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Space in the Bay Area

Research, Technology, and the Commercialization of Space

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The Pillars of Creation is a small star-forming region within the vast Eagle Nebula, which lies 6,500 light-years away.

Executive Summary

Silicon Valley and the Bay Area have long been identified with technological innovation, the creation of new industries, and the disruption of old ones. This applies to space. In the popular mind, the Bay Area—which includes Silicon Valley—is identified with industries such as computer hardware, software, semiconductors, or social media, while the space industry is identified with Southern California, Florida, or Texas. The Bay Area, however, has a deep history in the space sector and is playing a revolutionary role there as well.

The Bay Area plays a distinctive role due less to its size than to its orientation. The region is home to leading university research programs in astronomy and astrophysics and is more broadly the US epicenter for technology innovation and its leading center for startups. From this base, the Bay Area plays a unique role in advancing the national space enterprise through its entrepreneurial capacity and computational, software, and IT assets. Over time, it has evolved from being a leading base for space research to serving today as the intellectual heart of the space industry, focusing less on fabrication than on R&D. This enables the region to serve as an incubator for new technologies and for emerging space-related companies.

Rooted in Research

NASA Ames Research Center

NASA Ames Research Center, in the heart of Silicon Valley, supports research in a range of technologies with a primary focus on entry systems (safely delivering spacecraft to Earth or other celestial bodies), advanced computing and IT systems (enabling modeling and simulations), aeroscience (testing on the ground), air traffic management, biology and astrobiology (the origins and development of life in the universe), cost-effective space missions, intelligent/adaptive systems (complementing humans in space), and space and earth science (astrophysics, astrochemistry, and exoplanet detection). The Center is home to some of the most advanced computing and supercomputing facilities in NASA and is a leader in incorporating artificial intelligence and machine learning into space exploration. For the future, Ames is focusing on the return of humans to the Moon through the Artemis missions and informing preparations for human missions to Mars.

Ames has played a particularly important role in the development of the nation's commercial space industry, leveraging its technology to enable public-private partnerships that both reduce costs and accelerate the deployment of space technology. NASA Research Park is a hub for research collaboration between NASA and public and private sector entities. The park's location in the heart of Silicon Valley uniquely enables it to access the research and innovation coming from nearby companies and universities, leveraging NASA's deep research base with private sector agility.

In October 2023, the University of California, Berkeley, NASA Ames Research Center, and San Francisco developer SKS Partners announced the launch of the proposed **Berkeley Space Center** at NASA Research Park. The $2 billion innovation hub will be a 1.4 million-square-foot research and education campus where researchers, scientists, faculty and students from UC Berkeley, NASA, and private companies with aligned missions will conduct research in fields spanning aerospace, quantum computing, climate science, wildfire research, and urban air mobility.

In the latest expansion of its public education mission, **Chabot Space & Science Center** hosts the official visitor center of NASA Ames Research Center, under a five-year agreement that commenced in 2021. Located in the hills above Oakland, Chabot offers visitors a full suite of learning activities, including hands-on interactive exhibits, telescope viewings, workshops, summer camps, and planetarium shows.

SETI Institute

SETI Institute is a nonprofit research and education organization dedicated to astronomy, planetary science, astrobiology, and the search for extraterrestrial intelligence. Much of the SETI Institute's research today is conducted by scientists at its **Carl Sagan Center for Research**, where over 100 research scientists and affiliates work in more than 20 fields of inquiry, from chemistry and physics to geology and astronomy, biology, and the search for extraterrestrial intelligence and life (biology) in the solar system and beyond. The search for radio signals in the Milky Way and beyond occurs at SETI's **Allen Telescope Array (ATA)** at Hat Creek in Northern California.

Lick Observatory

At the top of 4,265-foot Mount Hamilton, the Lick Observatory is home to nine operating telescopes, including Shane, a 10-foot-wide mirror that targets stars as far as 150,000 light years away and celestial objects such as quasars that may be a billion light years from Earth. Operated by the University of California since 1888, Lick has pioneered the use of adaptive optics (AO) to compensate for the blurring of astronomical images that is caused by turbulence in the Earth's atmosphere. The observatory's facilities are actively used in training students and as the University of California's test bed for astronomical instrumentation.

SRI

SRI, an independent nonprofit research organization with both federal and private clients, has a rich history in space exploration research, development, and production, including CubeSats, SmallSats, large satellites, and ground-based telescopes, radars, and antennas.

University Programs

UC Santa Cruz

The University of California, Santa Cruz hosts a world-leading Department of Astronomy and Astrophysics. UCSC scientists have designed the Fermi Gamma-Ray Space Telescope, the Keck Observatory telescopes on Mauna Kea in Hawaii, and the Automated Planet Finder at Lick Observatory; have devised the fix for flawed optics on the Hubble Space Telescope; have partnered with NASA on projects including the Kepler planet-finding telescope and the Cassini mission to Saturn; and are leaders in the development of adaptive optics (AO).

UC Berkeley

UC Berkeley's astrophysics and planetary science programs, its research, and its external partnerships make it a leading center in the field. The campus has more than 300 active contracts and grants funded by NASA, supporting work by faculty across nine departments spanning five colleges. The **Space Sciences Laboratory (SSL)** is the heart of the university's space programs. Since its founding in 1959, SSL has participated in over 50 NASA space science missions, including the Apollo, Mars, and Explorer programs, and many international space missions. These relationships build on unique engineering and technical capabilities that enable the lab to develop and fabricate space instruments, complete scientific payloads, or implement from end-to-end the technical components of an entire space mission. Approximately 400 people work on SSL programs.

UC Davis

The UC Davis **Center for Spaceflight Research (CSFR)** investigates human spaceflight from multiple viewpoints, including engineering, computer science, chemistry, neuroscience, and psychology. Four labs form the CSFR: the Human/Robotics/Vehicle Integration and Performance Laboratory (HRVIP); the Cyber-Human Physical Systems Lab (CHPS); the Robotics, Autonomous Systems, and Controls Laboratory (RASCAL); and the Bioastronautics and eXploration Systems Laboratory (BXS). The labs also focus on robotics, control systems, prosthetics, and the human-machine interface. In other university departments, active research projects funded by NASA span spacecraft and habitat design, CubeSat design, human life-support systems and safety, space robotics, autonomous systems supported by machine learning, radiation protection, atmospheric entry, and metallic additive manufacturing.

Stanford University

The graduate program of Stanford's Department of Aeronautics and Astronautics ranks in the top three nationally. Research programs focus on autonomous systems and controls, cyber safety for transportation, aircraft design, computational aerosciences, materials and intelligent structures, and distributed space systems. The department is also home to three interdisciplinary research centers: the **Stanford Center for Position, Navigation and Time**, the **Federal Aviation Administration (FAA) Center of Excellence for Commercial Space Transportation**, and the **King Abdul Aziz City for Science Technology (KACST) Center of Excellence for Aeronautics and Astronautics**. CubeSat technology, which condenses all the requirements for a space vehicle in 10 cm cubes that can be packaged together and is now widely used in Low Earth Orbit satellites, was developed on the campus. Stanford also led the early development of computational fluid dynamics (CFD) and GPS high-orbit technology now widely used in navigation.

Federal Laboratories

Three National Laboratories—Lawrence Livermore National Laboratory (LLNL), Lawrence Berkeley National Laboratory (LBNL), and SLAC National Accelerator Laboratory—play research roles focused on high-risk engineering. LLNL is a leader in the development of adaptive lasers. LBL is a leader in the development of technology that supports ground-based astronomy. SLAC focuses particularly on instrumentation and data management. The proximity of these federal labs to UC Berkeley, UC Santa Cruz, and Silicon Valley has been instrumental in propelling the development of the Bay Area's space sector.

Lawrence Livermore National Laboratory

Lawrence Livermore's **Space Science Institute** is the lab's hub for developing new space science mission concepts, instruments, and enabling technologies. Key contributions are based on the lab's deep expertise in optics, plasma physics, nuclear science, high-performance computing, and data science, with applications including the study of dark matter, asteroids, and exoplanets. Lawrence Livermore's growing Space Program is the hub for analysis and mission support of new national security missions.

LLNL is one of the world's foremost centers of research in cosmochemistry (the study of extraterrestrial materials). In the field of planetary defense, LLNL scientists use large-scale simulations on supercomputers to develop methods for defending Earth from collisions by asteroids.

LLNL researchers designed the large camera lenses for the world's newest telescope being built for the Vera C. Rubin Observatory in Chile, including a 5.1-foot-diameter lens that is believed to be the largest high-performance optical lens ever fabricated. When operations begin in 2025, the Rubin Observatory will launch its ten-year Legacy Survey of Space and Time (LSST), surveying the entire visible sky to explore dark energy, exploding supernovae, and hazardous near-Earth asteroids.

For several decades, LLNL has also been at the cutting edge of adaptive optics (AO) that allow large telescopes on the ground (as opposed to telescopes in space) to compensate for the distortions of light caused by the Earth's atmosphere, enabling the detection of faint objects with very high resolution.

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory manages the Dark Energy Spectroscopic Instrument (DESI) project, an international collaboration of more than 900 researchers at 70 institutions. DESI studies the effect of dark energy on the expansion of the universe and has created the largest 3D map of the universe ever made, measuring its rate of expansion 11 billion years into the cosmic past with high precision. Researchers expect to map 3 million quasars and 37 million galaxies. Another major project, the Lunar Surface Electromagnetics Experiment-Night (LuSEE-Night), looks to close a 400 million year gap in our understanding of the history of the universe at a time known as the Dark Ages before stars were born.

The **Berkeley Accelerator Space Effects (BASE) Facility** provides beams of heavy ions, protons, and neutrons for radiation effects testing. Its equipment has been used by more than 40 space missions led by NASA research and space flight centers, the European Space Agency, and the Japan Aerospace Exploration Agency.

Berkeley Lab and the University of Chicago co-lead a Department of Energy and National Science Foundation project, the Cosmic Microwave Background Stage 4 (CMB-S4) experiment, to map the light from the cosmic microwave background (CMB), the oldest and farthest light we can observe in the universe. The LUX-ZEPLIN (LZ) experiment, an international collaboration led by Berkeley Lab, is the world's most sensitive detector of dark matter, the invisible substance that makes up most of the mass of the universe.

SLAC National Accelerator Laboratory

SLAC, a Department of Energy national lab operated by Stanford University, co-leads operations for the National Science Foundation-Department of Energy Vera C. Rubin Observatory, which will use the SLAC-built LSST Camera—the largest digital camera ever constructed—to search for dark matter and dark energy. SLAC managed the camera's design, fabrication, and final assembly. The Observatory will conduct the 10-year Legacy Survey of Space and Time (LSST), which will observe every part of the Southern Hemisphere sky, producing a massive amount of data that will help astronomers discover 37 billion new celestial objects. SLAC also runs Rubin's US Data Facility, which manages the massive amount of data the LSST Camera will produce.

In addition, SLAC houses the Linac Coherent Light Source (LCLS) and its Matter in Extreme Conditions (MEC) instrument. MEC is shedding light on some of the most extreme environments and states of matter in the universe, including diamond rain that forms on distant planets and the warm, dense matter found in the cores of giant gas planets and in the atmospheres of white dwarfs.

Hubble and Webb

From national defense missions to meteorology and Earth observation, Bay Area laboratories and companies have been major contributors to the two leading deep space observatories, the Hubble Telescope and the James Webb Space Telescope.

Sunnyvale's **Lockheed Martin Space Systems** designed and built the Hubble Space Telescope, which from its launch in 1990 until the launch of the James Webb Space Telescope in 2021 was the world's premier orbiting astronomical observatory, producing astronomical discoveries and images that amazed the world. Since 1990, Lockheed Martin personnel in Sunnyvale and at NASA's Goddard Space Flight Center in Maryland have managed the spacecraft operations of the telescope and provided preparation and training for in-space servicing missions that have repaired and replaced components and extended the telescope's life and performance.

As NASA searched for a worthy successor to Hubble, it tapped Lockheed Martin's Advanced Technology Center in Palo Alto to design, assemble, and support operations of the Near Infrared Camera (NIRCam), the primary imager deployed in the James Webb Space Telescope. NIRCam is able to detect light from the earliest stars and galaxies as they were formed, as well as stars in nearby galaxies and the Milky Way.

Coherent Tinsley Integrated Optics Systems, with facilities in eight Bay Area locations, fabricated, polished, and coated the mirror used in the James Webb Space Telescope.

The Hubble and Webb telescopes are complementary in their missions and capacities and frequently work together to produce the most definitive measurement of the rate of expansion of the universe. While Hubble has been operating for more than 30 years, Webb is only at the beginning of its voyage.

Industry Anchors

Mirroring the region's academic research infrastructure is a specialized industrial research and production pipeline dedicated to space.

Lockheed Martin Space

Lockheed Martin's Sunnyvale facility is home to more than 3,000 employees deployed across a range of missions. Its **Advanced Technology Center (ATC)**, located in Palo Alto, anchors research, development, and prototyping operations.

Lockheed Martin has distinctive strength in systems engineering and integration, where it often serves as the prime contractor for major projects. The company's activity in the Bay Area focuses on human space flight, robotic exploration, global communications, surveillance and navigation, strategic and defensive systems, command and control systems, and instrumentation, including imaging sensors, advanced materials, advanced space electronics, cryogenics for remote spacecraft cooling, and advanced optical systems for space observation. Its customers span commercial space, the intelligence community, the US Army, the US Navy, the US Space Force, the Space Development Agency, NASA, and NOAA. Increasingly supported by advanced AI and data analytics investments, Lockheed Martin's capabilities in space instrumentation lead the country.

Closer to home, the company is a major developer of early warning weather and climate observation satellites that help first responders, scientists, and businesses better prepare for increasing climate challenges such as severe storms, hurricanes, and wildfires.

Other Leading Space Companies

Other leading space companies in the region include **Maxar Space Systems** (formerly Space Systems/ Loral), with a 60-year history of designing and manufacturing satellites and spacecraft components for communications, Earth observation, and exploration. The company has customers in 70 countries, and with more than 90 of its satellites in orbit, Maxar-built satellites support broadcast services for 2.4 billion people. Its spacecraft are extensively used by commercial customers for weather monitoring, air traffic control, monitoring of maritime networks, support for emergency service operations, telemedicine and distance learning, and economic development in remote regions

Terrasat Communications, headquartered in Morgan Hill, manufactures microwave and satellite RF (radio frequency) equipment for more than 200 government and commercial satellite communication customers around the world.

Entrepreneurs and Commercial Space

The space economy is driven by several emerging sectors: space transportation (reducing launch costs through efficiency in rocket production and usability), in-space manufacturing (additive manufacturing in low-Earth orbit), in-space bioproduction (production of organs, tissues, and therapies in microgravity), nuclear launch and propulsion (utilizing nuclear energy as a potential substitute for chemical propellant fuels), space agriculture (the production of food in space), and satellite services and maintenance (expanding the role of satellites to include quantum communication and remote sensing). Satellite services applications include military uses but also GPS for personal location and public safety; the precision monitoring of agricultural resources; climate and environmental monitoring; the positioning of planes, trains, ships, and other vehicles; and phone and internet connectivity.

Silicon Valley is playing a central role in the development of the space sector, as private companies take on roles once played by government—often with government encouragement and support.

One driver behind recent commercial development in the region is the idea that successful space ventures can be expeditiously developed by small private enterprises building on federal research but using low-cost off-the-shelf technologies.

NASA Ames Research Center has played a pivotal role in defining the direction of the commercial space sector, initially serving as an incubator for talent. First-movers, many with connections to Ames, have shaped the region's and the nation's space industry include

- Satellite imaging company **Planet Labs** (with 150 satellites currently generating an average of 1,300 images of every location on Earth's landmass per day);
- Earth observation platform **Orbital Insight**;
- **Loft Orbital** (satellite subscription services);
- satellite bandwidth-as-a-service company **Astranis Space Technologies**;
- launch company **Astra**;
- space debris and satellite location management company **LeoLabs**;
- data analytics satellite company **Spire Global;**
- radiation-hardened computer companies **Ramon Space and Colossus Computing**; and
- Earth observation company **Capella Space**.

A National and Global Incubator and Innovation Platform

Silicon Valley has incubated important space companies and hosts offices and facilities of many companies that are headquartered elsewhere but support important Bay Area operations. **SpaceX**, launched in 2002, has revolutionized how rockets are launched and who launches them—in the United States and globally. Though SpaceX is headquartered in Southern California, its roots are in the Bay Area, and it was headquartered in Silicon Valley until the need for more space and more technicians led the company to move to a Southern California site close to LAX. Today, the SpaceX Falcon 9 rocket leads the commercial space launch industry, having perfected reusable rocket technology.

Defense tech startup **Anduril Industries**, based in Costa Mesa, was also founded in the Bay Area by a Facebook executive and funded by Bay Area VC Founders Fund. With a global presence today, the company maintains a footprint in Mountain View.

The reach of the region's research institutions and private companies is global, as seen in the extensive satellite systems operated by companies like Planet Labs. In addition to system-wide international partnerships in NASA, Ames today manages collaborative Space Act programs with the United Arab Emirates, the Canadian Space Agency, the Israel Space Agency, Swiss International Air Lines, the Mexican space agency AEM, the Korea Aerospace Research Institute, the European Space Agency, and Belgium's Von Karman Institute for Fluid Dynamics. Other international relationships include the Luxembourg Space Agency's participation as a sponsor of the Frontier Development Lab (FDL), a SETI Institute-operated public-private interdisciplinary PhD and postdoctoral program. Under an MOU signed in 2019, the Luxembourg Space Agency (LSA) is also a collaborator with NASA in the fields of space applications, space exploration, and the sustainable utilization of space resources.

Venture Capital Joins the Game

Venture capital is becoming increasingly active in the space and defense sectors, helping to bring Silicon Valley's innovative capability to a field that has historically been dominated by large companies and institutions. As this happens, the Bay Area is incubating the space sector, both nationally and globally.

Four of the ten most active firms investing in the sector from 2018 through 2022 are Bay Area firms **SOMA Capital**, **Founders Fund, Draper Associates**, and **Liquid 2 Ventures**. Other investors with a presence in the Bay Area/Silicon Valley include **Andreessen Horowitz**, **Khosla Ventures**, **Caffeinated Capital**, **General Catalyst**, **In-Q-Tel**, **The Yope Foundation** (formerly Founder.org), **True Ventures**, **Draper Nexus**, **Eclipse Ventures**, **Fusion Fund**, **Shield Capital**, **Y Combinator**, and **Plug and Play**. Without taking equity, the **Defense Innovation Unit** (DIU) contracts with defense and space-related startups, connecting Silicon Valley innovation to the Department of Defense and national security agencies.

Nonprofit and Public Engagement

The Bay Area is connected to an array of nonprofit organizations with inspirational visions for future human endeavors in space. They provide both practical support for specialized space technology advancements and educational support for public engagement with space science and exploration.

The **B612 Foundation's Asteroid Institute** brings together scientists, researchers, and engineers to develop tools for mapping the solar system, with a particular safety focus on asteroid discovery, characterization, tracking, and impact monitoring. **LunARC** looks to establish the first institution of higher learning—Lunar University—on another world.

An especially wide-ranging endeavor with Bay Area ties through its leadership is the privately-funded **Breakthrough Initiatives**, a suite of space science programs that delve into fundamental questions surrounding life in the universe. Breakthrough Listen, co-founded by Yuri Milner and Stephen Hawking, is a $100 million program of astronomical observation and analysis that searches for signs of other technological civilizations in the universe. Breakthrough Watch searches for potentially habitable exoplanets around nearby stars. Breakthrough Starshot is a $100 million research and engineering program that aims to develop a proof of concept for technology enabling uncrewed space flight at 20% of the speed of light.

Other Bay Area institutions also support public learning regarding space and our solar system. The **California Academy of Sciences** in San Francisco's Golden Gate Park presents award-winning programs in its Morrison Planetarium. Over the last 27 years, the **Exploratorium** public learning laboratory has partnered with NASA to send expeditions to cover total solar eclipses wherever they occur in the world, and it produces media products that are used by broadcast networks, NASA TV, online sites, schools, museums, and libraries to offer the eclipse experience to those unable to travel to see it in person.

Enabling Future Growth

Infrastructure

The Bay Area is an engine of innovation, and as long as it can sustain its research leadership and attract the world's best talent, it will continue to play a key role in the US space enterprise. A successful space economy fundamentally requires three things: capital, talent, and robust R&D. Fortunately, the Bay Area has all three in abundance.

The region is far from the only national center for space activity, however, and highly competitive clusters have developed elsewhere. One challenge is to produce an economic and policy environment that enables companies that start in the region to grow here. This issue is particularly tied to factors such as the availability and cost of housing, the cost of doing business, the cost of energy, and access to the right kind of physical space for production—issues that impact Bay Area industry across the board.

Talent

A second challenge concerns the space workforce. The region's space economy is built on technologists, engineers, and research scientists, who are at the heart of the region's innovation and R&D system. They are abundant. There is also an important place, however, for manufacturing, and the commercial space industry will need qualified employees at every level, from research scientists to machinists and technicians. At the technician level (drawing on high school or community college graduates), there is no dedicated workforce training program in the region that specifically focuses on space. As space companies grow and their production increases, however, so will their need for a diversified workforce. Connecting students, particularly those in less advantaged communities, to career opportunities in the space sector will require focused efforts. There is an important role for state and local governments to play here in supporting vocational training. Local and state governments can also contribute by expediting permits, reducing regulatory burdens, and generally lowering costs.

Technical skills that are applicable across multiple industries can be leveraged to support specific space industry applications. One strategy would be to leverage the resources of local Workforce Development Boards (WDBs) with community colleges, the state's Employment Training Panel (ETP), and its Division of Apprenticeship Standards (DAS) to create certification programs that support skills based on the needs of employers.

In August 2022, the Governor's Office announced the creation of a Space Industry Task Force to help California harness future growth in the space industry, both military and commercial. Led by the Governor's Office of Business and Economic Development (GO-Biz) with partnership support from leaders in the Governor's Military Council (GMC), the Office of Planning and Research (OPR), and the Labor and Workforce Development Agency, the Task Force works to attract new businesses in the sector, support existing space and aerospace businesses, grow the industry's workforce, create new career paths in fields such as quantum physics and AI, expand R&D in aerospace and advanced manufacturing, and create new models for public/private cooperation.

A binary pair of actively forming stars is responsible for this shimmering hourglass of gas and dust.

Silicon Valley and the Bay Area have long been identified with technological innovation, the creation of new industries, and the disruption of old ones. In recent years, digitalization has served as the unifying thread, as both large corporations and startups from across the United States and around the world have migrated to the region to be part of the digital revolution and contribute to its advancement. This movement isn't limited to one industry or sector but has spanned a broad range of disciplines as companies and governments consider the impact of digital technologies on their competitiveness. The region is also identified with entrepreneurship and the creation or application of technology by emerging companies that disrupt existing industries or create new ones.

This applies to space. In the popular mind, the Bay Area—which includes Silicon Valley—is identified with industries such as computer hardware, software, semiconductors, or social media, while the space industry is primarily identified with Southern California, Florida, or Texas. The Bay Area, however, has a deep history in the space sector and is playing a revolutionary role there as well. This report assesses the space industry in the region—its roots and development, its current focus, and its contributions to US competitiveness and the national space mission.

Rooted in Research

Space activity in the United States clusters in several regions. Most are home to NASA facilities, military facilities, or leading aerospace companies: Houston (the Johnson Space Center), Florida (the Kennedy Space Flight Center), Maryland and Northern Virginia (the Goddard Space Flight Center, the National Reconnaissance Office), Alabama (the Marshall Space Flight Center), Southern California (the Jet Propulsion Laboratory, Boeing, Lockheed Martin, Northrop Grumman, SpaceX), and Denver/Boulder (Ball Aerospace, Lockheed Martin, Northrop Grumman). Commercial space activity, including aerospace companies that contract with the Department of Defense, is drawn to these centers. The aerospace cluster in Southern California, for example, grew out of the military requirements of World War II and the Cold War, with the Los Angeles-Long Beach area hosting a range of defense contractors and other commercial enterprises.

In this context, the Bay Area plays a distinctive role due less to its size (NASA's Ames Research Center is small compared to other NASA facilities) than to its orientation. The region is home to leading university research programs in astronomy and astrophysics and is more broadly the US epicenter for technology innovation and its leading center for startups. From this base, the Bay Area plays a unique role in advancing the national space enterprise through its entrepreneurial capacity and computational, software, and IT assets. Over time, it has evolved from being a leading base for space research to serving today as the intellectual heart of the space industry, focusing less on fabrication than on R&D. This enables the region to serve as an incubator for new technologies and for emerging space-related companies.

The Mothership: NASA Ames Research Center

> “At the core of our mission is the development of capabilities to extend life beyond Low Earth Orbit to the Moon, to Mars and beyond.”
>
> Eugene Tu, Director, NASA Ames Research Center

Located in the heart of Silicon Valley, what is now NASA Ames Research Center began in 1939 with the construction of wind tunnels at the Ames Aeronautical Laboratory adjacent to the US Naval Air Station at Moffett Field. The tunnels were used to test models and full-scale aircraft during World War II, with the goal of increasing the speed of airplanes and improving the design of military aircraft. In subsequent years, the wind tunnels remained a key tool for research on both subsonic and supersonic aircraft.

With the launch of Sputnik in 1957, the lab's focus pivoted to space, and it was subsumed by NASA, becoming the Ames Research Center and adding space research to its existing focus on aeronautical engineering. Technologies developed at Ames played a critical enabling role in the Apollo, Mercury, and Gemini missions. The lab's innovations over time have included aircraft wing designs that enhance lift and reduce drag, and round noses on space vehicles (incorporated today into the design of vessels from NASA's Orion spacecraft to the SpaceX Dragon capsule) that dissipate heat during atmospheric re-entry.

As part of a national cycle of military base closures, the adjacent Moffett Field was turned over to NASA Ames Research Center in 1994, and 1995 brought a new pivot by Ames toward information technology, astrobiology, high-performance computing, and other fields rooted in Silicon Valley, which today are at the core of the Center's focus.

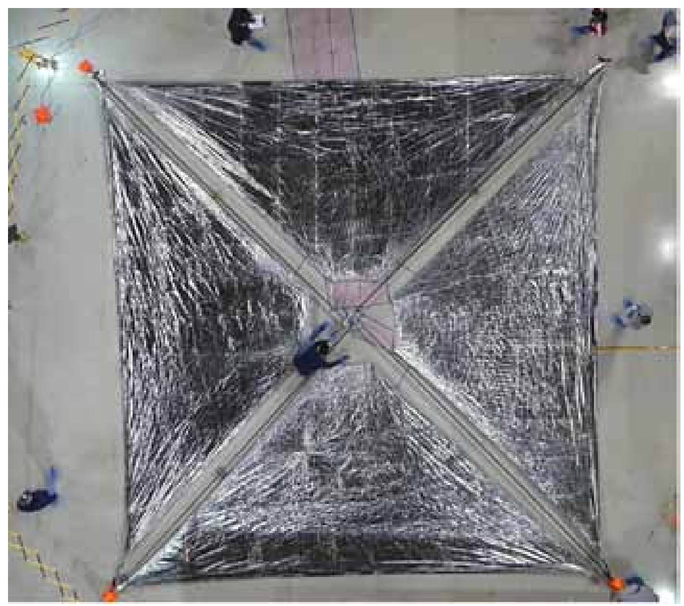
Today, Ames employs 3,200 people, with initiatives focused on agility and innovation. Research spans a range of technologies with a primary focus on entry systems (safely delivering spacecraft to Earth or other celestial bodies), advanced computing and IT systems (enabling modeling and simulations), aeroscience (testing on the ground), air traffic management, biology and astrobiology (the origins and development of life in the universe), cost-effective space missions, intelligent/adaptive systems (complementing humans in space), and space and earth science (astrophysics, astrochemistry, and exoplanet detection).[1] The field of astrobiology has deep roots at Ames.

The Center is home to some of the most advanced computing and supercomputing facilities in NASA and is a leader in incorporating artificial intelligence and machine learning into space exploration. It supports NASA's Artemis and Lunar Gateway programs to return humans to the Moon, NASA's Planetary Defense program (which focuses on the detection and neutralization of hazardous near-Earth objects such as asteroids), and its Small Spacecraft Virtual Systems Institute and SmallSat Data Explorer program (which organize data and learning from commercial small satellite data and missions to support NASA's earth science mission).

Current initiatives include

- development of software to coordinate the use of drones during wildfires;
- research to support the development of Urban Air Mobility;
- development of thermal materials to protect spacecraft, including heat shields used in the OSIRIS-Rex project that recently brought asteroid samples back to earth; and
- research on the next generation of space-based life support systems.[2]

Ames also manages NASA's Advanced Composite Solar Sail System project. Solar sails, supported by 23-foot booms and made from aluminum-coated polymer materials, can fold into a CubeSat package the size of a microwave oven that, when deployed, can propel space vehicles based only on pushes by particles of light from the sun. A promising technology to support space weather early warning satellites, near-earth asteroid reconnaissance, communications relays, and eventually deep space travel, the sail currently under development measures 17,780 square feet, with a thickness less than a human hair at two and a half microns.[3]



Engineers examine the unfurled solar sail, which is approximately 30 feet on a side. Solar radiation pressure is small, so the solar sail must be large to efficiently generate thrust. Source: NASA

For the future, Ames is focusing on the return of humans to the Moon through the Artemis missions, demonstrating how life in space can be sustained for very long durations and informing preparations for human missions to Mars. Projects include the development of entry systems such as heat shields and the development of artificial intelligence (AI) required to enable long-distance mission autonomy. Space missions, including the International Space Station (ISS), are currently managed from ground stations on Earth. Missions beyond the Moon will require onboard autonomy to overcome latency (the communications time delay that will come with missions to Mars and hinder real-time decision-making). A related focus is on how humans in space will relate to autonomous systems.[4]

Ames has played a particularly important role in the development of the nation's commercial space industry, leveraging its technology to enable public-private partnerships that both reduce costs and accelerate the deployment of space technology. Early motivation stemmed from the recognition that—unlike the Apollo era, when the government was prepared to spend heavily to send people to the Moon—future space missions would require private finance and leadership.

The multidisciplinary **Space Portal** office, created at Ames in 2005, was at the heart of that process, pioneering new ways to bring together commercial business ventures, financing options, and government space endeavors. Described by its founders as "a group of organizational disruptors," initial success came when Space Portal leaders devised a strategy later embraced by NASA that bypassed the traditional practice of paying companies for the costs incurred to develop a new launch vehicle, suggesting instead that NASA develop agreements with private companies under the Space Act to let rocket builders propose their own milestones, with payment received when the goals had been met. The strategy was successfully demonstrated in 2012 with the first commercial cargo delivery to the International Space Station by Space Exploration Technologies Corporation. Orbital Sciences Corporation completed its first paid cargo delivery in 2014.

The Portal also served as a touchpoint for entrepreneurs looking to collaborate with NASA. Early beneficiaries included Peter Platzer, a former Space Portal intern who later co-founded Spire Technologies (see below).[5] Since then, NASA has successfully nurtured a competitive commercial space industry. Ames Research Center Chief Scientist Jacob Cohen (who has witnessed the transition) observes, "In the Shuttle era, who flew into space? It was government. Then NASA decided to commercialize Low Earth Orbit with private communications satellites, but they still flew on government launchers. That changed too. The more space opens up, the more competition we're seeing."[6]

Founded in 1998 on the Ames campus, **NASA Research Park** is a hub for research collaboration between NASA and public and private sector entities. The park's location in the heart of Silicon Valley uniquely enables it to access the research and innovation coming from nearby companies and universities, leveraging NASA's deep research base with private sector agility. NASA Research Park Director Mejghan Haider describes the strategy: "The primary benefit for NASA is the collaboration. So to have these entities—whether they're industry or government or academic institutions on site—we look at programmatic synergies."[7]

The first large occupant was Google, which leased 42 acres in 2008 to create the Google Bay View campus. Opened in 2022, the 1.1 million-square-foot[8] facility is designed to flexibly accommodate 4,000 employees and includes a 1,000-person event center.[9]

In 2014, NASA and Google subsidiary Planetary Ventures, LLC executed another lease for 1,000 acres, including three historic hangers and Moffett Federal Airfield. Under the $1.6 billion 60-year lease, the hangers—including the iconic Hanger One, which was built in the 1930s to accommodate dirigibles—will be repurposed for research and development.[10] Extensive work removing toxic materials preceded the Hanger One restoration work, which began in 2022 with completion expected in 2025. [11] Google's Planetary Ventures unit will use the historic facility for research, development, assembly, and testing work in the fields of space exploration, aviation, rover/robotics, and other emerging technologies.[12]

Among other public-private partnerships at NASA Research Park are a 46-acre lease to housing developer Mountain View Housing Ventures LLC for the development of approximately 2,000 homes and a 36-acre lease in 2020 to the University of California for the development of the Berkeley Space Center.[13] In the spring of 2024, the US Geological Survey entered the final stages of its office move from Menlo Park to NASA Research Park, enabling further collaboration.[14]

Visitors tour the fan and test section of the 80-by-120-foot wind tunnel at Ames. Photo by Don Richey courtesy of NASA

Electricity for the Future
Bloom Energy

One product of NASA's strategy to commercially deploy the technologies that it originates is Bloom Energy, a San Jose company that uses solid oxide fuel cells that produce on-site energy for commercial facilities. Founded as Ion America in 2001, its technology was originally developed at NASA by founder KR Sridhar to convert atmospheric gases on Mars into oxygen for use for propulsion and life support.[15] Bloom's distributed energy generation platform is a technology that now supports decarbonization by converting natural gas, biogas, and hydrogen to electricity without combustion.[16] Bloom manufactures the solid oxide fuel cells contained in its Energy Servers, selling this modular system to its customers, with each "Bloom Box" producing approximately 300 kilowatts of electricity in a footprint about the size of a standard 30-foot shipping container.[17] Bloom Energy Servers can be integrated into microgrids capable of both generating and storing electricity on-site and operating independently of the utility grid, enabling business operations even during power outages.[18] Bloom's technology is deployed at an array of leading companies, including Honda, Owens Corning, Adobe, Sutter Health, Kaiser Permanente, Google, Medtronic, FedEx, Panasonic, Hines, Staples, Ikea, Intel, Agilent, Illumina, Target, Lockheed Martin, Verizon, Safeway, Macy's, Comcast, and Juniper Networks, among others.[19]

Vertical Takeoff and Landing
Electrified Urban Aviation

As a key element of its focus on how our airspace will be used in the future (including drones and unpiloted vehicles), NASA Ames Research Center is collaborating with electric vertical takeoff and landing (eVTOL) aircraft maker **Joby Aviation**, a Santa Cruz company, on air traffic control and how to help the Federal Aviation Administration (FAA) and air traffic controllers anticipate an urban transportation future that includes air taxis. Toyota is an investor and provides engineering expertise on factory layout, manufacturing process development, and high-volume production for electric air taxis for commercial passenger use. With its manufacturing facility in Marina (Monterey County), 1,500 employees, and offices and workshops in Santa Cruz, San Carlos, Washington, DC, and Munich, Joby produces eVTOL aircraft powered by six electric motors, aiming at a bookable commercial ridesharing market. Each air taxi is designed to carry a pilot and four passengers at speeds of up to 200 mph.[20]

With 30,000 miles flown on full-scale prototype aircraft, in 2020 Joby became the first eVTOL company to receive military airworthiness approval from the US Air Force, and its first aircraft was delivered to Edwards Air Force Base in 2023. Joby's partnership with the Department of Defense dates to 2016, when it was awarded early funding by DOD's Silicon Valley-based Defense Innovation Unit (DIU) and access to test ranges and development expertise.[21] Late-stage testing is currently underway with the FAA to certify the Joby aircraft for commercial operations.[22]

Joby is one of several Bay Area companies that focus on the development of advanced aircraft for civilian and military use as air taxis, including **EZ Aerospace** (which has been contracted by the US Air Force to explore the feasibility of using air taxis to transport personnel and cargo),[23] Santa Clara-based **Archer Aviation** (a producer of eVTOL aircraft, with partnerships with the US Air Force, United Airlines, and Abu Dhabi-based Falcon Aviation Services),[24] and **Wisk Aero** (a Mountain View-based autonomous eVTOL air taxi company, now a subsidiary of Boeing).[25] In June 2024, Archer signed an MOU with Kilroy Realty Corporation to develop Archer's planned Bay Area Urban Mobility Network to connect locations in South San Francisco, Napa, San Jose, Oakland, and Livermore, with Kilroy's 50-acre Oyster Point development in South San Francisco serving as a hub.[26] Palo Alto-based **Pivotal Aero** produces the single-seat Helix eVTOL aircraft, which currently qualifies as an ultralight personal recreational aircraft but could be repurposed as an air taxi as the market develops.[27]

Joby aircraft production prototype. Source: Joby Aviation

Ames Visitor Center at Chabot Space & Science Center. Photo by Don Richey courtesy of NASA

Making Science and Space Accessible to Learners of All Ages

Chabot Space & Science Center

Chabot Space & Science Center, located in the hills above Oakland, traces its roots to 1883 and the acquisition of an 8-inch refracting telescope donated by its founder, Anthony Chabot. A 20-inch refracting telescope was added in 1915[28] and a 36-inch reflector telescope in 2003.[29]

The Center's core mission is educational, offering visitors hands-on, interactive exhibits, telescope viewings, workshops, summer camps, and planetarium shows that explore the mysteries of the universe and life on earth.[30] In the latest expansion of its educational mission under a five-year agreement that commenced in 2021, Chabot hosts the official visitor center of NASA Ames Research Center. The two organizations' long-term collaboration was launched with "The NASA Experience," an immersive, dynamic STEAM (science, technology, engineering, art, and math) environment designed to bring engaging and accessible NASA learning opportunities to the Bay Area community.[31] In addition to hands-on design-and-build experiences, the Visitor Center features historic NASA cutting-edge technology items, including a replica of the VIPER rover developed at Ames to search for water on the Moon, spacesuits from the Mercury and Gemini missions, and a fan blade from the world's largest wind tunnel.[32]

Chabot's educational mission is embodied in the Oakland Space Academy, a workforce development initiative designed to connect Oakland youth, particularly those from low-income partner high schools, with career employment in the space sector. Starting in the tenth grade, it continues two years after graduation, spanning the transition from high school to initial college and career experiences. Beginning with the high school Galaxy Explorer (GE) program, students take on increasing levels of responsibility through work-based learning opportunities in the Science Center with a focus on building career-ready, durable skills. Concurrently, they participate in space-related challenges in astronomy, digital media, environmental imaging, and engineering. The experience can lead to internships at Chabot or Ames and to post-graduation career support.[33]

Berkeley Space Center at NASA Research Park

"This will represent the largest presence of the University of California in Silicon Valley."

Darek DeFreece, Regent Emeritus, University of California, Executive Director and UC Berkeley's lead representative, Berkeley Space Center

In October 2023, the University of California, Berkeley, NASA Ames Research Center, and San Francisco developer SKS Partners announced the launch of the proposed Berkeley Space Center at NASA Research Park. Building on a 99-year ground lease of 36 acres signed in 2020, the $2 billion innovation hub will be a 1.4 million-square-foot research and education campus that will also include student and faculty housing units and 18 acres of open space. The first building is expected to open in late 2028. An estimated 10% of the R&D space will initially be occupied by UC Berkeley,[34] and eventually, together with other UC affiliates, 40% or more occupied over time. The balance of the space (over 1 million square feet) will be available to private sector partners to lease or build bespoke facilities. Researchers, scientists, faculty and students from UC Berkeley, NASA, and private companies with aligned missions will conduct research in fields spanning aerospace, quantum computing, climate science, wildfire research, and urban air mobility. Related fields of research include the electrification of aircraft (alternative fuels), advanced materials, advanced manufacturing, life in extreme environments, and astrobiology (how to keep humans alive on future missions to Mars).[35]

When the Berkeley Space Center is operating, UC Berkeley students could spend a semester studying, working, or conducting research with NASA or private companies. UC shared facilities, programs, and services resources will be leveraged with NASA's wind tunnels, thermal testing facilities, flight simulators, and other labs to accelerate discovery and talent development, the commercialization of intellectual property, and the incubation of early-stage companies. As described by Darek DeFreece, who has worked on the project since inception and largely architected its unique structure, "For Berkeley, this represents a new business model. The collaboration with NASA is about strengthening and enabling research and doing bigger and better things. The other leg of the stool is engagement with private industry and connecting basic research to the market through public-private partnerships and the spurring of new startups and early-stage companies."[36]

This new research and training capacity, combined with the space sector in Southern California, will strengthen California's leadership in aerospace, advanced aviation, and deep technology at the national level.

SETI Institute

Launched in 1984 under the leadership of pioneering radio astronomer Dr. Jill Tarter and CEO Thomas Pierson, the SETI Institute is a nonprofit research, education, and public outreach organization dedicated to astronomy, planetary science, astrobiology, and the search for extraterrestrial intelligence. The Institute grew out of a small project being developed at Ames Research Center–NASA to search for artificially generated radio signals from a distance of up to 1,000 light-years. Due to the realization that the NASA project was seriously overscoped for the amount of funds available, a team came together to form the SETI Institute as a new nonprofit research institution that could maximize the effectiveness of grant funding, putting more money into research and less into institutional overhead. [37] The first project in the Institute's portfolio became known as the NASA SETI Program (later renamed the NASA Microwave Observing Project), but when Congress canceled federal support for radio astronomy technology searches in 1993, the Institute quickly evolved to operate with private funding. Head of research and development at Hewlett-Packard Barney Oliver, who had funded Tom Pierson's initial work to found the Institute,[38] called four of his personal friends in the high-tech sector—Microsoft co-founder Paul Allen, HP principals Bill Hewlett and Dave Packard, and Intel CEO Gordon Moore—who each agreed to contribute a million dollars annually over a five-year period.[39]

More recent supporters have included Franklin Antonio, a co-founder of Qualcomm and an active member of the SETI engineering team until his passing in 2022. Antonio left a sizable bequest to the Institute that continues to fund SETI research, postdoctoral fellowships, and internal research.[40] Much of the SETI Institute's research today is federally funded, predominantly by NASA, and conducted by scientists in its **Carl Sagan Center for Research.** Non-federal support, including donations, private grants from foundations and individuals, and corporate partnerships, make up the balance, accounting for approximately 13% of revenue.[41]

Over 100 research scientists and affiliates currently work in more than 20 fields of inquiry in the natural sciences. From chemistry and physics to geology and astronomy, biology, and the search for extraterrestrial intelligence, scientists at the Institute investigate the prospects for life (biology) in the solar system and beyond through laboratory research, global field expeditions, ground and space-based telescopes, radio telescopes and interferometers, advanced data analytics, machine learning, and other tools. Activity includes investigating planets and moons in our solar system and the study of Earth-like exoplanets that are orbiting other stars. Researchers look for signs of life (biosignatures) in these planetary environments and signs of engineered technologies that would constitute a definitive indication of extraterrestrial intelligence.[42]

Since Earth is the primary laboratory for astrobiology and the study of life in the universe, SETI research also produces valuable insights into life on earth in fields such as biodiversity, climate change, and habitability. Carl Sagan Center Director Nathalie Cabrol, who has studied how life survives in the harsh conditions of Chile's Atacama Desert as a stand-in for Mars, puts the carry-over of space research to environmental applications on Earth at the center of the discussion: "I just finished writing the Strategic Vision (for research) of the SETI Institute and in it, I made sure that the preservation of our environment is absolutely central. Our planet is front and center, and I open the CSC to more environmental sciences. I want us to take the science and technologies we develop for space and planetary exploration and use them for the benefit of our planet right here and right now."[43] Future plans call for the establishment of a new Climate and Earth Science Research Division.[44]

In addition to observational, experimental, and theoretical research, SETI Institute scientists also develop technology and instrumentation, including the CheMin (Chemistry and Mineralogy) x-ray diffraction instrument on the Mars Science Laboratory Curiosity rover[45] and highly sensitive Raman spectrometers[46] to look for life on future missions to Jupiter's moons Europa, Enceladus, and Titan.[47] The SETI Institute's primary science output consists of research published in peer-reviewed scientific journals, such as *Nature, Science, Monthly Notices of the Royal Astronomical Society, Journal of Applied Physics, and Proceedings of the National Academy of Sciences.*

Karl G. Jansky Very Large Array (VLA) radio telescopes observing together create—in effect—a single telescope many miles across on the Plains of San Augustin in central New Mexico. Photo by CGP Grey on Wikimedia Commons

Radio telescopes in the 42-dish Allen Telescope Array at Hat Creek Radio Observatory in California. Source: SETI Institute

The search for radio signals in the Milky Way galaxy and beyond occurs at SETI's **Allen Telescope Array (ATA)** in Hat Creek, Northern California. One of the largest searches for extraterrestrial life that humanity has ever undertaken is taking place on the Very Large Array (VLA) in New Mexico, the world's most productive radio telescope. In partnership with the National Radio Astronomy Observatory (NRAO), **COSMIC** (the Commensal Open-Source Multimode Interferometer Cluster), which operates on the VLA, is a SETI observation program targeting 40 million galactic star systems. A new program, Laser SETI, is an all-sky camera system deployed globally that is designed to look for pulses of laser light originating from beyond our solar system.[48]

The Allen Telescope Array is the first radio telescope designed and built specifically to search for technosignatures outside our solar system as a proxy for life and intelligence beyond Earth. Previous searches used radio telescopes, like the 305-meter dish in Arecibo, Puerto Rico, built for conventional astronomical observations. However, other experiments conducted at those facilities restricted the time available for SETI. Construction of the Allen Telescope Array and its 42 dishes sped stellar reconnaissance searches by 100x and allowed for the simultaneous search of multiple targets.[49] The array can form three simultaneous beams and can listen to 72 million 1 Hz radio channels simultaneously.[50]

In addition to scientific research, the SETI Institute carries out STEM education programs through its Center for Education. Programs include professional teacher development at the middle school, high school, and college levels and informal programs for young learners in partnership with organizations such as Girl Scouts USA[51] (for which SETI and NASA support now offers space science badges).[52] Its NSF and privately funded Research Experience for Undergraduates (REU) program is a summer internship for college undergraduates that will celebrate its 20th anniversary in 2026.[53] Now in its fourth year, a NASA-funded initiative, the NASA Community College Network, brings NASA Subject Matter Experts (SMEs), research findings, and science resources into the nation's community college systems, helping faculty to enhance science literacy.[54]

SETI-produced tools and curricula also support local programs. In the East Bay, Space Science for Families, a collaboration with the Chabot Space and Science Center, provides monthly lectures for families delivered by SETI scientists.[55] SETI also partners with Foothill

College in Silicon Valley to provide non-technical science lectures[56] and has partnered with Evergreen Valley College in San Jose on a paid internship for STEM students.[57] For a wider audience, the SETI Talks lecture series features scientists discussing new discoveries and cutting-edge research at free live events that are also recorded and made available on YouTube.[58]

SETI also operates the Frontier Development Lab (FDL) research initiative in a public-private partnership with NASA and the US Department of Energy.[59] FDL is an applied space science AI/machine learning research program that invites early-career PhDs to work in teams of science and domain experts on curated, tightly-defined science challenges in a 12-month definition-to-result cycle anchored by an 8-week summer research sprint. Each year, interdisciplinary teams of computer scientists and researchers with deep knowledge in the problem domains tackle intractable problems in heliophysics, astrobiology, astrophysics, planetary and lunar science, climate adaptation and resilience, disaster management, planetary defense, astronaut health, and more, applying the latest techniques and advances in artificial intelligence, machine learning, and computational power to explore the impact of AI and machine learning technology on basic research questions. Private sector partners include Google Cloud, NVIDIA, Lockheed Martin, Planet, and Intel.[60]

In 2024, the Institute launched its new postdoctoral research fellowship program, funded by the Franklin Antonio bequest. The initial two full-time, two-year fellowships are the Baruch S. Blumberg Postdoctoral Fellowship for Astrobiology (focusing on pioneering biosignature detection methods to push the boundaries of current research) and the William J. Welch Postdoctoral Fellowship for SETI and Technosignatures (focusing on radio astronomy techniques engineering for future cosmic exploration).[61] Also in late 2024, SETI announced the call for applications to the 2025 Frank Drake Postdoctoral Fellowship focusing on "Innovation in the Search for Life in the Universe" and covering a wide range of fields, including astronomy and astrophysics, astrobiology, climate and biogeosciences, exoplanets, planetary exploration, and SETI intelligence and technosignatures.[62] The fellowship honors astronomer Dr. Frank Drake, chairman of the SETI board of trustees for 19 years, who conceived the "Drake Equation" in 1961 to estimate the number of communicative extraterrestrial civilizations that might exist in our galaxy. The equation has continued to serve as an effective framework for the planning of efforts to detect extraterrestrial intelligence.[63]

Lick Observatory

At the top of 4,265-foot Mount Hamilton and viewable from much of the region, the Lick Observatory is home to nine operating telescopes,[64] including Shane, a 10-foot-wide mirror that targets stars as far as 150,000 light years away and celestial objects such as quasars that may be a billion light years from Earth.[65] Operated by the University of California since 1888 and close to San Jose, Lick was the first permanently occupied mountaintop observatory in the world.[66] In the late 1800s, its 36-inch refractor was briefly the world's largest telescope,[67] and later, for a time, its 120-inch telescope (Shane) was the world's second largest.[68] Completed in 1959, the Shane Telescope helped keep Lick Observatory at the forefront of modern astronomy, and it has continued to yield scientific discoveries and is still heavily used by UC astronomers.[69] Since the natural turbulence of the earth's atmosphere causes blurring of astronomical images recorded over a period of time, adaptive optics (AO) systems are needed to compensate, and Lick Observatory engineered the first astronomical Laser Guide Star (LGS) system, making AO more practical. Similarly, the Lick Infrared Camera—now retired but originally used with two Lick observatory telescopes, Shane and Nickel—was at the forefront of the development of infrared (IR) observation (the measurement of wavelengths that we perceive as heat), which is another compensating technology needed to meet the problem of light pollution from surrounding communities that reduces the accuracy of observatory observations.[70]

The Lick Observatory is also known for its two robotically operated telescopes. The Automated Planet Finder (APF) is the world's first robotic telescope capable of detecting possibly life-supporting planets in other solar systems, and by operating automatically on every clear night, it greatly increases the chances of detecting extrasolar planets.[71] The Katzman Automated Imaging Telescope (KAIT) is a 30-inch computer-operated robotic telescope that has achieved breakthroughs in the early detection of supernovas.[72]

View of Mount Hamilton, showing the Lick Observatory domes of the Shane telescope (left) and the Automated Planet Finder (right). Photo by Micheal from San Jose on Wikimedia Commons

Lick Observatory facilities are actively used in training students and as the University of California's test bed for astronomical instrumentation. The Observatory also hosts a robust visitors program, attracting tens of thousands of visitors annually to daytime and nighttime tours and events, and plays an active role in science education for California students of all ages.[73]

SRI

SRI, an independent nonprofit research organization with both federal and private clients, has a rich history in space exploration research, development, and production, including CubeSats, SmallSats, and large satellites, as well as ground-based telescopes, radars, and antennas. SRI's achievements and strategic initiatives include advancements in

- satellite communications and networking;
- positioning, navigation, and timing;
- imaging and radio frequency (RF) radar sensors, data processing, and exploitation;
- AI and ML algorithms;
- cybersecurity for a range of applications, including terrestrial observation;
- environmental and weather monitoring; and
- space situational and domain awareness.

One of SRI's communications advancements focuses on the development of optical arrays to enable communication across proliferated Low Earth Orbit (LEO) satellites. SRI scientists are developing compact, lightweight, optical arrays that use light to beam data at ultra-high-speed rates within constellations of satellites.[74]

Another area of SRI's many satellite sensor programs is the design, development, and production of custom-made cameras for space exploration, currently for imagers that NASA will use in its Ultraviolet Explorer (UVEX) mission. In 2030, this mission will survey ultraviolet light across the sky to further understand the evolution of stars. The new system is expected to be 50 times more sensitive than NASA's previous ultraviolet survey telescope, which was decommissioned in 2013.

Earlier versions of SRI's complementary metal oxide semiconductor (CMOS) imagers are orbiting the sun in NASA's Parker Solar Probe and the European Space Agency's Solar Orbiter, gathering data on the sun's corona to better understand and forecast solar weather events. SRI's CMOS imagers are also being used in NASA's recently launched Europa Clipper Mission, currently on a six-year trip to Jupiter to map the surface of its, moon Europa.[75]

University Programs

> “The Bay Area draws on the newest and most advanced technology to do things that wouldn’t otherwise be possible.”
>
> George Blumenthal, Chancellor, UCSC

UC Santa Cruz

The University of California, Santa Cruz hosts a world-leading Department of Astronomy and Astrophysics. Its inception dates to the 1960s, when Lick Observatory was incorporated into the UC campus structure as part of the **University of California Observatories (UCO)** unit headquartered at UCSC, and a group of professional astronomers working at Lick moved to the Santa Cruz campus, giving it a major department from the moment its doors opened in 1965.[1] Since then, UCSC scientists have designed the Fermi Gamma-Ray Space Telescope, the Keck Observatory telescopes on Mauna Kea in Hawaii, and the Automated Planet Finder at Lick Observatory, and they have figured out how to fix the flawed optics on the Hubble Space Telescope and have partnered with NASA on projects including the Kepler planet-finding telescope and the Cassini mission to Saturn.[2] UCSC’s faculty includes well-known scientists such as Professor of Astronomy and Astrophysics Jonathan Fortney and Professor/Astronomer Emeritus of Astronomy and Astrophysics Garth Illingworth, both of whom were recognized in the 2023 Highly Cited Researchers List compiled by Clarivate, which identifies researchers throughout the world whose papers rank in the top 1% of citations in their respective fields.[3]

UCSC offers undergraduate courses in astronomy and an undergraduate physics/astrophysics major through its Physics Department,[4] and it supports approximately 50 PhD students through the Astronomy and Astrophysics Department. Graduate students have access to the observational facilities operated by UCO—the Lick Observatory on Mount Hamilton (administered by UCSC), and the twin 10-meter telescopes, the world’s largest, at the Keck Observatory in Hawaii (which is jointly operated by UCSC, Caltech, and NASA).[5]

In addition to its UCO-managed participation in both the Lick and Keck observatories, the Department of Astronomy and Astrophysics works closely with other related research organizations and facilities that are located on the Santa Cruz campus or administered by UCSC. The **Other Worlds Laboratory (OWL)** seeks through observations and computer modeling to understand diversity within our own solar system, as well as the formation and evolution of planets around other stars and the potential for life on worlds beyond the Earth. The **Laboratory for Adaptive Optics (LAO)** focuses on exploratory research in the development of adaptive optics systems for astronomical telescopes. Theoretical Astrophysics Santa Cruz (TASC) is a new group of 14 faculty that constitutes the largest grouping of computational astrophysicists in the world. In collaboration with members of UCSC’s Digital Arts and New Media Center, TASC has launched an interdisciplinary program in scientific computation and visualization, and it is also spearheading a plan to create a PhD program in high-performance supercomputing in cooperation with the Baskin School of Engineering's Department of Applied Mathematics.[6]

The ability of UCSC and its partners to leverage the region's technology and computational capacity can particularly be seen in its role, together with Lawrence Livermore National Laboratory, in the development of adaptive optics (AO)—optical systems that can compensate for observational distortions caused by light and fluctuations in the Earth's atmosphere. Adaptive optics have also been used for applications connected to the human eye.

Another example is the transformational role that UCSC scientists are playing in telescope design. Large telescopes are extremely expensive, requiring deep glass fields that must be rigid, and heavy steel to prevent distortions as mirrors are moved. For these reasons, the 200-inch mirror at the Palomar Observatory in Southern California long represented the technology's practical limit. The challenge was how to break this barrier. The answer, first developed at UC Berkeley and later at UCSC, was the use of multiple mirrors, calibrated by computers, that fit together and adaptively change their orientation to produce a consistent field. The successful deployment of this technology—a "segmented mirror telescope"—at the Keck Observatory in Hawaii is framing the effort to develop a new 30-meter mirror, which once deployed will be the world's largest. The same technology—developed in the Bay Area—has been deployed in NASA's James Webb deep space telescope, now in orbit around the L2 Lagrange point in space.[7]

UC Berkeley

UC Berkeley's astrophysics and planetary science programs, its research, and its external partnerships make it a leading center in the field. The campus claims more than 300 active contracts and grants funded by NASA, supporting work by faculty across nine departments spanning five colleges: Astronomy, Chemistry, Civil and Environmental Engineering, Electrical Engineering and Computer Science, Energy and Resources Group, Environmental Science, Physics, Policy and Management, and Mechanical Engineering.

The **Space Sciences Laboratory (SSL)** is the heart of the university's space programs. Roughly 150 contracts and grants (about half of the NASA-funded total on the campus) are in place between NASA and the Lab, most with individual faculty members and small teams of researchers.[8] Since its founding in 1959, SSL has participated in over 50 NASA space science missions, including the Apollo, Mars, and Explorer programs, and many international space missions. These relationships build on unique engineering and technical capabilities that enable the lab to develop and fabricate space instruments, complete scientific payloads, or implement from end-to-end the technical components of an entire space mission.[9]

Approximately 400 people work on SSL programs, including faculty, research scientists, students, engineers, technicians, and programmers, split between the lab's own facilities and the adjacent Lawrence Berkeley National Laboratory.[10] Major areas of research include: the solar system (planetary science), geospace (Earth's space environment from the middle atmosphere to the outer edge of the magnetosphere), heliophysics (the Sun and its extended atmosphere), astrophysics and exoplanets (using measurements from space-based and ground-based instrumentation to gain understanding about the history and structure of the universe, and searching for habitable planets and extraterrestrial life), mission operations (through its Mission Operations Center, Ground Station Network, Flight Dynamics and Mission Design group, and Space Data Center), engineering (designing, building and testing hardware for a variety of space and ground based projects, and executing full space missions), and information technology (maintaining a network of servers, computer workstations, and test equipment for use by researchers and staff).[11]

Under a grant from NASA, UC Berkeley and four other universities (including Stanford University and UC Davis) participate in the **Center for the Utilization of Biological Engineering in Space (CUBES)** with the mission of enabling biomanufacturing that supports deep space exploration. CUBES divisions focus on Microbial Media and Feedstocks (transforming human and mission wastes into media and feedstocks for downstream process utilization), Food and Pharmaceutical Synthesis (using plant and microbial engineering in space to produce food and pharmaceuticals for astronauts), Biofuel and Biomaterial Manufacturing (the production of propellants, biopolymers, and chemicals to recycle products at end-of-life and to use generated biopolymers in 3D printing), and Systems Design and Integration.[12] Focal points include both synthetic biology and the in situ utilization of space resources. By recycling in situ resources to manufacture products needed in extended space missions, and by reducing the mass and costs of related manufacturing infrastructure, CUBES will ultimately support a manned mission to Mars.[13]

In its mission dedicated to training the next generation of researchers and educators, UC Berkeley's Department of Astronomy offers a full range of degree programs, including undergraduate majors and minors and graduate Masters and PhD programs.[14] Astronomy courses cover an array of topics, ranging from comprehensive overviews of modern cosmology, astronomy, and astrophysics to special courses and labs, including infrared, optical and radio astronomy, theoretical astrophysics, and spectroscopy.[15] The Astronomy graduate program offers a variety of specialized courses, including interstellar matter, high-performance computing, astrophysical fluid dynamics, and extragalactic cosmology and astronomy.[16] In addition, PhD degree programs offered by the UC Berkeley Physics Department include research opportunities in astrophysics and cosmology, space physics, and related fields.[17]

In the fall of 2022, UC Berkeley's College of Engineering launched a new comprehensive Aerospace Engineering program, anchored by a new undergraduate major initially hosted in the Department of Mechanical Engineering.[18] The program is designed to train leaders in emerging technologies related to sustainable aviation, autonomous flight, and space exploration and is built around a dual focus on space exploration and low-altitude mobility.[19] After the Berkeley Space Center at NASA Research Park is established, the university plans call for additional advanced degrees in aerospace engineering.[20]

Research led by students as well as faculty is breaking technology barriers to advance space missions. One example produced by a team of researchers led by PhD student Taylor Waddell is the development of a next-generation 3D printer that operates rapidly and effectively in microgravity. On June 8, 2024, the printer—dubbed SpaceCAL—was carried into space as part of the Virgin Galactic 07 mission. While in suborbital space for 140 seconds, it autonomously printed four test parts. CAL (Computed Axial Lithography) technology stands apart from other 3D printing systems because of its ability to produce parts extremely rapidly, in as little as 20 seconds, enabling astronauts to print needed parts on demand and in emergencies and reducing the need to carry spare parts into space. According to Waddell, "You can reduce that upmass, make these missions go faster, and reduce risk by bringing manufacturing technologies with you. So, with the cabin, if your spacecraft is breaking down, you can print O-rings or mechanical mounts or even tools. But CAL is also capable of repairing the crew. We can print dental replacements, skin grafts or lenses, or things personalized in emergency medicine for astronauts, which is very important in these missions too." Waddell and fellow researchers also see long-term benefits for residents on Earth. A team led by Hayden Taylor invented the CAL technology in 2017, and the space mission project grew out of years of research by all the students in Taylor's nanoscale manufacturing lab at Berkeley and was funded through a $1.4 million grant and engineering support provided by NASA.[21]

UC Davis

The UC Davis **Center for Spaceflight Research (CSFR)**, led by Professor Stephen Robinson (a former NASA astronaut) with collaborators Professors Zhaodan Kong, Sanjay Joshi, and Rich Whittle, investigates human spaceflight from multiple viewpoints, including engineering, computer science, chemistry, neuroscience, and psychology. Four labs form the CSFR: the Human/Robotics/Vehicle Integration and Performance Laboratory (HRVIP); the Cyber-Human Physical Systems Lab (CHPS); the Robotics, Autonomous Systems, and Controls Laboratory (RASCAL); and the Bioastronautics and eXploration Systems Laboratory (BXS). These labs investigate human performance in highly hazardous environments with the goal of improving safety, addressing physiological changes that the space environment induces in the human body, and developing tools, technologies, and countermeasures to minimize risk in human spaceflight.

The labs also focus on robotics, control systems, prosthetics, and the human-machine interface. One example is the development of a "space ambulance" that would transport an injured astronaut and an emergency medical crew member from the International Space Station to an airport on the ground within 90 minutes to get them to a hospital for medical treatment. The project is based on current and near-future space planes, whose wings could reduce the forces of atmospheric entry on astronauts and particularly the patient.[22]

Another noteworthy program is the Habitats Optimized for Missions of Exploration (HOME) Space Technology Research Institute (STRI) for Deep Space Habitat Design,[23] also led by Professor Robinson and launched with a $15 million award from NASA in 2019. UC Davis leads the project with partners at the University of Colorado Boulder, Carnegie Mellon University, the Georgia Institute of Technology, Howard University, the University of Southern California, and Texas A&M University.[24] A HOME STRI team of 75 researchers integrates engineering, research, and expertise in systems automation, machine learning, artificial intelligence, predictive analytics, robotics, and human-crewed spacecraft design to develop designs for deep-space habitats for NASA that are resilient and self-maintaining.[25]

Active research projects funded by NASA span the departments of Chemical Engineering; Civil and Environmental Engineering; Earth and Planetary Sciences; Land, Air, and Water Resources; Mechanical and Aerospace Engineering; Neurobiology, Physiology, and Behavior; Physics; and the School of Education.[26] These projects include spacecraft and habitat design, CubeSat design, human life-support systems and safety, space robotics, autonomous systems supported by machine learning, radiation protection, atmospheric entry, and metallic additive manufacturing.[27]

The Aerospace Science and Engineering program at UC Davis is housed in the Department of Mechanical and Aerospace Engineering (MAE). Founded in 1962 alongside the College of Engineering itself, an undergraduate MAE program prepares graduates to practice mechanical engineering and/or aerospace engineering across a range of professions.[28] In addition to traditional mechanical engineering fundamentals, fields of study include fluid mechanics and applied aerodynamics (with research in aeroacoustics, computational fluid dynamics, aircraft design and optimization, etc.); aerospace propulsion involving both air-breathing jet engines and rocket propulsion; structures and materials (with research in composite structures); and spacecraft engineering focusing on rocket propulsion, orbital mechanics, spacecraft design, human life-support in space, space environments, mission design, and systems engineering.[29] MAE also offers Master of Science and PhD degrees.[30] Research projects often result in internship and employment opportunities for students in organizations such as NASA, Lawrence Livermore National Laboratory, SpaceX, Blue Origin, Sierra Nevada, Lockheed Martin, Northrop Grumman, Aerospace Corporation, and Boeing.[31]

Ten campus research centers and over 23 individual research labs are associated with Mechanical and Aerospace Engineering faculty projects,[32] many sponsored by federal and state entities such as NASA (including NASA Ames Research Center and the Jet Propulsion Laboratory), the U.S. Army, the National Laboratories (Lawrence Livermore, Los Alamos, Sandia), the Wright-Patterson Air Force Research Laboratory, the National Science Foundation, and companies such as Boeing.[33]

Stanford University

Stanford's Department of Aeronautics and Astronautics was established in 1957 as a place to train future generations of aerospace and astronautical engineers. With a graduate program that ranks in the top three nationally,[34] the department added an undergraduate program in 2017.[35] Through the **Stanford Engineering Center for Global & Online Education (CGOE)** graduate certificates are also offered via courses delivered online that are tailored for students from industry.[36] Research programs focus on autonomous systems and controls, cyber safety for transportation, aircraft design, computational aerosciences, materials and intelligent structures, and distributed space systems. The department is also home to three interdisciplinary research centers: the **Stanford Center for Position, Navigation and Time**, the **Federal Aviation Administration (FAA) Center of Excellence for Commercial Space Transportation**, and the **King Abdul Aziz City for Science Technology (KACST) Center of Excellence for Aeronautics and Astronautics**.[37]

CubeSat technology, which condenses all the requirements for a space vehicle in 10 cm cubes that can be packaged together and is now widely used in Low Earth Orbit satellites, was developed on the campus by Professor Robert Twiggs with collaboration from Jordi Puig-Suari, a colleague at California Polytechnic University.[38] Stanford University Professor Antony Jameson led the early development of computational fluid dynamics (CFD).[39] GPS high-orbit technology, now widely used in navigation, was developed at Stanford by Professor Brad Parkinson through work originally done for the Air Force[40] and is the focus of an annual conference held at Stanford. The university also continues to play a leadership role in commercial space development. Professor Scott Hubbard, a former Director of NASA Ames, led the founding of COE CST (Center of Excellence for Commercial Space Transportation) and served as its first Program Director. Hubbard is currently the founding editor-in-chief of *New Space*, an independent peer-reviewed journal focusing on space entrepreneurship.[41]

Other University Programs

Other Bay Area universities support space research and training, including Sonoma State University and San Francisco State University through their Departments of Physics and Astronomy, and Santa Clara University through its Aerospace Engineering Program.

The International Space Station in Low Earth Orbit (LEO), approximately 250 miles above the Earth. Source: ISS National Laboratory

University and Industry Research on the International Space Station

University and industry-based specialists actively conduct research on the International Space Station (ISS). Through the ISS National Laboratory, more than 700 payloads have been delivered to the ISS since 2012, allowing a variety of users to advance research and technology that benefits humanity.[42] From 2014 to 2023, the Center for the Advancement of Science in Space (CASIS), which manages the ISS National Lab, has awarded 30 flight projects to researchers in the Bay Area across life and physical sciences, remote sensing, and space technology development, with studies ranging from fundamental science to later-stage applications and testing. Support from NASA for these projects (payload transport to orbit and back, astronaut time, terrestrial and orbital facilities) totals tens of millions of dollars, not including external R&D budgets that according to ISS data total more than $37 million.[43]

Twenty-three commercially owned and operated research facilities operated on the station in 2024.[44] Commercial space partners from the Bay Area that have been conducting research on the ISS include Skycorp and krtkl Inc. Non-commercial researchers represent many of the Bay Area's leading universities and research organizations, including the University of California, San Francisco, Palo Alto Veterans Research Institute, the University of California Berkeley, Lawrence Livermore National Laboratory, SRI International, and Stanford University.[45] NASA Ames Research Center is also closely allied with the International Space Station, and Ames scientists have an important research focus on better understanding the station's microbiome and how it evolves over time, so that solutions can be developed to mitigate future risks associated with crew health and mission integrity.[46] Novel biomedical research is the focus of multiple projects launched to the space station: 2024's projects included two involving the in-space production of stem cells, one testing the speed of stem cell growth and division in microgravity with an eye toward enabling future large-scale in-space biomanufacturing of cell-derived products for heart disease treatment, and the other aiming to develop a stem cell expansion bioreactor and protocols for its use in space.[47] Projects launched in 2023 included research being conducted by Dr. Joseph Wu at Stanford to test whether engineered heart muscle tissue grown in microgravity can be used as a model for heart failure to screen for potential new drugs.[48] The ISS National Lab issues a variety of research announcements throughout the year for which qualified researchers can apply.[49]

Federal Laboratories

Three National Laboratories—Lawrence Livermore National Laboratory (LLNL), Lawrence Berkeley National Laboratory (LBNL), and SLAC National Accelerator Laboratory—play research roles focused on high-risk engineering. LLNL is a leader in the development of adaptive lasers. LBL is a leader in the development of technology that supports ground-based astronomy. SLAC focuses particularly on instrumentation and data management. The proximity of these federal labs to UC Berkeley, UC Santa Cruz, and Silicon Valley has been instrumental in propelling the development of the Bay Area's space sector.

Lawrence Livermore National Laboratory

Lawrence Livermore's contributions build on decades of cutting-edge experiments and research in astrophysics and planetary science. Its Space Science Institute is the lab's hub for developing new space science mission concepts, instruments, and enabling technologies, and for growing the scientific and engineering workforce.[1] Multidisciplinary teams of researchers model, analyze, and interpret data generated by existing observatories and develop technologies and instrumentation for future ones.[2] Key contributions are based on the lab's deep expertise in optics, plasma physics, nuclear science, high-performance computing, and data science,[3] with applications including the study of dark matter, asteroids, and exoplanets.[4]

Lawrence Livermore's growing Space Program is the hub for analysis and mission support of new national security missions, as well as the development of payload technologies for missions in space. The Space Program utilizes novel instruments, advanced modeling and simulation tools, plus all-source intelligence analysis to support national security space programs.[5]

Planetary Science

LLNL is one of the world's foremost centers of research in cosmochemistry (the study of extraterrestrial materials). Researchers use its state-of-the-art suite of analytical equipment to study meteorites and extraterrestrial material returned to earth by space missions, with the goal of understanding the origin and evolution of the solar system and Earth's cosmic neighborhood. Advanced equipment for mass spectrometry has dated the first solids to form in the solar system, meteorites that formed beyond the orbit of Jupiter, rocks ejected from violent impacts on Mars, and lunar samples returned by Apollo missions. Discoveries include the timing of the Sun's creation and the age of the Moon (4.35 billion years).[6]

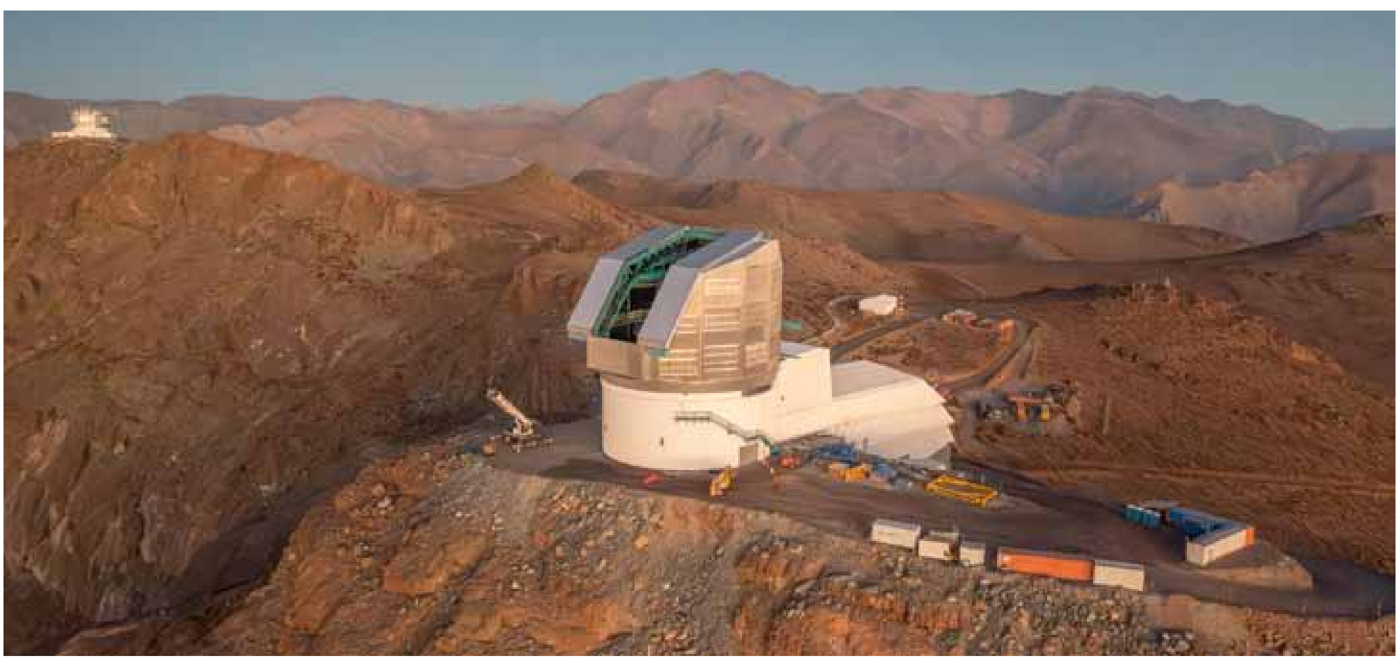
In the field of planetary defense, LLNL scientists use large-scale simulations on supercomputers to develop methods for defending Earth from collisions by asteroids. Researchers are developing methods for detecting and mitigating possible large Earth-bound objects, simulating methods to deflect or disrupt the trajectory of those that pose a threat, and modeling the consequences of an impact to inform emergency response. Lawrence Livermore researchers collaborated with NASA and the Johns Hopkins Applied Physics Laboratory on NASA's 2022 Double Asteroid Redirection (DART) test, the first successful demonstration of the kinetic impact technique[7] (which rams an unmanned spacecraft into an asteroid to transfer momentum that changes the asteroid's trajectory and motion in space).[8] In 2023, LLNL developed a modeling tool for assessing the potential use of nuclear devices to deflect potentially catastrophic asteroids.[9]

Astronomy and Astrophysics

Over several decades, Lawrence Livermore has produced advances in x-ray spectroscopic capabilities and associated plasma diagnostics for astronomy. Researchers work on instrument development and on science teams for x-ray astrophysics missions such as the joint NASA/JAXA X-ray Imaging and Spectroscopy Mission (XRISM) that launched in September 2023. Astrophysics work centers on the lab's Electron Beam Ion Trap (EBIT) facility, which provides high-accuracy measurements of x-ray emissions.[10]

LLNL researchers designed the large camera lenses for the world's newest telescope being built for the Vera C. Rubin Observatory in Chile, including a 5.1-foot-diameter lens that is believed to be the largest high-performance optical lens ever fabricated. Production was done by industry partners and delivered to SLAC (the SLAC National Accelerator Laboratory) in Menlo Park, which managed the design, fabrication, subcomponent integration, and final assembly of the Large Synoptic Survey Telescope's $168 million, 3,200 megapixel digital camera, the largest camera ever built for astronomy. LLNL's role has also included overall project management functions for the telescope's development.[11]

When operations begin in 2025, the Rubin Observatory will launch its ten-year Legacy Survey of Space and Time (LSST), surveying the entire visible sky to explore dark energy, exploding supernovae, and hazardous near-Earth asteroids. For more than a decade, Lawrence Livermore researchers have contributed to the Rubin survey strategy[12] and have developed new tools to analyze the massive image database that will record the estimated 17 billion stars and 20 billion galaxies that the LSST expects to view.[13] These advances include algorithms, machine learning techniques, and image processing tools deployed on supercomputers at LLNL and other national laboratories.[14]



Vera C. Rubin Observatory under construction on Chile's Cerro Pachón mountain in the Andes. Photo by Aliro Pizarro Dãaz, courtesy of Rubin Observatory/NSF/AURA

Researchers are developing new space mission concepts to study transient phenomena discovered by the Rubin Observatory and other facilities, including gravitational wave observatories.[15] This work combines LLNL's capabilities in optical astronomy with its expertise in small satellite payloads. Lawrence Livermore researchers are also contributing to the search for dark matter through their participation in initiatives such as the Axion Dark Matter Experiment (ADMX) and the International Axion Observatory (IAXO) experiment,[16] for which LLNL developed highly reflective mirrors that focus x-rays.[17]

Technology and Instrument Development

LLNL researchers are active in advancing capabilities for small satellites for both science and security missions. The lab's small satellite hardware team develops novel and cost-effective optical systems and technologies that emphasize the smallest form factors, to reduce the size of satellite payloads (the systems for control, communication, power, navigation and maneuvering). These systems are built in partnership with industry,[18] and a number of industrial partners are licensing these technologies. Efforts include the NASA-funded Pandora SmallSat mission to study exoplanets in conjunction with the James Webb Space Telescope,[19] as well as payloads for NASA's Small Satellite Technology Program and the US Space Force's Space Safari program.[20]

For several decades, LLNL has been at the cutting edge of adaptive optics (AO) that allow large telescopes on the ground (as opposed to telescopes in space) to compensate for the distortions of light caused by the Earth's atmosphere, enabling the detection of faint objects with very high resolution. Observations using adaptive optics have been used to advance our understanding of exoplanets (planets outside our solar system) and brown dwarfs (gas cloud formations lacking enough mass to become stars).[21]

Lawrence Livermore researchers have adapted gamma-ray spectroscopy technology (initially developed for terrestrial and national security applications) to build detector instruments deployed on current space missions, including NASA's Psyche mission to explore the unique metal-rich asteroid orbiting the Sun between Mars and Jupiter.[22] LLNL's GeMini-Plus gamma-ray detector is being used to determine the asteroid's elemental makeup, gravitational field, magnetic field, and geological features. These small, lightweight detectors are also planned for deployment on upcoming space missions to gather data on planet formation.[23]

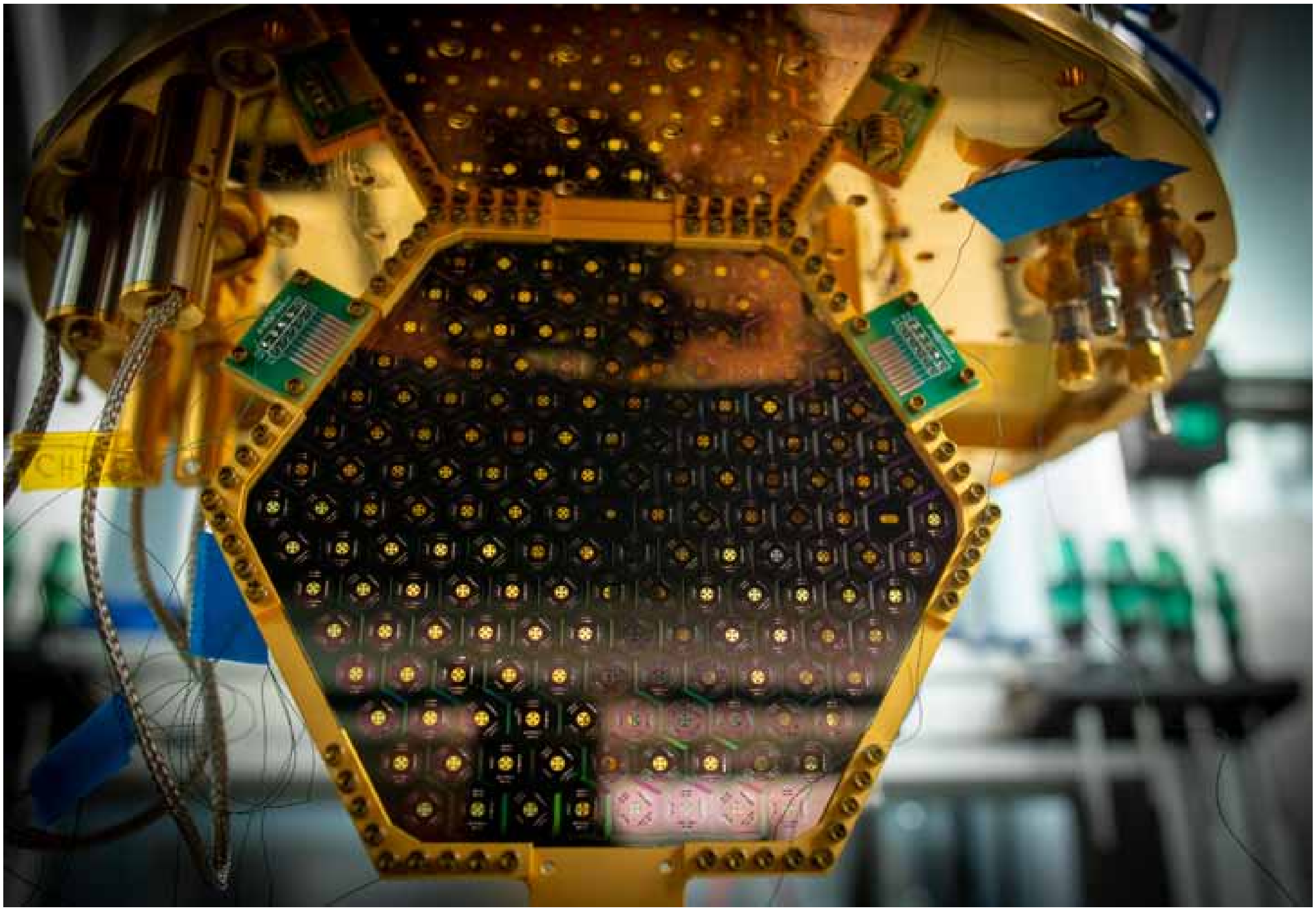
LLNL has developed and deployed multilayer coatings (thin-film layers deposited on an optical substrate) for the Atmospheric Imaging Assembly (AIA) instrument aboard NASA's Solar Dynamics Laboratory, the Solar Ultraviolet Imager (SUVI) telescopes aboard NASA/NOAA's Geostationary Operational Environmental Satellites (GOES), and other space missions. LLNL researchers develop optimized multilayer coatings and implement them for space missions to enable novel observations in the gamma-ray, x-ray, and extreme ultraviolet wavebands.[24]

Community Outreach

LLNL also engages in community outreach, particularly at the community college level. For the last 15 years, the Laboratory has organized with Las Positas College an annual LLNL-LPC Science and Engineering Seminar series, designed to connect the college community with research and the Lab[25] and highlight potential career pathways.

Lawrence Berkeley National Laboratory

Lawrence Berkeley National Laboratory manages the Dark Energy Spectroscopic Instrument (DESI) project, an international collaboration of more than 900 researchers at 70 institutions. Constructed and operated by the U.S. Department of Energy, DESI studies the effect of dark energy on the expansion of the universe and has created the largest 3D map of the universe ever made, measuring its rate of expansion 11 billion years into the cosmic past with high precision. Researchers have used 450,000 quasars (extremely distant bright galactic cores with black holes at their centers) to map pockets of dense matter and, by the end of the survey, plan to map 3 million quasars and 37 million galaxies.[26]



The CMB-S4 wafer detector is part of the advanced detector technology developed by Berkeley Lab. Photo by Thor Swift, courtesy of Berkeley Lab.

Operating in conjunction with the 88-inch cyclotron at Lawrence Berkeley National Laboratory, the **Berkeley Accelerator Space Effects (BASE) Facility** provides beams of heavy ions, protons, and neutrons for radiation effects testing. Its equipment has been used by more than 40 space missions led by NASA research and space flight centers, the European Space Agency, and the Japan Aerospace Exploration Agency.[27]

A current Berkeley Lab major project—in partnership with Brookhaven National Laboratory, UC Berkeley, and the University of Minnesota as part of a NASA and Department of Energy project collaboration—looks to close a 400-million-year gap in our understanding of the history of the universe at a time known as the Dark Ages before stars were born. The Lunar Surface Electromagnetics Experiment-Night (LuSEE-Night), using Berkeley Lab-built antennas to listen for those ancient radio waves, will be sent to the far side of the Moon in 2025. Berkeley Lab researcher Kaja Rotermund explains the experiment's uniqueness: "If you're on the far side of the Moon, you have a pristine, radio-quiet environment from which to detect this signal from the Dark Ages."[28]

Berkeley Lab and the University of Chicago co-lead a Department of Energy and National Science Foundation project, the Cosmic Microwave Background Stage 4 (CMB-S4) experiment, to map the light from the cosmic microwave background (CMB), the oldest and farthest light we can observe in the universe. The afterglow of the Big Bang, the CMB was first measured in 1964, revealing a snapshot of the universe as it existed almost 14 billion years ago.[29] Primordial gravitational waves, the ripples in space-time that would have been created if the universe did explode into being from a single space smaller than a subatomic particle, are a particular focus because they would interact with the CMB to create a distinct but extremely faint signature. Initial research focuses on the design of telescopes and cameras that will be used at locations in Antarctica and Chile to get a more precise picture of the cosmic microwave background, which will help scientists to understand the evolution and distribution of matter in the universe. The program is expected to provide unprecedented measurement precision, with fundamental new insights into physics.[30]

The LUX-ZEPLIN (LZ) experiment, an international collaboration led by Berkeley Lab, is the world's most sensitive detector of dark matter, the invisible substance that makes up most of the mass of the universe. Determining the nature of dark matter remains one of the greatest puzzles in physics. LZ has proved its ability to search for evidence of dark matter in previously unprobed areas and offers scientists the opportunity to push the search boundaries even farther in the future.[31]

SLAC National Accelerator Laboratory

SLAC, a Department of Energy national lab operated by Stanford University,[32] co-leads operations for the National Science Foundation-Department of Energy Vera C. Rubin Observatory, which will use the SLAC-built LSST Camera—the largest digital camera ever constructed—to search for dark matter and dark energy.[33] The Observatory will conduct the 10-year Legacy Survey of Space and Time (LSST), which will observe every part of the Southern Hemisphere sky, producing a massive amount of data that will help astronomers discover 37 billion new celestial objects.[34] SLAC also runs Rubin's US Data Facility, which manages the massive amount of data the LSST Camera will produce.[35] The Laboratory has a history of building such instruments and managing the data they collect, including the Large Area Telescope (LAT) which is the main instrument of the Fermi Gamma-ray Space Telescope.[36]

SLAC research also focuses on cosmology at the micro and macro scale, from cosmic rays impacting the Earth to the dark matter and dark energy that drive the evolution of the universe and the formation of galaxies. Fields of study include cosmic structure, the physics that shape the universe, extreme astrophysics (the laws governing phenomena such as black holes and neutron stars), and stellar, interstellar, and planetary astrophysics (the processes that govern the formation of stars and their planetary systems, including exoplanets).[37] Much of this work is done at the **Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)**, a Stanford University institute housed at SLAC.[38]

In addition, SLAC houses the Linac Coherent Light Source (LCLS)[39] and its Matter in Extreme Conditions (MEC) instrument. MEC is shedding light on some of the most extreme environments and states of matter in the universe,[40] including diamond rain that forms on distant planets[41] and the warm, dense matter found in the cores of giant gas planets and in the atmospheres of white dwarfs.[42]

Hubble and Webb

From national defense missions to meteorology and Earth observation, Bay Area laboratories and companies have been major contributors to US space capabilities, including the two leading deep space observatories, the Hubble Telescope and, more recently, the James Webb Space Telescope.

Sunnyvale's **Lockheed Martin Space Systems** designed and built the Hubble Space Telescope, which from its launch in 1990 until the launch of the James Webb Space Telescope in 2021 was the world's premier orbiting astronomical observatory, producing astronomical discoveries and images that amazed the world. Since 1990, Lockheed Martin personnel in Sunnyvale and at NASA's Goddard Space Flight Center in Maryland have managed the spacecraft operations of the telescope and provided preparation and training for in-space servicing missions that have both repaired and replaced components and extended the telescope's life and performance.[1]

As NASA searched for a worthy successor to Hubble, it tapped Lockheed Martin's Advanced Technology Center in Palo Alto once again to design, assemble, and support operations of the Near Infrared Camera (NIRCam),[2] the primary imager deployed in the James Webb Space Telescope. NIRCam is able to detect light from the earliest stars and galaxies as they were formed, as well as stars in nearby galaxies and the Milky Way. Pictures of very faint objects that have never before been seen around bright stars are now possible through technology that blocks the brighter objects' light.[3]

Tinsley Telescope and Instrument Company, now **Coherent Tinsley Integrated Optics Systems** with facilities in eight Bay Area locations, manufactures high-performance, large aperture optical mirrors for use in space, airborne, and ground-based astronomy, building on advanced capabilities in polishing, coating, assembly, and metrology. A producer of large-format optics for space exploration since the 1960s, providing universities and national laboratories with custom-built telescopes,[4] in 1993 Tinsley supplied the corrective mirrors used in the COSTAR instrument used to supply corrected light to compensate for a flaw in the shape of the Hubble Space Telescope's primary mirror.[5] More recently, Tinsley fabricated, polished, and coated the mirror used in the James Webb Space Telescope,[6] which is larger than Hubble and can use its deeper infrared vision to peer farther back into space and time. To shield itself from infrared radiation emanating from the Sun, Earth, and Moon, Webb needs to be much farther from Earth than Hubble is: Webb orbits the Sun with Earth at a distance of about one million miles from home, while Hubble orbits the Earth just above the atmosphere at a distance of 320 miles.[7] Coherent is the maker of 231 of the 492 hexagonal mirror segments required for the Thirty Meter Telescope,[8] which builds on the segmented mirror ideas of the existing telescopes at Keck Observatory in Hawaii but is designed with 3 times the aperture and 9 times the collecting power.[9]

The Hubble and Webb telescopes are complementary in their missions and capacities and frequently work together, teaming to produce the most definitive measurement of the rate of expansion of the universe. While Hubble has been operating for more than 30 years,[10] Webb is only at the beginning of its voyage, transmitting images and conveying data for less than two years.[11]

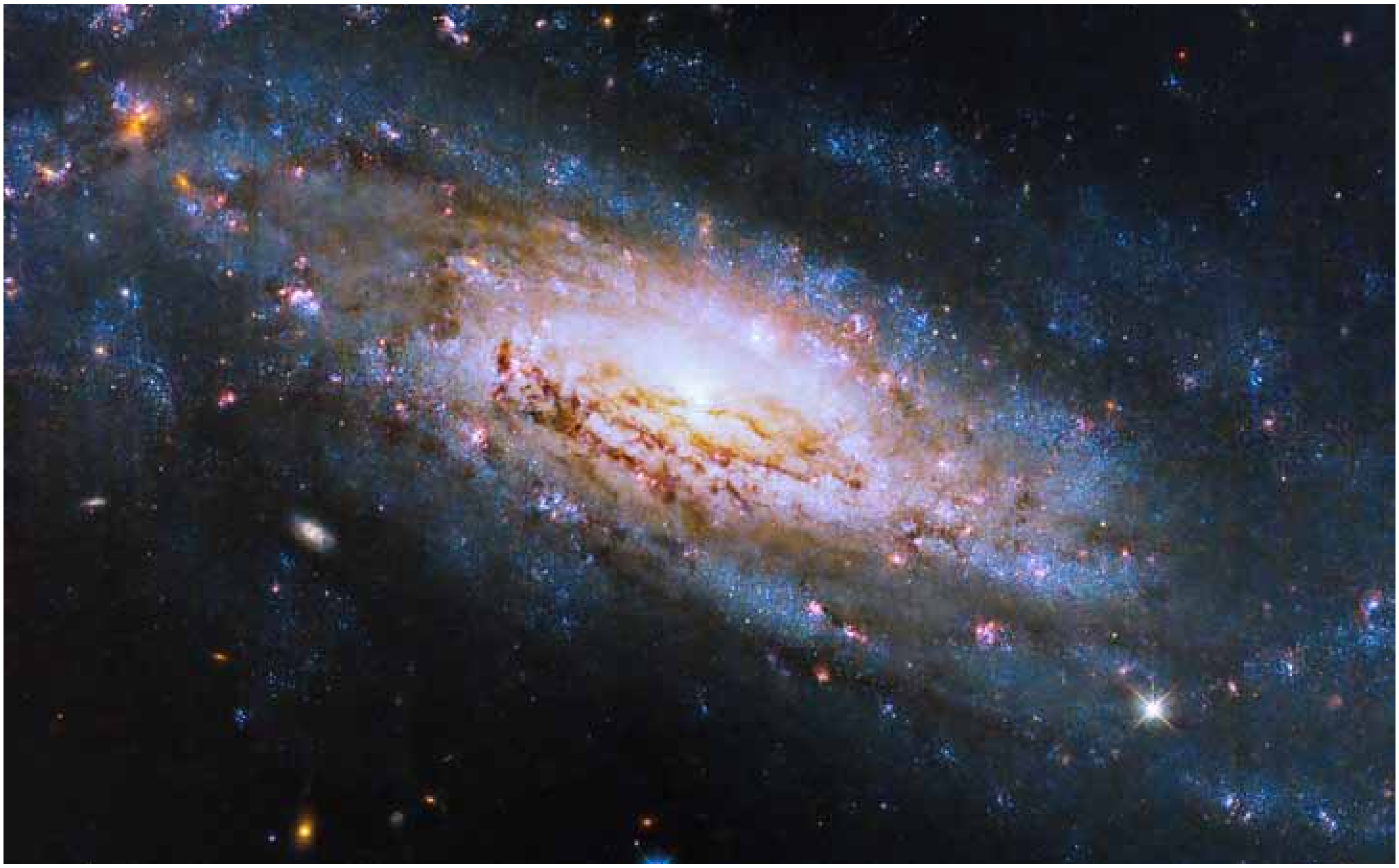
Changing Our View of the Universe

The Hubble Space Telescope

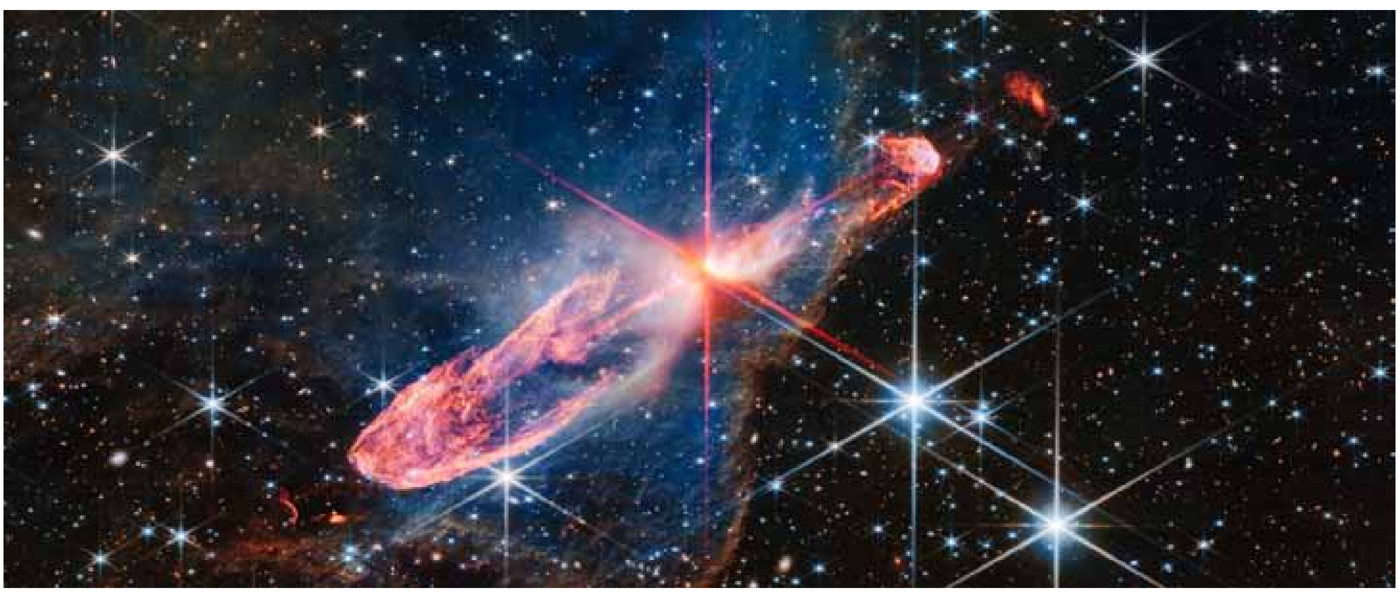
- has made over 1.6 million observations;
- has generated data used in more than 21,000 peer-reviewed scientific papers;
- transmits 150 gigabits of raw science to Earth each week;[12]
- helped confirm the age of the universe (1.38 billion years);
- helped determine the rate at which the universe is expanding;
- captured the first visual image of an exoplanet;
- detected organic molecules on an extrasolar planet;
- found water vapor erupting off the surface of Jupiter's moon Europa;
- discovered that nearly every major galaxy is anchored by a black hole at the center;
- discovered two moons of Pluto.[13]

The James Webb Space Telescope has

- discovered life-supporting molecules in the atmosphere of K2-18 b, a fairly nearby exoplanet that circles a cool star 120 light-years from Earth;
- detected galaxies formed close to the beginning of the universe, earlier than anyone had anticipated;
- detected the most supermassive black hole ever seen, which has a puzzlingly low mass—just 9 million times that of the sun (compared to most supermassive black holes, which weigh in at more than 1 billion solar masses);
- identified carbon dioxide in the salty liquid oceans of Jupiter's moon Europa;
- captured an image of 11 of the 13 known dusty rings around ice giant Uranus and an image of a previously unseen high-speed jet stream on Jupiter;
- found three bright objects that could possibly be stars powered by dark matter, the substance believed to make up most of the material universe but which cannot be seen by conventional telescopes;[14]
- detected the oldest known examples of complex organic molecules in the universe—similar to those found in smoke or soot on Earth—in a galaxy formed when the universe was just 10% of its current age;[15]



Hubble Space Telescope view of the black-hole-powered galaxy NGC 4951. Hubble helped prove that supermassive black holes exist at the core of almost every galaxy in our universe. Image credit: NASA, ESA, D. Thilker & Gladys Kober



James Webb Space Telescope view of two actively forming baby stars, buried deep in a disk of gas and dust that feeds their growth.
Over thousands of years, the pair repeatedly gobbled up, then spat out the material around them—producing the two asymmetrical fiery orange lobes whose shapes are influenced by interactions with a surrounding nebula, seen as a blue haze, as well as more recent ejections from the stars. Image credit: NASA, ESA, CSA. Image Processing: Joseph DePasquale (STScI)

Industry Anchors

Mirroring the region's academic research infrastructure is a specialized industrial research and production pipeline dedicated to space.

Lockheed Martin Space

A case can be made that the launch of Lockheed Martin's Bay Area facilities in 1956 played an important role in the creation of Silicon Valley and its technology economy. At that time, its Palo Alto research labs[1] were surrounded by orchards, and the takeoff of Silicon Valley in the early 1970s was still years away. Stimulated by Sputnik and the emerging space race with the former Soviet Union, the company's facilities attracted both talent and federal dollars. Its main facility in Sunnyvale, opened in 1957 adjacent to Moffett Field and NASA Ames Research Center, has over the years developed an array of innovations in both the space and defense sectors, including technology to help scientists monitor solar activity and track tornadoes, produce nanotechnology-based materials, design and produce satellites, and develop solar arrays that power satellites and the International Space Station. Today, the Sunnyvale facility is home to more than 3,000 employees deployed across a range of missions.

Lockheed Martin's **Advanced Technology Center (ATC)**, located in Palo Alto, anchors research, development, and prototyping operations that support the company's Space business. Other regional facilities are located in Pleasanton and Santa Cruz, which currently serves as a test site for space observation and laser technologies. Overall, Lockheed Martin employs nearly 10,000 individuals across California and a network of more than 2,100 suppliers who are central to the nation's defense industrial base.

Lockheed Martin has distinctive strength in the areas of systems engineering and integration, where it often serves as the prime contractor for major projects. The company's activity in the Bay Area focuses on human space flight, robotic exploration, global communications, surveillance and navigation, strategic and defensive systems, command and control systems, and instrumentation, including imaging sensors, advanced materials, advanced space electronics, cryogenics for remote spacecraft cooling, and advanced optical systems for space observation. Its customers span commercial space, the intelligence community, the US Army, the US Navy, the US Space Force, the Space Development Agency, NASA, and NOAA.

Increasingly supported by advanced AI and data analytics investments, Lockheed Martin's capabilities in space instrumentation lead the country. To date, the company's technologies have supported every NASA mission to Mars starting with the Mariner spacecraft in 1965 and have been instrumental in exploring every planet in the solar system. In all, more than 180 space instruments have been launched over six decades, with more than 800 years of collective operation.

Breakthrough innovations have included

- Tiros-1, the world's first weather spacecraft (1960);
- Viking, the first US mission to land a spacecraft on Mars and return images from the surface (1975);
- Ikonos, the world's first commercial remote sensing spacecraft (1999);
- Juno, the first solar-powered mission to Jupiter and the farthest spacecraft from the sun to operate on solar power (2011);
- the first test flight of the Orion spacecraft (2014);
- the launch of Lucy, NASA's first mission to visit Jupiter's Trojan asteroids (2021);
- the launch of Orion on Artemis I—the start of NASA's program to return humans to the lunar surface (2022); and
- the return of OSIRIS-REx, the first US mission to deliver samples from an asteroid to Earth (2023).[2]

Closer to home, the company is a major developer of early warning weather and climate observation satellites, having launched the newest and final satellite in the GOES-R series, GOES-U (now renamed GOES-19), from Kennedy Space Center in June 2024.[3] The GOES-R series, developed for NOAA, will be followed by a new series of geostationary weather satellites called GeoXO that will enter service in the 2030s to deliver more accurate weather forecasting and address emerging climate and environmental challenges. One GOES-R instrument of particular relevance to California is the Geostationary Lightning Mapper (GLM), developed in Palo Alto, that tracks lightning across the US in real time, taking 500 images every second and mapping both cloud-to-cloud and cloud-to-ground lightning.[4] Working with Santa Clara-based NVIDIA, the company is also building an AI-driven Earth and Space Observing Digital Twin (a software tool that provides a virtual representation of a real-world system) that will provide multi-sensor integration from numerous space and Earth-based sensors to give weather forecasters more accurate and timely depictions of global conditions.[5] This kind of data synthesis provides actionable intelligence that will help first responders, scientists, and businesses better prepare for increasing climate challenges such as severe storms, hurricanes, and wildfires.[6]

Building on a decades-long partnership with NASA, Lockheed Martin has developed a heat shield and thermal protection system (TPS) for Orion, the crewed spacecraft module at the core of the agency's Artemis program to return humans to the Moon,[7] and together with Ames Research Center has developed the Neutron Spectrometer System (NSS) designed to detect water under the surface of the Moon.[8] Lockheed Martin is on the National Team led by Blue Origin that NASA selected in 2023 to develop and build a sustainable human lunar lander for the Artemis mission, with an initial goal of performing a crewed demonstration flight to the lunar surface for Artemis V.[9] Lockheed Martin also produced one of three industry proposals selected by NASA to develop technologies for the Habitable Worlds Observatory, the first space telescope designed to search for life on Earth-like exoplanets orbiting sun-like stars outside our solar system. The mission will image planetary atmospheres for the chemical signatures of life.[10]

Lockheed Martin's Space 2050 vision anticipates what the space environment may look like in the future and the capabilities that should be developed now to meet them. Possibilities for major enabling capabilities include on-orbit refueling, servicing, and assembly of spacecraft;[11] nuclear thermal propulsion, which is two-to-five times more efficient than traditional chemical propulsion, to significantly cut travel times from Earth to the Moon and to Mars;[12] on-orbit manufacturing, including generative design and additive manufacturing to make parts, build structures, and create composites and other materials that will allow platforms to "self-heal" in the future;[13] and quantum technology, which enables the use of significantly less power to process more information and beam it securely at higher data rates.[14]

The company is also engaged with the region's broader innovation economy. Since 2007, Lockheed Martin Ventures, a $400 million early-stage fund, has invested in emerging space companies, providing intelligence to the company on future technology and market trends.[15] The Advanced Technology Center in Palo Alto makes its testing facilities available to smaller companies. It has strong ties with local universities, including Stanford, San Jose State University, and Berkeley, where it regularly recruits employees and interns.

Other Leading Space Companies

Headquartered in Palo Alto, **Maxar Space Systems** (formerly Space Systems/Loral) has a 60-year history of designing and manufacturing satellites and spacecraft components for communications, Earth observation, and exploration. Offerings span mission systems engineering, product design, spacecraft manufacturing, assembly, testing, and in-space servicing across telecommunications, defense, and intelligence applications. The company has customers in 70 countries; more than 90 of its satellites are currently in orbit; and Maxar-built satellites support broadcast services for 2.4 billion people.[16] Maxar spacecraft are extensively used by commercial customers for weather monitoring, air traffic control, monitoring of maritime networks, support for emergency service operations, telemedicine and distance learning, and economic development in remote regions.[17] The company is currently developing the Power and Propulsion Element (PPE) for NASA's Gateway project, a lunar orbiting module that, as part of the Artemis program, will support human missions to the Moon as a staging point for deep space exploration. When completed, the PPE will be the highest-power electric propulsion spacecraft ever built.[18]

Terrasat Communications, headquartered in Morgan Hill, manufactures microwave and satellite RF (radio frequency) equipment for more than 200 government and commercial satellite communication customers around the world,[19] producing Block Up Converters (BUC) used in the transmission (uplink) of satellite signals. Commercial markets include maritime, broadcast, oil and gas, and broadband backhaul applications. Government applications include military and critical infrastructure.[20]

Entrepreneurs and Commercial Space

"You're seeing more New Space activity in Northern California due to the increased importance of software talent for building small, flexible systems. The legacy space manufacturers and defense contractors are clustered in Southern California, but they represent the old way of doing things. The new way requires more software, like for our software-defined radio, as well as our core flight and ground software, and the best engineers in the world for that kind of work are based in the San Francisco Bay Area. We recruit less from Lockheed Martin and Boeing and more from Apple and Google. You'll see even more of that as the old gives way to the new in the space industry."

Christian Kiel, Vice President,
Astranis Space Technologies

The Aerospace Industry Association puts the size of the space economy at $469 billion, with 152,000 direct employees in the US in positions ranging from scientists and engineers to technicians and machinists. The space economy is driven by several emerging sectors: space transportation (reducing launch costs through scale and efficiency in rocket production and usability), in-space manufacturing (additive manufacturing in low-Earth orbit), in-space bioproduction (production of organs, tissues, and therapies in microgravity), nuclear launch and propulsion (utilizing nuclear energy as a potential substitute for chemical propellant fuels), space agriculture (the production of food in space), and satellite services and maintenance (expanding the role of satellites to include quantum communication and remote sensing).[1] Satellite services applications include military uses but also GPS for personal location and public safety; the precision monitoring of agricultural resources; climate and environmental monitoring; the positioning of planes, trains, ships, and other vehicles; and phone and internet connectivity.[2]

Emerging companies tend to cluster in cities and regions that host either federal research facilities or large aerospace companies, both of which attract talent. NASA plays a particularly prominent role in commercial space by supporting the development of public-private partnerships.[3] Silicon Valley is also playing a central role in the development of the space sector, as private companies take on roles once played by government—often with government encouragement and support. Silicon Valley's contribution to the sector builds on its deep talent base, on its strength in digital technology and data analytics, and on the entrepreneurial drive that typifies the region.

One driver behind recent commercial development in the region is the idea—supported by success in software, engineering, and consumer electronics—that successful space ventures can be expeditiously developed by small private enterprises building on federal research but using low-cost off-the-shelf technologies. In this respect, the evolution of the region's space sector differs from the historical experience in Southern California, which is more closely identified with aerospace and developed in the years following World War II as a base for large companies such as Boeing, Lockheed Martin, and Northrop Grumman with a major focus on aerospace manufacturing and defense contracting.

NASA Ames Research Center has played a pivotal role in defining the direction of the commercial space sector, initially under the leadership of Center Director Scott Hubbard and later under Pete Worden, who served as the Center's Director from 2006 to 2015. Soon after arriving at Ames, Worden seized on the Space Act of 1958 and its reauthorizations—which call on NASA to advance the competitiveness of US industry—as a vehicle. During Worden's service in the US Air Force before coming to NASA, the Defense Advanced Research Projects Agency (DARPA) had, on Worden's recommendation, awarded a contract to Elon Musk's fledgling company SpaceX to launch a small satellite on DARPA's behalf—an early test. One of Worden's aims was to create stronger links to Silicon Valley. Lower cost with faster innovation was the goal. Parts of NASA and the Department of Defense initially resisted the shift, which eventually won the day due to the growing cost of federal projects and concern with the monopoly position of major contractors and its effect on innovation.[4] When Elon Musk's SpaceX demonstrated the viability of commercial space products and services, the game was on.

Ames subsequently became an incubator for talent, attracting young engineers such as Chris Kemp, who went on to found Astra, and Chris Boshuizen, who later co-founded Planet Labs.

Startup Pioneers

Several first-movers, many with connections to Ames, have shaped the region's and the nation's space industry.

The founding vision of **Planet Labs PBC**—led by Will Marshall, Robbie Schingler, and Chris Boshuizen—was to produce and launch a fleet of satellites capable of imaging the whole of Earth every day. Arranged in constellations, hundreds of these satellites orbiting Earth in the right pattern would make it possible to continuously photograph every location on the planet, with the images available for anyone to access online for a modest fee. In the end, this would democratize space, such that anyone with a computer could access earth imagery in detail to gain a deeper understanding of different aspects of human activity.

To achieve this, an initial flock of small satellites known as Doves was launched into orbit, using technology invented by the company to locate, control, and command the group.[5] Like other Silicon Valley tech companies, Planet had its inception in a group house in Silicon Valley dubbed the Rainbow Mansion, where entrepreneurs and young engineers from NASA debated the economics of conventional satellites that took years to develop and were few, large, and cost between $250 million and $1 billion each. The question was whether it could be possible to produce large numbers of small, cheap satellites to blanket the earth while changing the economics of satellite development and deployment.[6]

With this goal, Planet was launched in San Francisco in 2011, with the first investment coming from Steve Jurvetson. The first Dove took eighteen months to produce, costing less than $1 million as opposed to $1 billion.[7] The first two Doves were sent into orbit in April 2013,[8] followed by an additional funding round led by Steve Jurvetson and joined by Peter Thiel and Eric Schmidt.[9] Funding reached $170 million in total after a Series C round in 2015,[10] and with the opening of a new manufacturing facility in 2018, production capacity grew to 30 satellites per week.[11] A large network of ground stations was established to communicate with the satellites.[12]

Typical launches send up "flocks" of 12 or more Doves,[13] with a rocket slowly rotating to release them, after which each satellite unfolds solar panels and antennas.[14] The satellites are spread out so that each one is responsible for photographing a specific zone below, as they collect thousands of images covering more than 350 million square kilometers of images per day.[15] When the images are downloaded to ground stations, software compiles and sorts them. Customers, including corporations, governments, media, and nonprofit, research, and environmental organizations, can browse the imagery at both medium and high resolutions and can pay for subscriptions based on their needs.[16]

With advances in technology, the more than 150 Planet satellites currently in orbit can generate each day an average of 1,300 images of every location on Earth's landmass.[17]

Planet's PlanetScope images of the Peace River, Alberta, Canada in 2023 on May 3 before wildfires (left) and on June 2 after wildfires (right).

Planet's PlanetScope images of the Gold Coast, Coolangatta, Australia before (left) and after (right) flooding in March 2022.

In 2019, Planet reported that it had used its images and AI to create a complete map of every road and building on earth,[18] and the company expanded its global analysis-ready data offerings in 2023[19] with a Forest Carbon global dataset of above-ground forest carbon, tree height, and canopy cover estimates covering all the world's forests and woodlands.[20] In the Amazon, Planet's technology has been used to monitor the rainforest and its health, and farmers around the world use it to monitor their crops. In California, its images support drought management by measuring the amount of water in reservoirs.[21] Other images target illegal operations, such as unauthorized logging on public lands,[22] and pinpoint areas that are at risk of wildfires, so foresters can know where mitigation is needed to remove excess fuel and make the landscape more resilient to fire.[23]

Its images have also been used to confirm China's building of illegal islands in the South China Sea, the expansion of Uyghur detention centers in Xinjiang, and the location of previously unconfirmed missile facilities in Iran.[24] In Russia's war on Ukraine, Planet satellites revealed Russian forces gathering on Ukraine's border, Russian convoys disabled outside Kyiv, and destroyed hospitals and schools that Russia claimed as military targets.[25]

Over 2,000 academic papers have been written leveraging Planet's images. In 2021, Planet Lab's subscription data service generated over $100 million in annual revenue. Sustainable management of the Earth's resources is at the heart of the company's current strategy. In its next phase of development, it plans to leverage machine learning (computer vision and predictive analytics) with data science to index change on Earth, making that data more accessible and actionable through a cloud-based platform. As described by the founders in 2022, "Five years after its founding, Planet was known as a satellite company. Today, ten years in, we are known as a data company. Five years from now, we expect to be known as a platform company, with the Earth as its center."[26]

Orbital Insight, a 2013 Bay Area-based Earth observation platform that was acquired by space data startup Privateer in May 2024,[27] has applied sophisticated analysis to images purchased from Planet in projects such as counting cars in Walmart parking lots during the holiday shopping season and tracking the health of cornfields to predict their productivity at harvest—analyses used by Wall Street investors and commodity traders to make market decisions.[28] Other AI systems track the movement of every ship at sea, estimate the amount of coal being produced by coal mines, estimate countries' GDP by counting the number of lights that are on at night, and measure global oil supply by analyzing images of oil storage containers.[29]

Based in San Francisco, Golden (Colorado), and Toulouse (France), **Loft Orbital** flies customer payloads aboard regularly scheduled satellite missions, handling the entire mission as a subscription service. The company essentially buys satellite platforms and loads them with payloads for customers. Customers pay for the resources required to support their specific payload as part of an aggregated launch service, avoiding the cost of purchasing, operating, and managing their own hardware. The company's software supports the launch and satellite management and orchestrates data under client service agreements.[30]

Extending that infrastructure-as-a-service model beyond hardware, in 2024 Loft began offering "virtual missions," which enable customers to put their software apps on a Loft satellite, allowing them to leverage its on-board resources: sensors, imagers, radio and inter-satellite links, CPUs, and GPUs. The spacecraft can be configured to perform different missions based on customer needs, developing software applications that leverage its capabilities. The Yam-6 satellite, launched on March 4, 2024, is fully dedicated to virtual missions.[31] CEO Pierre-Damien Vaujour described the strategy: "We started Loft because we heard repeatedly that customers wanted to get their missions to space faster. After a few years, the market told us that it wanted insights from satellite data faster."[32]

Founded in 2015,[33] San Francisco-based **Astranis Space Technologies** builds small, low-cost communications satellites designed to connect the 2.6 billion people on earth who don't have internet access.[34] Working in partnership with telcos and internet service providers, Astranis-owned-and-operated satellites provide low-cost turnkey bandwidth-as-a-service to customers at the national, state, and regional levels, supporting markets in remote and rural areas. In contrast to satellites in Low Earth Orbit (99 to 1,243 miles above Earth), Astranis' satellites fly in Geostationary Earth Orbit (GEO) more than 22,236 miles above Earth,[35] an altitude that allows them to be parked in fixed locations, rotating with the Earth, directly above the target service areas. Astranis's unique software-defined radio technology adds more frequency bands and allows maximum use of the available spectrum, no matter where the satellite is on its orbit.[36] Higher orbit comes with radiation challenges that are different from Low Earth Orbit but brings advantages when it comes to efficiently serving distinct geographies. Large government satellites also operate in Geostationary Earth Orbit, but Astranis's focus on compact size, speed of production, and low cost makes its MicroGEO satellites unique.[37]

While clients could purchase a slice of bandwidth from larger satellites, Astranis provides its customers with dedicated platforms, reducing the risk of disruption that can come with shared platforms. In March 2024, Astranis announced that its tenth MicroGEO satellite will be used by Thaicom, a leading Asian telecommunications satellite service provider, further expanding the internet coverage it already enables for millions of residents in places from Mexico to the Philippines.[38] The company also announced a new partnership to enable Latin American internet service provider Orbith to expand service in Argentina with a MicroGEO satellite to be launched in 2025. With more than 400 engineers and builders on staff, Astranis has raised $750 million[39] from investors such as BlackRock and Andreessen Horowitz.[40]

Launched originally in offices on San Francisco's Bryant Street, where its first satellite was built, the company today occupies the 150,000-square-foot historic Pier 70 in the city's Dogpatch neighborhood, where its satellites are designed and assembled.[41] Asked why it chose to manufacture in San Francisco, company officials point to talent: "This region has some of the world's best mechanical engineers and its best software engineers. There's simply nowhere better on Earth to find hard-tech talent." That capacity is particularly important because of Astranis' focus on software-defined radio as its key technology. Astranis' workforce is composed of scientists and highly educated engineers, but also skilled technicians and machinists who are employed in assembly, as well as interns across a range of disciplines. Company executives point out that degrees are important but not required. The company measures candidates against "Astranis Bar," a rigorous standard test that all employees must meet to demonstrate mastery of a craft and the ability to solve problems.[42]

On December 29, 2024, four Astranis MicroGEO satellites were carried into space on a dedicated SpaceX Falcon 9 launch and deployed for specific tasks. One is for use by Orbits Corp. to provide broadband access to the Philippines and is named AGILA (meaning "eagle," the national bird of the Philippines). Two satellites, named NuView Alpha and NuView Bravo, are for use by Anuvu to provide internet connectivity for airplanes and cruise ships. And UtilitySat, the fourth satellite, is a unique multi-mission GEO satellite designed to adjust its orbital position later on to support a mission different from its initial use by ISP Apco Networks to provide internet connectivity across Mexico, especially in remote areas.[43]

With a $200 million Series D round secured in July 2024, Astranis fully funded its next-generation Omega satellite, which offers five times the bandwidth capacity in a small form factor similar to the MicroGEO. With the first launch planned for 2026, each Omega will have a 10-year lifespan. The company plans to expand its workforce to support increased production from the previous four satellites per year to 24 satellites per year in 2025—all produced in San Francisco.[44]

Four MicroGEO satellites in the Astranis clean room prior to shipping to Cape Canaveral for launch aboard the SpaceX Falcon 9. Source: Astranis

Astra started life in 2005 as Ventions LLC, a startup based in San Francisco's SoMa district that built small, very low-cost rockets. While running technology operations at NASA, co-founder Chris Kemp had developed a project called OpenStack, which successfully built a cloud computing system within NASA that linked its databases, making it easier to communicate and collaborate. On leaving NASA in 2011, he formed his own startup, Nebula, based on OpenStack's computing technology, which had been open-sourced. Oracle later acquired its technology, and Kemp became an Entrepreneur-in-Residence at a Silicon Valley venture firm. In 2016, Kemp took the helm as CEO of Ventions, began operating in stealth mode (with the business often referred to as "Stealth Space Company"),[45] and moved the company to larger space in an industrial building without heat at the former Alameda Naval Air Station. In 2020, Kemp announced the company's launch as Astra.[46] The focus remained on building small, simple rockets that could achieve economies of scale through mass production. Where historically it took 6–10 years to produce a viable new rocket design, Astra produced one in slightly over a year. A major expansion occurred in 2019 when Astra took over and renovated a derelict 250,000-square-foot building nearby, creating a state-of-the-art factory.

As a Bay Area startup, Astra experienced multiple failures as it worked to develop a reliable and cost-effective launch system, with cash often in short supply. In 2021, the company went public on the NASDAQ, becoming the first pure rocket company ever to go public.[47] Later faced with liquidity challenges, however, the company's board approved an agreement to take the company private under a parent entity formed by its founders and a number of long-term investors, with the transaction successfully closed in July 2024.[48] Subsequently, the US Defense Innovation Unit (DIU) awarded Astra a contract with a ceiling of up to $44 million to advance and scale up the production capabilities for Astra's tactically responsive launch system, with a focus on point-to-point space delivery for national security and defense applications.[49] With this reinvigoration, Astra exemplifies the entrepreneurial nature of the region's commercial space industry, where entrepreneurs embrace risk to pursue innovative solutions to compelling goals.

LeoLabs, founded in 2016 in Menlo Park and today supported by more than $120 million in venture capital funding,[50] has developed a network of radar stations that provides complete global coverage of objects in Low Earth Orbit, including satellites and debris, with resolution capable of detecting objects sized as small as 5–10 centimeters. Its system monitors the path of satellites and possible collisions. This includes SpaceX's Starlink network and satellites produced by Planet Labs, with LeoLabs tracking the satellites to provide orbital location and identification support that allows the satellite operators to establish communication and begin mission operations within the first few hours of deployment.[51] LeoSafe, LeoLabs' collision avoidance service, tracks space debris and provides actionable information for preventing orbital collisions with real-time "conjunction" alerts when two objects in space make a close approach.[52] The nearly 260,000 conjunctions captured by the service in the first six months of 2022 are an indication of the growing collision risk in Low Earth Orbit and the need for mitigation efforts.[53]

Spire Global is a space cloud data analytics company that uses satellites to provide maritime, weather, and aviation tracking and data analytics. Co-Founder Peter Platzer began his career in space as an intern at NASA Ames Research Center. Founded in 2012 in a San Francisco garage where its first satellite was built, Spire had its first launch within nine months and by 2017 was operating a satellite constellation with full earth coverage. Revenues grew rapidly, reaching $100 million after five years. Spire has attracted $672.3 million in funding as of August 2024.[54]

With satellites covering every spot on earth 100 times each day,[55] the company now operates the world's largest satellite constellation using RF (radio frequency) technology to track and observe what is happening on and around Earth. Its datasets, drawn from multipurpose Low Earth Orbit satellites, use earth observations to inform decision-making in the maritime, aviation, supply chain and logistics industries, weather forecasting, global security, and earth intelligence R&D.

With its headquarters in San Francisco, the company has offices in Washington, DC and Boulder, Colorado and overseas offices in Singapore; Cambridge, Ontario; Luxembourg; Munich; Glasgow; and Oxfordshire, England.[56] Manufacturing is concentrated in Glasgow, while other sites are multipurpose. Activity in Luxembourg, for example, includes science, engineering software development, product development, sales, finance, and HR. Spire's CFO and SVP of global engineering are in the Bay Area, while its COO and its CTO (co-founders) are based in Luxembourg. Its activity in San Francisco includes software development, product development, satellite operations, launch, finance, communications, brand, and ground station operations.[57]

Based in Los Altos, **Ramon.Space** builds space-resilient, high-performance, radiation-hardened computers for use in satellites and space missions. Its software-based, low-power, reliable computing platform enables the realization of Earth-like computing capabilities in space, including ultra-high-density data storage recording, smart on-board data processing, and advanced space communication connectivity applications.[58] Under a grant awarded in March 2024 by the Swiss government and Innovate UK for the ENORMITY space project, Ramon.Space is collaborating with Swiss AI software company Klepsydra Technologies AG and the Center for Project Based Learning from ETHZ in Switzerland to combine Klepsydra AI software with Ramon.Space processors to enable the use of AI in autonomous satellites and spacecraft. Applications include Earth observation, telecom, navigation, defense satellites and landing capabilities for planetary missions, and increased autonomy for in-orbit service missions.[59]

Ramon.Space products have been used by NASA, the Israel Space Agency, and the Japan Aerospace Exploration Agency, and in more than 50 space missions. Launched in 2004, Ramon.Space received its first round of funding in 2021 and, including a $26 million round in 2023, has attracted $43.5 million in funding.[60]

Another company producing radiation-tolerant computer hardware for use in space is Oakland-based **Colossus Computing** (formerly Zephyr Computing Systems). Its products support sensors, autonomous operations, data collection and integration, and image processing. In 2021, Zephyr was one of the winners of the NASA Entrepreneurs Challenge,[61] followed by SBIR Phase I and II funding from NASA in 2022 and 2023.[62]

Founded in 2016, **Capella Space** is the first company to commercially use Synthetic Aperture Radar (SAR) technology for Earth observation in real-time, including the 75% of the planet that is covered by clouds or dark at night. The benefit of SAR comes from its ability to penetrate atmospheric conditions, either clouds or total darkness, to detect even small-scale movements. The vision to create the company grew out of a 2016 Stanford program that aimed to harness Silicon Valley innovation to address national security challenges. Capella's first test satellite (Denali) was launched in 2018 and its first operational commercial satellite (Capella-2) in 2020. As commercial production shifted into gear in 2021, the company scaled up with 40,000 square feet of manufacturing space and in 2022 was awarded a Commercial Radar Contract by the National Reconnaissance Office (NRO) to provide SAR data modeling and simulation and sample imagery delivery. In 2023, the company created Capella Federal to provide enhanced services to the US government, and NASA's Earth Sciences Division awarded Capella a sole-source five-year Blanket Purchase Agreement (BPA) for the purchase of imagery and data. Capella expanded its existing constellation in 2024 with three new wholly designed, assembled, and operated third-generation Acadia satellites.[63]

Other Emerging Space Companies

Other early-stage space companies in the region include

- **Xona Space Systems** (Low Earth Orbit commercial satellite constellation designed to provide high-precision positioning, navigation, and timing (PNT) services to meet to enable the scaling of technologies such as autonomous vehicles, unmanned aerial vehicles, mobile robotics, and other location-critical applications);[64]
- **Akash Systems** (space-qualified satellite radios, power amplifiers, and servers using advanced diamond cooling technology within semiconductors);[65]
- **Momentus Space** (transfer and service vehicles to carry satellites and hosted payloads between orbits in space);[66]
- **Antaris** (software platform for space used to simplify the design, simulation, and operation of satellites);[67]
- **Orbital Composites** (3D printing for in-space servicing, assembly, and manufacturing [ISAM]);[68]
- **StarDrive** (advanced electromagnetic propulsion systems for space transportation);[69]

- **Aadi Space** (space debris recapture and in-orbit vehicle reusability);[70]
- **Spike Dynamics** (lightweight, ultra-compact actuators for electromechanical devices in space, such as robotic arms, planet rovers, and pointing/balancing mechanisms and thrusters);[71]
- **Allocation.Space** (market platform for commercial space risk allocation and swaps);[72]
- **Zenith Aerospace** (earth imagery and telecommunications for commercial and defense clients using unmanned aircraft);[73]
- **Array Labs** (Earth observation satellites producing 3D imagery);[74]
- **Farcast** (formerly UTVate) (flat panel antennas with electronic beam scanning compensation for satellite and/or user movement that enable more affordable user terminals for satellite internet);[75]
- **mmTron** (components for mmWave and 5G satellite communications applications);[76]
- **Solideon** (3D robotic manufacturing for space and aerospace applications);[77]
- **krtkl** (satellite communications technology);[78]
- **Logos Space** (Low Earth Orbit satellites providing secure broadband service for enterprise customers);[79]
- **Orbital Sidekick** (hyperspectral earth observation satellites);[80]
- **Skycorp Inc. (Orbital Logistics Vehicle hosting customized** payloads for third parties);[81] and
- **Muon Space** (space-as-a-service design, construction, and operation of Low Earth Orbit satellite constellations for national security, climate monitoring, and other applications).[82]

Some emerging space companies divide their leadership between the Bay Area and their home countries. An example is **Solaris Suborbital Inc.**, a British-founded enterprise that does geostationary Earth observation from 20 kilometers up (versus 160–2,000 kilometers above Earth for LEO satellites and 35,786 kilometers for high-altitude geostationary satellites)[83] using solar-powered gliders. The company is incorporated in Delaware, with two of its founders in the UK and one in Silicon Valley. Design is based in the UK, with a separately incorporated company in Spain handling launch and testing, while the Bay Area-based CEO handles fundraising, commercialization, and market development. Asked why he's in Silicon Valley, CEO Daniel Doulton notes that while there is ample engineering talent in the UK, "this is where the VC money is, where the most likely exit is, and where the AI talent is."[84]

Most of these companies have received some level of venture investment, with Y Combinator being particularly active. With many companies in the Bay Area and elsewhere now in the business, their long-term viability will depend in part on the scale of the commercial market, which is only now emerging.

Protecting Earth's Ecosystems with High-Fidelity Data

Google Fights Wildfires With Satellites and AI

Google is investing in an effort using satellites and AI to spot small wildfires before they become big ones. Current satellite imagery used by firefighters is either low resolution or only updated several times a day, making it difficult to find fires at their inception. A new constellation of Low Earth Orbit satellites, FireSat, produced by Mountain View manufacturer Muon Space and equipped with custom-made infrared sensors produced by Google, will update images of fire zones every 20 minutes. With this technology, observers will be able to detect fires that are only 5 meters across, before they grow to football field size, the current state-of-the-art for early detection satellites. Other currently available systems scan at the kilometer level.[85]

The first satellite in the system is expected to go into orbit in 2025, ahead of phase one of the FireSat Constellation of three Muon Halo satellites in 2026. With more than 50 satellites being ultimately deployed, the FireSat Constellation will be able to observe almost every point on Earth every 20 minutes.[86] Google's $13 million in funding will combine with resources from the Gordon and Betty Moore Foundation to support the project, which will operate through the Earth Fire Alliance, a purpose-built non-profit created to serve communities and support climate resilience by producing accessible fire data on a global scale. Access to frequently updated, high-quality imagery, when combined with AI, will enable fire agencies to rapidly compare any place on Earth with its previous condition, detecting even the smallest fires and enabling more rapid and effective response.[87]

A National and Global Incubator and Innovation Platform

> "The Bay Area's influence in the commercial space sector isn't just about whether a company starts or finishes here. It's about what they learn here, which is unique. Innovation is an important driver. People come to Ames for collaboration. You can also interact here with every part of the space business, from investors to launch vehicles. The region's influence is large, and it attracts smart people."
>
> Jacob Cohen, Chief Scientist,
> NASA Ames Research Center

The Bay Area is one of a number of regions across the country where the commercial space industry is growing, including Denver, Los Angeles/Long Beach, Houston, and Seattle. While commercial space companies are growing outside the region, the Bay Area's position as the national epicenter for technology innovation draws both talent and companies. With that, Silicon Valley has incubated important space companies and hosts offices and facilities of many companies that are headquartered elsewhere but support important Bay Area operations.

SpaceX

SpaceX, launched by Elon Musk with $100 million of his own money in 2002,[1] has revolutionized how rockets are launched and who launches them—in the United States and globally. Though SpaceX is now headquartered in Southern California, its roots are in the Bay Area. Founder Elon Musk, who had just cashed out of PayPal, first met with Scott Hubbard, Deputy Director for Research[2] at NASA Ames Research Center, in 2001 to float the idea of a privately funded mission to Mars. Hubbard, who later became Center Director and is now a professor at Stanford and Founding Editor-in-Chief of New Space journal,[3] had played a central role in the development of NASA's emerging Mars strategy, including the Mars Pathfinder Mission. While Musk kept his long-term focus on the settlement of Mars, the conversations led to a nearer-term focus on developing inexpensive, reusable launch vehicles as an important contribution to space exploration. Incorporated in 2002, SpaceX was headquartered in Silicon Valley until the need for more space and more technicians led the company to move to a site in Southern California close to LAX.[4]

While developing his Dragon spacecraft and Falcon rocket, and seeing the success in 2006 of the PICA heat shield technology developed at NASA Ames Research Center, Musk approached NASA just as the Space Shuttle program was being wound down and the Ames Space Portal office was putting out a call for proposals under the Commercial Orbital Transportation Services (COTS) program to support missions to the International Space Station.[5] Musk's proposal to COTS was accepted, and SpaceX was awarded an initial $278 million contract. Under NASA's Other Transactions Authority (which allows the agency to share both technology and risk with private partners), it was a pay-for-results agreement with performance milestones and a requirement for SpaceX to share costs with NASA by contributing more than 50% of the funds needed for spacecraft development.[6] In 2008, SpaceX was awarded a $1.6 billion NASA contract for commercial resupply services. The risk was high as the first three launches of SpaceX's Falcon 1 rocket had failed, but the SpaceX Falcon 9 rocket performed successfully to deliver the Dragon capsule into space in 2010.[7] It was later determined in a NASA study that had NASA used its traditional cost model instead of the COTS program commercial partnership approach, the cost of the Falcon 9 development project would have approached $4 billion, whereas SpaceX has publicly indicated that the development cost for the Falcon 9 launch vehicle was approximately $300 million.[8]

SpaceX made history in the world of privately-funded space travel with its two versions of the Dragon spacecraft in combination with the Falcon 9 rocket. The Dragon cargo capsule was the first private spacecraft to berth with the International Space Station (ISS) in 2012, and in 2020 SpaceX became the first private spaceflight company to send a crewed spacecraft to space when its Crew Dragon capsule carried two NASA astronauts to the ISS and back.[9]

Today, the SpaceX Falcon 9 rocket leads the commercial space launch industry, having perfected reusable rocket technology. The Falcon 9 rocket is NASA's primary launch vehicle for orbital missions, taking astronauts to the International Space Station, and SpaceX is designing the Starship spacecraft for NASA's Artemis 3 mission to the Moon.[10] Also aligned with NASA's plans, the 400-foot-tall Starship rocket being built in South Texas embodies Musk's ultimate vision to put human settlements on Mars. Musk observes that "Starship will make life multiplanetary."[11]

As a further business, SpaceX has built and launched thousands of inexpensive satellites that support its Starlink internet system. SpaceX's Starlink satellites and antennas enable Ukraine's military to securely communicate and Ukrainian drones to be targeted. In these ways, commercial space pioneered in the Bay Area has taken on geopolitical dimensions. Satellites in Low Earth Orbit beam high-speed internet data via radio signals to ground antennas that allow anyone with a small Starlink satellite dish to access the internet, potentially enabling access anywhere for billions around the world who otherwise lack a high-speed connection. Today, SpaceX leads the commercial launch industry and builds and launches more satellites than any other company or country.[12]

The Intersection of Space and Defense

> “The next generation of military technology will depend less on advances in shipbuilding and aircraft design than on advances in software engineering and computing.”
>
> Anduril Industries mission statement

The region's space sector includes both commercial space and defense, with a Silicon Valley twist. Tech startup **Anduril Industries**, based in Costa Mesa, is a defense products company that uses privately funded R&D to produce off-the-shelf products that can be deployed in months as opposed to the years typical of large defense contractors. In this respect, Anduril is similar to its Bay Area counterparts in commercial space, accelerating the development of small-scale technology-based products at significantly lower costs.

Anduril was co-founded by Palmer Luckey, an executive at Facebook and creator of the Oculus Rift virtual reality headset, with investment from Silicon Valley venture firm Founders Fund. Co-founder Trae Stephens, a partner at Founders Fund, had been working at Palantir, and many of the company's early employees were drawn from Oculus and Palantir. The name Anduril was derived from the magical sword in J.R.R. Tolkien's Lord of the Rings novels.[13] With a presence across the United States and worldwide, the company has an office in Mountain View.[14]

Lattice, Anduril's core product, is a software platform for command and control using sensor fusion, computer vision, edge computing, machine learning, and AI to detect and track objects in battlefield environments, parsing data from multiple sources into a single operating landscape.[15] Other products include autonomous underwater and air vehicles (drones) that use Lattice for inspection, tracking, surveillance, and reconnaissance,[16] as well as solid rocket motors (SRMs) to power defense and space launch systems.[17] In early 2024, the company was awarded one of two contracts to develop uncrewed jet fighters for the US Air Force. Since its founding in 2017, Anduril has received $3.7 billion in venture funding, including $1.5 billion in August 2024.[18]

Silicon Valley engineers bring expertise in AI, robotics, advanced sensors, networking, virtual reality, and broader aerospace and modeling expertise, supporting government agencies such as the US Department of Homeland Security, the Australian Defence Force, the UK Ministry of Defence, and other partners. Other companies that have benefited from Silicon Valley's ecosystem include **Rocket Lab** (founded in New Zealand and headquartered today in Long Beach; the company began its expansion in 2013 when founder Peter Beck pitched Silicon Valley investors and secured funding from Khosla Ventures),[19] and **Redwire Space** (a Florida-based company focused on manufacturing in microgravity conditions that has roots at NASA Ames Research Center).[20]

International Collaboration and Global Reach

The reach of the region's research institutions and private companies is global, as seen in the extensive satellite systems operated by companies like Planet Labs and Spire Global. In addition to international partnerships in NASA that are system-wide, Ames today manages collaborative Space Act programs with the United Arab Emirates, the Canadian Space Agency, the Israel Space Agency, Swiss International Air Lines, the Mexican space agency AEM, the Korea Aerospace Research Institute, the European Space Agency, and Belgium's Von Karman Institute for Fluid Dynamics.[21]

International relationships include the Luxembourg Space Agency's participation since 2017 as one of the sponsors of the Frontier Development Lab (FDL), a SETI Institute-operated public-private partnership interdisciplinary PhD and postdoctoral program in applied AI research that leverages space and earth data to accelerate discoveries in high-risk/reward fields. Areas of inquiry at FDL include planetary defense, planetary science, heliophysics, disaster management, astrophysics, astronaut health, climate adaptation, and resilience and energy futures.[22] Under an MOU signed in 2019, the Luxembourg Space Agency (LSA) is a collaborator with NASA in areas such as space applications, space exploration, sustainable utilization of space resources, and sharing of scientific data and education.[23] Following from that, a US-Luxembourg framework agreement was signed in December 2024 to facilitate NASA's and LSA's cooperative development of sustainable space activities programs, including the exchange of terrestrial and space applications, research facilities, and scientific instruments.[24]

Manufacturing in Microgravity

The US and Israel Collaborate to Produce an Optical Lens in Space

NASA Ames Research Center is working with Israel's leading technology university, Technion, in the field of fluidic research. In the project, led by Technion Professor Moran Bercovici, light-reflecting liquid is launched into space, where it is injected into a peripheral frame. Through surface tension in a zero-gravity environment, it naturally takes the shape of a spherical mirror or lens that can be used in a telescope. Telescopes in space have the advantage of not being impacted by light pollution or the Earth's atmosphere, but their size is limited by the size of the launcher. Conventional technology for making optical lenses also requires the repetitive grinding and polishing of solid materials to produce precisely curved surfaces and mirrors, with 10 meters considered to be the maximum possible size. While telescopes on earth can be built with diameters of up to 40 meters, the largest space telescope with these constraints, the James Webb, is only 6.5 meters in diameter.

The Fluidic Telescope (FLUTE) being designed by Technion and NASA aims to produce a mirror with a diameter of 50 meters by taking advantage of the way that fluids behave in microgravity, where liquid can be made to adhere to the surface of a circular ring-like frame and be manipulated to form a curved surface. A mirror constructed in this way would have an extremely smooth surface for collecting light and the ability to self-repair if damaged.

The project also has implications for commercial manufacturing in space, where the same technology could potentially be used to produce optical lenses for glasses.[25]

Venture Capital Joins the Game

“Dual-use technology has gone in two directions. The government created technology through massive investment, leading to commercial applications like GPS. Now things are moving in reverse, and Silicon Valley is at the crossroads.”

David Rothzeid, Shield Capital

Venture capital is becoming increasingly active in the space and defense sectors, helping to bring Silicon Valley's innovative capability to a field that has historically been dominated by large companies and institutions. As this happens, the Bay Area is incubating the space sector, both nationally and globally.

PitchBook data shows that from 2016 to 2022, national venture capital investment in defense-tech reached $135.3 billion across 4,744 deals, with autonomous weapons, reusable rockets, cyber warfare, and AI emerging as major fields. Four of the ten most active firms investing in the sector from 2018 through 2022 are

- **SOMA Capital** (San Francisco), which has made 22 investments in aerospace, ranging from satellite imagery startups to hydrogen fuel jets;
- **Founders Fund** (San Francisco) with 17 investments, including Anduril;
- **Draper Associates** (San Mateo) with 15 investments in fields such as drones and aerial intelligence; and
- **Liquid 2 Ventures** (San Francisco) with 15 investments in satellite intelligence and related fields.[1]

Other investors with a presence in the Bay Area/Silicon Valley include **Andreessen Horowitz**, **Khosla Ventures**, **Caffeinated Capital**, **General Catalyst**, and **In-Q-Tel**.

For aspiring company founders just starting out, combination accelerator, co-creator, and investor organizations such as **The Yope Foundation** (formerly Founder.org and headquartered in San Francisco)[2], provide platforms for investors to support space companies in formation. One example is Finnish synthetic aperture radar (SAR) imaging satellite operator ICEYE (with ICEYE US headquarters in Southern California), which operates the world's largest SAR satellite constellation, serving government and commercial customers with intelligence in fields including insurance, natural disaster response and recovery, security, maritime monitoring, and finance.[3] Its founding team originated in the Aalto-1 University nanosatellite group and a course organized by the Aalto Business School and the Stanford University Technology Ventures program. Its earliest investors (2015) included Founder.org and San Francisco-based **True Ventures**. This was followed by an $8.5 million 2017 Series A round led by **Draper Nexus** and including further participation by True Ventures and Draper Associates, which also participated in a $13 million Series B funding round in 2018.[4]

Eclipse Ventures (Palo Alto) has invested in Colorado-based launch engine company Ursa Major, which provides propulsion systems for both the defense and commercial space sectors.[5] Another Eclipse investment is True Anomaly, a Colorado startup founded in 2022 that delivers a security platform with satellite, navigation, and data-capture capacity with a core focus on threat mitigation for the military and commercial space.[6]

Fusion Fund invests in space companies through its industrial tech vertical. Two more recent portfolio companies are Virginia-based Scout Space, which uses AI and optical sensors to detect space debris, and Starpath, a Los Angeles-based robotics company that aims to mine soil on the moon for oxygen that could be used as a liquid propellant for future missions.[7]

Burlingame-based **Shield Capital**, founded in 2021, is an early-stage investor with a primary focus on national security that includes space, artificial intelligence, drones, and cybersecurity, that co-invests with Bay Area venture firms such as Founders Fund, General Catalyst, In-Q-Tel, and Lightspeed Venture Partners.[8]

Y Combinator has invested in and accelerated emerging space companies such as Colorado-based Albedo, a Low Earth Orbit, high-resolution imaging company that launched in 2021 and later received funding from Shield Capital;[9] and Epic Aerospace, launched in 2019 and now headquartered in Argentina, which makes a nanosatellite orbit transfer vehicle capable of placing satellites in specific orbits.[10]

Plug and Play has supported emerging space companies for several years, initially through standalone transactions and more recently in Europe through a focused industry vertical. Plans are underway to launch similar industry verticals in the US. Plug and Play's primary focus is on companies at a very early stage of development, providing acceleration services such as business model validation and connections to potential partners. Those services may lead later to investment through its independent venture arm.

Plug and Play is invested in 21 space startups globally, with two located in the Western United States—one in Hawthorne (California) and the other in Redmond (Washington). It operates two space accelerators in Europe—the Turin-based Takeoff Accelerator, which engages small space companies with support from the Italian and European Space Agencies, and the Cassini Business Accelerator in the Netherlands, which helps early stage European space companies access the US market with support from the European Commission.[11]

Adapting Private-Sector Technologies for National Security

DIU

The **Defense Innovation Unit** (DIU) contracts with both defense and space-related startups, connecting the innovation of Silicon Valley to the Department of Defense and other national security agencies. DIU was founded in Mountain View in 2015 as DIUx (Defense Innovation Unit Experimental) with the goal of accessing and adapting for national security applications the innovative commercial technologies being developed in the Silicon Valley and other startup communities.[12] It operates by providing non-dilutive capital to accelerate the development of commercial technology, advancing already-developed products or services to prove their capability for specific government applications. In this way, it acts less as an investor (DIU does not take equity) than a customer, tapping into a pool of potential partners that are difficult to reach through conventional procurement processes. If a prototype developed with DIU support is successful, it becomes eligible for purchase by the Department of Defense and other government agencies.[13]

DIU also works to deepen technology collaboration and integration with the United States' most technologically capable allies and partners. There is growing interest in the organization in finding opportunities for companies in partner countries to participate in US technology procurements through DIU, and for U.S. companies to more actively engage with partners overseas on shared technology use cases. Active dialogues and engagements are currently underway with AUKUS (the Australia-UK-US security partnership), Singapore, Japan, Ukraine, NATO, and India.[14]

In 2017 the term "experimental" was dropped after the program proved its value.[15] In 2023, DIU was further elevated to become a direct adviser to the Secretary of Defense and the Department's principal liaison to global investors and the commercial technology sector.

Where exactly DIU directs its resources will often depend on the strengths of states or cities in the US and overseas in particular technologies (such as AI or machine learning). Between June 2016 and September 2023, DIU made 450 awards totaling $1.7 billion, with the largest share (159 contracts valued at $635.1 million) going to companies in California. The next largest states are Colorado (11 contracts valued at $109.6 million) and Texas (21 awards valued at $76.2 million).[16] This distribution suggests the national scope of the commercial space sector, but also the density of technology and innovation in California compared to other states. A significant factor is the presence of a strong Bay Area venture capital community, which has fueled a deep concentration of talent and innovation in the region that crosses most of the technology domains that DIU and its Department of Defense partners are interested in. The scale of that opportunity was behind the decision of DIU to locate its headquarters and the majority of its staff in Silicon Valley.[17]

Obligated funding for technology prototypes from June 2016 through September 2023 was spread across six domains: Artificial Intelligence and Machine Learning (49 awards for $144.6 million), Autonomy (142 awards for $452 million), Cyber and Telecommunications (67 awards for $112.9 million), Energy (51 awards for $200 million), Human Systems (69 awards for $320.3 million), and Space (72 awards for $440.1 million).

In the space sector, particularly, DIU's investment is accelerating transformative commercial technologies that strengthen US capabilities in fields such as responsive (rapid) launch, sensing, in-space servicing and logistics, and low-latency resilient communications. Partners include the Space Safari Program Office of the US Space Force's Space Systems Command (SSC).

Hybrid Space Architecture (HSA), a software-defined, multi-domain information distribution network, is another priority program. As described by DIU, "Legacy government space systems are extremely capable but are reliant on proprietary data architectures that are neither scalable nor easily integrated. However, commercial 'new space' systems that leverage modern information architectures are based on open standards which improve speed, latency, security, and interoperability.…Unlike terrestrial internet, the HSA is an open, scalable, multi-spectrum Internet of Things (IoT) environment…" DIU's Hybrid Space Architecture combines commercial solutions from four key technology areas: source, data transport, cybersecurity, and cloud. Not limited to terrestrial military applications, it can be extended to the Moon, Mars or beyond. For that reason, DIU is collaborating with NASA to support its LunaNet program by providing communications for the Artemis Program as American astronauts return to the Moon.[18]

Nonprofit and Public Engagement

The Bay Area is also connected to an array of nonprofit organizations with inspirational visions for future human endeavors in space. They provide both practical support for specialized space technology advancements and educational support for public engagement with space science and exploration.

Entirely funded by private individual donors, the **B612 Foundation** pursues a mission "to support research and technologies to enable the economic development of space and enhance our understanding of the solar system."[1] Its **Asteroid Institute** program brings together scientists, researchers, and engineers to develop tools for mapping the solar system, with a particular safety focus on asteroid discovery, characterization, tracking, and impact monitoring.[2]

An especially wide-ranging endeavor with Bay Area ties through its leadership is the privately funded **Breakthrough Initiatives**. Launched in 2015 with a board composed of Yuri Milner and his wife Julia Milner, Stephen Hawking, and Mark Zuckerberg, the Breakthrough Initiatives are a suite of space science programs that delve into fundamental questions surrounding life in the universe and our place in it:

Breakthrough Listen, co-founded by Yuri Milner and Stephen Hawking, is a $100 million program of astronomical observations and analysis to search for signs of other technological civilizations in the universe. Engaging the world's largest and most advanced telescopes, its survey targets one million nearby stars, the entire galactic plane, and 100 nearby galaxies using a wide range of radio and optical frequency bands.

Breakthrough Watch is a multi-million dollar Earth- and space-based astronomical program, operated by an international team of experts, that searches for potentially habitable exoplanets around nearby stars, including Alpha Centauri.

Breakthrough Starshot, also launched by Yuri Milner and Stephen Hawking, is a $100 million research and engineering program that is aiming to develop a proof of concept for technology that would enable uncrewed space flight at 20% of the speed of light, laying the foundation of a flyby mission to Alpha Centauri.[3] Breakthrough Starshot is currently being transitioned to university management.[4]

Also founded by Yuri and Julia Milner, along with Sergey Brin, Priscilla Chan, Mark Zuckerberg, and Anne Wojcicki, are the **Breakthrough Prizes**. Known as the "Oscars of Science" that recognize top scientists working in the fields of Life Sciences, Fundamental Physics, and Mathematics, the prizes are $3 million awards that have been sponsored by the personal foundations established by the founders, as well as Ma Huateng and Jack Ma.[5]

Inspired at Ames Research Center and founded by Dr. Lakshmi Karan and Topher Wilkins,[6] **LunARC** looks to establish the first institution of higher learning—Lunar University—on another world. Described by co-founder

Lakshmi Karan as “a global space initiative that transcends borders,” the initial idea behind LunARC was to send something to the Moon that represented the world’s marginalized communities. Seeing art as a universal language that’s accessible to everyone, LunARC solicited contributions of digital art from more than 30,000 people in 40 countries, including refugees and tribal groups, to create a Lunar Community Art Gallery that arrived on the Moon on March 2, 2025, in the payload of the Firefly Blue Ghost lunar lander.[7] Scheduled for late 2026, a mosaic of 25 images sourced from the Lunar Art Gallery will be sent into deep space aboard an AstroForge probe as a collective message from humanity, etched on nickel NanoFiche technology designed to last a billion years. Both missions have been developed through LunARC’s partnership with **LifeShip**, a San Francisco-founded company that develops capsules to take biodiverse DNA from Earth to the Moon.[8]

LunARC’s second lunar mission, scheduled for late 2025 aboard Astrobotic’s Griffin Lander, will send the perspectives of indigenous and tribal communities into space. Contributors will be asked to answer two questions: “What does the Moon mean for you?” and “What would your message be for humans in space?” Further down the road, LunARC looks to engage two million people on the theme of sustainability and interconnectedness, ultimately aiming to establish a physical learning institution in space. Karan says the project’s goals are democratic and inclusive: “LunARC envisions a future where space exploration is a collaborative global endeavor. We’re creating a platform for citizens worldwide to contribute their innovative solutions for both Earth and space, culminating in a tangible presence on the Moon.”[9]

In addition to the educational mission of the Chabot Space and Science Center (see Chapter 1), other Bay Area institutions also support public learning regarding space and our solar system. The **California Academy of Sciences**, in San Francisco’s Golden Gate Park, presents award-winning programs in its Morrison Planetarium.[10] Over the last 27 years, the **Exploratorium** public learning laboratory has partnered with NASA to send expeditions to cover total solar eclipses wherever they occur in the world. The expedition team also produces real-time high-resolution telescope imagery and supporting educational imagery, broadcasts, and videos to offer the eclipse experience to those unable to travel to see it in person. These media products are used by broadcast networks, NASA TV, online sites, schools, museums, and libraries, as well as being available on the Exploratorium’s website.[11]

Enabling Future Growth

Infrastructure

The Bay Area is an engine of innovation, and as long as it can sustain its research leadership and attract the world's best talent, it will continue to play a key role in the US space enterprise. A successful space economy fundamentally requires three things: capital, talent, and robust R&D. Fortunately, the Bay Area has all three in abundance.

As noted earlier, however, the region is far from the only national center for space activity, and highly competitive clusters have developed elsewhere. One challenge is to produce an economic and policy environment that enables companies that start in the region to grow here. This issue is particularly tied to factors such as the availability and cost of housing, the cost of doing business, the cost of energy, and access to the right kind of physical space for production—issues that impact industry in the Bay Area across the board.

Talent

A second challenge concerns the space workforce. The region's space economy is built on technologists, engineers, and research scientists, who are at the heart of the region's innovation and R&D system. They are abundant. There is also an important place, however, for manufacturing, and the commercial space industry will need qualified employees at every level, from research scientists to machinists and technicians. At the technician level (drawing on high school or community college graduates), there are currently no dedicated workforce training programs in the region that specifically focus on space. This may be due to the fact that startups in the sector lean more on scientists and engineers in their early years. As those companies grow and their production increases, however, so will their need for a diversified workforce. One reason that Elon Musk chose to grow SpaceX in Southern California was the lack of a sufficiently large technical workforce in the Bay Area.

Connecting students, particularly those in less advantaged communities, to career opportunities in the space sector will require focused efforts. Bruce Macintosh, the director of UC Observatories, notes that "The space workforce doesn't look like the population of California. Lots of talented young people don't know that opportunities in the field even exist."[1] At the entry (nondegree) level, the industry's requirements may focus less on industry-specific skills that require specialized training and more on generic skills that can be applied across multiple sectors and tailored to meet a company's requirements.

A particular concern for manufacturing is machining, since machine shops in California are closing due to retirements or lack of interest by younger workers. While technology is part of the solution, there is an important role for state and local governments to play in supporting vocational training. Local and state governments can also play an important role in expediting permits, reducing regulatory burdens, and generally lowering costs.

One strategy would be to leverage the resources of local Workforce Development Boards (WDBs) with community colleges, the state's Employment Training Panel (ETP), and its Division of Apprenticeship Standards (DAS) to create certification programs that support technical skills based on the needs identified by employers. Certificates in foundational fields such as welding, metal fabrication, or electrical engineering needed by multiple space companies or their suppliers could lead to career ladders that support both space and other industries.

In August 2022, the Governor's Office announced the creation of a Space Industry Task Force to help California harness future growth in the space industry, both military and commercial. Led by the Governor's Office of Business and Economic Development (GO-Biz) with partnership support from leaders in the Governor's Military Council (GMC), the Office of Planning and Research (OPR) and the Labor and Workforce Development Agency, the Task Force works to attract new businesses in the sector, support existing space and aerospace businesses, grow the industry's workforce, create new career paths in fields such as quantum physics and AI, expand R&D in aerospace and advanced manufacturing, and create new models for public/private cooperation.

The announcement of the Task Force states that California is home to nearly one-third of all US space tech companies and 10% of space tech companies globally, has in the years between 2011 and 2022 attracted nearly half of the nation's space tech investment capital, and in 2022 attracted more than 85% of the capital invested in the United States in space-related companies. The state has used its CalCompetes investment attraction incentive program to support activity in the sector, with $200 million in tax credits and grants awarded from 2019 through 2022 to aerospace companies, including capital provided to Astra to expand manufacturing and R&D capabilities in Alameda.[2]

The California Master Plan for Career Education will also address barriers that have made it difficult for Californians to gain new career skills. The initiative began with a webinar on January 24, 2024, hosted by the Governor's Council for Career Education with four main objectives: to create coordinating bodies at the state and regional levels that are informed by statewide data systems and supported through technical assistance networks; to create incentives and improve coordination to provide work-based learning opportunities for K-12 students and adult learners ; to align K-12, postsecondary, and workforce pathways using a skills framework; and to accelerate the use of public benefit programs to make training affordable and improve universal access.[3] The nine-agency California Jobs First Council, launched by the Governor's office on March 8, 2024, will work with the Council for Career Education to advance the Master Plan, including the identification of priority sectors and mapping of skills linked to industry clusters and base skills that can be transitioned to other sectors.[4] These initiatives are still in an exploratory stage but can lead to new or improved workforce programs that support technical skills needed in the space sector.

Reaching for the Stars

An Astronaut in the Community

Astronaut José Hernández was born in 1962 in French Camp, California and as a child moved between Mexico and the United States, where he worked with his family in the fields as an agricultural laborer. Growing up in Stockton, he later earned a Master of Science degree in Electronic Engineering, Signals, and Systems at UC Santa Barbara before going on to a 15-year career in engineering at Lawrence Livermore National Laboratory. At the lab he worked as an electronics engineer in the Materials Analysis Group, developing signal and imaging processing skills, and later on the Strategic Defense Initiative ("Star Wars"). In 2001, Hernández joined NASA, working initially at the Johnson Space Center. He and his colleagues are credited with developing a defense surveillance x-ray technology that went on to be used in creating a digital mammography device that provides improved image quality for more accurate early detection of breast cancer.[5]

Intent on going to space, after several applications, Hernández was selected in 2004 as an Astronaut Candidate, completed his training in 2006, and subsequently flew on a two-week mission to the International Space Station aboard the Space Shuttle

Discovery.[6] Today, he leads a space industry consulting firm in Stockton, Tierra Luna Engineering, and serves on the University of California's Board of Regents.[7]

Asked what initially focused him on space, Hernández points to the Apollo mission and watching the last lunar landing mission moonwalk and feeling, "This is what I want to do." His experience seeing the Earth from space made him intensely aware of its fragility: "I became an instant environmentalist as a result of what I saw. Our atmosphere is so thin, and we need to take care of it. Mars once had an atmosphere as dense as ours and lost most of it."

He also believes that Silicon Valley can lead the next wave of space exploration as the United States returns to the Moon and looks ahead to Mars: "We're going to retire the International Space Station and establish bases on the Moon as a way station to Mars. Silicon Valley is Silicon Valley. It has a reputation and has been connected to space for a long time. But other places—Colorado, Texas, Florida—are also leading, and we shouldn't allow ourselves to fall behind. Infrastructure is a challenge, and the region is expensive. As we return to the Moon and look to Mars and beyond, much of the technology that takes and sustains us there can come from Silicon Valley."[8]


Rising over the Washington Monument, the Moon is seen at its perigee (the point of its orbit when it is closest to Earth) on June 23, 2013.

Notes

Chapter 1
Rooted in Research

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