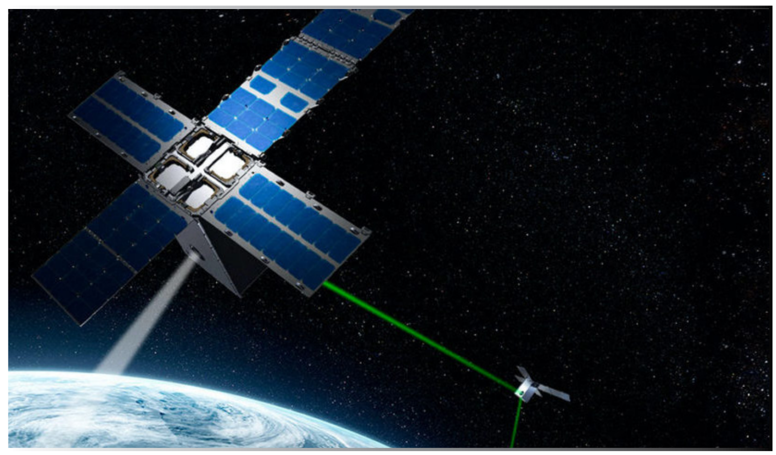
State of Play

LASERCOM KEY TO BUILDING INTERNET IN SPACE

Government and Private Sector Poised to Scale

Decades from now, historians are likely to point out that, in the 23rd year of the 21st century, a couple of U.S. government programs, combined with some major commercial initiatives, had a major role in suddenly expanding the internet into space. They will then telepathically generate, on a virtual chalk board, the letters JADC2 and SDA. And that's where our story starts today.



DOD test laser communication terminal in LEO. Credit: Space Development Agency.

Joint All Domain Command and Control, or JADC2, is a concept developed by the Department of Defense that aims to connect sensors from all branches of the armed forces into a unified network powered by artificial intelligence. A key goal of JADC2 is to connect data collected by various sensors to the shooters in near realtime across all five warfighting domains—land, sea, air, space, and cyberspace. In order to achieve that vision, the Pentagon has charged the Space Development Agency (SDA) with creating a global communications network known as a "transport layer" that will relay information between and among satellites in low Earth orbit (LEO), thereby creating that near realtime communications network for JADC2. To deliver on the JADC2 vision, SDA must create a near realtime communications network that is high-bandwidth, moves at light speed, and is difficult to intercept or jam. That calls for laser communications.

Break-Break—What Is Lasercom and Why Do We Care?

Laser communication systems (also known as optical communications, lasercom, and optical inter-satellite links (OISL) use infrared frequency to transmit information. Lasercom differs from radio waves because the infrared light packs the data into significantly tighter waves, meaning transmissions can send much more data. Lasercom systems have effective bandwidth increases of 10 to 100 times that of today's radio frequency (RF) systems. NASA noted in 2022, "The addition of laser communications to spacecraft is similar to switching from dial-up to high-speed internet." Lasercom systems need less volume, weight, and power than traditional RF systems, and they provide highly secure links that have a low probability of interception. Further, they can be used for both downlinks and high-speed, satellite-to-satellite crosslinks. With the increasing number of satellites crowding LEO space, there is also a limited permissible use of the RF spectrum for communications, a problem avoided by switching to lasercom.

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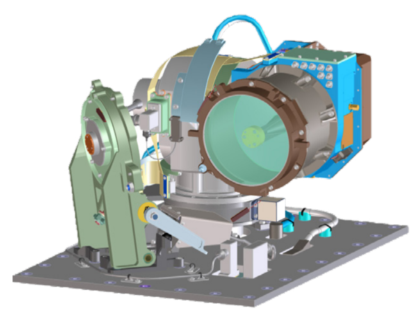


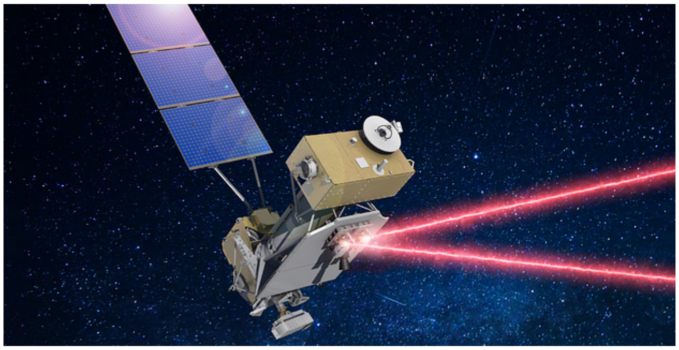
Computer rendering of the LADEE's lunar laser communication demonstration optical module. Credit: NASA.

Further, lasercom links are inherently protected from detection, interception, and interference because of the extremely narrow beamwidth of the laser and the narrow field of view of the receiver. This limits an adversary from being able to detect, intercept, jam, or otherwise interfere with a transmission unless it is physically located within the beam.

Limitations

The extremely narrow beamwidth of lasercom links also means that they are not ideal for broadcast communications. Whereas an RF link can be transmitted across a broad area for many users simultaneously, lasercom links are best suited for point-to-point communications that require dedicated high data rate links. Further, an optical communications telescope's pointing accuracy must be extremely precise—a deviation of a fraction of a degree can result in the laser missing its target.

All communication systems are limited by the medium through which they must travel, and lasercom is no exception. The primary environmental obstructions that can interrupt with a laser are clouds, mist, smog, and smoke.



Laser communication relay demonstration (LCRD). Credit: NASA.

Another limitation of optical communication systems has historically been the expense. Terminals have been produced in the $10 million range, which is cost prohibitive for most proliferated LEO systems to purchase or for new entrants in the marketplace to produce profitably. Nevertheless, improvements in technology, smaller terminals, and growing demand are expected to impact price in the coming years and create significant growth in lasercom terminal sales in the United States and internationally.

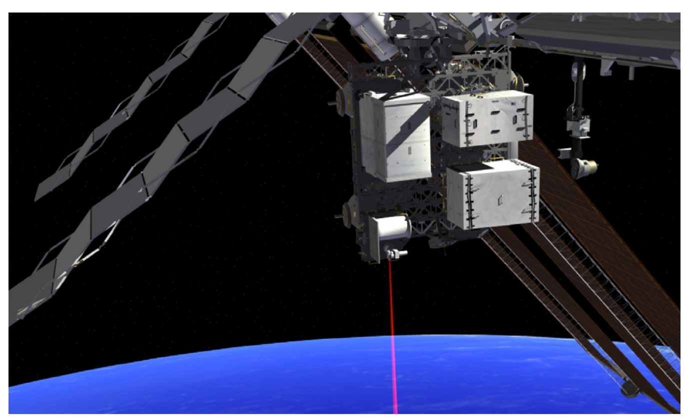
Back to Business

As noted above, speed is imperative for JADC2, and lasercom is the key to network speed. Of course, commercial constellations are seeking the same benefits from lasercom, including lasercom signals that will avoid having to wait for a ground terminal to become available and will avoid slower terrestrial networks by simply beaming signals relay-style across satellites until one is optimal for downlink. (In-space relays also avoid other terrestrial threats, like sabotage to undersea fiber optic cables.)

In recent news (May 2023), according to *Via Satellite*, NASA beat its previous record for the fastest lasercom link, achieving 200 gigabits per second from orbit to Earth.

Early Lasercom

It's worth noting that lasercom was not adult-born. A few select early events include research in the 1970s by The Aerospace Corporation entitled *Acquisition and Pointing for Laser Communications Between Low and High Altitude Satellites*. In 1995, the Japan Aerospace Exploration Agency (JAXA) demonstrated 1 megabit per second lasercom download speeds from its engineering test satellite KIKU-6 to a ground station in Tokyo. In 2016, Airbus launched its first high-speed lasercom satellite into the geostationary Earth orbit (GEO) belt. In 2018, The Aerospace Corporation and NASA demonstrated the first CubeSat-based laser downlink, followed in 2019 by the first in-space, CubeSat-to-CubeSat laser pointing demonstration.



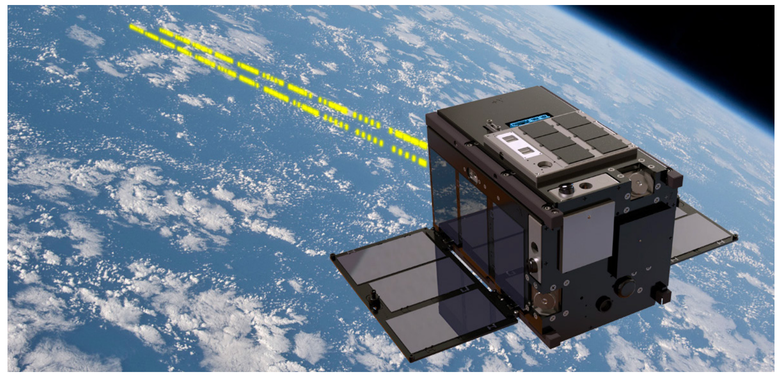
Optical Payload for Lasercomm Science (OPALS) was developed at JPL and tested on the ISS in 2014 to demonstrate laser communications between spacecraft and ground stations. Credit: NASA.

At about this time, maturing lasercom technology found its way into various space architectures as "proof of concept." **Defense Advanced Research Projects Agency's (DARPA's) Blackjack** program emerged to test OISLs, each developed by a different vendor.

In 2021, DARPA also kicked off the Space-Based Adaptive Communications Node, or Space-BACN, focused on optical communications to create an "internet of small satellites."

DARPA is working with commercial companies to create a standard, low-cost laser terminal that connects commercial and government constellations in LEO. Five commercial satellite operators—SpaceX, Telesat, SpaceLink, Viasat, and Amazon's Kuiper—are among 11 organizations selected by DARPA to help develop laser terminals and technical standards to connect satellites in space.

In 2021, **NASA's** Laser Communications Relay Demonstration (LCRD) launched into orbit to test its ability to receive optical communications from other satellites and spacecraft and beam them down to earth. LCRD is the agency's first technology demonstration of a two-way laser relay system. It will use a CACI-supplied ILLUMA-T lasercom terminal on the International Space Station (ISS), making the space station the first orbital user of LCRD.

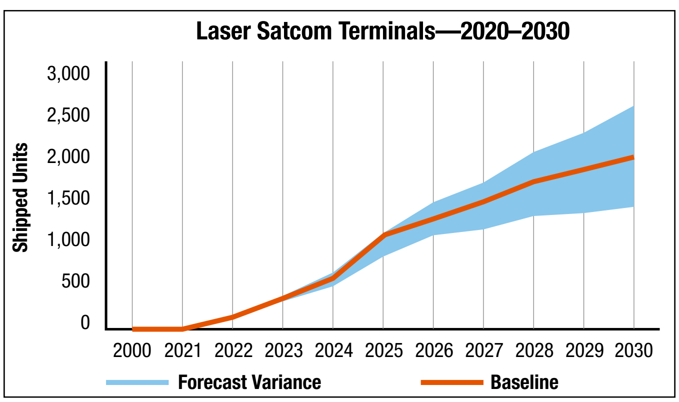


Artist's impression of the Optical Communications and Sensor Demonstration (OCSD). Credit: NASA.

Mynaric's CONDOR family of optical communications terminals were selected by **Northrop Grumman** for its SDA programs; **Capella** Space selected Mynaric for its commercial synthetic aperture radar (SAR) satellites, and **Telesat** went with them for its DARPA Blackjack program.

What's the State of Play Today? Purchasing Power Matters

The **SDA program** is a key market driver by virtue of volume and by virtue of having established the Optical Communications Terminal (OCT) Standard. According to the agency's website, SDA is planning from 300 to more than 500 satellites in LEO, ranging from 750 km to 1200 km in altitude. The constellation will be interconnected with OISLs, which have significantly increased performance over existing RF crosslinks. Each satellite will have anywhere from three to five laser links so it can talk to other satellites, airplanes, ships and ground stations. SDA is buying satellites from multiple manufacturers and all its satellites must be interoperable.



Source: NSR

Multiple companies are providing optical terminals for that effort, including **Mynaric**, **Airbus** subsidiary **Tesat**, **Skyloom** and partner **Honeywell**, and **SA Photonics** (CACI), according to the SDA.

Among other government investments in lasercom, in 2021, USSF's **SpaceWERX** invested in **Cambrian Works**, which is developing a dual-mode optical and RF satellite crosslink, and **SpaceMicro**, which developed a 100-Gbps lasercom terminal that has been on orbit for over two years, and announced a partnership with **BridgeCom** for ground terminals.

Commercial Constellations

Elon Musk's Starlink

SpaceX has successfully launched its early Starlink satellites, building the first internet in the sky using low-latency (high-speed) laser crosslinks. A high-speed internet hosted on LEO satellites is a game changer for military and civilian applications. SpaceX is funding the expensive technology and producing the terminals in-house.

Canada's **Telesat** is developing Lightspeed, a planned network of 188 LEO lasercom-connected telecommunications satellites. "Telesat Lightspeed will fully support both electronically steered antennas (ESAs) and mechanically steered antennas for commercial, government, and defence markets including requirements for land, land-mobile, aeronautical, maritime, and other platforms," the firm's website explains.

Starlink constellation.

In February 2023, **Terran Orbital** announced it had won a $2.4 billion contract to build 300 small satellites for **Rivada Space Networks**. Rivada then announced it would use **Aalyria Technologies'** lasercom terminal, known as Tightbeam, for ground-to-space, terrestrial, and airborne applications—technology Aalyria reported it had licensed from **Google parent Alphabet**. Eventually, Rivada wants to have full deployment of 600 satellites. The larger constellation would operate in 24 orbital planes and use laser communications to create a mesh network of 2,400 intersatellite links. According to the firm, the system is designed to serve as a secure, private space-based network for government and business customers, including militaries, diplomatic services, banks, telecommunication backhaul users, and cloud computing services, as well as industries that operate in remote regions such as the aviation, maritime, oil, gas, and mining sectors. **Amazon** is expected to install Department of Defense-compliant lasercom terminals on its internet satellites to allow the military to receive data directly from remote sensing satellites. According to news sources, the effort would "turn some Kuiper satellites into 'translators' that will support secure and high-speed data transfer from satellites to ground users," which would allow commercial providers to send imagery.

Commercial Market Movers and Shakers

Space Micro was acquired in 2022 by **Voyager Space** and is now developing an air-to-space lasercom pod that could be deployed on a variety of aircraft. Space Micro is partnered with Johns Hopkins University (JHU) and Rhea Space Activity (RSA) to develop an optics system that uses deformable mirrors to transmit a laser signal through turbulence up to awaiting satellites for communications relay. In June of 2022, Northrop Grumman announced it had invested in a successful ground demonstration of a secure networked lasercom system for proliferated-LEO constellations with partners **Mynaric** and **Innoflight**.

In May of 2022, **CACI International** announced that it had successfully demonstrated "space-to-space optical communications links in low earth orbit" with the **U.S. Defense Advanced Research Projects Agency** and the **Space Development Agency** as part of the **Mandrake II program**. Mandrake II is a joint risk-reduction program with DARPA, SDA, and the Air Force Research Laboratory's (AFRL's) Space Vehicles Directorate (AFRL/RV) to evaluate the pointing, acquisition tracking algorithms that allow for optical communication terminals to establish high-speed communication links in the upcoming Blackjack and SDA Transport and Tracking Layer constellations.

In June 2022, **Raytheon** announced that, as part of DARPA Blackjack, its SEAKR unit had demonstrated laser crosslink, where 280 GB of data was transferred at a 114 km range in a period exceeding 40 minutes.

Also in June 2022, the **AFRL** announced an $11 million contract with space technology developer **BlueHalo** to build a pair of OISL proto-flight terminals and a ground station to demonstrate GEO-to-LEO optical uplinks and downlinks, space-to-ground links, positioning and timing accuracies over optical communication links, and interoperability with multiple optical communications standards. That same month, **Sony Corporation of America**, after a collaboration with Japan's Aerospace Exploration Agency (JAXA) announced that, it would begin developing small optical communications devices to provide related services to connect microsatellites in LEO via a laser beam. Sony notes that by constructing an optical communications network, not only between satellites and the ground but also between satellites in orbit, Sony Space Communications Corp. (SSC) aims to enable realtime communications from anywhere on the ground to any satellite in space.

In August 2022, **SpaceLink** announced it was building a constellation of relay satellites in medium Earth orbit (MEO) that use optical intersatellite links to speed communications between spacecraft on orbit and users on the ground. Along with other contributors, SpaceLink will assist DARPA in studying and developing protocols for how commercial communication constellations will interact with Department of Defense (DOD) systems in a space-to-space interconnected future.

In October 2022, DARPA selected **Intel Corporation** and **Arizona State University** to design a reconfigurable optical modem that will support both current and new communication standards and protocols to enable interoperability among satellite constellations.

In March 2023, DARPA announced that it is now awaiting a launch slot, expected in January 2024, to demonstrate cross-satellite laser links.

In a request for information that was due in February 2023, **U.S. Space Force's Space Systems Command** requested information on an enterprise laser communications solution will build on existing OISL efforts in LEO. The solution will be for crosslinks from 10,000 km to approximately 70,000 km above the Earth's surface.

In April 2023, Canadian smallsat company **Kepler Communications** announced it had raised $92 million for an optical data-relay constellation to deploy in 2024. As reported by *SpaceNews*, the satellites will weigh "over 100 kilograms, and be placed along two near-orthogonal planes in sun-synchronous orbits to enable continuous communications with low Earth orbit (LEO) satellites." In another sign that standards matter, the network will adhere to standards developed by the SDA and use SDA-compatible optical user terminals.

University Research Programs

Universities have created programs focusing on laser communication research for professors and doctoral candidates. Historically, academic institutions have struggled with the capital necessary to test technology in space, but, with private corporations collaborating with universities, there are more opportunities to test the viability of their optical communication systems. Notable examples include **Ohio State University,** collaborating with **Mynaric** to investigate airborne, space-borne, terrestrial components, air-to-ground lasercom; **University of Dayton,** collaborating with partnered with Air Force, funded by Boeing, BAE Systems, Lockheed Martin, Northrop Grumman, Raytheon, and Textron Systems to investigate adaptive beaming and numerical analysis; **MIT**, working with Qualcomm on laser-pointing platform to improve downlink; and a number of others, some of which are listed below.

University Notables

Northumbria University (UK): received $1 million in funding for three lasercom CubeS ats to be launched in 2025.

DLR Institute in Oberpfaffenhofen (German/EU): laser ranging and identification.

Delft University of Technology and University of Twente (Netherlands/EU): professors and doctorate programs: geometric research/mapping.

Australian National University, University of Western Australia (Australia): using lasers to enhance optics and mapping, link acquisition and tracking, adaptive optics, quantum encryption, and ground-to-space communication.

Rensselaer Polytechnic: reserchers devised a method to make communications between satellites and the ground more effective no matter the weather. In research recently published, the team used ultrafast, femtosecond lasers to cut through the clouds and rain that commonly cause losses in free-space optical communication.

MIT: professors are working on a CubeSat lasercom mission, including a laser-pointing platform to improve downlink.

University of Florida: professors working on CubeSat lasercom mission, time-delay interferometry, and arm locking.

UCSD: offers doctorate program in lasercom system architecture and performance testing

Select International Activity

In March 2023, **Mynaric** announced a contract with the German government for development of a scalable optical ground station prototype capable of receiving quantum keys from ultra-secure satellite-based networks in space, as well as demonstration of an optical communications terminal for airborne high-altitude platforms that can exchange quantum keys through air-to-air and air-to-ground links.

ESA System

The European Space Agency, or ESA, has created public/private partnerships for financing optical communications systems. The agency believes this may prove to be a good example for benchmarking workable funding for new entrants to the marketplace.

Airbus produces most of what it calls “space equipment” in Europe, with its **Tesat-Spacecom** (Tesat) subsidiary, headquartered in Germany, developing lasercom terminals. Tesat already provides optical terminals to four U.S. prime contractors participating in SDA’s Transport and Tracking Layers as well as DARPA’s Blackjack program. Recently, Airbus has raised the idea of moving the production of satellite lasercom terminals to the United States.

The **Netherlands** ground-to-ground link A consortium led by TNO has established a laser communication link over 10 kilometers between the test site at the Royal Netherlands Meteorological Institute (KNMI) in Lopik and the Gerbrandy tower in IJsselstein. According to the partners of the Terabit Optical Communication Adaptive Terminal (Tomcat) project, it’s the first time a robust optical data connection has been set up in realworld conditions compatible with conventional infrastructure. They view the successful demonstration as a big step toward a commercial optical ground station and faster and more secure broadband connectivity in the Netherlands and Europe.

Future of Lasercom

With major government and commercial programs poised to leverage lasercom, the technology is positioned to deliver the winning combo of high-bandwidth and low-latency needed to expand the internet into space and deliver global, low-latency communications. In the future, we expect to see several large constellations exploit lasercom for high-speed crosslinks. We also expect to see growth in downlink, emerging up and downlink from airborne platforms and for deep space optical communications. In particular, we expect the initial operation and expansion of the **SDA’s** Proliferated Warfighter Space Architecture and its enabling optical communications network on a path to enabling JADC2, with its volume purchasing and focus on standards helping expand the market for lasercom. We’ll see the expansion of **SpaceX** Starlink satellites equipped with inter-satellite laser links (ISLs); **Rivada** should begin deploying laser communications on a path to creating their planned mesh network of 2,400 intersatellite links. Additionally, we’ll expect to see **Telesat’s** network of 188 LEO satellites, and **Amazon** is expected to install laser terminals on its Kuiper satellites.

According to research from NSR, they expect to see a large influx of optical terminals in the coming years, starting with all future Starlink satellites. NSR also estimates the market for lasercom terminals represents at least a $3 billion opportunity over the next 10 years, which could lead to new applications such as alternate positioning, navigation, and timing (PNT) solutions and quantum communications.

Farther from home, **NASA's** LunaNet is a proposed data network aiming to provide a "lunar internet" for cislunar spacecraft and installations. The specification for the system includes optical communications for links between Earth and moon as well as for links between lunar satellites and the lunar surface. To that end, **CommStar** Space and **Thales Alenia** Space have a partnership to deploy the CommSat-1 satellite in the cislunar service area for hybrid optical and radio frequency communications between the moon and Earth.

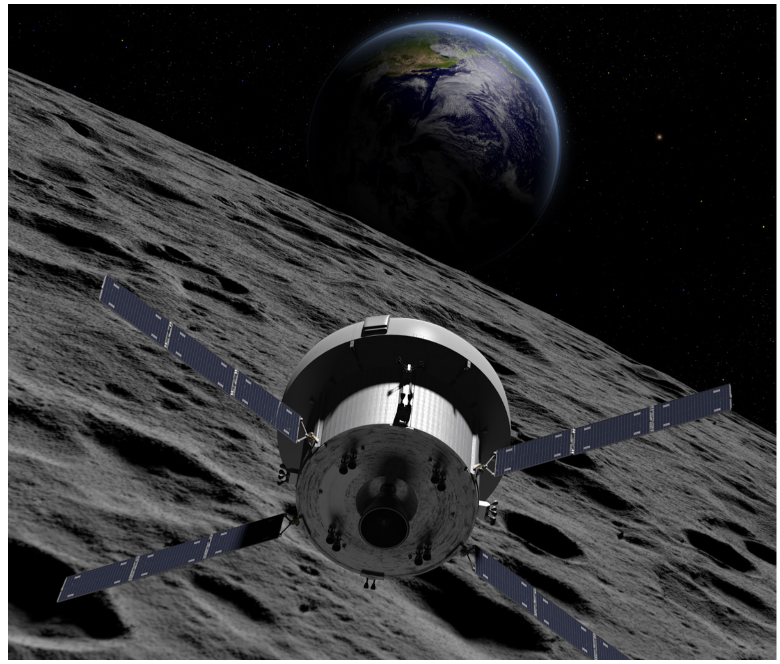


Illustration Orion over lunar surface with Earthrise. Credit: NASA.

NASA's Orion Artemis II Optical Communications System (O2O) will bring lasercom to the moon aboard NASA's Orion spacecraft during the Artemis II mission, currently planned to be launched in November 2024. According to NASA, O2O will be capable of transmitting high-resolution images and video when astronauts return to the lunar region for the first time in over 50 years. Artemis II will be the first crewed lunar flight to demonstrate lasercom technologies, sending data to Earth with a downlink rate of up to 260 megabits per second. Some industry experts have even speculated that a terabit (per second) is not that far away on the development roadmap.

Laser-Focused Epilogue

In the end, the scale of humans' ability to communicate is what separates us from other forms of terrestrial life. It has allowed us to share and expand knowledge and culture, and capitalize on insights down through generations and across epochs of time. Now we've entered an era where a network that moves voice, data, imagery, and, ultimately, knowledge around the world is poised to expand to the moon and other planets. These changes are liable to be impactful and far-reaching, and we're limited only by imagination in speculating what this means for our species down the generations and across epochs of time.

By Andre Doumitt and Laura Speckman with The Aerospace Corporation.

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