From Apollo to Artemis – a journey through the Universe

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The APOLLO program

When President John F. Kennedy announced in his speech on May 25th, 1961 that he would send a manned mission to the moon by the end of the 1960s, the technology to achieve it simply did not exist at the time. Several mission modes were considered, but it was John Houblot's concept, the Lunar Orbit Rendez-Vous that was chosen. We know that 90% of a rocket's weight is propellant and that travelling from the surface of Earth to Earth orbit is one of the most energy intensive steps of going anywhere else. A direct ascent mode would mean a heavier spacecraft that would travel directly to the moon surface. The Lunar Orbit Rendez-Vous was the riskier choice but would use an existing rocket technology plus a smaller lunar lander that was lightweight and easier to maneuver. This choice saved time and billions of dollars.

The Apollo program started in 1961 and ran until 1972. It was a NASA crewed spaceflight project that aimed at landing humans on the Moon but also had the goal of developing the needed technology for space exploration and carrying scientific experiments on the Moon. On July 16th, 1969 Apollo 11 was launched from Cape Kennedy in Florida carrying astronauts Neil Armstrong, Buzz Aldrin and Michael Collins. Four days later they landed on the Moon for the first time in history. Neil Armstrong and Buzz Aldrin ended up landing

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1 Astronaut Edwin E. Aldrin Jr. on the moon surface. NASA ID: as11-40-5875. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-as11-40-5875. Credit: NASA.

2 Astronaut Buzz Aldrin on the moon surface. Passive Seismic Experiment. Source: NASA Science Earth's Moon. Url: https://moon.nasa.gov/resources/13/apollo-11-seismic-experiment/. Credit: NASA.

almost 5 km away from the landing target and benefited from the clear view from the lunar module to avoid landing on a rocky crater. They explored the Sea of Tranquility for more than two hours, collected soil and rock samples. Several scientific experiments were deployed, a solar wind composition experiment, a seismic experiment package and a laser ranging retroreflector.

The astronaut's way out of the moon had never been tested. When they lifted off from the moon surface, they had to find their exact position in space by using a sextant and looking at the stars to confirm the location given by the onboard computer and then navigate to a *rendez-vouz* and docking. A very complex maneuver that had to be tremendously precise to ensure the astronauts return to Earth.

The images of the astronauts after placing an American flag on the Moon's surface during a television broadcast of the event (**fig. 1**) and of the Passive Seismic Experiment, the first seismometer placed on the Moon's surface (**fig. 2**), witness the decisive step of lunar´s research. The seismometer allowed scientists to learn about the internal structure of the Moon. This seismic experiment only lasted three weeks but further Apollo missions seismometers have detected moonquakes, impact from meteoroids and revealed insight into the

lunar interior and its layers. These data allowed scientists to conclude that the lunar solid core is rather small and comprises about 25% of its radius, with a lunar crust of about 60-70 kilometers thick.

The lunar core was estimated to be about 450 kilometers based on data from the Passive Seismic Experiments, the Laser Ranging Retroreflectors and the Lunar Surface Magnetometers.

During its lunar orbit mission Apollo 10 took a photo that was used to illustrate the landing sites for the Apollo 11 mission (**fig. 3**). The white overlay compares the size of Apollo 11 Landing Site 2 with that of the metropolitan New York City area. Apollo 11 did launch on schedule and landed on Site 2, southwestern of Sea of Tranquility.

3 Apollo 11 landing site. Source: https://www.nasa.gov/image-feature/apollo-11-and-landing-site-2-in-the-sea-of-tranquility. Credit: NASA.

The Apollo Moon rocks that were collected from several sites during the program and brought to Earth, helped us understand the origin of the Moon. In 1970, about 150 scientific articles were published on the Journal Science in a dedicated issue to lunar science. The age of the moon was estimated to be 4.5 billion years old, having been formed earlier in the solar system. The lunar rocks have been found to have a very similar chemical composition to the rocks found on Earth.

The most popular theory for the moon origin is the Giant Impact Hypothesis. This theory explains that the moon is a result of a collision between a Mars-sized planet and the Earth. The debris of this collision that stayed in Earth orbit have consolidated and formed the Moon.

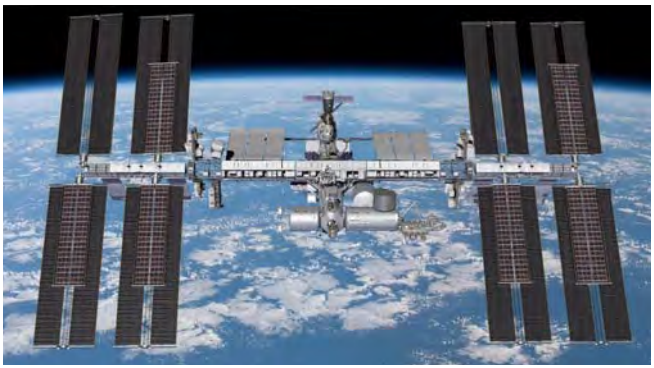
The Earth rising over the lunar horizon seen by Apollo 8 on December 24, 1968 (**fig. 4**) was a landmark. Scientists claim that this image was the beginning of the environmental movement. We saw our world as a small fragile planet just hanging against the blackness of space.

4 Earthrise. NASA Photo ID: as11-44-6552. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-as11-44-6552. Credit: NASA.

International Space Station

Since 1972 and the end of the Apollo program, no humans have landed on the Moon. The Russian Space Station Mir was the first module space station that operated in the Earth lower orbit for 15 years, from 1986 to 2001. The first module of the International Space Station has been launched in the low Earth orbit in 1998, a collaboration between the United States, Russia, Japan, Europe and Canada. It is a scientific platform enabling researchers to work in a micro-gravity environment and prepare us for our journey in deep space. The ISS orbits the Earth at an average altitude of 400 km and in one day circles the

Earth about 15.5 times (1 orbit takes 92 minutes). The images below (**fig. 5 and fig. 6**) show the space station flying above the Nile River Delta in Egypt with the SpaceX Dragon as a visiting vehicle to resupply ship attached.



5 The International Space Station. NASA ID: ISS_Rosa_correct_channels. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-ISS_Rosa_correct_channels. Credit: NASA.

6 The International Space Station. NASA ID: iss060e035437. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-iss060e035437. Credit: NASA.

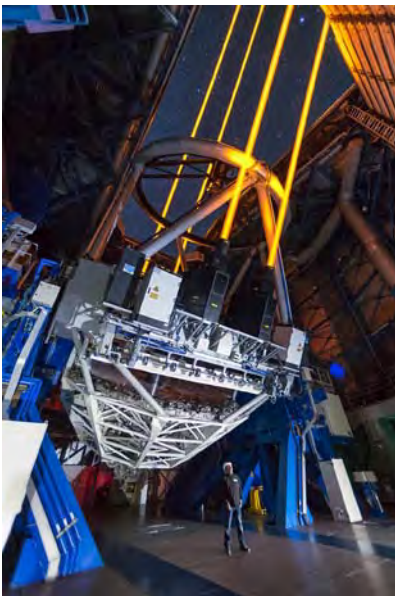
Ground based observations

Ground based observations have allowed astrophysicists to understand the Universe, observe distant galaxies, black holes, our own solar system and to look for planets orbiting other stars. Cerro Paranal Observatory (**fig. 7 and fig. 8**) is located in the Atacama Desert of Chile at 2600 meters of altitude. This is one of the best astronomical observing sites in the world and it's an intergovernmental organization with 16 member countries and Chile as a host. At Paranal we observe the southern sky (**fig. 9**). When we step into the platform in the middle of night, we can clearly see our own Galaxy, the milky Way, the Large and the Small Magellanic Clouds named after the Portuguese navigator Fernão de Magalhães and the Southern Cross. Back in the control room, astronomers operate the Very Large Telescope, four 8-meter telescopes that rotate between instruments during the observations from spectrographs to photometers and adaptive optics instruments correcting the atmospheric turbulence in real time using laser guide stars (**fig. 10**).

7 Aerial view of the ESO Very Large Telescope (VLT) platform, atop Cerro Paranal Observatory. Image ID: dauv_hude_aerial3. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/dauv_hude_aerial3/.
Credit: J. L. Dauvergne & G. Hüdepohl (atacamaphoto.com)/ESO.

8 Paranal Observatory and the volcano Llullaillaco. Image ID: eso-paranal-07. Source: European Southern Observatory Images. Url: https://www.eso.org/public/ireland/images/eso-paranal-07/. Credit: ESO/G.Hüdepohl (atacamaphoto.com).

9 Eclipsed moon, striking night sky. Image ID: potw1119a. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/potw1119a/. Credit: ESO/Y. Beletsky.

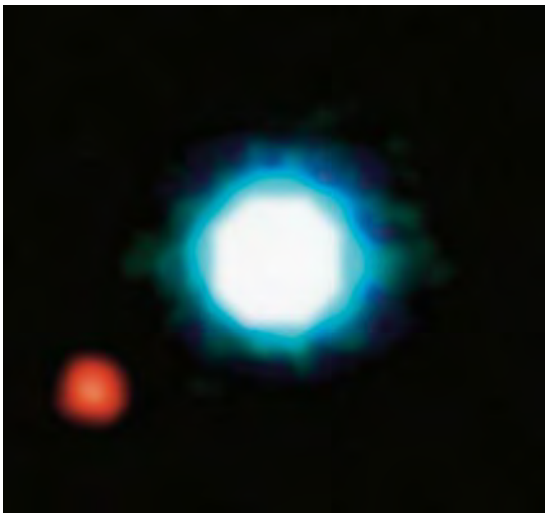


10 Unit Telescope 4 (UT4) of the Very Large Telescope (VLT). Image ID: potw1618a. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/potw1618a/. Credit: ESO/F. Kamphues.

Exoplanets

It was at ESO Paranal Observatory using the VLT that we obtained the first image of an exoplanet in 2004. Exoplanets are planets outside the solar system and were recently discovered in 1992. In 1995, Michel Mayor and Didier Queloz detected the first exoplanet orbiting a pre-main sequence star 51 Pegasi, at the Observatoire de Haute-Provence in France. The Swiss astronomers have just been awarded this week with the Nobel Prize in Physics in 2019 for this discovery.

The composite image (**fig. 11**) shows an exoplanet (the red spot on the lower left), orbiting the brown dwarf 2M1207 (center). 2M1207b is the first exoplanet directly imaged and orbiting a brown dwarf. Its planetary identity and characteristics were confirmed after one year of observations in 2005. It is a Jupiter-like planet, 5 times more massive than Jupiter. It orbits the brown dwarf at a distance 55 times larger than the Earth to the Sun, nearly twice as far as Neptune is from the Sun. This system lies at a distance of 230 light-years, in the constellation of Hydra. The photo is based on three near-infrared exposures (in the H, K and L wavebands) with adaptive-optics facility at the VLT.



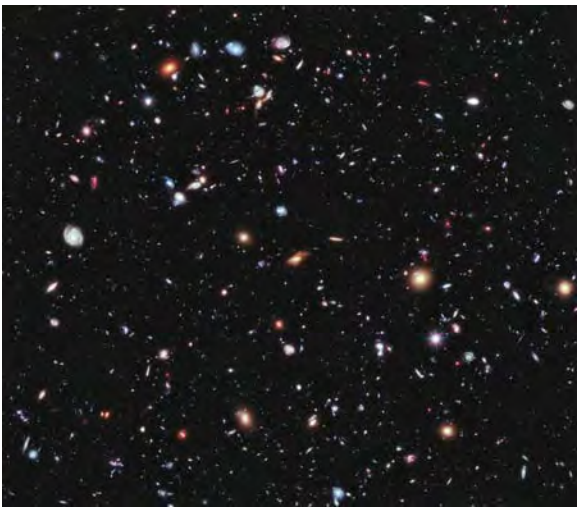
11 First image of an exoplanet. Image ID: 26a_big-vlt. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/26a_big-vlt/?lang. Credit: ESO.

Since then, more than 4000 planets have been confirmed outside our solar system. Most of these planets were discovered using indirect detection techniques such as radial velocity measurement and transit monitoring. The search for life in space requires finding habitable planets that are the right distance around stars which may have liquid water at the surface.

However, the prime candidate for life in the solar system is a moon of Jupiter – Europa. This moon has thick sheets of ice, 15 to 25 kilometers thick. Using ground based observations, data from the Galileo spacecraft and the Hubble Space Telescope, scientists measured the way Europa interacts with the magnetic field of Jupiter and by looking at the cracks in the ice, they have discovered that below the ice there's an ocean of liquid surrounding the whole moon that is 60 to 150 kilometers deep. Scientists believe its salt water. There might be more water in that moon of Jupiter than in all of the oceans combined. An exciting and beautiful discovery.

Space telescopes

The advantage of sending telescopes to space is that we do not have to compensate for atmospheric distortion and can obtain sharper images covering the whole electromagnetic spectrum.



12 The Hubble Deep Field. NASA ID: GSFC_20171208_Archive_e001651. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-GSFC_20171208_Archive_e001651. Credit: NASA Goddard.

The well-known image taken by the Hubble Space Telescope (**fig. 12**), which required an exposure time of 11.3 days between late 2003 and 2004, presents nearly 10,000 galaxies. Using NICMOS, its first near infrared camera, Hubble made infrared observations of the original Hubble Deep Field. These images revealed more distant objects, though the picture quality achieved by this instrument could not compete with optical images.

The smallest, reddest galaxies, about 100, may be among the most distant known, existing when the universe was just 800 million years old. The nearest galaxies – the larger, brighter, well-defined spirals and ellipticals – thrived about 1 billion years ago, when the cosmos was 13 billion years old.

The only way to see further than the Hubble Ultra Deep Field is to look beyond the optical wavelengths and observe in infrared instead. The next breakthrough came after the 2009 servicing mission in which astronauts installed

a new instrument capable of making greatly improved infrared observations. The resulting image, covering most of the field of view of the 2004 Ultra Deep Field observations, is the deepest ever made of the cosmos. It is unlikely to be surpassed until the James Webb Space Telescope is operational, later this decade.

The 2009 infrared image of the Hubble Ultra Deep Field has been an extremely fertile hunting ground for scientists who study the early Universe. Several candidates for the most distant galaxy ever observed have been spotted in this image.

Black holes

Until 2019 we had only been able to indirectly observe black holes. These objects are believed to be formed when a massive star is dying, they are so dense that no light can escape.

The first direct image of a black hole was revealed in April 2019 (**fig. 13**). Until then we have only indirectly observed black holes by looking at the behavior of stars, gases, and other matter located near black holes. The Event Horizon Team obtained an image of a supermassive black hole at the center of the galaxy Messier 87, which lies around 55 million light years from Earth. By combining simultaneous observations on eight radio telescopes around the world, they created the resolution of an Earth sized telescope. As Sagan writes on the images taken of the center of the galaxy M87, one with the VLT in visible wavelengths (**fig. 14**), and the other the radio image obtained by the EHT team: "This may seem a very blurred but generating this rough of a picture is the equivalent of reading a newspaper headline on the moon while standing on Earth" (Sagan 1994).

13 Black hole in the center of the galaxy M87. Image ID: eso1907a. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/eso1907a/. Credit: ETH Collaboration.

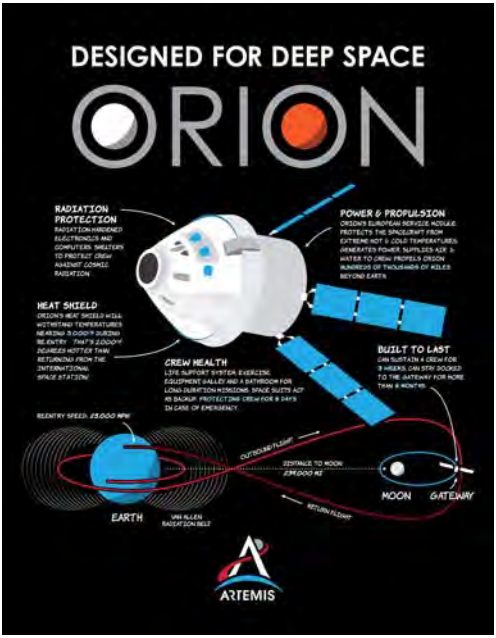
14 Messier 87 Captured by ESO's Very Large Telescope. Image ID: eso1907b. Source: European Southern Observatory Images. Url: https://www.eso.org/public/images/eso1907b/. Credit: ESO.

The ARTEMIS program

Fifty years later, NASA has announced its plan to land the first woman and the next man on the lunar south pole by 2024. The Artemis Moon program is named after Apollo's twin sister. The Artemis program is an ongoing crewed spaceflight program carried out by NASA, U.S. commercial spaceflight companies, and international partners such as ESA.

The NASA's Space Launch System (**fig. 15**), will carry an Orion spacecraft (**fig. 16**) beyond the Moon, on the mobile launcher. The Space Launch System is the only rocket that can send the Orion spacecraft, astronauts, and supplies to the Moon on a single mission. The Orion spacecraft was designed with protection against cosmic radiation, a heat shield, a service module that protects the spacecraft from hot and cold temperatures and can sustain a crew for 3 weeks. Commercial launch vehicles are planned for use to launch various other elements of the program.

15 The Artemis Program – Space Launch System. Source: NASA. Url: https://www.nasa.gov/exploration/systems/sls/artist-concept-of-the-sls-block-1-configuration.html. Credit: NASA/MSFC.



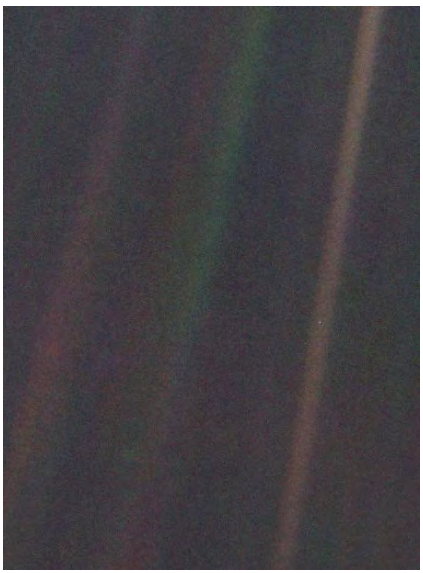
16 The ORION Spacecraft. Source: NASA. Url: https://www.nasa.gov/image-feature/orion-capabilities-for-deep-space-enable-crewed-artemis-moon-missions. Credit: NASA.

The second stage of the Artemis program aims at developing a sustainable human presence on the Moon by 2028. The lunar gateway will be a small spaceship that will orbit the moon. This spaceship will be a temporary home and office for astronauts, just about a five-day, 250,000-mile commute from Earth. The Gateway will have living quarters, laboratories for science and research, docking ports (like doors) for visiting spacecraft, and more. It will provide NASA and its partners access to more of the lunar surface than ever before, supporting both human and robotic missions.

The Gateway will be our home base for astronaut expeditions on the Moon, and future human missions to Mars. Even before our first trip to Mars, astronauts will use the Gateway to train for life far away from Earth, and we will use it to practice moving a spaceship in different orbits in deep space.

Pale blue dot

The image of the Earth taken by the Voyager 1 spacecraft on February 14, 1990 was suggested by Carl Sagan. When Voyager was orbiting the outer solar system, scientists turned it back and photographed the Earth from a distance of more than 6 billion kilometers (**fig. 17**). The Earth appears as a mere point of light, and the lines are scattered light rays resulting from taking the image so close to the Sun.



17 The Pale Blue Dot – Earth seen from more than 6 billion km. NASA ID: PIA00452. Source: NASA Image and Video Library. Url: https://images.nasa.gov/details-PIA00452. Credit: NASA/JPL.

The beautiful words of Carl Sagan (1994), taken from his book *Pale Blue Dot*, that were inspired by this image, make for a perfect conclusion:

> Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every

> king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there-on a mote of dust suspended in a sunbeam.
>
> It has been said that astronomy is a humbling and character-building experience. There is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly with one another, and to preserve and cherish the pale blue dot, the only home we've ever known.

Bibliography

SAGAN, Carl. 1994. *Pale Blue Dot: A Vision of the Human Future in Space*. New York: Random House.