

EVOLUTION OF OPTICAL SATELLITE TRACKING (3019)*

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Abstract

Optical observations of artificial Earth satellites by the Smithsonian Astrophysical Observatory grew from a concept in the mind of Dr. Fred Whipple, which he expounded at a gathering of artificial satellite enthusiasts in June 1954 in Washington, DC. The timeline of events that followed represents an historical saga that reached a milestone only a decade later with the advent of laser ranging to satellites. Another milestone in the evolution of optical satellite observations occurred in November 1969 when the first array of retroreflectors was placed on the Moon, which facilitated laser ranging to the natural satellite of the Earth.

Evolution of Optical Satellite Tracking

In the United States, plans for optical observations of satellites evolved from concepts in the mind of Dr. Fred L. Whipple, a Harvard University professor of astronomy. He expounded his thoughts at a gathering of artificial satellite enthusiasts in a Navy office in Washington D.C. in June 1954. Also present at the gathering was Dr. Wernher von Braun, then Director of the Guided Missile Development Division (GMDD) at Redstone Arsenal in Huntsville, Alabama. Whipple and von Braun knew each other from a previous collaboration on space articles in *Colliers Magazine*. At the gathering, von Braun related that by combining existing Army rockets, the capability existed to launch a small artificial satellite. The assembled group agreed that the time has come to seriously start to build, launch and observe an actual satellite. Commander George W. Hoover was acknowledged as leader of the group. Fred Whipple agreed to plan observation of the satellite. Shortly after the Washington meeting, the development effort was given the name, Project Orbiter [1].

The Project Orbiter team members communicated and met in the following months. A pivotal meeting was held at Cape Canaveral on May 23 and 24, 1955. The assembled team watched a successful launch of a Redstone Rocket. A modified version of that rocket would be the first stage of the multi-stage launch vehicle envisioned by von Braun. The vehicle would have three upper stages, assembled as clusters of existing solid propellant rockets.

On July 1, 1955, the Astrophysical Observatory of the Smithsonian Institution (SAO) officially moved to the Harvard University Campus, with Fred Whipple as its director. Meanwhile, the proposition that the U.S. should launch a satellite had been discussed in the highest levels of the Government. On July 29, the White House announced the U.S. intention to put a satellite in

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orbit for the coming International Geophysical Year (IGY). Whipple and SAO proposed to implement the optical tracking of U.S. satellites [2].

In August 1955, a Navy proposal to execute a satellite program for the IGY was selected by the U.S. Government. It was called Project Vanguard. However, the Army, recognizing potential Army uses for artificial satellites, continued the development of the launch vehicle that had been planned in Project Orbiter. Late in 1955, SAO was designated to implement an optical tracking capability for the U.S. satellites for the IGY, and on January 1, 1956, required funding reached SAO from the National Academy of Sciences. To be ready for the IGY, Whipple and his SAO team initiated a crash effort to establish a global network of Baker-Nunn satellite tracking cameras, timing systems, communication equipment and a central computing capability for orbit determination and geophysical analyses. These events are summarized in Figure 1.

Figure 1, OPTICAL TRACKING HISTORY TIMELINE

Nov 1951	Symposium on Manned Space Flight	Fred Whipple met Wernher von Braun
Mar 22, 1952	First Colliers Issue on Space Flight	Whipple and von Braun collaborated.
Jun 1954	First meeting of future Project Orbiter team of satellite enthusiasts	Whipple was an enthusiastic participant von Braun described launch vehicle using existing rockets All agreed time had come to begin development of an artificial satellite
May 23-24 1955	Project Orbiter meeting at Cape Canaveral	Watched launch of a Redstone Rocket, (To be booster for a satellite launch) Whipple expounded concept for tracking a satellite optically
Jul 1, 1955	Astrophysical Observatory of the Smithsonian Institution moved to Harvard Campus	Fred Whipple was appointed the SAO Director.
Jul 29, 1955	White House announced U.S. intention to launch at least one satellite for the IGY, scheduled for Jul 1, 1957 to Dec 31, 1958.	
Fall 1955	U.S. National Academy of Sciences assigned SAO to optically track U.S. satellites	
Jan 1, 1956	SAO funded to implement optical tracking and orbit determination.	SAO team initiated crash program to field Baker-Nunn cameras by start of IGY.

The SAO team was led by Whipple, J. Allen Hynek and Karl G. Henize, Figure 2.

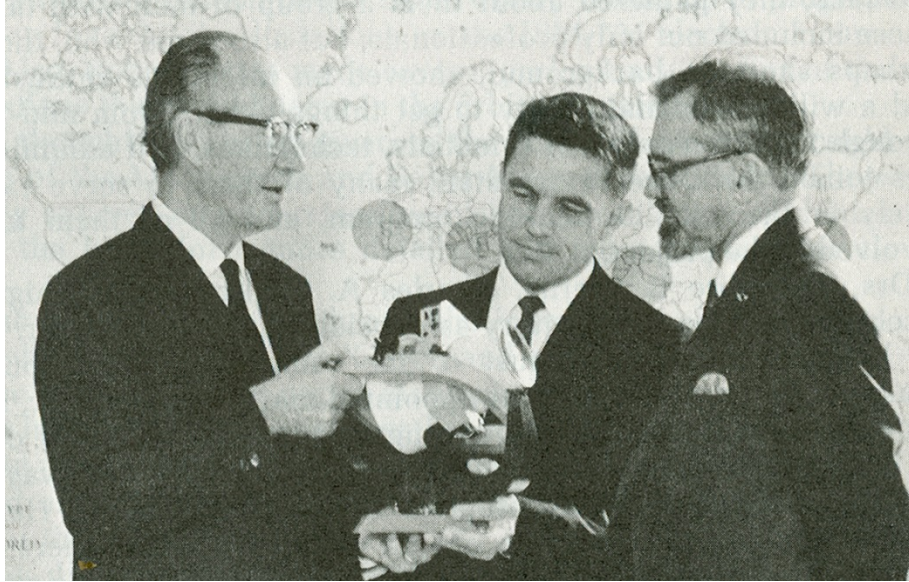


Figure 2, SAO Initial satellite optical tracking leadership. Fred L. Whipple, Karl G. Henize and J. Allen Hynek with a model of a Baker-Nunn Camera.

On February 1, 1956, The U.S. Army formed the Army Ballistic Missile Agency (ABMA) with the new mission to develop an intermediate range ballistic missile, the Jupiter. ABMA inherited the existing projects of the GMDD. The multistage, composite rocket from Project Orbiter was incorporated into the Jupiter Program as the Jupiter-C vehicle [3].

On October 4, 1957, the first artificial Earth satellite, Sputnik I, was launched by the USSR. By then the SAO tracking and orbit determination capability was ready for preliminary operations and it reached full capacity in a few months. On October 24, JPL was assigned to fabricate a scientific payload for a Jupiter-C vehicle. On November 1957, Sputnik II was orbited. On January 31, 1958, Jupiter-C #29 launched Explorer I, an evolutionary version of the envisioned Project Orbiter. Many other satellites followed in the next months and years. Photographic tracking of satellites became a routine operation by SAO and other organizations around the world. The derived geophysical results became increasingly accurate with experience and time [4].

Productive experience with geophysical studies based on satellite observations led to recognition that still more objectives could be accomplished with observations of greater accuracy. This motivated the development of laser ranging to cube-corner reflectors on satellites. This technology was pioneered by the NASA Goddard Space Flight Center in 1964. Other organizations soon embraced this technology, including SAO. In 1965, SAO introduced laser-ranging first at its Organ Pass, NM station. Other stations subsequently added laser ranging systems, Figure 3.

Figure 3, SAO Laser Ranging System

After prototype experiments at its Organ Pass NM site, a system of the configuration shown here was installed at the Baker Nunn sites at:

- Mount Hopkins, Arizona
- Arequipa, Peru
- Natal, Brazil (Moved to Matera, Italy in 1983); and
- Olifantsfontein, South Africa (moved to Orroral Valley, Australia in 1975)

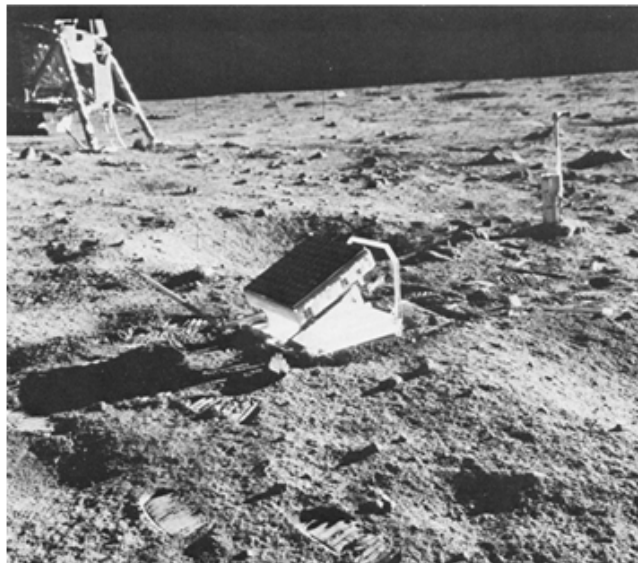
System Characteristics:

- Bi-Static, Az-Alt System
- Ruby oscillator/amplifier configuration
- Day and Night Time Tracking
- 4 – 30 ppm; 20 – 5 nsec pulse width



As laser-ranging to artificial satellites became routine, the possibility of ranging to Earth's natural satellite became possible as the Apollo Program approached reality. The NASA appointed Group for Lunar Exploration Planning (GLEP) indeed recommended that retroreflector arrays be placed on the Moon. That was done on the Apollo 12, 14 and 15 missions, Figure 4, and also by the USSR on its lunar rovers. Hence, the celestial mechanics community benefitted very fortuitously from the Apollo Program, which of course had other primary objectives.

Figure 4, Apollo 11 Retroreflector Array



The timeline of these and subsequent events is shown in Figure 5.

Figure 5, OPTICAL TRACKING HISTORY TIMELINE

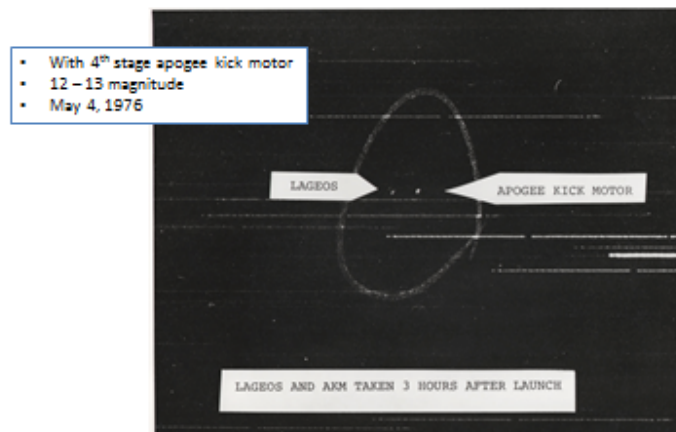
Oct 4, 1957	Sputnik I	SAO had minimal capability to begin optical tracking, and by
Nov 3, 1957	Sputnik II	summer 1958, SAO network had 12 Baker-Nunn stations.
Jan 31, 1958	Explorer I	Launched by Jupiter-C based on Project Orbiter development

In following months and years, many more satellites were placed in orbit and tracked routinely with cameras by several nations.

Oct. 1964	BE-B	Launched: First satellite with retroreflectors for laser ranging.
Oct 31, 1964		First successful satellite laser ranging by GSFC. CNRS (France) and SAO began laser ranging in 1965.
Jul 1969	Apollo 11	First retroreflector array placed on the Moon;
May 4, 1978	Lageos 1	Launched by NASA,

Lageos 1, launched in 1978, and later Lageos 2, became prime targets for laser ranging. They had orbits so stable that the motions on and of the Earth could be measured relative to them. The Baker-Nunn camera data were still useful in generating accurate prediction for the laser systems, Figure 6.

Figure 6, Lageos I Baker Nunn Photo after Launch taken from Maui



Looking to the future, the practical experience with Apollo suggests another fortuitous opportunity. The United States is considering a program to capture a small asteroid and move it to an orbit around the Moon. The operations involved in this program will surely benefit from, or require, accurate tracking. Of course, radio frequency tracking is a first possibility. Nevertheless, it would seem to behoove the laser-ranging community to interact with the asteroid program planning activity to see if a configuration of reflectors can be emplaced on the asteroid while it is orbiting the Moon. This would provide a chance to study a three-body system with very high accuracy, using the ground stations in place for lunar ranging.

References

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[4] Charles A. Lundquist, "Results from Photographic and Laser Tracking Systems", XVII International Astronautical Congress, Madrid, Spain, Oct 15, 1966.