

From Ballistic Ordnance to Planetary Observation: The Flight of V-2 Rocket Number 13 and the Inauguration of Exoatmospheric Photography

Abstract On October 24, 1946, an American-modified German Aggregat-4 (V-2) ballistic missile designated V-2 Number 13 ascended from Launch Complex 33 at the White Sands Proving Ground in southern New Mexico. Reaching an apogee of approximately 105 kilometers (65 miles), the vehicle crossed the altitude threshold later formalized as the Karman line, entering the lower thermosphere. Mounted within the midsection between the instrument bay and the propellant tanks was a modified 35-millimeter DeVry motion picture camera engineered by Clyde T. Holliday of the Johns Hopkins University Applied Physics Laboratory. Operating at a cadence of one frame every 1.5 seconds, the camera recorded the first photographic images of the Earth from outer space. This paper examines the technical architecture of the V-2 sounding rocket program, the fluid and thermodynamic propulsion mechanics that enabled early suborbital flight, the optical and mechanical engineering required to ensure data survival during high-velocity ballistic impact, and the foundational contributions of Flight 13 to atmospheric physics, remote sensing, and planetary science.

1. Introduction: The Threshold of the Exoatmosphere

Prior to the mid-1940s, the empirical study of the upper atmosphere was constrained by the physical limits of buoyancy. High-altitude research balloons, most notably the helium-filled *Explorer II* gondola launched jointly by the United States Army Air Corps and the National Geographic Society on November 11, 1935, represented the ceiling of human and instrumental ascent. *Explorer II* achieved an altitude of 22.06 kilometers (72,395 feet or 13.7 miles) over South Dakota, where Captain Albert W. Stevens captured photographs through the stratospheric haze that demonstrated a subtle, measurable curvature of the horizon. However, at 22 kilometers, a payload remains well within the lower stratosphere, beneath approximately 96 percent of the atmospheric mass, where Rayleigh scattering still produces a diffuse sky glow and aerodynamic forces govern flight dynamics.

To ascend beyond the stratosphere—through the mesosphere and into the thermosphere where atmospheric density drops by five to six orders of magnitude compared to sea level—required a propulsion system entirely independent of ambient atmospheric oxygen. The conclusion of the Second World War brought such a system into the custody of Allied scientific and military institutions. Through Operation Special Mission V-2 and Operation Paperclip, the United States Army Ordnance Corps secured enough components from the underground Mittelwerk manufacturing facility in Kohnstein, Germany, to assemble approximately one hundred Aggregat-4 (A-4) rockets, widely known by their propagandistic designation, *Vergeltungswaffe 2* (V-2).

Under the administrative supervision of Colonel Holger N. Toftoy and the technical execution of the General Electric Company under Project Hermes, these components were transported in roughly three hundred railcars to the Tularosa Basin in southern New Mexico. Recognizing that ballistic test firings required ballast to replicate the 738-kilogram (1,627-pound) amatol explosive warhead, the Army invited university and federal laboratories to populate the nose cones with diagnostic instrumentation. On February 27, 1946, an organizing committee convened at Princeton University to establish the Upper Atmosphere Research Panel (informally known as the V-2 Panel), chaired initially by Ernst H. Krause of the Naval Research Laboratory (NRL) and later by James A. Van Allen of the Johns Hopkins University Applied Physics Laboratory (APL).

The eighth successful suborbital flight of this scientific campaign, designated V-2 Number 13, lifted off on October 24, 1946. While its primary scientific manifest focused on cosmic ray flux and solar ultraviolet spectroscopy, an auxiliary engineering camera installed by APL engineer Clyde T. Holliday transformed the flight into a watershed moment in observational history. By elevating an optical lens to 105 kilometers, V-2 Number 13 bypassed the obscuring turbulence and scattering of the lower atmosphere, yielding the first visual record of Earth as an isolated planetary body set against the blackness of space.

2. Historical and Institutional Context: From Peenemünde to the Tularosa Basin

The transition of the V-2 from a tactical ballistic artillery piece into an upper-atmosphere sounding rocket involved significant logistical, industrial, and ethical complexities. Developed at the Peenemünde Army Research Center under the technical direction of Wernher von Braun and Walter Dornberger, the A-4 was conceived to deliver a one-metric-ton payload over a range of 320 kilometers. During the final years of the war, production of the rocket was relocated to the Mittelbau-Dora concentration camp complex, where tens of thousands of forced laborers perished under brutal subterranean conditions. Any technical evaluation of the postwar V-2 scientific program rests upon the acknowledgment that the hardware utilized at White Sands was the direct product of this wartime coercive manufacturing apparatus. When the American military inspected the captured inventory in late 1945, technicians discovered that virtually no complete, flight-ready missiles existed. Instead, the shipment consisted of mismatched subassemblies, corroded turbopumps, incomplete guidance gyroscopes, and wiring harnesses lacking comprehensive schematics. General Electric personnel, working alongside relocated German engineers at Fort Bliss and the newly established White Sands Proving Ground, initiated a process of hybrid reconstruction. V-2 Number 13 was emblematic of this transitional engineering: its airframe, combustion chamber, and turbomachinery were wartime German components, while sections of its internal wiring, stabilizing modifications, and payload fairings were newly fabricated to American industrial specifications.

The V-2 Panel allocated payload slots across a consortium of institutions, including the Naval Research Laboratory, the Applied Physics Laboratory at Johns Hopkins, the Army Signal Corps, Harvard University, Princeton University, and the University of Michigan. Because the Army

Ordnance Department stipulated that the fundamental upper-atmosphere measurements remain unclassified, the program fostered an open academic exchange that laid the institutional groundwork for the International Geophysical Year (1957–1958) and the eventual creation of the National Aeronautics and Space Administration.

Participating Institution	Principal Investigators	Primary Research Focus on Early V-2 Flights	Representative Instrumentation
Johns Hopkins University (APL)	James A. Van Allen, Clyde T. Holliday	Cosmic ray physics, vehicle attitude determination, optical aspect imaging	Geiger-Müller counter telescopes, 35-mm DeVry cine cameras, magnetometers
Naval Research Laboratory (NRL)	Ernst H. Krause, Richard Tousey, Herbert Friedman	Solar ultraviolet and X-ray spectroscopy, ionospheric electron density	Rowland concave grating spectrographs with lithium fluoride optics, radio propagation beacons
University of Michigan	William G. Dow, Nelson W. Spencer	Ambient atmospheric pressure, kinetic temperature, and density profiles	Pirani gauges, Philips cold-cathode ionization gauges, nose-cone pressure ports
Harvard University	Fred L. Whipple	Micrometeoroid flux, upper-atmosphere acoustic and density modeling	Acoustic impact plates, artificial meteoroid shaped-charge ejectors
U.S. Army Signal Corps	Marcel J. E. Golay	Stratospheric and mesospheric wind shear, acoustic temperature profiling	Grenade ejection arrays, ground-based ballistic camera and microphone

			networks
General Electric Company	Charles F. Green, Kenneth H. Kingdon	Propulsion performance, aerodynamic stability, Hermes missile development	Telemetry encoders, turbopump tachometers, carbon-vane actuators

3. Propulsion Mechanics and Aerodynamic Architecture of the V-2

To understand how V-2 Number 13 lifted a heavy suite of steel-encased scientific instruments to 105 kilometers, one must examine the thermodynamic and fluid-dynamic breakthroughs incorporated into the Model 39 propulsion system. Prior to the A-4, liquid-fueled experimental rockets constructed by pioneers such as Robert H. Goddard relied largely on pressure-fed propellant tanks, where inert gas forced fuel and oxidizer into the combustion chamber. Because the entire propellant tankage had to withstand pressures exceeding the combustion chamber pressure, tank walls required thick, heavy metal plating, which severely penalized the vehicle's mass ratio and restricted its maximum altitude.

3.1 Bipropellant Chemistry and Regenerative Cooling

The V-2 overcame the structural penalties of pressure-fed systems by employing high-capacity centrifugal turbopumps, allowing the main propellant tanks to be constructed from thin, lightweight aluminum and mild steel pressurized only slightly above ambient levels to prevent structural buckling. The rocket utilized a bipropellant combination consisting of 3,810 kilograms (8,400 pounds) of a fuel mixture—composed of 75 percent ethyl alcohol (ethanol) and 25 percent water by mass—paired with 4,910 kilograms (10,820 pounds) of cryogenic liquid oxygen (LOX).

The deliberate inclusion of 25 percent water in the ethanol fuel served two vital thermodynamic functions. First, pure ethanol burned with liquid oxygen generates a stoichiometric flame temperature approaching 3,000 degrees Celsius, which exceeded the melting point of the low-carbon steel alloys available for combustion chamber fabrication in the 1940s. Diluting the fuel with water reduced the combustion chamber flame temperature to approximately 2,500 degrees Celsius. Second, as the water flashed into superheated steam within the combustion zone, it lowered the average molecular weight of the exhaust gas mixture. According to the principles of compressible fluid flow through a converging-diverging Laval nozzle, the exhaust velocity of a rocket engine is inversely proportional to the square root of the molecular weight of the exhaust species. Thus, introducing low-molecular-weight water vapor maintained high exhaust efficiency while simultaneously reducing thermal stress on the chamber walls. Thermal management was further augmented through a dual-mode cooling architecture:

regenerative cooling combined with internal film cooling. Before entering the eighteen burner cups at the top of the combustion chamber, the cool alcohol-water mixture was pumped into a double-walled cooling jacket surrounding the nozzle throat and combustion chamber. As the fluid circulated upward through this jacket, it absorbed conductive and convective heat from the steel walls, cooling the metal while preheating the fuel prior to injection. Because regenerative cooling alone was insufficient at the narrow nozzle throat—where convective heat transfer peaks due to maximum mass flux—four rings of tiny perforations were drilled through the inner chamber wall. A small percentage of the alcohol-water mixture seeped through these orifices to form a cool, evaporating boundary layer along the interior metal surface, insulating the steel from direct contact with the incandescent core flow.

3.2 The Steam Turbopump Assembly

To achieve a sea-level thrust of approximately 250 kilonewtons (56,000 pounds-force), the engine consumed roughly 125 kilograms of combined propellants every second. Moving this volume against a combustion chamber pressure of 1.5 megapascals (approximately 15 atmospheres) required a 410-kilowatt (550-horsepower) steam turbine situated directly above the thrust chamber.

The turbine was driven by an independent gas generator fueled by concentrated hydrogen peroxide (80 percent concentration, designated *T-Stoff*) and catalyzed by an aqueous solution of sodium permanganate (*Z-Stoff*). When metered into a compact catalyst chamber, the permanganate stripped oxygen atoms from the hydrogen peroxide in a rapid exothermic decomposition reaction, converting the liquid into high-pressure superheated steam and oxygen gas at 420 degrees Celsius. This steam impinged upon the turbine blades, spinning a common shaft at 4,000 revolutions per minute. Mounted on opposite ends of this shaft were two cast-aluminum centrifugal impellers—one pumping the alcohol-water fuel, the other pumping the cryogenic liquid oxygen at minus 183 degrees Celsius. Exhaust steam from the turbine was routed out of the rear of the fuselage through two auxiliary heat-exchanger pipes, where a tiny portion of the liquid oxygen was vaporized and routed back to pressurize the main oxygen tank during flight.

3.3 Thrust Vectoring and Attitude Control

At liftoff, the V-2 possessed a gross mass of approximately 12,800 kilograms (28,200 pounds). During the initial seconds of ascent, the vehicle moved too slowly for the four external aerodynamic tail fins to generate restorative lift forces. To stabilize the vehicle in pitch, yaw, and roll from the moment of ignition, the V-2 utilized four refractory graphite (carbon) jet vanes suspended directly inside the supersonic exhaust plume exiting the nozzle, paired with four external aerodynamic rudder tabs on the trailing edges of the fins.

Two three-degree-of-freedom gyroscopes—one monitoring pitch and roll, the other monitoring yaw—detected angular deviations from the programmed vertical ascent profile. If the vehicle tilted away from its prescribed trajectory, the gyroscopes sent electrical error signals through an analog mixing amplifier to electro-hydraulic servo actuators. These actuators deflected the graphite exhaust vanes, redirecting the momentum vector of the rocket exhaust to torque the tail back into alignment.

Parameter Category	Technical Specification	Metric Value	Imperial / Conventional Equivalent
Dimensions	Overall Length	14.04 meters	46.05 feet
Dimensions	Fuselage Diameter	1.65 meters	5.42 feet
Dimensions	Tail Fin Span	3.56 meters	11.69 feet
Mass Properties	Dry Mass (Unfueled with Payload)	4,010 kilograms	8,840 pounds
Mass Properties	Fuel Mass (75% Ethanol / 25% Water)	3,810 kilograms	8,400 pounds
Mass Properties	Oxidizer Mass (Liquid Oxygen)	4,910 kilograms	10,820 pounds
Mass Properties	Scientific Warhead / Nose Cone Mass	1,000 kilograms (nominal)	2,200 pounds (modified for sounding)
Mass Properties	Gross Liftoff Mass	12,730 kilograms	28,065 pounds
Propulsion	Sea-Level Thrust	249 kilonewtons	56,000 pounds-force
Propulsion	Vacuum Specific Impulse	239 seconds	2,340 meters per second exhaust velocity
Propulsion	Nominal Powered Burn Duration	60 to 65 seconds	1.0 to 1.08 minutes
Flight No. 13 Metrics	Launch Date and Time	October 24, 1946	12:15 Mountain Standard Time

Flight No. 13 Metrics	Maximum Velocity at Engine Cutoff	1,520 meters per second	3,400 miles per hour (Mach 4.8)
Flight No. 13 Metrics	Apogee Altitude	104.6 kilometers	65.0 miles (343,000 feet)

4. Optical and Mechanical Engineering: Clyde Holliday's Camera System

While the physicists of the V-2 Panel focused on ionizing radiation and solar spectra, an acute operational problem arose almost immediately during the spring and summer launches of 1946. Once the rocket motor shut down—an event known as *Brennschluss*, occurring roughly 60 to 65 seconds after launch at an altitude of 28 to 32 kilometers—the graphite exhaust vanes became ineffective. Furthermore, as the vehicle coasted upward into the rarefied mesosphere, the dynamic pressure dropped to zero, rendering the external aerodynamic fins useless. Consequently, any tiny residual asymmetric thrust at engine cutoff imparted an uncompensated angular momentum to the airframe. During the four-minute unpowered ballistic coast to apogee and back down, the rocket tumbled, pitched, and spun unpredictably around its center of mass.

4.1 The Aspect Problem in Upper-Atmosphere Physics

For scientists like James Van Allen and Richard Tousey, this unrestrained tumbling created a severe analytical bottleneck. Cosmic ray Geiger-Müller telescopes exhibited directional sensitivity; to determine whether primary cosmic rays showed an east-west asymmetry induced by the Earth's geomagnetic field, researchers needed to know the exact three-dimensional orientation (the "aspect") of the rocket body at every second of the flight. Similarly, solar spectrographs required precise confirmation of when the optical apertures were pointed toward the solar disk. Ground-based optical tracking telescopes, such as modified Askania cinetheodolites and Mitchell ribbon-frame cameras positioned around the Tularosa Basin, could track the rocket's position in space, but from tens of kilometers away they could not reliably resolve the axial roll angle of the cylindrical fuselage once it passed above 50 kilometers.

To solve this aspect determination problem, APL engineer Clyde T. Holliday proposed a direct optical solution: install an automated motion picture camera inside the rocket looking outward at a ninety-degree angle to the longitudinal axis. By photographing the ground horizon and the position of the sun or cloud formations as the rocket rolled and pitched, geometric photogrammetry could reconstruct the exact attitude matrix of the vehicle throughout its exoatmospheric trajectory.

4.2 Modification of the DeVry 35-mm Cine Camera

Holliday selected a standard commercial DeVry 35-millimeter motion picture camera—a rugged, spring-wound or electric-motor-driven portable newsreel camera widely used by

combat photographers during World War II. However, a standard cinema frame rate of 24 frames per second was neither necessary for aspect reconstruction nor compatible with the limited film capacity over a five-minute flight. Holliday stripped the internal clockwork drive mechanism and replaced it with a motorized reduction gear train and an electromechanical intervalometer. This modification slowed the exposure cadence to exactly one frame every 1.5 seconds (0.67 frames per second), providing a continuous time-lapse sequence from launch through apogee.

The optical path utilized a standard wide-angle focal-length lens stopped down to maintain hyperfocal sharpness across infinite object distances, coupled with a minus-blue (yellow-red) optical filter to penetrate atmospheric Rayleigh haze and enhance the contrast between terrestrial desert terrain, white cloud decks, and the dark sky background. The camera was loaded with standard panchromatic black-and-white 35-millimeter motion picture film stock.

4.3 Structural Hardening for Terminal Ballistic Impact

The central engineering challenge confronting Holliday was not taking the photographs in the vacuum of space, but retrieving the photographic emulsion afterward. In 1946, television broadcast technology was far too heavy, bulky, and low-resolution to transmit photographic imagery via radio telemetry. Although the Naval Research Laboratory developed a multi-channel pulse-time-modulated radio telemetry system operating at 1,000 megahertz to broadcast voltage readings from Geiger counters and pressure gauges to ground stations, any optical or spectrographic data recorded on physical film had to be excavated from the crash crater.

A V-2 returning from a 105-kilometer apogee re-entered the lower atmosphere nose-first at supersonic speeds. Even when aerodynamically slowed by dense lower air, an intact rocket body struck the desert floor at terminal velocities approaching 800 meters per second (nearly 1,800 miles per hour, or Mach 2.35), releasing kinetic energy equivalent to the detonation of several hundred kilograms of high explosives and excavating a crater 10 meters wide and 5 meters deep. To mitigate this destructive energy, Army technicians installed severance charges—rings of TNT or primacord strapped to the interior structural bulkheads just aft of the warhead instrument section. During the descent phase, at an altitude of roughly 30 to 40 kilometers, a radio command or barometric timer detonated these charges, severing the heavy nose cone from the empty propellant tank fuselage. Destabilized into two aerodynamically blunt, tumbling bodies, the fragments experienced high drag deceleration in the troposphere, reducing terminal impact velocity to roughly 150 meters per second (about 500 feet per second, or 340 miles per hour).

Even at 150 meters per second, deceleration forces upon striking hard-packed gypsum and caliche soil exceeded several thousand times standard Earth gravity, pulverizing cast aluminum housings and shattering optical glass. Holliday accepted that the DeVry camera body, shutter assembly, and lens were expendable. To preserve the exposed film, he engineered a custom-machined take-up cassette milled from thick-walled, hardened armor steel. As each frame was exposed every 1.5 seconds, the transport sprockets drew the 35-millimeter acetate film strip through a narrow, light-tight labyrinth slot into the armored steel cylinder. The steel drum was hermetically gasketed to prevent light leaks if the outer camera chassis fractured

and to protect the film from flash heating or residual alcohol fuel fires in the impact crater. Holliday bolted the complete assembly inside the forward midsection of V-2 Number 13—specifically within the access compartment located between the warhead base and the forward liquid oxygen tank bulkhead—aligning the lens with a small circular viewing port flush-mounted in the outer sheet-metal skin of the fuselage.

5. The Flight Profile of V-2 Number 13 (October 24, 1946)

On the morning of Thursday, October 24, 1946, V-2 Number 13 stood upright on the concrete firing apron at Launch Complex 33. Inside the blockhouse—a reinforced concrete bunker capped with a 3-meter-thick pyramidal roof designed to withstand a direct impact from a malfunctioning missile—engineers from General Electric, the Army Ordnance Corps, APL, and NRL completed the pre-flight checkout.

5.1 Scientific Manifest of Flight 13

Flight 13 carried a multi-institutional payload led by the Johns Hopkins Applied Physics Laboratory. The primary warhead instrumentation included:

1. **Cosmic Ray Telescope Array (APL):** A geometric arrangement of Geiger-Müller tubes shielded with varying thicknesses of lead plates, designed by Van Allen's group to measure the flux and energy spectrum of primary cosmic radiation before it collided with atmospheric nitrogen and oxygen nuclei to produce secondary meson showers.
2. **Solar Ultraviolet Spectrograph (NRL/APL):** Mounted in a conical housing to record the solar spectrum below 2,900 Angstroms (290 nanometers)—wavelengths completely absorbed by the stratospheric ozone layer between 20 and 50 kilometers altitude and therefore unobservable from terrestrial mountain observatories.
3. **Ionospheric Propagation Transmitters:** Multi-frequency continuous-wave radio beacons transmitting phase-locked signals to ground receivers. By measuring the differential Doppler shift and phase retardation between frequencies affected by free electrons and higher reference frequencies unaffected by the ionosphere, physicists mapped ambient electron density across the D and E layers.
4. **Clyde Holliday's 35-mm Aspect Camera (APL):** Activated shortly before liftoff to record continuous horizon geometry and cloud topography.

5.2 Ascent, Coast, and Impact Sequence

At 12:15 Mountain Standard Time, the firing officer initiated the ignition sequence. First, a pyrotechnic pinwheel igniter spun inside the combustion chamber as main valves allowed alcohol and liquid oxygen to flow by gravity feed, establishing a preliminary low-thrust fire. Once visual observers in the blockhouse confirmed smooth preliminary combustion through periscopes, the firing officer triggered the hydrogen peroxide steam generator. Within three seconds, the turbopump spooled to full speed, main chamber pressure surged to 15 atmospheres, and V-2 Number 13 lifted off the launch ring.

For the first four seconds, the rocket rose vertically, stabilized entirely by its internal graphite exhaust vanes. As velocity increased, the onboard pitch gyroscope executed a mild programmed tilt slightly north-by-northeast to ensure the trajectory remained within the

boundaries of the White Sands range. The rocket traversed the sound barrier roughly 25 seconds into flight at an altitude of 6 kilometers. At approximately 60 seconds after liftoff, at an altitude of roughly 29 kilometers (18 miles), the propellant tanks neared depletion and the engine cut off at a velocity of 1,520 meters per second (3,400 miles per hour).

With thrust terminated, the vehicle entered a weightless parabolic coast phase. Momentum carried the 14-meter cylinder upward through the stratopause and mesopause. Throughout this ascent, Holliday's DeVry camera clicked steadily every 1.5 seconds. As the rocket climbed above 60 kilometers, the residual angular momentum imparted at engine cutoff caused the vehicle to roll slowly about its longitudinal axis while pitching end-over-end. Rather than ruining the photographic experiment, this slow rotation caused the camera port to sweep repeatedly across the southwestern horizon, scanning from the gypsum dunes of the Tularosa Basin across the Rio Grande valley toward Arizona and northern Mexico.

At approximately 185 seconds after launch (three minutes and five seconds into the flight), V-2 Number 13 reached its apogee of 104.6 kilometers (65.0 miles). At this elevation, atmospheric pressure is less than one ten-millionth of sea-level pressure, and the mean free path of gas molecules exceeds several meters. The camera captured frames looking out across an expanse of Earth's surface encompassing roughly 100,000 square kilometers (40,000 square miles) in a single field of view. Above the sharply curved terrestrial limb, the sky appeared completely black, devoid of Rayleigh scattering even in the middle of a bright New Mexico afternoon. Gravity then pulled the rocket back toward the desert. During descent, the airframe separation charges detonated as planned, separating the warhead from the aft fuselage to induce aerodynamic tumbling. Roughly five minutes after launch, the components slammed into the desert floor several miles downrange.

5.3 Recovery and Darkroom Processing

Tracking crews utilizing radar plots and optical cinetheodolite bearings guided a recovery party in Army trucks across the roadless desert scrub to the impact site. When Holliday and the technicians arrived at the wreckage, the aluminum and steel framing of the midsection was twisted and shredded. The DeVry camera body was wrenched from its mounting brackets, its optical lens sheared completely away and pulverized upon impact. However, the thick-walled steel film cassette remained intact and sealed among the debris.

Carried back to the White Sands photographic laboratory, the steel drum was opened in darkness and the 35-millimeter panchromatic film strip was developed in chemical baths. When the wet negative strip was hung for inspection and subsequently projected in a makeshift screening room for the assembled engineers and military personnel, every frame proved legible. Starting from the launch pad apron, the time-lapse sequence showed the desert floor receding rapidly, railroad tracks and mountain ranges shrinking into geometric textures, cumulus cloud formations flattening into two-dimensional sheets, and finally the unmistakable, stark curvature of the planet bending away against the black void of space.

6. Photogrammetric, Atmospheric, and Scientific Analysis of the Imagery

While the aesthetic and philosophical impact of seeing Earth from outer space eventually

captured public imagination, the immediate significance of the October 24, 1946 photographs within the scientific community was analytical. The imagery provided empirical verification across three distinct domains: atmospheric optics and the definition of the space boundary, meteorological remote sensing, and cosmic ray vehicle attitude reconstruction.

Mission / Platform	Date	Maximum Altitude	Atmospheric Layer	Horizon Curvature & Sky Appearance	Approximate Surface Area Visible
Explorer II Balloon	Nov 11, 1935	22.06 kilometers (13.7 miles)	Lower Stratosphere	Subtle horizon curve (~1.5 degrees dip); bright diffuse scattering haze along limb; dark blue overhead sky	~12,000 square kilometers (heavily obscured at oblique angles)
V-2 Number 13	Oct 24, 1946	104.6 kilometers (65.0 miles)	Lower Thermosphere (Above Karman Line)	Pronounced planetary curvature (~10.3 degrees dip); razor-sharp optical limb; pitch-black exoatmospheric sky	~103,000 square kilometers (40,000 square miles per frame)
V-2 Number 21	Mar 7, 1947	162.5 kilometers (101.0 miles)	Thermosphere	High-relief curvature; stitched mosaic spanning from Upper	~2,000,000 square kilometers (across composite panorama)

				California Gulf to Wyoming	
Aerobee / Viking 11	May 24, 1954	254.0 kilometers (158.0 miles)	Middle Thermosph ere	Deep spherical curvature; clear resolution of synoptic cyclonic weather systems across North America	~3,500,000 square kilometers

6.1 Atmospheric Physics and the Pre-History of the Karman Line

When V-2 Number 13 reached 104.6 kilometers in October 1946, no internationally recognized legal or physical definition of the boundary between the Earth's atmosphere and outer space existed. It was not until the mid-1950s that the Hungarian-American aerodynamicist Theodore von Karman calculated the physical altitude regime where aerodynamic flight becomes impossible.

Von Karman analyzed the relationship between atmospheric density, aerodynamic lift, and orbital mechanics. As an aircraft ascends, air density decreases exponentially, requiring the vehicle to fly progressively faster to generate sufficient dynamic pressure over its wings to support its own weight. At an altitude of approximately 85 to 100 kilometers, the atmospheric density drops so low—roughly one-millionth of sea-level density—that the airspeed required to generate aerodynamic lift equals orbital velocity (approximately 7.8 kilometers per second). At that velocity, centrifugal force alone supports the vehicle against gravity, rendering aerodynamic wings superfluous; moreover, flying at orbital speed within an atmosphere dense enough to provide lift would subject the airframe to catastrophic convective heating. Based on these physical considerations, the Fédération Aéronautique Internationale (FAI) subsequently standardized the Karman line at exactly 100 kilometers (62.14 miles) above mean sea level. Holliday's photographs from 104.6 kilometers provided the first direct optical demonstration of this physical transition zone. In terrestrial and stratospheric photographs—including the 1935 *Explorer II* plates—Rayleigh scattering of sunlight by air molecules creates a bright, glowing band of blue-white light that blurs the true geometric horizon. Because scattering intensity is directly proportional to the number density of gas molecules along the line of sight, looking upward or sideways from 105 kilometers passes through a negligible column mass of air.

Consequently, the photographs from V-2 Number 13 revealed a sharp transition: the entire optical thickness of the troposphere and stratosphere appeared compressed into a thin, bright rim hugging the planetary surface, surmounted immediately by a completely black sky.

6.2 Geometric Horizon Dip and Photogrammetric Reconstruction

From a purely geometric standpoint, the apparent curvature of the Earth in a photograph is governed by the horizon dip angle—the angular depression of the visible horizon below the local horizontal plane of the observer, which is mathematically determined by the inverse cosine of the ratio between the Earth's radius and the sum of the Earth's radius plus the observer's altitude.

At the 22-kilometer altitude of *Explorer II*, the horizon dip angle is approximately 4.7 degrees, and the maximum straight-line distance to the geometric horizon is roughly 530 kilometers. Across the standard field of view of a camera lens, a 4.7-degree dip produces only a slight sagittal rise at the center of the horizon line, requiring straight-edge rulers placed against the photographic print to verify curvature unambiguously. Conversely, at the 104.6-kilometer apogee of V-2 Number 13, the horizon dip angle increases to approximately 10.3 degrees, and the distance to the geometric tangent point on the horizon expands to 1,160 kilometers (720 miles). At this scale, the sagittal curvature across a wide-angle 35-millimeter frame is immediately evident to the unaided eye, even accounting for minor barrel or pincushion distortion when the horizon passes away from the optical center of the lens during vehicle tumbling.

By measuring the pixel-equivalent film coordinates of two variables in each frame—the orientation angle of the curved horizon line relative to the film frame borders, and the perpendicular distance from the center of the optical reticle to the horizon arc—APL analysts solved spherical trigonometry projections to determine the pitch and roll angles of the rocket. When combined with ground positions of identifiable landmarks (such as the dark basaltic lava flow of the Carrizozo Malpais, the bright gypsum flats of Lake Lucero, the Rio Grande river bend, and the Southern Pacific Railroad line), Holliday's team reconstructed the three-dimensional orientation of V-2 Number 13 to within two degrees of arc throughout the entire exoatmospheric trajectory.

6.3 The Birth of Space-Based Meteorology and Synoptic Geology

Beyond solving the rocket aspect problem, the October 24, 1946 film strip unexpectedly demonstrated the utility of exoatmospheric platforms for Earth sciences. Prior to 1946, meteorologists constructed weather maps by interpolating point measurements collected from ground weather stations, ship logs, and isolated radiosonde balloons. Because stations were separated by tens or hundreds of kilometers, mesoscale convective systems, frontal boundaries, and upper-level cloud streets could only be inferred indirectly.

In Holliday's photographs—and in subsequent high-resolution mosaic sequences he obtained on V-2 flights in March 1947 and July 1948 using larger-format Fairchild K-25 aerial reconnaissance cameras—meteorologists saw synoptic cloud patterns organized across hundreds of thousands of square kilometers simultaneously. Cumulus congestus towers, cirrus anvils, and the sharp boundaries of dry air intrusions over the Chihuahua and Sonoran deserts were visible in their true spatial relationships.

Harry Wexler, chief of the Scientific Services Division at the United States Weather Bureau, examined the V-2 photography closely. The realization that a single suborbital camera could capture the organization of storm systems across an entire region prompted Wexler and researchers at the RAND Corporation to begin formal feasibility studies on weather reconnaissance from orbital altitudes. This intellectual lineage led directly from Holliday's V-2 film strips to the launch of TIROS-1 (Television Infrared Observation Satellite) in April 1960, which inaugurated continuous operational satellite meteorology.

Similarly, geologists examining the stitched panoramas realized that high-altitude imagery revealed large-scale structural lineaments, fault scarps, volcanic calderas, and sedimentary basin geometries that were invisible to aerial photographers flying at standard altitudes of 5 to 8 kilometers. By integrating vast surface areas under uniform solar illumination angles, the V-2 images prefigured the multispectral planetary mapping later executed by the Landsat program.

7. Scientific Legacy and Historiographical Perspective

Despite the historic nature of the October 24, 1946 photographs, their dissemination to the broader public was gradual. Because the primary mission of V-2 Number 13 was upper-atmosphere physics and missile dynamics rather than public relations, the images initially circulated in technical memoranda issued by the Johns Hopkins Applied Physics Laboratory and the V-2 Panel. While selected frames from subsequent 1947 and 1948 flights appeared in newspaper wire reports, it was not until October 1950 that Clyde Holliday authored a comprehensive feature article in *National Geographic Magazine* titled "Seeing the Earth from 80 Miles Up," which presented the stitched panoramic composites and early 1946 frames to a global readership.

In that 1950 publication, Holliday articulated a remarkably prescient assessment of the technology he had pioneered. Reflecting on the stark, cratered appearance of the desert mountain ranges and the curved limb of the planet set against the blackness of space, he noted that the photographs illustrated for the first time how the Earth would appear to visitors arriving from another planet aboard a spacecraft. More practically, he predicted that within a generation, cameras mounted on guided rockets would routinely map inaccessible polar regions, track global weather fronts, and conduct geological surveys.

From a technical standpoint, the experimental methods validated on V-2 Number 13 established the foundational protocols for the early space age:

- **Physical Data Recovery from Space:** The structural engineering principles Holliday applied to his armored steel film cassette—specifically, isolating the recording medium within an impact-resistant, thermally insulated vault capable of surviving high-g deceleration—were directly scaled up during the late 1950s for the Corona (Discoverer) reconnaissance satellite program, where exposed film canisters were de-orbited in ablative reentry capsules and recovered mid-air or from the ocean.
- **Multi-Disciplinary Sounding Rocketry:** The success of the V-2 Panel demonstrated that complex, high-cost launch vehicles could be operated collaboratively by academic and military consortia. As the finite supply of captured German V-2 parts dwindled toward exhaustion around 1952, APL and NRL engineers applied the lessons learned at Launch Complex 33 to design purpose-built American sounding rockets, specifically the

compact Aerobee (developed by Van Allen and Aerojet) and the steerable Viking rocket (developed by NRL and the Glenn L. Martin Company).

- **Planetary Perspective:** Prior to October 24, 1946, astronomy and geology existed as observationally separate disciplines: astronomers looked outward through telescopes at other planetary disks, while geologists and geographers studied the Earth from within its atmospheric envelope. By placing an optical sensor outside the sensible atmosphere and pointing it backward at the launch planet, V-2 Number 13 unified the two perspectives, visually establishing the Earth as one astronomical body among many.

Every subsequent icon of space photography—from the first crude television scans of Explorer 6 in 1959, to the full-disk color imagery of ATS-3 in 1967, the *Earthrise* photograph captured by the Apollo 8 crew in 1968, and the *Pale Blue Dot* recorded by Voyager 1 from beyond the orbit of Neptune in 1990—traces its technical and conceptual ancestry back to the Tularosa Basin in autumn 1946. The grainy, scratched, black-and-white 35-millimeter frames spooled inside Clyde Holliday's battered steel cassette marked the precise moment humanity transitioned from observing the heavens from the bottom of an ocean of air to viewing its own world from the vantage point of the cosmos.

8. Conclusion

The flight of V-2 Rocket Number 13 on October 24, 1946, stands as a pivotal convergence of mid-twentieth-century propulsion engineering, high-altitude physics, and optical instrumentation. Repurposing a ballistic weapon designed for wartime bombardment, American scientists and engineers transformed the Aggregat-4 into humanity's first exoatmospheric research platform. By overcoming the severe mechanical constraints of unguided supersonic reentry and high-velocity desert impact through pragmatic mechanical hardening, Clyde T. Holliday secured the first photographic evidence of the Earth viewed from above the 100-kilometer threshold. In doing so, the mission resolved critical problems in cosmic ray telemetry, demonstrated the feasibility of space-based meteorology and geological reconnaissance, and permanently altered the visual and scientific comprehension of our planet.