include Antarctic-style habitats and harvesting helium-3 for unlimited fusion energy; Mars, which holds an inevitable attraction because of its size, its subsurface ice, its potential fossil traces of former life, and the dream to colonize or even terraform it for human habitation; metal-rich asteroids, which could be mined for a trillionaire's ransom of rare elements; and interstellar space, where science-fiction dreams of space colonies and multigenerational spaceships remain captivating.

Those aspirations are brought back to Earth with sobering discussions of radiation dosages in deep space and the relative costs of human versus robotic exploration. (The former bests the latter by a whopping 50 to 1.) Finally, a chapter on space law points out the importance of carrying out those endeavors in accordance with norms for environmental stewardship and international treaties on extraterrestrial governance, none of which, the authors point out, have spacefaring nations yet agreed on.

A number of themes underlie the author's arguments: that the rapid evolution of robotic and artificial-intelligence technology will supplant the need for human senses, strength, mobility, and judgment; that putting humans into space for long trips to Mars greatly increases costs while creating unnecessary risk; and that humans might pollute the very Martian environments where we wish to search for evidence of life.

As a child of the 1960s, I sat in darkened school gymnasiums watching Mercury and Gemini liftoffs and splashdowns in black and white. Later, I was awed by *Apollo 8*'s Christmas lunar flyby and proud of humankind's achievement in landing on and returning safely from the Moon. But, despite a nearly successful bid to enter the astronaut program myself in the early 1980s, I became bored with the slow pace of human expeditions as compared with the dramatic progress in robotic space exploration. The space shuttle operated in the cosmic equivalent of Earth's littoral waters, where it built the International Space Station, an artificial island just 250 miles offshore. In the meantime, the dark black of space and the distant shores of the Moon and Mars beckoned, unvisited.

In my 40-year career as an astronomer, I've worked on a succession of space telescopes of ever-greater power, culminating in the successful commissioning of the *JWST*. During that time, other colleagues studied Earth, Mars, and the outer planets with ever-more powerful capabilities and achieved astounding results. Children today are more likely to be awed by pictures from Mars rovers, the *New Horizons* spacecraft, and the *JWST* than by images from the International Space Station. In recognition of space science's growing importance, NASA increased its funding from about 15% of the agency's budget in the mid 1990s to over 30% today.

Will those trends change as the Artemis program proceeds and humans once again explore the Moon and begin training to go to Mars? Will the vision and drive of private space ventures—with their cheaper launch vehicles, commercial motivations, and acceptance of higher levels of risk than national agencies—change the dynamics and economics of human exploration? Will geopolitical competition with China extend to human spaceflight?

Goldsmith and Rees present a strong case that the cost–benefit and cost–risk ratios favoring robots over humans will only grow with time. But not all the reasons why we explore are rational. Strong political forces and more visceral, human desires will likely soon see astronauts on the surface of the Moon and, possibly, Mars.

*Disclaimer: The views expressed in this review do not necessarily represent the views of the Jet Propulsion Laboratory.*

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