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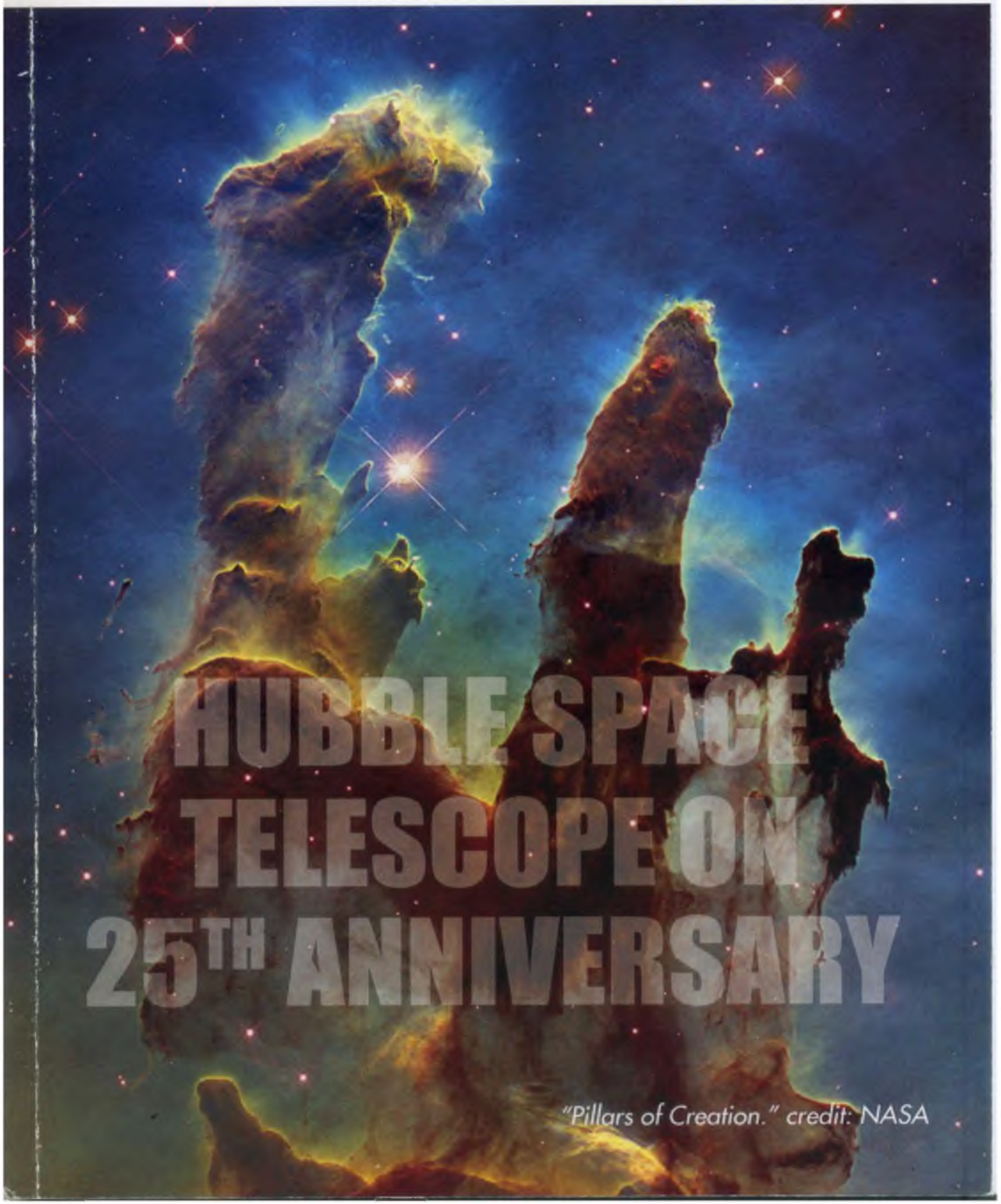


HUBBLE SPACE TELESCOPE ON 25TH ANNIVERSARY

"Pillars of Creation." credit: NASA

NASA-ESA Hubble Space Telescope
The Greatest Leap Forward in Astronomy since Galileo

by Umberto Cavallaro, SU 4755 and President, Italian Astrophilately Association, AS.IT.AF

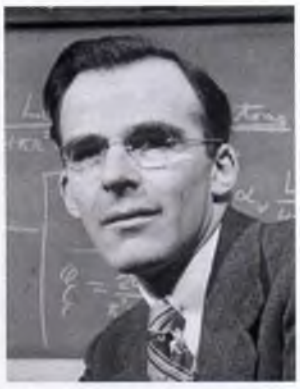
The Hubble Space Telescope (HST) is the most famous, and possibly the most successful, space observatory ever flown. HST is a cooperative NASA/ESA program conceived in order to operate a long-lived, space-based observatory for the benefit of the international astronomical community.

The 11 ton telescope was placed into a 570 km (380 mile) high orbit around Earth by Space Shuttle Discovery's STS-31 mission April 25, 1990. Circling our planet every 96 minutes, the HST has so far (Spring of 2015) traveled more than 6,5 billion km and has marked the most significant advance in astronomy since Galileo's telescope. Hubble has helped to determine the age and size of the Universe. Hubble's discoveries have revolutionized nearly all areas of astronomy, from planetary science to cosmology and has led to significant changes in our basic understanding in astronomy.

Hubble's 25th Anniversary Patch, Credit NASA

Hubble Prehistory

The idea of sending into space a telescope able to look into the universe from above the distortion of the Earth's atmosphere was first proposed by German rocket scientist Hermann Oberth (one of the fathers of modern rocketry, together with Robert Goddard and Konstantin Tsiolkovsky) in his book *"Die Rakete zu den Planeträumen" Rockets into Interplanetary Space*, as early as 1923, long before the first Earth satellite was launched.



Lyman Spitzer, 1948 (Credit: Al Fenn/ Time/Getty Images)

His legacy was advanced in the United States by astrophysicist Lyman Spitzer[1] who developed in 1946 a realistic plan for placing a large telescope in space, and described in detail the advantages in his paper entitled *"Astronomical Advantages of an Extra-Terrestrial Observatory"*.

Spitzer would work for several decades to explaining his vision to the World's scientific community – that often was against his idea of a space telescope, and concerned that the cost of this would reduce funding for ground-based astronomy – and for lobbying for his idea with the U.S. Congress. Spitzer's work then became instrumental in the design and development of the Hubble Space Telescope.

Soon after NASA was stood up in 1958, NASA established a set of scientific objectives that included an astronomical observatory and consequently carried out studies with the OAOs (Orbiting Astronomical Observatories)[2], four small satellites that, launched from 1966 onward, increased in the astronomical community awareness of the benefits of orbiting telescopes.

ESA-NASA Cooperation

Cooperation with ESA (European Space Agency) for a space telescope was first formally raised in 1973 when the Astrophysics Working Group recommended that Europe should consider and explore the possibility of participating with NASA in what was then known as the *Large Space Telescope* (LST). At that time Europe had something of a lead in the area of photon-counting imaging system that, developed by the University College London, was in routine use for optical astronomy, and would appear very appropriate in order to exploit the LST's potential to the fullest.[3]

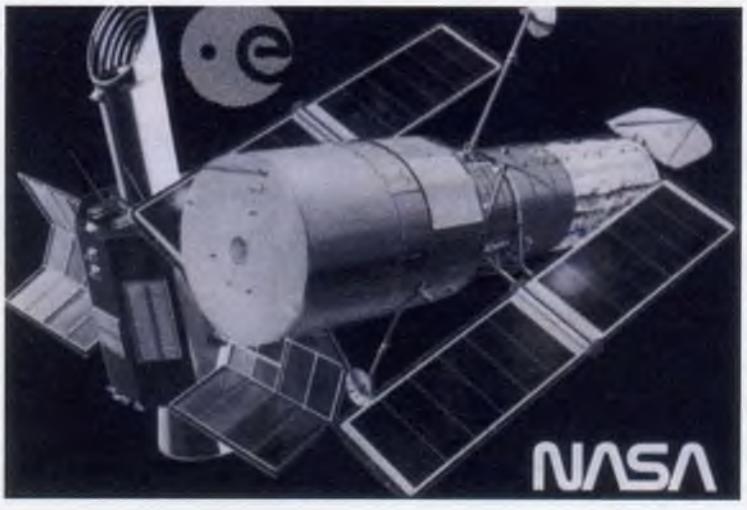
In 1976, NASA formally invited Europe to take a share in the LST and to contribute 15% of the costs. ESA requested, in return, to have a guaranteed share of 15% of the available observing time.

NASA accepted the offer, and in October 1976 ESA approved the European financial contribution. After the Tempel-2/Halley cometary project was aborted, the plans for co-operative utilization of the Shuttle/Spacelab system was delayed, and the joint ISPM mission was unilaterally abandoned by NASA as a consequence of budget cuts by the newly elected President. The *Large Space Telescope* remained the only ESA/NASA co-operative project, with ESA regarded as a "junior partner", according to ESA historians.[4]

But the precise instrument to be built by Europe was in some doubt, as was the question of what size of telescope, if any, the U.S. Congress would fund.[5]

In July 1977 the Congress approved funding for the *Large Space Telescope*. On NASA's side, it was decided to reduce the size of the telescope's primary mirror from 3 m to 2.4 m for cost reasons. The term '*Large*' was dropped from the telescope's name, which NASA later changed to the *Hubble Space Telescope* (HST) in honour of Edwin P. Hubble, (1889–1953), one of the great American pioneers of modern astronomy who identified galaxies outside the Milky Way and discovered that the Universe is expanding.

The Memorandum of Understanding (MoU) between ESA and NASA was formally signed October 7, 1977 and would last 11



years after launch in 1990 (expiring in April 2001, and would later be replaced by a new agreement. [6]

NASA chose its Marshall Space Flight Center in Huntsville, Alabama, as the lead NASA field center for the design, development, and construction of the Hubble Space Telescope. Marshall delegated the Perkin-Elmer Corporation (now, Hughes Danbury Optical Systems) the task of developing the Optical Telescope Assembly and the Fine Guidance Sensors for the telescope.

Lockheed Missiles and Space Company (now, Lockheed Martin) was selected by Marshall to build the cylindrical casing and the internal support systems (the Support Systems Module) and assembling the telescope together.

Goddard Space Flight Center in Greenbelt, Maryland, was designed to be the lead in scientific instrument design and ground control for the space observatory. Proposals were received from the scientific community and judged, and five science instruments were selected as the initial instruments that would be aboard the Space Telescope to study the Universe in infrared, visible, and ultraviolet light. The devices were the Faint Object Camera (FOC), the Wide Field/Planetary Camera, the Faint Object Spectrograph, the High Resolution Spectrograph, and the High Speed Photometer.

FOC was the main contribution of Europe, together with the solar array. The 318 kg FOC – which was not affected by the hairbreadth defect in the surface of the primary mirror and was removed as planned from Hubble in early 2002 and replaced by the more powerful *Advanced Camera for Surveys* – was one of the most crucial components on board, being an optical and ultraviolet camera able to count the individual rays of light or light particles, i.e. photons, as they arrived. The resolution of FOC was stunning: the camera was built by Dornier in Germany and Matra in France, with British Aerospace making the photon detector assembly. The detector was designed to very faint UV light sensitivity from 115 to 650 nanometers in wavelength, sensitive enough to pick up a single lighted candle at 40.000 km[7].

Since then, FOC has taken, thousands of photographs of outstanding quality and scientific interest.

By contrast the two solar arrays, provided by ESA were the largest attachments to the spacecraft and were required to produce 5kW of electricity.

Hubble Space Telescope Credit NASA.

Each had 24.380 cells and the overall span was 33 sqm.

The Johnson Space Center Houston, Texas, and the Kennedy Space Center, Florida supplied Space Shuttle capability to take the telescope to Earth orbit. In all, dozens of commercial contractors, a handful of universities, and several NASA centers, spanning 21 states and 12 other countries worldwide, to make the dream of a telescope above the clouds and in space a reality.

Seven Years of Delays for Hubble

Hubble was originally scheduled for launch on a Space Shuttle in December 1983 but the launch date had been put back at least five times, primarily because of NASA technical and budgetary limitations, resulting in a three-year overall delay. [8]

Finally the launch was scheduled for October 1986 but the Space Shuttle Challenger accident caused a further delay which had several repercussions concerning the ESA elements of the HST. The solar arrays had been delivered and installed in final flight configuration in early 1986. There was some concern as the further delayed launch date would coincide with a period of maximum solar activity, thereby exposing the HST, at its planned orbital altitude of approximately 600 km, to be exposed to a resulting expansion of the Earth's outer atmosphere and the deleterious and corrosive effects of atomic oxygen. The silver interconnects between the cells of the solar arrays would be particularly vulnerable. In addition, NASA's planned power utilization had increased, requiring improvements in power generation. The decision was therefore taken to remove the solar arrays from the HST and bring them back to Europe for upgrading. The two array wings were reworked in the course of 1988, with new blankets fitted with high-performance and atomic-oxygen-resistant cells and interconnects. The arrays were returned to the United States and refitted to the telescope in early 1989.

The telescope was finally launched into space on Space Shuttle Discovery's STS-31 mission April 24, 1990, and joining, to the benefit of the astronomy community at large, the European satellite Hipparcos, the first astrometric satellite already in orbit. Also in orbit – launched by ESA from Kourou on an Ariane rocket – was satellite Giotto, the Halley/Grigg-Skjellerup mission originally conceived as the ESA contribution to the joint ESA/NASA comet mission to be launched on the Space Shuttle, but canceled by NASA at the end of 1979 due to the cost of the shuttle program soaring and exceeding budget constraints.

Flawed Main Mirror and Consternation

When the first pictures returned from Hubble, the scientific community realized that the image quality obtained by the Hubble Space Telescope was drastically lower than expected, initially causing severe consternation amongst NASA, the scientific community, and the general public.

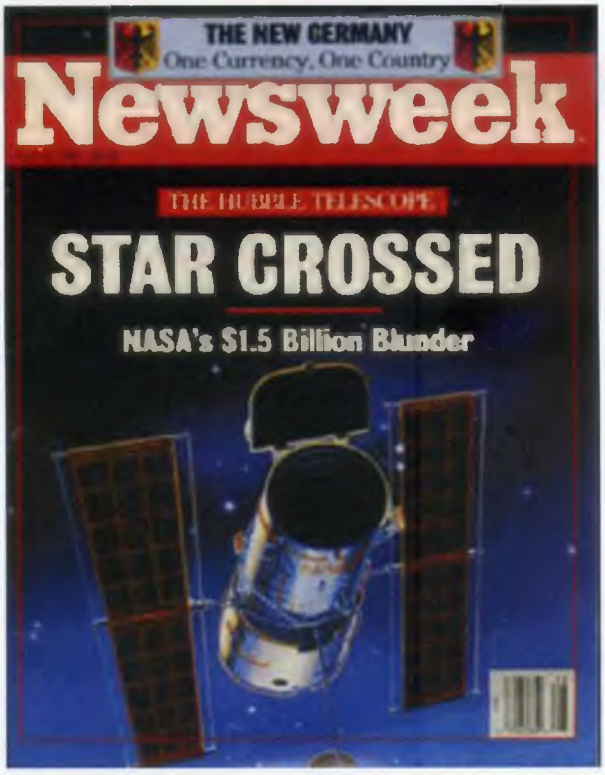
This comparison image of the core of the galaxy M100 shows the Hubble Space Telescope's dramatic improvement after the corrective optics was installed during the STS-61 Hubble Servicing Mission to fully compensate for optical aberration in Hubble's primary mirror.

Analysis of the flawed images showed that the cause of the problem was that 1 of 3 lens was out of position by 1.3 mm and consequently the primary mirror had a variation from the prescribed curve of the mirror by about 2,2 nanometers, severely reducing the usefulness of the telescope for faint objects. It was also realized that final tests had correctly reported spherical aberration, but the warning was overlooked and ignored by Perkin-Elmer and was heavily criticized by NASA for its managerial failings and was blamed for not supervising adequately the project and not involving the optical designers in the construction and verification of the mirror. NASA itself was criticized for not adequately managing quality control for the Hubble Space Telescope.

Repairing the Hubble Mirror to Restore NASA's Image

Except for the explosion of Space Shuttle Challenger that killed its crew of seven astronauts in 1986, no single event had damaged NASA's reputation and its own sense of achievement more than the discovery that, after more than a decade of development, the $1.6 billion USD Hubble Space Telescope had been launched with a serious manufacturing defect in the curvature of the telescope's main mirror.[9]

It would have been impossible to replace the mirror in orbit, and too expensive to bring the telescope back to Earth for a refit. Fortunately one of the innovative ideas behind Hubble was the Servicing Missions planned for keeping the observatory and its instruments in prime scientific condition. Periodic visits by astronauts were planned for replacing some instruments with state-of-the-



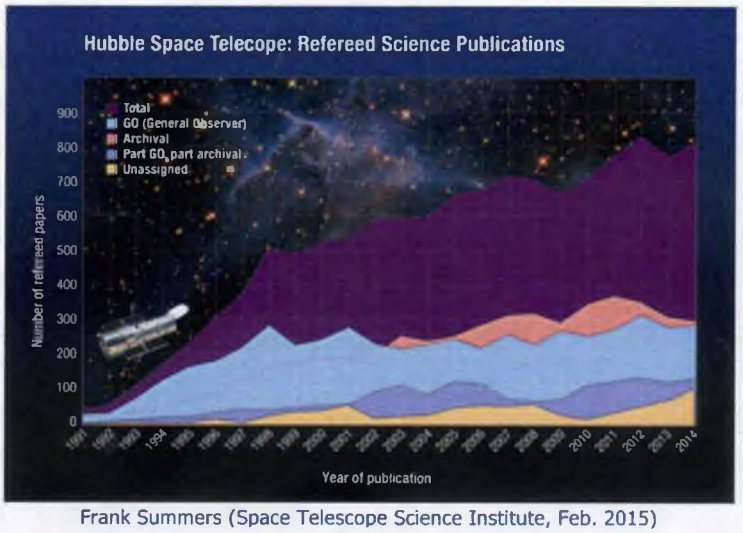
art versions. Originally, telescope maintenance visits were planned for every 2,5 years and a larger overhaul was envisaged every five years, when HST would have been brought back to the ground. This plan was changed somewhat over time and a servicing scheme that included Space Shuttle Servicing Missions every three years was finally decided upon.

This proved to be invaluable in this case. NASA considered at least 28 proposals for repairs on Hubble. At the end, new optical components were studied and designed with exactly the same error but in the opposite sense, acting as 'spectacles' to be added to the telescope to correct the spherical aberration. In this way the first maintenance mission by Space Shuttle Endeavour's STS-61 crew, launched December 2, 1993, repaired Hubble, December 4-9, successfully restoring Hubble's exceptional functionality as designed.[10]

Hubble–A Quarter Century of Success in Engineering, Science, and Culture

Hubble has since far exceeded its expectations and currently generates 844 gigabytes of data per month giving astronomers detailed information on supernovae, and galaxies in various evolutionary states.[11] Because of its versatility, the Hubble Observatory has made contributions to almost every branch of astronomy: from the studies of our own solar system, to the detailed observations of extrasolar planets, to a census of stellar populations in nearby galaxies, to the deepest views of the far distant Universe. The telescope was also instrumental in the discovery of dark energy, a little-known but ubiquitous force that works against gravity and contributes to the ongoing expansion of the Universe.

According to the statistics released



Frank Summers (Space Telescope Science Institute, Feb. 2015)

by NASA as of its 24th anniversary, April 2014,[12] Hubble has made more than 1 million observations and has observed 38,000 celestial targets. More than 100 terabytes of data has been accumulated so far. About 4,000 astronomers from all over the World have used the telescope to probe the Universe. Astronomers using Hubble data have published more than 11,000 scientific papers, making it one of the most productive scientific instruments ever built

One of the most popular and stunning images taken by Hubble is the so-called

"Pillars of Creation" which, taken in 1995, is reproduced on the cover of this issue. The image of stars being born in three clouds of near absolute zero intergalactic gas is so popular that it has appeared everywhere, including in movies and television shows, and even on a postage stamp.

This image from Hubble shows never-before-seen details of the three giant columns of cold gas from a cluster of young, massive stars in a small region of the Eagle Nebula, M16, as it looked about 7,000 years ago because the nebula is 7,000 light years away from Earth. The M16 image has arrived just now.

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[2] See "Orbiting Astronomical Observatory", in en.wikipedia.org

[4] R.J. Laurance, "The History of the Hubble Space Telescope and ESA's Involvement", in ESA Bulletin, n. 61 (February 1990), p.9-11

[4] According to ESA historians, in those years very little had survived of the ambitious plans for scientific cooperation which ESA and NASA had been discussing about fifteen years earlier. The reasons are deeply investigated and explained by A. Russo in its "The scientific programme between ESRO and ESA: choosing new projects (1973-1977)" (HSR- 16, ESA Publications Division, Estec, The Netherlands, February 1995) p. 75-79.
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[5] See: Brian Harvey, "Europe's Space Programme: To Ariane and Beyond", Springer Praxis Books, London & New York April 10, 2003 p.121-2. See also: J. Krige, A. Russo and L. Sebesta, " A History of the European Space Agency 1958–1987", SP-1235, ESA Publications Division, Estec, The Netherlands, April 2000, Volume II, p.40-41.

[6] See P. Benvenuti & L. Lindberg Christensen, "The Hubble Space Telescope – 10 Years On", in ESA bulletin 104 – November 2000, p. 10-19.

[7] The Faint Object Camera (FOC) had two complete detector systems, each producing an image on a phosphor screen that was 100.000 times brighter than the light received. A television camera then scanned this phosphor image. This television camera was so sensitive that objects brighter than 21st magnitude had to be dimmed by the camera's filter systems to avoid saturating the detectors.

[8] See: A. Russo, "The scientific programme between ESRO and ESA: choosing new projects (1973-1977)", HSR-16, ESA Publications Division, Estec, The Netherlands, February 1995, p.74. See also R.J. Laurance, "The History of the Hubble Space Telescope and ESA's Involvement", in ESA Bulletin, n. 61 (February 1990), p.10

[9] Irwin Goodwin, Denis F. Cioffi, "Hubble repair improves vision and helps restore NASAs image". Physics Today 47 (March 1994), p. 42

[10] Lynn Jenner ed., "The Hubble Story", in nasa.gov (May 18, 2009). See also Arthur Fisher, "The Trouble with Hubble", in Popular Science (October 1990), p.72.

[11] HST can observe the furthest away galaxies ever seen but there are a couple of nearby objects it cannot look at. These are the Sun (so bright it would damage its sensors) and the planet Mercury, which is too close to the sun.

[12] http://www.nasa.gov/content/goddard/a-look-at-the-numbers-as-nasas-hubble-space-telescope-enters-its-25th-year/